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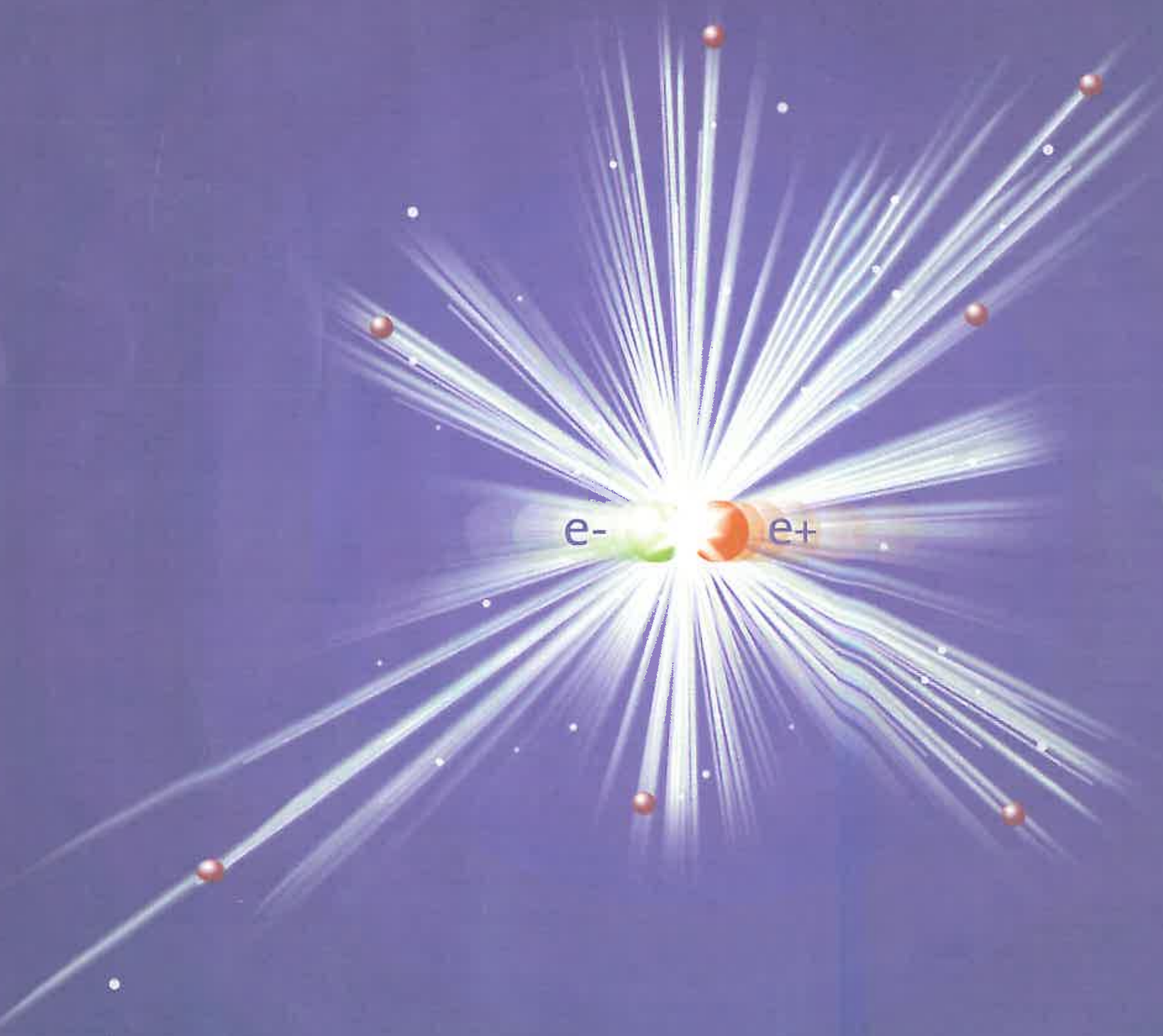
Accelerators special issue

Prepared under the supervision of the EPS Interdivisional Group on Accelerators



features

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cover
In the TESLA linear accelerator, electrons and positrons annihilate each other in a burst of pure energy giving rise to new elementary particles.
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features

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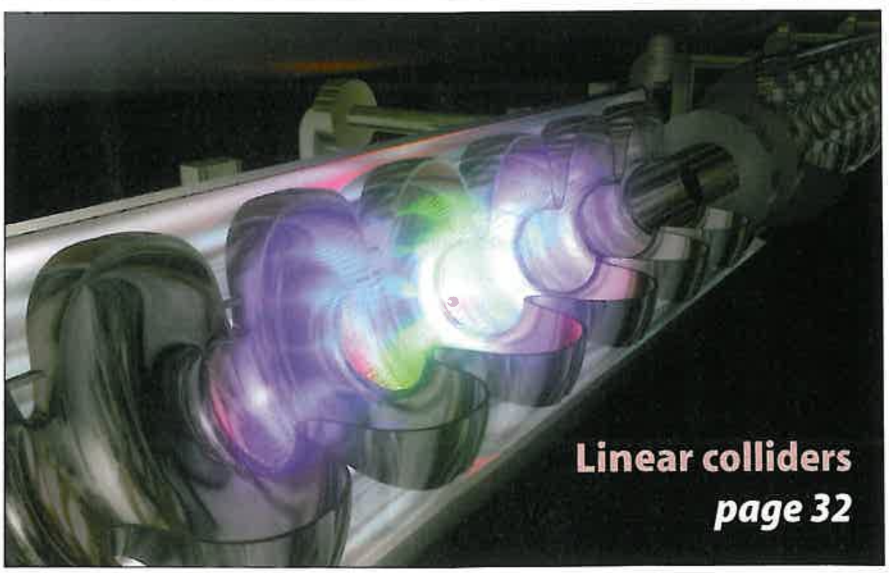
NEWS AND VIEWS

activities



Interdivisional Group on Accelerators

The Group, formed in 1988, unites individuals and Public Institutions (laboratories, etc.) interested in particle accelerators, storage rings and similar devices as used in scientific research and practical applications.

The aim of the Group is to promote research and development of accelerators, storage rings and similar devices as well as their applications. It encourages contacts between specialists in the field in European and non-European institutions. It stimulates international co-operation and exchange of information; it promotes efficient use of resources and fosters high standards.

Membership of the Group is open to individuals or Public Institutions (laboratories, etc.) interested in the topics mentioned above, and who are members of the European Physical Society under Articles 4a, 4c or 4d and 7 of the Constitution.

Activities

Apart from the organisation of EPAC, the main activities of the Group are:

- **Collaboration with Industry:**
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- **Student Aid Programme:**
  Financial provision is made to enable young scientists to attend EPAC meetings enabling them to benefit from international contacts in the field.
- **Eastern European Aid Programme:**
  Financial provision is made to enable colleagues in Eastern European countries to attend EPAC meetings.
- **The European Accelerator Prizes:**
  The EPS-IGA is sponsoring two European Accelerator Prizes. One prize is for a physicist or engineer who is under the age of 40 at the time of EPAC'96 and who has made a significant, original contribution to the accelerator field within the last six years. The other prize has no age limit, and is for an individual or group of individuals demonstrating achievement and innovation in the accelerator field since the commencement of EPAC in 1988. There is no restriction as to nationality.
- **CAS Scholarships:**
  The Group finances a scholarship, open to European university students, or persons without fixed employment, to attend the CERN Accelerator School General Basic Course.

For more information please contact:
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The importance of particle accelerators

Ugo Amaldi, University of Milano Bicocca and TERA Foundation, Italy

To discuss the relevance of particle accelerators to society it is useful to distinguish the three main uses of their primary, secondary and tertiary beams:
1. analyses of physical, chemical and biological samples,
2. modifications of the physical, chemical and biological properties of matter,
3. research in basic subatomic physics.

In this last application particles move close to the velocity of light and one should speak of 'massificators' rather than of 'accelerators'.

Sample analyses and modification processes

As far as the first two points are concerned, to a nice figure by K. Bethge [1] I have added the leaves representing the many applications that continue to sprout from its various branches (Fig. 1).

The trunk has its roots in the nuclear physics of the thirties and the pull towards higher energies and beam currents still comes today from the study of fundamental particles and their interactions. Some of the accelerator technologies mentioned in the figure became mature so long ago that they are no longer discussed at large international conferences.

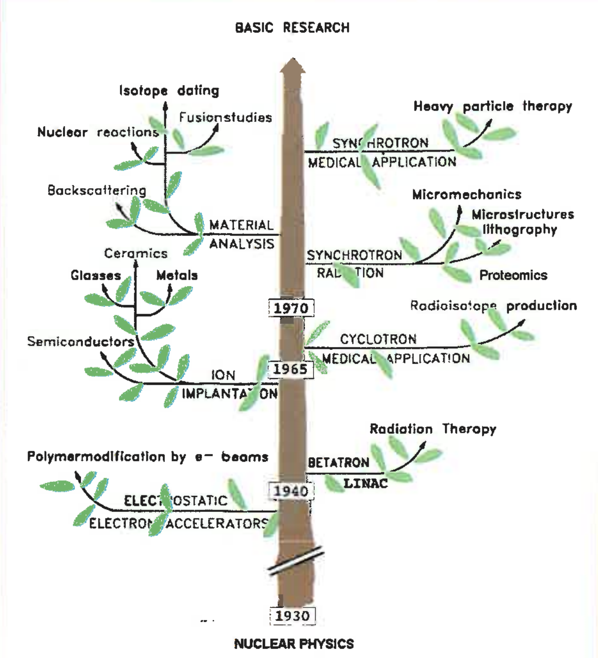

Fig 1: The Time Tree gives a pictorial view of the development of accelerators applications in both modification processes and sample analyses.

Already a cursory look at the figure proves that particle accelerators are very important, because they give irreplaceable contributions to many aspects of human life. The list of the fields of applications goes from A to Z, i.e. from art to zoology.

In the field of the *arts* one can consider the work done at the *Accélérateur Grand Louvre pour l'Analyse Élémentaire* (AGLAE) on a drawing made around 1450 and attributed to Pisanello. By means of the PIXE technique the attribution was falsified, since securely attributable drawings are characterised by much less copper than the amount observed [2].

For the letter B we consider *biology*. After the completion of the decoding of the human genome, the attention of molecular biologists has moved to 'structural genomics', the understanding of the shape and functioning of the proteins coded by each gene. X-ray diffraction of samples of crystallised proteins is at present the main tool in 'proteomics' and all suitable sources – in particular synchrotron radiation sources – are contributing and will continue to contribute.

Jumping for brevity down along the alphabet to medical *diagnostics*, cyclotrons are used to produce the isotopes used for *Positron Emission Tomography* (PET) and *Single Photon Emission Computed Tomography* (SPECT). Still, in about 80% of all examinations, isotopes (in particular Technetium 99m) produced at old reactors are used. It is high time to use for this type of production 100 - 150 MeV high-power cyclotrons instead of ageing reactors.

For curing some type of cancers, beams of 200 MeV protons are used with established medical protocols since almost 30'000 patients have been treated all over the world. At present the most promising new tool in radiotherapy is that form of *hadrontherapy* that utilises beams of light ions of atomic number around Z = 6. At variance with protons, which interact with the cells essentially as X-rays, light ions better control the slowly growing radioresistant tumours which represents about 20% of all the tumours irradiated with X-rays. Since 1994 at HIMAC in Japan about 800 patients have been treated with carbon ions with satisfactory results; moreover in 1998 the *carbon ion pilot project* was completed at GSI, where about 50 patients have been irradiated. In the years 1996-1999 an AUSTRON-CERN-GSI-TERA Collaboration has carried out the *Proton Ion Medical Machine Study* (PIMMS), a study of a light ion synchrotron optimized for medical applications [4]. PIMMS is the basys of the therapy centres proposed by the by the TERA Foundation [5] and by the Med-AUSTRON project [6] to their national authorities. Using PIMMS, preliminary proposals have also been prepared by TERA for the University Claude Bernard in Lyon and for the Karolinska Institute in Stockholm. Independently a hospital-based therapy centre has been designed by GSI for the Heidelberg University [7].

In *planetology* small beams of low energy protons are used. At the Heidelberg Proton Microprobe the PIXE elemental mapping of micrometeorites is done with a spatial resolution of a few microns [8]. Coming finally to the letter Z, in the field

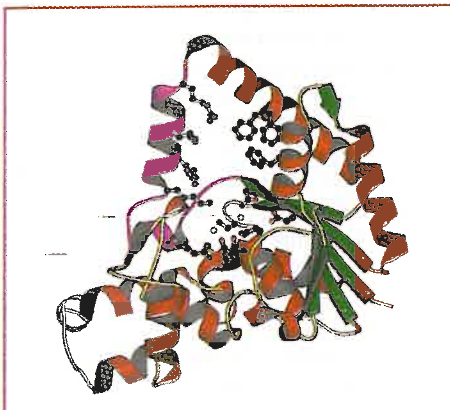

Fig 2: In 1996 the protein 5-exonuclease extracted from bacteriphage T5 was reconstructed from X-ray diffraction data collected at the ESRF [3].

of zoology one can quote the diffraction studies made at the European Synchrotron Radiation Facility of the isolated muscle fibre of a frog, excited at a frequency of 25 Hz [9].

The past spin-offs are impressive; what about the future? Spallation sources are moving to the unexplored territory of high power beams on target. Europe has a very good record with ISIS at RAL and two projects on the drawing table: the *European Spallation Source* [10] and the *AUSTRON project* [11]. In the USA the new generation facility SNS will produce beams by the year 2005 [12].

A completely new application of great importance is the development of X-ray emitting *Free Electron Lasers*. A project is underway in the USA [13] and another one is a parallel development of the work done for the TESLA linear collider centred at DESY [14]. A 5 Hz electron beam of 15-50 MeV formed of intense (1 nC) and short (80 fs) bunches radiates photons through *Self Amplified Spontaneous Emission* when moving through a long undulator. At 1 Å the peak brilliance will be at least ten orders of magnitude larger than the one achievable today.

Another recent developments centres on Rubbia's energy amplifier, a sub-critical lead-cooled fast fission reactor injected with the spallation neutrons produced by a powerful beam of 1 GeV protons. The main use would be the incineration of radioactive wastes, but through the *Adiabatic Resonance Crossing* method [15] it could replace the ageing fission reactors in the production of Technetium 99m.

Finally one should not forget that the results of the experiments going on in Japan, the USA and France on inertial fusion induced by laser beams converging on a pellet cannot be directly applied to reactor construction due to the low laser efficiency. The only viable solution is based on short and powerful ion bunches. The accelerator systems required are complicated but the components are based on reasonable extrapolations of existing technologies [16].

All these examples show the importance of particle accelerators in art, medicine, industry and non-nuclear sciences. The argument becomes even stronger when the number of accelerators is considered.

Table 1 shows that 55% of the 15'000 accelerators running at present in the world are devoted to modification processes: ion implantation, surface modification and industrial applications (mainly sterilisation and polymerisation). Electron linacs used in radiotherapy represent one third of all the existing accelerators. There are about 70 synchrotron radiation sources in the world, with the highest density in Japan, and more than 100 particle accelerators used for research in subatomic physics. In 1994 the total number of accelerators was about 10000, so that one can conclude that the progression rate is about 15% per year.

CATEGORY	NUMBER
Ion implanters and surface modifications	7'000
Accelerators in industry	1'500
Accelerators in non-nuclear research	1'000
Radiotherapy	5'000
Medical isotopes production	200
Hadrontherapy	20
Synchrotron radiation sources	70
Research in nuclear and particle physics	110
TOTAL	15'000

Table 1: Accelerators in the world. The data have been collected by W. Scarf and W. Wiesczycka [17].

Status of subatomic physics and its future accelerators

Subatomic physics covers two subjects: nuclear physics and particle physics. The former is concerned with systems having baryon numbers much larger than 1 and naturally subdivides in two chapters. The content of the first chapter, titled *high-temperature nuclear physics*, is best discussed with reference to the phase diagram of Fig. 3.

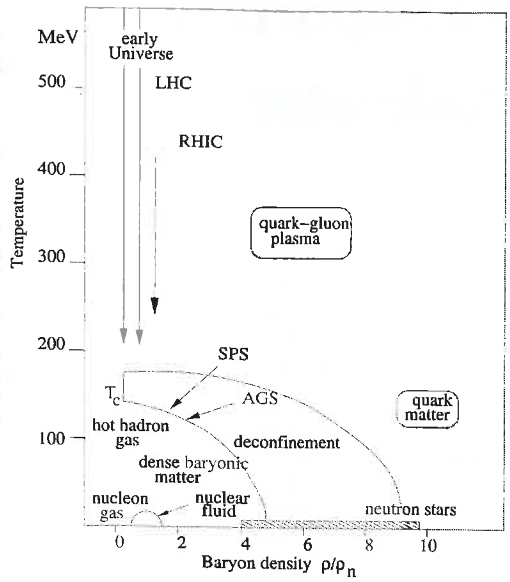

Fig 3: The expected deconfinement transition (also called quark-gluon plasma or parton-hadron transition) is shown together with the phase-space regions experimentally studied at the AGS, the SPS, RHIC and LHC. The horizontal axis represents the density measured with respect to the density existing at the centre of large nuclei.

On the horizontal axis the relative baryon densities of the smaller (the atomic nuclei) and the largest nuclear systems (the neutron stars) are indicated. On the vertical axis the temperature of systems having baryon number definetely larger than 1 is plotted in terms of the component kinetic energy, the correspondence being 100 MeV = 10^{12} kelvin. The problem here is the experimental study of the deconfinement transition predicted by the Standard Model description of the baryons in terms of quarks bound by the continous exchange of gluons. The oblique arrows indicate the approximate paths of the non-equilibrium baryonic systems studied by colliding heavy ions with heavy fixed targets at the AGS (Brookhaven) and at the SPS (CERN).

Recently the physicists working at the SPS have put together all the information, collected by many different experiments in ten years of work, coming to the conclusion that a *new state of matter* has been observed. The results soon expected from RHIC should bring very clear information on the deconfinement transition starting from temperatures which are about two times larger than the transition temperature (200 MeV). The lead-lead collisions to be studied with the ALICE experiment at the LHC will start with much larger temperatures, thus reproducing even more closely what happened in the early Universe. From this point of view it can be said that, if no other higher temperature transition is discovered, there will be no need of a ion-ion collider of even greater energy.

Fig. 4 reproduces the chart useful to describe the main issues encountered in the second chapter, which can be called *'low-temperature nuclear physics'*.

The dark and shaded area cover the well-studied stable and unstable

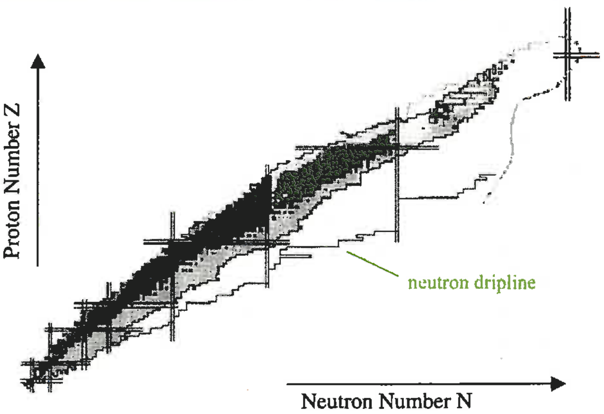

Fig 4: In this standard chart the nuclei that are below the neutron dripline are not bound. The crosses indicate the magic nuclei.

nuclei. Below, bounded by the neutron dripline one sees the area of neutron-rich nuclei that can be produced only by accelerating and colliding unstable (radioactive) nuclei with fixed targets. The frontier instruments of low-temperature nuclear physics are thus *accelerators of radioactive nuclei*. The phase space to be explored is very large, as indicated by the extension of the unknown white area lying above the *neutron dripline.*

The importance of these experiments also comes from the fact that here the so-called '*r-process*' takes place, i.e. the rapid neutron capture happening in supernovae and leading to the creation of many elements heavier than iron.

The links between subatomic physics and astrophysics are even stronger. Indeed all that one learns on the second subject of subatomic physics – i.e. 'particle physics' - is crucial for solving the first of the *three really important scientific problems*: the origin of the Universe, the origin of life and the origin of consciousness. This is possible because simple thermodynamic considerations connect the universal time *t* with the energy *E* available in the collisions of the particles forming the primordial soup:

$$t_{\text{microseconds}} \cong 1/\, E^2{}_{\text{GeV}}.$$

The collision and decay phenomena happening both at the beginning of the Universe and now around our massificators are determined by elementary emission and absorption processes that are governed by the numerical value of α^{-1}, the *inverse of the coupling.*

The reason is that for every interaction (strong, electromagnetic and weak) α^{-1} equals the number of times one has to observe the matter-particle before finding a virtual mediator close to it. If α^{-1} is of the order of 1, the matter-particle is always surrounded by a mediator and the force is strong.

The main point is that the value of α^{-1} depends upon the energy (or the momentum) *E* of the virtual force-particle. Indeed, when a blob of energy-momentum E surrounds a matter-particle, all particle-antiparticle pairs of energy smaller than *E* can be created for a very short time. They influence the interaction between the mediator and the matter-particle and change the value of α^{-1}. For instance, when a virtual photon of momentum larger than about 10 GeV is exchanged between two electrons passing by, the couplings are modified by the momentary creation of beauty-antibeauty quarks, each having a mass of about 5 GeV.

Quantum field theory allows precise calculations of the energy dependence of all couplings, once their values at a given energy are known together with the masses of all the particles that can temporarily be created. In 1991 the new accurate LEP measurements of the three fundamental couplings performed at E ≅ 100 GeV allowed for the first time their precise extrapolation [18] and a fact suspected for a few years became a certainty: in the Standard Model the forces do not unify at high energy. But unification is obtained if a theoretically more satisfactory model is adopted, the *Supersymmetric (SUSY) Mod-*

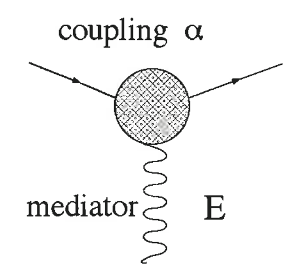

Fig 5: Emission and absorption of a mediator by a matter-particle, either quark or lepton.

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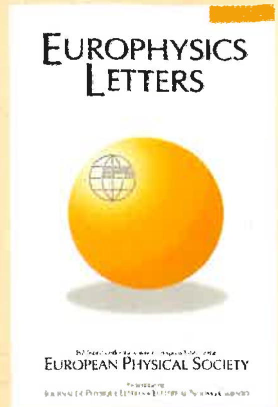

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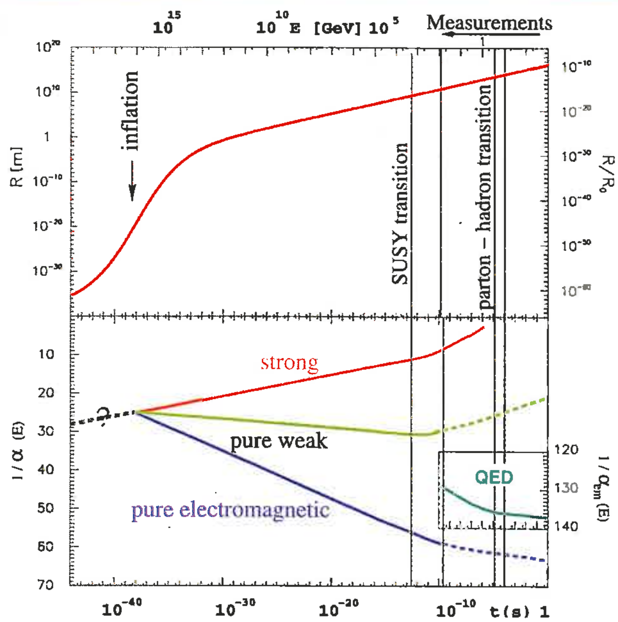

Fig 6: The lower graph shows the possible times of occurrence of the SUSY transition (i.e the disappearance of the superparticles) and of the parton-nucleon transition (i.e. the disappearance of the quark-gluon plasma). As indicated by the upper scale, in this graph energy goes from right to left, so that the universal time goes from left to right as indicated on the lower scale. The upper panel represents the inflation of the early Universe, which probably happened at the time of the divergence of the three fundamental couplings.

el in which there is *full symmetry* between the matter-particles (quark and leptons) and the force-particles (the boson transmitting the fundamental forces). In the minimal version of such a model - as in other less simple ones - new 'superparticles' are predicted at energies just above the about 100 GeV explored till now. Their existence would modify the energy dependence of the couplings, bending them towards a unification point at 10^{16} GeV, as shown in the lower part of Fig. 6. (Note that in this graph the energy scale goes from right to left and that experiments have been done only in the energy region marked 'measurements'.)

Fig. 6 shows that in this model the couplings diverged, at 10^{-38}s, and at 10^{-12}–10^{-10}s a transition took place, during which all superparticles decayed and could not be created any longer for the lack of energy in the collisions. (It is however possible that the lightest neutral superparticles did not decay and form today the so-called 'dark matter'.) Also other models of the events before 10^{-10}s are fashionable today. Anyway we know that around that time all the W and Z weak bosons decayed. Since then the pure weak and pure electromagnetic forces are mixed together to form the usual weak and electromagnetic forces (inset of Fig. 6). The only way to probe the possible SUSY transition is to study collisions at energies larger than 100-200 GeV. This is the energy domain of the LHC.

The *matter-particles of the Standard Model* are the second hot issue in particle physics. For the quarks the phenomenology is quite well known. In the collisions processes, the down, strange and beauty quarks are produced, but in the decay processes linear combinations of them - indicated as d', s' and b' - give the observed effects. The Cabibbo-Kobayashi-Maskawa matrix connects them and it took more than forty tears to have measurements of reasonable precision (Fig. 7). The three neutrinos are expected to display a similar behaviour. This is, in a sense, a theoretically 'simpler' and thus even more interesting phenomenon to constrain the hopefully 'final' theory that will embrace and supersede the Standard Model, since neutrinos do not feel strong interactions.

Quark mixing can be studied at colliders because all heavier quarks decay within a few millimetres. Neutrinos, being the lightest of all particles, do not have enough energy to decay and thus, once produced, travel for ever and one has to perform 'oscillation experiments' with very intense neutrino beams and long flight-paths. We already know the order of magnitude of some non-diagonal elements of the neutrino matrix, but only much better measurements will allow to falsify any 'theory of everything': certainly more than fifty years of experimental work will be needed. These are the arguments that in the last years have prompted the design of *neutrino factories*. They will become widely required accelerator complexes to be built together with the more standard hadronic and leptonic colliders in our accelerator centres, eventually sending beams to far away underground laboratories in a possible *World Wide Neutrino Web*.

This field is in full development while the future of lepton and hadron colliders is well defined. Precise experiments on the quark sector will continue at quark factories and possibly at a new Z-factory. As far as the high-energy frontier is concerned, while LHC experiments will be running, at least one high-energy electron-positron linear collider will have to be built to study in detail the new energy domain explored with the wide-band but less precise proton-proton processes. The energy attainable should be as large as feasible; the results obtained at LEP, Tevatron and LHC will indicate the optimal initial energy. Muon colliders are for later, when neutrino factories will have opened the way to intense muon sources.

It is interesting to remark that targets absorbing many megawatts of power carried by high energy proton beams are needed both for fundamental research (neutrino and muon factories), for research in non-nuclear sciences (spallation sources) and for energy and medical applications (accelerator driven subcritical reactors). This is a wonderful example of unexpected synergetic developments.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} 0.9740 \pm 0.0010 & 0.2196 \pm 0.0023 & 0.0040^{+0.0006}_{-0.0007} \\ 0.224 \pm 0.016 & \mathbf{0.91 \pm 0.16} & \mathbf{0.0402 \pm 0.0019} \\ < 0.010 & \simeq 0.0400 & 0.99 \pm 0.29 \end{pmatrix}$$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & c_{13}s_{12} & s_{13} \\ -c_{23}s_{12}e^{i\delta} - c_{12}s_{13}s_{23} & c_{12}c_{23}e^{i\delta} - s_{12}s_{13}s_{23} & c_{13}s_{23} \\ s_{23}s_{12}e^{i\delta} - c_{12}c_{23}s_{13} & -c_{12}s_{23}e^{i\delta} - c_{23}s_{12}s_{13} & c_{13}c_{23} \end{pmatrix}$$

Fig 7: The experimental CKM matrix connecting the quarks is given by neglecting the CP violating phase. A parametrisation of the neutrino mixing matrix is also shown.

Conclusion

Particle accelerators are important for the arts, the other sciences, medicine and high-tech industries so that their overall number increases by about 15% per year. The high energy ones are crucial for the understanding of the origin of our Universe and of the formation of heavy nuclei, without which the Earth could not exist. Moreover they give the information needed to falsify any new 'theory of everything'. Thus, the trunk of the Time Tree is strong and developing, the old leaves are green and new leaves are sprouting. If the accelerator specialists continue to invent and labour as in the past, the future of particle accelerators and massificators is secured.

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Accelerated beams of radioactive nuclei

W Gelletly

The study of nuclear physics demands beams of energetic particles to induce nuclear reactions on the nuclei of target atoms. It was from this need that accelerators were born. Over the years nuclear physicists have devised many ways of accelerating charged particles to ever increasing energies until today we have beams of all nuclei from protons to uranium ions available at energies well beyond those needed for the study of atomic nuclei. This basic research activity, driven by the desire to understand the forces which dictate the properties of nuclei, has spawned a large number of beneficial applications. Amongst its many progeny we can count reactor- and spallation-based neutron sources, synchrotron radiation sources, particle physics, materials modification by implantation, carbon dating and much more. It is an excellent example of the return to society of investment in basic research.

All of these achievements have been realised by accelerating the 283 stable or long-lived nuclear species we find here on Earth. We see them in fig. 1, the black squares, plotted as a function of the numbers of protons (Z) and neutrons (N) that they contain. In recent years, however, it has become evident that it is now technically possible to create and accelerate unstable nuclei and, as we see in fig. 1, there are some 6-7,000 distinct nuclear species which live long enough to be candidates for acceleration. They are the nuclei within the so-called drip-lines, the point where the nucleus can no longer hold another particle. It needs little imagination to see that this development might not only transform Nuclear Physics but could lead to many new, undreamed of, opportunities in industry, medicine, material studies and the environment.

In this short article I would like firstly to outline the ways in which we can produce them and secondly to describe some obvious applications of such beams.

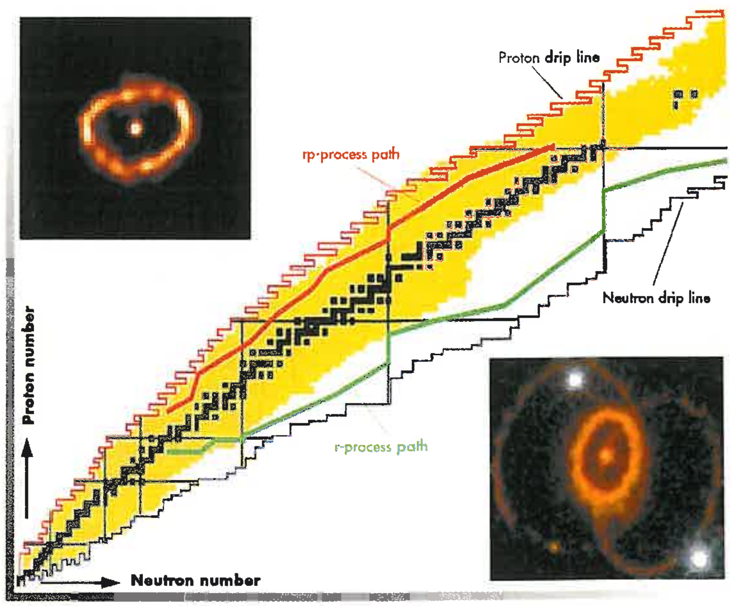

Fig 1: A chart of the nuclides with the black squares, representing the stable nuclei, plotted as a function of the number of protons and neutrons in the nucleus. It also shows the limits of observation of nuclei, the drip-lines and the astrophysical r- and rp-process pathways. The insets show Hubble Space Telescope images of the nova Cygni 1992, a possible rp-process site, and the afterglow of SN1987A, an r-process site.

How can we produce beams of unstable nuclei?

Fig. 2 shows schematically the two main methods of radioactive beam production which have been proposed. They are commonly known as the ISOL-Isotope separation on line – and In-flight techniques. In the ISOL method, we must first make the radioactive nuclei in a target/ion source, extract them in the form of ions and, after selection of mass by an electromagnetic device, accelerate them to the energy required for the experiments. In contrast, the in-flight method relies on energetic beams of heavy ions impinging on a thin target. Interactions with the target nuclei can result in fission or fragmentation, with the nuclei which are produced leaving the target with velocities close to those of the projectiles. A cocktail of many different species is produced which, since the ions have high velocities, does not need further acceleration to transport it to the secondary target. On route to the target the reaction products can be identified by mass, charge and momentum in a spectrometer (fragment separator). Thus a pure beam is not separated out from the cocktail. Instead each ion is tagged and identified by these primary characteristics and the secondary reactions are studied on an event-by-event basis. More recently US scientists have proposed a combination of the two methods in which the in-flight reaction products are brought to rest in a gas cell, sucked out and separated by mass and then re-accelerated to the required energy.

The ISOL and in-flight methods are complementary in almost every respect. With the ISOL technique one can produce beams of high quality, comparable to that of stable beams. Since we start with ions at the temperature of the target/ion source the process is similar to the way the beam is generated in a stable beam accelerator so one can produce beams of similar quality. Strong ISOL beams can be produced but the intensity varies markedly according to a) the chemical species involved and b) how far from stability they are. Refractory elements such as Zirconium and Molybdenum are extremely difficult to ionise and are not suitable for the method at present. This technique also relies on the diffusion and effusion of the radioactive atoms in the target, which is maintained at high temperatures (~2500°C) to speed the process up. Such diffusion processes vary a lot in speed. For short-lived nuclear species, with half-lives of milliseconds or less, this is often the limiting factor in intensity because the atoms decay before they reach the final target.

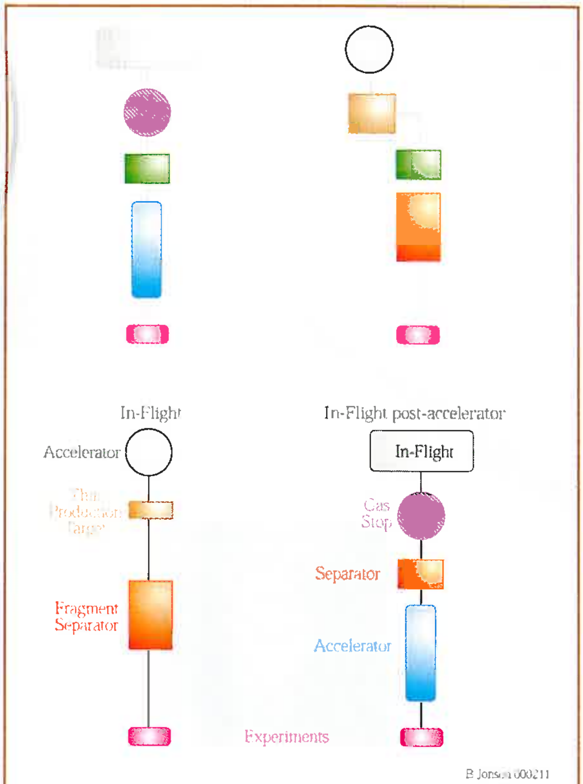

Fig 2: A schematic view of the basic methods of producing radioactive nuclear beams. At the top we see the ISOL method with and without a post-accelerator. Below we see the In-flight method and the proposed hybrid in which fragments are caught in a gas cell and then re-accelerated.

In contrast, in-flight facilities can produce all chemical species with half-lives greater than about 150ns, the time of transit through the fragment separator, and since the beams are produced at high energy they do not need re-acceleration. The main drawbacks of this method however are that a) the beams are weak, b) they are not separated physically – the individual ions are simply tagged electronically by A, Z and momentum and c) they are of poor quality in terms of energy and focussing.

The idea of combining the ISOL and in-flight methods by stopping fragmentation products in a gas cell is clearly aimed at getting the "best of both worlds". In principle the method should work but it requires considerable development to show that it is effective.

Uses of Radioactive Beams

What can we do with beams of radioactive ions? It turns out that they provide an analytical tool which can be used to probe the structures of atomic nuclei and materials as well as having applications in nuclear astrophysics, bio-medicine and the environment.

Thus ion implantation is widely used to modify the properties of materials. It is a versatile tool and can be used to alter the mechanical, electrical, optical, magnetic and chemical nature of materials. The process is independent of the normal solubility or alloying rules. Thus it has been used to create a wide range of semiconductor devices as well as machine tools and replacement parts for the human body which are wear resistant.

In general the modification required is achieved empirically. How much better, however, if we could determine where the implanted ions end up. We can do that by implanting radioactive ions of the same chemical species under exactly the same experimental conditions. As illustrated in fig. 3 the radiation pattern of the implanted ions is influenced and altered by the electric and magnetic fields in the material of the host. By monitoring these changes with various techniques we can obtain information on the nature of the sites they occupy and their surroundings. In some sense we can see the radioactive ions as "spies" on the microscopic environment. The information our spies glean allows us to understand the implantation process and hence design better devices.

Radioactive decay involves chemical transformation and is characterised by its half life. Thus it can provide a chemical signature at the atomic level. Many standard spectroscopic techniques used in materials studies, such as photoluminescence, electron paramagnetic resonance and deep level transient spectroscopy, are chemically blind. If they are used with radioactive implants this "chemical blindness" can be cured for these techniques by following the growth and decay of the signals. In other words using radioactive implants will take the "informed" guesswork about chemical species out of the use of these techniques.

Almost everyone must be aware of the widespread use of nuclear techniques in medicine for diagnosis and therapy. A simple example is the use of radioactive tracers in vivo. This has been done for a long time but is not fully exploited because of limitations on the range of tracers. Positron emitters provide the basis of PET (Positron Emission Tomography). Its use

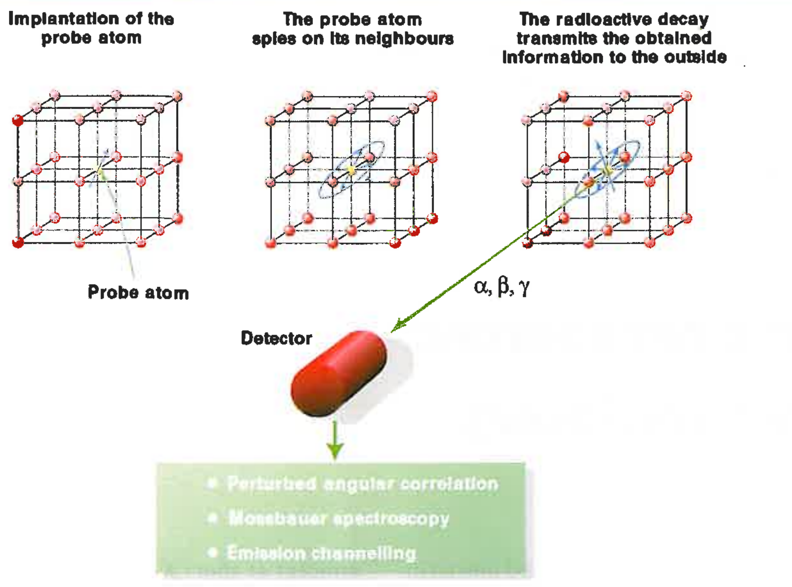

Fig 3: An illustration of how radioactive probe atoms implanted in a solid can act as "spies" on their microscopic environment. The properties of the probe atom are modified by the local microscopic environment and that information is carried away by the radiation emitted in the radioactive decay that follows.

is limited by the positron emitters available. Beta emitters have great potential for radionuclide therapy but with a few exceptions those of therapeutic interest are not commercially available. ISOL-based radioactive beam accelerators could repair this deficiency. Amongst many possible topics, therapeutic effects are known to depend on specific activity and so systematic studies of the relationship between the specific activity of tracers and the biological response are important to clinical research. Again the radio-lanthanides are non-specific "tumour-seeking" tracers, which could be produced "carrier-free" and in sufficient quantities in ISOL systems. So far we have only scratched the surface in this general area.

Environmental problems can also be tackled. When we investigate how to isolate and store nuclear waste we immediately worry about leakage of the long-lived, fission products. The general thrust of this research is to incorporate the waste into a solid which is then contained within a concrete or rock barrier. To be sure there is no external contamination we need to know all about how the radionuclides are transported in these materials. This can be investigated by implanting ions of shorter-lived radioactive fission products and determining how they move in the storage material.

For the nuclear physicist these facilities are a cornucopia of beams for all sorts of purposes. Amongst the many delights is that they will allow us to probe the limits of existence of nuclei. Basic theoretical predictions of how heavy a nucleus can be, or how many neutrons or protons it can hold will be tested much more vigorously than before. We now have little doubt that the basic idea behind "superheavy" elements is correct. To date we are fairly sure that a few atoms of elements up to Z=112 have been detected and there has been exciting but as yet unconfirmed evidence of the detection of elements 114, 116 and 118. However the heart of the predicted island of superheavies has many more neutrons than the species which have been created so far. One route leading closer to the centre of the Island would be to use nuclear reactions induced by beams of radioactive nuclei rich in neutrons.

Similarly we have little idea of the point where we can no longer add another neutron to the nucleus. Intriguingly we believe that neutron stars exist and they are, in essence, gigantic nuclei made of neutrons. Hence we might think that we could add neutrons forever. However neutron stars are so heavy that gravity plays a major role in stabilising them. We believe that there are limits but our present best guesses vary by 20-30 neutrons in the case of tin (Z=50) isotopes. Beams of radioactive nuclei will allow us to narrow the range of guesses if not decide where the neutron-rich nuclei come to an end by precise measurements of nuclear masses and the separation energies for the last neutron. In exploring these questions we will also encounter many new phenomena. We expect to see skins and haloes of neutrons in nuclei far from stability and we anticipate that the quantum shells which underpin nuclear structure in stable nuclei will disappear in these exotic nuclei.

Beams of radioactive nuclei open a gateway to better understanding in nuclear astrophysics as well. The generation of energy in stars, which stabilises them, and the creation of the elements is the result of nuclear reactions. Fusion processes fuel the Main Sequence stars and create the elements up to $^{56}Fe/^{56}Ni$. The process runs out beyond this point because it needs an input of energy for fusion to continue. In massive stars this is the root cause of their death in the massive explosions we see as supernovae. Most of the nuclear species beyond A=56 are created in type II supernovae. The death throes of these massive stars are accompanied by enormous fluxes of neutrons for short periods. This results in the rapid capture of many neutrons followed by beta decays ending up with heavy nuclei along the lines of stability. The pathway for this so-called r-process is shown in fig. 1. In other dramatic, explosive processes in stars such as novae and X-ray busters a similar process involving proton capture and beta decay, the rp-path (see fig. 1), may be involved in the creation of some of the proton-rich, stable nuclei. Testing these ideas requires the details of nuclear reactions and of the structure of nuclei involved. As we can see from fig. 1, the r- and rp-process pathways pass through large numbers of unstable nuclei. If a reaction involving such a nucleus is important to our understanding of what happens in stars the only way we can study them is to use a radioactive beam incident on a light target; hydrogen or helium. Hence the importance of radioactive beams for this field.

Where are they?

Given the ferment of ideas and activity in this field it is not surprising that there are many proposals to build new ISOL facilities around the World and to upgrade the four, major In-flight facilities at GSI (Germany), GANIL (France), RIKEN (Japan) and MSU (USA). It would be invidious to pick some out and not others and tedious for you the reader to list them all. If you are interested you can try the article by W Nazarewicz et al in Nuclear Physics News, Vol. 6, No. 3, p.17 (1996). Alternatively you can rest assured that "A Radioactive Beam Facility is coming soon to a neighbourhood near you!"

X-rays are an excellent probe for the structure of matter since their wavelengths are as short as the diameter of an atom. Employing a linac-based free electron laser, an international team at the DESY laboratory in Hamburg has obtained laser light with wavelengths below 100 nanometres.

The bright future of x-ray sources: Linac-based free electron lasers

Ilka Flegel and Joerg Rossbach /DESY

On February 22, 2000, an international team working at the TESLA Test Facility (TTF) at DESY, Hamburg, set a new record for the shortest wavelength of radiation ever achieved with a Free Electron Laser (FEL) [1]. The collaboration, involving around 140 scientists from 38 institutes in 9 countries, succeeded in generating ultraviolet radiation with a wavelength of 109 nm. The previous best using this type of SASE (Self-Amplified Spontaneous Emission) free electron laser was 530 nm obtained by a group at Argonne [2]. Within a few weeks, the TTF team pushed the wavelength down to 80 nm and tuned the FEL to various wavelengths up to 180 nm, demonstrating for the first time free wavelength tunability of SASE FELs over a large range.

To accomplish this decisive step towards shorter laser wavelengths, the TTF team made use of the electron beam from the superconducting linac of the TTF, set up for development and testing of new superconducting niobium cavities for DESY's planned 33-kilometre TESLA electron-positron linear collider. [3]

Having demonstrated SASE at wavelengths around 100 nm, the collaboration will soon extend the TTF into a 300-metre device to operate in the soft X-ray range around 6 nm [4]. This facility should become available for user experiments by the end of 2003.

The ultimate goal is to produce "hard" X-rays with a wavelength of 0.1 nm. Since this requires an electron beam of much higher energy, it is planned to integrate such a hard X-ray laser facility into the proposed TESLA linear collider.

Synchrotron radiation

Since its discovery in the mid-1940s, synchrotron radiation has evolved into an invaluable research tool for applications in many different fields of science — from surface physics, materials sciences and chemistry, to geophysics, molecular biology and medicine. Nowadays, third-generation synchrotron radiation sources produce high brightness photon beams covering the complete range from infrared to hard X-rays. However, the electrons producing these photons do not radiate in phase, and a true high-power X-ray laser has so far remained a dream.

How to reach this "ultimate" X-ray source has been the subject of many efforts, both theoretically and experimentally, over the last twenty years. During the past six to eight years, a consensus has developed that fourth-generation sources, implying a higher degree of coherence, higher power, brilliance, and ultrashort pulses, possibly at very short wavelengths in the hard X-ray region, would probably involve a linear accelerator driving a free electron laser.

This shift from storage rings to linear accelerators is necessary, because the quality of the electron beam — short bunch lengths and small beam emittance — is limited in storage rings, but crucially important for the FEL process. For the SASE concept at short X-ray wavelengths the limitations of storage rings become particularly noticeable.

Free electron lasers

The main ingredients of a free electron laser are a high-energy electron beam with very high brightness and a periodic transverse magnetic field, such as that produced by an undulator structure. As the electron bunches wiggle through the magnetic field, they emit synchrotron radiation around their direction of motion. For small undulations, the radiation is quasi-monochromatic. For every undulator period, the radiation phase moves ahead of

Fig 1: An international team using the superconducting linac at the TESLA Test Facility (TTF) at DESY, Hamburg, has set a new record for the shortest wavelength of radiation ever achieved with a Free Electron Laser (FEL) – Photo DESY.

the electrons by a distance equal to this specific resonance wavelength — keeping each electron in phase with the radiation field.

Depending on the relative phase between radiation and electron oscillation, electrons experience either a retardation or acceleration with respect to the mean electron velocity. To obtain SASE, the electron beam has to be of sufficient quality and the undulator long enough. In this case, the electron bunch starts to develop a longitudinal density modulation with a period length equal to the resonance wavelength of the undulator. This electron density modulation or "microbunching" reduces phase cancellation in the emission process, increasing the intensity of the emitted radiation. This radiation interacts further with the electron beam and enhances the bunch density modulation, thereby further increasing the intensity. The net result is an exponential increase of radiated power to a saturation value that is approximately six orders of magnitude higher than the power of conventional undulator radiation.

No mirrors

Like conventional lasers, most present free electron lasers use an optical cavity formed by mirrors to store the light from many successive electron bunches. Many of these FELs work in the infrared range, and some even reach ultraviolet wavelengths. However, extending them into the X-ray regime is difficult due to the lack of well reflecting surfaces at wavelengths below 150 nm and the increasing risk of radiation damage.

An alternative path to shorter wavelengths was found with the development of SASE free electron lasers. They start from noise and reach saturation within a single pass of a high-brightness electron bunch through a very long undulator, without any mirrors.

The concept of SASE free electron lasers was introduced in the early 1980s [5], and further explored in 1984 [6], soon leading to first experimental tests [7]. In 1997-98, a Los Alamos/UCLA experiment at Los Alamos [8] produced a gain of $3x10^5$ for the first time, and established the proof-of-principle of SASE theory at a wavelength of 12 micrometres. Recently, SASE at 530 nm was demonstrated at Argonne [2] and saturation power was reached a few months later [9].

Testbed

The TESLA Test Facility (TTF) was set up at DESY in 1993 to provide a testbed for

Fig 2: The undulator used in DESY's TTF free electron laser is a 15-metre magnetic structure comprising three 4.5-metre modules, each made up of 652 permanent magnets. To ensure that the electron beam does not deviate from a straight line by more than 50 micrometres, the magnets have to be fitted together to an accuracy of just a few microns. In addition, the undulator is set up in a special air-conditioned hutch where the temperature is held constant with a precision of 0.1 degrees in order to avoid expansion of undulator components.

the TESLA linear collider project, especially the superconducting niobium cavities for particle acceleration. In 1994, work began on the test accelerator which will finally be extended into a 300-metre soft X-ray FEL comprising all the basic elements that will be subsequently employed in the hard X-ray lasers integrated into TESLA.

In the first phase, operating around 100 nm wavelength, the TTF is equipped with a 15m long undulator, a bunch compressor reducing the bunch length thus increasing the peak current, and a radiofrequency (RF) photocathode electron gun. There are essentially two technical challenges to be met for an X-ray FEL. First, it is crucial to generate and accelerate a low emittance and high peak current electron beam. This can be achieved using a high-brightness radiofrequency photocathode gun as an electron source. The electron gun currently used at the TTF-FEL is a joint contribution of Fermilab, INFN/Mi-

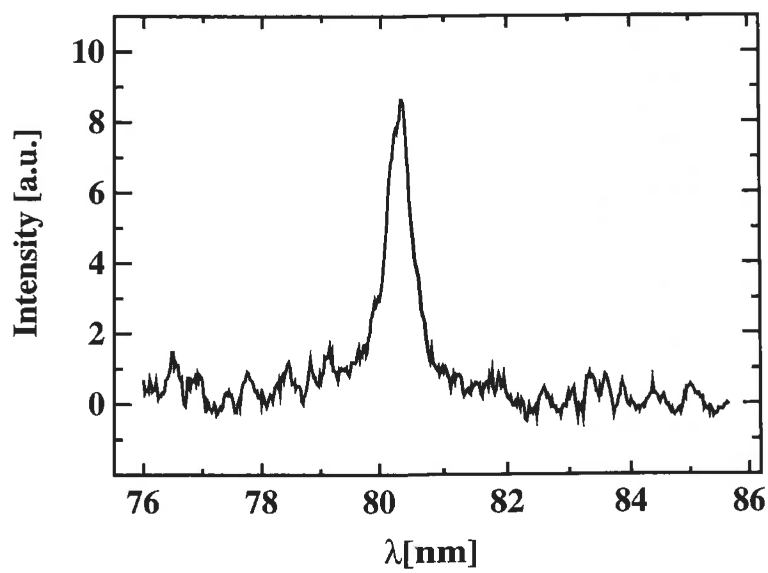

Fig 3: Spectrum of FEL radiation at a wavelength of 80 nanometres.

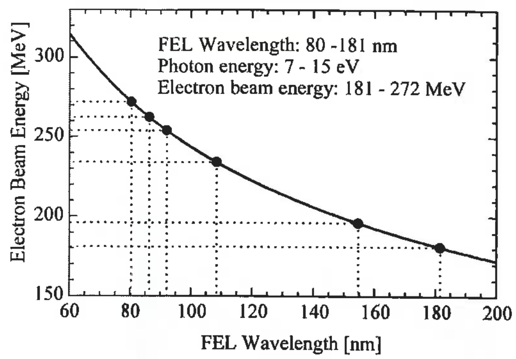

Fig 4: "Map" of wavelengths of SASE FEL radiation obtained at the TTF. The picture demonstrates the tunability of the wavelength which is achieved by a variation of the electron energy in the accelerator.

lan, Rochester, the Max Born Institute in Berlin, and DESY.

It has meanwhile been demonstrated that such a particle source can drive a facility 24 hours a day for weeks and even months. Since the RF gun performance is so critical for the further development, DESY is building up a stand-alone gun test facility at its institute in Zeuthen near Berlin.

The peak current of the electron bunches produced by the low-emittance gun is still not high enough to reach laser saturation within an undulator of reasonable length. The solution is to compress the bunches longitudinally to increase the peak current. This can be achieved by using a "bunch compressor chicane" - a sequence of deflecting magnets.

The principle is not new, but it is a challenge to reach a few kilo-amperes of peak current since this requires bunch lengths below 0.1 mm. Accelerating the beam off the crest of the RF wave in the linac creates an energy-phase correlation that can be used to shorten the bunch. When passing the chicane, electrons with different momenta travel different path lengths. The TTF-FEL currently uses a bunch compressor at 140 MeV which compresses the bunch length below 0.5 mm rms.

The second important technical challenge is to keep the electron beam (focused to a transverse beam size of about 0.1 mm) in essentially complete overlap with the photon beam as it passes through the undulator. This sets new standards for undulator alignment procedures and beam orbit control.

Interleaved operation

Combining the machine expertise at a high-energy physics facility with operation of a radiation source continues a long and fruitful tradition at DESY. Technically, both X-ray SASE FELs and linear colliders depend fundamentally on the generation of low-emittance, short electron bunches and on accelerating long bunch trains conserving the beam properties. This is best achieved with a superconducting linac, combining high accelerating gradients and low wakefield effects with long bunch trains at high duty cycle, due to low power losses.

For power cost reasons, a superconducting linear collider has an RF-on-time fraction of only 1%. Consequently, there is room for further RF pulses to accelerate an interleaved electron beam for FEL operation. In this way, the most expensive component of an X-ray laser, the linac, is shared with the high-energy physics community.

All TTF findings are consistent with existing models for SASE FELs. So far, a laser gain of a few thousand has been observed, while laser saturation is expected well beyond 10^6. Thus, the next steps will be focused on achieving higher laser gain by improving orbit control and electron beam quality. Operation with long trains of several thousand electron bunches will also be tested. The TESLA collaboration will then upgrade the superconducting linac to 1 GeV, bringing the FEL wavelength down to 6 nm [4]. The new user facility should be ready for experiments by the end of 2003. As for the TESLA Linear Collider with Integrated X-ray Lasers, a conceptual design was published in 1997 [3], and a Technical Design Report, including schedule and costs, will be presented in 2001 for evaluation by the German Science Council (Wissenschaftsrat), the German Federal Government's scientific advisory board. As a first step towards formal planning permission, an agreement between the relevant German federal states was signed in 1998.

The above article is an updated version of an article that appeared in CERN Courier, July/August 2000, pp. 26-28.

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Synchrotron light through ancient glass

I. De Raedt, B. Vekemans, K. Janssens, F. Adams

Synchrotron Radiation induced micro X-ray Fluorescence (μ-SRXRF) can provide complementary information on trace elements when used together with EPMA (Electron Probe Micro Analysis). EPMA has a limited sensitivity with detection limits of 0.1 % in the most favourable conditions. Offering ppm level detectability for many more elements, SRXRF is considerably more powerful for quantitative fingerprint analysis in order to gain a better understanding of the provenance of archaeological objects. In this paper, after a short description of the μ-SRXRF instrumentation, a study on sixteenth and seventeenth century glass objects from Antwerp will be briefly outlined.

Instrumentation

The μ-SRXRF measurements were executed at the Hasylab (Hamburger Synchrotron Labor, Hamburg, Germany) beamline L using a 20x20 μm² white synchrotron X-ray beam. A photograph and schematic drawing of the experimental set-up is shown in Figure 1. Quantification of the μ-SRXRF spectra was performed using a fundamental parameter method [1]. The accuracy of the method was checked as with the EPXMA measurements by means of a series of glass standards with certified trace composition [2].

Analysis of sixteenth and seventeenth century Antwerp glass vessels

Archaeological excavations in the historical center of Antwerp have yielded an important number of sixteenth and seventeenth century glass made 'à la façon-de-Venise' (Figure 2). The basic assumption is that most of these objects are locally manufactured, on the other hand some of them may have been imported from Venice. With the aim of making a distinction between local and Venetian production, the major and trace composition of about 130 soda-lime glass vessels was determined.

Figure 3(a), a binary plot of the amount of K_2O versus the amount of CaO, reveals the existence of four distinct compositional groups. Two groups, labeled 'Antwerp cristallo' and 'Antwerp vitrum blanchum', show major compositions nearly identical to the composition of two genuine Venetian glass types, 'cristallo' and 'vitrum blanchum' [3], suggesting that these objects might have been imported. The two other categories, named 'Antwerp façon-de-Venise' and 'Antwerp mixed alkali', appear to be specific for the Antwerp production. It is however surprising that the proportion of the cristallo and vitrum blanchum glass appears to be important among the Antwerp finds. In previous studies on glass from London and Amsterdam of the same period it seemed that only a few vitrum blanchum glasses are found and glass with the 'cristallo' composition occurred even more rarely [4, 5]. In order to investigate whether indeed the cristallo glass and vitrum blanchum glass was imported and made with the same raw materials as genuine Venetian glass vessels, i.e. very pure quartz pebbles and purified Levantine soda ashes, the trace element composition was determined. In addition, a number of glass vessels from Venice were analyzed as reference [3]. The study of the trace element content revealed that the amount of Zr was especially distinctive for differentiating local production from Venetian import. Figure 3(b) shows a binary plot of the amount of Zr versus the amount of Sr. Whereas the majority of the Antwerp finds features a Zr content between 40 and 100 ppm, the truly Venetian fragments and a limited number of Antwerp vessels show a significantly lower Zr concentration of 10-20 ppm.

Fig 2: Some examples of excavated façon-de-Venise glass objects

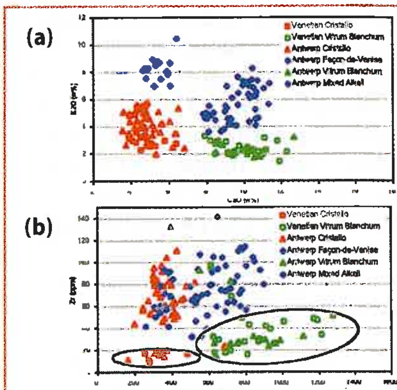

Fig 3: (a) CaO/K2O (w%) (EPMA) and (b) Sr/Zr concentration scatter plots (ppm) (μ-SRXRF) of different types of 16-17th century glass objects excavated in Antwerp, Belgium. Circle fields in (b) denote the majority of the genuine Venetian 'Cristallo' and 'Vitrum Blanchum' objects.

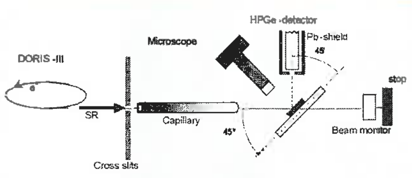

Fig 1: (left) a photograph of the μ-SRXRF spectrometer installed at beam line L, Hasylab with C: capillary unit, D: detector, M: microscope and S: sample holder on XYZ motor stage; (top) a schematic drawing of the SRXRF spectrometer

Conclusions

This work illustrates the complementary nature of EPMA and μ-SRXRF. The major and trace composition of the sixteenth and seventeenth century Antwerp glass objects was compared to the major and trace composition of two genuine Venetian glass types, cristallo and vitrum blanchum. The analysis of the trace composition with μ-SRXRF revealed that based on the impurity level of the used silica source, the zirconium content, we were able to make a distinction between local production and Venetian import.

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Will we need proton therapy in the future?

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Cancer is the second major cause of death (after cardiovascular diseases) in the developed countries. Cure from cancer can be achieved nowadays for about 45% of all cancer patients using currently available therapeutic strategies: surgery, radiation therapy and chemotherapy. For about 2/3 of the patients the disease is still well localized within a specific region of the body at the time when the patient is confronted with the diagnosis of cancer. For these patients the chances of cure using a local therapy, surgery or radiation therapy, are reasonably good.

Whenever possible, a radical surgical excision of the disease is the preferred therapeutic choice. The earlier the diagnosis and the smaller the tumor, the better the chances for a good therapeutic outcome. In this context screening plays an important role in the early detection of the disease. Surgery is the most successful therapy since it contributes 22% to the overall cure rate. Radiation therapy (RT) is the second most effective modality. RT is used with curative intent when the tumor is inoperable but is still well localized in a specific region of the body. RT contributes 12% to the cure rate alone and 6% in combination with surgery. When the disease has already spread in the whole body (with distant metastases) the chances of cure are correspondingly lower. Chemotherapy is then used with the intent to eliminate the diffused cancer cells. Chemotherapy and the other remaining modalities account for the last 5% of the total cure rate.

The largest effort in cancer research is undertaken today by big pharmaceutical companies on new developments based on modern biological sciences. The most promising ones are expected today from genetic technologies. Like other systemic therapies, these methods will face the problem of unwanted side effects of the drugs, which are inevitably spread through the whole body. The huge number of cancer cells involved in a solid tumor and the difficulty of transporting the drug into the center of the tumor are the major problems of the utilization of drugs for the elimination of advanced solid tumors. For these reasons the new biological methods still aim (like chemotherapy) in the first place at the inactivation of isolated cancer cells or small tumor volumes (metastasis) with the intent to control the microscopic spread of the disease.

It is the experts' opinion that for the foreseeable future, surgery and radiation therapy will continue to play a major role in the control of primary solid tumors. While waiting for an eventual breakthrough from genetic technologies, it is necessary to continue to improve the established local methods, surgery and radiotherapy. It is also important to note that the different types of therapy are not necessarily exclusive and are often used in a complementary way. Many recent successes in cancer management are in fact based on the combined use of different modalities. About 2/3 of all cancer patients receive radiation therapy alone or in combination with other modalities. A reduction of the toxicity of a therapy modality automatically improves the tolerance of the others in a combined treatment.

Improvements in RT were achieved in the past by using advanced treatment techniques (for example conformal radiation therapy) and/or by using unusual types of radiation (like external beam therapy with protons or light ions). In this report we will discuss primarily proton therapy. Many of the presented arguments apply as well to therapy with heavier ions.

The rationale for the use of protons for therapy

Protons have a well-defined range of penetration in materials (the range depends on the selected initial energy of the beam), and they show a pronounced dose maximum in the region where the beam stops. This region is called the Bragg peak. Fig. 1 shows the dose deposition of a mono-energetic proton beam as a function of the depth in water. The dose profile of a proton beam deposited with energy modulation, the so-called spread out Bragg peak (SOBP), is compared in the same picture with the corresponding dose profile of clinically used photons, which show a characteristic exponential fall-off of the dose with increasing depth.

The possibility to use the Bragg peak as a practical tool for the localization of the dose in depth has been known for more than 50 years (first proposed in 1946 by Robert R. Wilson). At that time modern computer technology for treatment planning and the precise physical description of the patient's anatomy provided by computer tomography (CT) were not available. Technological advances in both these areas allow us today to take full advantage of the inherent precision of this method.

The main advantage of proton therapy is expected from the superior capability to confine the dose on the target volume and so to reduce the dose burden to the surrounding healthy tissues. The major object of comparison for proton (and ion) therapy is clearly conventional therapy with photons. Protons are expected to produce superior results for the treatment of large tumors of complex shape, where a significant reduction of the dose outside of the target volume is clinically desirable. Compared to photons, one can expect to achieve with protons a general reduction of the integral dose deposited outside of

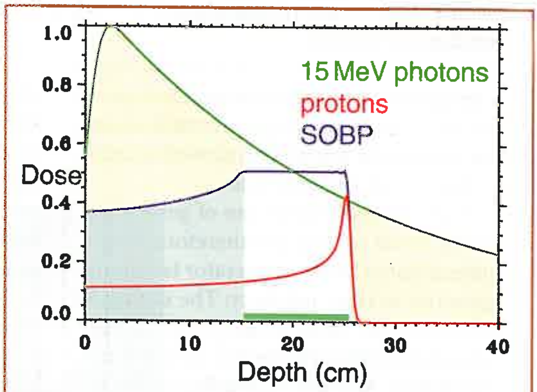

Fig 1: Comparison of the depth dose profiles of proton and photon beams. The photon dose falls off exponentially with depth (green curve). A mono-energetic proton beam is characterized by the presence of the Bragg peak in the region where the protons stop (red profile). Through the superposition (blue curve) of many proton beams of different residual range it is possible to deposit a homogenous dose (SOBP) in the region of the tumor (in this case from 15 to 25 cm depth). One recognizes from the picture the potential of dose sparing of the protons in the entrance and exit region of the beam (the unnecessary dose is painted in pale blue and light yellow).

the target volume by a factor of 2 or more. This dose sparing could be relevant in many situations, for example for radiation therapy of pediatric tumors. Children surviving cancer often present with severe consequences of the treatment in adulthood, like reduced intelligence after brain irradiation or an abnormal growth after treatments covering part of the skeleton. By using protons one can expect to reduce these deleterious effects. It is very important to note that the clinical goal of proton therapy is not only to increase patient survival but also to achieve a better quality of live after the treatment. From the radiobiological point of view protons behave like photons in conventional therapy. The experience acquired in the hospitals on the tolerances of the different organs and the response to radiation of the various types of cancers can be directly applied to protons.

The major disadvantage of proton therapy is the large size of the accelerator and of the beam lines needed for the transport of the beam. The maximum proton energy needed for applying proton therapy on deep-seated tumors is of the order of 230-250 MeV. Because of the resultant magnetic rigidity, the beam lines are heavy and the accelerators are rather large (4 to 7 m diameter) compared to electron linacs (a 1m long accelerator rotating on a gantry on a diameter of about 3m). It is therefore simply the question of size and costs, which hinders proton therapy to be more widely spread in the hospitals.

We should mention here briefly also ion therapy. Concerning the improved localization of the dose heavier ions behave similarly (to some extent better) to protons, but the magnetic rigidity needed for the transport of the beam is by a factor of 3 higher than with protons. The accelerator and beam lines are correspondingly larger and therefore even more expensive than for proton therapy. The most important issue is however the difference in the radiobiological behavior of these high-LET beams. We mention here the inhibition of spontaneous repair of radiation damages affecting both the cancer and healthy tissue cells. The high LET could bring advantages for the treatment of certain types of radio-resistant tumors but could also be a disadvantage for many other treatments with respect to a possibly higher rate of late complications of normal tissues. Ion therapy represents a very interesting addition to photon and proton therapy. However more scientific evidence of the merits, based on clinical results for selected indications is required, before thinking of an eventual diffusion of this method on a commercial basis. Ion therapy is still a matter of research as opposed to proton therapy, which could become soon a business issue.

The recent developments in conventional therapy: Photon IMRT

The success of RT in general is based on the ability to confine the dose delivery within a small region of the body (the target volume, which must contain the whole extent of the visible and invisible tumor). Ideally one would like to deposit only the necessary dose inside the target volume and zero dose outside. In practice we are faced with strong physical and technical limitations.

The state of the art in conventional radiation therapy is based on the use of very compact electron linacs mounted in the head of a rotating gantry. The photon beam is produced through the Bremstrahlung of the electrons impinging on a metallic target (the photon source). Through the use of a rotating gantry the beam can be directed onto the supine patient from several directions. The localization of the dose in depth is then achieved through the superposition of several converging beams.

The use of sophisticated beam delivery techniques, the implementation of computer technology and the information gained with modern diagnostic techniques (CT, MRI and PET) have been at the origin of the progress achieved in RT in the last two decades. These modern methods aim to shape the dose in all 3 dimensions to conform precisely to the individual shape of the target volume (conformal radiation therapy).

The use of dynamic computer-controlled multi-leaf collimators offers here new additional possibilities. The most interesting is to apply the dose with a non-uniform distribution of photon fluence for each of the constituent dose fields. The superposition of intentionally non-homogeneously shaped dose distributions can produce a resultant dose distribution of superior quality (with a higher degree of conformity, especially in the case of target volumes with concavities). This new approach is called intensity-modulated radiotherapy (IMRT). The optimization of the delivery of radiation using multiple beam ports is a typical "inverse problem" with a strong analogy to computer tomography (CT). With CT one uses multiple projections

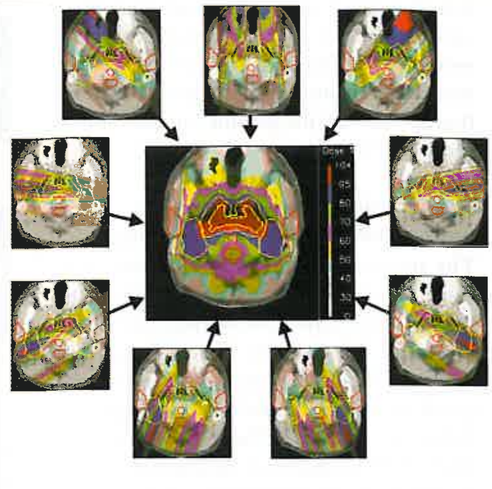

Fig 2: An example of intensity modulated treatment planning with photons. Through the addition of 9 fields it is possible to construct a highly conformal dose distribution with good dose sparing in the region of the brain stem (courtesy of T. Lomax, PSI).

(from many angles) to reconstruct complex density images. With IMRT one uses complex dose projections to produce more idealized dose distributions. Tomotherapy is a similar approach to IMRT, where the analogy with CT is at the closest also from the point of the beam delivery, since the beam is applied here slice by slice with gantry rotation in-between.

Fig. 2 shows an IMRT example with the dose distribution for a nasopharyngeal tumor. The calculation has been done with the treatment-planning package of PSI. The dose is delivered using 9 photon fields. Each field is applied with modulation of the photon flux. One recognizes immediately that the optimization algorithm avoids in this example to send photons towards the brain stem in each of the fields. The dose delivered to this sensitive organ gets reduced considerably in this way. The availability of a large amount of degrees of freedom in the beam delivery and the strength of the mathematical methods make it possible to produce very satisfying dose distributions, shaped in all 3 dimensions to conform precisely to the target volume.

Many of the professionals working in the hospitals are now convinced that photon IMRT will become soon established enough to make proton therapy unnecessary. IMRT is certainly an improvement for radiation therapy and a big challenge for all centers investigating the potential of proton therapy in the world. The fact that the majority of the medical physicists working in the hospitals are very excited about IMRT and not so much about proton therapy, is due to the fact that they consider proton therapy out of their personal reach. The question for the people working in proton therapy is: can proton therapy take up the gauntlet and do better than IMRT?

The equivalent developments for protons: RIMPT and beam scanning

The most elegant, flexible and efficient method for providing inverse planning with protons (IMPT) is by magnetic beam scanning. Protons are charged particle beams. The beam can be steered very quickly in the patient's body by magnetic deflection. This could be a more practical alternative to multileaf collimators. Fig.3 shows the basic principles of the beam scanning technology. The dose distribution of a proton pencil beam is characterized by a shallow entrance dose (the plateau region) followed by a well-localized peak at the end of the range (a dose hot spot of typically 1cm size). The pencil beam is scanned in the lateral direction by magnetic deflection in the beam line ahead of the patient. The modulation in depth is achieved by changing the range of the protons dynamically. A high conformity of the dose can be achieved by changing the exposure time and the position of each pencil beam individually under computer control. This method provides individually shaped dose distributions, which are conformed in all 3 dimensions, even when using a single beam direction (conformal therapy with variable modulation of the range). The required dose homogeneity inside the target volume is thus achieved separately for each constituent field.

Beam scanning is also well suited for the delivery of the dose, when the optimization is performed simultaneously on many fields, in order to take full advantage of all possible degrees of freedom. The constituent fields are then not necessarily homogenous but the result of the superposition of the dose is. This can improve dose sparing on some critical organs. In our terminology this technique was originally called simultaneous dose optimization. In order to make the analogy with conventional photon IMRT more obvious, we often call -improperly- this technique IMPT (intensity modulated proton therapy). The difference to IMRT is that with proton beam scanning, we can adjust also the proton range. Each parameter, proton flux (dosage), proton range and beam direction (gantry angle) can be independently varied in relation to the point of the Bragg peak inside the target volume. We should therefore call the method more properly Range-Intensity Modulated Therapy (RIMPT) to underline the added freedom to control directly the dose localization in depth.

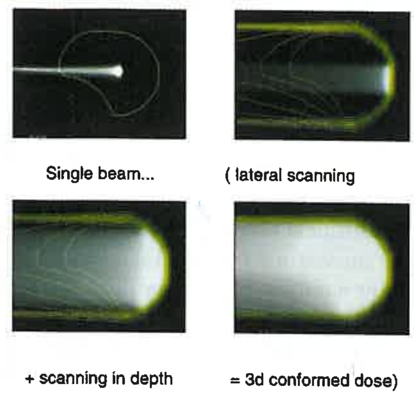

Fig 3: Basic principle used for beam scanning with protons. Through the delivery of individual proton pencil beams one can shape the distribution of the dose in three-dimensions at wish directly under computer control.

Fig. 4 shows an example of RIMPT. With only 4 modulated fields one can deliver a highly conformal dose to the primary target and a reduced dose to the affected lymph nodes (the secondary target) with a maximal sparing of the organs at risk (brain stem and parotid glands). With beam scanning, RIMPT can be calculated and delivered just under computer control without the need for any patient specific hardware. The main difference compared to photon IMRT is obviously the absence of the "dose bath" to the whole brain as depicted in figure 2.

The status of proton therapy in the world

The realization at the beginning of the 90's of the first hospital-based proton therapy facility of the world at the Loma Linda University Medical Center (LLUMC) in the Los Angeles area is a major milestone in the history of proton therapy. The components of the facility - a dedicated synchrotron feeding three proton gantries and two horizontal beam lines - were designed, realized and tested first at Fermilab (as a spin-off product from basic physics research) before being transferred to the LLUMC. Patient treatments were started in 1990. Up to now more than 5000 have been treated in this hospital with protons. Loma Linda is working since several years showing a steady improvement of patient throughput, which has recently reached the capability to treat close to 1000 patients per year. The big merit of this University is that it has paved the way for the development of proton therapy not only on scientific goals, but also on the basis of commercial criteria and routine use in a hospital environment.

Fig.5 shows as an example the layout of the North East Proton Therapy Center (NPTC) in Boston, which is the next hospital-based proton facility of the USA. This facility has been delivered by a European company and is expected to go into operation at the beginning of the next year at the Massachusetts General Hospital in Boston. The accelerator is in this case a cyclotron.

In Japan, there are several facilities already installed or under construction. The centers are in Chiba (for carbon ions), Kashiwa, Tsukuba, Shizuoka Prefecture, Wakasa Bay (for protons) and Hyogo (for protons and ions). These facilities are designed, delivered and operated by major Japanese industrial companies.

Concerning possible hospital-based solutions, in Europe we are still in the phase of discussions.

The time needed for the preparation of the patient before the treatment is usually a significant fraction of the total treatment time. This is why all new dedicated proton facilities are designed with one accelerator for the delivery of the beam sequentially into several treatment rooms. All new proton facilities use nowadays a rotating beam line for the beam delivery, the so-called isocentric gantry. All commercial facilities presently available are using a beam delivery method based on passive scattering. The idea is to produce with distant

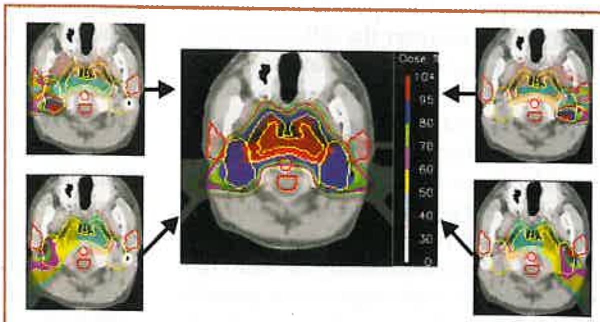
Fig 4: Example of intensity modulated therapy with protons. A high degree of conformity is achieved using a low number of dose fields. The advantage compared with photons is the general reduction of dose burden outside of the target volume (courtesy of T.Lomax, PSI)

scatterers a homogeneous flux of protons in the solid angle covering the target volume. The lateral conformation of the dose is then achieved by using individually shaped collimators. The conformation of the dose in depth is controlled by the use of range-shifter wheels and individually shaped compensators. The method has been developed in close analogy to conventional therapy with photons. The passive scattering technique requires a long throw of the beam on the gantry head (the distance between the last bending magnet and the patient). The proton gantries dedicated to scattering are for this reason very large, with a diameter of the rotating structure of the order of 10-12 meters. The passive scattering technique relies almost completely on the use of several beam modifiers machined individually for each patient and each dose field, and consequently the manipulation of the equipment is cumbersome and time consuming. The passive method is also difficult to upgrade to RIMPT.

The new aproach chosen at PSI (A GSI for ion therapy): Active beam scanning

The delivery of proton therapy by beam scanning

At present the proton facility of PSI in Switzerland is the only one capable of delivering proton therapy on a very compact gantry using a dynamic beam scanning technique (spot scanning). GSI (Darmstadt Germany) has developed a similar beam delivery system (raster scanning) in a horizontal beam line for the delivery of scanned ion beam therapy (with carbon

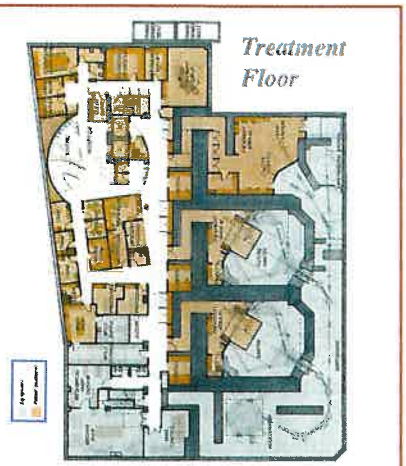

Fig 5: Layout of the NPTC proton therapy facility of the Massachusetts General Hospital in Boston U.S.A. The facility has been delivered by a Belgian company (courtesy of J. Flanz, MGH).

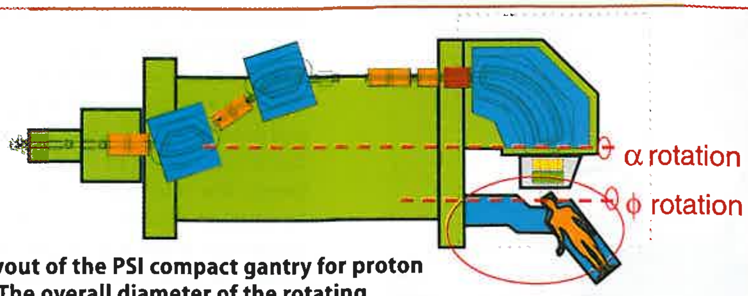

Fig 6: Layout of the PSI compact gantry for proton therapy. The overall diameter of the rotating structure is 4 m, the length 10m and the weight 110 tons. This system is the only one capable of delivering dose by RIMPT.

ions). If Europe is last in providing dedicated facilities to the hospitals, it is first in the related technological developments.

Figure 6 shows the layout of the compact eccentric gantry of PSI. The gantry is dedicated to beam scanning and is the only system currently capable of delivering proton RIMPT. The lateral scan of the beam is performed in one direction magnetically before bending the beam towards the patient. The space between the bending magnet and patient can then be reduced essentially to zero. The other lateral scan motion is obtained by moving the patient table. An eccentric mounting of the patient table on the gantry reduces further the gantry diameter, which at only 4m is the most compact of all present designs. The goal was here to achieve a radius of the rotating structure similar to the conventional photon gantries in the hospitals. Fig.7 shows a picture of the PSI treatment room. The system at PSI has been operational since 1996 for patient treatments. The typical throughput of the facility is about 2 patients per hour. This comprises the administration of several fields (3 on the average) in the same session. The change of gantry angle is performed without the need of intervention of the personnel inside the treatment room.

The positive experience gained with this system has now convinced the PSI directorate of the necessity to provide a dedicated medical accelerator for the project, in order to provide all year round beam for medical treatments, and in order to commercialize the developed technology. For the last goal PSI plans the development of a second gantry, an improved version of the present design, with the patient table mounted at the isocenter. The second gantry is foreseen as a more general and more user friendly instrument for use in the hospitals.

The interest in the spot scanning technology is steadily increasing in the world, mainly due to the challenge posed by photon IMRT. All dedicated proton facilities are now planning to develop beam scanning in addition to scattering on the long throw gantries.

The debate within proton therapy: beam delivery by scattering or scanning? or both?

Beam delivery methods for IMRT with protons will be needed soon for the competition with photon IMRT. One could think eventually to use dynamic multileaf collimators on top of the passive scattering technique (with compensators and range shifter wheels). In this case the modulation of the range would remain constant. For the delivery of true RIMPT, however, with active control of the local modulation of the range, beam scanning is probably the only reasonable solution. The next question is then, why not choose for dedicated proton facilities industrial solutions based only on scanning and consequently take advantage of small compact gantries?

The major point advanced in favor of the scattering method, is the higher sensitivity of the dynamic beam scanning technique with respect to dose errors due to organ motion compared to passive scattering. This is the Achilles' heel of all dynamic beam delivery methods, including IMRT with photons. The best solution would be to try to improve the speed of scanning to allow for multiple repaintings of the target volume. This is the subject of studies for the next gantry of PSI (gantry 2). Another possible solution is to trigger the beam within a phase interval of the breathing cycle of the patient (this technique has been developed by our colleagues in the Japanese hadron therapy centers). PSI is also investigating the use of small magnetic sensors for monitoring the position of moving tumors during treatment (project TULOC). All these solutions are under consideration for the next development phase of the PSI project.

The medical doctors seem at the moment to be very reluctant to abandon the

Fig 7: **Photograph of the PSI proton treatment room with the head of the compact gantry dedicated to proton beam scannning.**

traditional passive scattering method. In principle nothing forbids to perform the scanning with a broad beam on a very coarse grid to produce a flat field of homogeneous dose and to carve out the edges of the field with collimators and compensators, as this is done with the passive scattering technique. By using a broad beam we could increase the grid spacing of the scan and so afford to repaint the target several times. This approach could simulate scattering well enough to convince people to replace scattering by scanning without the fear of loosing something. To this purpose we are improving the design of our beam delivery system to allow for much larger variations of the beam size.

Gantry systems providing both beam delivery techniques, scanning and scattering, are expected to be complex, large and expensive. In the long range the development of more advanced beam scanning techniques capable of replacing passive scattering is probably a necessary condition if we want proton therapy to be economically more competitive with photons.

Discussion

Radiotherapy represents an important instrument in the fight against cancer in a field of continuous evolution. In conventional therapy we expect to be able to observe in the near future a significant progress using very advanced beam delivery techniques with photons (IMRT). Similar more advanced developments are in principle possible also with charged particle beams (RIMPT). The physical advantages of protons applied with new beam delivery techniques are expected to produce superior results. This is why we believe that beam scanning will be soon a necessary option for any new proton and ion beam therapy center.

Just from physical arguments we should always obtain with protons superior dose distributions compared to photons (with marginal exceptions like the skin-dose or the lateral fall-off in very deep-seated tumors). The selection of the patients could be quickly decided just on the basis of treatment planning. If proton therapy would be widely available with a similar routine as for the photons, it would be technically possible to offer an (objectively) better treatment to a very large number of patients.

Let us consider now the question of the costs.

The equipment of a proton therapy center is more expensive, of the order of 25-40 M$ (depending on the number of treatment rooms used in the facility), than the 3-5 millions needed for the corresponding units in a modern radiotherapy department. The amount of trained personnel needed for the delivery of a sophisticated radiation treatment is however expected to be very similar with protons or photons. The personnel costs for running the facility are expected at the end to be the major expenditure in the budget for the total lifetime of a dedicated proton facility.

Very rough estimates indicate that the costs for a high-tech proton treatment could be about the double of the costs for an average conventional treatment. The costs of general radiotherapy are similar to surgery, but much cheaper then chemotherapy and genetic technologies (chemotherapy is generally used with less chances of success than radiotherapy even if it is more expensive). The difference in costs between proton and photon therapy is very modest in relation to the general medical costs of handling cancer as such, independently of the results. If the treatment with protons avoids some treatment complication (with all the related expenses over years to cope with them), protons can be justified purely on the basis of economical arguments. Our conviction is that the additional costs for proton therapy are worthy of consideration.

The attempt to quantify scientifically the benefits is one of the main goals of the clinical trials being performed in the research centers offering proton therapy for research purposes, like ours. The process of assessing results in the treatment of cancer is a difficult one and requires many years. The group at the Harvard cyclotron and MGH/Boston has delivered most of the existing scientific evidence in favor of the protons. We mention here the very good results for tumors close to the base of the scull and treatments of eye melanoma (at PSI alone more than 3000 eye patients have been treated for this indication). World wide the experience of using charged particle beams has reached already a total of about 30000 patients. However, with the new beam scanning methods the experience is still very limited.

If proton therapy centers would be widely available offering proton therapy on the basis of a well-established know-how, the majority of cancer patients would probably prefer to be treated with this method without waiting for further scientific results of clinical studies. Everybody would choose for himself a treatment with a lower burden to the healthy tissues compared to photons, even if the photon dose is declared to be below the tolerance level for complications. In view of the growing wealth and requirements on quality of life in western society, it is not an unrealistic scenario to assume that many people would probably be ready to pay for the difference or to put pressure on their health insurance companies.

Thanks to the pioneering work done at scientific institutions, a lot is known on the use of charged particle beams. The feasibility of further improvements has been also demonstrated at research centers.

Proton therapy and ion therapy is now in a transition characterized by the imminent availability of many new dedicated hospital facilities in Japan and U.S.A.

It is reasonable to assume that something similar will happen also in Europe. This could be even through private clinics financed by profit oriented organizations with the sole purpose of earning money. Even this would be good news for cancer patients. To say the least, we would not have missed another important opportunity for spin-offs from basic research in physics.

Acknowledgments

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Accelerator driven systems: an application of proton accelerators to nuclear power industry

Robert Klapisch

Why accelerators can help nuclear energy

10 000 nuclear reactor-years of operation have witnessed 2 major accidents (Three Mile Island and Chernobyl) both caused by critical power excursions. It is clear *a posteriori* that this is too much for the public to neglect. It is certainly possible (at a cost) to decrease the probability of an accident to the 10^{-5} or 10^{-6} level, but this might not suffice to allay the fears and one has to seriously consider intrinsically safe reactors, in which by physical laws, serious accidents cannot occur. Another major (and growing) concern is that of the fate of long-lived radioactive nuclear waste.

Over this background, a small group at CERN led by Carlo Rubbia began in 1993 to look into novel solutions for nuclear energy based on the use of accelerators and developed the Energy Amplifier project. [Figure 1]

Proposals to use a particle accelerator as an adjunct to a nuclear reactor date back to the beginnings of nuclear energy, but at the time they were deemed unrealistic. The situation has changed largely because of the progress in key technologies in accelerator and computer technologies. The energy efficiency of accelerators has improved in the last thirty years from 0.1% to some 50% and their reliability is now at the industrial level (beam on 95 to 99% of the scheduled time). Also progress in computing power allowed to simulate in detail devices and processes which had never before been investigated at any degree of usable detail. These detailed simulations showed the necessity of discarding some schemes and of introducing new ideas.

Energy amplification, concept and experimental proof

In a sub-critical reactor, the number of neutrons originating from fission is not sufficient to overcome the losses (due to leaks and absorption of neutrons by some materials). Therefore, under no circumstances can a chain reaction be self-sustained and in order for the reaction to proceed, one needs to continuously supply neutrons from an external source. In an Accelerator Driven System, this external source consists of neutrons created by spallation when a medium energy proton beam reacts with a heavy target (usually Lead). The supply of neutrons is proportional to the proton intensity, which can be modified precisely and with a very short time constant. The proton beam plays the role of the control bars in a reactor, the difference being that it is proactive rather than reactive: if it fails, the reaction stops and it can never lead to an overheating.

In contrast to fission, spallation costs energy and the ability to steer the fission process will come at a cost, coming from the accelerator beam power needed, and that cost has to be minimized for the proposal to remain economical.

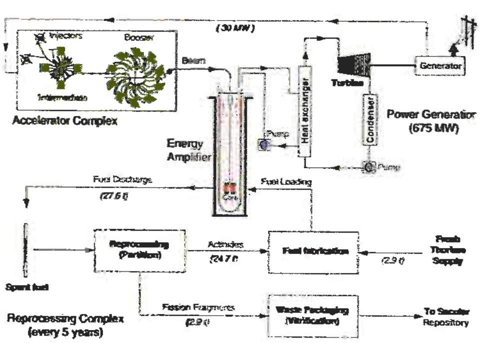


Fig 1: Closing the nuclear cycle with the Energy Amplifier, a sub-critical device with a Th $-{}^{233}$U fissile core fed with a supply of spallation neutrons. There is no criticality , no plutonium and no problem of actinide waste . At the end of the cycle, ^{233}U and the other uranium isotopes are recycled to serve as the initial fissile part of a new load of fuel. Thorium is an abundant resource (much more than uranium) and supplies could last thousands of centuries.

The energy of an incoming proton results – because it initiates nuclear fission cascades – in the production of a much larger energy. We say it is amplified (by fission) and call the device an Energy Amplifier (EA). The ratio between the incoming energy and the total energy is called the gain G of the amplifier. G is related to the neutron multiplication factor k.

$$k = \frac{\text{Production}}{\text{Absorption} + \text{Losses}}$$

For an efficient control of the reaction, it is enough for the EA to be weakly sub-critical. This is evident from figure 2, which compares the safety margin provided by delayed neutrons in critical reactors with that of a sub-critical device. We see that k=0.98 is sufficient to ensure that the EA is sufficiently far from criticality conditions. [Figure 1]

Setting k=0.98, the neutron deficit, to be supplied by spallation is s=0.02

For each 100 neutrons, there will be 98

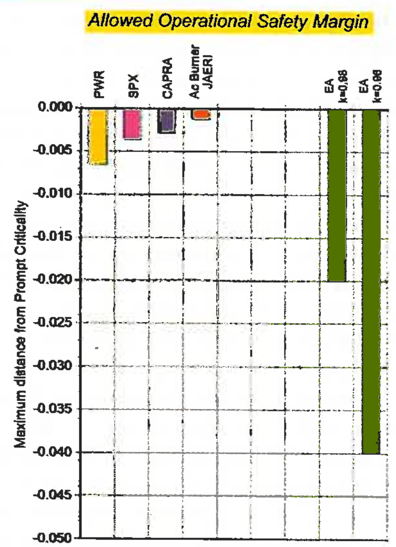


Fig 2: Even with k=0.98, the EA has a much higher safety margin than the one offered by b delayed neutrons. The fact is even more striking when one considers heavy actinides.

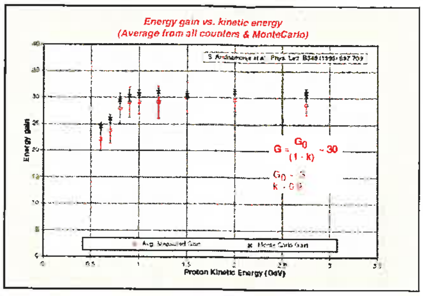


Fig 3: Variation of gain with incident proton energy. The gain is constant for energies larger than 1 GeV. The relevant figure is the beam power (GeV × mA) over 1 GeV.

fission and 2 spallation neutrons (each costing 30 MeV), in the mix. Only part of the neutrons (40%) will induce fission and bring 200 MeV of energy, the rest will be captured or leaked out. Therefore:

$$G = \frac{\text{Return}}{\text{Cost}} = \frac{200 \times 0.4 \times 98}{2 \times 30} = 130$$

The gain will be smaller (G≈50) if 5% of the neutrons comes from spallation and more generally, it can be shown to be:

$$G = G_0 \frac{1}{1-k}$$

This simple concept was first tested experimentally when a small number of protons 109 per pulse ie 10^{-4} of the total intensity of the CERN Proton Synchrotron was sent on an existing "pedagogical" subcritical assembly consisting of natural uranium rods (3.5 tons) immersed in water and known to have k=0.90. The energy produced (of the order of 1 Watt) was measured by determining the temperature elevation (millikelvins) in the insulated vessel, using very sensitive thermometers.

The energy gain was measured as a function of the proton energy ((Figure 3) and shown to be constant at energies larger than 1 GeV . As shown in Figure 4, only a small proportion of the energy produced by the Energy Amplifier (4 to 6%) will have to be recirculated into running the accelerator .

What accelerator?

It is within the possibilities of present-day technologies to build an accelerator for the EA (15mA@1GeV). There are two possible solutions: an isochronous cyclotron or a linac. Both technologies are well proven and would give 50% efficiencies. The cyclotron (an extrapolation of the machine running at the Paul Scherrer Institute near Zurich) has the advantage of being more compact and a simpler technology. The linac solution would presently be more based on the LEP-type superconducting cavities than on the Los-Alamos LAMPF, even though a superconducting linac would need a warm machine as an injector at some 400 MeV. The real advantage of the Linac is the possibility of going to much higher currents (say 30 to 50 mA) if they were needed. The cyclotron does not involve superconductive technology, takes less floor space and is therefore probably more adapted to industrial type applications.

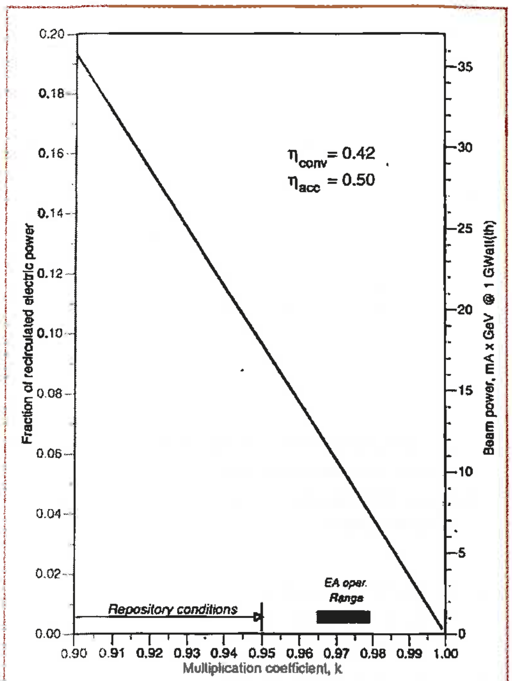


Fig 4: Fraction of energy recirculated to run the accelerator, assuming 42% energy conversion and 50% accelerator efficiency.

The Energy Amplifier: basic concept

Neutrons are created by spallation when a beam of protons coming from the accelerator interacts with a Lead target. Neutrons lose their energy and diffuse to interact with a sub-critical fissile core. The heat created by fission is evacuated from the core by natural convection in molten Lead, through a heat exchanger to a secondary circuit. The presence of Lead results in a harder neutron spectrum than is the case in usual, sodium-cooled fast reactors. As shown in Figure 6, this is opens up the very important ability of the device to fission practically all actinides with a reasonable probability.

The use of Lead as a heat carrying medium has important safety implications. In comparison with Sodium (which has been used extensively in critical fast reactors, Lead is chemically inert and it has a low vapour pressure even at a high temperature. Its high density allows the use of cooling by natural convection which avoids using pumps. This is a safety feature: no pumps, no failure. The nuclear properties are also remarkable: Lead being a doubly-closed shell nucleus (the nuclear equivalent of a noble gas, it has a very low absorption by neutrons. Together with its high mass, this makes for properties of slowing down of neutrons which we will discuss in the next section.

One safety problem which is specific to the EA and has been much talked about is the window separating the beam from the target. There is at CERN and other labs an extensive experience with proton beams of a fraction of a millimetre diameter and an average intensity of one microampere. The EA would admittedly involve beams of 10 000 times higher intensity, but then the beam spot would be of some 10 centimetre diameter so that the current density would actually be smaller. All this has obviously been included in the detailed simulation and there is a further plan to test experimentally at a lower proton energy (where the energy loss, going as 1/E is actually greater). One has therefore confidence that the window concept is sound. One cannot argue that the window would be a weak point in the barrier insulating the reactor core from the outside world. In

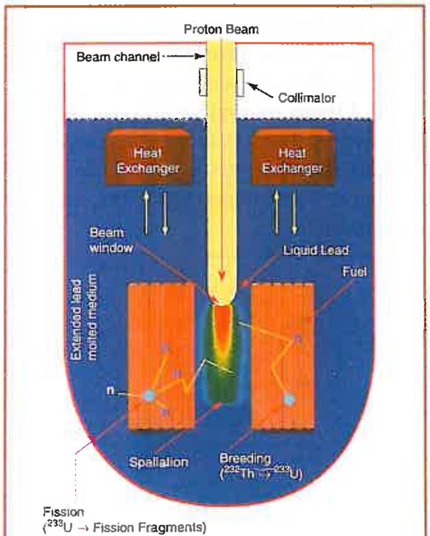


Fig 5: Schematic principle of the Energy Amplifier.

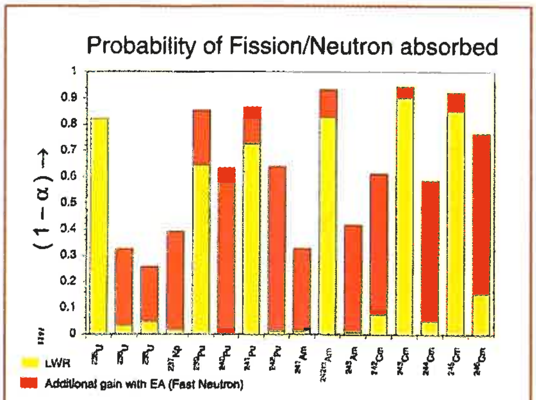


Fig 6: Because of the Lead neutron diffusing medium, all elements will fission to some degree, this opens the way to destroying actinide waste.

fact, should the window break, it would immediately be replaced by liquid lead flowing up the beam tube, preventing the beam from reaching the target and thus stopping fission processes occurring in the core.

Destroying long-lived nuclear waste

The EA can destroy long-lived waste coming from reactors.This is principally plutonium and higher actinide elements. Typical half-lives are 24000 years for ^{239}Pu and 6500 years for ^{240}Pu. As for fission products, after a few years of swimming pool storage, the vast majority of their radiotoxicity is carried by just two isotopes (^{90}Sr and ^{137}Cs with half-lives of about thirty years. In addition to the 30 year component, there are a few very long-lived fission products such as ^{99}Tc and ^{129}I with respective half-lives of 200000 and 15 million years. Even though not highly radioactive they are very worrying because some of them are soluble in water and can therefore easily migrate into the biosphere. We have demonstrated a possibility for the EA to transmute them into stable, innocuous products.

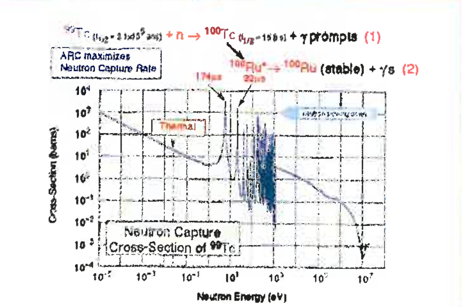


Fig 7: Transmutation of ^{99}Tc with a high efficiency using resonances.

In the EA, the transuranic elements (TRU) coming from the reprocessed spent fuel from an LWR will fission (producing energy) and the excess neutrons, captured on the fertile ^{232}Th will breed ^{233}U (which is in itself valuable, either as seed for an EA or as fuel for a critical reactor. To give some numbers, an EA of nominal power 1500 MW_{th} with a burnup cycle of 120 GW-day/t refilled after 2 years would incinerate 402kg of TRU per year, breeding at the same time 175kg per year of ^{233}U, which can itself power an LWR.

If we now turn to long-lived fission products, we shall take as an example ^{99}Tc which is the most worrying. By capture of a neutron and subsequent beta decay, it is transformed (after 15 seconds) into stable ^{100}Ru. In a reactor neutron energy spectrum that cross section is extremely low (if not, there would be no ^{99}Tc left !). Since we cannot envisage to leave ^{99}Tc in a reactor for hundred years or have a correspondingly high flux (people have tried), one has to find a better idea. At a slightly higher energy, the capture cross section of ^{99}Tc shows a series of resonances, the most important one being at 5.6 eV where the cross section is about three orders of magnitude larger than for thermal neutrons. Can we make use of that resonant property?

For that purpose, Rubbia has come forward with the concept of Adiabatic Resonance Crossing.

Let us assume a volume of Lead bombarded by 1 GeV protons which is large enough to contain the majority of the cascade. A number of neutrons are created and since Lead does not absorb neutrons, they will undergo a large number of elastic collisions and lose their kinetic energy in small decrements governed solely by the kinematics and the masses. This coefficient which is called lethargy results in the neutron losing at each step a fraction ($\approx$ 1%) of its actual energy. It is easy to see that in the region of the resonances, the actual energy losses are much less than the width of the resonance and therefore, a slowing down neutron cannot miss it. If the impurity to be destroyed is placed inside a volume where there is no competing absorbing material, it should be destroyed with a high efficiency.

This concept was successfully tested at CERN by an experiment (TARC) supported by the European Union.

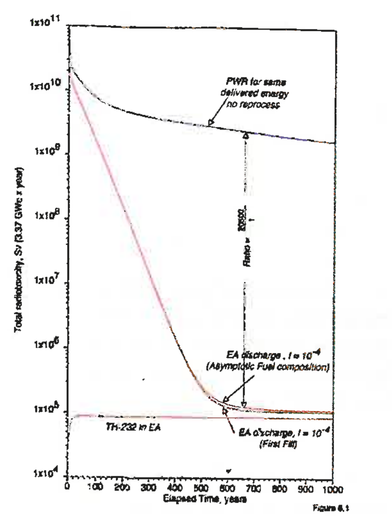


Fig 8: Comparison of radiotoxicity of nuclear waste of the EA and an ordinary reactor for the same amount of energy produced.

The results also served to validate the Monte Carlo simulation program so that one can now predict the performance of the EA in transmuting of ^{99}Tc and ^{129}I. A practical transmutation scheme would locate the technetium at a large distance from the strongly absorbing core– more precisely at a distance larger than the diffusion length of neutrons in Lead –. One can safely assume that neutrons that have travelled that far would have a negligible chance of diffusing back to the core. Therefore, one is using for transmutation neutrons which would otherwise be lost by capture on the wall. This means there is no penalty on energy production.

An Energy Amplifier would typically destroy without loss its own production of technetium (obviously coming from the preceding cycle). In order to transmute other species (for instance coming from LWR waste, one would have to accept a small loss of neutrons, hence of energy production.

Conclusion

There is presently a large and growing interest from the European Union and several countries (in Europe and elsewhere) to explore the possibilities of transmuting nuclear waste by Accelerator Driven Systems. It is likely that a demonstration prototype will be funded in the Framework Program 6. If the method shows promise, it would open a new and important field of application for high intensity medium energy proton accelerators.

2000 Physics Nobel Prize

Alexander Hellemans

The Nobel committee has honored important inventions of the 20th century, such as the transistor (invented in 1947 by Shockley) or the laser. Now the committee seems to have rectified an omission by granting Jack Kilby the Nobel Prize "for his part in the invention of the integrated circuit."

Zhores Alferov, director of the Ioffe Physico-Technical Institute in Petersburg and Herbert Kroemer, professor at the University of California at Santa Barbara, share the second half of the prize for "developing semiconductor heterostructures used in high-speed- and opto-electronics." "The integrated circuit is probably the invention of the century; this invention has the greatest impact at the moment on society and the economy--the way the world works," says Jim Gimzewski who heads the nanoscale science group at the IBM Research Laboratory in Zurich.

If, in hindsight one could have expected this prize, to Kilby, who is an electronics engineer by training, it came as a surprize. "I had no idea I would be considered," says Kilby. When Kilby made his invention nobody had any idea how it would spur the development of electronics, almost allowing it to take on a life of its own. "At that time I thought it would be important for electronics as we knew it then. What I did not understand is how much the lower cost would expand the field of electronics," says Kilby.

Jack Kilby
Photo courtesy of Texas Instruments

The initial problem that Kilby tried to solve was quite mundane. During the 1950s computer manufacturers had switched to the use of circuit boards for mounting discrete components, such as transistors. However, building computers remained very labour intensive because the sheer number of components that had to be interconnected, including tens of thousands of transistors. Kilby, who just had joined Texas Instruments, had the idea of mounting several components on a single semiconductor chip, and in 1958 he demonstrated a working oscillator. Robert Noyce, who died in 1991, also developed an integrated circuit and used "planar" technology to lay out interconnections on the chip itself. Noyce is viewed as the coinventor of the microchip.

Herbet Kroemer

Gordon Moore of INTEL, who fathered "Moore's law" which says that the number of components on a microchip doubles every year, agrees that the invention of the microchip was an important step in the evolution of technology: "It was the beginning of what allowed us to decrease the cost of electronics," he says.

Both Alferov and Kroemer increased the possibilities of semiconductors by applying the superlattice concept initially proposed by Leo Esaki and Raphael Tsu. Kroemer built the first transistors and solid-state lasers incorporating heterostructures, while Alferov created the first GaAs heterostructure lasers. Heterostructures allow the "engineering" of the band gap in semiconducting materials. During the mid-fifties Kroemer wondered how one could speed up semiconductor devices and argued that an energy band gap with a gradient would do the trick by adding a force to the electrons. "This was a purely theoretical speculation, and not everyone believed that there was such a force," says Kroemer, whose experiments proved him right.

Modern epitaxial growth techniques have allowed this idea to be incorporated in semiconductor devices, lasers, and light-emitting diodes. "It took a long, long time until the first technologies emerged to do that," says Kroemer. Heterojunctions remained a research curiosity for many years. "In the 1990s it really became a key ingredient in solid-state electronics," says Kroemer. "Compact disks wouldn't exist without heterostructure lasers," he adds. Achim Wixforth of the Univerity of Munich says that the multijunction technique "gave not only scientists but also engineers a huge tool to engineer matter". As an example he mentions the quantum cascade laser, which would have been impossible without this technique.

To Alexander Govorov, a researcher at the Siberian Institute of Semiconductor Physics at Novosibirsk, the fact that Alferov received the Nobel prize for physics is a strong encouragment for science in Russia. Research there is severely beleaguered with insufficient funding, a severe brain drain and the loss of prestige as an activity. "This is very encouraging for young people starting out with physics," he says. Alferov is known internationally as a strong defender of Russian science and international collaboration, and obviously the Nobel prize will greatly help him in these endeavours.

Zhores Alferov

Interviewed in EPN 31/5, Professor Alferov is the 1978 Laureat of the EPS Hewlett Packard Europhysics Award (now known as the Agilent Technologies Europhysics Prize) for his [then] recent work in the area of heterojunctions.

noticeboard

Call for nominations: PPD

Elections of 3 members to the Board of the Plasma Physics Division are currently being organized. The elected members of the current Board are:

Alejaldre, C. (Spain) *
Alladio, F. (Italy) *
Gresillon, D. (France)
Koch, R. (Belgium) *
Kroesen, G.M.W. (Netherlands)
Lister, J. (Switzerland)
Meyer-ter-Vehn, J. (Germany)
Stöckel, J. (Czech Republic)
Tendler, M. (Sweden)
Van de Sanden, M.C.M. (Netherlands)
Wagner, F. (Germany)
Winter, H.P. (Austria)

* retiring from the board on 31 December, 2000 and not re-eligible.

The Board has nominated the following candidates:

Michel Decroisette (France)
Robert Bingham (UK)
Rosario Bartiromo (Italy)

Further nominations may be put forward by Individual Ordinary Members and members of the Plasma Physics Division. Please send nominations, no later than 15 December 2000, accompanied by a short cv, candidate's election statement and agreement to serve if elected to the EPS Secretariat, PPD Elections, BP 2136, 68060 Mulhouse

Nominees: Macromolecular Physics Section

Following the call for nominations to the Board of the EPS Macromolecular Physics Section of the CMD published in EPN 31/4, the Board would like to welcome its new members:

A. Cunha (Portugal)
A. Donald (UK)
R. Schirrer (France)
G. Strobl (Germany)
G.J. Vansco (Netherlands)
J. Manson (Switzerland)

The Board would like to express it thanks for the hard work and dedication of the outgoing members E. Atkins, F. Balta Calleja, H. Laun, P. Navard, and G. Ten Brinke.

Call for nominations: AMPD

Elections to the Board of the EPS Atomic and Molecular Physics Divisions will take place during the 7th ECAMP Conference on Atomic and Molecular Physics to be held in Berlin from 2 to 6 April 2001 (www.ecamp7.de).

The elected members of the current Board are:

D. Dowek (France) *
E. A. Hinds (UK)
L. Moi (Italy)
R. Morgenstern (Netherlands) *
V. Ostrovsky (Russia)
H. P. Winter (Austria) *

* retiring from the board in 2001 and not re-eligible.

E.A. Hinds, L. Moi and V. Ostrovsky will stand for re-election. The Board has nominated N. Mason (UK) as a candidate. Further nominations are requested and should be sent no later than 1 March 2001 to Prof. H.P. Winter, Institüt für Allgemeine Physik, Technische Universität Wien, Wiedner Hauptstrasse 8-10, A-1040 Wien/Austria, fax: + 431 58801 13410, e-mail: winter@iap.tuwien.ac.at
Nomination should be accompanied full co-ordinates of the candidate (fax, telephone and e-mail), a short cv and candidate's election statement and agreement to serve if elected. Endorsement by other members of the AMPD is also invited.

Call for Nominations for the 2001 Agilent Technologies Europhysics Prize

(formerly the Hewlett Packard EP Prize)

Nominations are invited from members of the EPS and the European Physics Community for the Agilent Technologies Europhysics Prize for Outstanding Achievement in Condensed Matter Physics. The award is given in recognition of a recent work (completed within the last 5 years) by one or more individuals in the area of physics of condensed matter, specifically work leading to advances in the fields of electronic, electrical and materials engineering. The award may be given for either pure or applied research.

Only complete nominations will be considered. For a nomination to be complete, the must include:
- a complete CV
- a complete publication list
- an indication of the three most relevant papers to the nomination
- a description of the work justifying the nomination
- a suggested short citation

The deadline for the receipt of nominations is 15 February 2001. Nominations should be sent to David LEE, EPS, 34 rue Marc Seguin, BP 2136, 68060 Mulhouse Cedex, France, to the attention of the Agilent Technolgies Europhysics Prize Selection Committee. All nominations will be acknowledged.

Women in Physics: Is a career in physics dependent on gender?

Ana Maria Eiro

Although women represent about half of the population, the statistics undeniably show that they are under-represented in sciences, as students and career professionals, in business as well as in academia. Only 16% of all scientists are women, the fraction being much lower in physics than in other sciences. In fact less than 8% choose physics for their professional life. In general, there were very few women in physics before the 20th century: the Royal Society of London founded in 1662 elected its first female member in 1945, and the Academie des Sciences of Paris founded in 1662 didn't elect its first female member until 1962! If we remember that it was only a few decades ago that women had free access to college education, and that even today, parents and educators in general find it "more appropriate" for their sons to follow a physics course rather than their daughters, the numbers are not surprising.

Yet women are as able as men in tackling technical problems, are as bright as men when reasoning about theoretical issues, and have eventually more skills for the sort of teamwork and project management that are becoming the workings of science. It is really impressive what women have achieved: see www.physics.ucla.edu/~cwp/

The automatic dishwasher was invented by woman named Josephine Cochrane and received an award for her invention at the 1893 World's Fair in Chicago. The company she founded to market the dishwasher was purchased in the 1920's by the Hobart Corporation who introduced the "KitchenAid" brand name.

In many countries the under-representation has been identified as a problem, and many associations exist in USA, Australia and UK to help and encourage women to follow physics, engineering or mathematics. However, a woman will not embrace a scientific career if she anticipates major conflicts with her family life, and, unfortunately, this is often true in the case of physics. Looking at Western Europe, there is a curiously unbalanced situation between the north and the south. It is easy to find female physicists in France, Italy or Portugal, but much harder to find them in UK, Sweden or Germany. In my opinion, this is just a consequence of the way society is culturally organised in those countries. To fulfil their potential, women need support from their employers and their companions: equal opportunity, flexible working hours, keeping in touch during career breaks, and returning to a worthwhile job after time out.

Clearly the ability to think physics is not gender dependent, and the full use of all intellectual potential can only be obtained if we have a healthy competition on the basis of competence, but it is essential that society creates the infrastuctures that allow women in all countries to have the freedom to make their choices for science.

The EPS Medal for the Public Understanding of Physics

The EPS has approved the creation of "The European Physical Society Medal for the Public Understanding of Physics". Nominations are being sought from EPS Divisions and constituent societies. The deadline for nominations is 31 December 2000. Below, please find the full regulations.

Terms and Conditions

1. This Annual Medal in intended to honour an individual who has contributed greatly to the Public Understanding of Physics
2. In addition to the Medal, there is a small financial prize (Euro 500) and cover for expenses to attend a major conference at which the award will be given.
3. Nominations are invited from, and must be endorsed by, constituent member societies and EPS divisions and interdivisional groups; normally only one candidate will be expected from each constituent society and/or EPS division or interdivisional group.
4. The judges will be the EPS Executive Committee.
5. The winner will be an individual who has, for example, contributed very considerably to "educating the Public" in the joys of Physics.
6. The closing date will be the end of the calendar year; the announcement of the winner will be made at the EPS Council meeting.
7. Nominations, limited to 4 A4 pages and accompanied by 3 supporters statements, should be sent to the EPS Headquarters in Mulhouse (for the attention of the Secretary General).

Secretary General's Report

New Sections

The Executive Committee has approved a Gravitational Physics Section in the Joint Astrophysics Division, as well a second on the Electronic and Optical Properties of Solids of the Condensed Matter Division. If you are interested in joining, or of obtaining more information, please see www.eps.org

COST

The European Physical Society has been given observer status to the Physics Technical Committee of COST (European Co-operation in the field of Scientific and Technical Research). COST was created in 1971 to provide a flexible framework for the implementation of pre-competitive research projects of European significance corresponding to clearly focused needs and best conducted through co-operation between industry, scientific institutes, universities and national research centres.

Physics On Stage

Physics On Stage, organized by the CERN, ESO, ESA, sponsored by the EPS and European Association for Astronomy Education brought together over 500 participants and presentations from 22 countries showing interesting and innovative methods for teaching physics. A good summary of the programme and events is available at cern.web.cern.ch/CERN/Announcements/2000/PhysicsOnStage. A series of recommendations from each of the various workshops has been established, which will be studied by the EPS Physics Education Division to see where the EPS can help.

David Lee is the Secretary General of the EPS
***email* d.lee@univ-mulhouse.fr**

Linear colliders

Alexander Hellemans

Early in November CERN, Europe's particle physics laboratory near Geneva announced that it closed down its Large Electron-Positron Collider (LEP) after its operation was extended for one month and its collision energy reached 209 gigaelectronvolts (GeV). CERN considered extending the life of LEP for another year to confirm the possible observation of traces of the elusive Higgs particle. The decision, which, as Europhysics News is going to press, still has to be endorsed by the Committee to Cern Council, meeting on 17 November. A further postponement of the dismantling of LEP will delay for a few months the start of operations of the Large Hadron Collider (LHC), which will be built in the same tunnel that now houses LEP.

The Higgs particle is the missing piece of the complicated jig-saw puzzle known as the "Standard Model", the theory for describing elementary particles and their interactions. The Higgs particle is the only remaining one described by the Standard Model that up to now had escaped detection. It also holds an important key to the whole of physics by conveying mass to the fundamental particles. For years the only other particles that were predicted but did not show up were the top quark and the tau neutrino: both were discovered at Fermilab, the first in 1995, the second in 2000.

With 209 GeV center-of-mass collision energy, LEP has reached close to the ultimate limit that it can achieve for stored electrons and positrons. Circular machines have the advantage that accelerated particles can go around and around through the same accelerating cavities, increasing their energy with every pass. However, the energy these particles can reach is limited because as their speed increases, they also start shedding energy in the form of synchrotron radiation when they are made to go in circles by bending magnets. These losses are the strongest for light particles, such as electrons and positrons, which lose 10^{13} times as much as protons of the same energy. The LHC, a circular machine, will be able to accelerate protons to a center-of-mass collision energy of 14 teraelectronvolts (TeV) because the particles have larger mass. However, because protons are made up of quarks and gluons, individual collisions between quarks will yield up to 2 TeV in available energy.

Because electrons and positrons produce collisions that are much "cleaner," they are viewed to have certain advantages above the colliding protons in the LHC for investigating energies above those reached by LEP. There is much less background, and the production rates for new particles or events are not that different from the known production rates, says Peter Zerwas, a theorist at DESY, the German particle physics laboratory near Hamburg. "You can project out the new physics elements much easier," he adds. The strength of the LHC will be as an exploratory machine, says John Ellis, a theorist at CERN.

The only machine that can produce high collision energies for electrons and positrons is the linear collider. Because there are no bending magnets, there are no synchrotron radiation losses. Electrons and positrons accelerated in straight paths by two separate accelerators facing each other, collide head-on or at very small angles. Existing designs call for two accelerators that will impart 250 Gev to the leptons, which will release 500 GeV when they collide. In a later stage, the machine may be expanded up to 800 or even 1000 GeV by upgrading the two linacs, either by adding cavities, or by increasing the accelerating power delivered to the existing cavities.

The scientific case

Recently, a group of high-energy physicists met at Fermilab (*) to discuss the "scientific case" for such a linear collider. The study of the Higgs particle will be one of the most important aims of this machine. "Since you operate with a precise energy in a nearly background-free environment, in a certain sense, such a machine can be described as a 'Higgs factory,'" says Zerwas. "We will be able to confirm that the Higgs mechanism is actually responsible for generating the mass of the fundamental particles," says Zerwas.

A second important aim is the study of so-called supersymmetric particles. Many physicists are convinced that all elementary particles that are currently known have a matching supersymmetric partner. "We will study a complete new world, and the supersymmetric world is larger than the Standard-Model world," says Zerwas. And supersymmetry would allow physicists to get a handle on gravitation--one of the fundamental forces. Gravitation has not yet been unified with the three other fundamental forces, the electromagnetic, the weak and the strong nuclear forces. Once the masses of the supersymmetric particles are determined with high precision, "we will be able to do extrapolations to scales close to the 'Planck scale'. We hope that by reconstructing the theory at such a high energy scale we will see for the first time the interaction between gravity and particle physics," says Zerwas.

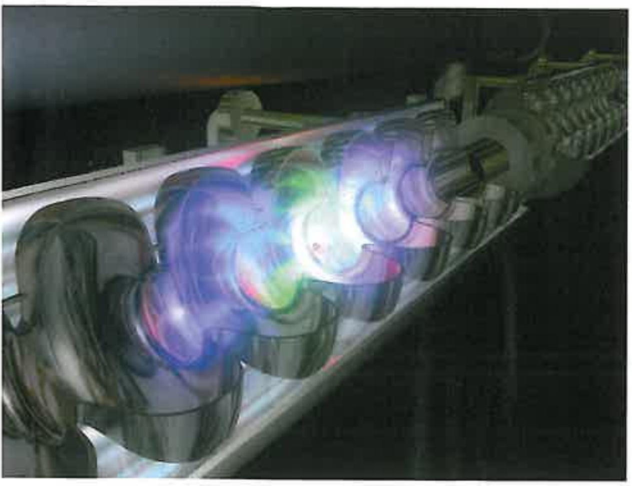
Prototypes

Several particle-physics laboratories are now experimenting with prototype sections for a linear collider. The Stanford Linear Accelerator Center (SLAC) completed the Next Linear Collider Test Accelerator (NLCTA). At DESY an international collaboration of scientists from 40 institutes from 9 countries built the Tera Electron Superconducting Linear Collidér (TESLA) Test Facility, and Japan's National Laboratory for High-Energy Physics (KEK) in Tsukuba completed a test facility for the Japan Linear Collider (JLC). CERN is experimenting with the Compact Linear Collider (CLIC), with the aim of developing a linac that would reach beyond 1 TeV, possibly up to 2 or 3 TeV, farther in the future. CERN is not planning to partake in an important way with a first 500 MeV linear collider design, says Ellis.

However, the high-energy community agrees that the construction of a full-size machine can only be achieved by an international collaboration. "Even a large lab such as SLAC cannot carry this program by itself," says Gregory Loew at SLAC. This collaboration will not only have to select a site where the accelerator can be built, but also the technology that will be used to accelerate the electrons and positrons.

Key components of the future machine are the accelerator structures. These structures are arrays of cylindrically shaped cavities in which powerful radiowaves accelerate the particles that ride in the accelerating part of the electric field component of the wave. Several thousands of them will be used, and the higher electric gradient they can sustain, the shorter the machine will be. The length, probably around 30 km, will still be daunting.

Two main types of cavity technologies now exist: 'warm' and 'cold' cavities. The warm technology has been developed first: the cavities are made of copper and sup-



n the superconducting linear accelerator electro-magnetic 'ields accelerate the electrons to almost the speed of light. © DESY Hamburg

plied with radiofrequency power at the highest frequency feasible. Both the NLC-TA and the JLC use copper cavities powered with radiowaves at 11.4 GHz (X-band) produced by klystrons, and achieve an accelerating field of about 50 megavolts per metre. Japan is also studying a machine that would operate at an alternate frequency of 5.7 GHz (C-band). Also CLIC will use copper cavities that will be powered by a 'drive linac' installed along the main linac. In this linac an electron beam supplies the rf power at a frequecy of 30 GHz, hopefully allowing a higher gradient and therefore a shorter machine for the same energy. The drive linac will also allow the machine to operate beyond 1 TeV. At these energies, driving the cavities with klystrons is expected to be problematic, says François Richard, Director of the Laboratoire de l 'Accélérateur Linéaire (LAL) at Orsay in France.

The warm cavities lose energy in the form of ohmic dissipation by induced currents in the cavity walls. TESLA uses a so-called 'cold' technology. The cavities are made from niobium and cooled to liquid-helium temperatures. At these temperatures the cavity walls become superconducting, almost completely eliminating ohmic losses. As a result, almost 100 percent of the radiowave power is transferred to the accelerated electrons or positrons. Today the cavities routinely achieve an accelerating gradient of 25 MV/m, which for an 800-GeV design would be upgraded to 35 MV/M, while 42 MV/m have been already reached in test cavities.

A difficult choice

Now as the technical problems for building a linac are being solved, the next problem the international high-energy physics community will have to deal with is the creation of an "actual machine," says Richard. First, the different participating labs will have to decide which technology will be used. Representatives of these labs have been exchanging ideas regularly at meetings organised by the International Conference for Future Accelerators (ICFA). In 1996 the International Linear Collider Review Committee, also known as the "Greg Loew" committee, compared the different designs. "I worked with about sixty scientists from all over the world--at that time there were eight different approaches to the future linear collider," says Gregory Loew of SLAC, who chaired this committee. Now the situation is somewhat simplified. "We currently have two major competing approaches: the TESLA machine at DESY in Germany, and the X-band machine studied collaboratively at SLAC in the US and KEK in Japan," says Loew. However, since complete design reports and current cost estimates are not yet available, a rational choice cannot yet be made.

And making this choice may remain a major problem for some time. "I don't think any expert can say that this one technology is better than the other," says Hirotaka Sugawara, Director General of KEK. The decision between a cold and a warm technology will depend on many factors, including who will participate in the funding of the project and who will host it, says Sugawara. "If Germany will host it, then probably they will choose TESLA, and if the US or Japan is going to host it, it probably will be the warm technology," says Sugawara, adding that the choice of technology will also depend on the decision on the expandibility of the machine. Loew argues that both designs should be explored further "until we know which of the two basic technologies is more robust and less costly". Focussing on just one design at this point could result in making a premature and incorrect choice. "In about two or three years from now we should have enough information to make an educated comparison and selection," says Loew.

The second choice will be the siting of the machine in one of the three "regions," Europe, Japan, or the United States. According to Richard, there is general agreement that this machine should be built in an existing lab to reduce overheads and to make use of an existing high-energy research infrastructure. "If any of regions would be willing to finance more more than 50 percent of the machine, it is imaginable that the other regions will accept the idea of the first region hosting the machine," says DESY's Director General Albrecht Wagner. And Loew argues that because the US is funding the LHC at a rate of about $600 million, Europe might in exchange agree with a US site.

SLAC, collaborating with KEK, the Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL) and Fermilab, and DESY are each working on their designs in great detail. According to Richard, DESY has progressed furthest in hammering out the technical specifications for a 500- 800 GeV machine and will present its Technical Design Report for the TESLA Linear Collider and Free-electron Laser in March of next year to Germany's Science Council (Wissenschaftsrat). Germany will take a final decision on its part of the funding of the international project around 2003. Last year, SLAC completed a preliminary design with a cost estimate of $7.9 billion, including detectors and all staff salaries. It was perceived by the Department of Energy (DOE) in the US as too expensive, and now SLAC is working to reduce this cost substantially, reports Loew. DESY will include its cost estimate in its Technical Design Report.

The linear collider project will also have to compete for funding with other projects, such as a possible muon collider or long-baseline neutrino project in the US, or the international fusion-energy project ITER, or a neutron source, the European Spallation Source. Wagner is confident that the free-electron laser developed conjointly with the accelerator enhances the value of the project because, in addition to the high-energy physicists, it also appeals to the X-ray synchrotron radiation community. "This is the kind of synergy you look for frequently and hardly ever find," he says." So, what's next? "Particle physics world-wide needs to develop a strategic road map," says Wagner. Loew agrees: "We must break new scientific ground to build this machine internationally."

(*) Linear Collider Workshop, Fermi National Accelerator Laboratory, 24-28 October 2000

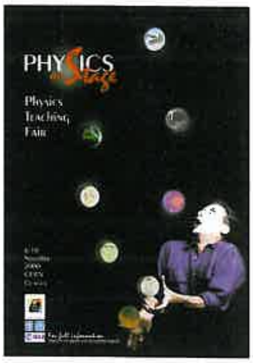
features

Letters

Congratulations to Physics on Stage

Congratulations to Physics on Stage, which was extremely useful for the exchange of teaching ideas. The stands from individual EU countries had a fascinating (and often inexpensive) array of demonstrations. Together with the presentations and shows they were of enormous potential benefit to teachers, in terms of simple, effective demonstrations.

One of the 'artistic/science' highlights was the performance 'The oracle of Delphi'. A professional theatre company presented Dirac's discovery of anti-matter through the medium of mime, acrobatics and wonderful visual displays using a vast three dimensional space on stage (much in the style of the work of 'Cirque de Plume'.) It was an excellent example of how to enable the public to think about science.



Every effort should be made to maintain the momentum, by communicating these ideas to physics teachers and those concerned with public awareness of science.

Alison Hackett
School of Science and Technology,
Dun Laoghaire, Ireland

Why is there no Paulium?

I read Charles Enz's note on Wolfgang Pauli's 100th birthday in Europhysics News 31/4 with great interest, also with pleasure. I have strong memories of Pauli, I was secretary of the Swiss Physical Society in 1956 while he was President. Charles Enz's article re-activates a thought that occurs to me every time I read that a new element has been discovered and named: Why was Pauli never honored? After all, one of Pauli's great contributions is the exclusion principle which explains the periodic system of the elements; previously the periodic system was merely a chart based on measurements, with no explanation as to its structure. – My position is very remote from the circles where the names of new elements are discussed and decided, but can one of the readers give a reason why Pauli was consistently passed over?

Ambros P. Speiser
Baden, Switzerland

Letters, opinions, comments... please send them to:
Europhysics News, 34 rue Marc Seguin, BP-2136,
68060 Mulhuose Cedex, France
email: epn@evhr.net

News

How Much Information?

http://www.sims.berkeley.edu/how-much-info/

Suffering from information overload? According to this new study from the School of Information Management and Systems at the University of California at Berkeley, "the world's total yearly production of print, film, optical, and magnetic content would require roughly 1.5 billion gigabytes of storage." Magnetic storage is by far the most common medium for storing information, accounting for an estimated 635,660 to 1,693,000 terabytes per year. Print documents only accounted for 0.003 percent of the total yearly production of content. The study is divided into content types, including Internet, magnetic, broadcast, phone, and mail. For each medium, the report offers a detailed chart of information types and the estimated amount of information produced yearly. The report includes a concise introduction and executive summary and links to myriad current articles from reputable publications and agencies.

ICSTI Secretariat changes

Paris, September 2000--ICSTI, the International Council for Scientific and Technical Information, is pleased to announce the appointment of a new Executive Director, Mr. Barry Mahon. Mr Mahon, who was Executive Director of Eusidic between 1991 and 1996, has a long history of involvement with scientific and technical information and international bodies. He worked under contract with Directorate General 13 of the EU for a number of years and also as a contractor to UNESCO and UNIDO in many locations in Europe, Africa and Asia. In the role of Executive Director he will be primarily concerned with providing ICSTI Members with news and information on developments in scientific publishing and in preparing position and policy papers for consideration. He will also represent ICSTI at international fora.

ICSTI is an international non-profit organization dedicated to increasing accessibility to and awareness of scientific and technical information. All participants in the information transfer chain - generators, processors, intermediaries at large and users - are represented in ICSTI membership which provides a forum for sharing common interests and expertise across the interfaces of scientific and technical disciplines and across international boundaries. Web site: www.icsti.org

The 13th IYPT in Budapest, July 2000

The 13th International Young Physicists' Tournament was held this year in Budapest, in July. Dr Zsuzsanna Rajkovits from the Eötvös Loránd University and her collaborators in the local organising committee had done a magnificent job to arrange for the participators, including high school students, team leaders and international jury members. This year there were 19 teams from 17 different countries entering the competition which is no longer a European/Asian affair. Mexico and Australia were also represented, just like last year in Vienna.

The 17 problems to be dealt with in the tournament are prepared and made known to the participating teams in November of the preceding year. An internationally composed group of physicists work on selecting the problems in October.

The tournament starts with several qualifying "fights" in which all teams participate. Three teams take part in each event, and in turn, during the event, they take the rôles of reporter, opponent and reviewer. The nine best of the teams go to the three semi-finals, and the winners of these are the finalists. In the final the competing teams are free to choose the problem to which they present their solutions to the other two competing teams. Otherwise the opponent challenges the reporting team for a problem. However, the reporter has the possibility to refuse a problem twice, without being punished by a reduction of points. A rather elaborate set of rules regulates the procedure in each part of such a "fight" A full event where the three teams have assumed all three roles takes about three hours. The international jury consists mostly of university physicists.

This year the teams Poland 2 (from Katowice), Russia and Germany reached the final. The three teams had chosen the following problems from the list:

Two identical open glasses, filled with hot and warm water, respectively, begin to cool under normal room conditions. Is it possible that the glass filled with hot water will ever reach a lower temperature than the glass filled with warm water? Make an experiment and explain the result. (Poland 2)

Using a bulb, construct the optimum transmitter of signals without any modulation of the light beam between transmitter and receiver. Investigate the parameters of your device. The quality of the device is defined by the product of the information rate (bits/sec) and the distance between transmitter and receiver. (Russia)

Use efficient methods to collect as much radioactive material as you can in a room. Measure the half-life of the material you have collected. (Germany)

The jury, with 11 physicists from 10 countries, gave the victory to the Polish team from Katowice, with Germany and Russia in second place.

Next year the 14th IYPT will be held in Espoo, just outside Helsinki, and already some countries are willing to host the competition in the following two years.

Gunnar Tibell

CCSD

Through the efforts of French scientists, including F. Laloe, member of the EPS Action Committee on Publications and Scientific Communications, the CNRS will invest in electronic publications through the creation, of a small service unit known as the CCSD (Centre pour la communication scientifique directe) which will try to take a more active part in the Los Alamos type activities, in close collaboration with the other European and American initiatives. The mission of the CCSD is to improve and expand electronic communication techniques to permit researchers from around the world to directly communicate their research results by including them in free access document servers.The unit in question will be located in Lyon, in the CNRS computing center on the University Campus (La Doua), and will hopefully work with EPS. C. Monttonen chairman of the ACPuSC is on the steering committee. A first meeting of the European xxx mirrors was held on Monday 30 October, and was attended by representatives from Germany, Italy, the UK and the US. More information is available at http://ccsd.cnrs.fr/

New Director of the European Optical Society

The European Optical Society (EOS) has appointed as its first executive director Klaus-Dieter Nowitzki. This is the first step towards the professionalization of the EOS, a process that will significantly strengthen the society and further improve the benefits to the European Optics Community. Through its national member optical societies, the EOS today represents more than 5000 optics professionals throughout Europe.

Mr. Nowitzki, who is 43 years old, holds a Masters degree in sociology. He worked as technical co-ordinator, consultant and as deputy head of the laser technology department of the German Engineering Association (VDI). For two years Mr. Nowitzki was vice national delegate in Brussels for the EU program MONITOR (strategic research planning). Mr. Nowitzki continues to work part-time for the German association WLT (Wissenschaftliche Gesellschaft Lasertechnik) in Hannover, whose CEO he has been since 1996.

Corrections from the Nuclear Physics Division

In EN 31/5 2000 the Nuclear Physics Division Conference on Nuclear physics in Astrophysics, to be held in Eilat, Israel (EILAT 2001 from 15-19 January 2001) was not included in EPS Europhysics Conferences Planner.

R.A.Ricci should be included as the past-Chairman of the Nuclear Physics Division information in the Directory of the EPS in EPN 31/4.

Top of the pops?

The Physics Department of Trinity College Dublin has seen visits to its web site increase dramatically over the past year. From a regular four or five hundred hits per month on the top page, traffic climbed steadily from September 1999 to reach the dizzy heights of 2500 hits per month in February 2000, and has remained on this plateau ever since. If only it was our share price, say the physics staff, grateful that all those people out there don't send admiring or disappointed emails...

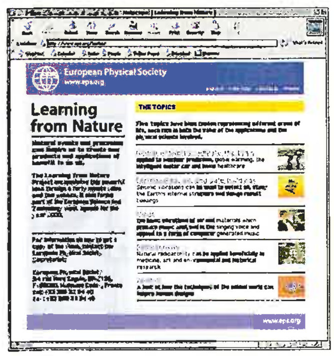
The increased traffic may be due to the prominent listing of the site on Yahoo's Science/Physics page. Visit http://dir.yahoo.com/science/physics/ to see if it's still there. Yahoo also listed the department's new web site for secondary schools. Bright and breezy, is designed to stimulate students' interest in the subject. Or you can go direct to www.tcd.ie/Physics/ and www.tcd.ie/Physics/Schools/welcome.html

It takes a lot of hard work (or money) to design a good web site. But this experience suggests that it is well worth the effort. Do you have a similar story? Tell us.

Another interesting site:

Are you interested in Physics, Astronomy and Science in general? Then check out: http://www.physlink.com

Learning from Nature



Take a look at the EPS web site (www.eps.org) to see a visual presentation of the Learning from Nature project (Leafon). A video is now available from the EPS Secretariat. The EPS unveiled its projects for European Science and Technology Week in Bruxelles on 7 November. Attended by European MPs, and EC officials, the event was opened by A. Wolfendale, the EPS President. Physics on Stage was presented by M. Huber. The Public Awareness of Nuclear Physics project, which had separate exhibitions in France, Italy and Germany was introduced by J. Deutsch. The EPS would like to thank the EC's DG Research and the IHP programme for its financial support for all of its programmes.

Contact **Susan Mackie** • EDP Sciences • 250, rue Saint Jacques • F-75005 Paris • France
Phone +33 (0)1 55 42 50 51 • fax +33 (0)1 46 33 21 06 • e-mail mackie@edpsciences.org

University of Zurich, Switzerland

The Faculty of Science invites applications for a

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Candidates with a recognized scientific record in theoretical elementary particle physics are asked to send their curriculum vitae, list of publications and a summary of their research to the Dean of the Faculty of Science (Mathematisch-naturwissenschaftliche Fakultaet), Prof. K. Brassel, University of Zurich, Winterthurerstrasse 190, CH-8057 Zurich, by **November 30, 2000**.

For more information, contact Prof. D. Wyler (wyler@physik.unizh.ch). Please visit our website at http://www-theorie.physik.unizh.ch.

The University encourages female candidates to apply with a view towards increasing the proportion of female professors.

The forthcoming deadline for applications for magnet time allocation (February to July 2001) at the

GRENOBLE HIGH MAGNETIC FIELD LABORATORY

is **November 10, 2000**.

Scientists of EU countries and Associated States* are entitled to apply under the HPP Programme «Transnational Access to Major Research Infrastructures» to obtain a financial support according to rules defined by the EC. Application forms are available on request.

* Bulgaria, Czech Republic, Republic of Cyprus, Estonia, Hungary, Iceland, Israel, Latvia, Liechtenstein, Lithuania, Norway, Poland, Romania, Slovakia, Slovenia.

Please contact:

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CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

CNRS - Centre National de la Recherche Scientifique France
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Research Associate Position

The Laboratoire d'Aérothermique invites a senior scientist for a stay of 1 (or two) year(s) for experimental research in the field of plasma physics dealing with rarefied hypersonic plasma flow around Martian probes. Experiments will be carried out in ground test facilities with optical diagnostics (optical emission spectroscopy in the visible, near UV, IR ranges, LIF), electrostatic probes. Plasma flow will be analyzed in order to detail the non equilibrium processes appearing in supersonic plasma flow (SR1 and SR5 facilities) and in hypersonic flow in a new facility (Hibiscus project).

The study will be performed in the research group " Plasma et sondes spatiales " in the frame of a program on the aerothermodynamics of planetary plasma entries.

The Laboratoire d'Aérothermique is located at Orléans, France (130km in the South of Paris). The Laboratory is studying space problems especially for satellites, re-entry and propulsion. It is associated to a cluster of laboratories called Federation EPEE at Orléans (Energetics, Propulsion, Space, Environment).

The successful candidate will have to participate directly in the research program and in the analysis of the results and will be fully supported, including travelling and salary (minimum : 1 year) by the Studium organization. The position is available starting in the first half-part of 2001.

Applicants should submit a detailed vita to :
Dr Viviana Lago
Laboratoire d'Aérothermique http : web.cnrs.orleans/~webaero/aerola.html
1C Avenue de la Recherche Scientifique
45071 Orléans cedex, France
tel: (33) (0)2 38 25 77 15, fax: (33) (0)2 38 25 77 77,
Email lago@cnrs-orleans.fr

ETH ZÜRICH

The Swiss Federal Institute of Technology Zurich (ETHZ) invites applications for a

Professor in Physics (experimental Nuclear Physics)

The post is based in the Institute of Particle Physics (IPP). The goal of the Institute is to maintain leading research in nuclear physics with links to particle physics and/or astrophysics. The new professor is expected to carry out first-rate experimental research in nuclear and particle astrophysics, nuclear neutrino physics or in the study of fundamental interactions at low energies. He/she is encouraged to take advantge of the existing facilities at the Paul Scherrer Institute (PSI), Villigen or of the Accelerator Mass Spectrometer (AMS) located at ETHZ.

The new professor is expected to participate in teaching physics in all departments of ETHZ, including propaedeutic physics and specialized nuclear physics courses up to the level of the ETHZ diploma.

Applicants with internationally recognized research credentials are asked to send their curriculum vitae, list of publications, names of at least 3 references, and a short overview of their research interests **to the President of ETH Zürich, Prof. Dr. O. Kübler, ETH Zentrum, CH-8092 Zürich, no later than January 31, 2001.** The ETHZ specifically encourages female candidates to apply with a view towards increasing the proportion of female professors.

General information on ETH Zürich and its Department of Physics is available on 'http://www.phys.ethz.ch' Questions referring to this position should be mailed to Prof. Dr. R. Eichler, Institute of Particle Physics, ETH Hönggerberg, CH-8093 Zürich (E-mail : eichler@particle.phys.ethz.ch).

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For further information please contact Dr. Lerch, tel. +41 56 310 3231, e-mail: philippe.lerch@psi.ch; or Dr. Zehnder, tel. +41 56 310 36 15, e-mail: alex.zehnder@psi.ch.

Please send your application to:
PAUL SCHERRER INSTITUT, Human Resources, ref. code 1512, CH-5232 Villigen PSI, Switzerland.

Further job opportunities: www.psi.ch

FACULTY POSITION IN EXPERIMENTAL ATOMIC AND MOLECULAR PHYSICS
Department of Physics
Université Catholique de Louvain

The Rector of the Catholic University of Louvain (UCL) in Louvain-la-Neuve, Belgium, invites applications for a full-time academic position beginning in fall 2001. Applicants will have a Ph.D. or equivalent and postdoctoral experience in experimental atomic and molecular physics.

The appointed person is expected to teach physics courses in the university and play a leading role in both shaping and implementing the research program in experimental atomic and molecular physics. This program presently includes quantum optics, the study of cold atoms, condensates, molecules and aggregates and their interaction with intense laser pulses. All these activities are pursued within national and international collaborations.

Only a good knowledge of English is required initially but, since the appointed candidate is to teach in French, she/he should acquire a reasonable command of the language within two years. Rank and salary will depend upon qualification and experience.

The successful candidate should sustain a strong program of research with significant undergraduate and graduate involvement. Although she/he will be primarily based in Louvain-la-Neuve, her/his research within the atomic and molecular group will imply stays abroad in one of the large European centers for physics with lasers.

Candidates should submit a letter of application, a curriculum vitae, a copy of their final diploma, a list of publications, four letters of recommendation, a copy of their five most representative publications. In addition they should describe their research project within the next five years (2 pages) and explain their pedagogical views and the type of teaching they want to promote (2 pages). All these documents should be sent to Professor M. Crochet, Rector, The Catholic University of Louvain, Halles Universitaires, place de l'Université 1, B-1348-Louvain-la-Neuve, Belgium.

The closing date for applications is January 15, 2001.

For further information, please consult http://www.phys.ucl.ac.be/offres_en.html .

You can also write or call Prof. J.P. Antoine, Chairman of the Department of Physics, chemin du Cyclotron 2, B-1348-Louvain-la-Neuve, Belgium. Tel. +32-10-473283. Fax +32-10-472414 (E-mail : antoine@fyma.ucl.ac.be).