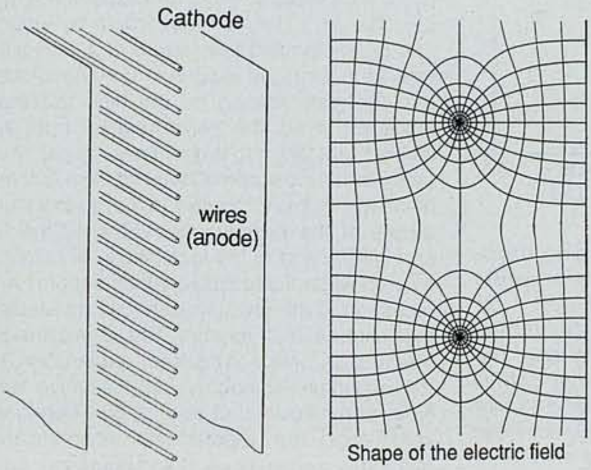
1992 NOBEL PRIZE FOR PHYSICS

Wire Chambers for Exploring the Elementary Constituents of Matter

W. Bartl and M. Regler of the Institute of High Energy Physics, Vienna, Austria, discuss the 1992 Nobel Prize in Physics that was awarded to Georges Charpak for his invention and development of particle detectors, in particular the multiwire proportional chamber.

Georges Charpak has been a Professor with the Ecole supérieure de physique et chimie inustrielle de la Ville de Paris *since 1948. Born in 1924 in Poland, he emigrated in 1931 to France and studied in Paris, Montpellier and Lyon. After war service, he resumed his studies at the* Ecole des Mines, *Paris, receiving his diploma in 1948. His doctorate in experimental nuclear physics was awarded by the* Collège de France *in 1954 while working for the French* CNRS. *He joined the team making the first precision measurement of the muon's magnetic moment soon after moving to CERN, Geneva, in 1959. Professor Charpak retired from CERN in 1991 but remains active in the company Biospace that he created in order to comercialise his detectors in biological fields. He is a member of the French Academy of Sciences and won the French Physical Society's 1980* Prix Ricard *as well as several other French and international awards.*



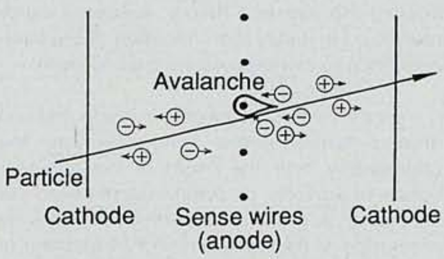


Fig. 1 — Multiwire proportional chamber: a, upper left) The basic structure showing the plane array of parallel anode wires placed between two planar cathodes separated by a gas-filled volume; b, upper right) Equipotential and field lines; c, lower) After a charged particle has transversed showing the initial ionization and the subsequent drop-like avalanche that develops around an anode wire.

Georges Charpak's principle invention is the wire chamber, a detector consisting of an unconventional juxtaposition of a number of proportional counters, with the walls between the wires eliminated to give parallel wires arranged in a plane located between two cathode planes (Fig. 1a). He realised that for operation in an appropriate gas mixture, each wire would behave as a proportional counter when the wire diameter was of the order of 1% of the wire spacing. This behavior can be understood in terms of the almost concentric field lines around the anode wires (Fig. 1b). A charged particle passing through the gas-filled chamber ionizes the gas and, in the electric field, the electrons move towards one of the anode wires (Fig. 1c). Charge multiplication occurs in the region around the wire where the field strength increases as $1/r$, r being the distance to the wire axis. Most of the electron-ion pairs are created in the vicinity of the wire so the time behaviour of the signal is primarily determined by the motion of the ions, which are travelling reasonably rapidly in the electric field. The energy resolution of the detector is comparable to that of a conventional cylindrical proportional chamber.

Charpak worked with anode wire spacings down to 1 mm (the spacing determines the intrinsic space resolution if the drift time is not measured). However, he at an early stage reported experimental evidence showing that the time delay of the pulse (drift time of electrons migrating towards the wires) can be used to measure particle tracks more accurately than the limitation imposed by the wire spacing.

Pioneering Work

Spark chambers had been used for some time to determine the trajectories of particles in the selective search for elementary particles in dedicated electronic detectors ("counter physics" in contrast to "bubble chamber physics"). But they had considerable drawbacks such as poor multi-hit efficiency, large dead time, and the production of a huge amount of electromagnetic noise which disturbed nearby electronics. It was also impossible to include information about the trajectories in the detector's high-speed trigger circuit. The spark chamber technique had reached its limits and this partly determined progress in particle physics.

Charpak published his pioneering work on multiwire proportional chambers [1] at this crucial juncture. It was some 40 years after the famous work by the Austrian physicists G. Ortner and G. Stetter on the development of Geiger-Müller and proportional tubes and their application for physical measurements [2]. Charpak's first report indicates very clearly a new direction and all the main advantages for particle detectors. It is amazing to find here remarks concerning possibilities, sometimes realised many years later, that led to various new types of detectors, notably:

- different forms of drift chambers;
- time-projection chambers (the "heart" of modern storage-ring detectors);
- detectors for particle identification (deposit of the energy E with distance x, transition radiation and Čherenkov detectors, and calorimeters of various types);
- X-ray detectors for biology, medicine and astrophysics.

Owing largely to Charpak's work, particle physicists have been able to focus their interest on new physics: on the production and interaction of very rare particles which often reveal the secrets of the innermost constituents of matter; on measuring differential cross-sections over many orders of magnitude, with both low background and high precision; and on understanding the corrections needed to take measurement errors into account. Further advantages of multiwire proportional chambers are:

- event rates of 10^6 Hz and more can be handled;
- DC-powered: can be used in a trigger requiring processing times below 100 ns;
- the degree of ionization produced locally by the particles does not affect the overall efficiency (even the multi-hit efficiency can exceed 99%);
- a local dead time of short duration;
- relatively unaffected by strong magnetic fields;
- good signal-to-background ratio.

Charpak has been at the forefront of the development of multiwire proportional chambers for more than two decades, and various versions of his detectors were decisive for many discoveries in particle physics. Nobel Prizes have been awarded for some of these, notably for the discoveries of the

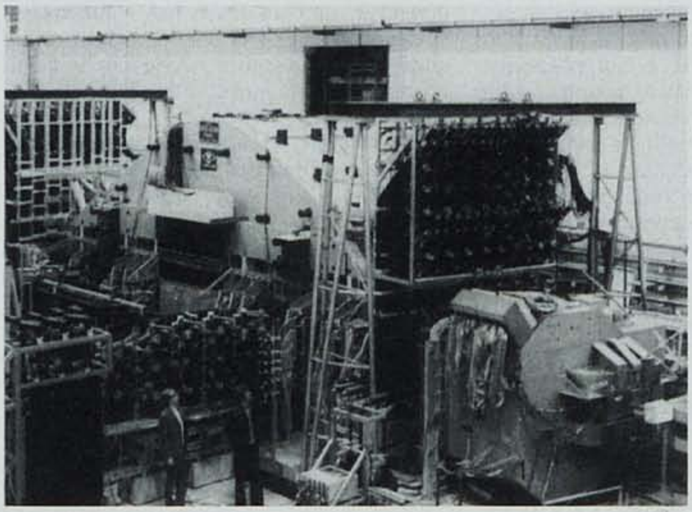


Fig. 2 — The Split Field Magnet Facility at Intersection 4 of CERN's ISR facility in October 1973. The spectrometer magnet is filled with detectors, including proportional wire chambers.

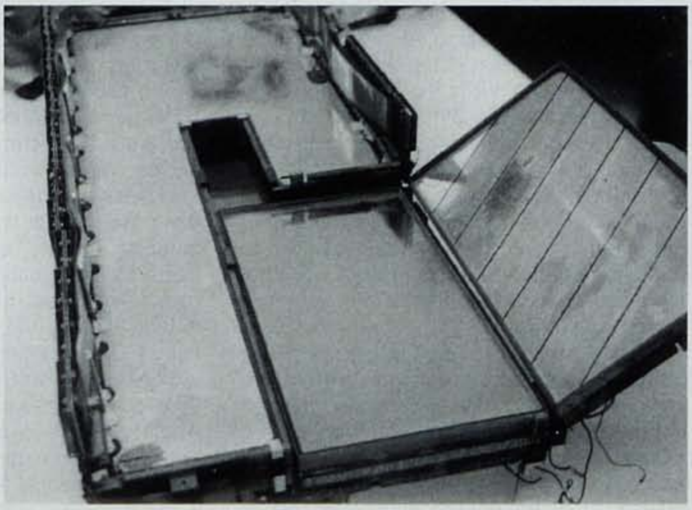


Fig. 3 — A multiwire proportional chamber built at the Institute for High-Energy Physics, Vienna, in 1973. The open part shows the cathode readout strips. (Courtesy: R. Eitelberger)

charm quark (B. Richter and S.C.C. Ting) and the intermediate bosons (C. Rubbia and S. Van der Meer).

It is pleasing that with G. Charpak a detector expert has received the Nobel Prize, for people developing and working with experimental techniques are often somewhat shadowed by those who search for (and find) new particles.

Early History

In order to understand the authors' enthusiasm one must go back to the late-l960's. The construction at CERN of the Intersecting Storage Rings (ISR) was well underway, and the highest collision energies in the world were expected (63 GeV center-of-mass energy). However, nobody was able to deal with event rates of the order of several tens of kHz, to design selective triggers with sufficiently low accidental rates, and to measure particle tracks with the necessary precision. All hopes were directed at Charpak's invention, who was (together with A. Minten) responsible for the basic instrumentation of the largest spectrometer magnet called SFM, the Split Field Magnet (Fig. 2). As our collaboration (CERN-Hamburg-Orsay-Vienna) was supposed to perform the first large-scale experiment (Intersect 4-01) at this facility, scientists had been assigned to Charpak's group [3]. One of us (W.B.) was responsible for designing the special detectors specific for our experiment (Fig. 3) while another (M.R.) was responsible for Monte Carlo simulations to study the optimal detector layout, and for developing high-speed algorithms able to handle the impressively large flow of information that was expected.

It should also not be forgotten that Charpak's invention was immediately taken up by the group of J. Steinberger, the Nobel laureate, for a fixed-target, high-precision CP-violation experiment. This was in collaboration with the University of Heidelberg, Germany [4], which also gave an essential impetus to the initial development of drift chambers.

Many problems had to be studied in depth during this exciting period, including spurious currents, breakdowns, electrostatic instabilities, and the optimum gas mixture. Some of these studies were soon to be assisted by scientists from the USA and the former USSR (who organized the first international wire chamber conference). Many years later, Charpak's opening talk at the Vienna Wire Chamber Conference began with the phrase "*Les funérailles des chambres à fils* (the burial of wire chambers)". But wire chambers are still very much alive. This year's conference in Vienna demonstrated that considerable progress in fundamental understanding is still being made (time development of chamber pulses, precise calculation of the Townsend coefficient, ageing studies, gas microstrip detectors, *etc.*).

Other Developments

Nuclear and particle physics

The discovery of the wire chamber opened up an avalanche of new developments, both at CERN and elsewhere. **Drift chambers** came into being by simply using a larger anode wire distance (a few centimetres) together with a potential wire to generate a drift field in between the wires. In an improved version, field shaping wires replaced the cathode foil, thus creating a fairly homogeneous drift field in the direction towards the cathode wire (Fig. 4). This technique improves the spatial resolution to about 100 μm but with the drawback of a reduced trigger rate capability as one anode wire samples a large area.

Using new construction methods, the original idea of circular cathodes was taken up again to develop the **straw tube** comprising pipes of thin, metallised plastic foils of a few millimetres in diameter for applications in high-intensity environments near the intersection areas of high-energy particle colliders. Tubes of different sizes are preferred, with extended gas amplification on the anode wire (*i.e.*, in a streamer mode). At least ten times more charge compared to the proportional mode is created in this mode since streamers develop from a thicker anode wire (about 100 μm diameter) in the strong electric field penetrating into the gas volume. The time development of the collected charge is dominated by a more rapid motion of the electrons so the gain and power dissipation (and cost) of subsequent amplifiers can be reduced.

An important field, namely high-energy particle identification (energies up to several 100 GeV/*c*) became feasible. Relativistic effects introduced by charged particles having different Lorentz factors are used to distinguish between different particles. Two approaches are well-established:

1) d*E*/dx method, where the number of electron/ion pairs produced by a highly energetic particle traversing a medium increases with increasing energy (relativistic rise). If the volume of gas transversed is large enough, a sufficient number of ion pairs are produced for distinguishing, in spite of statistical fluctuations, between particles of the same momenta, but different masses. Particle type and direction are simultaneously registered by a large number of sampling wires. In practice, electrons drift several metres towards a wire chamber where the

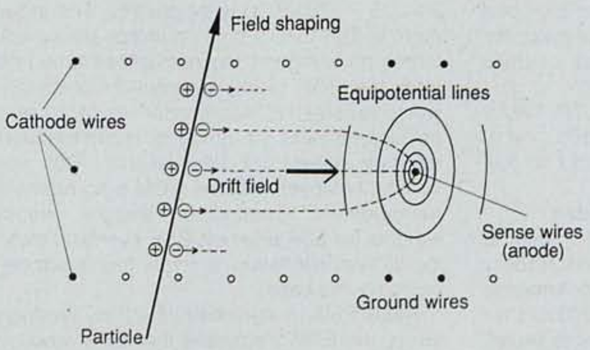


Fig. 4 — Schematic illustration of a drift chamber. The distance between anode wires is fairly large (a few cms) and field shaping wires replace the cathode foil to create a fairly homogeneous drift field towards the cathode wire .

projection of the track is detected. Enormous gas volumes (up to 40 m^3) are used to deposit the ionization of the particle. A common type of detector is the Time Projection Chamber where the drift distance is computed from the drift time to determine the track position in space.
2) Photon method, which uses the transition radiation of radiators interleaved between multiwire proportional chambers sensitive to photons of about 10 eV to provide powerful π/e discrimination for particles with extremely high γ-factors.

Finally, one should not forget the **Ring Imaging Čherenkov** detector (RICH) for π/K/p separation, where Čherenkov photons ionize the gas of a drift chamber containing a small quantity of a special gas (TMAE); and **calorimetry**, which has become a powerful tool for energy measurements in particle physics using arrangements of material for shower production alternating with wire chambers.

Other fields

Charpak's work and influence did not stop with the successful exploitation of wire chambers in nuclear and particle physics for he also developed applications in biology, medicine, synchrotron radiation, and astrophysics. For X-ray measurements in nuclear medicine, he worked on a high-pressure, xenon filled, gas scintillation counters and continued with photoionization proportional scintillation detectors, where the energy resolution went down to less than 10% FWHM at 5.9 KeV. Indeed, the required radiation dose to a patient is reduced by an order of magnitude using a wire-chamber imaging camera. The multistep avalanche chamber has been used for radiochromatography (tritium loaded) and, in conjunction with optical CCD readout, renal ducts of about 50 µm are visible with 100 times less exposure time as compared to photographic methods. Another device is the spherical drift chamber for X-ray imaging applications: the drift space is spherical and the electric drift field is radial, giving an ideal detector for a point-like source. It is employed successfully for protein diffraction pattern measurements.

Various systems for medical imaging are used in hospitals. One is a positron emission tomography camera for routine tomographic imaging consisting of two or more wire chambers (Rutherford-Appleton Laboratory, UK; Cantonal Hospital, Geneva.) Another is a computer-assisted digital X-ray diagnostic camera which has improved resolution and requires only one-tenth of the dose compared with conventional methods (in clinical use in Moscow and Novosibirsk).

In addition to scientific accomplishments, George Charpak is distinguished by his humanitarianism. Aside from his involvement in medical applications of wire chambers, he has been a strong defender of human rights, the most spectacular action being in defense of Yuri Orlov, an internationally renowned Russian accelerator physicist who founded the Moscow-Helsinki Watch Group in 1976. Orlov was set free in 1986 following international pressure. Charpak was also a beloved teacher, and many of his former disciples were glad to become his friends, including the authors.

REFERENCES

[1] Charpak G., *et al., Nuclear Inst. & Methods* **62** (1968) 262.
[2] Ortner G. and Stetter G., *Mitteilungen des Instituts für Radiumforschung*, No. 228 (1928).
[3] Charpak G., *et al., Nuclear Inst. & Methods* **97** (1971) 377.
[4] Schilly P., *et al., ibid.* **91** (1971) 221.

Europhysics Notes

● Donated Proceedings to be Available

The International Centre for Theoretical Physics in Trieste distributed during the last 12 months some 37 000 donated volumes of journals, books and proceedings to over 1500 institutes in developing countries *via* its Donation Programme. However, owing to the explosion in scientific publishing and to an increased interest in the programme, donations in the last four years have run at roughly twice the average distribution rate of 40 000 - 50 000 volumes p.a. Some 170 000 volumes are now in commercial storage, mostly unpacked. About 60% of the volumes are proceedings of roughly 300 conferences in physics and mathematical physics dating from 1988-1991 as publishers such as World Scientific, APS and North-Holland and organizations such as IUPAP frequently send multiple copies of meetings they handle.

Professor H.R. Dalafi who runs the programme say he plans to start sending the volumes in bulk to institutes in developing countries from next March.The ICTP is also seeking funds to extend the regular distribution scheme to include East and Central Europe. He invites the region's scientists to get in touch with him next Spring so that they can benefit from the programme. It may eventually be possible for them to pick up volumes directly in Trieste.

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● First Four Physics ERC's Funded

The first selection round this summer of the current EC Human Capital and Mobility programme allocated physics conferences with 68% (697 kECU) of the 1020 kECU recommended by the CODEST physics panel. This is 22% of the total allocation of 3200 KECU for euroconferences (line 4 of the programme). Some 1100 kECU comprised a grant to the European Science Foundation for European Research Conferences (physics ERC's are organized by the ESF based on proposals from EPS Divisions that are coordinated by the EPS Working Group on ERC's). The grant has been assigned chronologically which means that the four physics series of two meetings slated for late-1992 and early-1993 have 205 kECU available. The roughly 20-25 kECU per meeting would seem to be the level of EC support one can expect for ERC's.

Although the CODEST physics panel approved on a case-by-case basis the full programme of 1993 ERC's in physics proposed to it by the ESF, the panel also approved other events. The final result was to recommend 25.5% of the 1020 kECU for ESF events. Chemistry, on the other hand, recommended 58% of its total, and both life sciences and earth sciences 74%. The ESF is concerned that the low percentage for physics appears to reflect poor support for its ERC's. Indeed, "renormalising" by multiplying the allocations for the various disciplines by the percentages recommended by the corresponding CODEST panels for ESF events gives a total of 1243 kECU of which only 697 x 0.255 = 178 kECU is for physics. The argument is that ERC's could perhaps be expected to be assigned the normalised amounts from the ESF grant, whereupon chemistry would receive 122%, life sciences 110% and physics 68 % of the amounts recommended by their panels for ESF events. This assumes, however, that the HCM programme's management committee assigns equal weights for ESF and non-ESF events in making its final allocation: *a priori*, this is not necessarily the case.

Klaus Bethge who chairs the EPS Working Group on ERC's stresses that EPS, and by implication the physics community, is fully behind the ERC's. He sees no reason for thinking that the ERC programme is jeopardised if a CODEST panel recommends a relatively large number of non-ESF events. The EC has provided valuable support to the ERC's since the start and is clearly continuing to do so.

It is estimated that a further 307 kECU will be needed in order to cover the rest of the planned programme of nine two-meeting series of physics ERC's for 1993. There will be two HCM selection rounds in 1993 involving 7 MECU in total (roughly the same amount per round as for the 1992 round) so it is perhaps reasonable to assume that the additional sum will be found. But it is essential that this is so as the ESF is announcing ERC's in physics in this Meetings Issue which are not yet covered by EC funds.

Another concern involves the interpretation of HCM rules regarding what can be paid for. The Commission of the EC now accepts that the ESF's EC grant can in principle cover sizable participation fees for young scientists, and not just their travel and accommodation. Although this interpretation will have to be tested as accounts are returned to the CEC by the ESF, it will essentially allow expenses for invited speakers to be met by the EC grant — a vital feature for organizers planning meaningful events which attract young scientists.

● Journals to the FSU

K.K. Phua, Chairman of World Scientific Publishing, writes to say that the WSP is currently sending complimentary copies of *Int. J. of Modern Phys. A* and *Modern Phys. Lett. A* to 27 institutes in the former Soviet Union. Twelve institutes also receive *Int. J. of Modern Phys. B* and *Modern Phys. Lett. B.* He stress the importance of providing current issues since it is esential to help transfer the latest information.