Wire Chambers for Exploring the Elementary Constituents of Matter

W. Barti 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'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-ions, which are travelling reasonably rapidly in the electric field, are accelerated towards the anode wires (Fig. 1c). Charge multiplication occurs 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 physicist 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 Cherenkov 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 \(10^5\) 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
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-1960'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 (Intersection 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 for developing high-speed detectors, including proportional wire chambers.

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)

stabilities, 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 cham­tres 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) dE/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...
projection of the track is detected. Enor-
mous gas volumes (up to 40 m³) are used to
deposit the ionization of the particle. A com-
mon type of detector is the Time Projection
Chamber where the drift distance is com-
puted 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 extreme-
ly high γ-factors.

Finally, one should not forget the Ring
Imaging Čerenkov detector (RICH) for z/Kp separation, where Čerenkov photons
ionize the gas of a drift chamber containing
a small quantity of a special gas (TMAE); and
calorimetry, which has become a power-
ful 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 astro-
physics. For X-ray measurements in nuclear
medicine, he worked on a high-pressure,
Xenon filled, gas scintillation counters and
continued with photoinionization proportional
scintillation detectors, where the energy res-
olution went down to less than 10% FWHM
at 5.0 KeV. Indeed, the required radiation
loss 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 opti-
cal CCD readout, renal ducts of about 50
μm are visible with 100 times less exposure
limits as compared to photographic methods.

Another device is the spherical drift cham-
ber 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 emis-
tion tomography (PET) system, which uses
the tomographic imaging of consisting of two or more
wire chambers (Rutherford-Appleton Labor-
atory, UK; Cantonal Hospital, Geneva.) An-
other is a computer-assisted digital X-ray
diagnostic camera which has improved re-
solution and requires only one-tenth of the
cost 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 involve-
ment in medical applications of wire cham-
bers, he has been a strong defender of
human rights, the most spectacular action
being in defense of Yuri Orlov, an interna-
tionally renowned Russian accelerator phy-
sicist who founded the Moscow-Helsinki
Watch Group in 1976. Orlov was set free
in 1980 as a result of international pro-
tests. Charpak was also a beloved teacher,
and many of his former disciples were glad
to become his friends, including the authors.

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Europhysics News

Donated Proceedings to be Available
The International Centre for Theoretical
Physics in Trieste distributed during the last
18 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, dona-
tions in the last four years have run at rough-
ly 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 organi-
sations such as IUPAP frequently send mul-
tiple copies of meetings they handle.

Professor H.R. Dalafi who runs the progra-
mme says he plans to start sending the vol-
umes in bulk to institutes in developing coun-
tries next March. The ICTP is also sending
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 eventu-
ally 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 ESF Human Capital and Mobility
programme allocated physics conferences
with 68% (697 KECU) of the 1020 KECU re-
commended by the CODEST physics panel.

This is 22% of the total allocation of 3200
KECU for euroconferences (line 4 of the pro-
grame). Some 1100 KECU comprised a grant to
the European Science Foundation for European Research Conferences (phys-
ic 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 chron-
ologically 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 pro-
sposed to it by the ESF, the panel also ap-
proved other events. The final result was to
recommend 25.5% of the 1020 KECU for ESF
events, Chemistry, on the other hand, recom-
manded 58% of its total, and both life scien-
ces and earth sciences 74%. The ESF is
concerned that the low percentage for physi-
cis appears to reflect poor support for its
ERC’s. Indeed, "renormalising" by multi-
plying the average percentage of the groups
would give a total of 1243 KECU of which 697
x 0.255 = 178 KECU is for physics. The argu-
ment is that ERC’s could perhaps be expec-
ted to be assigned the normalised amounts
recommended if a CODEST panel recommends a rel-
tively large number of non-ESF events. The
EC has provided valuable support to the
ERC’s since the start and is clearly continu-
ing 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 involv-
ing 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 essen-
tial 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
sizeable participation fees for young scientists,
and not just their travel and accommodation.
Although this interpretation will have to be
tested in practice once accounts are returned to the CEC
by the ESF, it will essentially allow expenses
which are not yet covered by EC funds.

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