Side view of the TPC configuration as it will be installed on PEP. It has the experiment number PEP-4 and will be integrated with an experiment, PEP-9, to measure two photon processes. The locations of the different elements of the TPC facility can be seen.

The energy resolution ranges from 4.5 mm for low energy photons (about 100 MeV) to 1.5 mm for energies over 1 GeV. The energy resolution is 9% \( (1/E)^{0.55} \) with \( E \) in units of GeV.

Identification of low momentum muons is done using \( dE/dx \) in the TPC, while at higher momenta they are identified by their ability to penetrate a thick iron absorber which surrounds the TPC and the photon calorimeter. The iron (including the magnet yoke) is 1 m thick, resulting in a hadron ‘punch through’ probably of only 1%. Proportional chambers detect the muon after the iron with a spatial resolution of 1 cm.


**CERN**

Still greater accuracy from MWPCs

Further studies on the abilities of multiwire proportional chambers indicate that the localisation of ionizing radiation in space can be achieved with an accuracy of around 30 \( \mu \)m (or better for heavily ionising particles). These results came from a simple system and it is possible to use a single sense wire plane, together with signals from cathode wires, in the collection of two dimensional information with a time resolution of 30 ns.

Since the initial development of multiwire proportional chambers by the group of Georges Charpak at CERN in 1968, they have come into very widespread use in high energy and nuclear physics. They are also beginning to have interesting applications in solid state physics and biomedical research. They offer the possibilities of good spatial resolution, almost continuous sensitivity, multiparticle detection and (in special systems) two dimensional read-out and the detection of neutral particles.

In most of the existing chambers the accuracy with which the particle position can be located is dictated by the
A heavy target, nicknamed STAC, will be used in the large spectrometer for the study of muon-nucleon scattering in the North Area of the SPS by the European Muon Collaboration. It has been built and successfully tested in an electron beam at DESY and is now being tested in an SPS hadron beam in the West Hall. It consists of 26 iron/scintillator sandwich elements to measure the energy which the 280 GeV primary muon looses during its interaction in the target.

Several Laboratories, particularly Berkeley and Oak Ridge, have worked on the possibility of achieving two dimensional information from a MWPC. One technique is the clever use of signals from the cathode plane which eventually receives the pulse induced by the positive ions generated around the anode wire receiving the electron avalanche. The ions move away from the anode plane and distribute pulses on the wires or strips of the cathode plane. By measuring the 'centre of gravity' of the distribution it is possible to estimate where the avalanche originated. Crossed cathode strips on the two sides allow a two dimensional detection ability that is particularly useful for neutral radiation (neutrons, X-rays and gammas), since they produce electrons which may not have enough energy to traverse several chambers. Such MWPCs are beginning to find applications in medicine and biology.

The latest work at CERN has attempted to push the technique of 'centre of gravity' measurement to its limits. Using modestly priced amplifiers it was found that a 'gate' of 30 ns was sufficient to provide enough information to give excellent two-dimensional accuracy. This sets the time resolution of 30 ns. Gases were chosen to give moderate amplification (argon or xenon, with isobutane and methylal, with and without freon). This avoids loss of precision which can result from saturation due to space charge when using the 'magic gas'. The achieved spatial precisions are about 30 µm for soft X-rays (1.5 keV) and this limit is set by features of the physical phenomena which are happening in the chamber (such as the path lengths of photoelectrons). Work is in progress to measure the accuracy obtainable for minimum ionizing particles. For heavily ionizing particles, the situation should be even better and precisions of a few microns may be feasible depending more on the associated electronics.

Multiwire proportional chambers with parameters pushed to these levels of accuracy will have important applications in high energy physics, since they provide resolutions equivalent to drift chambers (with a resolution time better by an order of magnitude), and in X-ray imaging. Some chambers built at CERN are being used at the synchrotron radiation facility, LURE, on the electron-positron storage ring DCI at Orsay (see October 76, page 350). They plan to study proteins and viruses with exposure times a factor of a thousand down on conventional detectors (reducing the risk of damage to molecular structures) while giving better quality images.

**Channelling our energies**

Channelling — the effect of direction on the propagation of particle beams through crystals — is usually studied only at low energies (typically around 1 MeV). An experiment on channelling in the GeV energy range at the CERN 28 GeV proton synchrotron, therefore, needed a special collaboration of physicists (from Aarhus, CERN and Strasbourg) to provide the necessary expertise in both high energy and channelling techniques. The skills and
knowledge of particle and solid state physicists complemented each other excellently in a first investigation at high energies. Some promising spin-off applications have become apparent and the experiment is continuing.

When a low energy (MeV) beam of positively charged particles is shone on a crystal, the incident particles, in general, pick their way round the atoms in the target in a more or less random way. However, if the beam comes in at a glancing angle to one of the principal axes of the crystal, an incident particle effectively sees strings of connected atoms. Interaction with this string gives many small momentum transfers from a large number of atoms to the particle and it is thereby gently steered away. The particle emerges with essentially an unaltered angle to the string although its azimuthal angle may be changed.

A common misunderstanding in channelling is that particles may be trapped in a tube, for example, between four strings in a cubic lattice. This has led some people to hope that channelling could be exploited to bend high energy beams by transmission through a bent crystal. Actually, channelled particles spend much of their time far from the atoms, they experience less energy loss than a particle moving in a random direction.

Channelling sets in when the incident angle to the atomic strings is below a critical angle which depends on both crystal type and energy. Typically the critical angle is of the order of a degree for low energy channelling but only a fraction of a milliradian for GeV particles.

To complete the picture it should be noted that atomic planes as well as strings can affect the motion of the beam through a crystal. If the incident angle to an atomic plane is below a critical angle (which is a little less than critical angles for strings) the beam is reflected by the plane, again because of the cumulative effect of many soft collisions with atoms in the plane.

Below the critical angle, the particles are transmitted with an angular distribution which is much different from the distribution obtained for incidence above the critical angle (where a scattering pattern is similar to that seen using targets of amorphous material). Furthermore, since channelled particles spend much of their time far from the atoms, they experience less energy loss than a particle moving in a random direction.

At GeV energies, the channelling effects were found to be very strong. Even for incidence up to about ten times the critical angle (2 mrad) on a 4 mm germanium crystal, the emerging beam is still distorted because of channelling effects. This is presumed to be because the beam is multiply scattered through the crystal so that part of the beam reaches angles to the atomic strings of the order of the critical angle.

Negative charged particles are also influenced by the channelling effects. Actually, negative well channelled particles have a tendency to stay rather close to the atomic strings and were therefore expected to suffer increased energy loss compared to randomly scattered particles. In fact, experiment clearly demonstrated, for the first time, the increased energy loss of well channelled negative pions.

A simple way of demonstrating channelling for positive particles is to look for the yield of some nuclear reaction as a function of the incidence angle to the strings. A dramatic decrease in the yield by a factor of about a hundred is found in low energy channelling when the angle is below the critical angle. The collaboration found a simple way to demonstrate this effect at high energies by using the germanium crystal as an intrinsic energy loss detector. In a nuclear reaction at GeV energies, several particles emerge from the reaction, and this...
'Channelling' of charged particles through a crystal was seen for the first time at high energies in an experiment at the CERN PS.
1. The emerging beam intensity distribution when 6 GeV/c positive pions are shone on a 0.3 mm crystal of germanium. It shows a strong peak at the centre in the direction of the atomic 'string' within the crystal (the channelling direction) with well pronounced crests at angles to it corresponding to channelling planes.
2. The emerging beam intensity distribution when 15 GeV/c protons are shone on a 0.74 mm crystal of germanium. The asterisk marks the direction of the incident beam and the three dimensional plot has a hole along the main crystal direction, where no particles are transmitted.

means that an exceptionally large energy loss is recorded by the crystal. This suggests the possibility of using solid state detectors to measure charged particle production cross sections.

In low energy physics, applications of channelling are well known, covering, for example, measurements on lattice locations, radiation damage effects and nuclear lifetimes. As a result of the pioneer work by the Aarhus / CERN / Strasbourg collaboration, potential applications can now be seen in high energy physics and could include measurements of particle lifetimes and triggering in production experiments.

The effect can also be used as a very effective and fast slit system for a divergent high energy beam. For example, low energy loss particles can cover an angle as low as 0.2 milliradians. If about 10 per cent of incident particles suffered little energy loss, the emergent intensity could be around $10^6$ particles per second.

Omega at the SPS

The large superconducting 'Omega' spectrometer was originally built for the experimental programme at the CERN PS and was used by a number of teams from 1973 to 1975. The spectrometer was then substantially upgraded to provide improved performance for physics with the higher energy beams from the SPS.

The existing optical spark chambers were interspersed with 0.5 and 1.0 mm pitch multiwire proportional chambers, two four-plane drift chamber modules of $3.2 \times 1.6 \text{ m}^2$ were placed at the exit of the magnet and a large photon detector was added downstream of an improved gas-filled threshold Cherenkov counter. Special trigger counters were provided by user groups for specific experiments based on the incident 40 GeV/c hadron or 80
A downstream view of the Omega spectrometer in the West Area at CERN, showing just some of the additional equipment installed for the SPS physics programme. New hodoscopes, drift chambers and shower detectors abound, but dominating the picture (centre) is the large photon detector, consisting of a 700 element hodoscope array, followed by 340 lead glass counters. The spectrometer magnet itself is almost invisible under its ‘igloo’ (top centre).

(Photo CERN 181.7.77)

An enlarged view of an interaction in an emulsion plate exposed to the Omega tagged photon beam. Over 600 such plates have been exposed, and are being scanned and analysed in detail in a search for decays of charmed states. The emulsion plate is exposed to the beam in place of the liquid hydrogen target.

3 x 10^{12} protons per pulse. After several early test runs, a 20-day run in July and August succeeded in recording over one million hadronic events onto magnetic tape and these are now being avidly scanned for signs of charm production.

The lifetime of photoproduced charm decays is being investigated using emulsion techniques by a Bologna / CERN / Florence / Genoa / Paris / Santander / Valencia collaboration supported...
Excavation and construction work for PEP is now well underway while the linear accelerator is switched off. The two-storey beam switchyard housing is seen in the foreground and the klystron gallery in the background. The steelwork in the foreground will reinforce the floor of the PEP injection tunnel. Since this photo was taken, the linear accelerator housing has been pierced at this point to provide access from the injection tunnel.

The Mark II detector is now being made ready for installation in SPEAR to replace the famous Mark I detector which found the psis, etc. The photo shows the mounting of lead strips nearing completion for the liquid argon shower chamber end caps.

(Photo Joe Faust)

by the WA4 group (not the Birmingham / CERN / Ecole Polytechnique / Munich / Neuchâtel collaboration as reported in May). In this experiment, information from the Omega electronic detector is used to pinpoint the vertex of a charm decay in a thin emulsion plate. Some 600 plates have been exposed to the tagged photon beam and thousands of photo-hadronic events have been stored in the emulsions.

As part of a plan to provide a 40 GeV/c r.f. separated beam for Omega, two accelerating sections, each consisting of five welded cavities, have been constructed at the Nuclear Research Institute at Karlsruhe. These sections now produce reliable fields of 1.4 MV/m and will be installed in the Omega beam-line before the end of the year. This will provide enriched beams of kaons and antiprotons greatly extending the scope for hadronic experiments at the SPS. Further plans for Omega include the replacement of the existing optical spark chambers by multiwire proportional chambers, allowing experiments to be run with lower deadtime losses and enabling smaller cross-sections to be measured.

With the first experimental results from the SPS already to their credit, the Omega teams are eagerly awaiting further exciting results.

STANFORD
Construction work starts for PEP

While the ground-breaking ceremony for PEP (pictured on the cover of the June issue) took place on 2 June, construction work began in earnest when the electron linac beam was turned off on 27 June. The immediate task was to add the PEP North and South injection tunnels to the existing linear accelerator housing before the beam is turned on again at the end of October. During this period, workers must ex-