The HARP TPC

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The HARP experiment, at the CERN Proton Synchrotron, measures hadron production cross sections of protons of known momenta (1.5 - 15 GeV/c) impinging on different solid and liquid targets. The HARP TPC provides tracking and particle identification. It is a cylindrical 3D imaging chamber which surrounds the experimental target hit by an extracted beam. The first calibration run was completed and preliminary detector performances for X-rays energy resolution, momentum and $\mathrm{d}E/\mathrm{d}x$ resolution were evaluated. The preliminary results of an analysis of elastic scattering using a H_2 target completes the evaluation of TPC performance.

1. Introduction

The HARP experiment [1] (see Fig. 1), at the CERN Proton Synchrotron, measures hadron production cross sections of protons of known momenta (1.5 - 15 GeV/c) impinging on various solid and liquid targets. Precise pion yield measurements, for neutrino factory studies [2] and atmospheric neutrino experiments [2], have been completed over almost the full solid angle.

2. The chamber

The HARP TPC [3],[4] is formed by two coaxial cylinders of stesalit of radius 51 mm and 420 mm, immersed in electric and magnetic fields oriented parallel to the beam. The electric field of 111 V/cm, that causes the electrons' drift, is provided by a system of mylar strips attached to the inner surface of the outer cylinder and the outer surface of the inner cylinder and maintained at a potential gradient. The magnetic field of 0.7 T, that allows the evaluation of the momentum of the tracks, is provided by a solenoid surrounding the TPC.

The drift volume of 150 cm length is delimited on one side by a wire chamber and on the other side by a mylar membrane held at high voltage and by a honey-comb plate. This plate avoids deformations of the HV Mylar membrane due to any differences between the internal gas pressure and atmospheric pressure. The wire chamber consists of a readout pad-plane, a plane of sense wires, a plane of cathode wires and a plane of gate wires kept at ground potential. To minimize the dead region due to the wire support, the wire plane is formed only by a wire fixed only to the pins located on the sectors' support of the pad plane. The pad plane consists of 6 sectors with

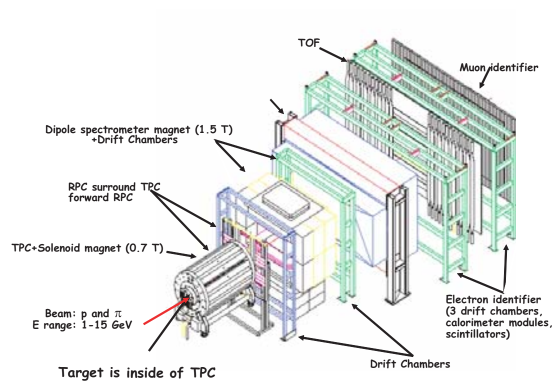

Figure 1. The HARP experiment consists of: a) a large angle spectrometer with TPC as tracking detector and RPC as complementary PID detector; b) a forward spectrometer with NDC as tracking detector and TOF, Cerenkov and Calorimeter for the particle identification.

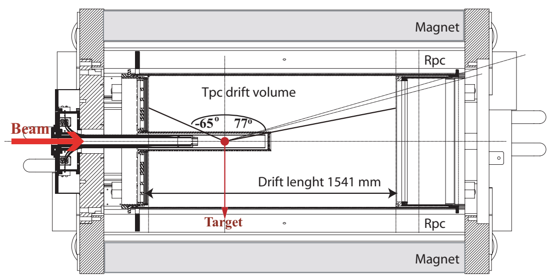

Figure 2. One of the main features of HARP TPC is the target placed inside the drift volume. The TPC acceptance covers almost the full angle including also the backward tracks. Considering tracks crossing at least 10 rows the TPC covers angles between -69° and 77°.

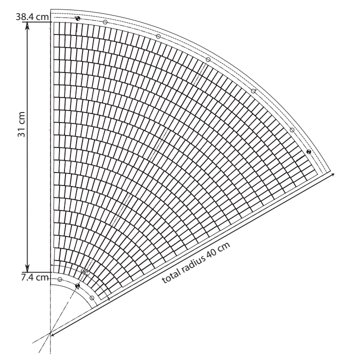

Figure 3. One sector of the TPC is composed by 20 rows and 662 pads.

a cylindrical geometry of 20 rows and 662 pads (see fig. 3), comprising a total number of pads is 3972. The size of a pad is approximately 15.0 mm length and 6.5 mm width. The pads cover, between a radius of 74 mm and 384 mm, the full active volume except for the spokes between two sectors, where the pins holding the wires are located.

The gas mixture used is argon-methane (91%-9%). The measured drift velocity of electrons is 5.17 $cm/\mu s$ and for the nominal magnetic and electric field the transverse and longitudinal diffusion are 378 μm and 208 μm per $\sqrt{cm}$ of drift, respectively. The inner cylinder houses the target at a depth of about 50 cm from the upstream end of the TPC (see fig. 2). This permits the chamber to track and to identify secondary particles over nearly the full solid angle, including the backward hemisphere: between -65° and 77° for tracks crossing only half of the TPC along the radial direction, and between -52° and 69° for tracks crossing the full radial extent of the TPC.

The analog signal is digitized with a 10 MHz 10 bit Analog to Digital Converter (ANALOG DEVICES AD9200)[5]. The ADC boards, originally developed for the ALICE Collaboration, allow online pedestal subtraction and the compression of the data above threshold. The DAQ for the HARP TPC was developed using a LHC architecture based on event building on a switching network [6]. The raw data were written in real-time to the Objectivity database and automatically transferred to the offline database (CDR). The full chain VME-Event Building-Objectivity-CDR works with a sustained data rate of 20 MB/s. The event rate was 3 kHz.

3. Calibration and equalisation

Due to the chamber geometry and to a spread of 25% in the preamplifier gain, the read-out signals must be normalized. The normalization is determined by injecting ^{83}Kr gas into the TPC volume. Dedicated krypton runs have been taken periodically during the normal data taking. This gas is radioactive and has different Auger-electron emission lines between 10 and 50 keV. The normalization of the channels is based on the fact that the signal illumination of the chamber is homogeneous.

During the calibration runs of 2003 the energy spectra of ^{55}Fe and ^{83}Kr X-rays were measured to scan the full energy spectrum and so evaluate the energy resolution of the TPC. The spectrum is observed in the three pads in front of the Fe and Kr sources, setting the center of X-ray clusters to be localized in front of the chosen three pads. The

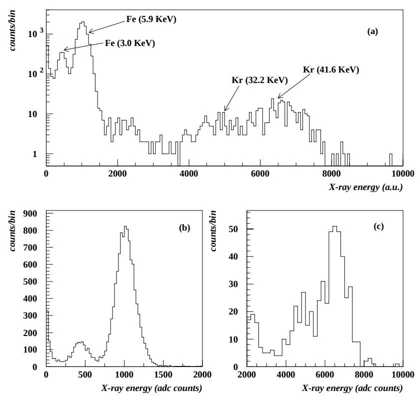

Figure 4. The X-ray energy spectra of ^{55}Fe and ^{83}Kr X-rays:(a) Full energy spectrum, (b) magnified view of the low energy region below 10 keV dominated by iron events, (c) magnified view of the high energy region where the krypton events are present [7].

sum of the X-ray energy spectra shows clearly the 3.0 keV and 5.9 keV peaks due to ^{55}Fe, plus the 9-14 keV complex and the 32.2 keV and 41.6 keV peaks due to krypton, as shown in fig. 4 [7].

4. Software reconstruction chain

A full reconstruction chain has been developed. The chain can be divided into the following steps: 1) a calibration algorithm applies the equalisation and flags the noisy or dead channels, 2) a clustering algorithm identifies the spatial 3D points associated to a physical signal [8]; 3) a pattern recognition algorithm looks for possible candidate track without any request about the shape of the tracks [9]; 4) a fitting algorithm evaluates the momentum and the direction of a defined track [10]; 5) a second fitting algorithm based on the Kalman Filter Package [11] handles the effect of multiple scattering and to the energy loss in the material surrounding the target and allows extrapolation of the track to any point in HARP detectors.

5. Characterization of the detector

The cosmic data taking during the summer of 2003 was used to make a first study of the performance of our detector. These runs used a particular scintillator as trigger. This detector was placed inside the inner field cage and parallel to the beam axis; it covered the z coordinate between -345 mm and 255 mm. This kind of trigger allowed us to register the cosmic rays that crossed the TPC in the blind central region. The pattern recognition algorithm reconstructs one single cosmic as two different tracks in the two opposite sectors of the TPC. One could compare the two transverse momenta to evaluate the momentum resolution using the following formula

$$\frac{\Delta p_t}{p_t} = \frac{\rho_1 + \rho_2}{\sqrt{2}\,\rho_{tot}}$$

where ρ is the inverse of radius of curvature. Its sign describes the direction associated to the track: positive if the direction is clockwise and negative if the direction is anticlockwise, with the hypothesis that the particles are coming from the beam axis. Under this hypothesis the clockwise or anticlockwise direction can also be associated to the charge of the particle. Therefore it is proportional to the inverse of transversal momentum. Moreover the $\Delta\rho$ is centered in 0 and has a continuous and gaussian distribution, as opposed to the trasverse momentum that has a discontinuity at infinity where the charge changes sign. The ρ_1 and ρ_2 are associated to the two branches and ρ_{tot} is obtained fitting the two branches together.

Fig. 5 (on the left) shows the transverse momentum resolution. This resolution varies between 18% and 35% between 200 and 500 MeV/c, where the peak of the production cross section (for example for the neutrino-factory relevant data) occurs. For the same run of cosmics the $\mathrm{d}E/\mathrm{d}x$ spectrum (see fig. 5 on the right) shows that most of the particles are identified as muons and only a few percent as protons.

6. Elastic scattering

The first analysis performeded is the measurement of the elastic cross-section. One could use

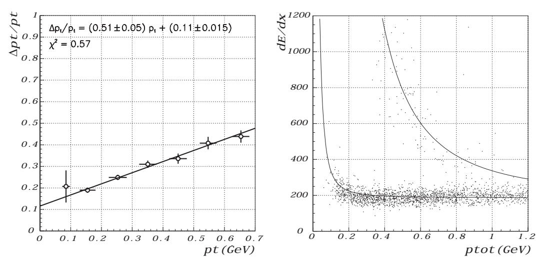

Figure 5. On the left the momentum resolution and on the right the dE/dx for the cosmic data taking in 2003.

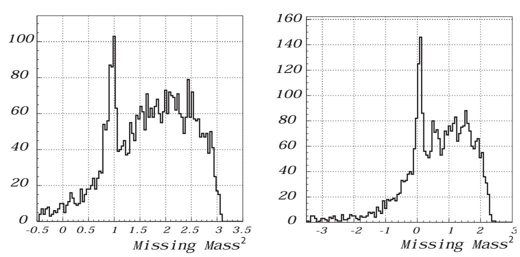

Figure 6. The spectrum of missing mass of the particle going into the forward spectrometer for a proton beam (on the left) and for a pion beam (on the right), selecting only one positive track in the TPC.

this scattering to normalize the data, since the elastic cross section is well known, and to evaluate the acceptance in space of the TPC. Moreover it could be a good calibration tool for the merging of forward and large-angle tracks. The first study on pp→pp and πp→ πp scattering used a liquid target of H_2 (cryogenic target) with a length of 18 cm, with a beam of protons and pions of 3 GeV/c. The beam particles are identified by the Beam TOF detectors. The missing mass of the particle in the forward direction is calculated using the parameters of the track reconstructed in the TPC. In this first analysis events were selected having only one positive track in the TPC, without any particle identification and no extrapolation to the primary vertex. The missing mass is calculated using the following formula:

$$m_x^2 = (p_{beam} + p_{target} - p_{TPC})^2$$

The square of missing mass spectra are shown in fig. 6, where the peaks due respectively to proton and pion are clearly visible.

7. Conclusions

The HARP TPC was designed for and fulfilled high rate requirements of about 3 kHz. The calibration strategy has been devised based on a large spectrum of characterization methods. The first run of calibration is completed and this has permitted the study of preliminary physics performances. In particular the $\Delta p_t/p_t$ and dE/dx were evaluated from cosmic data. The pp elastic scattering was used as a benchmark and will be used to study the merging of tracks from the large-angle and forward spectrometers. We will complete the calibration loop during the summer to reach optimum performances. This will allow the physics analyses including low energy and large angle particles.

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