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Status of the HARP hadroproduction measurements

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Abstract. The atmospheric neutrino flux as measured deep underground is predicted by combining the measurend primary cosmic ray fluxes with the geomagnetic field and simulating the interactions in the upper atmosphere. The lack of detailed measurements of the hadron interactions on nuclear targets is the major source of uncertainty in the neutrino fluexs. The HARP experiment at CERN is making extensive measurements of the cross sections and secondary particle distributions to address this problem. Carbon, aluminium, liquid nitrogen and liquid oxygen targets will be exposed to both positive and negative particle beams with momenta between 2 and 15 GeV/c at the CERN PS during 2001. The detector consists of a TPC surrounding the target and a spectrometer with Cherenkov and time of flight particle identification covering the forward region.

1 Introduction

Even before the first indication of a signal for neutrino oscillations emerged from the interaction of atmospheric neutrinos in underground detectors (Kamiokande–II Collaboration (1988)), the lack of good data samples of hadron collisions severely limited the accuracy to which the underground neutrino fluxes were known. Now that the effect of neutrino oscillations with $\sin^2 2\theta \simeq 1$ and $\Delta m^2 \simeq 3 \times 10^{-3}$ eV^2 has been clearly observed in the SuperKamiokande detector (Super–Kamiokande Collaboration (1998)) and ever larger underground detectors are being operated and proposed, the need for appropriate samples of hadroproduction data is long overdue.

The HARP experiment (HARP collaboration (1999)) has been constructed at the PS accelerator at CERN in Geneva. It is now taking data which will allow a comprehensive picture of low energy cosmic ray interactions in the atmosphere to be built up. A further experiment at the CERN SPS accelerator (Catanesi et. al. (2001)) which uses the existing NA49

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apparatus is being proposed to extend these measurements to higher energies.

The HARP data are also being obtained in order to optimise the pion production and collection for use in muon storage rings. These devices will be capable of producing very intense man-made neutrino beams, and ultimately, may be used to prepare beams for injection into a muon collider. The data will also be used for detailed studies of 'conventional' man-made neutrino beams, such as the K2K beam between KEK and SuperKamiokande and the NuMI beam at Fermilab. It is expected that large general purpose Monte-Carlo simulation codes such as GEANT will be adjusted to the HARP data so that this information may be used in a wide range of future applications.

This paper describes the HARP experiment. Sect. 2 gives details of the beam and of the beam instrumentation. The details of the targets is given in Sect. 3. HARP consists of two separate detection and trigger systems, one for particles which emerge with a large angle with respect to the incoming beam (described in Sect. 4) and the other for 'forward' particles which have a large momentum along the direction of the incoming beam (described in Sect. 5). Finally, conclusions are given in Sect. 6.

2 Beam and beam instrumentation

The HARP experiment is located in the T9 secondary beamline at the CERN PS accelerator. The intense 24 GeV proton beam from the accelerator hits a target which supplies secondary beams to the entire east experimental hall where HARP is situated. Bending magnets allow particles of a particular momentum (in the range 2 to 15 GeV/c) to travel along the entire beam line to the HARP experiment. The momentum spread at the experiment is about 1%. The beam is focused down to a 10 mm spot on the HARP target which is about 80 m downstream of the east hall target. The CERN accelerator complex is controlled within a 16.8 s super cycle. During this time, the PS accelerator performs seven separate
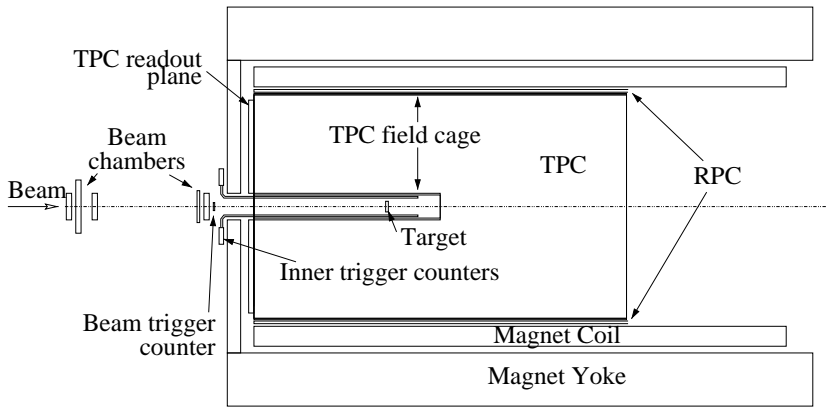
Fig. 1. Schematic of the detector components surrounding the target showing the beam chambers, trigger counter, TPC, RPCs and the inner trigger.

acceleration cycles which provide bunches of particles to the different parts of CERN. In either one or two of these cycles, protons are provided to the east hall. They are extracted in 'slow extraction mode' yielding a beam of uniform intensity over a period of 0.4 s. About 10^5 particles are delivered to the HARP beam line per cycle.

Since the beam is produced from interactions on the primary east hall target, it contains a mixture of different particle types (protons, pions, kaons, muons) all at the same momentum. The beam line is instrumented with two time-of-flight counters separated by 24 m and with two N_2 gas filled threshold Cherenkov detectors to individually tag the identities of the particles in the beam. This is done in the offline data analysis.

The trajectories of the beam particles are individually measured with four $ArCO_2$-filled multiwire proportional chambers so that their impact position on the HARP target may be precisely reconstructed.

A 2 cm diameter beam trigger scintillation counter is suspended in the beam 1 m upstream of the target. This counter is used in the trigger decision to define particles which hit the target. A separate thin scintillation counter is used to define the event time in the trigger decision logic.

An iron-scintillator muon range stack covering the area of the beam is situated behind the entire HARP experiment identifier. This is used to measure the fraction of muons in the beam which are difficult to distinguish otherwise from pions.

3 Targets

Data will be collected with a range of different target materials. Thin targets (approximately 2% of an interaction length) will be used for the basic cross section and particle production measurements. These measurements will be done with liquid hydrogen, beryllium, carbon, liquid nitrogen, liquid oxygen, aluminium, copper, tin, tantalum and lead. In addition, the specific materials used in the K2K and MINI-BOONE experiments will be used. Data points will be collected using several energy points between 2 and 15 GeV/c for both positive and negative particles.

A subset of these data points will also be collected using thick (up to 100% of an interaction length) targets. This will generate a superposition of secondary and tertiary interactions similar to those produced in a neutrino target and will be used to check that a Monte-Carlo tuned using the basic thin-target measurements correctly predicts the response of the thick targets.

4 Detection of particles with high transverse momentum

The layout of the detectors surrounding the target are shown in Fig. 1. The main detection system comprises a time projection chamber (TPC) for tracking and dE/dx particle identification immersed in a 0.7 T solenoidal magnetic field for momentum measurement and a cylindrical resistive plate detector (RPC) for accurate measurement of time of flight. The target is mounted inside the active volume of the detectors so that particles emerging backwards with respect to the beam direction are also measured. The target is surrounded by a cylindrical scintillating fibre counter for triggering.

The TPC consists of a cylindrical volume of 91% Ar, 9% CH_4 gas 1.5 m long and 80 cm diameter which is ionised by the passage of particles from the interaction. A 12 kV/m electric field along the axis of the cylinder causes the ionisation to drift with velocity 5 cm/μs to readout planes on the front (upstream) face of the TPC. The 3972 pads are arranged in 20 concentric rows and are instrumented with electronics which digitise the level of ionisation on each pad in bins of 100 ns. These data are used offline to make three-dimensional reconstruction of all the tracks in the event. The curvature of the tracks in the magnetic field is used to determine the momentum, and the amount of ionisation per unit
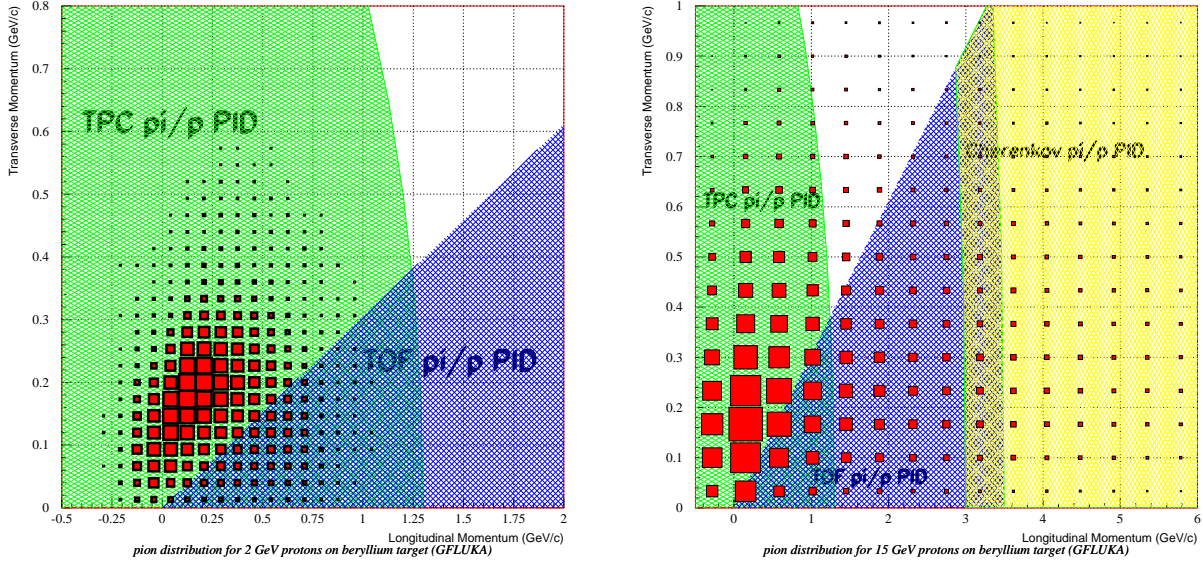
Fig. 2. Expected particle distributions as a function of the longitudinal and transverse momenta. Superimposed are the regions where the particle identification detectors are effective for pion/proton separation.

length is used to distinguish between particle types. Figure 2 shows the expected distribution of particles in longitudinal p_L and transverse p_T momentum and indicates the regions in the (p_L, p_T) plane where the pion-proton differentiation from the TPC is effective.

The ring of resistive plate detectors (RPCs) which surround the TPC are made of four layers with gap size 0.3 mm. They are filled with 90% Ar, 5% iC_4H_{10}, 5% SF_6 gas and run at 3kV per gap. They measure the time of crossing tracks with a resolution of around 150 ps which is used for time-of-flight measurement for electron-pion separation.

5 Detection of particles with high forward momentum

The particles which leave the target in the forward direction leave the downstream end of the TPC and enter the following detection systems which are shown in Fig. 3. The tracks produced by these particles when projected onto the TPC pad plane are short and hence poorly measured in the TPC alone.

Immediately behind the TPC is a plane of trigger scintillation counters and a further plane of RPCs for electron identification by time of flight. These are the same design as the RPCs surrounding the TPC.

The spectrometer comprises four stations of drift chambers with a 0.68 Tm vertical magnetic field between the first and second stations. The gas is 90% Ar, 9% CO_2, 1% CH_4 and the drift velocity is about 5 cm/μs. Each drift chamber station consists of four sets of three planes of wire chambers oriented vertically to measure (resolution 100 μm per set of three planes) the coordinates of the tracks in the analysing plane of the spectrometer . The three planes within each set of chambers are inclined at angles of $-5°$, $0°$ and $+5°$ in

order to measure the vertical coordinate of the tracks with a resolution of 1 mm.

A Cherenkov detector consisting of a 30 m^3 volume of C_4F_{10} gas at atmospheric pressure and a system of mirrors to collect the light into an array of 38 phototubes is used for identification of the particles. The thresholds are 2.6 GeV/c, 9.3 GeV/c and 17.6 GeV/c. for π, K and p respectively. The sensitive region of pion-proton separation is shown in Fig. 2.

A time-of-flight wall of 39 scintillator counters is used for particle identification of slower particles as shown in Fig. 2. This is done with a resolution of better than 300 ps by measuring the transit time between the small beam scintillation counter and the counters in the wall.

The electron identifier consists of lead/scintillating fibres organised into 142 modules. This device covers an area of 6.7 m × 3.3 m.

Many of the detector systems in HARP are refurbished components which have been recuperated from earlier experiments.

During runs with thin targets, a plane of trigger counters is used to trigger on events where an interaction took place.

The data acquisition system combines the data from all of the detectors including the ones surrounding the target and the ones instrumenting the beam line. It is based on the ALICE prototype data acquisition system DATE and has the capacity to take 1000 events per 0.4s burst.

6 Conclusions

The HARP experiment has been constructed to make comprehensive new measurements for the provision of accurate hadroproduction models. These will find many applications,
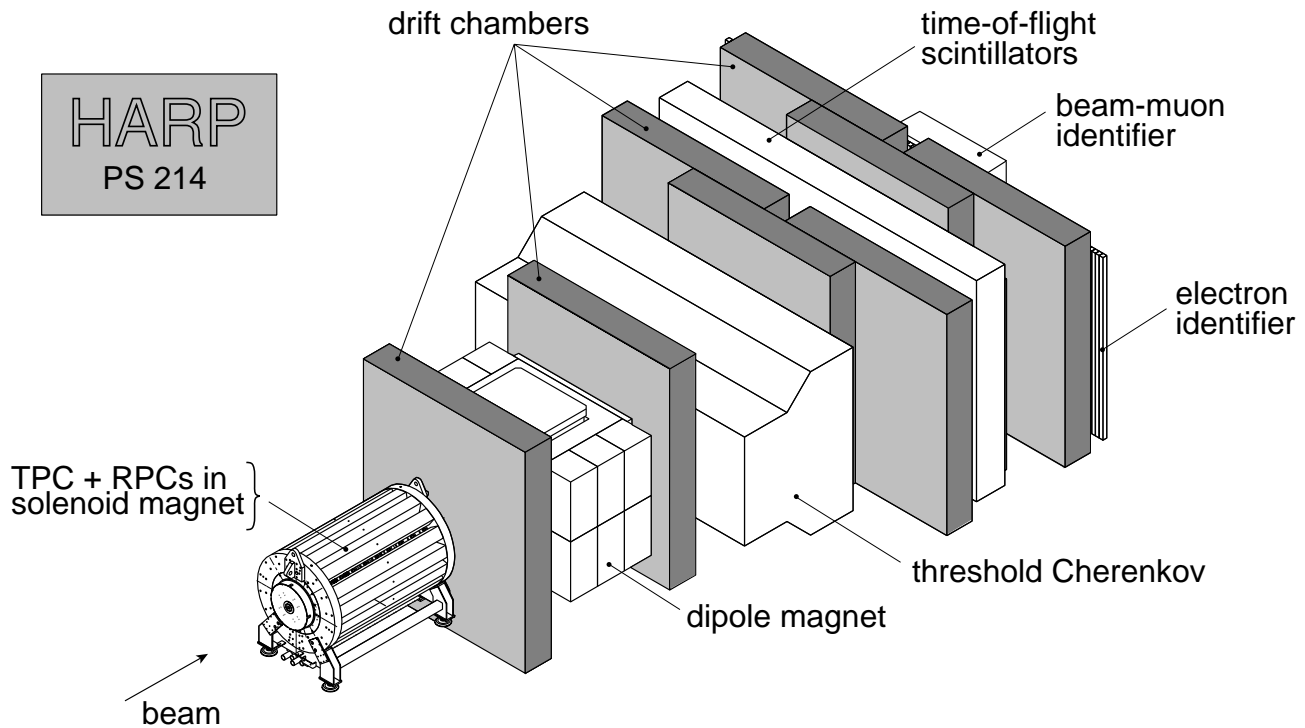
Fig. 3. Schematic of the components of the detector

but will be most important for improving the atmospheric neutrino flux predictions. The measurements will also find immediate applications in predicting neutrino spectra from accelerator beams of neutrinos. Data collection will continue throughout 2001 and first results will be expected soon.

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