International Journal of Modern Physics A

Results from HARP

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Received (20th November 2004)
Revised (Day Month Year)

The HARP experiment at CERN is performing extensive measurements of hadron production cross sections and secondary particle yields in the energy range 1.5-15 GeV over the full solid angle, using a large set of cryogenic and solid targets. The hadron production in this region is a relevant ingredient in several branches of neutrino physics, including the characterization of neutrino beams, precise prediction of atmospheric neutrino fluxes, and quantification of pion production and capture for neutrino factory design. An overall precision of a few percent is required from the experiment to reach the final aim. The experimental layout comprises two spectrometers to perform momentum measurement of the secondaries produced in the target. The track momentum reconstruction in the spectrometers is complemented by a set of particle identification detectors that allow, with some redundancy, the particle type discrimination. Approximately 30 TB of data corresponding to 420 millions of events have been collected. The measurements of hadron production cross sections in the forward region (up to about 250 mrad) are reported using the K2K replica targets and a proton beam of 12.9 GeV/c. This is an appealing physics case given the immediate interest for those experiments and for the neutrino community.

Keywords: hadron; production

1. Introduction

The HARP experiment [1] was designed to perform a systematic and precise study of hadron production for beam momenta between 1.5 and 15 GeV/c and target nuclei ranging from hydrogen to lead. The detector was located at CERN, in the PS beam, and took 420 million events during the years 2001 and 2002.

The physics program of HARP includes: a) the measurement of pion yields for a variety of energies and targets relevant for the design of the proton driver of a future neutrino factory [2]; b) the measurement of pion yields on light Z targets as well as on cryogenic Oxygen and Helium targets, useful to improve the precision of atmospheric neutrino flux calculations [3]; and c) the measurement of pion and kaon yields, relevant for the calculation of the neutrino fluxes of experiments such as MiniBooNE [4] and K2K [5].

HARP (Fig. 1) is a large acceptance spectrometer, with two distinct regions. In the forward part of the apparatus (up to polar angles of about 250 $mrad$), the main tracking devices are a set of large drift chambers. Magnetic analysis is provided by a 0.4 Tesla dipole magnet and particle identification relies on the combination of a threshold Cherenkov, a time-of-flight wall and an electromagnetic calorimeter. In the rest of the solid angle the main tracking device is a TPC, which is complemented by a set of RPC detectors for time of flight measurements. In addition, a sophisticated beam instrumentation system (including three timing detectors and threshold Cerenkov detectors) allows identification of the incoming particle and provides the interaction time at the target, located inside the TPC.

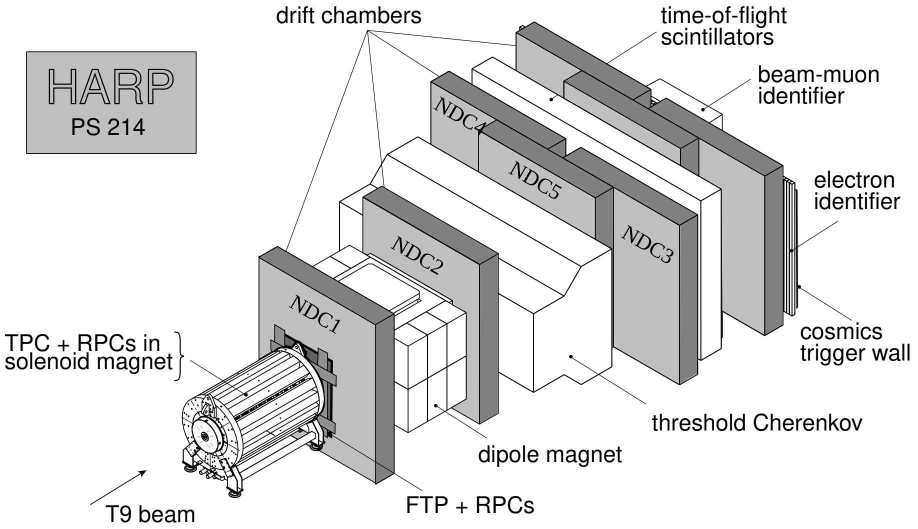

Fig. 1. Schematic layout of the HARP spectrometer.

Given the immediate interest of the MiniBooNE and K2K experiments in a measurement of the production cross sections for pions and kaons at the energies and targets relevant for their beam setups, the HARP collaboration has given priority to the analysis of those particular data sets. In particular, we present in this article an initial result relevant for the K2K experiment. Specifically, we measure pion yields from proton-nucleus collisions, for a thin Al target (5% λ) and a beam energy of 12.9 GeV. The K2K neutrino beam is produced from the decay of hadrons (primarily pions) emanating from a 2 λ Al target, at the KEK PS proton driver energies of 12.9 GeV. Further details about the motivation of this analysis can be found in [6].

2. Forward Tracking and Particle Identification

2.1. *Tracking*

Tracking of forward going particles is done by a set of large drift chambers (NDC) placed upstream and downstream of the dipole magnet. The chambers were recuperated from the NOMAD experiment and their properties have been described elsewhere [7]. The performance of the NDC is inferior to the one measured in NOMAD, where the hit efficiency was close to 95% and the resolution approached 150 μm. This is mainly due to the fact that, for HARP, the NDC used a gas mixture and voltage settings different from the ones in NOMAD[a].

Due to the low hit efficiency, the algorithm used in NOMAD, based in building up space points (with an efficiency of about $.95^3 = 85\%$) is not viable (for Harp we would obtain $.8^3 = 51\%$). Instead, the reconstruction algorithm builds $2D$ and $3D$ track segments in each NDC module (12 hits maximum), which are fitted to a straight line model via a Kalman Filter fit [9].

2.2. *Particle Identification*

Particle identification in the forward region of the spectrometer combines the information provided by beam detectors and the three systems located downstream from the dipole magnet. These subsystems have been described in [6]. The combined information results in good PID over the whole range of relevant momenta, as well as redundancy due to overlaps. Pion/proton separation is provided by TOF up to 4.5 GeV/c, and by the CKOV above 3 GeV/c. Electron/pion separation is covered by the CKOV below 3 GeV/c and by the EID above 2 GeV/c. Finally the kaon contamination can be estimated with the CKOV above 3 GeV/c and with the TOF below this energy.

3. The analysis

About one sixth (1 million events) of the "K2K thin target" data has been analysed. The unnormalised pion production differential cross section can be computed as follows:

$$\sigma_i^\pi = \frac{1}{\varepsilon_i^{acc}} \frac{1}{\varepsilon_i^{track}} \sum_{t=1}^{3} \left[M_{ij}^{(t)} \frac{1}{\varepsilon_j^{(t)-\pi}} \eta_j^{(t)-\pi} \cdot N_j^{(t)-\pi} \right] \tag{1}$$

where the sum runs over track types (I = $3D$-$3D$, II= $3D$-$2D$, III=$3D$-vertex) and the indices i and j correspond to true and reconstructed (p, θ) bins respectively. ε_i^{acc} is the geometrical acceptance, ε_i^{track} is the tracking efficiency, M_{ij} is the migration matrix from reconstructed bin j to true bin i, ε_j^π is the pion identification efficiency, η_j^π is the pion purity and N_j^π is the observed pion yield. The pion purity is defined as $\eta_j^\pi = N_j^{true-\pi}/N_j^\pi = (N_j^\pi - N_j^{bkg})/N_j^\pi$, where $N_j^{true-\pi}$ is the number of true observed pions in the bin j, and N_j^{bkg} is the number of particles misidentified as pions in the same bin j. That means that η_j^π is just the probability of the correct identification of a pion. The pion identification efficiency, ε_j^π is the fraction of times that a tracked pion is identified as such.

[a] $Ar(90\%) - CO_2(9\%) - CH_4(1\%)$, a non-flamable gas mixture

Fig. 2 shows the pion yield after the succesive corrections (acceptance, tracking efficiency and pion correction factor) have been applied. No attempt to deconvolute the data (e.g. correct for migrations) have been done yet, and no absolute normalization is computed.

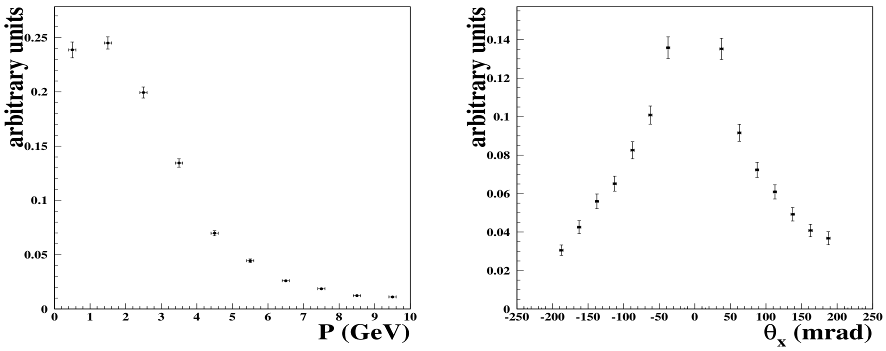

Fig. 2. Pion yield from the K2K replica target as a function of momentum and angle.

4. Conclusions

We have presented a preliminary analysis of one of Harp data samples, corresponding to a thin Al target, at beam energies of 12.9 GeV. This analysis is relevant for the K2K experiment and a first step towards an upcoming measurement of the fully corrected production cross section.

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