Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008

Vol. 4 (HE part 1), pages 683–686

ID 1039

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Pion production in proton- and pion-carbon collisions at 12 GeV/c measured with HARP

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Abstract: Motivated by the importance of the measurement of proton and pion interactions with light nuclei for tuning hadronic interaction models used in neutrino flux and extensive air shower simulations, we analyze pion production in p-C and pi-C reactions at 12GeV/c measured in the fixed target experiment HARP at CERN-PS. We present momentum spectra of positive and negative pions and compare them with predictions of frequently used hadronic interaction models.

Introduction

The current generation of astroparticle physics detectors or experiments allows high precision and high statistics measurements. Part of the gain in precision of these experiments is related to the increase of available computing power and recent progress in developing detailed Monte Carlo simulations for calculating predictions for both detector signals and background effects. One central element of these complex calculations is often the simulation of particle interactions and particle production. Whereas it is known how electromagnetic or electroweak interactions can be simulated, hadronic interactions are still not sufficiently well understood. In fact, in several areas, our limited understanding of hadronic interactions has become the dominating source of systematic uncertainties (see, for example, [1, 2, 3, 4]).

Within the foreseeable future no breakthrough in the calculation of particle production processes within QCD is expected, underlining the importance of hadron production measurements. Data on the interactions of protons and pions with light nuclei of the Earth's atmosphere, as they are needed in particular in astrophysical applications, are very sparse [5, 6, 1].

In this work we present double-differential pion production spectra of proton and pion interactions

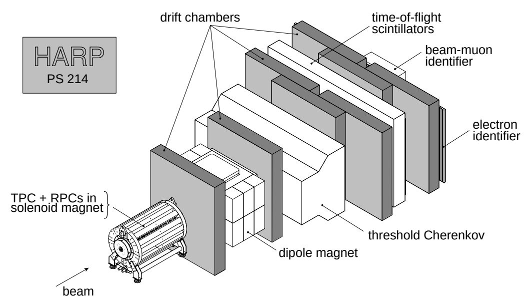

Figure 1: Setup of the HARP detector [7].

with carbon nuclei at 12 GeV/c beam momentum. The measurements were done with the fixed target HAdRon Production experiment PS214, HARP[1], at the CERN proton synchrotron (PS). Note that hadron production spectra on carbon are expected to be very similar in shape to those on nitrogen and oxygen [5].

Experimental setup and data analysis

The HARP setup [7] consists of a forward spectrometer (TOF, drift chambers, Cherenkov detector, electromagnetic calorimeter) and a large-angle detection system (TPC), see Fig. 1. The forward

1. http://harp.web.cern.ch/harp/

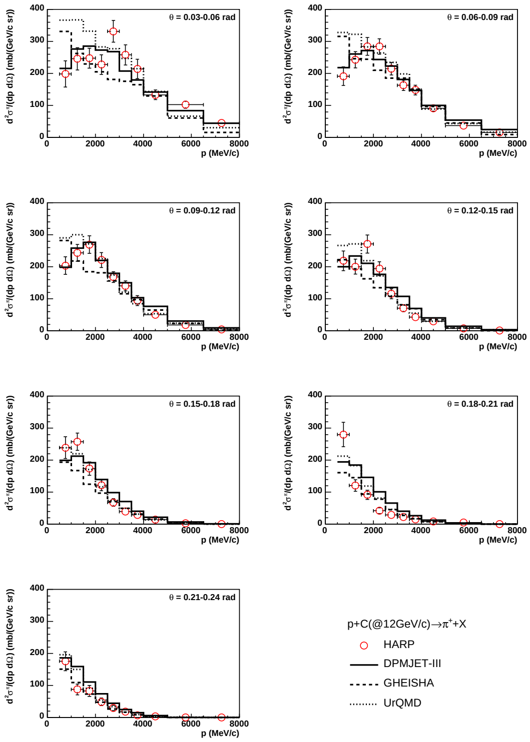

Figure 2: Inclusive production cross section of π^+ in p-C interactions at 12 GeV/c. The predictions of the models DPMJET III [10, 11], GHEISHA [12], and UrQMD [13] are also shown.

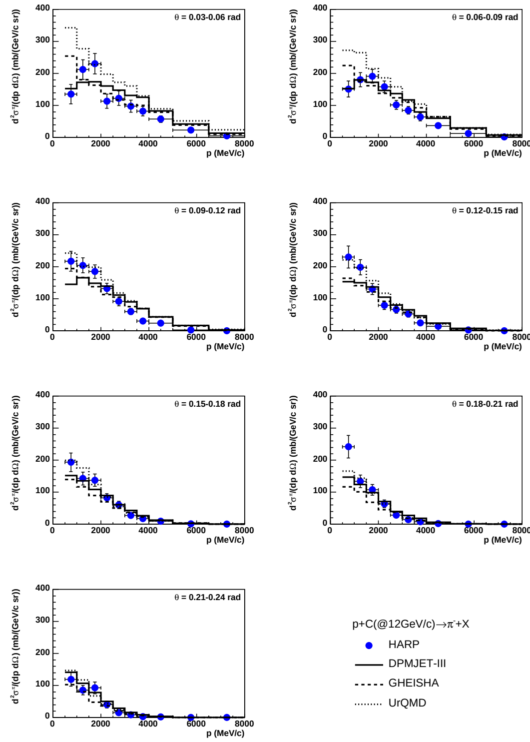

Figure 3: Inclusive production cross section of π^- in p-C interactions at 12 GeV/c. The predictions of the models DPMJET III [10, 11], GHEISHA [12], and UrQMD [13] are also shown.

spectrometer is built around a dipole magnet with an integral field of 0.66 Tm for momentum reconstruction. The forward detector system covers angles up to 250 mrad and is ideally suited for minimum bias particle production measurements. It is employed in the analysis presented here.

A detailed description of the event selection and track reconstruction of the carbon data set can be found in [8]. In the following only a brief overview is given. Particle identification is discussed in [9].

The pion and proton data sets were taken in two short runs in June and September 2002. More than one million triggers with positive beam and half a million triggers with negative beam were collected. In addition about 900k empty target events were recorded to correct for background interactions. A thin carbon target of thickness of 5% of an interaction length was used. Events were selected according to the detected beam particle and beam position. After quality cuts about 460k p-C and 350k π^--C events were left for analysis.

To ensure high quality track reconstruction, secondary particle tracks were selected only in the detector hemisphere in which the magnetic field of the dipole would bent the particle trajectory towards the beam axis. A matched hit in the TOF wall and several hits in the drift chamber system were required. About 100k secondary particle tracks in p-C and a similar number of tracks in π^--C interactions passed the selection cuts.

The measured particle spectra were corrected for detector acceptance and reconstruction resolution effects using the Bayesian unfolding technique of D'Agostini [14]. The detector acceptance and resolution is calculated by reconstructing a set of single track Monte Carlo simulations based on GEANT4 [15]. All relevant processes such as energy loss, absorption and re-interaction are considered. Empty target subtraction and a correction for kaons being misidentified as pions is applied.

Results

The double-differential pion production cross sections in proton-carbon interactions are shown in Figs. 2 and 3. The leading particle effect is clearly seen for positively charged pions.

The error bars indicate statistical and systematic errors added in quadrature. The size of both errors is of the same order and varies from 4% to 14% depending on the secondary particle momentum. Only for the highest momenta the statistical error clearly dominates and reaches more than 20%. The dominant sources of systematic uncertainty are the subtraction of tertiary interactions and the overall momentum scale.

The data are compared with predictions of the models DPMJET III [10, 11], GHEISHA [12], and UrQMD [13]. There is no obvious trend of one model giving a much better description of the data sets than the others. For example, the DPMJET predictions give a good description of the π^+ spectra but clear discrepancies are seen for π^- cross sections. The situation is similar for the other models.

In Fig. 4 we show the pion production cross sections for π^--carbon interactions. These cross sections are particularly valuable for estimating tertiary interactions and give also a low-energy anchor point for tuning models used in air shower simulations. Again the error bars indicate both the systematic and statistical errors. A comparison of this data set with model predictions is in preparation.

Finally it should be mentioned that the analysis of pion production in proton-nitrogen and proton-oxygen interactions at 12 GeV/c is in progress. First results will be shown at the conference.

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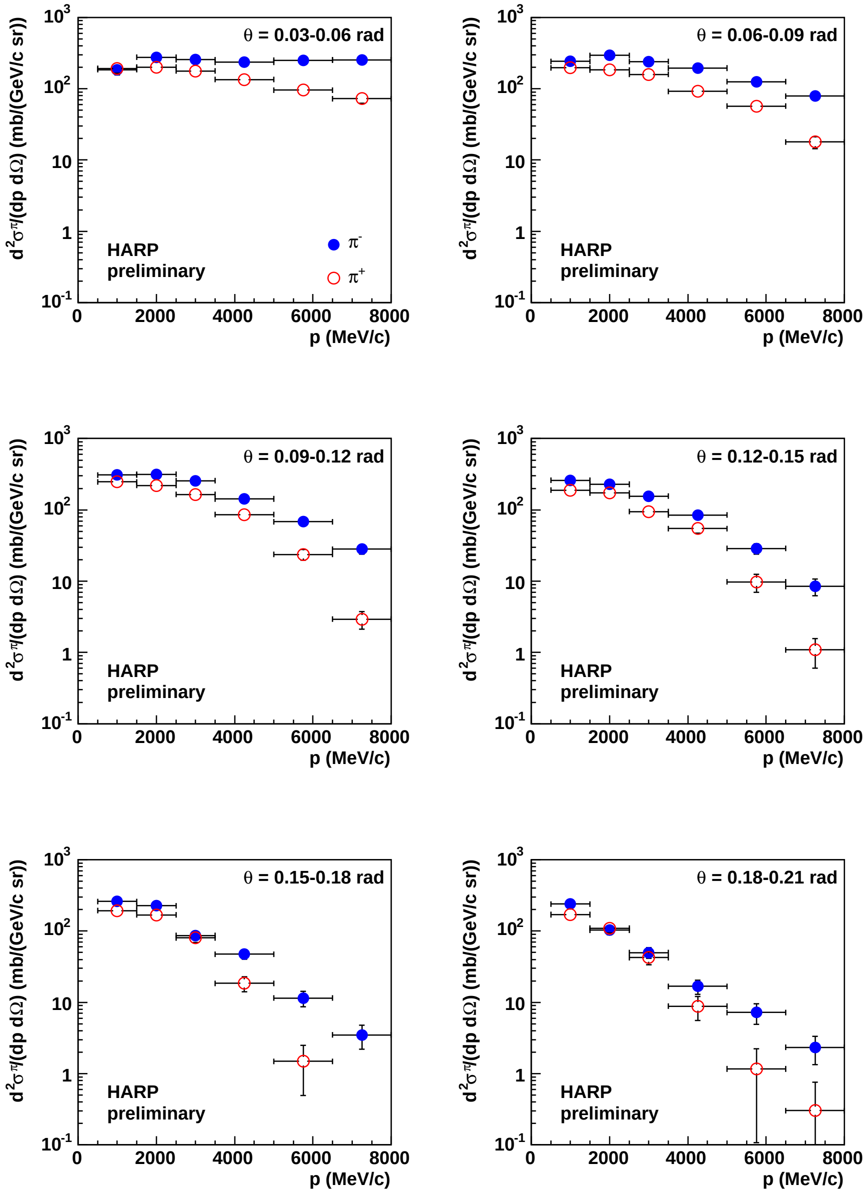

Figure 4: Inclusive charged pion production cross section in π^--C interactions at 12 GeV/c.