Large-angle hadron production cross-sections for the neutrino factory

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Precise measurements of neutrino oscillation parameters and of neutrino–nucleon cross-sections require a good understanding of neutrino beams: flux as a function of energy, transverse beam profile, and flavour composition. For this, hadron production spectra in proton–nucleus collisions are essential. We report on double-differential inclusive large-angle cross-sections of the production of secondary protons and charged pions, in the interactions with a 5% $\lambda_{\rm abs}$ thick stationary beryllium target, of proton and pion beams with momentum from ± 3 GeV/c to ± 15 GeV/c. Our results show cross-sections reported by the 'HARP Collaboration' to be wrong by factors of up to two.

1. INTRODUCTION

Precise cross-sections of secondary hadron production from the interactions of protons and pions with nuclei are, *inter alia*, of importance for the understanding of the characteristics of muons from the decay of pions that are produced by the proton driver of a neutrino factory. Surprisingly, inclusive differential cross-sections of hadron production in the interactions of few GeV/c protons with nuclei are known only within a factor of two to three. Consequently, the HARP detector was designed to carry out a programme of systematic and precise measurements of hadron production by protons and pions with momenta from 1.5 to 15 GeV/c.

The detector combined a forward spectrometer with a large-angle spectrometer. The latter comprised a cylindrical Time Projection Chamber (TPC) around the target and an array of Resistive Plate Chambers (RPCs) that surrounded the TPC. The purpose of the TPC was track reconstruction and particle identification by $\mathrm{d}E/\mathrm{d}x$. The purpose of the RPCs was to complement the particle identification by time of flight.

The HARP experiment was performed at the CERN Proton Synchrotron in 2001 and 2002 with a set of stationary targets ranging from hydrogen to lead, including beryllium.

We have measured [1, 2] the inclusive cross-sections of the large-angle production (polar angle θ in the range from 20 to 125°) of secondary protons and charged pions in the interactions with a 5% $\lambda_{\rm abs}$ beryllium target of protons and pions with beam momenta of ± 3.0, ± 5.0, -8.0, $+8.9$, ± 12.0, and ± 15.0 GeV/c.

2. DETECTOR CHARACTERISTICS AND PERFORMANCE

For the work reported here, only the HARP large-angle spectrometer was used [3, 4]. Its salient technical characteristics are stated in Table I. The good particle identification capability stemming from $\mathrm{d}E/\mathrm{d}x$ in the TPC and from time of flight in the RPC's is demonstrated in Fig. 1.

Table I: Technical characteristics of the HARP large-angle spectrometer

TPC	**RPCs**
$\sigma(1/p_{\rm T}) \sim 0.20 - 0.25$ (GeV/c)$^{-1}$	Intrinsic efficiency $\sim 98\%$
$\sigma(\theta) \sim 9$ mrad	σ(TOF) ~ 175 ps
$\sigma(\mathrm{d}E/\mathrm{d}x)/\mathrm{d}E\mathrm{d}x \sim 0.16$	

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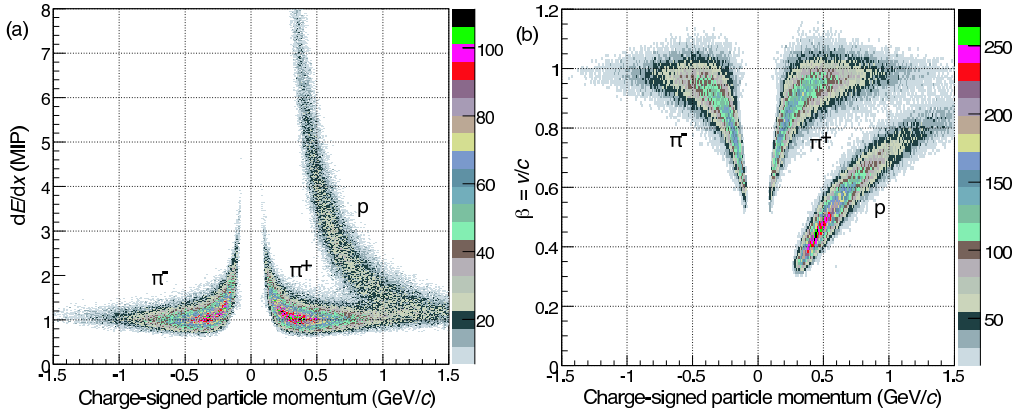

Figure 1: Specific ionization $\mathrm{d}E/\mathrm{d}x$ (left panel) and velocity β (right panel) versus the charge-signed momentum of positive and negative tracks in +8.9 GeV/c data.

3. INCLUSIVE CROSS-SECTIONS

Figure 2 shows examples of inclusive cross-sections of proton and $\pi^{\pm}$ production on beryllium nuclei. Double-differential cross-sections with a typical precision of a few per cent are available in tabular form in Refs. [1, 2] for the polar-angle range of 20 to 125° and for the p_{T} range of 0.10 to 1.25 GeV/c.

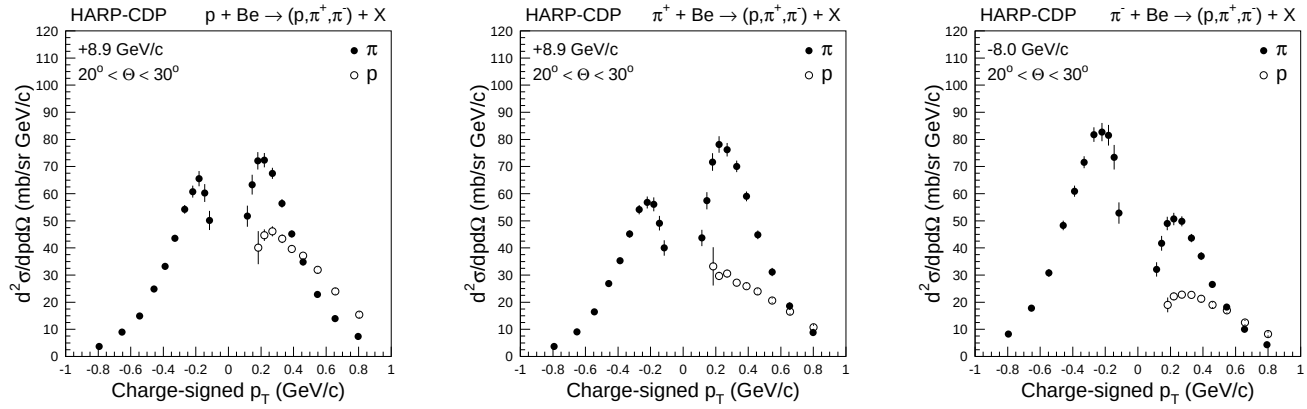

Figure 2: Inclusive cross-sections of the production of secondary protons, π^+'s, and π^-'s, in the polar-angle range 20 to 30°, by protons (left panel), π^+ (middle panel) and π^- (right panel) with beam momentum of +8.9 GeV/c on beryllium nuclei, as a function of the charge-signed p_{T} of the secondaries; the shown errors are total errors.

4. COMPARISON WITH CROSS-SECTIONS FROM THE E802, E910, AND HARP COLLABORATIONS

The left panel in Fig. 3 shows the Lorentz-invariant cross-section of π^+ and π^- production by +14.6 GeV/c proton interactions with beryllium nuclei, in the rapidity range $1.2 < y < 1.4$, published by the E802 Collaboration [5]. Their data are compared with our cross-sections from the interactions of +15.0 GeV/c protons, expressed in E802 units. We note good agreement.

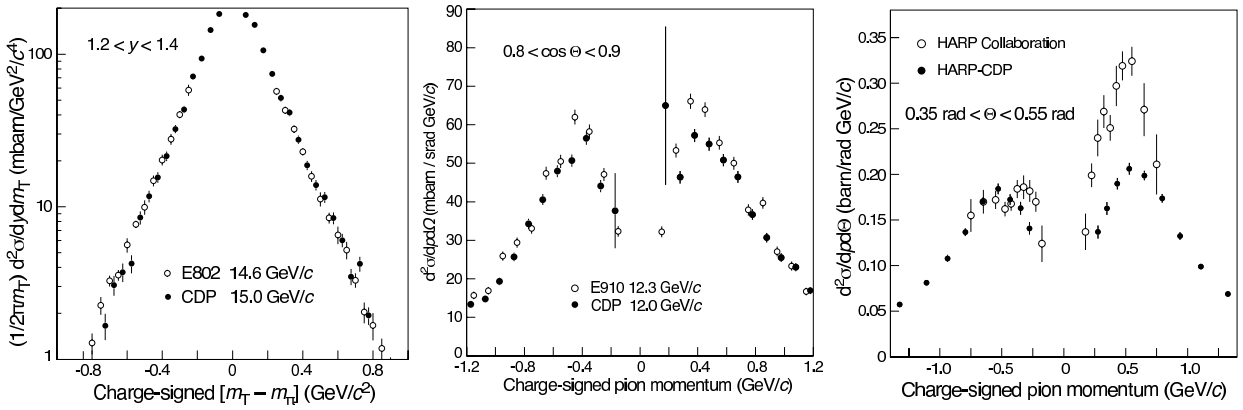

Figure 3: Left panel: comparison of our cross-sections (black dots) of $\pi^{\pm}$ production by +15.0 GeV/c protons off beryllium nuclei with the cross-sections published by the E802 Collaboration for the proton beam momentum of +14.6 GeV/c (open circles); middle panel: comparison of our cross-sections (black dots) of $\pi^{\pm}$ production by +12.0 GeV/c protons off beryllium nuclei with the cross-sections published by the E910 Collaboration for the proton beam momentum of +12.3 GeV/c (open circles); right panel: comparison of our cross-sections (black dots) of $\pi^{\pm}$ production by +12.0 GeV/c protons off beryllium nuclei with the cross-sections published by the HARP Collaboration (open circles).

The middle panel in Fig. 3 shows the cross-section $\mathrm{d}^2\sigma/\mathrm{d}p\mathrm{d}\Omega$ of $\pi^{\pm}$ production by +12.3 GeV/c protons, in the polar-angle range $0.8 < \cos\theta < 0.9$, published by the E910 Collaboration [6]. Their data are compared with our cross-sections from the interactions of +12.0 GeV/c protons, expressed in E910 units. We note reasonable agreement.

The right panel of Fig. 3 shows the HARP Collaboration's cross-sections [7] of $\pi^{\pm}$ production by +12.0 GeV/c protons off beryllium nuclei. Their data are compared with our respective cross-sections, expressed in the units used by the HARP Collaboration. We note striking disagreement.

As detailed in Ref. [8] and in references cited therein, the HARP Collaboration's data analysis is affected by their lack of understanding of TPC track distortions which leads to (i) a bias of $\Delta(1/p_{\mathrm{T}}) \simeq 0.3$ (GeV/c)$^{-1}$; (ii) a resolution of $\sigma(1/p_{\mathrm{T}}) \simeq 0.6$ (GeV/c)$^{-1}$ which is by a factor of two worse than claimed by them; and (iii) a bad overall RPC time-of-flight resolution of 305 ps and an apparent advance of the timing signal of protons with respect to that of pions by ∼500 ps ('500 ps effect'). All this causes distorted momentum spectra of secondary hadrons especially in regions where there is a strong momentum dependence, and the misidentification of protons as pions. The HARP Collaboration's pion production cross-sections are fatally biased and unsuitable for the design of a neutrino factory.

References

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