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Pion Yield Studies for Proton Driver Beams of 2-8 GeV Kinetic Energy for Stopped Muon and Low-Energy Muon Decay Eexperiments *†

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Abstract

Energy dependence of slow pion yield in proton-nucleus interactions is analyzed. Experimental data of the HARP collaboration is fitted using two-fireball model with $\chi^2/n_d \sim 1$ from 3 to 8 GeV/c. It is shown that low momentum negative pion yield rises almost linearly with proton kinetic energy. Normalized low momentum positive pion yield is larger at lower proton energy.

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1 Introduction

There are a variety of experiments using intense muon sources and offering the possibility of probing New Physics in ways complementary to the collider program. Most of such experiments require a source of stopped muons, and thus require an intense source of low energy (momentum $\leq$ 100 MeV/c) muons, which in turn originate from low energy (momentum $\leq$ 200 MeV/c) pions. The two accelerator designs (with beam energies at 2 and 8 GeV) are under consideration at Fermilab. Estimate of the slow pion yields at these energies is important to explore the opportunities presented by above designs.

2 Experimental data

Very few pion production measurements in the challenging region of 2-8 GeV and wide angle range are reported in literature. HARP collaboration [1] presented comprehensive data set of double differential $\pi^{\pm}$ cross sections in the range of momenta from 100 to 800 MeV/c and angles from 0.35 to 2.15 radian. Recently low angle (from 0.025 to 0.25 radian) measurements [2] in the range of pion momenta from .5 to 8 GeV/c were published. In both cases the results were obtained mainly at four incident proton beam momenta (3,5,8 and 12 GeV/c). The HARP collaboration performed comparisons with publicly available Monte Carlo simulations: GEANT4 [3] and MARS15 [4]. None of the considered models describe fully HARP data.

Negative pion production has been measured at KEK using a FANCY spectrometer [5]. The spectrometer covers angular and momentum ranges of 0.64-1.57 radian and 0.2-0.9 GeV/c, respectively. The measurements were performed for 3 and 4 GeV/c proton beam and aluminum/lead targets. In order to take into account the different angular binnings in HARP and FANCY results, which prevent direct comparison, a two-moving-source fit is using to present the FANCY measurements. To take into account different beam momenta, FANCY fit was multiplied by a ratio of the beam kinetic energies. As shown in Fig.1-2 FANCY fit is in a reasonable agreement with HARP data at large angles where FANCY measurements were performed.

3 Two-fireball parameterization

Experimental data of the HARP collaboration were fitted using a two-component model

$$E\frac{d^3\sigma}{dp^3} = \sum_{i=1}^{2} a_i(1+\alpha_i z)exp\{-\frac{T(1-\beta_i z)}{T_i}\}, \quad (1)$$

where T is pion kinetic energy, z is cosine of pion azimuthal angle, $a_i, \beta_i, T_i, \alpha_i$ are model parameters. HARP large angle data [1] are fitted with $\chi^2/n_d \sim 1$ for charged pion production in proton-tantalum and proton-carbon interactions at 3 and 8 GeV/c. Accuracy of the fit becomes worse when low angle data [2] at 8 GeV/c were included ($\chi^2/n_d \sim 3$). Statistical errors of the data are large at low angles and 3 GeV/c proton momentum, so, including this data does not change the fit quality. Comparison of the fit with HARP data is presented in Fig.1-2.

4 Thick target effects

A pion production target in low energy muon experiments usually is long enough (about 1.5 interaction length) with a small radius. Secondary/tertiary interactions and ionization energy losses could

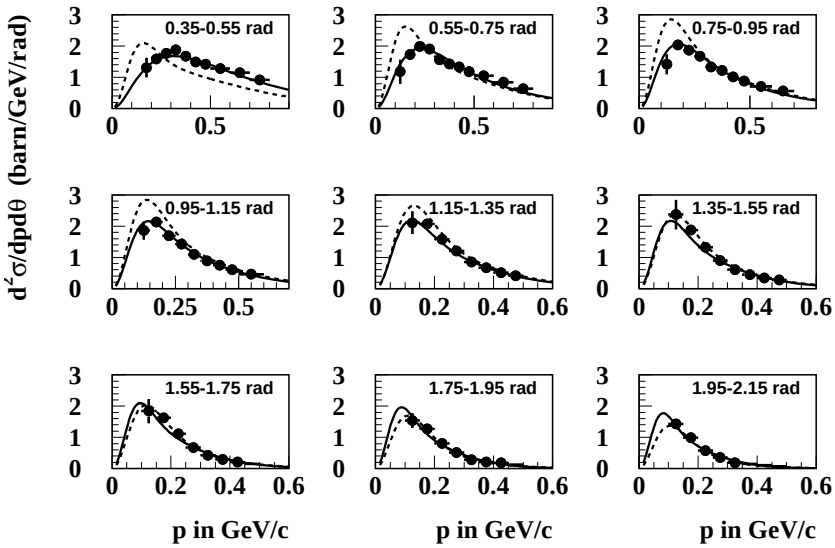

Figure 1: Cross section of π^- production in proton-tantalum interaction at 8 GeV/c. Symbols – HARP data, full lines – two-fireball fit, dashed lines – FANCY fit.

modify pion spectra in comparison with proton-nucleus interaction. MARS simulation shows that track length distribution of low energy pions has maximum near target radius. In the gold target with 3 mm radius, pions lose only about 10 MeV before they reach the target surface.

In the interactions of 8 GeV/c protons with a 16 cm gold target, 20-30 % of low energy negative pions are produced in secondary/tertiary interactions. But a large part (about 50%) of these interactions is quasi-elastic negative pion scattering. So, low energy pion yield from the "thick" target is within $\sim$ 10 % proportional to low energy pion yield in proton-nucleus interactions.

5 Conclusion

Charged pion momentum distributions (divided by primary proton kinetic energy) at 3 and 8 GeV/c are presented in Fig.3. They were obtained by angular integration of the two-fireball parameterization. It is seen that energy dependence of slow negative pion production from heavy (tantalum) target is almost linear. Normalized positive pion yield from heavy target is larger at 3 GeV/c than at 8 GeV/c. More positive pions are produced from light (carbon) target at low proton momentum.

References

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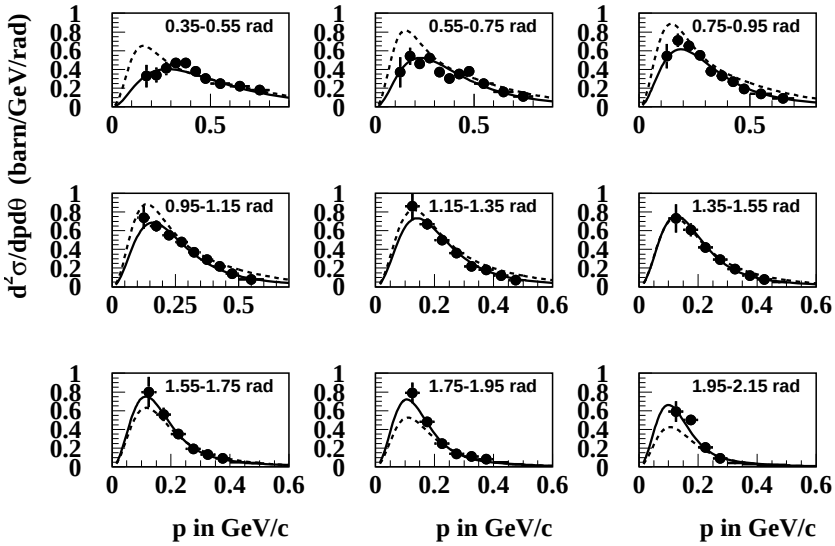

Figure 2: Cross section of π^- production in proton-tantalum interaction at 3 GeV/c. Symbols – HARP data, full lines – two-fireball fit, dashed lines – FANCY fit

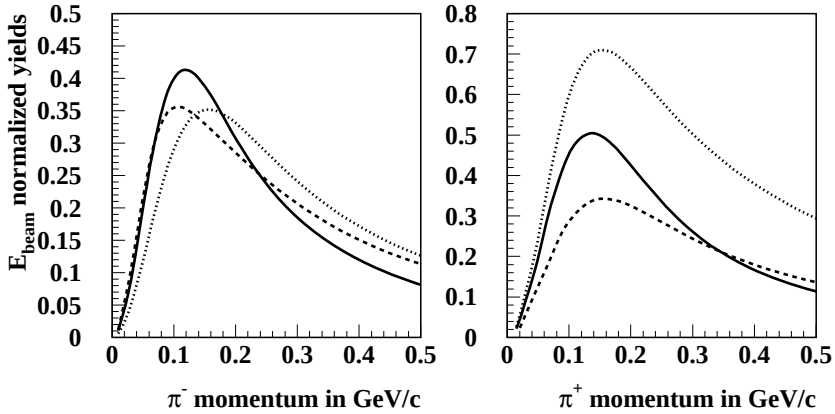

Figure 3: Normalized pion yield in proton-nucleus interactions. Full lines – pTa at 3 GeV/c, dashed lines – pTa at 8 GeV/c, dotted lines – pC at 3 GeV/c