Photo-pion Production with JLab at 12 GeV

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The $\gamma n \to \pi^- p$, $\gamma p \to \pi^+ n$ and $\gamma p \to \pi^0 p$ reactions are essential probes of the transition from meson-nucleon degrees of freedom to quark-gluon degrees of freedom in exclusive processes. The differential cross-section for many exclusive reactions [1], at high energy and large momentum transfer, appear to obey the quark counting rule. These rules were first obtained based on dimensional analysis [2] but later they were confirmed in the short-distance pQCD framework [3]. In recent years, a similar trend has been observed in deuteron photo-disintegration experiments at SLAC and JLab [4]-[6], in fact the onset of scaling is observed at a surprisingly low momentum transfer of 1.0 $(\mathrm{GeV/c})^2$ to the nucleon involved. In addition to the early onset of scaling, some exclusive processes such as pp and πp elastic scattering, show a striking oscillation in the scaled differential cross-section about the predicted quark counting rule behavior (s^{-10} for pp elastic scattering). One of the explanation [8] for these oscillations in the pp cross-section, involves the interference between short-distance and long-distance (Landshoff [7]) amplitudes. This QCD process is analogous to the QED effect of Coulomb-nuclear interference observed in low energy charged particle scattering. An alternative explanation interprets the oscillations in terms of production of charm resonance states ($uuduudc\bar{c}$).

The photo-pion production reactions are well suited for investigation of the scaling behavior ($\frac{ds}{dt} \propto s^{-7}$) and also for studying oscillatory behavior around the quark counting rule prediction, because the cross section of these processes decrease relatively slower with energy compared with other photon-induced processes. The relatively higher rates for these processes will also allow angular scans to investigate the the momentum transfer (t) and transverse momentum (p_T) dependence of the scaling behavior in addition to the usual energy scan looking at the center-of-mass energy ($W = \sqrt{s}$) dependence. Recent results from deuteron photo-disintegration (E96003) [6] have shown the importance of doing such angular scans.

An experiment studying these reactions (E94104) was completed recently. The preliminary results from E94104 at 90^o c.m. angle, suggest an onset of scaling behavior and show very interesting hints of oscillation in the $\gamma n \to \pi^- p$ and $\gamma p \to \pi^+ n$ channels.

There is enormous interest in confirming whether the oscillation observed in pp elastic scattering is a general feature of QCD in exclusive processes. Measurements of these fundamental cross-sections would be a timely guide for theoretical efforts on this subject and would help understand the exact mechanism behind the scaling behavior observed in exclusive processes. An experiment (E02-010) to perform a fine scan of the region between 2.3 GeV$< \sqrt{s} <$ 3.4 GeV with photo-pion production from nucleons was recently approved. However, with the upgrade of JLab to 12 GeV, these measurements can be extended up to $\sqrt{s} = 4.6$ GeV. At these energies one can investigate both above and below the charm threshold in photo-pion production and test the interpretation of the observed oscillation in terms of charm resonance state. The requirement of two spectrometers capable of reaching high momenta of about 6.5 GeV, make these measurements ideal in Hall C using the HMS and the planned Super-HMS. Furthermore, using a combination of the HMS spectrometer and the large acceptance photon calorimeter, Bigcal, it would also be possible to perform measurements of the cross-section for $\gamma p \rightarrow \pi^0 p$. The proton and the π^0 would be measured in coincidence in the HMS and the calorimeter respectively. These measurements can be carried out using a 50 μA electron beam impinging on a 6% copper radiator, a liquid hydrogen and a liquid deuterium target.

In addition to these fundamental cross-section measurements, yet another method of studying the transition region involves inclusive measurement of photo-produced $\frac{\pi^-}{\pi^+}$ ratio from a deuterium target. Since the recently completed measurements up to 5.6 GeV from experiment E94104 barely reach the quark-gluon regime, it is very important to extend these measurements to higher energies. With a beam energy of 11 GeV and the HMS, one can extend these measurements to t = -19 GeV^2.

One can also measure the photo-pion production from nuclear targets. Using the ratio of photo-pion (π^-) yield from heavy nuclei to the yield from ^{2}H, one can extract the nuclear transparency of photo-pions. This would allow us to study the novel effect of nuclear filtering and the complementary color transparency effect. Nuclear filtering refers to the suppression of the oscillations in the cross-section due to the nuclear medium, which in turn give rise to oscillations in the transparency 180^0 out of phase with the oscillations in the free cross-section. The nuclear filtering effect which is expected to be larger in heavier nuclei, can be studied with photo-pion production from nuclei such as ^{12}C. The preliminary results from the exploratory data taken on a ^{4}He target during E94104 give us confidence in this technique. With JLab at 12 GeV these measurements in search of nuclear filtering and color transparency can be extended beyond the charm threshold. The projected results are shown in Fig 6. The complementary effect of color transparency is expected to have an earlier onset in lighter nuclei. Thus measurement of the photo-pion transparency in ^{4}He, can be used to explore the color transparency effect. The projected results are shown in Fig 7. Both the ^{12}C and the ^{4}He measurement can be extended to the highest energies in Hall C ($\sqrt{s}$ = 4.6 GeV/c). This would be complementary to similar programs in Hall A where the transparencies can be measured only up to $\sqrt{s}$ = 3.9 GeV/c but can be done faster because of the larger acceptance of the spectrometers.

In our estimates we have used HMS angular acceptance of 6.5 msr, super HMS angular acceptance of 4 msr (for momentum < 8.5 GeV/c and 2.5 msr otherwise) and a 15 cm target length. The time estimated includes time for running without a radiator.

The projected results for an angular scan of $\gamma p \to \pi^+ n$ at $E_e = 6$ and 11 GeV is shown in Fig 1. The uncertainties shown include 5% systematic uncertainty along with a 2% statistical uncertainty. The beam time requirements for these measurements are estimated to be 150 hrs total at the two energies shown. Fig. 2, 3 and 4 show the projected results for an energy (s) scan of $\gamma p \to \pi^+ n$, $\gamma n \to \pi^- p$ and $\gamma p \to \pi^0 p$ respectively. In these figures a 3% point-to-point systematic uncertainty along with 2 (2.5) % statistical uncertainty for ^{1}H (^{2}H) is shown. According to our estimates the projected results can be achieved with 25 days of beam time for the charged pions and 15 days for the neutral pion. This does not include estimates of the overhead required for such a measurement. Fig 5 shows the projected results for $\frac{\pi^-}{\pi^+}$ ratio measurement from a ^{2}H target at $E_e = 6$, 8 and 11 GeV. The beam time estimates are 40, 40 and 280 hours respectively.

References

[1] R. L. Anderson *et al.*, Phys. Rev. D **14**, 679 (1976); G. White *et al.*, Phys. Rev. D **49**, 58 (1994).

[2] S. J. Brodsky and G. R. Farrar, Phys. Rev. Lett. **31**, 1153 (1973); Phys. Rev. D **11**, 1309 (1975); V. Matveev *et al.*, Nuovo Cimento Lett. **7**, 719 (1973).

[3] G.P. Lepage, and S.J. Brodsky, Phys. Rev. D **22**, 2157 (1980).

[4] J. Napolitano *et al.*, Phys. Rev. Lett. **61**, 2530 (1988); S.J. Freedman *et al.*, Phys. Rev. C **48**, 1864 (1993); J.E. Belz *et al.*, Phys. Rev. Lett. **74**, 646 (1995).

[5] C. Bochna *et al.*, Phys. Rev. Lett. **81**, 4576 (1998).

[6] E. C. Schulte *et al.*, Phys. Rev. Lett. **87**, 102302 (2001)

[7] P. V. Landshoff, Phys. Rev. D **10**, 1024 (1974).

[8] J.P. Ralston and B. Pire, Phys. Rev. Lett. **61**, 1823 (1988); J.P. Ralston and B. Pire, Phys. Rev. Lett. **65**, 2343 (1990).

[9] "Photoproduction of Elementary Particles", edited by H. Genzel, P. Joos and W. Pfeil pp16-268, (1973); M. A. Shupe *et al.*, Phys. Rev. D. **19**, 1921 (1979).

[10] P. Jain, B. Kundu, and J. Ralston, hep-ph/0005126, to appear in Phys. Rev. D.

[11] H. Gao, R. J. Holt and V. R. Pandharipande, Phys. Rev. C. **54**,2779 (1996).

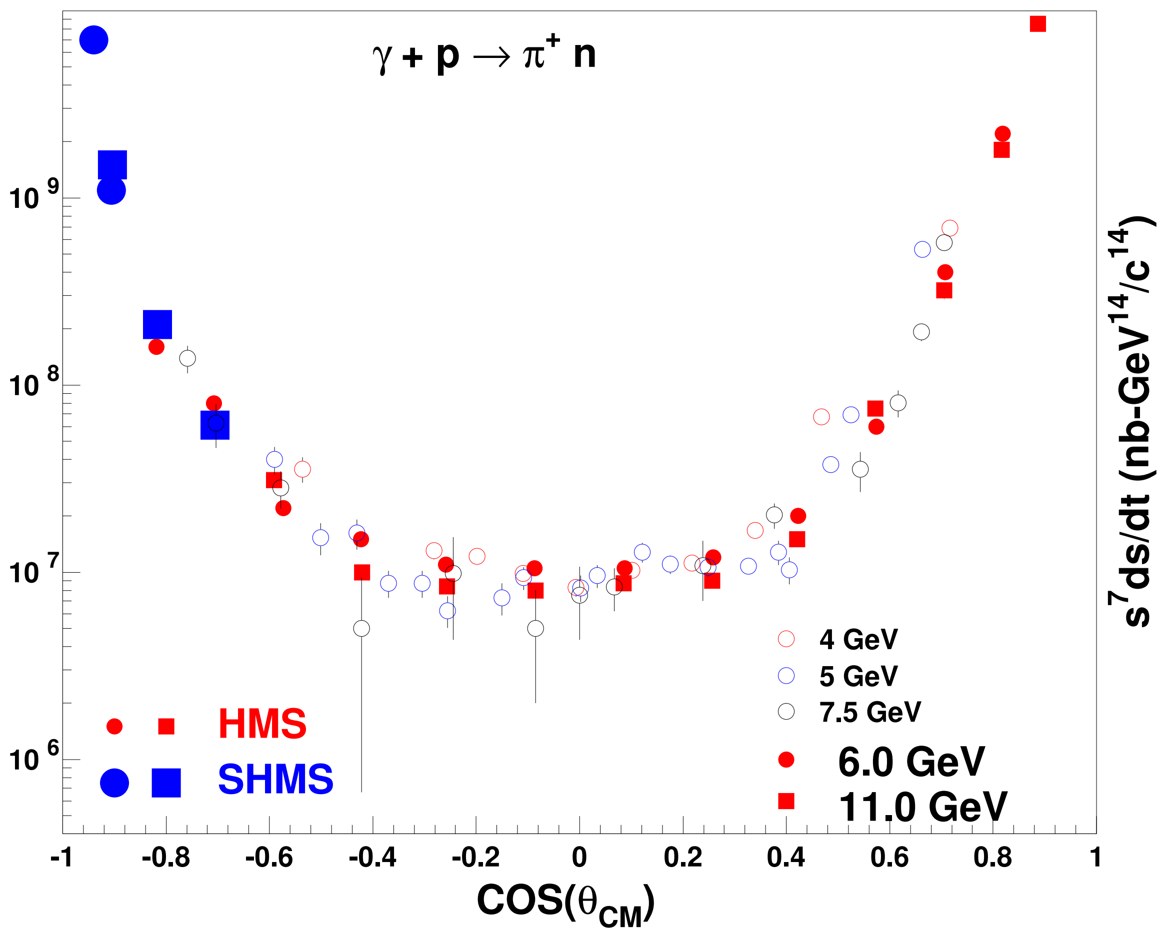

Figure 1: The scaled cross-section $s^7\frac{d\sigma}{dt}$ for the $p(\gamma,\pi^+)n$ process as a function of $\cos(\theta_{CM})$. The solid symbols are the projected results while the open symbols are existing data [1].

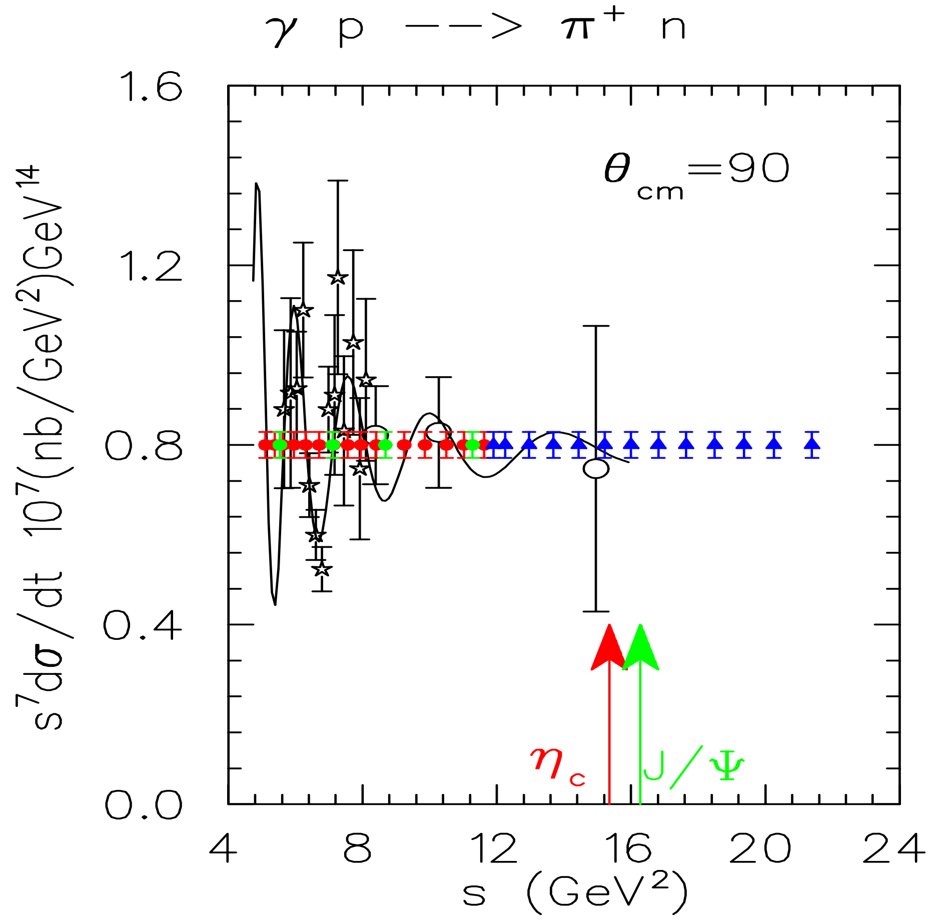

Figure 2: The scaled differential cross-section for the $p(\gamma, \pi^+)n$ process at C.M. angle of $90°$, as a function of cms energy $\sqrt{s}$ in GeV along with the projected measurements for JLab at 11 GeV (blue solid points).The red solid points are the projected results from E02-010 and the green solid points show the completed E94-104 data points. The open symbols are the existing data [9] while the solid line is a fit to the existing data based on the two component interference model of Ref. [10]. The red and green arrows indicate the η_c and J/ψ thresholds respectively.

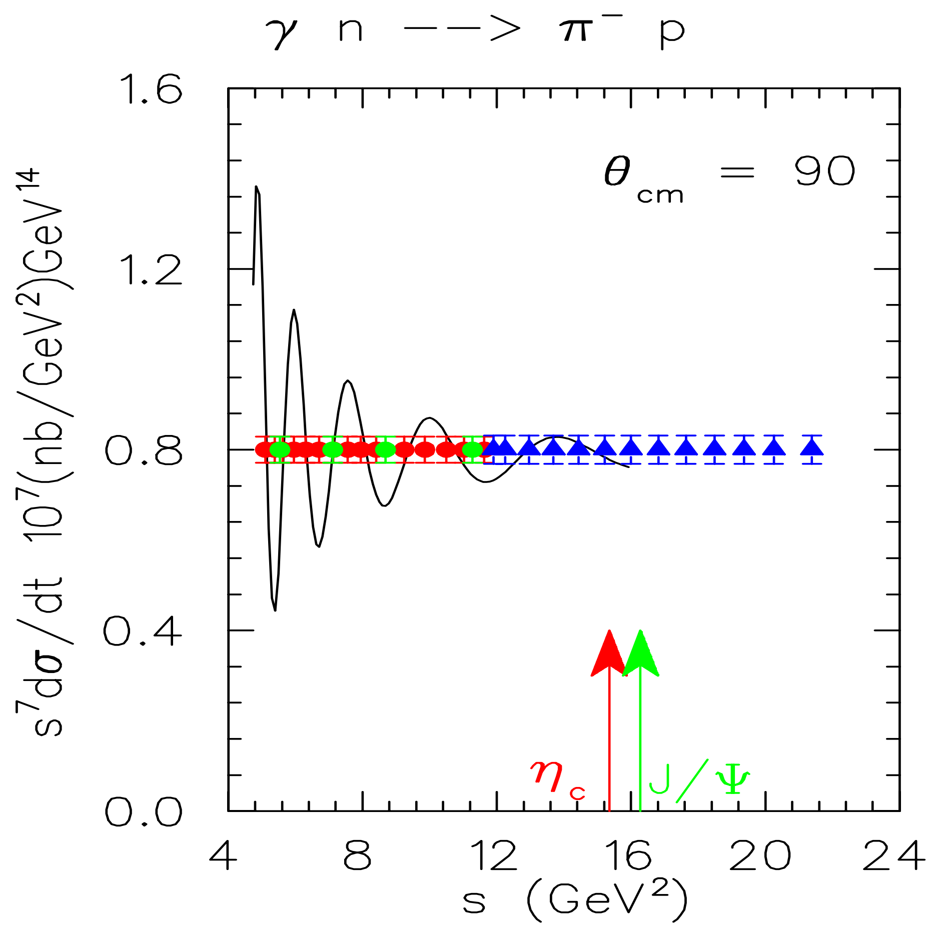

Figure 3: The projected measurement for JLab at 11 GeV (blue solid points) for the scaled differential cross-section for the process $n(\gamma, \pi^- p)$ as a function of cms energy $\sqrt{s}$ in GeV. The red and green arrows indicate the η_c and J/ψ thresholds respectively.

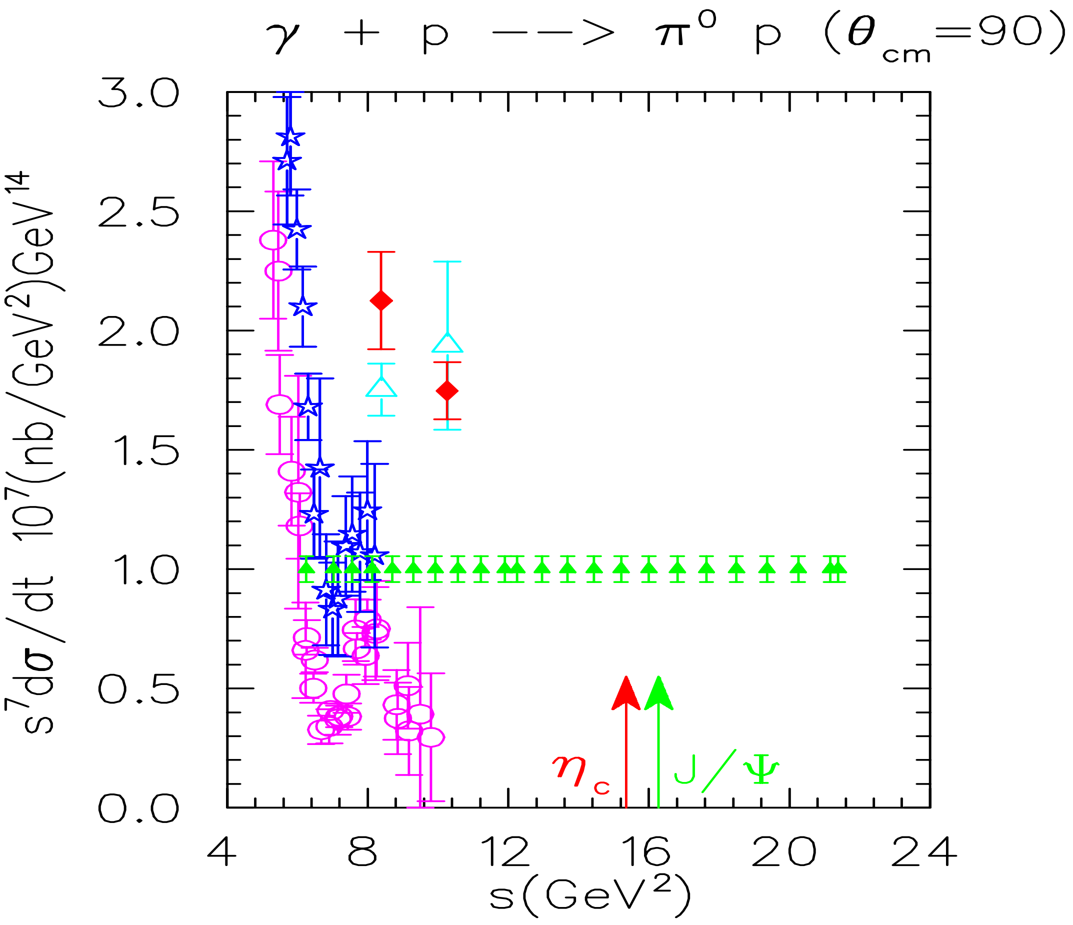

Figure 4: The projected measurement for JLab at 11 GeV (green solid points) for the scaled differential cross-section for the process $p(\gamma, \pi^0 p)$ as a function of cms energy $\sqrt{s}$ in GeV. The open symbols are the existing data [9]. The red and green arrows indicate the η_c and J/ψ thresholds respectively.

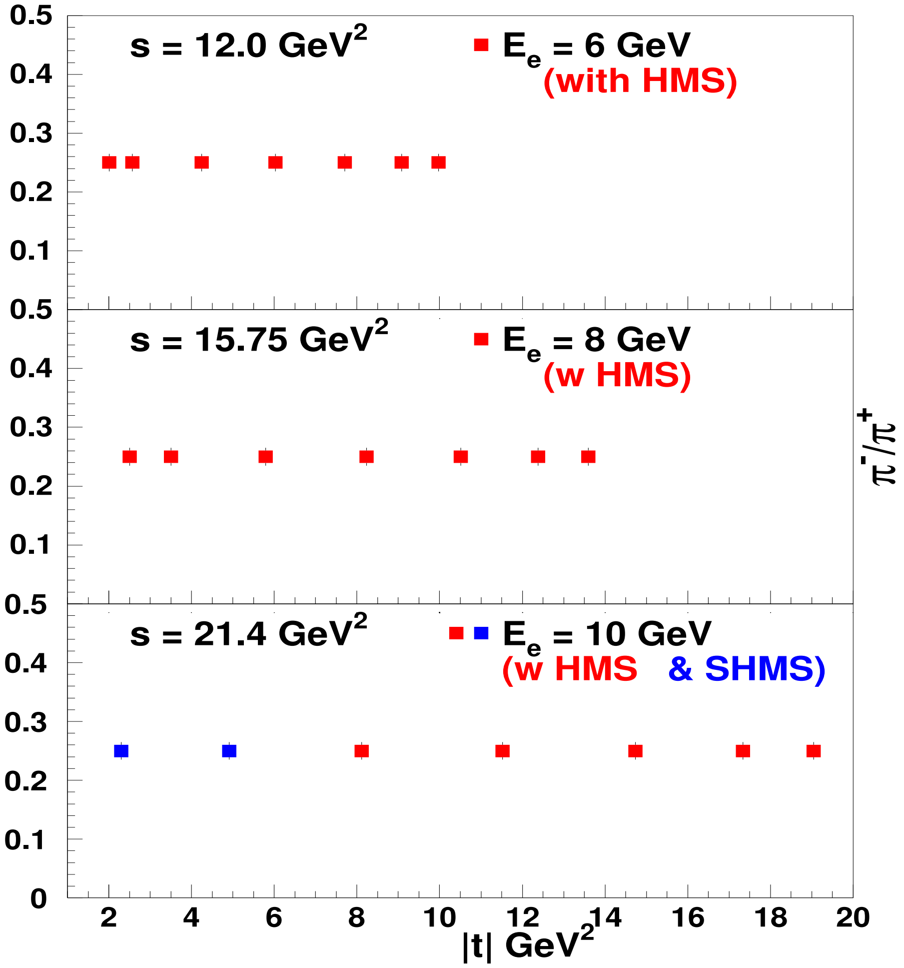

Figure 5: The projected results of a $\frac{\pi^-}{\pi^+}$ ratio measurement from a ^{2}H target at E_e = 6, 8 and 11 GeV.

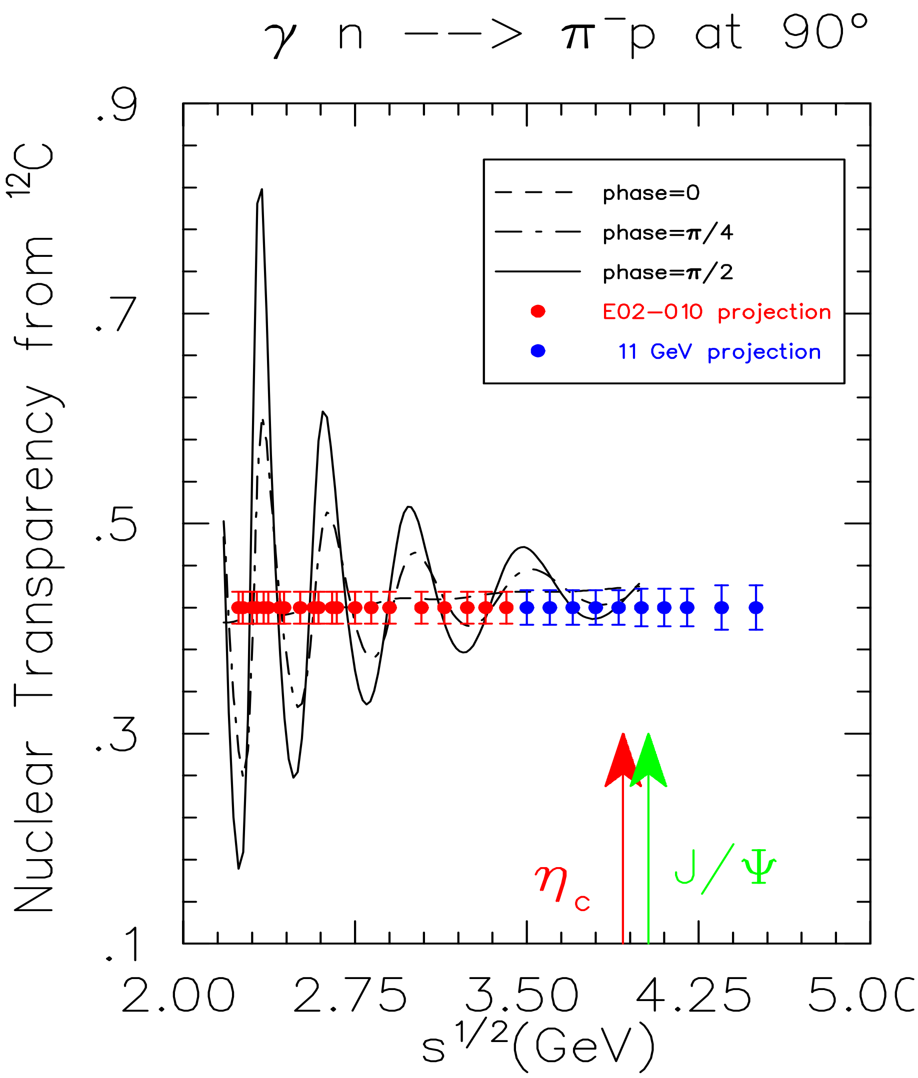

Figure 6: The projected results for nuclear transparency for photo-pions production from a ^{12}C target. The lines are calculations from Ref [10] using the two component model and and additional nuclear phase.

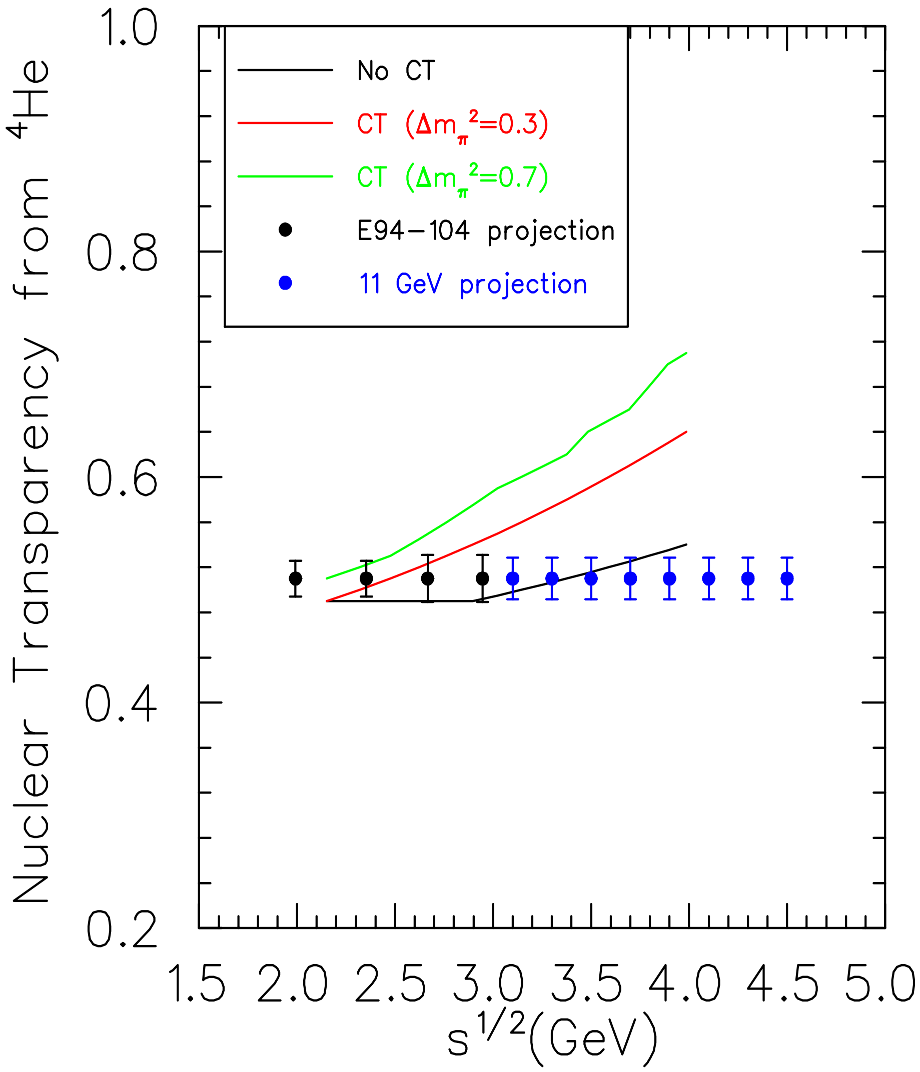

Figure 7: The projected results for nuclear transparency for photo-pions production from a ^{4}He target. The lines are CT calculations from Ref [11].