On the difference between np and pp reaction cross sections below 20 GeV/c beam momentum

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Abstract

We examine in detail the differences between np and pp reactions in the regime of 20 GeV/c beam momentum or lower and demonstrate that np cross sections cannot be deduced from pp cross sections alone. We employ isospin analysis over the exclusive reactions $pp \rightarrow pn\pi^+$, $np \rightarrow pp\pi^-$ and $pp \rightarrow pp\pi^0$. The reactions $nn \rightarrow X$ can be deduced from the reactions $pp \rightarrow \bar{X}$, where $\bar{X}$ is the I_3 reflected state of X, by charge symmetry. The np reactions do not reflect over to pp reactions and cannot be deduced in the energy range of interest to the ILC from measuring pp reactions.

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I. INTRODUCTION

It has been correctly pointed out by William Morse that I_3 reflection can be used to deduce the nn cross sections once the pp cross sections have been measured. However, the nuclei in calorimeters are not isoscalar in general and contain a varying number of neutrons and protons. For instance, lead has 82 protons and 121 neutrons, and tungsten has 74 protons and 110 neutrons. A proton beam in lead will get a chance to participate in 82 pp and 121 np interactions whereas a neutron beam in the same material will get a chance to participate in 82 np and 121 nn reactions per nucleus. So knowing the behavior of the np cross section is of importance in deducing the behavior of neutrons in calorimetry. In what follows, we show that np reaction cross sections cannot be deduced from pp reactions in the beam momentum range below ≈ 20 GeV/c. The text given below is taken almost verbatim from my Ph.D thesis [1] which concerned the diffractive channel $np \rightarrow pp\pi^-$.

II. ISOSPIN ANALYSIS OF THE NP REACTION CHANNELS

The paper by Dahl-Jensen et al. [2] analyzes the reactions $N_1N_2 \rightarrow N_3(N_4\pi)$ (where N_i is either a neutron or a proton) in terms of three isospin amplitudes $M_I^{I_x}$ where I_x and I are the isospins of the exchanged particle and the $N_4\pi$ combination respectively. Their analysis, (in which they use three reactions $pp \rightarrow pp\pi^0$, $pp \rightarrow pn\pi^+$ and $pn \rightarrow pp\pi^-$) shows that the isospin zero exchange amplitude $M^0_{1/2}$ is dominant at 19 GeV/c and higher. Comparing data at 7,12, 18 and 28 GeV/c, they find that the rate of fall off with respect to energy of the $M^0_{1/2}$ amplitude is much smaller than those of the $M^1_{1/2}$ and the $M^1_{3/2}$ amplitudes.

The reaction $np \rightarrow pp\pi^-$ in this picture is seen to be the sum of two distinct processes which are summarized by the diagrams in Figure 1. It may be shown [2] that

$$\sigma_{diagram\ a} = \frac{2}{3}\int (M^0_{1/2} + \frac{1}{3}M^1_{1/2} - \frac{1}{3}M^1_{3/2})^2 dR \tag{1}$$

$$\sigma_{diagram\ b} = \frac{2}{27}\int (2M^1_{1/2} + M^1_{3/2})^2 dR \tag{2}$$

where dR denotes the Lorentz invariant phase space element. The other two reactions can be expressed as different linear combinations of the same amplitudes. Parametrizing each of the integrated cross sections by the form αp^n where p is the beam momentum yields the values of n given in table I. The authors thereby conclude that below 7 GeV/c, the $M^1_{3/2}$

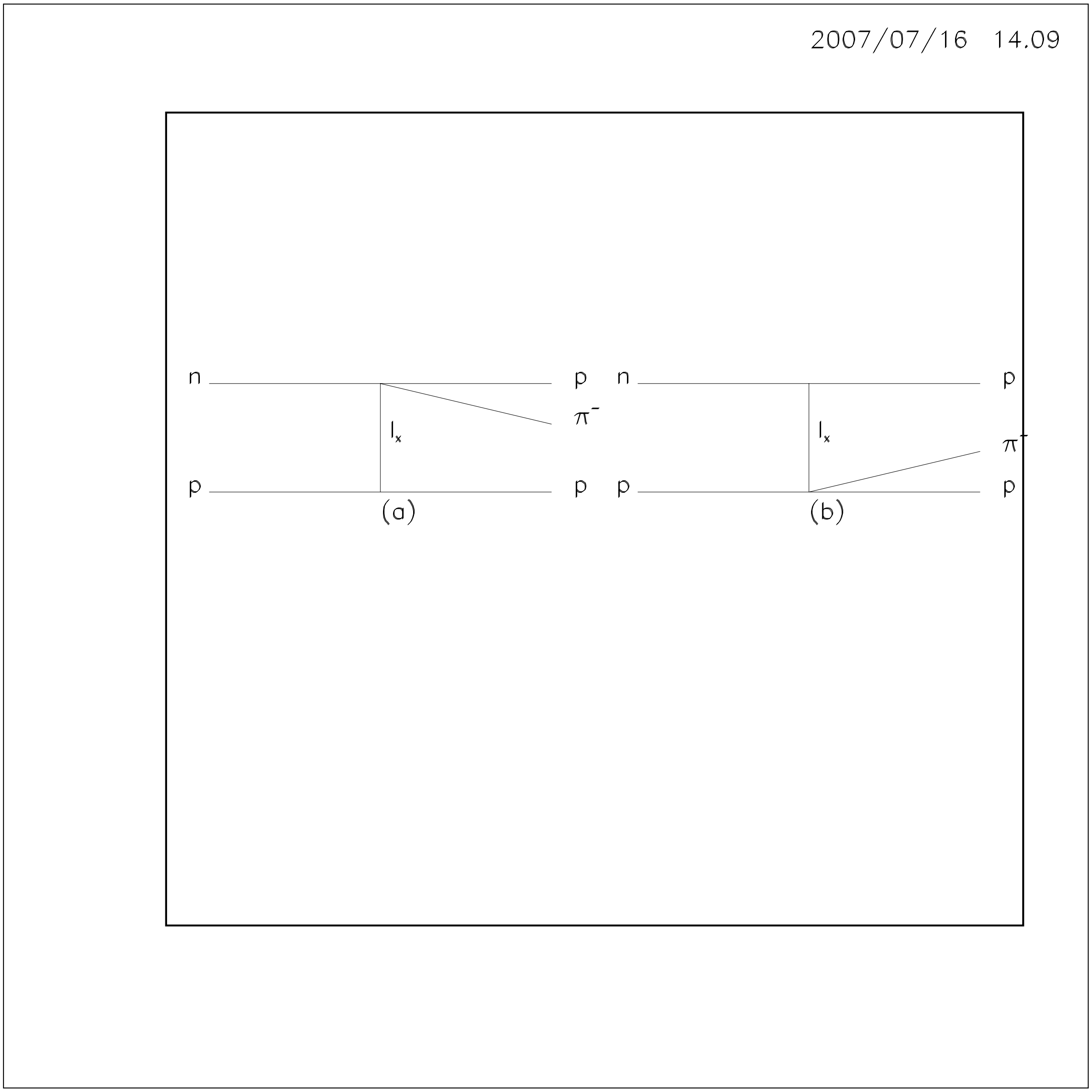

FIG. 1: Isospin exchanges for the reaction $np \to pp\pi^-$.

amplitude is dominant and above 7 GeV/c, the $M^0_{1/2}$ amplitude is dominant. They formally ascribe the $M^1_{3/2}$ contribution as being due to pion exchange and the $M^0_{1/2}$ contribution as being due to pomeron exchange. The $M^1_{1/2}$ contribution had the energy dependence of ρ and A_2 exchange or a mixture of $\rho(A_2)$ and π exchange.

The consequence of Pomeron exchange had previously also been investigated by Rushbrooke [3] who arrived at a conclusion similar to the Scandinavian group that at 7.0 GeV/c

TABLE I: Power law behavior of the Isospin amplitudes with respect to momentum

Cross Section due to Amplitude	n
$M^0_{1/2}$	-0.33
$M^1_{1/2}$	-1.37
$M^1_{3/2}$	-1.84

the I=0 exchange amplitude plays an important but not dominant role. A consequence of pure Pomeron exchange (I=0) he derives is the equality

$$\sigma(pp \rightarrow (p\pi^0)p) = \sigma(np \rightarrow (p\pi^-)p) = \frac{1}{2}\sigma(pp \rightarrow (n\pi^+)p) \tag{3}$$

These three quantities are plotted in Figure 2. It can be seen that the Rushbrooke equality is obtained only at $\approx$ 20 GeV/c or higher beam momentum when pomeron exchange dominates and the other two amplitudes die away. Above 20 GeV/c one can equate the cross section $np \rightarrow pp\pi^-$ and the cross section $pp \rightarrow pp\pi^0$. But both these are half the diffractive cross section $pp \rightarrow (n\pi^+)p$.

From this discussion, it can be seen that below $\approx$ 20 GeV/c beam momentum, the reaction $np \rightarrow (p\pi^-)p$ cross section (both total and differential) cannot be deduced from pp cross section measurements alone but require isospin amplitudes which are deduced from all three reaction channels. The discussion carries over to all diffractive channels with multi-pion production in both pp and np reactions. It is the intention of the MIPP upgrade to measure the cross sections on a variety of thin target nuclei (30 nuclei have been listed) using 6 beam species $\pi^\pm, K^\pm, p^\pm$ in the momentum range 1 GeV/c to 85 GeV/c. Using these we will not be able to deduce the np cross sections below 20 GeV/c. The tagged neutral technique [4] opens up a unique opportunity to measure these cross sections as well on a tertiary thin target [5]. The tagged neutral technique will also yield K^0_L and $\bar{n}$ cross sections.

Once the MIPP electronics upgrade is made to work, the tagged neutral beams can also be made to study the responses of n, K^0_L and $\bar{n}$ in calorimeters. This additional step does not require much additional effort. From the discussion above, it would behoove the proponents of the PFA algorithm to measure the tagged neutral particle responses in the calorimeters directly rather than attempting to deduce these from charged particle response data.

As has been pointed out [4], the simulators currently used do not necessarily get the exclu-

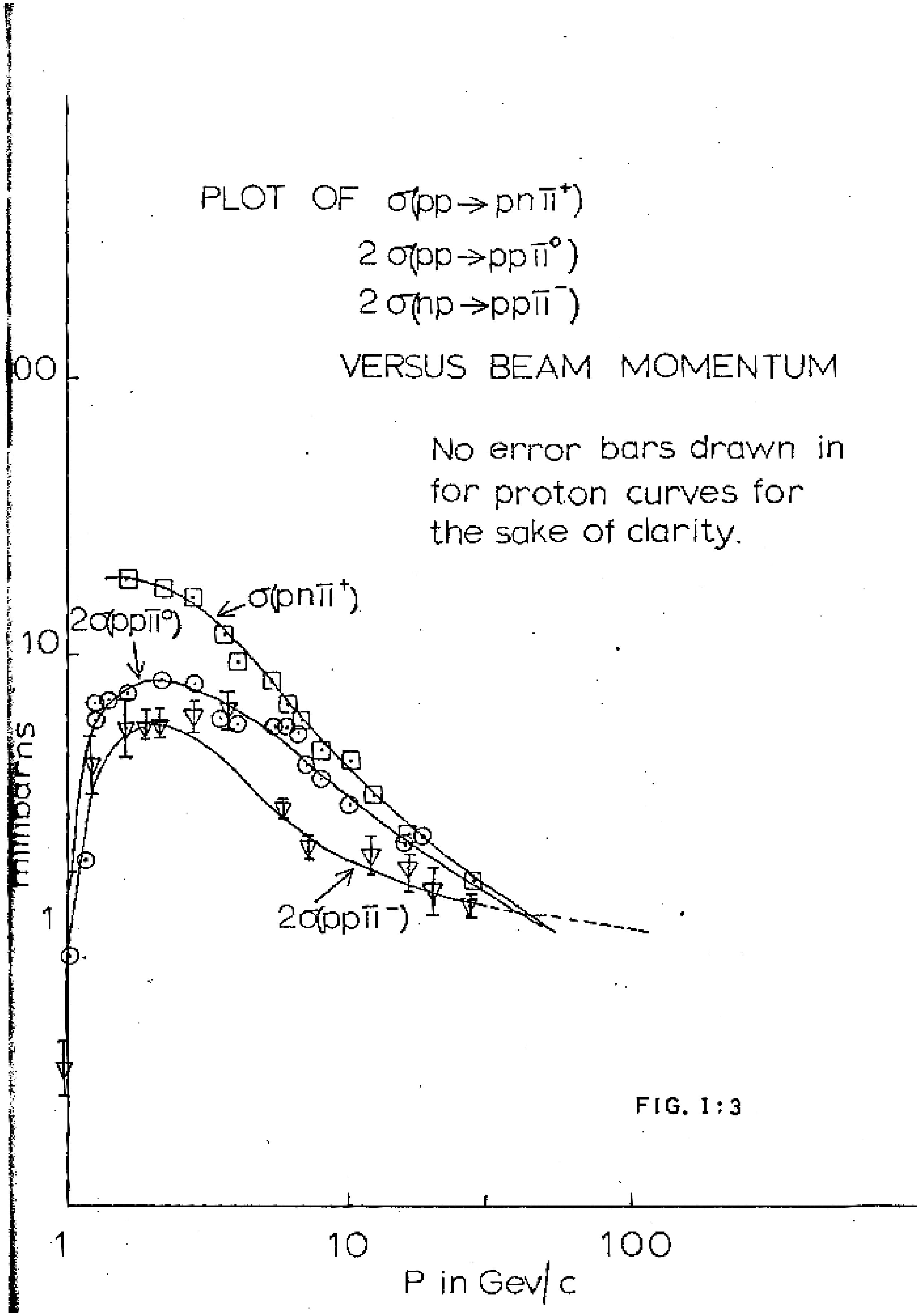

FIG. 2: The experimentally measured cross section [1] for the reaction $\sigma(pp \rightarrow pn\pi^+)$ compared with $2\sigma(pp \rightarrow pp\pi^0)$ and $2\sigma(np \rightarrow pp\pi^-)$. Pomeron exchange dominates only above $\approx$ 20 GeV/c beam momentum. . The curves are drawn to guide the eye.

sive np and pp channels correctly. The program DPMJET, which is widely used to simulate low energy diffractive phenomena, gets the $pp \rightarrow pn\pi^+$ cross section wrong, underestimating it by a factor of 4.8 at 20 GeV/c.

The ILC testbeam effort will be crucial in helping choose the calorimeter technology for the ILC detectors. However, after the detector is built, one would still need a good shower simulator to help analyze the data. The MIPP upgrade data on thin targets will help improve the simulators considerably.

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[1] "The reaction $np \rightarrow pp\pi^-$ in the momentum range 9.0 GeV/c to 24.0 GeV/c in a 2 metre liquid Hydrogen Bubble Chamber", Rajendran Raja, Ph.D thesis, Cavendish Laboratory, 1975.

[2] E. Dahl-Jensen et al., ISOSPIN analysis of single pion production in pp and pn collisions at 19 GeV/c, submitted to the XVII Conference on High Energy Physics London, 1974.
Nucl. Phys. B87, 426 (1975).

[3] J. G. Rushbrooke, "The Pomeron Exchange contribution to $NN \rightarrow NN\pi$, Lett. al. Nuov. Cim. **2** (1971) 181.

[4] R. Raja, "Tagged Neutron, Anti-neutron and K^0_L beams in an Upgraded MIPP Spectrometer",hep-ex/0701043.

[5] It is far cleaner to use tagged neutral beams than to use protons on deuterium to obtain np cross sections especially at lower momenta, since Fermi motion and other nuclear effects are absent in the tagged neutral beam technique.