PI P AND PI PI SCATTERING: TOWARDS THE FIRST LHC RESULTS

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Can we get the information on π p and π π scattering from the LHC data? I present briefly recent results of the IHEP Diffractive Group, which include all the steps: formulation of the problem, an idea how to solve it, experimental tools, Monte-Carlo simulation and preliminary expectations concerning the first data from the LHC.

INTRODUCTION

At the moment we have large amount of data on p p and anti-p p scattering in the energy range up to several TeV and also on γ p scattering up to several hundreds GeV [1]. Strictly speaking, we cannot separate all the viable models for high energy diffractive scattering without the information on the cross-sections of other initial states, for example, pions. We could also check the universality of high energy behavior of any total cross-section independently of the initial state. And for other initial states we have only rather low energy data. For example, π p cross-sections are known up to about 40 GeV [1].

Even if we use an old idea of Goebel and Chew-Low [2, 3] based on virtual particles, at low energies we have no much possibilities to extend our knowledge. From exclusive channels we have π π cross-sections in the energy range up to 18.4 GeV [4, 5], and for π p, with some model dependence, up to 50 GeV [6, 7].

At very high energies, say, at the LHC, it is rather difficult to use exclusive channels. It is more convenient to use inclusive spectra of fast leading neutrons. In this case we could obtain π p and π π cross-sections in the TeV energy range.

1.1 CALCULATION OF CROSS-SECTIONS

In this section there is an outline of calculations of pion exchange processes with leading neutron production. Diagrams for Single (SπE) and Double (DπE) processes are presented in Fig.1. Form-factors F can be normalized to the low energy data [8, 9] and expressed as

$$F_\pi(\xi,t) = \frac{G^2_{\pi^+pn}}{16\pi^2}\frac{-t}{(t-m_\pi^2)^2}e^{2bt}\xi^{1-2\alpha_\pi(t)} \qquad (1)$$

where

$$-t \approx \frac{\vec{q}^{\,2}+m_p^2\xi^2}{1-\xi}, \qquad \frac{G^2_{\pi^+pn}}{8\pi} = 13.75 \qquad (2)$$

$$\alpha_\pi(t) \approx 0.9(t-m_\pi^2), \quad b\sim 0.3\ GeV^{-2} \qquad (3)$$

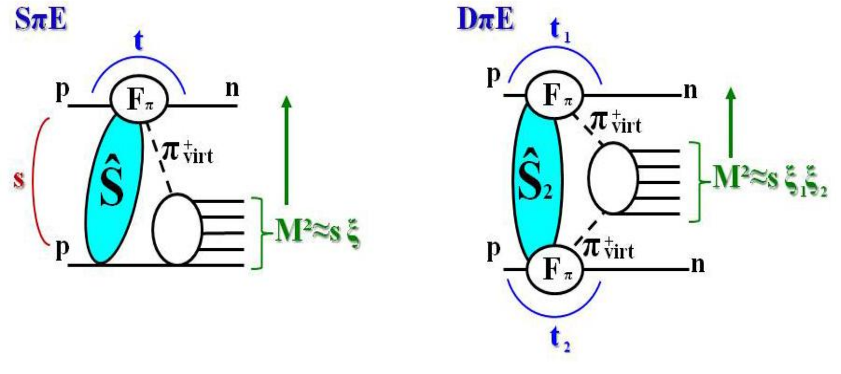

Fig. 1: Diagrams of Single (SπE) and Double (DπE) pion exchanges.

Absorbtive corrections Ŝ can be estimated in some model for high energy diffractive scattering [10, 11]. Final formulas for cross-sections look as follows

$$\frac{d\sigma_{S\pi E}}{dt\,d\xi} = F_\pi(\xi,t)\,S\left(\frac{s}{s_0},\xi,t\right)\sigma_{\pi^+p}(s\,\xi), \tag{4}$$

$$\frac{d\sigma_{D\pi E}}{dt_1 dt_2\, d\xi_1 d\xi_2} = F_\pi(\xi_1,t_1)F_\pi(\xi_2,t_2)\,S_2\left(\frac{s}{s_0},\xi_{1,2},t_{1,2}\right)\sigma_{\pi^+\pi^+}(s\,\xi_1\xi_2), \tag{5}$$

Here

$$\sigma_{\pi^+p}(s\,\xi) \cong \sigma_{\pi^+_{virt}p}(s\,\xi;t)|_{t\to 0}, \qquad \sigma_{\pi^+\pi^+}(s\,\xi_1\xi_2) \cong \sigma_{\pi^+_{virt}\pi^+_{virt}}(s\,\xi_1\xi_2;t_{1,2})|_{t_{1,2}\to 0},$$

since the main contribution comes from pions with very low virtualities less than 0.3 GeV^2.

1.2 EXTRACTION PROCEDURE

How to extract π p and π π cross-sections from the data on SπE and DπE? The exact procedure is the following:

$$\sigma_{\pi^+p}(s\,\xi) = \lim_{t\to m_\pi^2} \sigma_{\pi^+p}(s\,\xi)\frac{S\left(\frac{s}{s_0},\xi,t\right)t}{m_\pi^2} = \lim_{t\to m_\pi^2} E(\xi,t)\,\frac{d\sigma_{S\pi E}}{dt\,d\xi} \tag{6}$$

$$\begin{aligned}\sigma_{\pi^+\pi^+}(s\,\xi_1\xi_2) &= \lim_{t_{1,2}\to m_\pi^2} \sigma_{\pi^+\pi^+}(s\,\xi_1\xi_2)\frac{S_2\left(\frac{s}{s_0},\xi_{1,2},t_{1,2}\right)t_1 t_2}{m_\pi^4}\\ &= \lim_{t_{1,2}\to m_\pi^2} E(\xi_1,t_1)E(\xi_2,t_2)\,\frac{d\sigma_{D\pi E}}{dt_1 dt_2\, d\xi_1 d\xi_2}\end{aligned} \tag{7}$$

$$E(\xi,t) = -\frac{(t-m_\pi^2)^2}{m_\pi^2}\,\frac{16\pi^2}{G^2_{\pi^+pn}e^{2bt}\xi^{1-2\alpha_\pi(t)}} \tag{8}$$

The behavior of corresponding functions is shown in the Fig.2. When t is equal to mass of a pion squared, we have no absorbtion at all (S=1) and extracted cross-sections are model independent.

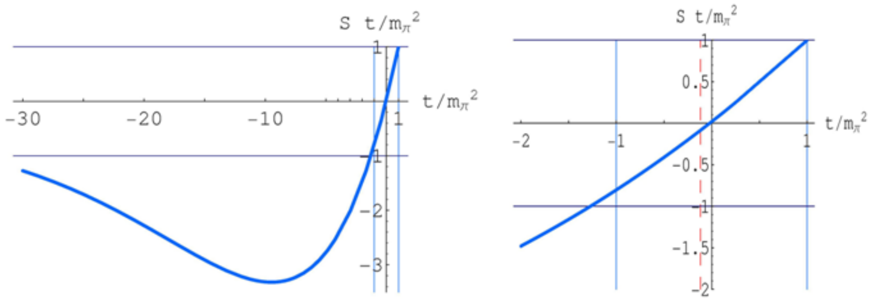

Fig. 2: Function from the expression (6) at fixed ξ=0.05. The boundary of the physical region t≈-m^{2}ξ^2/(1-ξ) is represented by vertical dashed line.

But our experience shows that the real situation is more complicated, especially from the experimental point of view. It is rather difficult to measure transverse momentum of a fast leading neutron, we can only get some restrictions on t from the acceptance of detectors. We propose to use the model dependent integrated method

$$\tilde{S}(s,\xi) = \int\limits_{t_{min}}^{t_{max}} dt\; S\left(\frac{s}{s_0},\xi,t\right) F_\pi(\xi,t), \qquad \sigma_{\pi^+p}\left(M^2_{\pi p}\right) = \frac{\frac{d\sigma_{S\pi E}}{d\xi}}{\tilde{S}(s,\xi)},\;\; \xi \approx \frac{M^2_{\pi p}}{s} \tag{9}$$

$$\tilde{S}_2(s,\xi_0) = \int_{-y_0}^{y_0} dy \int_{t_{min}}^{t_{max}} dt_1\, dt_2\, S_2\left(\frac{s}{s_0},\xi_0 e^{\pm y},t_{1,2}\right) F_\pi(\xi_0 e^{y},t_1) F_\pi(\xi_0 e^{-y},t_2), \tag{10}$$

$$\sigma_{\pi^+\pi^+}(M^2_{\pi\pi}) = \frac{\frac{d\sigma_{D\pi E}}{d\xi_0}}{\tilde{S}_2(s,\xi_0)},\;\; \xi_0 \approx \frac{M_{\pi\pi}}{\sqrt{s}}, y_0 = ln\frac{\xi_{max}\sqrt{s}}{M_{\pi\pi}} \tag{11}$$

Models for rescattering give us theoretical errors. If we have the data on p p and anti-p p total and elastic cross-sections, these uncertainties could be reduced to the errors of the data. For example, without LHC measurements at 10 TeV theoretical uncertainties can be estimated only from model predictions and can reach 20%. At 900 GeV these errors are low, since we have precise measurements up to Tevatron energies about 1.9 TeV.

Our method (9) with very narrow t interval was applied to extraction of π+ p total cross-sections at low energies [10]. It was shown in [10] that extracted points are close to the real data and four different model predictions which is the clear signal of the validity of our method.

2.1 EXPERIMENTAL TOOLS AND MONTE-CARLO SIMULATION

We propose to use Zero Degree Calorimeters (ZDC) for neutron detection [10, 11]. Unfortunately, at the present design we can measure only the energy of neutrons and there are some possibilities to have restrictions on transverse momentum from ZDC acceptance. For example, we have t<1.2 GeV² at 10 TeV and t<0.3 GeV² at 900 GeV, which is rather optimistic for the integral procedures (9)-(11). For the modernization of ZDC we could use THGEM plates [12, 13], which are cheap, fast, have high radiation resistance and allow transverse measurements.

Monte-Carlo generator for single and double charge exchanges was written (MonChER1.0 [14]) to estimate signal (π exchanges) and background (ρ, a_2 exchanges; Single, Double and Central Diffraction; Minimum Bias) events. Of course, there are also uncertainties when we use PYTHIA for hadronization and diffraction simulation, and we assume no pile-up events at first low luminosity runs of the LHC. Since SπE and DπE have rather large cross-sections about1.5 mb and 0.2 mb at 10 TeV, statistics is high enough.

In principle, it is possible to suppress all the backgrounds in the case when we extract total π+ p and π+ π+ cross-sections without transverse momentum measurements by the use of ZDC acceptance and CMS detectors only. In the Table 1 you see the summary of simulations at 900 GeV. We use the following selections:

CE1: {N_f >0 & N_b =0 or N_f =0 & N_b >0}, CE2: N(hits in EBARREL)>100,

DCE1: {N_f >0 & N_b >0}, DCE2: N(hits in EBARREL)>20,

where N_f (N_b) are number of forward (backward) neutrons detected by ZDCs. By the use of double selections CE1&CE2 (DCE1&DCE2) we can reach S:B~10-30 at 900 GeV. In this case Minimum Bias is suppressed in the ZDC acceptance by the effective cut t<0.3 GeV² and single selections CE1 (DCE1), at higher energies the situation is not so good. Diffraction is reduced by CE2 (DCE2) cuts. These cuts lead to rather low efficiencies, 1% (CE) and 4.6% (DCE), but it is compensated by the high rates. It is possible to extract π+ p (π+ π+) cross-sections in the energy range 200-600 (50-350) GeV by the use of (6)-(9).

Table 1
Signal to background ratios for different selections for Charge Exchange (CE) and Double Charge Exchange (DCE) processes.

CE selection	**CE**	**DCE**	**Diffraction**	**MB**	**$(S:B)_{CE}$**
NO	1	0.08	10.3	19.5	1:30
CE1	1	0.11	0.44	0.07	10:6
CE1&CE2	1	0.07	0	0.007	100:8
DCE selection	**DCE**	**CE**	**Diffraction**	**MB**	**$(S:B)_{DCE}$**
NO	1	12.5	128.8	243.8	1:385
DCE1	1	0.1	0.04	0	100:14
DCE1&DCE2	1	0.03	0	0	100:3

Another source of background comes from reggeon exchanges, which is dominated after all the above selections. Recent simulations for 900 GeV and 7 TeV energies show contributions of ρ and a_2 exchanges (see Table 2). Now we can use only ZDC acceptance to reduce these backgrounds. In this case at 900 GeV we have $N_{\rho+a2}/N_\pi$=3% (19.3%) for CE (DCE).

Table 2
Contributions of reggeon exchanges to CE and DCE processes.

E, TeV	$\sigma_{\rho+a2}/\sigma_\pi$, % CE (DCE)	ZDC acceptance (%)			$N_{\rho+a2}/N_\pi$, %
		SπE (DππE)	SρE (DρπE)	Sa_2E ($Da_2\pi E$)	
0.9	10.7 (47.3)	27.8 (4.8)	10.8 (0.28)	6.7 (0.65)	3 (19.2)
7	8.2 (43.4)	86.6 (99.6)	86.8 (99.8)	86.7 (99.7)	8.2 (43.4)

SUMMARY

In this short review we have considered the possibility to extract π+ p and π+ π+ cross-sections from the data on leading neutrons at the LHC. The main conclusion is the following: at present time we have some chances to extract total π+ p cross-sections from the first LHC data at 900 GeV (7 TeV). Preliminary analysis shows the presence of CE events in the data.

We have studied some other issues like the extraction of elastic π+ p and π+ π+ cross-sections [11]. It is more delicate task, since we have to detect exclusive channel with fast neutrons and pions with very large pseudorapidities greater than 9. So, there is no signal in CMS detectors, and we can use it to suppress backgrounds. Good signal to background ratio can be obtained only with t and η cuts. For a pion detection it is possible to use FSCs [11, 15]. There are some other prospects like inclusive jet measurements for the extraction of pion PDFs.

We have to stress, however, that detectors like ZDC need modernization to improve the level of our study.

ACKNOWLEDGEMENTS

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