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Compilation of cross sections for proton–nucleus interactions at the HERA energy

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Abstract

This work compiles information concerning the total, inelastic and diffractive cross sections for proton–nucleus interactions. The values are fitted together with the expression $\sigma = \sigma_0 A^{\alpha}$, where A is the target atomic mass number. Also discussed is the amplitude of the diffractive components of the inelastic cross section.

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1. Introduction

HERA-B is a fixed target experiment using the HERA 920 GeV proton beam to study the proton–nucleus interactions in wire targets of different materials (carbon, alluminium, titanium and tungsten) placed in the beam halo [1]. The physics program includes the measurement of the $b\bar{b}$ and strange particles production cross sections [2,3].

The measurement of any cross section implies the knowledge of the produced luminosity. In HERA-B the produced luminosity is extracted from the inelastic cross section, simply counting the number of inelastic events (N) in minimum bias data:

$$L = \frac{N}{\sigma_{\text{inel}}}, \tag{1}$$

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where σ_{inel} is the inelastic cross section. The total cross section can be divided into two parts, the elastic and the inelastic cross sections:

$$\sigma_{\text{total}} = \sigma_{\text{elast}} + \sigma_{\text{inel}}. \tag{2}$$

All the measurements of nucleon-nuclei interaction cross section were done a long time ago and at lower center-of-mass energies than the HERA proton beam. As the cross section dependence with the energy and the differences between neutron, proton and anti proton cross sections are expected to be small for high energy beams, the results obtained by previous experiments were compiled and fitted together.

2. Previous experiments

The published papers present results obtained with very different detectors, beams, technologies and experimental techniques, but the results are in general compatible. The cross sections, both total and inelastic, follow the dependence in the target atomic mass number A (for $A > 6$):

$$\sigma = \sigma_0 A^{\alpha}. \tag{3}$$

In Fig. 1 an example is shown of a fit to previously published data [4] of σ_{total} versus A with the above mentioned expression (the first parameter is σ_0 and the second α). The fit

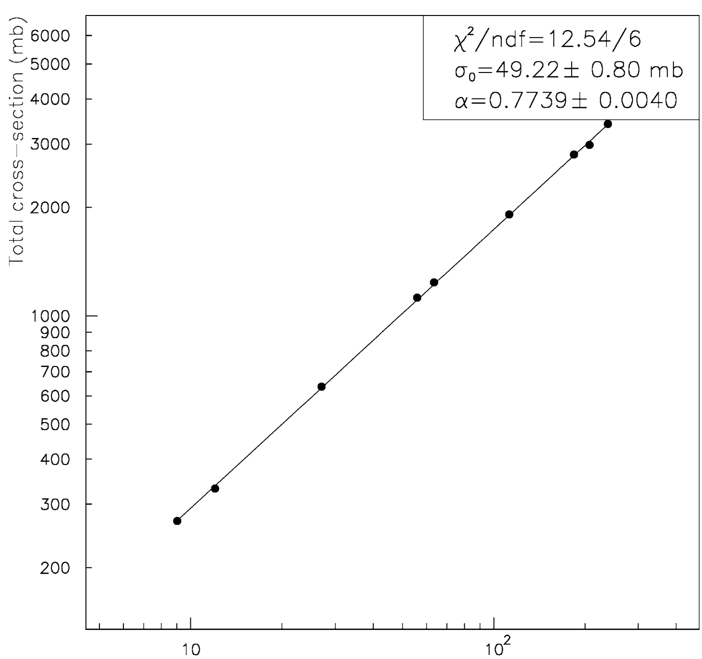

Fig. 1. Fit of the total cross section obtained by Murthy et al. [4], with a proton beam of 80 GeV in different target materials, as a function of the atomic mass number A, with the expression in the text.

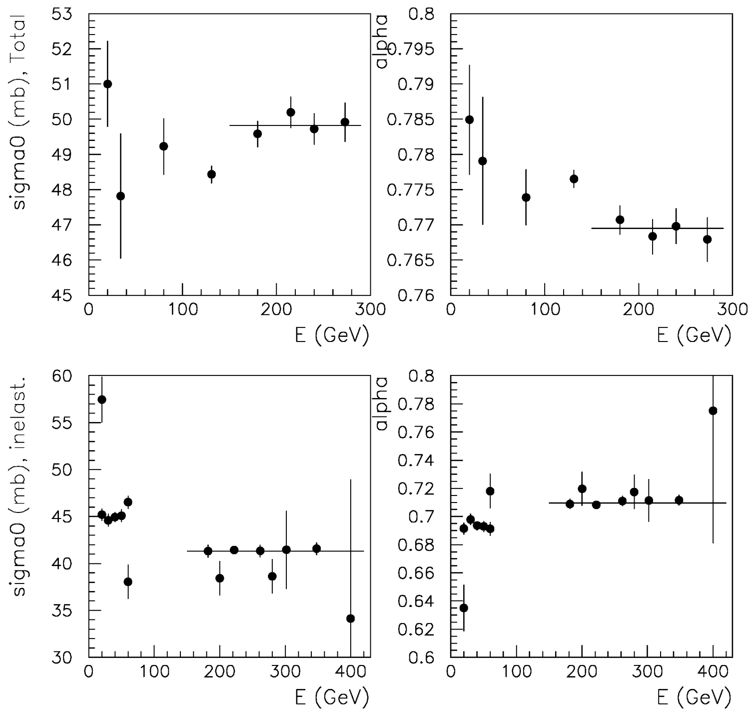

Fig. 2. Top row: fit parameters of the total cross section as a function of A, by different experiments, σ_0 (left) and α (right), as a function of the beam energy. Bottom row: the same for the inelastic cross section. The line is the result of a fit with a constant, for a beam energy greater than 150 GeV.

is good, as in most of the other measurements. In Fig. 2 are plotted the values obtained for σ_0 and α by different experiments, as a function of the beam energy, for the total and the inelastic cross sections. For a beam energy greater than 150 GeV, the parameters are compatible, within the errors, with a constant.

The experimental values of the total and inelastic cross sections, obtained by different authors, for beam energies greater than 150 GeV are plotted in Fig. 3, and fitted with the above mentioned expression. The cross sections measured at different energies were scaled to the HERA proton energy (920 GeV) using the total hadronic cross section dependence on the center of mass energy, as given by the review of particle properties [12],

$$\sigma_{pp} = X_{pp} s^{\epsilon} + Y_{1pp} s^{-\eta_1} - Y_{2pp} s^{-\eta_2}, \tag{4}$$

where s is the square of the center of mass energy (in GeV^2), $\epsilon = 0.093(2)$, $\eta_1 = 0.358(15)$, $\eta_2 = 0.560(17)$, $X_{pp} = 18.751(27)$ mb, $Y_{1pp} = 63.58(26)$ mb and $Y_{2pp} = 35.46(34)$ mb. The extrapolation errors are very small, and the cross section changes by only 7% when the beam energy increases from 150 to 920 GeV.

The fit results from Fig. 3 are:

$$\sigma_{\text{total}} = (52.86 \pm 0.23)\ \text{mb}\, A^{0.7694 \pm 0.0012}, \tag{5}$$

$$\sigma_{\text{inel}} = (43.55 \pm 0.40)\ \text{mb}\, A^{0.7111 \pm 0.0011}. \tag{6}$$

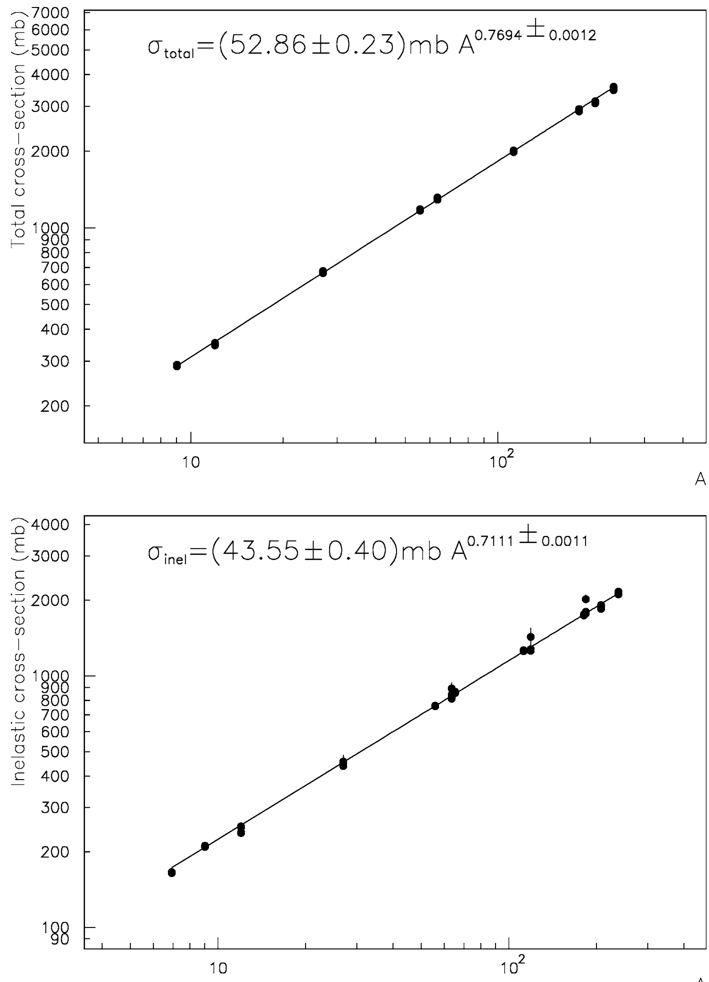

Fig. 3. Fit of the total (top) and inelastic (bottom) cross section as a function of the atomic mass number A, measured by different experiments (with beam energy greater than 150 GeV), scaled to the HERA proton energy, see text for details.

The compilation was done with results from the references [4–11]. The results from [10,11] were not considered due to the low energy of the beam. Table 1 shows a brief description of the experiments beam and targets.

3. Diffractive cross section

The inelastic cross section can be further divided into a diffractive component and a non-diffractive part (which will be called the minimum bias component, σ_{MB}). The diffractive

Table 1
Previous experiments beams and targets

Reference	Beam	E_{beam} (GeV)	Targets	Cross section	Year
Fumuro et al. [7]	p	400	Al, Cu, Sn, W	Inel.	1979
Carroll et al. [6]	$\pi, K, p, \bar{p}$	60–280	Li, C, Al, Cu, Sn, Pb	Inel.	1979
Bellettini et al. [5]	p	20	^{6}Li, ^{7}Li, Be, C, Al, Cu, Pb, U	Tot. and Inel.	1966
Murthy et al. [4]	n	30–300	H, D, Be, C, Al, Fe, Cu Cd, W, Pb, U	Tot.	1975
Roberts et al. [9]	n	160–375	H, D, Be, C, Al, Fe, Cu Zn, Cd, Ta, W, Pb, U	Tot. and Inel.	1979
Denisov et al. [8]	$\pi^\pm$, $K^\pm$, p, $\bar{p}$	20–60	Li, Be, C, Al, Cu, Sn, Pb, U	Inel.	1973
Atkinson et al. [11]	n	5	H, C, Al, Cu, Sn, Pb	Tot. and Inel.	1961
Bobchenko et al. [10]	p, π^-	5-9	Be, B, C, F, Mg, Al, S, Cu, Ti V, Fe, Cu, Cd, Sn, Ta, Pb, U	Inel.	1979

part can be further divided in a single diffractive (σ_{SD}) and a double diffractive (σ_{DD}) parts, and the single diffractive part into target (σ_{TSD}) and beam (σ_{BSD}) components:

$$\sigma_{\text{inel}} = \sigma_{\text{MB}} + \sigma_{\text{diff.}} = \sigma_{\text{MB}} + \sigma_{\text{SD}} + \sigma_{\text{DD}} = \sigma_{\text{MB}} + \sigma_{\text{TSD}} + \sigma_{\text{BSD}} + \sigma_{\text{DD}}. \tag{7}$$

The single diffractive events are of the type $pA \to pX$ (TSD) or $pA \to XA$ (BSD). In the single diffractive dissociation the beam particle or the target nucleus remain in its ground state, receiving onlys a small recoil momentum while the other is excited and dissociates.

The HELIOS experiment [13] measured the target single diffractive cross section with a 450 GeV proton beam and different target materials (Be, Al and W), and obtained the expression, from a fit to the data points of Be, Al and W,

$$\sigma_{\text{TSD}} = (3.84 \pm 0.94)\ \text{mb}\ A^{0.35\pm0.02}. \tag{8}$$

The integration was done over t (momentum transfer) and $0 < (1 - x_F) < 0.075$ (x_F is the Feynman variable), so it can be slightly underestimated (about 10%) because it does not include the full x_F range.

EHS/NA22 Collaboration [14,15] measured the nucleus target dissociation in π^+ and K^+ collisions with p, Au and Al at 250 GeV. They fit σ_{TSD} as a function of A with the usual expression, and they found

$$\sigma_{\text{TSD}} = (1.68 \pm 0.18)\ \text{mb}\ A^{0.579\pm0.061} \tag{9}$$

which is in disagreement with the HELIOS results, in particular the value of α.

Batista et al. [16] produced a phenomenological analysis of the diffractive dissociation of nuclei in proton–nucleus and meson–nucleus collisions ($hA \to hX$) and they were able to explain the different atomic mass dependences as measured by HELIOS ($\alpha = 0.35 \pm 0.02$) and EHS/NA22 ($\alpha = 0.58 \pm 0.06$) with the effect of using different beam hadrons. The results are shown in Fig. 2 of [16].

Covolan and Montanha [17] also developed a phenomenological model to describe hadron diffractive dissociation, starting with the generalized optical theorem. They presented an extension of the model for diffractive dissociation of nuclei in proton–nucleus interactions, which describes well the HELIOS results.

Ranft and Roesler [18] studied the single diffractive hadron–nucleus interactions in the framework of the dual parton model. They implemented the incoherent diffractive hadron–nucleus interaction, $hA \to hA^*$ and $hA \to h^*A$, into the Monte Carlo event generator DTUNUC, which are treated as mainly peripheral processes, confirmed by measurements. The cross section obtained was overestimated, as compared with HELIOS, but this may happen due to considering both TSD and BSD processes where HELIOS only measured TSD.

Frankfurt et al. [19] studied the phenomenon of color coherence in QCD and its implications for hard and soft processes with nuclei. They demonstrated that it plays an important role in the processes of soft diffraction of nuclei, and calculate an expression for the diffractive cross section for BSD ($hA \to XA$), which is compared with the available (very limited) experimental data (see Fig. 19 in [19]). The result agrees well with the measurement by Boos et al. [20] of the coherent production, in interactions of 400 GeV protons in emulsion nuclei ($A \sim 47$). Several experiments measured the partial diffractive cross sections for particular channels, as [21], but these measurements are not useful for us.

4. Conclusions

A compilation of published results in nucleon–nucleus interaction cross section was presented together with the result of its fit.

Considering the compiled and fitted values of the cross sections, the values of the different components of the cross sections for the HERA-B target materials are presented in Table 2. The DD component is of the order of $\sim \sigma_{\mathrm{TSD}} \cdot \sigma_{\mathrm{BSD}}/\sigma_{\mathrm{inel}}$ and then it is small. The BSD is poorly measured in hadron–nuclei interactions, but it seems to be of the same order of magnitude as the TSD; the calculations by Frankfurt et al. [19] give an idea of the order of magnitude of the BSD cross section. The sum of the TSD cross section (as measured by HELIOS) with the BSD cross section (as calculated by Frankfurt et al. [11]) is about 2–5% of the total cross section and about 4–7% of the total inelastic cross section.

The measurement of the luminosity in HERA-B uses the inelastic cross section, but it has to be corrected for the diffractive component, for which the HERA-B acceptance is small (diffractive events have low multiplicity and high or low rapidity tracks). Due to its small amplitude and acceptance, it can be subtracted from the inelastic cross section (the

Table 2
Measured and/or fitted values of the cross section components for pA interactions in the HERA-B target materials

σ (mb)	C	Al	Ti	W
σ_{Tot}	358.0 ± 1.7	667.4 ± 3.1	1037.6 ± 4.9	2922 ± 14
σ_{Inel}	255.0 ± 1.8	453.5 ± 3.3	681.7 ± 4.9	1775 ± 13
σ_{TSD}	9.2 ± 2.3	12.2 ± 3.1	14.9 ± 3.8	23.8 ± 6.3
σ_{BSD}	8.4 ± 1.7	15.0 ± 3.0	21.7 ± 4.3	41.2 ± 8.2
σ_{MB}	237.4 ± 3.4	426.3 ± 5.4	645.1 ± 7.5	1710 ± 17

DD component was neglected). The minimum bias cross section is shown in the last line of Table 2.

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