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Extrapolation of hadron cross sections to supercollider energies within the two-component dual parton model

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In the framework of a two-component dual parton model we perform a fit to $p\bar{p}$ total, elastic, inelastic, and single-diffractive cross-section data at collider energies. The fit including diffractive data gives better results using the supercritical soft Pomeron instead of the critical one. Because of the different structure function parametrizations the predictions of cross sections at supercollider energies are subject to large uncertainties.

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Measurements of total and elastic cross sections at the Fermilab Tevatron [1] give the opportunity to confront the old dual parton model (DPM) [2] with these new high-energy data and to adjust the parameters of the Pomeron. In the present two-component DPM the rise of the cross sections is due to two mechanisms: (i) soft hadronic collisions described by the Pomeron and (ii) semihard collisions (production of minijets) as described by the QCD parton model. The first cross-section fit using the model together with a supercritical soft Pomeron was performed in 1987 by Capella, Tran Thanh Van, and Kwiecinski [3]. At the same time a fit with a critical soft Pomeron was investigated by Durand and Pi [4]. Further details of this model have been worked out [5] and a detailed description of inelastic hadronic reactions up to the energies of present colliders has been obtained using the model with a supercritical Pomeron [6,7]. Including the triple-Pomeron graph, the loop Pomeron graph, and a two-channel eikonal formalism, this model was extended to describe single- and double-diffractive cross sections [7].

In the past few years new deep inelastic scattering data have become available. Collins [8] discussed a new conjecture about the behavior of the structure functions at small x, a $x^{-1.5}$ singularity instead of conventional x^{-1} singularity. Kwiecinski, Martin, Stirling, and Roberts [9] used the new data and ideas to perform new fits of the structure functions using three different assumptions about shadowing corrections [10] for x values smaller than 10^{-4}.

The model can be used to predict the total, elastic, and diffractive cross sections and the properties of hadronic particle production at the multi-TeV energies of future supercolliders. It was shown recently by Pertermann, Bopp, and Ranft [11] that many properties of multihadron production at supercollider energies sensitively depend on the choice of the hadronic structure functions used to calculate the semihard scattering input cross sections.

Here we will investigate the influence of these structure functions on cross sections. We will perform new fits to the cross-section data including single-diffractive cross sections with different structure functions and in addition using either the supercritical or critical soft Pomeron.

The two-component DPM has been described in detail in [7]. We refer to this paper and give here only a short account on how to calculate the total, elastic, and the single-diffractive cross sections. Hadron-hadron interaction at higher energies is governed by Pomeron exchange. In the model the important driving components are the soft Pomeron and a hard Pomeron.

The input cross section σ_s for the soft Pomeron is $\sigma_s = g^2 s^\Delta$ with the effective exponent $\Delta = \alpha(0) - 1$. For the supercritical Pomeron we have $\Delta > 0$; for the critical Pomeron it is $\Delta = 0$. In the impact parameter representation the eikonal function is written as

$$\chi_s(B,s) = (\sigma_s / 8\pi b_s) \exp(-B^2/4b_s) , \tag{1}$$

where $b_s = b_0 + 2\alpha'(0)\ln(s)$. The value $b_0 = 1.37$ mb and the slope $\alpha'(0) = 0.093$ are regarded as fixed and well determined by the evolution of the nuclear slope of the differential cross section.

The hard QCD input cross section σ_h is calculated using lowest-order QCD parton-parton scattering cross sections as described in [6]. We use different parton structure functions and a minimal parton transverse momentum cutoff of 2 GeV/c. In the impact parameter representation we get the same dependence as in Eq. (1) with σ_s and b_s replaced by σ_h and b_h. The slope of the hard component is assumed to be constant [12] $b_h = b_0$.

The model treats high and low mass diffraction in a separate way. In order to describe high mass single and double diffraction we use as a further input the triple-

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Pomeron eikonal function $\chi_{TP}(B,s)$ and the loop Pomeron eikonal function $\chi_l(B,s)$ as in [7]. These functions depend on the triple-Pomeron coupling Γ as described in [7].

The low mass diffraction is introduced by an excitation coupling constant λ using a two-channel eikonal formalism. This coupling constant appears in all graphs resulting in low mass diffractive dissociation of one or both scattered particles (for the complete formulas we refer to [7]).

Both the bare soft and the bare hard cross section rise faster than $\ln^2 s$ and a generalized eikonal unitarization scheme has to ensure that the total cross section does not violate the Froissart bound [13]. Within the unitarization scheme the interesting cross sections are obtained as follows: We define the eikonal function

$$\chi(B,s)=\chi_s(B,s)+\chi_h(B,s)-\chi_{TP}(B,s)-\chi_l(B,s)$$

and the impact parameter representation of the scattering amplitude

$$a(B,s)=\tfrac{1}{2}i(1-e^{-\chi(B,s)}) . \tag{2}$$

From there the cross sections can be calculated in the standard way [7,14].

Eventually we have to adjust the following free parameters by an appropriate fit to high-energy data: the proton Pomeron coupling g; the soft Pomeron intercept $\alpha(0)$; the excitation coupling constant λ. Furthermore, since we use only lowest-order QCD perturbation theory we multiply the minijet cross section σ_h with a K factor in the range of $1.5<K<2.0$. For the triple-Pomeron coupling which enters $\chi_{TP}(B,s)$ and $\chi_l(B,s)$ a fixed value ($\Gamma=0.42$) of [7] is used, when diffraction is taken into account.

The fit is done separately for various choices of structure functions used to calculate the hard input cross sections. Five different parametrizations of the structure functions [9,15] are considered: an old parametrization Martin-Roberts-Stirling (MRS [set 1]) [15] and a new parametrization Kwiecinski-MRS (KMRS [B0]) [9] which contain a x^{-1} behavior for small x; new parametrizations KRMS [B-], KMRS[B-5], and KMRS[B-2] [9] which contain a $x^{-1.5}$ behavior for small x without, with weak, and with strong shadowing, respectively.

We performed the fits using the data of total, elastic, inelastic, and single-diffractive cross sections [1,16] in a range of $\sqrt{s}$ from 60 GeV up to 1.8 TeV. To compare the results of our fits with Pomeron parameters obtained previously [3,4,5,17] we first performed fits (numbered 1) which ignore the diffractive data. Our final fits (numbered 2) use the single diffractive cross sections in addition to the cross sections before.

For the fits denoted 1a we treated $\alpha(0)$, g, and λ as free parameters. In Table I(a) we show the fitted parameter sets together with the appropriate χ^2 divided by the degrees of freedom. We got good fits for all considered structure functions. In Fig. 1(a) we compare the fitted cross sections with the data. We observe that the predictions for the cross sections at supercollider energies depend sensitively on the choice of the parton distributions,

TABLE I. (a) Fit of type 1a to all available cross sections, excluding single-diffractive cross sections. The obtained values of $\alpha(0)$ always correspond to a supercritical Pomeron. (b) The two best fits of type 1b to all available cross sections, excluding single-diffractive cross sections. The intercept of the soft Pomeron is set to $\alpha(0)=1$. The couplings Γ and λ were set to zero to get a fit comparable with other groups [4,17].

(a)

Structure function	g^2 (mb)	$\alpha(0)$	λ	$\frac{\chi^2}{N_{DF}}$
MRS[set 1]	43.4±3.0	1.052±0.005	0.22±0.09	0.6
KMRS[B0]	52.2±2.5	1.040±0.003	0.39±0.07	0.6
KMRS[B-]	41.7±0.5	1.061±0.001	0.33±0.03	1.5
KMRS[B-5]	40.9±2.3	1.063±0.005	0.34±0.06	1.3
KMRS[B-2]	38.9±3.5	1.062±0.006	0.10±0.05	0.8

(b)

Structure function	g^2 (mb)	$\alpha(0)$	$\frac{\chi^2}{N_{DF}}$
KMRS[B0]	53.7±0.4	1.0	1.5
KMRS[B-2]	54.8±0.4	1.0	3.4

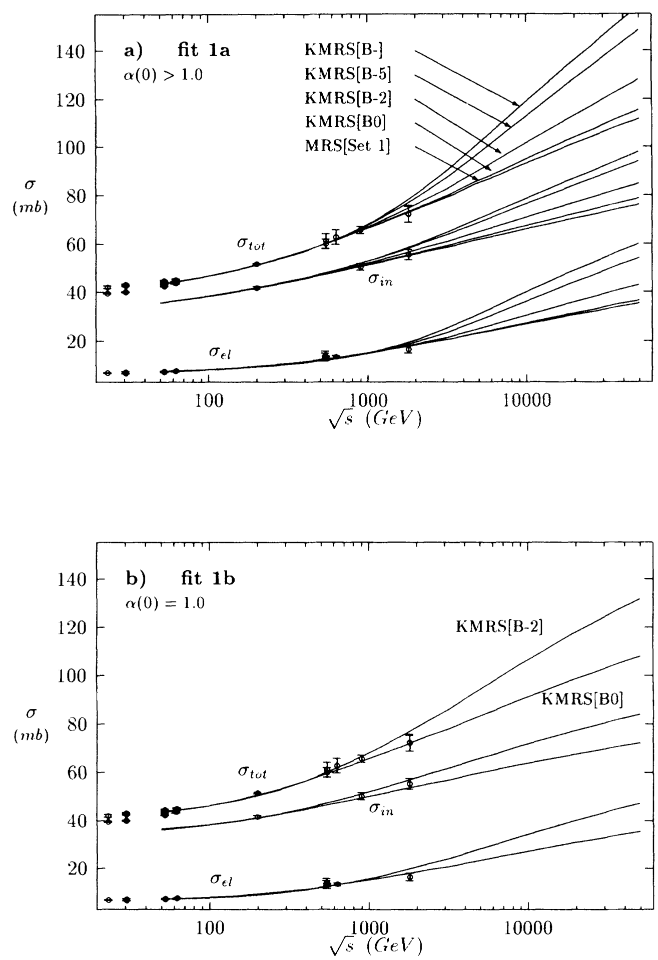


FIG. 1. Comparison of the fits of (a) type 1a and (b) 1b to the data (σ_{tot}, σ_{in}, and σ_{el}) excluding diffractive cross sections.

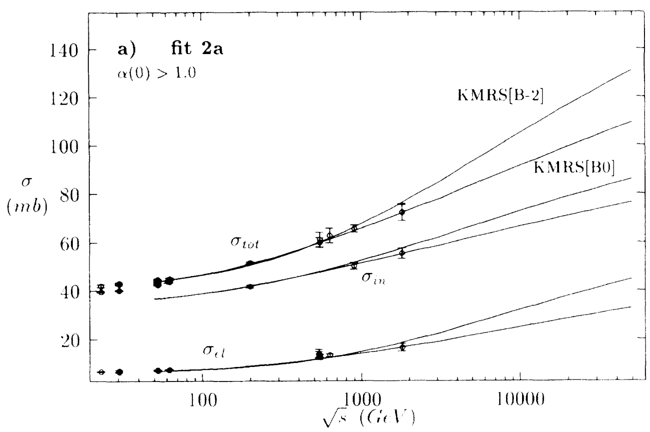
TABLE II. (a) Fits of type 2a to all available cross sections, including single-diffractive cross sections. The obtained value of $\alpha(0)$ always corresponds to a supercritical soft Pomeron. (b) The two best fits of type 2b to all available cross sections, including single-diffractive cross sections. The intercept of the soft Pomeron was fixed at the critical value $\alpha(0)=1$.

(a)

Structure function	g^2 (mb)	$\alpha(0)$	λ	$\frac{\chi^2}{N_{\rm DF}}$
MRS[set 1]	55.2±1.4	1.057±0.003	0.66±0.03	3.1
KMRS[B0]	63.5±1.3	1.037±0.001	0.60±0.01	1.3
KMRS[B-]	61.7±1.5	1.048±0.003	0.66±0.02	2.7
KMRS[B-5]	63.1±1.5	1.045±0.003	0.65±0.02	2.5
KMRS[B-2]	66.1±1.3	1.038±0.004	0.63±0.02	1.6

(b)

Structure function	g^2 (mb)	$\alpha(0)$		$\frac{\chi^2}{N_{\rm DF}}$
KMRS[B-5]	83.1	1.0	0.24	10.3
KMRS[B-2]	79.5	1.0	0.10	7.0



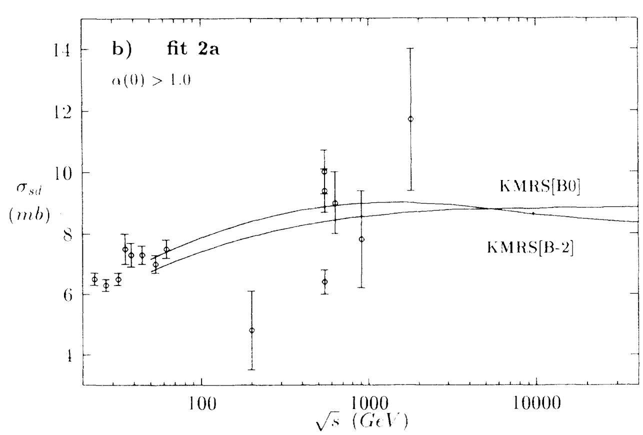


FIG. 2. Cross sections (a) $\sigma_{\rm tot}$, $\sigma_{\rm el}$, and $\sigma_{\rm in}$ and (b) $\sigma_{\rm SD}$, compared with the two-component DPM for our final two best fits of type 2a. The fit of type 2a involves a supercritical Pomeron.

TABLE III. Predictions of the total cross sections $\sigma_{\rm tot}$ (mb) for CERN Large Hadron Collider and Superconducting Super Collider energies resulting from our fits of type 2a (critical Pomeron with diffractive cross sections). The measured value of $\sigma_{\rm tot}$ at $\sqrt{s}=1.8$ TeV is 72.1±3.3 mb [1].

Structure function/$\sqrt{s}$	1.8 TeV	16 TeV	40 TeV
MRS[set 1]	71±3	97±4	108±4
KMRS[B0]	72±2	96±2	106±3
KMRS[B-]	79±2	134±2	157±3
KMRS[B-5]	79±2	129±3	150±3
KMRS[B-2]	75±2	109±3	124±3

but the large differences between the hard input cross sections (see [11], at $\sqrt{s}=40$ TeV σ_h differs from 165 to 2620 mb) are greatly reduced by the unitarization. The high mass and low mass diffractive cross sections contribute in this fit to the total cross section, but we note that the parameter obtained in the fit (especially $\lambda<0.4$) would not give a good description of the single-diffractive cross section.

For the fits denoted 1b we used the critical soft Pomeron to describe the soft processes fixing $\alpha(0)=1$. To compare our fit directly with the results of [4,17] concerning the critical Pomeron we also set the triple-Pomeron coupling $\Gamma=0$ and the low mass diffraction coupling $\lambda=0$. In this case we have neither high mass diffractive processes nor low mass diffractive dissociation included. Therefore we have fitted only the parameter g. Only for the structure functions KMRS[B0] and to a less extent KMRS[B-2] we found a good description of the total, elastic and inelastic cross sections. In Table I(b) we summarize the resulting parameters for the two acceptable fits. These fits are compared to the data in Fig. 1(b). From this restricted fit we conclude in accord with [4] and [17] that it is possible to describe the total and elastic cross sections with minijets together with a critical soft Pomeron.

In the fits denoted 2a, now including the diffractive data, we treated the parameters $\alpha(0)$, g, and λ as free. As seen in Table II(a) we found some difference in the quality of the fit results concerning different structure functions. The best fits are obtained either with the conventional parametrization KMRS[B0] or the reasonably strong shadowed structure function KMRS[B-2]. We compare these two results to the cross section data in Fig. 2. The resulting fit parameters are listed in Table II(a).

In the fit denoted 2b we demand a critical soft Pomeron now including the diffractive cross sections in the fit. This corresponds to a model analogous to [4,17] but with a diffractive component defined as in [7]. Only the parameters g and λ were fitted. It was not possible to get an acceptable fit with any of the structure functions. We got χ^2 values significantly higher than in the fits obtained using the supercritical Pomeron. In Table II(b) we give the parameters of the two best fits.

To conclude, with the present experimental cross section data we get acceptable fits with all parton structure functions used. Therefore none of these structure functions can be excluded at present. It follows that the extrapolations of total, elastic, and diffractive cross sections are subject to large uncertainties which we illustrate in Table III. These uncertainties could only be reduced after the measurement of the structure functions, in particular the gluon structure function, at small x values at the DESY *ep* collider HERA.

Regarding the uncertainty, the following point is remarkable. If one believes that the structure function is presumably steeper than $1/x$, our second best fit which uses the KMRS[B-2] structure function is preferred. This fit gives a cross-section extrapolation which agrees with the extrapolation due to Block, Halzen, and Margolis [18] within the uncertainties.

Another conclusion concerns the Pomeron. Including diffractive cross sections we get only acceptable fits using the supercritical Pomeron. On face value, this seems tc exclude the critical pomeron. However, considering the large uncertainties even of the present data of single-diffractive cross sections we feel that such a conclusion might become definite only with more accurate data on single-diffractive cross sections and after more versatile attempts to implement diffraction in critical Pomeron models.

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