

σ_{tot}^{pp} Estimations at very High Energies

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Abstract

Proton-proton total cross sections (σ_{tot}^{pp}) are measured with present day high energy colliders up to 2 TeV in the centre-of-mass of the system (10^{15} eV in the laboratory). Several parameterizations, very succesful at low energies, can then be used to extrapolate the measured values and get estimations of cross sections to higher energies (10^{17} eV). On the other hand, from very high energetic cosmic rays ($\geq 10^{17}$ eV) and using some approximations, it is possible to get a value for σ_{tot}^{pp} from the knowledge of the σ_{tot}^{p-air} at these energies. Here we use a phenomenological model to estimate σ_{tot}^{pp} at cosmic ray energies. On the basis of regression analysis we show that the predictions are highly sensitive to the employed data for extrapolation. Using data at 1.8 TeV our extrapolations for σ_{tot}^{pp} are incompatible with most of cosmic ray results.

1 Hadronic σ_{tot}^{pp} from accelerators and cosmic rays:

Since the first results of the Intersecting Storage Rings(ISR) at CERN arrived in the 70s, it is a well-established fact that σ_{tot}^{pp} rise with energy (Amaldi et al, 1973; Amendiola et al, 1973). The CERN $S\bar{p}pS$ Collider found this rising valid for σ_{tot}^{pp} as well (Bozzo et al, 1984). Several parametrizations (purely theoretically, empirical or semi-empirical based) fit pretty well the data. All of them agree that at the energies (14 TeV in the centre-of-mass) of the future CERN Large Hadron Collider (LHC) or higher the rise will continue. A thoroughful discussion on these problems may be found in Matthiae (1994), and Proc. VIIIth Workshop on EDS (1997).

For our purposes we have chosen a parametrization used by experimentalists to fit their data (Augier et al, 1993a). The most interesting piece is the one controlling the high-energy behaviour, given by a $\ln^2(s)$ term, in order to be compatible, asymptotically, with the Froissart-Martin bound (Froissart, 1961). The parametrization assumes σ_{tot}^{pp} and $\sigma_{tot}^{p\bar{p}}$ to be the same asymptotically. It has shown its validity predicting, from the ISR data (23-63 GeV in the center of mass), the σ_{tot}^{pp} value found at the $S\bar{p}pS$ Collider (546 GeV), one order of magnitude higher in energy (Amaldi et al, 1977; Bozzo et al 1984).

With the same well-known technique and using the most recent results it is possible to get estimations for σ_{tot}^{pp} at the energies of the LHC and beyond (Augier et al, 1993a). These estimations, together with our present experimental knowledge for both σ_{tot}^{pp} and $\sigma_{tot}^{p\bar{p}}$ are summarized in Table 1 and plotted in figure 1. We have also plotted the cosmic ray experimental data (Honda et al, 1993; Baltrusatis et al, 1984). The curve is the result of the fit described in (Augier et al, 1993a).

The increase in σ_{tot} as the energy increases is clearly seen. The main conclusion from this analysis based on accelerators results are the predictions $\sigma_{tot} = 109 \pm 8$ mb at $\sqrt{s} = 14$ TeV and $\sigma_{tot} = 130 \pm 13$ mb at $\sqrt{s} = 40$ TeV.

\sqrt{s} (TeV)		σ_{tot} (mb)
0.55	Fit	61.8 ± 0.7
	UA4	62.2 ± 1.5
	CDF	61.5 ± 1.0
0.90	Fit	67.5 ± 1.3
	UA5	65.3 ± 1.7
1.8	Fit	76.5 ± 2.3
	E710	72.8 ± 3.1
	CDF	80.6 ± 2.3
14	Fit	109.0 ± 8.0
40	Fit	130.0 ± 13.0

Table 1: σ_{tot}^{pp} data from high-energy accelerators. Fits values from Augier et al (1993a).

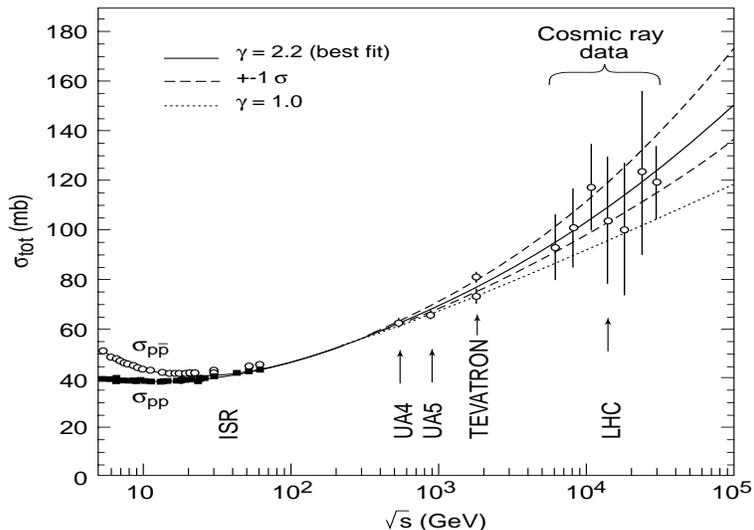


Figure 1: σ_{tot}^{pp} and σ_{tot}^{pp} with the prediction of Augier et al (1993a).

Cosmic rays experiments give us σ_{tot}^{pp} as derived from cosmic ray extensive air shower (EAS) data (Wibig and Sobczyńska, 1998). The primary interaction involved in EAS is proton-air; what it is determined through EAS is the p -inelastic cross section, σ_{inel}^{p-air} . But the determination of σ_{inel}^{p-air} (or its relation with σ_{tot}^{pp}) is model dependent. A theory for nuclei interactions must be used. Usually is Glauber's theory (Glauber et al 1956). The AKENO Collaboration has quoted, from their results for a center-of-mass energy in the interval 6-25 TeV, $\sigma_{tot}^{pp} = 133 \pm 10$ mb at $\sqrt{s} = 40$ TeV. On the other hand, an analysis of the Fly's Eye experiment results [?] claims $\sigma_{tot}^{pp} = 175^{+40}_{-27}$ mb at $\sqrt{s} = 40$ TeV. It has been argued by Nikolaev that this contradiction in the values of both experiments disappears if, in the AKENO analysis, the σ_{inel}^{p-air} is identified with an absorption cross section (Nikolaev, 1993). He obtains $\sigma_{tot}^{pp} = 160 - 170$ mb at $\sqrt{s} = 40$ TeV, which solves the discrepancy.

2 Are Accelerators and Cosmic Ray σ_{tot}^{pp} Compatible?:

The results from cosmic ray experiments, from the previous analysis, have been made compatible among themselves. But they have shifted away from the estimations obtained with extrapolations using the data from accelerators.

The validity of these extrapolations, of course, may be discussed. But we would like to point to the fact that most extrapolations (as those using a $\ln(s)$ term to control the high-energy behaviour)

predict even lower values for σ_{tot}^{pp} . That makes the difference bigger.

We have tackled the problem using the multiple-diffraction model (Glauber et al, 1956; Glauber and Velasco, 1984). In a recent version of it (Martini and Menon, 1997) the parameters of the model are determined fitting the pp accelerator data in the interval $13.8 \leq \sqrt{s} \leq 62.5$ GeV. The σ_{tot}^{pp} values obtained when extrapolated to higher energies seem to confirm the above quoted compatible values of the cosmic ray experiments. That would imply the extrapolation cherished by experimentalists is wrong. But this approach predicts a value for σ_{tot}^{pp} at the Fermilab Collider (1.8 TeV) which seems to be very high: 91.6 mb (no error quoted). In table 1 we see that the measured σ_{tot}^{pp} at that energy is much smaller. It may be argued that σ_{tot}^{pp} and $\sigma_{tot}^{\bar{p}p}$ are different at high energies. This is the ‘‘Odderon hypothesis’’, which has been very much weakened recently (Auger et al, 1993b).

Taking this into account, in our multiple-diffraction analysis it is assumed the same behaviour for σ_{tot}^{pp} and $\sigma_{tot}^{\bar{p}p}$ at high energy. Results are summarized in table 2 and plotted in figure 2.

\sqrt{s} (TeV)	σ_{tot} (mb)	σ_{upp} (mb)	σ_{low} (mb)	σ_{tot} (mb)	σ_{upp} (mb)	σ_{low} (mb)
0.55	69.39	77.77	62.0	62.24	63.56	60.98
0.9	78.04	89.62	67.87	67.94	69.35	66.59
1.8	91.74	108.64	76.99	76.44	78.14	74.84
14	143.86	182.45	110.32	104.17	108.57	99.85
40	177.23	230.32	130.95	118.99	125.98	111.75

(a)

(b)

Table 2: Predicted σ_{tot}^{pp} from fitting accelerator data at (a) $\sqrt{s} \leq 62.5$ GeV; (b) including data at 546 GeV and 1.8 TeV.

Our results indicate that, if in the phenomenological multiple-diffraction approach we limit our fitting calculations to the accelerator domain $\sqrt{s} \leq 62.5$ GeV, the extrapolation to high energies is in complete agreement with the analysis carried out by Nikolaev (Nikolaev, 1993), and with the experimental data of the Fly’s Eye (Gaisser et al, 1987) and the Akeno (Honda et al, 1993) collaborations, because their quoted errors fall within the error band of our extrapolations. That is, such an extrapolation produces an error band so large at cosmic ray energies that any cosmic ray results become compatible with results at accelerator energies. However, if additional data at higher accelerator energies are included and then the error band obviously narrows, things change. This can be seen in figure 2b, where we have considered data at 0.546 TeV and 1.8 TeV (according to Table 1), in which case the predicted values of σ_{tot}^{pp} from our extrapolation at $\sqrt{s} = 40$ TeV, $\sigma_{tot}^{pp} = 119 \pm 7$ mb are much lower than those illustrated in figure 2a, and clearly incompatible with the reinterpreted Fly’s Eyes and Akeno results by several standard deviations. Concerning the quoted error bands we employed the so called forecasting technique of regression analysis (Mendenhall and Sincich, 1996).

3 Conclusions:

We conclude in this preliminary work that, when all experimental available data is taking into account, the estimated values for σ_{tot}^{pp} obtained from extrapolation from present high-energy accelerators and those obtained from cosmic ray experiments are incompatible in the region around $\sqrt{s} = 40$ TeV.

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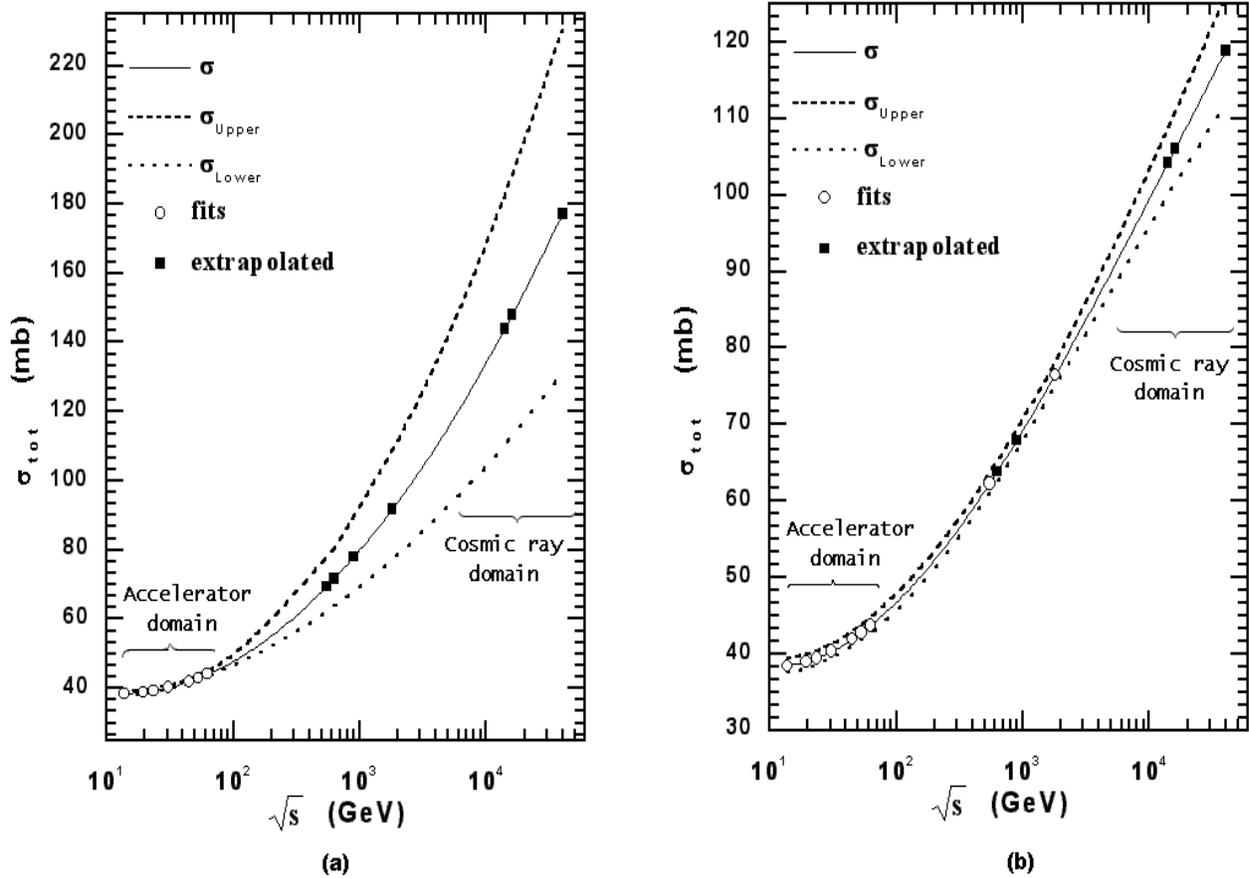


Figure 2: Predictions (black squares) of σ_{tot}^{pp}
 (a) data at $\sqrt{s} \leq 62.5$ GeV; (b) including data at 546 GeV and 1.8 TeV (open circles).

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