

$\sigma_{tot}^{pp}$  ESTIMATIONS AT VERY HIGH ENERGIES

J. Velasco<sup>c</sup>, J. Pérez-Peraza<sup>a</sup>, A. Gallegos-Cruz<sup>b</sup>  
 M. Alvarez-Madrigoal<sup>a</sup>, A. Faus-Golfe<sup>c</sup>, A. Sánchez-Hertz<sup>a</sup>

<sup>a</sup>*Instituto de Geofísica, UNAM, 04510, C.U., Coyoacan, Mexico D.F.. MEXICO*

<sup>b</sup>*Ciencias Básicas, UPIICSA, I.P.N., Te 950, Iztacalco, 08400, Mexico D.F, MEXICO*

<sup>c</sup>*IFIC, Centro Mixto CSIC-UV, Dr. Moliner 50, 46100 Burjassot, Valencia, SPAIN*

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**Abstract**

Proton-proton total cross sections ( $\sigma_{tot}^{pp}$ ) 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  $\sigma_{tot}^{pp}$  from the knowledge of the  $\sigma_{tot}^{p-air}$  at these energies. Here we use a phenomenological model to estimate  $\sigma_{tot}^{pp}$  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  $\sigma_{tot}^{pp}$  are incompatible with most of cosmic ray results.

**Hadronic  $\sigma_{tot}^{pp}$  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  $\sigma_{tot}^{pp}$  rise with energy [1], [3]. The CERN  $S\bar{p}pS$  Collider found this rising valid for  $\sigma_{tot}^{\bar{p}p}$  as well [4]. 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 [8], [9].

For our purposes we have chosen a parametrization used by experimentalists to fit their data [7]. 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 [5]. The parametrization assumes  $\sigma_{tot}^{pp}$  and  $\sigma_{tot}^{\bar{p}p}$  to be the same asymptotically. It has shown its validity predicting, from the ISR data (23-63 GeV in the center of mass), the  $\sigma_{tot}^{\bar{p}p}$  value found at the  $S\bar{p}pS$  Collider (546 GeV), one order of magnitude higher in energy [2], [4].

With the same well-known technique and using the most recent results it is possible to get estimations for  $\sigma_{tot}^{pp}$  at the energies of the LHC and beyond [7]. These estimations, together with our present experimental knowledge for both  $\sigma_{tot}^{pp}$  and  $\sigma_{tot}^{\bar{p}p}$  are summarized in Table 1 and plotted in fig. 1. We have also plotted the cosmic ray experimental data [13], [14]. The curve is the result of the fit describe in [7].

$\sqrt{s}$ (TeV)		$\sigma_{tot}$ (mb)
0.55	Fit	$61.8 \pm 0.7$
	UA4	$62.2 \pm 1.5$
	CDF	$61.5 \pm 1.0$
0.90	Fit	$67.5 \pm 1.3$
	UA5	$65.3 \pm 1.7$
1.8	Fit	$76.5 \pm 2.3$
	E710	$72.8 \pm 3.1$
	CDF	$80.6 \pm 2.3$
14	Fit	$109 \pm 8$
40	Fit	$130 \pm 13$

Table 1:  $\sigma_{tot}^{pp}$  data from high-energy accelerators. Fits values from [7].

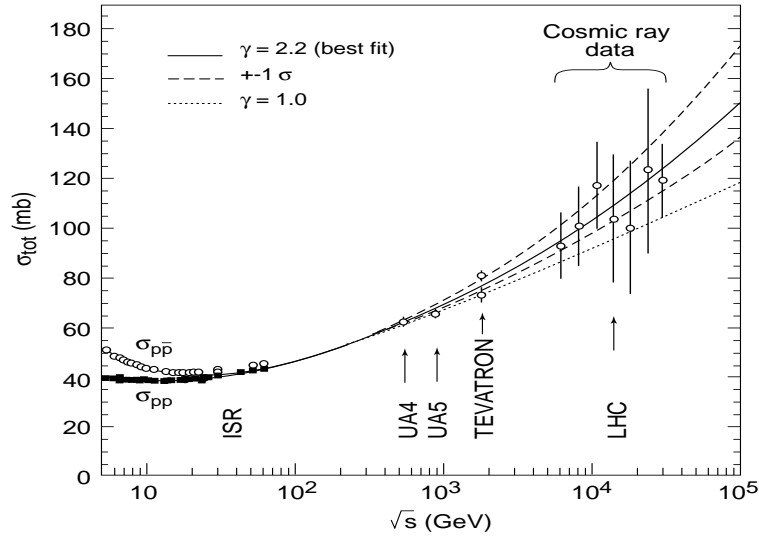


Figure 1:  $\sigma_{tot}^{pp}$  and  $\sigma_{tot}^{p\bar{p}}$  with the prediction of [7].

The increase in  $\sigma_{tot}$  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.

Cosmic rays experiments give us  $\sigma_{tot}^{pp}$  as derived from cosmic ray extensive air shower (EAS) data [10]. The primary interaction involved in EAS is proton-air; what it is determined through EAS is the  $p$ -inelastic cross section,  $\sigma_{inel}^{p-air}$ . But the determination of  $\sigma_{inel}^{p-air}$  (or its relation with  $\sigma_{tot}^{pp}$ ) is model dependent. A theory for nuclei interactions must be used. Usually is Glauber's theory [11]. 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 [15] claims  $\sigma_{tot}^{pp} = 175_{-27}^{+40}$  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  $\sigma_{inel}^{p-air}$  is identified with an absorption cross section [16]. He obtains  $\sigma_{tot}^{pp} = 160 - 170$  mb at  $\sqrt{s} = 40$  TeV, which solves the discrepancy.

## Are accelerators and cosmic ray $\sigma_{tot}^{pp}$ 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  $\sigma_{tot}^{pp}$ . That makes the difference bigger.

We have tackled the problem using the multiple-diffraction model [11], [12]. In a recent version of it [17] 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  $\sigma_{tot}^{pp}$  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  $\sigma_{tot}^{pp}$  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  $\sigma_{tot}^{pp}$  at that energy is much smaller. It may be argued that  $\sigma_{tot}^{pp}$  and  $\sigma_{tot}^{p\bar{p}}$  are different at high energies. This is the ‘‘Odderon hypothesis’’, which has been very much weakened recently [6].

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

$\sqrt{s}$ (TeV)	$\sigma_{tot}$ (mb)	$\sigma_{upp}$ (mb)	$\sigma_{low}$ (mb)	$\sigma_{tot}$ (mb)	$\sigma_{upp}$ (mb)	$\sigma_{low}$ (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  $\sigma_{tot}^{pp}$  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 [16], and with the experimental data of the Fly’s Eye [15] and the Akeno [13] 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 fig.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  $\sigma_{tot}^{pp}$  from our extrapolation at  $\sqrt{s} = 40$  TeV,  $\sigma_{tot}^{pp} = 119 \pm 7$  mb are much lower than those illustrated in fig. 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 [18].

We conclude that, when all experimental available data is taking into account, the estimated values for  $\sigma_{tot}^{pp}$  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 mb.

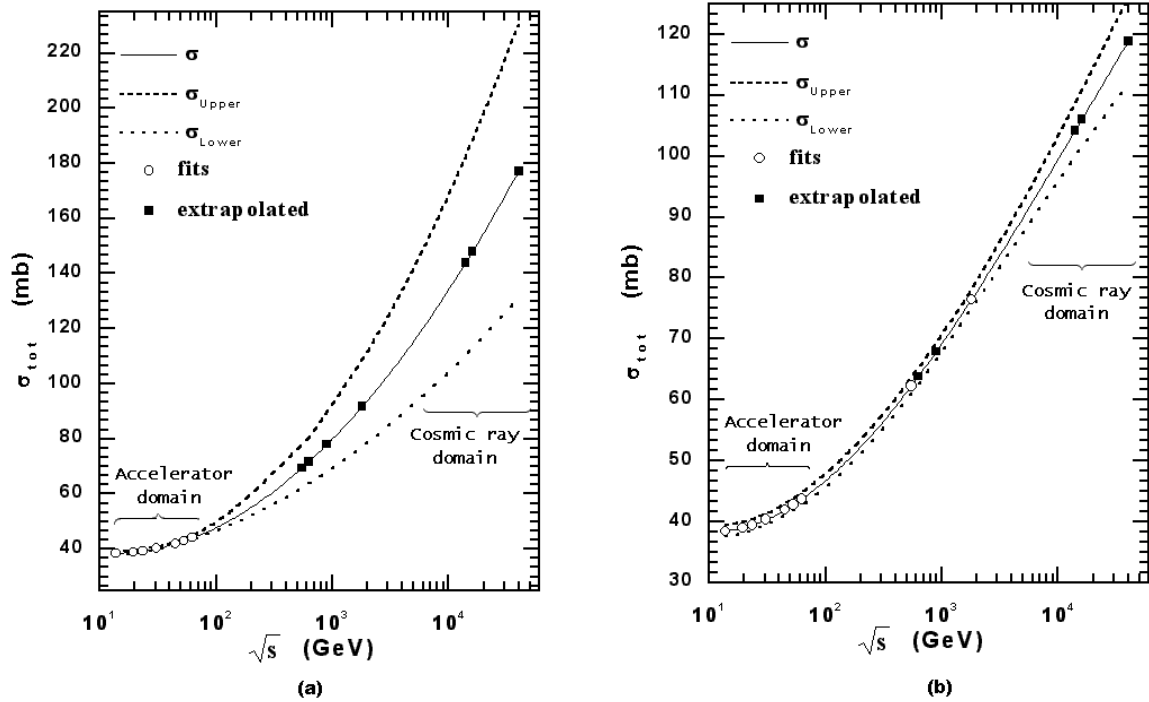


Figure 2: Predictions (black squares) of  $\sigma_{tot}^{pp}$ : (a) data at  $\sqrt{s} \leq 62.5$  GeV; (b) including data at 546 GeV and 1.8 TeV (open circles).

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