Inelastic proton-air cross section in U.H.E.

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Abstract

We calculate the inelastic proton-air cross section σ_{in}^{p-air} (mb) by means of the Glauber model. As input, we use acceletator experimental data on the total proton-proton cross section. We present also a paramentrization with the energy for this cross section and compare with cosmic ray experimental data and with Monte Carlo simulation.

In this paper we determine the inelastic $p-air$ and $\bar{p}-air$ cross section in the Glauber framework (Glauber 1959; Glauber et al. 1970) using experimental data on the total pp and $\bar{p}p$ cross section (Caso et al. 1998) and compare with experimental data cross sections from Akeno Collab. (Honda et al. 1993), Fly's Eyes Collab. (Baltrusaitis et al. 1985) and EASTOP Collab. (Aglietta et al. 1998). In the Glauber model the relationship between the inelastic hadron-air cross section. The σ_{in}^{h-air} $(h \equiv p, \bar{p})$ and total hp cross section σ_{tot}^{hp} , is given by

$$\sigma_{in}^{h-air} = \int d^2b \left[1 - \exp[-\sigma_{tot}^{hp} A T(\mathbf{b})]\right] \tag{1}$$

where **b** is the impact parameter, $T(b)$ is the nuclear thikness,

$$T(b) = \int dz \rho(b,z) \tag{2}$$

given in terms of the nuclear distribution $\rho(b,z)$.

In order to calculate the nuclear thickness $T(b)$ we use here the Woods-Saxon model (Woods & Saxon 1954; Barrett & Jackson 1977) for the nuclear distribution which is given by

$$\rho(r) = \rho_o \left[1 + \exp[\frac{r - r_o}{a_o}\right]^{-1} (1 + \omega \frac{r^2}{r_o^2}) \tag{3}$$

where the factor $(1 + \omega\frac{r^2}{r_o^2})$ correspond to the Fermi parabolic distribution correction. The parameter ρ_o is a normalization factor derived by means of

$$\int d^3 r \rho(r) = 1 \tag{4}$$

The parameters r_o, a_o and ω can be derived from experimental data (Barrett & Jackson 1977) . Fitting the experimental data we have $r_o = 0.976 A^{1/3}$ fm , $a_o = 0.546$ fm , and for the parameter ω we have

$$\begin{array}{c} \omega = -0.25839, \quad if A \leq 40 \\ \omega = 0 \quad if A > 40 \end{array} \tag{5}$$

The total proton-proton and antiproton-proton cross sections are well known at low energies, but the highest energy data is undefined both from accelerator and cosmic ray point of views. The last accelerator data came from E710 (Abe et al. 1992) and CDF Collab. (Amos et al. 1994) and reported discrepant measurements of total anti-proton-proton cross section obtained at the Tevatron Collider ($\sqrt{s} = 1.8$ TeV). From cosmic ray measurements, the last data from wich one can derive nucleon-nucleon total cross section were reported by the Akeno Collab. (Honda et al. 1993) and EASTOP Collab. (Agliettan et al. 1998).

We calculate here the $\sigma_{in}^{h-air}(mb)$ using equation (1), and as input for $\sigma_{tot}^{h-p}(mb)$ we use accellerator experimental data (Caso et al. 1998). In Figure 1 we show the calculated $\sigma_{in}^{h-air}(mb)$ as function of p_{lab}. We also show in this figure the following fit for the inelastic $h - A$ cross section $(h \equiv p$ and $\bar{p})$

$$\sigma_{in}^{h-A} = \sigma_o(p_{lab}) A^{\alpha(p_{lab})} \tag{6}$$

where

$$\sigma_o(p_{lab}) = a_1 p_{lab}^{\epsilon} + a_2 p_{lab}^{-\eta} \tag{7}$$

and

$$\alpha(p_{lab}) = b_1(1 + \frac{1}{p_{lab}}) + b_2 p_{lab}^{\xi} \tag{8}$$

with $A = 14.5$. The values of the constants are given in Table 1. This parametrization, at the Tevatron energy, goes between the values of σ_{in}^{h-A} as calculated using the values of $\sigma_{tot}^{\bar{p}p}$ from E710 (Amos et al. 1992) and CDF (Abe et al. 1994) Collaborations, respectively.

reaction	a_1	a_2	ϵ	η	χ^2
pp	20.08 ± 2.11	27.51 ± 1.28	0.0852 ± 0.0029	-0.2045 ± 0.0092	3.21
$\bar{p}p$	39.34 ± 3.40	27.51 ± 1.28	0.0852 ± 0.0029	-0.2045 ± 0.0092	3.21

reaction	b_1	b_2	ξ	χ^2
pp	-0.19357 ± 0.01945	0.91999 ± 0.02093	-0.00534 ± 0.00022	2.08×10^{-3}
$\bar{p}p$	-0.19357 ± 0.01945	0.91999 ± 0.02093	-0.00934 ± 0.00097	2.08×10^{-3}

In Figure 2 we compare our calculated σ_{in}^{p-air} (mb) with results from Monte Carlo simulation in CORSIKA Code (Knapp et al 1996). Our calculation is in agreement with results from the hadron dual parton model (HDPM). In this figure we also show the values of σ_{in}^{p-air} (mb) as presented by the Akeno Collab. and the values as derived by Bellandi et al (Bellandi et al 1997) assuming single-diffractive and non diffractive contributions to the hadronic flux in the atmosphere.

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References

Abe, F. *et al.* (CDF Collab.) 1994 - Phys. Rev. **D 50** 5550.
Aglietta, M. *et al.* (EASTOP Collab.) 1998
Amos, N.A. *et al.* (E710 Collab.) 1992 - Phys. Rev. Lett. **68** 2433.
Baltrusaitis, R.M. (Fly's Eyes Collab.) 1985 - Nucl. Instrum. and Meth. **A 240**, 410.
Barrett, R.C. & Jackson, D.F. 1977 - Nuclear Sizes and Structure, (Reading: Clarendon Press, Oxford).
Bellandi, J. *et al.* 1997 - J. of Phys. G: Nuclear and Particle Physics **23**, 125.
Caso, C. *et al.* (Particle Data Group) 1998 - European J. Physics **3C**.
Fletcher, R.S. *et al.* 1994 - Phys. Rev. **D 50**, 5710.
Gaisser
Glauber, R.J. 1959 - Lect. Theor. Phys. Vol. 1, Edited by W. Britten and L.G. Dunhan (Reading: Interscience, NY).
Glauber, R.J. *et al.* 1970 - Nucl. Phys. **B 12**, 135.
Hara T. *et al* 1983 - Phys. Rev. Lett. **50** 2058.
Honda M. *et al* (Akeno Collab.) 1993 - Phys. Rev. Lett. **70** 525.
Kalmykov, N.N. & Ostapchenki, S.S. 1993 - Phys. At. Nucl. **56**, 346.
Knapp, J., Heck, D., Ostapchenko, S.S., Schatz, G. 1996 (Kascade Collab.)- "Comparison of Hadronic Interaction Models used in Air Shower Simulations and of their Influence on Shower Development and Observables" - (Draft, July 31).
Mielke H. H. *et al* (Kascade Collab.) 1993 - Proc. $23^{\rm th}$ ICRC (Calgary, 1993) **4**, 155.

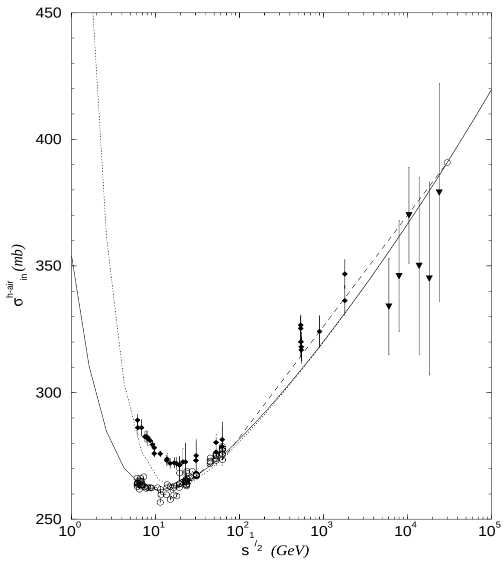

Figure 1: Open cicle is $p - air$ inelastic cross section. Close diamond is $\bar{p} - air$ inelastic cross section. Solid line is our paramentrization to σ_{in}^{p-air} (mb). Dot line is our parametrization to $\sigma_{in}^{\bar{p}-air}$ (mb). Down triangle is Akeno data with Bellandi correction (Bellandi et al. 1997). Open diamond is EASTOP (Aglietta et al. 1998). Star is Fly's Eyes data (Baltrusaitis et al. 1985).

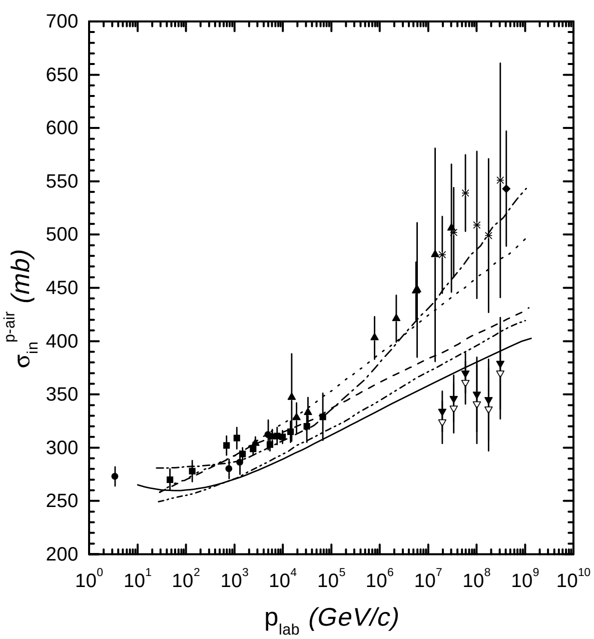

Figure 2: From Corsika Code: dot line is QGSJET model (Kalmykov et al. 1993) ; dash line is VENUS model (Werner 1993) ; dash-dot line is SIBYLL model (Fletcher et al. 1994) ; short-dash line is DPMJET model ; dash-dot-dot line is HDPM model. Solid line represent our paramentrization to . σ_{in}^{p-air} as in Figure 1. Solid square is from Yodh (Yodh et al. 1983). Solid circle from Mielke (Mielke et al. 1993; Mielke et al. 1994). Star from Akeno (Honda et al. 1993). Down triangle is Akeno data with Bellandi correction(Bellandi et al. 1997). Open diamond from EASTOP (Aglietta et al. 1998). Solid diamond from Fly's Eyes (Baltrusaitis et al. 1985).

Mielke H. H. *et al* (Kascade Collab.) 1994 - J. Phys. G: Nucl. Part. Phys. **20** 637.
Werner, K. 1993 - Phys. Report **232**, 87.
Woods, R.D. & Saxon, D.S. 1954 - Phys. Rev. **95**, 577.
Yodh, G.B. *et al.* 1983 - Phys. Rev. **D 27**, 1183.