Towards simulation of anti-ion – ion interactions

A. Galoyan, V. Uzhinsky   01.12.2010

For the first time a good description of Pbar D interactions was reached in the paper by **V. Franco, R.J. Glauber, Phys. Rev. 142 (1966) 1195**

High-energy deuteron cross-sections.

$$F_{fi}(\mathbf{q})=\langle f|\exp(\tfrac{1}{2}i\mathbf{q}\cdot\mathbf{s})\frac{ik}{2\pi}\int\exp(i\mathbf{q}\cdot\mathbf{b})\Gamma_n(\mathbf{b})d^{(2)}\mathbf{b}+\exp(-\tfrac{1}{2}i\mathbf{q}\cdot\mathbf{s})\frac{ik}{2\pi}\int\exp(i\mathbf{q}\cdot\mathbf{b})\Gamma_p(\mathbf{b})d^{(2)}\mathbf{b}$$

$$-\frac{ik}{2\pi}\int\exp(i\mathbf{q}\cdot\mathbf{b})\Gamma_n(\mathbf{b}-\tfrac{1}{2}\mathbf{s})\Gamma_p(\mathbf{b}+\tfrac{1}{2}\mathbf{s})d^{(2)}\mathbf{b}|i\rangle$$

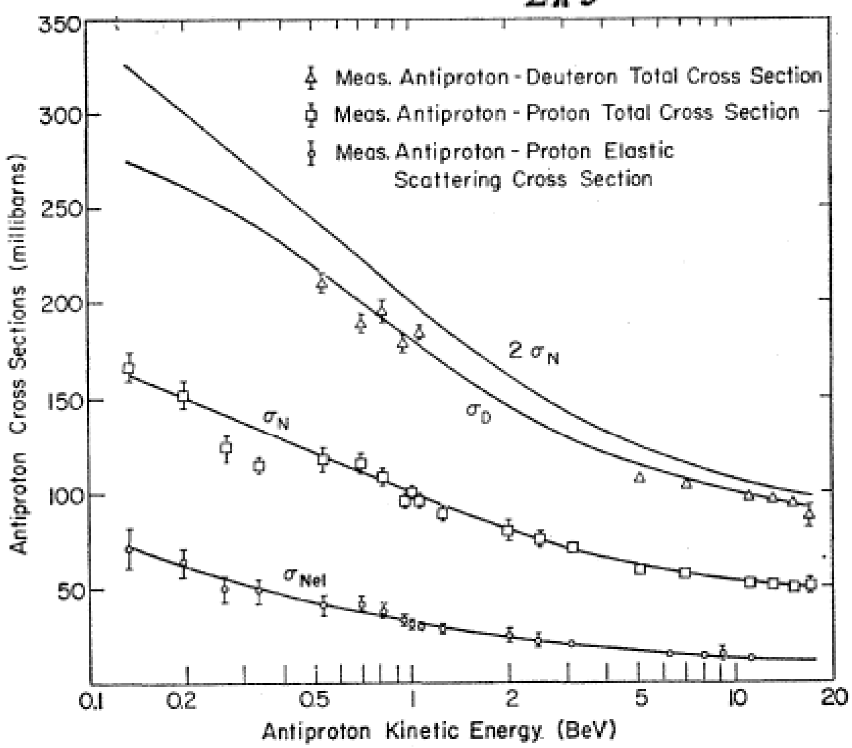


FIG. 1. The theoretical total cross sections for antiproton-deuteron collisions as a function of the incident antiproton laboratory kinetic energy. The deuteron wave function used is ϕ_3, Eq.

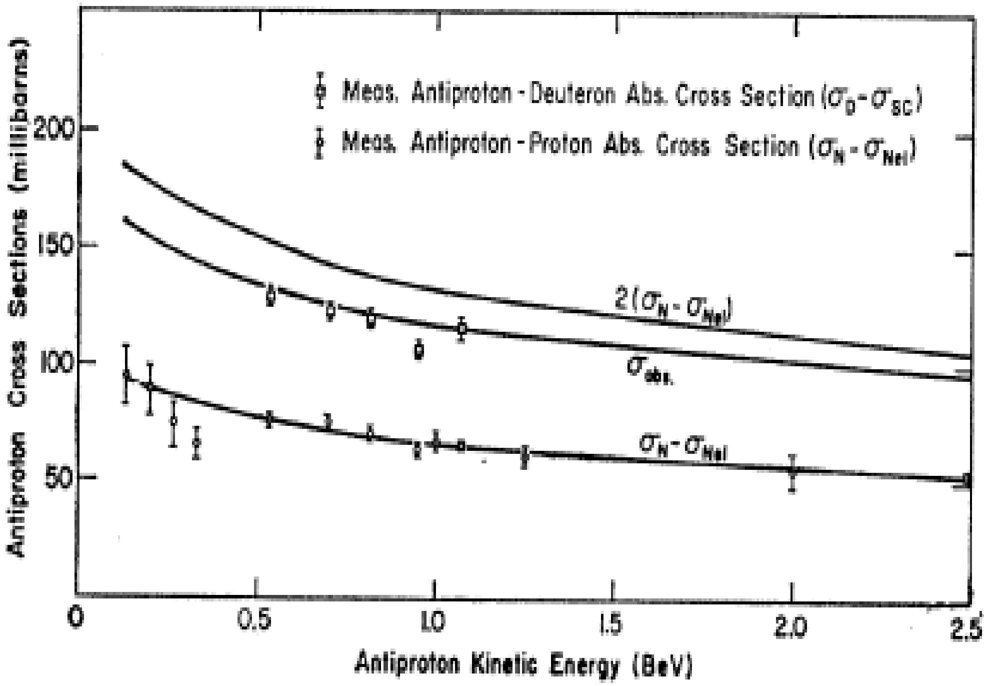


FIG. 2. The theoretical absorption cross section for antiproton-deuteron collisions as a function of the incident antiproton laboratory kinetic energy. The deuteron wave function used is ϕ_3, Eq.

Application of the Glauber theory to Pbar A interactions

Scattering Of Low-Energy Anti-Protons From Nuclei.
O.D. Dalkarov, V.A. Karmanov Nucl.Phys.A445:579-604,1985.

In the Glauber approximation the amplitude of elastic scattering from a nucleus A without Coulomb effects can be represented in the standard form [3])

$$F_{ii}(q) = ik \int_0^\infty \Gamma(b) J_0(qb) b \, \mathrm{d}b \,,$$

where $J_0(qb)$ is a Bessel function,

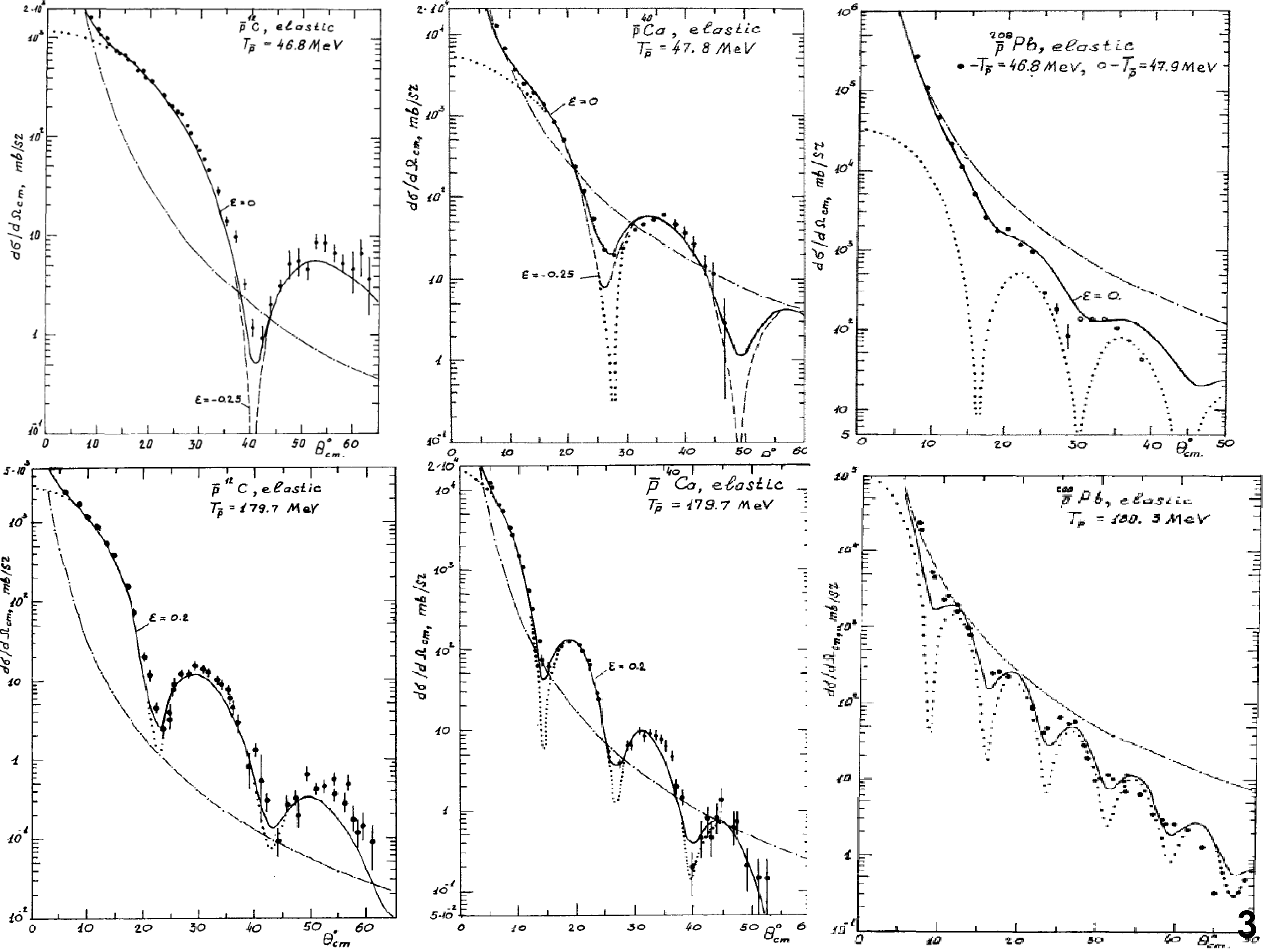
$$\Gamma(b) = 1 - \exp\left(i\chi_{\mathrm{N}}(b)\right) \,,$$

$$\chi_{\mathrm{N}}(b) = \frac{A}{2\pi k} \int \mathrm{e}^{-i\boldsymbol{q}\cdot\boldsymbol{b}} f_{\mathrm{N}}(q) \phi(q) \, \mathrm{d}^2 q \,,$$

$\phi(q)$ is the elastic nuclear form factor, parametrized (at $4 \leqslant A \leqslant 16$) in the form

$$\phi(q) = \left(1 - \frac{A-4}{6A} R^2 q^2\right) \exp\left(-\tfrac{1}{4} R^2 q^2\right) \,,$$

$$f_{\mathrm{N}}(q) = \frac{k\sigma(i+\varepsilon)}{4\pi} \mathrm{e}^{-Bq^2/2} \,.$$



$\bar{p}\,^{12}C$, elastic
$T_{\bar{p}} = 46.8$ MeV
$\varepsilon = 0$
$\varepsilon = -0.25$
$d\sigma/d\Omega_{cm}$, mb/sr
θ°_{cm}
$\bar{p}\,^{40}Ca$, elastic
$T_{\bar{p}} = 47.8$ MeV
$\varepsilon = 0$
$\varepsilon = -0.25$
$\bar{p}\,^{208}Pb$, elastic
• – $T_{\bar{p}} = 46.8$ MeV, o – $T_{\bar{p}} = 47.9$ MeV
$\varepsilon = 0.$
$\bar{p}\,^{12}C$, elastic
$T_{\bar{p}} = 179.7$ MeV
$\varepsilon = 0.2$
$\bar{p}\,^{40}Ca$, elastic
$T_{\bar{p}} = 179.7$ MeV
$\varepsilon = 0.2$
$\bar{p}\,^{208}Pb$, elastic
$T_{\bar{p}} = 180.3$ MeV

Theoretical Anti-Deuteron Nucleus Absorptive Cross-Sections

W.W. **Buck** , J.W. Norbury, L.W. Townsend, J.W. Wilson

Phys.Rev.C33:234-328,1986

From eikonal scattering theory, the absorption (reaction) cross section is

$$\sigma_{abs} = 2\pi \int_0^\infty \{1 - \exp[-2\,\mathrm{Im}\chi(b)]\} b\, db \ ,$$

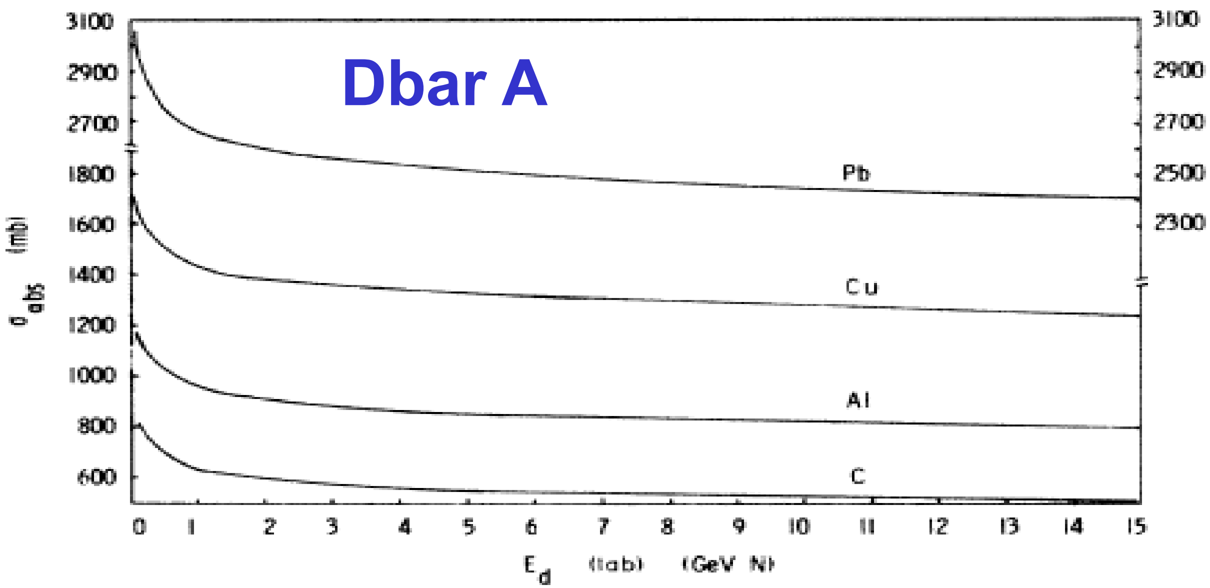
where the complex phase function is (with $\hbar = 1$)

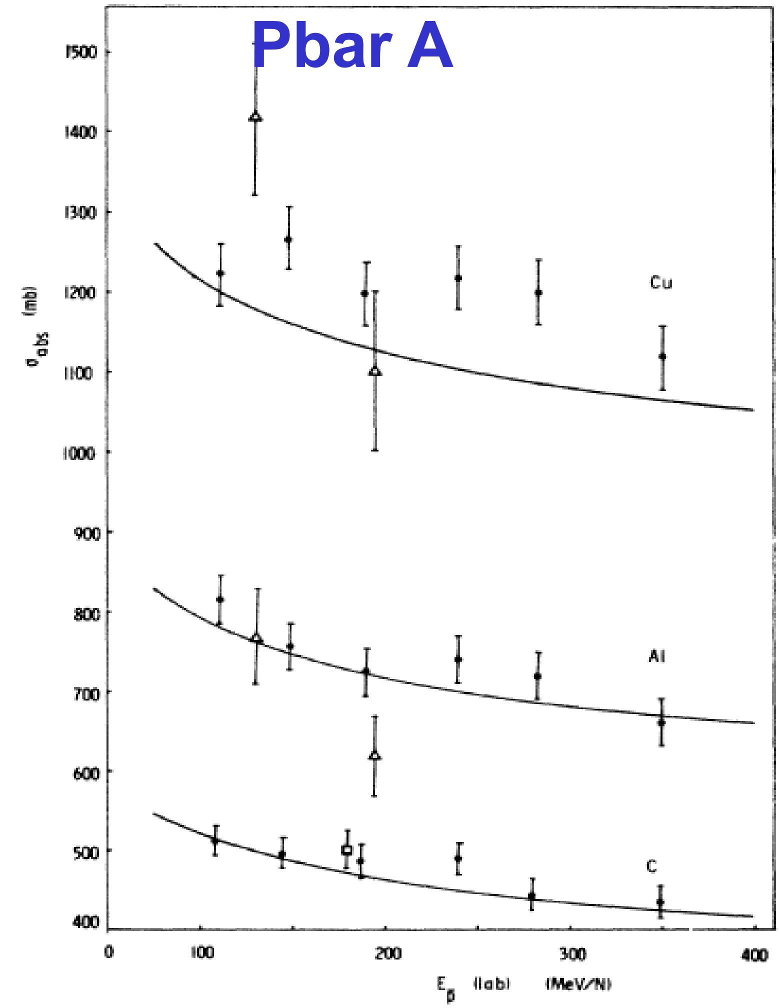
$$\chi(b) = -(2k)^{-1} \int_{-\infty}^{\infty} U(b,z) dz \ ,$$

with k the projectile momentum wave number and b denoting the impact parameter. The reduced potential is then obtained from the optical potential as

$$U(x) = 2m A_P A_T (A_P + A_T)^{-1} W(x) \ ,$$

$$W(x) = A_P A_T \int d^3z\, \rho_T(z) \times \int d^3y\, \rho_P(x+y+z) \tilde{t}(e,y)$$





Generator of inelastic nucleus-nucleus interaction diagrams

Computer Physics Communications, V 54, 1989, Pages 125-135

S. Yu. Shmakov, V. V. Uzhinskii, A. M. Zadorozhny

As is well known, the scattering amplitude of two nuclei with the mass numbers A and B in the impact parameter representation is given by [3–6]

$$F(\boldsymbol{b})\,|_{\substack{A(i\to f)\\ B(i\to f)}} = \left\langle \psi_A^f;\ \psi_B^f \left| 1 - \prod_{j=1}^{A} \prod_{k=1}^{B} \left[1 - \gamma(\boldsymbol{b} - \boldsymbol{s}_j + \boldsymbol{\tau}_k)\right] \right| \psi_B^i;\ \psi_A^i \right\rangle$$

where $\boldsymbol{b}$ is the impact parameter vector. The angle brackets mean the average over the initial ψ_A^i, ψ_B^i and final ψ_A^f, ψ_B^f state wave functions of nuclei A and B. $\gamma(\boldsymbol{b})$ is the amplitude of elastic nucleon–nucleon (NN) scattering in the impact parameter representation

$$\gamma(\boldsymbol{b}) = \frac{1}{2\pi i p} \int e^{i\boldsymbol{q}\cdot\boldsymbol{b}} f(\boldsymbol{q})\, d^2q.$$

p is the momentum of nucleus A per nucleon in a system where the target nucleus B is at rest. $f(\boldsymbol{q})$ is the NN – elastic scattering amplitude in the momentum representation.

$\{\boldsymbol{s}_A\}$ and $\{\boldsymbol{\tau}_B\}$ are the coordinates of the nucleons with regard to the centers of mass of nuclei A and B, respectively, in the plane of the impact parameter (i.e. in the plane perpendicular to the momentum $\boldsymbol{p}$).

Using (1) one can find different nucleus–nucleus interaction characteristics. For example, on the simple assumption * that

$$|\psi_A^i|^2 = \prod_{j=1}^{A} \rho_A(\boldsymbol{s}_j, z_j), \quad |\psi_B^i|^2 = \prod_{j=1}^{B} \rho_B(\boldsymbol{\tau}_j, \xi_j),$$

$$\sigma_{AB}^{tot} = 2\,\mathrm{Re} \int d^2b\, F(\boldsymbol{b})\,|_{\substack{A(i\to i)\\ B(i\to i)}}$$

$$= 2\,\mathrm{Re} \int d^2b \left\{ 1 - \prod_{i=1}^{A} \prod_{j=1}^{B} \left[1 - \gamma(\boldsymbol{b} - \boldsymbol{s}_i + \boldsymbol{\tau}_j)\right] \right\} \left\{ \prod_{i=1}^{A} \rho_A(\boldsymbol{s}_i, z_i)\, d^3r_i \right\} \left\{ \prod_{i=1}^{B} \rho_B(\boldsymbol{\tau}_i, \xi_i)\, d^3t_i \right\},$$

$$\sigma_{AB}^{in} = \int d^2b \left\{ 1 - \prod_{i=1}^{A} \prod_{j=1}^{B} \left[1 - \gamma(\boldsymbol{b} - \boldsymbol{s}_i + \boldsymbol{\tau}_j) - \gamma^*(\boldsymbol{b} - \boldsymbol{s}_i + \boldsymbol{\tau}_j) + \gamma(\boldsymbol{b} - \boldsymbol{s}_i + \boldsymbol{\tau}_j)\gamma^*(\boldsymbol{b} - \boldsymbol{s}_i + \boldsymbol{\tau}_j)\right] \right\}$$

$$\times \left\{ \prod_{i=1}^{A} \rho_A(\boldsymbol{s}_i, z_i)\, d^3r_i \right\} \left\{ \prod_{i=1}^{B} \rho_B(\boldsymbol{\tau}_i, \xi_i)\, d^3t_i \right\}.$$

Ingredients of Glauber model

1. Nuclear density

R (He3) = 1.81 fm, R(He4) = 1.37 fm   Deutron - Hulthen wave function.

W. Broniowski, M.Rzyczynski, P. Bozek, CPC, 180, (2009), 69

$$n_e(r) = c\,\frac{4\pi r^2\left(1 + W_e \frac{r^2}{R_e^2}\right)}{1 + \exp\left(\frac{r - R_e}{a_e}\right)},$$

$$R = \left(1.113A^{1/3} - 0.277A^{-1/3}\right)\ \mathrm{fm},$$

$$a = 0.45\ \mathrm{fm} \quad (d = 0.4\ \mathrm{fm}),$$

2. New parametrisation of total and elastic cross-sections of pbar-p interactions

J.R. Cudell et al. (COMPLETE collab.) Phys. Rev. **D65** (2002) 074024;
W.-M. Yao et al. (PDG), J. Phys. **G33** (2006) 337;
M. Ishida and K. Igi, Phys. Rev. **D79** (2009) 096003.

$$\sigma^{tot}_{ab,asmpt} = Z_{ab} + B\ \ (log(s/s_0))^2$$

$$B = 0.3152,\ s_0 = 34.0\ (COMPLETE,\ 2002)$$

$$B = 0.308,\quad s_0 = 28.9\quad (PDG,\ 2006)$$

$$B = 0.304,\ s_0 = 33.1\ (M.Ishida,\ K.Igi,\ 2009)$$

Low energy extension

A.A. Arkhipov, **hep-ph/9909531** (1999), **hep-ph/9911533** (1999)

$$\sigma^{tot}_{\bar{p}p} = \sigma^{tot}_{asmpt}\left[1 + \frac{C}{\sqrt{s - 4m_N^2}}\frac{1}{R_0^3}\left(1 + \frac{d_1}{s^{0.5}} + \frac{d_2}{s^1} + \frac{d_3}{s^{1.5}}\right)\right]$$

$$\sigma^{tot}_{asmpt} = 36.04 + 0.304\ \ (log(s/33.0625))^2$$

New parameterization of PbarP cross sections

$$\sigma_{\bar{p}p}^{tot} = \sigma_{asmpt}^{tot}\left[1 + \frac{C}{\sqrt{s-4m_N^2}}\frac{1}{R_0^3}\left(1+\frac{d_1}{s^{0.5}}+\frac{d_2}{s^1}+\frac{d_3}{s^{1.5}}\right)\right]$$

$$\sigma_{asmpt}^{tot} = 36.04 + 0.304\ \left(log(s/33.0625)\right)^2$$

$$R_0 = \sqrt{0.40874044\,\sigma_{asmpt}^{tot} - B}$$

$$B = 11.92 + 0.3036\ \left(log(\sqrt{s}/20.74\right)^2$$

$$C = 13.55,\ d_1 = -4.47,\ d_2 = 12.38,\ d_3 = -12.43$$

$$\sigma_{\bar{p}p}^{el} = \sigma_{asmpt}^{el}\left[1 + \frac{C}{\sqrt{s-4m_N^2}}\frac{1}{R_0^3}\left(1+\frac{d_1}{s^{0.5}}+\frac{d_2}{s^1}+\frac{d_3}{s^{1.5}}\right)\right]$$

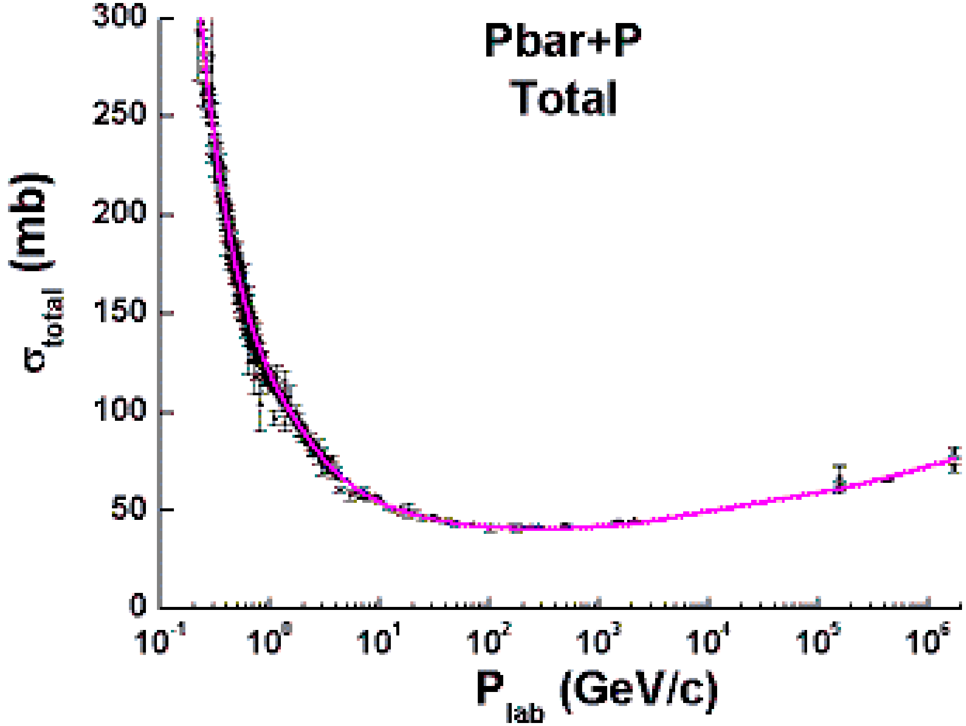
$$\sigma_{asmpt}^{el} = 4.5 + 0.101\ \left(log(s/33.0625)\right)^2$$

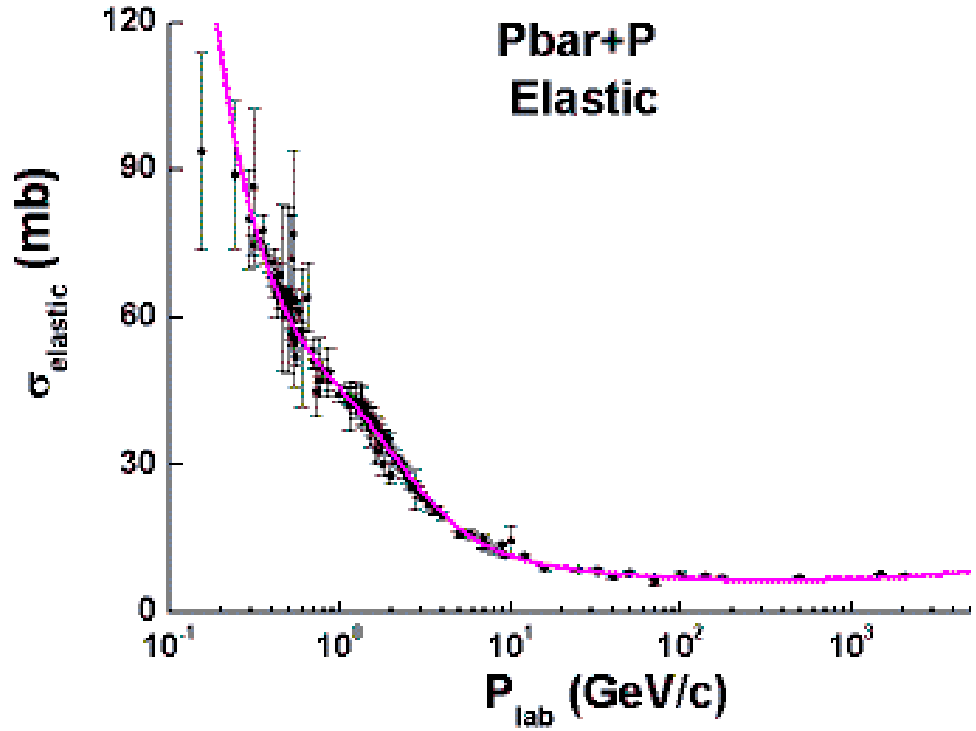
$$R_0 = \sqrt{0.40874044\,\sigma_{asmpt}^{tot} - B}$$

$$B = 11.92 + 0.3036\ \left(log(\sqrt{s}/20.74\right)^2$$

$$C = 59.27,\ d_1 = -6.95,\ d_2 = 23.54,\ d_3 = -25.34$$

$\sigma_{el}/\sigma_{tot}=1/(2\ C_{sh})\approx 1/3$, according to the quasi-eikonal approach of the reggeon field theory (K.A. Ter-Martirosyan, A.B. Kaidalov)

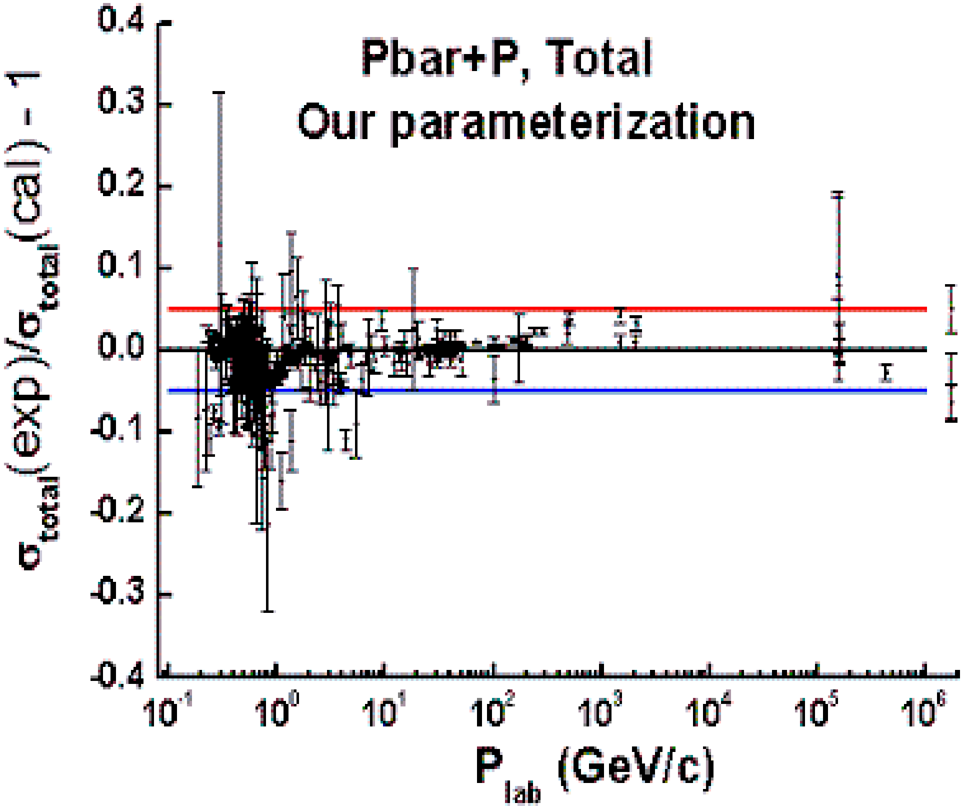


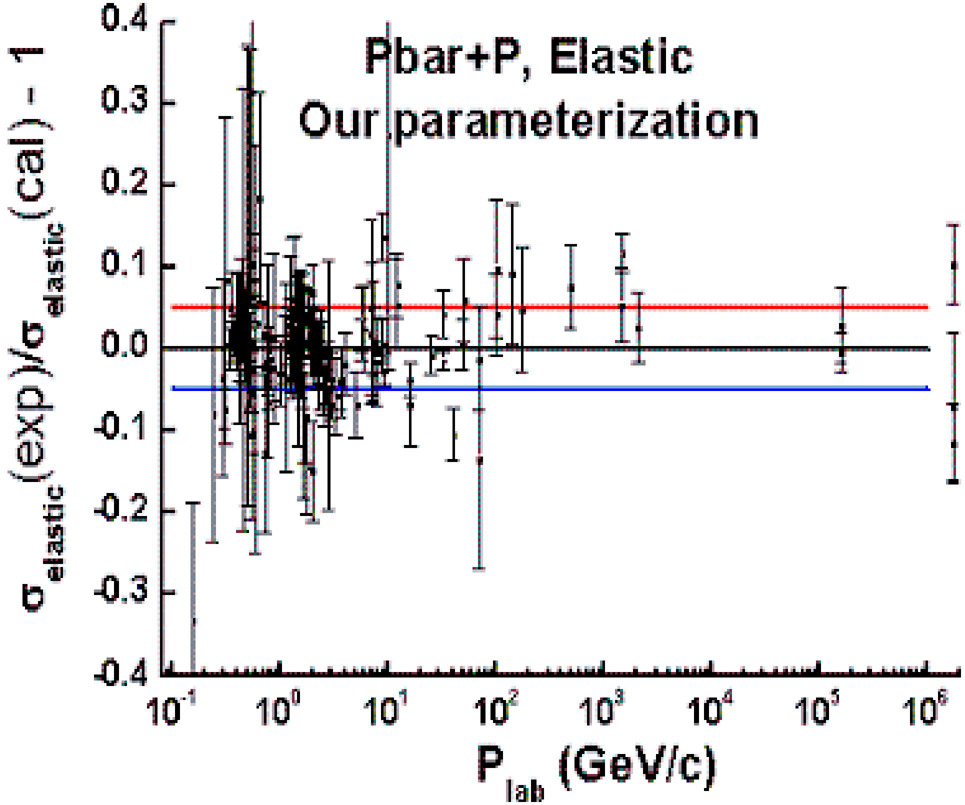


New parameterization of PbarP cross sections

Chi^2/NoF =6652/440≈15 (total), without 15 points – 4371/429 ≈10

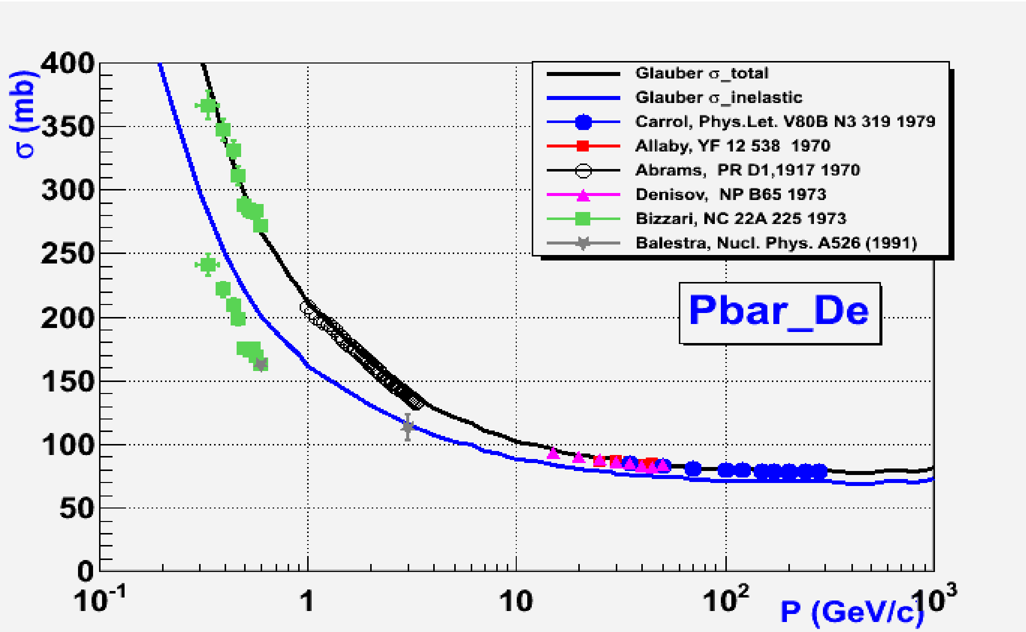
Chi^2/NoF =148/137≈1 (elastic)



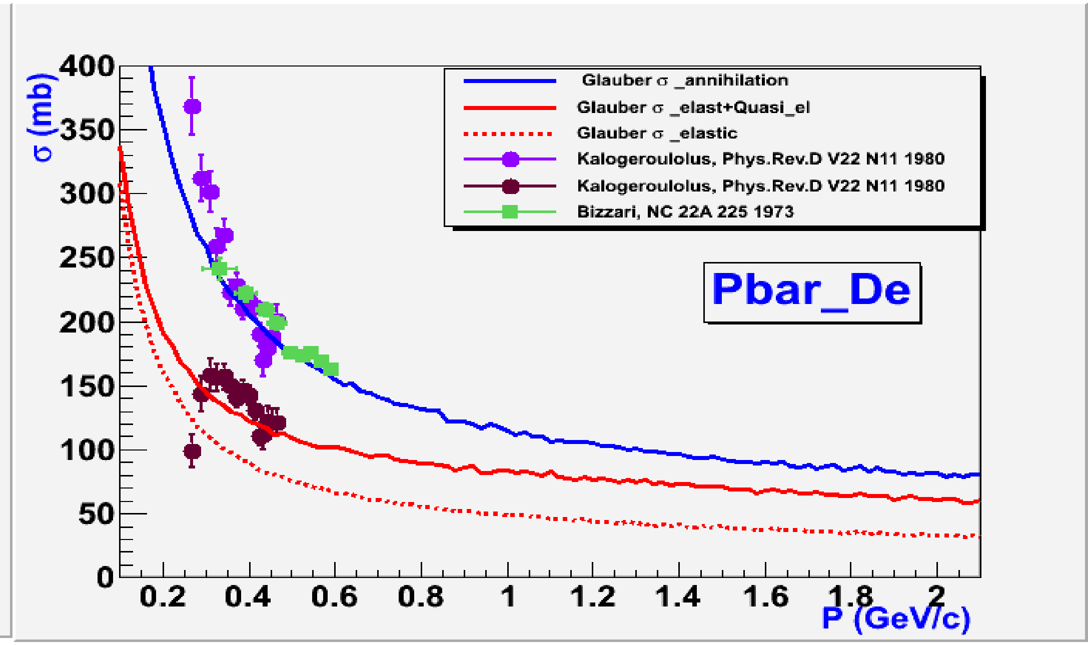


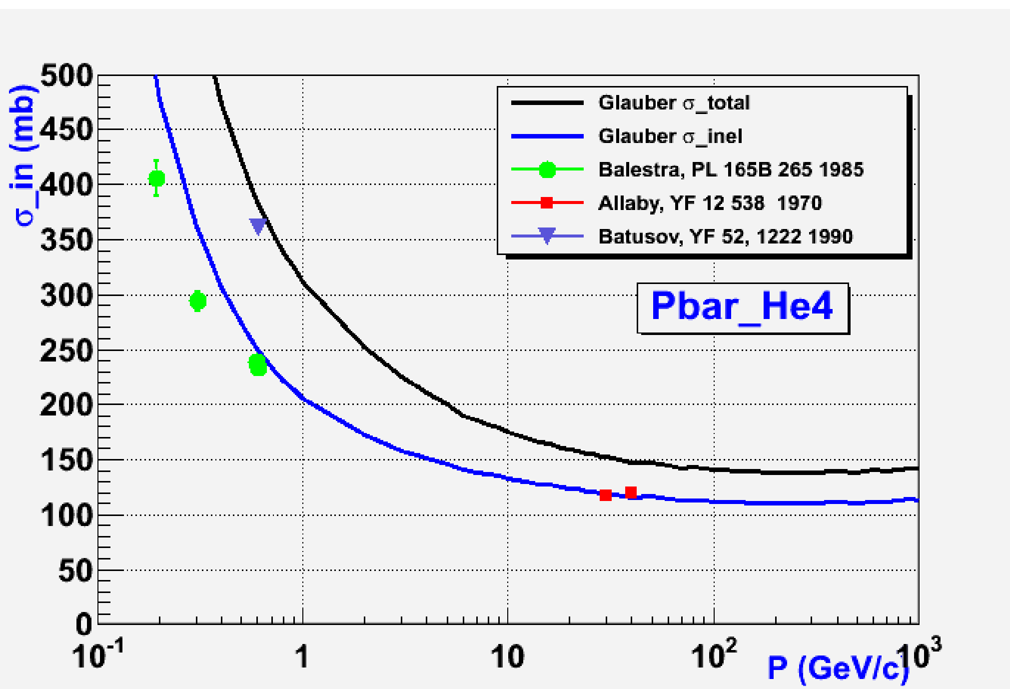
Calculation results in Glauber approach, light nuclei

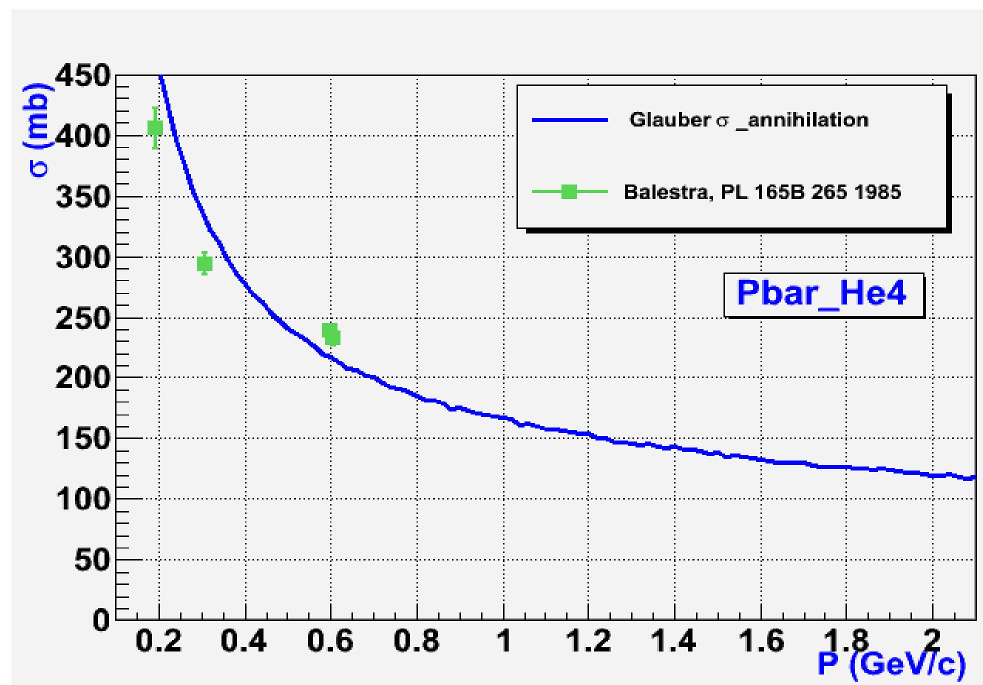
***Total** and **inelastic** cross sections*



***Annihilation**, **elast+Qelast** cross sections*

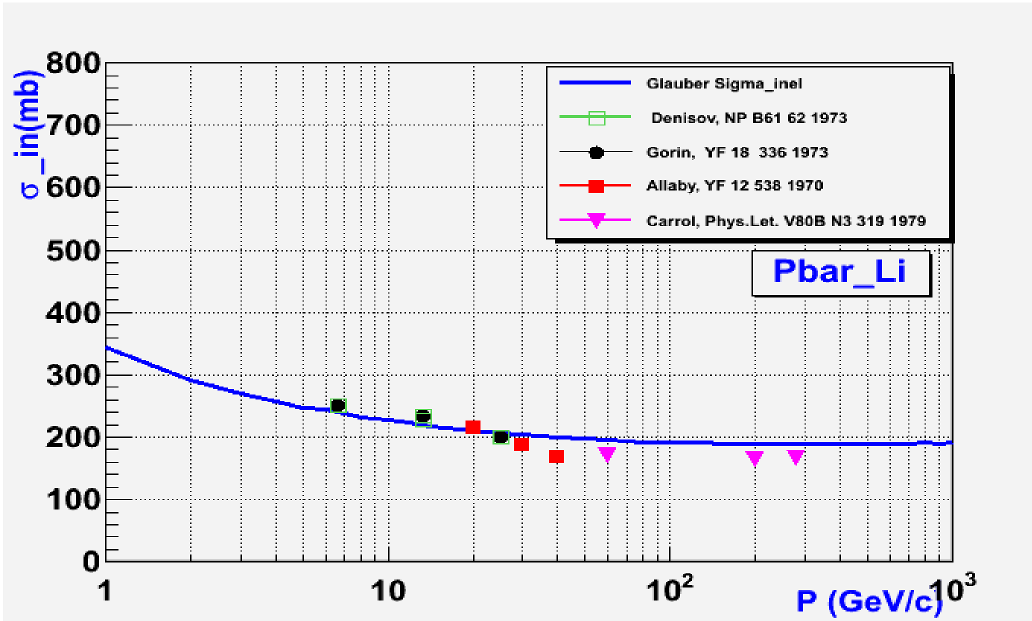


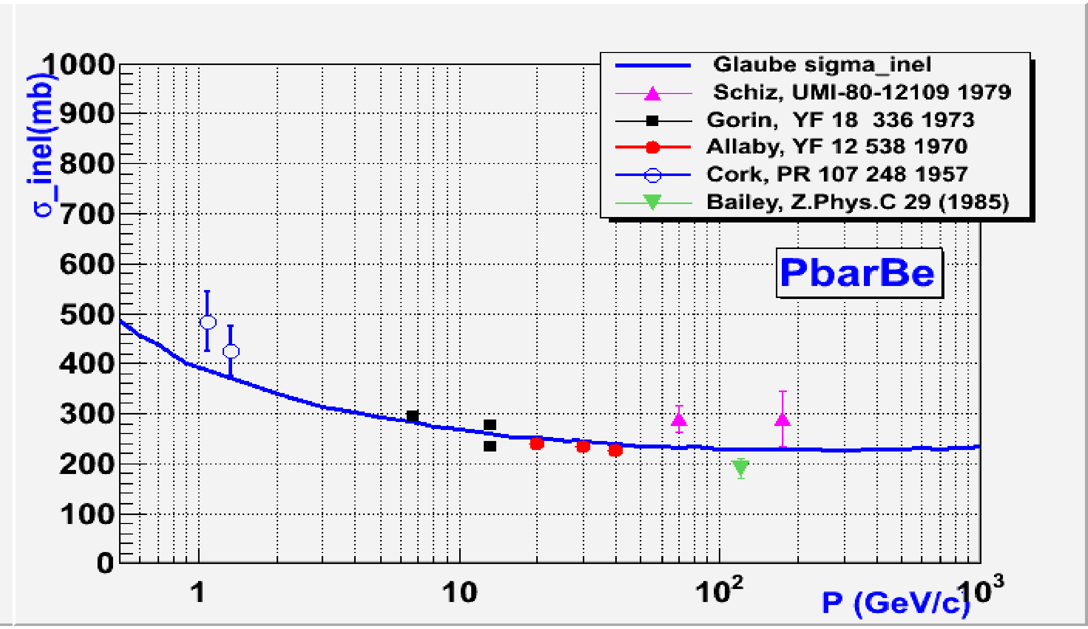


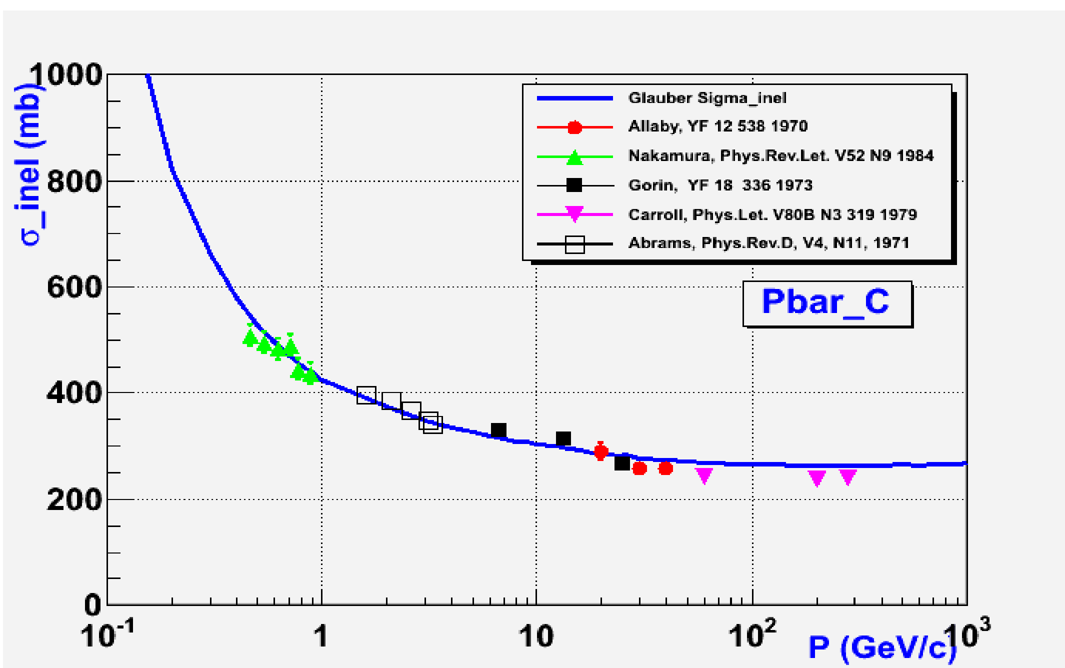


Calculation results in Glauber approach, light nuclei

Inelastic (absorption) cross sections

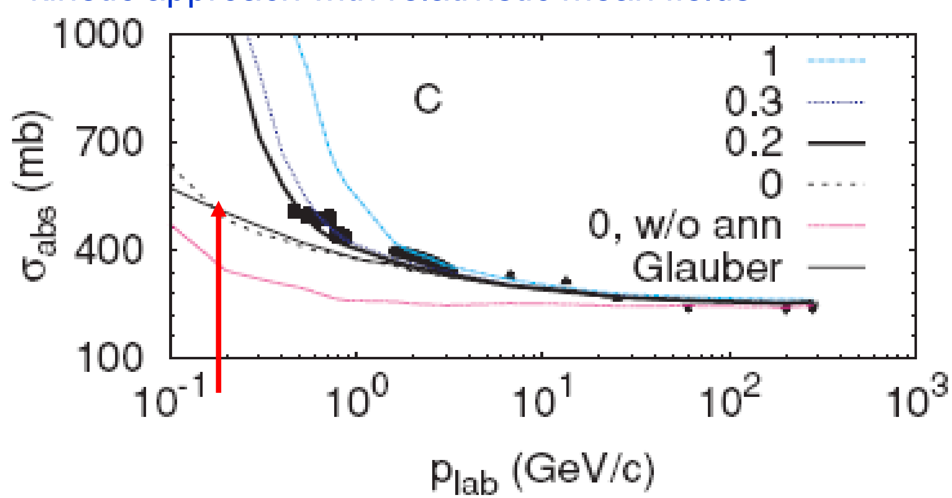






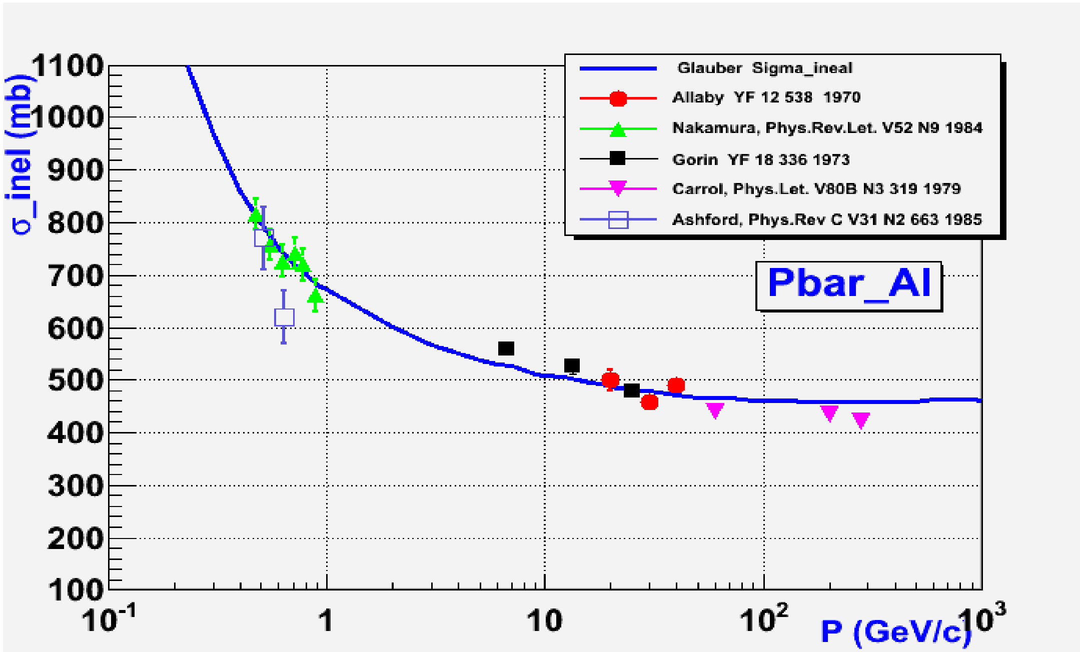
A.B. Larionov, , I.A. Pshenichnov, I.N. Mishustin, W. Greiner, Phys. Rev. C80(2009)021601,2009

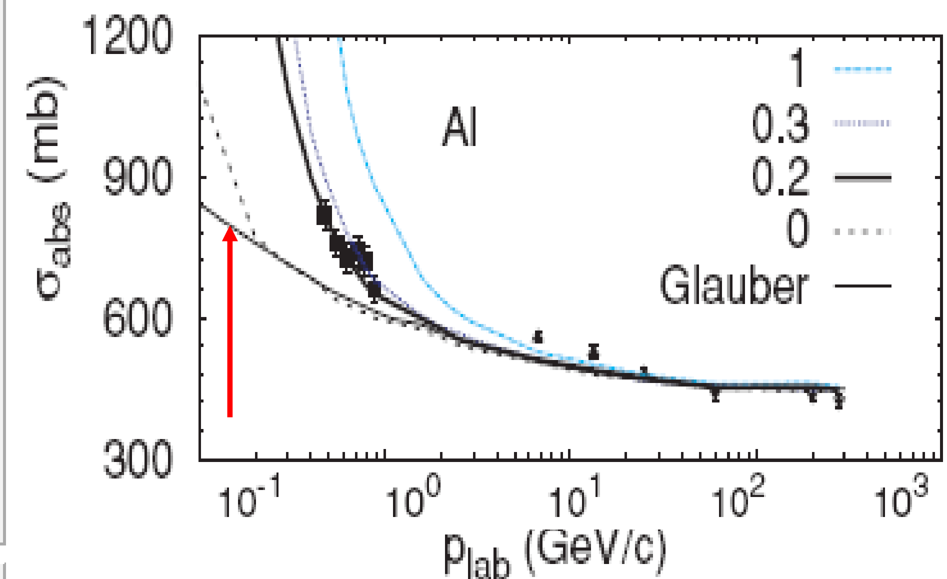
Anti-proton - nucleus collisions simulation within a kinetic approach with relativistic mean fields

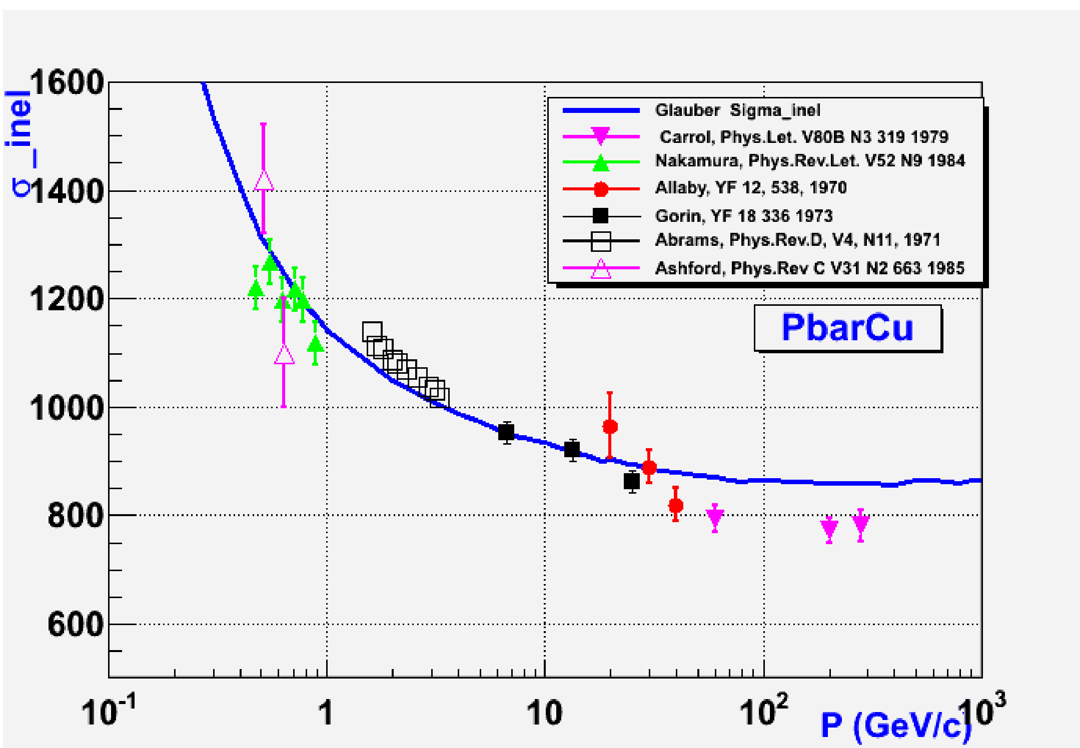


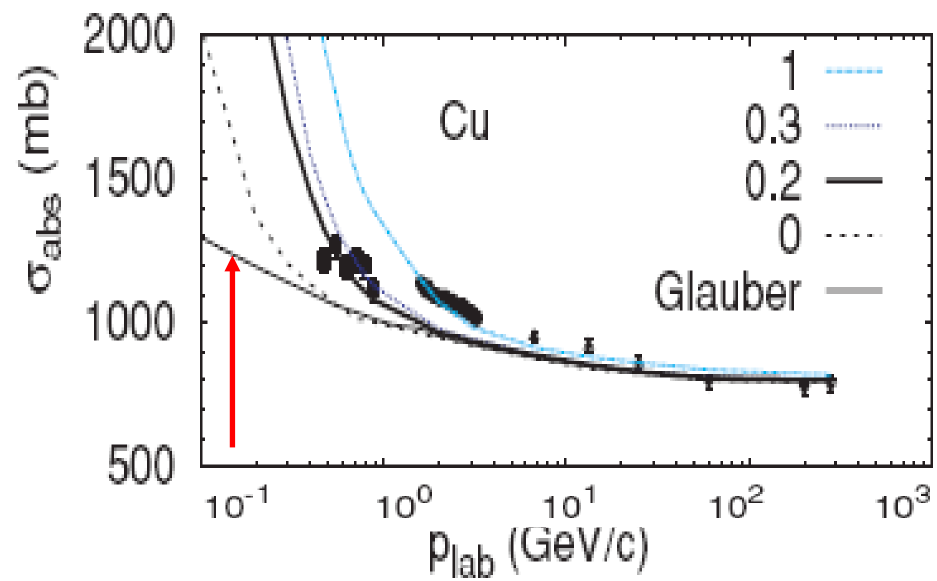
Calculation results in Glauber approach for Pbar + A

A.B. Larionov, , I.A. Pshenichnov, I.N. Mishustin, W. Greiner, Phys. Rev. C80(2009)021601,2009
Anti-proton - nucleus collisions simulation within a

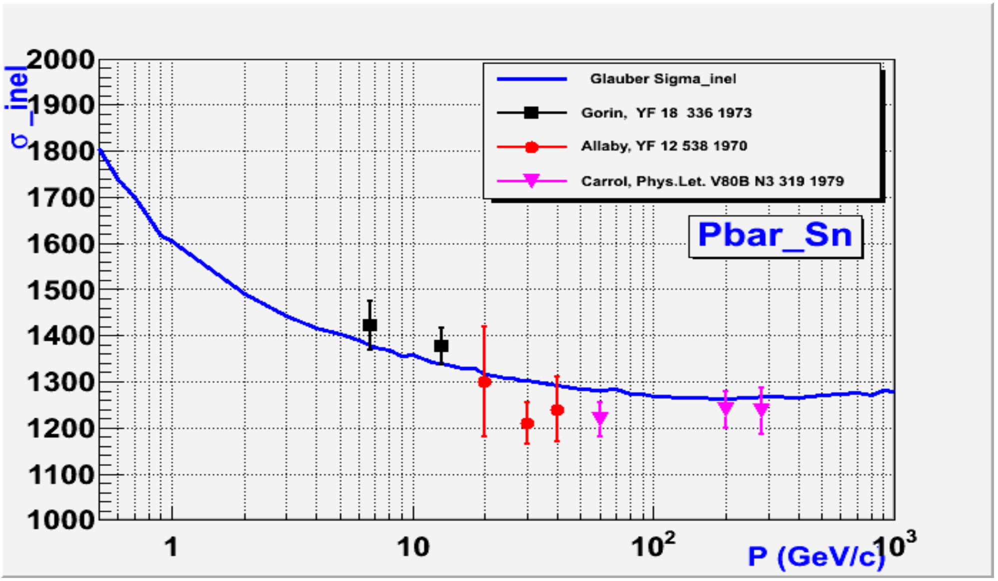


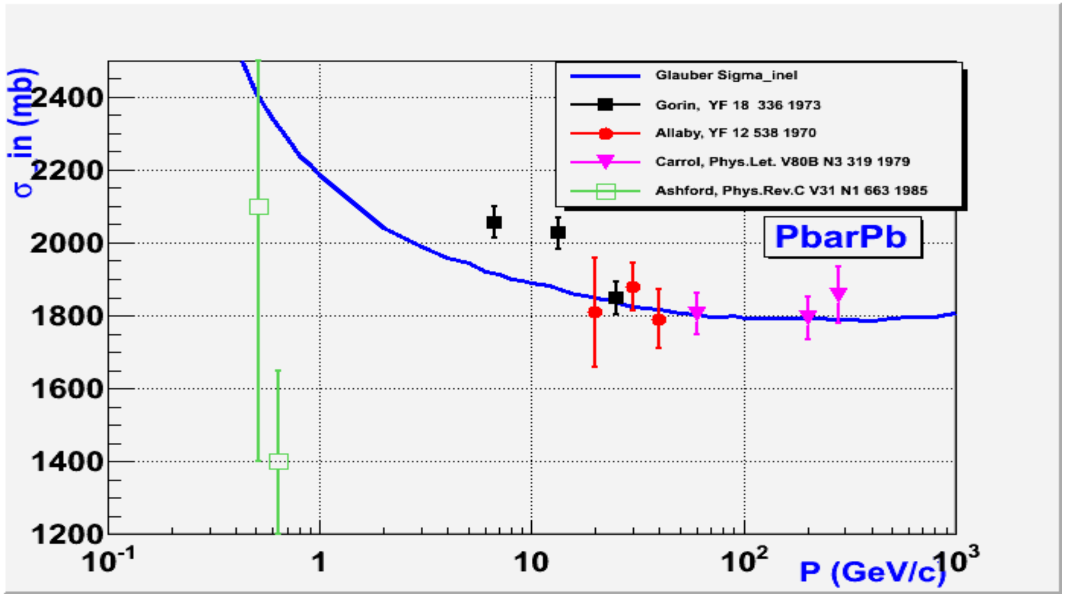


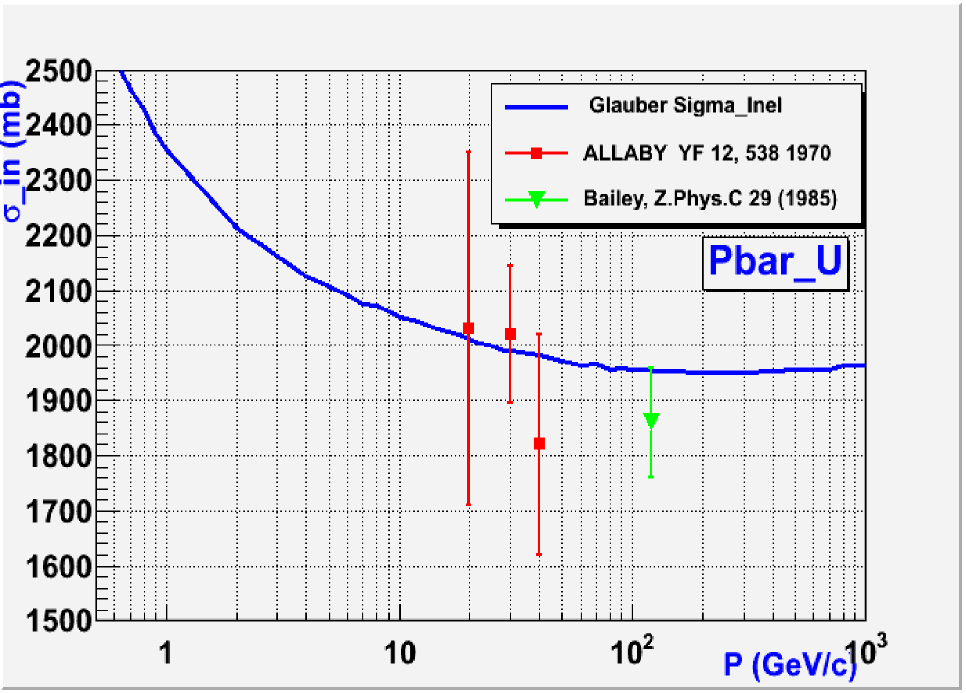




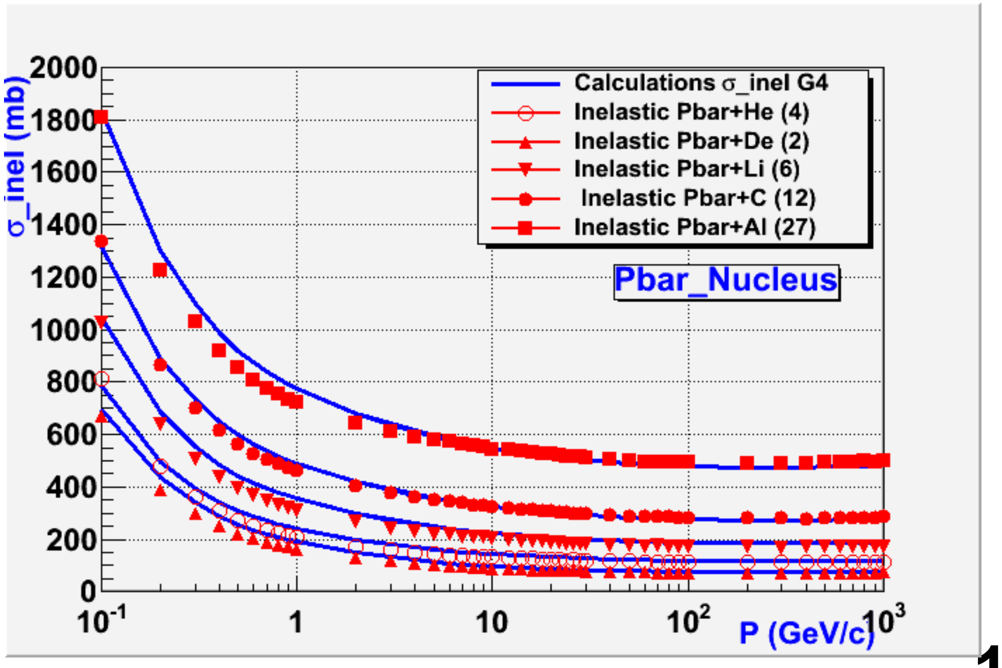
Calculation results in Glauber approach for heavy nuclei







parametrization and Glauber



Parameterization of Anti-Ion-Ion cross-sections

A simplified Glauber model for hadron-nucleus cross sections.
V.M. Grichine Eur.Phys.J. C62: 399-404, 2009.

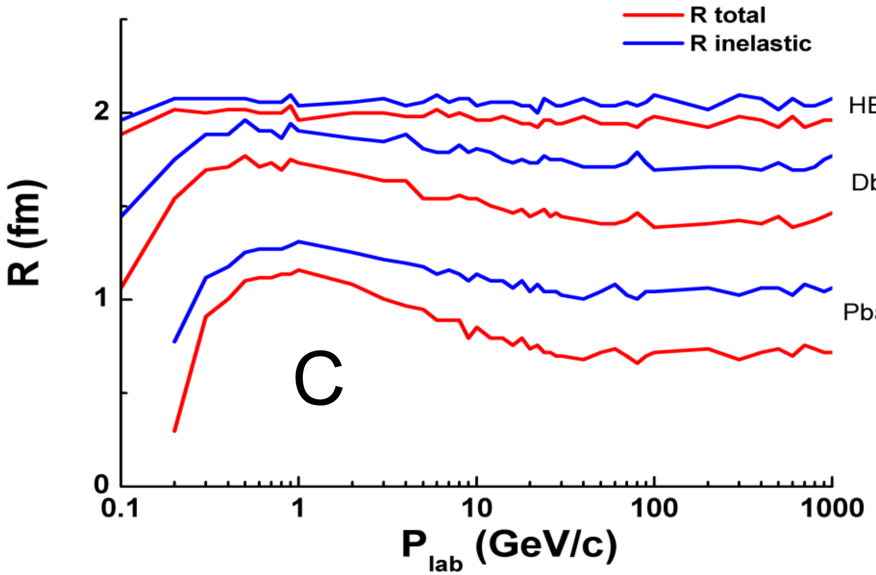
A simple model for integral hadron-nucleus and nucleus-nucleus cross-sections.
V.M. Grichine, Nucl.Instrum.Meth. B267: 2460-2462, 2009

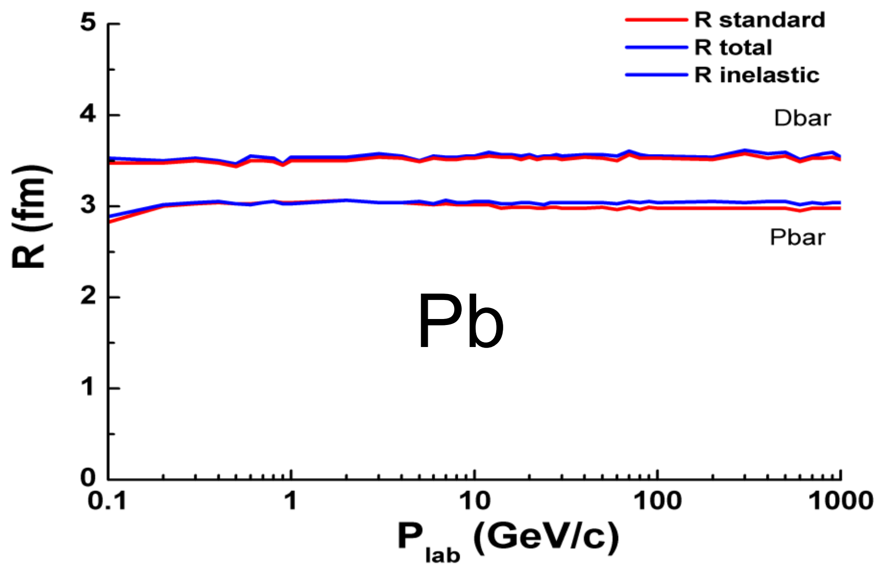
$$\sigma_{\rm tot}^{hA} = 2\pi R^2 \ln\left[1 + \frac{A\sigma_{\rm tot}^{hN}}{2\pi R^2}\right],$$

$$\sigma_{\rm in}^{hA} = \pi R^2 \ln\left[1 + \frac{A\sigma_{\rm tot}^{hN}}{\pi R^2}\right].$$

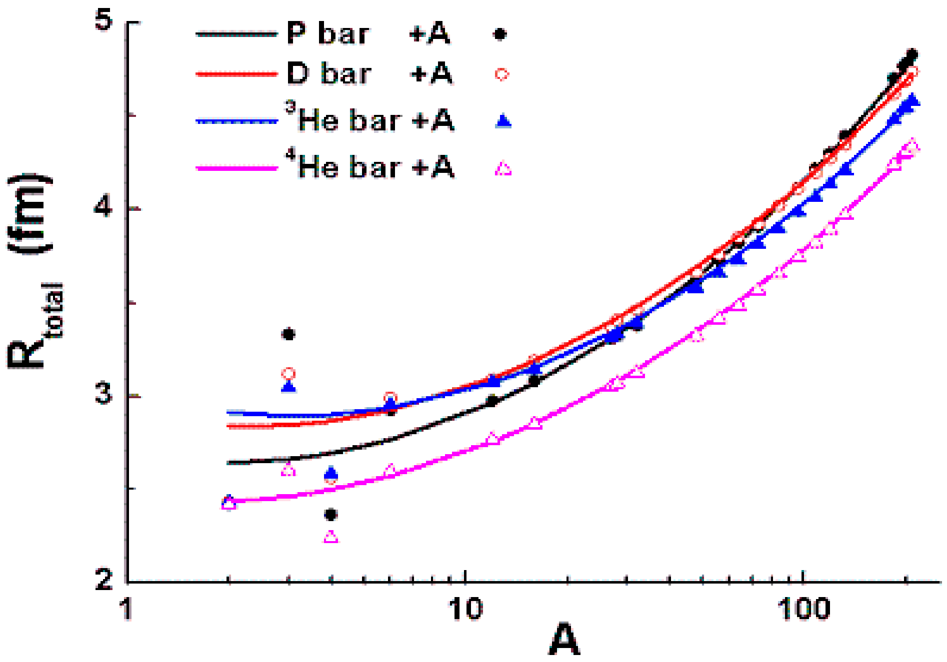
$$\sigma_{tot}^{A_pA_t} = 2\pi(R_p^2 + R_t^2)\ln\left[1 + \frac{A_pA_t\sigma_{tot}^{NN}}{2\pi(R_p^2+R_t^2)}\right],$$

$$\sigma_{in}^{A_pA_t} = \pi(R_p^2 + R_t^2)\ln\left[1 + \frac{A_pA_t\sigma_{tot}^{NN}}{\pi(R_p^2+R_t^2)}\right],$$

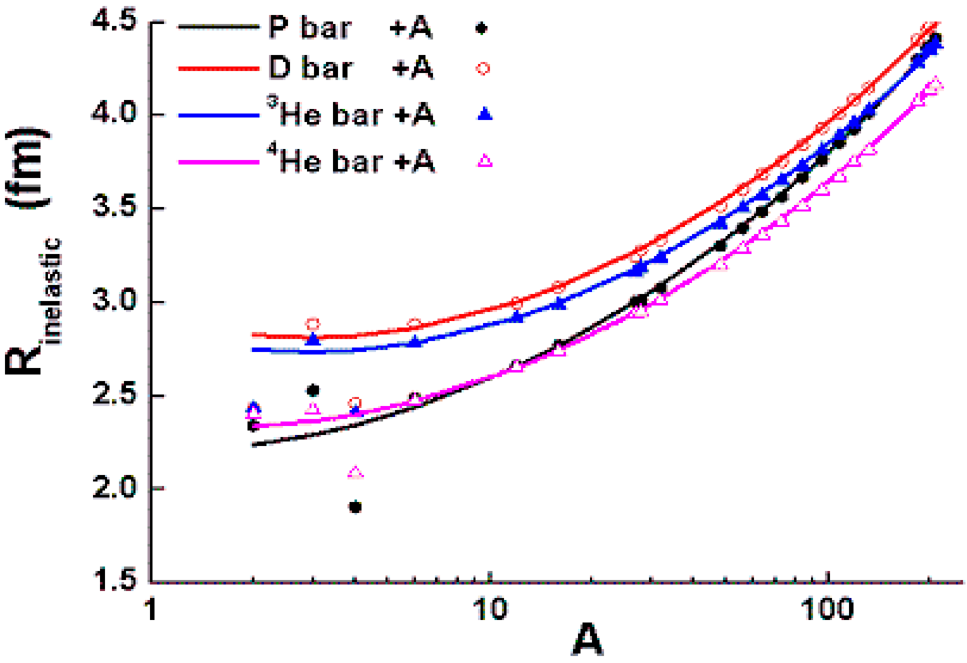




Parameterizations of radii



Total cross section parameters

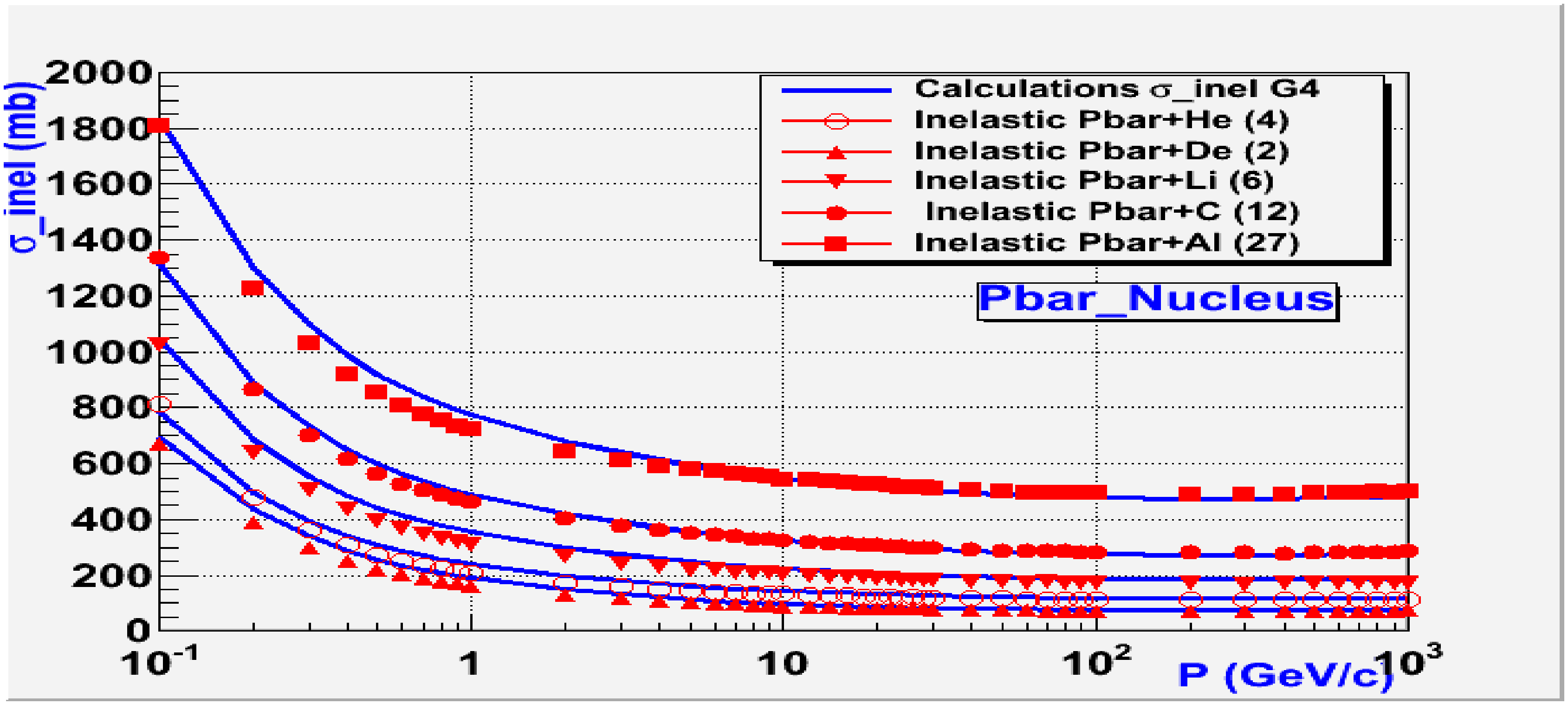


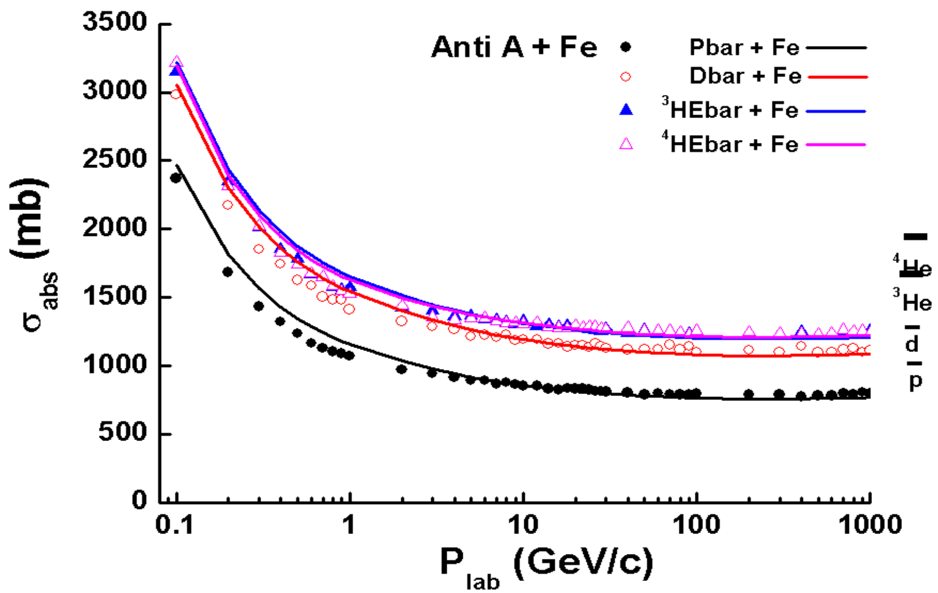
Inelastic cross section parameters

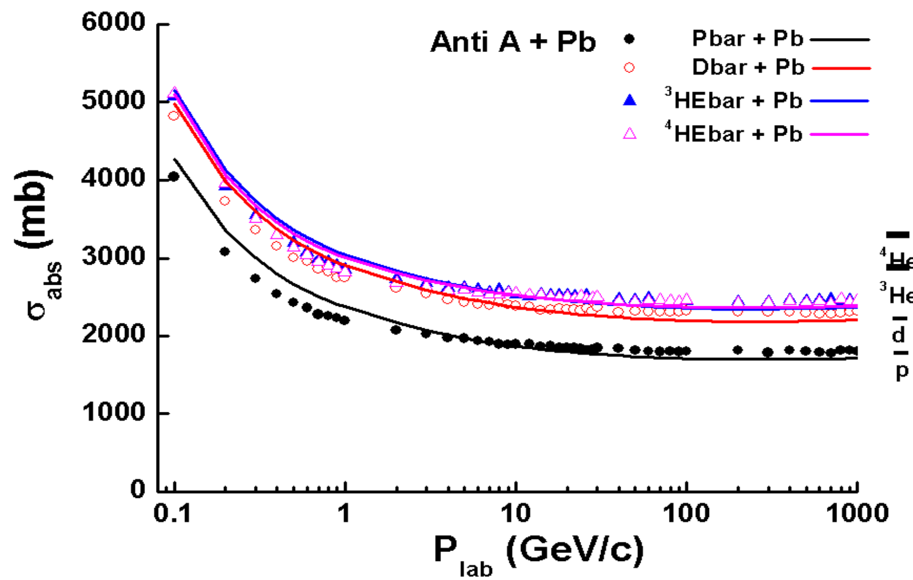
$$\bar{p}A \quad R_A = 1.34\ A^{0.23} + 1.35/A^{1/3} \quad (mb)$$
$$\bar{d}A \quad R_A = 1.46\ A^{0.21} + 1.45/A^{1/3} \quad (mb)$$
$$\bar{t}A \quad R_A = 1.40\ A^{0.21} + 1.63/A^{1/3} \quad (mb)$$
$$\bar{\alpha}A \quad R_A = 1.35\ A^{0.21} + 1.10/A^{1/3} \quad (mb)$$

$$\bar{p}A \quad R_A = 1.31\ A^{0.22} + 0.90/A^{1/3} \quad (mb)$$
$$\bar{d}A \quad R_A = 1.38\ A^{0.21} + 1.55/A^{1/3} \quad (mb)$$
$$\bar{t}A \quad R_A = 1.34\ A^{0.21} + 1.51/A^{1/3} \quad (mb)$$
$$\bar{\alpha}A \quad R_A = 1.30\ A^{0.21} + 1.05/A^{1/3} \quad (mb)$$

Comparison of the Glauber calculations and the parameterization







GEANT4

Class:

Base class

G4VComponentCrossSection

New class

G4ComponentAntiNuclNuclearXS

Derived methods

ComputeTotalCrossSection(Particle, Ekin,Z,A)
GetTotalZandACrossSection(Particle, Ekin,Z,A)
ComputeInelasticCrossSection(Particle, Ekin,Z,A)
GetInelasticZandACrossSection(Particle, Ekin,Z,A)
Compute ElasticCrossSection(Particle, Ekin,Z,A)
GetElasticZandACrossSection(Particle, Ekin,Z,A)

Calculation of Anti-Hadron Nucleon σ_tot, σ_el

Methods:

GetAntiHadronNucleonTotCrSc(Particle, Ekin)

GetAntiHadronNucleonElCrSc(Particle, Ekin)

Data of class:

fRadiusEff, fRadiusNN2,
fTotalXsc, fElasticXsc, fInelasticXsc et al.

Summary

1. New parametrization of pbar-nucleon total and elastic cross sections is proposed

2. With new parameterization calculations of pbar – nucleus cross sections in Glauber approach and comparison with exp.data were performed. It is shown that the Glauber theory works well.

3. With new parameterization anti-nucleus nucleus cross sections were calculated in Glauber approach.

4. According to Grichine formulae, anti-nucleus nucleus cross sections have been parameterized using new nuclear effective radii.

5. Class for calculation of anti-nucleus nucleus cross sections is created in Geant4

Plans

Implementation of simulation of Pbar - P multi-paticle production in Geant4;
Implementation of simulation of Pbar - A interactions in Geant4;
Implementation of simulation of AntiA - A interactions in Geant4