Integral hadron-nucleus and nucleus-nucleus cross sections in the Glauber-Sitenko-Gribov framework

Vladimir Grichine

P.N. Lebedev Physical Institute of RAS

e-mail: Vladimir.Grichine@cern.ch

Abstract

Simple relations for the integral hadron-nucleus and nucleus-nucleus cross sections in the Glauber-Sitenko approach with the Gribov correction for inelastic screening were derived. The model provides fast and robust calculations of the total, inelastic, production, elastic, quasi-elastic and single diffraction cross sections. Comparisons with experimental data in a wide energy range of projectiles are presented. The model was developed for the simulation of high energy physics (in particular LHC) experiments and has broad applications in nuclear medicine, cosmic rays and astrophysics.

1 Outline

1. Glauber-Sitenko-Gribov model for the total, inelastic, production, single diffraction, elastic and quasi-elastic hadron-nucleus and nucleus-nucleus cross-sections.

2. The model parameters.

3. Comparison with experiment.

4. Conclusions.

2 Hadron-nucleus cross sections

In the framework of simplified (Gauss distributed point-like nucleons in a nucleus) Glauber-Sitenko-Gribov model the cross sections read [1, 2]:

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

$$\sigma_{prod}^{hA} = \pi R^2 \ln\left[1 + \frac{A\sigma_{in}^{hN}}{\pi R^2}\right], \quad \sigma_{el}^{hA} = \sigma_{tot}^{hA} - \sigma_{in}^{hA}, \quad \sigma_{qe}^{hA} = \sigma_{in}^{hA} - \sigma_{prod}^{hA},$$

$$\sigma_{sd}^{hA}(hA \to XA) = \pi R^2 \left\{\alpha - \ln\left[1+\alpha\right]\right\}, \quad \alpha = \frac{A\sigma_{tot}^{hN}}{2\pi R^2 + A\sigma_{tot}^{hN}}.$$

Where σ_{tot}^{hA}, σ_{in}^{hA} and σ_{prod}^{hA} are the total, inelastic and production cross section of a hadron on a nucleus with A nucleons. They depend essentially on the hadron-nucleon cross sections, σ_{tot}^{hN}, and, for the production cross section, on σ_{in}^{hN}. R is the RMS radius of nucleon distribution inside the nucleus and can be considered to some extent as a free parameter.

3 Nucleus-nucleus cross-sections

The Glauber model with Gaussian distributed (R is the RMS radius) point-like nucleons in a nucleus results in the following nucleus-nucleus cross-sections [3]:

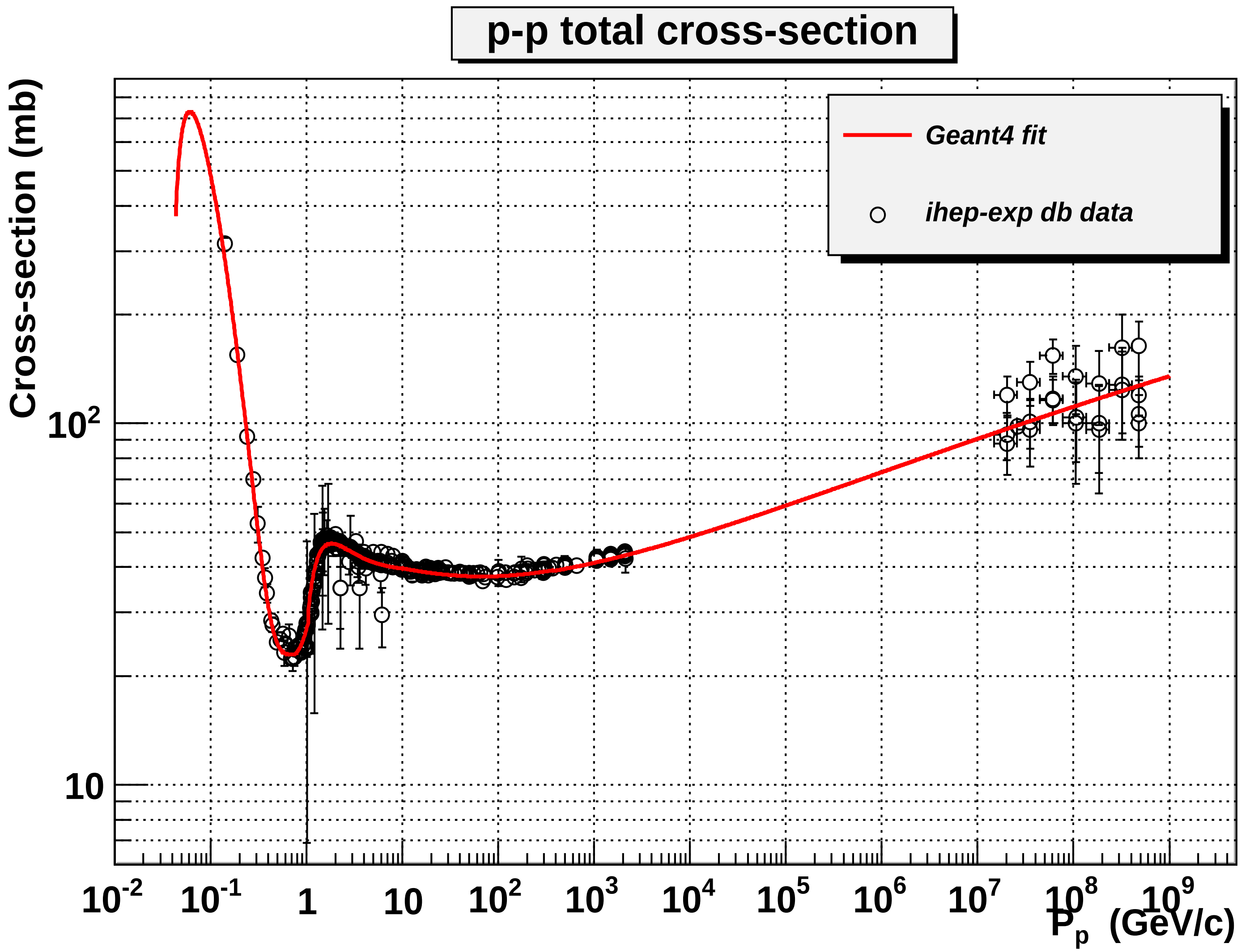
$$\sigma_{tot}^{A_pA_t} = 2\pi(R_p^2 + R_t^2)\ln\left[1 + \frac{A_pA_t\sigma_{tot}^{NN}}{2\pi(R_p^2 + R_t^2)}\right],$$

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

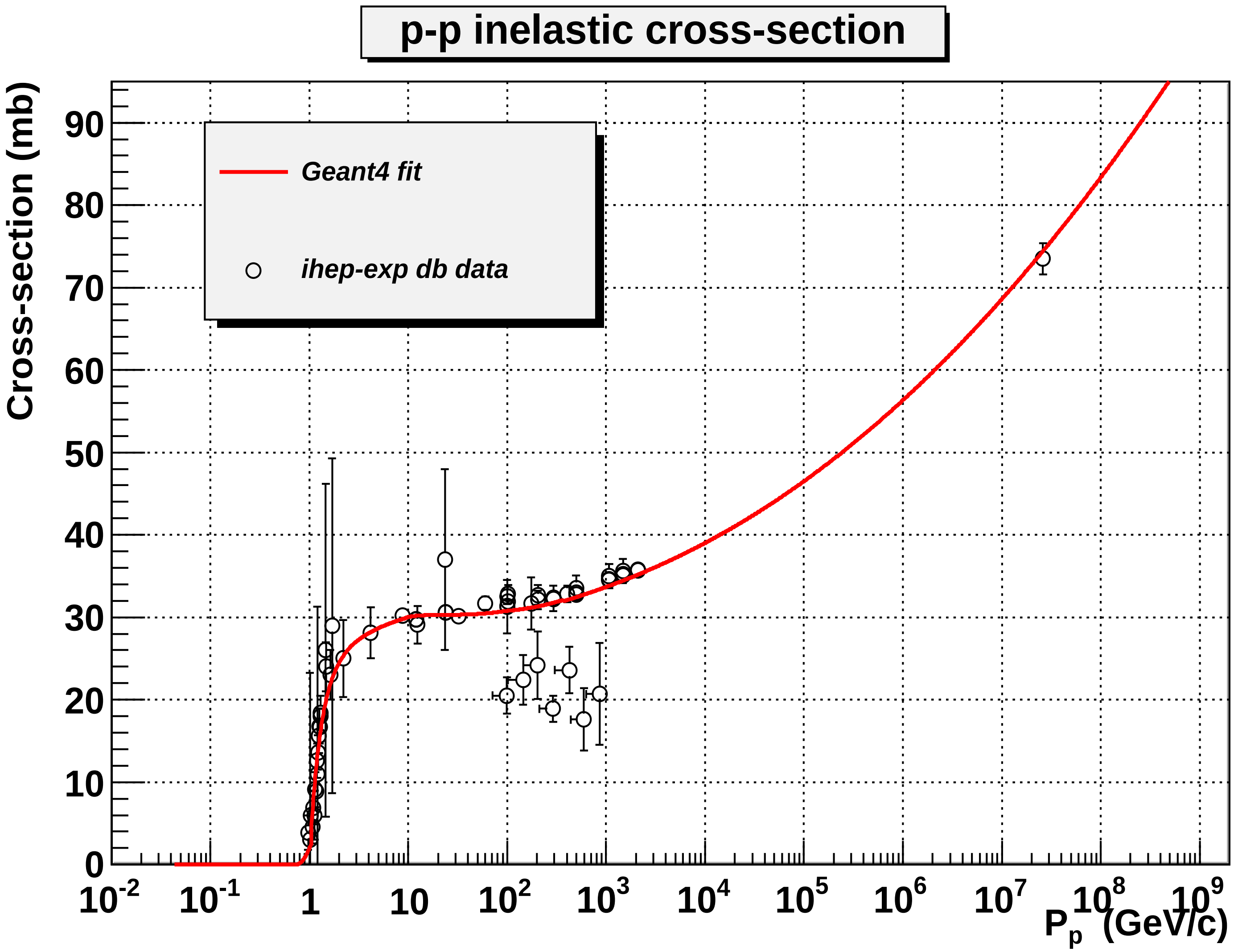
$$\sigma_{el}^{A_pA_t} = \sigma_{tot}^{A_pA_t} - \sigma_{in}^{A_pA_t}, \qquad \sigma_{qel}^{A_pA_t} = \sigma_{in}^{A_pA_t} - \sigma_{prod}^{A_pA_t},$$

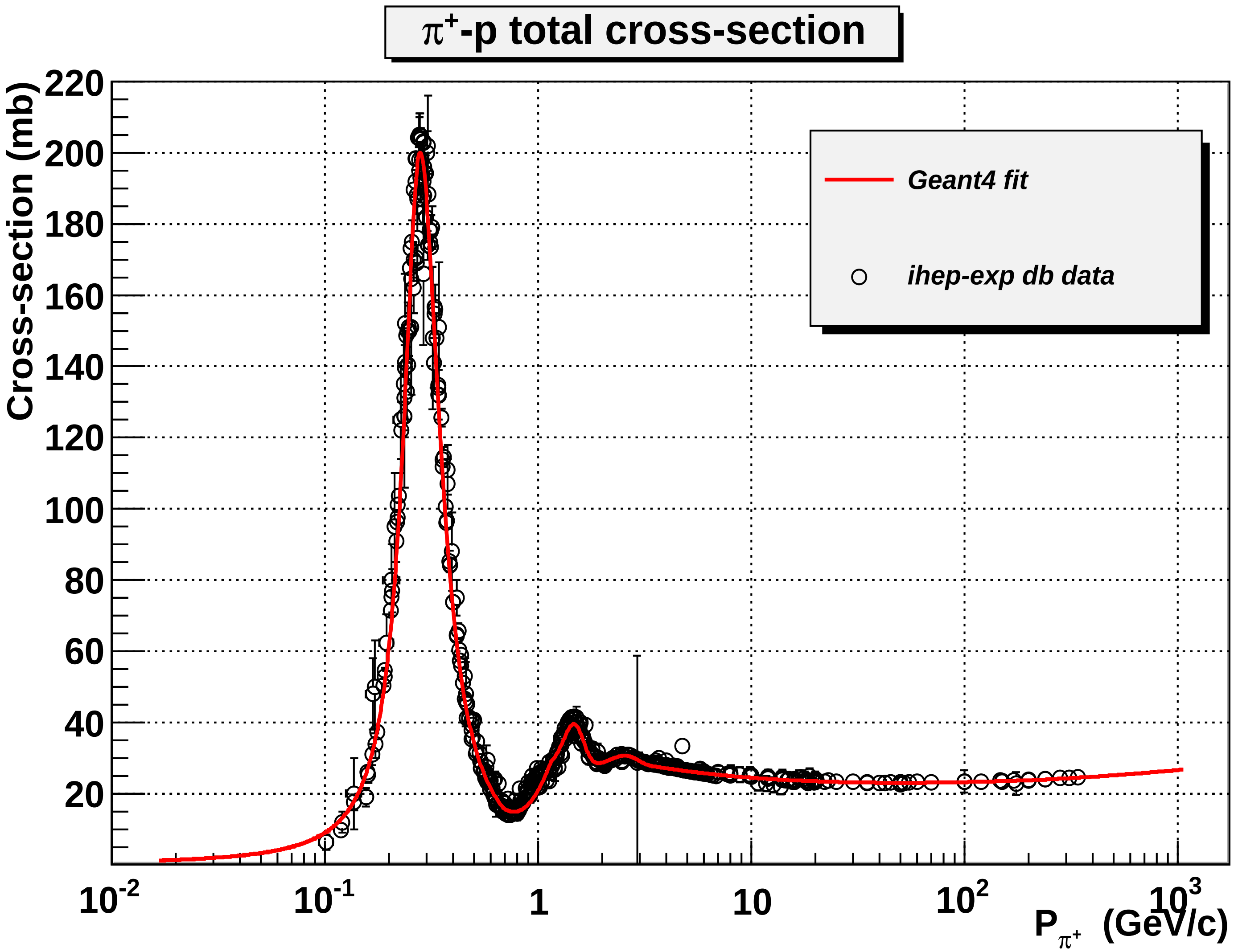
Where $\sigma_{tot}^{A_pA_t}$, $\sigma_{in}^{A_pA_t}$, $\sigma_{prod}^{A_pA_t}$, $\sigma_{el}^{A_pA_t}$, and $\sigma_{qel}^{A_pA_t}$, are the total, inelastic (reaction), production, elastic and quasi-elastic cross sections, respectively. The projectile and the target nucleus weights are, $A_p = Z_p + N_p$, and, $A_t = Z_t + N_t$, respectively. The values of Z and N are the corresponding numbers of proton and neutrons in the nuclei, $\sigma_{tot/in}^{NN}$ are the nucleon-nucleon cross-sections.

$$A_pA_t\sigma_{tot}^{NN} = Z_pZ_t\sigma_{tot}^{pp} + N_pN_t\sigma_{tot}^{nn} + (Z_pN_t + N_pZ_t)\sigma_{tot}^{pn}.$$

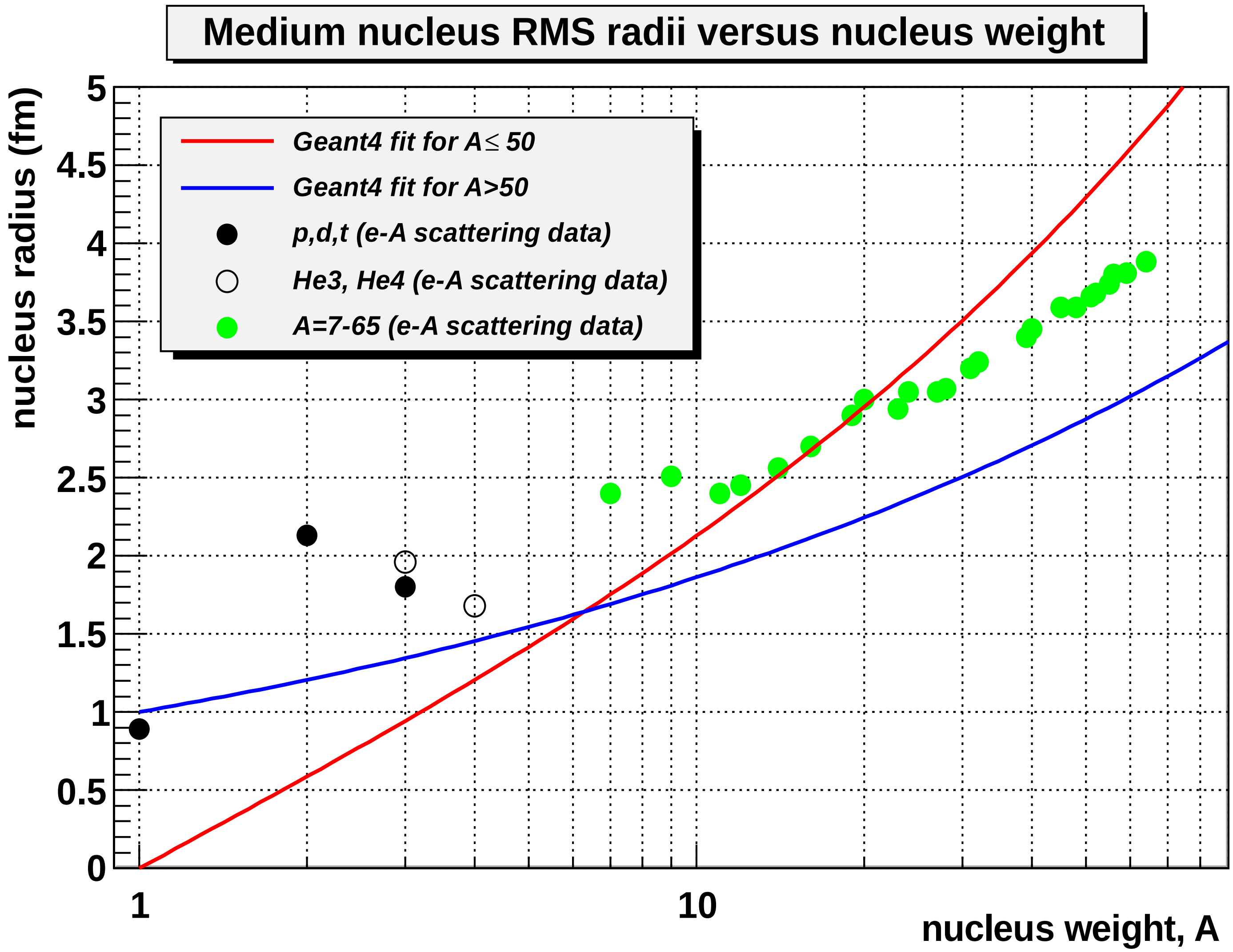


The accurate TOTEM measurement allows us to FIX σ_{tot}^{pp} parametrization

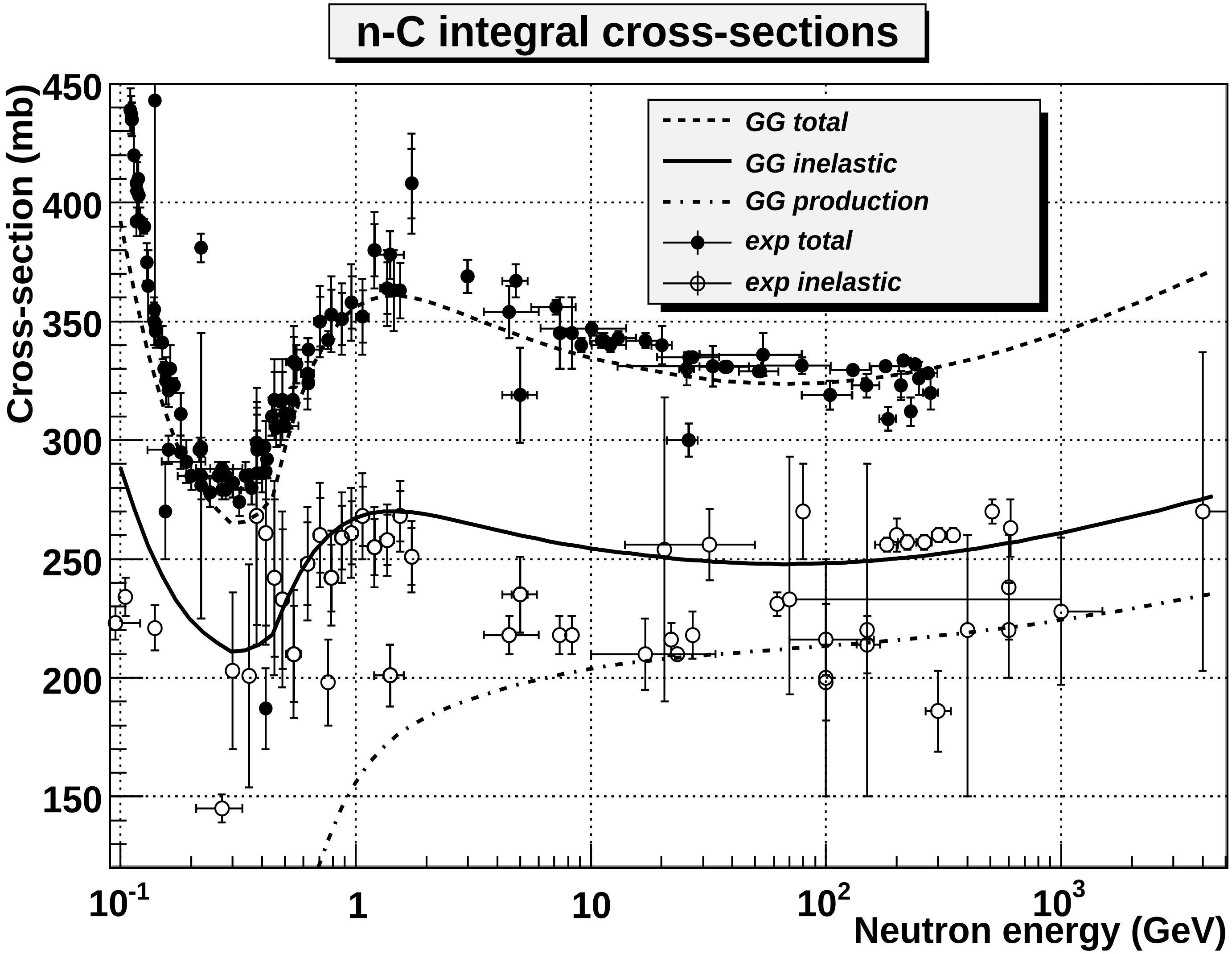

p-p inelastic cross-section
Geant4 fit
ihep-exp db data
Cross-section (mb)
0
10
20
30
40
50
60
70
80
90
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
P_p (GeV/c)



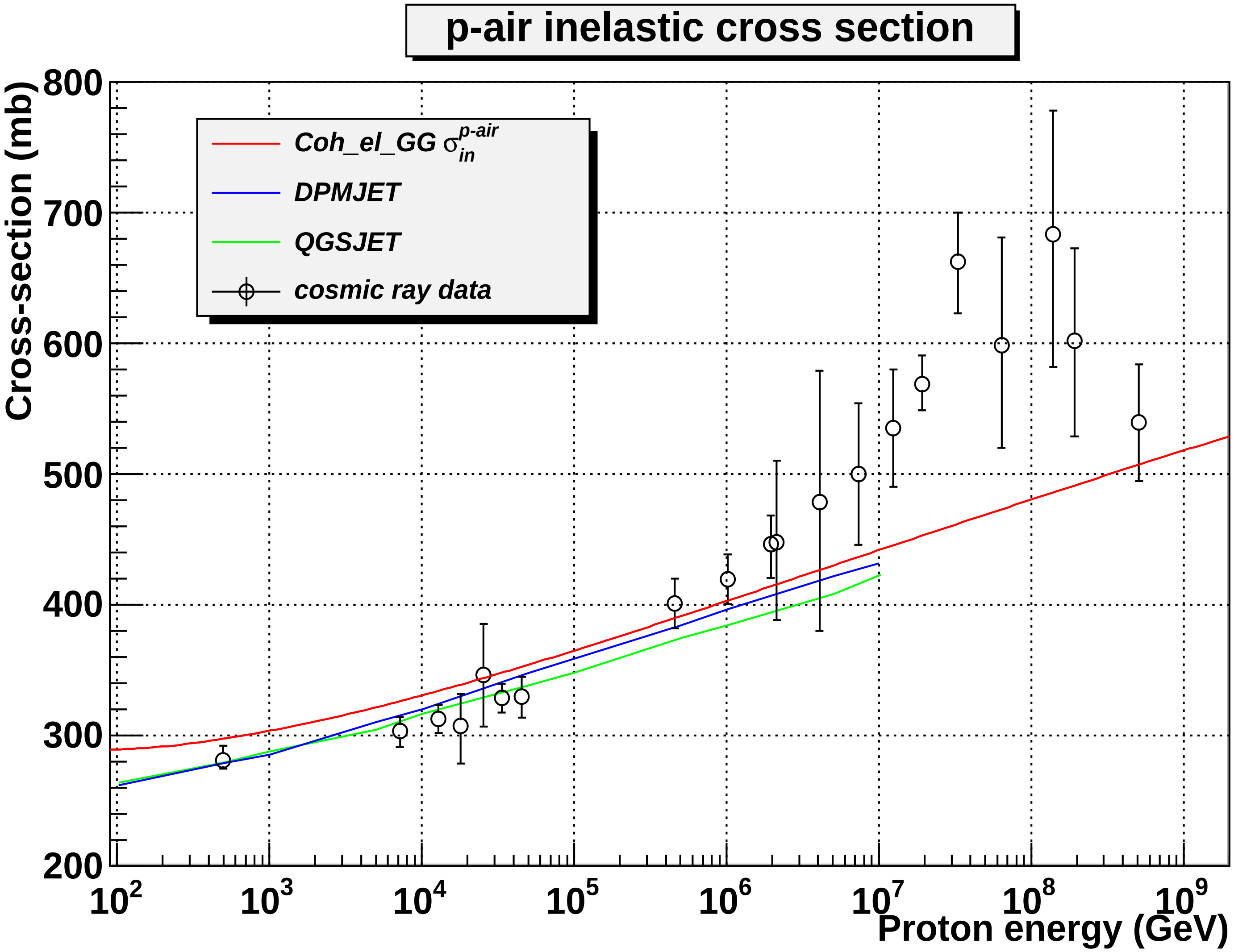
π^+-p total cross-section
Cross-section (mb)
220
200
180
160
140
120
100
80
60
40
20
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
P_{π^+} (GeV/c)
Geant4 fit
ihep-exp db data



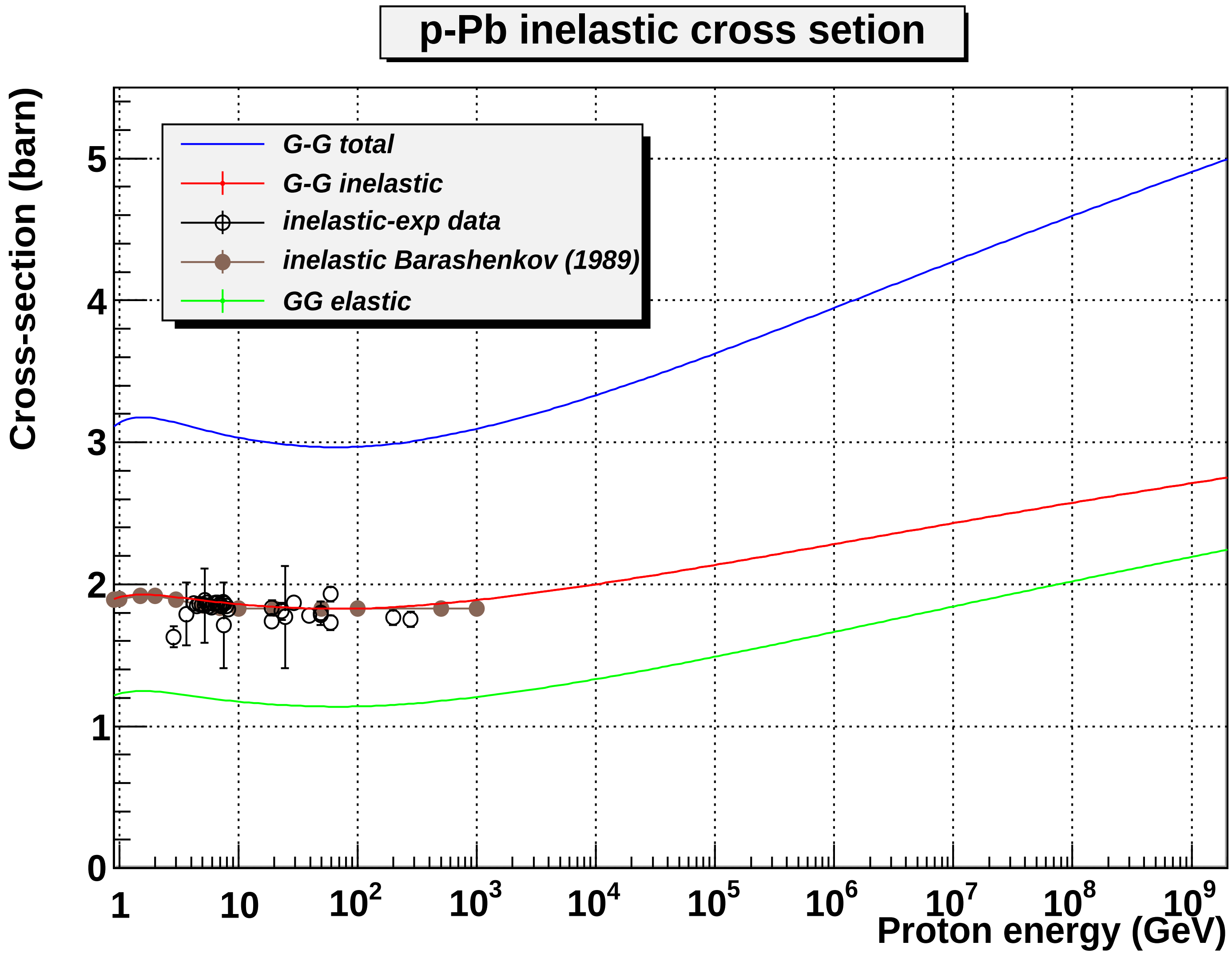
Ligh nucleus radii are implemented separately, while for $A > 10$ parametrization $R(A)$ is used.



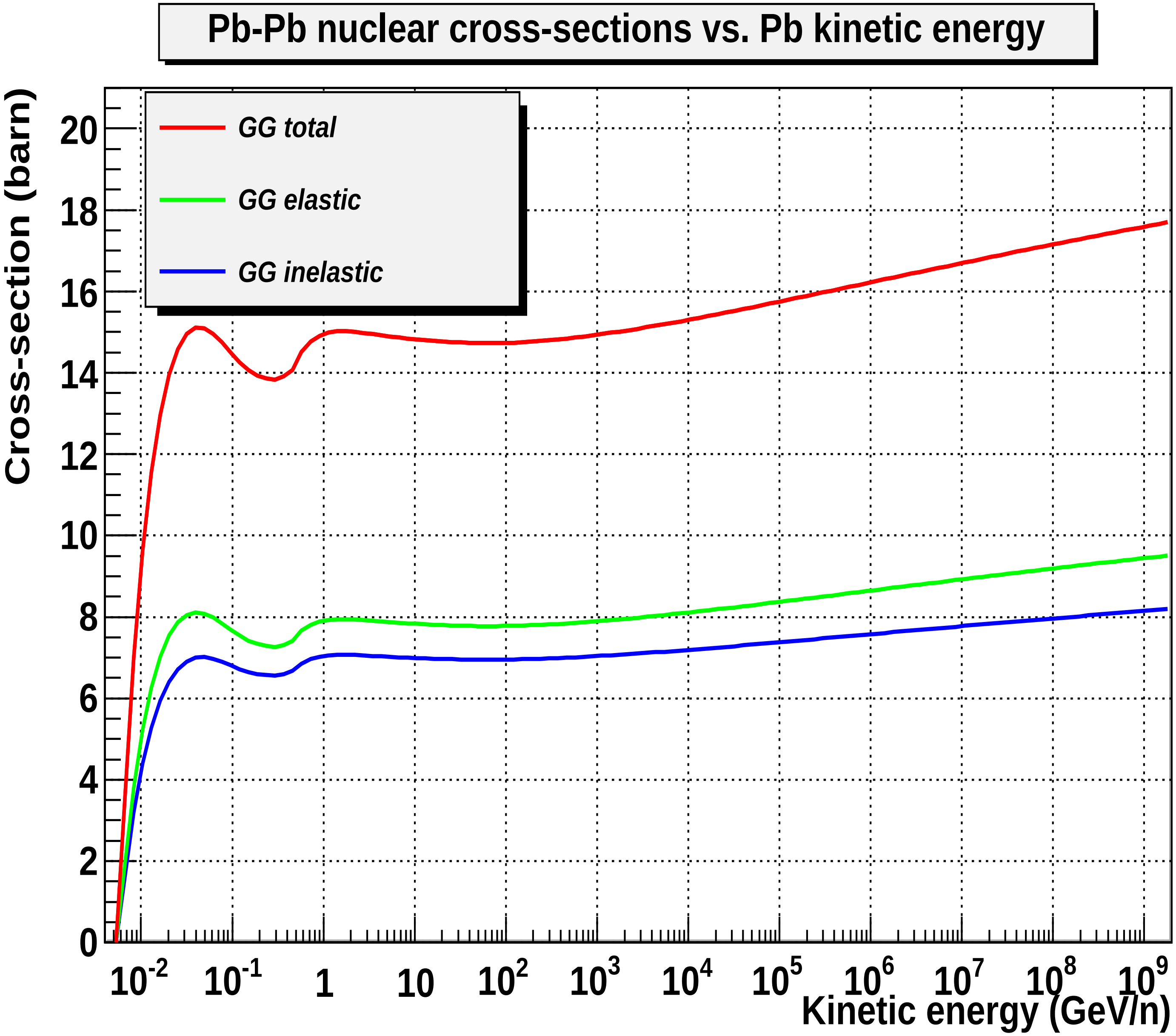
The total, inelastic and production n-C cross sections.



The GEANT4 p-air inelastic cross section vs. cosmic ray data and the predictions of DPMJET and QGSJET generators.



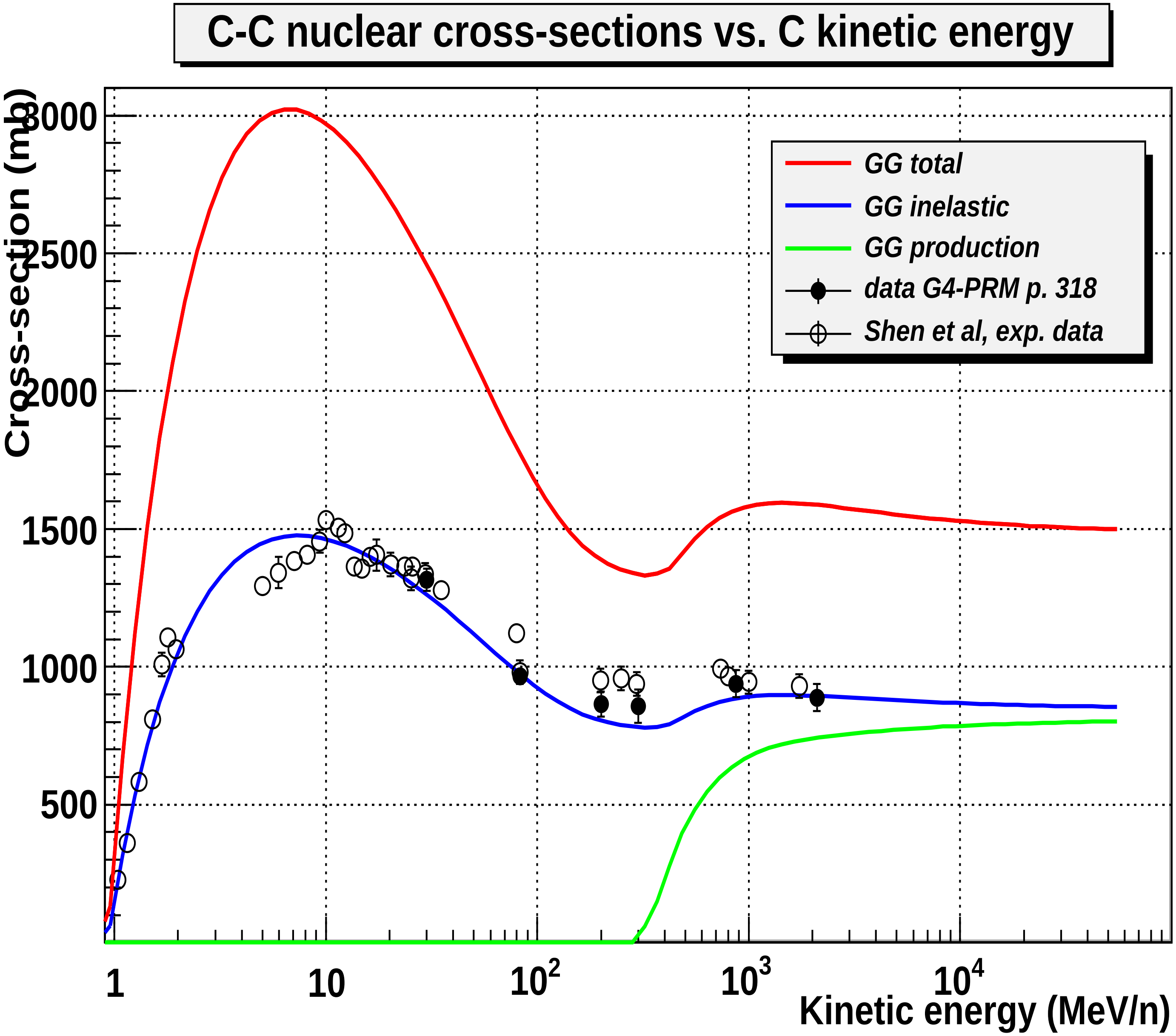
The p-Pb cross sections vs. the proton kinetic energy in the lead rest frame.

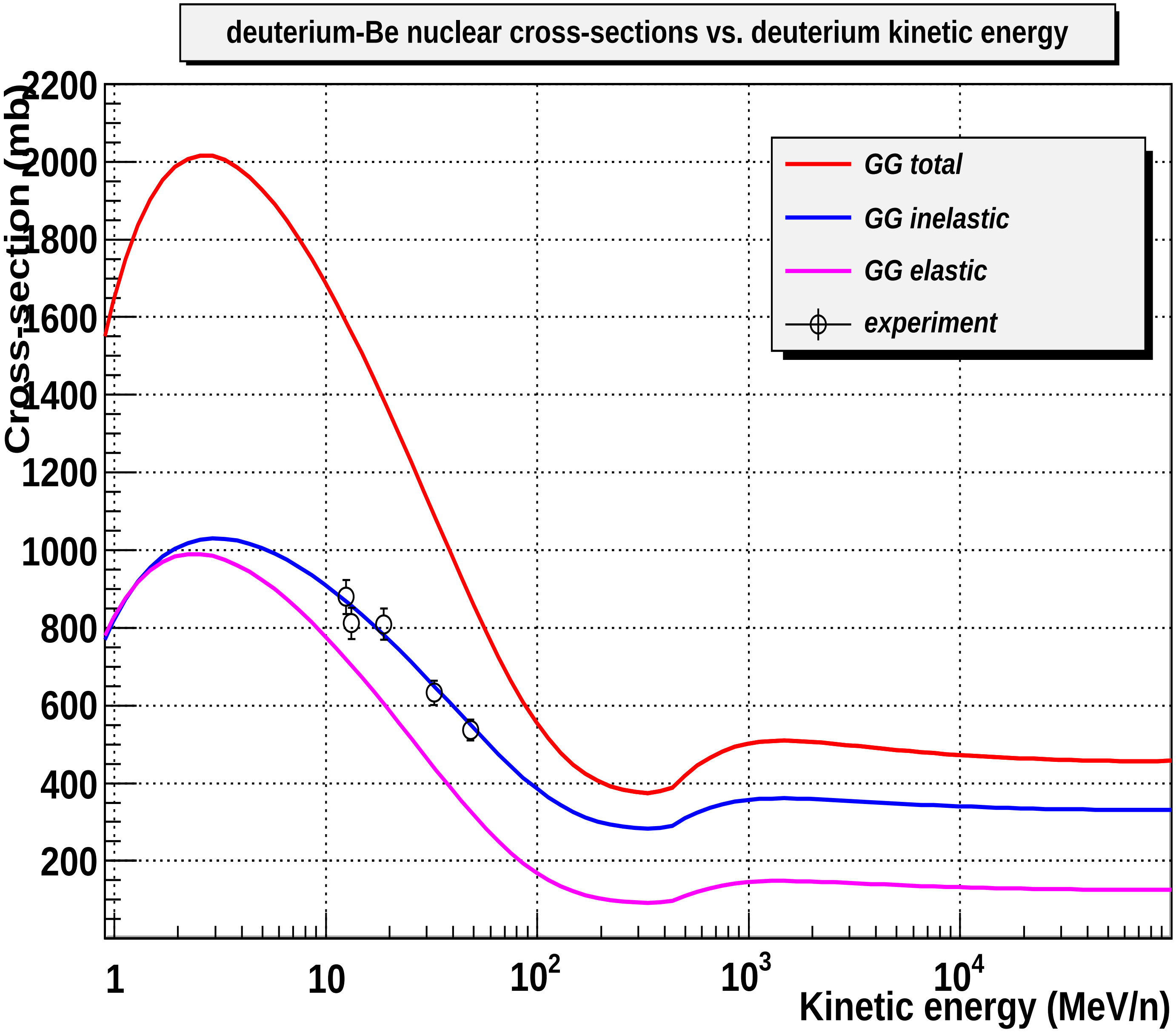

Pb-Pb nuclear cross-sections vs. Pb kinetic energy
GG total
GG elastic
GG inelastic
Cross-section (barn)
0
2
4
6
8
10
12
14
16
18
20
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
Kinetic energy (GeV/n)

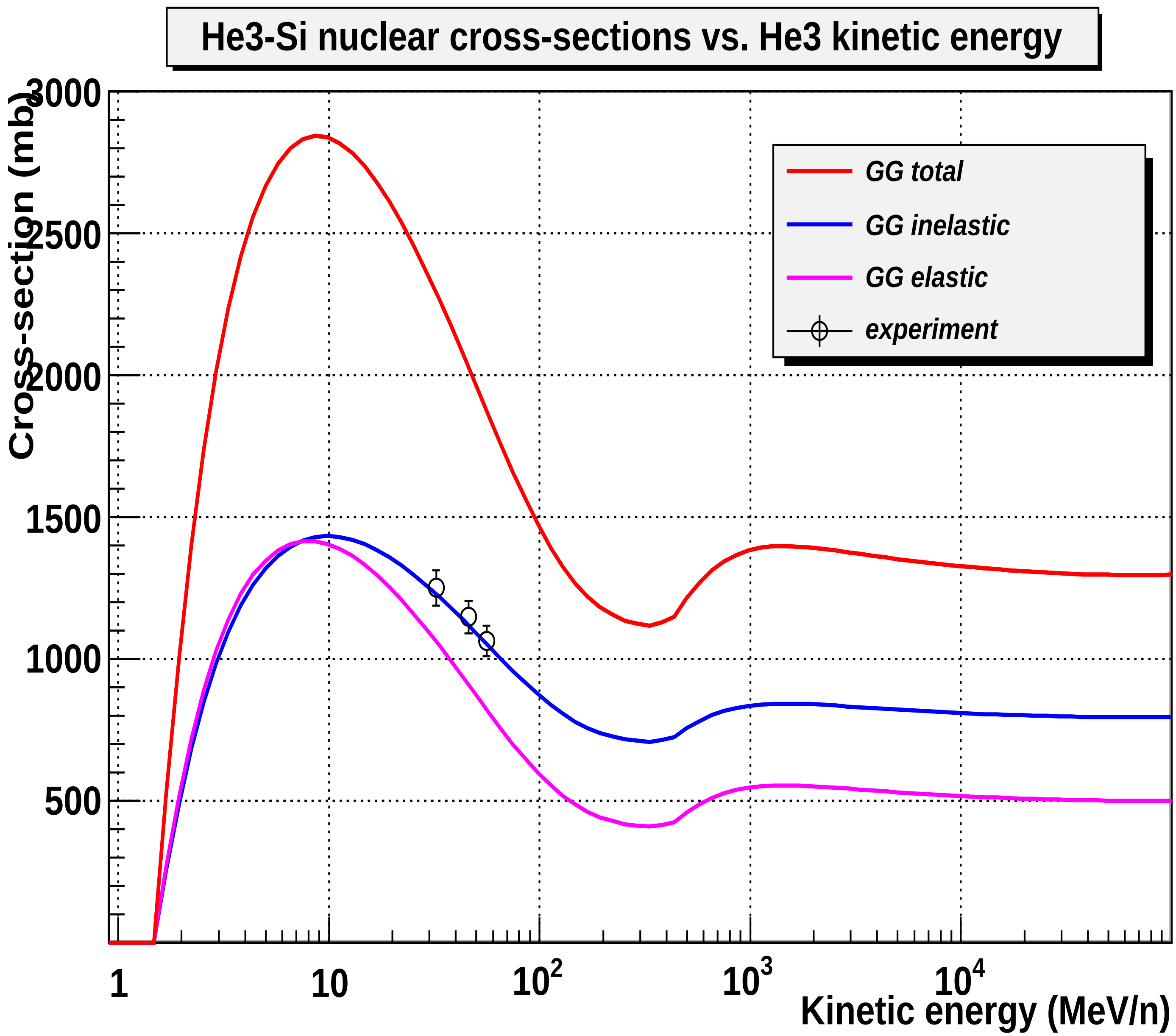
The Pb-Pb cross sections (barn) at $\sqrt{s}$= 7 TeV

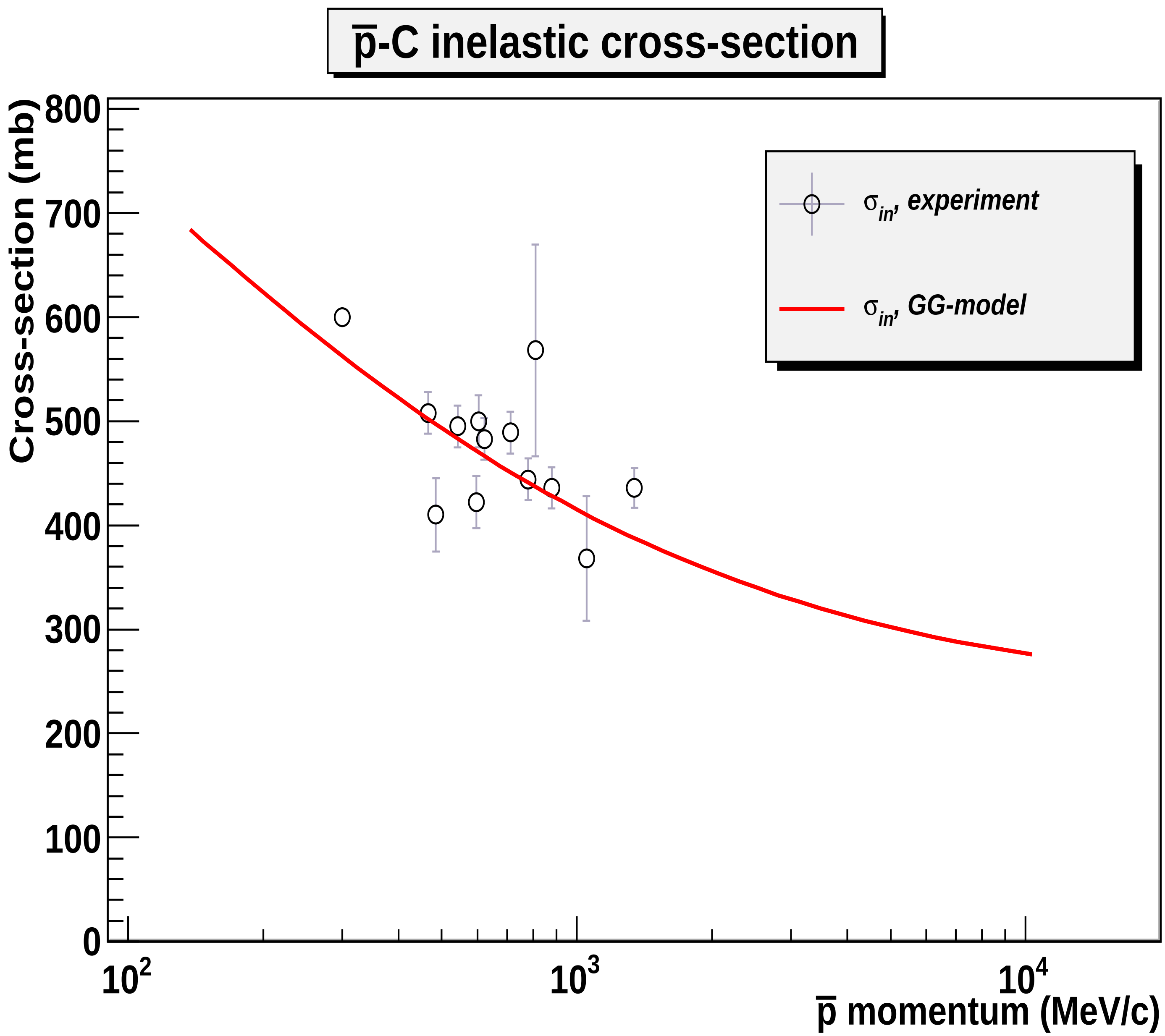
Cross section model	σ_{tot}	σ_{el}	σ_{in}
Glauber-Sitenko-Gribov	16.89	9.037	7.853
Dubna-DIOGEN Glauber	16.79	7.771	8.997

The models predict very close total cross sections, while they differ in the definitions of the elastic and inelastic cross sections. The performance gain is $\sim 10^4$


C-C nuclear cross-sections vs. C kinetic energy
Cross-section (mb)
3000
2500
2000
1500
1000
500
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG production
data G4-PRM p. 318
Shen et al, exp. data


deuterium-Be nuclear cross-sections vs. deuterium kinetic energy
Cross-section (mb)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG elastic
experiment


He3-Si nuclear cross-sections vs. He3 kinetic energy
Cross-section (mb)
3000
2500
2000
1500
1000
500
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG elastic
experiment


p̄-C inelastic cross-section
Cross-section (mb)
800
700
600
500
400
300
200
100
0
10^2
10^3
10^4
p̄ momentum (MeV/c)
σ_{in}, experiment
σ_{in}, GG-model

4 Conclusions

1. Fast Glauber-Sitenko-Gribov model provides the total, inelastic, production, elastic and quasi-elastic hadron-nucleus and nucleus-nucleus cross-sections in a wide range of energies and projectile-target combinations.

2. The model algorithm is fast and as robust as $\sigma^{NN}_{tot/in}$ parametrization.

3. The model was extended to high energies of the cosmic ray range using recent accurate measurements of the TOTEM collaboration.

4. Nucleus-nucleus cross sections have broad applications in nuclear medicine and astrophysics.

5. More extended comparison with experimental data and other models, tuning of the model parameters, testing and integration in the simulation physics lists are current plans.

References

[1] B.Z. Kopeliovich, Phys. Rev., C68 (2003) 044906.

[2] V.M. Grichine, EPJ C62 (2009) 399.

[3] V.M. Grichine, Nucl. Instr. and Meth., B267 (2009) 2460.