Cross sections of light nuclei in the Glauber-Gribov representation

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Abstract

The Glauber-Gribov representation of nucleus-nucleus cross sections is reviewed for light nuclei. The model provides fast and robust calculation of total, inelastic, elastic and production nucleus-nucleus cross sections. Comparisons with experimental data are presented in broad range of nucleus energies and weights.

1 Glauber-Gribov model for nucleus-nucleus cross-sections

The Glauber-Gribov model with Gaussian distributed of point-like nucleons in a nucleus results in the following nucleus-nucleus cross-sections:

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

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

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

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-setions.

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

2 The model parameters

The model is reduced to the selection of $\sigma_{tot/in}^{NN}$ and $R(A)$ values.

The nucleon-nucleon cross-sections are well tabulated and can be found in literature (PDG) or in Geant4 class G4HadronNucleonXsc.

$R(A)$ is the RMS radius of nucleon distribution inside the nucleus.

For low energies the inelastic and the total cross-sections are corrected for Coulomb barrier:

$$\sigma_{tot}^{A_p A_t} \to \sigma_{tot}^{A_p A_t} \left[1 - \frac{B_c}{T_{kin}^{cm}} \right], \quad B_c = \frac{\alpha \hbar c Z_p Z_t}{R_{min}},$$

where $R_{min} \sim R_t + R_p$, $(\alpha = e^2/\hbar c)$.

3 The light nucleus radii

The RMS radius of nucleon distribution inside a nucleus, $R(A)$ in the medium range of $A \leq 50$ is fitted in GEANT4 by the following expression:

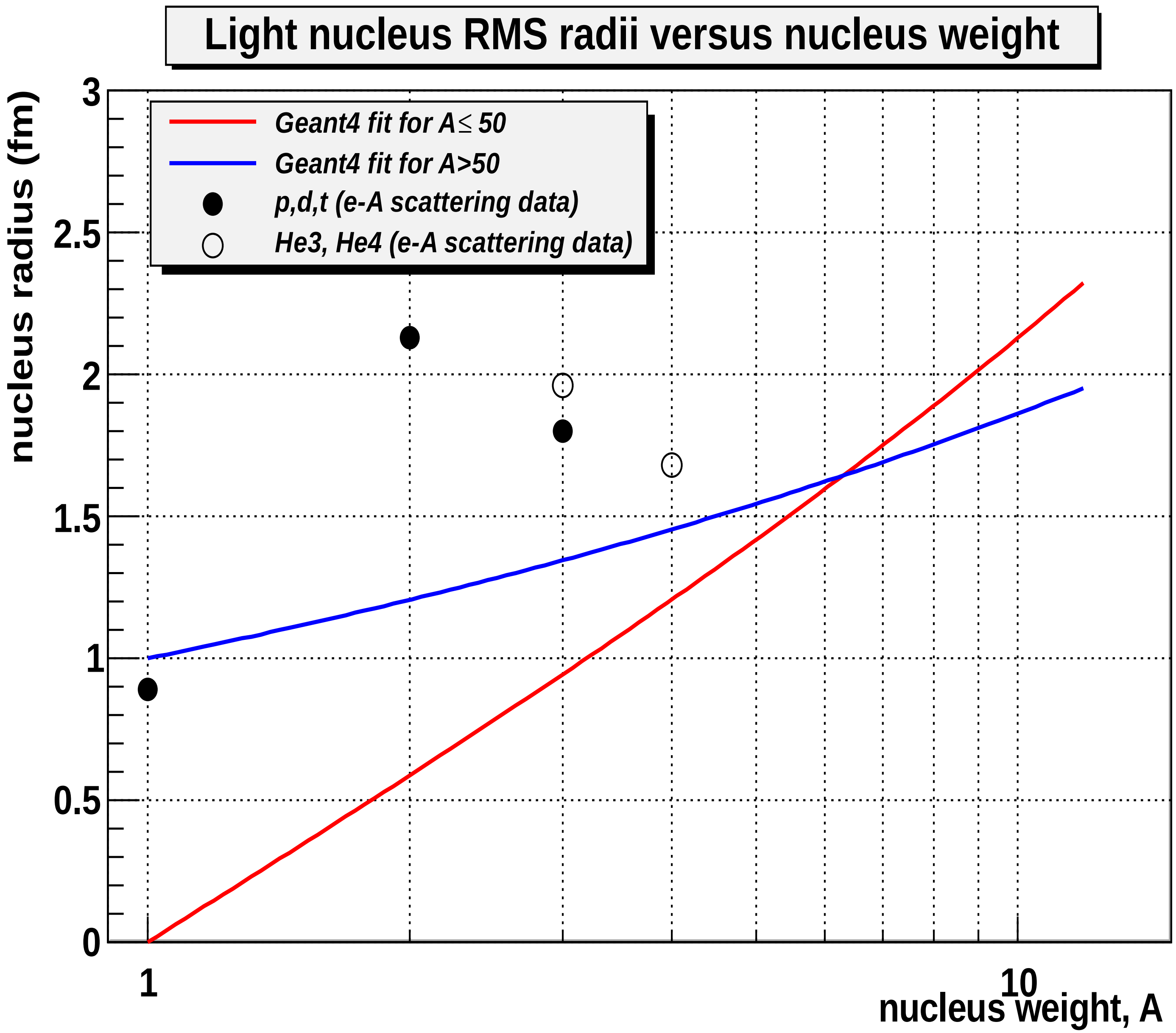
$$R \sim r_o(A)A^{1/3}(1 - A^{-2/3}),$$

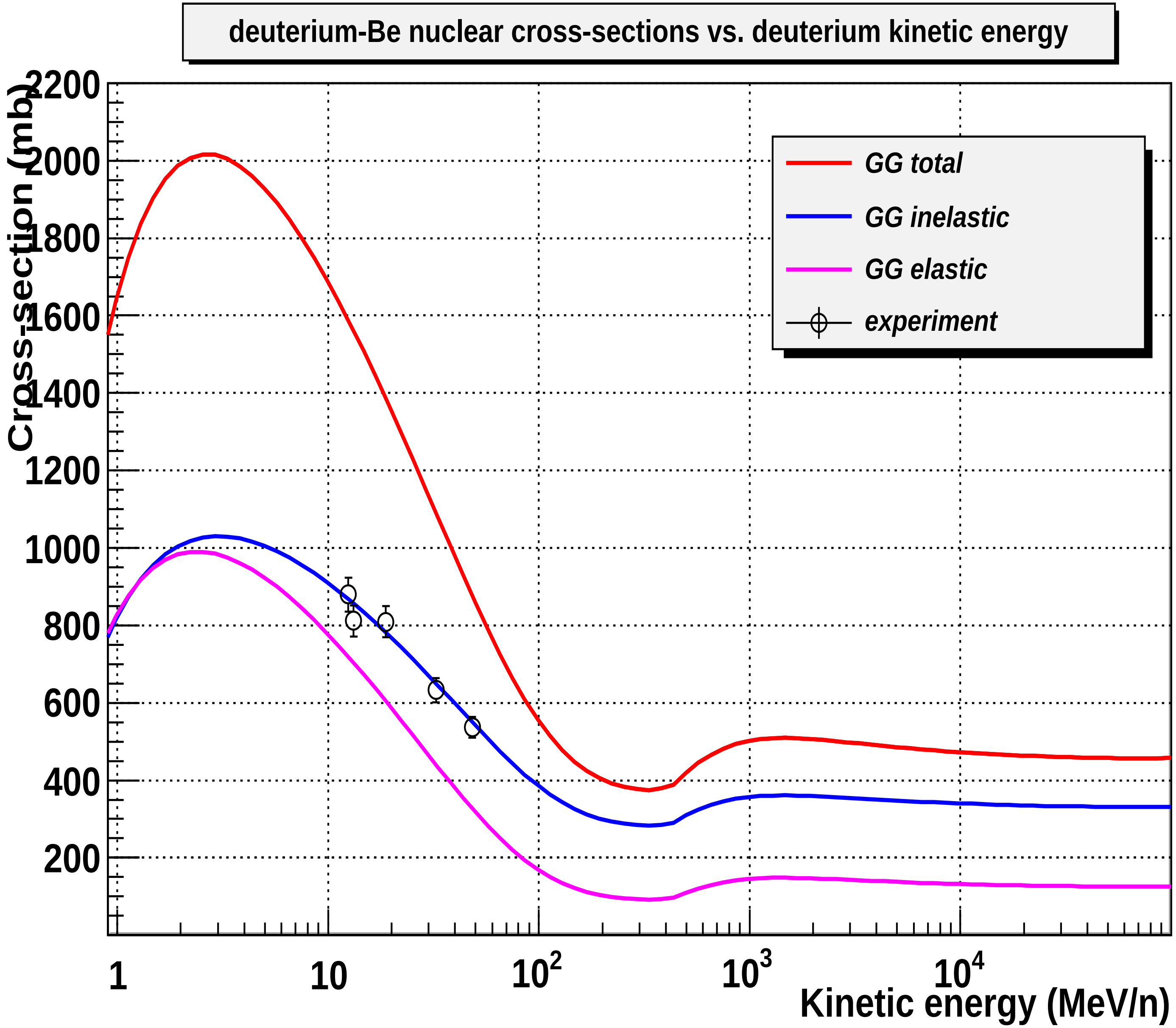
where $r_o(A) \sim$ 1.1-1.26 fm is fitted by experimental data. For heavy nuclei $A > 50$ the GEANT4 parametrization reads:

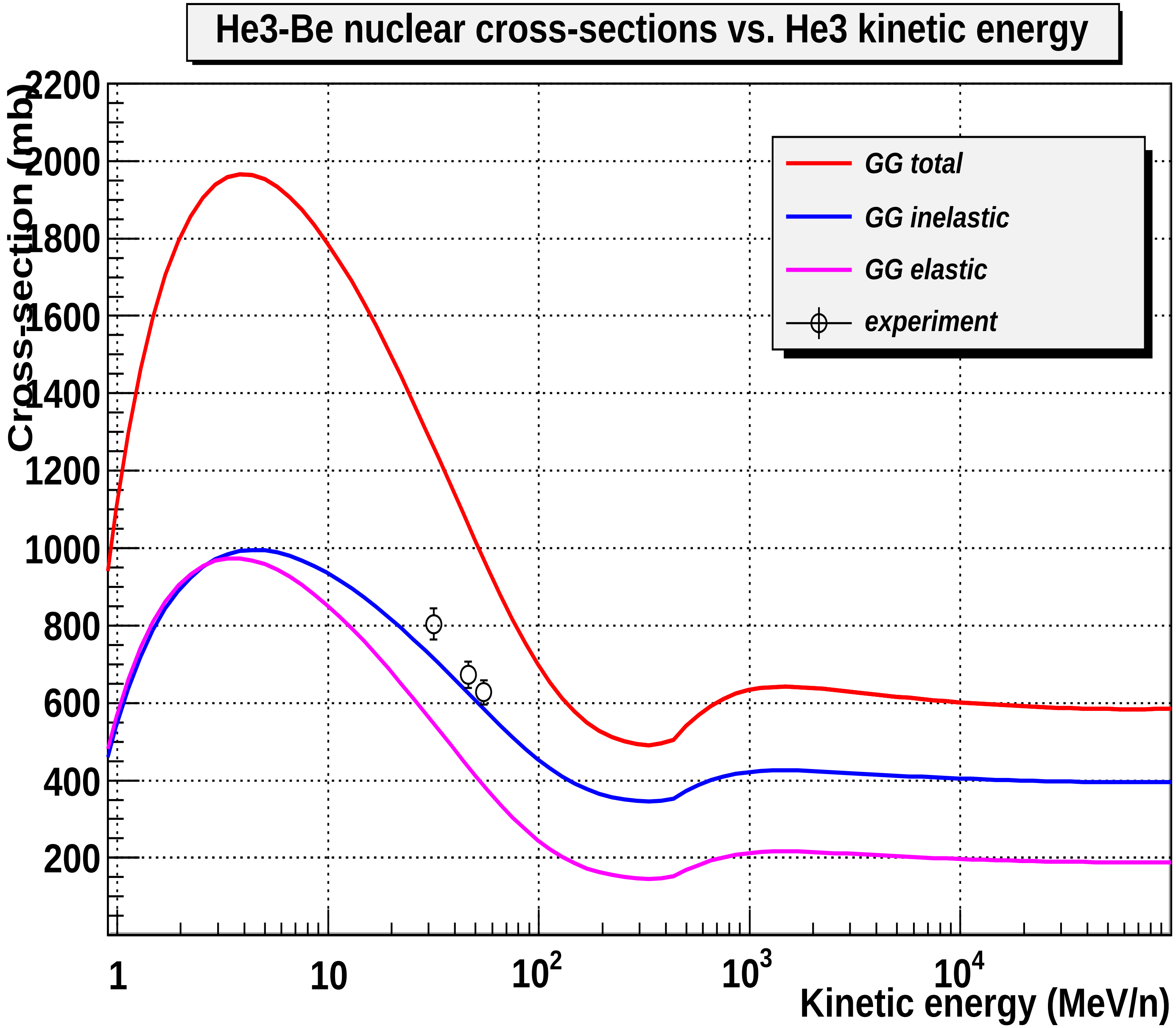
$$R \sim r_o(A)A^{0.27},$$

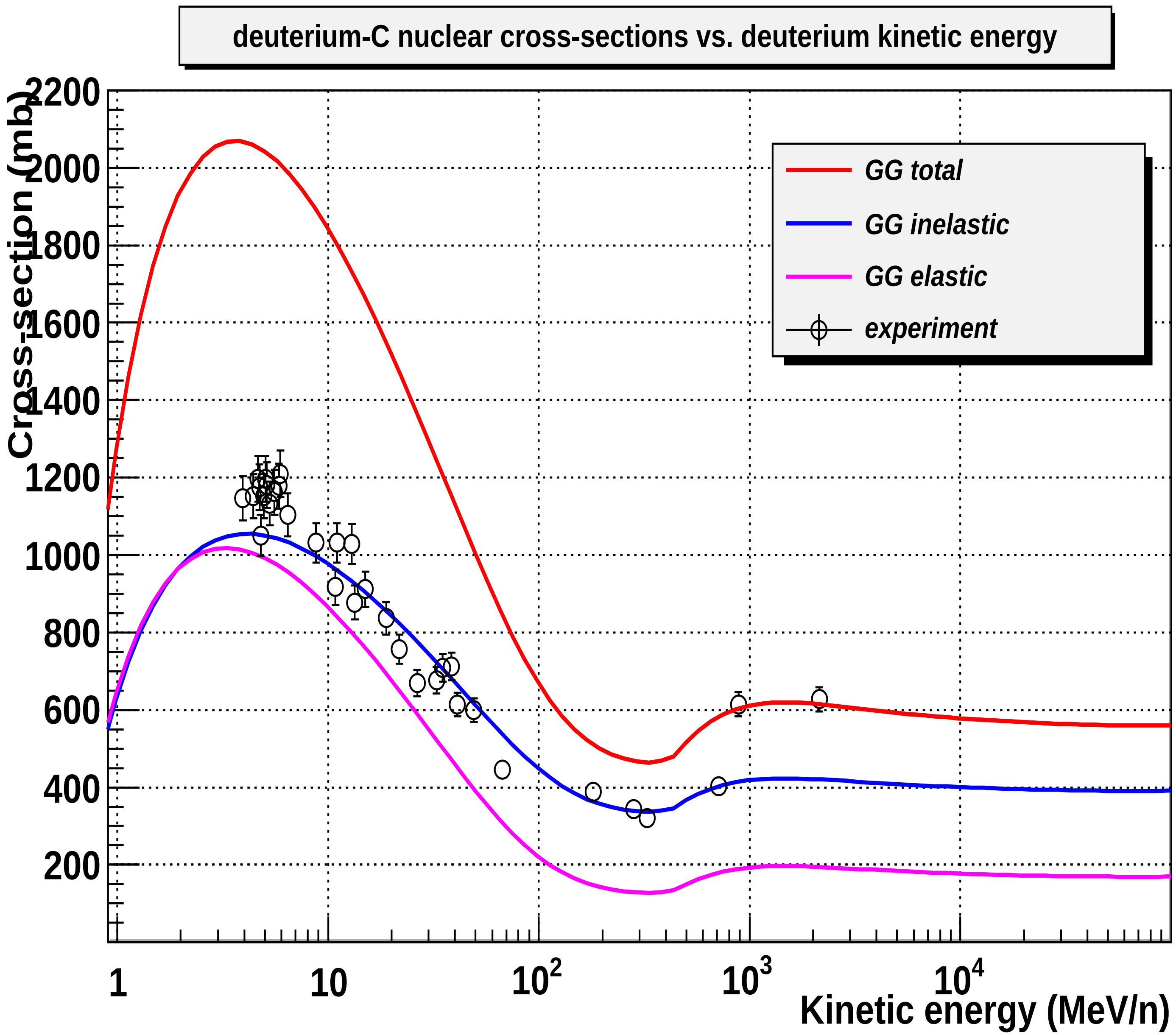
where $r_o(A) \sim 1$ fm is fitted by experimental data.

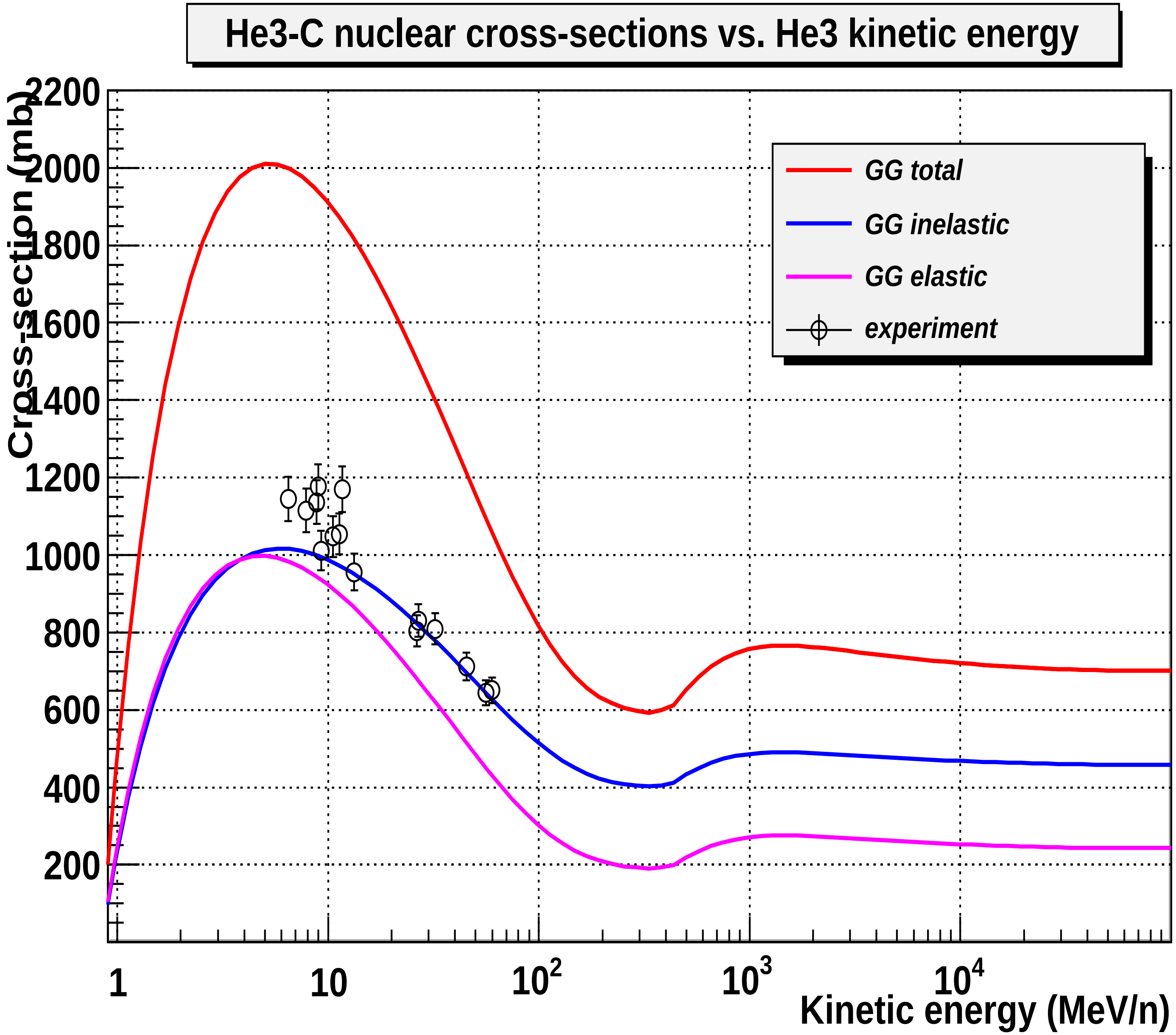
For light nuclei, however, these expressions do not describe experimental data (a compilation of different measurements is shown). The light nucleus-nucleus cross-section experimental data are in agreement with RMS radii extracted directly from electron-nucleus scattering experiments.

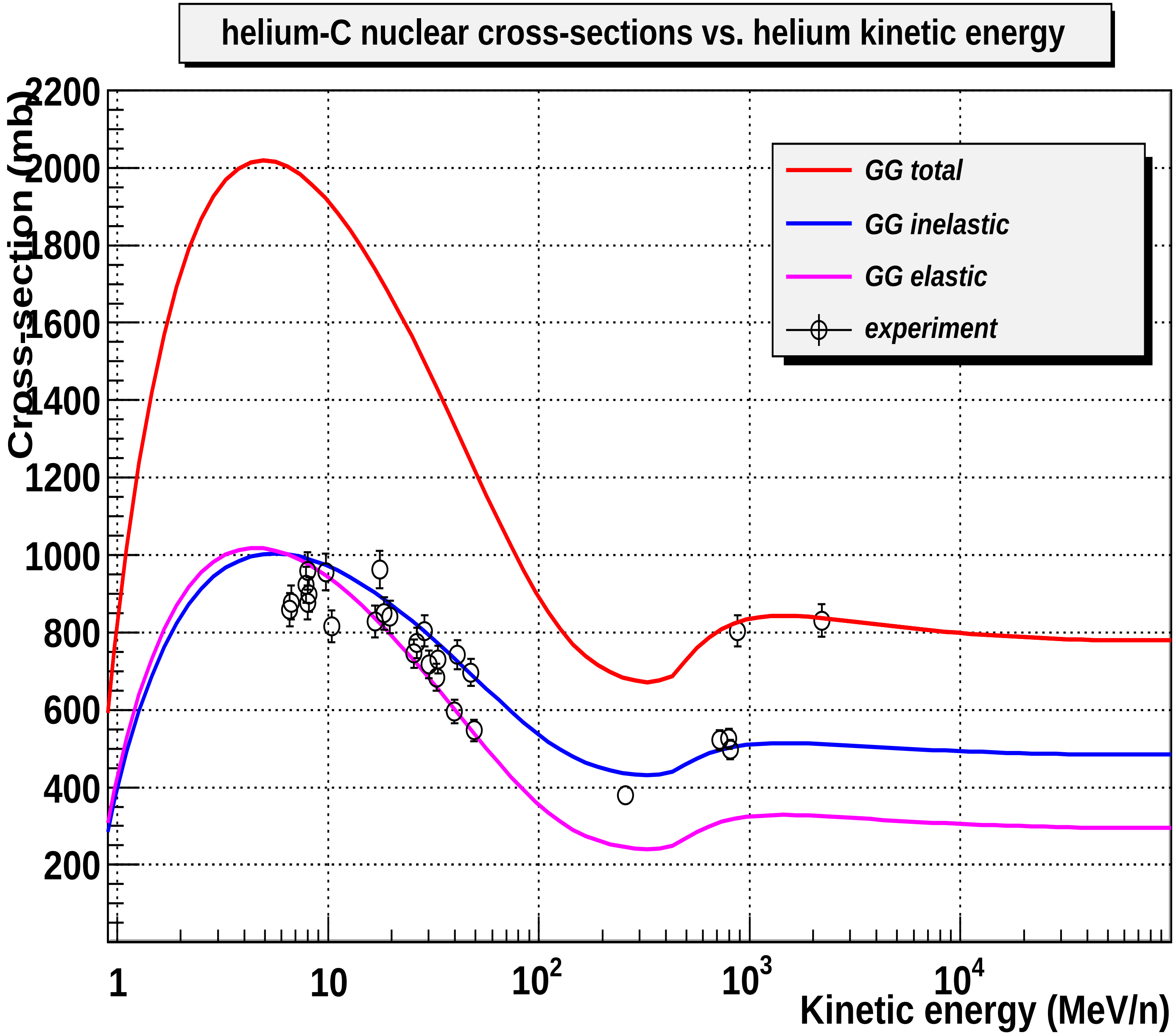

Light nucleus RMS radii versus nucleus weight
Geant4 fit for A≤ 50
Geant4 fit for A>50
p,d,t (e-A scattering data)
He3, He4 (e-A scattering data)
nucleus radius (fm)
3
2.5
2
1.5
1
0.5
0
1
10
nucleus weight, A

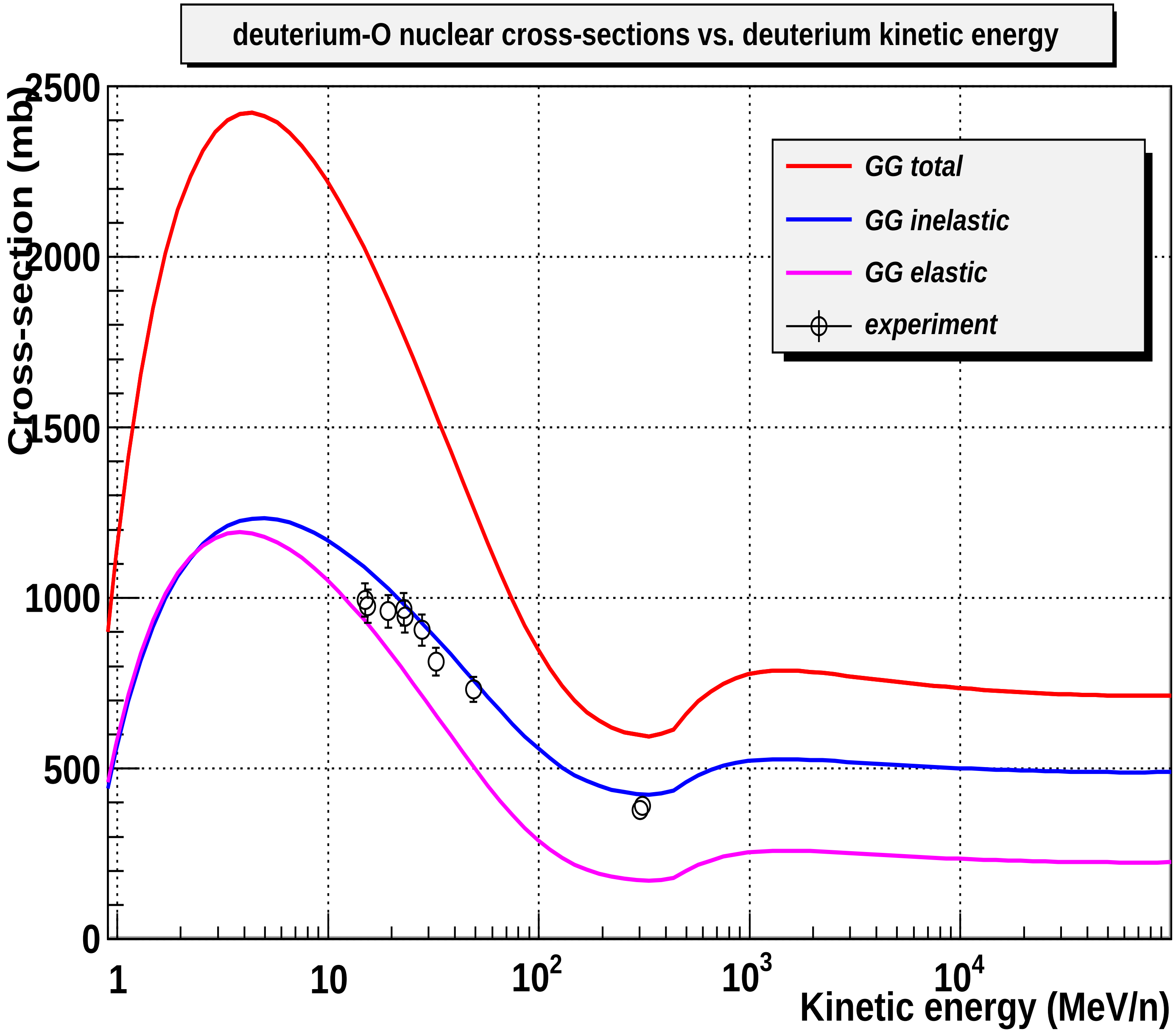

deuterium-Be nuclear cross-sections vs. deuterium kinetic energy
Cross-section (mb)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG elastic
experiment

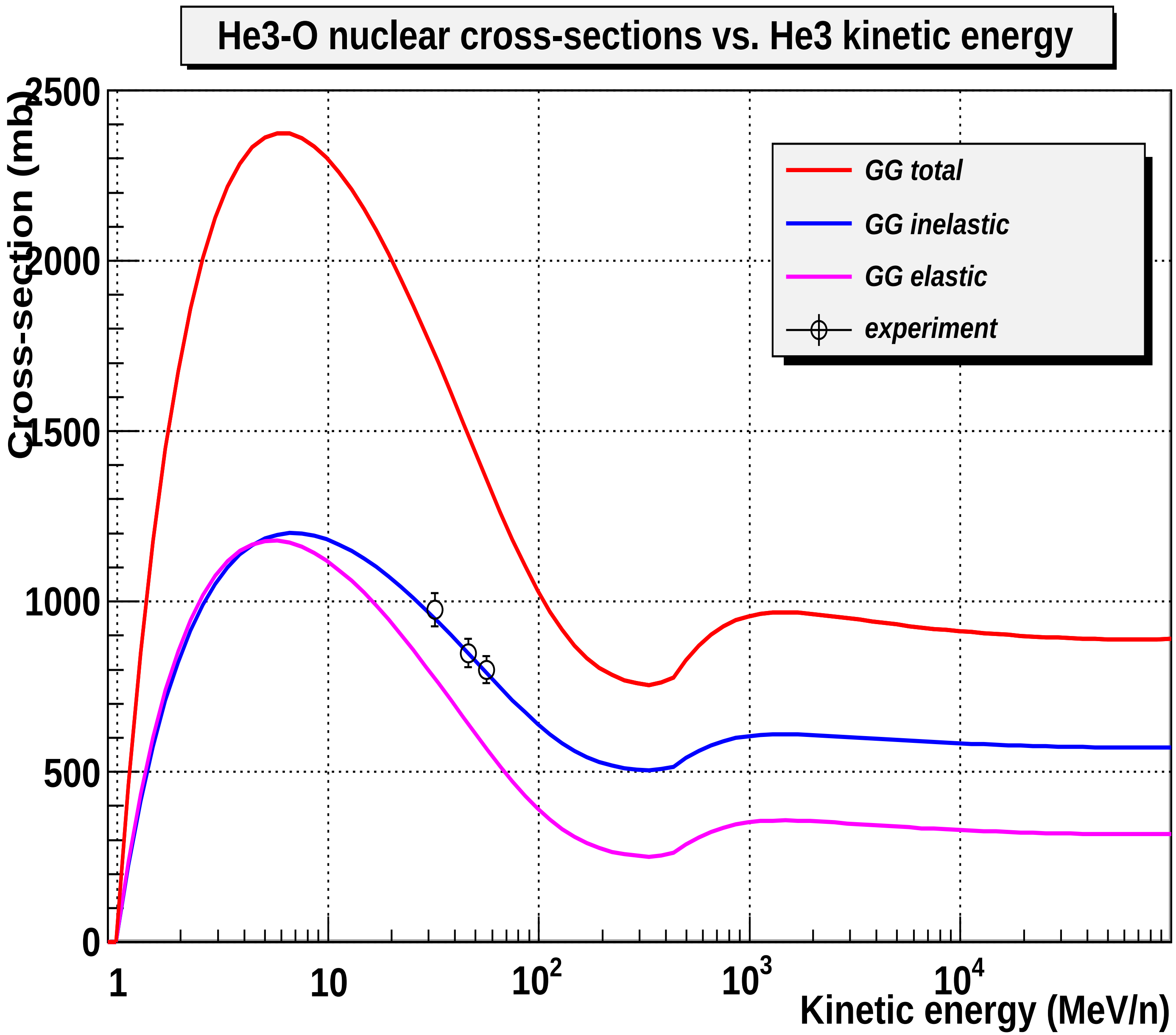

He3-Be nuclear cross-sections vs. He3 kinetic energy
Cross-section (mb)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG elastic
experiment

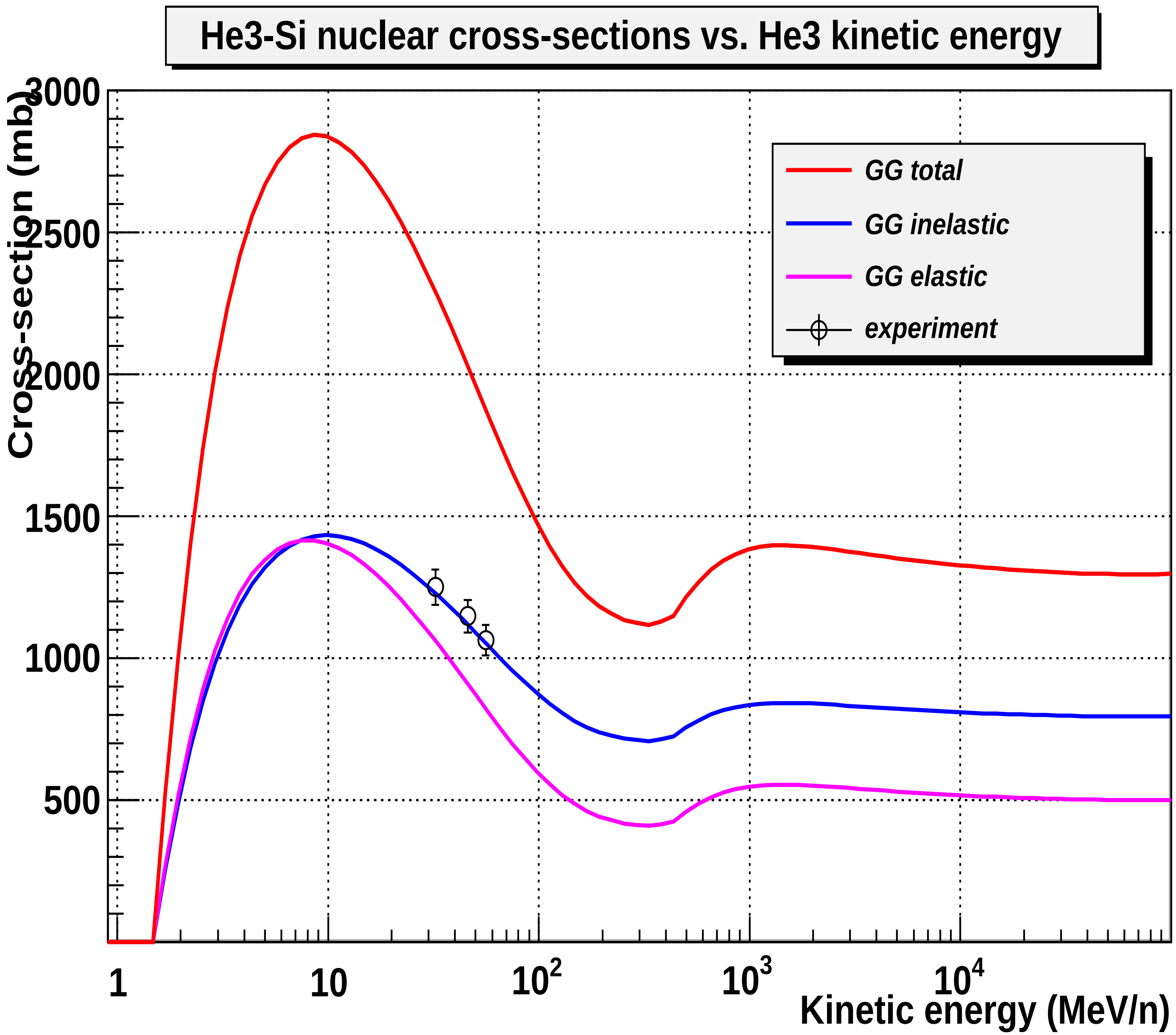

deuterium-C nuclear cross-sections vs. deuterium kinetic energy
Cross-section (mb)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG elastic
experiment

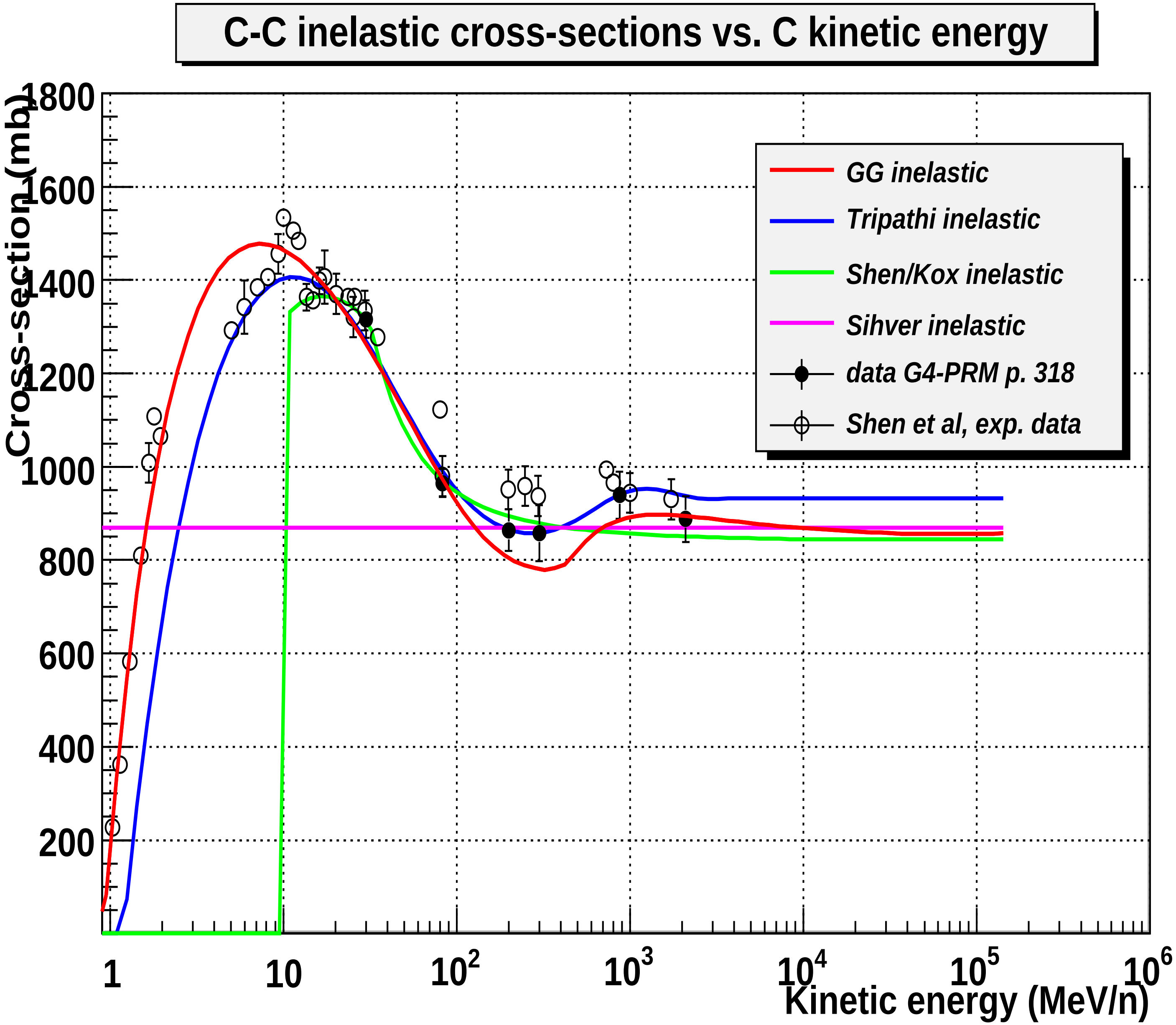

He3-C nuclear cross-sections vs. He3 kinetic energy
Cross-section (mb)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG elastic
experiment

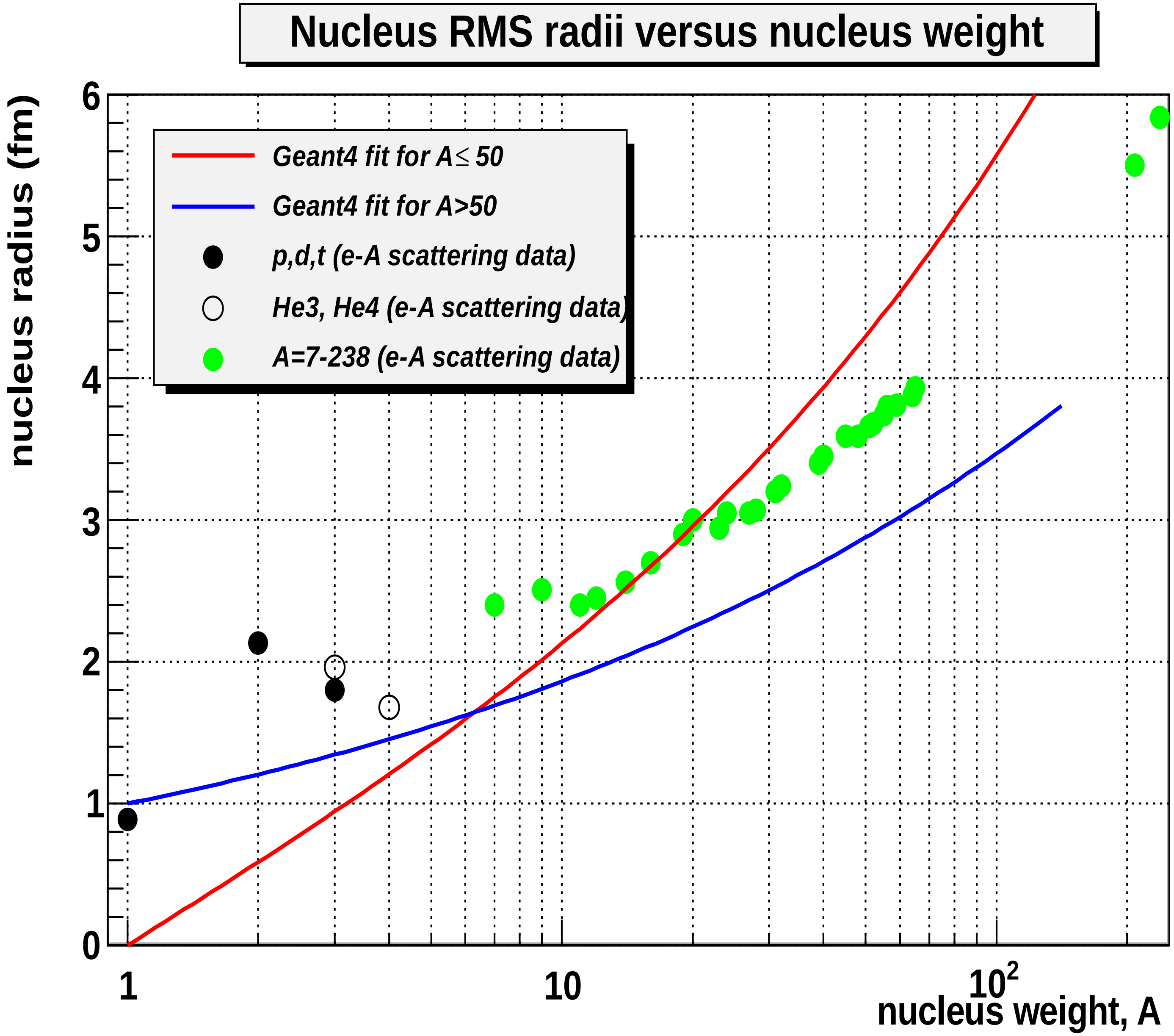

helium-C nuclear cross-sections vs. helium kinetic energy
Cross-section (mb)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG elastic
experiment


deuterium-O nuclear cross-sections vs. deuterium kinetic energy
Cross-section (mb)
2500
2000
1500
1000
500
0
1
10
10^2
10^3
10^4
Kinetic energy (MeV/n)
GG total
GG inelastic
GG elastic
experiment


He3-O nuclear cross-sections vs. He3 kinetic energy
Cross-section (mb)
2500
2000
1500
1000
500
0
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


C-C inelastic cross-sections vs. C kinetic energy
Cross-section (mb)
1800
1600
1400
1200
1000
800
600
400
200
1
10
10^2
10^3
10^4
10^5
10^6
Kinetic energy (MeV/n)
GG inelastic
Tripathi inelastic
Shen/Kox inelastic
Sihver inelastic
data G4-PRM p. 318
Shen et al, exp. data


Nucleus RMS radii versus nucleus weight
nucleus radius (fm)
nucleus weight, A
Geant4 fit for A≤ 50
Geant4 fit for A>50
p,d,t (e-A scattering data)
He3, He4 (e-A scattering data)
A=7-238 (e-A scattering data)
0
1
2
3
4
5
6
1
10
10^2

4 Summary

1. Glauber-Gribov approach provides the total, inelastic, and elastic light nucleus-nucleus cross-sections in a wide range of energies and projectile-target combinations.

2. The model algorithm is fast and as robust as $\sigma^{NN}_{tot/in}$ and $R(A)$ parameterizations.

3. The model is in agreement with the experimental data for the inelastic cross-section. The model is applicable starting from ~ 1 MeV/n up to TeV/n range (ALICE, Pb-Pb data). The both limits are defined mostly by the accuracy of the $\sigma^{NN}_{tot/in}$, $R(A)$ parameterizations and the Coulomb barrier phenomenology.