Hadron-Nucleus Cross Sections and Ratios

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Abstract

Hadron-nucleus cross sections are discussed. Models based on optical approach as well as simplified Glauber theory are considered. Different Geant4 models are compared with experimental data. Quai-elastic and sing-diffration ratios are discussed.

1 Introduction

Here it is reported on verification of total and inelastic cross-sections for hadrons on different targets. The definitions are: $\sigma_{tot} = \sigma_{in} + \sigma_{el}$, and $\sigma_{in} = \sigma_{prod} + \sigma_{qel}$. GEANT4 has (historically) the following models:

1. G4HadronCrossSections class for inelastic and elastic hadron (inelastic and elastic) cross sections in the spirit of GHEISHA.
2. G4Proton/NeutronInelasticCrossSection class for HPW-Axen parametrization model. Inelastic cross section only.
3. G4Pi/ Nucleon NuclearCrossSection class for Barashenkov (optical) data interpolation for pions/nucleons on nuclei. Total, inelastic and elastic (tot-in) cross sections are available.
4. G4GlauberGribovCrossSection class for total and inelastic (also production and single-diffraction!) hadron cross sections in the spirit of Glauber model with Gribov correction. $\sigma_{el} = \sigma_{tot} - \sigma_{in}$.

Experimental data were taken from http://wwwppds.ihep.su IHEP-PDG database, and Dubna set http://wwwnea.fr/html/dbdata/bara.html.

2 Barashenkov Method

The Barashenkov interpolation is essentially based on quasi-optical model for high energies (T > 2 GeV) and on phenomenology like $\pi r_o A^{2/3}$, $r_o \sim 1$ fm with corrections. The total, inelastic (and elastic) cross sections are interpolated using:

$$\sigma(T, A) = \pi \left[r_o A^{1/3} + \lambda(T, A) \right]^2 f(T) \phi(A)^{\alpha(T)},$$

where λ is de Brojlie length of projectile in CM system, T is the kinetic energy of projectile in laboratory system, A is the atomic weight, and $r_o \sim 1$ fm. Functions $f(T)$, $\phi(A)$ and $\alpha(T)$ are series like:

$$\sum_i a_i T^{b_i} \quad \text{and} \quad \sum_i a_i A^{b_i}.$$

The general disadvantage of optical models is the prediction of constant cross-sections for very high energies. Experimental data show, however, small relativistic rise of hadron-nucleus cross-sections. This is the reason to consider Glauber model for the description of hadron-nucleus cross-sections in the high (more than 100 GeV) energy region.

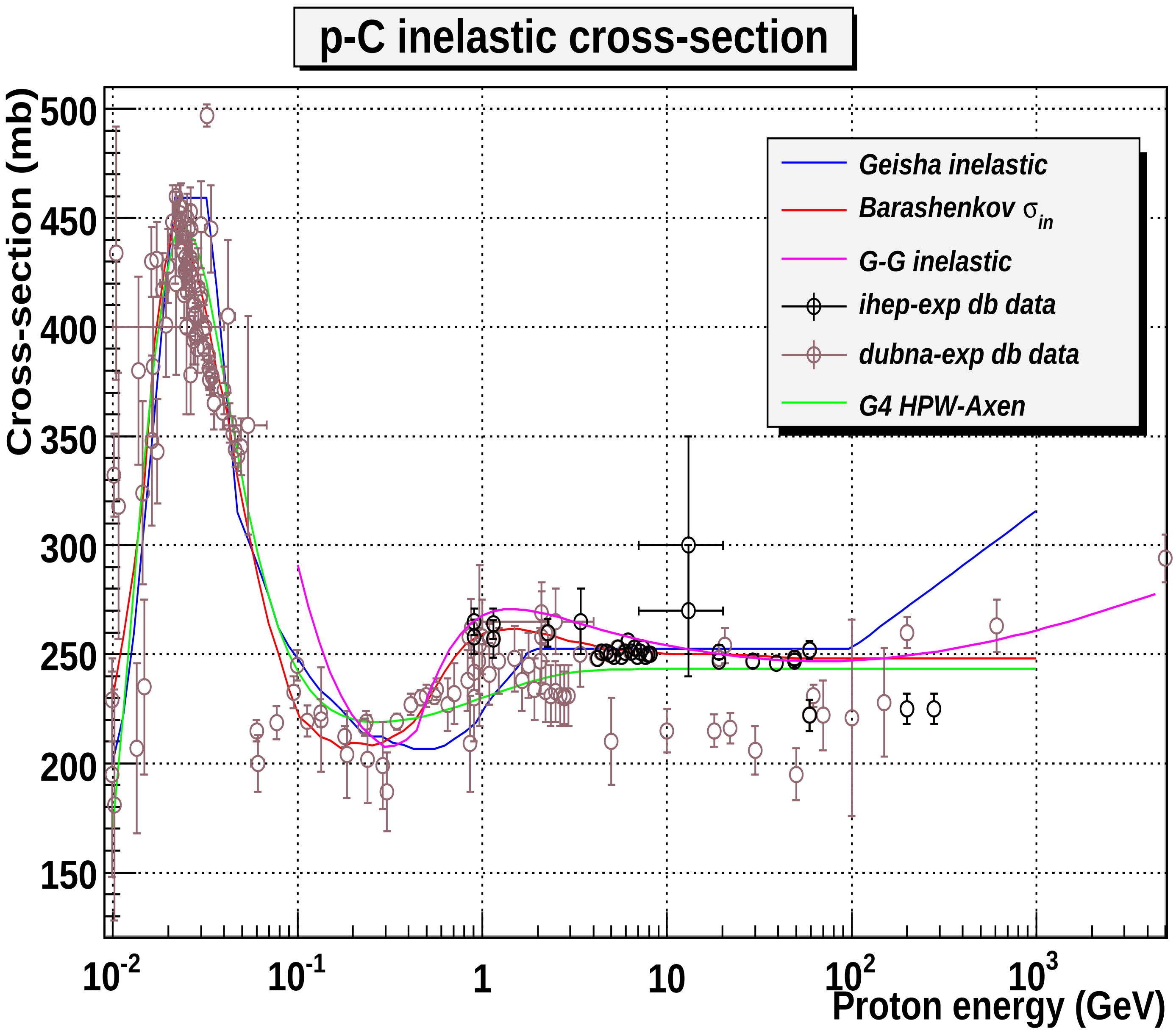
3 Simplified Glauber model

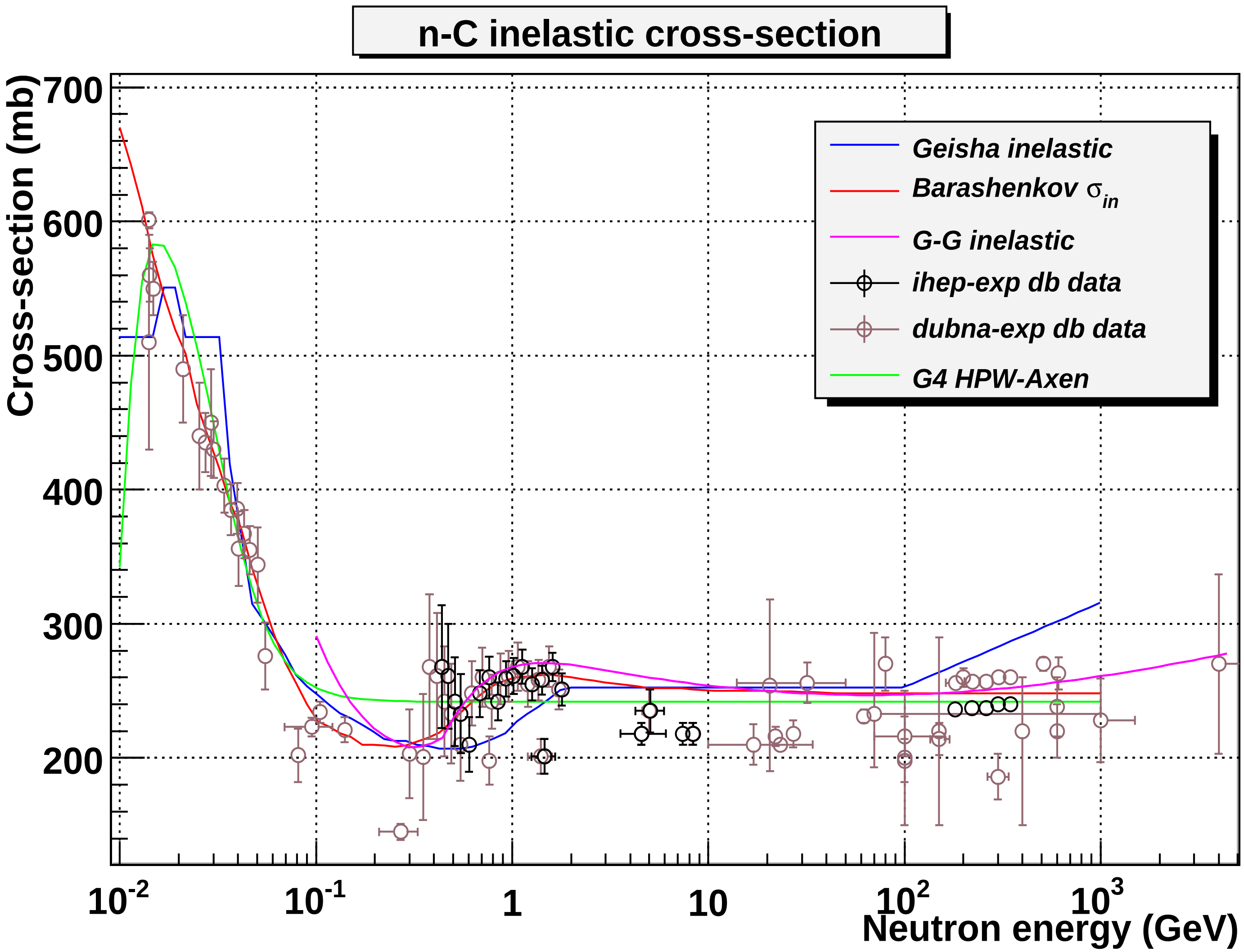
Simplified (Gauss distributed point-like nucleons) Glauber model cross sections read:

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

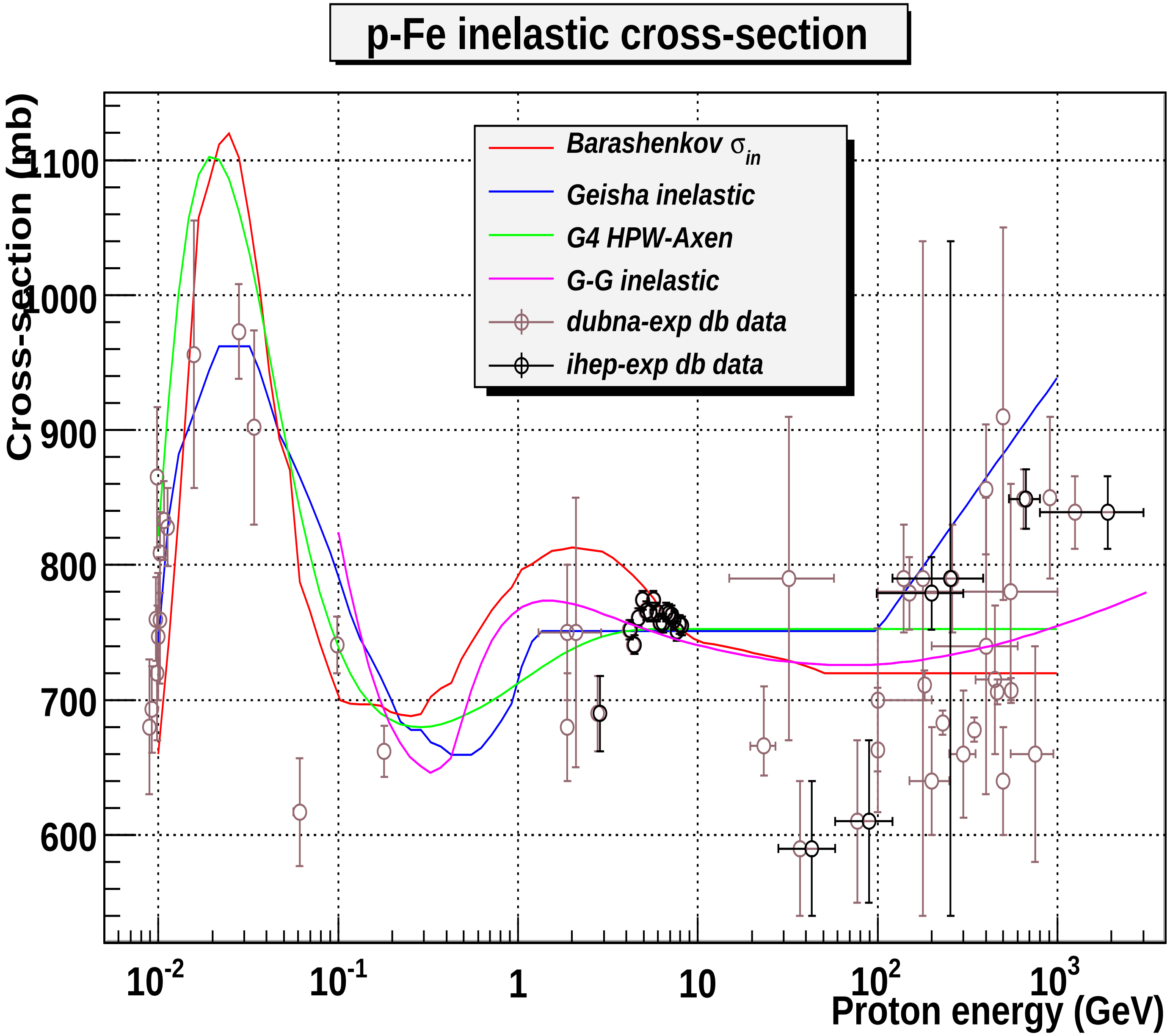
Where σ_{tot}^{hA}, σ_{in}^{hA}, and σ_{el}^{hA}, are total, inelastic and elastic cross sections, respectively.

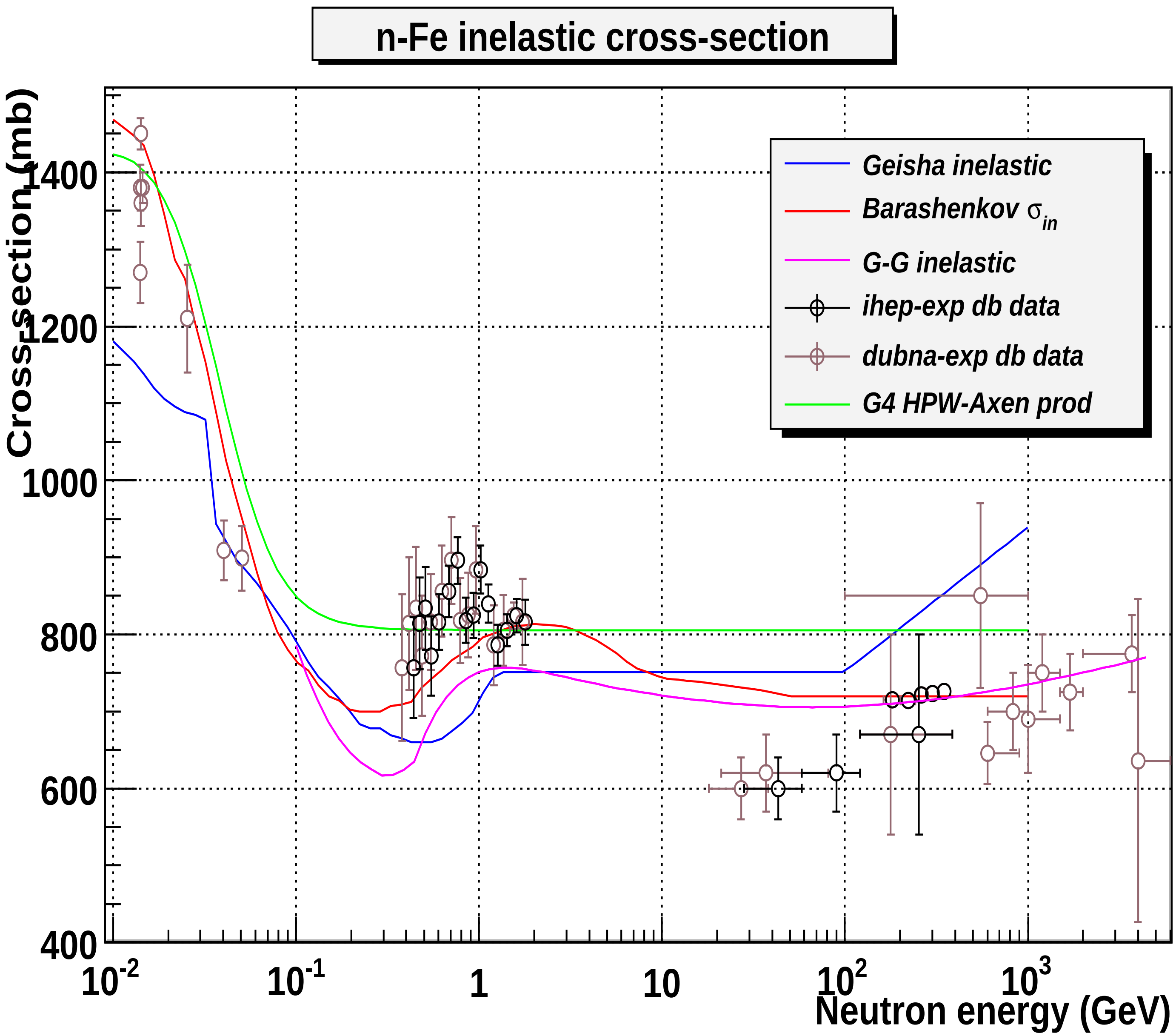
The model is reduced to the selection of σ_{tot}^{hN} and $R(A)$ values. We use the latest edition of PDG and GEANT4 parameterizations for σ_{tot}^{hN}, including the total cross sections of p, $\bar{p}$, n, $\pi^{\pm}$, $K^{\pm}$ and Σ^{-} on protons and neutrons (http://pdg.lbl.gov/2006/reviews/hadronicrpp.pdf). For known cross sections on proton and neutron, $A\sigma_{tot}^{hN} = N_p\sigma_{tot}^{hp} + N_n\sigma_{tot}^{hn}$, where N_p and N_n are the number of protons and neutrons in the nucleus. The nuclear radius is parametrized by $R(A) = r_o A^{\frac{1}{3}} f(A)$, $r_o \sim 1.1\ fm$, where for $A > 21,\ f(A) < 1$, while in the opposite case $3 < A < 21,\ f(A) > 1$ in the limits of 20%. Below are the model predictions for the total neutron cross sections on different targets.


p-C inelastic cross-section
Cross-section (mb)
500
450
400
350
300
250
200
150
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Proton energy (GeV)
Geisha inelastic
Barashenkov σ_{in}
G-G inelastic
ihep-exp db data
dubna-exp db data
G4 HPW-Axen

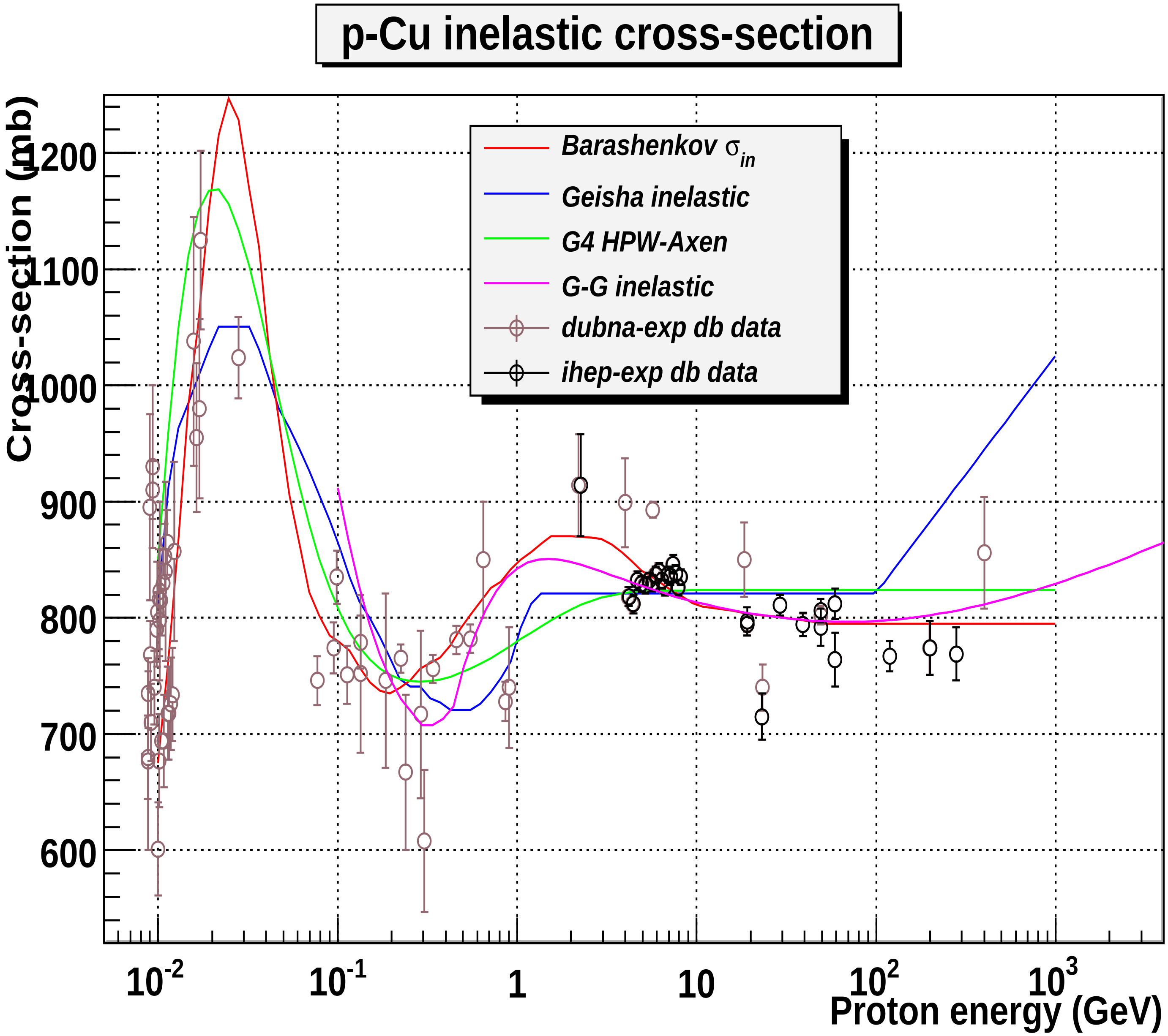


In some cases (see below) inelastic data from http://wwwnea.fr/html/dbdata/ bara.html are corrected on quasi-elastic cross sections in the form $0.1\pi r_o^2 A^{2/3}$

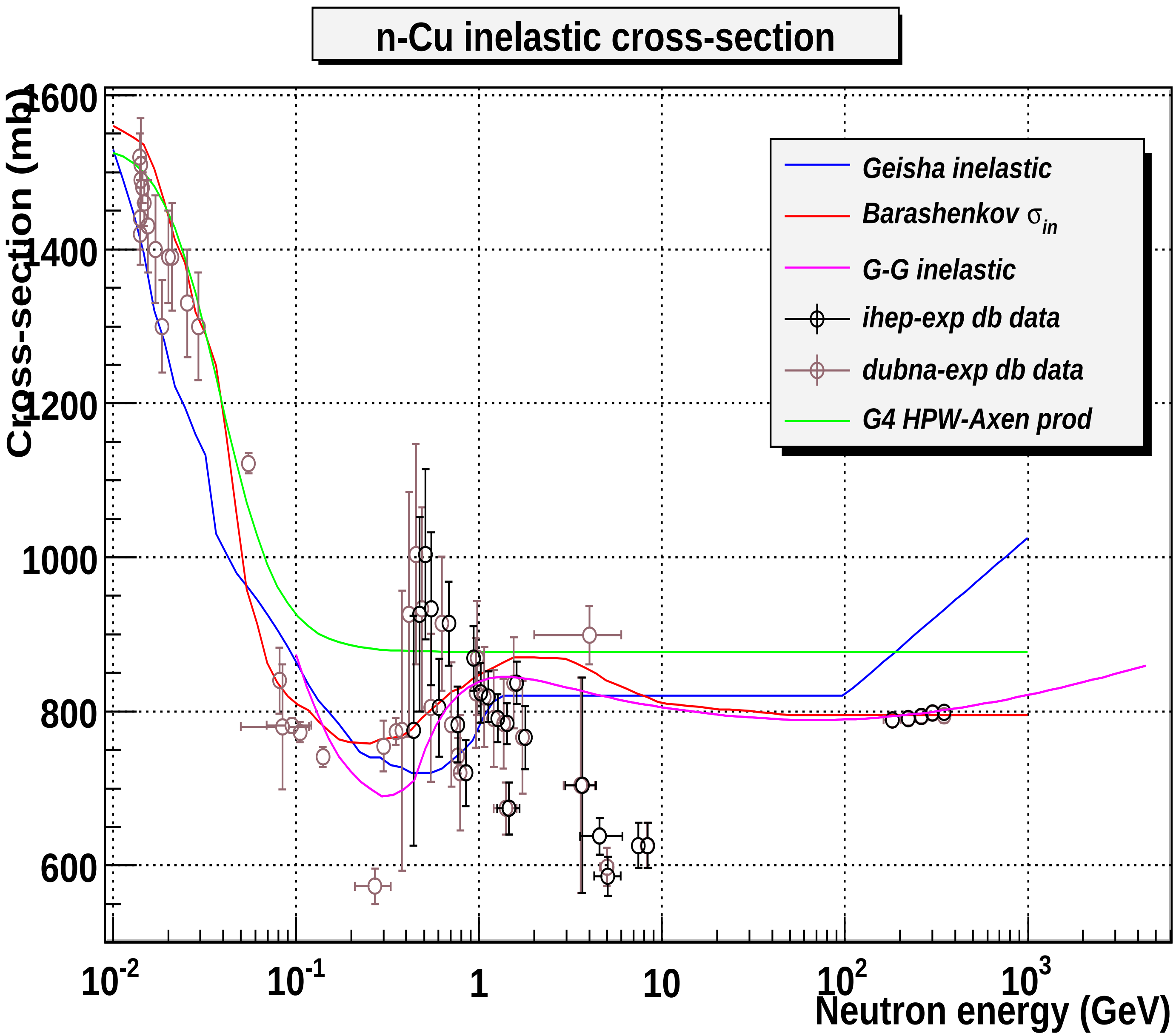

p-Fe inelastic cross-section
Barashenkov σ_{in}
Geisha inelastic
G4 HPW-Axen
G-G inelastic
dubna-exp db data
ihep-exp db data
Cross-section (mb)
1100
1000
900
800
700
600
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Proton energy (GeV)

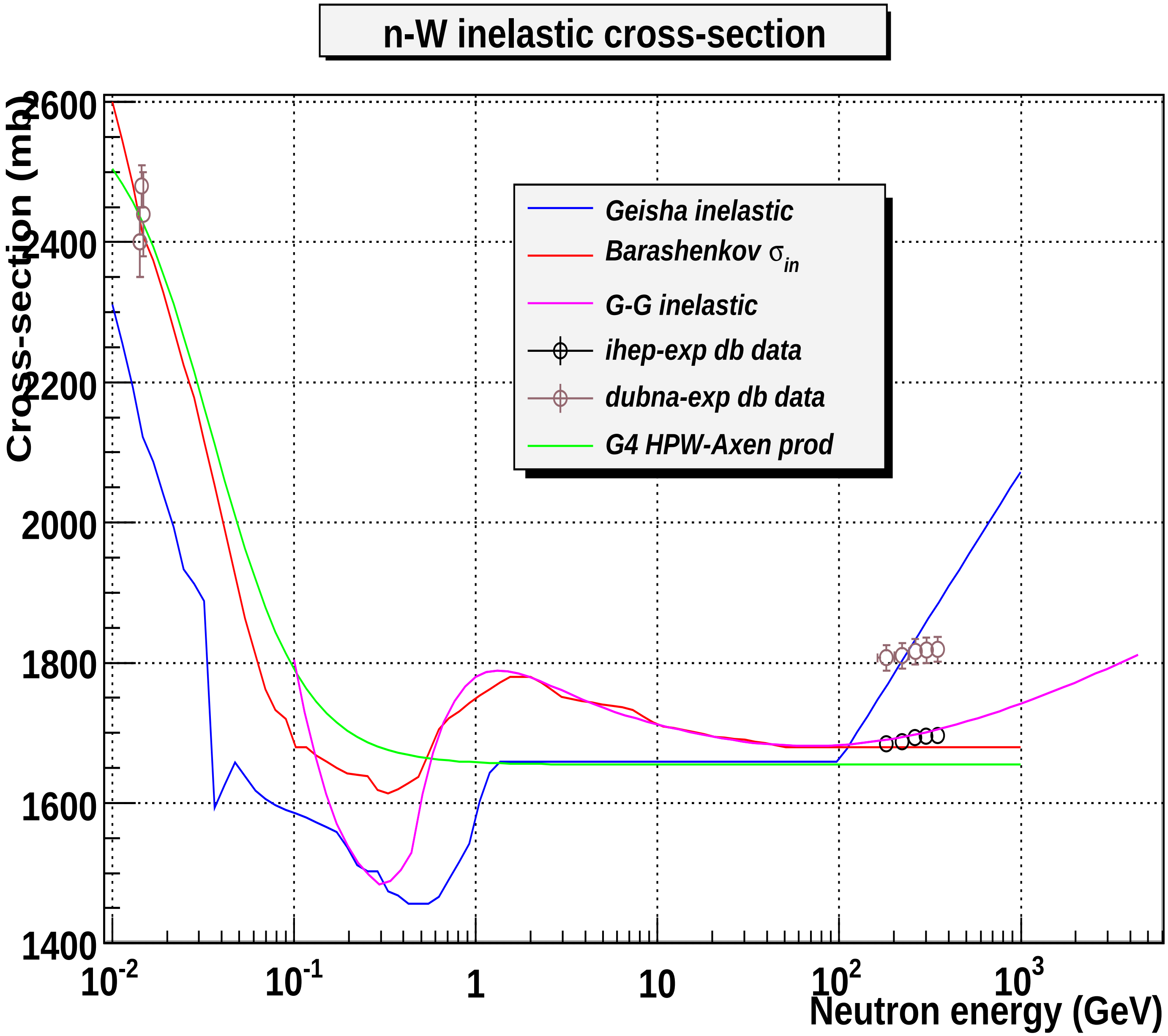


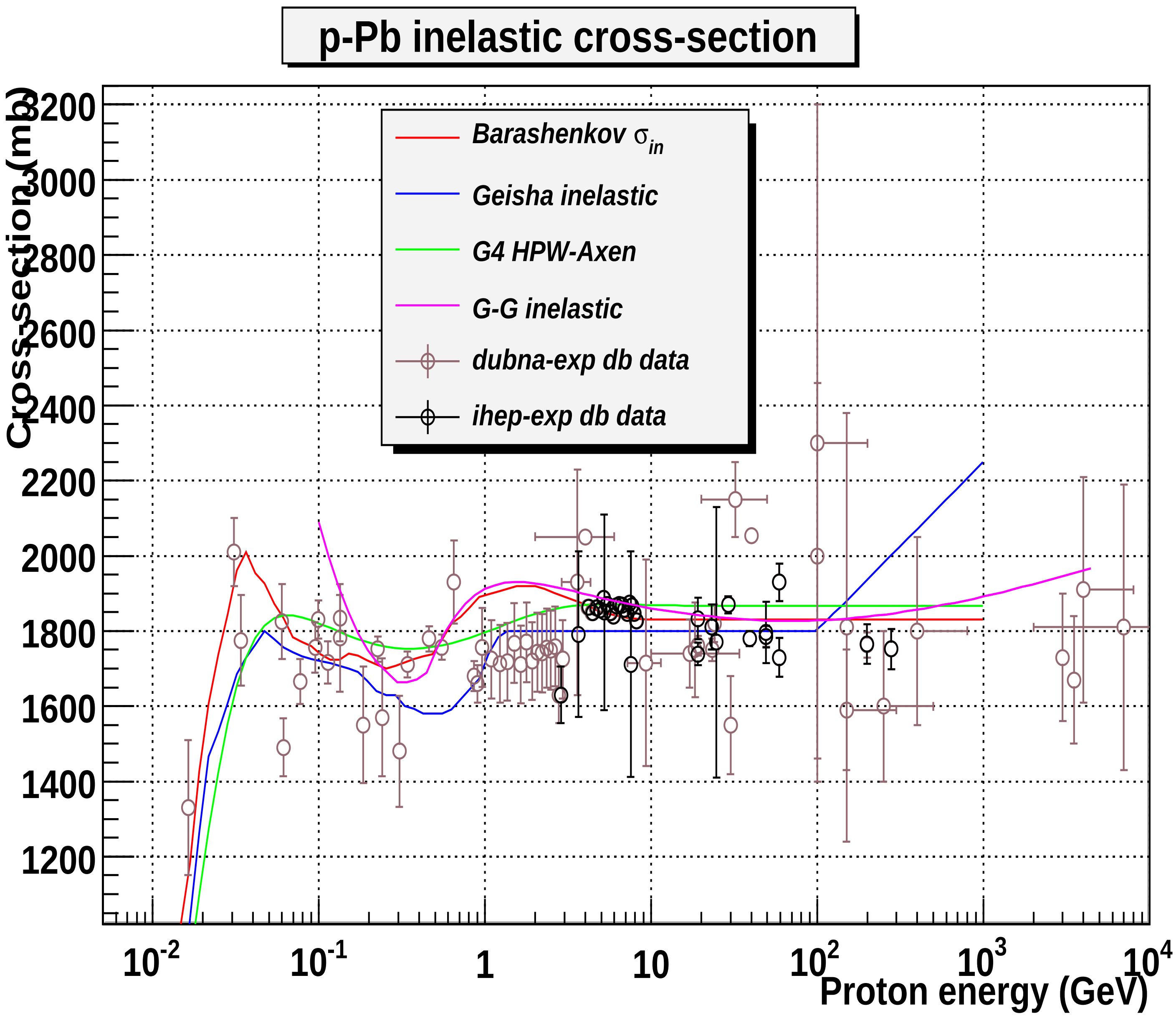
n-Fe inelastic cross-section
Geisha inelastic
Barashenkov σ_{in}
G-G inelastic
ihep-exp db data
dubna-exp db data
G4 HPW-Axen prod
Cross-section (mb)
400
600
800
1000
1200
1400
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Neutron energy (GeV)

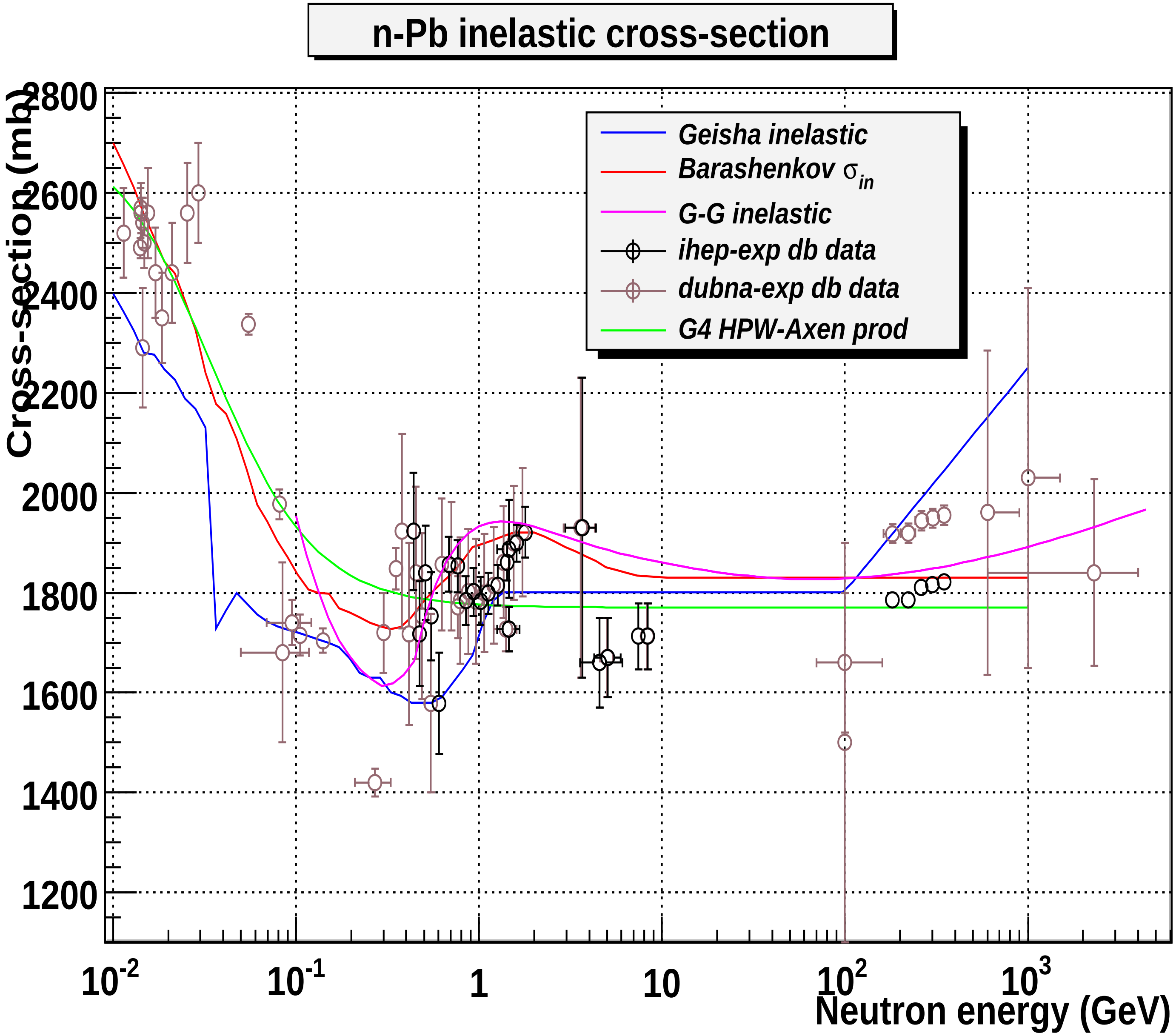


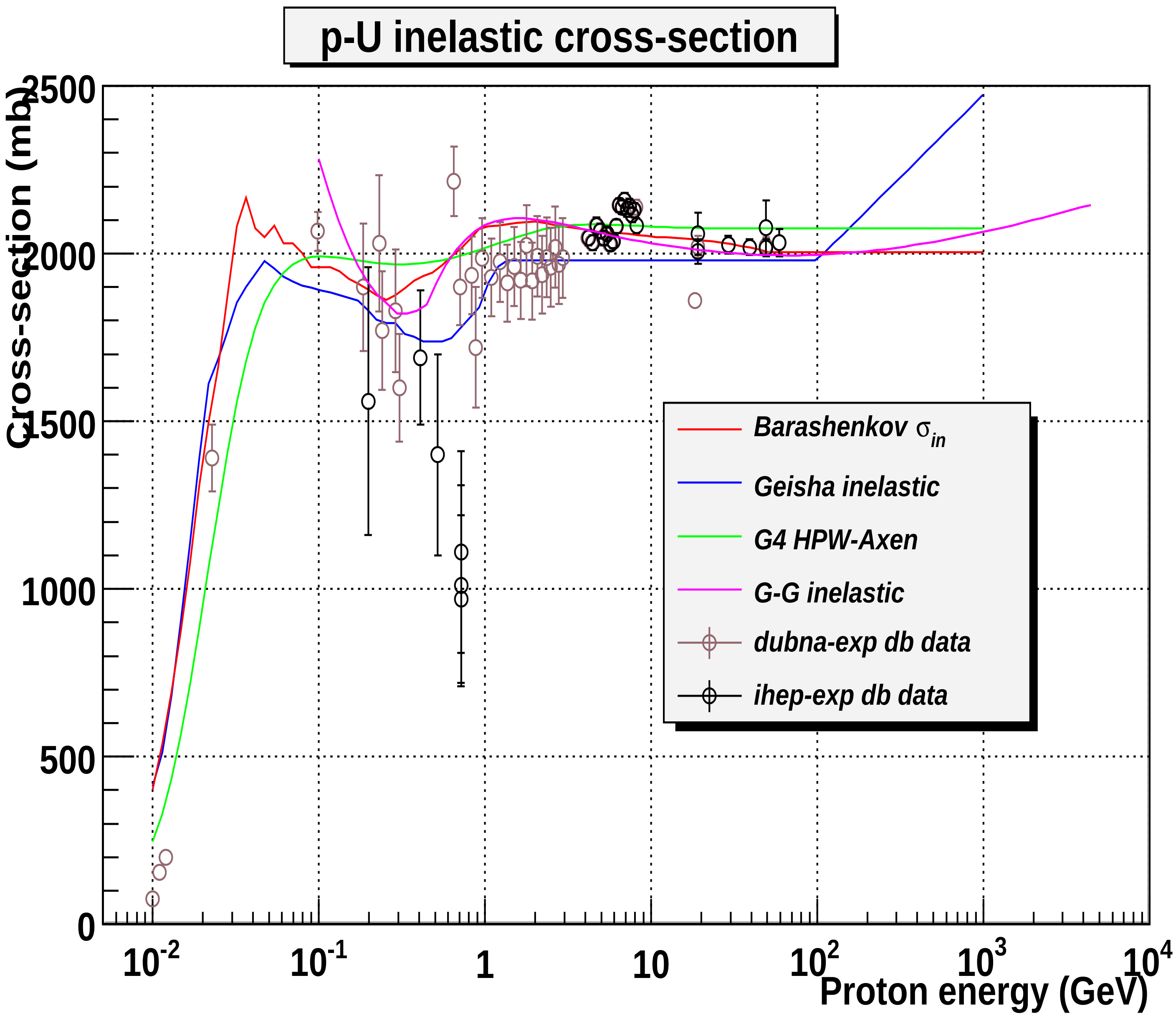
p-Cu inelastic cross-section
Cross-section (mb)
1200
1100
1000
900
800
700
600
Barashenkov σ_{in}
Geisha inelastic
G4 HPW-Axen
G-G inelastic
dubna-exp db data
ihep-exp db data
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Proton energy (GeV)


n-Cu inelastic cross-section
Cross-section (mb)
1600
1400
1200
1000
800
600
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Neutron energy (GeV)
Geisha inelastic
Barashenkov σ_{in}
G-G inelastic
ihep-exp db data
dubna-exp db data
G4 HPW-Axen prod

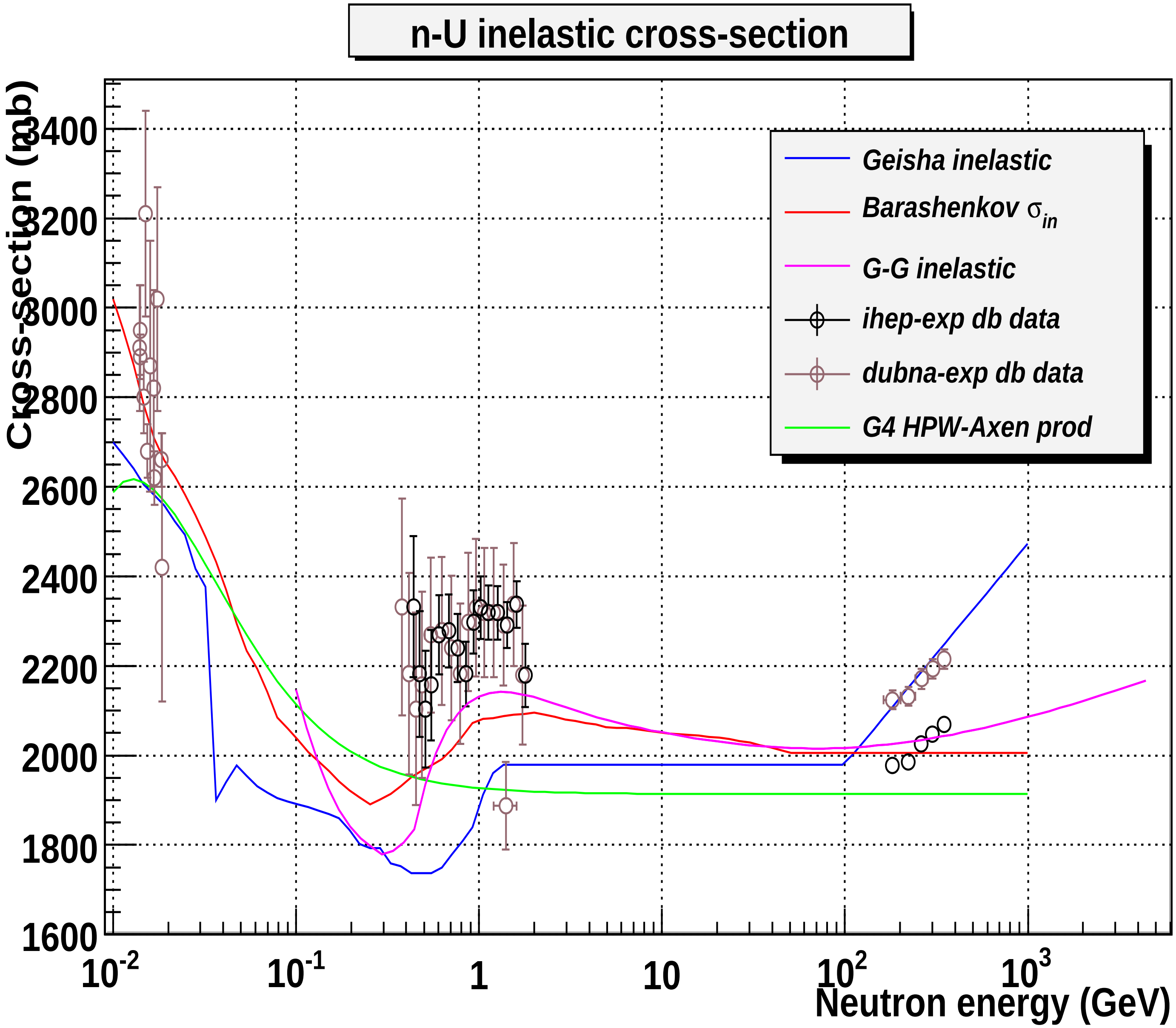

n-W inelastic cross-section
Cross-section (mb)
2600
2400
2200
2000
1800
1600
1400
Geisha inelastic
Barashenkov σ_in
G-G inelastic
ihep-exp db data
dubna-exp db data
G4 HPW-Axen prod
10^-2
10^-1
1
10
10^2
10^3
Neutron energy (GeV)

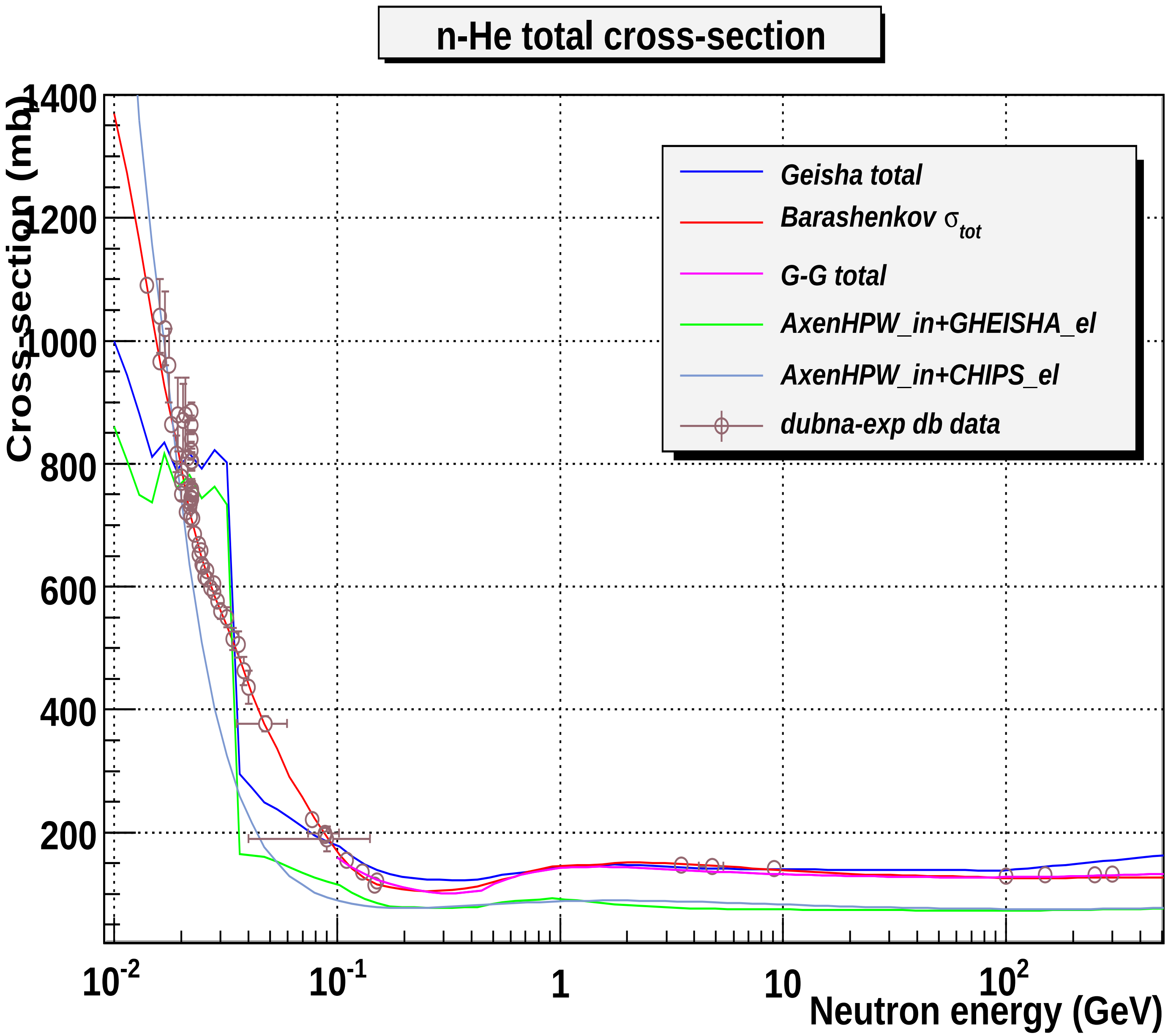

p-Pb inelastic cross-section
Cross-section (mb)
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
Barashenkov σ_{in}
Geisha inelastic
G4 HPW-Axen
G-G inelastic
dubna-exp db data
ihep-exp db data
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
Proton energy (GeV)

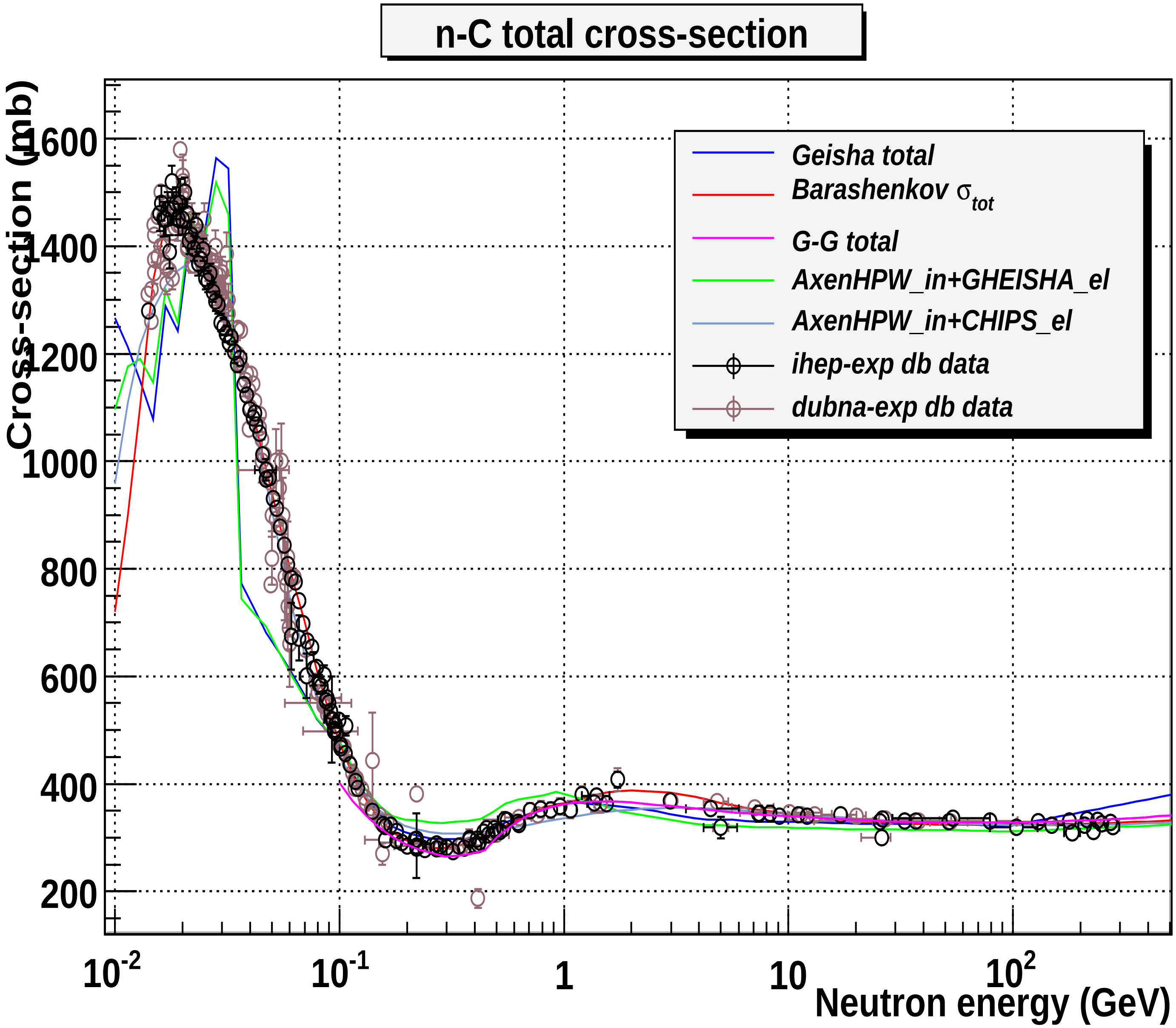

n-Pb inelastic cross-section
Geisha inelastic
Barashenkov σ_{in}
G-G inelastic
ihep-exp db data
dubna-exp db data
G4 HPW-Axen prod
Cross-section (mb)
2800
2600
2400
2200
2000
1800
1600
1400
1200
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Neutron energy (GeV)

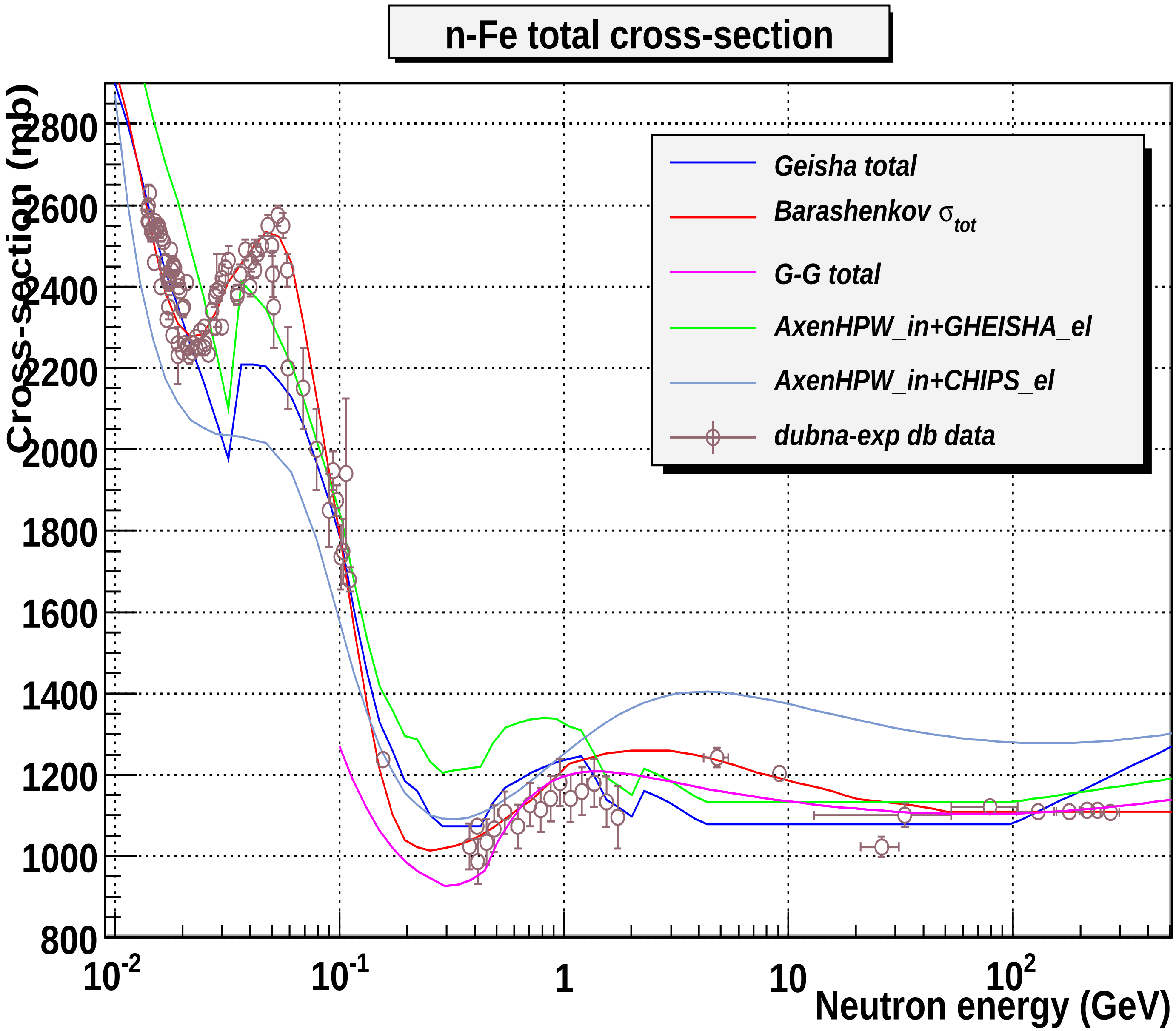


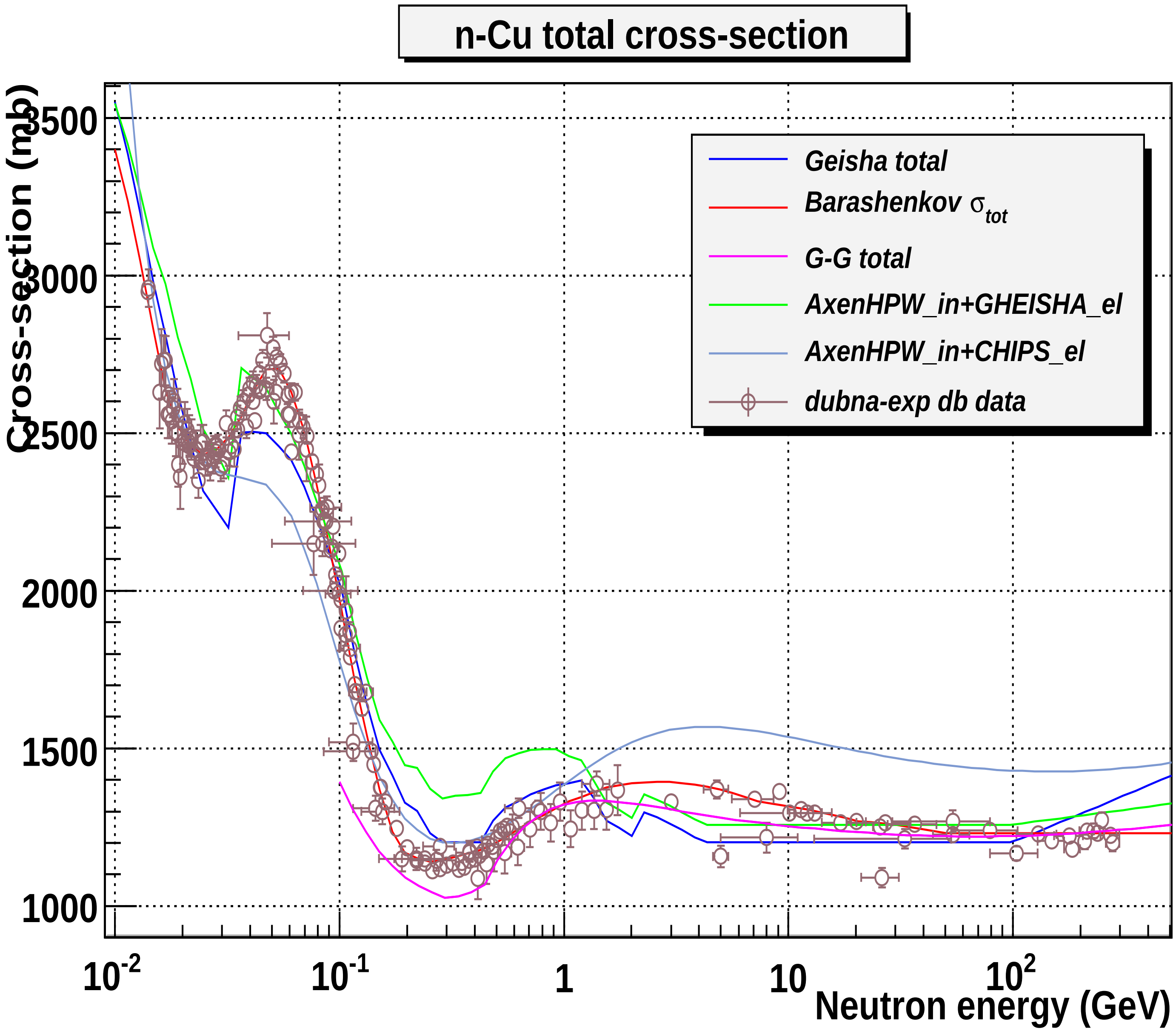
p-U inelastic cross-section
Cross-section (mb)
2500
2000
1500
1000
500
0
10^-2
10^-1
1
10
10^2
10^3
10^4
Proton energy (GeV)
Barashenkov σ_in
Geisha inelastic
G4 HPW-Axen
G-G inelastic
dubna-exp db data
ihep-exp db data

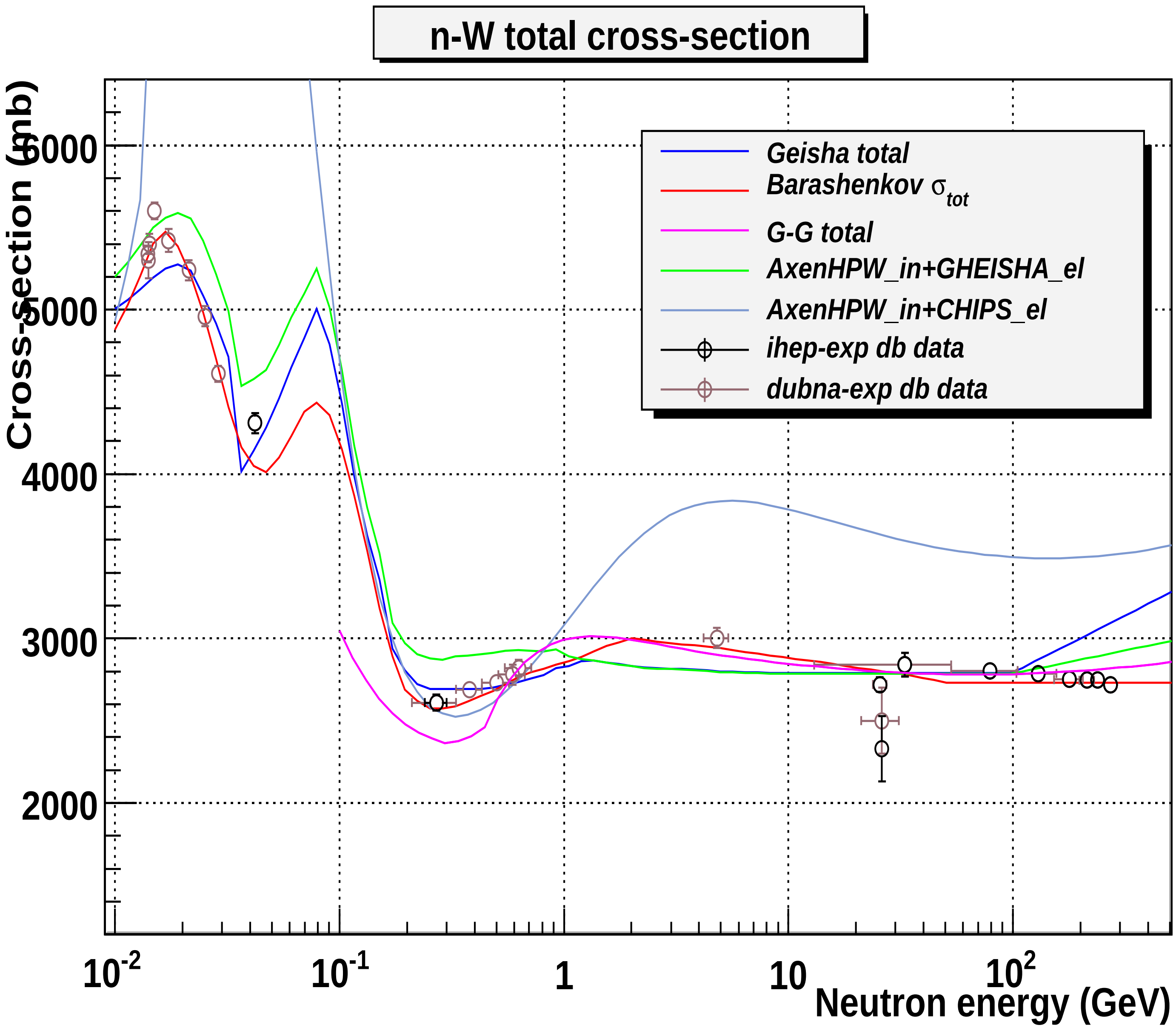

n-U inelastic cross-section
Cross-section (mb)
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
Geisha inelastic
Barashenkov σ_{in}
G-G inelastic
ihep-exp db data
dubna-exp db data
G4 HPW-Axen prod
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Neutron energy (GeV)

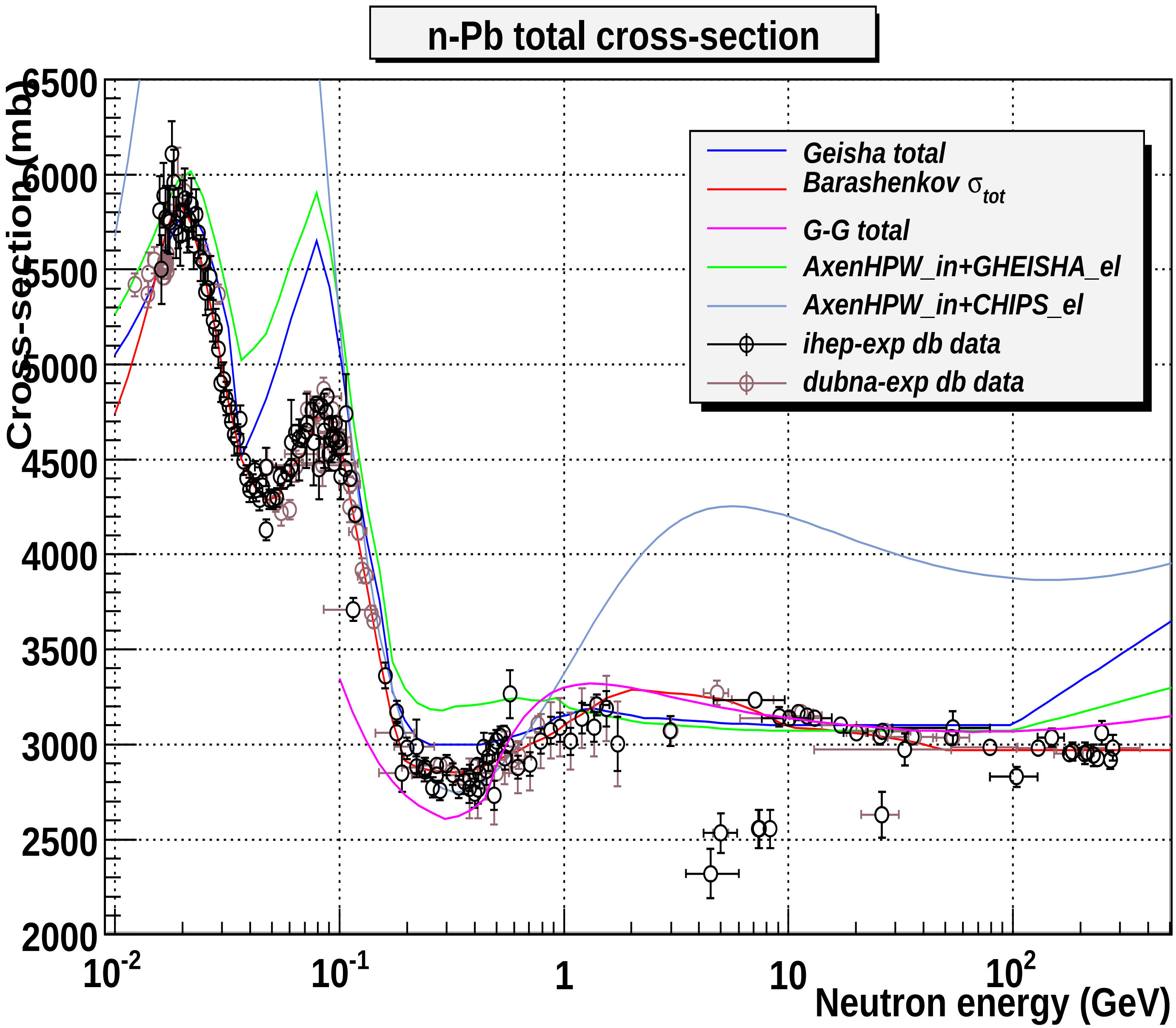

n-He total cross-section
Cross-section (mb)
1400
1200
1000
800
600
400
200
Geisha total
Barashenkov σ tot
G-G total
AxenHPW_in+GHEISHA_el
AxenHPW_in+CHIPS_el
dubna-exp db data
10-2
10-1
1
10
102
Neutron energy (GeV)

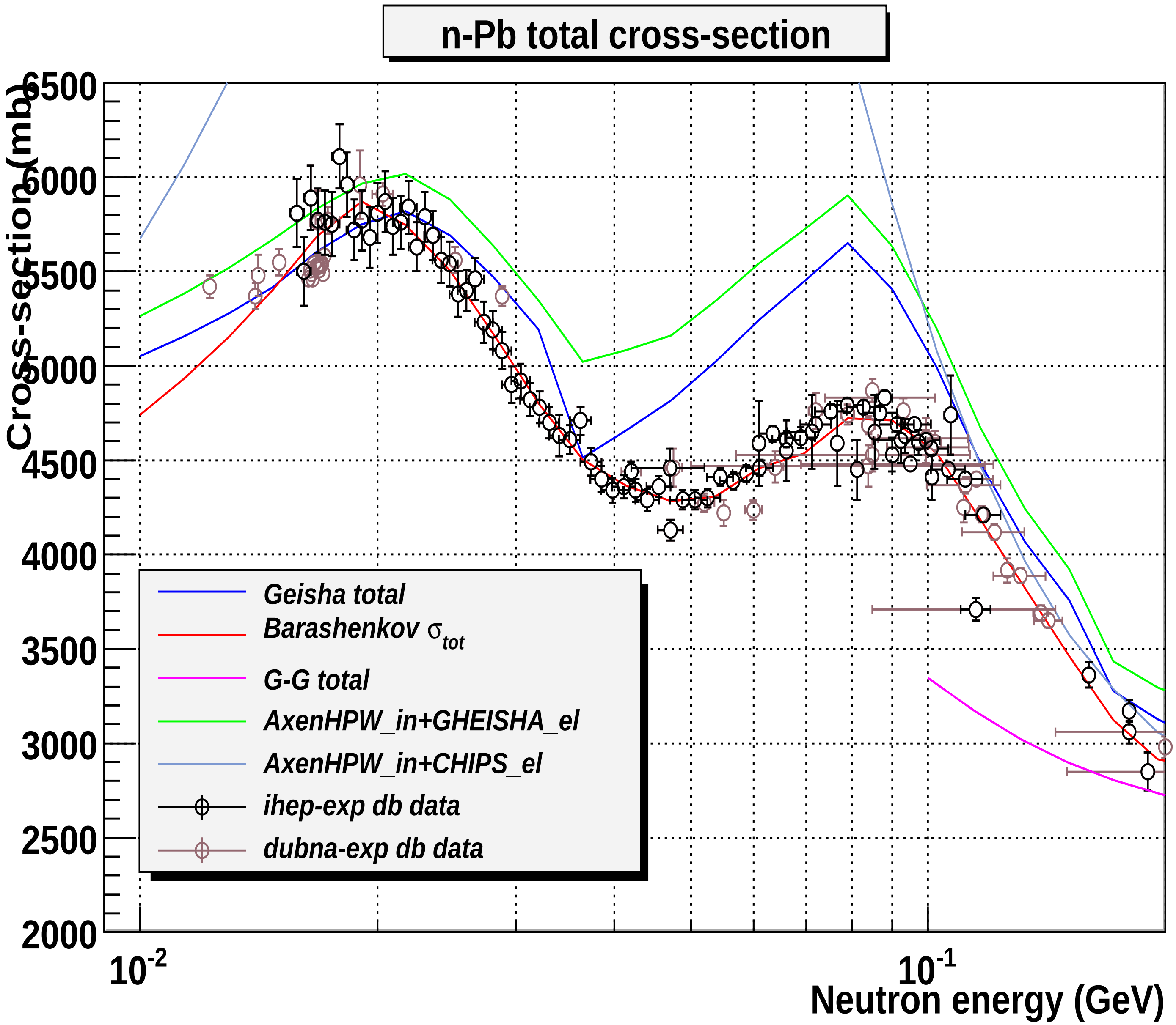

n-C total cross-section
Cross-section (mb)
1600
1400
1200
1000
800
600
400
200
10^{-2}
10^{-1}
1
10
10^{2}
Neutron energy (GeV)
Geisha total
Barashenkov σ_{tot}
G-G total
AxenHPW_in+GHEISHA_el
AxenHPW_in+CHIPS_el
ihep-exp db data
dubna-exp db data

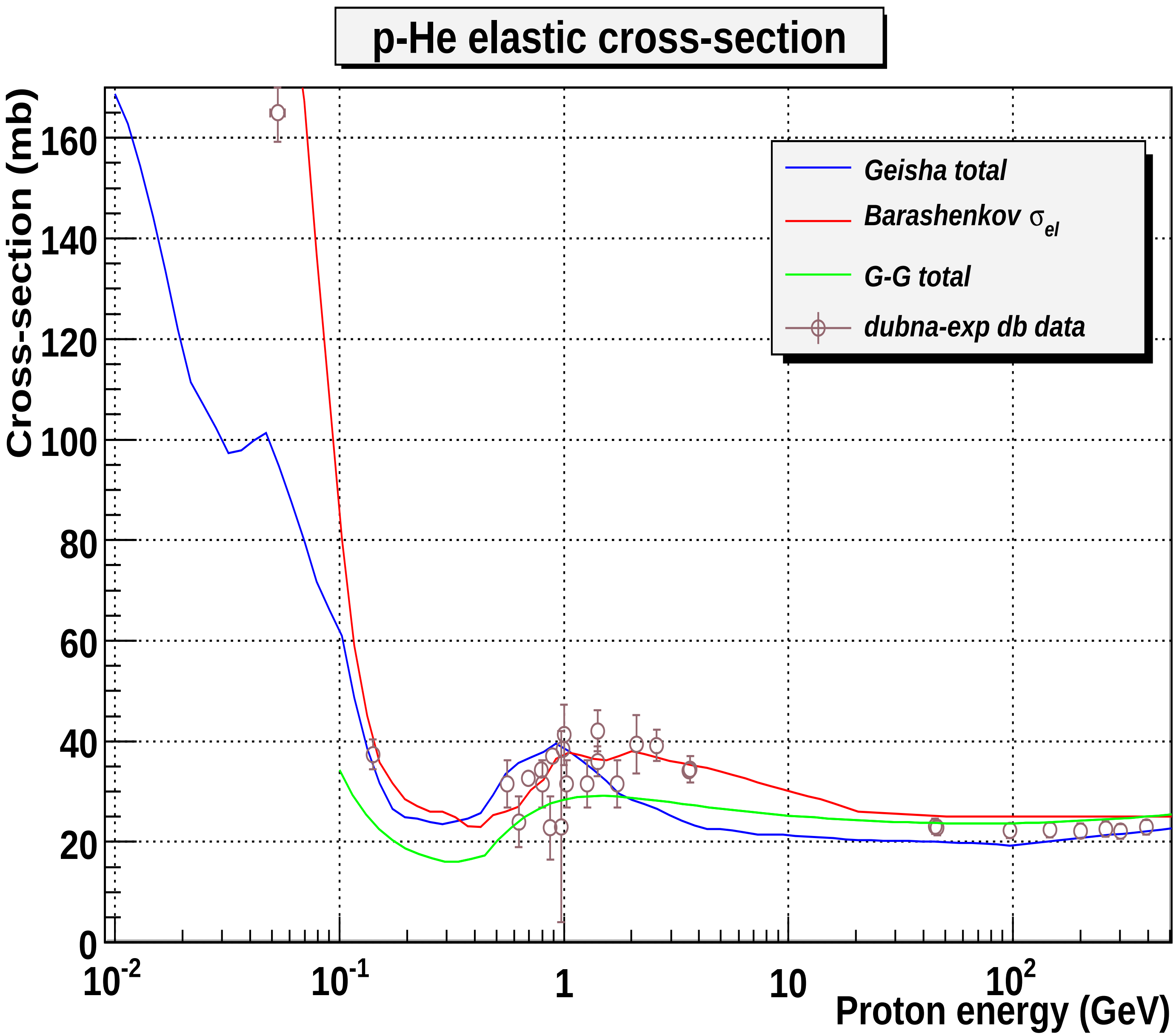

n-Fe total cross-section
Cross-section (mb)
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
10^{-2}
10^{-1}
1
10
10^{2}
Neutron energy (GeV)
Geisha total
Barashenkov σ_{tot}
G-G total
AxenHPW_in+GHEISHA_el
AxenHPW_in+CHIPS_el
dubna-exp db data

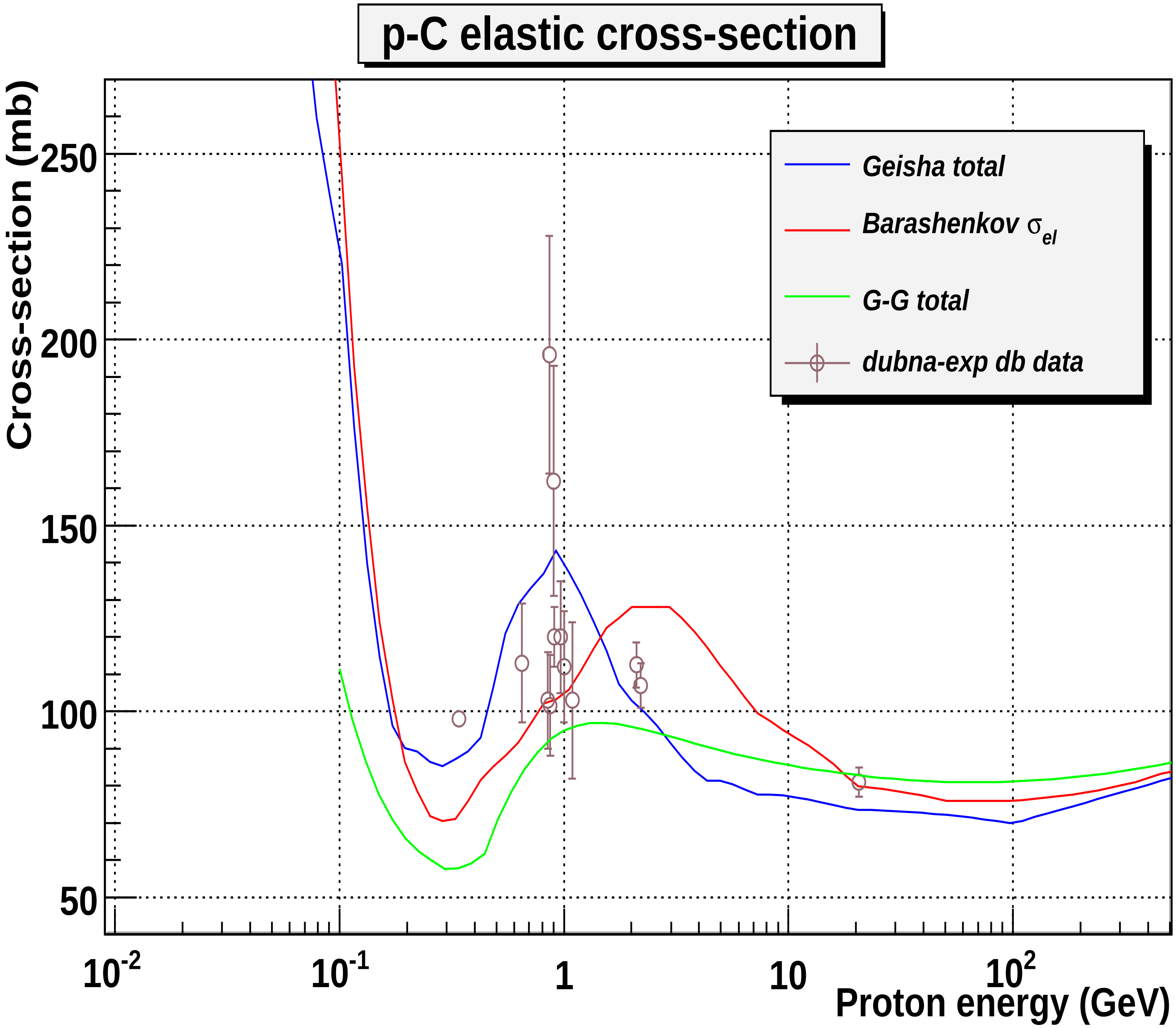

n-Cu total cross-section
Cross-section (mb)
3500
3000
2500
2000
1500
1000
10^{-2}
10^{-1}
1
10
10^{2}
Neutron energy (GeV)
Geisha total
Barashenkov σ_{tot}
G-G total
AxenHPW_in+GHEISHA_el
AxenHPW_in+CHIPS_el
dubna-exp db data

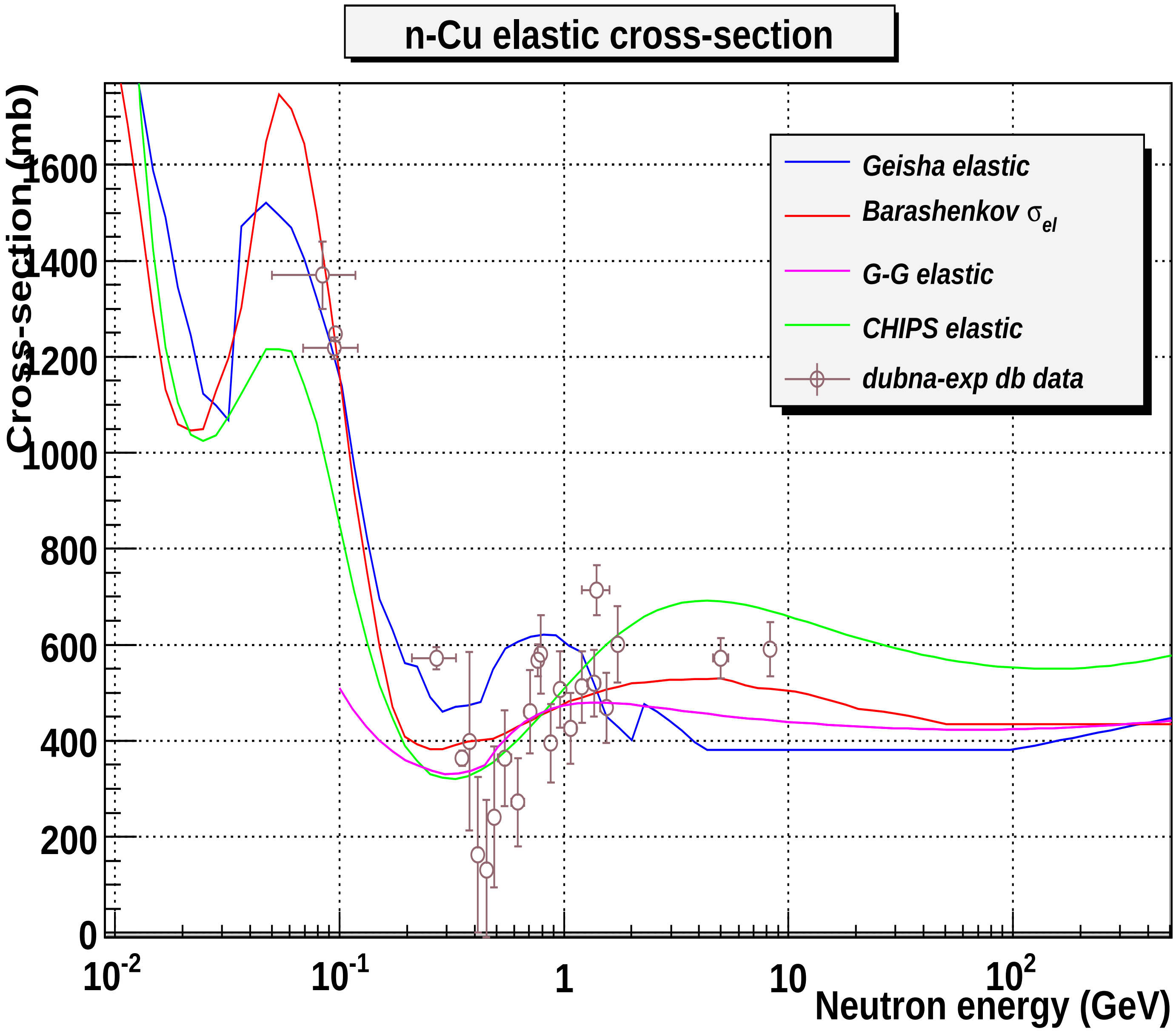

n-W total cross-section
Cross-section (mb)
6000
5000
4000
3000
2000
Geisha total
Barashenkov σ tot
G-G total
AxenHPW_in+GHEISHA_el
AxenHPW_in+CHIPS_el
ihep-exp db data
dubna-exp db data
10-2
10-1
1
10
10 2
Neutron energy (GeV)


n-Pb total cross-section
Cross-section (mb)
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
10^-2
10^-1
1
10
10^2
Neutron energy (GeV)
Geisha total
Barashenkov σ_tot
G-G total
AxenHPW_in+GHEISHA_el
AxenHPW_in+CHIPS_el
ihep-exp db data
dubna-exp db data


n-Pb total cross-section
Cross-section (mb)
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
10^{-2}
10^{-1}
Neutron energy (GeV)
Geisha total
Barashenkov σ_{tot}
G-G total
AxenHPW_in+GHEISHA_el
AxenHPW_in+CHIPS_el
ihep-exp db data
dubna-exp db data


p-He elastic cross-section
Geisha total
Barashenkov σ_{el}
G-G total
dubna-exp db data
Cross-section (mb)
0
20
40
60
80
100
120
140
160
10^{-2}
10^{-1}
1
10
10^{2}
Proton energy (GeV)


p-C elastic cross-section
Cross-section (mb)
250
200
150
100
50
10^{-2}
10^{-1}
1
10
10^{2}
Proton energy (GeV)
Geisha total
Barashenkov σ_{el}
G-G total
dubna-exp db data


n-Cu elastic cross-section
Cross-section (mb)
0
200
400
600
800
1000
1200
1400
1600
10^{-2}
10^{-1}
1
10
10^{2}
Neutron energy (GeV)
Geisha elastic
Barashenkov σ_{el}
G-G elastic
CHIPS elastic
dubna-exp db data

4 Simplified Glauber model cross section ratios

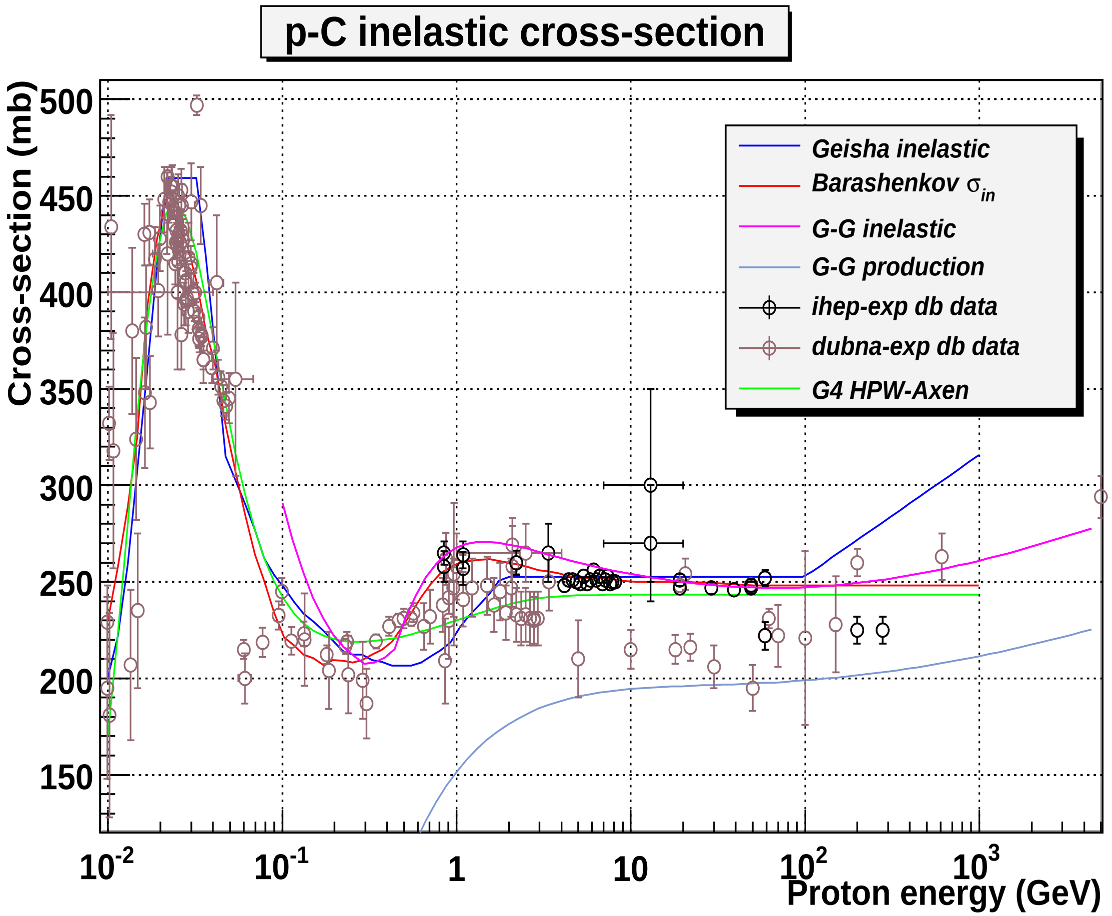
In the framework of simplified Glauber-Gribov model the cross sections read:

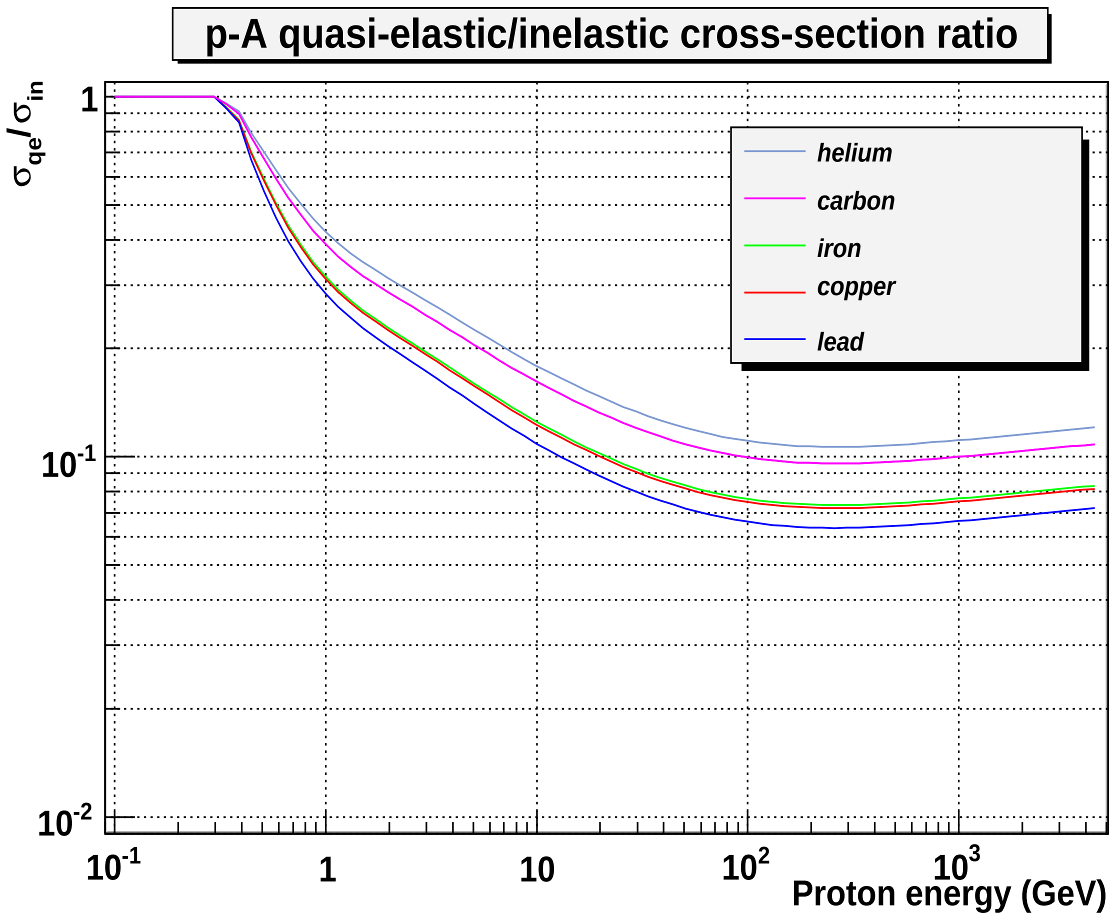
$$\sigma_{tot}^{hA} = 2\pi R^2 \ln\left[1 + \frac{A\sigma_{tot}^{hN}}{2\pi R^2}\right], \quad \sigma_{in}^{hA} = \pi R^2 \ln\left[1 + \frac{A\sigma_{tot}^{hN}}{\pi R^2}\right].$$

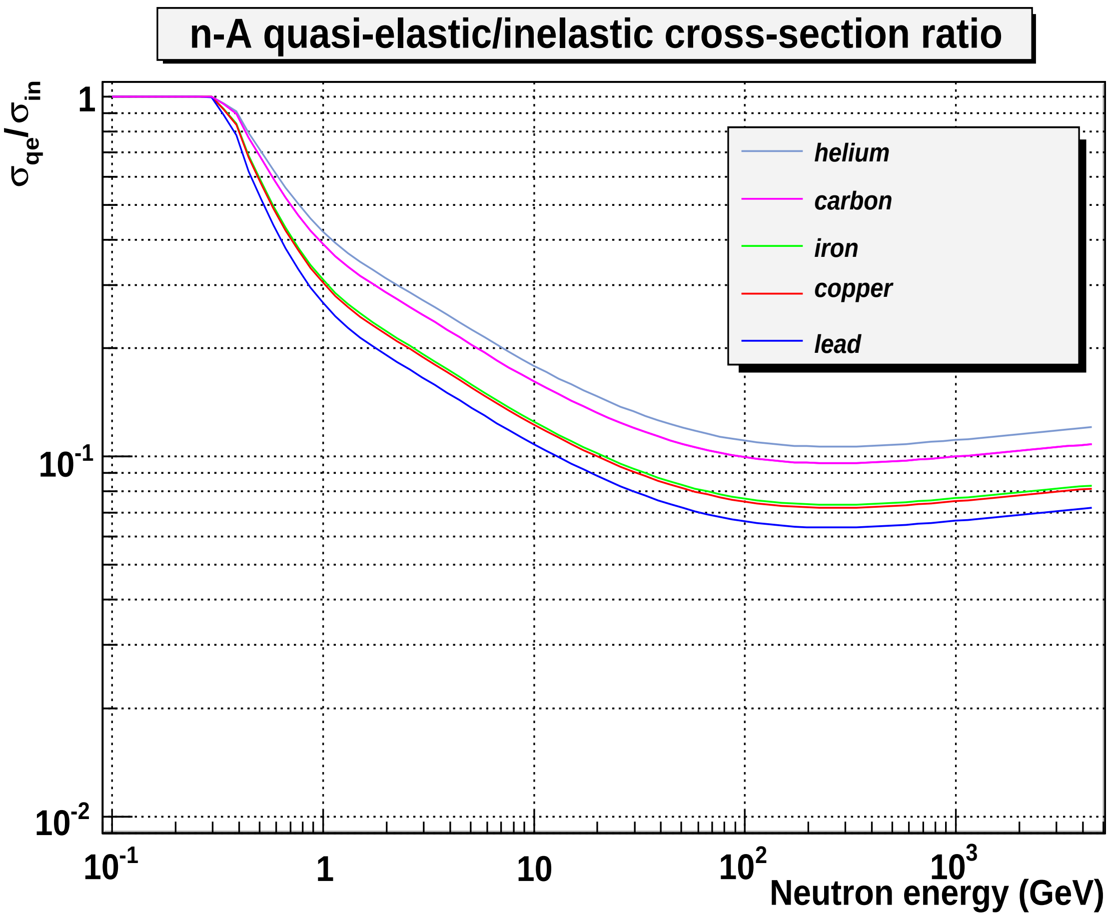
$$\sigma_{prod}^{hA} = \pi R^2 \ln\left[1 + \frac{A\sigma_{in}^{hN}}{\pi R^2}\right], \quad \sigma_{qe}^{hA} = \sigma_{in}^{hA} - \sigma_{prod}^{hA}$$

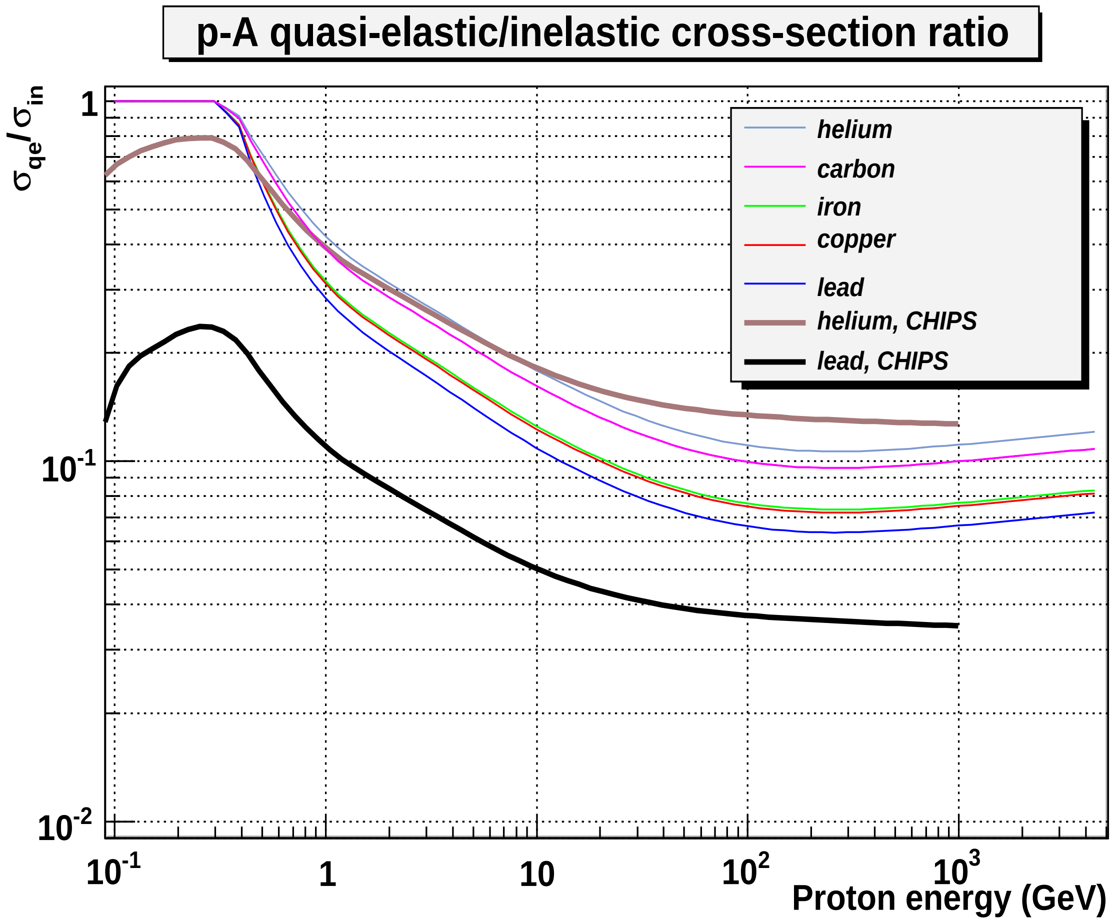
$$\sigma_{sd}^{hA}(hA \to XA) = \pi R^2 \left\{\alpha - \ln\left[1+\alpha\right]\right\}, \quad \alpha = \frac{A\sigma_{tot}^{hN}}{2\pi R^2 + A\sigma_{tot}^{hN}}.$$

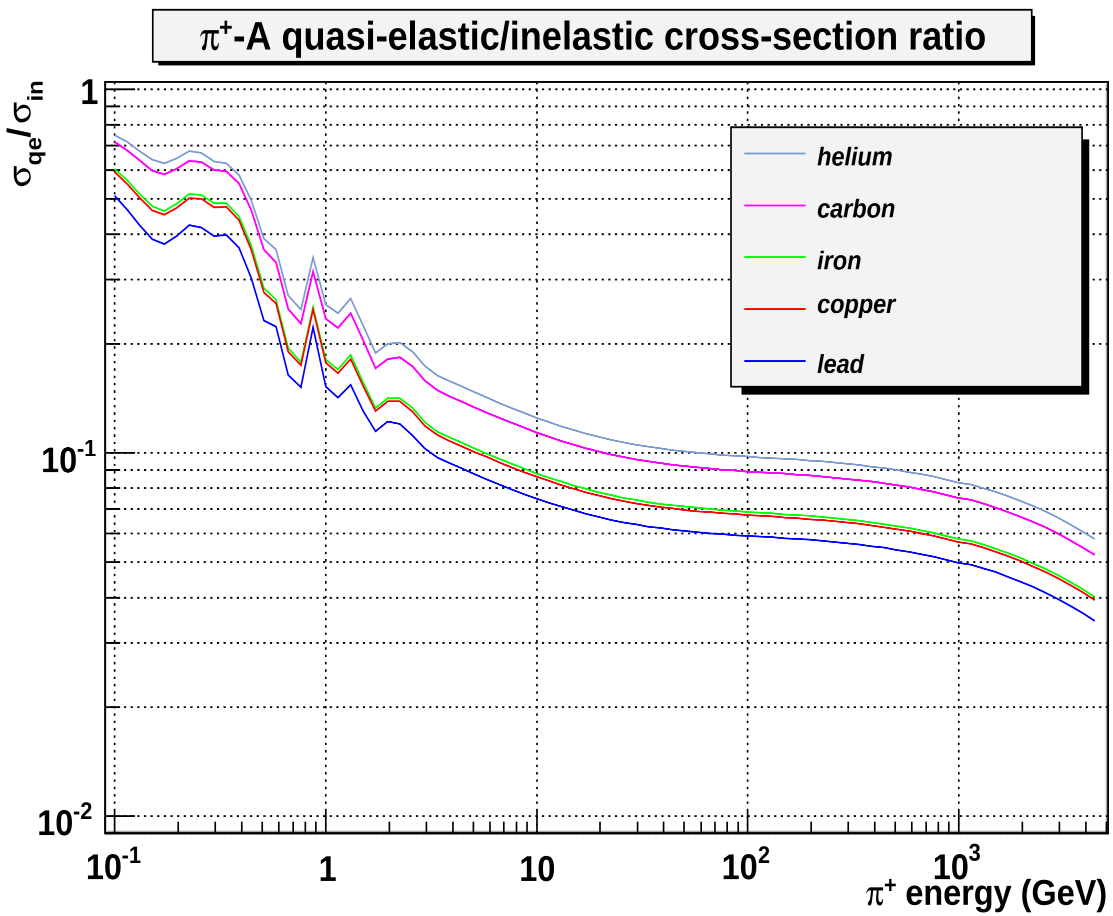
Where σ_{tot}^{hA}, σ_{in}^{hA}, σ_{prod}^{hA}, σ_{qe}^{hA} and $\sigma_{sd}^{hA}(hA \to XA)$ are the total, inelastic, production, quasi-elastic and single-diffraction cross section of a hadron on a nucleus A, respectively. They depend essentially on the hadron-nucleon cross sections, σ_{tot}^{hN} and now for the production cross section σ_{in}^{hN}. R is the RMS radius of nucleon distribution inside the nucleus.


p-C inelastic cross-section
Cross-section (mb)
500
450
400
350
300
250
200
150
10^-2
10^-1
1
10
10^2
10^3
Proton energy (GeV)
Geisha inelastic
Barashenkov σ_in
G-G inelastic
G-G production
ihep-exp db data
dubna-exp db data
G4 HPW-Axen

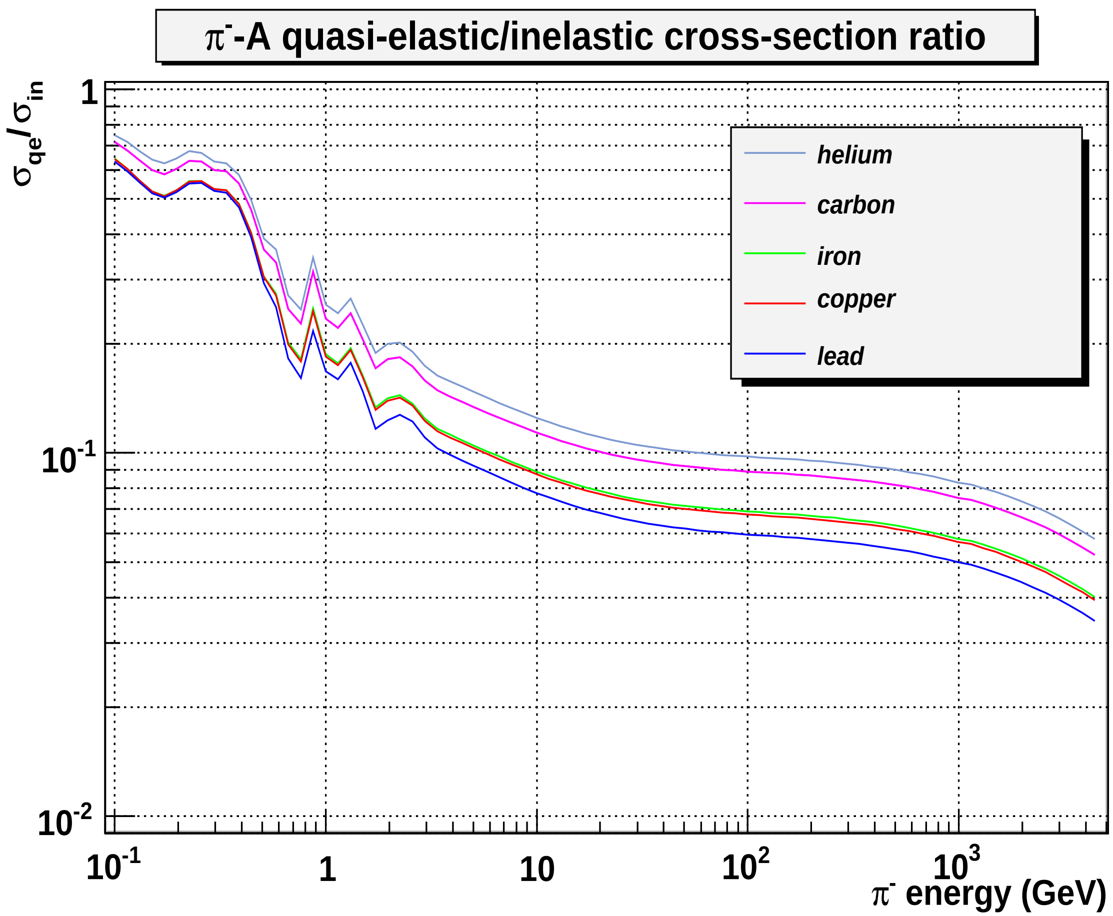

p-A quasi-elastic/inelastic cross-section ratio
σqe/σin
1
10-1
10-2
10-1
1
10
102
103
Proton energy (GeV)
helium
carbon
iron
copper
lead


n-A quasi-elastic/inelastic cross-section ratio
σ_{qe}/σ_{in}
1
10^{-1}
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Neutron energy (GeV)
helium
carbon
iron
copper
lead

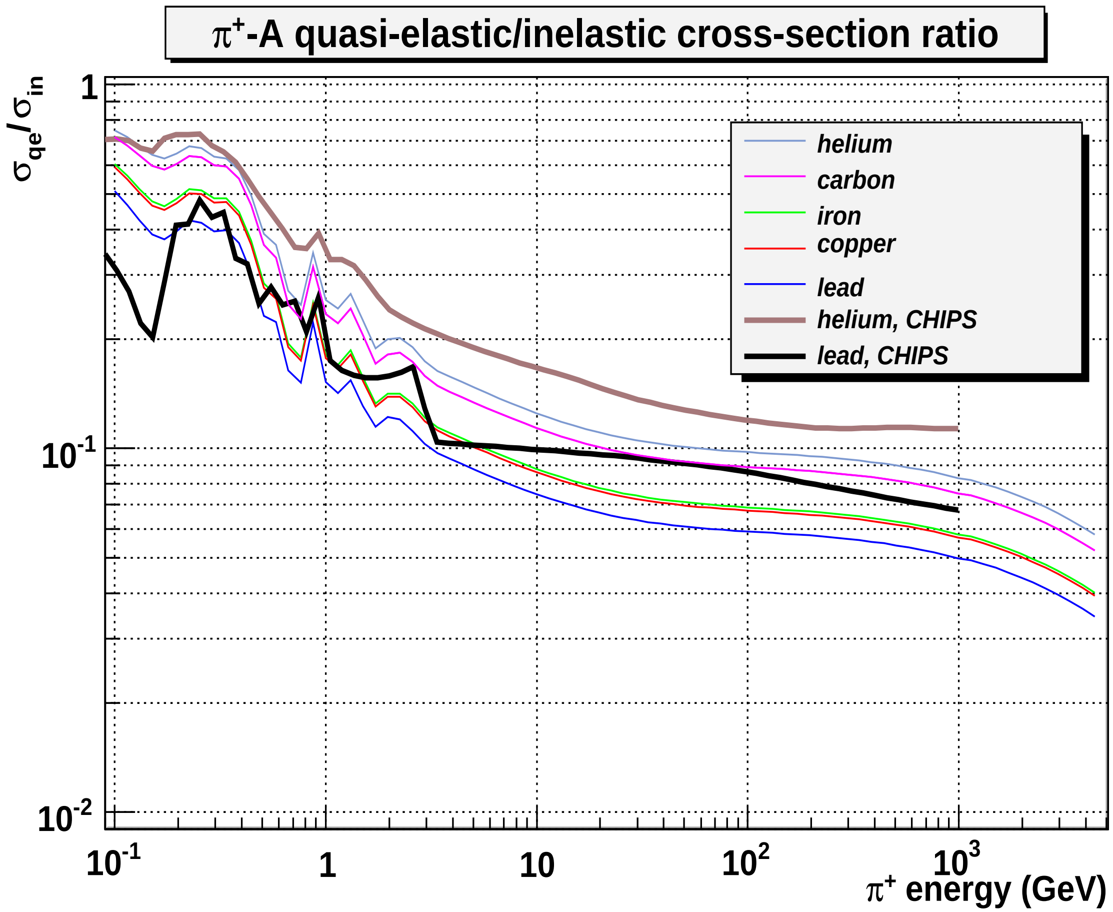

p-A quasi-elastic/inelastic cross-section ratio
σ_{qe}/σ_{in}
1
10^{-1}
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Proton energy (GeV)
helium
carbon
iron
copper
lead
helium, CHIPS
lead, CHIPS

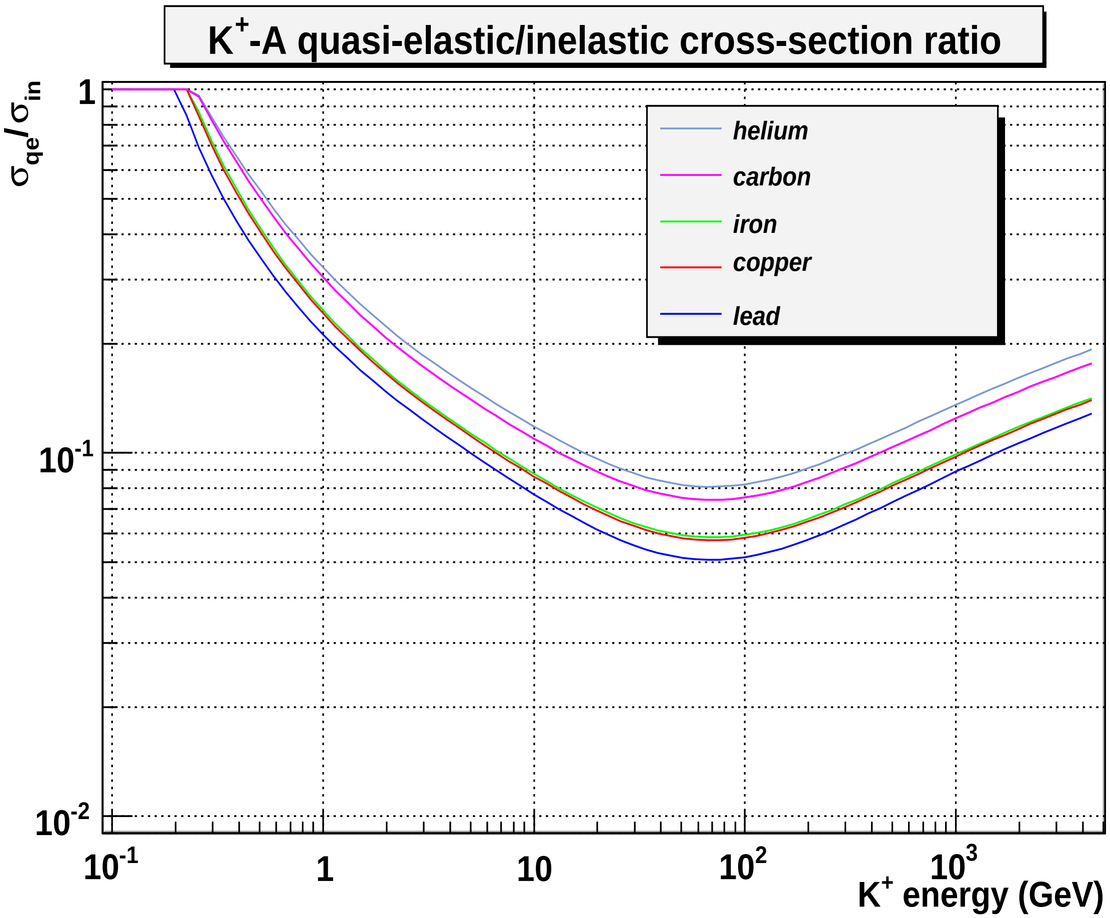


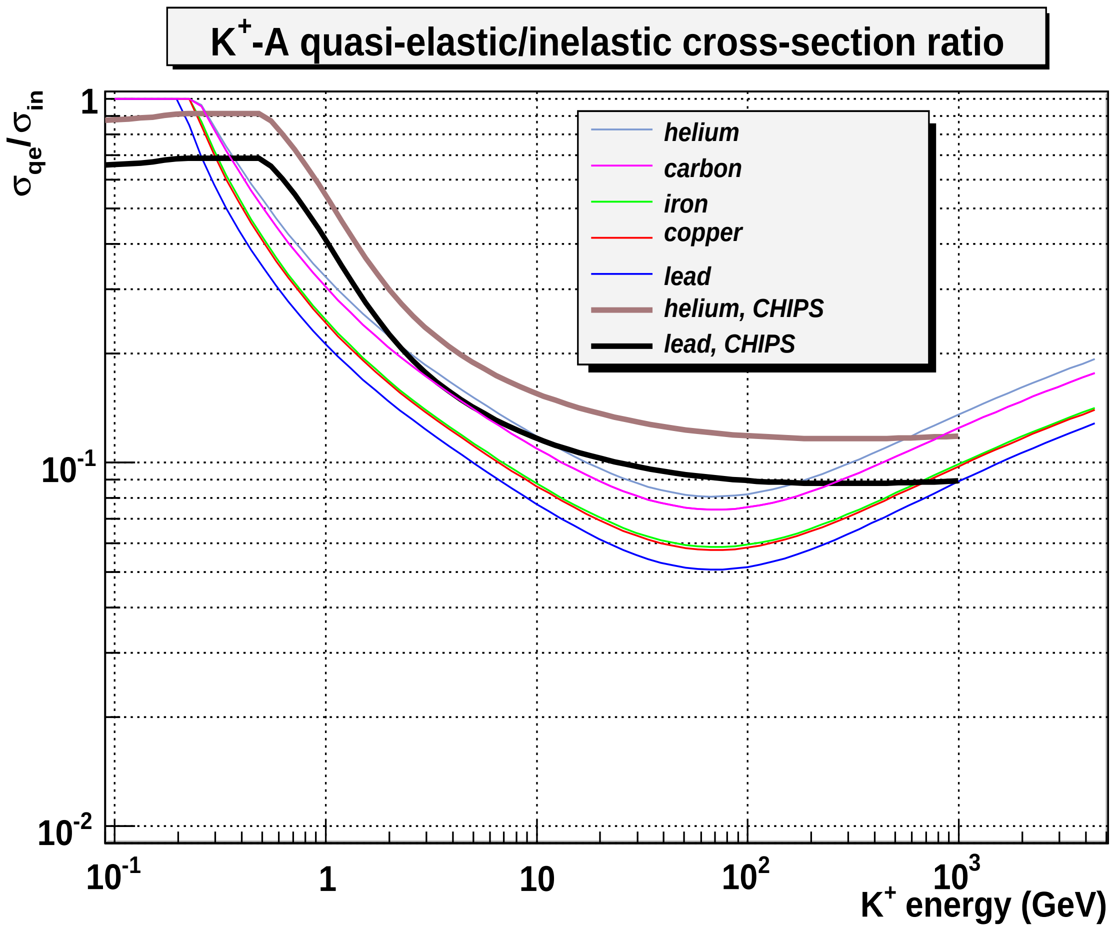
π+-A quasi-elastic/inelastic cross-section ratio
σqe/σin
1
10-1
10-2
10-1
1
10
102
103
π+ energy (GeV)
helium
carbon
iron
copper
lead



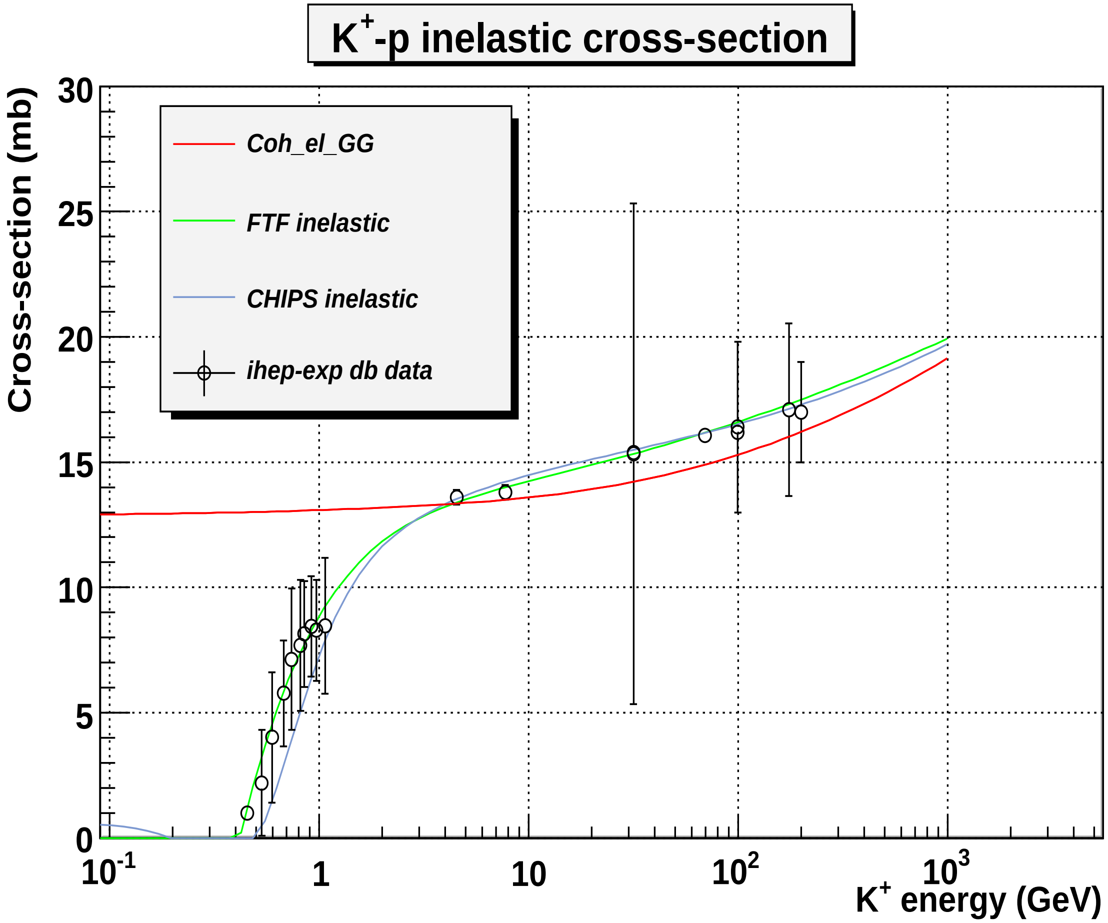
π⁻-A quasi-elastic/inelastic cross-section ratio
σqe/σin
1
10-1
10-2
10-1
1
10
10²
10³
π⁻ energy (GeV)
helium
carbon
iron
copper
lead


π+-A quasi-elastic/inelastic cross-section ratio
σqe/σin
1
10-1
10-2
10-1
1
10
102
103
π+ energy (GeV)
helium
carbon
iron
copper
lead
helium, CHIPS
lead, CHIPS

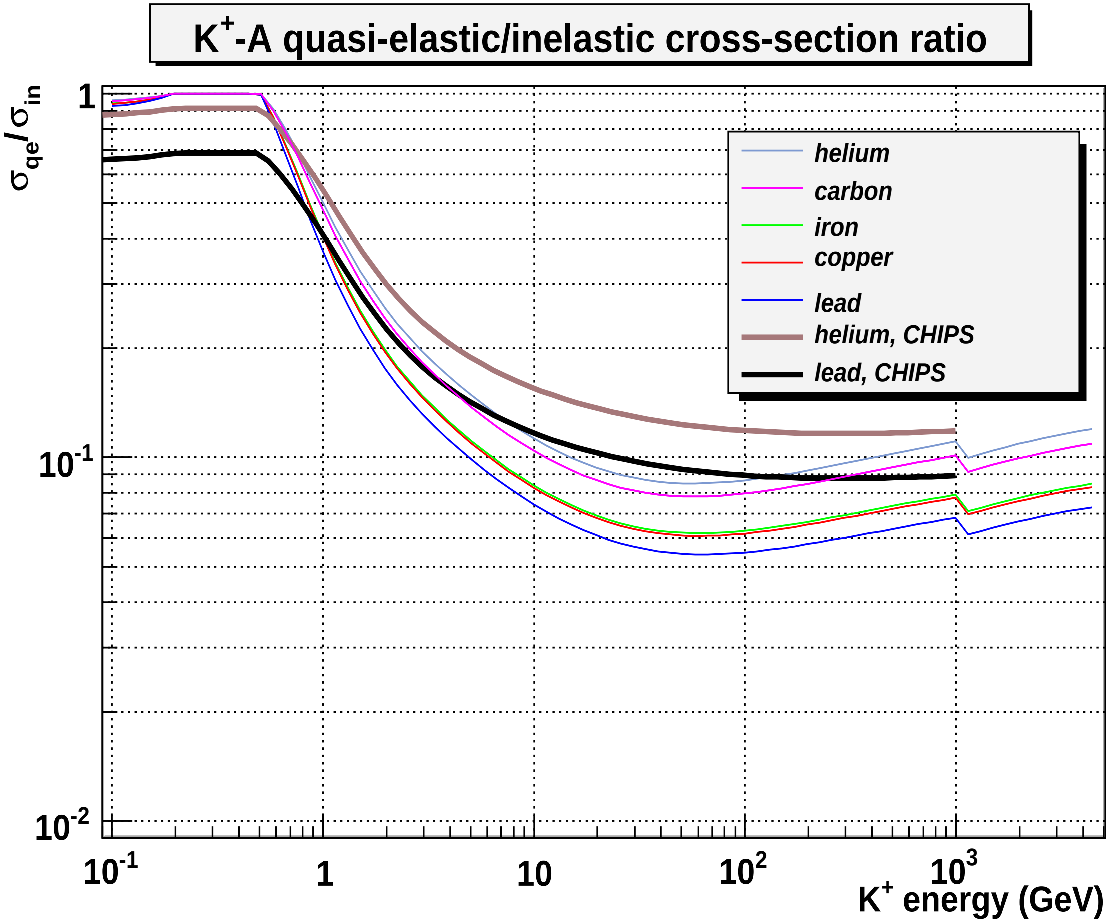

K+-A quasi-elastic/inelastic cross-section ratio
σqe/σin
1
10-1
10-2
10-1
1
10
102
103
K+ energy (GeV)
helium
carbon
iron
copper
lead



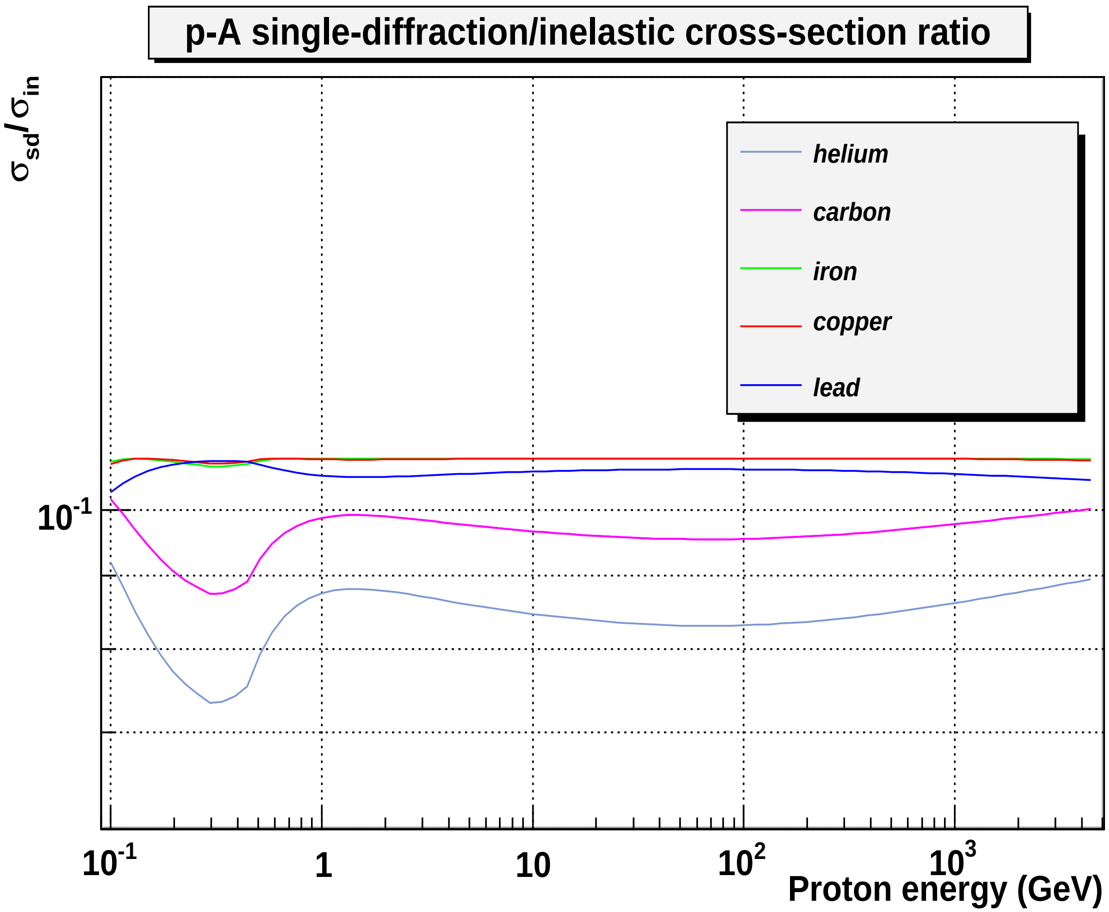
K+-A quasi-elastic/inelastic cross-section ratio
σqe/σin
1
10-1
10-2
10-1
1
10
10^2
10^3
K+ energy (GeV)
helium
carbon
iron
copper
lead
helium, CHIPS
lead, CHIPS



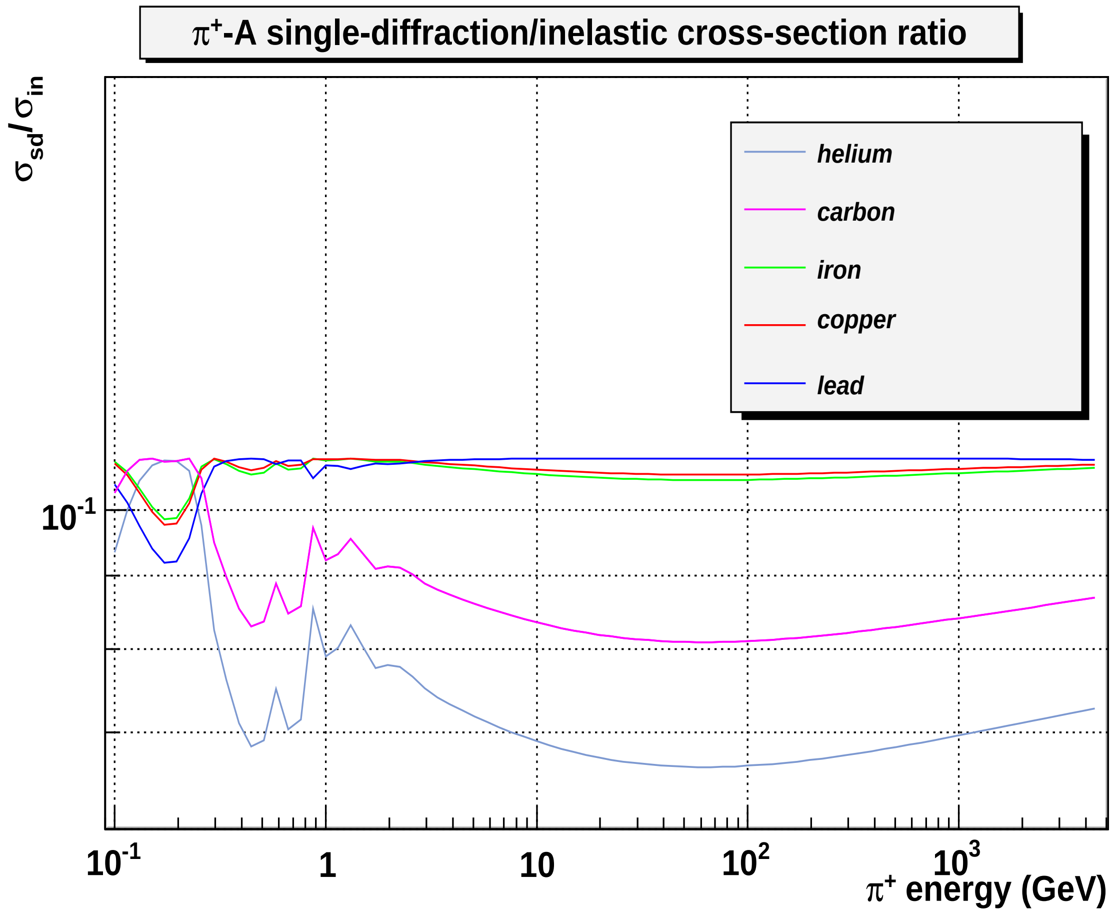
K+-p inelastic cross-section
Cross-section (mb)
30
25
20
15
10
5
0
Coh_el_GG
FTF inelastic
CHIPS inelastic
ihep-exp db data
10-1
1
10
102
103
K+ energy (GeV)

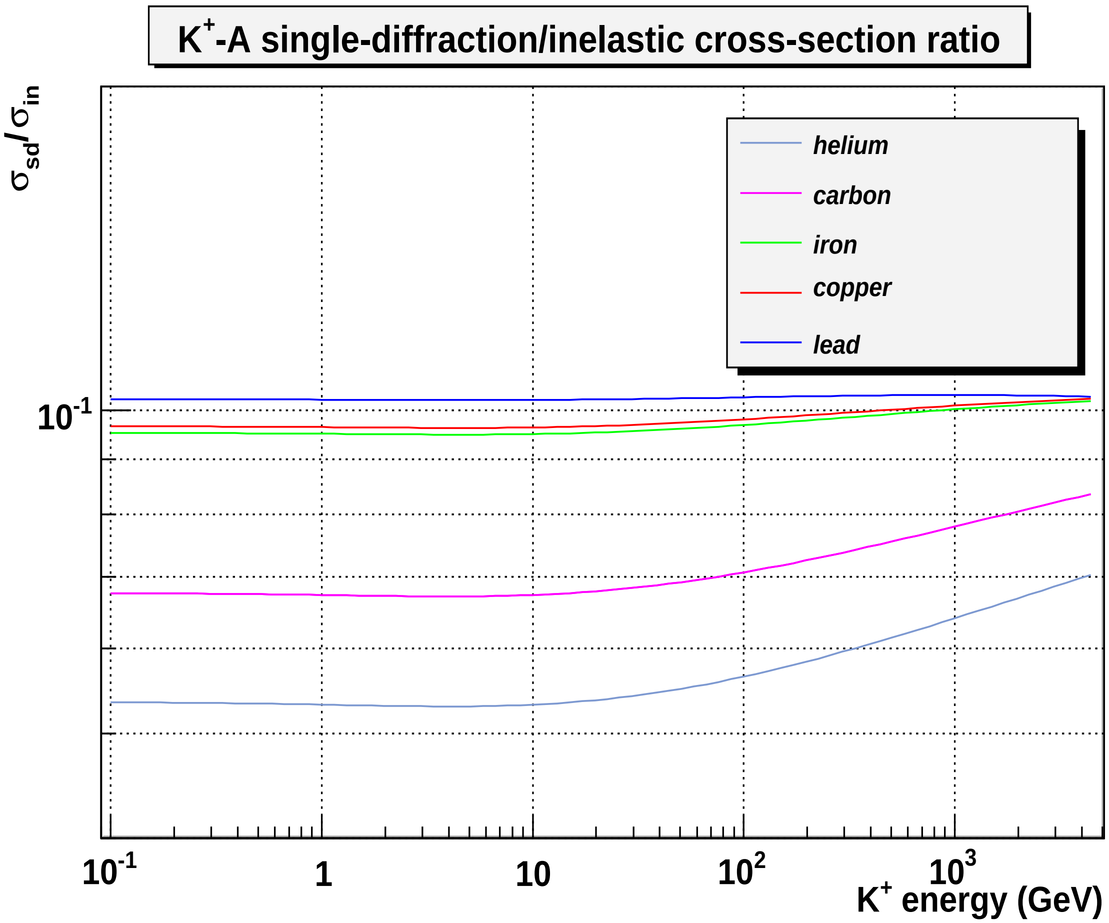


K+-A quasi-elastic/inelastic cross-section ratio
σqe/σin
1
10-1
10-2
10-1
1
10
102
103
K+ energy (GeV)
helium
carbon
iron
copper
lead
helium, CHIPS
lead, CHIPS



p-A single-diffraction/inelastic cross-section ratio
σsd/σin
helium
carbon
iron
copper
lead
10-1
10-1
1
10
102
103
Proton energy (GeV)


π+-A single-diffraction/inelastic cross-section ratio
σsd/σin
10-1
helium
carbon
iron
copper
lead
10-1
1
10
102
103
π+ energy (GeV)


K+-A single-diffraction/inelastic cross-section ratio
σsd/σin
helium
carbon
iron
copper
lead
10-1
10-1
1
10
102
103
K+ energy (GeV)

5 Conclusions

1. G4Pi/NucleonNuclearCrossSection classes based on Barashenkov parametrization show good agreement with experimental data for total, inelastic and elastic cross sections in the wide energy range 10 MeV - 1 TeV.

2. Simplified Glauber model can be used as prolongation of Barashenkov cross sections for the energy range $>$ 100 GeV.

3. Simplified Glauber model was extended for the description of h-A production and single-diffraction cross sections.

4. The quasi-elastic/inelastic and single-diffraction/inelastic cross section ratios are available for different projectiles and targets. It is in qualitative agreement with CHIPS predictions in the energy range 1-100 GeV.