NA2 VALSIM Task 2007 report

J. Apostolakis, G. Folger, V.Grichine, A. Howard, V.Ivantchenko, M. Kossov, A. Ribon, V. Uzinskiy

Outline

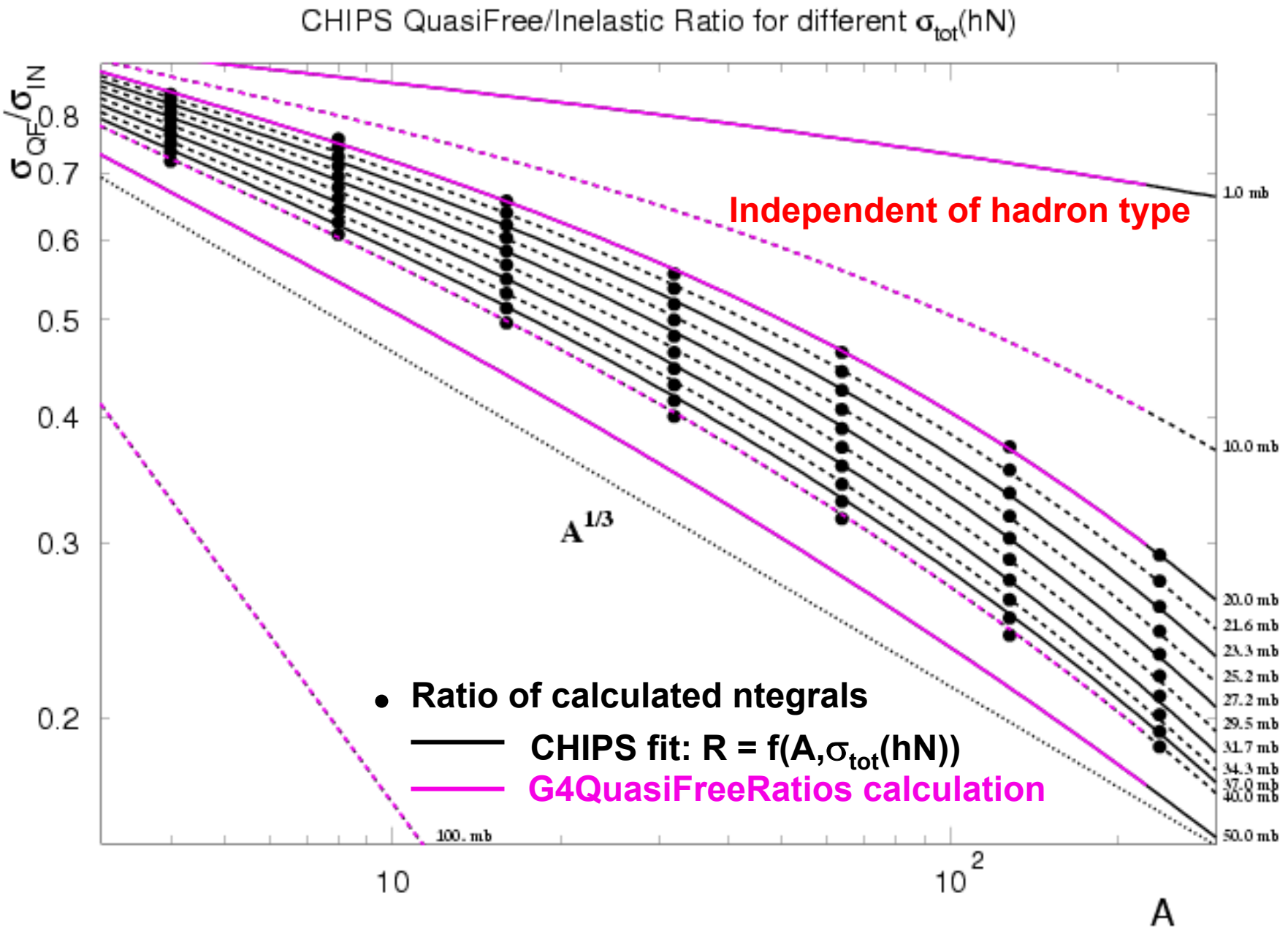
- Introduction
- Model improvements
- Geant4 Releases
  - Quasi-elastic channel
  - Revised FTF model
- Validation
  - Cross sections (EUDET-Memo-2007-18)
  - Hadron elastic scattering
  - Comparisons with TARC experiment data
- Open Issues

Model improvements

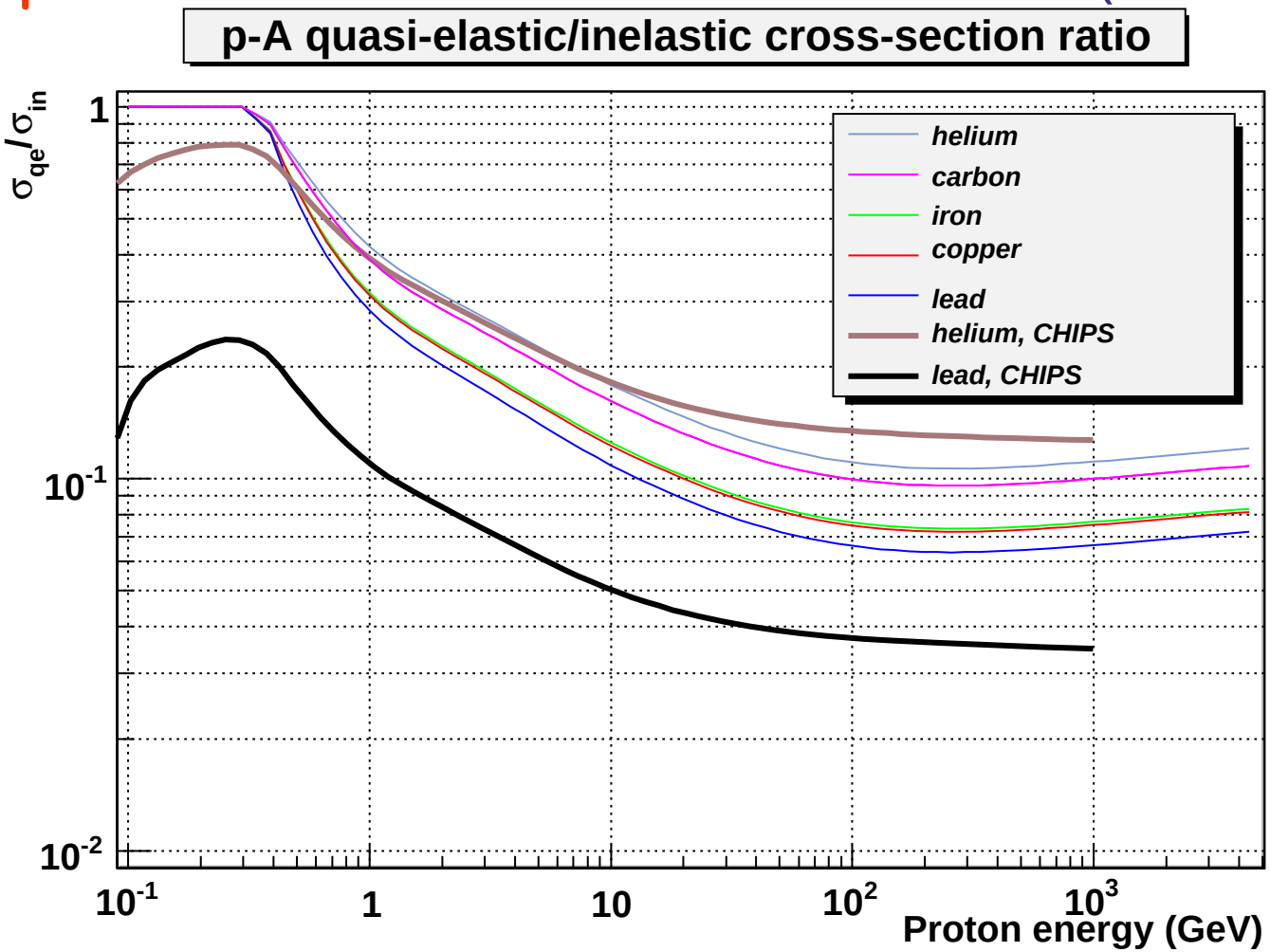
- Identified diffraction and quasi-elastic channels as key channels (more longitudinal)
  - Influence shower shape significantly
  - Need for extended validation
  - String models (Geant4) deficient in modeling these
- Improvements undertaken
  - Geant4 FTF model revised
  - Separate Quasi-elastic channel used with our QGS model
  - Elastic scattering models: t-distribution data fits, diffuse model

Quasi-elastic and inelastic

- To model Quasi-elastic interactions
  - Calculated ratio of cross-sections
    - Quasi-elastic / Inelastic
    - Single-diffraction/Inelastic
  - Split inelastic cross-section of QGS
    - Deep inelastic for our QGS model
    - Quasi-elastic for new model


CHIPS QuasiFree/Inelastic Ratio for different σ_{tot}(hN)
σ_{QF}/σ_{IN}
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Independent of hadron type
$A^{1/3}$
1.0 mb
10.0 mb
20.0 mb
21.6 mb
23.3 mb
25.2 mb
27.2 mb
29.5 mb
31.7 mb
34.3 mb
37.0 mb
40.0 mb
50.0 mb
100. mb
• Ratio of calculated ntegrals
CHIPS fit: R = f(A,σ_{tot}(hN))
G4QuasiFreeRatios calculation
10
10^2
A

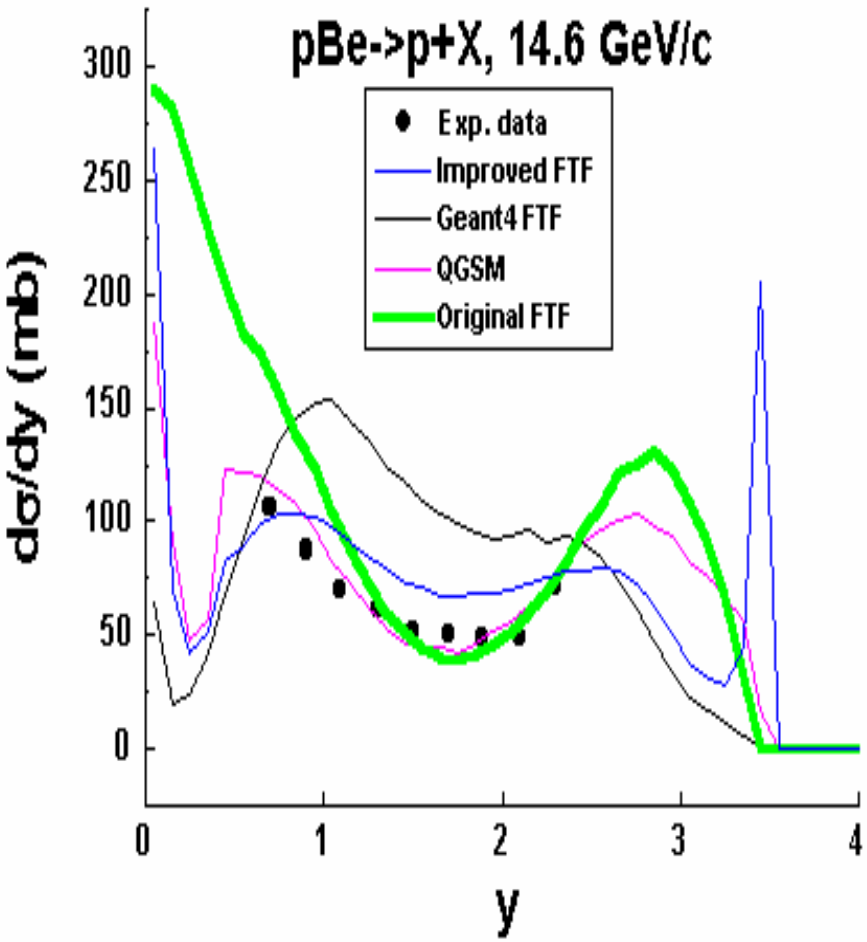
Simplified Glauber model vs. CHIPS (V. Grichine)

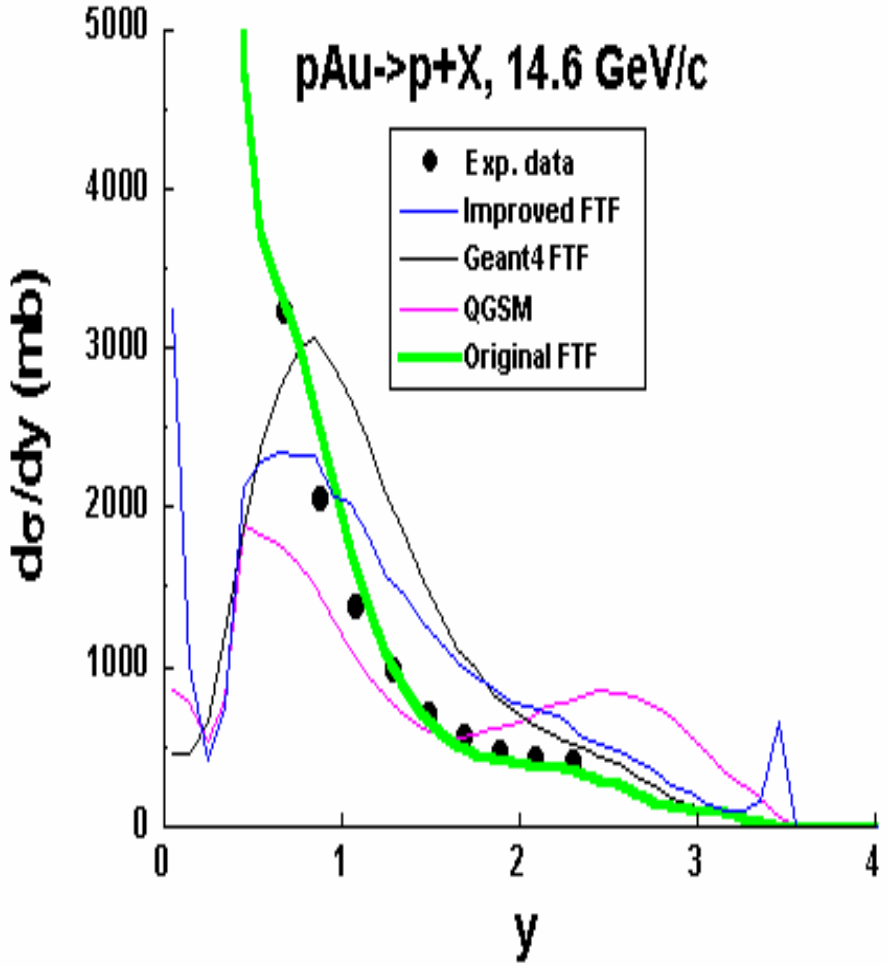


p+Be, p+Au interactions at 14.6 GeV/c

T. Abbott et al. (E-802 Callab.), Phys. Rev. D45 (1992) 3906

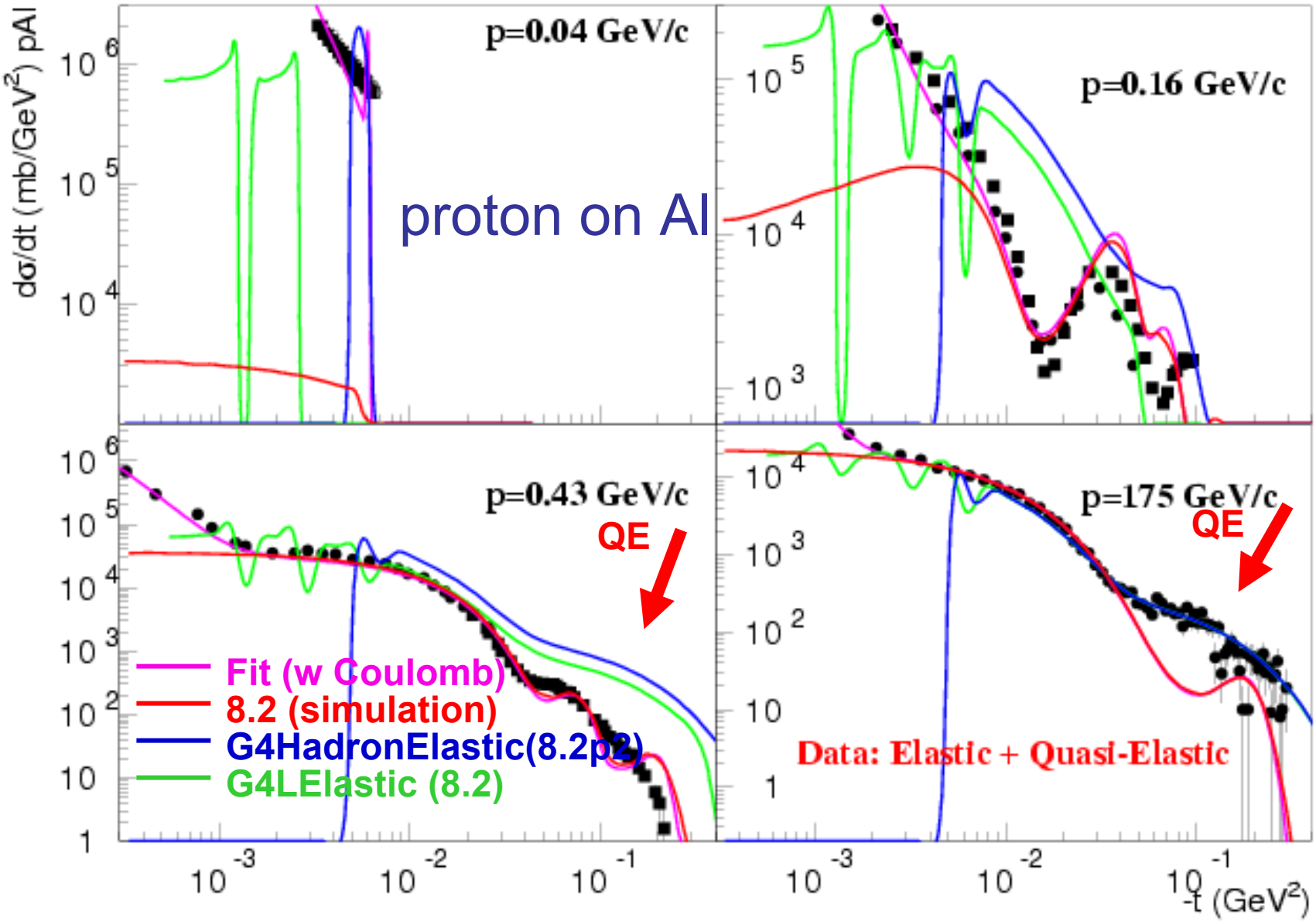
Improvement of Geant4 FTF model





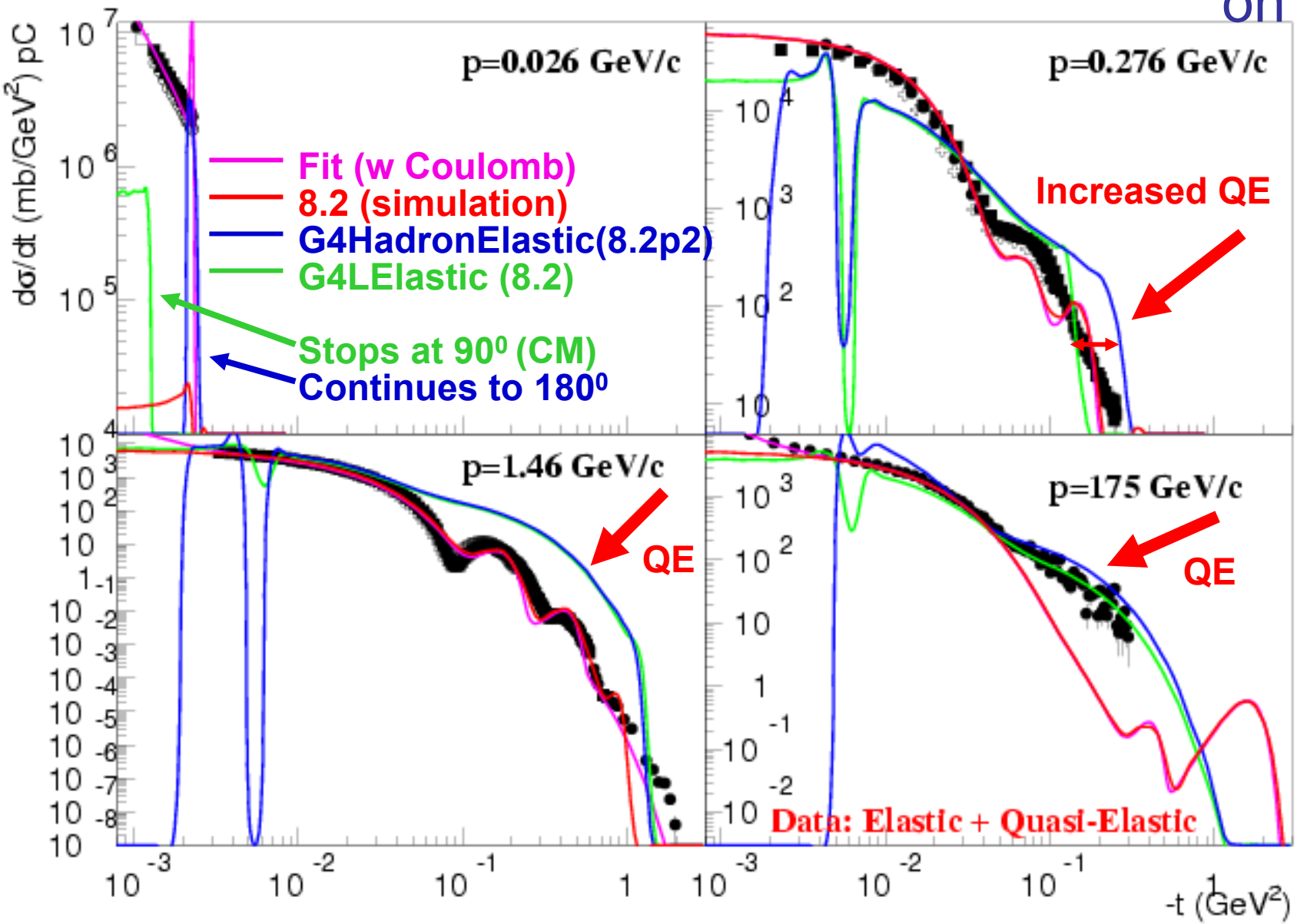
In **Geant4-FTF** model probabilities of intra-nuclear collisions were taken from QGSM. In the original FRITIOF model - from Glauber approximation

CHIPS fit of Elastic Scattering



New Elastic process (CHIPS fit)

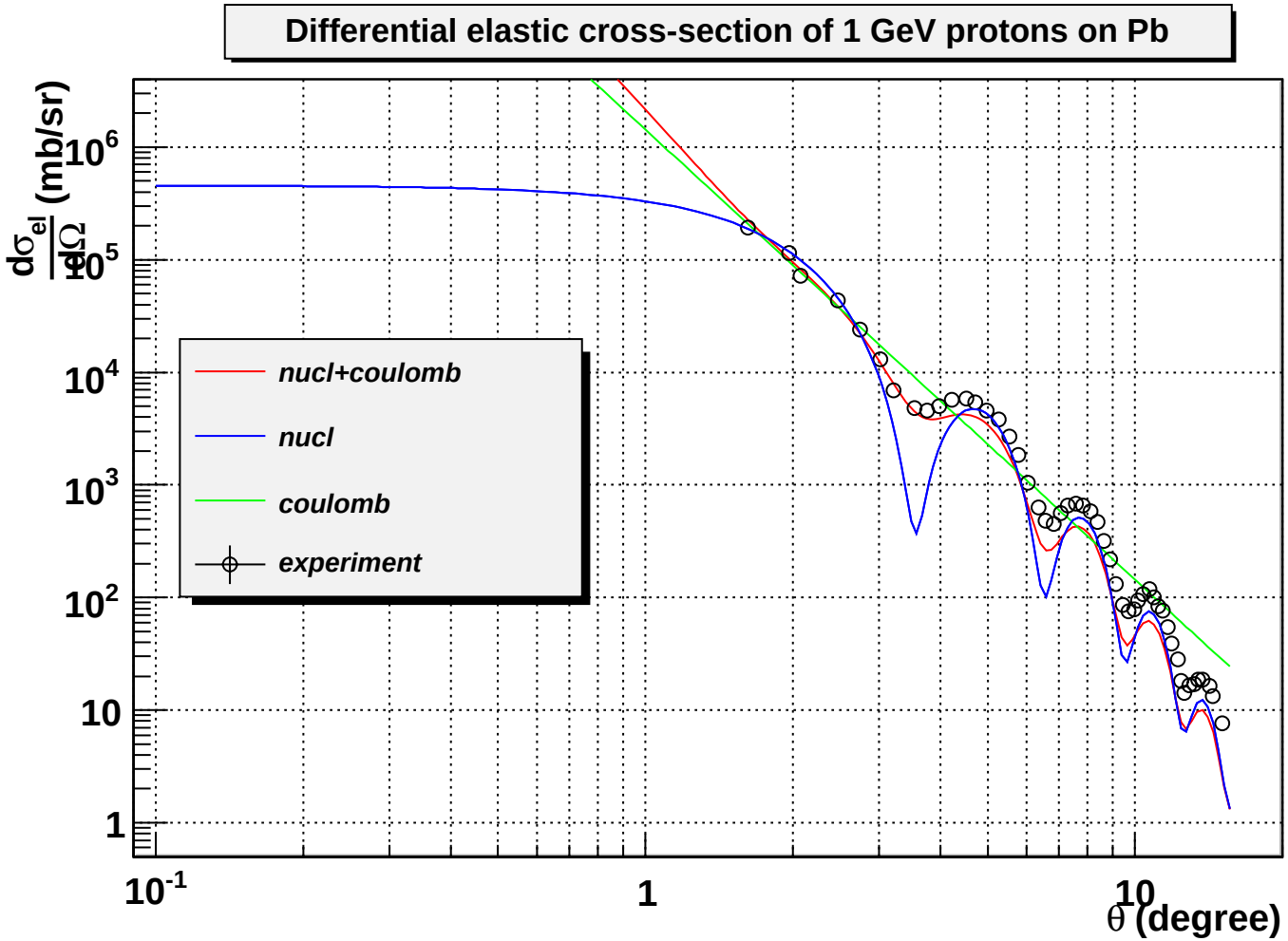
proton on C



Process is called 'QElastic'

M. Kosov

Diffuse charged (&Coulomb) hadron elastic scattering model (details in || NA2 session)



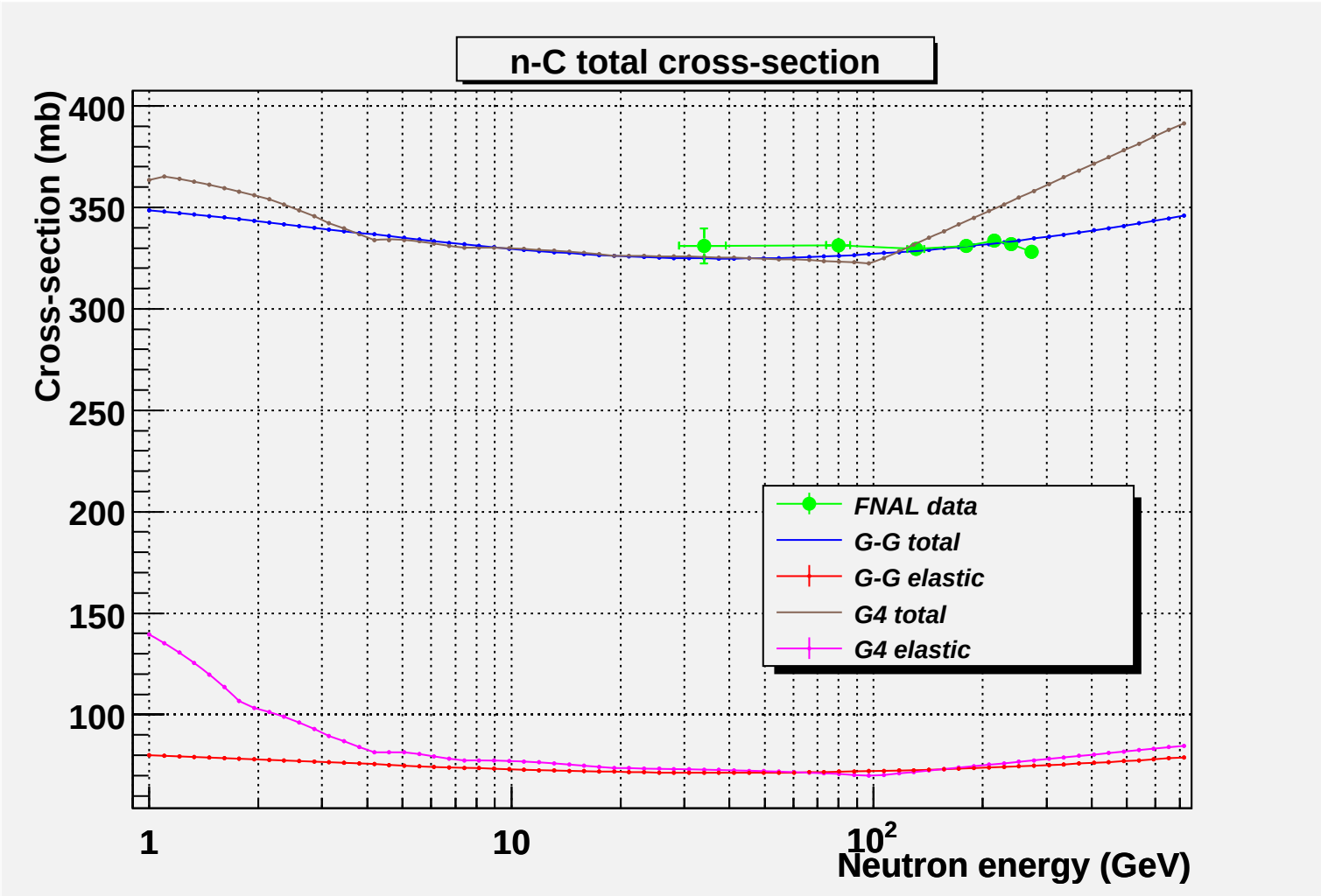
Physics lists and the Quasi-elastic channel

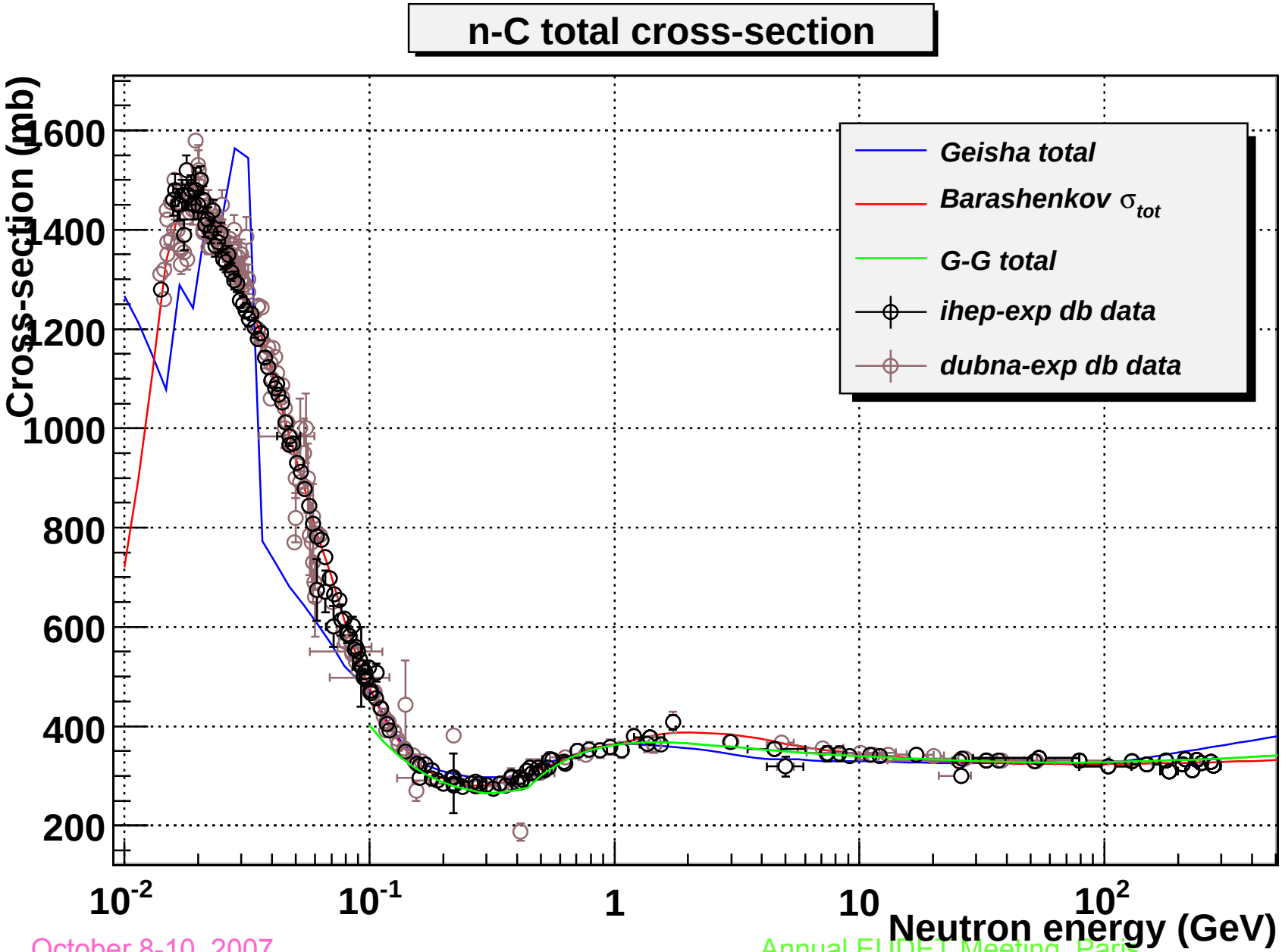
- The new quasi-elastic channel takes part of cross-section (using quasi-elastic/inelastic ratio)
  - from the Quark Gluon String (QGS, since G4 8.3)
  - from FTF (since 9.0) model
- It is activated in QGS physics lists:
  - QGSP, QGSC, QGSP_BERT, QGSP_BIC
  - QGSP_EMV, QGSP_BERT_EMV (faster EM)
  - QGSP_BERT_HP, QGSP_BIC_HP (precision neutron)
- Except in new QGSP_NQE, QGSP_BERT_NQE where this inelastic channel is inactive
  - Temporary lists (NQE = No Quasi-Elastic).
- Not relevant to LHEP physics list
  - It (HEP) does not use a string model.

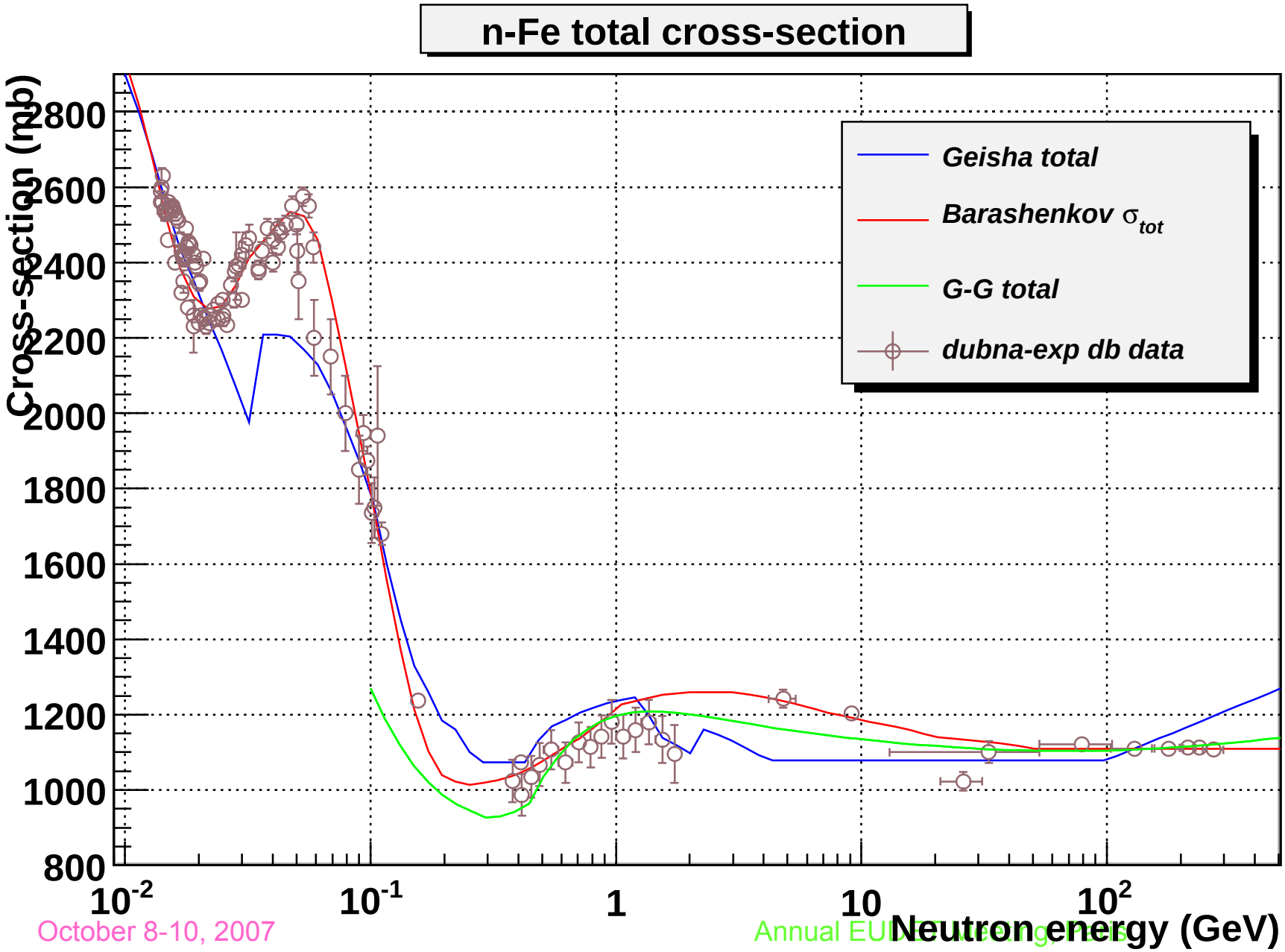
Cross sections

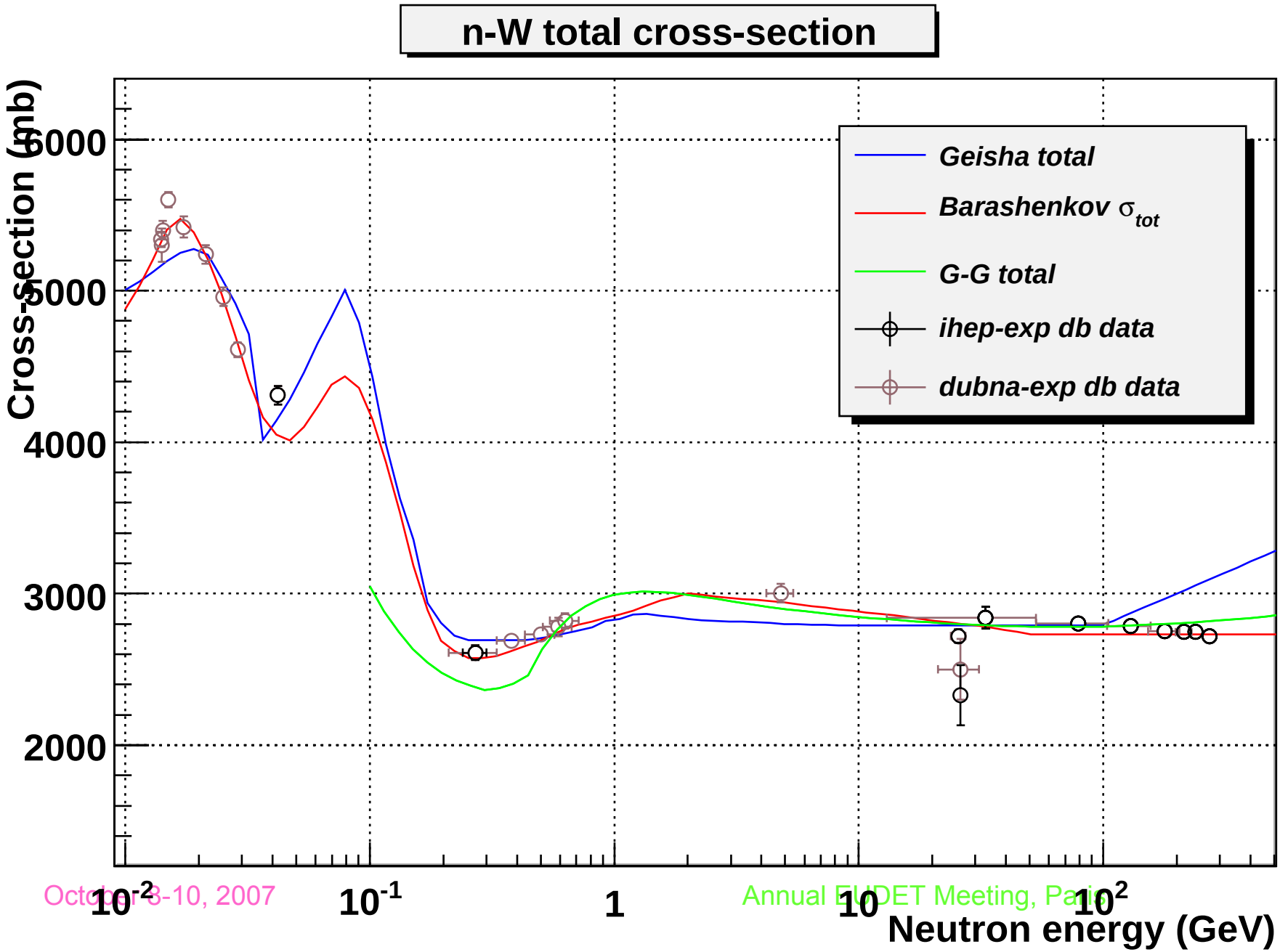
- Review and validation of G4 cross-sections
  - Inelastic hadron-nuclear
  - Total hadron-nuclear
    - Note: In Geant4 the elastic and inelastic are separate
      - The total is taken from the sum elastic & inelastic, as used in different physics lists (means: el = tot – in)
- As a result, created two new cross section classes (EUDET-Memo-2007-18):
  - Optical model interpolation cross-sections for nucleons (tot,in: el=tot-in)
  - Simplified Glauber model for scaling E>100 GeV

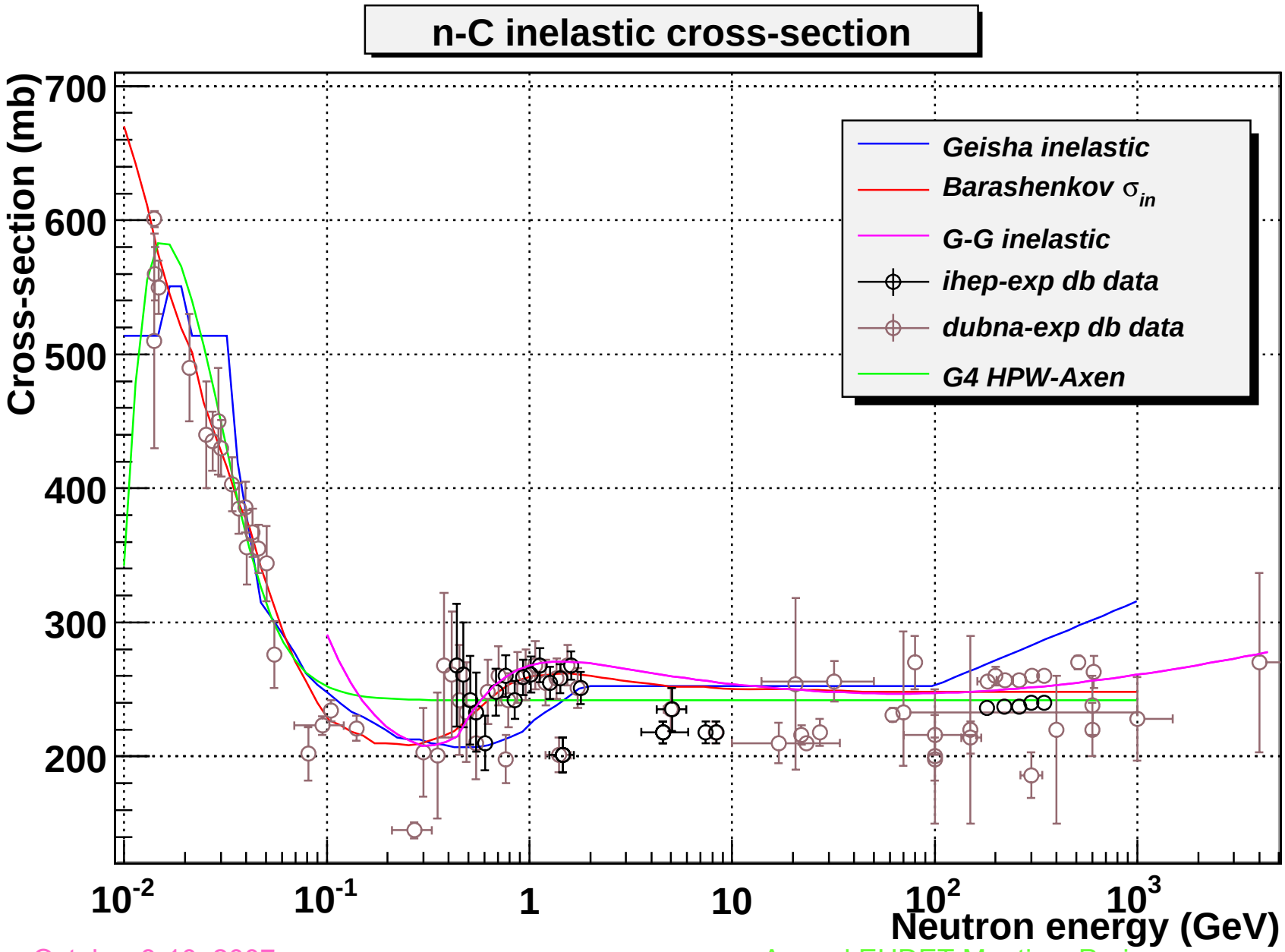
Munich, Oct. 2006



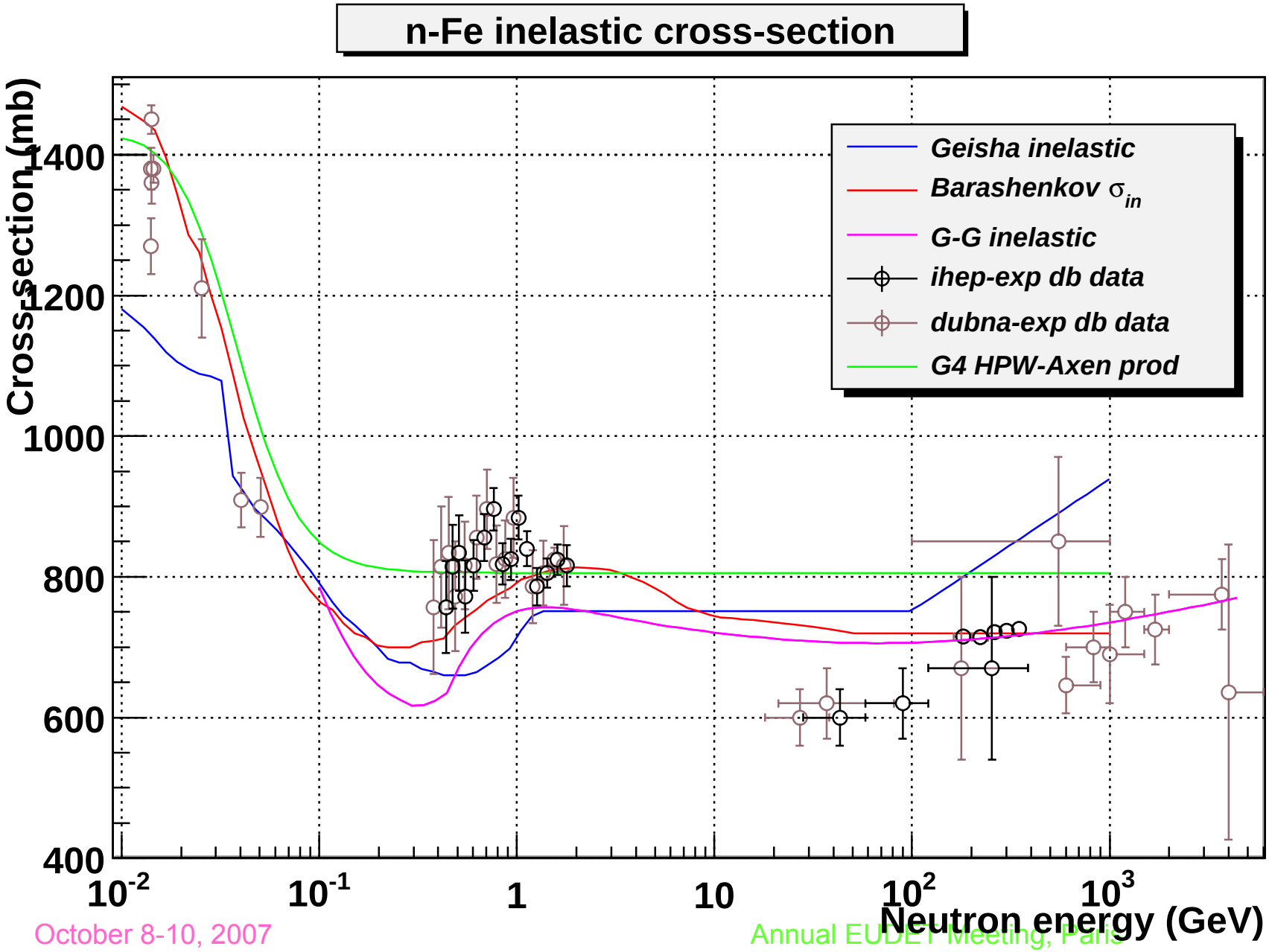

n-C total cross-section
Cross-section (mb)
1600
1400
1200
1000
800
600
400
200
10^{-2}
10^{-1}
1
10
10^{2}
Neutron energy (GeV)
Geisha total
Barashenkov σ_{tot}
G-G total
ihep-exp db data
dubna-exp db data


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
dubna-exp db data


n-W total cross-section
Cross-section (mb)
6000
5000
4000
3000
2000
10^{-2}
10^{-1}
1
10
10^{2}
Neutron energy (GeV)
Geisha total
Barashenkov σ_{tot}
G-G total
ihep-exp db data
dubna-exp db data

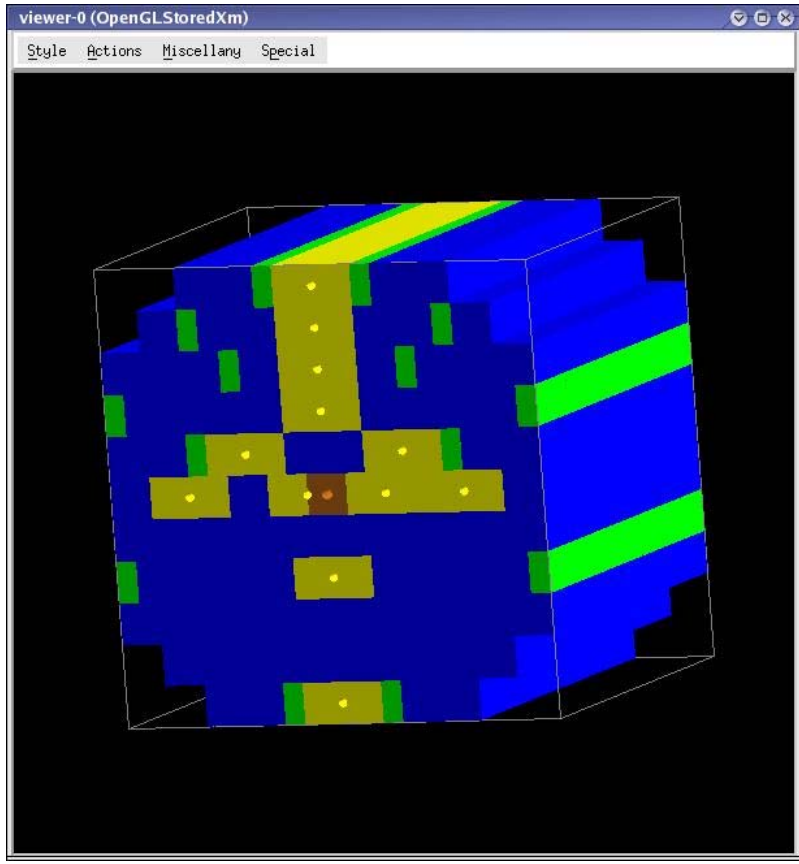

n-C inelastic cross-section
Cross-section (mb)
700
600
500
400
300
200
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Neutron energy (GeV)
Geisha inelastic
Barashenkov σ_{in}
G-G inelastic
ihep-exp db data
dubna-exp db data
G4 HPW-Axen

Details in recent EUDET-Memo-2007-18



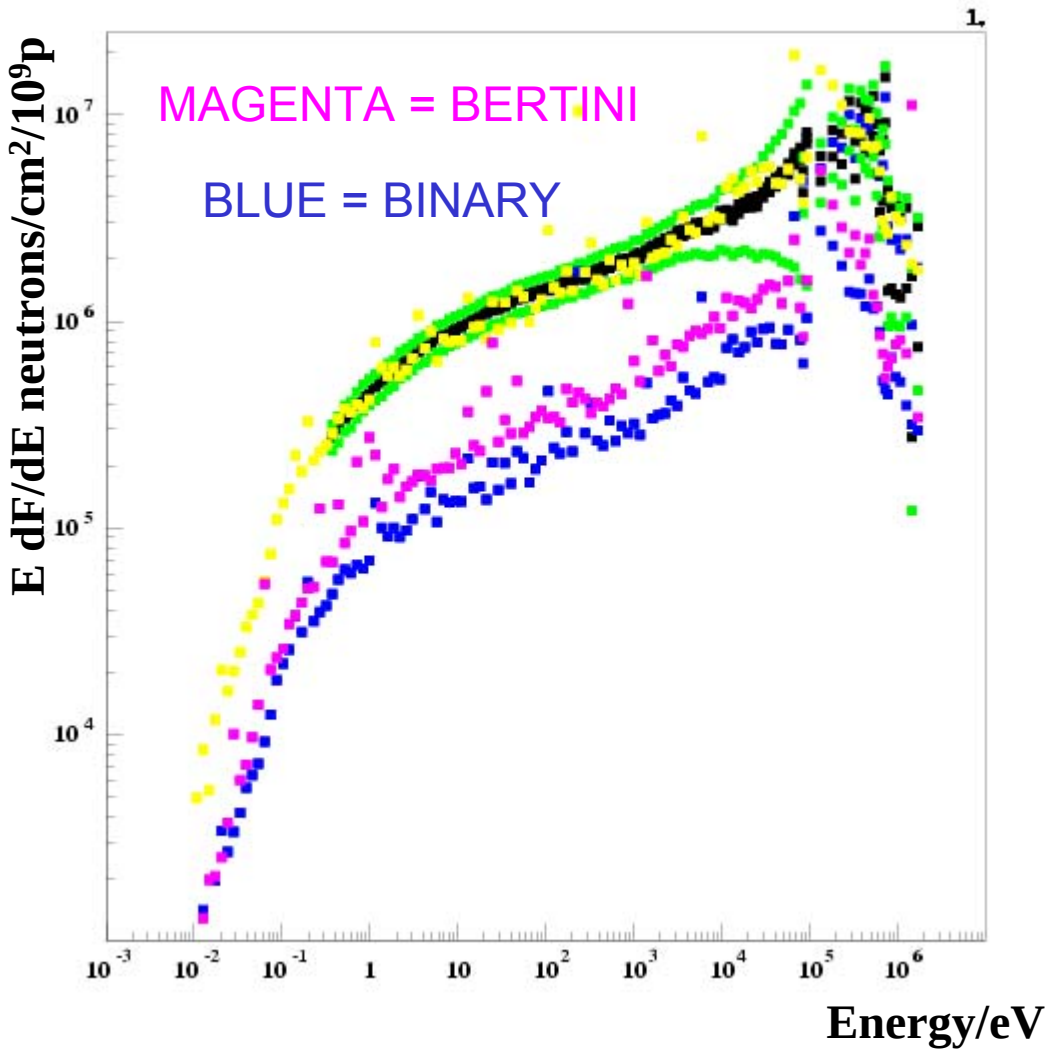
The TARC Experiment Geant4 n-Benchmark

- Neutron Driven Nuclear Transmutation by Adiabatic Resonance Crossing (Cern 96-97)
- 2.5 or 3.5 GeV/c proton beam.
- 334 tons of Pb in cylindrical 3.3m x 3.3m x 3m block.
- The lead is 99.99% pure.
- Beam enters through a 77.2mm diameter blind hole, 1.2m long.
- 12 sample holes are located inside the volume to measure capture cross-sections on some isotopes (energy-time curve).



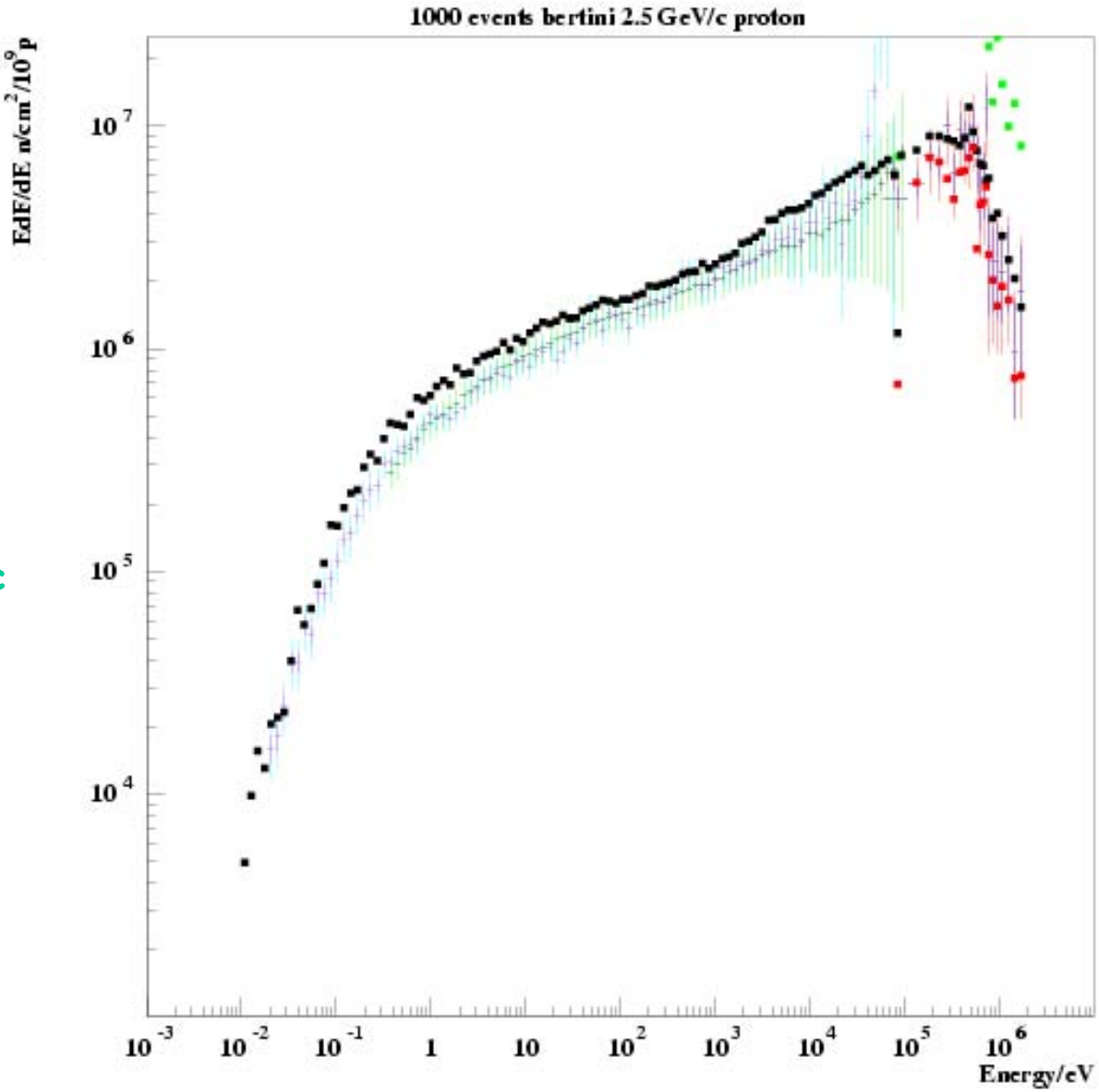
TARC Fluence. Munich. Oct. 2006

- Spectral fluence is determined from the energy-time correlation with cross-checks (lithium activation and He3 ionisation detectors)
- The simulated fluence is still below measurement
- The Bertini cascade gets closest to the data
- The spectral shape looks reasonable
- Yellow curve is ~ 4xBERTINI



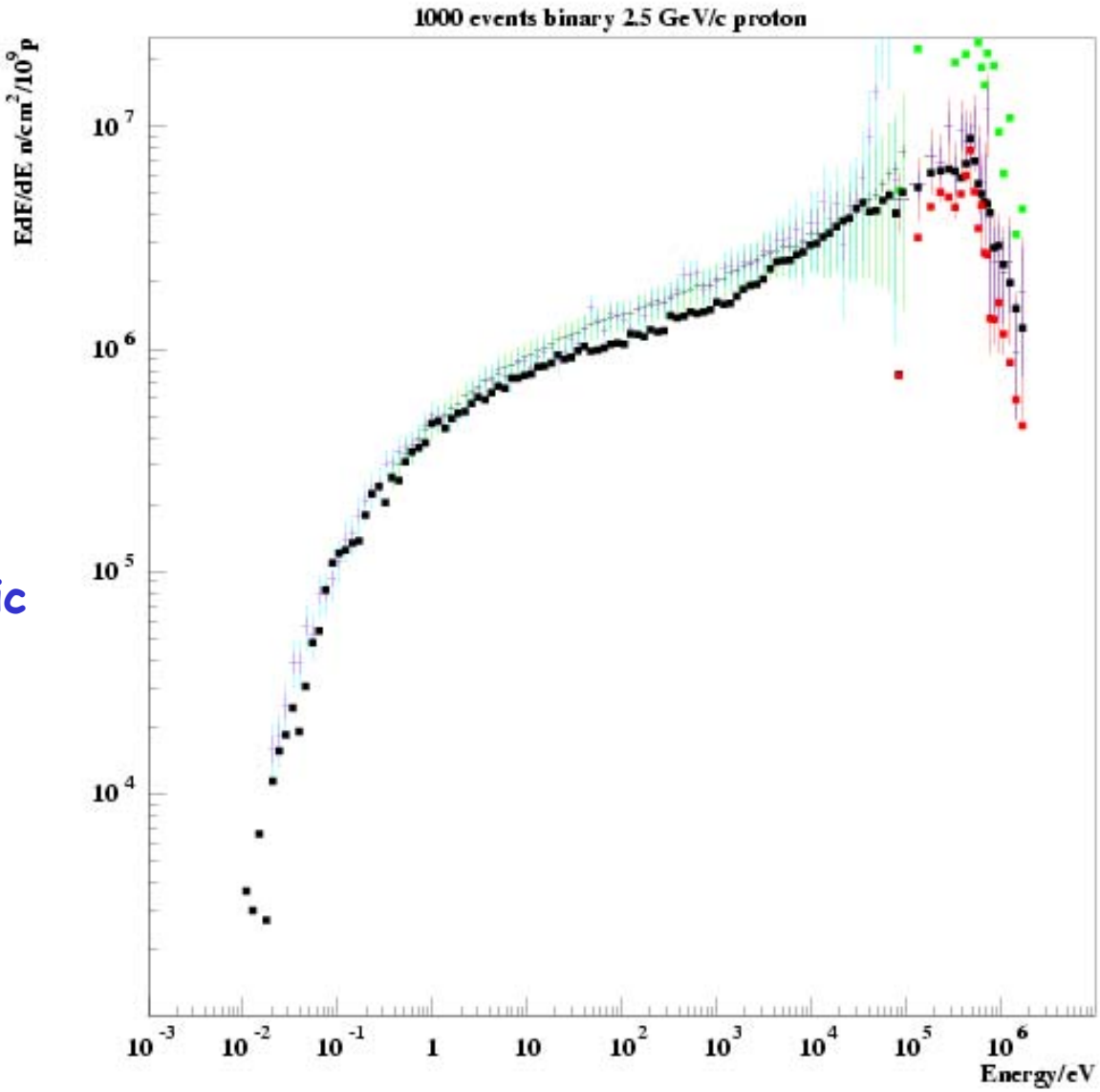
Fluence Bertini cascade 2007

- Yellow: sphere
- Red: cylinder
- Black: Full 4π shell
- Bins: <E>*dP/dE
- 50-60% overestimated
- Dominated by systematic

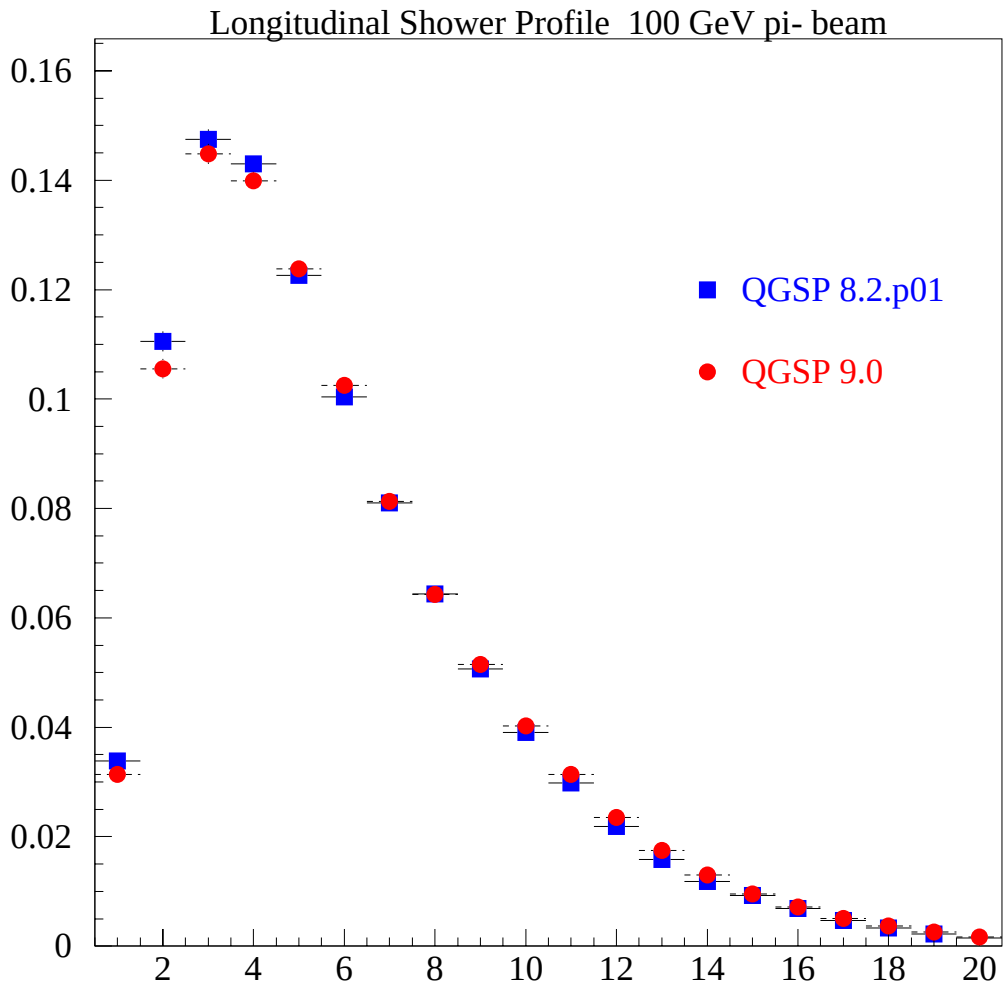


Fluence Binary cascade 2007

- Yellow: sphere
- Red: cylinder
- Black: Full 4π shell
- ~ 15% underestimated
- Dominated by systematic of experiment



Longitudinal Shower Shape Profiles of Iron-Scintillator Calorimeter (simplified ATLAS TileCal)A. Ribon



The shower (10 λ) becomes a bit longer due to quasi-elastic processes

Quasi-elastic & Fritiof model

Considering a 100 GeV π^- beam on a Iron-Scintillator sampling calorimeters (a kind of simplified version of the ATLAS TileCal calorimeter), we can look how the visible energy is distributed in four longitudinal quarters:

	G4 8.2.p01		G4 9.0		
	QGSP	FTFP	QGSP	FTFP	
f_{L1}	55.7%	56.5%	54.5%	52.2%	
f_{L2}	33.6%	33.6%	34.0%	34.6%	
f_{L3}	8.9%	8.2%	9.5%	10.6%	(smaller for Cu)
f_{L4}	1.8%	1.6%	2.0%	2.6%	

The longitudinal shower shapes are longer in G4 9.0 because of the quasi-elastic scattering. Furthermore, Fritiof model has been improved (thanks to V.Uzhinskiy).

Ongoing work

- **Comparisons of proton-nucleus target diffraction (pA->pX) underway. A lot to do!**
  - Data from HELIOS experiment, 450 GeV/c
- **TARC**
  - Radial fluence distribution
  - True calorimetry
  - Neutron capture
  - Write-up
- **Review of pre-compound and de-excitation**
  - Mini-workshop at CERN, July 17-21, 2007
  - Improvements of models underway
- **New Diffuse Elastic for differential σ (msc, NIEL)**

Summary

- **Improvements released in Geant4 8.3 (4 May 2007):**
  - First revision of FTF model
  - Quasi-elastic channel coupled with QGS model
- **Improvements in Geant4 9.0 (30 June 2007)**
  - Further revision of FTF model (for pions)
  - Quasi elastic added to FTF physics lists
  - QElastic used for all nucleon projectiles (all targets)
- **Already released**
  - Elastic scattering process (QElastic: 8.1 p/n on H, 8.2 p/n on all)
- **Cross-section review (EUDET-Memo-2007-18)**
- **Validation of neutron transport in TARC**

Backup slides

Deliverable

- VALSIM month 18 milestone (June 2007)
  - "First release of improved version of the hadronic processes and physics lists in GEANT4“
- Improvements identified and undertaken:
  - Issues identifies as a result of validation
  - Revised FTF model, improving diffraction
  - New modeling of quasi-elastic channel

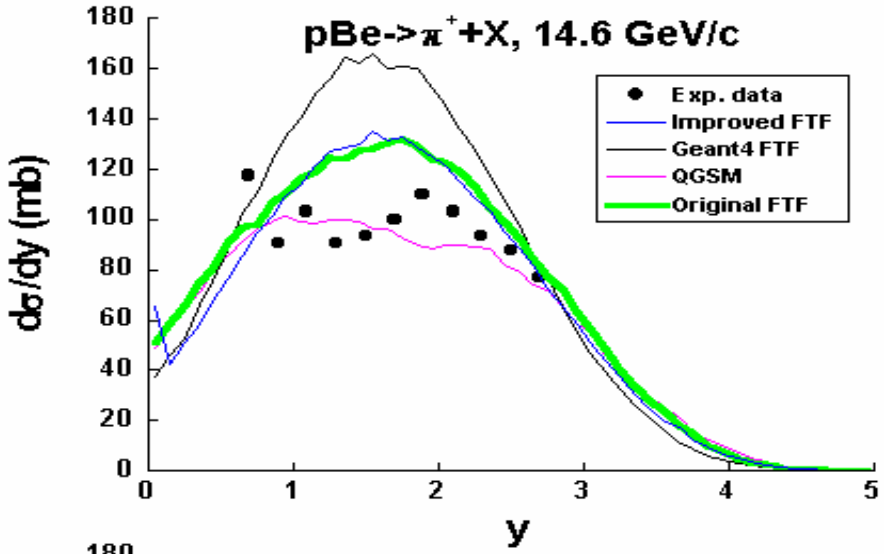
Geant4 Releases

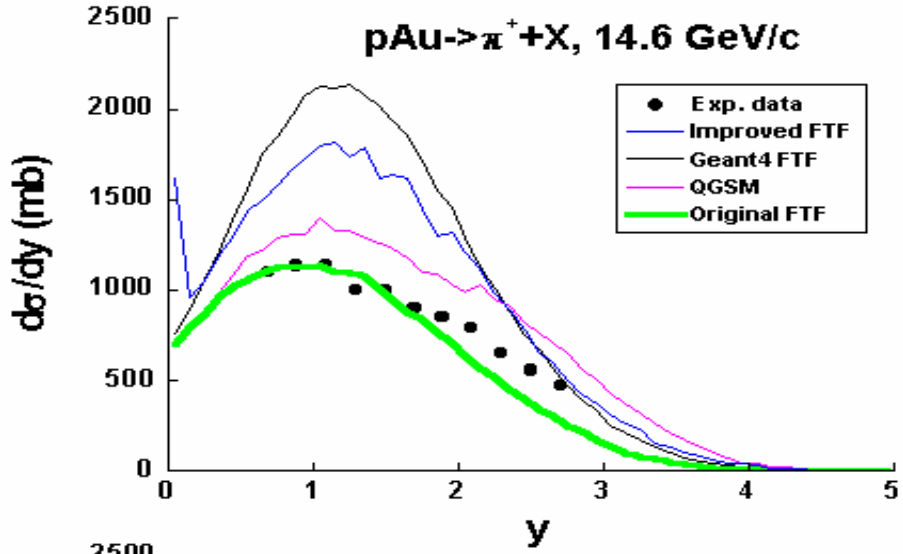
- The upcoming minor release Geant4 8.3 includes
  - the revised FTF model (in place of the original)
  - Option to split the inelastic cross-section between the QGS model and a quasi-elastic interaction
    - Activated in QGSx family of Physics lists (see next page)
  - Fix to Copper cross-section
    - which was reduced in 7.0 (tbv) by 4% compared to data
- It is planned for public release on 9th May 2007
- Geant4 9.0 is the scheduled release of June.

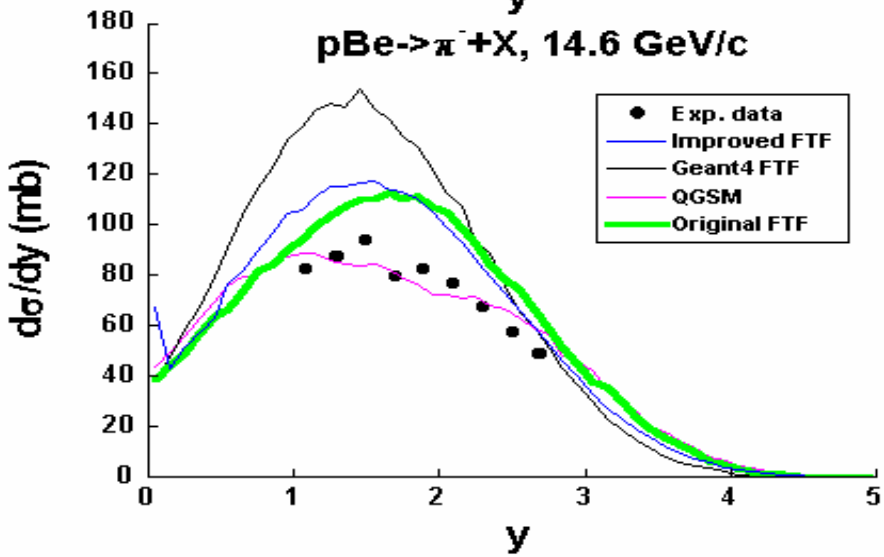
Releases and Elastic improvement

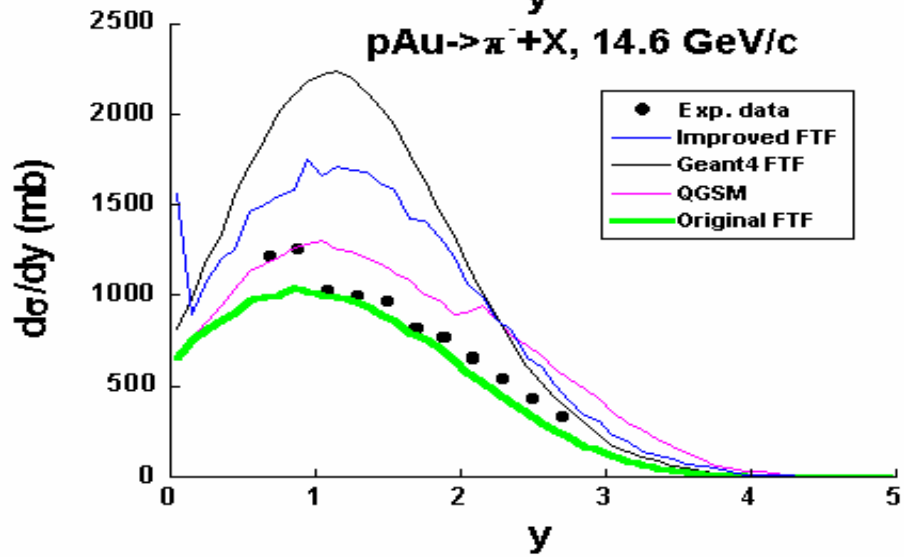
- Improved Elastic scattering
  - Most important for Hydrogen
  - Most relevant for light targets, but all improved
- The new ‘QElastic’ (M. Kossov)
  - As a process available for all elements in 8.2
    - Used in QGSC and QGSP_QEL
- Intermediate solution (since Geant4 8.1)
  - HadronElastic (V. Ivantchenko) used QElastic for Hydrogen
    - Used in QGSx , FTFx physics lists in 8.1-8.3

Comparison with exp. data



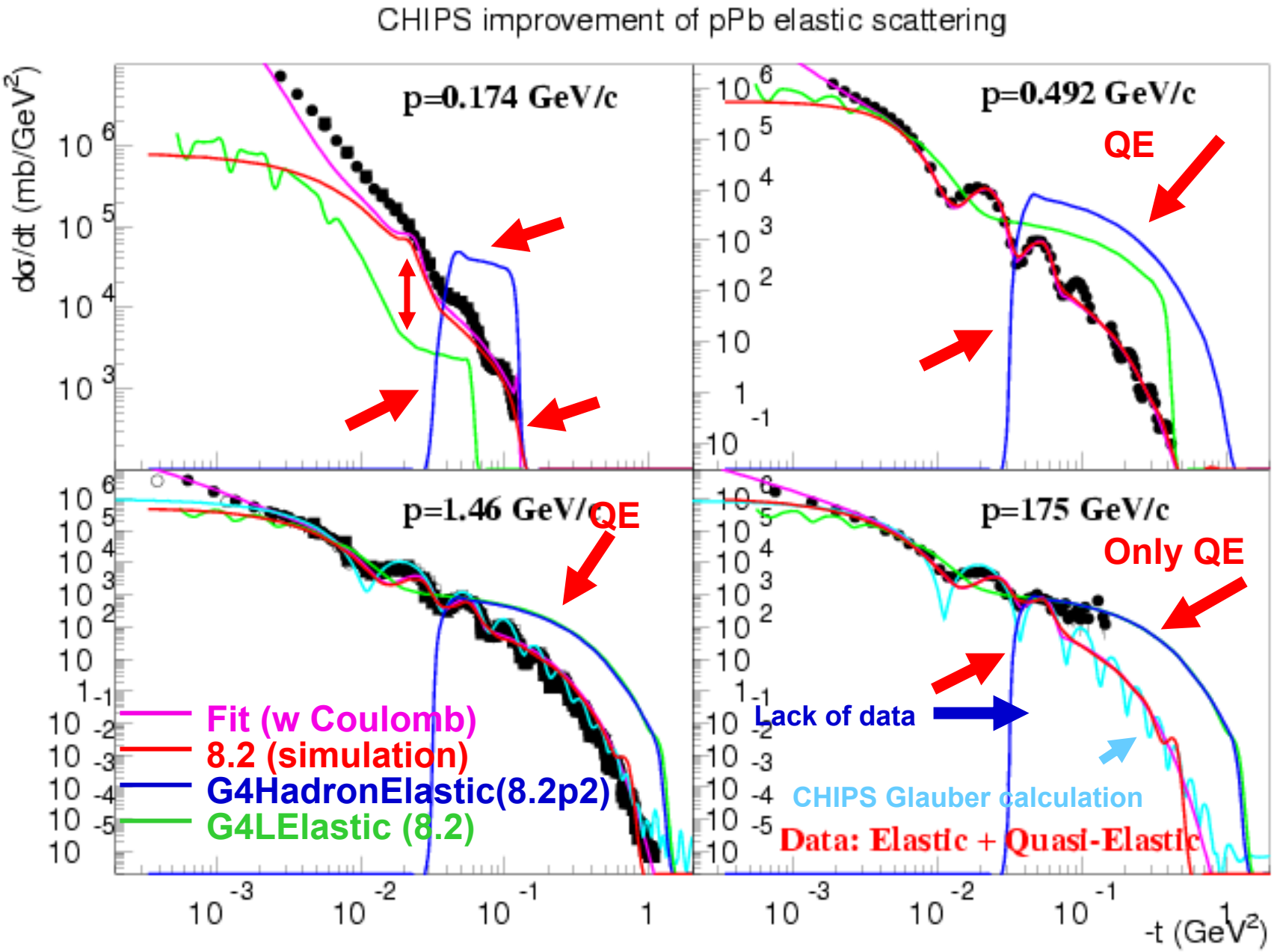






Octot

There is a problem with description of rapidity distributions

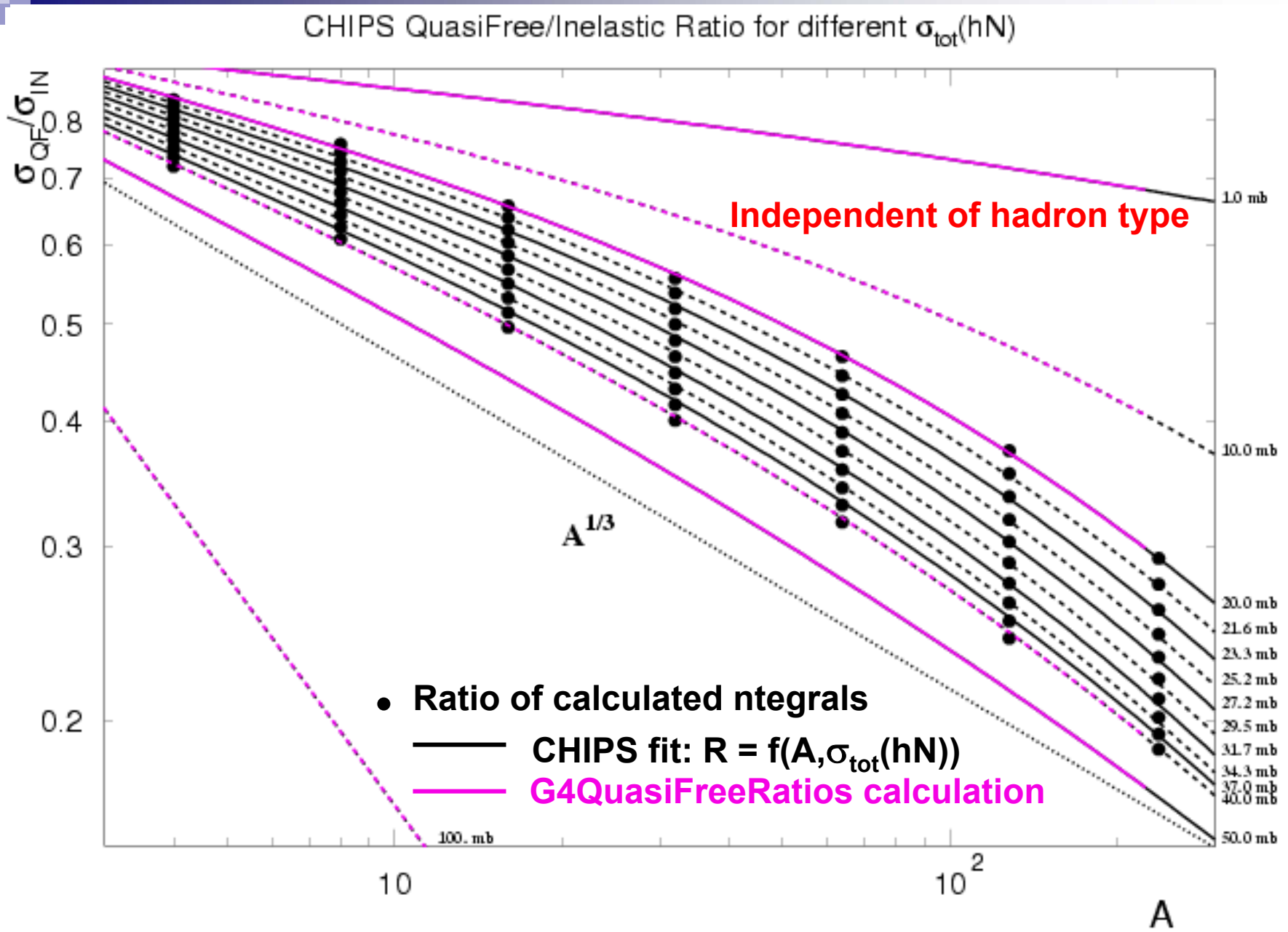

CHIPS improvement of pPb elastic scattering
dσ/dt (mb/GeV²)
p=0.174 GeV/c
p=0.492 GeV/c
QE
p=1.46 GeV/c
QE
p=175 GeV/c
Only QE
Fit (w Coulomb)
8.2 (simulation)
G4HadronElastic(8.2p2)
G4LElastic (8.2)
Lack of data
CHIPS Glauber calculation
Data: Elastic + Quasi-Elastic
-t (GeV²)

CHIPS method for quasi-elastic scattering

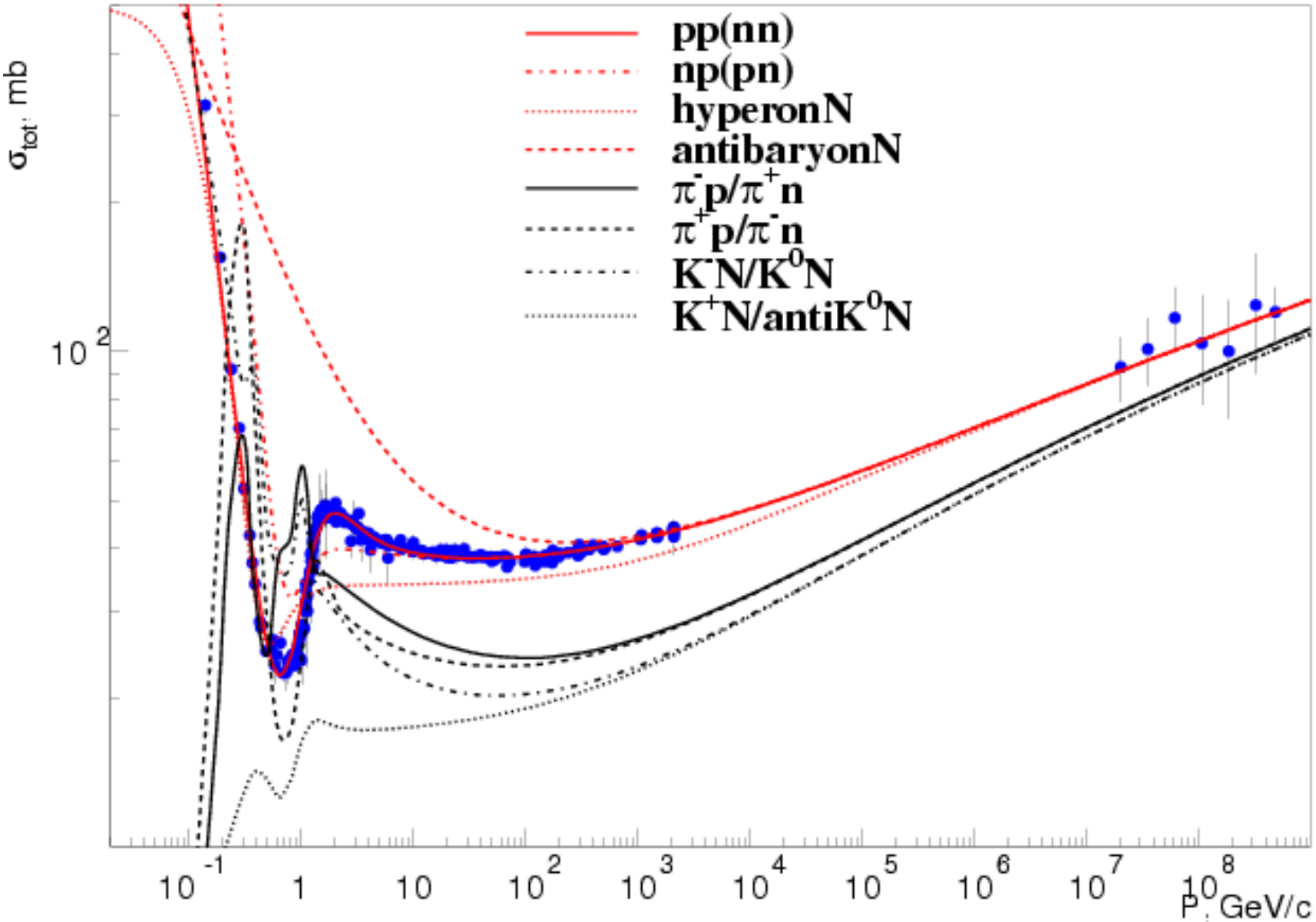
- Calculate and approximate R=QE/Inelastic
  - Probability of interaction: $\sigma_{in}=\int 1-e^{-\sigma\cdot T(b)}d^2\mathbf{b}$, $\sigma=\sigma^{tot}(hN)$
  - Probability to interact once: $\sigma_{QF}=\int\sigma\cdot T(b)\cdot e^{-\sigma\cdot T(b)}d^2\mathbf{b}$
- Precize approximation of $\sigma^{el}(hN)$ & $\sigma^{tot}(hN)$
  - $n\bar{n}/pp$ and $np/p\bar{n}$ interactions
  - N-N and Hyperon-N interactions
  - π^-p/π^+n and $\pi^+p/\pi^-\bar{n}$ interactions
  - K^-N/K^0N and $K^+N/\bar{K}^0N$ interactions

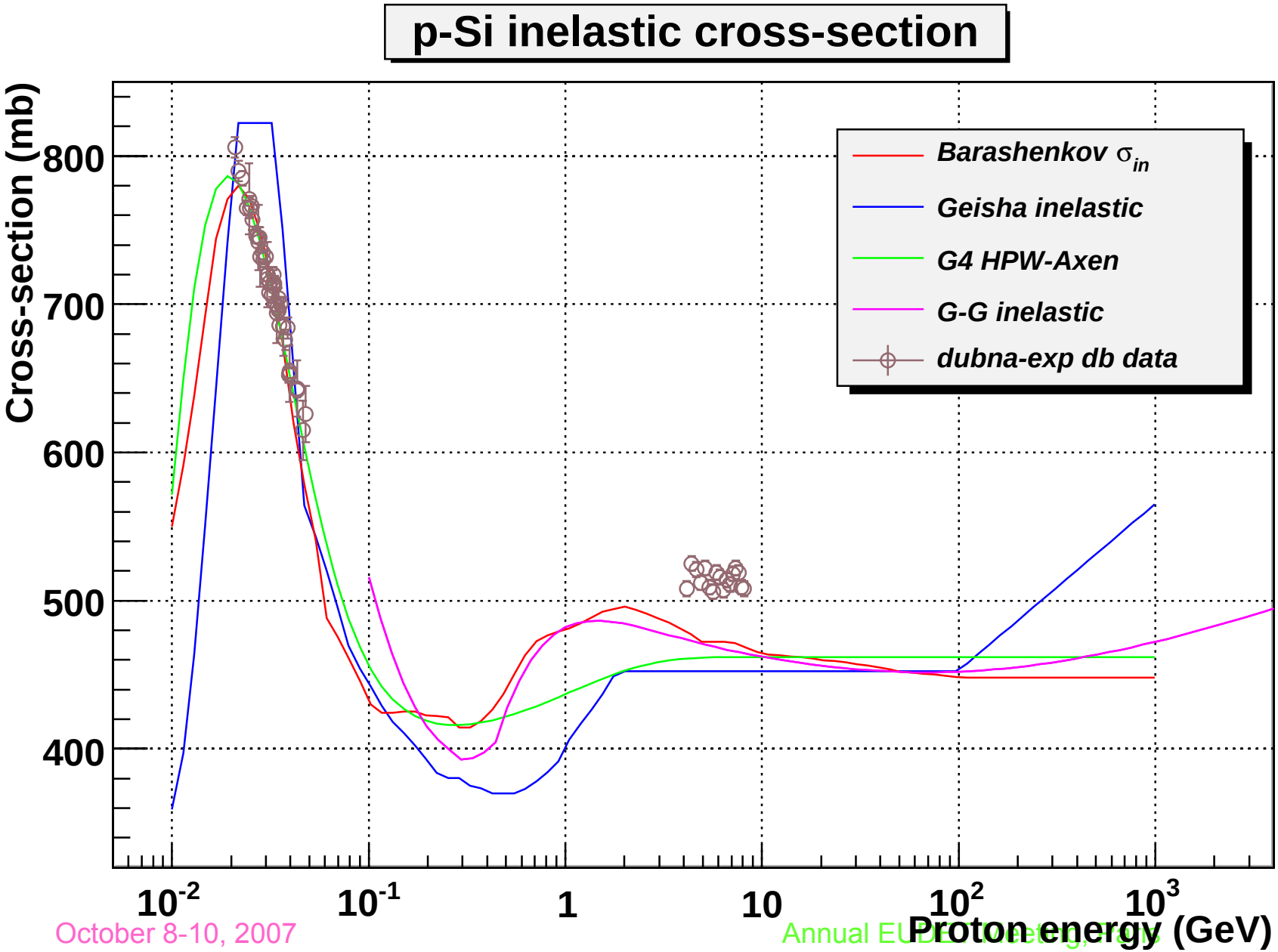
  } **8 isotopic groups**

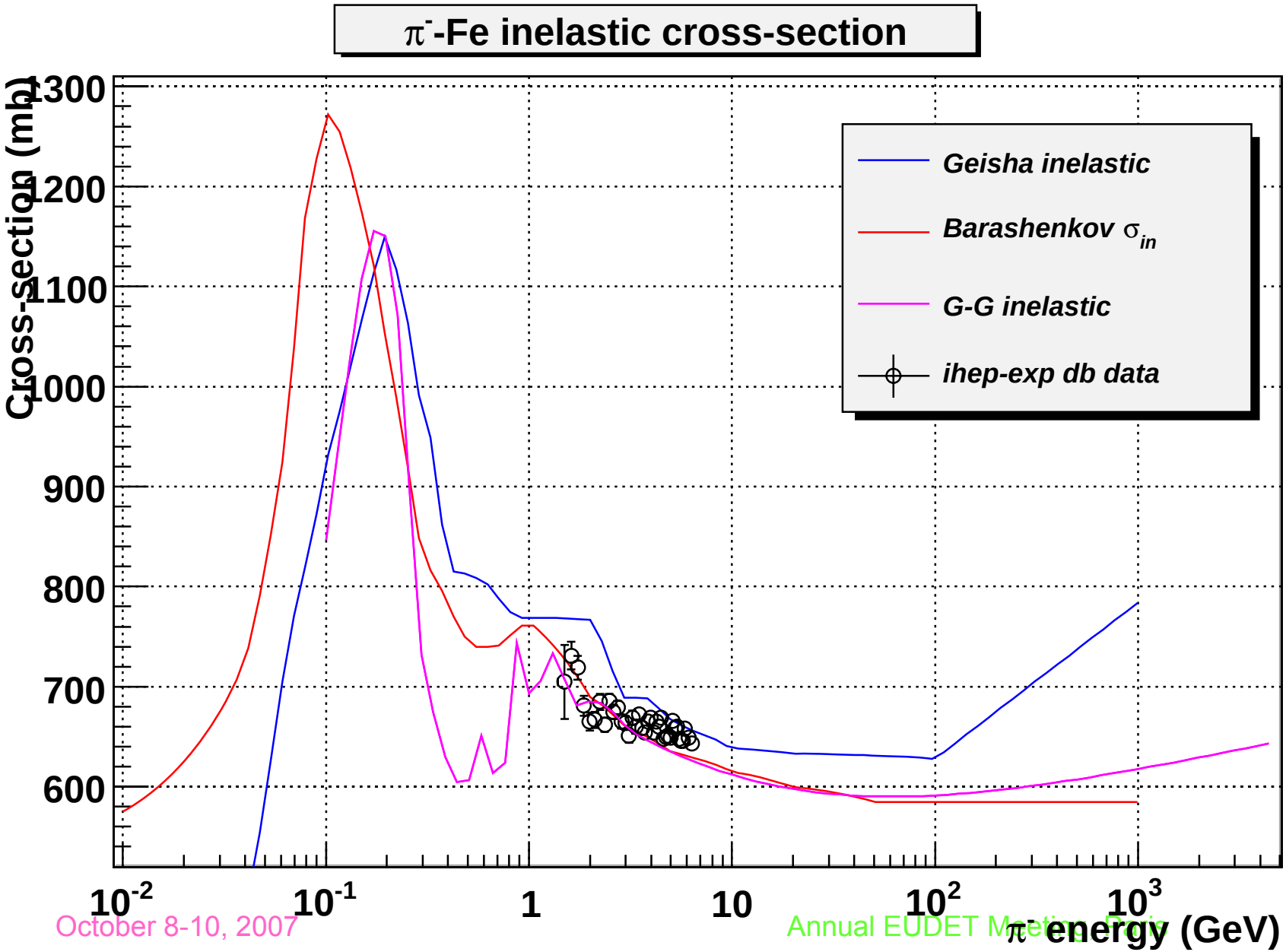
- Calculation of QElastic/In & QFree/In ratios


CHIPS QuasiFree/Inelastic Ratio for different σtot(hN)
σQF/σIN
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Independent of hadron type
A1/3
1.0 mb
10.0 mb
20.0 mb
21.6 mb
23.3 mb
25.2 mb
27.2 mb
29.5 mb
31.7 mb
34.3 mb
37.0 mb
40.0 mb
50.0 mb
100. mb
• Ratio of calculated ntegrals
CHIPS fit: R = f(A,σtot(hN))
G4QuasiFreeRatios calculation
10
10 2
A

CHIPS improvement of hadron-nucleon total cross-section

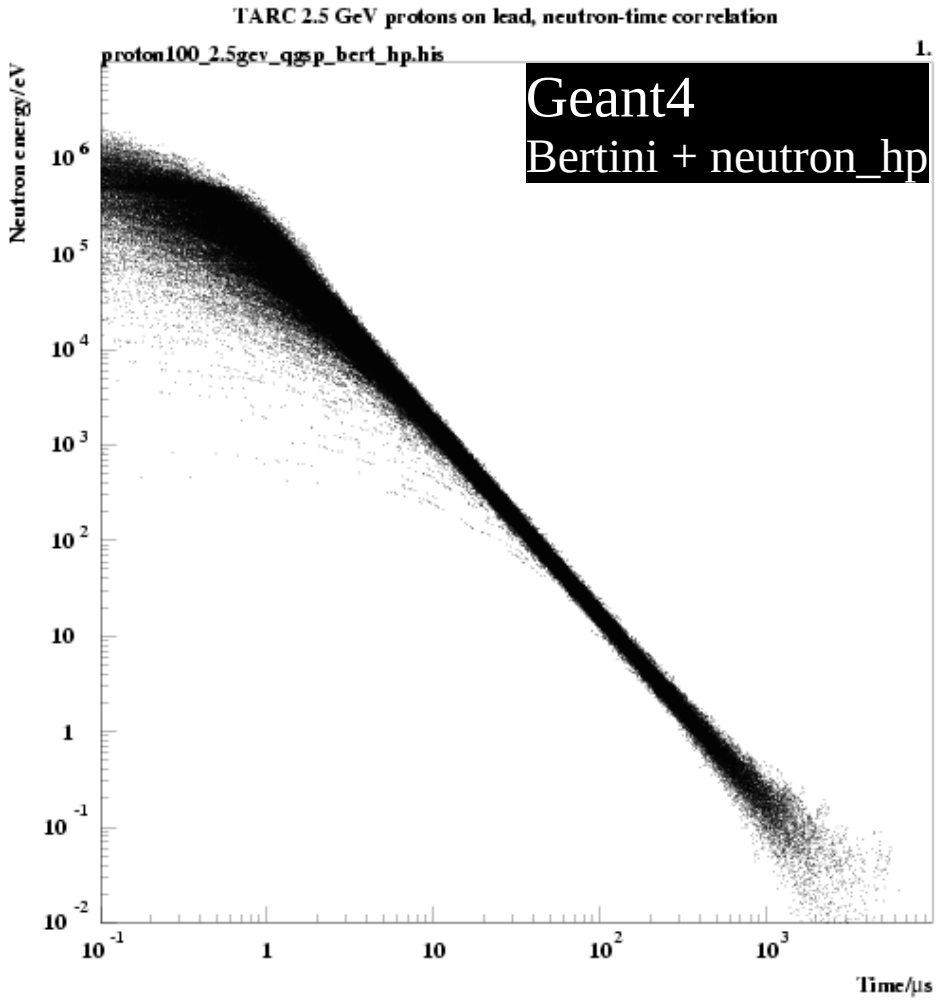



p-Si inelastic cross-section
Cross-section (mb)
800
700
600
500
400
Barashenkov σin
Geisha inelastic
G4 HPW-Axen
G-G inelastic
dubna-exp db data
10-2
10-1
1
10
102
103
Proton energy (GeV)


π⁻-Fe inelastic cross-section
Cross-section (mb)
1300
1200
1100
1000
900
800
700
600
10⁻²
10⁻¹
1
10
10²
10³
π⁻ energy (GeV)
Geisha inelastic
Barashenkov σin
G-G inelastic
ihep-exp db data

Neutron Energy-Time Correlation

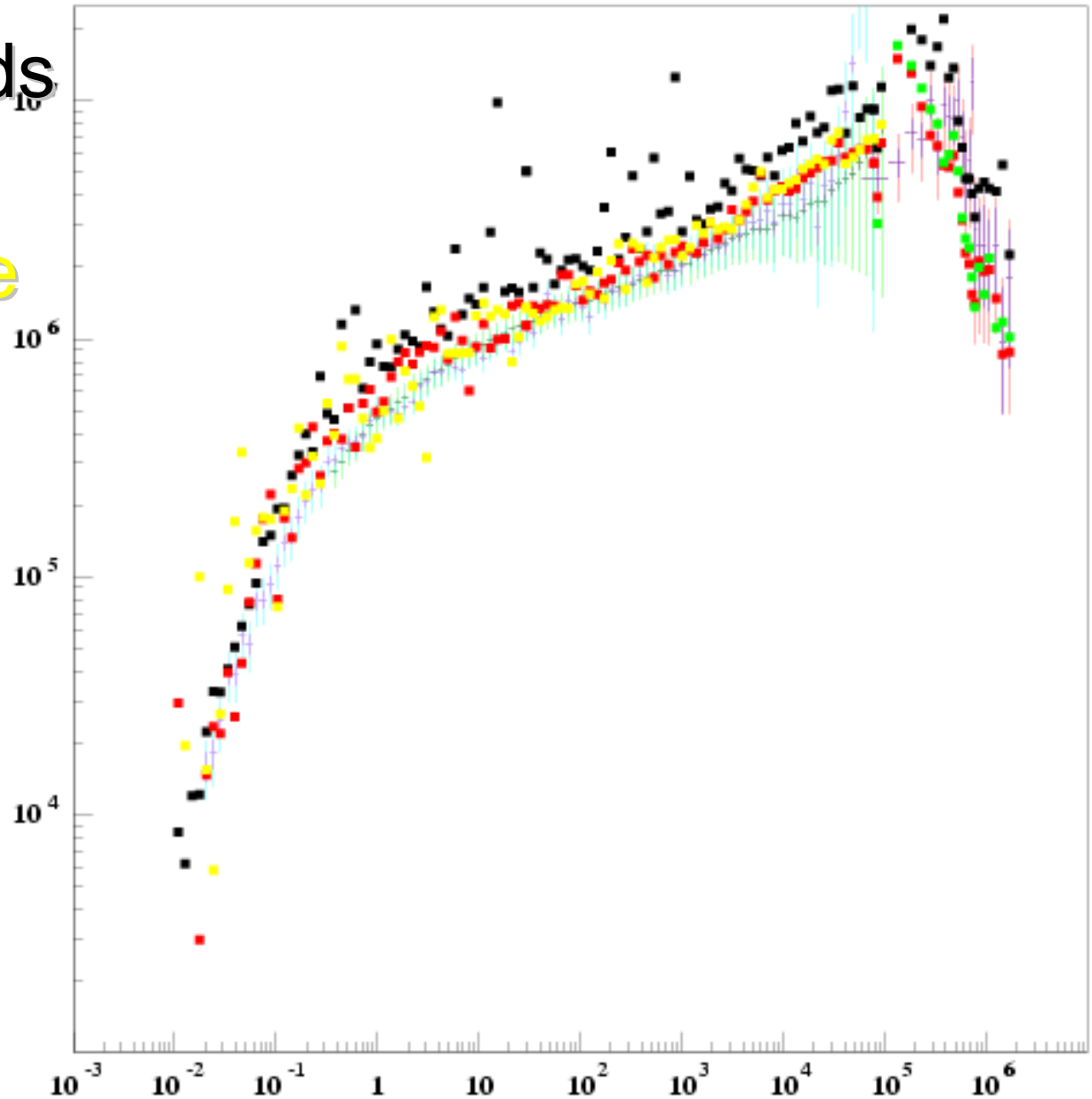
- A first test of neutron transportation in Geant4 is to look at energy-time correlation
- This relies heavily on the high precision neutron_hp model for neutrons < 20 MeV
- Neutron energy and time are stored for the flux through a given radial shell
- Reasonable agreement with expectation, although the low energy population is quite different between physics list (as expected)



Fluence Bertini cascade 2007

Different methods to measure:

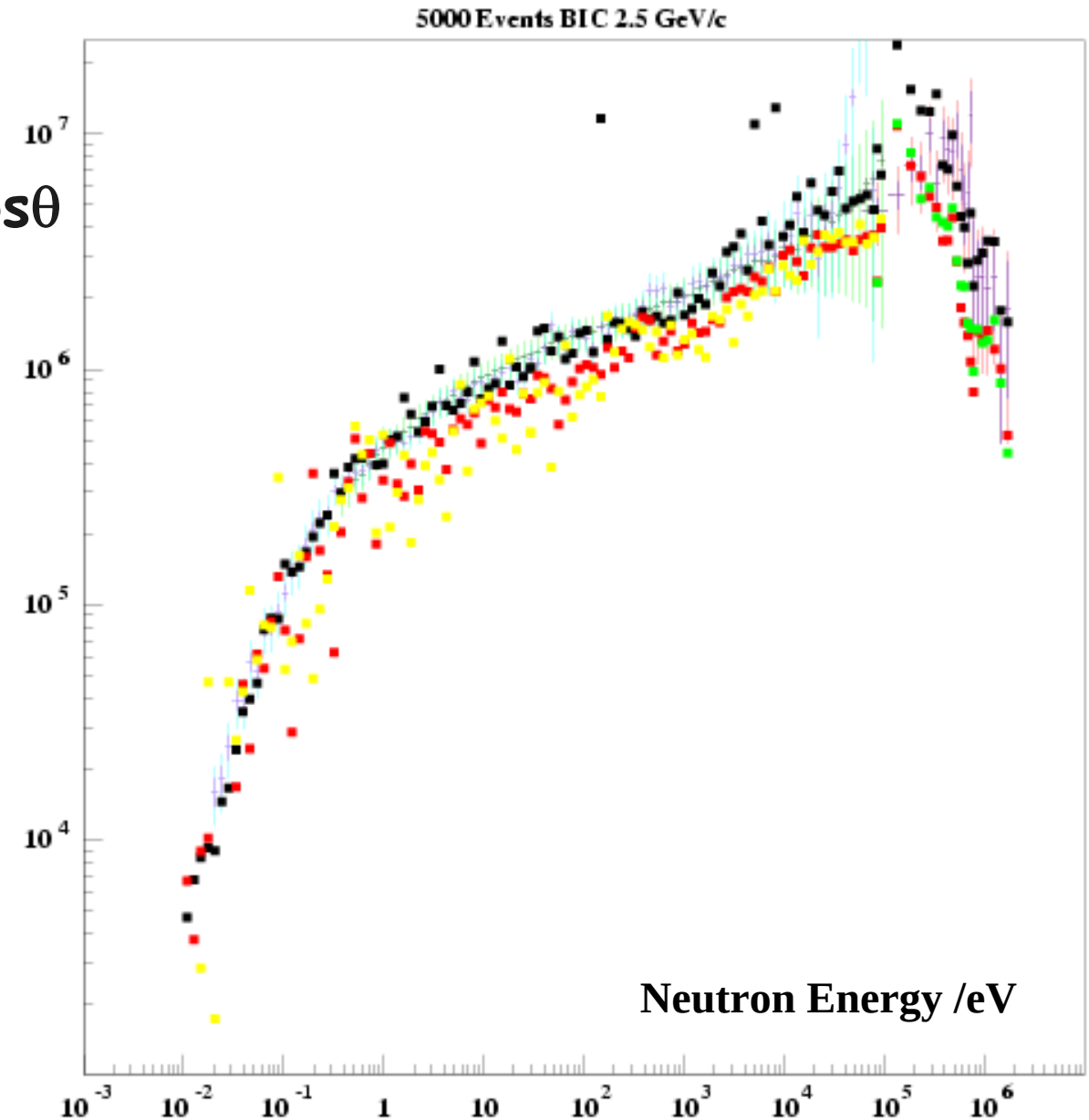
- Yellow: sphere
- Red: cylinder
- Black: Full $4\pi/\cos\theta$



5000 Events
BERTINI 2.5 GeV/c

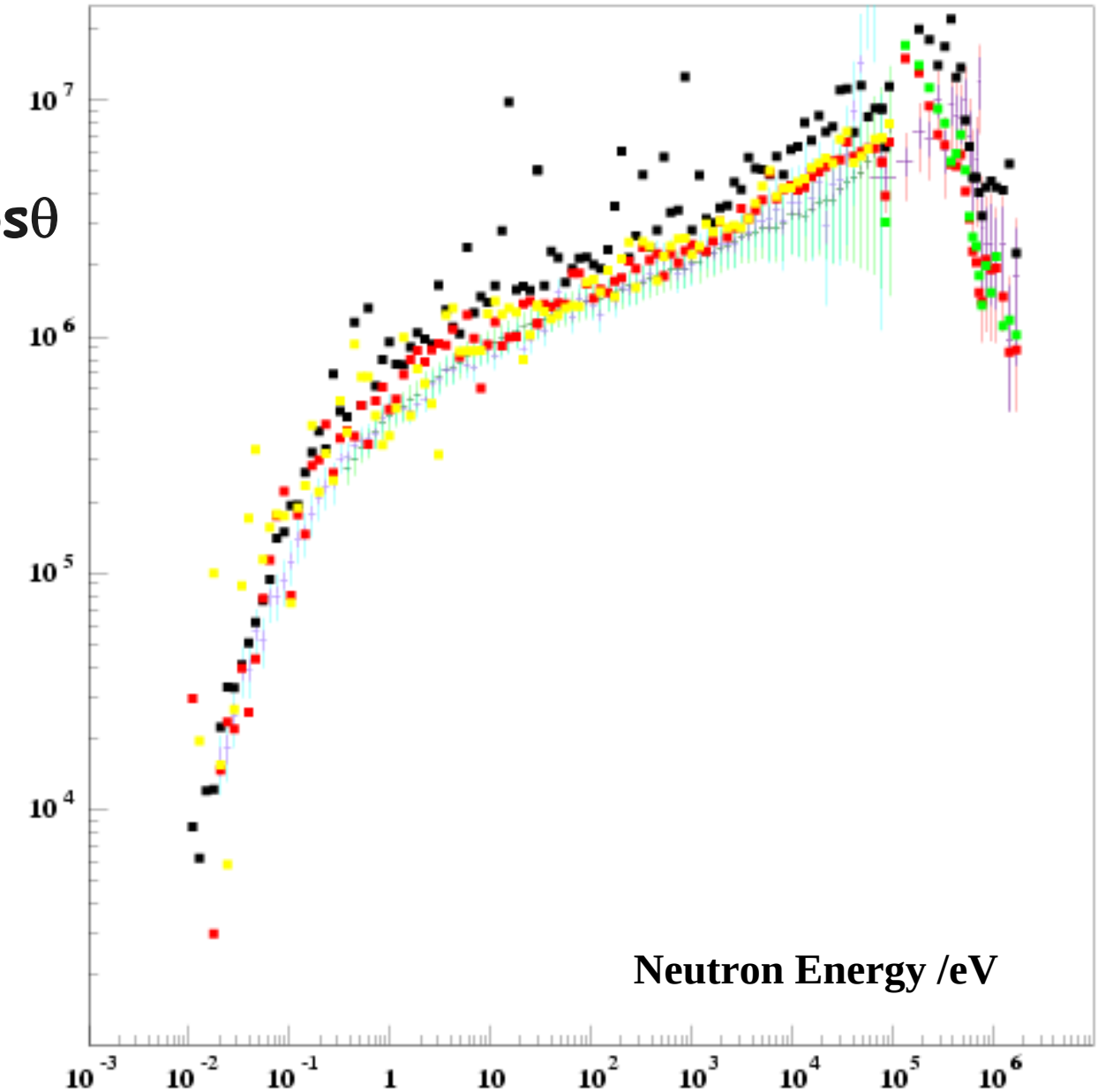
Fluence Binary cascade

- Yellow: sphere
- Red: cylinder
- Black: Full $4\pi/\cos\theta$



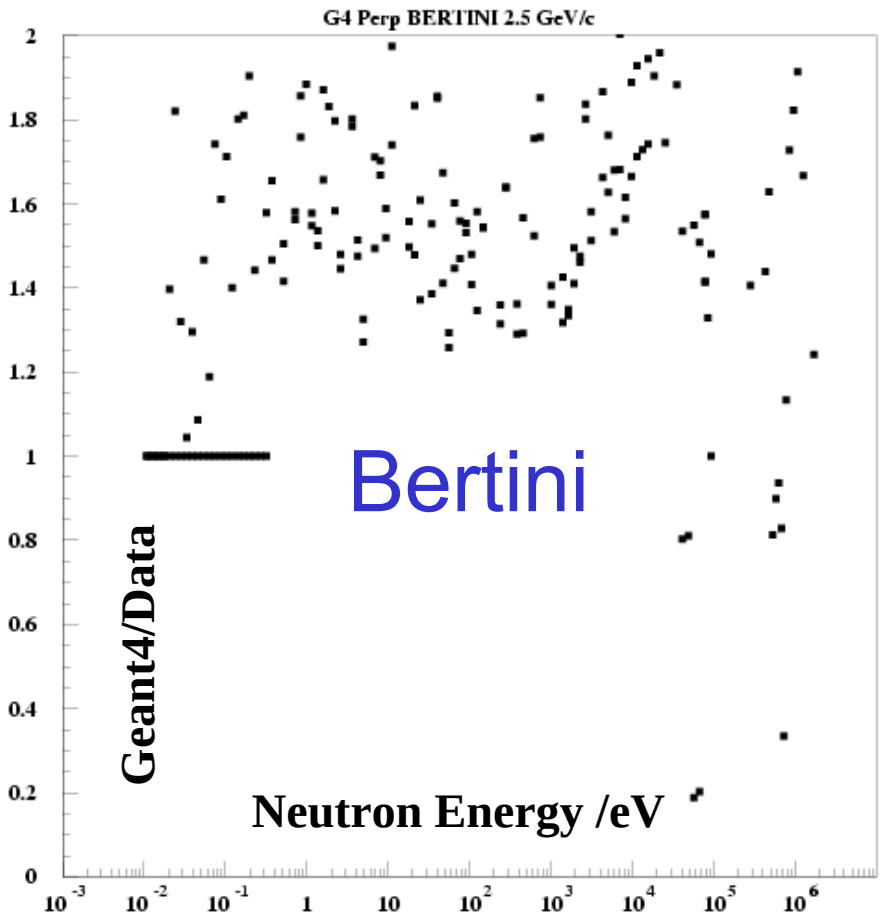
Fluence Bertini cascade

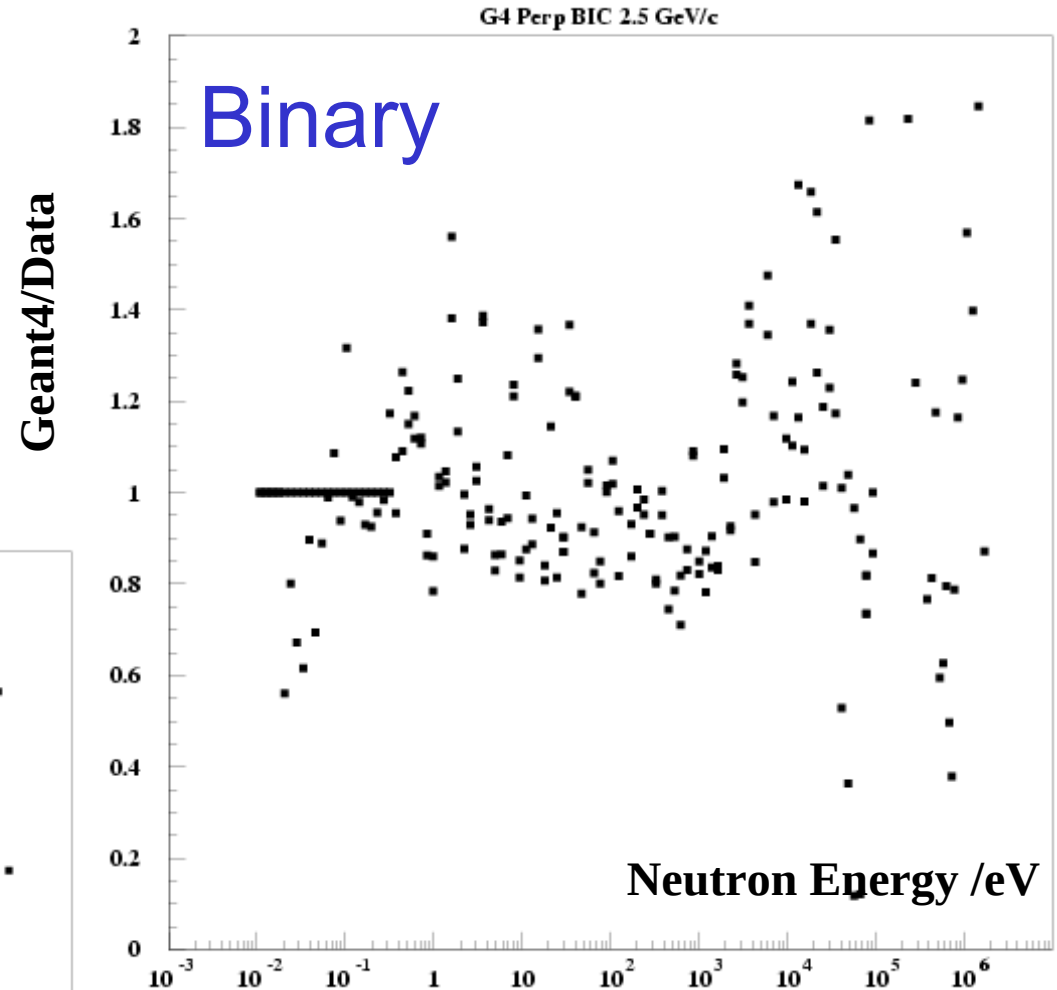
- Yellow: sphere
- Red: cylinder
- Black: Full $4\pi/\cos\theta$



Ratios of fluence

- Ratio of simulated $4\pi/\cos\theta$ versus Data
- Two-sets of data
- Dominated by systematic errors of experiment

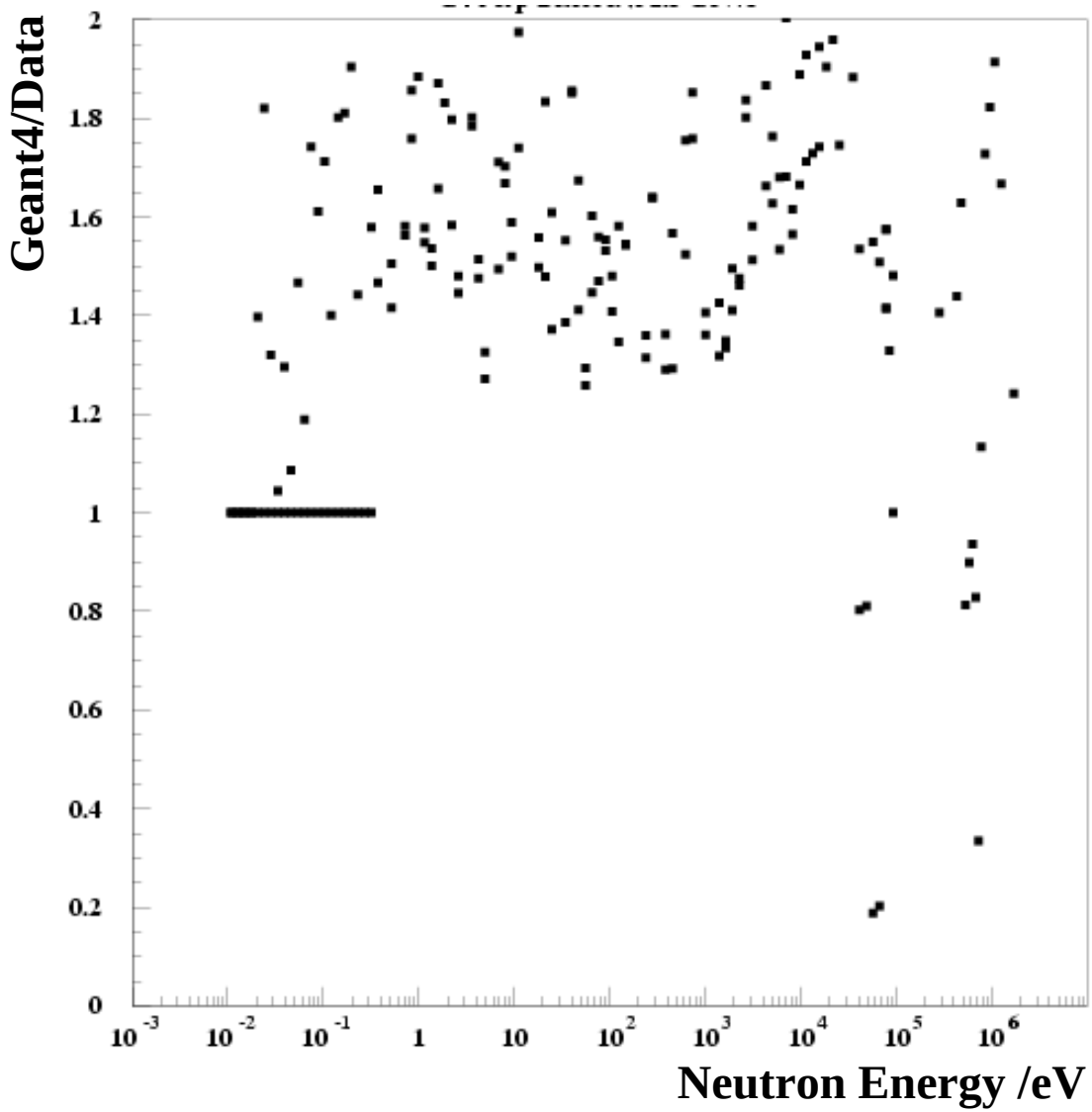




- **Binary**
  - Approximately agrees
    - ~10% under-estimated
- **Bertini:**
  - Overestimated ~ 50-60%

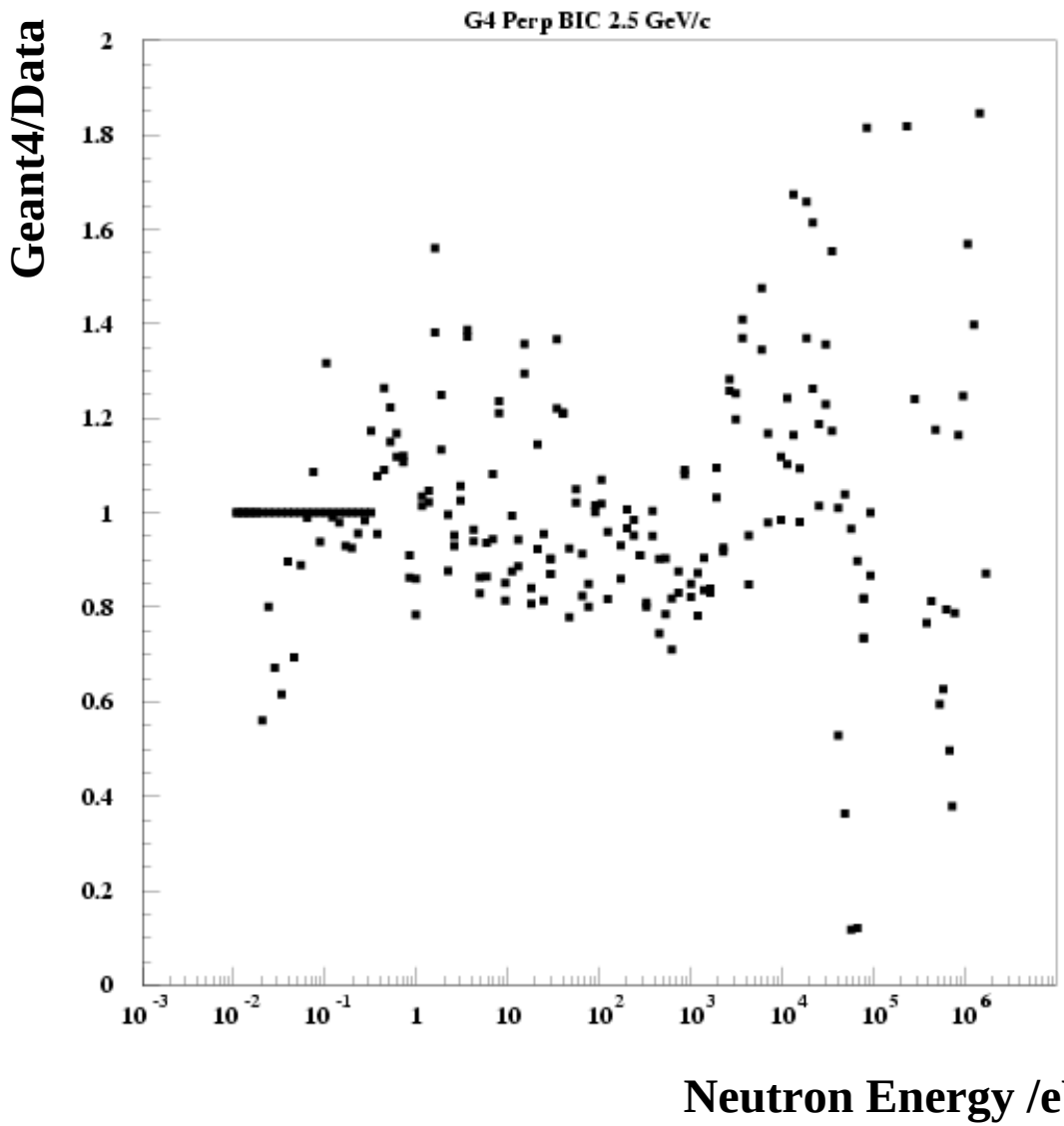
Ratio of fluence G4/Data – Bertini

- Ratio of $4\pi/\cos\theta$: Data
- Two-sets of data
- Approximately 50-60% overestimated
- Dominated by systematic errors of experiment



Ratio of fluence G4/Data – Binary

- Ratio of $4\pi/\cos\theta$: Data
- Two-sets of data
- Approximately agrees (~10% under-estimated)
- Dominated by systematic errors of experiment



Other cross sections

- **In addition created and validated**
  - cross sections for elastic scattering of p, n
    - Released H, D, He in G4 8.1 (June 2006) and other elements in G4 8.2 (December 2006)
    - Final state t-distribution also fitted to data.

M. Kossov