NA2 VALSIM Task 2007 report

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Abstract

Recent improvements in the Geant4 toolkit directed towards better simulation of hadronic shower shapes.

Introduction

Due to discrepancies between simulation and test-beam data some effort has been made in understanding and improving the simulation of hadronic shower shapes in Geant4. The effort has concentrated on understanding and improving the internal models used across the full energy spectrum. This report contains a brief summary of the recent modifications and improvements specifically looking at:

- Geant4 Modelling:
  - Quasi-elastic interactions
  - Revision of the Fritiof (FTF) high energy string model
- Validation:
  - Cross sections (EUDET-Memo-2007-18)
  - Hadron elastic scattering
  - Comparisons with the TARC experimental data

At the end of the report we discuss remaining open issues and future development areas.

Model Improvements

Upon detailed investigation it was clear that the longitudinal shower shape is significantly influenced by the diffraction and quasi-elastic interactions. The string models within Geant4 were previously deficient in this area, especially the Quark Gluon String (QGS) model for diffraction and both high energy models (FTF and QGS) for the quasi-elastic component.

The FTF model was revised for release 8.3 of Geant4 with further improvements in the subsequent releases. A separate quasi-elastic channel was implemented for the QGS model in 8.3 and included for both models thereafter. The elastic scattering models have been further modified with t-distribution fitted to available data and the inclusion of a diffuse model.

Quasi-elastic and inelastic

In order to model the quasi-elastic and diffraction interactions separately from other inelastic interactions the branching ratio of these components has to be calculated. In the case of the QGS model, the inelastic cross-section is split into Deep Inelastic for the existing QGS model and quasi-elastic for the new model.

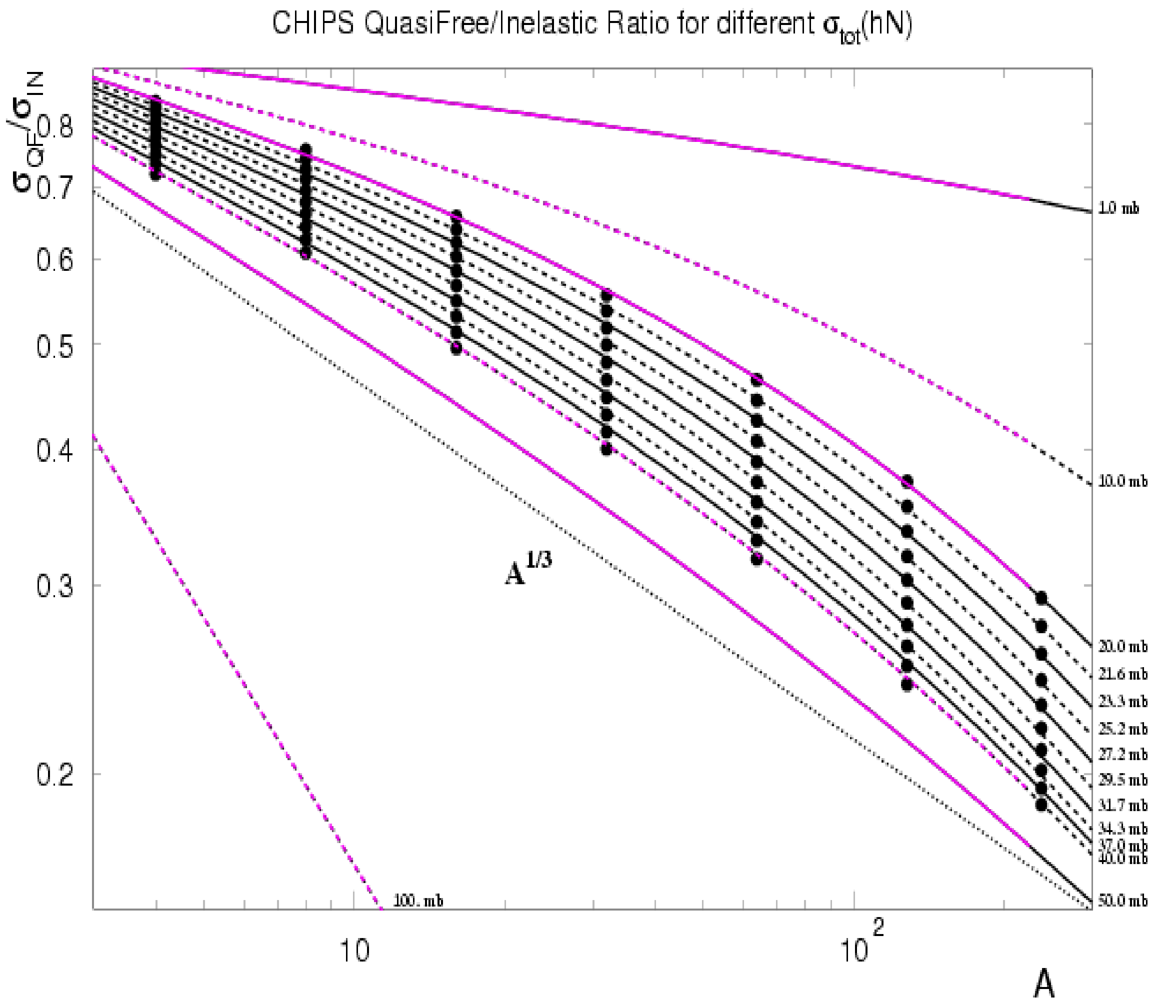

Fig.1: Quasi-free to inelastic cross-section ratios versus the nucleus atomic weight according to the prediction of CHIPS model [2].

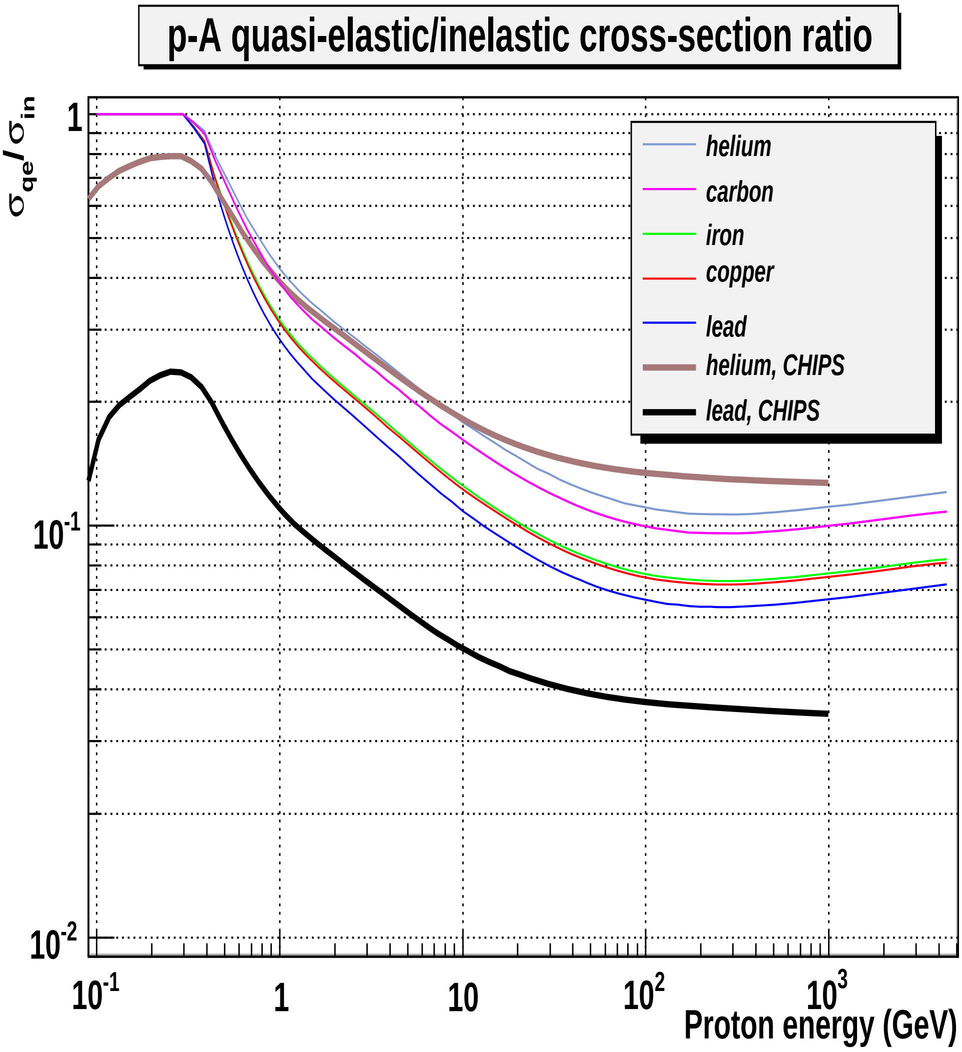

Fig. 2. Quasi-elastic to inelastic cross-section ratios for protons on different nuclei versus the proton energy. Curves are the prediction of simplified Glauber model [3]. Thick curves are the prediction of the CHIPS model [2].

Physics lists and the Quasi-elastic Channel

The new quasi-elastic channel takes away part of the cross-section (using quasi-elastic/inelastic ratio) from the Quark Gluon String model (QGS, since G4 v8.3) and from the FTF model (since G4 v9.0). This component is activated in the following physics lists:

- QGSP, QGSC, QGSP_BERT, QGSP_BIC
- QGSP_EMV, QGSP_BERT (faster EM, less precise)

- QGSP_BERT_HP, QGSP_BIC_HP (precision neutron)

Quasi-elastic is not included in the QGSP_NQE and QGSP_BERT_NQE to allow backward consistency, but these are temporary packaged physics lists.
The issue of quasi-elastic is not relevant to the LHEP physics list as it does not include a high energy string model.

Cross-Sections

The cross-sections within Geant4 have been extensively validated for inelastic hadron-nuclear interactions and also the total hadron-nuclear cross-section. In Geant4, the elastic and inelastic cross-sections are handled independently as a probability, so the total cross-section is taken as the sum of these two as they are applied in the different physics lists.

Two new cross-section classes have been added to Geant4 (EUDET-Memo-2007-18):

- Optical model interpolation cross-sections for nucleons, which provides the total and inelastic cross-section (the elastic being the difference between the two).
- Simplified Glauber model for scaling with energy greater than 100 GeV.

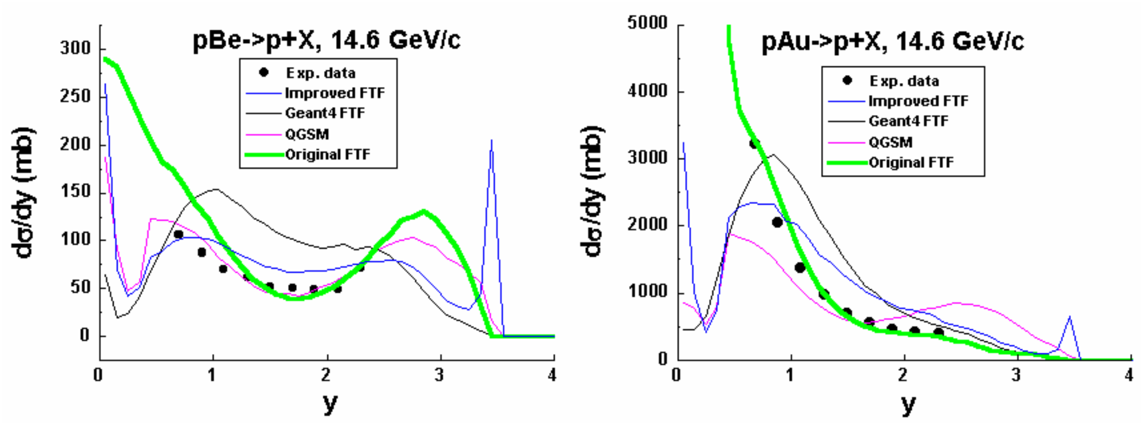

Fig. 3. The inclusive rapidity distributions of protons generated in p-Be and p-Au reactions at 14.6 GeV/c. Curves correspond to different Geant4 string models. Points are experiment [3].

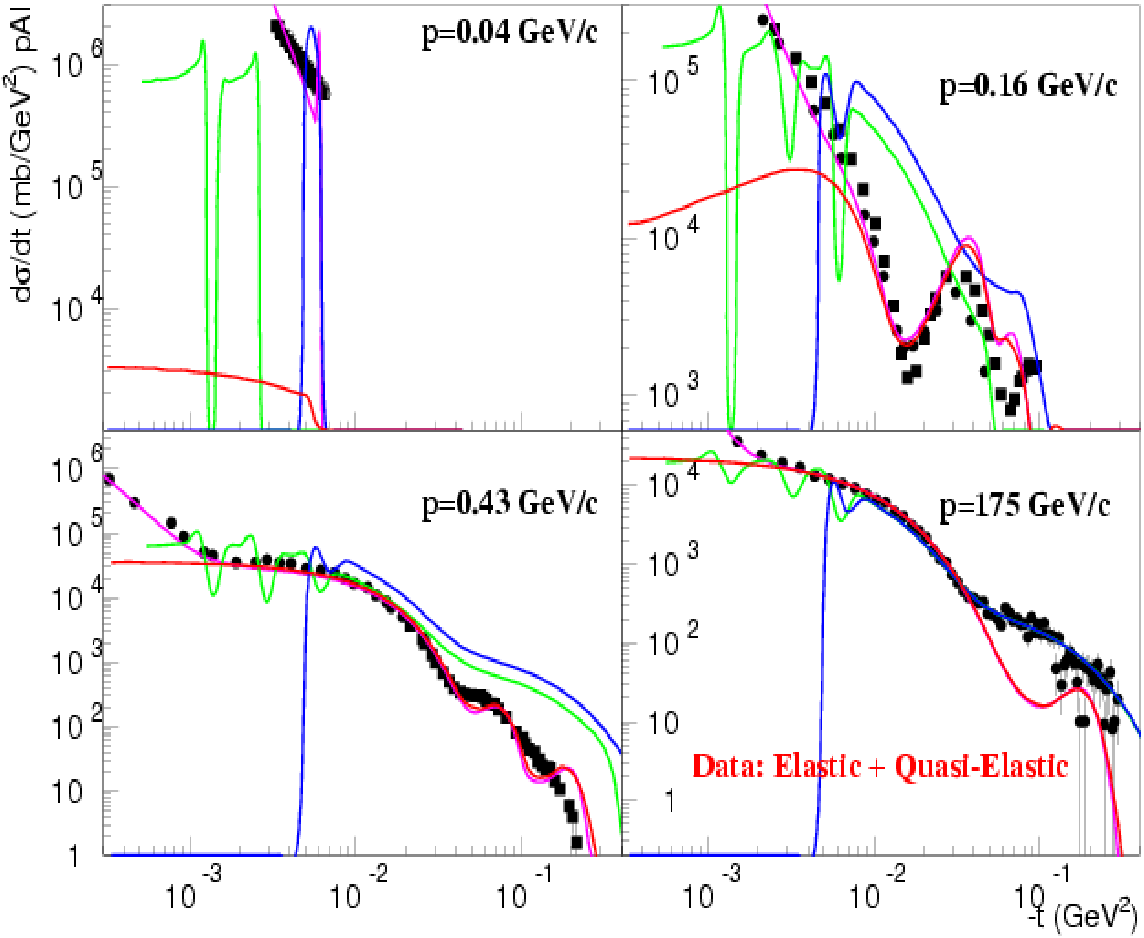

Fig. 4. Differential elastic cross-sections of protons on aluminum at different proton momenta. Points are experimental data, curves: pink – CHIPS, blue – Glauber model, green – GHEISHA parameterization.

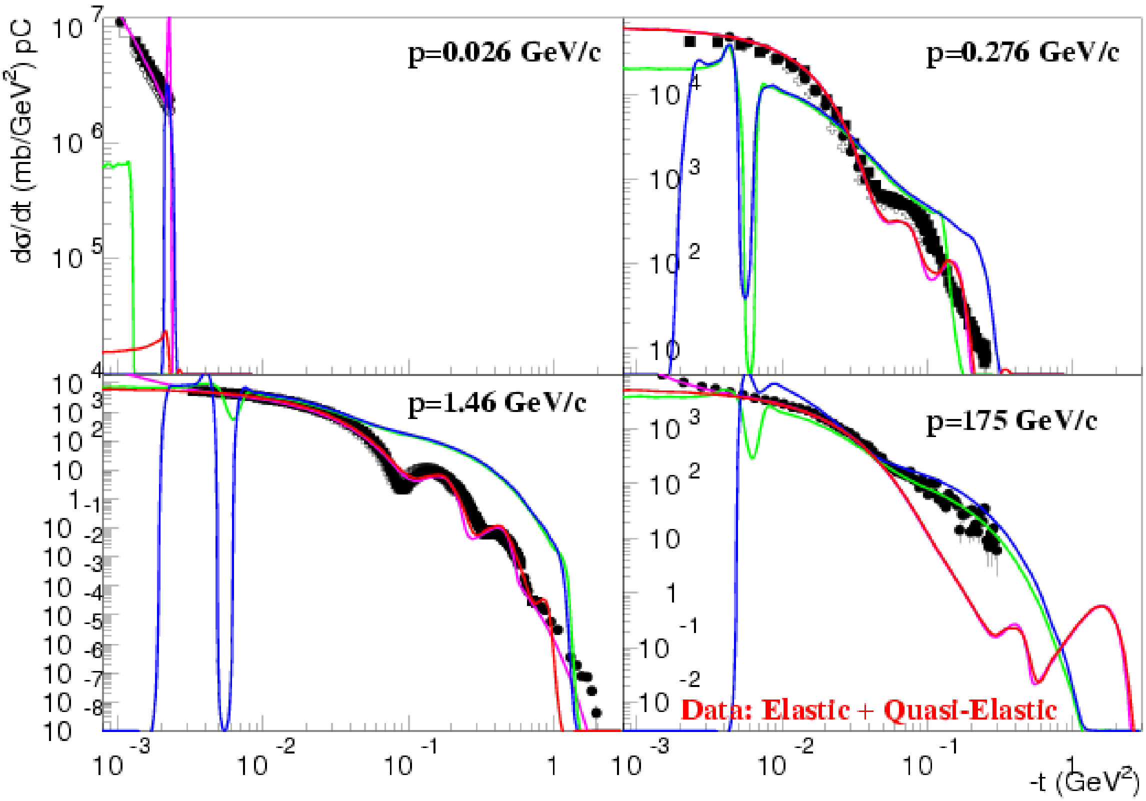

Fig. 5. Differential elastic cross-sections of protons on carbon at different proton momenta. Points are experimental data, curves: pink – CHIPS, blue – Glauber model, green – GHEISHA parameterization.

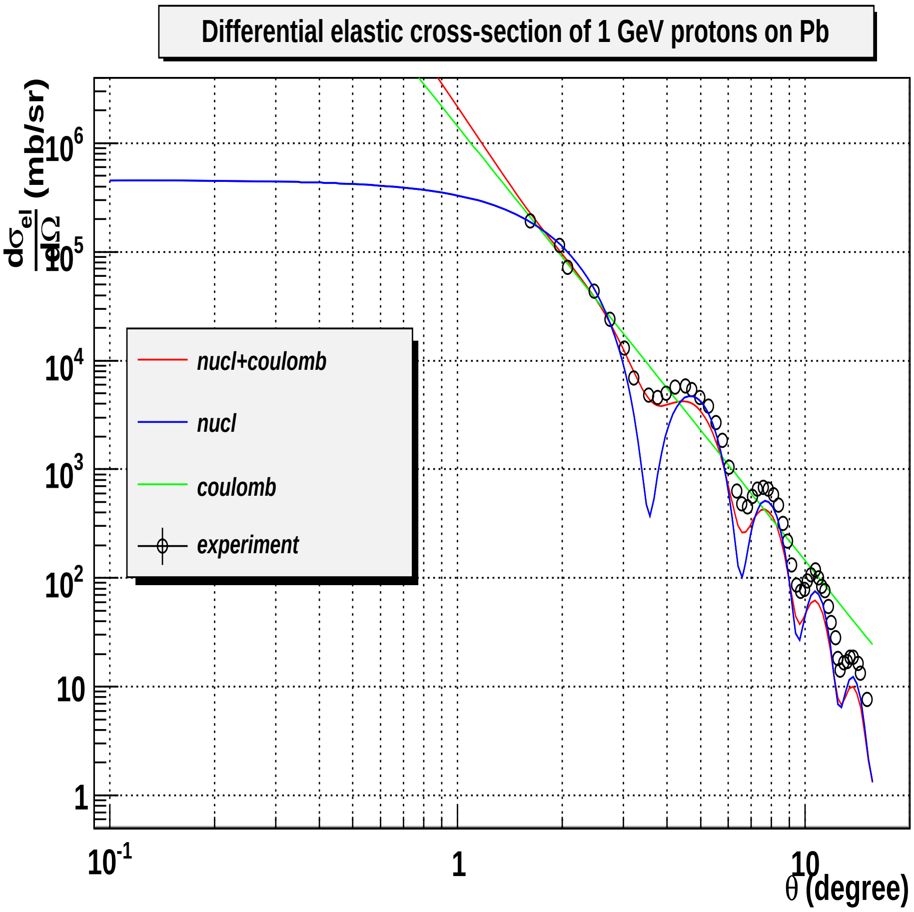

Fig. 6. Differential elastic cross-sections of 1 GeV protons on lead. Points are experimental data, curves: red – diffuse elastic model with Coulomb correction; blue – pure diffuse elastic hadron model; green - Coulomb scattering.

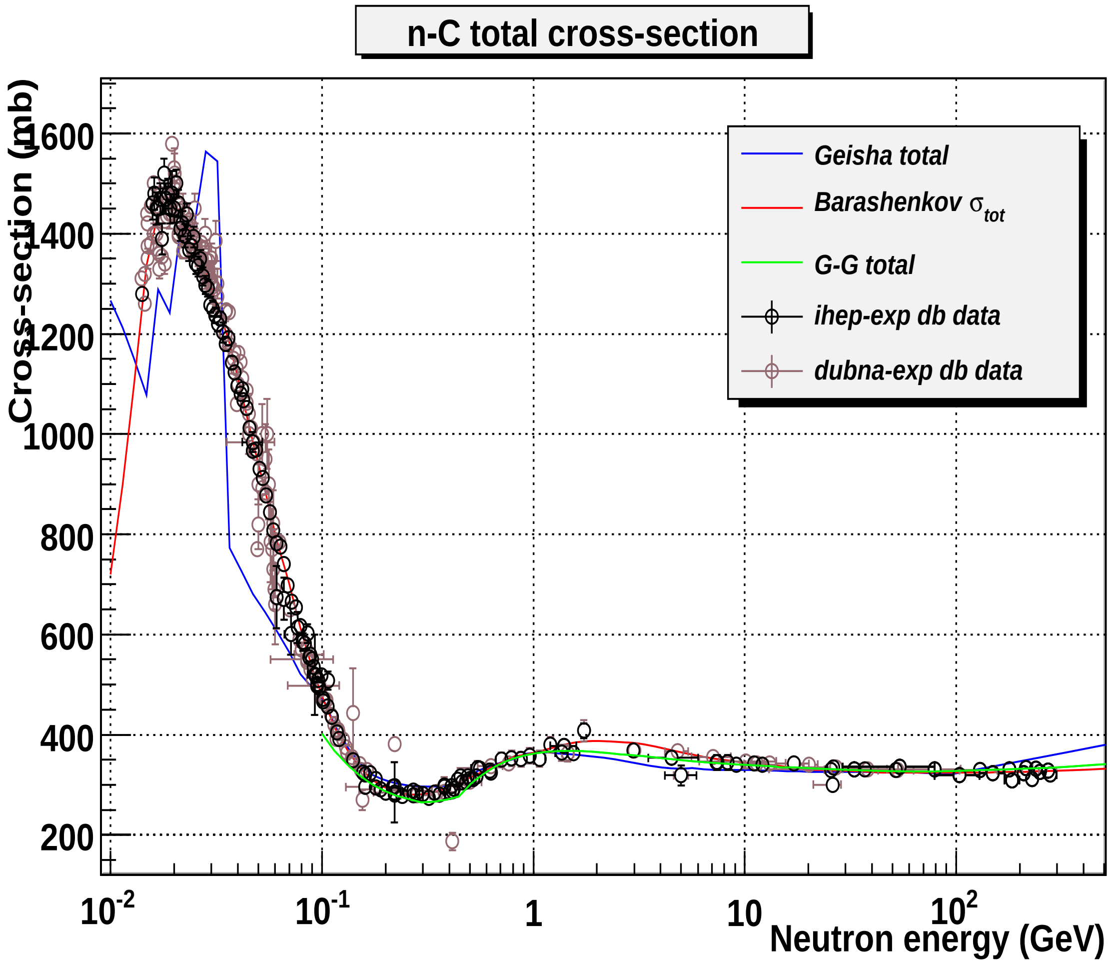

Fig. 7. Total cross-section of neutrons on carbon target versus the neutron energy. Points are experimental data [4,5]. Curves correspond to different Geant4 models.

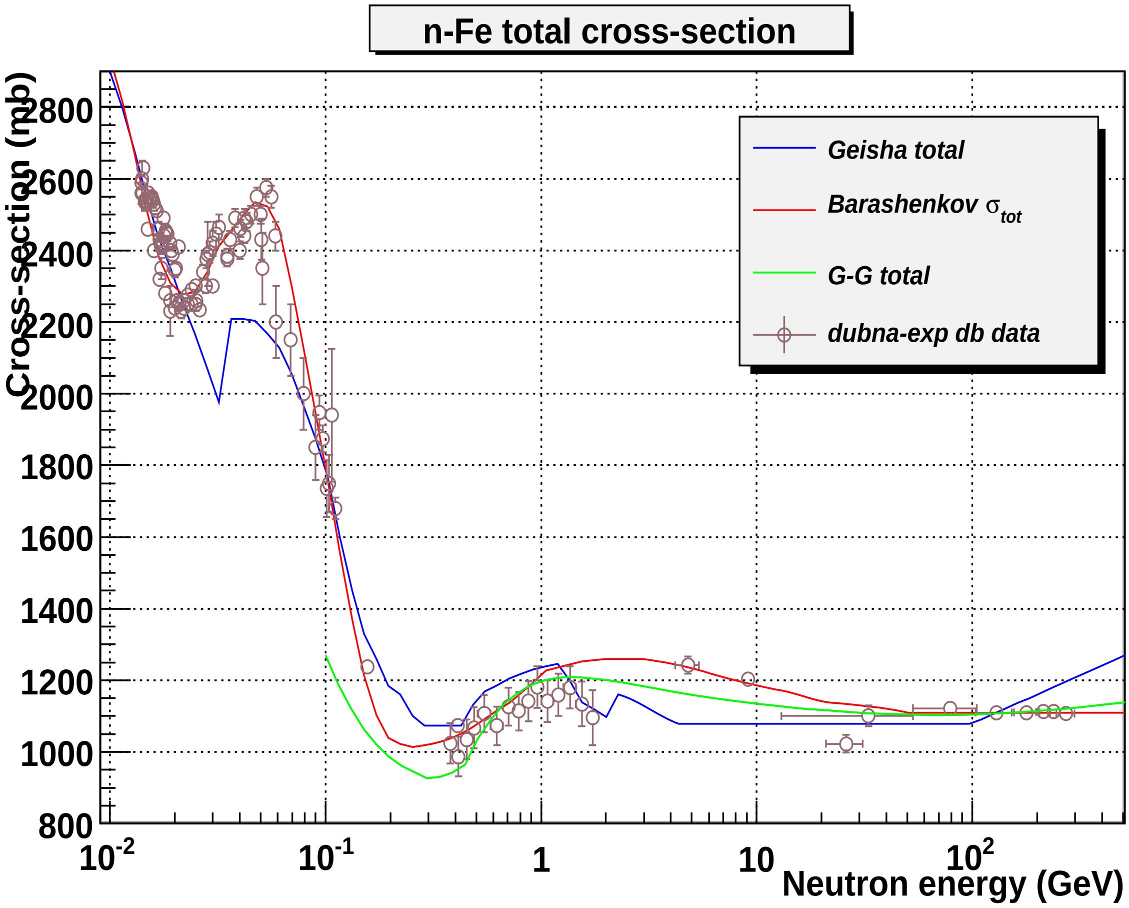

Fig. 8. Total cross-section of neutrons on iron target versus the neutron energy. Points are experimental data [4,5]. Curves correspond to different Geant4 models.

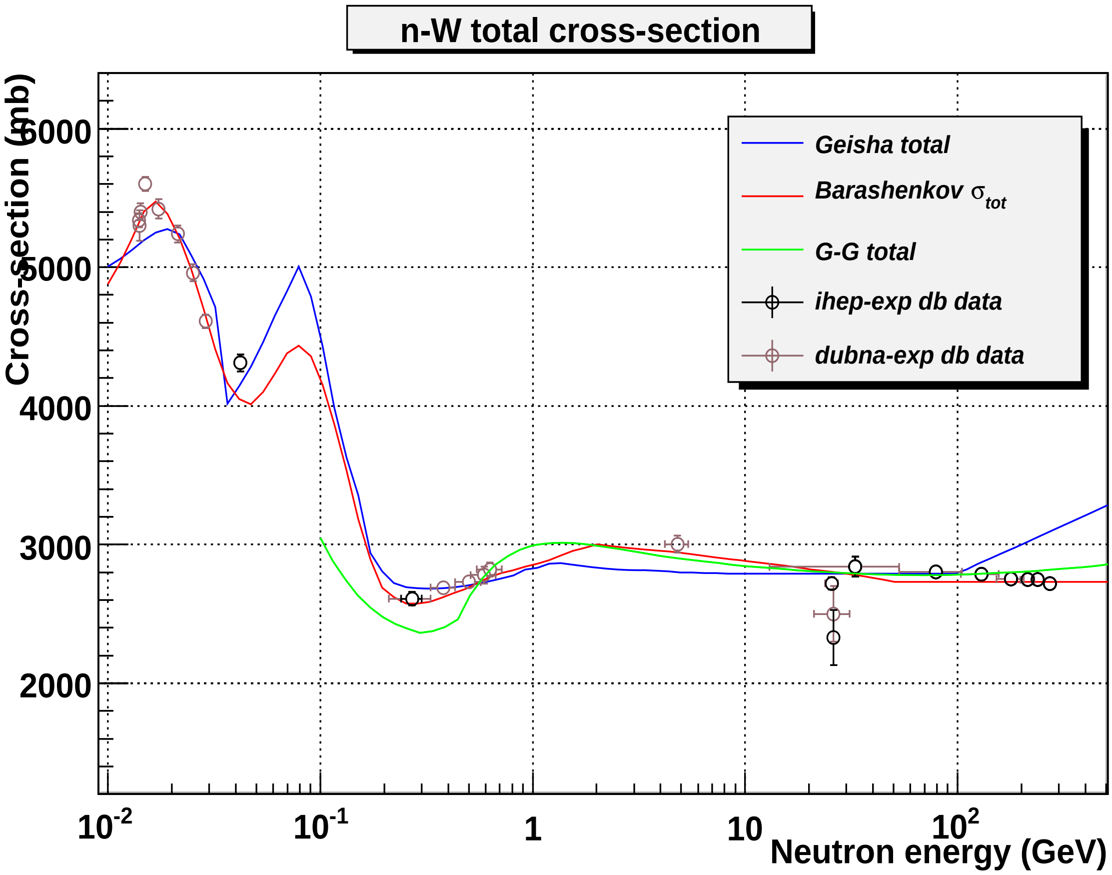

Fig. 9. Total cross-section of neutrons on tungsten target versus the neutron energy. Points are experimental data [4,5]. Curves correspond to different Geant4 models.

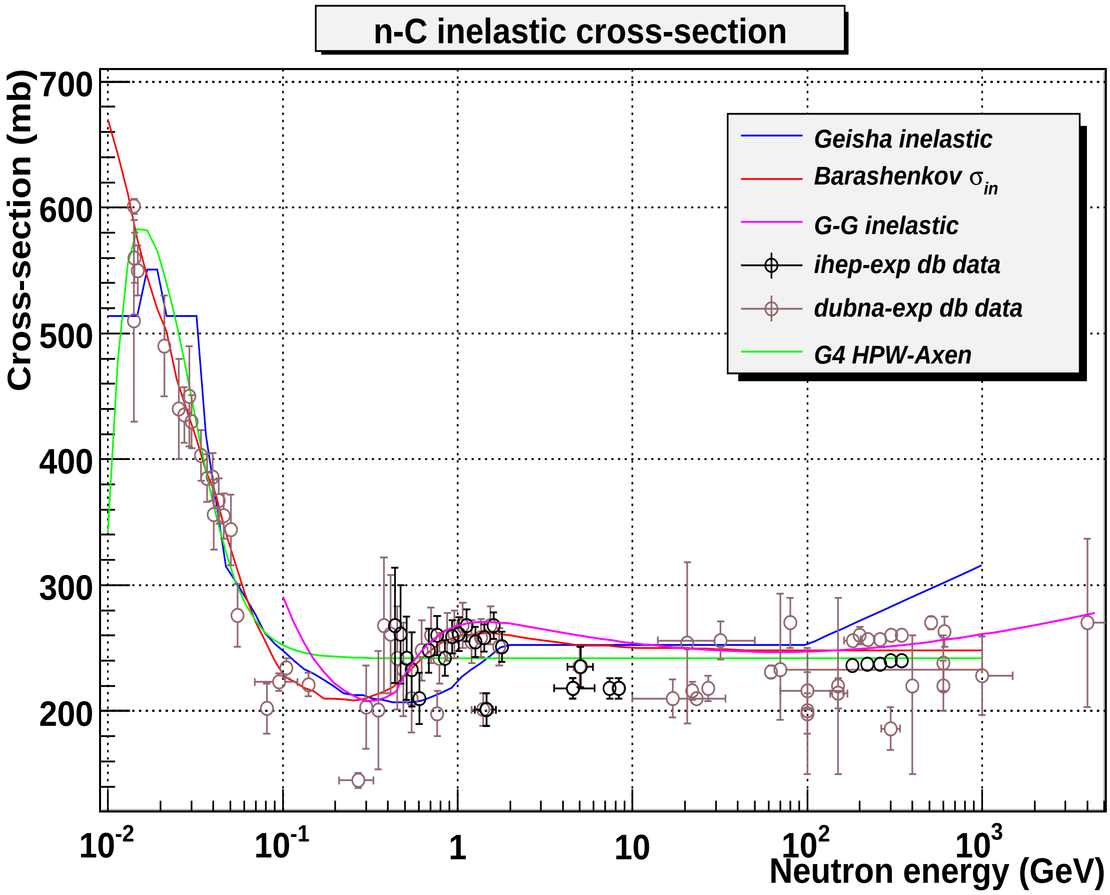

Fig. 10. Inelastic cross-section of neutrons on carbon target versus the neutron energy. Points are experimental data [4,5]. Curves correspond to different Geant4 models.

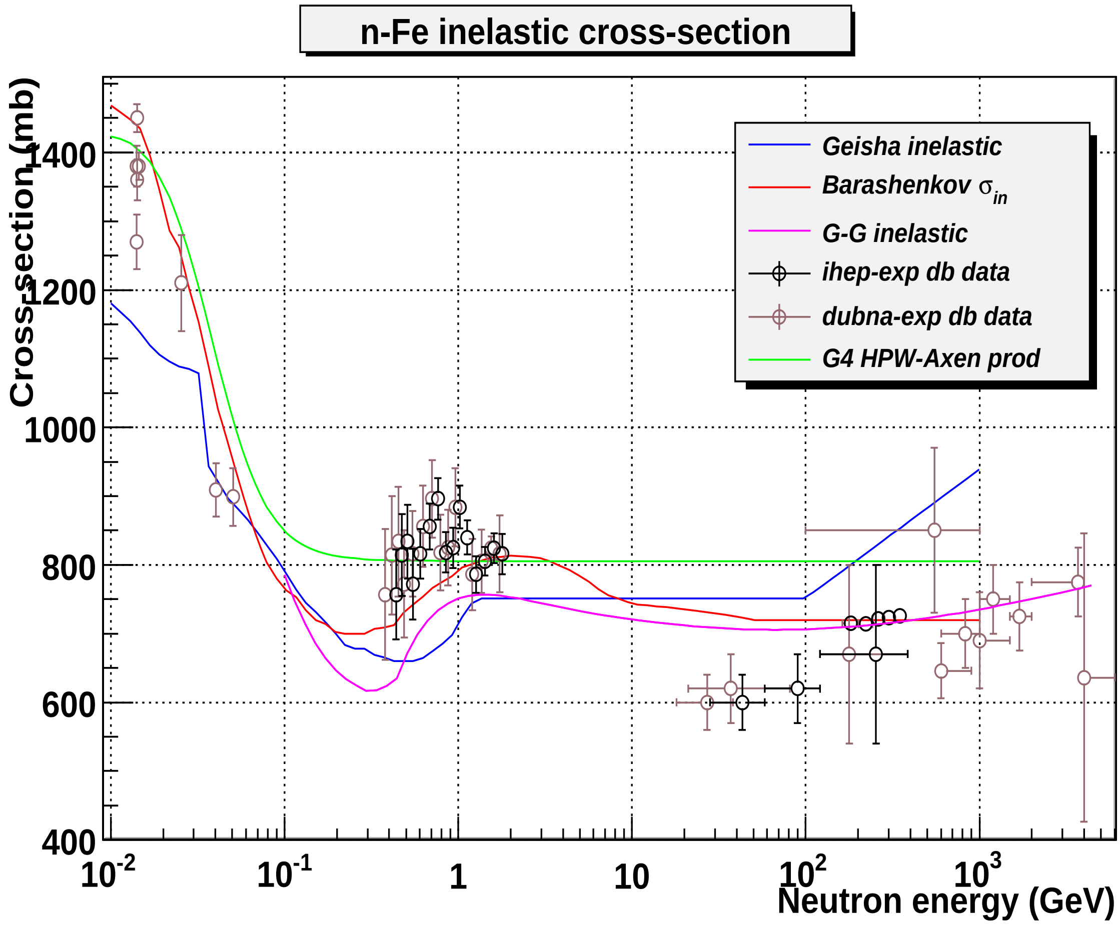

Fig. 11. Inelastic cross-section of neutrons on iron target versus the neutron energy. Points are experimental data [4,5]. Curves correspond to different Geant4 models.

The TARC Experiment Benchmark for neutrons in Geant4

The TARC experiment was used to measure neutron driven nuclear Transmutation by Adiabatic Resonance Crossing. It took data from 1996-7 at CERN using a 2.5 or 3.5 GeV/c proton beam incident on a pure (99.9%) lead target of 334 tons (3.3m x 3.3m x 3m). The beam entered through a 77.2mm diameter blind hole of length 1.2m. Resulting in an interaction shower approximately centred within the lead volume. Twelve sample holes located throughout the volume allowed measurement of neutron fluences and capture rates as function of distance from the interaction point. Due to the high mass and low inelastic cross-section in lead the secondary neutrons are multiply scattered throughout the target, resulting in a strong energy-time correlation.

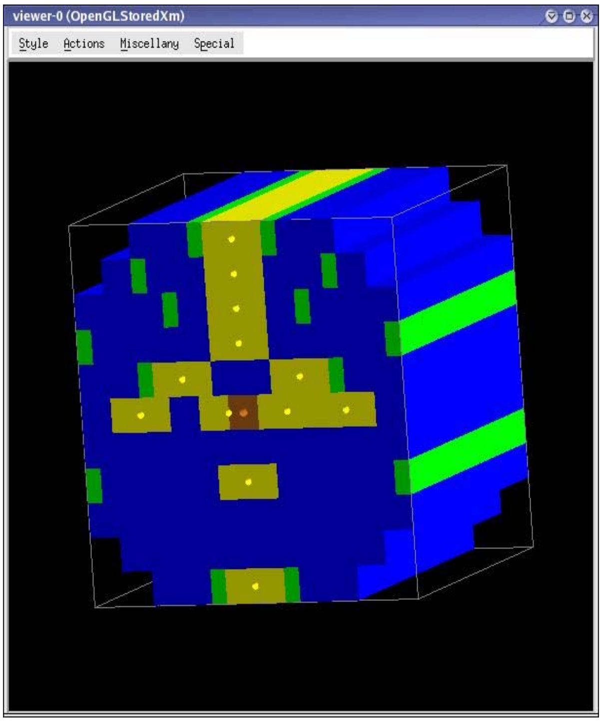

Fig. 12. TARC experiment view.

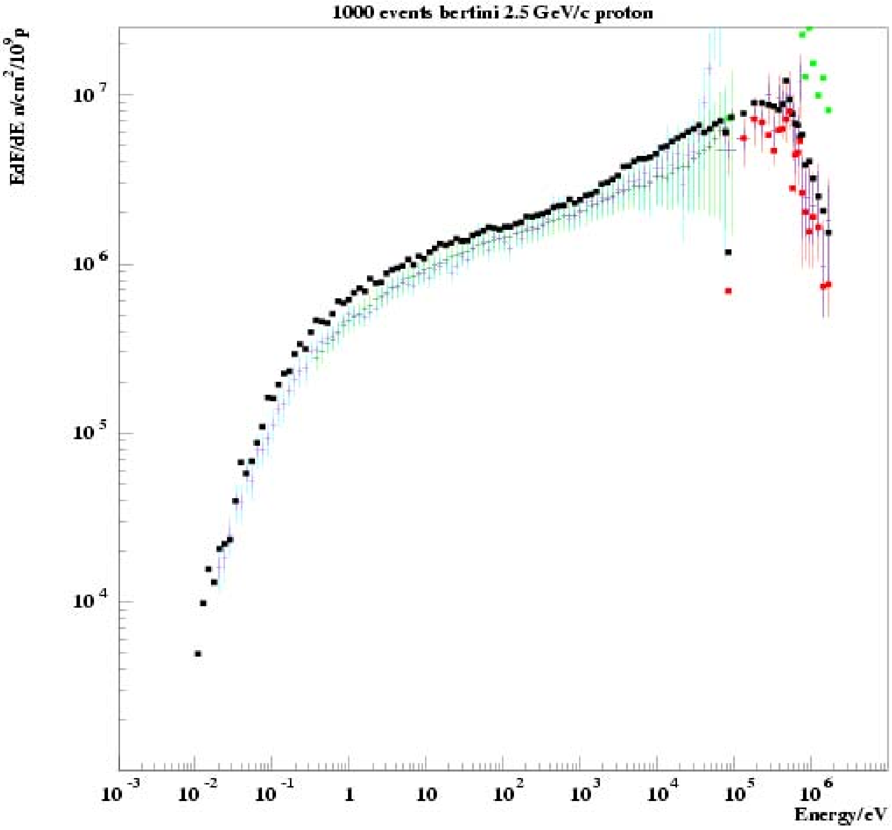

Fig. 13. Neutron fluence versus energy. Points with errors are TARC experiment. Other points are Bertini cascade with geometry

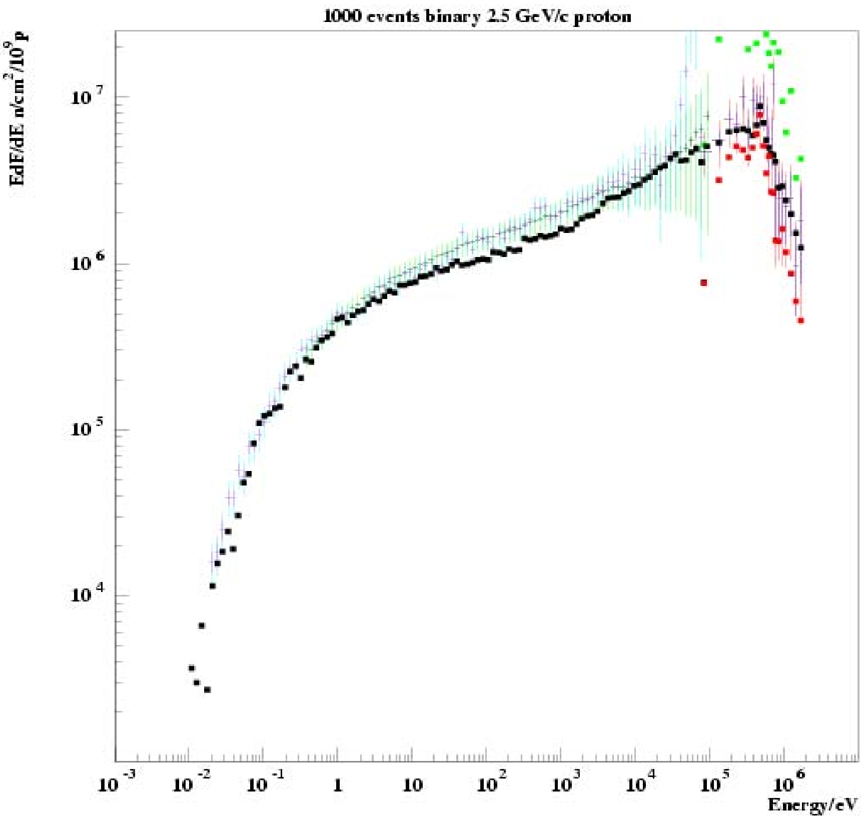

Fig. 14. Neutron fluence versus energy. Points with errors are TARC experiment. Other points are Binary cascade with geometry.

Shower Shape

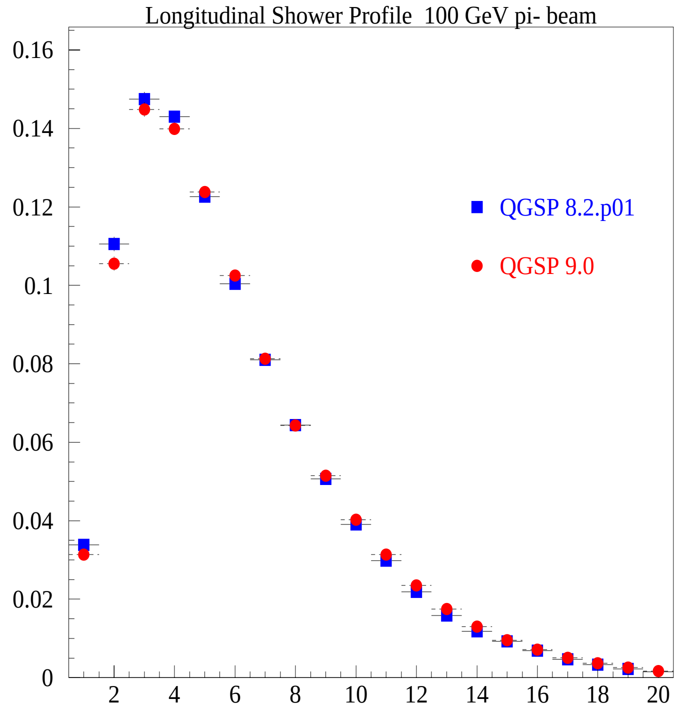

Fig. 15. Longitudinal Shower Shape Profile of Iron-Scintillator Calorimeter (simplified ATLAS TileCal) A. Ribon. The shower (10 ƒI) becomes a bit longer due to quasi-elastic processes

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**	
fL1	**55.7%**	**56.5%**	**54.5%**	**52.2%**	
fL2	**33.6%**	**33.6%**	**34.0%**	**34.6%**	
fL3	**8.9%**	**8.2%**	**9.5%**	**10.6%**	**(not Cu)**
fL4	**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, the Fritiof model has been improved (thanks to V.Uzhinskiy).

Ongoing Work

Comparisons of proton-nucleus target diffraction (pA→pX) is underway. The HELIOS experiment at 450 GeV/c is being used a comparative benchmark.

The TARC benchmark will be completed with radial fluence distribution comparisons, true calorimetry, neutron capture and a write up.

Recently the pre-compound and de-excitation models have been reviewed in Geant4. This began with a mini-workshop at CERN (July 17-21, 2007) and resulted in modifications and improvements that are included in the upcoming release 9.1, with further developments planned.

A new diffuse elastic model has also been introduced for differential hadronic scattering (relevant for multiple scattering and NIEL).

Conclusions

Several improvements to Geant4 were made in the release 8.3 (4 May 2007):

- First revision of the FTF model
- Quasi-elastic channel was coupled to the QGS model

In Geant4 9.0 (20 June 2007) the following improvements were made:

- Further revision of FTF model for pions
- Quasi-elastic channel added to the FTF packaged physics lists
- CHIPS QElastic is now used for all nucleon projectiles and all targets

The QElastic process was previously included in Geant4 releases but only used (by default) for proton/neutrons on hydrogen (v8.1) and protons/neutrons on all targets for release 8.2.

The hadronic interaction cross-section has been extensively reviewed (EUDET-Memo-2007-18).

The TARC benchmark has been used to successfully validate neutron production, interaction and transportation.

Acknowledgement

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References

[1] Geant4 Collaboration, Geant4: A Simulation Toolkit, Nucl. Instr. And Meth. A506 (2003) 250; see also http://cern.ch/geant4

[2] P.V. Degtyrenko, M.V. Kossov and H.P. Wellisch, Eur. Phys. J., A8 (2000) 217

[3] G. Folger, V. Grichine, EUDET-Memo-2007-18

[4] http://wwwppds.ihep.su

[5] http://wwwnea.fr/html/dbdata/bara.html

Deliverables

- VALSIM month 18 milestone (June 2007)
  - "First release of improved version of the hadronic process and physics lists in Geant4"
- Improvements identified and undertaken
  - Issues identified as a result of validation
  - Revised FTF model, improving diffraction
  - New Modelling of the quasi-elastic channel

Geant4 Releases

The minor release of Geant4 8.3 includes:

- The revised FTF model
- The option to split the inelastic cross-section between the QGS model and a quasi-elastic interaction
- By default this is activated in the QGSx family of packaged physics lists
- Fix to Copper Cross-section
- In release 6.2 the inelastic cross-section of pions on copper was reduced by 4%. With the introduction of the quasi-elastic channel this modification was removed.