Status report on VALSIM deliverable of June 2007

J. Apostolakis, G. Folger, V. Grichine, A. Howard, V. Ivantchenko, M. Kossov and V. Uzhinsky

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Abstract

This short report summarises a number of improvements and developments included in Geant4 version 8.3, released 4th May 2007, and in Geant4 release 9.0, made available on June 28th 2007. These changes were undertaken to improve the modelling of hadronic showers.

New quasi-elastic channel

Geant4 8.3 improved the modelling of final states of interactions that involve quasi-elastic interactions of nucleons at high energies. In these the incident nucleon interacts elastically with a single nucleon in the target nucleus. This channel is now modelled separately in high energy hadronic interactions, and replaces part of the inelastic cross section previously used for the Geant4 QGS model (E>12 GeV). The reason for this change is that the existing Geant4 implementation of QGS models primarily deep inelastic interactions.
The cross-section for the quasi-elastic channel was determined as its fraction of the inelastic cross section. It has been calculated utilising a Glauber model approach (either using difference between inelastic and production cross sections or calculating of elastic hadron-nucleon cross section). The fraction of quasi-elastic cross-section is typically 4-15% of the inelastic cross-section in the energy range used (> 12 GeV). The final state (for elastic hadron-nucleon cross section) is also modelled.

The new quasi-elastic channel is provided in Geant4 release 8.3, and is utilised in several physics lists for HEP applications since this release. In particular the QGSP and QGSC physics lists and their variants utilise it, including QGSP_BERT (which includes the Bertini cascade), QGSP_BIC (with the Binary cascade). Their variants with simpler multiple scattering (with the _EMV extension, e.g. QGSP_EMV) and more precise treatment of low-energy neutrons (with the _HP extension, for example QGSP_BERT_HP) include it as well. The result is a reduction in the cross section for deep inelastic (or production) reaction, and, as the quasi-elastic interaction results typically in small reductions of a high energy projectile's momentum, enabling a larger fraction of the initial particles to proceed further. Studies using a simplified calorimeter set-ups demonstrated a longer shower profile.

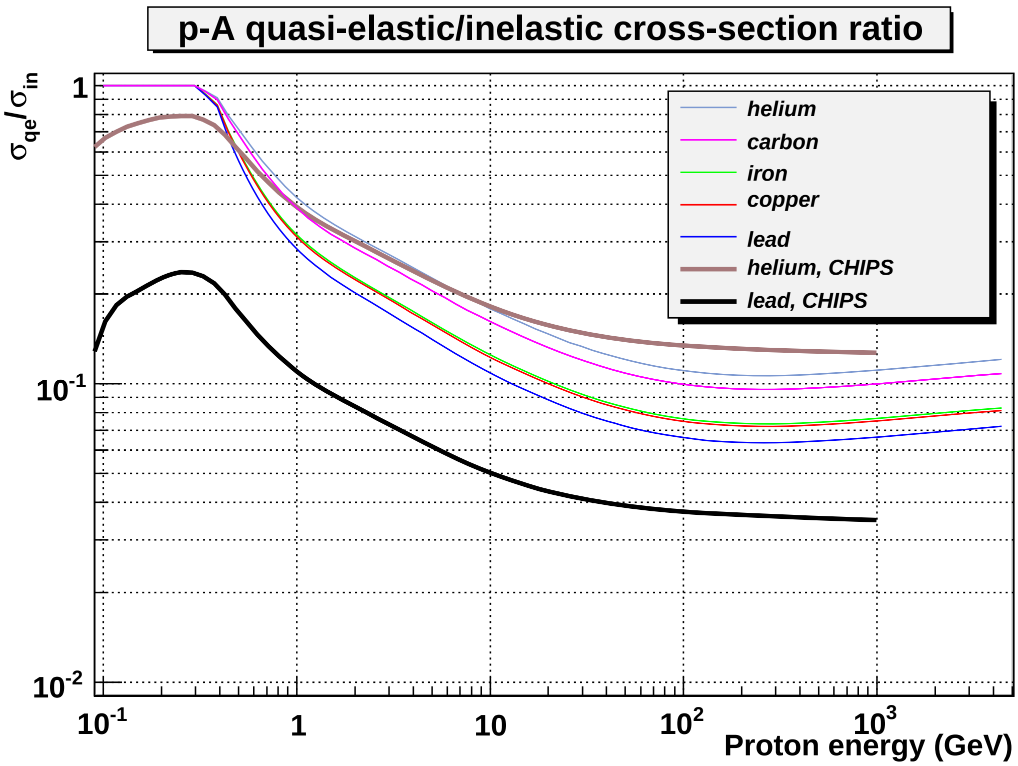

Figure 1: The ratio of the quasi-elastic and inelastic cross-sections (σ_{qe}/σ_{in}) for protons on different targets (He, C, Fe, Cu, and Pb) as a function of the proton energy. The CHIPS predictions for He and Pb are shown for comparison. This ratio is used to determine the cross-section for the quasi-elastic channel, which replaced part of the QGS model inelastic interaction. We note that the unlabelled calculation is not expected to be reliable below about 1 GeV.

Review and revision of hadronic cross-sections

Accurate hadron-nucleus cross-sections are vital for the simulation of hadronic showers. A review of Geant4 hadron-nucleus cross-sections has been performed in 2006-2007, comparing with a growing suite of experimental data.

Cross sections in Geant4 are separated from the choice of interaction models, and the creation of reaction end-products. This review considered the different available cross section implementations, including the original cross sections (taken from Gheisha, with small revisions), the Axen-Wellisch parameterisation of proton-nucleus cross-sections [2], the SAID cross-sections [3] for nucleons with energy up to about 1 GeV, and the low energy neutron cross-sections. Comparisons span the energy range of 10 MeV to 1 TeV.

A few discrepancies were identified in these comparisons: the scaling of cross sections above 100 GeV, and the values below 100 MeV. To correct the first, 'high energy' issues an initial revision of the cross-section making it constant was put in place, and a new optical model calculation was undertaken. For the low energy limit a new implementation based on interpolating the available values of the Barashenkov evaluations [4] was undertaken.

New cross sections implementations were created. One is based on an interpolation of cross-section calculations using Barashenkov optical model parameterisation of experimental data for proton and neutron total and inelastic cross-sections on nuclei (in the class *G4NucleonNuclearCrossSection*) [4]. The other is a simplified Glauber model, in which point-like nucleons are Gauss distributed in a nucleus (*G4GlauberGribovCrossSection*). These and existing Geant4 cross-sections were compared against data from cross-section databases from IHEP-PDG [5] and Dubna [6]. The comparison shows that optical model interpolation provides **good** agreement with experimental data in wide hadron energy range, 0.01- 500 GeV. The Simplified Glauber-Glauber model shows the expected small relativistic rise for the hadron energies starting between 100-500 GeV. It can be used as high energy prolongation of the optical model or to extend existing cross-sections in the region above 100 GeV. Figure 2 shows the total cross section of neutrons on iron, and figure 3 for neutrons on tungsten.

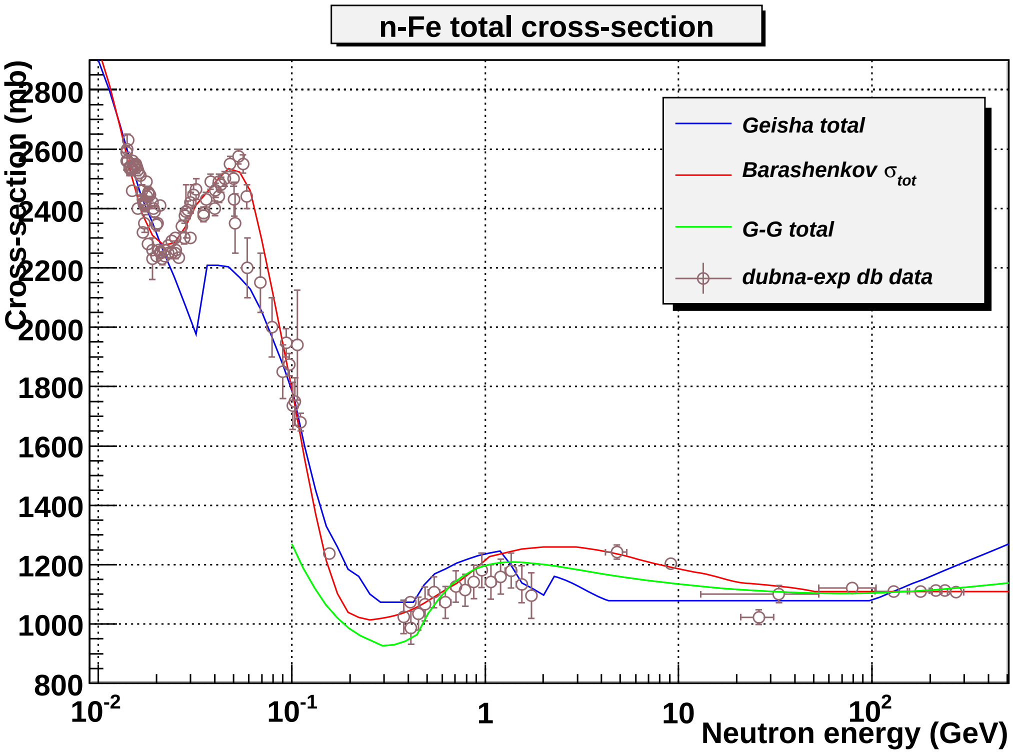

Figure 2: The total cross-section of neutrons on iron target is shown versus the neutron energy. Experimental data (points), from reference **[5]** and the Geant4 parameterisations (curves) are shown: the original Geant4 one using Gheisha and extending it above 100GeV (labelled Gheisha), the new simplified Glauber-Gribov (labelled G-G) and the new implementation of the Barashenkov evaluations.
The 'imported' Gheisha cross-sections stopped at 100 GeV, and the original extension above 100 GeV is seen to disagree with experimental measurements. The improvements in the Barashenkov and simplified Glauber-Gribov (G-G) cross sections in this energy range are evident.

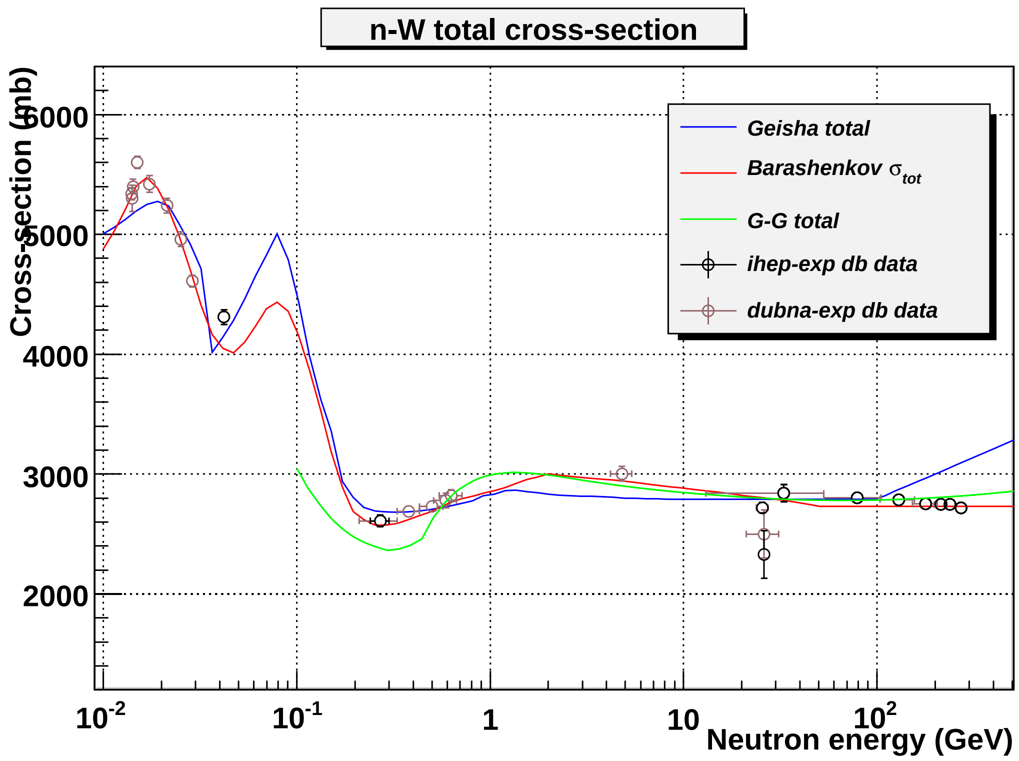

Figure 3: Total cross-section of neutrons on tungsten target versus the neutron energy. Different Geant4 models (curves) and experimental data (points[5]) are shown.

To summarise, in addition to the review of cross-sections the following new cross-section classes were extended or newly implemented:

1. Total and inelastic cross-sections based on optical model parameterization were implemented for protons, neutrons and pions in the energy range 0.01 - 1000 GeV for nuclei from H to U. These are implemented in the classes G4PiNuclearCrossSection and G4NucleonNuclearCrossSection.

2. Simplified Glauber-Gribov model was implemented for the description of hadron-nucleus cross-sections (total, inelastic and elastic) for energies more than 100 GeV. The class for this is G4GlauberGribovCrossSection.

3. Simplified Glauber-Gribov model [7] was modified to provide the production and single-diffraction cross-sections. It can be used for calculations of quasi-elastic/inelastic and single-diffraction/inelastic cross-section ratios needed in Geant4 string models.

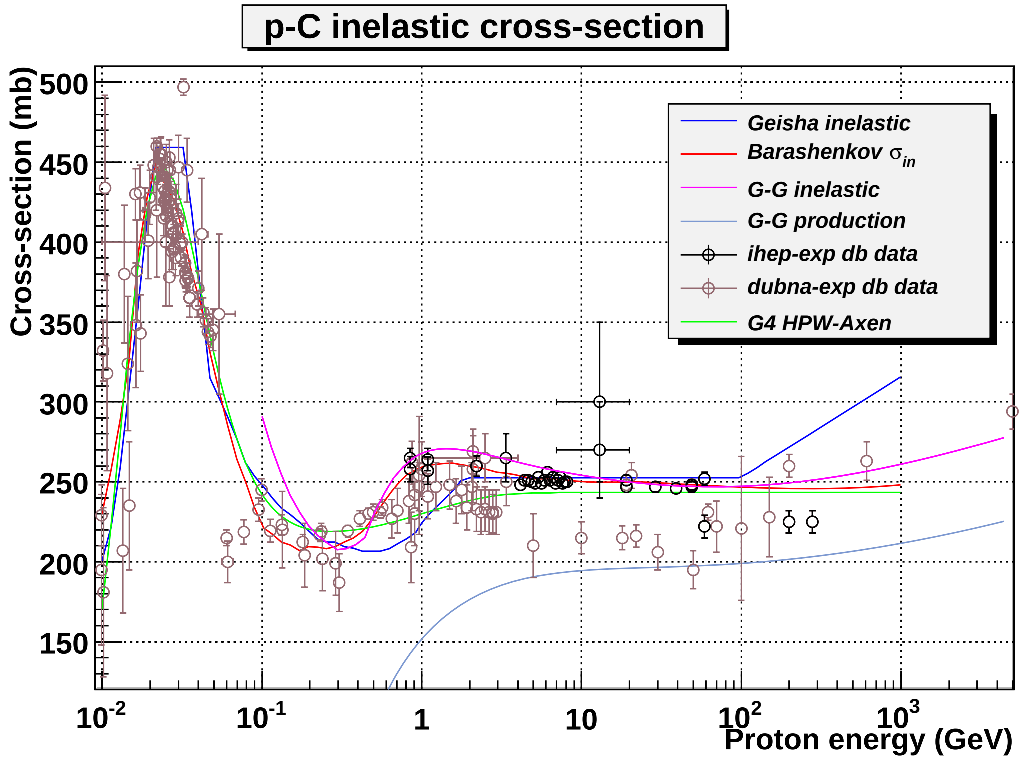

Figure 4: Inelastic cross-section of proton on carbon target versus the proton energy. Points are experimental data [5,6] The Axen-Wellisch parameterisation is included, labelled G4 HPW-Axen. In addition to the inelastic cross sections, also the production cross-section, which does not include the inelastic channel, is shown according to the simplified Glauber approach.

The review of cross-sections is reported in depth in G. Folger, V. Grichine [7].

Additional comparisons and improvement

An extended validation of Geant4 cascade models was undertaken against isotope production experiments at medium energy (800-1000 MeV). This comparison identified a deficiency in the Pre-compound/de-excitation evaporation module of Geant4, used by the Binary cascade. This problem stopped the production of fission fragments from heavy nuclei. A first assessment of the implementation of the de-excitation module was carried out, against the reference physics models. It was found that the probability for fission was calculated erroneously. This excluded the fission channel and skewed the probabilities for all evaporation channels. A correction was undertaken, enabling the fission model to produce isotopes.

Acknowledgement

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