The development and validation of the Geant4 Bertini cascade models

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Abstract

I review the validation of the Geant4 Bertini cascade models and discuss recent updates in the Bertini cascade including Kaon extension and elastic scattering interface. I review the validation done for the models, such as isotope production studies.

Outline

- Introducing Bertini models

- Recent updates

- Bertini cascade validations – review on recent publications

Bertini Cascade Models

The intra-nuclear cascade model developed by Bertini solves on the average the Boltzmann equation.

We present here an implementation of this classic INC model.

In inelastic particle-nucleus collisions

- a fast phase (10^{-23} – 10^{-22} s) of INC results in a highly exited nucleus, and is followed
- by fission and
- pre-equilibrium emission;
- a slower (10^{-18} – 10^{-16} s) compound nucleus phase follows with
- evaporation.

Bertini Cascade Models

The Bertini nuclear model[1] consist of a

- three-region approximation to the continuously changing density distribution of nuclear matter.
- Relativistic kinematics is applied throughout the cascade and
- the cascade is stopped when all the particles, which can escape the nucleus, have done so.

Pauli exclusion principle

- is taken into account and
- conformity with the energy conservation law is checked.

[1] A. S. Iljinov, M. V. Kazarnovsky and E. Ya. Paryev, *Intermediate-energy Nuclear Physics*, CRC Press, Boca Raton, Florida (USA). (1994).

Bertini Cascade Models

- Path lengths of nucleons in the nucleus
  - are sampled according to the local density and
  - free nucleon-nucleon cross-sections.
- Angles after collisions are sampled from experimental differential cross-sections.
- Tabulated total reaction cross-sections are calculated by Letaw's formulation[1].

[1] S. Pearlstein, "Medium-energy Nuclear Data Libraries. A Case Study, Neutron and Proton -induced Reactions in ^{56}Fe," *The Astropysical Journal*, **346**, pp. 1049-1060 (1989).

Implementing Bertini Cascade

Following the coding guidelines provided by the hadronic framework,

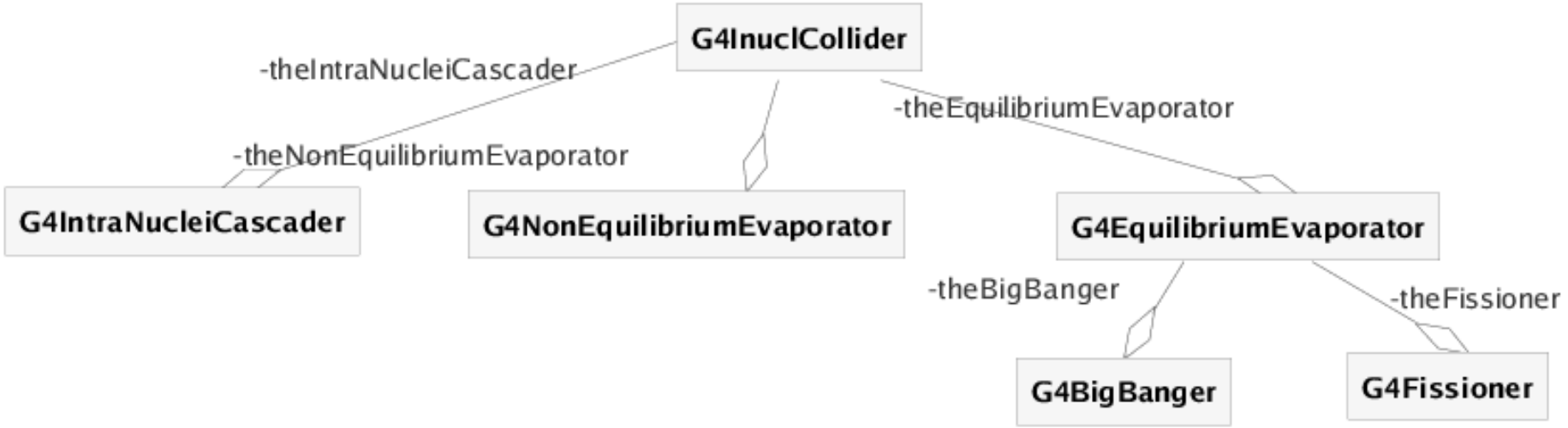
- Bertini cascade model interface class *G4CascadeInterface* inherits from *G4VIntraNuclearTransportModel* and
- implements hadronic final state generator with more than 35 classes.

Responsibilities of key classes in Geant4 Bertini cascade implementation.

Responsibility	Class name	Note
Interface	*G4CascadeInterface*	Implements INC framework.
Colliding particles	*G4ElementaryParticleCollider*	
Sub-model management	*G4InuclCollider*	
Nuclei model	*G4InuclNuclei*	
INC model	*G4IntraNucleiCascader*	Actual Bertini cascade treatment
Exiton model	*G4NonEquilibriumEvaporator*	Integrated with INC model.
Explosion model	*G4BigBanger*	
Fission model	*G4Fissioner*	Uses *G4FissionConfiguration*.
Evaporation model	*G4EquilibriumEvaporator*	Full de-exitation of nuclei.

Implementing Bertini Cascade

Unified Modeling Language diagram demonstrating relationships between key classes in Geant4 Bertini cascade implementation.



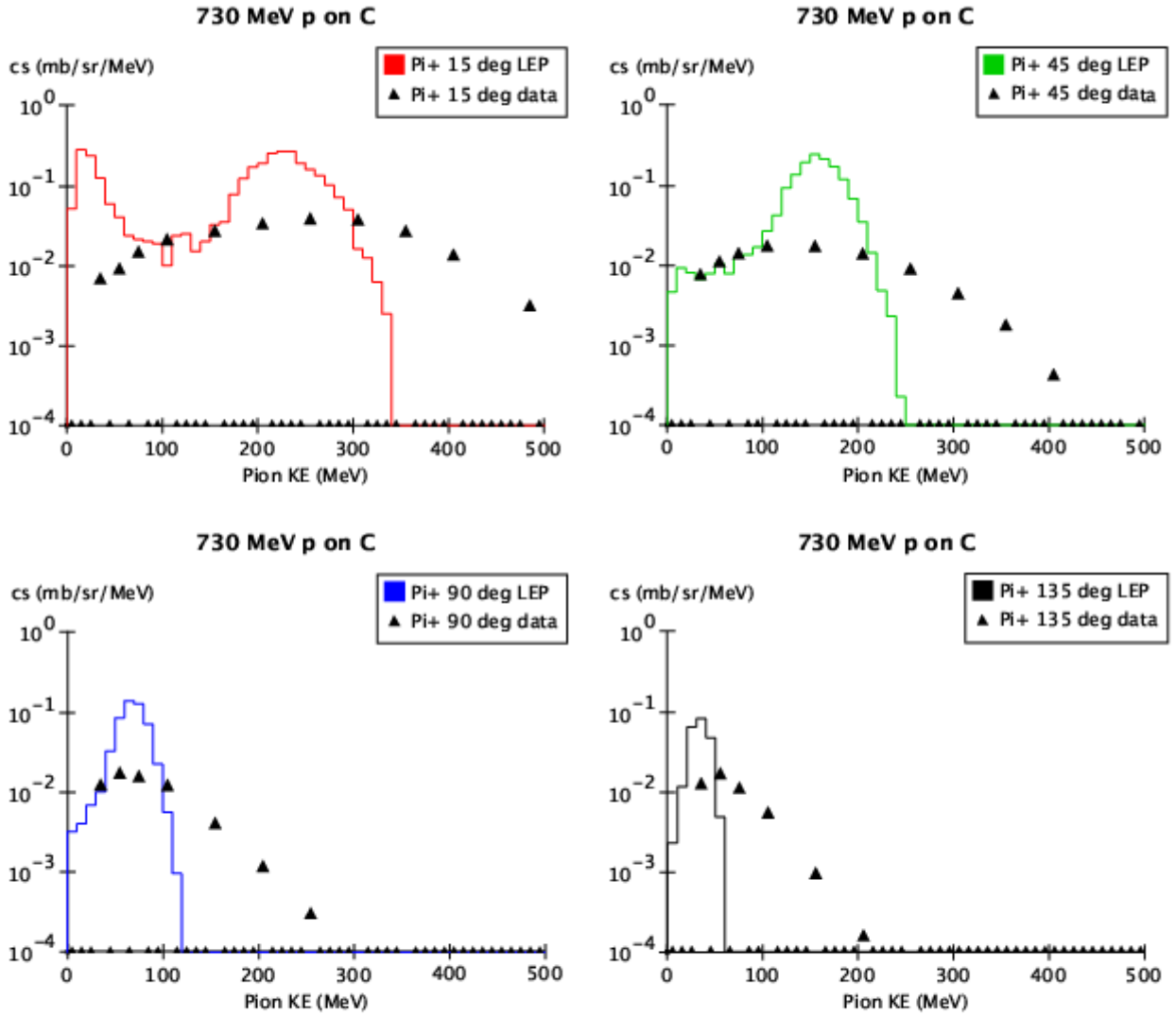


Fig. 5. Cross section for π^+ production from 730 MeV protons on carbon at 15°, 45°, 90° and 135°. Histogram: prediction of the Low Energy Parameterized (LEP) model in Geant4. Data points are from Ref. [5].

Strong features of the Bertini cascade in the 100 MeV – 3 GeV energy region are:

- isotope production
- speed compared to Binary cascade
- pion production compared to LEP

Dennis Wright: The Geant4-based BABAR Simulation.

A. Heikkinen: The development and validation of the Geant4 Bertini cascade models.

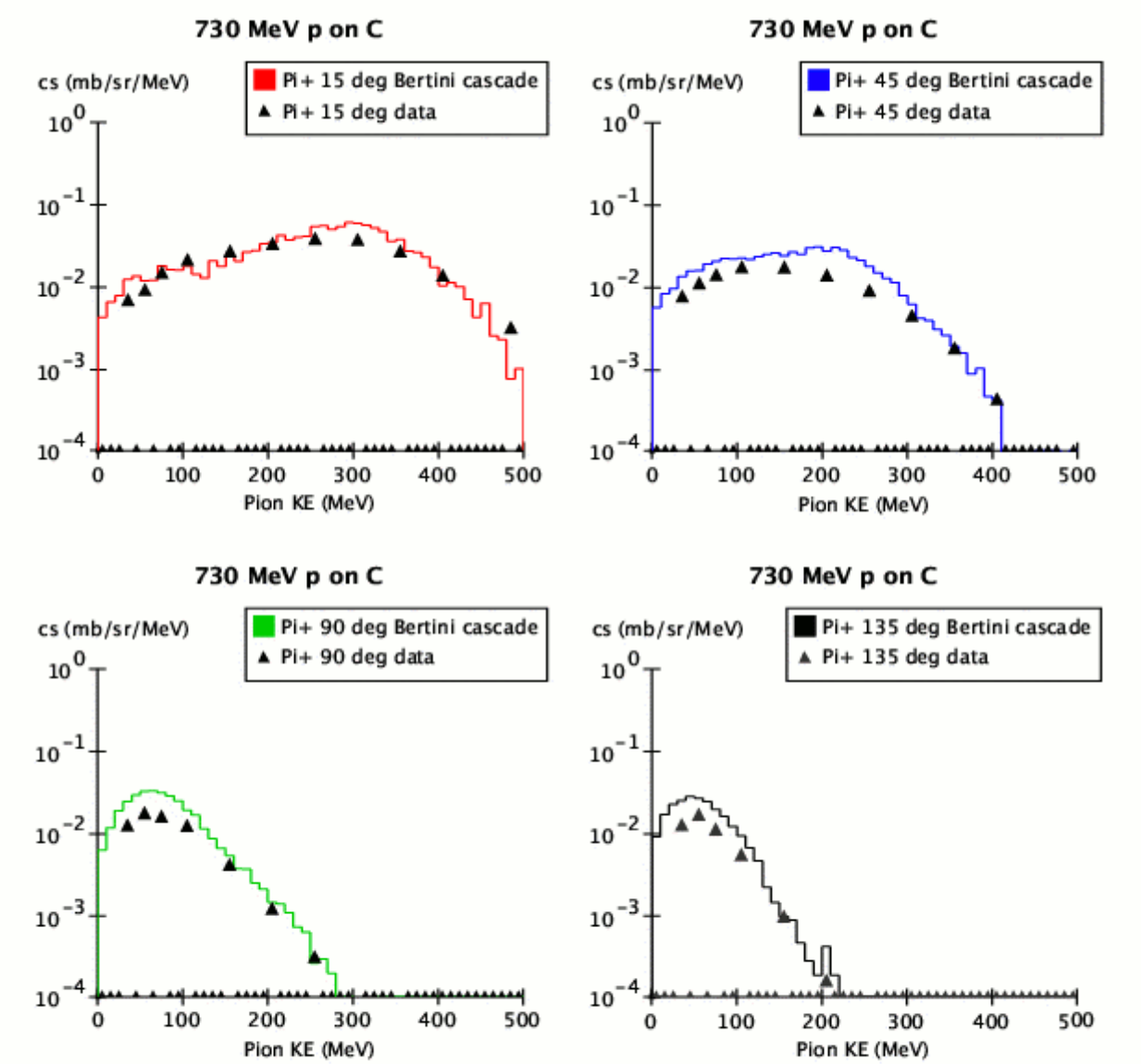
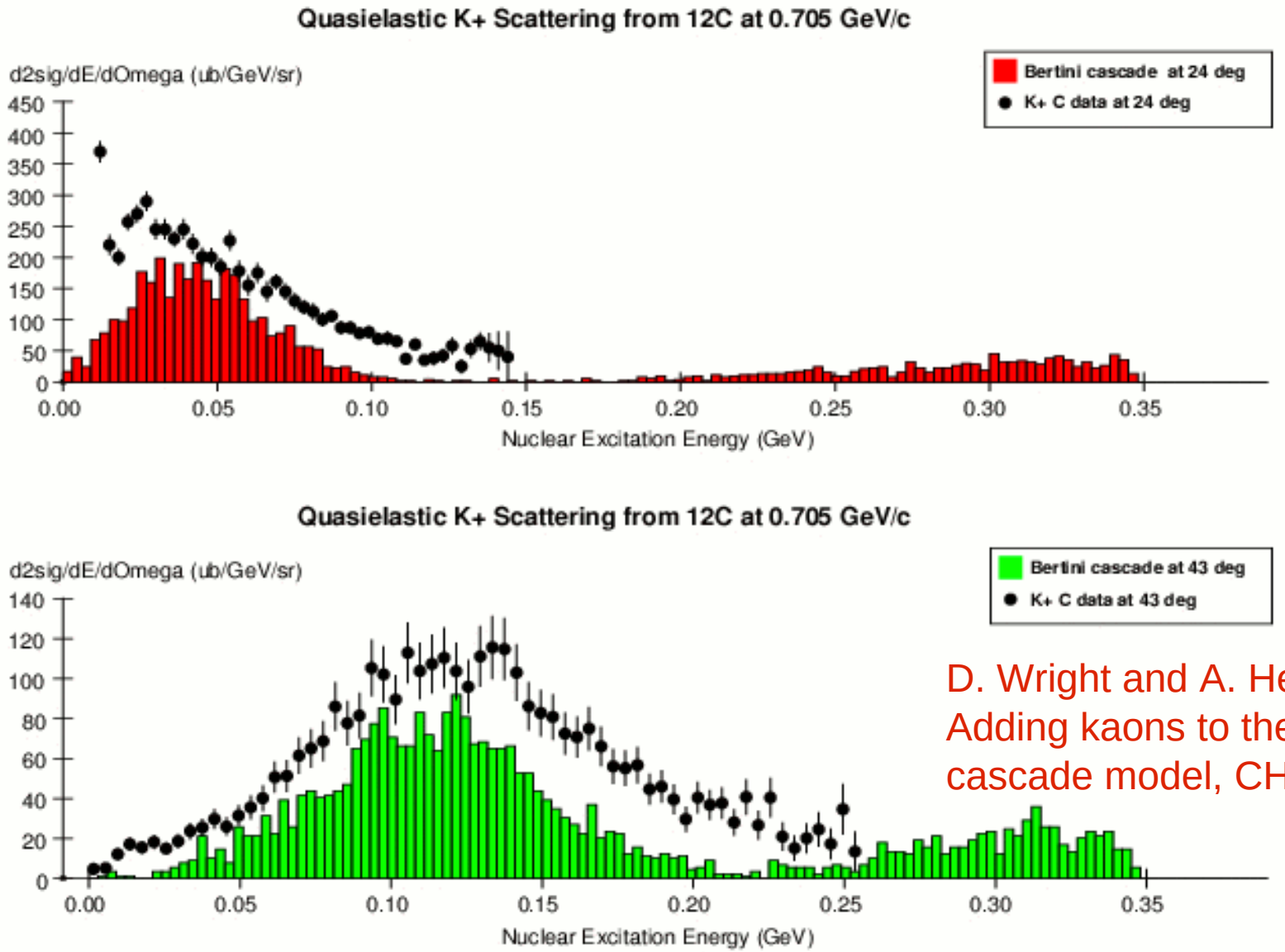


Fig. 6. Cross section for π^+ production from 730 MeV protons on carbon at 15°, 45°, 90° and 135°. Histogram: prediction of the Bertini cascade model in Geant4. Data points are from Ref. [5].

Latest updates to Bertini cascade

- Elastic scattering interface (Geant4 8.0 release)
  - Currenly beeing validated
- Tool for isotope production verification
- Treatment for incoming kaons (summer 2005 release)
- Adding ion treatment and extending kaon treatment will be our major task for the year 2006



D. Wright and A. Heikkinen: Adding kaons to the Bertini cascade model, CHEP 2004.

Figure 1: Inelastic K+ scattering from C at 24 and 43 degrees. The incident K+ momentum was 0.705 GeV/c. The horizontal axis is the nuclear excitation energy in GeV, so that elastic scattering would appear at 0. The vertical axis is the double differential cross section, $d^2\sigma/dE/d\Omega$, in μb/GeV/sr.

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model tag	brief description
G3-GHEISHA	GHEISHA, parametrized hadronic shower development
G3-FLUKA-GH	FLUKA, for neutrons with $E < 20$ MeV GHEISHA
G3-FLUKA-MI	FLUKA, for neutrons with $E < 20$ MeV MICAP
G3-GH SLAC	GHEISHA with some bug fixes from SLAC
G3-GCALOR	$E < 3$ GeV Bertini cascade, $3 < E < 10$ GeV hybrid Bertini/FLUKA, $E > 10$ GeV FLUKA, for neutrons with $E < 20$ MeV MICAP
G4-LHEP	GHEISHA ported from GEANT3
G4-LHEP-BERT	$E < 3$ GeV Bertini cascade, $E > 3$ GeV GHEISHA
G4-LHEP-BIC	$E < 3$ GeV Binary cascade, $E > 3$ GeV GHEISHA
G4-LHEP-GN	GHEISHA + gamma nuclear processes
G4-LHEP-HP	as G4-LHEP, for neutrons with $E < 20$ MeV use evaluated cross-section data
G4-QGSP	$E < 25$ GeV GHEISHA, $E > 25$ GeV quark-gluon string model
G4-QGSP-BERT	$E < 3$ GeV Bertini cascade, $3 < E < 25$ GeV GHEISHA, $E > 25$ GeV quark-gluon string model
G4-QGSP-BIC	$E < 3$ GeV Binary cascade, $3 < E < 25$ GeV GHEISHA, $E > 25$ GeV quark-gluon string model
G4-FTFP	$E < 25$ GeV GHEISHA, $E > 25$ GeV quark-gluon string model with fragmentation ala FRITJOF
G4-QGSC	$E < 25$ GeV GHEISHA, $E > 25$ GeV quark-gluon string model

Table 1: a brief line of description per studied model.

G. Mavromanolakis and D. Ward: Comparisons of hadronic shower packages. LC-TOOL-2004-019, arXiv: physics/0409040.

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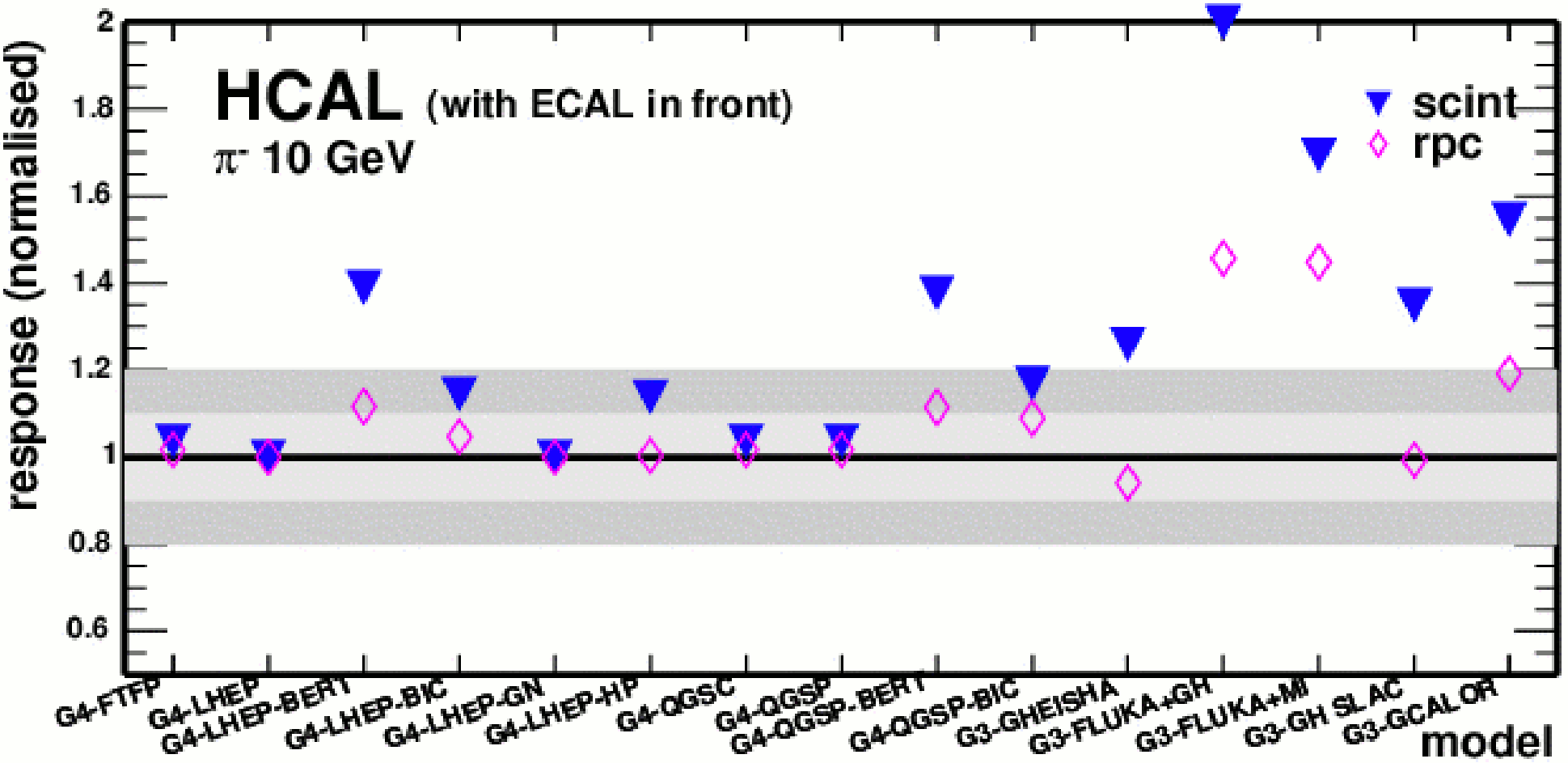

G. Mavromanolakis and D. Ward: Comparisons of hadronic shower packages. LC-TOOL-2004-019, arXiv: physics/0409040.

This verification uses calorimeter prototype for Future Linear Collider. Results are normalized to the G4-LHEP case.

Predictions from different models vary significantly, illustrating the necessity of testbeam data to resolve the situation.

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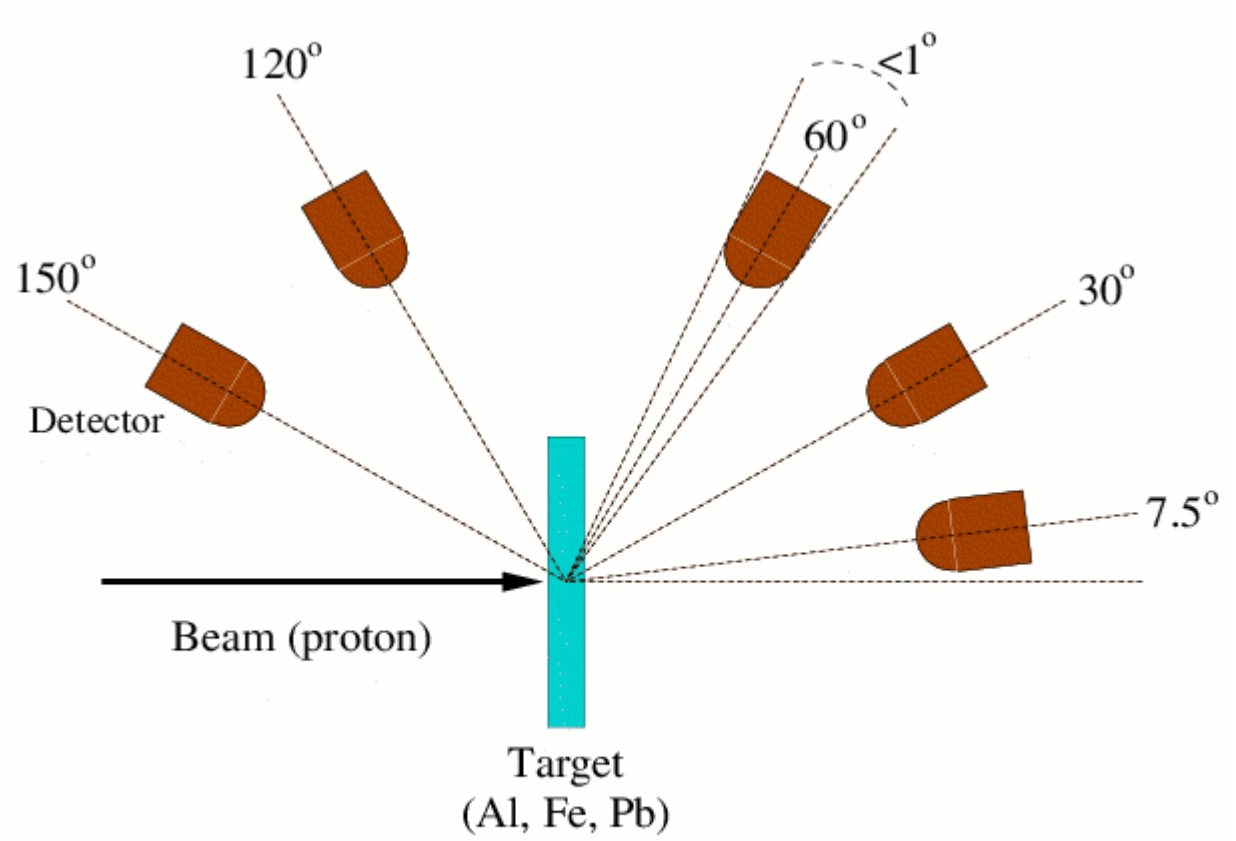
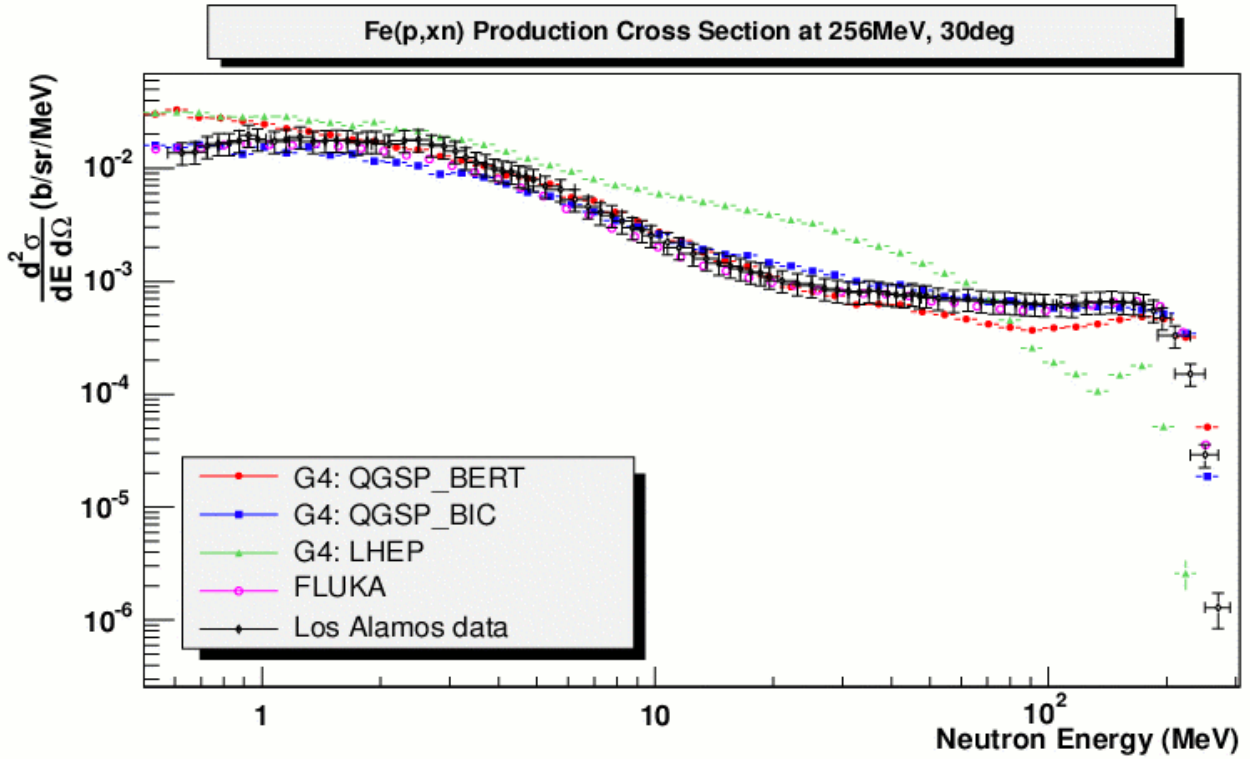


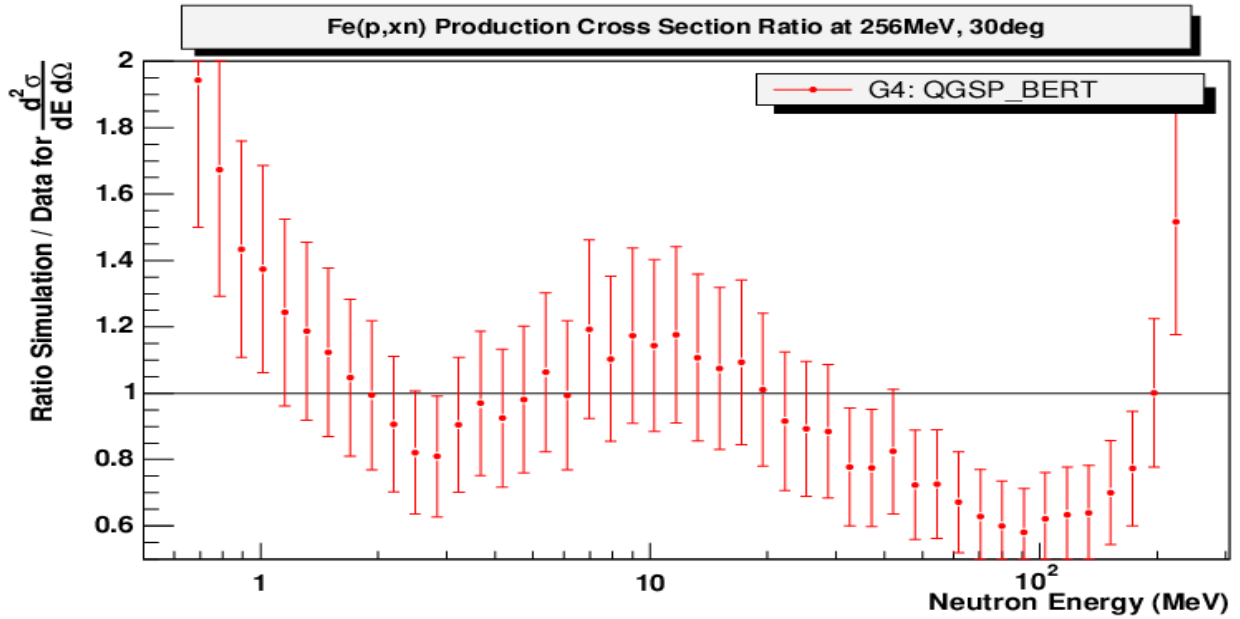
Fig. 6. Setup of the neutron production *(p, xn)* measurements at Los Alamos Meson Physics Facility (LAMPF).

Incident 113 - 800 MeV protons on thin Al, Fe, and Pb targets. In comparison with Los Alamos National Laboratory data 20 - 50 % agreement is found.

Jurg Beringer: (p,xn) Production Cross Sections: A Benchmark Study for the Validation of Hadronic Physics Simulation at LHC, CERN-LCGAPP-2003-18.

A. Heikkinen: The development and validation of the Geant4 Bertini cascade models.





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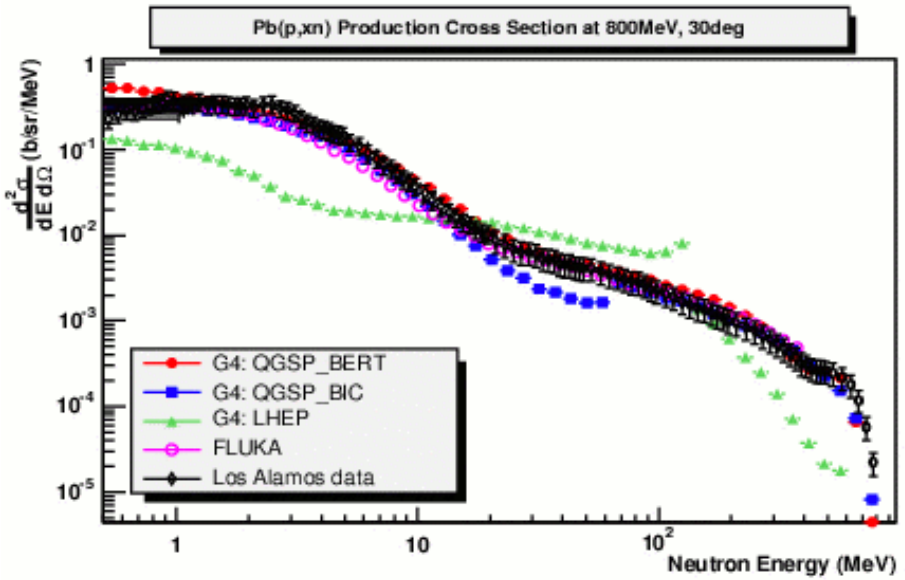

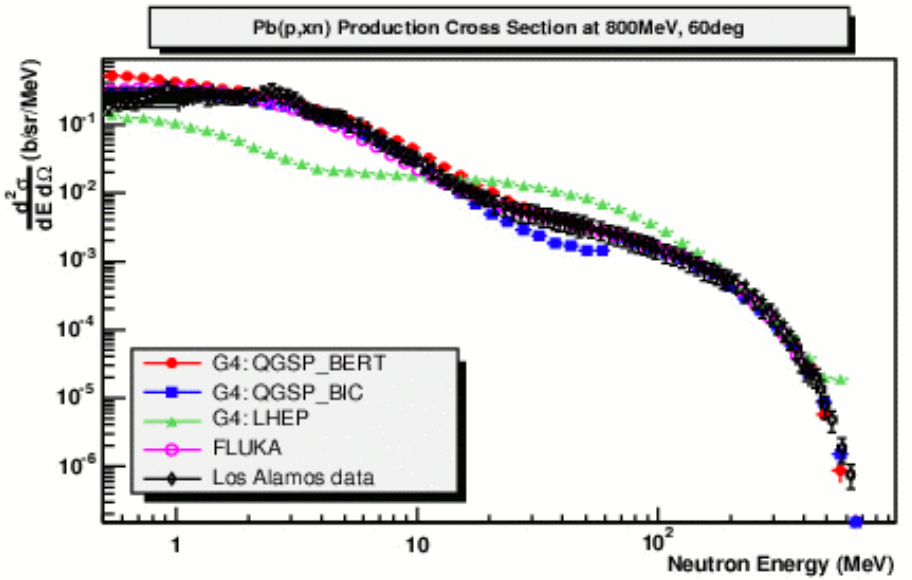

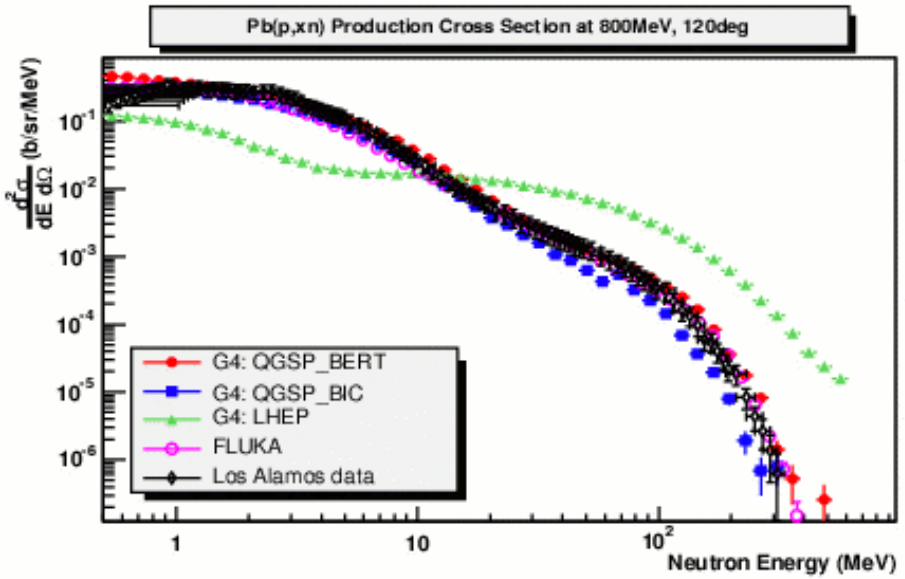

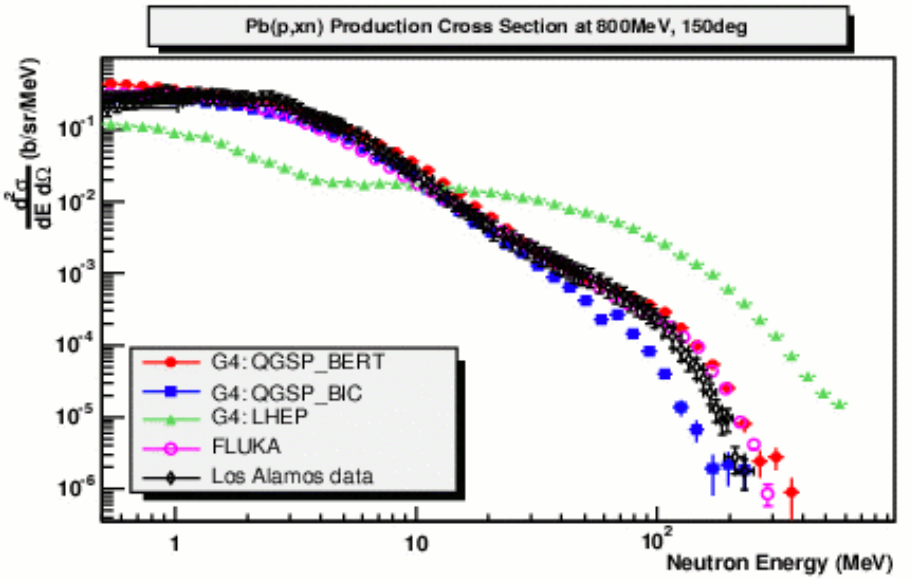

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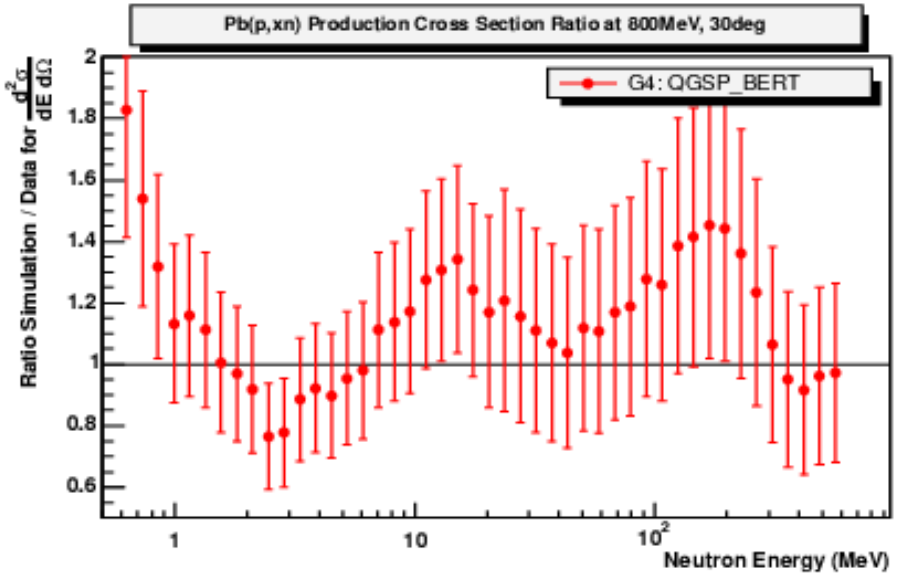

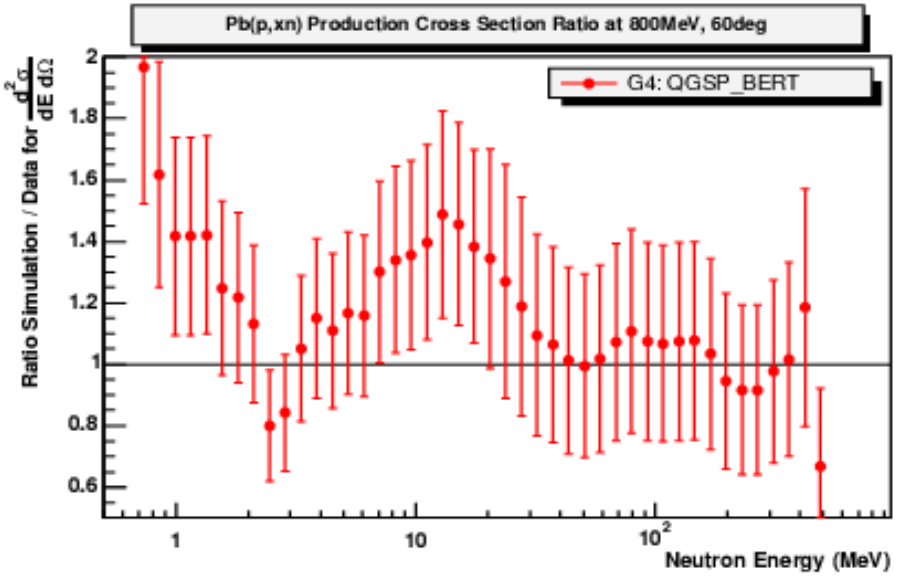

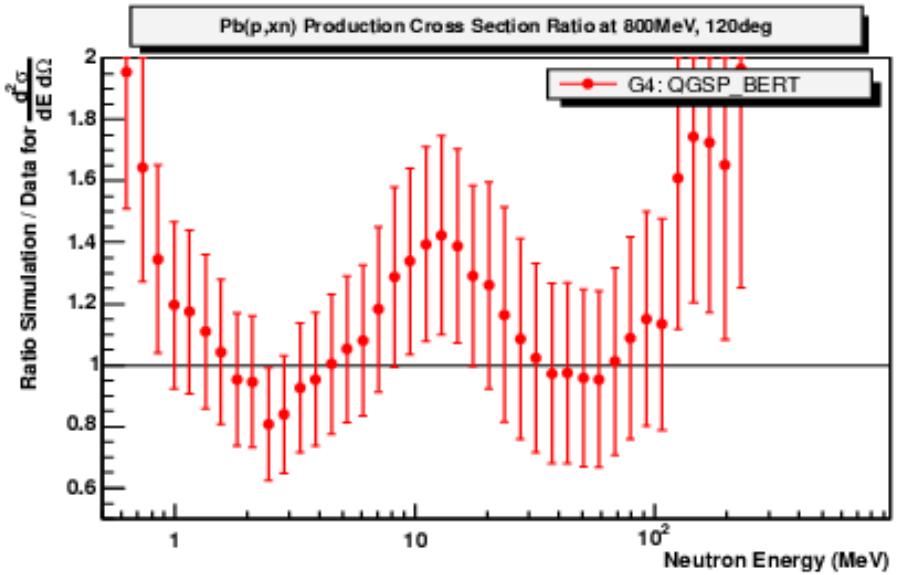

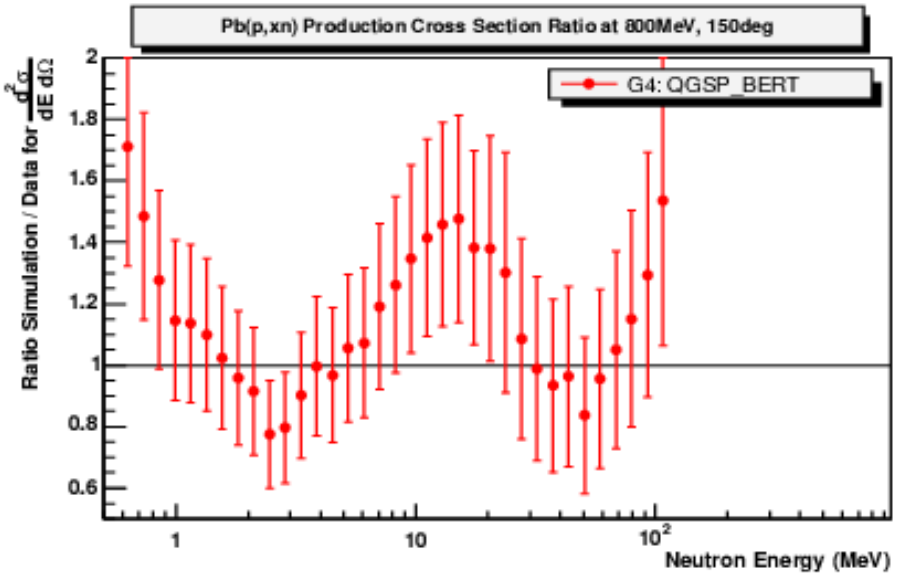

Jurg Beringer: (p,xn) Production Cross Sections: A Benchmark Study for the Validation of Hadronic Physics Simulation at LHC, CERN-LCGAPP-2003-18.

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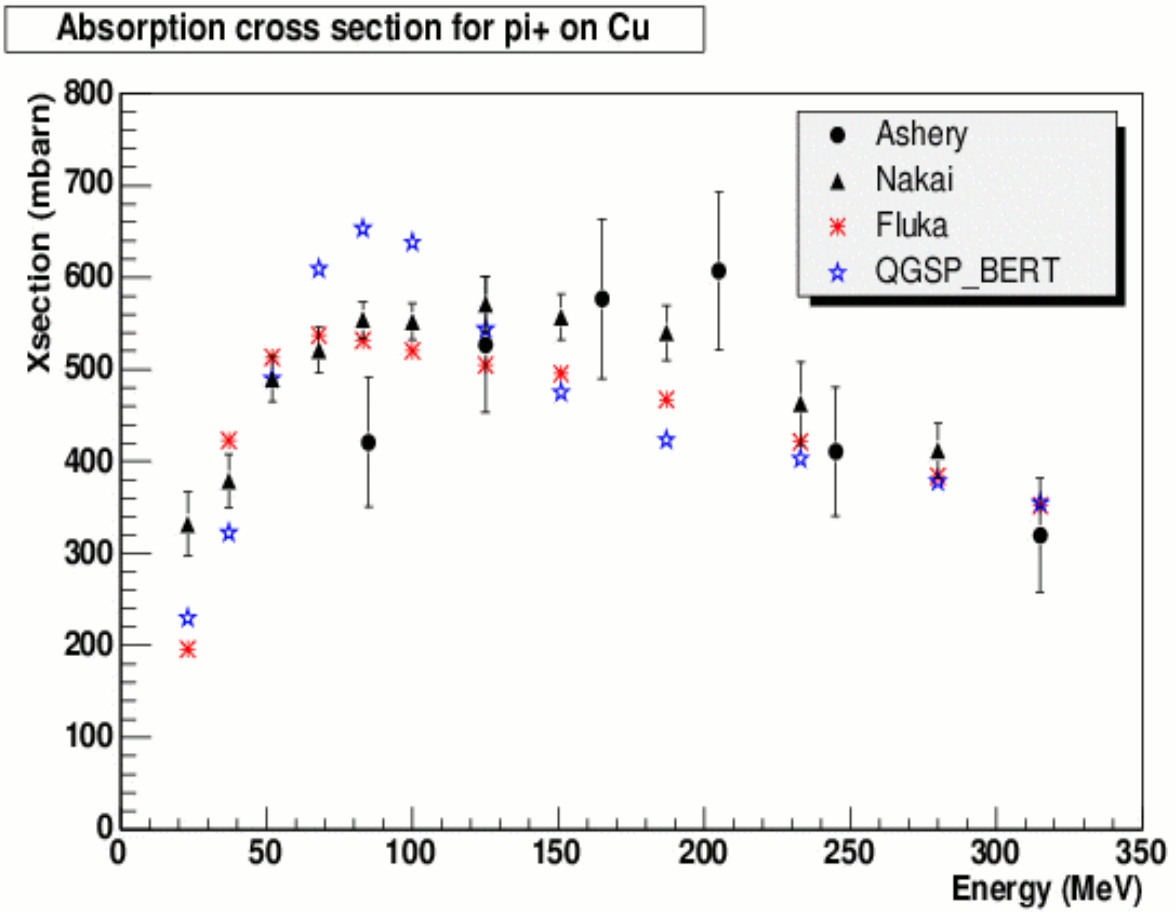
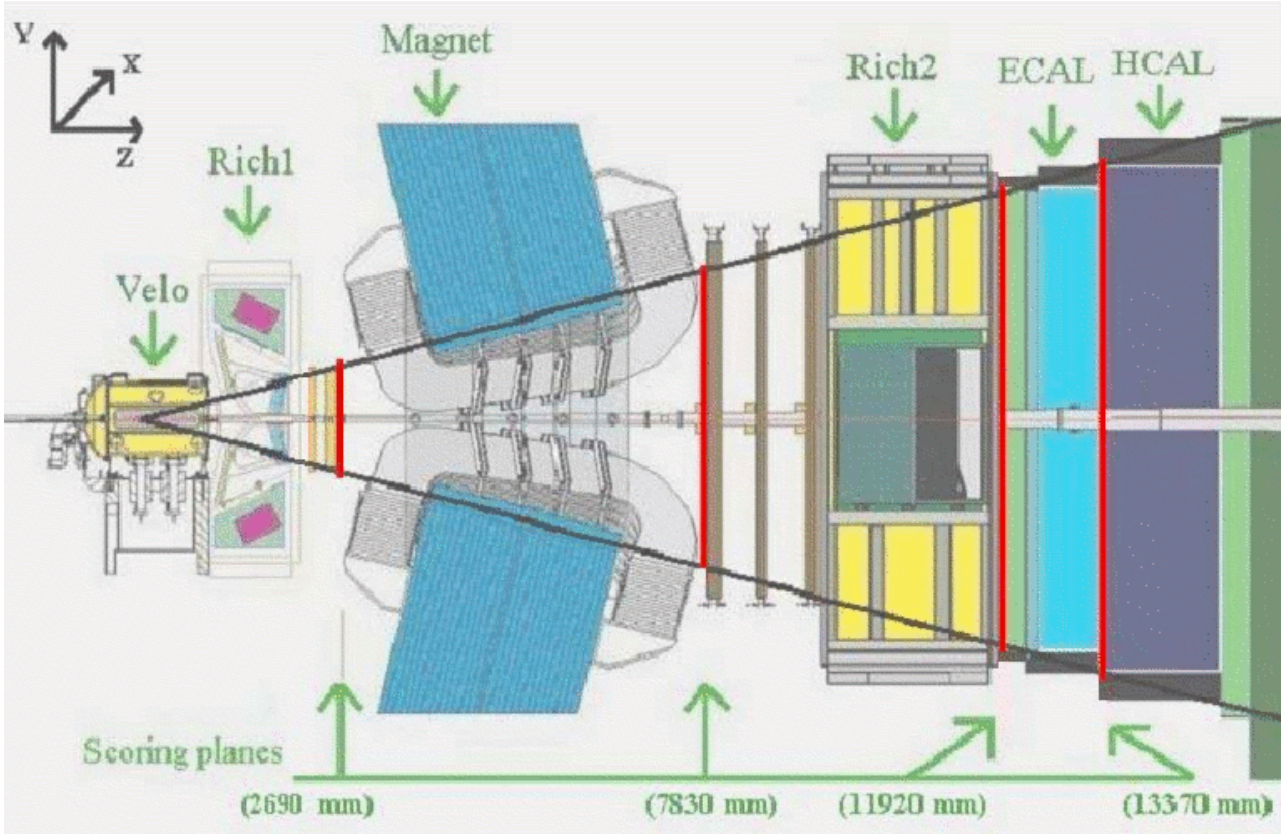


Figure 17: Total absorption cross section for π^+ on copper as a function of energy

Pi+ and pi- beams of energies between 23 MeV and 315 MeV and targets made of Al, Cu, and Au.

Witold Pokorski: In-flight Pion Absorption: Second Benchmark Study for the Validation of Hadronic Physics Simulation at the LHC. CERN-LCGAPP-2004-11.

A. Heikkinen: The development and validation of the Geant4 Bertini cascade models.



LHCb verification study how to use Geant4 for the background studies.

Scoring doses and fluences in four planes.

From six hadronic Geant4 physics lists studied, GQSP_BERT_HP was found to give best answer to the problem requirements.

Giuseppe Daquino: Update on background radiation studies in LHCb with GAUSS/Geant4.

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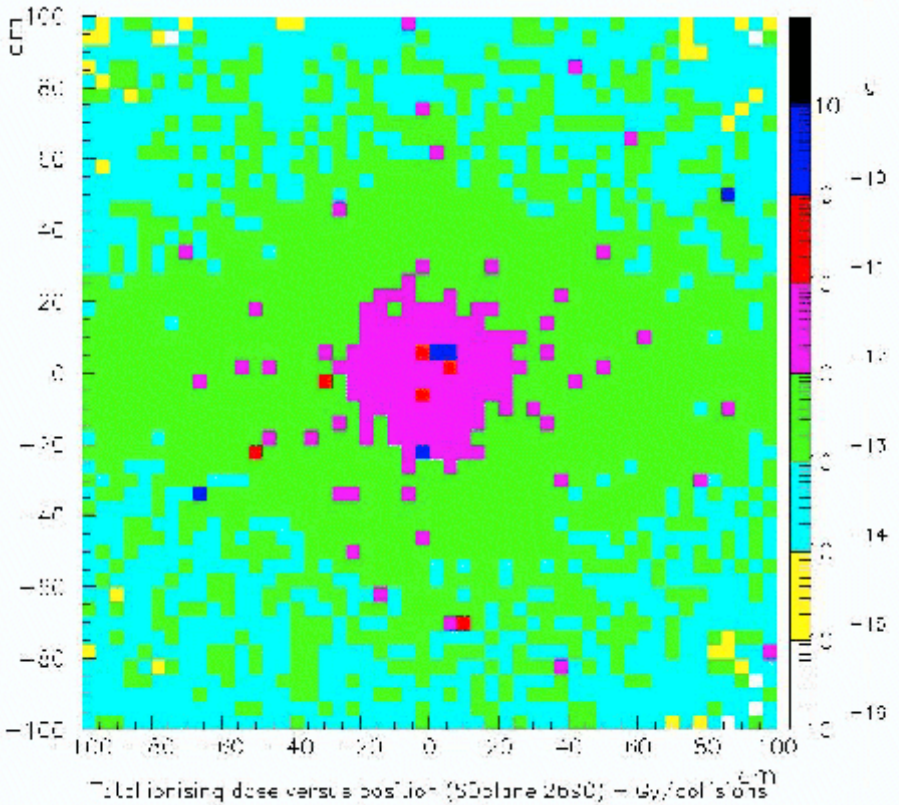
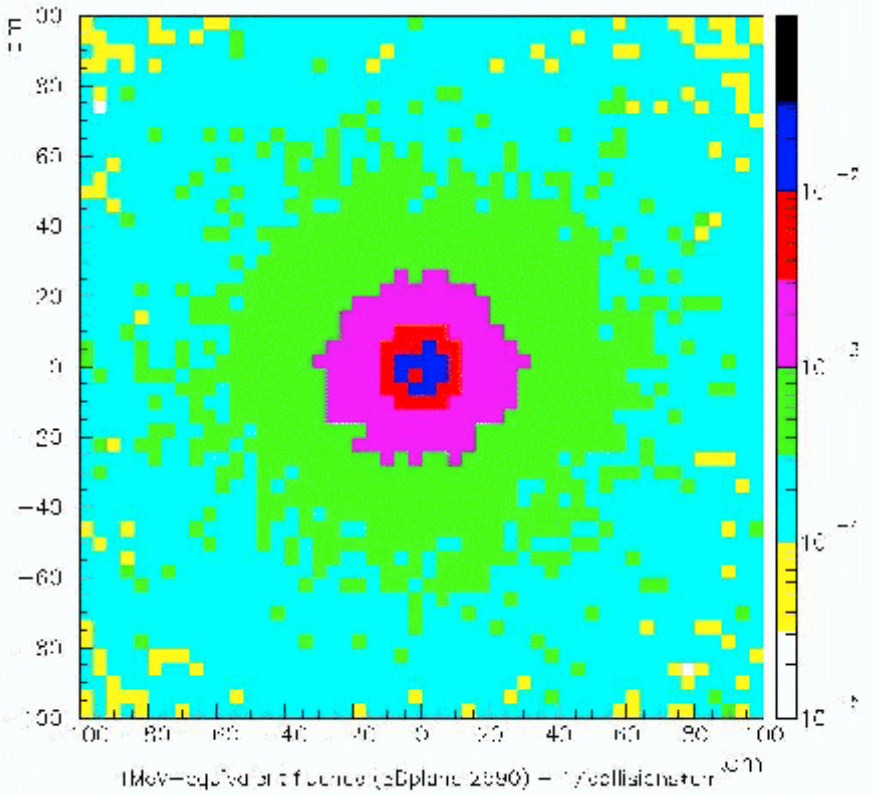
QGSP_BERT_HP results

Scoring plane @ 2960



Total ionising dose



1 MeV neutron equivalent fluence

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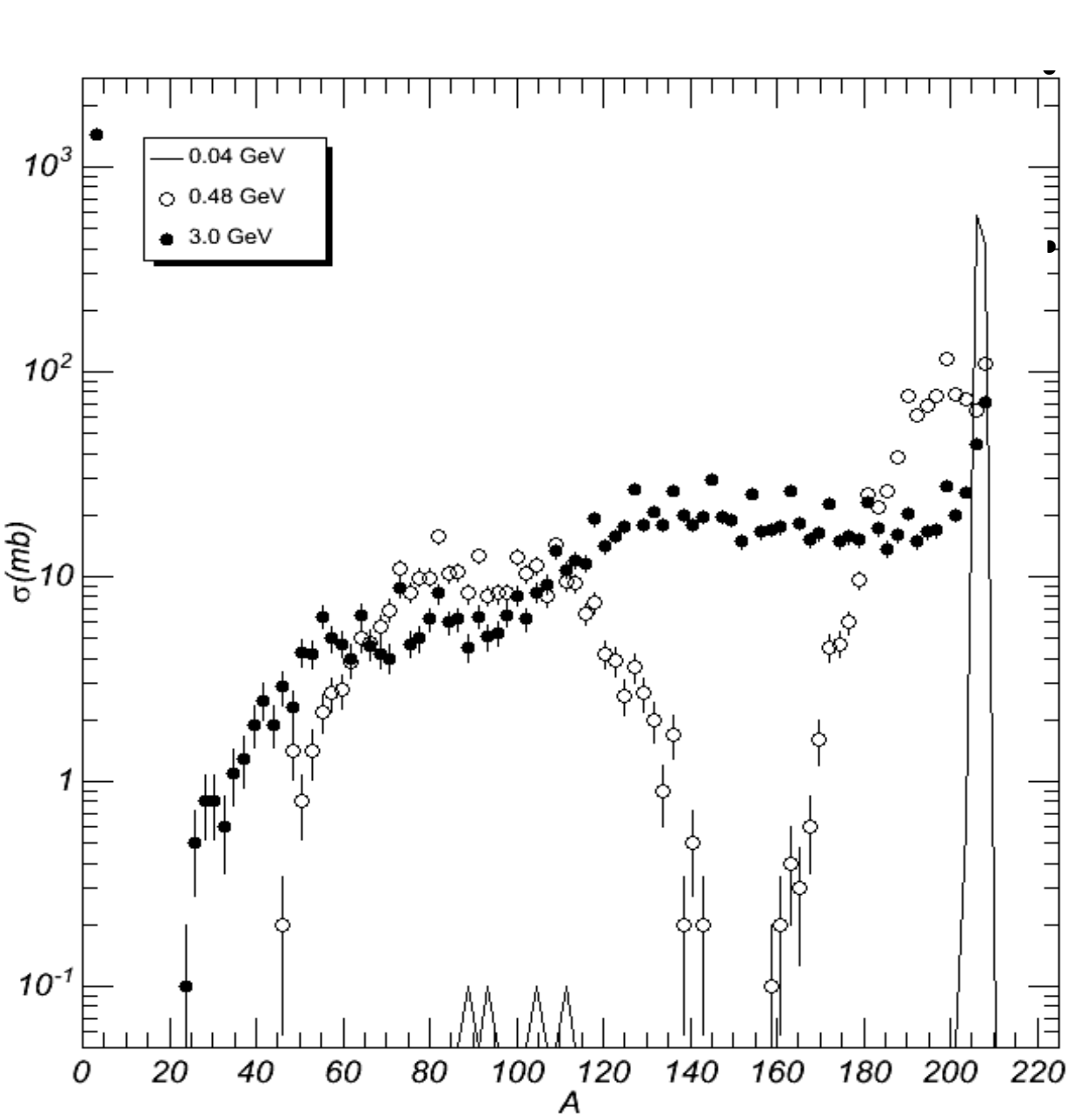
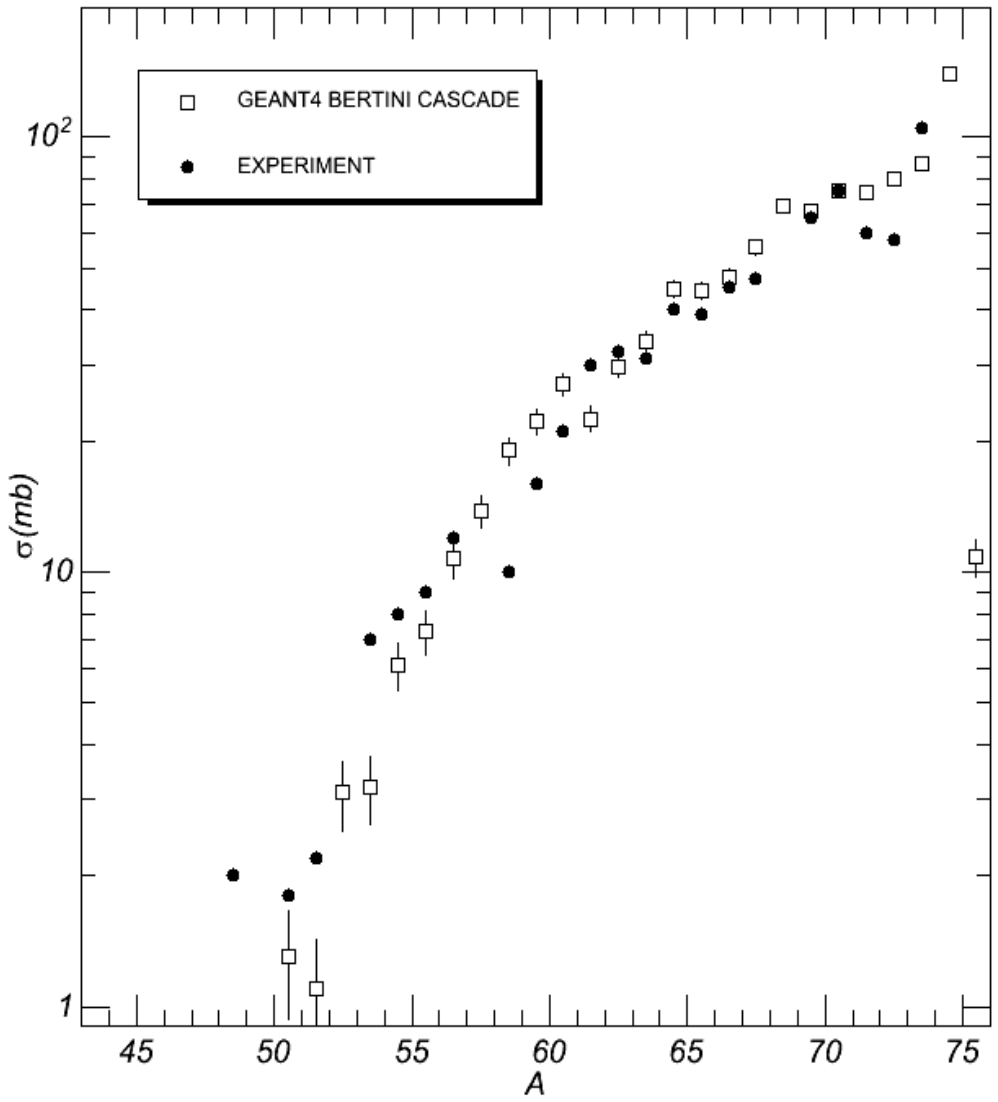


Verification and validation of Geant4 Bertini cascade nuclide production.

Proton-induced reactions on various targets.

A. Heikkinen: Validation of Geant4 Bertini cascade nuclide production. To be published in the proceedings of the FrontierScience 2005.

A. Heikkinen: The development and validation of the Geant4 Bertini cascade models.

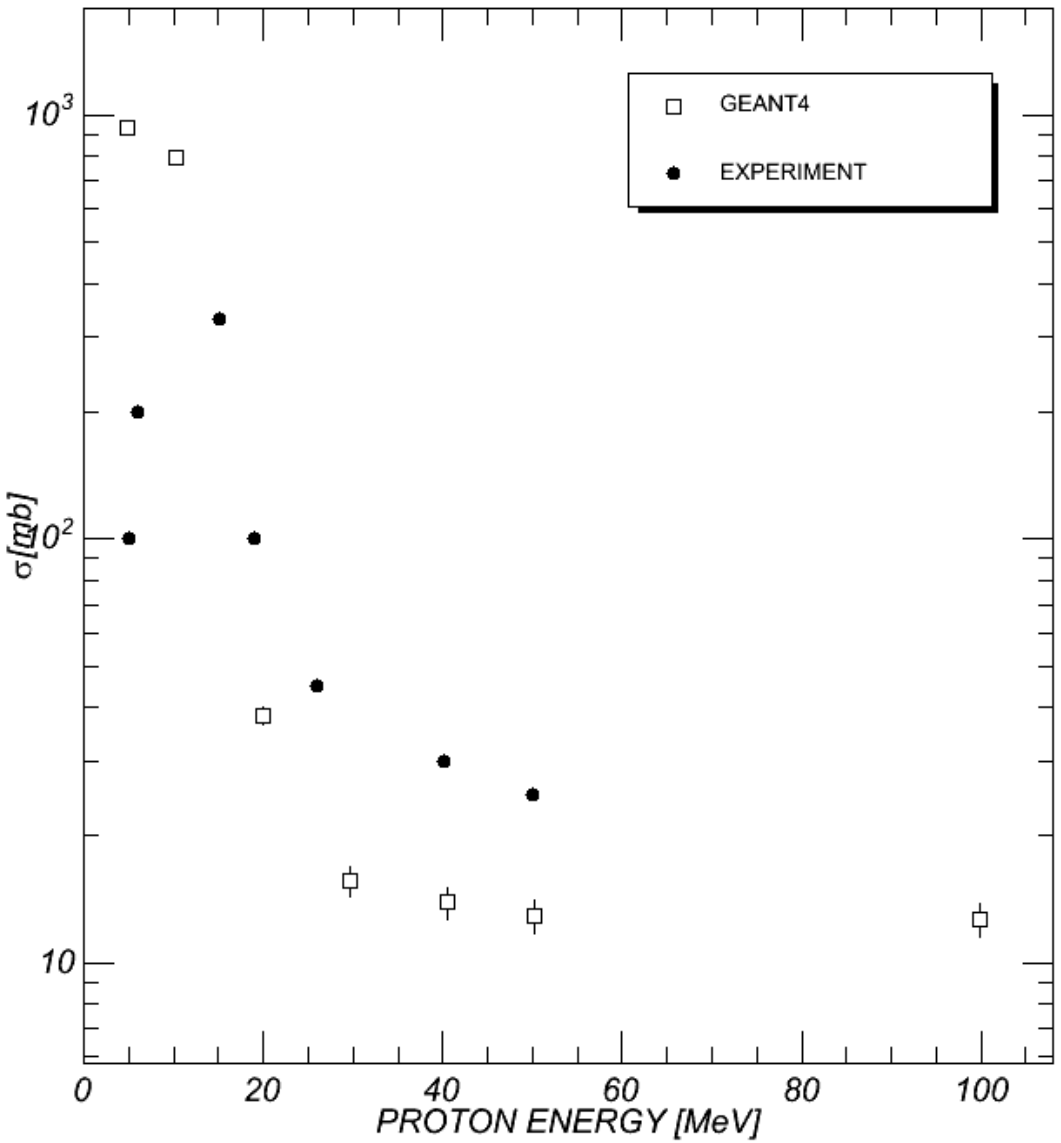


Typical performance of Geant4 Bertini is found to be comparable to codes such as CEM, LAHET, or CASCADE.

A. Heikkinen: Validation of Geant4 Bertini cascade nuclide production. To be published in the proceedings of the FrontierScience 2005.

A. Heikkinen: The development and validation of the Geant4 Bertini cascade models.

ISOTOPE PRODUCTION 31-GA-69(P,N)32-GE-69

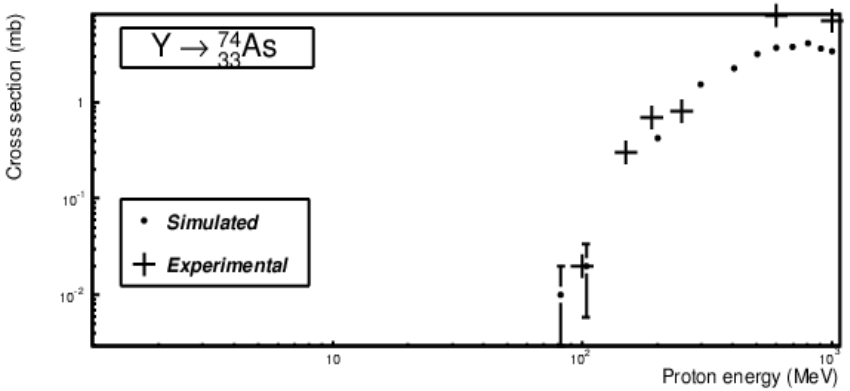


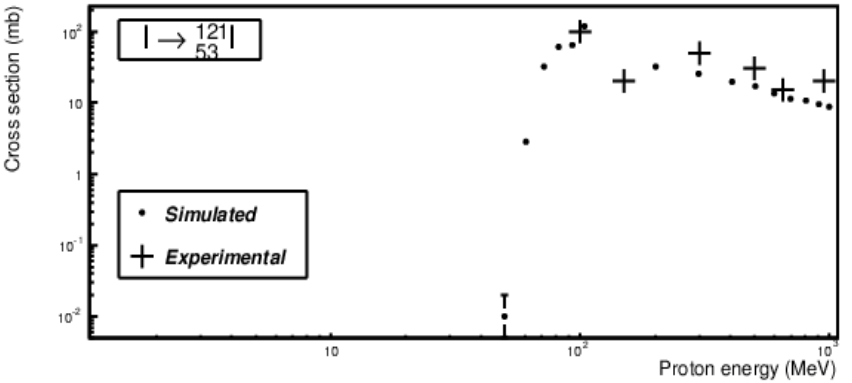
Exitation functions of special interst to underground experiments.

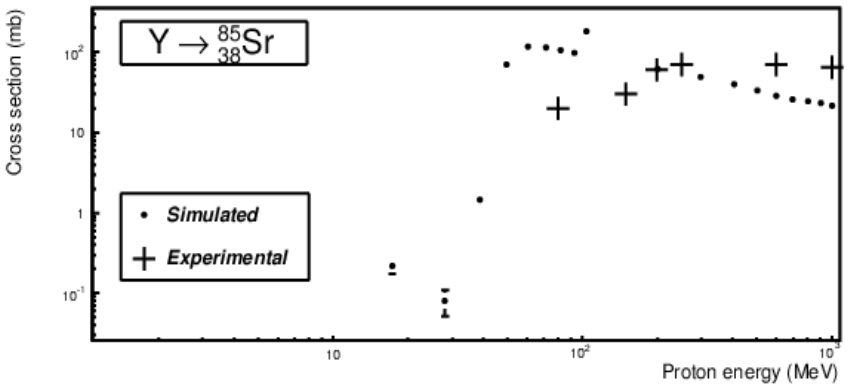
Here we have verified that germanium is produced from gallium target.

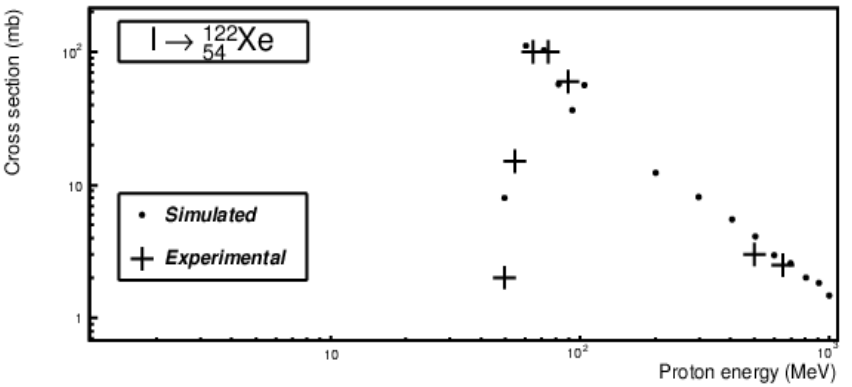
A. Heikkinen: Validation of Geant4 Bertini cascade nuclide production. To be published in the proceedings of the FrontierScience 2005.

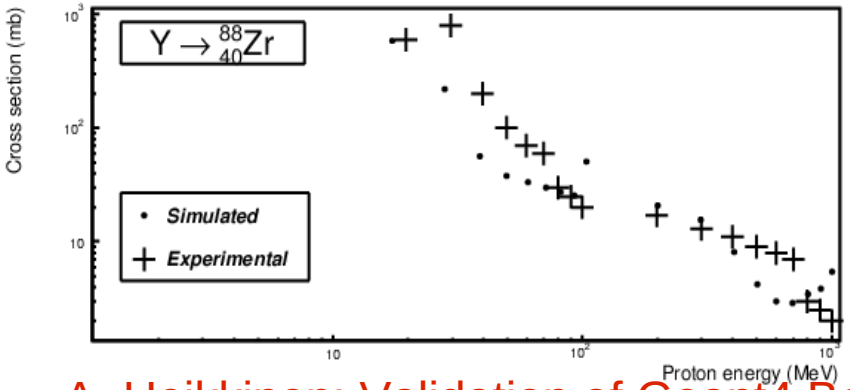
A. Heikkinen: The development and validation of the Geant4 Bertini cascade models.

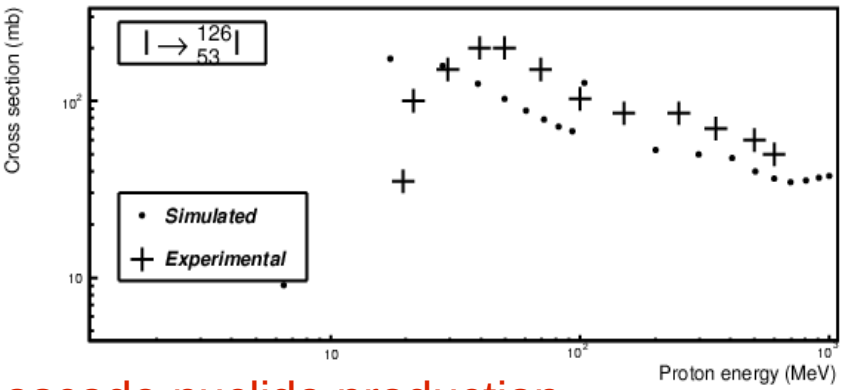












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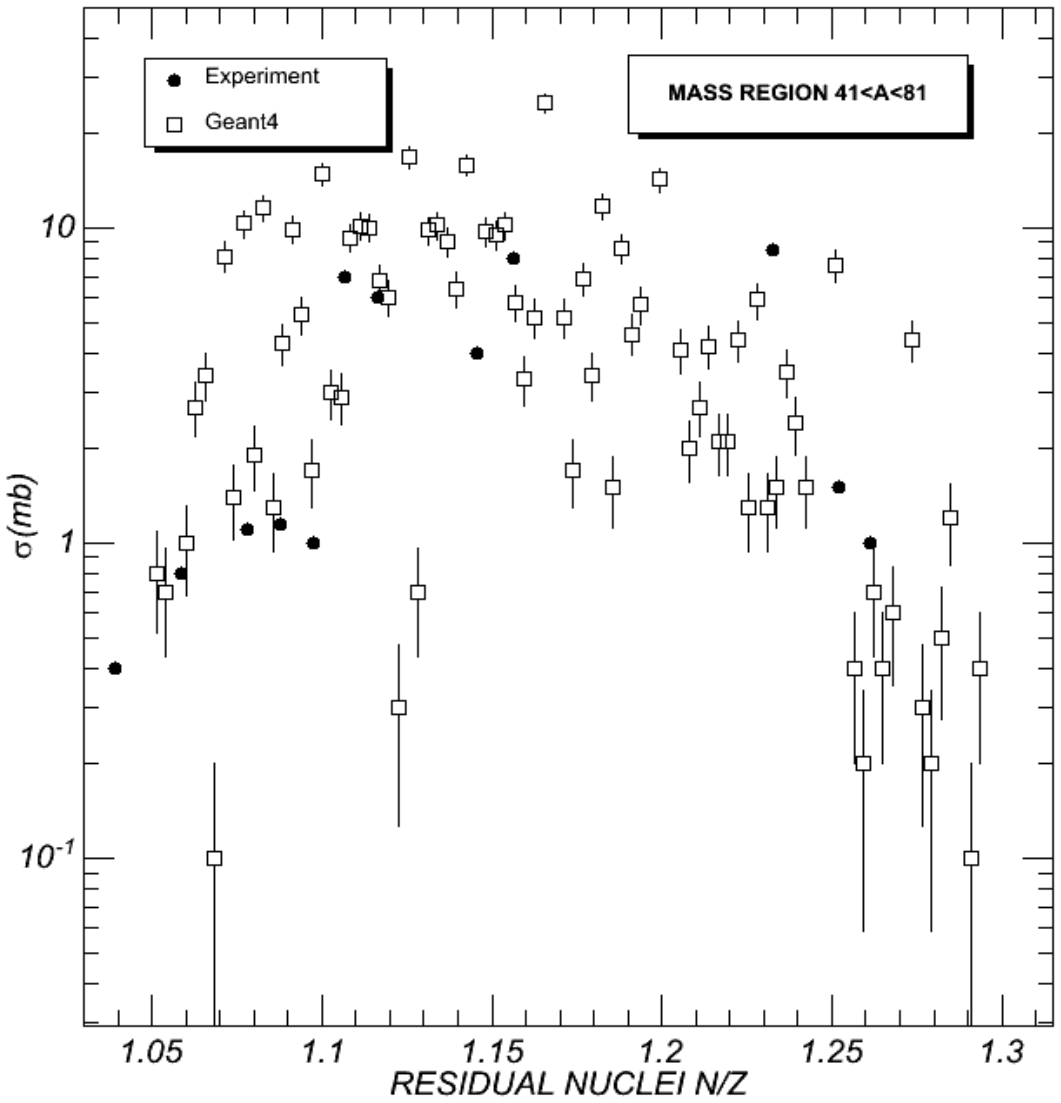
8.1 GeV proton + $^{118}_{50}Sn$



Usually Bertini models are used below 3 GeV.

Yet the performance above this energy might be good enough for some applications.

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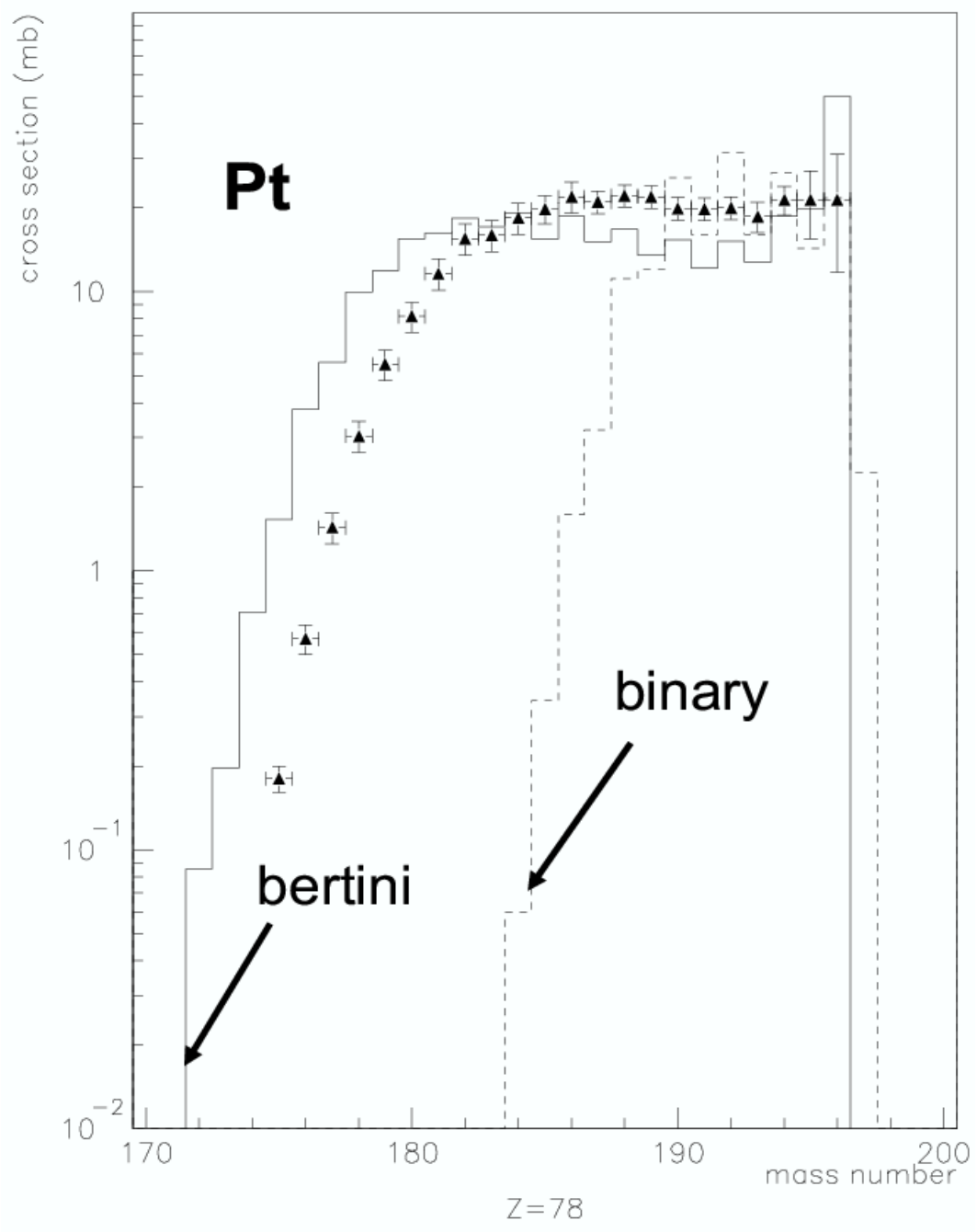
A. Heikkinen: The development and validation of the Geant4 Bertini cascade models.



H. M. Günter, Comparison of Geant4 hadronic models against experimental data.

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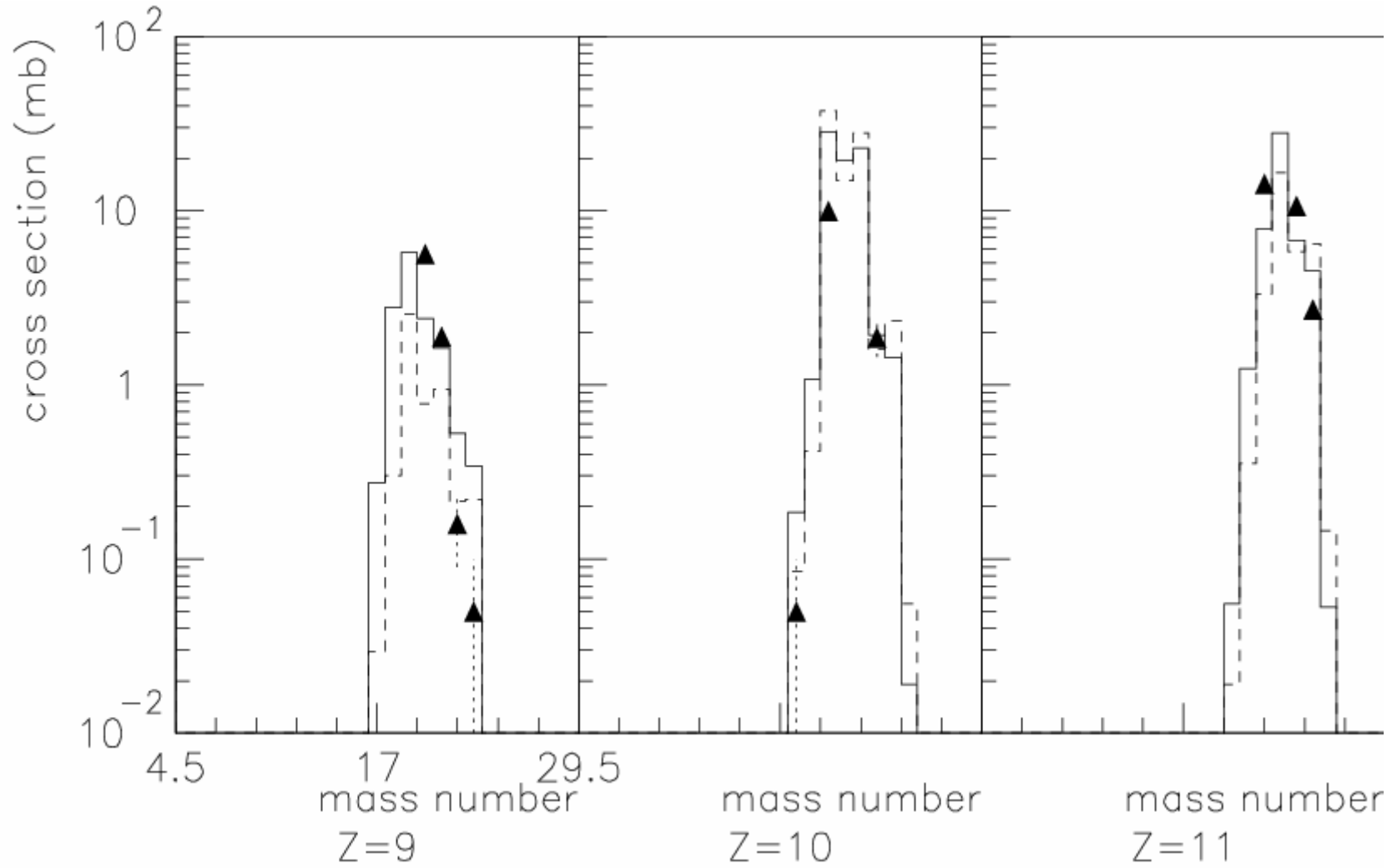

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