Code improvements and shielding benchmarks for Geant4 version 10.02

KOI, Tatsumi on behalf of Geant4 collaboration
SD/EPP/Computing
SLAC National Accelerator Laboratory

Outline

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Highlights of Geant4 v10.01 and v10.02
- The third General Paper
- Usolids
- Many-core
- Generic biasing framework
- Supported platform
- ParticleHP and LEND

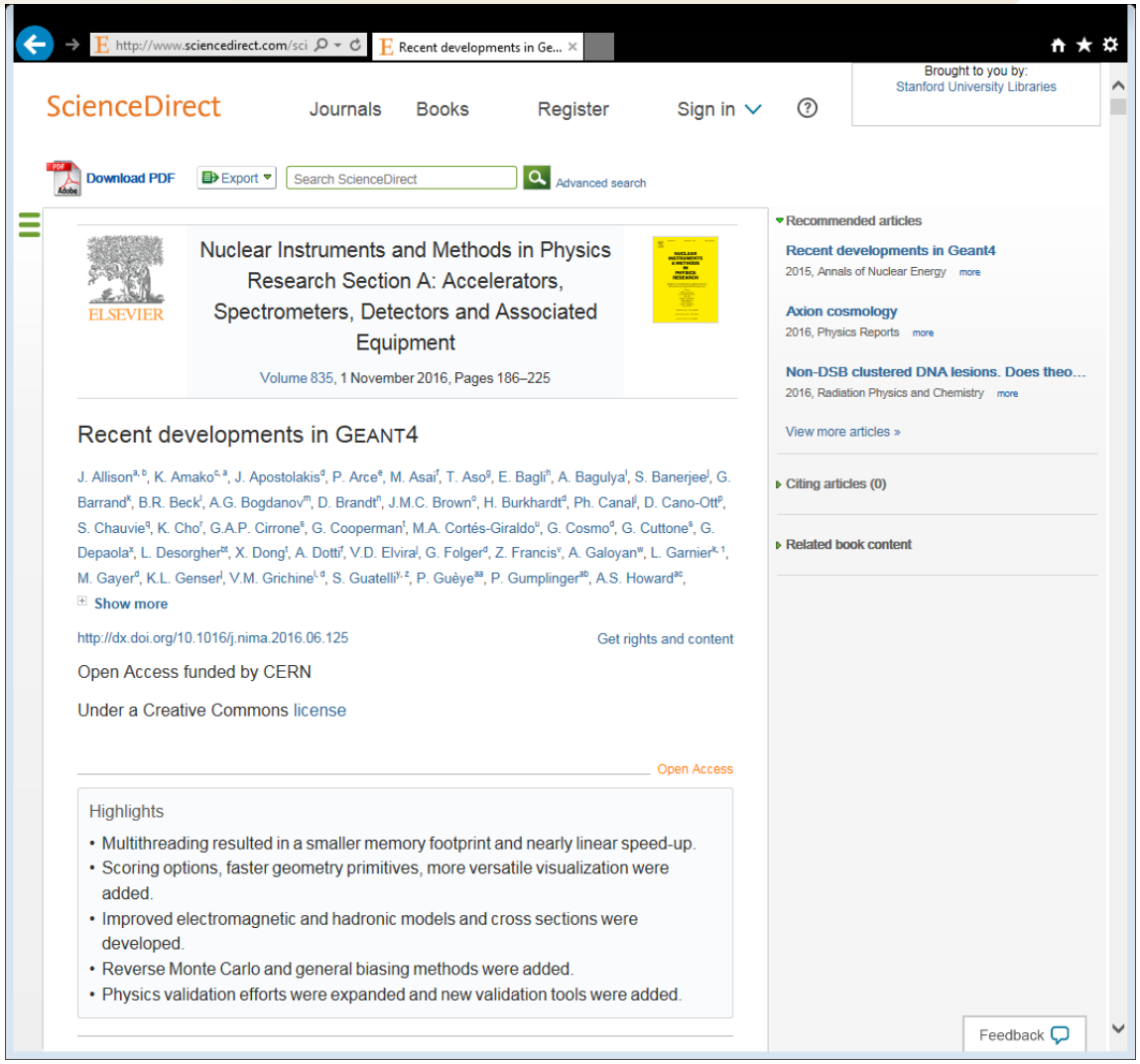
Shielding benchmarks
- Inter-comparison
- SATIF BNL
- Radioactive spallation products
- Toys SINQ

Summary

Appendix

The third general paper is published

http://www.sciencedirect.com/science/article/pii/S0168900216306957



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ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 835, 1 November 2016, Pages 186–225

Recent developments in GEANT4

J. Allison[a, b], K. Amako[c, a], J. Apostolakis[d], P. Arce[e], M. Asai[f], T. Aso[g], E. Bagli[h], A. Bagulya[i], S. Banerjee[j], G. Barrand[k], B.R. Beck[l], A.G. Bogdanov[m], D. Brandt[n], J.M.C. Brown[o], H. Burkhardt[d], Ph. Canal[j], D. Cano-Ott[p], S. Chauvie[q], K. Cho[r], G.A.P. Cirrone[s], G. Cooperman[t], M.A. Cortés-Giraldo[u], G. Cosmo[d], G. Cuttone[s], G. Depaola[v], L. Desorgher[bt], X. Dong[t], A. Dotti[f], V.D. Elvira[j], G. Folger[d], Z. Francis[y], A. Galoyan[w], L. Garnier[k, 1], M. Gayer[d], K.L. Genser[j], V.M. Grichine[i, d], S. Guatelli[y, z], P. Guèye[aa], P. Gumplinger[ab], A.S. Howard[ac],

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Highlights

- Multithreading resulted in a smaller memory footprint and nearly linear speed-up.
- Scoring options, faster geometry primitives, more versatile visualization were added.
- Improved electromagnetic and hadronic models and cross sections were developed.
- Reverse Monte Carlo and general biasing methods were added.
- Physics validation efforts were expanded and new validation tools were added.

Recommended articles

Recent developments in Geant4
2015, Annals of Nuclear Energy more

Axion cosmology
2016, Physics Reports more

Non-DSB clustered DNA lesions. Does theo…
2016, Radiation Physics and Chemistry more

View more articles »

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Geometry
Geometrical primitives - USolids

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Motivations for a common solids library

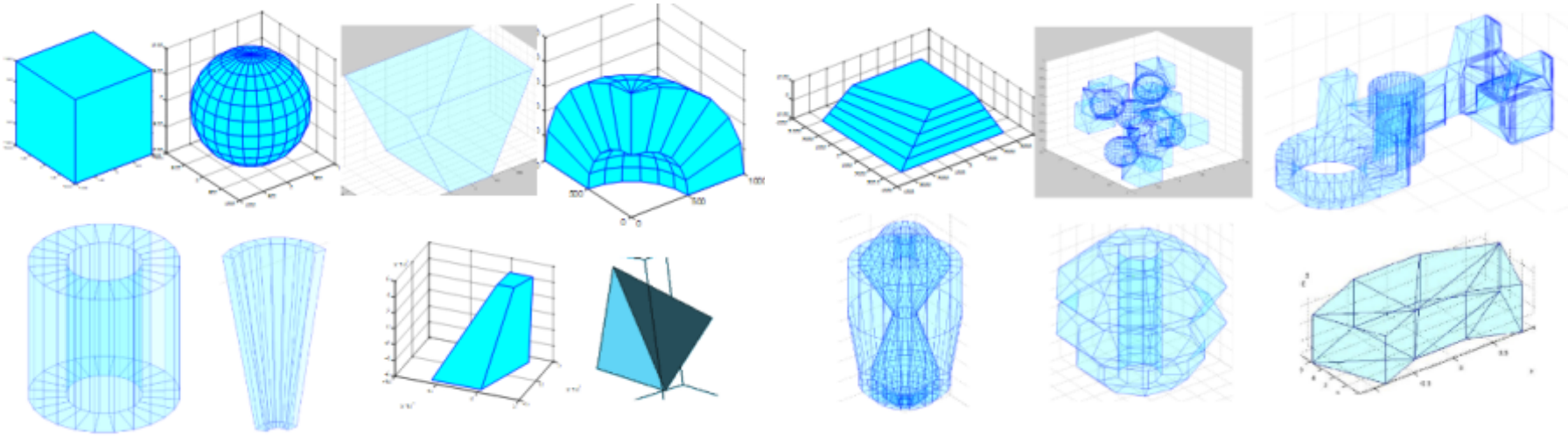
- Optimize and guarantee better long-term maintenance of

Geant4 and **ROOT** solids libraries

- Create a single high quality library to replace solid

libraries in Geant4 and ROOT

- A new minor release of the **GDML** schema, GDML-3.1.1, is used, supporting the new MultiUnion structure. This new feature is available only in installations which use the USolids library



Performance Linearity on *Intel Xeon Phi*

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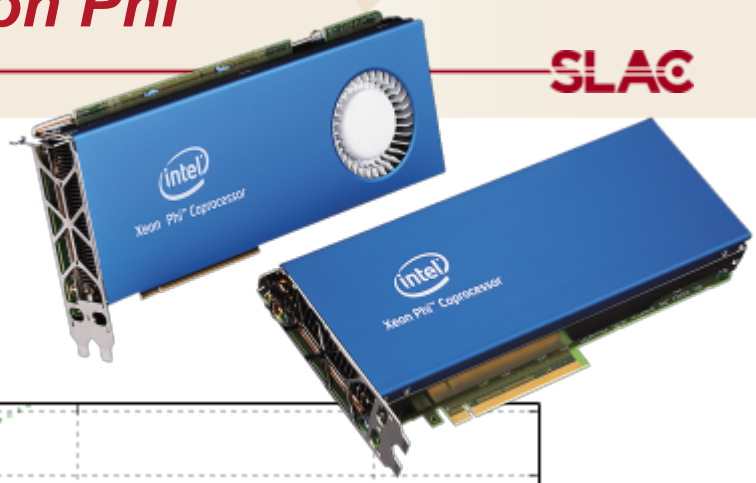
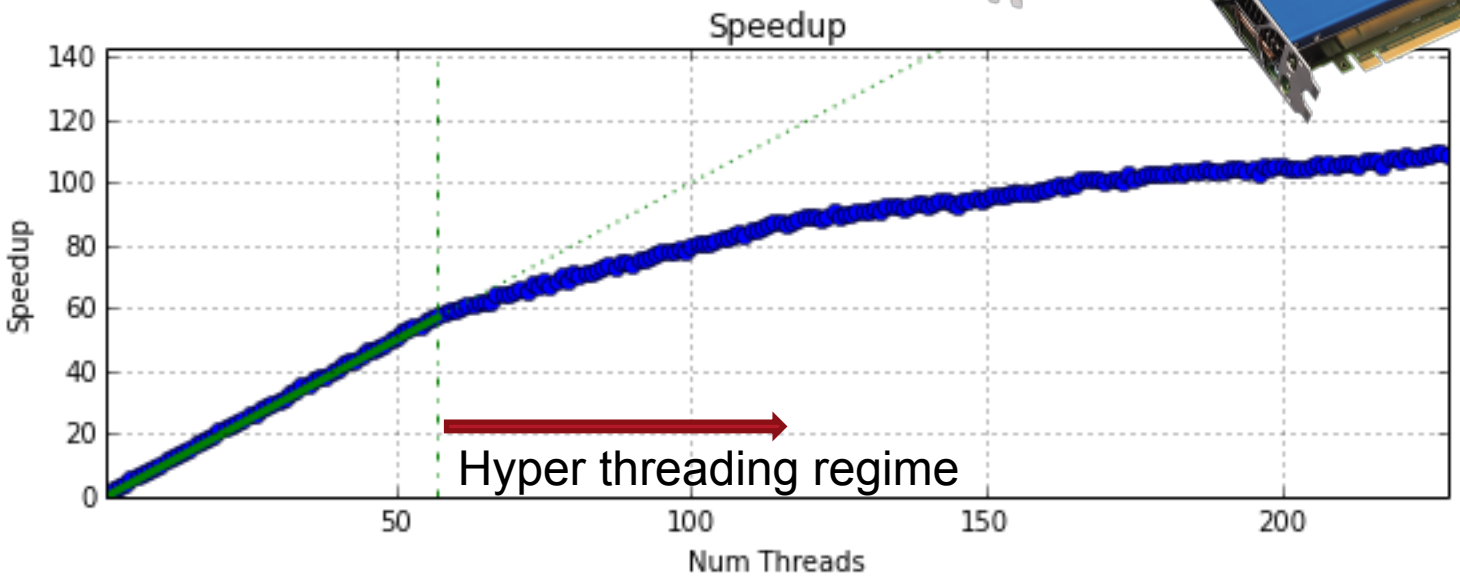
CMS geometry
π- @ 50 GeV with 4T field





Showing highly scalable performance improvement in many-core platform

New framework for "generic" biasing for physics-based biasing

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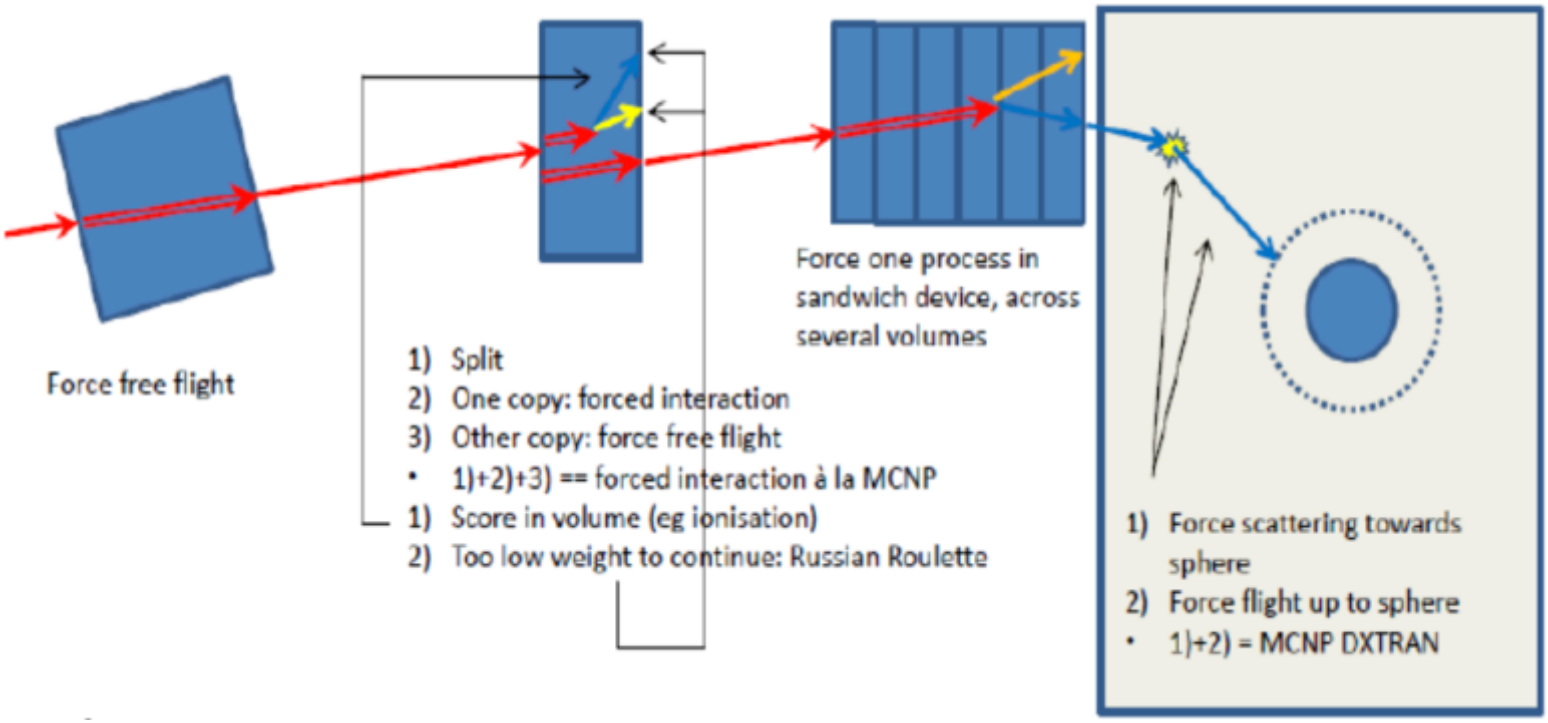
Now providing easier access to cross sections/mean-free-paths of wrapped physics processes.



Physics-based biasing and non-physics-based biasing are now handled through a set of common classes: G4VBiasingOperator, G4VBiasingOperation.

Other new features

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- **C++11** native code
- G4SynchrotronRadiation process for all charged particles
- **Phonon** physics with the concept of crystal structure
- Updated Goudsmit- Saunderson multiple scattering model for e+/e-
- Full Auger atomic de-excitation cascade simulation
- Alternative **Geant4-DNA** physics models for liquid water
- NeutronHP is merged into **ParticleHP**, which also deals with proton, deuteron, triton, ^{3}He and alpha
- Dedicated thread of Visualization for “real-time” event display
- ,,,,,,

Supported Platforms for Geant4 v10.02

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Compilation using the C++11 Standard is now **mandatory**.
Cmake 3.3 or higher is **required**.

Platforms:

- Linux gcc-4.8.3 on 64 bit architectures (Intel or AMD) with CERN CentOS Linux 7 (CC7) (based on CentOS Linux 7)
- MacOSX 10.11(El Captian) with clang-3.7 (Apple LLVM/Clang-7.0.0)
- Windows7 with Visual C++ 14.0 (Visual Studio 2015)

More verified and tested configurations (64 bits):

- Linux, gcc-4.9.3, gcc-5.2.0, clang-3.6
- Linux, Intel-icc 15.0, 16.0
- MacOSX 10.10(Yosemite) with clang-3.6
- MacOSX 10.9(Marveric) with clang-3.5
- Windows7 with Visual C++ 12.0 (Visual Studio 2013)
- Linux for Intel Xeon Phi with Intel-icc15.0, 16.0 (gcc-4.9 compatibility layer)

Note: Windows platforms are supported/verified only for the sequential mode.
Multithreading capability is not yet supported on Windows.

ParticleHP
What is it?

NeutronHP package uses evaluated nuclear data bases for neutron interactions:

- Total cross sections
- Inelastic channel cross sections
- Double differential spectra of outgoing particles
- Gamma emission because of nuclear level transitions

ParticleHP does the same for (inelastic) interactions of other particles (p, d, t, He3, α) E < 200 MeV

Why ParticleHP?

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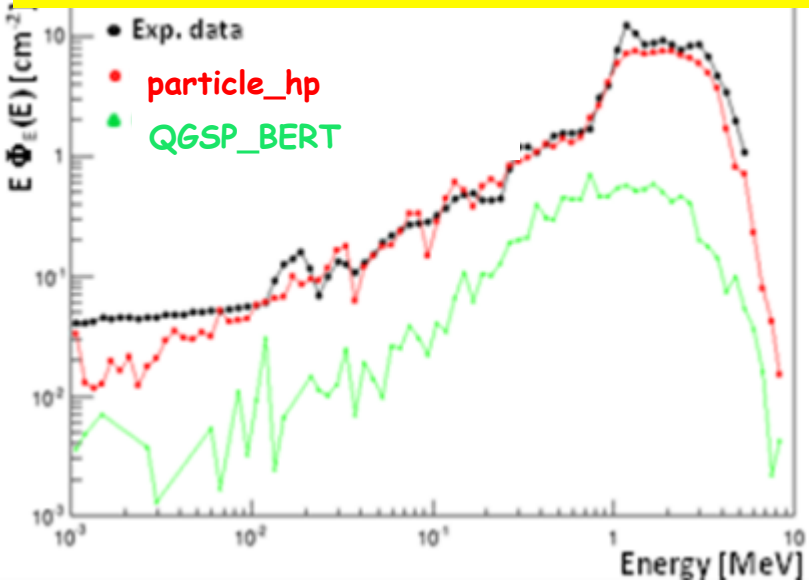
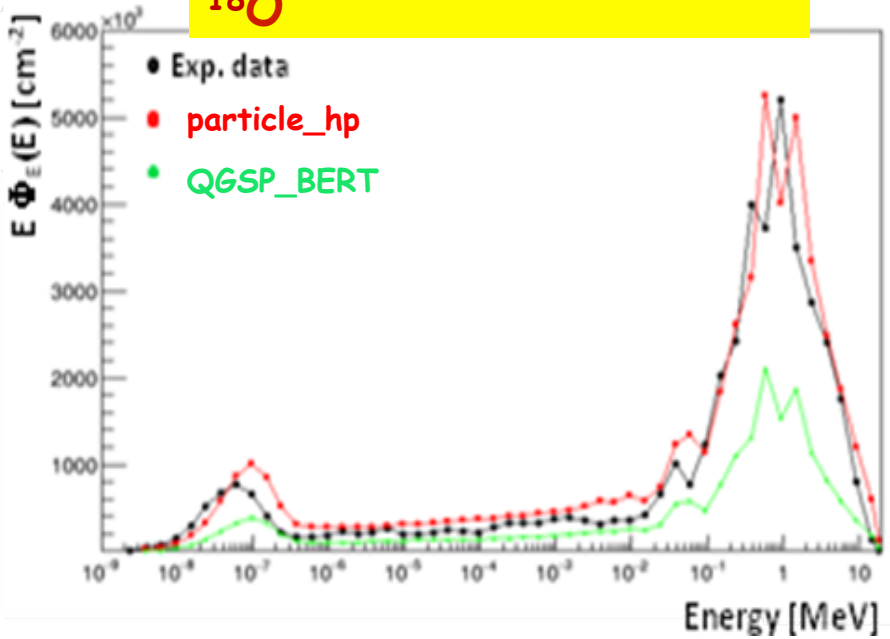
Theory models or semi-empirical models sometimes cannot reproduce experimental data at low (10-100 MeV), especially for low Z elements

n spectra from p (10MeV) + AL6082



n spectra p(18 MeV) + ^{18}O



ParticleHP (now includes NeutronHP)

NeutronHP and ParticleHP was successfully merged in v10.02

- Header files of NeutronHP still remains in the release. Therefore, users still be able to use G4NeutronHPXXX in their codes.

G4TENDL data

- Data files for ParticleHP
- Inelastic reactions of light ions (p, d, t, He3 and a) are supported
  - G4NDL(Based on **ENDF-VII.r1**) provides neutrons data for ParticleHP
- Derived from **TENDL-2014** or **ENDF-VII.r1**
  - ~400 isotopes are compiled in G4TENDL1.x
  - Those isotopes present in the G4NDL4.5 have been included in the data set.
  - Rest of isotopes (>2000) will be provided through IAEA web page
  - Total size of data files was 2.5Gb (v10.02)

GND, GIDI and G4LEND

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GND: Generalized Nuclear Data

- New, modern structure to replace legacy nuclear data formats (e.g., ENDF-6)
- International collaboration (WPEC SG38) has been formed to design a new format for storing nuclear data, and to oversee the transition from ENDF-6 to the new format.

GIDI: General Interaction Data Interface

- Interface to GND

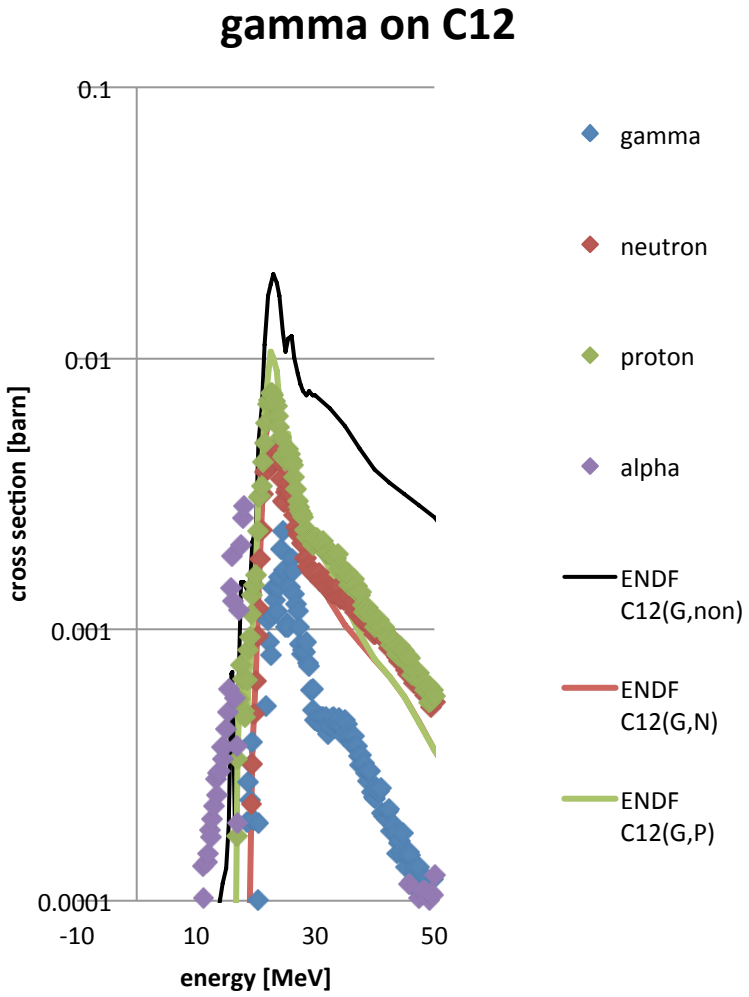
G4LEND: Geant4 Low Energy Nuclear Data

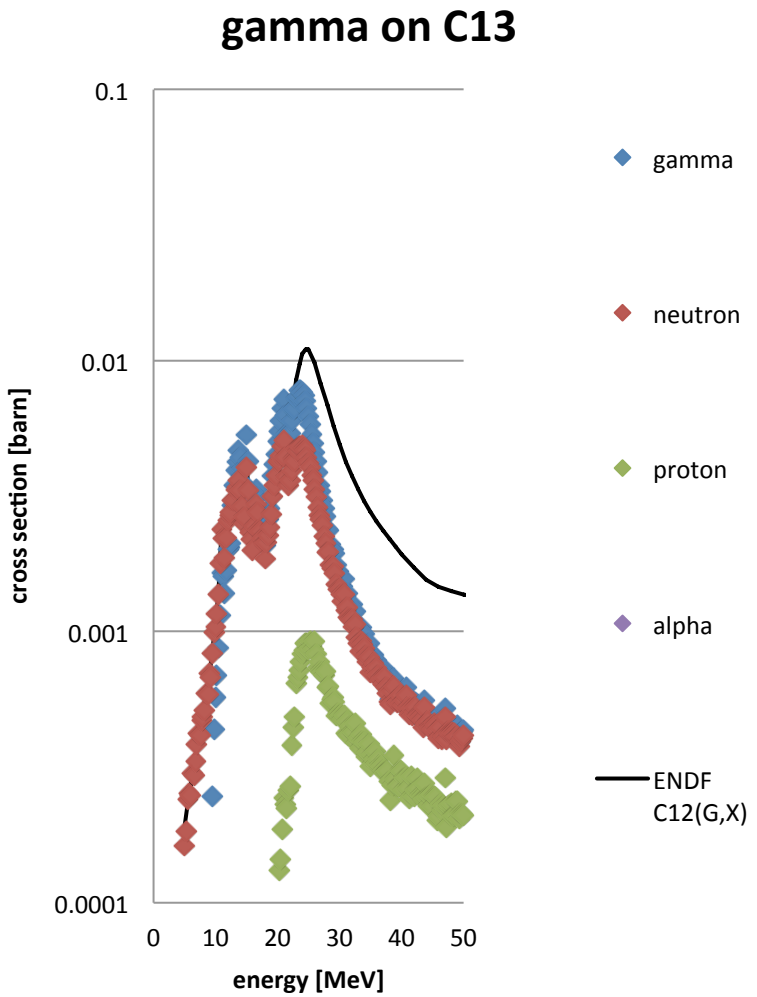
- G4LEND is a package of low energy nuclear interaction model of Geant4. It uses data written in **GND** format through **GIDI** interface.

G4LEND has been in release of Geant4 since v9.5 (2011) and it had major update at v10.02

- Migrated recent update of GND and GIDI
- Introduced gamma as projectile
- New data translated from ENDF/BVII.1 was prepared
  - Neutrons projectile: 421 nuclides, from H to Es
  - Gamma projectile 162 nuclides, from H to Pt

Validation of gamma incidence reaction





Shielding benchmarks for Geant4 version 10.02

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SATIF13 Inter-comparison

SATIF BNL Benchmark

Benchmark for radioactive spallation products in a thick Cu target

Benchmark for ToySINQ model

SATIF13 Inter-comparison

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1. Incident particle

   Pencil beam of protons with 1, 10. 100 GeV

2. Target materials and their size

   Targets geometry is the cylinder.

   Source protons incident on the center of the cylinder bottom.

   Target detector distance from the center of the cylinder is 500cm.

   (a) Al : length 40cm, diameter 4.0cm and density 2.7g/cm^3

   (b) Cu : length 16cm, diameter 1.6cm and density 8.63 g/cm^3

   (c) Au : length 10cm, diameter 1.0cm and density 19.3 g/cm^3

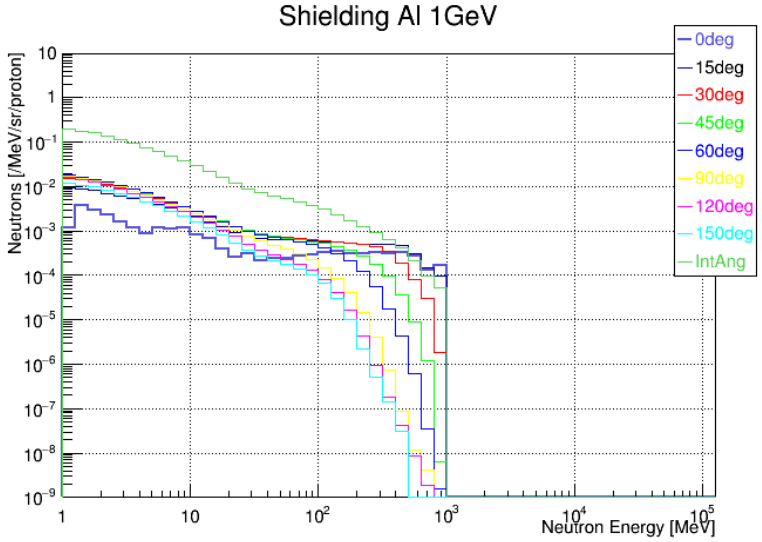
3. Quantities to be calculated

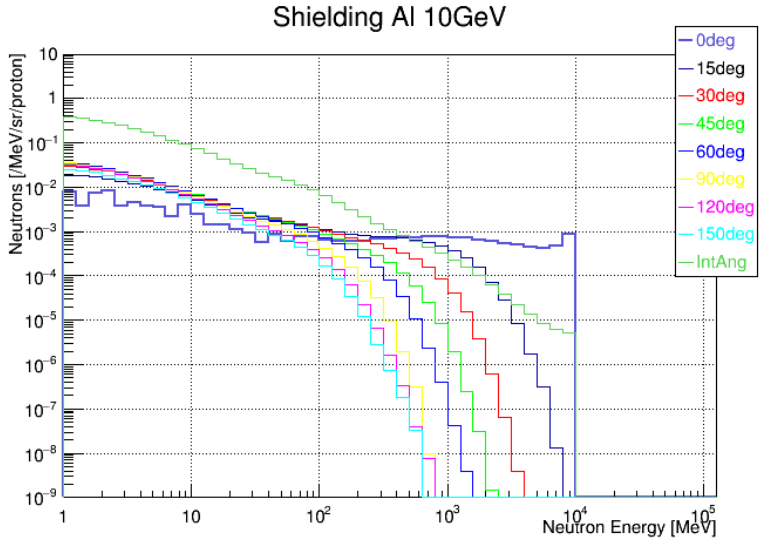
   Neutron spectrum above 20 MeV in n/MeV/sr/proton at **0**,15, 30, 45, 60 ,90,120,150 degrees with angular width ±0.5 degrees and **angular integrated**

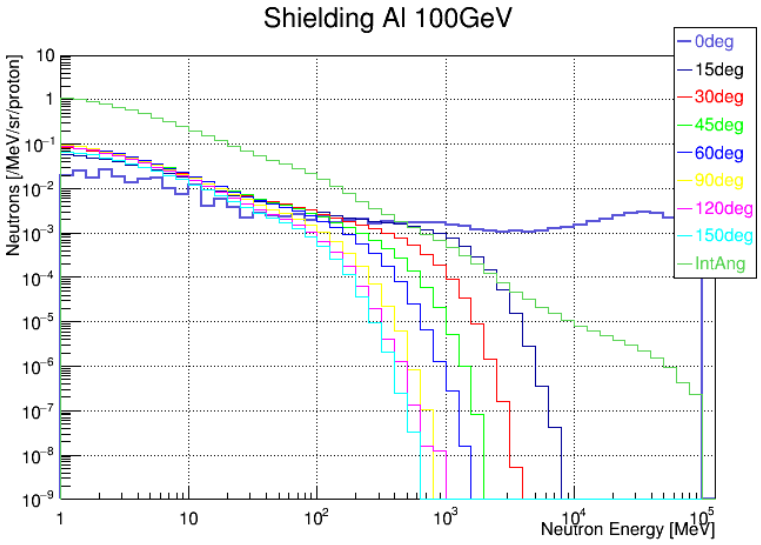
See Hiryama's presentation on Wed

- Submitted Geant4 results are calculated on Geant4 10.02.p02 with Shielding physics list
- Configuration of Shielding physics list now close to FTFP_BERT_HP which uses BERT style cascade, FTF model in high energy and neutronHP models for low energy (<20MeV) neutron transportation

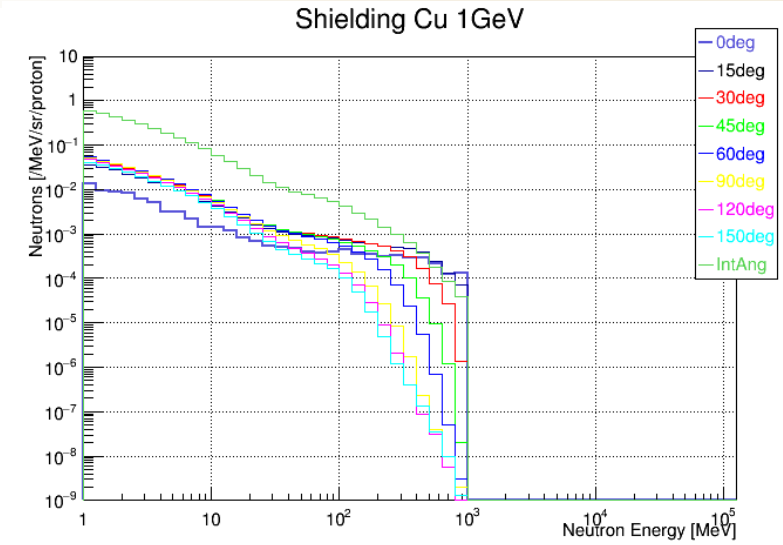
Geant4 results for SATIF13 inter-comparison
Al target

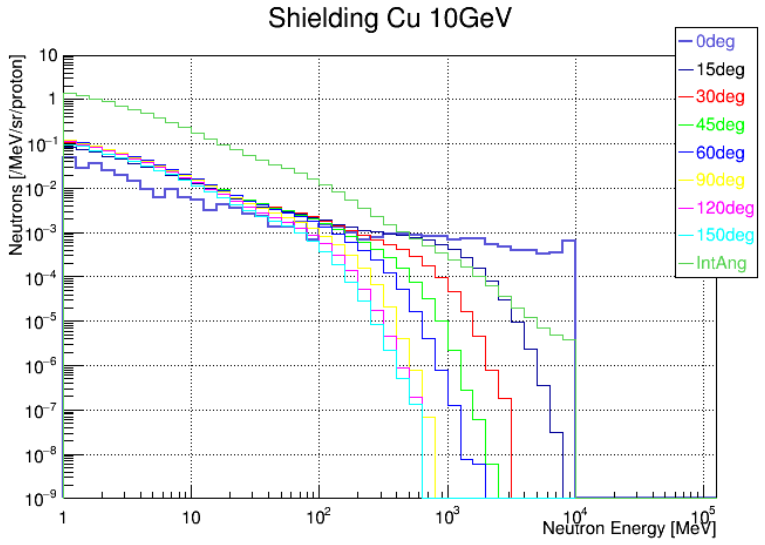


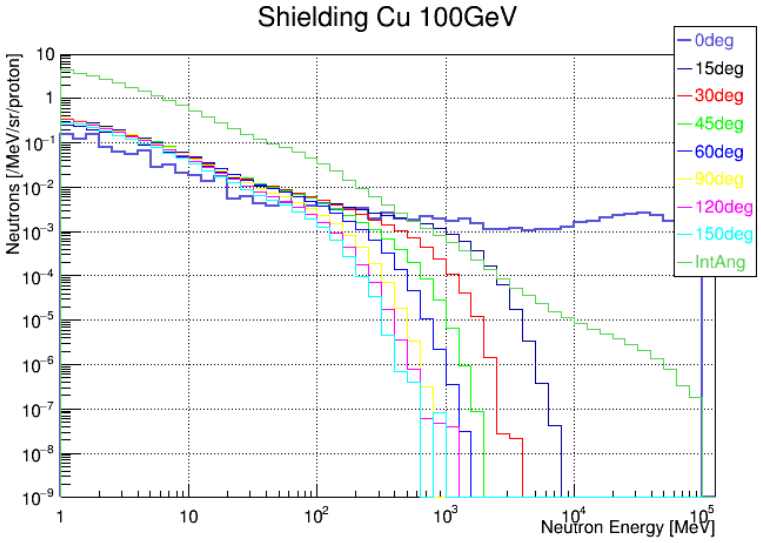




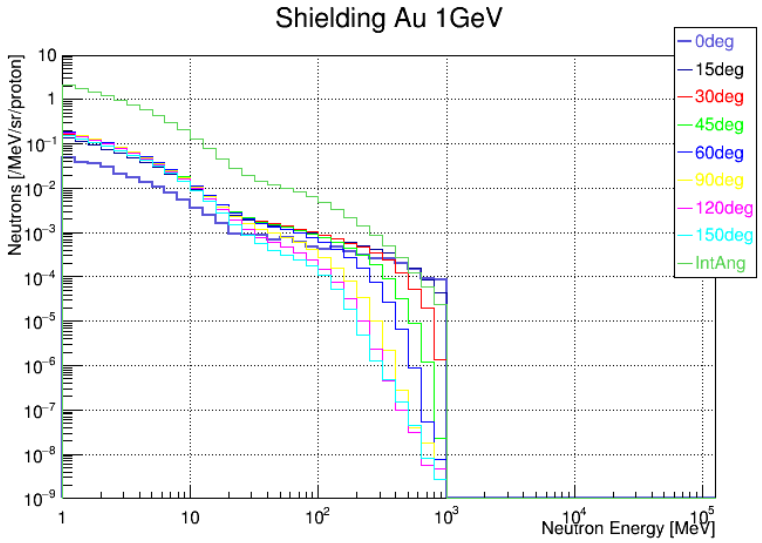
Geant4 results for SATIF13 inter-comparison Cu target

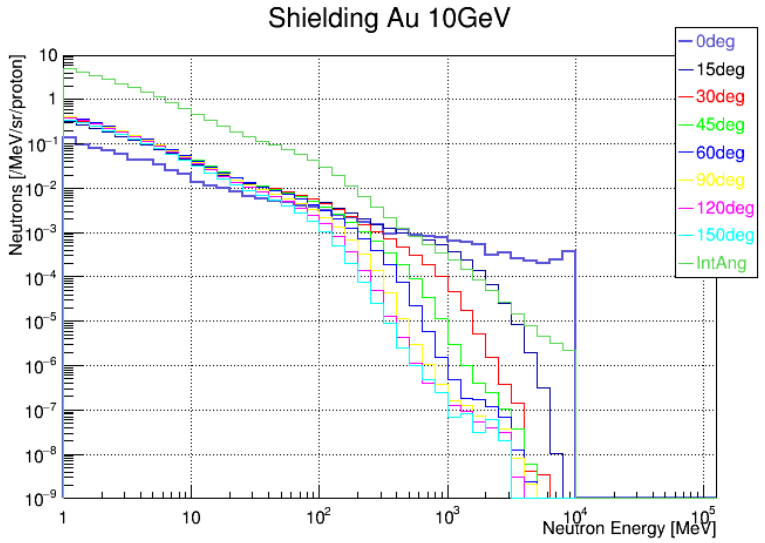


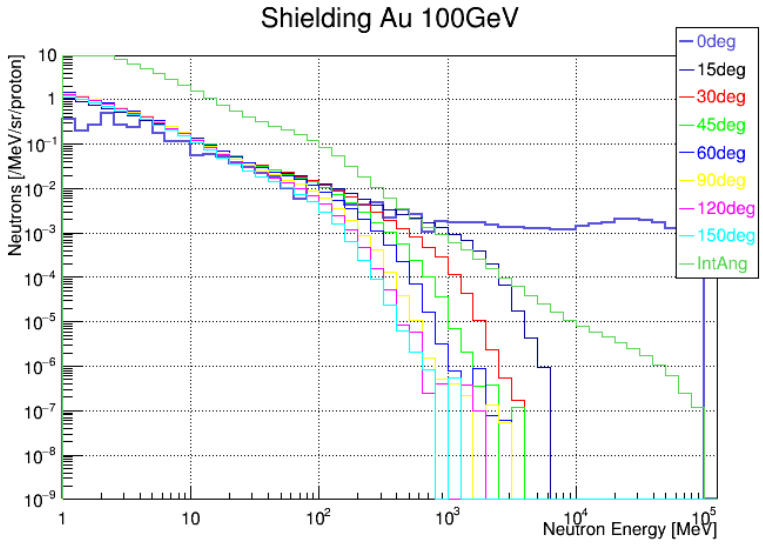




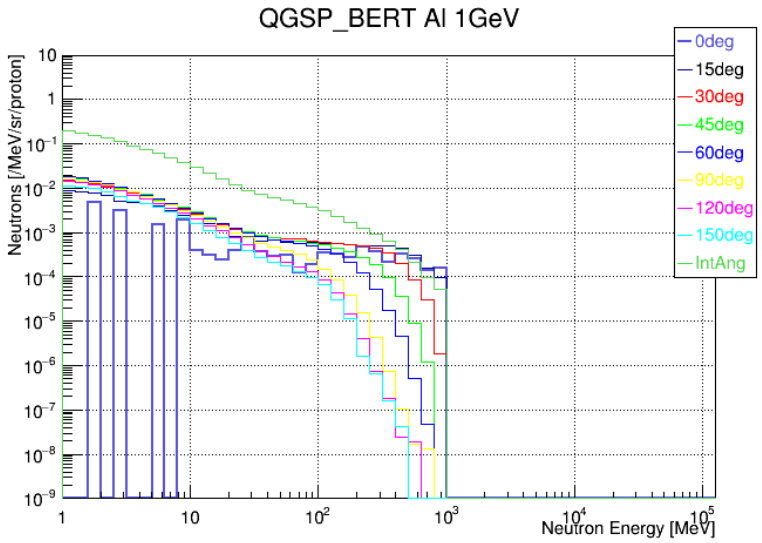
Geant4 results for SATIF13 inter-comparison
Au target

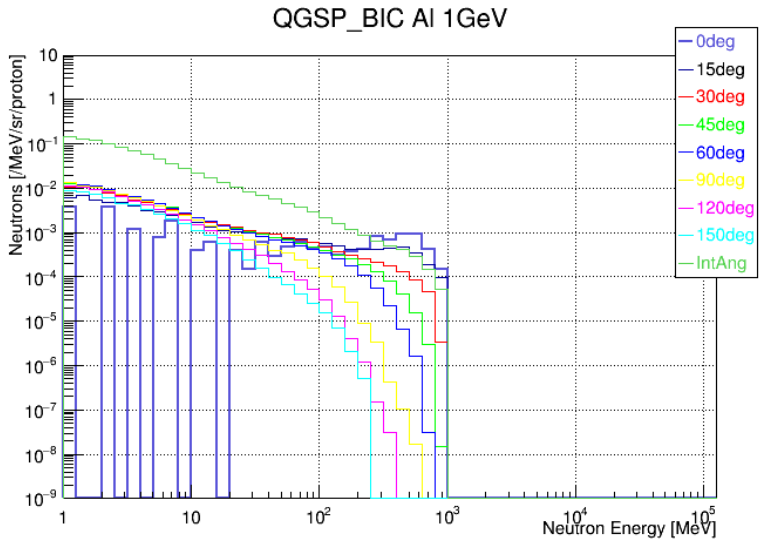


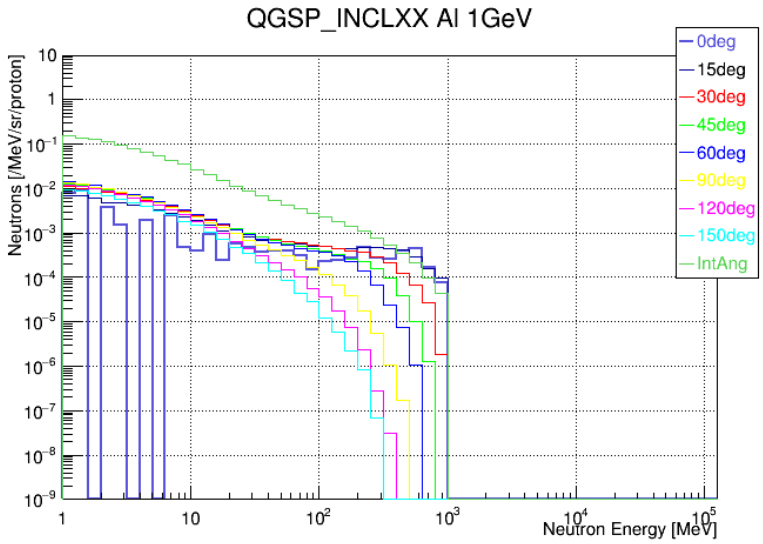




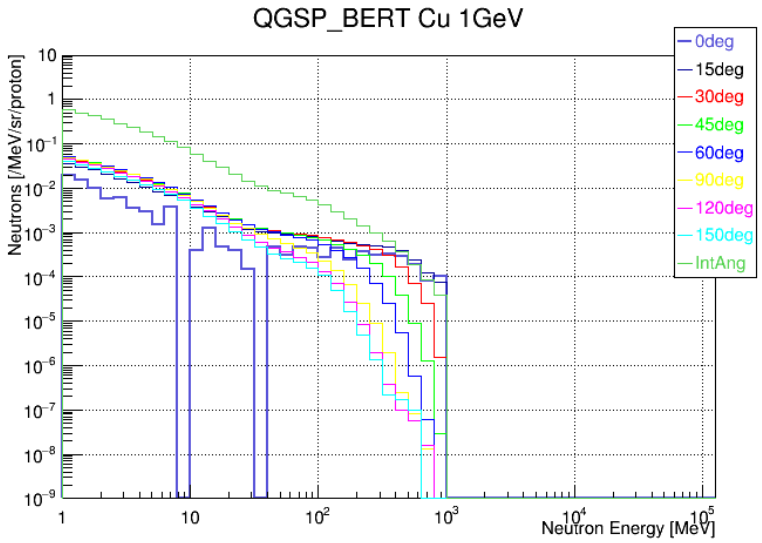
Comparison among cascade models
Al 1 GeV

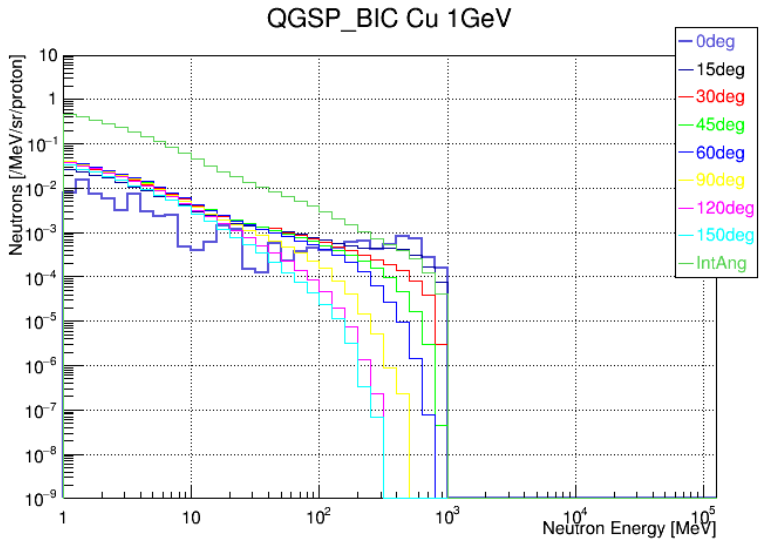


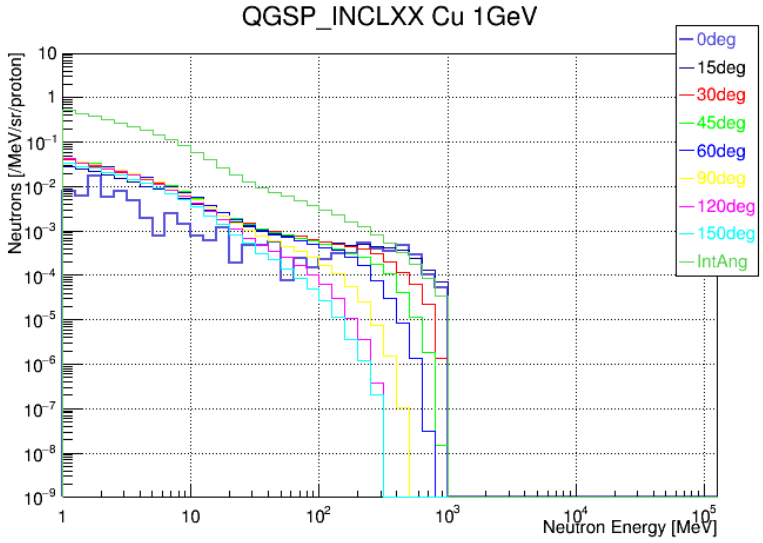




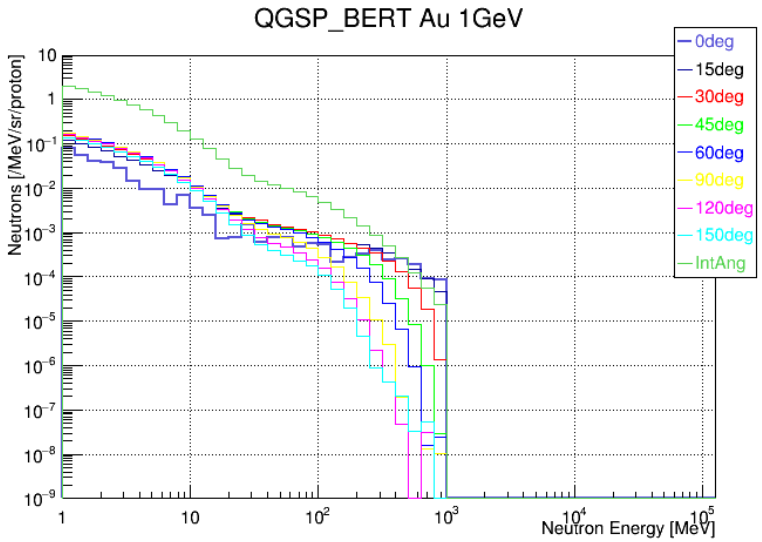
Comparison among cascade models
Cu 1 GeV

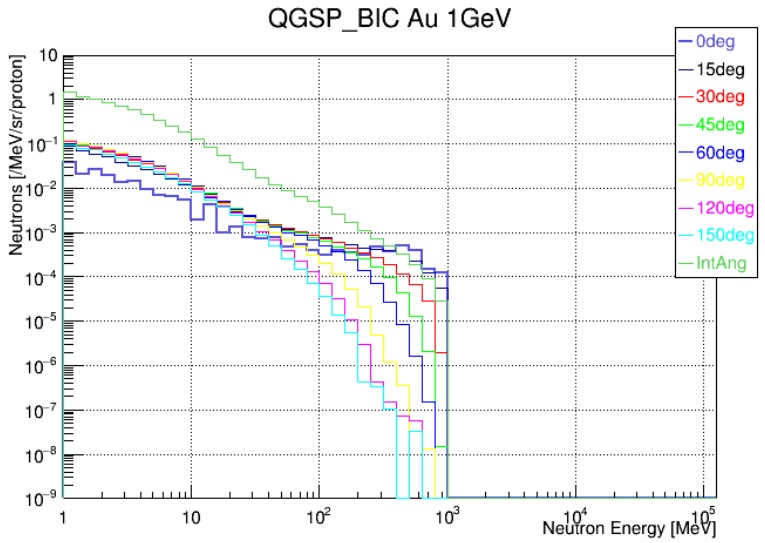


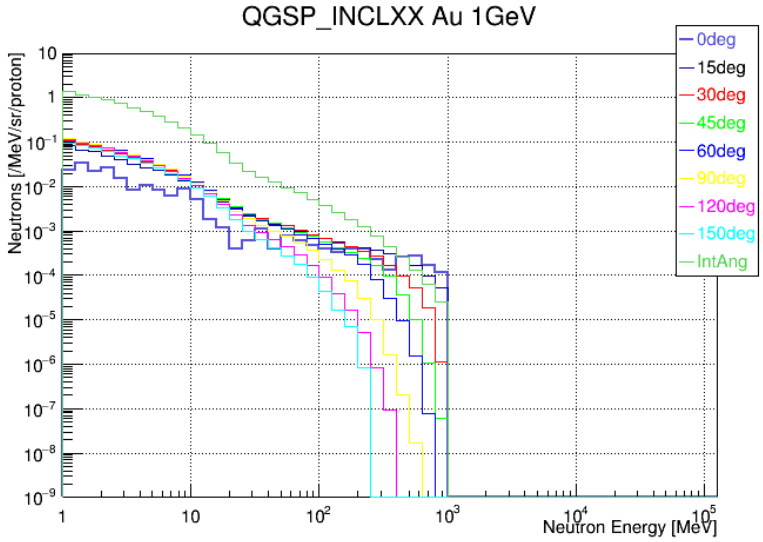




Comparison among cascade models
Au 1 GeV

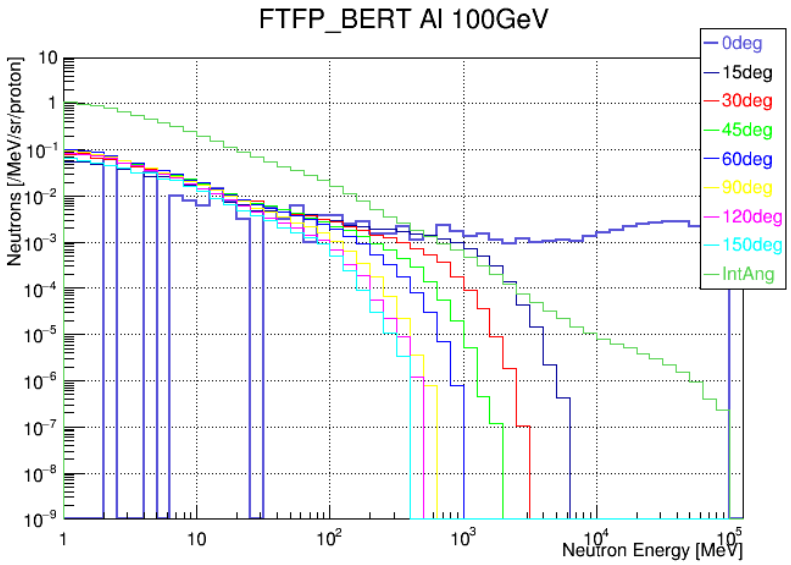




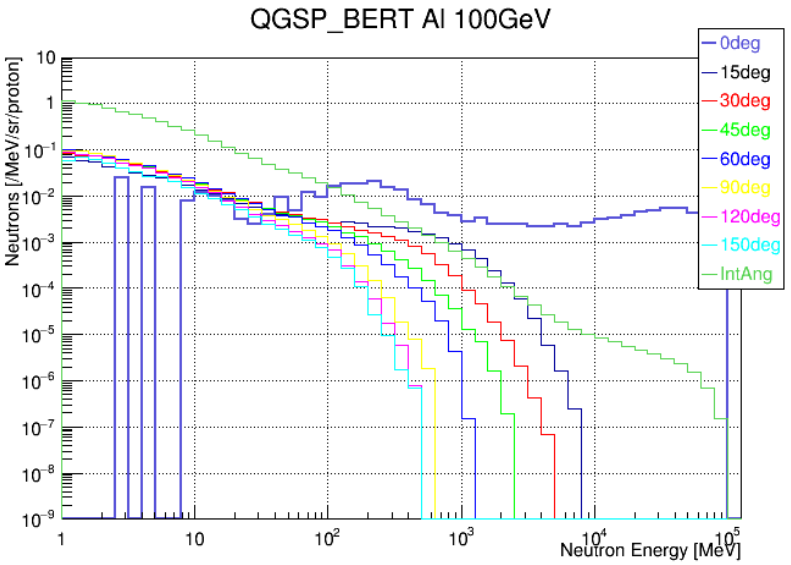


Comparison among high energy models
Al 100 GeV

FTFP_BERT

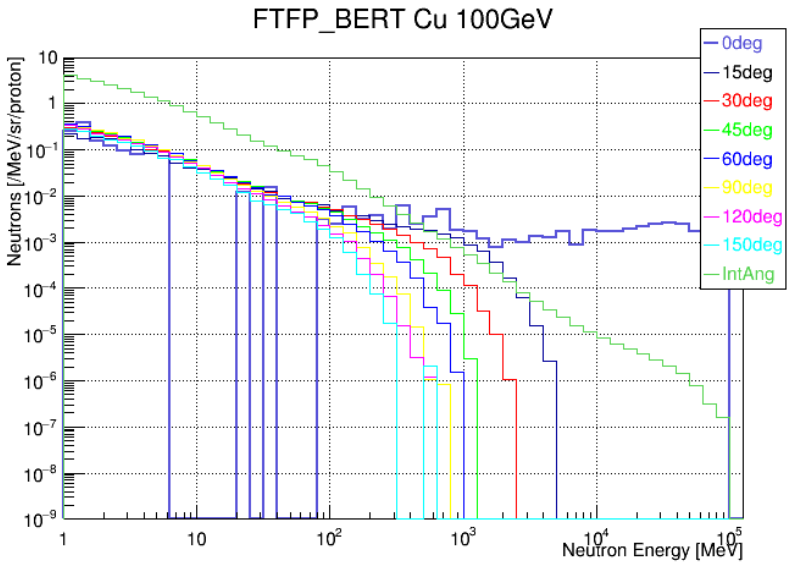


QGSP_BERT



Comparison among high energy models
Cu 100GeV

FTFP_BERT



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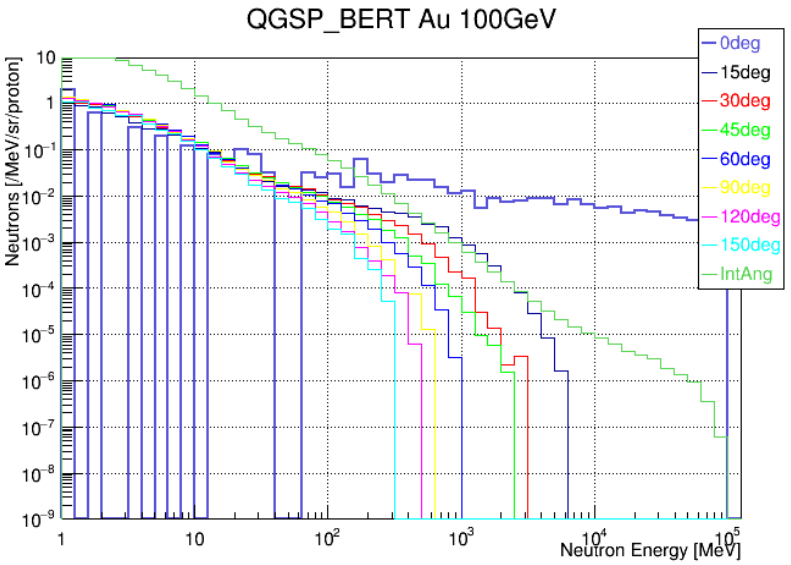
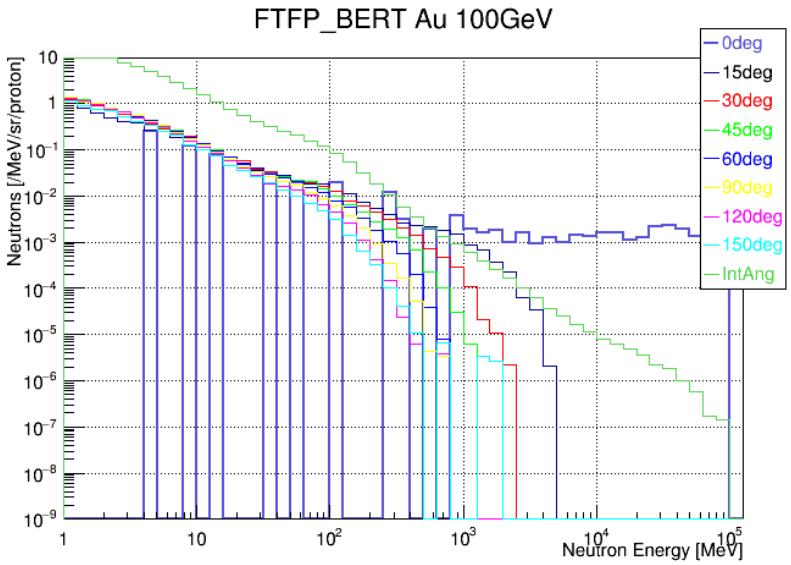


Comparison among high energy models
Au 100GeV

FTFP_BERT



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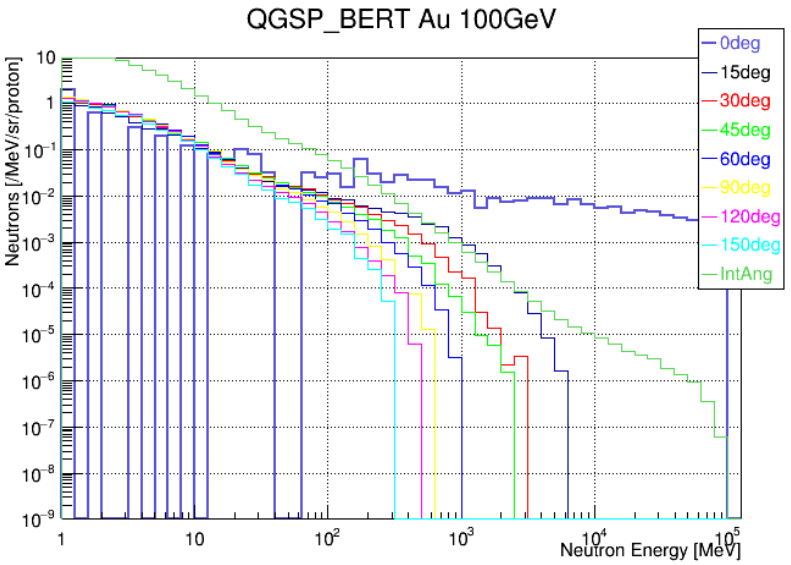

SATIF BNL Benchmark

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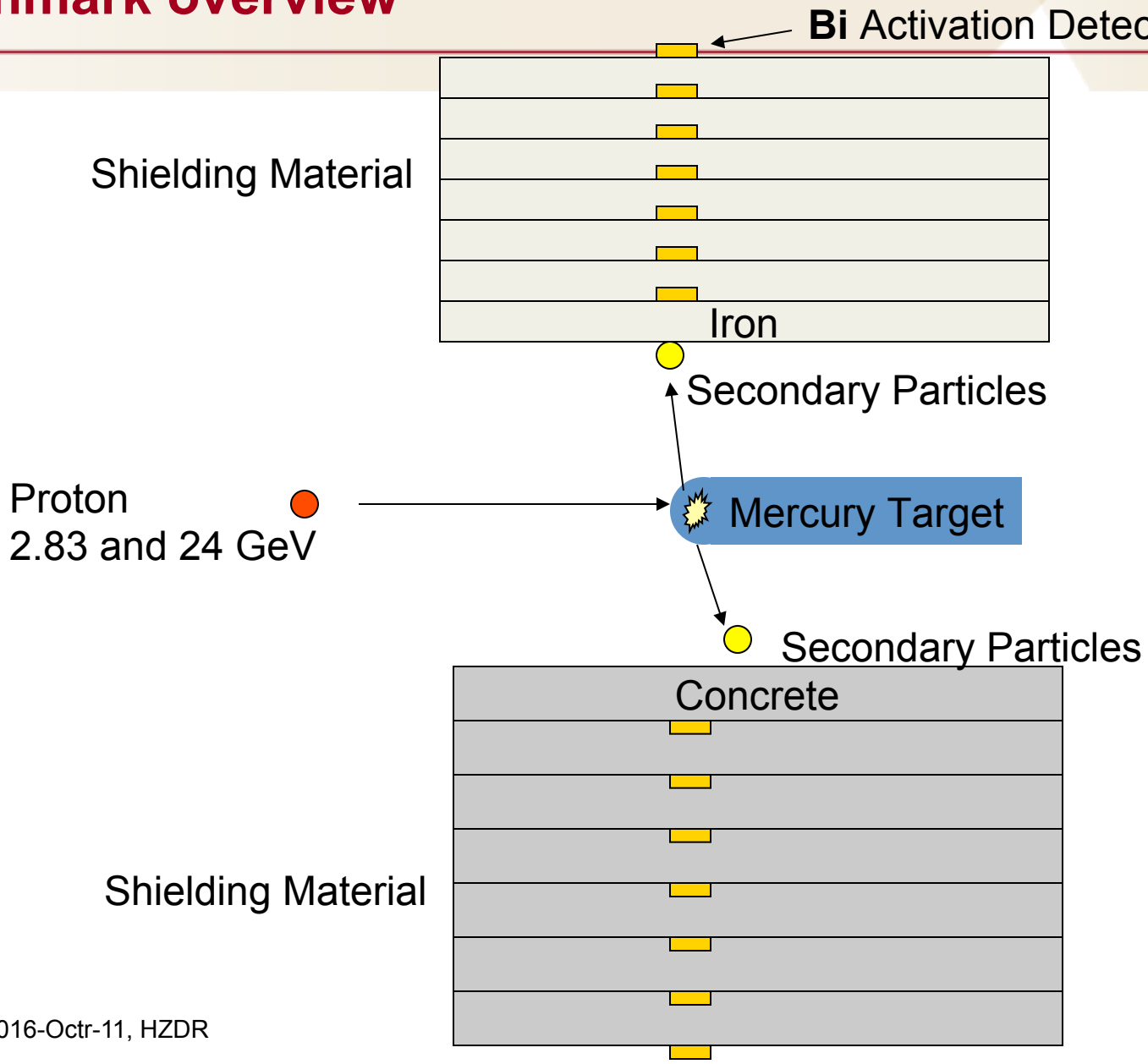
Deep penetration experiments through steel and concrete shields for neutrons generated at mercury target irradiated by 2.83-and 24-GeV protons

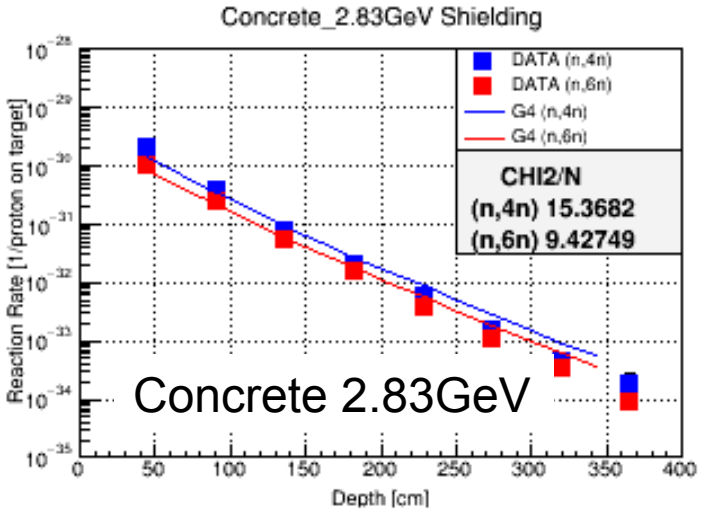
Benchmark problem

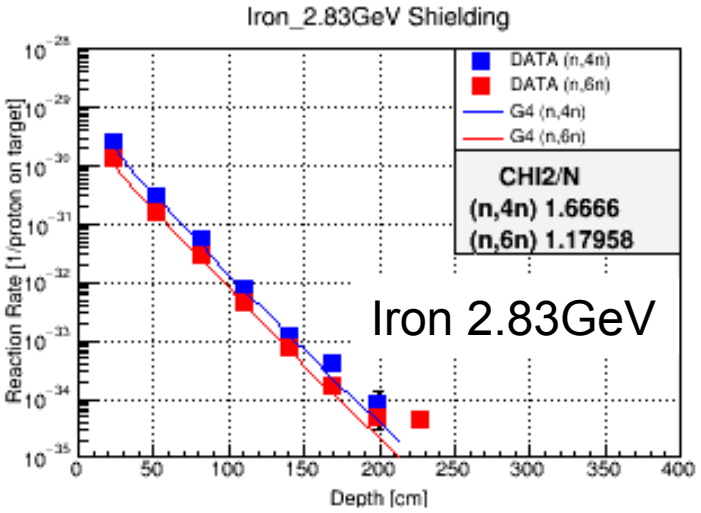
- 1) Accelerator (Organization): AGS (Brookhaven National Laboratory)
- 2) Projectile (Energy): Proton (2.83 and 24 GeV)
- 3) Target Material : Mercury
- 4) Shielding Material : Steel and Concrete
- 5) Geometry : Slab Geometry
  - implemented as Cylindrical Geometry for better simulation efficiency
- 6) Instruments : Activation Detector (Bi) with HP-Ge Detectors
- 7) Measured Quantities : Neutron Reaction Rate
  - 209Bi(n,4n)206Bi Threshold Energy of 22.6 MeV
  - 209Bi(n,6n)204Bi Threshold Energy of 38.1 MeV
  - Reaction rate of them are given as a function of neutron flux from SATIF organizer

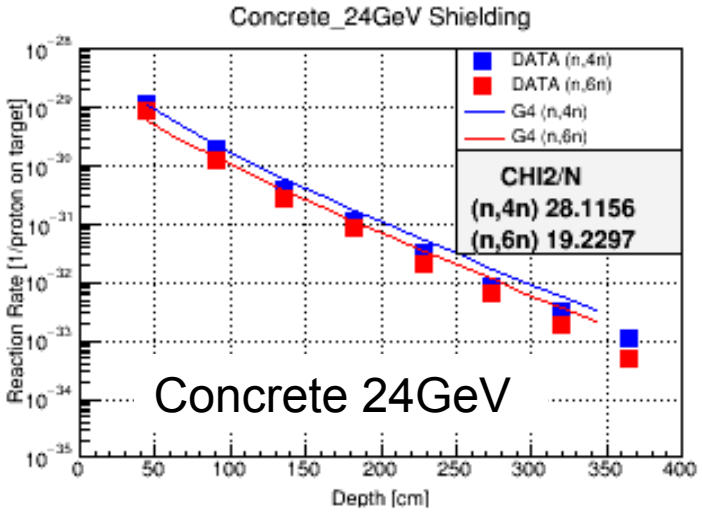
Benchmark overview

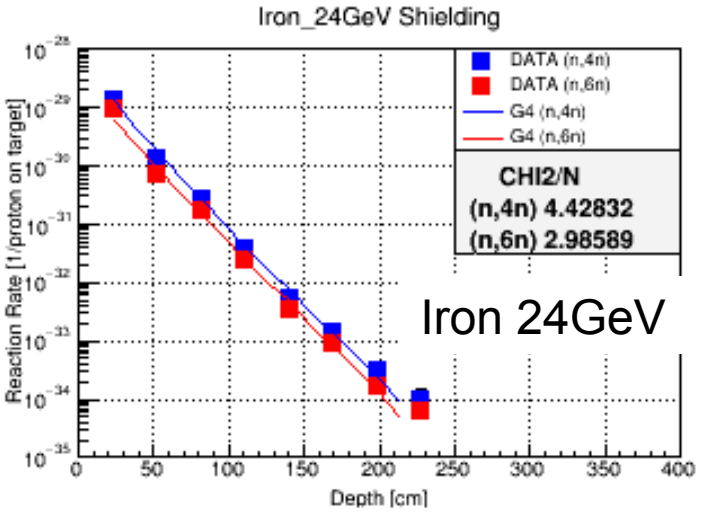


Results of Shielding Physics List





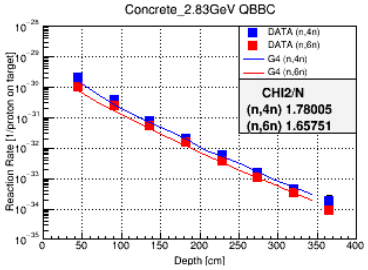


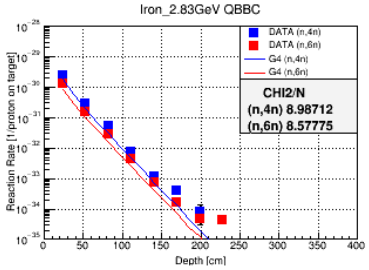


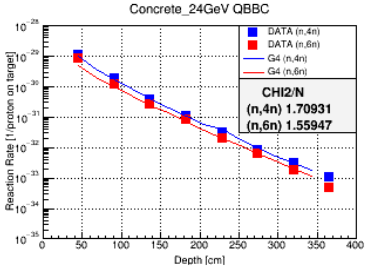
209Bi(n,4n)206Bi Threshold Energy of 22.6 MeV ■ data — simulation
209Bi(n,6n)204Bi Threshold Energy of 38.1 MeV ■ data — simulation

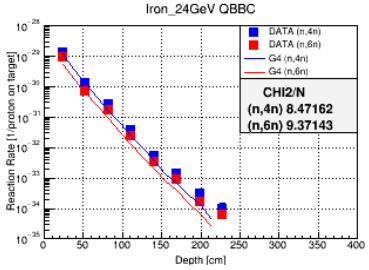
Results from other physics lists

QBBC

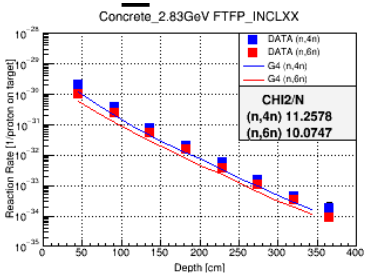


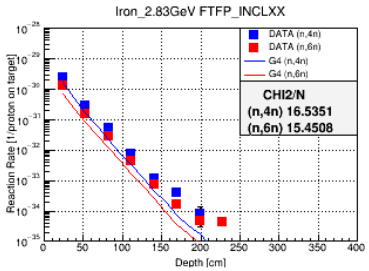


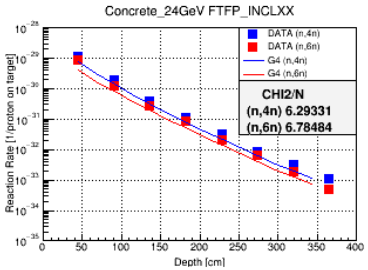


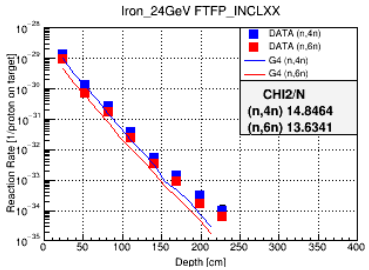


FTFP_INCL++

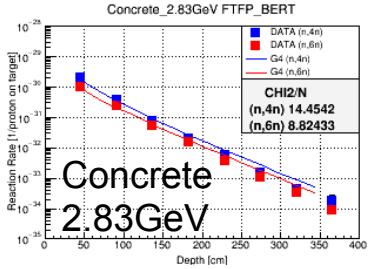


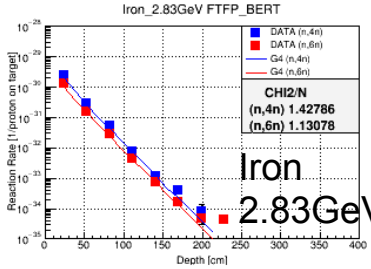


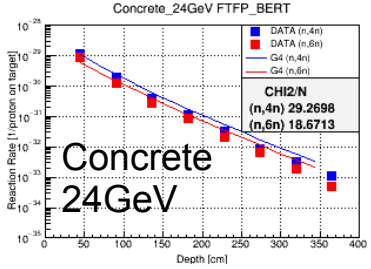


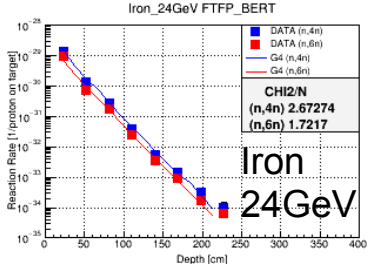


FTFP_BERT





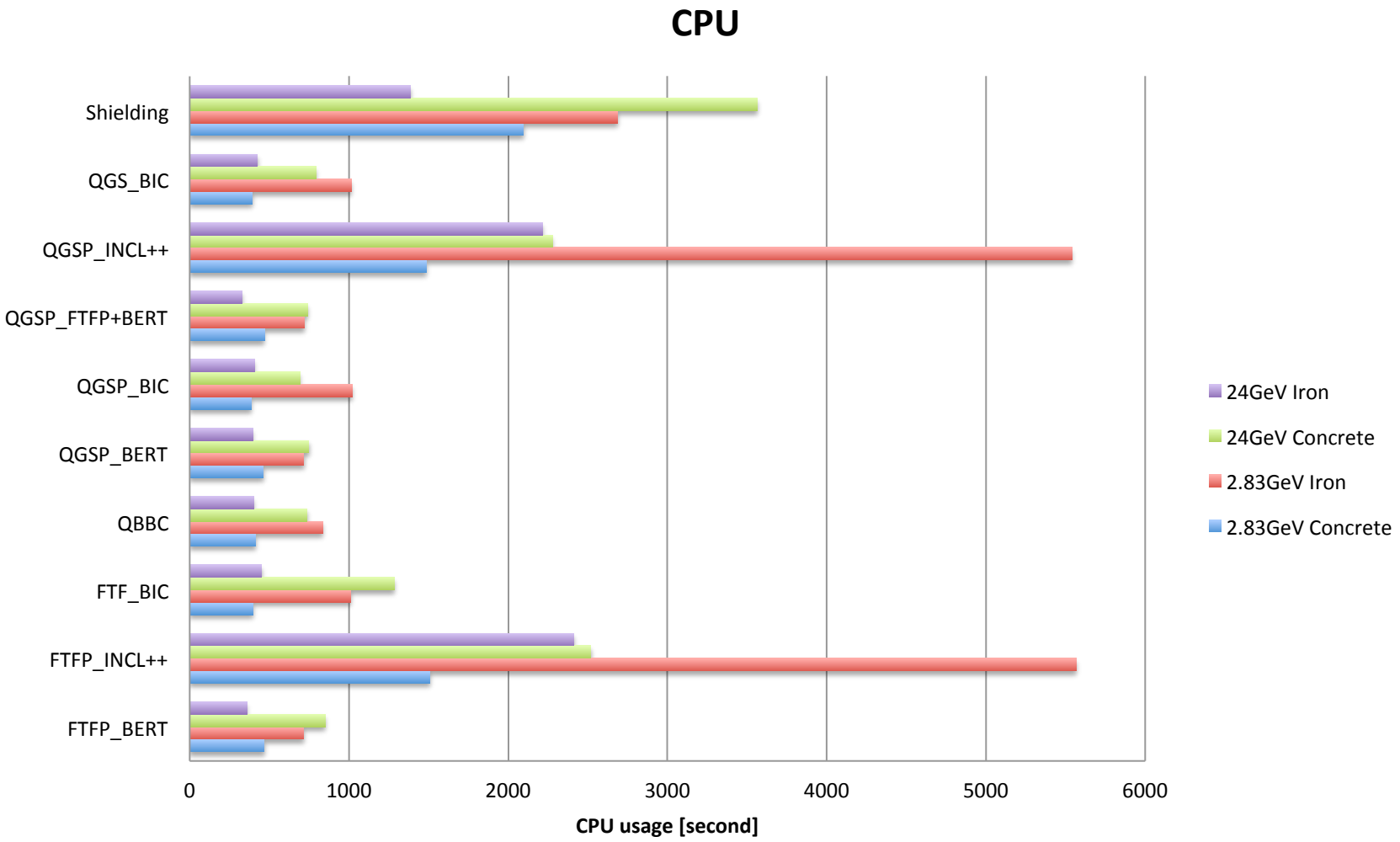




209Bi(n,4n)206Bi
■ data — simulation

209Bi(n,6n)204Bi
■ data — simulation

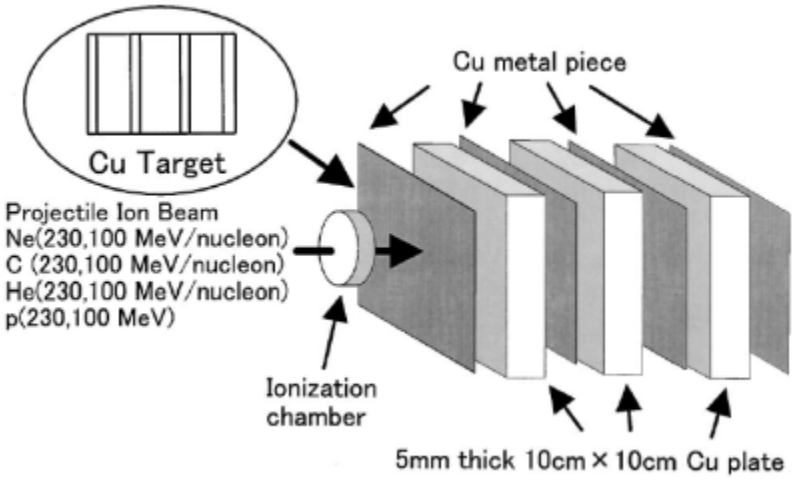
CPU usages among Geant4 physics lists



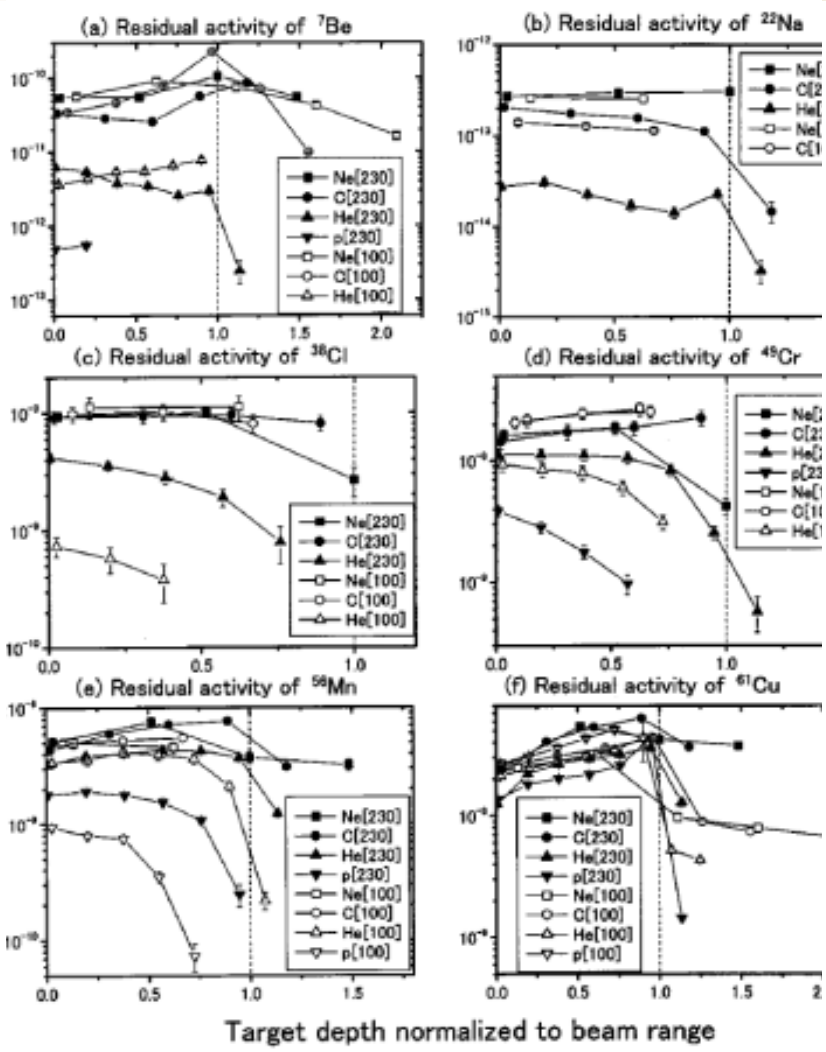
Benchmark for radioactive spallation products

Measuring radioactive spallation products in a thick Cu target were obtained for 230 and 100 MeV/nucleon Ne, C, He, and p ions.

"Projectile dependence of radioactive spallation products induced in copper by high-energy heavy ions" Yashima H. el al, PHYSICAL REVIEW C 66, 044607



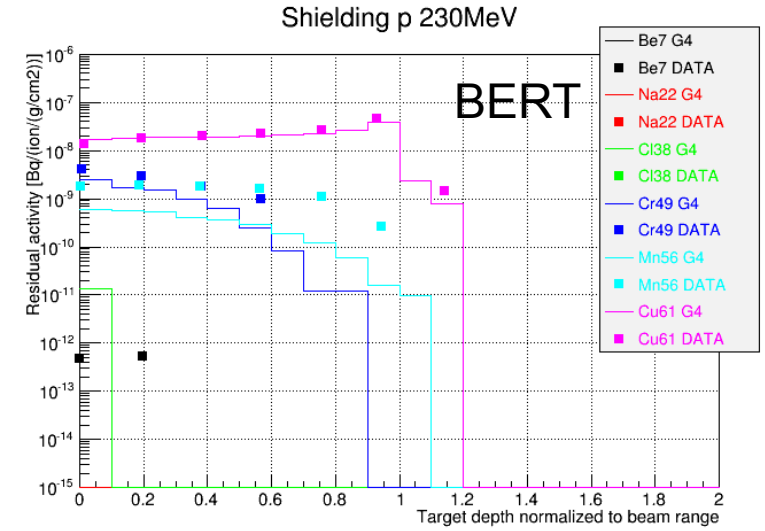
Measured residual activities of various nuclides

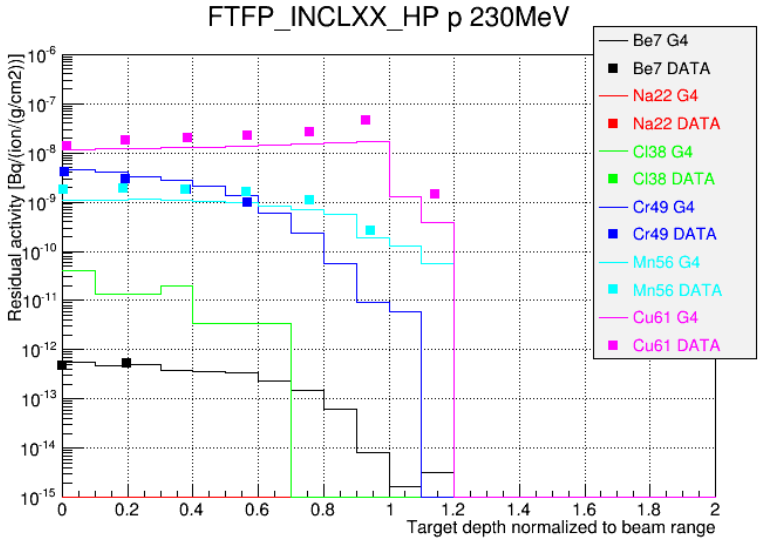


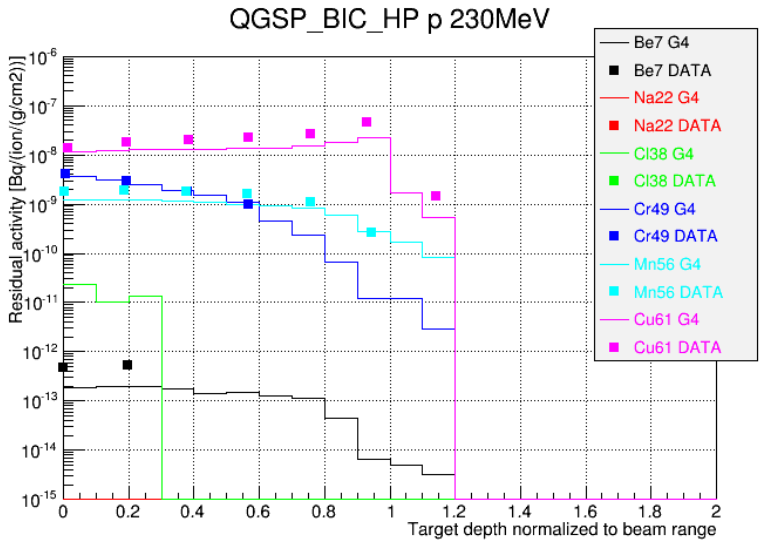
Residual nuclides	Type of Yield	Gamma-ray energy [keV]	Branching ratio [%]	Half-life
7Be	*I*	477.61	10.5	53.29*D*
22Na	*C*1	1274.53	99.9	2.6019*Y*
38Cl	*C*2	1642.71	31.9	37.24*M*
49Cr	*C*1	90.64	53.2	42.3*M*
56Mn	C2	1810.72	27.2	2.5785*H*
61Cu	*C*1	282.96	12.2	3.333*H*

I :independent
*C*1:cumulative positron
*C*2:cumulative electron

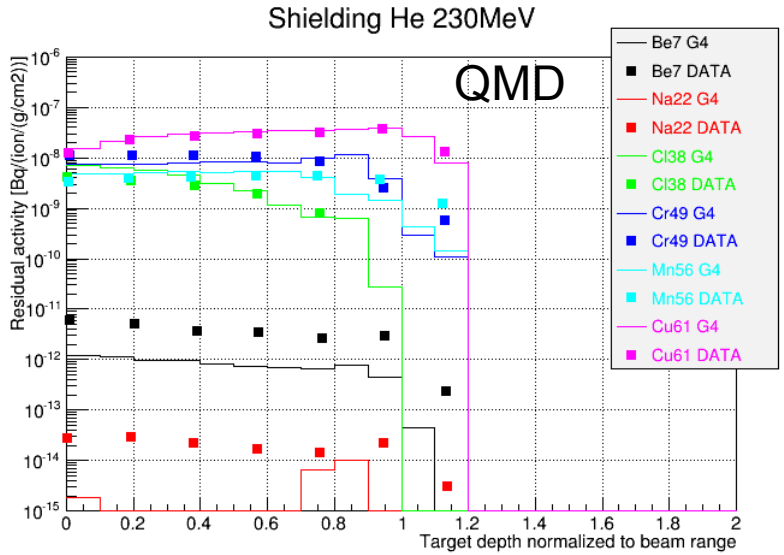
Depth distribution of residual activities in Cu target Proton 230MeV

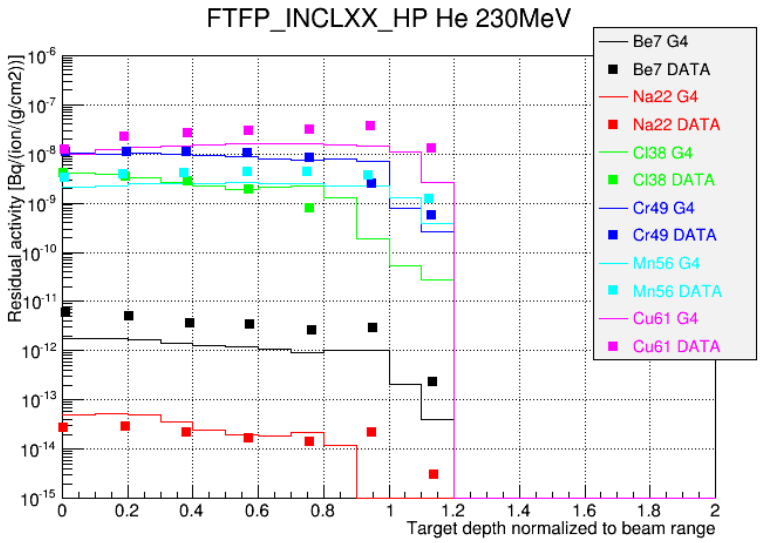


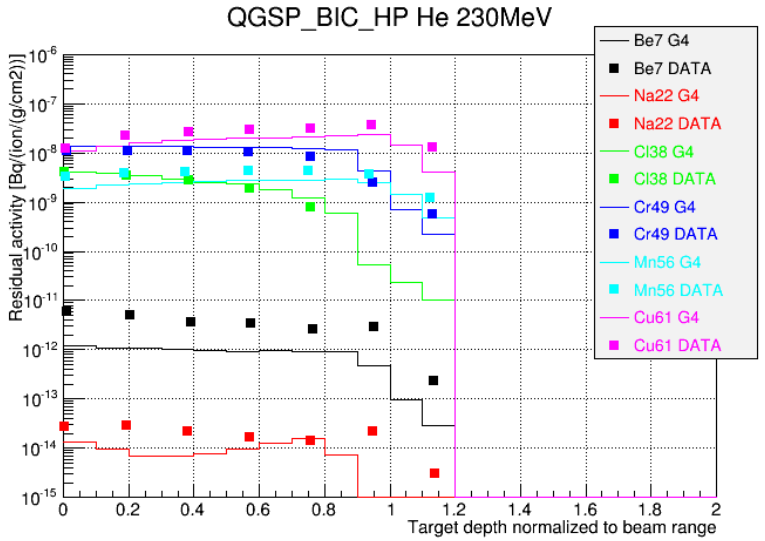




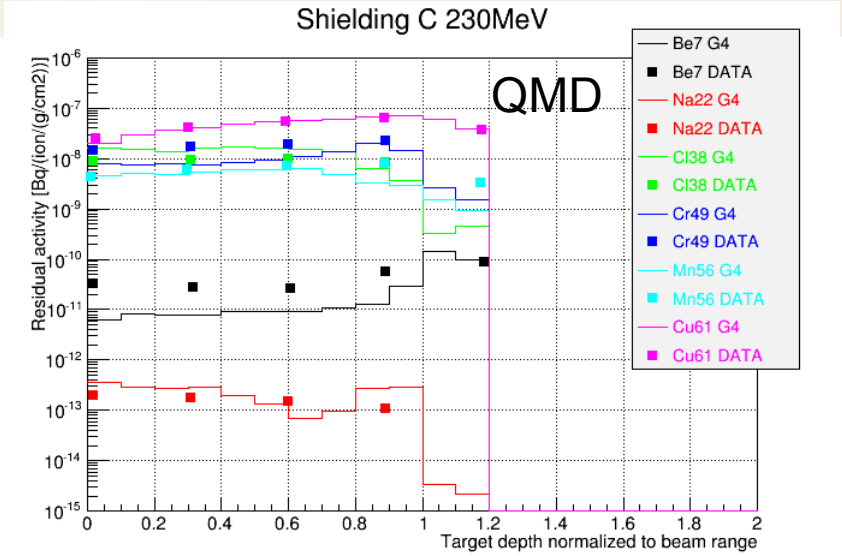
Depth distribution of residual activities in Cu target Helium 230MeV/n

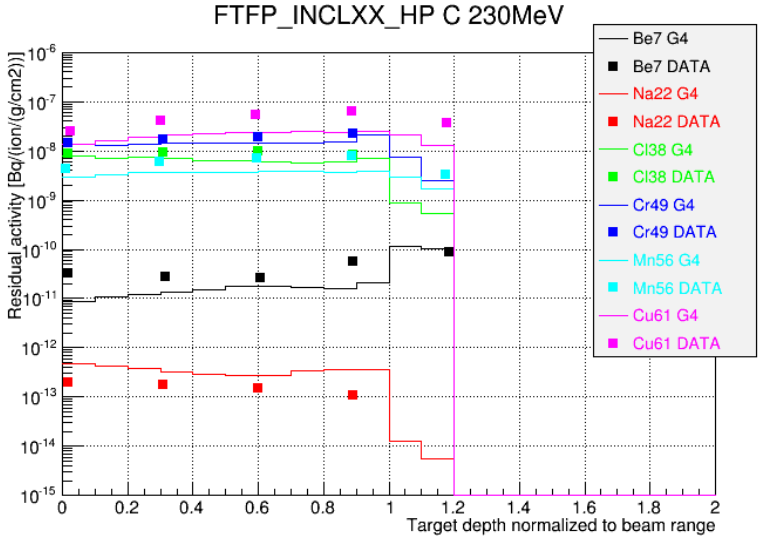


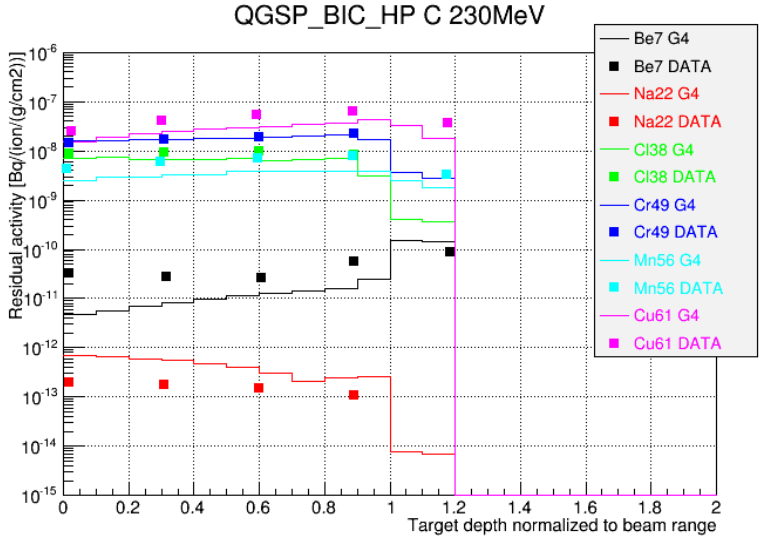




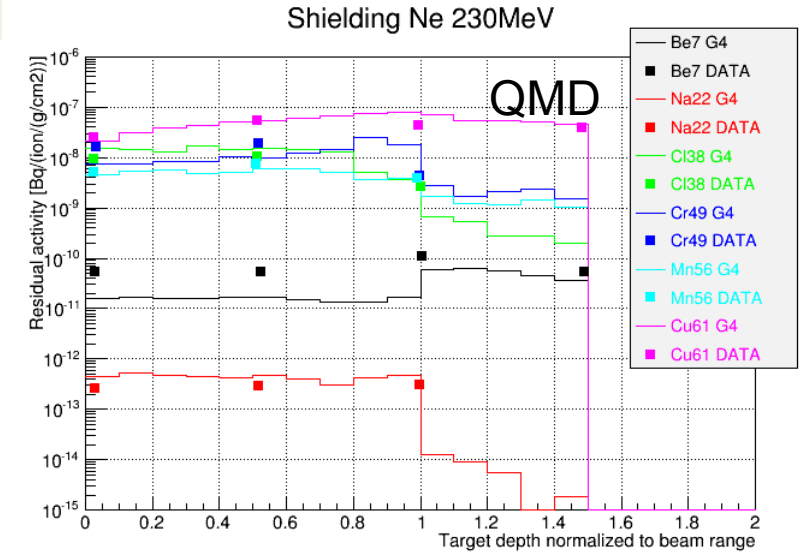
Depth distribution of residual activities in Cu target Carbon 230MeV/n

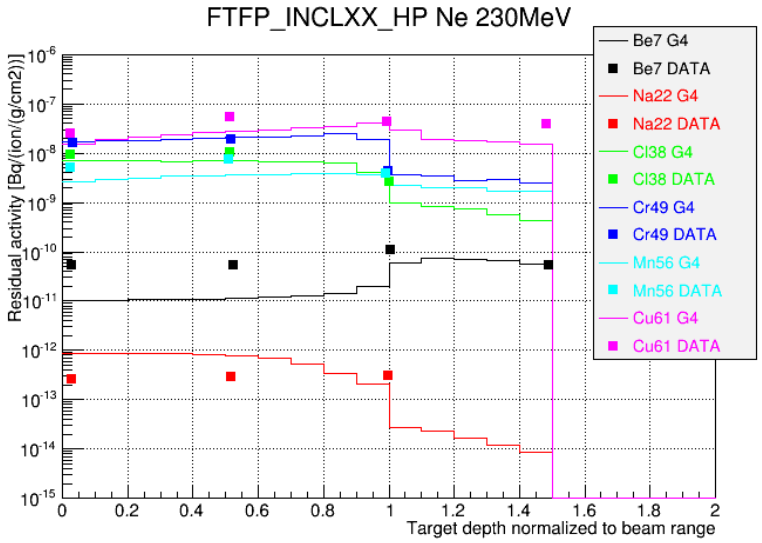


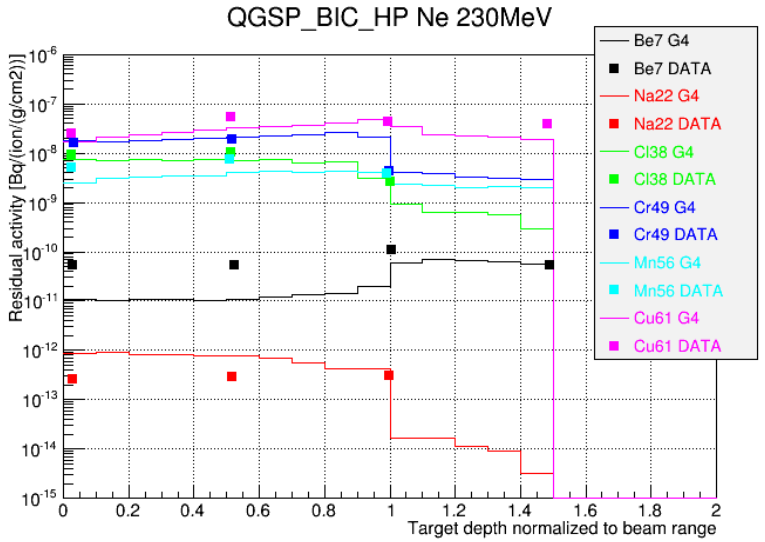




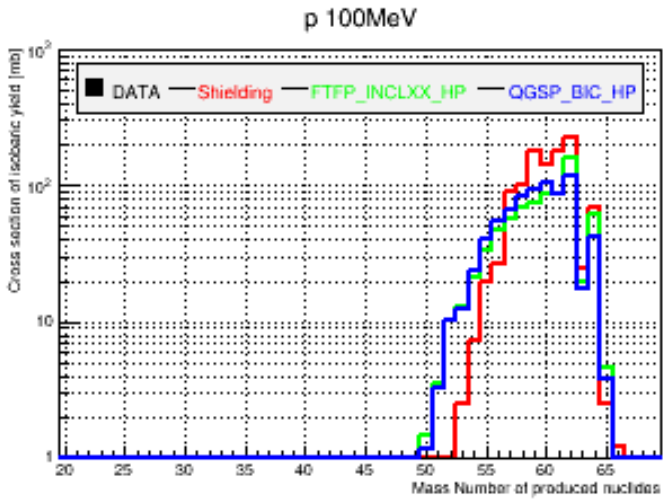
Depth distribution of residual activities in Cu target Neon 230MeV

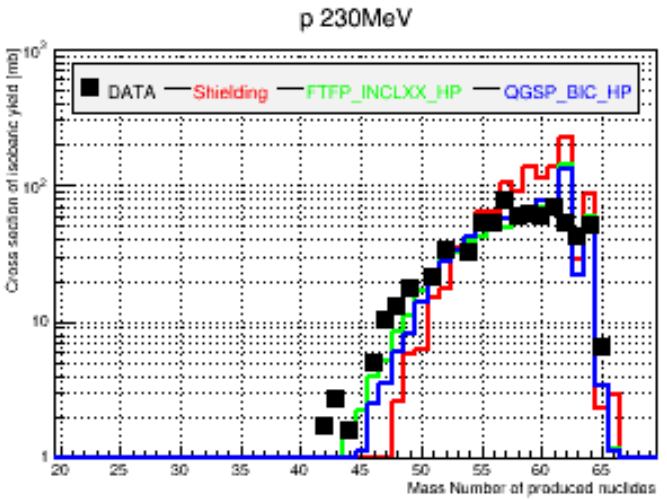


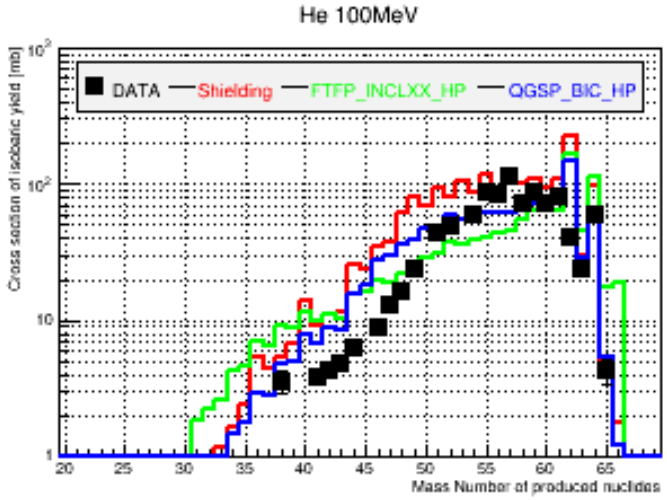


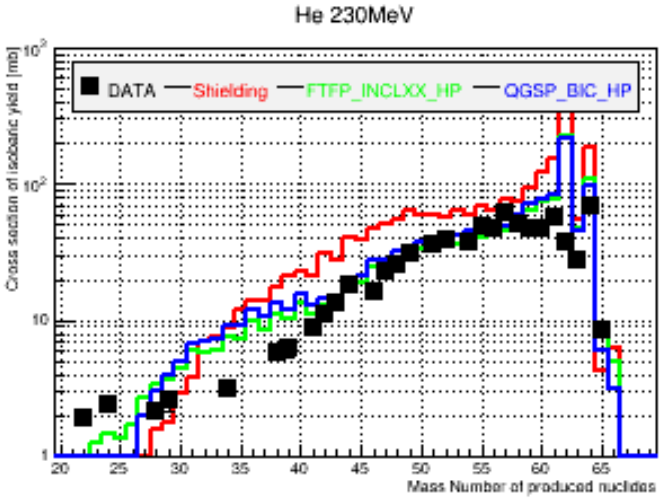


Comparison of mass yield curve to measurement Proton and Helium projectiles



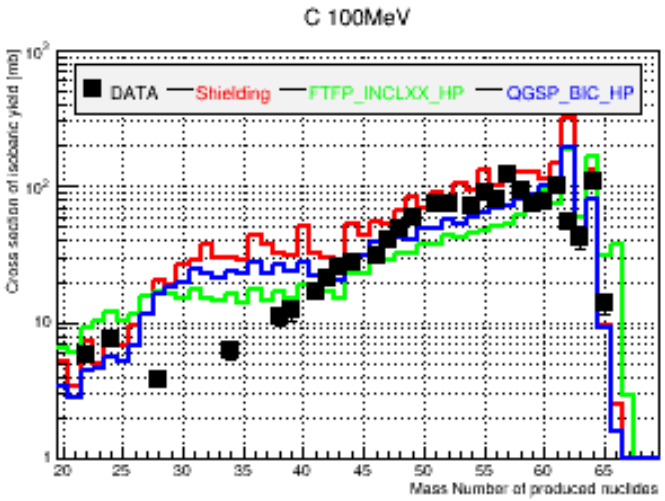


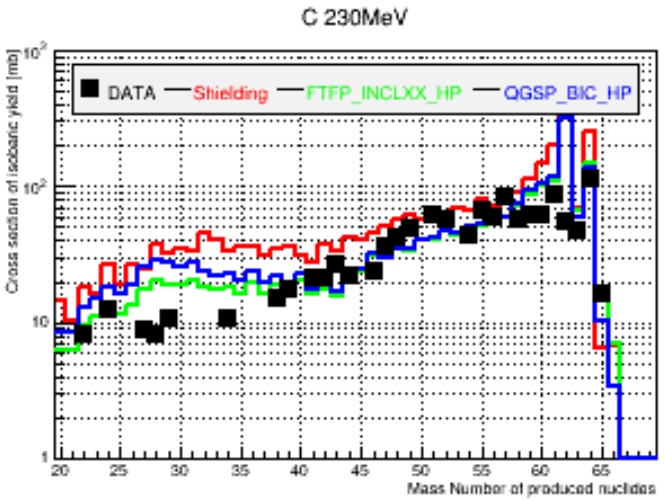


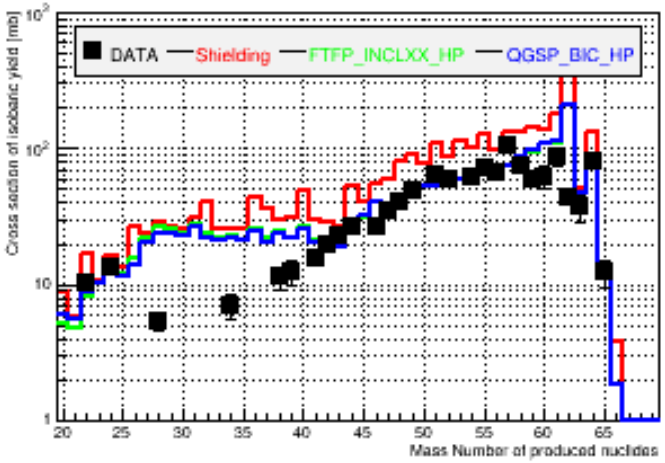


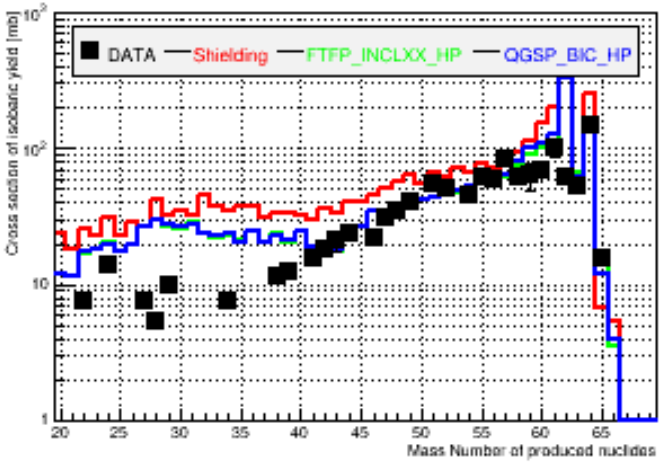
Comparison of mass yield curve to measurement Carbon and Neon projectiles

SLAC









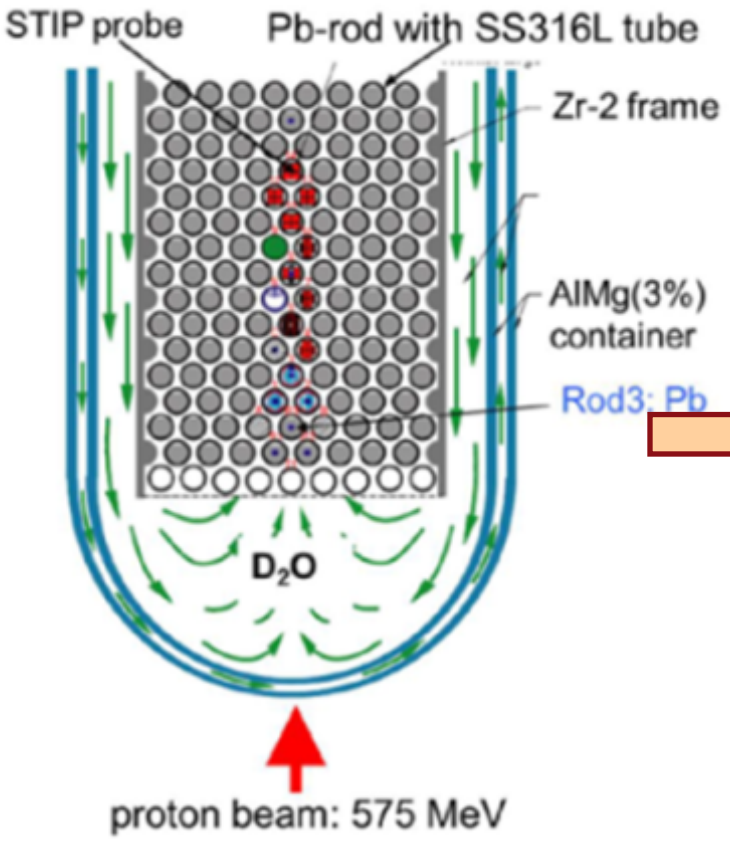
Benchmarks for target activation of SINQ

SLAC

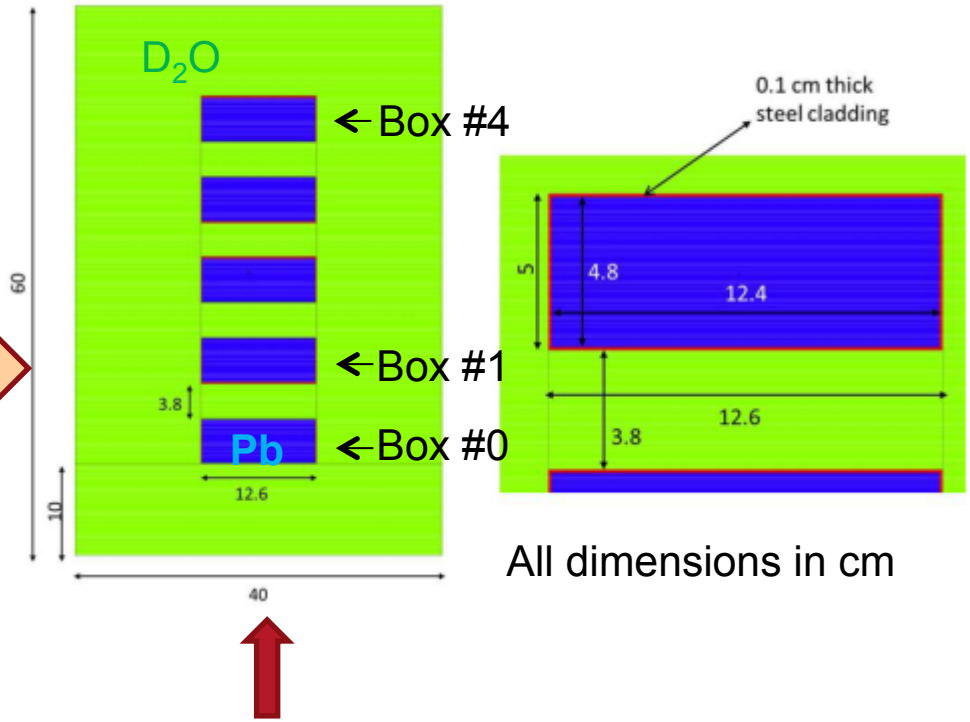
SINQ : The Swiss Spallation Neutron Source

A MW-class neutron spallation source operated in PSI

Sketch of the lower part of SINQ target-4 with safety hull.



ToySINQ
Simplified Geometry for inter-comparison proposed by Daniela (PSI)

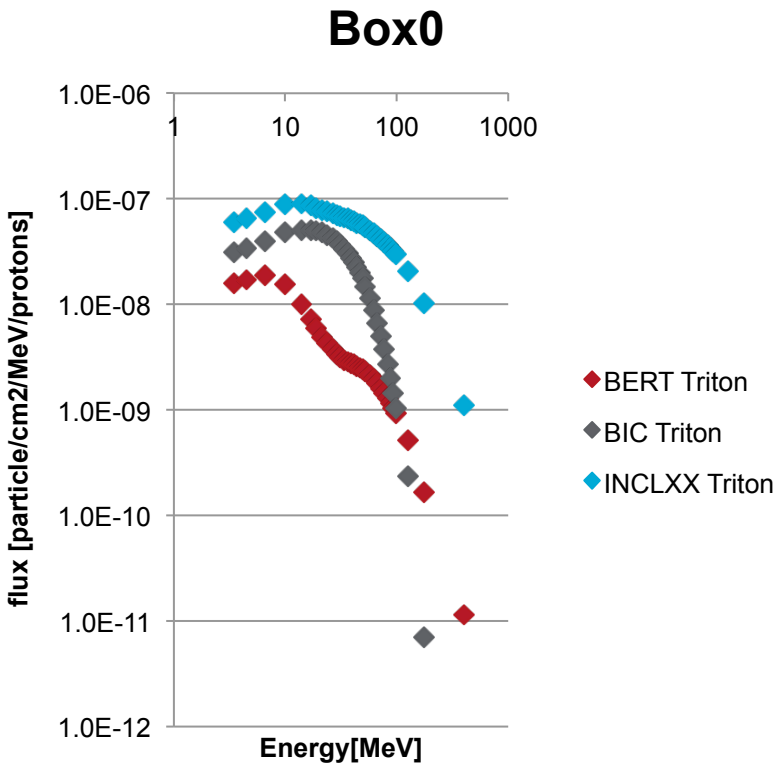


All dimensions in cm

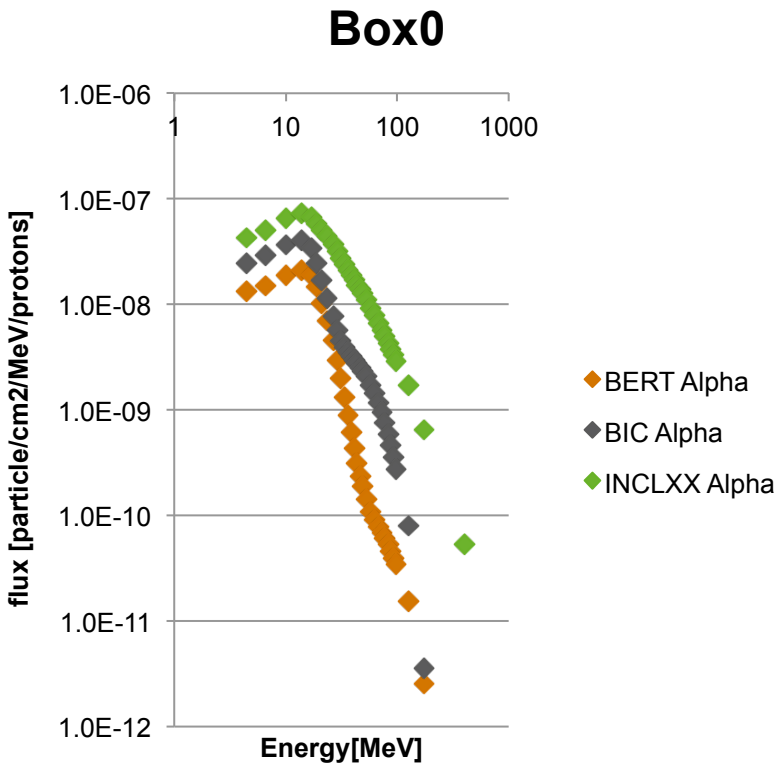
Particle Energy Spectra in Box0 among cascade models in Geant4

We provide INCLXX result as Geant4 result to Daniela for her presentation on Wed.

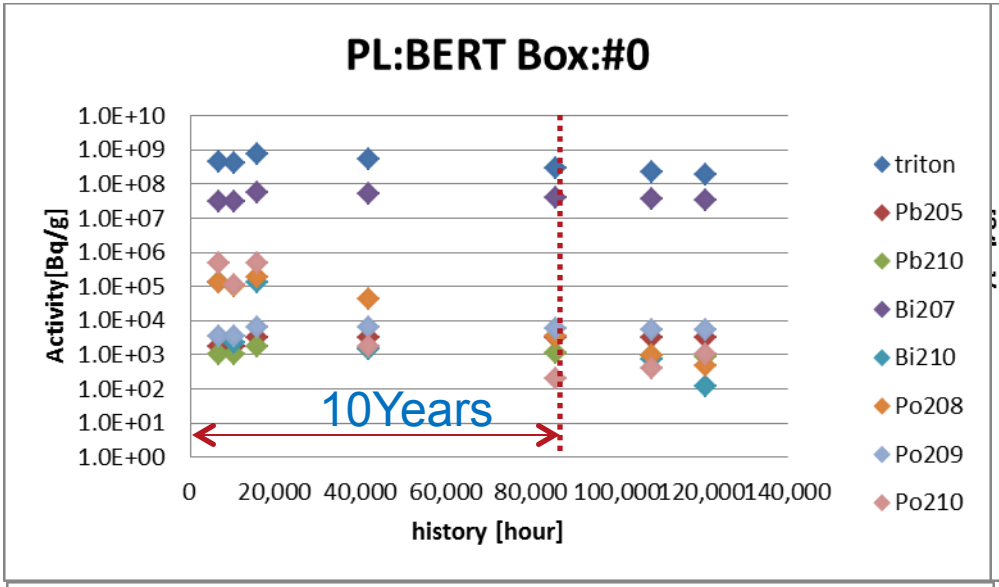
Triton

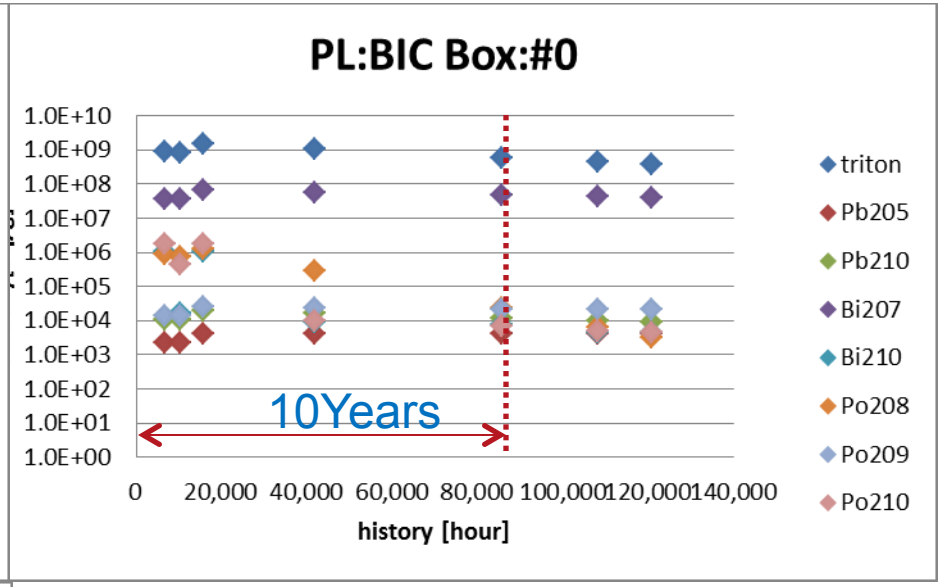


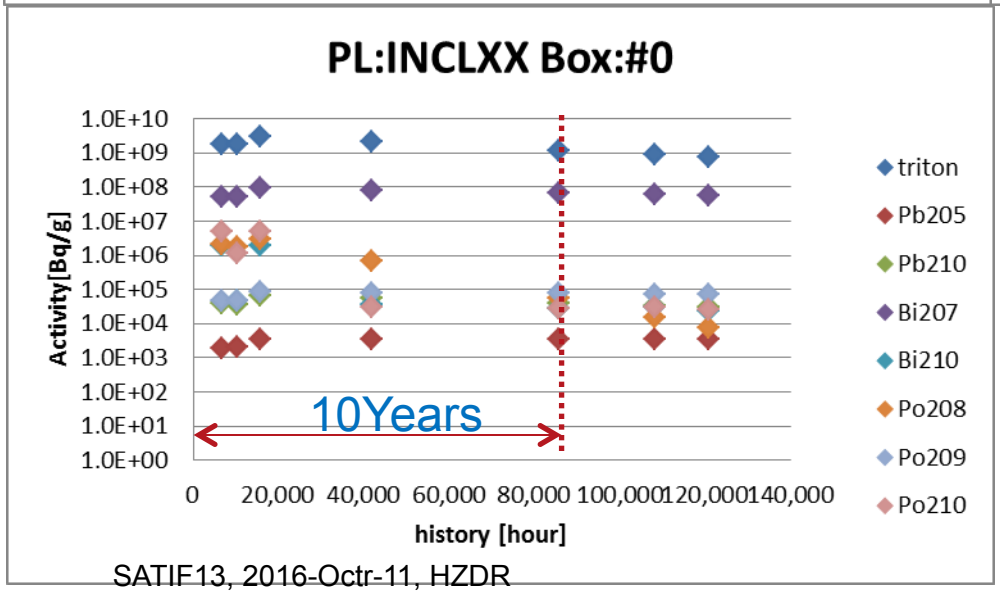
Alpha



Activities of lead block (Box0)
Difference among cascade models of Geant4







Activities of the lead blocks are derived from convolution of beam time and intensity profile with the produced particle profile source term

- Does not assume radioactive equilibrium
- Does not use external tools like CINDER

G4 result through CIDER is shown in Daniela's Wednesday talk

Summary

- The third general paper of Geant4 is published
  - It is an open access paper, you can download it for free
- Many new features improvements both in physics and non-physics have been introduced to Geant4 since last SATIF meeting
- Multi-threading application shows highly scalable performance improvement in many-core platform
- Shielding physics list which we recommend for shielding calculations uses Bertini-like cascade now, however, INCL cascade shows better result in several benchmarks
  - Switch the cascade model or provide an option for the physics list in future.
- We will continue to develop and support Geant4 for the foreseeable future.

Appendix

SLAC

Comparison between Physics Lists on SATIF13 inter-comparison

- FTFP_INCXX vs FTFP_BERT

Comparison against measurement of thick target neutron production

- FTFP_BERT
- QGSP_BIC
- FTFP_INCLXX

Comparison to target measurement

SLAC

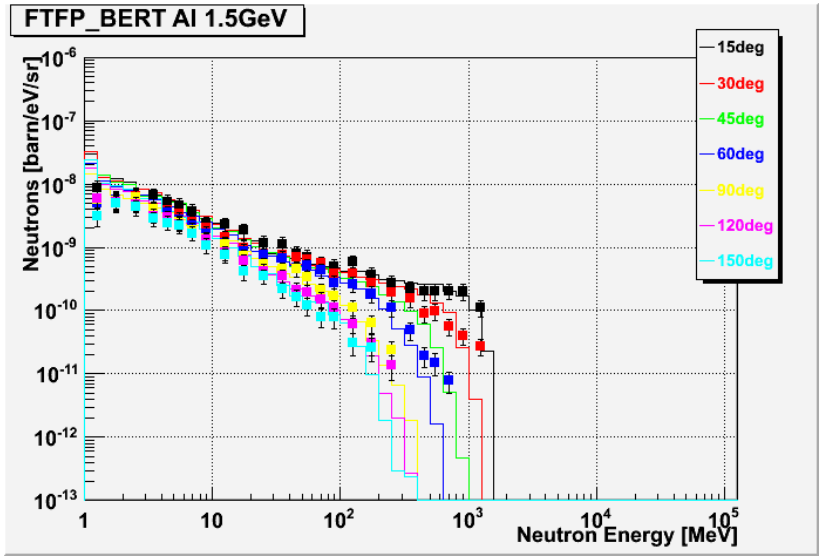
Measurement of Neutron-Production Double-Differential Cross Sections for Nuclear Spallation Reaction Induced by 0.8,1.5 and 3.0 GeV Protons

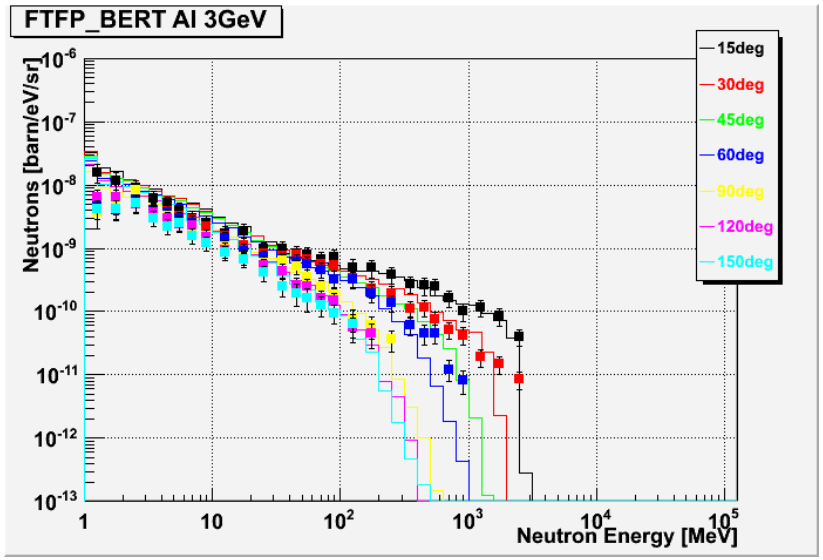
Jour. of Nuclear Science and Technology; Vol.34, Issue.6, p. 529 (1997)

Thickness of target

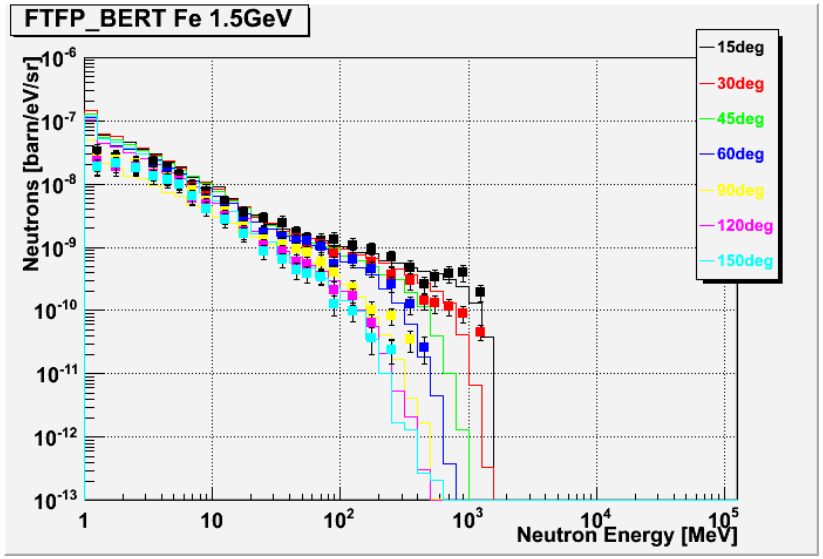
- Al 4cm
- Fe 2cm
- Pb 1.2cm

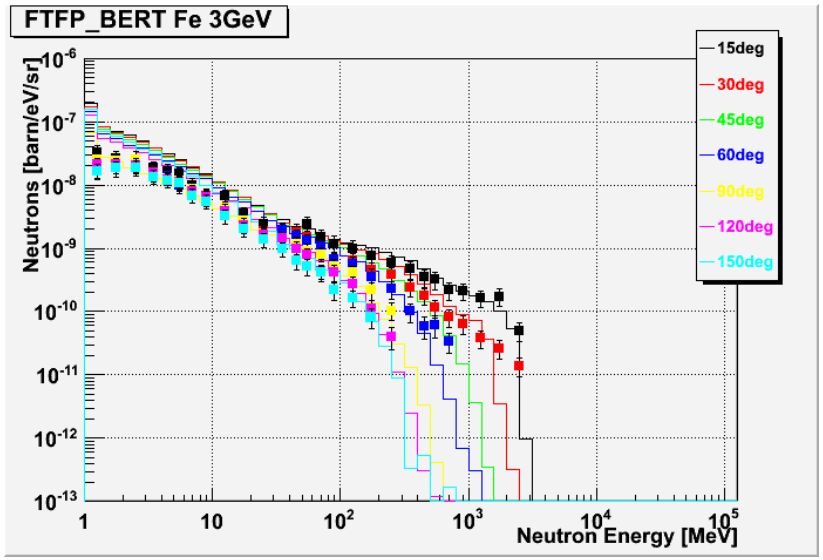
FTFP_BERT
neutron production from proton on Al



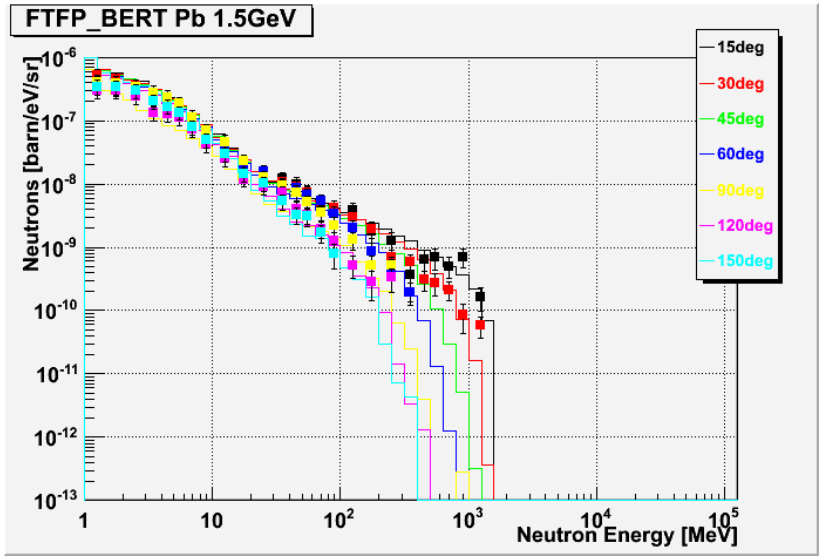


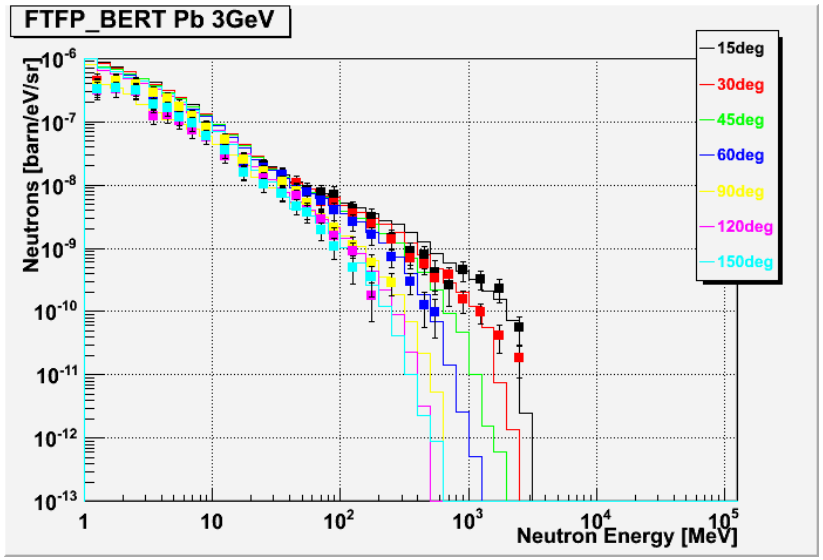
FTFP_BERT
neutron production from proton on Fe



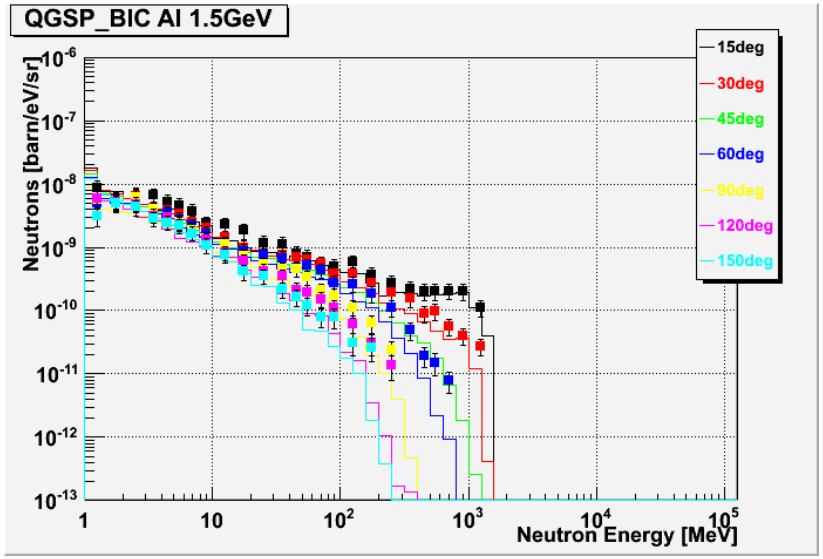


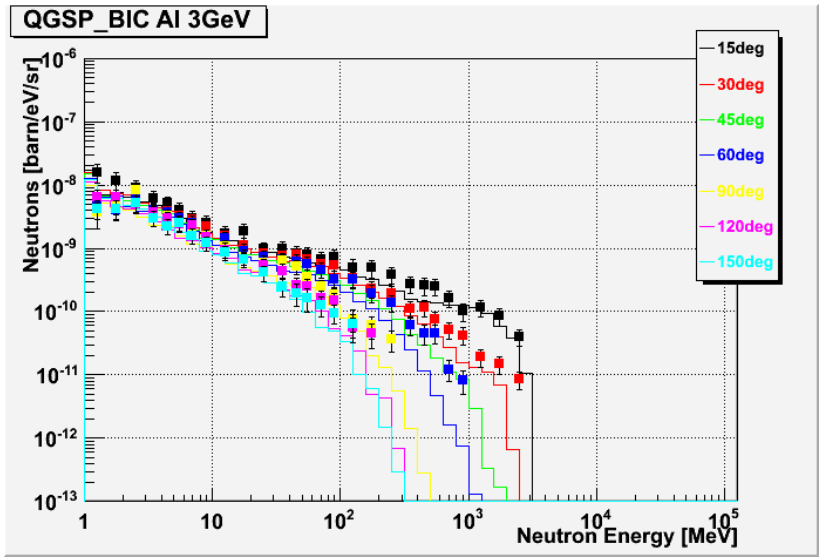
FTFP_BERT
neutron production from proton on Pb



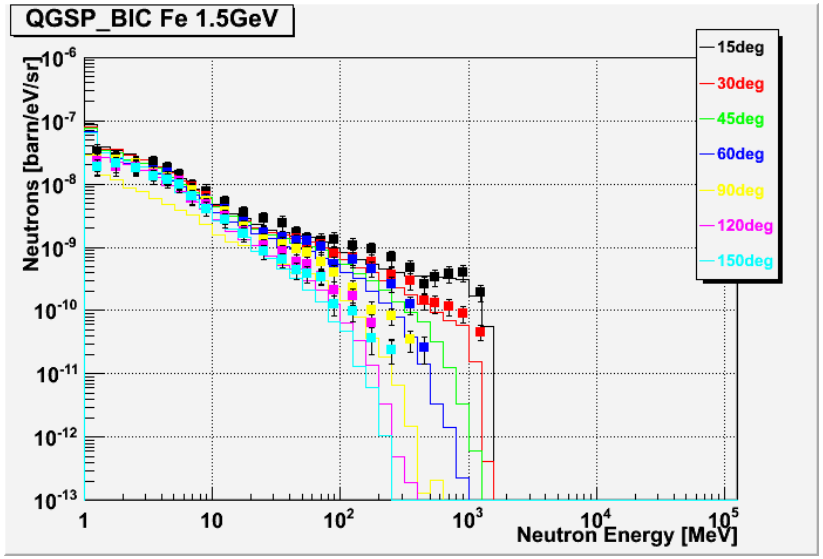


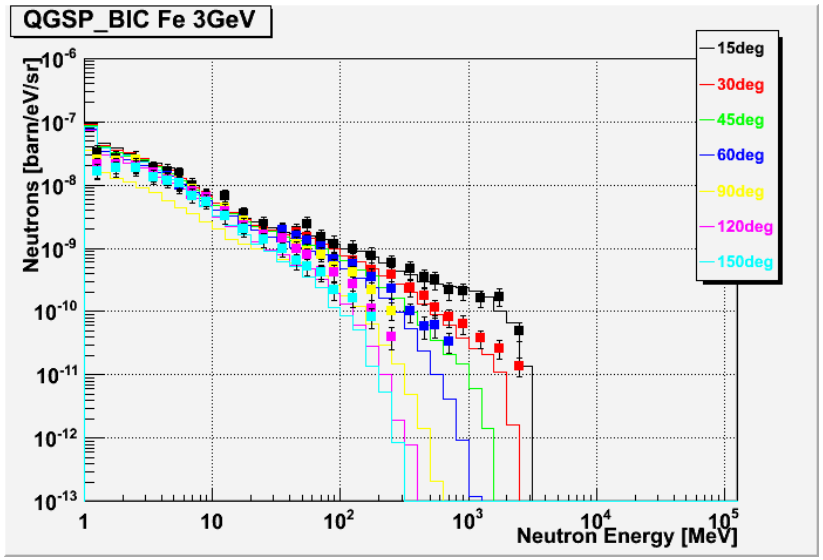
QGSP_BIC
neutron production from proton on Al



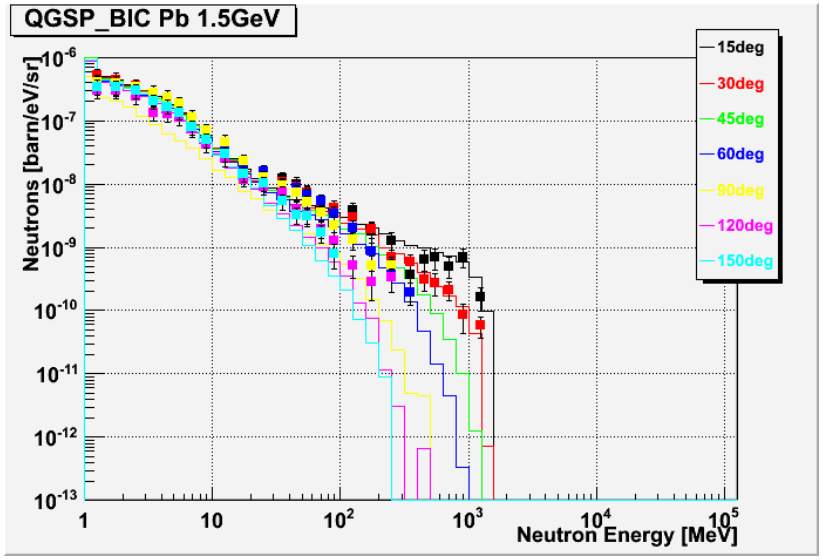


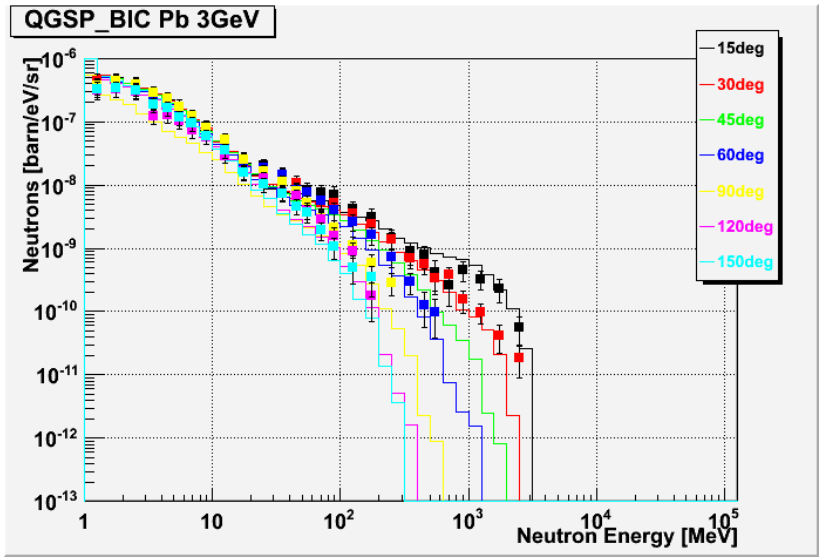
QGSP_BIC
neutron production from proton on Fe



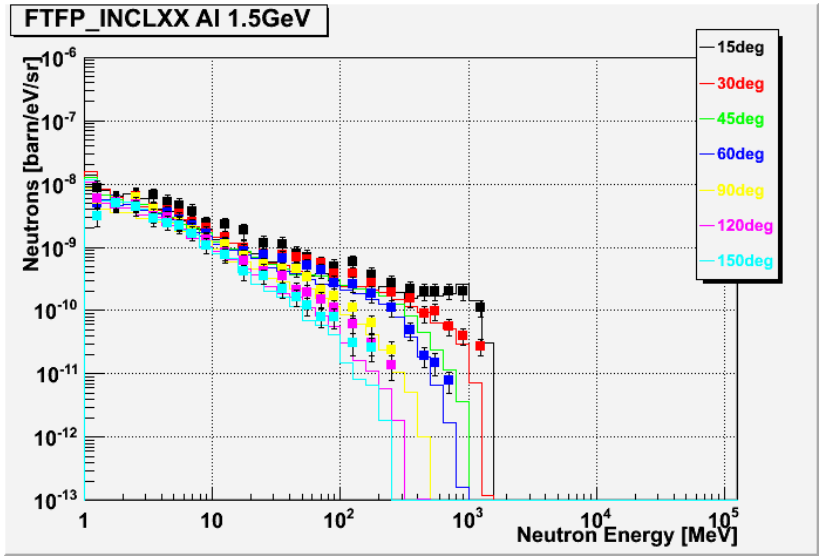


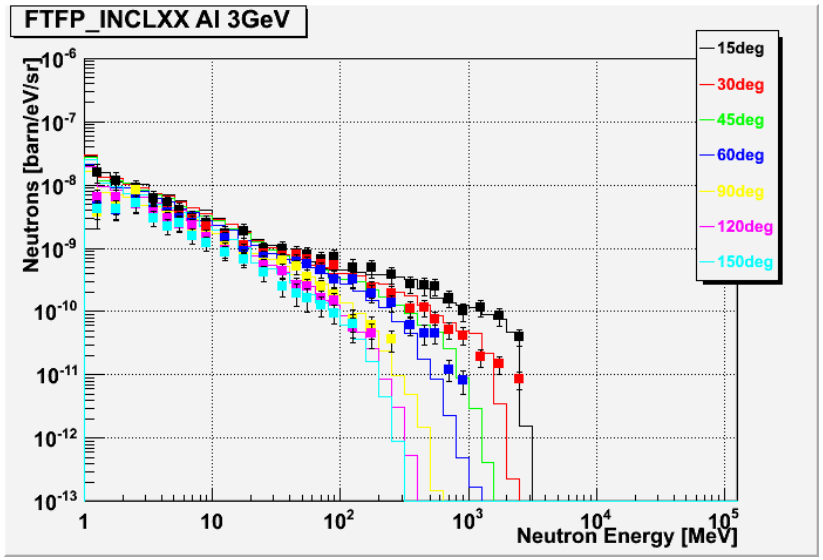
QGSP_BIC
neutron production from proton on Pb



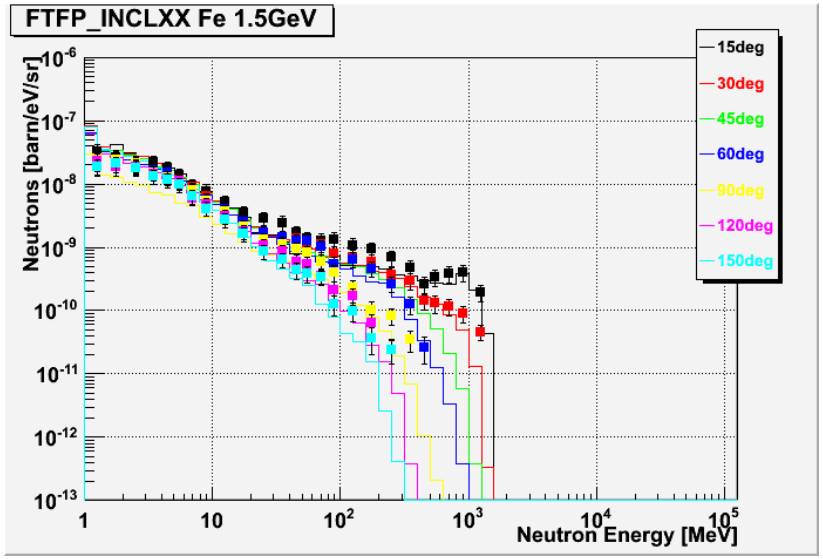


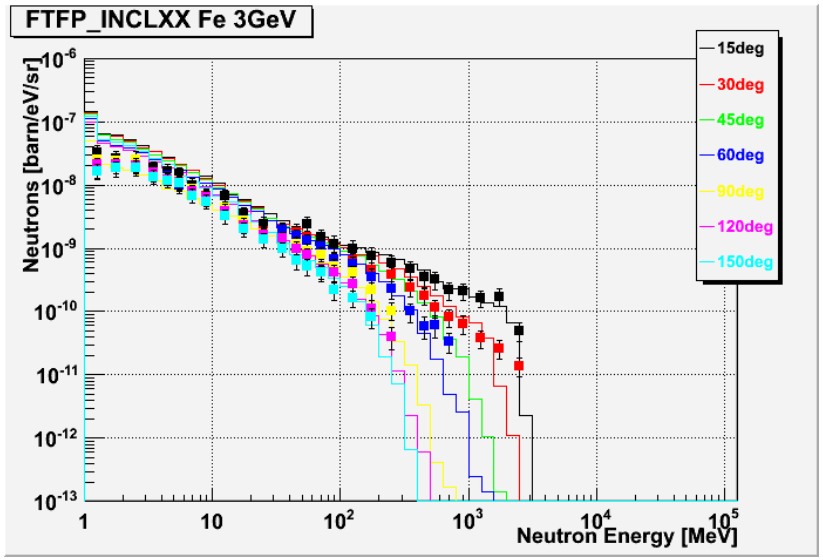
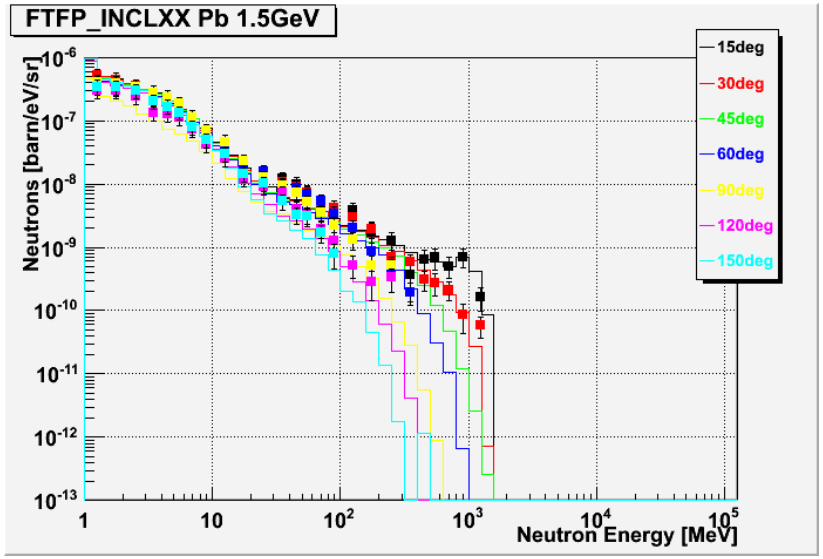
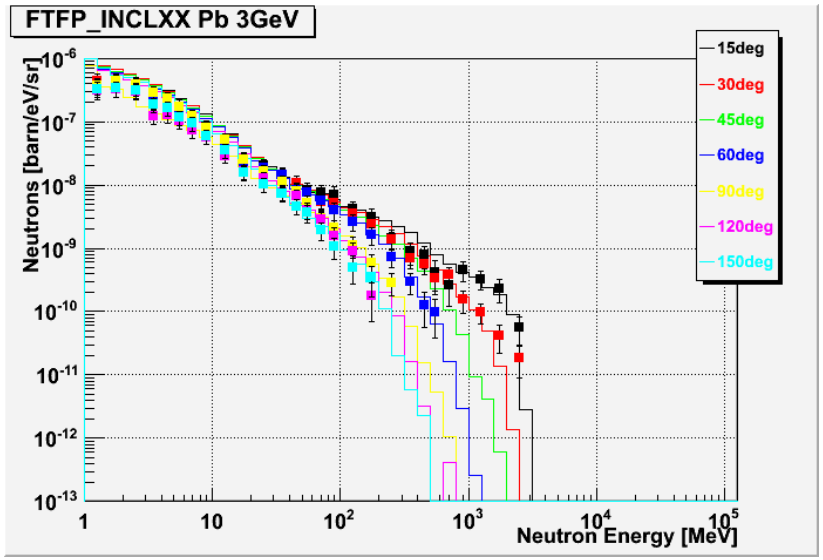
FTFP_INCLXX
neutron production from proton on Al





FTFP_INCLXX
neutron production from proton on Fe





FTFP_INCLXX
neutron production from proton on Pb