Target Simulation Studies

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People

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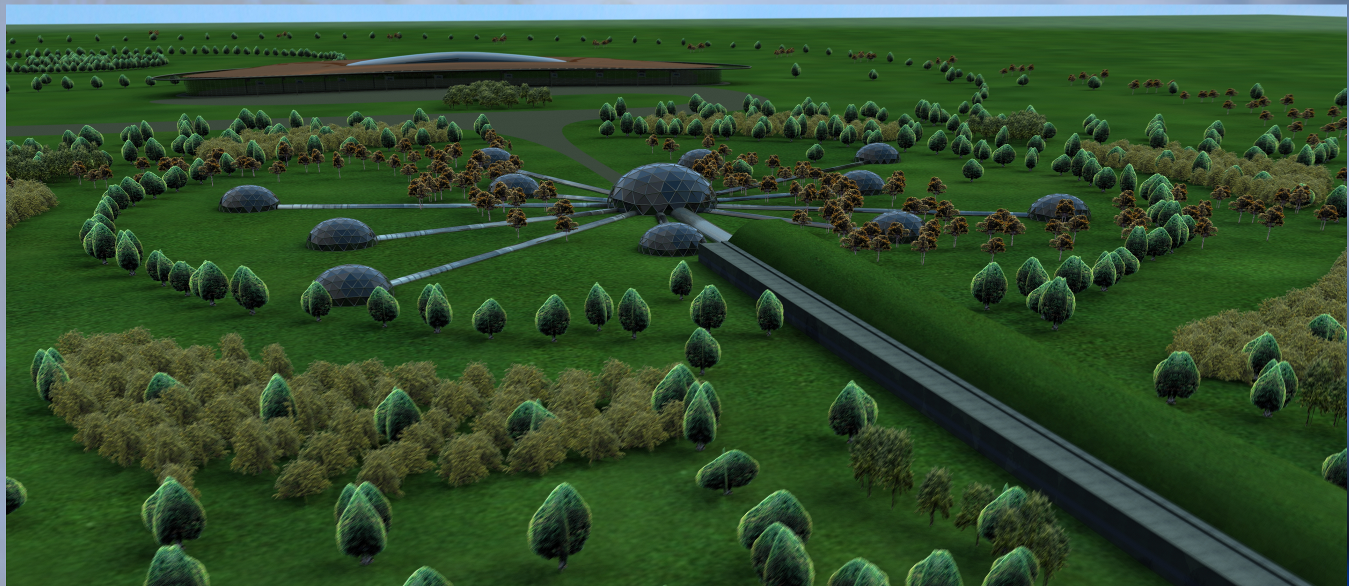
- Naomi Ratcliffe – PhD Student

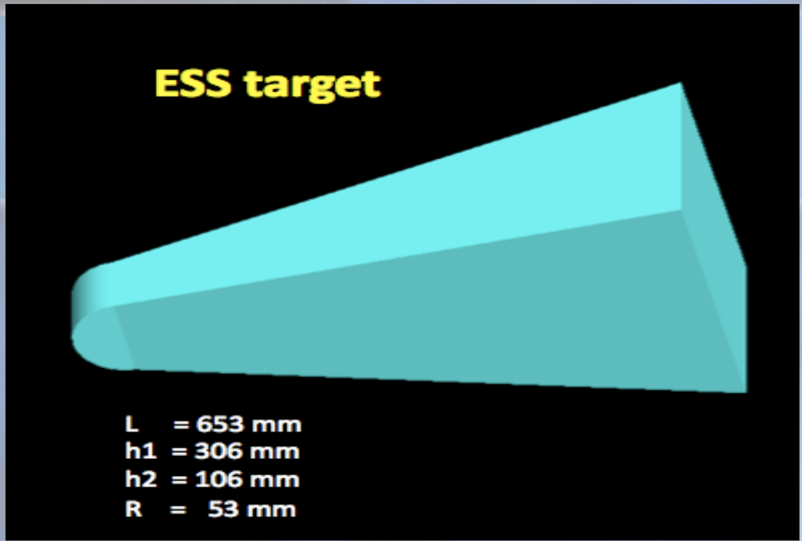
Projects: ESS, ISIS, BNCT, ADS

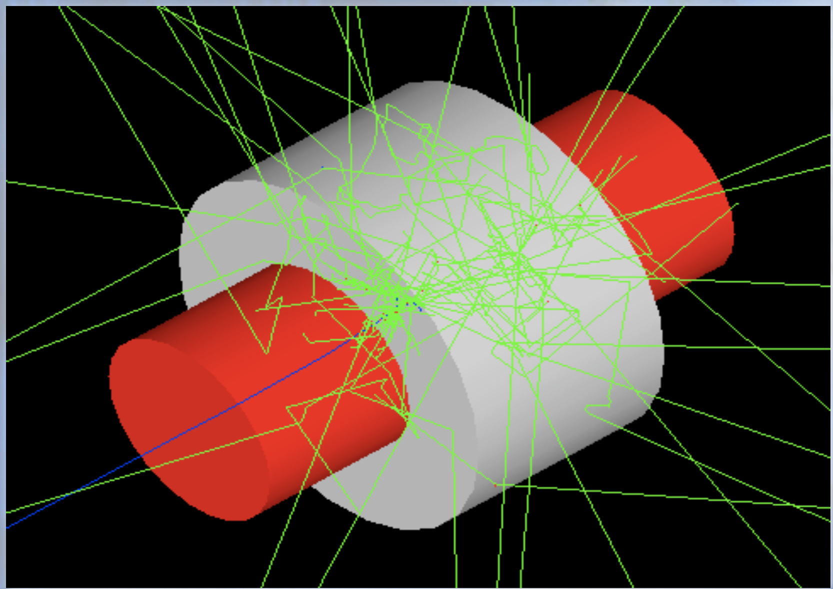
Continuation of Neutron Target Optimization Studies for the European Spallation Source

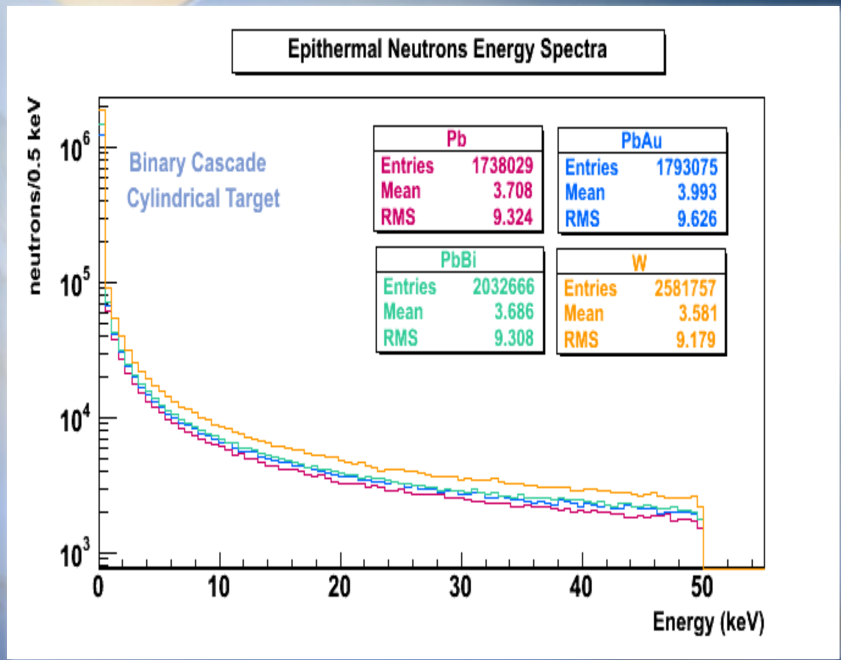


Target Design

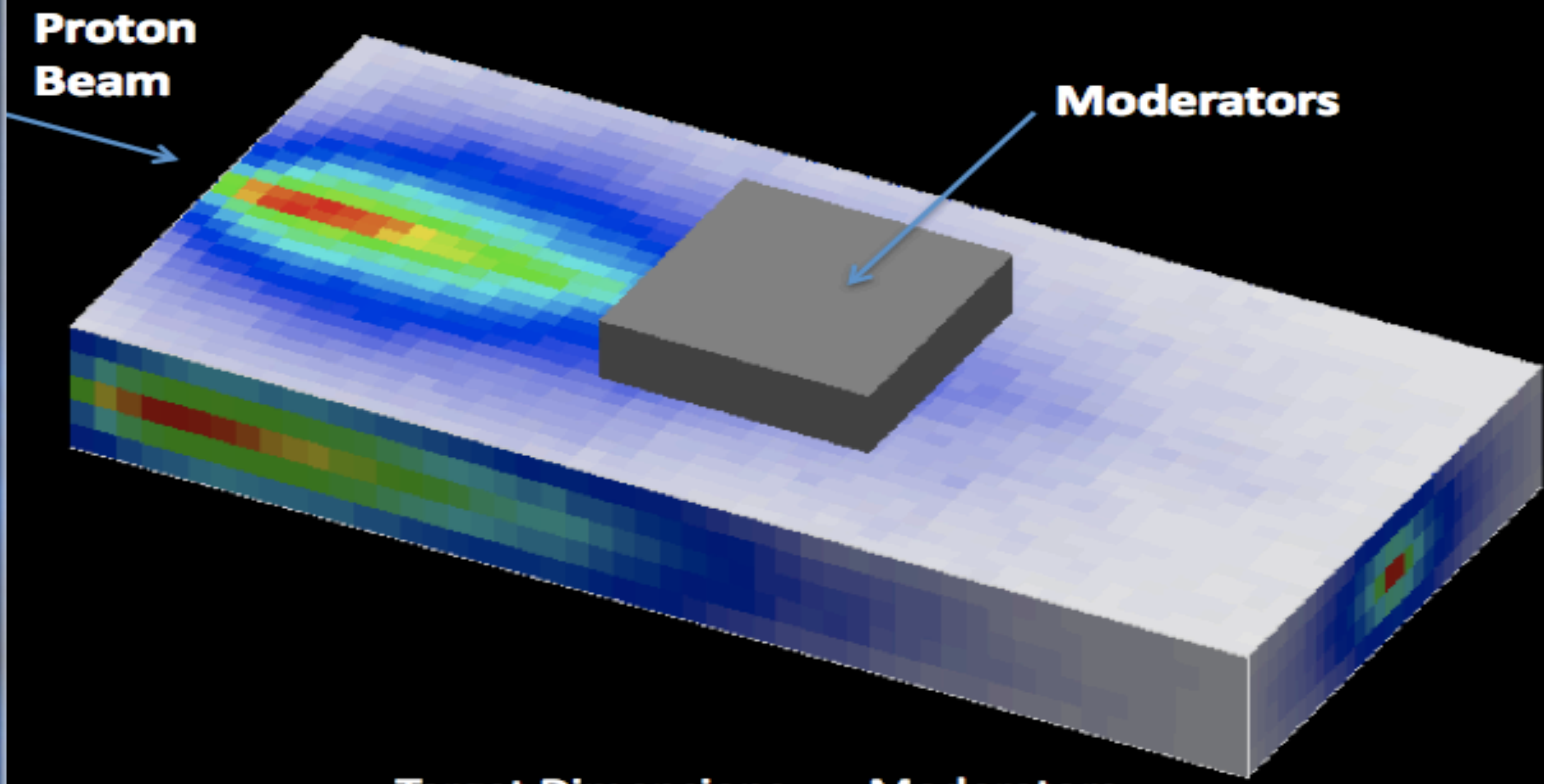
- Optimization of the current target design
- Material choice for the target (Pb, PbAu, Hg, W);







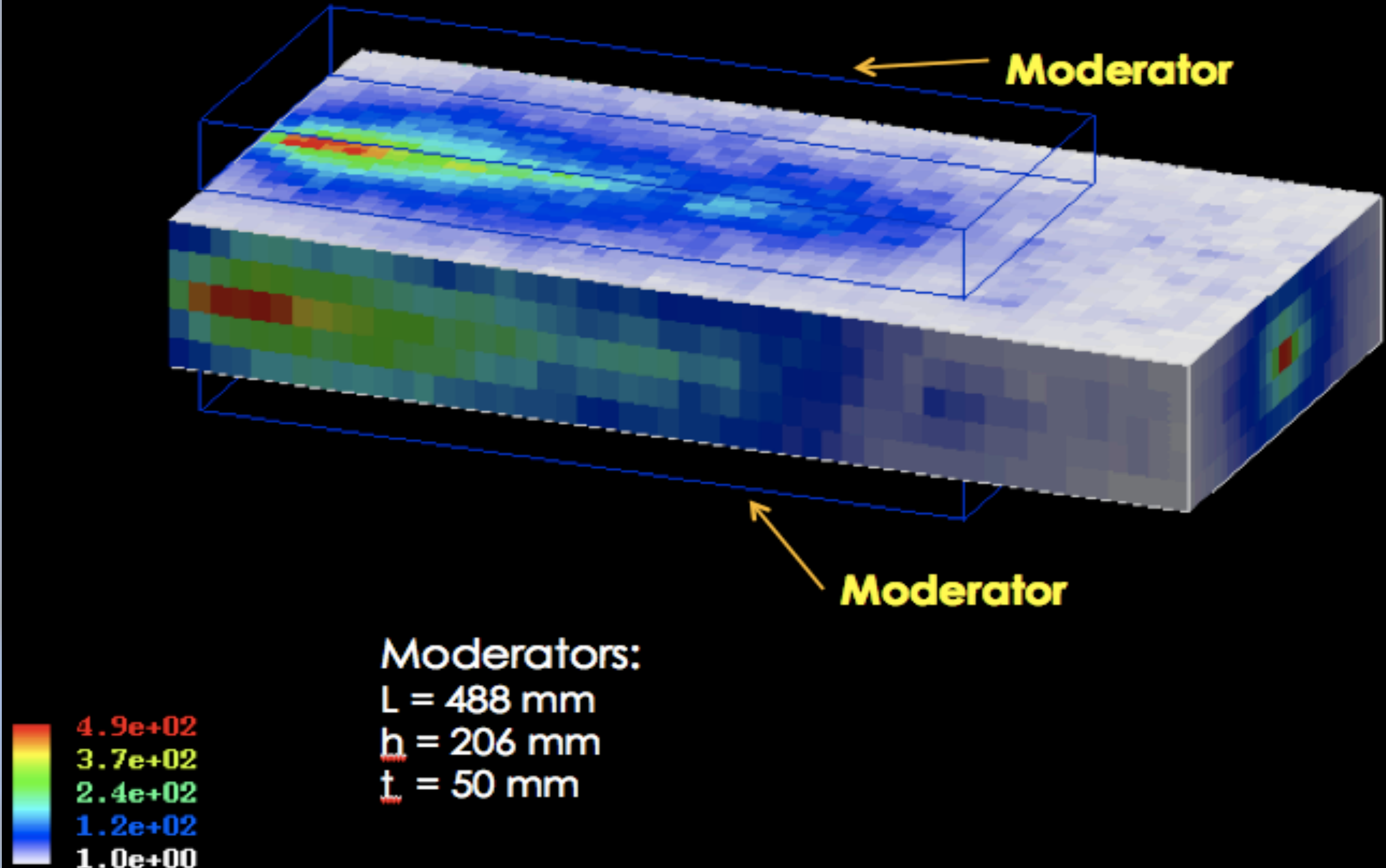
Neutron Density Inside the ESS Target
Proton energy : 1.3 GeV



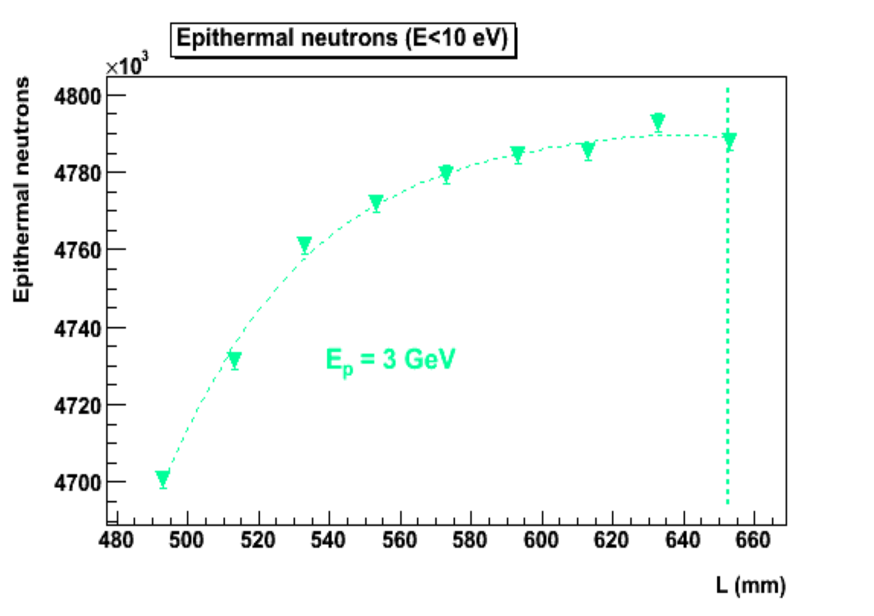
Target Dimensions:
L = 653 mm
h = 306 mm
t = 106 mm

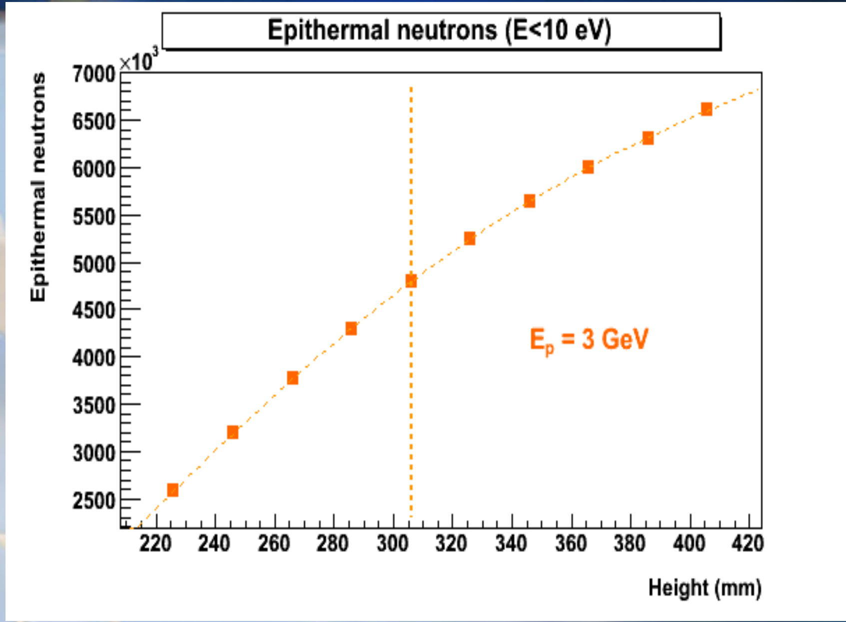
Moderators:
L_m = 150 mm
h_m = 150 mm
t_m = 50 mm

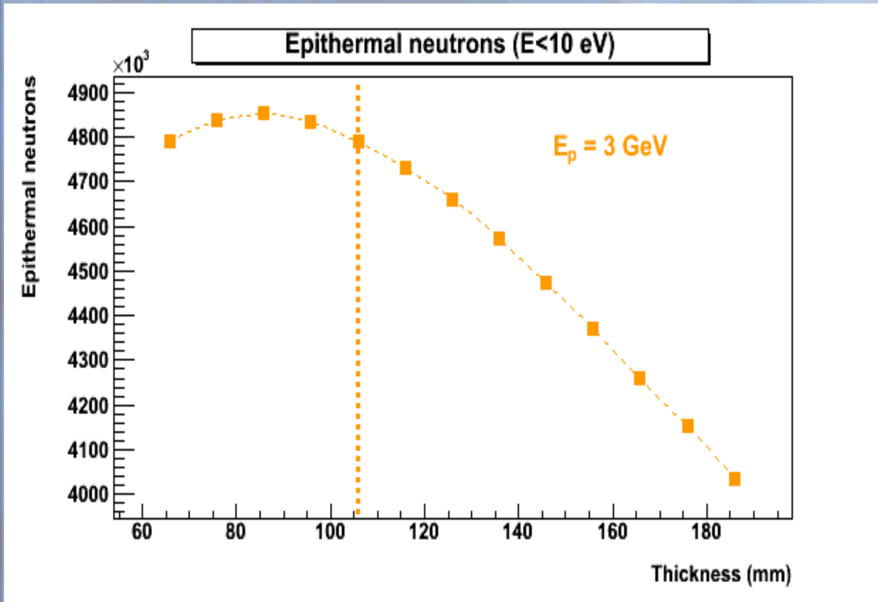
New dimensions and position of the moderators (shown in wireframe)



Moderators:
L = 488 mm
h = 206 mm
t = 50 mm

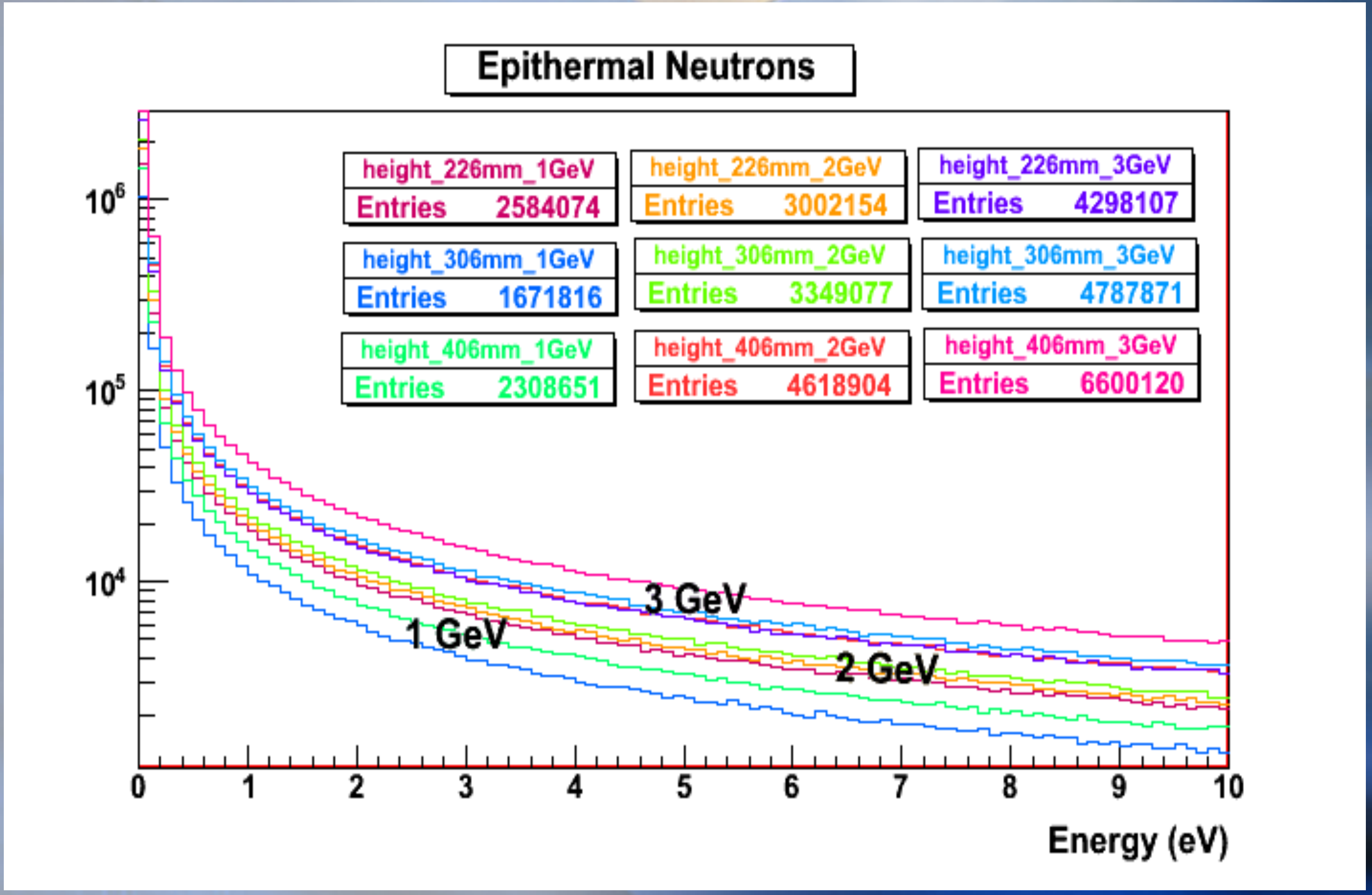






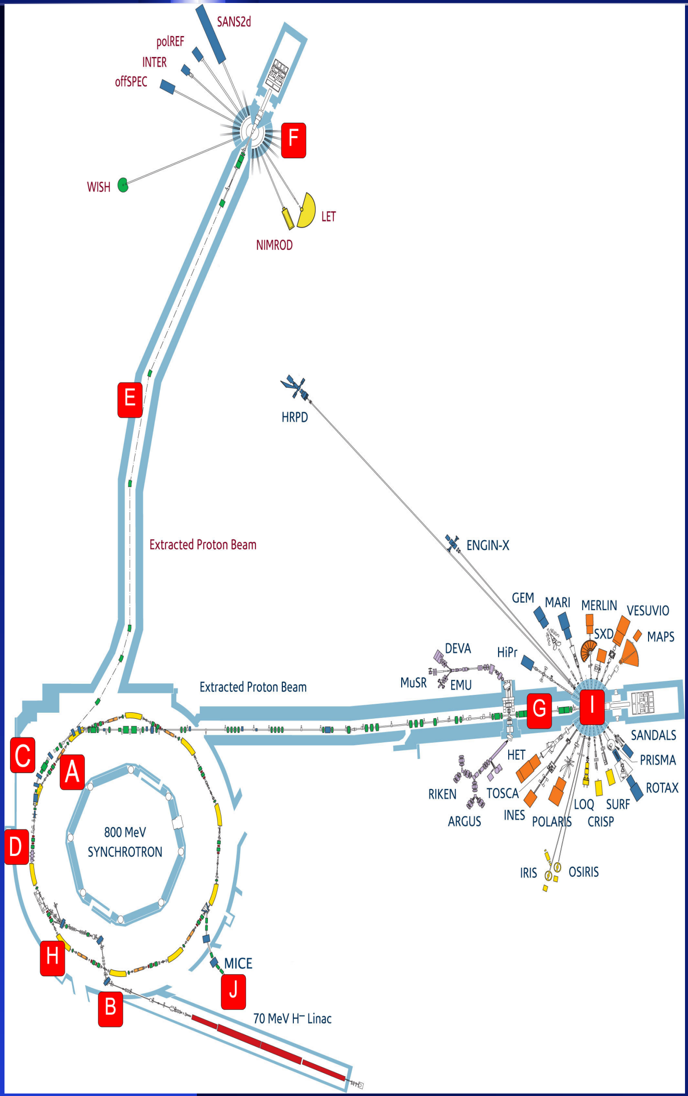
- Current plots represent the epithermal neutron yield versus target length, thickness and height for 3 GeV incident proton energy

Epithermal neutrons for 1, 2, 3 GeV for three different heights



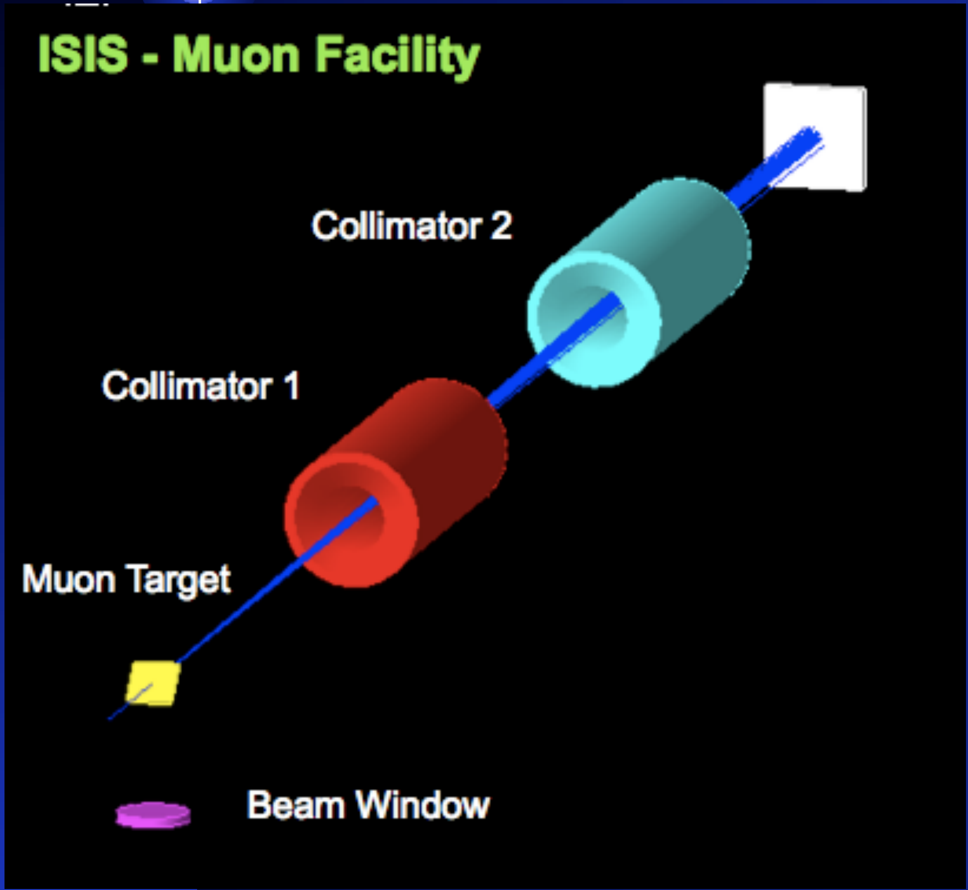
Neutron Production and Moderation Studies for ISIS Upgrades

Why we need target optimization



- Every year hundreds of experiments are performed at ISIS
- Neutrons and muons are used to study the atomic and dynamic properties of matter
- Experimental studies require intense muon beams of high quality
- The μSR scientific community are currently well served by muon beam facilities at: PSI, TRIUMF, J-PARC, ISIS
- Neutron and muon experiments are carried out all together

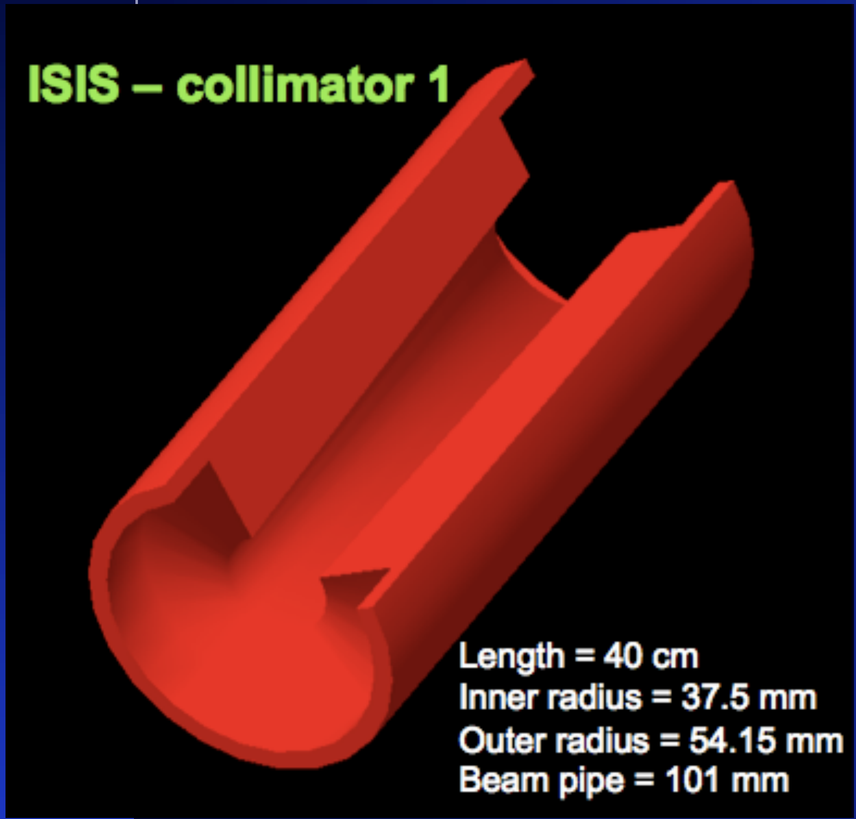
GEANT4 Modeling of the Muon Target



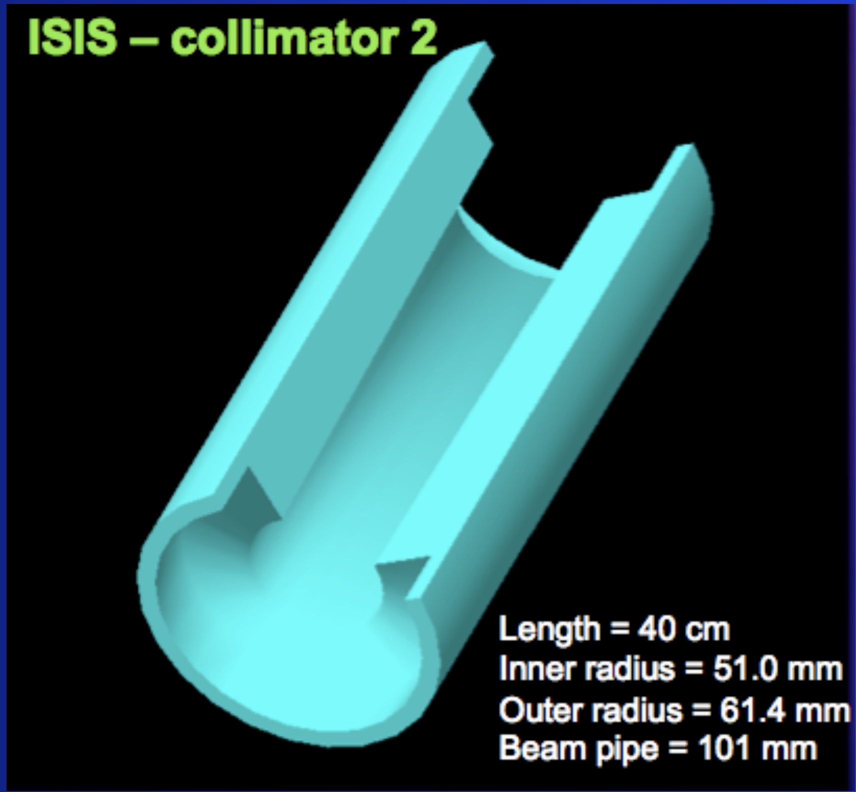
Geant4 modeling of the ISIS muon facility

- Graphite plate (dimensions are 5x5x0.7 cm)
- 45 deg. Orientation
- Proton transmission: 96%
- Water cooled
- Muon beam extracted at 90 deg to the proton beam
- Aluminum window (r=8 cm) at 15 cm from target centre

GEANT4 modeling of the collimators inside the beam pipe



Proton interception beyond 41.6 mrad



Proton interception beyond 28.8 mrad

Hadronic Models in GEANT4

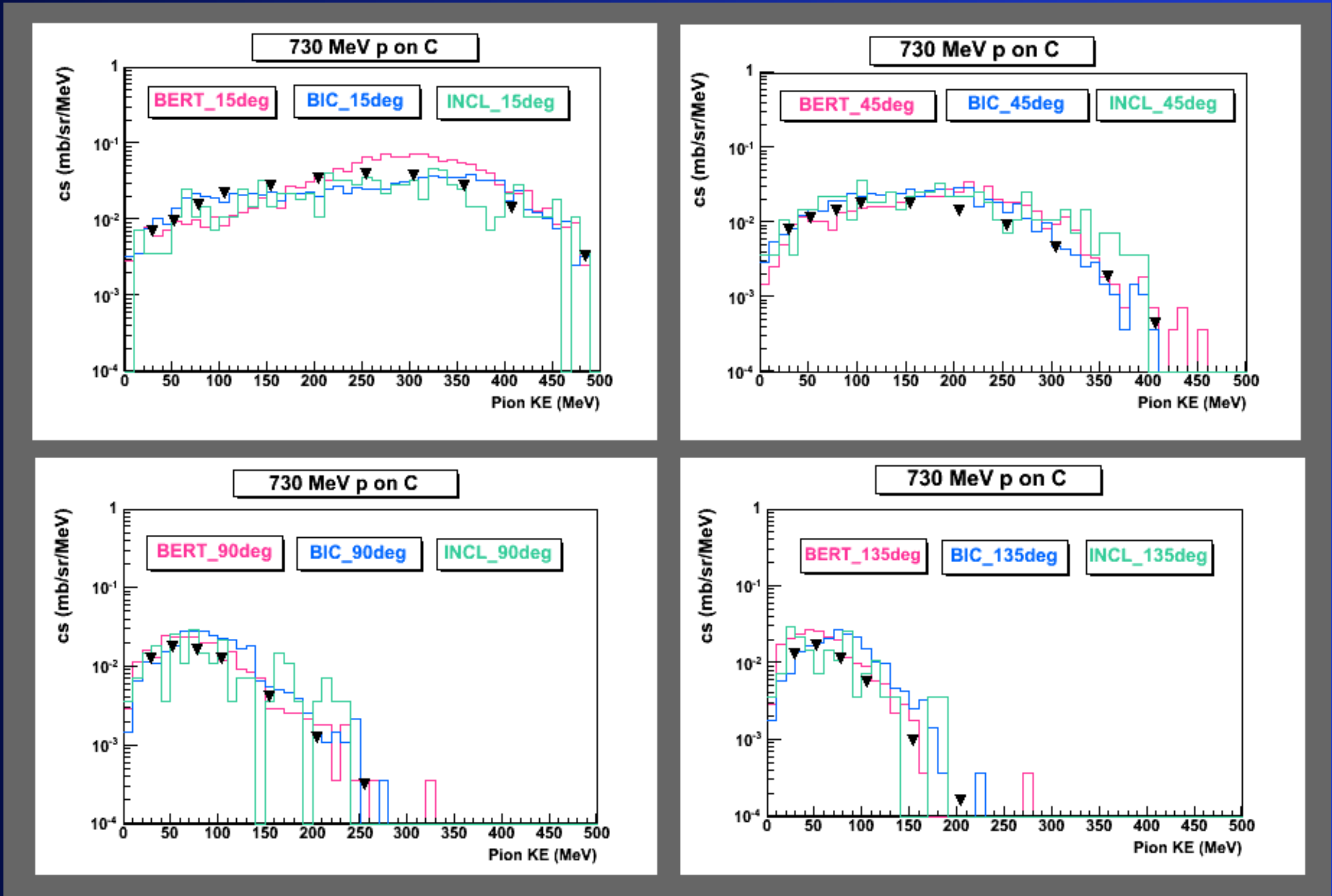
- A SINGLE HADRONIC MODEL WOULD NOT BE ABLE TO SUPPORT ALL USER REQUIREMENTS

- GEANT4 provides an extensive set of hadronic models corresponding to incident particles momenta
- Each model is defined for a given type of interaction within a specified range of energy
- There are 3 hadronic models applicable in the interest energy range for ISIS
  - Bertini Cascade Model
  - Binary Cascade Model
  - INCL - ABLA

GEANT4 Model Validation

- Validation was performed for 730 MeV incident protons on a Carbon target
- Experiment was done at Lawrence Radiation Laboratory
- Several beam channels over a wide range of angles were viewed by the magnetic spectrometer
- The differential cross-section for pion production on 11 targets provided a reliable guide for the design of pion beams at various facilities
- A thin (1 cm) C target was simulated; four pion detectors were placed at 15, 45, 90, 135 deg with respect to the proton beam

GEANT4 Validation

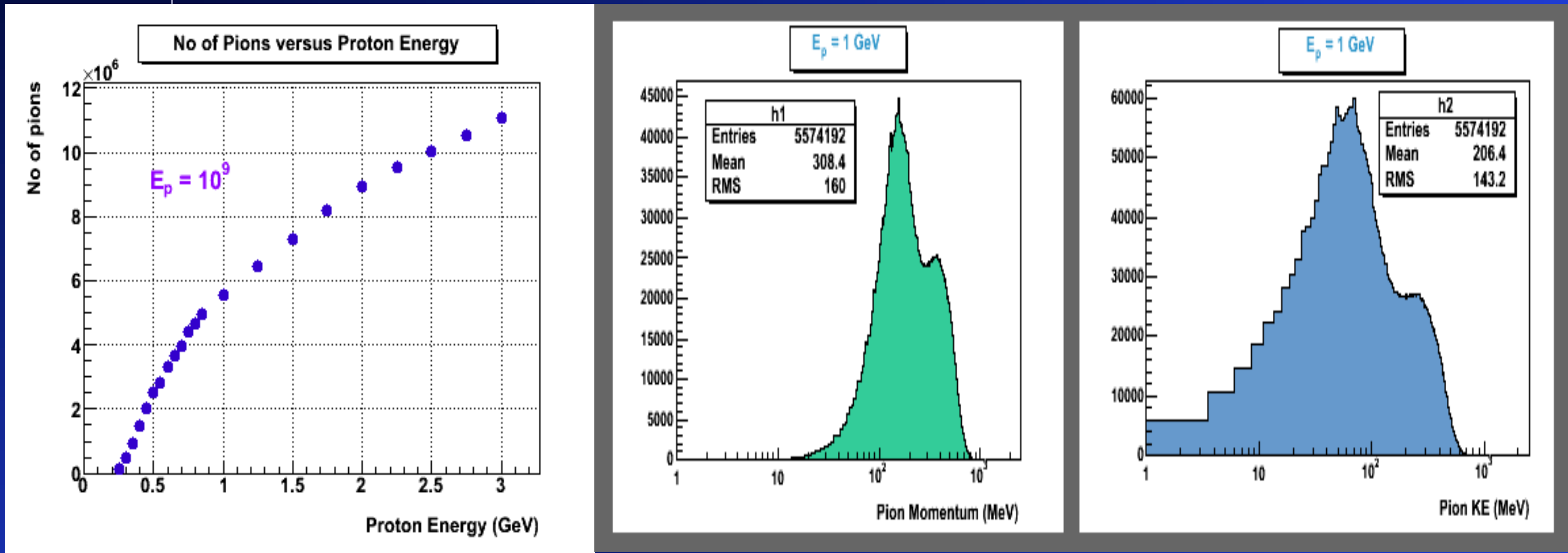


How do we increase the muon production?

- Increase the energy of the proton driver
- Find the optimum material
- Change the target geometry

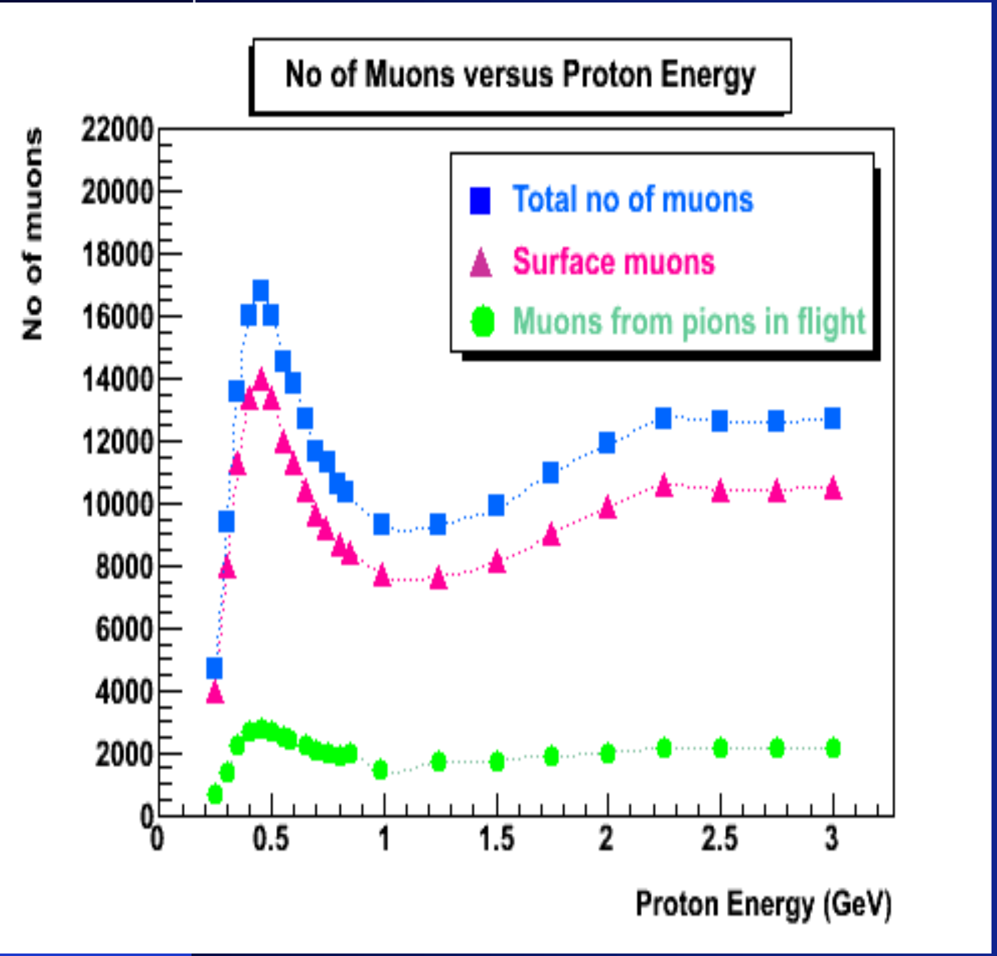
IMPACT OF THE ENERGY OF THE PROTON DRIVER

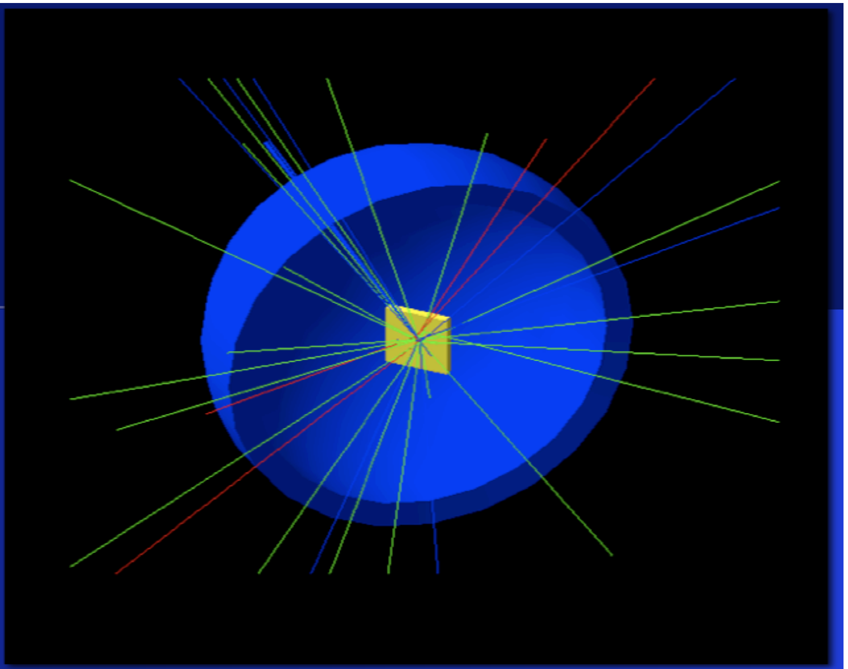
Pion Production



- Pion production increases rapidly with energy
- a fraction stop at the surface after losing momentum (producing surface muons); others decay in flight
- double pion production reactions occur when there is sufficient energy in the collision

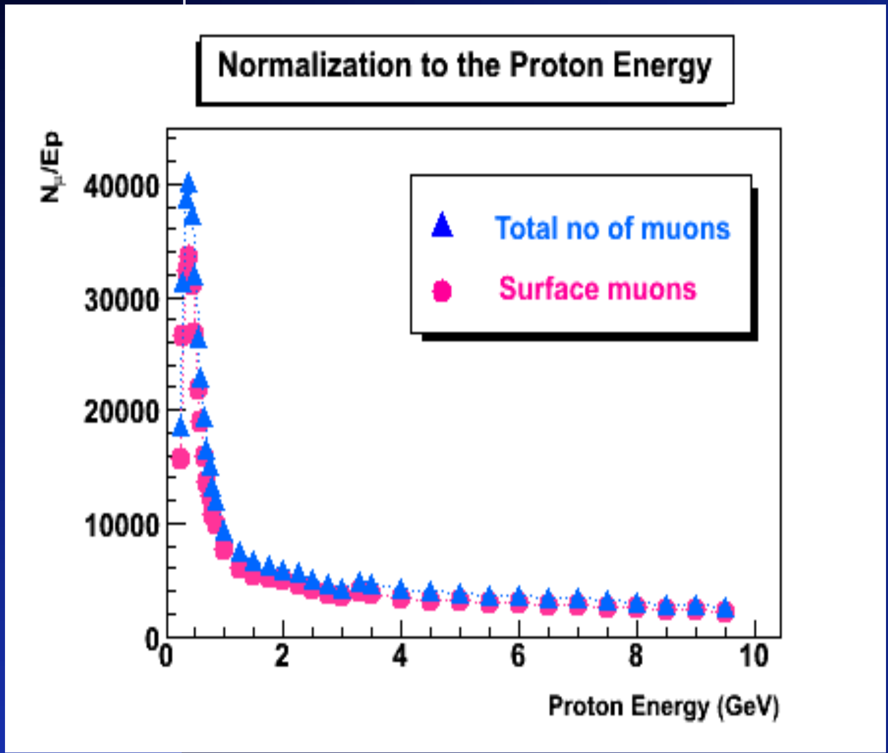
Muon Production

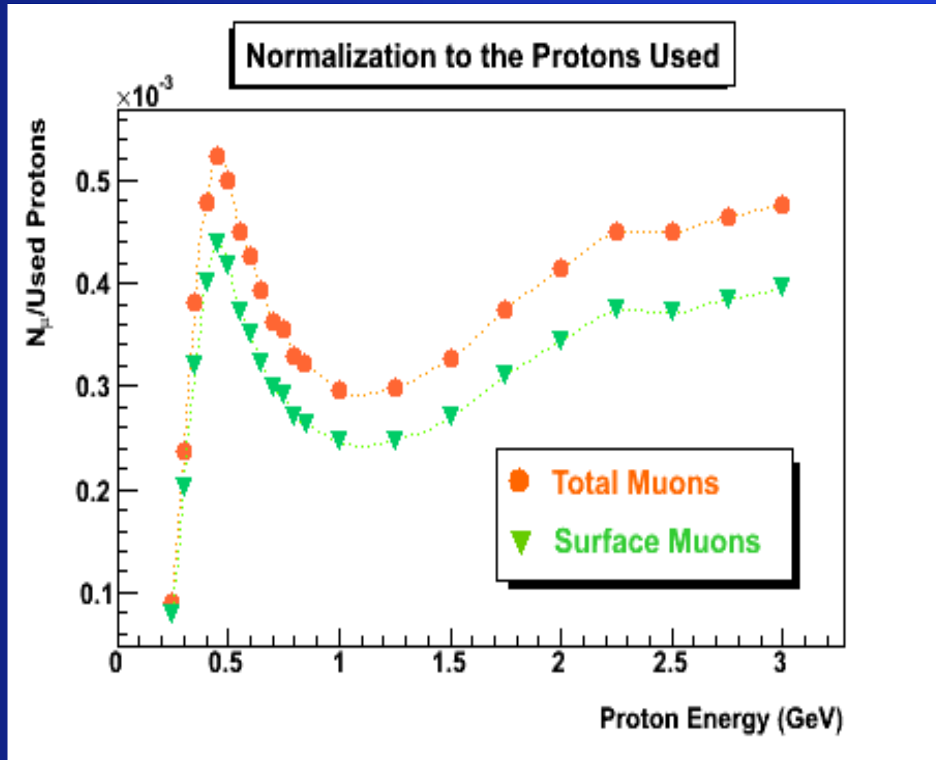




- Target surrounded by a spherical shell to detect all muons
- Surface muons have a momentum range 0-30 MeV/c
- A peak at about 500 MeV can be observed
- Increased energy merely produces more pions well outside the momentum range likely to be used by a decay beam

Normalization to the Proton Energy and the Number of Protons used in the Target





No gain is achieved in going to higher energies for this particular target geometry and material

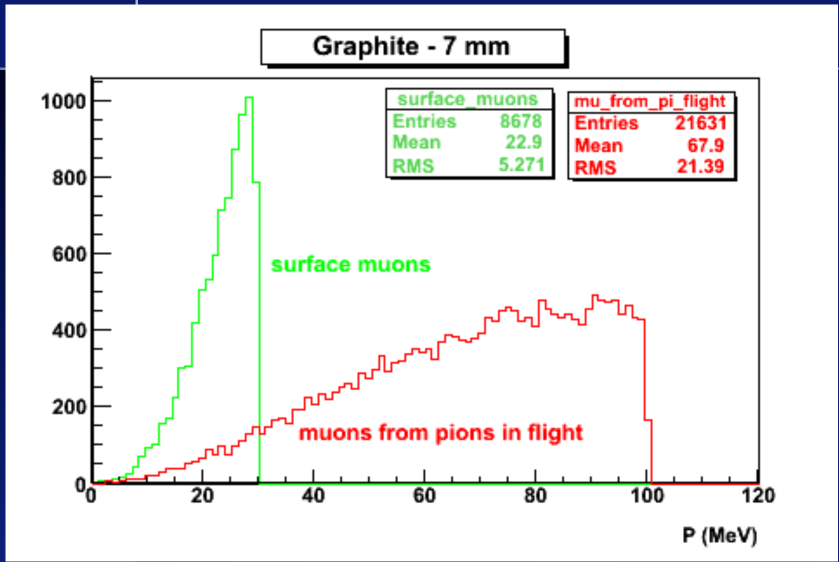
500 MeV proton energy is the optimal energy and one should aim for this value at a stand alone muon facility.

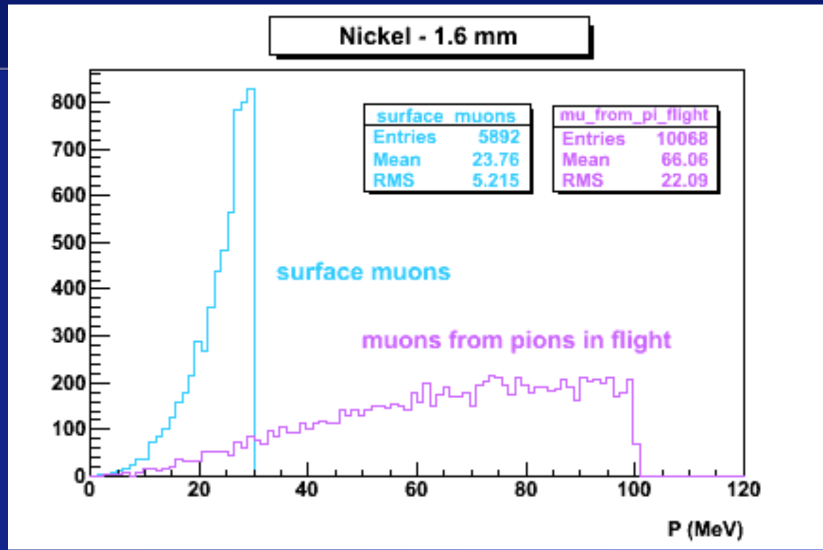
MATERIAL CHOICE FOR THE MUON TARGET

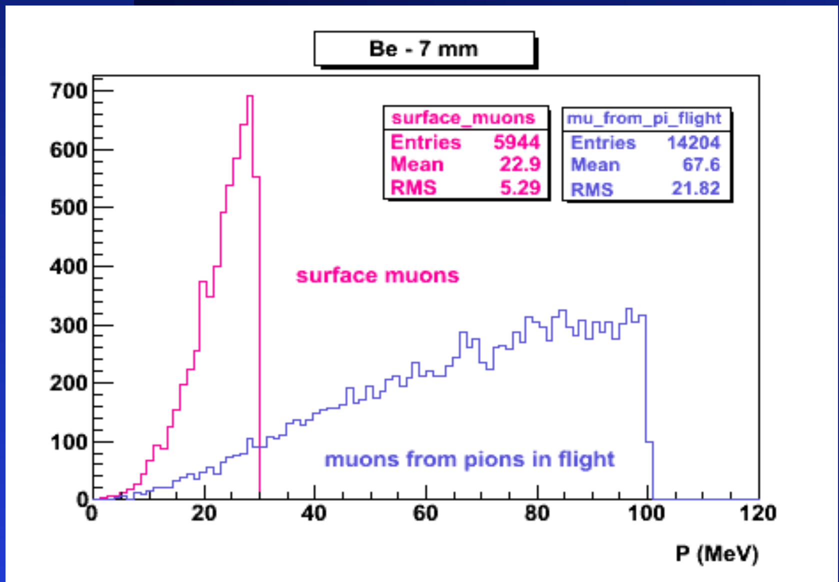
- Target should produce a high yield of pions and muons
- Small unwanted particles (electrons, positrons etc)
- Low-Z materials to maximize pion production and minimize the proton scattering
- Generate little heat and dissipate heat easily
- Keep the proton transmission at 96%

-> Materials proposed: graphite (7mm), Beryllium (7 mm), Nickel (1.6 mm) and Beryllium coated with 0.5 mm Nickel

Total Muon Production



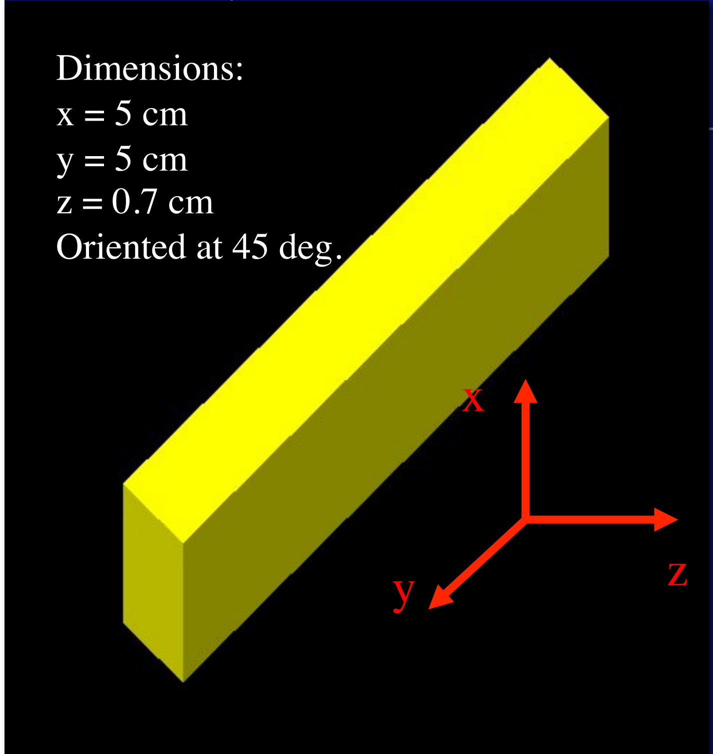


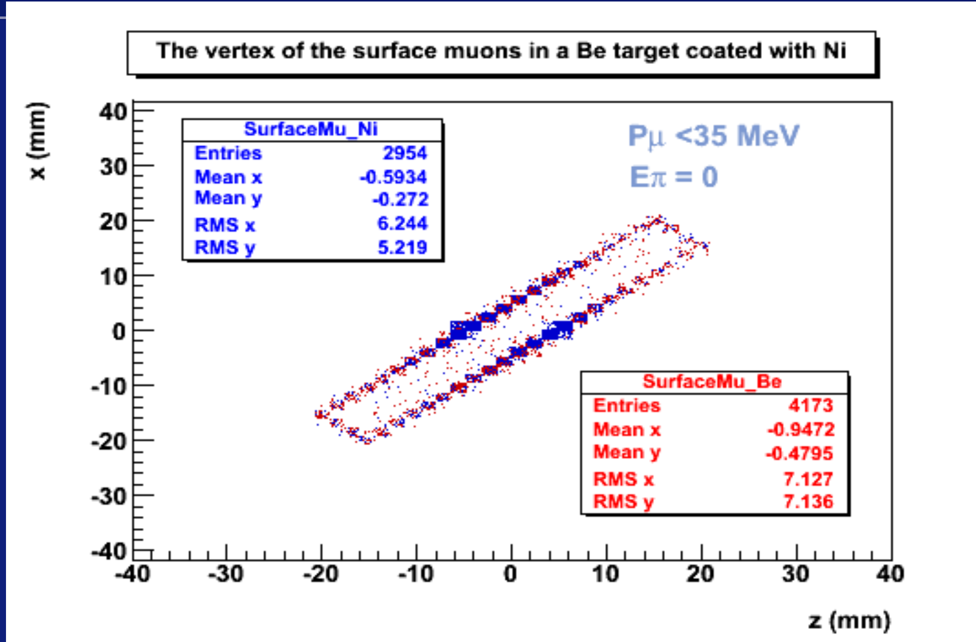


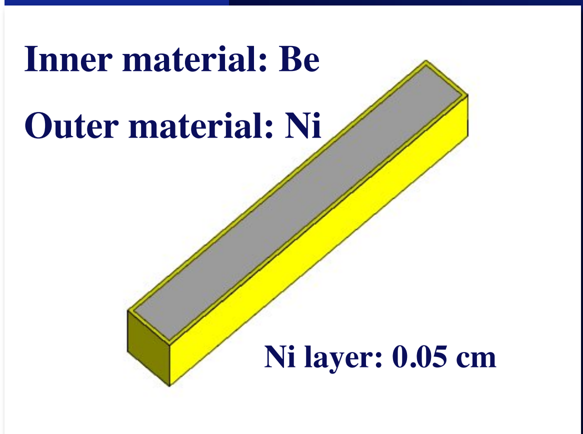
- For similar proton beam loss**, the graphite target gives a higher muon yield**

- for a cut at 30 MeV/c applied in practice, background muons are detected together with the surface muons

Be Coated with Ni Target







- Be surface is rough and coating is required to prevent Be diffusing through

- different colors represent the contribution of both materials to surface muons production

Material performance

Detector: Spherical Shell	Plain Be	Beryllium Coated with Ni			Graphite
		Beryllium	Nickel	Total	
Total mu	7257	5107 (59%)	3515 (41%)	8622	10450
Surface mu	6015	4173 (59%)	2954 (41%)	7127	8622

The muon production rates are higher in a coated Be target than in a plain one

THE BEST MATERIAL CHOICE IS GRAPHITE

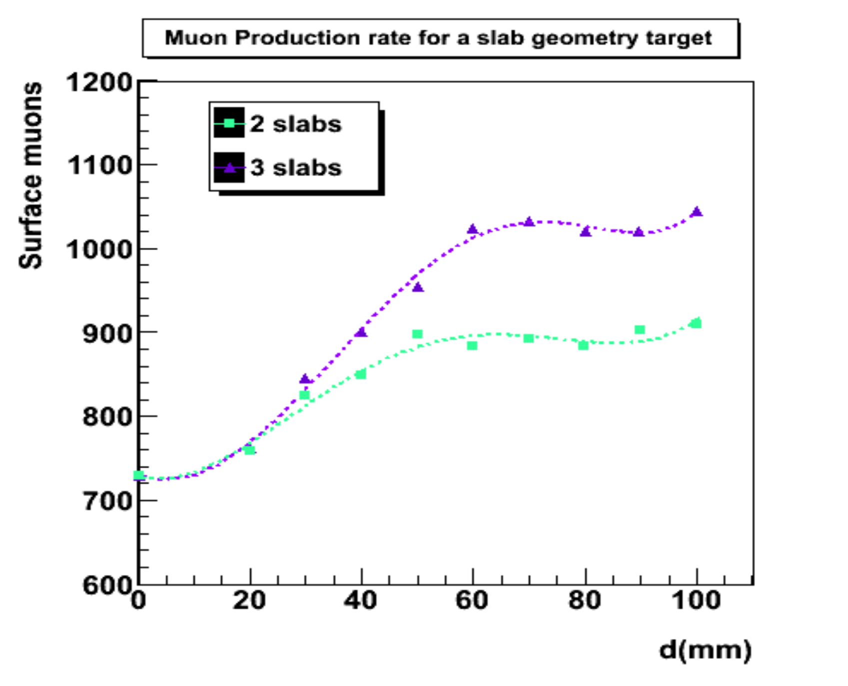
OPTIMIZATION OF THE TARGET GEOMETRY

Slice Target Geometry

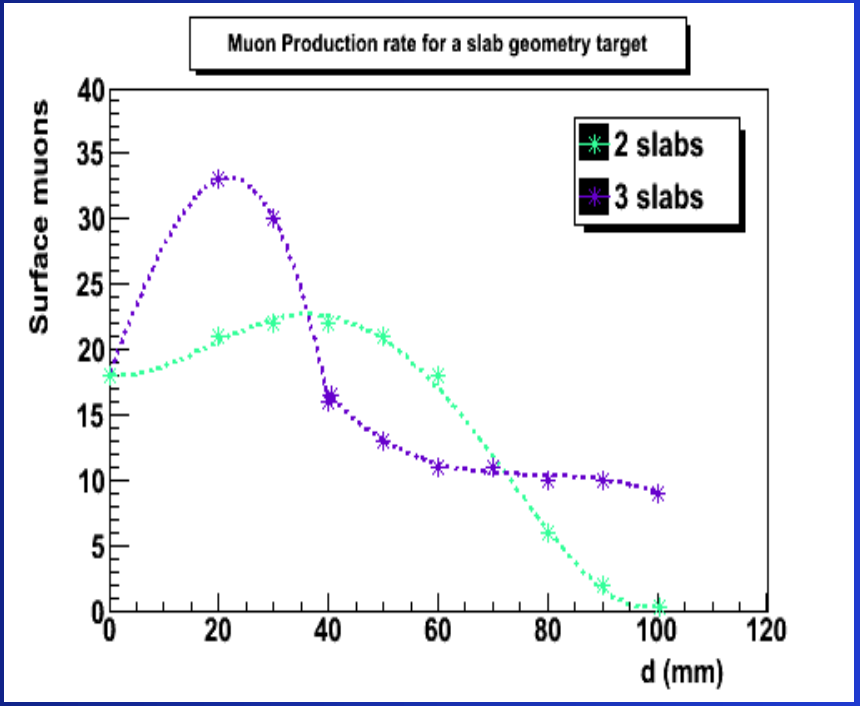
- To preserve the proton transmission we cannot increase the target thickness
- Target is split into two and three slices (total thickness is still 7 mm)
- Distance between slices is varied
- Muons are detected in the spherical shell and also in the ISIS beam window

Variation with Distance

Detector: spherical shell



Detector: ISIS beam window



-When slices are too close, a fraction of muons do not reach the detectors because of channeling between slices

- muons with divergence of 35 mrad horizontally and 180 mrad vertically are accepted in the beam window

Muon Yield

- Having a slices target design results in a higher surface muon yield
- **For two slices geometry, the muon yield is increased by 28% for 40 mm distance with respect to the present target design configuration**
- **For three slices geometry, the muon yield increases by 88% for the optimum distance of 20 mm**

BNCT and Radioisotope Production

BNCT (Boron Neutron Capture Therapy)

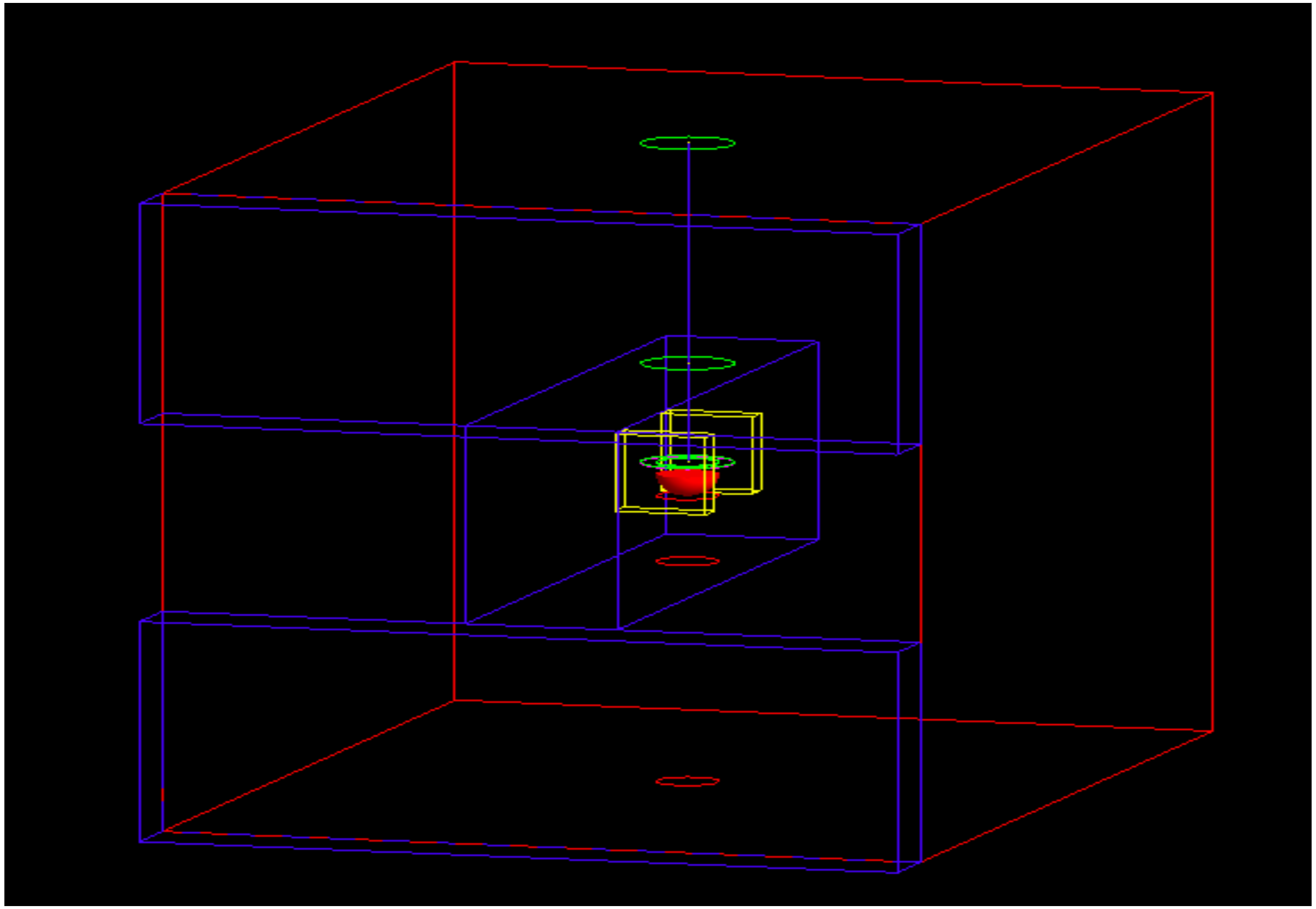
- Study is part of a proposal to establish a BNCT facility at University of Birmingham
- Facility based on high current, low energy accelerator

Aim : to irradiate the B containing tumor with thermal neutrons

$$^{10}B + n \rightarrow {}^{7}Li + {}^{4}He$$

- n produced in a natural Li target
- n moderated to epithermal energies with D2O poisoned with ^{6}Li to remove thermal neutrons
- Ep = 2.5 – 3 MeV ; proton beam current 10 mA
- healthy tissues spared if the B is located only within the tumor

BNCT – schematic design

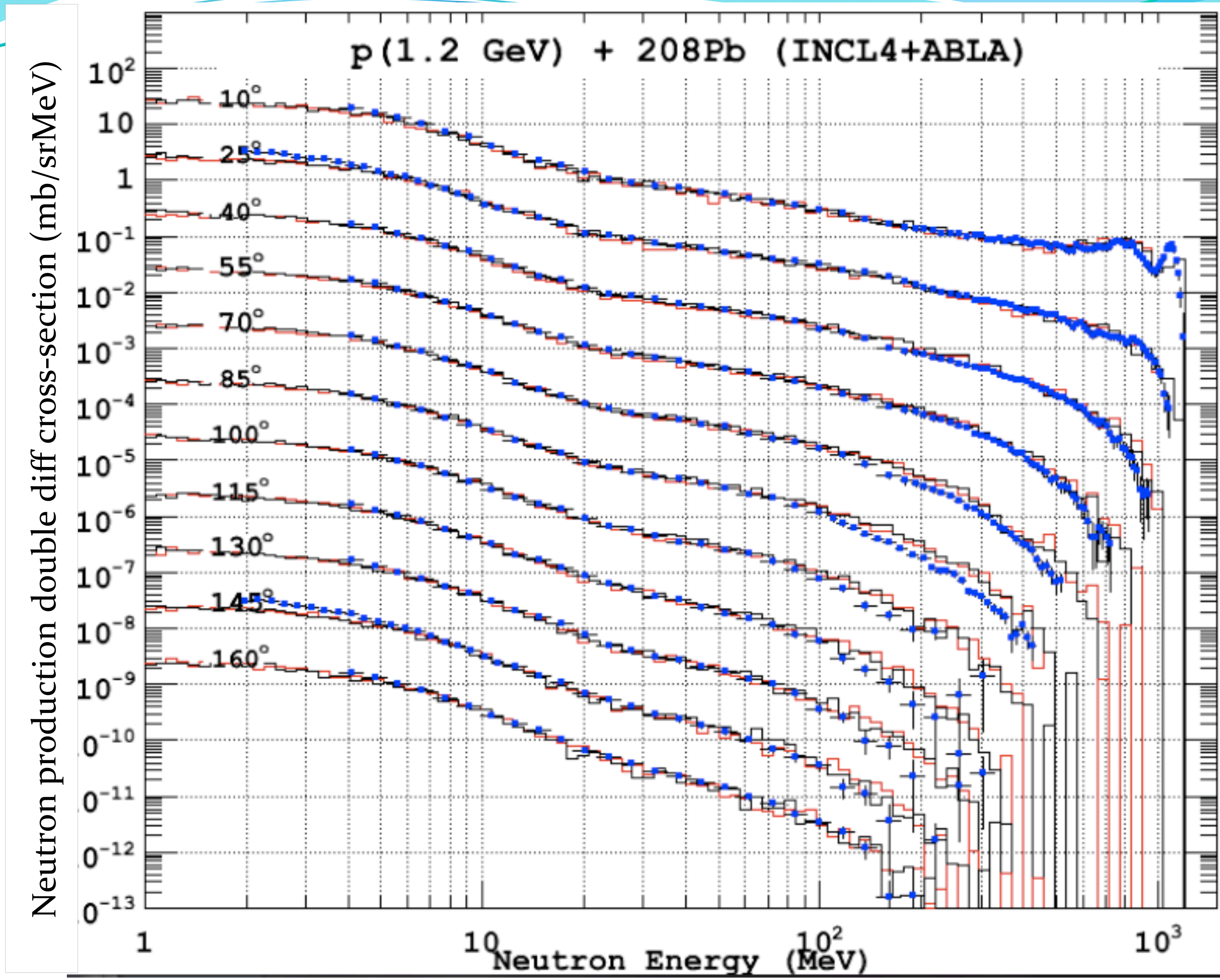


Work is ongoing (PhD student Naomi Ratcliffe)

Modeling neutron spallation processes in ADS using GEANT4

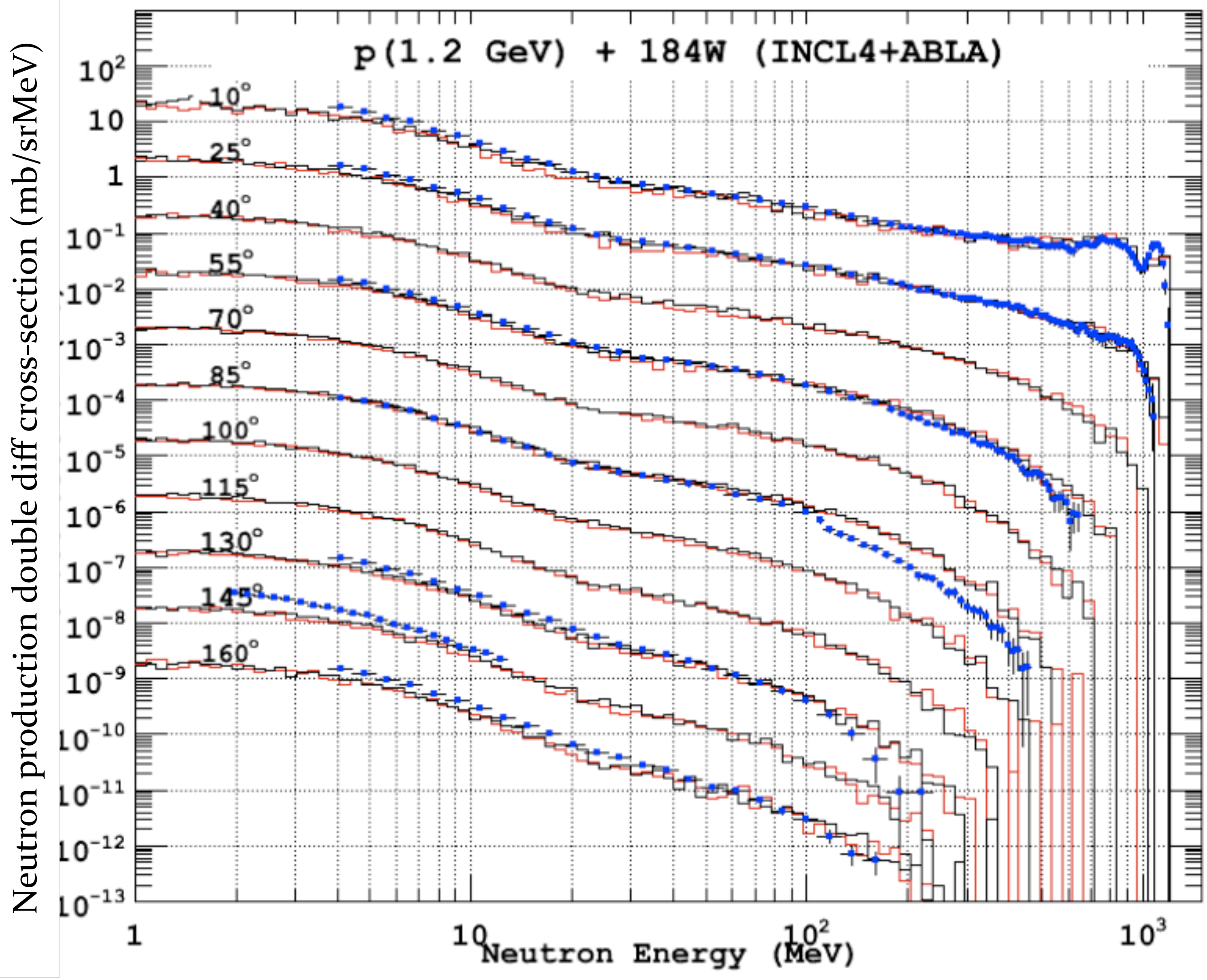
GEANT4 simulation details

- For neutron energies below 20 MeV, the high-precision models were selected. These models use the ENDF/B-VII, JENDL, MENDL-2 and other data libraries.
- The S(a,b) coefficient for the correct treatment of neutron scattering on chemically bound elements in the thermal region has also been implemented in GEANT4.
- The Liege intra-nuclear cascade model was selected together with the independent evaporation/fission code ABLA. This model has been validated against experimental data for spallation processes in many different heavy elements. The Liege model is largely free of parameters and is preferred by validation. The incident energies below 100 - 150 MeV the GEANT4 PreCompound model is being used.
- In MCNPX, the Bertini model is used by default for nucleons and pions, while the ISABEL model is used for other particle types. The Bertini model does not take into account the nuclear structure effects in the inelastic interactions during the intra-nuclear cascade, effects which become important at incident energies below 100 MeV.

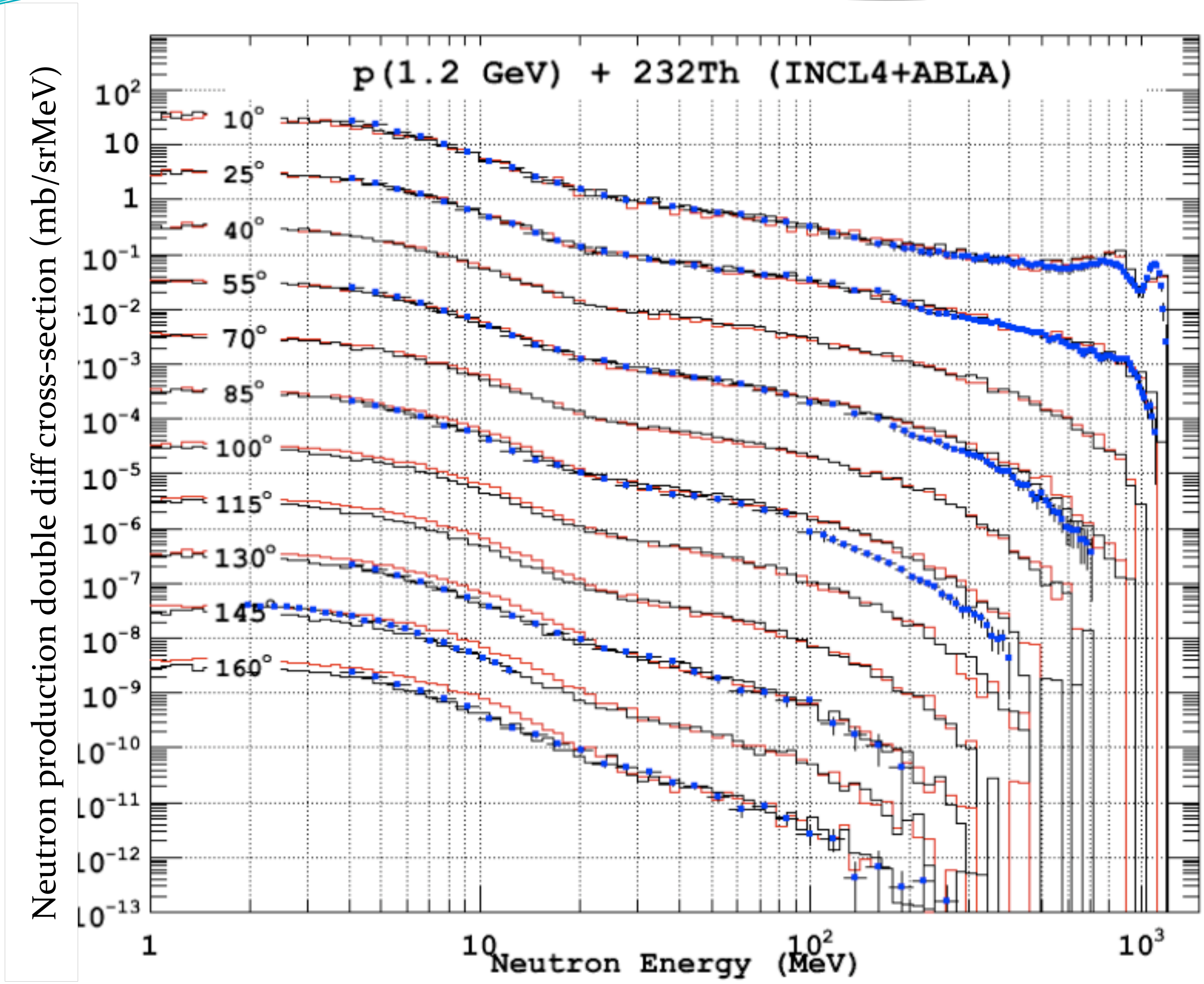


p(1.2 GeV) + 208Pb (INCL4+ABLA)
Neutron production double diff cross-section (mb/srMeV)
Neutron Energy (MeV)
10°
25°
40°
55°
70°
85°
100°
115°
130°
145°
160°

and for Tungsten :



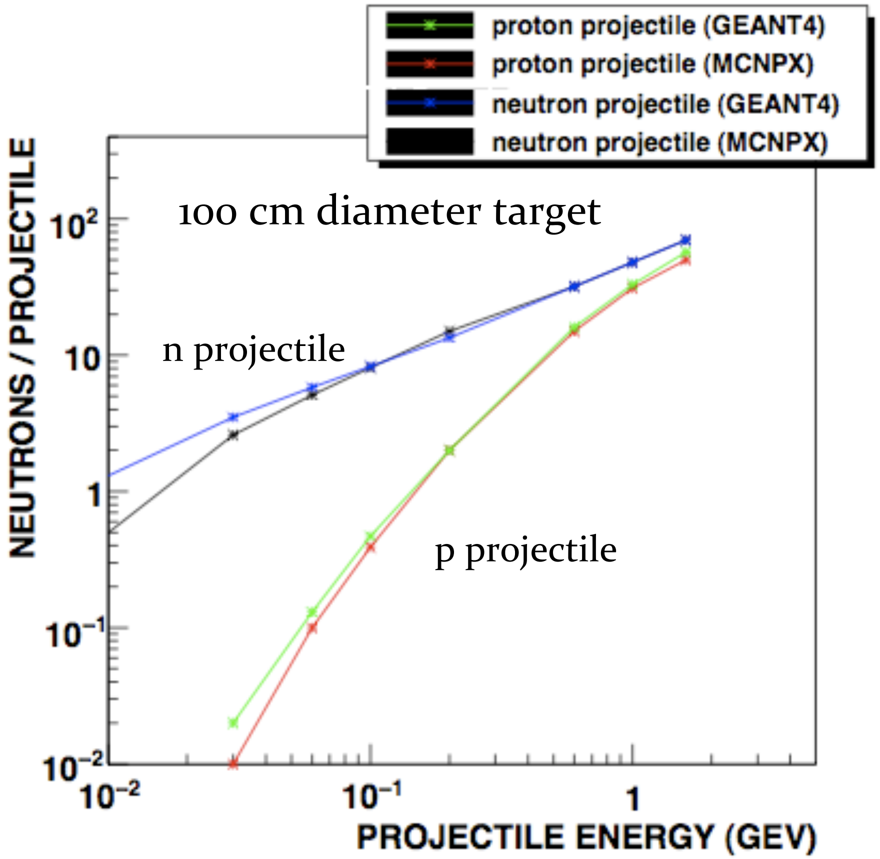
and for Thorium :

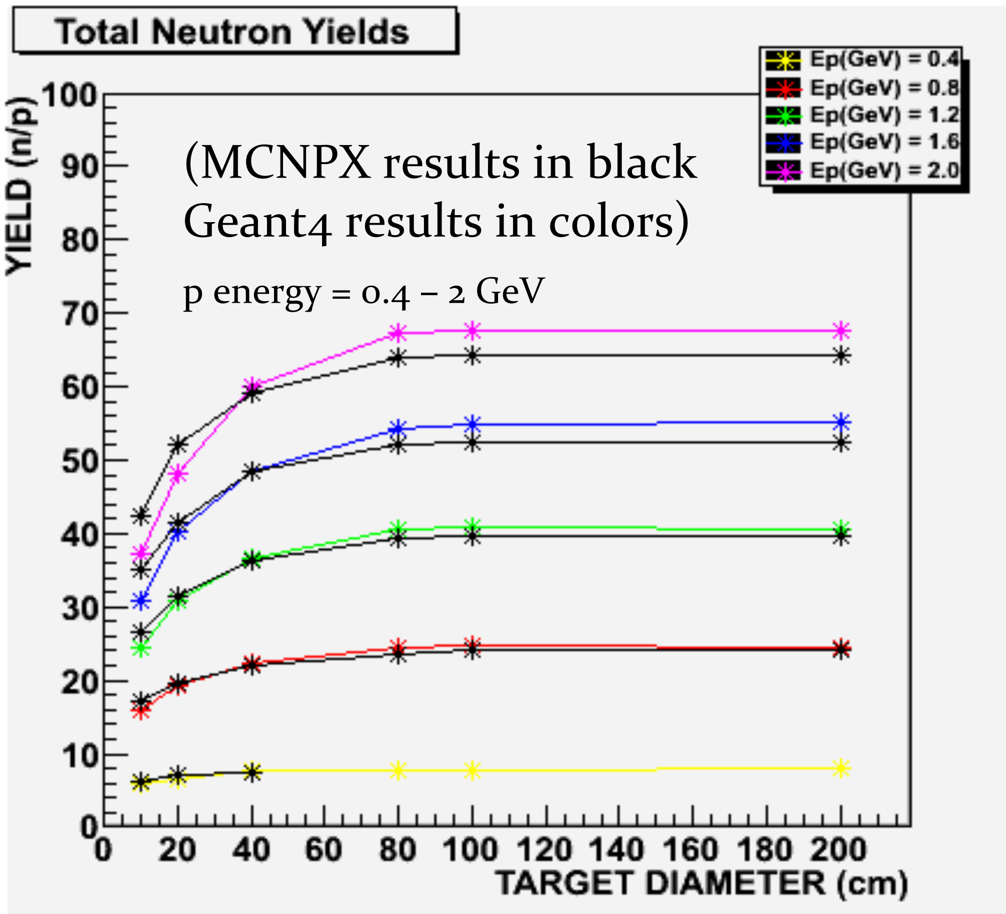


Geant4 – MCNPX benchmarking

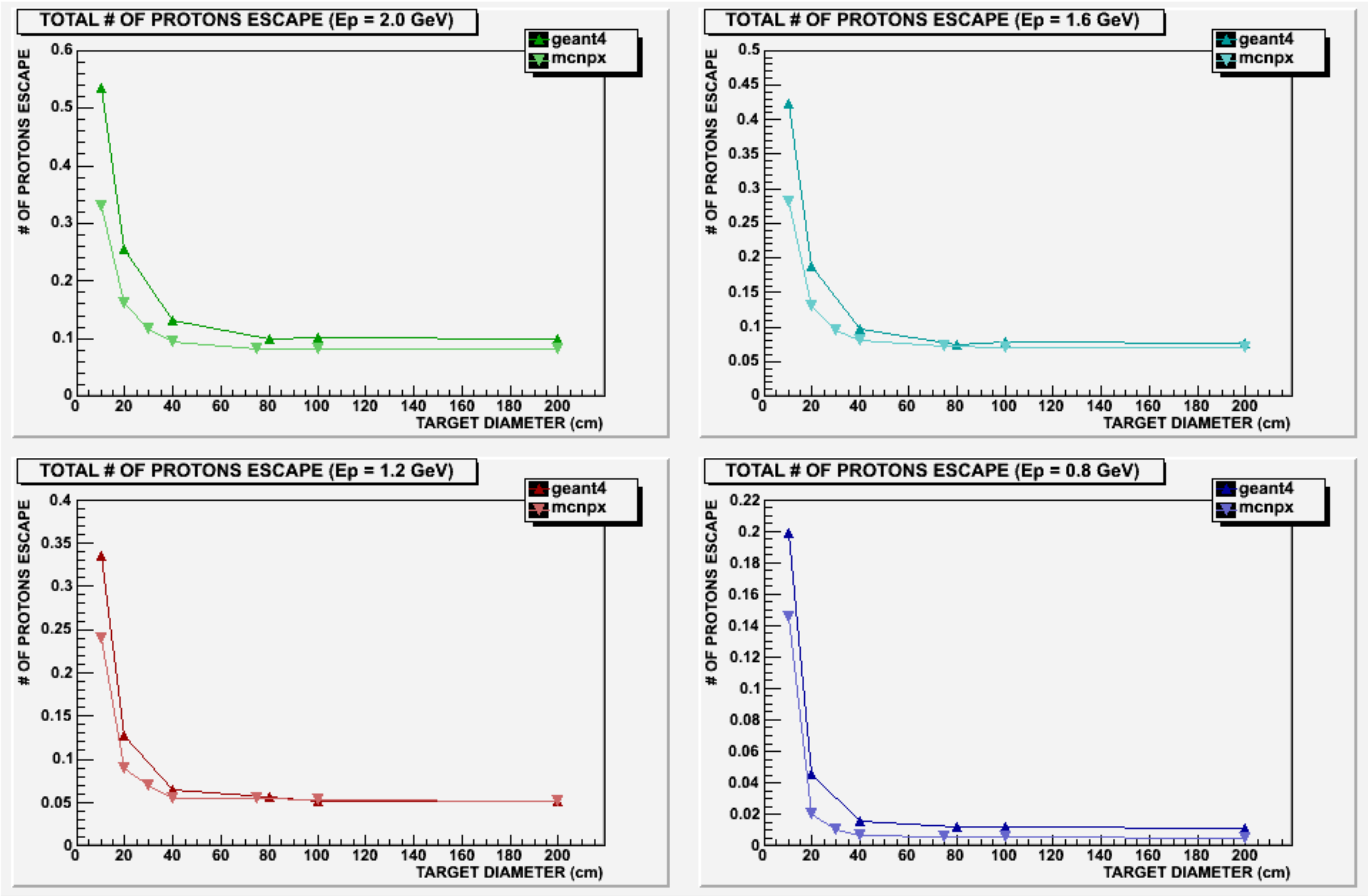
The MCNPX results are taken from previous published work (M.A. Lone and P.Y. Wong, Nucl. Inst. Meth. A 362 (1995) 499-505). The Geant4 results are my own current results.

Neutron yields vs. projectile energy and target diameter

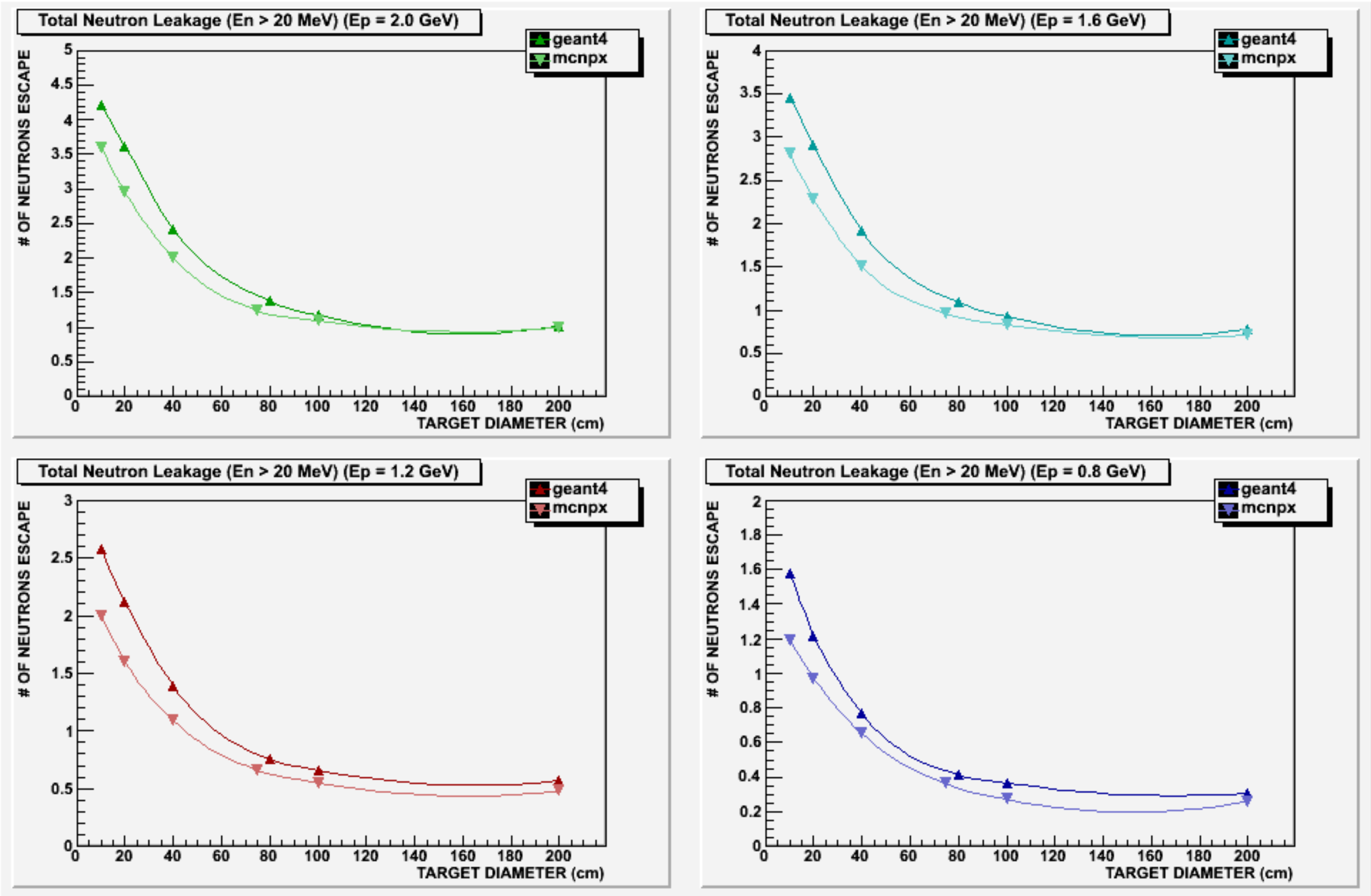




Proton leakage from the target for different proton energies vs. target diameter (GEANT4 vs MCNPX) (per incident proton)



(High-energy) neutron leakage from the target for different proton energies vs. target diameter (GEANT4 vs. MCNPX) (per incident proton)



Future Plans

- a continuation of neutron optimization studies for the ESS;
- neutron production and moderation studies for the ISIS upgrades;
- generic neutron studies for possible future projects such as ADS;