EUROPEAN SPALLATION SOURCE

Geant4 tools for simulating instrument backgrounds

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Overview

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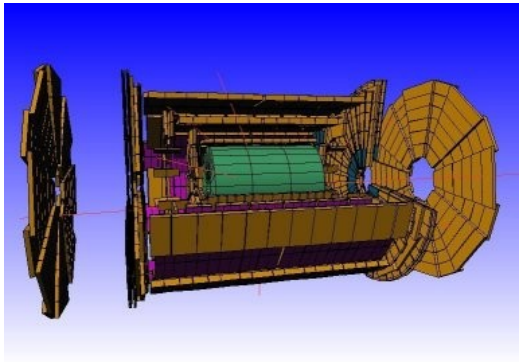
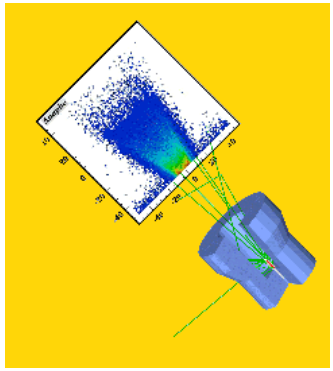
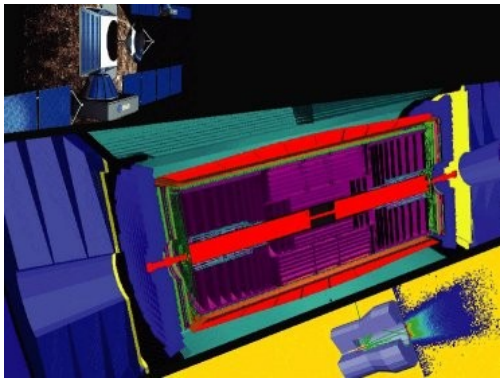
- Geant4 overview
- Physics Benchmarking
- Geant4 tools
  - Long beamline simulations
  - Supermirror physics
  - Grain size patch
  - (Global weight window generator)
- Outlook

Geant4 overview

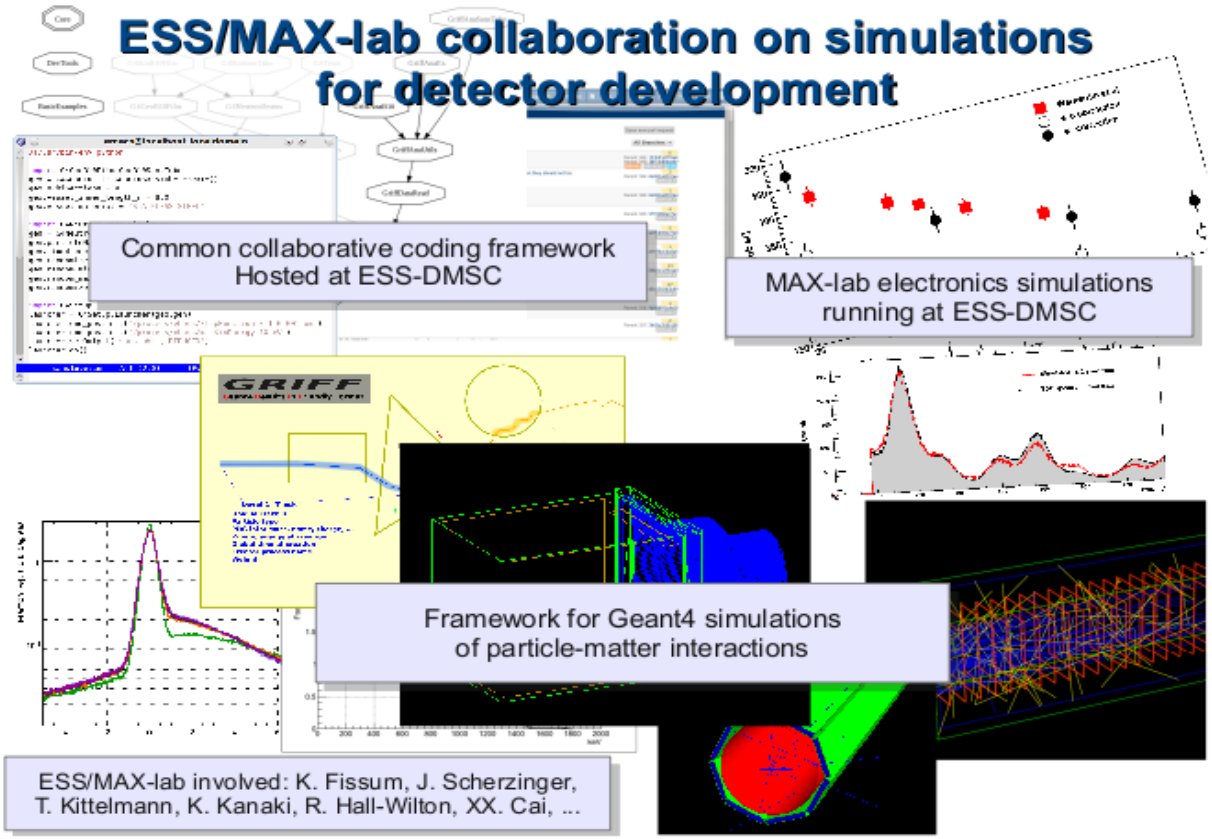
- High-energy physics code: https://geant4.web.cern.ch/geant4
- Open source code
- Object oriented (C++)
- International Geant4 collaboration (large user base)
- Used in nuclear and particle physics, medical sciences and space sciences



Geant4 simulations

- Heavily using the detector group framework
- Also running vanilla geant4 10

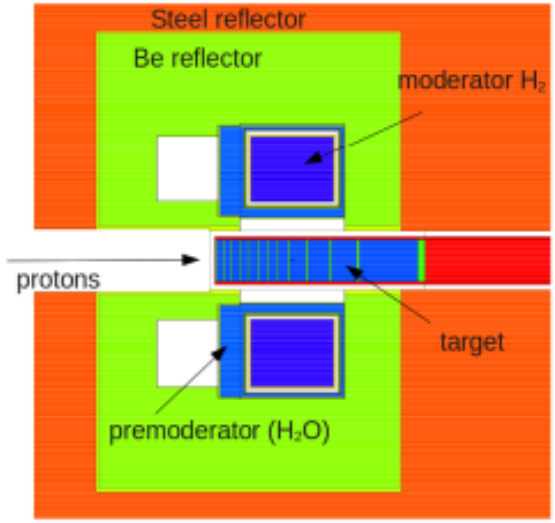


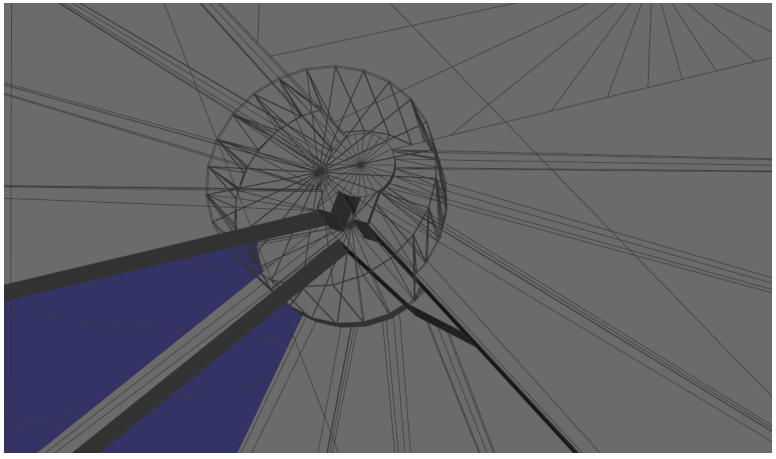
Some relevant features of Geant4

- Reference physics lists packaged with geant4 contain best guesses for the physics
  - All standard EM processes
  - Several high-energy cascade models available, Bertini, Binary, and INCL++
  - High-precision neutron data (G4NDL) based largely on ENDF/B-VII and also on JENDL
  - Thermal scattering for ~20 materials (LH_2,H_2O…)
- Supports weight windows and geometrical splitting
- Users should be aware of:
  - No weight-window generator packaged with Geant4
  - No error calculation included by default (user must program the calculation in)

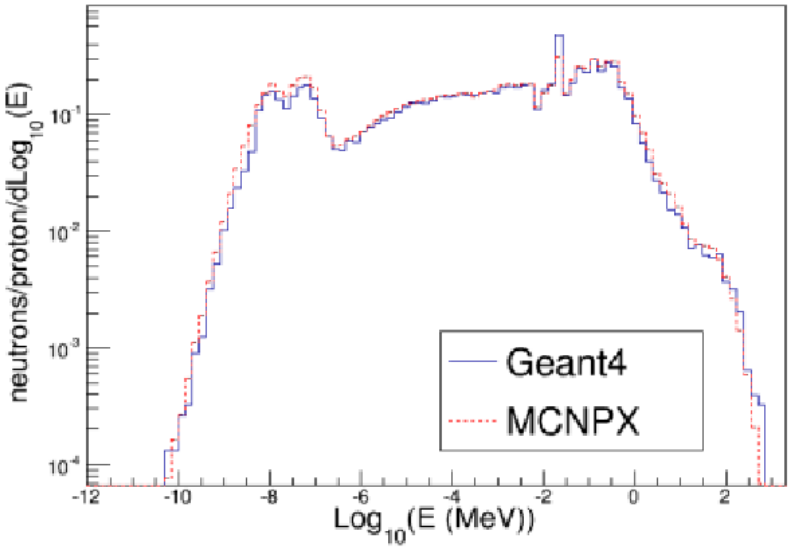
Spallation target benchmarking

MCNPX ESS TDR model





Geant4 model



Sum over all extraction areas

Long beamline simulation

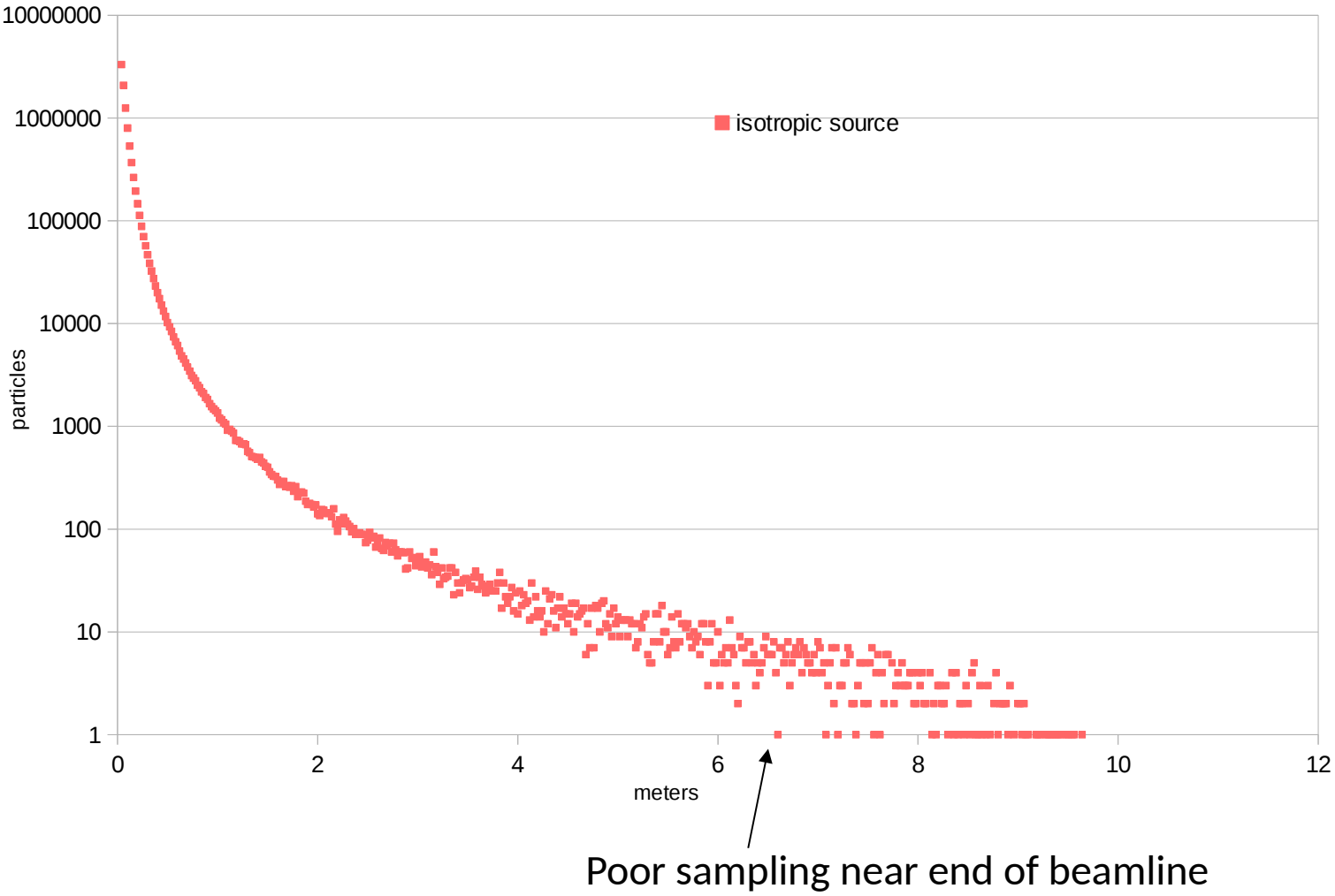
- Current through a beamline decreases as $1/r^2$ as distance from source

- The current crossing the wall of the beamline at 150 m is roughly seven orders of magnitude smaller than at 1 m

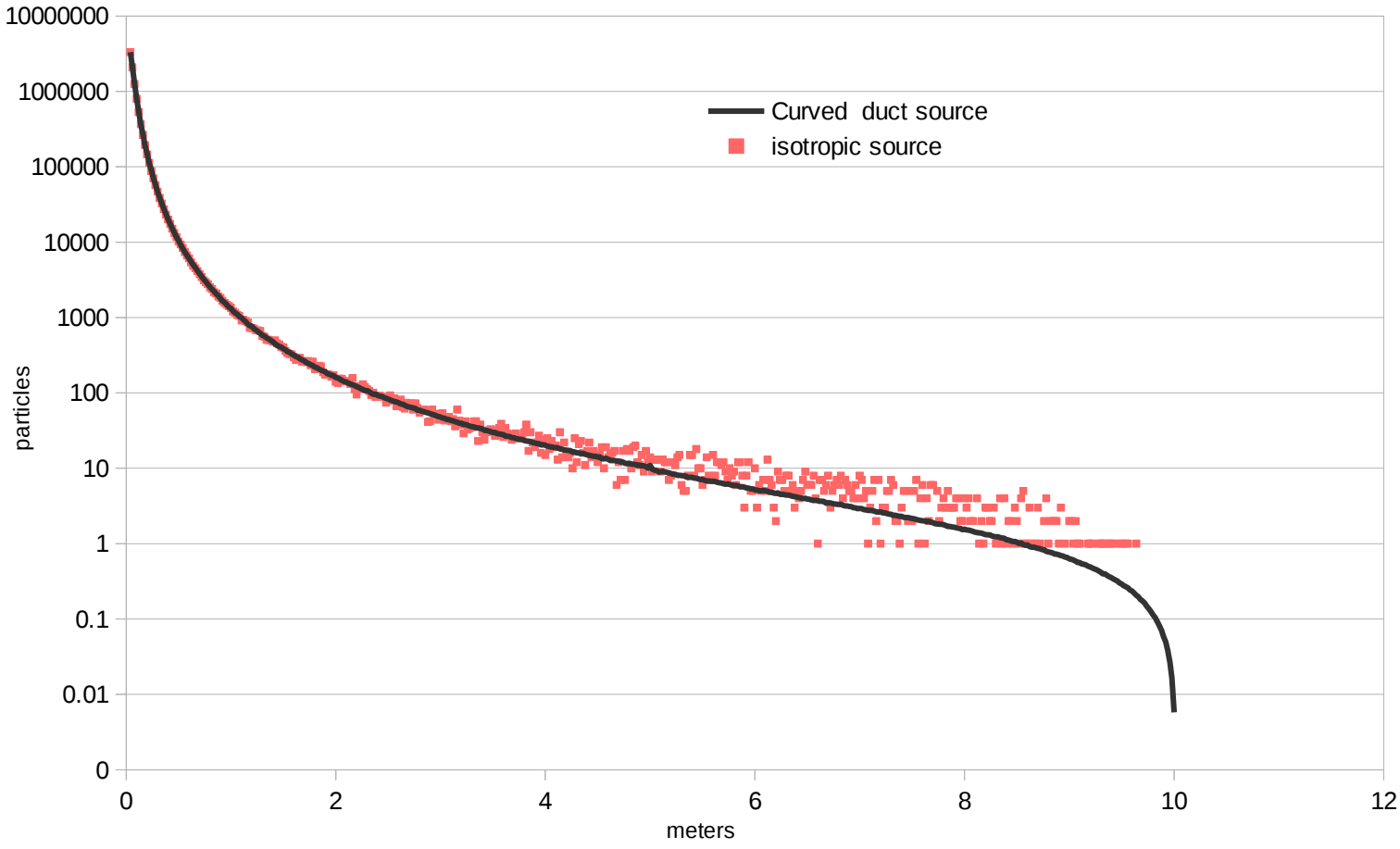
- To reduce the variance, we introduced a duct source option in Geant4, following the work in K. Nita et al., Progress in Nucl. Sci. and Tech. 1 (2011) 1

- The idea is to equalize the wall current at any point in a beamline by changing the weights of the neutrons

Long beamline simulation

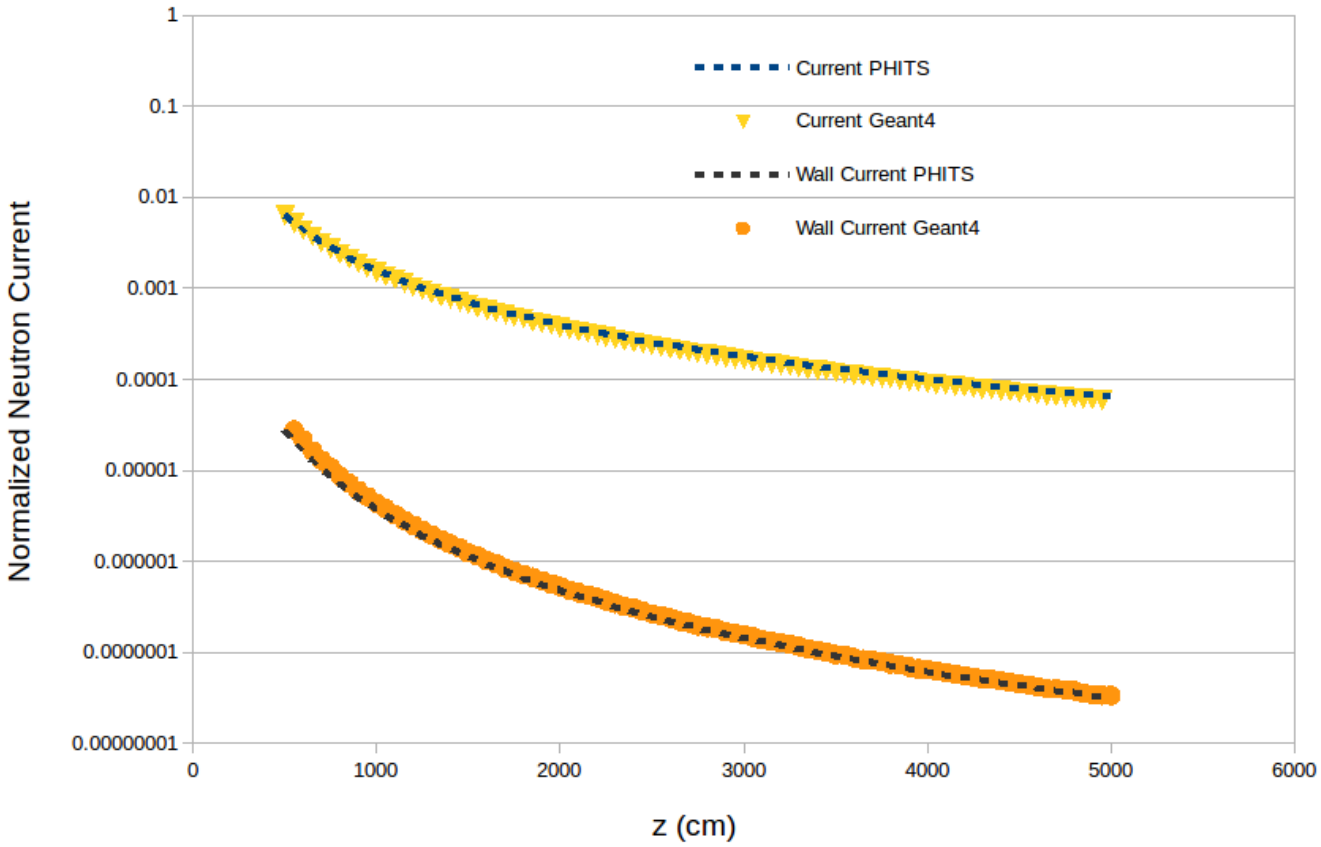


Duct source variance reduction



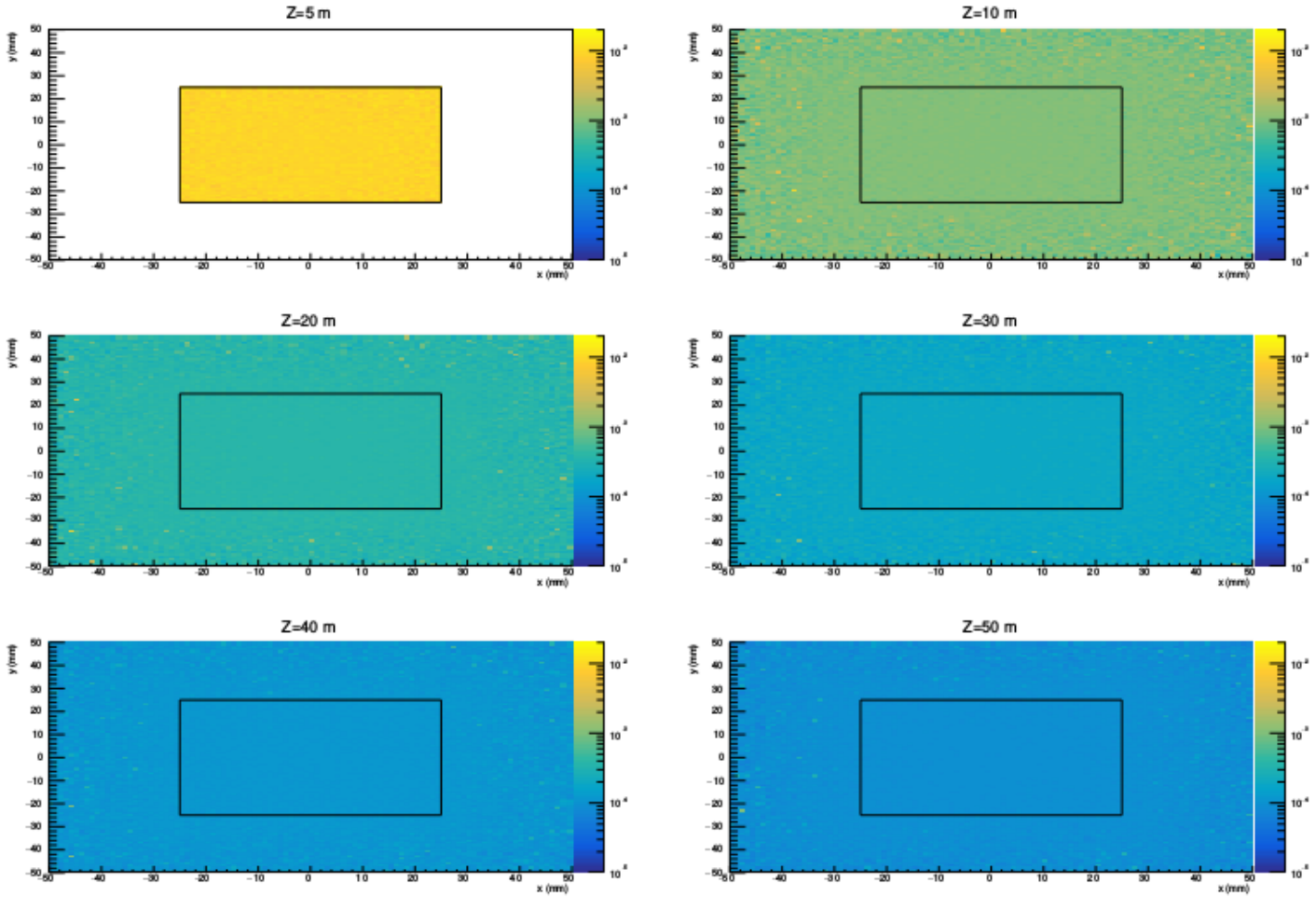
With duct source – uniform sampling along entire beamline

Duct source variance reduction



Benchmarked against PHITS

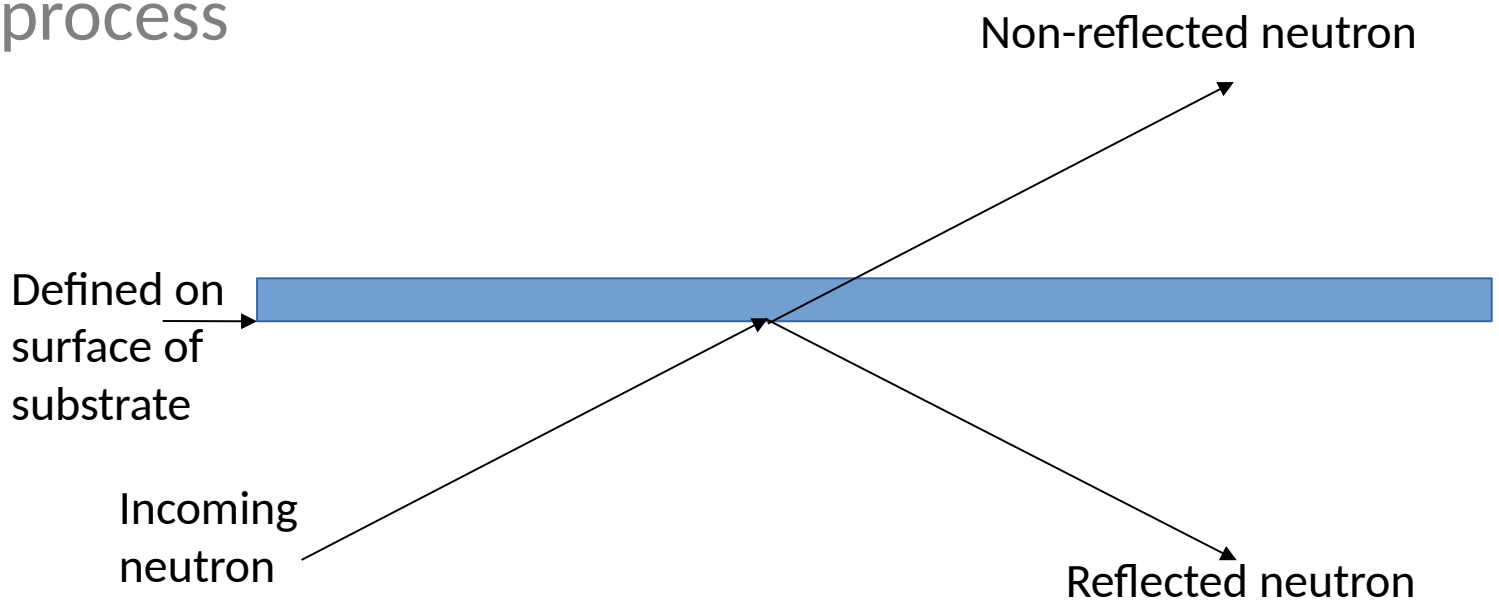
Duct source variance reduction



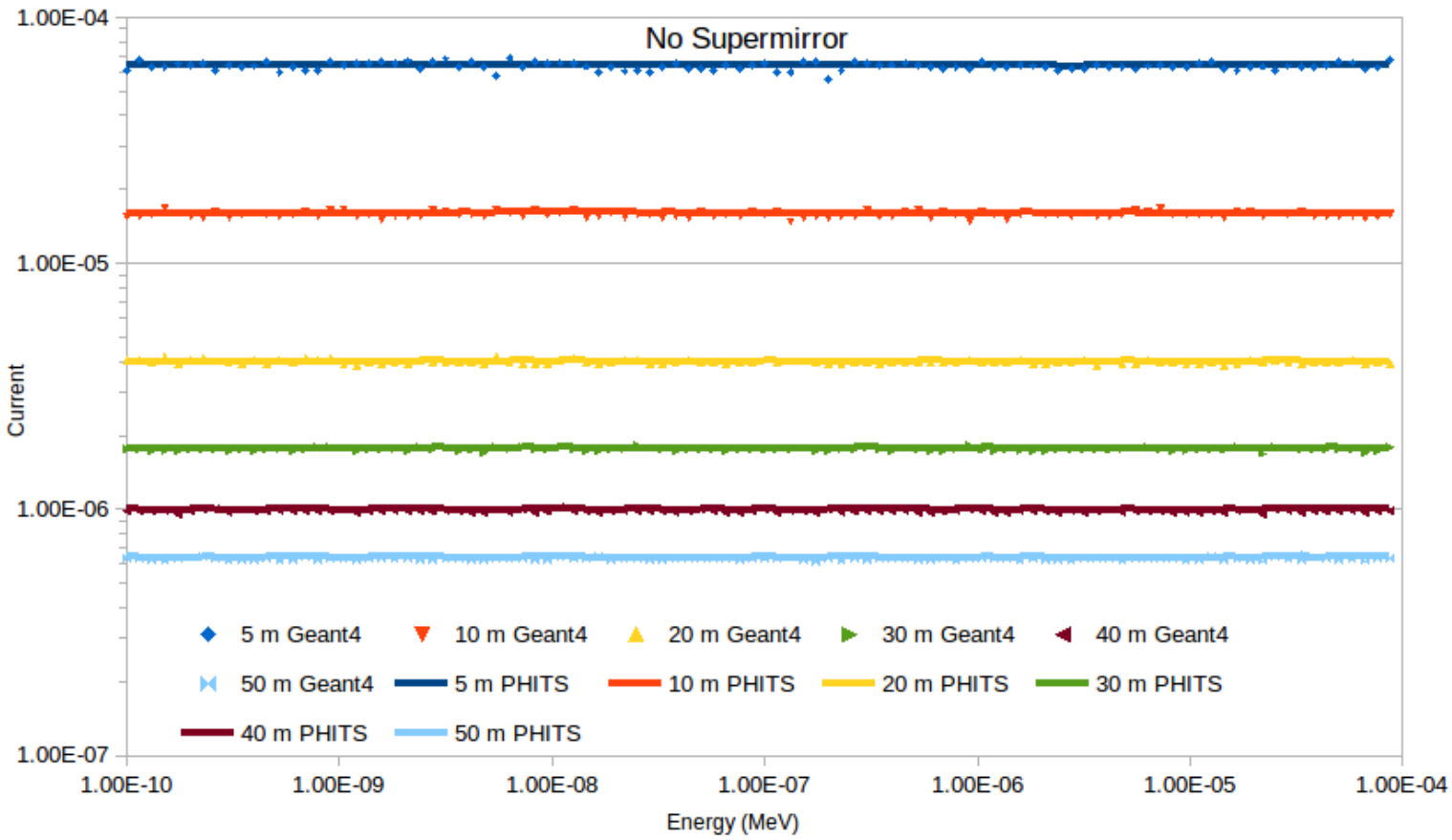
Uniform neutron distribution along the guide

Supermirror physics

- Supermirror physics not included in standard Geant4, therefore we have implemented a supermirror physics module
- Super-mirror reflectivity function defined as a biasing process

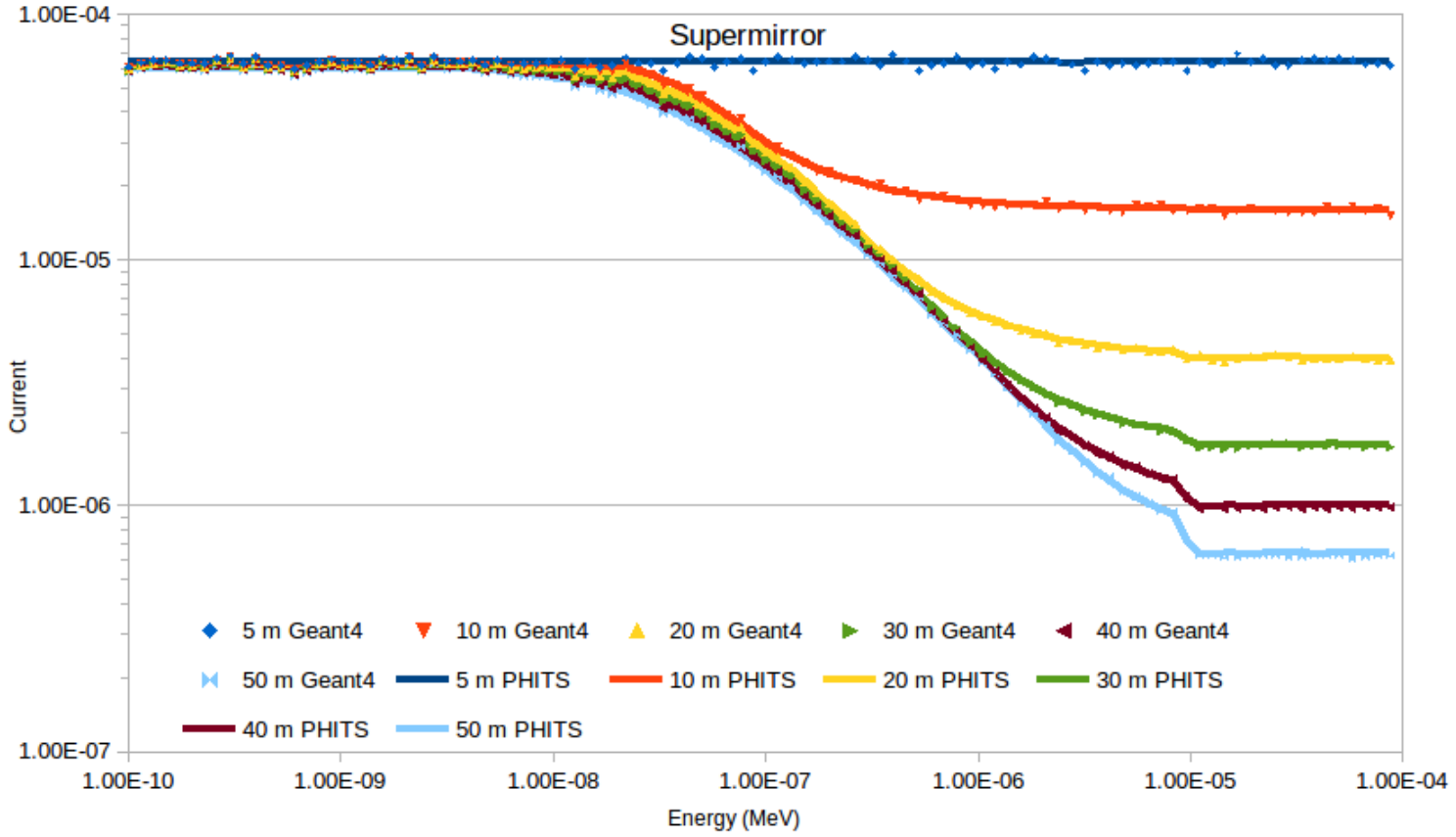


Supermirror physics – no supermirror + duct source



Benchmarked against PHITS

Supermirror physics – with supermirror + duct source



Benchmarked against PHITS

Supermirror physics – neutrons outside the guide

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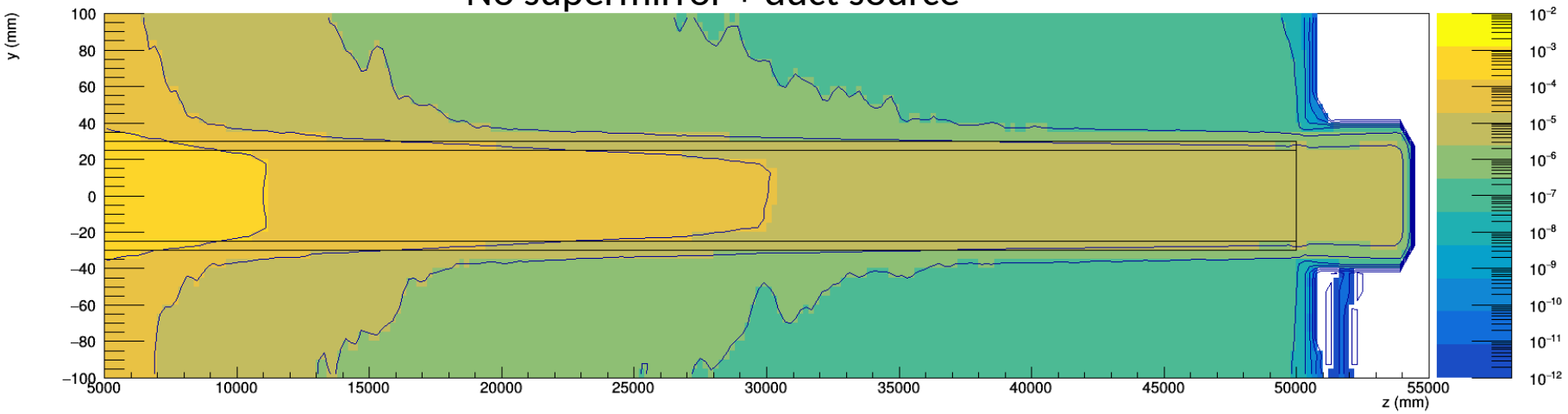
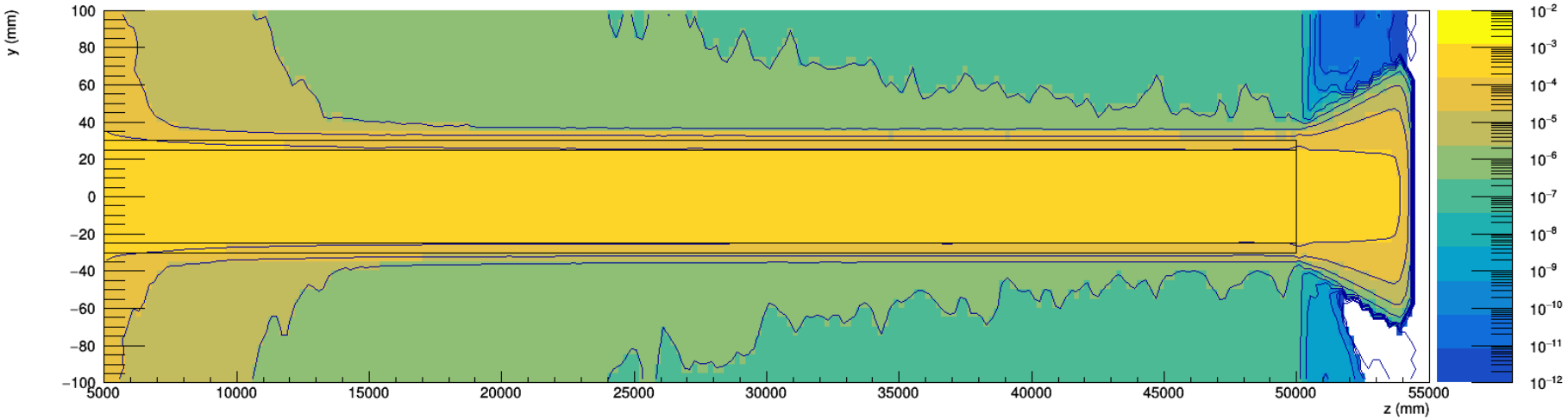
No supermirror + duct source

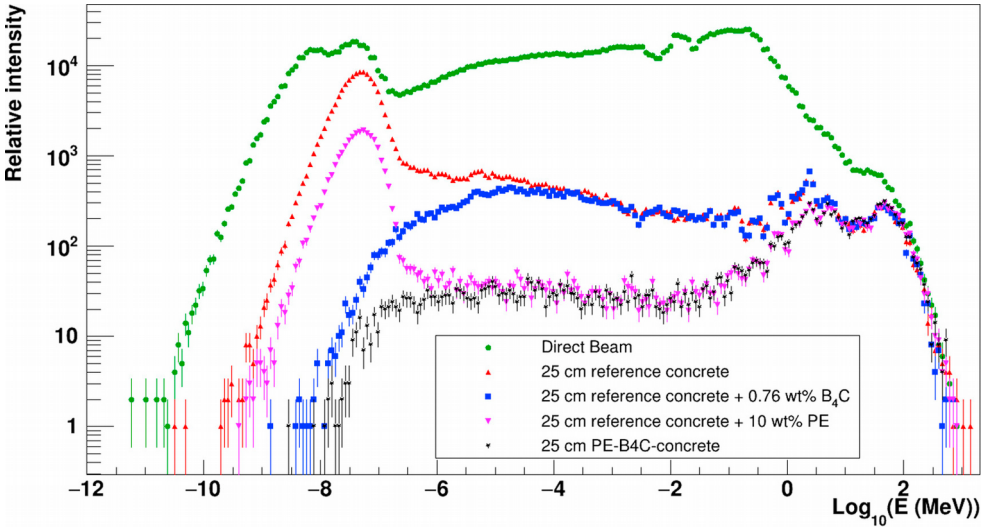


Supermirror + duct source



Grain size patch

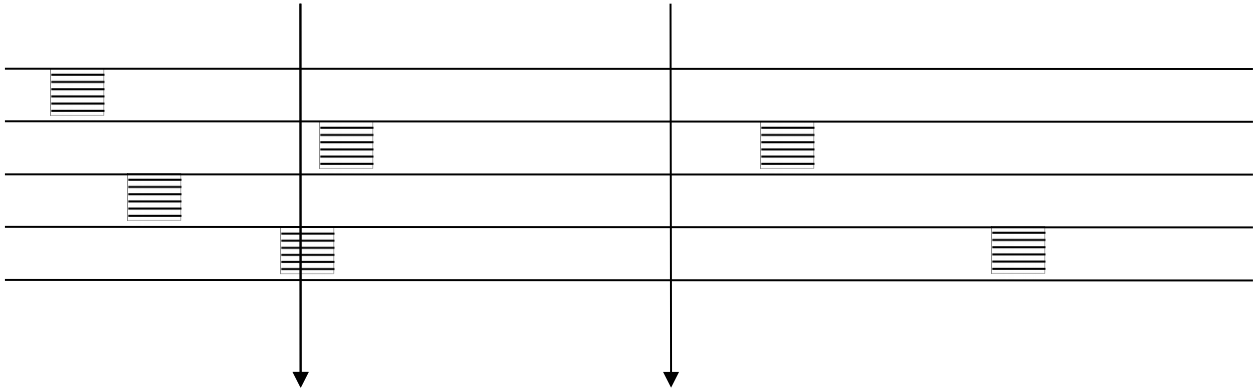
- ESS has developed it’s own specialized shielding concrete
- Contains plastic beads and B4C grains



D.D. DiJulio et al., NIMA 859 (2017) 41

Grain size patch

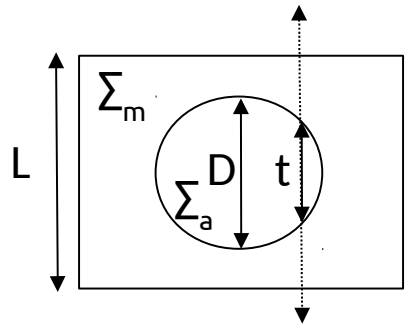
- At low energies, the grain sizes can result in a reduced absorption for the material



- A simple model was proposed by W.R. Burrus, “Raidation Transmission Through Boral and Similar Heterogenous Materials Consisting of Randomly Distributed Absorbing Materials”, ORNL-2528 1960

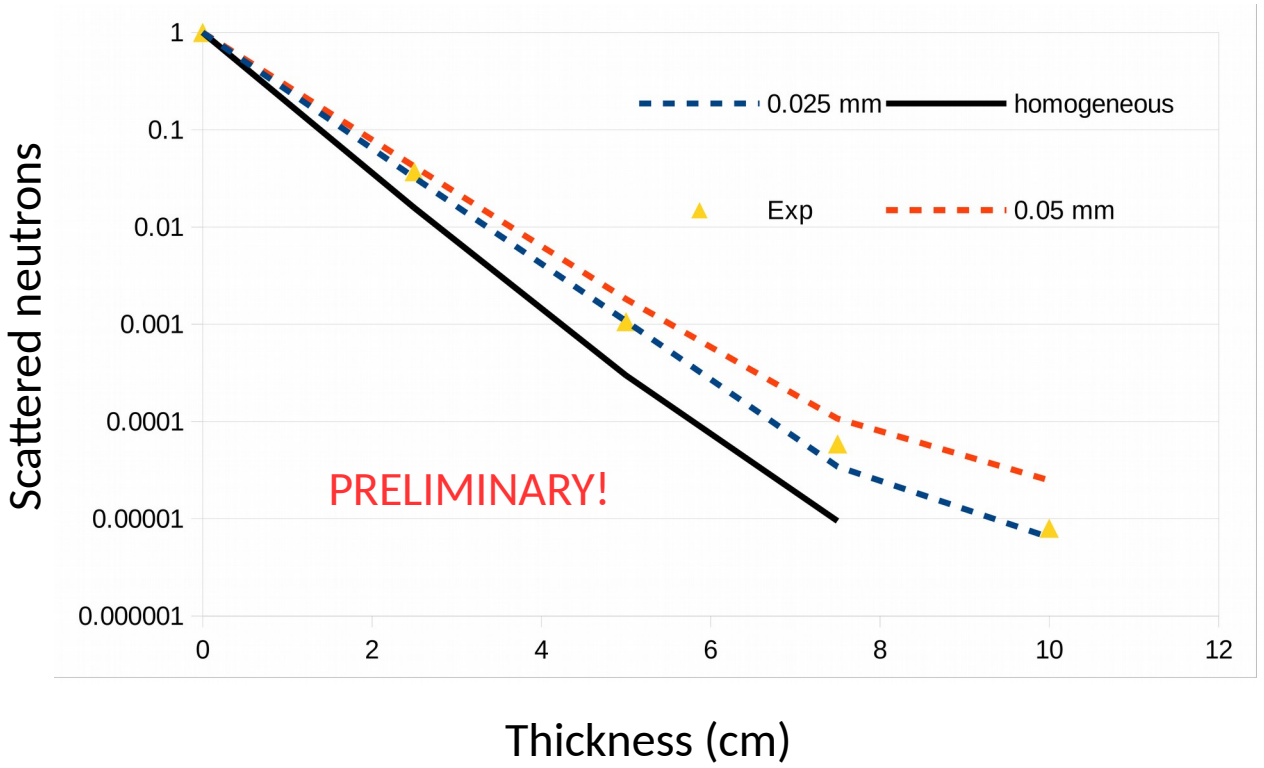
Grain size patch

- We created a Geant4 patch, based on the work presented in the paper, T. Yamamoto, Progress in Nucl. Sci. and Tech. 4 (2014) 404
- The model assumes the material is divided in N layers with the following structure



- An effective homogenized macroscopic cross-section is calculated for a specific grain size
- Cross-section data is modified on the fly during the Geant4 simulation.

Grain size patch



Conclusions

- Several tools in Geant4 for simulation of long beamlines and neutron transport
- Grain size patch implemented for borated shielding materials
- Future work: Realistic beamline geometry

Spallation target benchmarking

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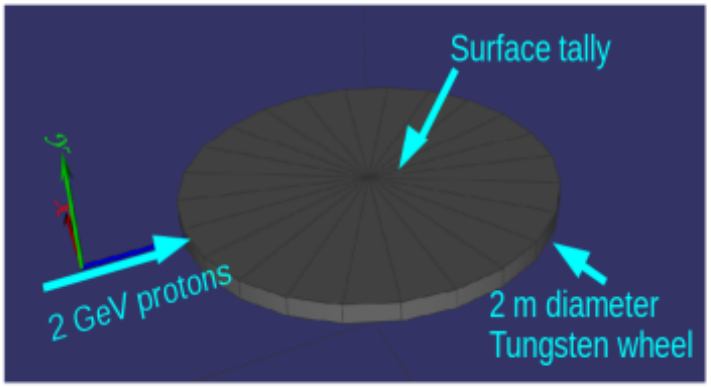
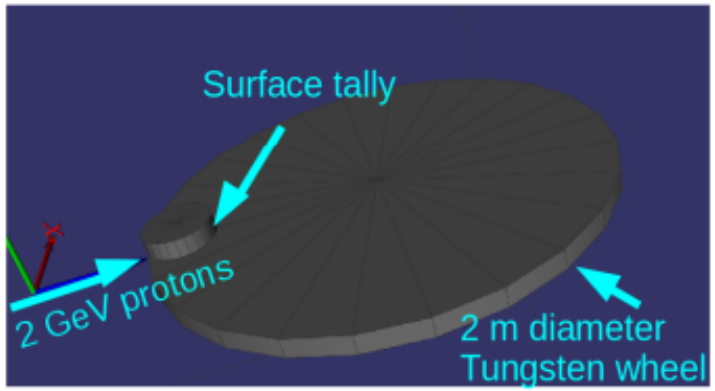
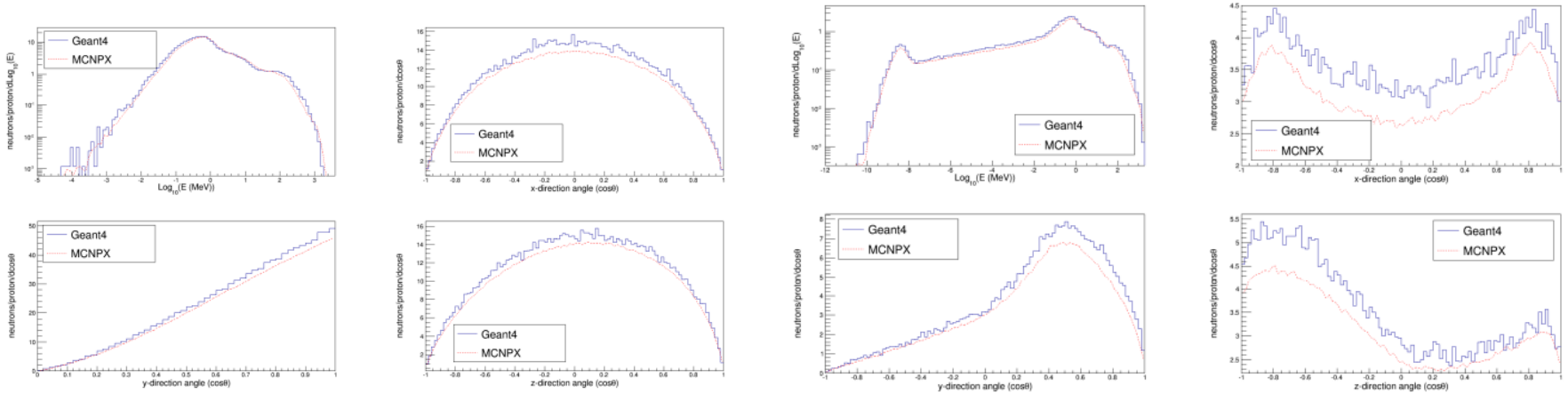
Benchmarking against MCNPX







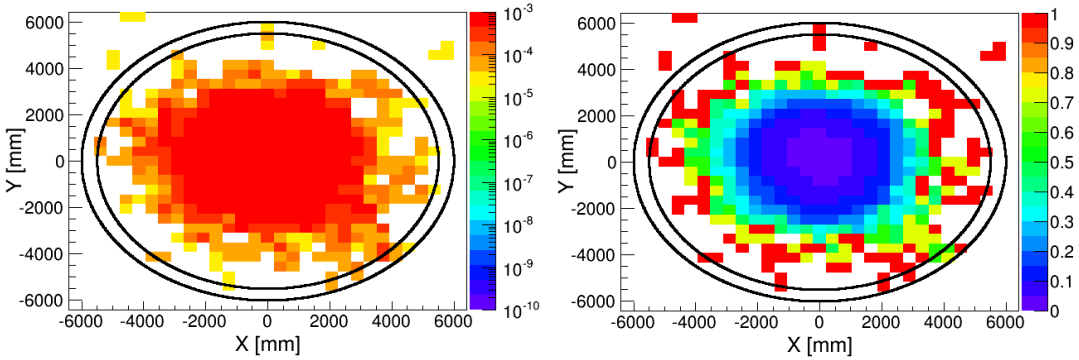
MCNPX simulations provided by Konstantin Batkov

Weight-window generator

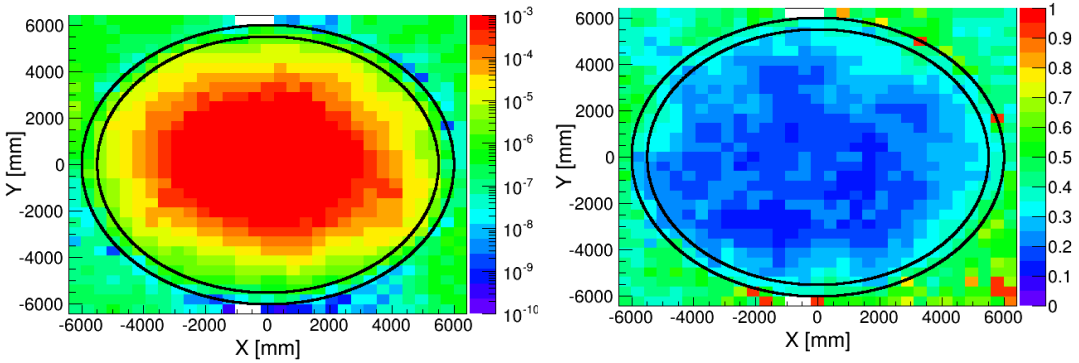
- Implemented a general weight-window generator for Geant4 based applications
- Uses a Global Variance Reduction (GVR) method
- Encourages a uniform population of flux throughout the whole geometry

Flux maps

Relative error maps



Analog simulation of ESS monolith



GVR simulation of ESS monolith

J. Stenander and D.D. DiJulio 2015 Nucl. Instrum. and Meth. in Phys. Res. A 798 167