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Spallation neutron distributions

Area of growing interest: Neutron production by spallation

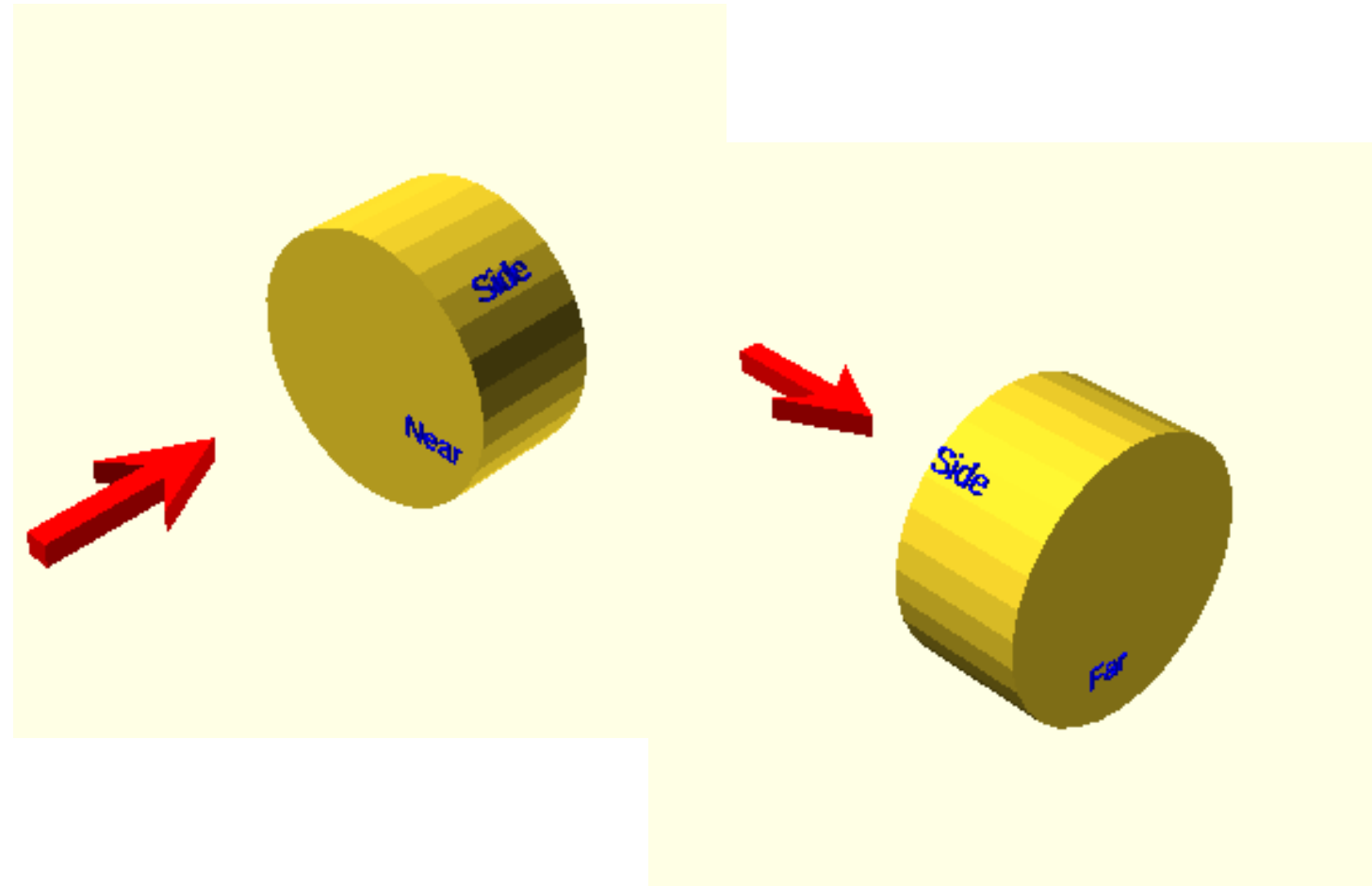
Purpose: To define the spallation neutrons in simple source terms for neutronic studies for ADSR reactors.

Target and beam:

Target- lead target, a cylinder with 30 cm radius and 30 cm length.

Beam - ranging from 100 MeV to 1400 MeV

Neutron distributions recorded from near end , far end and the sides of the cylindrical target.



Simulation programs

Geant4 versus MCNPX

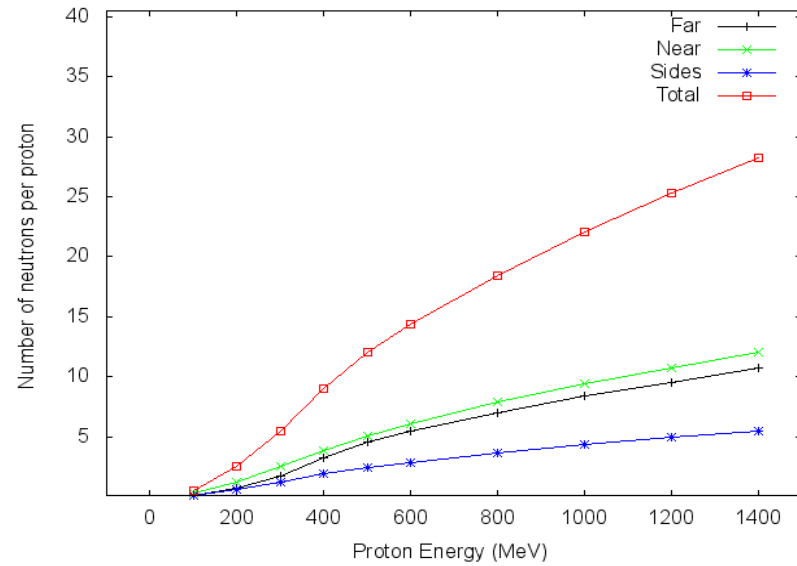
GEANT4 : Computations are performed using GEANT4 simulation code.

Physics lists: QGSP_BERT_HP and QGSP_BIC_HP.

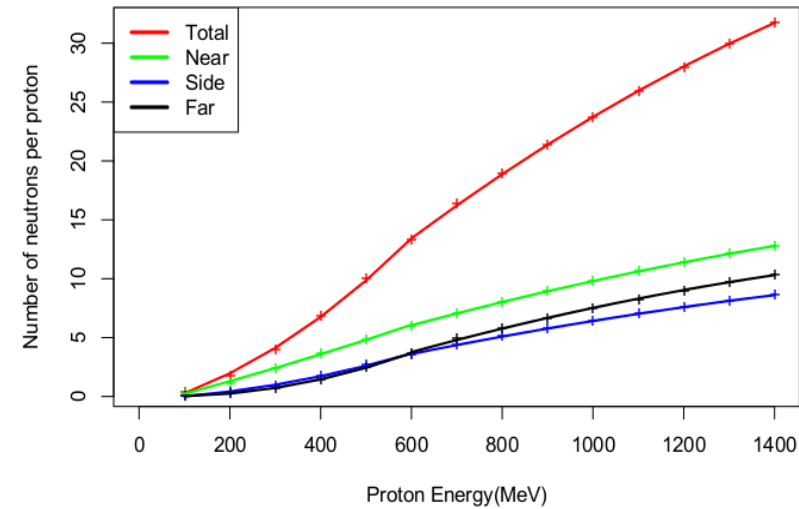
The data driven high precision neutron package (NeutronHP) is included in these models to transport neutrons below 20 MeV.

Benchmarking: The results obtained with GEANT4 are compared with the corresponding MCNPX predictions which was used with the default ENDF/B-V library.

Overall Numbers



GEANT4



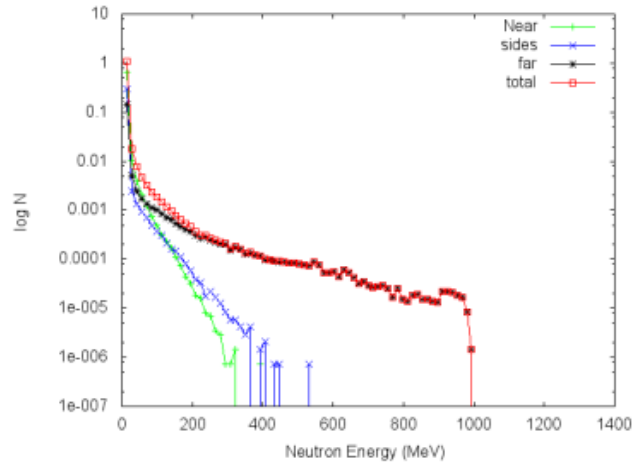
MCNPX

Good agreement between Geant4 and MCNPX.

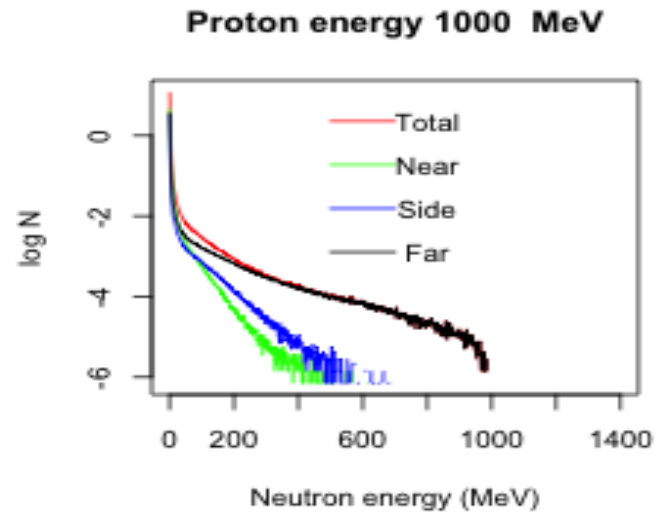
More neutrons are available at near face where the proton beam falls.

Very roughly linear. More accurate fit through two parabolas above and below 600 MeV.

High energy neutrons



GEANT4



MCNPX

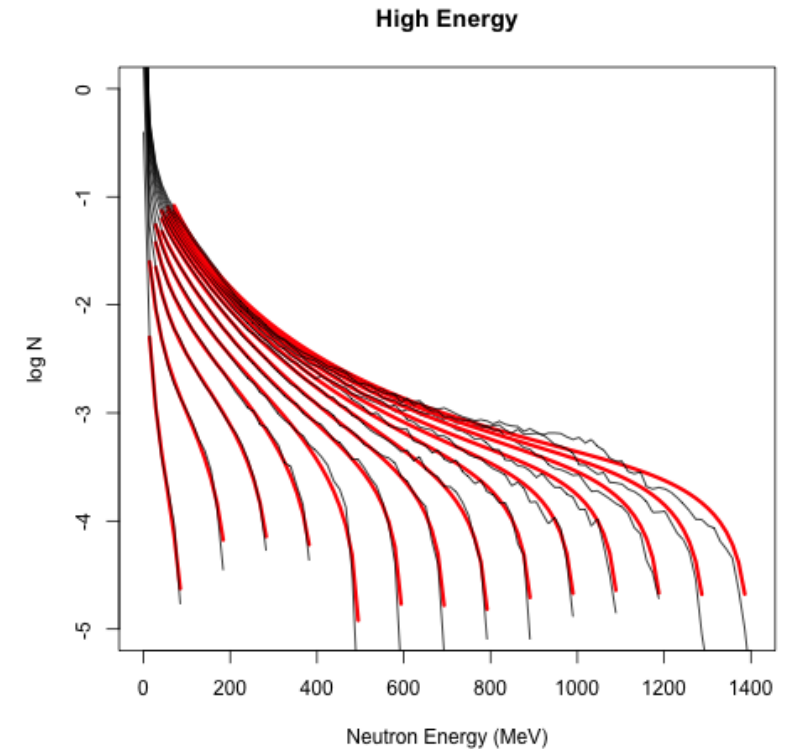
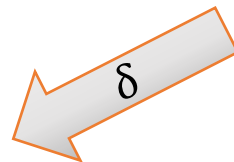
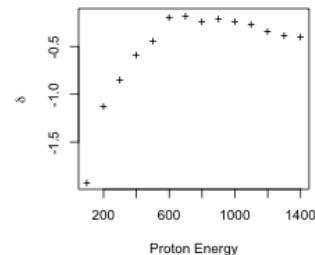
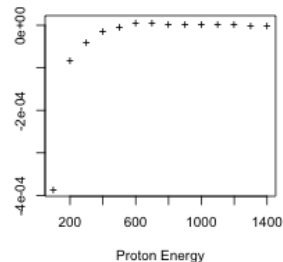
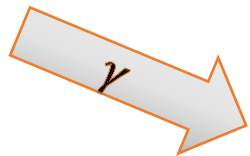
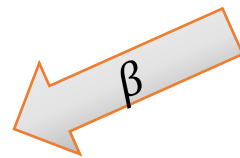
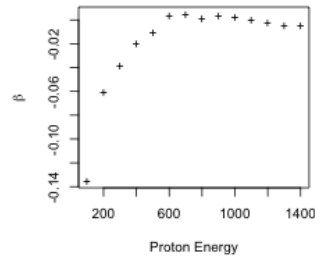
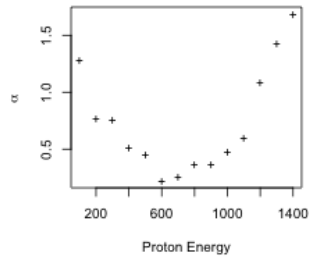
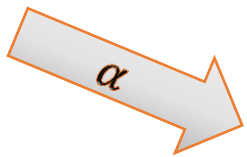
Effects of spallation appear in a tail of neutrons which falls roughly exponentially with energy, with an additional cutoff as the energy of the original proton is reached.

Spectra are plotted for 1000 MeV beam energy.

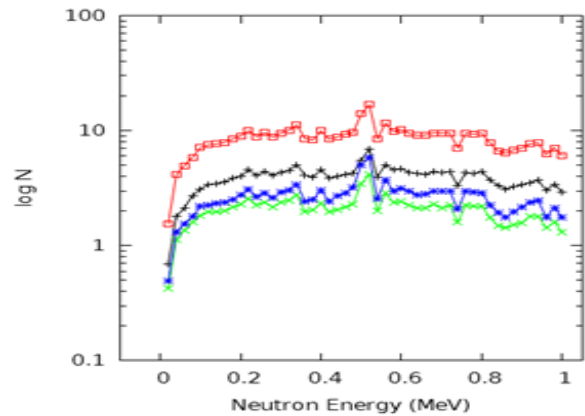
Parameterisation

These curves can be defined by

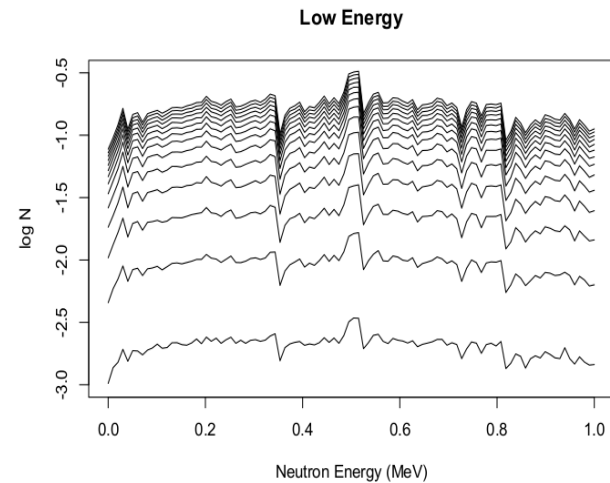
$$P(E) = \alpha \exp\left(-\beta E + \gamma E^2 + \delta \sqrt{E}\right) \left(1 - \frac{E}{E_p}\right)$$



Low energy neutrons



GEANT4



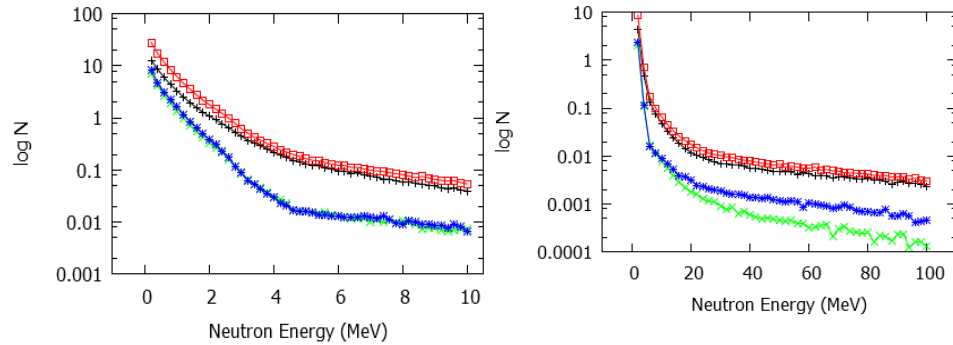
MCNPX

At low energies (below 1 MeV) the neutron spectrum is fairly flat and is similar from each face, in contrast to the high energy spectra (GEANT4)

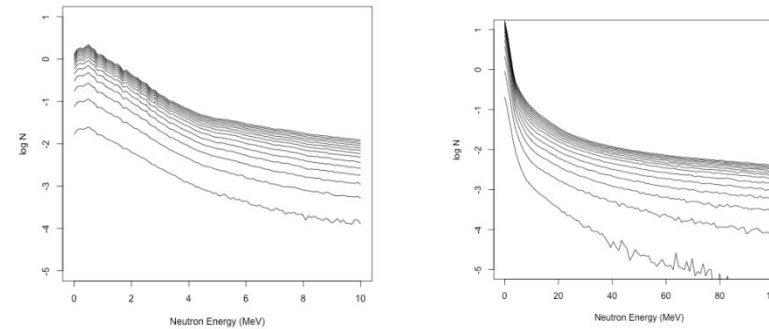
MCNPX figure shows that the spectrum is independent of beam energy.

The shape of neutron spectrum at low energies is dominated by cross sections in lead.

Intermediate energy neutrons



GEANT4



MCNPX

At low neutron energies - shape of spectrum independent of proton energy and faces.

(only size changes) and is complicated to parameterize.

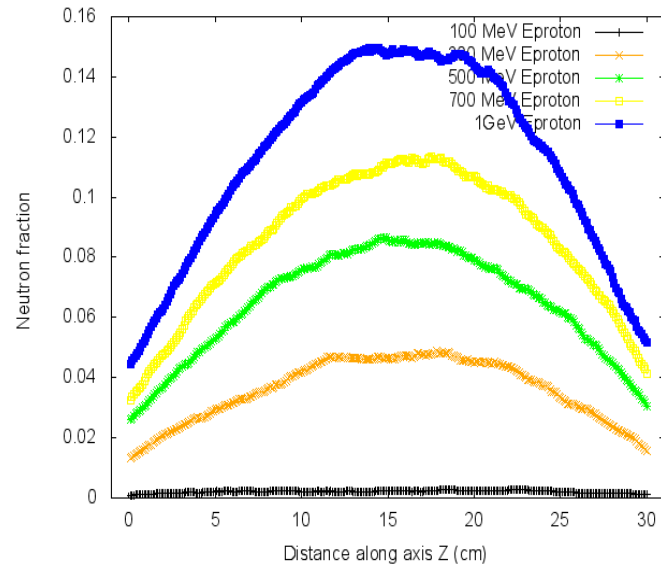
At high neutron energies – shape of spectrum depends on proton energy and faces and is simple (exponential with cutoff)

What is ‘high’ and ‘low’

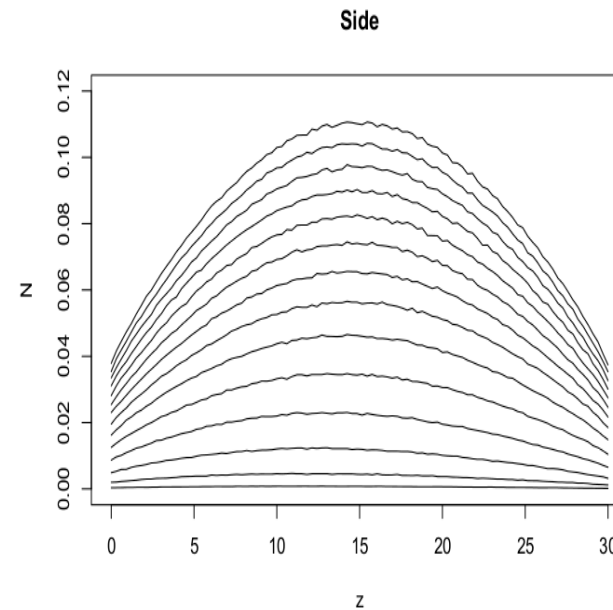
~ 10 MeV for proton energy dependence and ~2 MeV for faces.

Spatial distributions

longitudinal



GEANT4



MCNPX (100 MeV to 1400 MeV)

Similar behavior for Geant4 and MCNPX.

Similar shapes for all proton energies, almost symmetric about mid plane.

Longitudinal distribution varies remarkably little with energy.

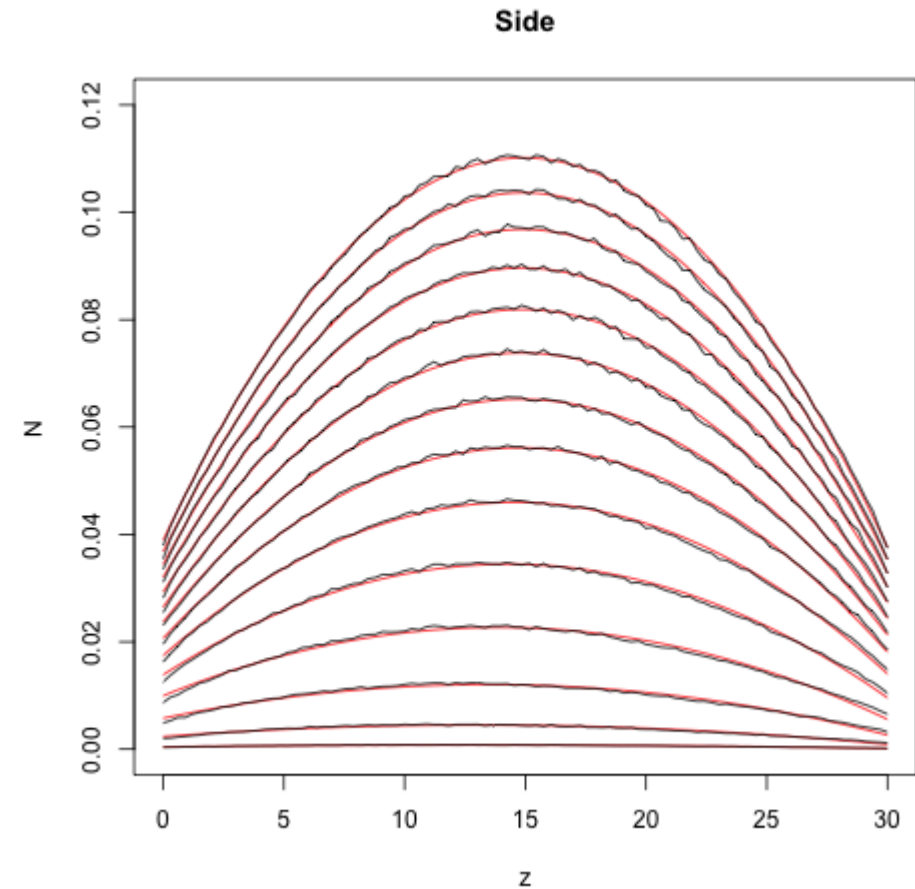
Spatial distributions

Parameterisation

It is well described by a parabola.

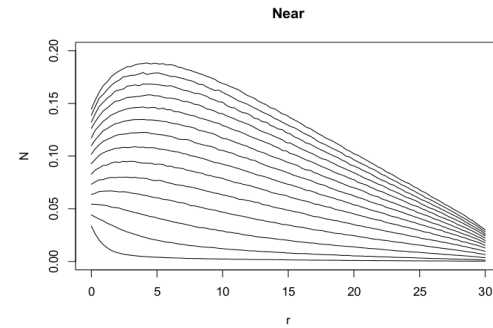
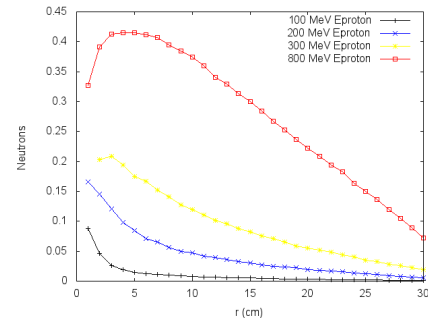
The center of the parabolas increases only very slowly with proton energy .

Proton energy - 100 MeV to 1400 MeV

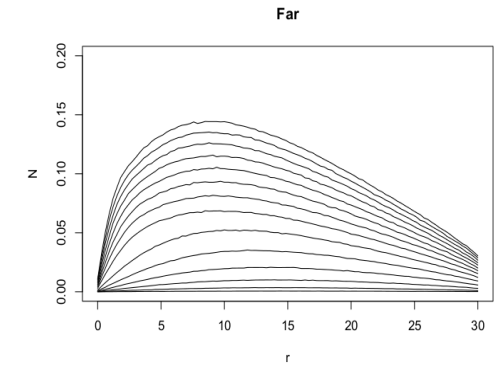
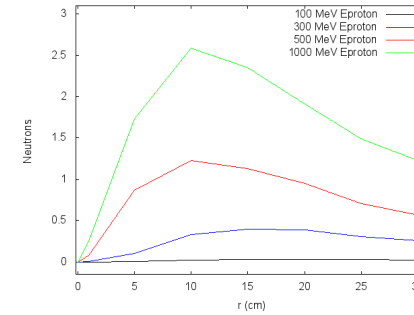


Spatial distributions

Radial



Near end (left Geant4, right MCNPX)



Far end (left Geant4, right MCNPX)

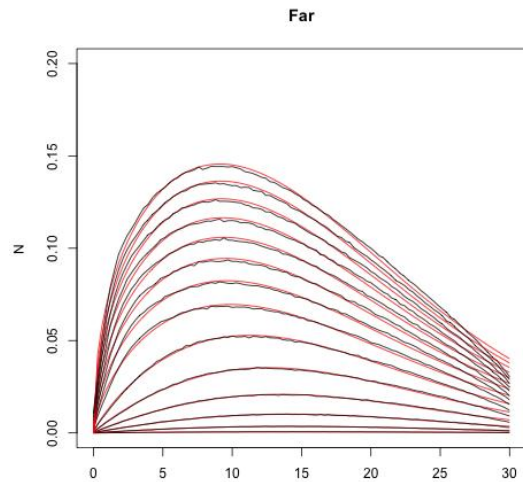
Similar at large r but interestingly different at $r = 0$ for the two ends.

For the far face the distribution falls to zero at small r while for near it does not.

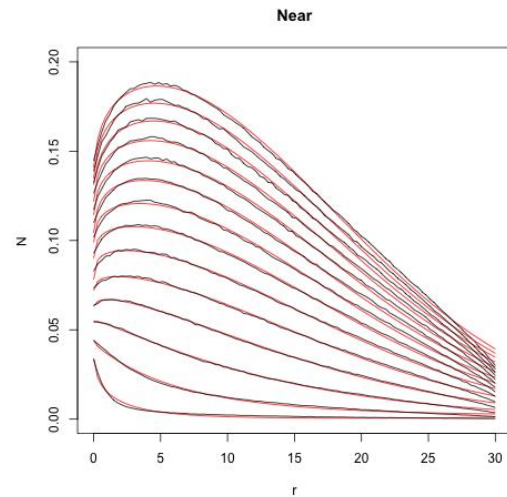
The prediction of the two programs agrees for the two faces.

Radial distributions

Parameterisation

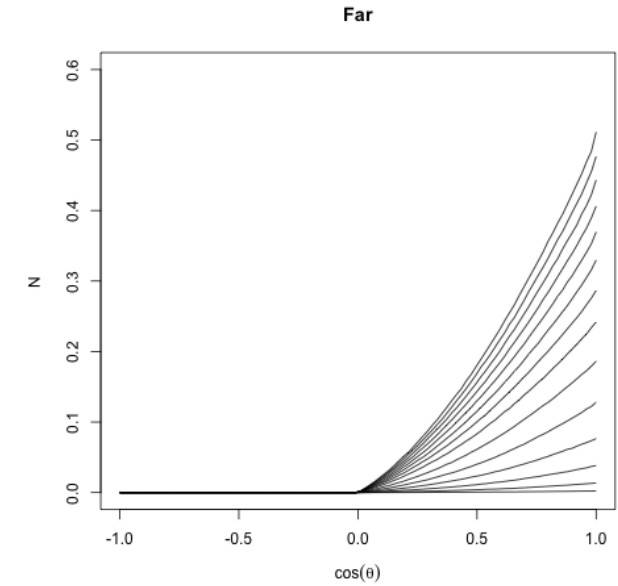
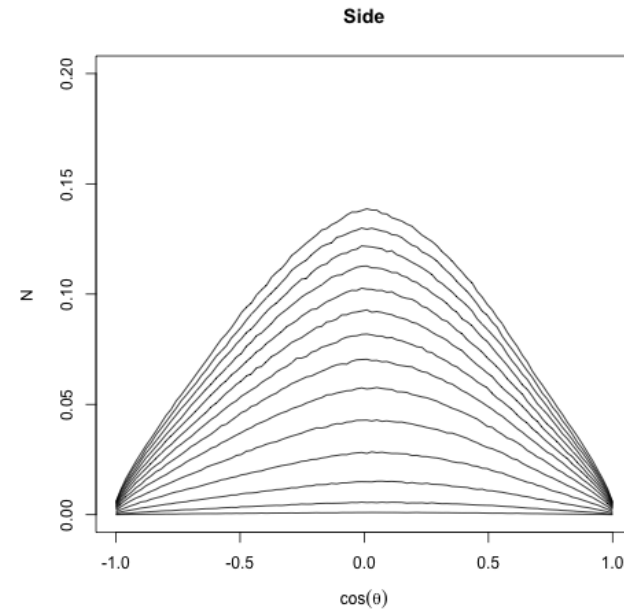
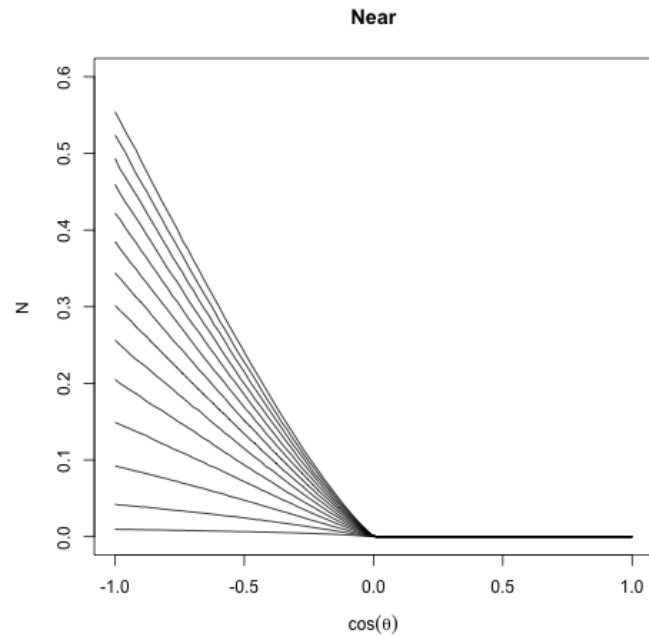


Far face: $P(r) \propto r^a \exp(-br - cr^2)$



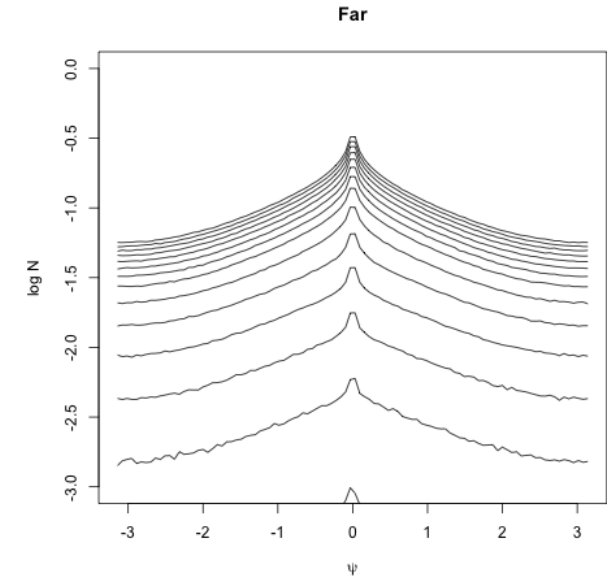
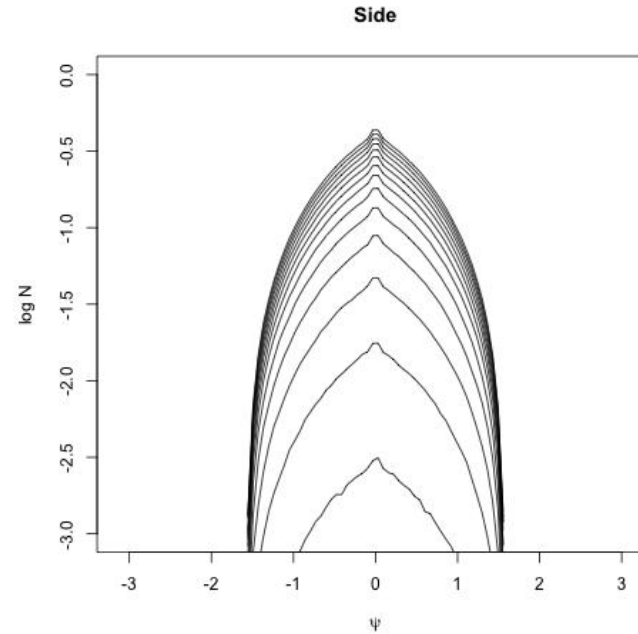
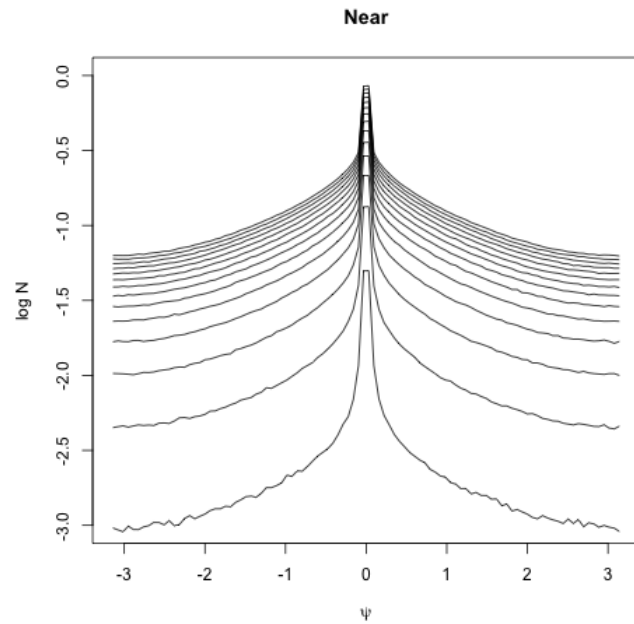
Near Face: $P(r) \propto (r - d)^a \exp(-br - cr^2)$

Directions in θ

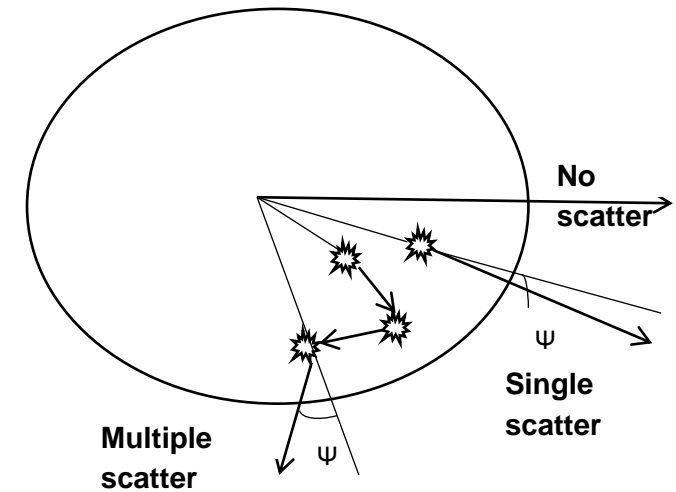


The directions are roughly isotropic.

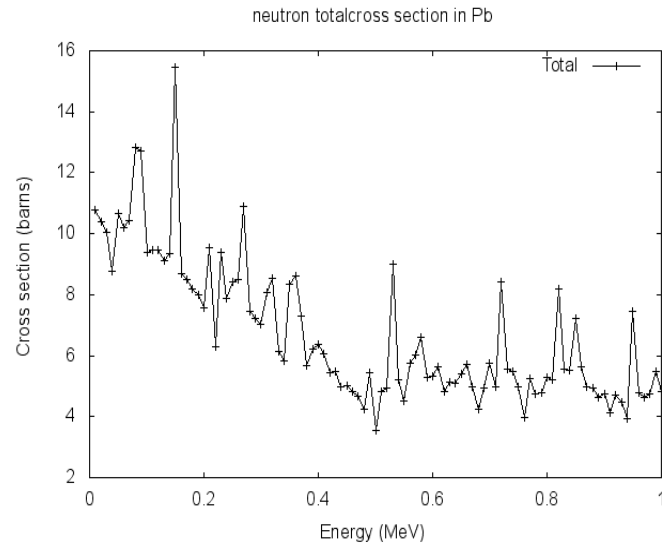
Distribution in ψ



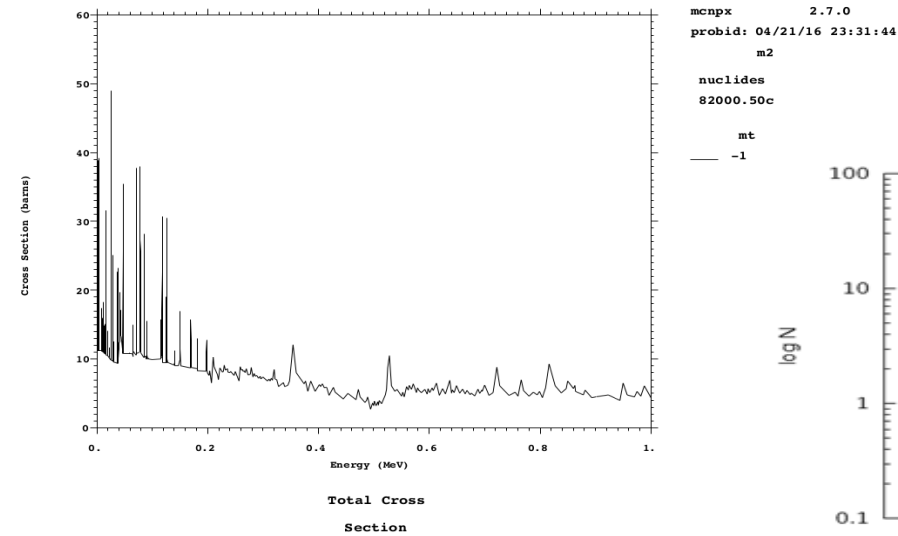
Difference between the azimuthal position and direction.



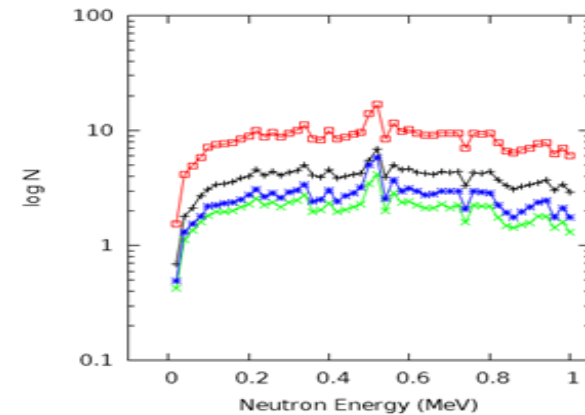
Cross sections



GEANT4



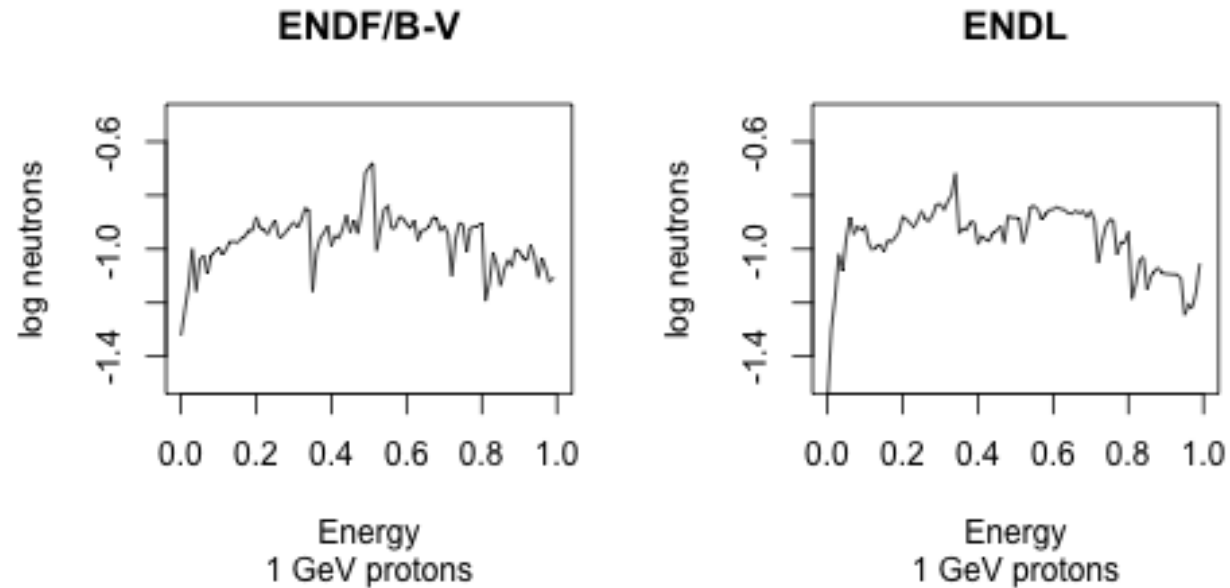
MCNPX



Correlation between the energy spectrum of spallation neutrons and their cross sections in lead.

Peak in the spectrum matches the dips in the cross section.

Model dependence



It is found that the binary cascade BIC_HP model agreed better with the MCNPX predictions than BERT_HP.

Conclusions:

- Good agreement between Geant4 and MCNPX for the neutron distribution in lead.
- Interestingly the neutrons come out backwards from the target.
- The high energy neutron spectrum is dominated by proton energies while the low energy spectrum is dominated by the neutron cross section in Pb.
- Spallation neutrons can be parameterized by simple forms.