Geant4 Simulation of Fast Neutron Backgrounds at the Spallation Neutron Source

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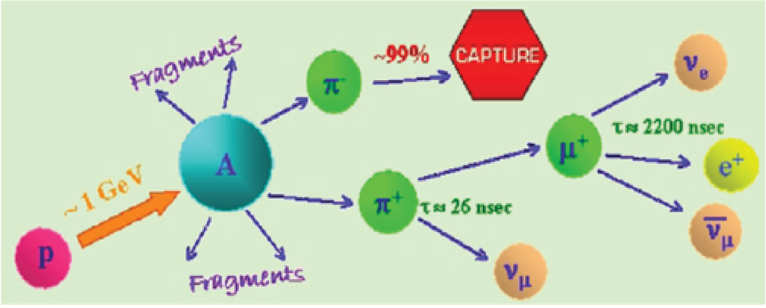
Abstract

We have simulated the high energy neutron flux from the Spallation Neutron Source (SNS) in a CsI detector located in the basement of the facility. The neutron background is due to the interactions of 1 GeV protons with mercury. We used Geant4, an Object Oriented Monte Carlo simulation toolkit in C++, on the midway computer cluster at the University of Chicago. The importance sampling was used to bias the neutrons to track them through large volumes of shielding. A computation time of 180K cpu hours was used to optimize and run the simulations.

Neutrino-Nucleus interactions

Coherent neutral-current (NC) neutrino-nucleus scattering was first predicted theoretically in 1974 but has never been observed experimentally. The neutrino-nuclear interactions are important to understand nuclear structure related to weak interaction, the mechanism by which core collapse supernovae explode, the resulting nucleosynthesis, and the results of neutrino astronomy.

The Spallation Neutron Source facility at Oak Ridge National Laboratory provides a unique opportunity to study the neutrino scattering. The neutrinos are produced via stopped pion decay.



Experimental Facility at ORNL

Coherent Neutrino Scattering Detector

C°sI, Coherent Neutrino Scattering with Cesium Iodide, is an experiment that has been built at KICP, UChicago (Juan Collar's Group) to detect the coherent interactions of neutrinos with nuclei. C°sI is being installed at the Spallation Neutron Source (SNS) facility at Oak Ridge National Lab.

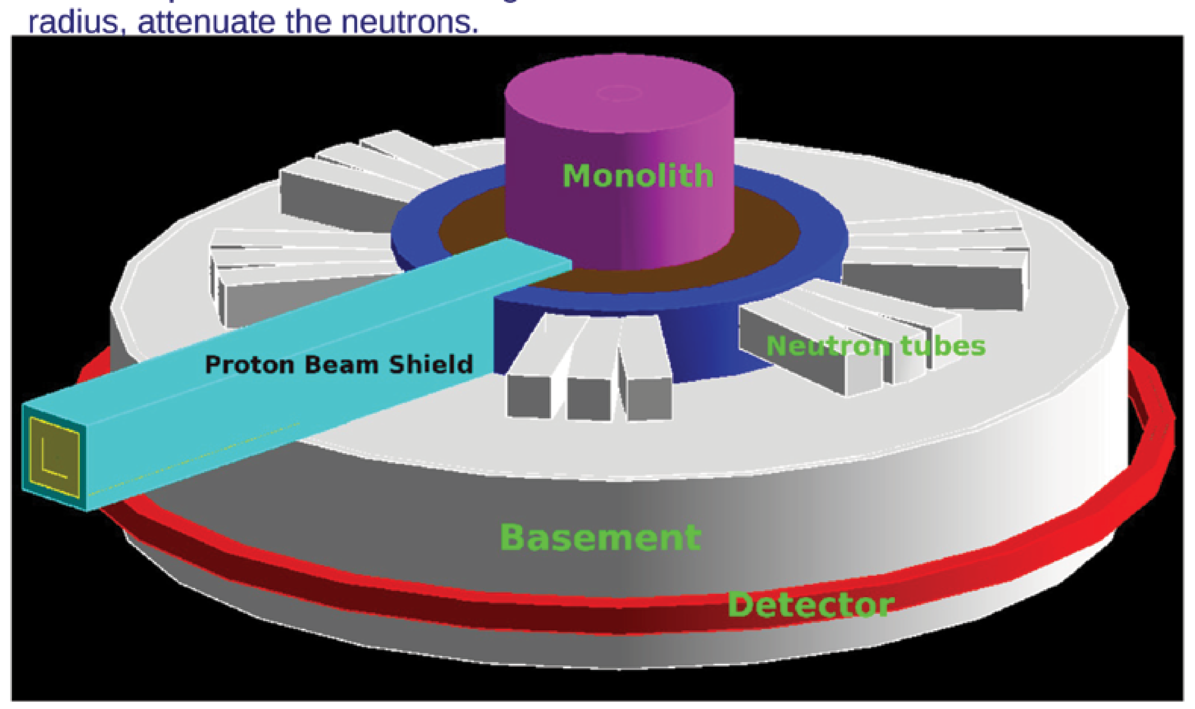
Backgrounds for Coherent Neutrino Scattering

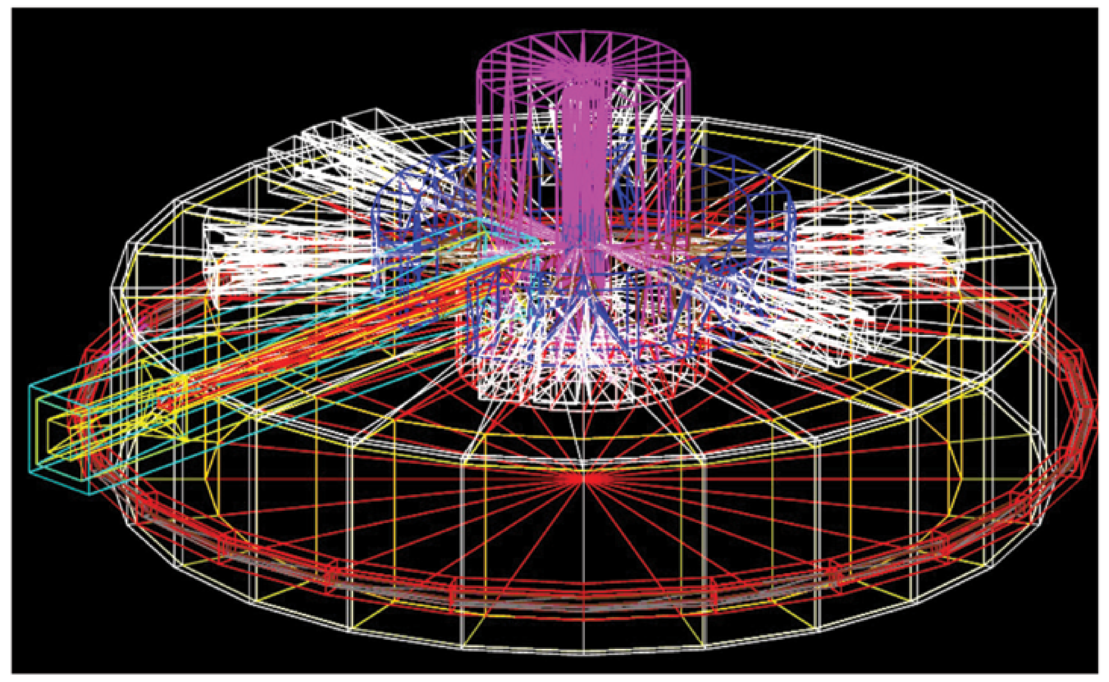
For the upcoming neutrino measurements, understanding and reducing backgrounds is of vital importance. A beam-related background for this neutrino measurement is the flux of high-energy neutrons that can penetrate significant amounts of shielding and which can, occasionally, mimic a neutrino interaction in the detector.

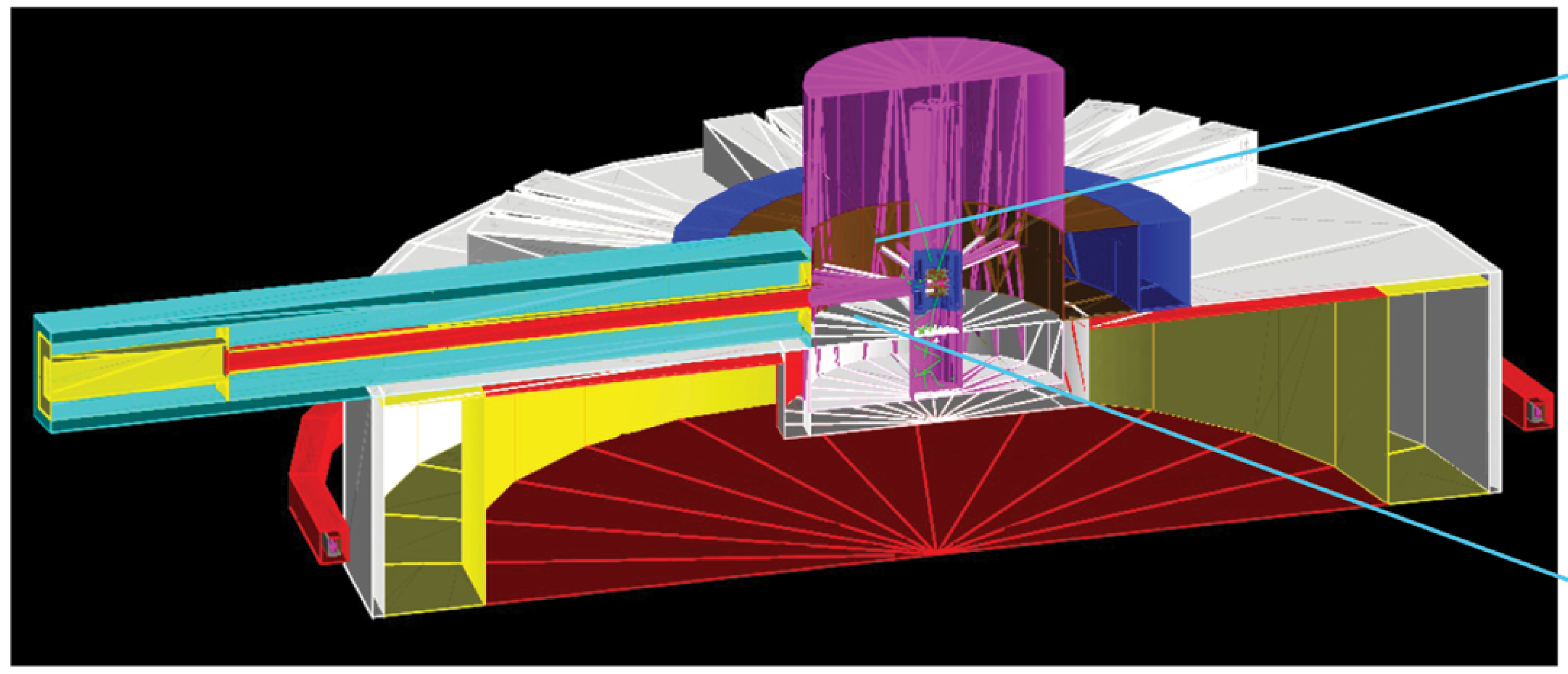
To estimate neutron fluxes at the neutrino detector location, the method of Monte Carlo simulation was used.

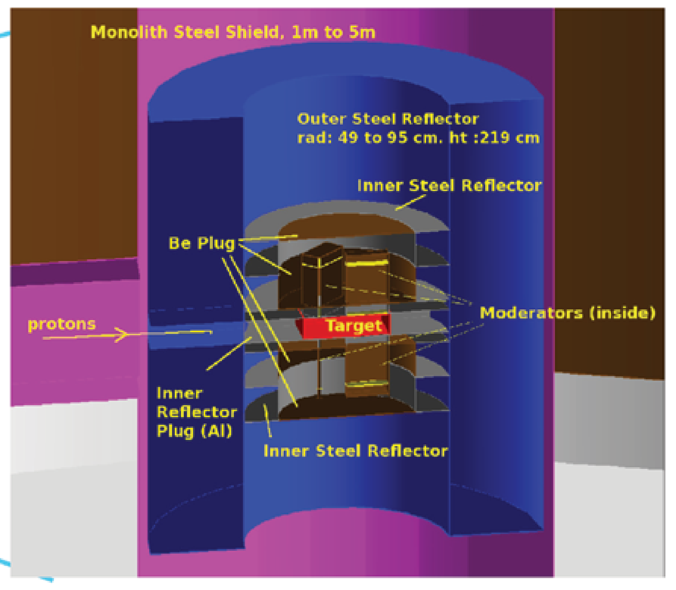
Simulation of Neutron Flux by Monte Carlo Method

Geant4 (http://geant4.cern.ch) is a Object Oriented C++ toolkit for the simulation of the passage of particles through matter. It was used to develop an application to simulate the neutron flux due to the proton beam entering through the proton shield and hitting the target inside the monolith. The geometry, created using OpenGL visualization, is shown here as full view, wire frame, and cut view. I GeV protons are shoot into the mercury target and the resulting neutrons produced In all the stages are tracked down to the detector in the basement (red strip). The basement and shielding, having about 25 meters in radius, attenuate the neutrons.









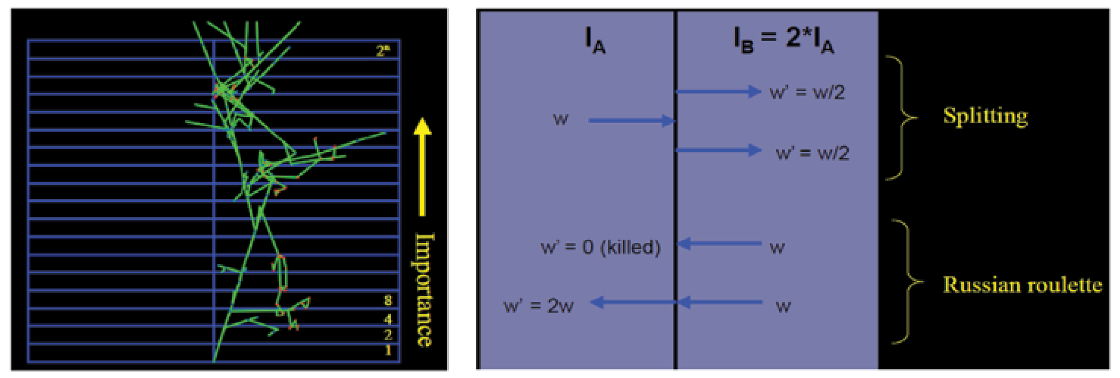
The simulation of 1 billion protons did not produce any neutrons in the detector. This problem was overcome by using a method called event biasing or importance sampling.

Mercury Target and Moderators

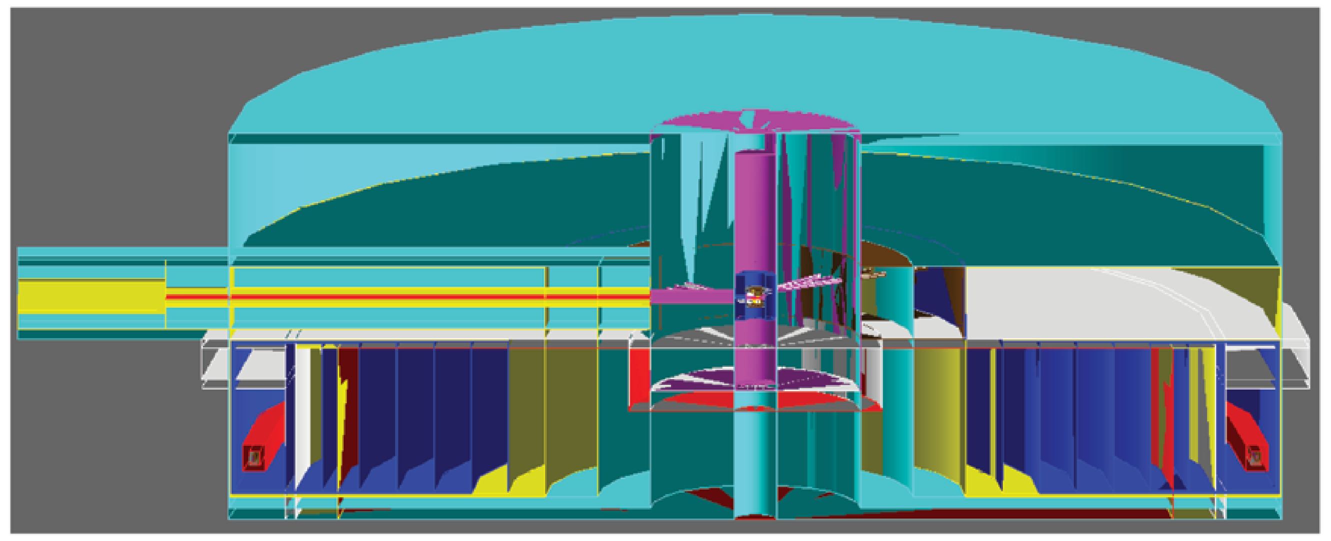
Blue: Steel Cylinder, Magenta: Outer Steel Cylinder, Red: Hg Target, Yellow (Brown inside): Moderators,

Importance Sampling (event biasing)

An importance value is set in each volume. The particles in relevant volumes are multiplied (split) by the importance value (weight factor). Main (mass) volumes are not affected by the biasing volumes set in 'parallel' geometry. A fraction of the particles crossing to less important regions are killed based on the importance value in the cell. This is called Russian Roulette. Track weight is its inverse. This weight is used to multiply by the detection so as to compensate for the splitting effect.

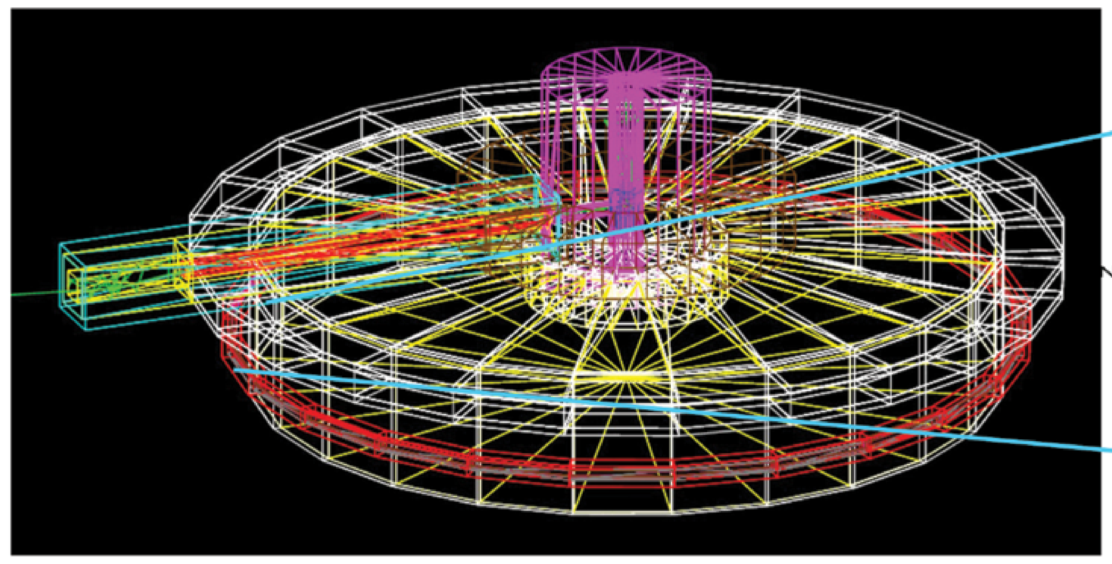


Geometry with Sampling Volumes

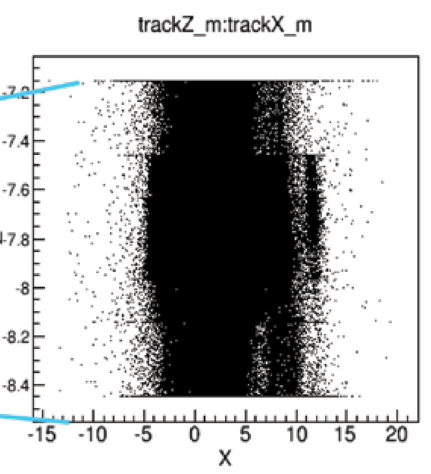


Importance value for the innermost cell, in the case of 46 sampling volumes = 2^{65} = 3.7 x 10^{19}. Track weight = 2.7 x 10^{-18}.

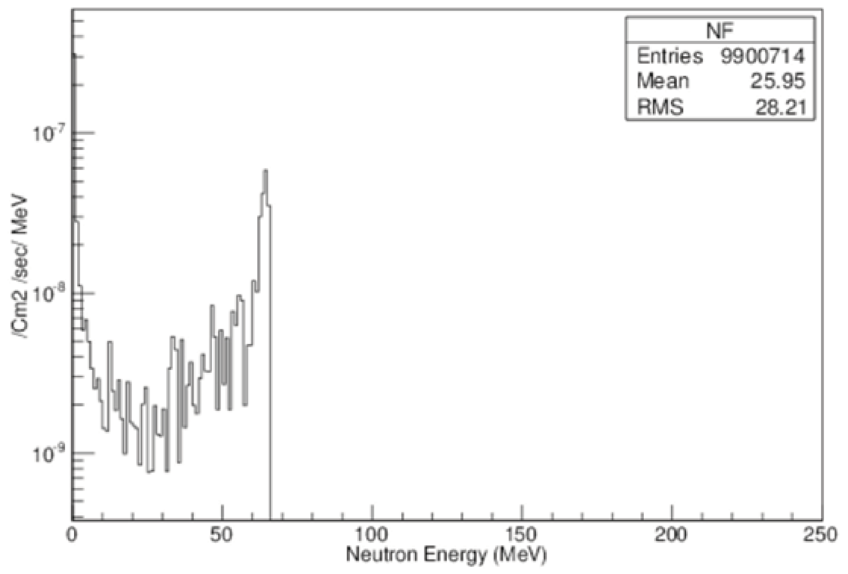
Left Figure: 10 volumes shown for simplicity. The volumes start 1m off the axis of the cylinder to avid splitting the neutrons where th are created. The innermost cell encapsulate the detector and it has the highest importance value, so that the particles can be tracked down there. The sampling volumes should have the shape of cells but not slices, in order to avoid creation of huge number of particles in a single step, when the particles move from volumes of small importance to that of large importance.



Without biasing: Re-run using the seed of a single event without importance sampling. This is not reaching the detector, shown as red circular strip on the bottom.



With sampling: Detector hits below the proton beam box.
Run time: 5 days.
Not possible to visualize !



Neutron flux due to the event shown in the left figure. Hits are not at the location where the actual CsI detector is installed.

Result

High energy neutron flux and the resulting energy deposition were obtained as shown in the plots. The flux is 10^{-13} /cm2/sec/MeV in the forward direction of the proton beam and 10^{-14} at the location where the detector is being installed. A proton rate of 6.56 x 10^{15} /second of energy of 1GeV was used in the simulation. More runs are being done to increase the statistics of the neutrons that seed the cascades.

Computation Time

Due to the large volume of shielding and basement, the number of sampling cells needed is high. But a very high number can result in never-ending runs due to large number of particles created in the important volumes. Considerable time had to be spent in optimizing this number. We have used 65 cells of parallel volumes. Total computation time used for optimizing and running the simulations : 180,000 CPU hours.

Summary

We have done Monte Carlo simulation using Geant4 to simulate the high energy neutron flux and the resulting energy in detector. Particle biasing (important sampling) was used to sample them in important regions in order to compensate for the attenuation between the neutron production volume and the detector. The result is useful to analyze the data from the detector which is being installed at Oak Ridge National Laboratory. The midway cluster is used for running the simulations. Efforts are on to improve the efficiency of the simulation by using parallel processing.

Acknowledgements:

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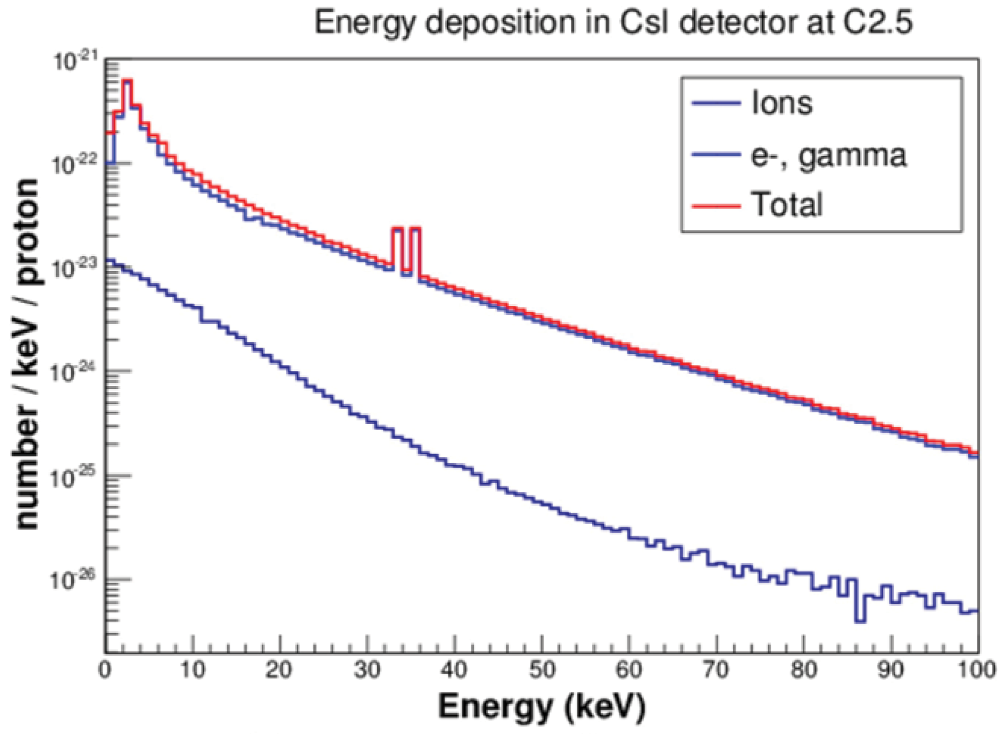
* Coherent Collaboration.

Energy deposition in CsI detector at C2.5



Neutron Flux at SNS : in Basement