Geant4 Simulation of the Energy Resolution Function for the CSNS Back-n Facility

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Outline

- Introduction
- Geant4 simulation
- RPI function
- Results and summary

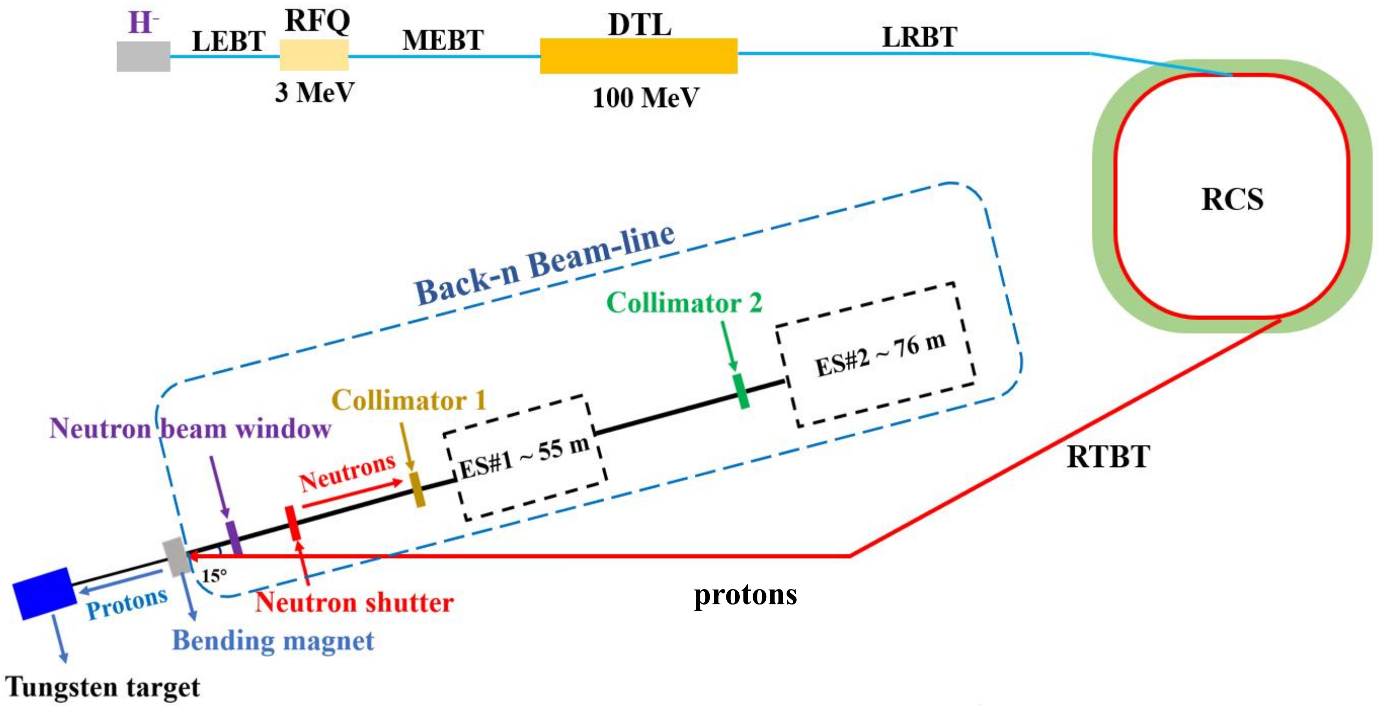
Introduction

Back-n facility at CSNS

Back-n is a time-of-flight facility based on the China Spallation Neutron Source (CSNS). Characterized by its high flux (~10^7 n/cm^2/s at ES#1), wide energy range(~0.5 eV to 300 MeV) and good time resolution, it's well-suited for nuclear data measurement and neuron technology application.

- 1.6 GeV protons bombard tungsten target
- Repetition frequence: 25 Hz
- Current beam power: ~170 kW

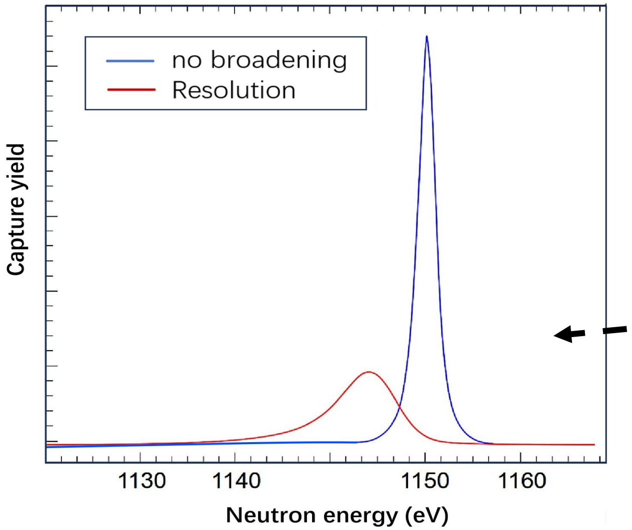
  upgrade to 500 kW (2019-CSNS-II)



Layout of the CSNS and Back-n facility

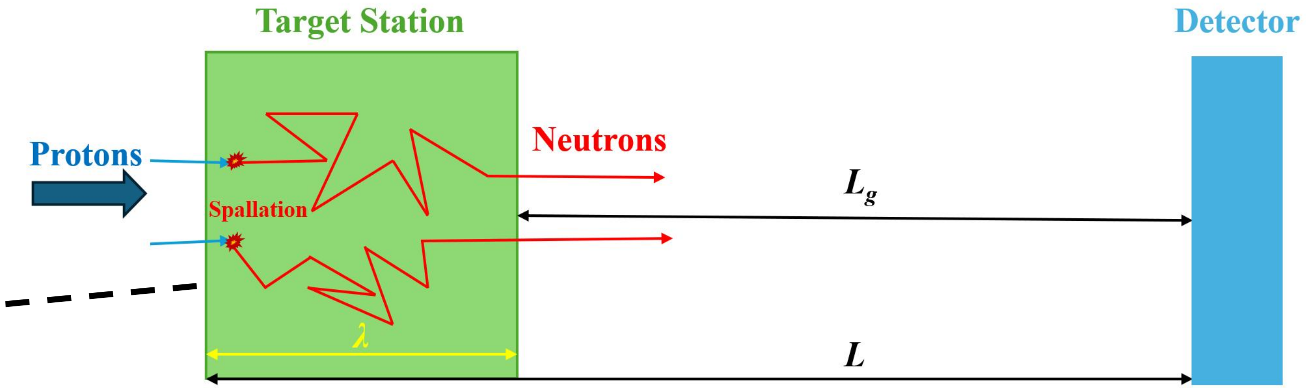
Energy Resolution Function

The Energy Resolution Function (ERF) of a neutron spectrometer is a key parameter in nuclear data analysis, particularly in the **resonance energy region**, which is essential for applications such as Neutron Resonance Analysis(NRA) method.



The influence of the ERF

-Frank Gunsing, CEA Saclay, Irfu,2019



The Schematic drawing of neutron production, transport, and detection

For ERF, the most crucial component that needs to be investigated is **the neutron production and transport within the spallation target**, which is too difficult to be obtained from the experiment.

Geant4 simulation

Geometry

The **Target-Moderator-reflector (TMR)** model is the essential component of the CSNS, it mainly consists of :

- **spallation Target :**

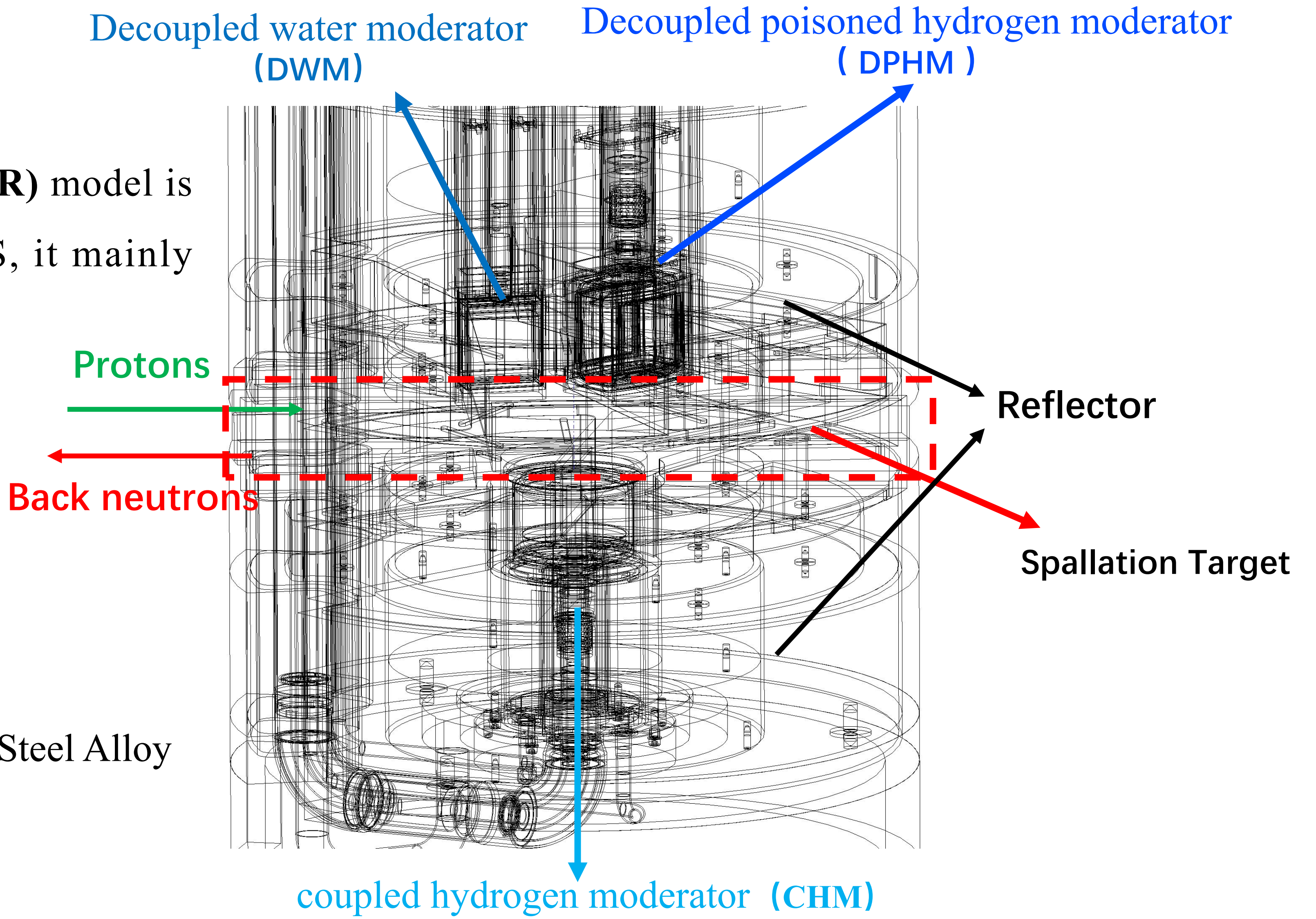
  11 pieces of tungsten targets

- **Moderator :**

  DWM、DPHM、CHM

- **Reflector:**

  Composed of beryllium and Stainless-Steel Alloy

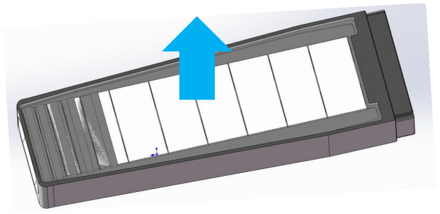


Geant4 simulation

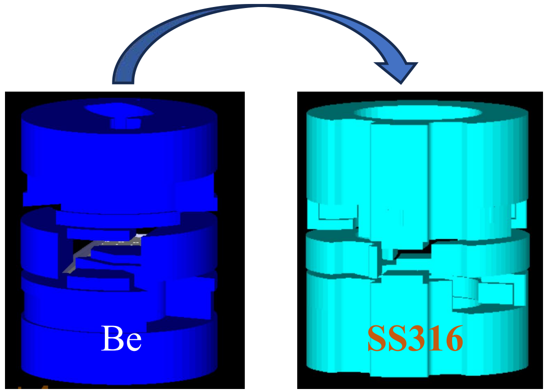
MC simulation

Geant4 11.2.0 version (2023), Physics List: **QGSP_INCLXX_HP**

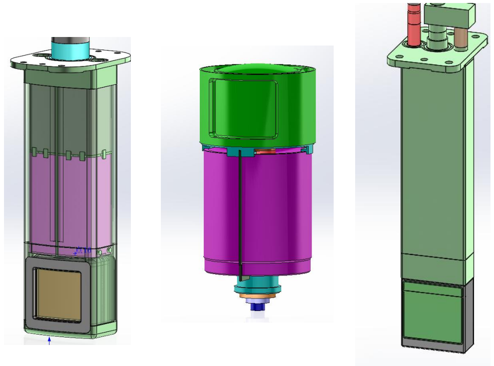
Spallation Target



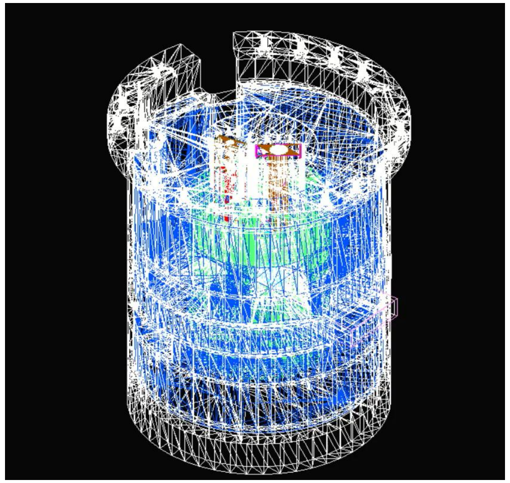
Target vessel



Reflector model



DPHM **CHM** **DWM**



Model in simulation

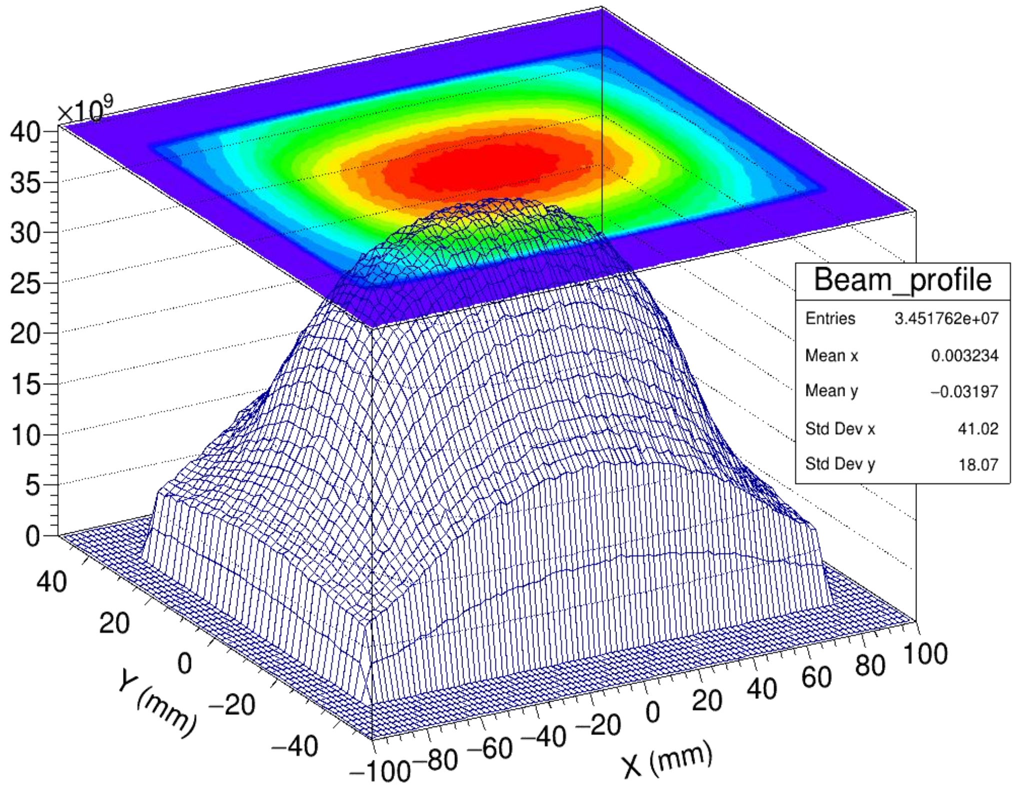
Components of the simulation model

Module	Feature
Target	Tungsten (11 pieces, Total length:650 mm) Cross section:170 mm(H) × 70 mm(V)
Tantalum cover	Thickness: 0.3 mm
Target vessel	SS316 alloy
Reflector	Be+SS316 alloy
Moderator	DWM: Water CHM: Liquid hydrogen DPHM: Liquid hydrogen

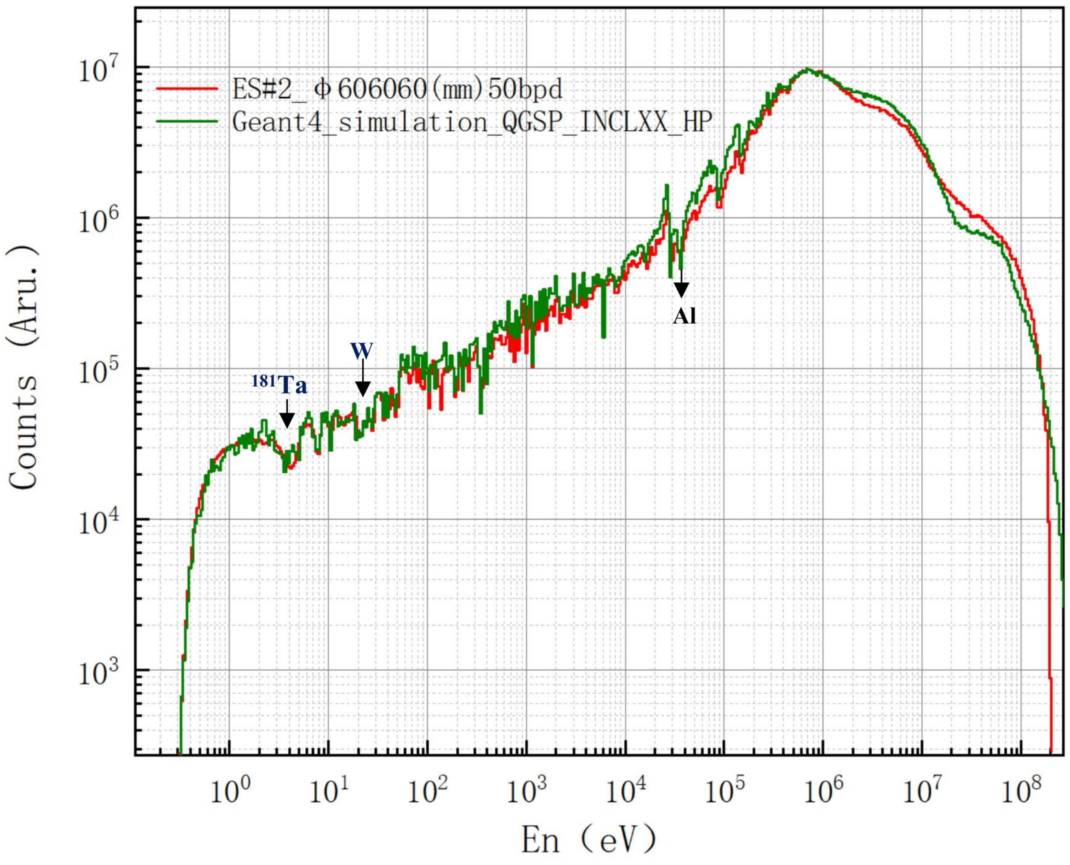
SCORING PLANES:
Towards Back-n (at the entrance of the Target surface)

Geant4 simulation

MC simulation



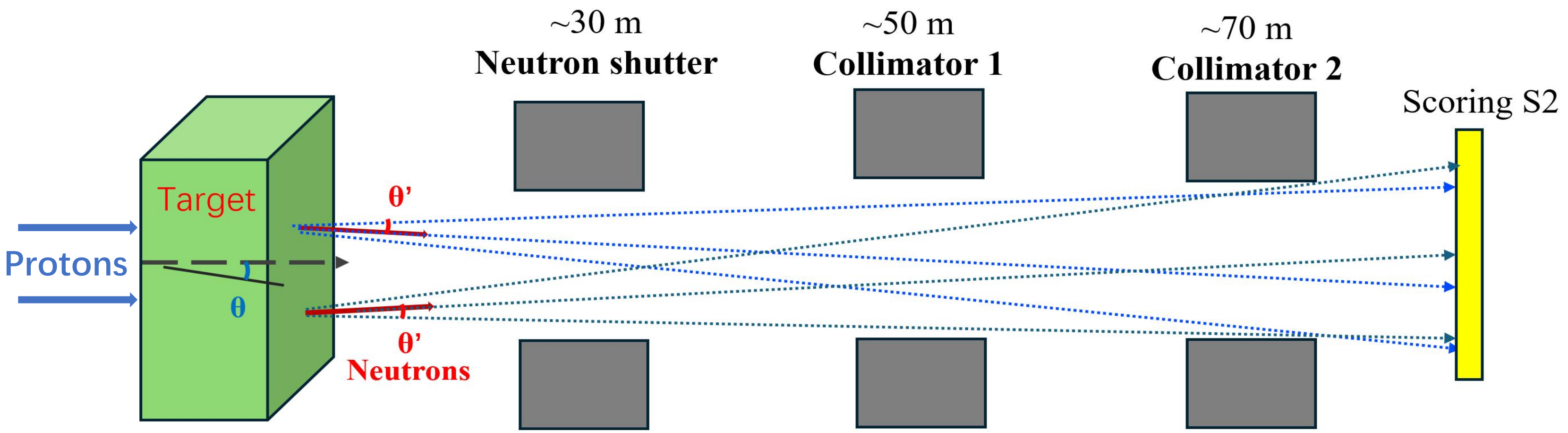
Spatial distribution of neutrons at scoring plane surface



Typical shape of neutron spectrum

Geant4 simulation

Resampling

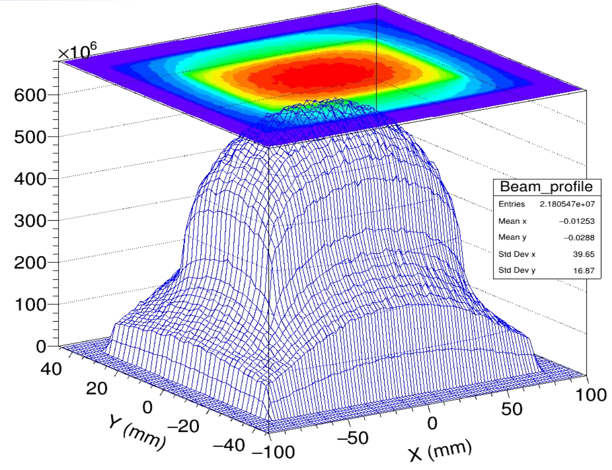


Neutron Resampling

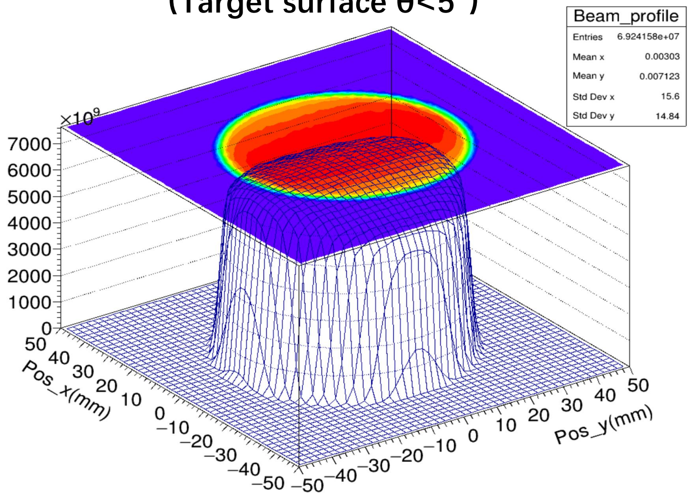
10^8 protons ⇨ <100 neutrons (ES#2 ~75 m)
100 threads simulation ≈ 2 Weeks !!!

- Only neutrons can reach the experiment location should be considered.
- The "Resampling" method is used to enhance neutron statistics at the measurement location.[1]

1. J. Lerendegui-Marco,et al., Eur. Phys. J. A (2016) 52: 100



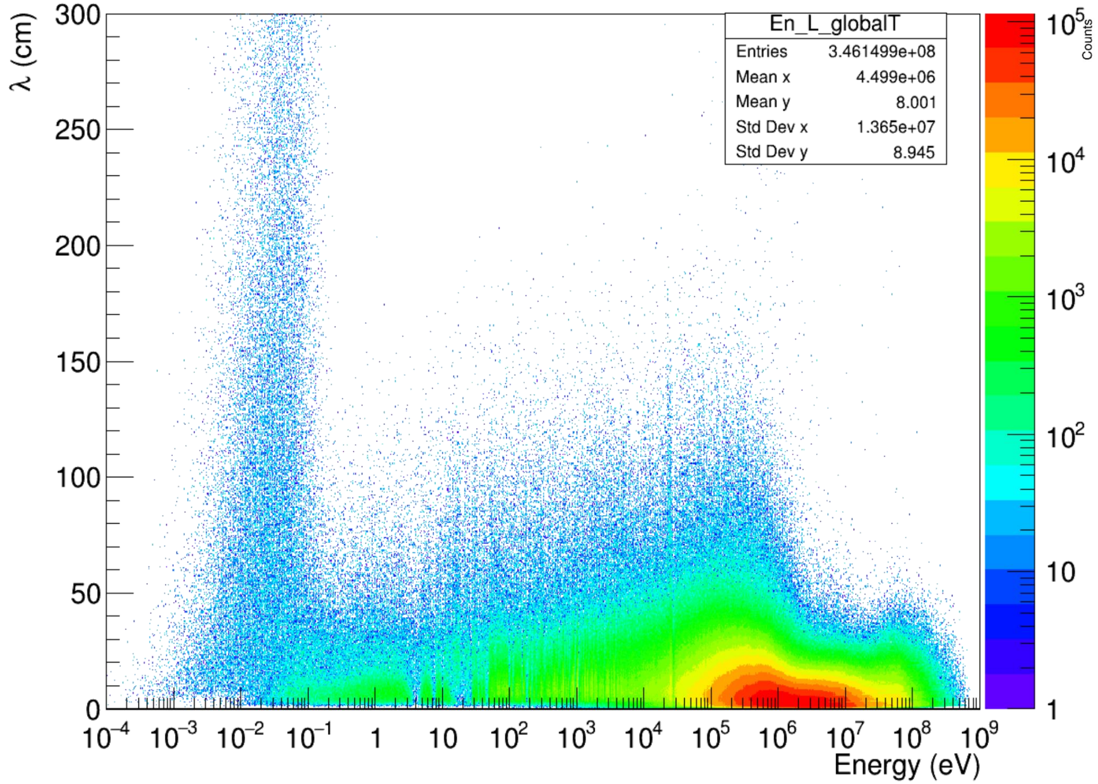
Emission neutrons
(Target surface θ<5°)



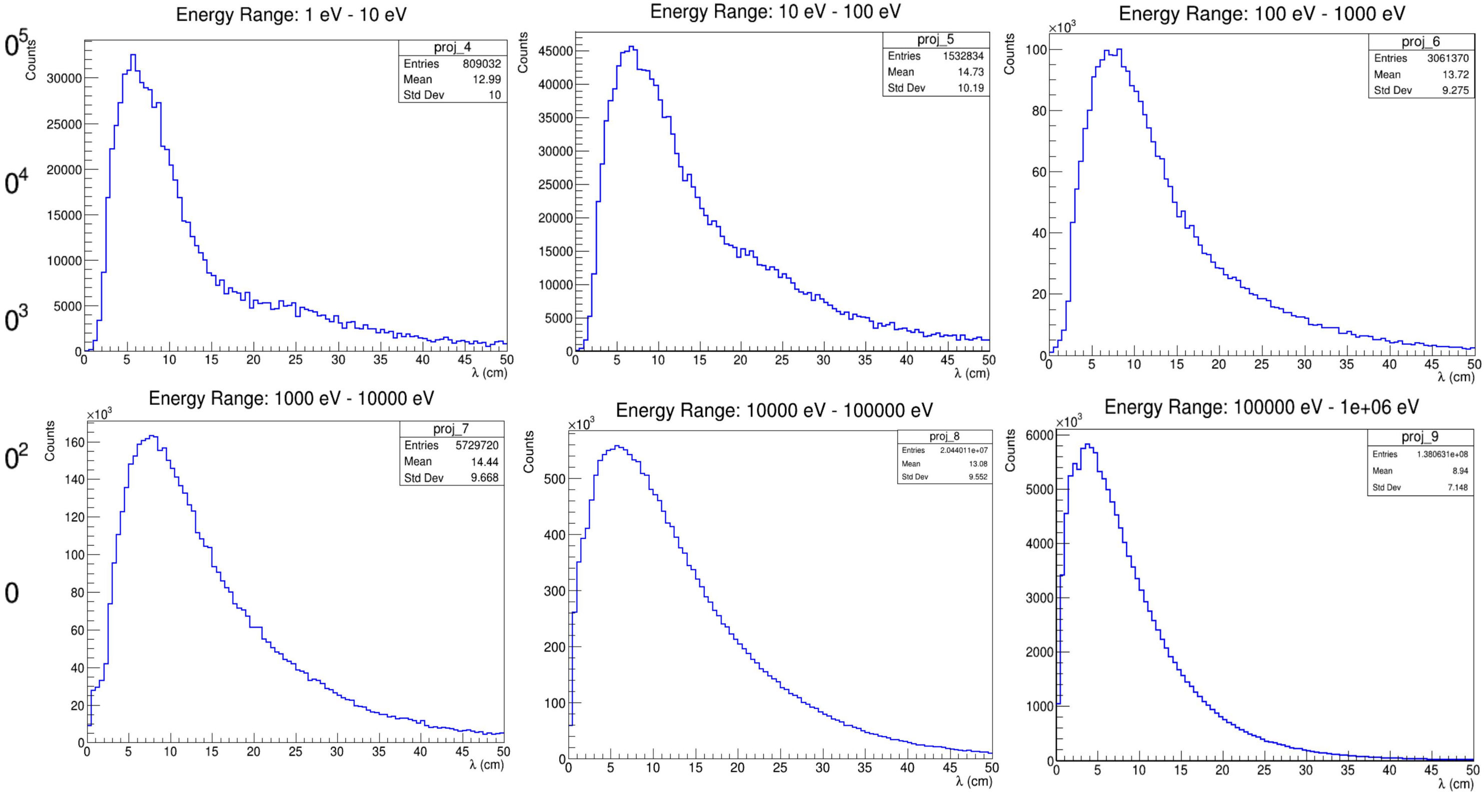
Neutrons at scoring S2 after resampling (θ'<2°)

Geant4 simulation

Equivalent moderation Length



The distribution of the equivalent moderation length, as a function of the neutron energy



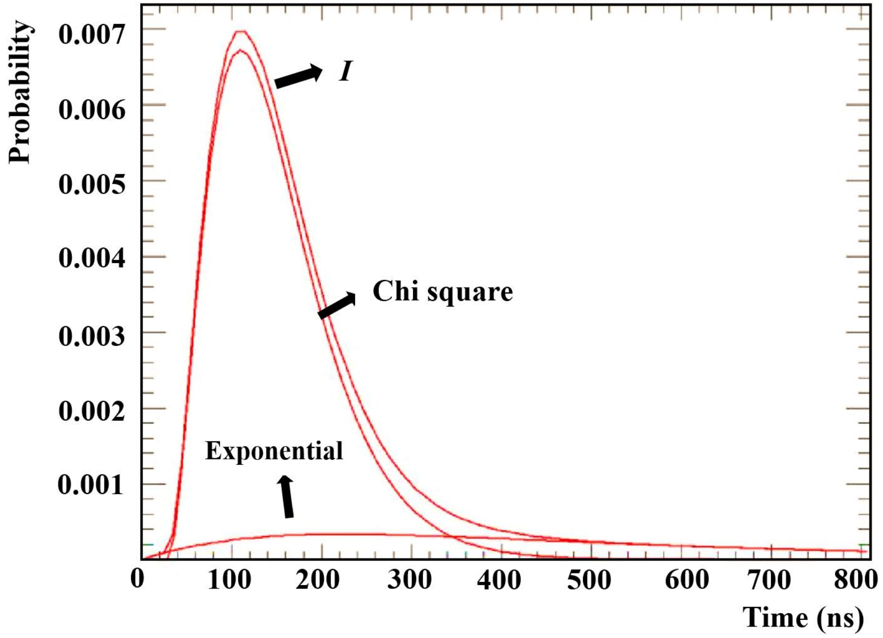
The distribution of equivalent moderation length in different neutron energy ranges

The equivalent moderation length ($\lambda = v \cdot T_{mod}$) distribution in different neutron energy ranges are obtained.

The energy resolution at the low-energy range is significantly influenced by λ.

RPI function

A couple of distinct types of analytical ERFs have been designed to describe different experimental setups, the Rensselaer Polytechnic Institute (RPI) resolution function is used to characterize the simulated equivalent moderation distance.



The components of the RPI function

Larson NM, Volev K N. Validation of multiple-scattering corrections in the analysis code SAMMY. 2002

$$I(t) = A_0\{\frac{t+\tau}{2!\ \Lambda^3} e^{-\frac{t_2+\tau}{\Lambda}} + A_1\left[A_2 e^{-A_3(t_2+t_0)} + A_4 e^{-A_5(t_2+t_0)}\right]X(t_2) \quad (1)$$

$$\tau(E) = \tau_1 e^{-\tau_2 E} + \tau_3\ e^{-\tau_4 E} + \tau_5 + \tau_6\ E^{-\tau_7} \quad (2)$$

$$\Lambda(E) = \Lambda_0 + \Lambda_1 \ln(E) + \Lambda_2[\ln(E)]^2 + \Lambda_3 E^{\Lambda_4} \quad (3)$$

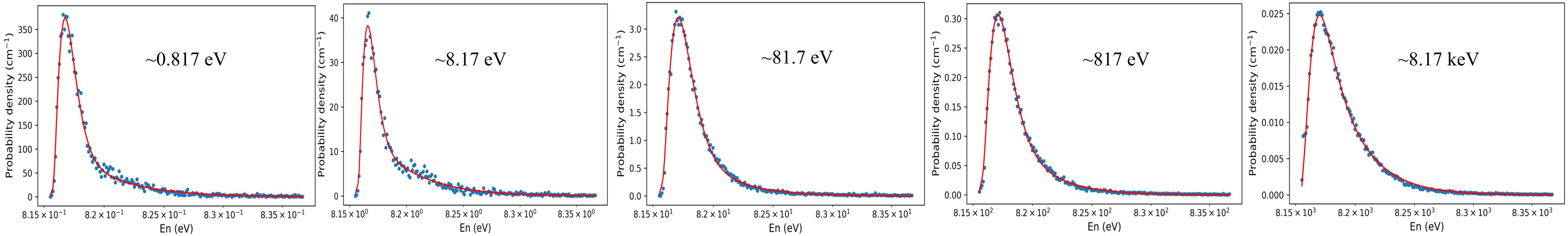
$$A_i(E) = \{a_{i1} e^{-a_{i2}E} + a_{i3} e^{-a_{i4}E} + a_{i5} + a_{i6} e^{-a_{i7}E}\} a_i \quad (4)$$

The simulation results are adapted to the RPI function by adjusting the energy dependent parameters(τ_i, Λ_i, A_{ij}).

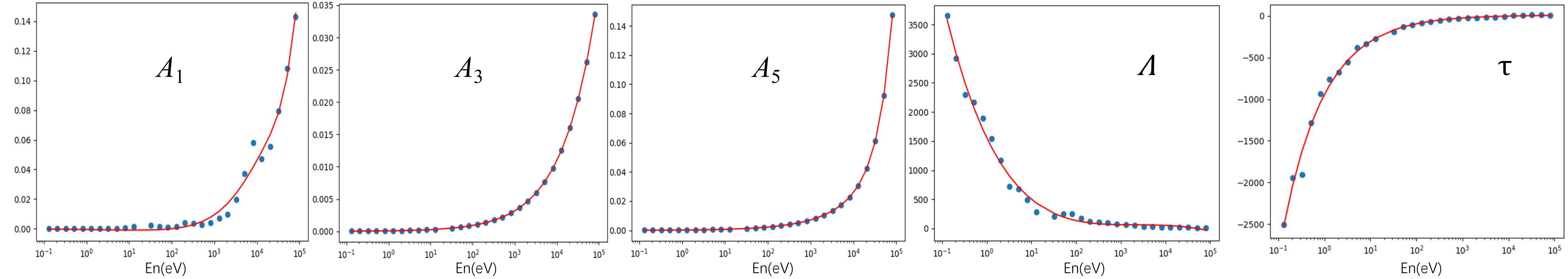
RPI function

Fitting results

RPI Fitting for different neutron energy



Fitting A_1、A_3、A_5、Λ、τ



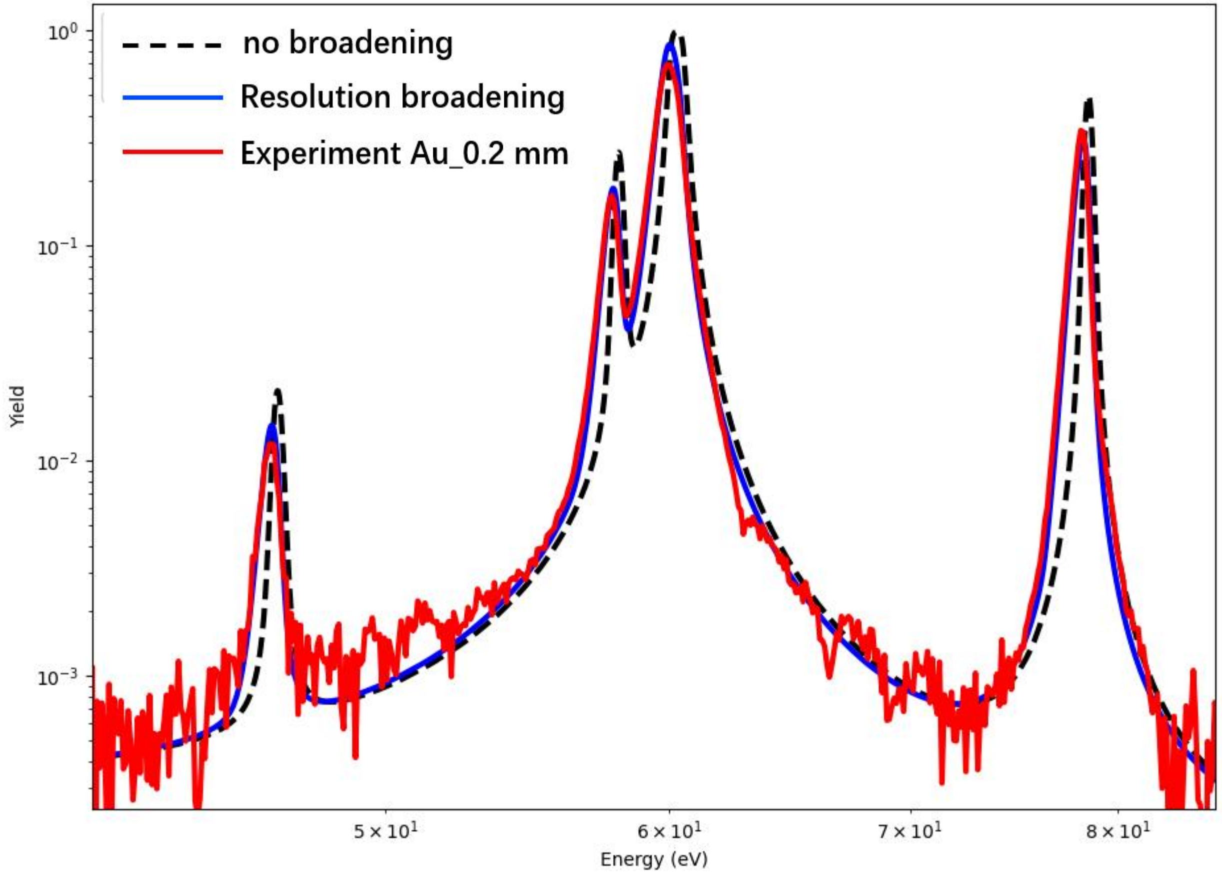
Results

RPI verification

The evaluation data was convoluted with the RPI resolution function and showed good agreement with the experimental results below 100 eV.

Result list of τ_i, A_i, A_{ij}

A_0 : -9.58647109e+06	A_{14}: -6.55705130e-03
A_1: 1.58815024e+05	A_{15}: -1.05917698e+03
A_2: -1.20520197e+03	A_{16}: 1.18404653e-02
A_3: 9.5880484e+06	A_{17}: 9.96205577e-01
A_4: -1.66386582e-02	A_{35}: 1.13085799e-04
τ_5: 1.51482644e+01	A_{36}: 3.12018773e-06
τ_6: -9.22537775e+02	A_{37}: 3.01325136e-01
τ_7: -4.77991758e-01	A_{53}: 4.27711906e-02
A_{11}: 1.05919149e+03	A_{34}: -1.86183811e-07
A_{12}: 1.09397701e-05	A_{35}: -4.26419945e-02
A_{13}: -9.36831526e-08	



RPI Function Validation with ^{197}Au yield (-*Experiment by* ***Wei Jiang, Gaole Yang***)

Summary

- A TMR (Target-Moderator-Reflector) model was established, and the equivalent moderation length distribution was obtained.
- The contribution of the λ to the energy resolution function (ERF) was incorporated via convolution with the RPI function. The broadened evaluation data showed good agreement with the experimental results below 100 eV.

- The accurate simulation of ERFs is influenced by factors such as reaction cross sections; physics lists and physical models. Further optimization of the ERF is necessary by refining these components.

Thank you very much, any questions?