Simulation and determination of the absolute neutron detection efficiency in large neutron detectors

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Abstract

While neutrons emitted in intermediate heavy-ion collisions are essential to understand the properties of the strongly interacting baryonic matter, detection of neutrons and simulations of neutron detector performance and efficiencies are difficult. We have developed a SCINFUL-GEANT4 based on the reaction channels and cross-sections in the SCINFUL-QMD simulation code [1] which has a fixed cylindrical detector backed by one photo-multiplier. The fixed geometry in SCINFUL-QMD limits its use to non-cylindrical shaped detectors especially detectors with two or more photo-multipliers. By implementing the GEANT4 toolkit into SCINFUL-GEANT4, the new code can be applied to a variety of the detector geometries, including the Large Area Neutron Array (LANA) in and the Facility for the Rare Isotope Beams (FRIB), U.S.A. used to measure neutron emitted in heavy ion collisions. LANA consists of two walls. Each 2x2 m² wall has 25 rectangular pyrex bars stacked on top of each other. Each bar is a 2 meter long with a cross-sectional area of 7.62x6.35 cm² filled with NE-213 liquid scintillator. The Pyrex is 3 mm thick.

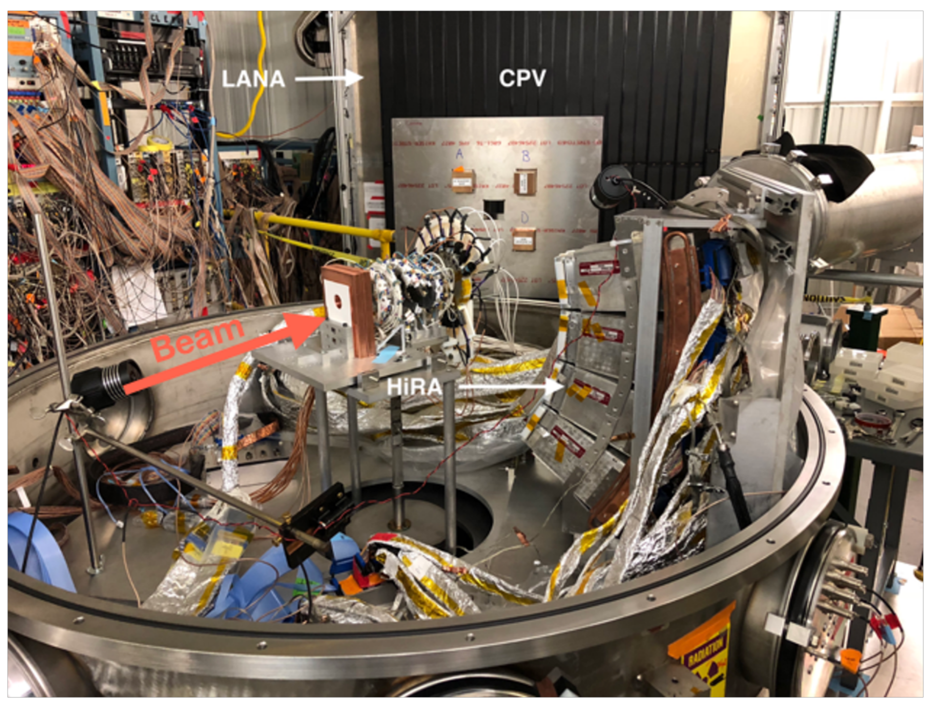
LANA has been used successfully in several heavy ion experiments at the National Superconducting Cyclotron Laboratory (NSCL) that measured both neutrons and charged particles in an effort to understand the symmetry energy term in the nuclear equation of state. Neutron spectra have been generated from the collisions of ^{40,48}Ca beams on ^{58,64}Ni and ^{112,124}Sn targets. To understand the properties of nuclear forces that depend on neutron-to-proton imbalance, the proton and neutron spectra obtained from reactions formed by different combinations of the projectile and targets will be compared. While proton detection with Si detectors is near 100% efficient, neutron detection is often less than 10% and requires accurate detection efficiency corrections.

Comparison of the simulation results from SCINFUL-GEANT4 to the NSCL data including closure tests to verify our estimation about the neutron detection efficiencies of LANA will be discussed at the presentation.

[1] Daiki SATOH, Tatsuhiko SATO, Akira ENDO, Yasuhiro YAMAGUCHI, Masashi TAKADA & Kenji ISHIBASHI(2006), Journal of Nuclear Science and Technology, 43:7, 714-719, DOI: 10.1080/18811248.2006.9711153

Large Area Neutron Array(LANA)

- Heavy ion collision system
  - ^{58,64}Ni and ^{112,124}Sn target with ^{40,48}Ca beam @ 56, 140 AMeV
  - 16 different systems
- Neutron detection was performed by LANA
  - NWB(Neutron Wall B, front) + NWA(Neutron Wall A, back) : 2 walls consisting of 50 bars
  - 1 bar : NE213 liquid scintillator(7.62 x 6.35 cm²) + Pyrex glass container(3 mm thickness)

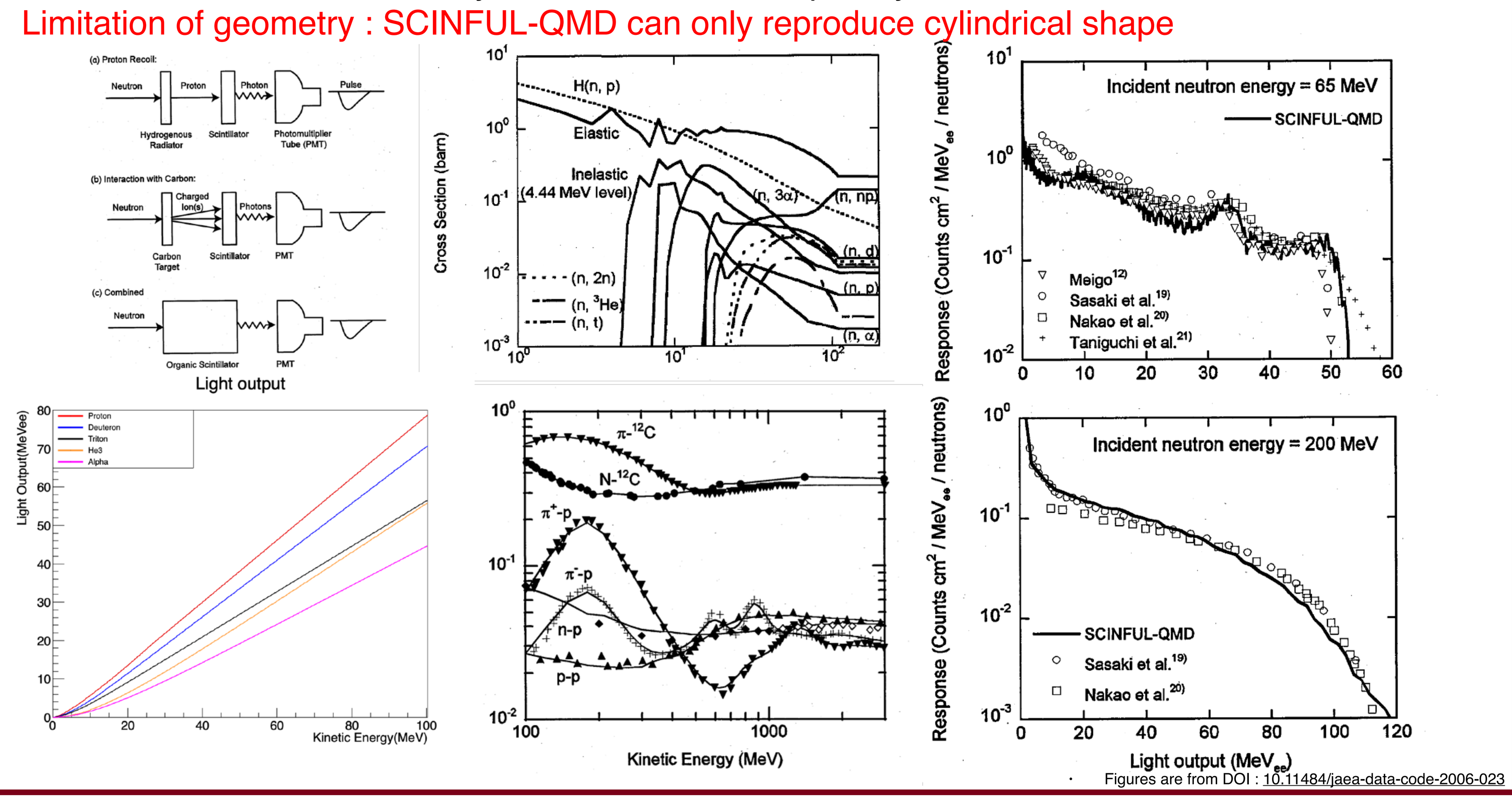


- LANA is placed at 39.37° with respect to the beam direction.

- Neutrons from couple MeV to about 300 MeV will be detected in this experiment setup.

SCINFUL-QMD

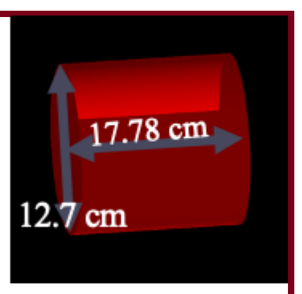
- SCINFUL-QMD is combined simulation of SCINFUL and JQMD
  - SCINFUL : Simulation developed by J.K. Dickens to provide scintillator full response(NE213, NE110)
  - JQMD : Quantum Molecular Dynamics model developed by JAEA
  - Limitation of geometry : SCINFUL-QMD can only reproduce cylindrical shape

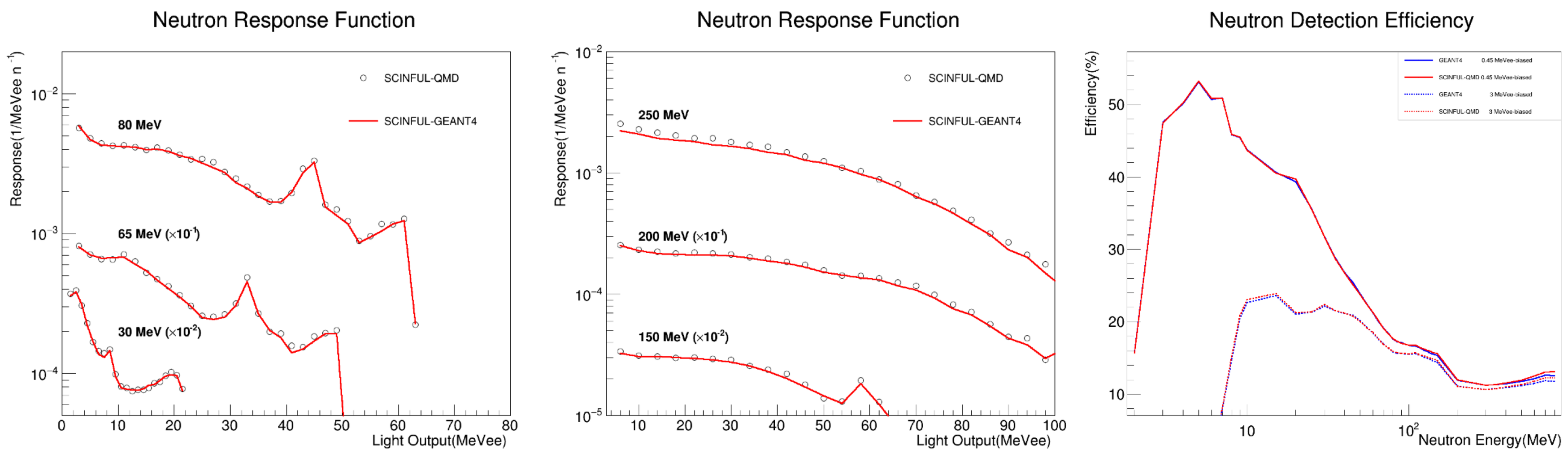


- Figures are from DOI : 10.11484/jaea-data-code-2006-023

SCINFUL-GEANT4(Cylinder)

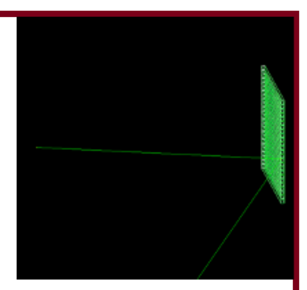
- GEANT4 is a powerful simulation toolkit.
- SCINFUL-GEANT4 has been developed based on the reaction channel and neutron cross-section of SCINFUL-QMD.
- Comparison with the same detector geometry was done to verify the implementations.
- Neutron detection efficiency can be calculated by the integration of neutron response function.

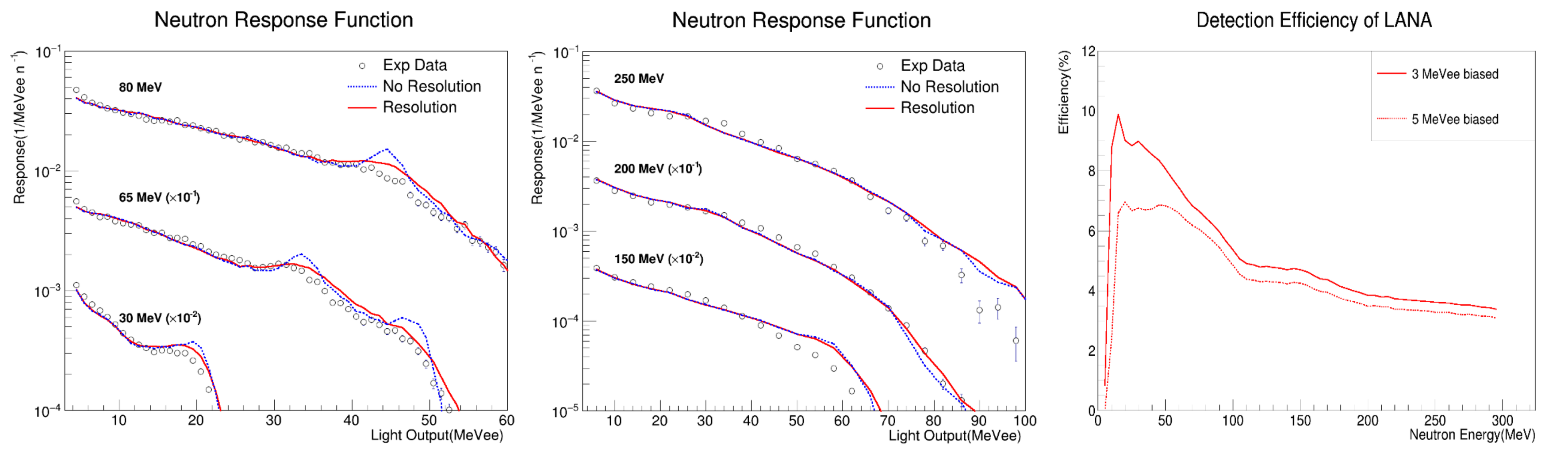




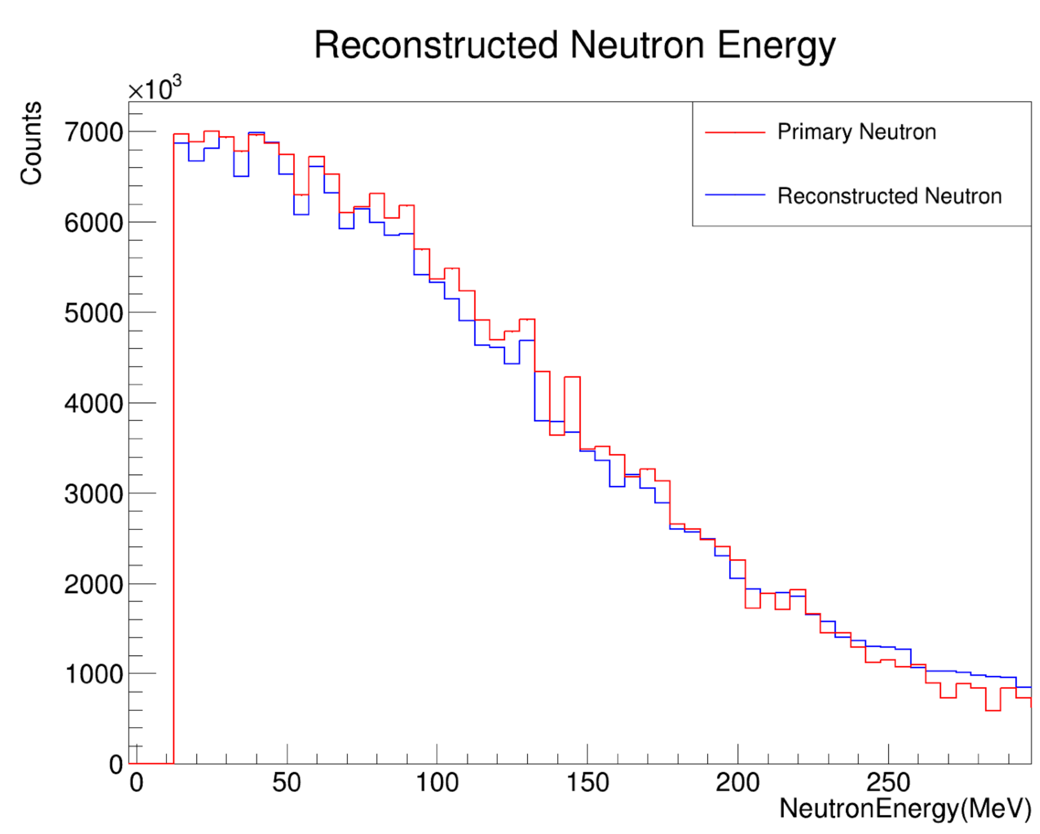
SCINFUL-GEANT4(LANA)

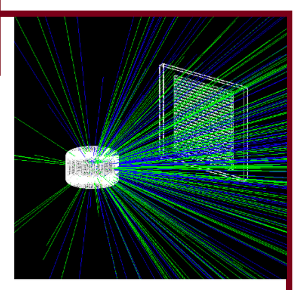
- Detector geometry is changed to LANA configuration.
  - 25 bars, each having 198.3 x 7.62 x 6.35 cm³ rectangular volume
  - 3 mm thick Pyrex glass
- Resolution effect has been adopted to describe experimental data.
  - A : Light collection, B : Statistical variation, C : Electronic noise.
  - FWHM : $\frac{dL}{L}=\sqrt{A^2+\frac{B^2}{L}+\frac{C^2}{L^2}}$ (A = 17 %, B = 15 %, C = 2 %)
- Only NWB was considered in SCINFUL-GEANT4 simulation.
- Detection efficiency threshold : 3 MeVee, 5 MeVee





SCINFUL-GEANT4(EventGenerator)

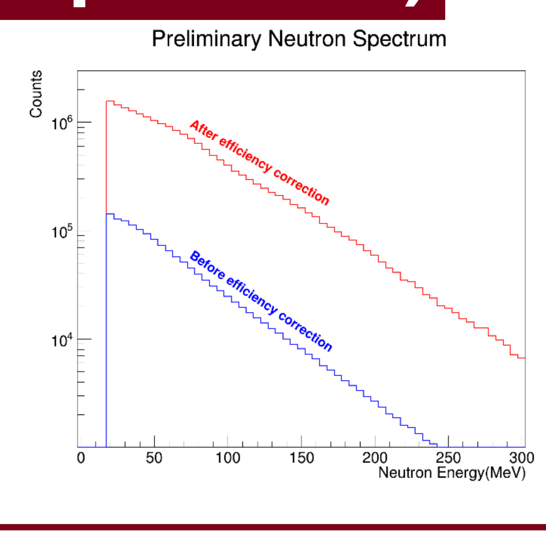




- Physics Event Generator was performed to validate detection efficiency and neutron response function of LANA.
  - IQMD Soft model : Au+Au collision @ 250 AMeV
  - 1 million events of collision
  - Only neutrons are emitted in SCINFUL-GEANT4
- Reconstructed neutron spectrum by 3 MeVee threshold

SCINFUL-GEANT4(Neutron spectrum)

- Preliminary neutron energy spectrum
  - ^{48}Ca+^{64}Ni @ 140 AMeV
- Only data taken by NWB.
- Since Charged Particle Veto(CPV) and NWA contributions were not considered, SCINFUL-GEANT4 will include CPV and NWA.



Summary

- We developed SCINFUL-GEANT4 to estimated the absolute detection efficiency of LANA based on the reaction channels and cross-sections of SCINFUL-QMD.
- To describe neutron response function of experimental data, resolution effect has been applied.
- Further configurations including CPV and NWA efficiency will be performed in SCINFUL-GEANT4.

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