# MONTE CARLO SIMULATIONS OF THE N_TOF LEAD SPALLATION TARGET WITH THE GEANT4 TOOLKIT: A BENCHMARK STUDY


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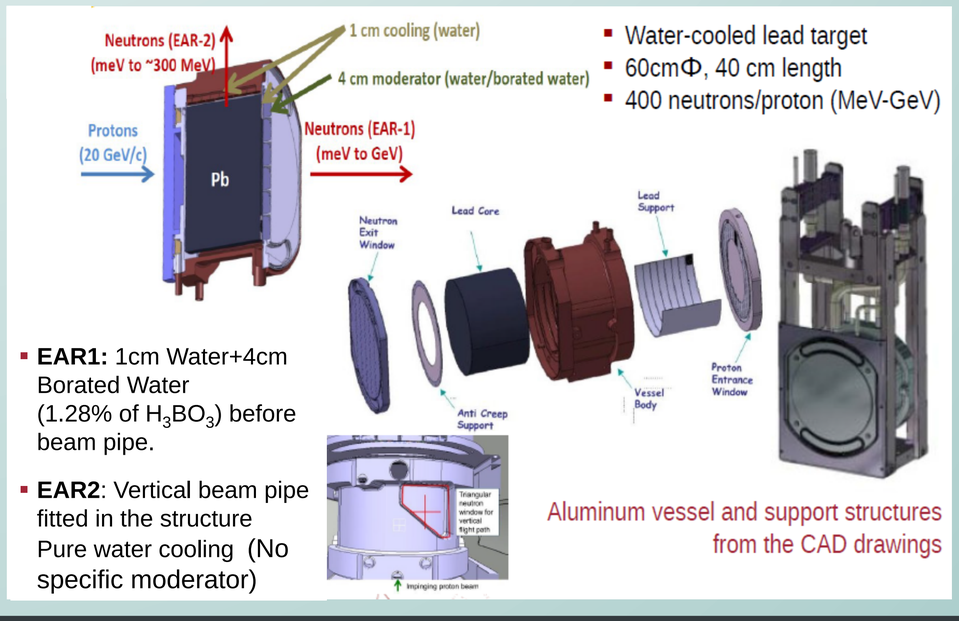
## Introduction

Monte Carlo (MC) simulations are an essential tool to determine fundamental features of a neutron beam, such as the neutron flux or the γ-ray background, that sometimes can not be measured or at least not in every position or energy range. Until recently, the most widely used MC codes had been MCNPX [1] and FLUKA[2] . However, the Geant4 toolkit [3] has become a competitive code also in this field, especially after the work done by Mendoza et al. [4] to adapt the evaluated neutron libraries to the native Geant4 format, called G4NDL. In this context, we present the Geant4 simulations of the neutron spallation target of the n_TOF facility at CERN, done with version 10.1 of the toolkit.

The first goal was the validation of the intra-nuclear cascade models implemented in the code using, as benchmark, the characteristics of the neutron beam measured at the first experimental area (EAR1) [5], especially the neutron flux and energy distribution, and the time distribution of neutrons of same kinetic energy (the so-called "resolution function"). The second goal was the development of a Monte Carlo tool aimed to provide useful calculations for both the analysis and planning of the upcoming measurements at the new experimental area (EAR2) of the facility [6].

## The n_TOF spallation target




- Water-cooled lead target
- 60cmΦ, 40 cm length
- 400 neutrons/proton (MeV-GeV)

- **EAR1:** 1cm Water+4cm Borated Water (1.28% of $H_3BO_3$) before beam pipe.
- **EAR2**: Vertical beam pipe fitted in the structure Pure water cooling (No specific moderator)

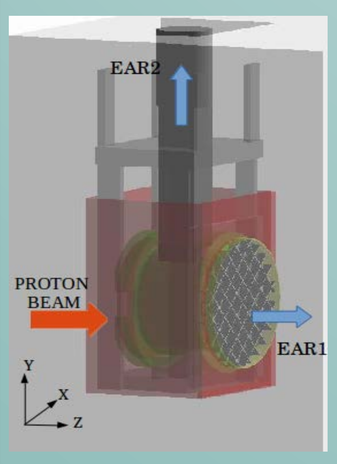
Aluminum vessel and support structures from the CAD drawings

## Geant4 simulation description

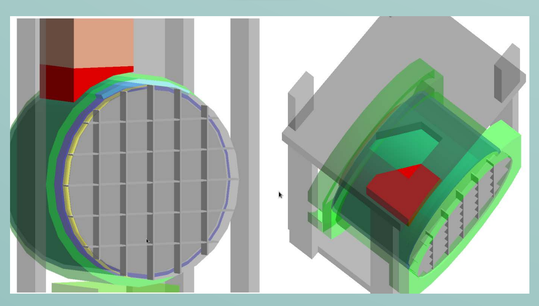
### Geometry Model


Inner components target assembly:

Proton entrance window + vessel+ Lead Core + Moderator/absorber + neutron exit window + beam line entrance

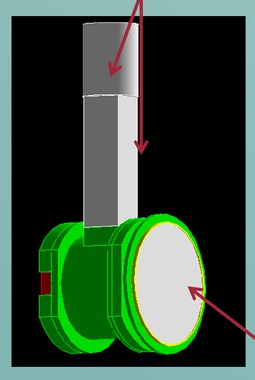



Detailed implementation of the n_TOF Target-moderator assembly



### Scoring Methods

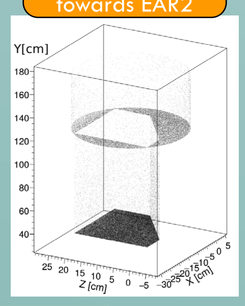
EAR2 : Detailed 3D scorer, beam line shape



- **Scoring surfaces** defined as in **previous simulations** at n_TOF
- **Angular acceptance** limited to 4 deg ↔ isotropic spectra within this solid angle.
- **Collected information at scorer:** Position, momentum, energy, type of particle and time.

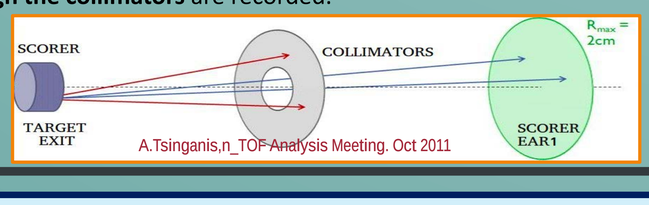
EAR1: 2D scorer @ entrance of beam line

Neutrons' spatial distribution scorer towards EAR2



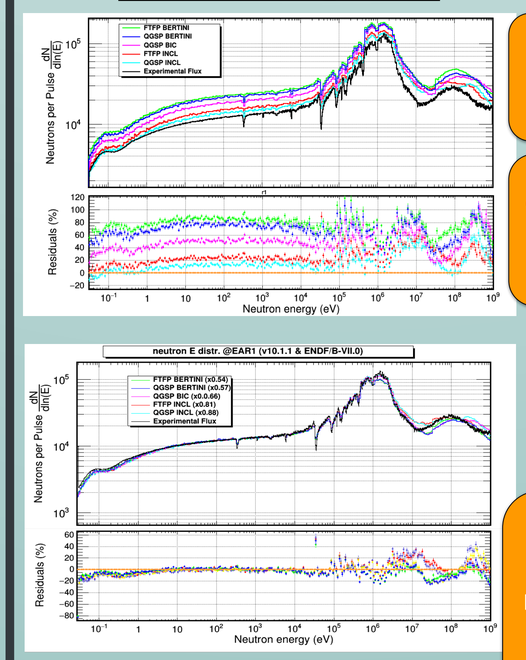

## Simplified "optical" transport to EARs

- **Real simulation** to the EAR's : **Unaffordable CPU Time**
- Each **scored neutron** (with θ ≤ 4 deg) is **resampled** scanning a 2 cm radius scorer placed in EAR1 (185 m distance) or EAR2 (19 m); only those that fly **through the collimators** are recorded.




## EAR1: Geant4 simulation benchmarking [5]

### Neutron flux @ EAR1



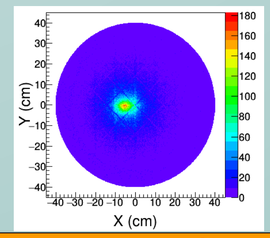

Sizable differences among the Geant4 Physics Lists (PL) in absolute flux.

All PLs above the experimental flux [7]. Closest: QGSP_INCLXX_HPT (+12%)

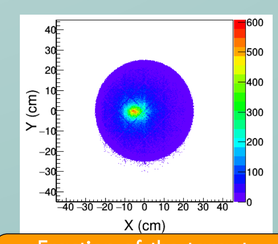



Remarkable reproduction of the spectrum shape. Differences at energies above 20MeV: Intranuclear cascade models

### Beam profile



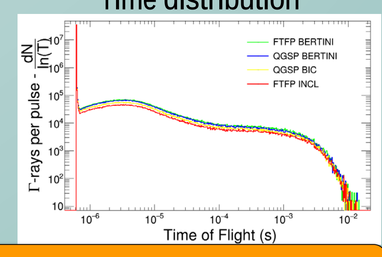

Neutron beam profile at EAR1 beam line entrance.




Fraction of the target "seen" from EAR1 after collimation

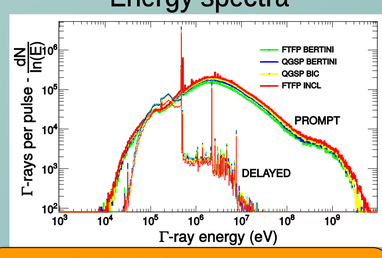
### γ-ray flux @ EAR1

Time distribution




Prompt (TOF<1us): Spallation (γ-flash)
Delayed: γ-rays after neutron captures

Energy spectra

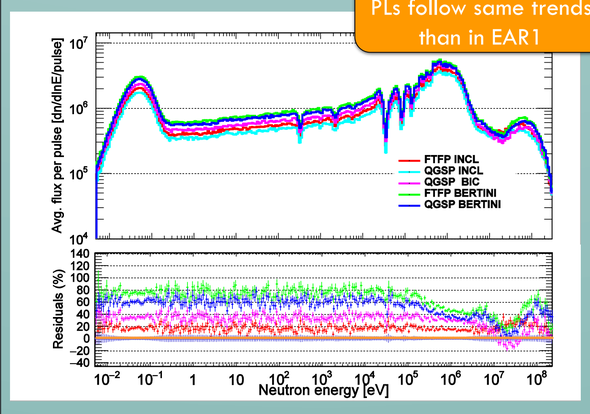



γ-flash: High energy g-rays
Delayed: Characteristic capture peaks ($^1$H, $^{10}$B, $^{27}$Al)

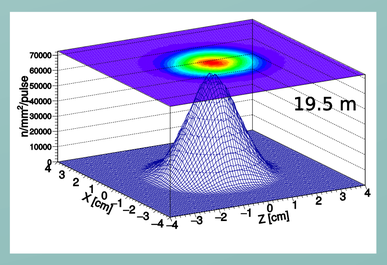
## EAR2: Simulation characteristics & prospects [6]

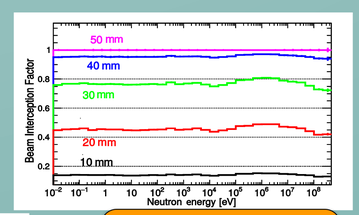
### Neutron flux

Ratio between Geant4 PLs follow same trends than in EAR1



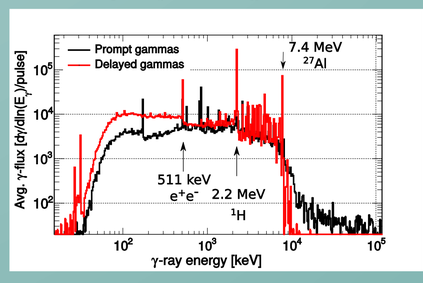

### Beam profile



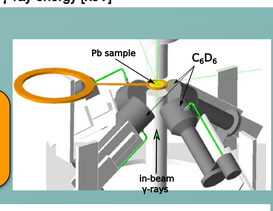




Fraction of the beam intercepted by a sample @19.5m

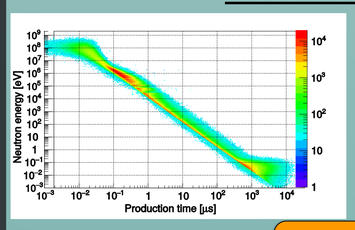
### γ-ray background

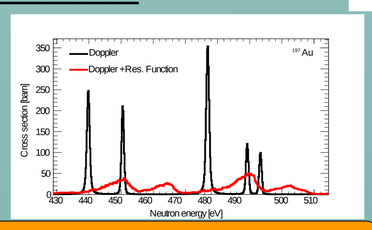



Capture setup C6D6 detectors

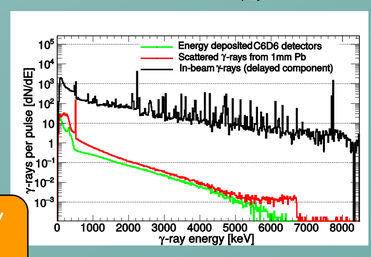



### Resolution Function




Non-univocal energy- time relation induces resonance broadening




Expected γ-ray background conditions

## References


1.-D.B. Pelowitz (Editor), MCNPX User's Manual, Version 2.7.0, LANL rreport, LA-CP-11-00438 (2011).
2.- A. Ferrari et al., FLUKA: A Multi-Particle TransportCode, CERN-2005-10, INFN/TC 05/11, SLAC-R-773 (2005).
3.- S. Agostinelli et al., Nucl. Instrum. Methods A **506**, 250 (2003).
4.- E. Mendoza, D. Cano-Ott, T. Koi, C. Guerrero, IEEE Trans. Nucl. Sci. **61**, 2357 (2014).
5.- S. Lo Meo, M.A. Cortes-Giraldo, C. Massimi, J. Lerendegui-Marco et al., Eur. Phys. J. A **51**, 160 (2015).
6.- J. Lerendegui-Marco, S. Lo Meo, C. Guerrero, M.A. Cortes-Giraldo et al., Eur. Phys. J. A ***52***, 100 (2016).
7.- The n_TOF Collaboration (M. Barbagallo et al.), Eur. Phys. J. A 49, 156 (2013).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