Update on Geant4 Simulations of Lead Spallation Target at n_TOF Facility

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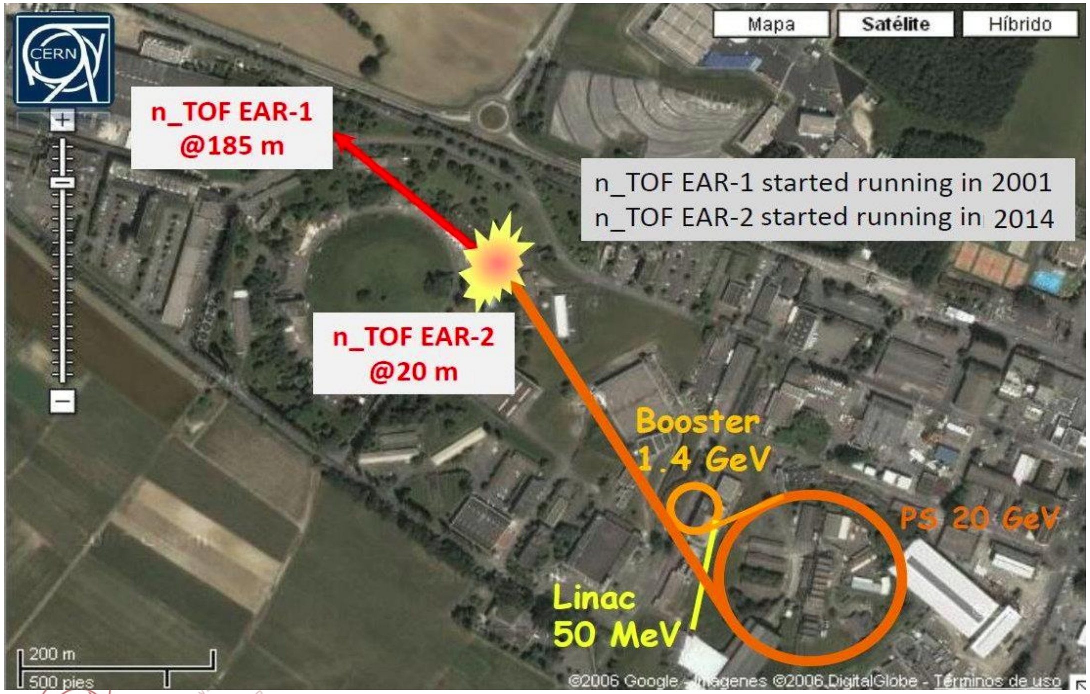
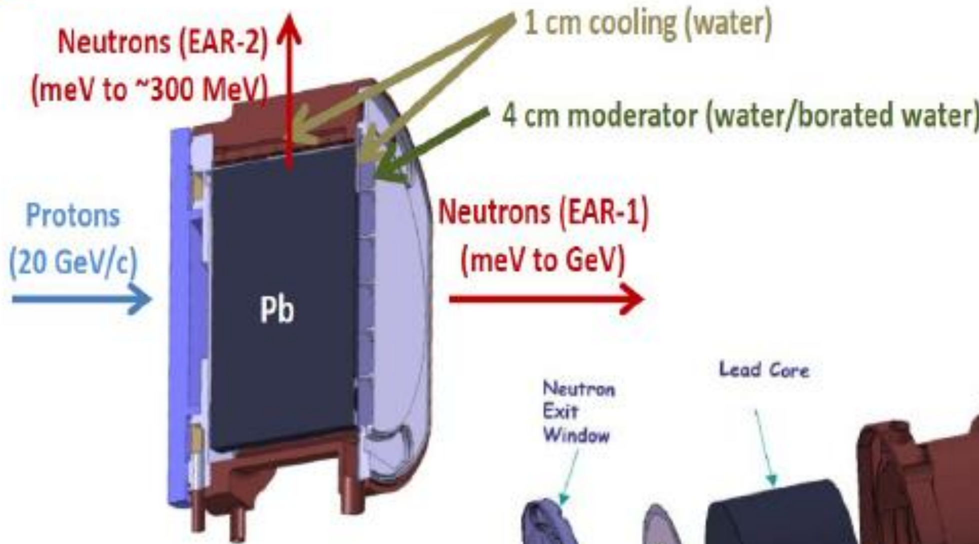
The n_TOF facility at CERN

- High resolution neutron cross section measurements
  - Time of Flight (ToF) Technique
  - **ΔE/E(1keV) :** EAR1 (185m)→ ~$3\cdot10^{-4}$, EAR2(19m) → ~ $8\cdot10^{-3}$
  - **Flux** (n/cm^2/pulse)**: EAR1:** ~$4\cdot10^{5}$ **EAR2:** ~$7.5\cdot10^{6}$
  - Neutron spectrum from **thermal to few GeV** (highest among similar facilities)

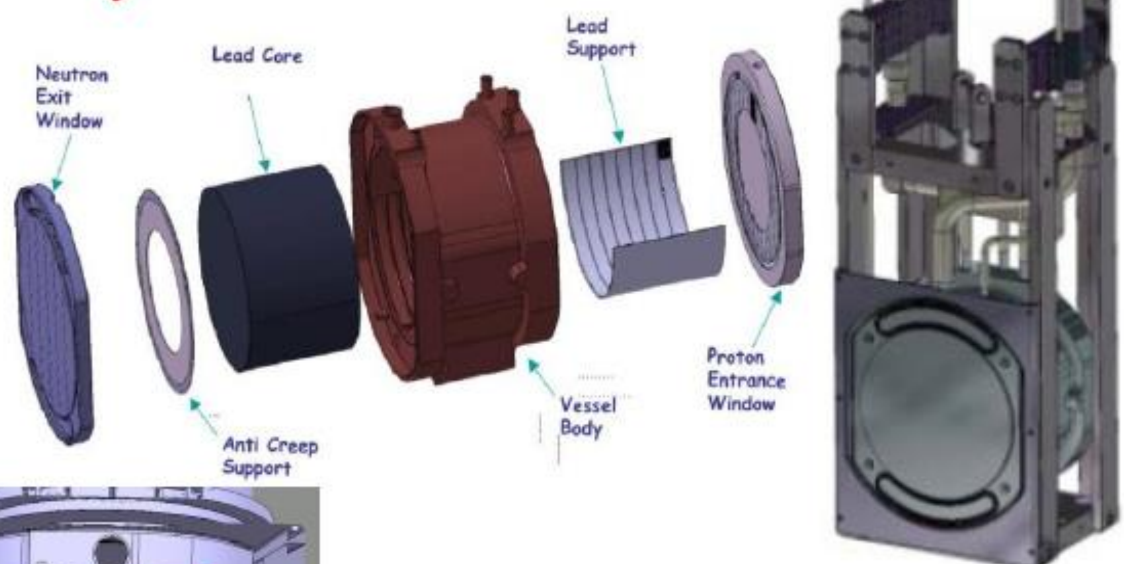


- Applications:
  - <u>Nuclear Technologies</u>
    - ADS, Fast reactors
  - <u>Astrophysics</u>
    - s-process (AGB stars)
  - <u>Basic Nuclear Physics</u>

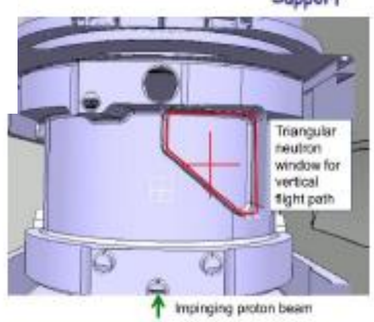
Pb Spallation Target – Technical Details



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



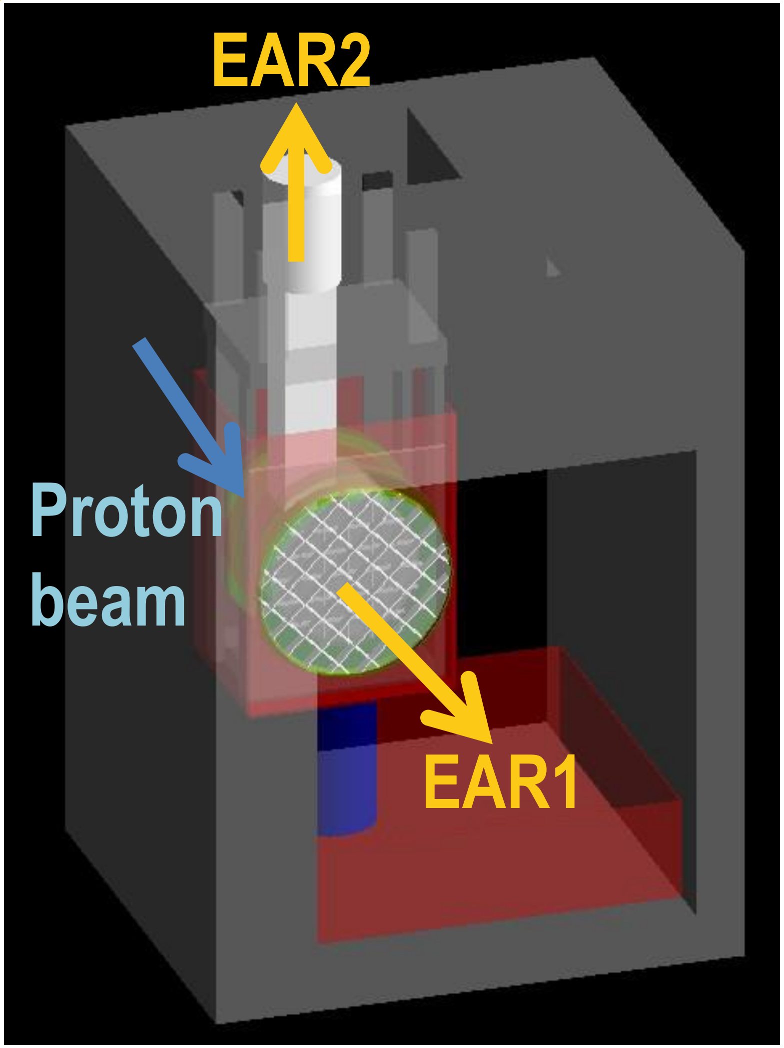
- **EAR1:** 1cm Water+4cm Borated Water (1.28% of H_3BO_3) before beam pipe.



- **EAR2**: “triangular” shape entrance to beam line. NO Boron, just water.

Aluminum vessel and support structures from the CAD drawings

Full Geometry Model

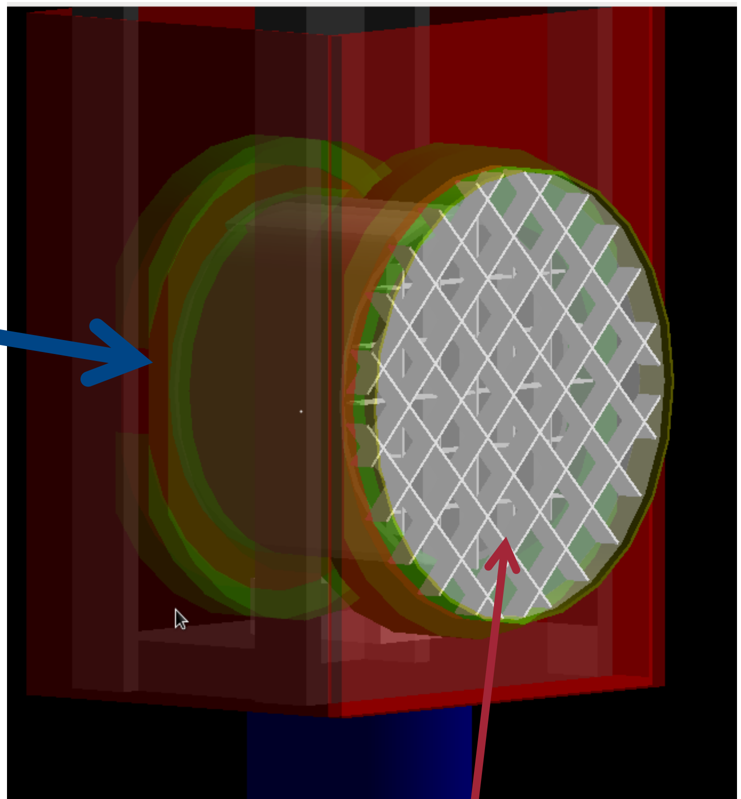


- 20 GeV/c protons, with an incidence angle of 10 deg.
- Gaussian profile proton beam (FWHM=3.53cm).
- Precise implementation of the cooling and moderation layers.
- All the components have been implemented **following the technical drawings.**
- **Special care** in the **composition** of the lead target and the surrounding materials.

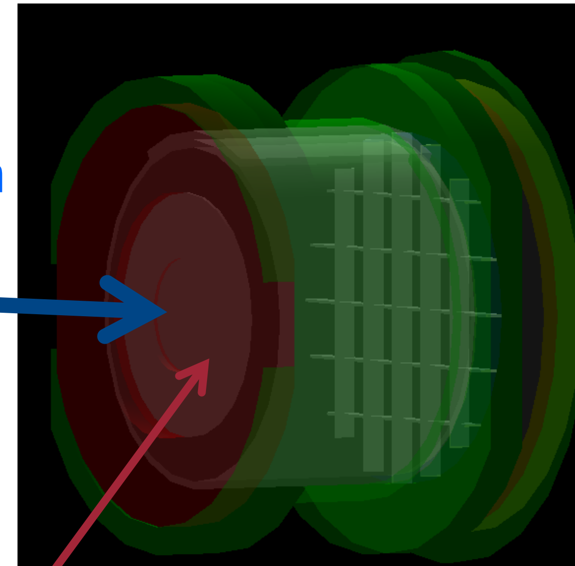
Geometry Model – Details

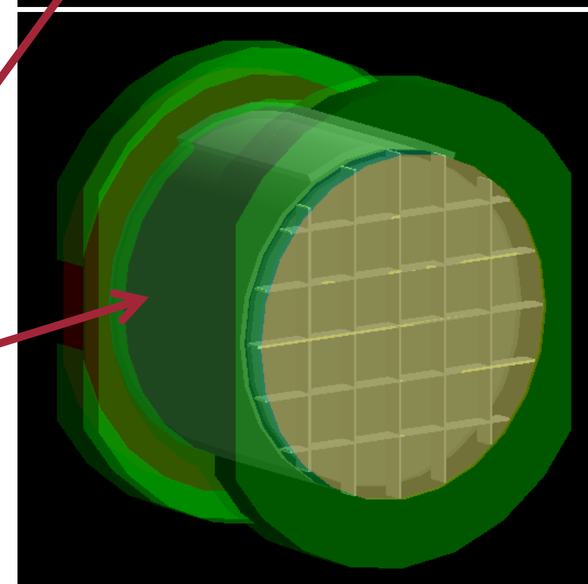
Lead Target with surrounding vessel and structural support (Al-alloys)

Proton Beam



Proton Beam



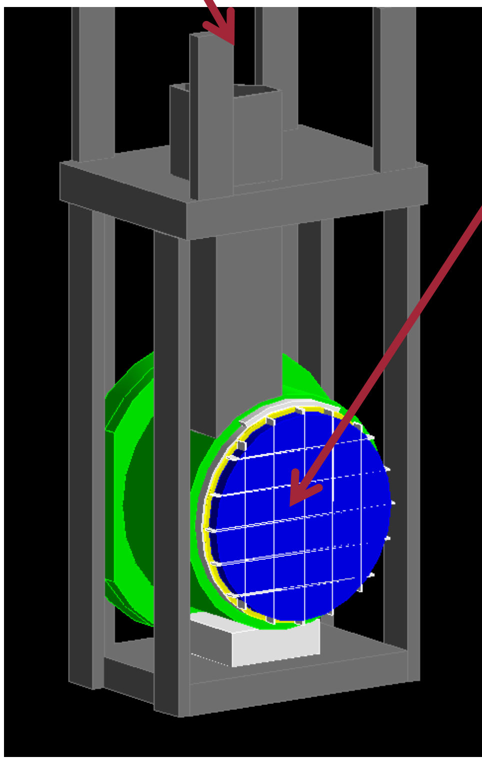


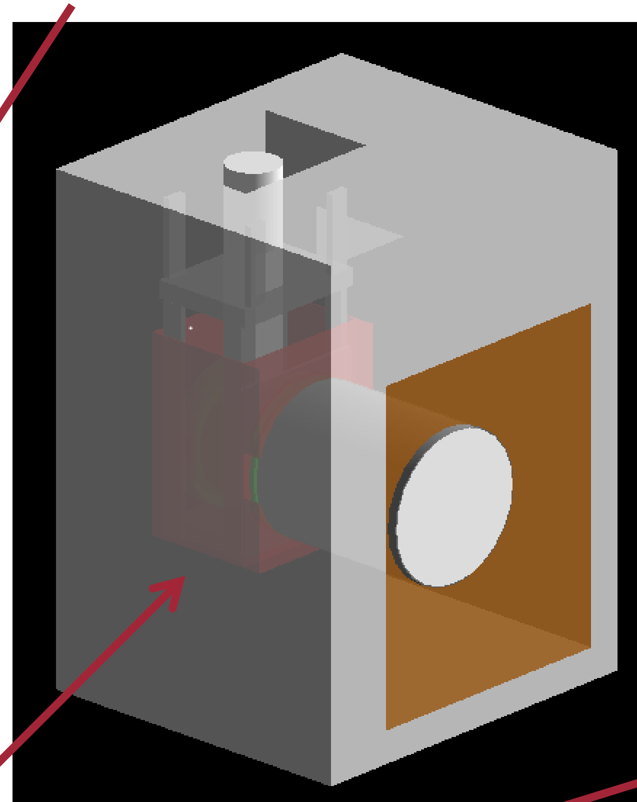
Detail on the proton entrance and neutron exit windows

Grid beam line entrance turned 45º

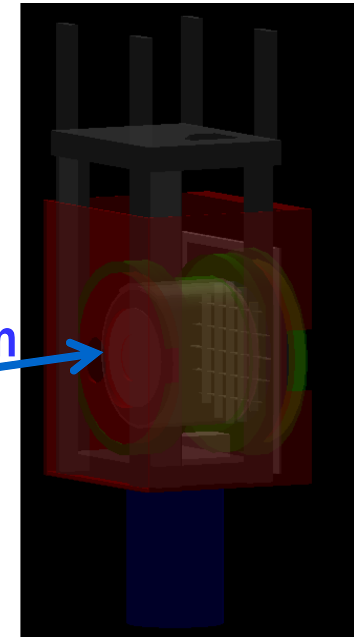
Geometry Model – Details

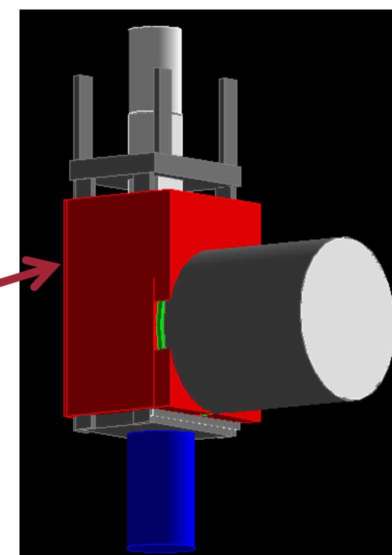
Exit toward EAR2 and Moderator layer with aluminum Support grid





Proton beam

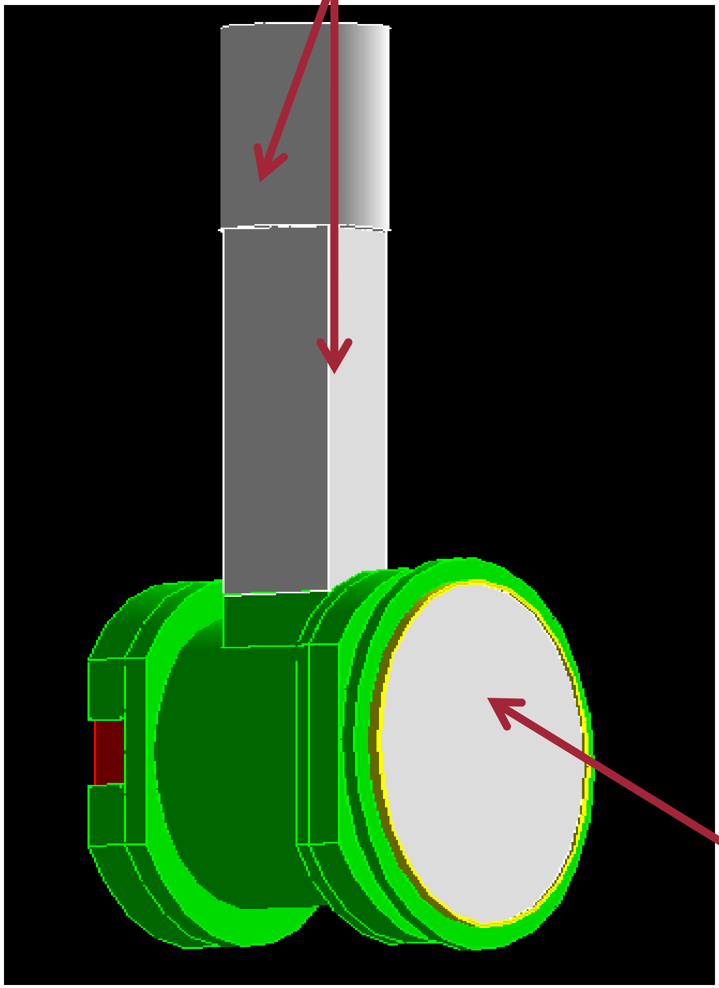




Target support structures, concrete container and beam lines

Simulation Output: Scorers @ target exit

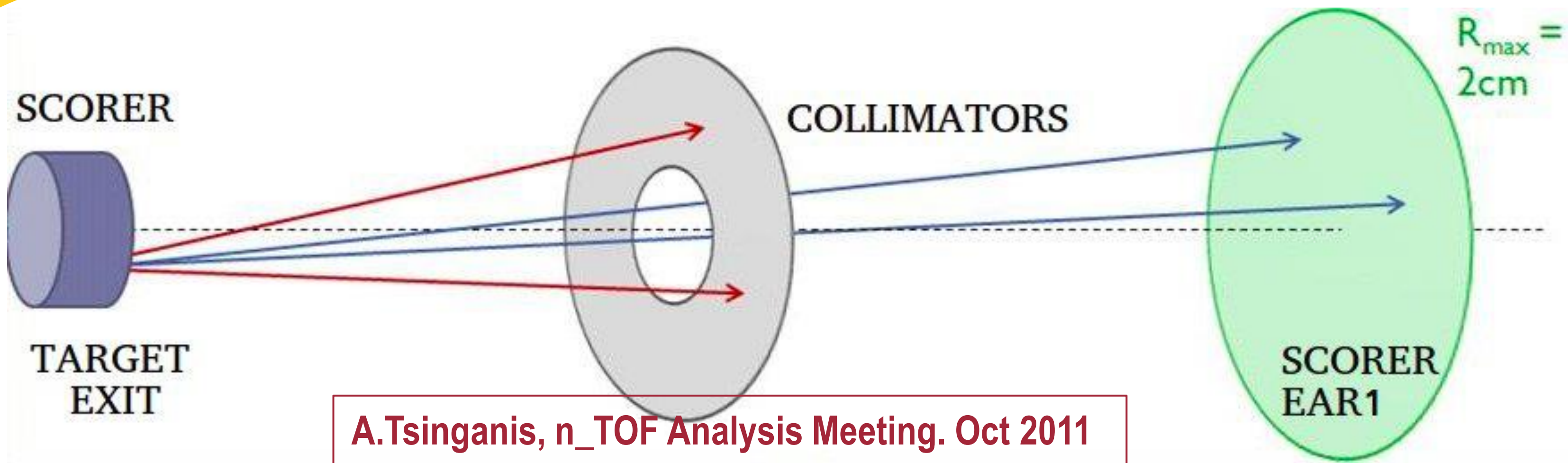
EAR2 : Detailed 3D scorer, beam line shape



- Scoring surfaces defined as in simulations with FLUKA carried out by n_TOF collaboration.
  - To use existing transport codes to get results at EAR1 and EAR2 from the GEANT4 simulation @ target.
- Angular acceptance limited to 4 deg @EAR1 and 10 deg @EAR2 ↔ 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

Transport Code



A.Tsinganis, n_TOF Analysis Meeting. Oct 2011
V. Vlachoudis, private communication

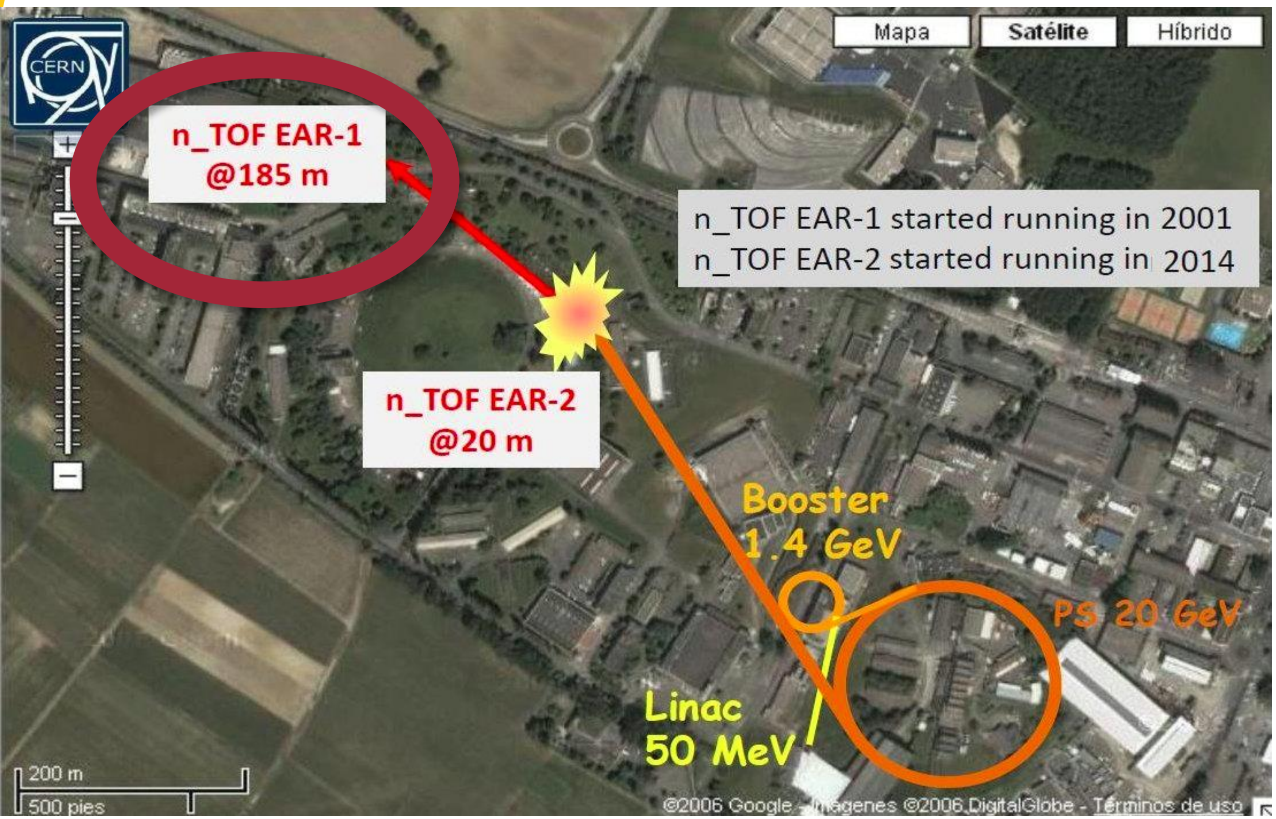
- **Real simulation** to the EAR's : **Unaffordable CPU Time**

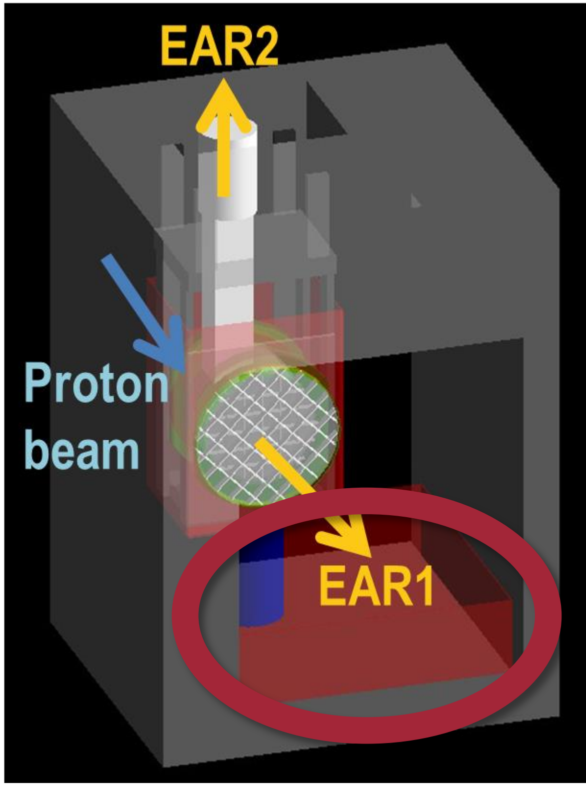
- ~Thousands of instances are created for each scored neutron (with θ ≤ 4 deg) and sent scanning a 2cm radius scorer in EAR1 (185 m distance) or EAR2 (~19 m)

- Input with the position and dimensions of the collimators in both beam lines

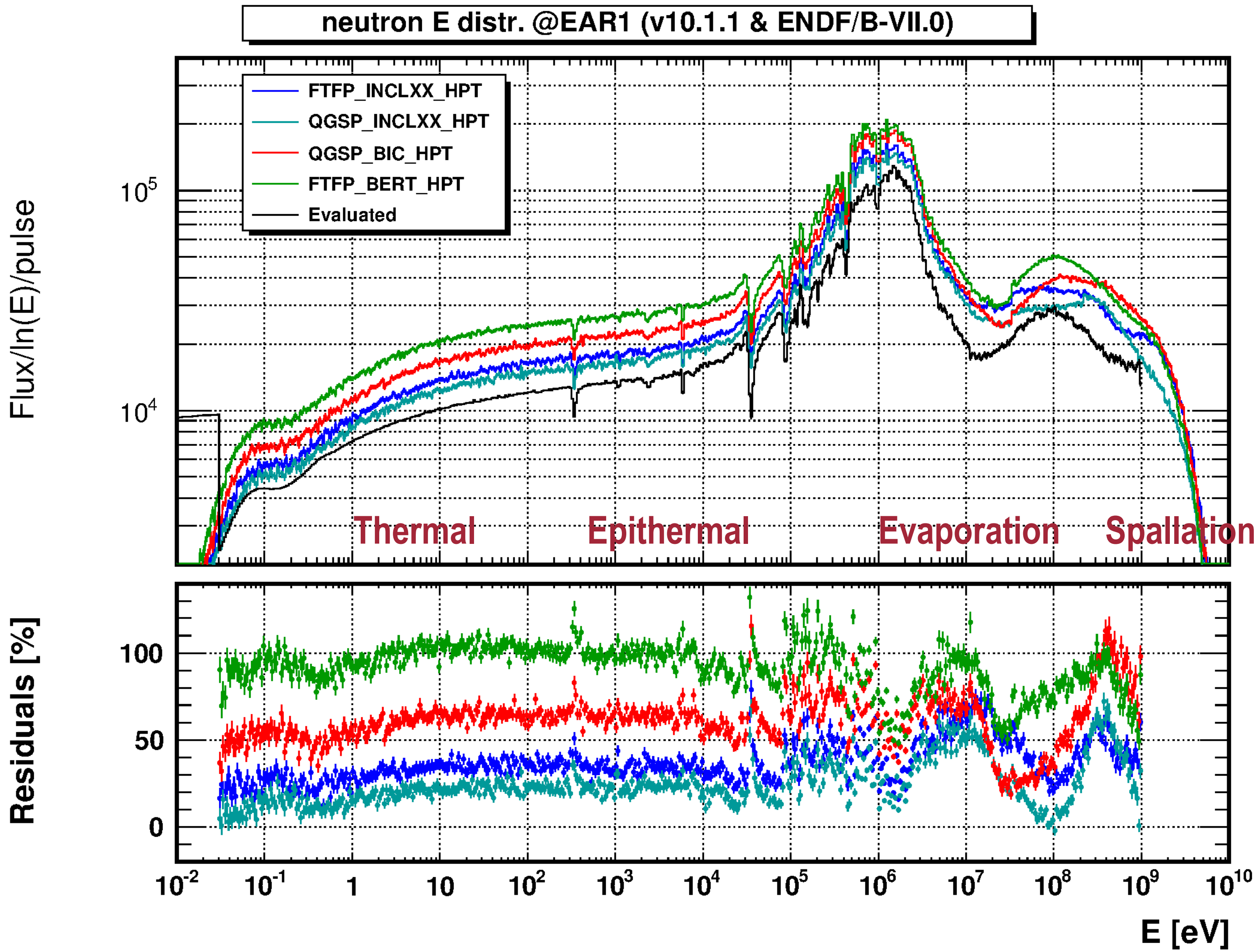
- **Simplified transport**: If a neutron hits a collimator is discarded

Results after transport to EAR1

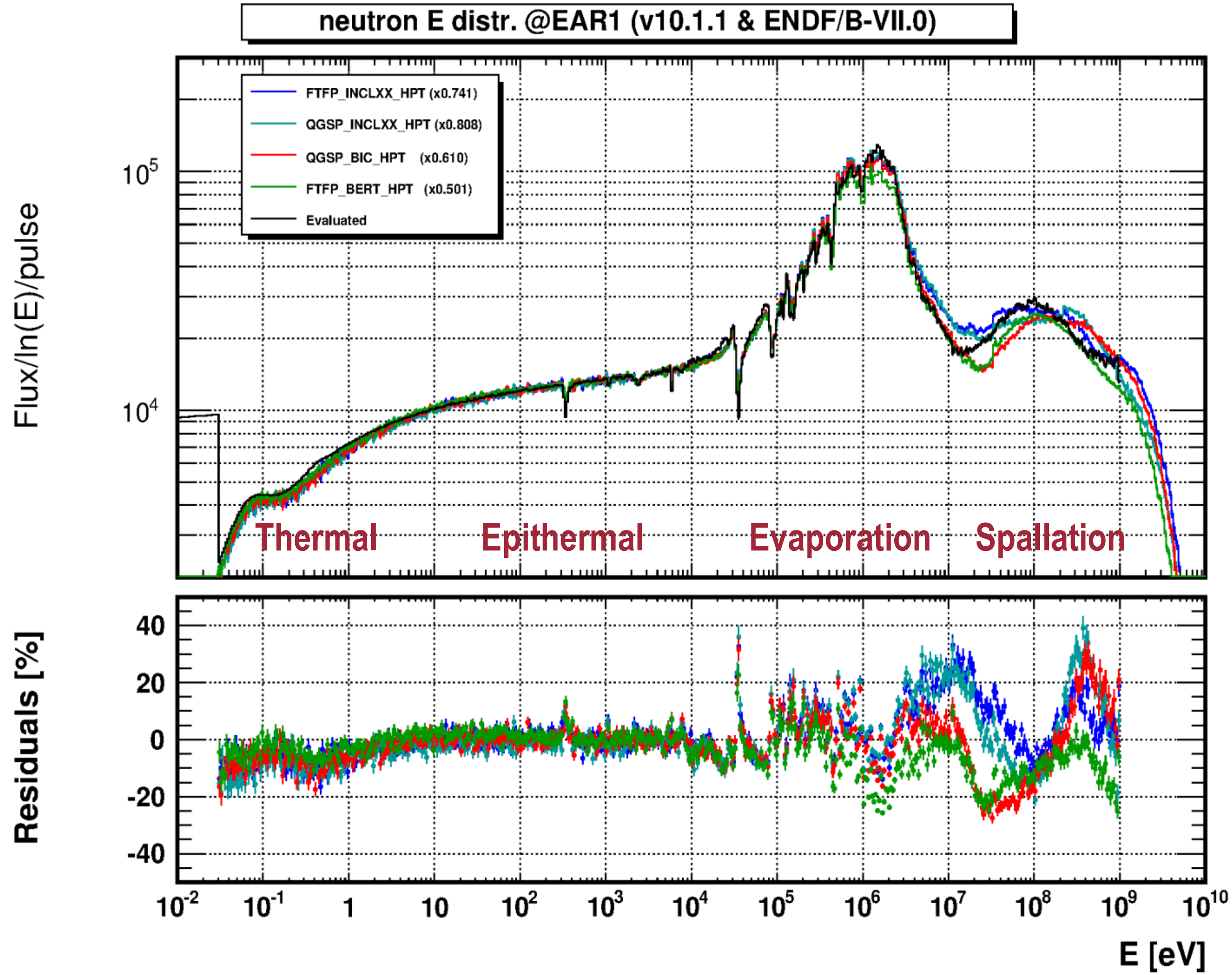




Neutron Energy Distribution @ EAR1 (v10.1.1)



Neutron Energy Distribution @ EAR1 (v10.1.1)



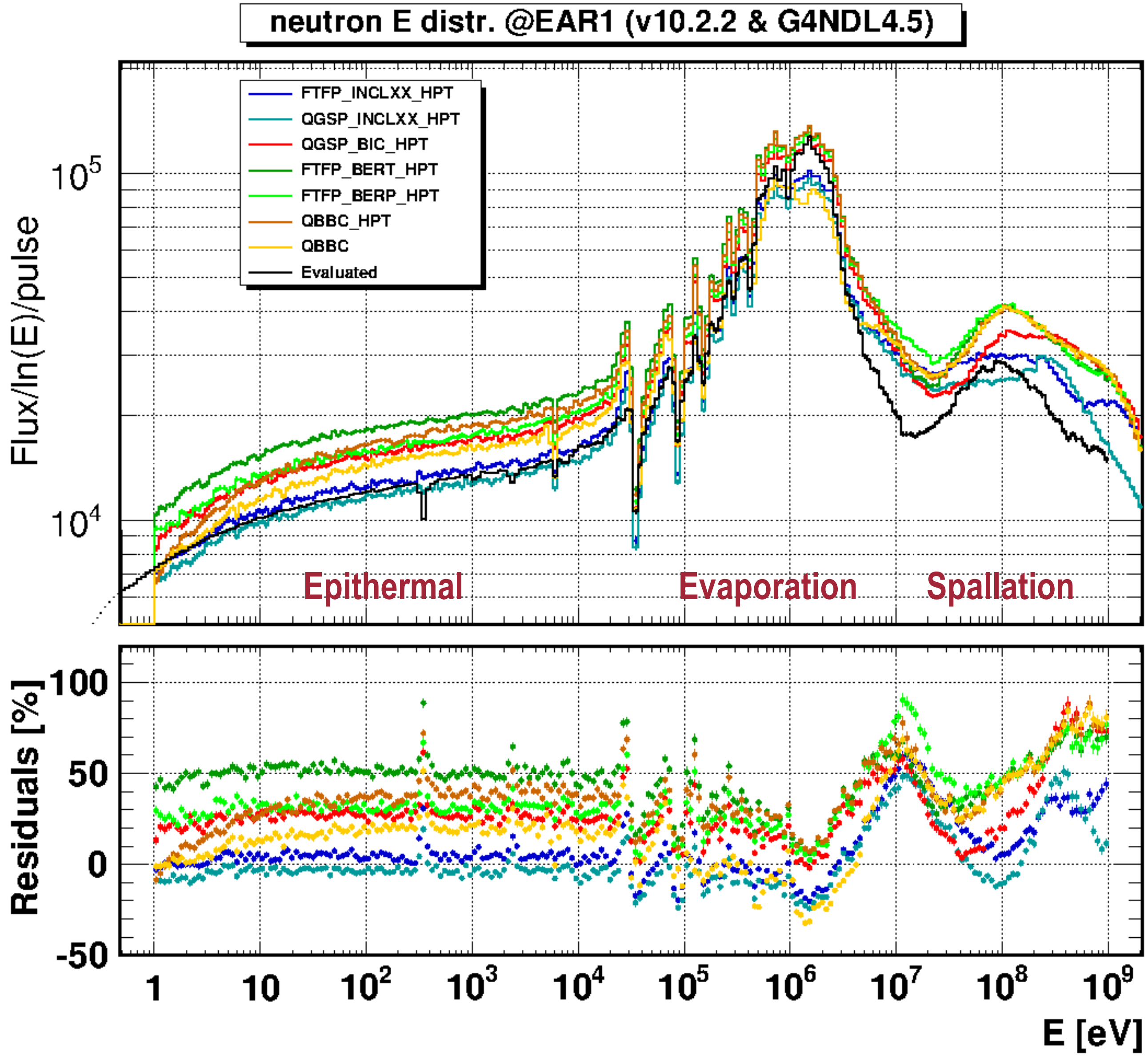
Normalization factors calculated using flux integral in **1-10 keV**.

*_INCLXX_HPT physics lists provide better normalization factors.

Once normalized, **FTFP_BERT_HPT** follows slightly better the spectrum shape at **spallation** energies, but it has the largest deviation as for **yield**.

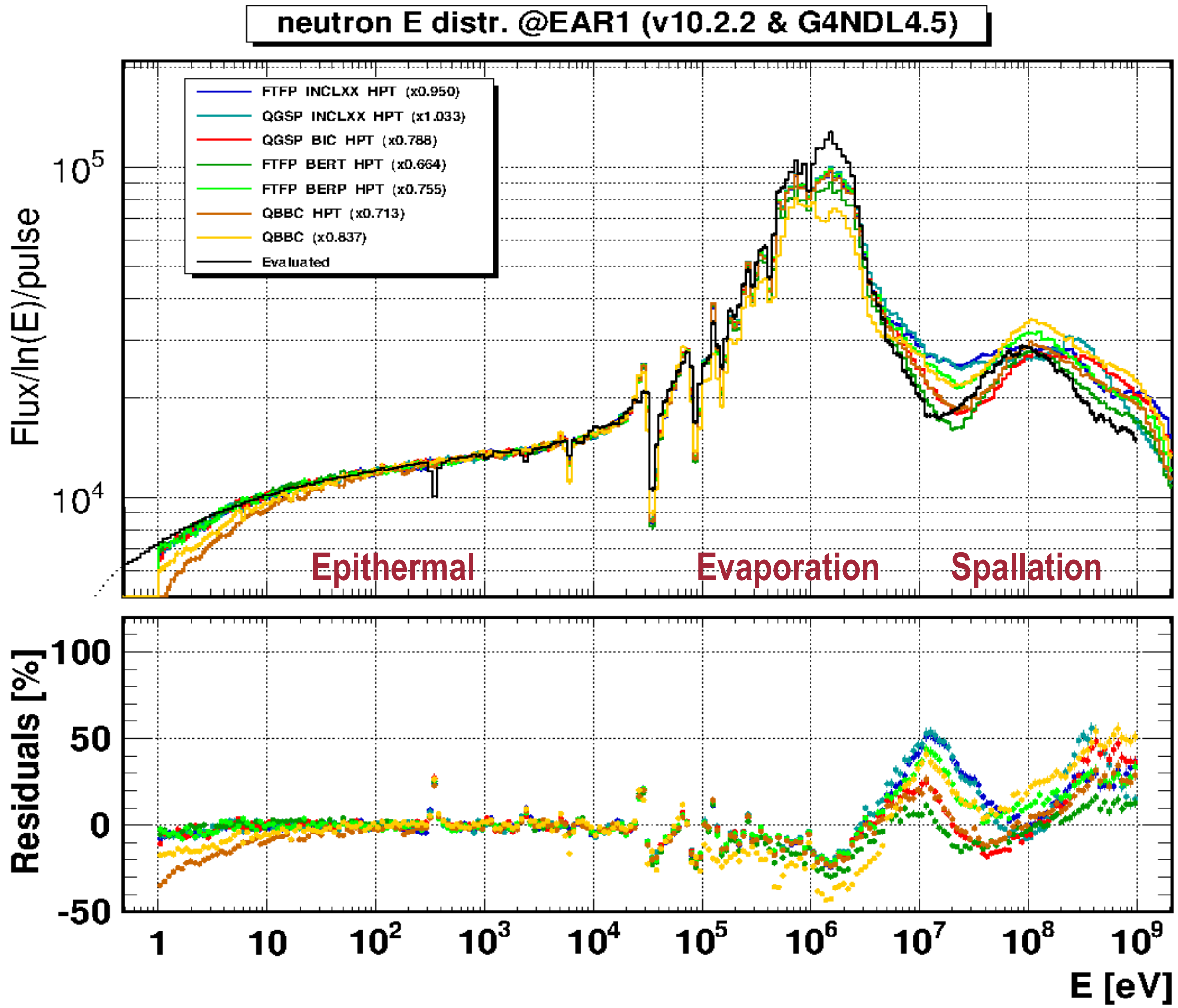
- **Norm factor** varies from **0.808** (**QGSP_INCLXX_HPT**) to **0.501** (**FTFP_BERT_HPT**).

Neutron Energy Distribution @ EAR1 (v10.2.2)



- **More precise collimation data used.**
  - It improves significantly the integral flux calculated.
- **Trends between PLs are similar to those found with v10.1.1**
- Tracking of **neutrons** was **suspended below 1 eV** to improve simulation speed (more on this, later).

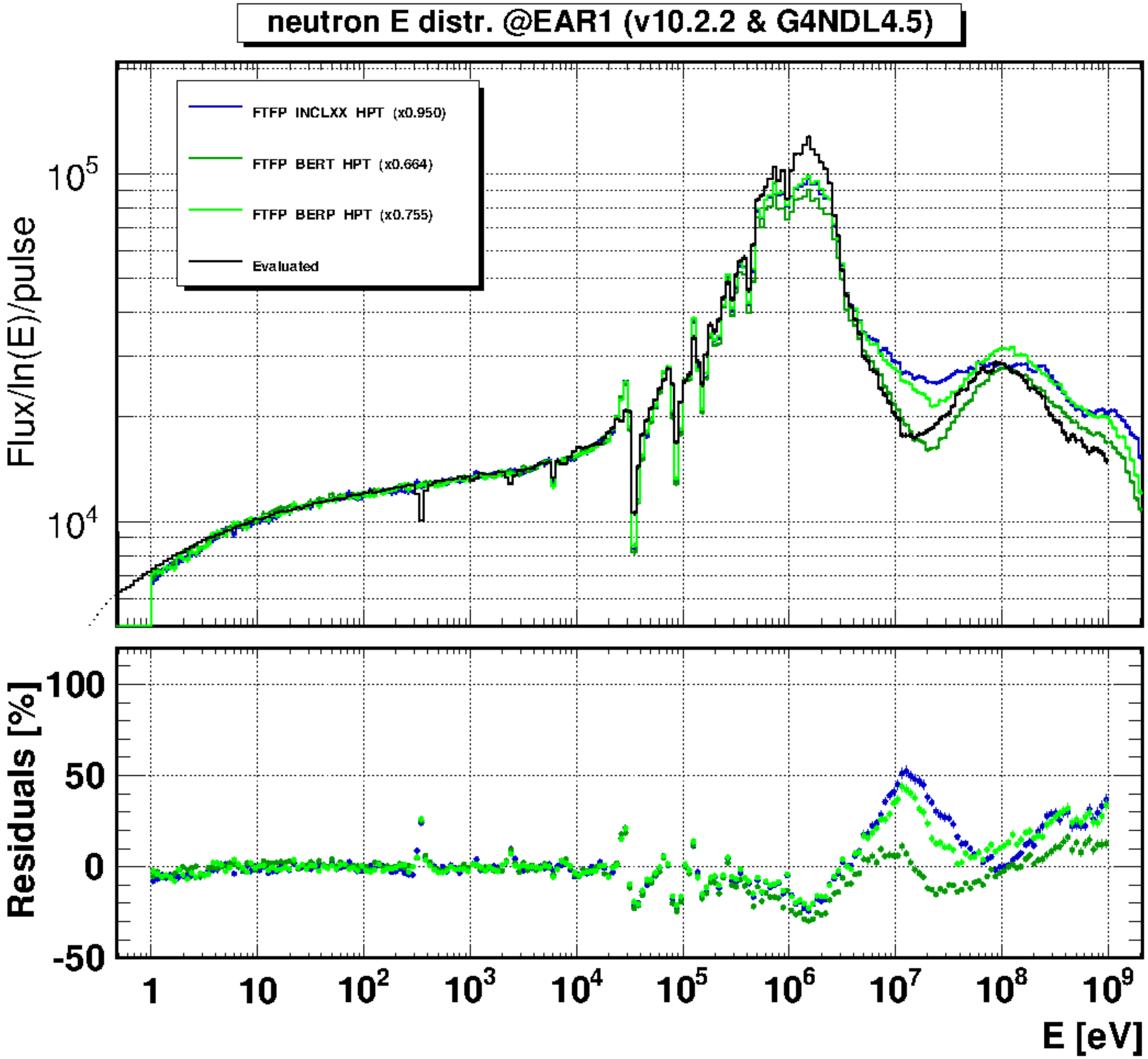
Neutron Energy Distribution @ EAR1 (v10.2.2)



- **Normalization factors** calculated using integral for **1-10 keV**.
- *_INCLXX_HPT physics lists provide better normalization factors.
- FTFP_BERT_HPT follows better the spectrum shape at **spallation** energies, but it still presents the largest deviation w.r.t. to integral flux.

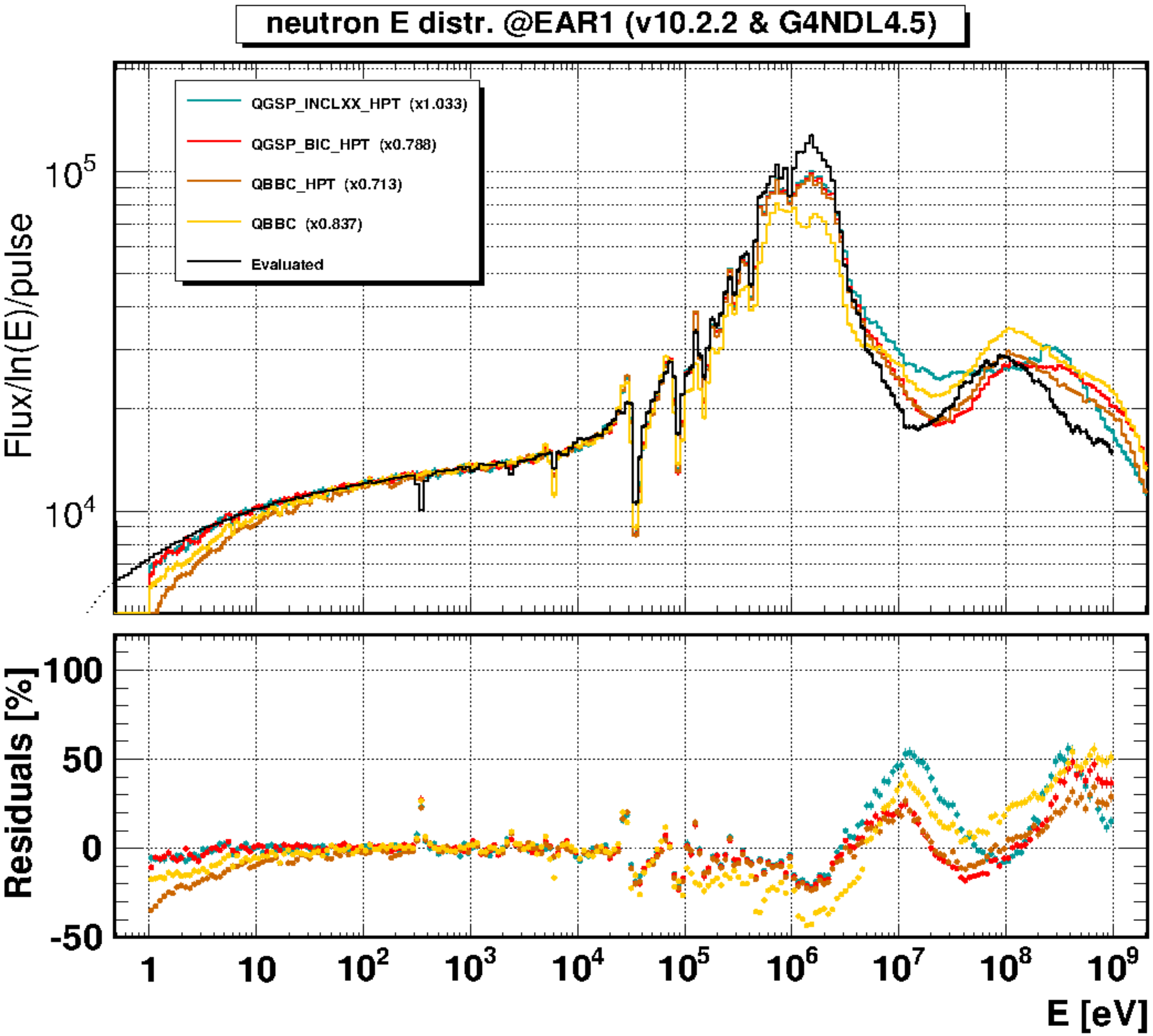
- **Norm factor** varies from **1.033** (QGSP_INCLXX_HPT) to **0.664** (FTFP_BERT_HPT).

Neutron Energy Distribution @ EAR1 (v10.2.2)



- **FTFP-based PLs only!**
- **BERP** produces a lower amount of neutrons compared to **BERT** (good), but does not reproduce the spectrum shape so well at spallation energies.

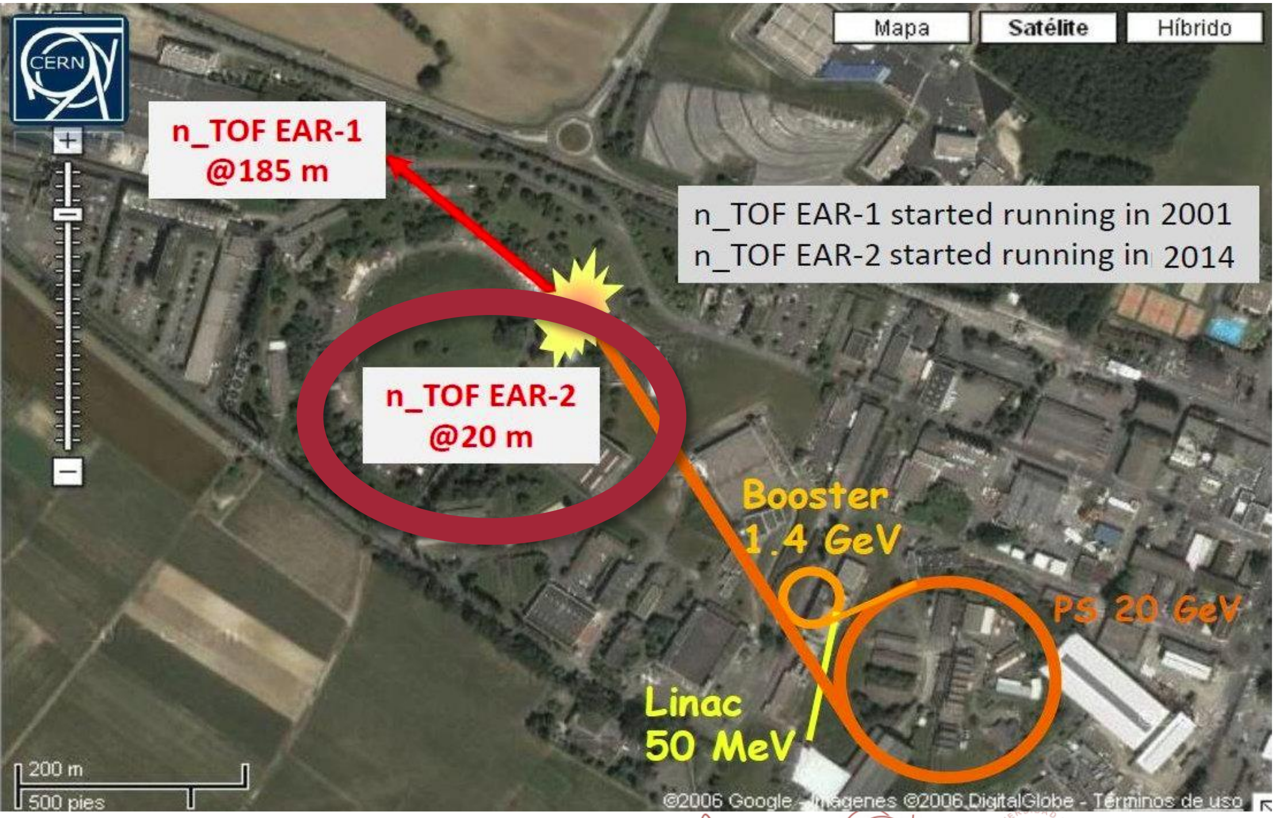
Neutron Energy Distribution @ EAR1 (v10.2.2)

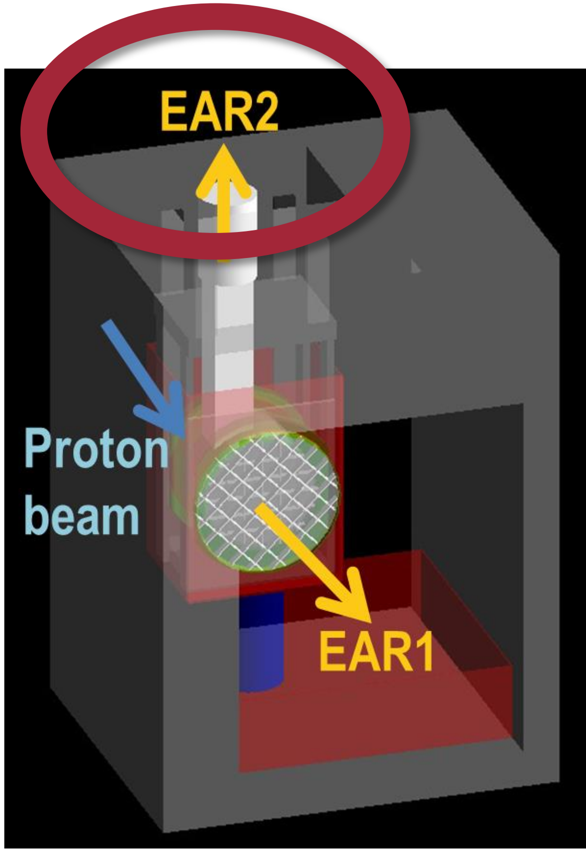


- **QGS-based PLs only!**
- **BIC** seems to worsen above ~200 MeV w.r.t. v10.1.1.
- Custom implementation of **QBBC with NeutronHP + neutron Elastic XS for Thermal Energies (<4 eV) (QBBC_HPT)**, please take this calculation as preliminary

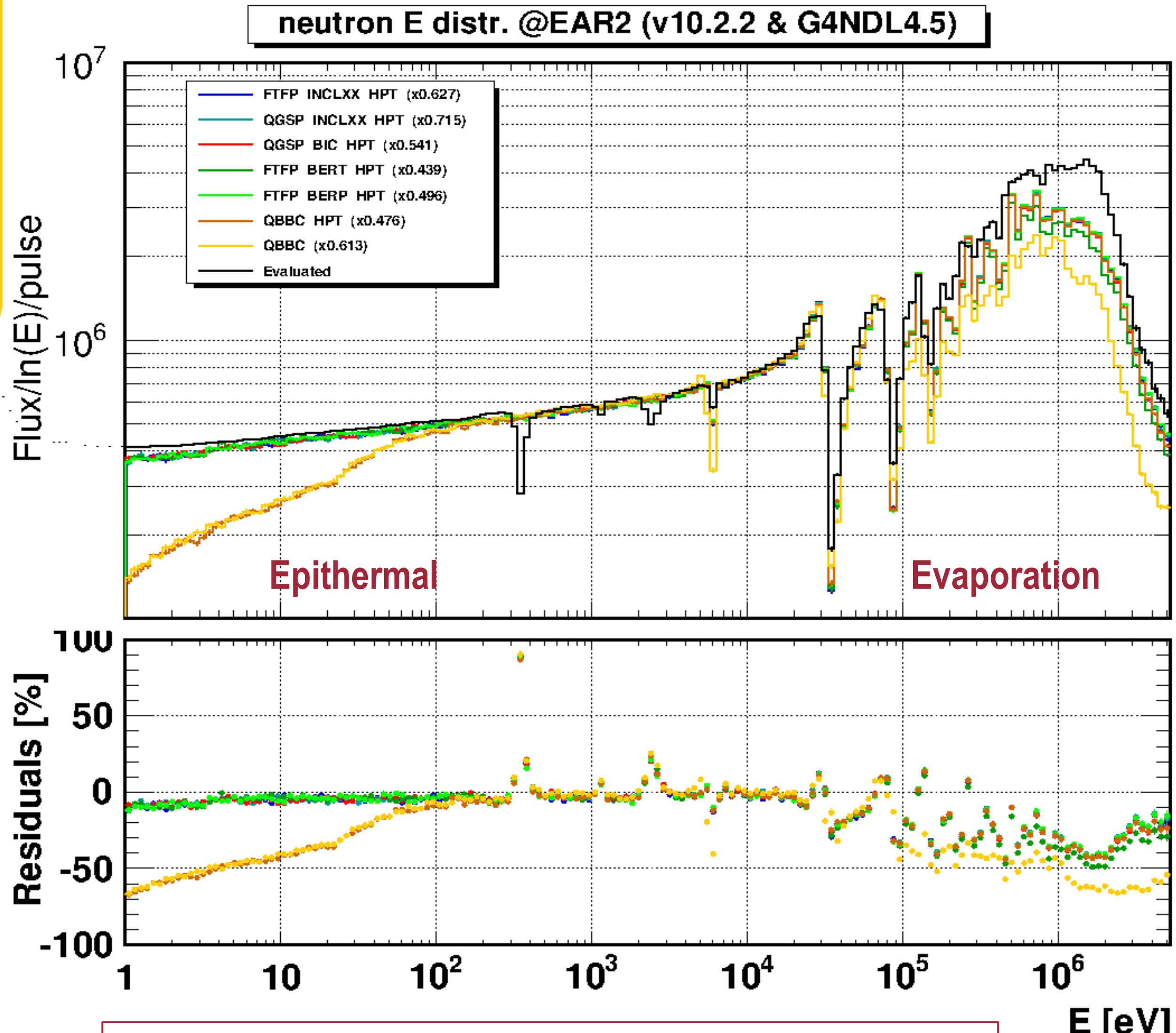
nTOF CERN Geant 4

Results after transport to EAR2





Neutron Energy Distribution @ EAR2 (v10.2.2)



M. Sabaté-Gilarte, M. Barbagallo et al., in preparation
N. Colonna et al., *Nuc. Phys. News* 25: 19-23 (2015)

- **Norm factor** varies from **0.715** (**QGSP_INCLXX_HPT**) to **0.439** (**FTFP_BERT_HPT**).
- **Actual distance from EAR2 ground to target to be accurately determined.**
  - It may improve agreement between calculations and experimental neutron flux
- **Precise quantification of neutrons scattered at collimators might also change the calculated spectrum shape.**
  - Transport through collimators is done “ideally”.

Conclusions

Conclusions

- Slightly better agreement as for neutron integral flux calculation @EAR1 thanks to more accurate collimation data.
- Experimental integral flux evaluated @EAR2 still preliminary – need to know accurate total distance.
  - More accurate simulation of collimators closer to EAR2 may be needed.
- Unexpected CPU overhead observed when using NeutronHP (with Thermal Scattering XS). Work in progress to figure out what causes this.
- Study on reaction multiplicities ongoing to try to explain differences between PLs.

Thanks for your attention