# Geant4 models for nuclear de-excitation

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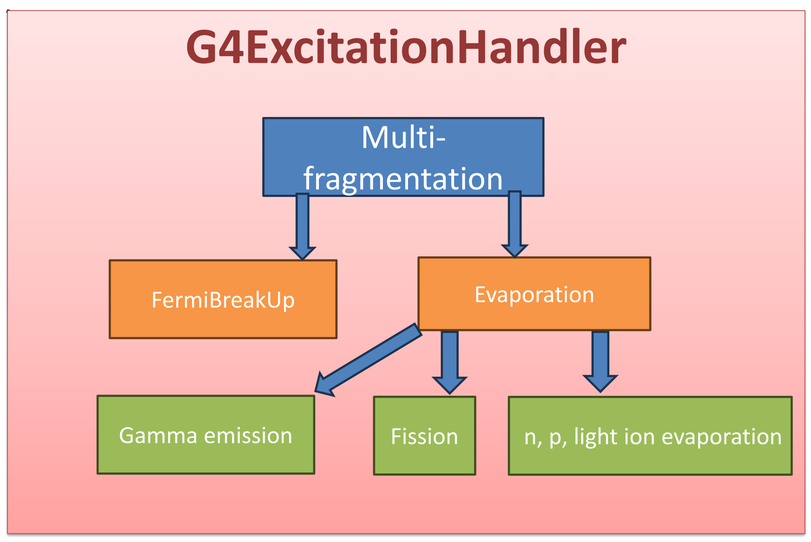
## Abstract

**Geant4 hadronic physics sub-library includes a wide variety of models for high and low-energy hadronic interactions. We report on recent progress in development of the Geant4 nuclear de-excitation module. This module is used by many Geant4 models for sampling of de-excitation of nuclear recoil produced in nuclear reactions. Hadronic shower shape and energy deposition are sensitive to these processes.**

**We will present de-excitation module structure, and comparisons of Geant4 predictions for the thin target experiments using different Geant4 hadronic physics models for the new Geant4 version 11.3, which will be publicly released in December 2024.**

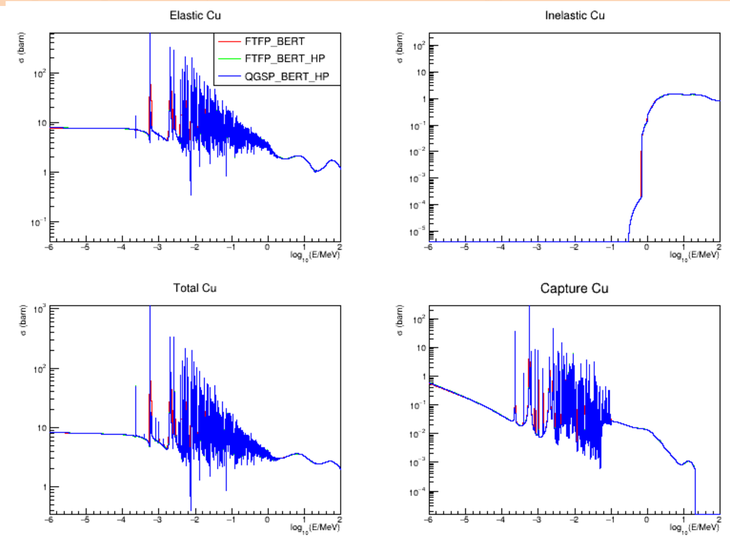
## De-excitation module structure




- *G4FermiBreakUpVI is applicable for Z <9, A <17*
  - *991 reaction channels*
- *G4EvaporationFactory has 68 channels*
  - *gamma,*
  - *fission,*
  - *light fragments*

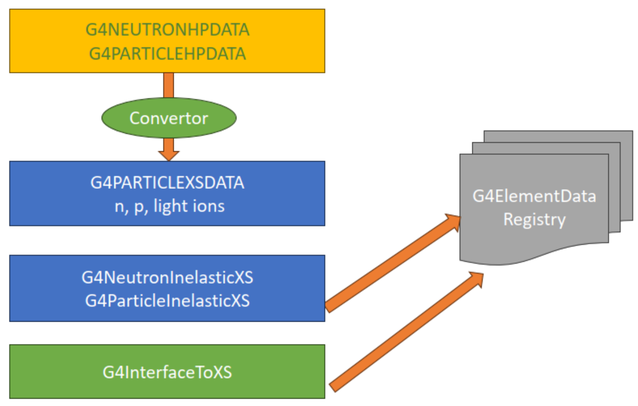
## The new Geant4 cross section dataset

The new cross section data set G4PARTICLEXS4.1 is produced from G4NDL4.7.1 and G4TENL1.4 high precision data base of Geant4. The scale of the new data vectors is logarithmic, low-energy limits are chosen individually for each nucleus. Below this limit the cross section is constant for the elastic and inelastic processes and scaled as *1/v* for the capture process (*v* is the neutron velocity).



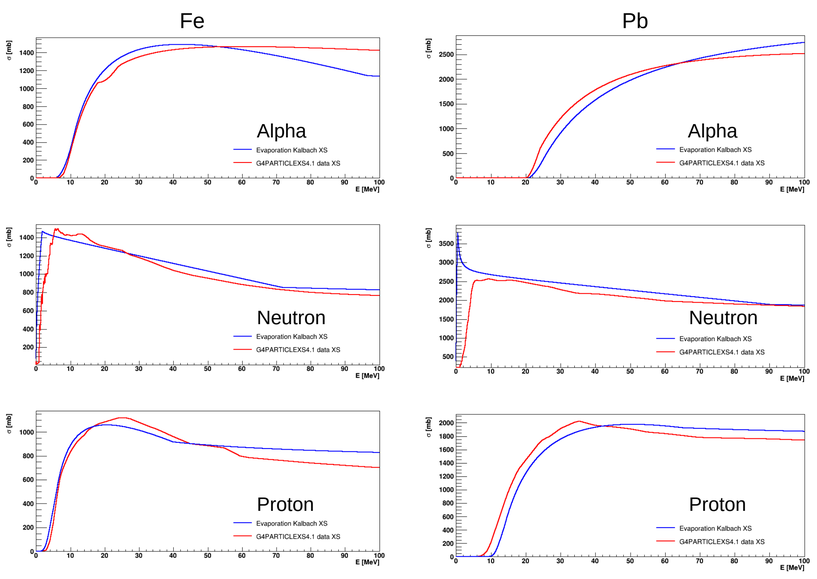

The elastic, inelastic, total, and capture neutron cross sections off the Copper target. Three Physics Lists are shown: FTFP_BERT uses G4PARTICLEXS4.1, FTFP_BERT_HP and QGSP_BERT_HP use HP data directly.

## New G4InterfaceToXS class




- *Cross section classes store data in the G4ElementDataRegistry allowing sharing data between threads*
- *The new G4InterfaceToXS allows to access these data from any hadronic model*
- *Initialization of data done thread safely – no dependency on order of initialization from various classes.*
- *The destruction end of run is performed by the G4ElementDataRegistry class.*

## Cross section comparison




*Parameterization of inverse cross section for alpha, neutron, and proton: red curve – data from G4PARTICLEXS4.1, blue – Kalbach parameterization [5]; left – Iron, right – Lead.*

## Evaporation model

Probability that parent nucleus *i* with en excitation energy $E_x$ emits a particle *j* in its ground state with kinetic energy $\varepsilon$ [4]*:*

$$P_j(E_x,\varepsilon)d\varepsilon = g_j\sigma_{\text{inv}}(\varepsilon)\frac{\rho_d(E_x-\varepsilon)}{\rho_i(E_x)}\varepsilon d\varepsilon, \qquad (1)$$

where $\rho_i(E_x)$ is the level density of the evaporating nucleus, $\rho_d(E_x-\varepsilon)$ that of the daughter (residual) nucleus after emission of a fragment *j*. With the spin $s_j$ and the mass $m_j$ of the emitted particle, $g_j$ is expressed as $g_j = (2s_j+1)m_j/\pi^2\hbar^2$.

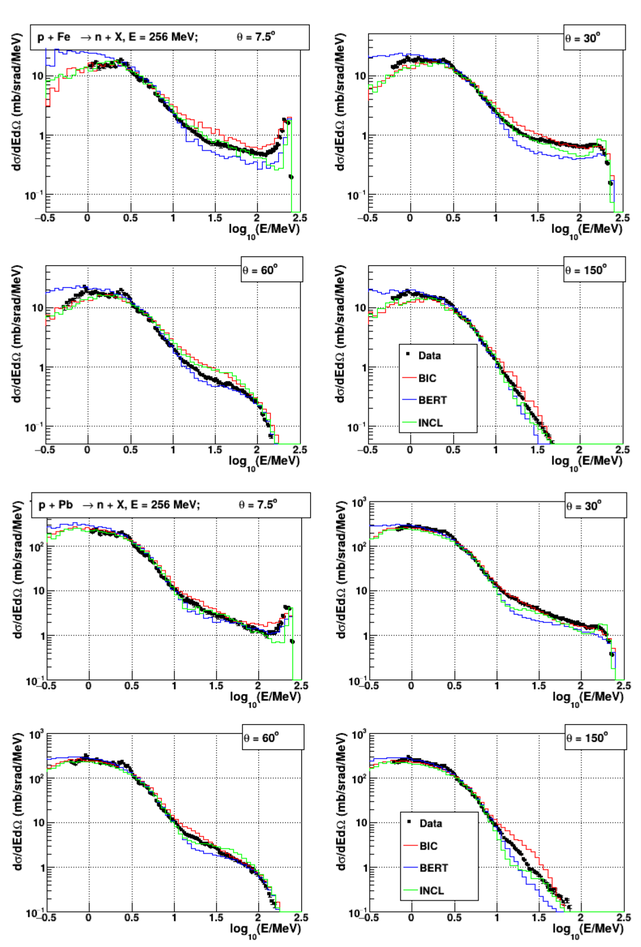
The cross section for inverse reaction $\sigma_{\text{inv}}(\varepsilon)$ is expressed by means of empirical function (Kalbach parameterization [5]) or using G4PARTICLEXS4.1 data via the new interface class G4InterfaceToXS.

Probability density function is expressed by the formula:

$$\rho(E) = C\exp\left(2\sqrt{aE'}\right), \qquad (2)$$

where *C* is a constant, $E' = \max(E_x-\delta,0)$, $\delta$ is the pairing energy correction of the daughter nucleus and *a* is the level density parameter.

## Neutron production




*Double differential cross section of neutron production by proton beam at 256 MeV. Points – data from [6], Geant4 models: BIC – the Binary cascade [7], BERT – the Bertini cascade [8], INCL – INCL++ model [9, 10]. The new interface G4InterfaceToXS is enabled for the Binary cascade.*

## References

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