# Modification on thermal motion in Geant4 for neutron capture simulation in Gadolinium loaded water

**#38**


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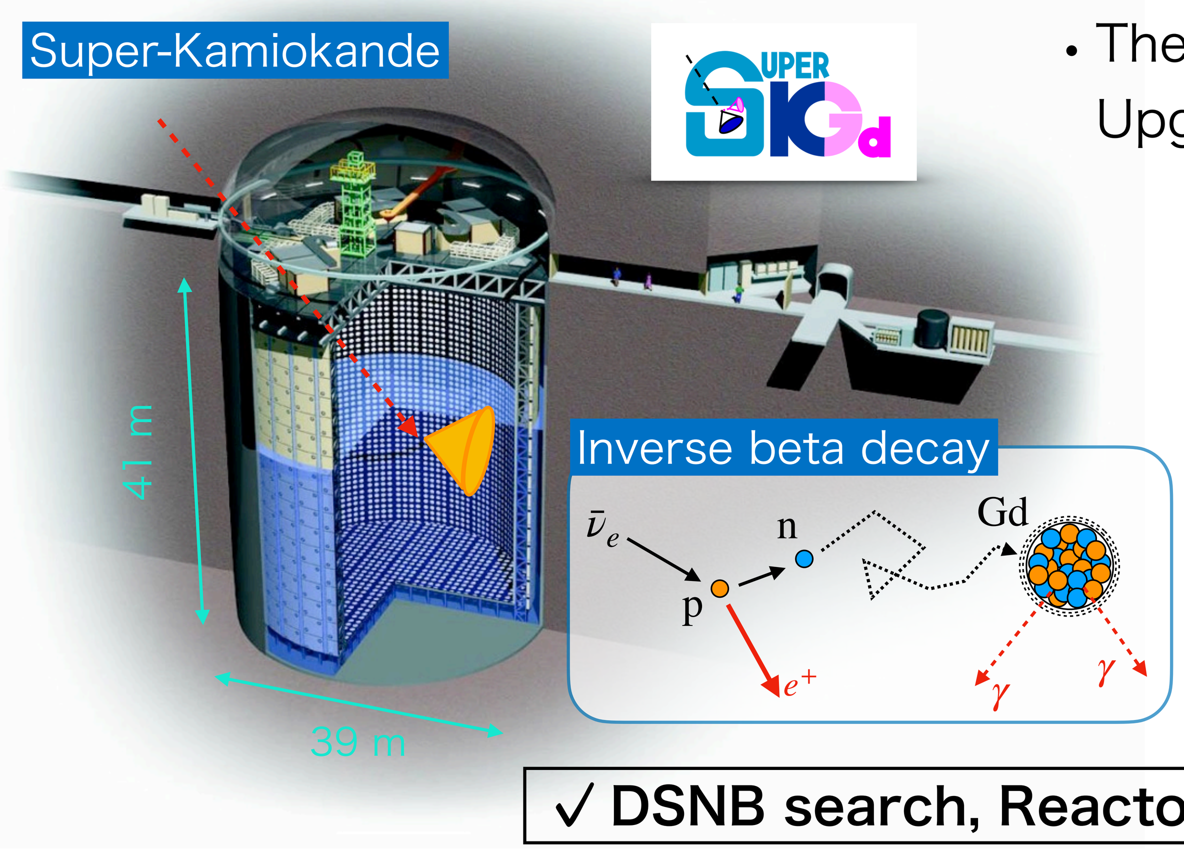
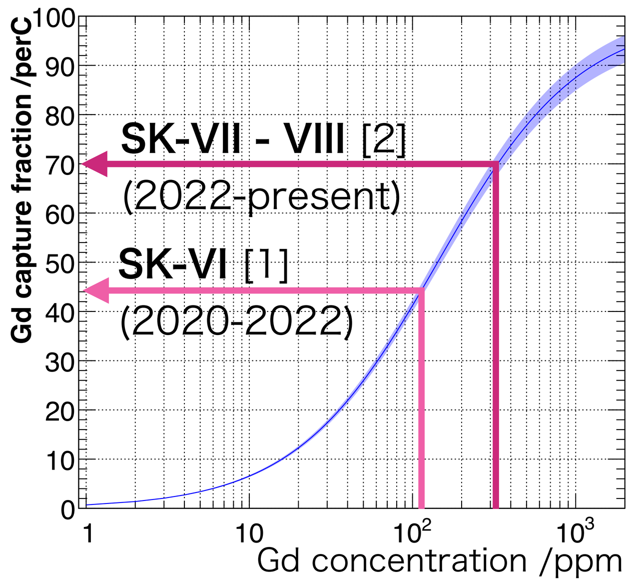
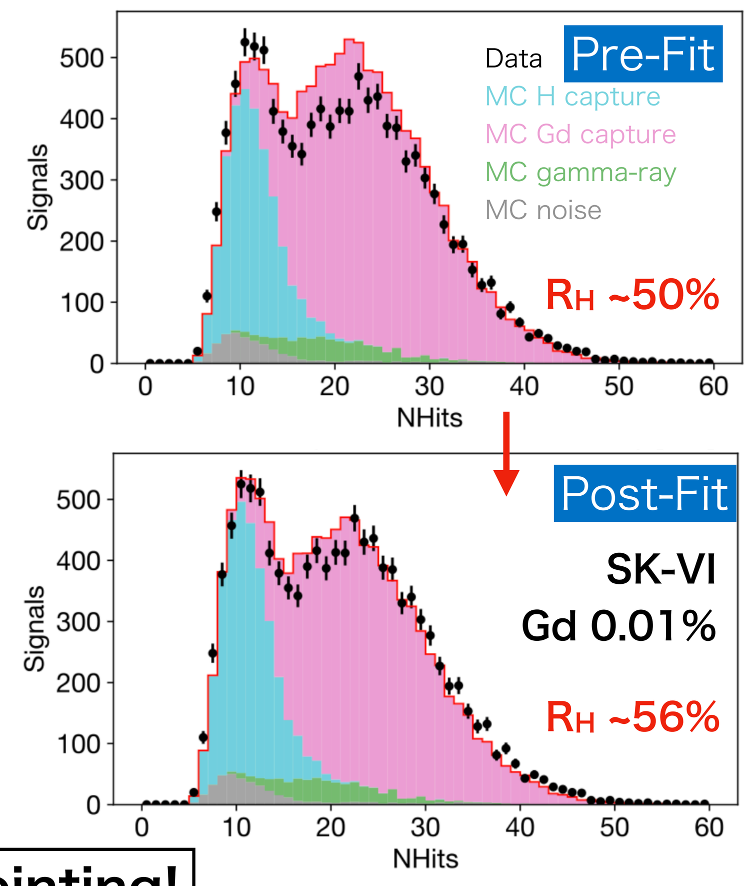
## 1. Introduction




- 50 kton Gadolinium-loaded water Cherenkov detector
- The sequential Gd conc. Upgrade in 2020 and 2022.

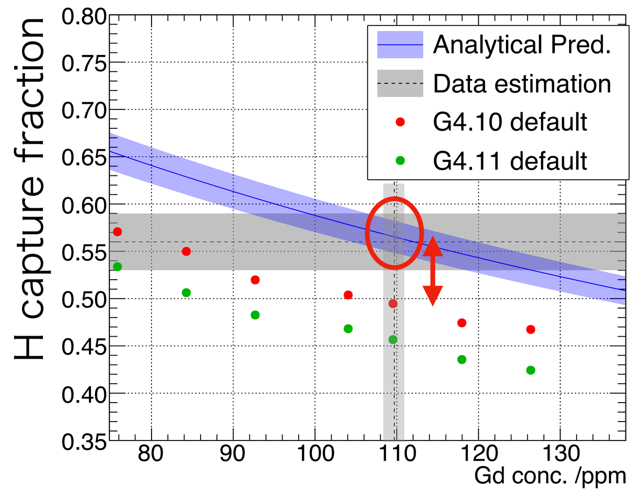



NHits dist. of ncap. events [4]



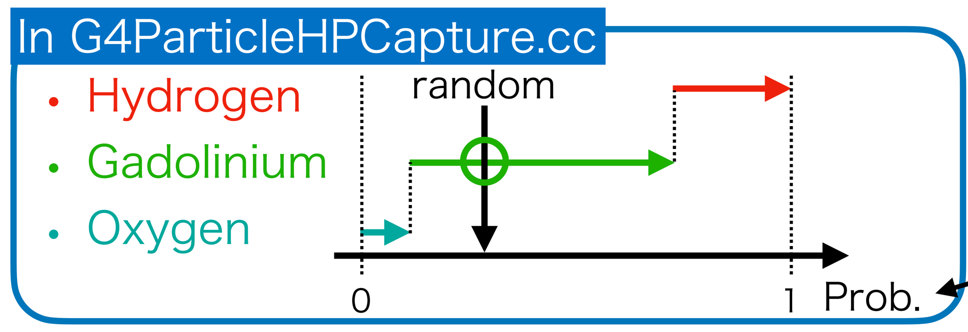

✓ DSNB search, Reactor neutrino, SN burst pointing!

- The neutron tagging calibration using Am-Be source indicated discrepancies b/w data and MC sim.
  - MC predicted +8.5% higher efficiency than the data in SK-VI [3].
  - The data favored the larger fraction of capture on Hydrogen, consistent with the analytical calculation (but MC does not) [4].




**-> Incorrect capture fraction in MC? What is the cause??**

## 2. Implementation Check

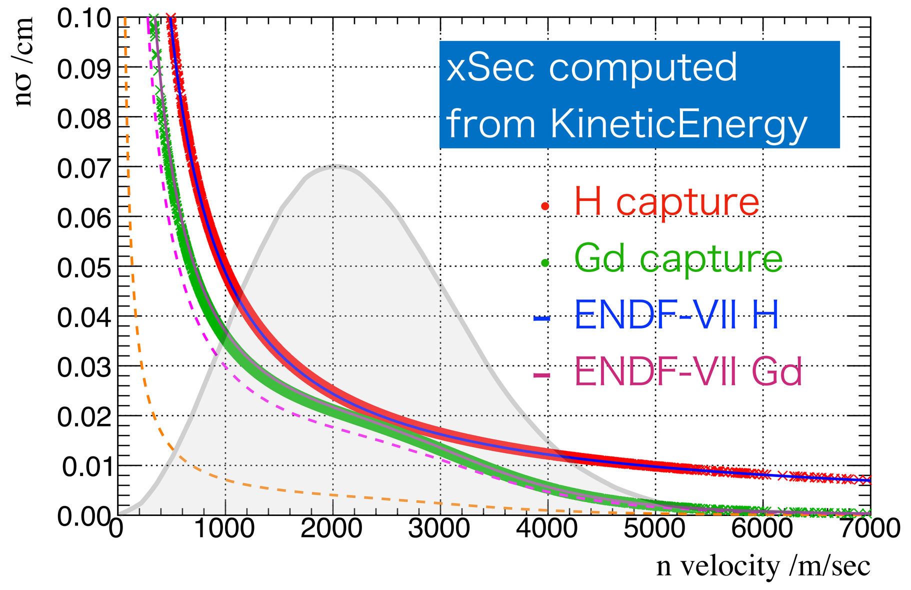


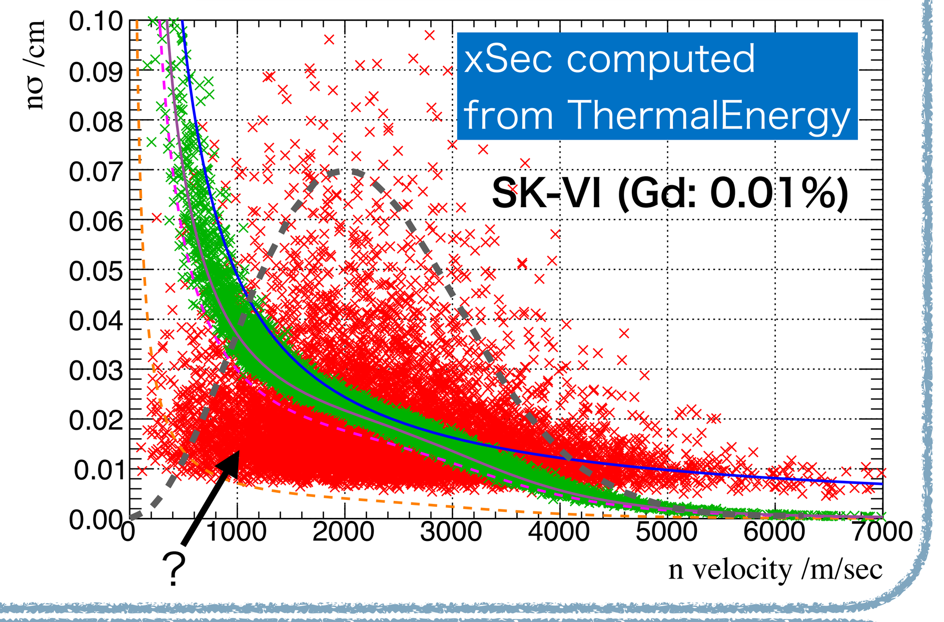

- The capture nucleus is chosen from the elements of the target material in G4ParticlHPCapture:

Probability ∝ (number density) × (cross section)

a function of **neutron energy**

- The cross section data in Geant4 are identical to the value from ENDF-VII -> G4 & calculation had to be consistent ideally. . .
- "**thermal motion**" uniquely considered in G4 may lead to H cap. underestimation.




## 3. ThermalBoost Modification

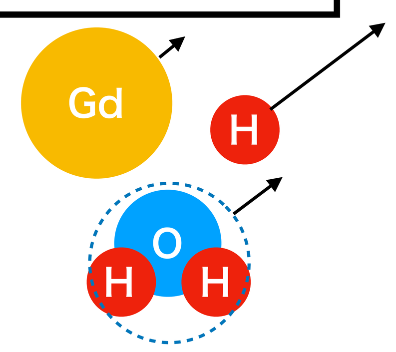
- In the thermal neutron region, the effects of the thermal motion of material cannot be ignored.
- Thus, G4ParticleHPThermalBoost::GetThermalEnergy() computes the neutron energy relative to the thermal motion of the target material in retrieving the cross section value. ↓

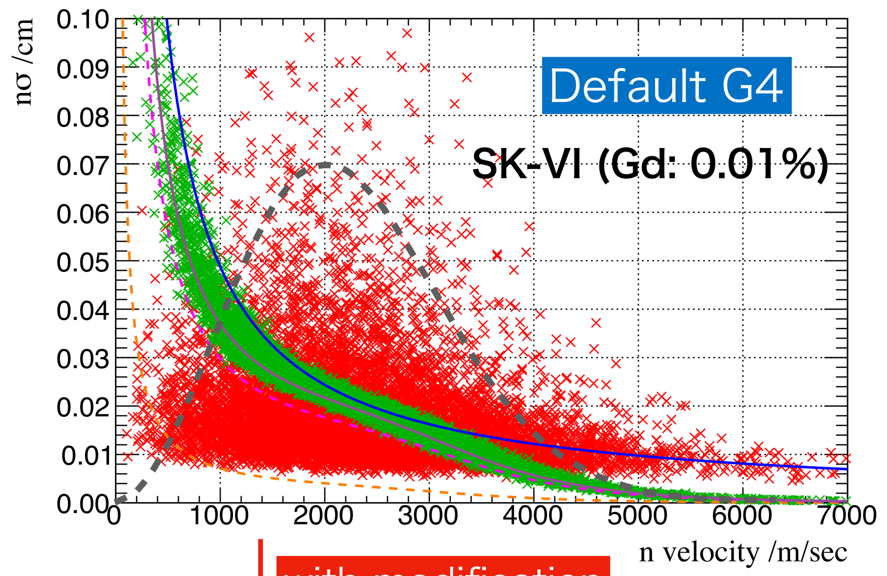
G4ParticleHPThermalBoost::GetThermalEnergy()

```
// prepare properly biased thermal nucleus
G4Nucleus aNuc;
G4double eps = 0.0001;
G4double eleMass;
eleMass = ( G4NucleiProperties::GetNuclearMass( static_cast<G4int>(theA+eps) , static_cast<G4int

G4ReactionProduct aThermalNuc = aNuc.GetBiasedThermalNucleus(eleMass, neuVelo, aT);

// boost to rest system and return
G4ReactionProduct boosted;
boosted.Lorentz(theNeutronRP, aThermalNuc);
return boosted.GetKineticEnergy();
```

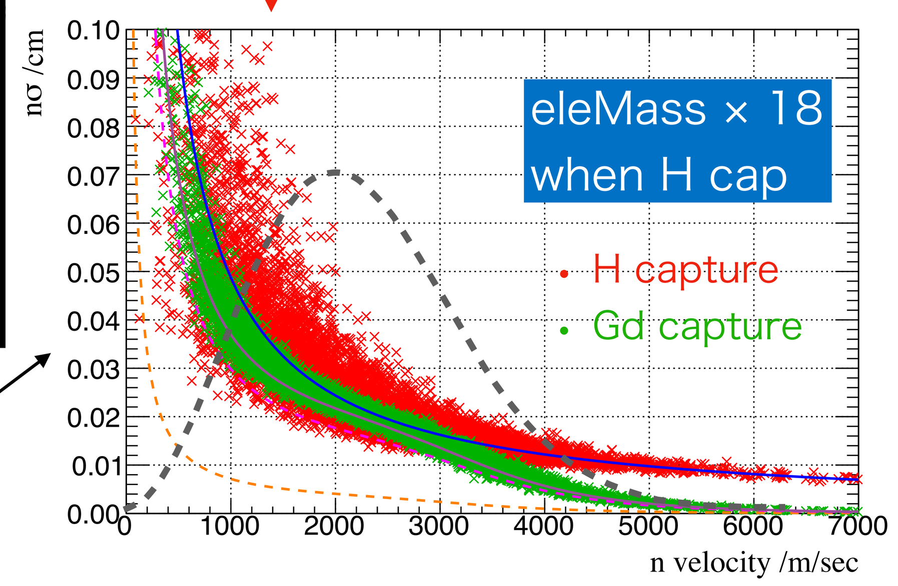
Thermal motion computed as monoatomic molecular gas!

- The lighter the nucleus, the larger the correction
  - relative neutron speed ↑ = cross section ↓
    => H capture becomes less likely to occur!
- But in reality, H exists as a part of $H_2O$:




with modification




-> Modified the code to **use $H_2O$ mass** instead, thereby **suppressing the thermal motion** effect.

## 4. Validation

- The Geant4 simulation results are compared to the calculation and the measured values in SK:

Capture time constant

$$\tau = \frac{1}{\sum_i n_i g_w^i(T)\,\sigma_i^{therm}\,v_{therm}}$$

-> in good agreement regardless of the thermal boost modification.

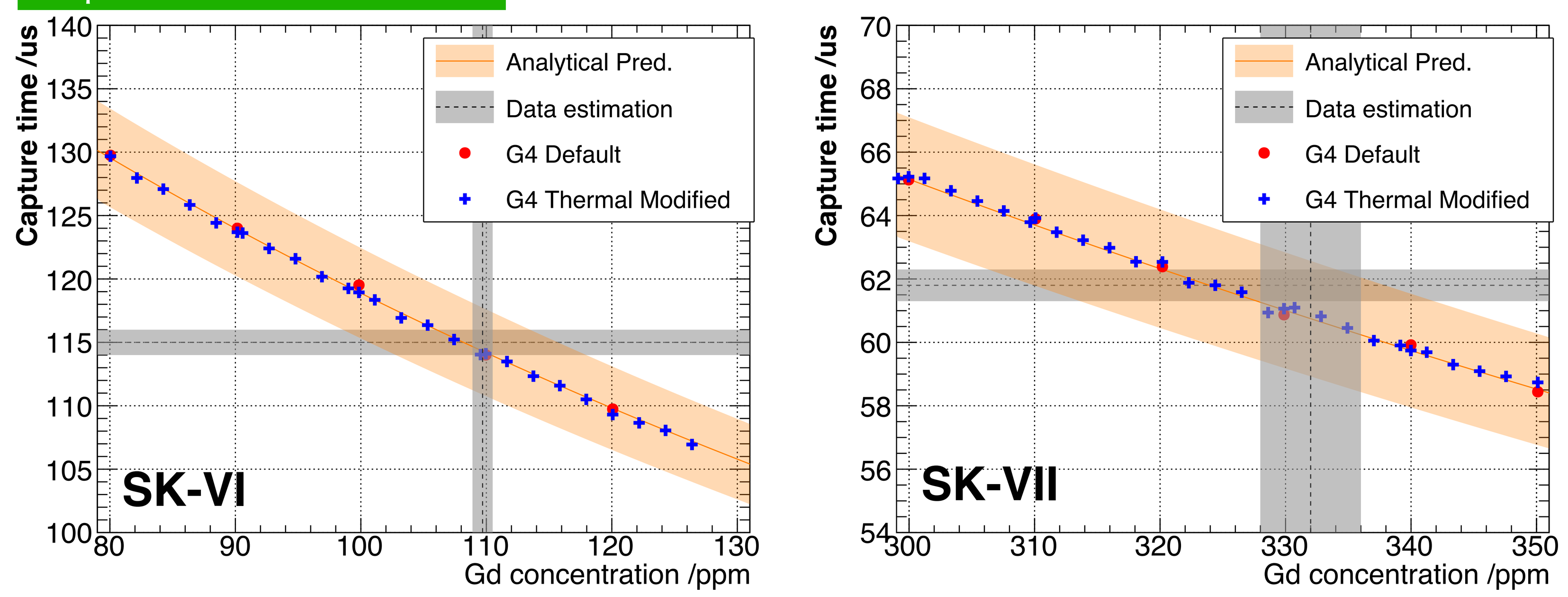
H capture fraction

$$R_H = \frac{n_H\, g_w^H(T)\,\sigma_H^{therm}}{\sum_i n_i\, g_w^i(T)\,\sigma_i^{therm}}$$

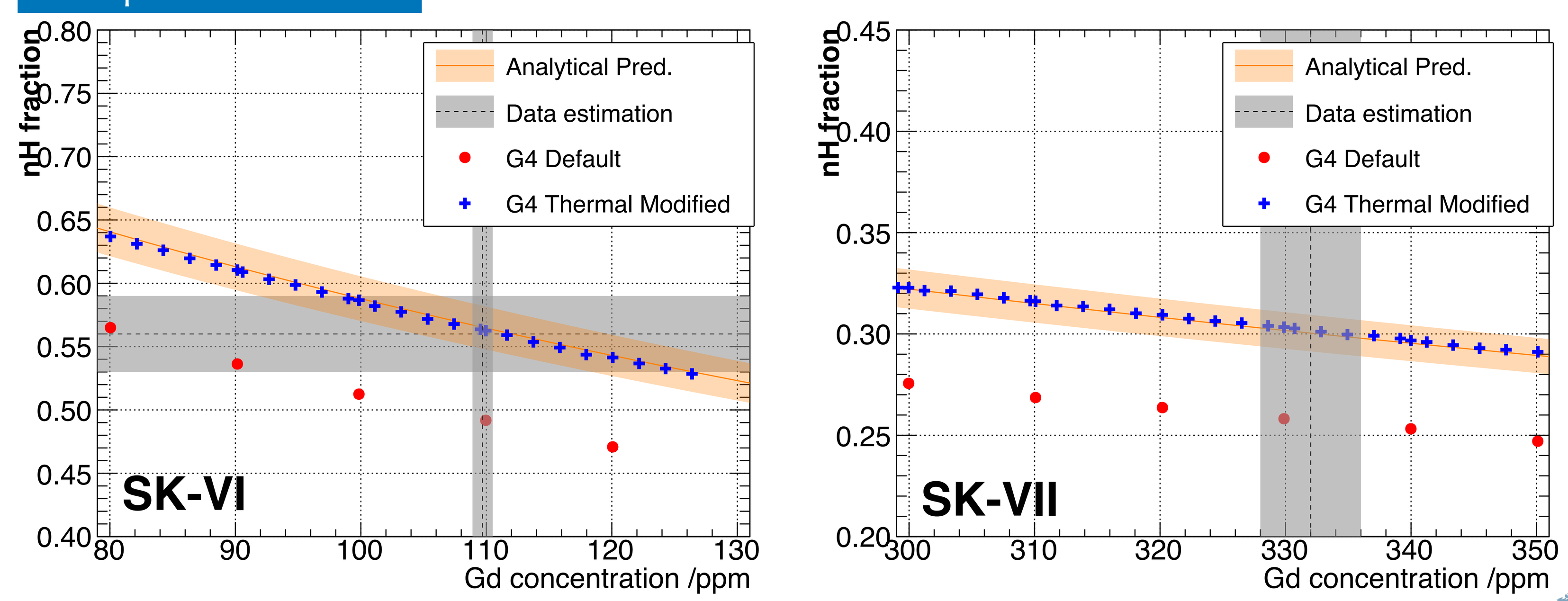
-> the modification succeeded to reproduce the calc. and the data!

- The details of neutron tagging calibration -> see **Poster#102**.

Capture time constant




H capture fraction




## 5. Summary

- Found that Geant4 overestimated the thermal motion effect for the lightest nucleus (H) in neutron capture simulation.
- The modified simulation well reproduced the observables of the neutron capture estimated by the data and calculation.

## 6. Reference


[1] NIM A, 1027 (2022) 166248.
[2] NIM A, 1065 (2024) 169480.
[3] M. Harada, PoS ICHEP2022
[4] S. Han, Ph. D. Thesis (2023).