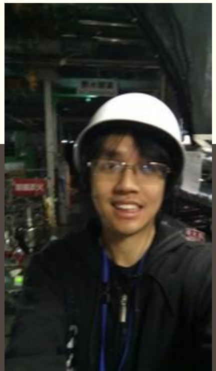
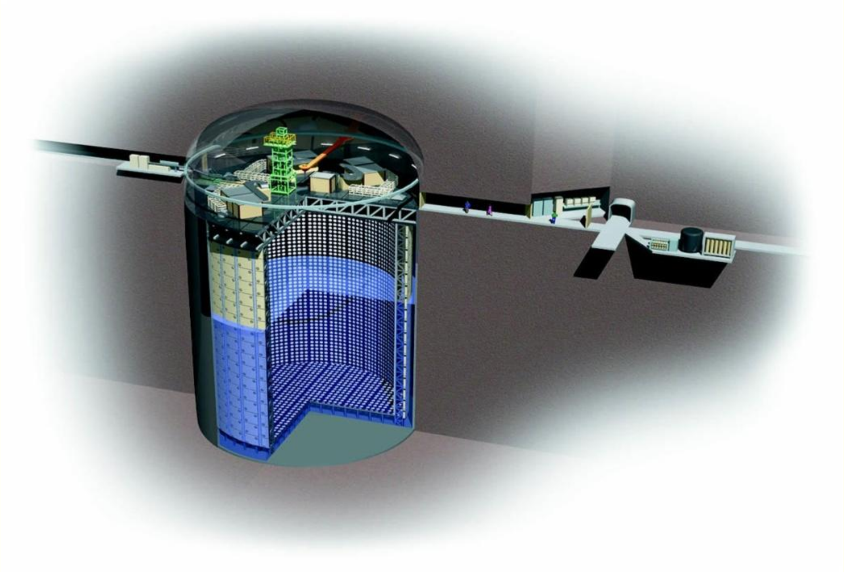
Neutron capture simulation and neutron tagging in SK-Gd

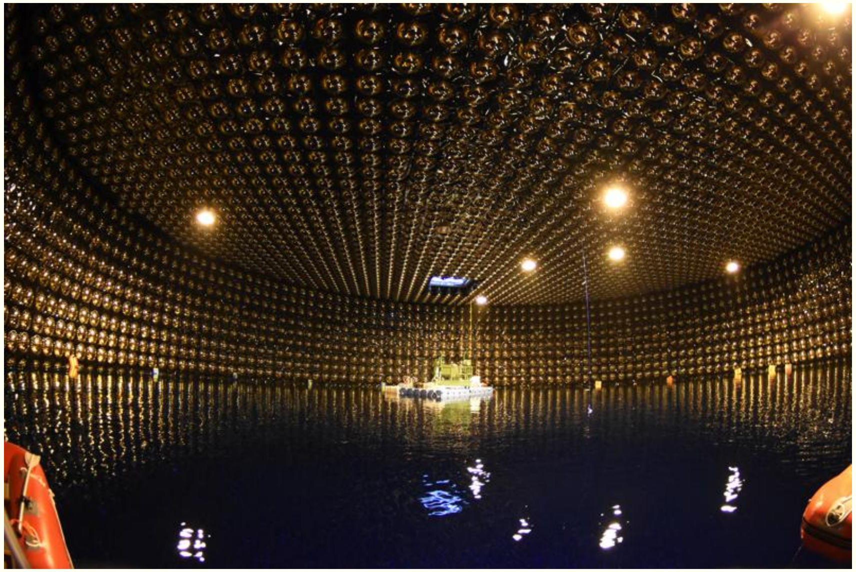
Ka Ming Tsui
K.M.Tsui@liverpool.ac.uk
University of Liverpool



Caveat

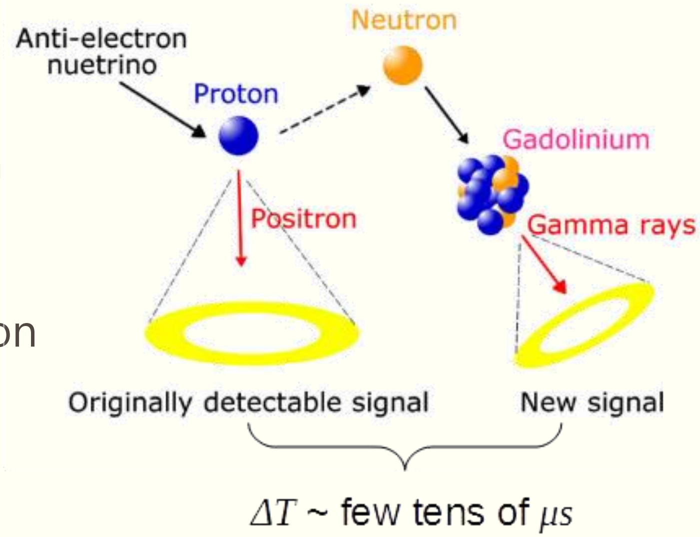
- Studies done 2 years ago. May have better models now.
- No data yet. Everything is MC.
- Results based on 0.2% Gd conc
  →next year SK is dissolving 0.02% Gd first, need to revise tools





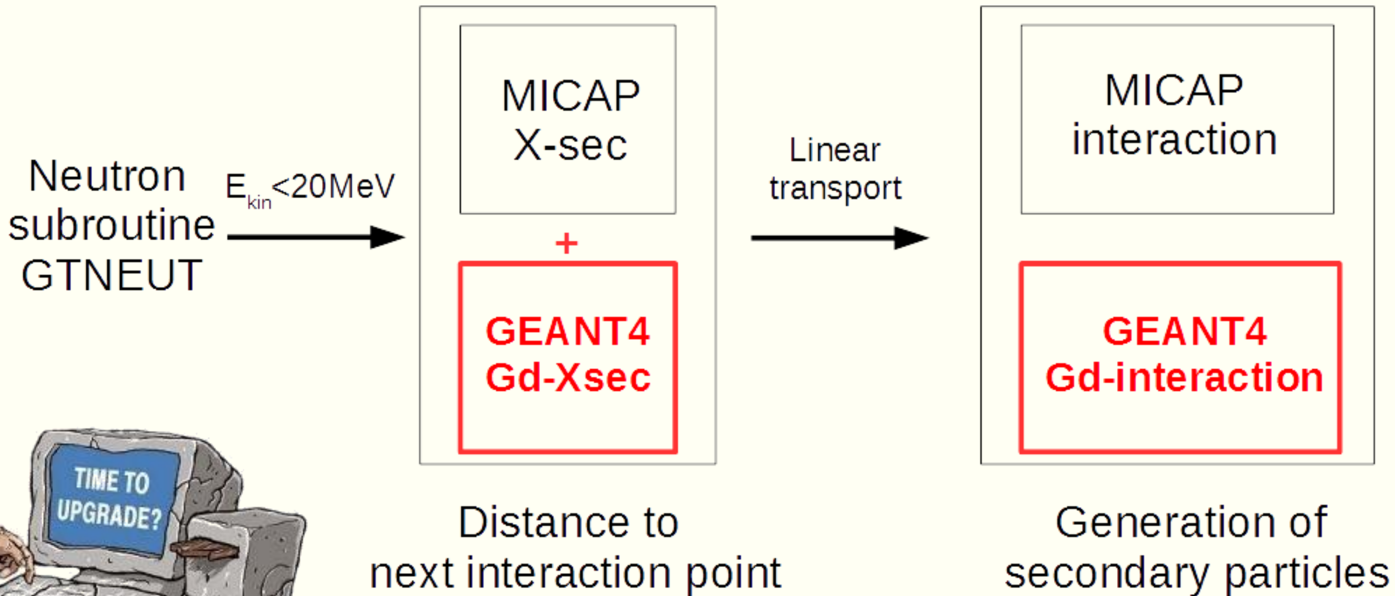
SK-Gd: what is it?

- Super-K Gd Project: 0.2% $Gd_2(SO_4)_3$ dissolved in water, enables efficient neutron tagging with neutron capture on Gd
- Physics
  - Neutrino-antineutrino discrimination
  - Supernova relic neutrino detection
  - Proton decay background reduction
  - Neutron production in neutrino interaction
- My work:
  - Implement Gd-capture module in simulation
  - Develop neutron tagging tools



Gd-capture: what is the problem?

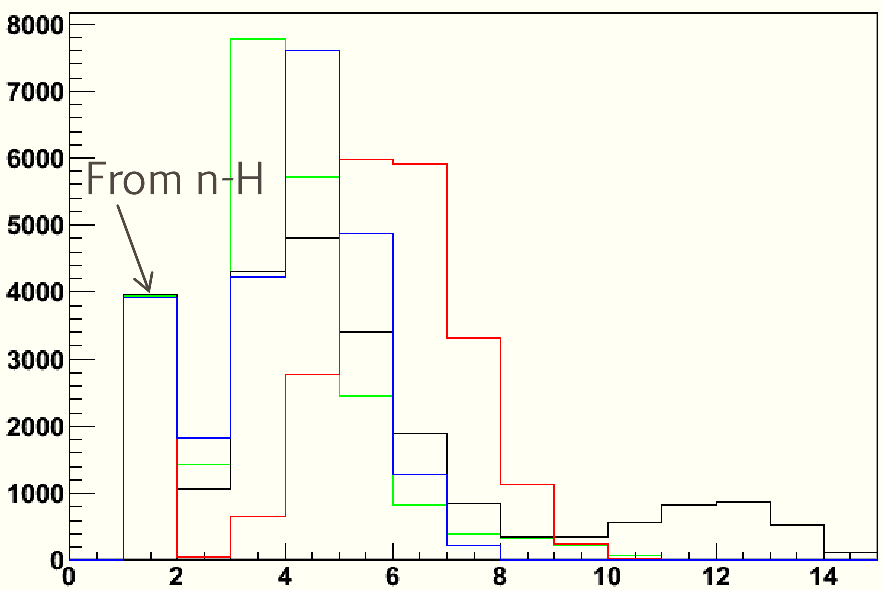
- Our simulator is too old (GEANT3). No support for Gd-capture
  → Interface with more user-friendly GEANT4



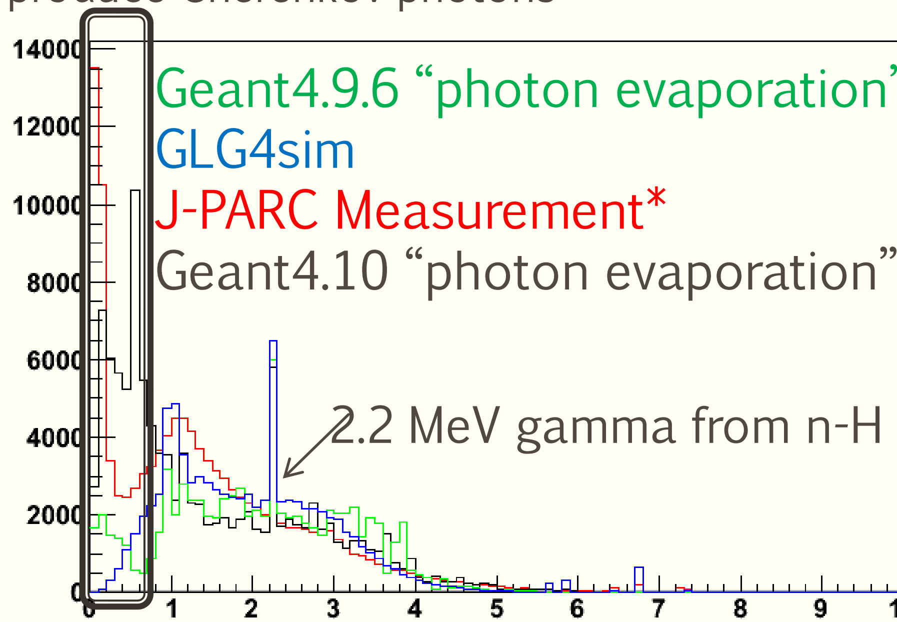
Gamma model: why bother?

- Gamma cascade emitted by Gd-capture
  - Large impact on visible energy

Less likely to produce Cherenkov photons



Gamma cascade multiplicity

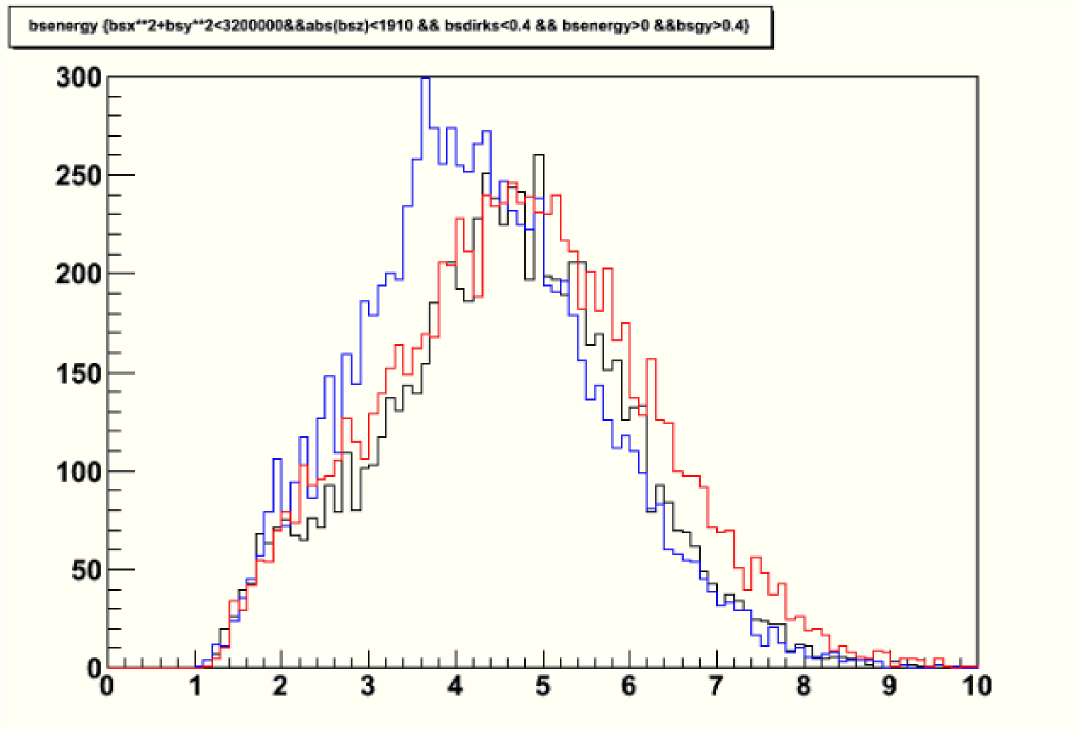


Individual gamma energy (MeV)

*K.Hagiwara *et al.* (2017), 035. 10.22323/1.294.0035.

Gamma model: why bother?

- Gamma cascade emitted by Gd-capture
  - Maybe calibration can tell



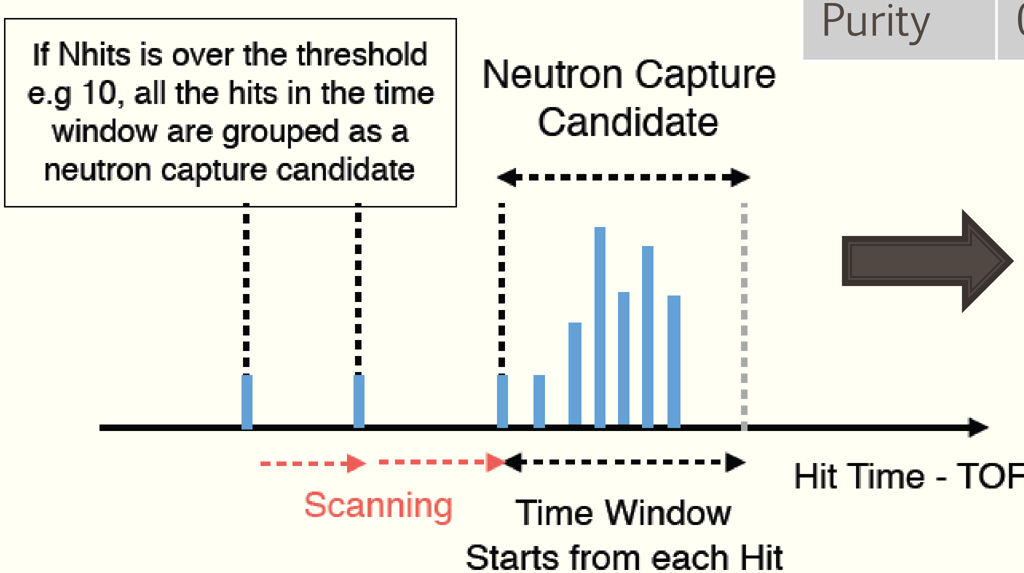
Reconstructed energy (MeV)

Selection criteria:
Goodness > 0.4
DirKS < 0.4
Selection efficiency:
Default GEANT4: 90.3%
GLG4sim : 89.1%
Sample spec: 89.6%

Neutron tagging: how to do?

- **Step one: Initial candidate selection**
  - Use a 10ns time window to search for PMT hit clusters
  - 7 ≤ N10 ≤ 50, N200 ≤ 140

$N10_{cut}$	6	7	8	9	10	11
Eff.	0.87	0.84	0.81	0.78	0.75	0.71
Bkg/evt	6.72	2.20	0.90	0.44	0.26	0.18
Purity	0.23	0.47	0.67	0.80	0.87	0.90

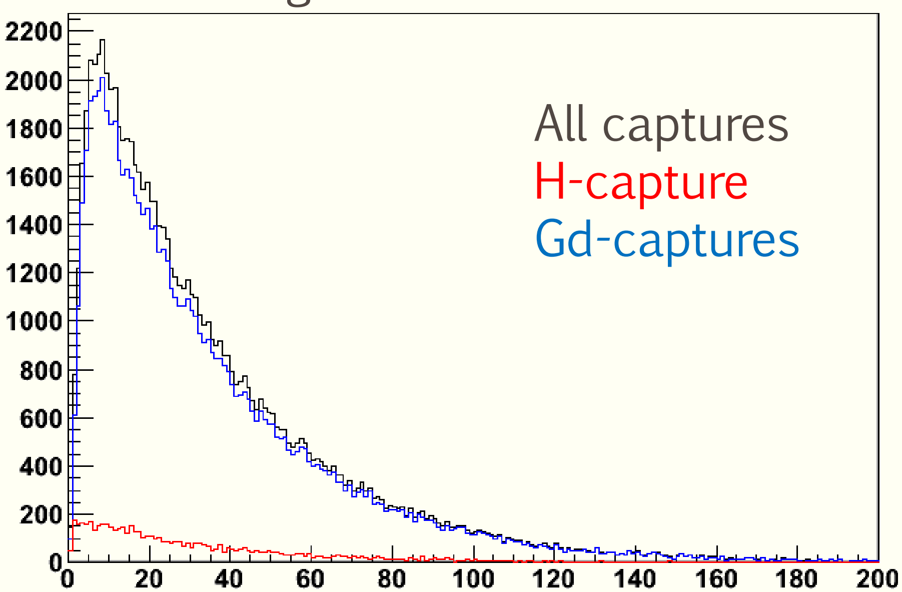


Signal/Background: determined from MC truth

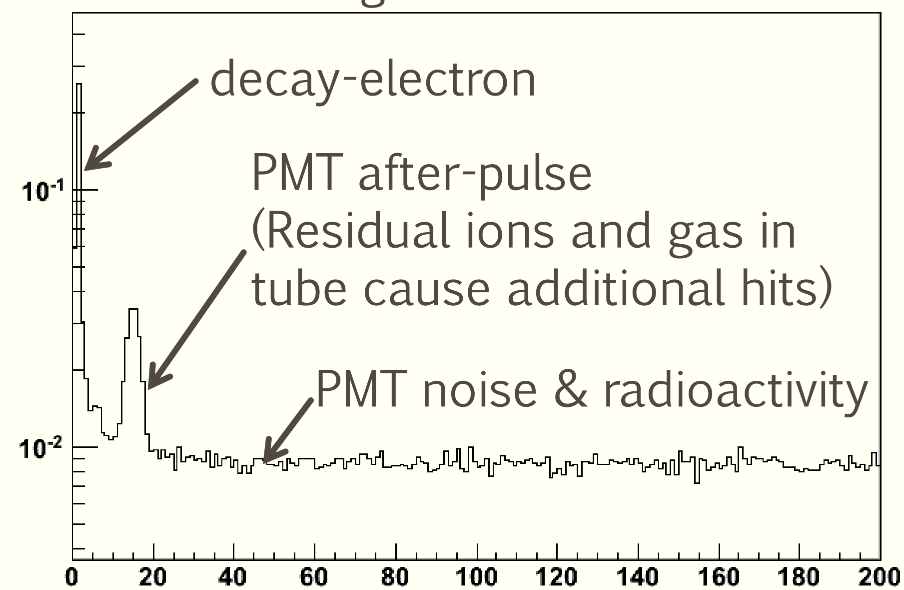
Neutron tagging: how to do?

- **Step one: Initial candidate selection**
  - Use a 10ns time window to search for PMT hit clusters
  - $7 \leq N10 \leq 50$, $N200 \leq 140$

Signal events



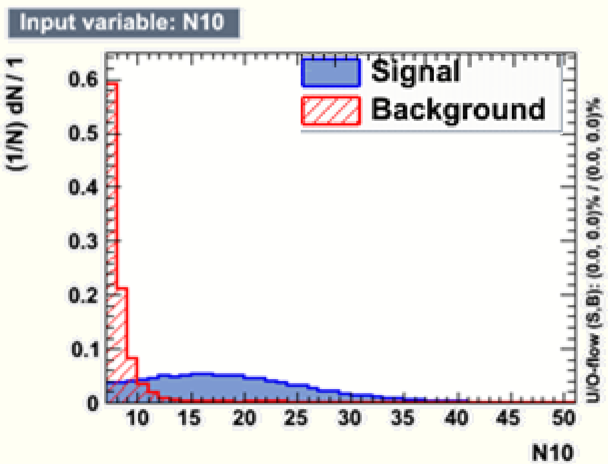
Background events

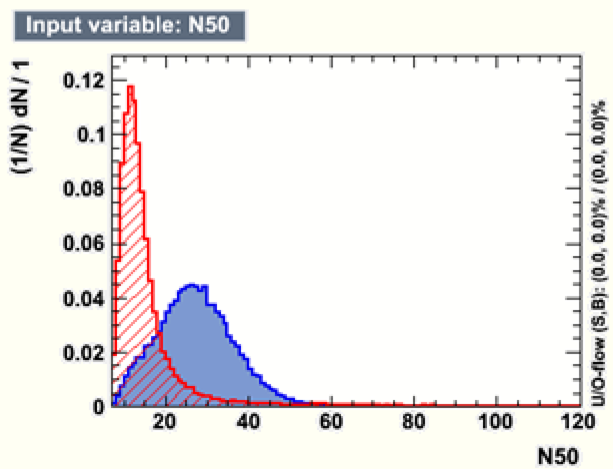


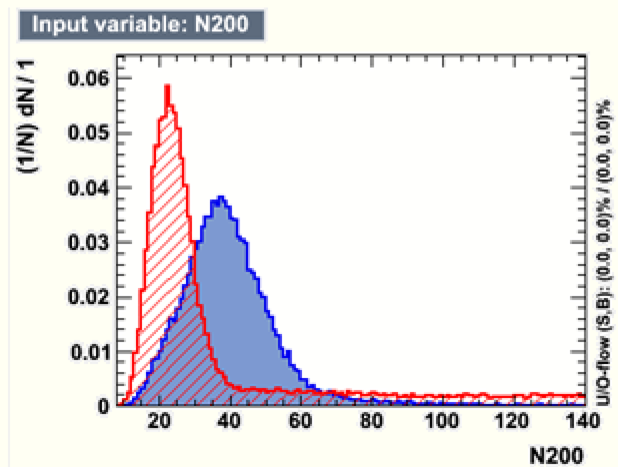
Neutron candidate time dt (μs)

Neutron tagging: how to do?

- **Step two: Signal/Background classification with BDT (TMVA)**
  - Input variables
  - ① Basic hit variables: dt, N10, N50, N200, sum of hit charges, spread of hit time

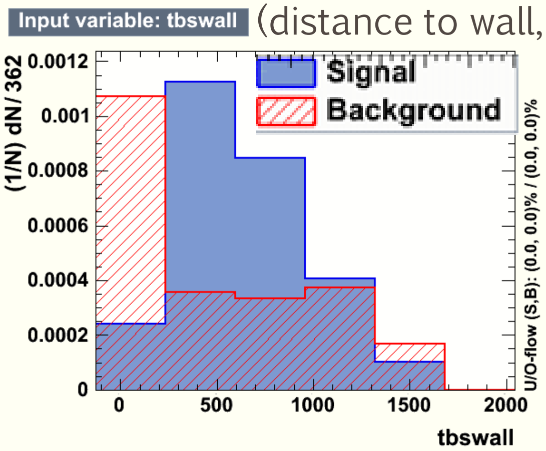




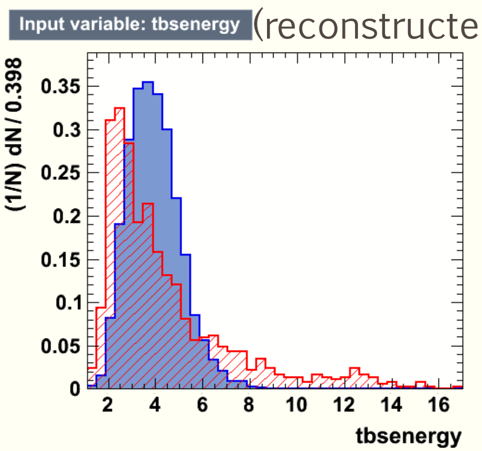


Neutron tagging: how to do?

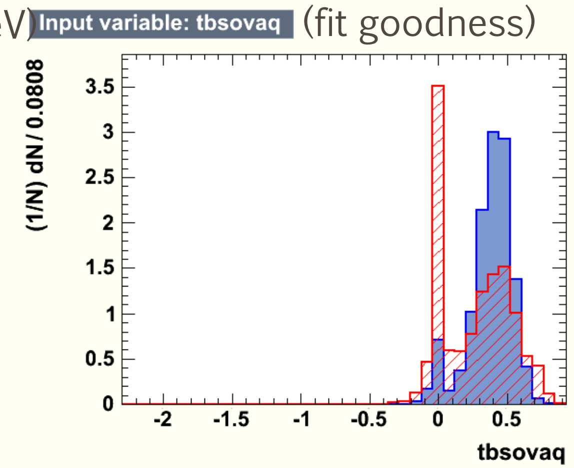
- **Step two: Signal/Background classification with BDT (TMVA)**
  - Input variables
  - ② Neutron fitter variables: vertex position, energy, fit goodness



(distance to wall, cm)



(reconstructed energy, MeV)



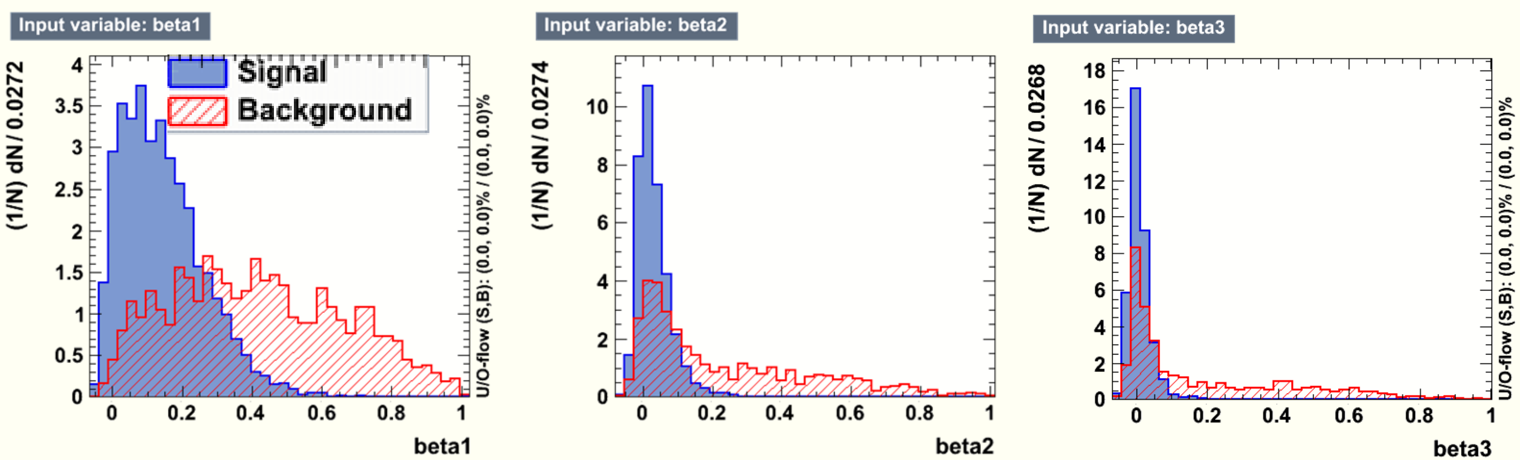
(fit goodness)

Neutron tagging: how to do?

- **Step two: Signal/Background classification with BDT (TMVA)**
  - Input variables
  - ③ Isotropy variables β_l: measures the isotropy of PMT hits in space*

$$\beta_l = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} P_l(\cos\theta_{ij})$$

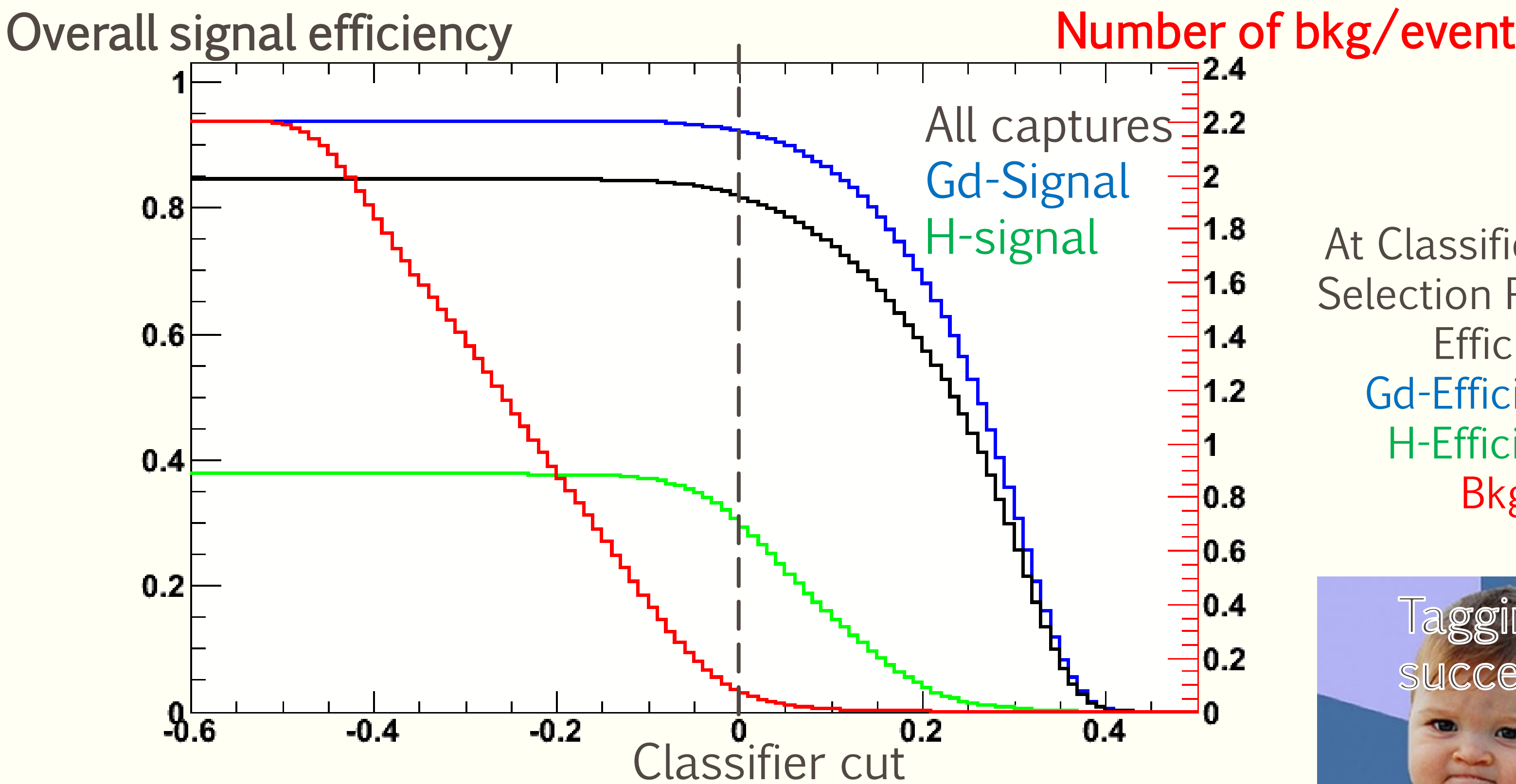
Angle between PMT hits



* S. N. Ahmed *et al.* (SNO Collaboration), Phys. Rev. Lett. 92, 181301

Neutron tagging: how to do?

- **Overall signal efficiency & background rate (after Step one & two)**



At Classifier cut = 0.00 :
Selection Purity = 0.97
Efficiency = 0.81
Gd-Efficiency = 0.92
H-Efficiency = 0.29
Bkg/evt = 0.06

Neutron tagging: how to do?

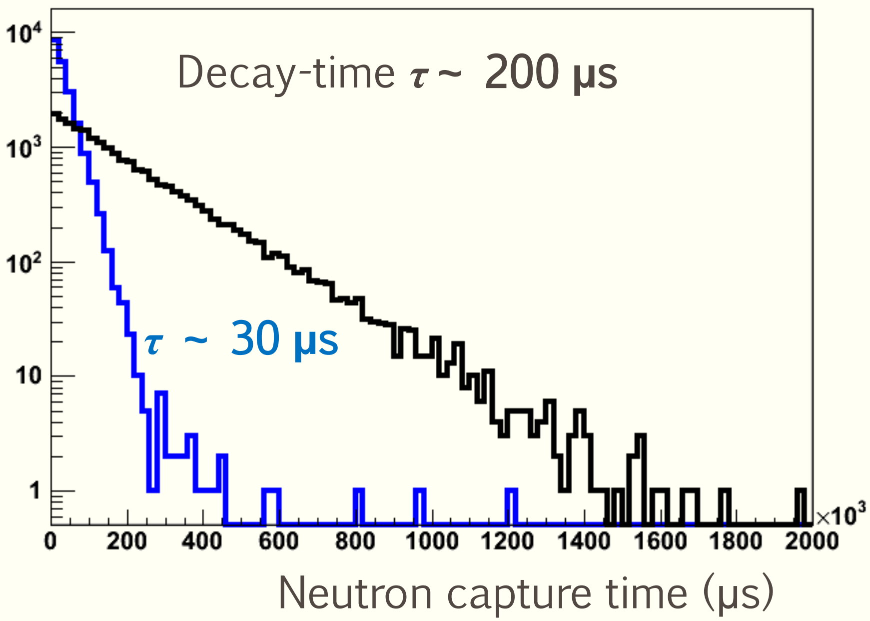
- First estimate of errors by applying to different MC:

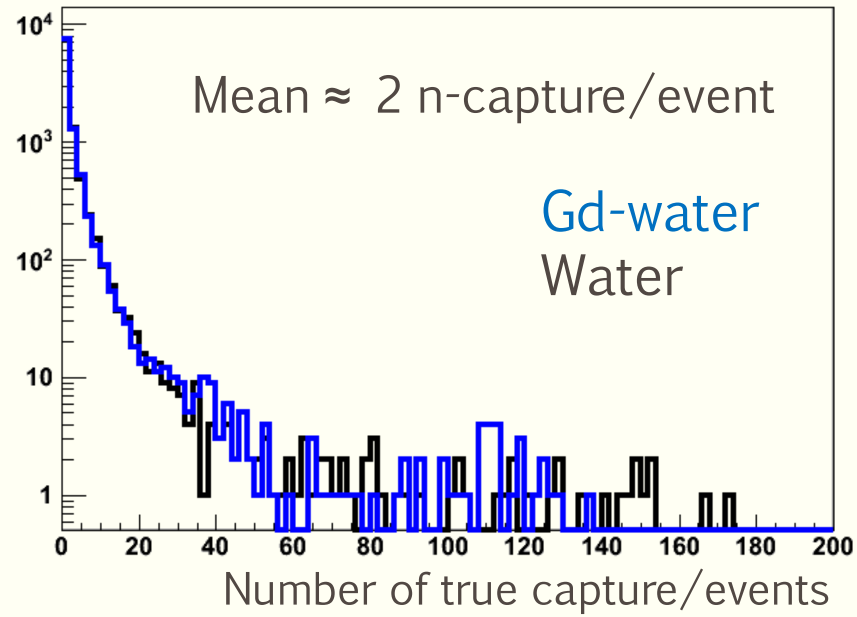
		Change in Gd-gamma model			Change in water quality
Setting	**Default: Geant4.9 gamma**	**GLG4sim gamma**	**Hagiwara et al. gamma**	**Geant4.10 gamma**	**Degraded-water transparency**
Efficiency	0.81	0.81	0.90	0.78	0.80
Gd-Efficiency	0.92	0.91	0.90	0.87	0.91
H-Efficiency	0.29	0.29	0.29	0.29	0.25

Neutron capture: what to learn?

- From atmospheric neutrino simulation

Neutron multiplicity measurement?

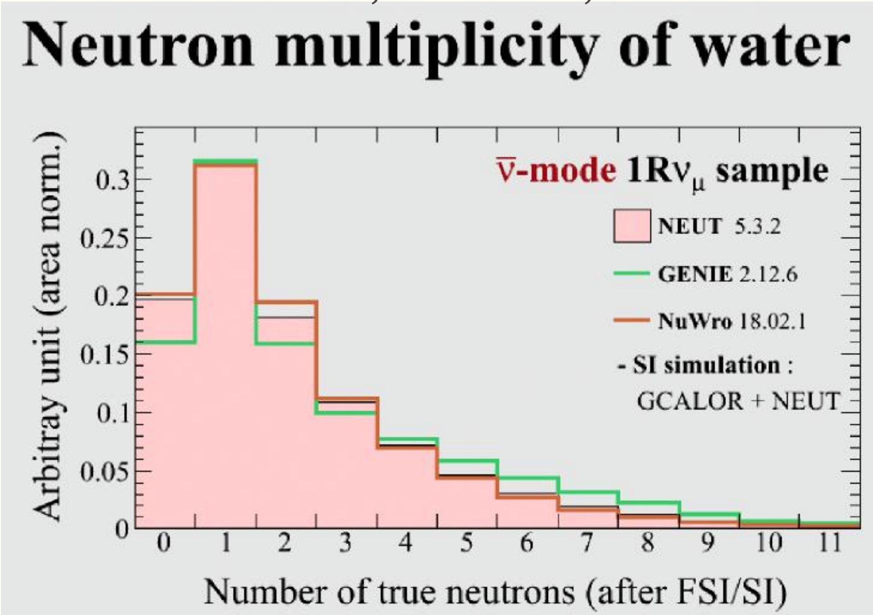




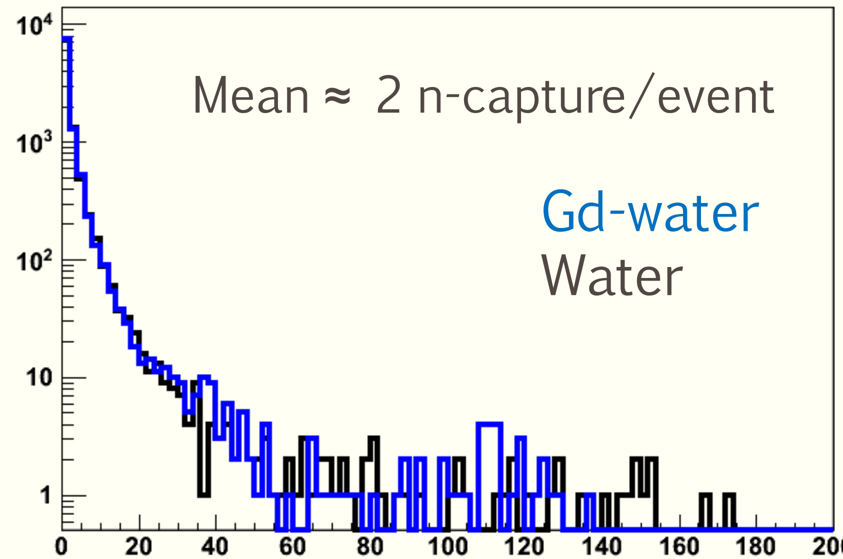
Neutron capture: what to learn?

- From atmospheric neutrino simulation

Neutrons in T2K, R.Akutsu, TAUP 2019

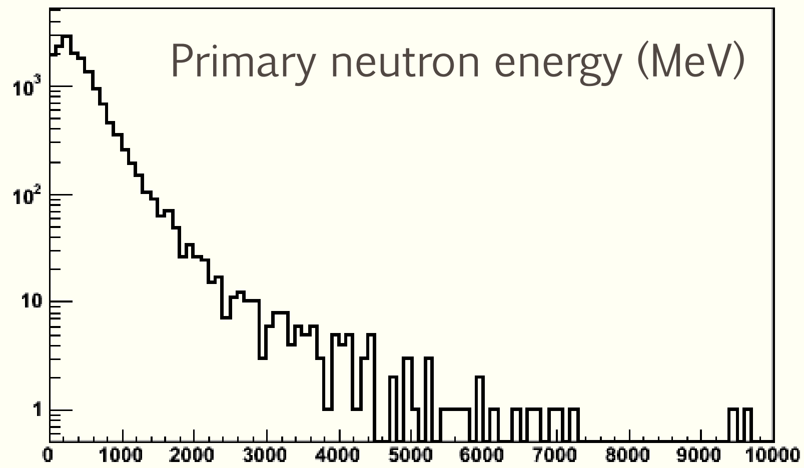


Neutron multiplicity measurement?

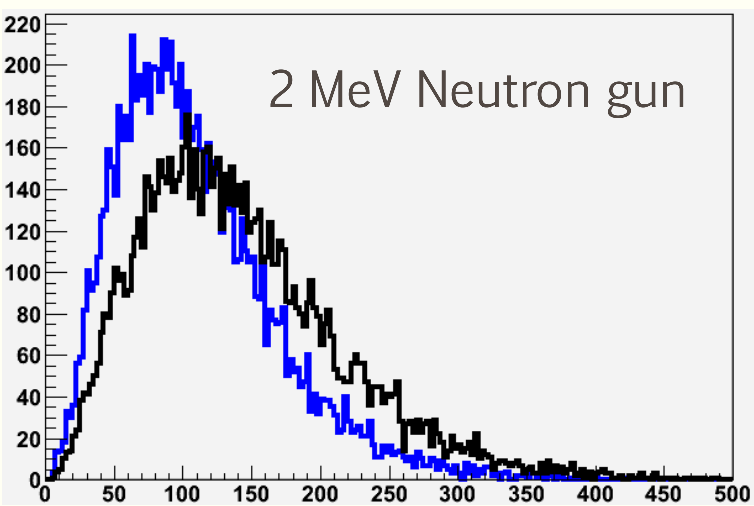


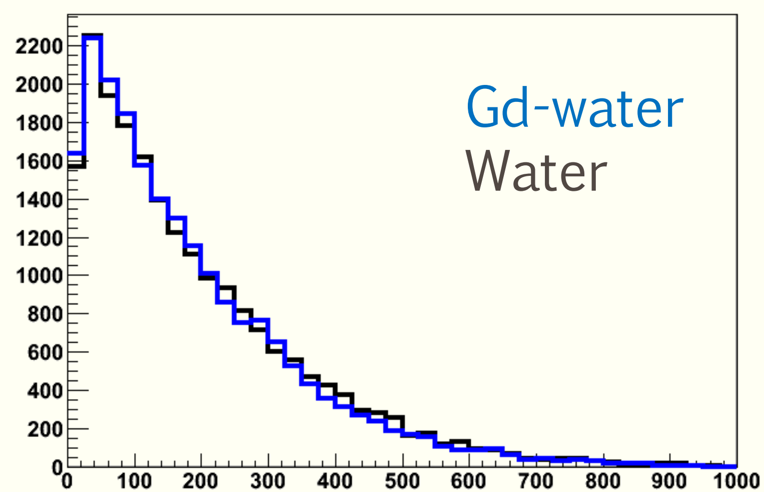
Neutron capture: what to learn?

- From atmospheric neutrino simulation



Neutron kinematics measurement?

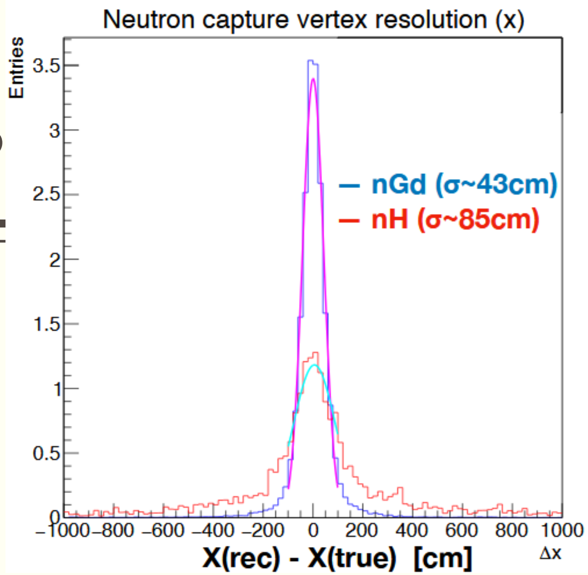


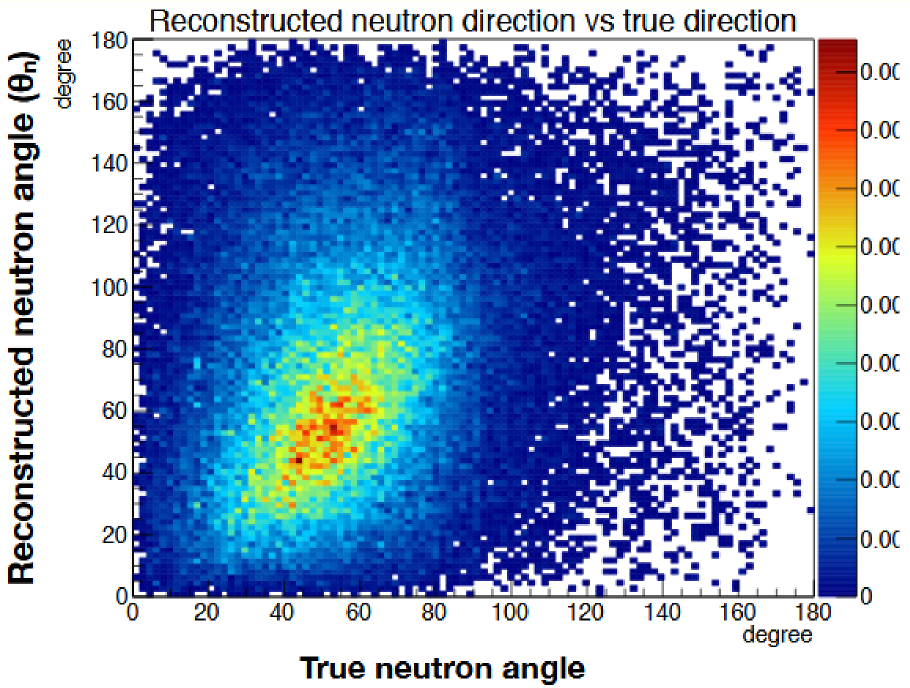


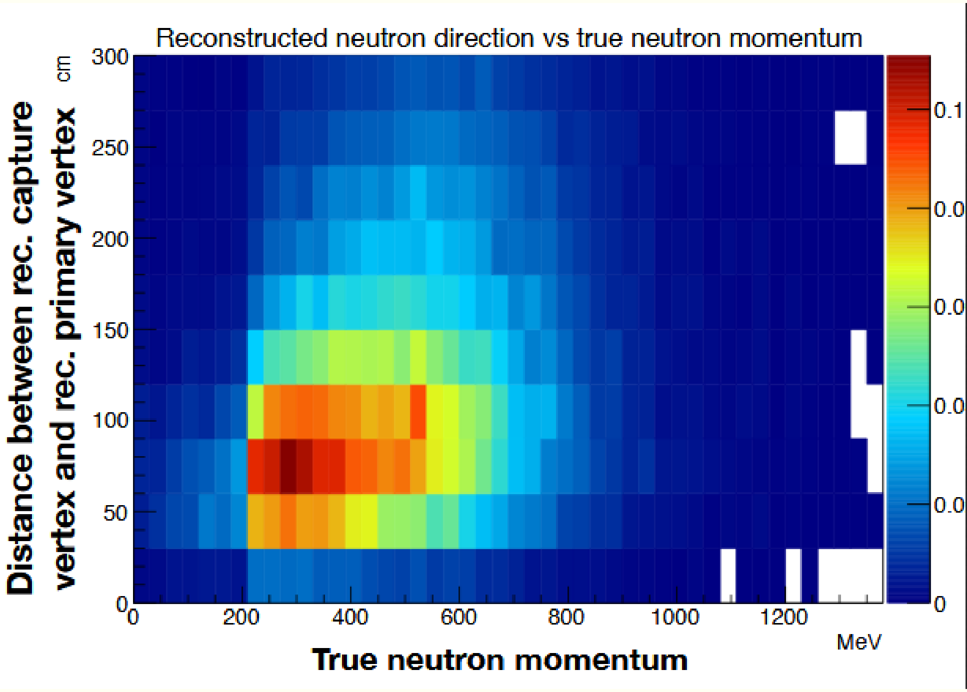
Distance from neutrino to n-capture vertices (cm)

Neutron capture: what to learn?

- T2K simulation







Outlook

- SK-Gd tools available, wait for first data next year
- Much better neutron tagging efficiency, we can study
  - Neutron multiplicity
  - Neutron kinematics
- Application to e.g. neutrino oscillation measurements
  - Neutrino/anti-neutrino separation
  - Better energy reconstruction