Evaluation of neutron tagging efficiency for SK-Gd experiment

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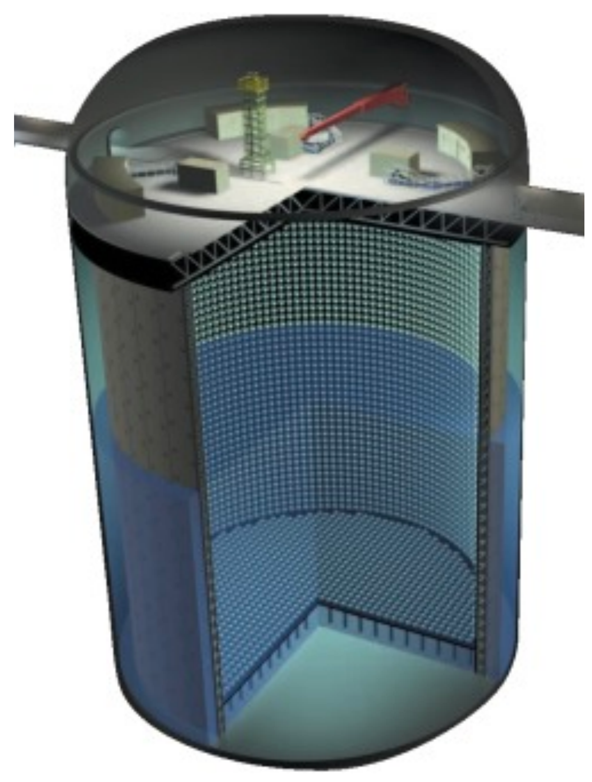
1.Introduction

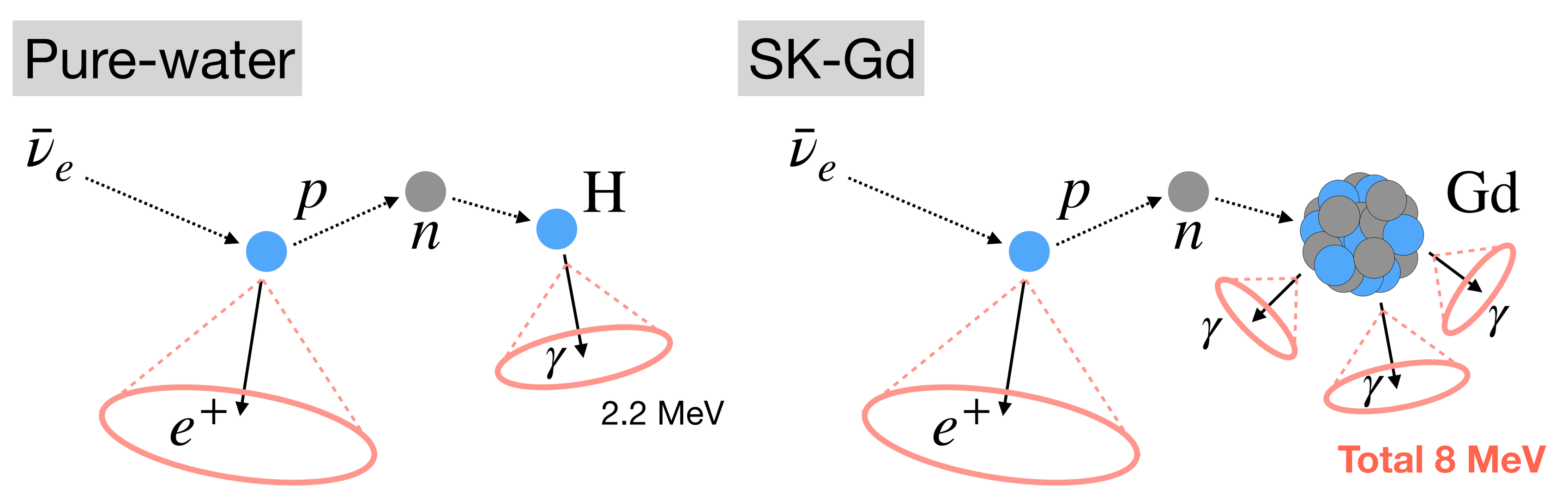
Detector | Super-Kamiokande(SK)



- 50 tons water Cherenkov detector @Kamioka, Japan
- D:39.3 m × H:41.4 m
  Fiducial volume: 22.5 ktons
  - ~11000 PMTs on inner detector(ID)
  - ~1900 PMTs on outer detector(OD)

SK-Gd experiment

- Started from 2020 as a new phase of SK experiment[1]
  - Improve the neutron detection eff. by thermal n-capture on Gd
  - Major purpose: IBD detection from supernova relic neutrinos[2]
- Gadolinium sulfate ($Gd_2(SO_4)_3 \cdot 8H_2O$) was dissolved in SK water[3]
  - Gd mass concentration: ~ 110 ppm
  - Neutron capture on Gd: ~ 50%, Time constant: ~ 115 μs
- Evaluation of neutron tagging efficiency for SK-Gd is important.

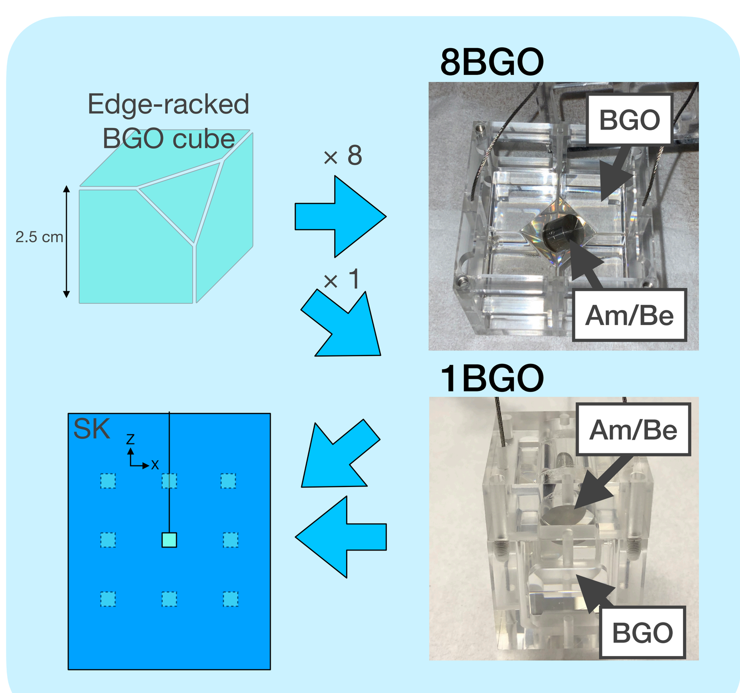


2. Measurement | Am/Be source

Purpose: Evaluation of n-tagging efficiency for SK-Gd

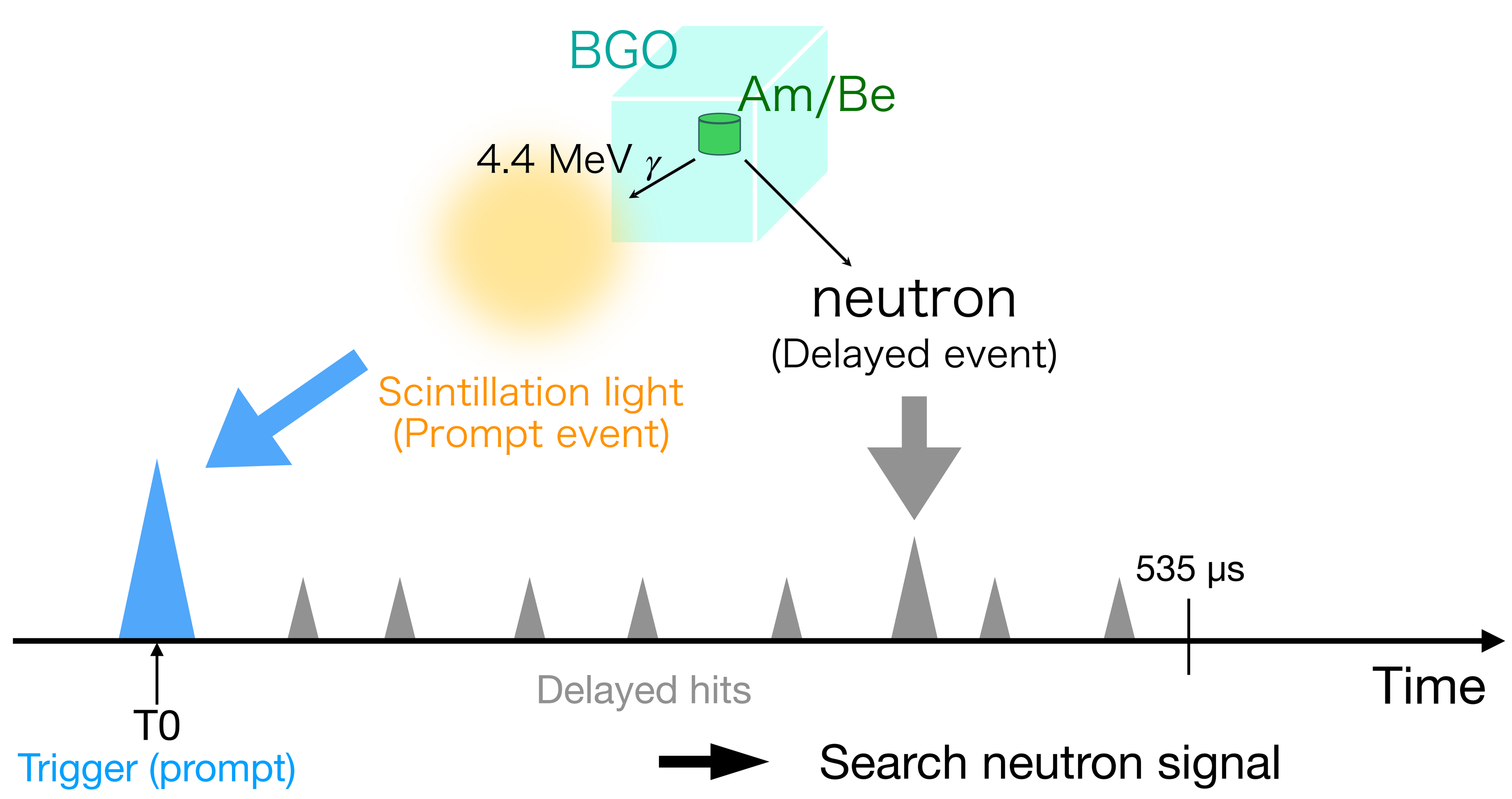
Experimental settings

- Source: Am/Be
  - n (+ 4.4 MeV γ-ray) is emitted.
  - Installed with BGO scintillator to enhance 4.4 MeV gamma-ray
- Use coincidence method with 4.4 MeV γ-ray and neutron
- 9 Positions (X,Z)=(-12, 0, 12) m



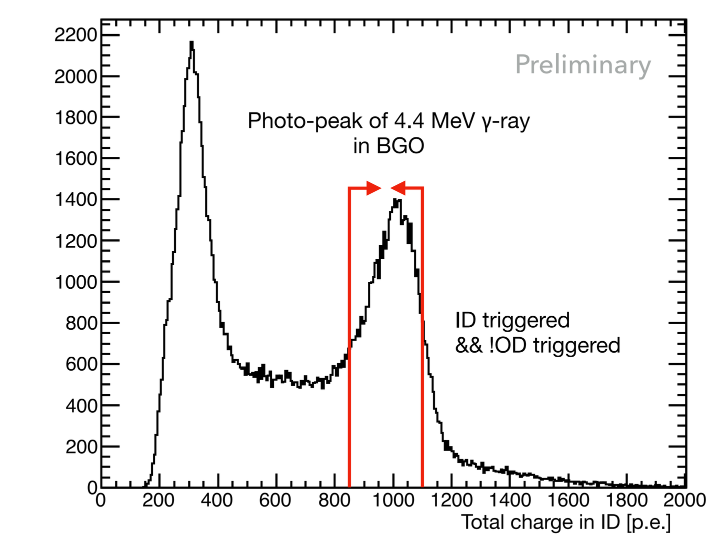
DATA acquisition structure

- PMT hits in 500 μs window are saved after trigger by large light yield(>60 hits/200 ns)
  - 4.4 MeV γ-ray light is enhanced by BGO and issue trigger.
  - Neutron signal will be searched from hits after scintillation light.



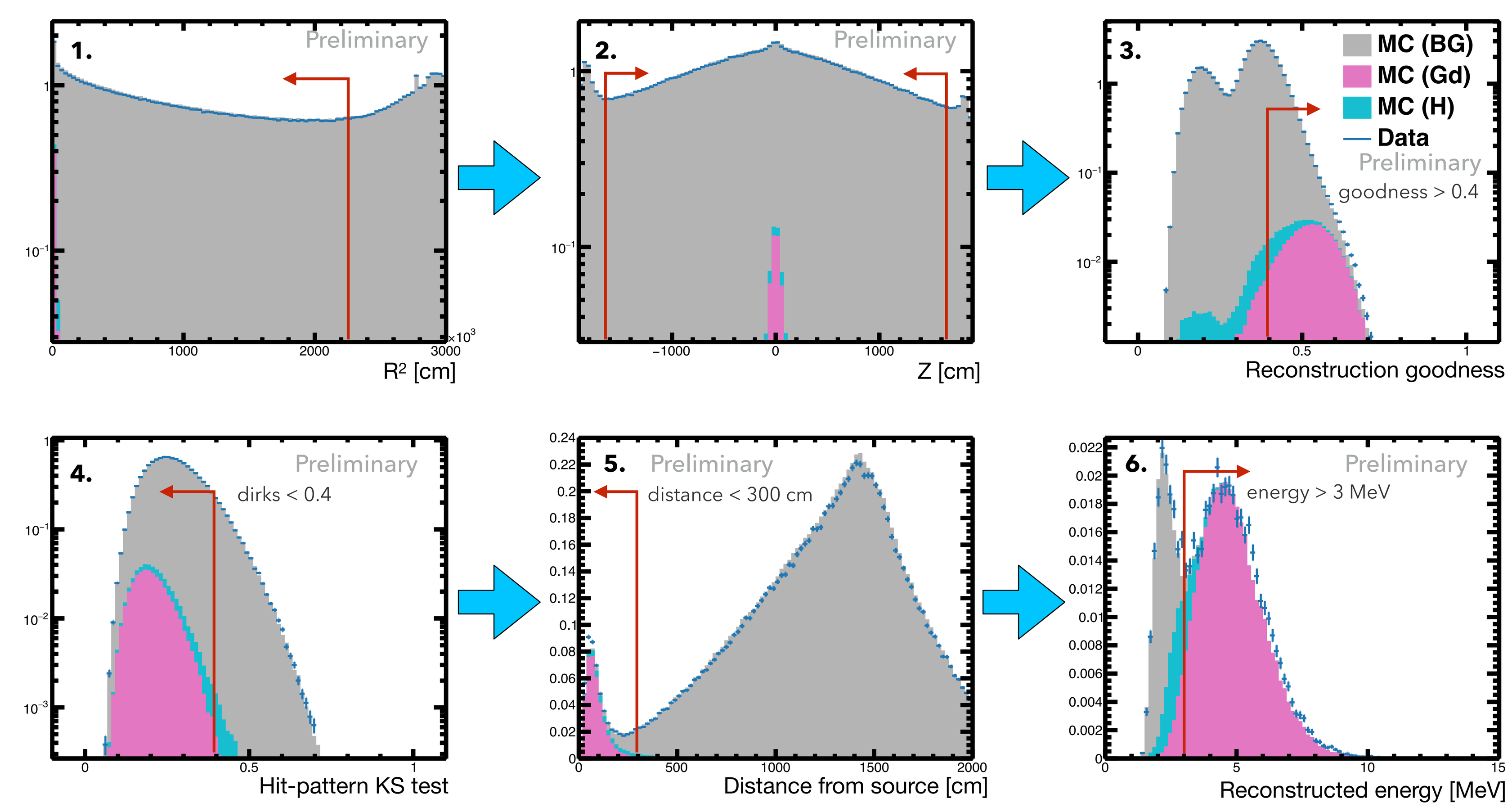
3. Event selection

Prompt event



Delayed event

- Candidate search for hit cluster (>25 hits/200 ns)
- Gd(n, γs)Gd signal is selected by using reconstruction info.
  - Mis-ID probability: 0.18%
- ~40% of Gd signal can be selected

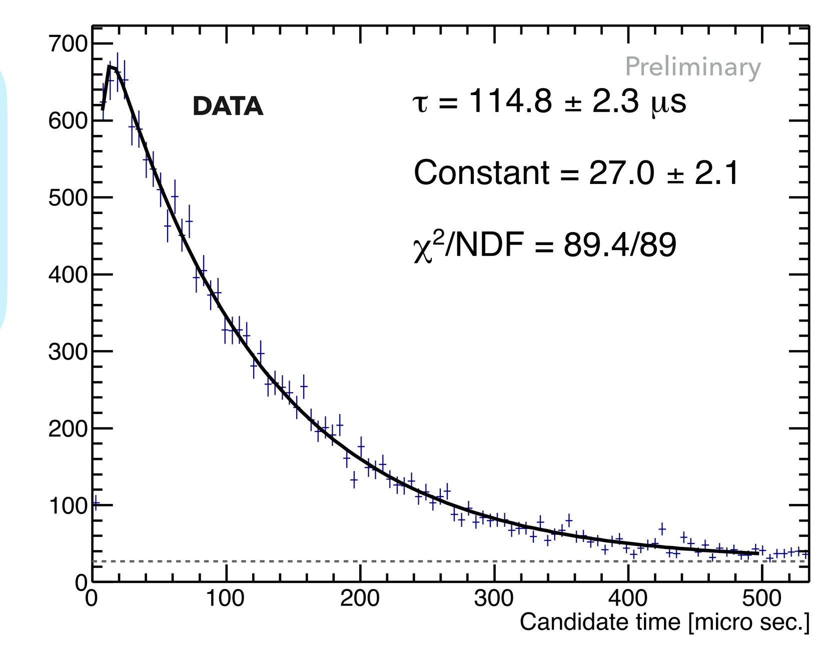


4. Neutron tagging efficiency

Definition

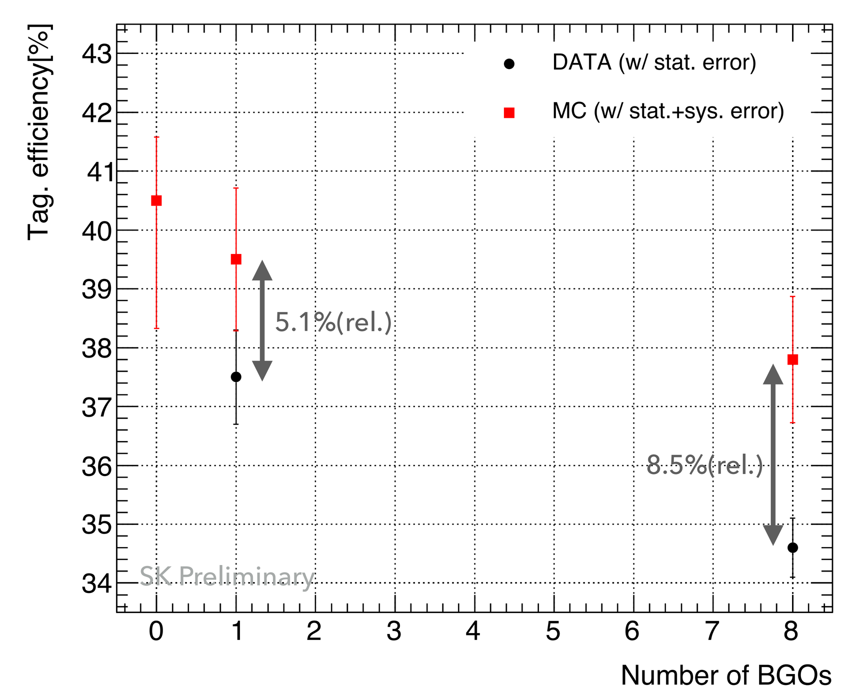
$$\varepsilon_n = \frac{T - B}{P}$$

- ε_n : Tagging efficiency
- T : # of tagged candidates
- B : # of bkg. candidates evaluated by exp. fit
- P : # of prompt events



Results

- Capture time constant: **114.8 μs**
- Tagging efficiency w/o BGO(MC):
  $40.5 \pm 0.1(\mathrm{stat.})^{+1.0}_{-2.1}(\mathrm{sys.})\%$
  - x2 efficiency than pure-water
- MC shows difference with DATA 8.5%(8BGO), 5.1%(1BGO)
  - Come from data structure and BGO effect
  - Sys. error for the efficiency w/o BGO includes this effect



5. Summary and prospects

Summary

- SK-Gd has started from Sep. 2020 to enhance neutron signal
- We evaluated neutron tagging efficiency in SK-Gd by using Am/Be
  - Efficiency for noBGO case: **$40.5 \pm 0.1(\mathrm{stat.})^{+1.0}_{-2.1}(\mathrm{sys.})\%$**
  - Efficiencies are uniform in entire tank.

Future prospects

- Upgrade Gd concentration to ~300 ppm: Gd capture eff. ~70%.
- Efficiency will be further increased by applying NN method.
- Several physics studies can be improved with neutron tag.

Reference
[1] K. Abe et al., Phys. Rev. D 104, 122002 (2021)
[2] J. F. Beacom and M. R.Vagins, Phys. Rev. Lett. 93, 171101 (2004)
[3] K.Abe et al., Nucl. Instrum. Methods Phys. Res. A 1027 166248(2022)