Prospects for supernova relic neutrino search in SK-Gd experiment with 0.03% Gd mass concentration

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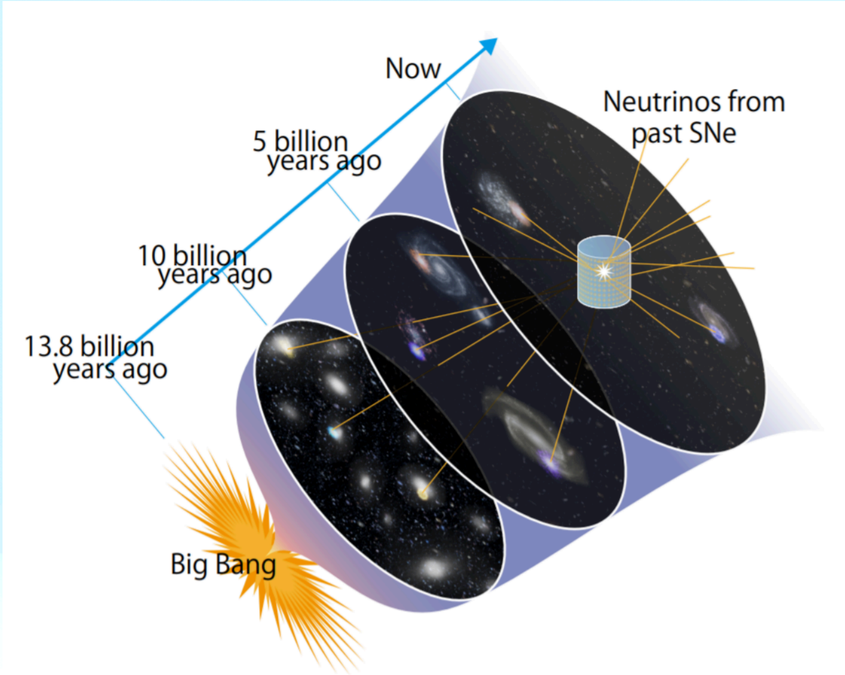
10th Supernova neutrino workshop @Okayama University (Feb. 29 - Mar. 1)

Content

- Supernova relic neutrino (SRN)
- SK-Gd experiment
- SRN search in SK-Gd
  - Analysis
  - Search result in SK-Gd with 0.01w%
  - Current study for SRN search in SK-Gd
  - Prospects for upgraded SK-Gd
- Summary

Supernova relic neutrinos



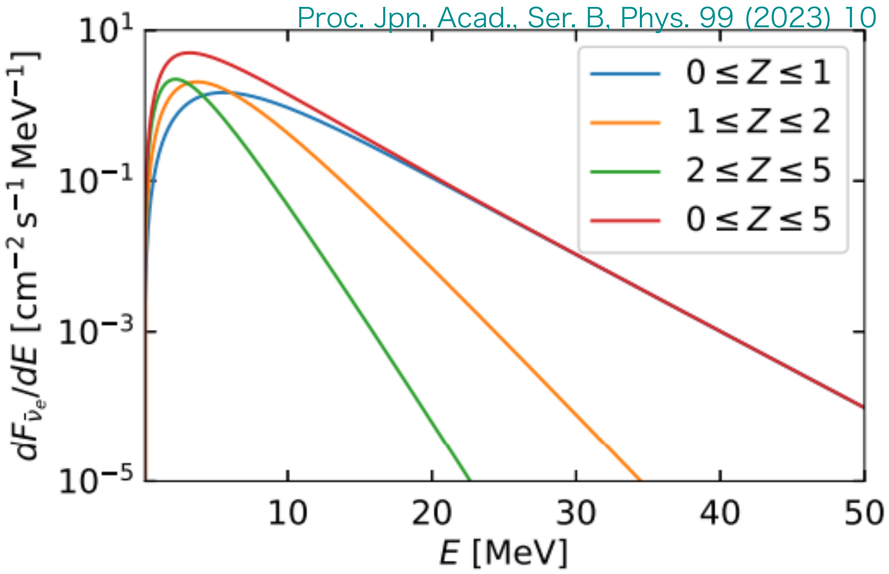
- **Supernova relic neutrinos (SRN)**
  An integrated flux of the neutrinos from all past CCSNe

- SRN flux:

$$\Phi_{\mathrm{SRN}} \propto \int [\ \text{SN rate}\ ] \otimes [\ \nu\ \text{emission from SN}\ ] \otimes [\ \text{Redshift}\ ]$$

  → Information for star formation history

  - Evolution of star formation rate
  - SN neutrino flux
  - Black hole formation rate
  - Neutrino physics…



Supernova relic neutrinos

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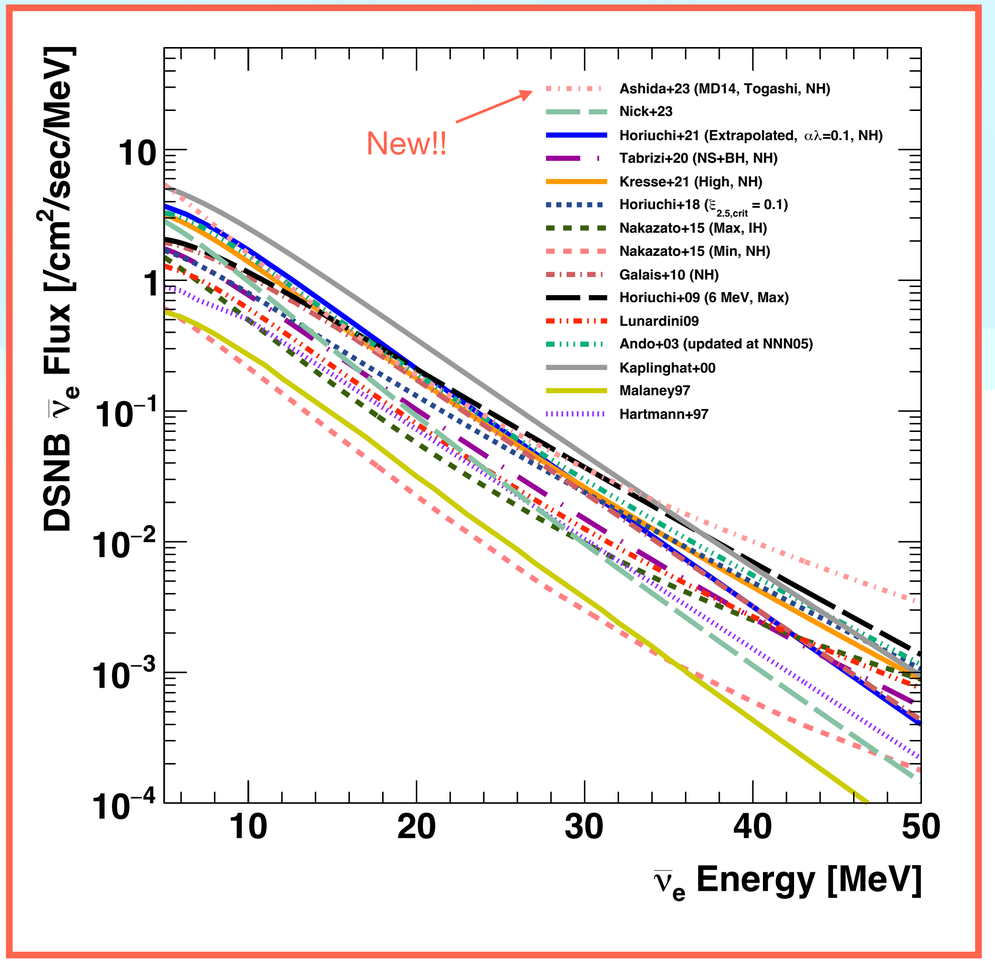
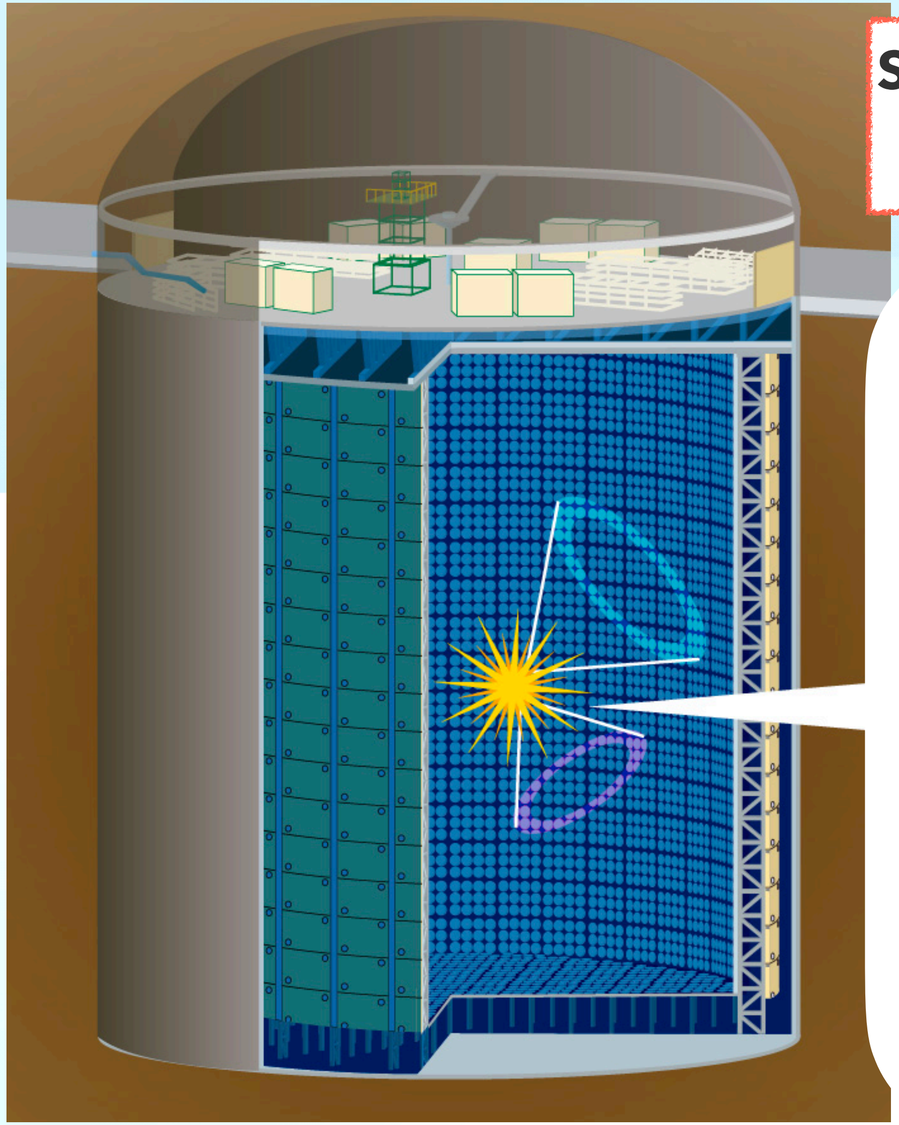


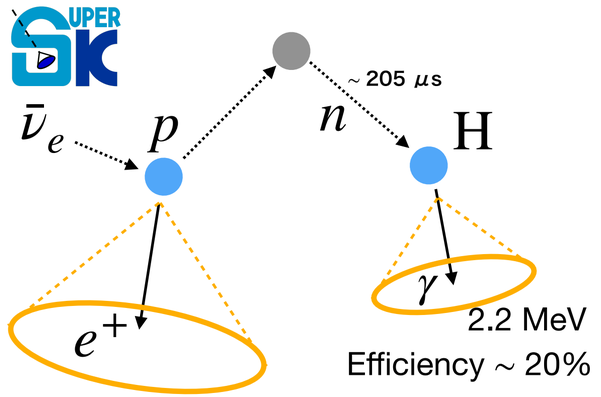
Flux search from *O*(1-10) MeV → **SK-Gd experiment**

SK-Gd experiment

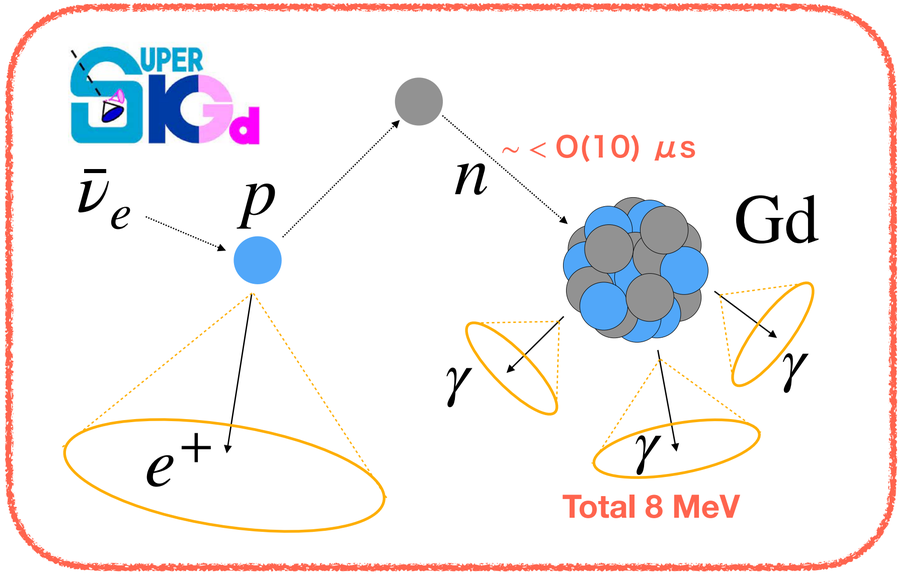


SK-Gd experiment:

Improved neutron detection by loading Gd to the Super-K

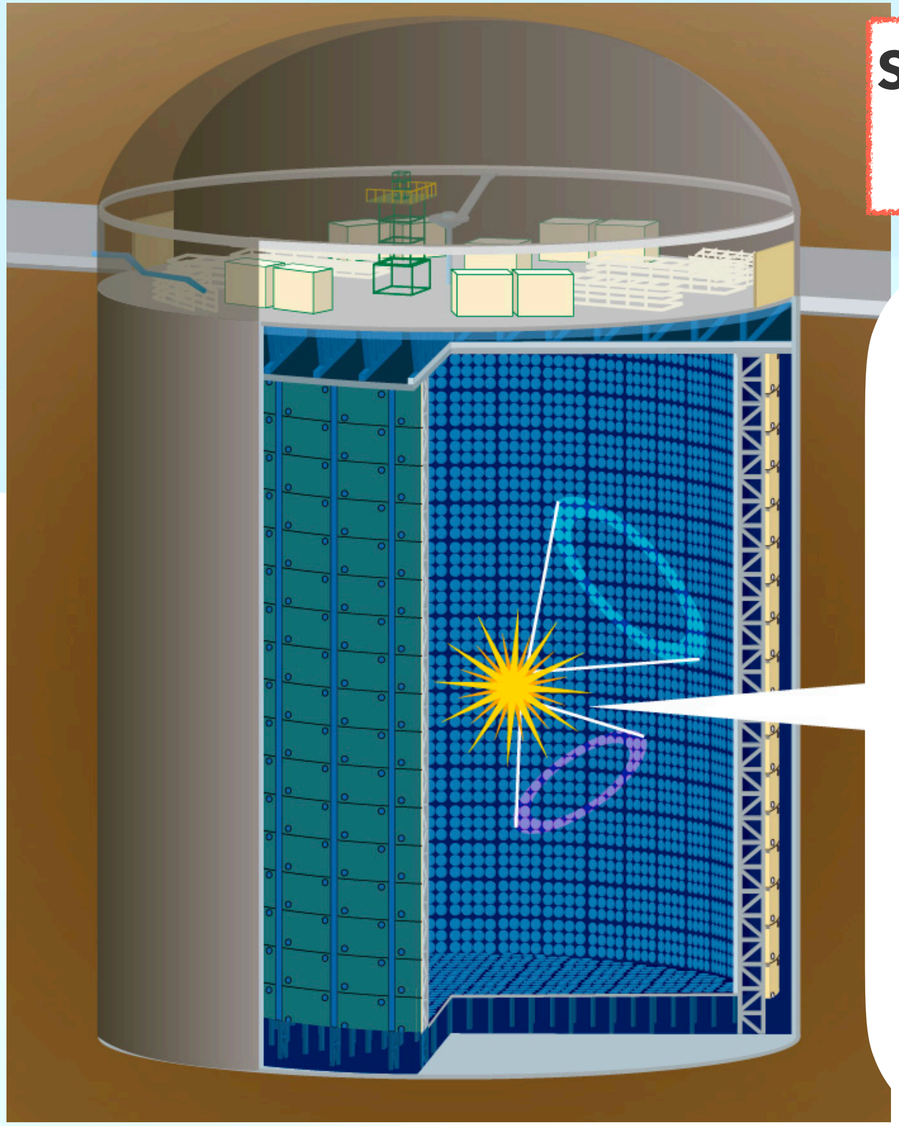


Loading Gd



Neutron signal is enhanced by Gd !

SK-Gd experiment



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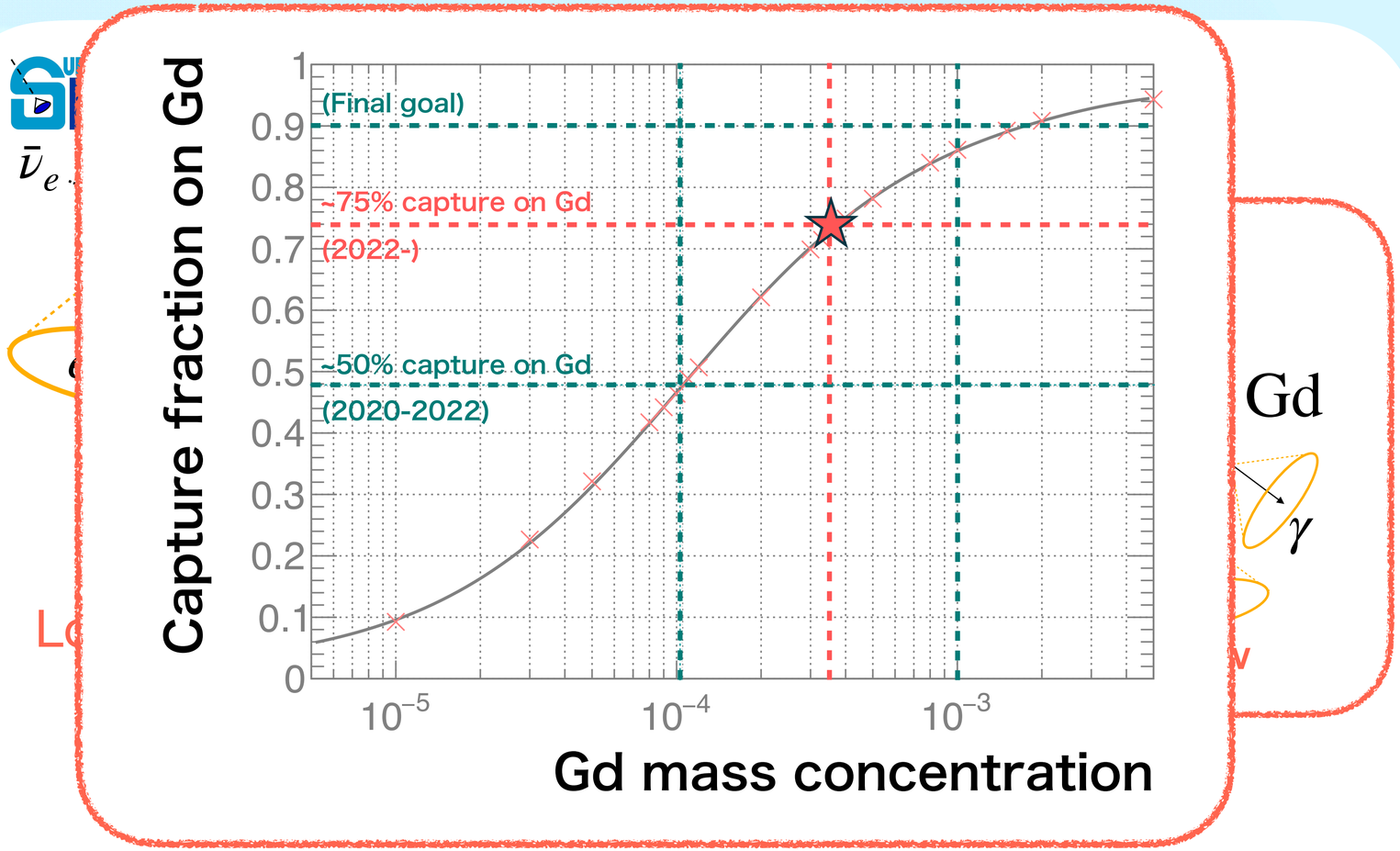


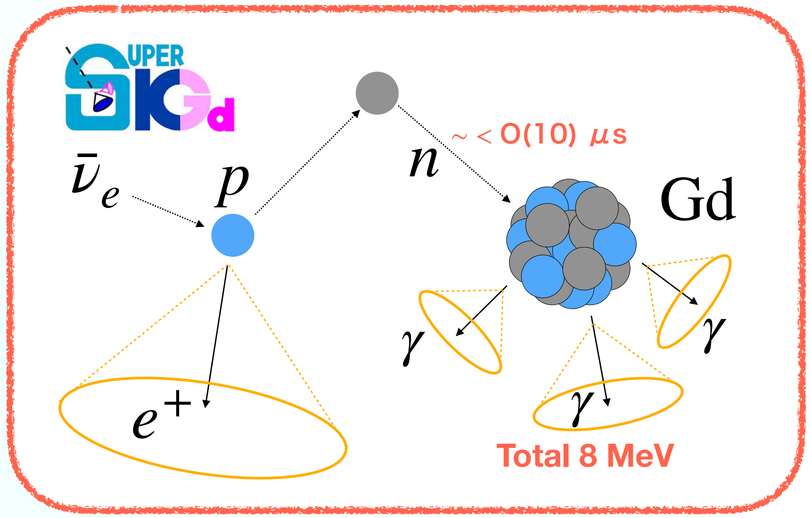
Analysis and results

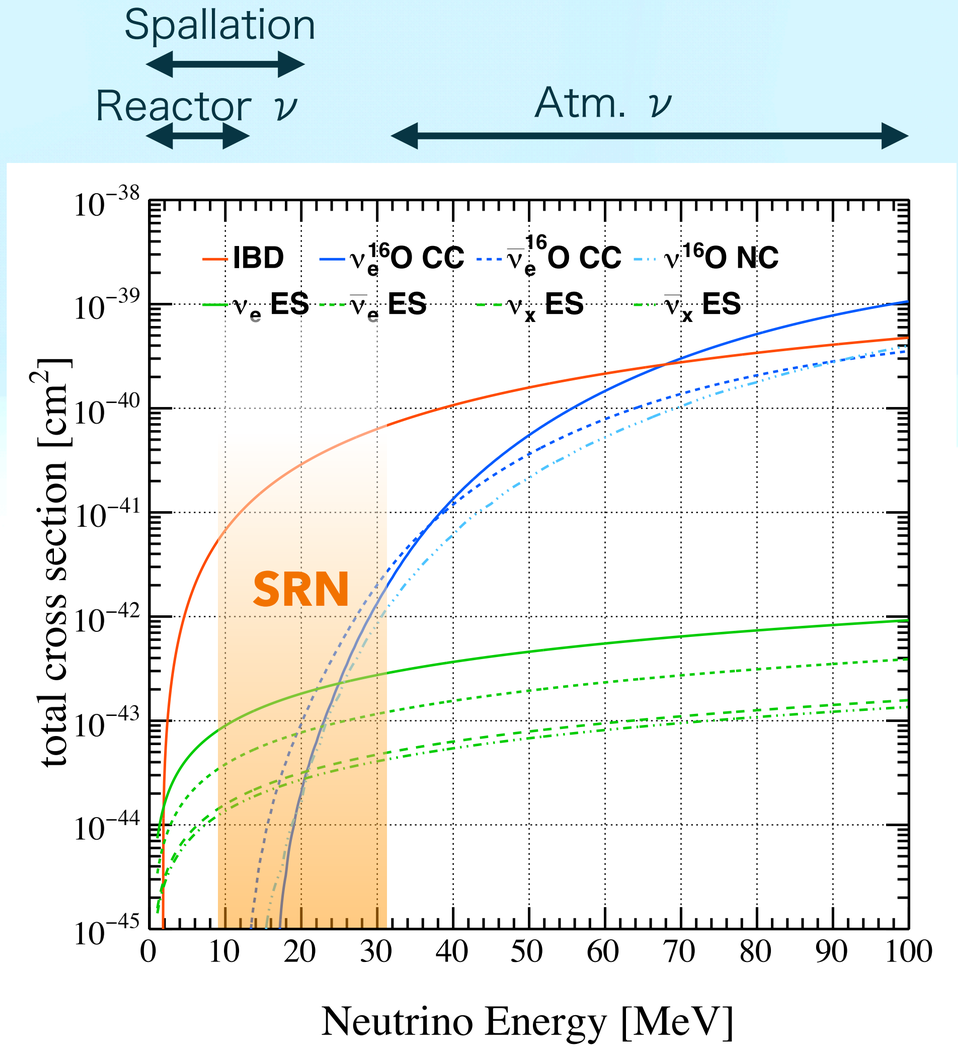
SRN signal in SK-Gd

- Search for inverse-beta decay (IBD) of electron anti neutrinos

$$\bar{\nu}_e + p \longrightarrow e^+ + n$$

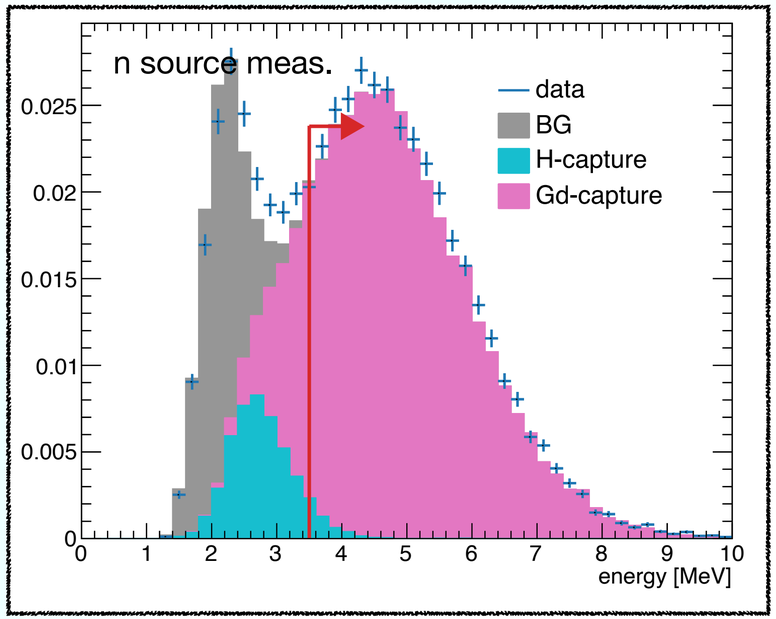
  - Largest cross-section @ SRN signal range
  - Simple event topology: 1 positron and 1 neutron
    → **Require only one delayed neutrons signal**



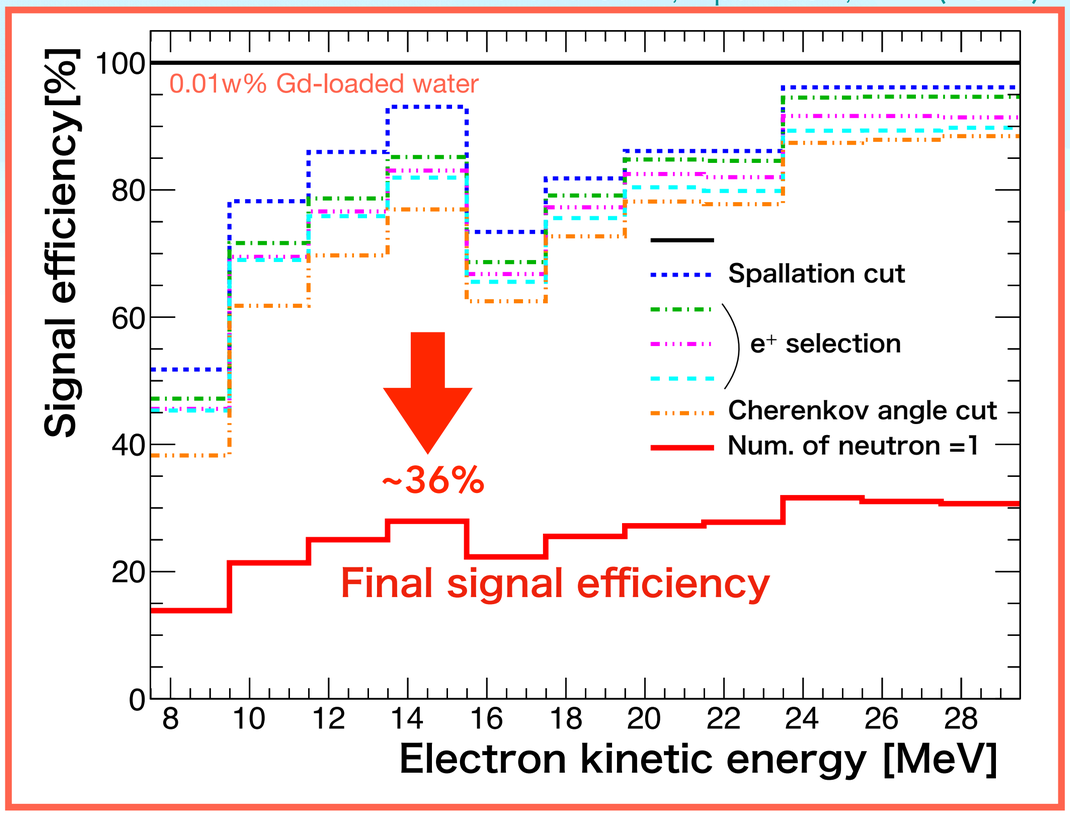


SRN search result @0.01w% Gd

- Search for SRN in the initial stage of SK-Gd was published
- Neutron detection with cut-based method (Efficiency ~ 35.6%)



M. Harada et al., ApJL 951, L27 (2023)



SRN search result @0.01w% Gd

- Ovserved 16 events
  → consistent with background

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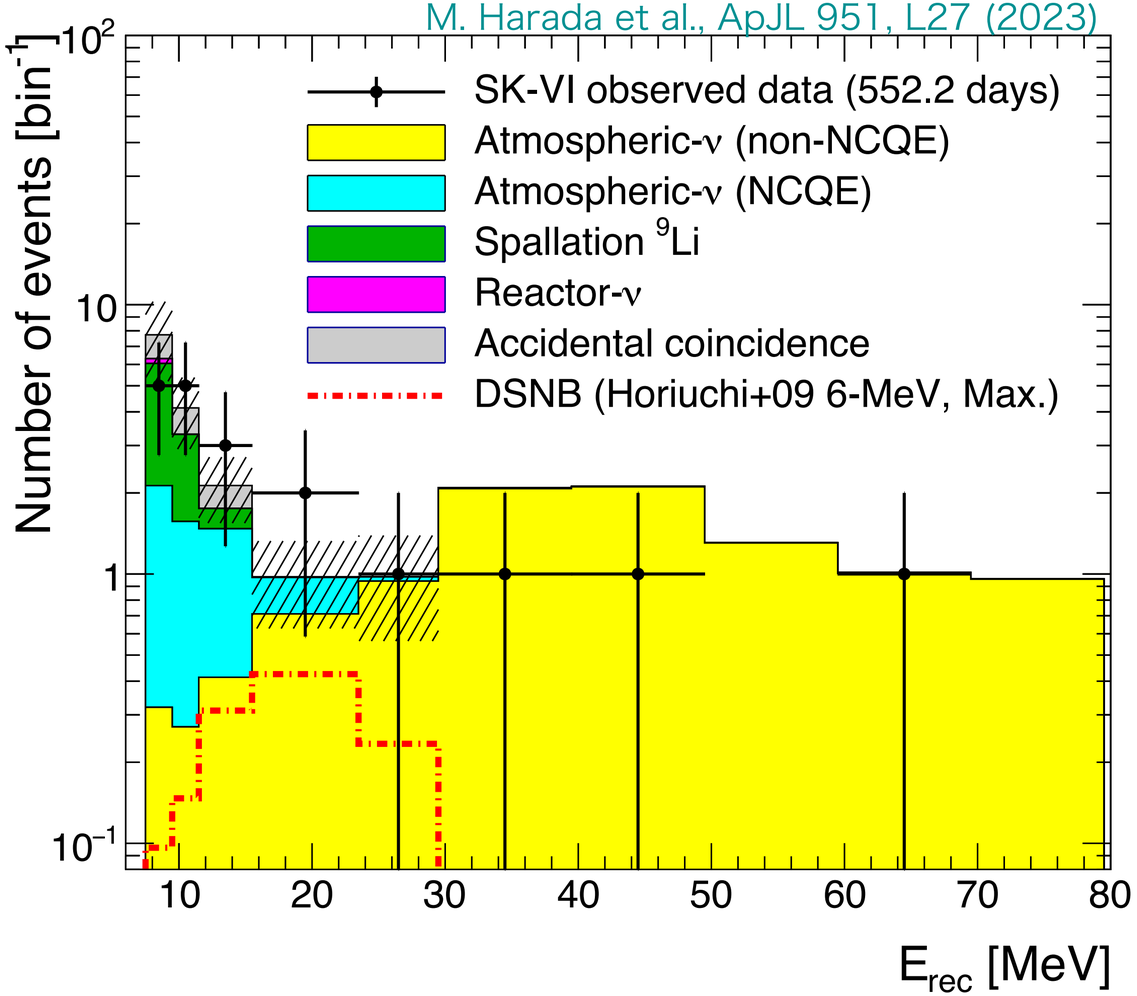
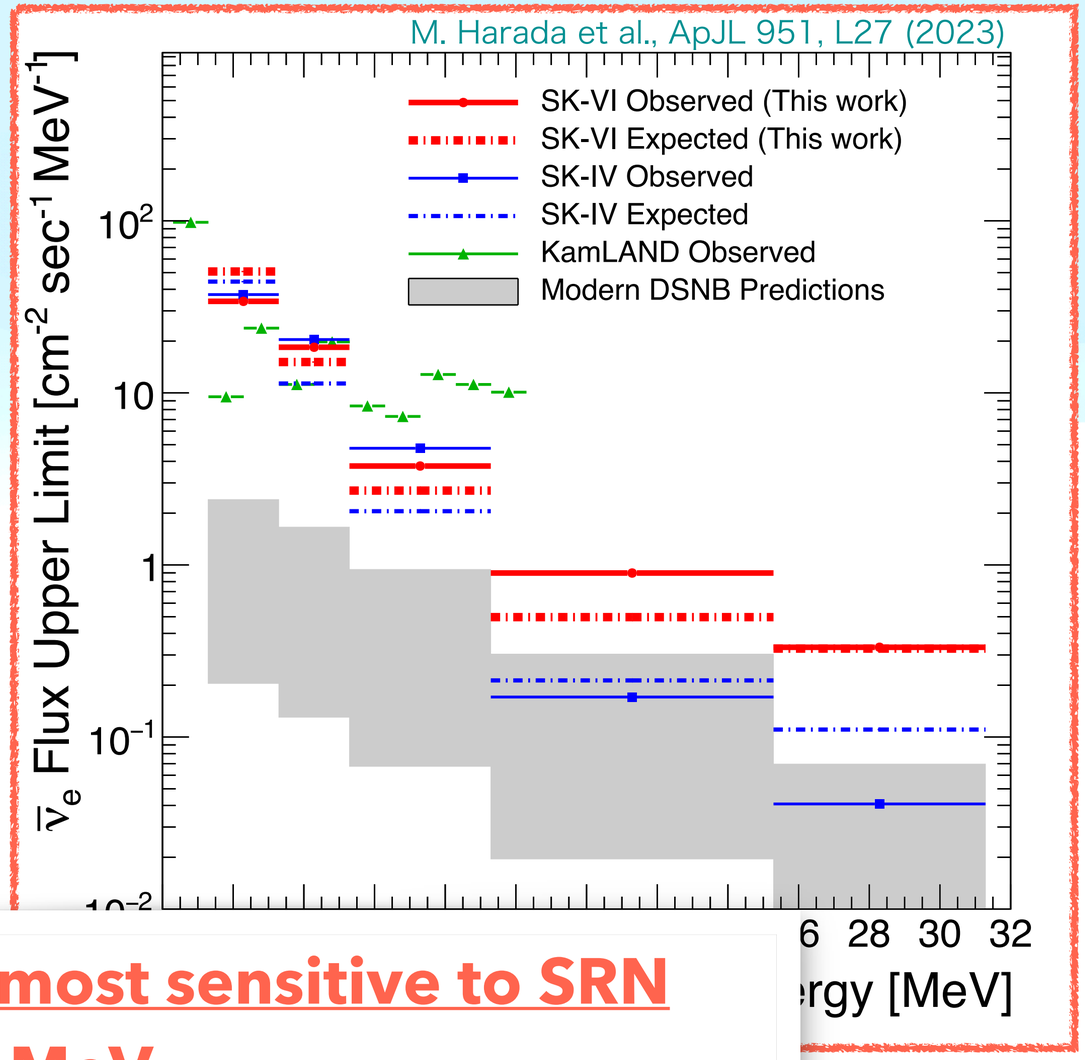


SRN search result @0.01w% Gd

- Ovserved 16 events
  → consistent with background
- Placed model-independent
  flux upper limit
- **Comparable result with pure-water SK (<20% of live-time)**



→**Proves SK-Gd is world's most sensitive to SRN above 13 MeV**

Current status and prospects

Analysis update

- Developing multiple scattering reduction variable
- Neutron tagging using neutral network
- Better understanding of the NCQE interaction (→later talks)
- Investigation for new neutrino interaction model

Analysis update

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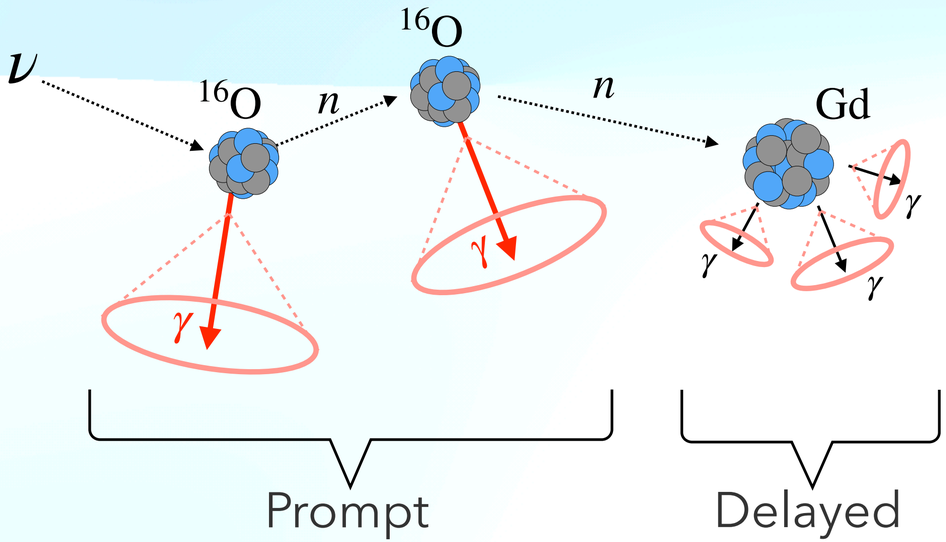
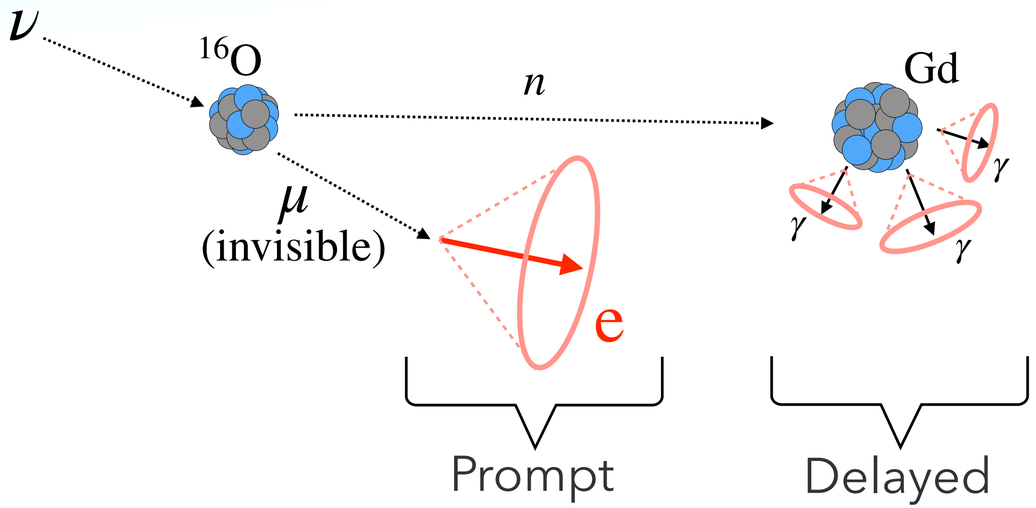
Background: Atmospheric neutrinos

- Hadronic interaction with oxygen nucleus leads to neutron emission

NCQE



non-NCQE (CCQE)



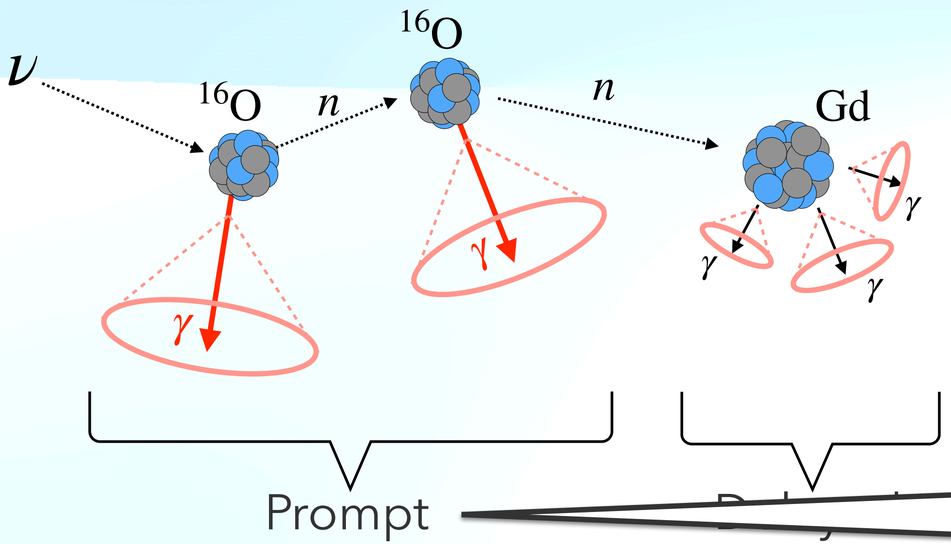
➡ Remove using PMT hit pattern, charge, existence of other hit cluster

Background: NCQE event reduction

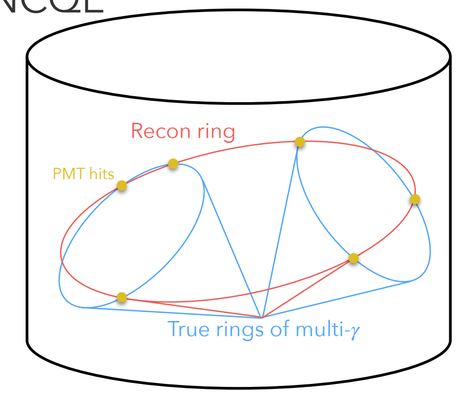
📌 Reduce by Cherenkov angle

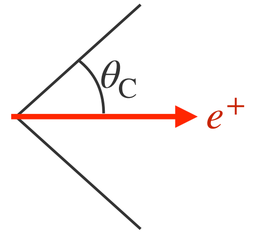
✓ NCQE events tend to have larger angle

NCQE

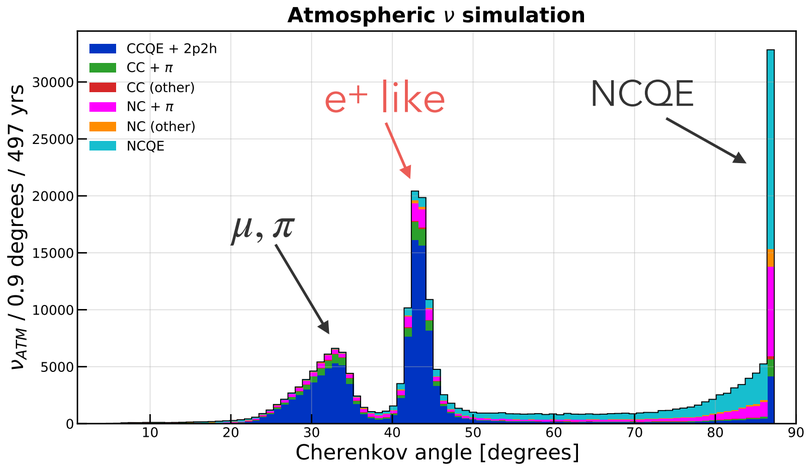


NCQE



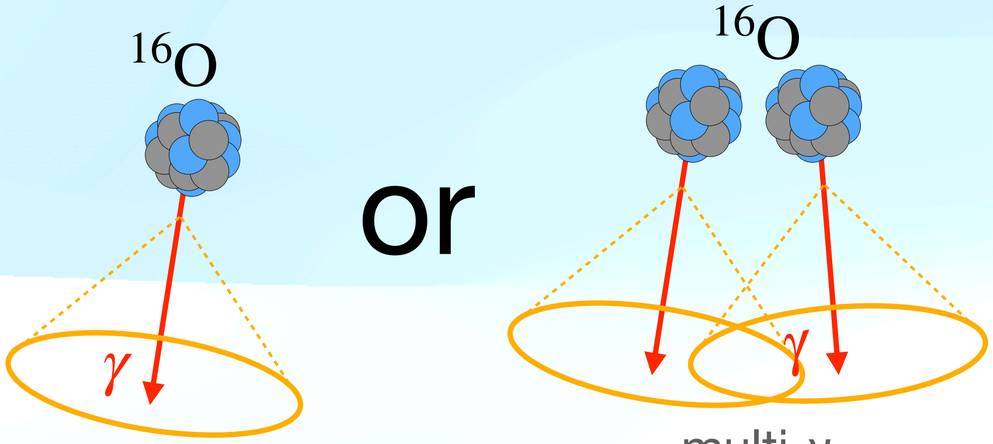


Appeared in Cherenkov angle



Improvement of NCQE reduction

- Remaining NCQE events: Cherenkov angle is reconstructed to ~42 deg



CANNOT distinguish from SRN

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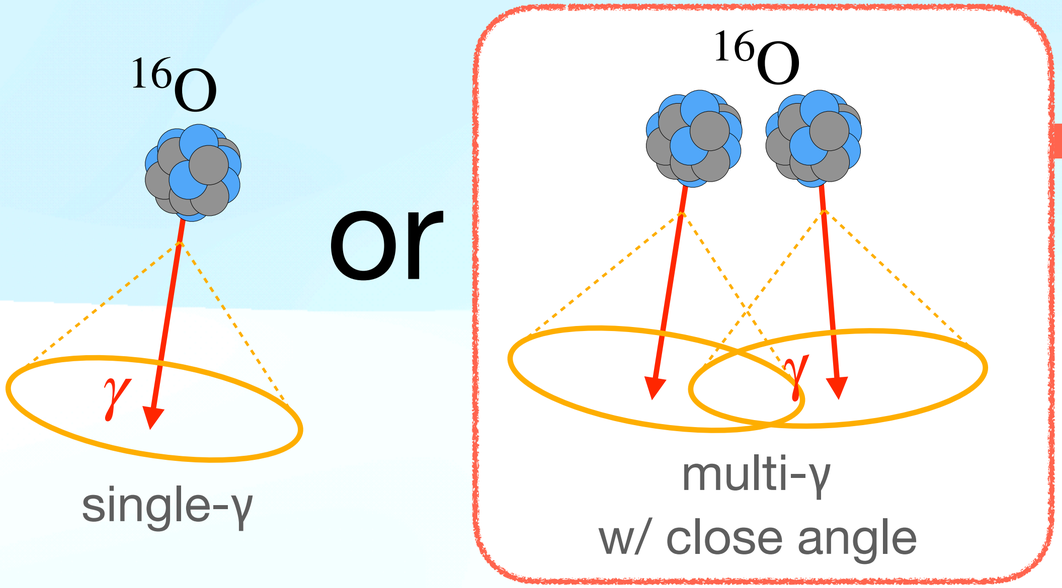

Looks like an event with
more multiple scattering than electrons

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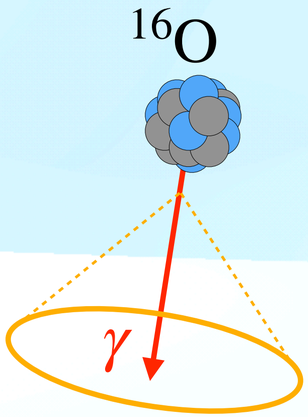
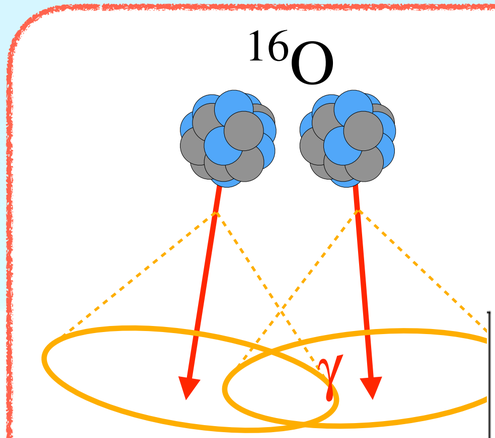


single-γ

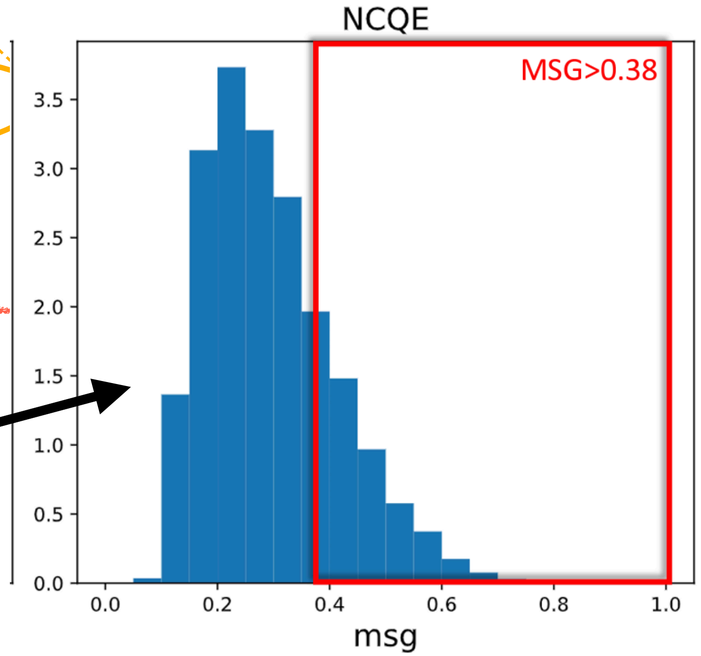
or

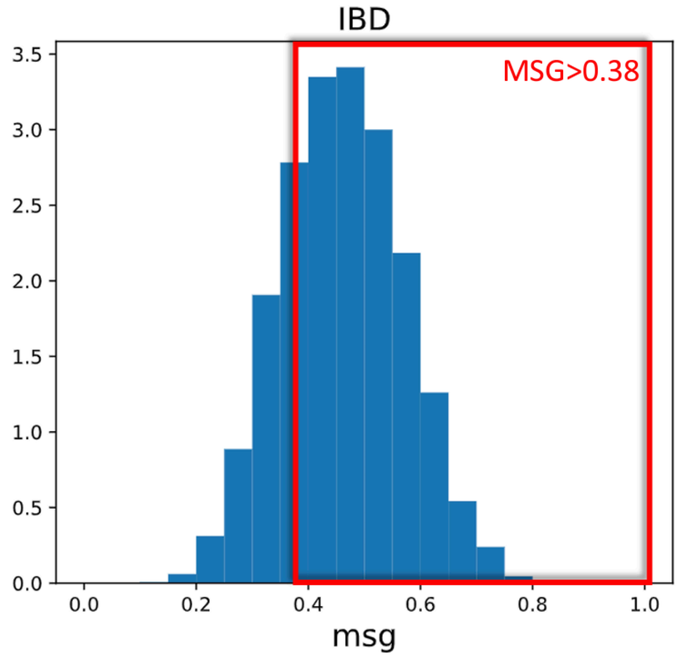


multi-γ
w/ close angle

Looks like an event with
more multiple scattering than electrons

New variable
Multiple-scattering goodness (MSG)





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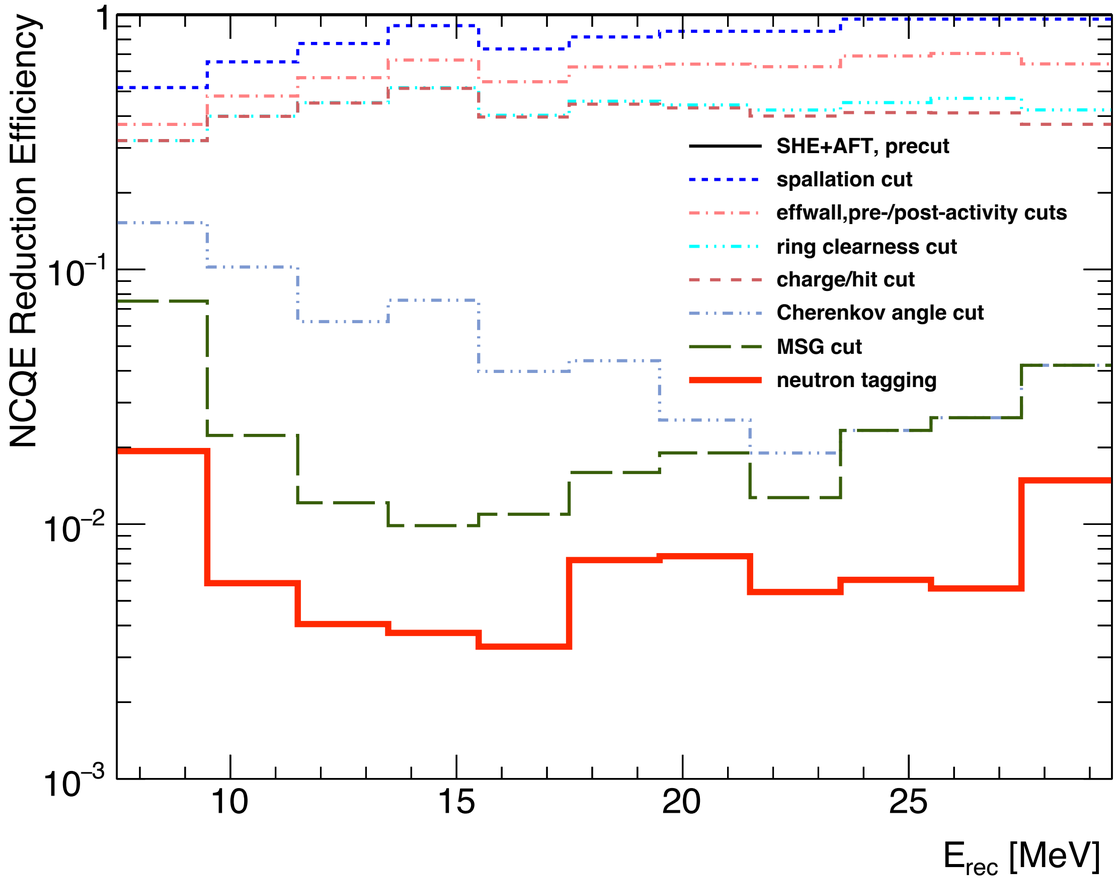


MSG cut significantly reduces NCQE events at low-energy region

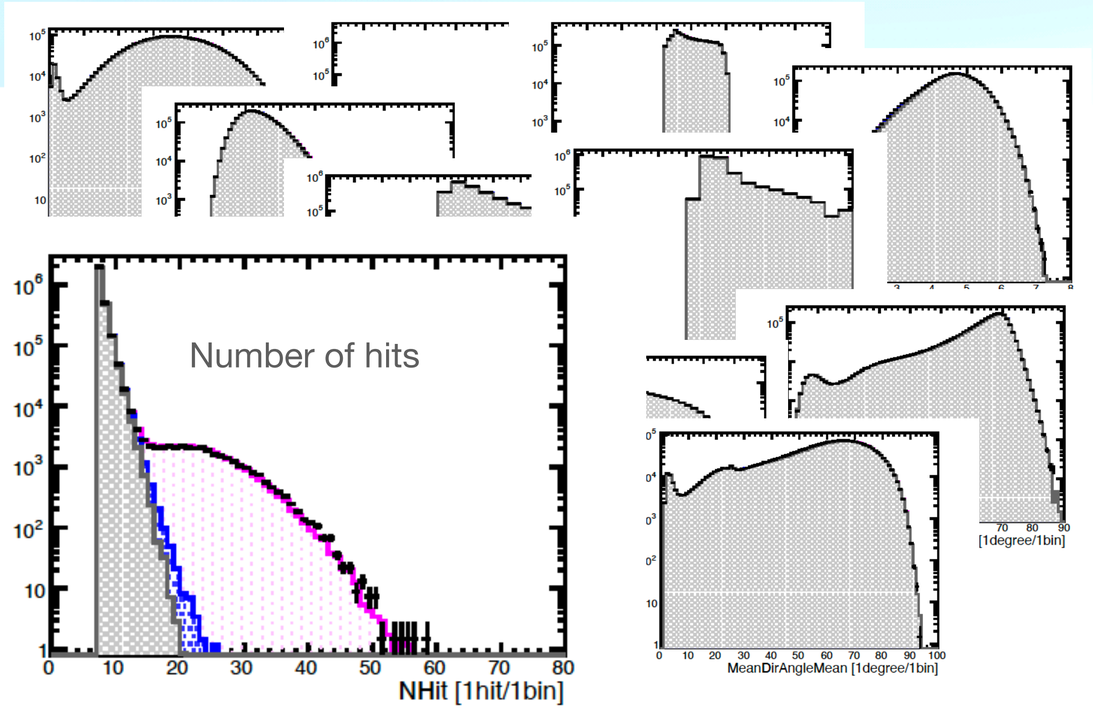
In future:
Develop ML-based NCQE reduction including MSG cut

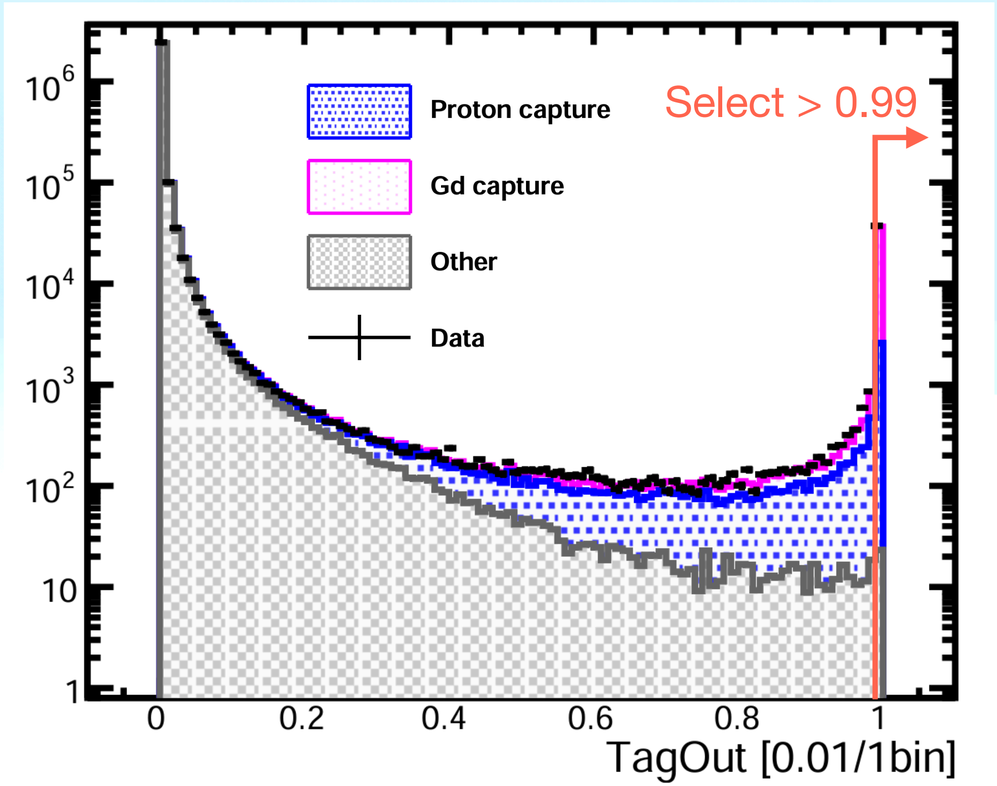
Improvement of neutron tagging

📌 Neutron tagging using Neural Network

✓ Well understanding for Gd-capture gamma-rays

12 Feature variables

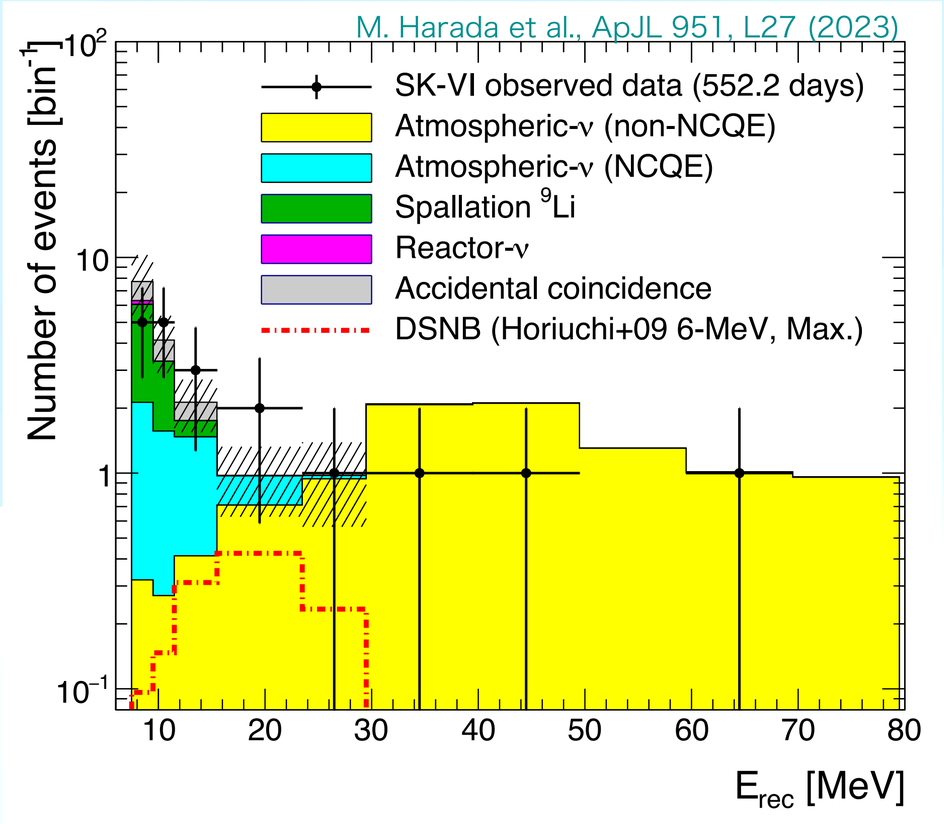


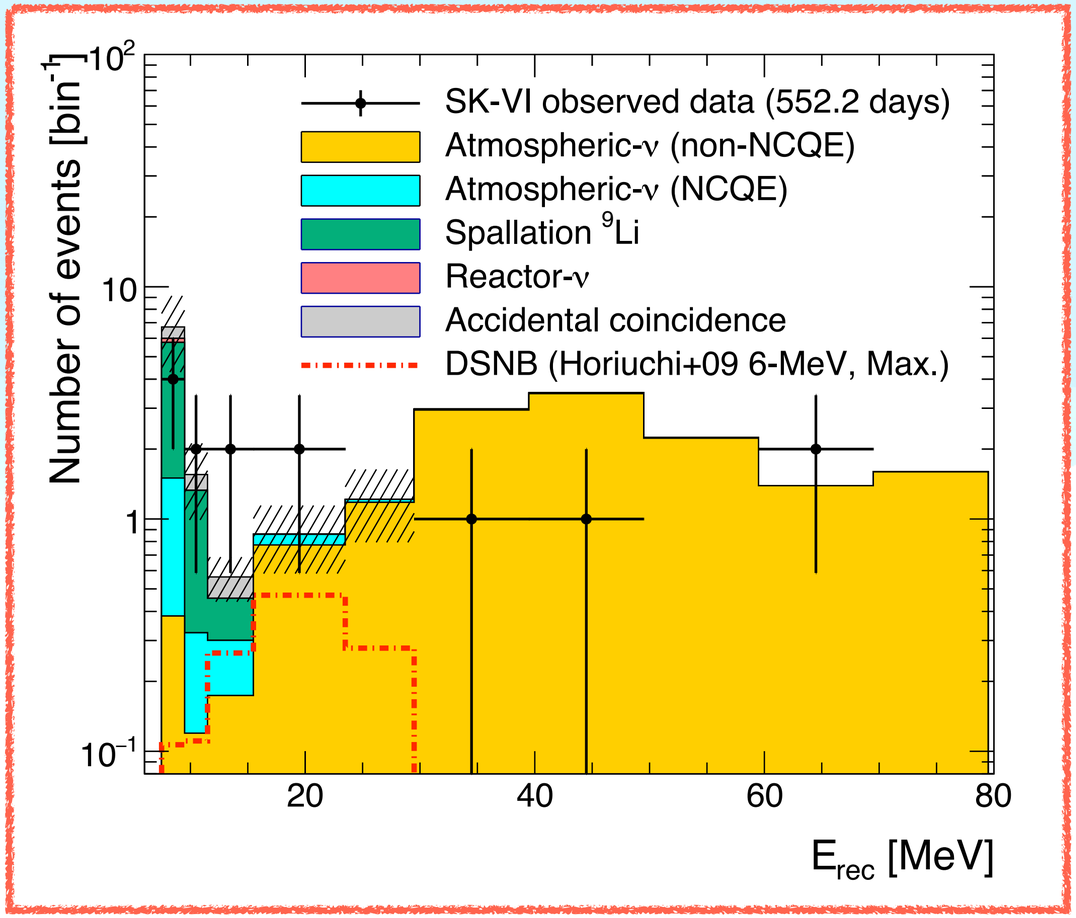


✓ **45.4±3.9% with 0.02% mis-ID**

→1.3 times improvement

Result of improvement

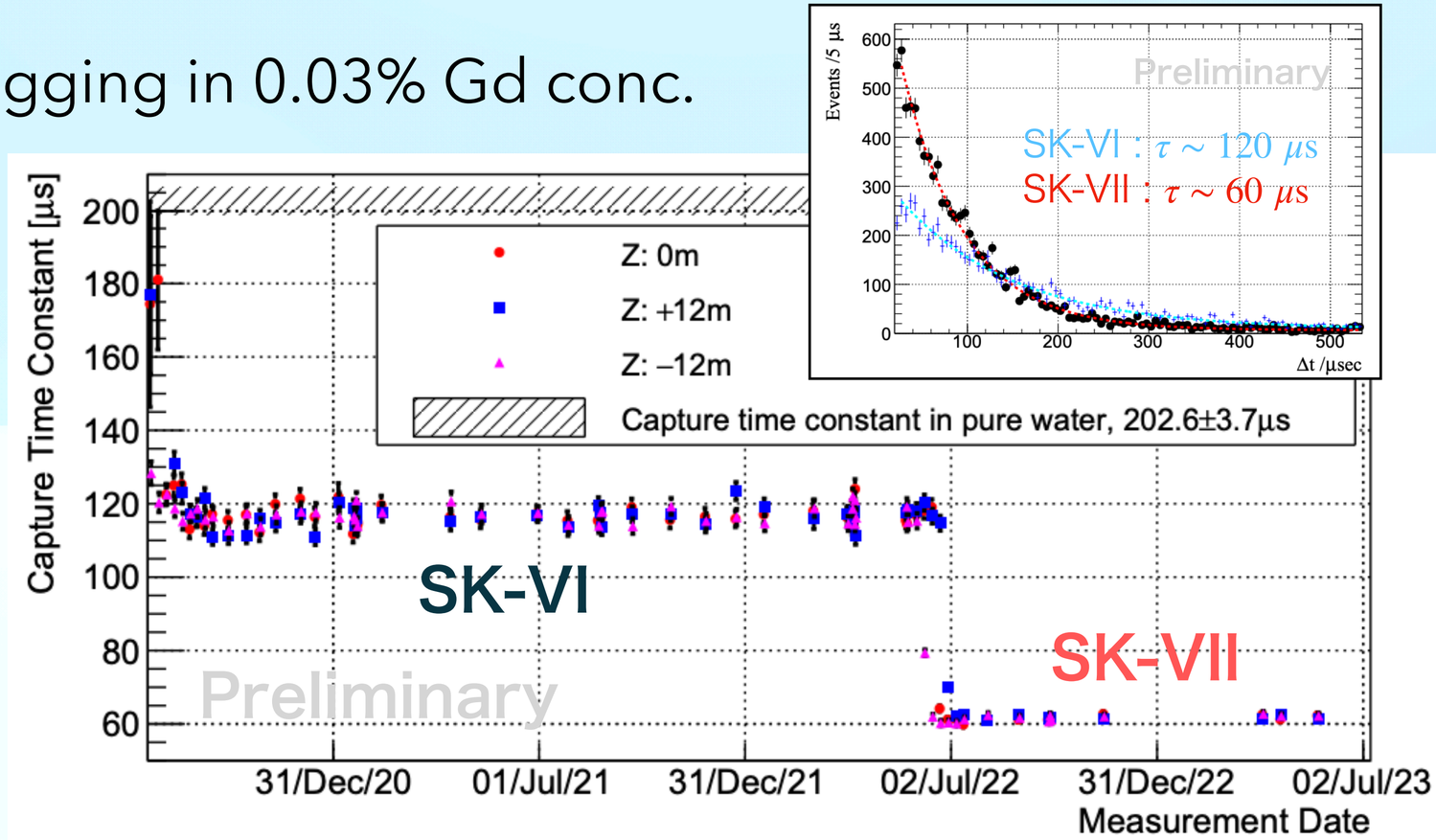




- Significantly improved NCQE reduction
- x1.3 better neutron tagging

Neutron tagging in 0.03% Gd conc.

📌 Neutron tagging in 0.03% Gd conc.



Apply same NN method to SK-VII data

✓ **63.1±1.1% with 0.02% mis-ID**
→1.4 times improvement

Summary

- First result of SRN search in SK-Gd was published
- In 2022, the Gd concentration was increased to 0.03%
  → neutron tagging efficiency x1.4!
- Multitude of efforts towards understanding and reducing NCQE events
  - ✓ Multiple scattering reduction
  - ✓ Neutron tagging using neutral network
  - ✓ Better understanding of the NCQE interaction (later talk)
- Analysis of data up to 2023 is also on-going.