Measurements from JSNS^2 and the status of JSNS^2-II

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JSNS^2 / JSNS^2-II Collaboration

(J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source)

KEK
JAEA
J-PARC
Tsukuba University
Osaka University
Tohoku University
Kitasato University
Kyoto Sangyo University

Soongsil University
Dongshin University
Seoyeong University
Kyung Hee University
Gwangju Institute of Science and Technology
Seoul National University of Science and Technology
Sungkyunkwan University
Chonnam National University
Jeonbuk National University
Kyungpook National University

Brookhaven National Laboratory
University of Michigan
University of Utah

Sun Yat-sen University

University of Sussex

23 institutions & 5 countries

Indication of a sterile neutrino ($\Delta m^2 \sim 1 eV^2$)

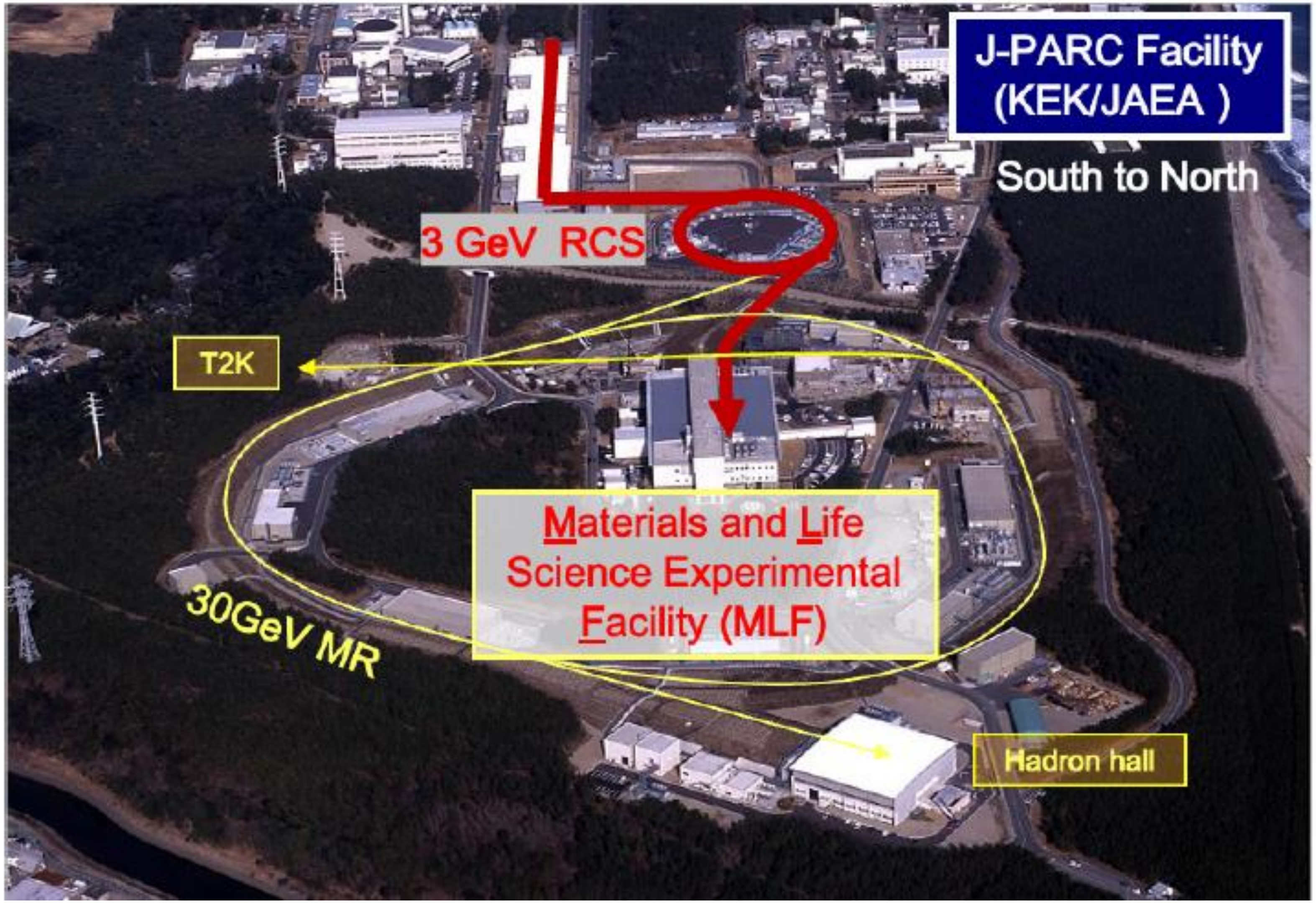
- Anomalies, which cannot be explained by standard neutrino oscillations for ~20 years are shown

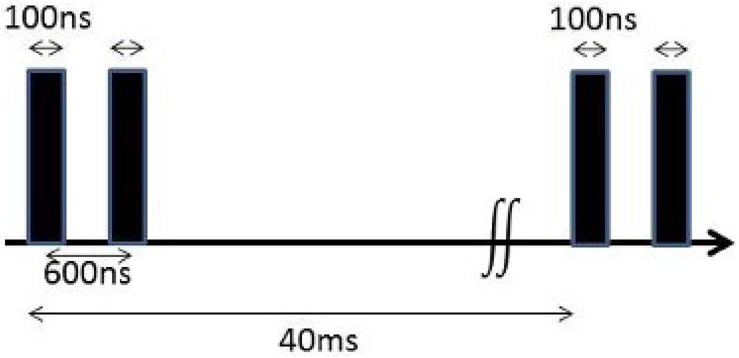
Experiments	Neutrino source	Signal	Significance	E(MeV)	L(m)
LSND	μ Decay-At-Rest	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.8σ	40	30
MiniBooNE	π Decay-In-Flight	$\nu_\mu \rightarrow \nu_e$ $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	4.8σ	800	600
BEST	e capture	$\nu_e \rightarrow \nu_x$	4.2σ	<3	10
Reactors	Beta decay	$\bar{\nu}_e \rightarrow \bar{\nu}_x$	3.0σ	3	10-100

- JSNS^2 uses the same neutrino source (μ), target (H), and detection principle (IBD) as the **LSND**

- Even if the excess is not due to the oscillation, JSNS^2 can catch this directly
- two advantages : short-pulsed beam and used the gadolinium(Gd)-loaded liquid scintillator(GdLS)

J-PARC facility





Low duty factor beam
(short-pulses + low repetition rate)
Gives an excellent signal to noise ratio

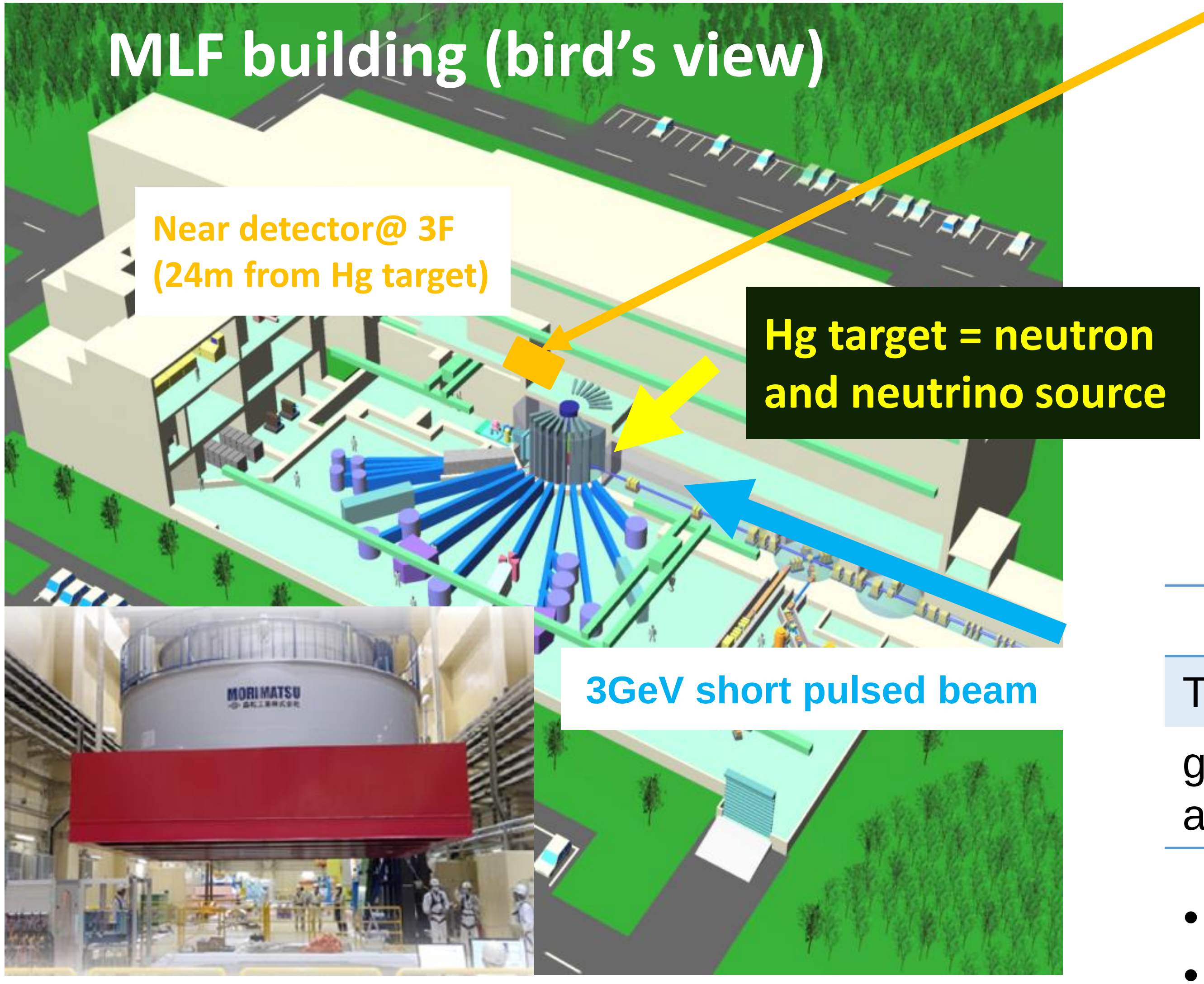
1 MW (design)

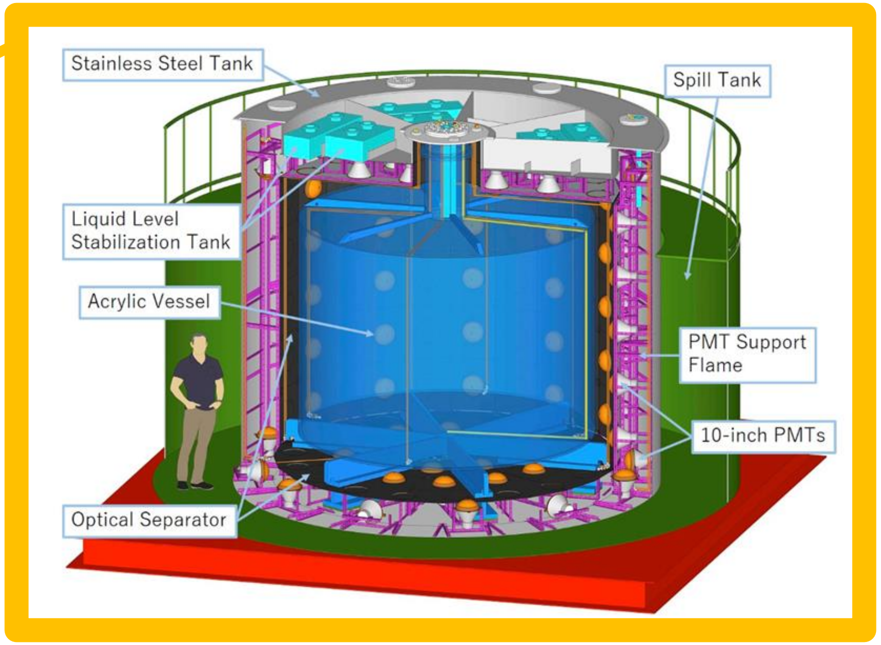
0.6-0.7MW (2021)
0.7-0.8MW (2022)
0.84MW (2023)
0.88-0.95MW (2024)

@ MLF

JSNS^2 detector

Nucl. Instrum. Methods A 1014 165742 (2021)





	Liquid	Volume
Target	GdLS + DIN (10%)	17 tons
gamma-catcher and veto	Pure LS	31 tons

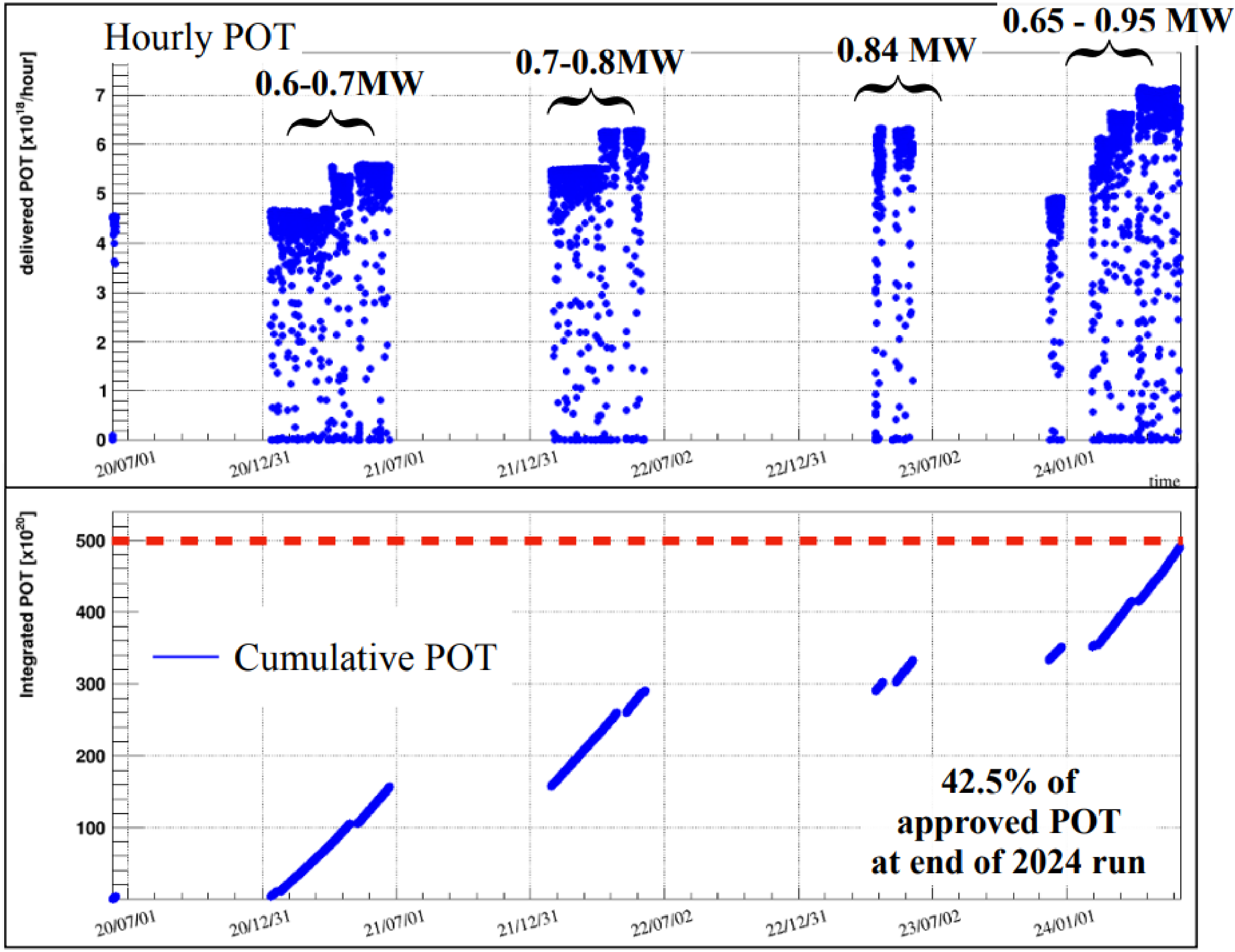
- 96, 10-inch PMTs for the inner detector
- 24, 10 inch PMTs for the veto

Operation

- Data taking
  - Commissioning (2020)
  - Four long term physics run (2021 – 2024)

- 1MW beam power (design)
  - achieve 950kW at MLF

- 4.85×10^{22} POT so far
  - 42.5% of approved POT

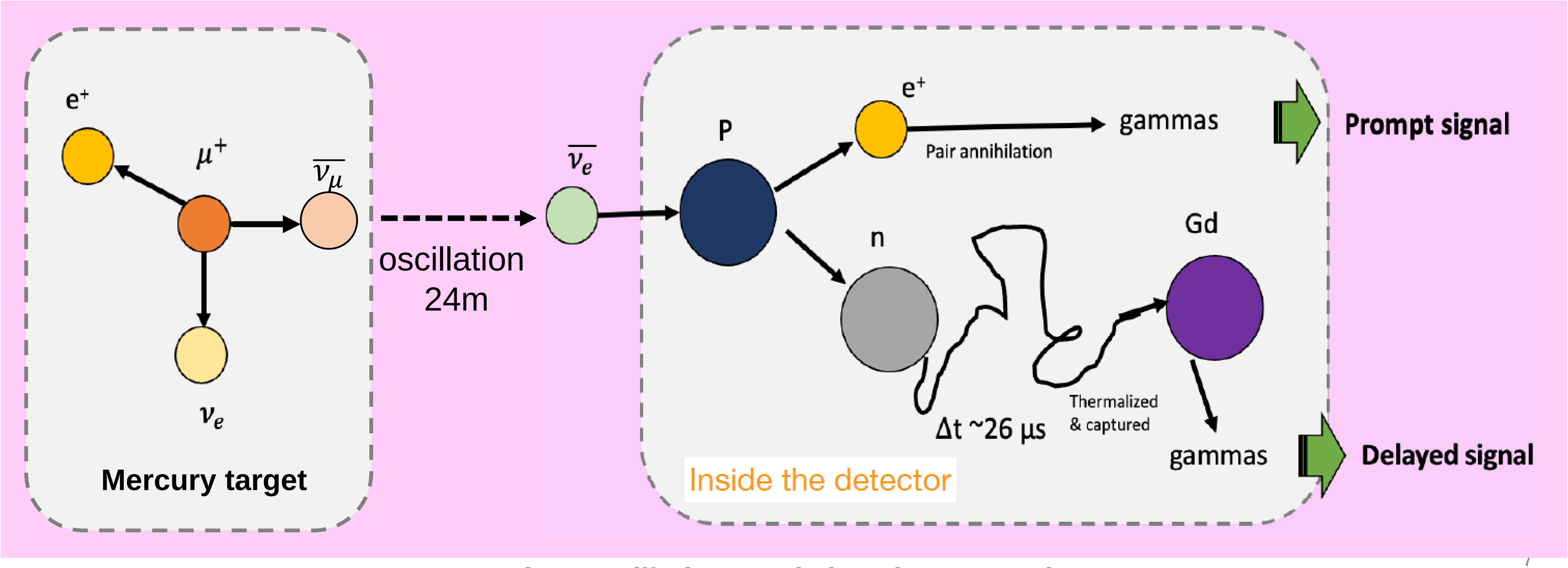


Production and detection

- If sterile ν exist, $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation occurs with 24m.

- Coincidence of Inverse Beta Decay (IBD)
  - Positron annihilation
  - Neutron capture on Gd

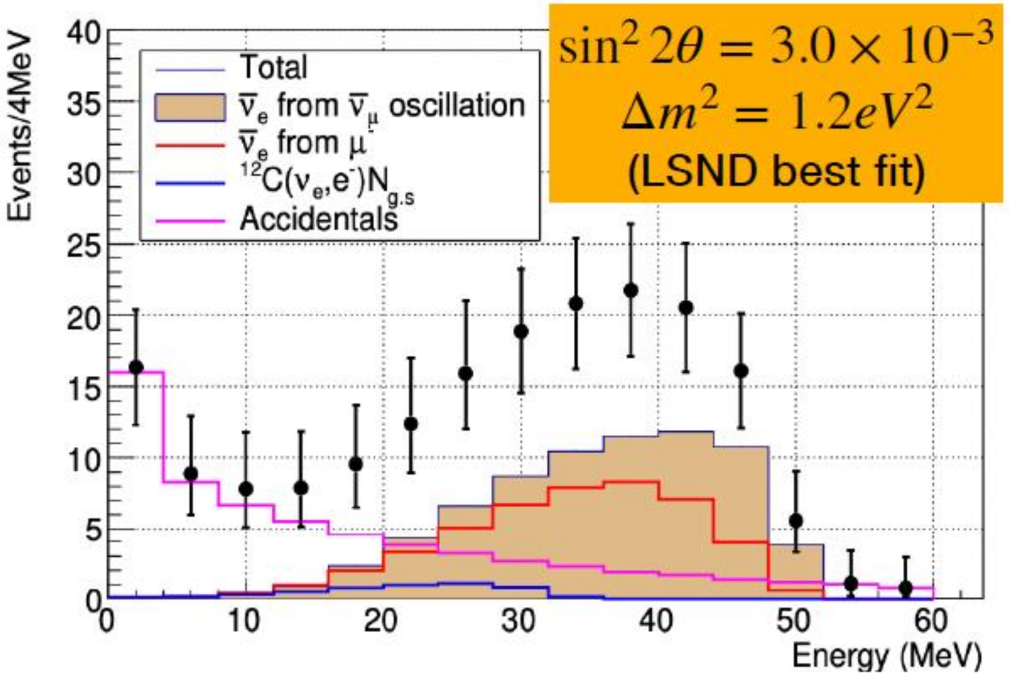
	Timing	Energy
Prompt	$1.5 < \mathrm{T}_p < 10\ \mu\mathrm{s}$	$20 < E < 60$ MeV
Delayed	$\Delta\mathrm{T}_{p-d} < 100\ \mu\mathrm{s}$	$7 < E < 12\ MeV$

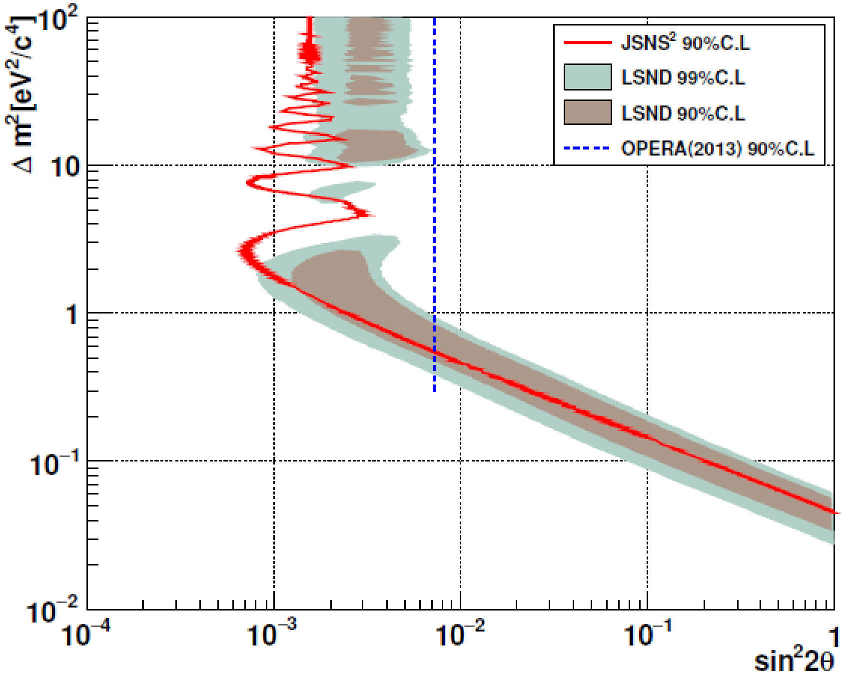


Expected energy spectrum and sensitivity

- $\bar{\nu}_e$ follows decay-at-rest $\bar{\nu}_\mu$ energy distribution
- Will cover the LSND allowed region at 90%C.L.
  - 3 years with 1MW

Signal	$sin^2 2\theta = 3.0 \times 10^{-3}$ $\Delta m^2 = 2.5eV^2$ (Best fit values of MLF)	87
	$sin^2 2\theta = 3.0 \times 10^{-3}$ $\Delta m^2 = 1.2eV^2$ (Best fit values of LSND)	62
background	$\overline{\nu}_e$ from μ^-	43
	$^{12}C(\nu_e, e^-)^{12}N_{g.s.}$	3
	beam-associated fast n	≤2
	Cosmic-induced fast n	negligible
	Total accidental events	20



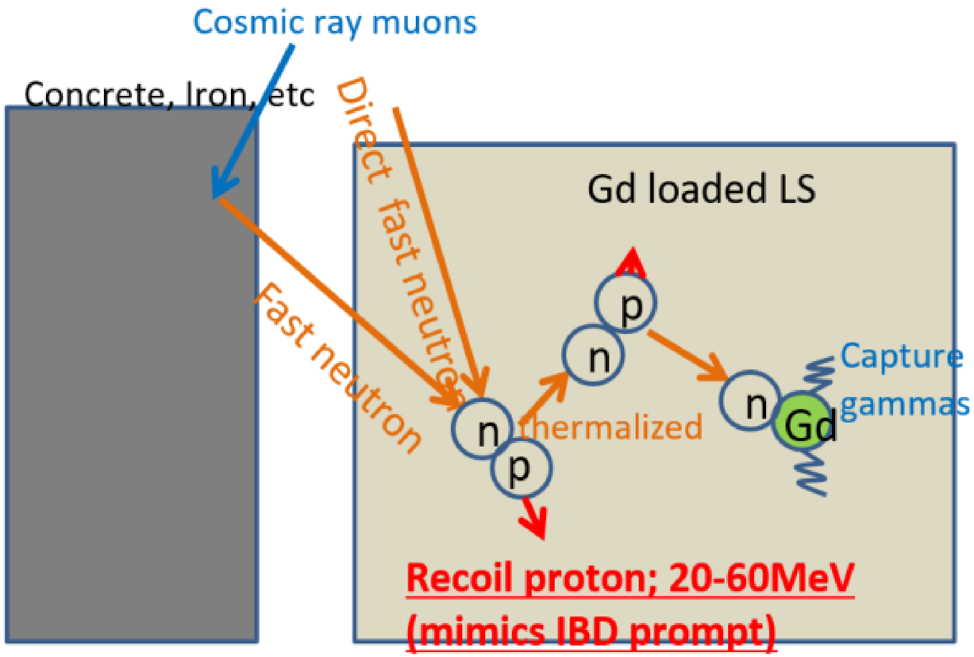


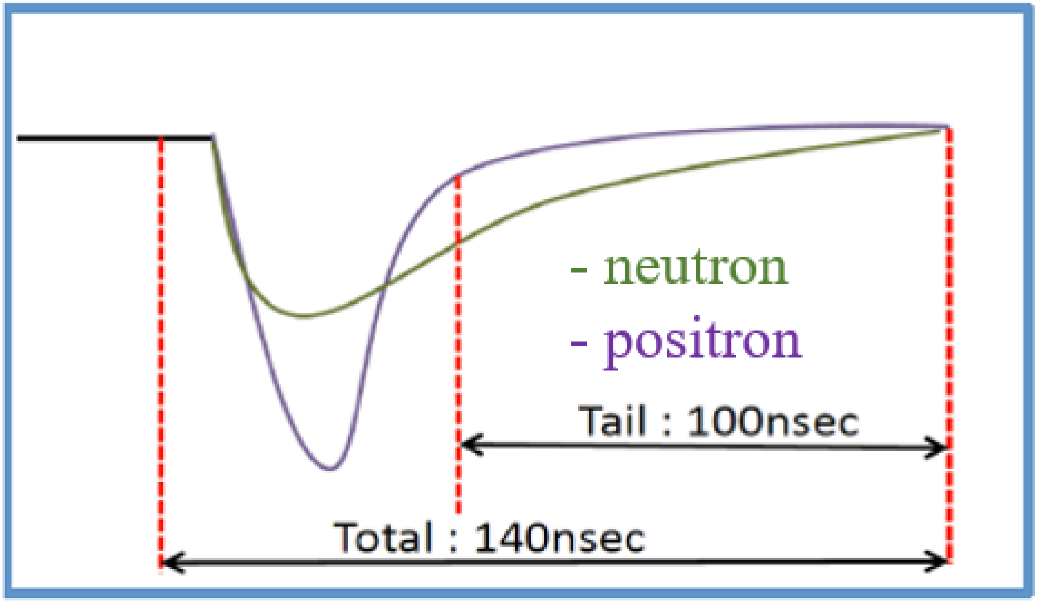
Pulse shape discrimination

Pulse Shape Discrimination (PSD)

- Fast neutrons can mimic IBD signals from electron anti-neutrino.
  - correlated background
  - difficult to remove from IBD signals

- PSD can separate the IBD signals and fast neutrons.

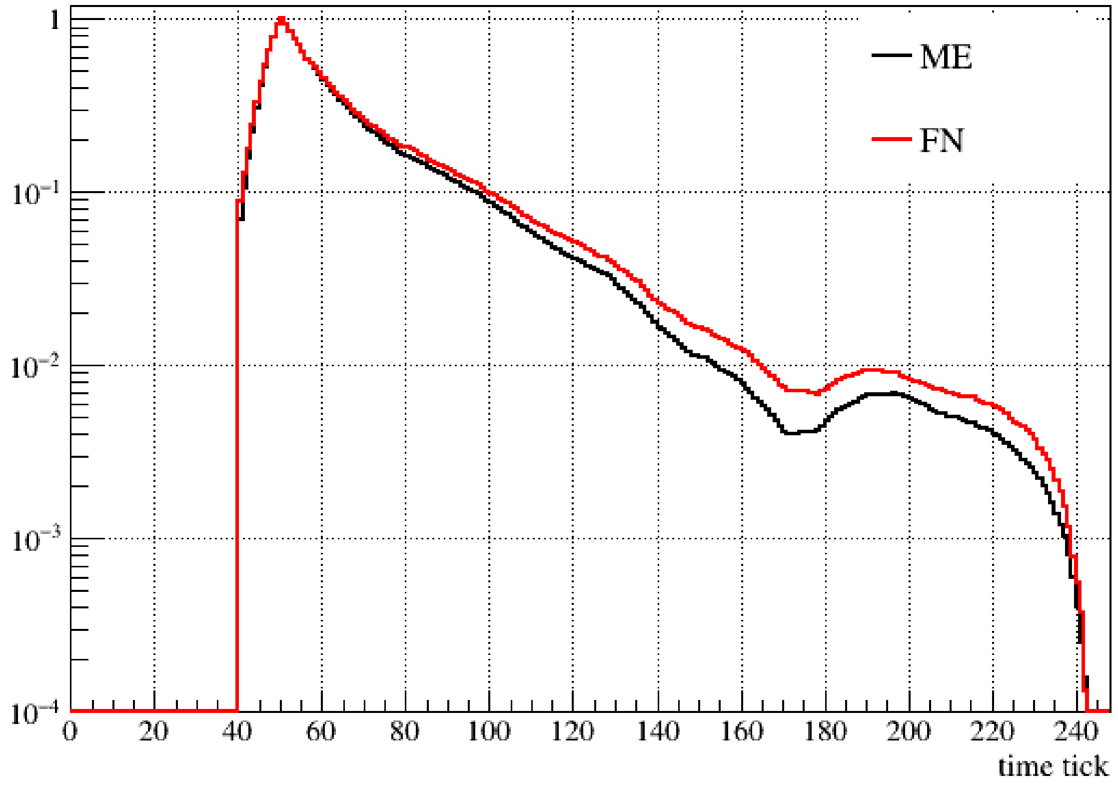




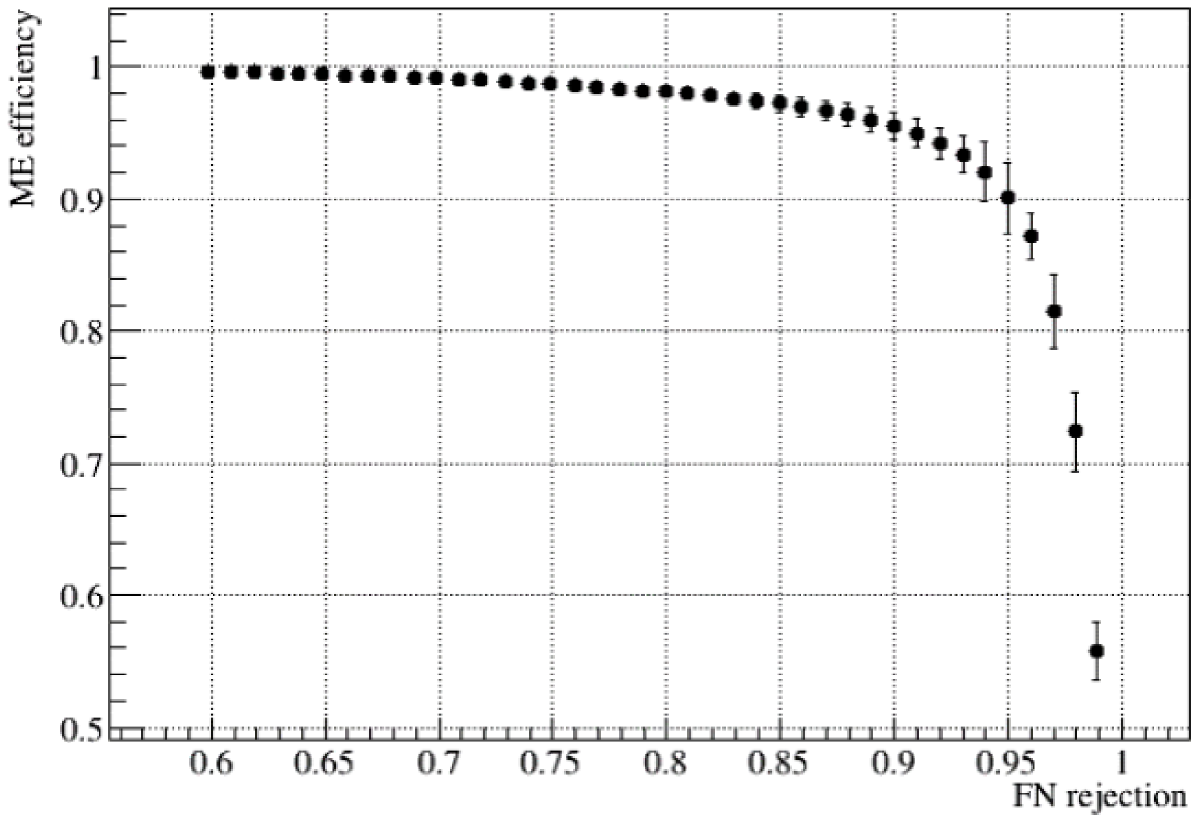
- A log-likelihood method has been developed to improve the PSD performance.

- The full information of waveform height are used for the PSD.
  - control sample : Michel electron (ME) and fast neutron (FN)
  - each PMT has its own PDF and separation power

average waveform (one PMT)



PSD capability



CNgs measurement

CNgs measurement

- No π or K production rates measurements with Hg - p (3GeV) reaction so far.
- **Provides a normalization of IBD signals**.

CNgs — IBD/Sterile

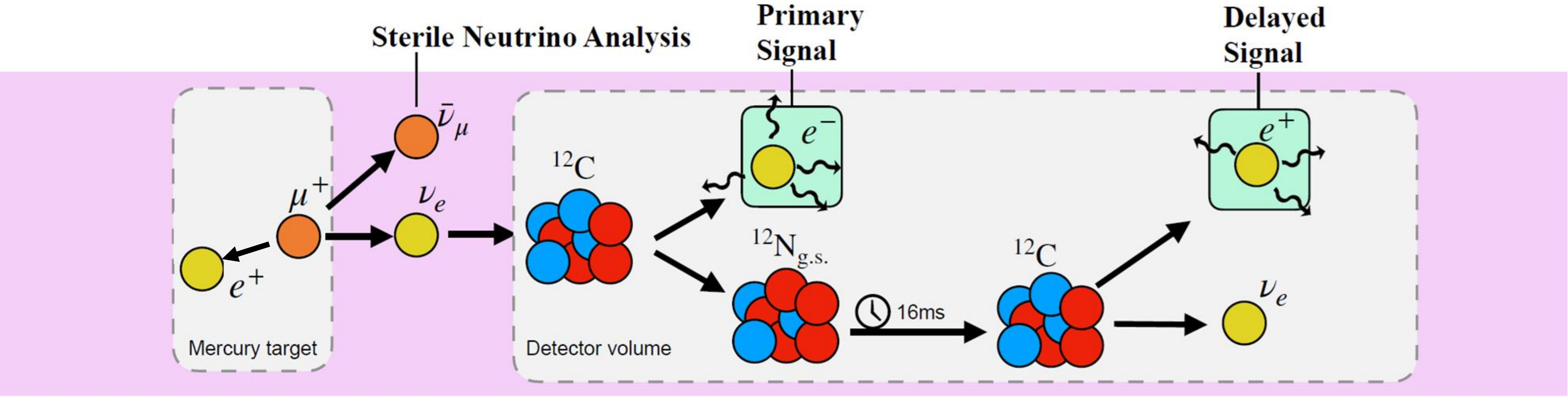
$$\mu^+ \rightarrow e^+ + \boxed{\nu_e} + \boxed{\bar{\nu}_\mu}$$

prompt

$$^{12}C + \nu_e \rightarrow {}^{12}N_{g.s.} + \boxed{e^-}$$

$$^{12}N_{g.s.} \rightarrow {}^{12}C + \nu_e + \boxed{e^+}$$

delayed



Observed events

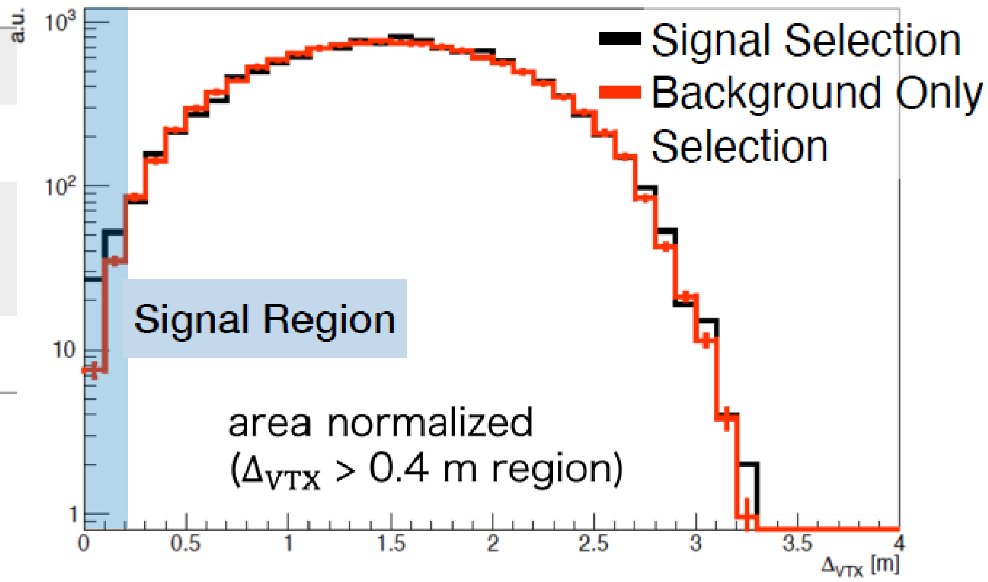
CNgs candidate

： 79 events

Background rate

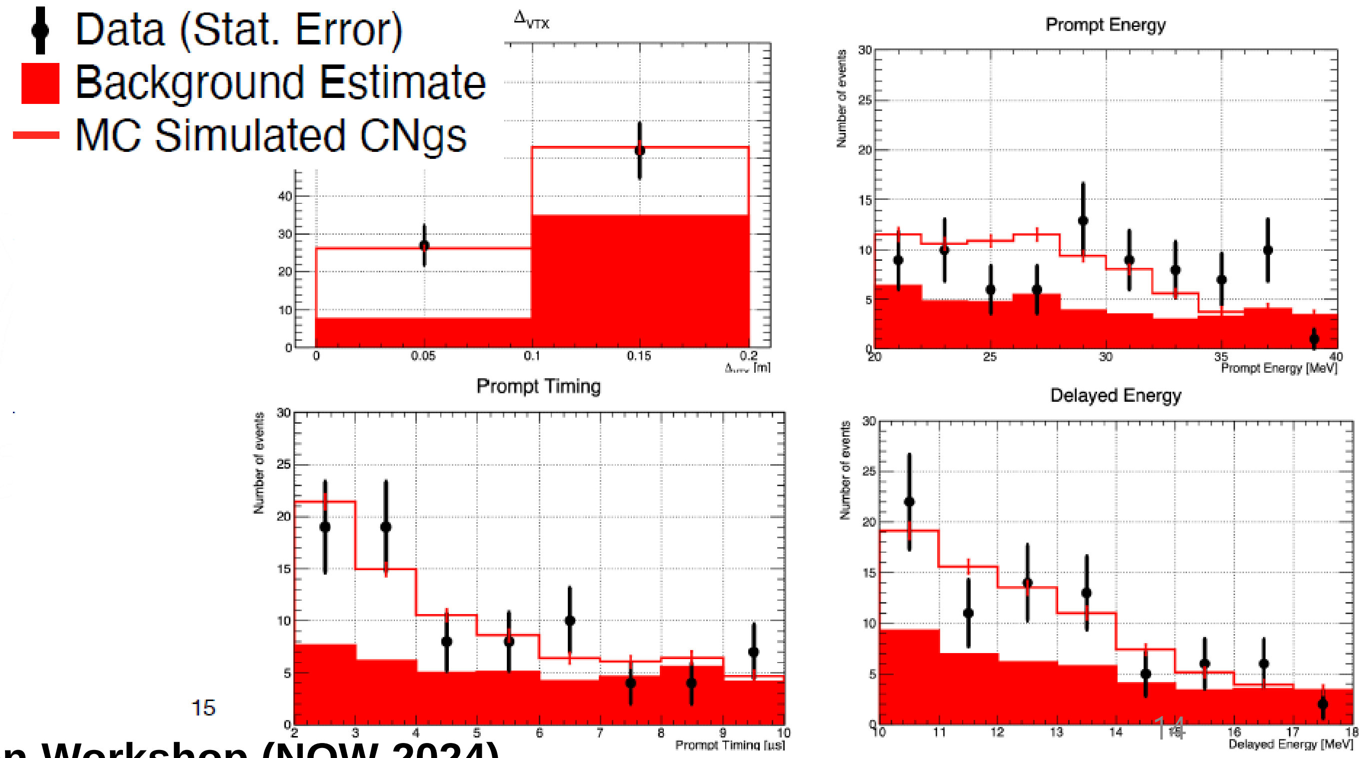
： $42.2 \pm 6.5(\mathrm{stat.}) \pm 1.7(\mathrm{syst.})$

Event selection
$20 < E_p < 40$ MeV
$10 < E_d < 18$ MeV
$0.2 < \Delta t <$ 12ms (2021) 25ms (2022)
$\Delta VTX <$ 20cm

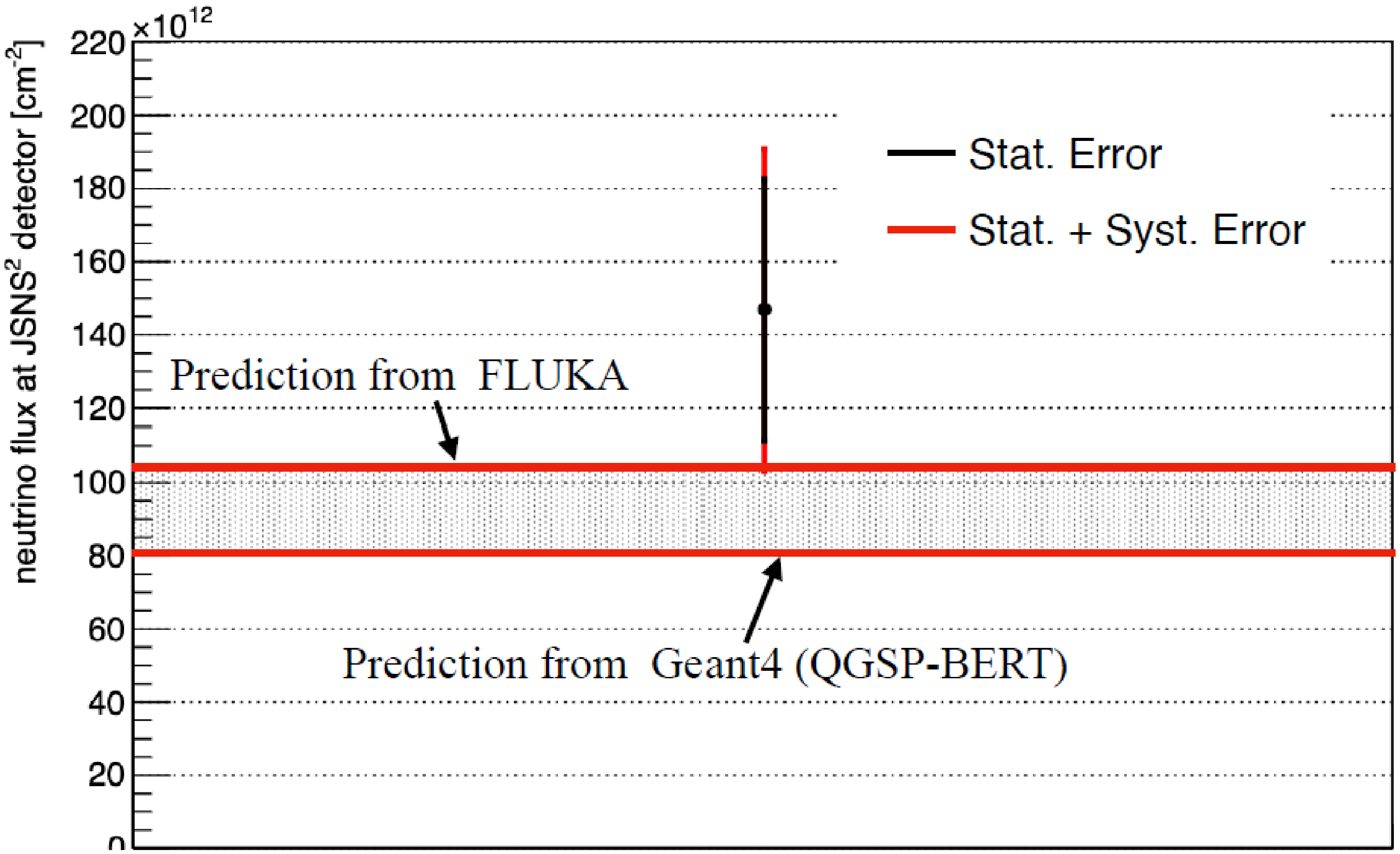


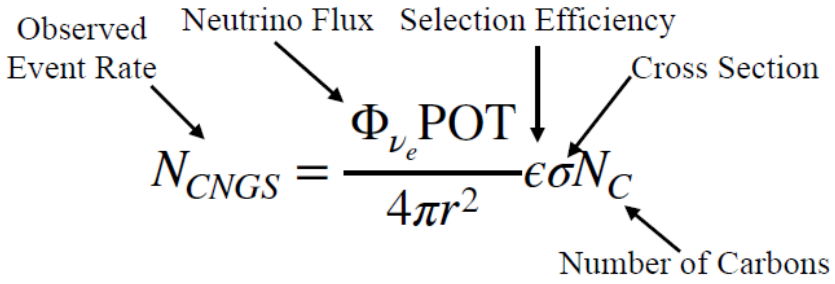
- The accidental event is dominant background.
  - estimated by normalization from high ΔVTX region

- All distributions for selected variables seem to be reasonable.



CNgs results





$$N_{CNGS} = \frac{\Phi_{\nu_e} POT}{4\pi r^2} \epsilon \sigma N_C$$

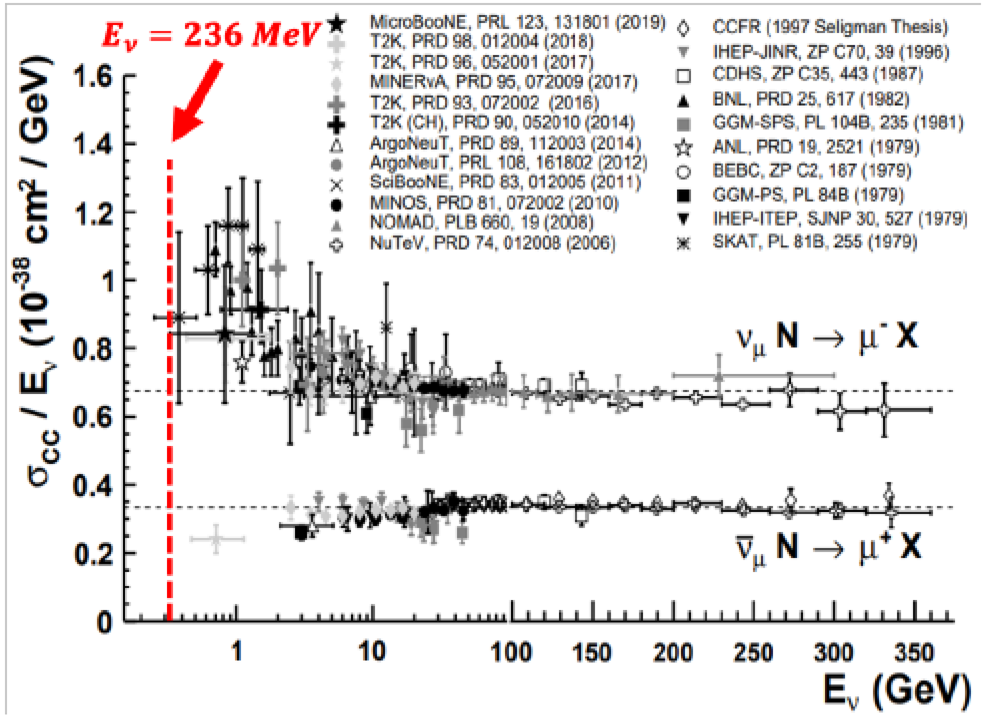
- Detection efficiency
  - 0.0588 ± 0.0021
- Cross section
  - LSND + KARMEN
  - $9.1 \pm 0.7 \times 10^{-42} \mathrm{cm}^2$
- Statistical error is dominated

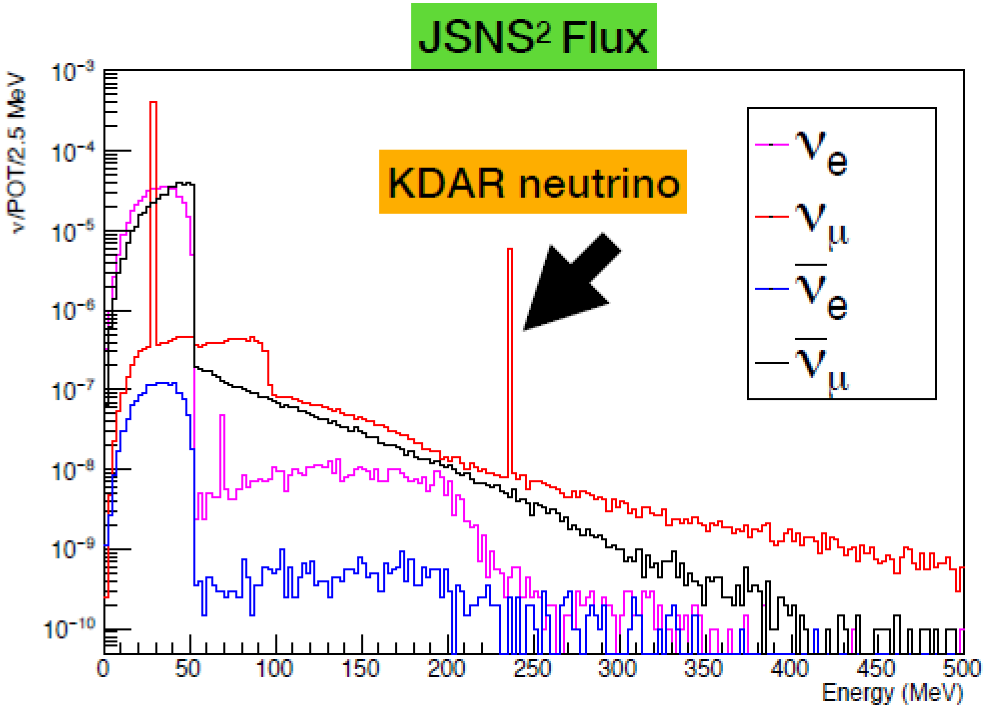
KDAR neutrino measurement

Kaon Decay-At-Rest neutrino measurement

(KDAR neutrino: 236 MeV mono-energetic)

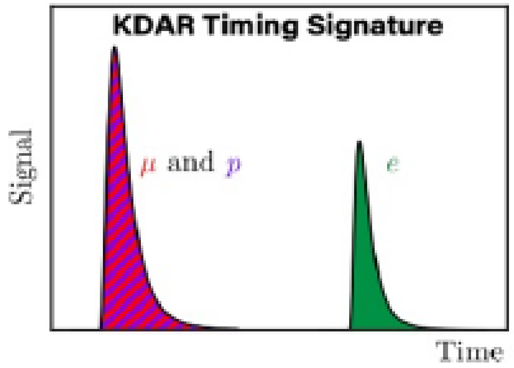
- A few cross-section measurements at low energies.
- **The mono-energetic KDAR neutrino events in the JSNS^2 detector**
- Nuclear effects in mono-energetic neutrino interactions on carbon

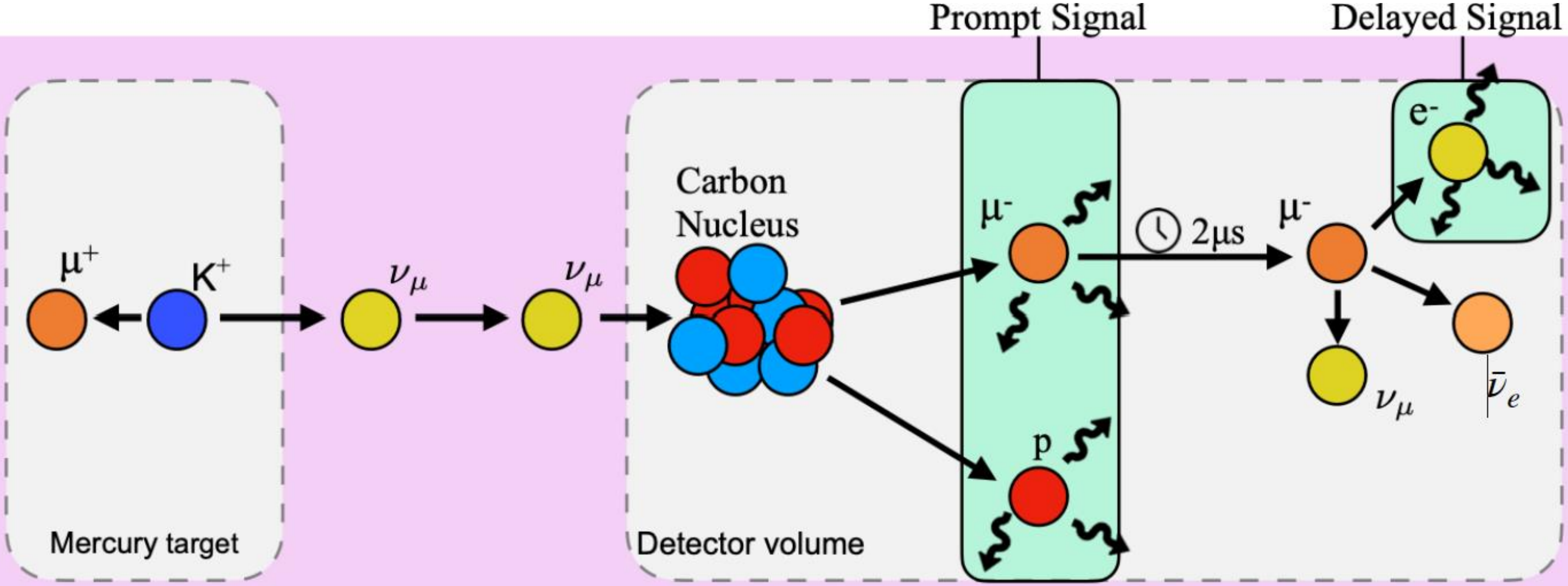




KDAR signal measurement

- A double coincidence
  - prompt : muon and proton
  - delayed :electron from muon decay



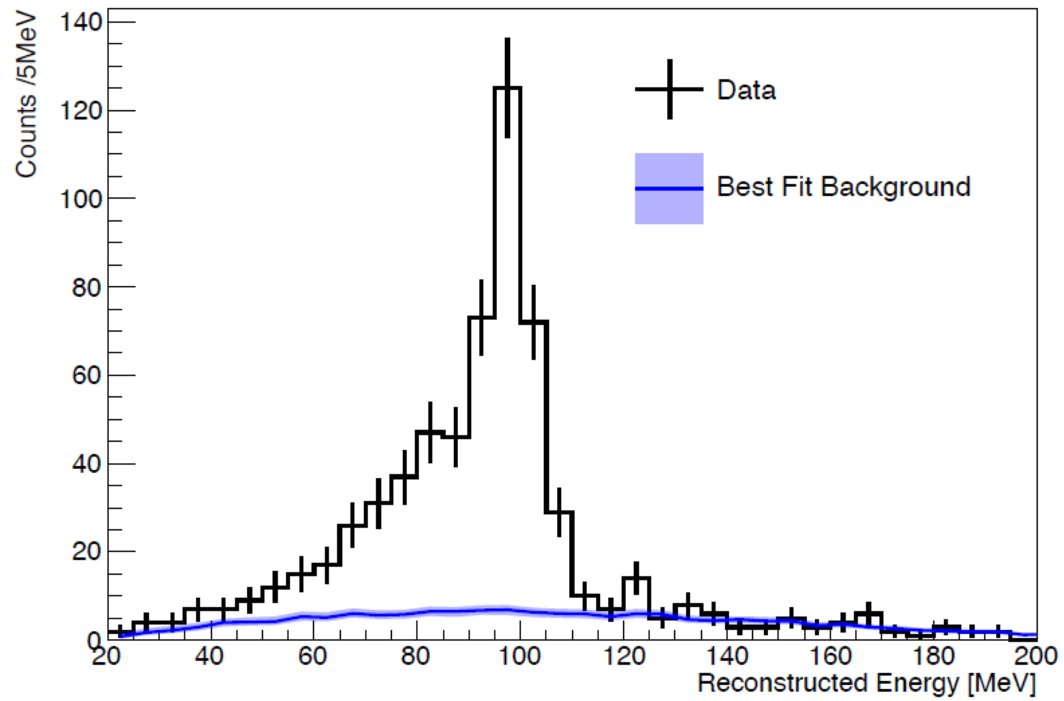


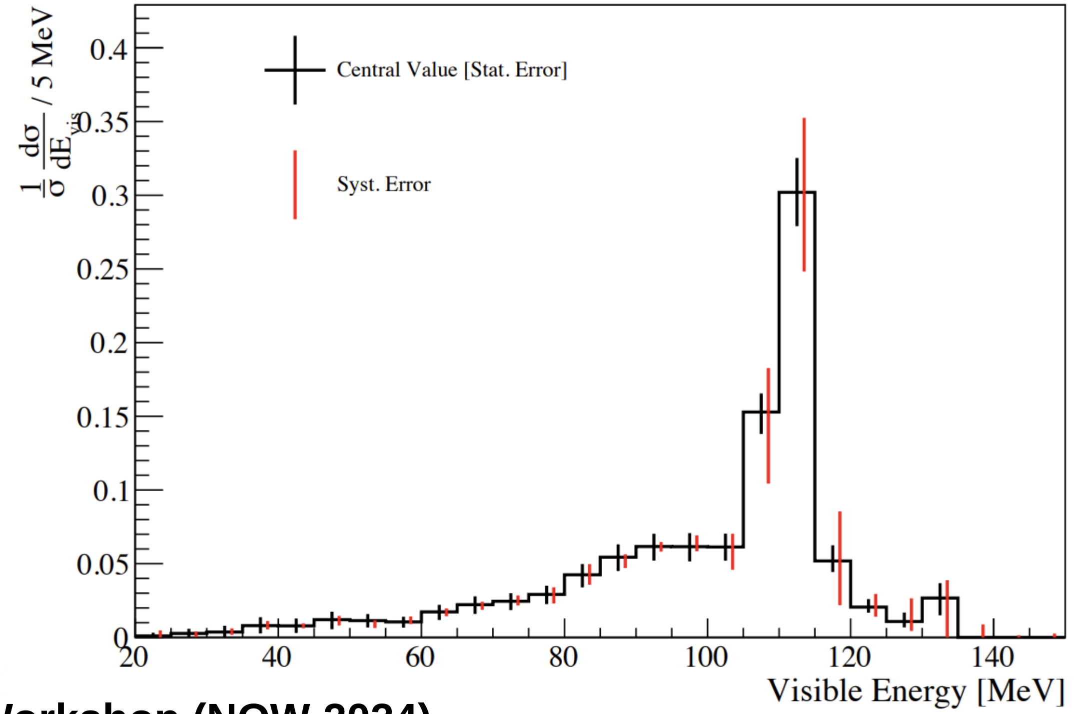
KDAR Results (shape only measurement)

- KDAR candidates : 621 events

- True visible energy was estimated with Iterative Bayes (D' Agostini) unfolding
  - provide better understanding of the low energy interaction

	Prompt	Delayed
Energy	20-150 MeV	20-60 MeV
Timing	2x150ns Beam centered windows	Δt < 10μs
Position	Fiducial Volume: R<1400mm -1000mm < z < 500mm	ΔVertex< 300mm

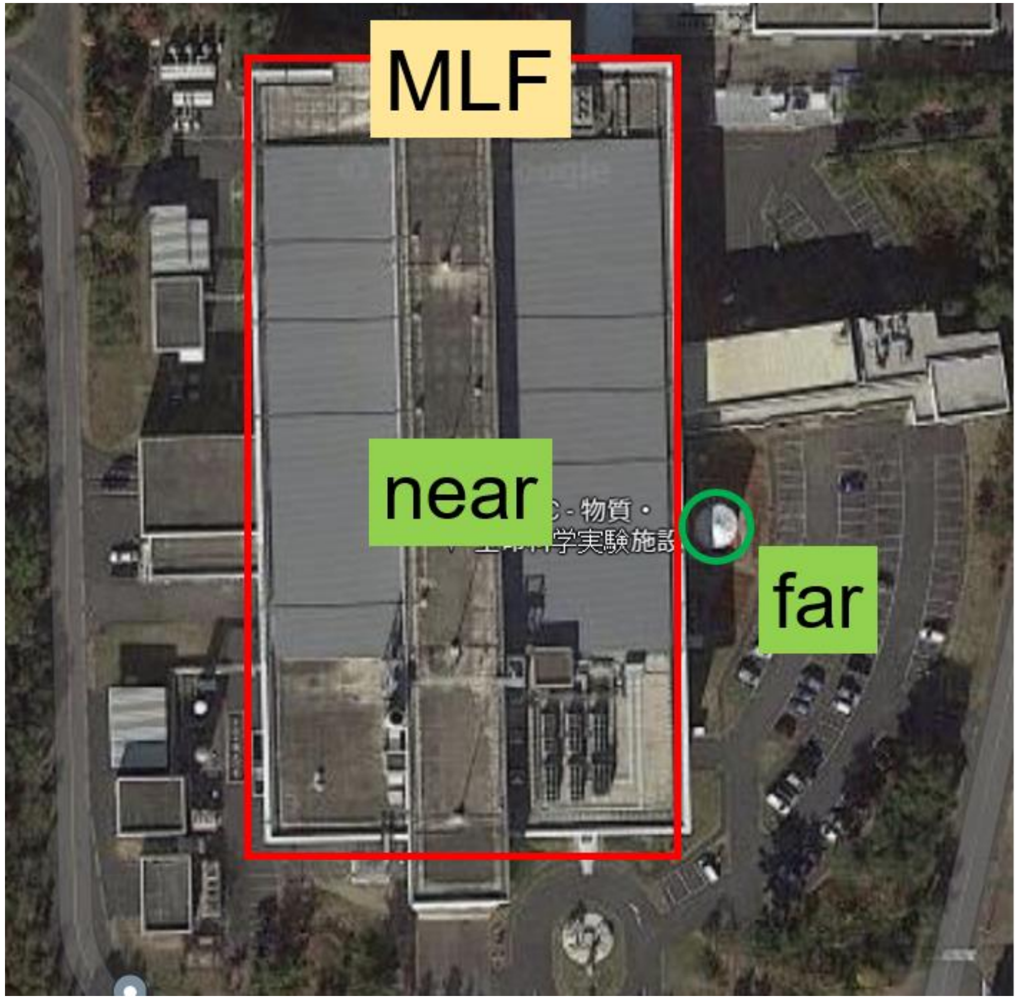




JSNS^2-II

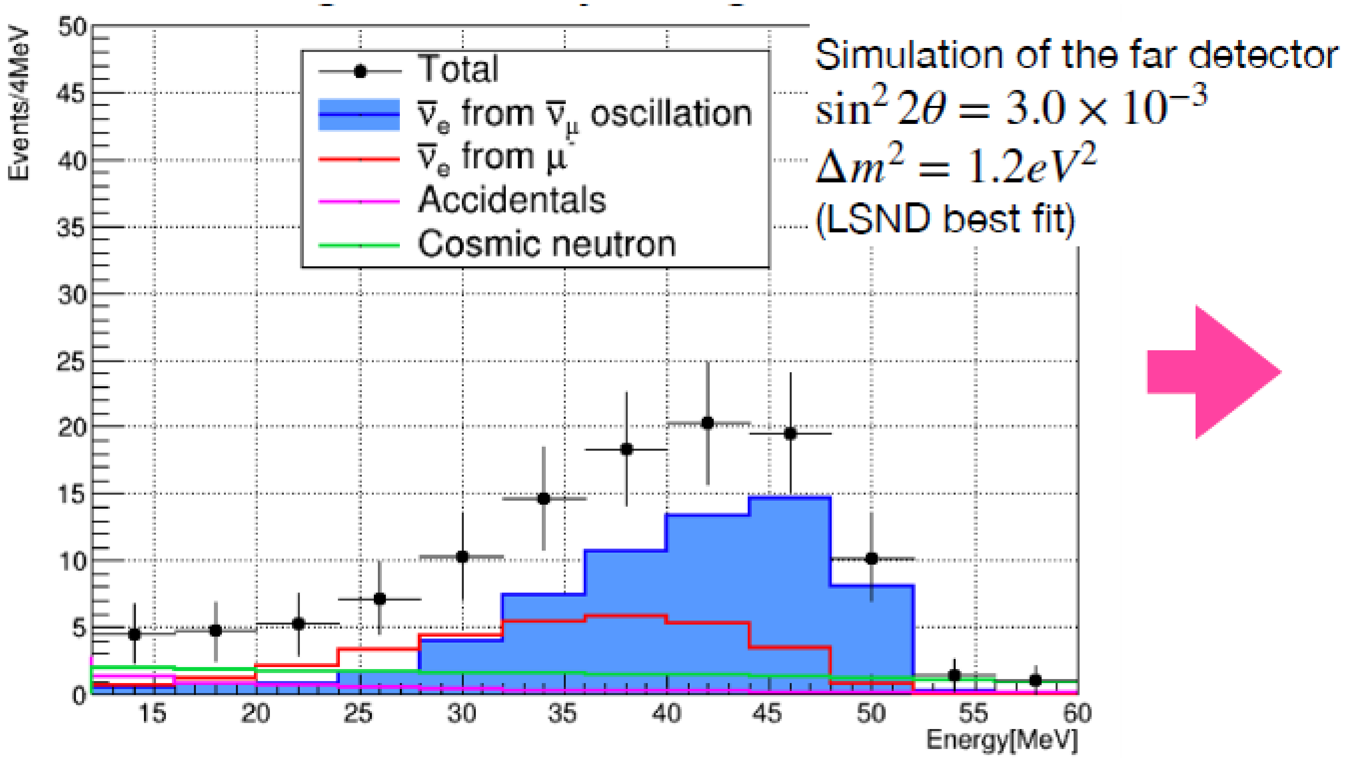
JSNS^2-II (Second phase of JSNS^2)

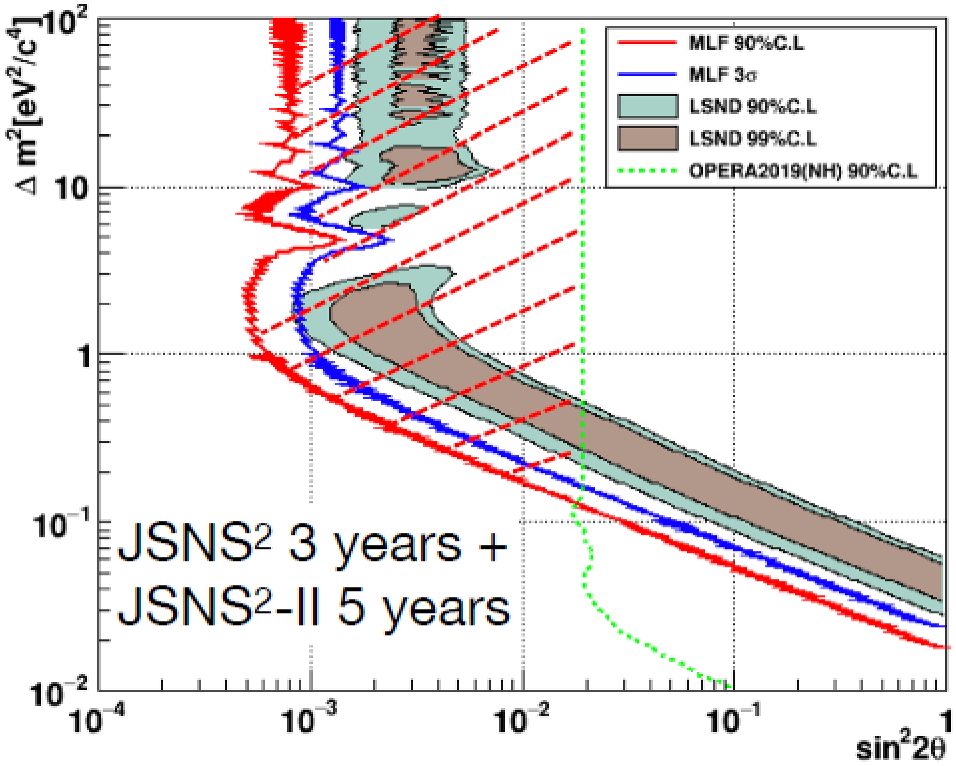
- New far detector
  - Almost identical to the near detector
  - fiducial 32 tonnes and 48 m location
- Two detectors with two different baseline
  - a solid conclusion on LSND anomaly
- The final phase of the detector construction



Sensitivity of JSNS^2-II

- Each background simulation was done based on the JSNS^2 data.
- The sensitivity becomes better in the low Δm^2 region.



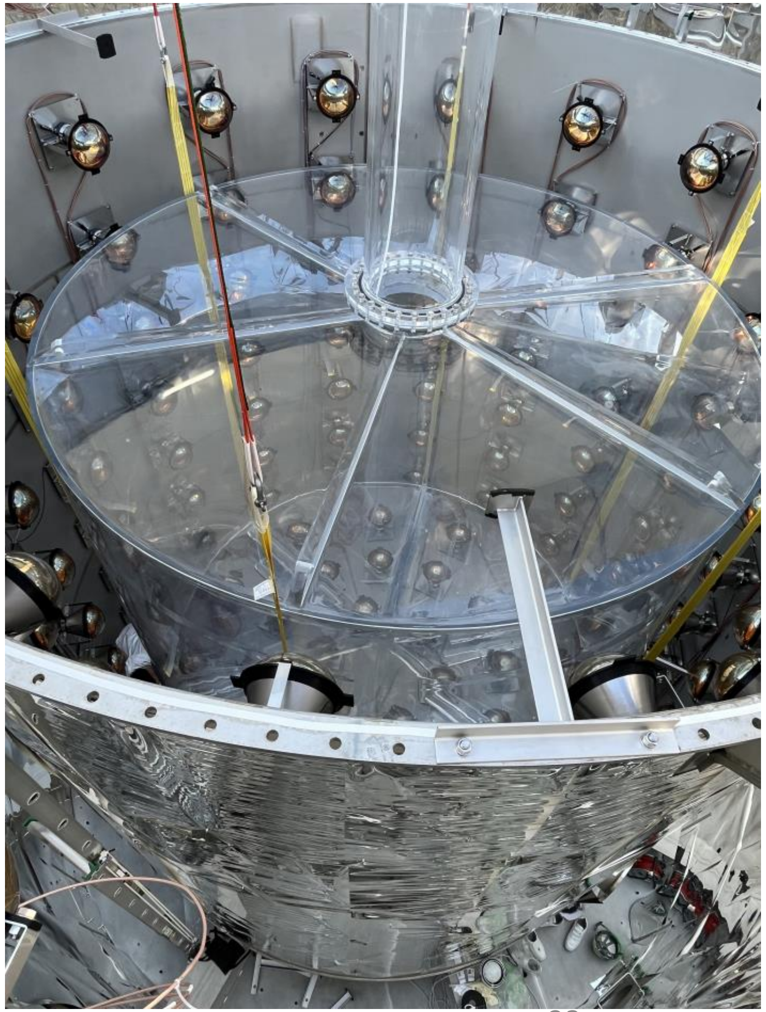


Detector construction (1)

SUS tank
(Mar. 2022)

PMT install (inner tank)
(Aug. 2023)

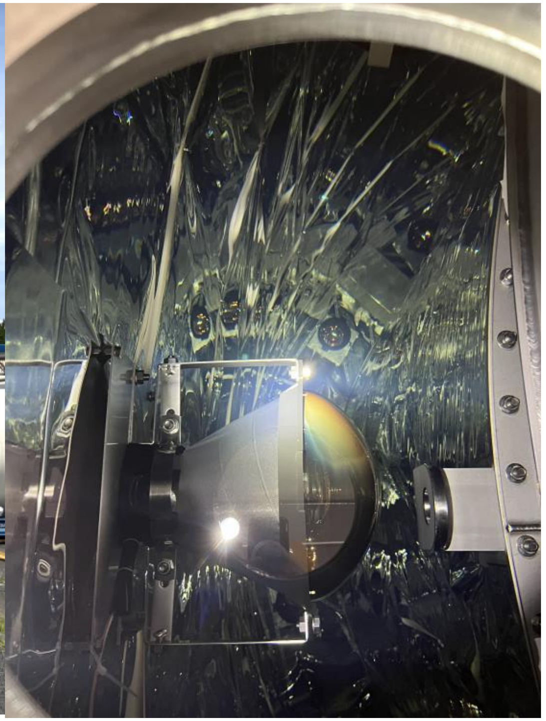
Acrylic vessel
(Feb. 2024)



Detector construction (2)

PMT install (veto)
(Apr. 2024)

LS filling
(Aug. 2024)



- We will have an LED test soon.

Summary

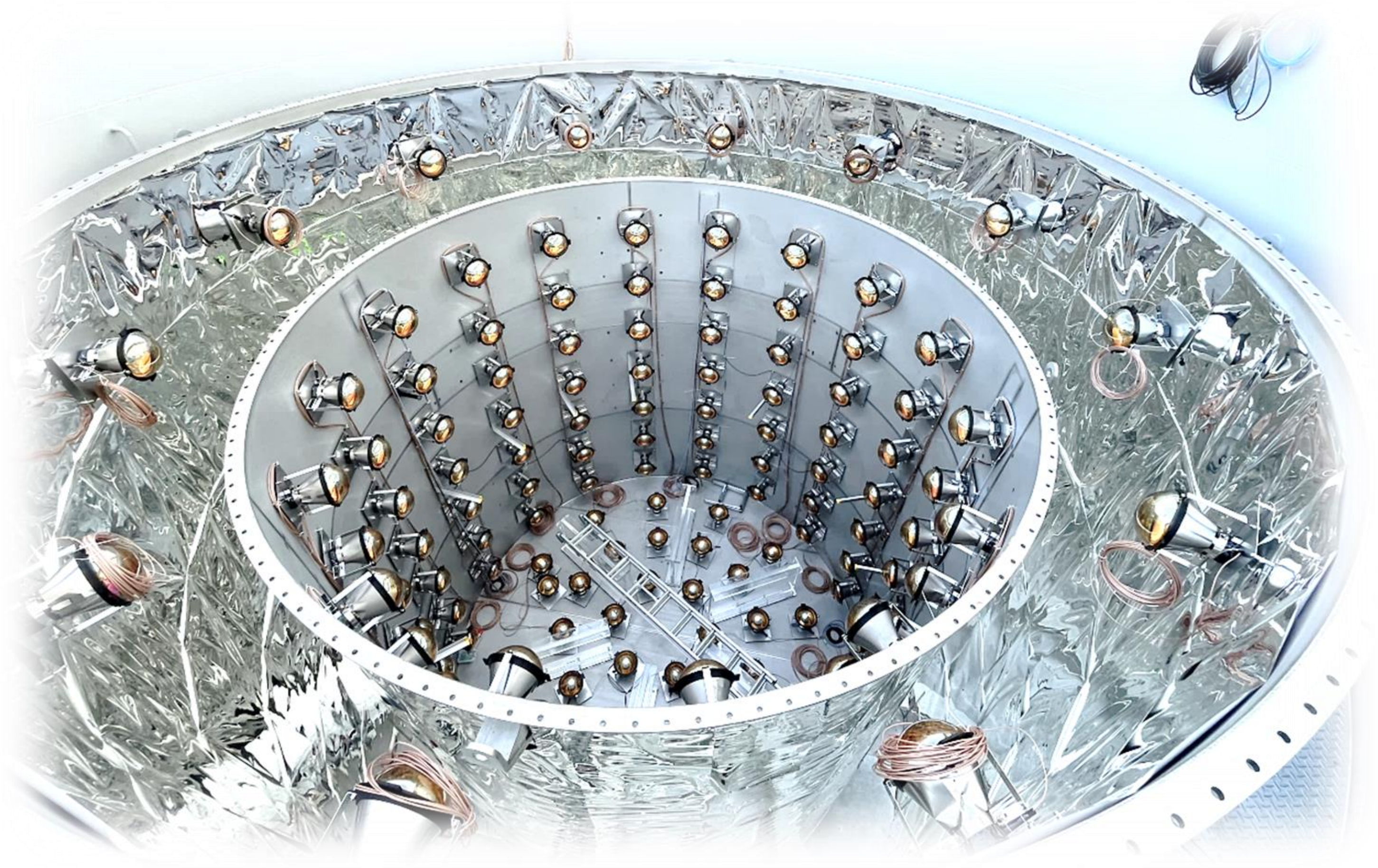
- There have been four long physics runs (2021~2024) in JSNS^2.

- The analysis for the sterile neutrino search is ongoing.

- We obtained other physics results
  - CNgs measurement
  - KDAR measurement (shape only)
  - Detector is working well!

- We are facing the final phase of detector construction of JSNS^2-II

Thank you for your attention



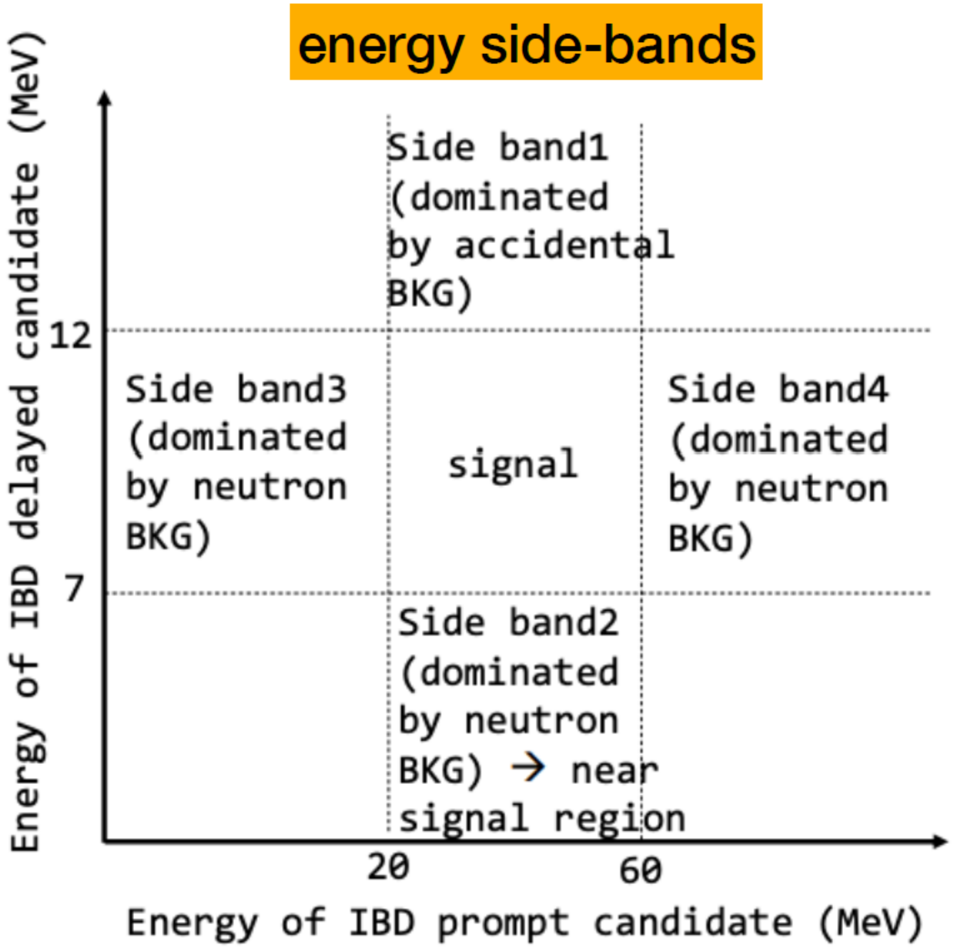
acknowledgements:
- MEXT, JSPS (Japan)
- Korea Ministry of Science, NRF (Korea)
- DOE, Heising-Simons Foundataion (US)
- Royal Society (UK)

Backup

Blind analysis

Blind analysis for sterile neutrino search

- Energy side-bands should be understood before opening the signal region.
- The rates in the side-band regions will be predicted by the control samples driven by data



Side-band #4

$$60 < E_{prompt} < 100\ MeV$$
$$7 < E_{delayed} < 12\ MeV$$

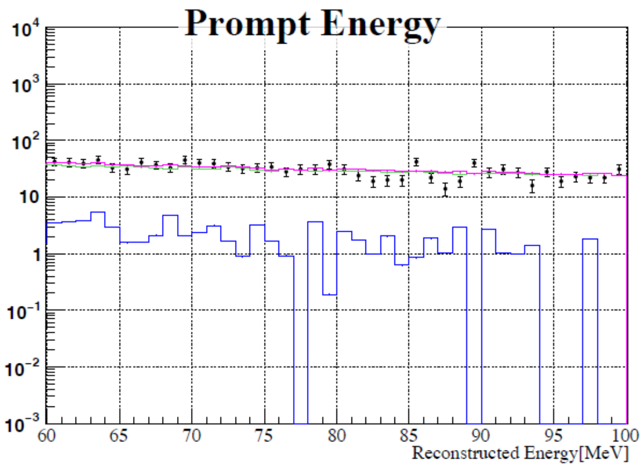
	Observed	Estimated
Accidentals	-	71.6±1.2
Fast Neutrons	-	1178±4.4
Total	1224±35.0	1250±4.6

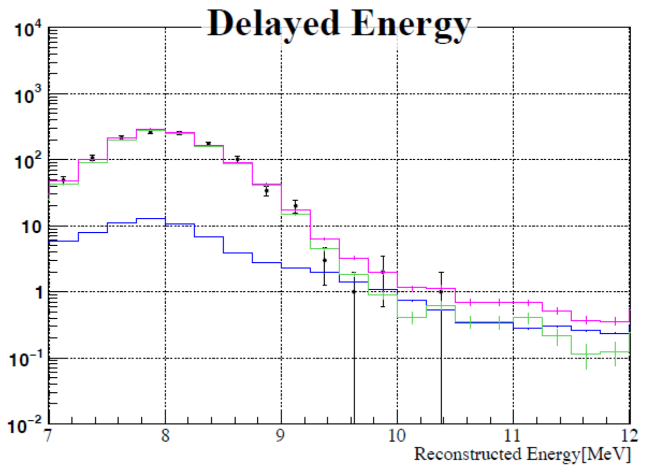
- All background estimates are data driven

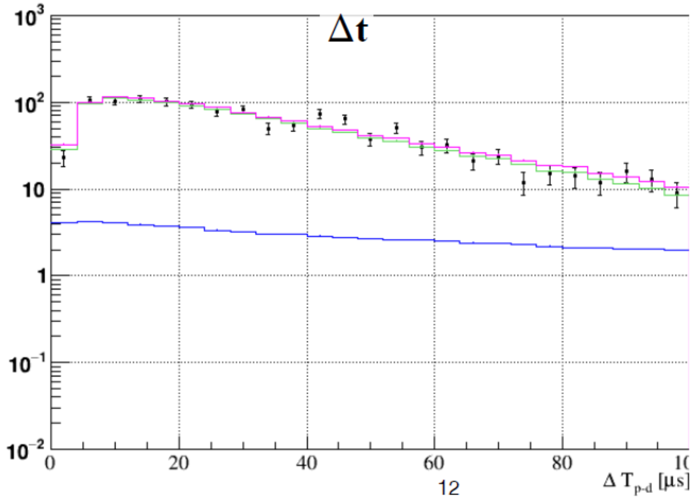
- Accidental rates are estimated via “spill-shift” method
  - Prompt-delayed pairs from different beam spills

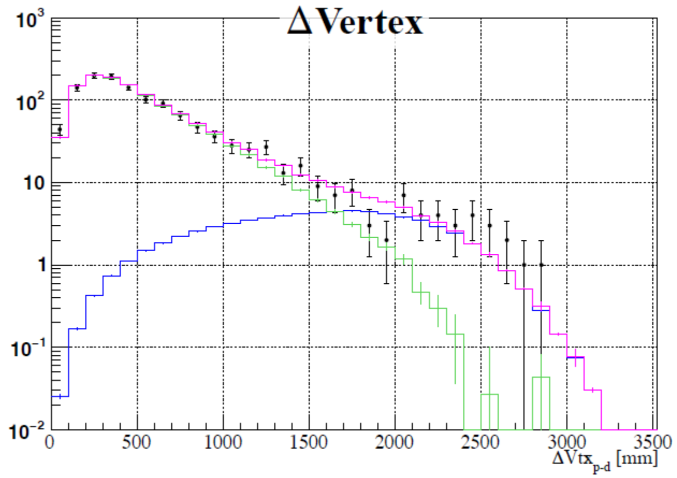
- Cosmic fast neutron rate is estimated by looking in late time window (>1ms after beam)

- Observed data is consistent with estimation









12

New far detector

- Almost identical to the existing near detector
  - 37m^3 Gd-LS for the neutrino target
  - 150m^3 no Gd-loaded LS for the veto and gamma catcher.
  - 228 PMTs will be used

- The detector is placed outside of building
  ➔ Electronics in the “roof space”