

Status of the JSNS^2-I / II

ChangDong Shin (DSU)
On behalf of the JSNS^2 I / II collaboration

JSNS^2 / JSNS^2-II Collaboration

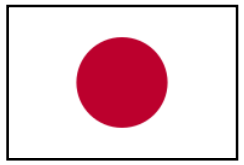
(J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source)

Collaboration meeting @ J-PARC (2026/Feb)



JSNS^2 / JSNS^2-II
Collaboration (58 collaborators)

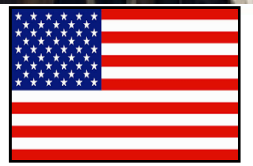
- 7 Japanese institutions (25 members)
- 9 Korean institutions (24 members)
- 3 US institutions (5 members)
- 1 Chinese institutions (3 members)



JAEA
KEK
Kitasato
Kyoto
Osaka
Tohoku
Tsukuba



Chonnam National
Dongshin
GIST
Jeonbuk National
Kyungbook National
Kyung Hee
Seoyeong
Soongsil
Sungkyunkwan
Seoul National of
sci and tech



BNL
Michigan
Utah



Sun Yay-sen
(Zhongshan)

Spokesperson : T. Maruyama (KEK, Japan)
Co-spokesperson : M. Y. Pac (DSU, Korea)

Neutrino anomalies

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

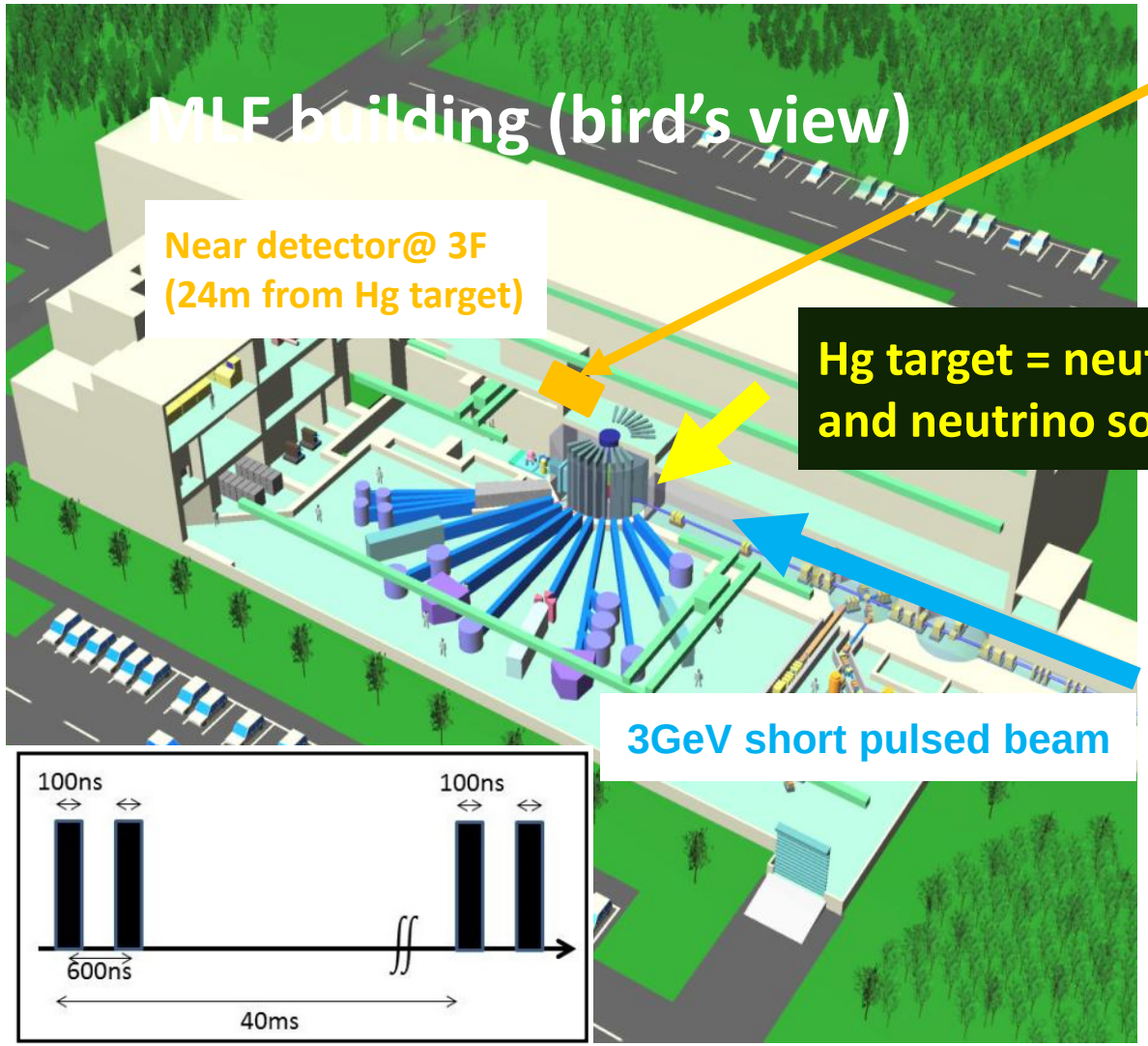
Experiments	Neutrino source	Signal	Significance	E(MeV)	L(m)
LSND	μ Decay-At-Rest	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.8σ	40	30
MiniBooNE	π Decay-In-Flight	$\nu_\mu \rightarrow \nu_e$	4.7σ	800	600
		$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$			
BEST	e capture	$\nu_e \rightarrow \nu_x$	4.2σ	<3	10
Reactors	Beta decay	$\bar{\nu}_e \rightarrow \bar{\nu}_x$	3.0σ	3	10-100

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

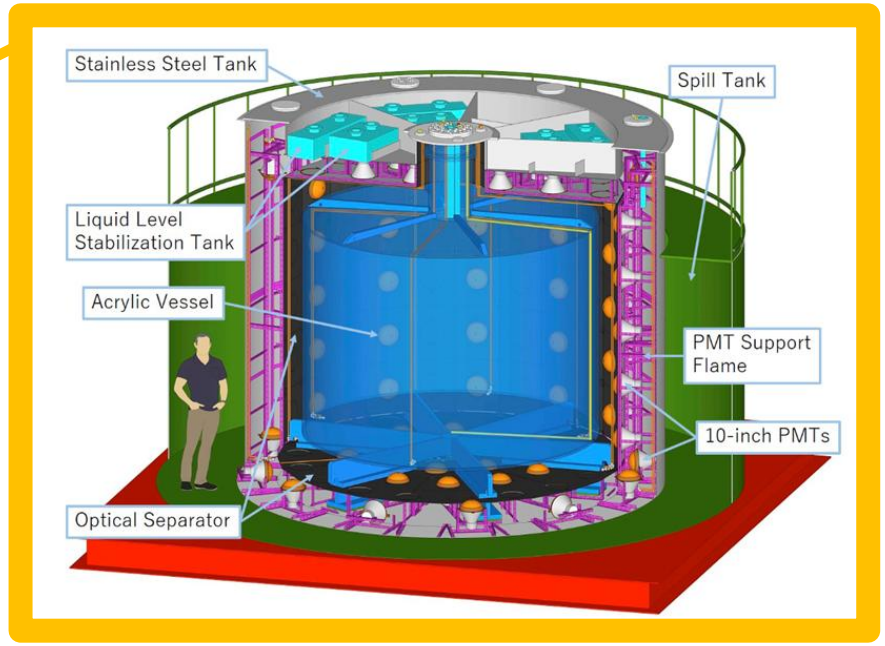
  - two advantages : short-pulsed beam and used the gadolinium(Gd)-loaded liquid scintillator(GdLS)
  - Two different baselines can provide a test of the LSND anomaly regardless of the oscillation.

JSNS² detector (Near)

Nucl. Instrum. Methods A 1014 165742 (2021)



Short pulse and small repetition rate

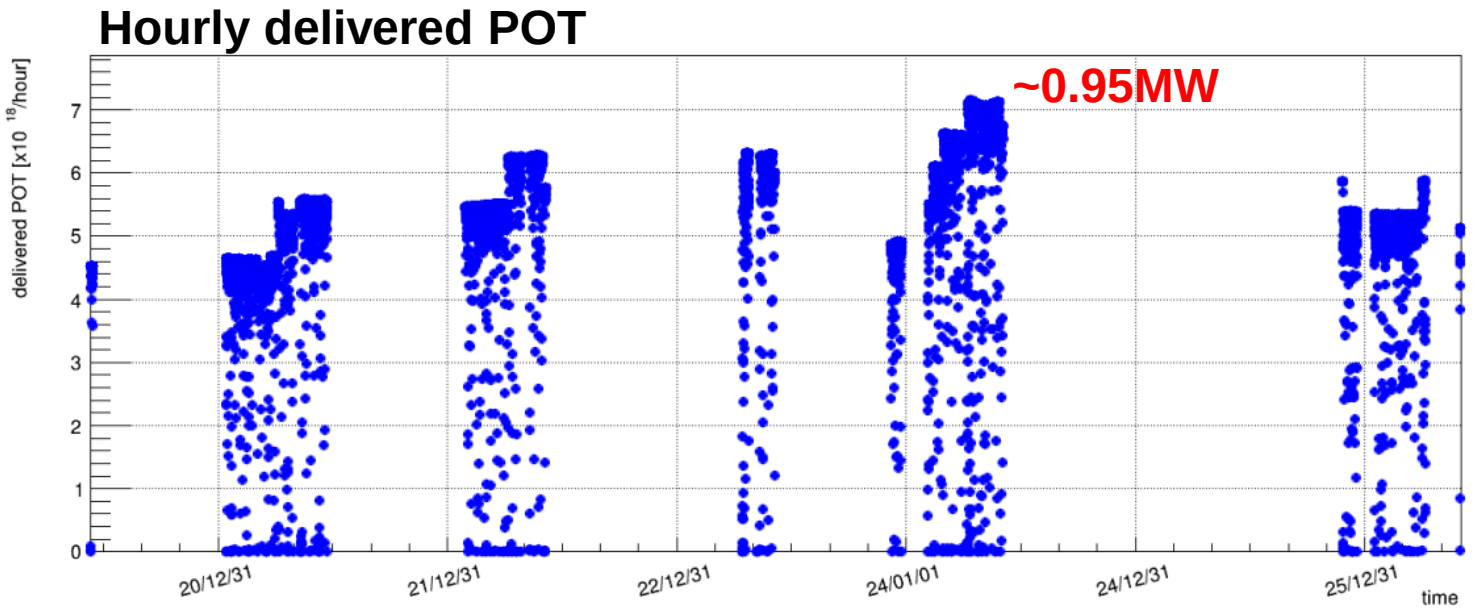


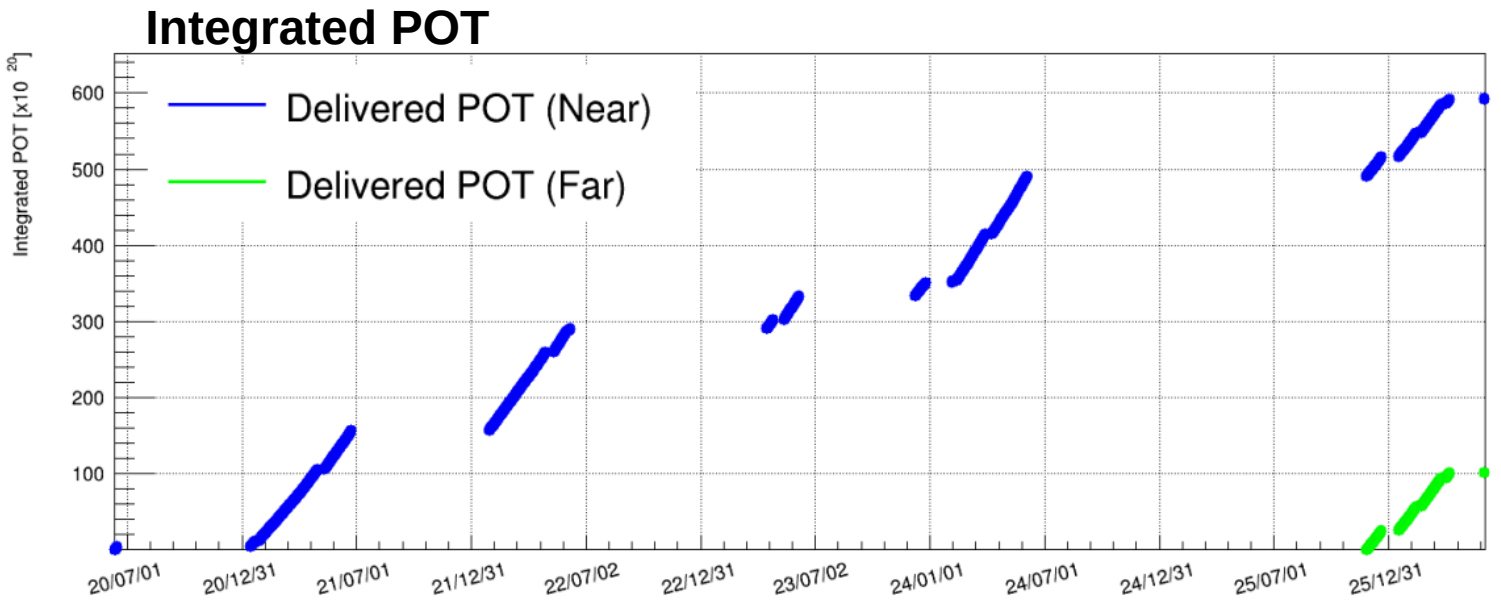
	Liquid	Volume
Target	GdLS + DIN (10%)	17 tons
gamma-catcher and veto	Pure LS	31 tons

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

Operation

- 0.95 MW operation at MLF in 2024.
- 5.977×10^{22}POT has been delivered.
  → ~50% of approved POT of JSNS^2
- Some physics results based on partial data have already been published.
  → The analysis is ongoing with data from additional physics runs.



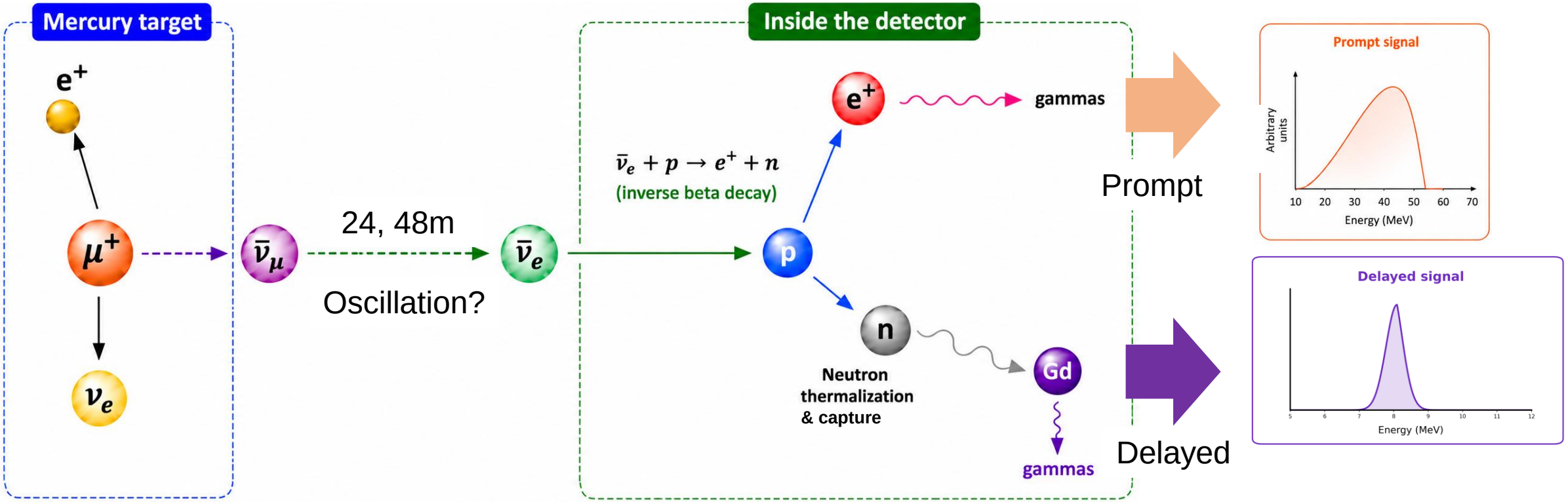


Detection principle

- If sterile ν exist, $\bar{\nu}_\mu$ → $\bar{\nu}_e$ oscillation occurs with 24m, 48m.

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

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

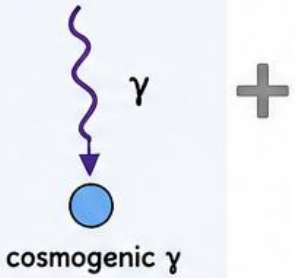


Background in JSNS²

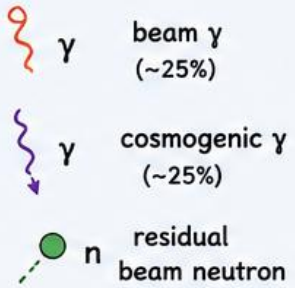
1 Accidental Background

Uncorrelated prompt–delayed coincidence

Prompt-like
(e^+-like)



Delayed-like
(n capture on Gd)



Suppression

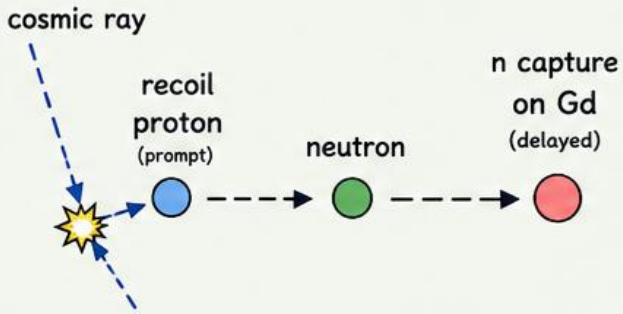
- Coincidence cut
- Likelihood (LLK) selection



≈ 95%
rejection

2 Cosmogenic Neutron Background

Dominant correlated background
Mimics IBD signature



Suppression

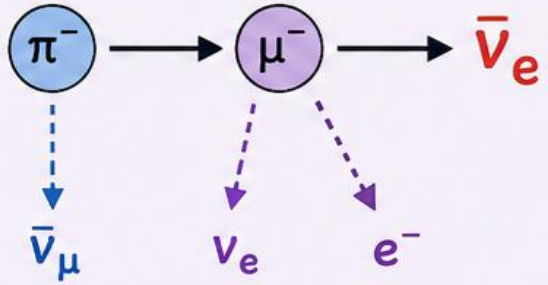
- Pulse Shape Discrimination (PSD)
- Likelihood (LLK) selection



>99%
reduction by PSD
+ few × by LLK

3 Beam-Intrinsic $\bar{\nu}_e$ Background

Produced in π^- / μ^- decay chain
Same IBD signature as signal



Treatment

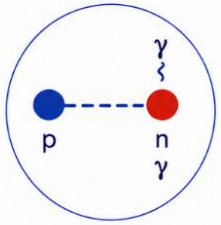
- Estimated by MC



Irreducible
Cannot be rejected
(event-by-event)

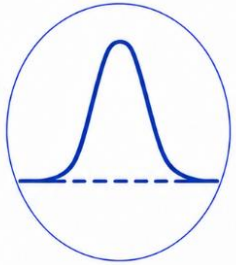
Analysis Framework

Background rejection



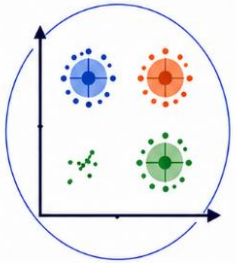
IBD coincidence

- Identify prompt-delayed coincidences
- Suppress random coincidences



Pulse Shape Discrimination

- Separate neutron-like from gamma-like events
- Reject neutron-induced backgrounds

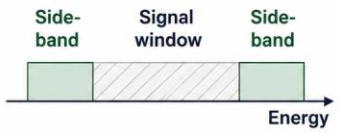


Likelihood

- Energy
- Timing
- Vertex

Physics Analysis

Blind Analysis



Side-band studies

- Use energy regions outside the signal window

Consistency

- Check data-MC agreement in side-band regions

Finalize analysis

- Develop and validate the analysis without accessing the signal window

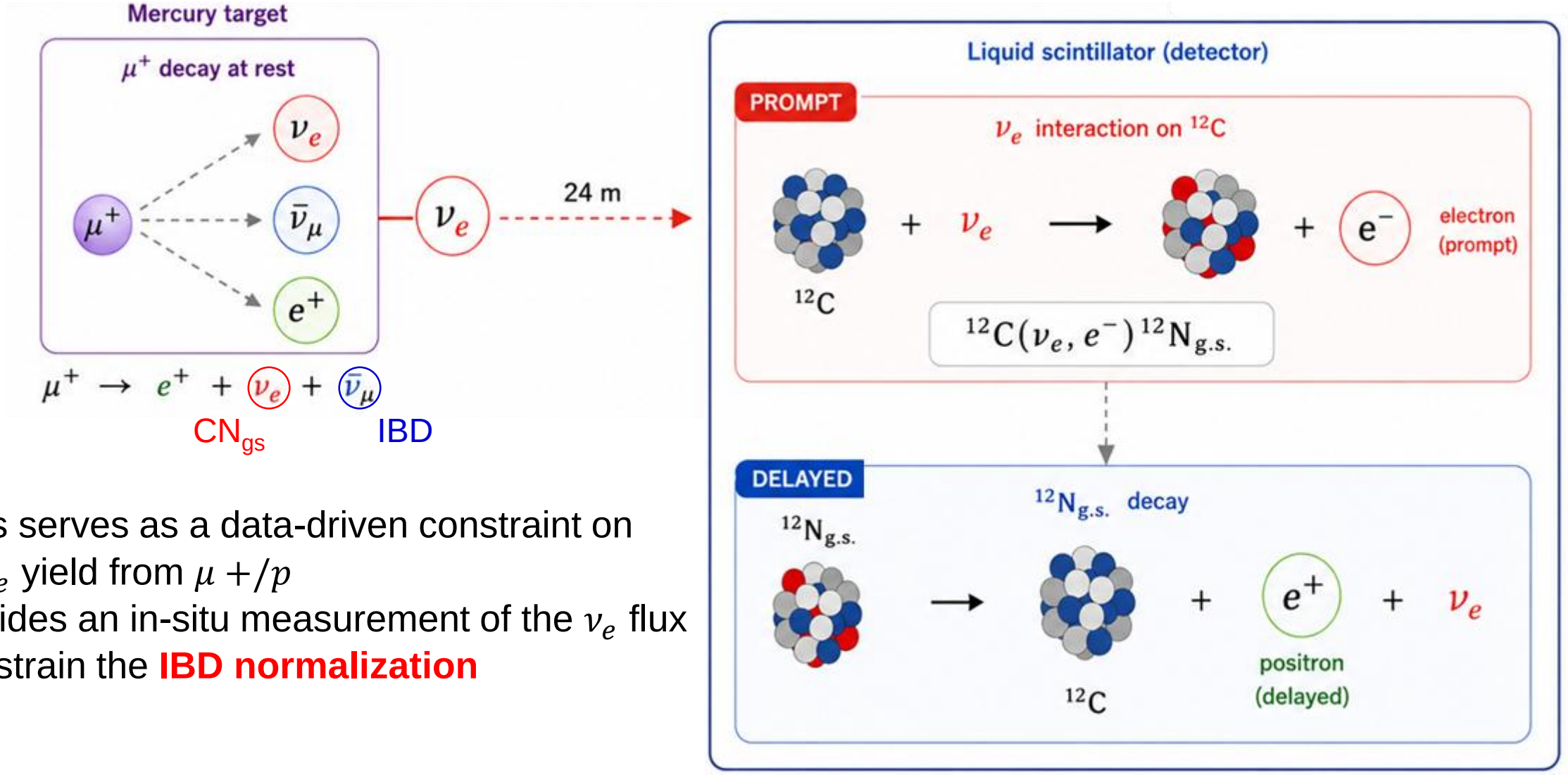
Neutrino Flux

$$^{12}C(\nu_e, e^-)^{12}N_{g.s.}$$

In-situ neutrino flux measurement

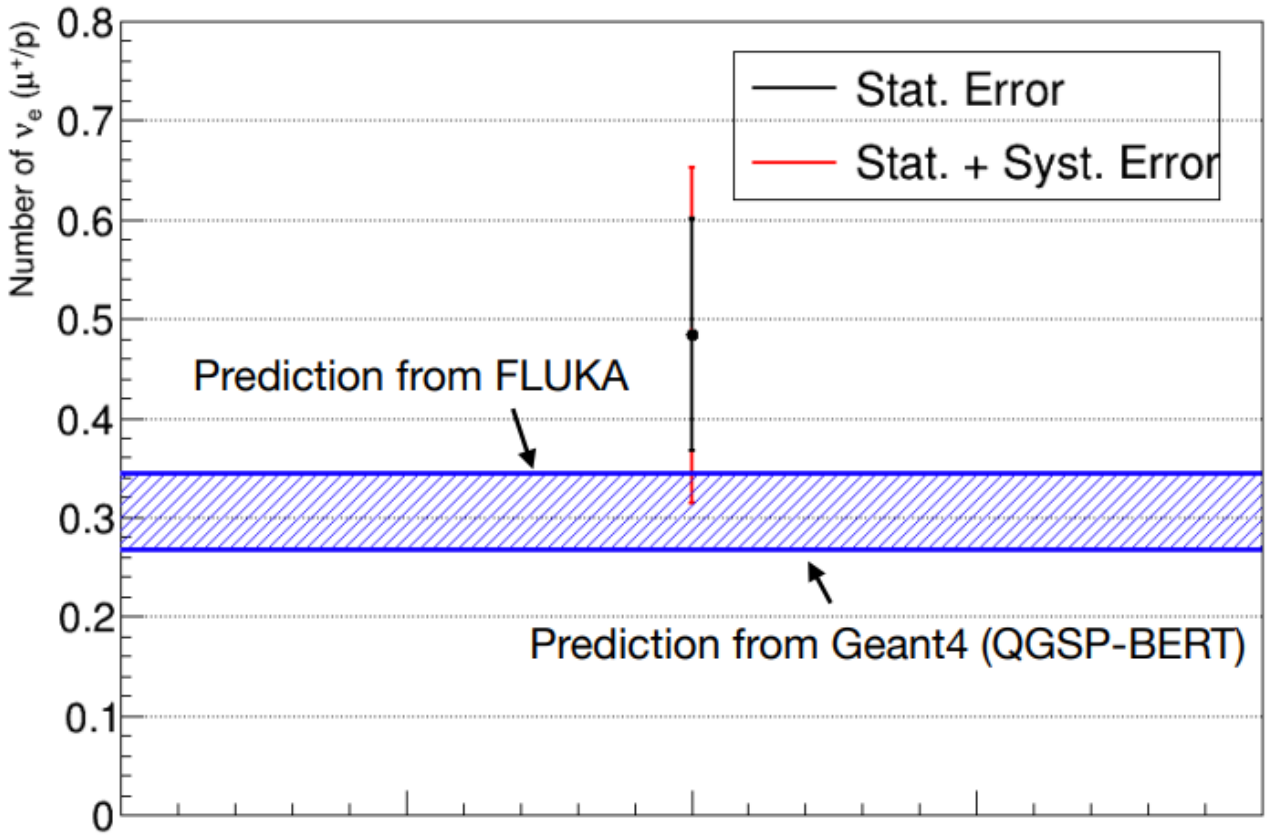
Constrain $\bar{\nu}_\mu$ flux uncertainty

$^{12}C(\nu_e, e^-)^{12}N_{g.s.}$ measurement



- CNgs serves as a data-driven constraint on the ν_e yield from $\mu+/p$
  - provides an in-situ measurement of the ν_e flux
  - Constrain the **IBD normalization**

$^{12}C(\nu_e, e^-)^{12}N_{g.s.}$ measurement



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

- Efficiency (ϵ) = 5.88±0.21%
- Cross section (σ) = $(9.1 \pm 0.7) \times 10^{-42}\ cm^2$ (LSND+KAREMEN)
- # of carbon (N_C) = $(4.68 \pm 0.94) \times 10^{29}$
- # of $\nu_e(\mu^+/p, \Phi_{\nu_e})$
  = **0.483 ± 0.117 (stat.) ± 0.123 (syst.)**
  (FLUKA : 0.344, QGSP-BERT : 0.268)

➡ **Direct input to the IBD normalization**

PHYSICAL REVIEW D **112**, 032012 (2025)

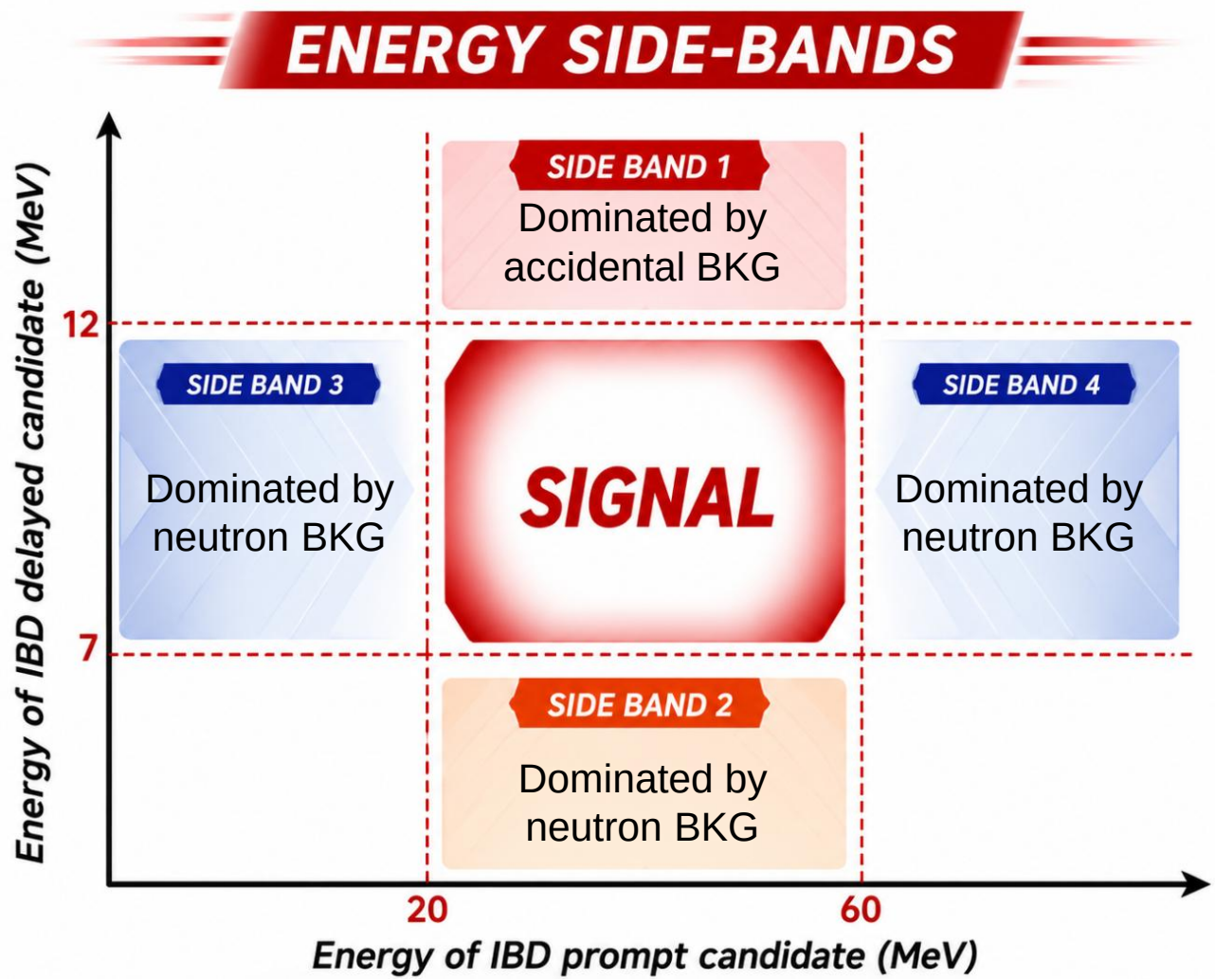
Energy side-bands

- Define energy side-bands

- Predict event rates from data-driven control samples
  - Fast neutron
    : T_{beam} > 1ms
  - Accidental background
    : dedicated calibration runs

- Validate PSD and likelihood methods

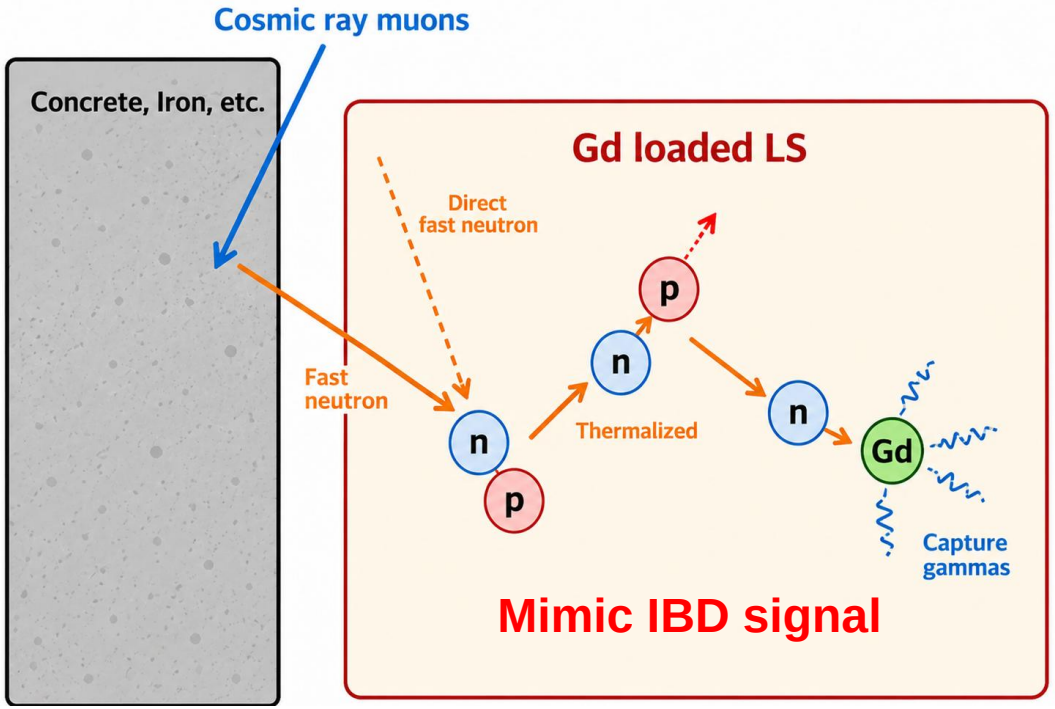
- Consistency between observation and expectation

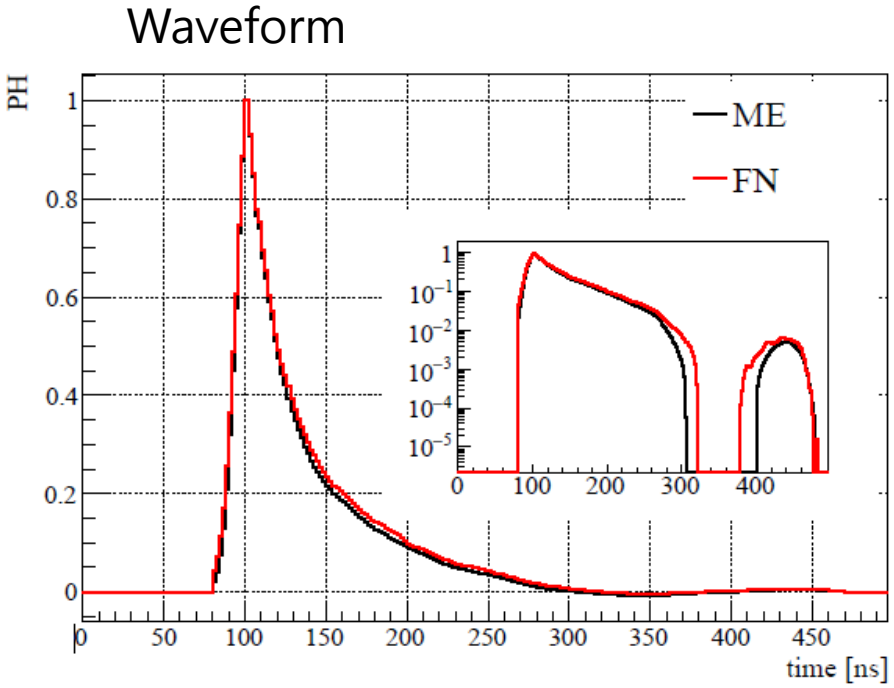


Pulse Shape Discrimination (PSD)

- Fast neutrons can mimic IBD events and are the dominant correlated backgrounds.

- Michel electrons (ME) and fast neutrons (FN) are used as control samples for PSD development.

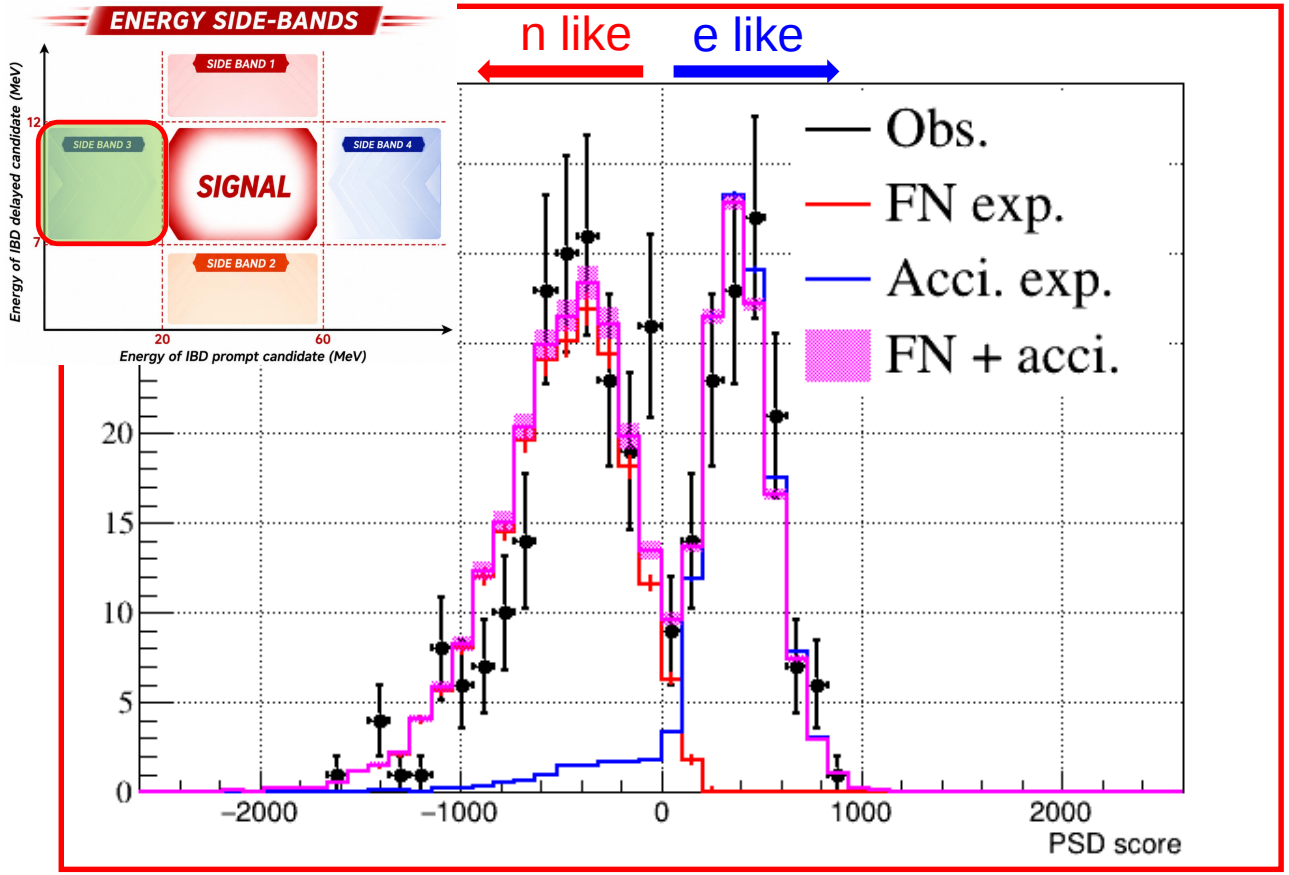




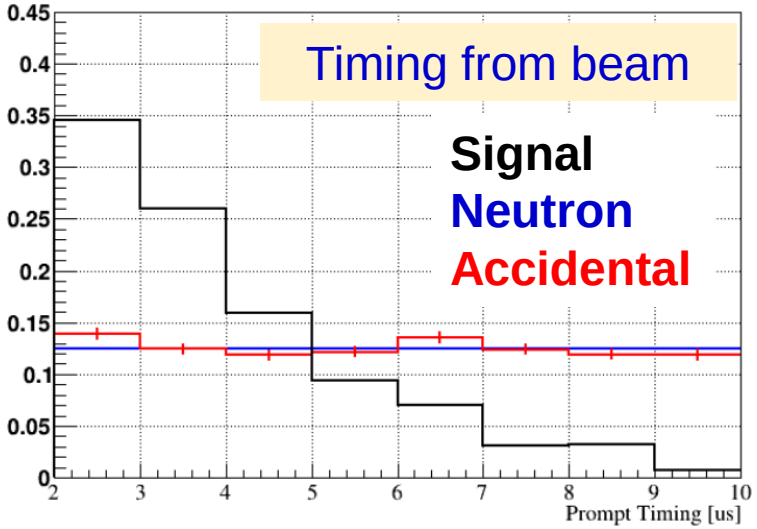
PSD application

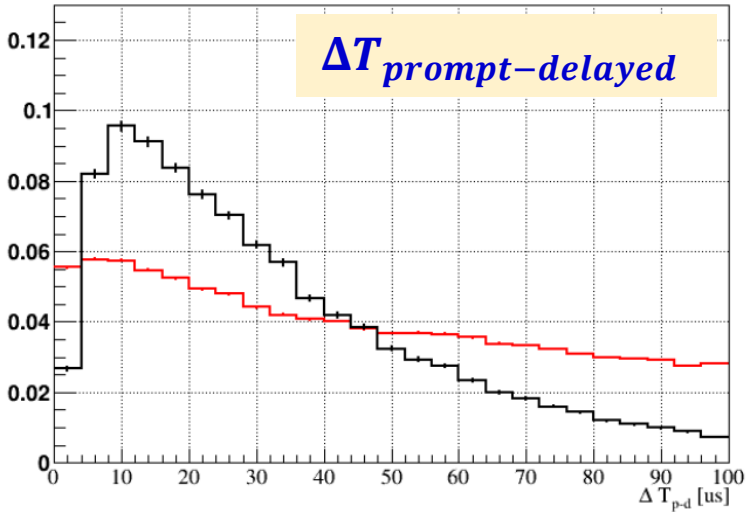
- Log-likelihood ratio classifies events as neutron-like and electron-like events.
- PSD templates provide a reasonable description of FN and accidental control sample.
- Good agreement between observation and data-driven prediction in energy side-bands.

PSD on side-band 3

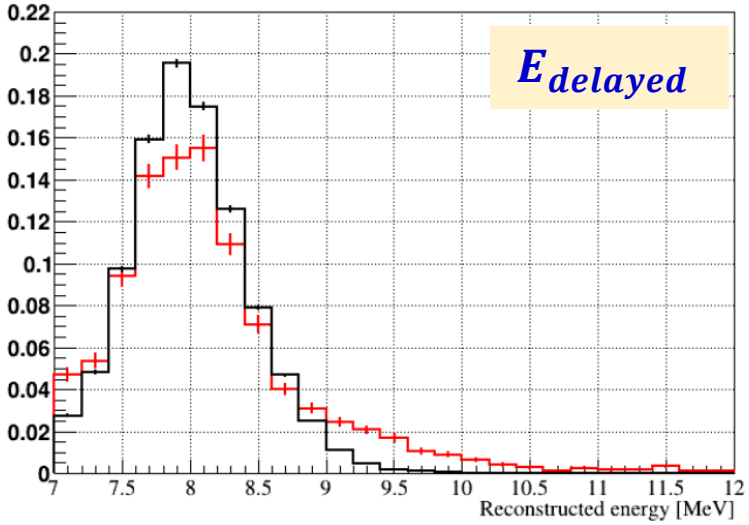


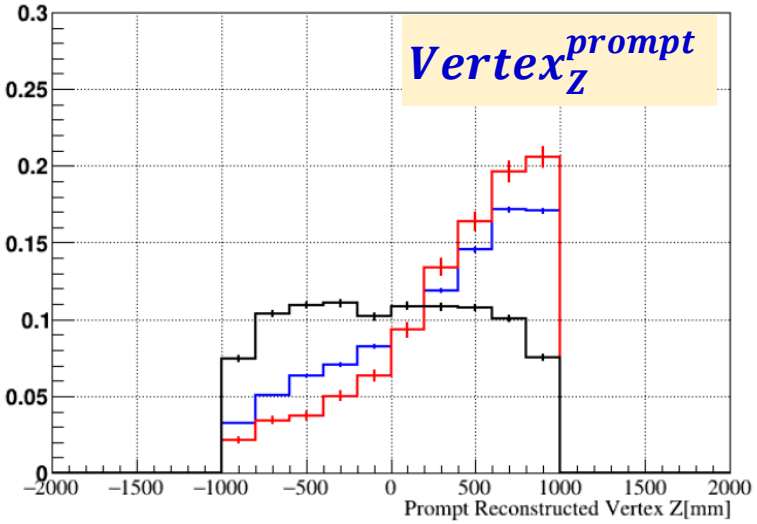
Likelihood (Timing/energy/vertex)





PDFs	Source
Signal	MC
Neutron	Control sample (Data)
Accidental	Control sample (Data)

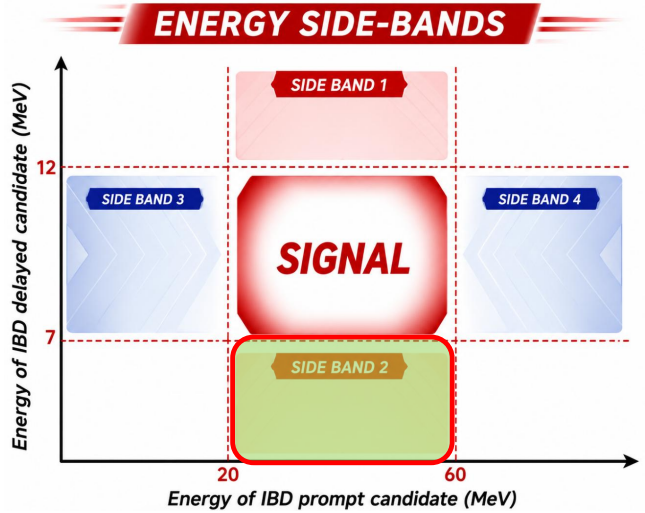


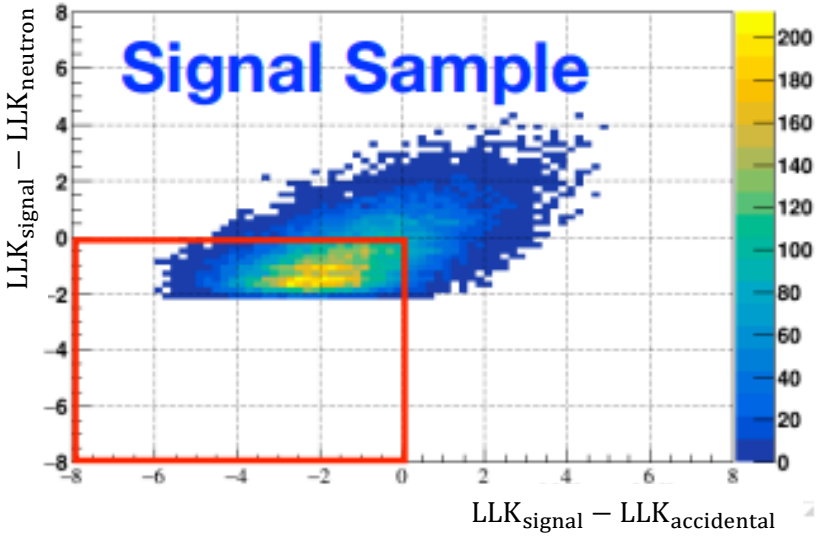


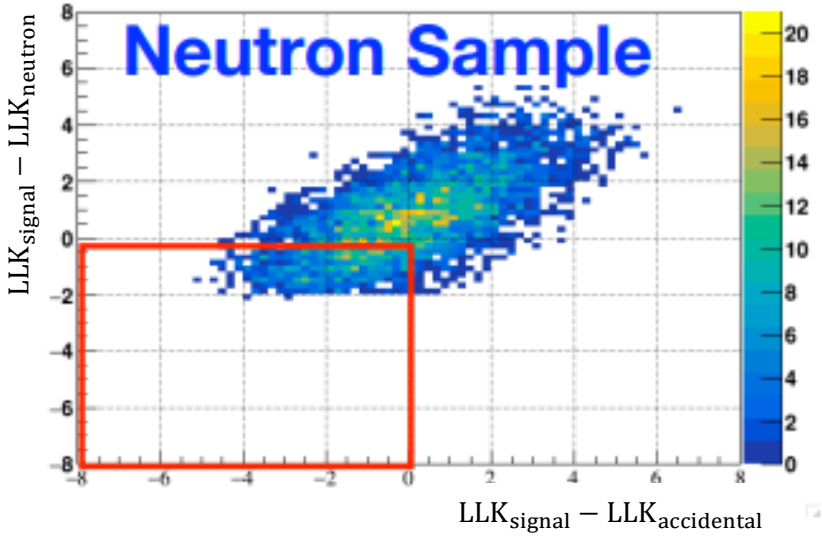
- **Neutron**
  - cosmogenic
- **Accidental**
  - prompt : cosmogenic
  - delayed : beam neutrons + cosmogenic
- **Cosmogenic backgrounds**
  - no correlation with beam timing
  - Downward-going

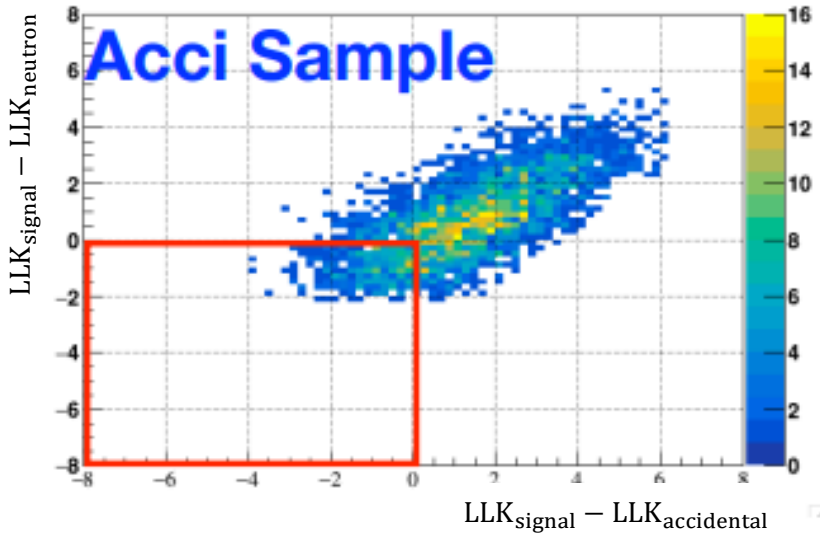
Likelihood application

- Side-bands are used to evaluate the likelihood performance.
- Signal-like events are selected in the red-box region.
- The likelihood selection retains 68% of signal events while rejecting 74% of neutron and 84% of accidental backgrounds.



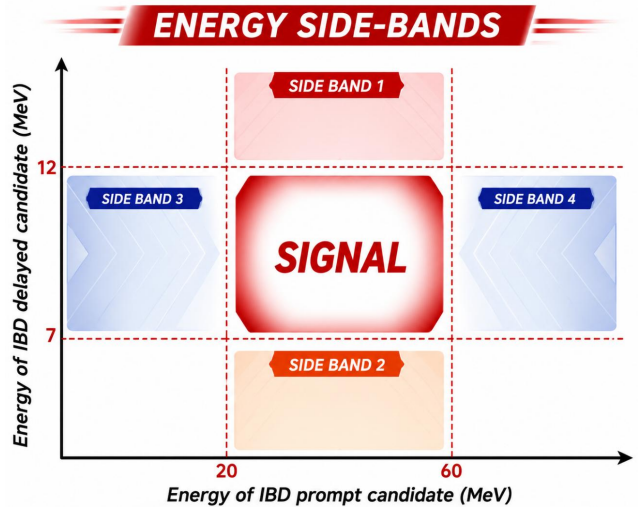






Energy side-band validation

- Data-driven background predictions are compared with observations at each analysis stage.
- Agreement is preserved after PSD and likelihood selections.
- These results validate the analysis method before opening the signal region.



2022 Physics run

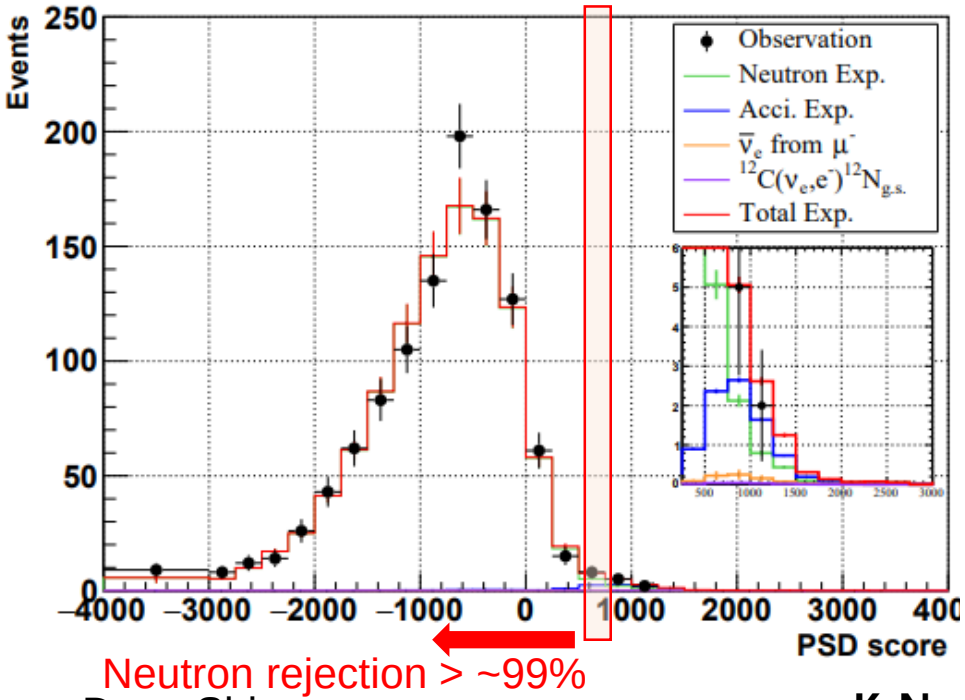
Cases		Side-band 1		Side-band 2		Side-band 3		Side-band 4	
		Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
w/o PSD	w/o LLK	3	3.5±0.7	91	106.3±2.7	703	711.7±16	191	184.6±5.2
w/o PSD	w/ LLK			25	27.4±0.8	240	213.6±4.8	49	50±1.5
w/ PSD	w/o LLK			2	5.1±0.3	5	5.4±0.3	6	3.3±0.2
w/ PSD	w/ LLK			0	0.9±0.1	1	1.2±0.2	0	0.5±0.08

Signal region validation

- PSD performance:
  ~87% signal efficiency
  @ ~99.7% neutron rejection

- Good agreement between observation and prediction is observed for both the PSD score and likelihood variables.

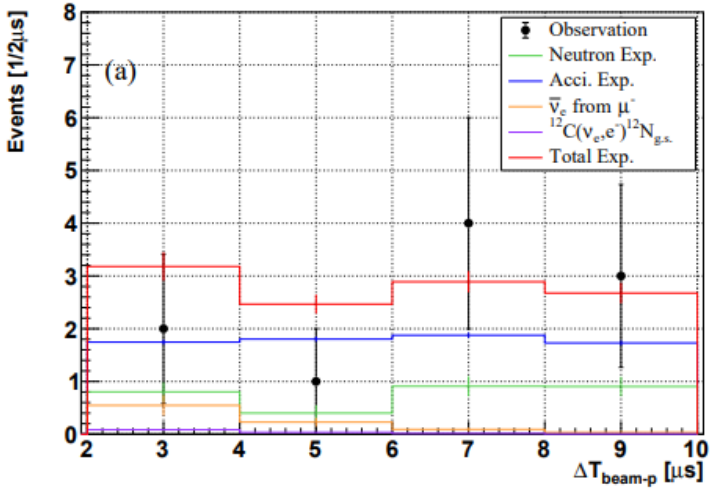
Before LLK



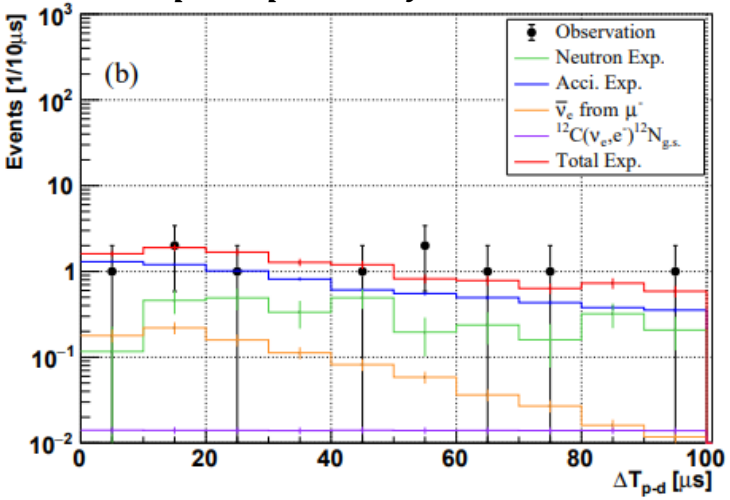
Neutron rejection > ~99%

After PSD

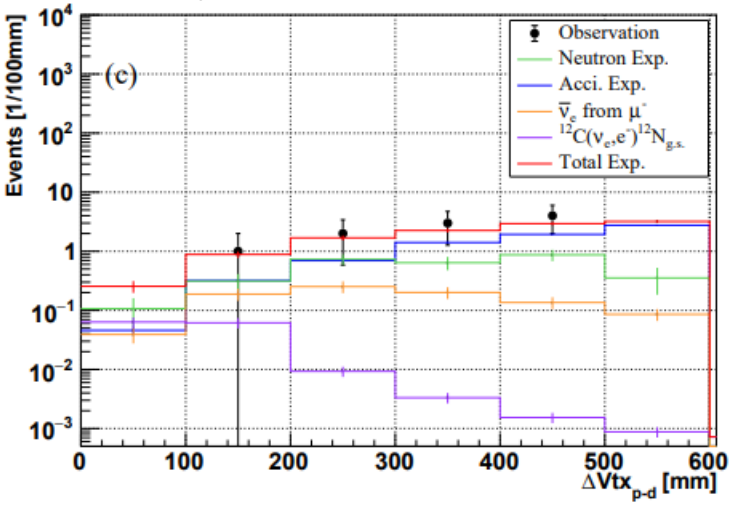
Prompt timing



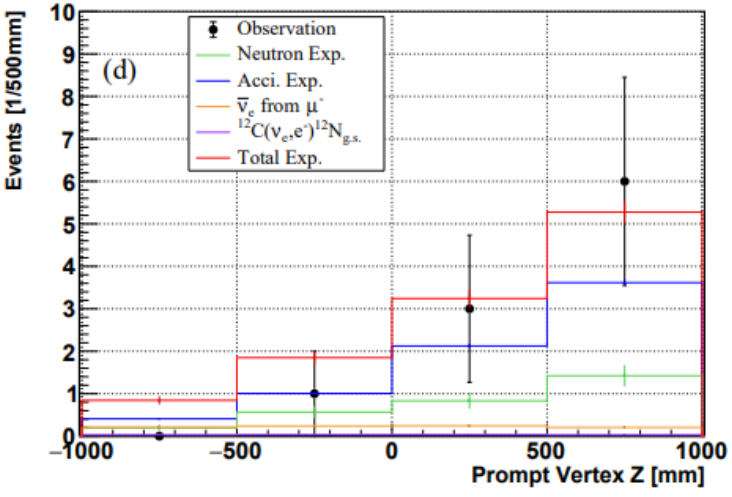
$\Delta T_{prompt-delayed}$



$E_{delayed}$



$Vertex_Z^{prompt}$



Event selection efficiency

2022 Physics data

Requirement	Relative Efficiency (%)
–Prompt Candidate–	
$20 \leq E_{\mathrm{p}} \leq 60$ MeV	100.0
$2 \leq \Delta T_{beam-p} \leq 10$ μs	46.5±0.5
PSD	87.2±9.1
–Delayed Candidate–	
$7 \leq E_{\mathrm{d}} \leq 12$ MeV	75.3±0.9
Beam neutron rejection	94.1±0.1
–IBD paired Candidate–	
$\Delta T_{p-d} \leq 100$ μs	$96.6^{+3.4}_{-5.6}$
$\Delta \mathrm{VTX}_{p-d} \leq 60$ cm	83.4±10.0
Background rejection likelihood	70.5±1.5
–Muon and Michel electron rejections–	
Muon rejection	92.8±0.5
Michel electron rejections (veto layer)	97.0±0.03
Michel electron rejections (baseline)	86.1±1.4
Chimney passing muon rejections	98.7±0.1
Cumulative total efficiency	$12.4^{+2.1}_{-2.2}$

- Fiducial volume
  : R<140cm and |Z|<100cm
- Signal efficiency is evaluated using both data and Monte Carlo simulation.
- The cumulative efficiency is **12.4%** after all selections.
- 55.0±0.4% (2024 data)

Total efficiency of 2024 data : 13.6%

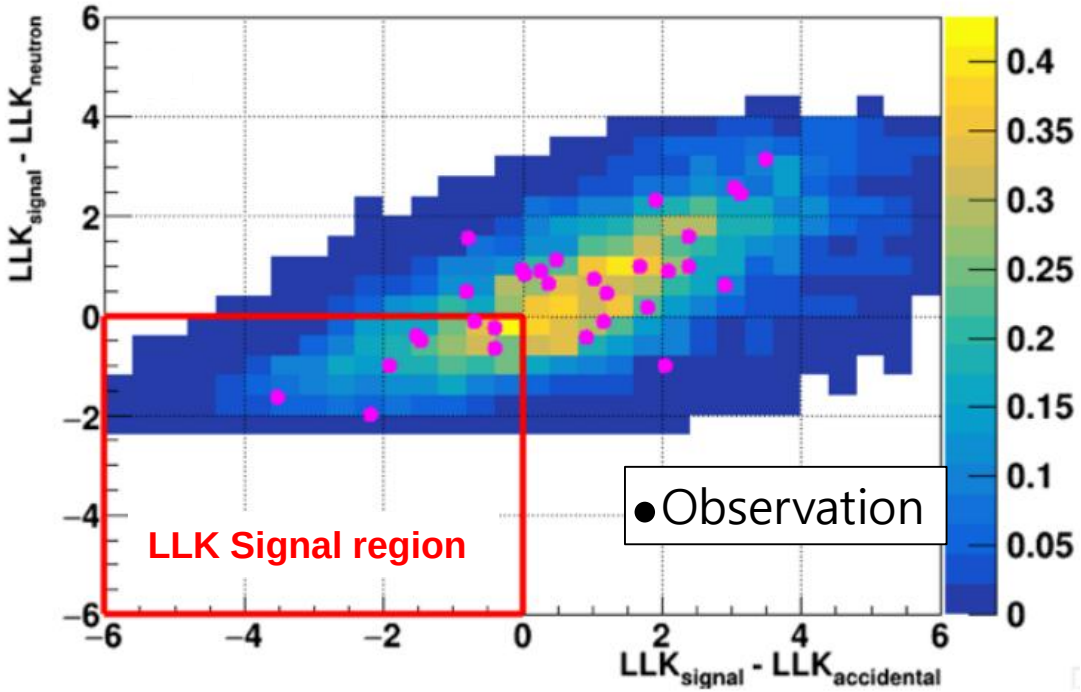
Un-blinding signal region

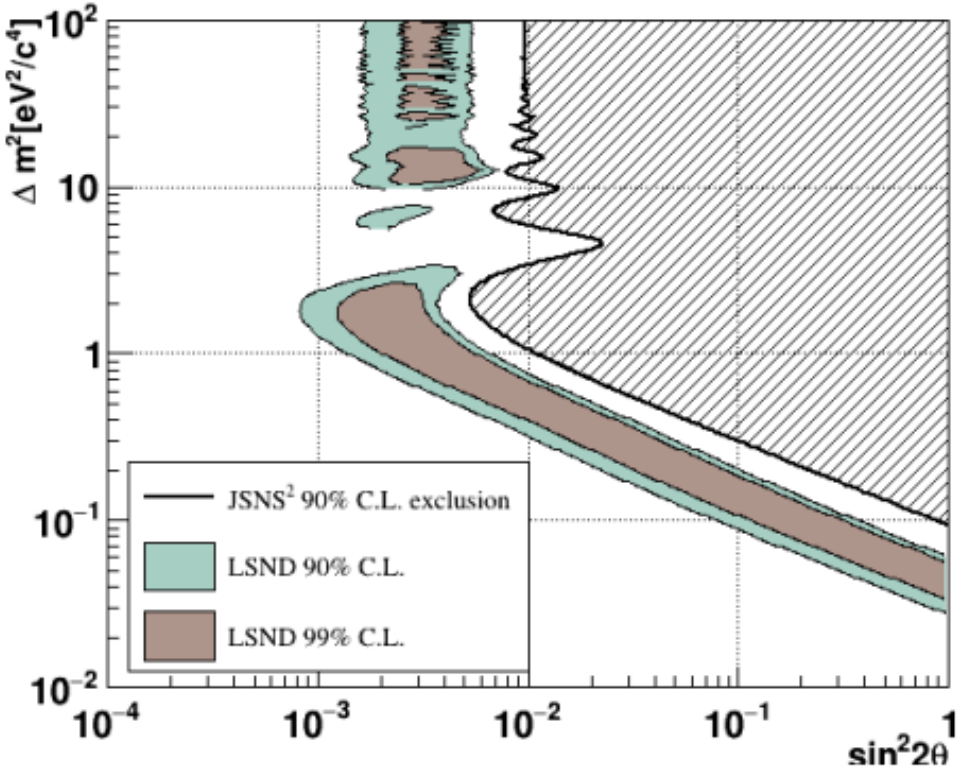
2022 +2024 Physics data

- Recently we performed analysis using 2024 data.
  - POT : (2022) 0.8×10^{22}, (2024) 1.4×10^{22}

- The observation is consistent with both the background-only and background-plus-LSND expectations within uncertainties.

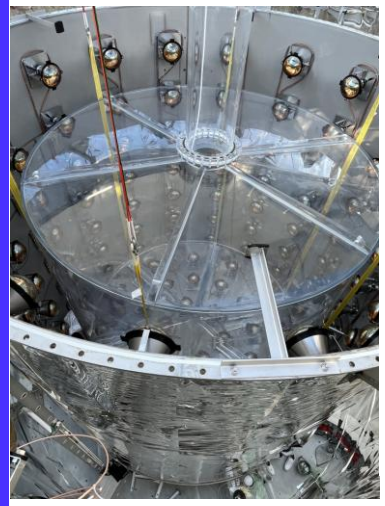
	observation	prediction
Total	8	8.9±1.6
JSNS total BKG.		6.1±1.0
LSND excess (scale)		2.8±1.3



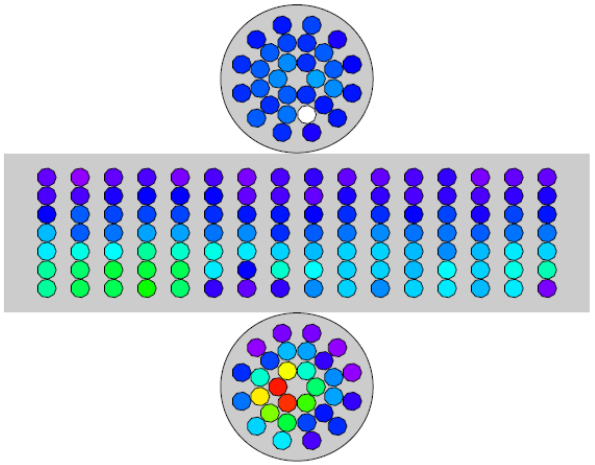


JSNS²-II (Second phase of JSNS²)

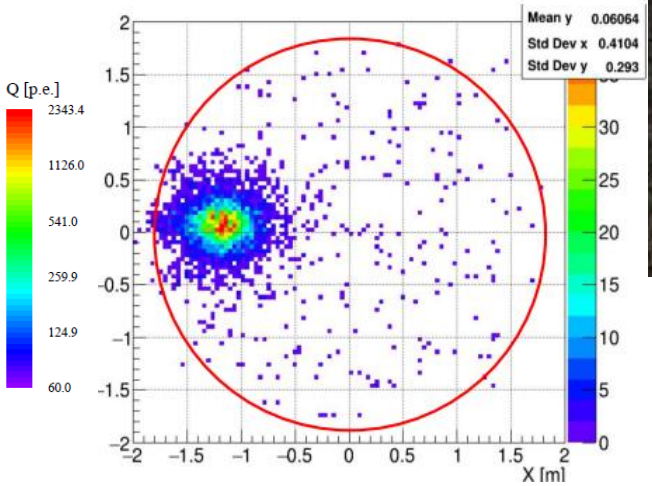
- Two detectors with two different baseline
  - a solid conclusion on LSND anomaly
- We filled liquid scintillator on Aug. 2024.
- Now we are having commission phase.

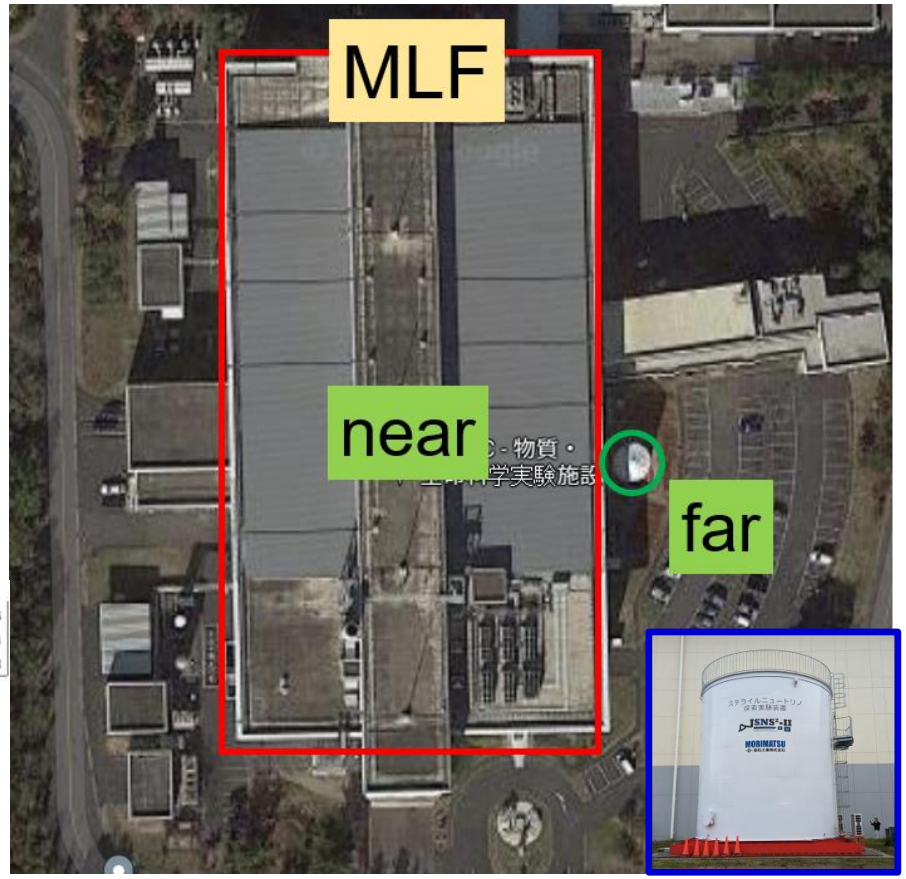


LED calibration

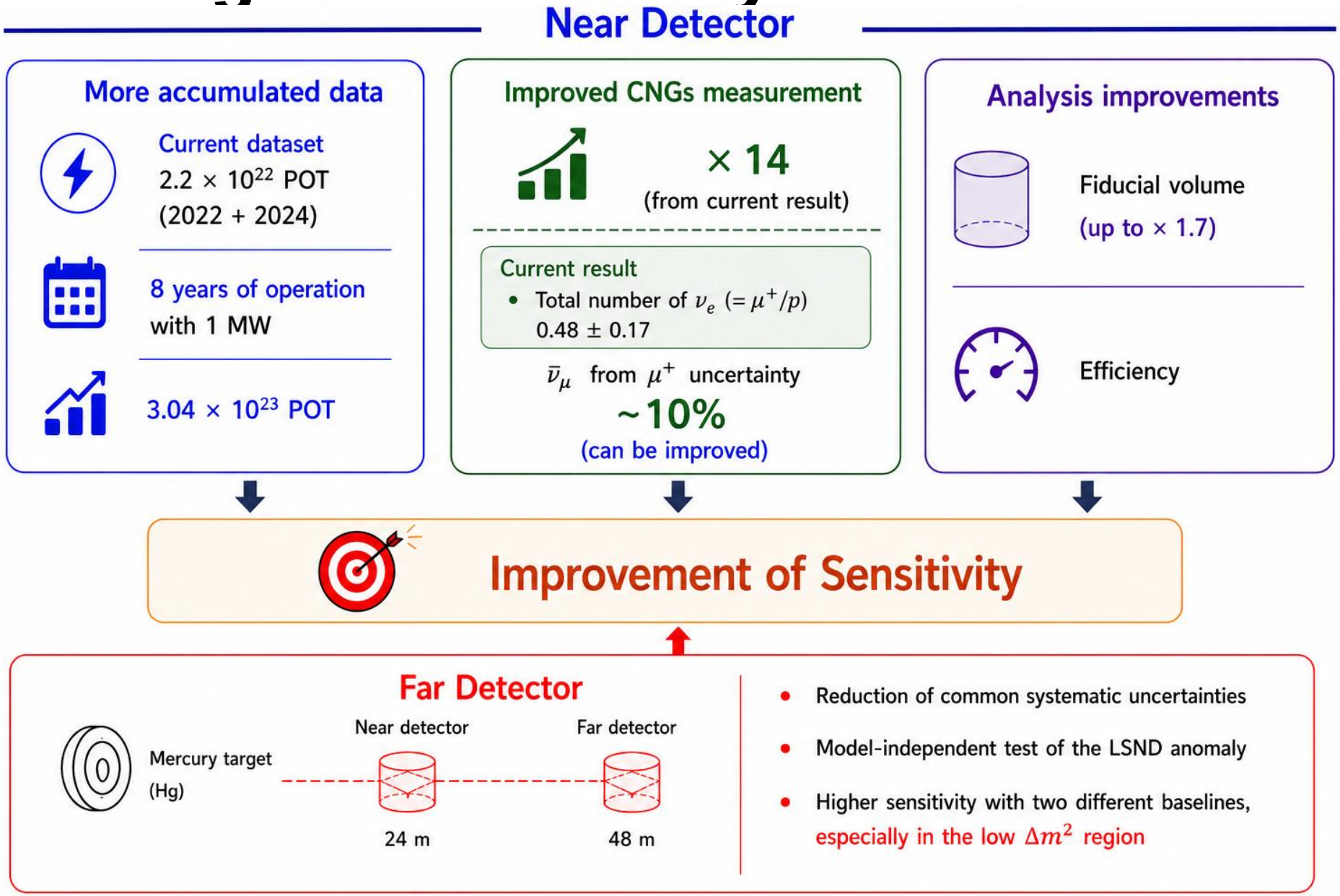


Cf source data





Toward higher sensitivity



Summary

- JSNS²-II continues to accumulate physics data, and the far detector is currently under commissioning.

- A blind analysis framework has been established using
  - data-driven background
  - PSD
  - likelihood

- In the signal region, **8 events are observed**, consistent with the expectation of **8.9±1.6 events** using the 2022+2024 dataset.

- The sensitivity is expected to improve substantially in the coming years.

Thank you for your attention



Backup

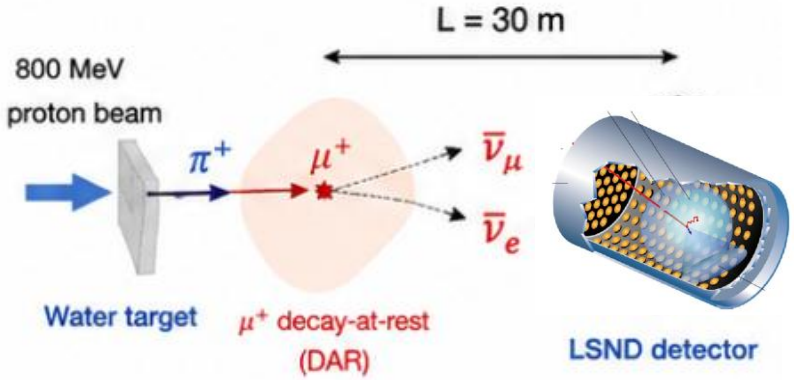
Direct test of LSND anomaly

LSND

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance

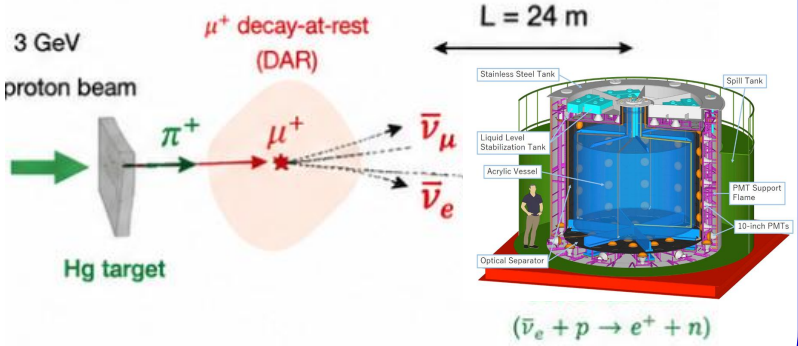
87.9 ± 23.1 excess events

3.8σ significance



JSNS²

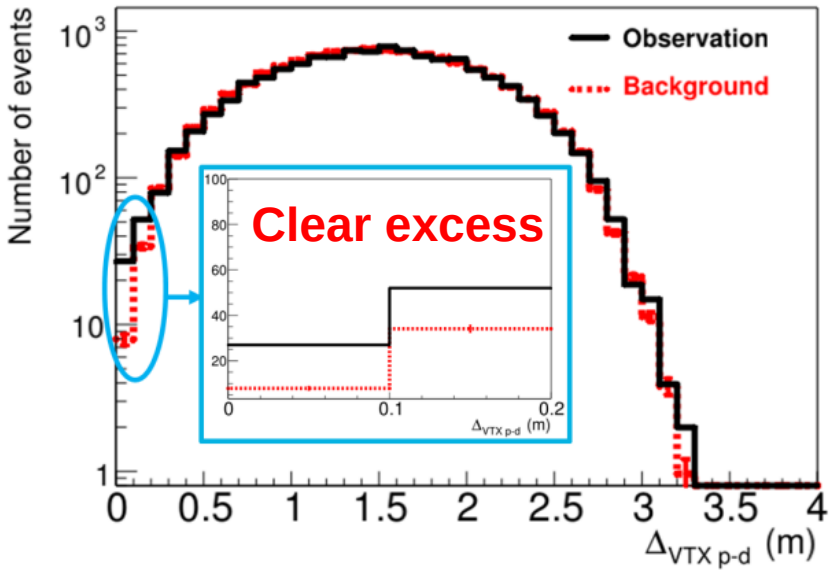
- ✓ **Same** neutrino source (μ^+ DAR)
- ✓ **Same** oscillation channel ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$)
- ✓ **Same** detection channel (IBD)
- ✓ **Similar L/E** (~30 m / 30 MeV)



- Other experiments provide important constraints on sterile neutrinos.
- They use different neutrino sources and different detection technologies.
- The LSND anomaly remains unresolved.
- JSNS² reproduces the essential conditions of LSND.
  - with improved technologies

Most direct and model-independent test of the LSND anomaly

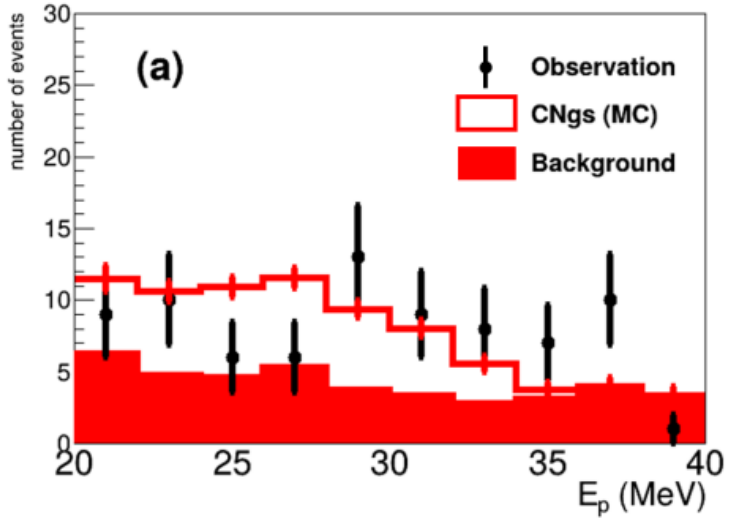
$^{12}C(\nu_e, e^-)^{12}N_{g.s.}$ measurement



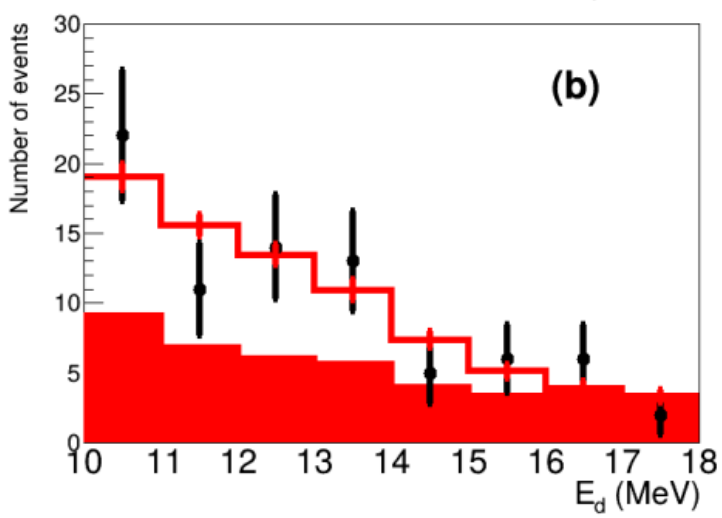
	# of events
Observed	79
Background	42.2±4.8
CNgs	36.8±8.9(stat.)±4.8(syst.)

- 2021 and 2022 physics data

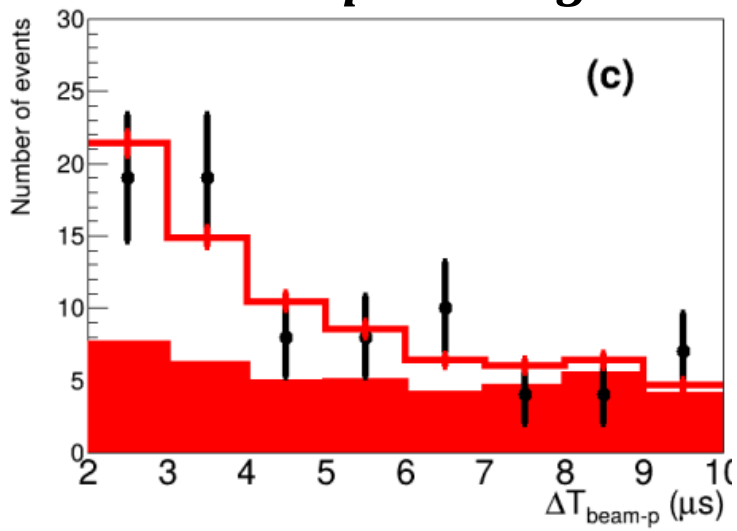
E_{prompt}



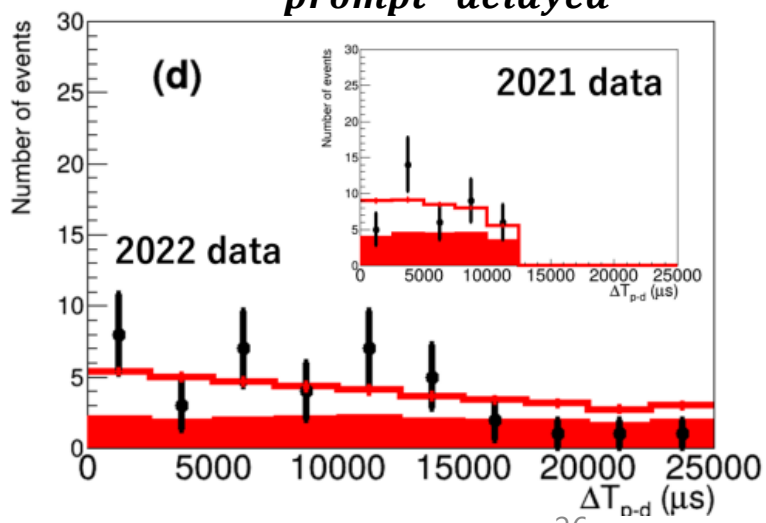
$E_{delayed}$



$Prompt\ timing$



$\Delta T_{prompt-delayed}$



Comparison with LSND excess

2022 Physics data

Neutrino flux at detector # of target efficiency

$$N_{JSNS^2} = \frac{\Phi_{JSNS^2} \cdot \sigma \cdot N_{T\ JSNS^2} \cdot \epsilon_{JSNS^2}}{\Phi_{LSND} \cdot \sigma \cdot N_{T\ LSND} \cdot \epsilon_{LSND}} \times N_{LSND}$$

- Using the LSND excess as a normalization reference, the expected signal in the 2022 JSNS² dataset is 1.1 ± 0.5 events.
- The uncertainty is dominated by the muon production measurement in JSNS² and the LSND measurement.
- The current statistics are insufficient for a conclusive test of the LSND anomaly.

Expected number of events from the LSND anomaly

item	LSND	KARMEN	JSNS^2
ν flux $(\#\nu/cm^2)$	1.26×10^{14}	6.89×10^{13}	5.47×10^{13}
(POT	1.81×10^{23}	6.05×10^{22}	0.82×10^{22})
$(\#\mu/\mathrm{p}$	0.079	0.0448 ± 0.0030	0.48 ± 0.17)
(baseline	30 m	17.7 m	24 m)
N_T	7.4×10^{30}	4.5×10^{30}	7.48×10^{29}
efficiency (%)	42.0 ± 3.0	19.1 ± 1.45	$12.5^{+2.1}_{-2.2}$
N_{eve}	87.9 ± 23.1	12.6 ± 3.3	1.1 ± 0.5

Un-blinding signal region

2022 Physics data

- Observation is consistent with the background prediction in all analysis stages.
- Two events are observed, consistent with the expected background of 2.3±0.4 events.

arXiv:2602.06274v1 (Accepted in PRD)

cases		observation	prediction
w/o PSD	w/o LLK	1079	1063.0±25.7
w/o PSD	w/ LLK	304	315.8±8.0
w/ PSD	w/o LLK	10	11.2±0.7
w/ PSD	w/ LLK	**2**	**2.3±0.4**

