Current status & plan of JSNS^2/JSNS^2-II

XIX International Workshop on Neutrino Telescopes
18-26 Feb 2021

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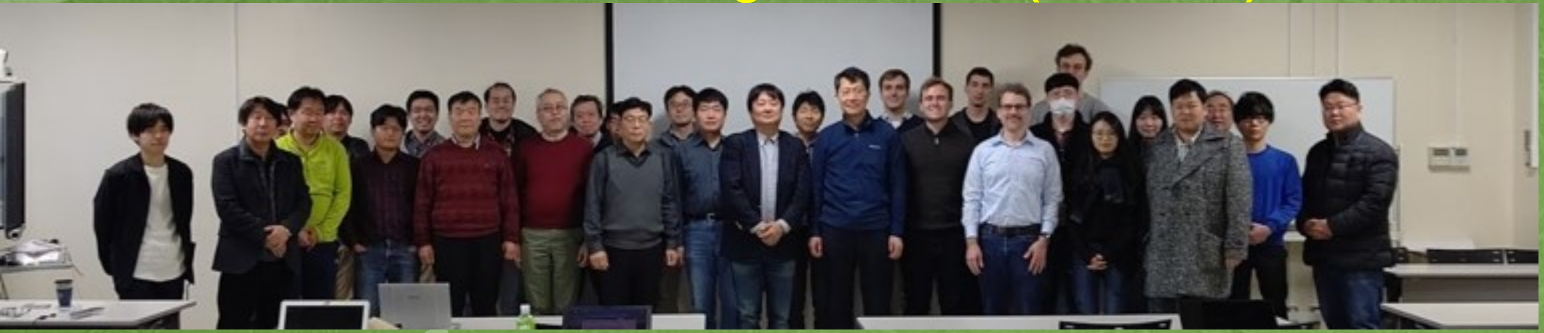
J-PARC Sterile Neutrino Search
at J-PARC Spallation Neutron Source

JSNS^2 experiment

Direct test of LSND.

Collaboration meeting @ J-PARC (2020/Feb)



JSNS^2 collaboration (65 collaborators)

- 6 Japanese institutions (31 members)
- 10 Korean institutions (26 members)
- 1 UK institution (1 member)
- 4 US institutions (7 members)

JAEA
KEK
Kitasato,
Kyoto Sangyo
Osaka
Tohoku

Soongsil
Dongshin
GIST
Seoyeong
Chonnam National
Kyung Hee
Chonbuk Natinal
Kyungpook national
Sungkyunkwan
Seoul National of sci and tech

Alabama
BNL
Florida
Michigan

Sussex

Spokesperson: T.Maruyama (KEK)
Co-spokesperson: S.B.Kim (SKKU)

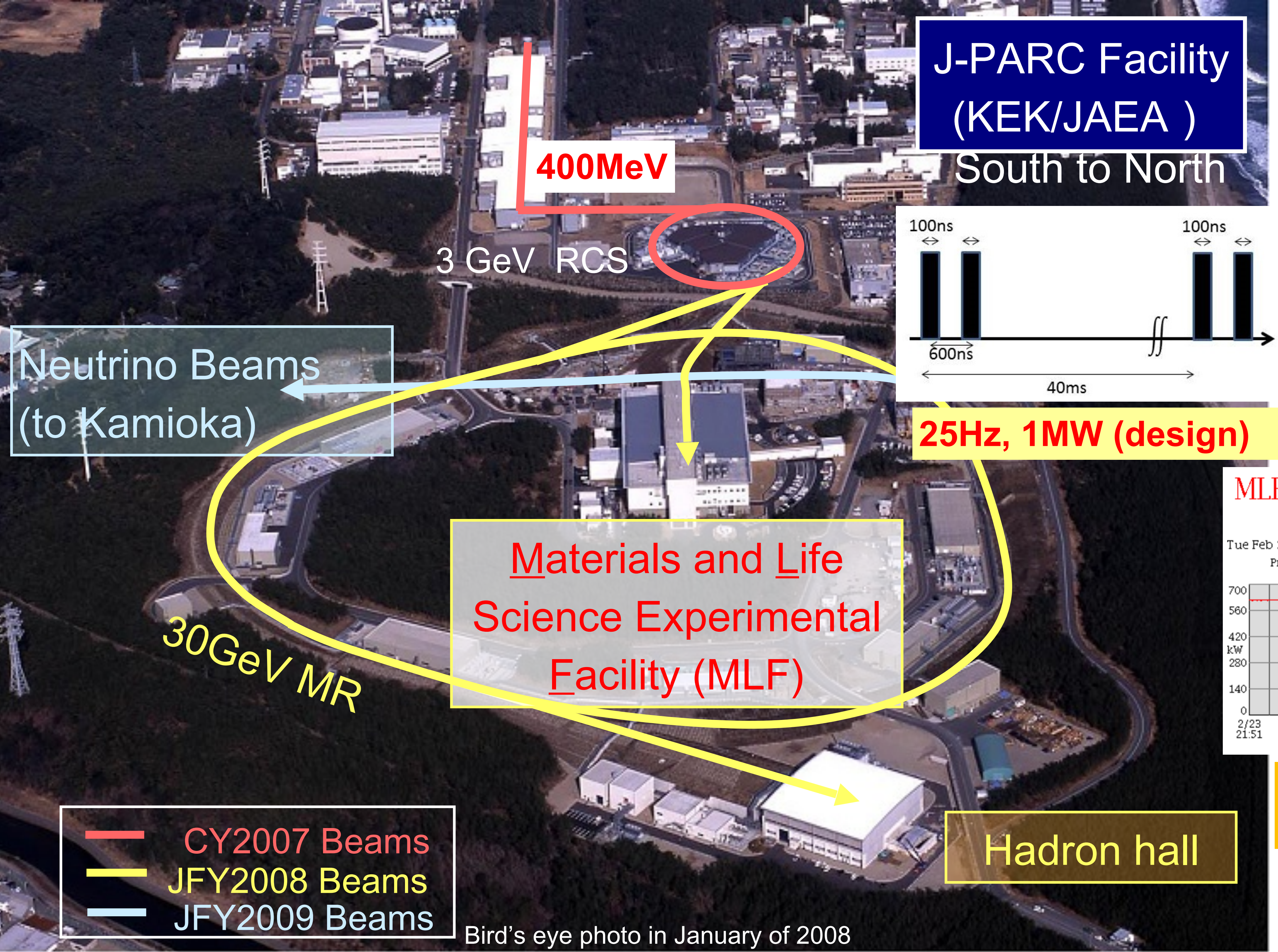
Indication of a sterile neutrino ($\Delta m^2 \sim 1 eV^2$) ?

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

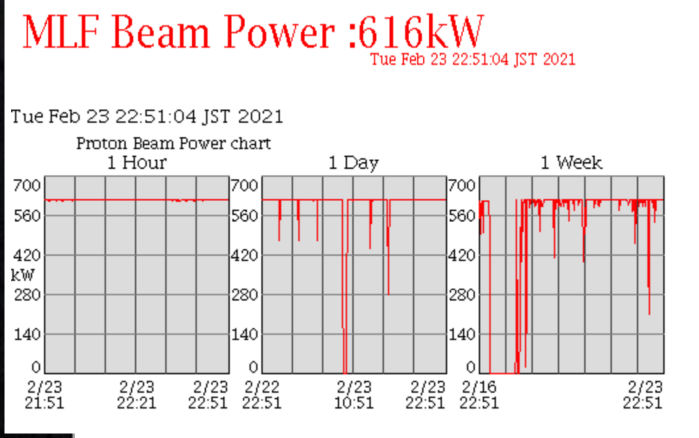
Experiments	Neutrino source	signal	significance	E(MeV),L(m)
LSND	μ Decay-At-Rest	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.8σ	40,30
MiniBooNE	π Decay-In-Flight	$\nu_\mu \rightarrow \nu_e$	4.5σ	800,600
		$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	2.8σ	
		combined	4.7σ	
Ga (calibration)	e capture	$\nu_e \rightarrow \nu_x$	2.7σ	<3,10
Reactors	Beta decay	$\bar{\nu}_e \rightarrow \bar{\nu}_x$	3.0σ	3,10-100

We aim to have a direct test for this

- Excess or deficit do really exist?
- Note: JSNS^2 uses the same neutrino source (μ), target (H) and detection principle (IBD) as the LSND → even if this is not due to the oscillation, we can catch this directly

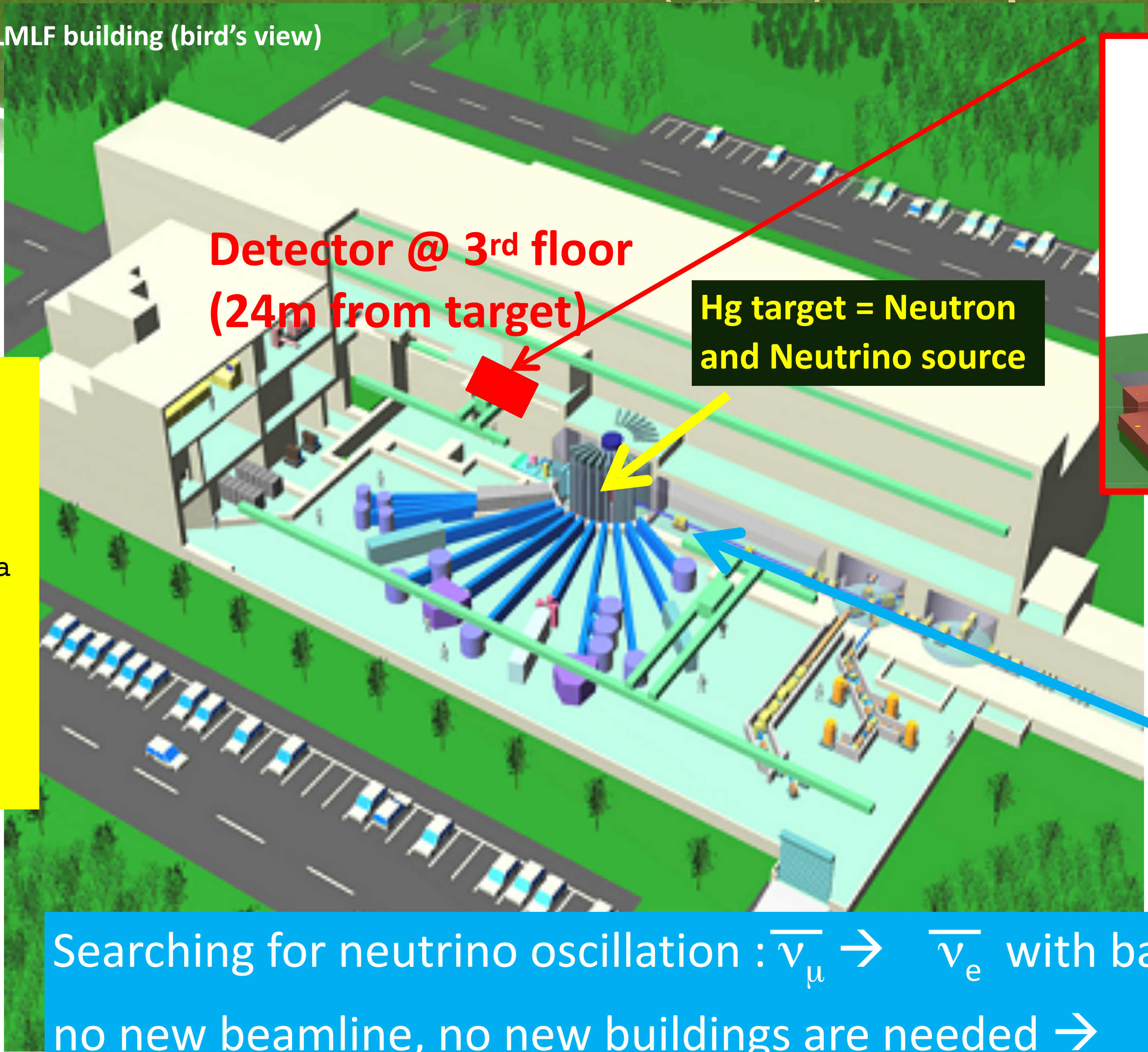


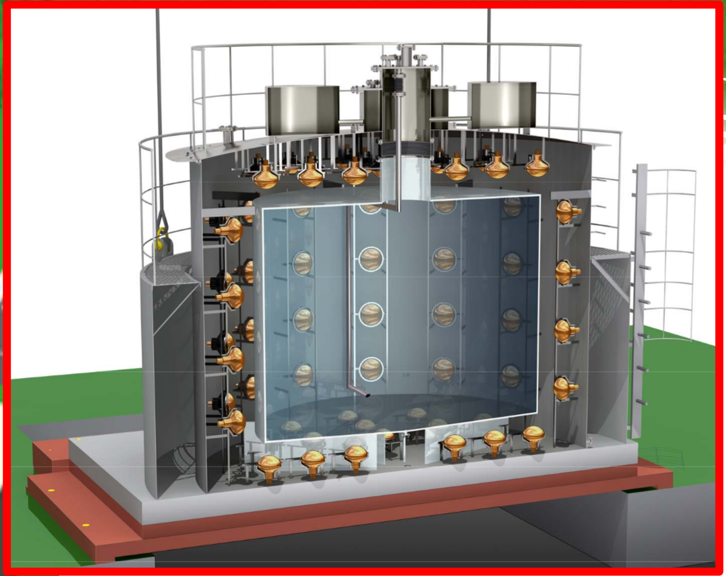
Low duty factor beam (short pulse + small repetition rate) gives very nice S/N ratio.



Currently ~0.6MW beam was utilized for users

JSNS^2 (E56) setup





50t (Gd-loaded + unloaded) liquid scintillator detector (4.6m diameter x 4.0m height)
120 10" PMTs

3GeV pulsed proton beam

1st data taking:
2020/June/(5-15)
→ Most of this talk is dedicated using this data

2nd data taking:
2021/Jan/12-
(half of year)
→ We are taking data now.

Searching for neutrino oscillation : $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ with baseline of 24m.

no new beamline, no new buildings are needed → already started.

of expected events (1MW x 3 years x 1 detector (17tons))

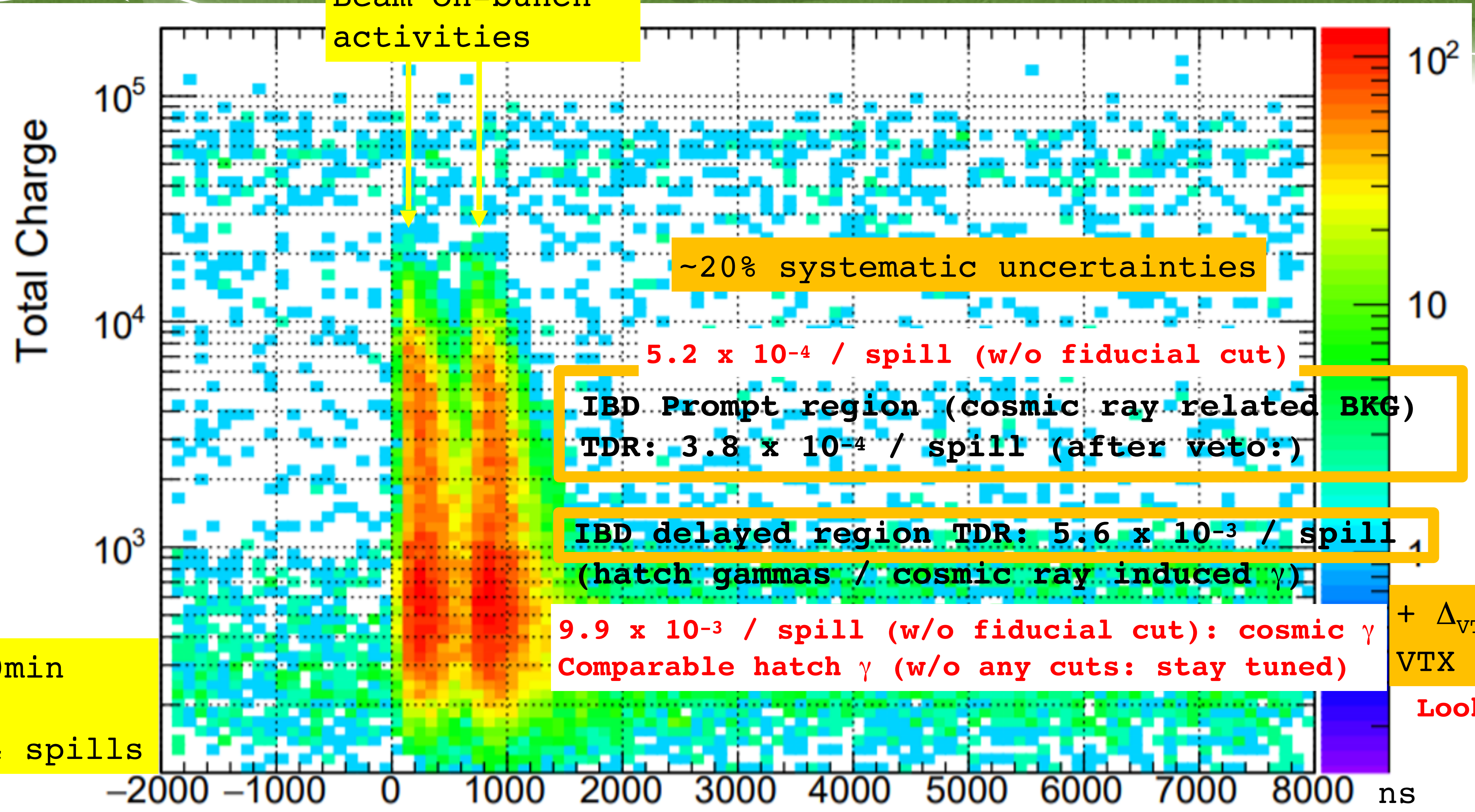
Source	contents	#ev.(17tons x 3years)	comments
background	$\bar{\nu}_e$ from μ-	43	Dominant BKG
	$^{12}C(\nu_e,e^-)^{12}N_{g.s.}$	3	
	Beam fast neutrons	< 2 (90%CL UL)	
	Fast neutrons (cosmic)	~0	
	Accidental	20	
signal		87	Δm^2=2.5, $\sin^2 2\theta$=0.003
		62	Δm^2=1.2, $\sin^2 2\theta$=0.003

We are investigating now!!

Accidental BKG is calculated by;R acc = $\Sigma R_{prompt} \times \Sigma R_{delay} \times \Delta_{VTX} \times N_{spill}$

- ΣR_{prompt}, ΣR_{delay} are probability of accidental BKG for prompt and delayed.
- Δ_{VTX} ; BKG rejection factor of **50**.
- N_{spill}(#spills / years) = 4.5 x 10^8

Background activities around beam timing



Beam on-bunch activities

~20% systematic uncertainties

5.2 x 10-4 / spill (w/o fiducial cut)

IBD Prompt region (cosmic ray related BKG)
TDR: 3.8 x 10-4 / spill (after veto:)

IBD delayed region TDR: 5.6 x 10-3 / spill
(hatch gammas / cosmic ray induced γ)

9.9 x 10-3 / spill (w/o fiducial cut): cosmic γ
Comparable hatch γ (w/o any cuts: stay tuned)

+ Δ_{VTX} (by VTX rec.)

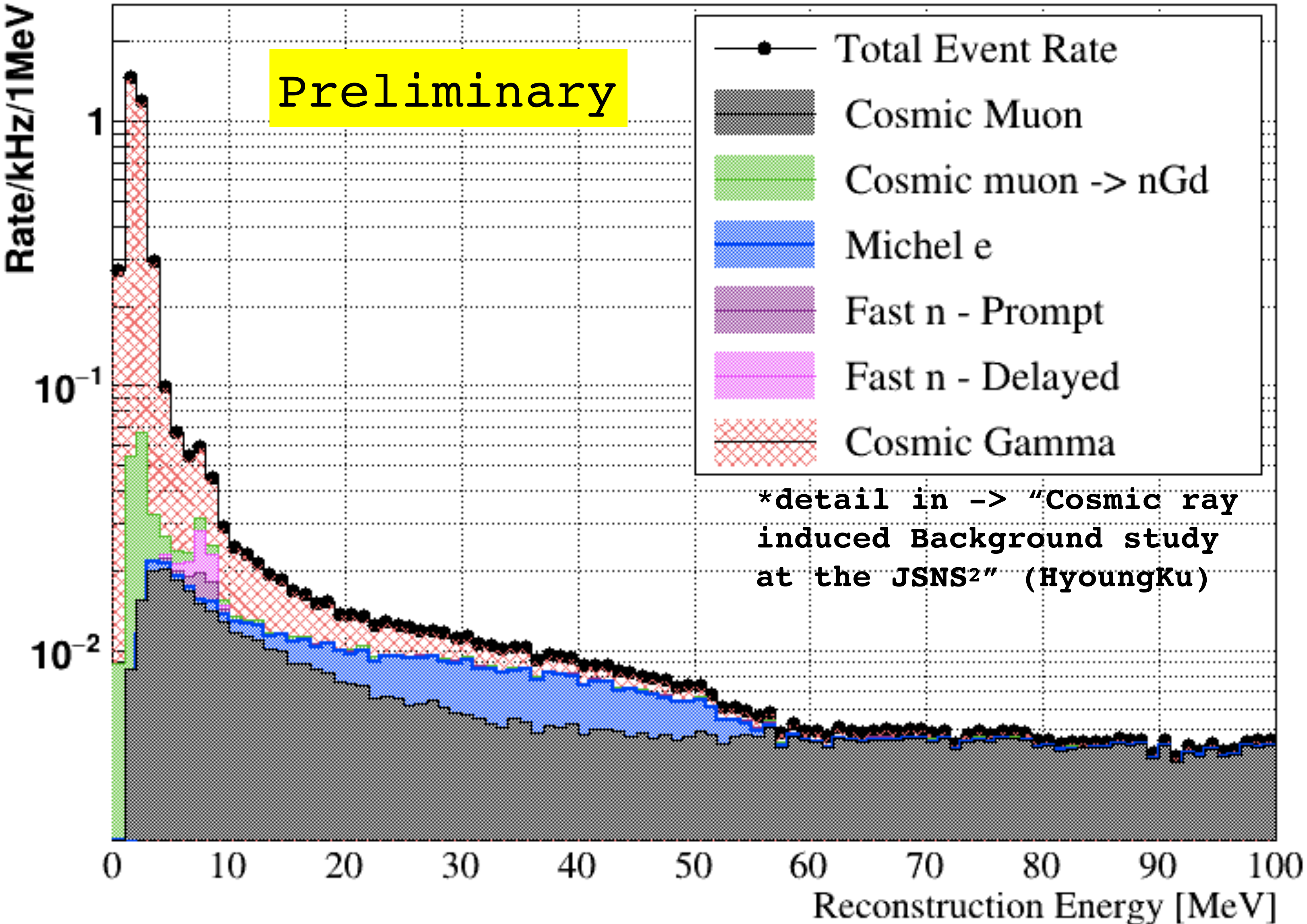
Looks OK

First 30min data
-> 46524 spills

Fast beam n + X → π + Y ; π→μ→e

Careful checks now: KDAR ν vs BKG

Data w/o beam (cosmic ray induced BKG)



- J-PARC has a day for the beam maintenance / week. (i.e. : no beam in the day)
- Left plot shows the preliminary plots for the background components taken by self-trigger. (2020/6/10)
  - Cosmic ray μ: ~2.3kHz (all energy range. Including >100MeV)
  - Michel e : ~85Hz (20-60MeV)
  - Fast neutrons: ~3.6Hz (20-60MeV)
  - Cosmic gamma: ~58Hz. (20-60MeV)
  - Cosmic gamma: ~100Hz (7-12MeV)

  (note1: uncertainties for all components are 20% level)

  (note2: these numbers have no fiducial volume cuts. BKG in the Catcher region are included in addition to target region. (target $20m^3$ vs catcher $12.2m^3$))

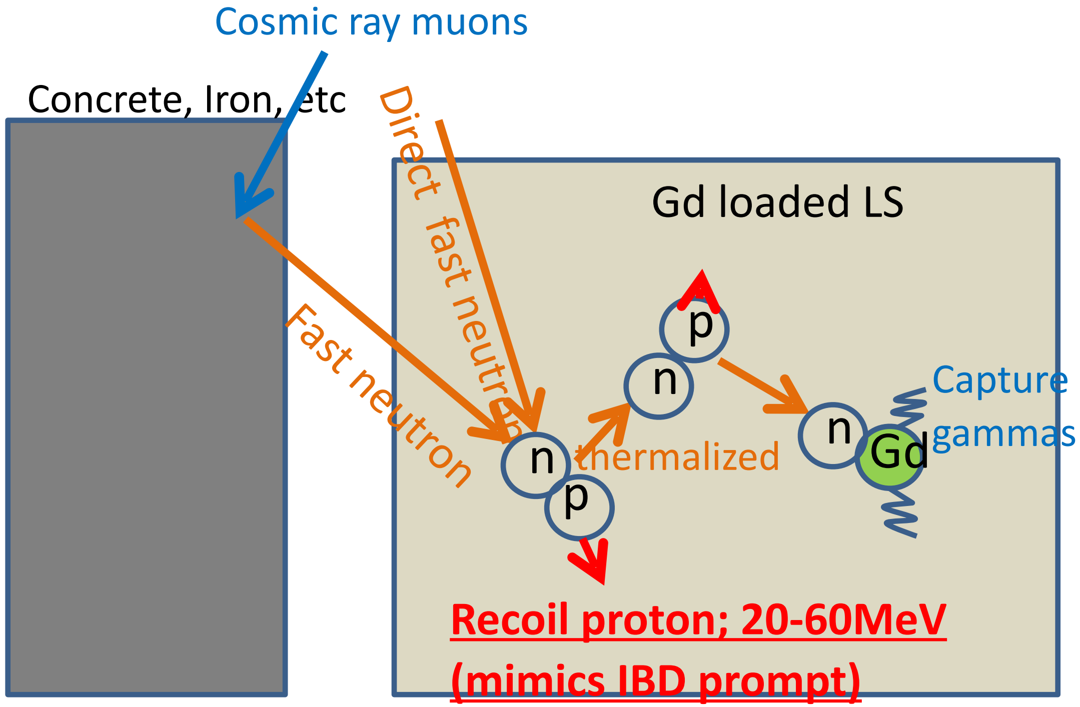
  (note3: fast neutrons and gammas rays are induced by cosmic muons)

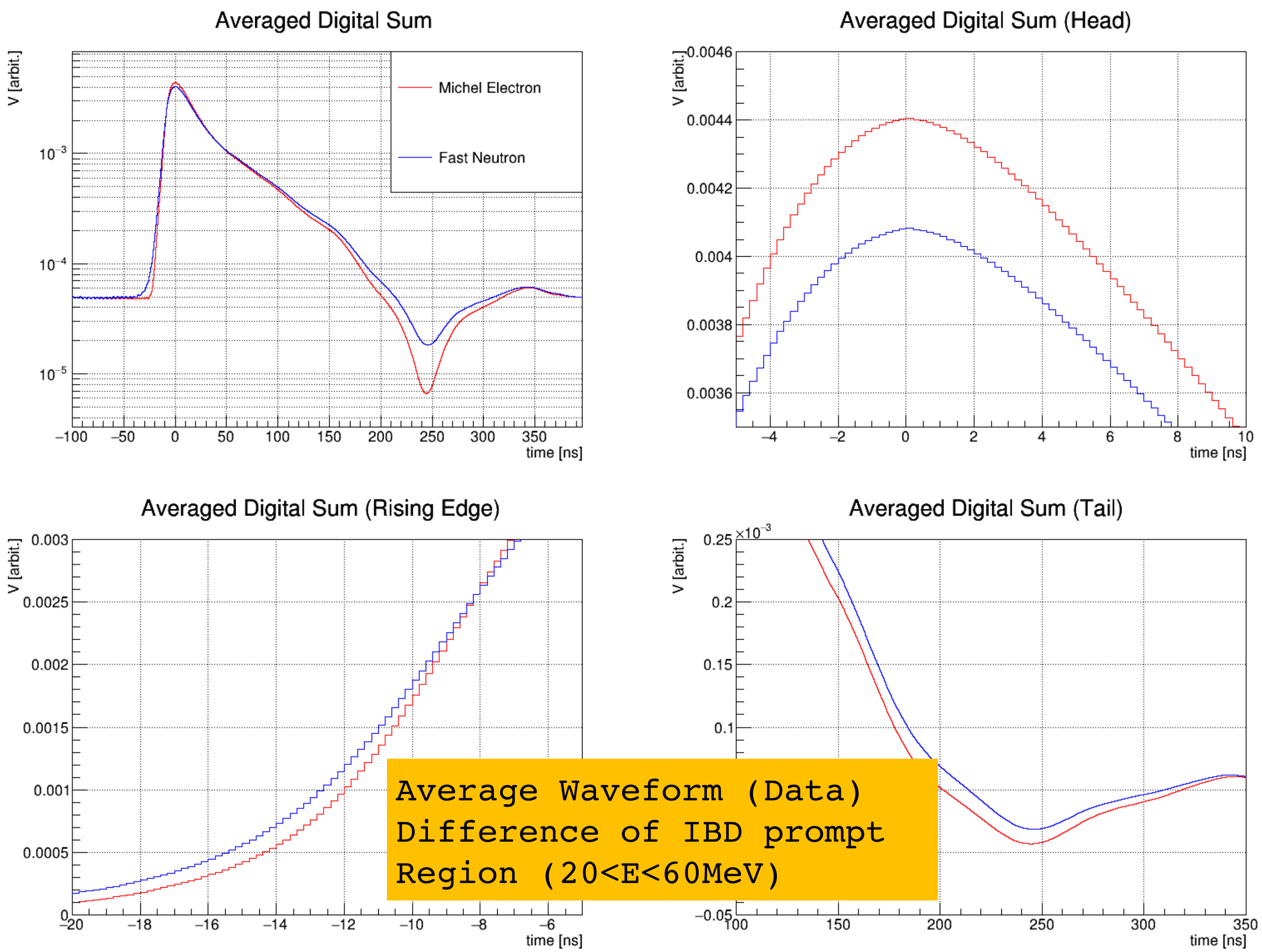
  (note4: the efficiency to tag the cosmic muons in the veto: better than 99%)
- Time window to select IBD is powerful to reject these. ($9\mu s$ = ~10^{-5} reduction for IBD prompt, 100us = 10^{-4} reduction for IBD delayed)

PSD capability for fast neutrons

*detail in -> "PMT Waveforms for Pulse Shape Discrimination in JSNS²" (Sanghoon)

Fast Neutrons are severe background because it is "correlated" BKG.

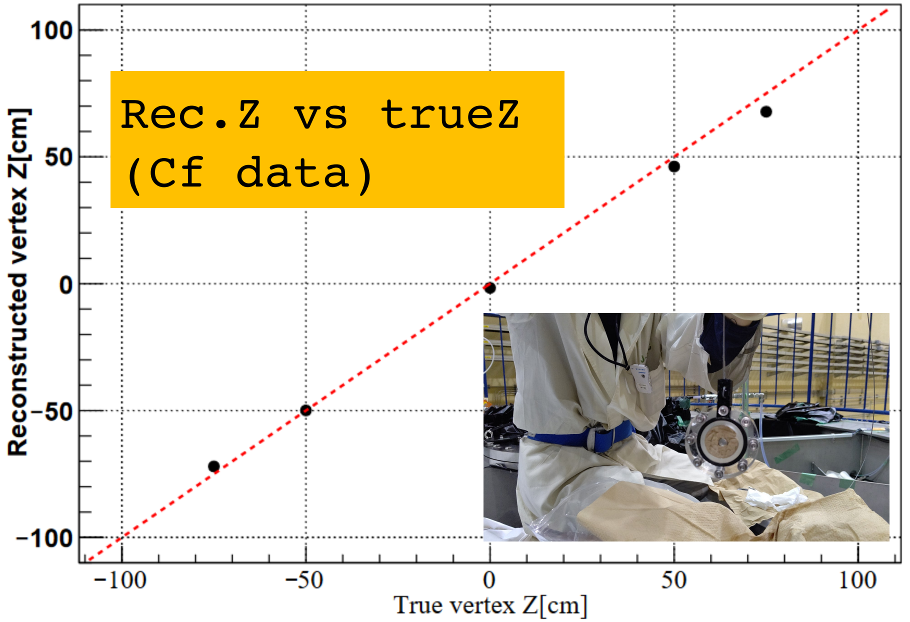


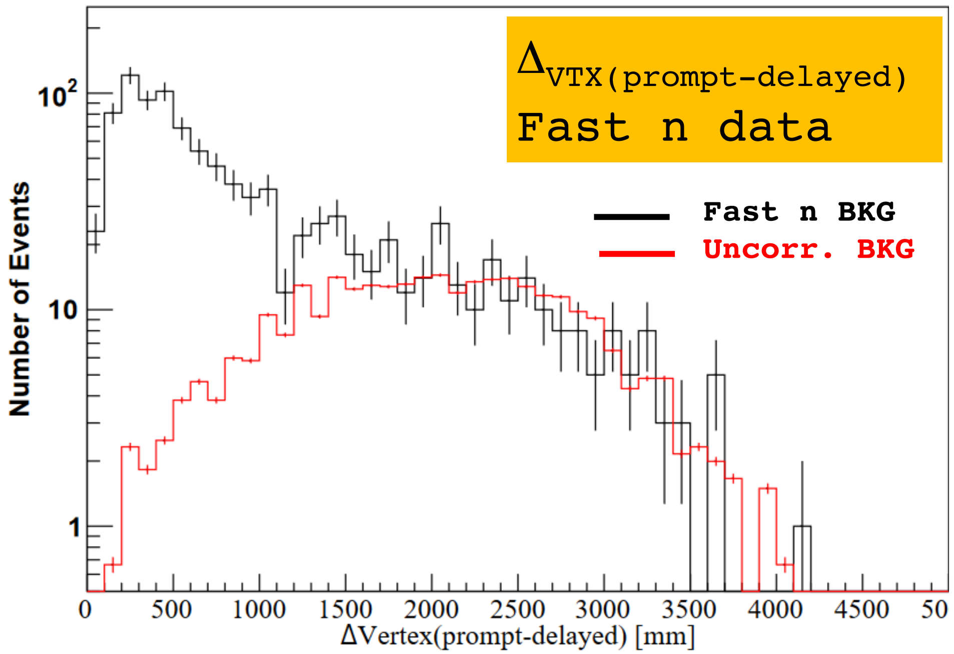


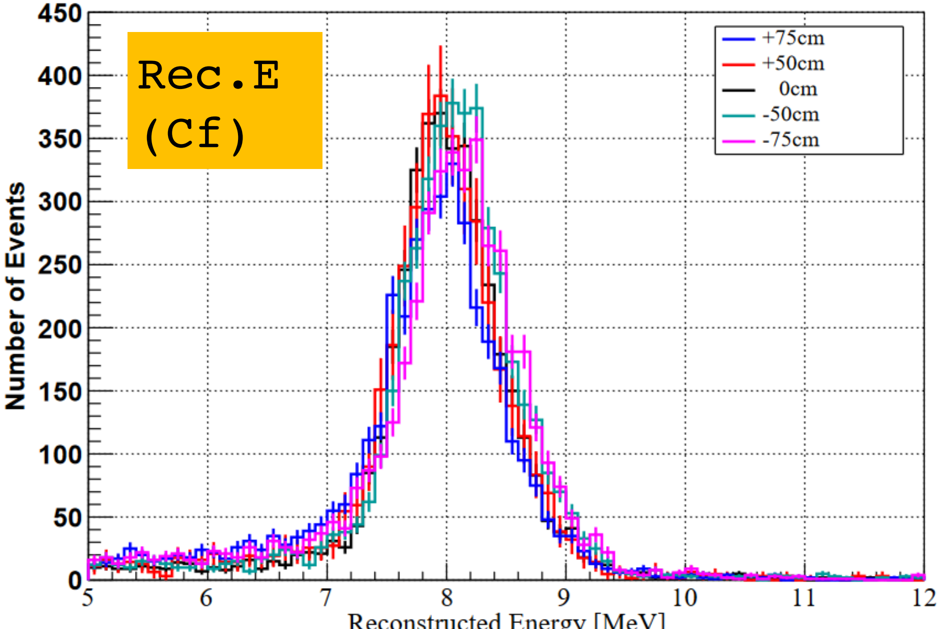
Average Waveform (Data)
Difference of IBD prompt
Region (20<E<60MeV)

- We are trying various methods to distinguish these waveforms.
- we are studying the difference of waveforms

Vertex/Energy reconstruction performance





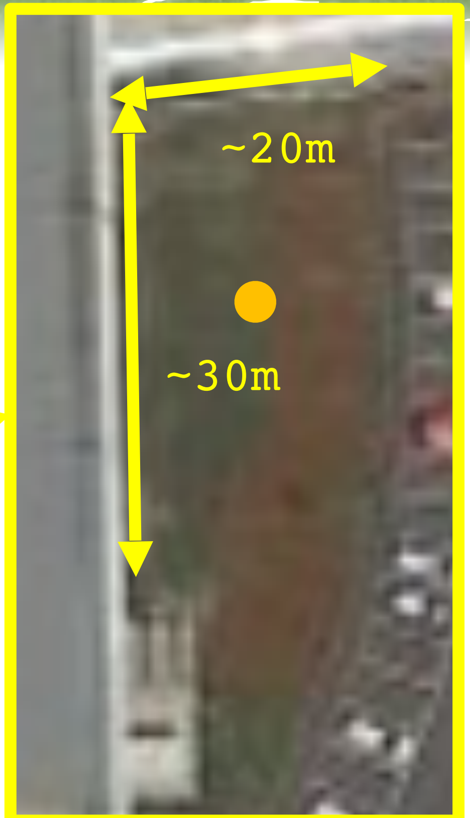


	Vtx Resolution (Cf)
data	92±3mm
MC	78±2mm

	E Resolution (Cf)
data	5.1±0.1%
MC	5.3±0.2%

- Top-left: almost no bias for vertex reconstruction for z-direction.
  - We are checking the bias for the R direction carefully.
- Bottom-left: no obvious bias for energy
- Top-right: Δ_{VTX} for prompt – delayed in fast neutrons. Spatial correlation is seen well.
- Bottom-right: energy and vertx resolutions comparison.

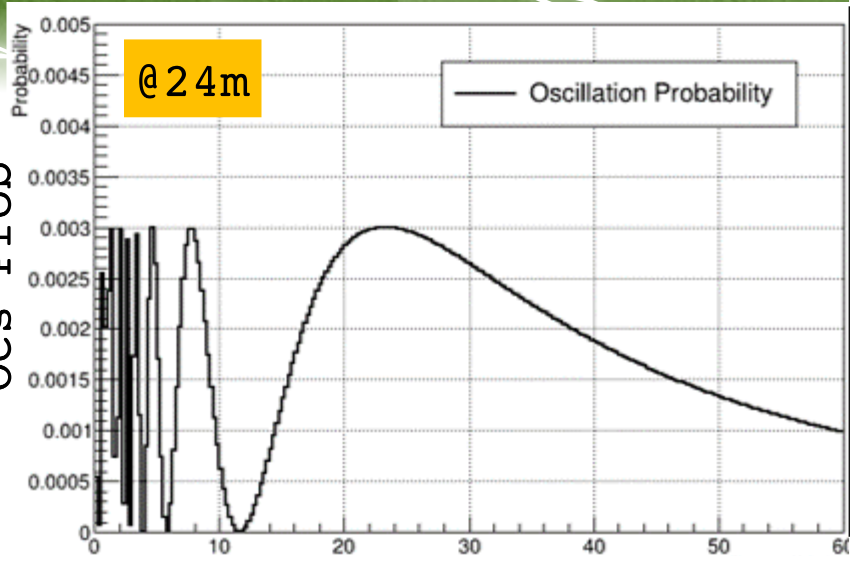
JSNS^2-II : 2nd detector location (outside of MLF)



- Baseline is ~48m.
- No detector buildings.
- **MLF approved to use this space for the detector (2020/Dec-15)**

Merit of 2 detector configuration

@24m

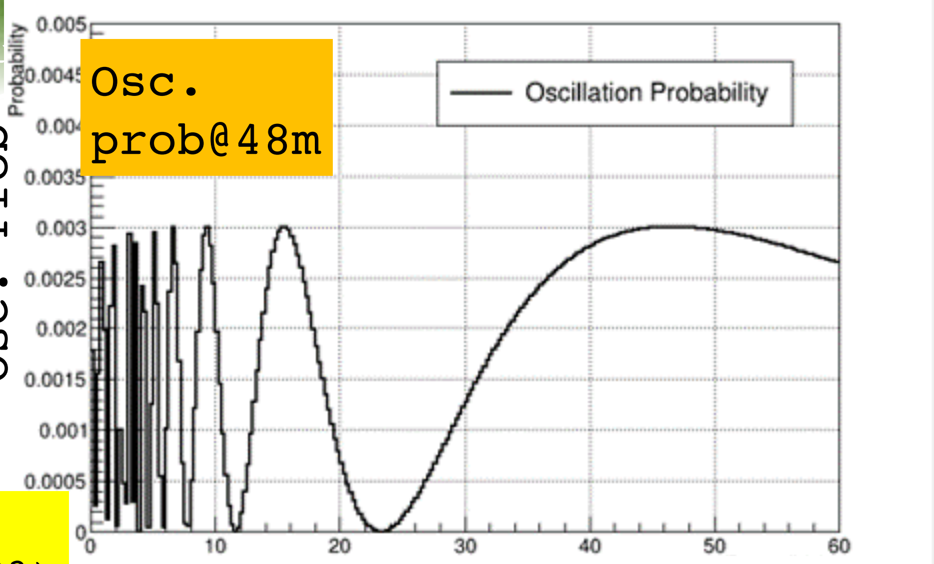


Ocs Prob

Energy (MeV)

Difference Of osc. Prob.

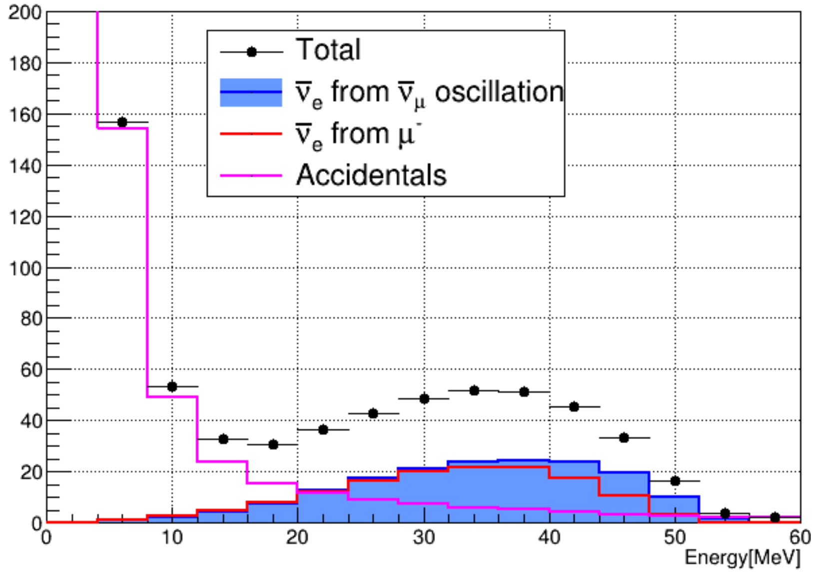
Osc. prob@48m



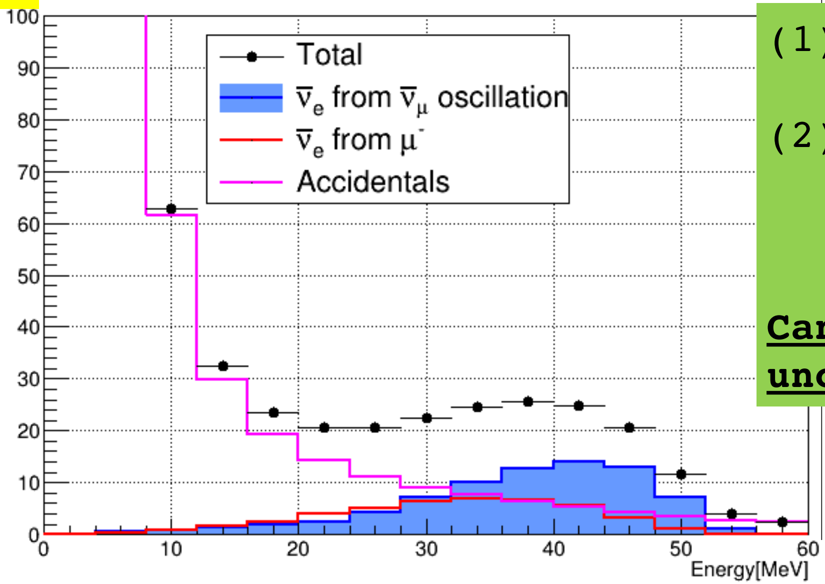
Osc. Prob

Energy (MeV)

$(\Delta m^2, \sin^2 2\theta)$
$= (1.2\mathrm{eV}^2, 0.003)$
LSND best fit



Number of events

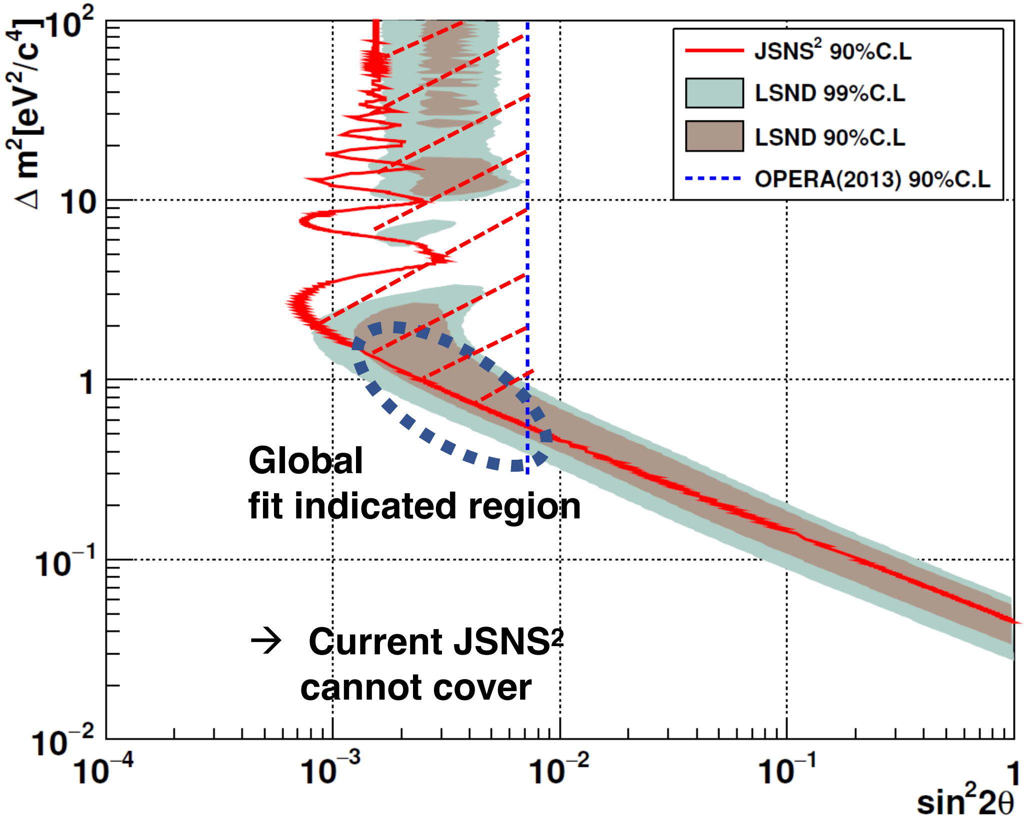


Number of events

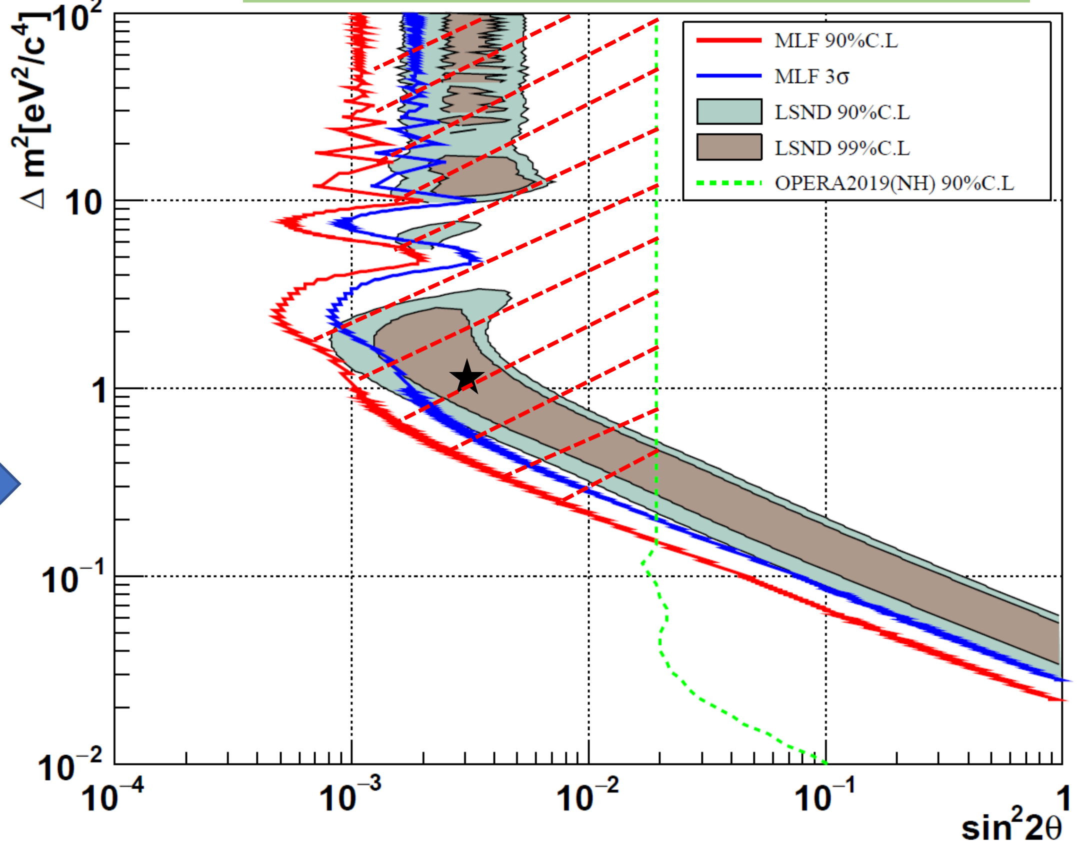
(1) Beam related BKG
→ $1/r^2$
(2) Cosmic ray BKG
→ no difference

Canceling the syst. uncertainties also

JSNS^2-II sensitivity



5 years running after current JSNS^2



Shaded region can be searched.

Covers the almost whole LSND region with 3σ C.L.

Timescale of JSNS^2/JSNS^2-II

		2020		2021				2022				2023			
		8-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
JSNS^2									running						
JSNS^2-II	proposal		submit												
	TDR						submit								
	Law/Facility														
	Detector building														
	Data taking														

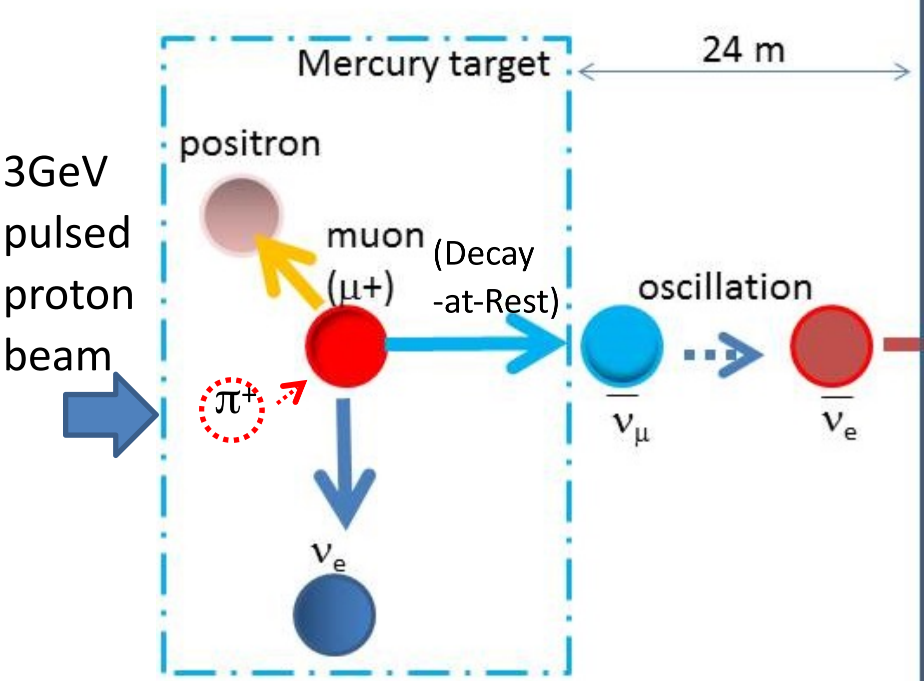
Summary

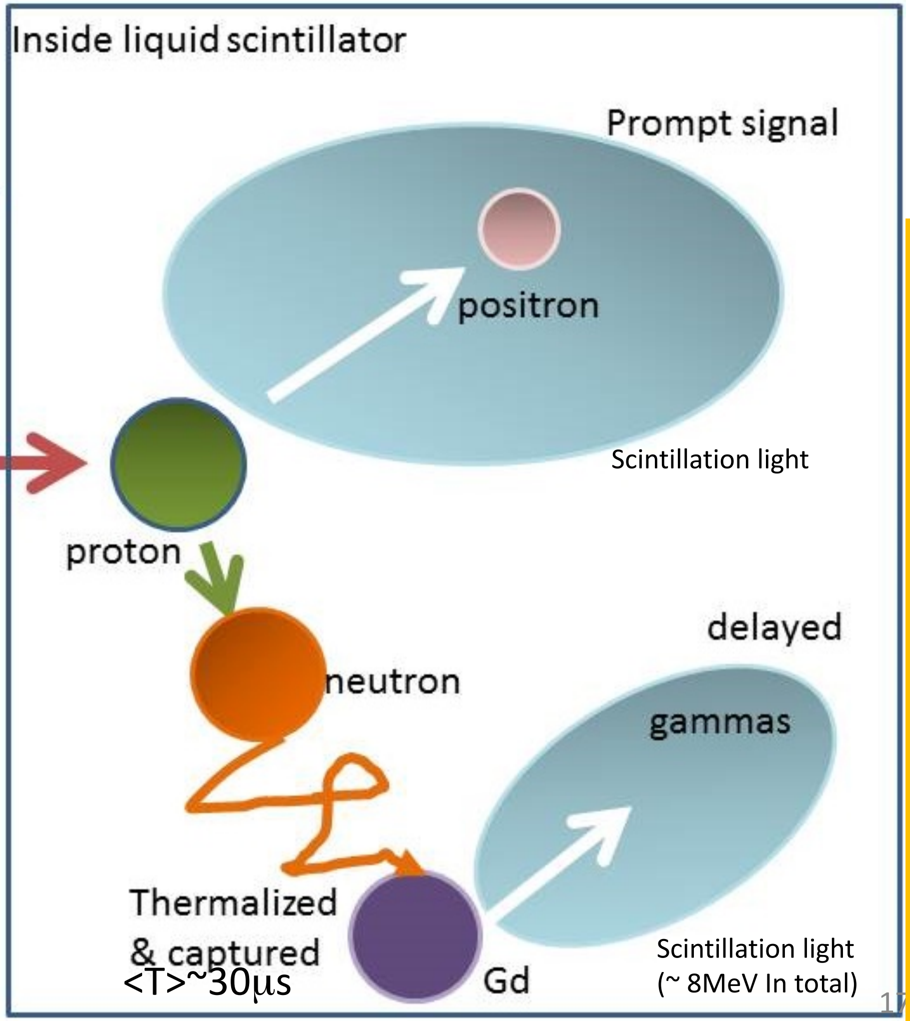
- JSNS^2 aims to test the LSND anomaly directly.
  - uses the same neutrino source (muon), target (H) and detection principle (IBD), but much smaller accidental background due to Gd-loaded LS and low duty factor J-PARC MLF beam.
- We started data taking from 2020-June.
  - Preliminary number of BKG, energy resolutions (@ Cf peak), Δ_{VTX} dist. are almost as expected.
  - We are finalizing numbers.
- Physics Run was resumed with the beam from Jan-12 even under COVID-19. → New trigger implementation (for sterile neutrino search)
- JSNS^2-II using two detectors is newly proposed.
  - The sensitivity for the sterile neutrino search (especially, in the low Δm^2 region) will be improved a lot.
  - With seeing the performance of the 1st detector, the 2nd detector conceptual design must be the similar as the 1st detector.
  - MLF approved the space, Fire Law part has no issues.
  - Daya-Bay finished the experiment, thus they donated the GdLS / LS for JSNS^2-II.
  - The stainless steel tank and acrylic vessel are being discussed with the same companies as the 1st detector.
  - Aim to start the JSNS^2-II from 2023.

backup

Production / Detection

- Large amount of parent $\mu+$ in Hg target → $\bar{\nu}_\mu$ are produced.
- If sterile ν exist, $\bar{\nu}_\mu$ → $\bar{\nu}_e$ oscillation occurs with 24m.
- Oscillated $\bar{\nu}_e$ is detected by Inverse Beta Decay (IBD): $\bar{\nu}_e + p$ → $e^+ + n$ w/ well established detector technique





IBD criteria	Timing	Energy
Prompt	$1<T_p<10\mu s$	20<E<60MeV
Delayed	$T_p<T_d<100\mu s$	7<E<12MeV

Most of them are same as the LSND.
→ Direct ultimate tests for LSND.

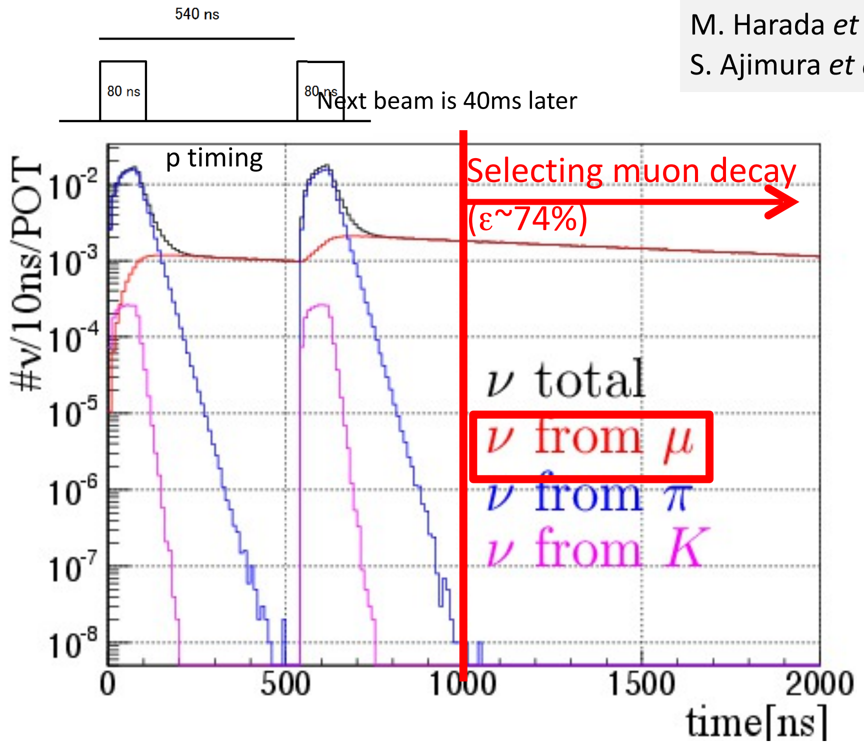
But use much better beam and Gd loaded LS.
→ Much better S/N
→ Much better systematics

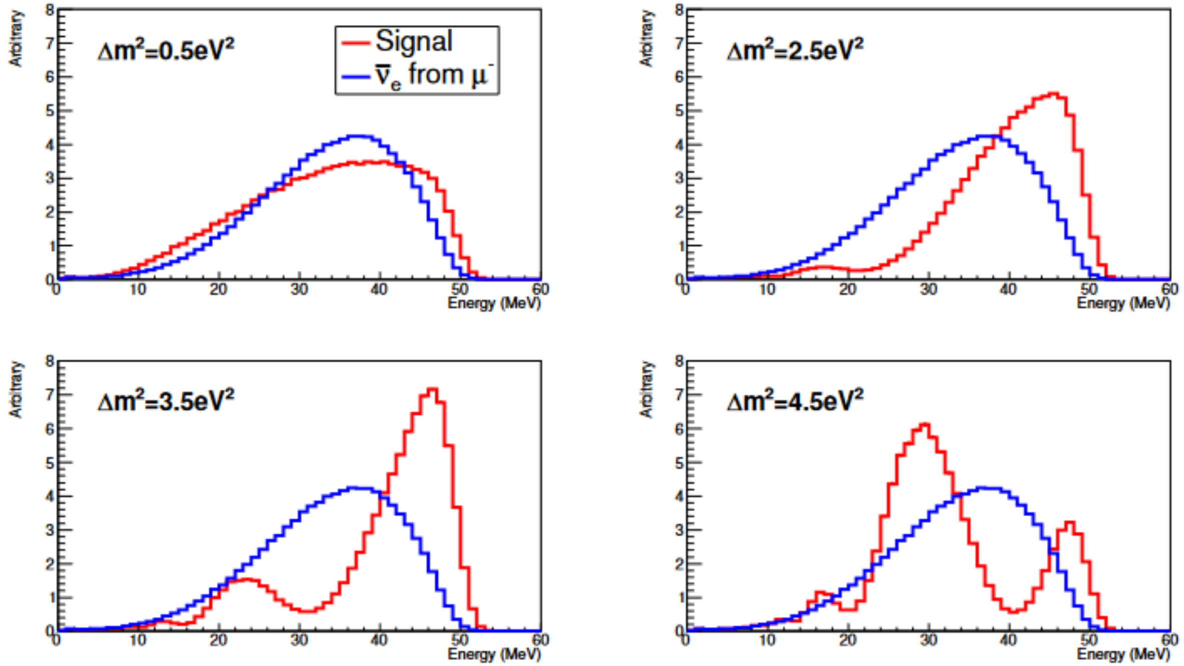
Timing and Energy

M. Harada *et al*, arXiv:1310.1437
S. Ajimura *et al*. arXiv:1705.08629

Timing and Energy are friends of JSNS²

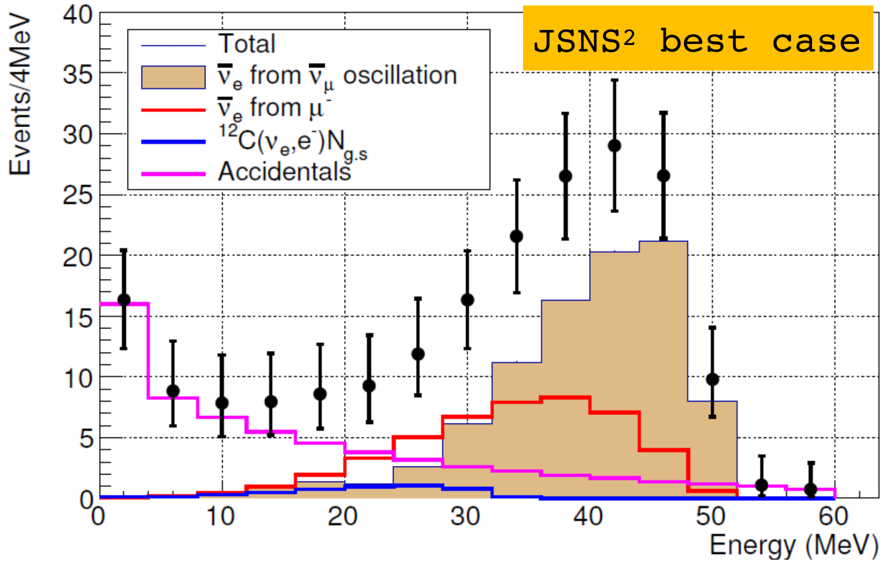
- Timing: Ultra-pure ν from μ^+ Decay-at-Rest
  - ν from π and K -> removed with timing
  - Beam Fast neutrons -> removed w/ time
  - Cosmic ray BKG -> reduced by 9μs time window.
- Energy: signals / BKG separation by energy.
  - ν from μ has well-known spectrum.
  - Energy reconstruction is very easy at the IBD. (Eν ~ Evis + 0.8MeV)
  - ν from μ- is high suppressed.

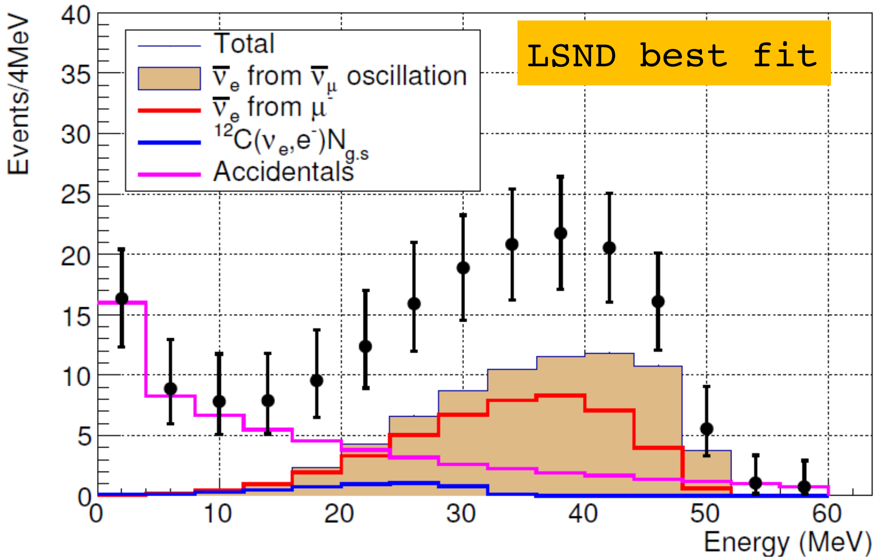




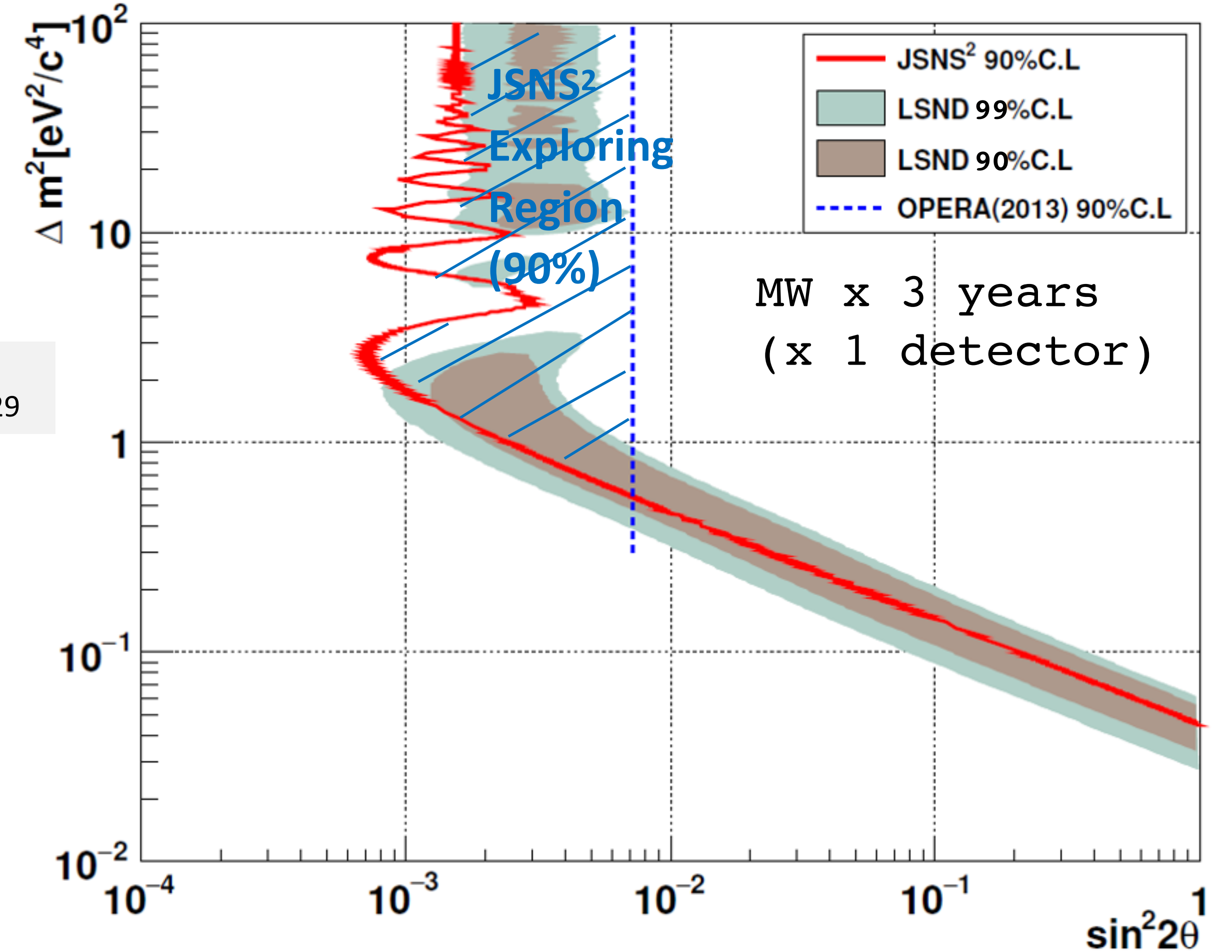
Energy Spectrum and Sensitivity (by MC simulation)

- Left: Energy spectrum; (Top: $\Delta m^2=2.5eV^2$, Bottom; $1.2eV^2$ $\sin^2 2\theta$ = 0.003)
- Right: Sensitivity of 3 years physics running of JSNS² with one detector.





S. Ajimura *et al.*
arXiv:1705.08629

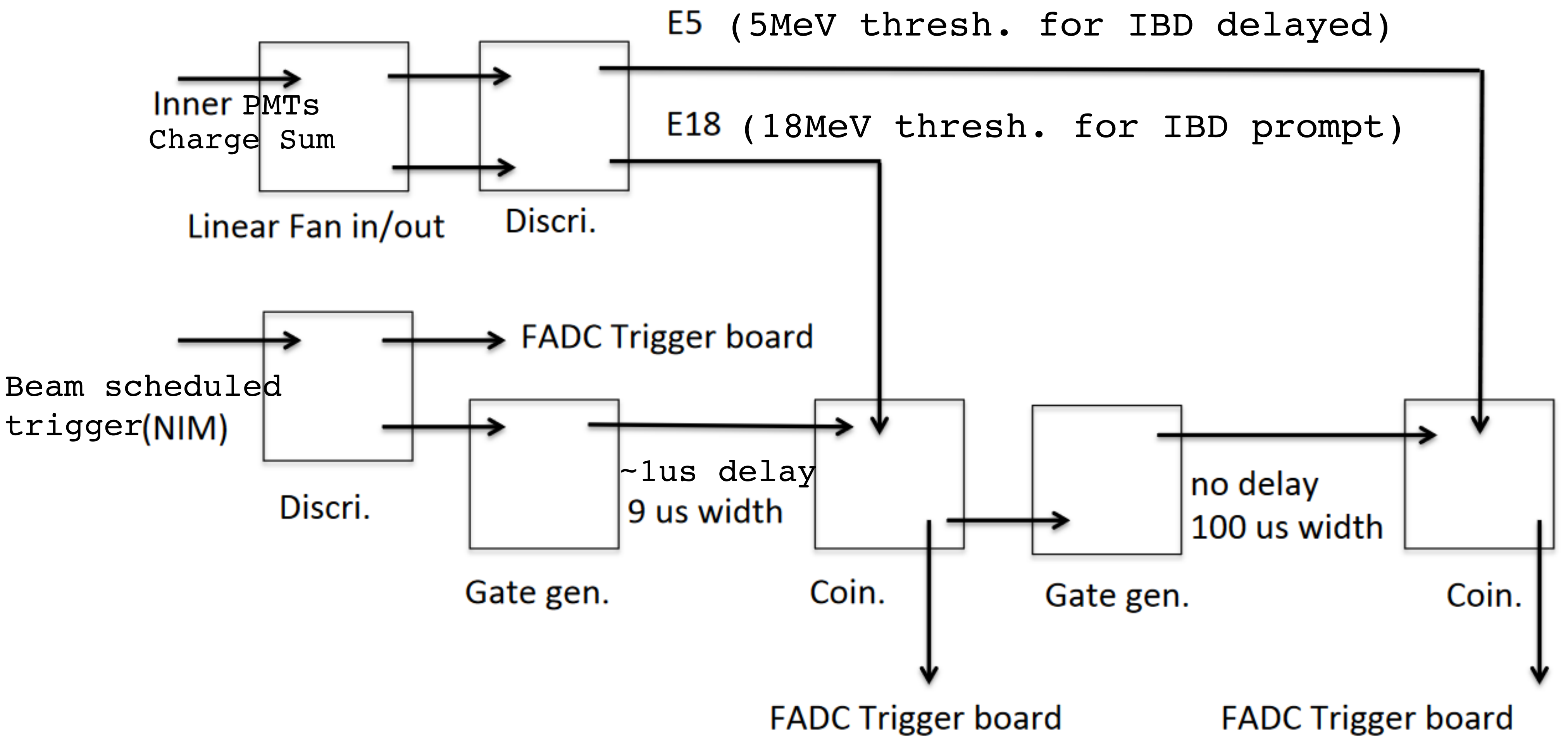


JSNS^2 vs LSND

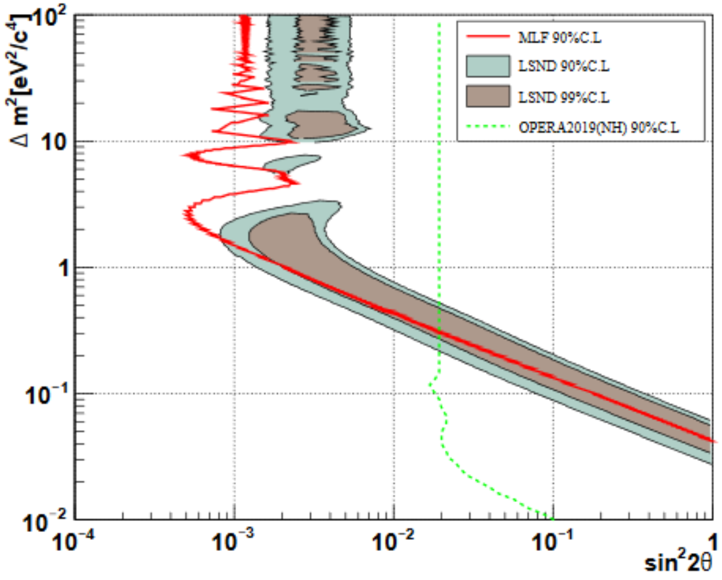
	JSNS^2	**LSND**
Target Mass	17 tons	167 tons
Baseline	24 meters	30 meters
Beam energy	3 GeV (larger # π^+ but also π^-)	0.8 GeV
Beam Duty Factor	**0.8/40000 (by Synchrotron)**	**1/14 (by Linac)**
Stopping μ^-/μ^+	1.7×10^{-3}	6.5×10^{-4}
Liquid Scintillator	**Gd-loaded** + large scint. light	Small #scinti. Light (to see Cherenkov), no Gd
Delayed signal	**Etot~8MeV, Δt~30μs**	**Etot~2.2MeV, Δt~200μs**
ΔE/E	2.4% @ 45MeV	7% @ 45MeV
Fast neutron rejection	Pulse Shape Discrimination	Cherenkov
# of IBD signal		

New Trigger scheme for sterile ν search

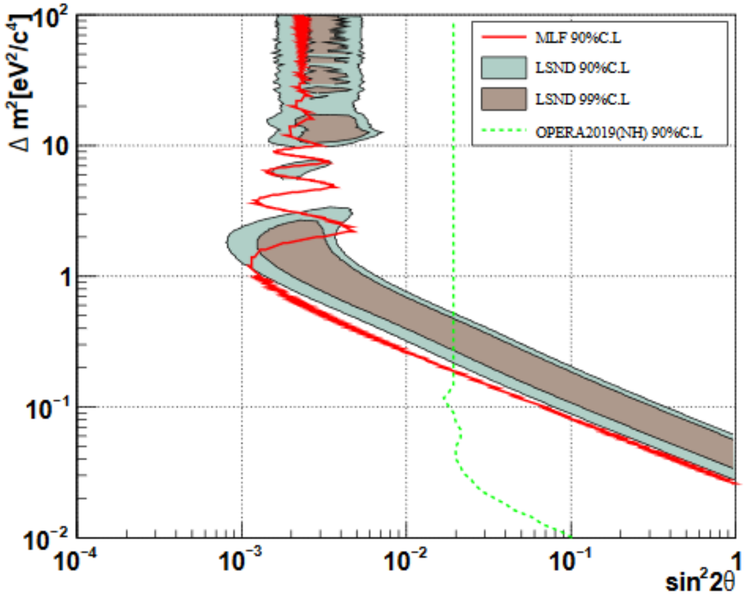
- Will be tested after PAC.
- Trigger rate is below the band width.



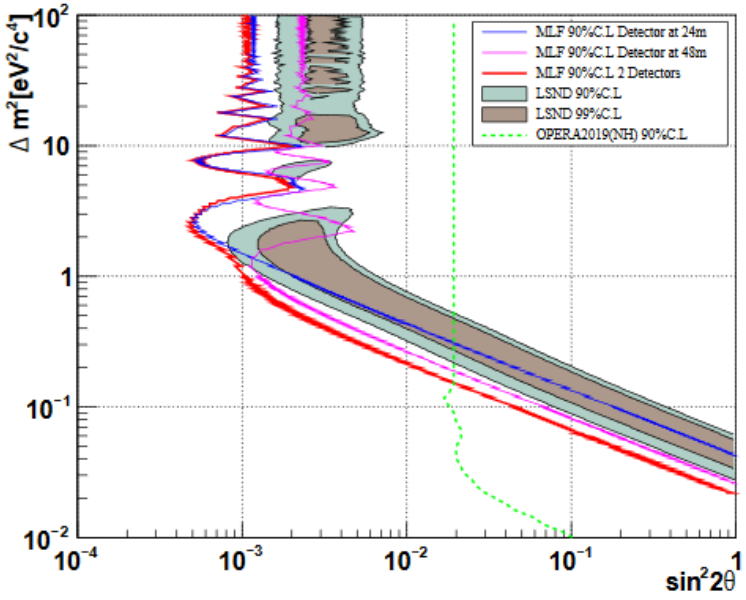
Each detector / combined (JSNS2-II)



(a) near (24 m)



(b) far (48 m)



(c) each detector/combined

Conceptual design of the 2nd detector

- JSNS2-II already started to negotiate with Fire Department to discuss Japanese Fire Law. → currently, no show stoppers.
- The stainless steel tank and acrylic vessel can be made by the same companies as the 1st detector. (already making the drawings)
- Daya-Bay already approved to donate the GdLS for the target region and LS for the cather region. → Now, how to transport is being discussed.