JSNS² Experiment

Takasumi Maruyama (KEK)

Direct test of LSND.

Collaboration meeting @ J-PARC (2020/Feb)

JSNS² collaboration (61 collaborators)
- 6 Japanese institutions (27 members)
- 10 Korean institutions (26 members)
- 1 UK institution (1 members)
- 4 US institutions (7 members)

JAEA
KEK
Kitasato,
Kyoto
Osaka
Tohoku

Soongsil
Dongshin
GIST
Seoyeong
Chonnam National
Seoul National
Chonbuk Natinal
Kyungpook
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;

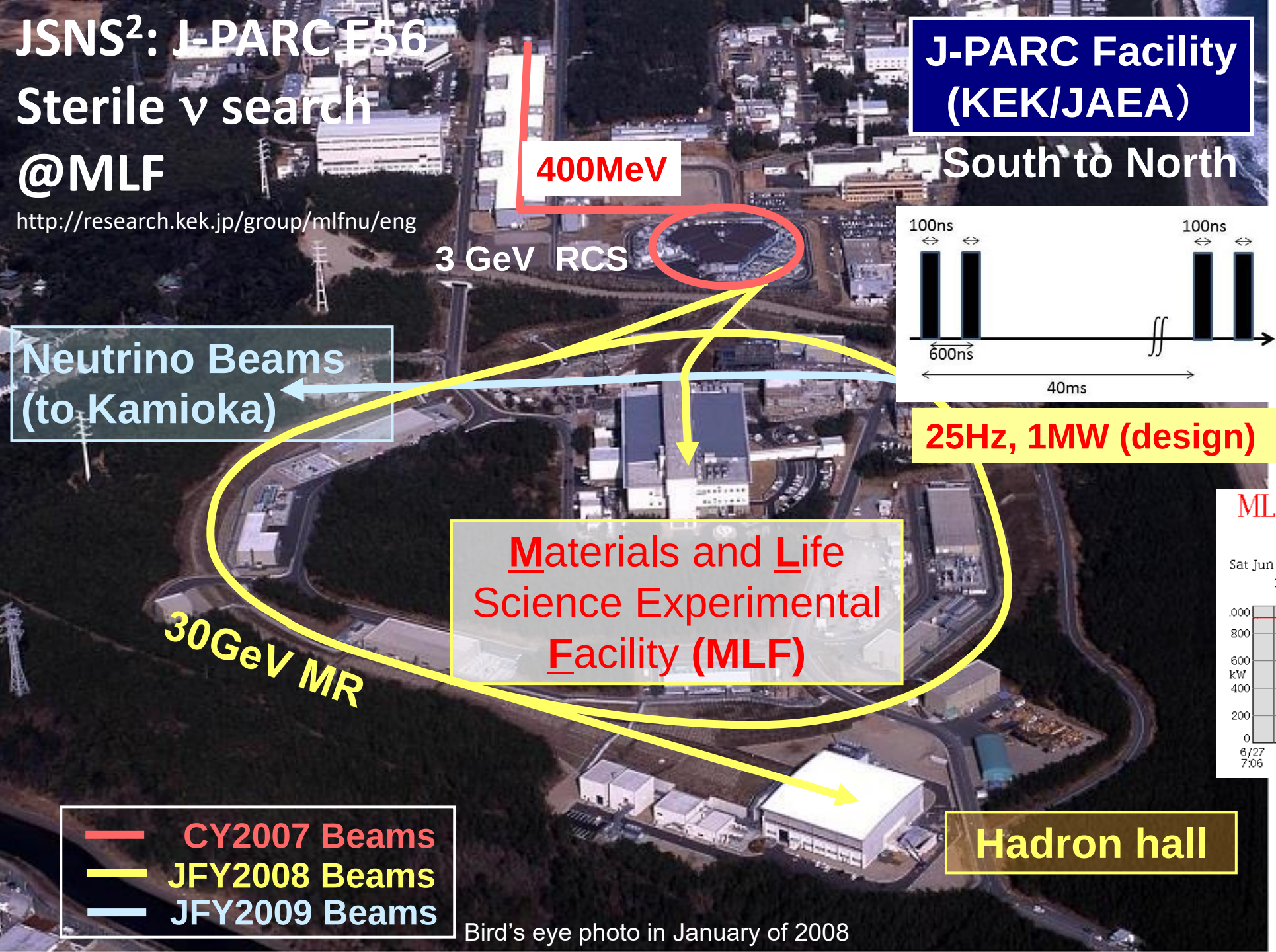
Experiments	Neutrino source	signal	significance	E(MeV),L(m)
LSND	μ Decay-At-Rest	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.8σ	40,30
MiniBooNE	π Decay-In-Flight	$\nu_\mu \rightarrow \nu_e$	4.5σ	800,600
		$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	2.8σ	
		combined	4.7σ	
Ga (calibration)	e capture	$\nu_e \rightarrow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

JSNS^2: J-PARC E56 Sterile ν search @MLF

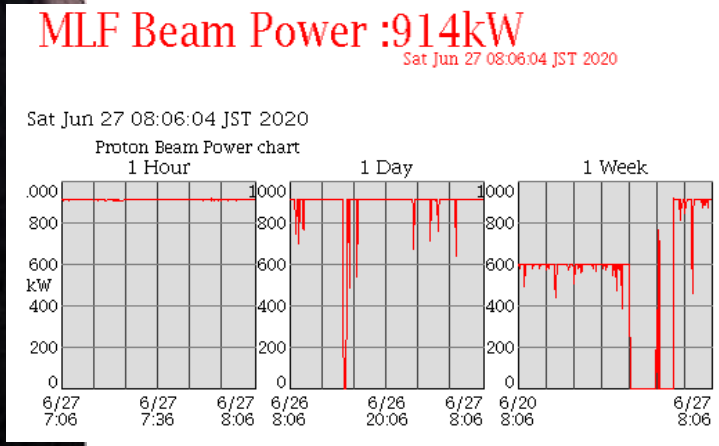
http://research.kek.jp/group/mlfnu/eng



Bird's eye photo in January of 2008

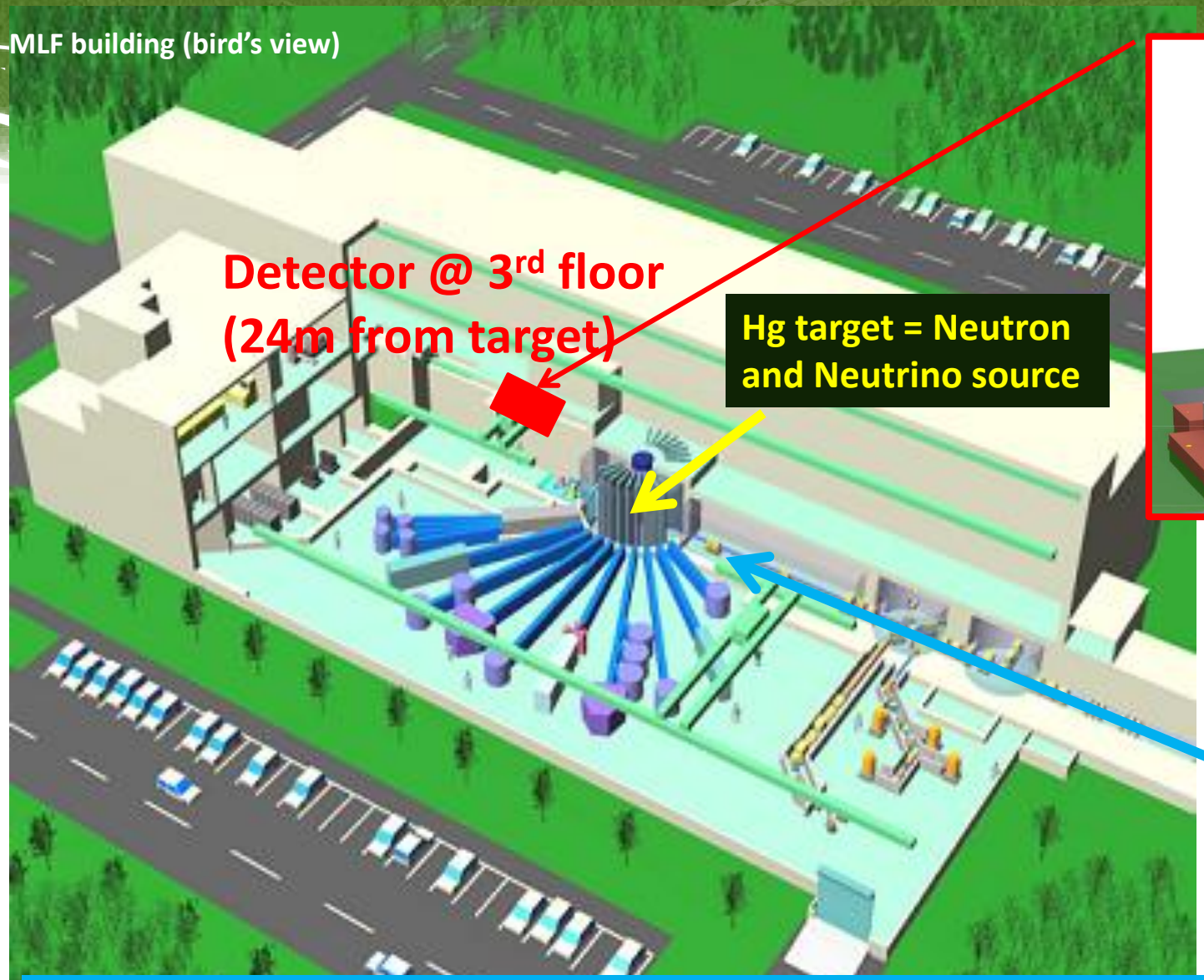
25Hz, 1MW (design)

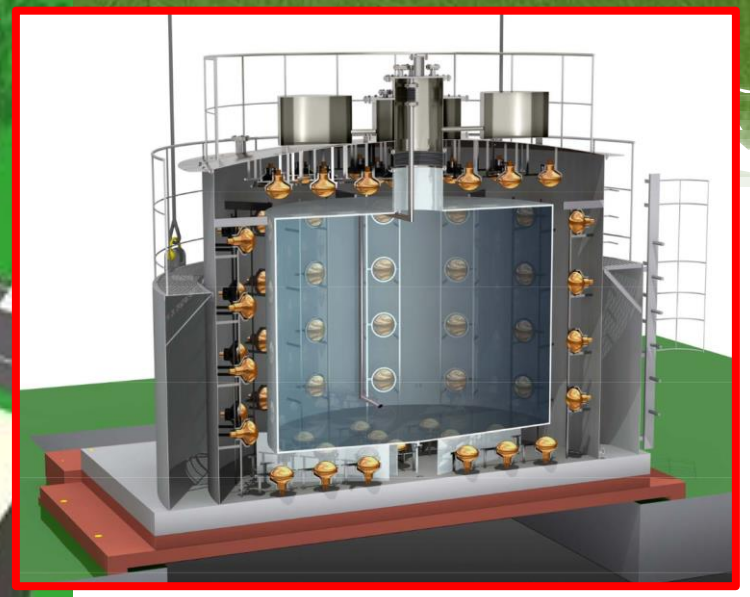
Low duty factor beam (short pulse + small repetition rate) gives very nice S/N ratio.



>0.9MW beam was utilized for users from Jun-25 to 27 in 2020.

J-PARC MLF : one of the world best environments





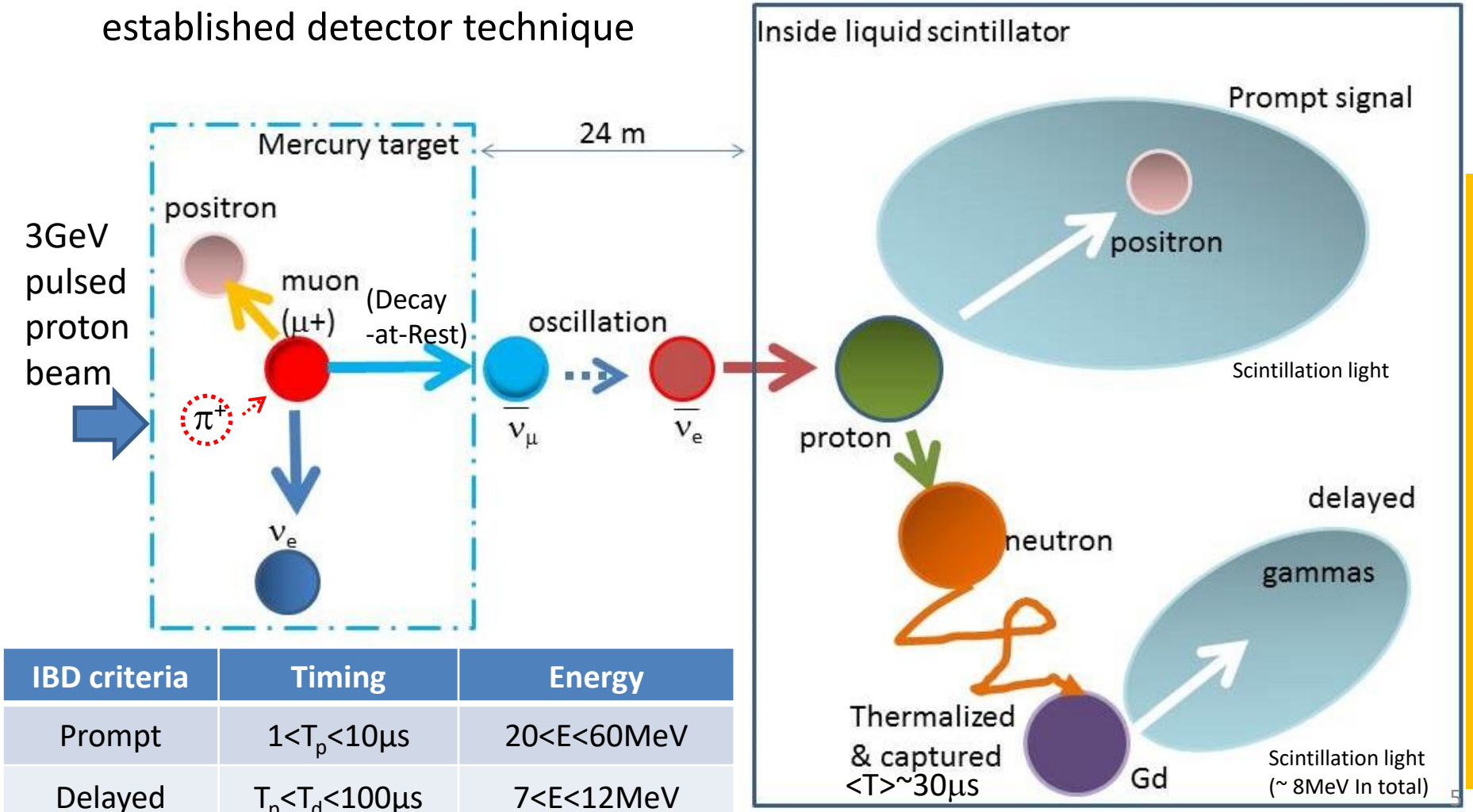
50t (Gd-loaded + unloaded)
liquid scintillator detector
(4.6m diameter x 4.0m height)
120 10" PMTs

3GeV pulsed proton
beam

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.

Production / Detection

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

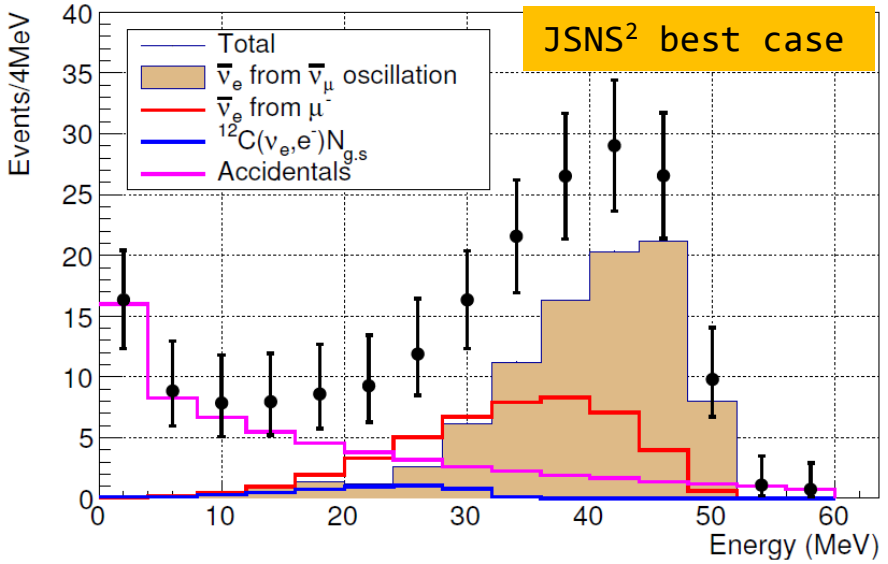
But use much better beam and Gd loaded LS.
→ Much better S/N
→ Much better systematics

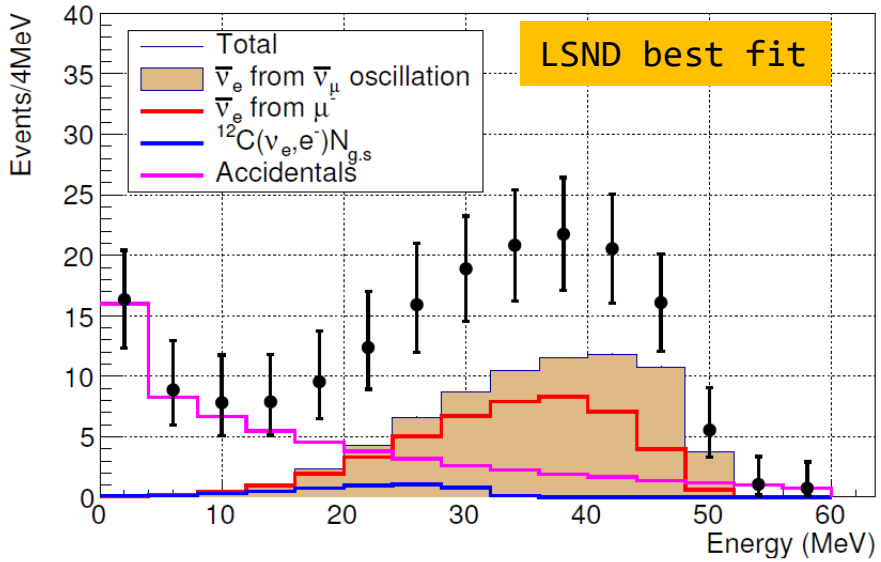
JSNS^2 vs LSND

	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
$\Delta E/E$	2.4% @ 45MeV	7% @ 45MeV
Fast neutron rejection	Pulse Shape Discrimination	Cherenkov
# of IBD signal events (after offline cuts)	~20 events / year (LSND best fit (Δm^2=1.2eV^2, $\sin^2 2\theta$=0.003))	15 / year

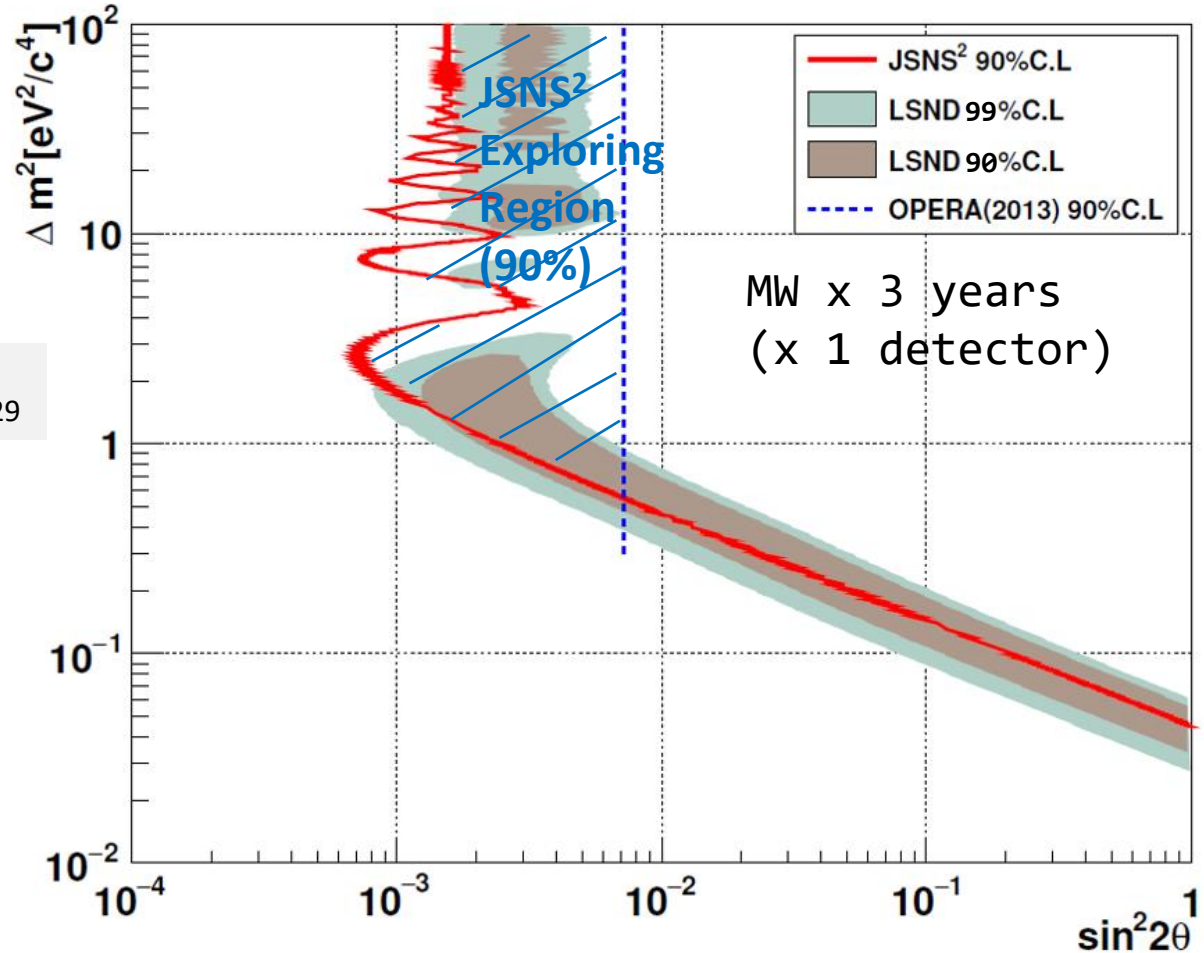
Energy Spectrum and Sensitivity (by MC simulation)

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





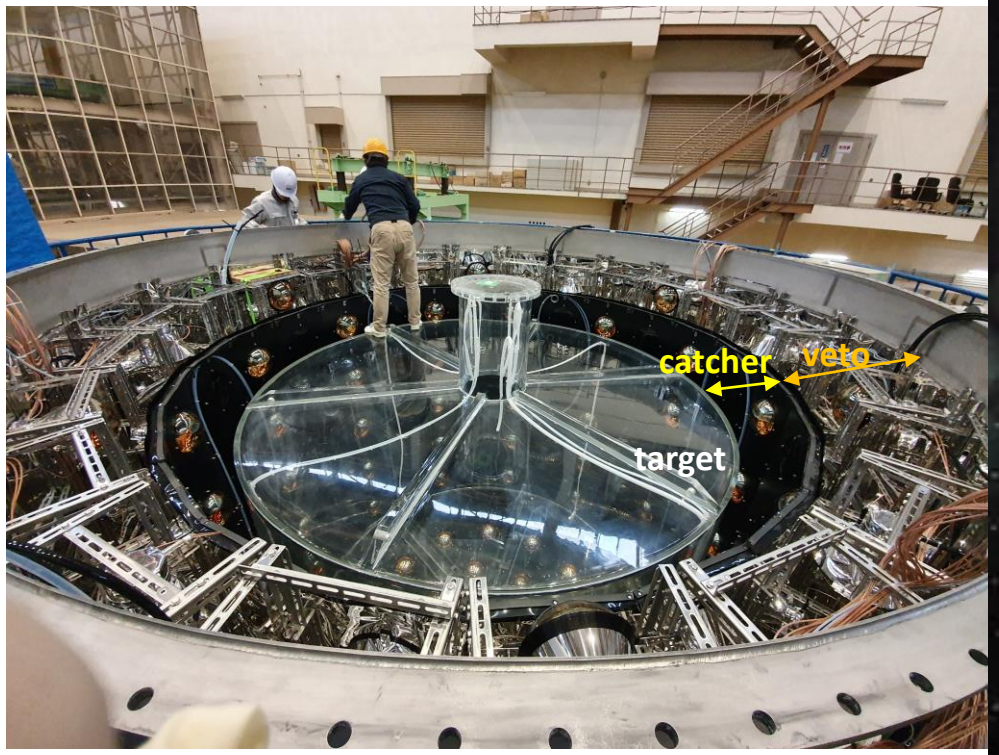
S. Ajimura *et al.*
arXiv:1705.08629



Detector construction (2017–2020)

- The detector construction was finished 2020-Feb.
  - Stainless steel tank was produced by Japanese company (2017-2018: Morimatsu) JINST 14 (2019) no.09, T09001
  - Acrylic tank was produced by Taiwan company (2018-2019: Nakano).
  - 10” PMTs : arXiv:2005.01599 (also accepted by JINST)
    - ~53% is reused from RENO.
    - ~30% is newly purchased.
    - ~17% is reused from Double-Chooz.
  - 35 ton of pure liquid scintillator was produced by Korean collaborators at RENO site (2018) JINST 14 (2019) no.09, T09010
  - 17 tons Gd loaded liquid scintillator was donated by Daya-Bay (2019).
  - Electronics and DAQ system: arXiv:2006.00670
    - FADCs are donated by DC – Japan.
    - Front End Elec. are donated by DC.
    - HV are reused from DC.
    - Elec. upgrade will be done (See backup)
  - New Fast LED calibration system

Very efficient experiment using reused or donated materials from various experiments. We do appreciate Daya-Bay, RENO and DC.



See also posters #353, 355, 444

Detector Assembly Building -> MLF （2020/Feb-19）

After this exciting time, COVID-19 affects to JSNS^2 for a while.

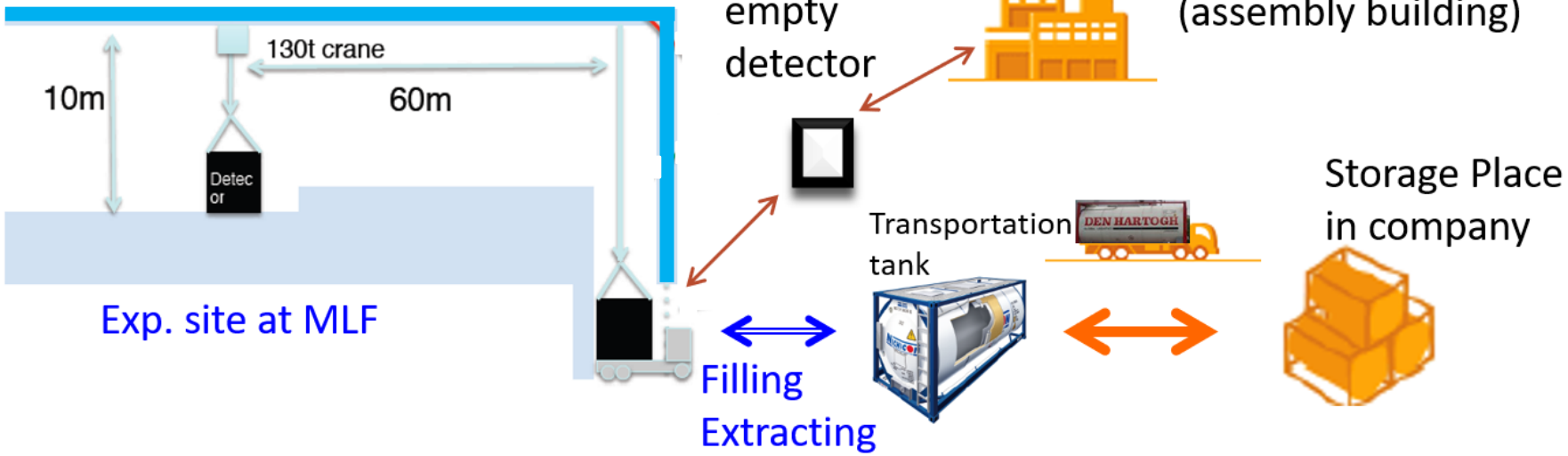
Annual operation of Liquid Scintillator (JSNS^2 specific features)

- MLF 3rd floor is the maintenance area for the mercury target and beam equipment. → need to bring in and out the detector during summer beam shutdown every year (4 months).
- I.e. : we have to fill in and extract out (Gd)LS during short time.
- We have used iso-tanks (transportation / storage tanks) for the transportation and the storage.

- Iso Tank

Capacity; 24000 L
Tare Mass; 3.8T
With valves

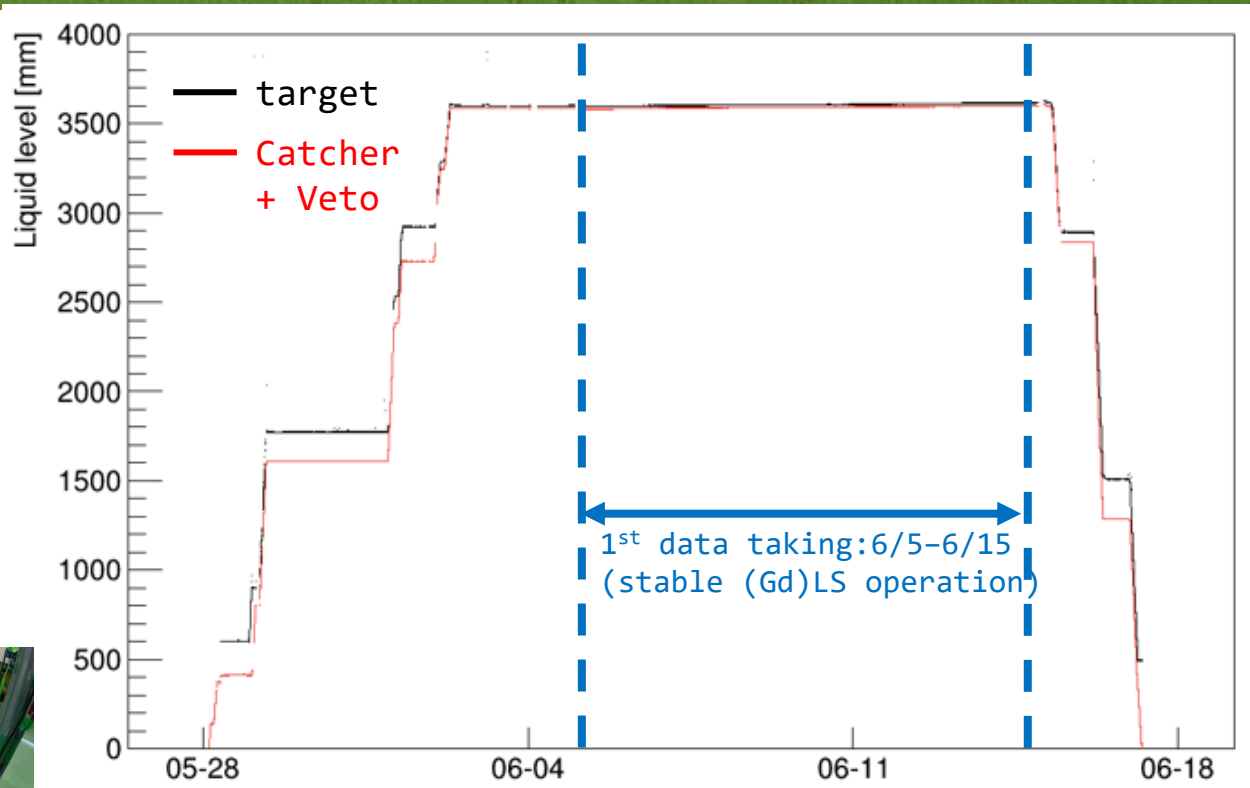
LS operation / transportation in Japan



First (Gd)LS filling and extraction (2020-June)

- 5/26-27: 3 iso-tanks were installed
- 5/28-6/2:(very smooth) filling
- **6/5-15 : first physics run**
- 6/15-17: (very smooth) extraction

- Our detector has only 2 layers, so easier than reactor experiments.



Very quick filling (5days) and extraction(3 days)!

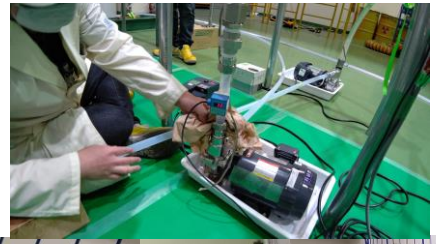
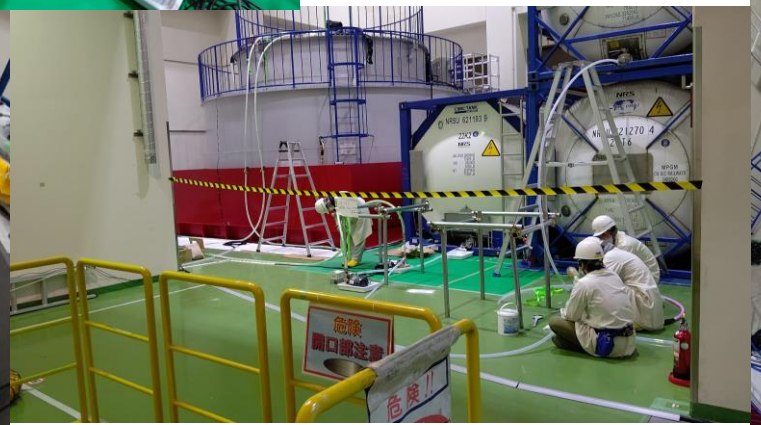
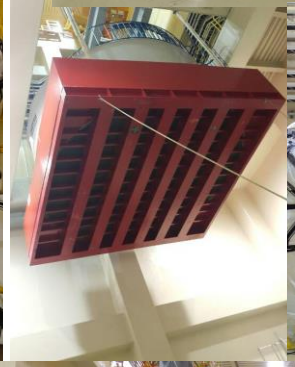


photo by Camera (inside)



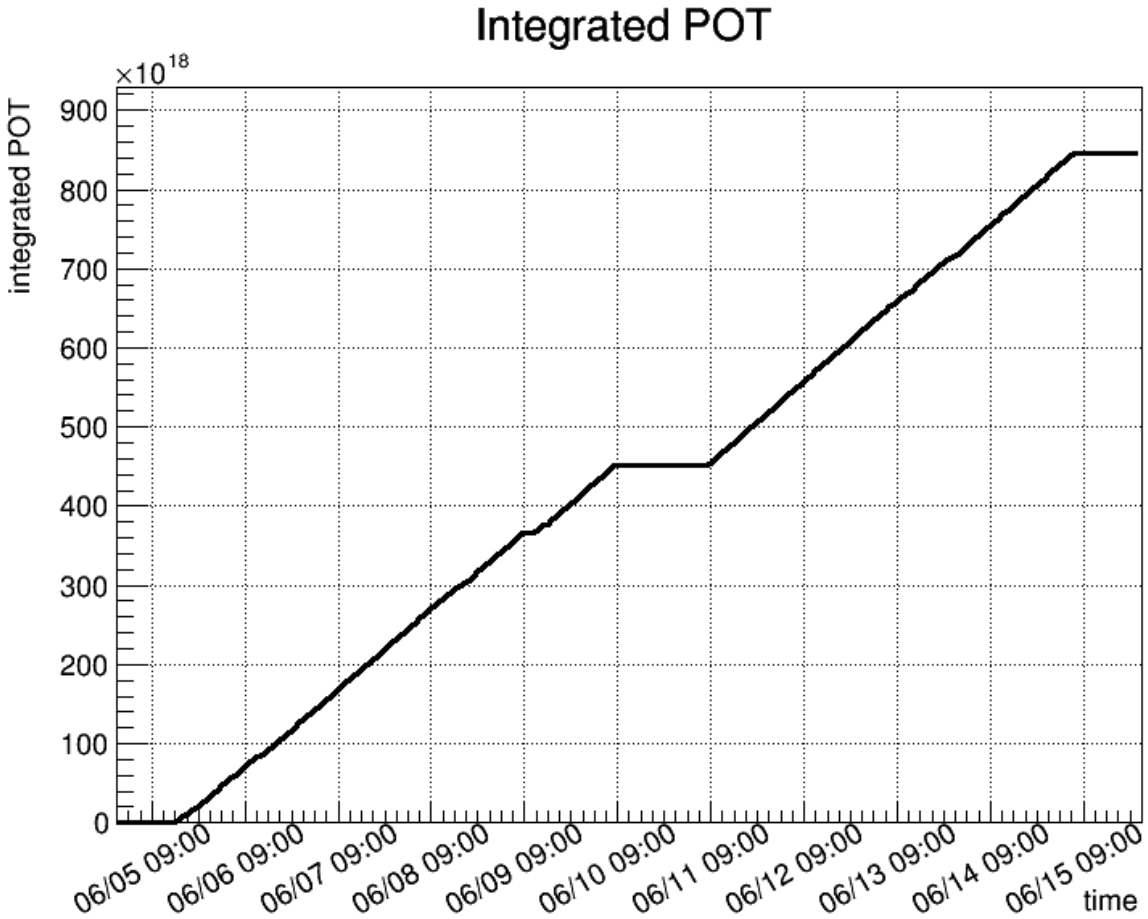
June-5 : detector : MLF 1st to 3rd floors



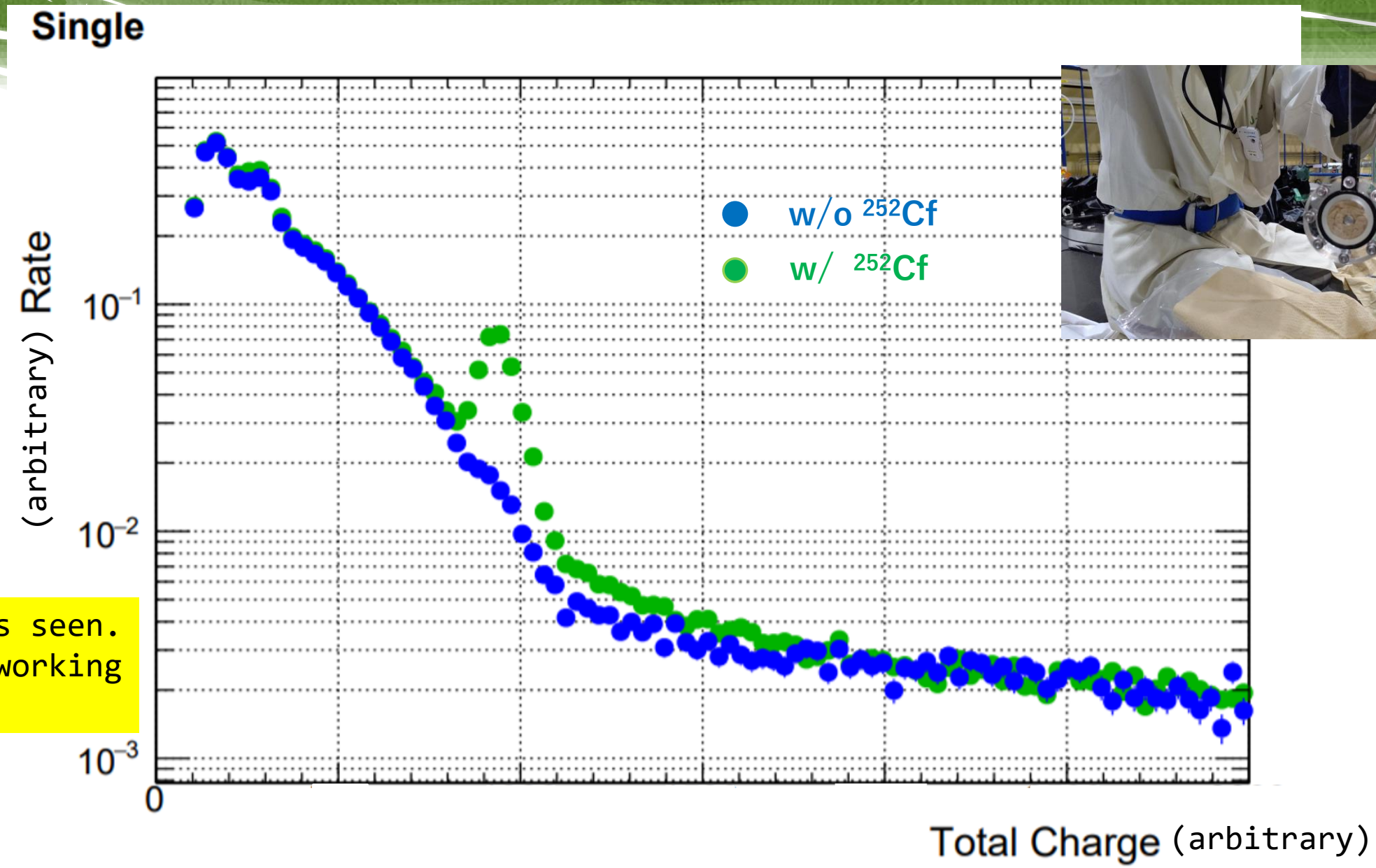
Highlight of the 1st run
(note : just 2.5 weeks ago!!)

Beam power / POT

- Average Beam power: 602kW (4.97×10^{13} POT/spill)
- We have mini beam maintenance period (12 or 24 hours) on every Wed.
  - June-10: 24 hours mini-shutdown.
  - We use this period for calibration campaign (LED, ^{252}Cf, run w/o beam)
- 8.46×10^{20} POT for the 1st physics run
  - 0.8% of approved POT (by J-PARC PAC)
  - Less than 1 IBD event are expected.
  - However, our detector is working well, and JSNS2 shows strong potential from the next physics run (from this fall).
- J-PARC and MLF aims to have a design beam power (1MW) as soon as possible.
  - As mentioned, the MW beam was utilized for MLF users from June-25 to 27.

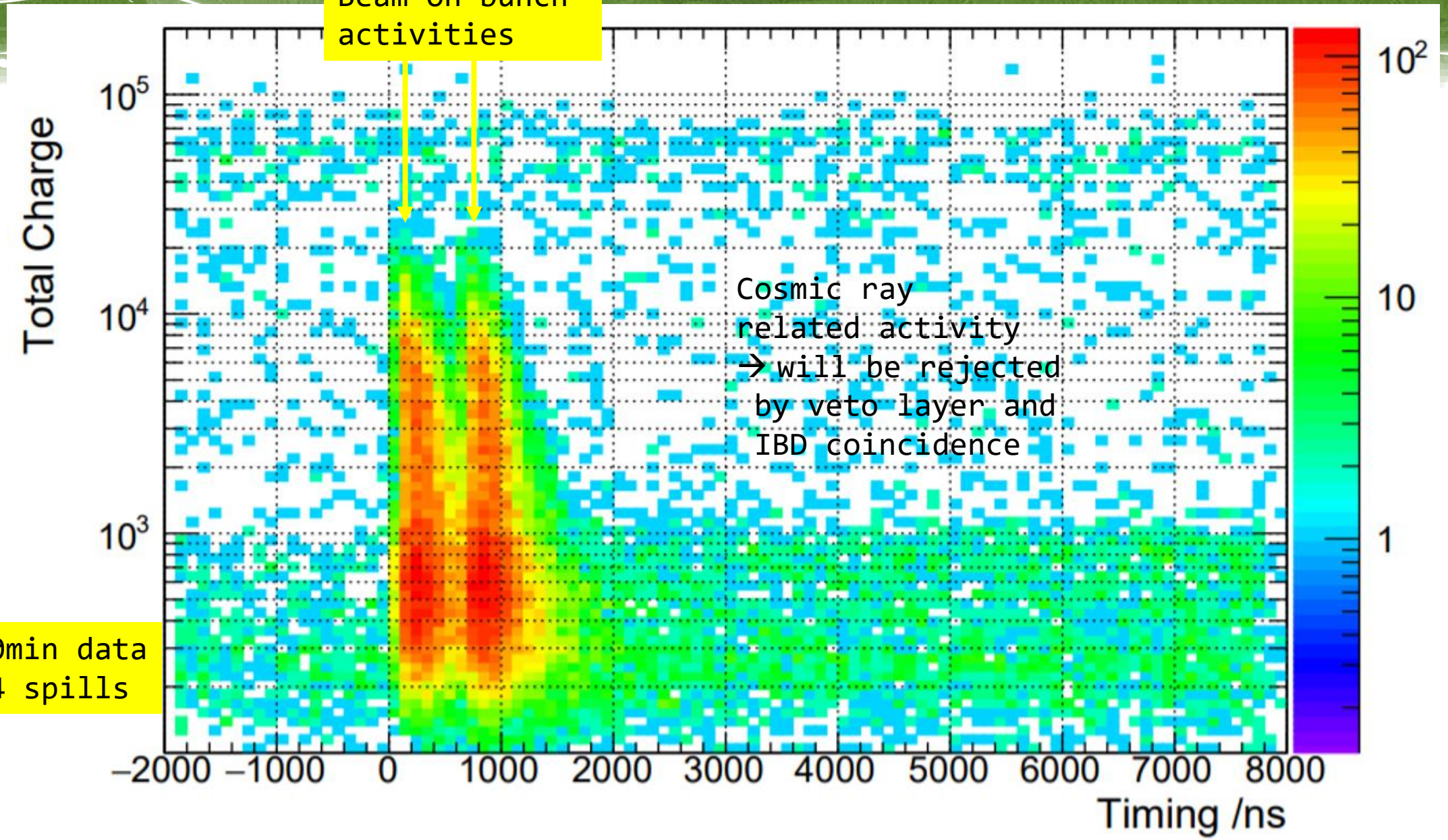


^{252}Cf calibration data (source is put on center)



Clear peak is seen. Detector is working well.

Activities around beam timing



First 30min data
-> 46524 spills

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.
- Just started data taking from 2020-June.
  - Operation (filling/extraction) of (Gd)LS have been very smooth and there have been no issues.
  - With data taking for 10 days (0.8% of data compared to the approved POT), we saw a good potential of this experiment as expected.
    - response of neutron capture signal is clear.
    - activities around beam timing looks as expected (similar to 2014 background measurements, and TDR). In near future, we will make quantitative statements for IBD (sterile neutrino search) background.
  - You will see the physics results from JSNS^2 soon!
- Aim to upgrade electronics in this year.
- We plan to construct the 2nd detector: essential to improve the sensitivity → actively seeking supports.

Thank you for your attention !!

acknowledgements:

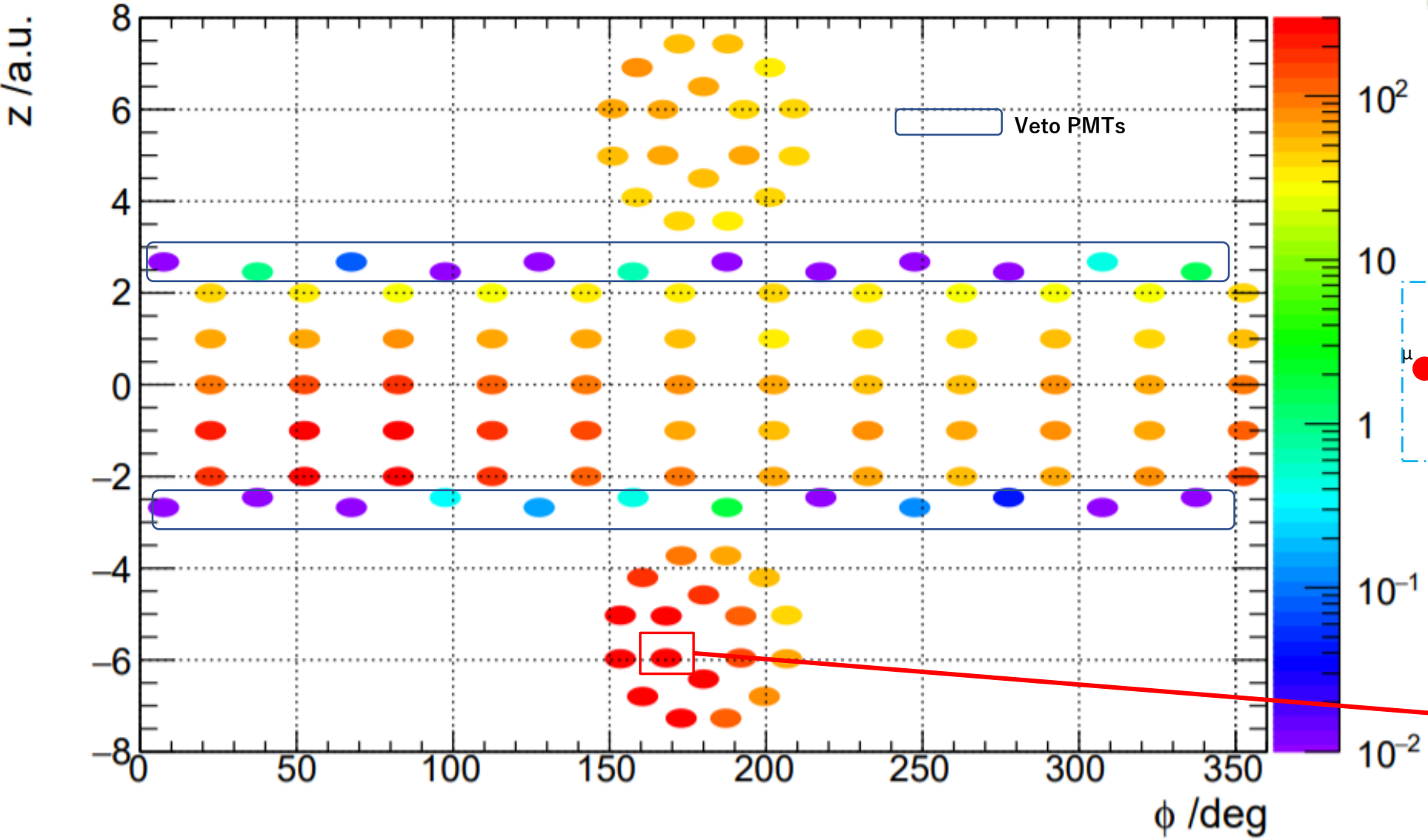
- MEXT, JSPS (Japan)
- Korea Ministry of Science, NRF (Korea)
- DOE, Heising-Simons Foundation (US)
- Royal Society (UK)

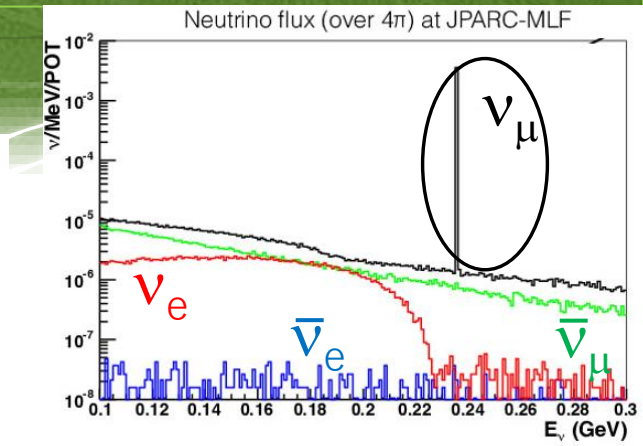
Posters of JSNS^2:

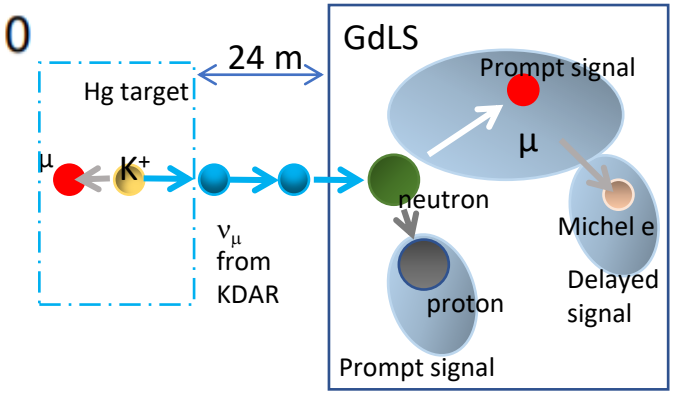
- Measurement of beam related gamma background using plastic scintillator at JSNS^2 (#332: D.E.Jung)
- PMT gain calibration for the JSNS^2 Experiment (#353: H.K.Jeon)
- Efforts for Launching JSNS^2 Experiment at J-PARC (#355: Y.Hino)
- The Design and Development of the JSNS^2 DAQ Upgrade (#367: E.Marzec)
- Signal Timing Analysis from the Dry Run in the JSNS2 experiment (#444: S.H.Jeon)
- KDAR Neutrino Measurements with JSNS^2(#482: J.R.Jordan)

KDAR (Kaon Decay-At-Rest) ν candidate: event display

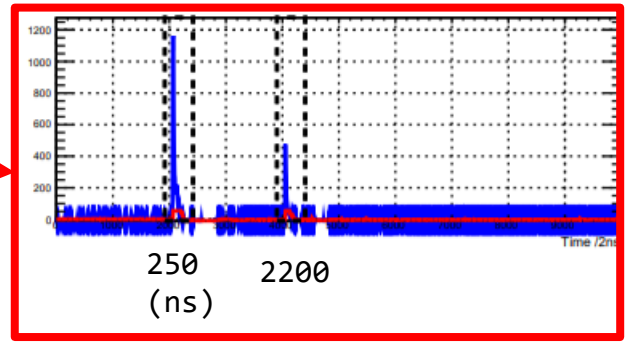
Another interesting topic for physics (see also poster #482)
(200-400 KDAR events / 10 days are expected for xsec meas.)







νμ int?



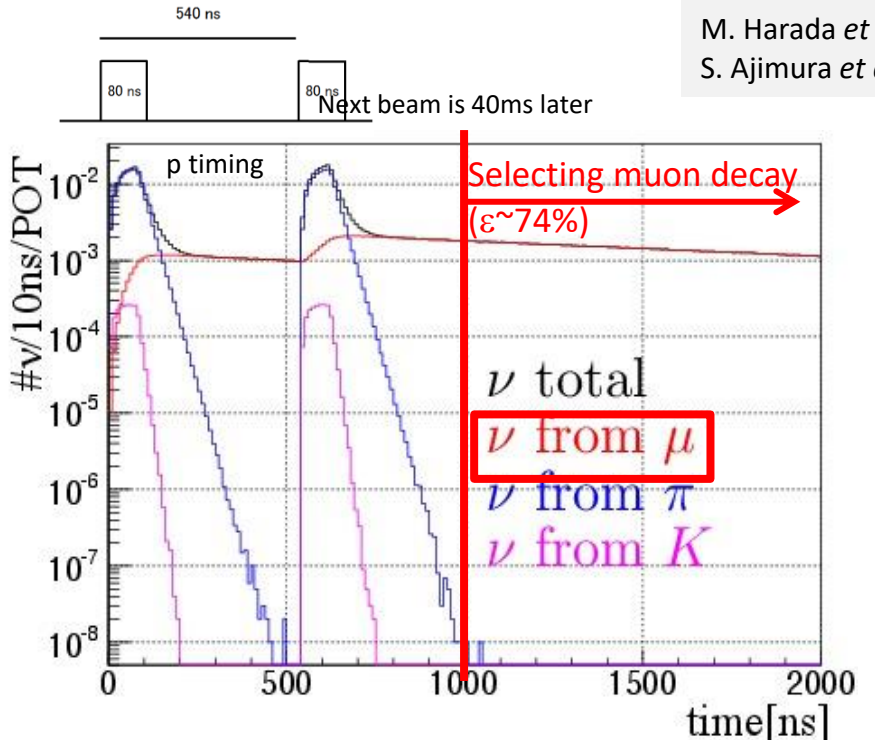
backup

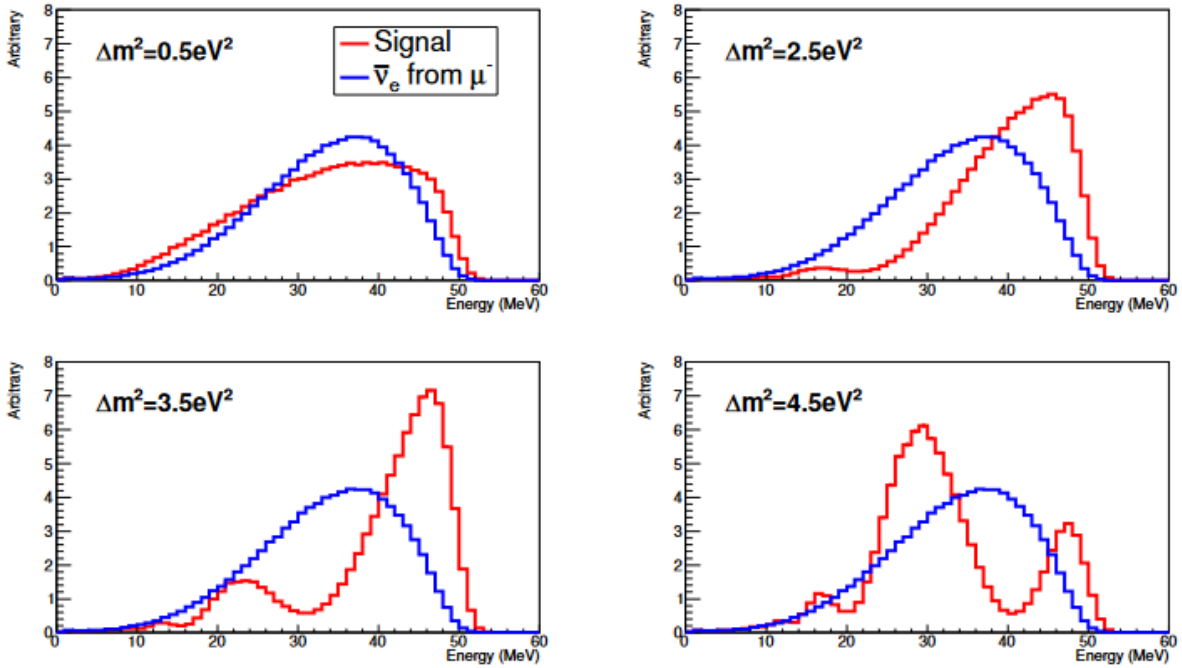
Timing and Energy

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.





#events (1MW x 3 years x 1 detector (17tons))

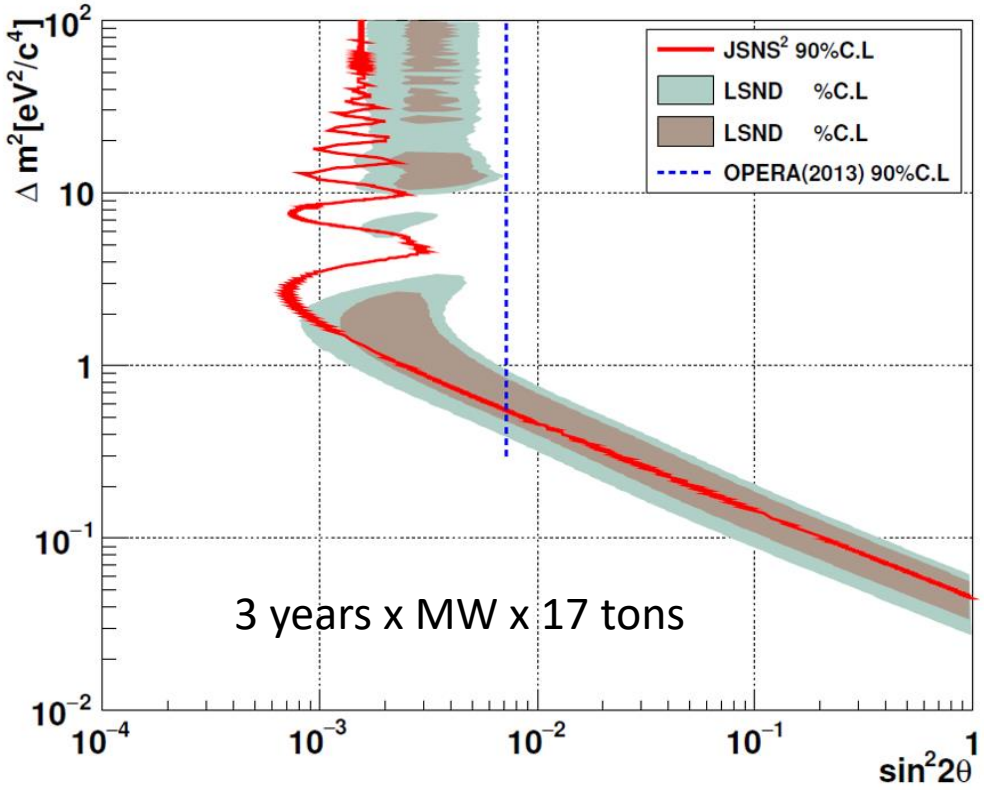
Source	contents	#ev.(17tons x 3years)	Reference : SR2014 (50tons x 5 years)	comments
background	$\overline{\nu}_e$ from μ-	43	237	Dominant BKG
	$^{12}C(\nu_e,e^-)^{12}N_{g.s.}$	3	16	
	Beam fast neutrons	**Consistent with 0 < 2 (90%CL UL)**	**<13**	**Based on real data**
	Fast neutrons (cosmic)	~0	37	
	Accidental	**20**	**32**	**Based on real data**
signal		87	480	Δm^2=2.5, $\sin^2 2\theta$=0.003
		62	342	Δm^2=1.2, $\sin^2 2\theta$=0.003

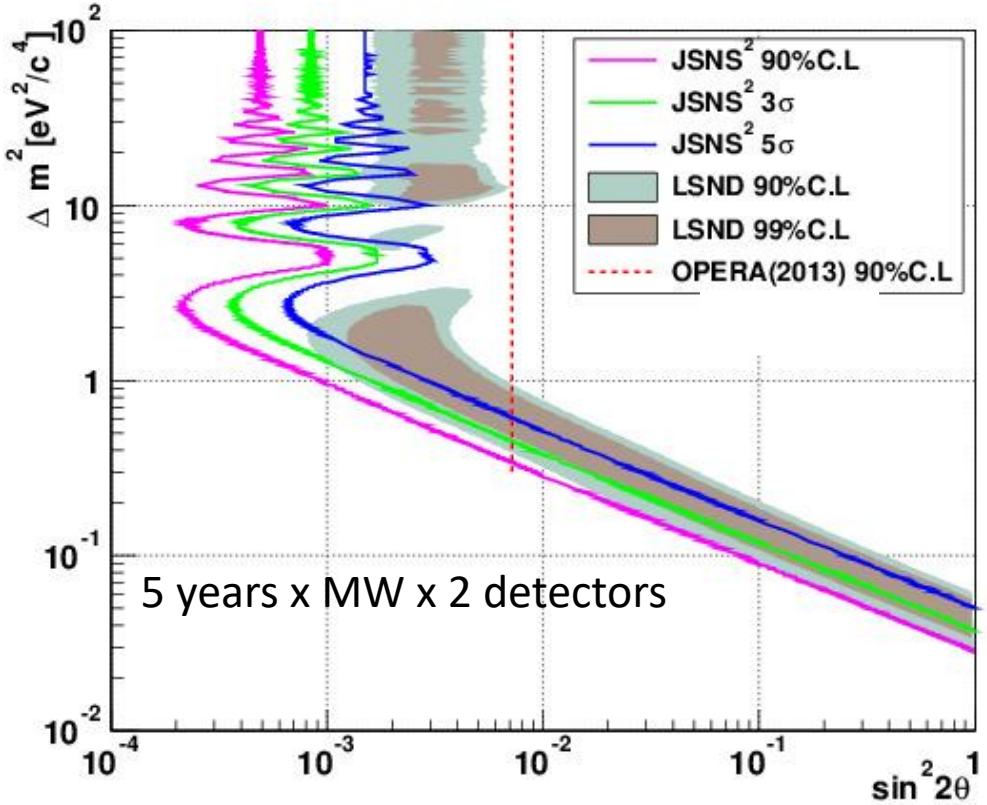
Accidental BKG is calculated by; $R_{acc} = \Sigma R_{prompt} \times \Sigma R_{delay} \times \Delta_{VTX} \times N_{spill}$

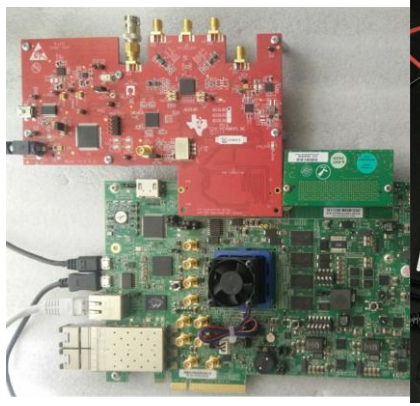
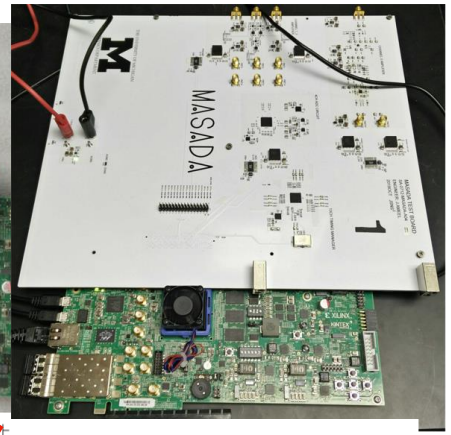
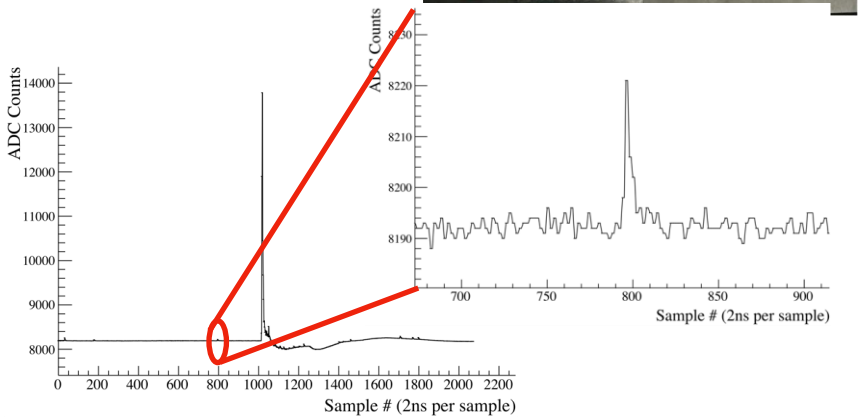
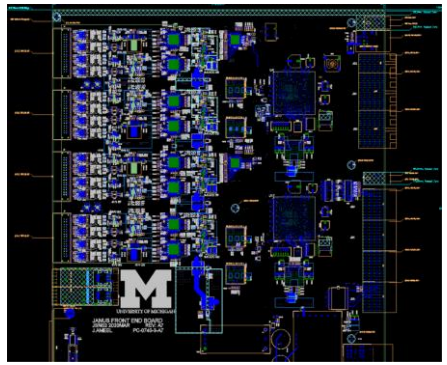
- ΣR_{prompt}, ΣR_{delay} are probability of accidental BKG for prompt and delayed.
- Δ_{VTX} ; BKG rejection factor of **50**.
- N_{spill}(#spills / 5 years) = 1.9×10^9

2nd detector

- To have a good international competition capability, we started the experiment with one detector (17tons fiducial volume).
- Even with one detector, we have a good 90% C.L constraints with 3 years. Left plot
- Meanwhile, we are making effort to obtain the budget to build the 2nd detector. This upgrade can provide the significant improvements for the sensitivity.





DAQ Upgrade in Progress

- New DAQ will incorporate beam timing signals and digitized PMT signals in complex FPGA based trigger scheme.
- PMT signals will be digitized at 14-bit resolution providing a large dynamic range without sacrificing single-PE signals.
- FPGA trigger will allow trigger logic based upon the timing and energy signatures of neutrino interactions.
- Will increase detector sensitivity especially at high energies e.g. KDAR neutrinos.
- PCB development & testing is underway. Aim to have the commissioning in this year.
- See poster #367 for more info!