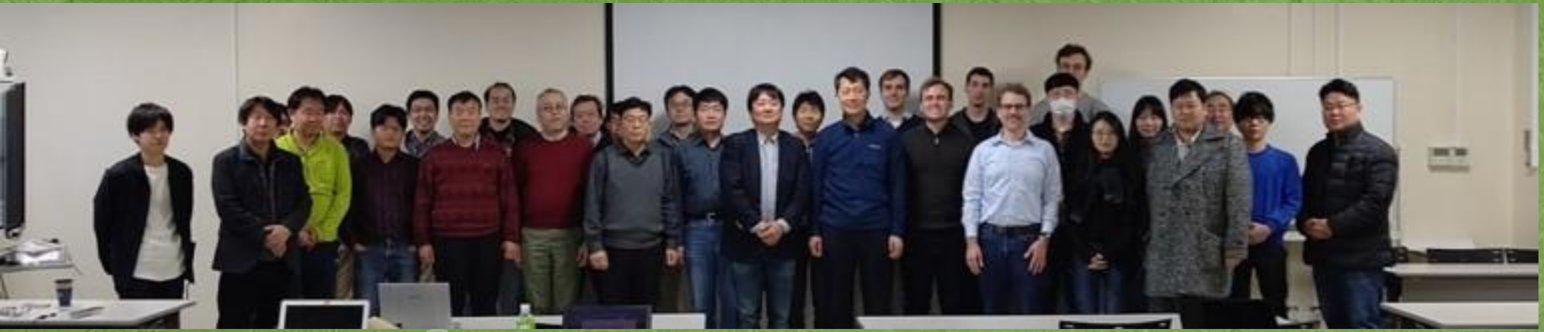
JSNS^2 (J-PARC Sterile Neutrino search at J-PARC Spallation Neutron Source)

Takasumi Maruyama (KEK)

JSNS^2 J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source

Direct test of LSND.

Collaboration meeting @ J-PARC (2020/Feb)



JSNS^2 collaboration (63 collaborators)
- 6 Japanese institutions (27 members)
- 10 Korean institutions (28 members)
- 1 UK institution (1 member)
- 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;

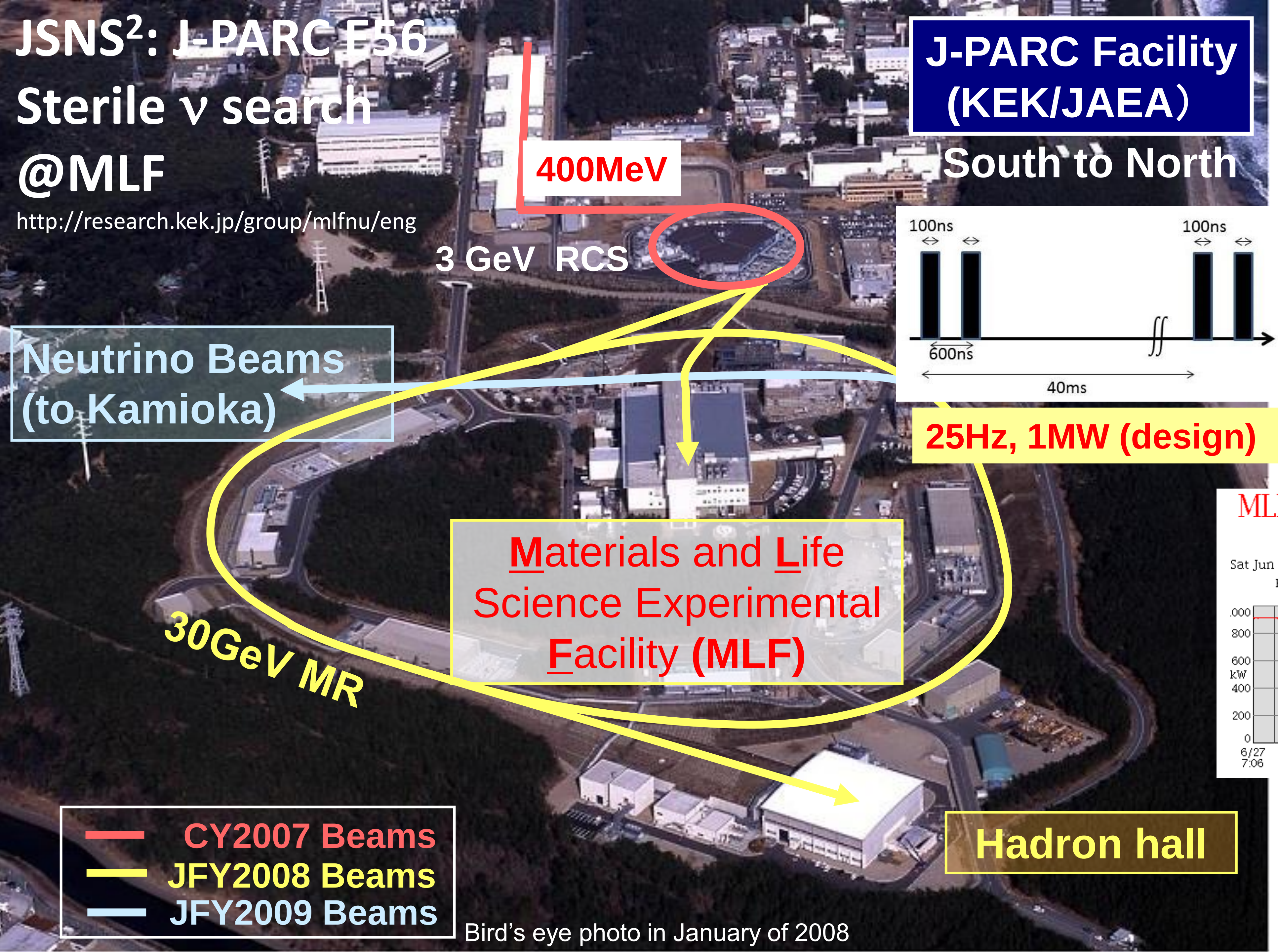
Experiments	Neutrino source	signal	significance	E(MeV),L(m)
LSND	μ Decay-At-Rest	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.8σ	40,30
MiniBooNE	π Decay-In-Flight	$\nu_\mu \rightarrow \nu_e$	4.5σ	800,600
		$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	2.8σ	
		combined	4.7σ	
Ga (calibration)	e capture	$\nu_e \rightarrow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

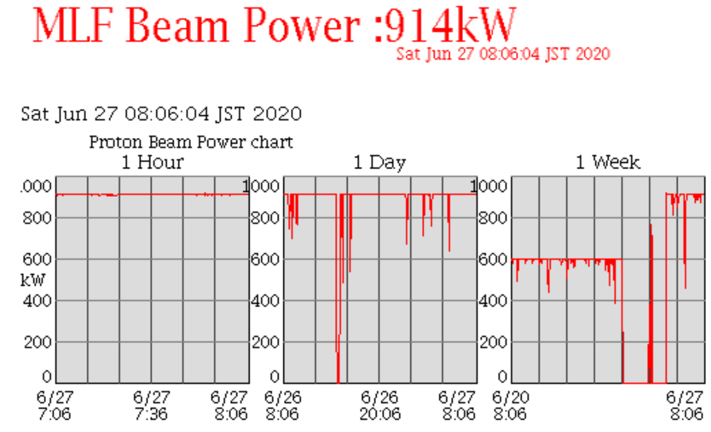
JSNS^2: J-PARC E56 Sterile ν search @MLF

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



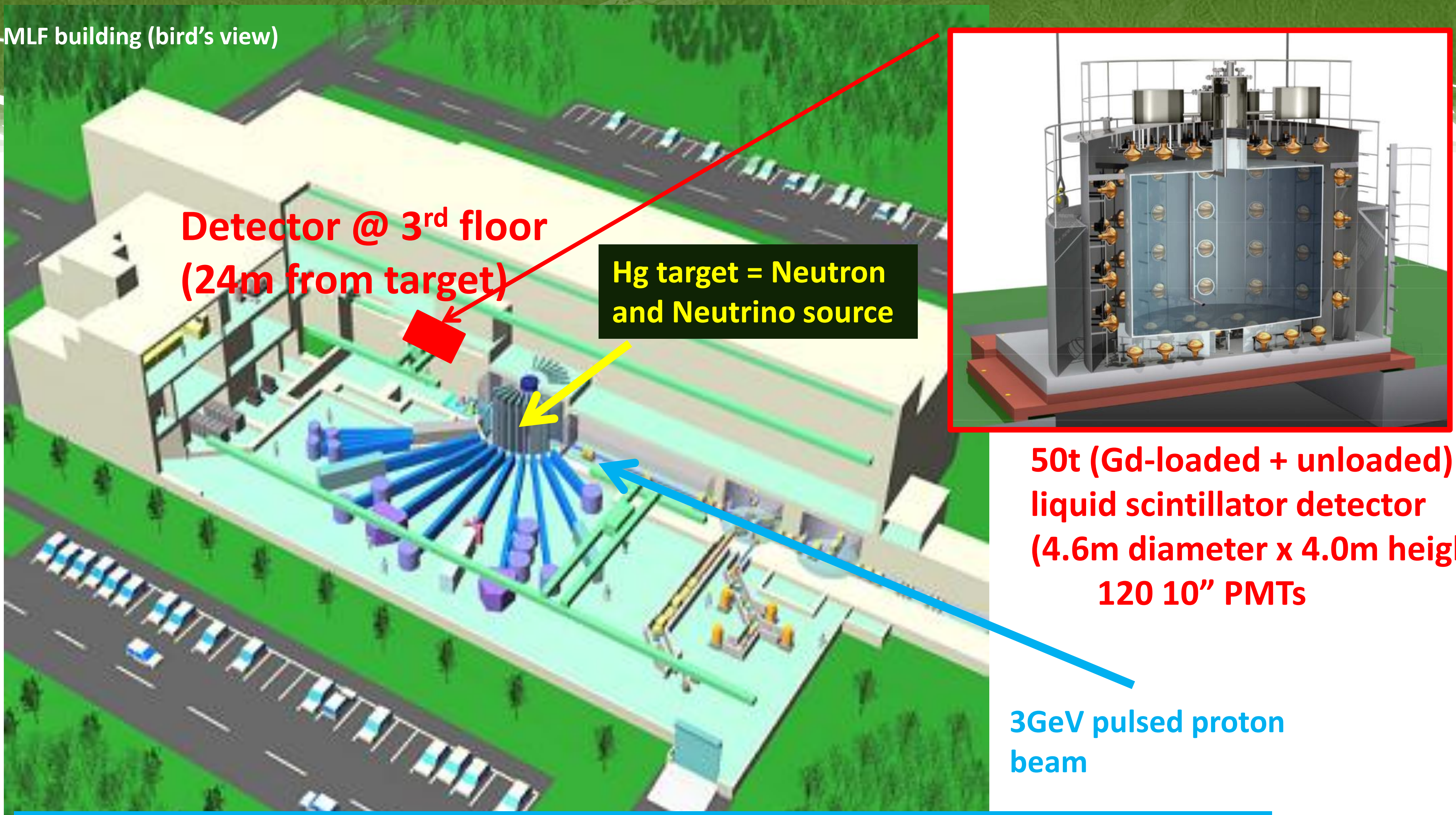
Bird's eye photo in January of 2008

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



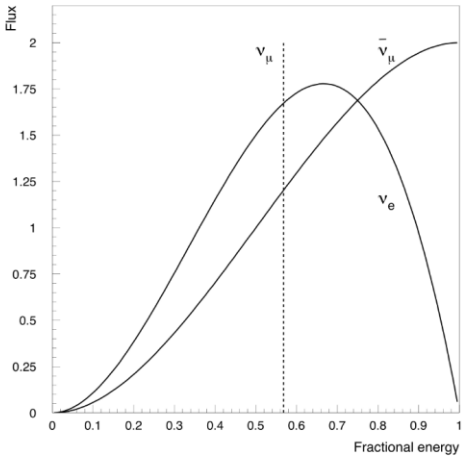
50t (Gd-loaded + unloaded)
liquid scintillator detector
(4.6m diameter x 4.0m height)
120 10" PMTs

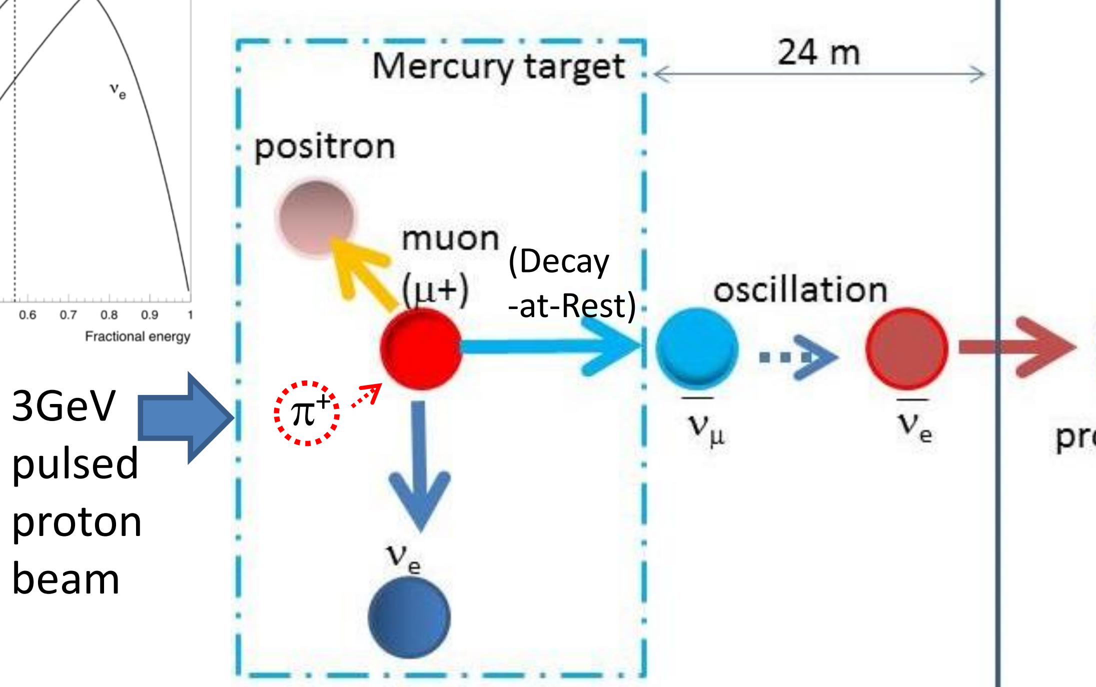
3GeV pulsed proton beam

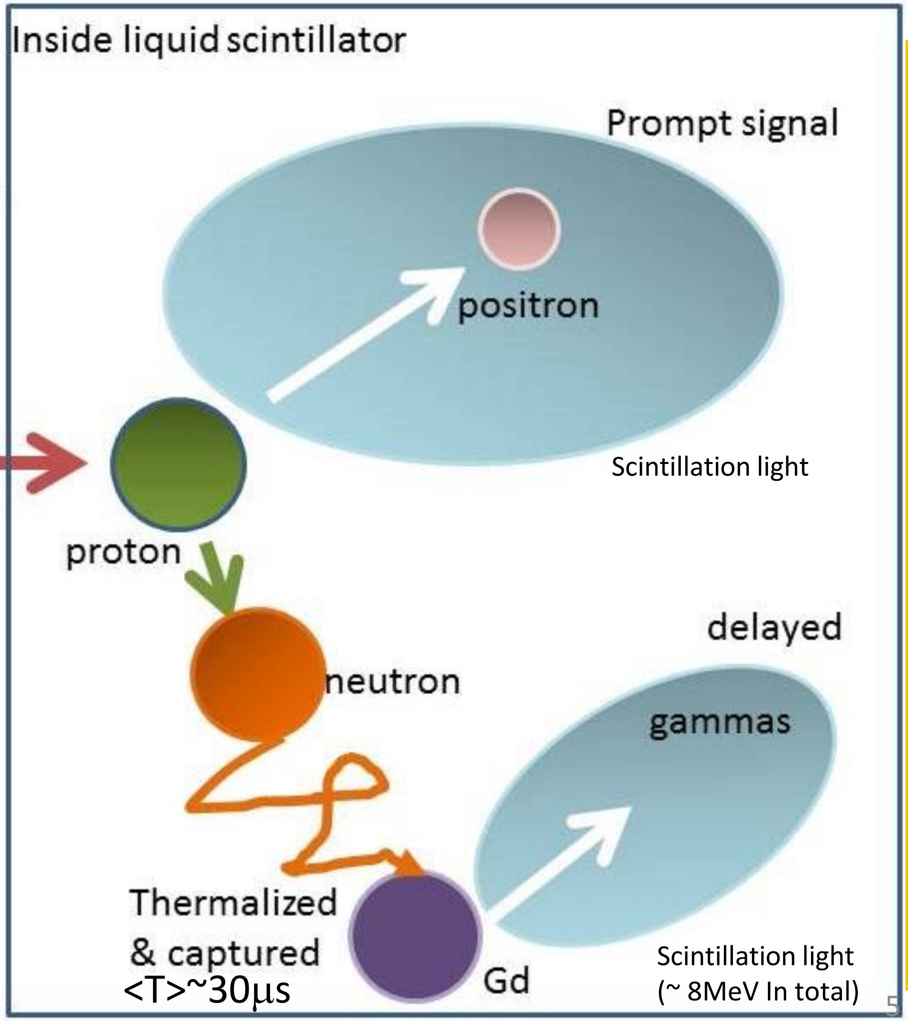
Searching for neutrino oscillation : $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$ with baseline of 24m.
no new beamline, no new buildings are needed → already started.

Production / Detection

- Large amount of parent $\mu+$ 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): $\bar{\nu}_e + p \rightarrow e^+ + n$ 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

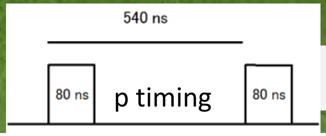
Most of them are same as the LSND.
→ Direct ultimate tests for LSND.

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

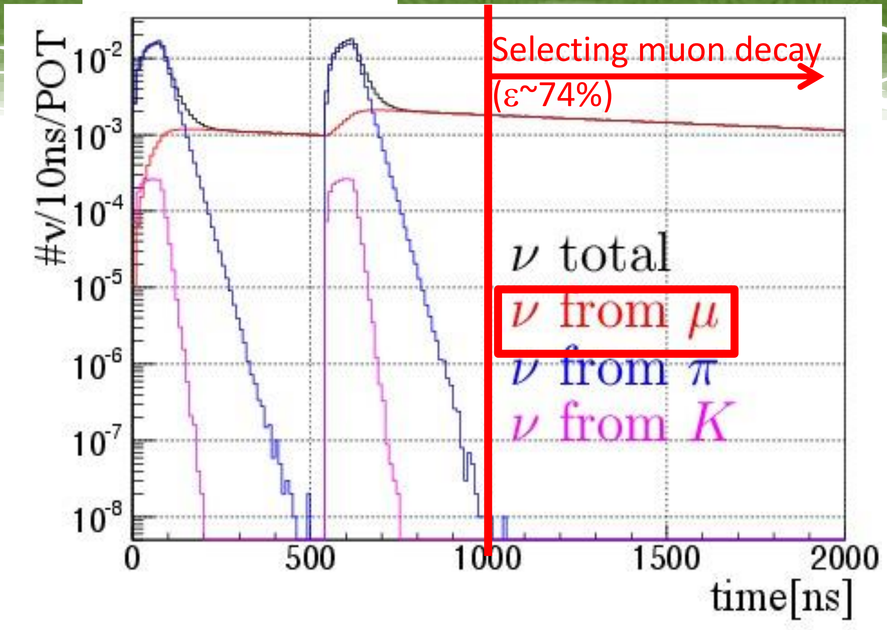
→ See page7 for more details

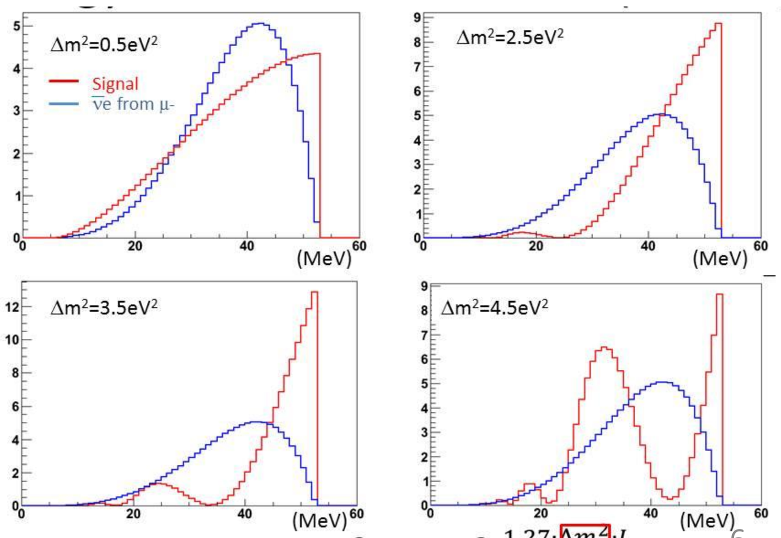
Pros (and Cons) of DAR beam (especially, spallation neutron source)

Next beam is 40ms later



M. Harada *et al*, arXiv:1310.1437





$$P(\nu_\mu \to \nu_e) = \sin^2 2\theta \cdot \sin^2\left(\frac{1.27 \cdot \Delta m^2 \cdot L}{E_\nu}\right)$$

- Energy is smeared by 15%/sqrt(E) (detector E resolution)

Pros (including JSNS²)

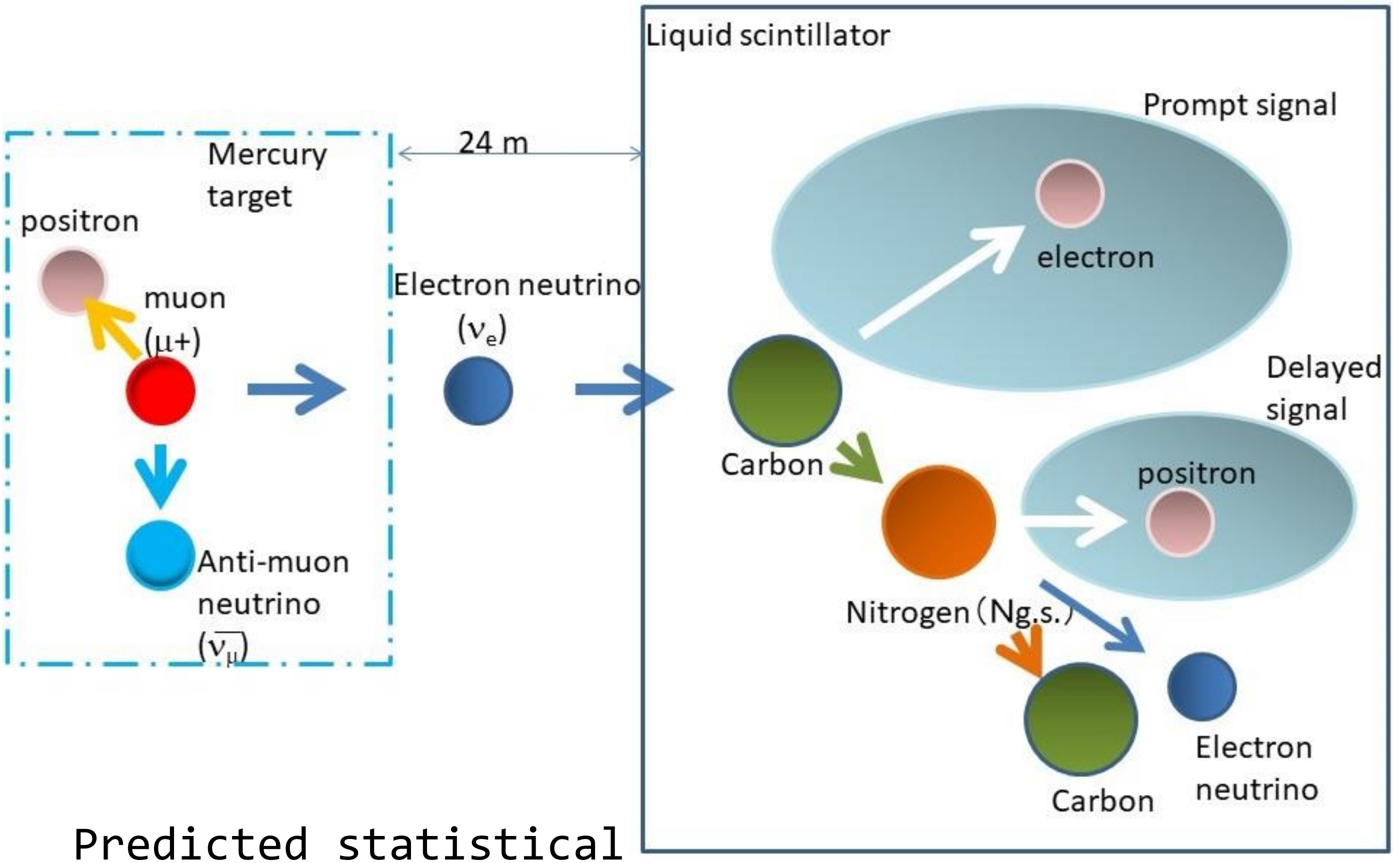
- Timing can select the signal tightly: π(->μ)->ν (or Kμ2)
  - ν from π and K → concentrating around beam timing.
  - ν from μ → tight selection by timing as well
  - Beam Fast neutrons → concentrating around beam timing.
  - Cosmic ray BKG → reduced by signal time window.
- Energy can be used for the signals / BKG separation.
  - ν from π/K/μ (DAR) has well-known spectrum. (0 momentum at the neutrino production)
  - Energy reconstruction is very easy at the IBD. (Eν ~ Evis + 0.8 MeV)
  - ν from μ- is highly suppressed. (small intrinsic BKG rate) (due to double absorptions: π- and μ-)

Cons: smaller # of signal events

- Neutrino flux is weaker than horn focused beam. (4π vs forward direction)
- Relatively low energy beam

The largest uncertainty on the beam

- Basically, there have been no pion production rate meas. (at the mercury target with 3 GeV protons) so far.
- For flux of numubar (before oscillation) can be estimated by the reaction shown in right. Good theoretical precision for cross section
- stat. could be too small, but ν_e + e -> ν_e + e may also be a candidate.
- For flux of nuebar from μ- is the largest uncertainty on the beam. We assigned 50% uncertainty for the flux. (due to production rate and geometry)
- Some of JSNS² members will join the NA61/SHINE experiment to understand the pion (and K) production rates from Hg target.



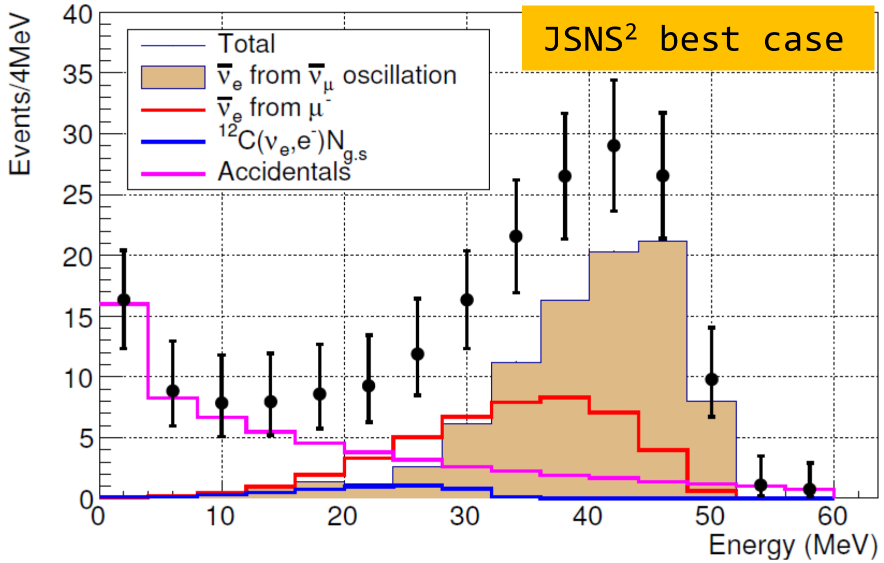
Predicted statistical uncertainty is ~6%
(arXiv:1601.01046)

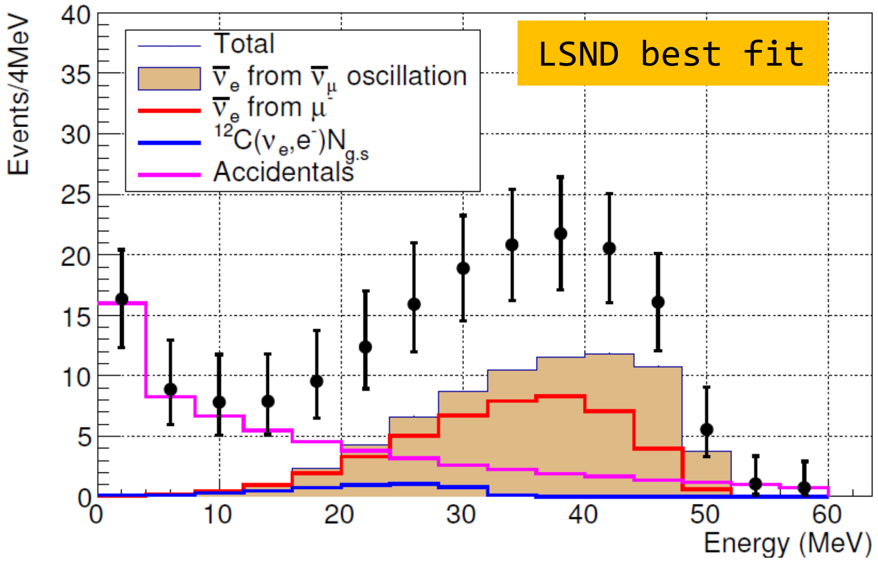
JSNS^2 vs LSND

	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)** ↔ >~1000	**1/14 (by Linac)**
Stopping μ^-/μ^+	1.7 x 10^{-3}	6.5 x 10^{-4}
Liquid Scintillator	**Gd-loaded** + large scint. light	Small #scinti. Light (to see Cherenkov), no Gd
Delayed signal	**Etot~8MeV, Δt~30μs** ↔ ~100	**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

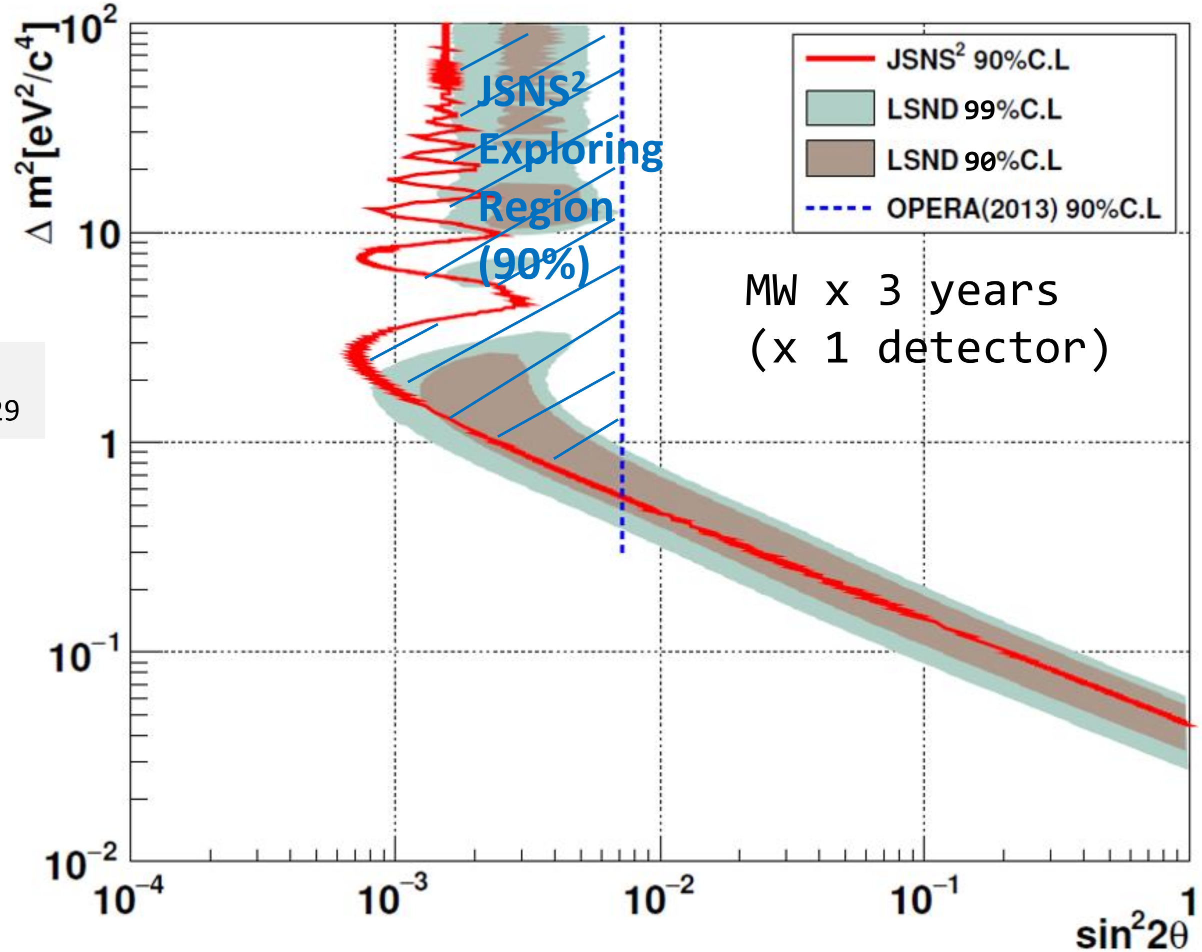
Energy Spectrum and Sensitivity (by MC simulation)

- 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.



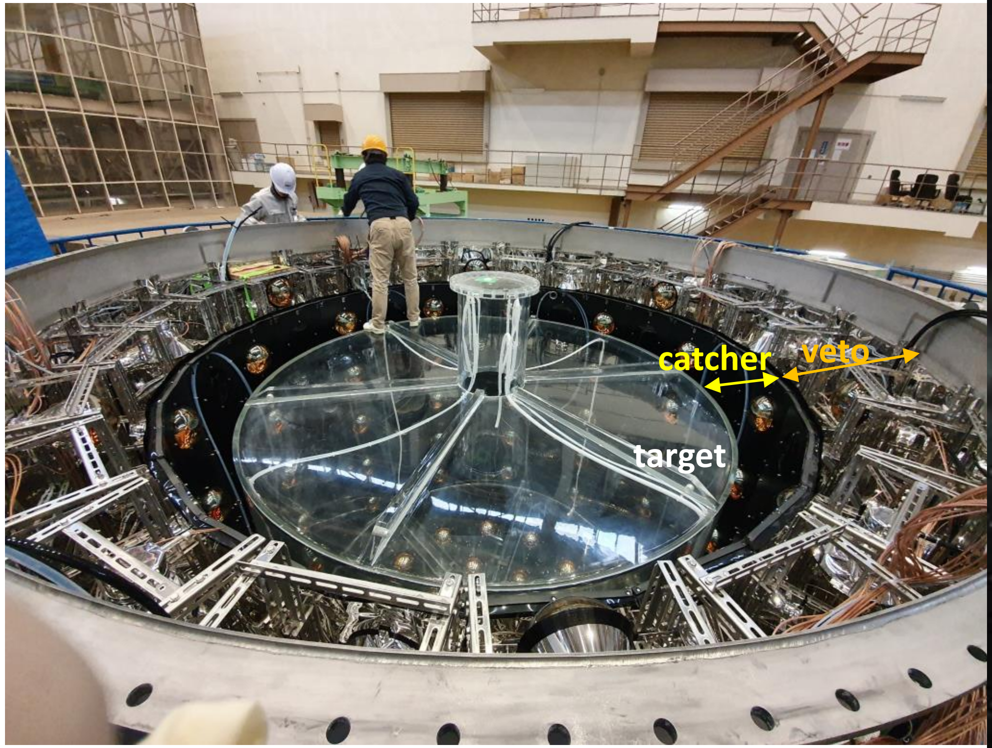


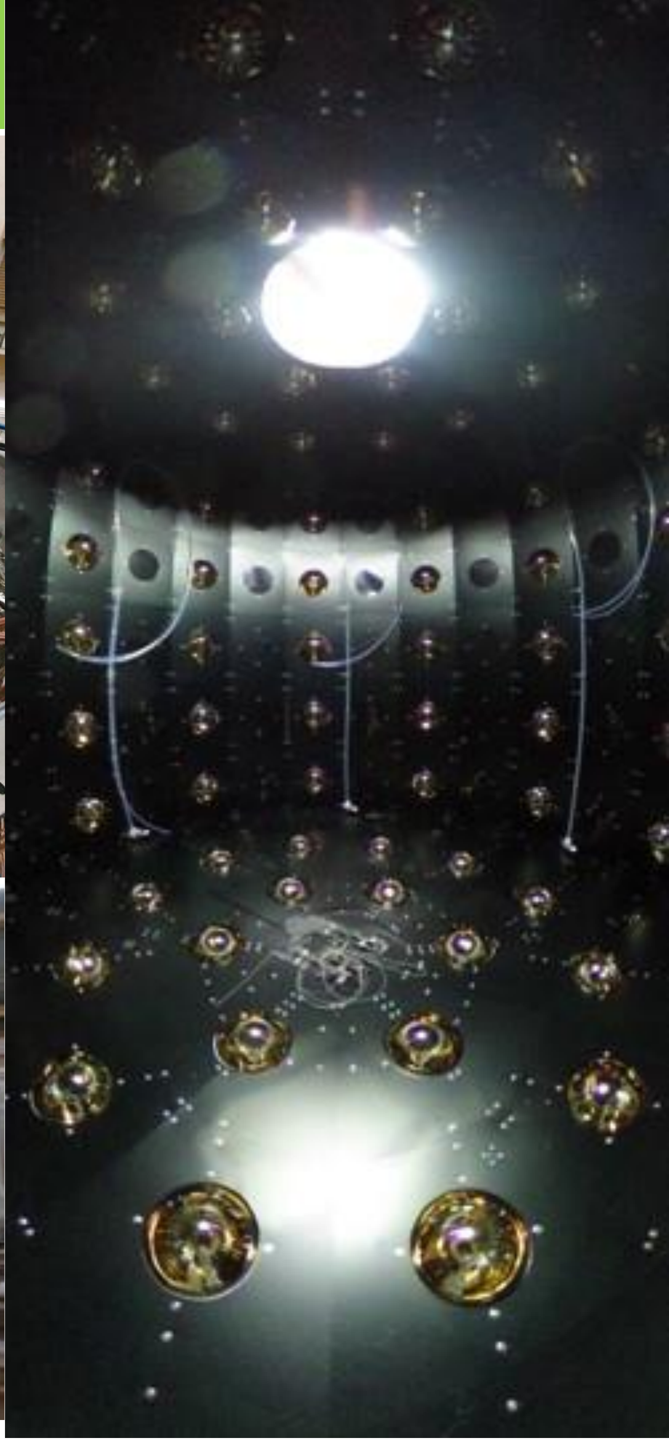
S. Ajimura *et al.*
arXiv:1705.08629



Detector construction (2017–2020)

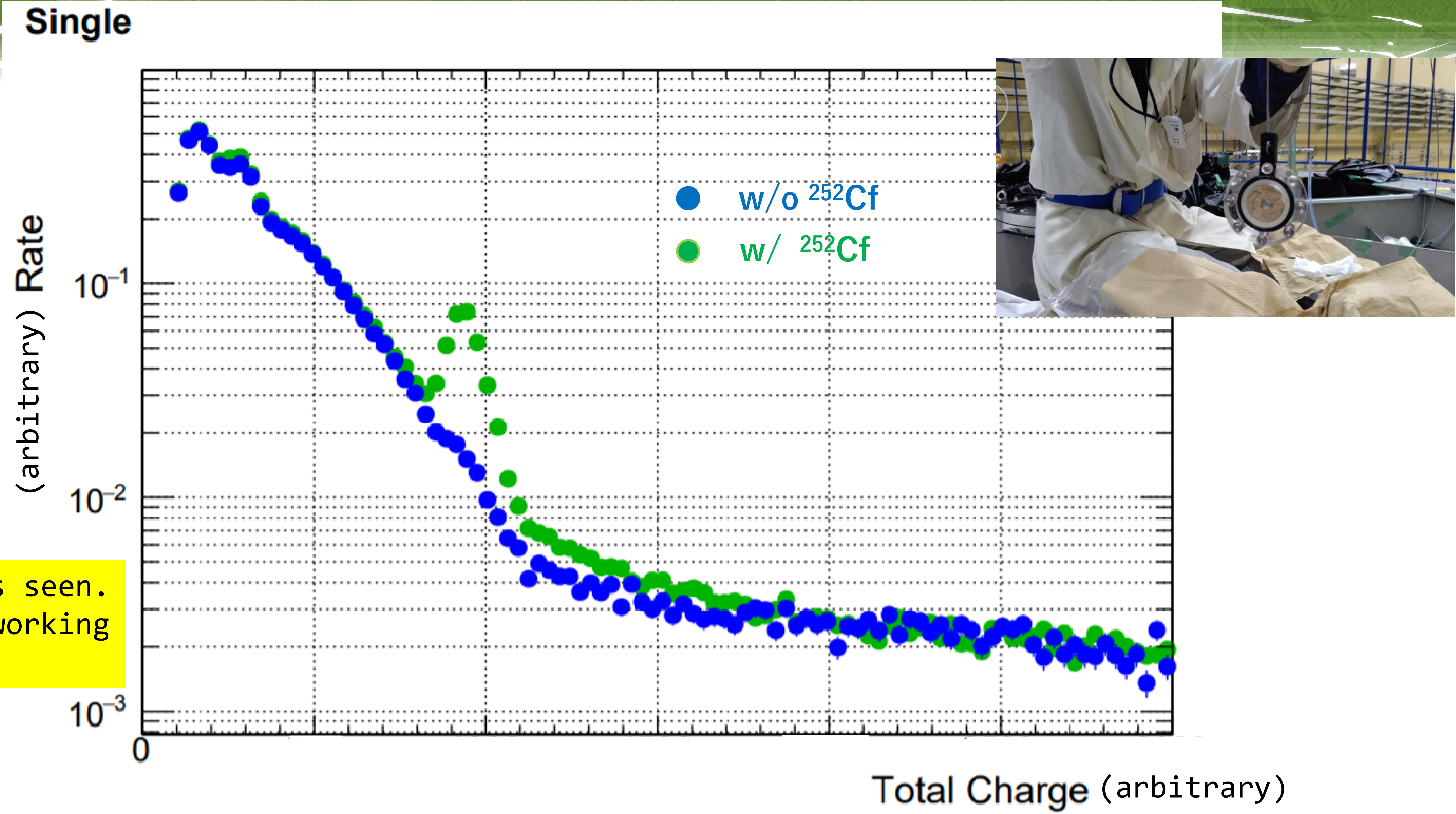
- The detector construction was finished 2020-Feb.
  - Stainless steel tank was produced by Japanese company (2017-2018: Morimatsu) JINST 14 (2019) no.09, T09001
  - Acrylic tank was produced by Taiwan company (2018-2019: Nakano).
  - 10” PMTs : JINST
    - ~53% is reused from RENO.
    - ~30% is newly 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: JINST
    - 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





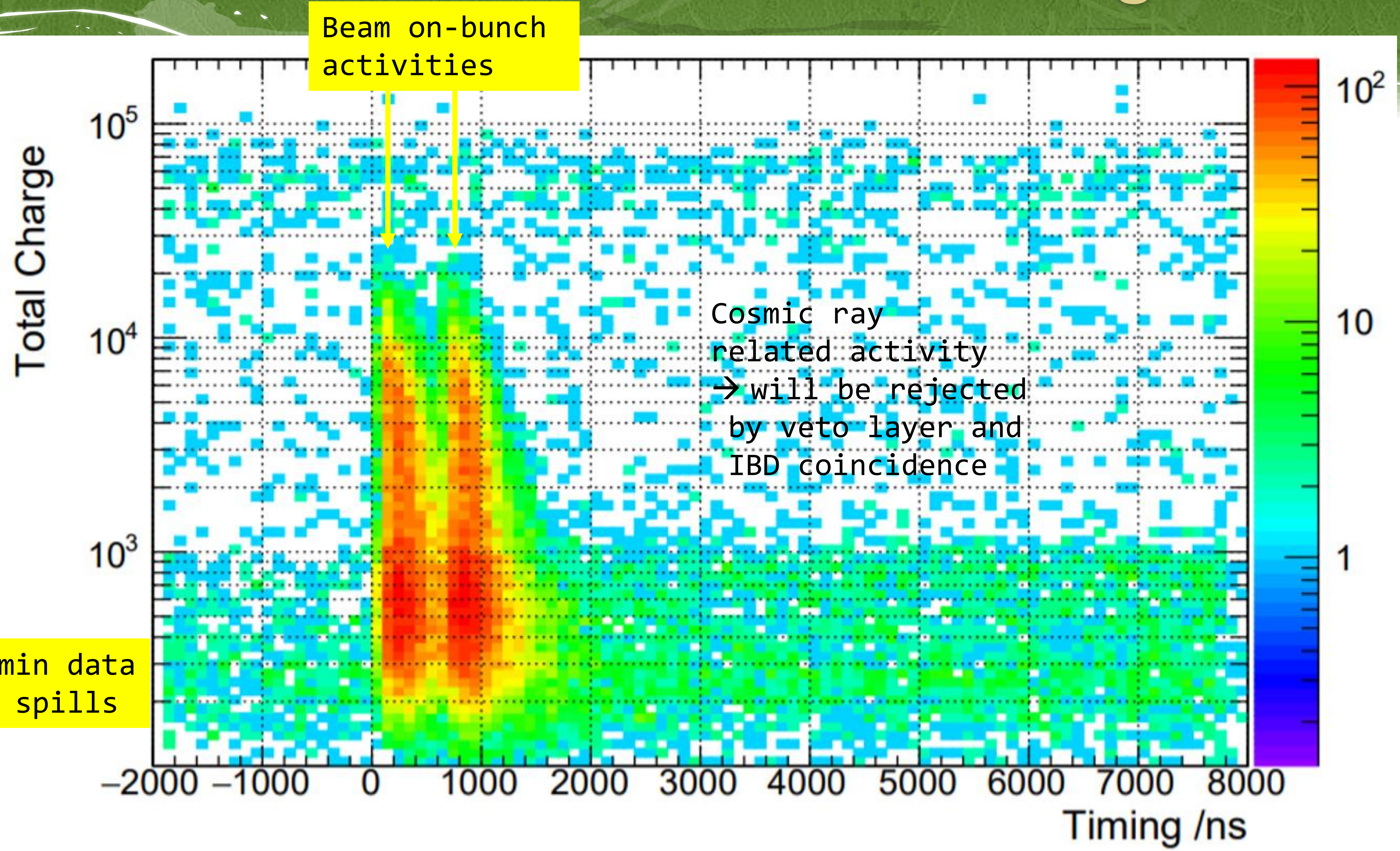
Very efficient experiment using reused or donated materials from various experiments. We do appreciate Daya-Bay, RENO and DC.

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



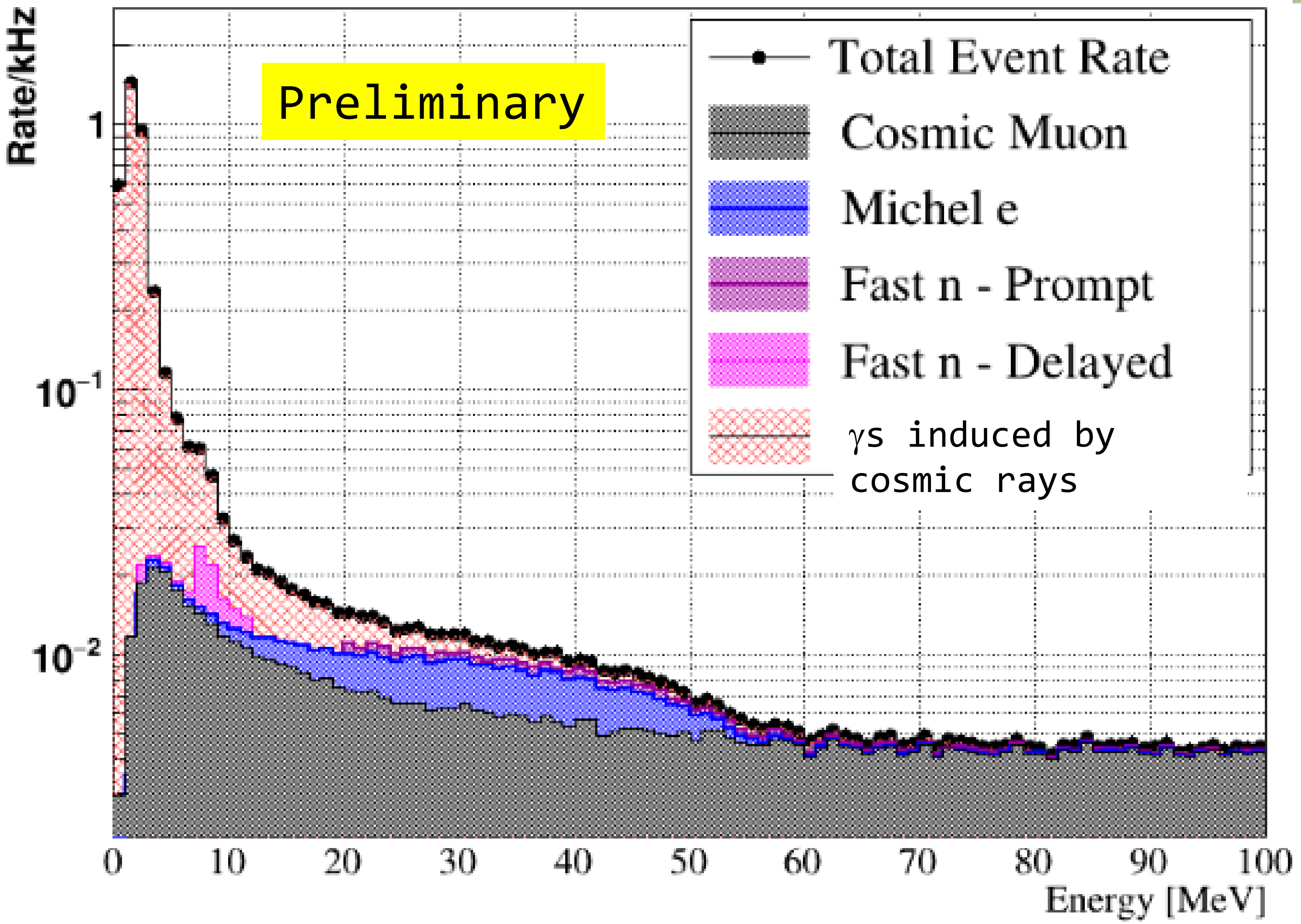
Clear peak is seen.
Detector is working well.

Activities around beam timing



First 30min data
-> 46524 spills

No beam data (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.
  - Cosmic ray μ: ~2kHz (all energy range. Including >100MeV)
  - Michel e : ~100Hz (20-60MeV)
  - Fast neutrons: <~10Hz (20-60MeV)
  - Cosmic gamma: ~50Hz. (20-60MeV)

  (note1: fast neutrons and gammas rays are induced by cosmic muons)

  (note2: the efficiency to tag the cosmic muons in the veto: better than 99%)
- Time window to select IBD is powerful to reject these. (10μs = 10^{-5} reduction)
- Main BKG for the IBD prompt region is gammas induced by cosmic muons. The rate is similar to expected # in our TDR. (arXiv:1705.08629)

Timescale of JSNS^2 / JSNS^2-II (upgrade)

Note: JSNS^2 will take data in the next physics run from this Dec.

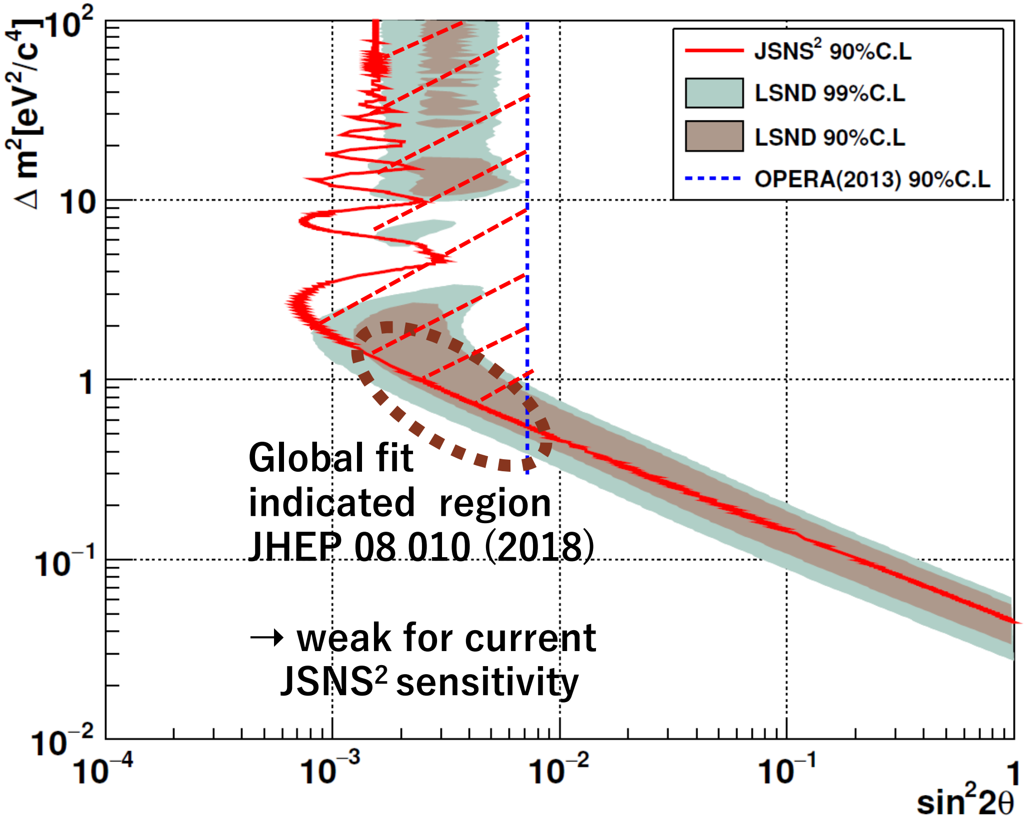
		2020		2021				2022				2023			
		8-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
JSNS^2									Running (data taking)						
JSNS^2-II	proposal		submit												
	Technical Design Report						submit								
	Fire Law /Facility														
	Detector building														
	Data taking														

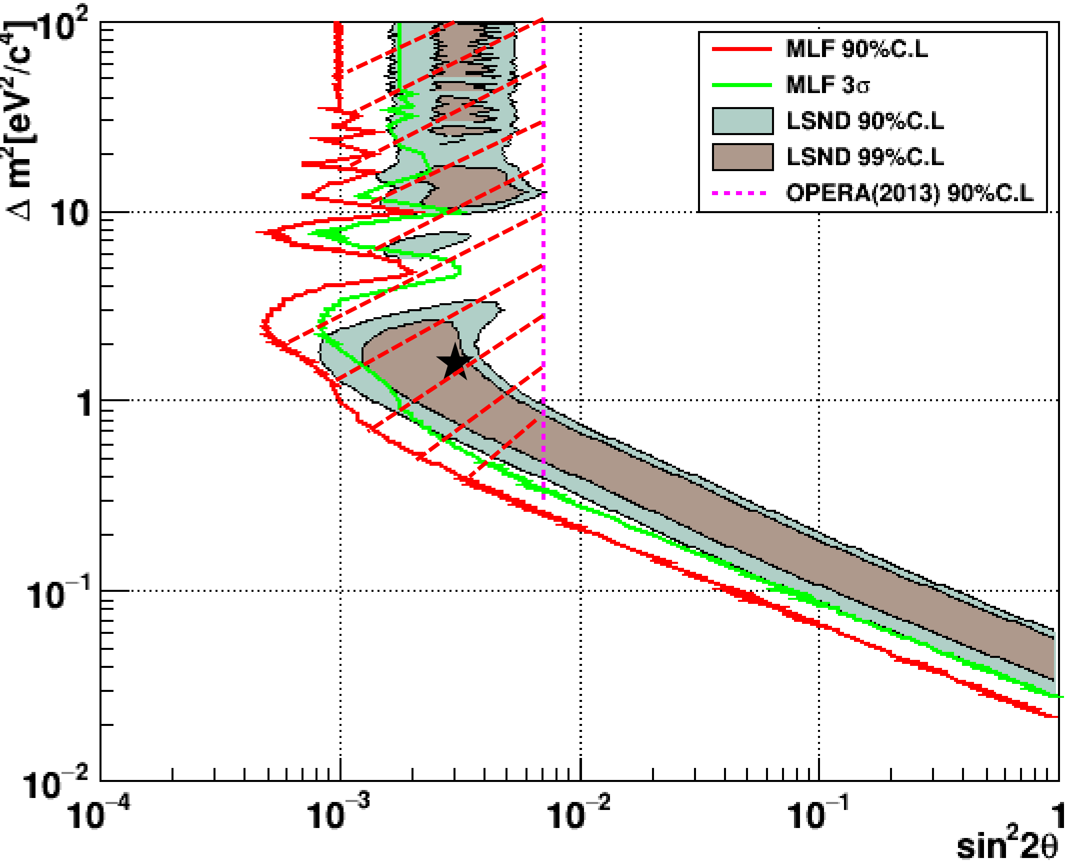
The grant to build the 2nd detector was approved recently (2020-Aug)
→ We upgrade the project (JSNS^2-II); see next page.

JSNS^2-II

→ Putting 35 tons fiducial GdLS detector at 48m baseline (outside of MLF)

→ 5 years after current JSNS2





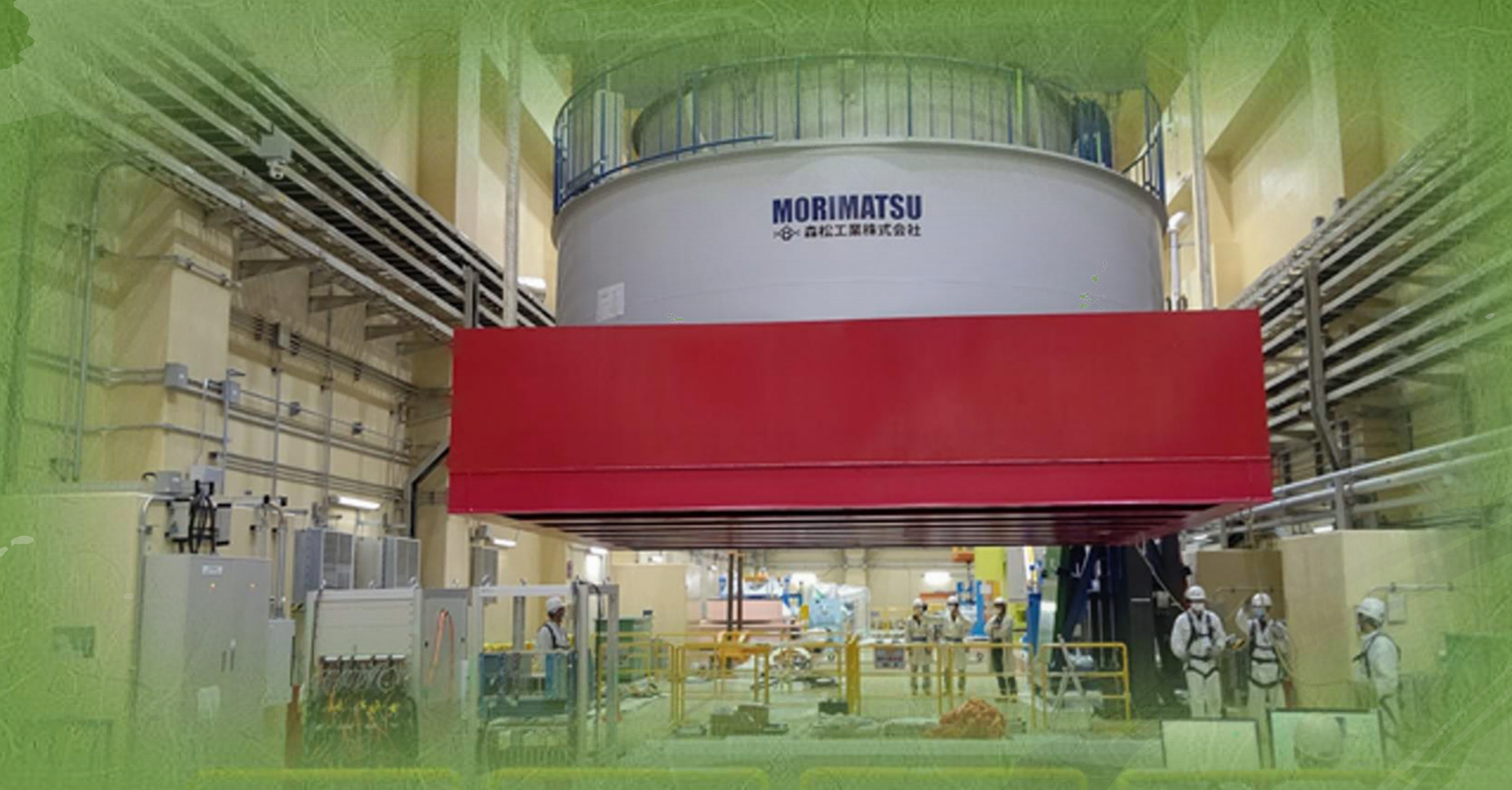
Shaded region is the 90% C.L. exclusion

Nicely covers the lower Δm^2 region.

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.
- Spallation Neutron source is a nice neutrino source as well as for the neutron (good timing & energy info., small intrinsic BKG)
- JSNS^2 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 and induced by cosmic rays look as expected (similar to 2014 background measurements, and TDR).
- Next physics run will be started in this Dec.
  - You will see the physics results from JSNS^2 soon!
- Aim to upgrade electronics in next year.
- We plan to construct the 2nd detector with the newly approved grant : essential to improve the sensitivity.

Thank you for your attention !!



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

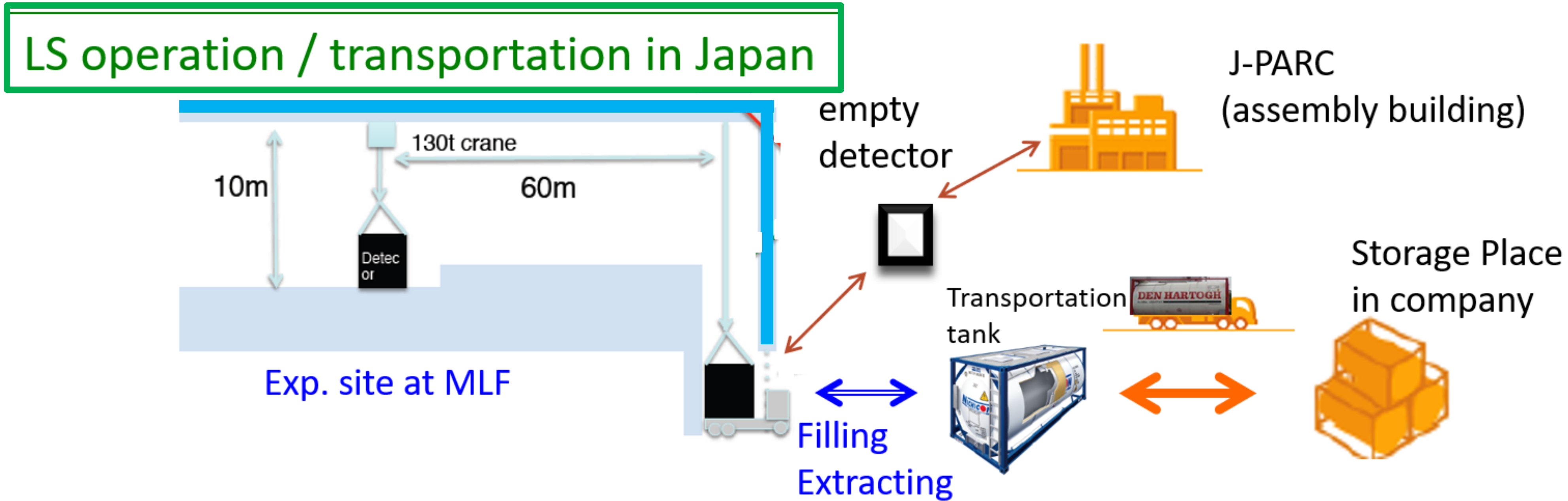
backup

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 (JSNS² specific features)

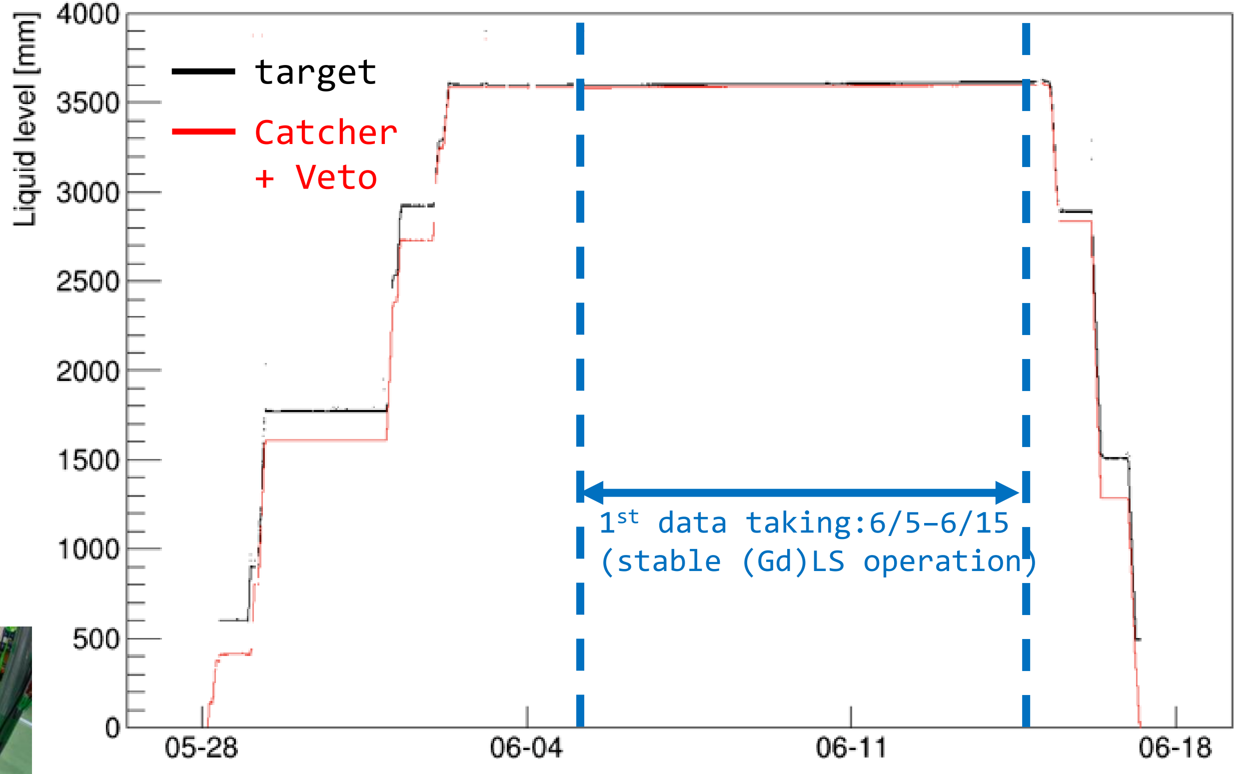
- MLF 3rd floor is the maintenance area for the mercury target and beam equipment. → need to bring in and out the detector during summer beam shutdown every year (4 months).
- I.e. : we have to fill in and extract out (Gd)LS during short time.
- We have used iso-tanks (transportation / storage tanks)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



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

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

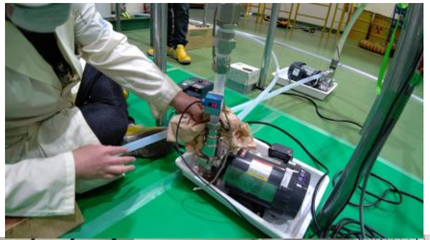
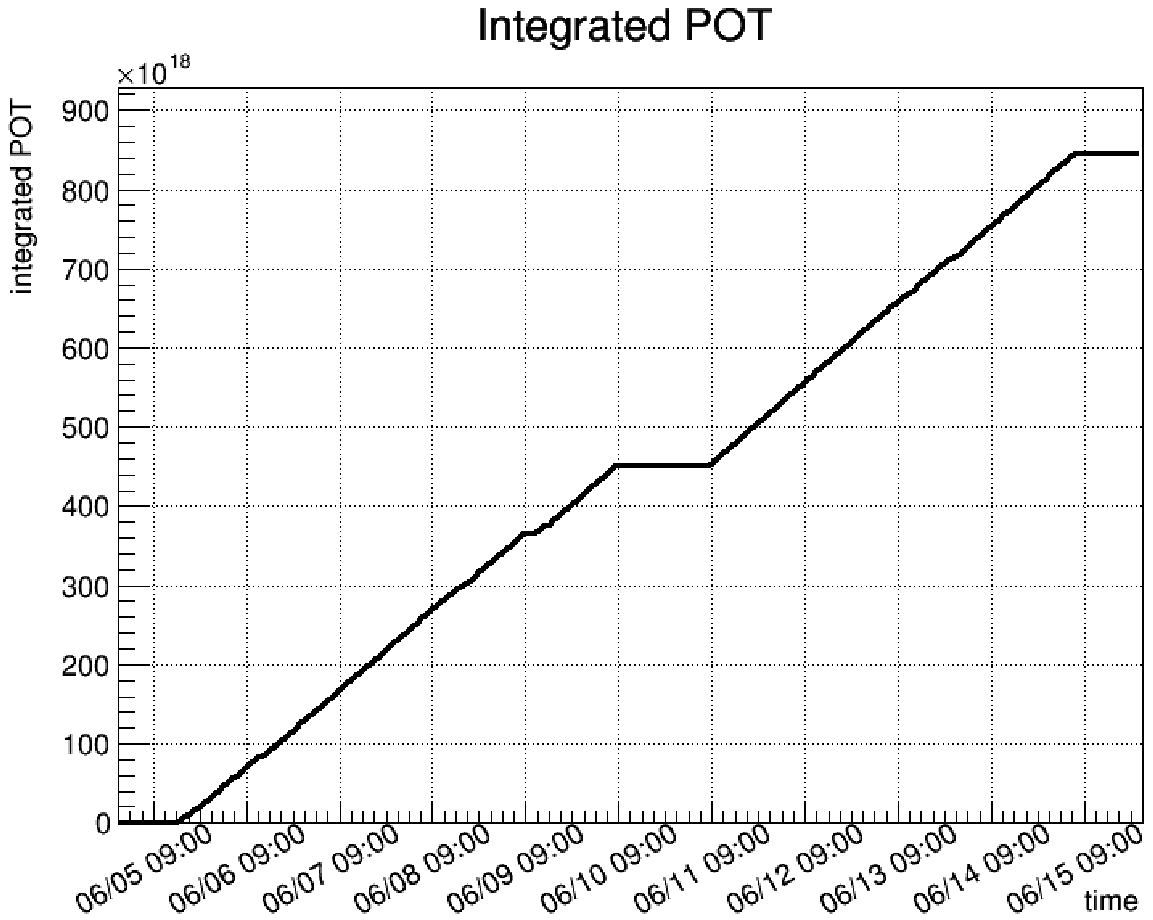


photo by Camera (inside)

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

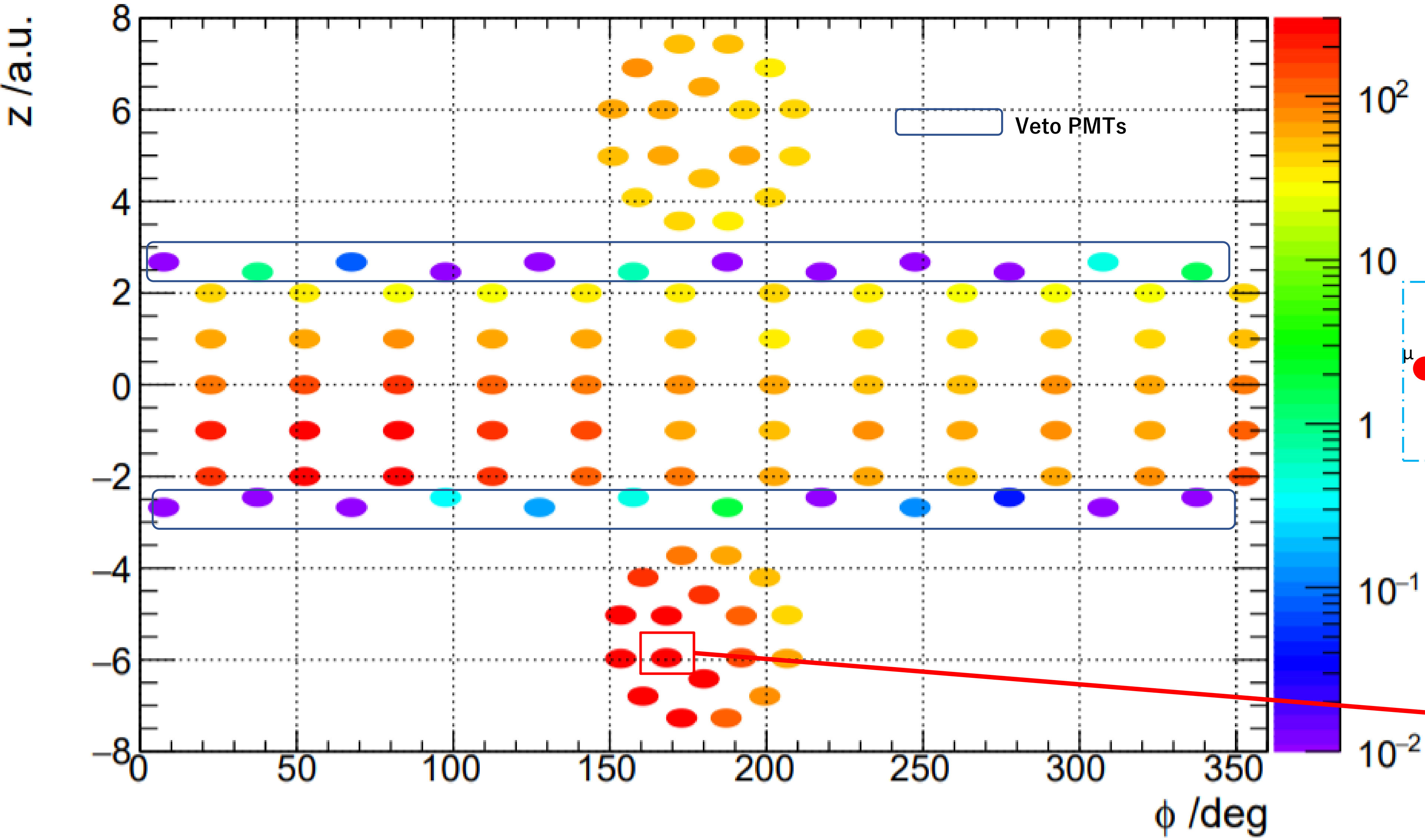
Beam power / POT

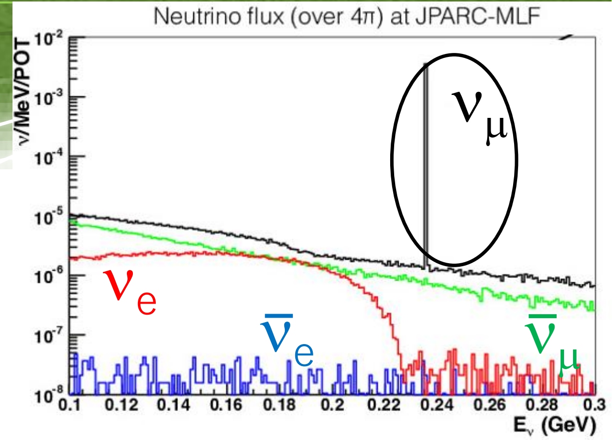
- Average Beam power: 602kW (4.97×10^{13} POT/spill)
- We have mini beam maintenance period (12 or 24 hours) on every Wed.
  - June-10: 24 hours mini-shutdown.
  - We use this period for calibration campaign (LED, ^{252}Cf, run w/o beam)
- 8.46×10^{20} POT for the 1st physics run
  - 0.8% of approved 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.

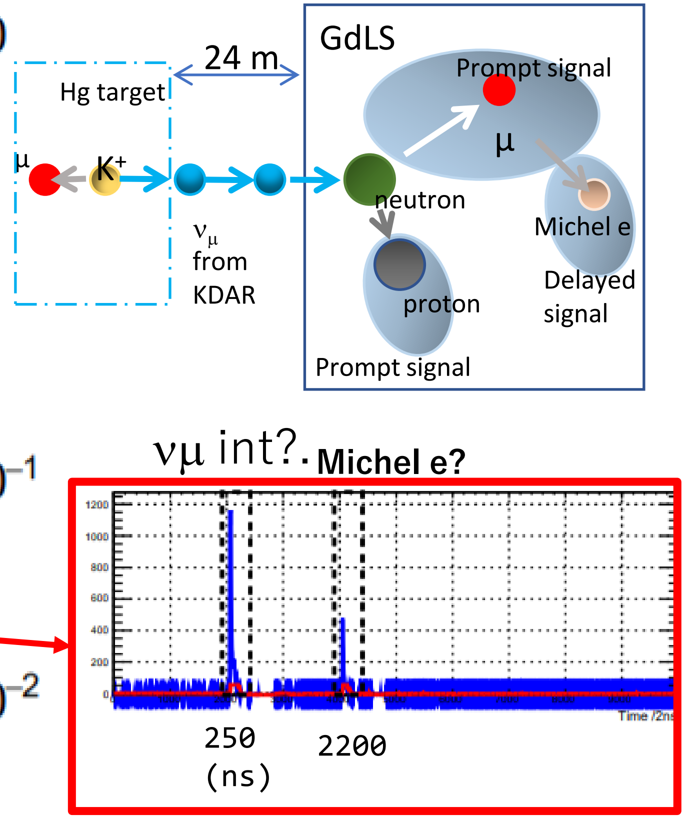


KDAR (Kaon Decay-At-Rest) ν candidate: event display

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







#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 = ΣR_{prompt} x ΣR_{delay} x Δ_{VTX} x 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

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!