E477
“Feasibility study on fast neutron rejection capability of the JSNS^2 detector”

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Physics (sterile neutrino search)

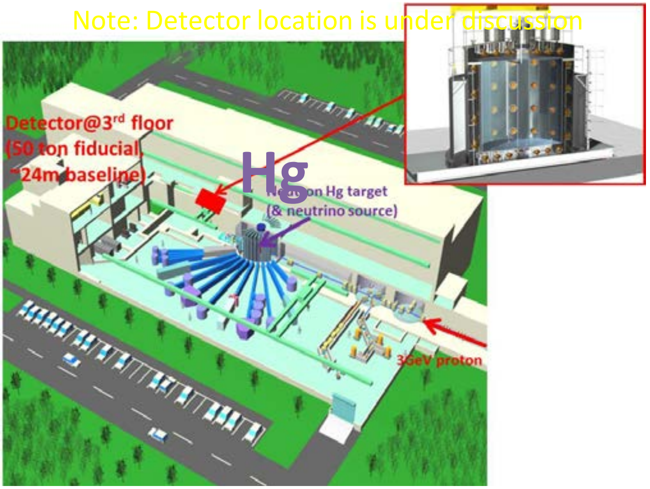
- Anomalies, which cannot be explained by standard neutrino oscillations for 15 years are shown;

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	$\nu_\mu \rightarrow \nu_e$	3.4σ	800, 600
		$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	2.8σ	
		combined	3.8σ	
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

- Excess or deficit does really exist?
- The new oscillation ($\Delta m^2 \sim 1 eV^2$) between active and inactive (sterile) neutrinos?
- One of the hottest topics in the neutrino community;
  - About quarter of the Neutrino2014 talks mentioned sterile νs
  - A lot of experiments are planned/on-going (especially, using reactors). E56 stands at good position to verify or refute $\nu_\mu \rightarrow \nu_e$ **definitely.**

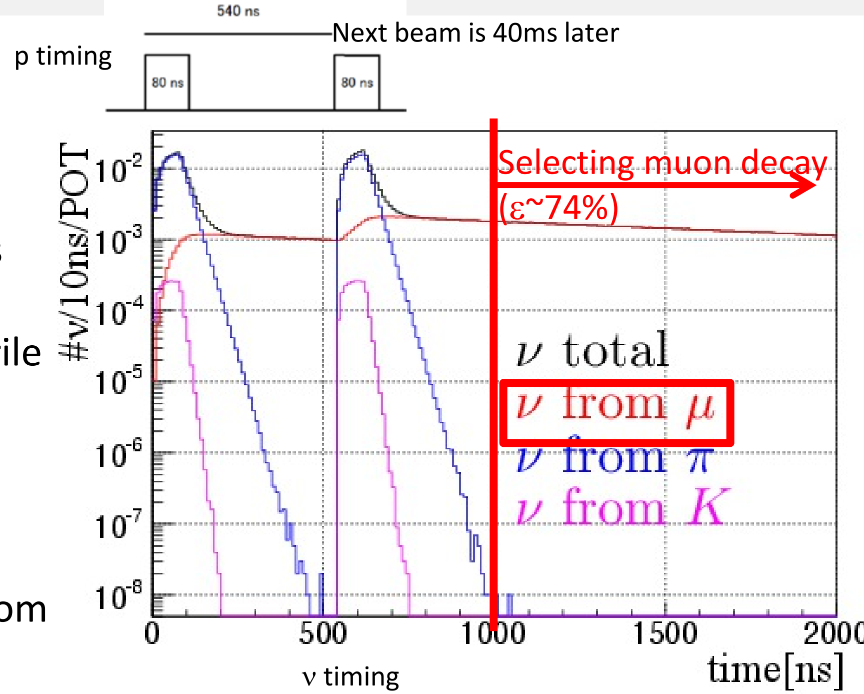
Sterile neutrino search @MLF (J-PARC E56, JSNS^2)

M. Harada *et al*, arXiv:1310.1437 [physics.ins-det]

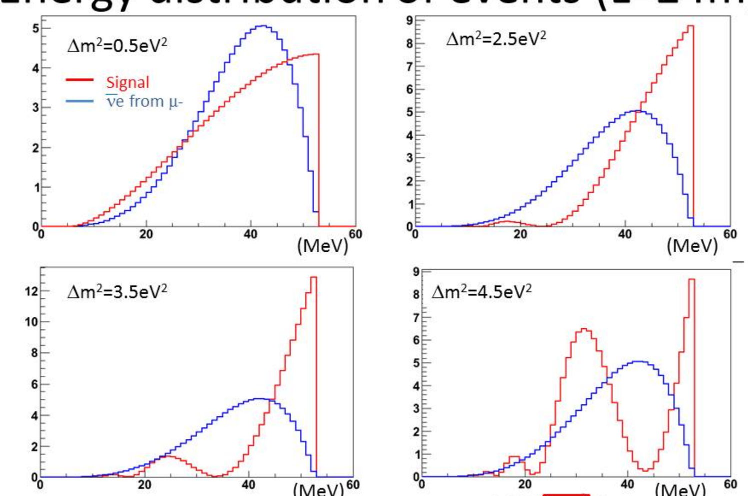


J-PARC E56

- confirms or refutes the neutrino oscillation with sterile neutrino($\overline{\nu}_\mu \rightarrow \overline{\nu}_e$)
- uses ultra-pure neutrinos from stopping μ^+
- separates signals from BKG by measuring energy distortion

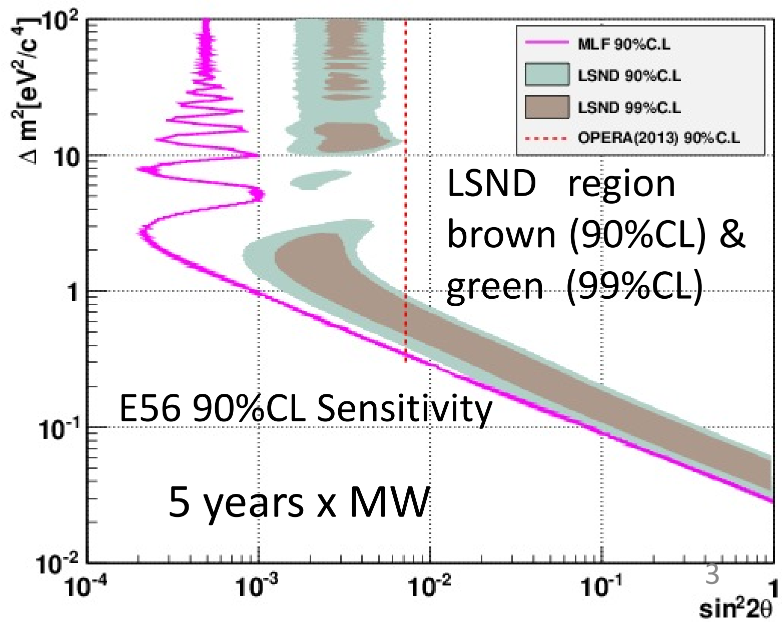


Energy distribution of events (L=24m)



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

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



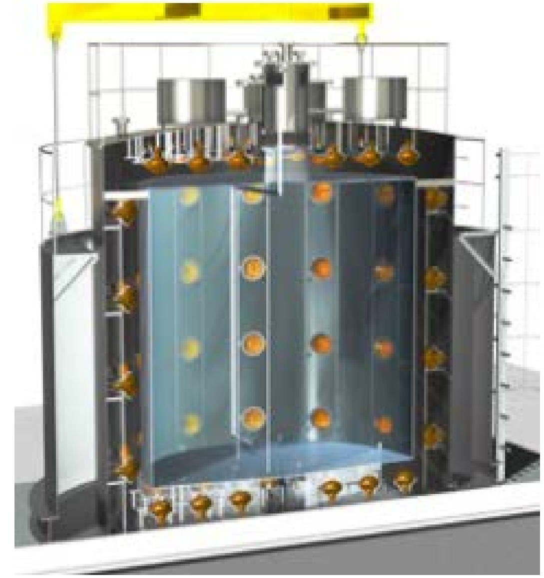
Detector and Detection Principle (reminder)

Detector

Target volume => **Gd-loaded LS**
(25tons x 2 detector ~ total 50tons)

150 10” PMTs/detector
E resolution ~ 15%/√MeV

Height 4.5m
Diameter 4.5m
X 2

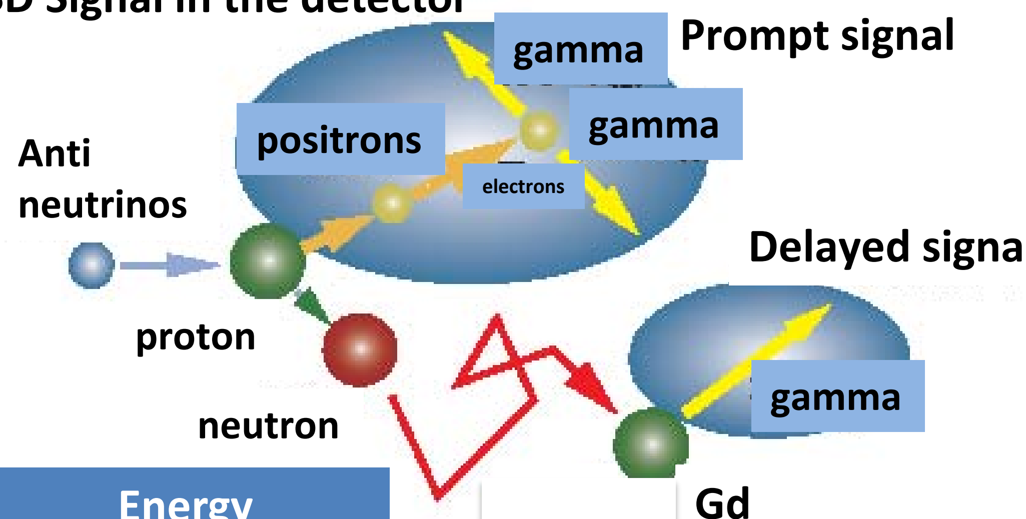


Delayed Coincidence (IBD)

$$\bar{\nu}_\mu \xRightarrow{\text{oscillation}} \bar{\nu}_e + p \rightarrow e^+ + n$$

Identify ν with detecting
e^+ and γs from n capture on Gd.
=>Can reduce accidental BKG
(Gd~8MeV γs, capture time ~ 30 µs).

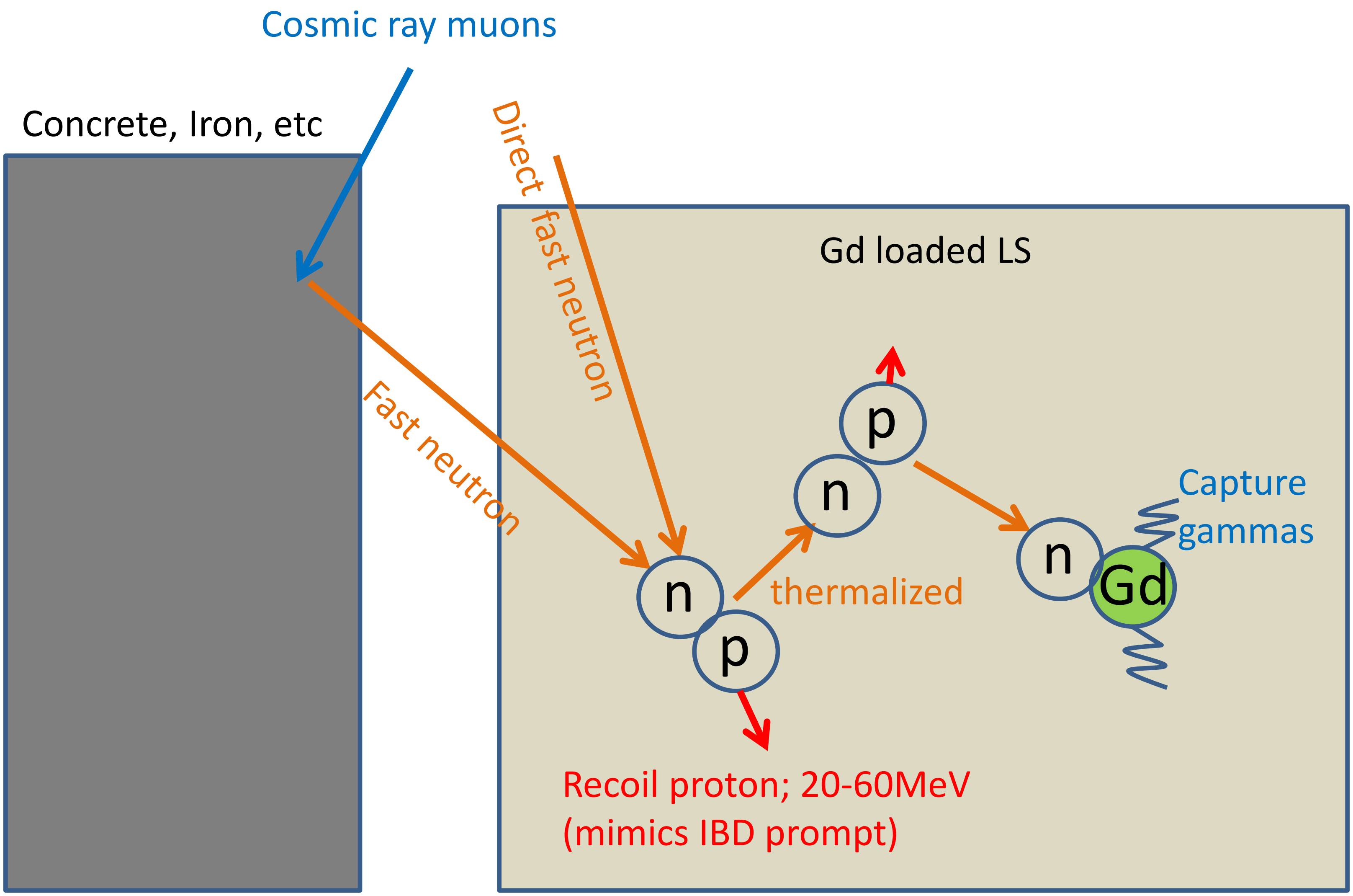
IBD Signal in the detector



Selection criteria for IBD

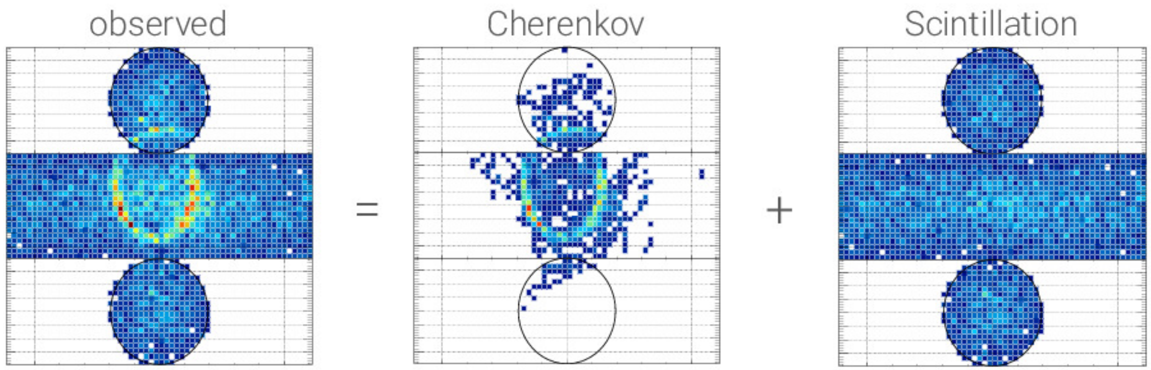
	Time from beam	Energy
Prompt signal	$1<T_p<10\mu s$	20<E<60MeV
Delayed signal	$T_p<T_d<100\mu s$	7<E<12MeV

Fast Neutrons from Cosmic Rays

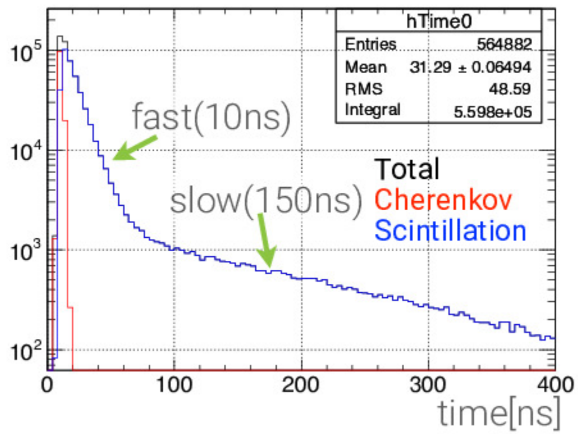


- If recoil protons enter the time window after the 1-10μs, these events can be the correlated background.

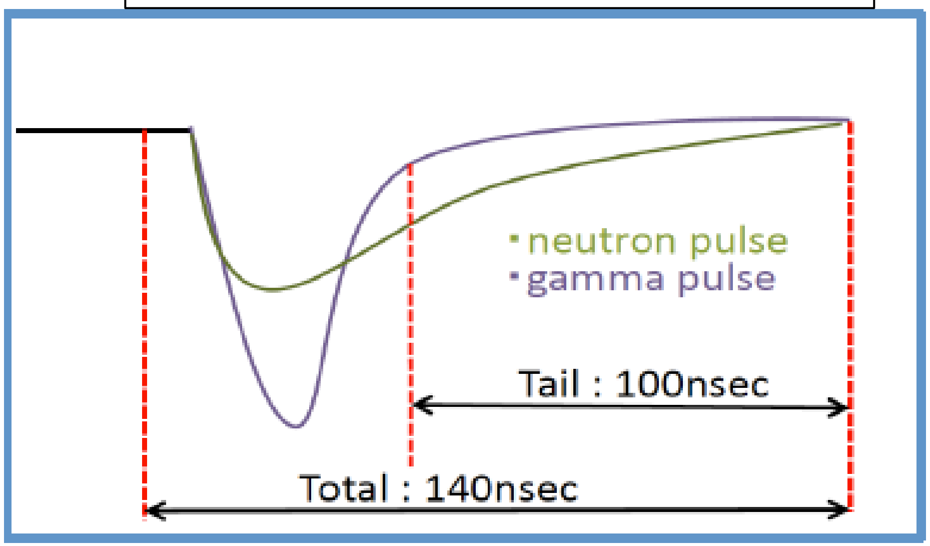
Cherenkov or/and PSD



- Left ; with small amount of scintillation light, Cherenkov light can be seen with timing.



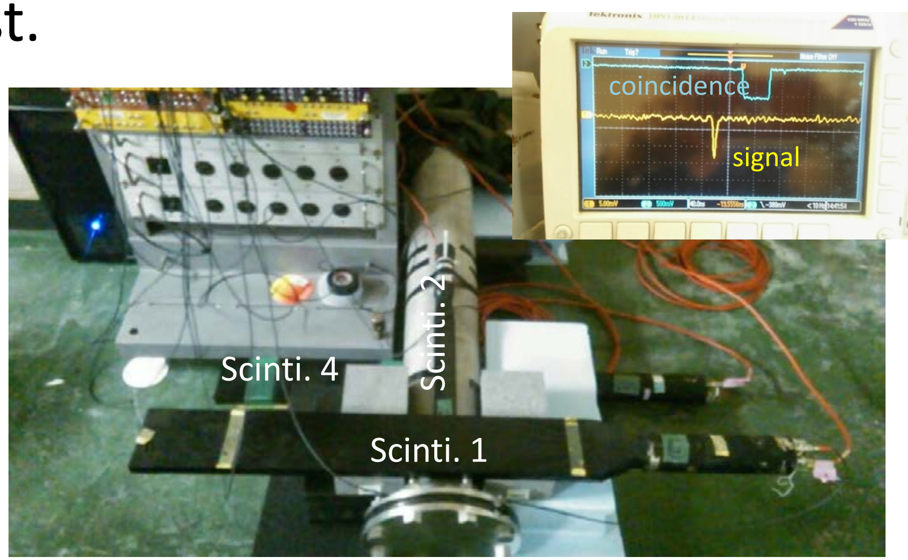
- **PSD variable → tailQ/totalQ**

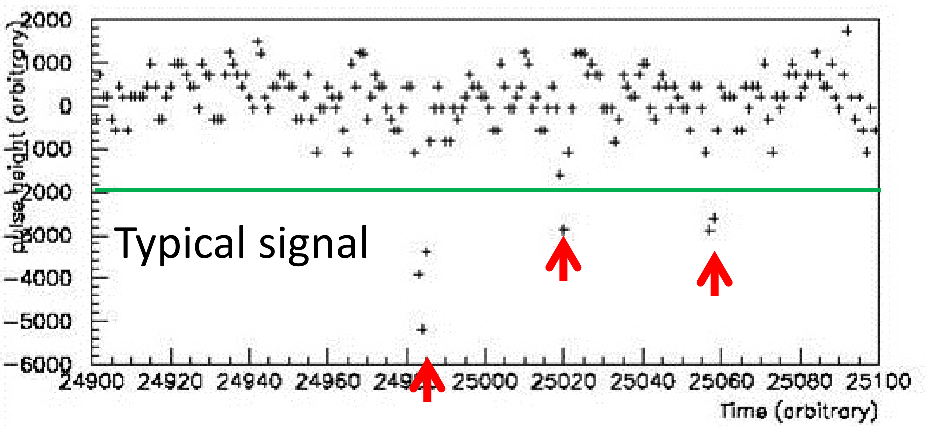


- Right: Pulse Shape Discrimination between positron (IBD signal) and neutron-proton recoil BKG.

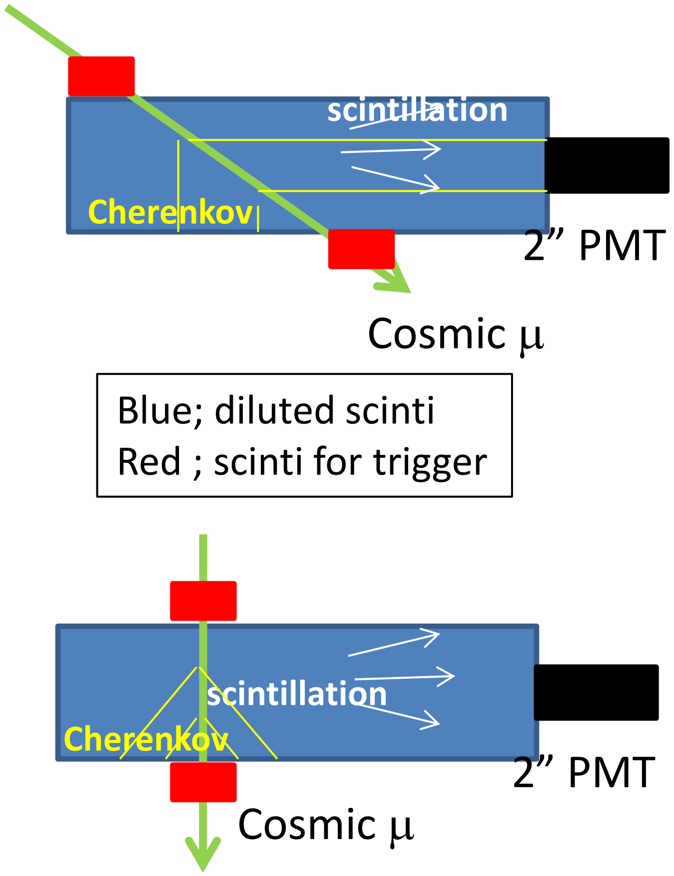
Setup for Cherenkov test

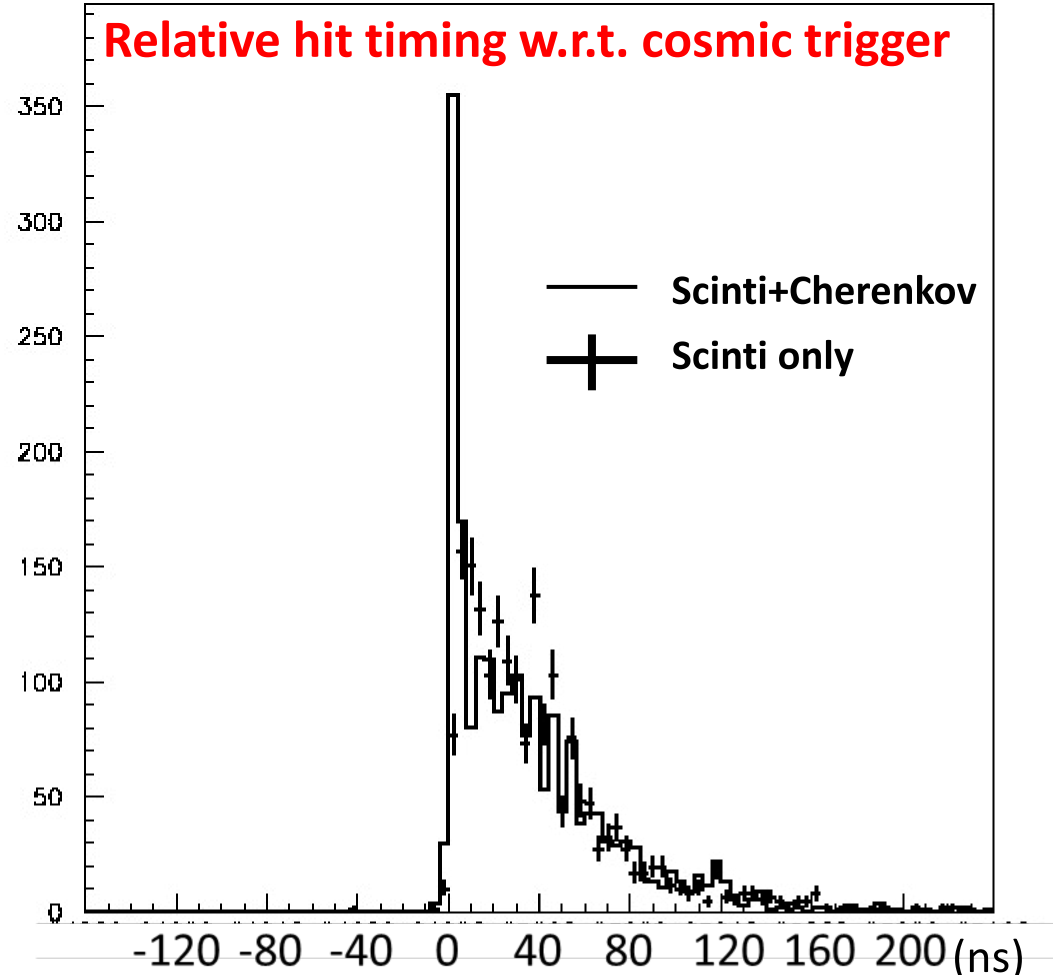
- The setup at KEK building for chemistry.
- 130mm(diameter) x 1000mm (height) cylinder was filled with diluted scintillator. (diluted = small amount of 2ndary light emission materials.). Cosmic μ is used for test.
- We tested
  - LAB + 0.03g/L b-PBD (for JSNS^2)
  - mineral oil+0.03g/L b-PBD (LSND case)
- Typical scintillation light signal are shown in the bottom plot for LAB case.
- Analysis
  - Hit finder threshold is 2000 (~1/3 p.e. : green line)
  - Red arrows show the hit positions.
  - Hit time = the fastest point inside the hit.





Cherenkov vs scinti (LAB+0.03g/l b-PBD)





- Clear excess around fast timing from direct Cherenkov light are seen.
- Amount of the Cherenkov vs scintillation light around ~0ns bin is 4:1
- If we choose only 1st bin, rejection factor of scintillation is ~20.
- Estimated light yield is ~1600 scintillation photon/MeV (1/5 of normal)

E477: motivation, setup, expected results

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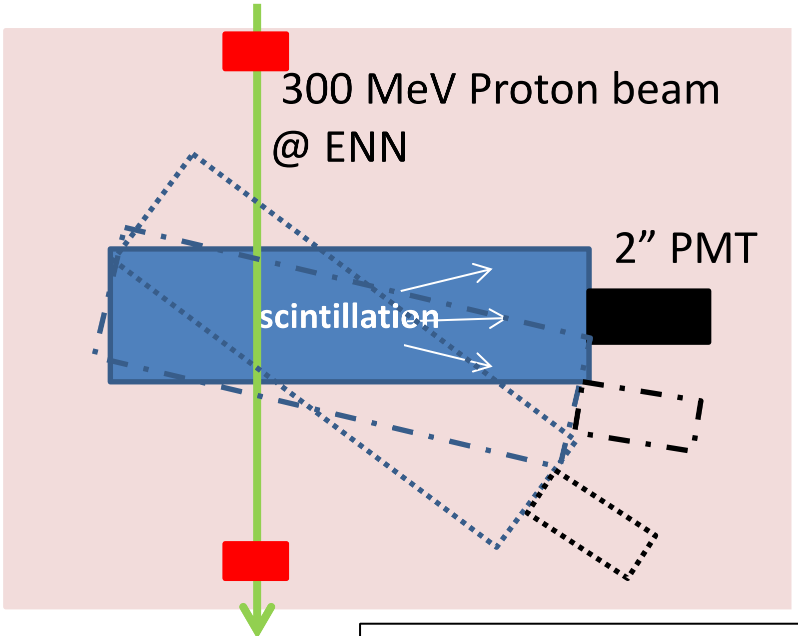
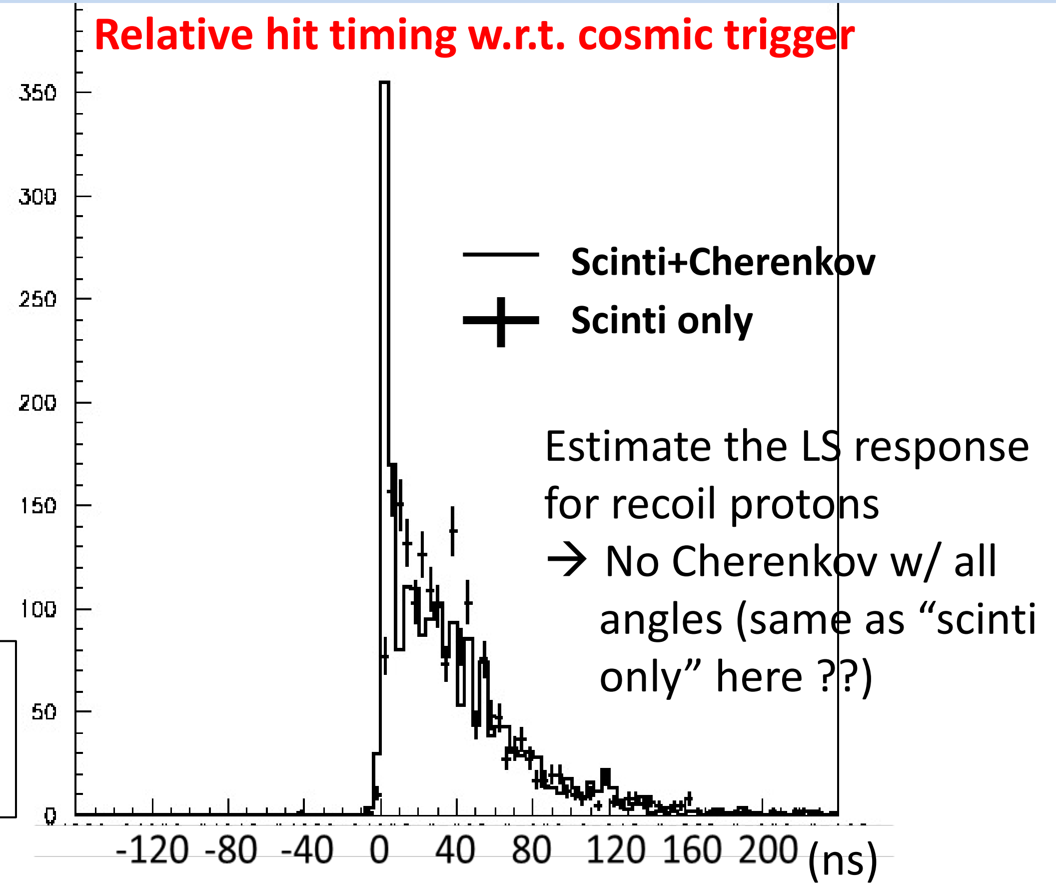
Meas.(A): Proton response confirmation



Infrastructure is already existing.
→ **Earlier is better**

Blue; diluted scinti
Red ; scinti for trigger
Pink; stage for detectors

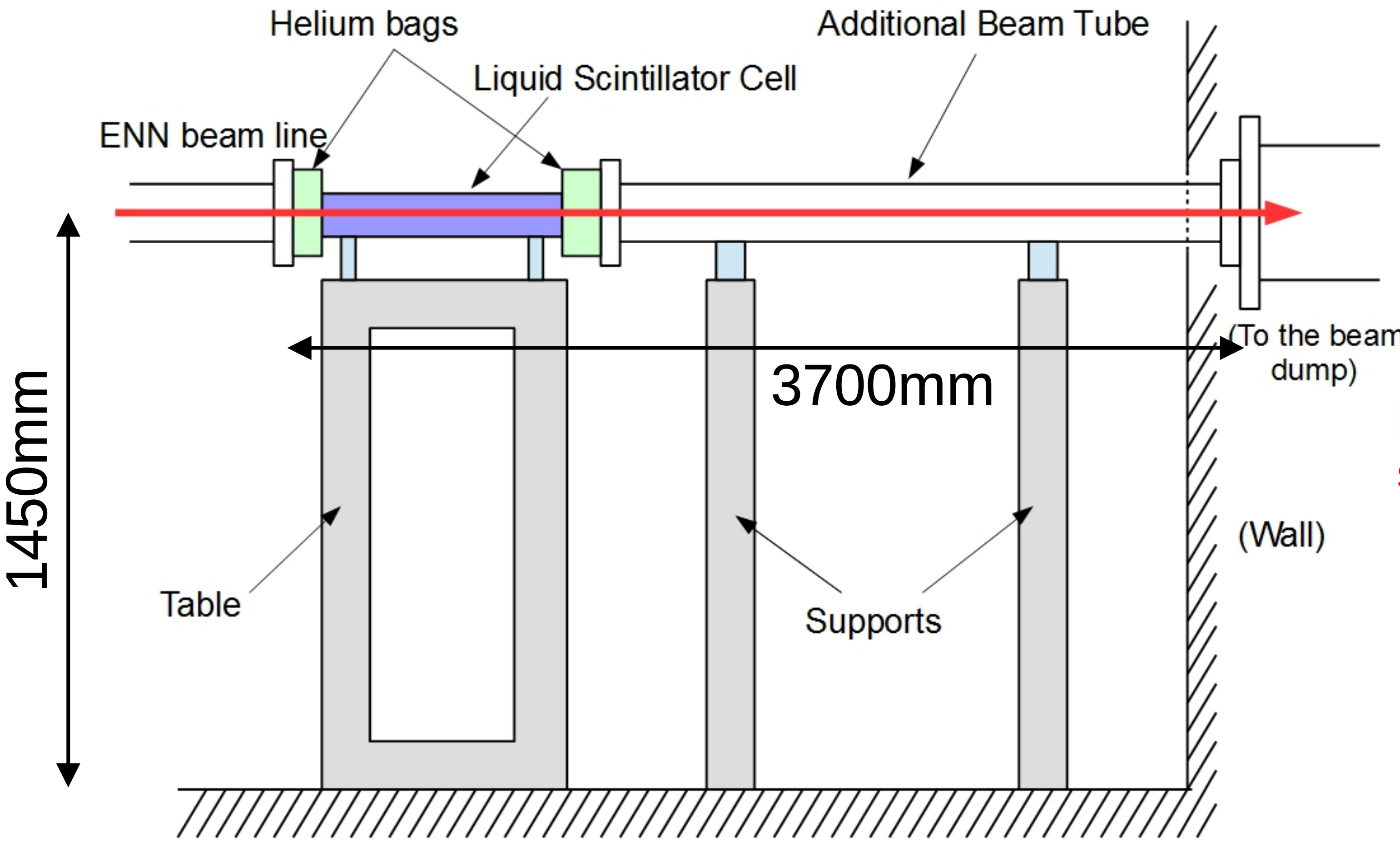


Estimate the LS response for recoil protons
→ No Cherenkov w/ all angles (same as "scinti only" here ??)

- Motivation: Confirming LS response for protons using same prototype. (i.e.: we don't see Cherenkov light for protons in any beam angles.)
- We will try to have proton beam with angles for 0-60 degrees with 10 degree steps (7 meas. points) → takes 1 day.
- Intensity: as low as possible, up to ~100Hz for trigger.

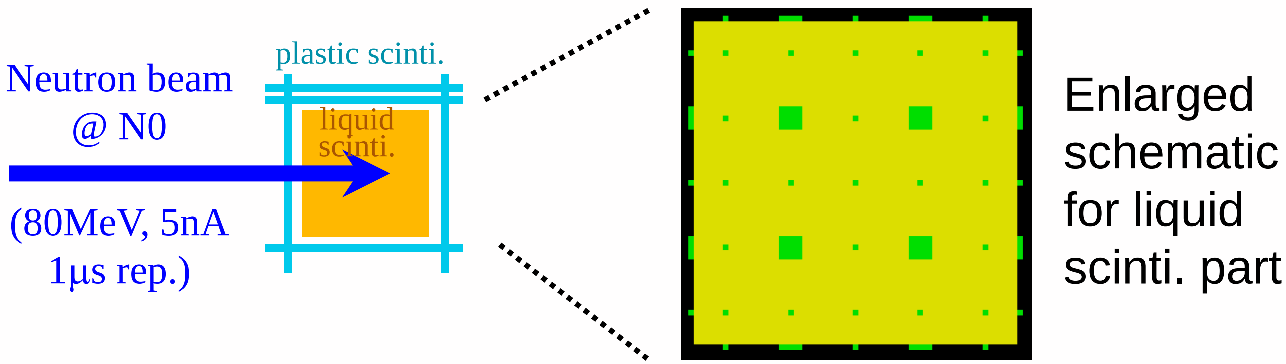
ENN setup (side view)

Note: Direction of the picture and the schematic is opposite



Proton is not stopped in air

Exp B: 300 kg LAB + neutron beam



- **Need some time to prepare. (time scale is different from Meas. (A))**

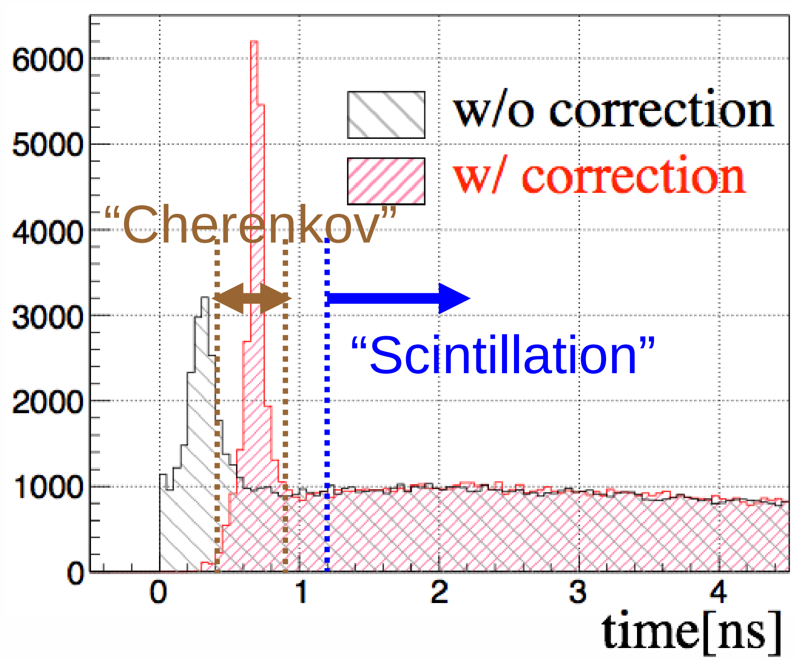
Motivation;

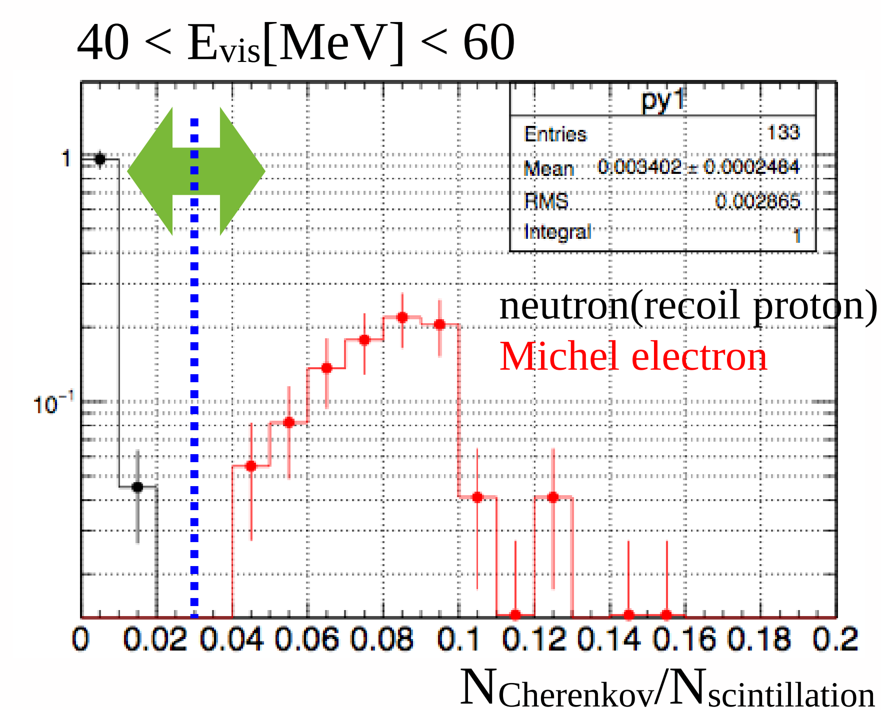
to understand the rejection factor of fast neutrons with a prototype (same structure) and MC simulation.

- Setup
  - 80 MeV neutron beam @ N0 beamline
  - Intensity = 5nA, repetition rate = 1μs
  - 20 m from the target (ToF: 170 ns for E_K=80 MeV)
  - 70 cm cubic LAB (340L/300kg)
  - 150 SiPMs
  - plastic scintillator layers which surrounds LAB cubic
    - charged particle veto (including cosmic muons)
    - tag Michel electrons as a reference of IBD positrons

Expected performance (Exp. B)

- Hit timing distribution: propagation time correction by calculating the effective vertex based on the charge information
- taking ratio of Cherenkov lights to scintillation lights





Questions to Meas.B (1)

1. What is the goal of this measurement? Is it to compare the timing distribution with the simulation as shown in Fig. 4?

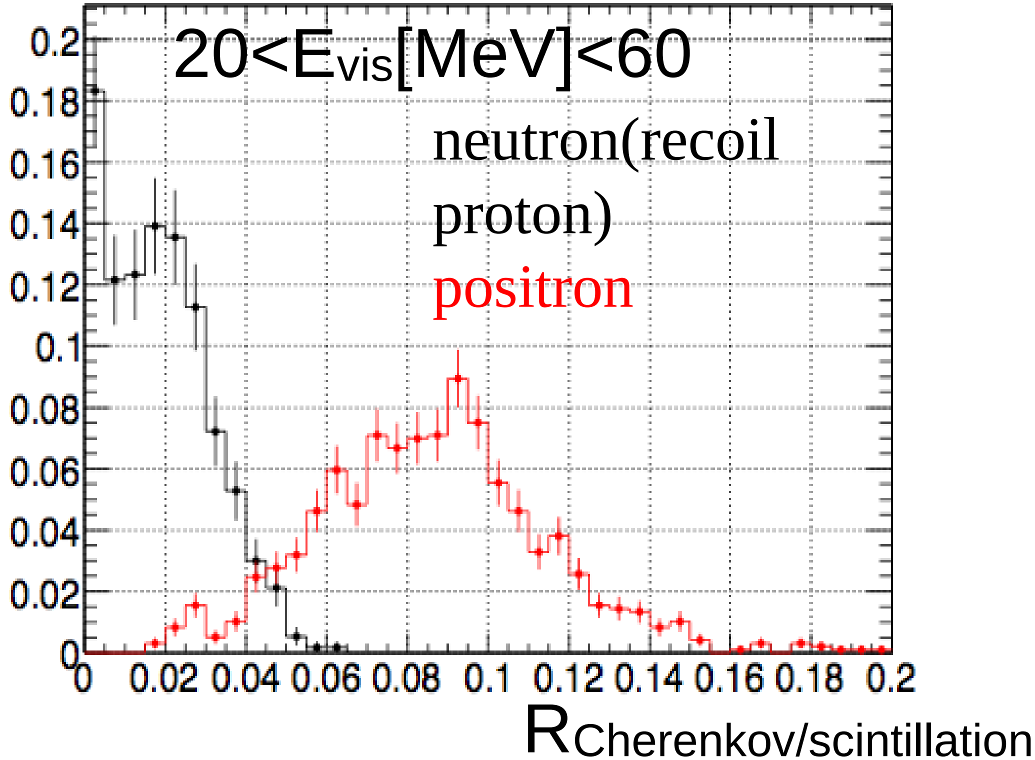
✓ To demonstrate the neutron rejection power, including neutron reactions, by using known neutron beam with a realistic setup. (Fig.4 in the proposal)

2. How the rejection power of 100 will be achieved?(in JSNS2 real size detector) Simulation indicates such rejection power?

✓ A MC study tells the rejection power of 100 is capable also for $JSNS^2$ (below)

✓ The LSND experiment also achieved the rejection power of 100 with Cherenkov

✓ Fig.4 in the proposal shows the test-beam case.



Questions to Meas.B (2)

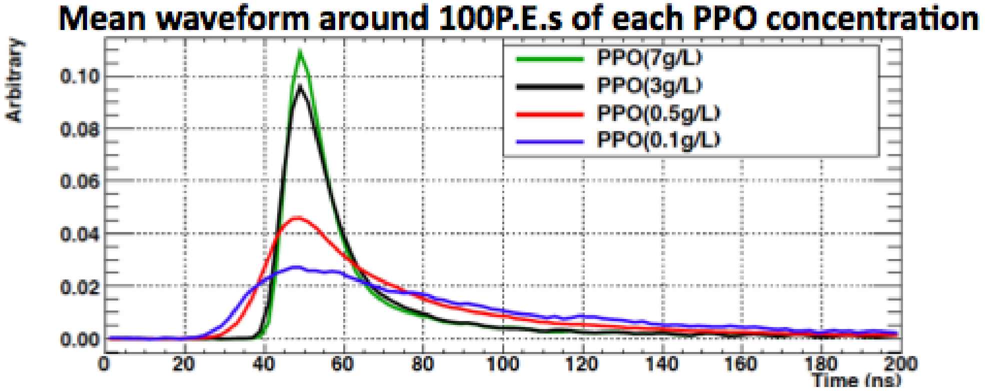
(Q) Then, what is the plan to feed back the result to improve the setup?

- If the rejection power of 100 is not convinced by the beam test results, we will re-tune the LS parameters

lower PPO concentration gives …

- smaller scintillation lights
- longer time constant

➡ better Cherenkov/Scinti ratio



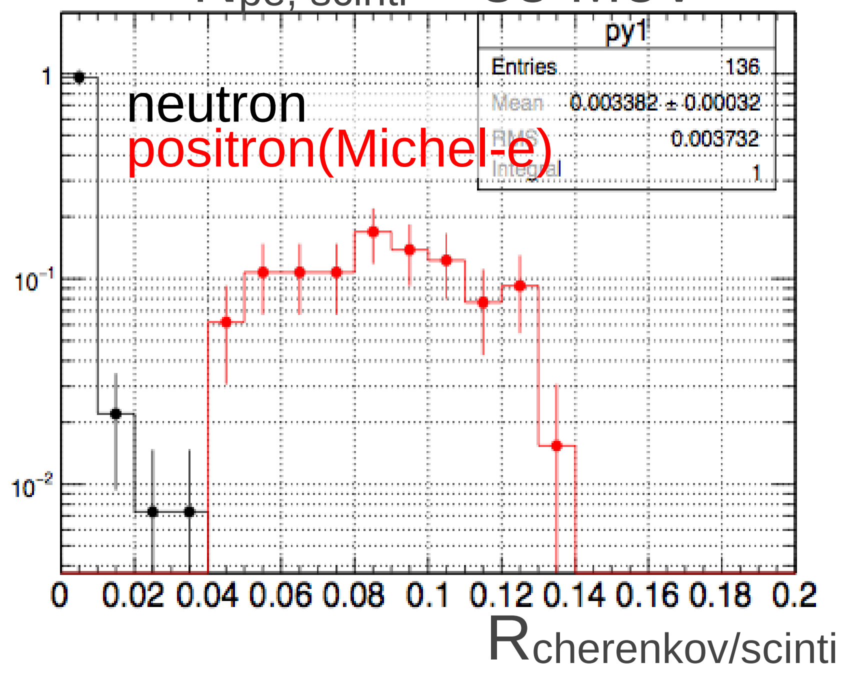
- If the rejection factor is satisfied, we will optimize the detector performance
  - further rejection of neutrons
  - recover energy resolution (light yields)
  - photo-sensor geometry
  - analysis methods/tools

Questions to Meas.B (3)

(Q) It is written that the size of the detector and number of SiPM channels may change depending on the budget. In case detector size and SiPM channels are small, is it still possible to demonstrate the feasibility? What is the plan in such case?

✓ The smaller detector with the dimensions of 50x50x50 cm^3 (=125L) and 54 SiPMs can be acceptable. It is just a matter of the size of the fiducial volume (i.e. beam time to take good/meaningful samples) -> results are shown below

$N_{pe,\ scinti}$ > 35 MeV



Summary

- The $JSNS^2$ experiment aims to search for neutrino oscillation with $\Delta m^2 = O(\sim 1eV^2)$, which is numubar → nuebar at J-PARC MLF
- The key of the experiment is the rejection factor of fast neutrons induced by cosmic rays.
- To check the capability of the rejection factor, it is crucial to have RCNP-E477.
  - To confirm the LS response for protons (E477(A))
  - To check the rejection factor using Cherenkov. (E477(B)).
- From RCNP-E477 information, the feasibility of the JSNS2 experiment is crucially checked.

Supplements

Number of expected events

Source	contents	#ev./50tons/5years	comments
background	$\overline{\nu}_e$ from μ-	237	Baseline 24m
	$^{12}C(\nu_e,e-)^{12}N_{g.s.}$	16	
	Beam fast neutrons	Consistent with 0 < 13 (90%CL UL)	
	Fast neutrons (cosmic)	**37**	**Rejection factor = 100**
	Accidental	32	
signal		480	Δm^2=2.5, $\sin^2 2\theta$=0.003
		342	Δm^2=1.2, $\sin^2 2\theta$=0.003

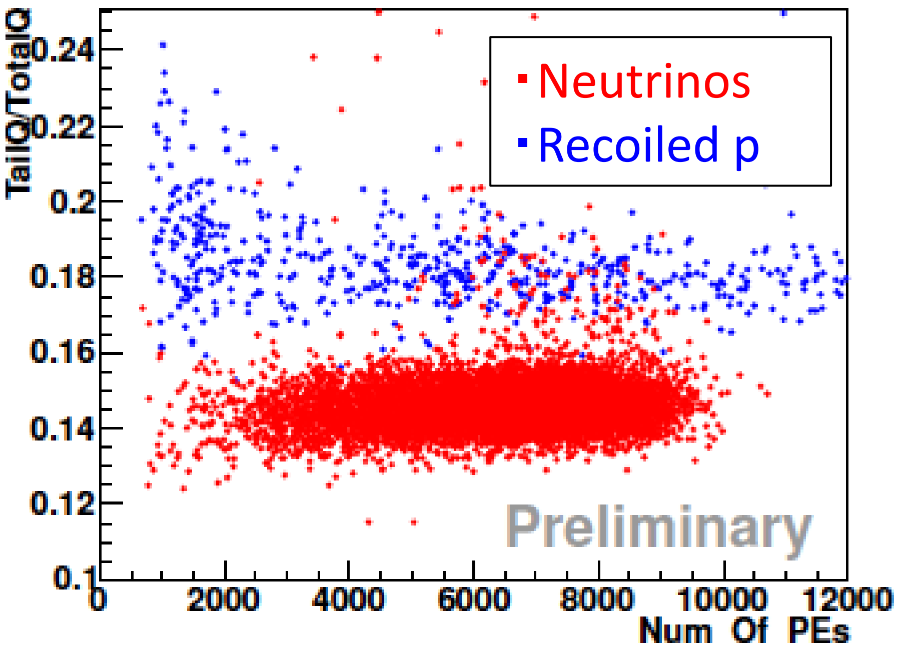
Accidental BKG is calculated by;R acc = $\Sigma R_{prompt} \times \Sigma R_{delay} \times \Delta_{VTX} \times N_{spill}$

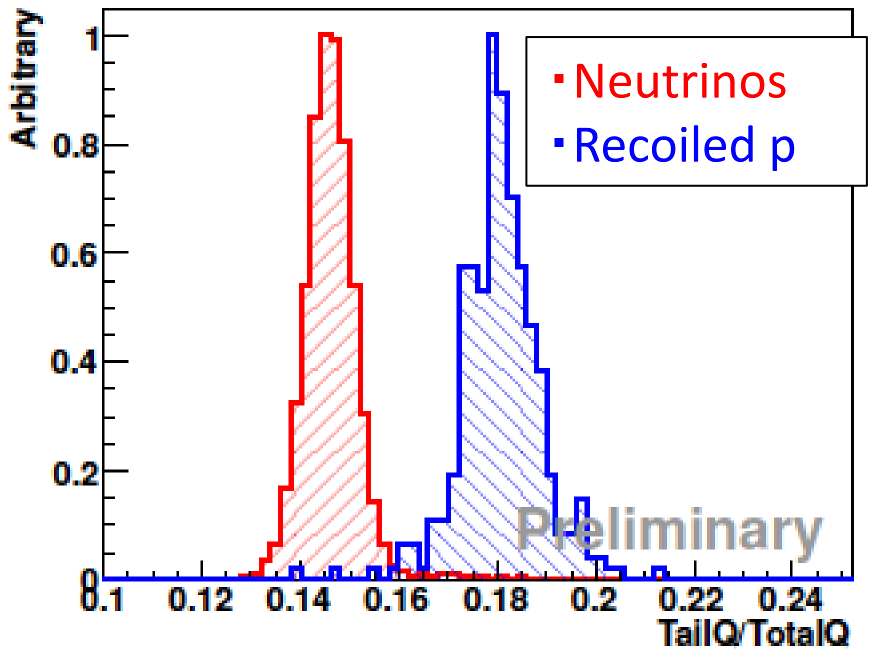
- ΣR_{prompt}, ΣR_{delay} are probability of accidental BKG for prompt and delayed.
- Δ_{VTX} ; BKG rejection factor of **50**.
- N_{spill}(#spills / 4 years) = 2.3×10^9

Evaluation of the PSD capability by Geant4 MC simulation

PSD capability with JSNS² detector (MC)

100% oscillated neutrinos and cosmic induced fast neutrons with same method as proposal.
=>Check the TailQ/TotalQ ratio as a function of #p.e.s due to ν and recoiled p by the neutron.





The plots indicate good separations between neutrinos and recoiled p events.

⇒Need to check with measured data.
⇒Actually, there is following **γs due to inelastic or spallation reaction of ^{12}C** (the PSD may becomes worse) => need to check it.

Measurement of the PSD capability with test beam (next topic)

location and beam power

- Assumptions
  - DAQ rate: 500 Hz
  - neutron interaction rate: 0.5 (MC: 0.6 for E_{dep}>10 MeV)
  - beam spread: 6 cm-square at the 6 m (the last collimator) from the target by adding materials in to the beam hole
  - beam repetition rate: ~1µs
  - neutron flux: $2x10^9$ n/MeV/sr/uC

location and beam power

- detector location: 20 m from the target
  - ToF=170 ns for E_k=80 MeV
  - ToF=67 ns for β=1
  - ToF=328 ns for E_k=20 MeV
- beam spread@20 m ~ 20 cm-square ~ 1×10^{-4} sr
  - 200 kHz/MeV/μA@20 m
  - 5 nA ⇔ DAQ rate: 500 Hz

Beam Request for Exp. B

- Running time: 3 days
- Beam line: N0
- Type of particle: neutron
- Beam energy: 80 MeV
- Beam Intensity: 5 nA
- Repetition rate: ~1µs

- comment: need some time to prepare apparatus

Expected timing information in the real size detector.