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Status of the KDAR neutrino search with JSNS^2 Experiment

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

Introduction of JSNS^2 experiment

@ 10th JSNS^2 Collaboration meeting (7-9 Feb, 2020)

- The **J**-PARC **S**terile **N**eutrino **S**earch at the **J**-PARC **S**pallation **N**eutron **S**ource (JSNS^2) experiment has started a study of neutrino oscillations with $\Delta m^2 \sim 1\ eV^2$ from anti-muon neutrinos to anti-electron neutrinos detected via inverse beta decays(IBD) which are tagged via gammas from neutron captures on Gadolinium.

- JSNS^2 is the only experiment that can directly test the LSND anomaly without having to rely on theoretical scaling assumptions.

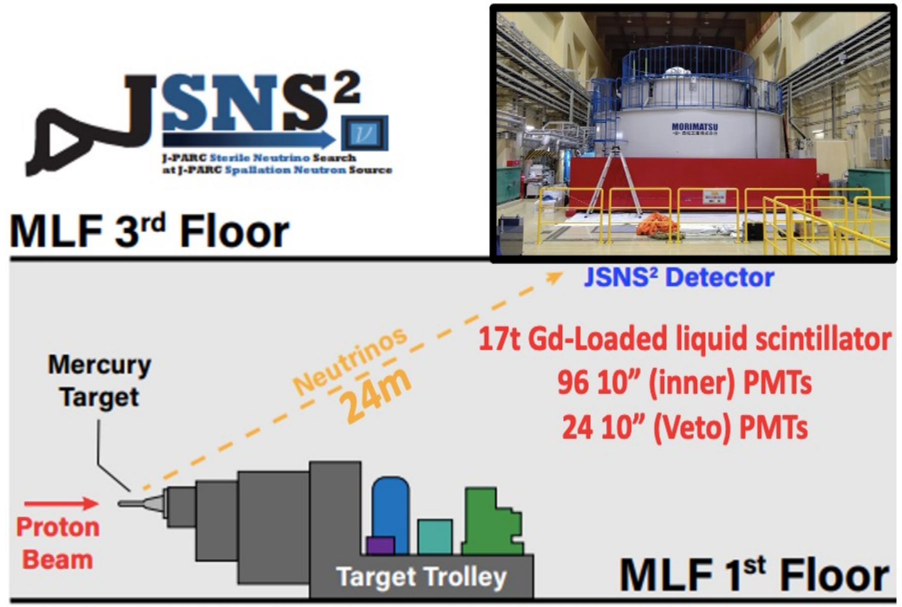
*** See more JSNS^2 info**

Latest results from JSNS^2 and status of JSNS^2-II"

Aug 2 - Jungsic Park [Oral talk]

Gain Calibration using dark hits in off-time region of regular data at JSNS^2 experiment

Aug 2 - Ryeonggyoon Park [Poster]



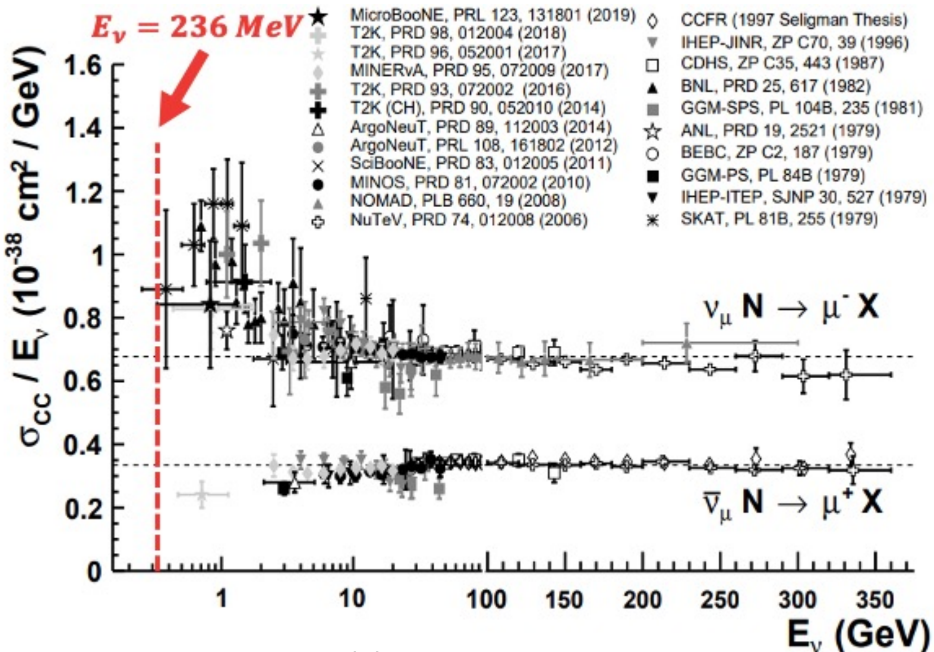
J-PARC MLF : Ideal environment for the JSNS^2 experiment

- The J-PARC MLF 3 GeV primary proton energy is sufficient to produce kaons efficiently. In consideration of the facility's beam intensity (eventually 1 MW, currently 0.7 - 0.8 MW), represents the best facility in the world to accomplish KDAR analysis.

- **We expect to make a more precise measurement of the Kaon Decay-At-Rest (KDAR) neutrino interaction cross-section.**

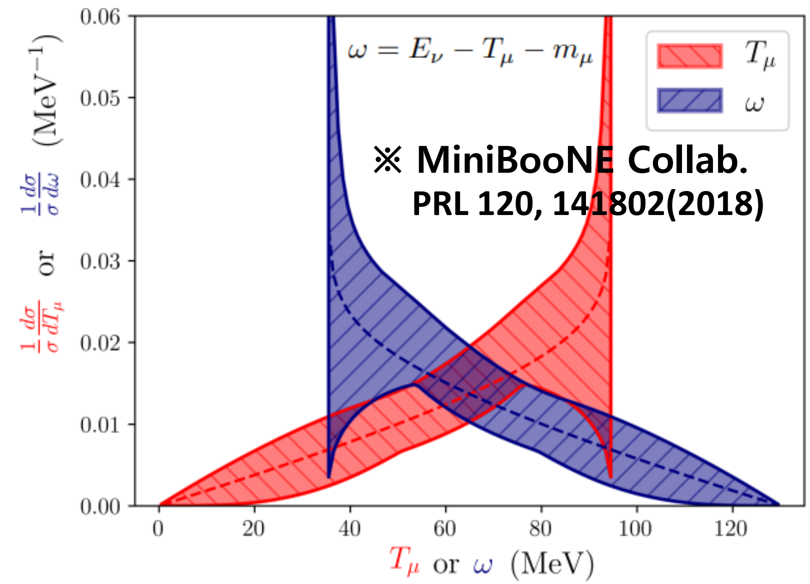
- **We will be able to measure the visible energy spectrum of KDAR primary event for the first time.**

Motivation



- Neutrino is invisible!
  → We can only detect when they interact.
- Neutrino cross section at low E is poorly known.
  1) Knowing neutrino energies is difficult.
  2) Hard to model and reconstruct.
- But the case of KDAR Neutrinos,
  1) Monoenergetic energy (236 MeV)
  2) CCQE : Relatively simple interaction process.

Shape-only differential cross sections in terms of T_μ and $\omega(\nu - n\ energy\ trasfer)$ with 1σ error bands.



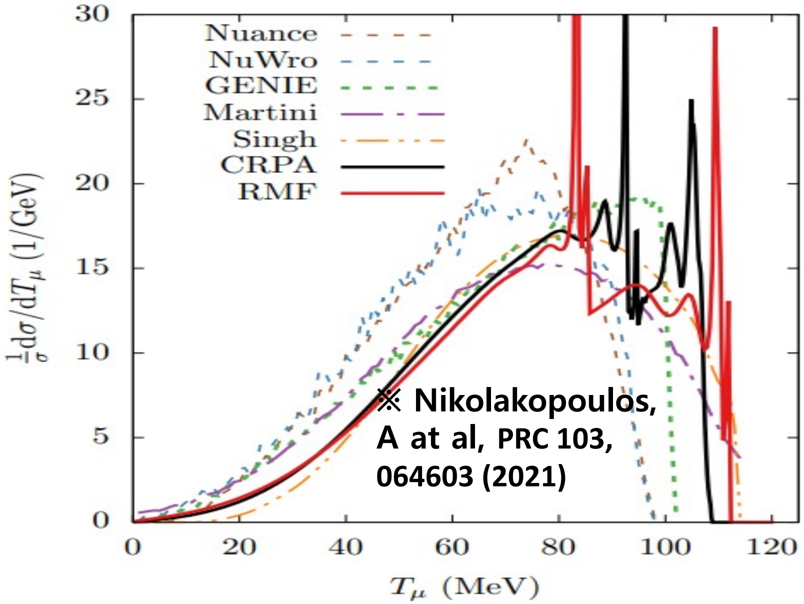
- Recently, MiniBooNE measured the KDAR neutrinos for the first time.

Total ν_μ CC cross section at $E_\nu = 236$ MeV:
$(2.7 \pm 0.9 \pm 0.8) \times 10^{-39} \text{cm}^2/\text{neutron}$

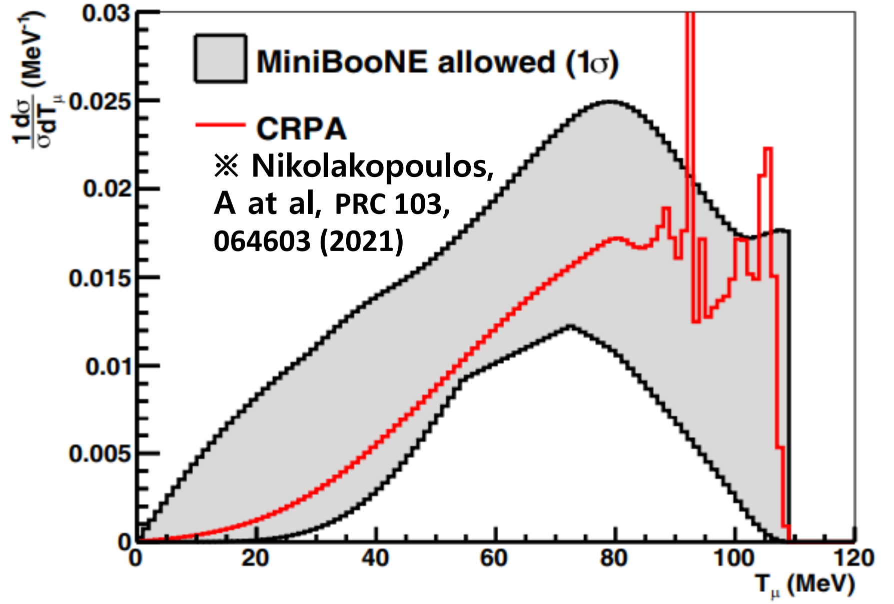
- Shape-only differential KDAR cross sections was measured in terms of energy.
  → Due to High DIF backgrounds rate.
- JSNS[2] is expected make a better shape-only cross section measurement.

Motivation

KDAR for the various nuclear models



MiniBooNE result with a prediction



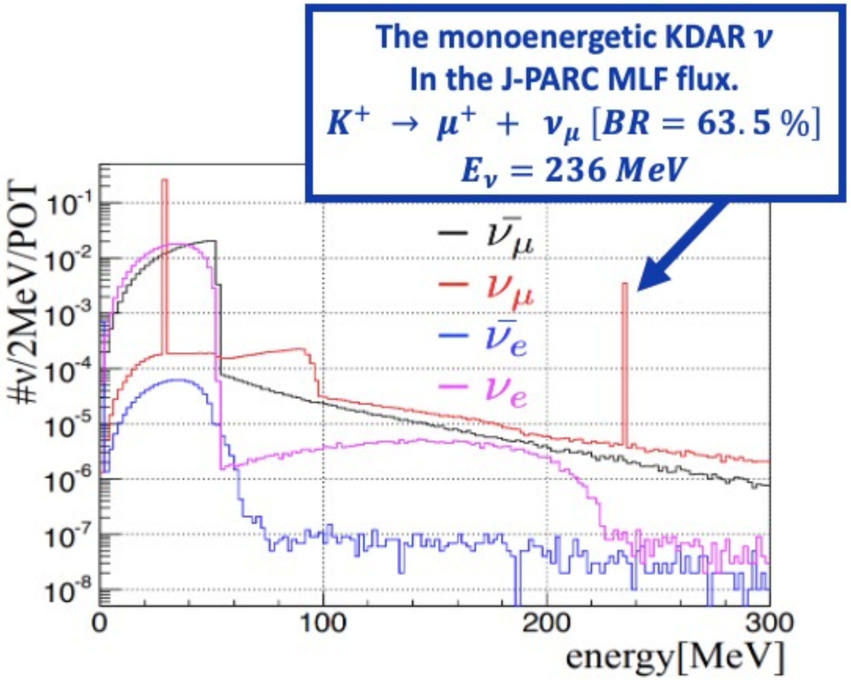
- Electron scattering has been the dominant tool for understanding the nucleus so far.
- We can probe the nucleus through neutrino.

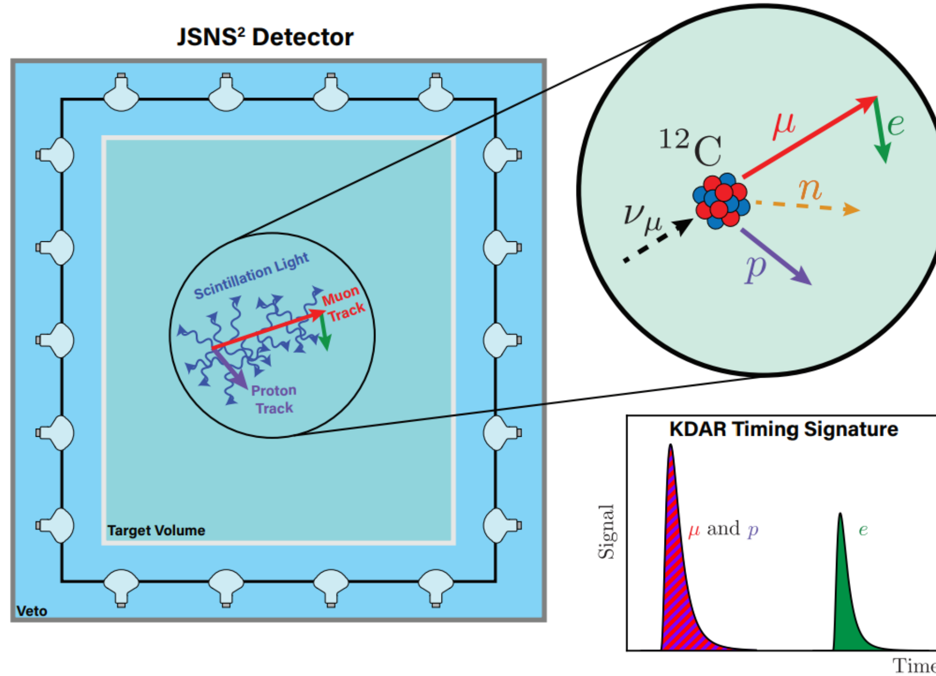
- But the difficulty is,
  1) Knowing neutrino energies is difficult.
  2) The transition region between neutrino-nucleus and neutrino nucleon scattering are hard to model.

- One golden way: KDAR Neutrinos
  1) Known energy (Monoenergetic neutrino)
  2) Right at the transition between neutrino-nucleus and neutrino nucleon scattering

KDAR : What are we measuring?

※ **JSNS² TDR** arXiv:1705.08629





- When charged kaons decay at rest, they can produce monoenergetic neutrinos from the two-body decay.

$$K^+ \rightarrow \mu^+ + \nu_\mu\ [BR = 63.5\ \%]$$

- In the case that the kaon is at rest when it decays, the emitted muon neutrino is monoenergetic.

$$E_\nu = 236\ MeV$$
$$E_{vis} = E_\nu - m_\mu(106\ MeV) - T_X$$

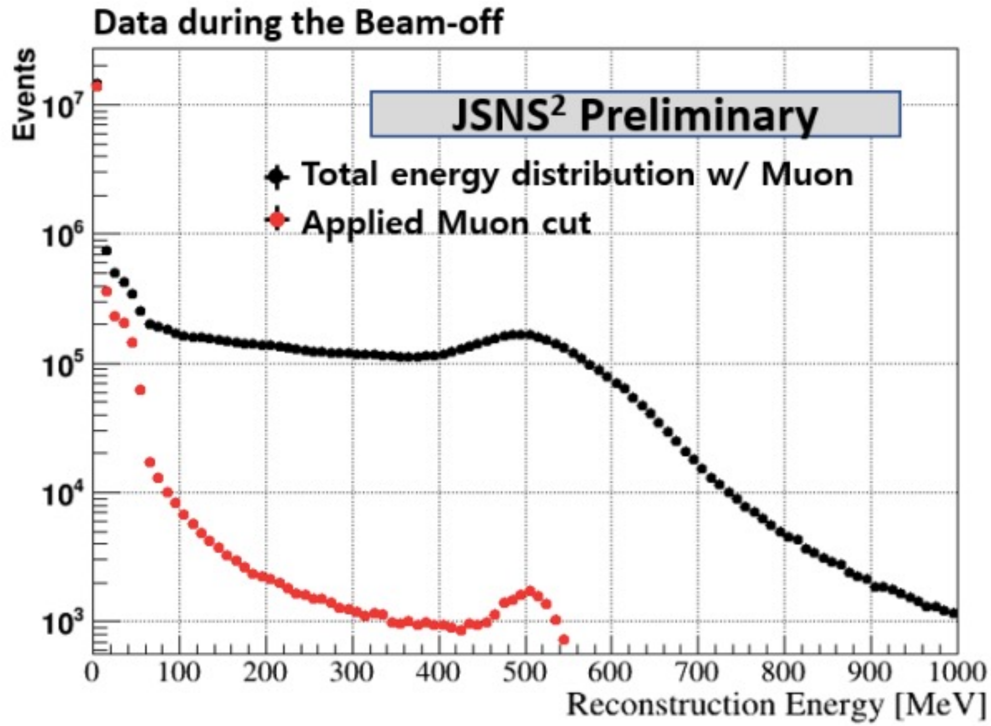
Backgrounds [Cosmic ray induced]

KDAR $K^+ \rightarrow \mu^+ + \nu_\mu$

Prompt $\nu_\mu + {}^{12}C \rightarrow X + \mu^-$

Delayed $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

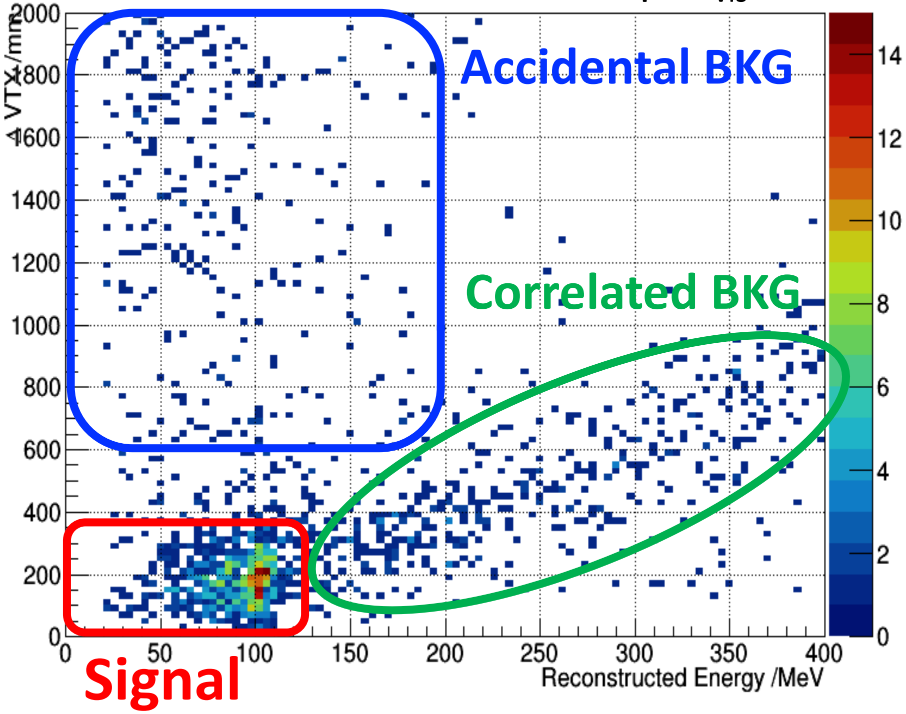
$$cosmic\ \mu \xrightarrow{decay} Michel\ e$$



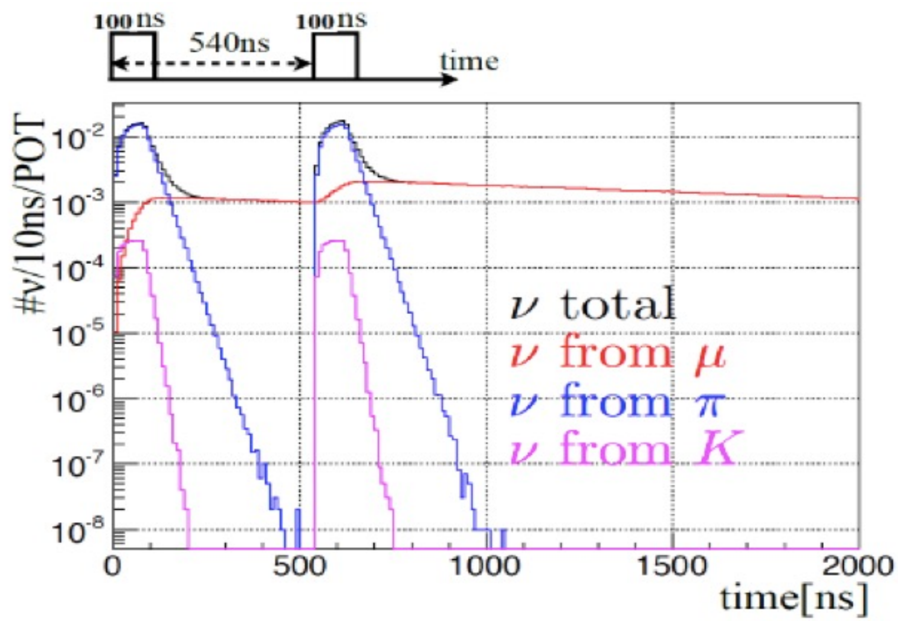
- As JSNS^2 is a surface based detector, we expect cosmic induced events to be the dominant source of backgrounds for this measurement.
- Cosmic muons can be produce a prompt & delayed event signature that is similar to that of KDAR neutrinos.
- We already measured the muon veto condition with no-beam data which means there is alm ost zero to muon interaction without cosmic induced muon.
  → Cosmic muon rejection with 99% efficiency.

Backgrounds [Correlated & Accidental]

ΔVTX versus KDAR Prompt E_{vis}



∗ *ΔVTX* **: Reconstructed vertex difference between prompt and delayed event of KDAR coincidence.**



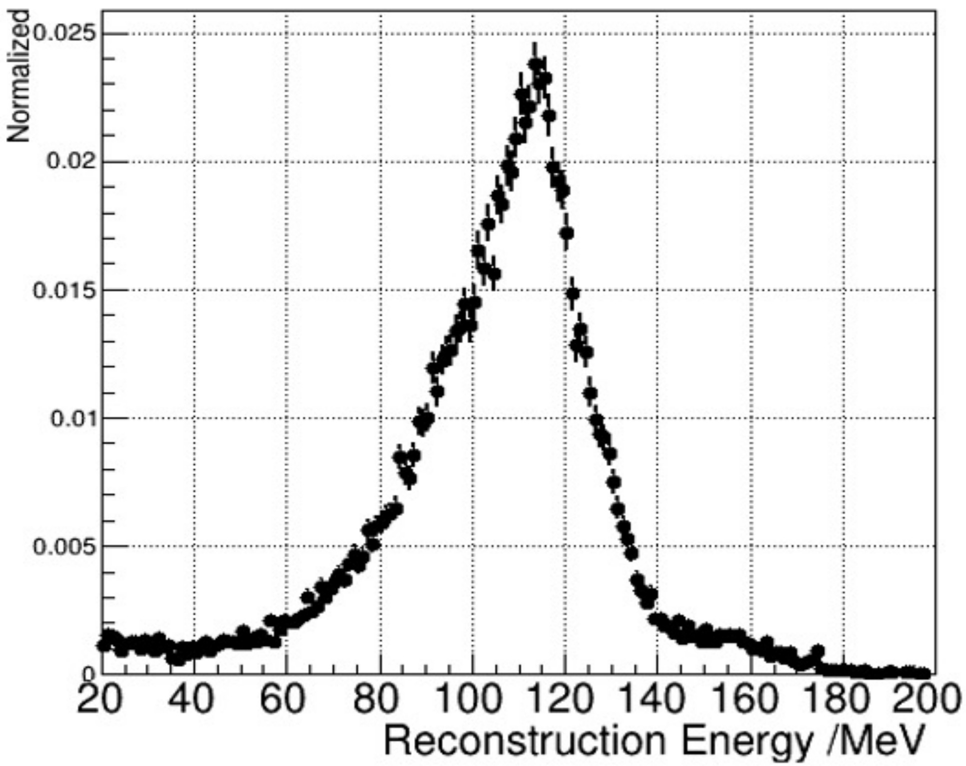
- **Accidental BKG** : Randomly paired as KDAR coincidence from single-particle events.

- **Correlated BKG** : Non-KDAR event have there own subsequence particle whose structure mimics KDAR event. (e.g. Cosmic ray induced muon and Michel e^-)

- The time distribution of neutrinos from pion, muon and kaon decays.
- the neutrino from kaon is concentrated at the proton beam bunch timing.
- Reject events from most non-KDAR sources by selecting only events within a narrow timing window following the beam.

KDAR signal measurement in JSNS^2

MC : KDAR Prompt event ($\mu + X$)



Above shows the MC simulated KDAR energy spectrum as predicted by the NuWro simulation packaged.

KDAR $K^+ \rightarrow \mu^+ + \nu_\mu$

Prompt $\nu_\mu + {}^{12}C \rightarrow X + \mu^-$

Delayed $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

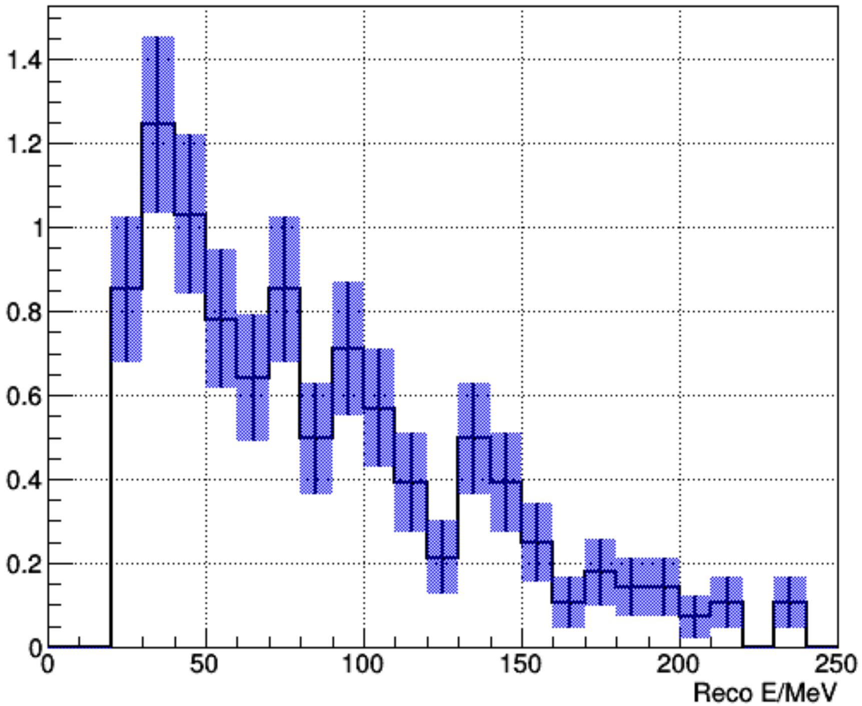
- **KDAR Prompt E : 20 – 140 MeV**

$$E_\nu = 236\ MeV$$
$$E_{vis} = E_\nu - m_\mu(106\ MeV) - T_X$$

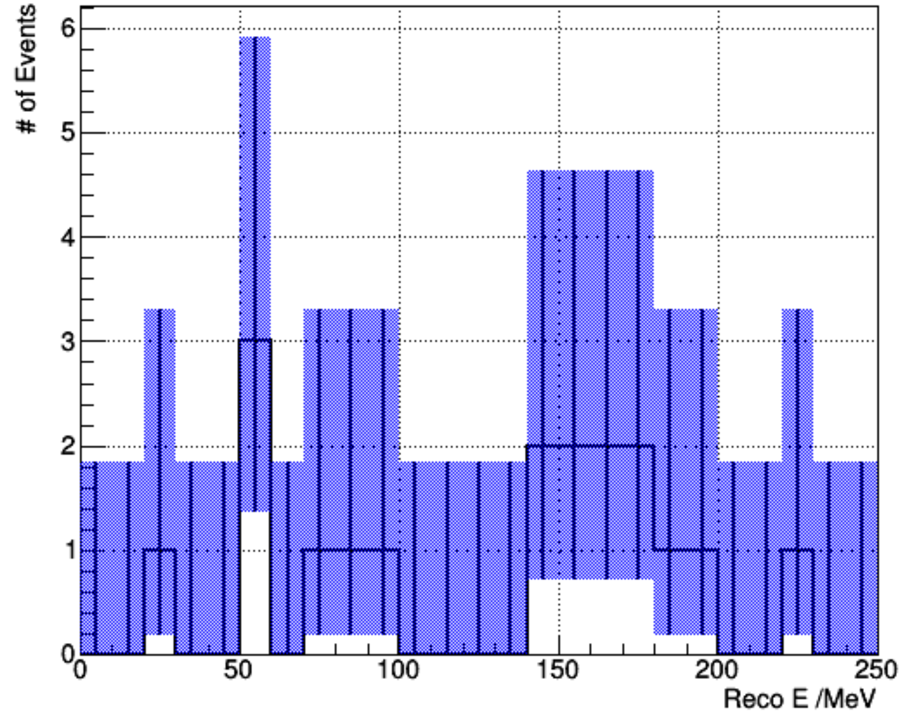
- **KDAR delayed E : 20 – 60 MeV**
- **Time coincidence limit : < 10 us**
- **Beam-timing cut (150 ns each)**
- **Vertex difference criteria : 0.3 m**
- **Fiducial volume cut**

Backgrounds Estimation

Template of Accidental BKG



Template of Correlated BKG

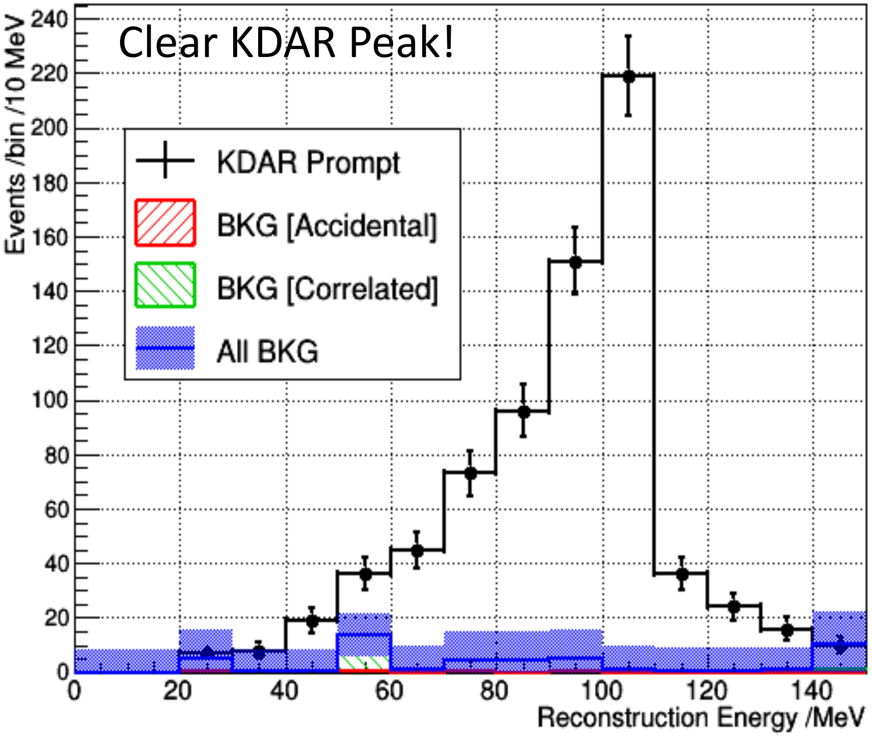


- The correlated background energy spectrum was modeled via the sideband beam timing.
- The accidental background was obtained from random coincidence sample.
- The energy spectrum template was normalized by BKG dominant area, 140 – 250 MeV.

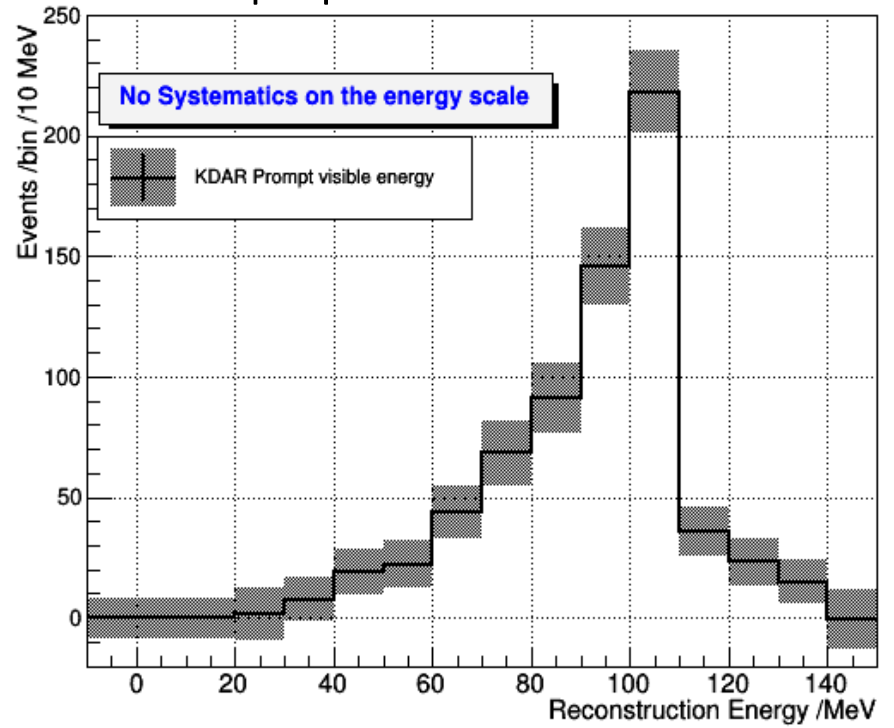
  → Expected no KDAR signal region.

Analysis Result

KDAR Prompt visible spectrum with BKG



KDAR Prompt spectrum with BKG subtraction



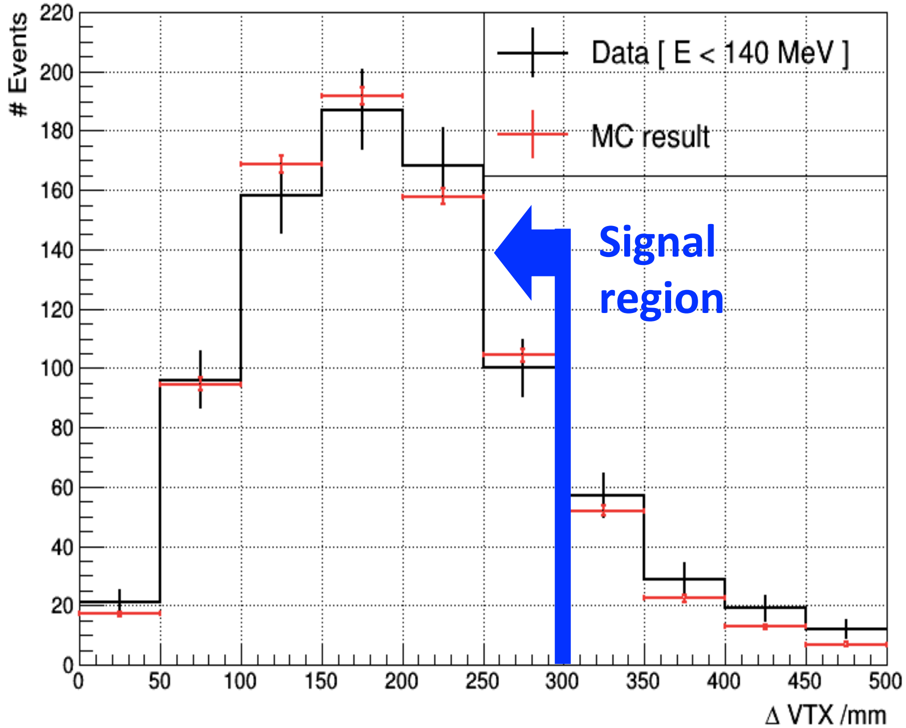
- The KDAR neutrino interaction is observed 691.9 ± 46.9 events.
  → 38.1 ± 38.4 backgrounds (5.2%)

- Note that the systematics on the energy scale are not included yet.

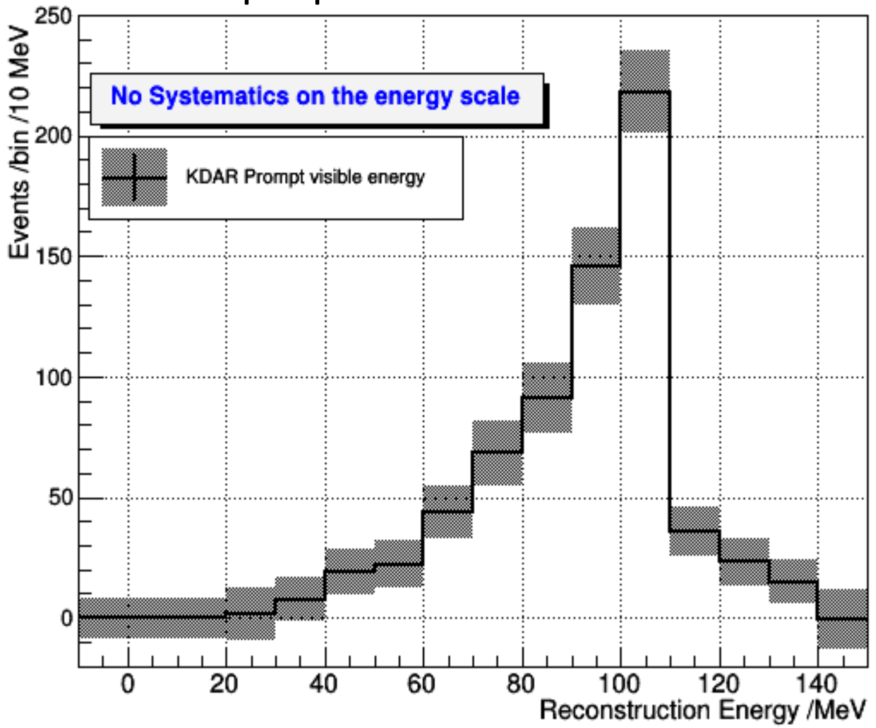
BKG ID	Correlated/ Accidental	BKG (# of events)	
1	**Correlated**	**36.6 ± 34.8**	**5.0 ± 5.1%**
2	**Accidental**	**1.5 ± 0.1**	**0.2 ± 0.01%**
KDAR Signal **730 events**		**38.1 ± 38.4**	**5.2 ± 5.3%**

Analysis Result

∗ *ΔVTX* : **Reconstructed vertex difference between prompt and delayed event of KDAR coincidence.**



KDAR Prompt spectrum with BKG subtraction



- The vertex difference distribution between data and MC shows the consistent within the error.
- It means that a high purity of KDAR signal is obtained in signal result, 20 – 140 MeV.

BKG ID	Correlated/ Accidental	BKG (# of events)	
1	Correlated	36.6 ± 34.8	5.0 ± 5.1%
2	Accidental	1.5 ± 0.1	0.2 ± 0.01%
KDAR Signal 730 events		38.1 ± 38.4	5.2 ± 5.3%

Conclusion

- JSNS^2 has observed the neutrino interaction from KDAR through the visible energy spectrum using the first long-term physics data.
- This is the world first measurement of the neutrino visible energy with a 5.2 % level of the backgrounds.
- The KDAR neutrino interaction is observed 691.9 ± 46.9 events with statistical error only.
- For the future analysis,
  → KDAR analysis from JSNS2 is not complete yet. More improvement and detailed analysis are actively ongoing.

  → Low-energy neutrino cross section measurement

  → KDAR energy spectrum as a function of neutrons produced in the interaction, as measured via neutron capture.