Summary

T. Nakaya
(Kyoto University)

Thank you very much for your active participation and excellent presentation

38 participants

+19 Students

from 11 countries

Japan (17), US (6), China (4), Vietnam(4) , Spain, Korea, Italy, India, France, Australia, Russia

First Day

Neutrinos are interesting!

Research is international.

Your contributions are essential.

Let's begin the exciting symposium on neutrino frontiers!

Program Outline

- Monday (+Tuesday)
  - Mainly, on-going projects with artificial neutrinos (accelerators, reactors, etc..)
- Tuesday
  - Mainly, on-going projects with natural neutrinos (Sun, Astronomical sources, + more …)
  - Young Physicist talks
- Wednesday
  - Theories, dark matter & $\beta\beta$, Exotic search
- Thursday
  - Mainly future projects, $\beta\beta$ and synergy with cosmic neutrinos

Neutrino Programs in this symposium

Accelerator

- T2K
- NOvA
- MINOS/MINOS+
- NC-γ
- MicroBooNE
- LHC
- JSNS2
- OPERA
- (WAGASCI)YP
- Hyper-K
- DUNE
- DsTau
- SHiP

+YP talks

Reactor

- Daya Bay
- RENO
- STEREO
- DANSS
- JUNO
- KamLAND

Natural ν

- Super-K
- Borexino
- IceCube

$\beta\beta$

- Panda-X
- AXEL
- KamLAND-Zen

Atom & Cosmic ν

- SPAN
- COBAND
- Simons Array

Theories

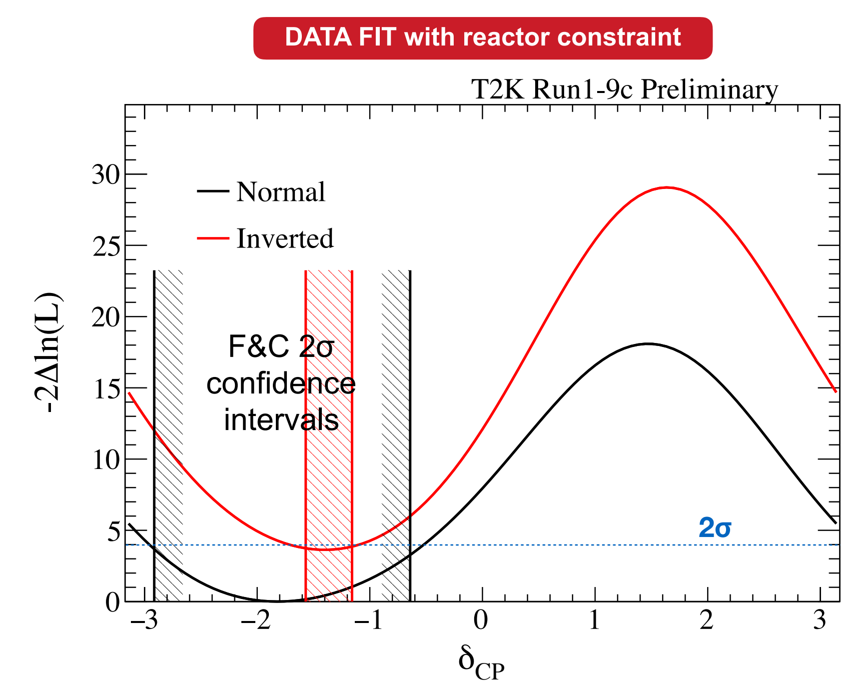
- Overview
- EW ν_R
- Ultra-High Energy Neutrinos
- νMSM
- Leptogenesis
- New Physics in LBL
- Dirac or Majorana

The future program is rich.

We look forward to the results.

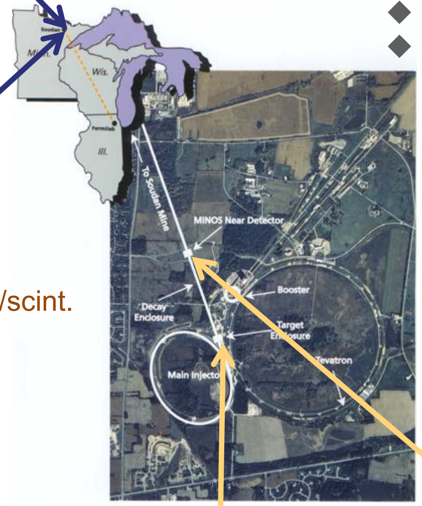
δ_{CP} 1D contour

- CP conserving values (δ_{CP}=0 & δ_{CP}=π) outside of **2σ region** for both hierarchies.



MINOS, MINOS+, and NuMI

- Far Detector (FD) on axis
- 735 km from target
- 5.4 kt, 8m octagon
- ~1.2 T B field
- Segmented, sampling, iron/scint. tracking calorimeter



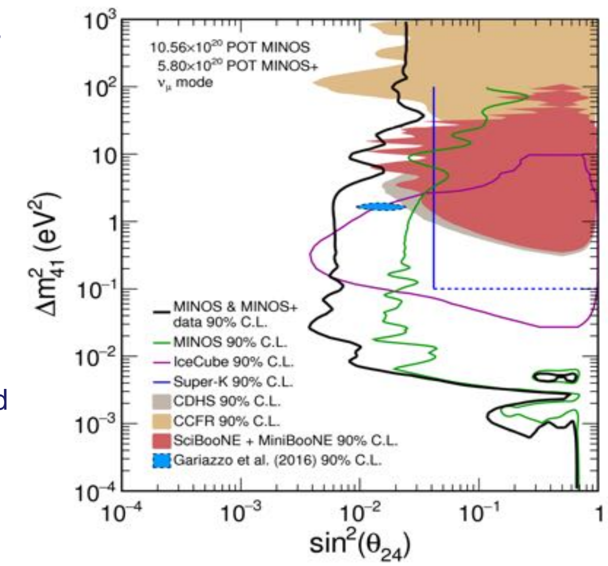
- MINOS Proposed 1995
- Main Injector 2000
- Beam data 2005-2012
- NuMI reconfigured for NOvA 2013
- MINOS+ 2013-2016

- Near Detector (ND) on axis
- 1,040 m from target
- 1kt, 4m `squeezed' octagon
- ~1.2 T B field
- Same technology as FD

- 2-horn focusing 185 kA
- 2λ graphite target (movable)
- Up to ~600 kW beam
- 3.5×10^{13} ppp
- 1.33 s cycle time

Sterile neutrino bounds

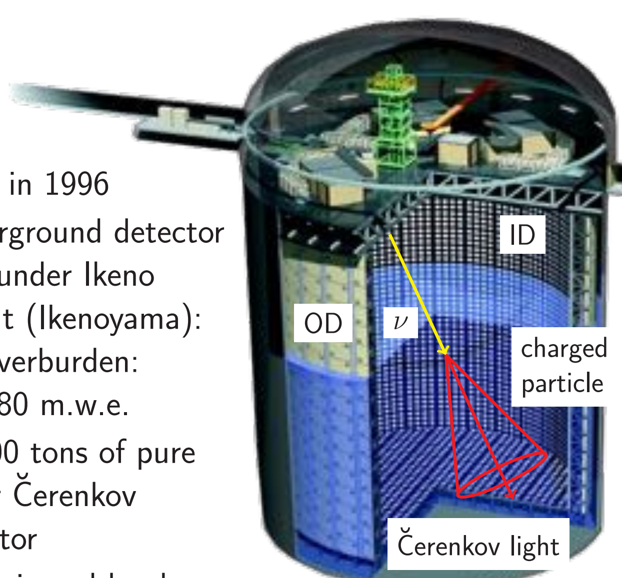
- MINOS and MINOS+ 90% C.L. exclusion limit over 7 orders of magnitude in Δm^2_{41}
- Improvement at large Δm^2_{41} over previous MINOS result due to:
  - Near Detector statistical power
  - Sensitivity to normalization shifts
  - Improved binning around atmospheric dip in Far Detector
- Increased tension with global best fit
  - Displayed here with $|U_{e4}|^2 = 0.023$
- Posted to arXiv:1710.06488 and submitted to PRL
  - See arXiv paper and ancillary materials for more details
- Final year of data is still to be analyzed



*S. Gariazzo, C. Giunti, M. Laveder, Y.F. Li, E.M. Zavanin, J.Phys.G43, 033001 (2016)

Super-Kamiokande

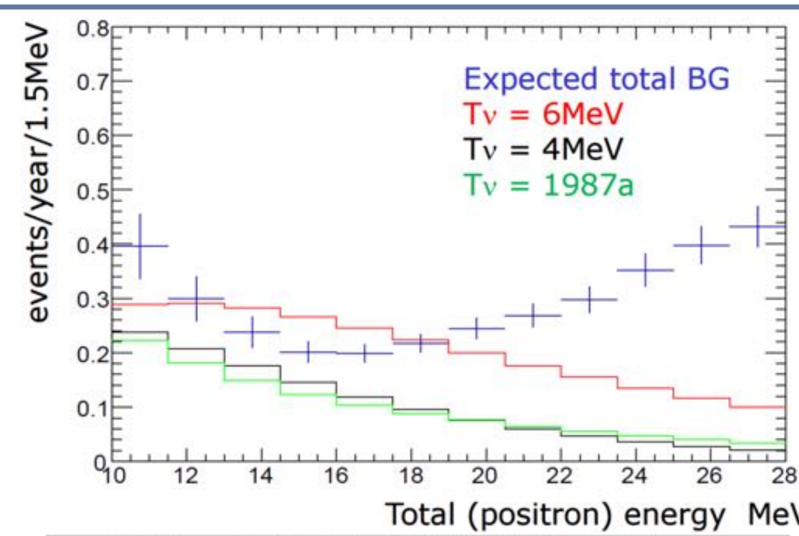
- International collaboration ∼120 collaborators in 10 different countries
- Build in 1996
- Underground detector 1km under Ikeno mount (Ikenoyama): → Overburden: ∼ 2780 m.w.e.
- 50 000 tons of pure water Čerenkov detector
- Analysis and hardware regularly improved since the construction



For Solar neutrino analysis

Phase	Period	Livetime (days)	Fiducial vol. (kton)	# of PMTs	Energy thr.(MeV)
SK-I	1996.4 ~ 2001.7	1496	22.5	11146 (40%)	4.5
SK-II	2002.10 ~ 2005.10	791		5182 (20%)	6.5
SK-III	2006.7 ~ 2008.8	548	22.5 (>5.5MeV) 16.5 (<5.5MeV)	11129 (40%)	4.5
SK-IV	2008.9 ~	2860	22.5 (>5.5MeV) 16.5(4.5<E<5.5) 8.9 (<4.5MeV)		3.5
		total 5695 days		(coverage)	(Kinetic energy)

Supernova Relic Neutrino in SK-Gd



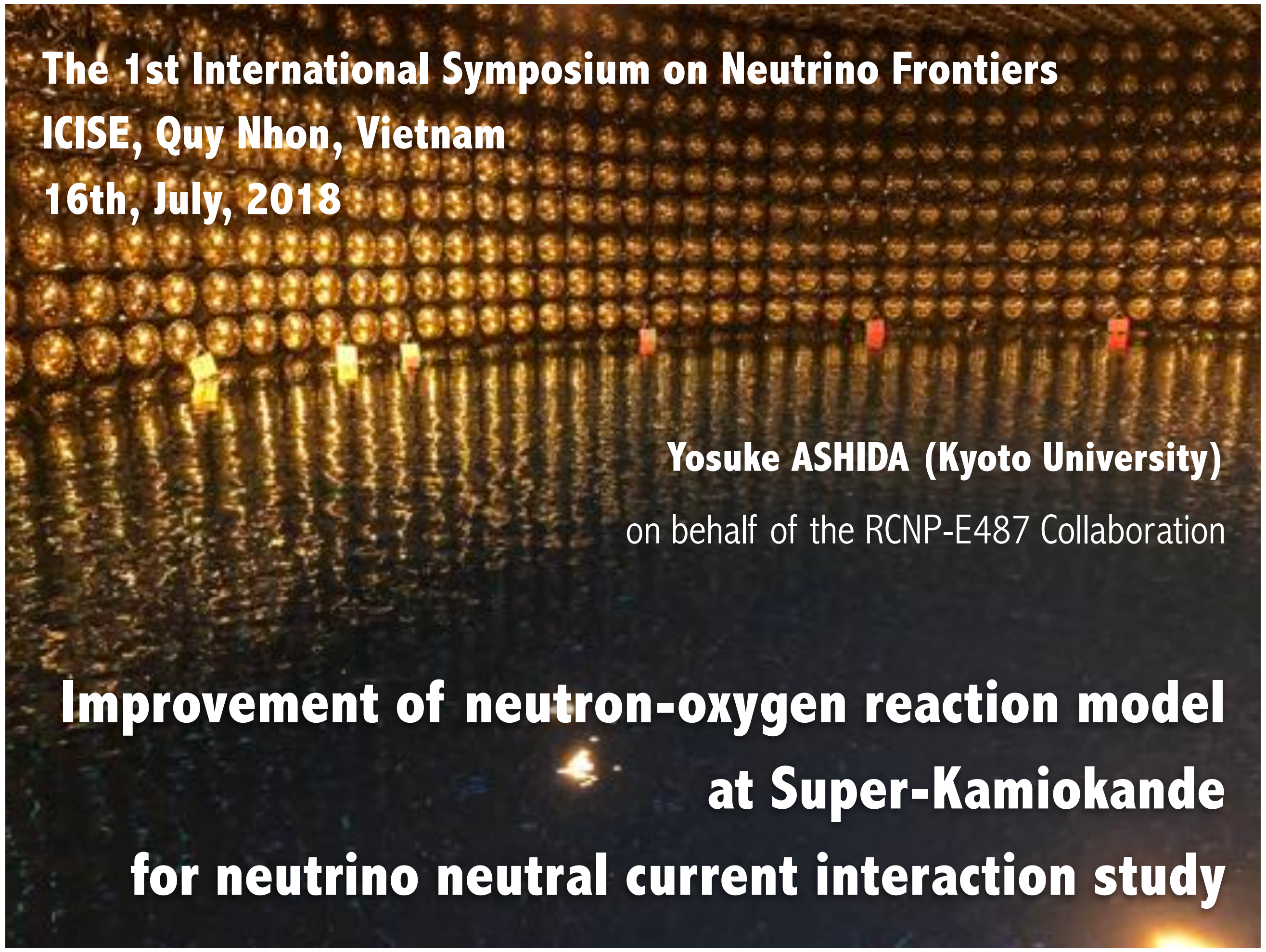
Dependence on the typical SN emission spectrum

HDB*	10-16 MeV	16-28 MeV	Total	significance
T_{eff} 8 MeV	11.3	19.9	31.2	5.3 σ
T_{eff} 6 MeV	11.3	13.5	24.8	4.3 σ
T_{eff} 4 MeV	7.7	4.8	12.5	2.5 σ
T_{eff} SN1987A	5.1	6.8	11.9	2.1 σ
BG	10	24	34	–

In events/10years

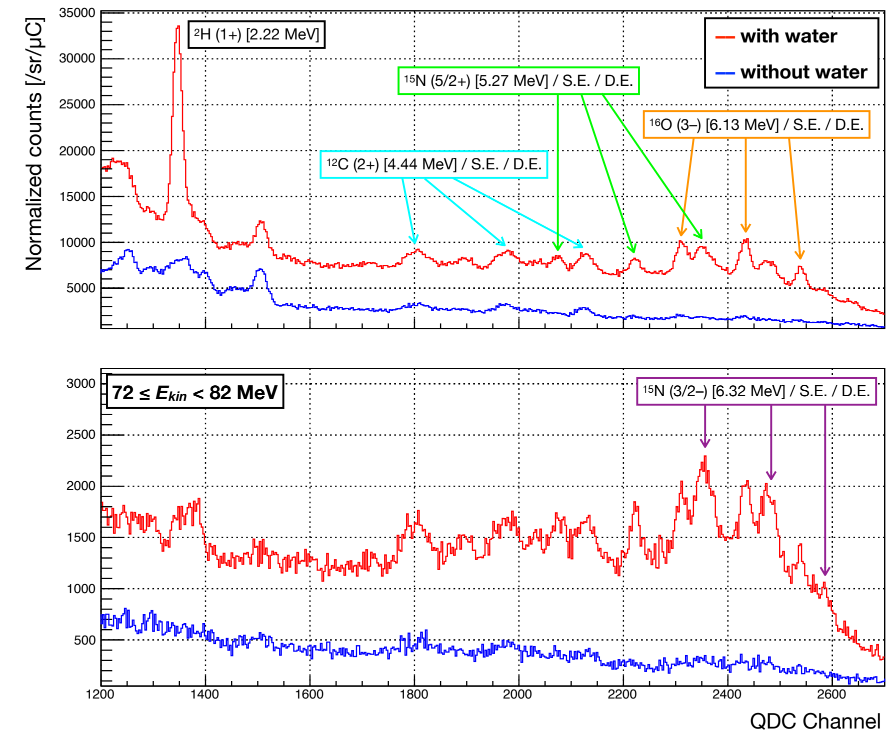
Significance is determined with 2 energy bins

* Horiuchi, Beacom and Dwek, Phys Rev D 79 083013 (2009)

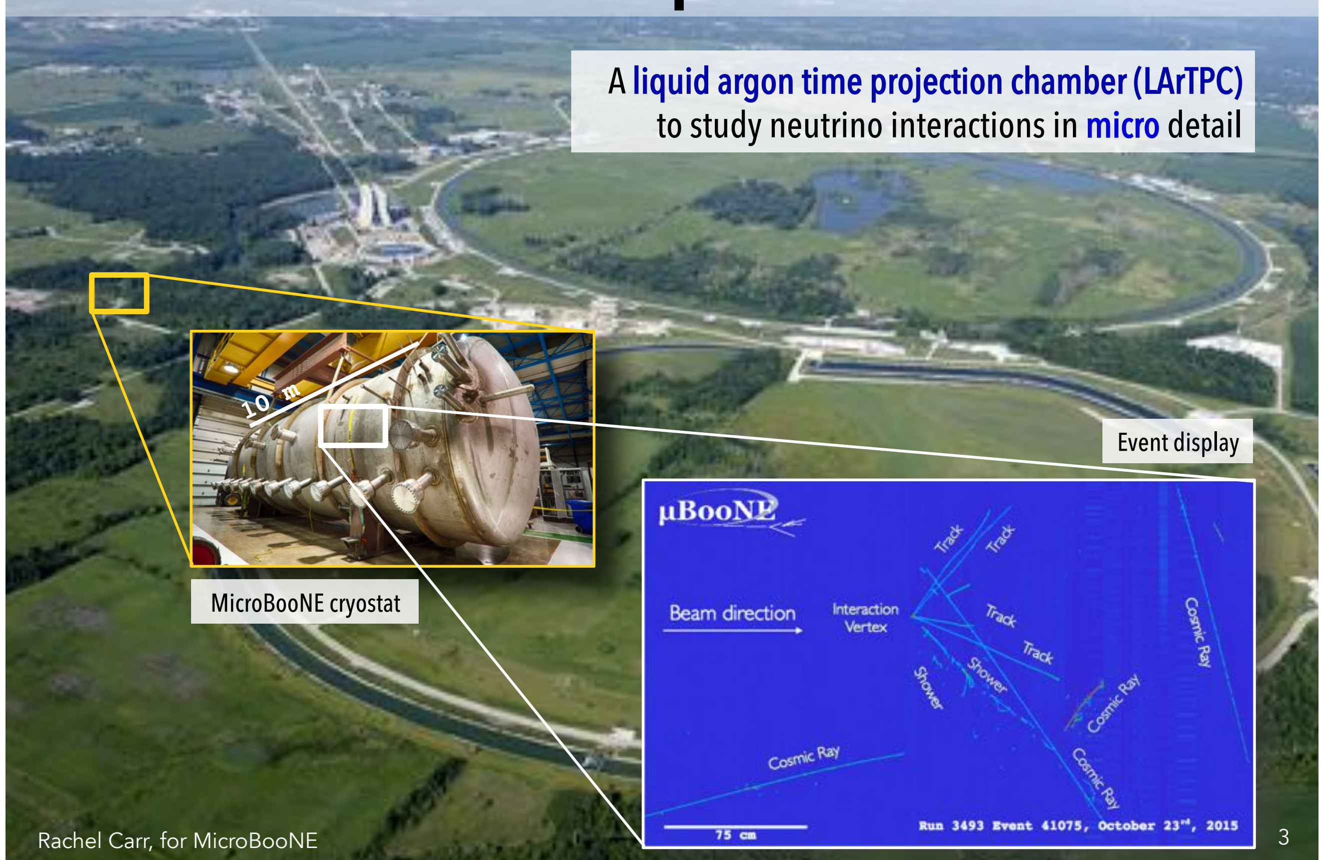


2. GAMMA-RAY (LaBr SPECTRUM)

- Referring to HPGe spectrum, each peak in LaBr spectrum is identified.
- LaBr data has time information, then spectrum with neutron energy cut is also obtained.



The MicroBooNE experiment at Fermilab

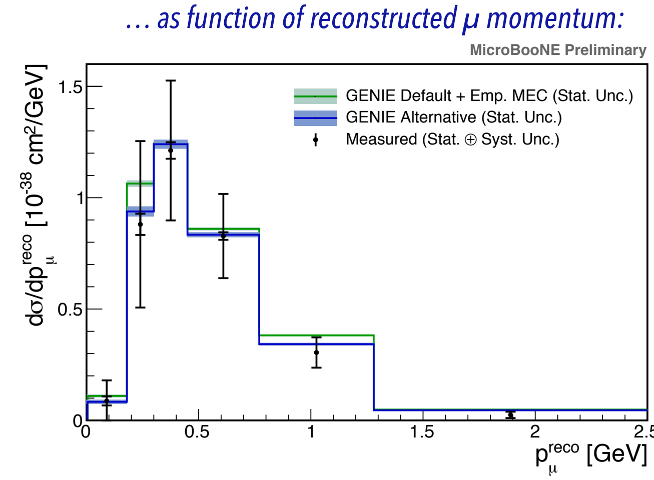


Rachel Carr, for MicroBooNE

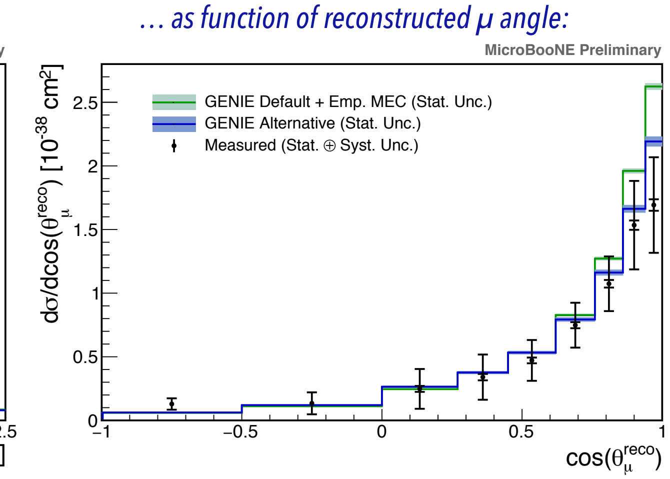
First ν_μ-Ar CC inclusive cross section

First absolute cross section from MicroBooNE:
Charged current ν_μ on argon, inclusive of all interaction modes & final states

… as function of reconstructed μ momentum:



… as function of reconstructed μ angle:

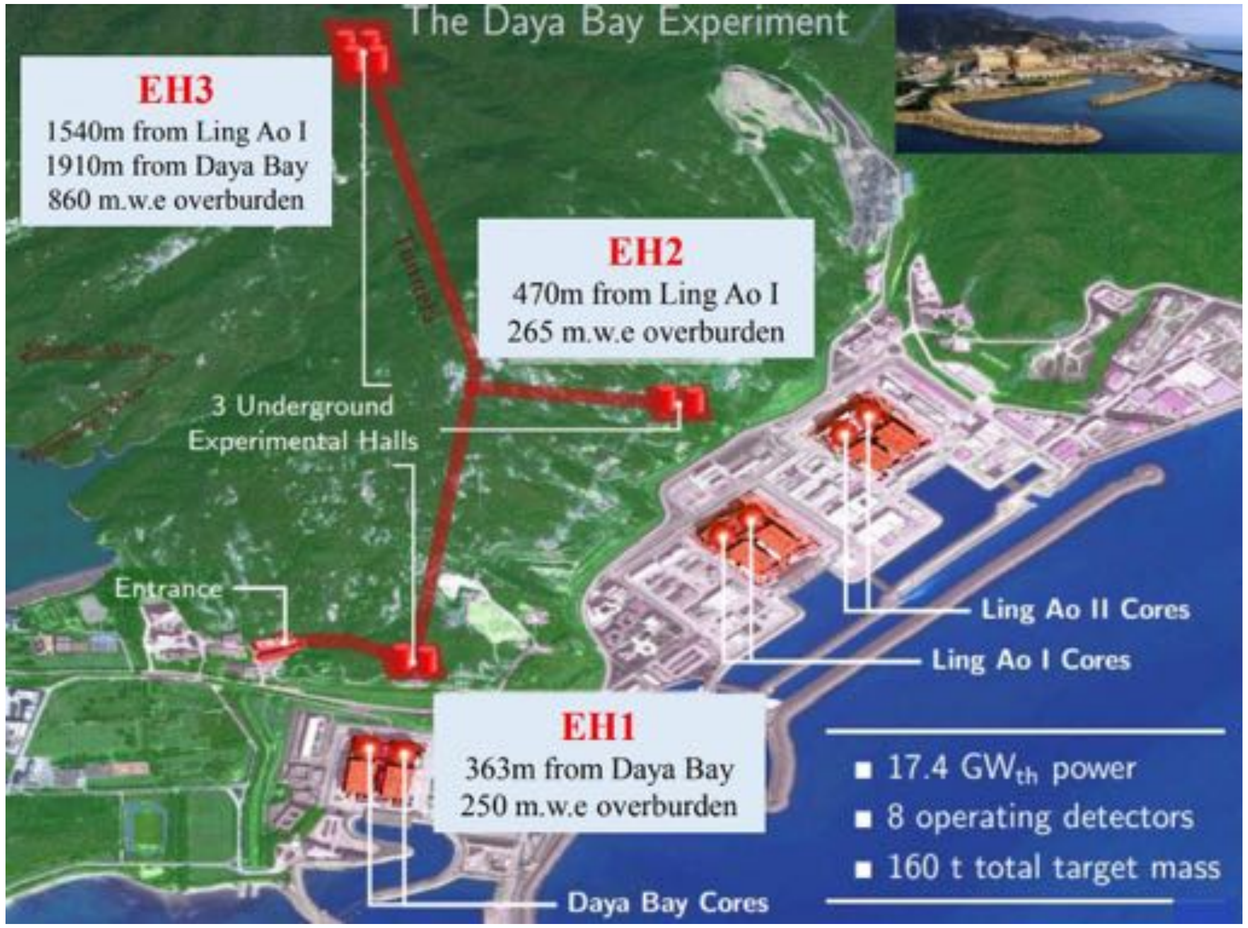


NEW RESULT: **First Muon-Neutrino Charged-Current Inclusive Differential Cross Section Measurement for MicroBooNE Run 1 Data**
Public note: MICROBOONE-NOTE-1045-Pub (2018)

GENIE Empirical MEC = ad hoc model for meson exchange current

Alternative = theory-motivated MEC & more recent models for CCQE, coherent, resonant reactions

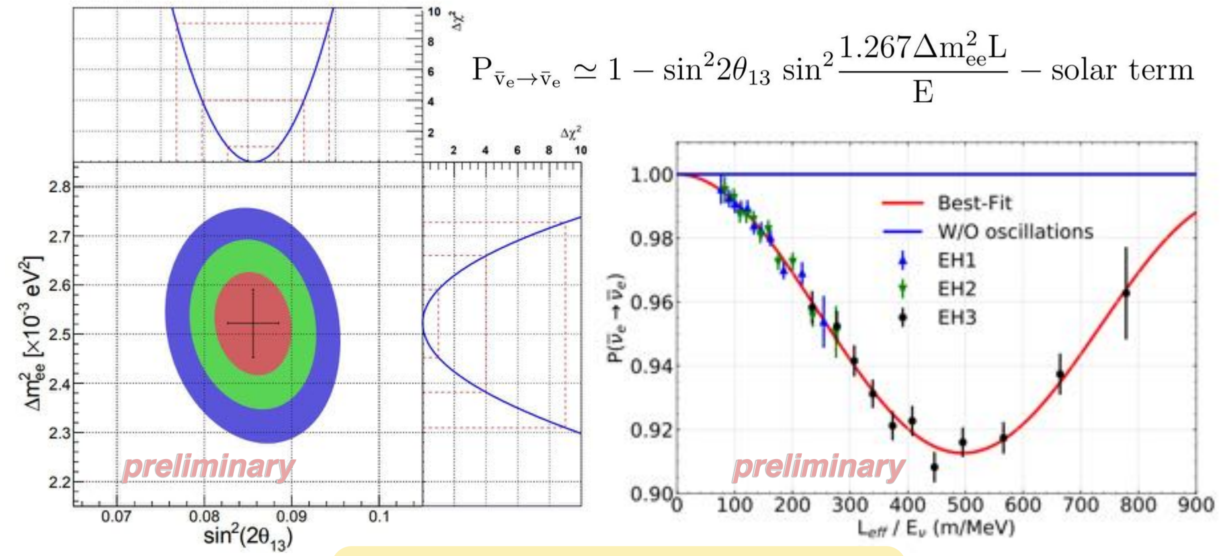
Rachel Carr, for MicroBooNE



Oscillation Results from 1958 Days

- Uncertainty of $\sin^2 2\theta_{13}$ and Δm^2_{ee}: 3.4% and 2.8%
- Statistical uncertainty contributes 60% for $\sin^2 2\theta_{13}$ and 50% for Δm^2_{ee}

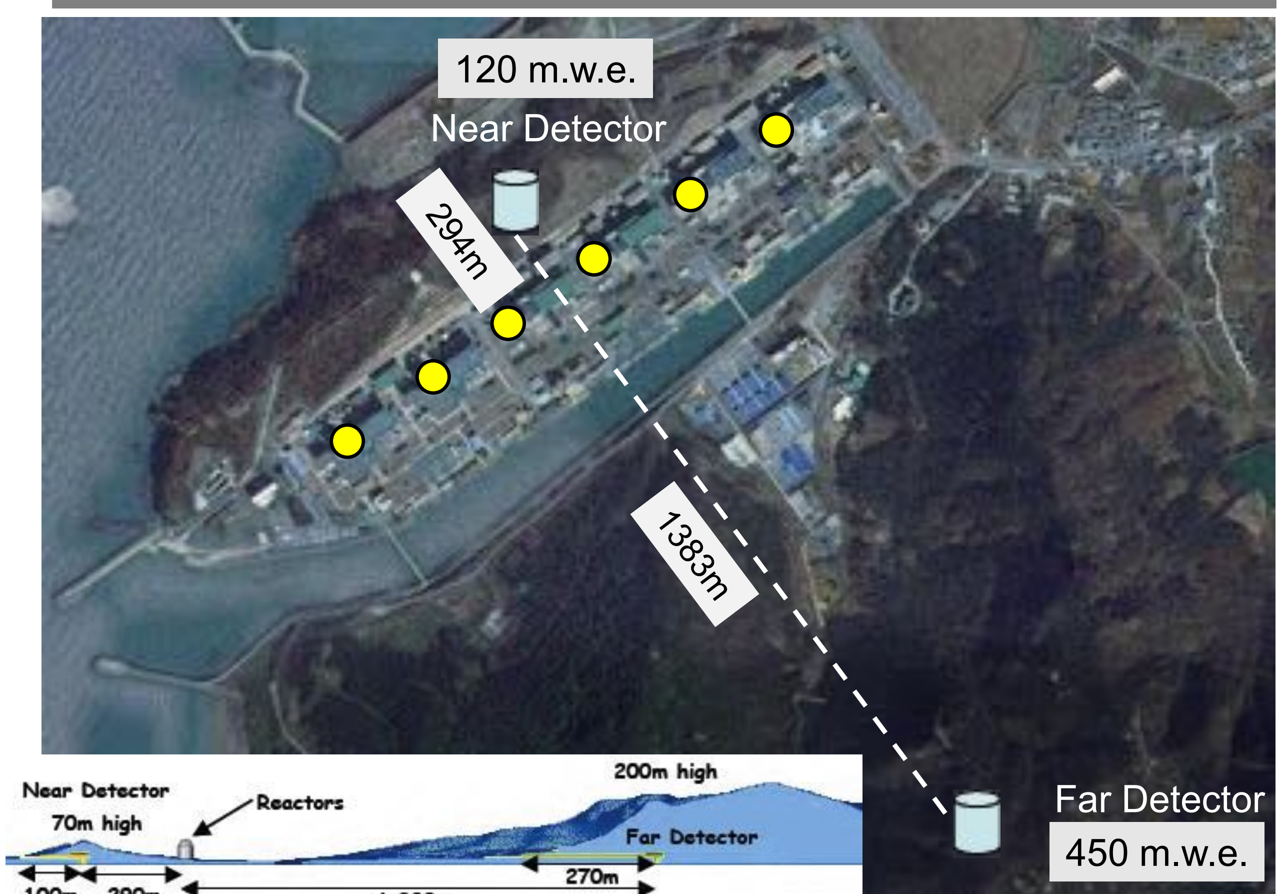
$$P_{\bar{\nu}_e \to \bar{\nu}_e} \simeq 1 - \sin^2 2\theta_{13} \sin^2 \frac{1.267 \Delta m^2_{ee} L}{E} - \text{solar term}$$



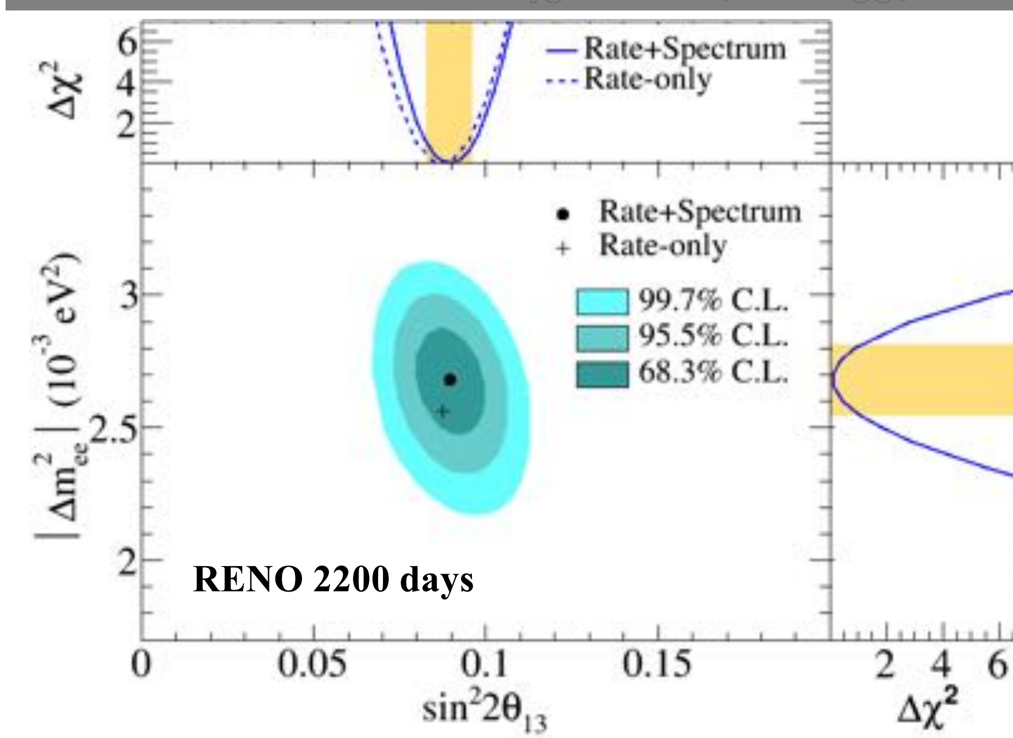
$\sin^2 2\theta_{13} = 0.0856 \pm 0.0029$

$|\Delta m^2_{ee}| = (2.52 \pm 0.07) \times 10^{-3}$ eV^2

RENO Experimental Set-up



Results of θ_{13} and $|\Delta m^2_{ee}|$



$\sin^2 2\theta_{13} = 0.0896 \pm 0.0048(\text{stat.}) \pm 0.0047(\text{syst.})$

$|\triangle m_{ee}^2| = 2.68 \pm 0.12(\text{stat.}) \pm 0.07(\text{syst.})$ ($\times 10^{-3}$ eV^2)

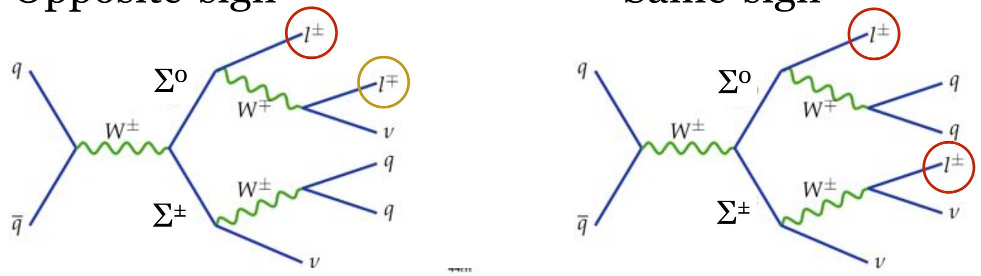
Type-III - dilepton channel

ATLAS: ATLAS-CONF-2018-020

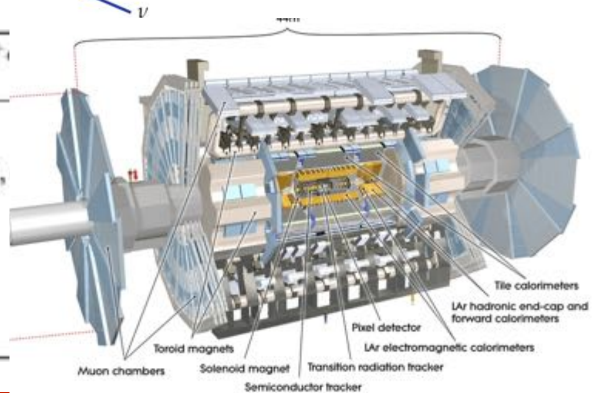
- **pp → $\Sigma^0 \Sigma^\pm$**
- Opposite and same -sign optimised independently.
- Two resolved jets in final state. M(j,j) consistent with W mass and E_T^{miss}.
- Scalar sum of $p_T(\ell)$, called H_T, and E_T^{miss} are combined as primary discriminant.

Opposite-sign

Same-sign

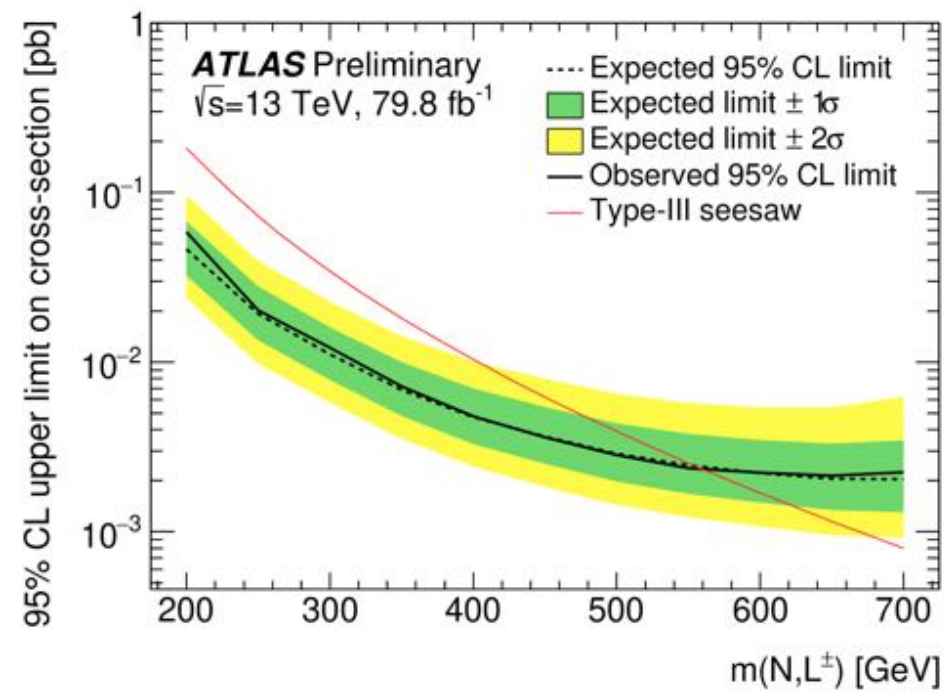


	OS ($\ell^+\ell^- = e^+$… Top CR	Z + jets VR		…$^\pm, e^\pm\mu^\pm, \mu^\pm\mu^\pm$) m_{jj} CR	SR
N(jet)	≥ 2	≥ 2		≥ 2	≥ 2
N(b-jet)	≥ 2	0		0	0
m_{jj} [GeV]	[60, 100)	[60, 100)	[35,	[0, 60) ∪ [100, 300)	[60, 100)
$m_{\ell\ell}$[GeV]	[110, ∞)	[70, 110)		[100, ∞)	[100, ∞)
Sig(E_T^{miss})	≥ 5	≥ 5		≥ 5	≥ 7.5
$\Delta\phi(E_T^{miss}, l)_{min}$					
$p_T(jj)$ [GeV]					[60, ∞)
$p_T(\ell\ell)$ [GeV]					[100, ∞)
$H_T + E_T^{miss}$ [GeV]	[300, ∞)	[300, ∞)		[300, 500)	[300, ∞)



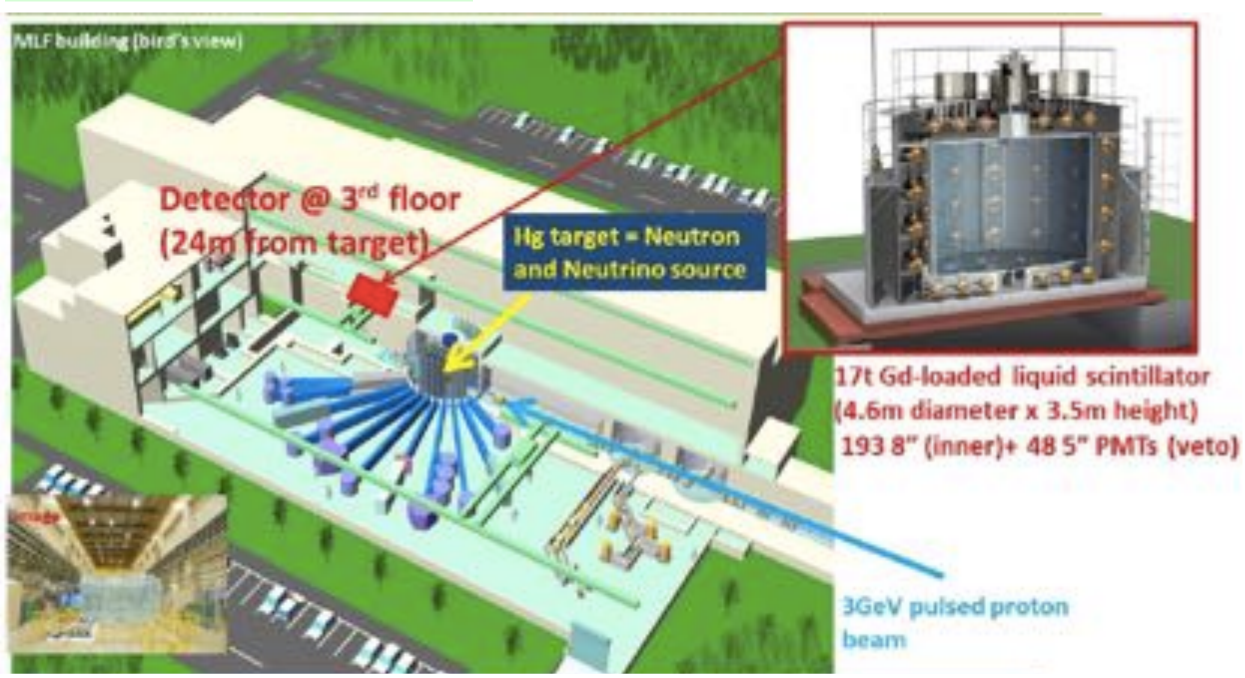
Type-III - dilepton channel

ATLAS: ATLAS-CONF-2018-020



- All channels are combined to derive the final limit.
- Assume "flavour democratic" scenario with equal branching ratios to all leptonic decays.

Experimental site at MLF



Quick start-up is possible due to use exist building and beam line facility

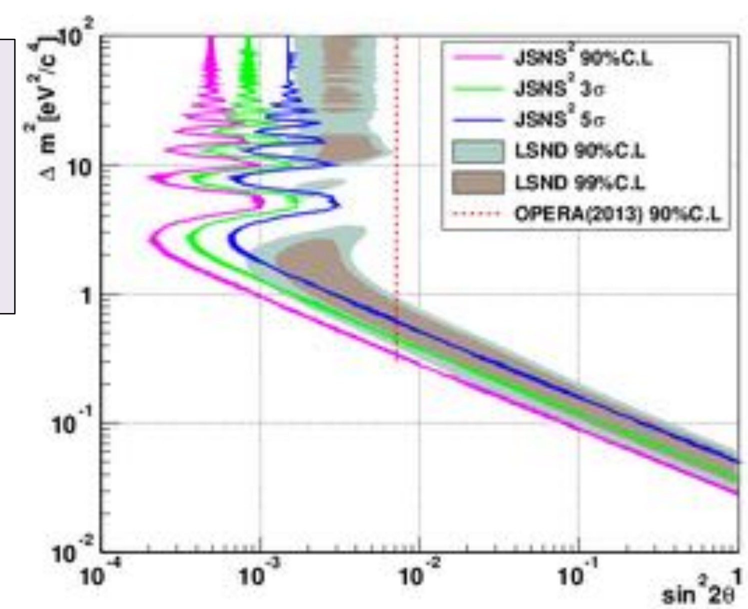
How to increase sensitivity

Add one more detector (Initial proposal).

From the stats report of 2014 (arXiv : 1502.02255)

- 50 tons of total volume
- 5 years of data taking
- 1 MW Beam power

On-going effort to get budget for second detector



The case for the missing right-handed neutrinos

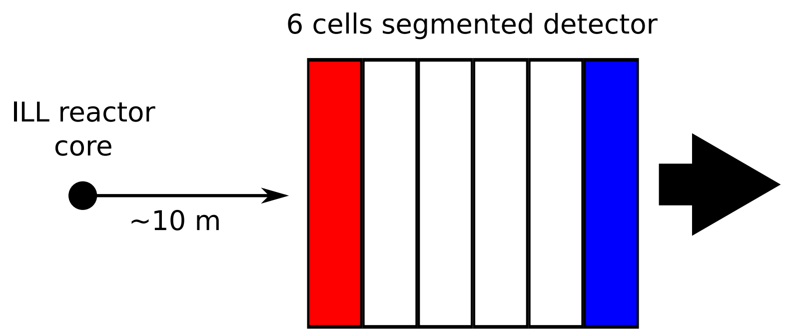
- A sense of "doom" seems to pervade over the particle physics community: After spending billions of dollars building the LHC, the only thing that we have found- and that "may be" all- is the SM Higgs? No signs of Physics beyond the SM (BSM)?
- Patient please! We still have a few more years of data taking and data analysis. Who knows what will show up? This is what this workshop is all about!
- First of all, it is far from clear that the 125-GeV scalar is the lonely SM Higgs.
- Secondly, it is not true that we have not seen any sign of physics BSM: neutrino oscillations $\Rightarrow$ neutrino masses $\Rightarrow$ BSM $\Rightarrow$ Most likely the existence of right-handed neutrinos ν_R.
- Where are they? There are indirect experimental proofs that they exist. Have we been up-until-now going on a "wild-goose chase"?

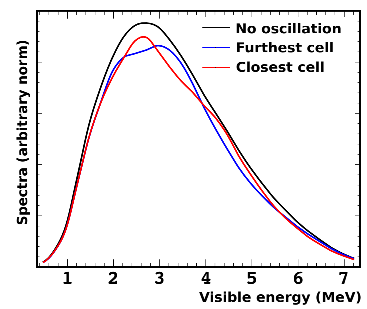
Conclusions

What does the EW-scale ν_R model accomplish?

- The EW-scale ν_R model provides a test of the seesaw mechanism at collider energies since ν_R's are now fertile and "light"! Rich studies involving the search for the mirror sector at the LHC with in particular characteristic signals such as $\boxed{\text{DISPLACED VERTICES}}$. Mirror fermions are $\boxed{\text{Long-Lived-Particles}}$!
- There seems to be a deep connection between $\boxed{\text{neutrino physics}}$ and $\boxed{\text{QCD}}$ in the solution to the strong CP problem.
- Nielsen-Ninomiya theorem: The EW-scale ν_R model evades the N-N theorem and one can now study EW phase transition on the lattice.
- If space is indeed discrete at the Planck scale then the Nielsen-Ninomiya no-go theorem requires the existence of mirror fermions. Deep implications for Quantum Gravity?

The STEREO experiment





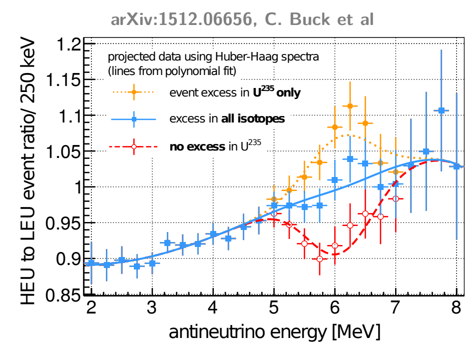
1- Designed to probe the RAA region by measuring **relative distortions** of the $\bar{\nu}_e$ energy spectrum as a function of the distance [9-11m]

✓ **Independent from predicted energy spectrum**

2- Measurement of a **pure ^{235}U $\bar{\nu}_e$ energy spectrum**

→ Help to understand Daya Bay results

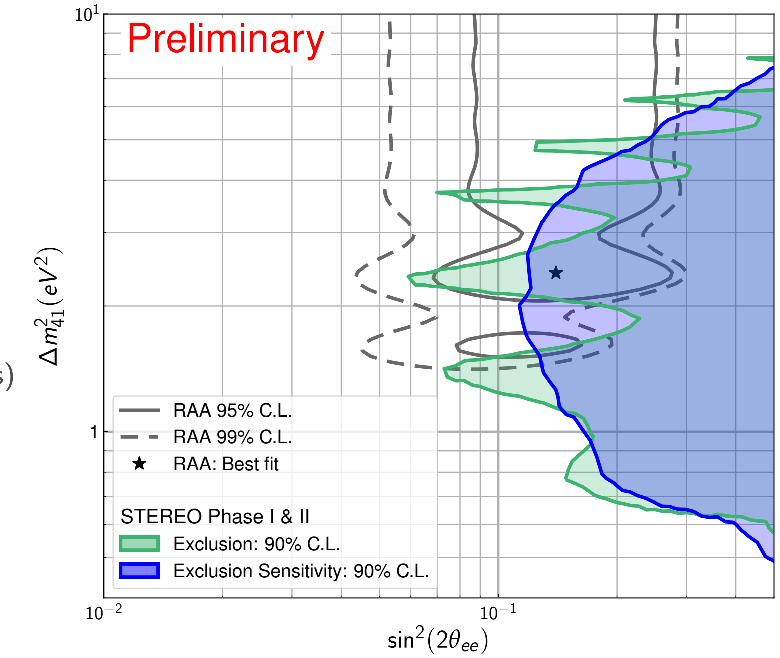
→ Could indicate if the bump is related to ^{235}U



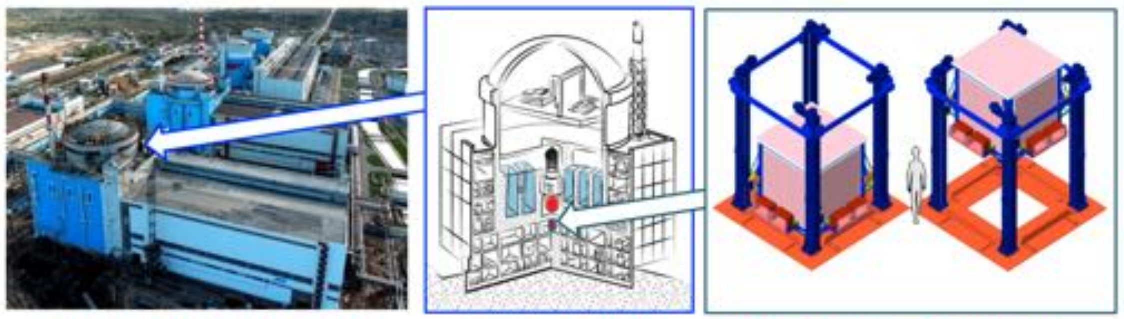
Exclusion contours Phase-I+II combined

- **Phase-I + Phase-II combined results**
  (66+47) days reactor-ON
  (396 ± 4) $\bar{\nu}_e$ day^{-1}

  Considered as two **independent measurements**:
  $\chi^2 = \chi^2_I(\overrightarrow{\alpha_I}) + \chi^2_{II}(\overrightarrow{\alpha_{II}})$
  $\overrightarrow{\alpha_I} \neq \overrightarrow{\alpha_{II}}$
- **Raster-scan** approach (Δ^2_m slices)
- $\Delta\chi^2$ distributions estimated by MC pseudo experiments
- Best-fit value of the **RAA rejected at 98 % C.L.**



Detector site

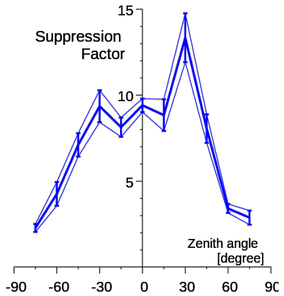


KNPP - Kalinin Nuclear Power Plant, Russia, ~350 km NW from Moscow

Below 3.1 GW commercial reactor ~ 5·10¹³ ν·cm⁻²c⁻¹ at detector position

DANSS on a lifting platform A week cycle of up/middle/down position

- No flammable or dangerous materials – can be put just after reactor shielding
- Reactor fuel and body with cooling pond and other reservoirs provide overburden ~50 m w.e. for cosmic background suppression
- Lifting system allows to change the distance between the centers of the detector and of the reactor core from 10.7 to 12.7 m on-line
- The top position corresponds to ~15000 IBD events per day for 100% efficiency



Cosmic muon suppression measured

Preliminary results

Exclusion region was calculated using Gaussian CL$_s$ method (X.Qian et al. NIMA, 827, 63 (2016)). CL$_s$ method is more conservative than usual Confidence Interval method

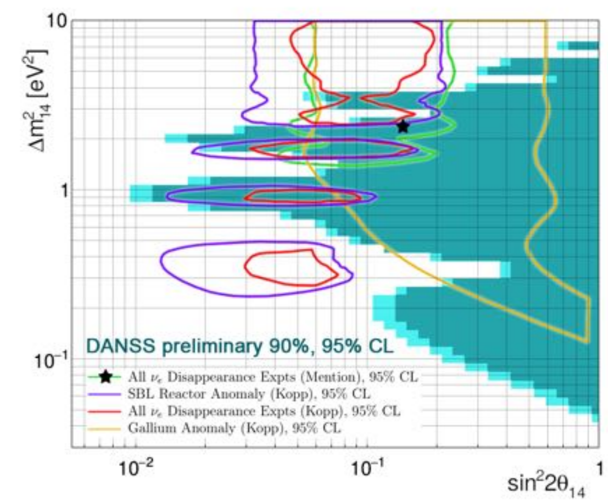
Systematics studies include variations in:

- Burning profile in reactor core
- Energy resolution ±10%
- Level of cosmics background 0.5%
- Energy intervals used in fit (1.5-6)MeV

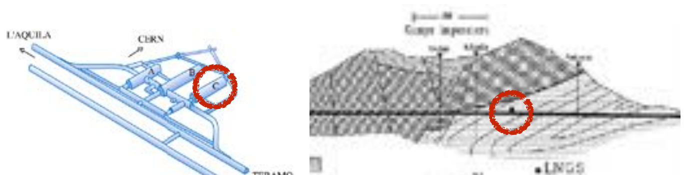
Systematics is small

A large fraction of allowed parameter region is excluded by DANSS results using only ratio of e$^+$ spectrum at different L (independent on ν spectrum, detector efficiency,. . .)

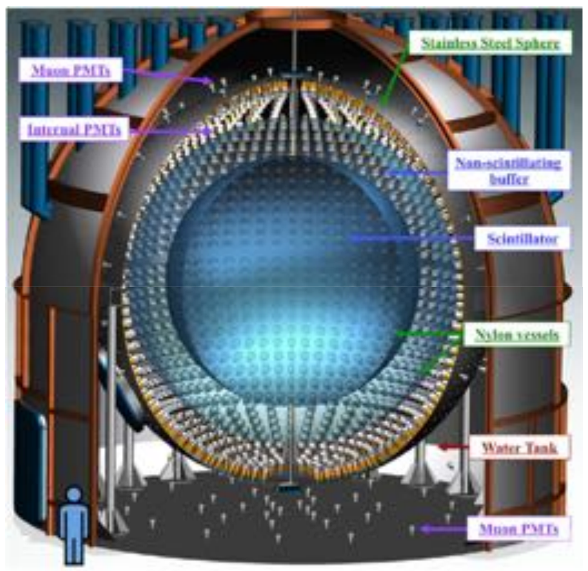
- DANSS plans to collect more data and to include into analysis all available data
- Detector calibration and systematics studies will be continued



Borexino experiment

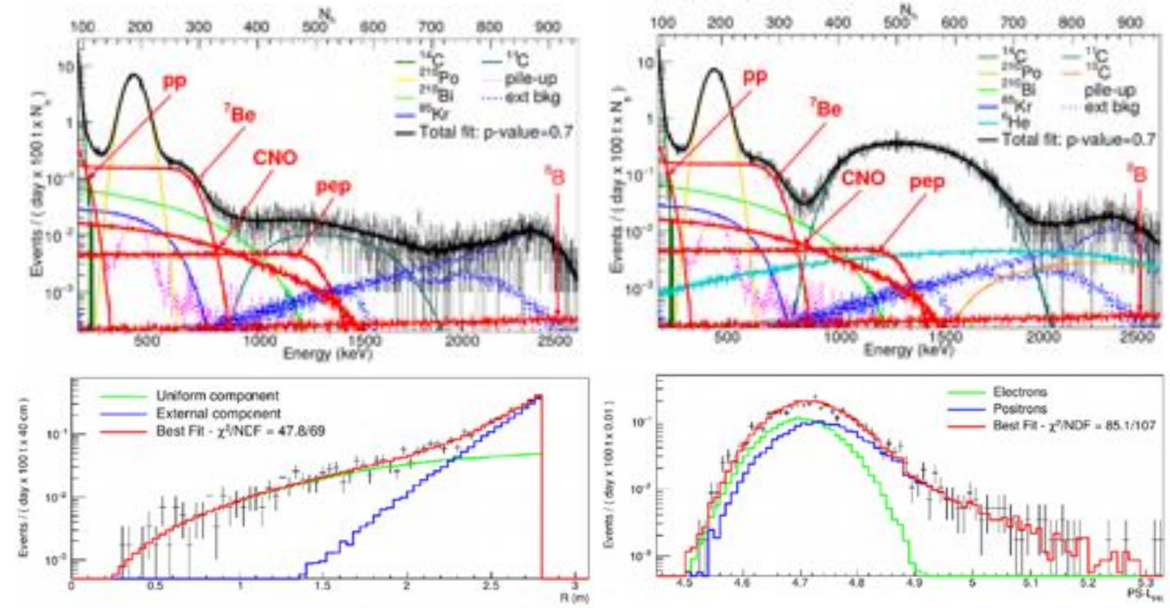


1400 rock, 3800 m.w.e.



- @ LNGS, 3800 m.w.e.
- **Center detector**:
  - Liquid scintillator + PMTs
- **Important characteristics**
  - **σ_E** 5%, **σ_V** 10 cm @ 1 MeV
  - IV ~300 ton, FV ~75 ton
  - LS ^{238}U, ^{232}Th ~ 10^{-19} g/g

LER Highlight: Multi-Variate analysis



$$\mathcal{L}_{\mathrm{MV}}\left(\vec{\theta}\right) = \mathcal{L}_{\mathrm{TFC-sub}}\left(\vec{\theta}\right) \cdot \mathcal{L}_{\mathrm{TFC-tagged}}\left(\vec{\theta}\right) \cdot \mathcal{L}_{\mathrm{RD}}\left(\vec{\theta}\right) \cdot \mathcal{L}_{\mathrm{PS}}\left(\vec{\theta}\right)$$

- Scaling factor introduced to remove bias.

[1] S. Davini, "Measurement of the pep and CNO solar neutrino interaction rates in Borexino-I," Eur. Phys. J. Plus, vol. 128, no. 8, p. 89, Aug. 2013.

New Results from IceCube and Future Prospects

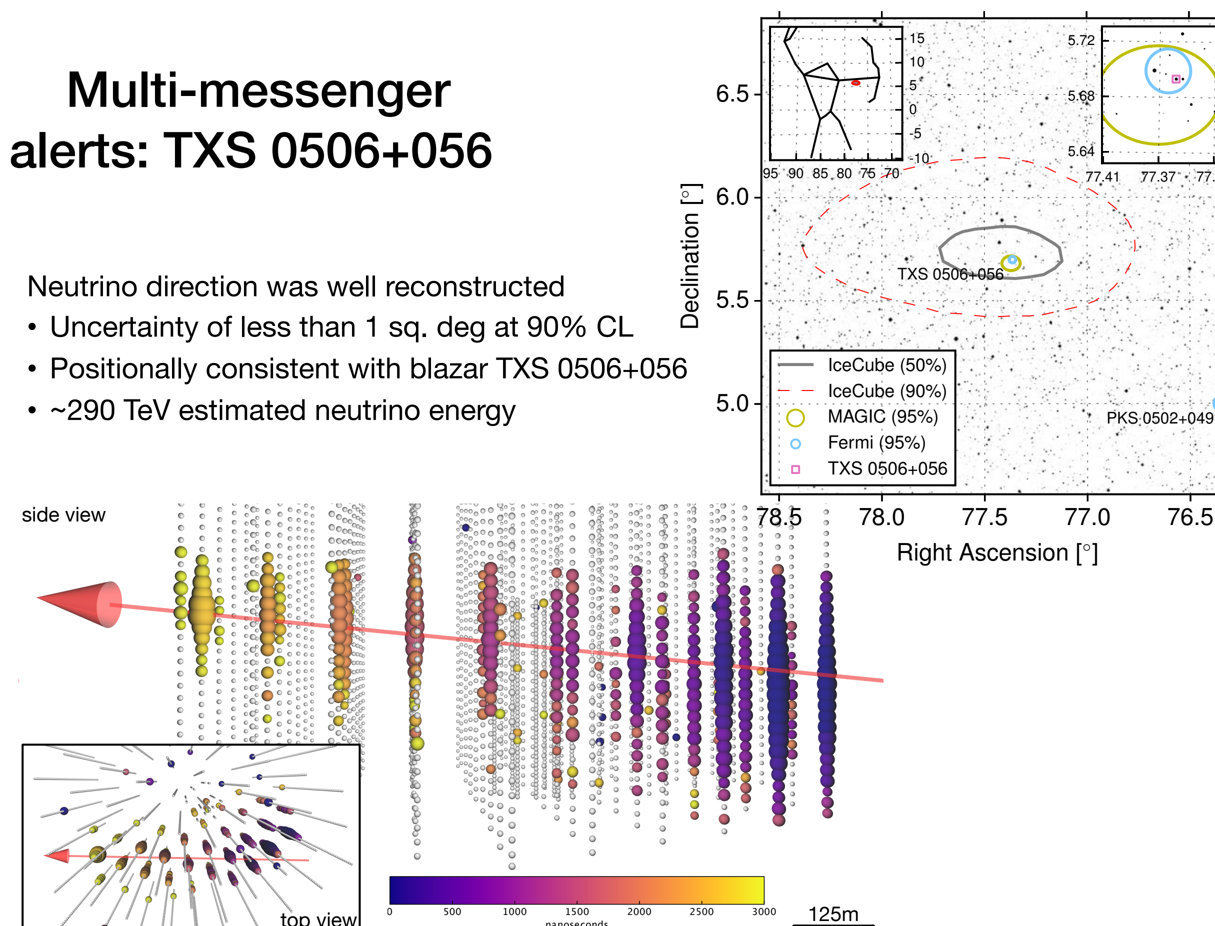
Erik Blaufuss
University of Maryland
for the IceCube Collaboration

International Symposium on Neutrino Frontiers
ICISE, Quy Nhon, Vietnam

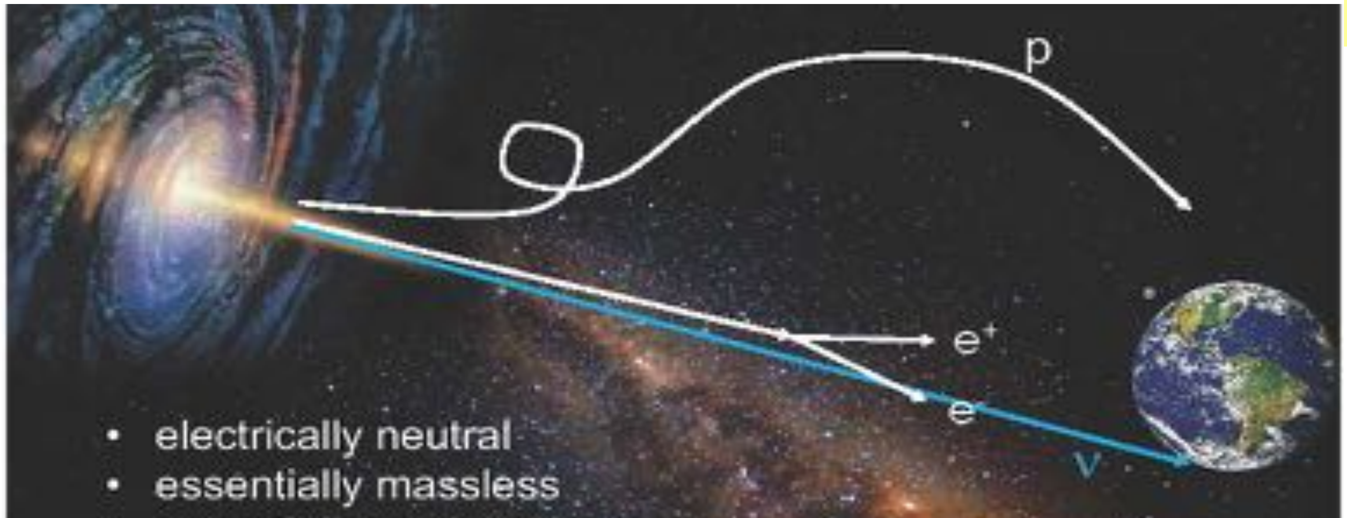
Photo credit: J. Werthebach IceCube/NSF

Multi-messenger alerts: TXS 0506+056

Neutrino direction was well reconstructed
- Uncertainty of less than 1 sq. deg at 90% CL
- Positionally consistent with blazar TXS 0506+056
- ~290 TeV estimated neutrino energy

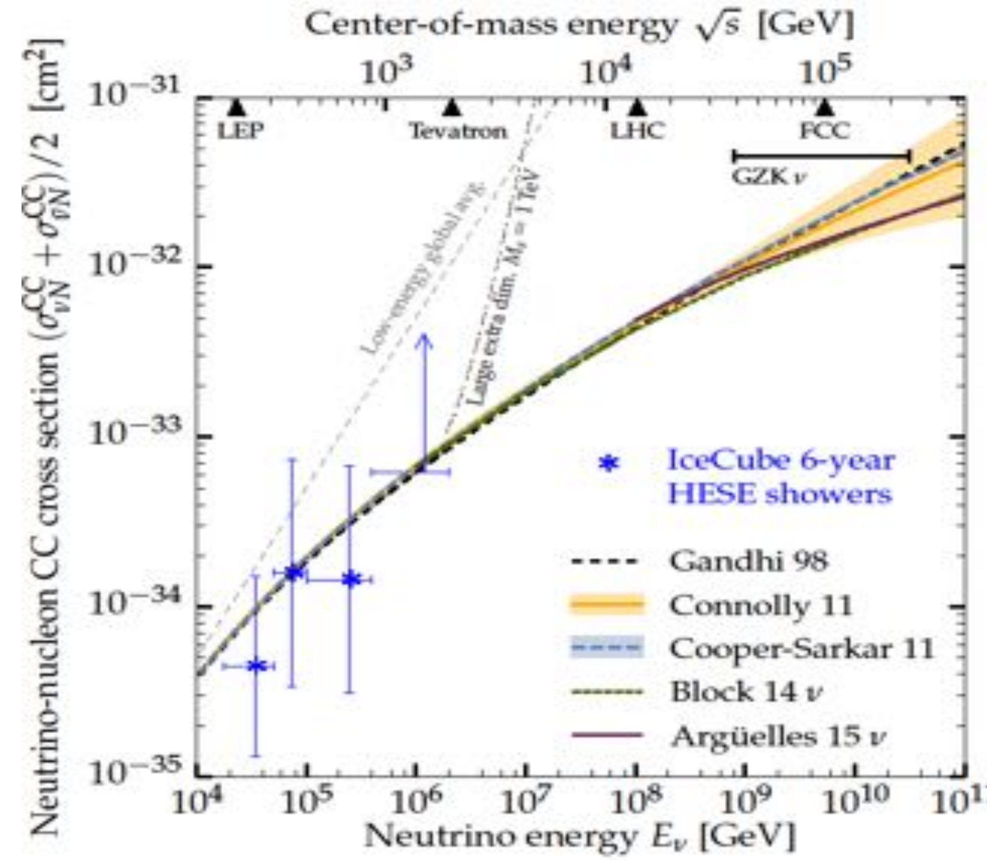


Introduction



- Neutrinos are important messengers that give us useful information about the origin of the Universe.
- Neutrinos interact weakly so they can travel very long distance and are not deflected by galactic magnetic field.
- Direction of arrival points back towards their origin.

- Probing the quantum structure of space-time.
  - Rules out e.g. large new dimensions at low scales.

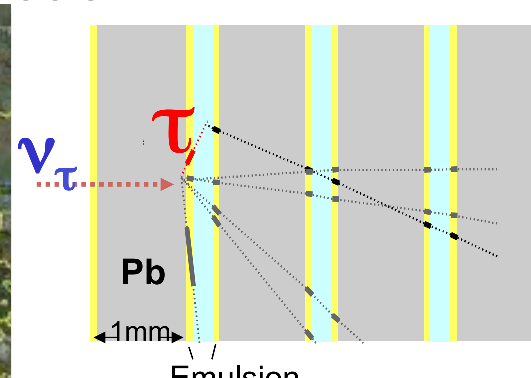


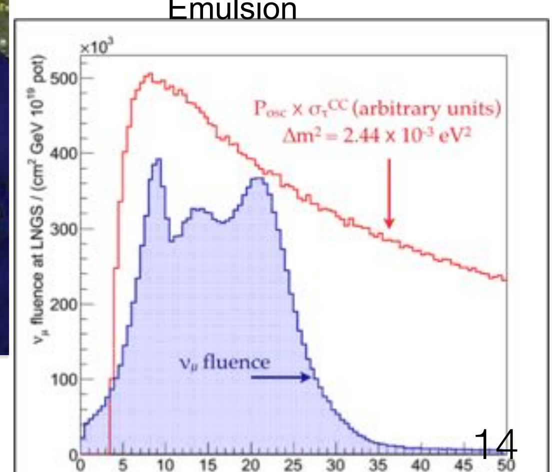
Bustamante & Connolly: arXiv:1711.11043

OPERA experiment

CERN Neutrinos to Gran Sasso

< Eν >	17 GeV
L/E	43 km/GeV
$(\nu_e + \bar{\nu}_e) / \nu_\mu$	0.9 %
$\bar{\nu}_\mu$ / ν_μ	2.0 %
ν_τ prompt	Negligible





$$P(\nu_\mu \to \nu_\tau) \sim \sin^2(2\theta_{23}) \cdot \sin^2\left(1.27 \cdot \Delta m^2_{23} \cdot \frac{L}{E}\right) \sim 1.77\%$$

$\sin^2 2\theta_{23} = 1.0$, $\Delta m_{23}^2 = (2.43 \pm 0.13) \times 10^{-3}$ eV²

SIGNIFICANCE OF THE ν_τ APPEARANCE

PHYSICAL REVIEW LETTERS **120**, 211801 (2018)

$$\mathcal{L}(\mu, \beta_c) = \prod_{c=1}^{4} \left(\mathrm{Pois}(n_c | \mu s_c + \beta_c) \prod_{i=1}^{n_c} f_c(x_{ci}) \right) \cdot \prod_{c=1}^{4} \mathrm{Gauss}(b_c | \beta_c, \sigma_{b_c})$$

signal strength; true bkg (floating param.); uncertainty on exp bkg; channels; obs events in the c^{th} channel; expected signal; BDT response; expected bkg

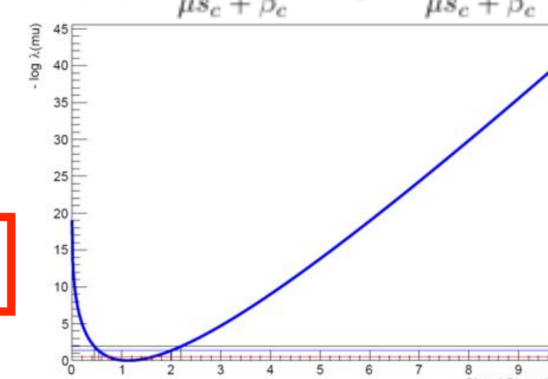
$$f_c(x_{ci}) = \frac{\mu s_c}{\mu s_c + \beta_c} \mathrm{PDF}_c^{sig} + \frac{\beta_c}{\mu s_c + \beta_c} \mathrm{PDF}_c^{bkg}$$

Test statistic: Likelihood ratio

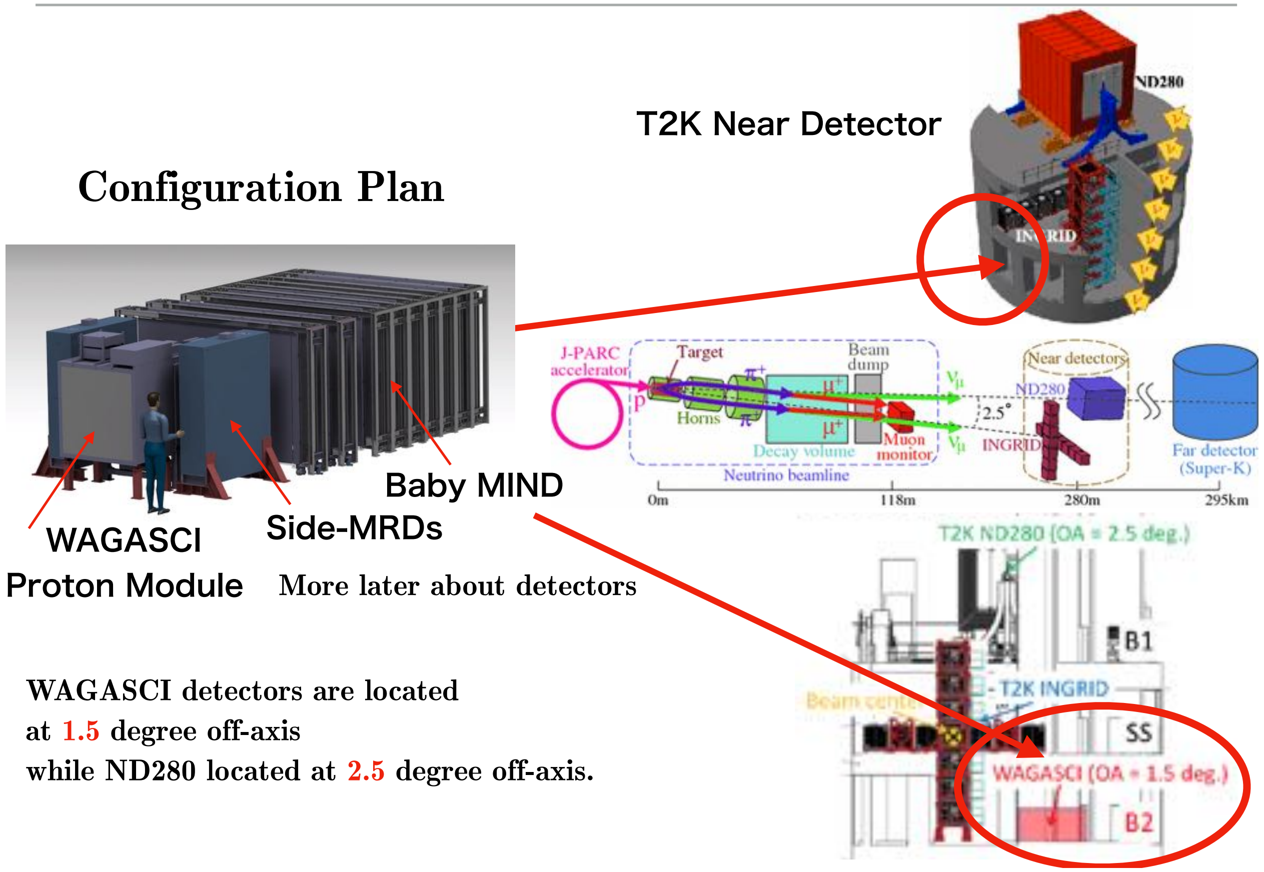
Results: $\mu = 1.1^{+0.5}_{-0.4}$

$P_{value} = 4 \cdot 10^{-10}$

$\boxed{\text{Significance} = 6.1\ \sigma}$

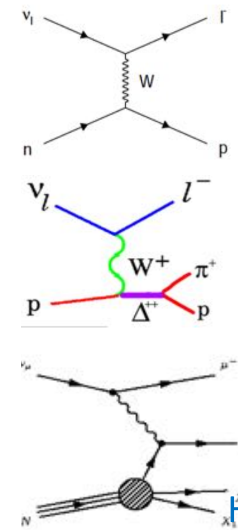


WAGASCI PROJECT OVERVIEW



WAGASCI detectors are located at 1.5 degree off-axis while ND280 located at 2.5 degree off-axis.

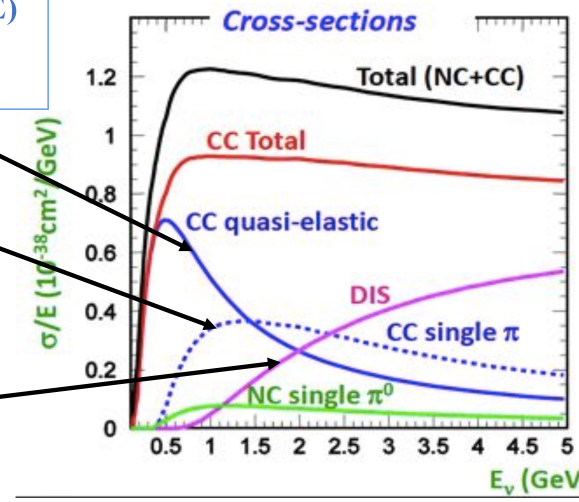
Major Neutrino interactions



Charge Current Quasi Elastic (CCQE)
Neuclon changes but doesn't break-up
$\nu + n \rightarrow \ell^- + p$

CC Single Meson Resonance (RES)
Neuclon excites to resonance states
$\nu + N \rightarrow \ell^- + N' + \pi\ (\eta, K)$

Deep Inelastic Scattering
Neuclon breaks up
$\nu + N \rightarrow \ell^- + N' + m.\pi\ (\eta, K)$



YP talks

T2K(-II) and NOvA experiments

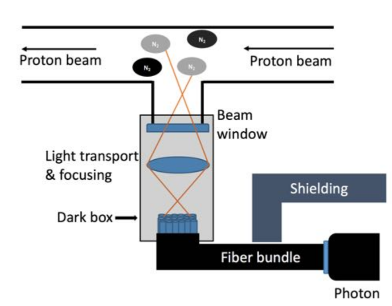
Off-axis long baseline neutrino oscillation experiments

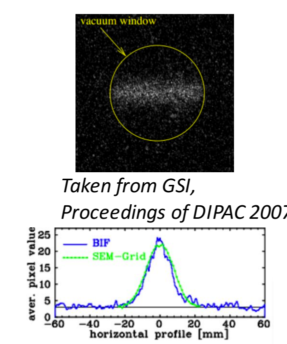
T2K(-II) experiment

NOvA experiment

Beam Induced Fluorescence (BIF) monitor

Uses fluorescence induced by proton interactions with gas injected into beamline. Transverse profile of fluorescence will match its of proton beam





Taken from GSI, Proceedings of DIPAC 2007

Fluorescence induced by proton-gas interactions

1D profile resulted when viewing from the side

BIF is under development at J-PARC ν beamline with **some requirements**:

- **Localize gas in the beamline**: gas normally ~ 10^{-6} Pa, is not enough to see BIF signal. Gas need to be injected & pressure increased but only near measurement point
- **Space charge effect**: fast readout is an option → use e.g Multi-pixel photon counters (MPPC)
- **High radiation environment**: e.g. MPPC is not radiation-hard → need to operate at sub-tunnel. Also optical fiber need to meet this requirement → choose silica-core optical fibers

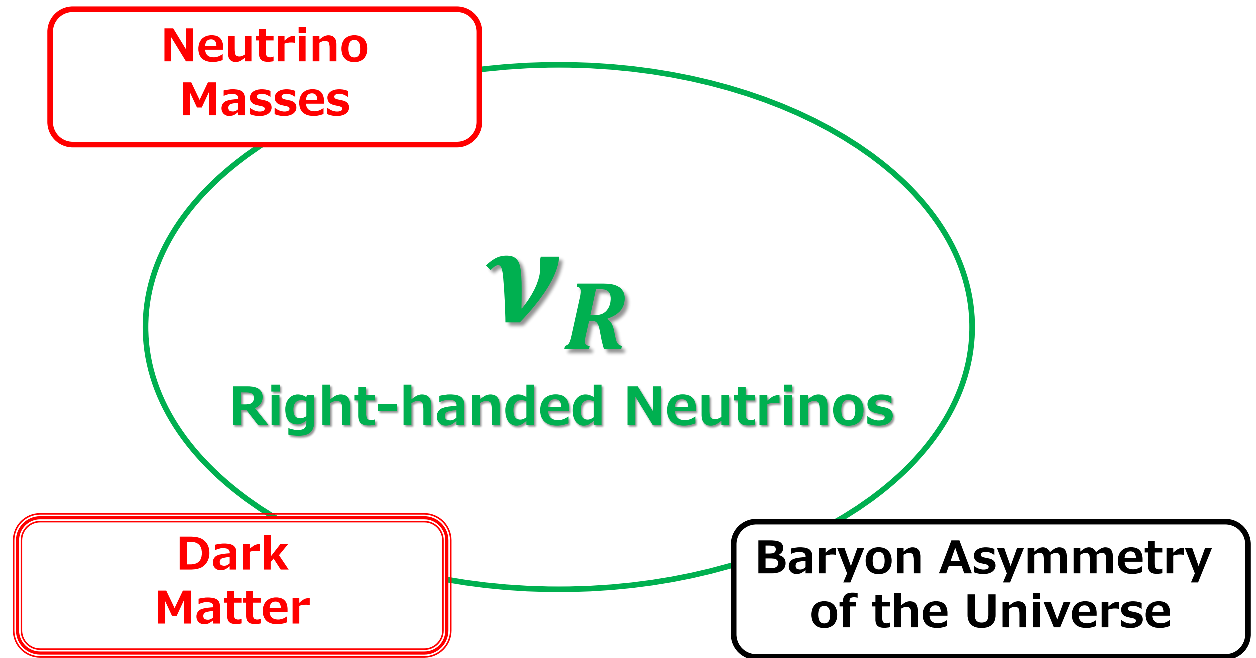
The νMSM, Dark Matter and Neutrino Masses

Takehiko Asaka (Niigata Univ.)

The 14th Rencontres du Vietnam,
International Symposium on Neutrino Frontiers
(16-19 July, 2018, ICISE center, Quy Nhon, Vietnam)

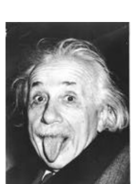
@Vietnam (2018/07/18)

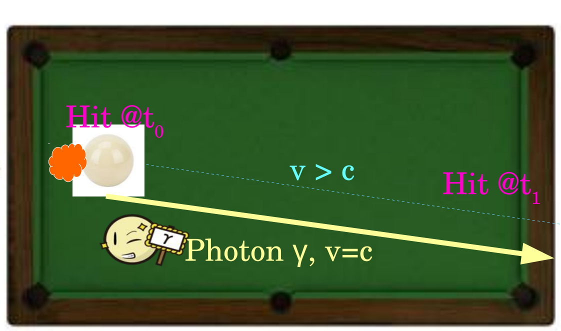
Overview



Why people like Lorentz invariance

- Lorentz invariance is one of our most fundamental symmetries → underlying all our physics laws!
- What are the consequences of breaking the Lorentz invariance ?
  - 1. Physics depends on the observer referential → Measure different mixing angle θ at different time of the year…
  - 2. c may depend on observer referential→ Tachyons (v > c) are possible
  - 3. Causality can be broken (consequence of #2) :

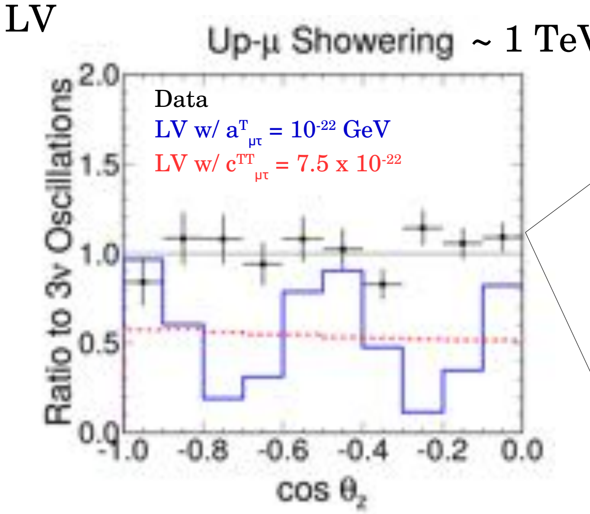


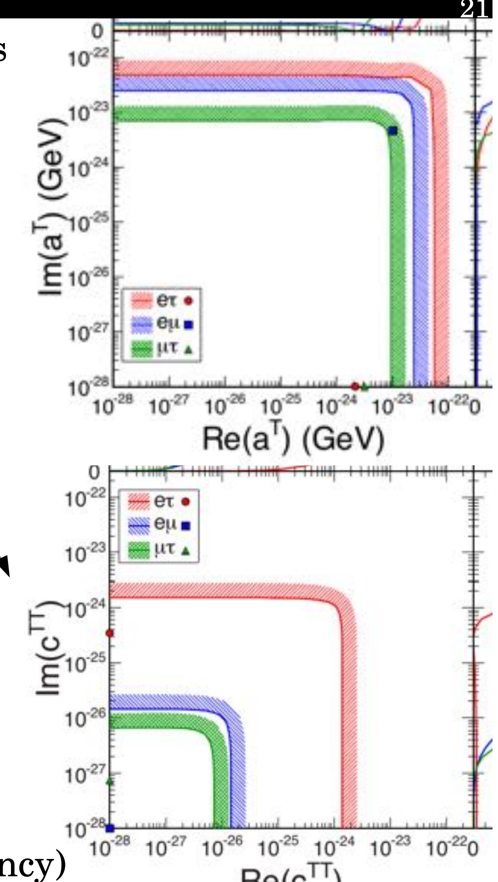


- Since v > c : see Albert missing before he shot.
- If I send information @v>c : tell Albert he will miss before he shots

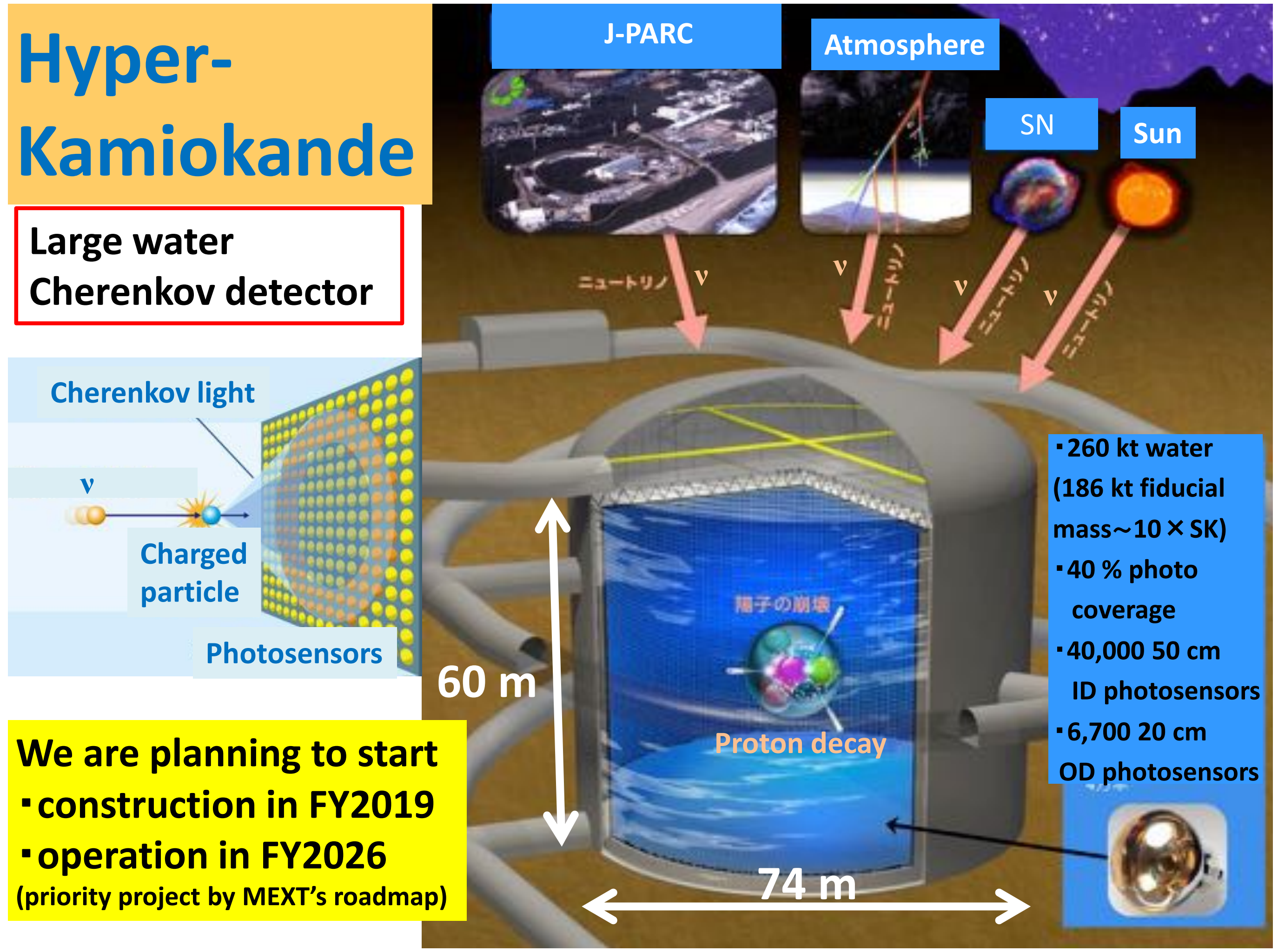
LV search using atmospheric neutrino @SK

- Do likelihood fit on all the atmospheric samples assuming LV



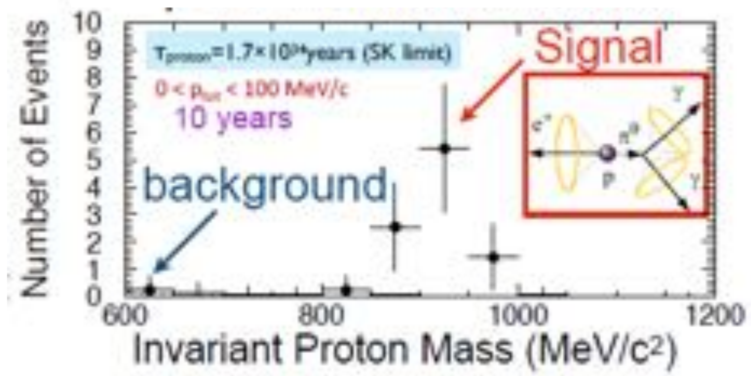


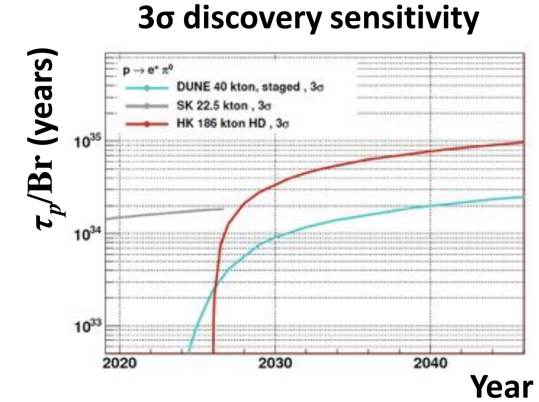
- Compatibility with no-LV scenario: $\Delta\chi^2 < 1.4$
- World-leading limits on time-independent parameters
  - → $a^{TT} < 10^{-23}$ GeV
  - → $c^{TT} < 10^{-27}$ (High sensitivity from E-dependency)



Proton decay searches

■$p \rightarrow e^+\pi^0$ search





BG free measurement
- **0.06 BG events/Mt-year**
- **High efficiency neutron veto by doubled photon sensitivity**
  - **Most atm ν BG has neutrons**
  - **Tag 2.2 MeV γ from $np \rightarrow d\gamma$**

3σ discovery sensitivity :
τ_p/Br = 10^{35} years
for 20 year operation.

Leptogenesis

Ryo Nagai
Tohoku University

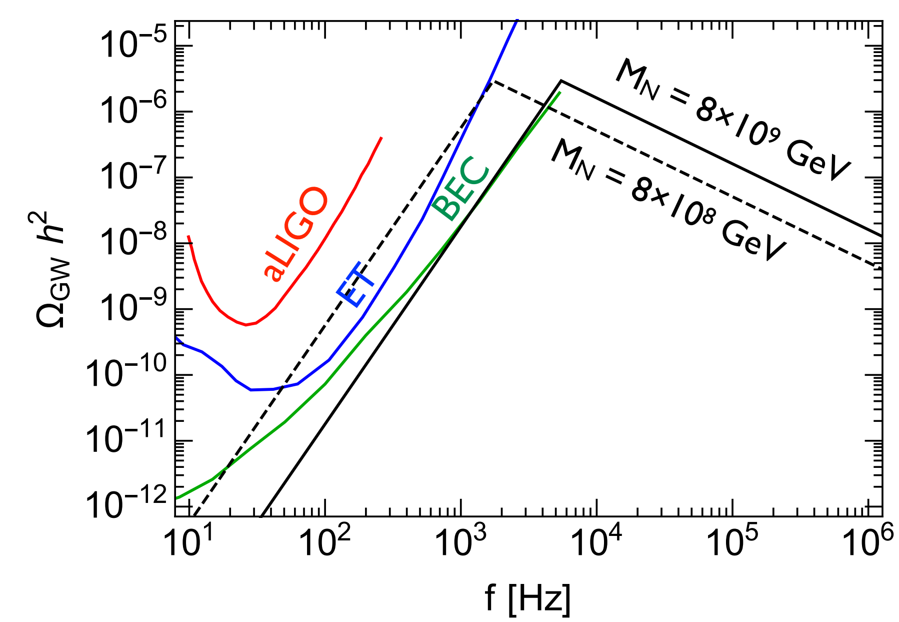
Collaborators:
Fuminobu Takahashi (Tohoku U.)
and Norimi Yokozaki (Tohoku U.)

International Symposium
on Neutrino Frontiers
Thu, Jul. 18, 2018

Cosmological implications

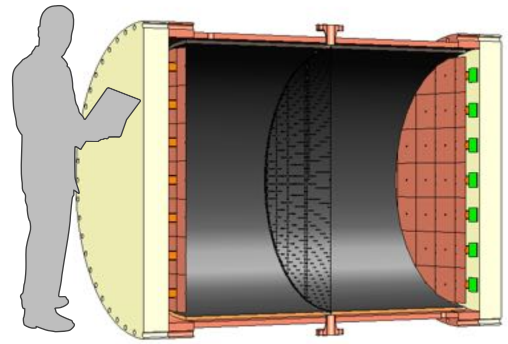
- Produced GW

R = 0.07

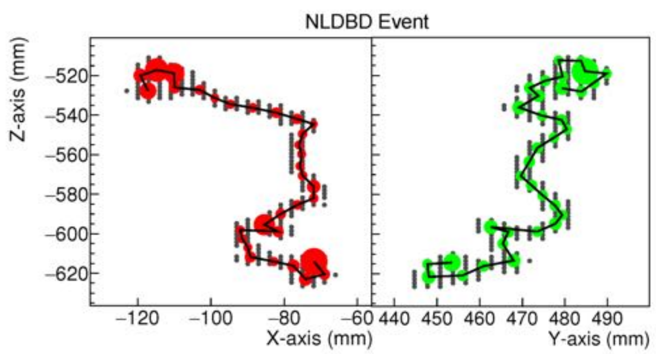


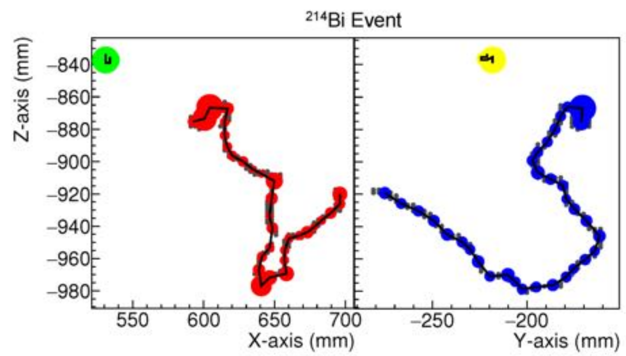
PandaX-III: high pressure gas TPC for $0\nu\beta\beta$ of ^{136}Xe

- TPC: 200 kg scale, symmetric, double-ended charge readout, with 10 bar of ^{136}Xe
- Main features: good energy resolution and background suppression with tracking



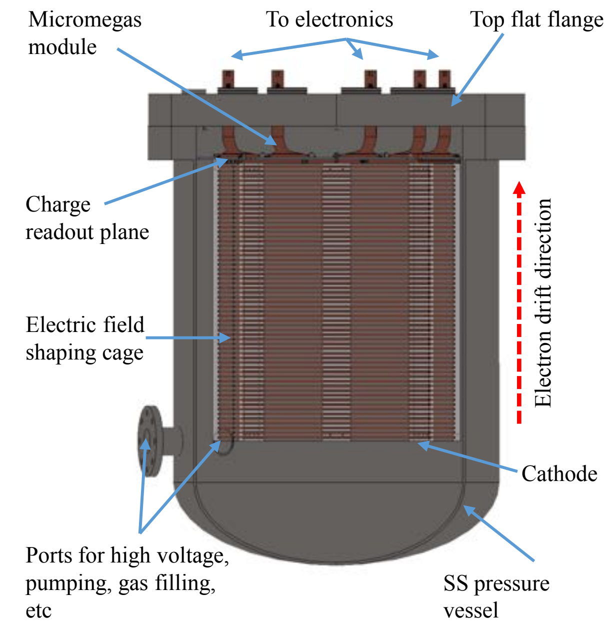
arXiv:1610.08883





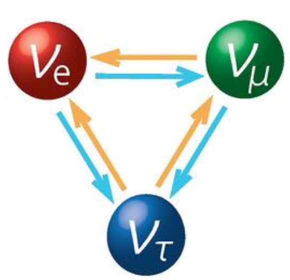
Prototype TPC at Shanghai

- To see MeV electron tracks and demonstrate required energy resolution with a large-scale high pressure TPC
- Field cage: 66 cm diameter, 78 cm drift length, single-ended
- 600 L of inner volum16 kg of xenon at 10 bar
- 7 Microbulk Micromegas modules



Impact of new physics in the context of long baseline experiments

Poonam Mehta



School of Physical Sciences,
Jawaharlal Nehru University, New Delhi

Jogesh Rout, Samiran Roy, Sheeba Shafaq, Mehedi Masud, Animesh Chatterjee, Mary Bishai

DEEP UNDERGROUND NEUTRINO EXPERIMENT

INO Collaboration

"Neutrino Frontiers", Vietnam, 18 July 2018

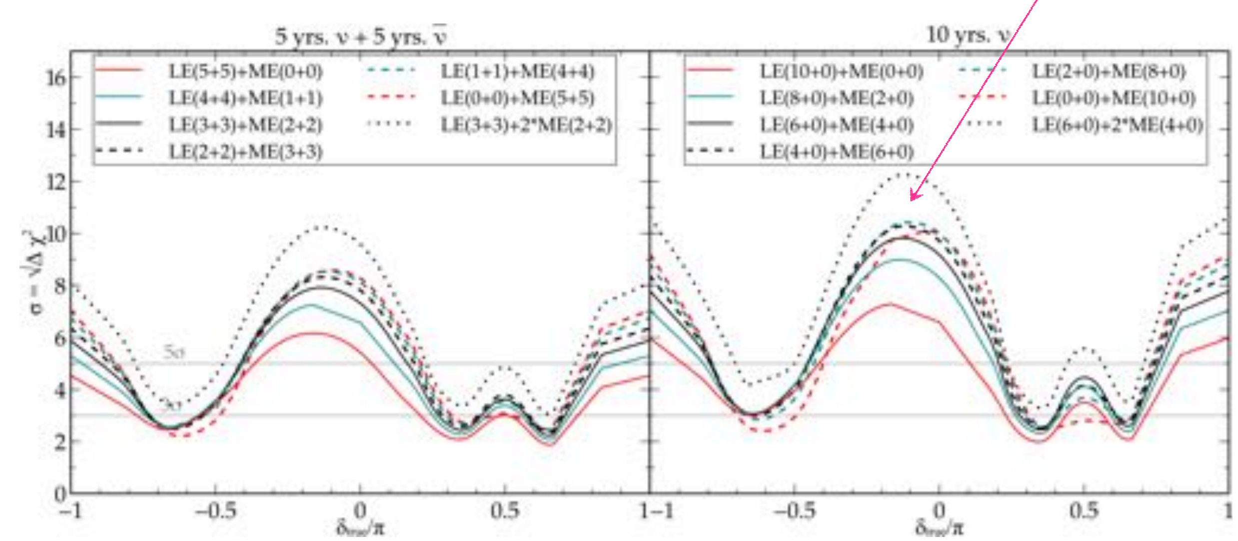
SI-NSI separation at DUNE

Theoretical metric

$$\chi^2(\delta_{tr}) = \min_{\delta_{ts}} \sum_{i=1}^{x}\sum_{j}^{2} \frac{\left[N^{i,j}_{NSI}(\delta_{tr},|\varepsilon|,\varphi) - N^{i,j}_{SI}(\delta_{ts}\in[-\pi,\pi])\right]^2}{N^{i,j}_{NSI}(\delta_{tr},|\varepsilon|,\varphi)}$$

Neutrino only run allows for better discrimination between SI and NSI

Better ability at CP conserving values



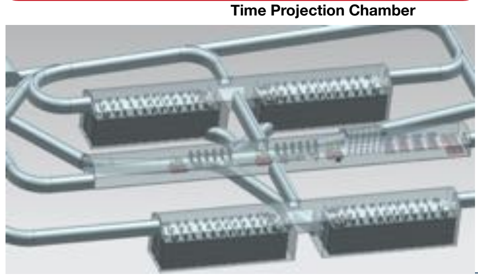
M. Masud, M. Bishai and P. Mehta, 1704.08650 [hep-ph]

Deep Underground Neutrino Experiment

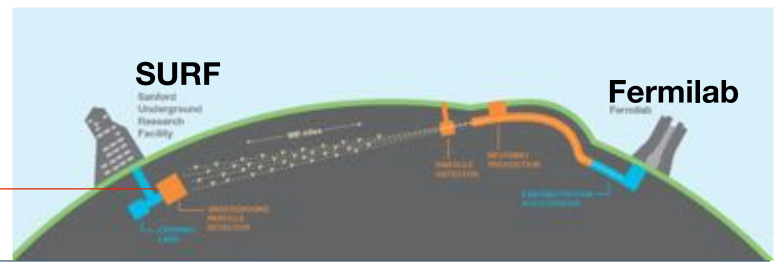
- Next generation neutrino oscillations experiment
  - Measure δ_{CP} and **mass hierarchy** in a single experiment
- Enabled for other physics w and w/o beam:
  - Beyond Standard Model (BSM) Physics, Nucleon Decay, SuperNova Bursts (SNB), etc

40 Kton far detector using Liquid Argon TPC technology

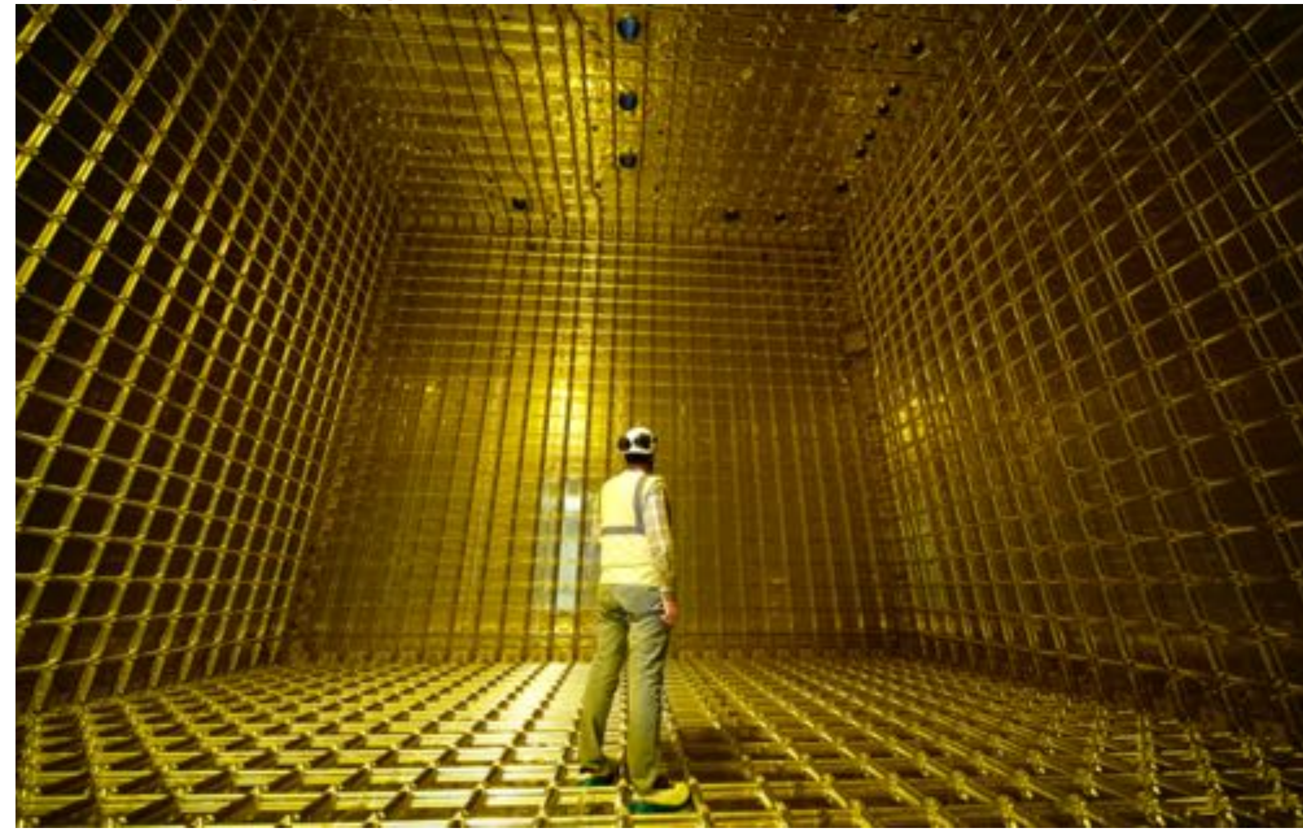
Time Projection Chamber



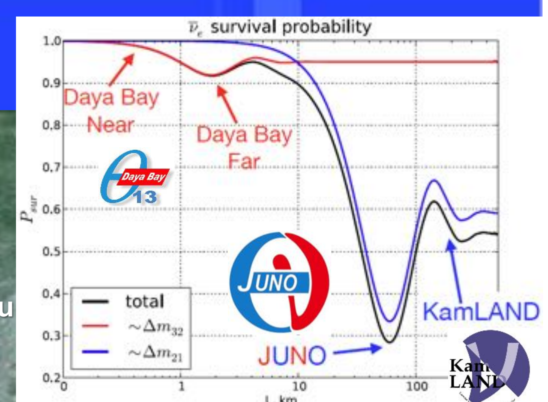
High power *wide band* muon neutrino beam from Fermilab to SURF, in South-Dakota, 1300 km away



Empty cryostat



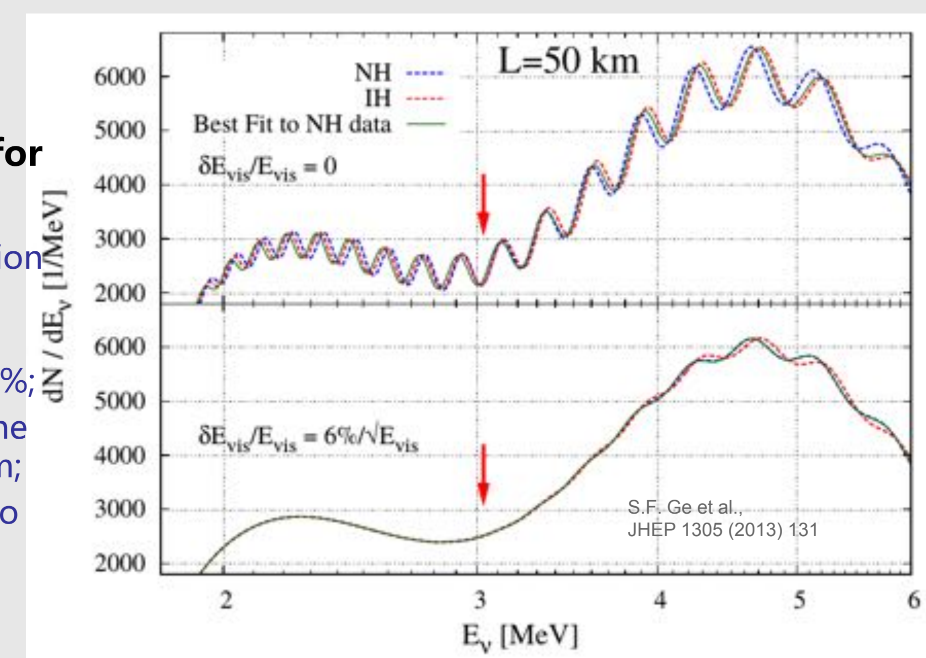
JUNO Location



Cores	YJ-C1	YJ-C2	YJ-C3	YJ-C4	YJ-C5	YJ-C6
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9
Baseline(km)	52.75	52.84	52.42	52.51	52.12	52.21
Cores	TS-C1	TS-C2	TS-C3	TS-C4	DYB	HZ
Power (GW)	4.6	4.6	4.6	4.6	17.4	17.4
Baseline(km)	52.76	52.63	52.32	52.20	215	265

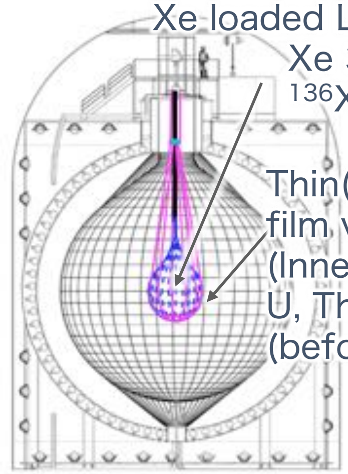
Neutrino Mass Hierarchy

- **"Small" distortion from Δm^2_{31} and θ_{13}.**
- **Requirement for the JUNO:**
  - Energy resolution ~**3%/√E**;
  - Energy scale uncertainty <1%;
  - Reactor baseline spread <0.5 km;
  - Lots of neutrino events;



KamLAND-Zen

Zero-neutrino double-beta decay search



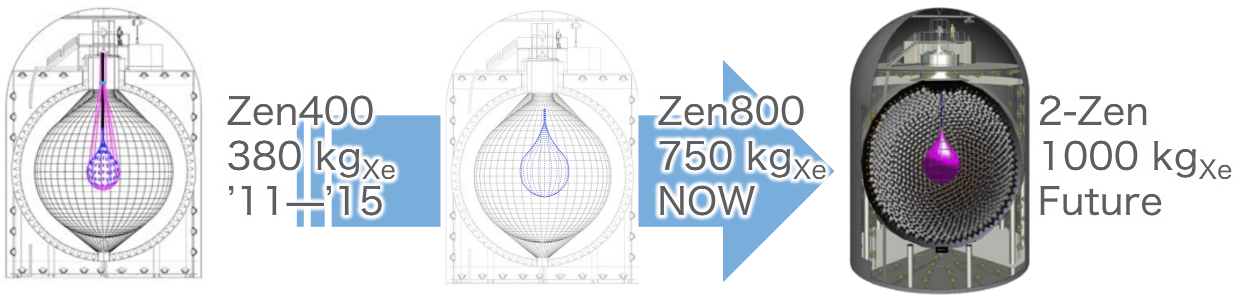
Isotope: ^{136}Xe

- Dissolve into LS (3 w%).
- On/off measurement.
- Easy to purify.

$$^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2e^-$$
$$Q = 2.46\ \mathrm{MeV}$$

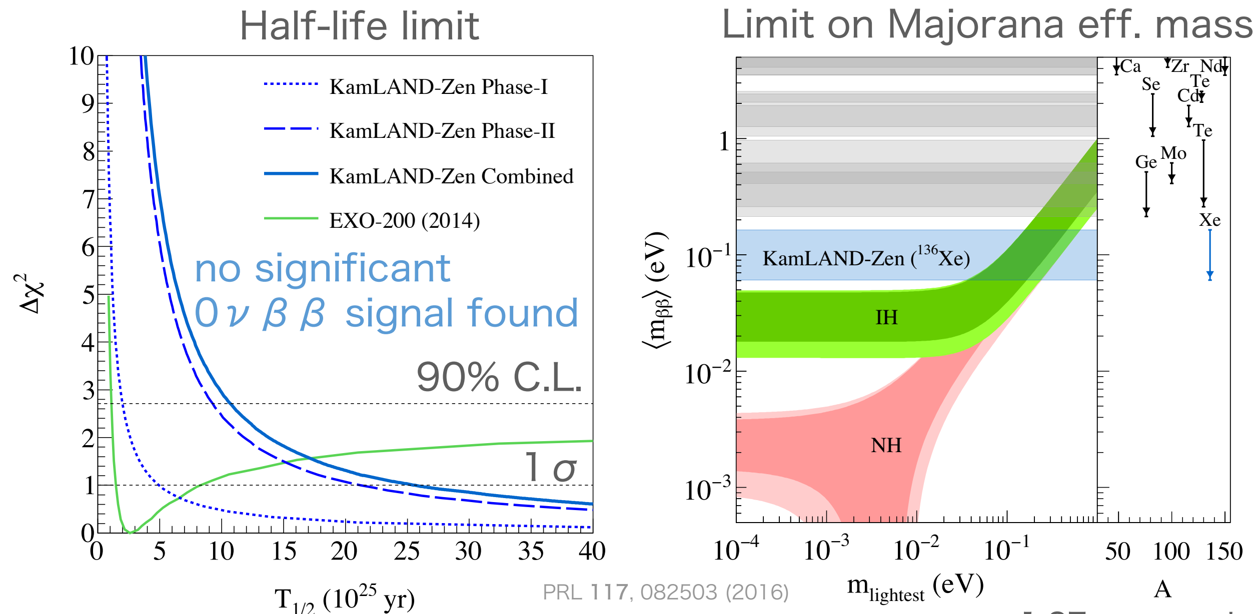
Pros of using KamLAND

- Already running, quick start.
- Large mass & Scalable
- Low BG
- Active veto with Outer-LS



6

$0\nu\beta\beta$ search results



g_A~1.27 assumed

Phase-I: $T_{1/2} > 1.9\times10^{25}$ yr
Phase-II: $T_{1/2} > 9.2\times10^{25}$ yr
Combined: $T_{1/2} > 1.07\times10^{26}$ yr

$\langle m_{\beta\beta}\rangle < 61$—$165$ meV
most stringent limit so far

*90% C.L.

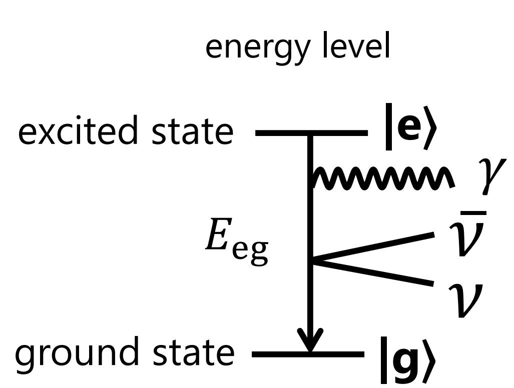
11

6

Experimental principle

Radiative Emission of Neutrino Pair (RENP)

$$|e\rangle \rightarrow |g\rangle + \gamma + \nu + \bar{\nu}$$



- threshold energy of photon

neutrino absolute mass

$$E_{th} = \frac{E_{eg}}{2} - \frac{(m_\nu + m_{\bar{\nu}})^2}{2E_{eg}}$$

✓ The emitted photon contains information of neutrinos

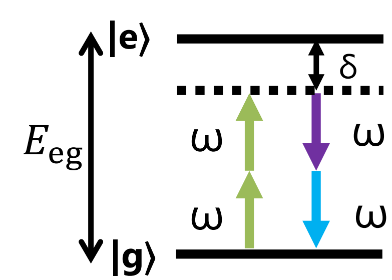
20

23

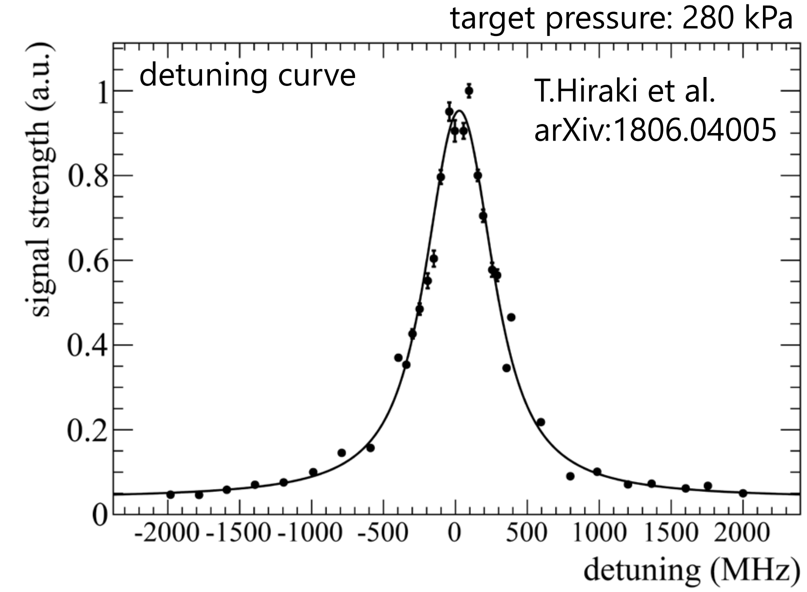
Results: detuning dependence

- use the new mid-infrared laser as both pumps and trigger
  - pump energy: ~1 mJ/pulse, trigger energy: ~ 0.6 mJ/pulse

✓ vary the detuning δ



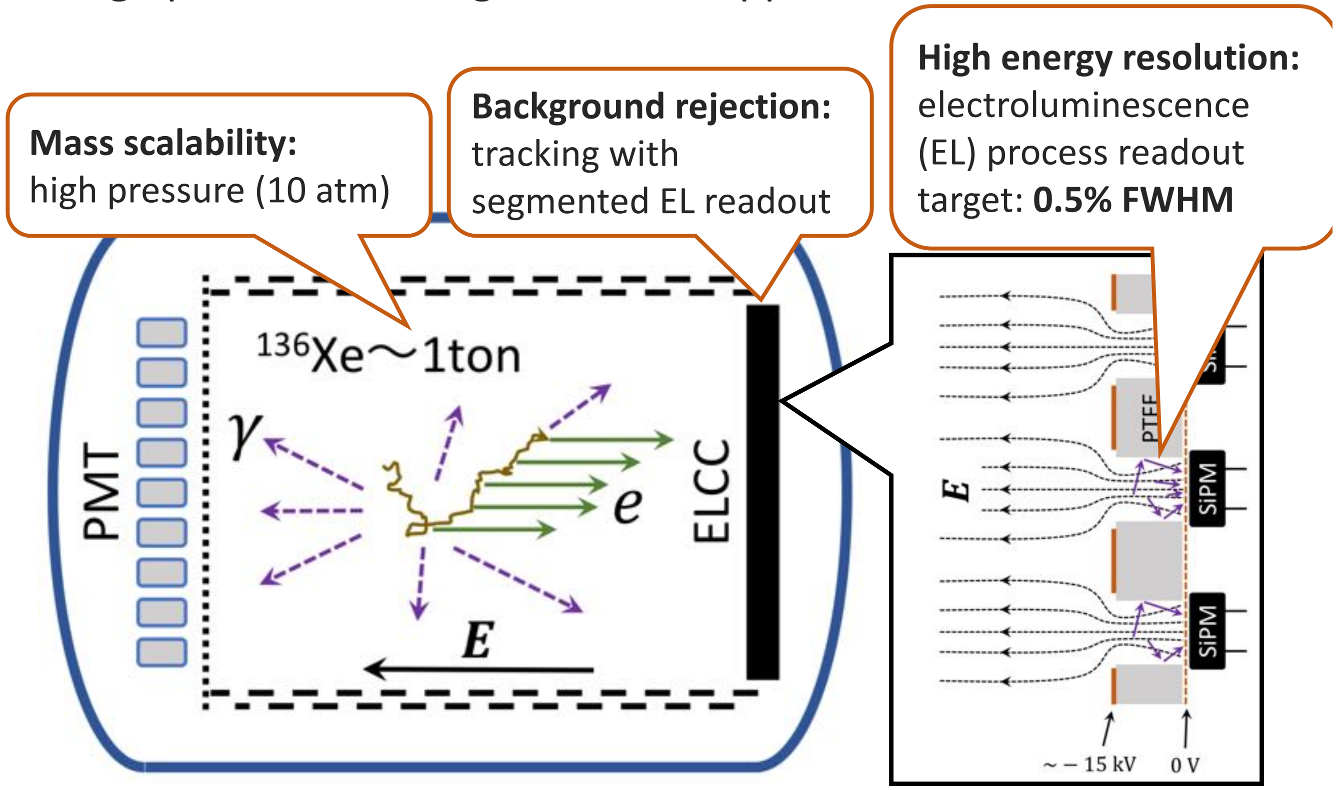
target pressure: 280 kPa



✓ Successfully observed a clear signal peak!

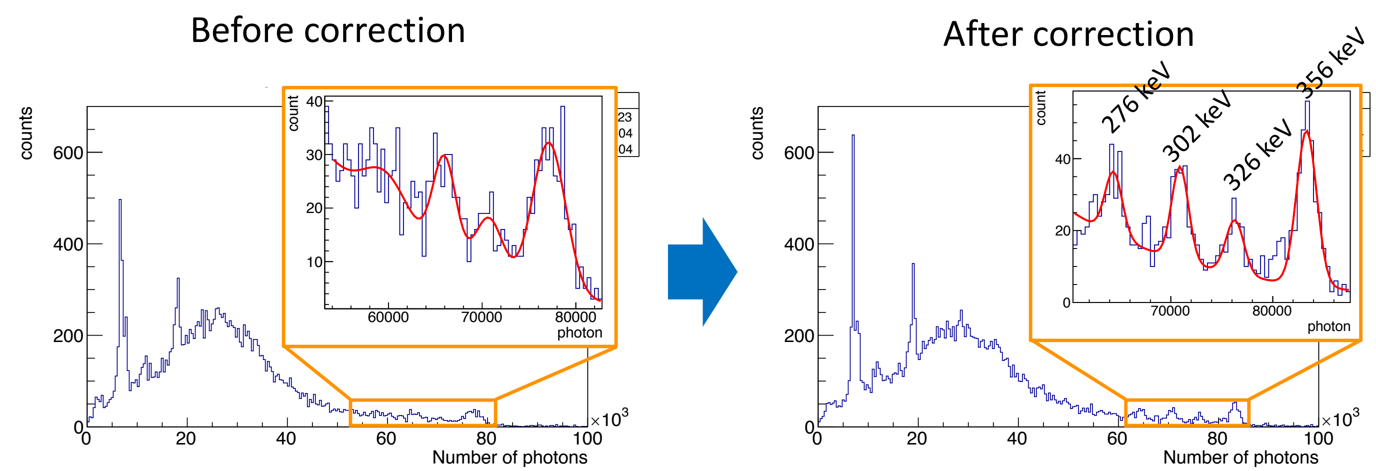
AXEL experiment

- High pressure xenon gas TPC for 0νββ search



Improvement of energy resolution

- Energy resolution is improved by correcting MPPC non-linearity
  - ^{133}Ba 356 keV peak
  - Energy resolution: **5.4%→2.5%**@356 keV

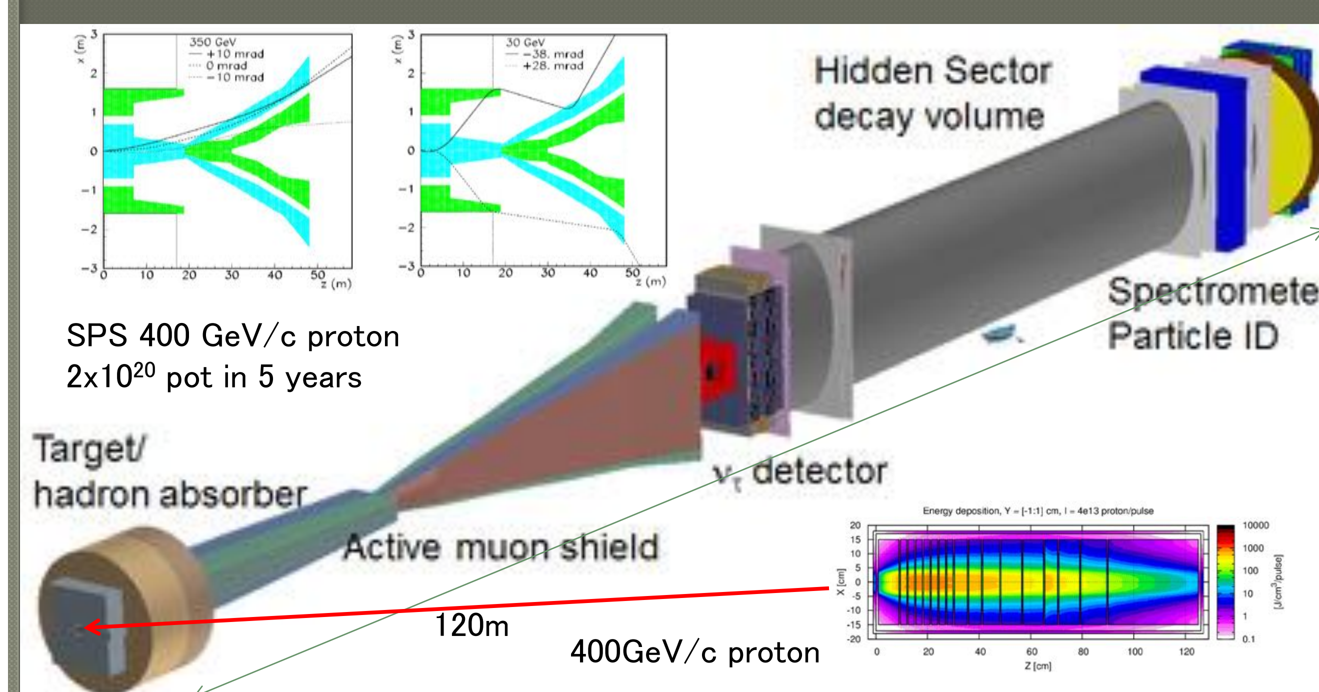


Dirac vs. Majorana neutrino: how can we tell? *Boris Kayser*

DsTau Summary

- The goal of the DsTau project is
  the reduction of tau neutrino production uncertainty
  by precise measurement of **1,000 Ds->tau->X**.
- **Test beam exposure performed in 2016 and 2017**
  In 2016 test beam, a proof of principle was done.
  Improvement on uniformity of track density in 2017 test beam.
  The **tracking efficiency** is confirmed > **95%** / emulsion film.
- **New analysis scheme is under development.**
- **A pilot run in 2018 will collects 2. x 10^7 events .**
- **Physics run from 2021.**
- **2.3 x 10^8 proton + W interactions will be analyzed in total**

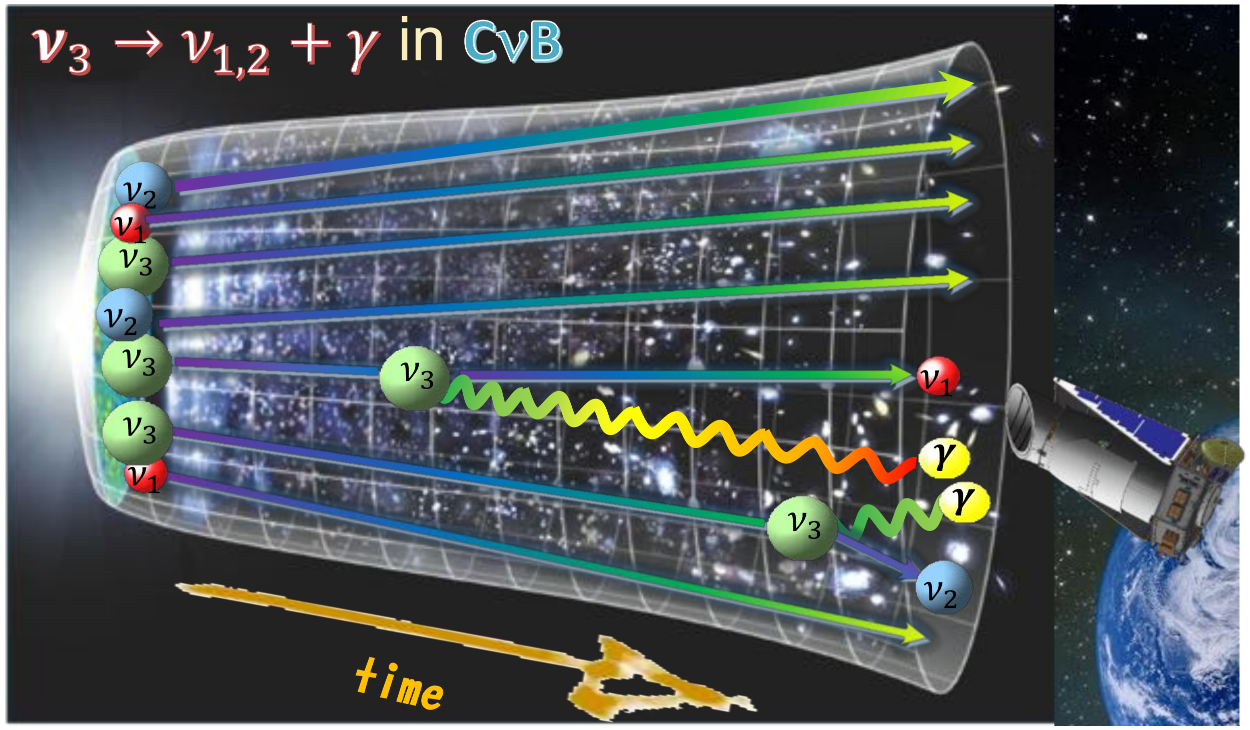
Beam dump facility and SHiP detector



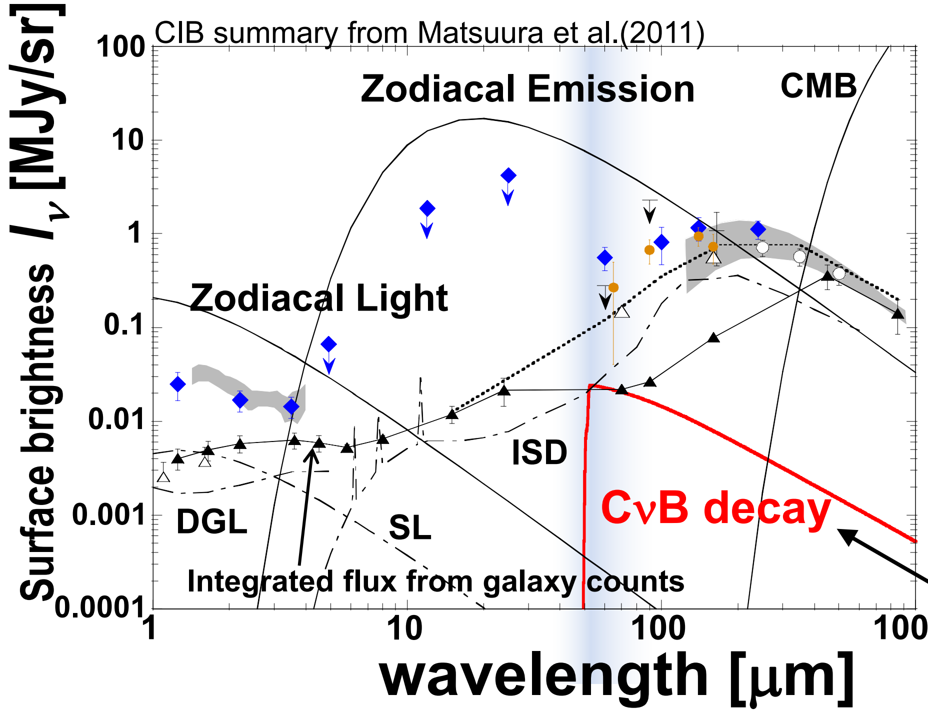
COBAND (COsmic BAckground Neutrino Decay)

Search for Neutrino decay in Cosmic background neutrino

➔To be observed as photons in neutrino decays



Neutrino Decay signal and backgrounds



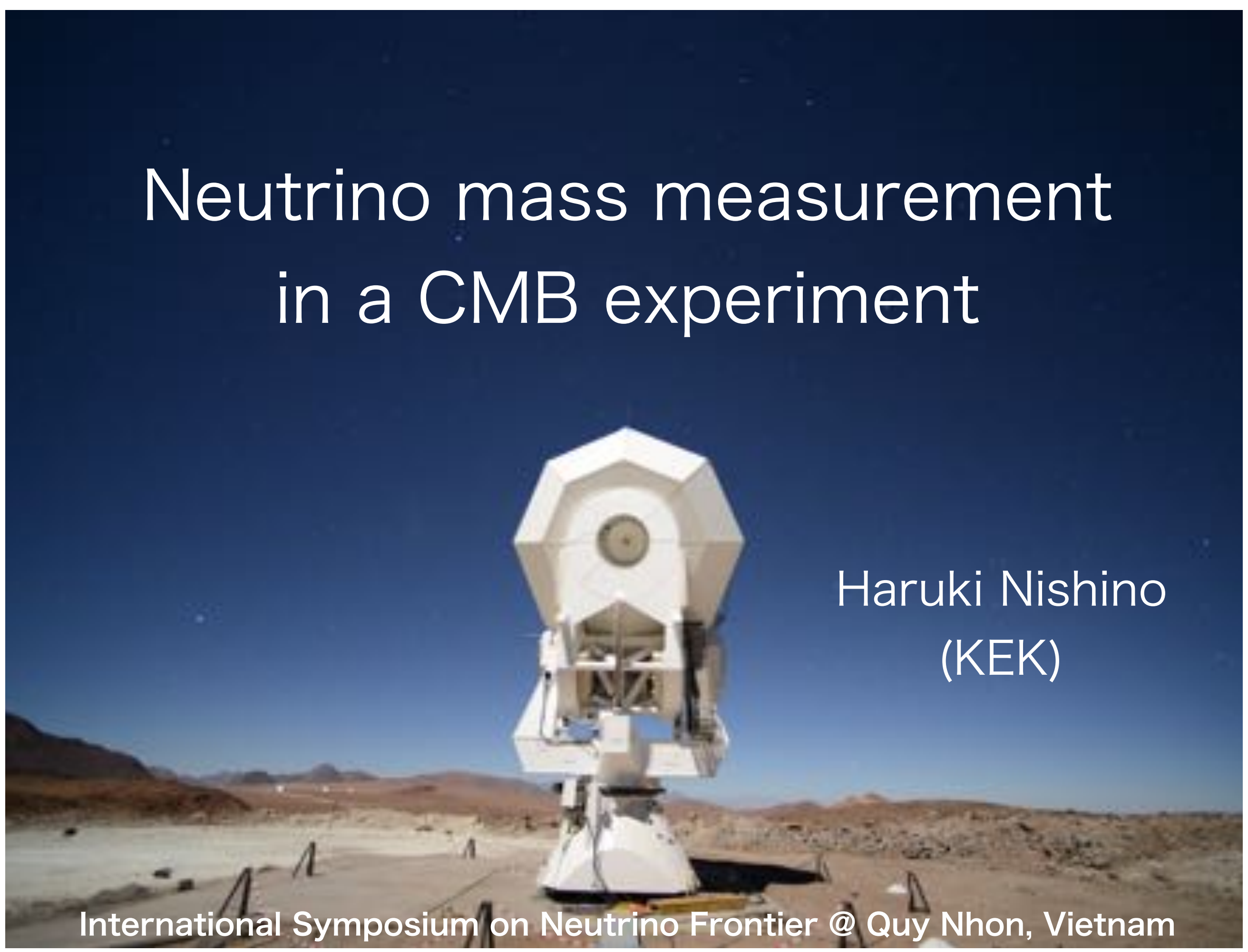
Zodiacal Emission
I_{ZE}=8MJy/sr

Neutrino Decay
I_ν=25kJy/sr

$\tau = 1 \times 10^{14}$yrs
$m_3 = 50$ meV

We can identify the contribution from CνB decay!!

7



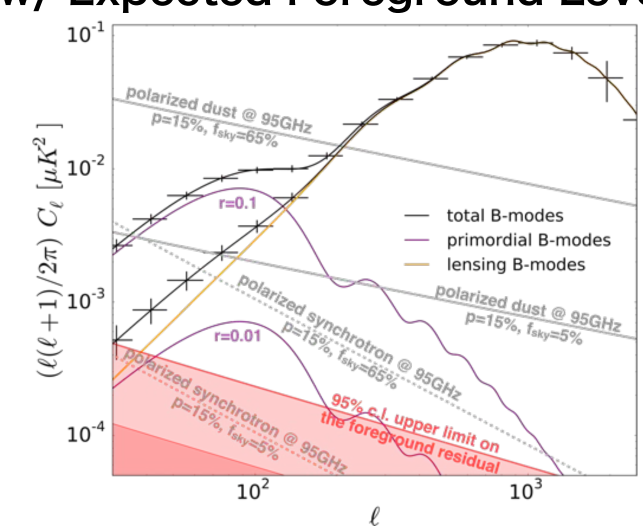
Neutrino mass measurement in a CMB experiment

Haruki Nishino
(KEK)

International Symposium on Neutrino Frontier @ Quy Nhon, Vietnam

Simons Array: Prospects for Sensitivity

B-mode Power Spectrum
w/ Expected Foreground Level



- Three year Simons Array observation (w/ foreground subtraction by PLANCK 353GHz and C-BASS 5GHz)
  - Primordial gravitational wave: $\sigma(r=0.1)\sim 6\times10^{-3}$
  - Sum of neutrino mass: $\sigma(\Sigma m_\nu)$=40meV (combined w/ DESI BAO)

35

Rich Physics with Neutrinos

- Neutrino mass
  - ν_R, Heavy Neutrino, Majorana Neutrino, Mass Hierarchy
- Baryon Asymmetry in our universe
  - δ_{CP}, Leptogenesis,
- Dark Matter
  - ν_R, Sterile
- Grand Unification (and Symmetry)
  - Neutrino mass, mixing angles, symmetry between quarks and leptons, proton decay in a neutrino detector
- Exotic
  - CPT violation, Sterile, Non-standard Interaction
- Neutrino astronomy

Reminder

Accelerator

- T2K
- NOvA
- MINOS/MINOS+
- NC-γ
- MicroBooNE
- LHC
- JSNS2
- OPERA
- (WAGASCI) —YP
- Hyper-K
- DUNE
- DsTau
- SHiP

+YP talks

Reactor

- Daya Bay
- RENO
- STEREO
- DANSS
- JUNO
- KamLAND

Natural ν

- Super-K
- Borexino
- IceCube

$\beta\beta$

- Panda-X
- AXEL
- KamLAND-Zen

Atom & Cosmic ν

- SPAN
- COBAND
- Simons Array

Theories

- Overview
- EW ν_R
- Ultra-High Energy Neutrinos
- νMSM
- Leptogenesis
- New Physics in LBL
- Dirac or Majorana

Summary and Outlook

- Accelerator Neutrinos
  - Hyper-K and DUNE are under preparation.
  - Several experiments are on-going.
- Reactor Neutrinos
  - JUNO is under construction.
  - Several sterile neutrino search experiments are on-going.
- Natural Neutrinos
  - Neutrino Astronomy begins! Solar and Astronomical sources
- $\beta\beta$ decay search
  - Many $\beta\beta$ decay search experiments. Discovery may be around the corner.
- Cosmic Neutrinos
  - More synergy with experiments in a laboratory and observation cosmology.
- Theory
  - More links between theories and experiments