Neutrino 2022 Catch Up

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BNL

June 7, 2022

Brookhaven National Laboratory

Brookhaven NDI Neutrino Discovery Initiative

Speaking from Setauket land

Global fit: Schwetz

Evolution of global 3 flavour fit

Gonzalez-Garcia, Maltoni, TS [arXiv:2111.03086]

	2012 NuFIT 1.0	2014 NuFIT 2.0	2016 NuFIT 3.0	2018 NuFIT 4.0	2021 NuFIT 5.1	
θ_{12}	15%	14%	14%	14%	14%	**1.07**
θ_{13}	30%	15%	11%	8.9%	9.0%	**3.3**
θ_{23}	43%	32%	32%	27%	27%	**1.6**
Δm^2_{21}	14%	14%	14%	16%	16%	**0.88**
$\lvert\Delta m^2_{3\ell}\rvert$	17%	11%	9%	7.8%	6.7% [6.5%]	**2.5**
δ_{CP}	100%	100%	100%	100% [92%]	100% [83%]	**1 [1.2]**
$\Delta\chi^2_{\text{IO-NO}}$	± 0.5	-0.97	$+0.83$	$+4.7$ [$+9.3$]	$+2.6$ [$+7.0$]	

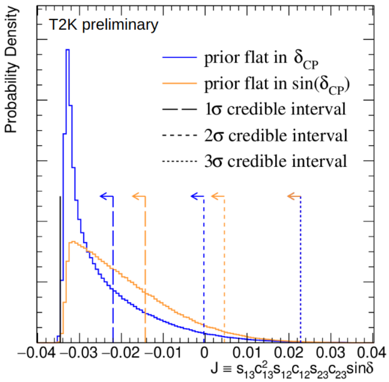
w/o [w] SK atm data

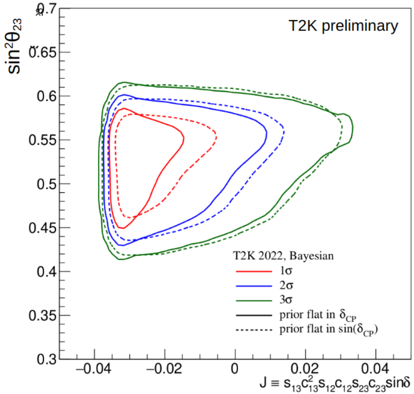
relat. precision at 3σ : $\frac{2(x^+ - x^-)}{(x^+ + x^-)}$

improvement factor from 2012 to 2021

New oscillation result
Jarlskog invariant

- Can search for potential CP violation by looking at the posterior probability and credible intervals for J_{CP}
- Results depend on the metric in which we assume the prior for δ to be uniform





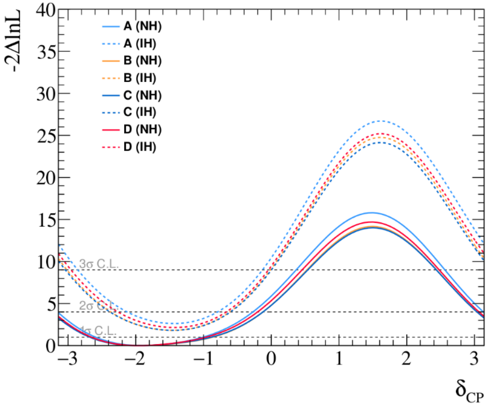
Marginalized over mass ordering hypotheses

Using θ_{13} constraint from reactor experiments: $\sin^2(2\theta_{13}) = 0.0861 \pm 0.0027$

T2K: Bronner

New oscillation results
Effect of analysis change - δ_{CP}

A: Neutrino 2020 result
B: New interaction model and near detector fit
C: B + new θ_{13} reactor constraint (PDG 2019 → PDG2021)
D: C + new sample (ν_μ CC1π^+)



new analysis of old data
first use of multi-ring
less constraining than previously

Using θ_{13} constraint from reactor experiments: $\sin^2(2\theta_{13}) = 0.0861 \pm 0.0027$

NOvA: Hartnell

2020 3-Flavour Frequentist Result

Best Fit

Normal hierarchy

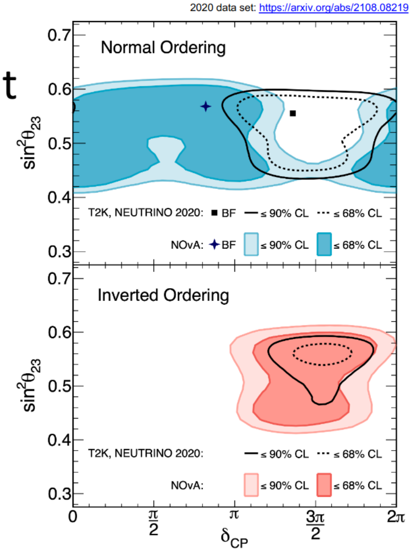
$\Delta m^2_{32} = (2.41 \pm 0.07) \times 10^{-3}\ \text{eV}^2$

$\sin^2\vartheta_{23} = 0.57^{+0.04}_{-0.03}$

$\delta = 0.82\pi$

Poster 318
Liudmila Kolupaeva
Andrew Sutton

- Significant progress on joint fit with T2K
  - coming this year



University of Sussex

Jeff Hartnell, Neutrino 2022 NOvA 23

new analysis of old data
new statistical techniques
no significant change
new sterile search: not competitive

Mixing, CPV, Unitarity: Denton

Cosmology: $m_1 + m_2 + m_3 < 90$ meV at 95% CL

E. Valentino, S. Gariazzo, O. Mena 2106.15267

$\rightarrow$ 20 meV precision with DESI, EUCLID, ...

From oscillations:

$$\text{Normal}: \quad m_1 + m_2 + m_3 > 60 \text{ meV} \qquad \text{Inverted}: \quad m_1 + m_2 + m_3 > 100 \text{ meV}$$

See also KATRIN 2105.08533

PRIORS?

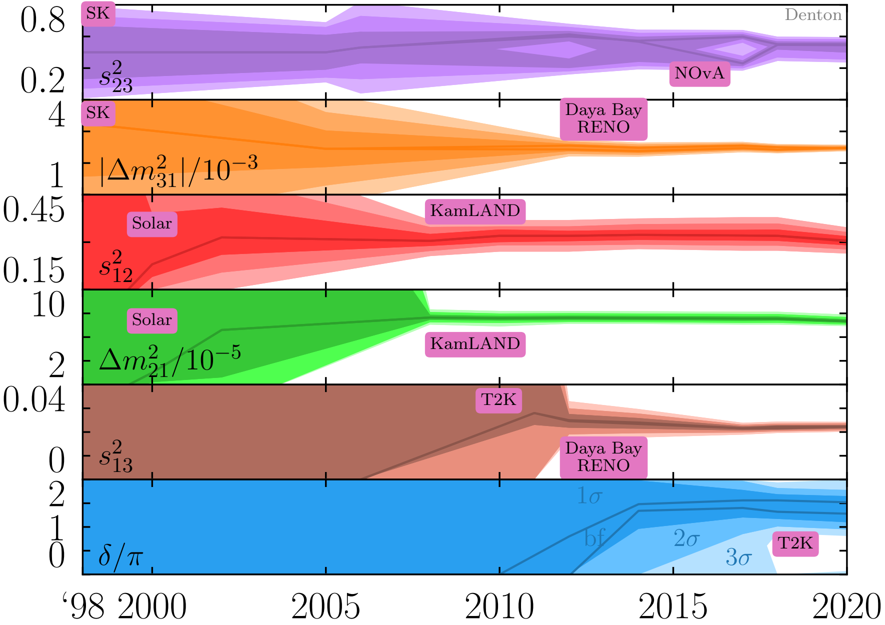
Some claim "decisive" Bayesian evidence for normal ordering

R. Jimenez, et al. 2203.14247

More general prior assumptions $\Rightarrow$ no significant information from cosmology

S. Gariazzo, et al. 1801.04946

S. Gariazzo, et al. 2205.02195



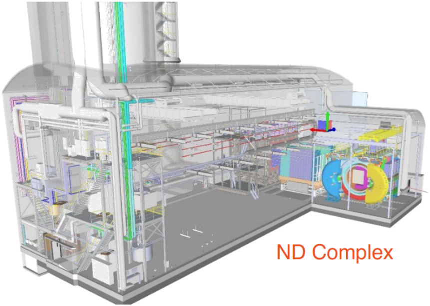
0.8
0.2
SK
Denton
s^2_{23}
NOvA
4
1
SK
Daya Bay
RENO
$|\Delta m^2_{31}|/10^{-3}$
0.45
0.15
Solar
KamLAND
s^2_{12}
10
2
Solar
KamLAND
$\Delta m^2_{21}/10^{-5}$
0.04
0
T2K
Daya Bay
RENO
s^2_{13}
2
1
0
1σ
bf
2σ
3σ
T2K
δ/π
'98 2000
2005
2010
2015
2020

HyperK: J. Wilson, DUNE: Muether

Under construction
Rich physics program

Near Site Progress

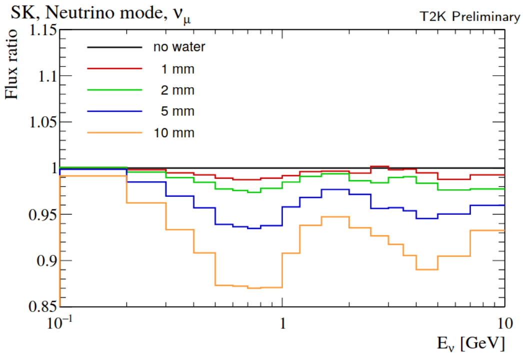
- Beamline Complex and Near Detector Complex Design 100% complete.



25 6/2/2022 Neutrino 2022 – Virtual Seoul – M. Muether

Accelerator Neutrino Fluxes: M. Friend

Horn Cooling Water



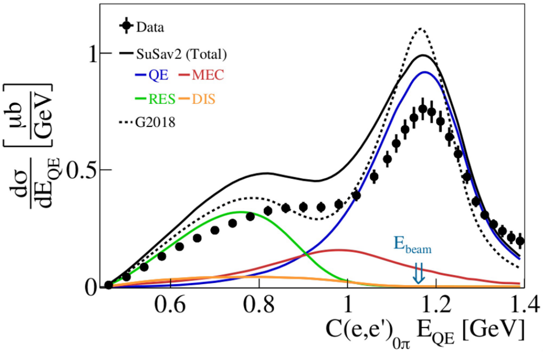
- Focusing horns are cooled by water sprayed between inner and outer conductors

- Difficult to precisely measure thickness of water layer pooled at horn inner conductor (3 mm $\pm$ 2 mm assigned at J-PARC now)
- Significant impact on flux due to pion absorption/scattering
- Precise dedicated measurements needed (underway at J-PARC)

T2HKK/KNO, ESSnuSB, and THEIA: Hyunsoo Kim

NNLO experiments
Will do better than NLO experiments

$(e,e')_{0\pi}$ Data-Theory Disagreements



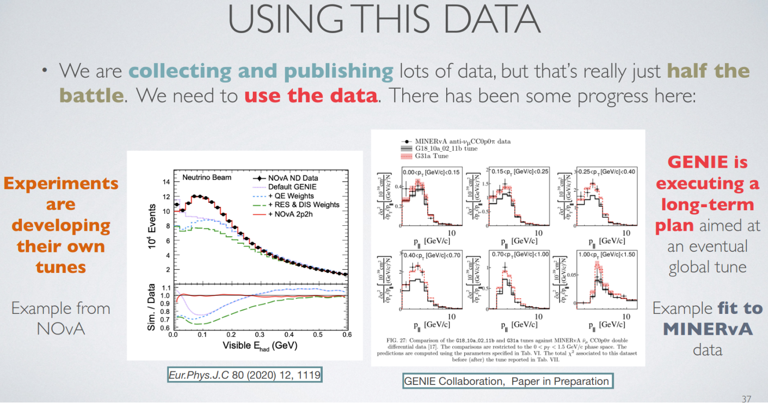
Khachatryan, Papadopoulou, and Ashkenazi et al.
(CLAS & e4v collaborations), Nature **599**, 565 (2021).

$$E_{QE} = \frac{2M\epsilon + 2ME_l - m_l^2}{2\left(M - E_l + |k_l|\cos\theta_l\right)}$$

Neutrino Interactions: Natalie Jachowicz, Laura Fields, Xianguo Lu, Steven Gardiner

Theory: Hard but making progress

Measurements: Bad but getting better



CEvNS: Carla Bonifazi, Dan Pershey, Carlo Giunti

Test of SM

Test of BSM scenarios (sterile, NSI, DM, dark sector, ...), nuclear physics, etc.

Important for DM direct detection, SN dynamics

π-DAR (mostly coherent) measured by COHERENT in 2017, many updates

Quenching factors are super important

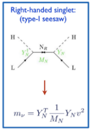
Reactor experiments (fully coherent) pushing to low thresholds, background measurements, and understanding detectors: at the edge of a detection

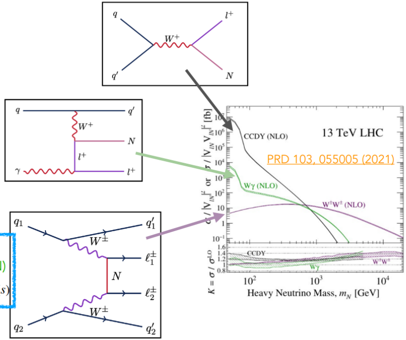
NSI: Yasaman Farzan

Vector NSI affects oscillations, CEvNS, etc.
Models with large $\mathcal{O}(1)$ NSI are viable with light mediators
Also possible to get larger off-diagonal than diagonal: $|\epsilon_{\alpha\beta}|^2 > |\epsilon_{\alpha\alpha}\epsilon_{\beta\beta}|$ (opposite is typical)

HNL at LHC: Jie Xiao

Probing heavy Majorana neutrinos & Weinberg op. via pp→μ±μ±jj

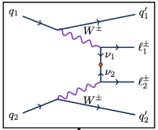




Type-I Seesaw Heavy Majorana neutrino (HMN)

$$\sigma^{\ell\ell'}(s) \equiv \left|V_{\ell N} V^*_{\ell' N}\right|^2 \times \sigma_0^{\ell\ell'}(s)$$

Dim-5 Weinbreg Operator (WO)



Wilson Coefficients

$$\mathcal{L}_5 = \frac{C_5^{\ell\ell'}}{\Lambda}\left[\Phi \cdot \overline{L}_\ell^c\right]\left[L_{\ell'} \cdot \Phi\right] + \text{H.c.}$$

EFT Scale

$$v = \sqrt{2}\langle\Phi\rangle \approx 246 \text{ GeV}$$

$$m_{\ell\ell'} = C_5^{\ell\ell'} v^2/\Lambda$$

Effective Majorana Mass

$$\nu_\ell(p) \quad \nu_{\ell'}^c(-p) = \frac{i\not{p}}{p^2}\,\frac{-iC_5^{\ell\ell'}v^2}{\Lambda}\,\frac{i\not{p}}{p^2} = \frac{im_{\ell\ell'}}{p^2}$$

Phys. Rev. D 103, 115014

$$\sigma \sim |m_{\ell\ell'}|^2 \propto \left|C_5^{\ell\ell'}/\Lambda\right|^2$$

- The "neutrinoless double-β decay" version of the LHC
- Signal topology: two **same-sign muons** + **two jets**

LAr TPC ideas: Angela Fava

Dual readout TPCs
Radial geometry for the TPC, with the intent of creating and detecting electroluminescence
Combined light & charge readout with pixel detectors
Near Infrared in liquid argon
Magnetized LAr-TPC detectors

Beam upgrades for HK, DUNE: Tetsuro Sekiguch, Rob Ainsworth

J-PARC 2021: 0.5 MW, 2.6×10^{14} p/pulse, 2.48 s/cycle
Upgrade: 1.3 MW, 3.2×10^{14} p/pulse, 1.16 s/cycle
Horn, target upgrades

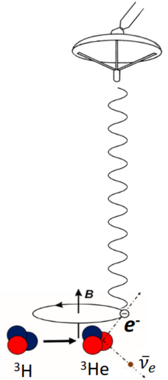
DUNE: use the recycler as a stacker
Cycle reduced from 2.2s to 1.2s in 2019, reached 0.9 MW last week
Plans to push to 1.2 MW
To get 2.4 MW need to upgrade the booster

Emulsion detection: Toshiyuki Nakano, Hiroki Rojuko

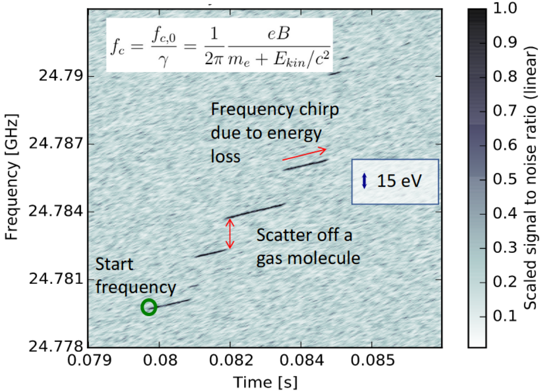
Improvements to scanning techniques
Novel 3D emulsion?
Used in NINJA (Neutrino Interaction research with Nuclear emulsion and J-PARC Accelerator), FASERnu and SND, DsTau, cosmic gamma rays from pulsars, pyramid imaging

Project 8: Elise Novitski

A new approach:
Cyclotron Radiation Emission Spectroscopy (CRES)

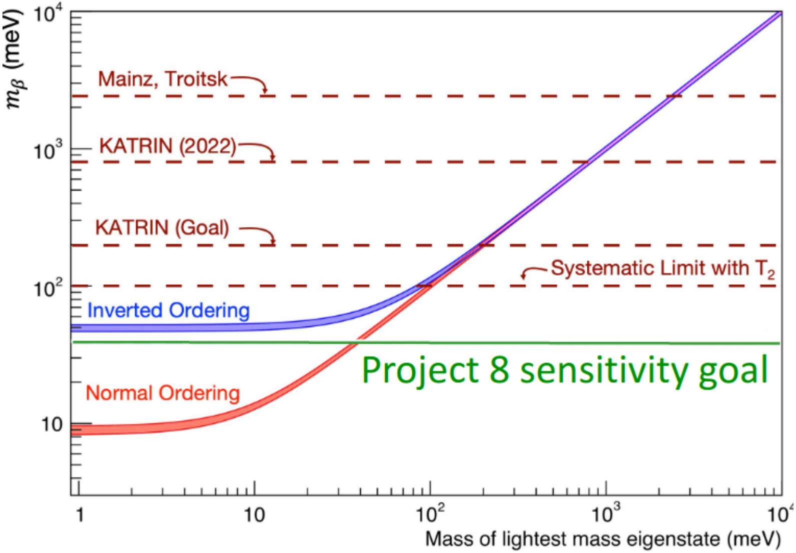


Fourier-transform

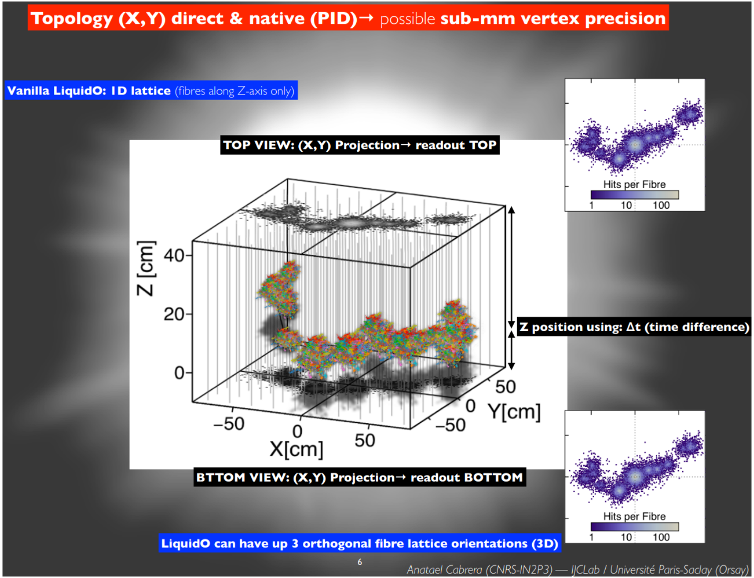


4 June 2022 Neutrino 2022 -- Elise Novitski 5

Project 8: Elise Novitski



Liquid O: Anatael Cabrera, see also Christian Buck



WbLS: Michael Wurm

ANNIE+SANDI: WbLS test deployment

→ **next step: SANDI**
acrylic vessel with 365 kg of WbLS submerged in ANNIE

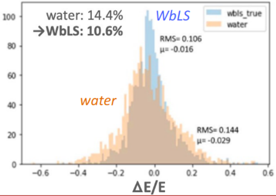
- resolve scintillation light from hadronic recoils, improve neutrino energy determination
- higher light output for neutron captures on gadolinium
  → improved neutron detection efficiency & vertex reco
- first attempt of C/S separation for neutrinos with LAPPDs

→ test WbLS performance for future use in long-baseline exp.s!

Preparations are on-going

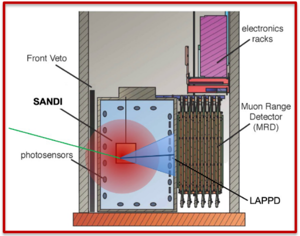
- 3‘ x 3‘ vessel already on-site at Fermilab
- (Gd-loaded) WbLS to be produced at BNL (M. Yeh)

SANDI vessel at Davis



MC with idealized reco and machine learning

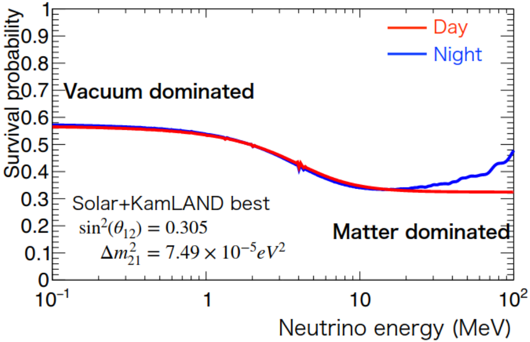
ANNIE vs. SANDI WbLS vessel

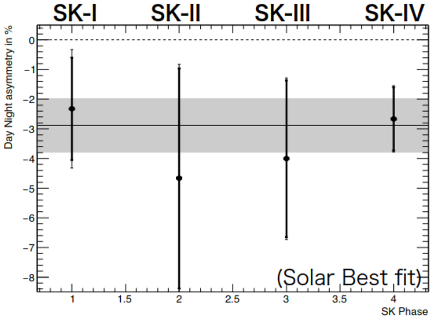


Day-Night flux difference

Direct MSW effect

Neutrino oscillation (MSW-LMA)





The importance of studying CNO

The solar metallicity puzzle

1998

GS98*: high metallicity

Uses 1D hydrodynamical model of solar atmosphere

Z/X= 0.023

Helioseismology: ok

Grevesse et al.,Space Sci.Rev. **(1998)85]*

→

2009

AGS09met*: low metallicity

Uses 3D hydrodynamical model of solar atmosphere

Z/X= 0.018

Helioseismology: ko

**A. Serenelli er al., Astr. J. 743,(2011)24*

→

2011

Caffau11*: low metallicity

Uses 3D hydrodynamical model of solar atmosphere

Z/X= 0.0209

Helioseismology: ko

**E.Caffau et al., Sol.Phys. (2011) 268*

→

2021

AGG21*: low metallicity

Uses 3D hydrodynamical model of solar atmosphere

Z/X= 0.0187

Helioseismology: ko

**Asplund et al .Rev.Astr.Astr A&A (2021) 653*

→

2022

MB22*: high metallicity

Uses 3D hydrodynamical model of solar atmosphere

Z/X= 0.0225

Helioseismology: ok

Magg et al., arXiV:2203.02255

DSNB w/Gd: Andrew Mastbaum, Mark Vagins

SuperK

DSNB Search Results: Model-Independent

Model-Independent Results (SK IV, $N_n = 1$)

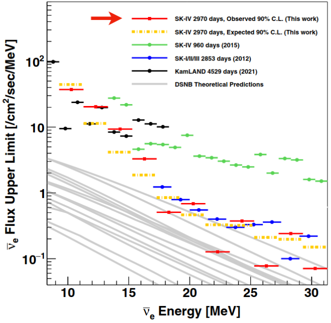
- No excess observed
- No single bin above 2σ relative to backgrounds
- Strongest constraints for $E_\nu > 11.3$ MeV
- Disfavors the most optimistic DSNB models

TABLE V. Summary on the 90% CL expected sensitivities and observed upper limits as well as the corresponding p-values in each electron antineutrino energy bin ($E_\nu = E_{rec} + 1.8$ MeV).

E_ν (MeV)	Expected (cm^{-2} sec^{-1} MeV^{-1})	Observed (cm^{-2}sec^{-1} MeV^{-1})	p-value
9.3–11.3	4.44×10^{1}	3.71×10^{1}	0.346
11.3–13.3	1.14×10^{1}	2.04×10^{1}	0.886
13.3–15.3	4.17×10^{0}	9.34×10^{0}	0.938
15.3–17.3	1.87×10^{0}	3.29×10^{0}	0.830
17.3–19.3	8.48×10^{-1}	5.08×10^{-1}	0.243
19.3–21.3	4.64×10^{-1}	6.84×10^{-1}	0.686
21.3–23.3	3.28×10^{-1}	1.27×10^{-1}	0.073
23.3–25.3	2.11×10^{-1}	3.75×10^{-1}	0.597
25.3–27.3	2.13×10^{-1}	7.77×10^{-2}	0.051
27.3–29.3	1.98×10^{-1}	2.42×10^{-1}	0.605
29.3–31.3	1.50×10^{-1}	7.09×10^{-2}	0.126

PRD **104**, 122002 (2021)

PRD **104**, 122002 (2021)



Super-Kamiokande Collaboration, Phys. Rev. D **104**, 122002 (2021)

Closing

Theory review: Silvia Pascoli
Experimental outlook: Yifang Wang
Neutrino 2022 Review: Sunny Seo
Future: Stephen Parke: 2024: Milano, 2026 Irvine