

# Outlook into the Future

Neutrino 2026  
26<sup>th</sup> June 2026  
Callum Wilkinson



CHOOSE YOUR  
OWN ADVENTURE®

Given all we have seen this week,  
what am I excited for in the future?

Disclaimer/  
potential for bias:

**DUNE**  
DEEP UNDERGROUND  
NEUTRINO EXPERIMENT

**T2K**

# Overall impression from the past week

- Exciting times ahead!
- The field is poised to make significant advances in a number of areas ... or already is
- Many(!) new results presented
- Generally I was also struck by the range of physics each experiment is reporting
  - +Planned multi-purpose observatories with broad physics programs

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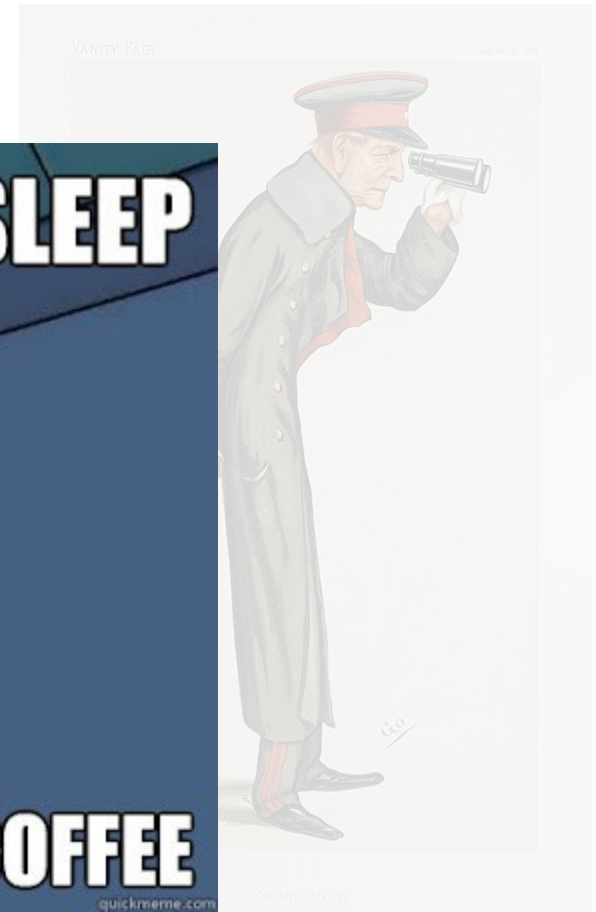
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“No plan survives first contact with the enemy neutrino community”  
-- H. von Moltke, possibly 4

# Plan B

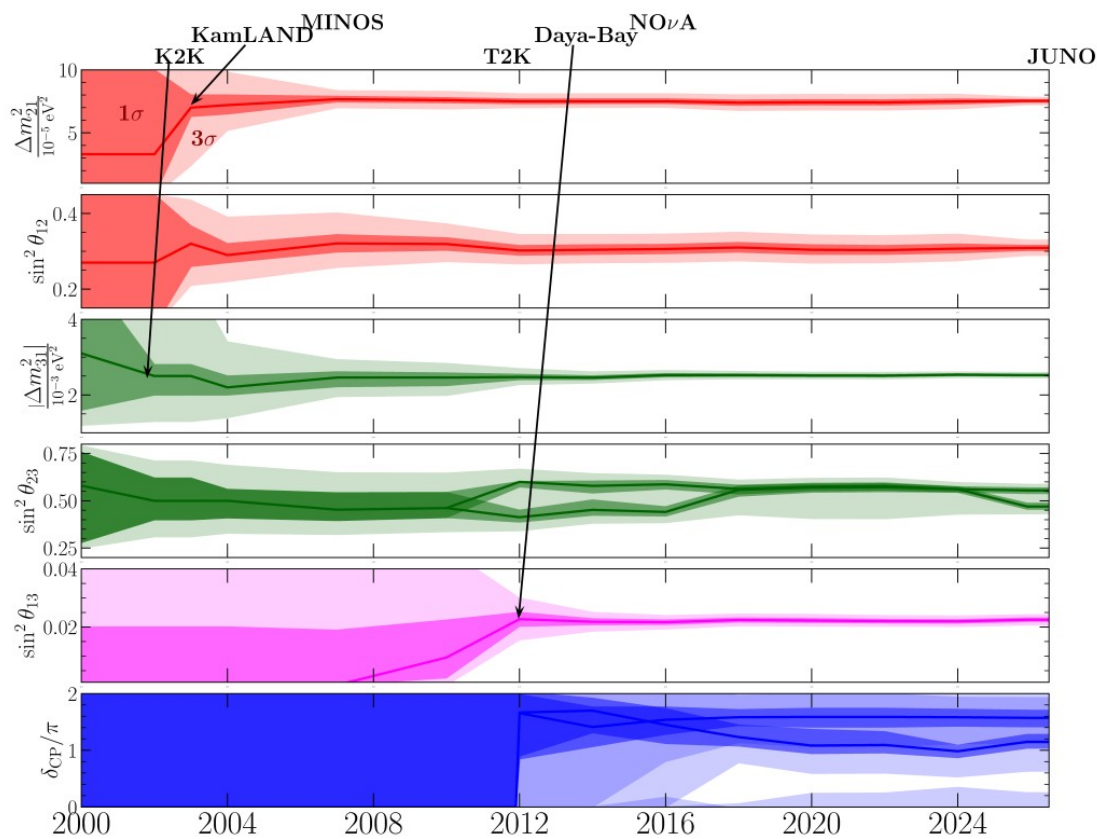
- Exciting times ahead!
  - The field is poised for major advances in a number of areas ... or already is
  - Many(!) new recruits
  - Generally I was involved in a number of physics each year
- +Planned multi-year program with broad physics programs



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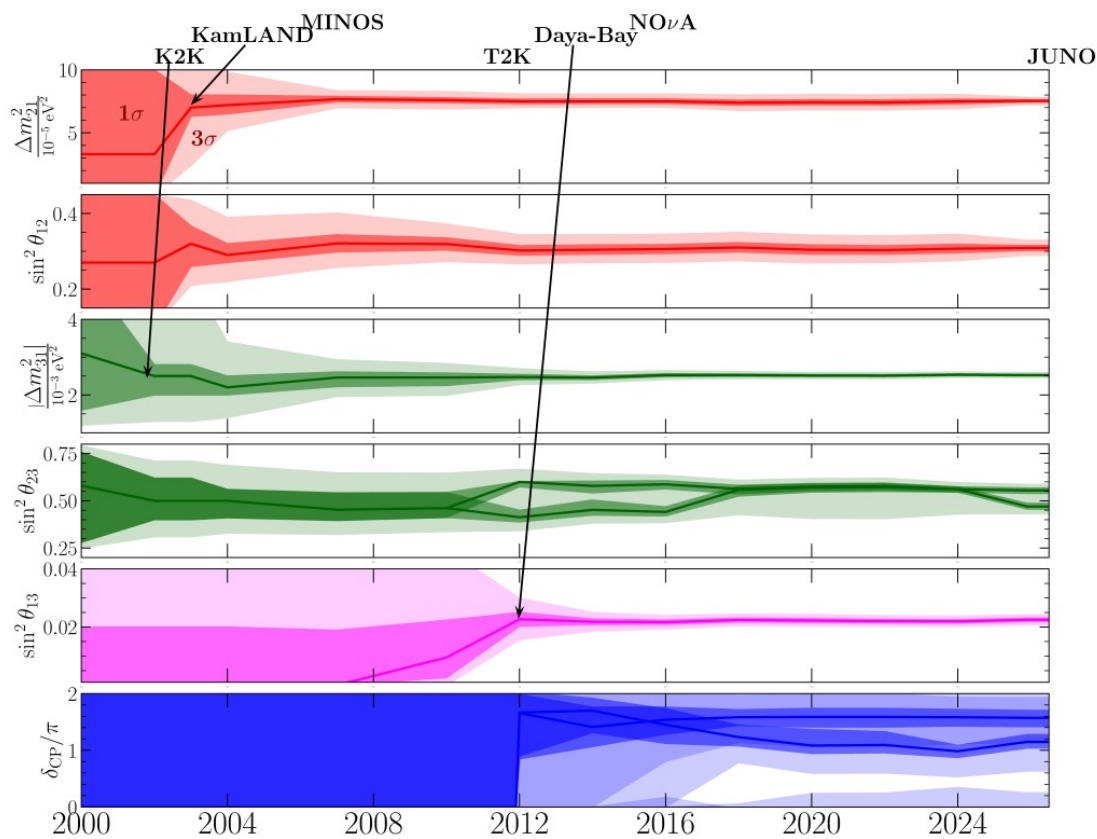
# Neutrino mixing status

- Strong constraints on *most* 3ν mixing parameters, powerful new experiments under construction or already online
- Some mild tension and anomalous data



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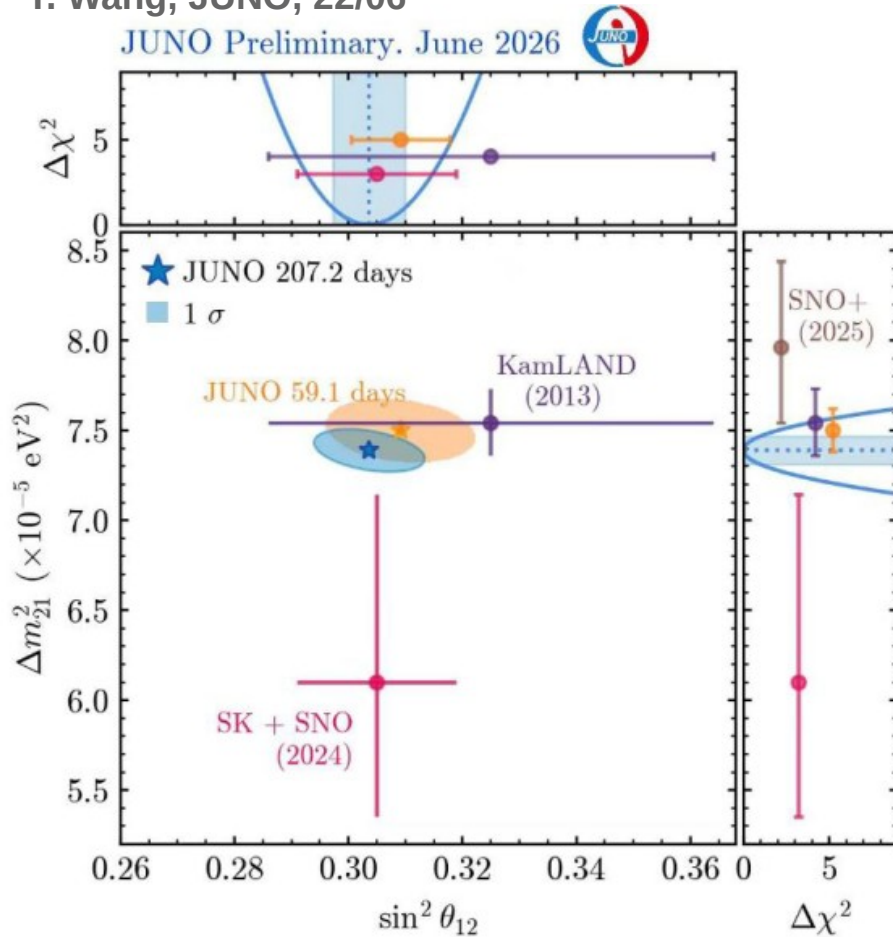
C. Gonzalez-Garcia, 22/06



Visual gag credit to Adam Lister (complaints to me)

# JUNO

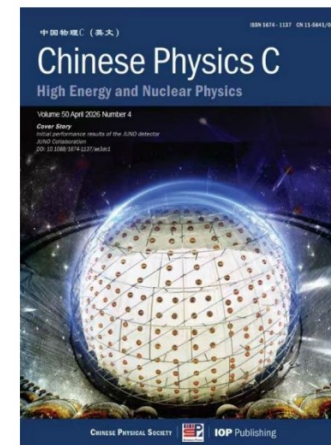
Y. Wang, JUNO, 22/06



- Neutrino 2024: “aim to finish construction in 2024”
- Neutrino 2026: world-leading  $\Delta m_{21}^2$  and  $\sin^2 2\theta_{12}$
- Very impressive effort to commission, calibrate and analyse JUNO + JUNO-TAO

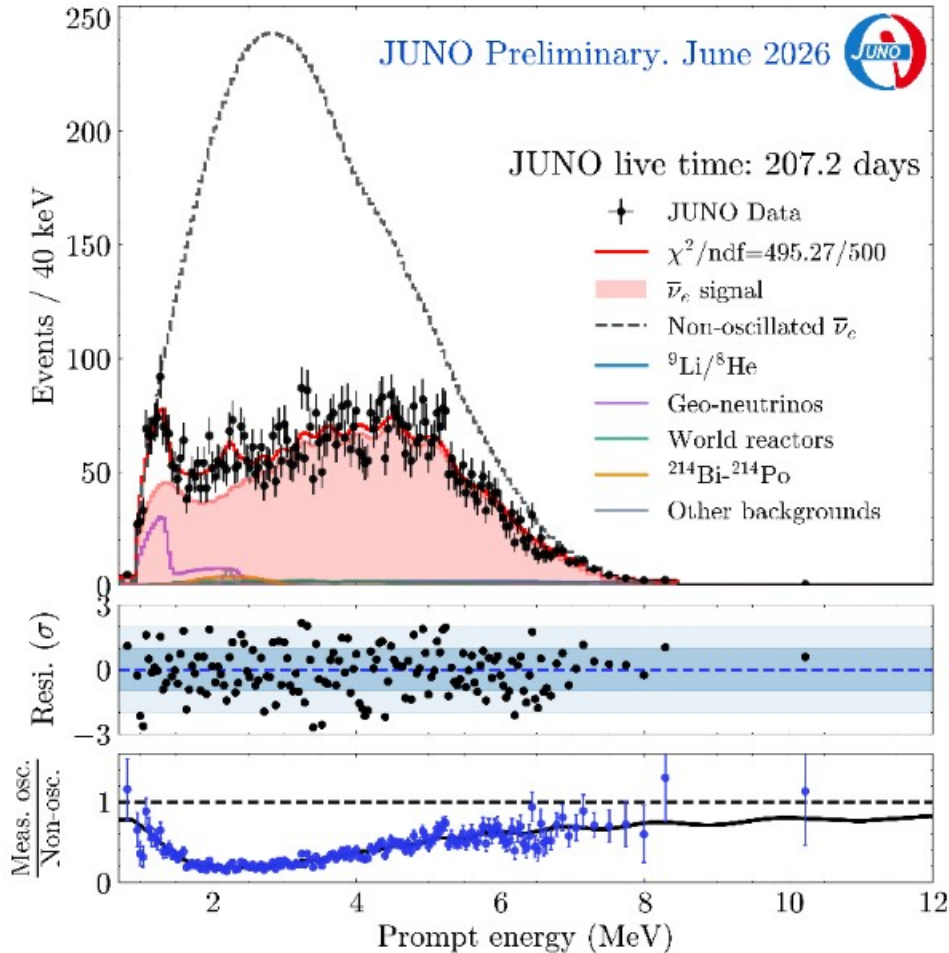
$\Delta m_{21}^2$	$7.388 \pm 0.078$ (1.60% $\rightarrow$ 1.06%)
$\sin^2 \theta_{12}$	$0.3036 \pm 0.0064$ (2.8% $\rightarrow$ 2.1%)

(59  $\rightarrow$  207 days)

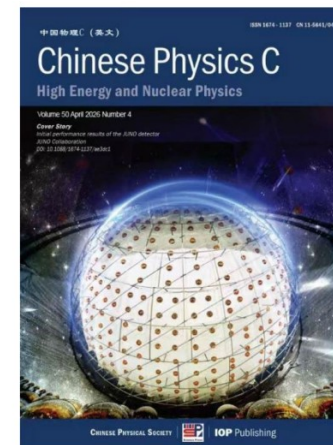


# JUNO

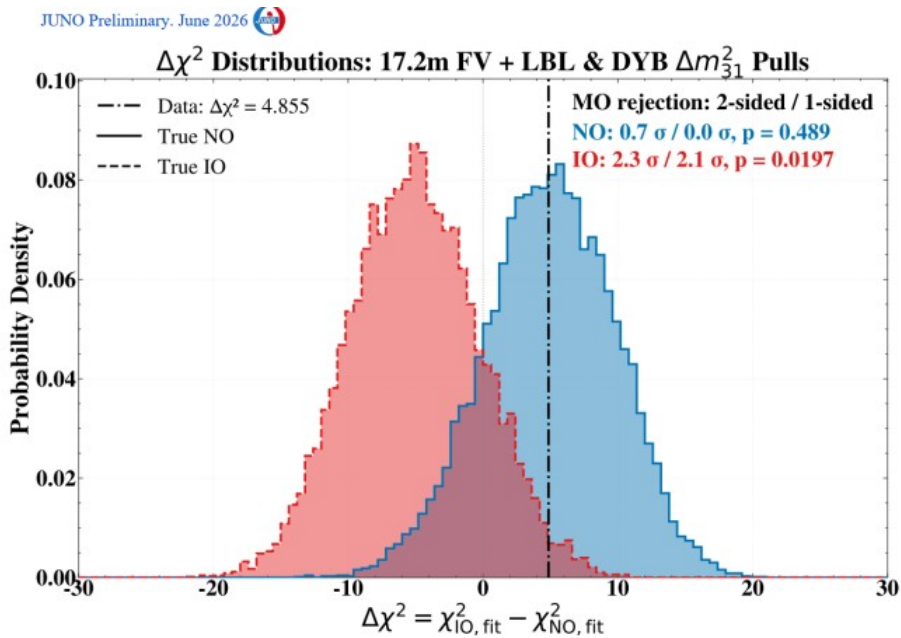
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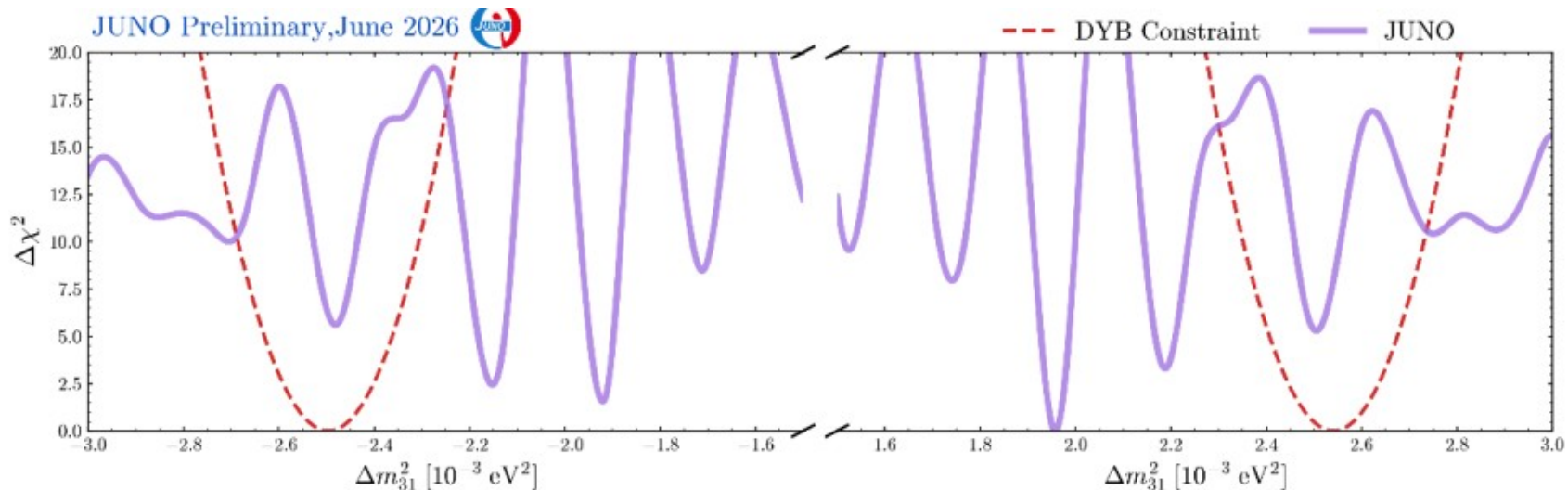


# JUNO



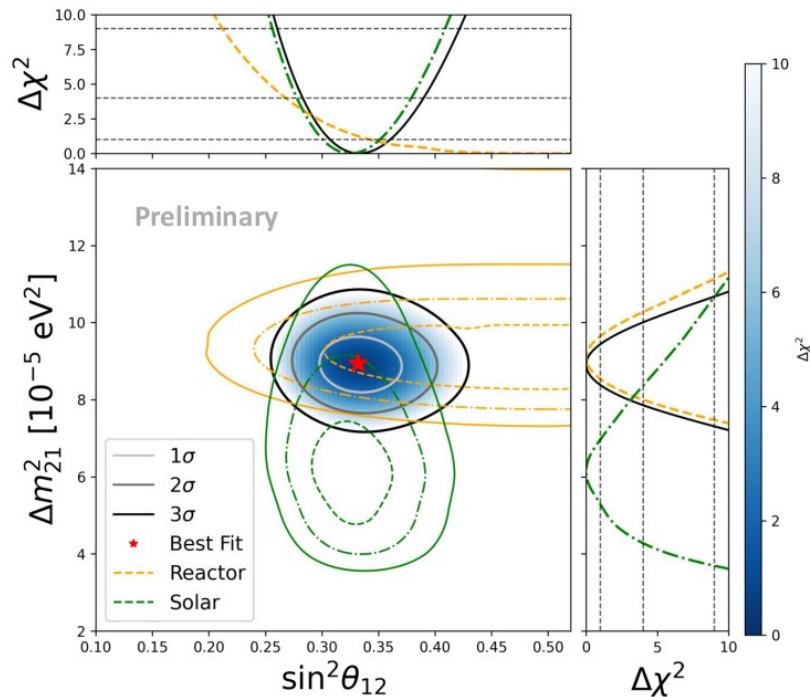
- 1%  $\Delta m_{31}^2$  with Daya Bay
- 2.3 $\sigma$  NO hint with Daya Bay + NuFit-LBL constraints
- Very excited to see future high stats  $\Delta m_{31}^2$  results!
- Also, will eagerly await energy resolution updates for standalone MO measurement!

Y. Wang, JUNO, 22/06



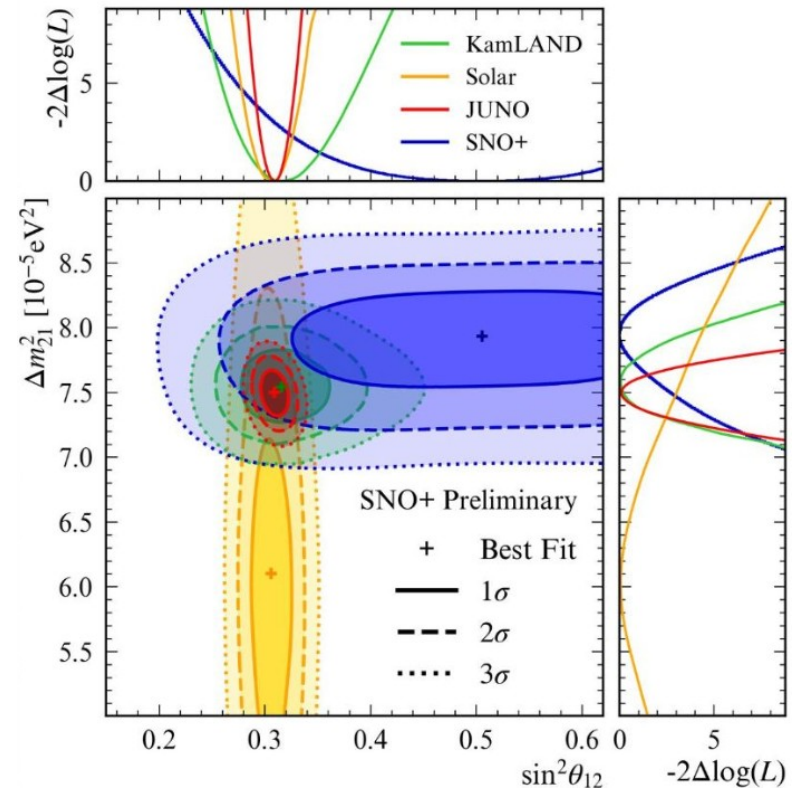
# Other $\Delta m^2_{21}$ - $\sin^2\theta_{12}$ measurements

**SK:** 1.94 $\sigma$  tension between reactor (SK VI-VII) and solar (SK I-IV) measurements



Z. Hu, SK, 24/06

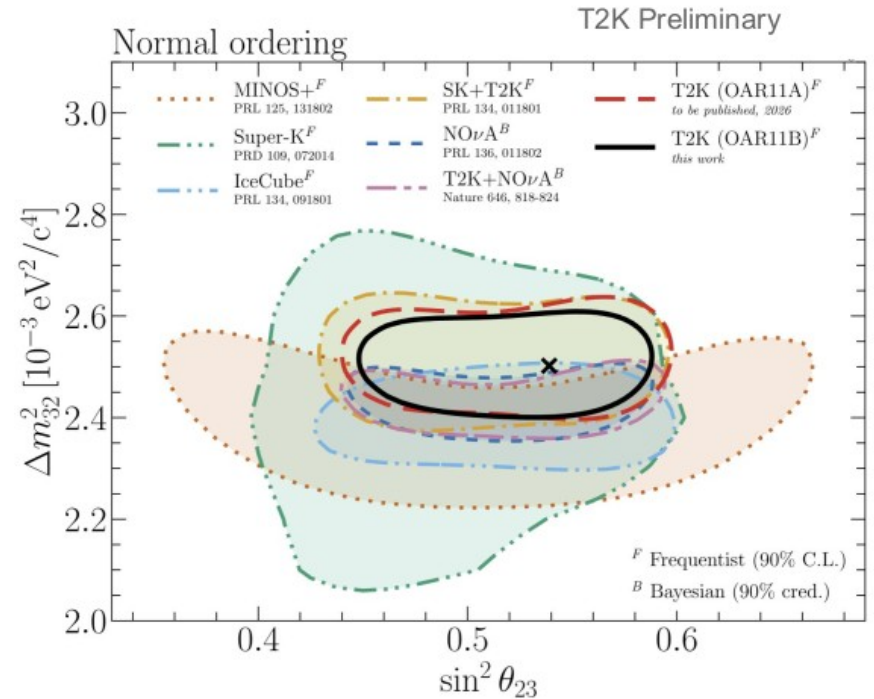
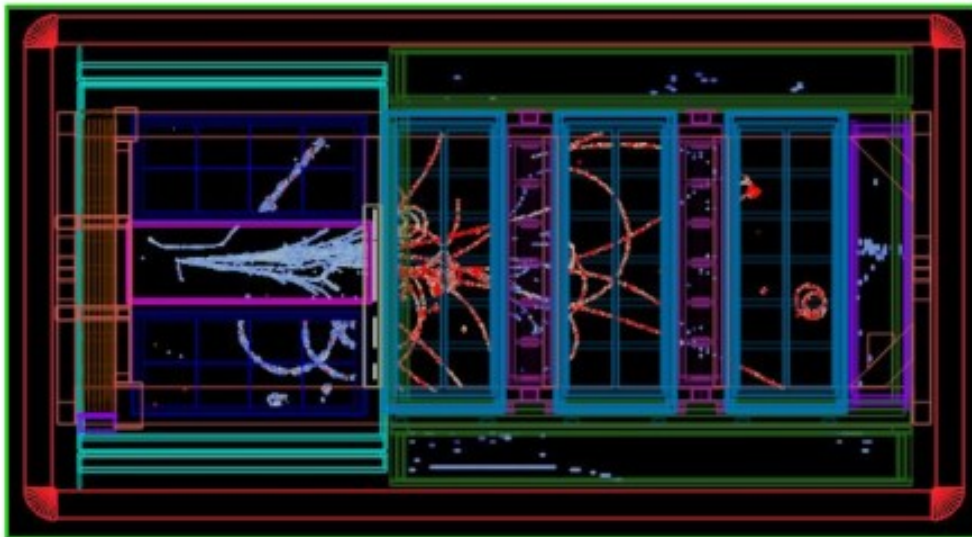
**SNO+:** tension between joint solar+reactor measurement and NuFit solar



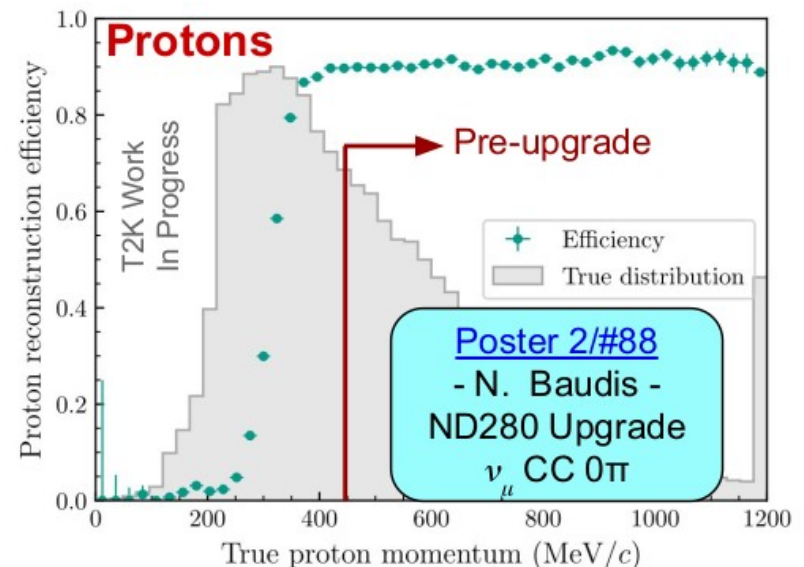
T. Kaptanoglu, SNO+, 24/06

# T2K

- New results with same dataset: key changes are interaction model; new ND samples
- Exclude CP-conservation at 95%, competitive in  $\Delta m^2_{32}$ - $\sin^2\theta_{23}$
- **Neutrino 2028**: new results incorporating the broader acceptance ND-upgrade???

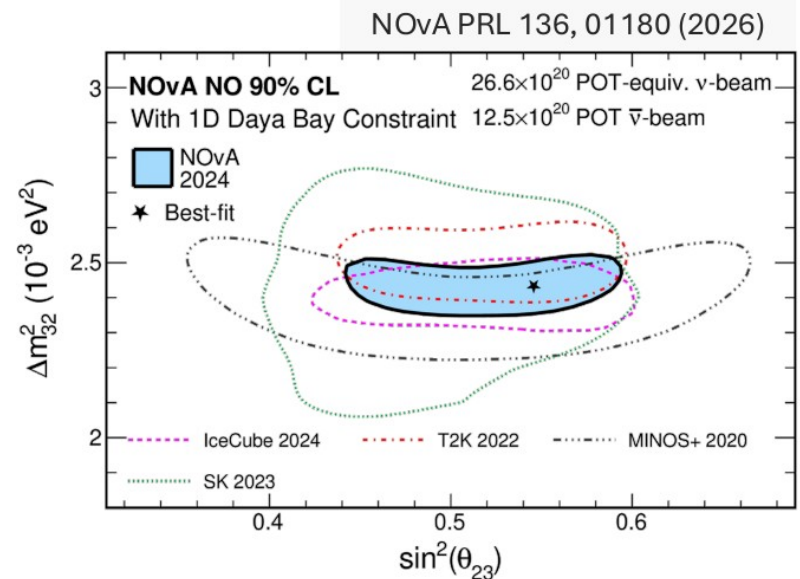
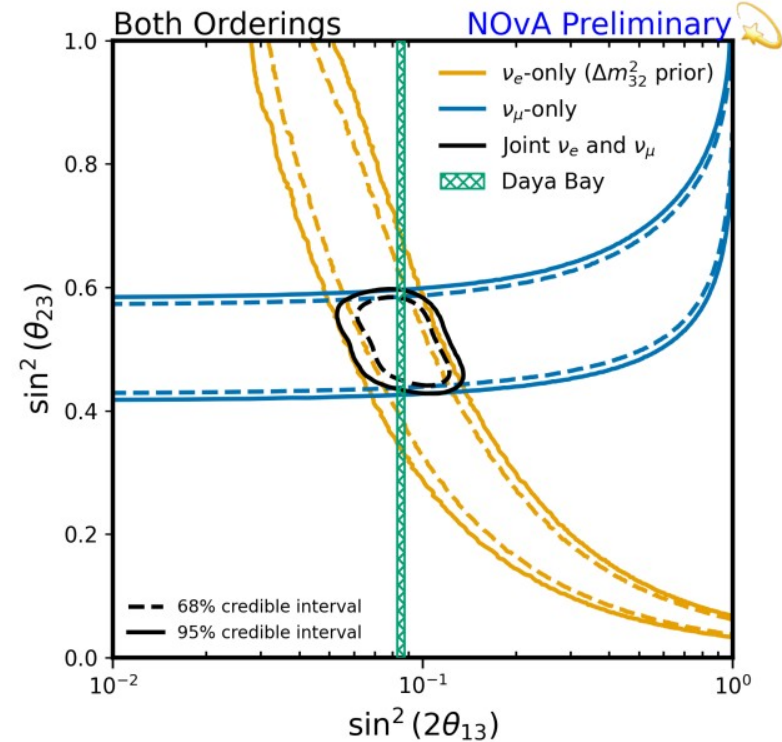


S. King, T2K, 23/06



# NOvA

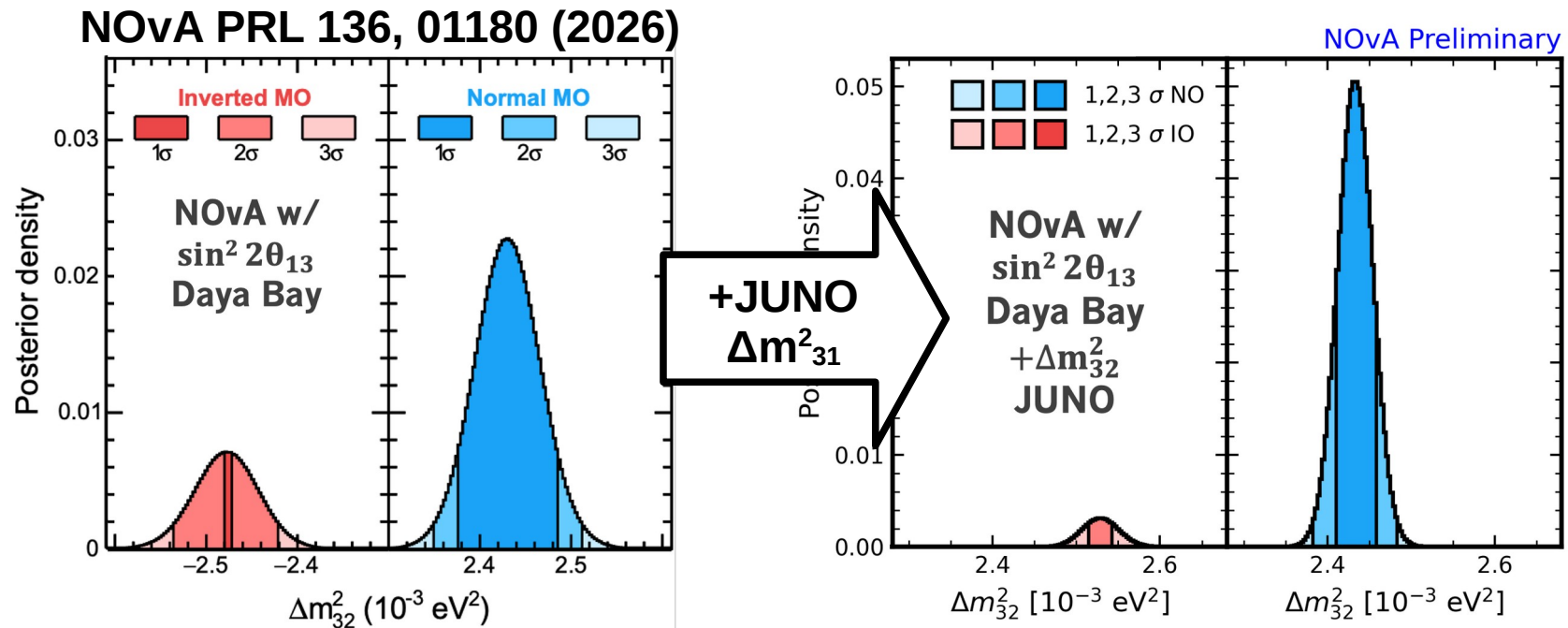
- New results showing consistency of  $3\nu$  with different samples
- Mild preference for NO
- Expect final run from 09/2026 + some unanalysed  $\bar{\nu}$  data
- +Improved reco, interaction model and systematics
- **Neutrino 2028:** final results? New T2K-NOvA joint fits?



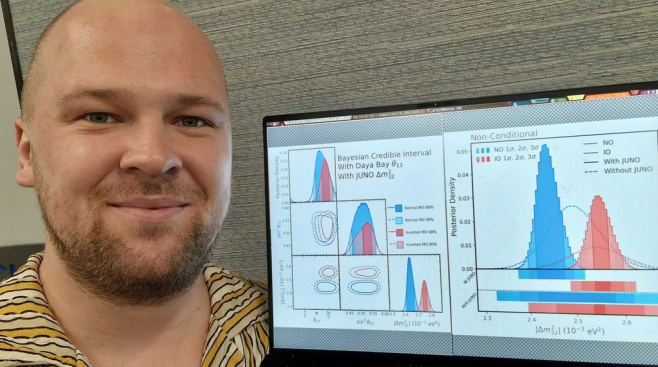
Zoya, NOvA 23/06

# JUNO + NOvA

- Impressively, NOvA produced updated plots with the JUNO  $\Delta m^2_{31}$  constraint in <24 hours
- Impressive  $\Delta m^2_{32}$  agreement in NO
- Other projections of the 4D likelihood in Zoya's talk!



Zoya, NOvA 23/06

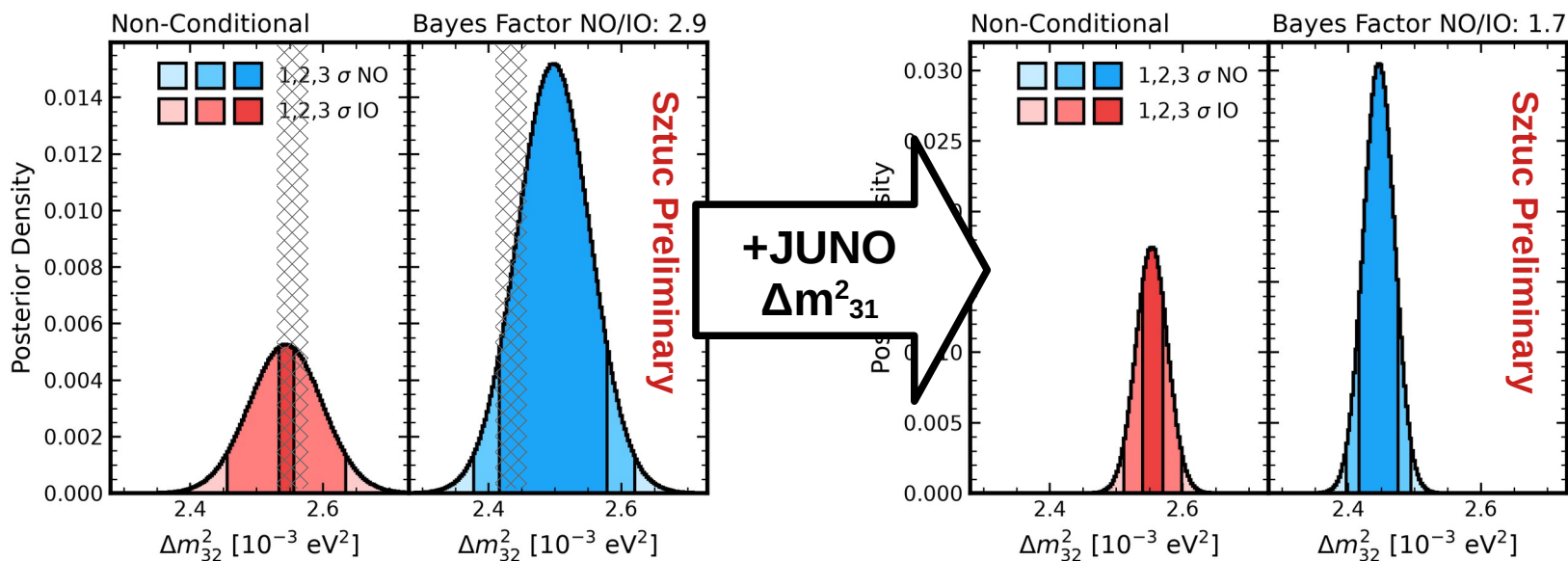


Plots from Artur Sztuc

# What about JUNO + T2K?

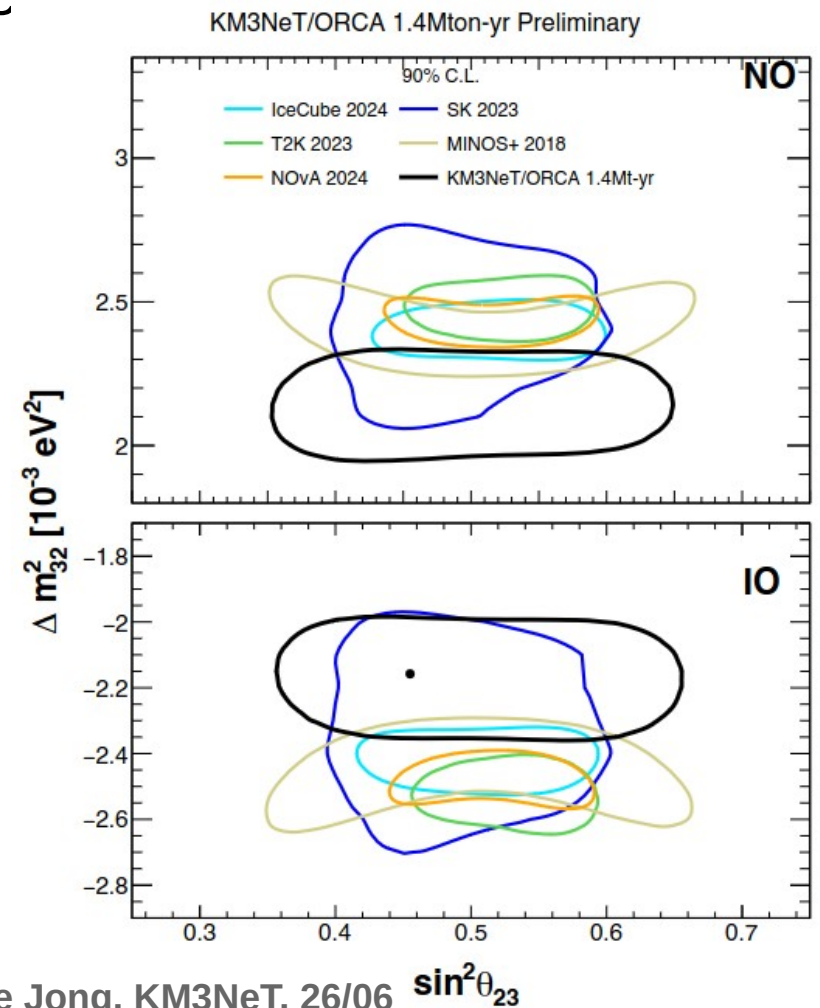
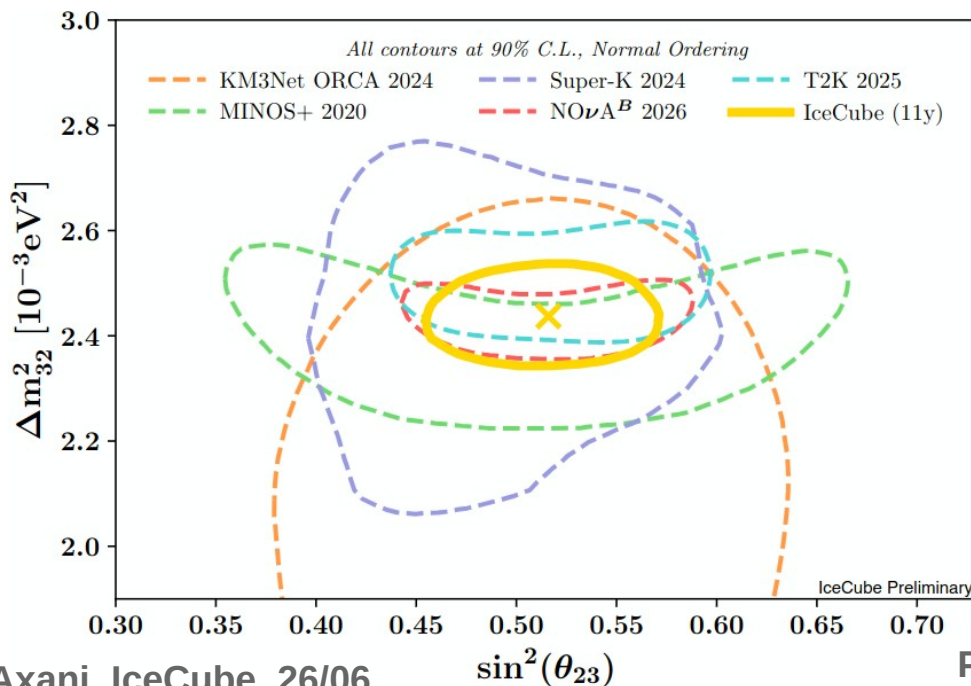
- Naive addition of JUNO  $\Delta m^2_{31}$  measurement decreases T2K's NO preference
- Clearly interesting to conduct full joint analyses
- But we should be wary of strong conclusions
- Highlights value of detailed data releases such as MCMC chains

T2K PRL 135, 261801 (2025)  
w/ DB  $\sin^2 2\theta_{13}$



# Atmospheric neutrinos

- New ATM results from IceCube, ORCA + others
- No strong mass ordering preference
- Healthy competition in  $\Delta m^2_{32}$ - $\sin^2\theta_{23}$



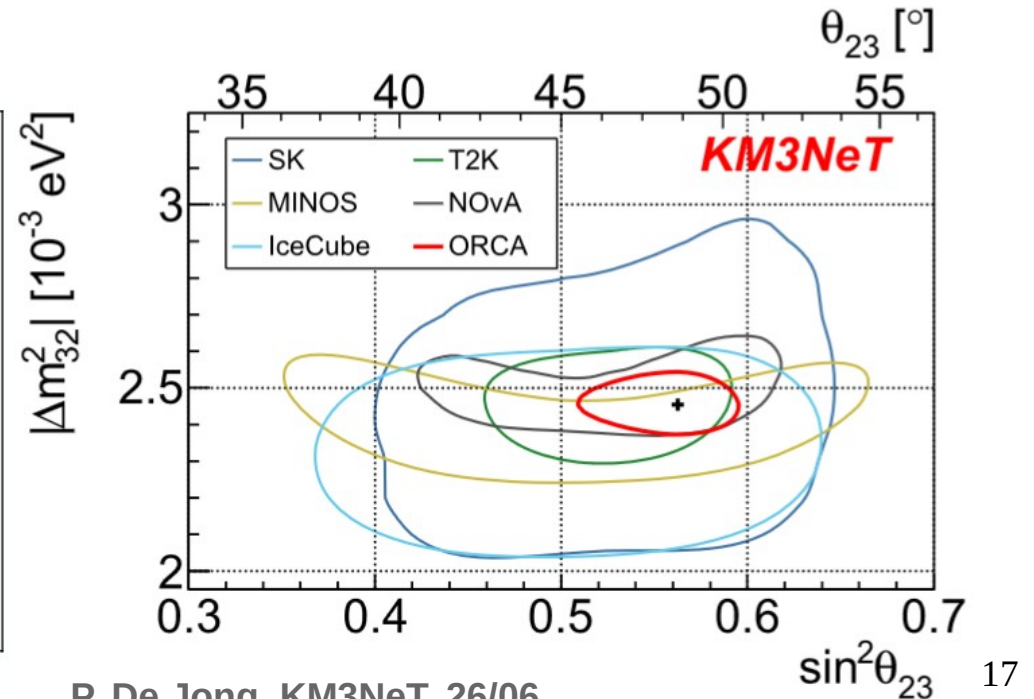
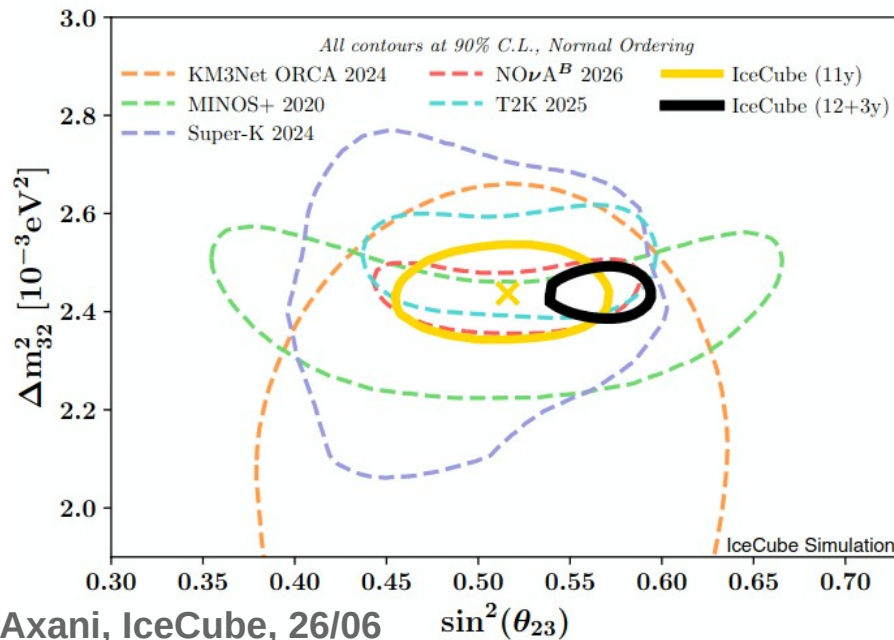
# Atmospheric future

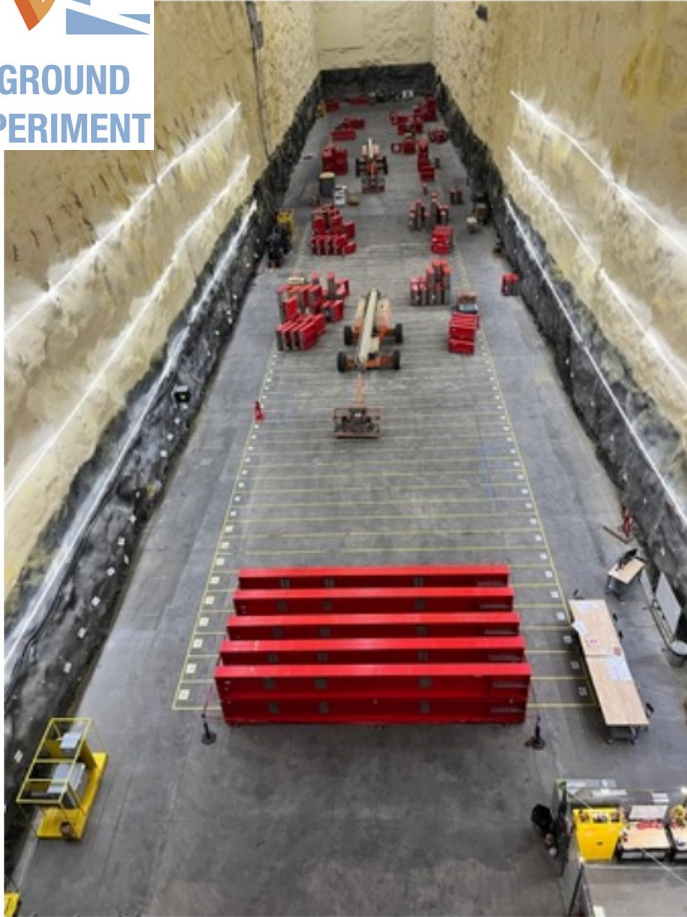
R. Akutsu, Hyper-K, 23/06

- Expect large sensitivity increases!
- IceCube-upgrade
- Continued KM3NeT deployment
- SK → Hyper-K

Hyper-K, NO, 10 years 1.3 MW

	True $\sin^2\theta_{23}$	Atmospheric only	Atmospheric + accelerator
Mass ordering	0.40	2.2 $\sigma$	3.8 $\sigma$
	0.60	4.9 $\sigma$	6.2 $\sigma$
$\theta_{23}$ octant	0.45	2.2 $\sigma$	6.2 $\sigma$
	0.55	1.6 $\sigma$	3.6 $\sigma$





- FD excavation complete
- Installation phase has begun
- FD and ND prototype data!
- FD first data 2030, beam 2031



- FD excavation complete
- Tank lining work ongoing
- IWCD excavation ongoing
- Experiment start planned 2028

# DUNE and Hyper-K sensitivities

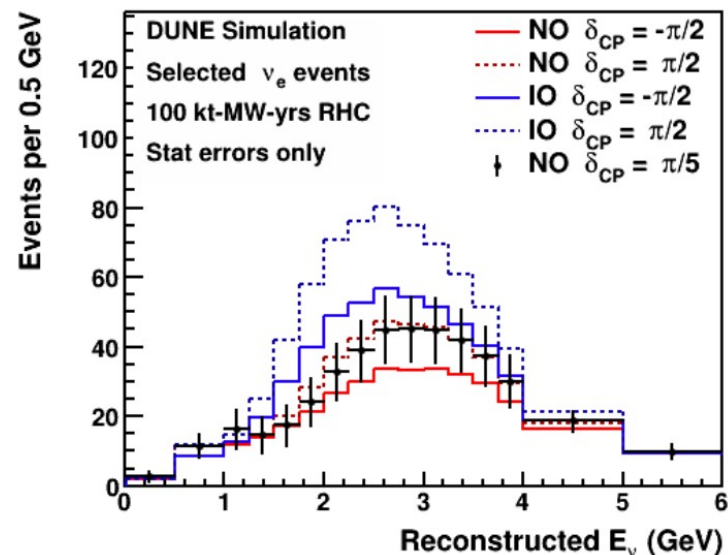
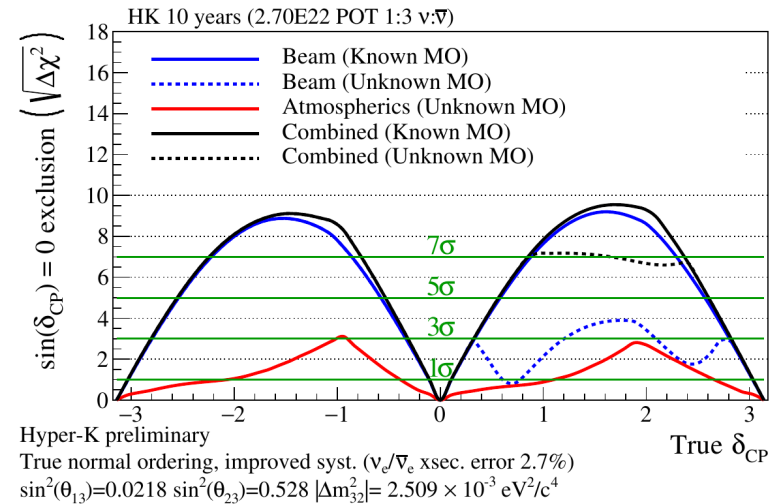
R. Akutsu, Hyper-K, 23/06

- Expect precision measurements of  $\delta_{CP}$ ,  $\Delta m^2_{32}$ ,  $\theta_{23}$ ,  $\theta_{13}$

- + Powerful CPV and MO probes

P. Denton note: JUNO  $\Delta m^2_{21}$  will slightly reduce DUNE and HK CPV sensitivities [JHEP 06 (2023) 090]

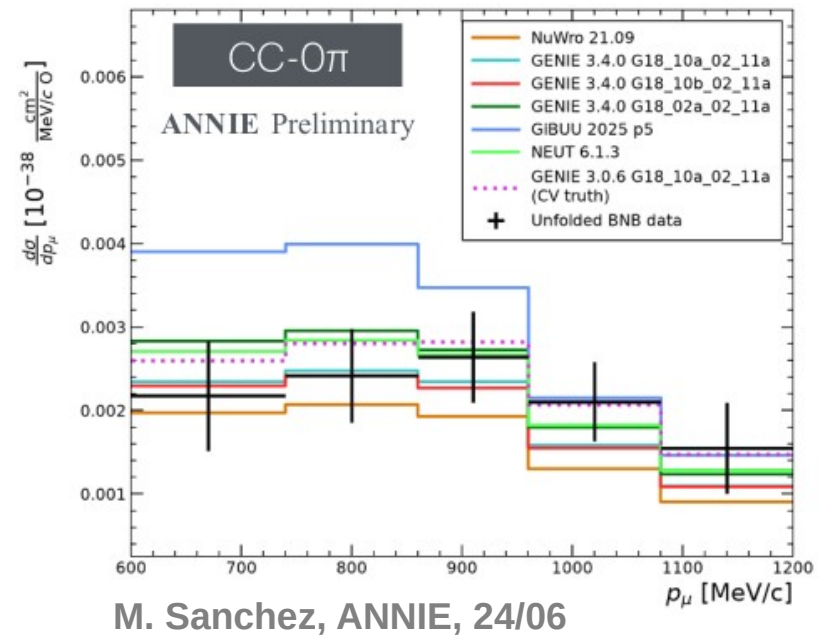
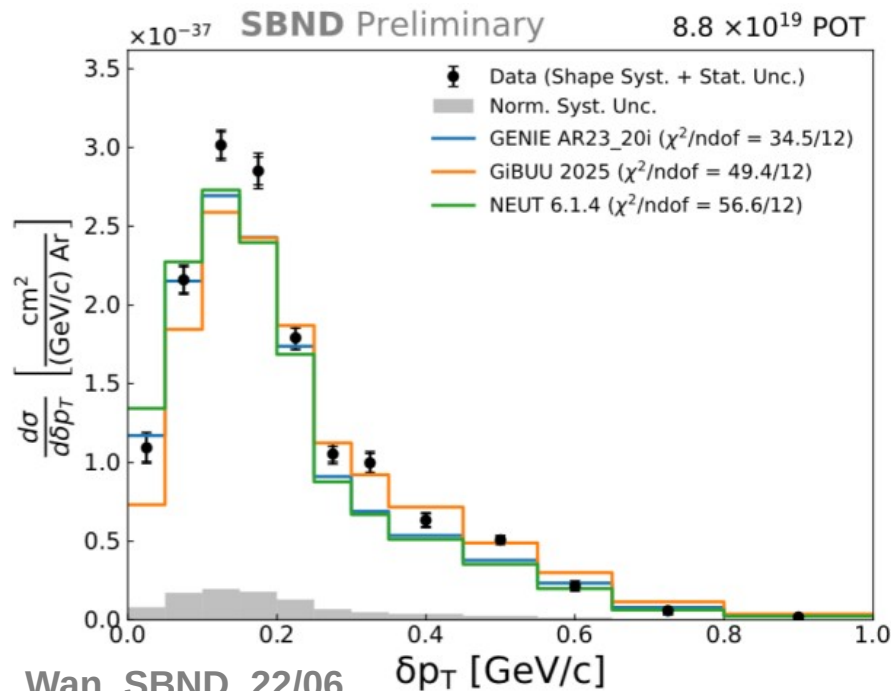
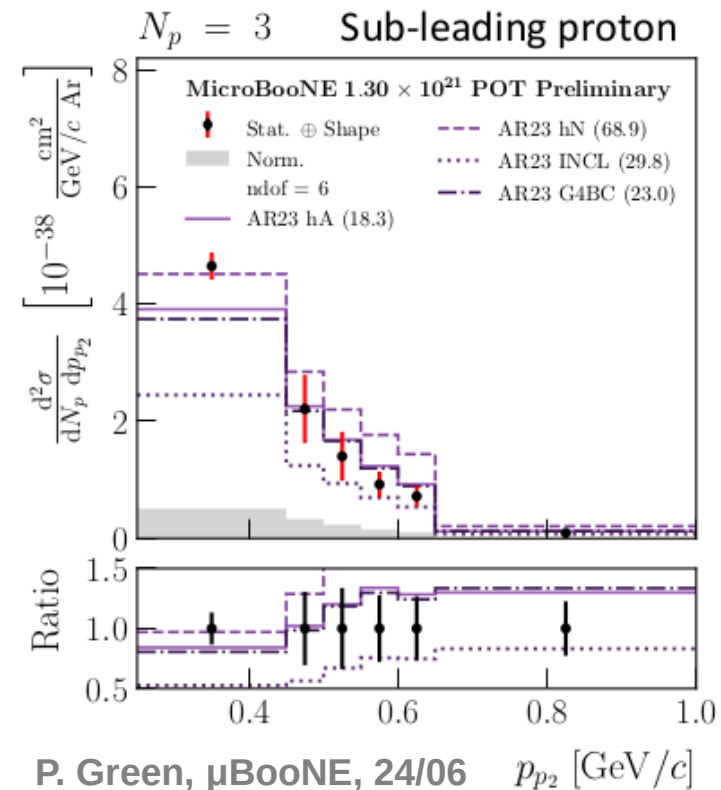
- Expect a strong community desire for joint fits (+JUNO)
- **Major community challenge:** how to facilitate testing against diverse models + historic data?



S. Gollapinni, DUNE, 23/06

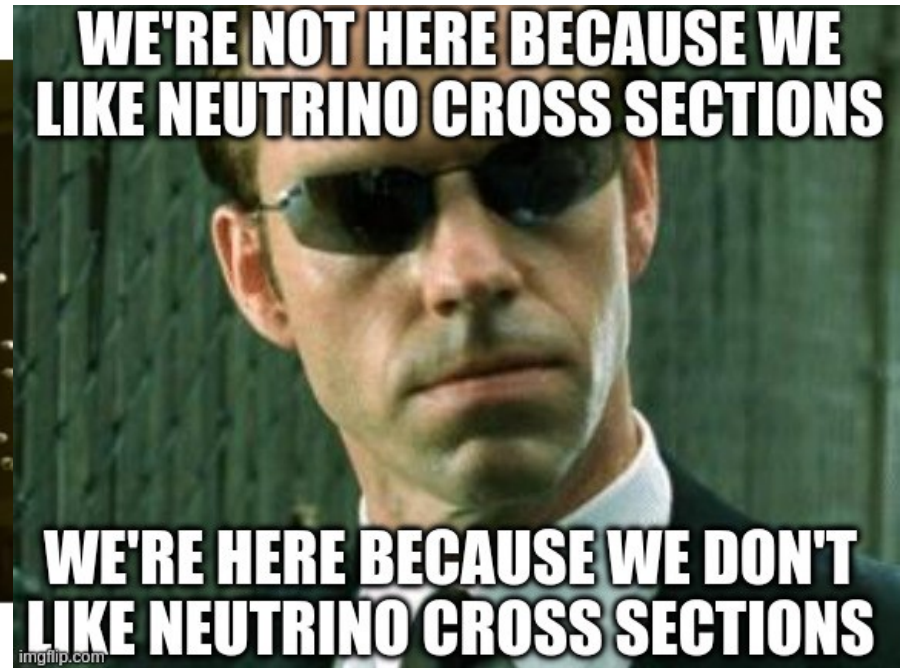
# Few-GeV cross-sections

- Several new results shown this week!
- Many more recent results: T2K, ICARUS, NOvA, MINERvA, uBooNE, SBND, ANNIE
- **Neutrino 2028**: expect an SBND data flood





- Data and MC usually show strong tension, more  $\nu$ -A measurements are good, but won't fix this alone
- Risk of unknown biases increases in the precision era...
- DUNE-PRISM and IWCD partially mitigate this issue
- Continued theory development and support is essential
- +new experimental ideas: [see L. Munteanu's talk for more](#)

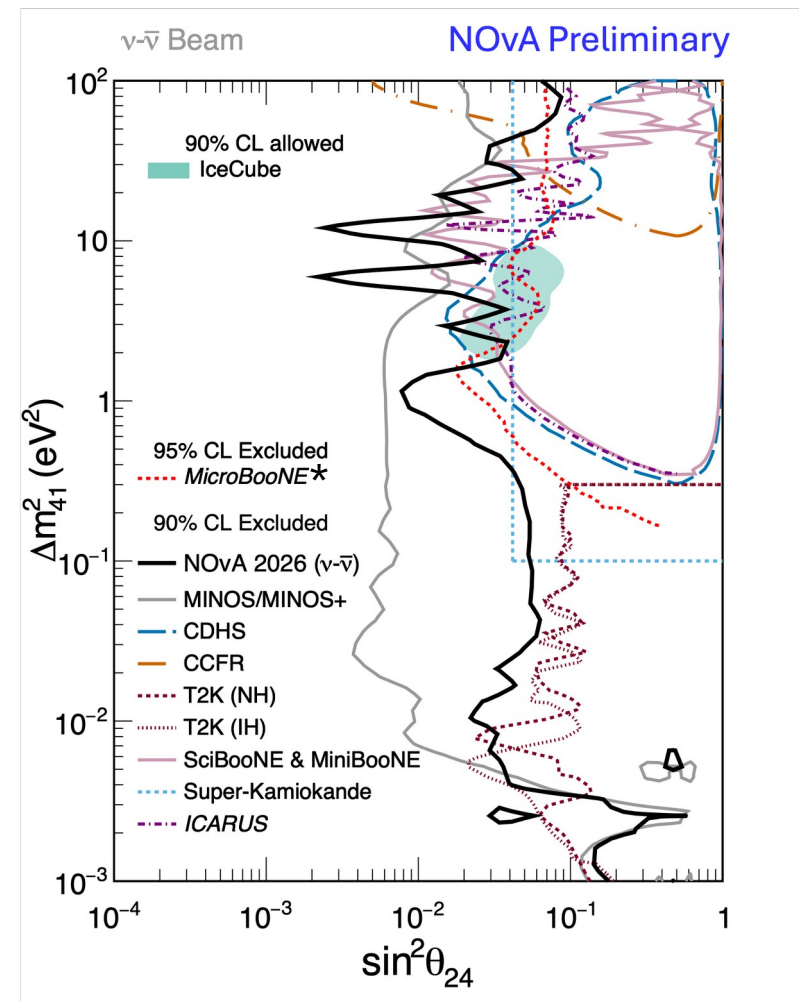
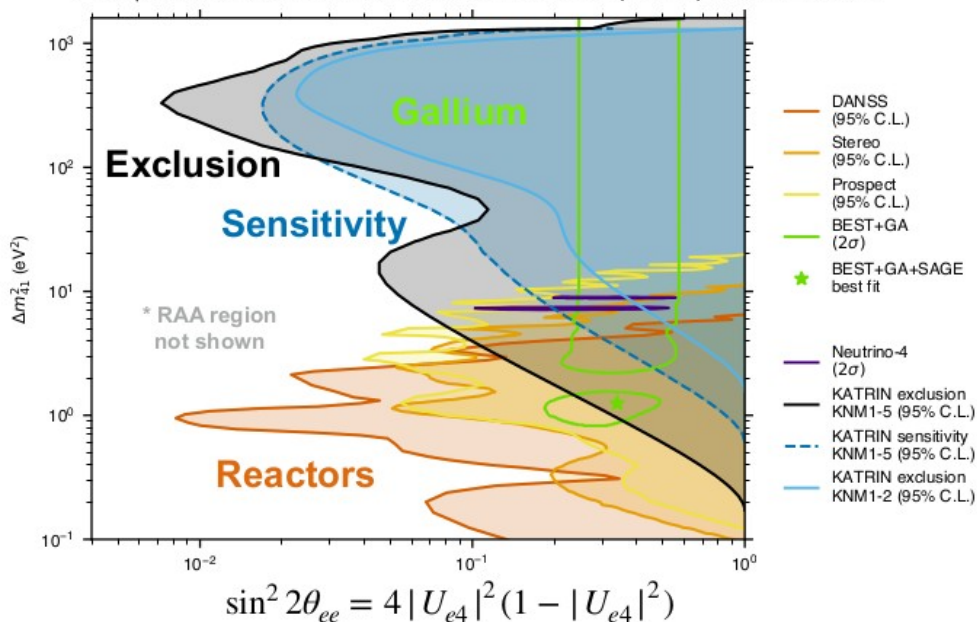


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# Sterile neutrino oscillations

- Recent measurements disfavour previous hints – some updates this week
- +Lots of valuable work done in understanding anomalies with data
- **Neutrino 2028: full SBN results?**

Adapted from KATRIN coll. [Nature 648 \(2025\) 8092, 70-75](#)



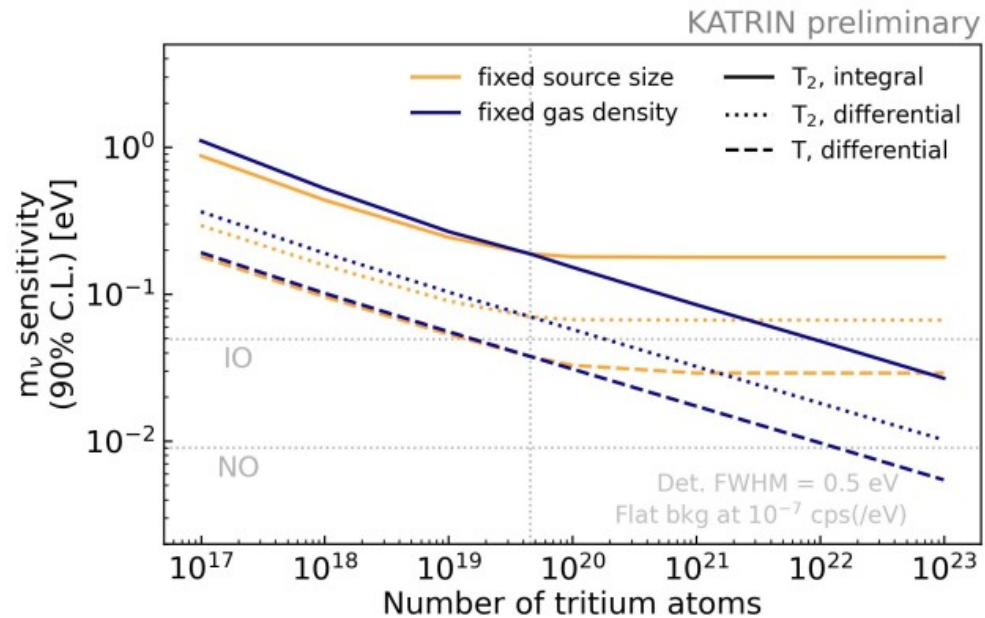
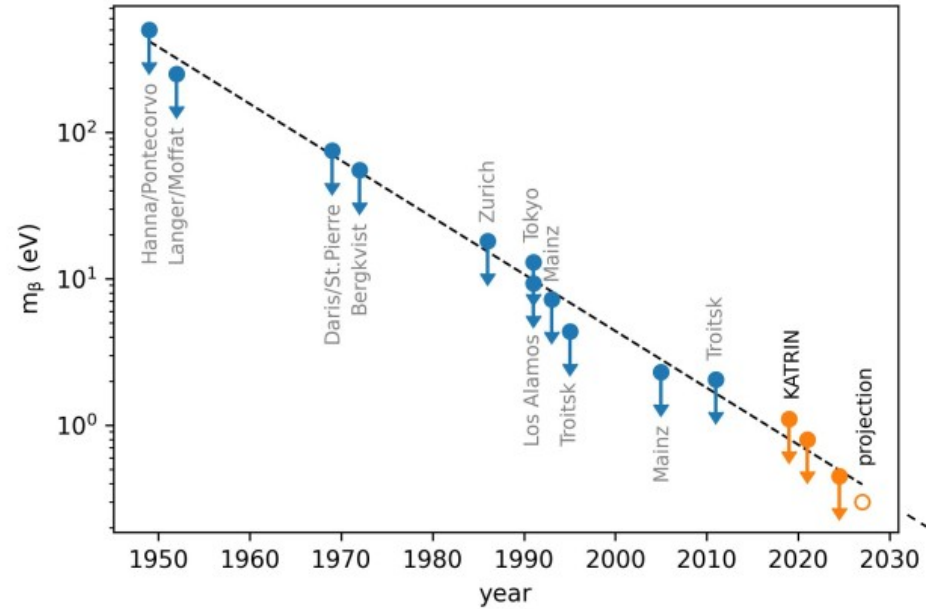
Zoya, NOvA 23/06

*\*Neutrino 2026 update  
(Once again, I am amazed at how quickly NOvA update plots!)*



- Current:  $m_\beta < 0.45$  eV (90% CL) 259 days [Science 388 (2025) 6743]
- **Neutrino 2028(?)**: 1000 day result, stat. sens.  $m_\beta < 0.28$  eV (90% CL)
- Further future: KATRIN++ potential for below IO measurement?

C. Wiesinger KATRIN, 23/06



# Other neutrino mass measurements

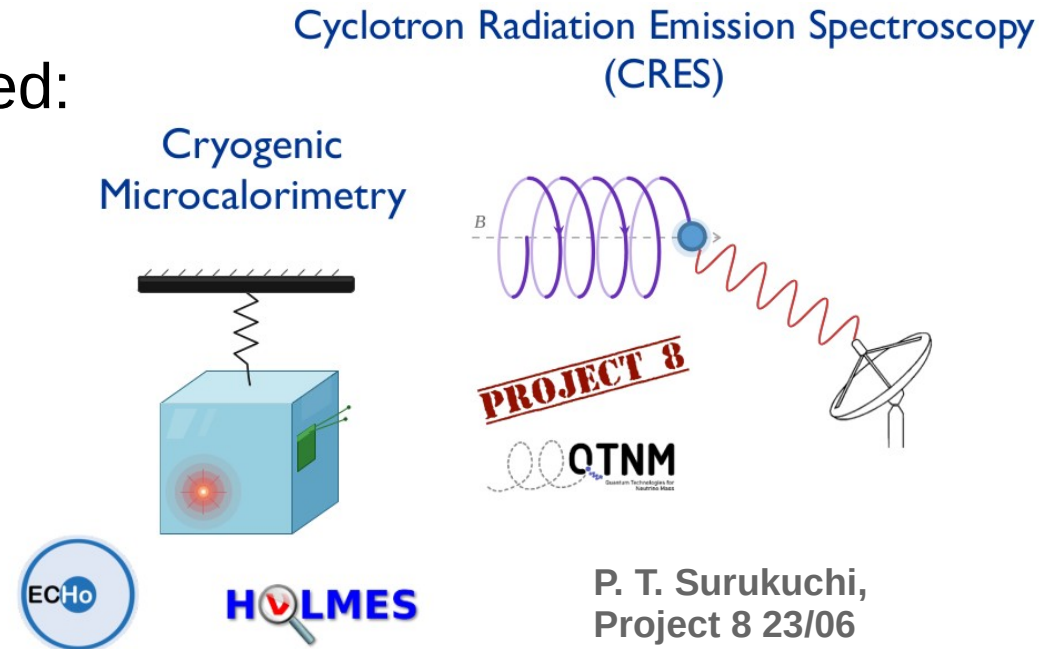
- Other approaches being explored:

- Project 8
- Ptolemy
- Holmes
- Echo

- Promising, but ~decade+ time horizon to competitive results

- Potential for definitive measurement of neutrino mass

- Personally, I'm excited by the idea of direct measurements being able to inform cosmological models



# $0\nu\beta\beta$

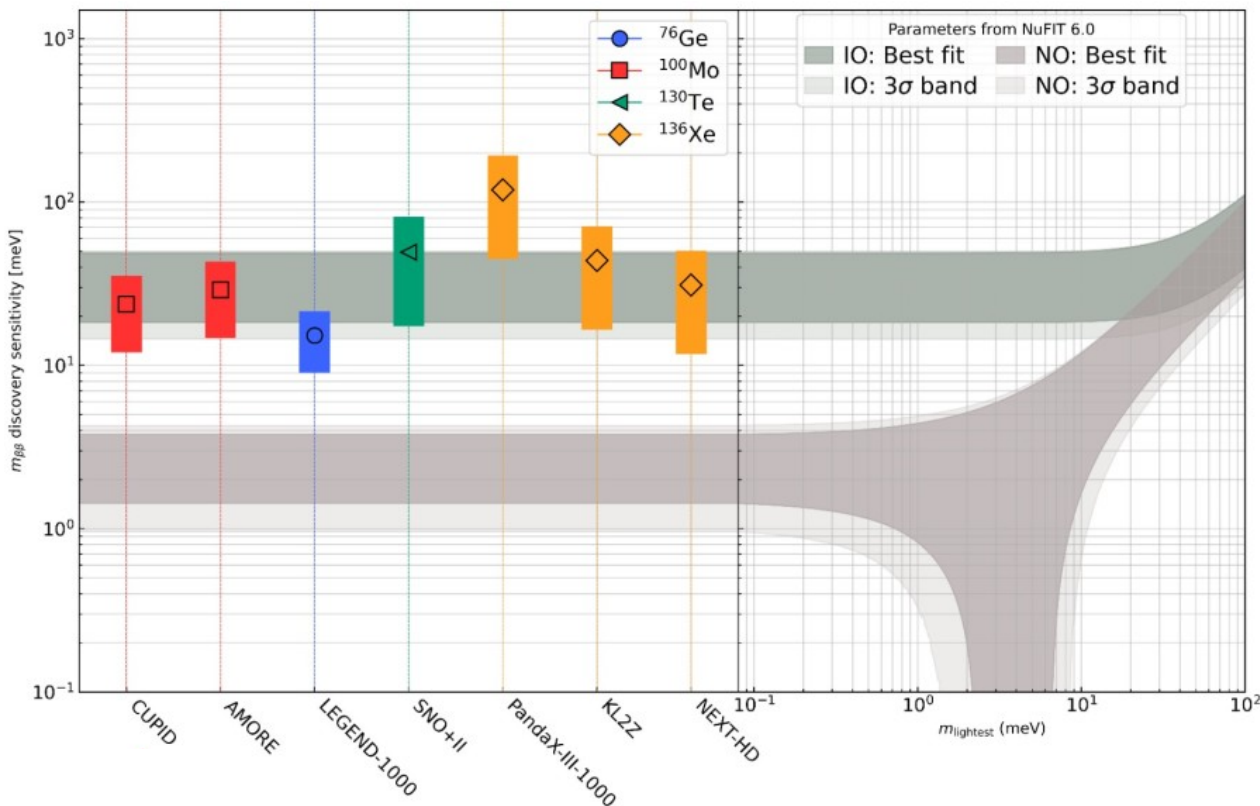


- [See G. Orebi Gann's great summary!](#)
- My less well informed take: the field has spent a significant time developing detectors and methods, carrying out long term tests at intermediate scales, and is on the cusp of scaling
- An equally impressive campaign [still in progress \(J. Engel\)](#) to calculate  $\beta\beta$  nuclear matrix elements for the nuclei of interest
- Many short term targets/landmarks to look forward to:
  - 2025-: SuperNEMO taking data
  - 2026: CUORE completed 10 year campaign
  - 2027: SNO+  $^{130}\text{Te}$  loading
  - 2028: KamLAND2-Zen DAQ start
  - 2028: Panda-20T physics data
  - 2028: LEGEND-200 3x current exposure

# $0\nu\beta\beta$ future

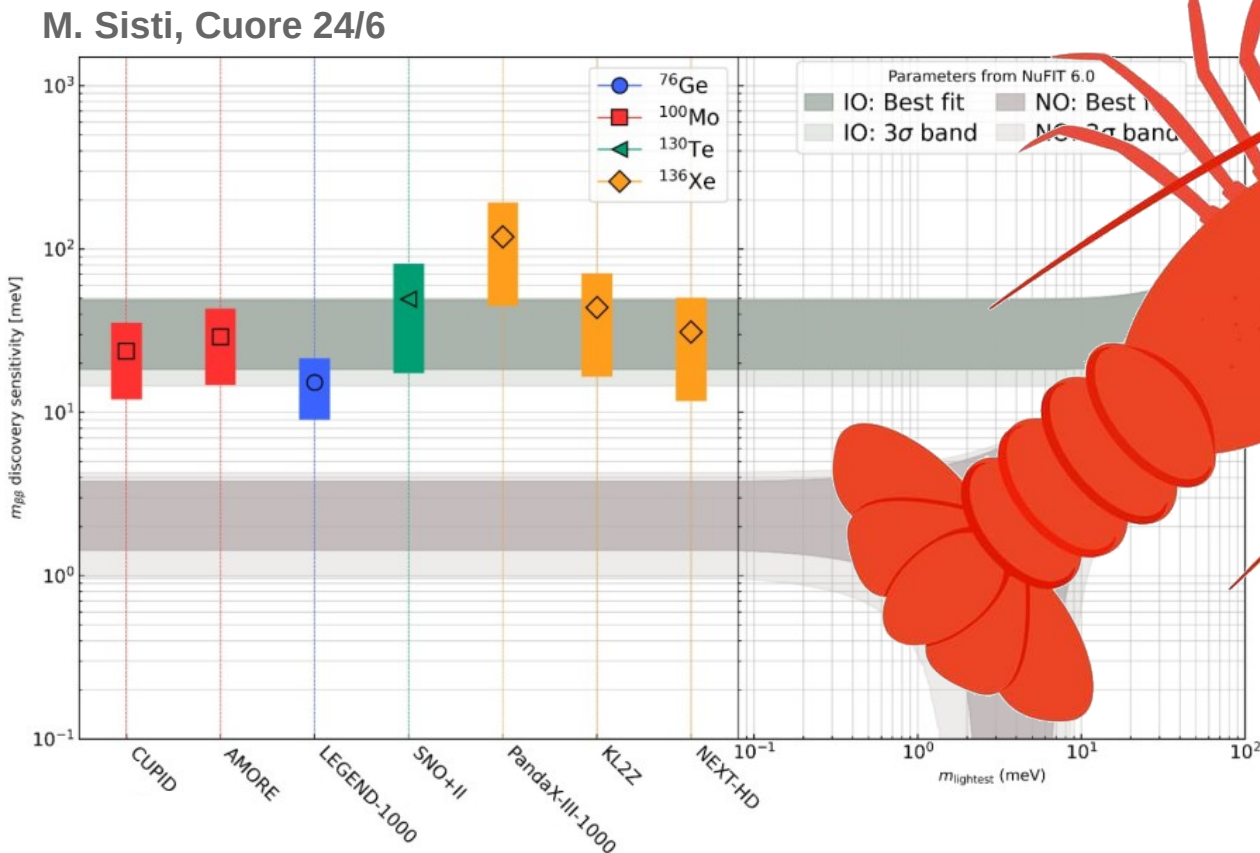
- Next ~decade: expect next generation experiments to start taking data, building on past lessons
- Multiple efforts are complementary, will help to understand any positive signal

M. Sisti, Cuore 24/6



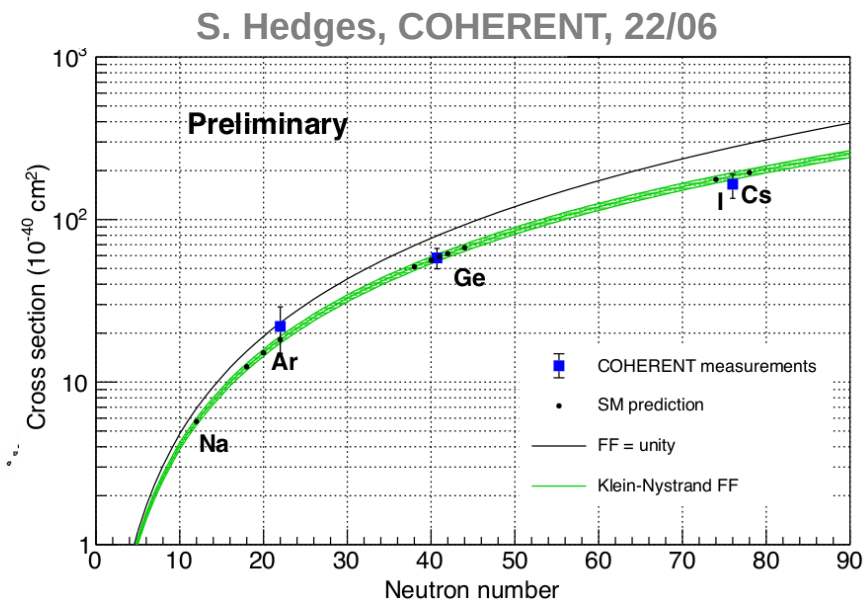
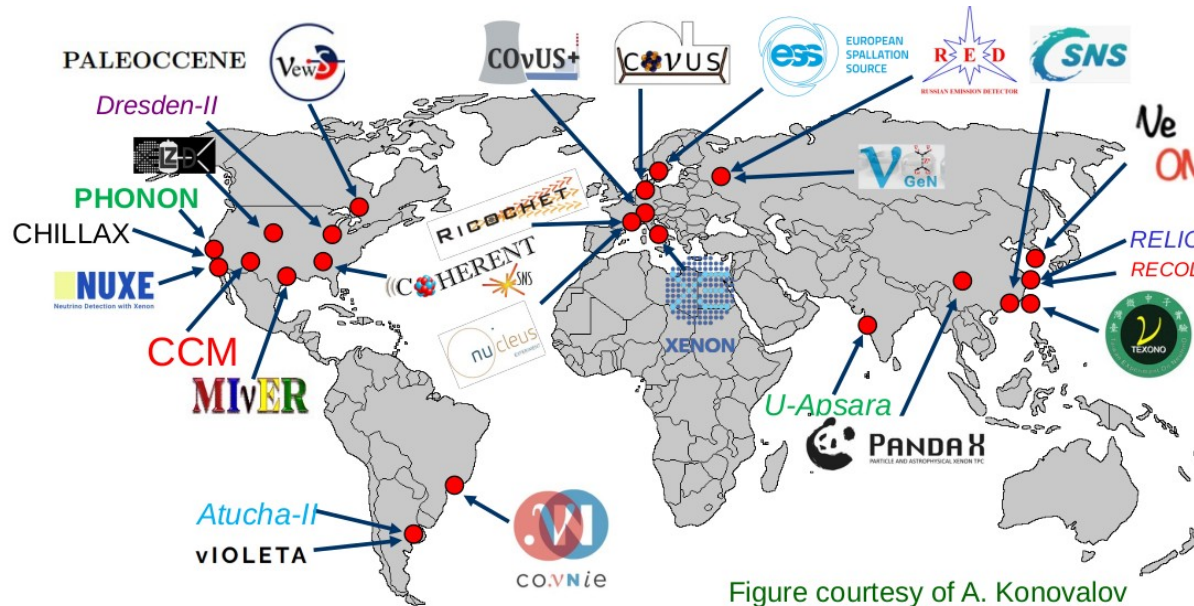
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# CEvNS

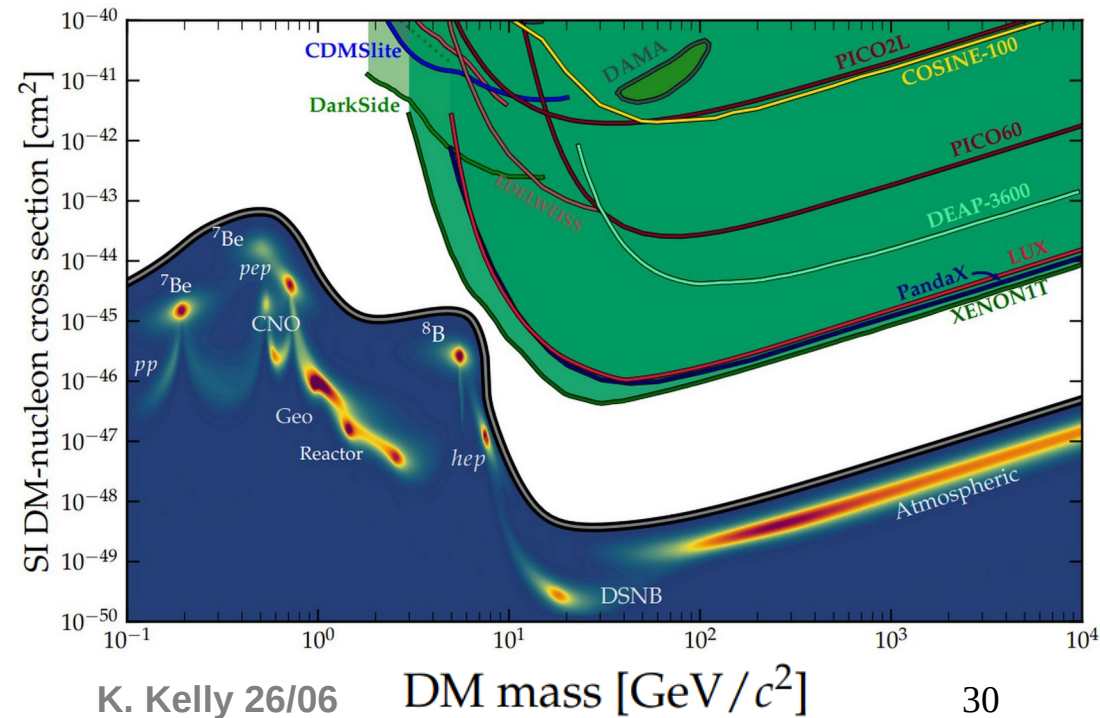
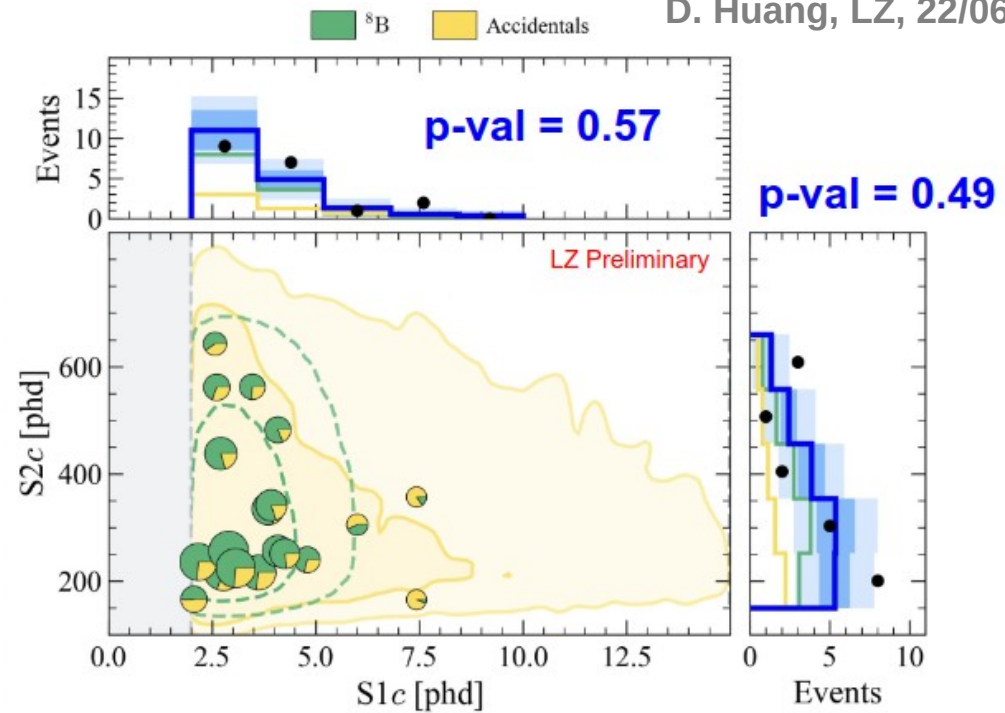
- Development from first discovery to a multi-target global precision program in less than a decade
- Observation from SNS and reactors
- Essential to understand various natural neutrino sources



**More mass! Lower threshold! Combined analyses! More exposure!**  
**→ start of precision era of CEvNS detection to probe the SM and beyond**

# $^8\text{B}$ Solar neutrinos

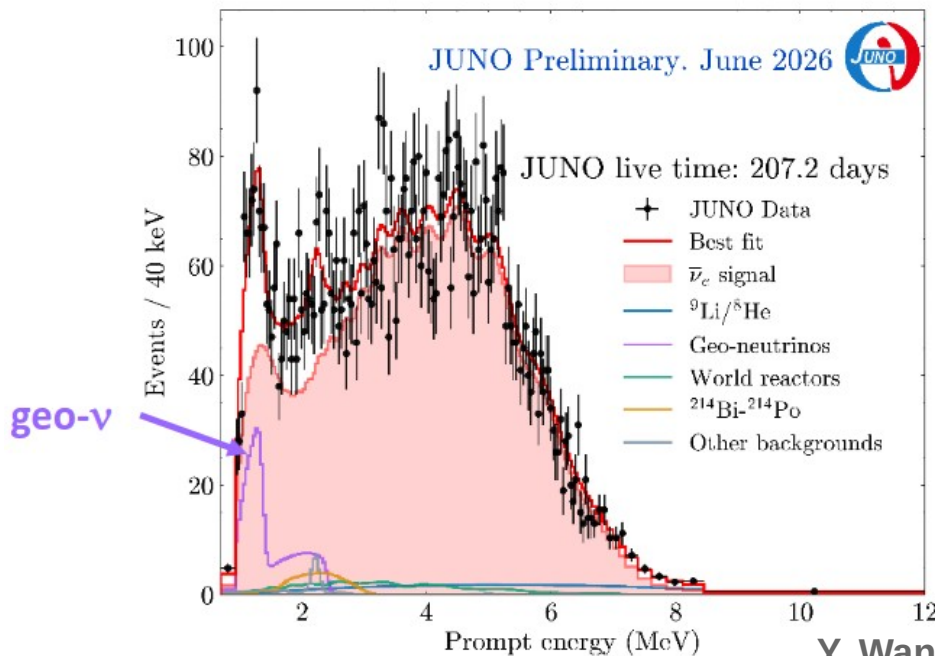
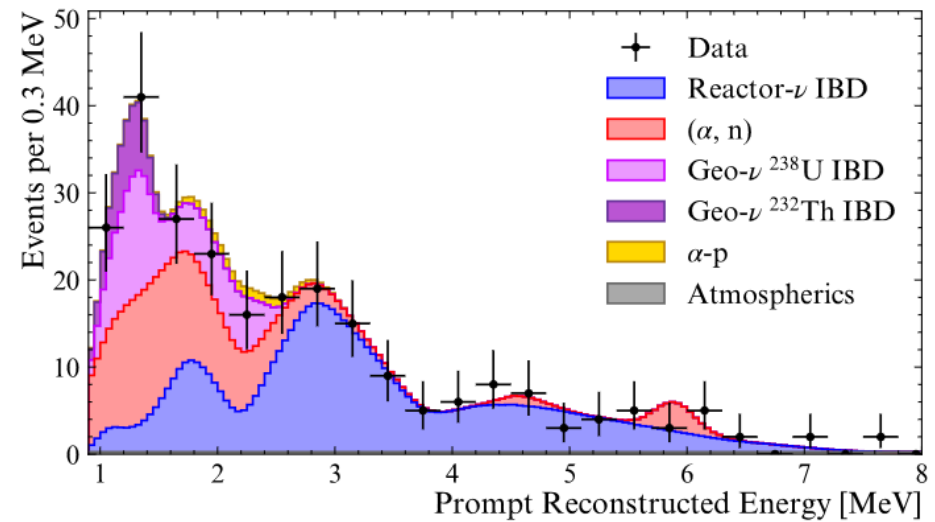
- LZ  $4.5\sigma$  measurement of  $^8\text{B}$  neutrinos through CevNS, in “neutrino fog”
- We’re thinking about how to expand the physics reach of our detectors...
- So are other communities!
- [See K. Kelly’s talk](#)
- Highlights the value of precision measurements: facilitate new probes



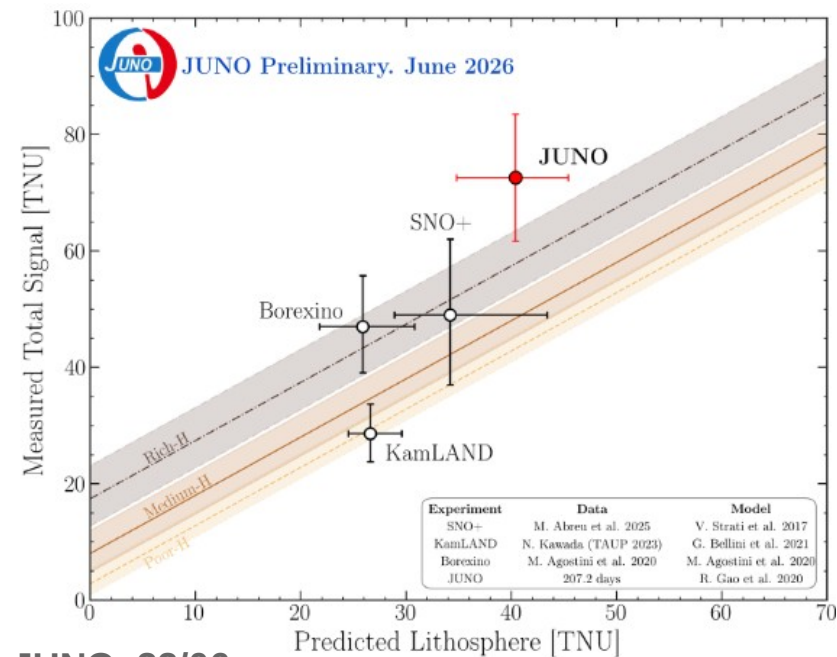
# Geoneutrinos

T. Kaptanoglu, SNO+, 24/06

- New and recent results from JUNO and SNO+
- Consistent with prediction, but still low statistics
- New background reduction techniques being explored



Y. Wang, JUNO, 22/06



# SN: the epoch of belief?

J. Beacom, 25/6

## Super-Kamiokande (32 kton water)

$\sim 10^4$  inverse beta decay on free protons

$\sim 10^2$  CC and NC with oxygen nuclei

$\sim 10^2$  neutrino-electron elastic scattering

$\sim 10x$  for HK

Best for anti- $\nu_e$

## JUNO (20 kton mineral oil)

$\sim 10^4$  inverse beta decay on free protons

$\sim 10^3$  neutron-proton elastic scattering

$\sim 10^2$  CC and NC with carbon nuclei

$\sim 10^2$  neutrino-electron elastic scattering

Best for  $\nu_x$

## IceCube ( $10^6$ kton water)

Burst is increase over background rate

Possibility of precise timing information

And many other detectors

## DUNE (34 kton liquid argon)

$\sim 10^3$  CC and NC with argon nuclei

$\sim 10^2$  neutrino-electron elastic scattering

Best for  $\nu_e$

Main message: the low-energy program is extremely important, need to maintain capabilities

*"It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of light, it was the season of darkness, it was the spring of hope, it was the winter of despair."*

*-- A Tale of Two Cities, Charles Dickens*



# SN: the epoch of belief?

J. Beacom, 25/6

Super-Kamiokande (32 kton water)

$\sim 10^4$  inverse beta decay on free protons

$\sim 10^2$  CC and NC with oxygen nuclei

$\sim 10^2$  neutrino-electron elastic scattering

$\sim 10\times$  for HK

Best for anti- $\nu_e$

JUNO (20 kton mineral oil)

$\sim 10^4$  inverse beta decay on free protons

$\sim 10^3$  neutron-proton elastic scattering

$\sim 10^2$  CC and NC with carbon nuclei

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Best for  $\nu_x$

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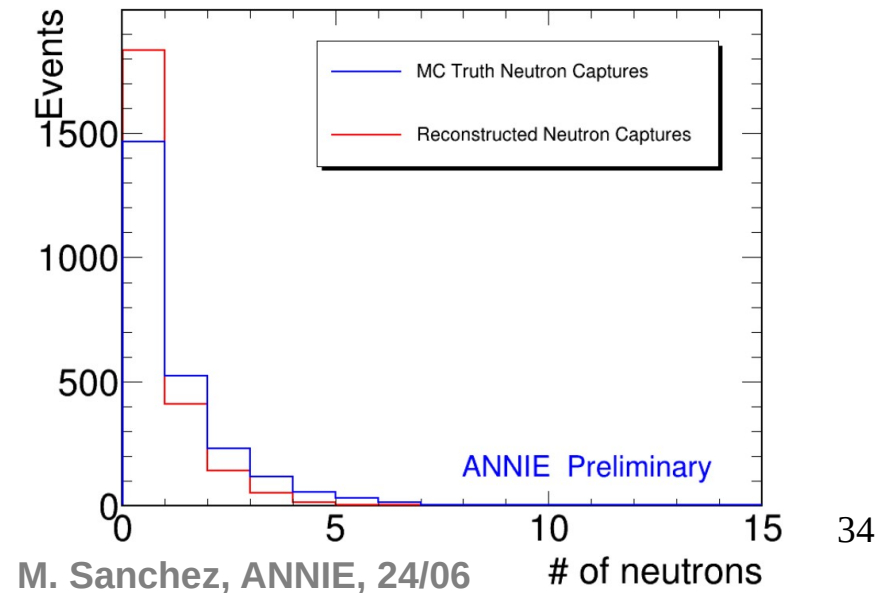
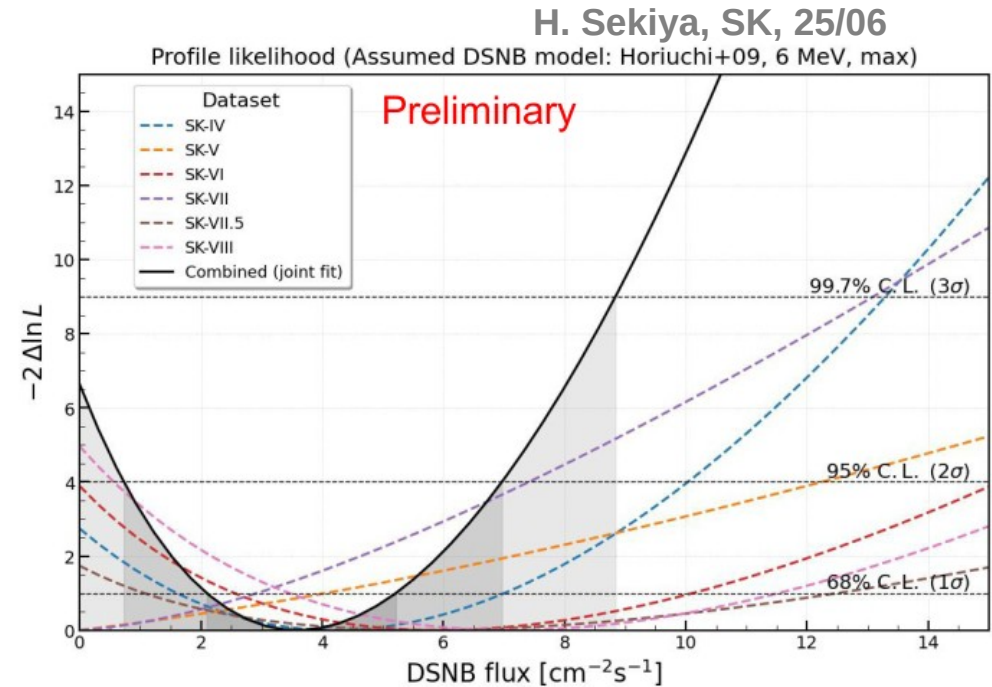
Also, explosions are cool

-- Maybe Charles Dickens?



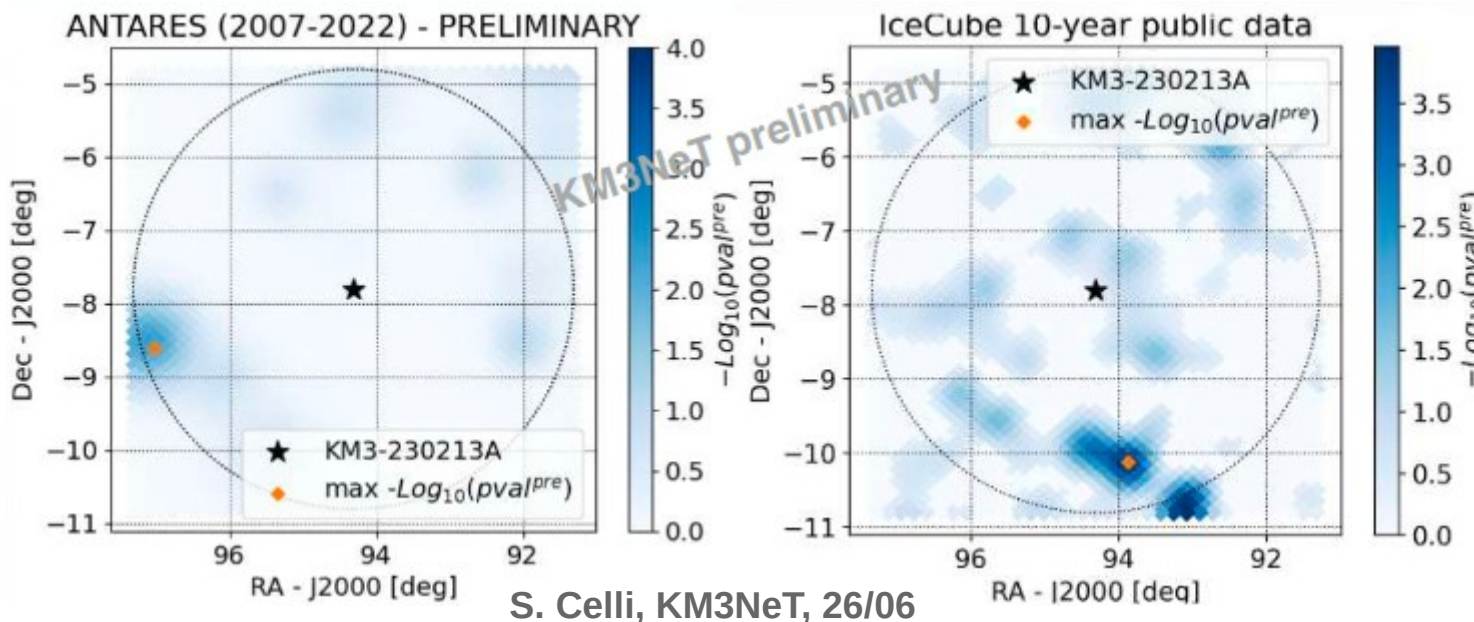
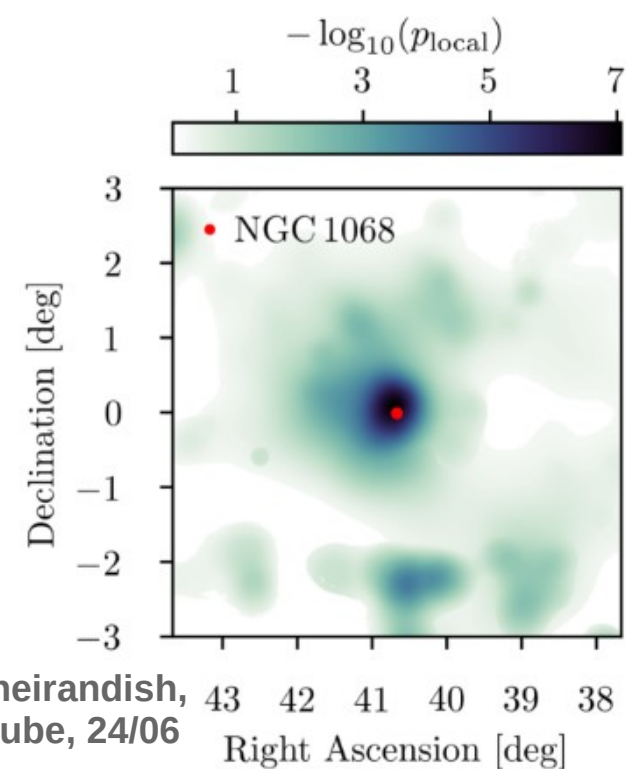
# Diffuse supernova neutrino backgrounds

- **New SK result SK:  $2.3\sigma \rightarrow 2.6\sigma$**
- Potential future improvements:
  - Neutron multiplicity (ANNIE!)
  - T2K NCQE+de-excitation  $\gamma$ 's
  - Improved spallation  ${}^9\text{Li}$  model
- **Strong motivation for more SK-Gd data!**



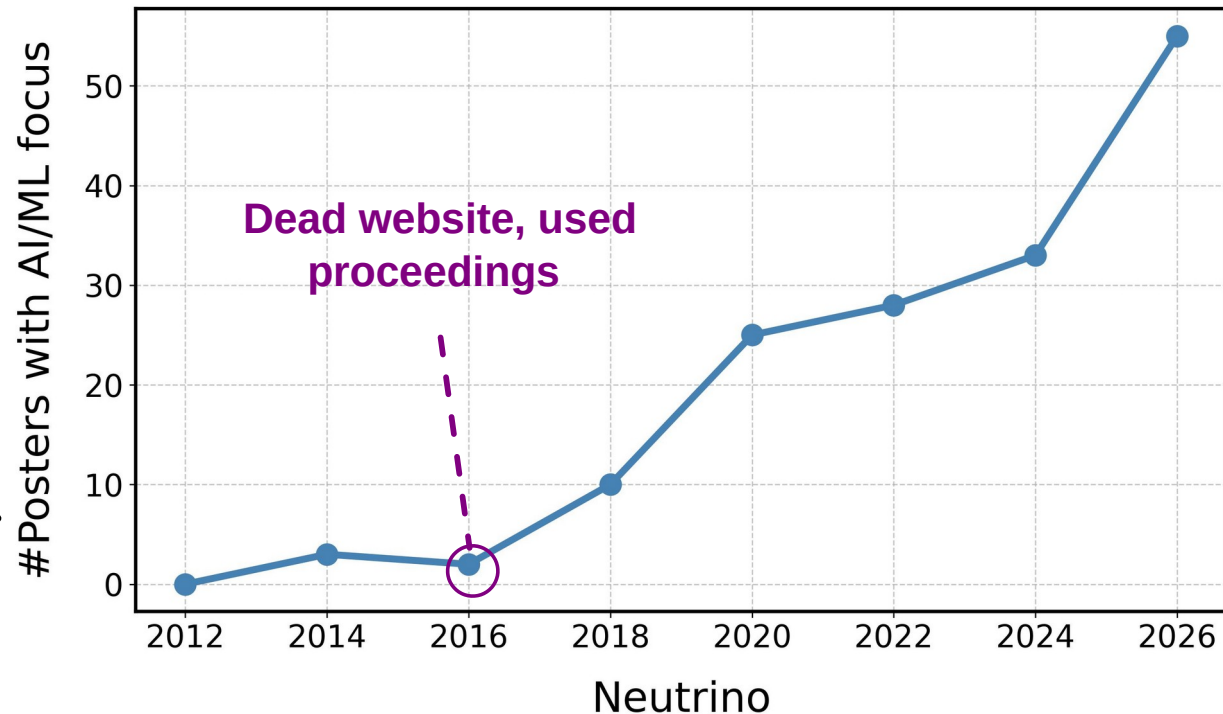
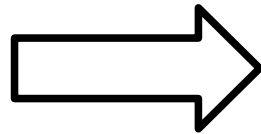
# High energy neutrino astronomy

- Many interesting searches from a variety of experiments: KM3NeT, IceCube, ...
- [Great summary of future efforts – I. Morton-Blake](#)
- Expect new results from existing facilities, and new/expanded facilities over next decade + Radio neutrino astronomy!



# Impact of AI/ML on Neutrino

- 2020 summary noted 15 posters with ML in the title
- I asked Claude to identify AI/ML focused posters from books of abstracts



- Widespread adoption of ML methods for sim/reco/analysis “chunks”
- Current exploration of bigger changes: fully differentiable workflows; foundation models; agentic workflows
- Supercharged in the US by Genesis, similar focus elsewhere

# Things I'm excited about: next 2 years

- More JUNO results,  $\Delta m^2_{31}$  with more precision?
- T2K and NOVA final(?) results
- + more joint analyses?
- IceCube-upgrade ATM results?
- A flood of SBND  $\nu$ - $^{40}\text{Ar}$  cross section data
- First full SBN oscillation results
- Final KATRIN dataset
- Further UHE neutrino
- New neutrino telescope test deployments

Things I'm excited about: next ~~70~~ 7 years

“It's tough to make predictions, especially about the future future” - R.Svoboda

# Things I'm excited about: next ~~70~~ 7 years

- Early data with both DUNE and Hyper-K
- JUNO MO measurement?
- Next generation  $0\nu\beta\beta$  experiments?
- Scaling new direct mass measurement approaches?
- DSNB progress/ discovery? Will SK-Gd be running?
- LHC Run 4 higher-stats neutrino measurements?
- What will the AI/ML landscape look like?

“It's tough to make predictions, especially about the future future” - R.Svoboda

# Parting thoughts

- The conference has been inspiring!
- I am leaving with the strong impression of a field that is on the cusp of reaping the rewards from years of effort in several key areas
- My predictions will be wrong... but that's the exciting part!
- Thanks to the organizers and all of the local and international support for all of their hard work to make this conference a success!

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OWN ADVENTURE®**