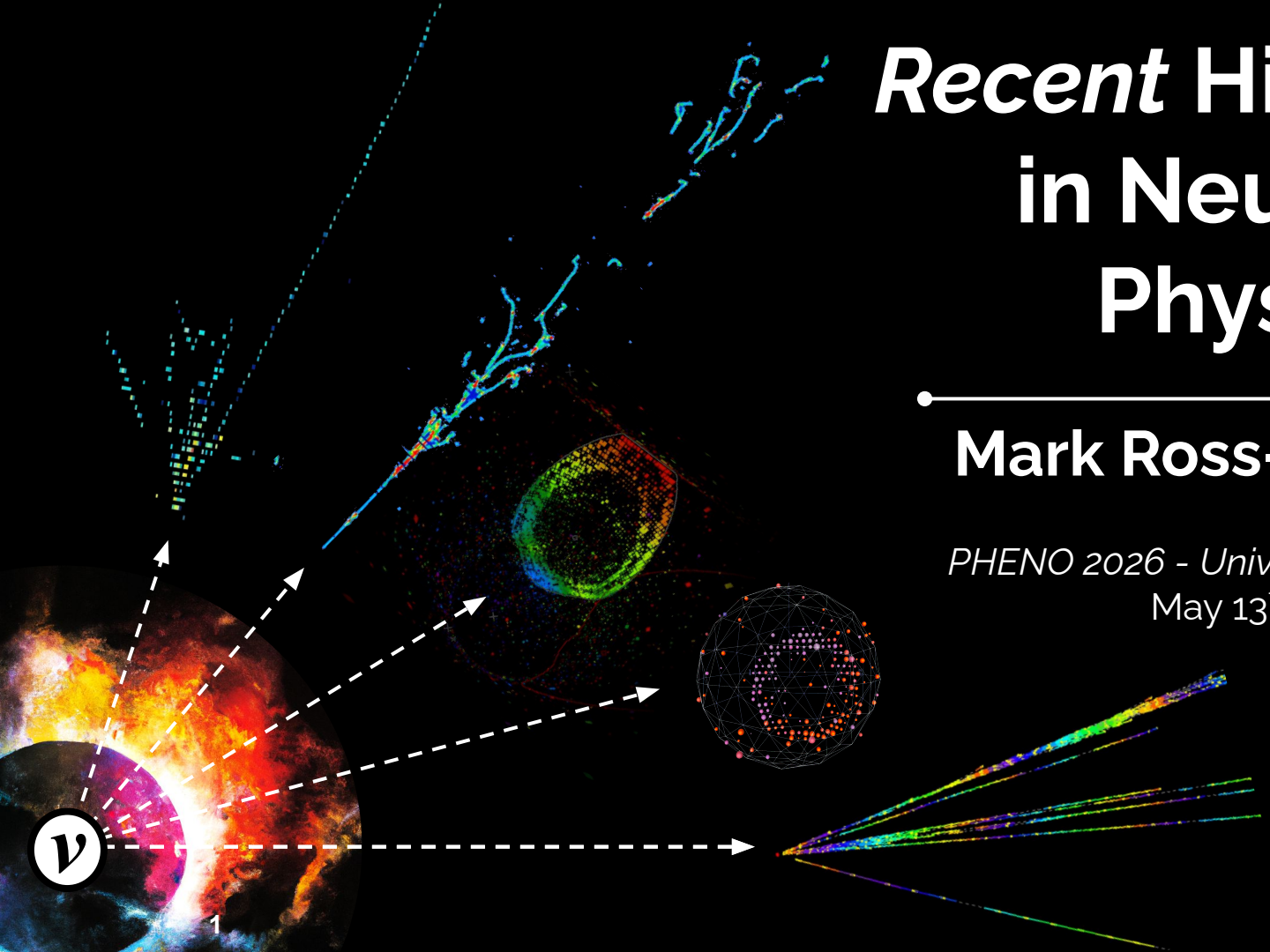


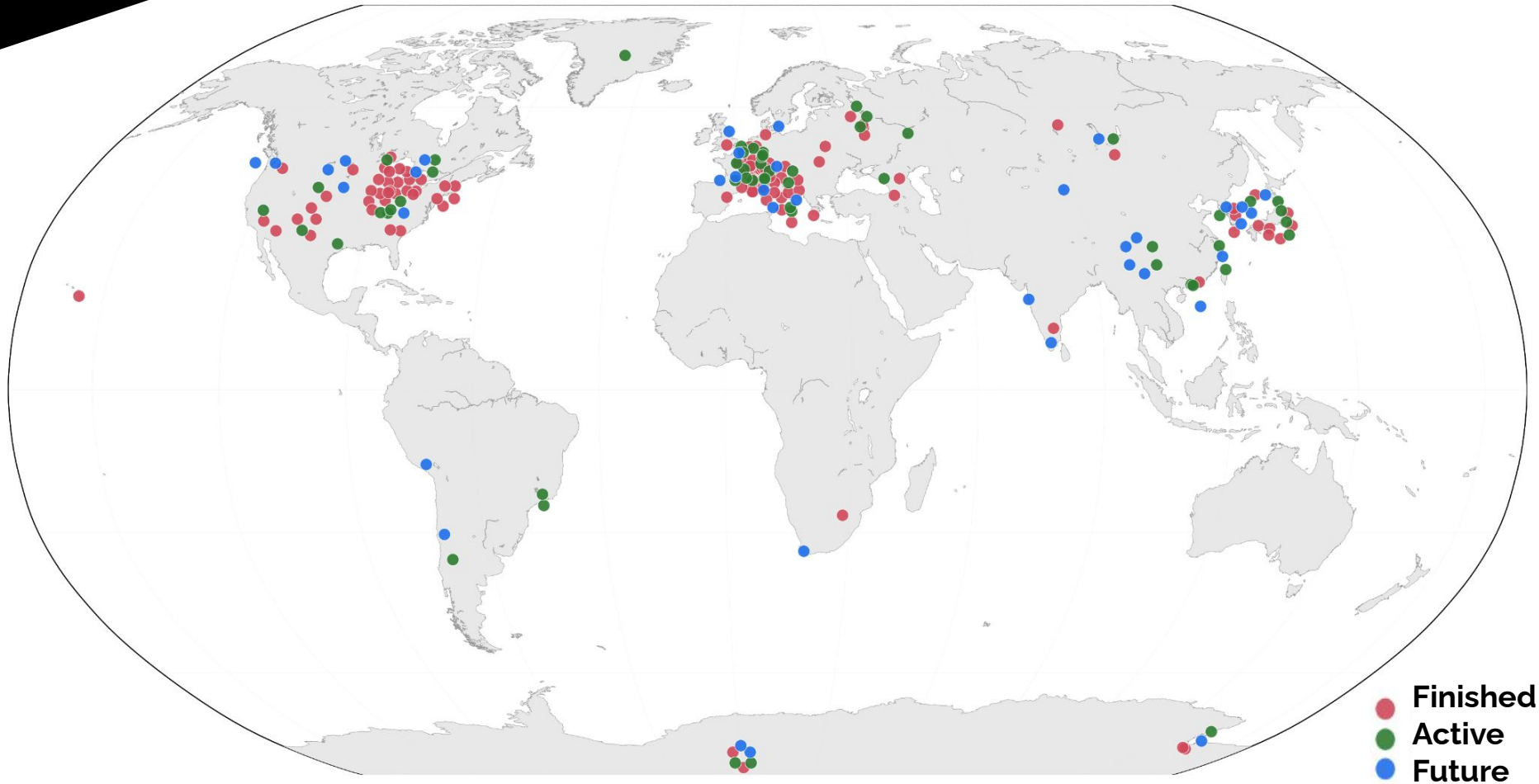
Recent Highlights in Neutrino Physics

Mark Ross-Lonergan

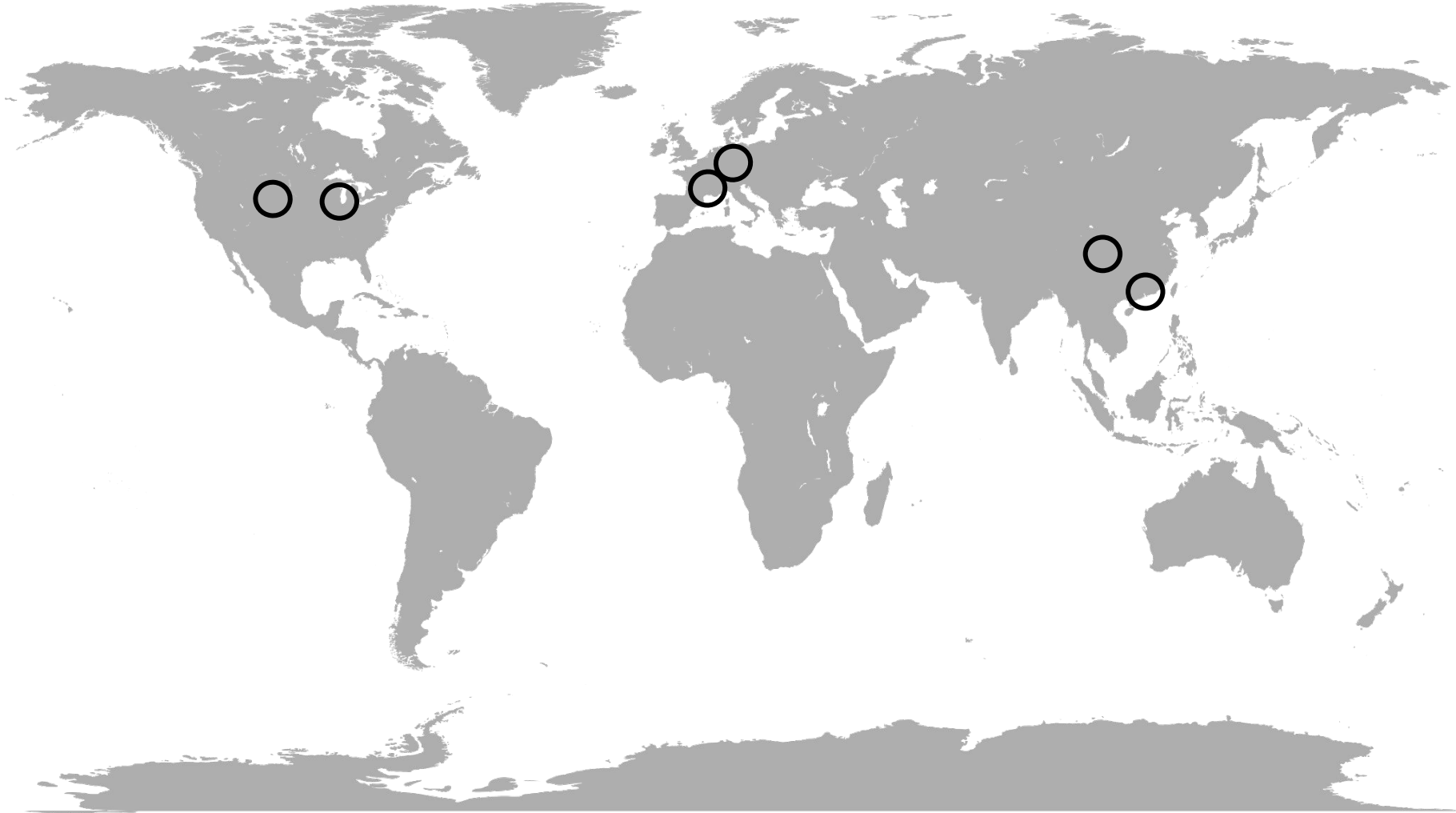
PHENO 2026 - University of Pittsburgh
May 13th 2026

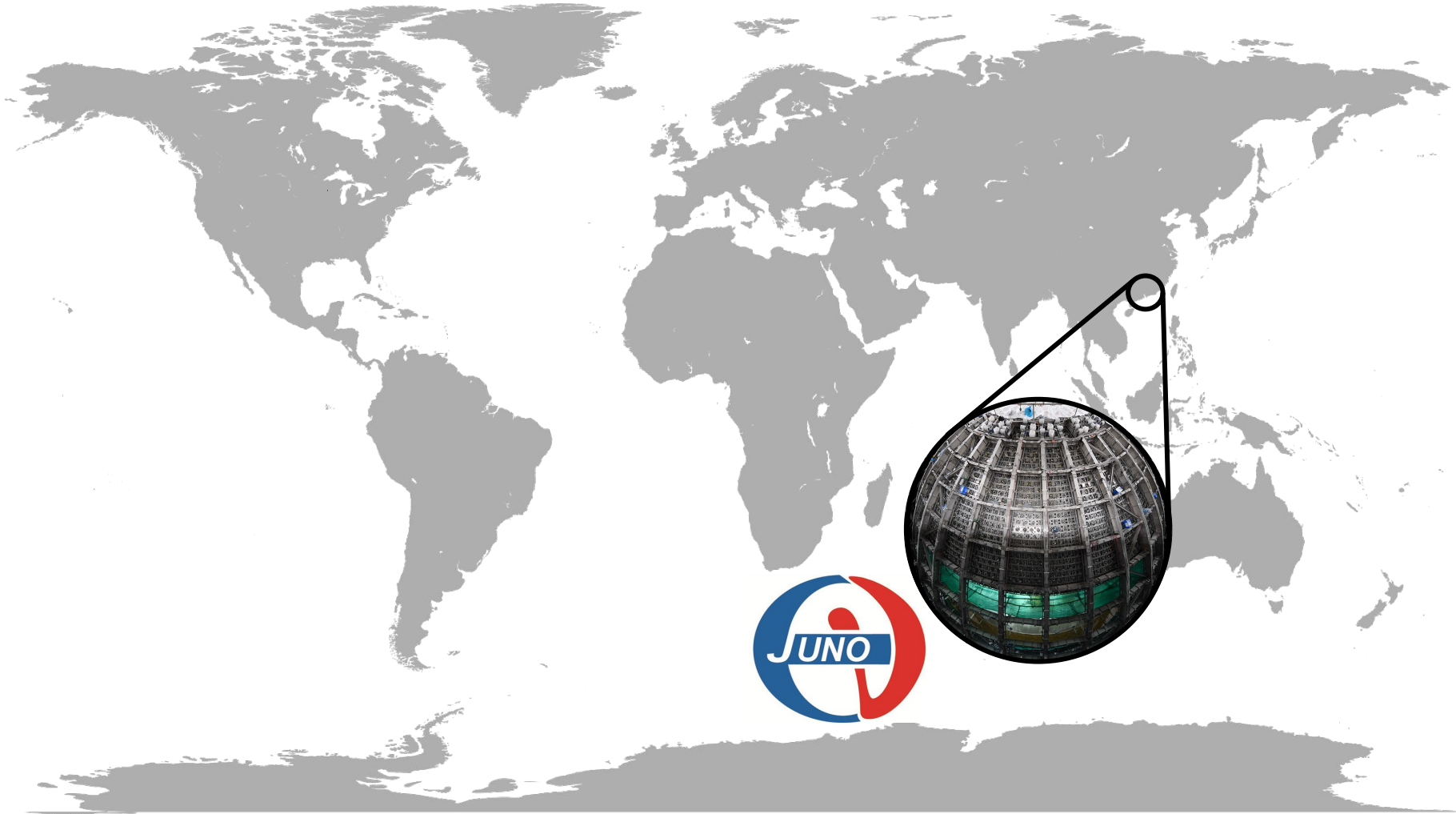
COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Neutrino Experiments of the World > 200



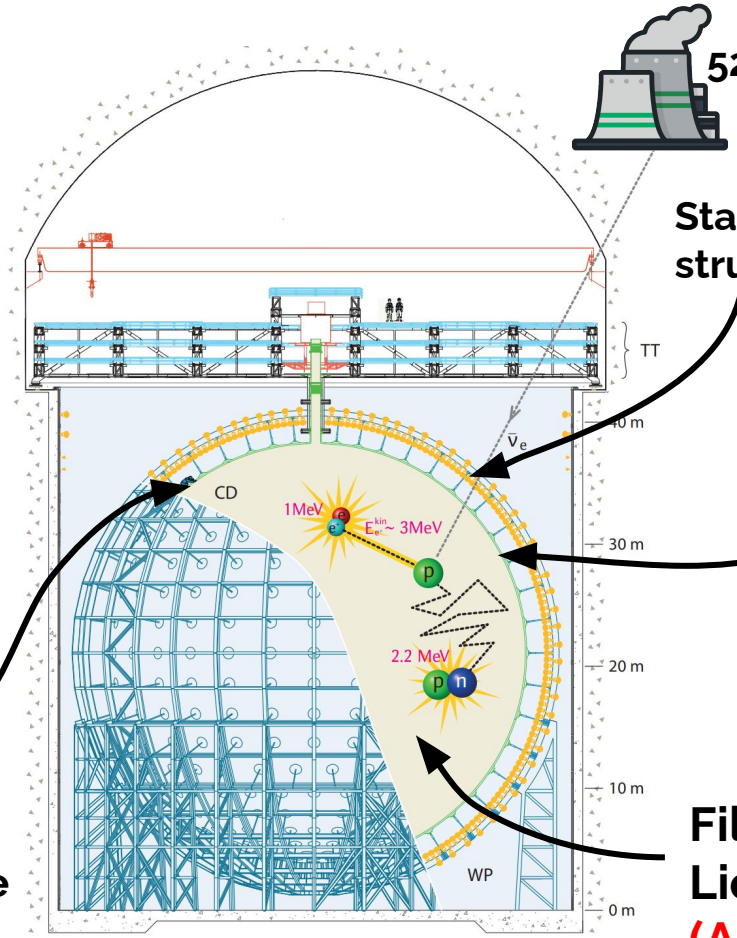
Focus on last ~6 months




JUNO

JUNO: Jiangmen Underground Neutrino Observatory

20,012 20'' PMTs
25,600 3'' PMTs
(Dec 2024)
75% photocathode coverage

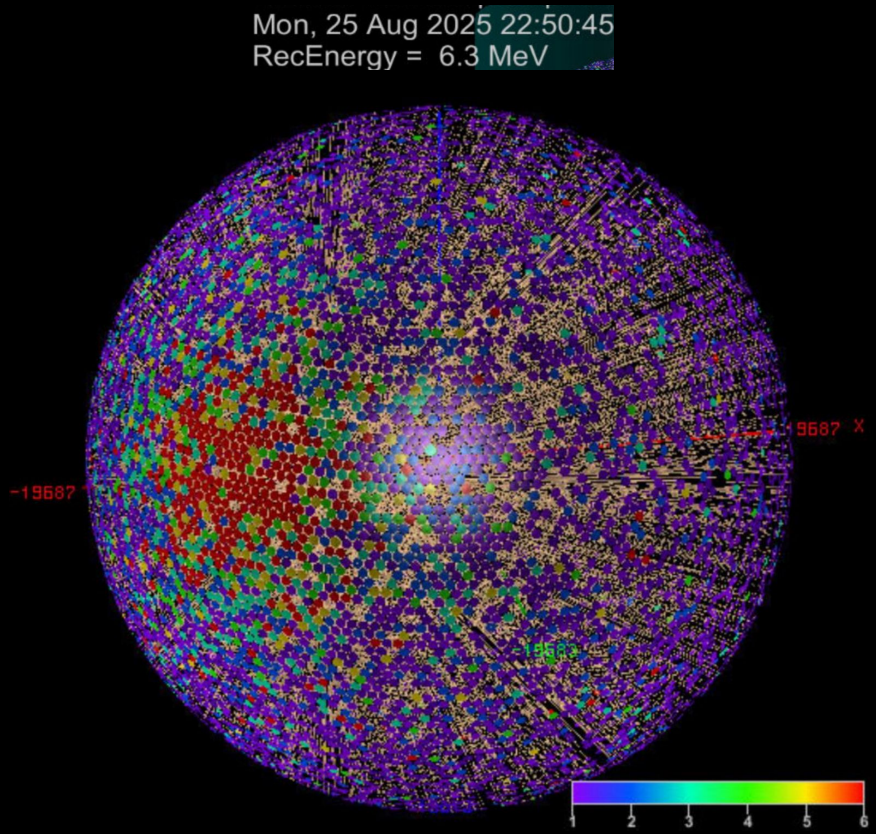


Stainless Steel structure (June 2022)

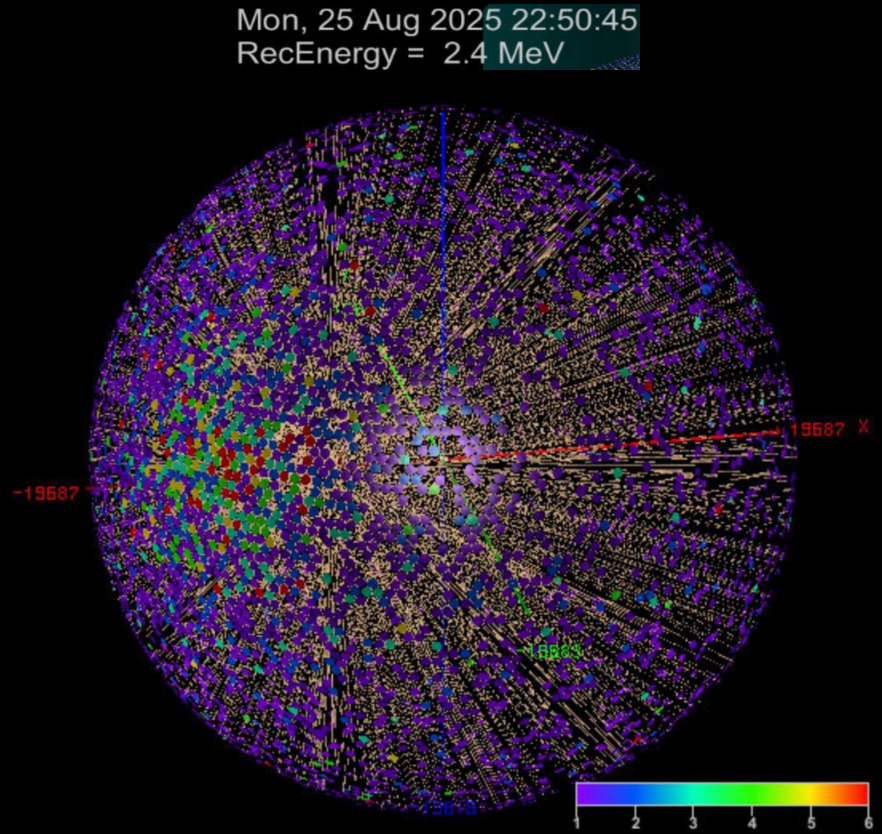
35.4m diameter Acrylic sphere (Oct 2024)

Filled with 20kt Liquid scintillator (Aug 2025)

JUNO : Reactor Inverse Beta Decay Event



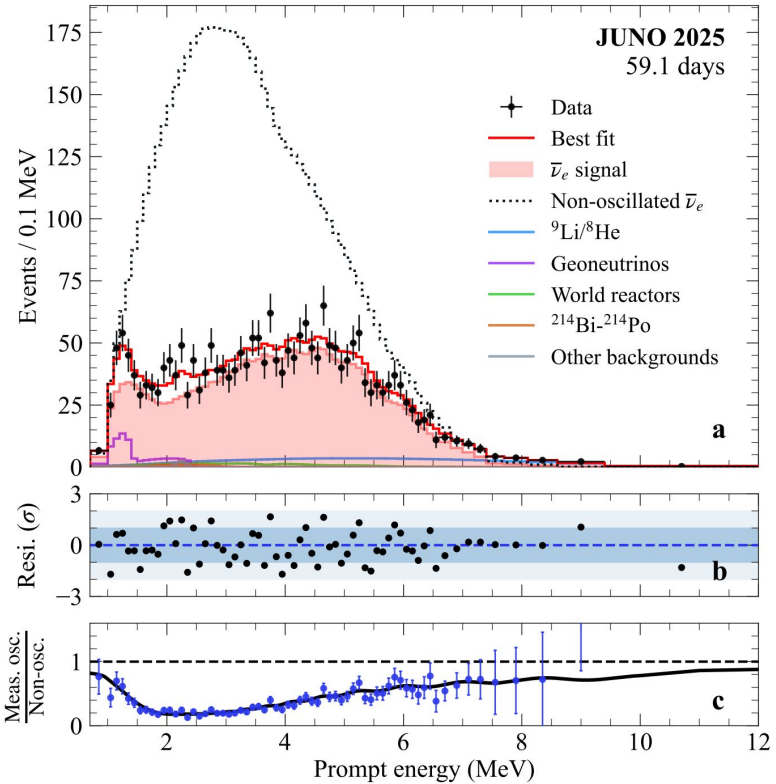
Prompt e+ signal



Delay neutron signal

JUNO: First Results

- First results released with just **59.1 days of data collected**



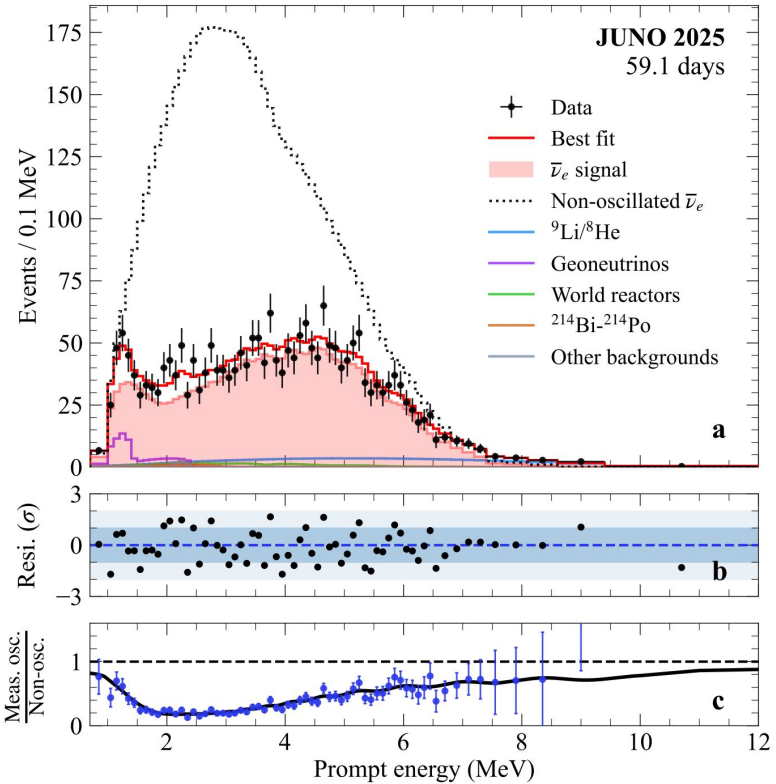
- **2,379 ν_e IBD candidates**
- **69.9% Signal Efficiency**

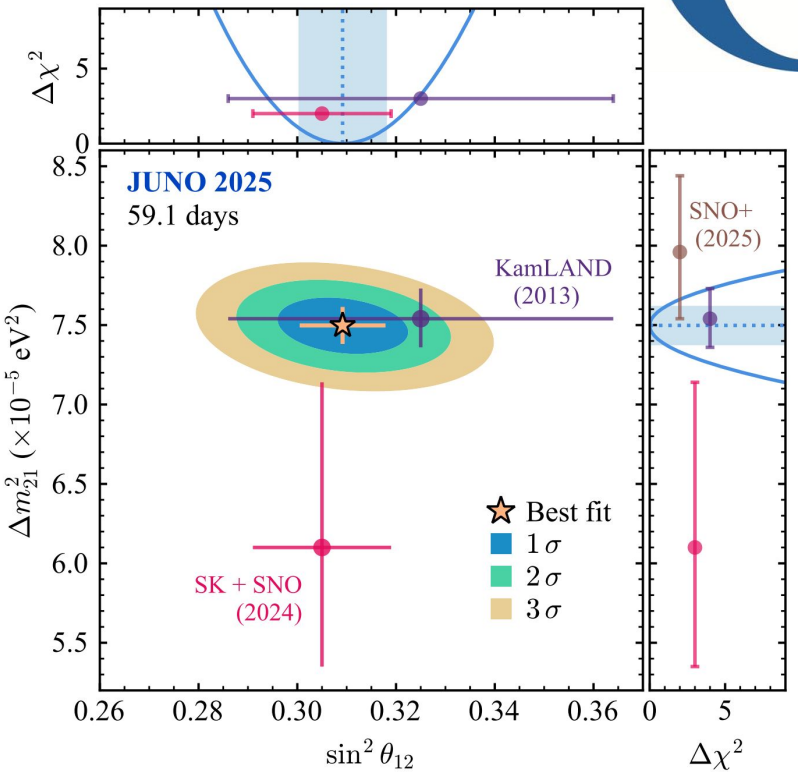
Largest **backgrounds** being

- **^{9}Li/^{8}He** (~4.3 events per day)
- **Geoneutrinos** (~1.2 events per day)
- **World Reactors** (<1 event per day)

JUNO: First Results

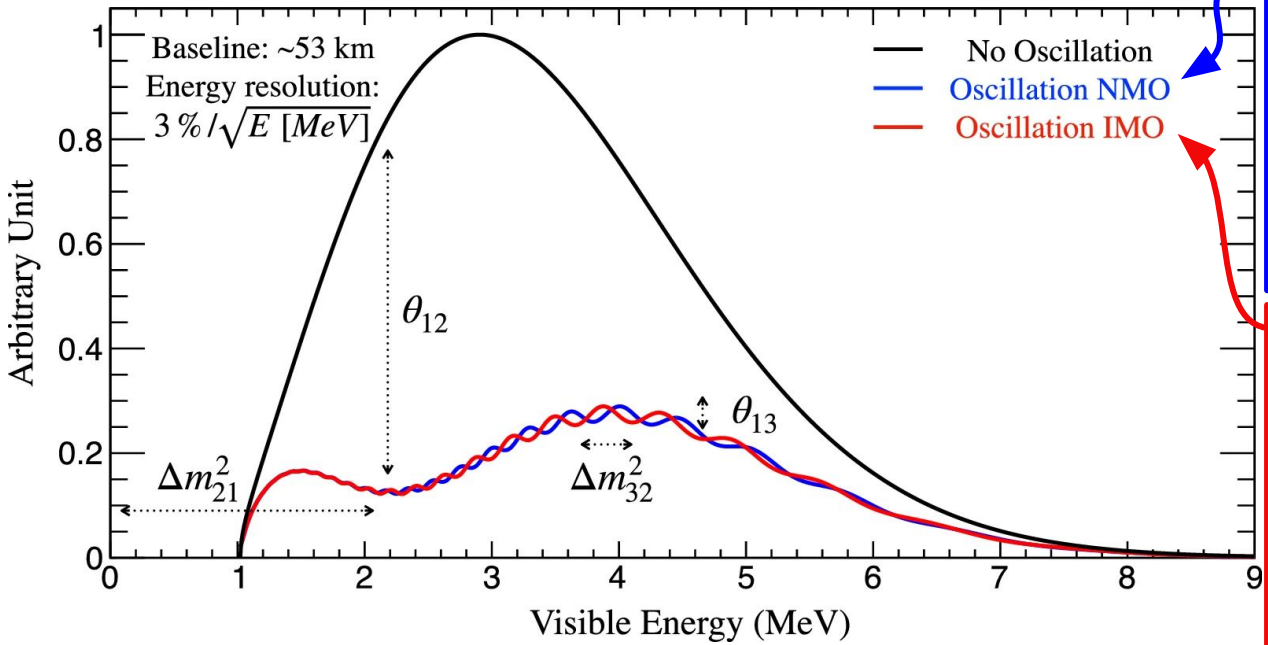
- First results released with just **59.1 days of data collected**

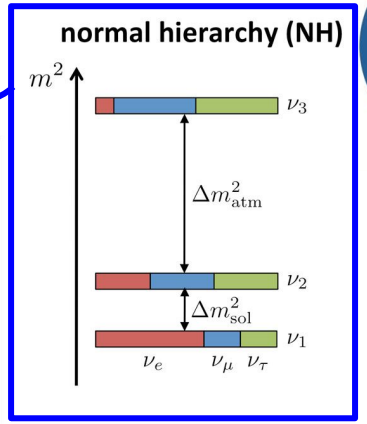


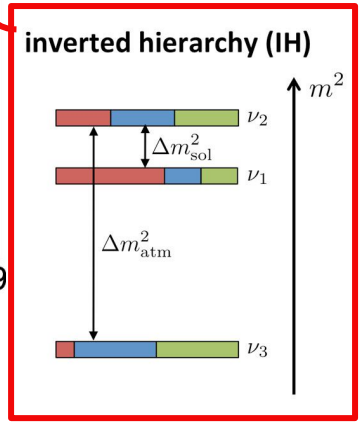


JUNO First Physics arXiv:2511.14593

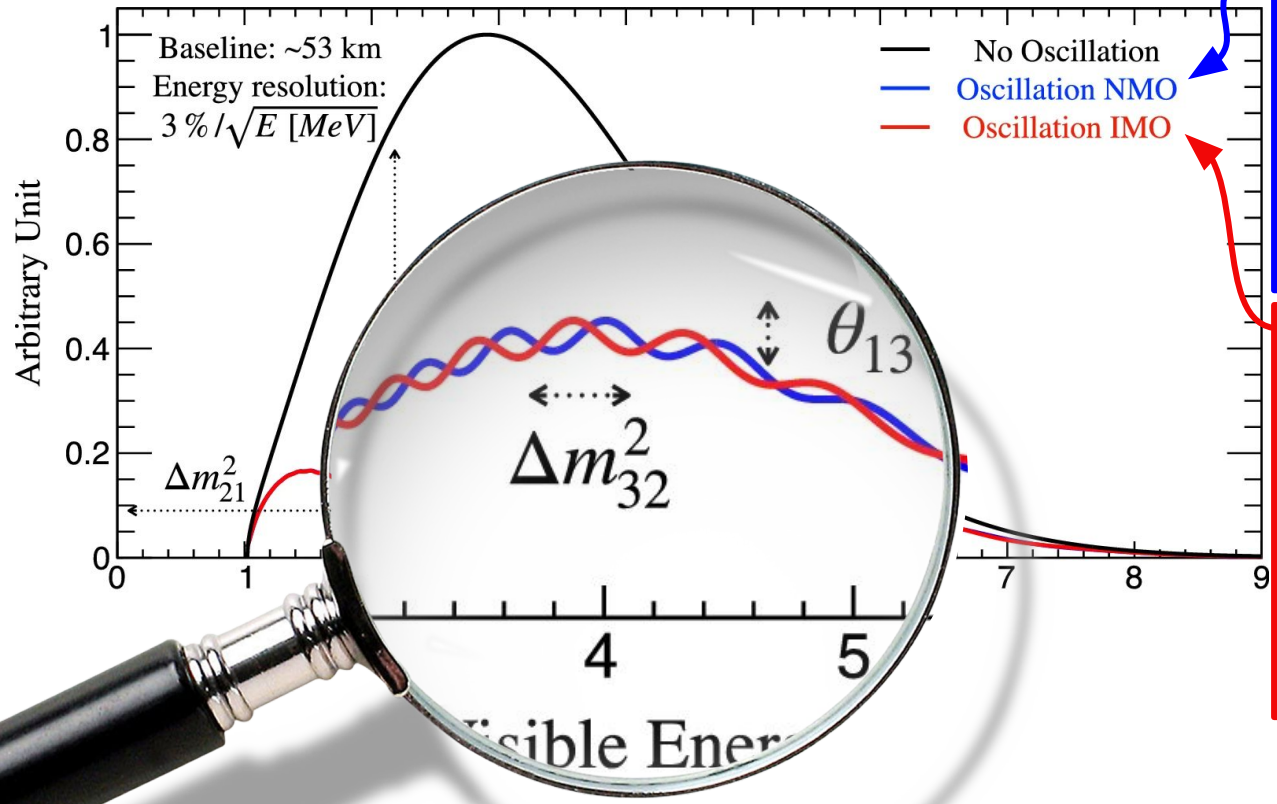
JUNO: Towards the Mass Hierarchy

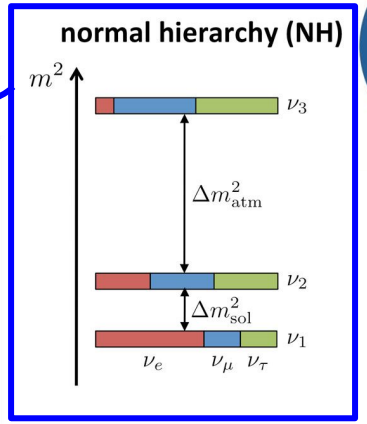


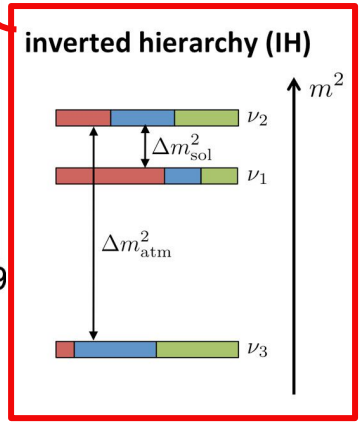




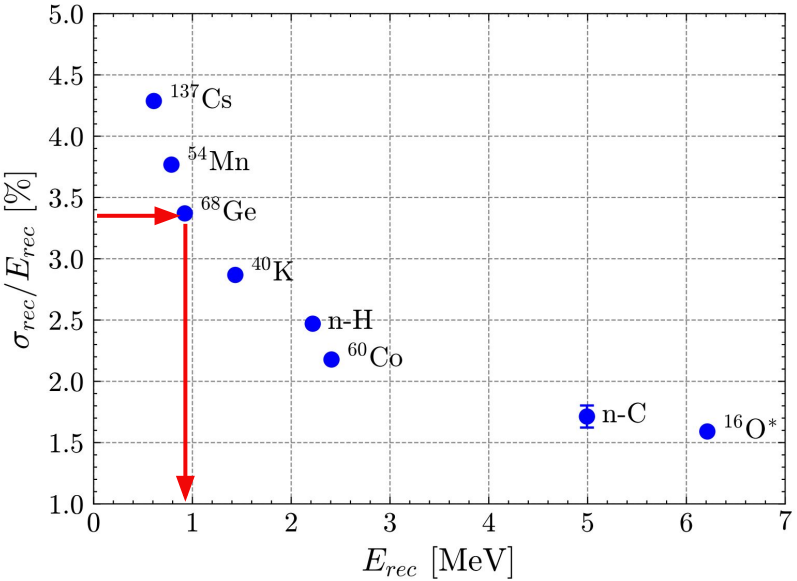
JUNO: Towards the Mass Hierarchy







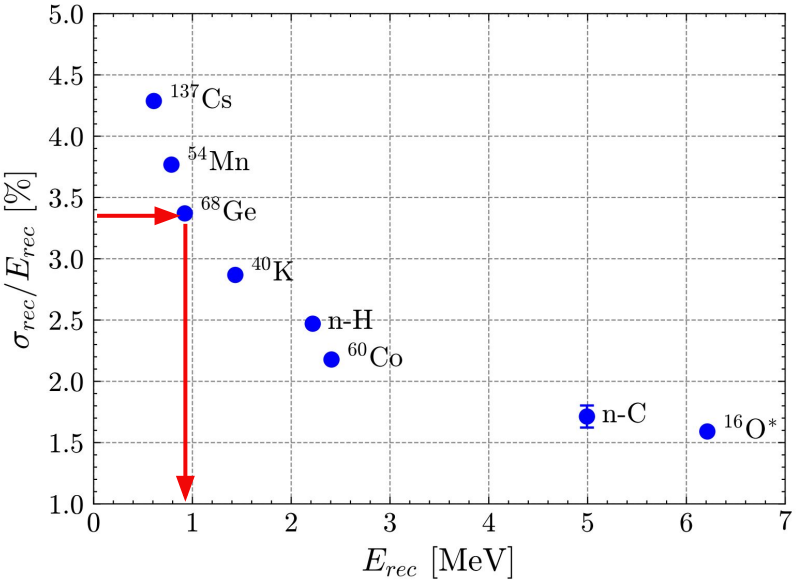
Energy Resolution **design goal** (~3% @ 1 MeV)



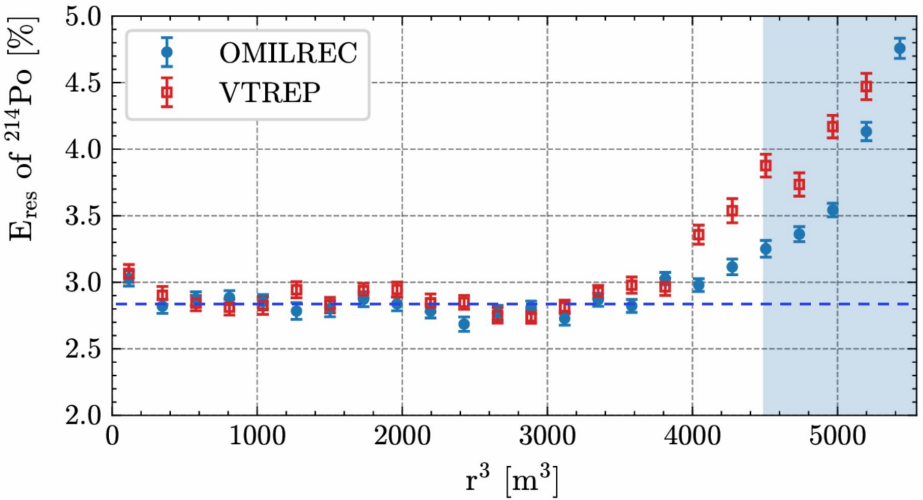
Calibration γ source efficiency at **center of detector**

JUNO Detector Performance arXiv:2511.14590

Energy Resolution **design goal** (~3% @ 1 MeV)

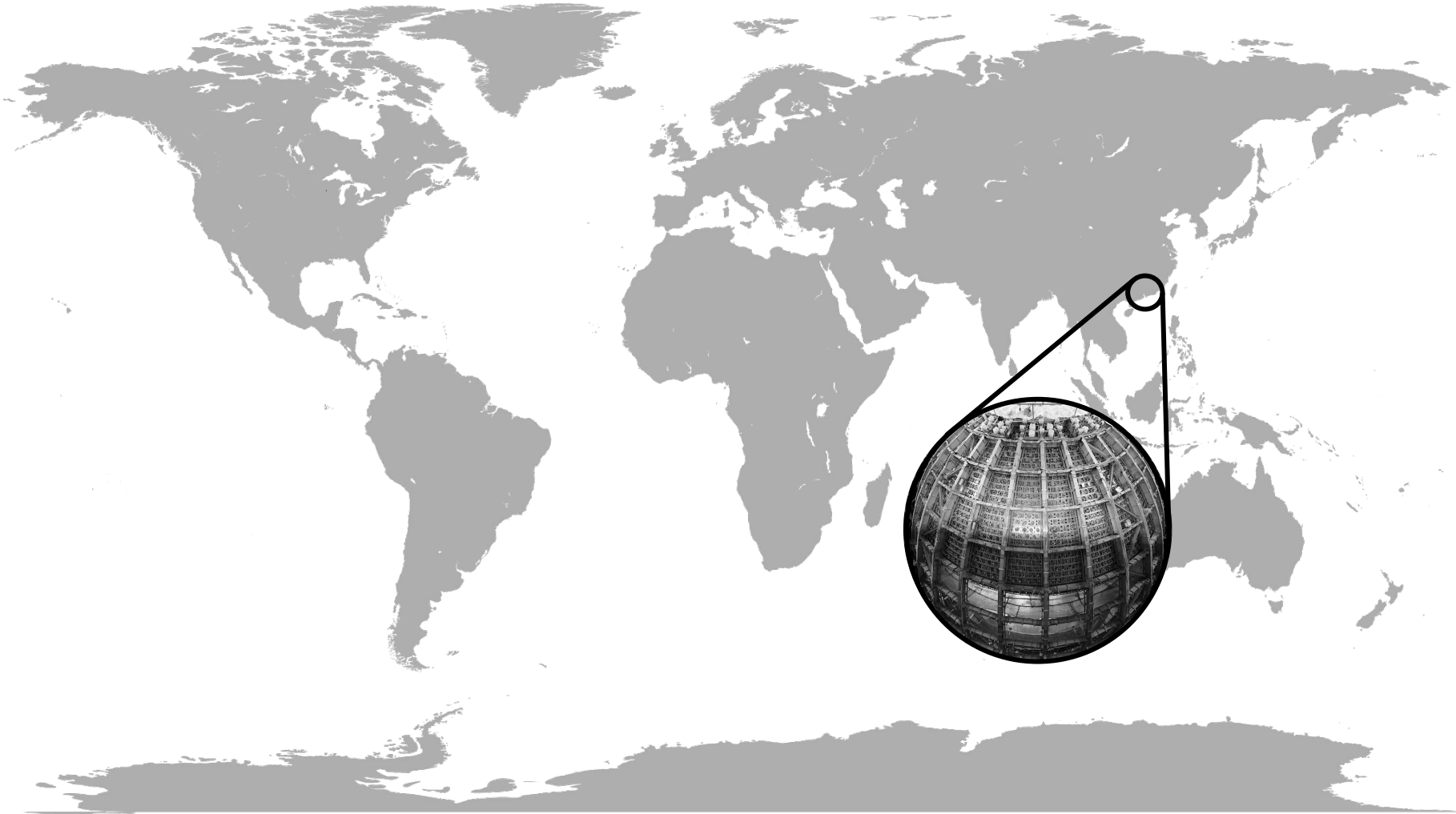


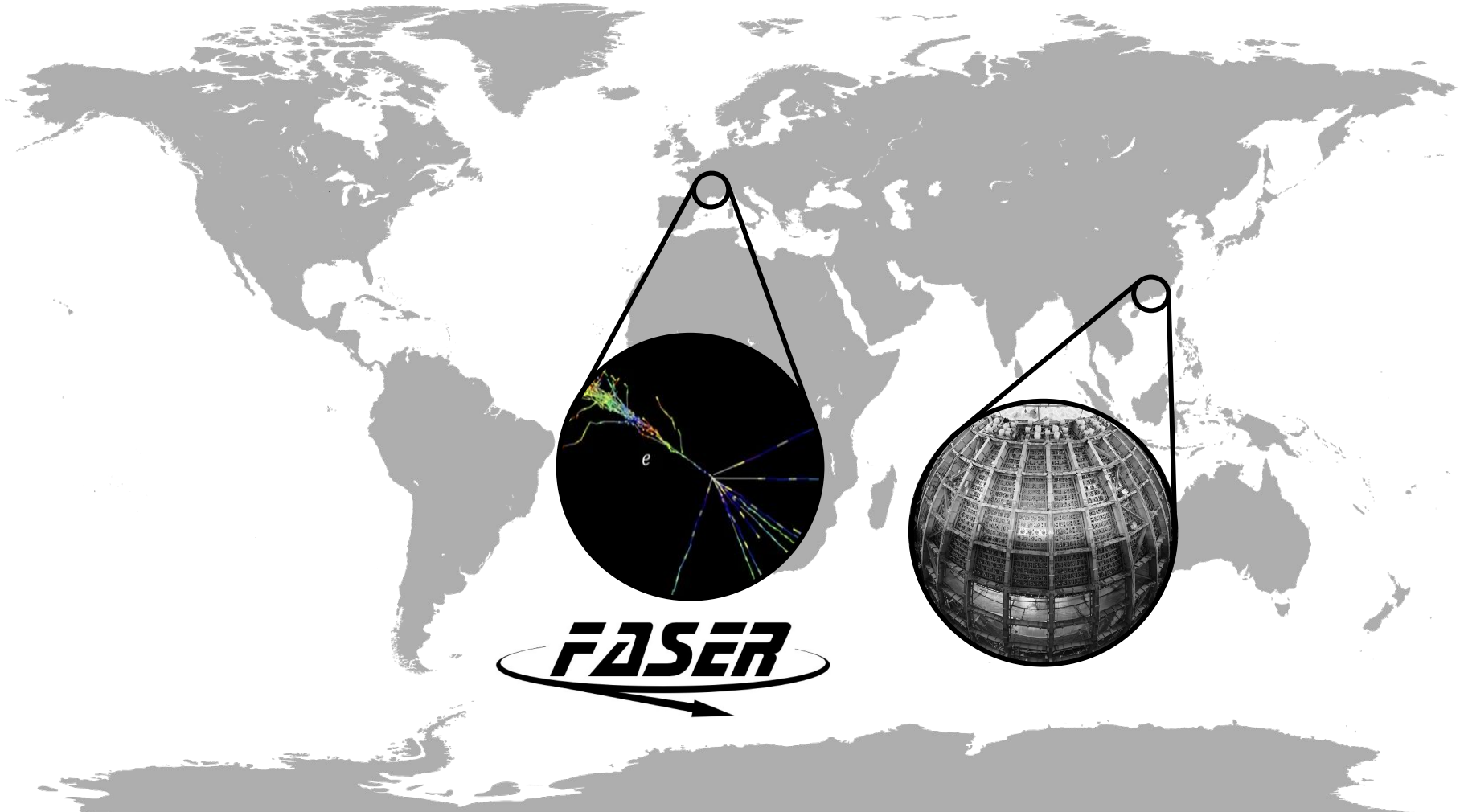
Calibration γ source efficiency at **center of detector**



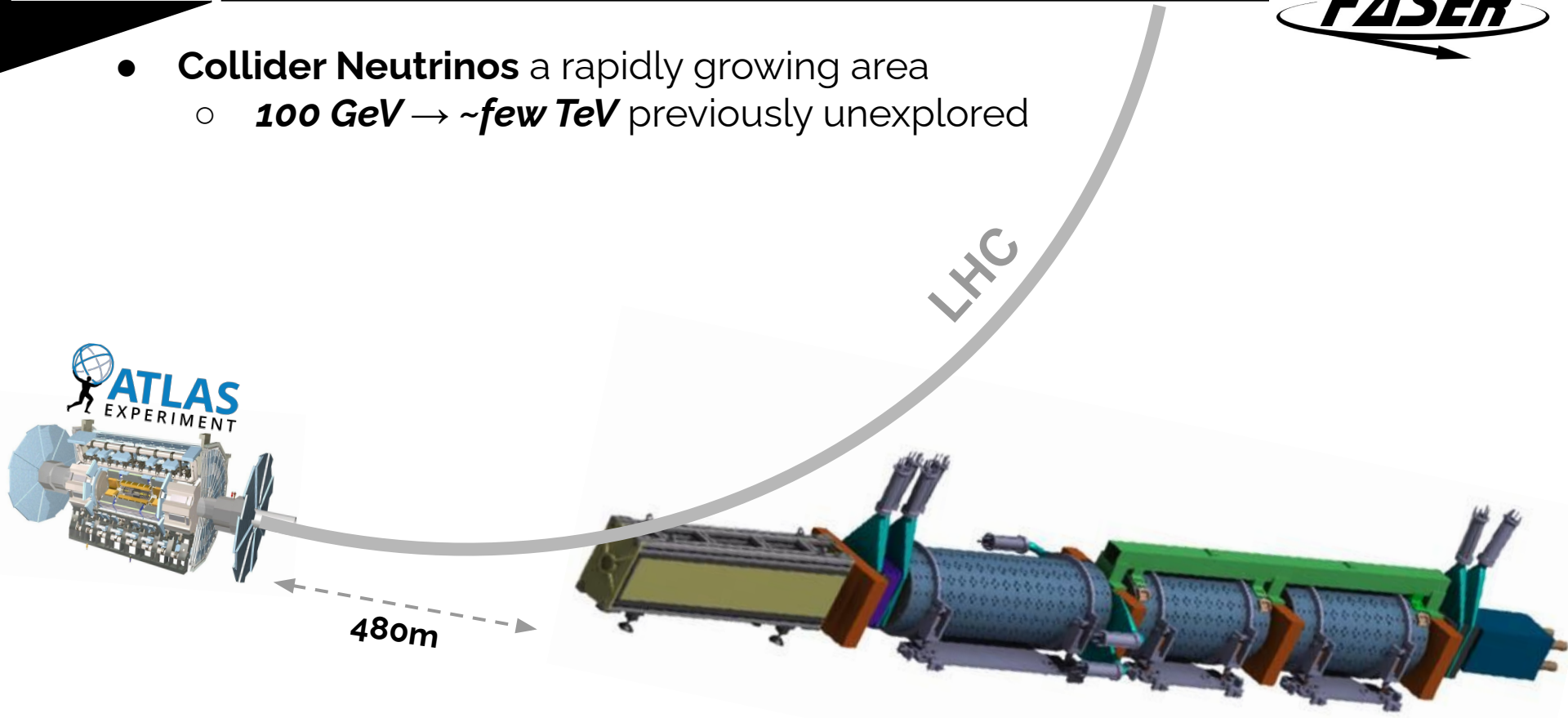
2.9 % Energy Resolution for a 0.94 MeV **^{214}Po α decays** from natural ^{238}U decay chain

JUNO Detector Performance arXiv:2511.14590




e
FASER

- **Collider Neutrinos** a rapidly growing area
  - ***100 GeV → ~few TeV*** previously unexplored



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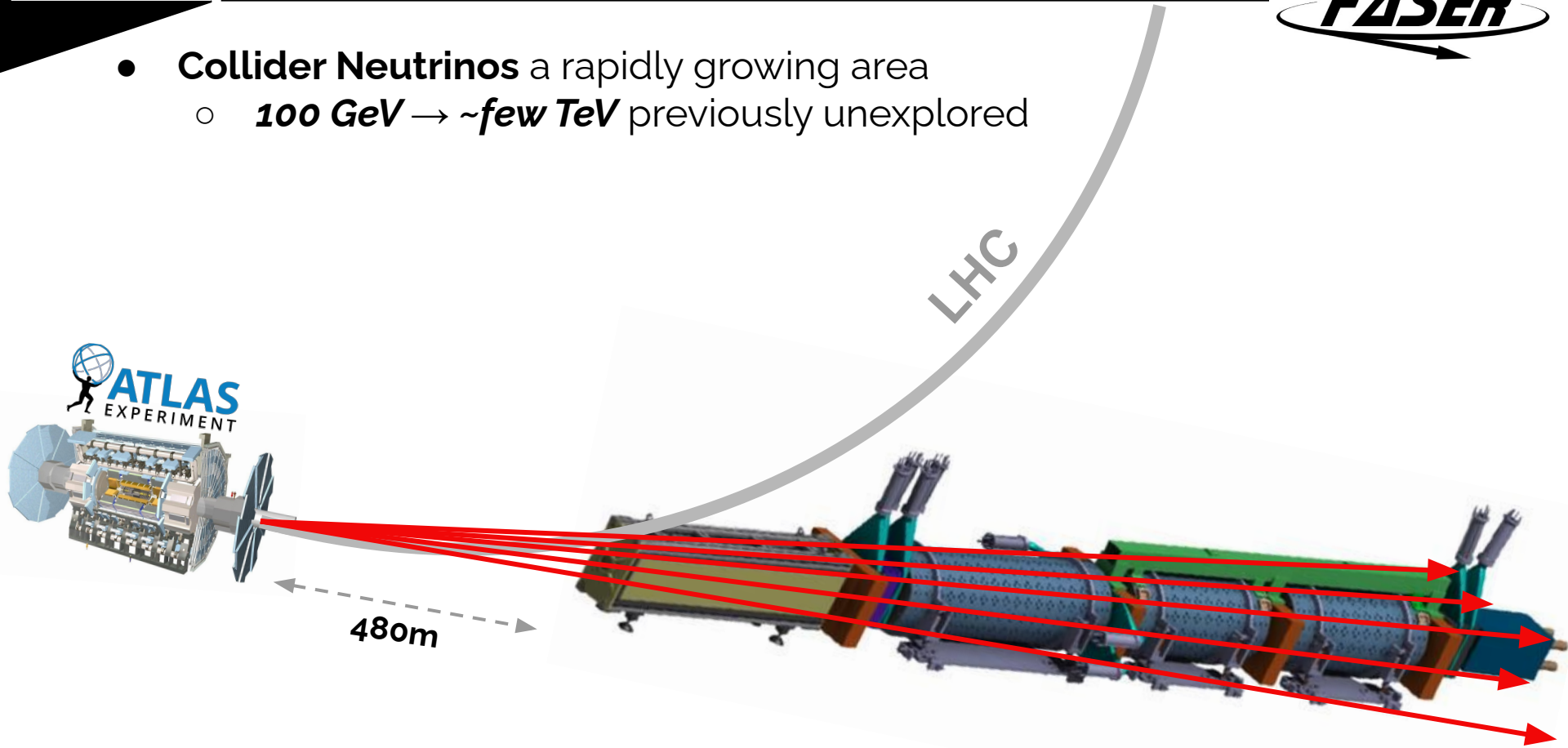
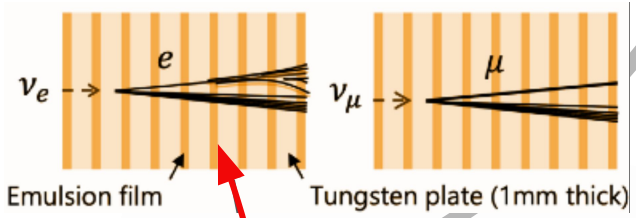
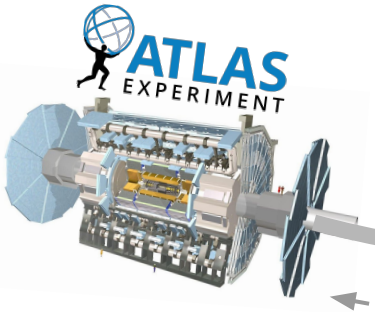


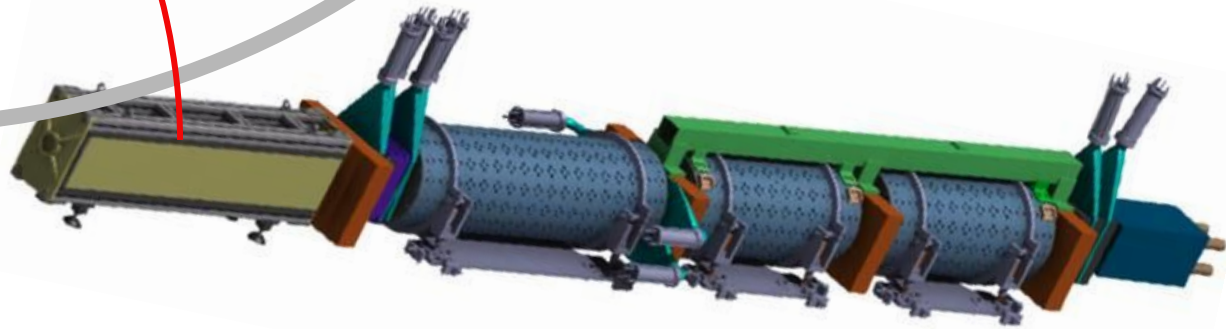
Emulsion detector:

- Sensitive to **all neutrino flavours**
- **Excellent spatial resolution** (0.3μm)
- **Slow** (film must be scanned, digitised, and processed)



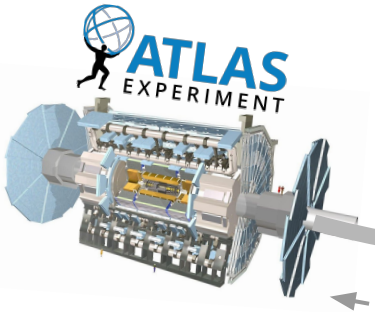


480m



Electronic spectrometer:

- **Fast** analysis (only using electronic components)
- **Neutrino/anti-neutrino separation**
- **EM Calorimeter**



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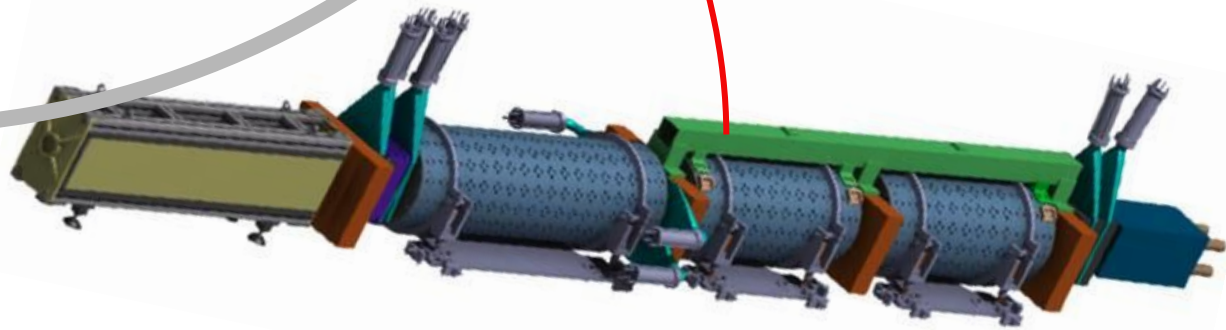
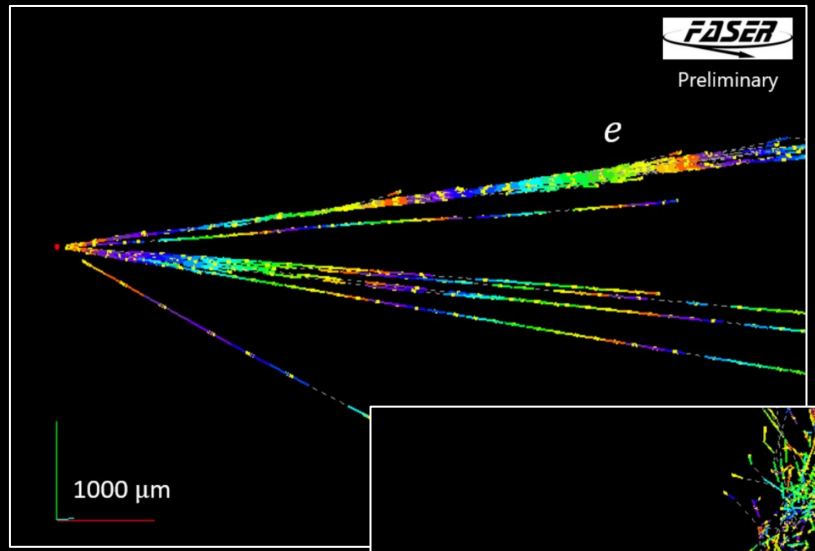
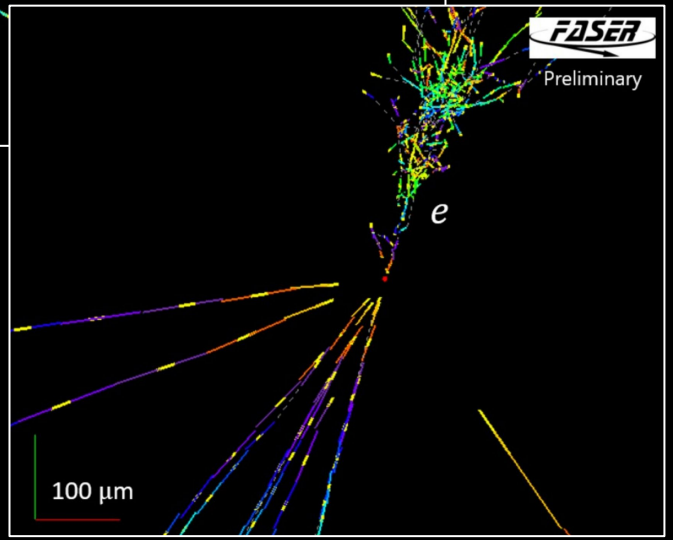
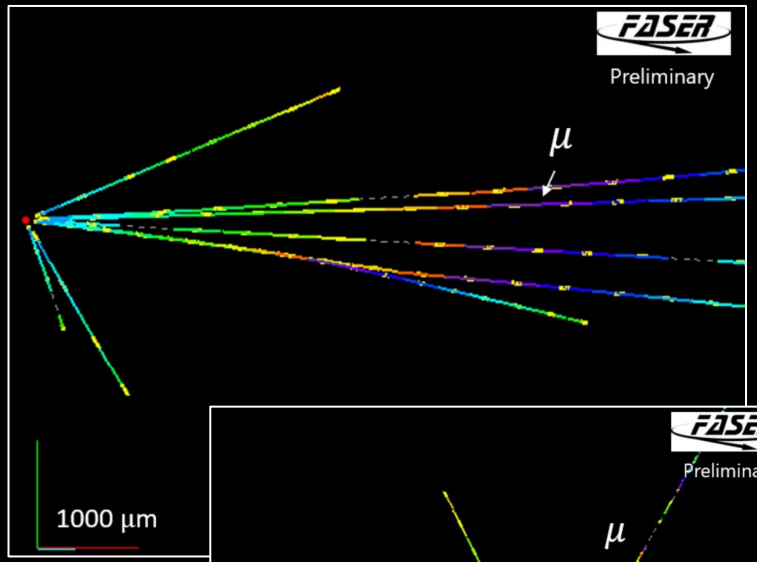
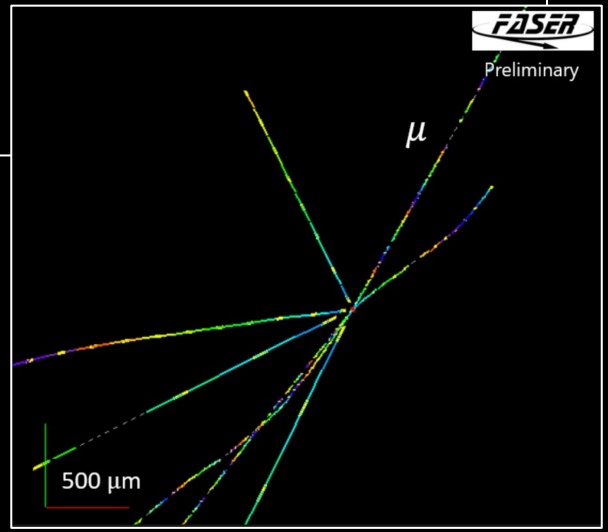


FASER : Emulsion Detector Events

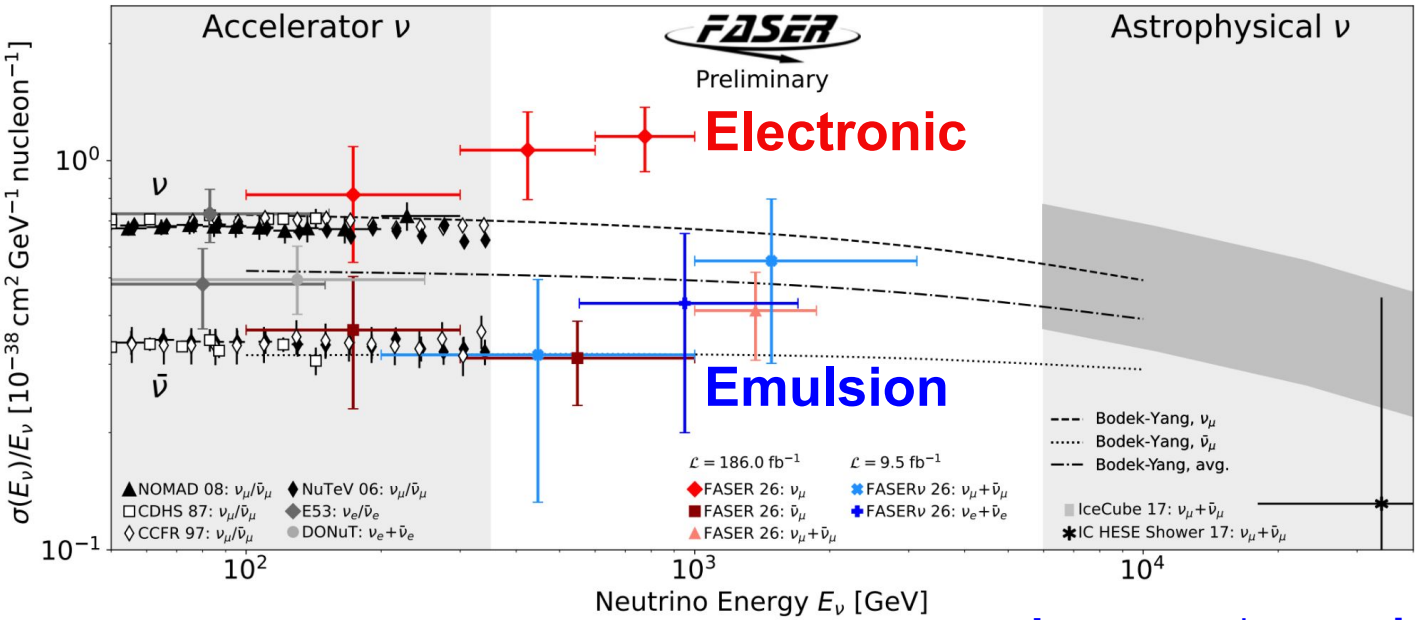








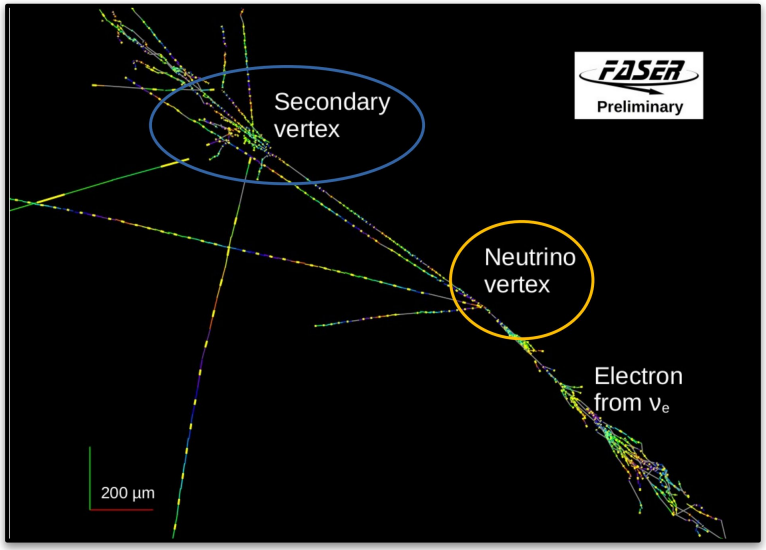
~x2.8 increase in **electronic data analyzed** studied



~x5 increase in **emulsion mass** studied

First Search for **Neutrino-Induced Charm Production** CERN-FASER-CONF-2026-003

- Direct handle on charged charm decays
- Benchmark for **τ reconstruction**

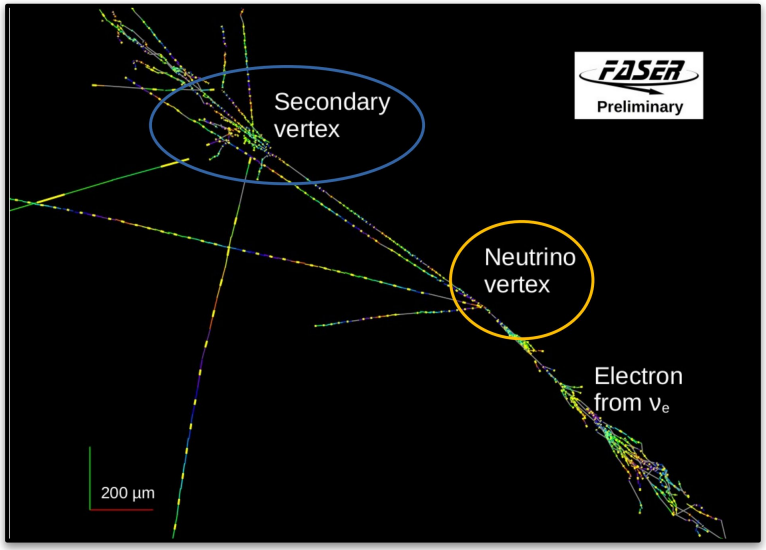


Displaced secondary vertex

FASER : New Analysis Updates

First Search for **Neutrino-Induced Charm Production** CERN-FASER-CONF-2026-003

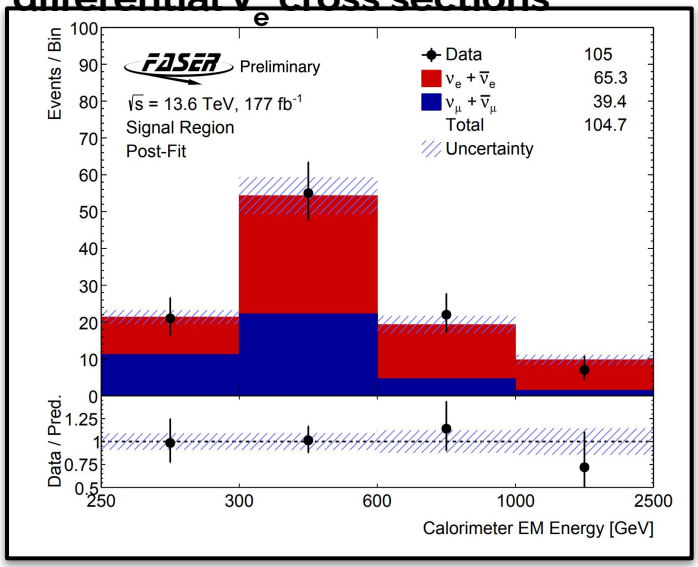
- Direct handle on charged charm decays
- Benchmark for **τ reconstruction**

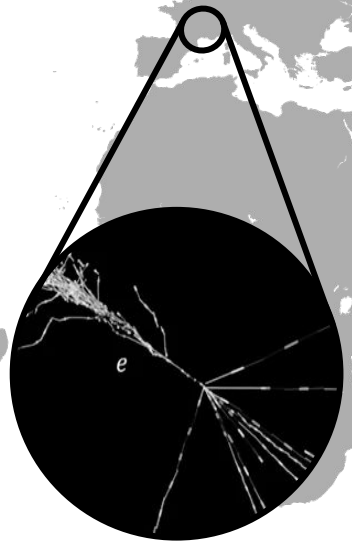


Displaced secondary vertex

First ν_e identified with **FASER electronic components** (not emulsion) CERN-FASER-CONF-2026-004

- ~65 ν_e events observed above an expected ~40 background **(5.5σ significance)**
- **Milestone** towards **Energy dependent differential ν_e cross sections**

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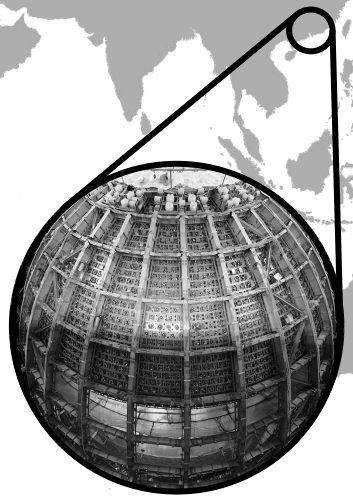
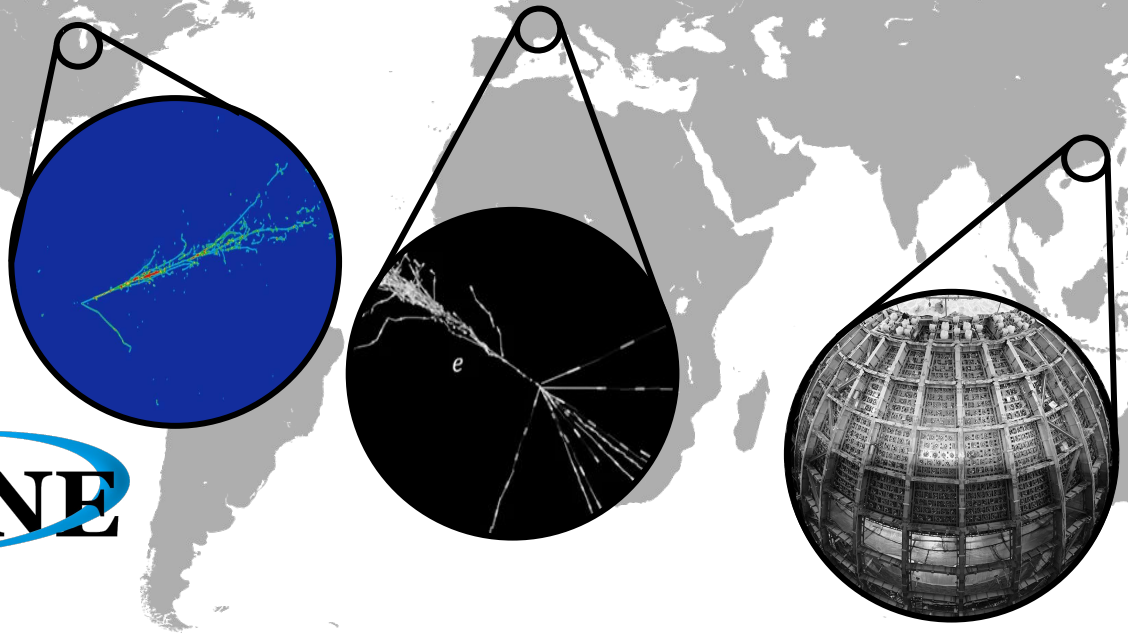
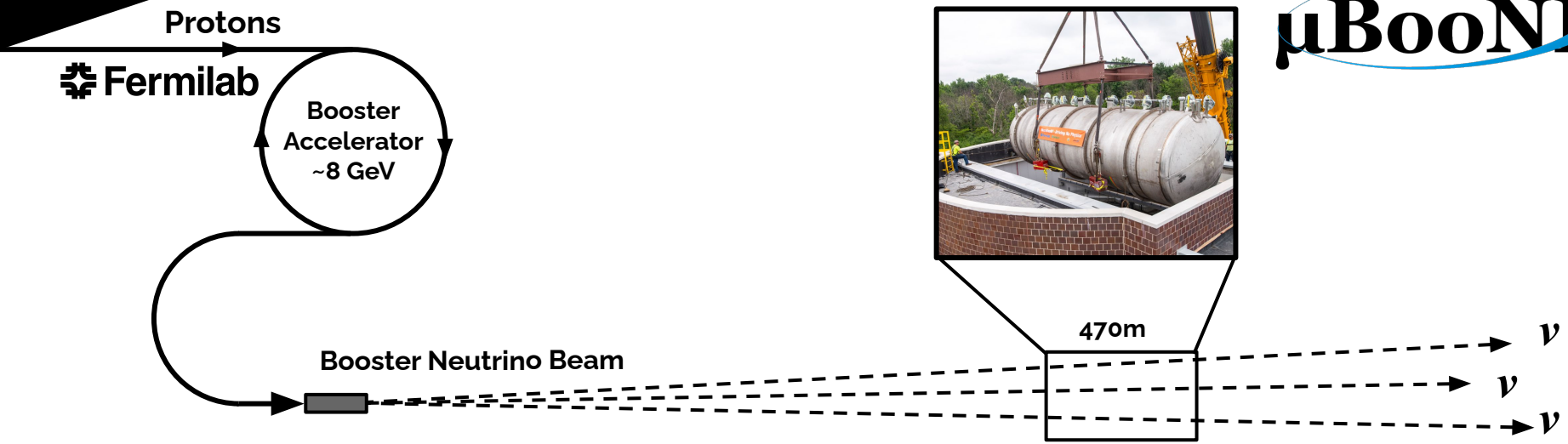


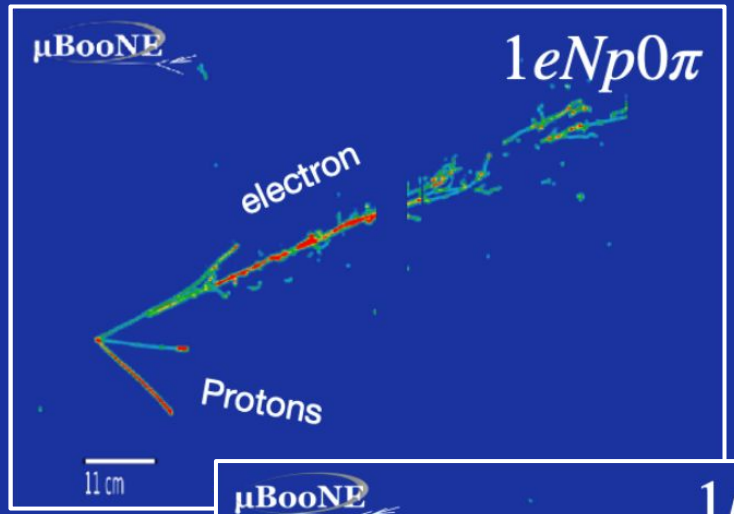


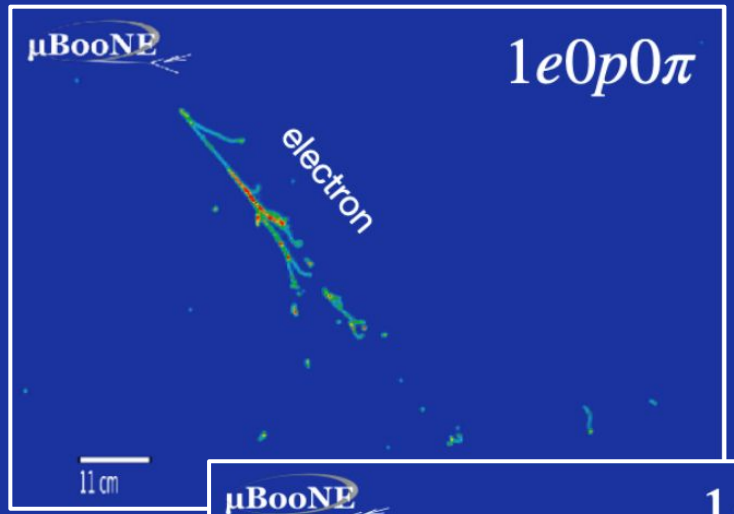
μBooNE

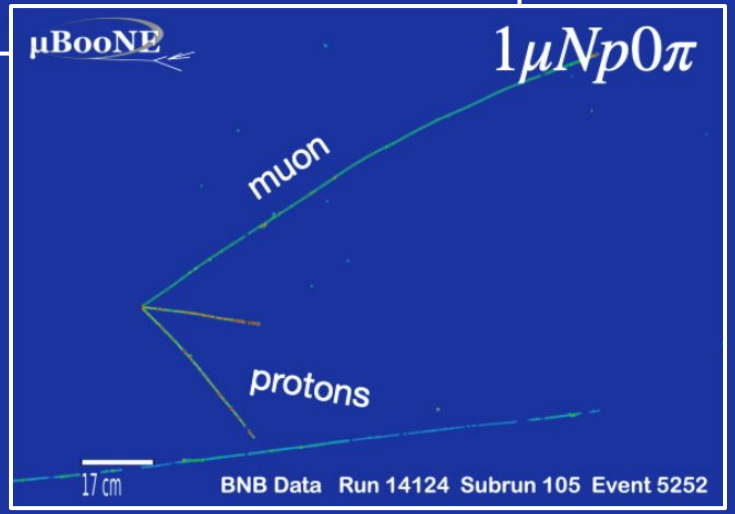


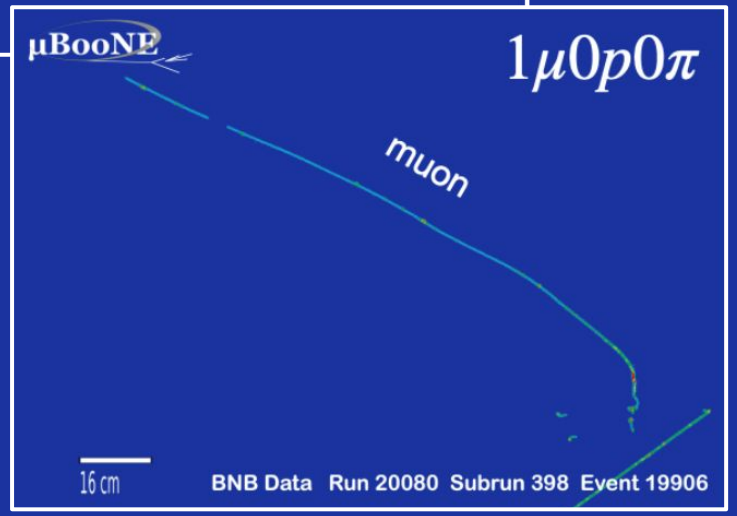
MicroBooNE is a **90 metric ton LArTPC** sitting in the **Booster Neutrino Beam** (BNB) at Fermilab, taking data **2015-2021**

MicroBooNE

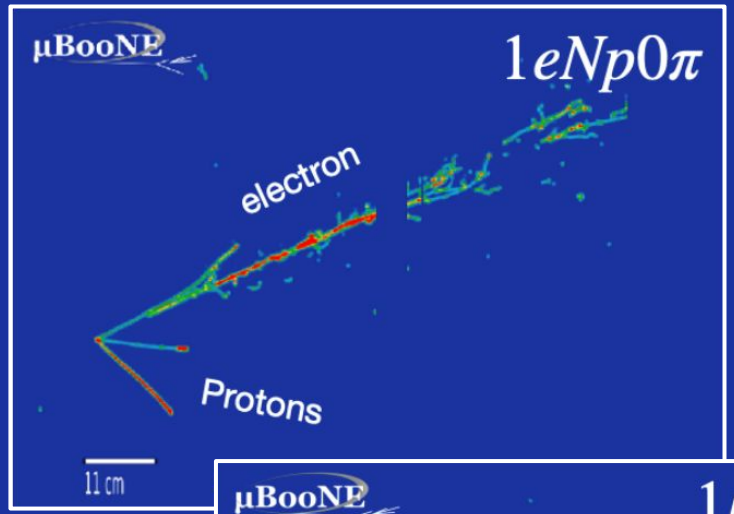

μBooNE
1eNp0π
electron
Protons
11 cm

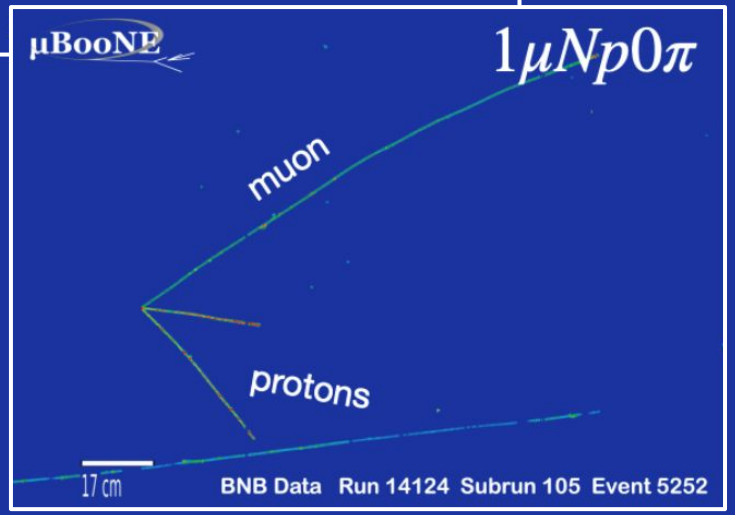

μBooNE
1e0p0π
electron
11 cm

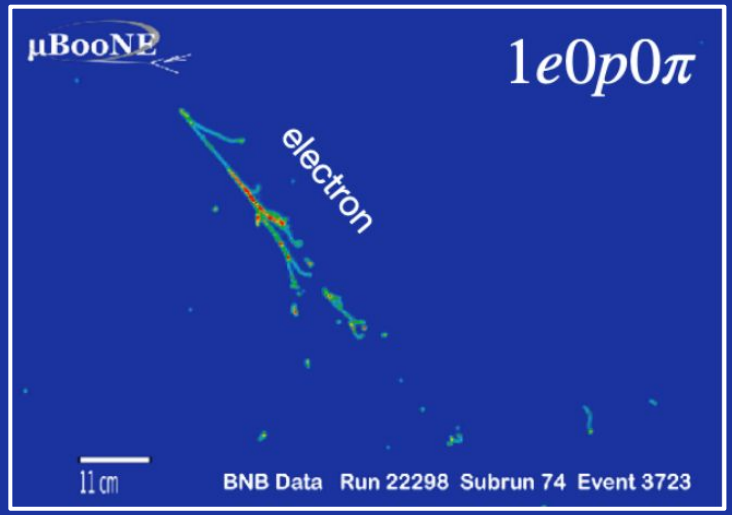

μBooNE
1μNp0π
muon
protons
17 cm
BNB Data Run 14124 Subrun 105 Event 5252


μBooNE
1μ0p0π
muon
16 cm
BNB Data Run 20080 Subrun 398 Event 19906

MicroBooNE



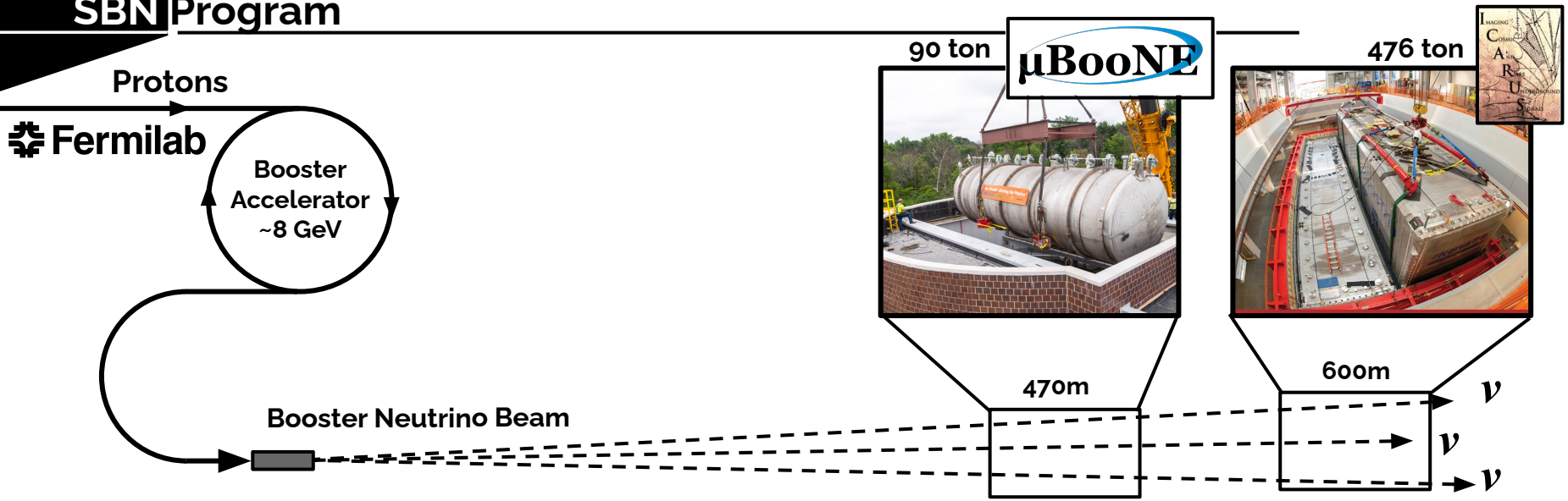




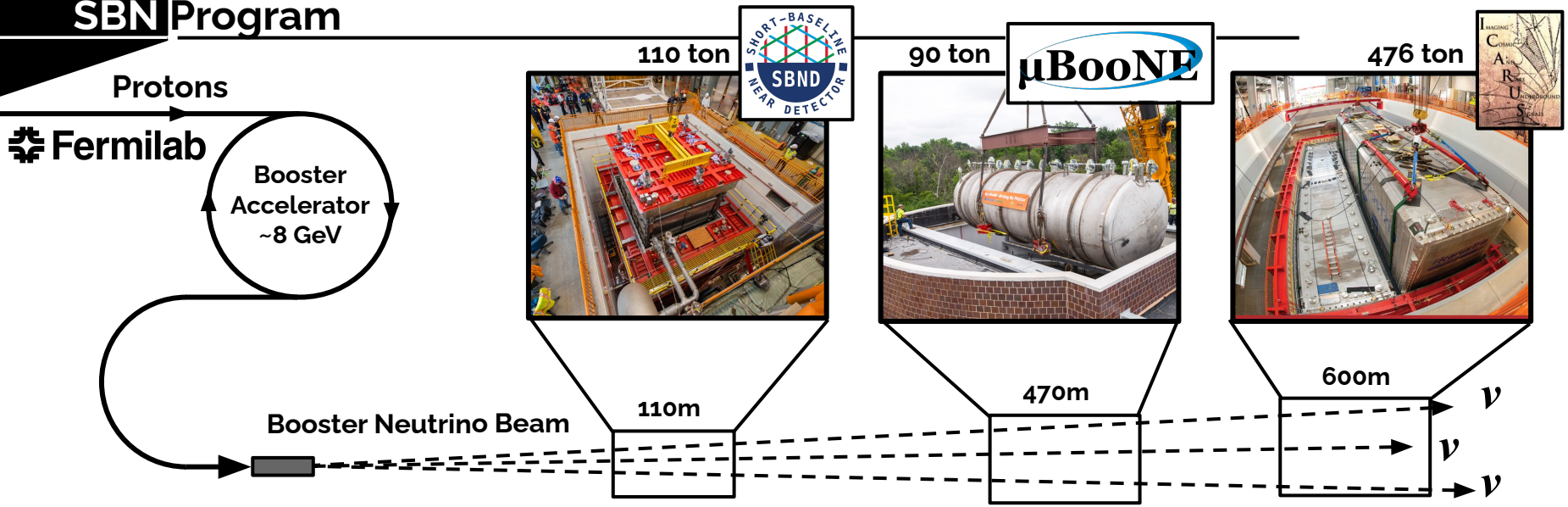
LArTPC Technology enables

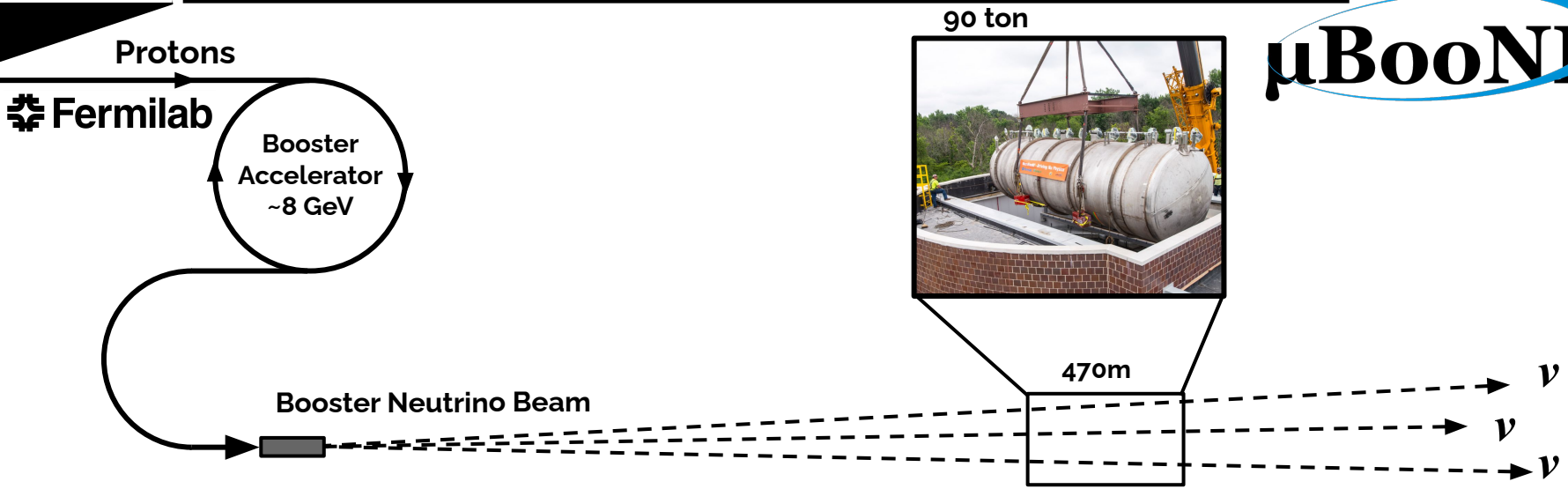
- 3 Millimeter Scale Resolution
- Calorimetry & Energy Measurement
- Powerful Particle ID

SBN Program

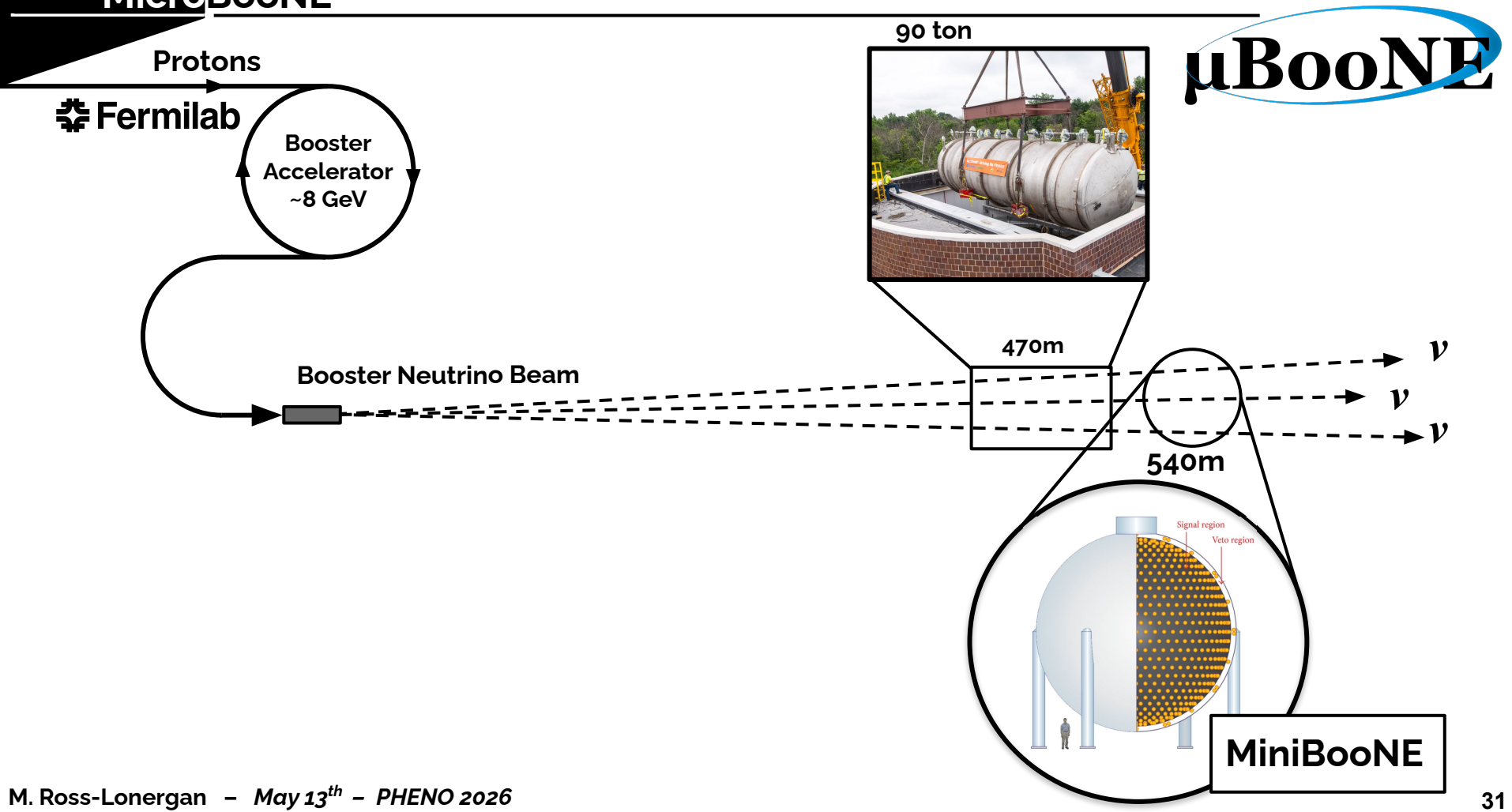

Protons
Fermilab
Booster
Accelerator
~8 GeV
Booster Neutrino Beam
90 ton
μBooNE
476 ton
ICARUS
470m
600m
ν
ν
ν

SBN Program

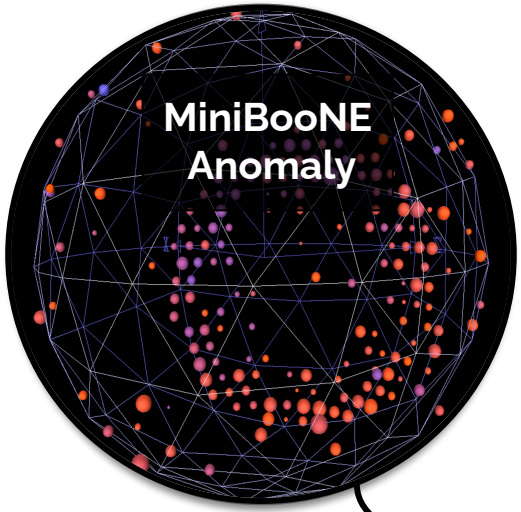

Protons
Fermilab
Booster
Accelerator
~8 GeV
Booster Neutrino Beam
110 ton
SBND
110m
90 ton
μBooNE
470m
476 ton
600m
ν
ν
ν

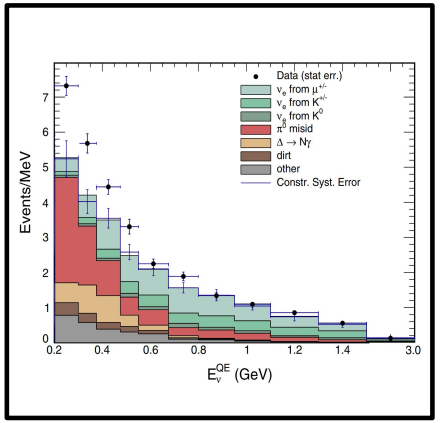

Protons
Fermilab
Booster
Accelerator
~8 GeV
Booster Neutrino Beam
90 ton
470m
ν
ν
ν

μBooNE


Protons
Fermilab
Booster
Accelerator
~8 GeV
Booster Neutrino Beam
90 ton
μBooNE
470m
540m
ν
ν
ν
Signal region
Veto region
MiniBooNE

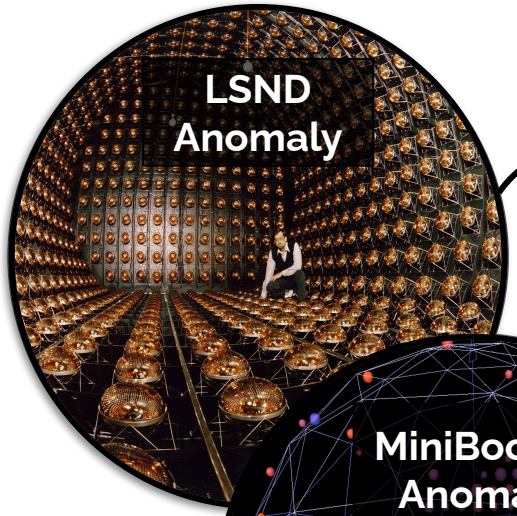
MiniBooNE Anomaly



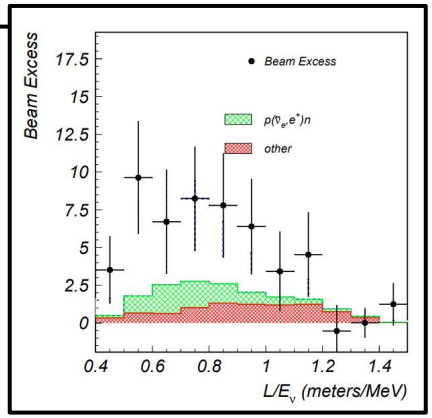


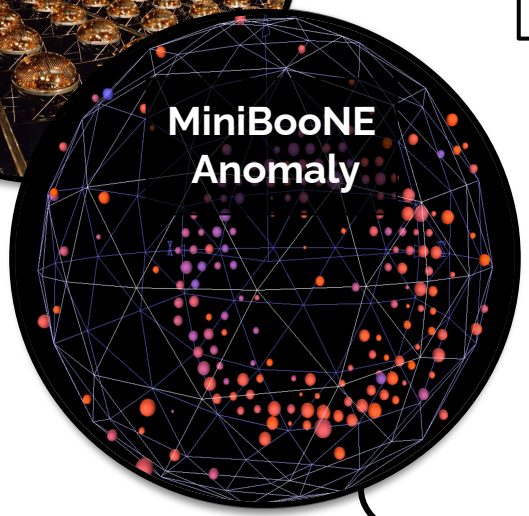
4.8σ Excess

LSND Anomaly

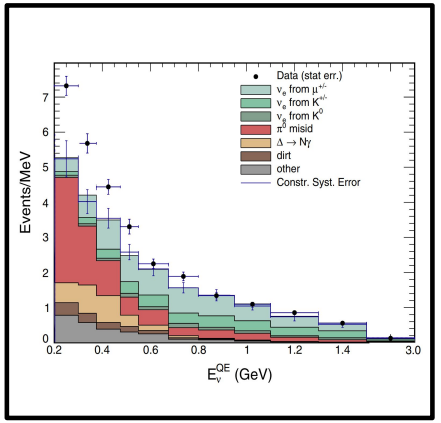


3.8σ
Excess

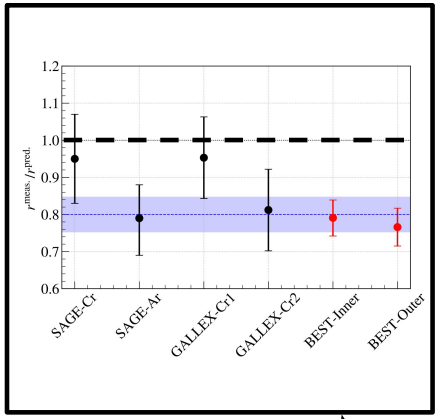




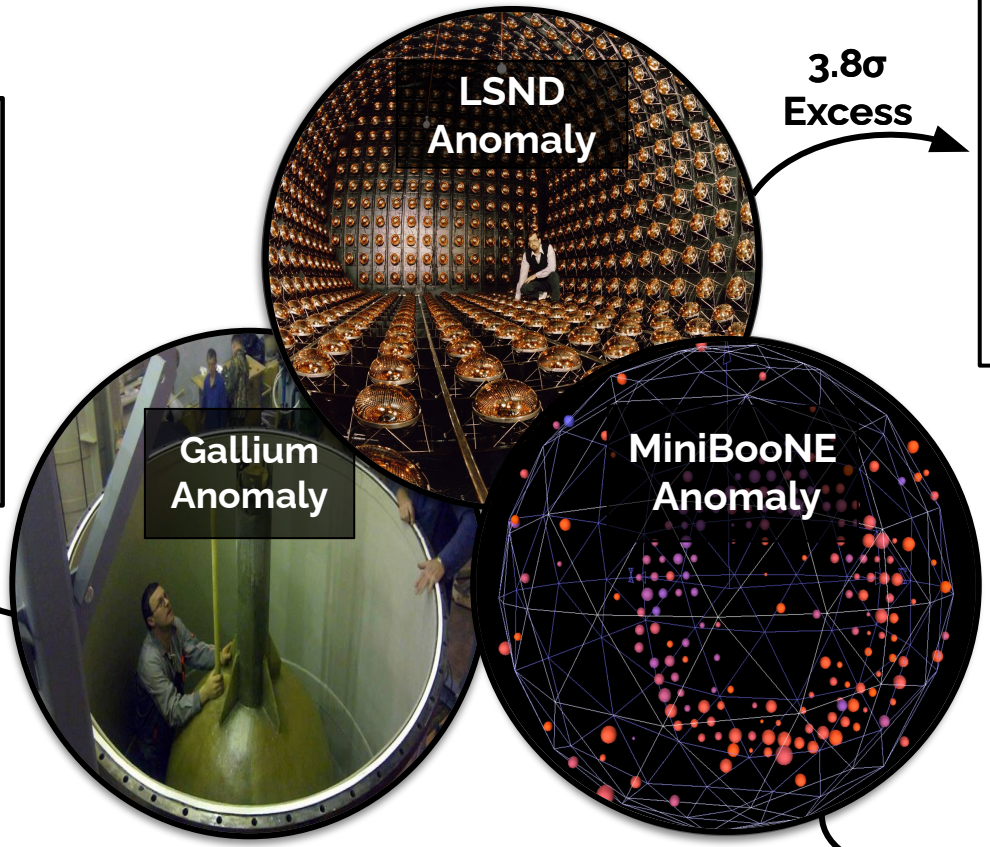
4.8σ
Excess



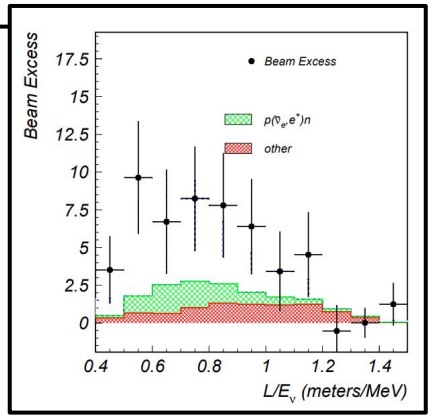
Gallium Anomaly



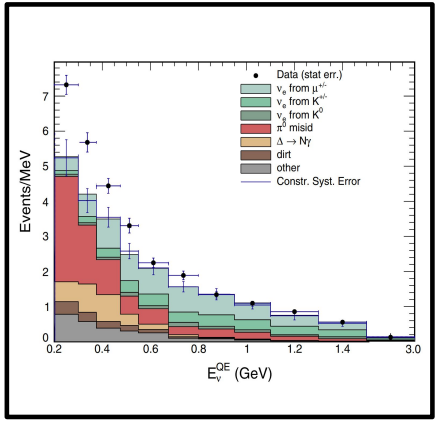
4.0σ
Deficit



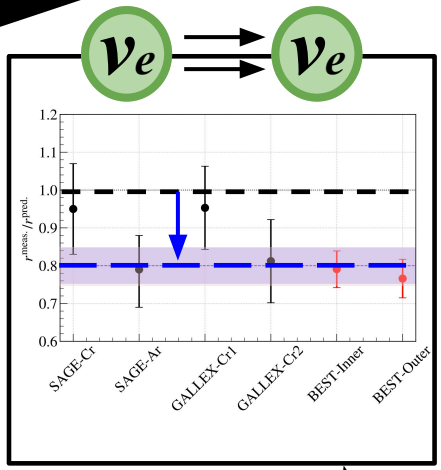
3.8σ
Excess



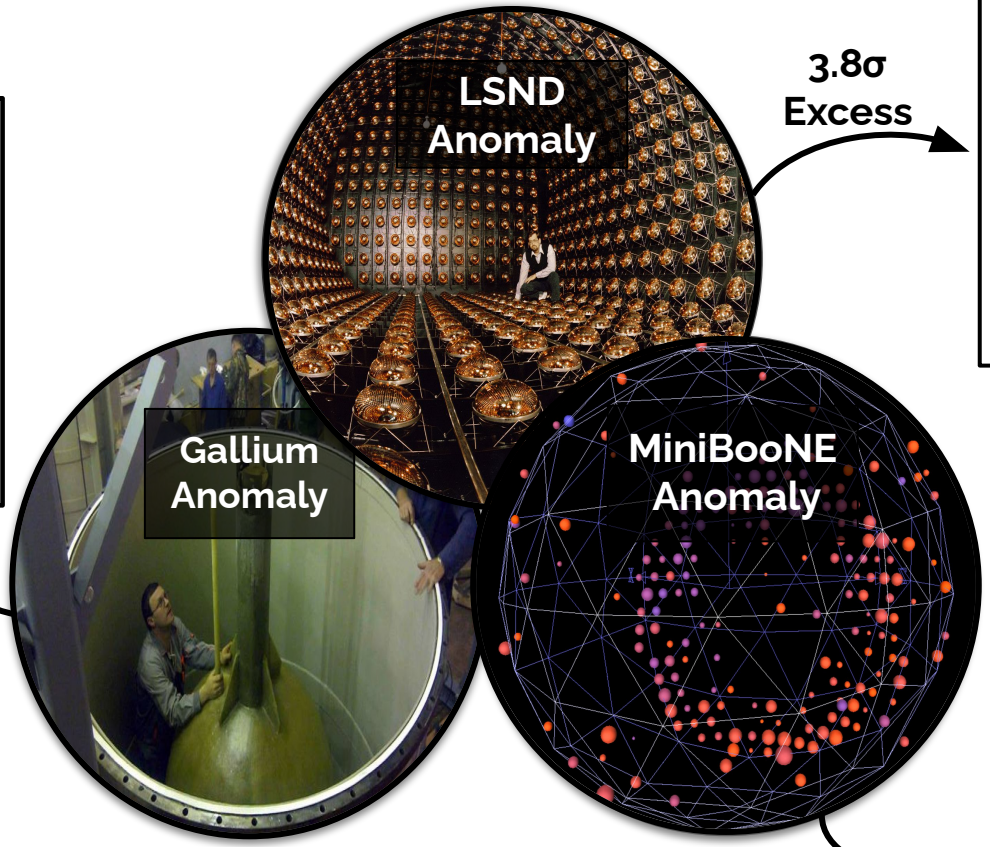
4.8σ
Excess



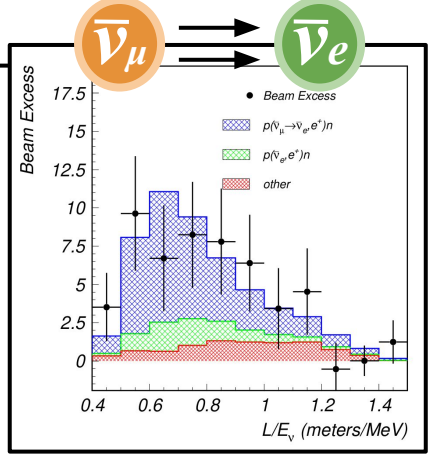
Short Baseline Neutrino Anomalies

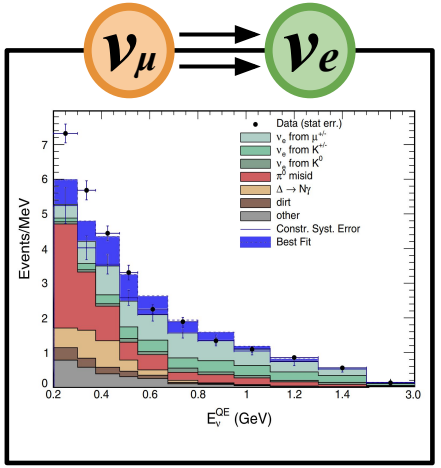


4.0σ
Deficit



3.8σ
Excess

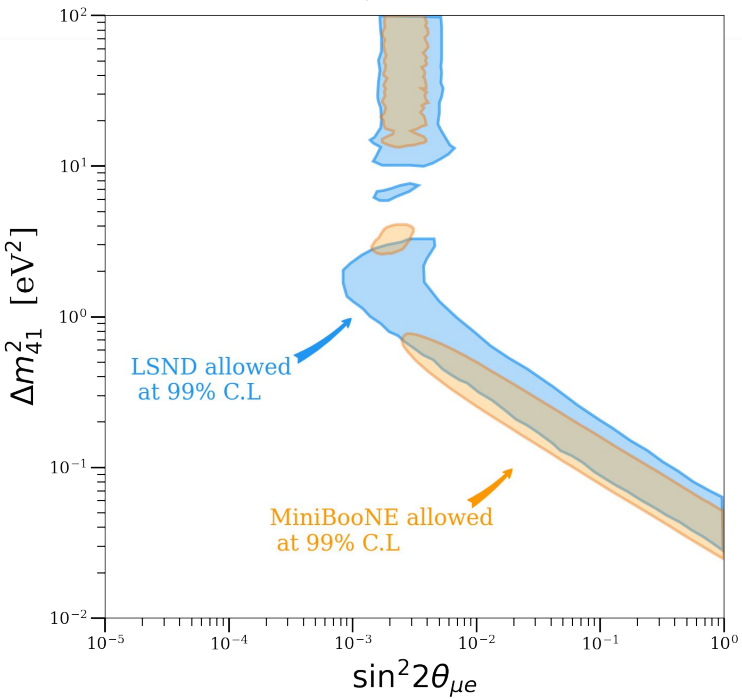




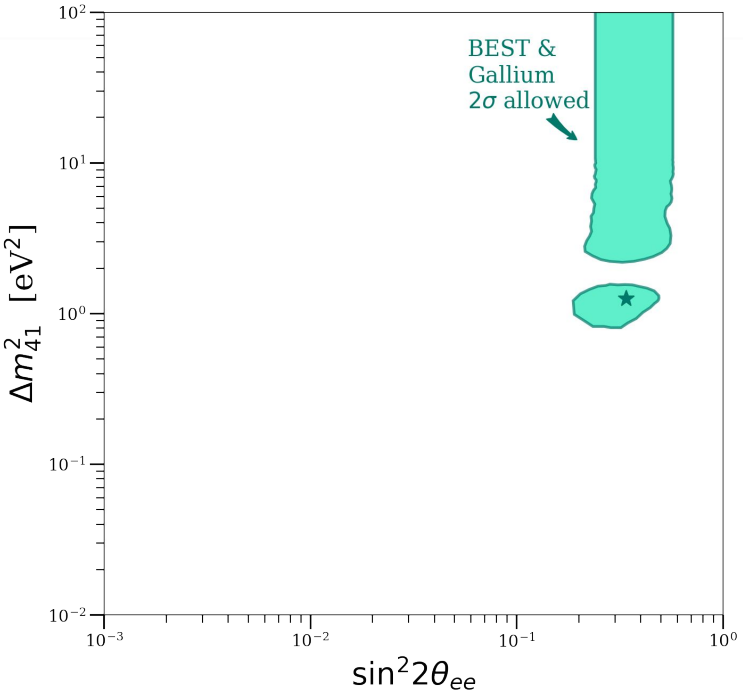
4.8σ
Excess

Individually **consistent with eV² sterile neutrinos**

$\nu_\mu \rightarrow \nu e$

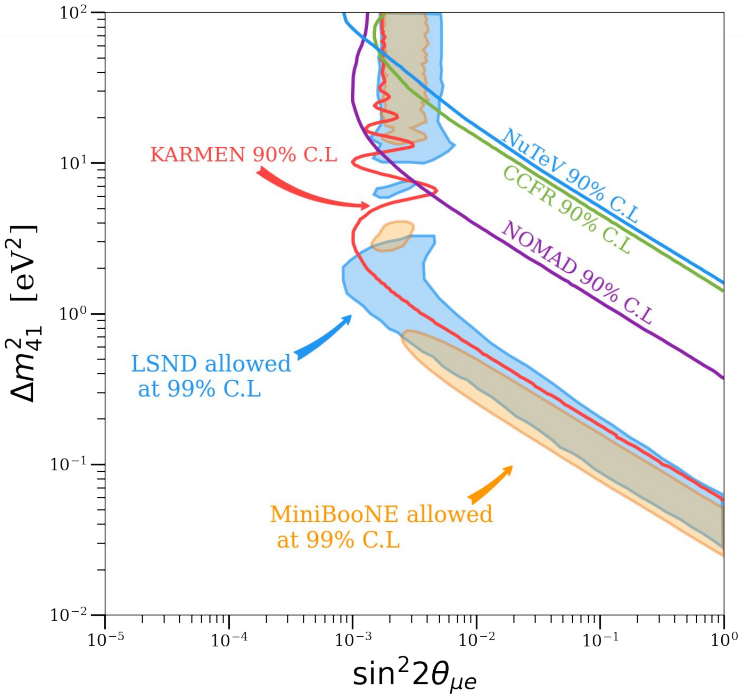


$\nu e \rightarrow \nu e$



νe Appearance

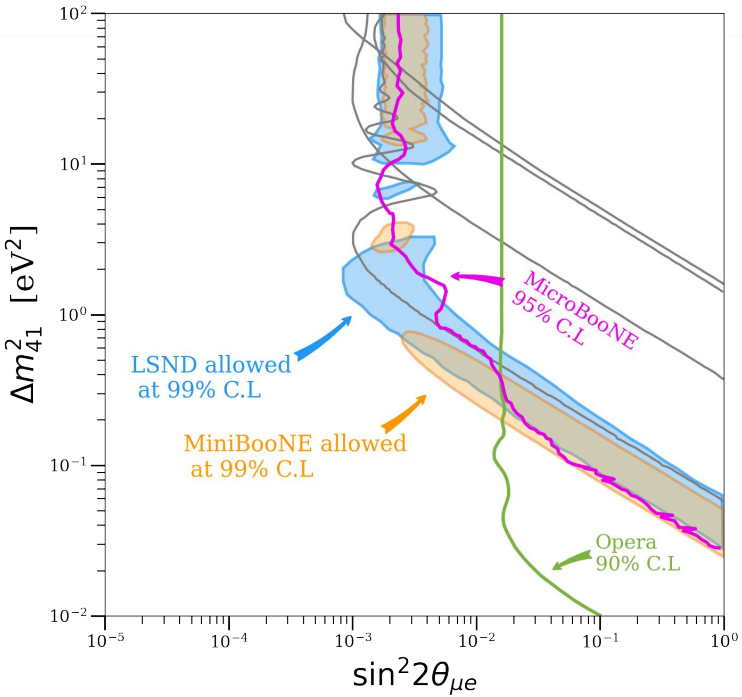
$\nu_\mu \longrightarrow \nu e$



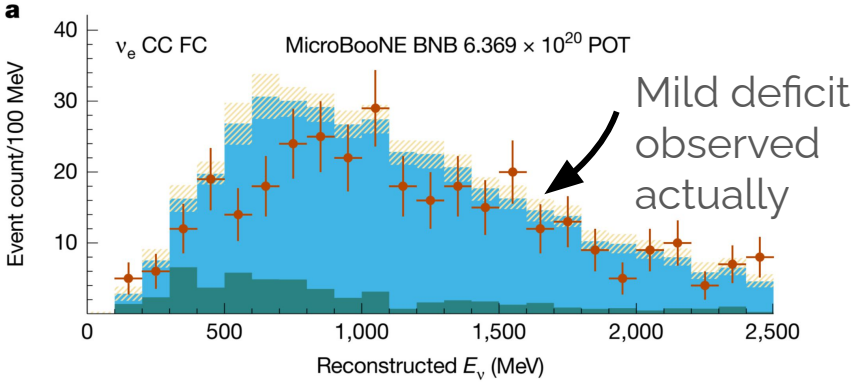
- **CCFR [1984]** @ Fermilab
  - PhysRevLett.52.10.1103, 1984
- **KARMEN [2002] @ RAL (UK)**
  - Phys.Rev.D65:112001,**2002**
- **NuTeV [2002]** @ Fermilab
  - Phys.Rev.Lett.89:011804,2002
- **NOMAD [2003]** @ CERN
  - Phys.Lett.B570:19-31,2003

νe Appearance

$\nu_\mu \rightarrow \nu e$

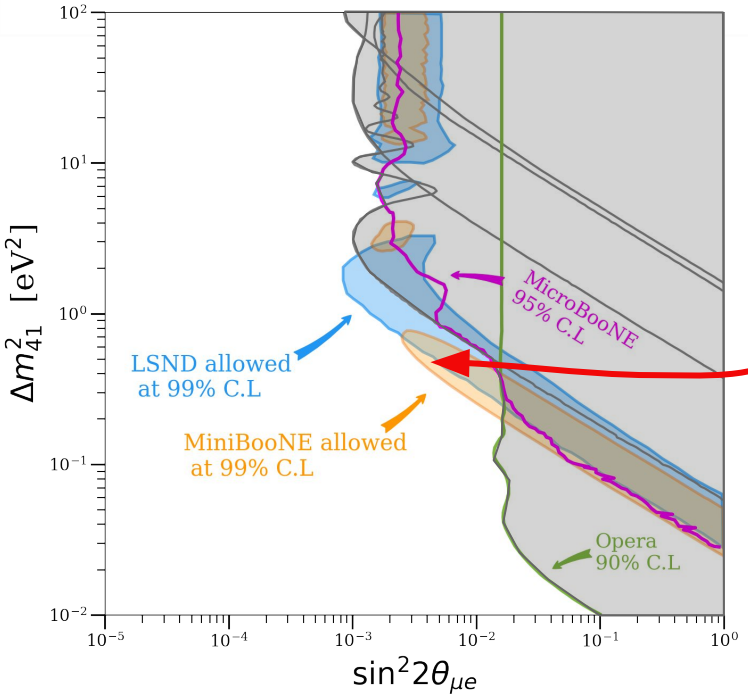


- **OPERA [2019]** @ Gran Sasso
  - Phys. Rev. D 100, 051301 (2019)
- **MicroBooNE [2023]** @ Fermilab
  - Phys. Rev. Lett. 130, 011801 (2023)



νe Appearance

$\nu_\mu \longrightarrow \nu e$



As of ***PHENO 2025***, pesky region unprobed..

Protons

Fermilab

Booster Accelerator ~8 GeV

Booster Neutrino Beam

90 ton

μBooNE

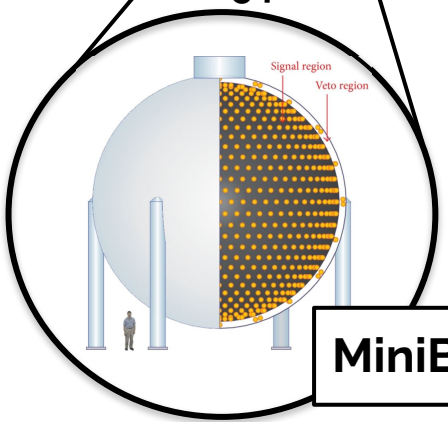
470m

540m

ν

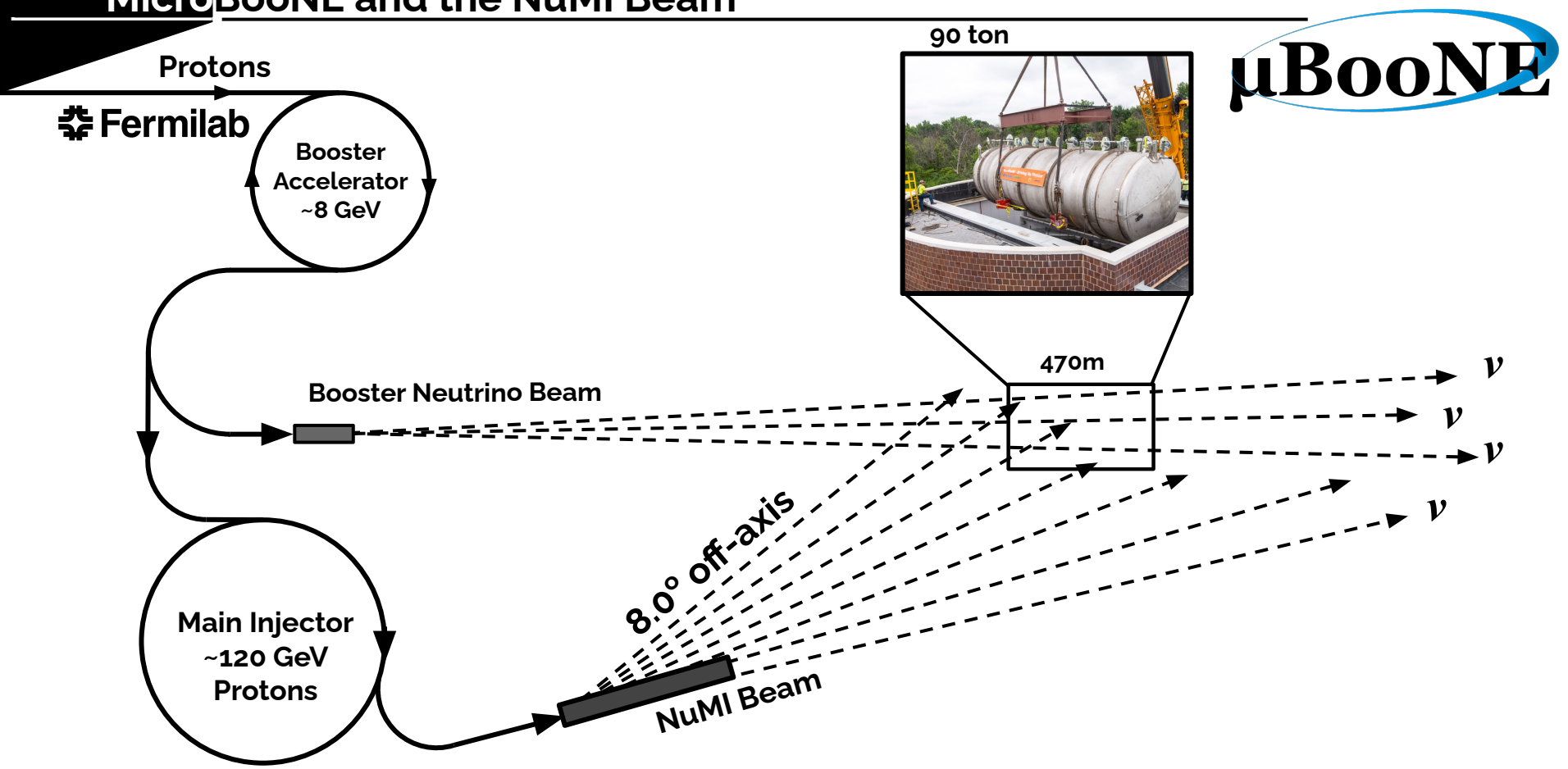
ν

ν

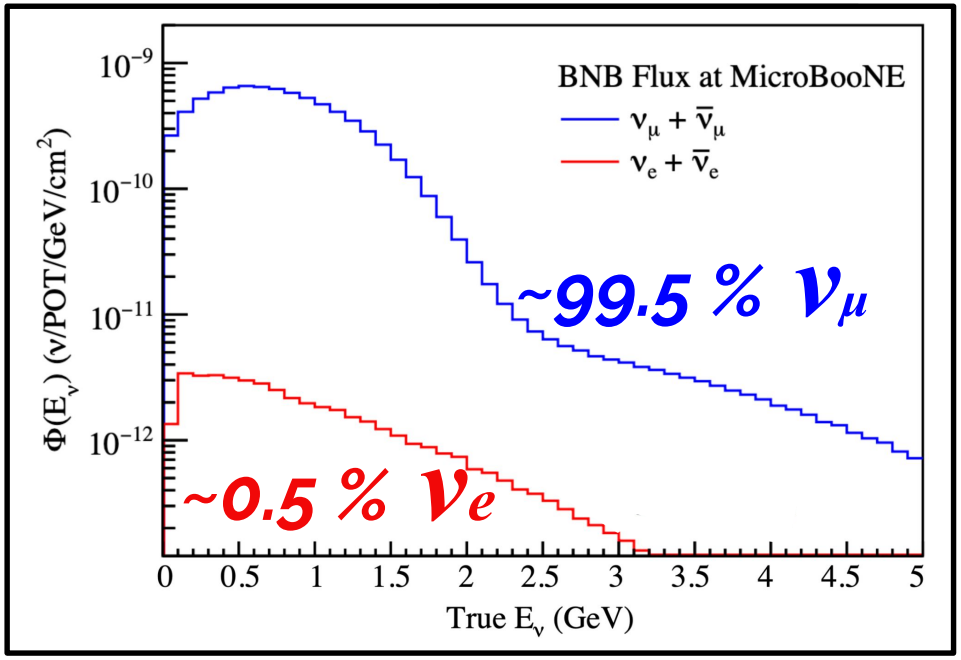


MiniBooNE

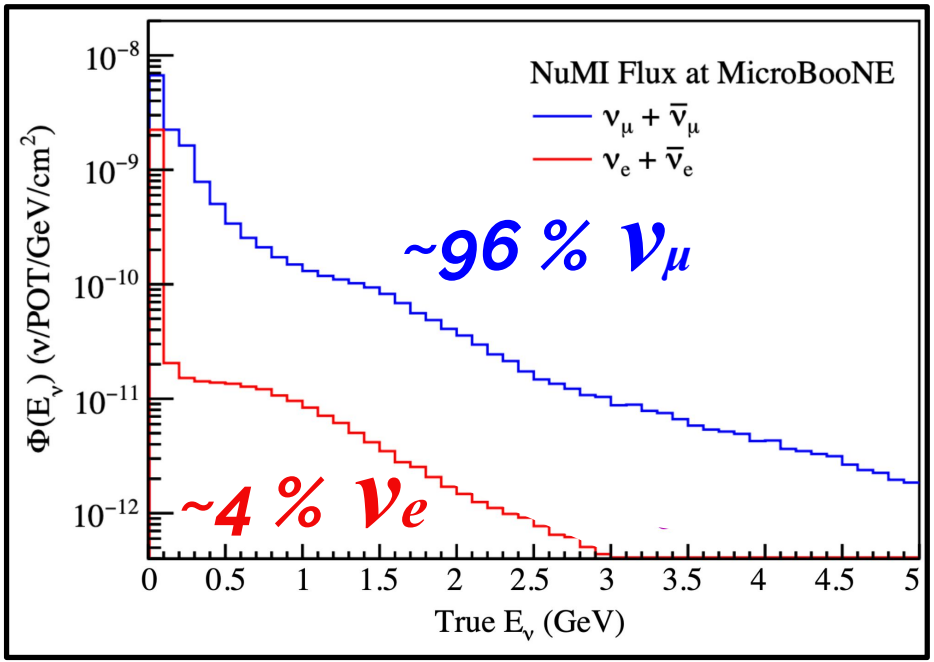
MicroBooNE and the NuMI Beam



BNB On Axis

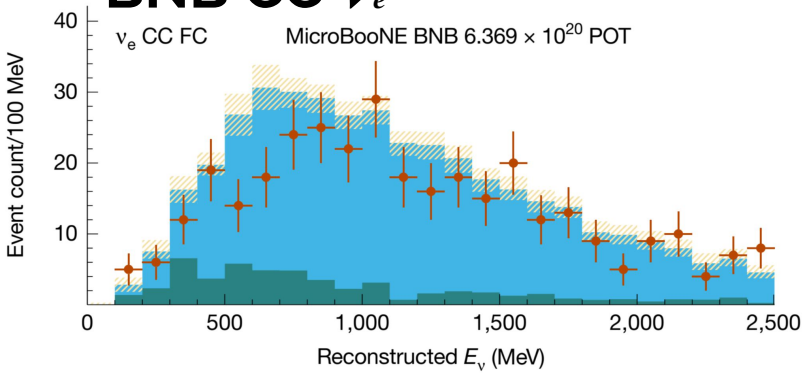


NuMI 8° off-axis

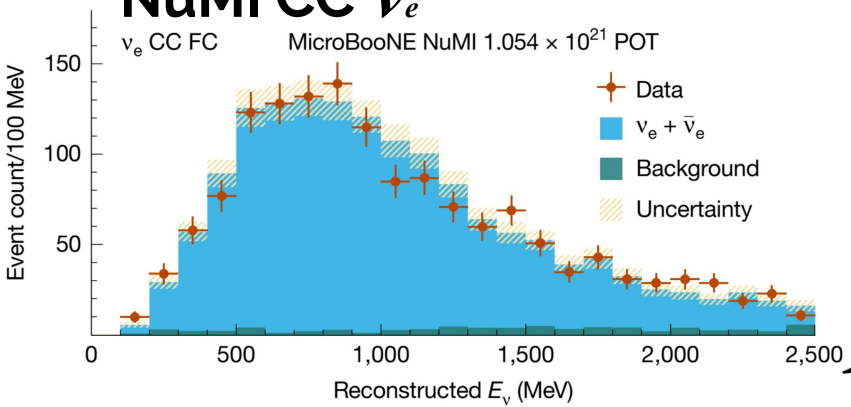


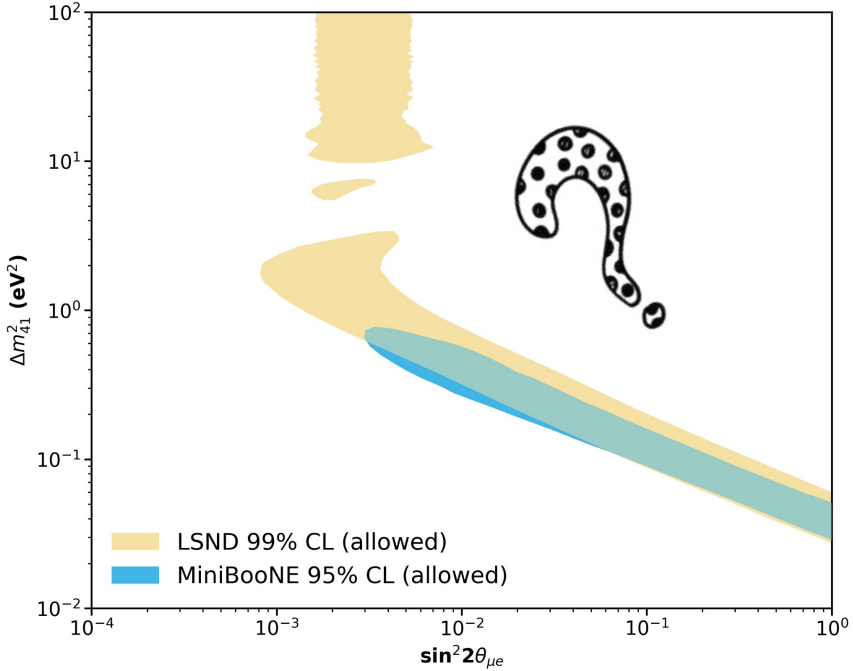
MicroBooNE and the NuMI Beam

BNB CC ν_e



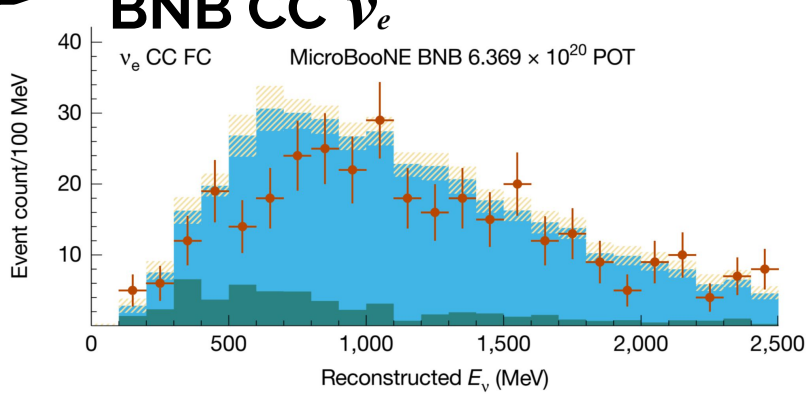
NuMI CC ν_e



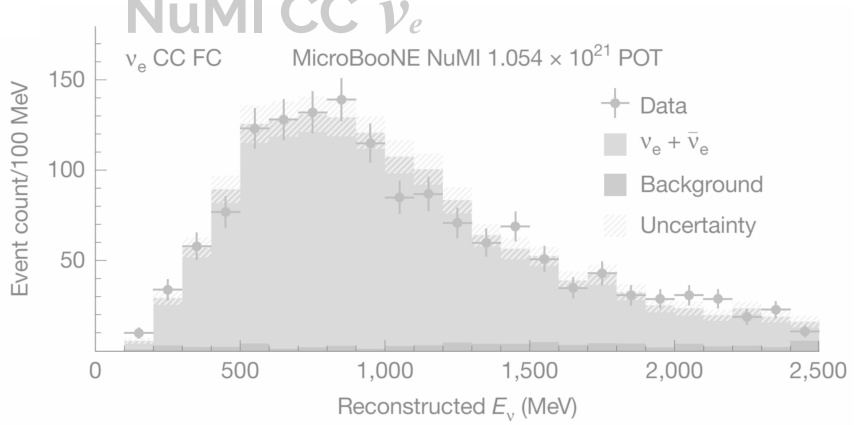


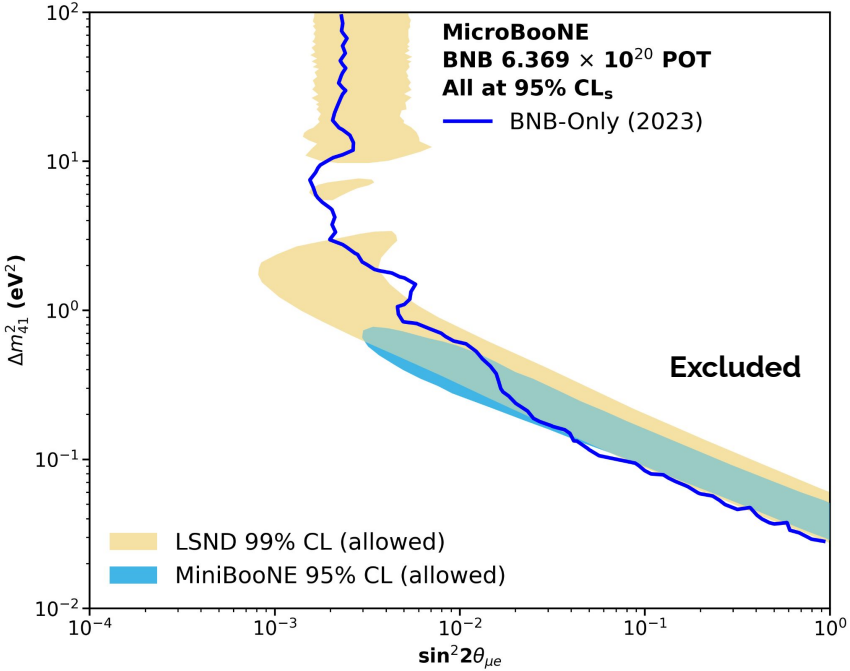
MicroBooNE BNB Only Result (2023)

BNB CC ν_e



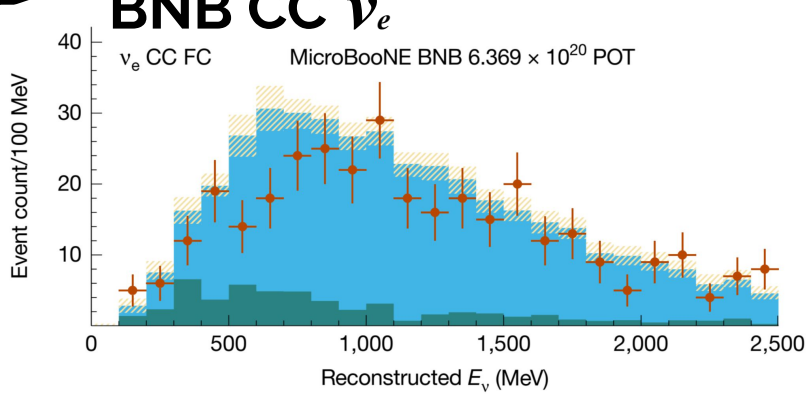
NuMI CC ν_e



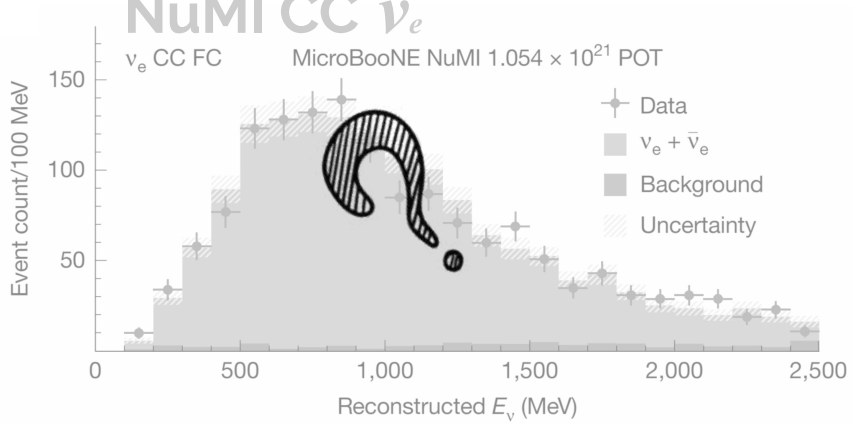


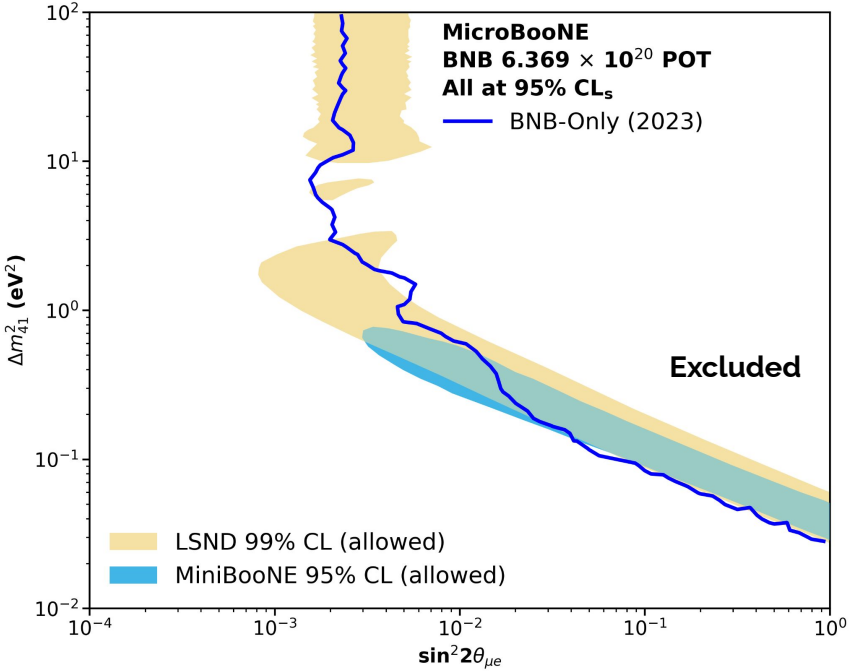
MicroBooNE BNB Only Result (2023)

BNB CC ν_e

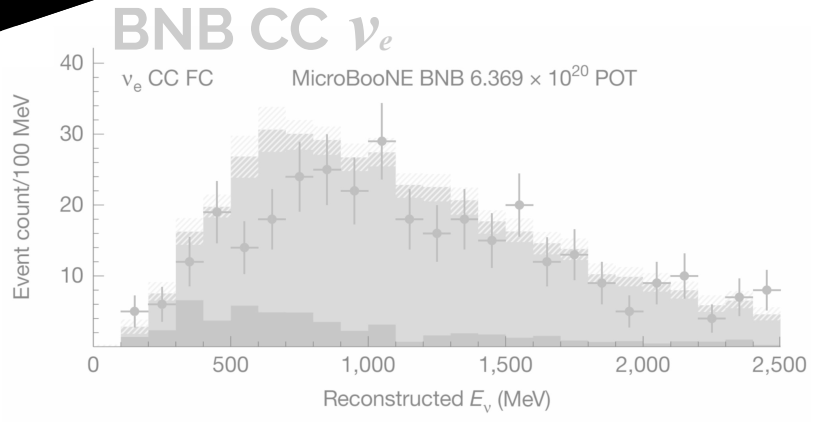


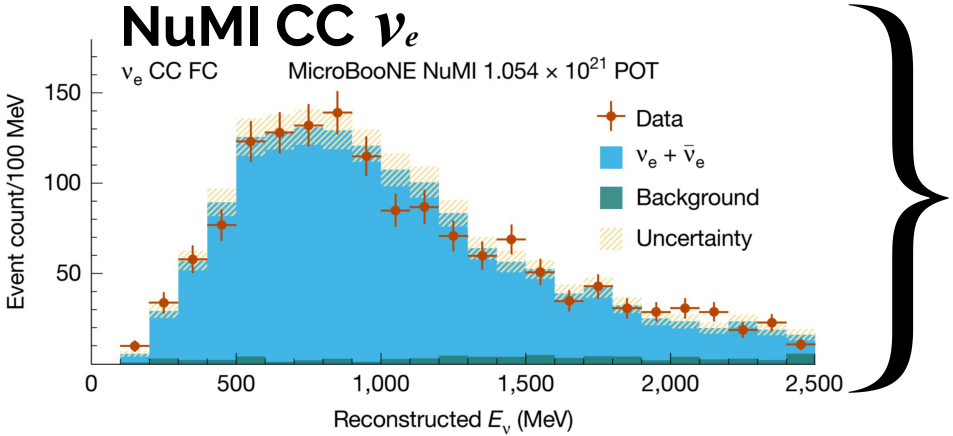
NuMI CC ν_e

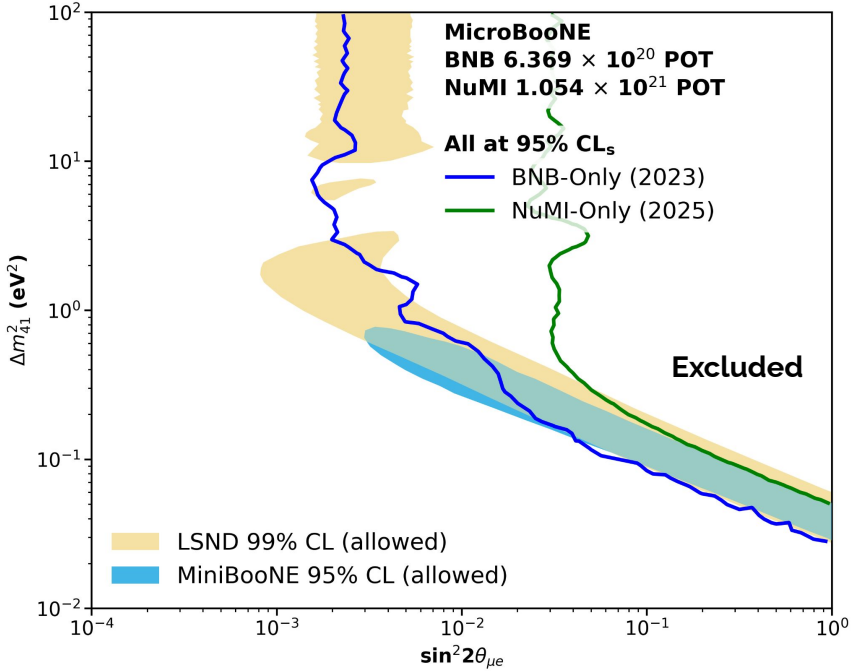




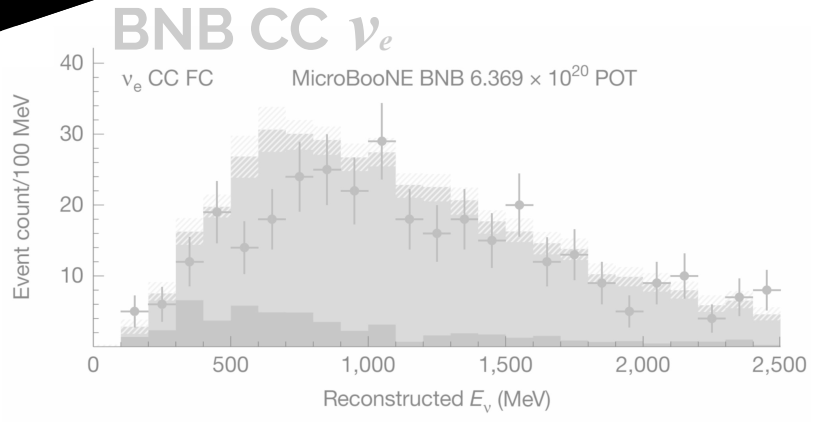
MicroBooNE NuMI Only Result

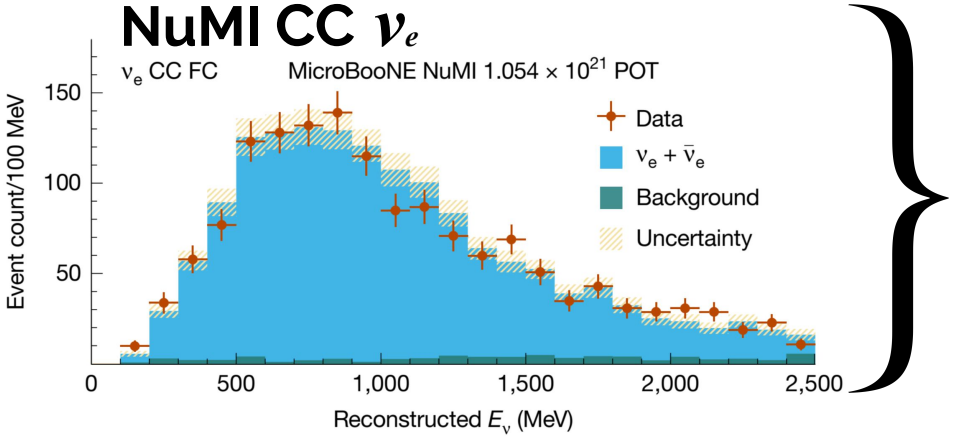


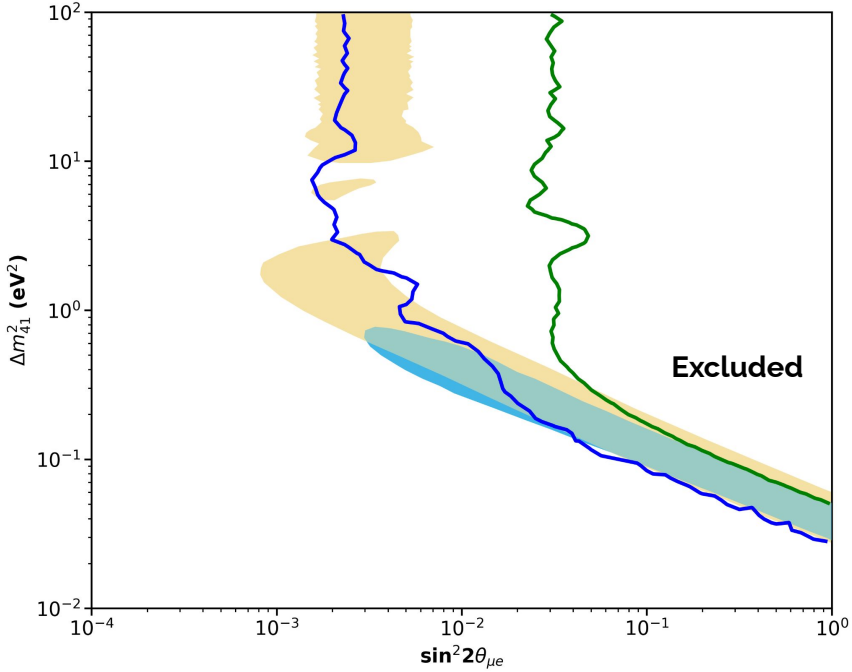




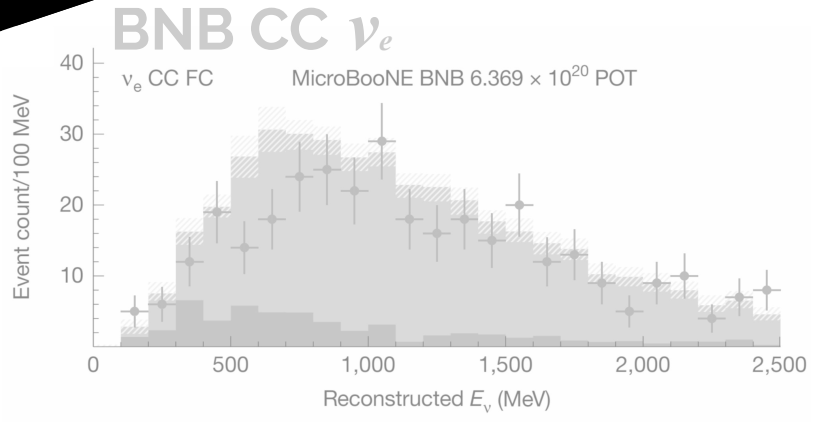
MicroBooNE NuMI Only Result

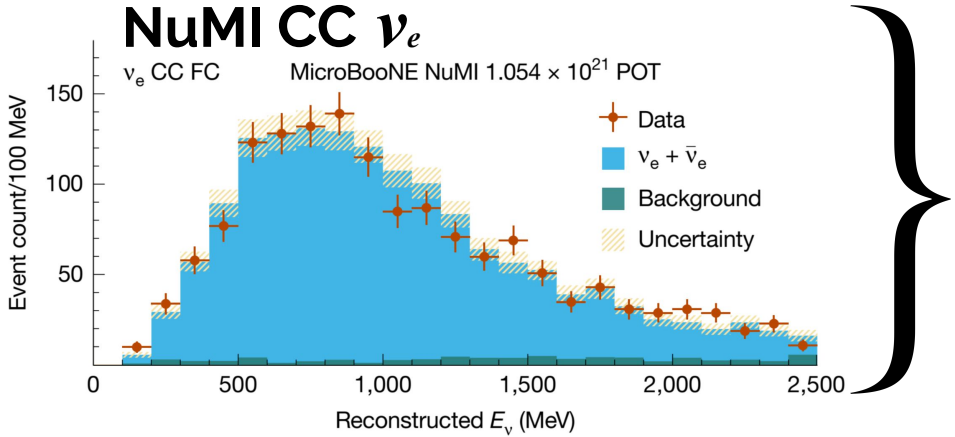


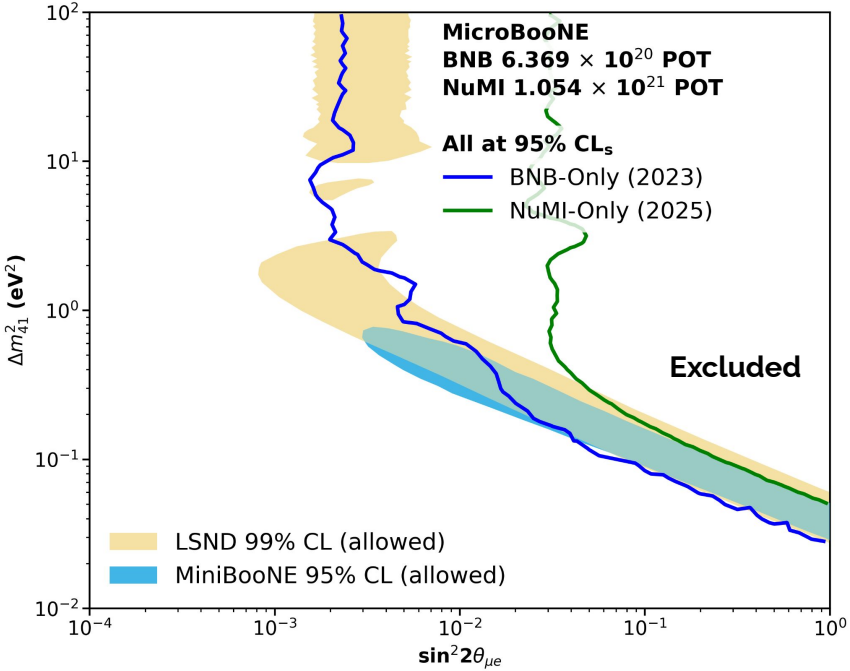




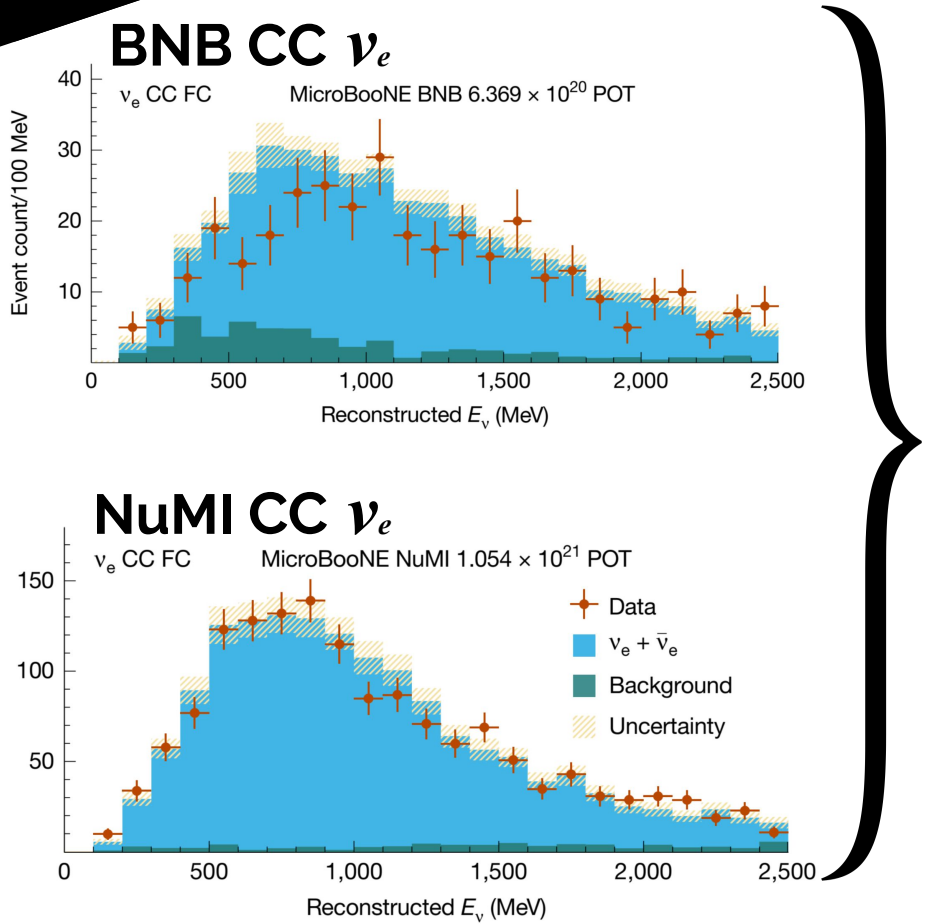
MicroBooNE NuMI Only Result

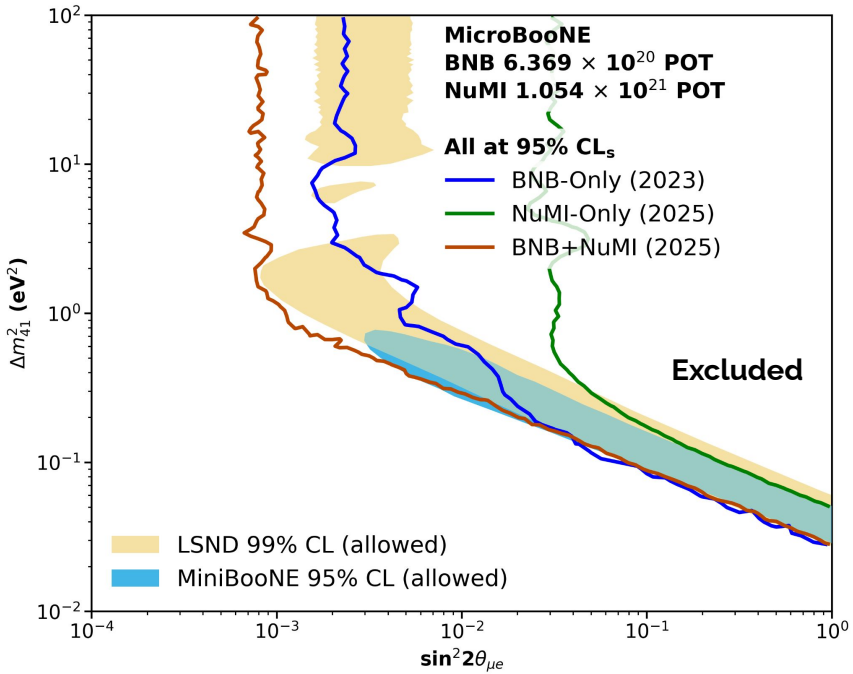






MicroBooNE BNB+NuMI Dual Beam Result (2026)



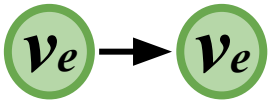


MicroBooNE: Nature volume 648, 64–69 (2025)

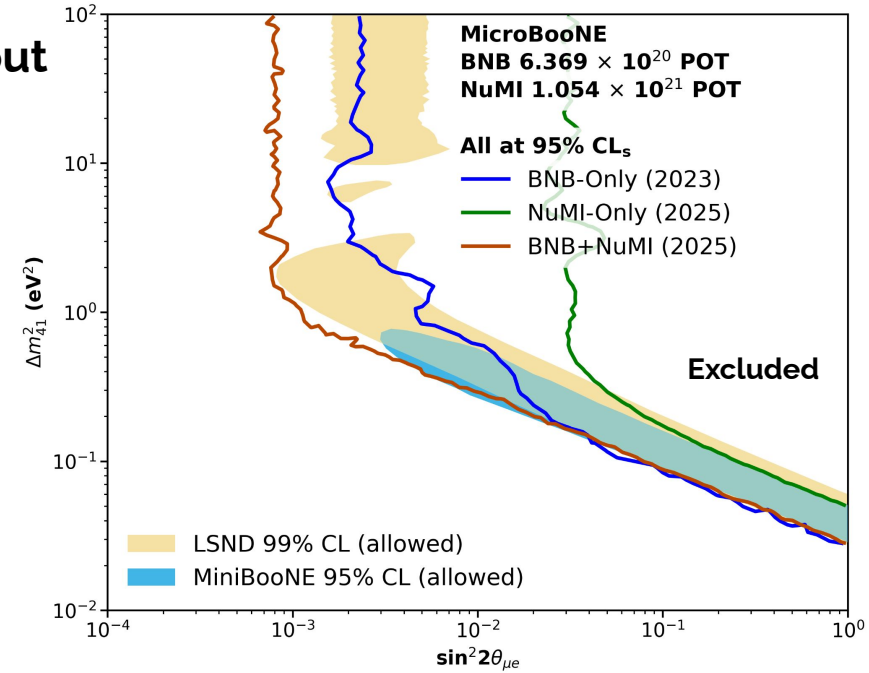
MicroBooNE 3+1 Degeneracy

ν_e appearance

ν_e disappearance



Not independent
Can't have appearance without associate disappearance



MicroBooNE 3+1 Degeneracy

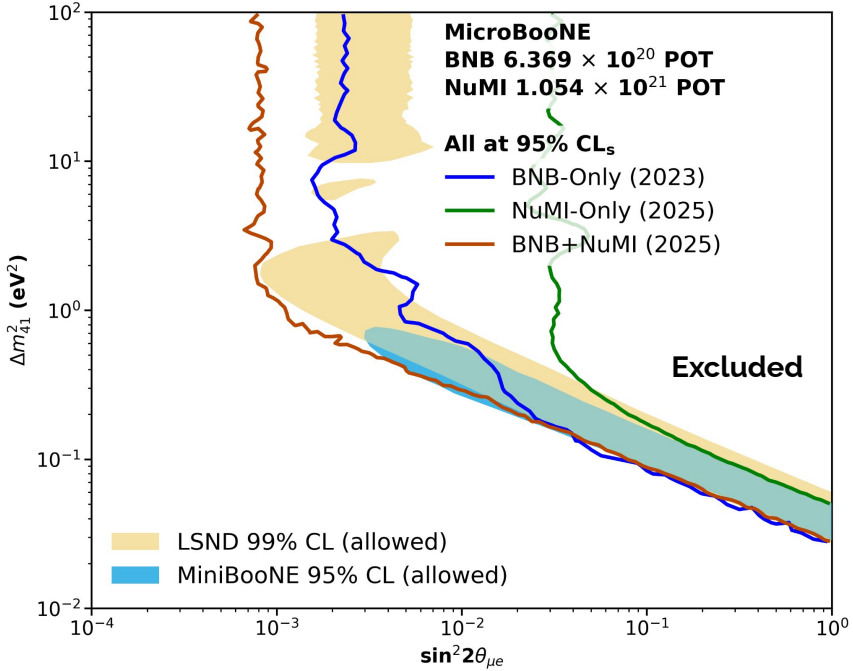
ν_e appearance

$\nu_\mu \rightarrow \nu_e$

ν_e disappearance

$\nu_e \rightarrow \nu_e$

$$\propto N_{\nu_\mu} \times \sin^2 2\theta_{\mu e}$$

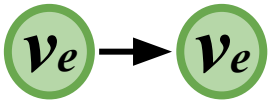


MicroBooNE 3+1 Degeneracy

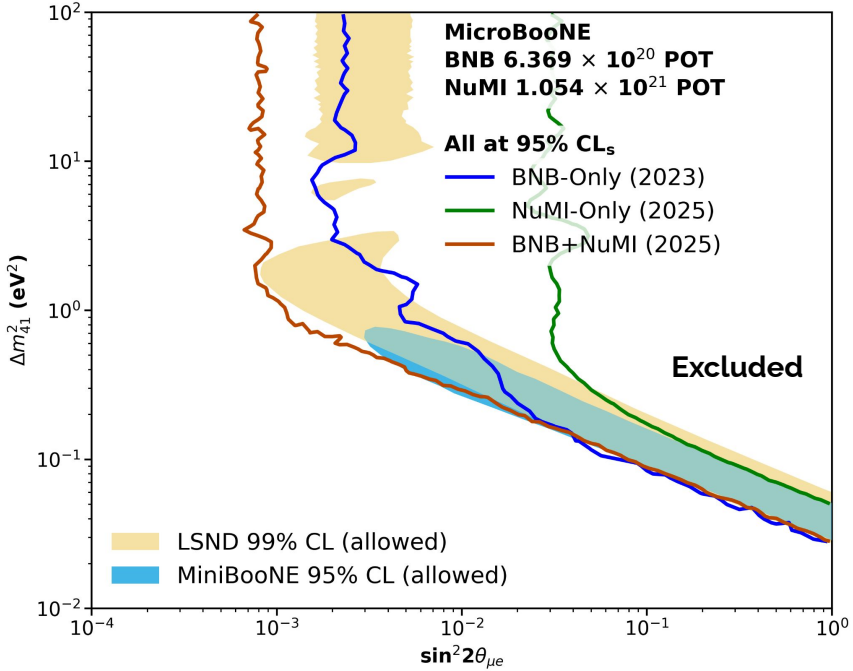
ν_e appearance

$\propto N_{\nu_\mu} \times \sin^2 2\theta_{\mu e}$

ν_e disappearance



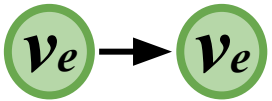
$\propto N_{\nu_e} \times \sin^2 2\theta_{ee}$



MicroBooNE 3+1 Degeneracy

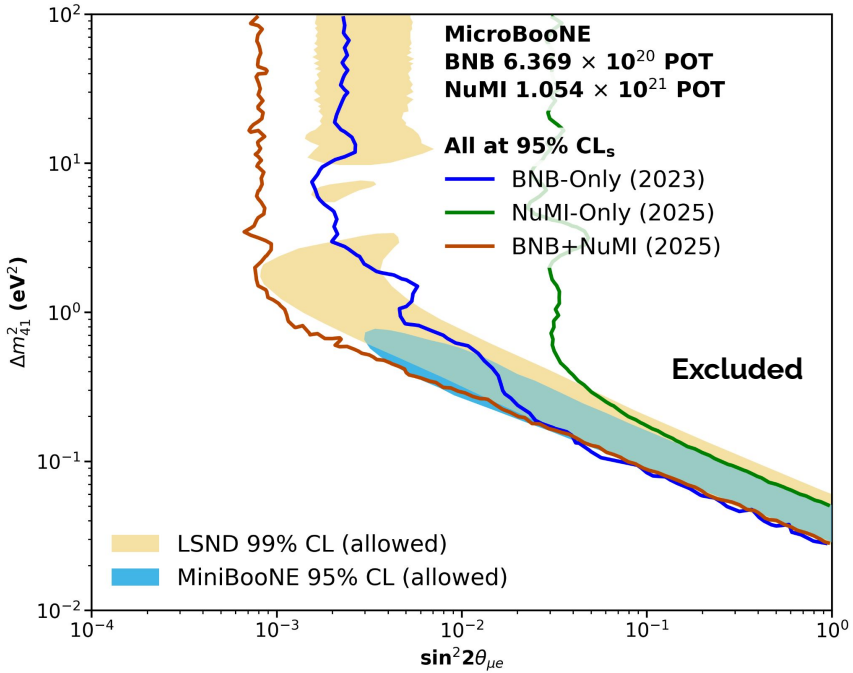
ν_e appearance

ν_e disappearance



$$\propto N_{\nu_\mu} \times \sin^2 2\theta_{\mu e}$$

$$\propto N_{\nu_e} \times \sin^2 2\theta_{ee}$$

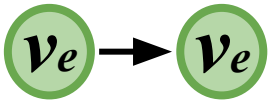


MicroBooNE 3+1 Degeneracy

ν_e appearance

$\propto N_{\nu_\mu} \times \sin^2 2\theta_{\mu e}$

ν_e disappearance

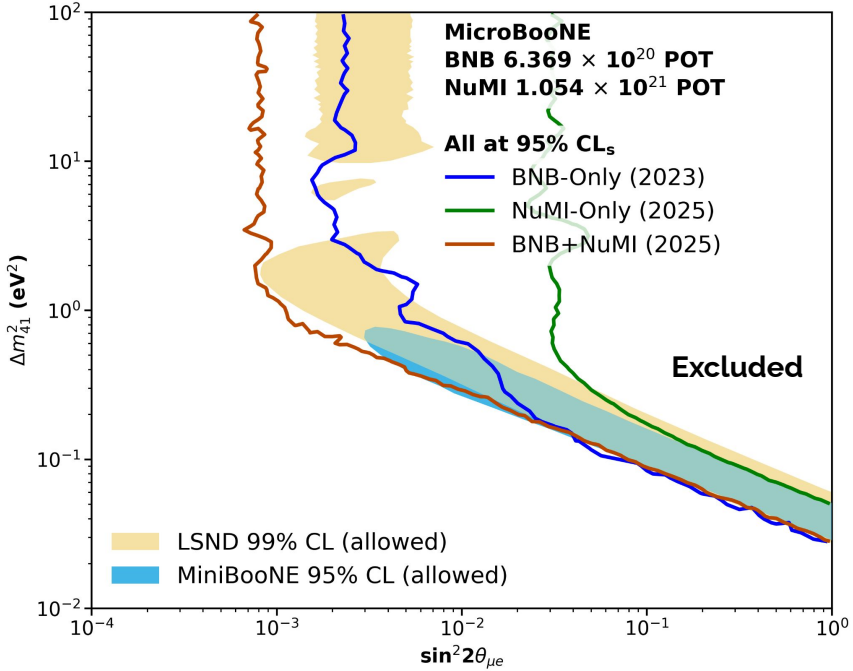


$\propto N_{\nu_e} \times \sin^2 2\theta_{ee}$

Cancellation/Degeneracy point

Disappearance Cancels Observable Appearance

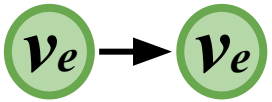
$$\frac{N\nu_\mu}{N\nu_e} = \frac{\sin^2 2\theta_{ee}}{\sin^2 2\theta_{\mu e}}$$



MicroBooNE 3+1 Degeneracy

ν_e appearance

ν_e disappearance



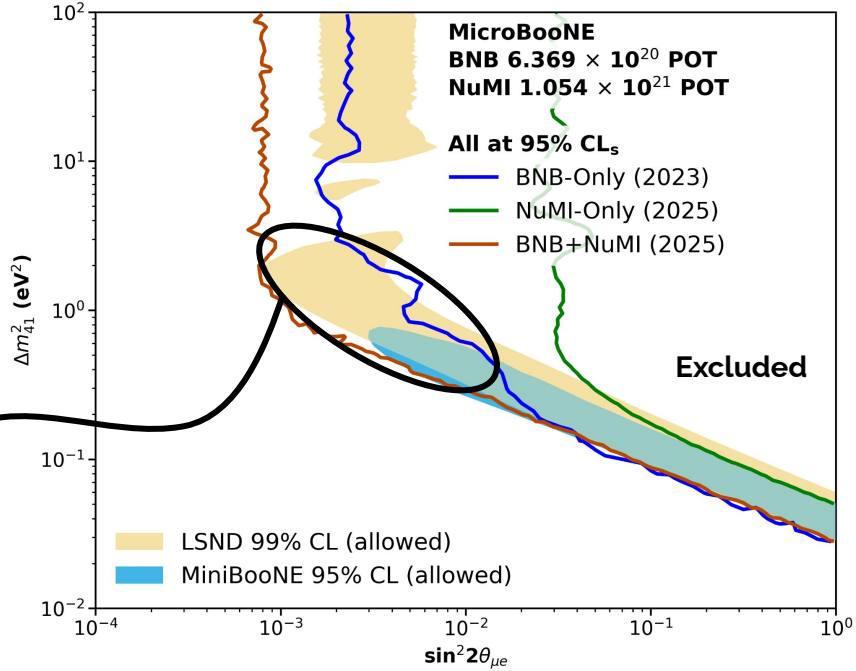
$$\propto N_{\nu_\mu} \times \sin^2 2\theta_{\mu e}$$

$$\propto N_{\nu_e} \times \sin^2 2\theta_{ee}$$

Cancellation/Degeneracy point

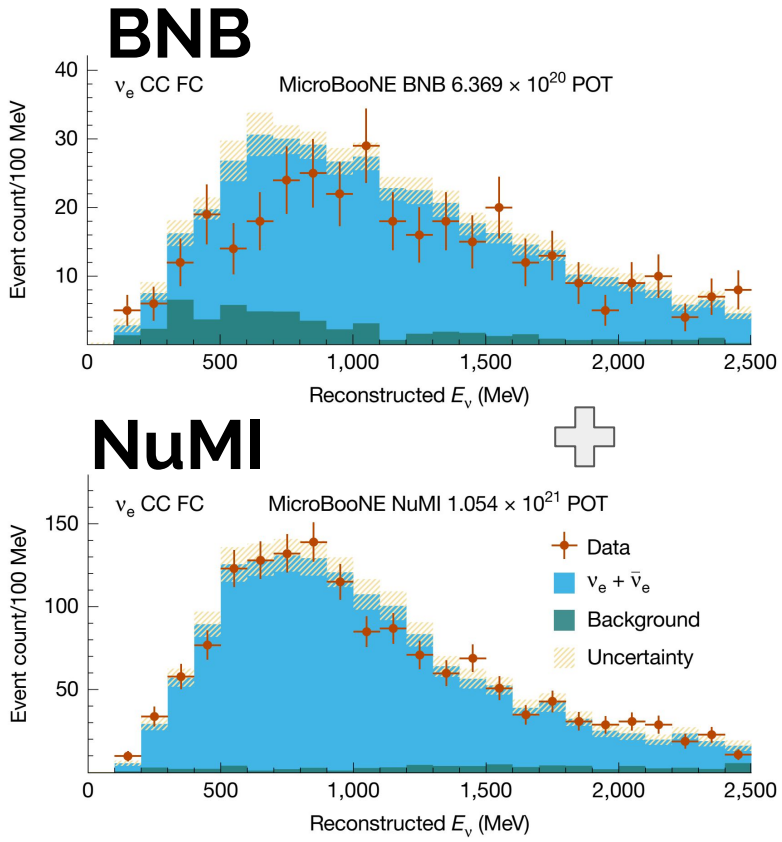
Disappearance Cancels Observable Appearance

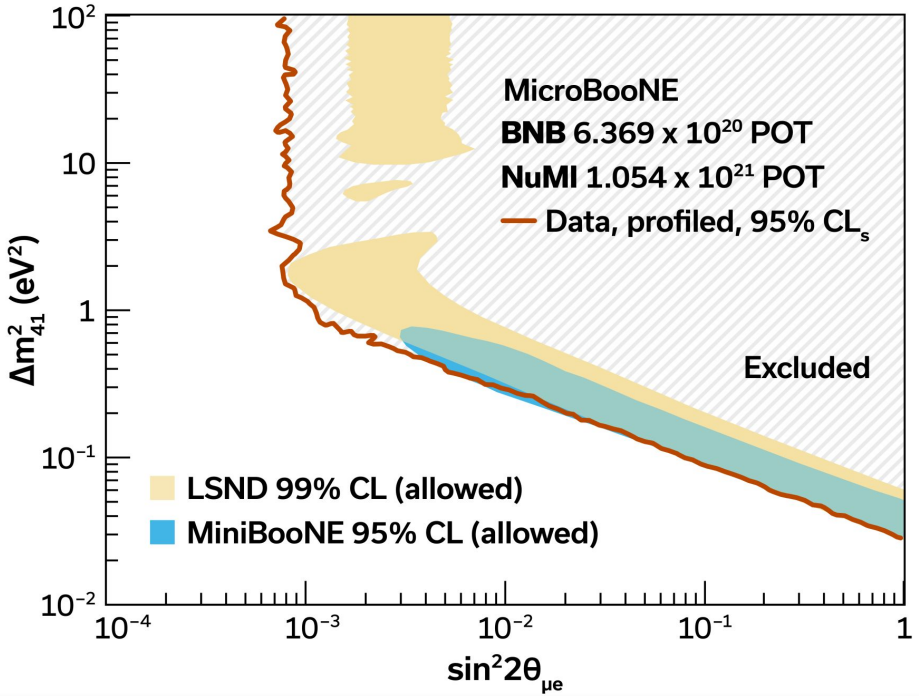
$$\frac{N\nu_\mu}{N\nu_e} = \frac{\sin^2 2\theta_{ee}}{\sin^2 2\theta_{\mu e}}$$



BNB+ NuMI Two Beam Result (2025)

MicroBooNE: Nature volume 648, 64–69 (2025)



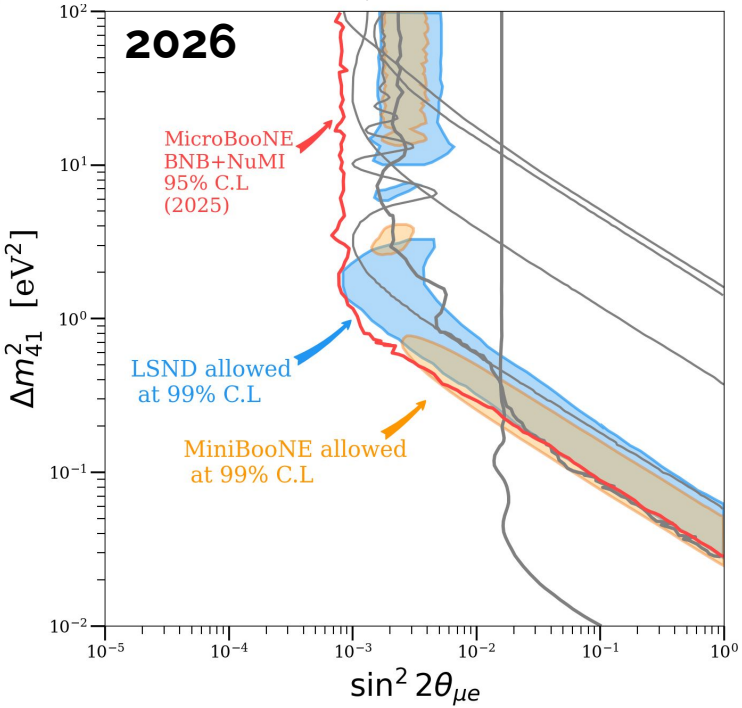


MicroBooNE 95% CL result

- **Excludes entire LSND** 99% allowed region
- **Excludes vast majority of MiniBooNE** 95% allowed region

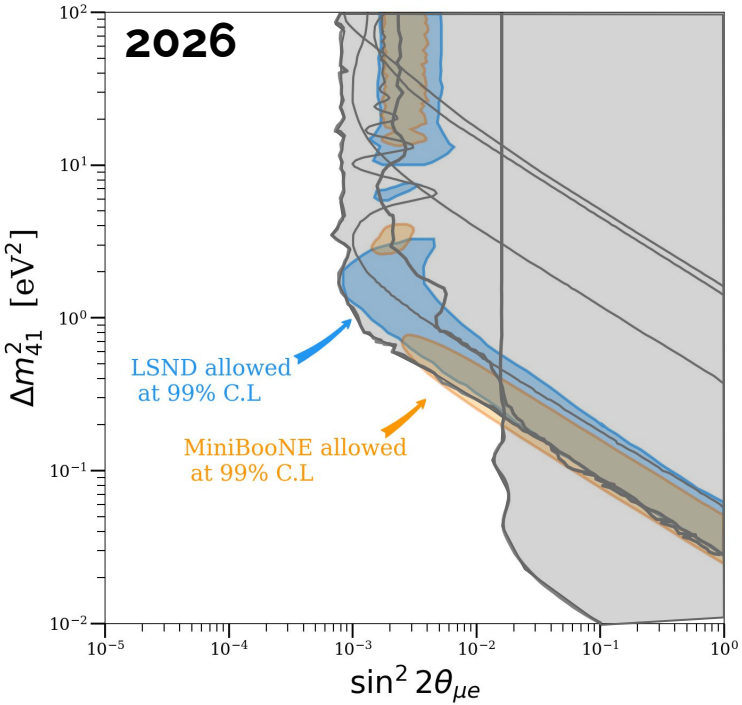
νe Appearance

$\nu_\mu \longrightarrow \nu e$



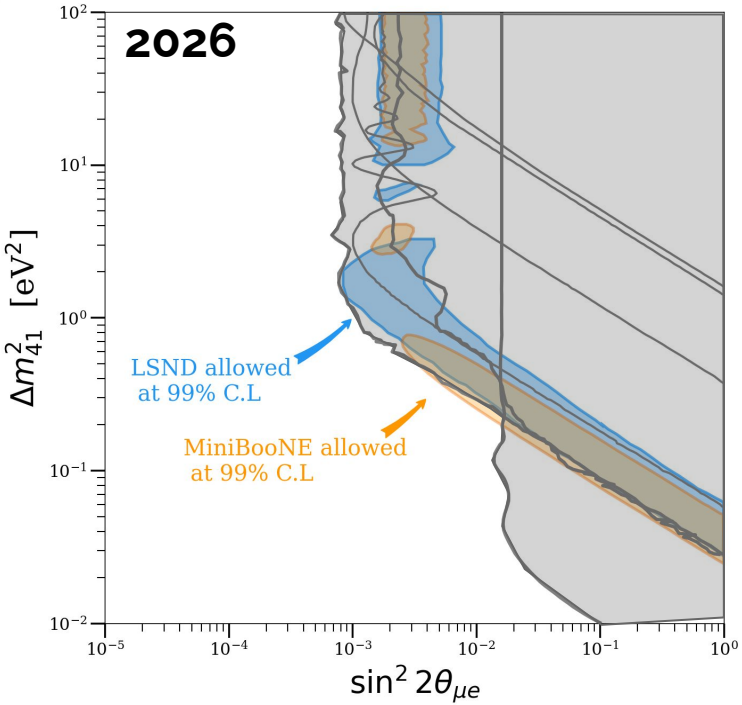
νe Appearance

$\nu_\mu \longrightarrow \nu e$

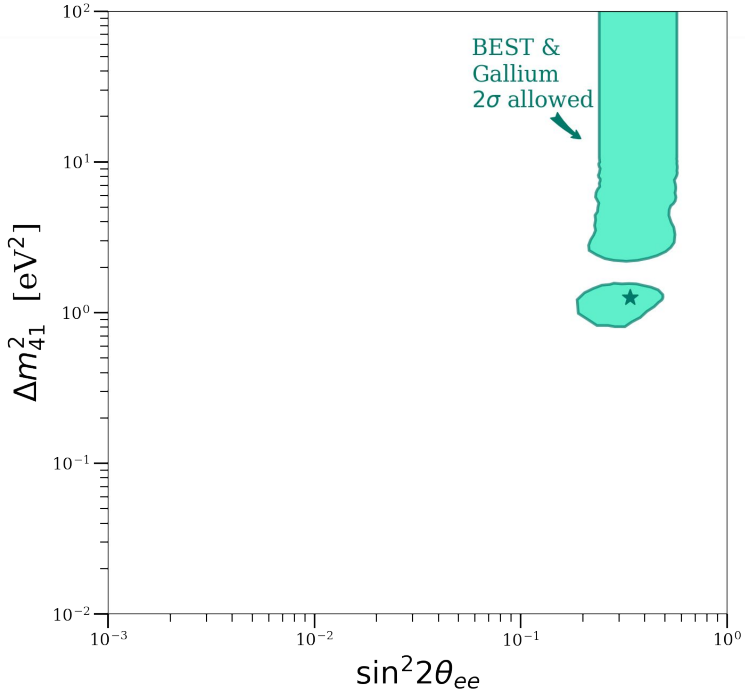


νe Disappearance

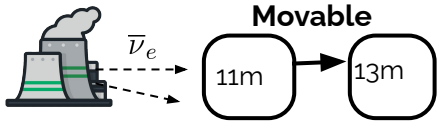
$\nu_\mu \longrightarrow \nu e$



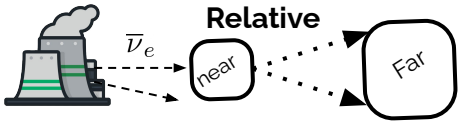
$\nu e \longrightarrow \nu e$



νe Disappearance

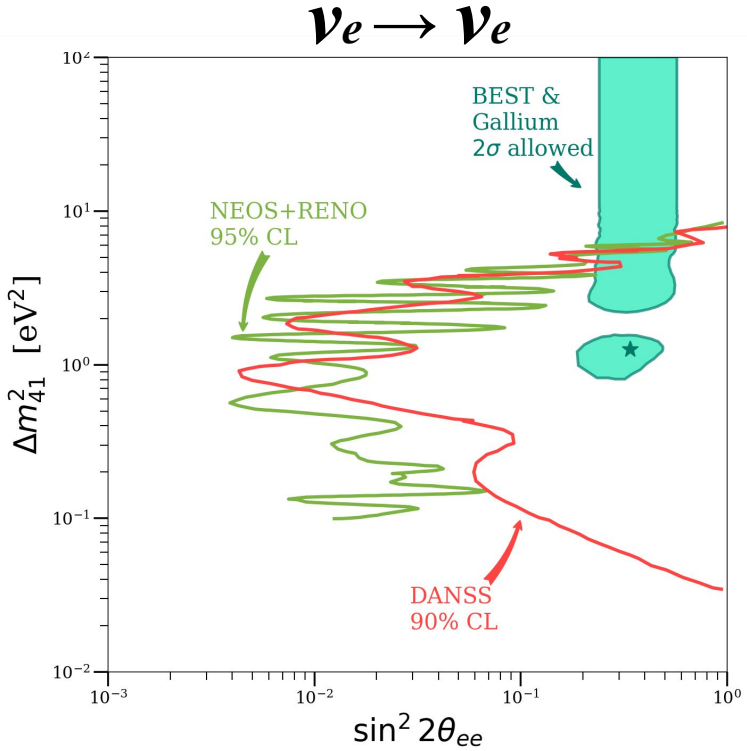


DANSS, Movable detector in Russia,
Phys.Lett.B 787(2018)56-63

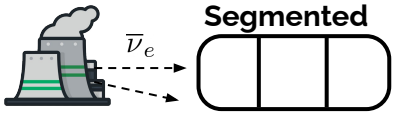


NEOS+RENO, relative 419 m RENO and 24m NEOS detectors in Korea
Phys. Rev. D 105, L111101 (2022)

Need to get closer to reactors!



νe Disappearance

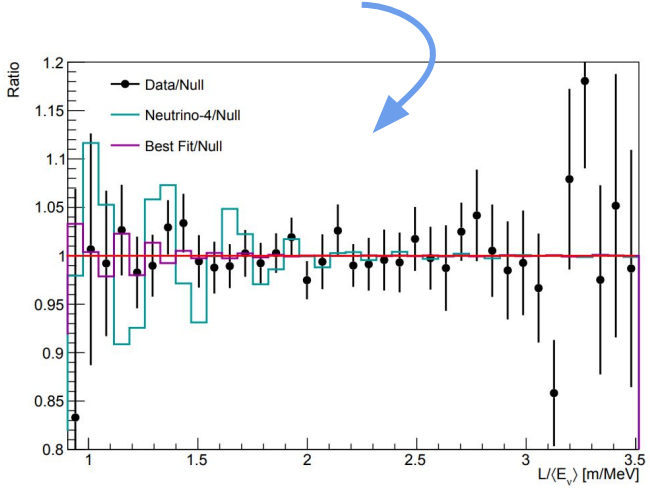


STEREO (ILL, Grenoble, France)

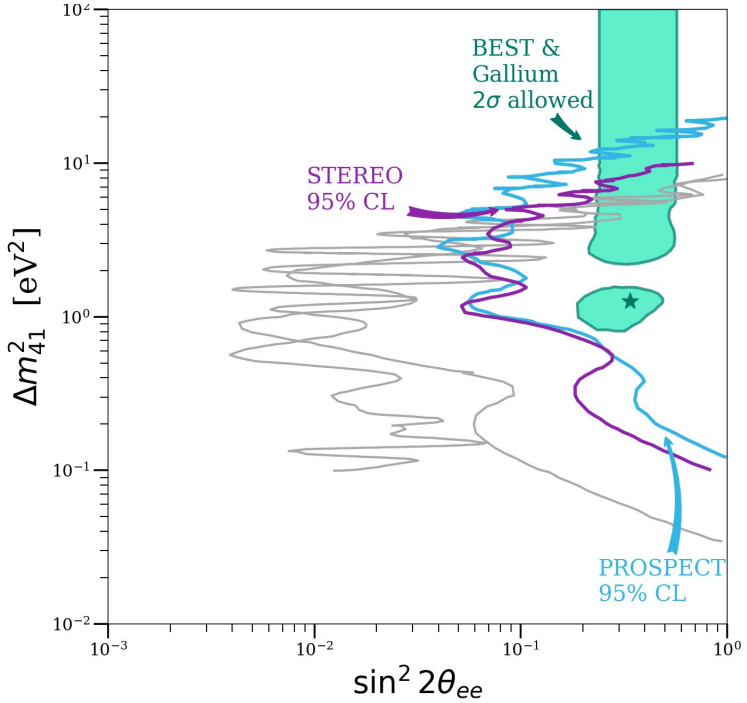
- Nature 613, 257–261 (2023)
- **9.4 to 11.1 m Baselines**

PROSPECT (Oak Ridge National Lab, USA)

- arXiv:2406.10408 [hep-ex] (2024)
- **7-9 m Baselines**



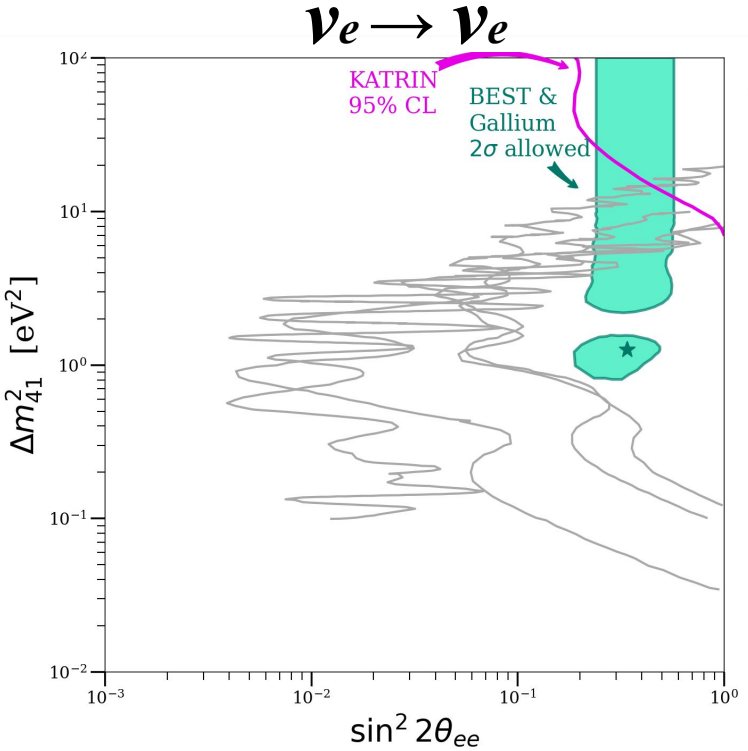
$\nu e \longrightarrow \nu e$



νe Disappearance

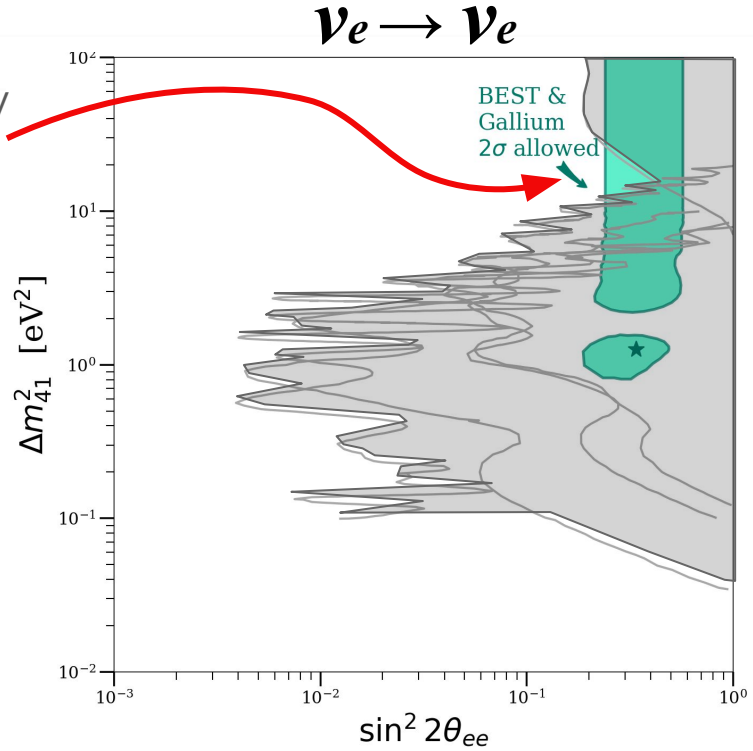
KATRIN in Karlsruhe Germany
Designed to determine the **neutrino mass** from kinematic measurements of the **β-decay of tritium**
PhysRevD.105.072004 (2022)

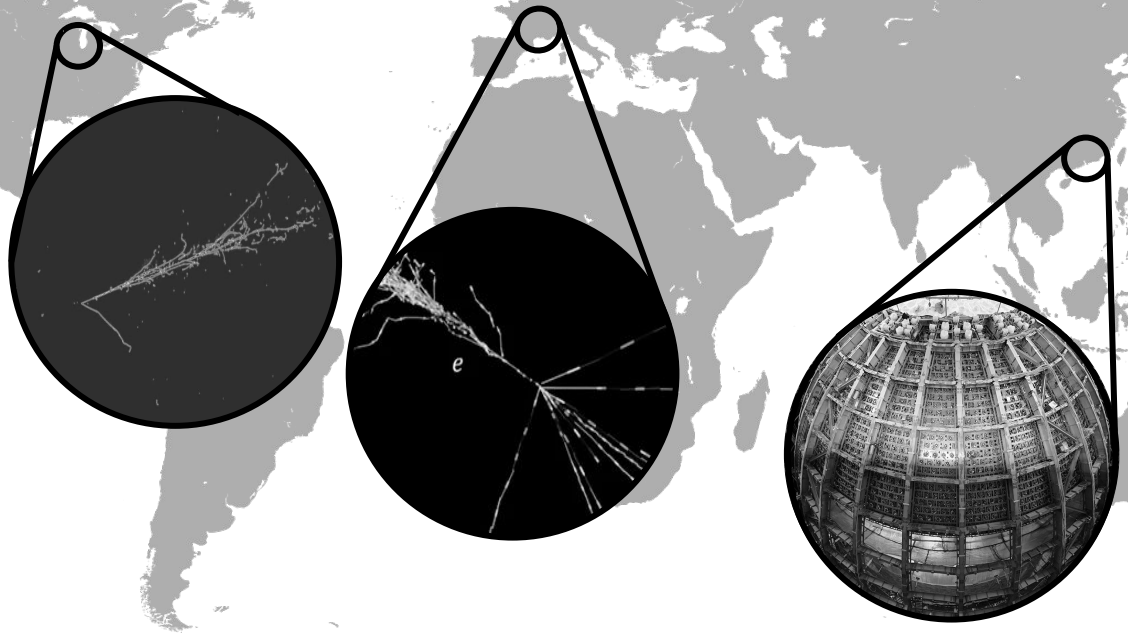
Unique! KATRIN is a **non-oscillatory** lab experiment sensitive to relevant solutions at large Δm^2 values!

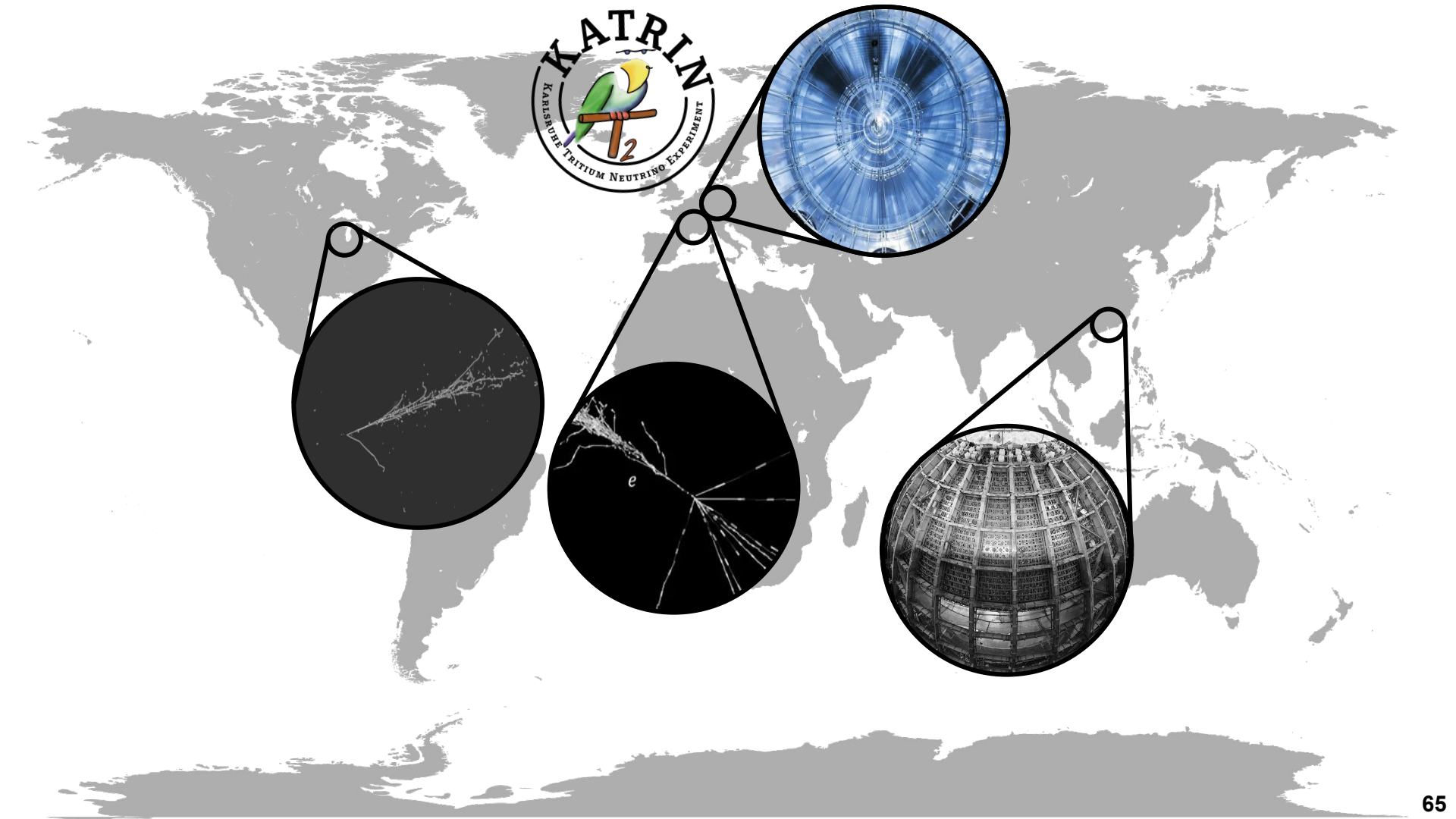


νe Disappearance

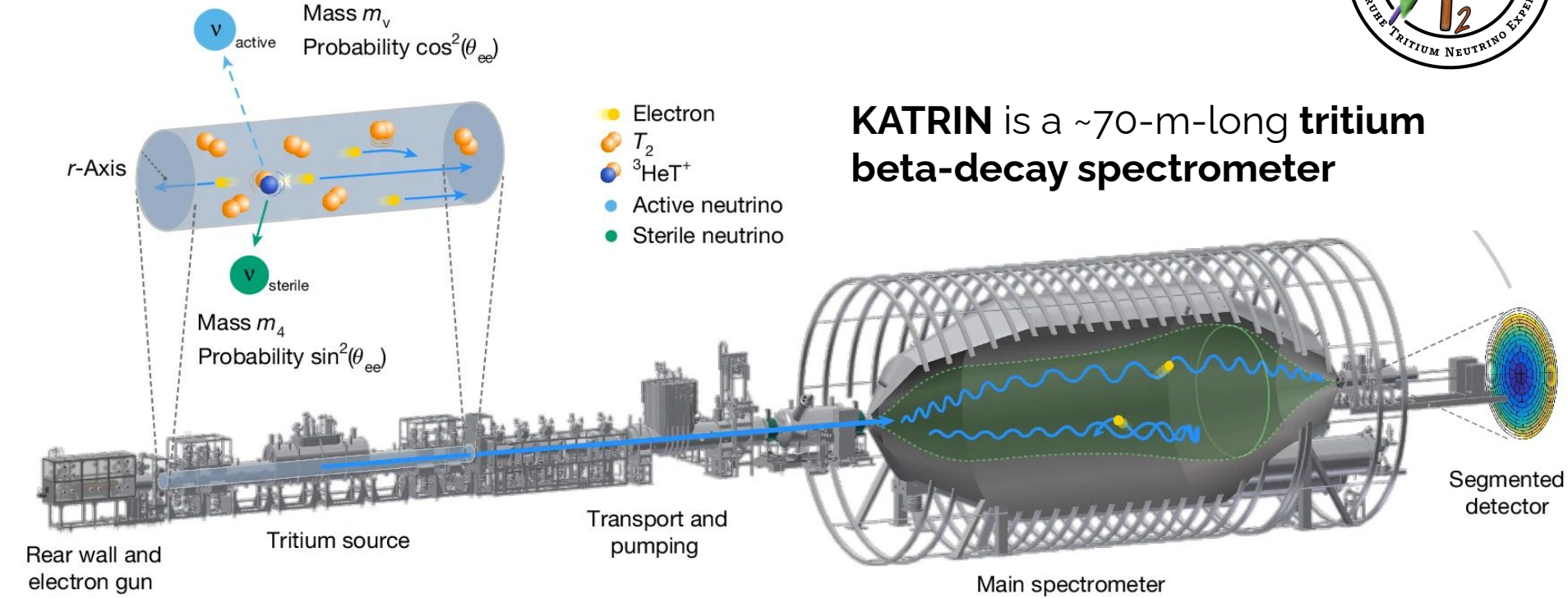
As of **PHENO 2025**, pesky **"Gap"** region unprobed..




e


KATRIN
Karlsruhe Tritium Neutrino Experiment
T2
e

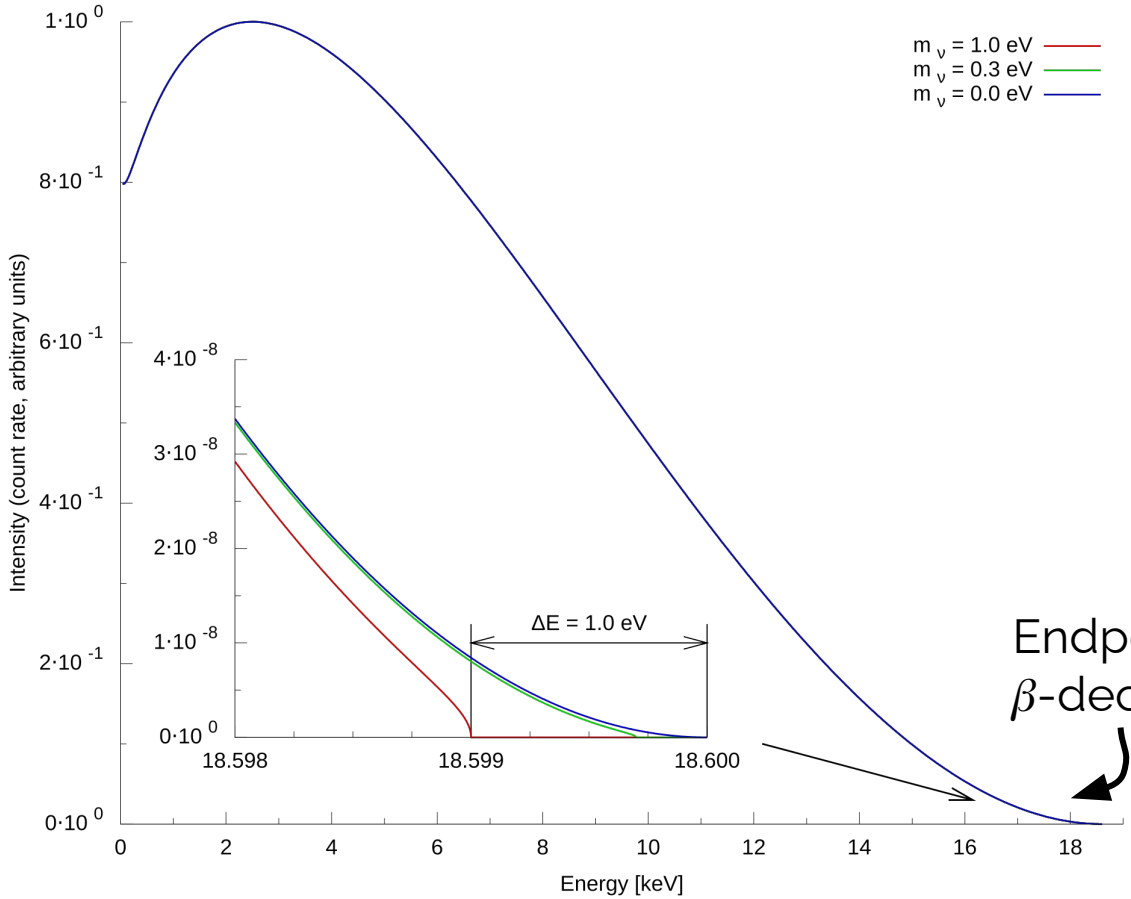
KATRIN: Karlsruhe Tritium Neutrino Experiment



KATRIN is a ~70-m-long **tritium beta-decay spectrometer**

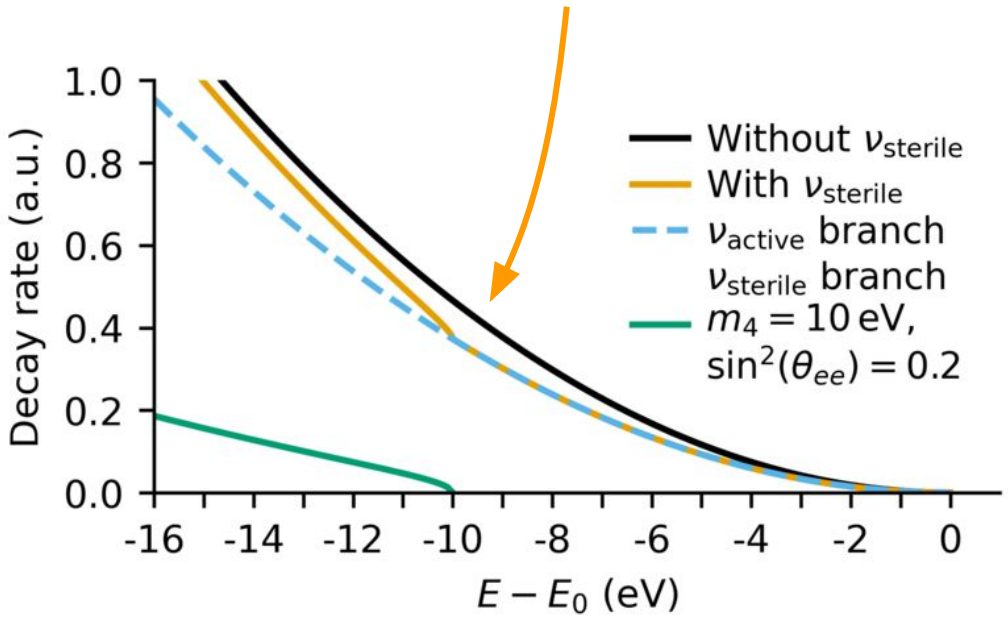
MAC-E-Filter

KATRIN: Absolute Neutrino Mass Measuement



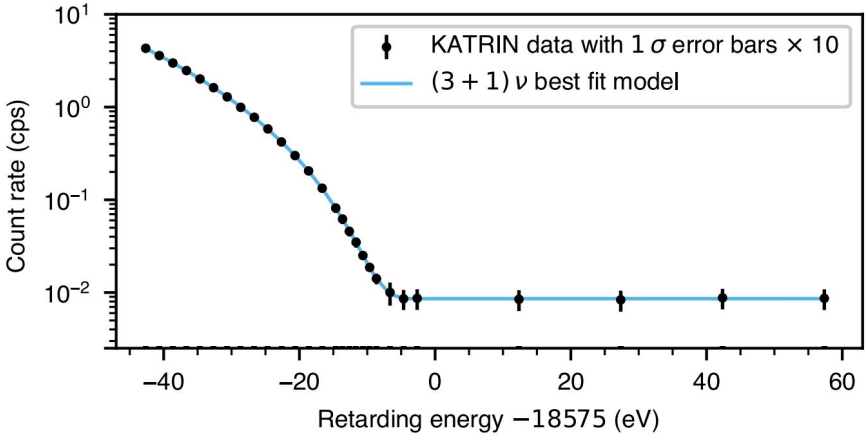
Endpoint of Tritium β-decay ~ **neutrino mass**

"Kink" further up from endpoint of Tritium β-decay ~ **Sterile neutrinos**



KATRIN *Nature* 648, 70–75 (2025)

KATRIN: Updated Sterile Search

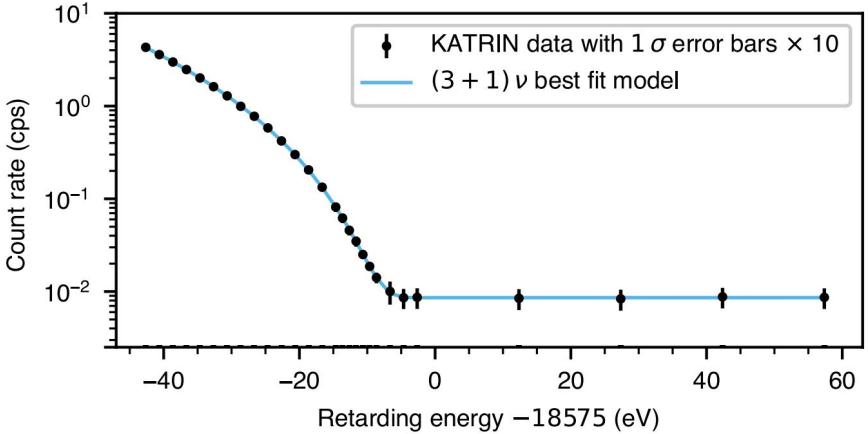


Analyzed **36 million tritium β-decay electrons** in a data set taken over **259 days**

- **A sixfold increase in statistics** over 2022 results
- **Substantial improvements** understanding of **systematics.**

KATRIN *Nature* 648, 70–75 (2025)

KATRIN: Updated Sterile Search



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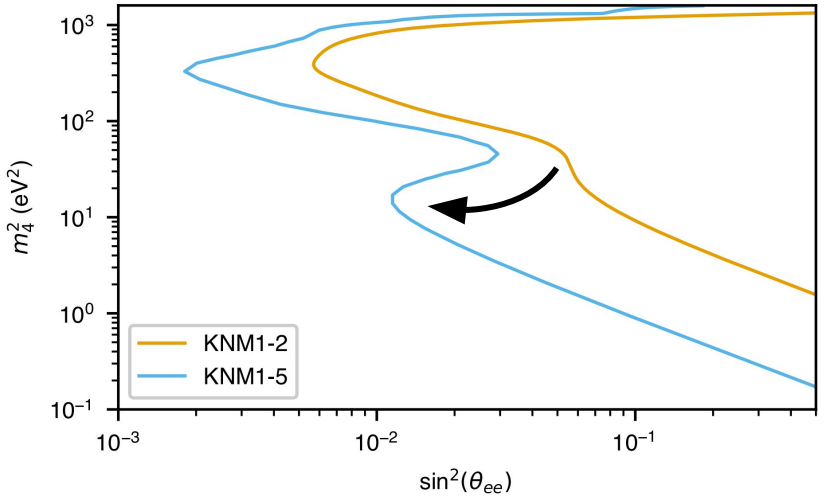
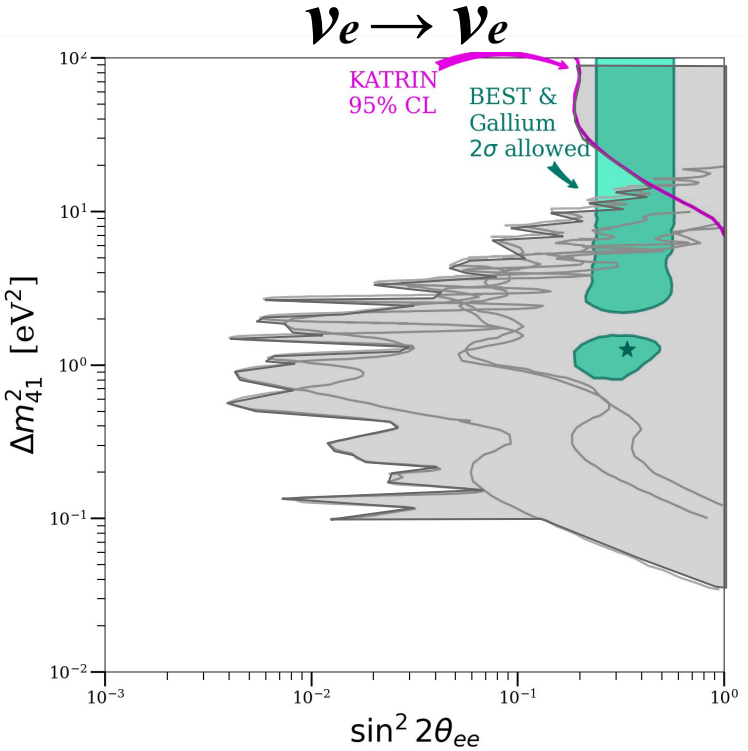


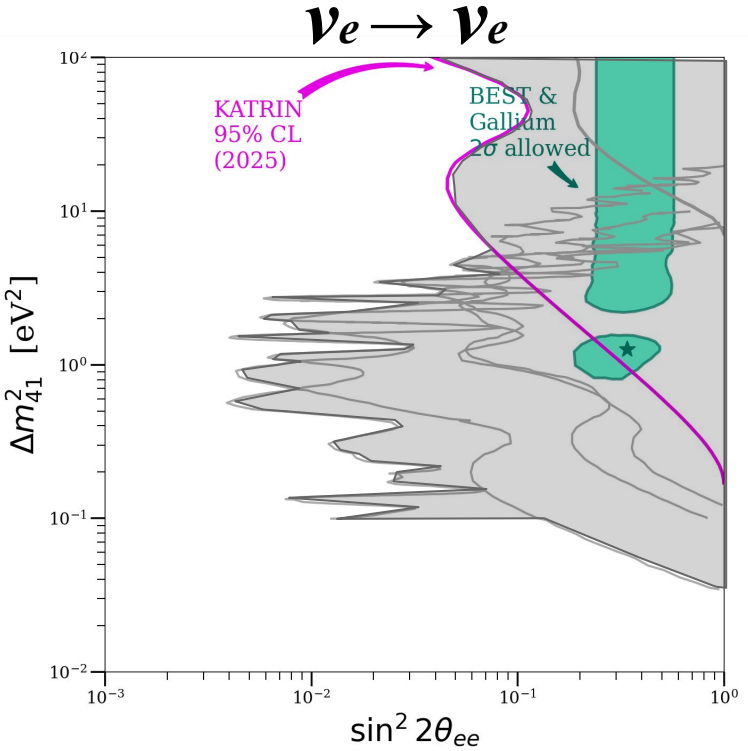
KATRIN *Nature* 648, 70–75 (2025)

νe Disappearance



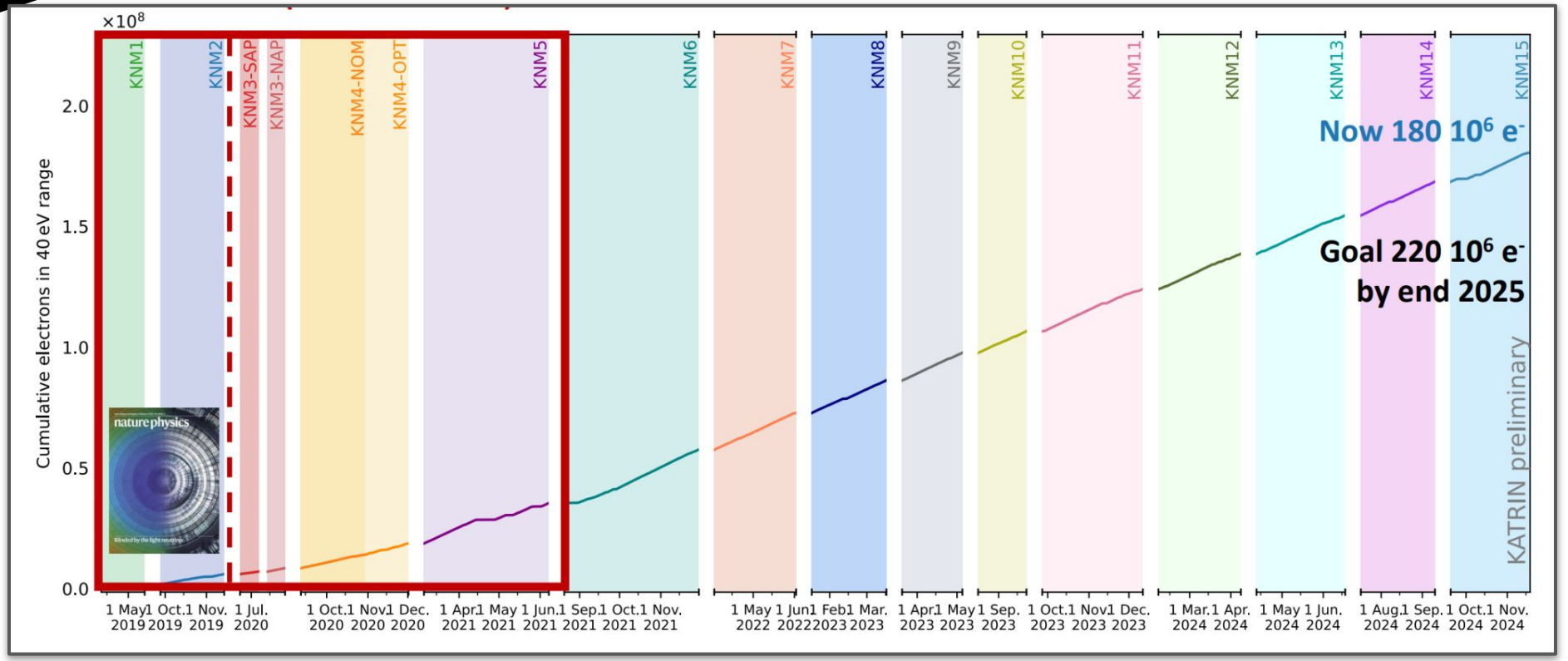
KATRIN *Nature* 648, 70–75 (2025)

νe Disappearance

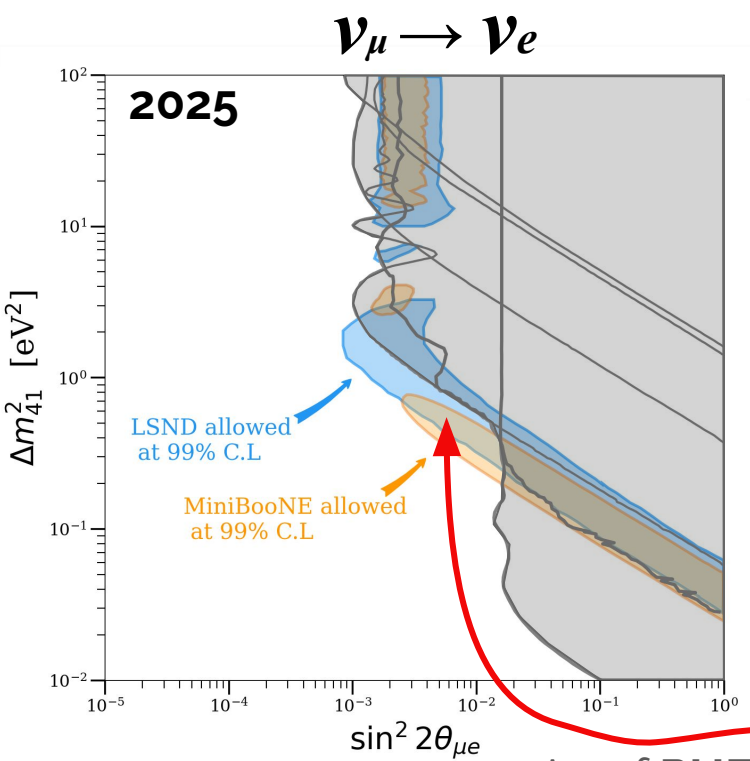


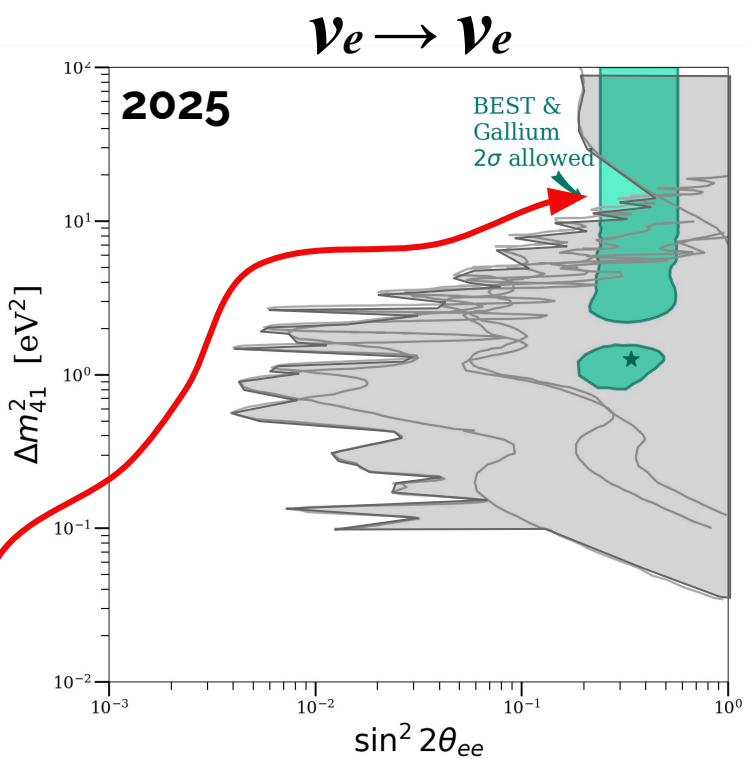
KATRIN *Nature* 648, 70–75 (2025)

A Lot More Data to Come

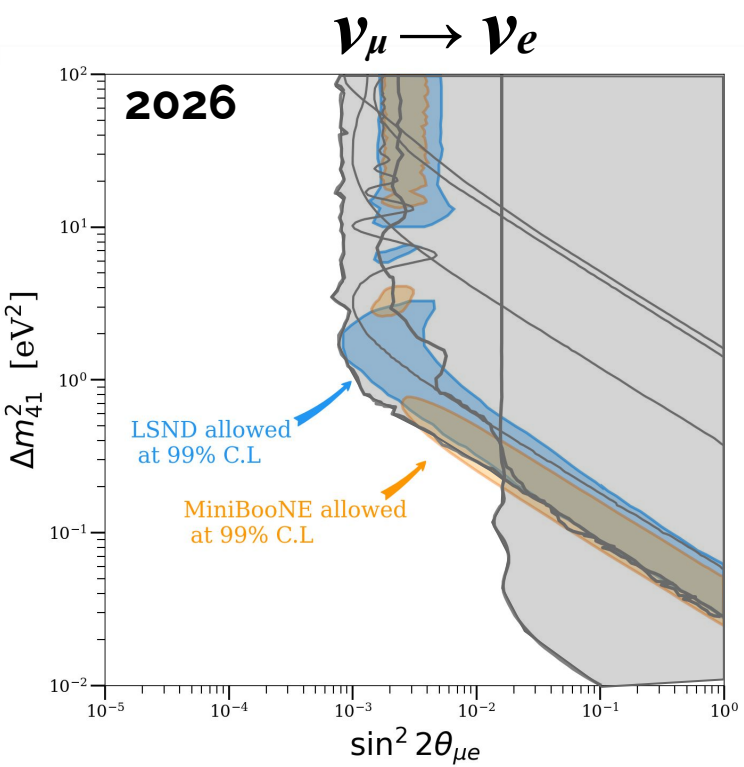


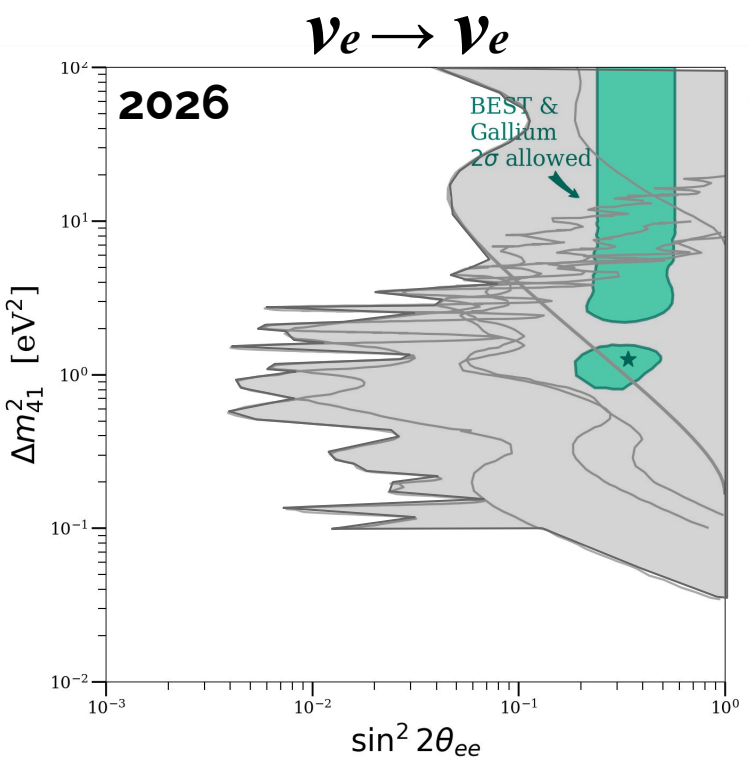
Slide from Thierry Lasserre





As of **PHENO 2025** pesky "***Gap***" regions unprobed..



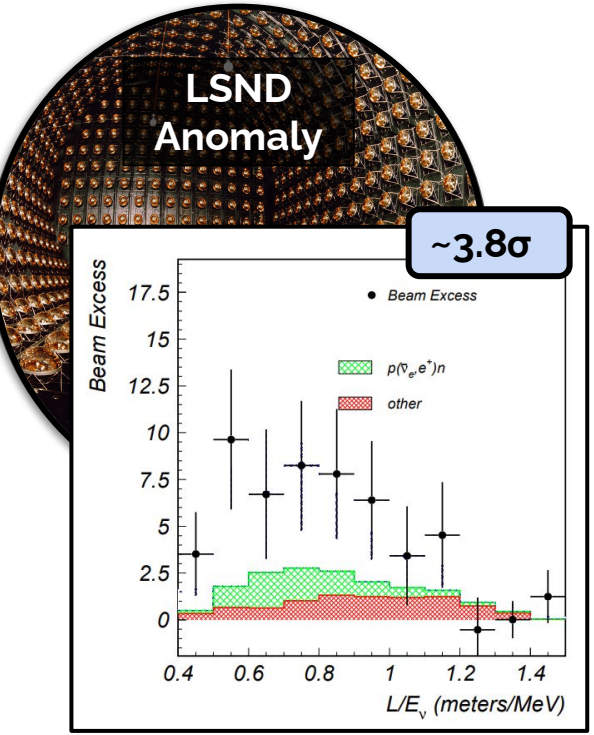


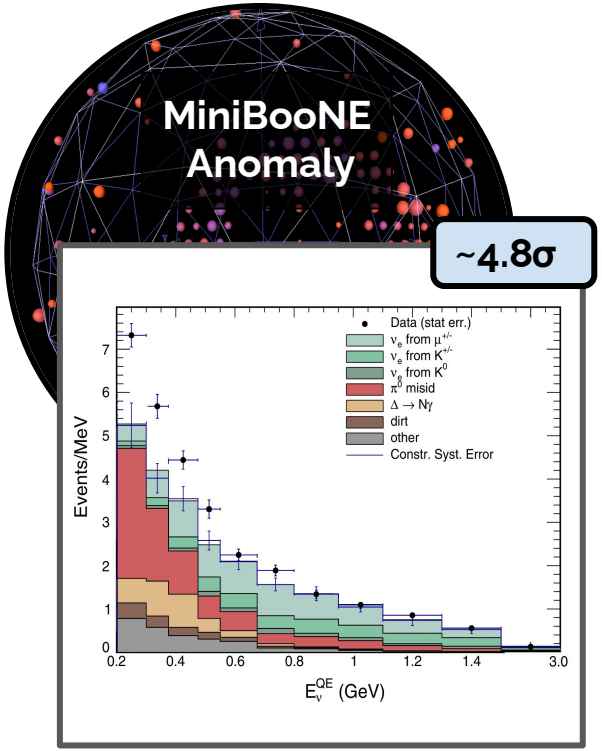
Last ~6 months have been an impressive time for advancing our understanding of light sterile neutrinos!

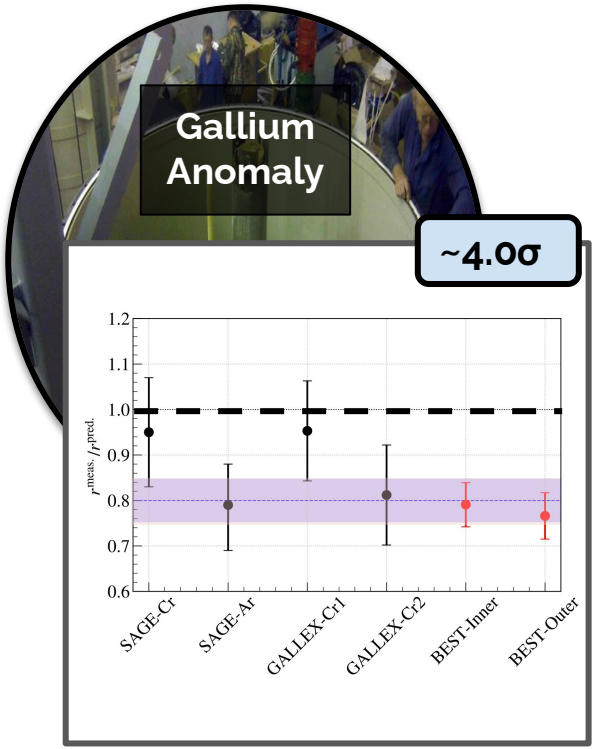
A single light eV scale sterile is **no longer a viable solution** for short-baseline anomalies

If a model fails to explain the data *throw out the model*, not the data.

If not eV^2 scale sterile neutrinos, then what?







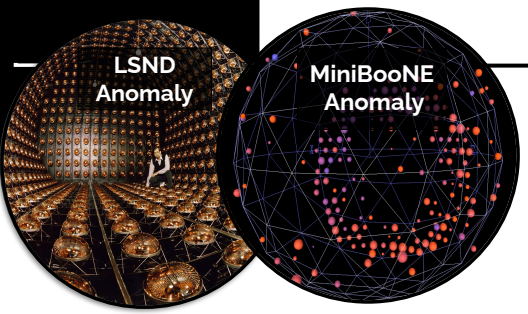
Beyond Single Light Steriles

Additions/Modifications to light sterile neutrino oscillations* I.e 3+1 + something else

- **3+2** and **3+3** (more light steriles)
  - C. Giunti *et al* Phys.Rev.D 84 (2011) 9, 073008
- **3+1+Non-Standard interactions** (NSI)
  - J. Liao *et al* Phys.Rev.D 99 (2019) 1, 015016
- **3+1+Decay**
  - Z.Moss et al Phys.Rev.D 97, (2018) 055017
- **3+1+Decoherence**
  - C.A. Argüelles *et al* C.Phys. Rev. D 107 (2023), 036004
- **3+1+Resonance Matter Effects**
  - D.Alves *et al* JHEP08 (2022) 034

Lots of effort in this direction, to **keep the core 3+1 light oscillating sterile neutrino model** and modify slightly to **help reduce tension**

*Just a few references, many many more



BSM explanations beyond "oscillating" steriles have grown in popularity.

Many exploiting the fact that the **MiniBooNE excess could in fact be photons or e+e- pairs** and not electrons

Category	Model	Signature	Anomalie		References
			LSND	MiniBooNE	
Flavor transitions Secs. 3.1.1-3.1.3, 3.1.5	(3+1) oscillations	oscillations	✓	✓	Reviews and global fits [93, 103, 105, 106]
	(3+1) w/ invisible sterile decay	os ns w/ ν_4 i e decay	✓	✓	[151, 155]
	(3+1) w/ sterile decay	$\nu_4 \to \phi\nu_e$	✓	✓	[159–162, 270]
Matter effects Secs. 3.1.4, 3.1.7	(3+1) w/ anomalous matter effects	$\nu_\mu \to \nu_e$ via matter effects	✓	✓	[143, 147, 271–273]
	(3+1) w/ quasi-sterile neutrinos	$\nu_\mu \to \nu_e$ w/ resonant ν_s matter effects	✓	✓	[148]
Flavor violation Sec. 3.1.6	Lepton-flavor-violating μ decays	$\mu^+ \to e^+\nu_\alpha\overline{\nu_e}$	✓	✗	[174, 175, 274]
	neutrino-flavor-changing bremsstrahlung	$\nu_\mu A \to \nu_e A$	✓	✓	275
Decays in flight Sec. 3.2.3	Transition magnetic mom., heavy ν decay	$N \to \nu\gamma$	✗	✓	207
	Dark sector heavy neutrino decay	$\nu(X \to$	✗	✓	208
Neutrino Scattering Secs. 3.2.1, 3.2.2	neutrino-induced upscattering	$N \to \nu$	✓	✓	205, 206, 209–216
	neutrino dipole upscattering	$N \to \nu$	✓	✓	[40, 185, 187, 188, 190, 193, 233, 276]
Dark Matter Scattering Sec. 3.2.4	dark particle-induced upscattering	$e^- \to e^-$	✗	✓	[217]
	dark particle-induced inverse Primakoff		✓	✓	217

Signals

- Electron
- Photon
- Di-Photon
- e+e-

30+ dark-sector models in last few years with Incredibly rich and varied phenomenology

Table modified from Snowmass White Paper on Light Sterile Neutrino Searches and Related Phenomenology

BSM explanations beyond "oscillating" steriles have grown in popularity.

Many exploiting the fact that the **MiniBooNE excess could in fact be photons or e+e- pairs** and not electrons

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	(3+1) w/ invisible sterile decay	os ns w/ ν_4 in decay	✓	✓	[151, 155]
	w/ sterile decay	$\to \phi\nu_e$	✓	✓	[159–162, 270]
Matter effects Secs. 3.1.4, 3.1.7	w/ anomalous ter effects	$\nu_\mu \to \nu_e$ via matter effects	✓	✓	[143, 147, 271–273]
	quasi-sterile inos	$\nu_\mu \to \nu_e$ w/ resonant ν_s ter effects	✓	✓	[148]
Flavor violation Sec. 3.1.6	Le -violating μ decays		✓	✗	[174, 175, 274]
	neutrino-flavor-changing bremsstrahlung	$\nu_\mu A \to$	✓	✓	275]
Decays in light Sec. 2.3	Transition magnetic mom., heavy ν decay	$N \to \nu\gamma$	✗	✓	207]
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Ne rino Sca ering Secs. 3. 1, 3.2.2	neutrino-induced upscattering	$\to$ $N \to \nu$	✓	✓	205, 206, 209–216]
	neutrino dipole upscattering	$\to$	✓	✓	[40, 185, 187, 188, 190, 93, 233, 276]
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Table modified from Snowmass White Paper on Light Sterile Neutrino Searches and Related Phenomenology

Signals

- Electron
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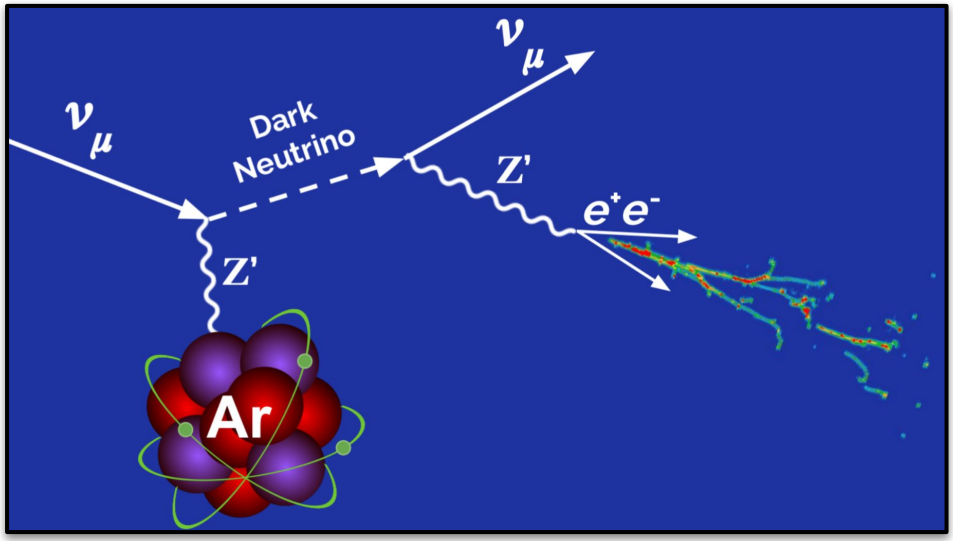
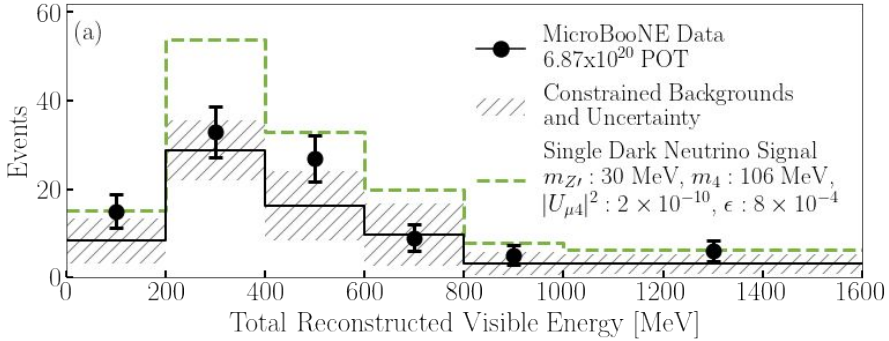
30+ dark-sector models in last few years with Incredibly rich and varied phenomenology

MicroBooNE Dark Sector e^+e^- Search



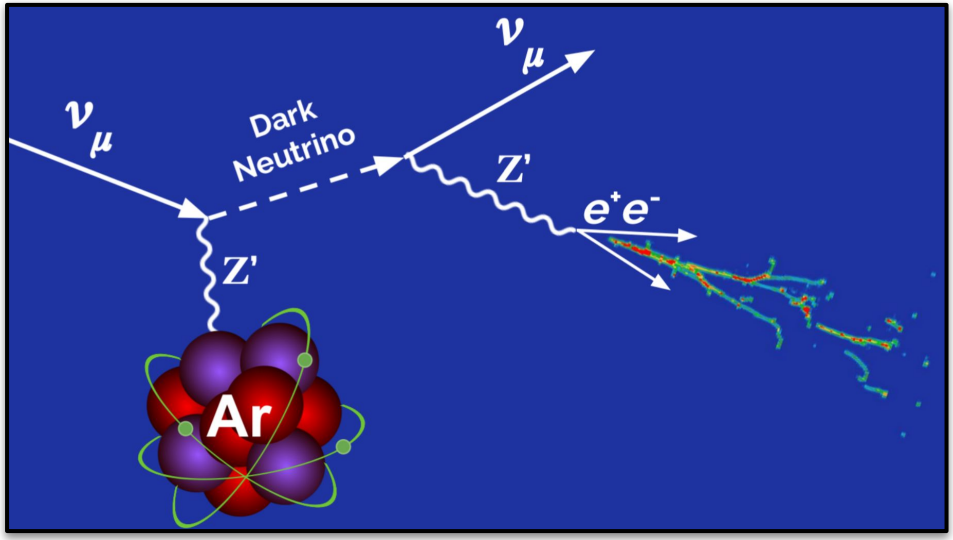


Bkg Prediction : **69.7 ± 17.3** events

Observed Data : **95** events

Search for forward going e+e- pairs from neutrino induced upscattering producing an unstable HNL (Dark neutrino)

MicroBooNE Phys. Rev. Lett. 136, 121804 (2026)



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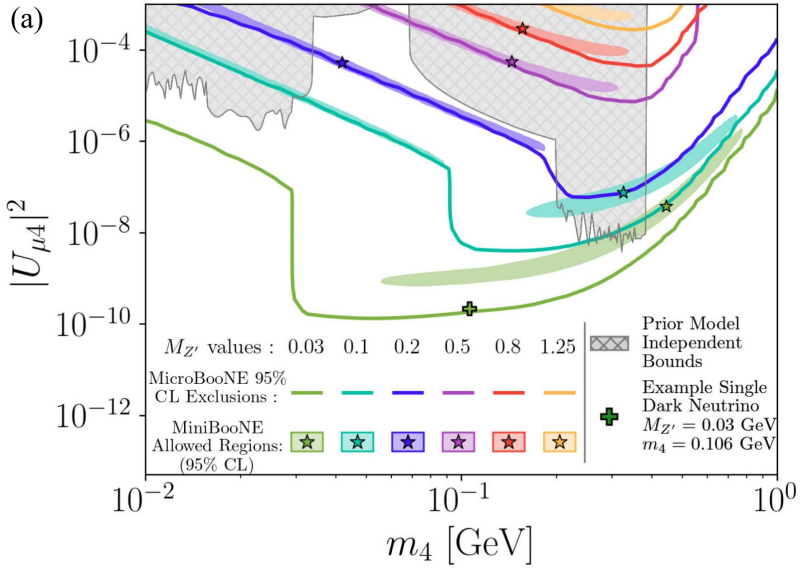
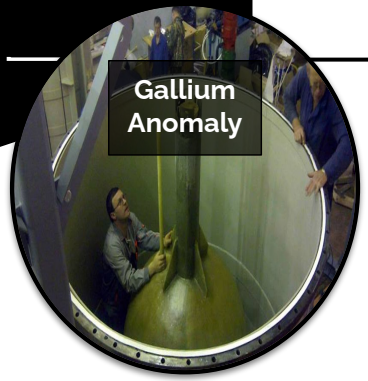
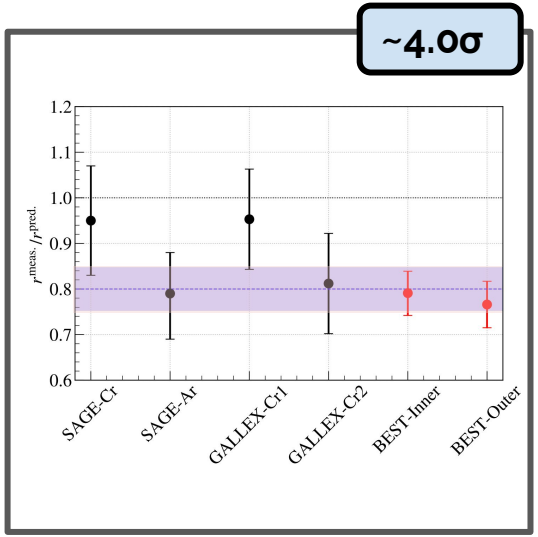


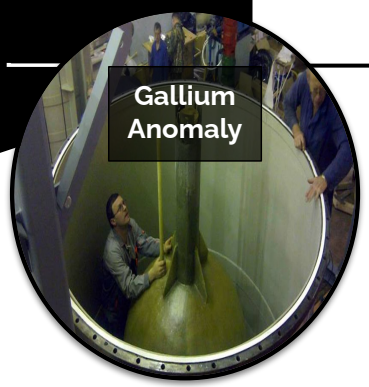
The **world's first direct limits** on these dark sector models and, at the 95% confidence level, **excludes the majority of the parameter space viable as a solution to the MiniBooNE anomaly**

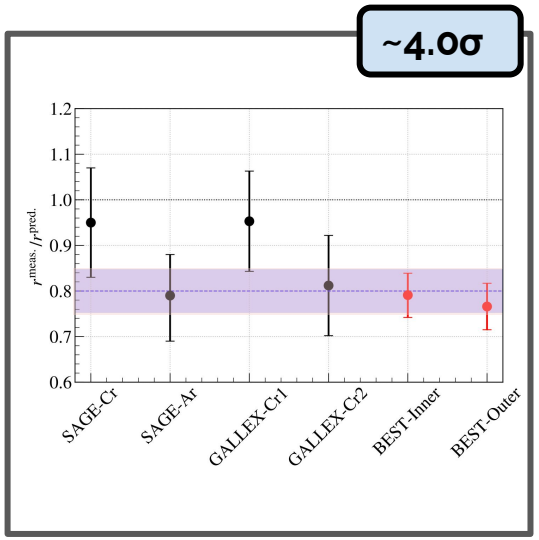
MicroBooNE Phys. Rev. Lett. 136, 121804 (2026)





A **~20% disappearance effec**t in electron neutrinos is very difficult to engineer in BSM models without breaking many LEP and EW bounds





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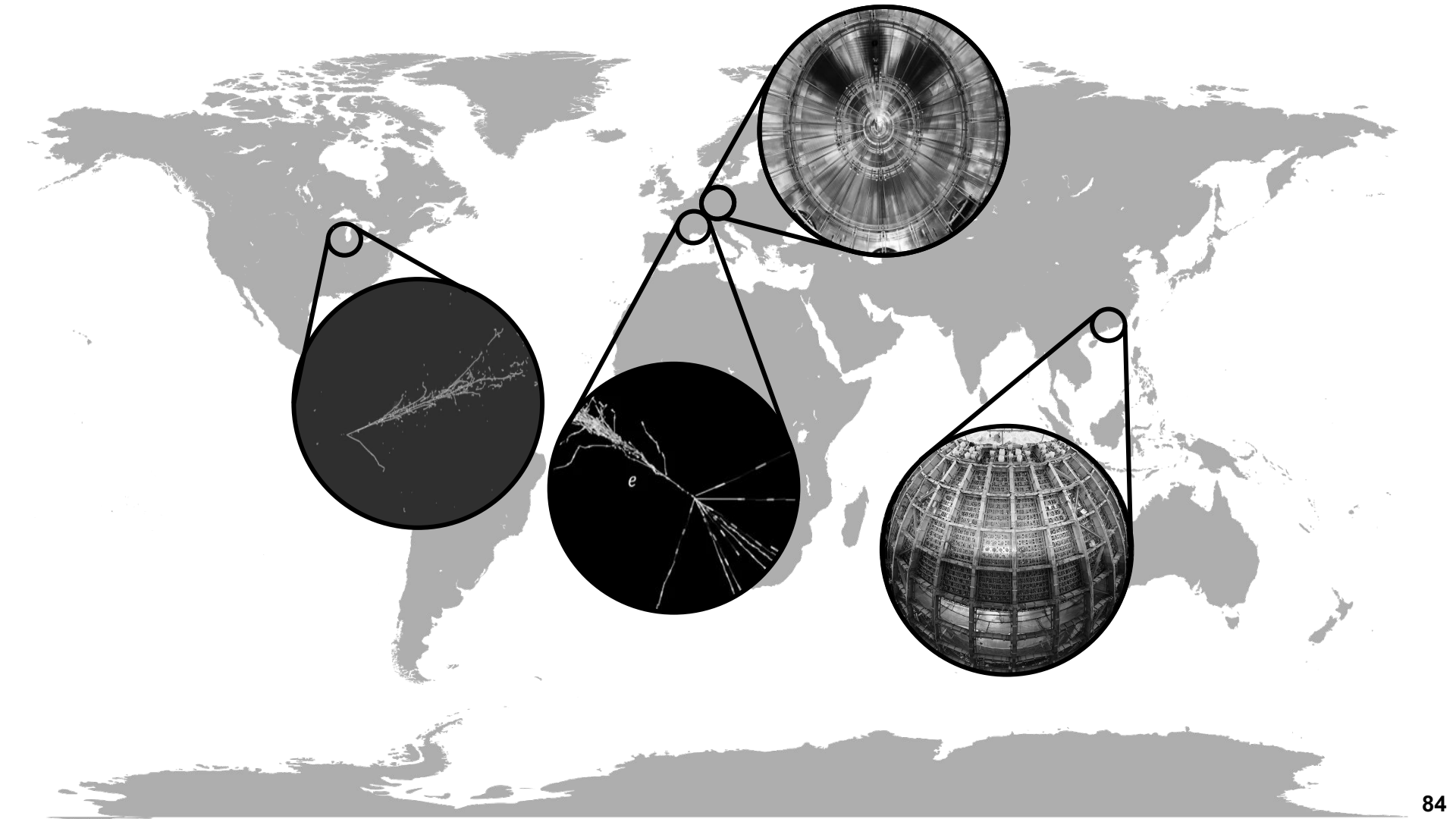
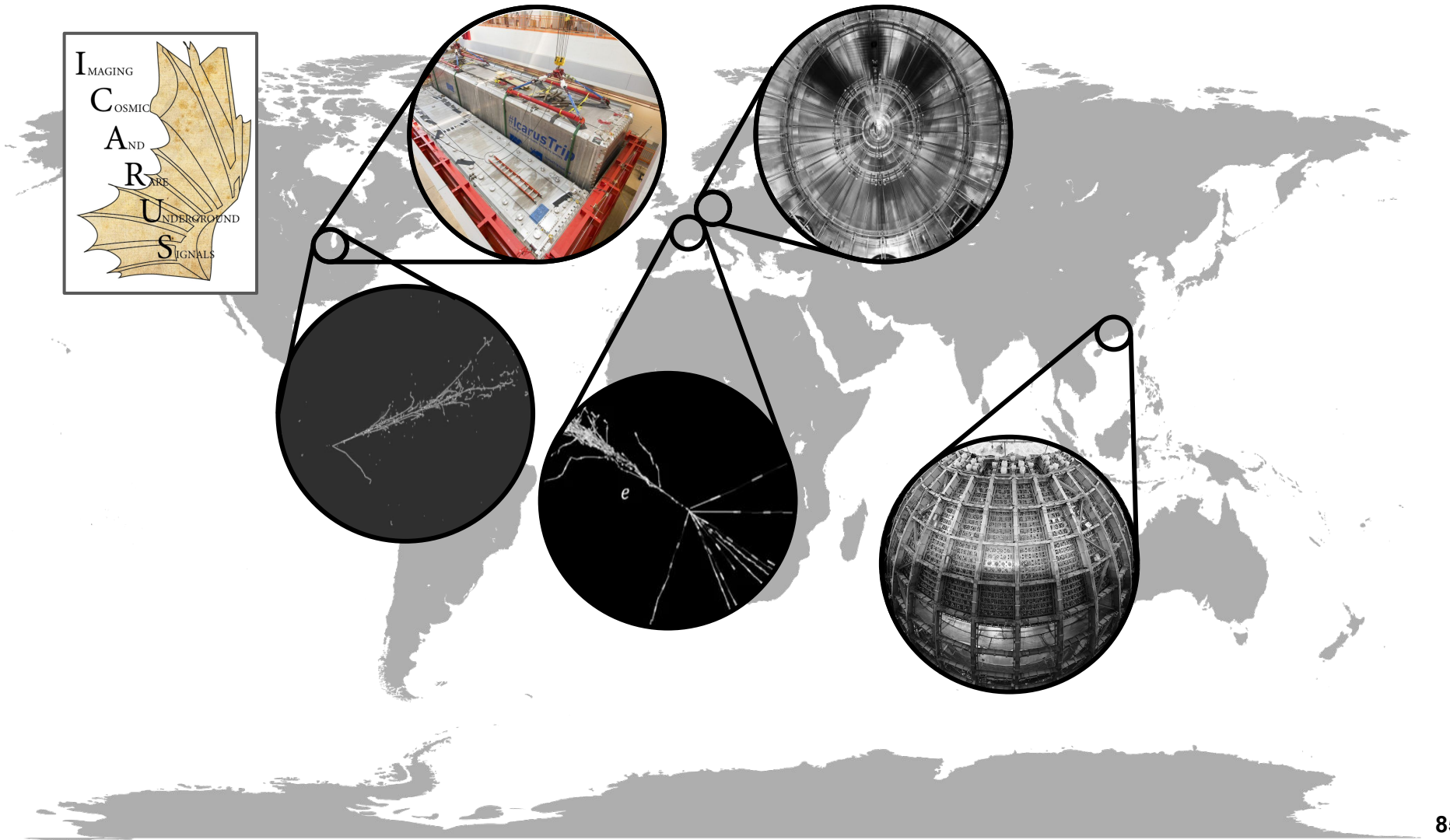
Recent paper

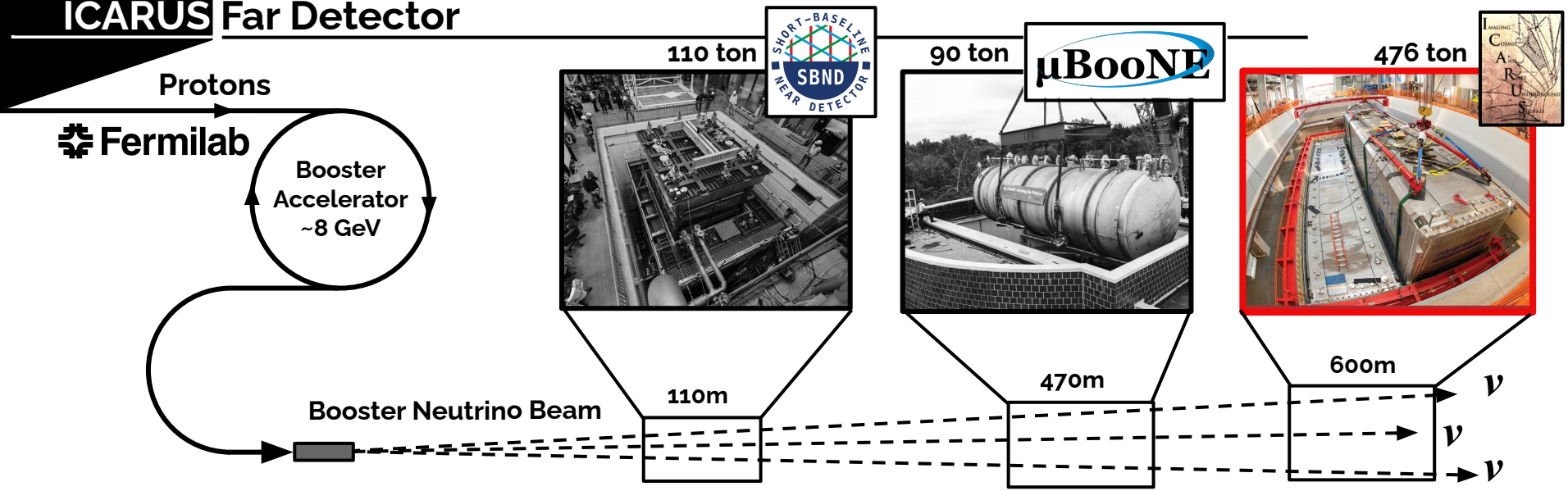
Cadeddu et al., *"A possible solution to the gallium anomaly moving beyond the leptonic wave function factorization" arXiv:2512.20560 [hep-ph]*

- Questions the **detailed-balance link between ν–^{71}Ga capture and ^{71}Ge electron capture**, valid only under factorization of nuclear and leptonic matrix elements (i.e. lepton wave functions constant over the nuclear volume).
- Drop that factorization and the cross-section *potentially* falls by up to ~20%

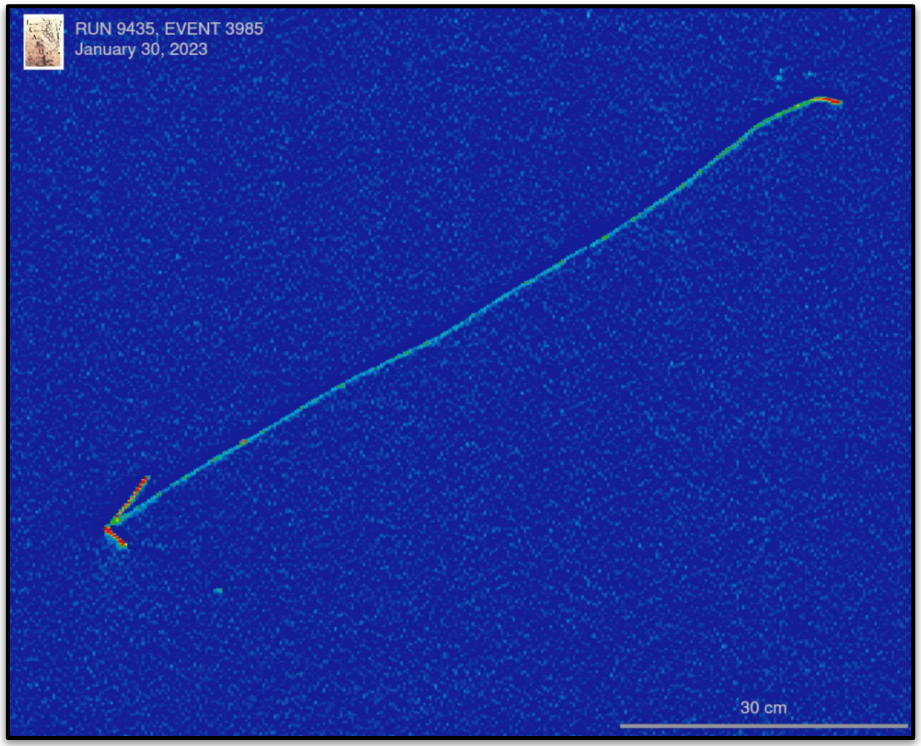

e


IMAGING
COSMIC
AND
RARE
UNDERGROUND
SIGNALS
e

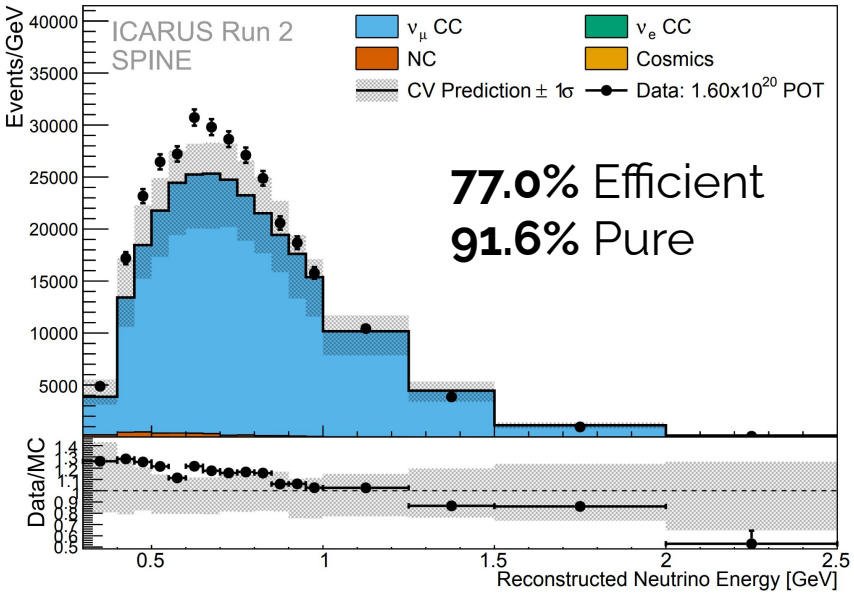
ICARUS Far Detector



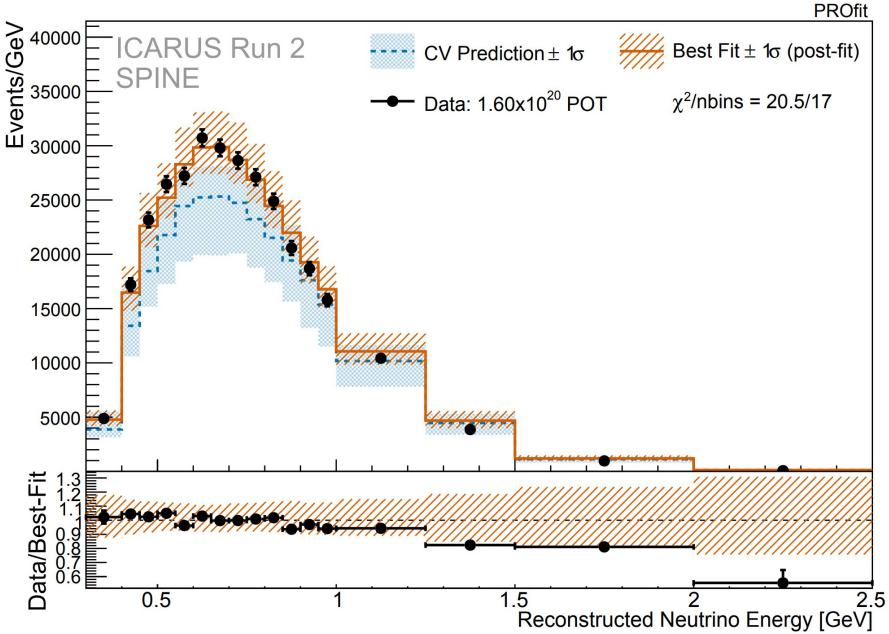
Search for muon neutrino disappearance



- Two seperate, independent analyses
  - Pandora and **SPINE** (shown)

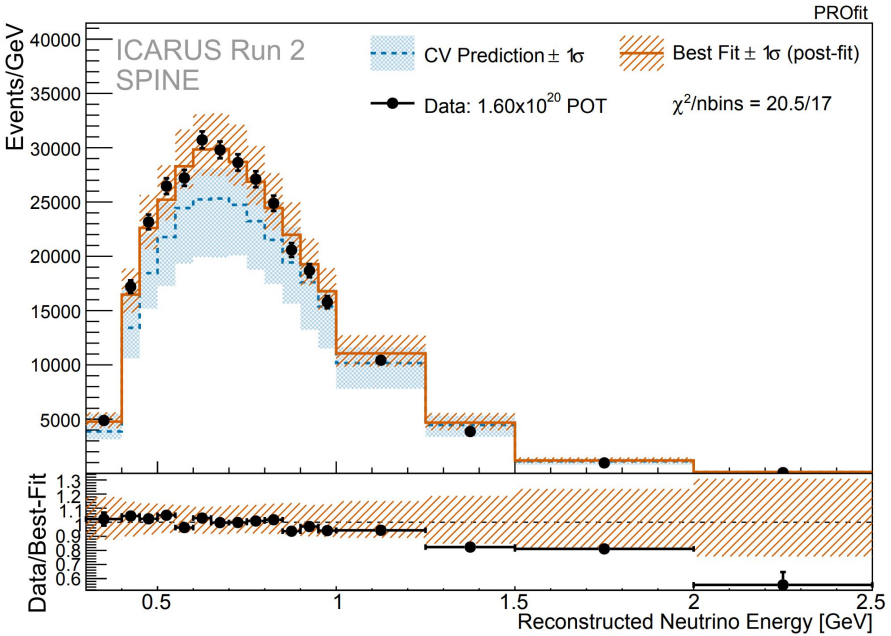


Background Only Fit



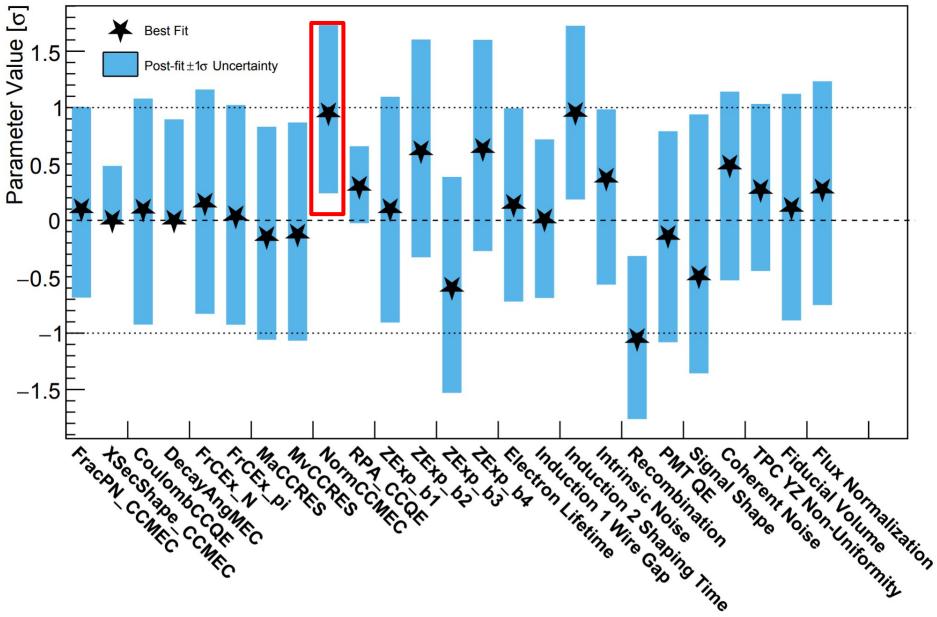
Fit to Background Systematics only

Background Only Pulls

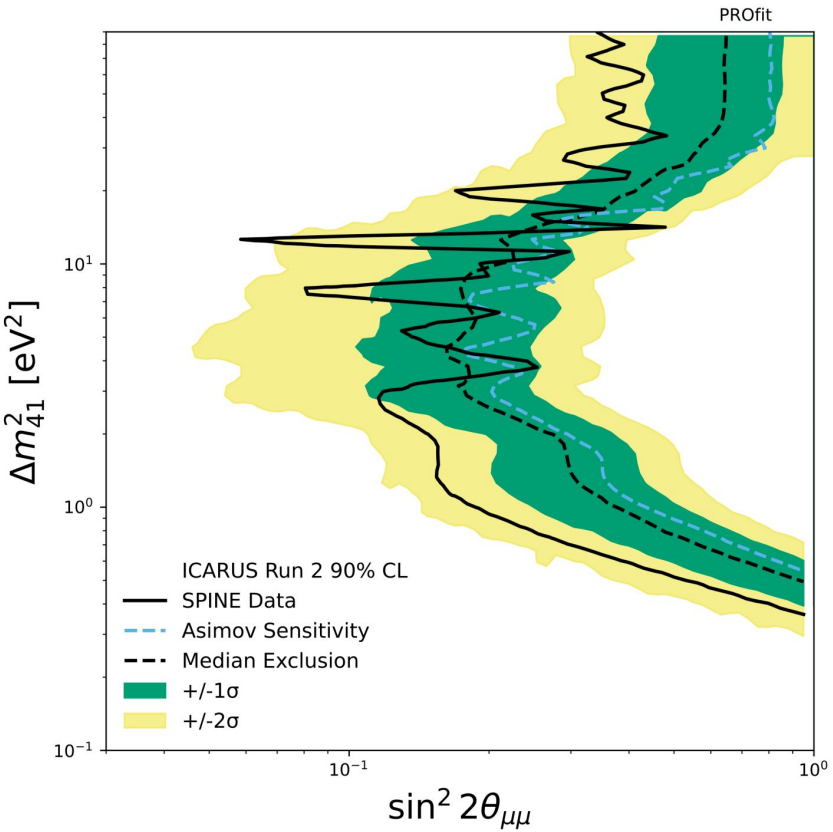


Fit to Background Systematics only

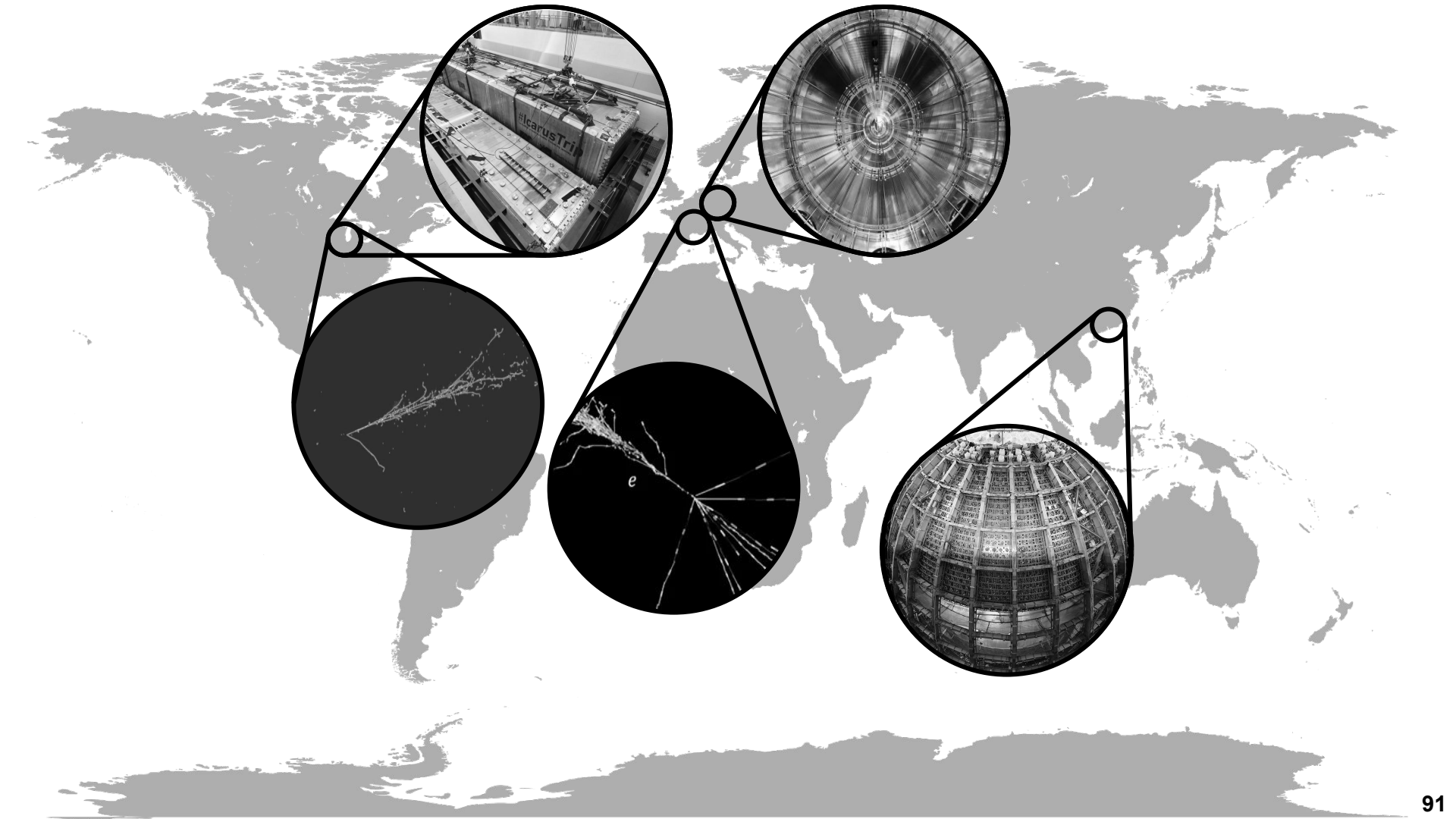
CC MEC Normalization: +1σ



Feldman Cousins Exclusions



- Full end-to-end oscillation analysis exercised
- **No evidence for ν_μ disappearance.**
- Extremely Systematics Limited
  - Joint fit with **SBND** near detector will **reduce systematics** from **~20% to few percent level**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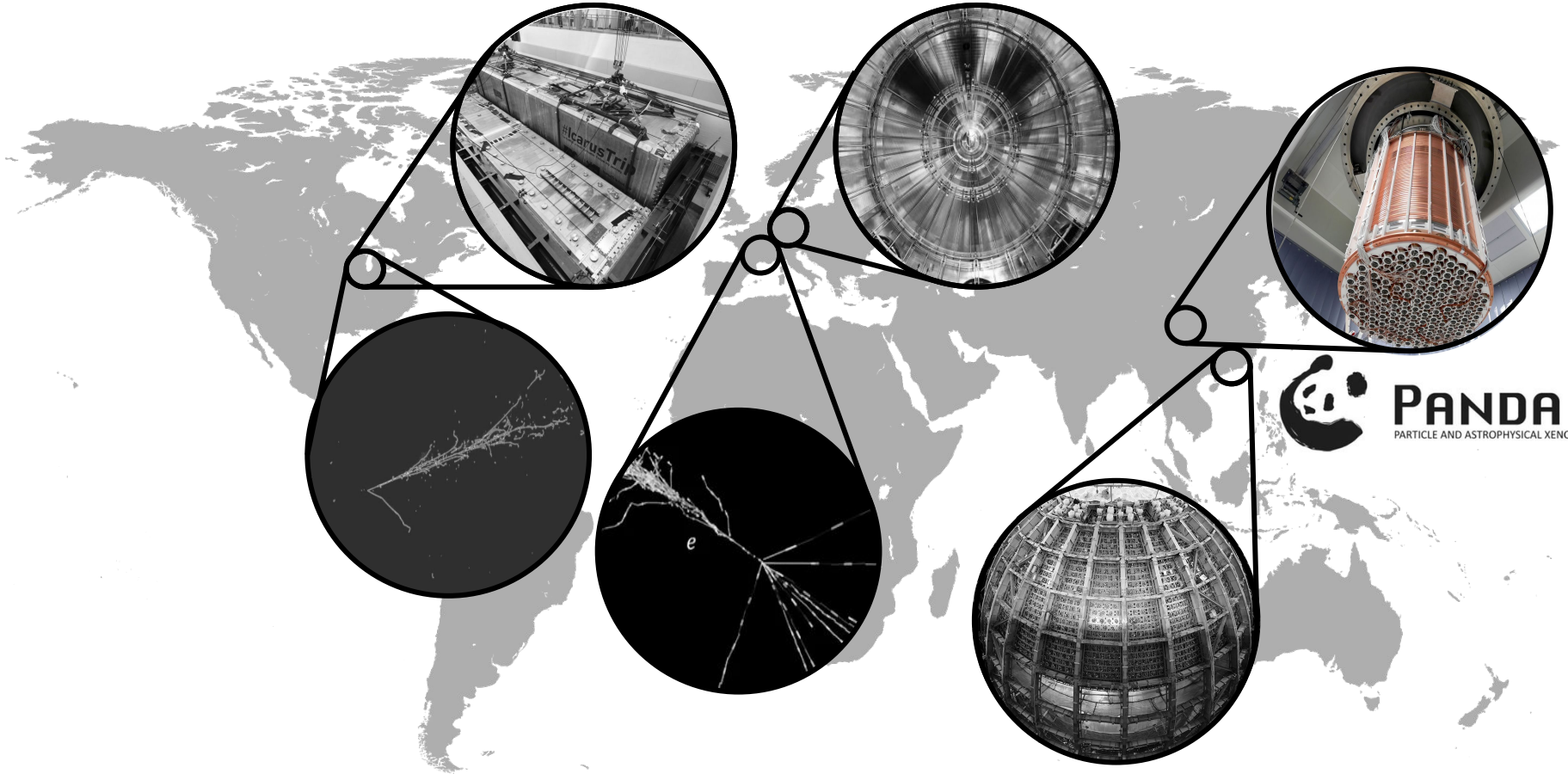
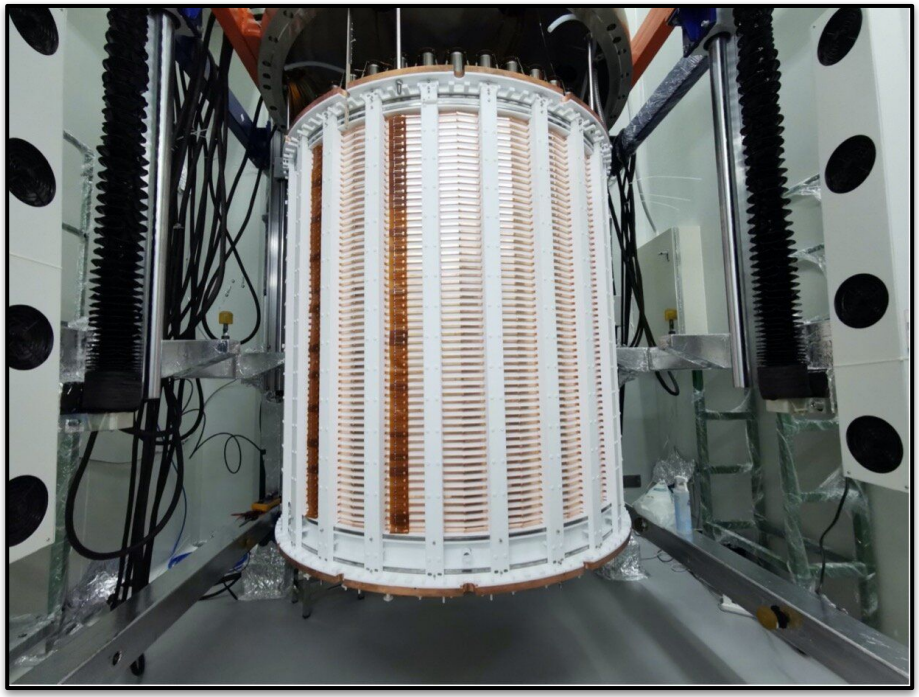


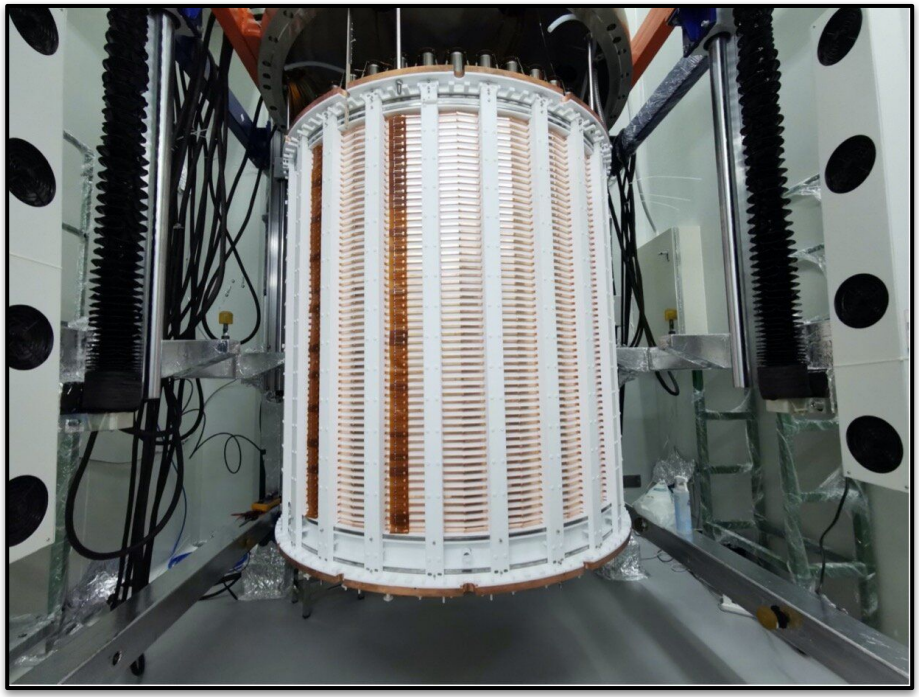
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

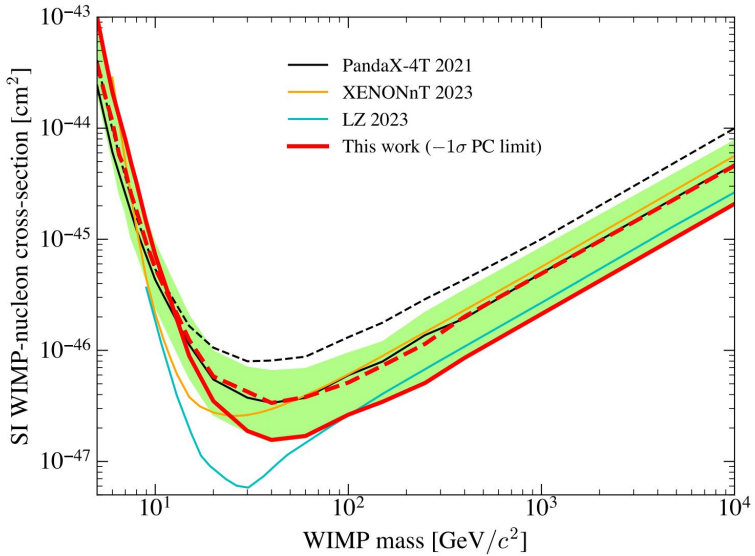


Dual-phase liquid xenon TPC China Jinping Underground Laboratory with 2,400 m rock overburden, **deepest lab in the world**

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC



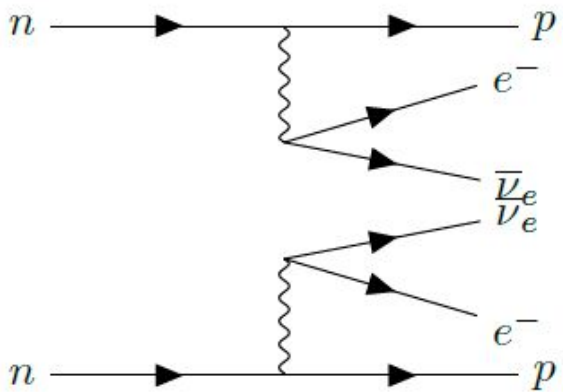
Dual-phase liquid xenon TPC China Jinping Underground Laboratory with 2,400 m rock overburden, **deepest lab in the world**



PandaX: Phys. Rev. Lett. 134, 011805 (2025)

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

3.7 tonnes of natural xenon of which
8.58% is naturally abundant ^{136}Xe



$2\nu\beta\beta$

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

3.7 tonnes of natural xenon of which
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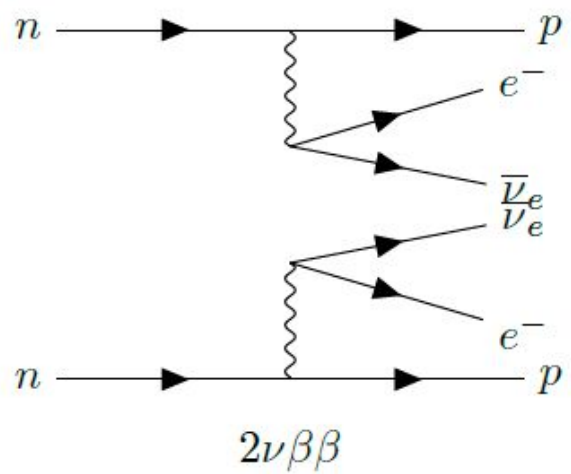
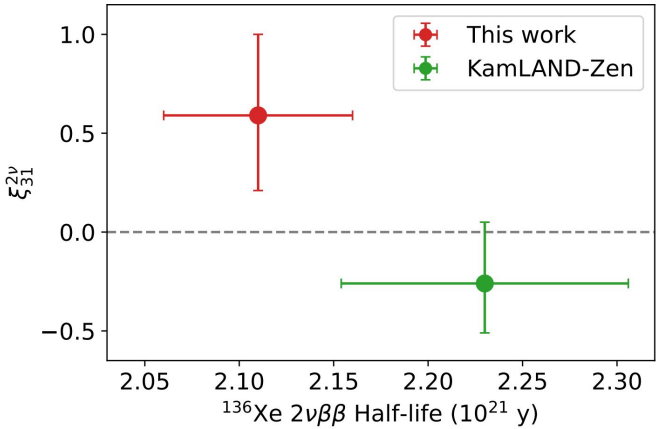


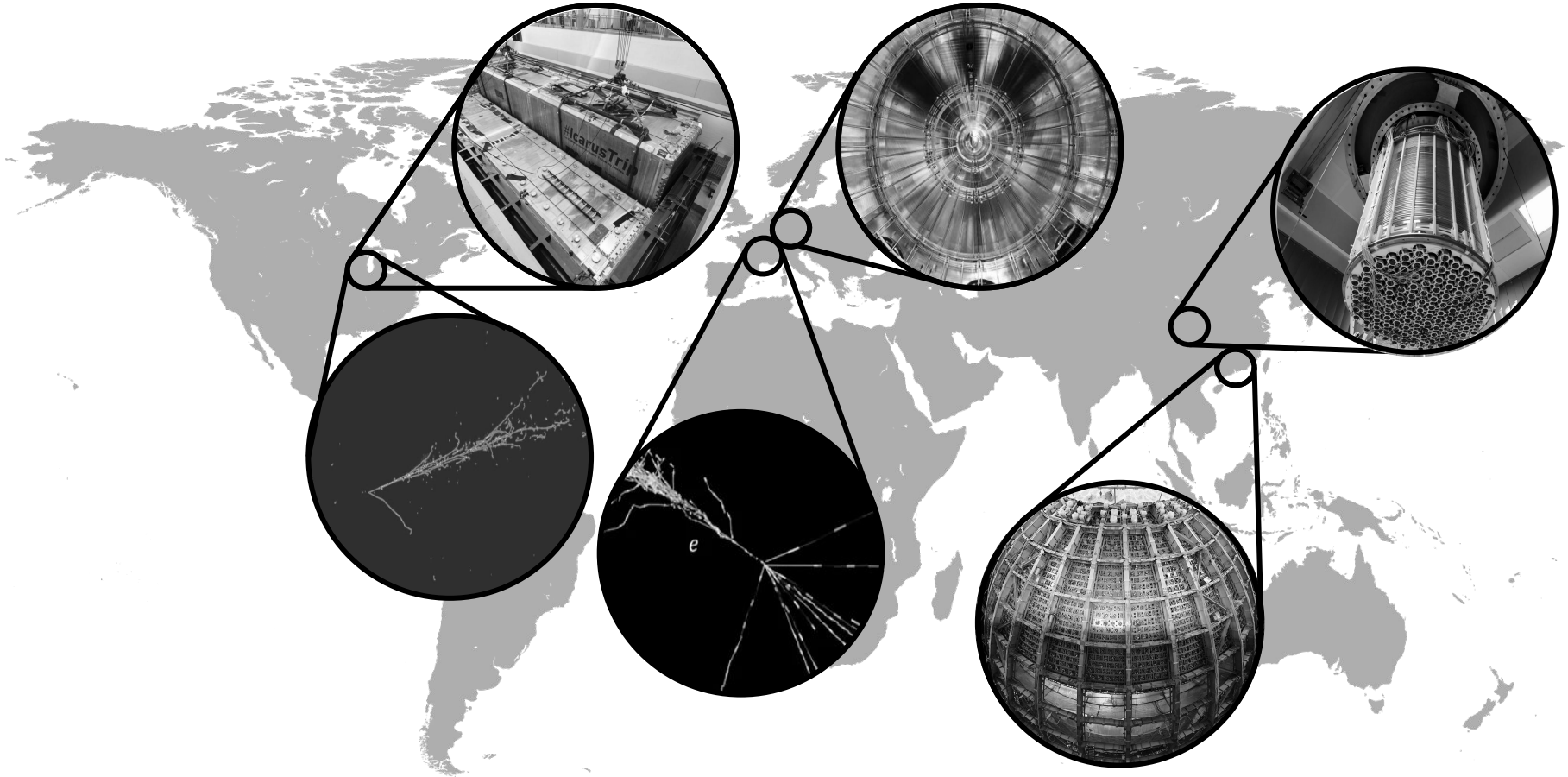
258 Days of data (~25% of planned exposure)

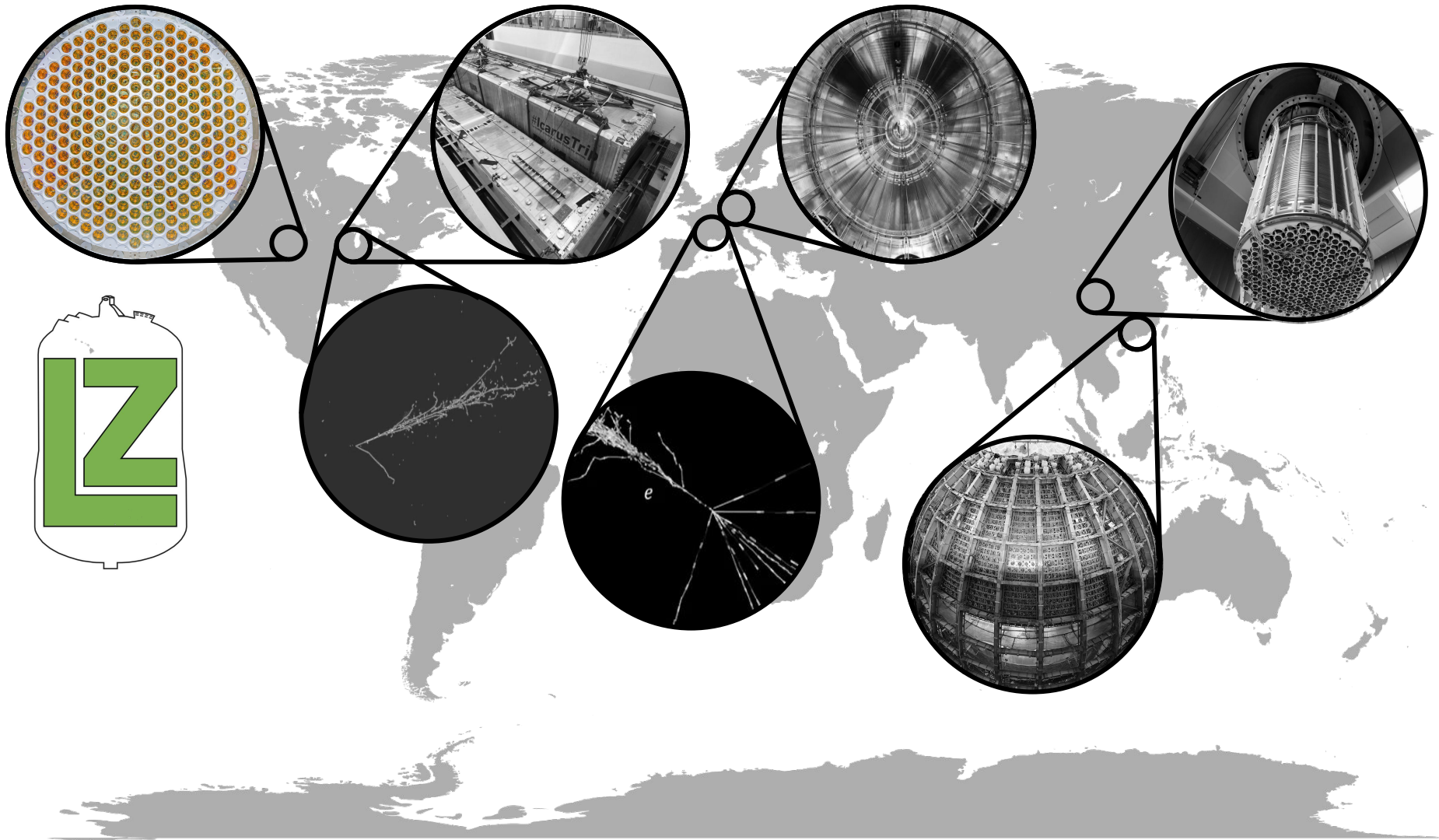


$T_{1/2}(2\nu\beta\beta) = (2.14 \pm 0.05) \times 10^{21}$ yr

PandaX-4T is now the world's most **precise ^{136}Xe 2νββ spectrometer** and is starting to **constrain the same nuclear matrix elements** that 0νββ-to-$m_{\beta\beta}$ conversions depend on.

PandaX arXiv:2512.04849


ICARUS T1
e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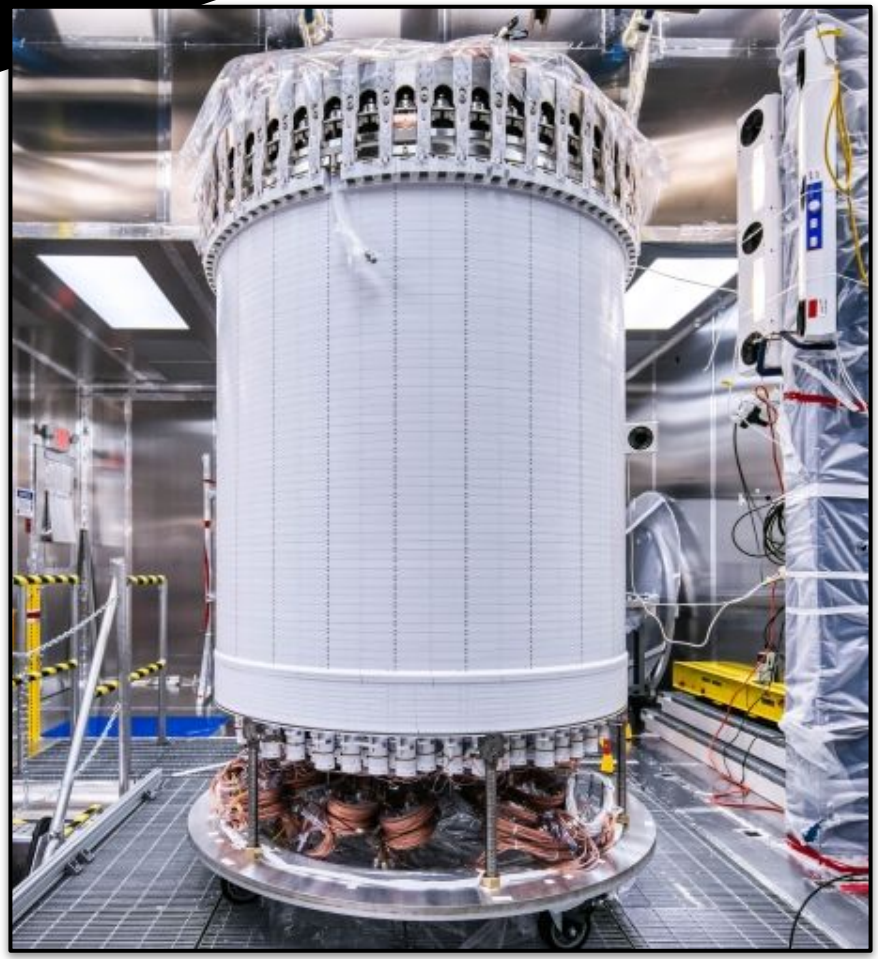
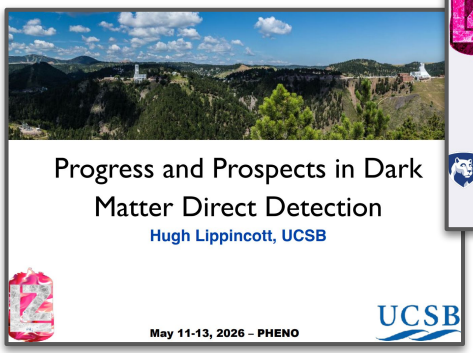
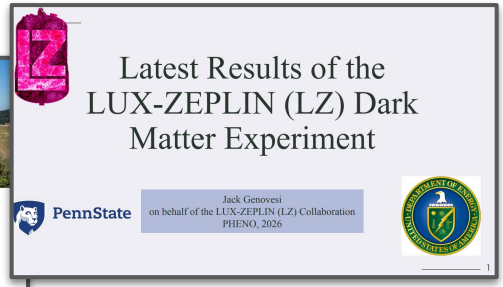
LZ : LUX-ZEPLIN



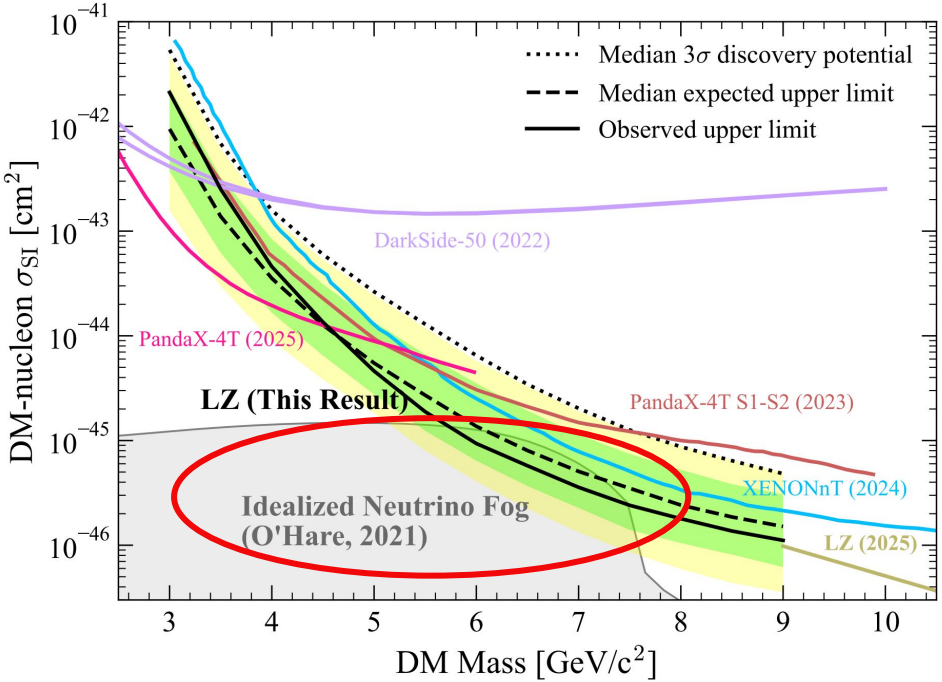
7-tonne dual-phase liquid-xenon TPC dark-matter experiment located 4,850 ft underground in SURF, South Dakota

See talks by Hugh Lippincott and Jack Genovesi Monday!





LZ : LUX-ZEPLIN



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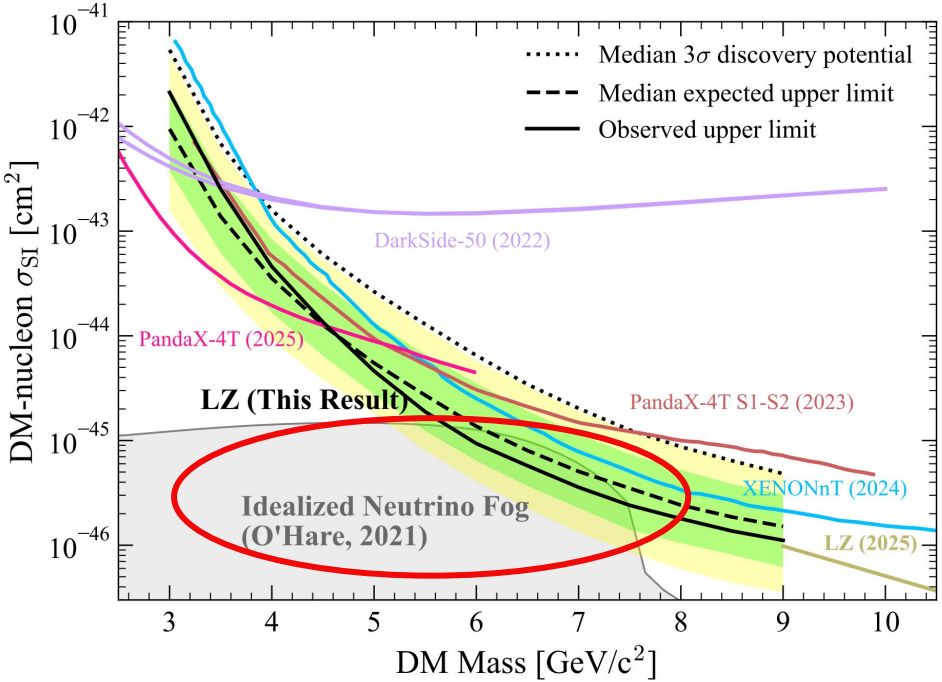
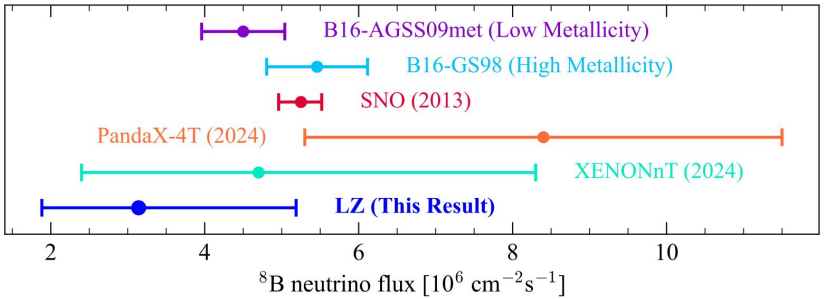


*"..observe a signal consistent with **Solar ^{8}B CEvNS** events, corresponding to a **4.5σ statistical significance**"*

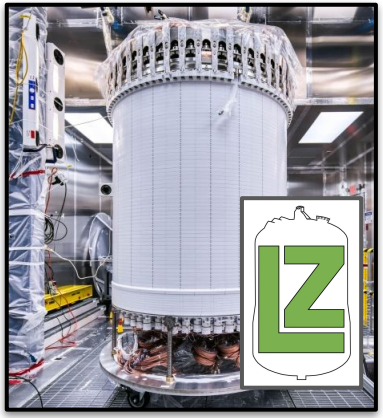


LZ arXiv: 2512.08065 Dec 2025

Into the Neutrino Fog

The same CEvNS events that *limit* dark matter searches are a **new measurement of the solar ^{8}B flux** independent of SNO/Super-K.

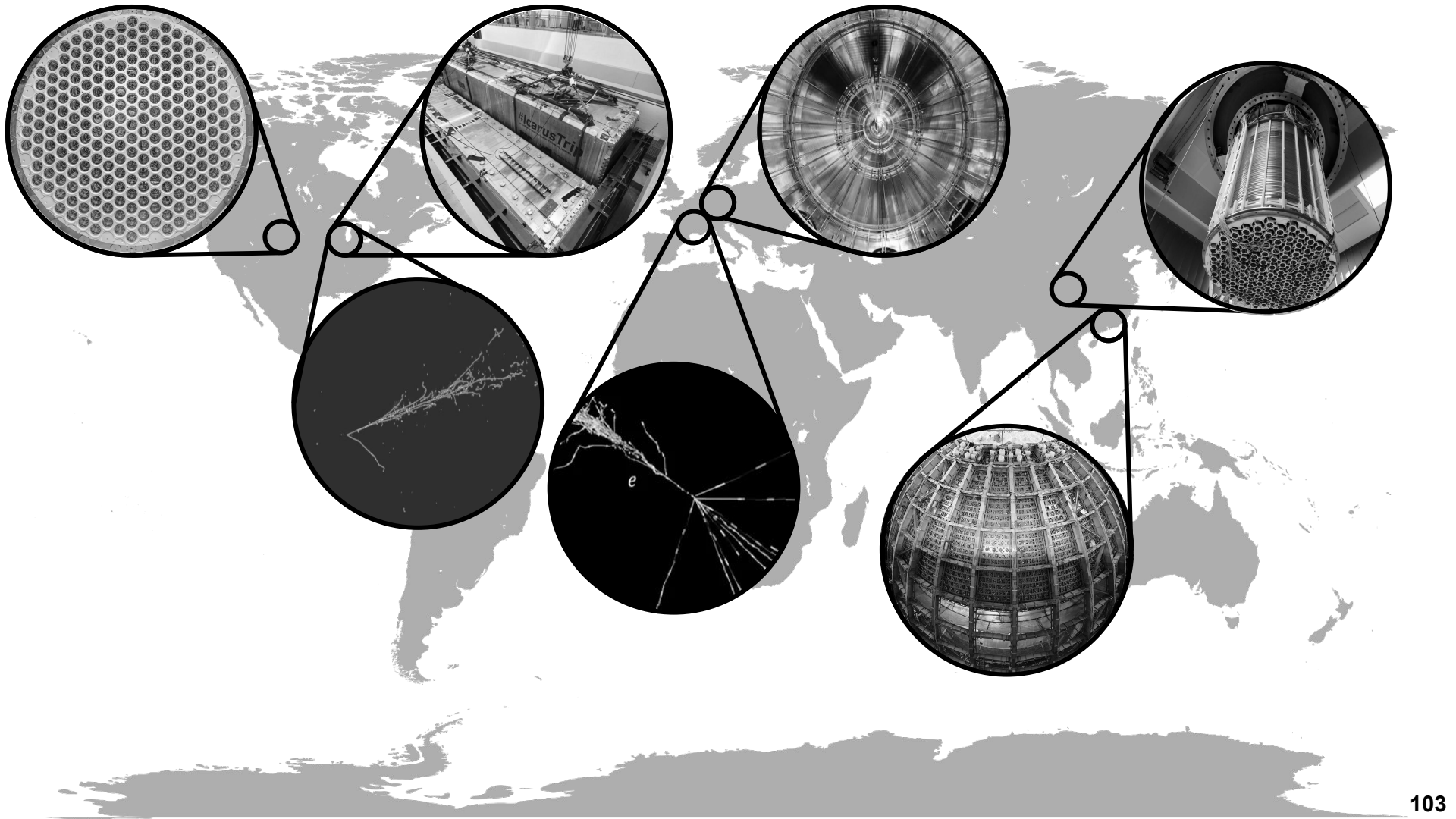
As exposure grows they become a clean low-Q^2 probe of NSI, neutrino magnetic moments, light mediators, and the weak mixing angle.



+

- DarkSide 20 (LAr)
- XLZD
- PandaX-xT
- ARGO (LAr)
- …

Tonne-scale+ DM detectors have effectively become solar neutrino observatories in the past 18 months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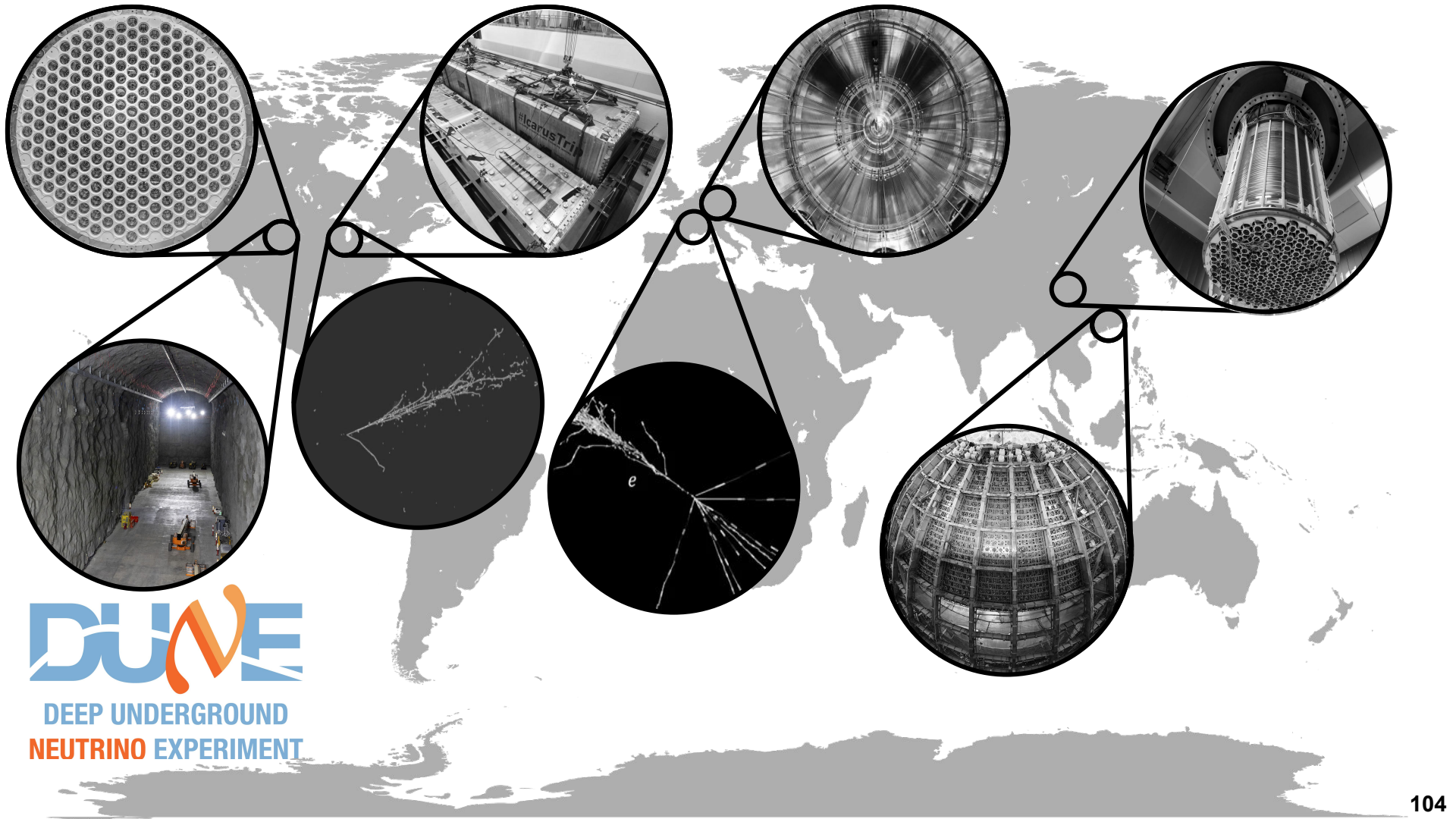
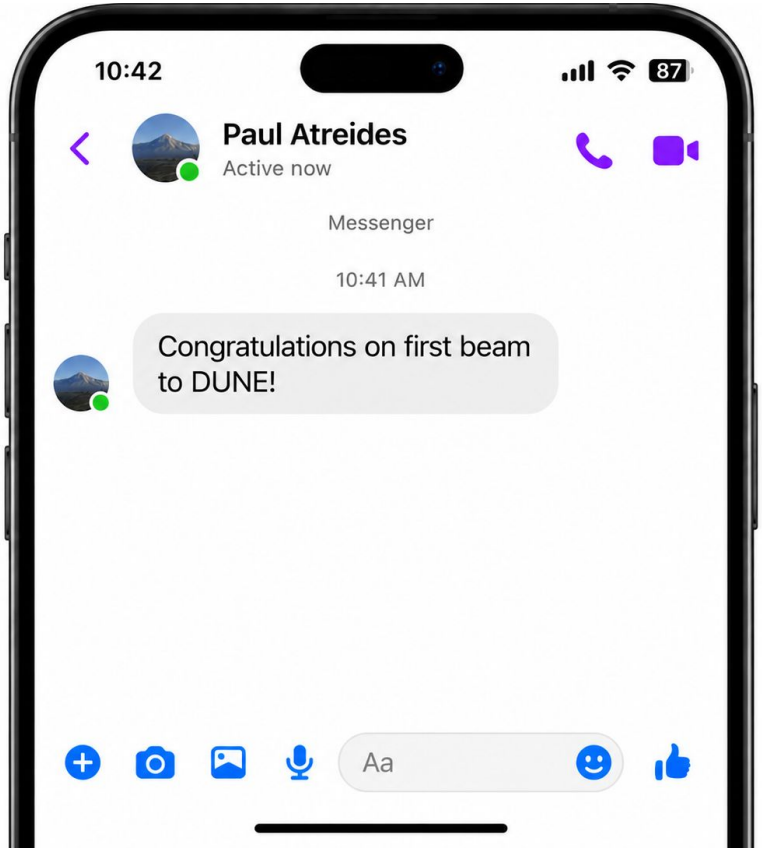


DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

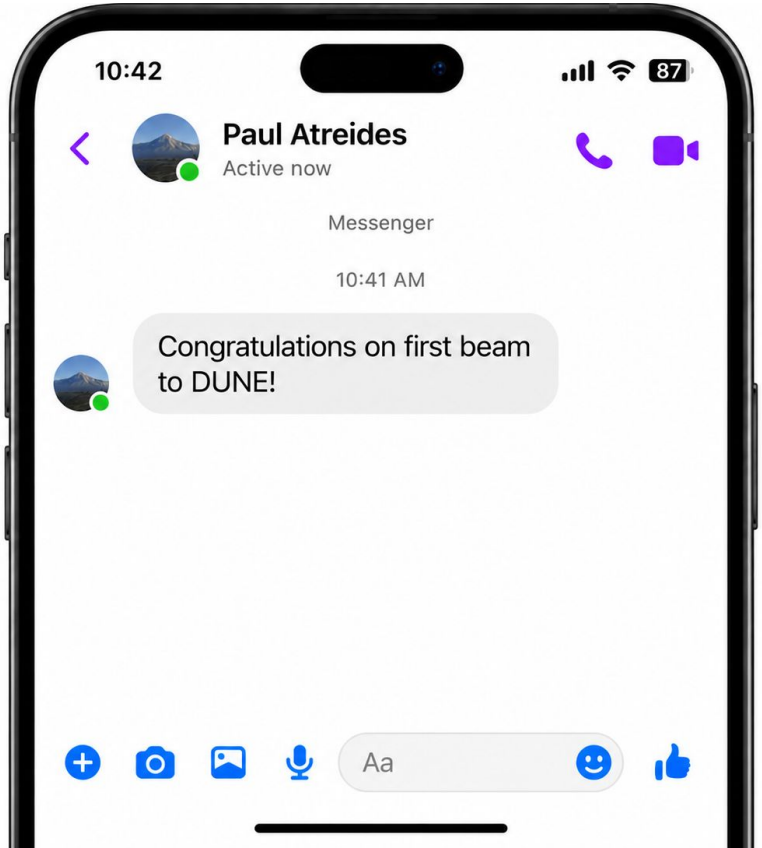
DUNE: Deep Underground Neutrino Experiment

DEEP UNDERGROUND NEUTRINO EXPERIMENT



DUNE: Deep Underground Neutrino Experiment

DEEP UNDERGROUND NEUTRINO EXPERIMENT

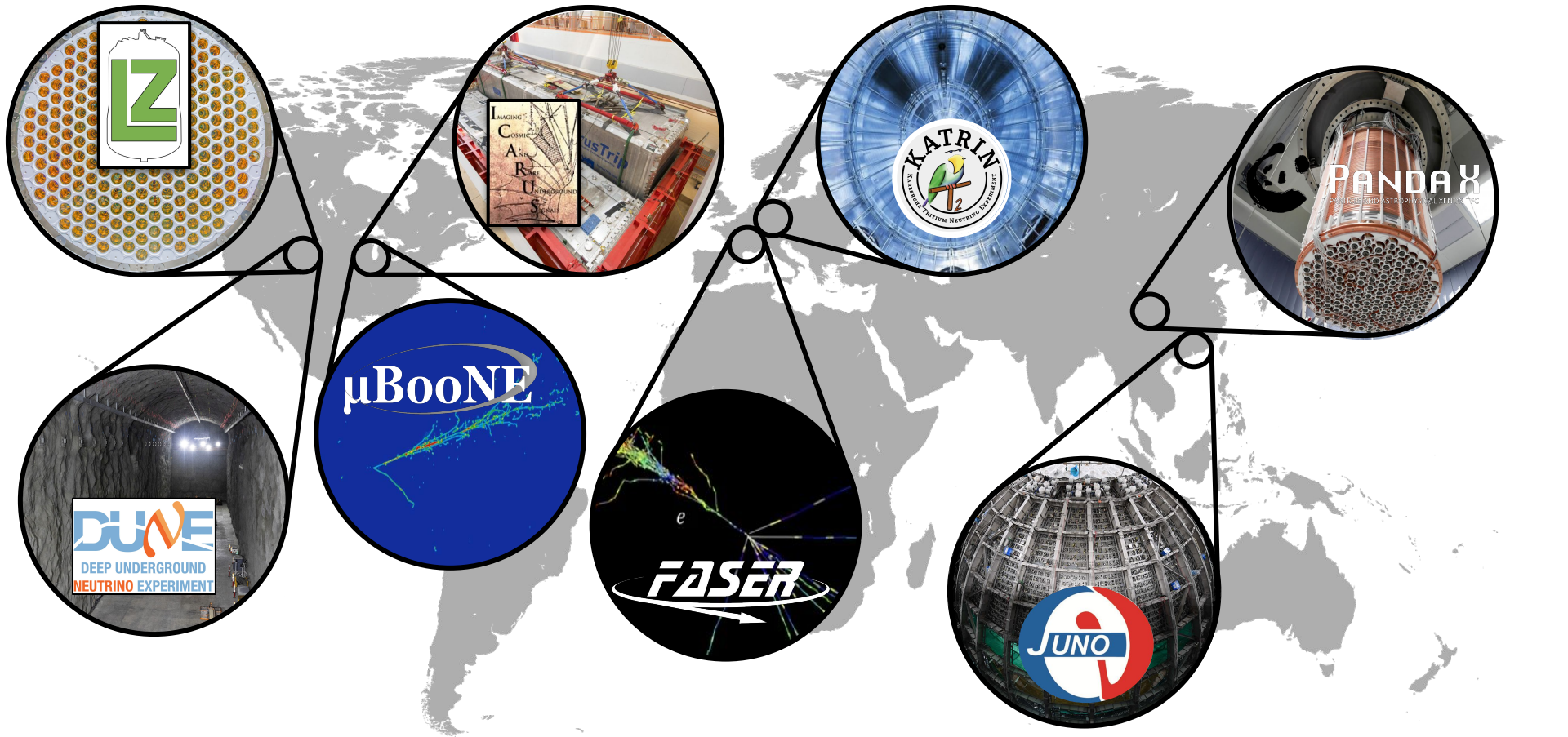


First of of 1,360 steel beams for cryostat construction lowered into DUNE caverns (4,500 Metric Tonnes of steel) on **May 7th**

DUNE: Deep Underground Neutrino Experiment

All caverns complete in 2024, first *beams* lowered mark the **start of detector construction**

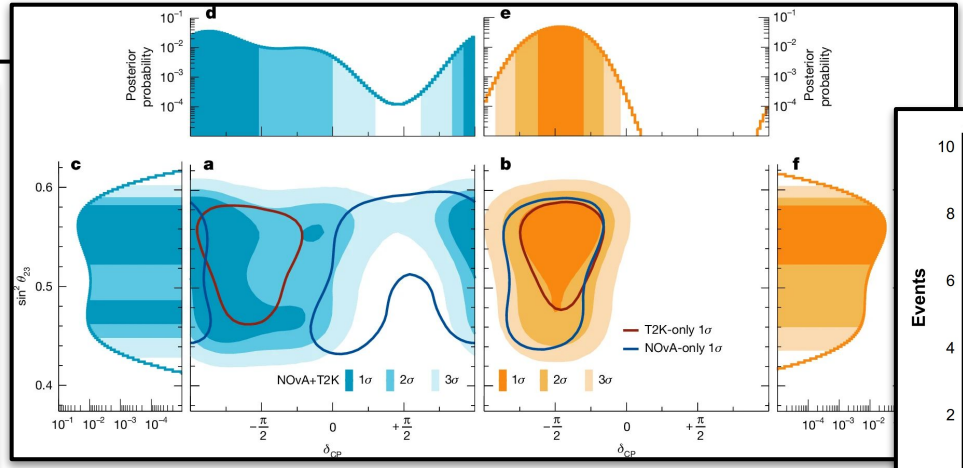
DEEP UNDERGROUND NEUTRINO EXPERIMENT



Last ~6 months

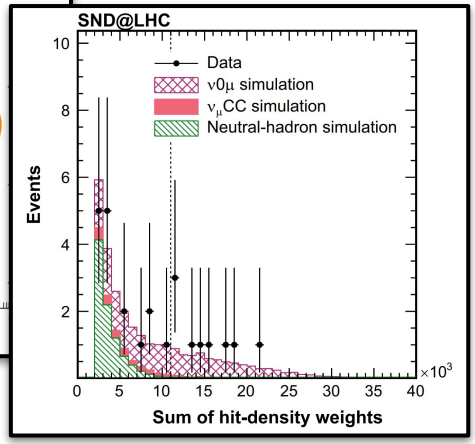
Plus many many more..

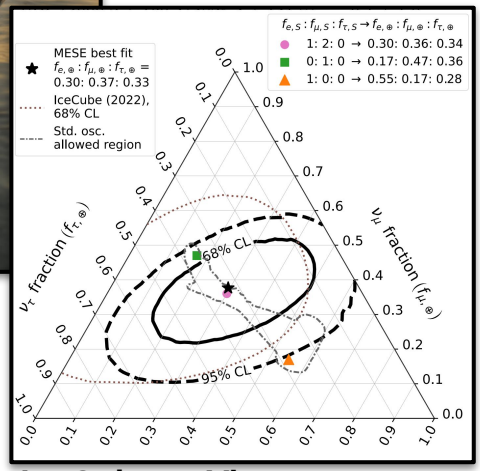
The KM3NeT Collaboration Nature volume 638, 376–382 (2025)



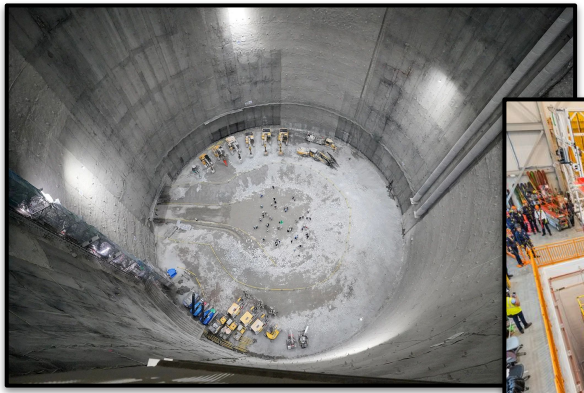
NoVA & T2K Joint Fit Nature volume 646, 818–824 (2025)

SND@LHC Phys. Rev. Lett. 134, 231802



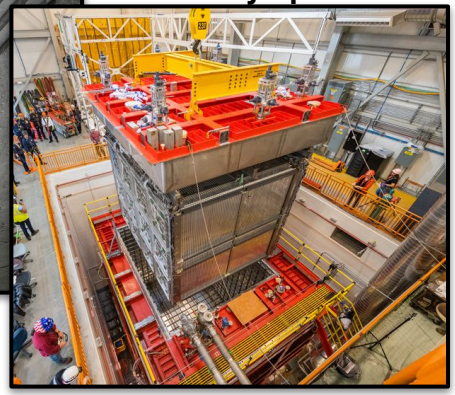


IceCube: arXiv:2510.24957



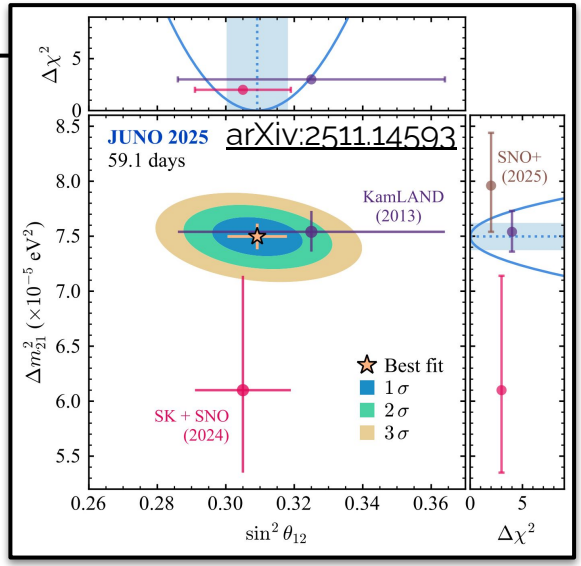
HyperK Cavern Complete (Aug 2025)

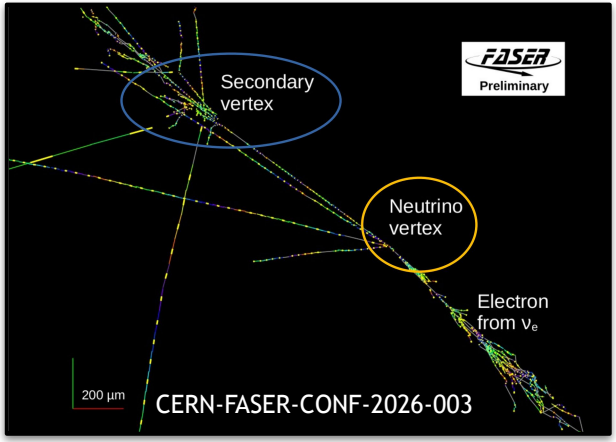
SBND fully operational



Conclusions I

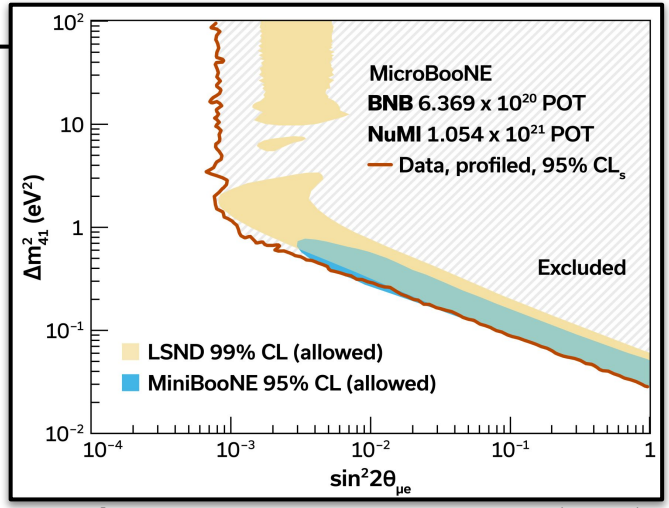
- Next generation **precision measurement experiments** are here with **JUNO** successful commissioning and operation
- Significant ramp up of **collider neutrino data and capabilities** which, alongside **xenon dark-matter TPCs,** are rapidly what we call neutrino experiments at the TeV and MeV scale



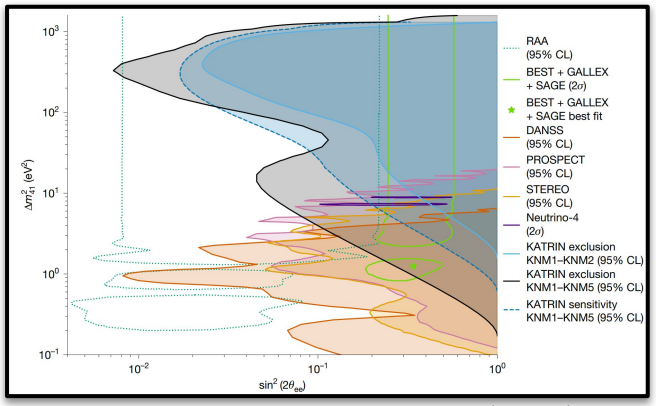


Conclusions II

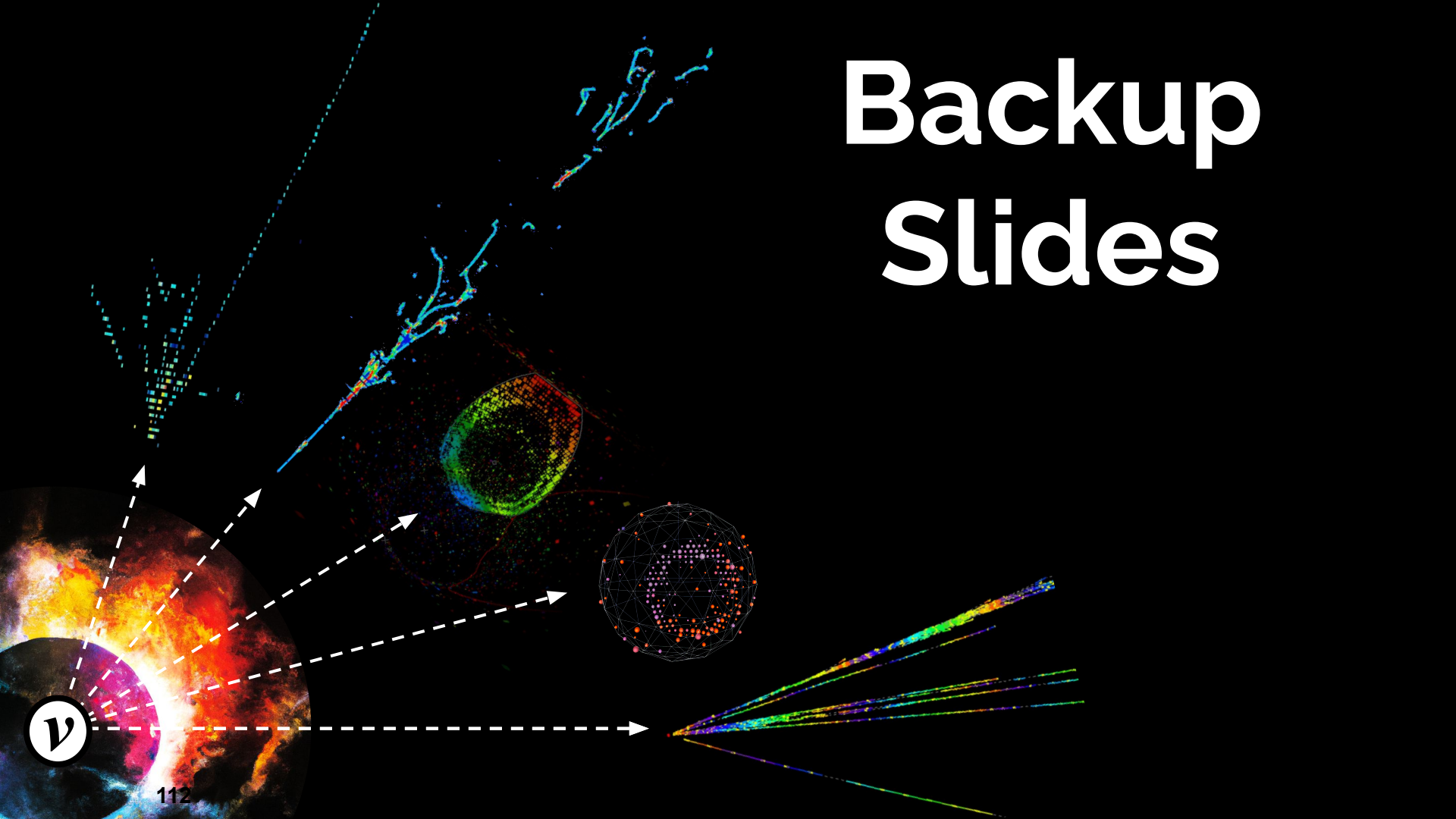
- Next generation **precision measurement experiments** are here with **JUNO** successful commissioning and operation
- Significant ramp up of **collider neutrino data and capabilities** which, alongside **xenon dark-matter TPCs,** are rapidly what we call neutrino experiments at the TeV and MeV scale
- There has been **extreme tension** in global data for a "light 3+1 sterile" for years. **Not just "global tension" anymore**, with new results **directly ruling out** almost the entire viable parameter space of various anomalies.
    - *But the anomalies themselves remain and need explanations!*



MicroBooNE: Nature 648, 64–69 (2025)



KATRIN: Nature 648, 70–75 (2025)



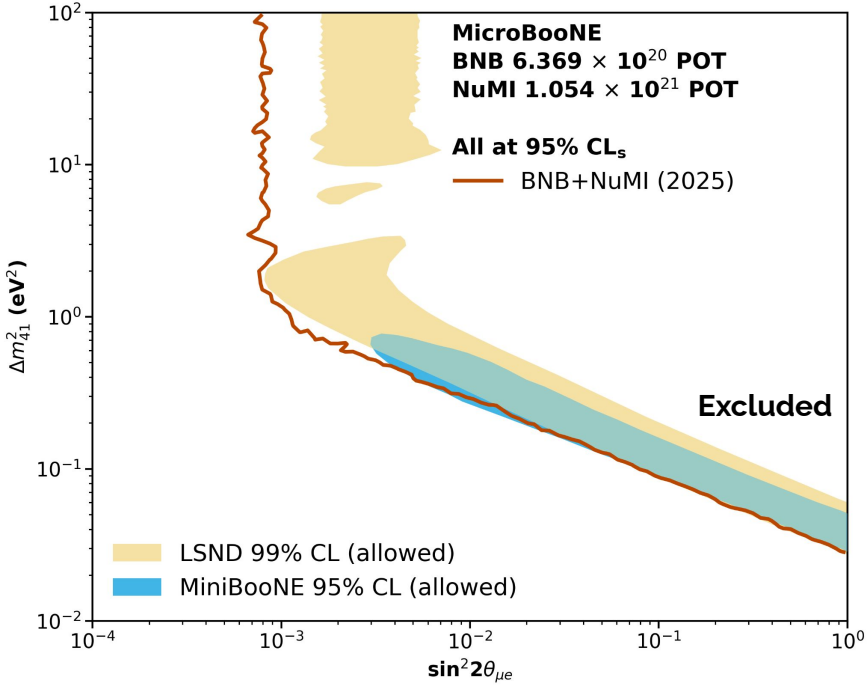
Backup Slides

Sources/Processes	Type	Radiation
^{137}Cs	γ	0.662 MeV
^{54}Mn	γ	0.835 MeV
^{60}Co	γ	1.173 + 1.333 MeV
^{40}K	γ	1.461 MeV
^{68}Ge	e^+	annihilation 0.511 + 0.511 MeV
^{241}Am-Be	n, γ	neutron + 4.43 MeV (^{12}C*)
^{241}Am-^{13}C	n, γ	neutron + 6.13 MeV (^{16}O*)
(n,γ)p	γ	2.22 MeV
(n,γ)^{12}C	γ	4.94 MeV or 3.68 + 1.26 MeV

First Dual Beam Sterile Neutrino Constraints

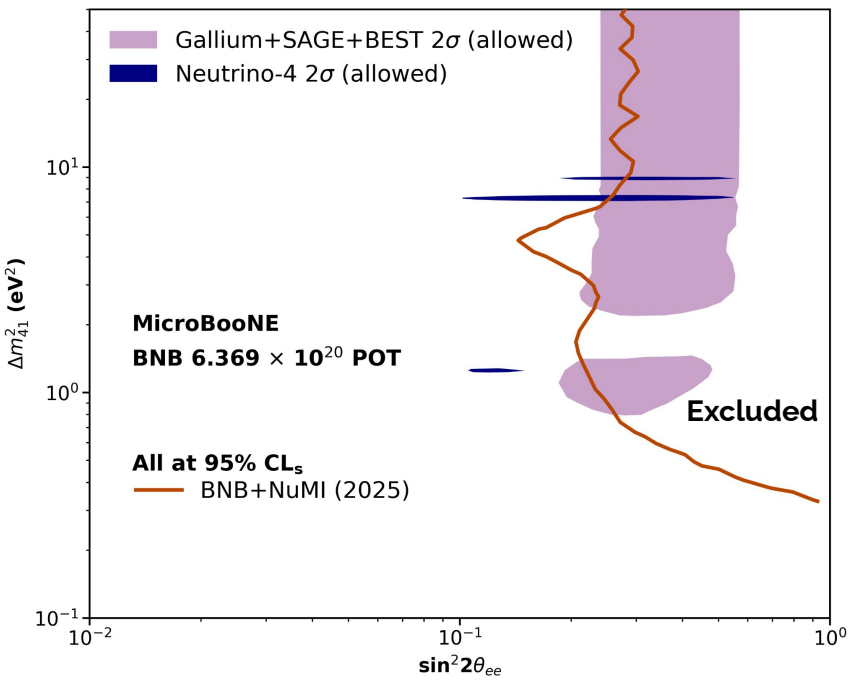
MicroBooNE: Nature volume 648, 64–69 (2025)

$\nu_\mu \rightarrow \nu_e$



- Excludes LSND 99% allowed region
- Excludes vast majority of MiniBooNE 95% allowed region

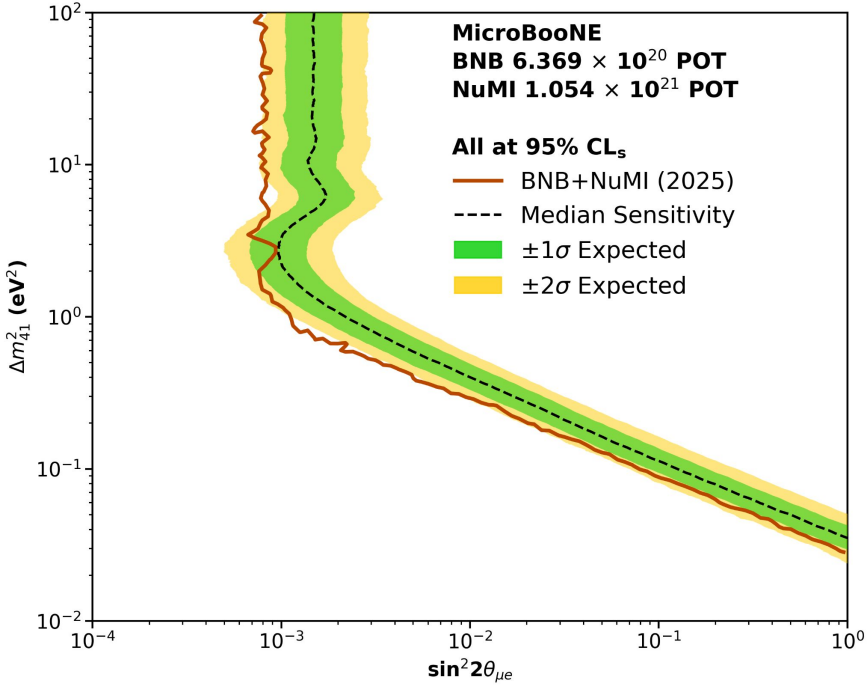
$\nu_e \rightarrow \nu_e$



- Provides an **internal, self-consistent ν_e disappearance constraint**
- Covers most of Gallium allowed region and part of Neutrino-4 allowed region

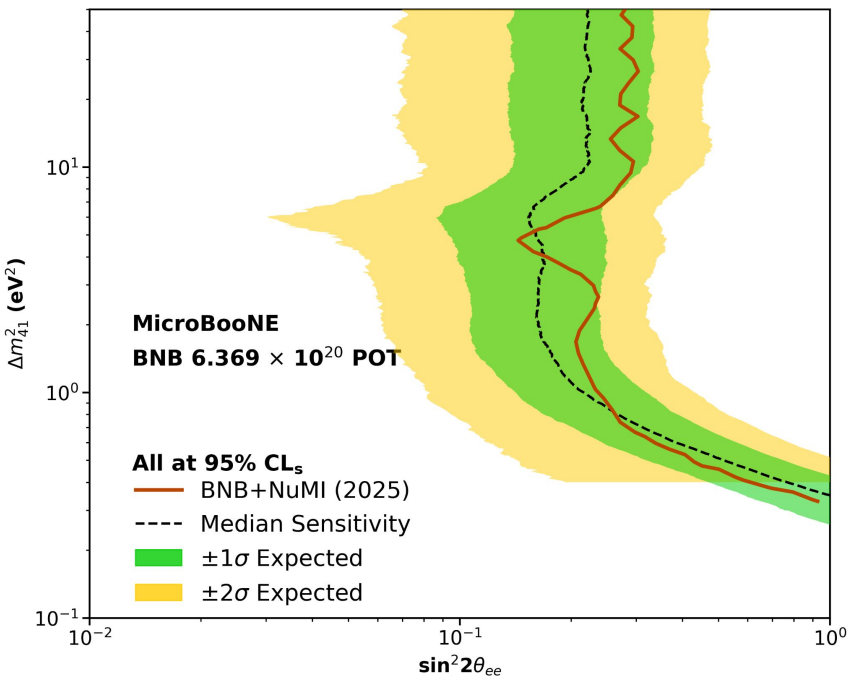
Predicted Sensitivities

$\nu_\mu \rightarrow \nu_e$



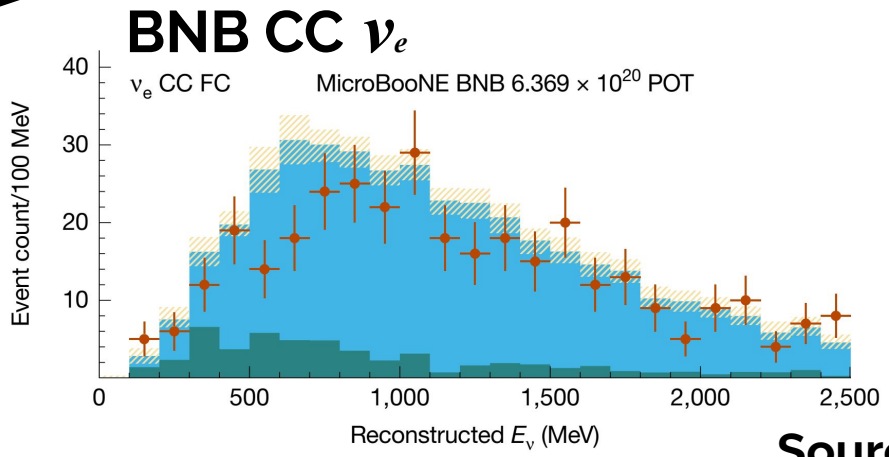
Data exclusion is stronger than median sensitivity.
Lies around the 2σ expected experiment

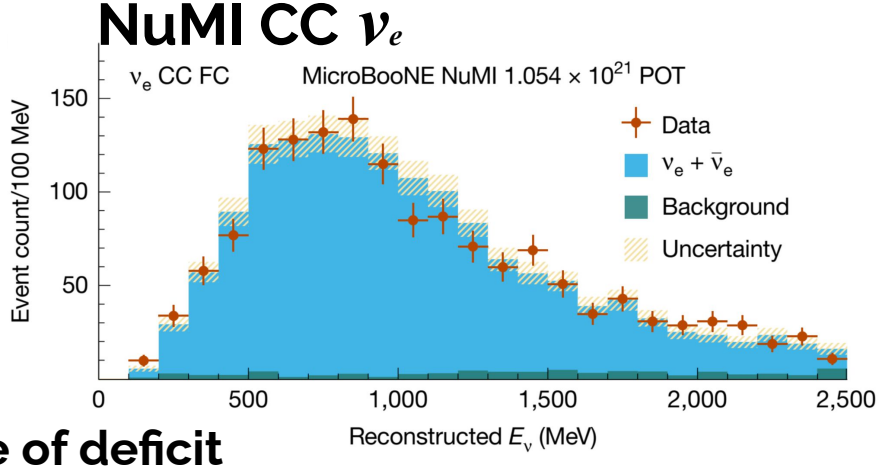
$\nu_e \rightarrow \nu_e$



Data exclusion is slightly weaker than median sensitivity.

Strength of Result Driven by BNB ν_e



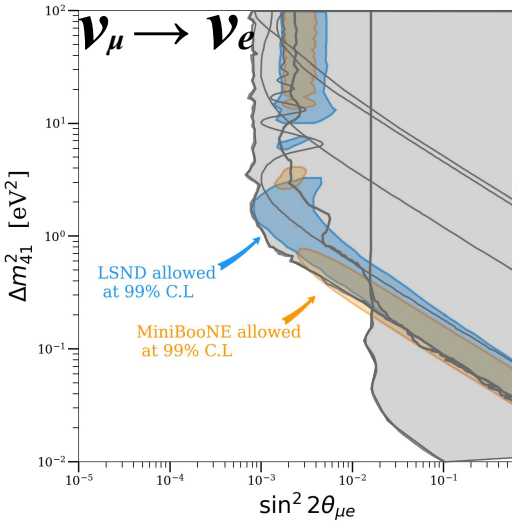


Source of deficit

- *Interaction Modelling?* ***Same Model***
- *Detector Modelling ?* ***Same Detector/treatment***
- *Reconstruction Effect ?* ***Same Reco Framework***
- *Flux Modelling ?* ***Different Fluxes/Beams***
- ***Statistical***
- ***New Physics Driven***

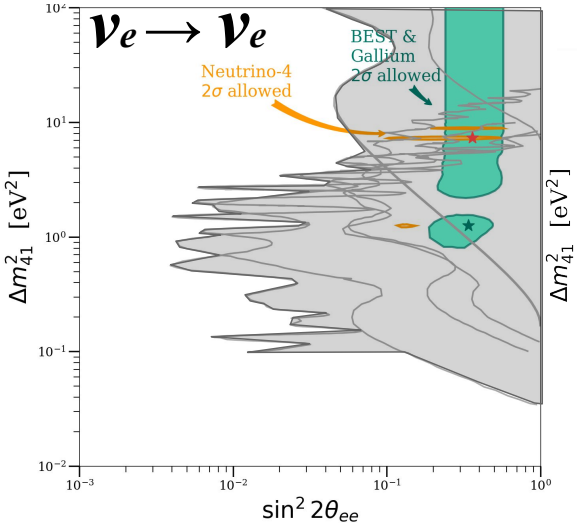
} Investigations Continue **~Double the Data**

Where we Stand?



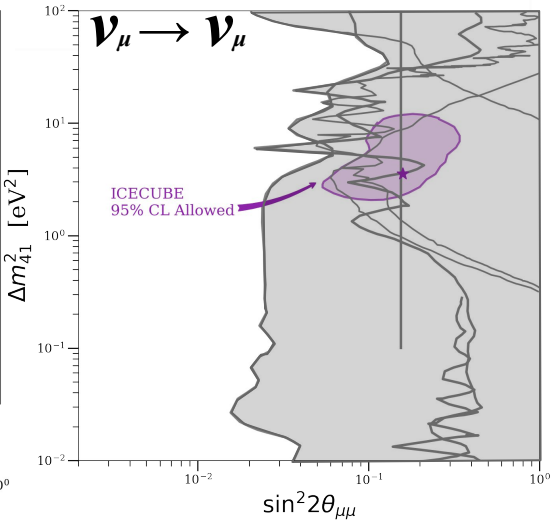
Positive Hints
- LSND
- MiniBooNE

Null Results
- Karmen
- NuTeV
- CCFR
- NOMAD
- OPERA
- MicroBooNE



Positive Hints
- Gallium
- Neutrino-4

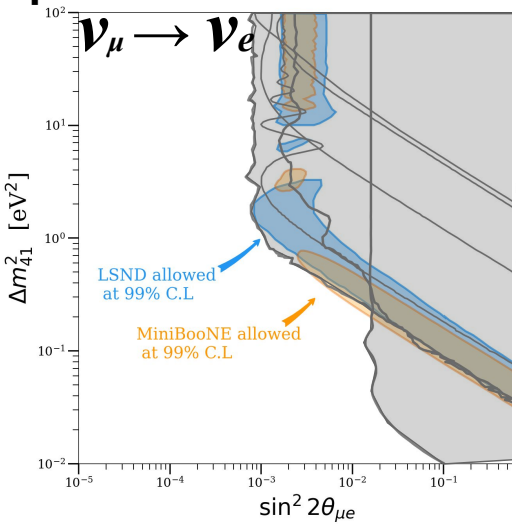
Null Results
- NEOS+RENO
- DANSS
- PROSPECT
- STEREO
- KATRIN

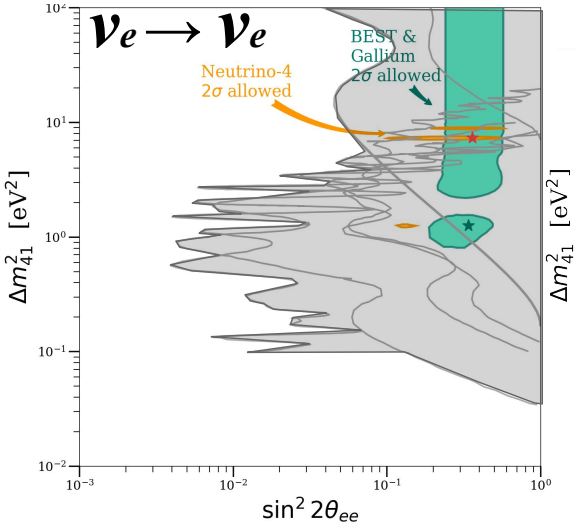


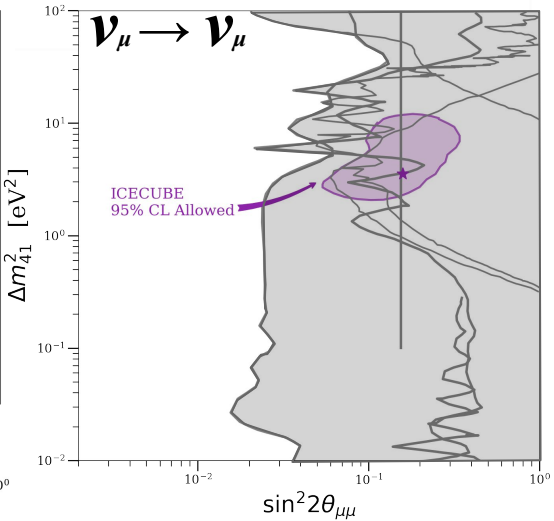
Positive Hints
- IceCube

Null Results
- MiniBooNE
- CDHS
- CCFR
- T2K
- NoVA
- MINOS
- Super-K

The Elephant in the Room...

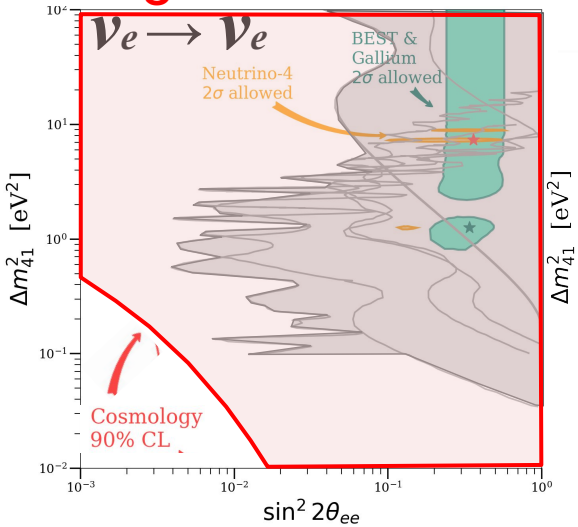


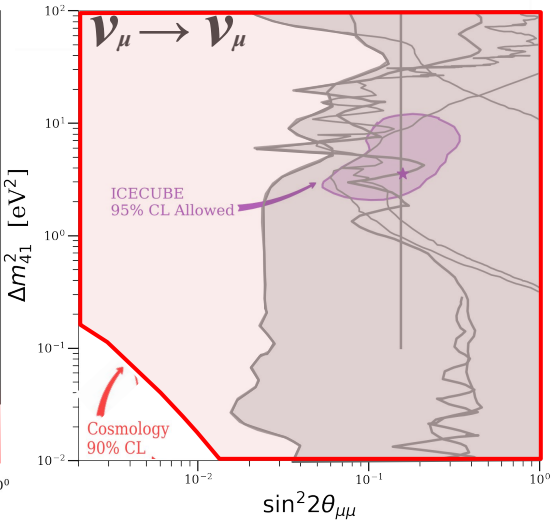




The Elephant in the Room… Cosmological Bounds

HUGE tension between cosmological bounds and ***vanilla*** **3+1 short-baseline steriles**





S. Hagstotz et al, PhysRevD.104.123524

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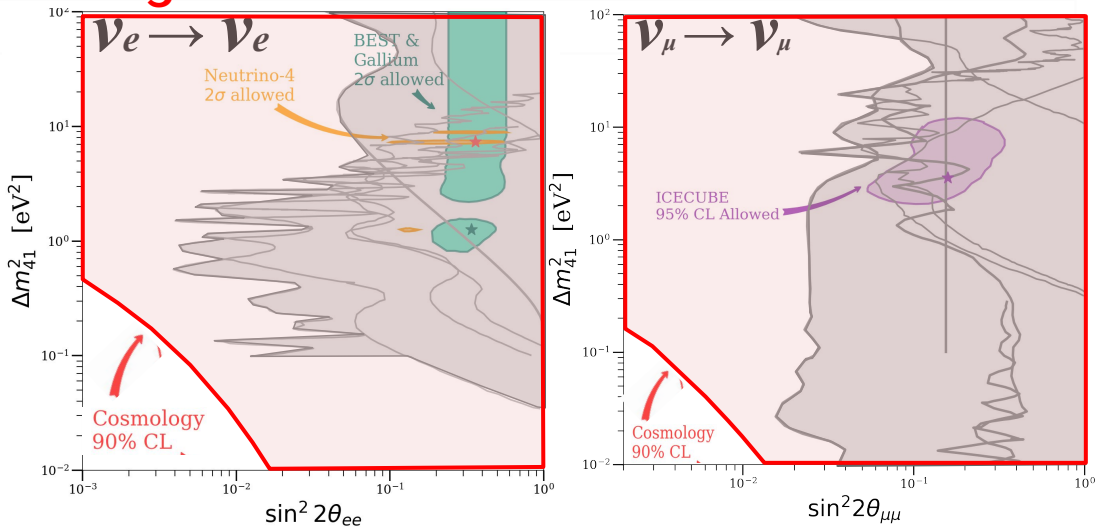

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Energy density of **Relativistic Neutrinos**

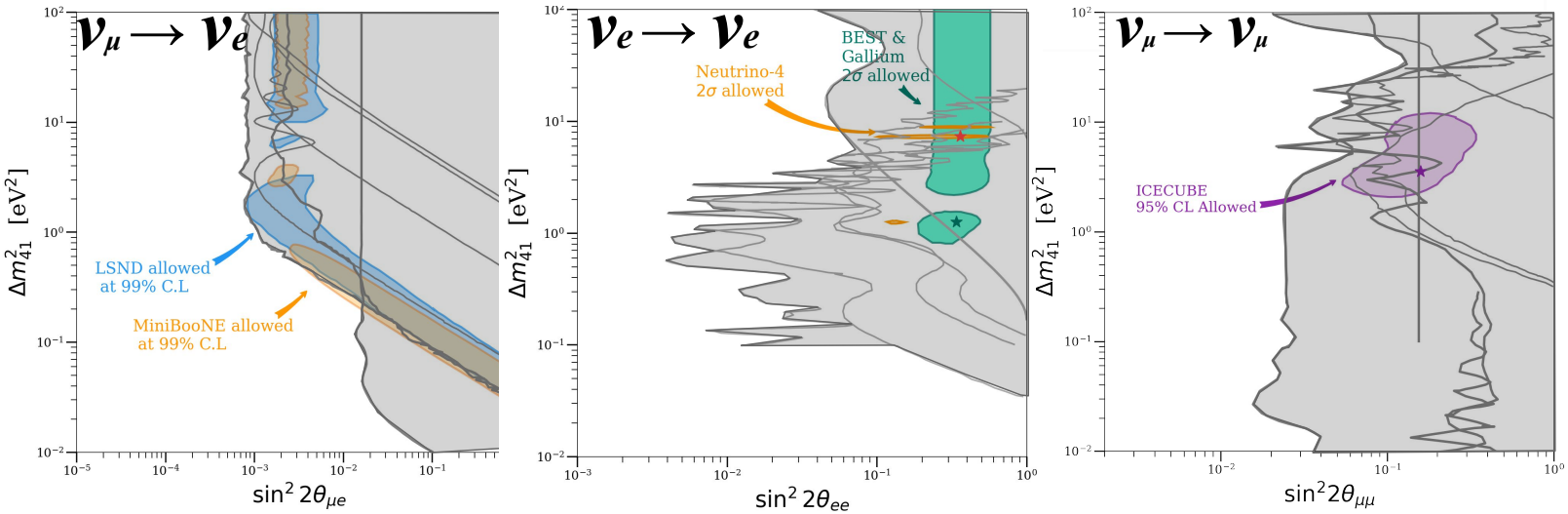
$$N_{\text{eff}}^{\nu} = \frac{8}{7}\left(\frac{11}{4}\right)^{4/3}\frac{\rho_\nu}{\rho_\gamma}$$

N_{eff} = 2.99 ± 0.17 (CMB+lens+BAO) Plank2018

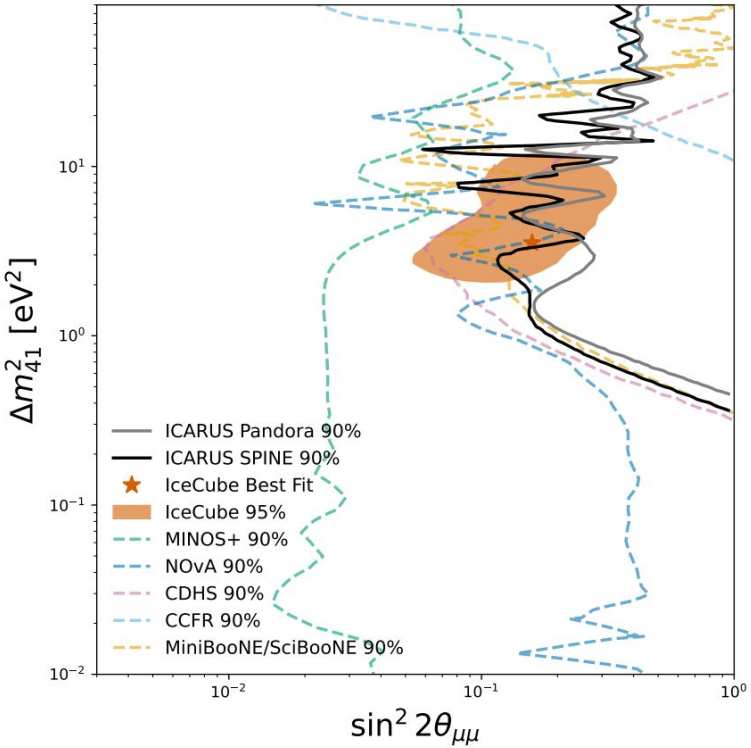
Can this be avoided? Is this dependent on specific models of ΛCDM?

Possibly, but you have to add more new physics! It's no longer a simple vanilla "3+1" model

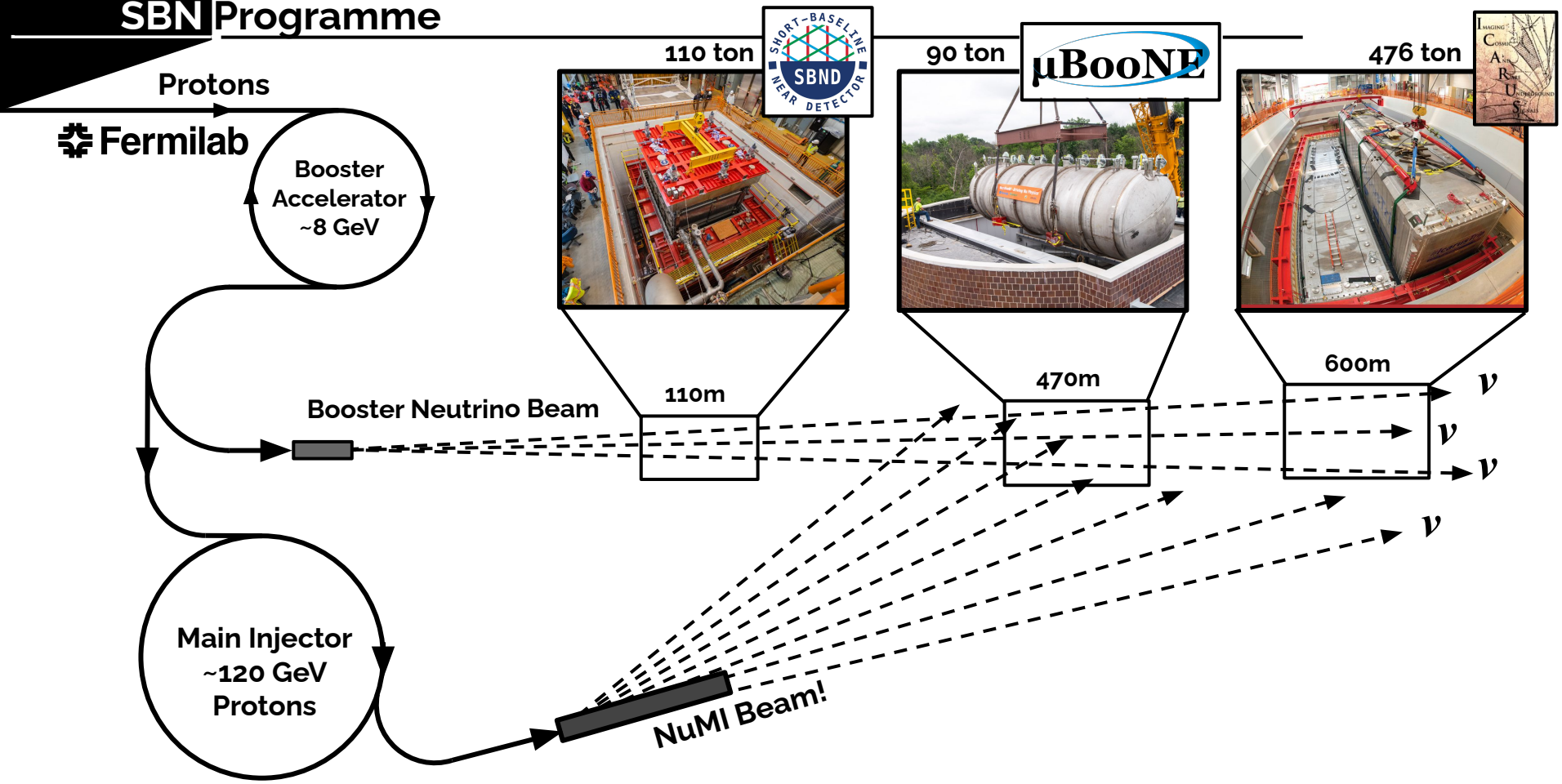
Where We Stand – 2026



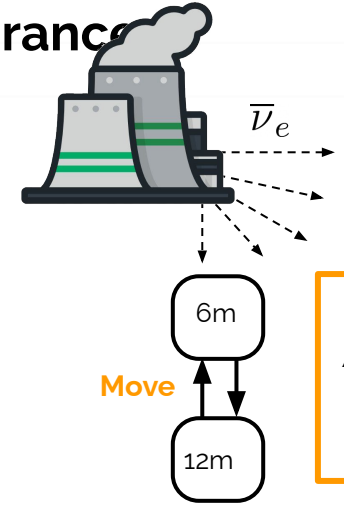
- There has been **EXTREME tension** in global data for a "light 3+1 oscillating sterile neutrinos" for years, gets ***much worse*** with **cosmology** included


ICARUS Pandora 90%
ICARUS SPINE 90%
IceCube Best Fit
IceCube 95%
MINOS+ 90%
NOvA 90%
CDHS 90%
CCFR 90%
MiniBooNE/SciBooNE 90%
Δm^2_{41} [eV^2]
$\sin^2 2\theta_{\mu\mu}$
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-2}
10^{-1}
10^{0}

SBN Programme



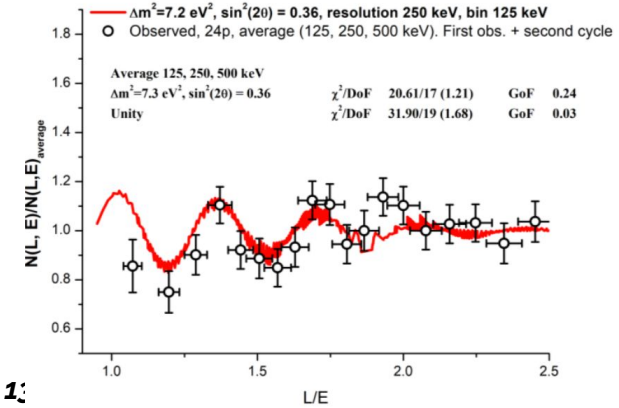
ν_e Disappearance



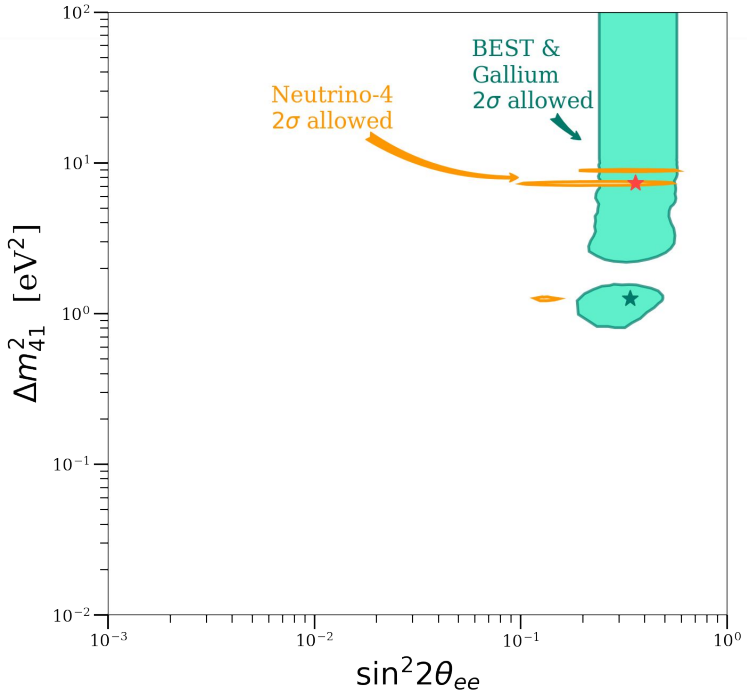
Neutrino-4 Positive Signal?

Best-Fit oscillation $\Delta m^2 = 7.3\ eV^2$, $\sin^2 2\theta = 0.36$ @ **2.9σ significance**

- Commercial reactor, 100 MW_{th} in Russia

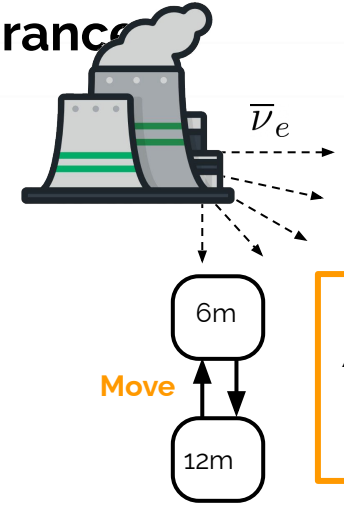


$\nu_e \rightarrow \nu_e$



Neutrino4: PhysRevD.104.032003

νe Disappearance



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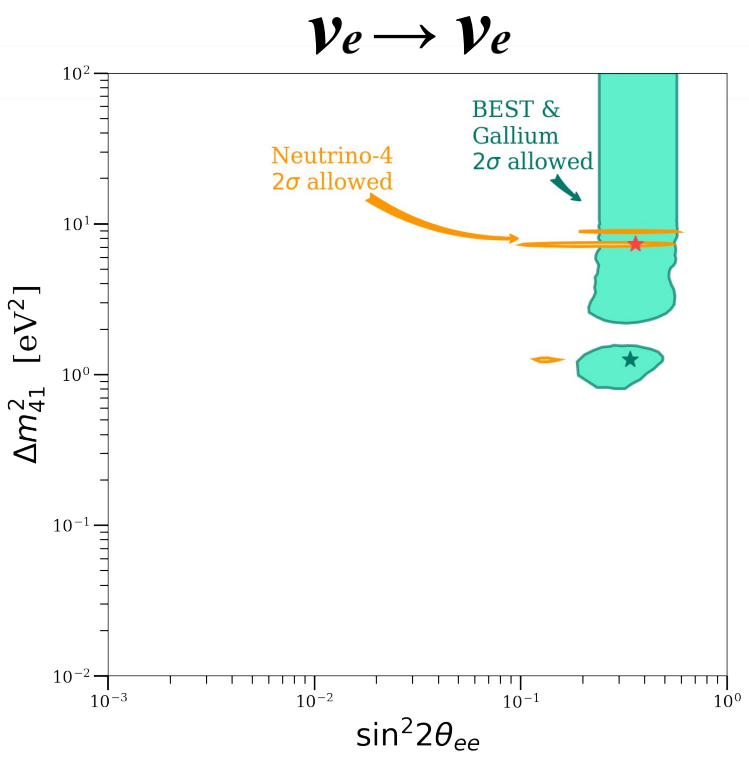


Several questions have been raised by community so far, including the **effects of the statistical approach used,** and impact of **systematics** and **expected backgrounds**

- H. Almazán et al, arXiv:2006.13147
- C. Giunti et al j.physletb.2021.136214

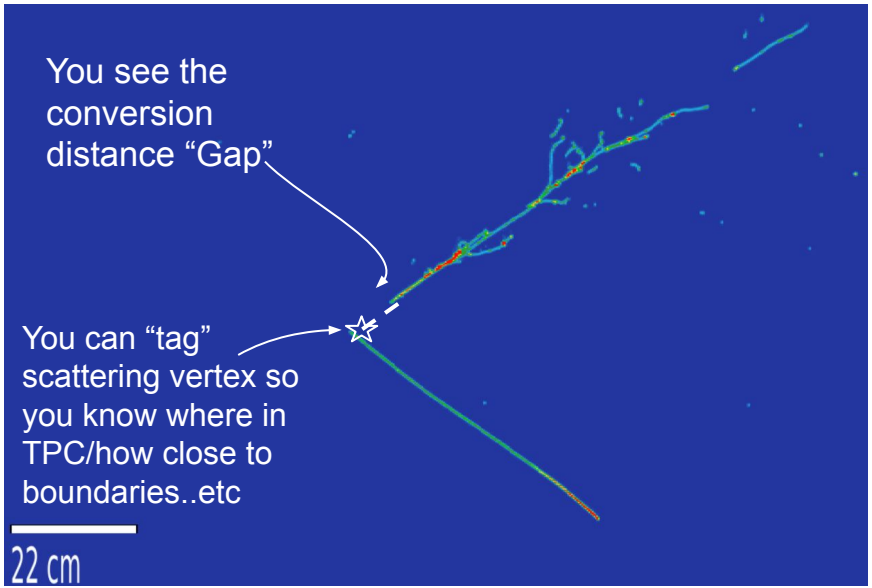
> *"Therefore, we conclude that the claimed Neutrino-4 indication in favor of short-baseline neutrino oscillations with very large mixing is rather doubtful."*

Neutrino4: PhysRevD.104.032003

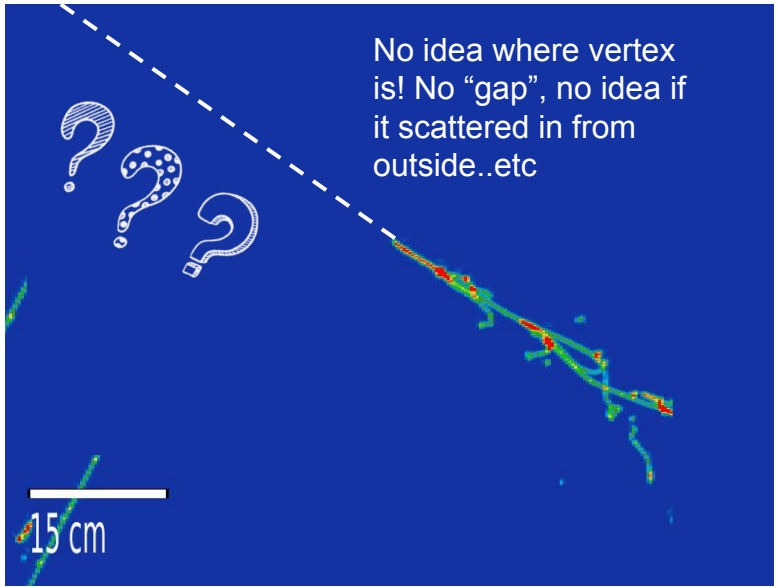
Two key facts to understand photon/e+e- searches

1. π^0's are the dominant, and often irreducible, background
2. **Broadly speaking two categories of searches, photons with and without hadronic/proton activity**

Photon + Protons



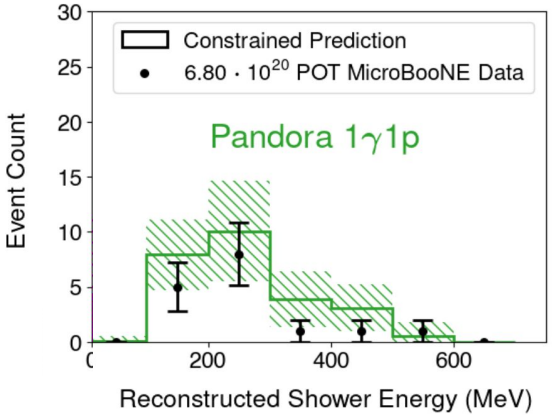
Photon + No Protons

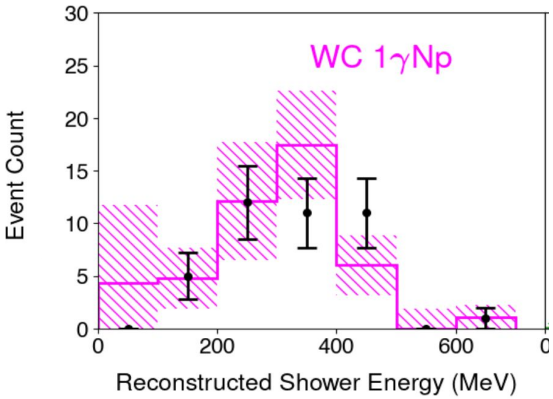


Single-Photon with Protons

Enhanced Search for Neutral Current **Δ Radiative** Single-Photon Production in MicroBooNE

- arXiv:2502.05750 [hep-ex] (2025)





Inclusive Search for Anomalous Single-Photon Production in MicroBooNE

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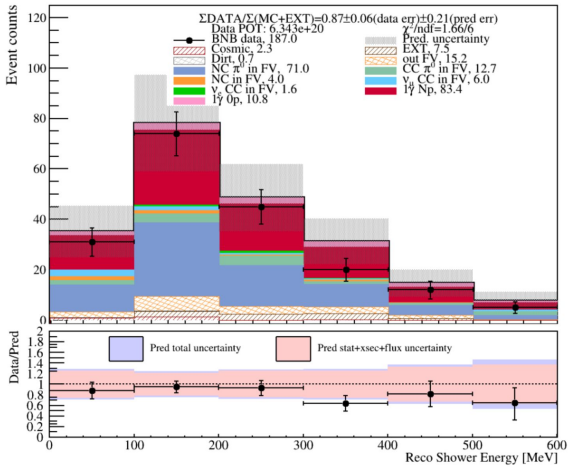

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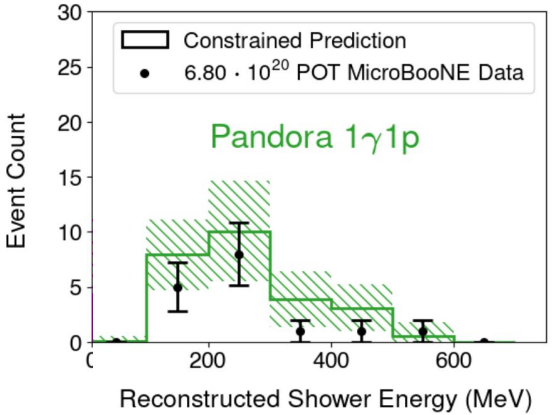

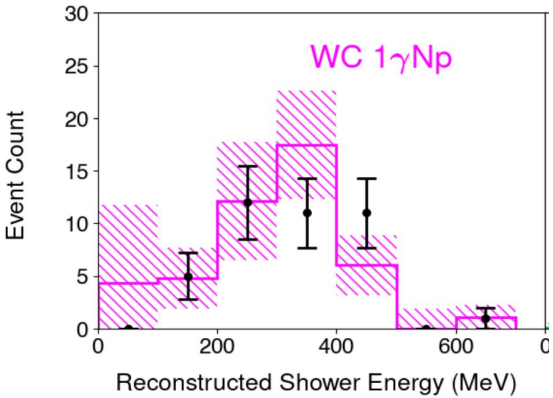

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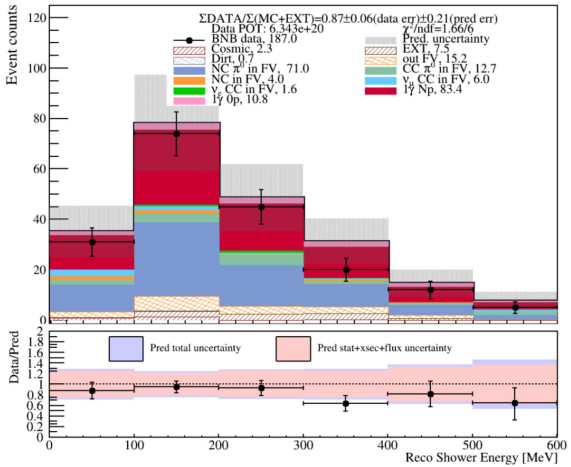
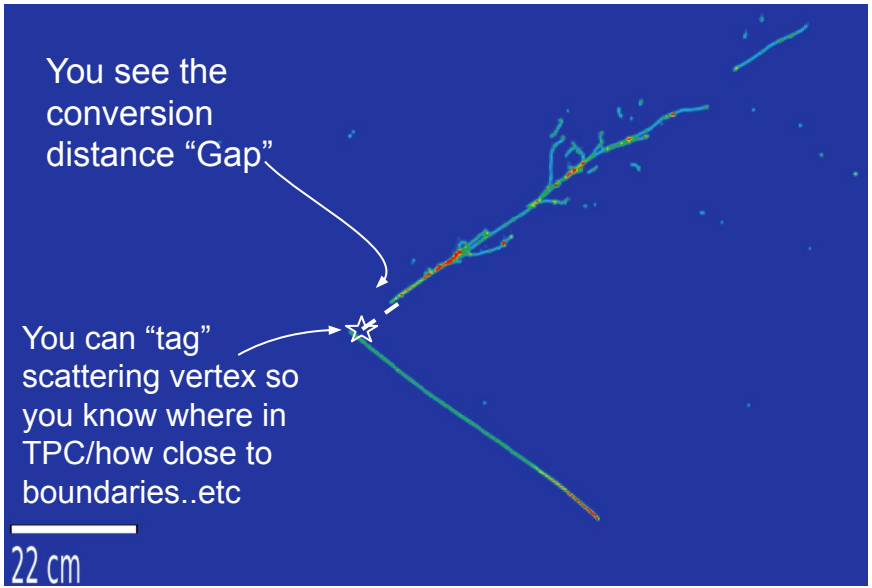


- In all cases, consistent picture, good agreement with predictions
  - **No Anomalous Excess**
- Backgrounds ~70→80% NC π^0 but we would expect to be sensitive to a MiniBooNE size signal,

Two key facts to understand photon/e+e- searches

1. π^0's are dominant, and often irreducible, background
2. **Broadly speaking two categories of searches, photons with and without hadronic/proton activity**

Photon + Protons



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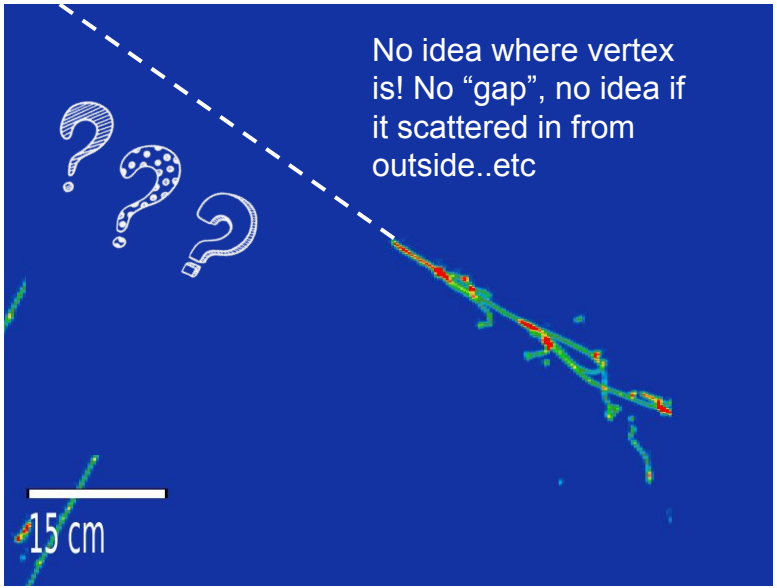

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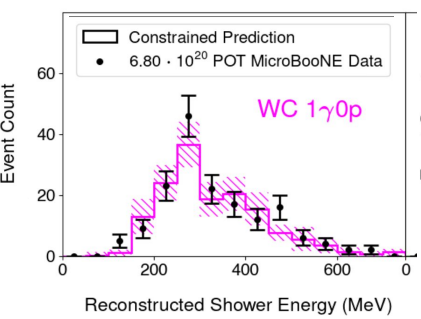
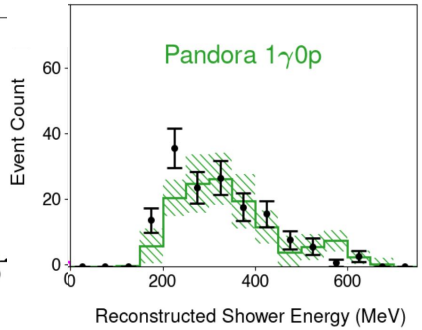
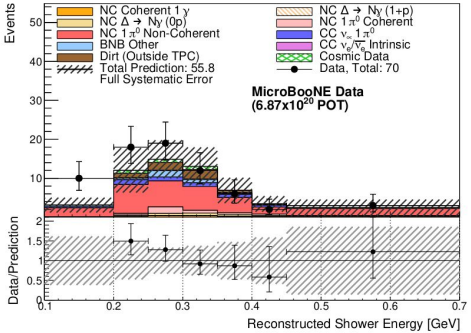
- arXiv:2502.06091 [hep-ex] (2025)







- *Broadly* good agreement with predictions…
- A few local bumps ~insignificant, and crucially **none of them were particularly sensitive!** NC π^0 backgrounds much harder with no vertex!

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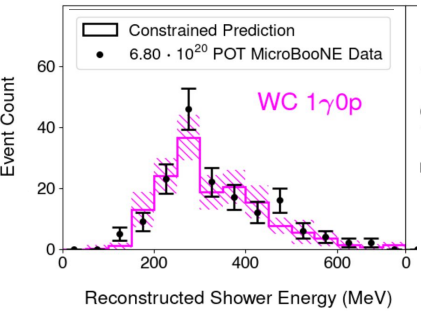
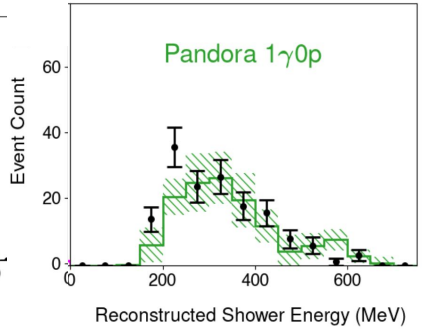
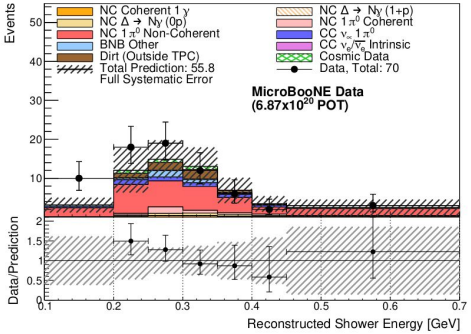
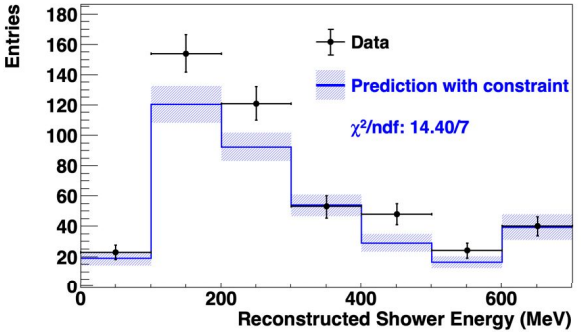








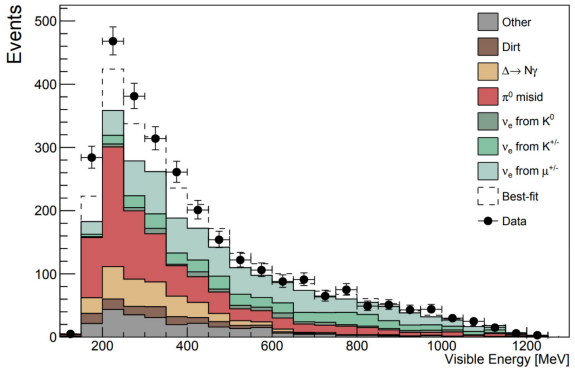
Excess of **93 ± 22(stat.) ± 35 (syst.)** data events **(2.2σ)** from 0-600 MeV

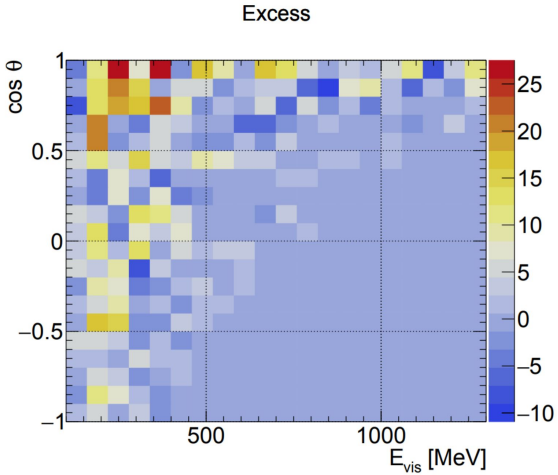
- *Broadly* good agreement with predictions…
- A few local bumps ~insignificant, and crucially **none of them were particularly sensitive!** NC π^0 backgrounds much harder with no vertex!
- The one analysis that *is more sensitive*, the inclusive analysis, sees a mild **2.2σ** excess, contained below 600 MeV

Overall Kinematic Agreement

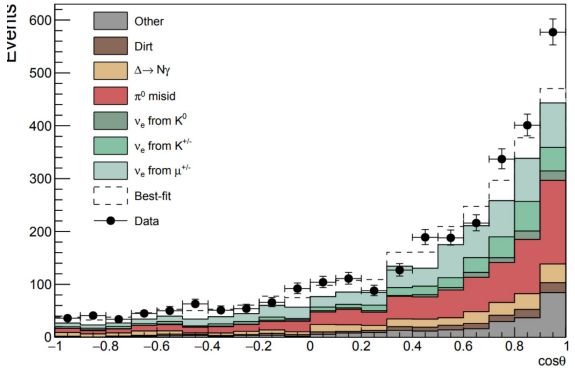
MiniBooNE

Shower/Visible **Energy**





Shower/Visible **Angle**



MicroBooNE