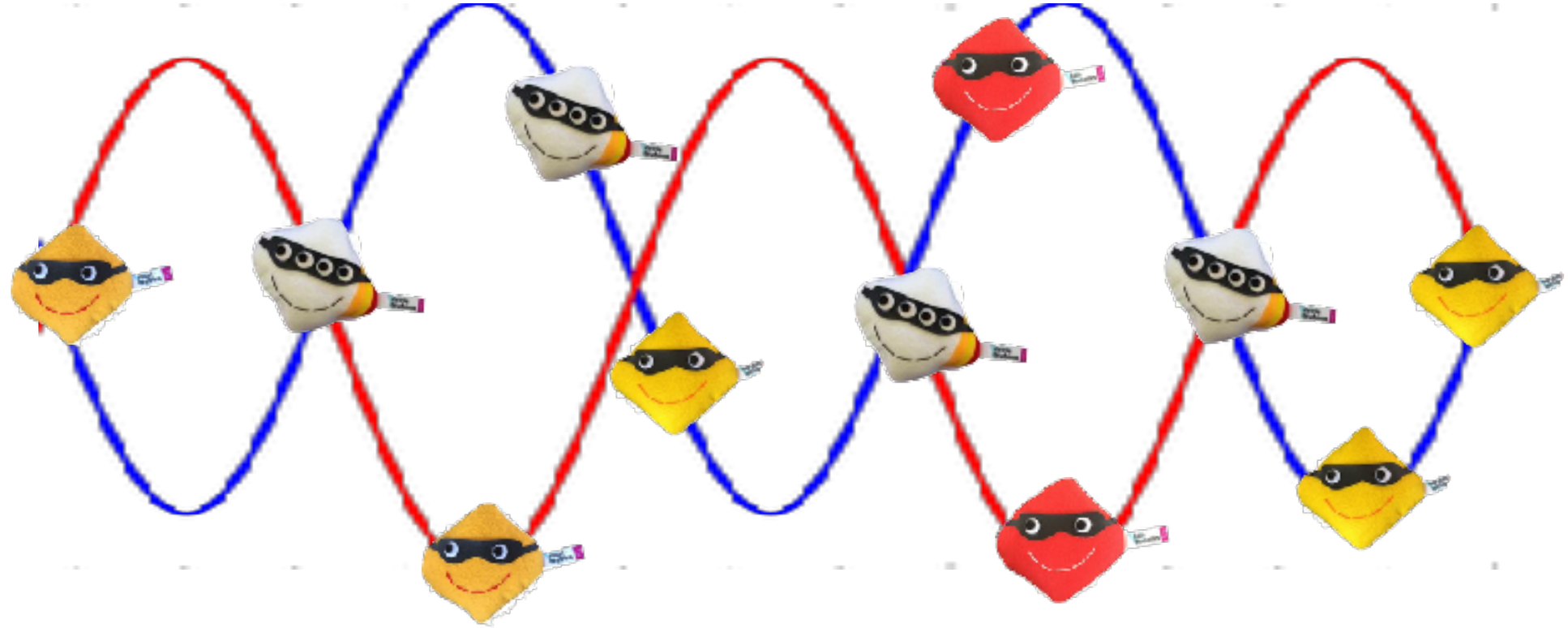


Search for sterile neutrinos with short baseline neutrino experiments

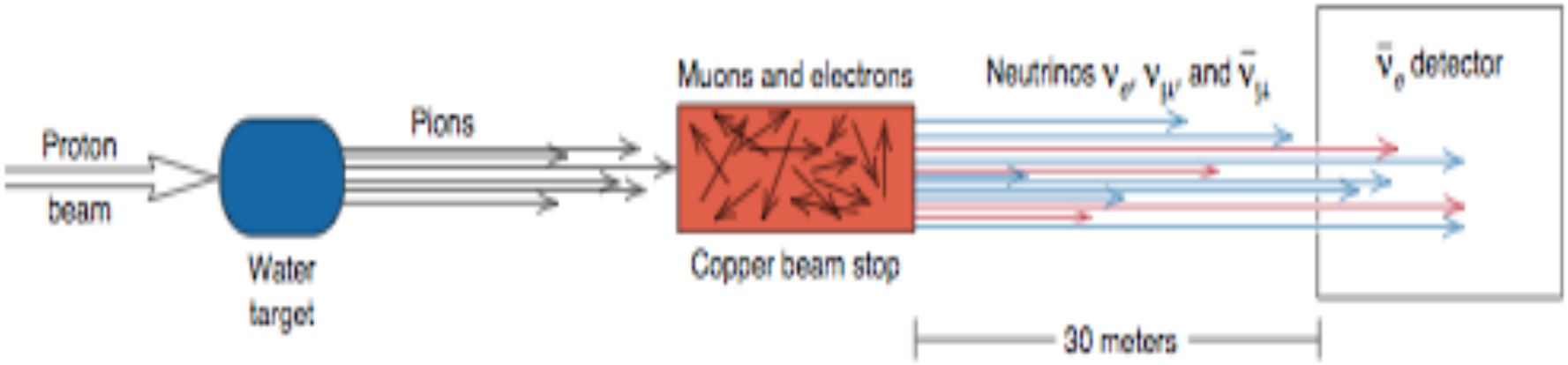
Roxanne Guenette

TAU 2021
27 - 30 September 2021

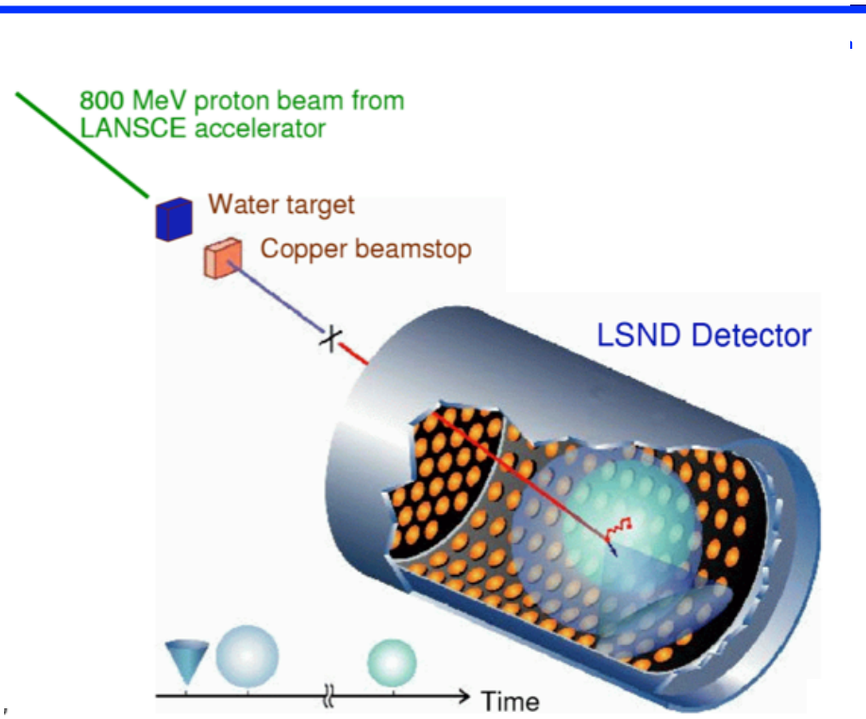
A brief (historical) tour of the anomalies…

- There are a lot of ups and downs with short baseline neutrino experiments
- Contradictory results make it very difficult to get a coherent picture that could explain it all
- Let's review (quickly!) the anomalies…

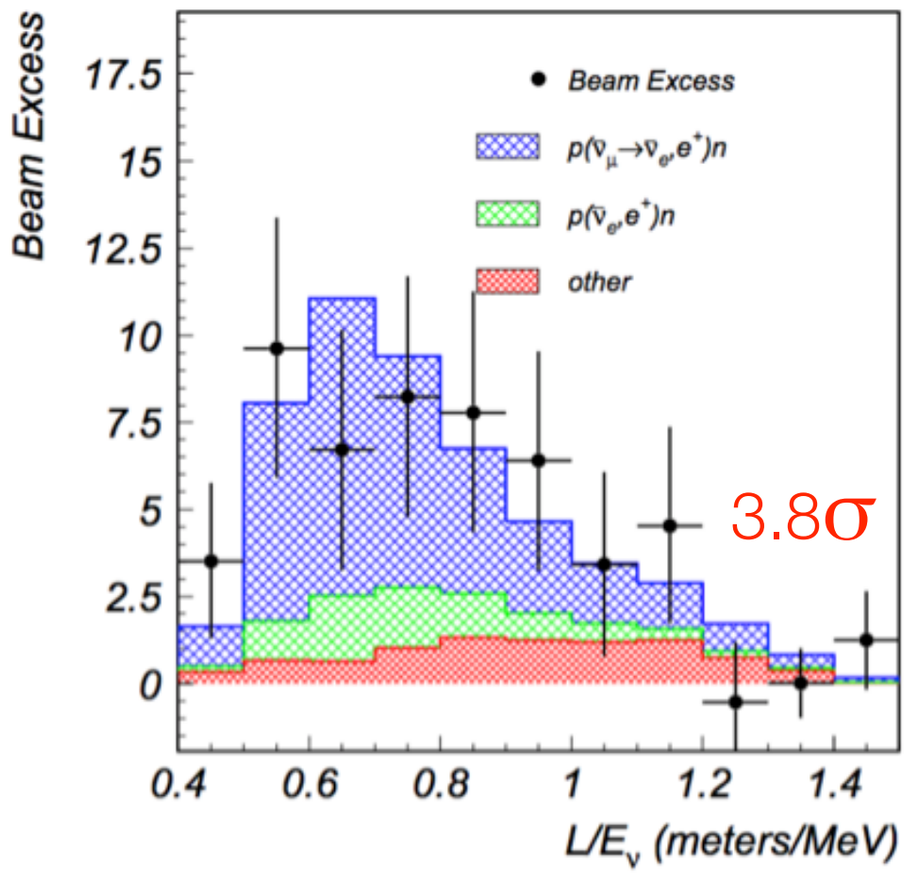
LSND (2001)



$$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$$



$$\bar{\nu}_e p \rightarrow e^+ n$$



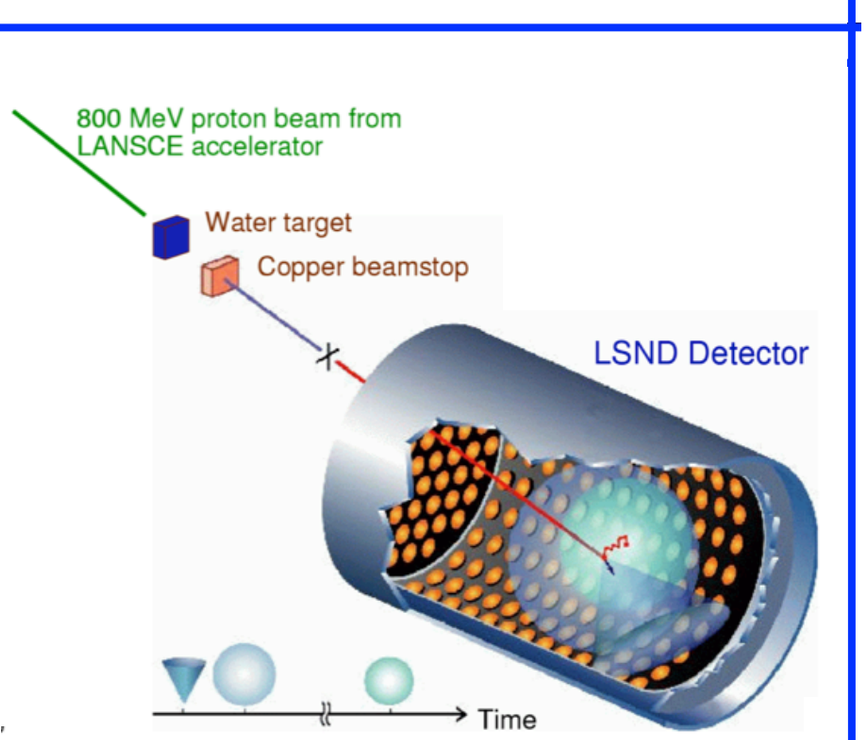
LSND (2001)

PRD 64 (2001) 112007

LSND (2001)

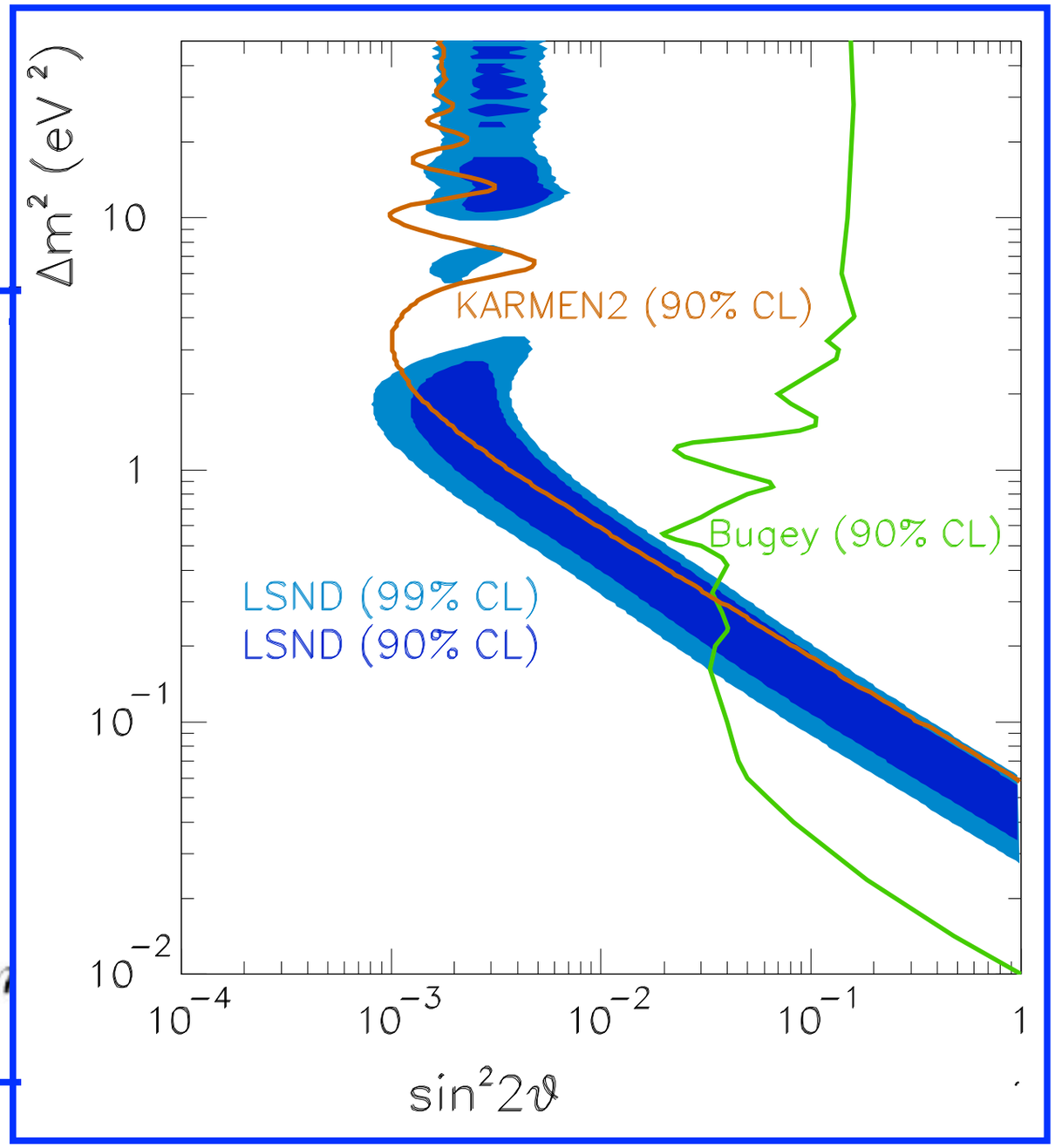
$$P_{\nu_\alpha \to \nu_\beta}(L,E) = sin^2 2\theta sin^2\left(1.27\frac{\Delta m^2(eV^2)L(km)}{E(GeV)}\right)$$

$\bar{\nu}_\mu \to \bar{\nu}_e$



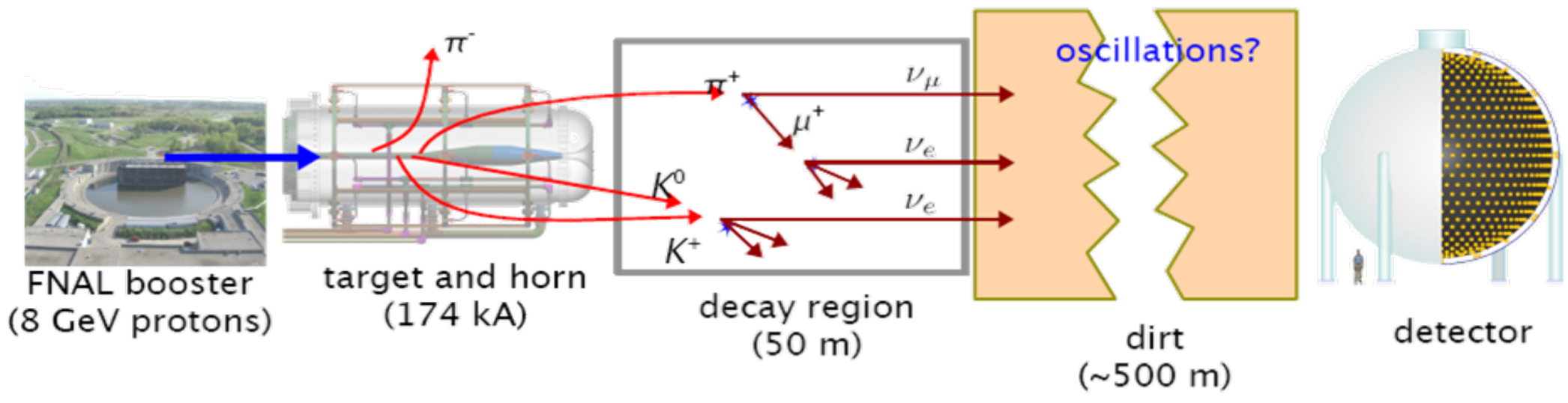
$\bar{\nu}_e p \to e^+ n$

LSND (2001)



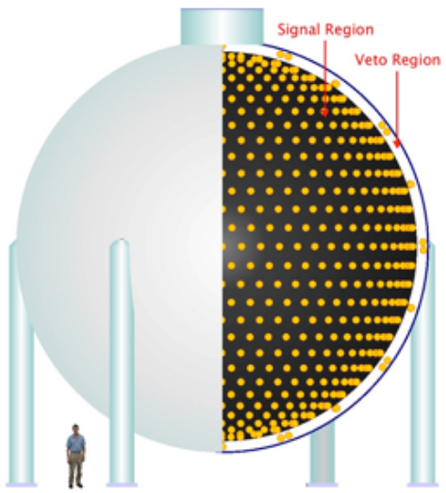
PRD 64 (2001) 112007

MiniBooNE (2009)

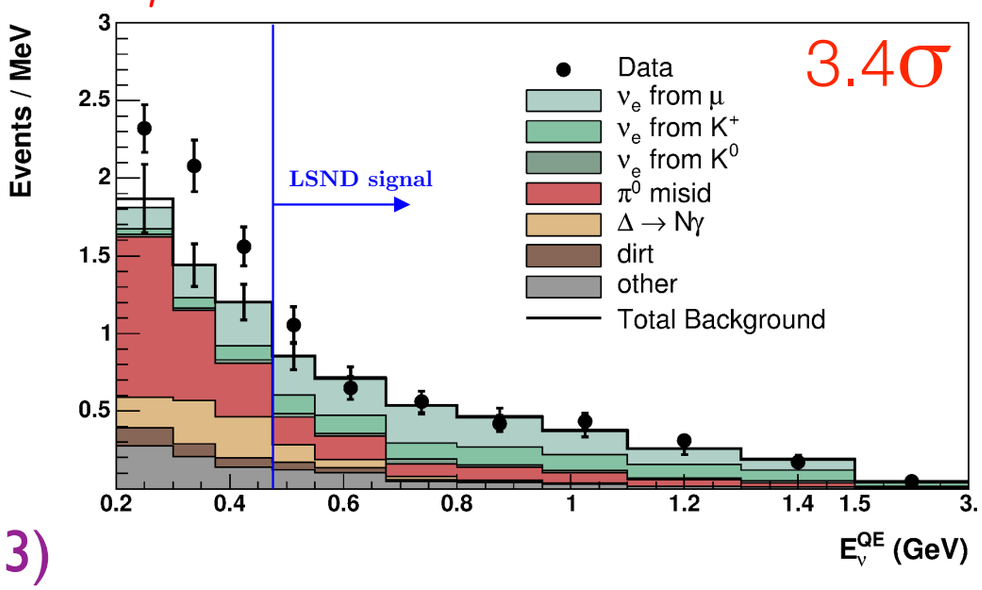


$\nu_\mu \rightarrow \nu_e$

MiniBooNE Detector

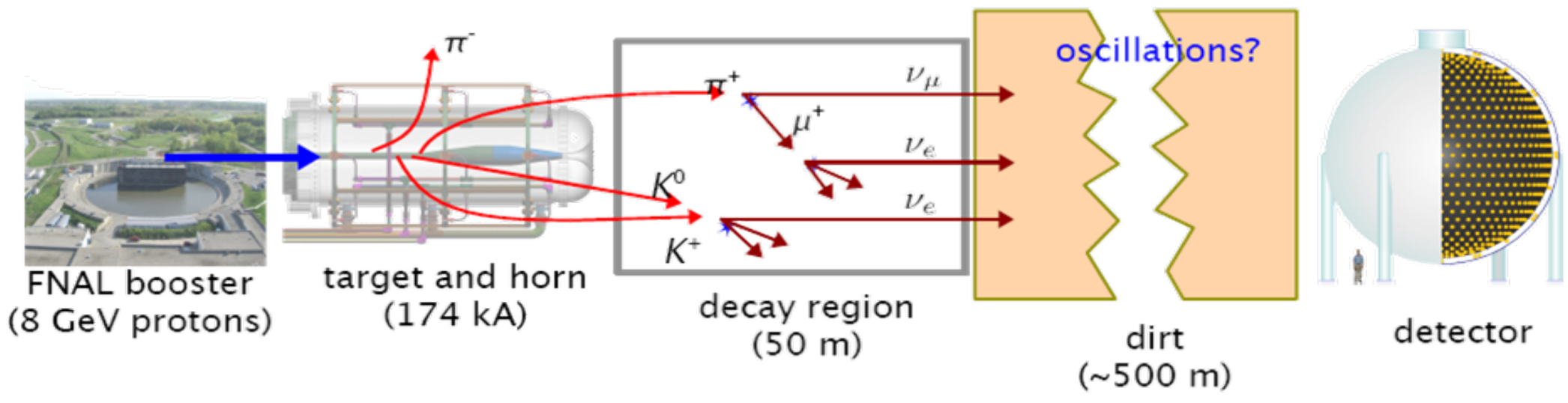


$\nu_\mu \rightarrow \nu_e$ [PRL 102 (2009) 101802]



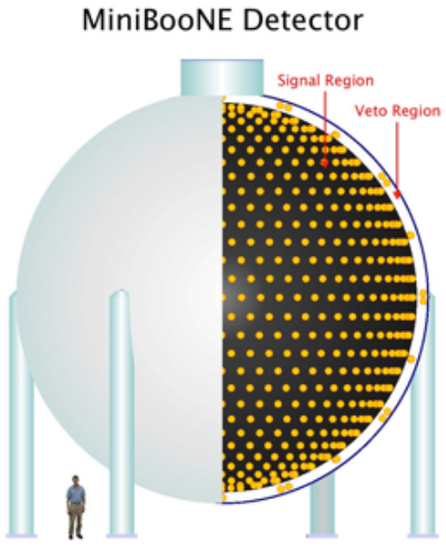
MiniBooNe (2009-2013)

MiniBooNE (2009 & 2011)



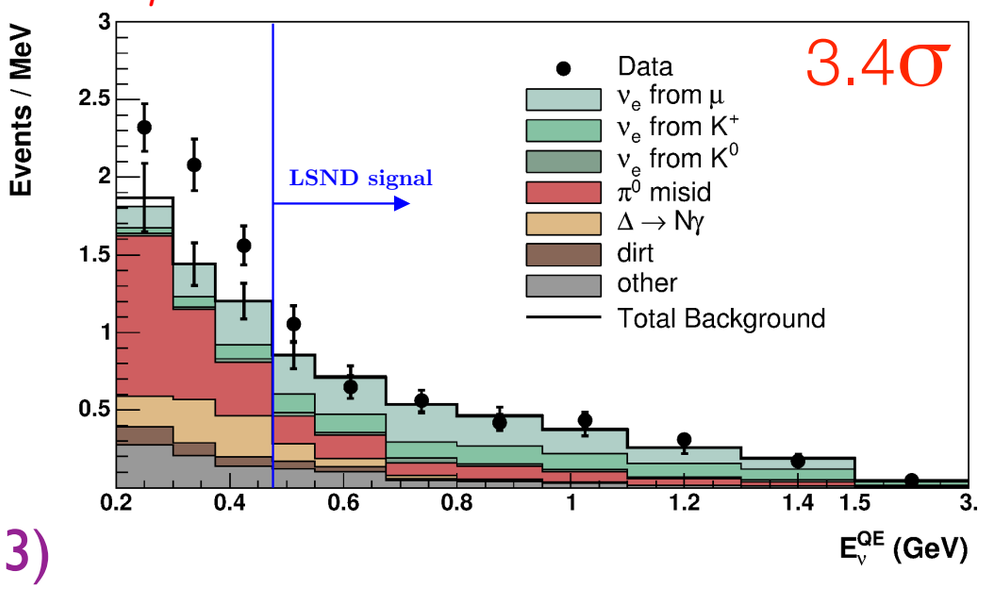
$\nu_\mu \rightarrow \nu_e$

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

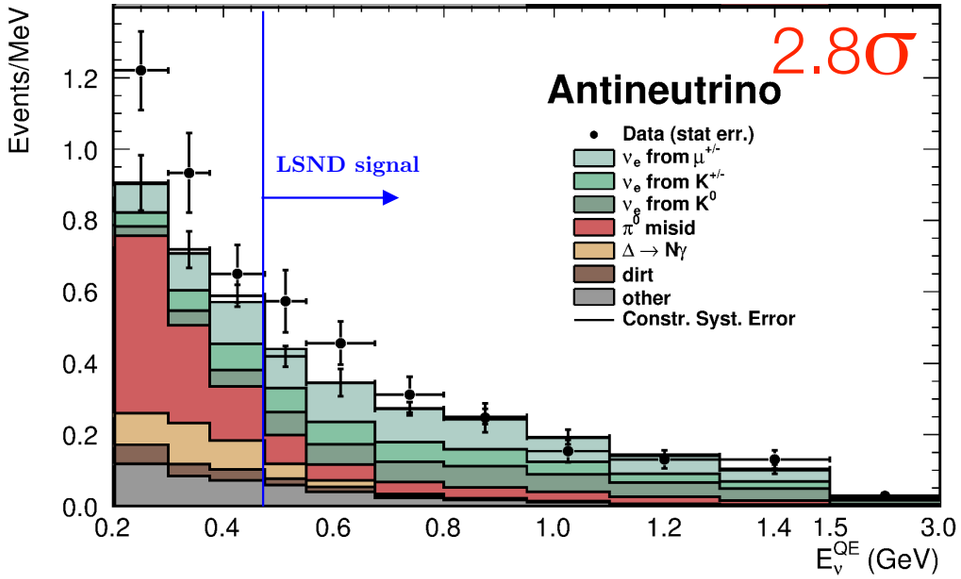


MiniBooNe (2009-2013)

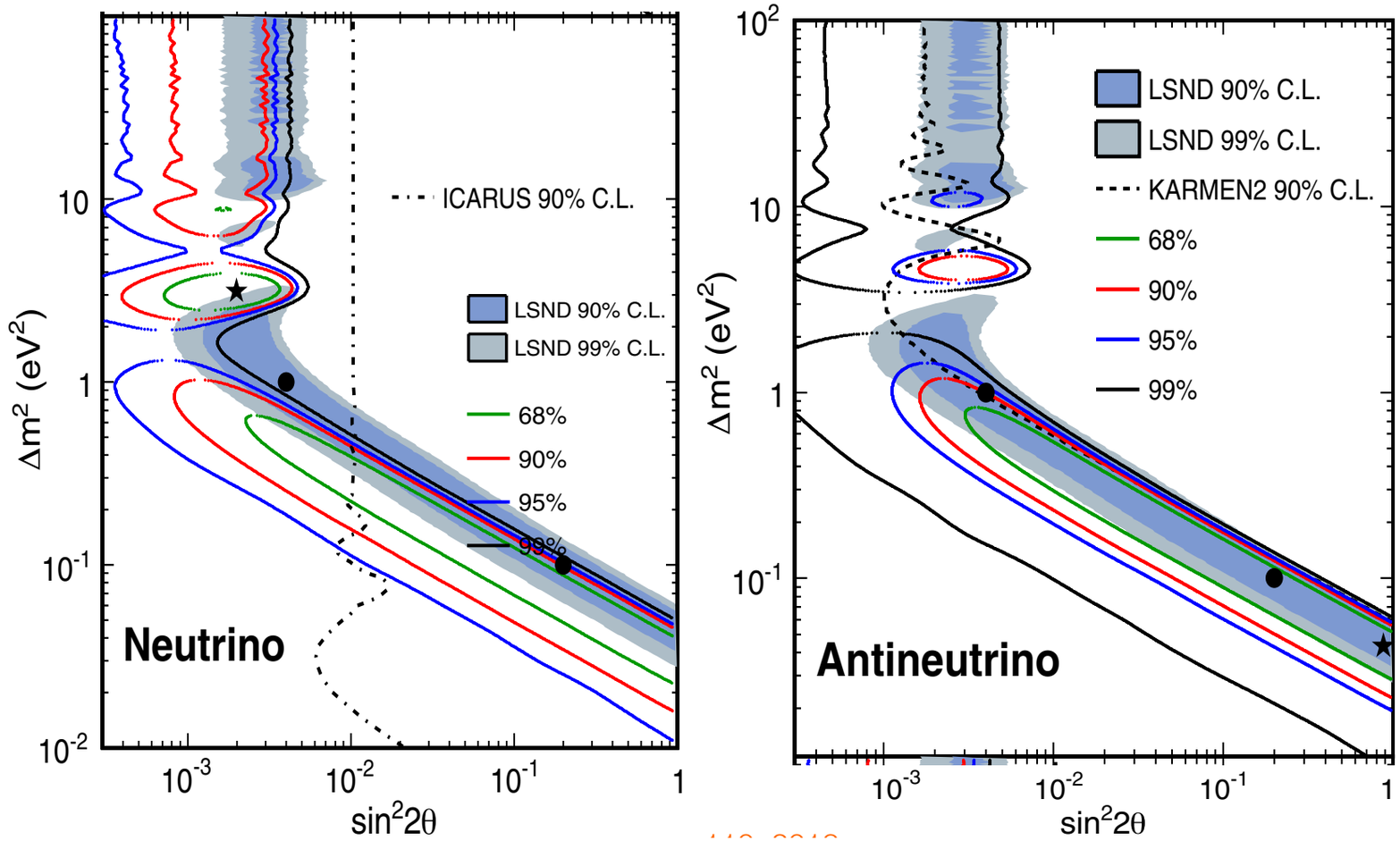
$\nu_\mu \rightarrow \nu_e$ [PRL 102 (2009) 101802]



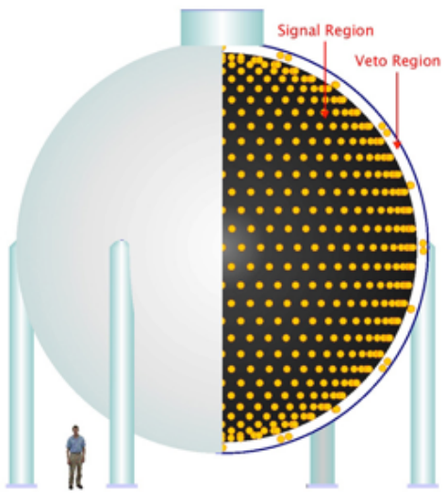
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ [PRL 110 (2013) 161801]



MiniBooNE (2009 & 2011)

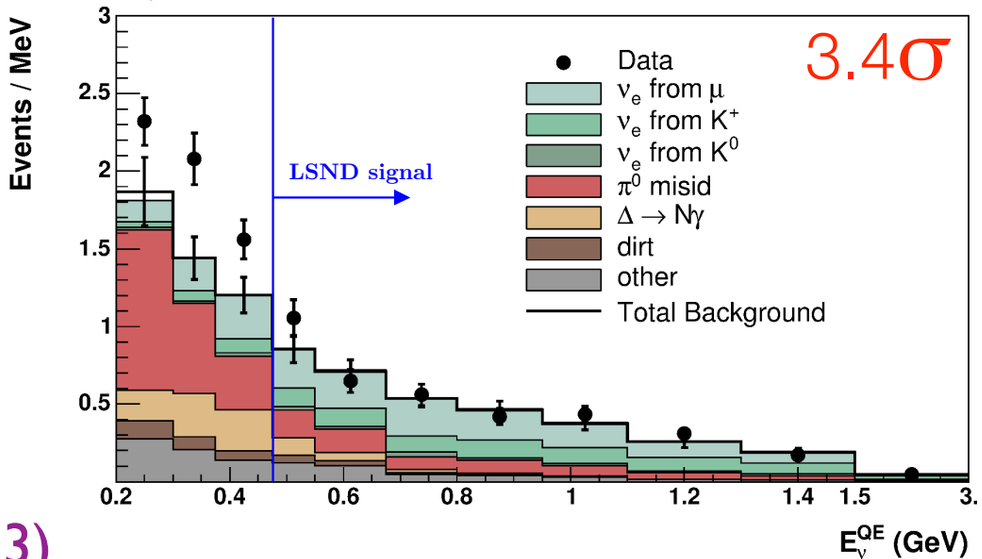


MiniBooNE Detector

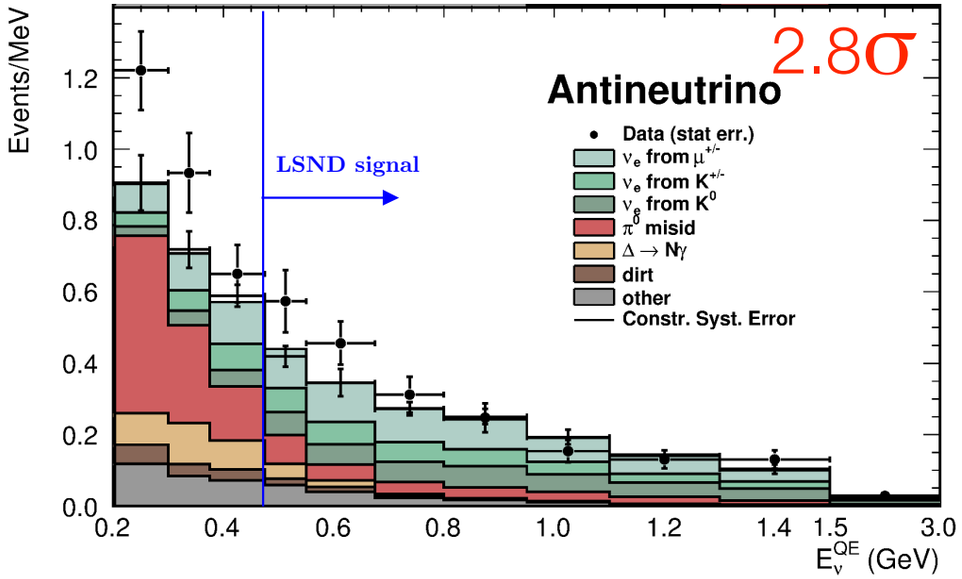


MiniBooNe (2009-2013)

$\nu_\mu \rightarrow \nu_e$ [PRL 102 (2009) 101802]



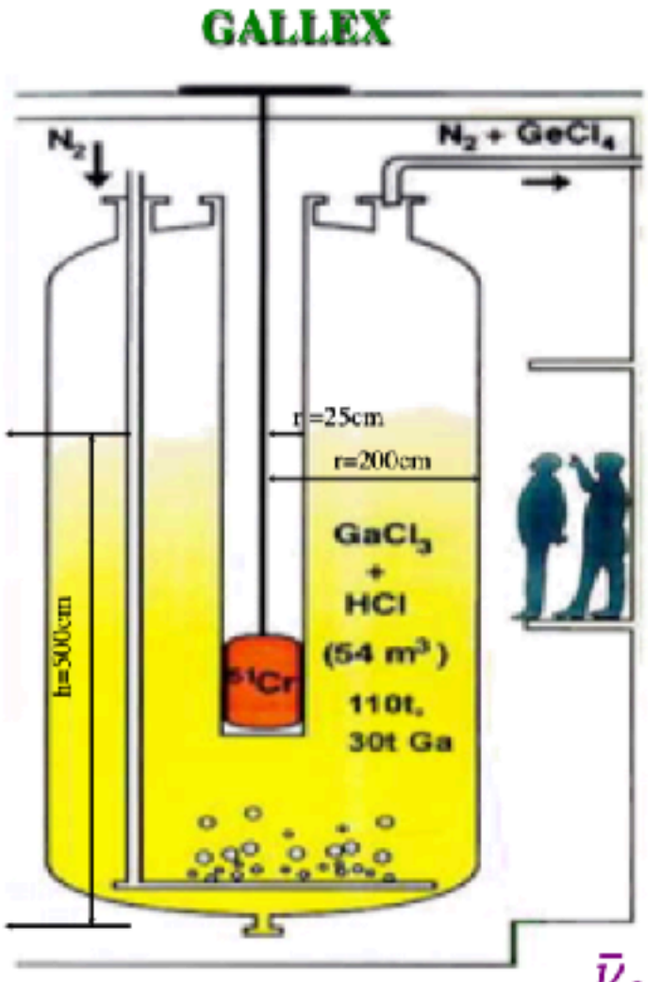
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ [PRL 110 (2013) 161801]

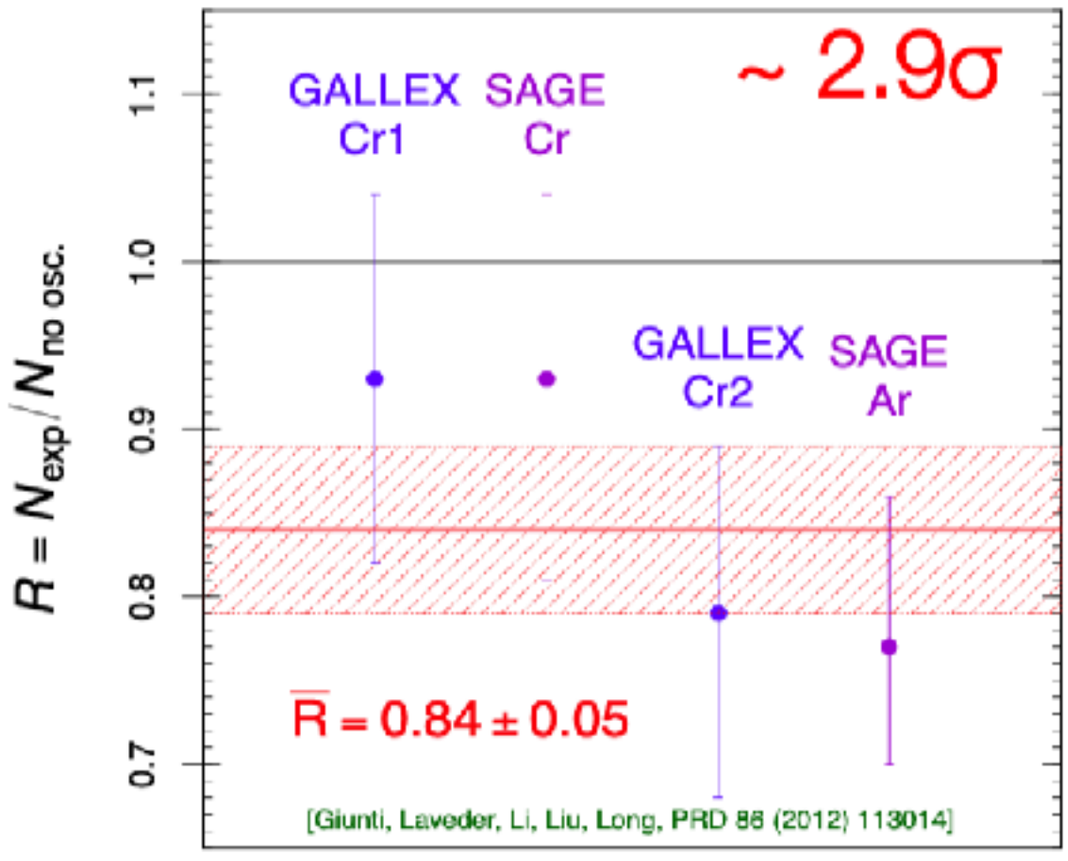


Gallium anomaly (2011)

- Use of radioactive sources (ν_e) for solar neutrino detectors

$$\nu_e \rightarrow \nu_e$$





$\bar{\nu}_e \rightarrow \bar{\nu}_e$ $E \sim 0.7\,\text{MeV}$

$\langle L \rangle_{\text{GALLEX}} = 1.9\,\text{m}$

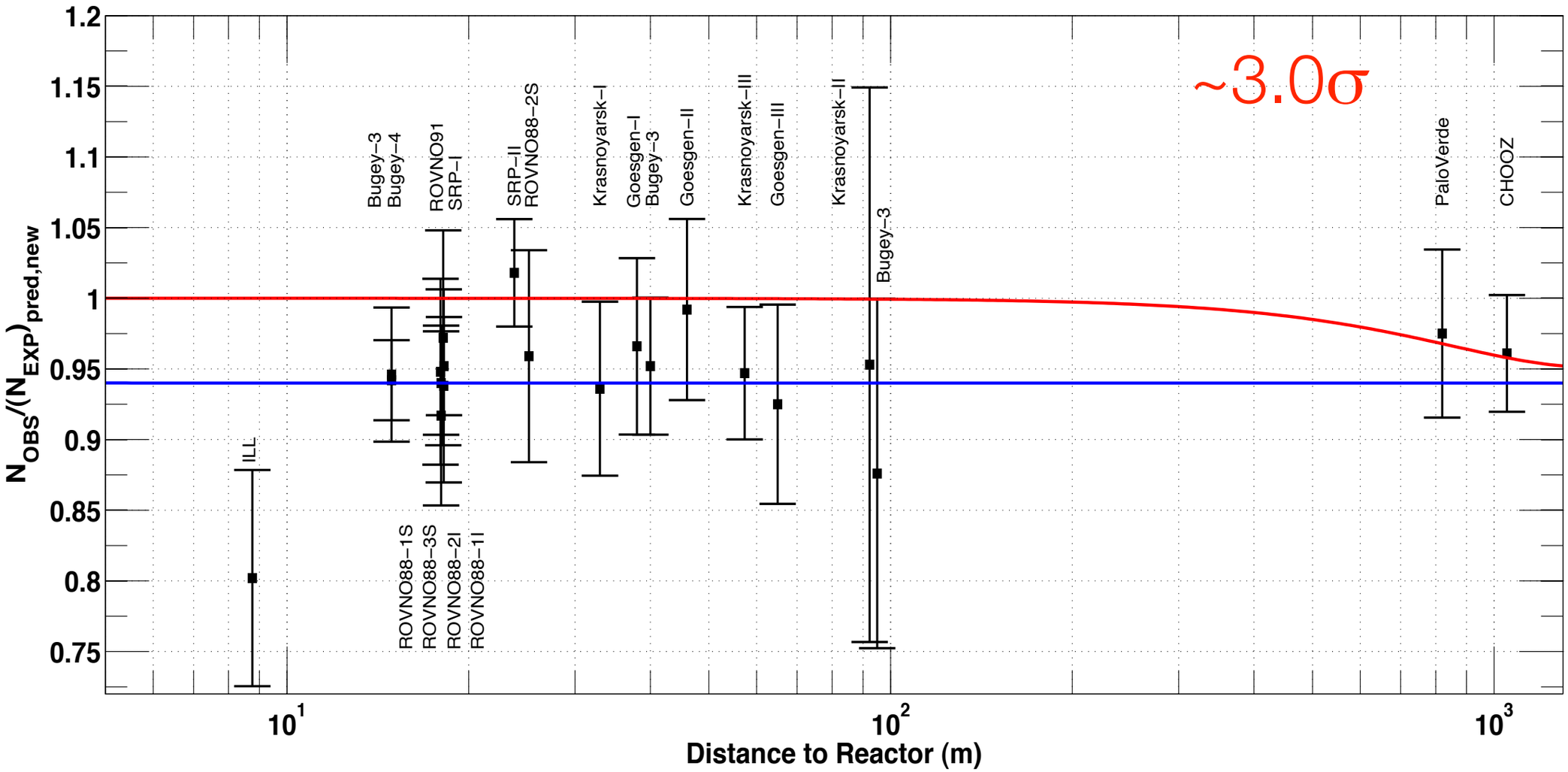
$\langle L \rangle_{\text{SAGE}} = 0.6\,\text{m}$

Reactor anomaly (2011)

- Re-evaluation of reactor flux by several groups* led to higher flux predictions → reactor experiments see a deficit of events

* T.A. Mueller *et al.*, Phys. Rev. **C83** (2011) 054615 [arXiv:1101.2663].
P. Huber, Phys. Rev. C **84** (2011) 024617 [arXiv:1106.0687].
G. Mention *et al.*, Phys. Rev. **D83** (2011) 073006 [arXiv:1101.2755].

$\bar{\nu}_e \rightarrow \bar{\nu}_e$



G. Mention et al., Phys. Rev. D83 (2011) 073006

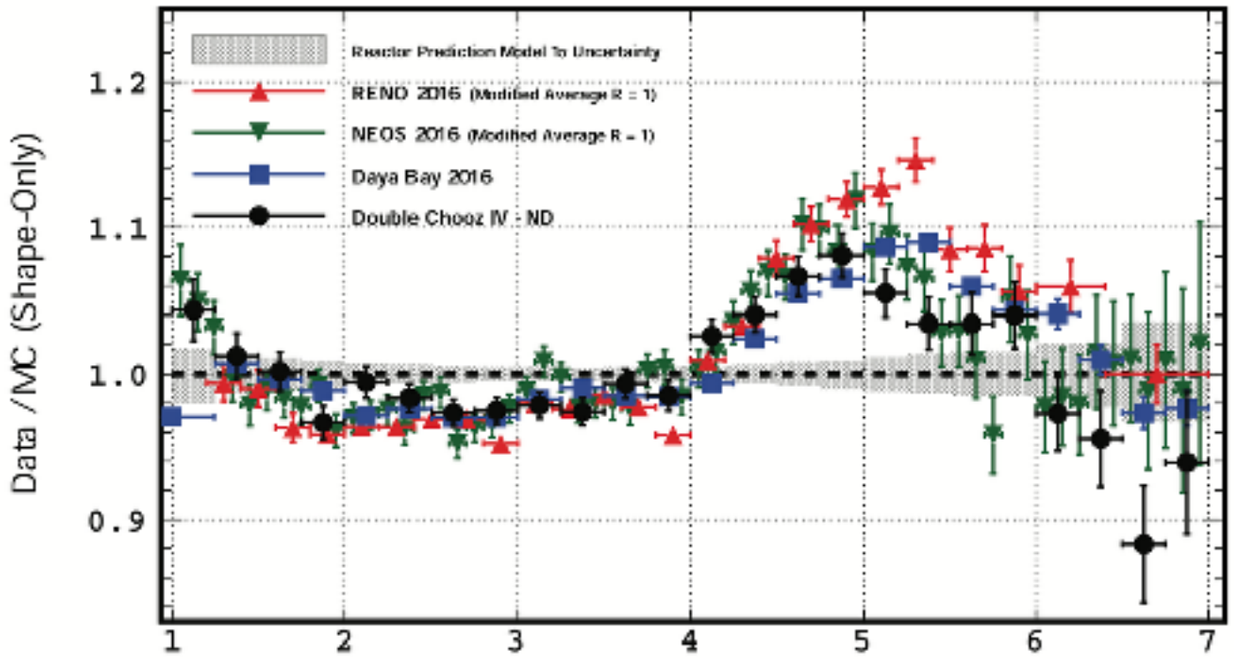
Reactor anomaly revisited (2014 - …)

- Further results from reactor experiments (Reno, Double Chooz, Day Bay…) have shown a bump at 5 MeV

- Could be attributed to ^{235}U

  e.g. P. Huber, Phys. Rev. Lett. 118 (2017) 042502

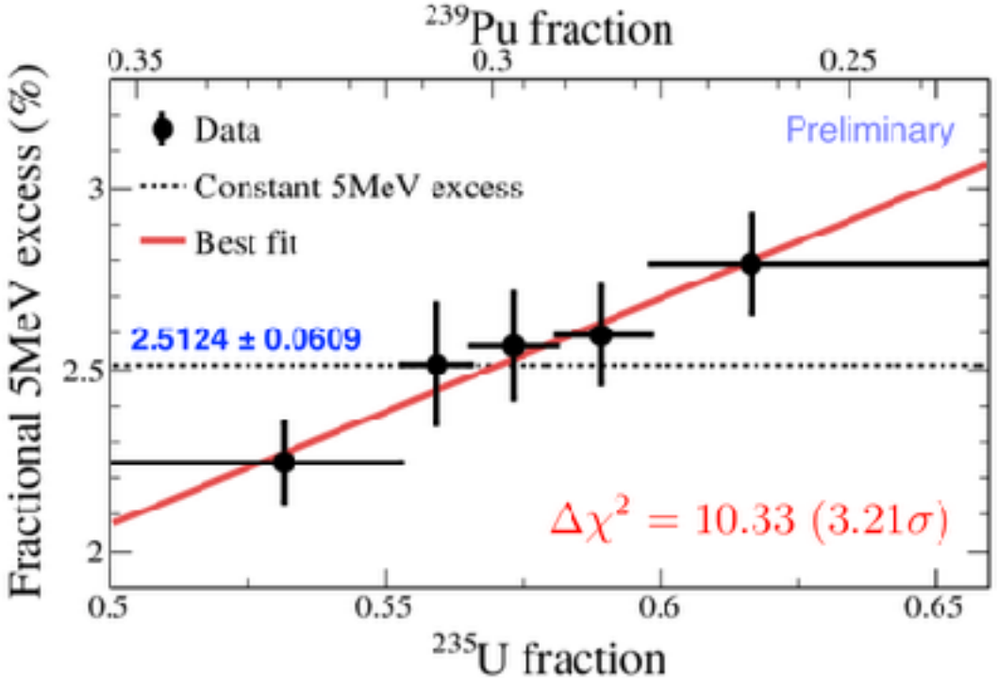
- But the exact answer is complex when looking at different results



[Double-Chooz collab] @ Neutrino 2020

- While it is clear that there are things we need to understand regarding the flux, sterile interpretations of the reactor results not necessarily impacted

  M. Dentler et al., arxiv:1709.04294



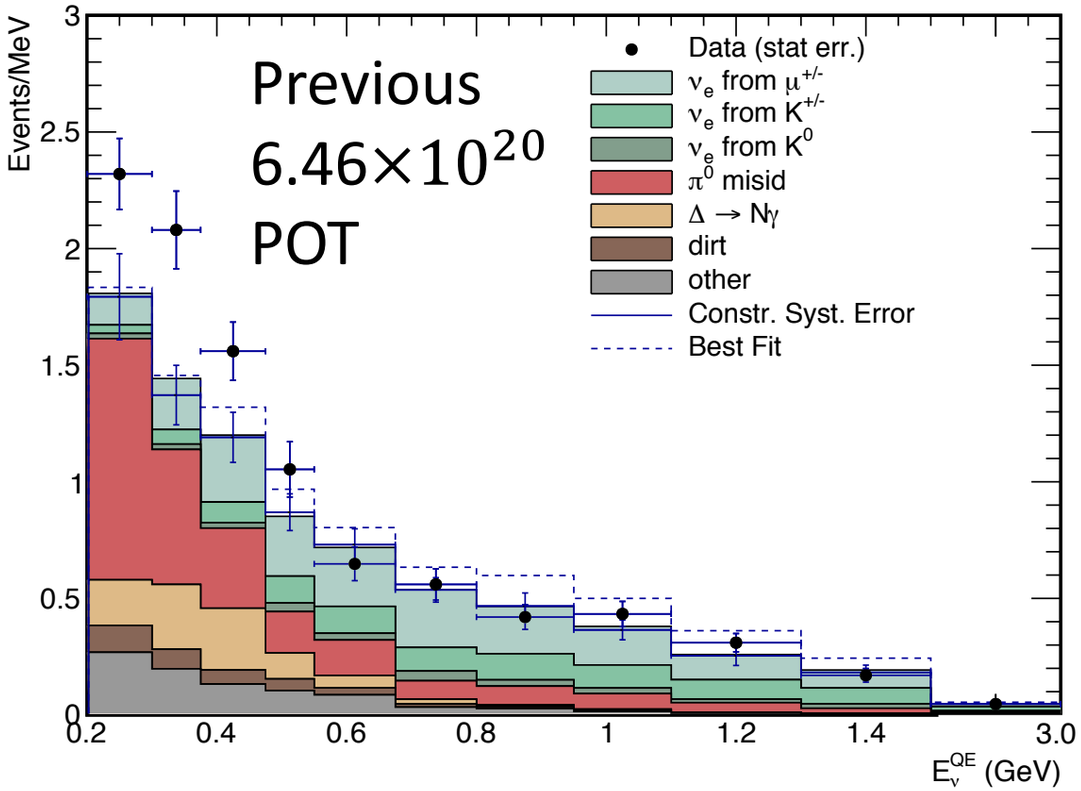
Yoo-2020-06-25 @ Neutrino 2020 for RENO Collaboration

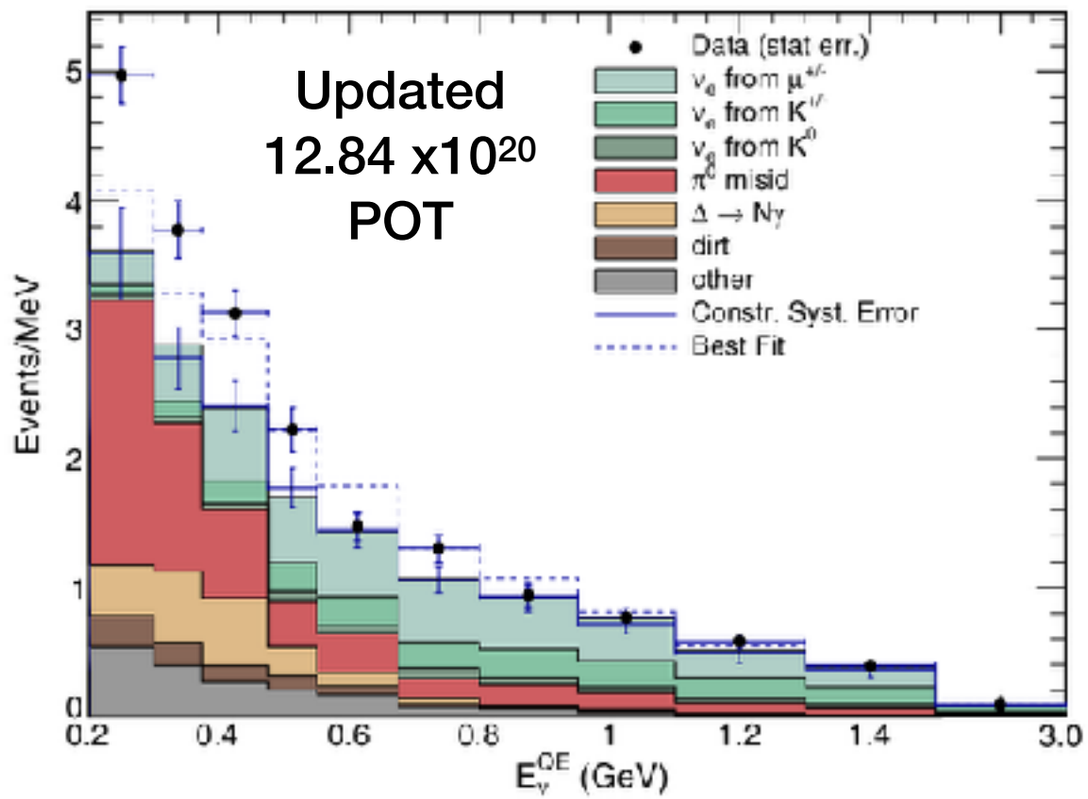
New MiniBooNE results (2018)

- New neutrino data show an increased significance for the excess

- Neutrino results now in agreement with anti-neutrino data and with LSND

$\nu_\mu \rightarrow \nu_e$





Phys. Rev. Lett. **121**, 221801

4.8σ excess

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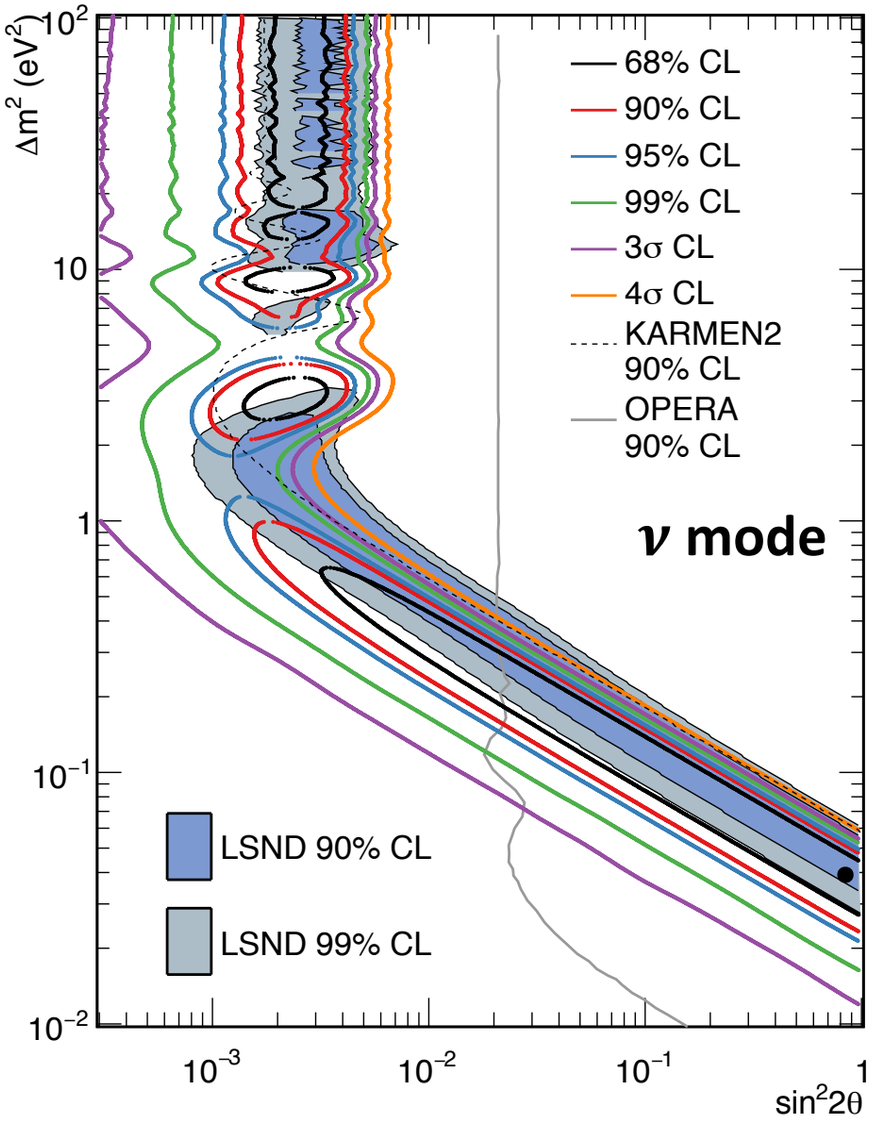
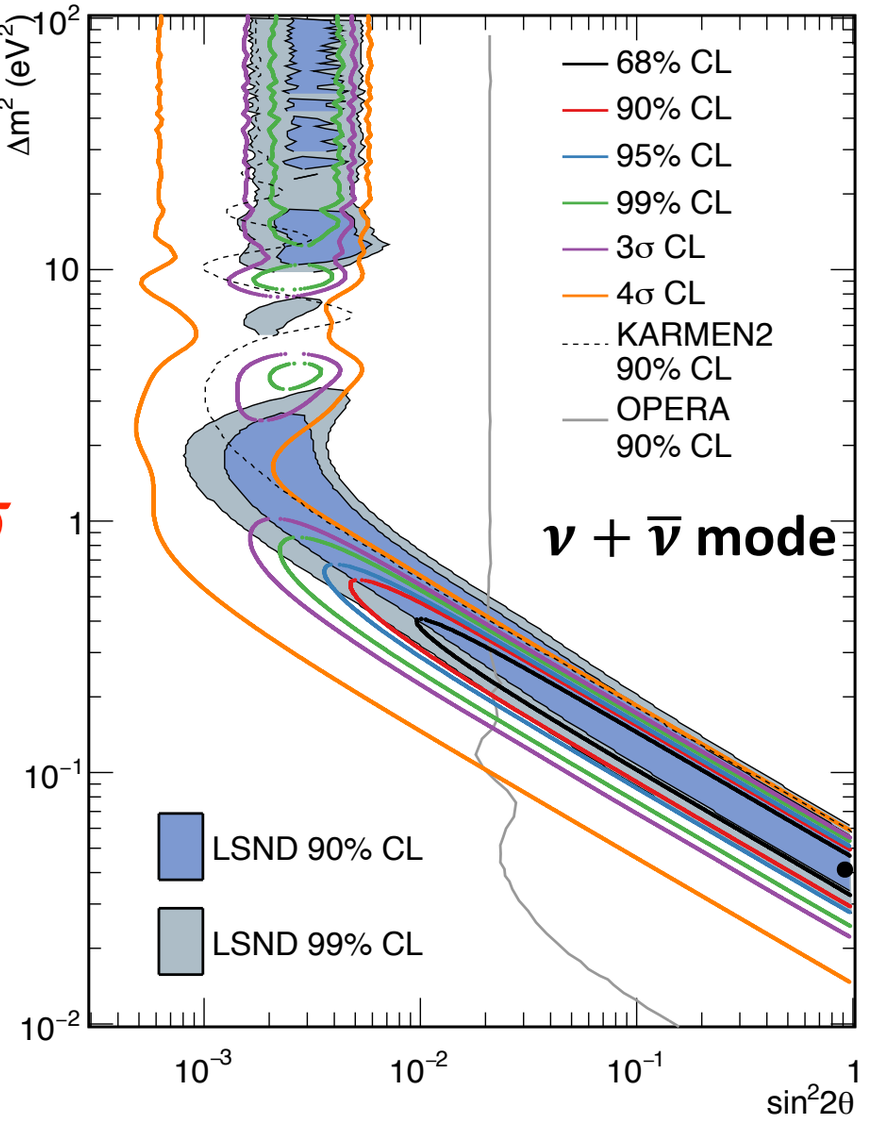


4.8σ



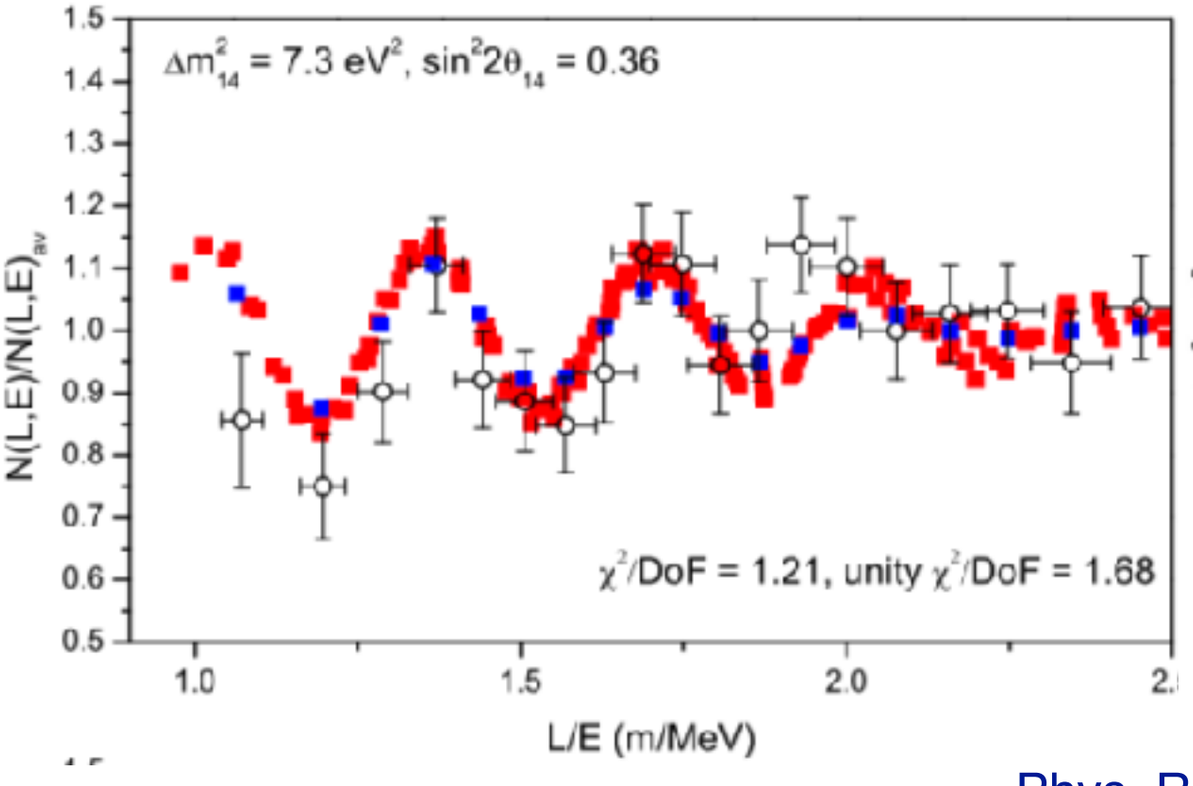
Phys. Rev. Lett. **121**, 221801

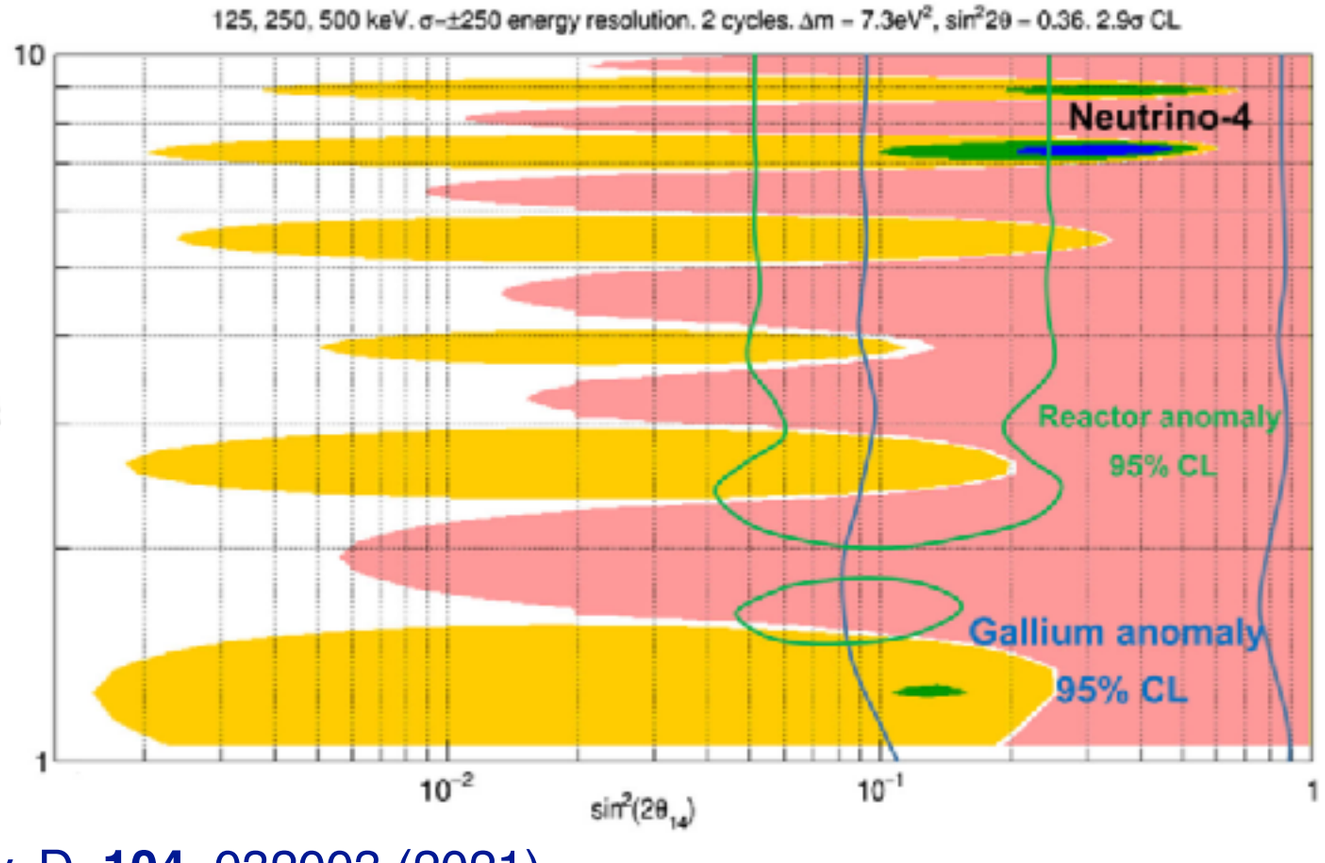
Neutrino-4 results (2020)

- The Neutrino-4 reactor neutrino experiment has observed an oscillation signal in their movable detector located near a reactor core

- Movable detector allows to scan the L/E region

$\bar{\nu}_e \rightarrow \bar{\nu}_e$





Phys. Rev. D. **104**, 032003 (2021)

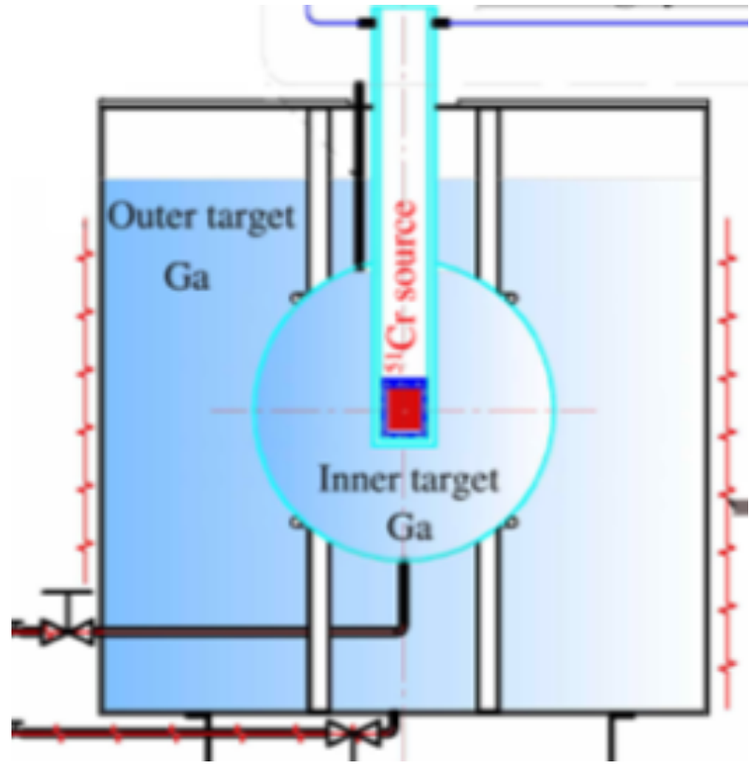
BEST (2021)

- Baskan Experiment on Sterile Transitions (BEST) was designed to address the Ga anomaly

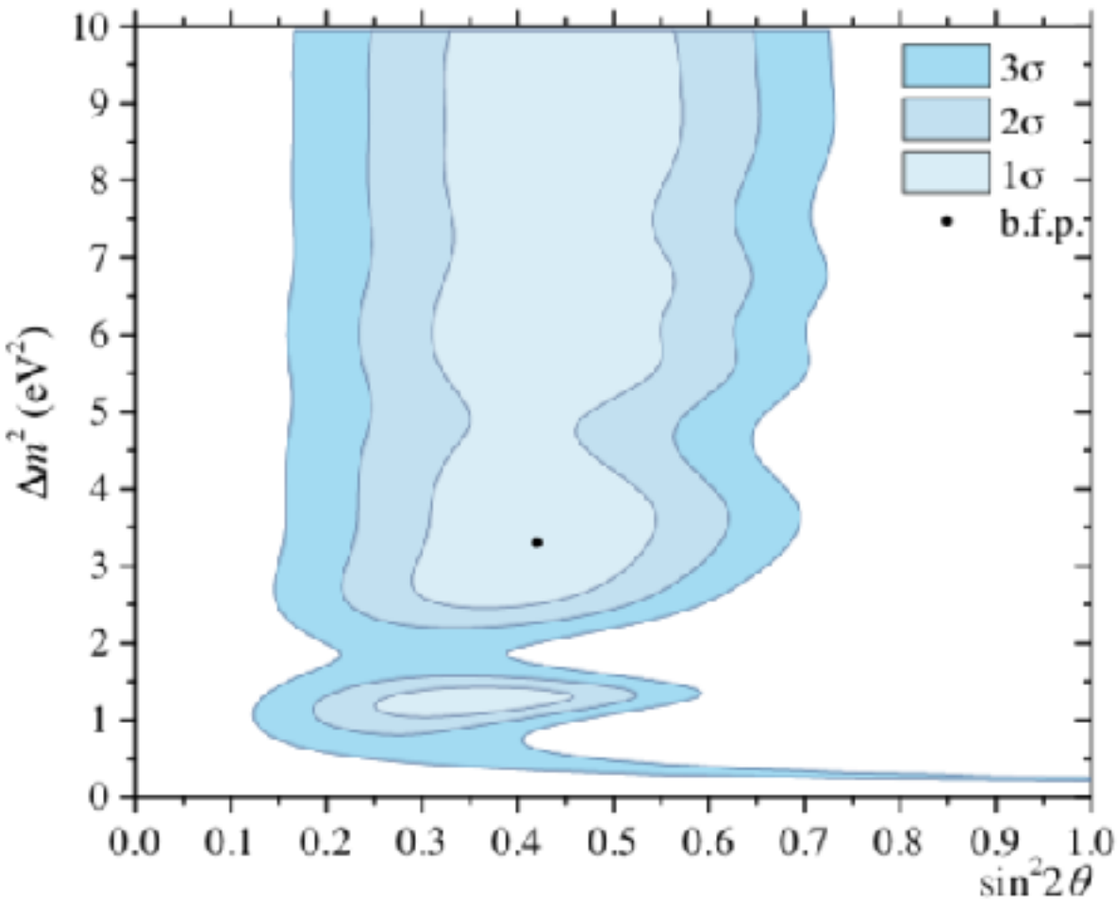
- Use a strong ^{51}Cr ν_e source and look for

$$^{71}\mathrm{Ga} + \nu_e \rightarrow {}^{71}\mathrm{Ge} + e^-$$

- They observe a deficit of ~20%

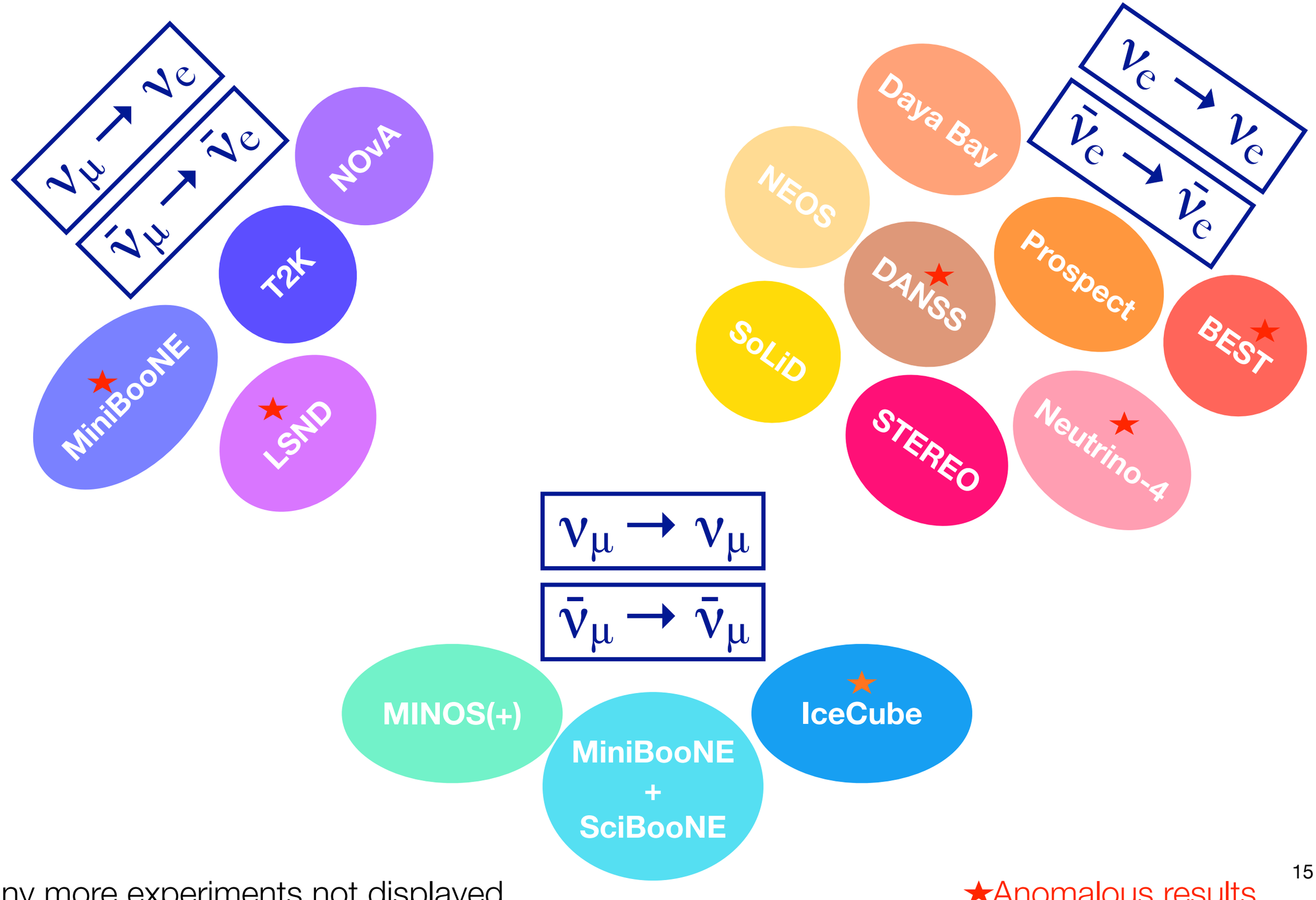


$\nu_e \rightarrow \nu_e$



arXiv:2109.11482

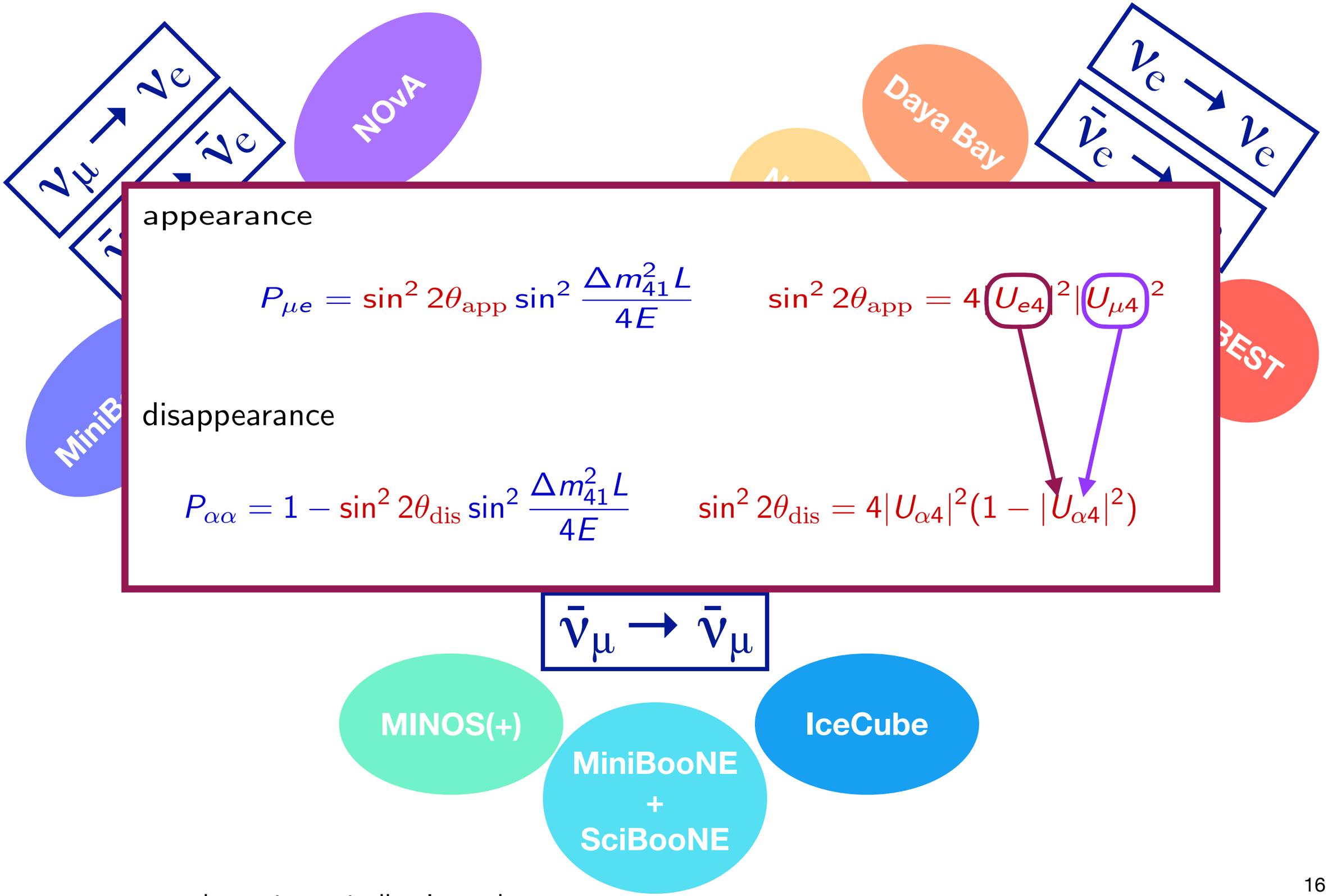
Putting this all together*



*Many more experiments not displayed

★Anomalous results

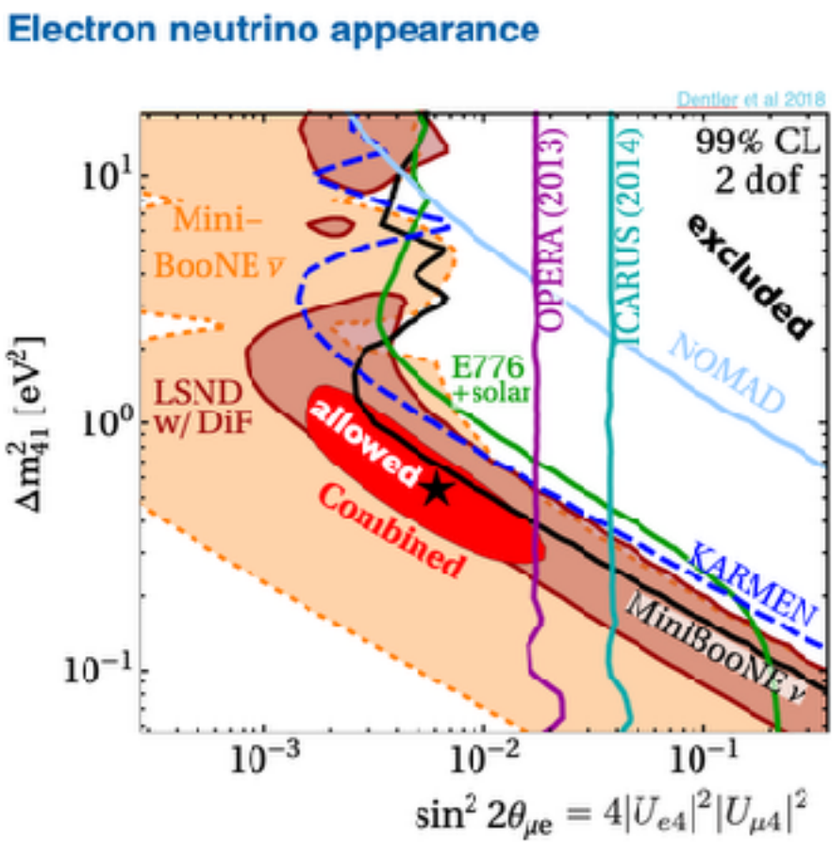
Putting this all together*

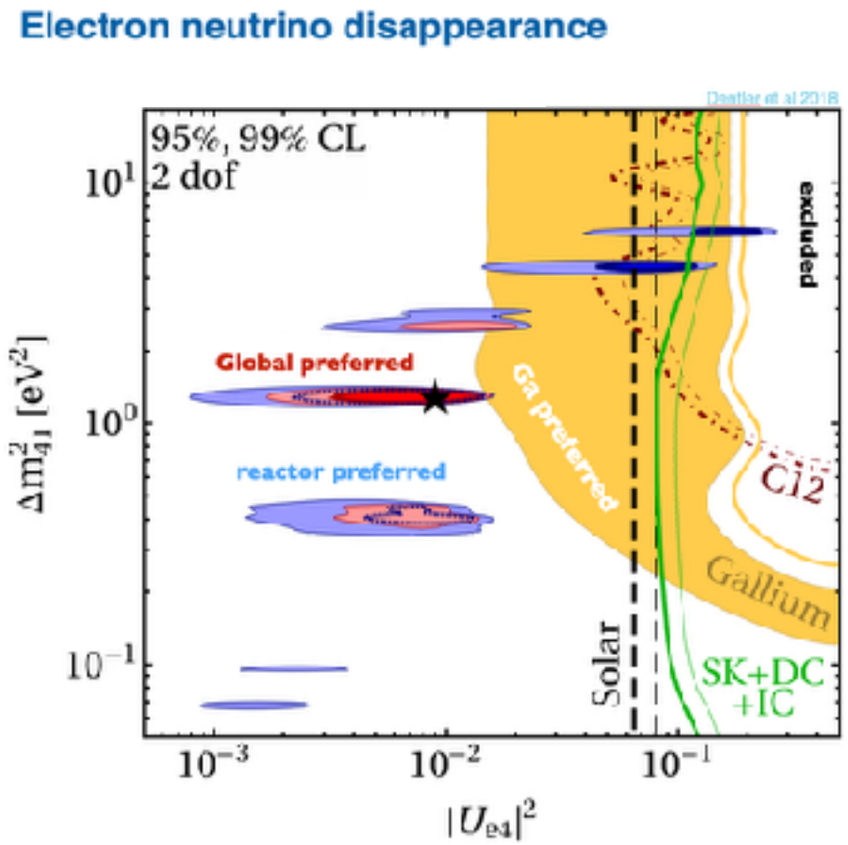


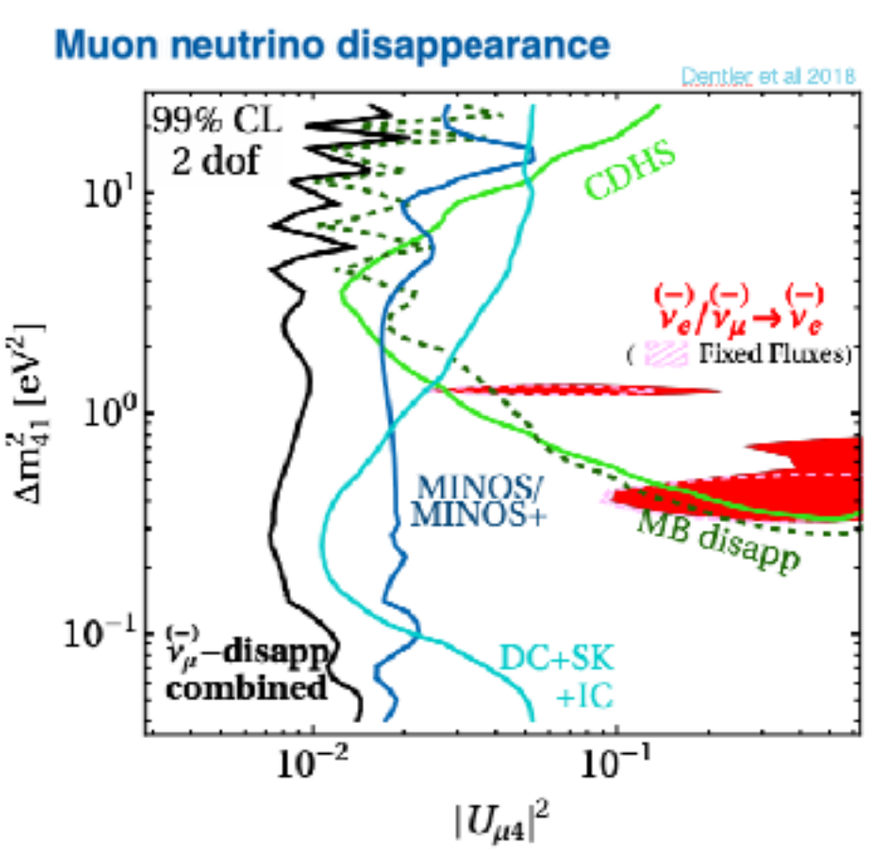
*Many more experiments not displayed

Putting this all together

- Anomalies are definitely intriguing
- But they do not come together coherently





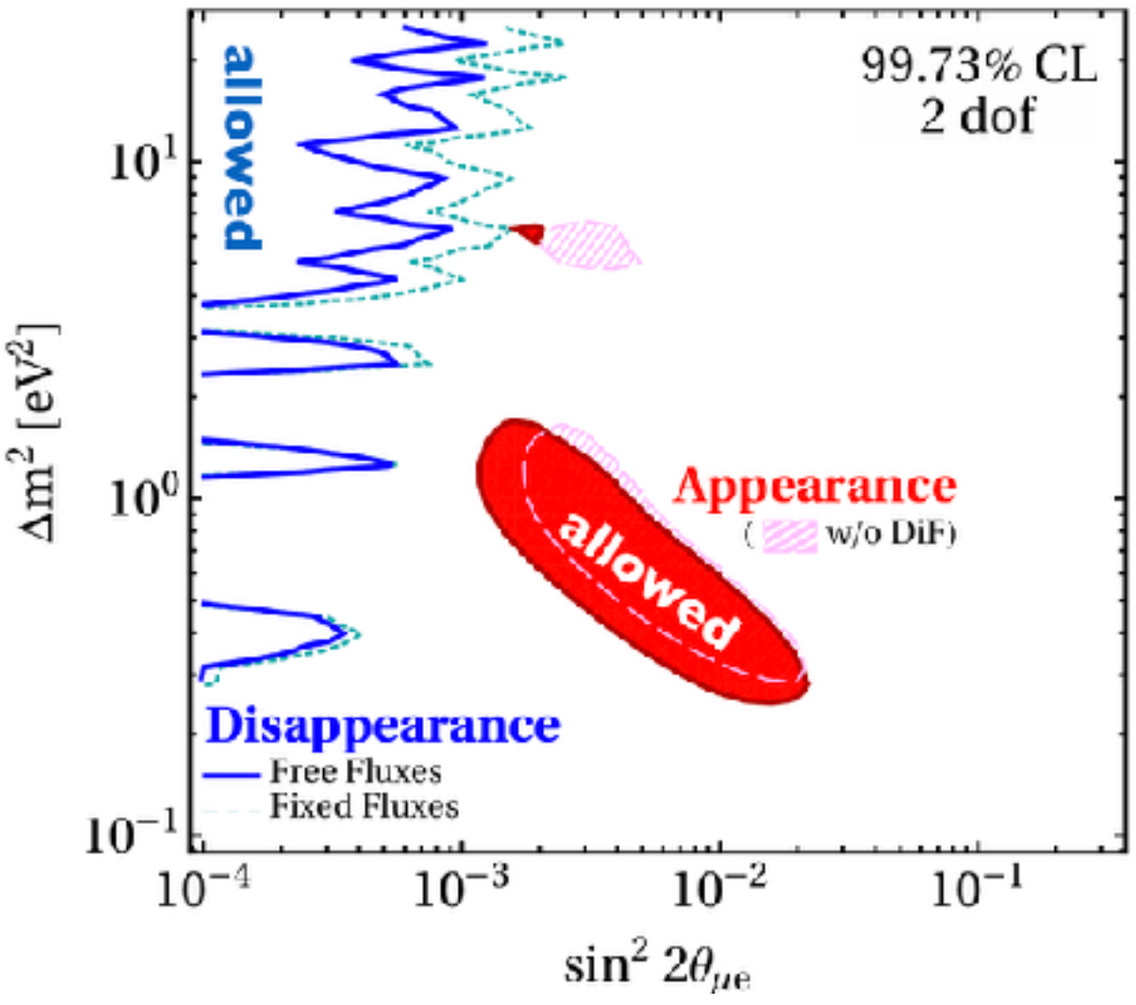


From P.Machado's talk @ Neutrino2020

Putting this all together is not possible

- Anomalies are definitely intriguing
- But they do not come together coherently

M. Dentler et al., JHEP08 010, 2018

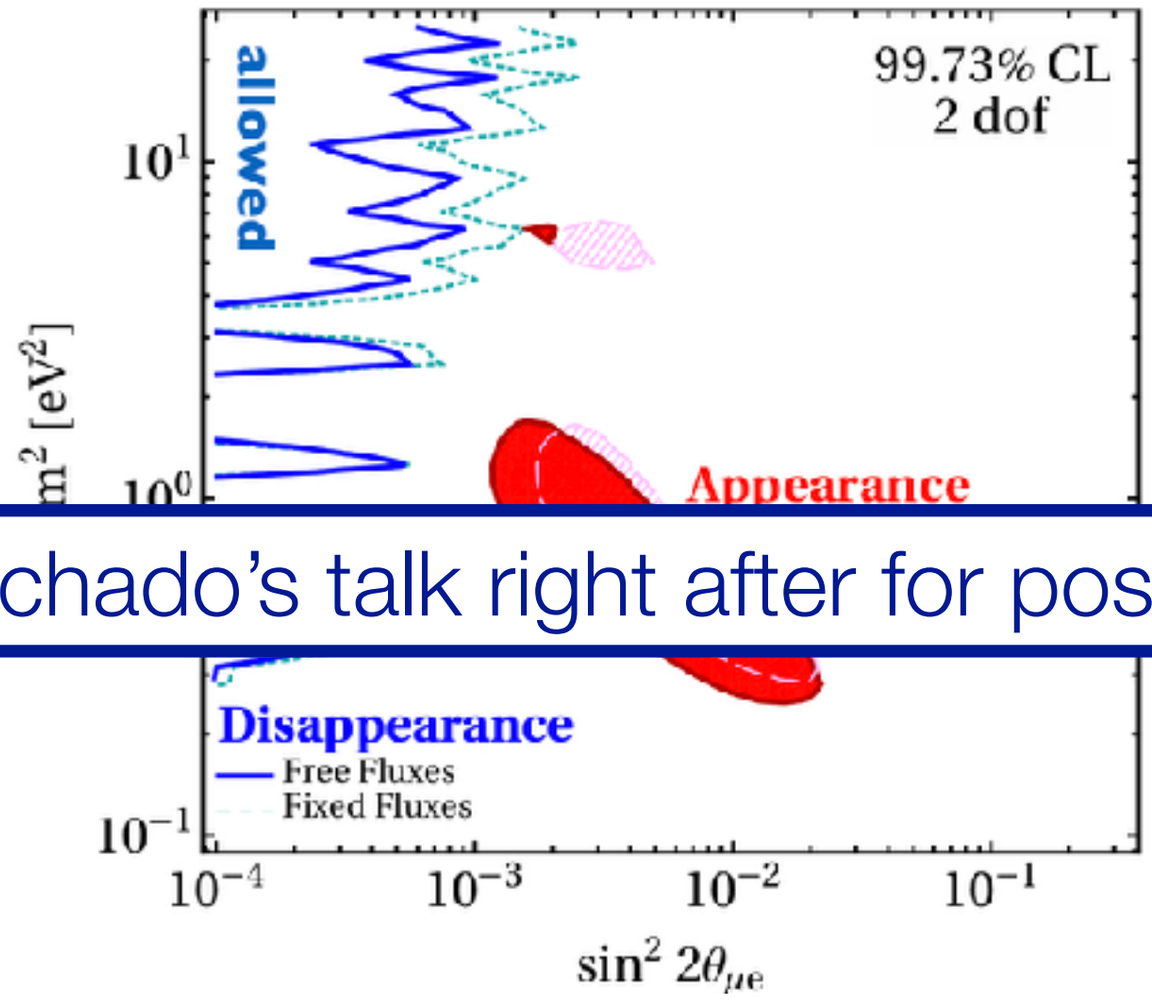


- Definite tension between appearance and disappearance

Putting this all together is not possible

- Anomalies are definitely intriguing
- But they do not come together coherently

M. Dentler et al., JHEP08 010, 2018



See Pedro Machado's talk right after for possible alternatives!

- Definite tension between appearance and disappearance

What's next?

- In the history of particle physics, following up on anomalous results have been worth it!

- Many experiments are still running and searching for sterile neutrinos in their data

  ✓ Long-baseline: T2K, NOvA

  ✓ Reactor: Prospect-II, SoLiD, NEOS, DANSS, Neutrino-4

- However, the picture is now so unclear that dedicated experiments may help to shed light on the various anomalies

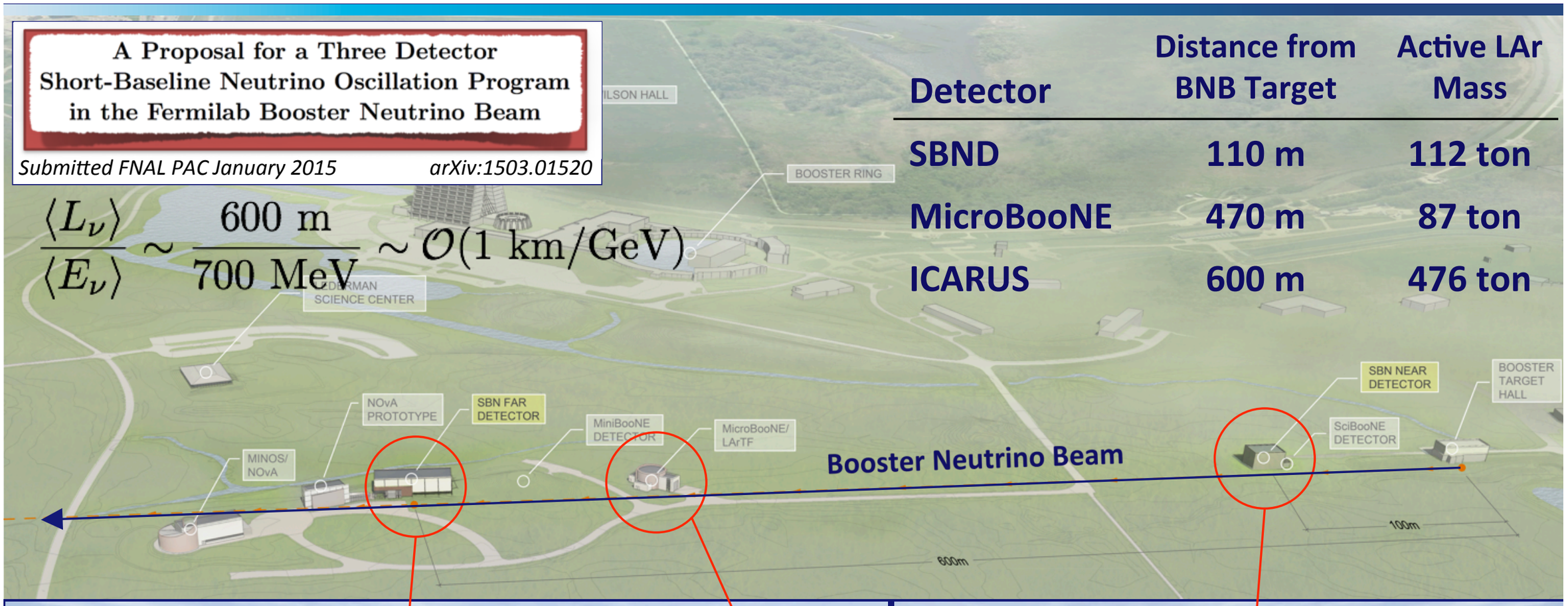
Short-baseline Neutrino (SBN) program at Fermilab

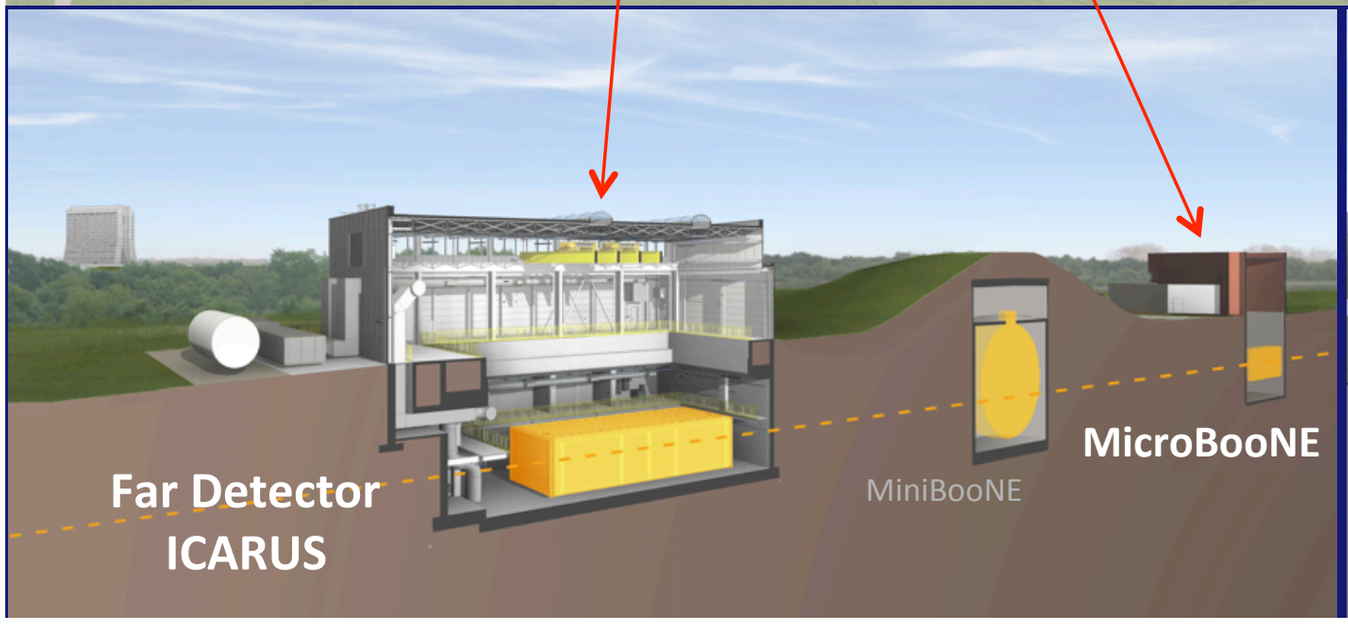
A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

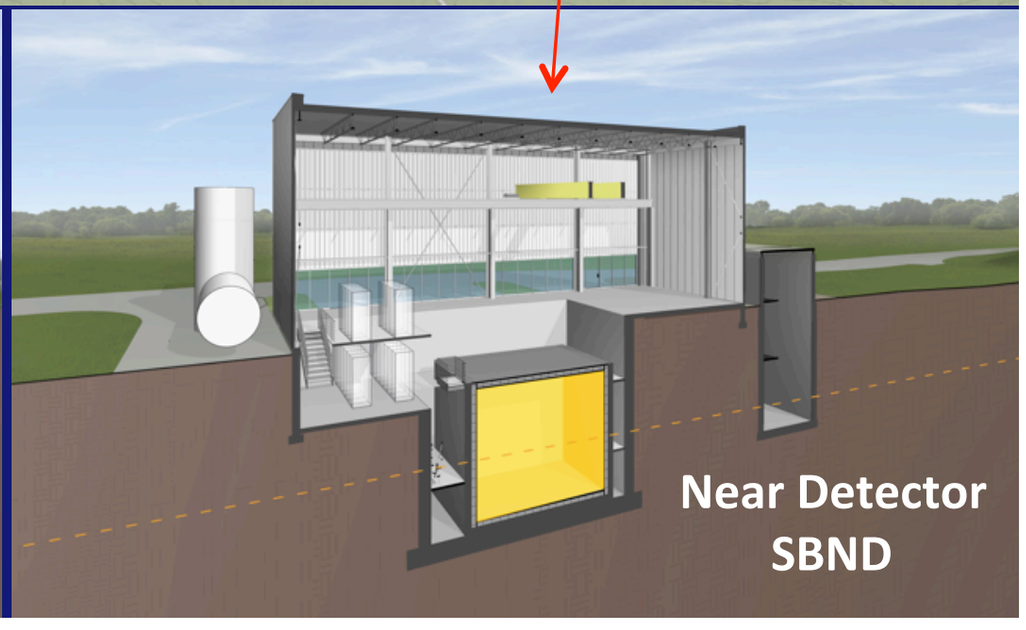
Submitted FNAL PAC January 2015 *arXiv:1503.01520*

$$\frac{\langle L_\nu \rangle}{\langle E_\nu \rangle} \sim \frac{600\ \text{m}}{700\ \text{MeV}} \sim \mathcal{O}(1\ \text{km/GeV})$$

Detector	Distance from BNB Target	Active LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS	600 m	476 ton

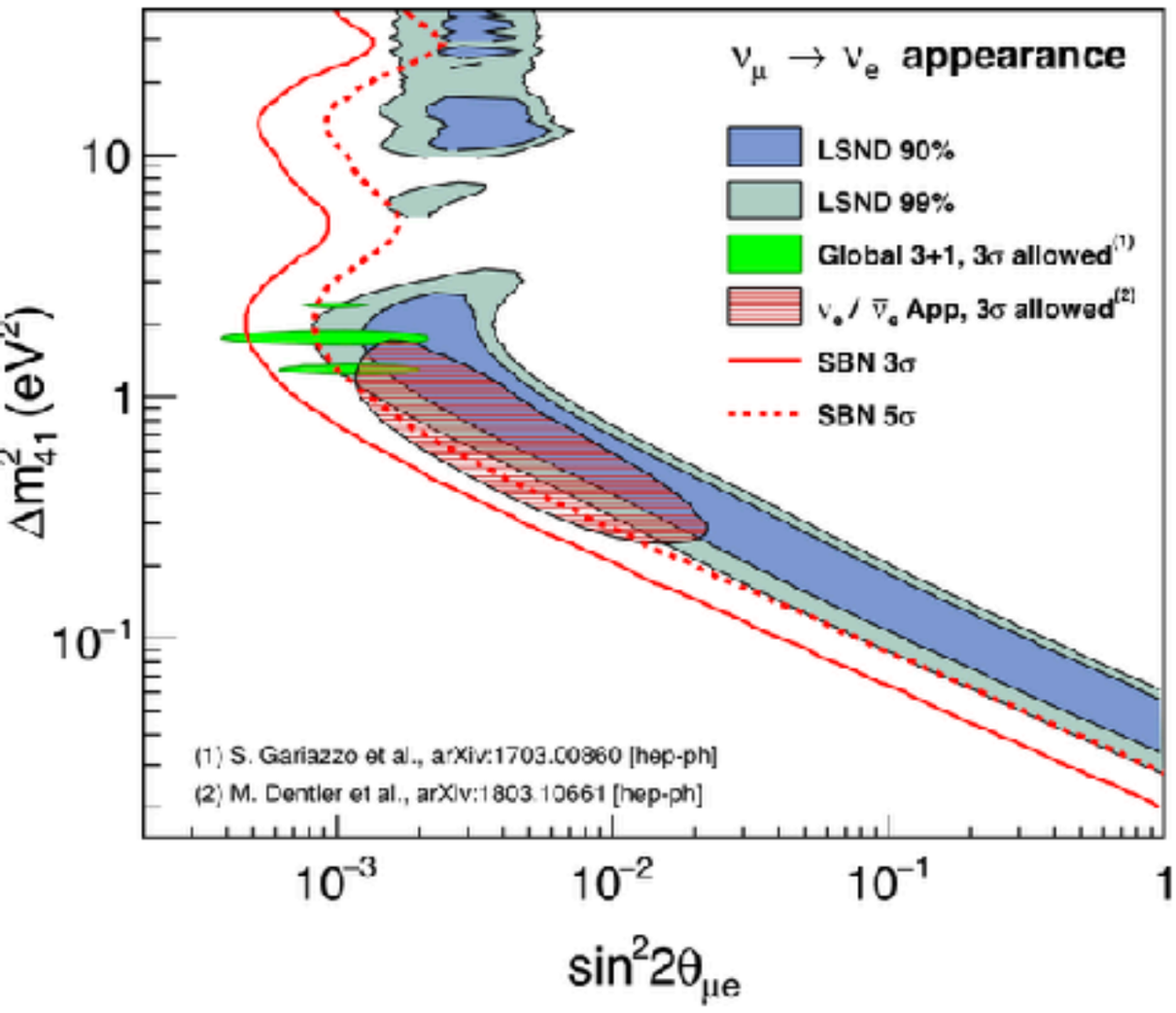


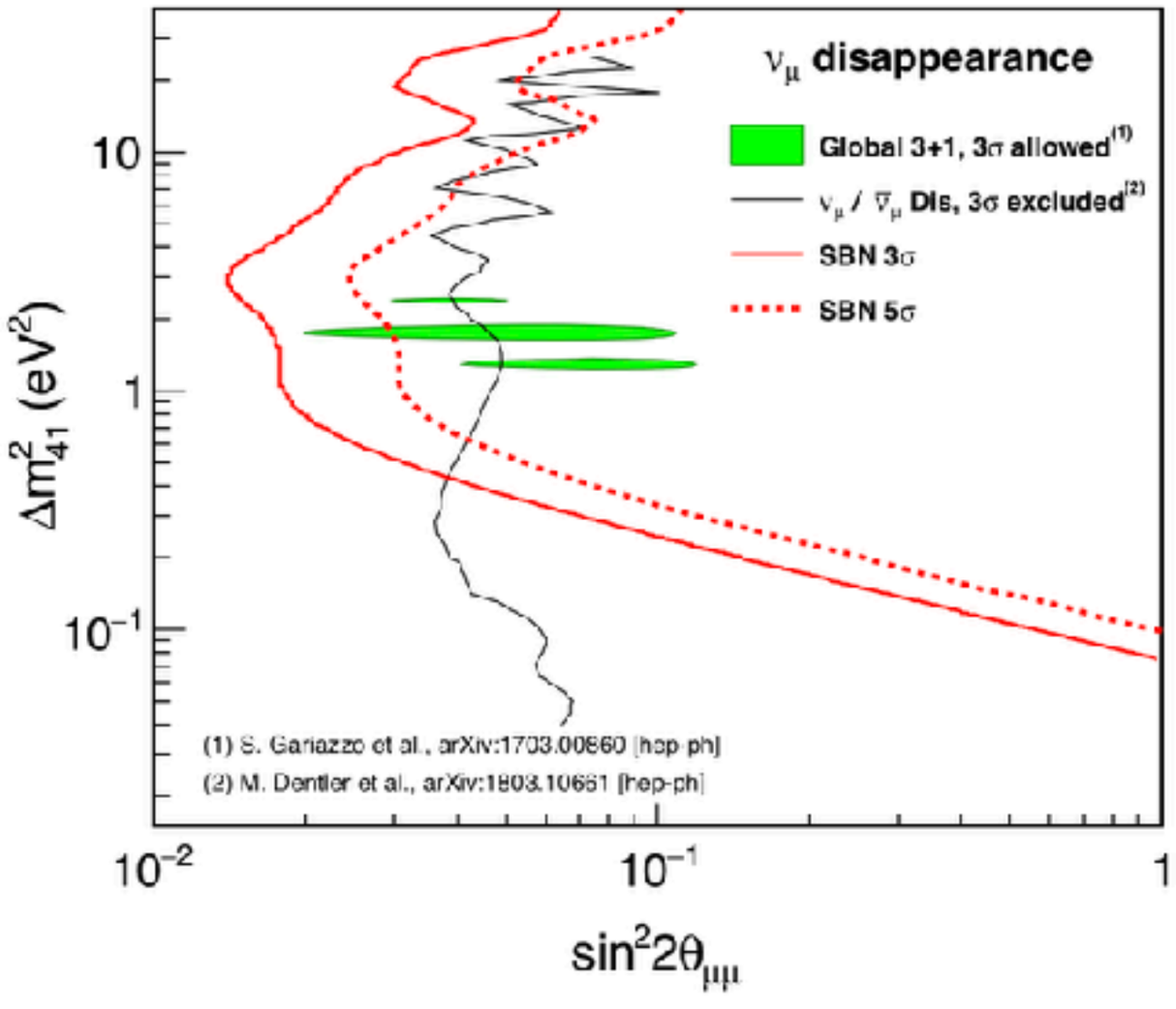




SBN program at Fermilab

Chance to definitely test appearance <u>AND</u> disappearance at the same time





Annual Rev. Nucl. Part. Sci. 2019.69:363-387

SBN program at Fermilab

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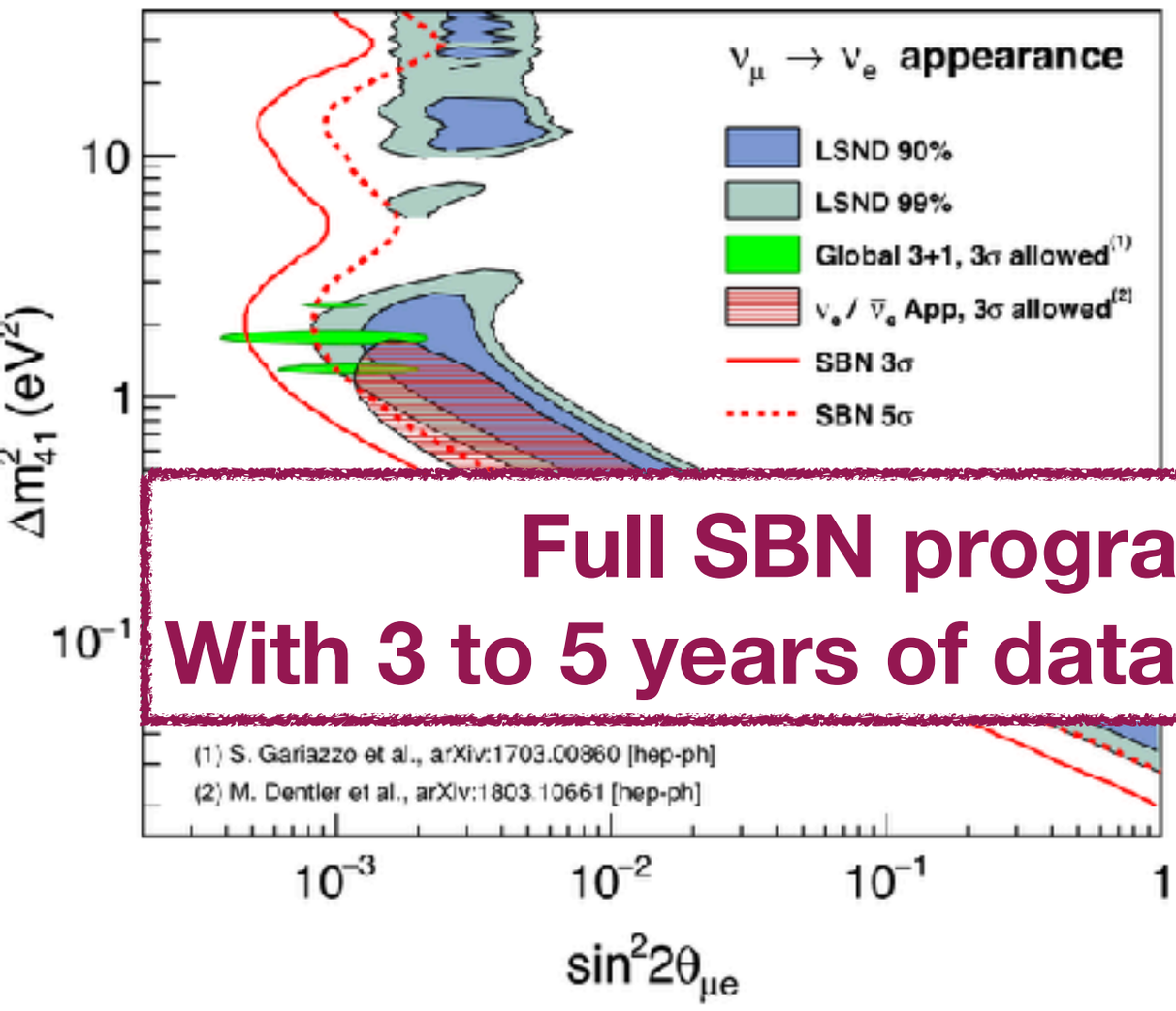
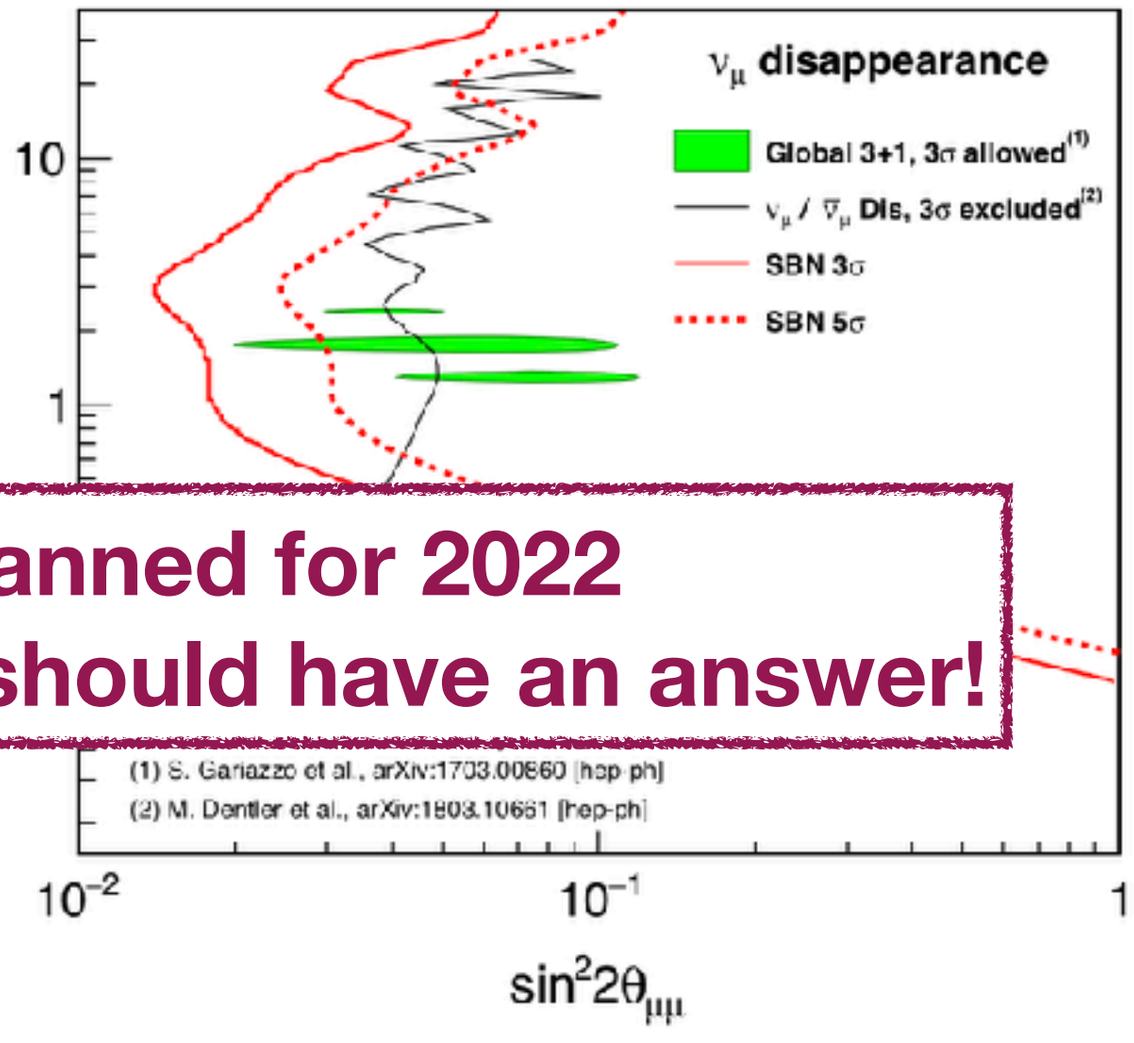




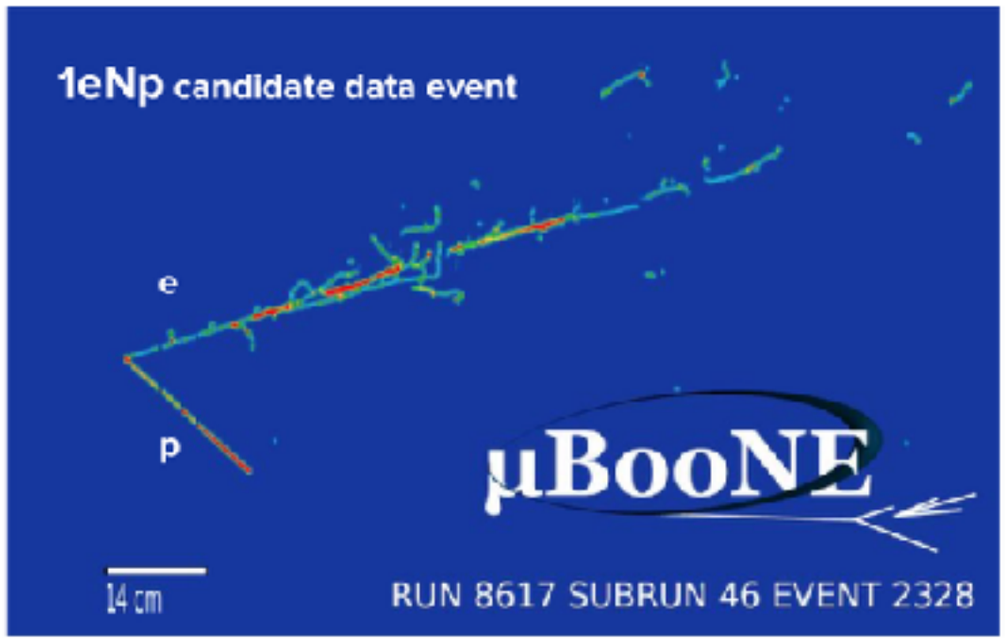
Full SBN program planned for 2022

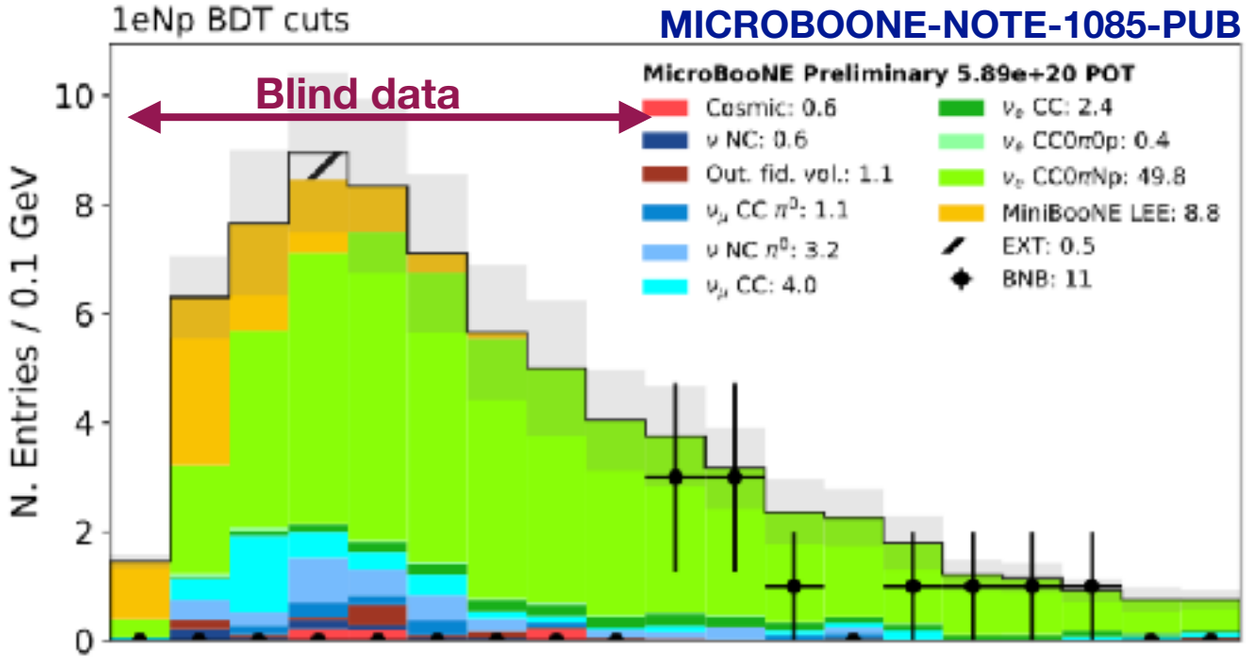
With 3 to 5 years of data we should have an answer!

Annual Rev. Nucl. Part. Sci. 2019.69:363-387

MicroBooNE

- First detector of SBN program (470m baseline), dedicated to address the MicroBooNE low-energy excess
- Data taking since 2015
- Recent progress on search for low-energy excess





Validation and extra cross checks with NuMI beam

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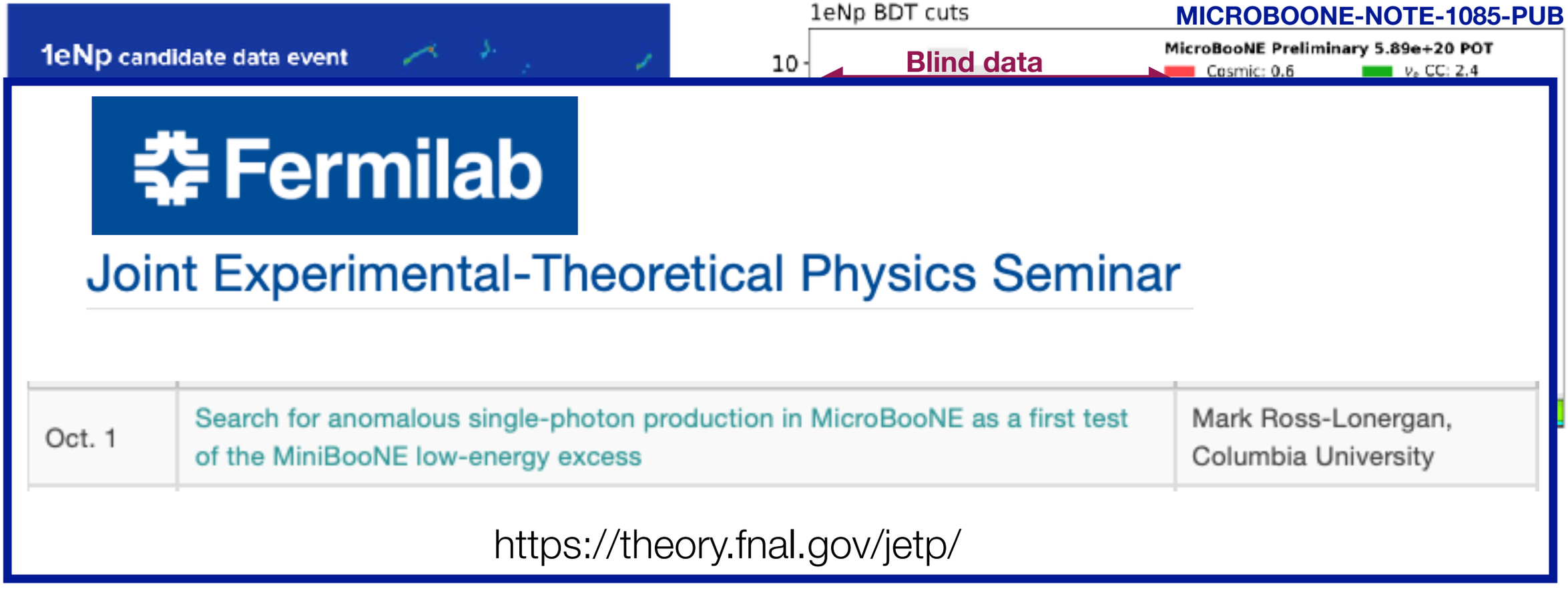
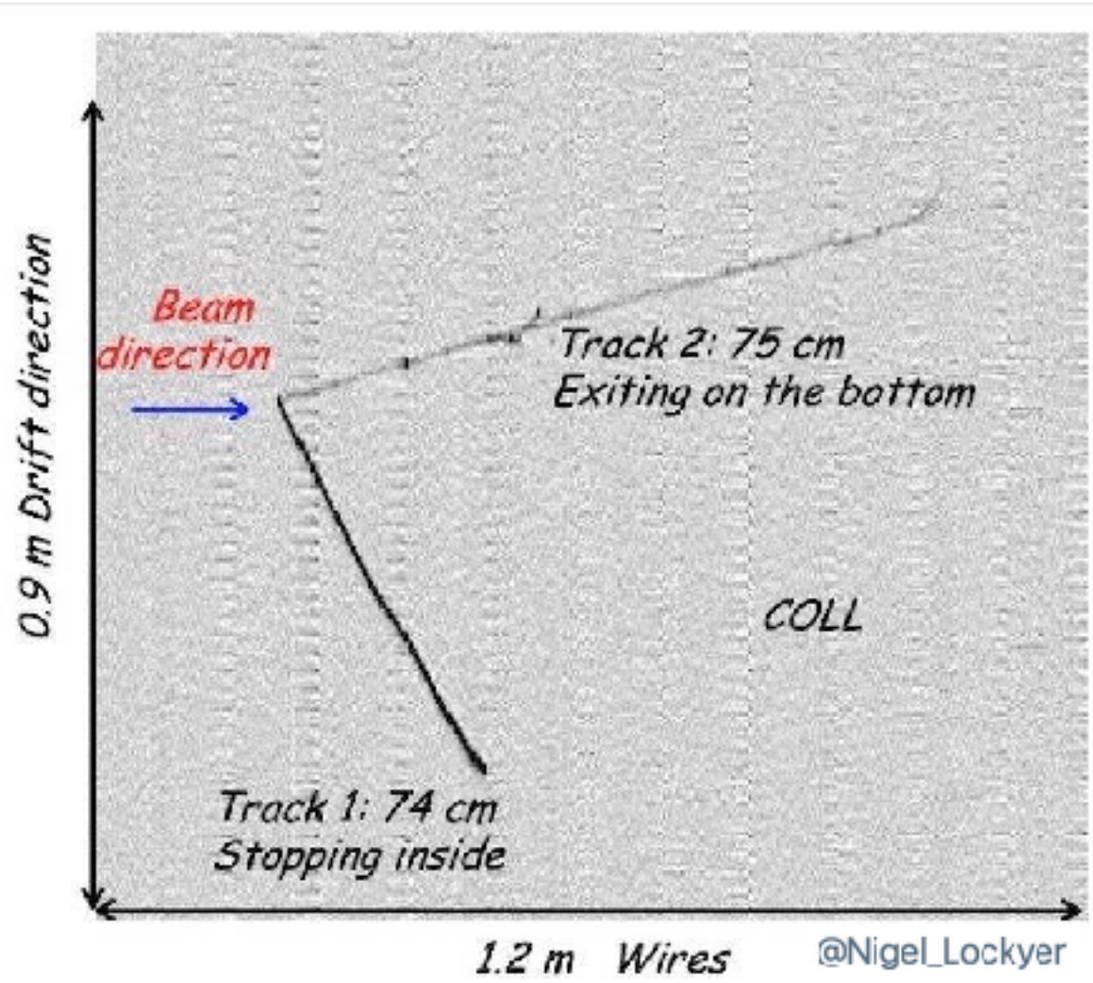
- Recent progress on search for low-energy excess



ICARUS

- Far detector fo the SBN program (600m baseline)
- Commissioning on going and data taking planned for Fall 2021

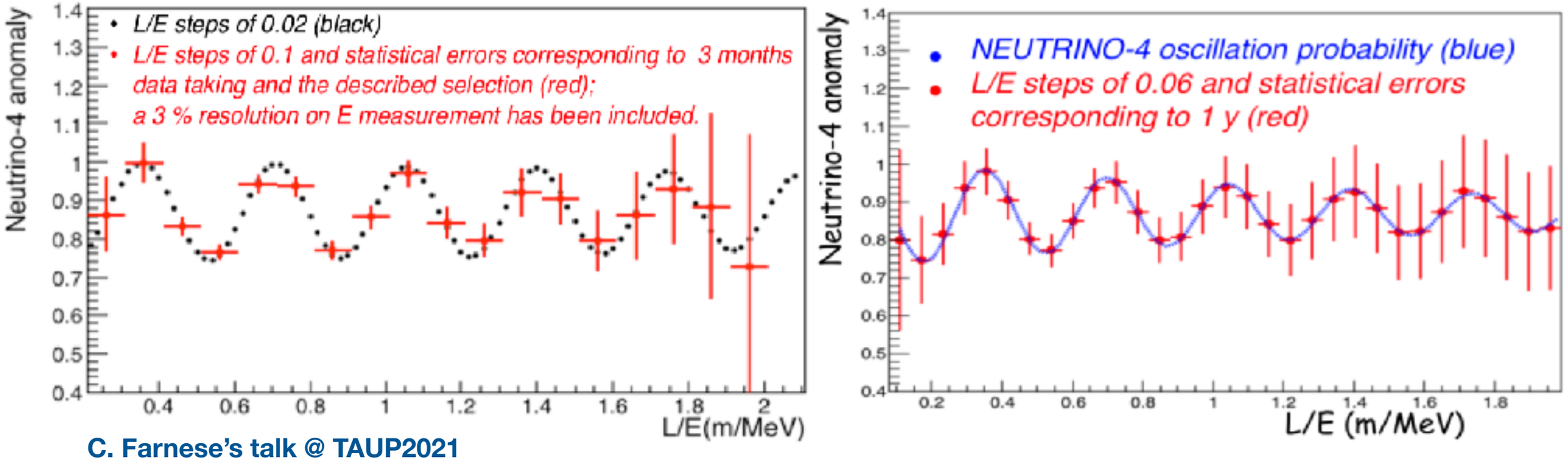


ICARUS

- ICARUS & Neutrino-4

- Using ν_μ disappearance with BNB and ν_e appearance with NUMI beam

BNB (ν_μ) **NuMI (ν_e)**

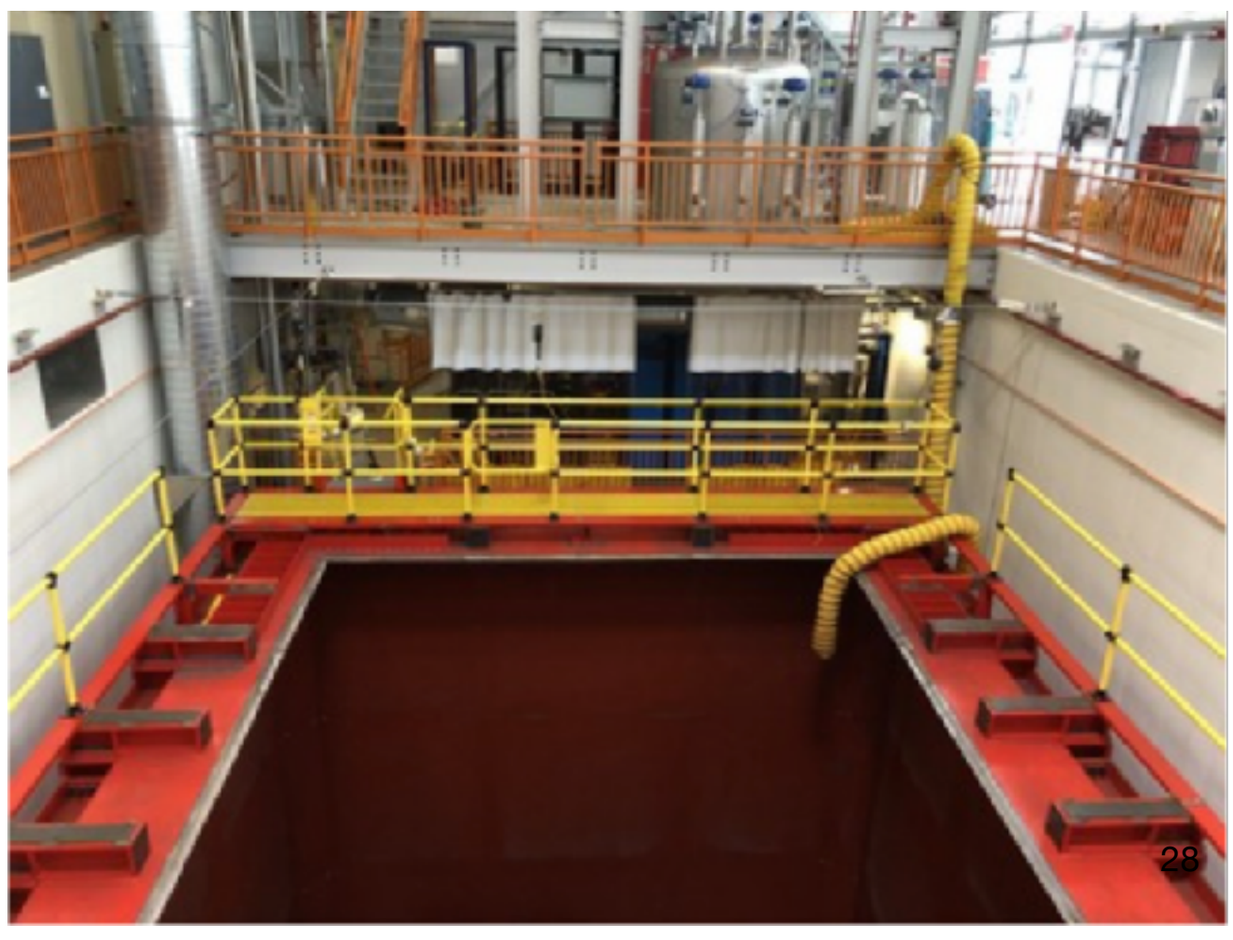


C. Farnese's talk @ TAUP2021

(Δm^2=7.25 eV^2 and sin^2 2θ~0.26)

SBND

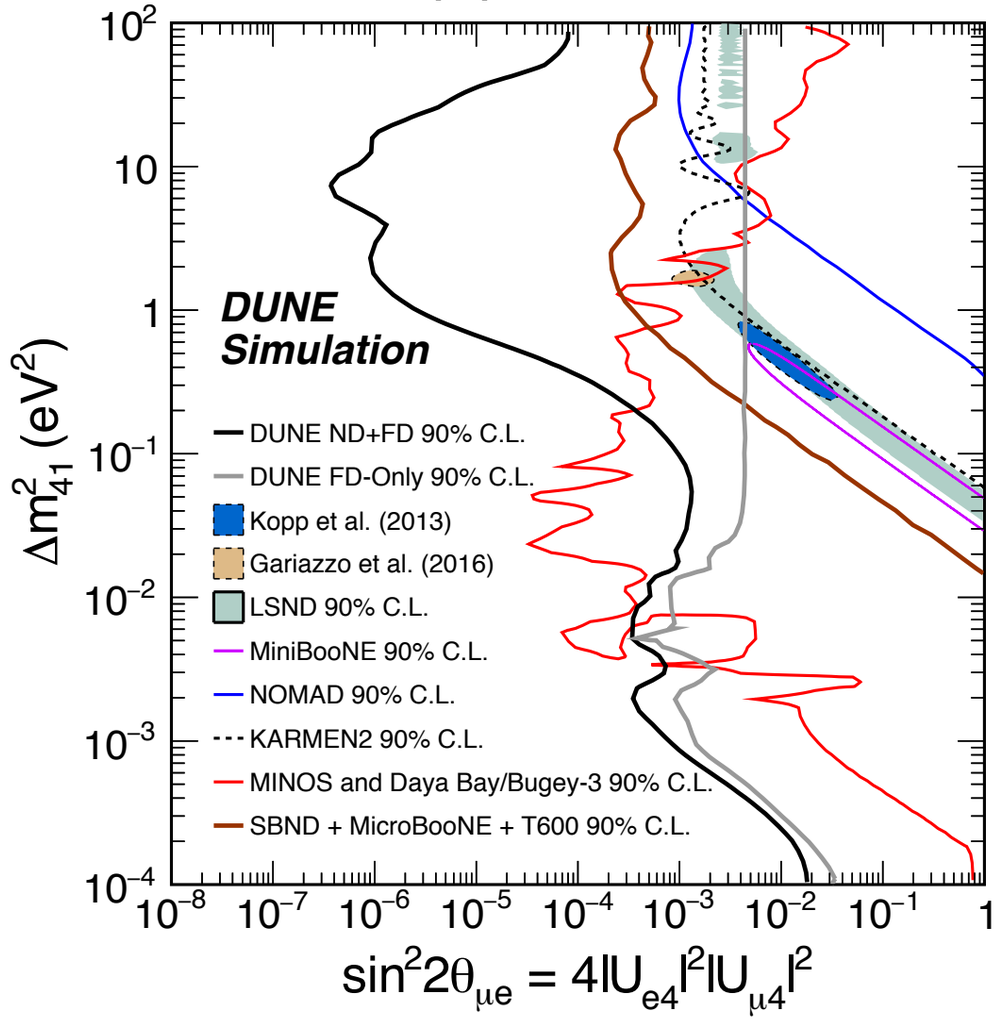
- Near detector of SBN program (110m baseline)
- Constrain the unoscillated neutrino spectrum
- Precise measurement of neutrino interactions (10^6 events)
- Construction well advanced
- Commissioning planned for 2022



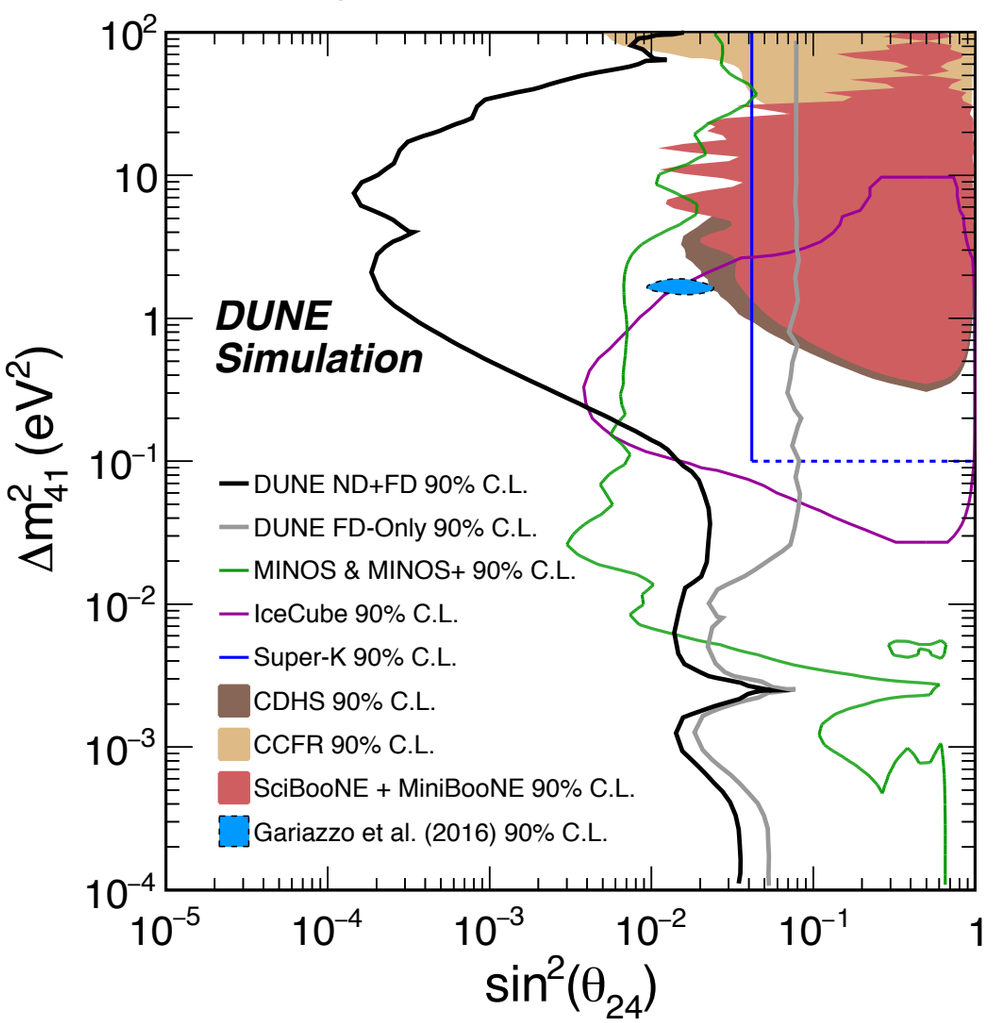
DUNE

- The combination of the near and far detectors and of CC/NC channels will allow DUNE to study sterile neutrinos

ν_e appearance



ν_μ disappearance



DUNE BSM Paper, arXiv:2002.03005

Summary

- The question of sterile neutrinos is very important for our field
  - ✓ Proof of new physics
  - ✓ Needed for proper interpretation of long-baseline experiments
- Anomalies are not consistent with each other
- New sensitive experiments are needed to answer the question
- The SBN program should shed light directly on the MiniBooNE/ LSND anomalies