eV Scale Sterile at LBL & SBL (Accelerator-based searches)

Roxanne Guenette
University of Oxford

26 August 2016
NuFact 2016 - Les Rencontres du Vietnam

Sterile neutrinos?

Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	3.8σ
MiniBooNE	SBL accelerator	$\nu_\mu \to \nu_e$ CC	3.4σ
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	2.8σ
GALLEX/SAGE	Source - e capture	ν_e disappearance	2.8σ
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance	3.0σ

K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)

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This talk

Next talk

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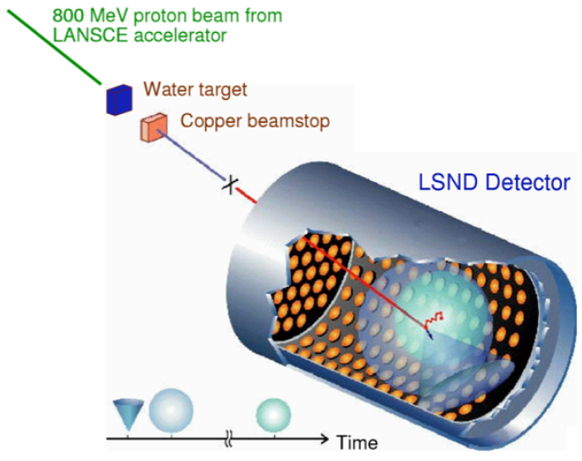
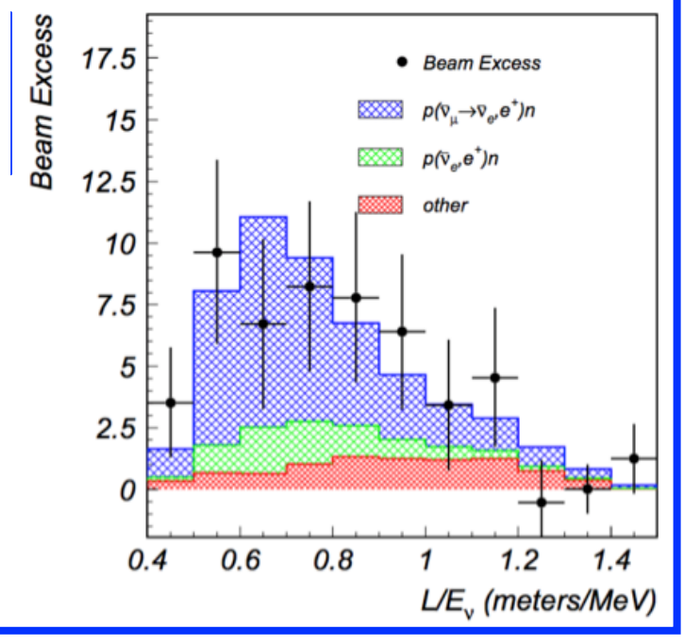
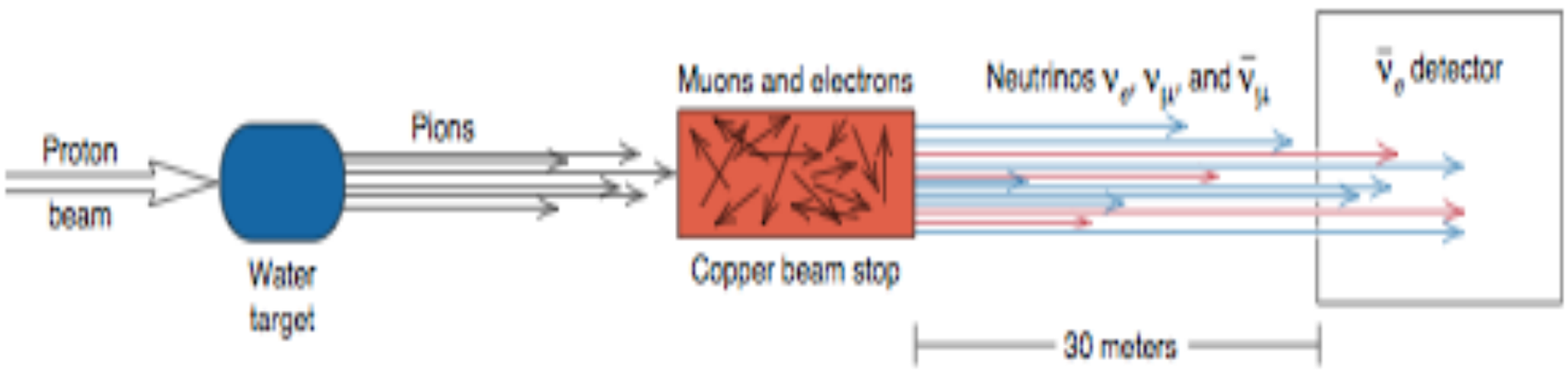
Sterile neutrinos at accelerator experiments?



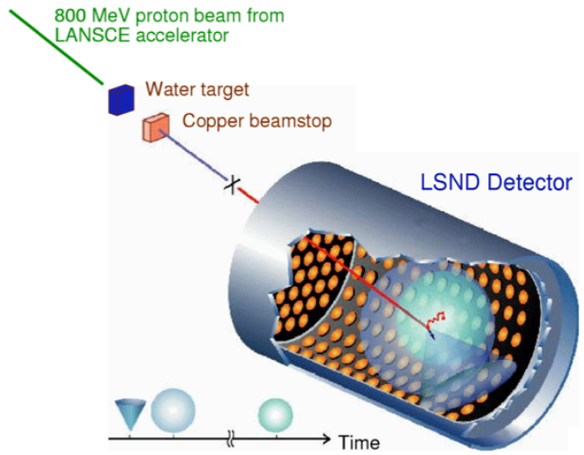


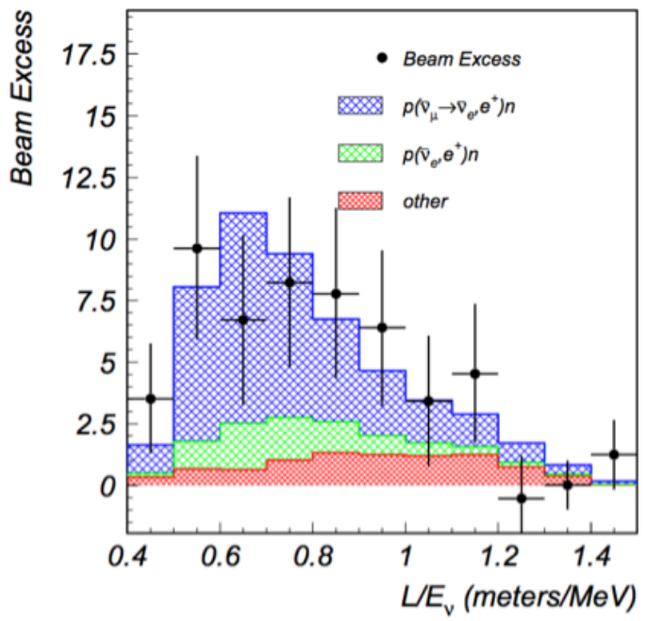
LSND (2001)



PRD 64 (2001) 112007

Sterile neutrinos at accelerator experiments?





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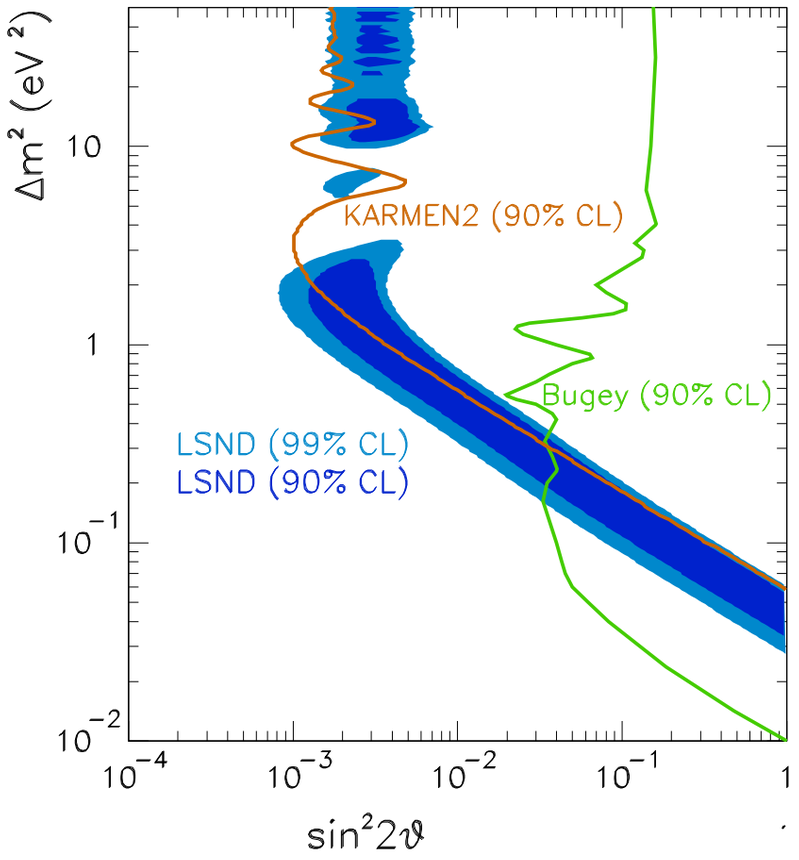

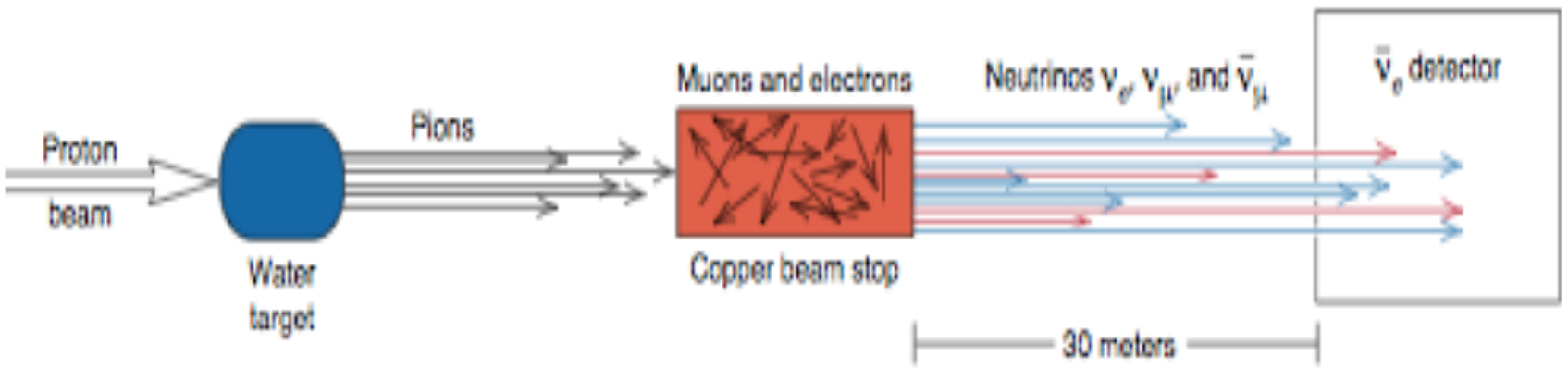

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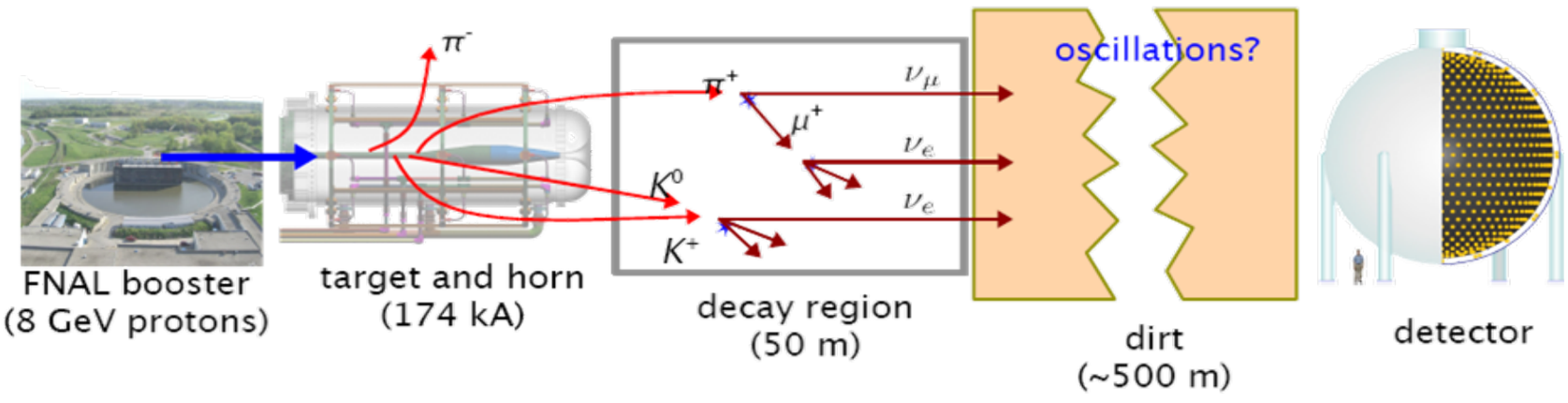
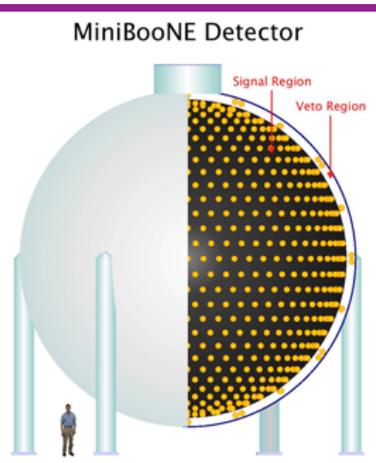
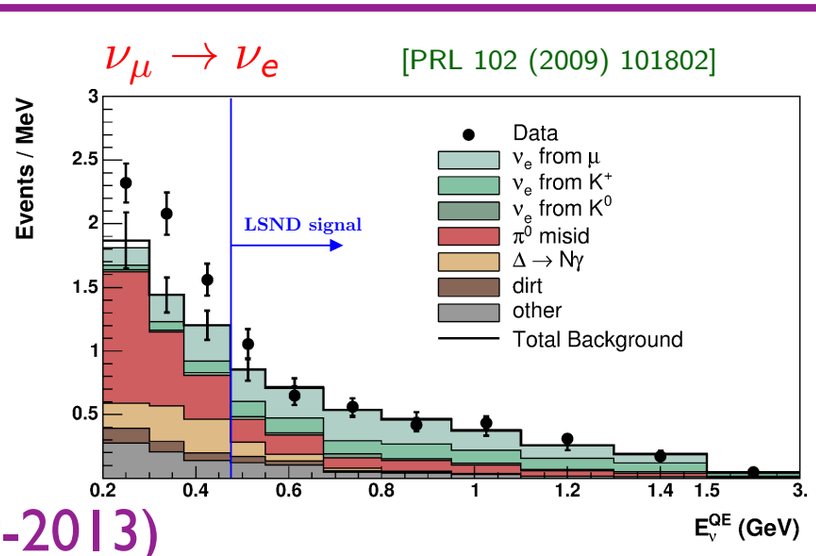
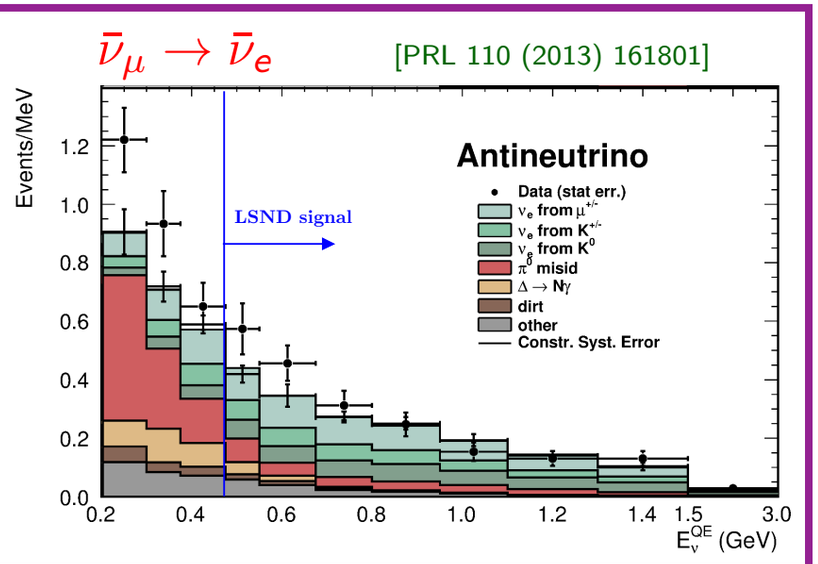




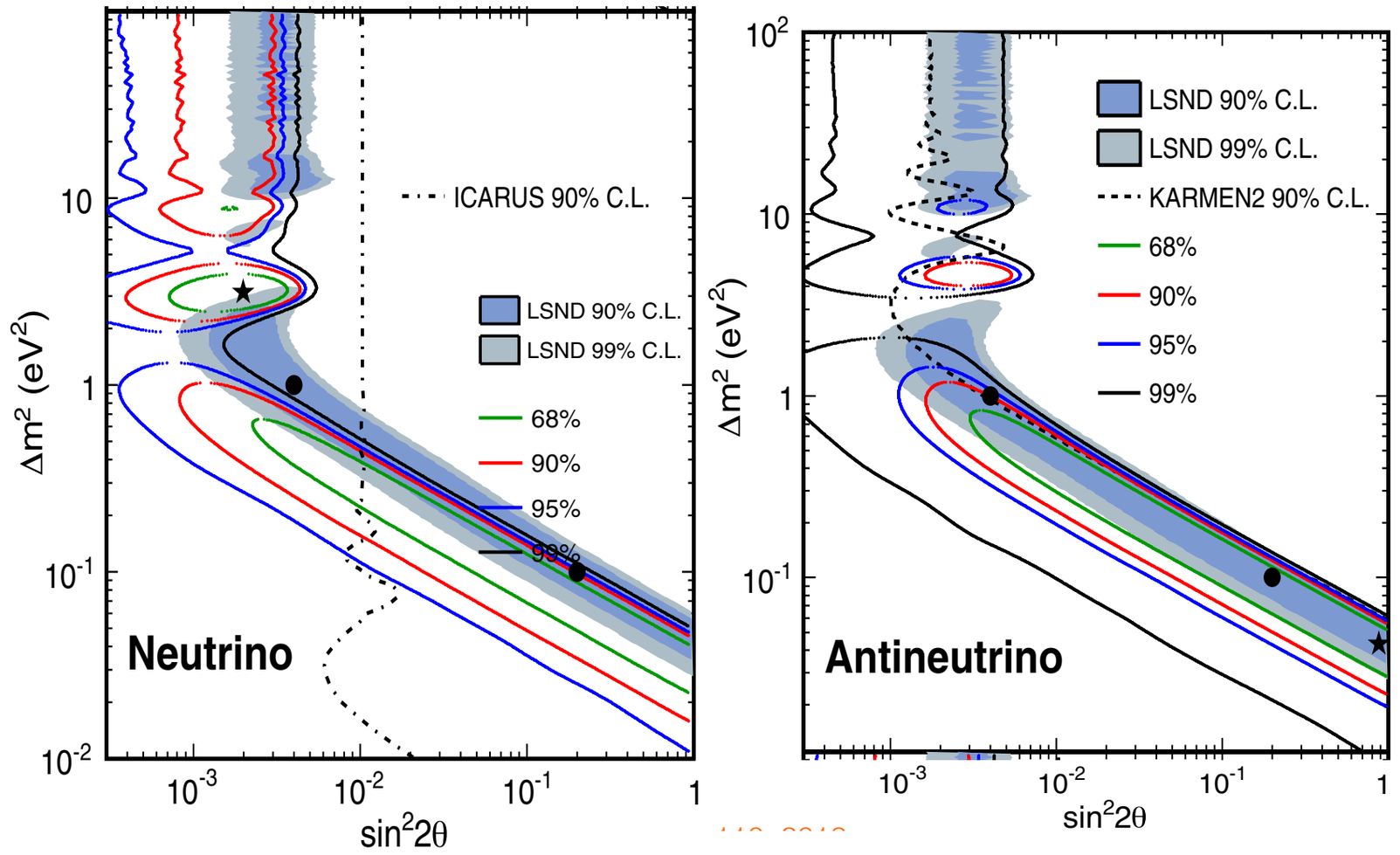


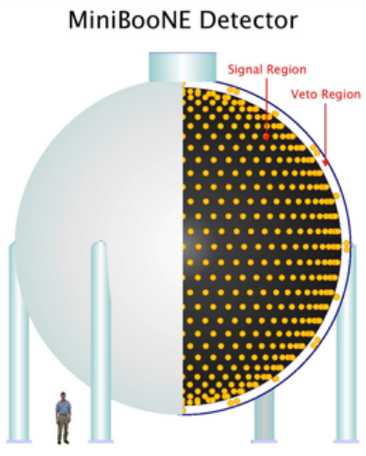


MiniBooNe (2009-2013)

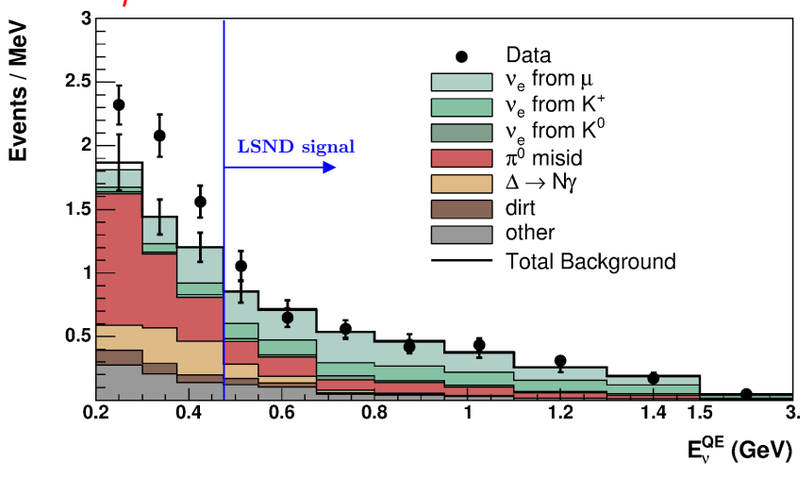
PRL 110 (2013) 161801

Sterile neutrinos at accelerator experiments?





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



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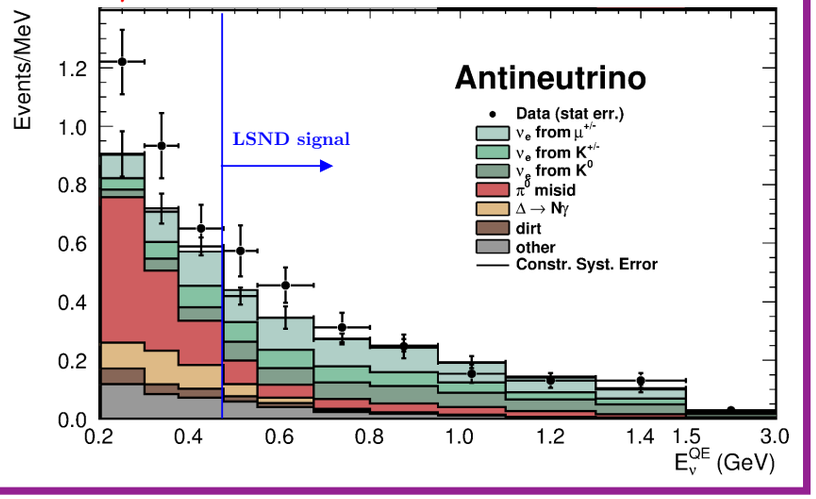
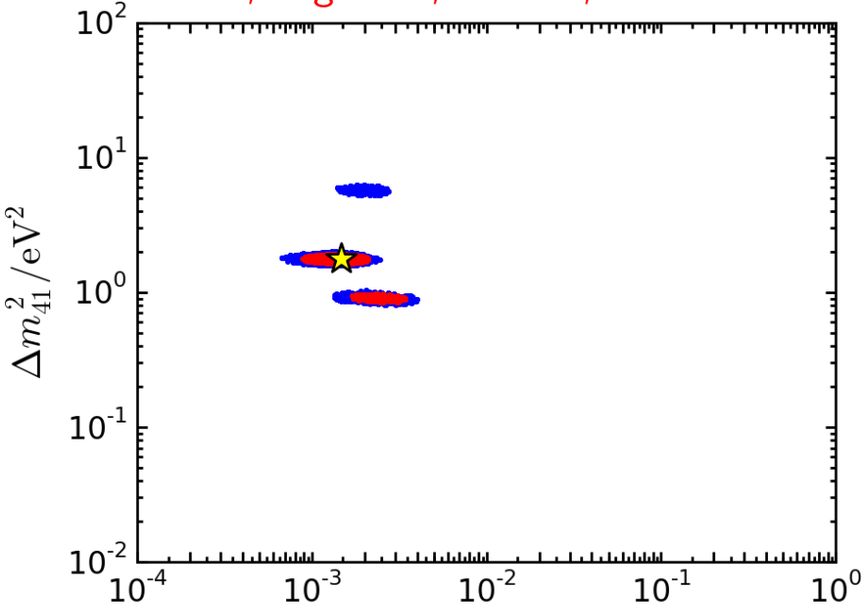


MiniBooNe (2009-2013)

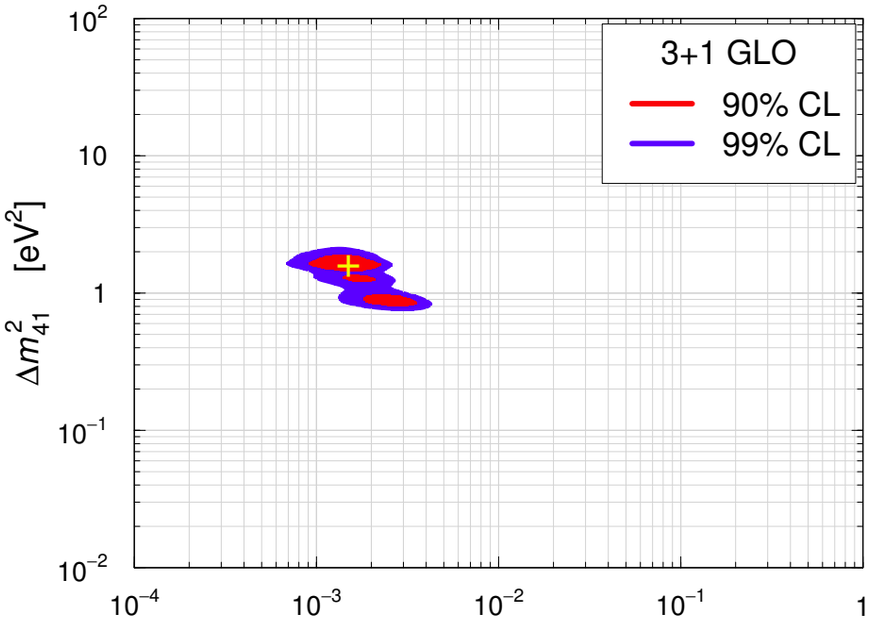
PRL 110 (2013) 161801

Global explanation?

[NPB 908 (2016) 354]
Collin, Arguelles, Conrad, Shaevitz

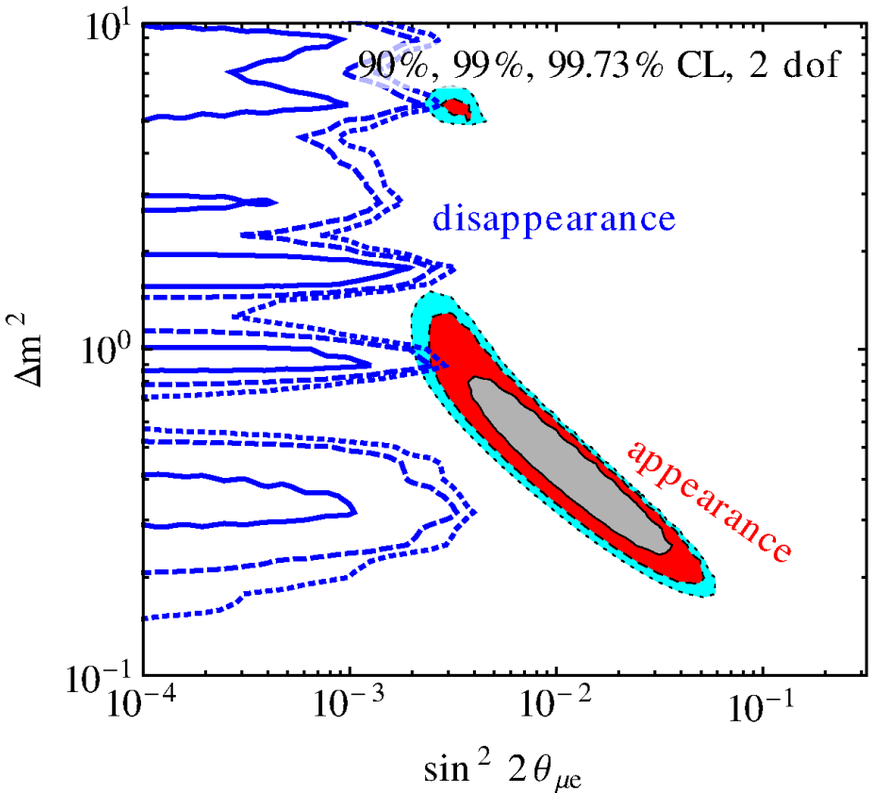


Update of [Gariazzo, CG, Laveder, Li, Zavanin, JPG 43 (2016) 033001]



Region of allowed parameter space is getting small!

· Kopp, Machado, Maltoni, Schwetz
[JHEP 1305 (2013) 050]



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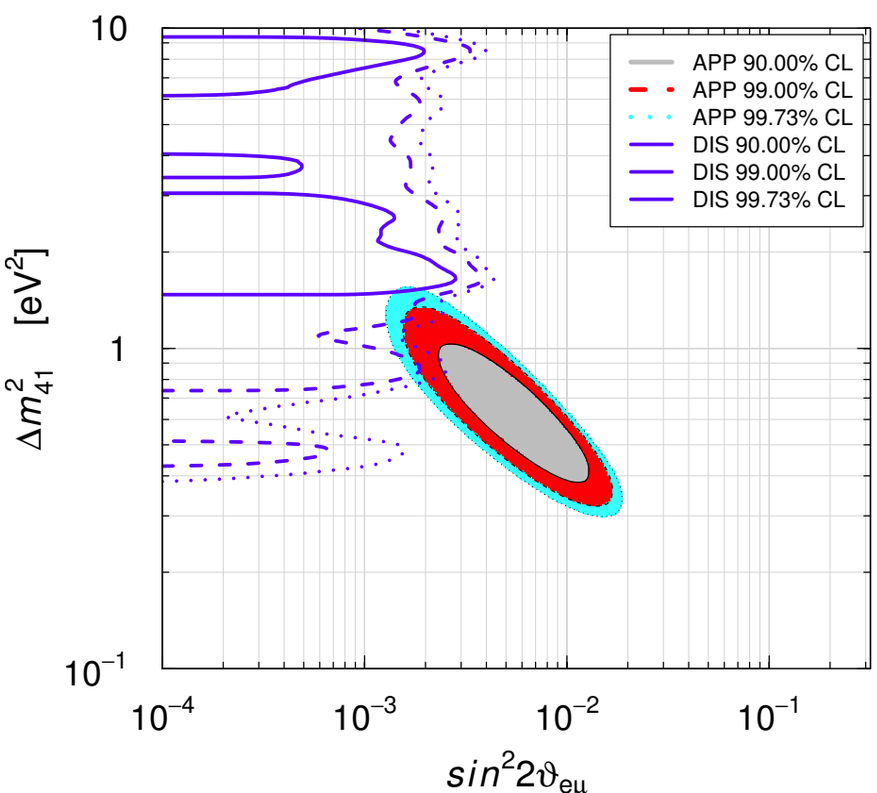
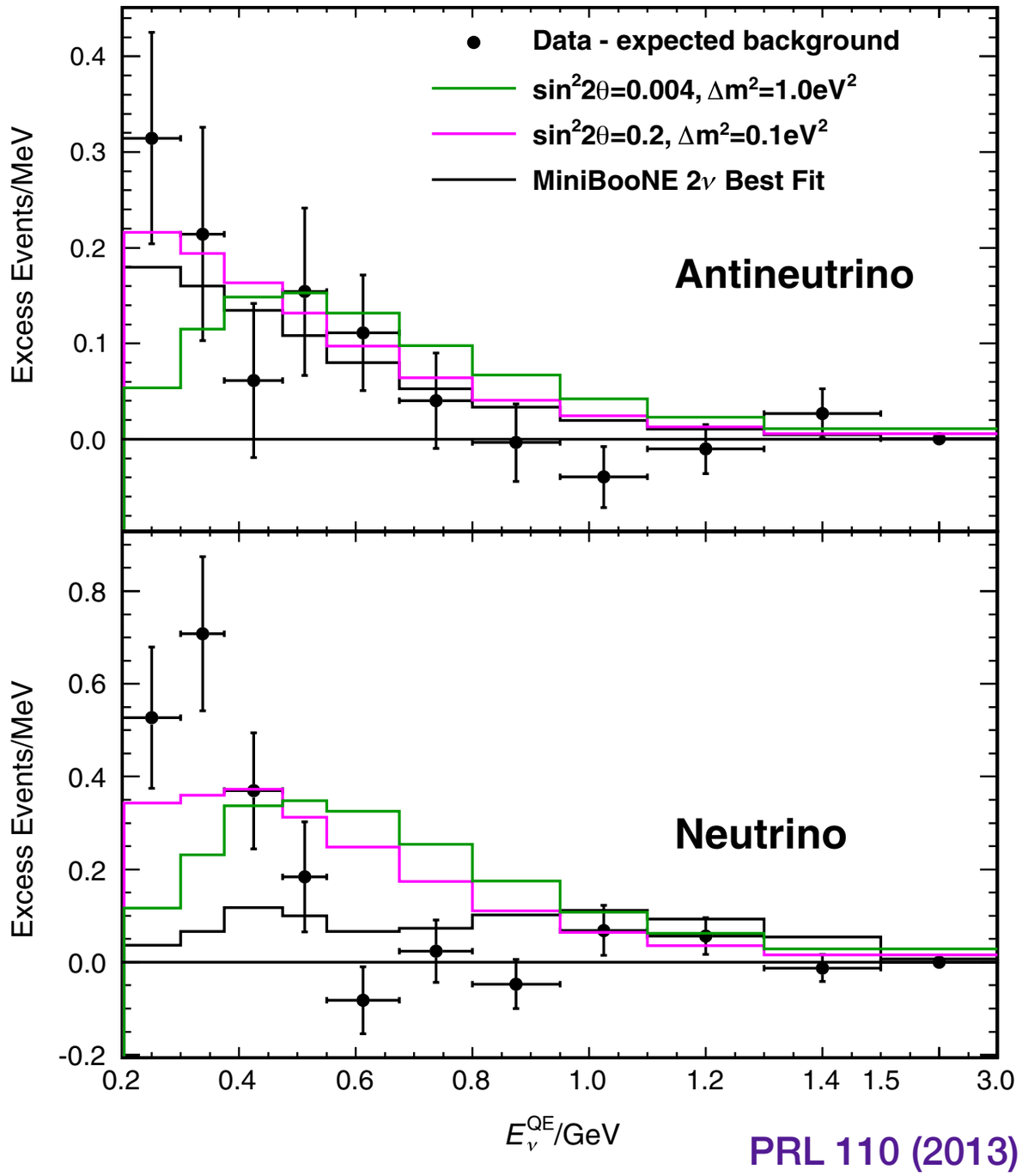


Severe tension between appearance and disappearance

MiniBooNE low-energy excess tension

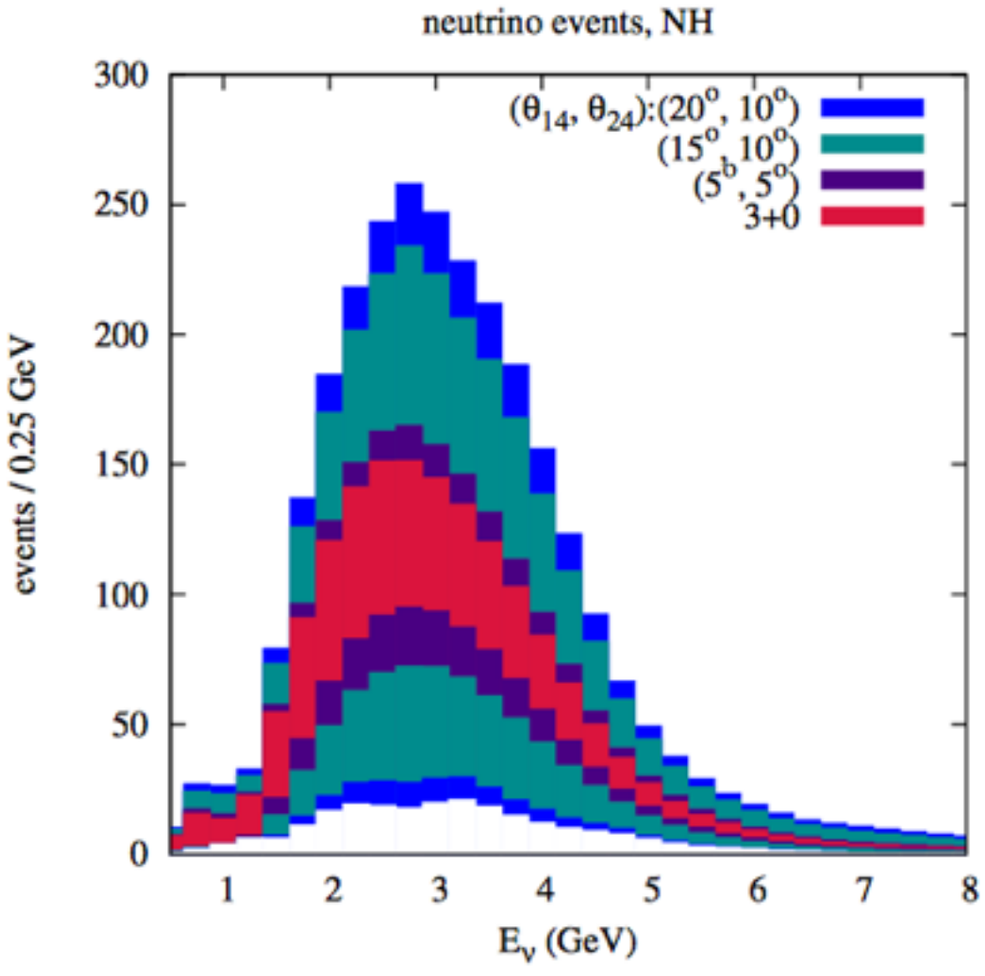
- MiniBooNE low-energy excess (neutrino mode) is hard to explain with additional neutrino(s)

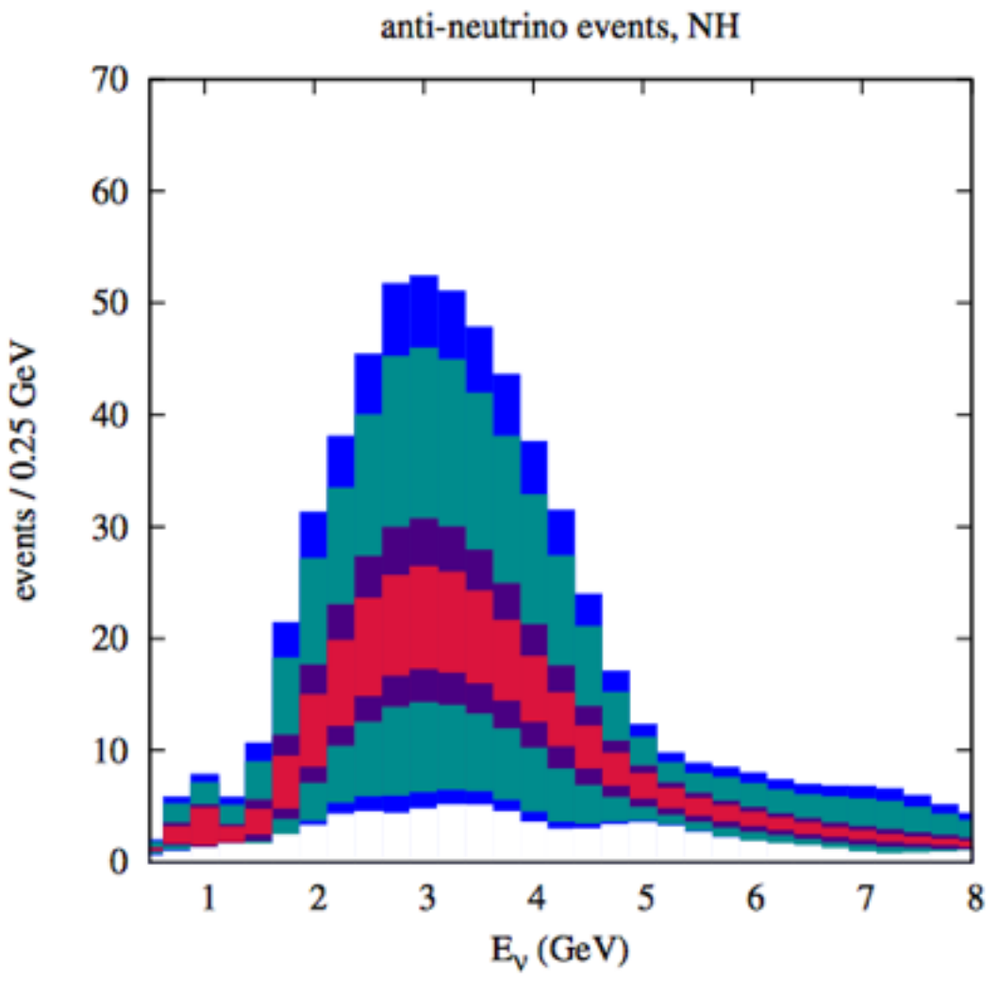


PRL 110 (2013) 161801

Impact on future LBL

- CP-violation and MH measurements will be impacted by the presence of sterile neutrinos





R. Gandhi, B. Kayser, M. Masud, S. Pakrash, arXiv:1508.06275

Supposed to be the previous talk

Recent results

- IceCube B. Jones' talk
- Reactor experiments A. Minotti's talk
- Long-baseline experiments have looked for sterile neutrinos
  - ➡ T2K
  - ➡ Minos/Minos+
  - ➡ Nova

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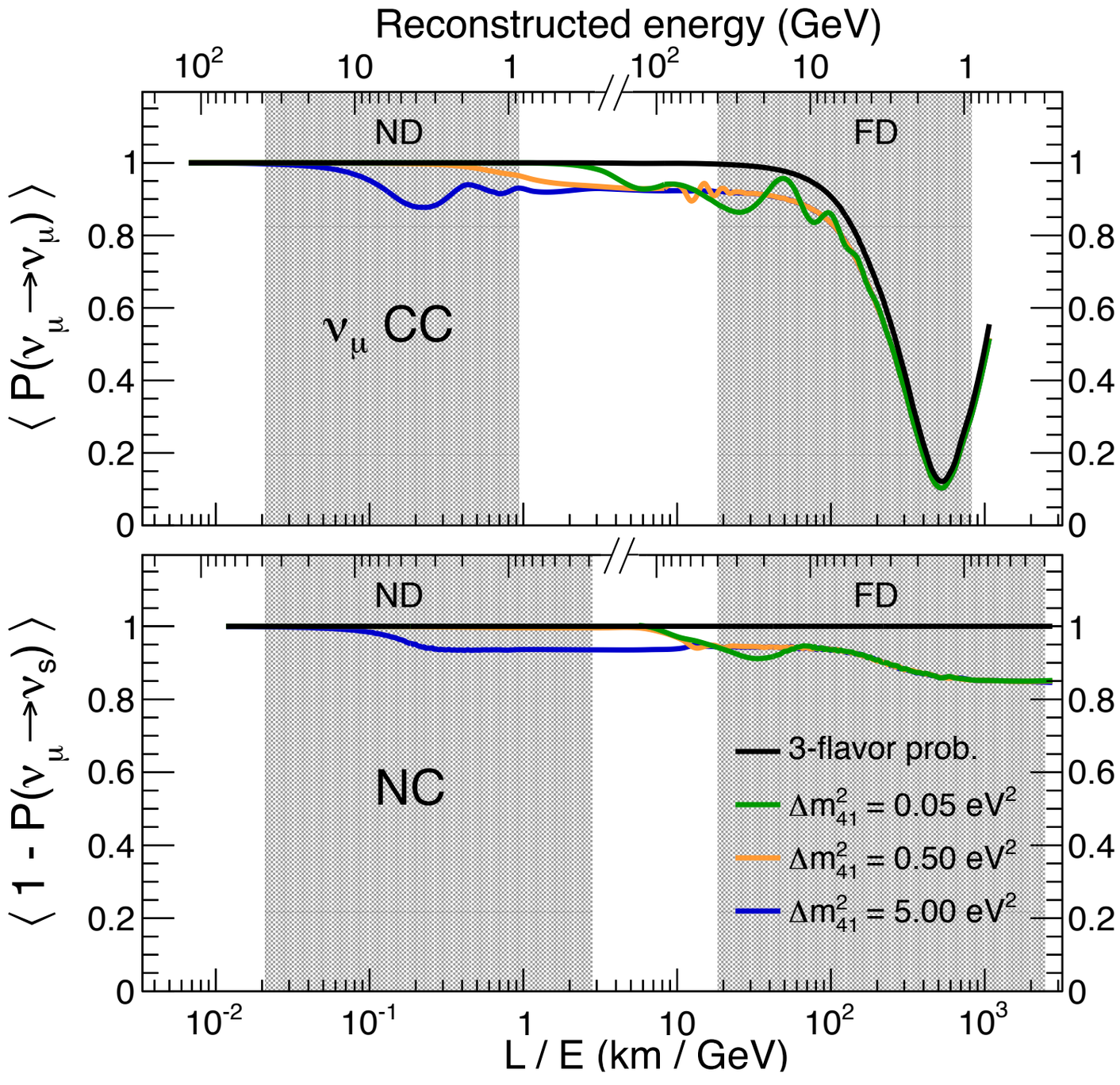
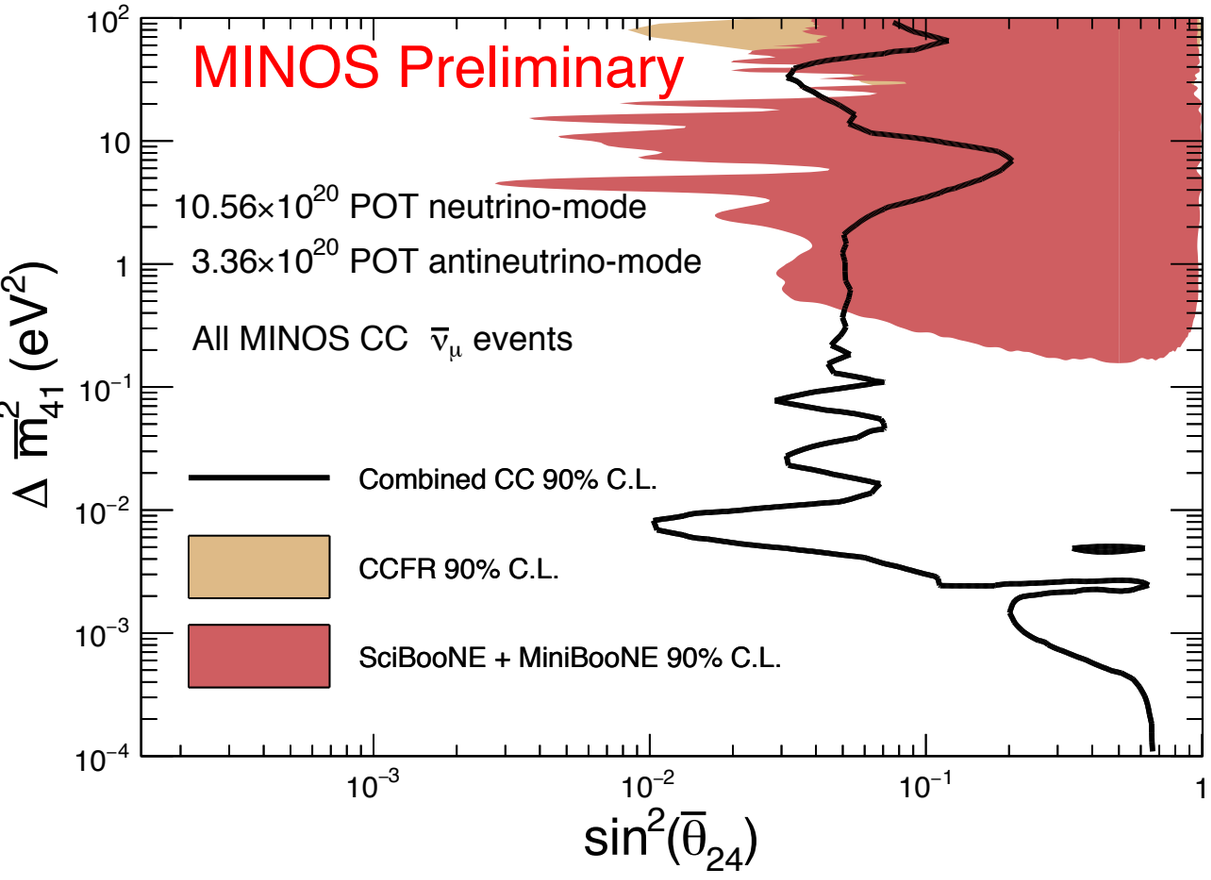
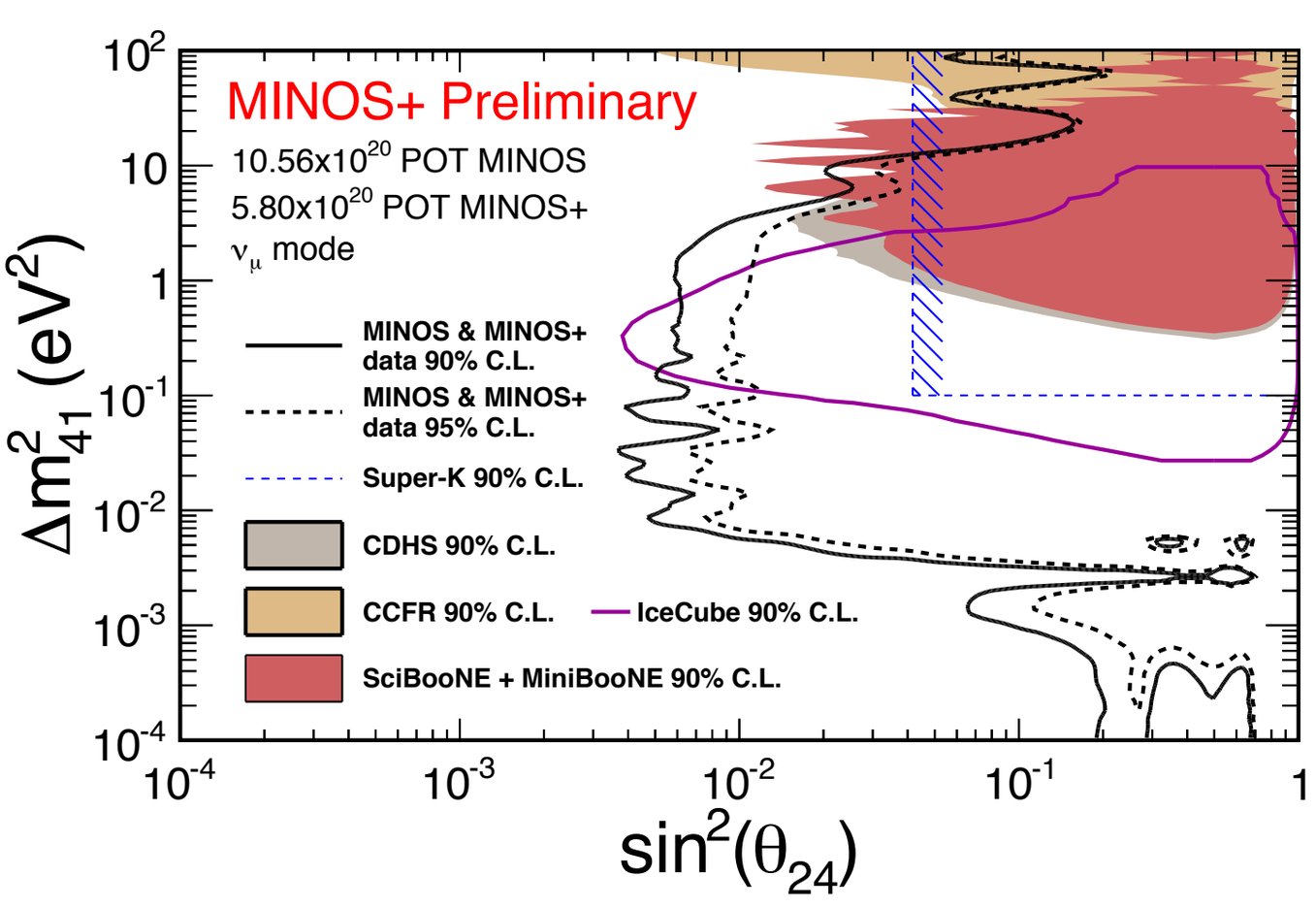


MINOS arxiv:1607.01176

Minos / Minos +

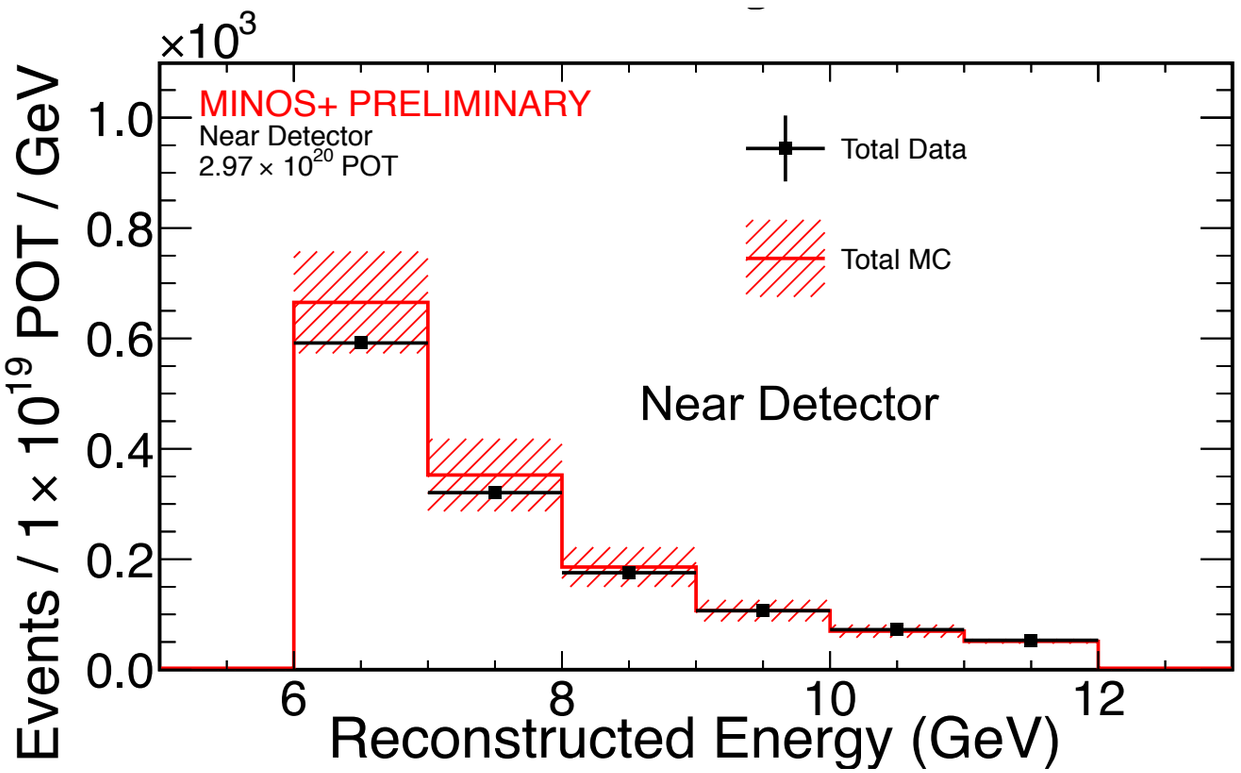


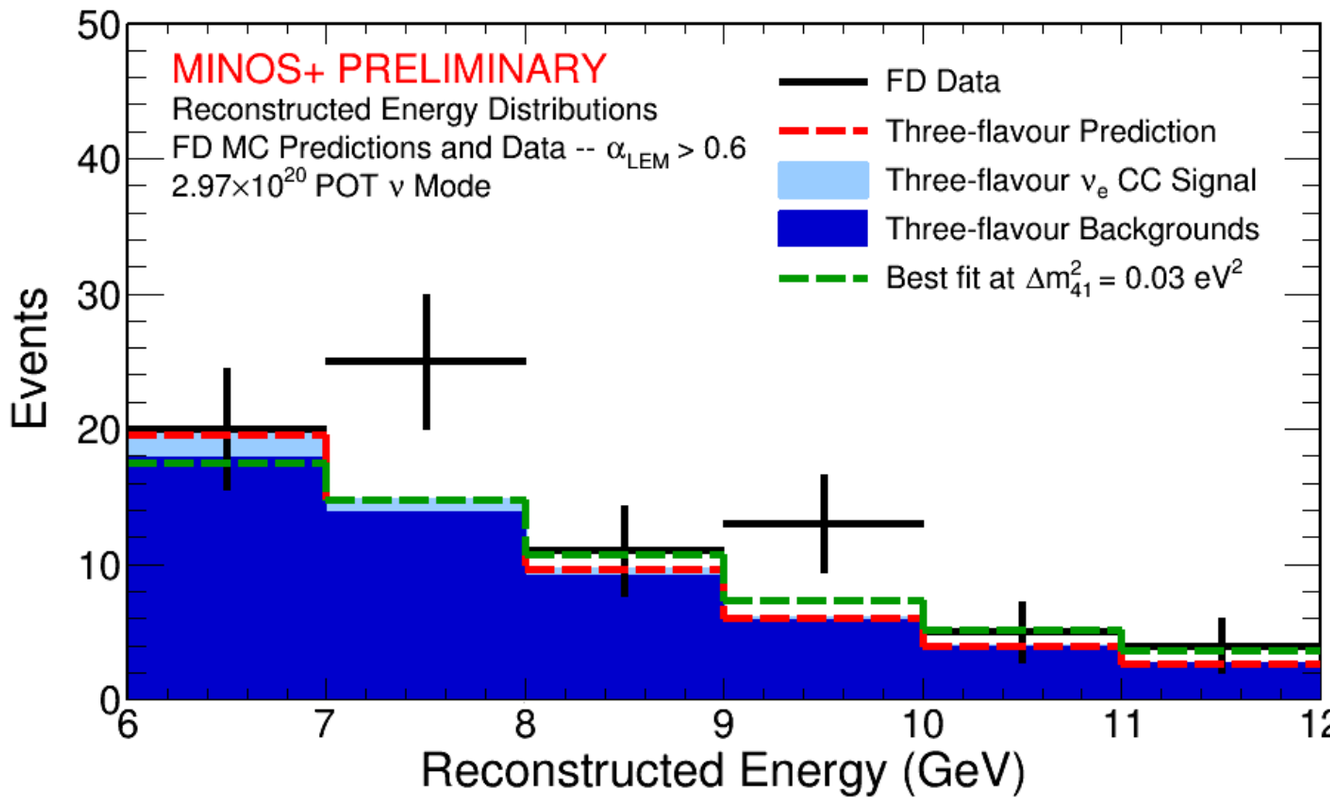


J. Evans, Neutrino 2016

Minos / Minos +

- Look at ν_e appearance in FD based on ND predictions



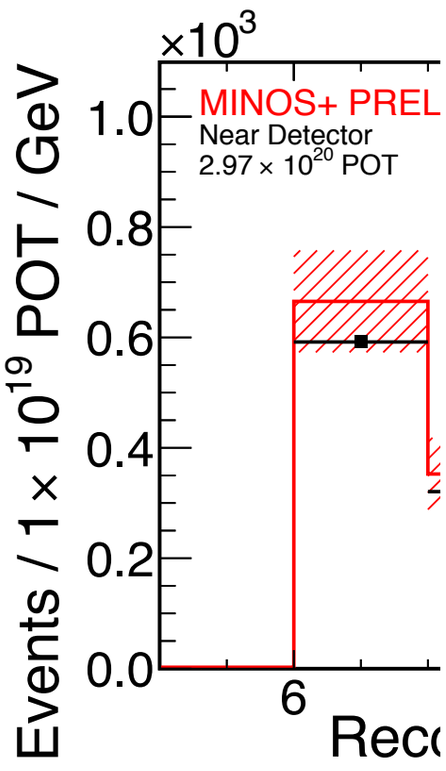


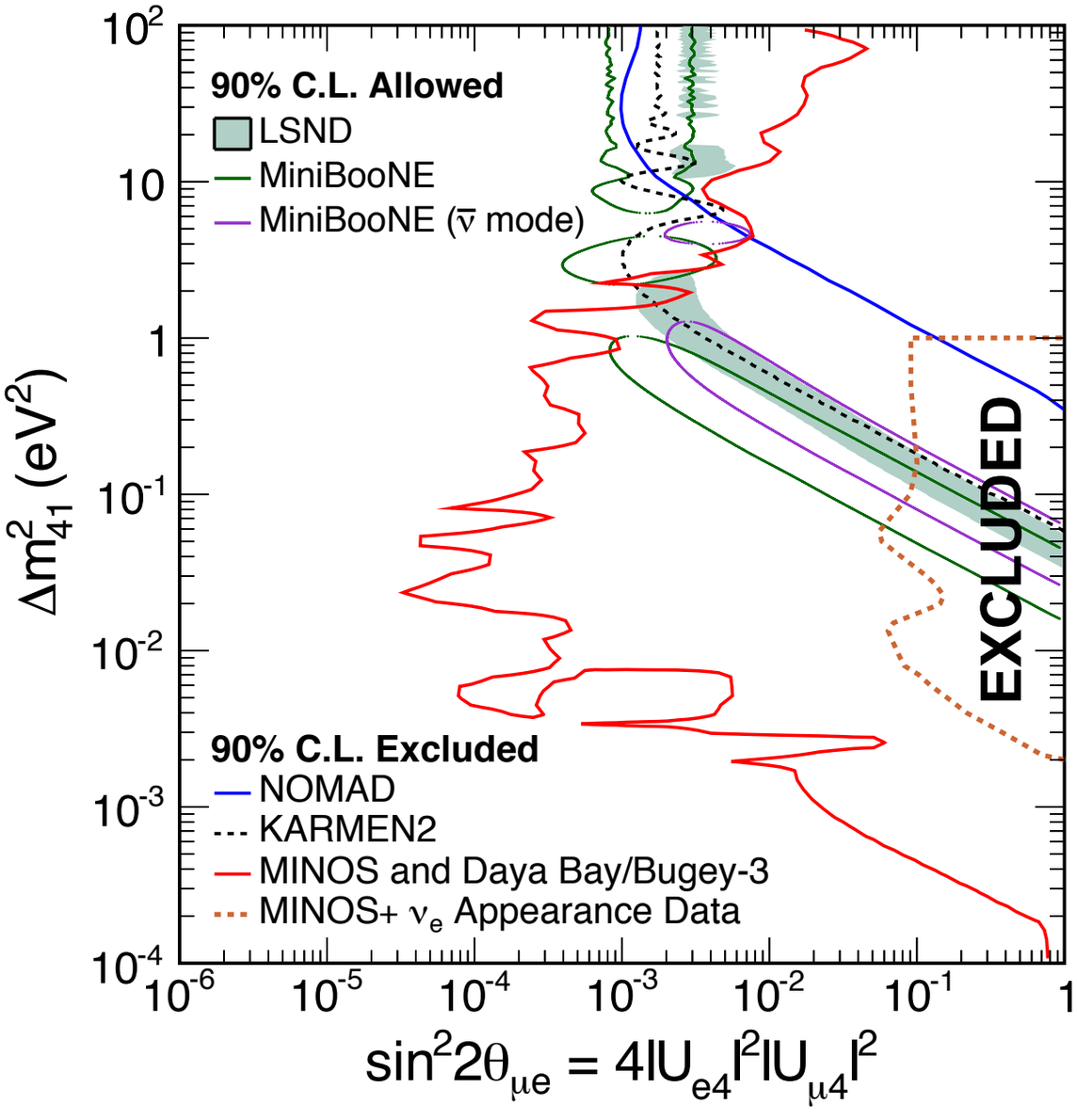
Expect 56.7 events, observe 78

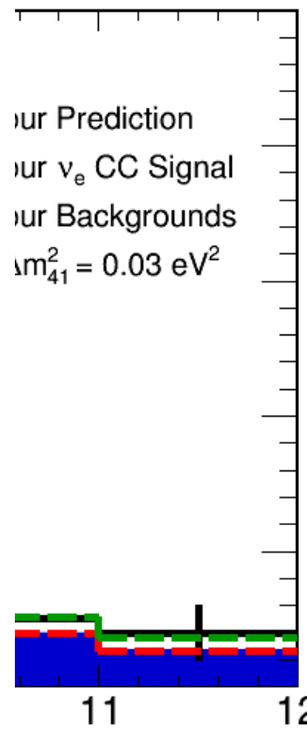
- 2.3σ excess

Minos / Minos +

- Look at







/e 78

- 2.3σ excess

What's next then?

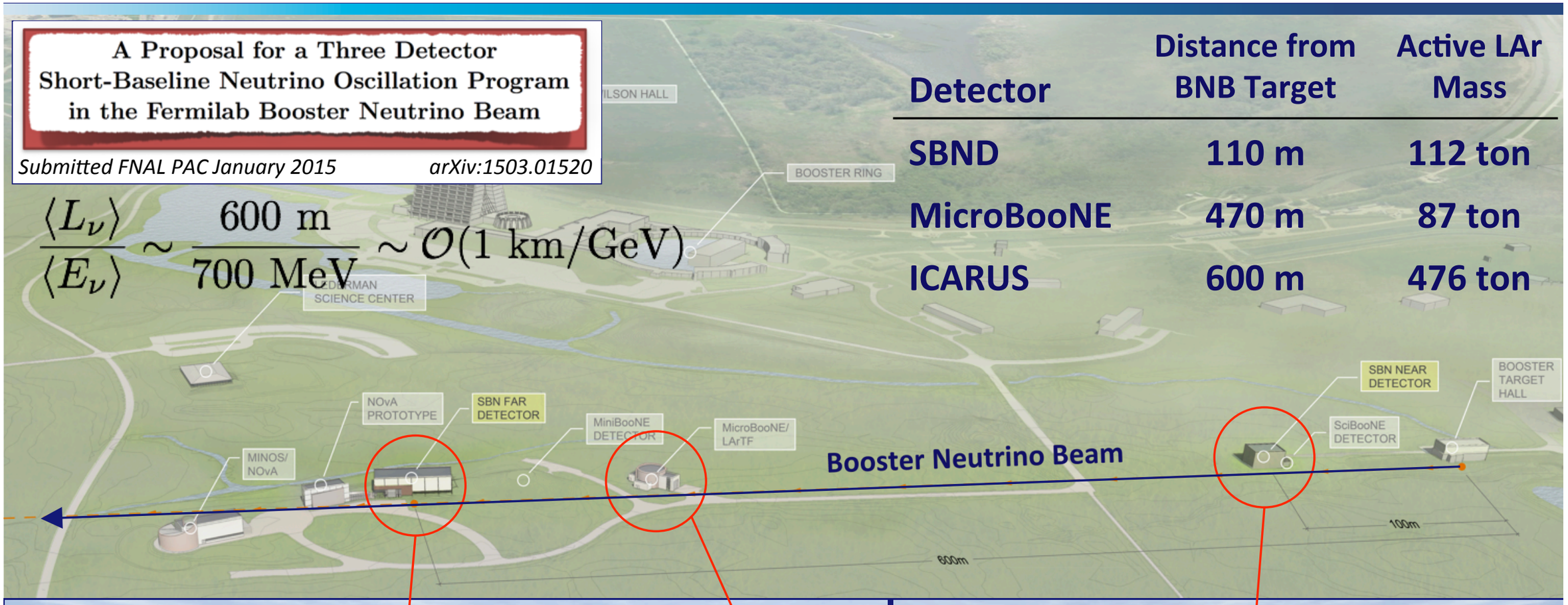
SBN programme at Fermilab

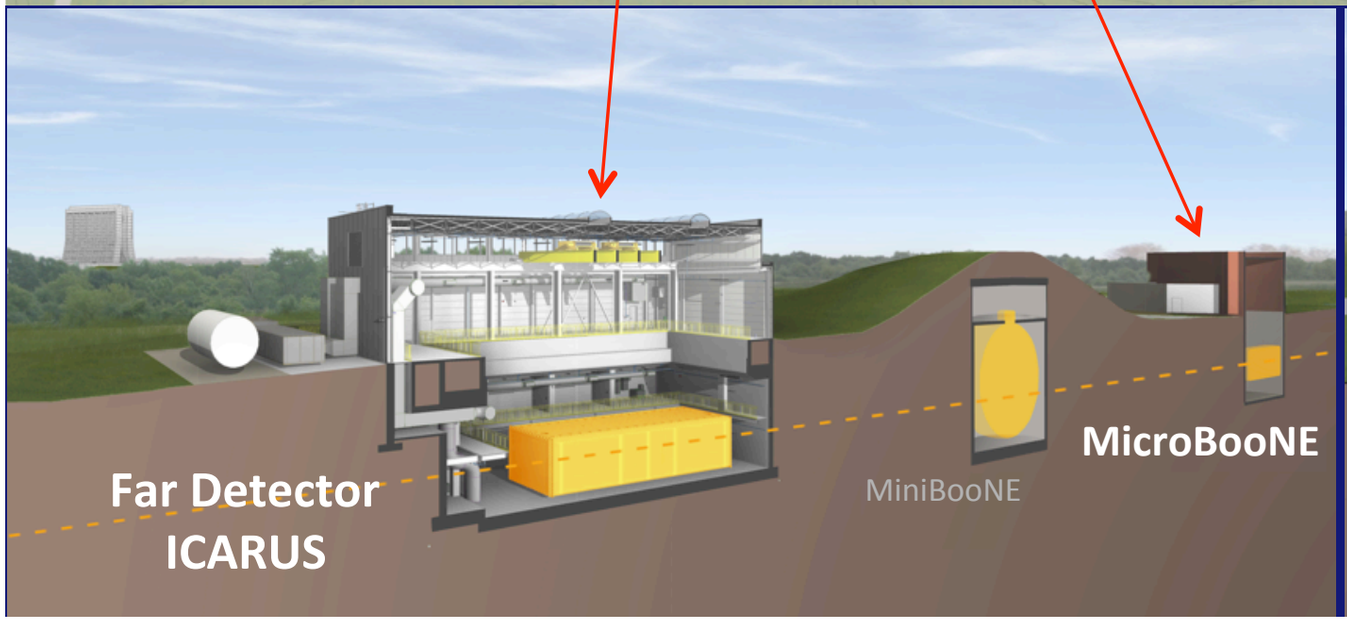
A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

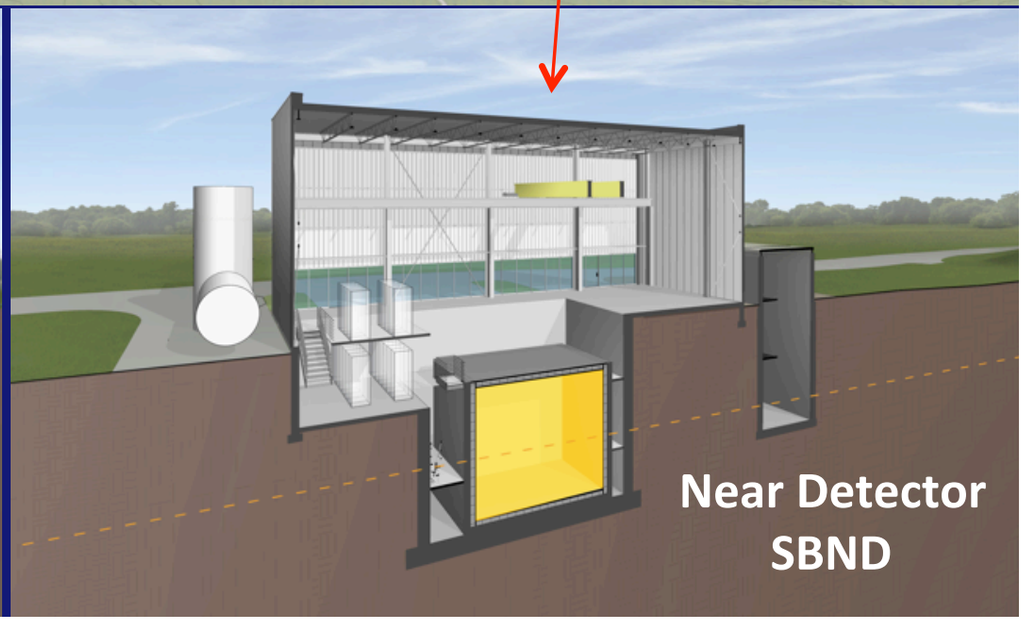
Submitted FNAL PAC January 2015 *arXiv:1503.01520*

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

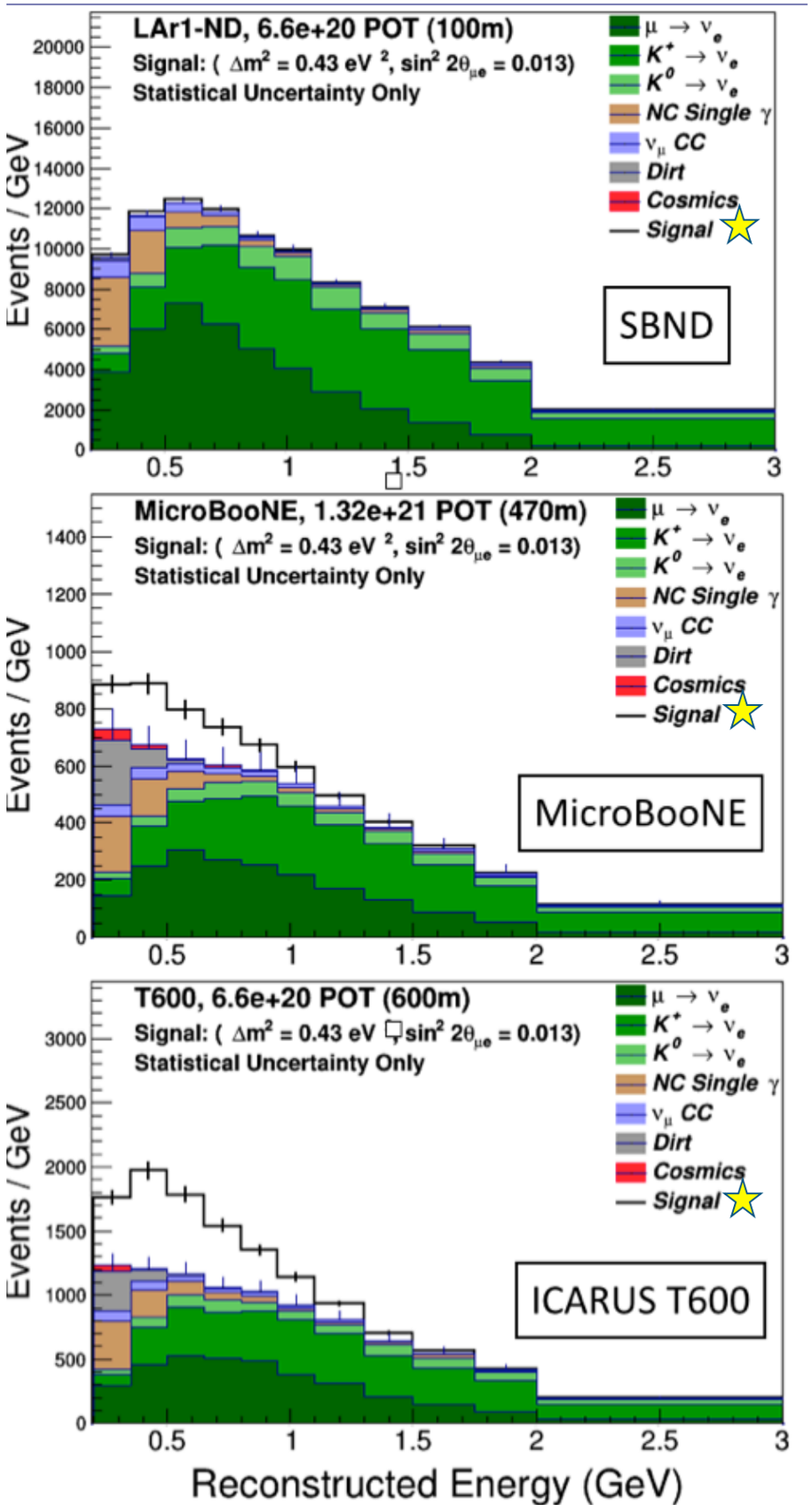
Detector	Distance from BNB Target	Active LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS	600 m	476 ton

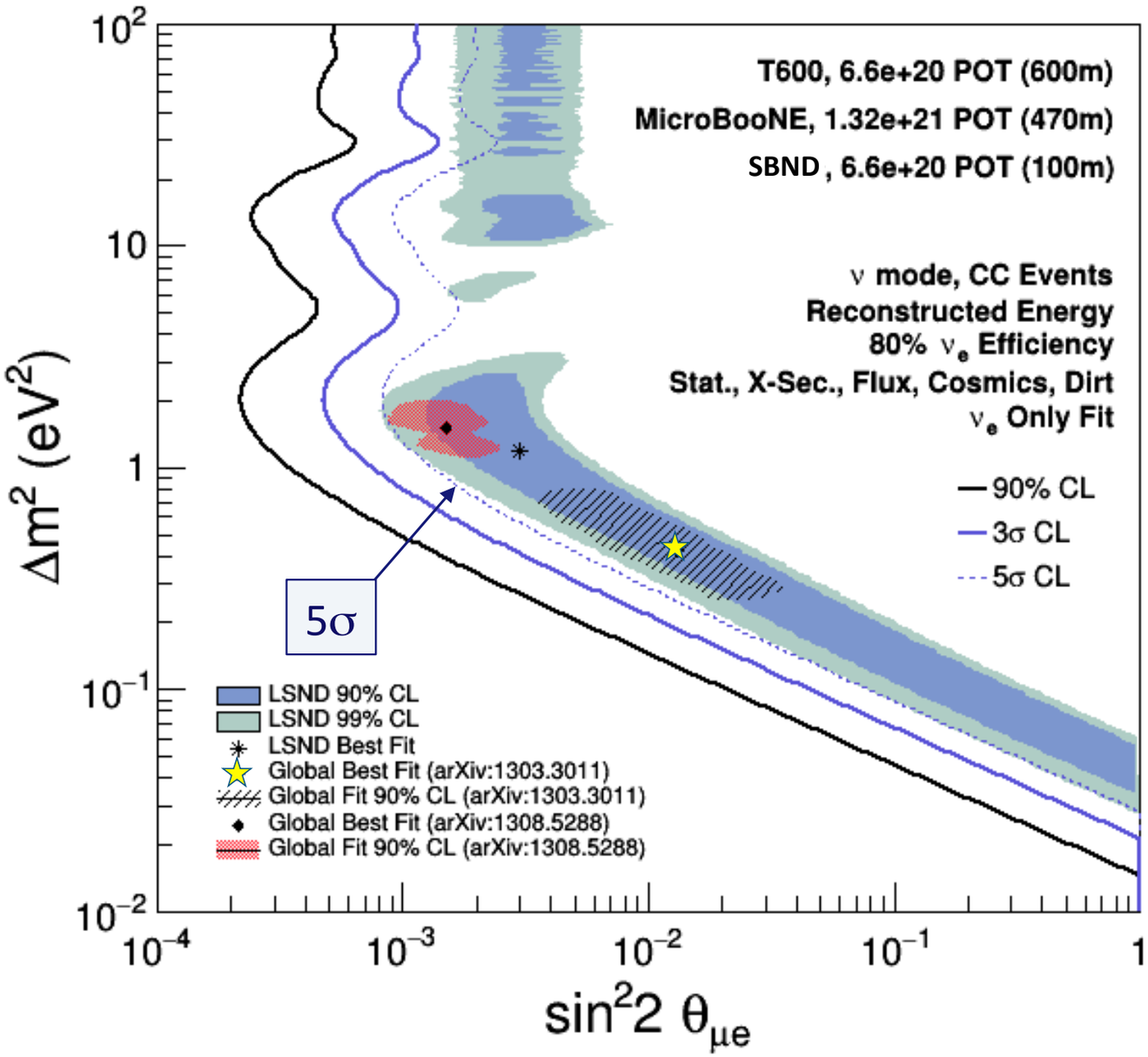






SBN programme at Fermilab



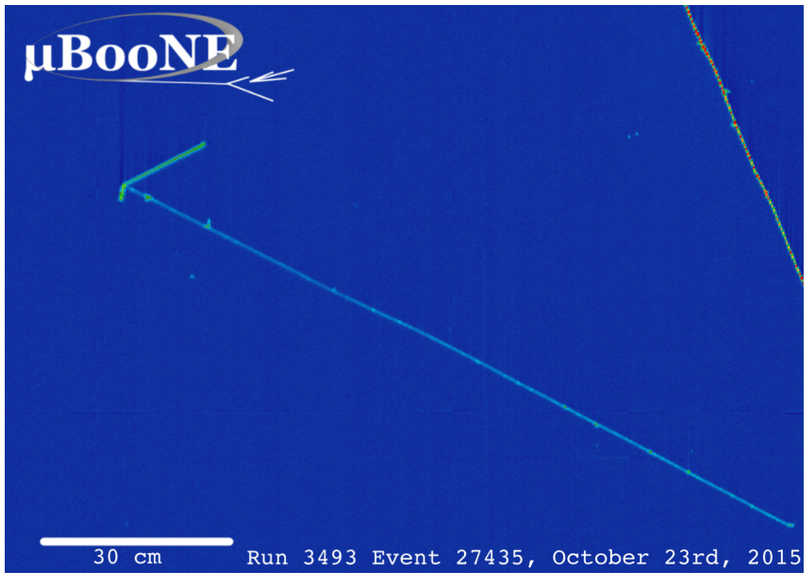


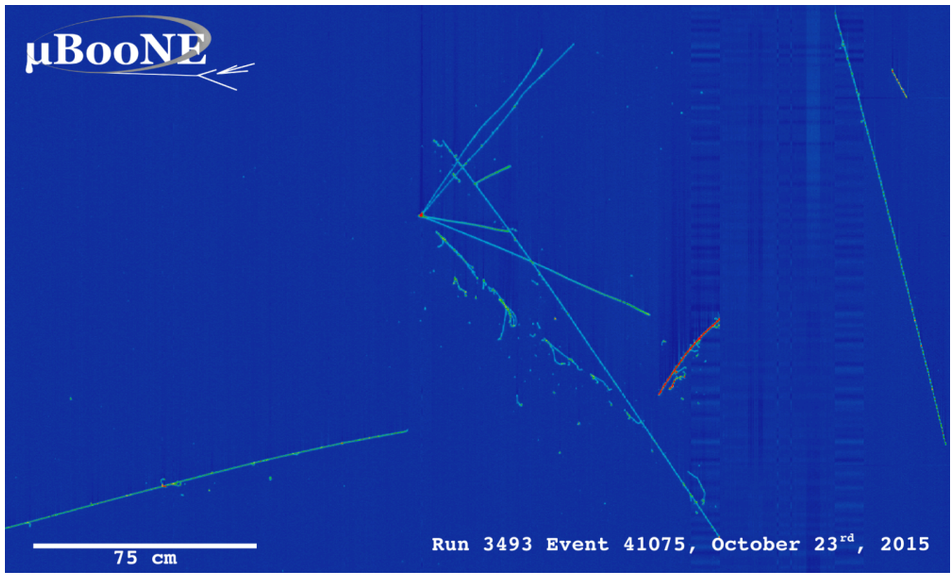
SBN proposal arxiv:1503.01520

Status of SBN -> MicroBooNE

- MicroBooNE has been taking neutrino data since October 2015
- > 1/2 data set accumulated in first year
- Upgrades underway

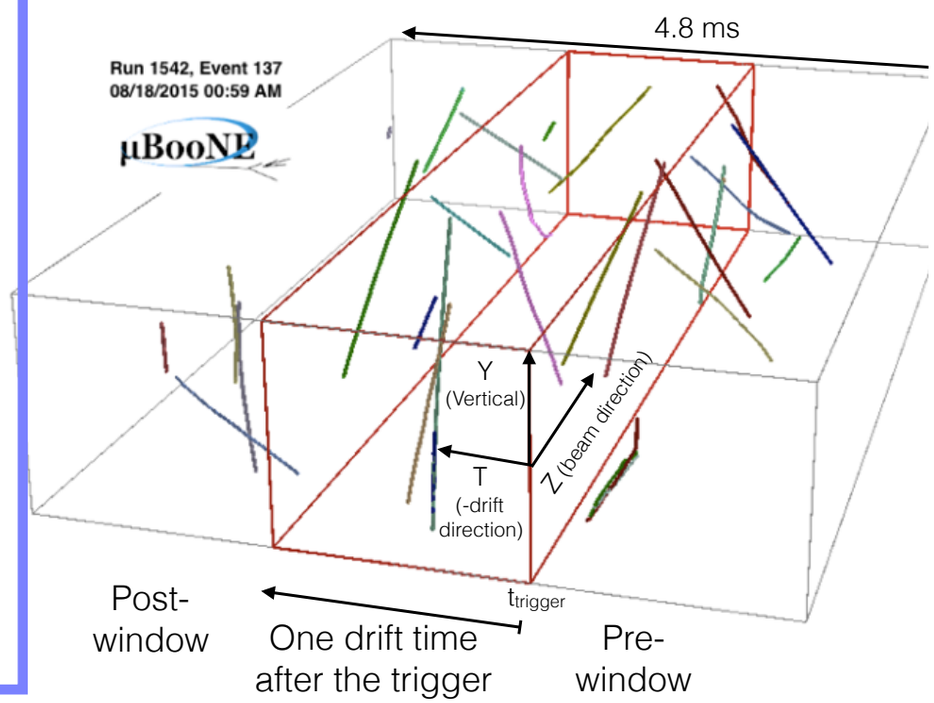
Pip Hamilton's talk

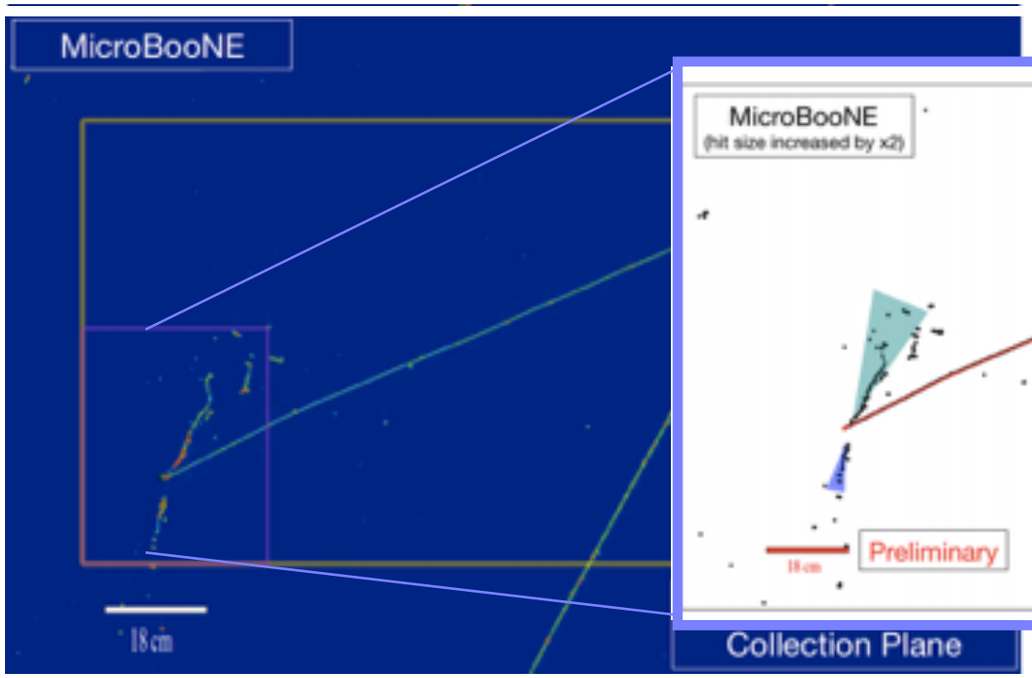




Automated Reconstruction!

Reconstructed cosmic tracks in MicroBooNE data
(assuming $t_0 = t_{trigger}$)

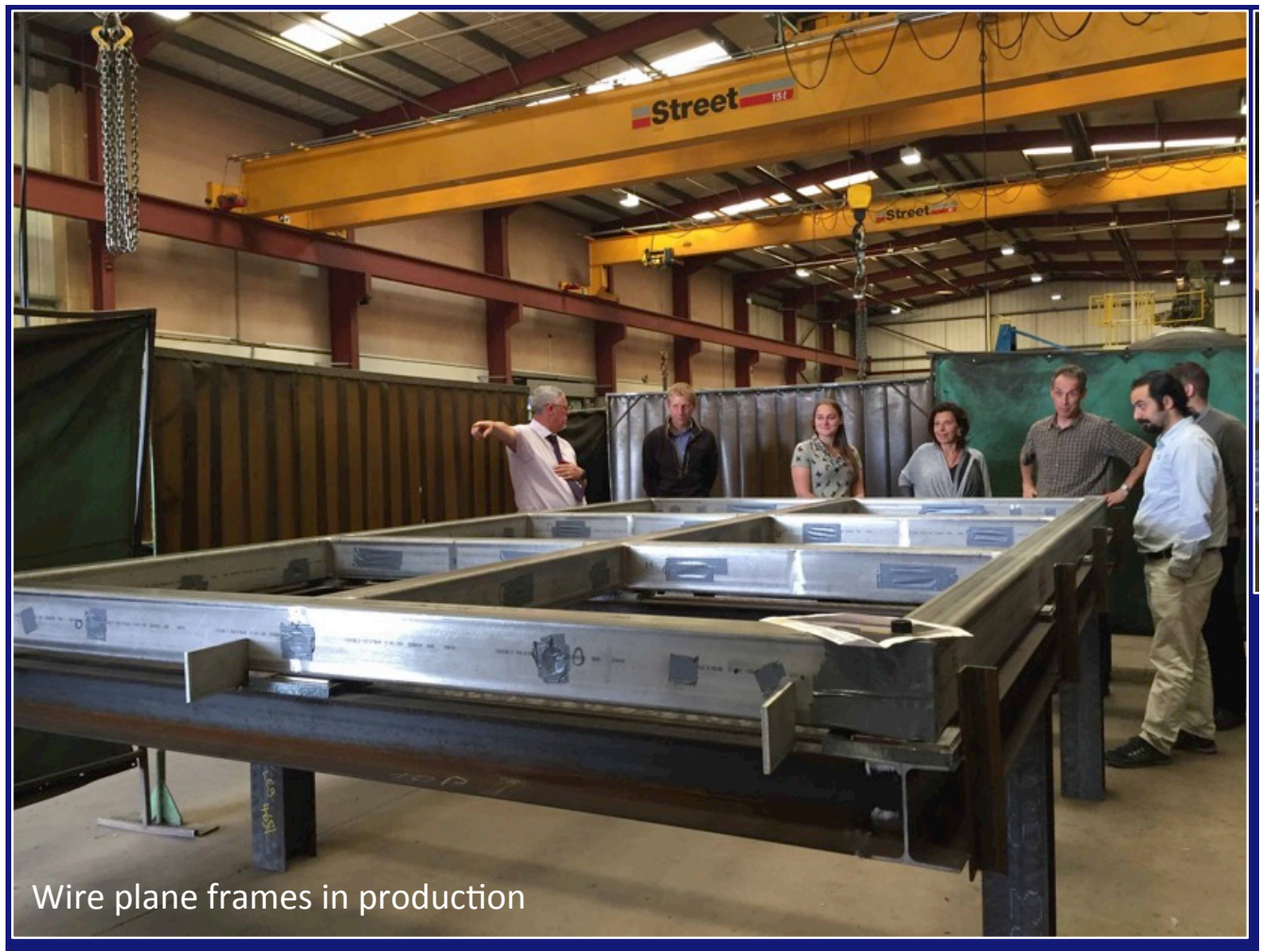


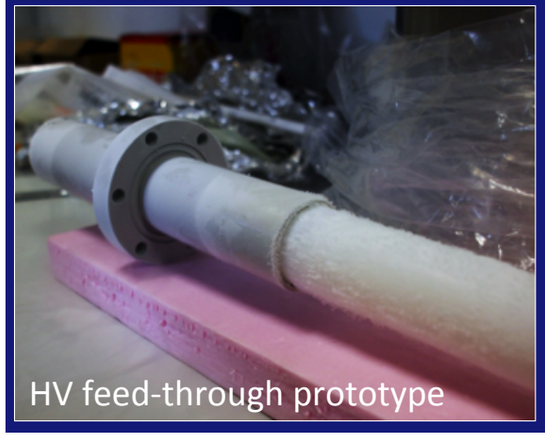


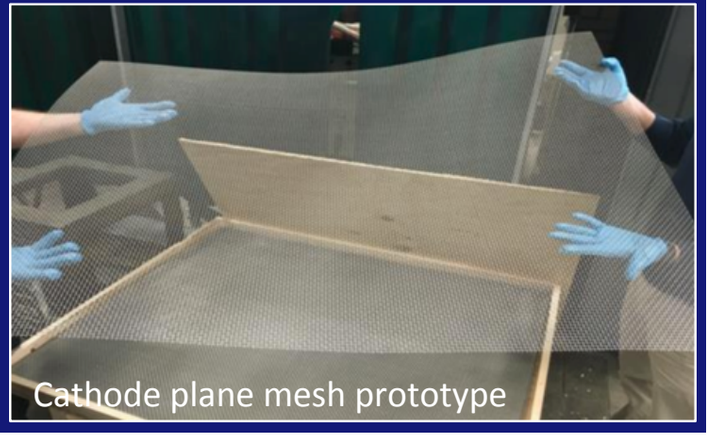
Status of SBN

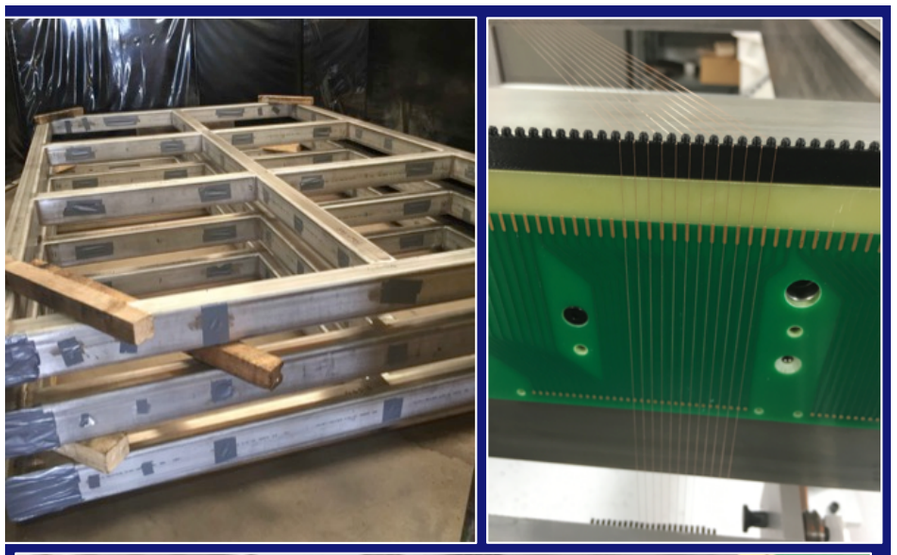
Status of SBN -> SBND

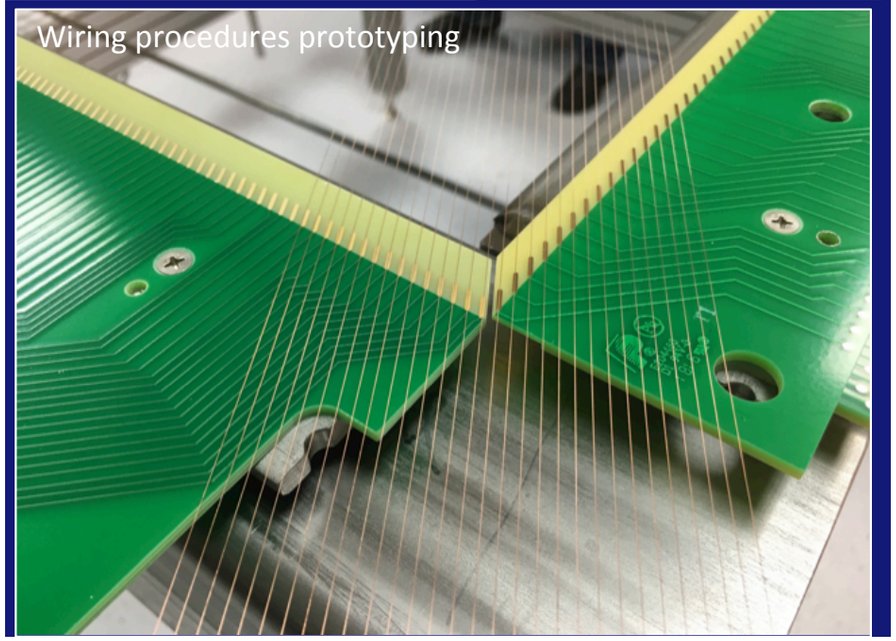
- TPC construction has begun!
- Detector installation planned for Summer 2017
- Commissioning and operation in 2018





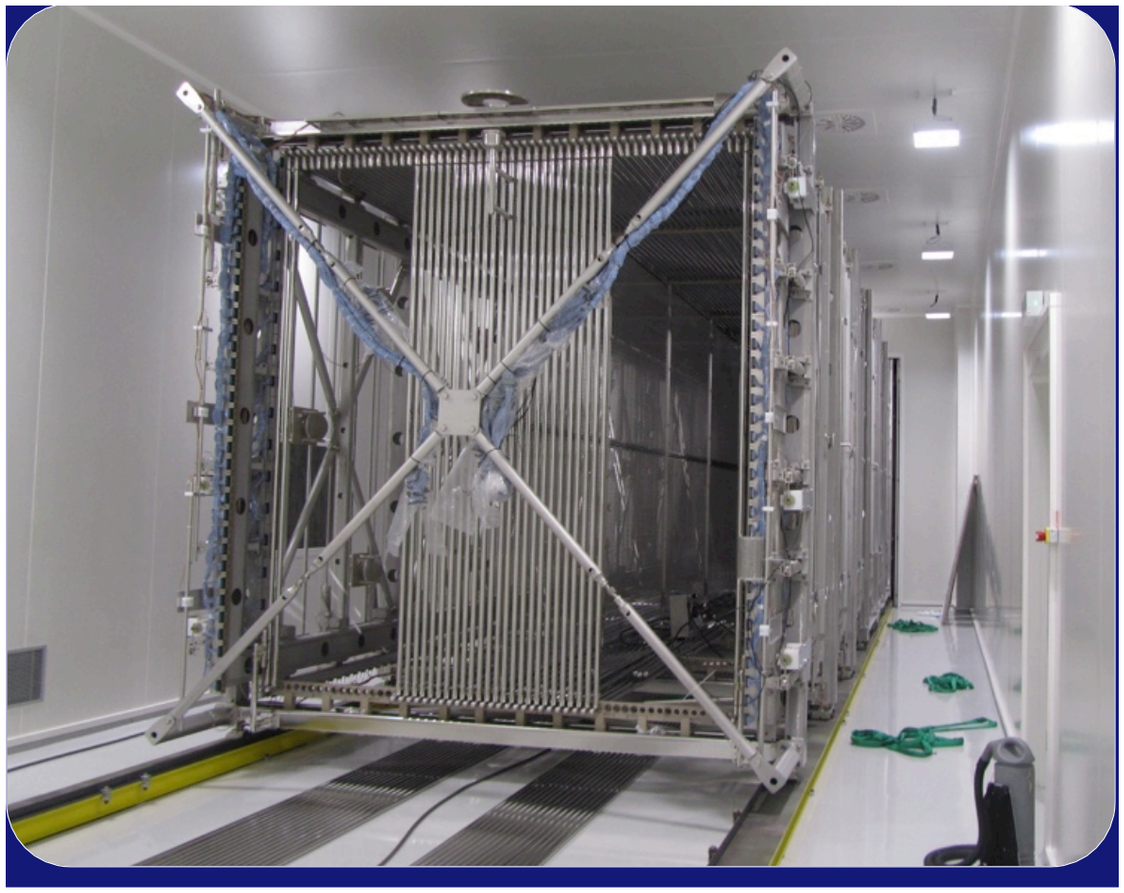




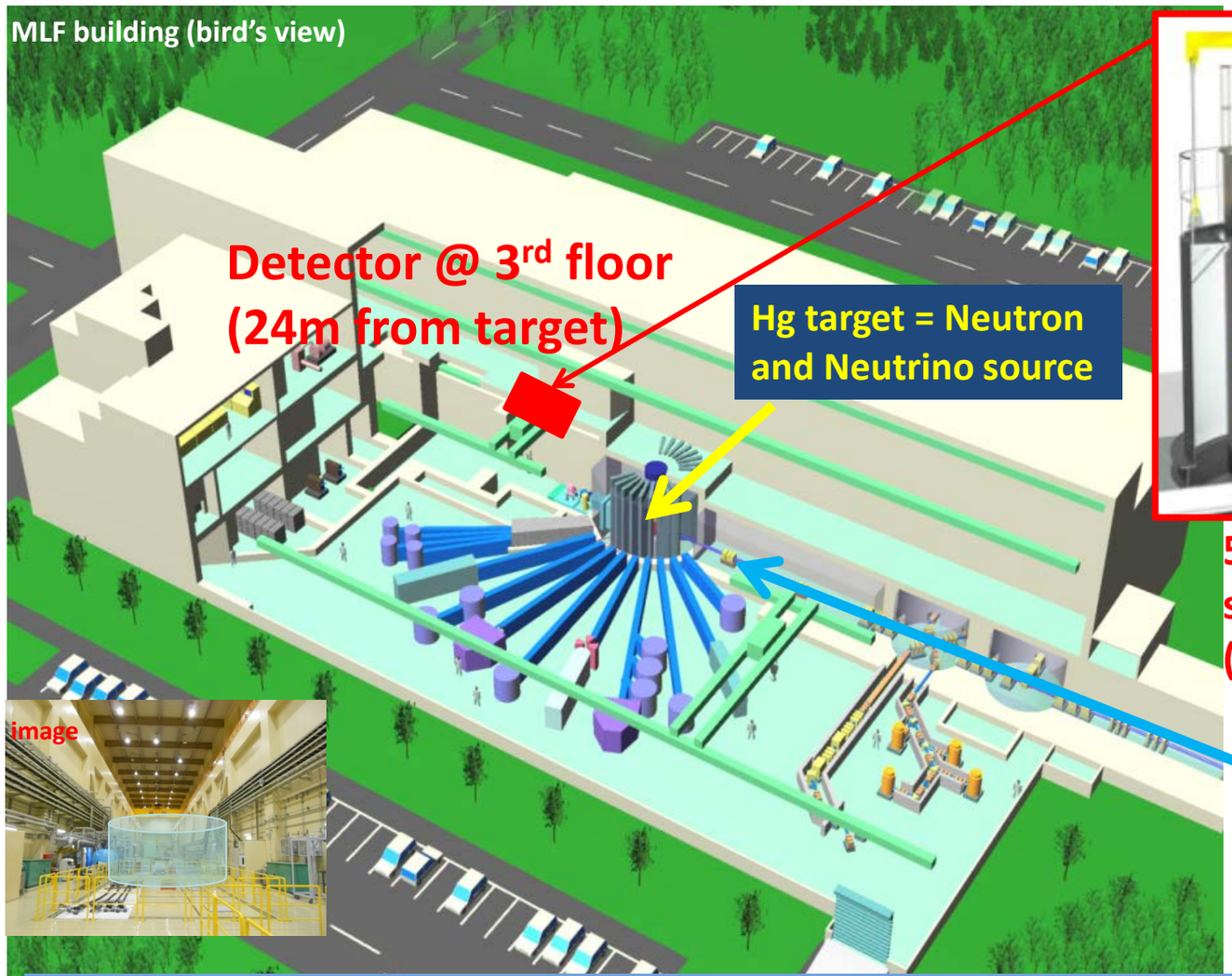


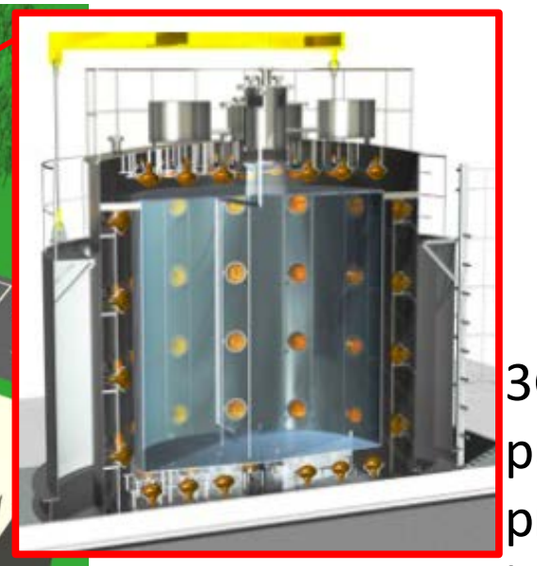
Status of SBN -> ICARUS

- Detector refurbishment is underway (complete early 2107)
- Installation at FNAL in 2017
- Commissioning and operations 2018

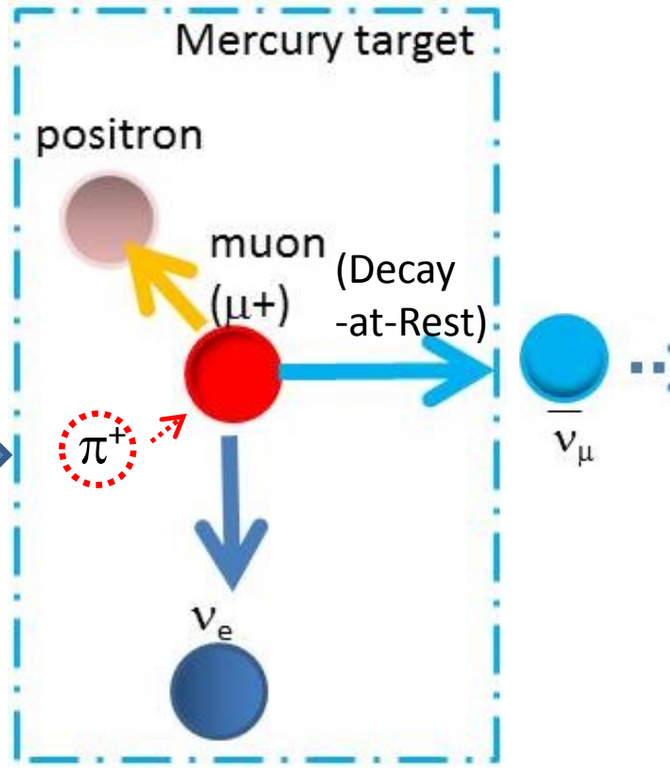


JSNS^2 (J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source)





3GeV pulsed proton beam



Searching for neutrino oscillation : $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ with baseline of 24m.
no new beamline, no new buildings are needed → quick start-up

7

T.Maruyama, ICHEP 2016

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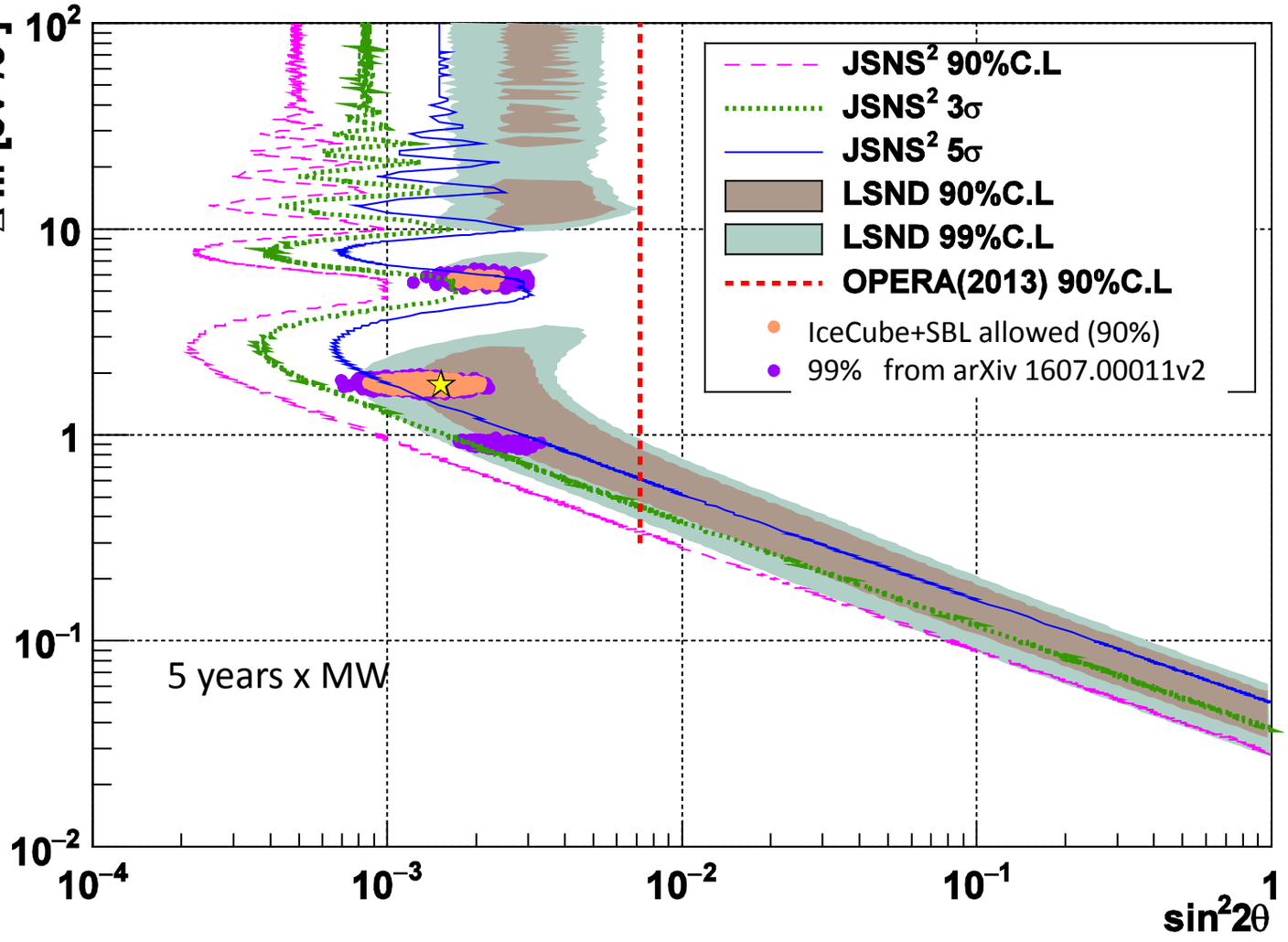


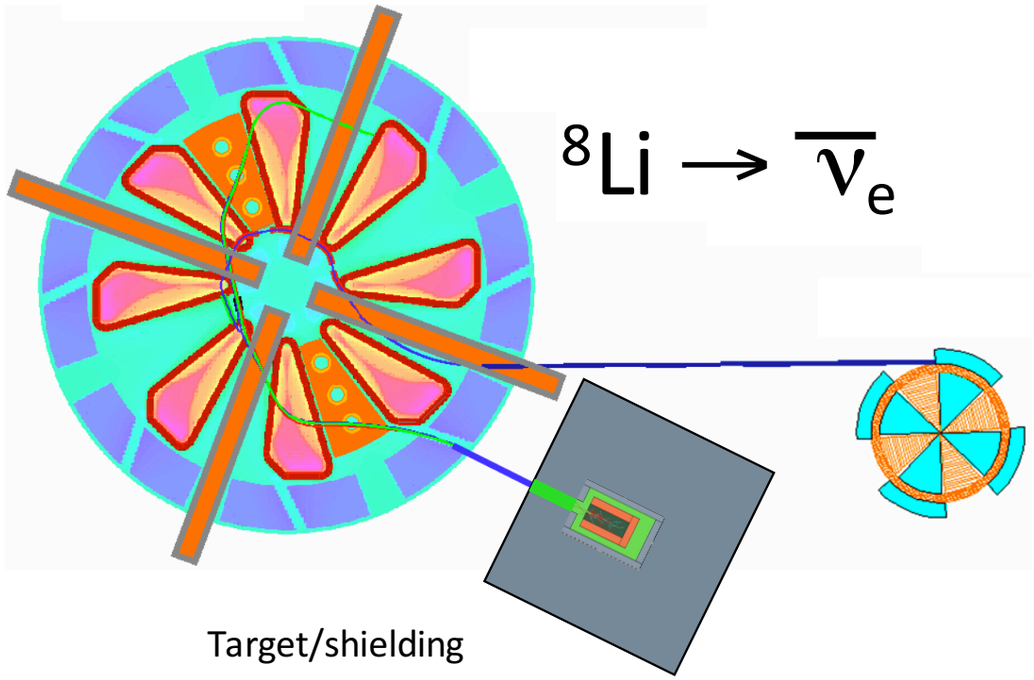
- Received Stage-1 approval from KEK and J-PARC directorates in March 2015
- Recently received funding to build first of two detector modules
- JSNS^2 expects to take data in 2018-2019

Direct test of LSND!

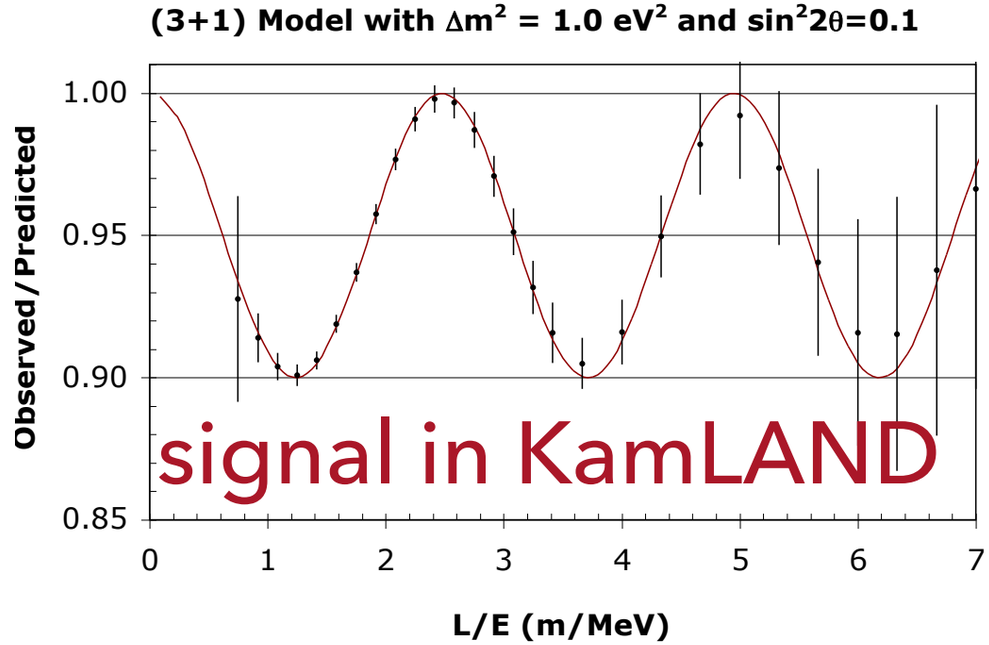
T.Maruyama, ICHEP 2016

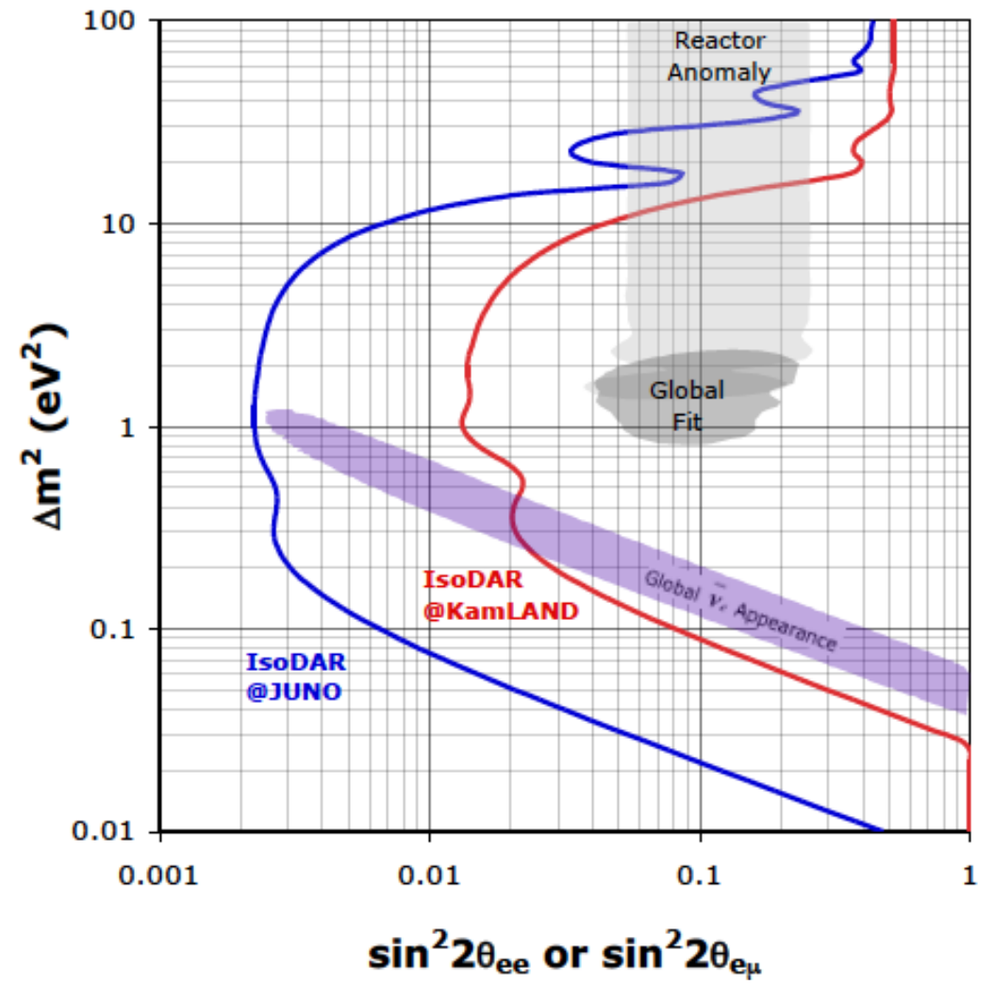
Decay-at-rest options (IsoDAR)

- IsoDAR -> Using cyclotron to produce isotope ^{8}Li that will decay at rest



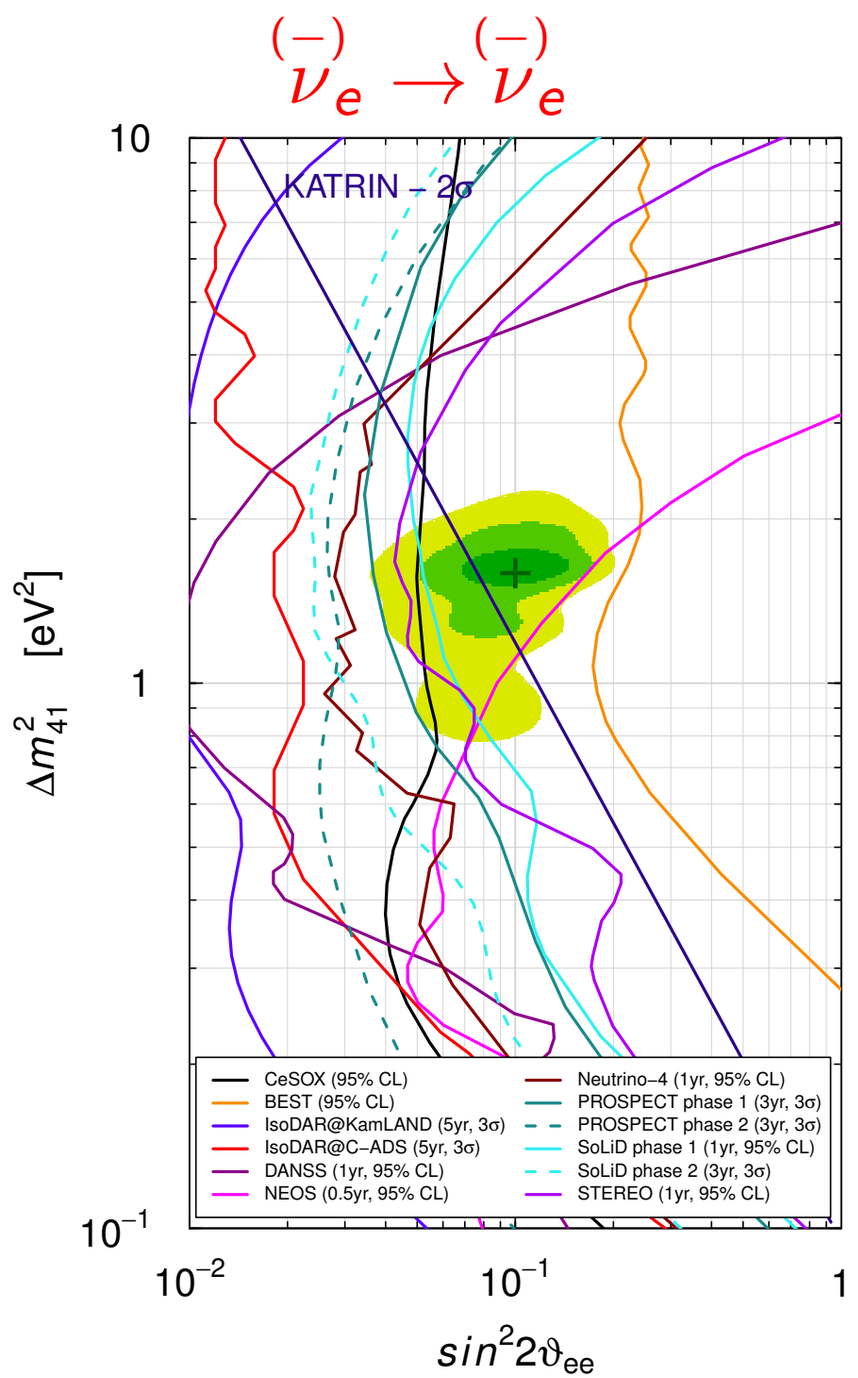
J. Alonso talk

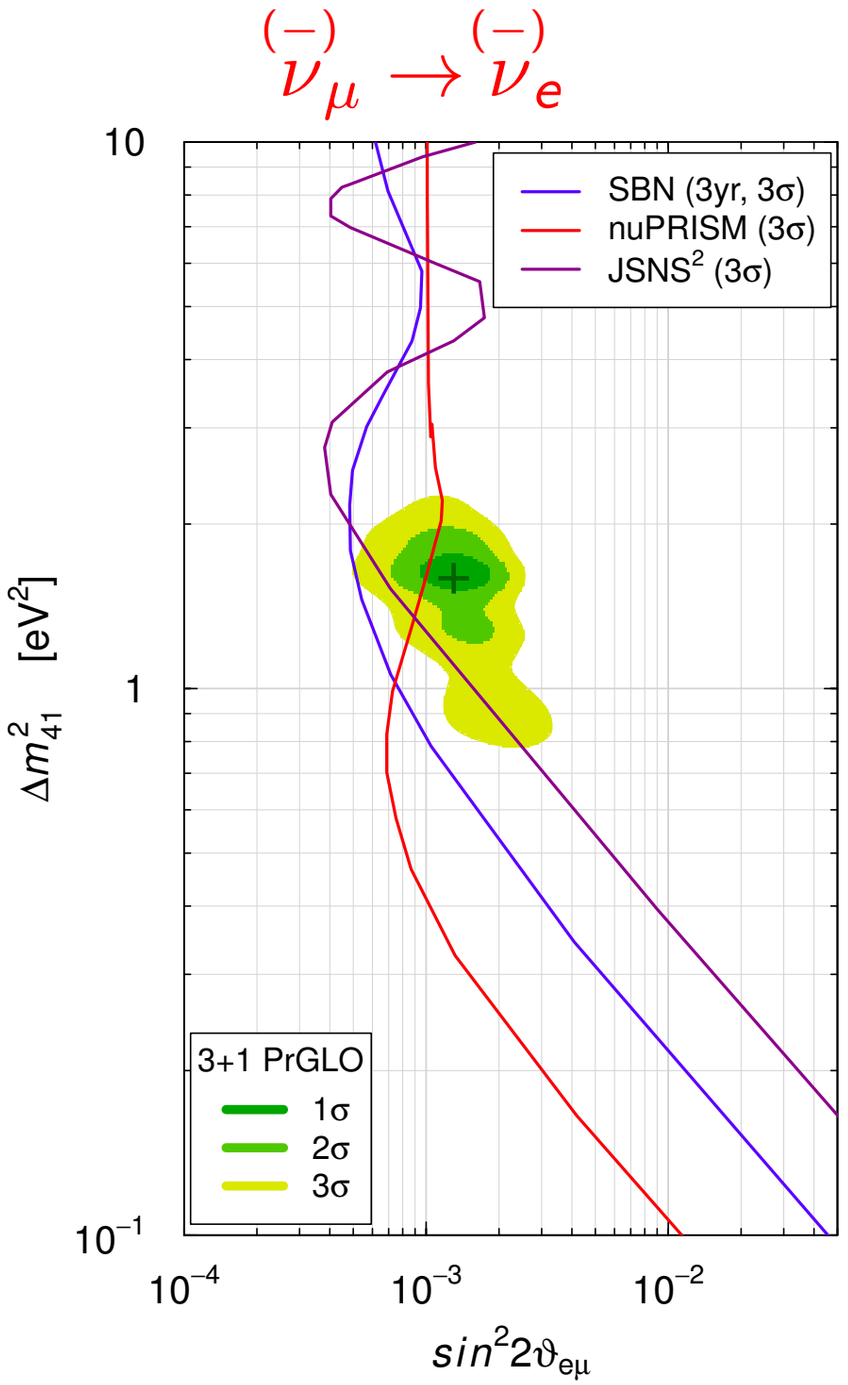


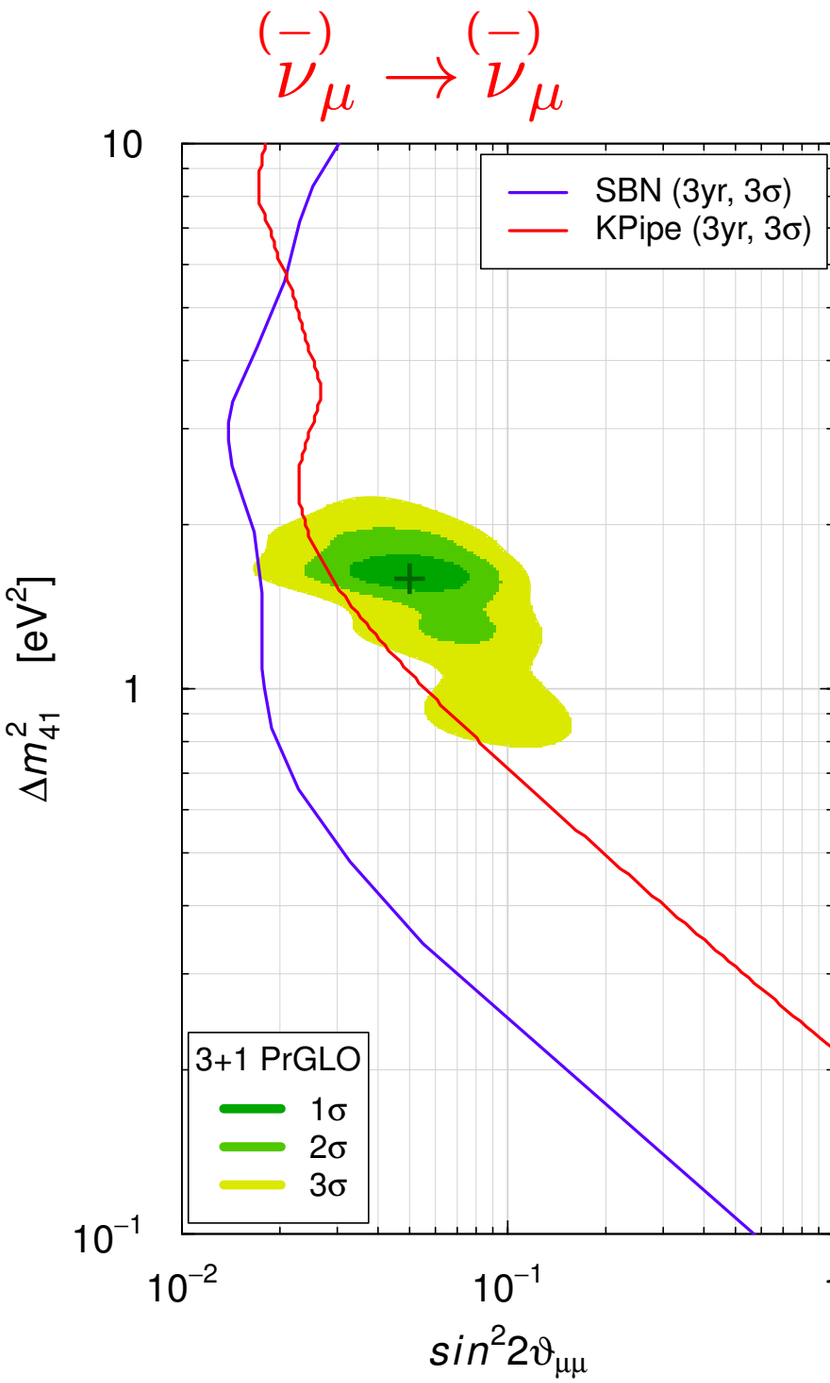


T.Wongirad, Neutrino 2016

Summary


$\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e$
KATRIN – 2σ
CeSOX (95% CL)
BEST (95% CL)
IsoDAR@KamLAND (5yr, 3σ)
IsoDAR@C–ADS (5yr, 3σ)
DANSS (1yr, 95% CL)
NEOS (0.5yr, 95% CL)
Neutrino–4 (1yr, 95% CL)
PROSPECT phase 1 (3yr, 3σ)
PROSPECT phase 2 (3yr, 3σ)
SoLiD phase 1 (1yr, 95% CL)
SoLiD phase 2 (3yr, 3σ)
STEREO (1yr, 95% CL)
Δm^2_{41} [eV^2]
$sin^2 2\vartheta_{ee}$


$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$
SBN (3yr, 3σ)
nuPRISM (3σ)
JSNS^2 (3σ)
3+1 PrGLO
1σ
2σ
3σ
Δm^2_{41} [eV^2]
$sin^2 2\vartheta_{e\mu}$

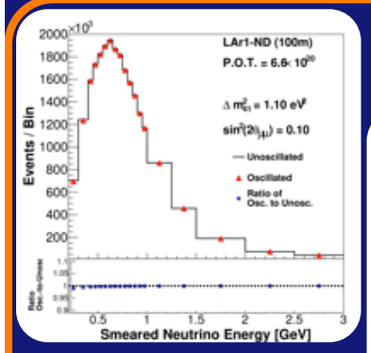

$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$
SBN (3yr, 3σ)
KPipe (3yr, 3σ)
3+1 PrGLO
1σ
2σ
3σ
Δm^2_{41} [eV^2]
$sin^2 2\vartheta_{\mu\mu}$

Conclusion

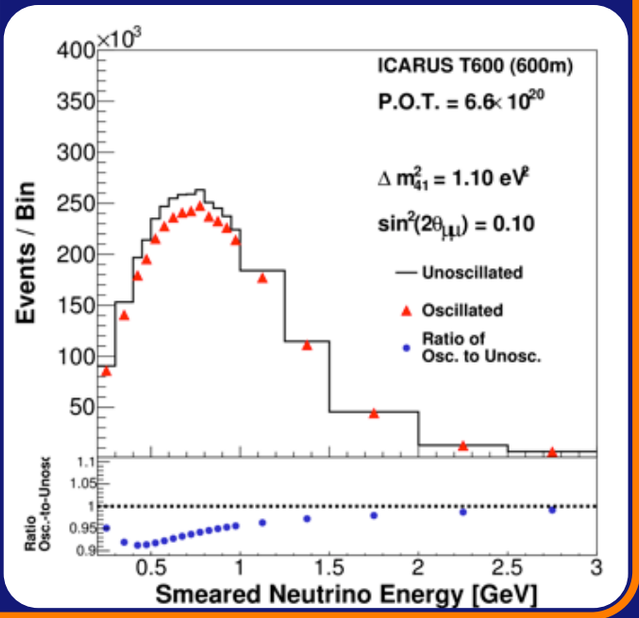
- Several anomalies in neutrino experiments (all ~3σ)
- No clear coherence in the results (a lot of tension)
- Need to test the anomalies directly
- Understanding these anomalies is crucial for the future LBL experiments in order to properly interpret CP-violation and MH measurements
- Some approved experiments will help (*e.g.* SBN), but we are cutting it fine!
- The next years will be critical for sterile neutrino searches, stay tuned!

SBN programme at Fermilab (disappearance)

$\Delta m^2 = 1.1$ eV^2

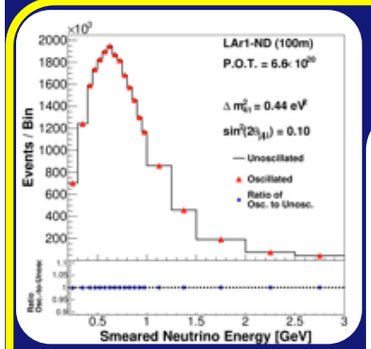


Near Det

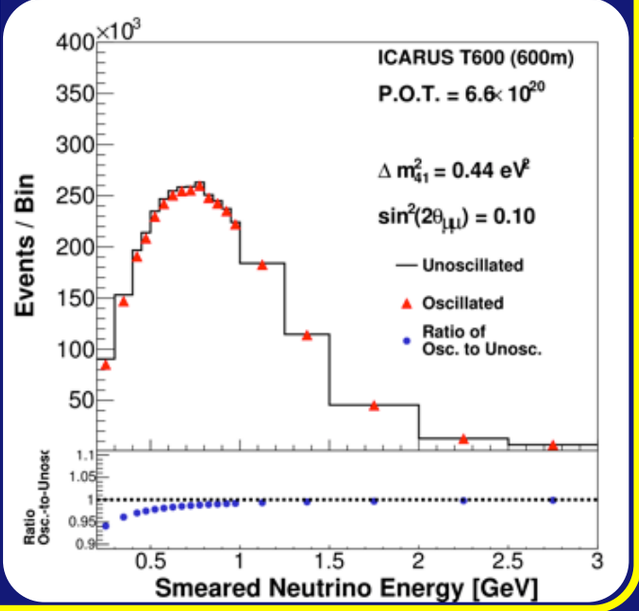


Far Det

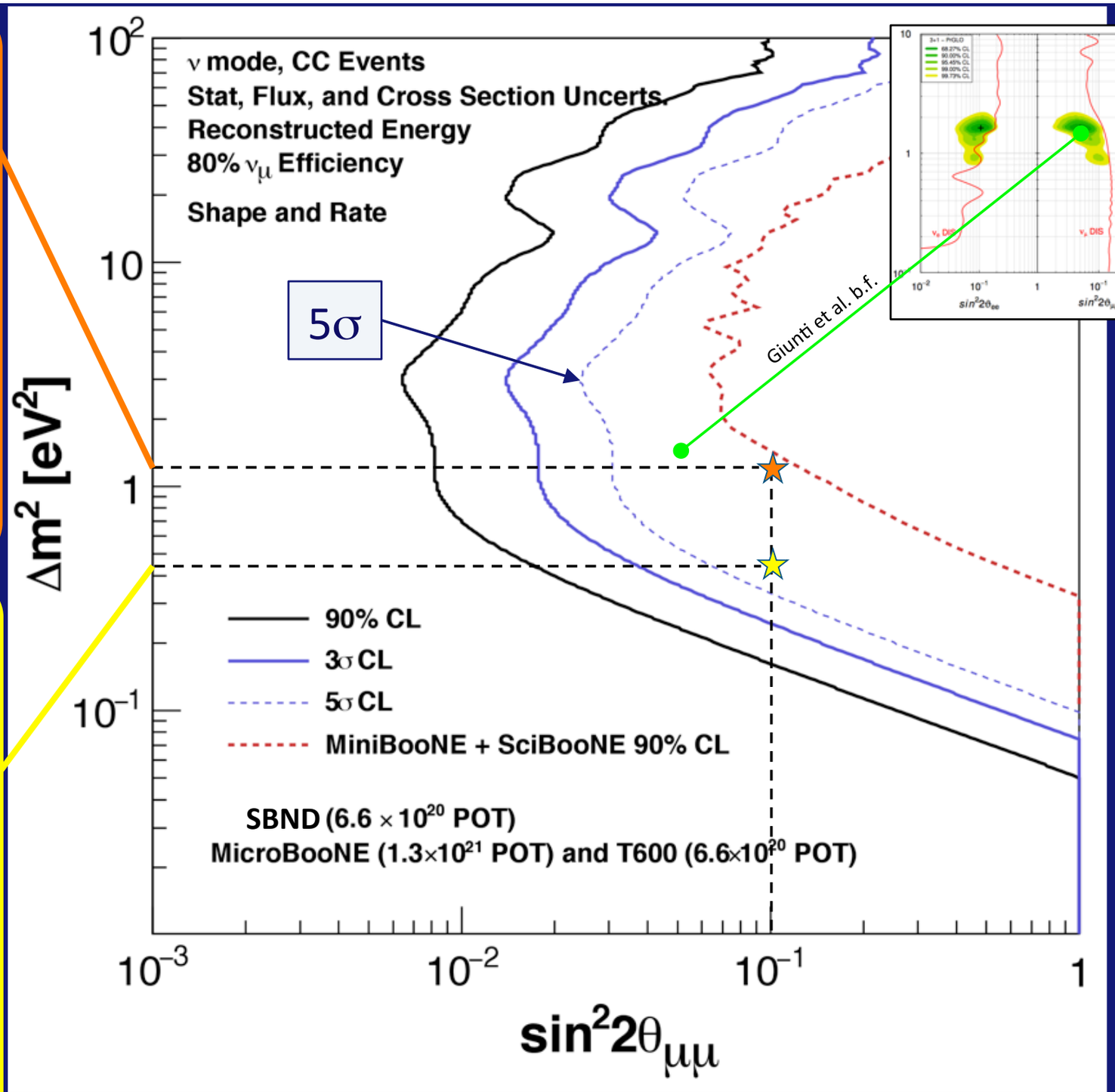
$\Delta m^2 = 0.44$ eV^2



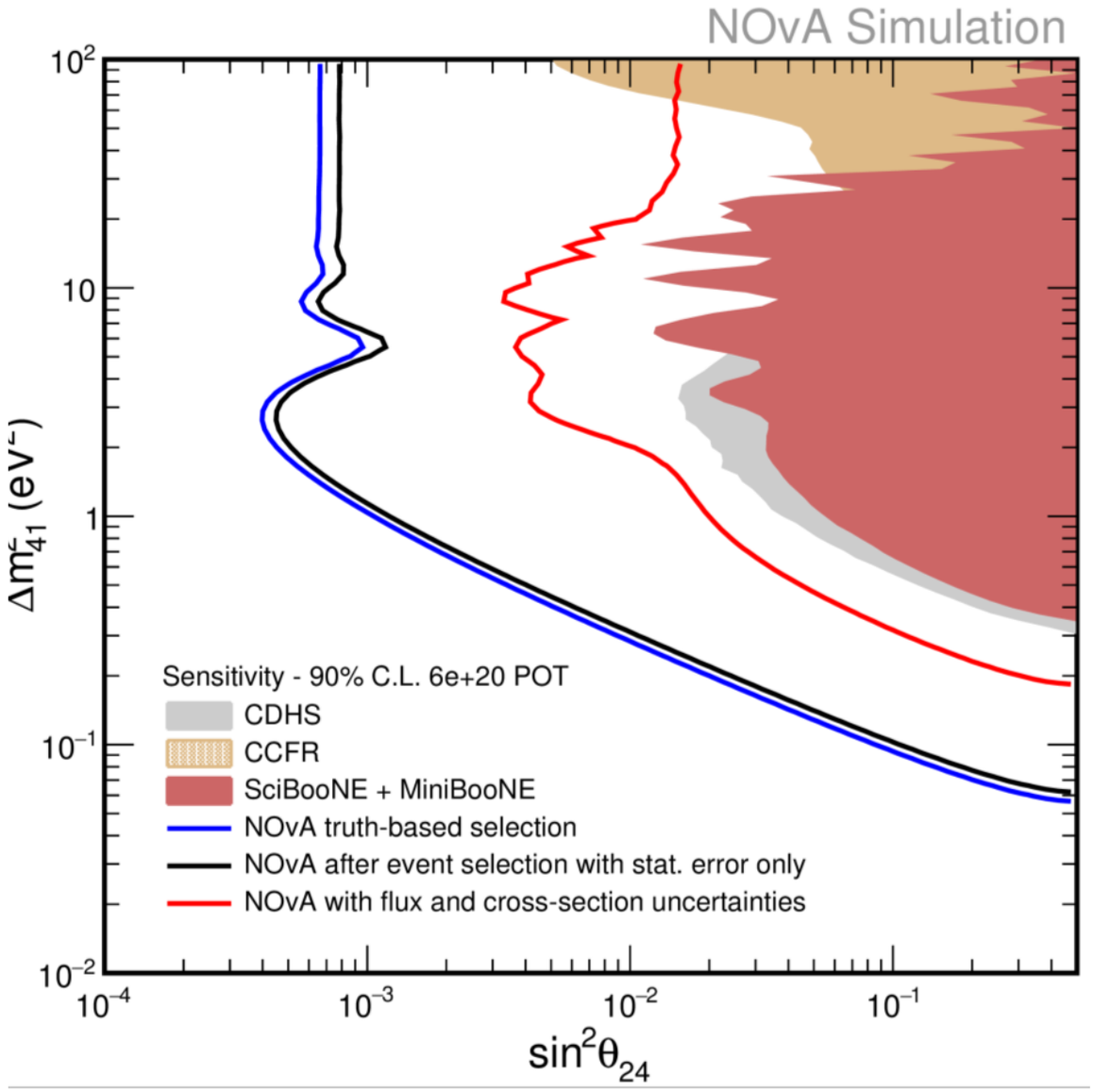
Near Det

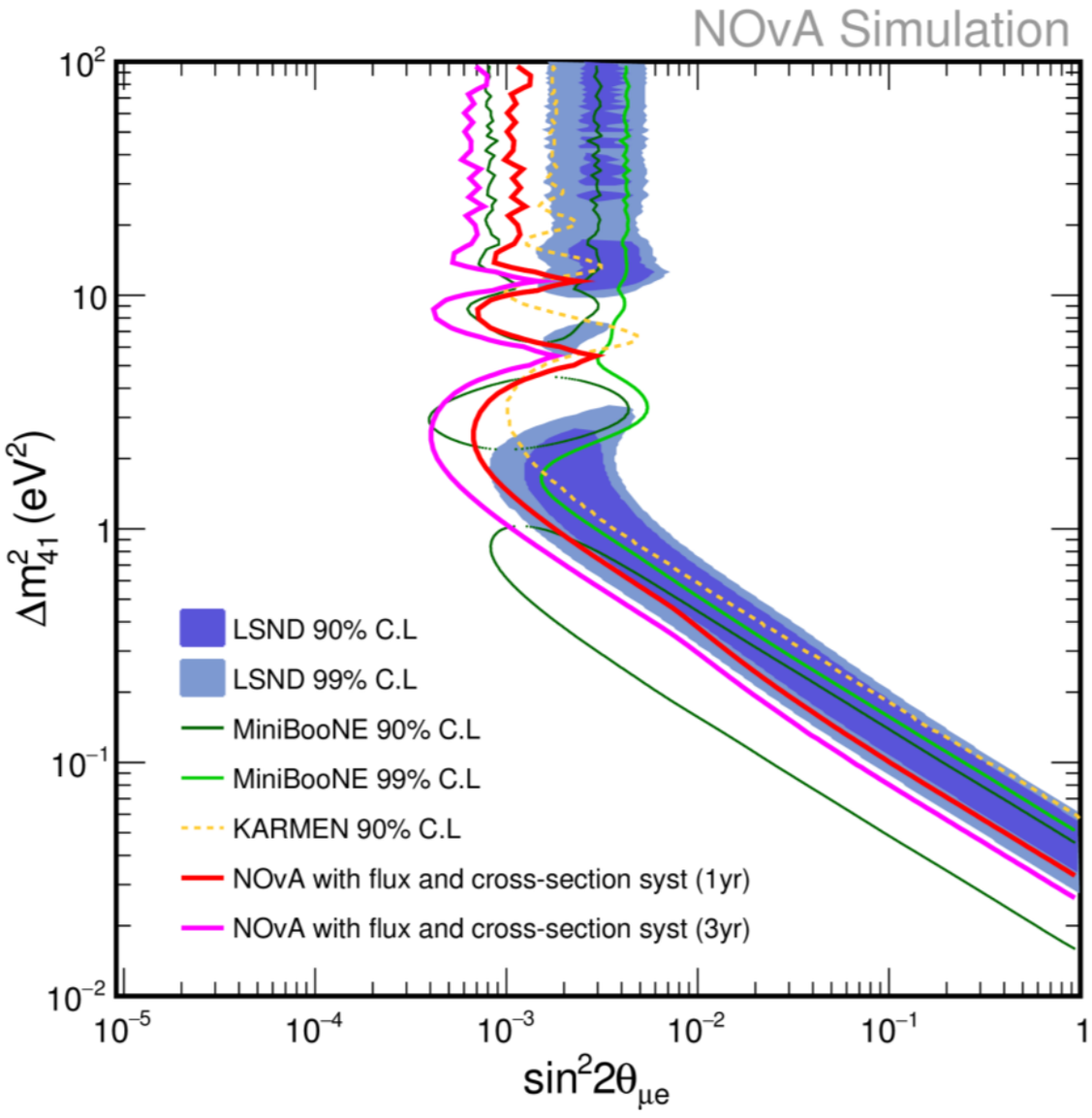


Far Det



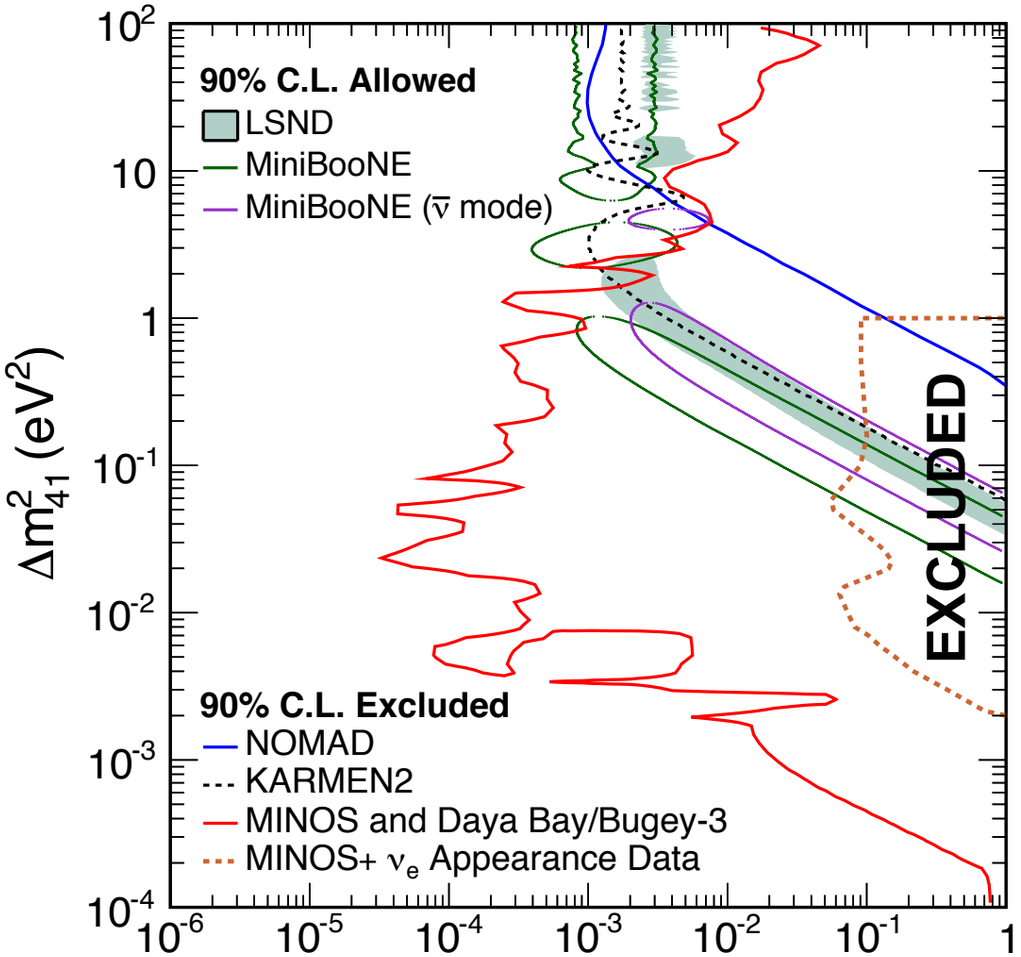
Nova





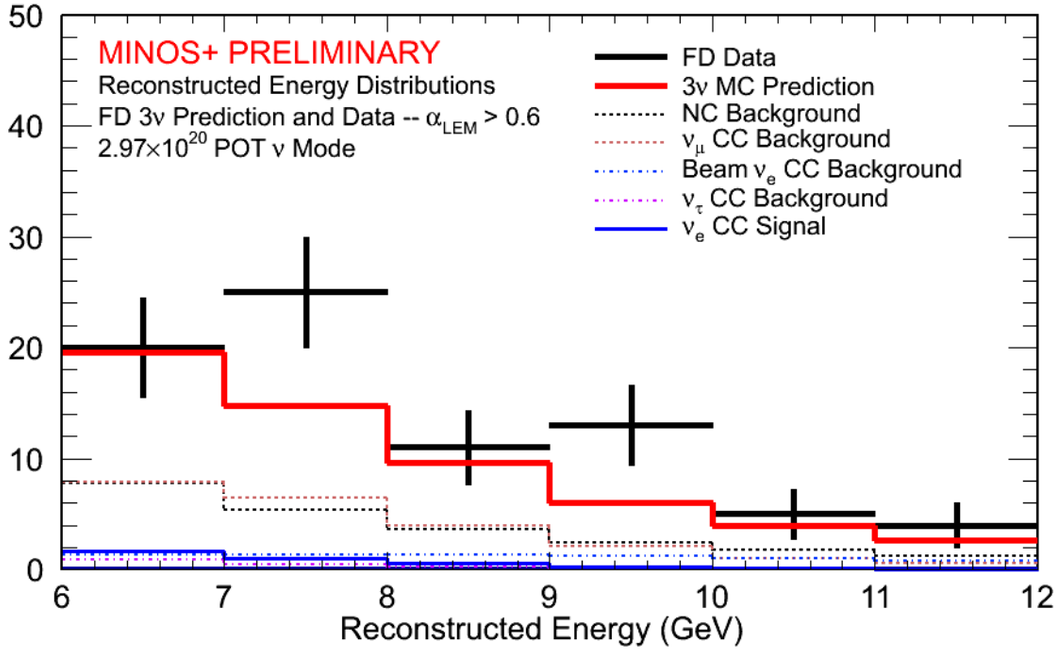
G. S. Davies, Joint Exp. Theo. Phys. Seminar, FNAL, 2016

Minos+

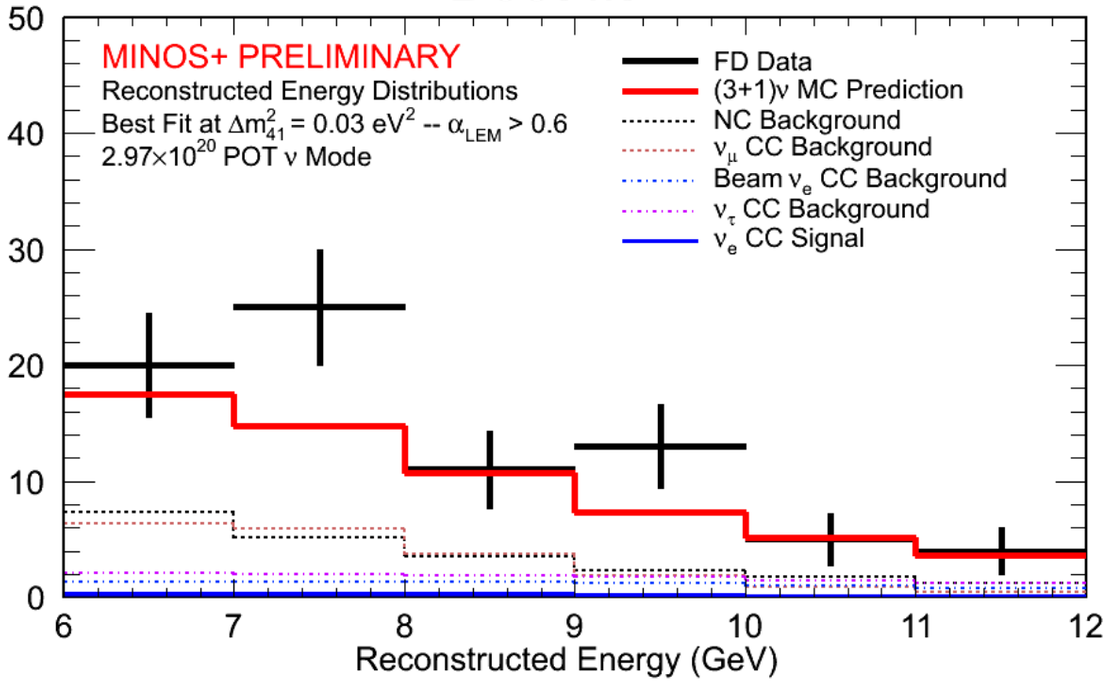


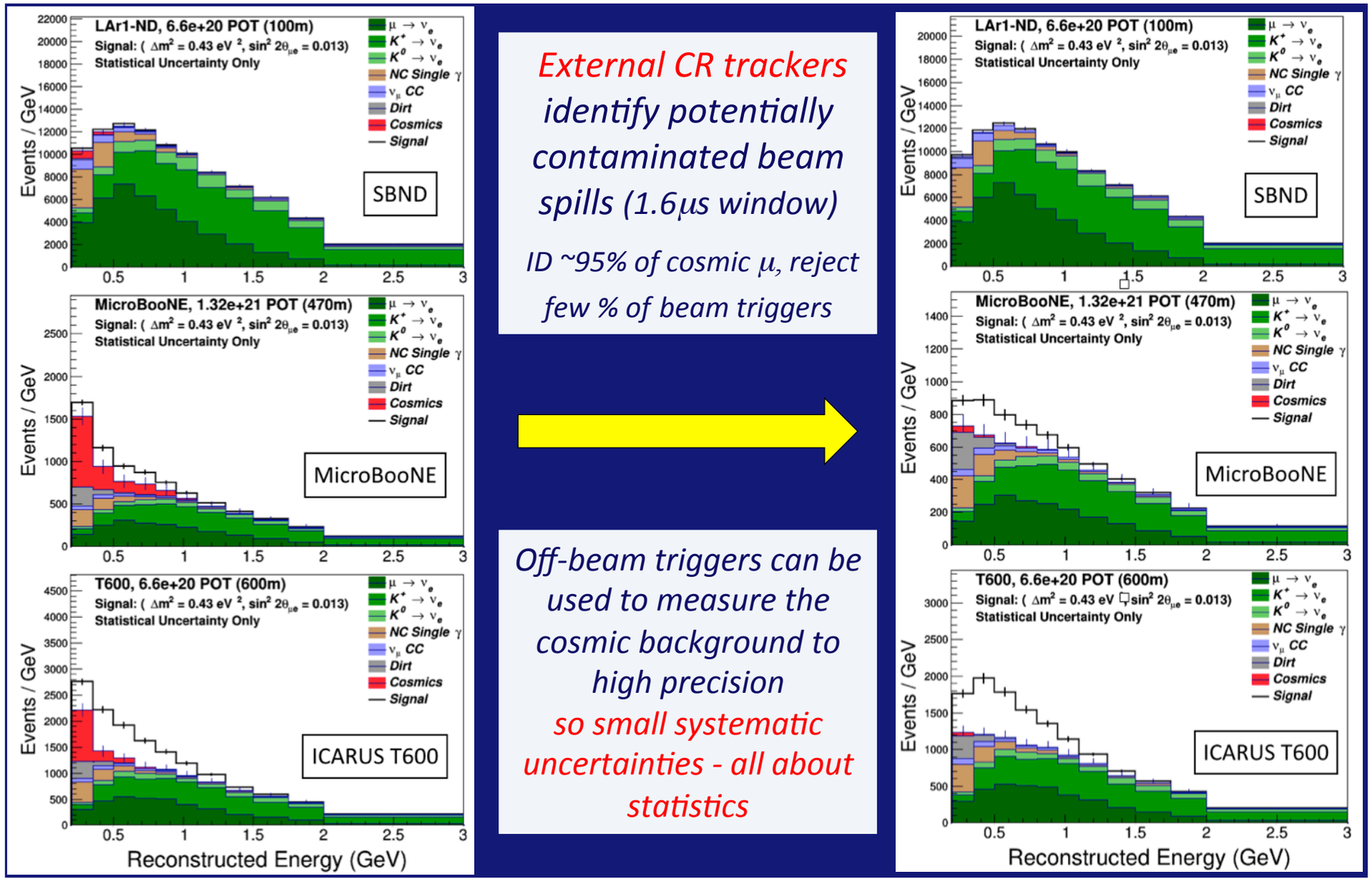
$\sin^2 2\theta_{\mu e} = 4|U_{e4}|^2|U_{\mu 4}|^2$

Three-neutrino hypothesis

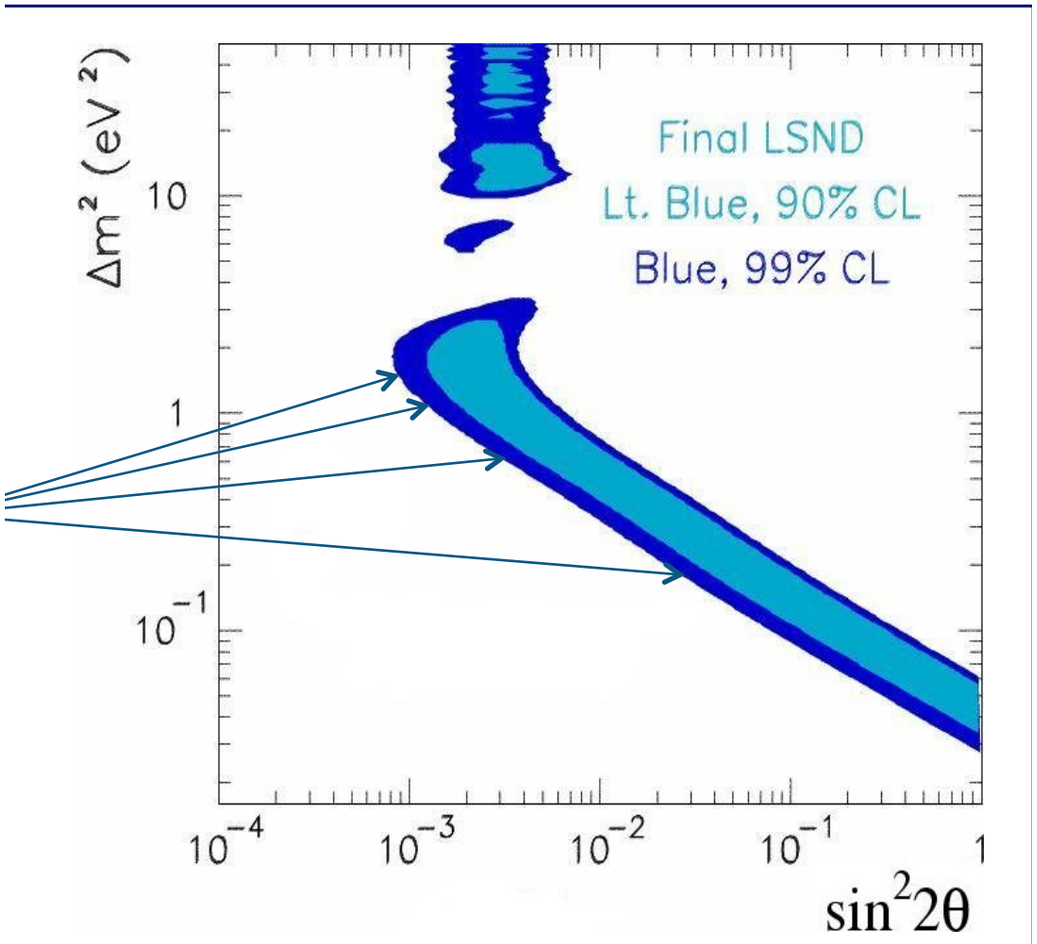


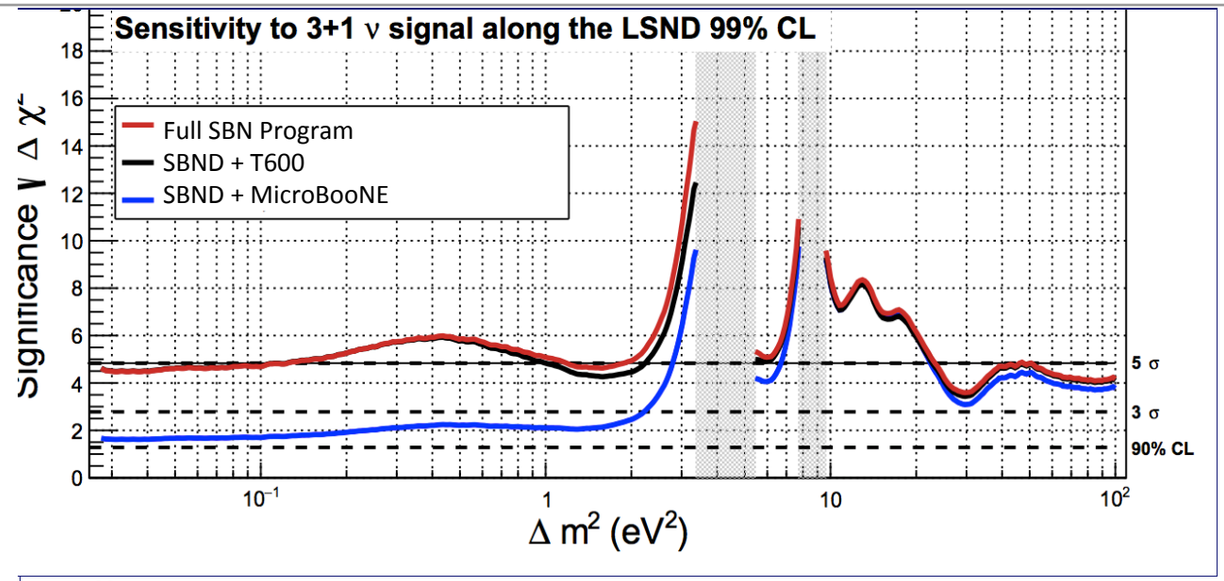
Best fit

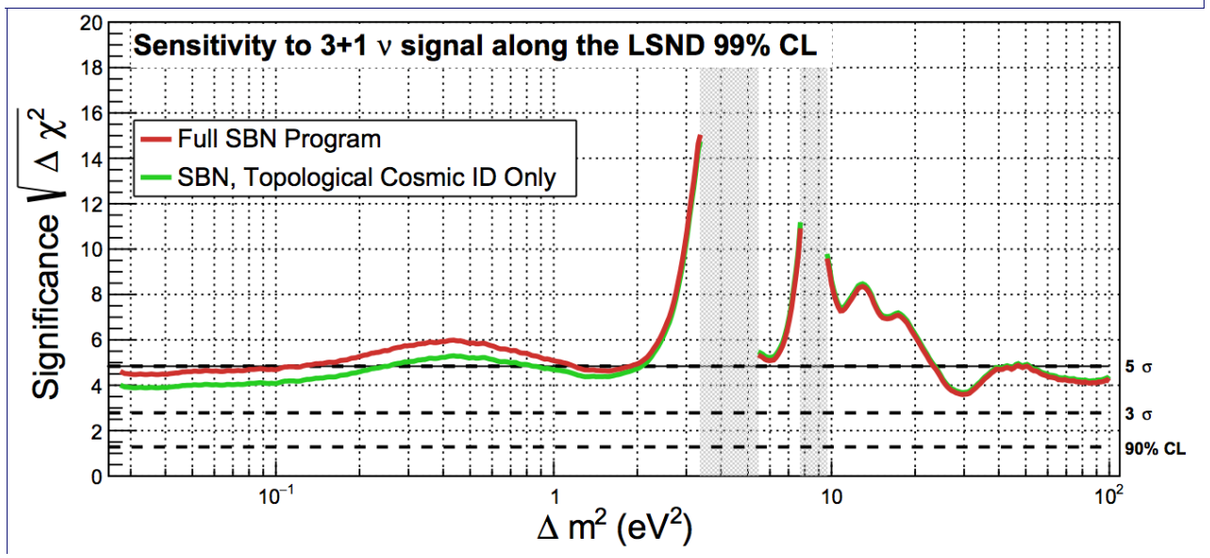


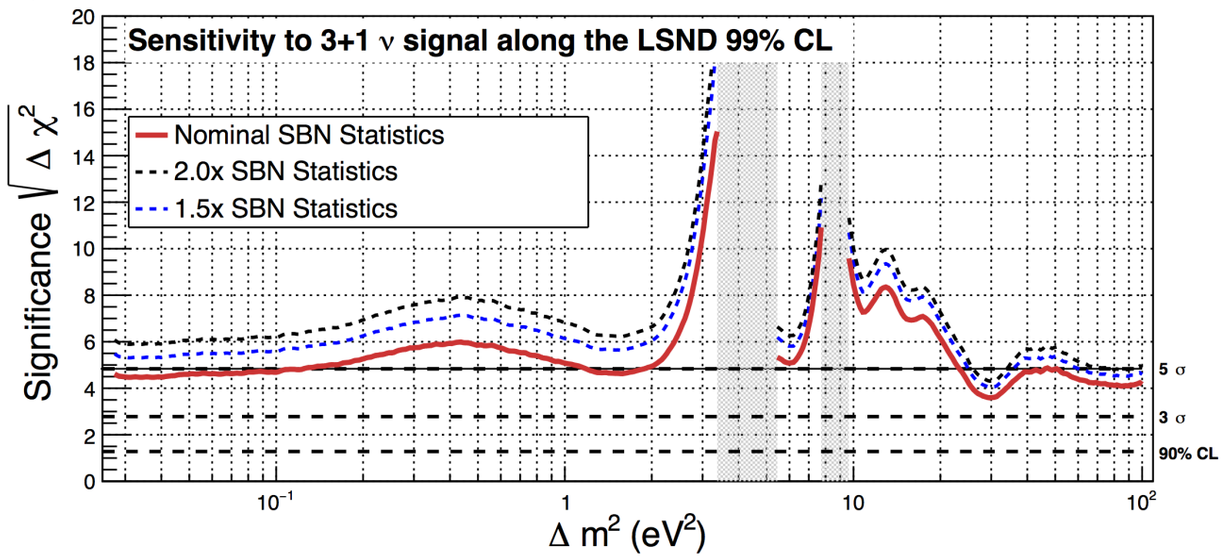

LAr1-ND, 6.6e+20 POT (100m)
Signal: (Δm² = 0.43 eV², sin² 2θμe = 0.013)
Statistical Uncertainty Only
SBND
MicroBooNE, 1.32e+21 POT (470m)
MicroBooNE
T600, 6.6e+20 POT (600m)
ICARUS T600
Events / GeV
Reconstructed Energy (GeV)
μ → νe
K+ → νe
K0 → νe
NC Single γ
νμ CC
Dirt
Cosmics
Signal
External CR trackers identify potentially contaminated beam spills (1.6μs window)
ID ~95% of cosmic μ, reject few % of beam triggers
Off-beam triggers can be used to measure the cosmic background to high precision
so small systematic uncertainties - all about statistics

SBN programme at Fermilab

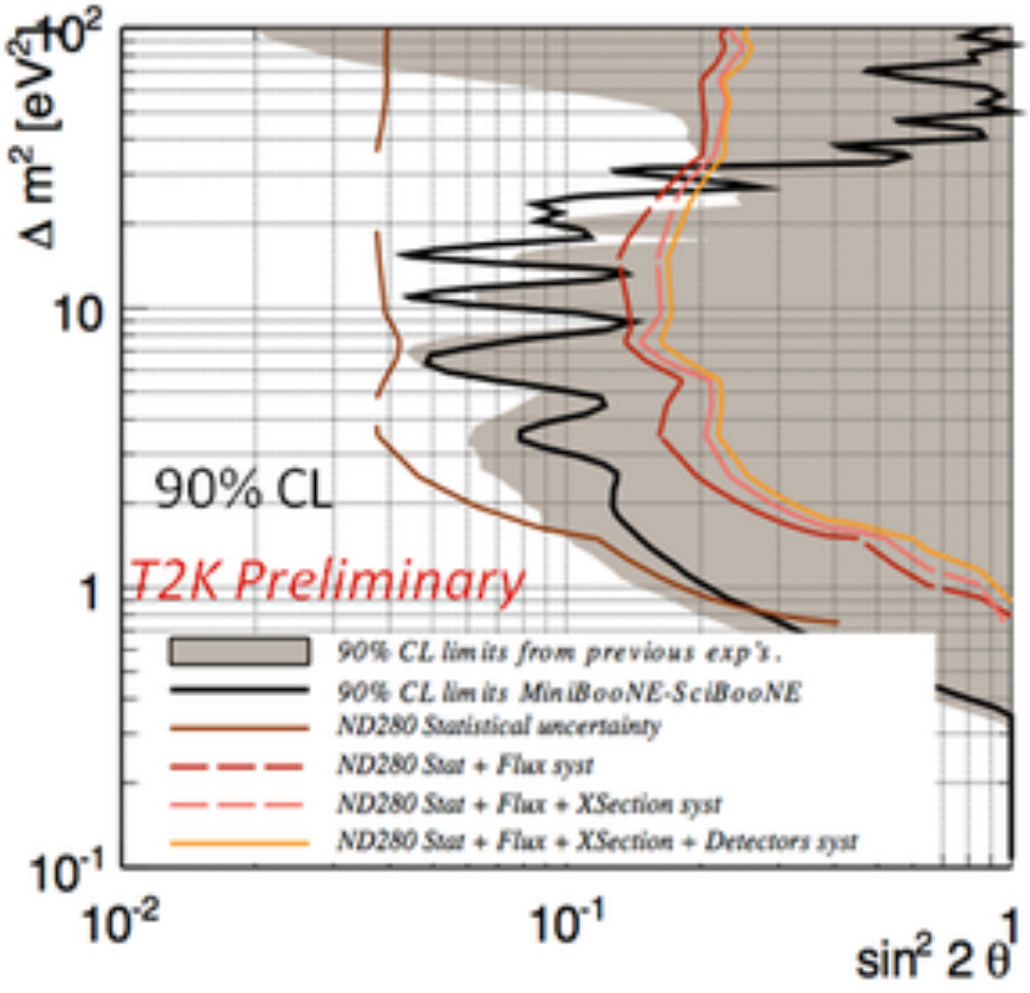


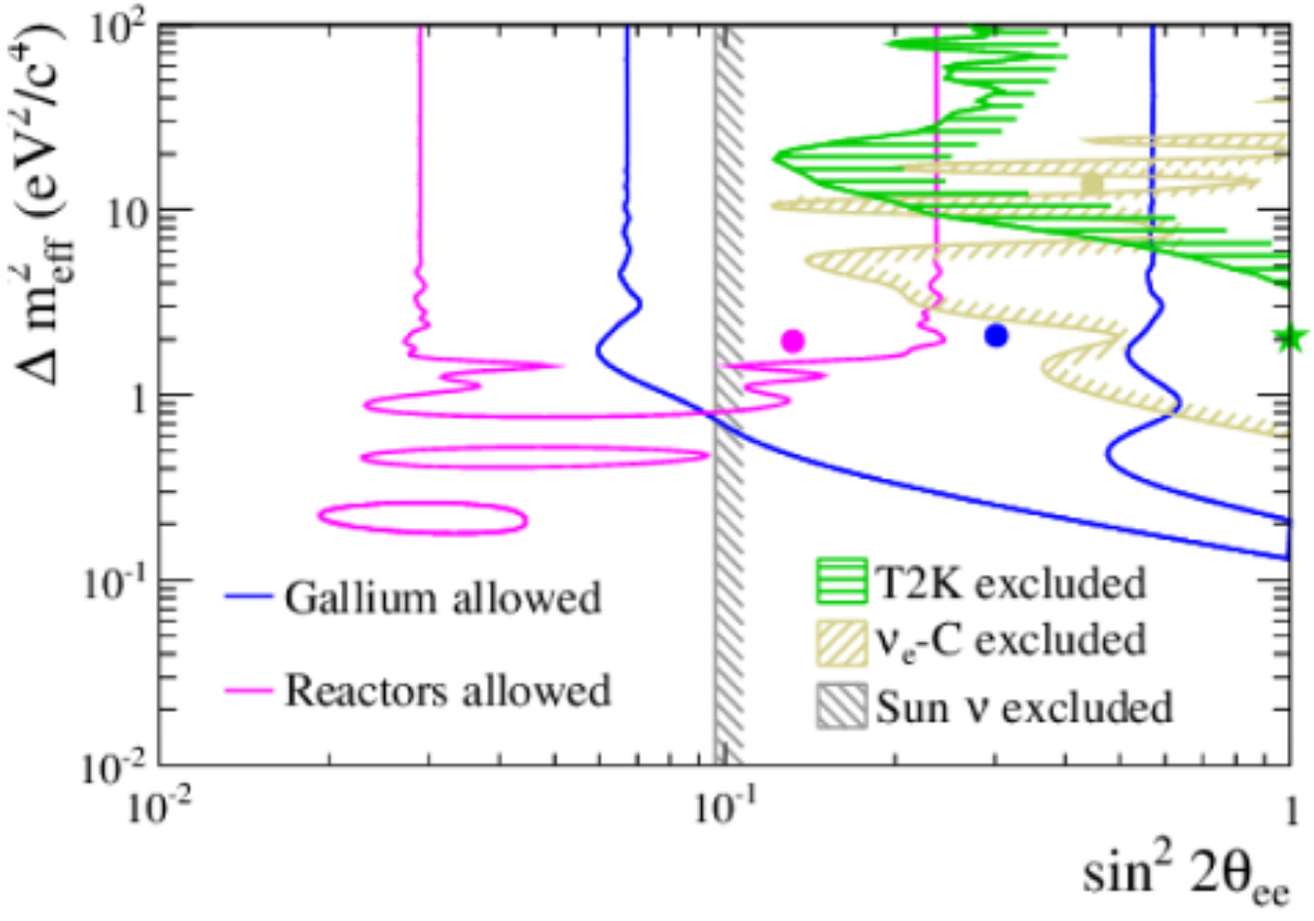






T2K


90% CL
T2K Preliminary
90% CL limits from previous exp's.
90% CL limits MiniBooNE-SciBooNE
ND280 Statistical uncertainty
ND280 Stat + Flux syst
ND280 Stat + Flux + XSection syst
ND280 Stat + Flux + XSection + Detectors syst
Δ m² [eV²]
sin² 2 θ


Gallium allowed
Reactors allowed
T2K excluded
ν_e-C excluded
Sun ν excluded
Δm^2_{eff} (eV²/c⁴)
$\sin^2 2\theta_{ee}$