Luca Stanco,
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Steriles at Long- and Short- Baseline

(with accelerators)

- The **NEUTRINO** scenario and the "sterile" issue at 1 eV mass scale
- LBL, results for $\nu_\mu \rightarrow \nu_\tau$, ν_e appearances and $\nu_\mu \rightarrow \nu_\mu$ disappearance (OPERA, MINOS)
- SBL, is there any chance with accelerators ?
  (T2K, SBN and missing NESSiE)
- Perspectives and Conclusions

High Sensitivity Experiments Beyond the Standard Model

Quy Nhon, Vietnam, July 31 – August 7, 2016

The present neutrino scenario

From masses to flavours:

$$|\nu_e\rangle = U_{e1}|\nu_1\rangle + U_{e2}|\nu_2\rangle + U_{e3}|\nu_3\rangle$$

$$|\nu_\mu\rangle = U_{\mu 1}|\nu_1\rangle + U_{\mu 2}|\nu_2\rangle + U_{e\mu 3}|\nu_3\rangle$$

$$|\nu_\tau\rangle = U_{\tau 1}|\nu_1\rangle + U_{\tau 2}|\nu_2\rangle + U_{\tau 3}|\nu_3\rangle$$

U is the 3 × 3 Neutrino Mixing Matrix,

mixing given by 3 angles, θ_{23}, θ_{12}, θ_{13} and one phase δ (CPV for $\delta \neq 0, \pi$).

Oscillations have *amplitudes* driven by the mixing angles and *frequencies* by
$\delta m^2_{solar} = \Delta m^2_{21}$
$\Delta m^2_{atm} = |\Delta m^2_{31}| \approx |\Delta m^2_{32}|$
(with L, E experimental parameters)

E.g. if only two flavours are taken, at leading order, neglecting interference terms, and with some approxs:

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta_{\alpha\beta} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right)$$

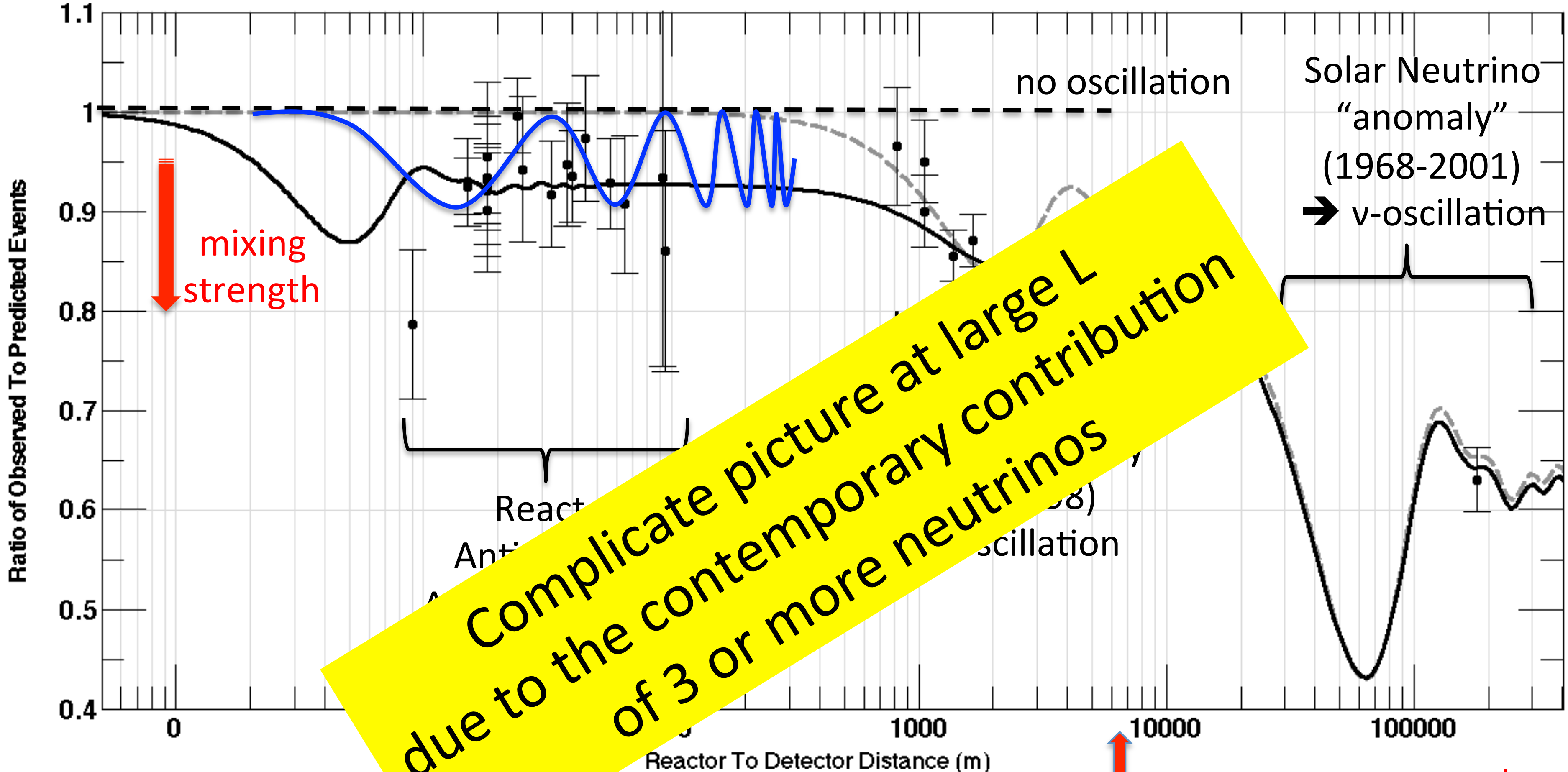
APPEARANCE

$$P(\nu_\alpha \rightarrow \nu_\alpha) = 1 - \sin^2 2\theta_{\alpha\alpha} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right)$$

DISAPPEARANCE

amplitude   frequency

The oscillation scenario in terms of distance **L** from the (***reactor***) source



At first order
phase given by $\Delta m^2 L/E$

Long-Baseline
exps with ν_μ-beams
(OPERA, MINOS, NOνA, „T2K")

➔for L/E >>1 the disappearance averages to ½ of mixing strength: $\sin^2(\Delta m^2 L/4E)=0.5$

The recent Neutrino History

1998

1rst Annus Mirabilis

Oscillations :
- Observation by *SuperK*
- Reactor exclusion by *Chooz*

2002

2nd A. M.

3 x 3 matrix :
- Solar by *SNO*
- Reactor by *KAMLAND*

2012

3rd A. M.

θ_{13}:
- Reactor by *Daya Bay*, *RENO, Double Chooz, T2K*…

2017 ?

4th A. M. ?

- Mass Hierachy by *NOvA* ?
- CPV by *T2K* ?

≥ 2020 ?

δ_{CP} ?

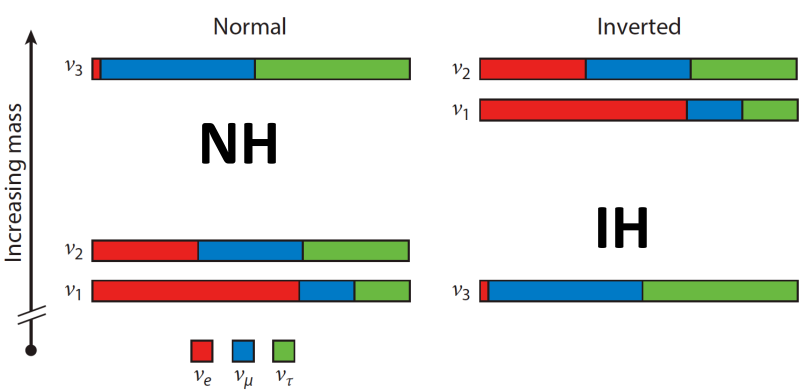
– δ_{CP} by *T2K* ?

L. S., Rev. in Phys. 1 (2016) 90

The wonderful frame pinpointed for the **3 standard neutrinos**, beautifully adjusted by the θ_{13} measurement, left out some relevant questions:

- Leptonic CP violation
- Mass of neutrinos
- Anomalies and discrepancies in some measurements
- Dark Matter

Mass Ordering



One or two states at higher mass ?

before really entering in the precision era, there are still 4 results to be obtained, at least at first order :

1) Leptonic CP violation
2) Mass ordering (MO)
3) (θ_{23} octet)
4) **Presence or not of sterile neutrinos at eV scale**

≥ 2018 ? —— **sterile ?**

L. S., S. Dusini and M. Tenti, arXiv:1606.09454

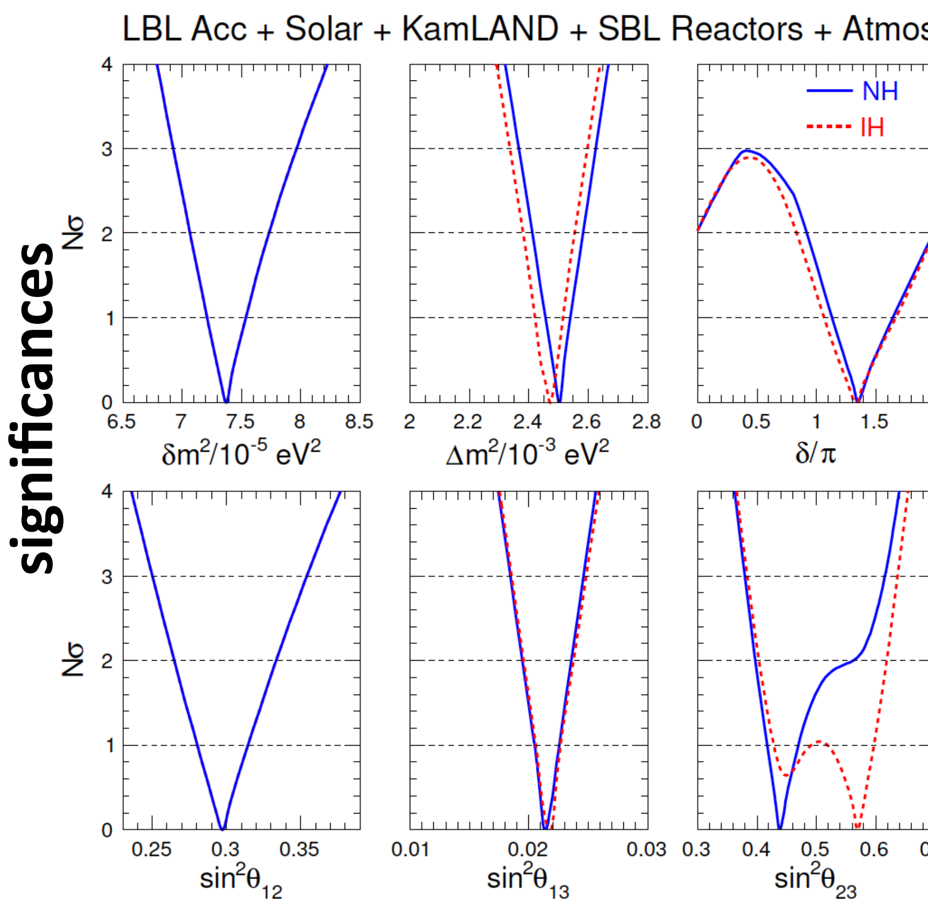
A.Palazzo: arXiv:1509.03148

These 4 items are interconnected,
They are ALL crucial for the near future !

L. S., Rev. in Phys. 1 (2016) 90

Present knowledge
(from Global Fits)

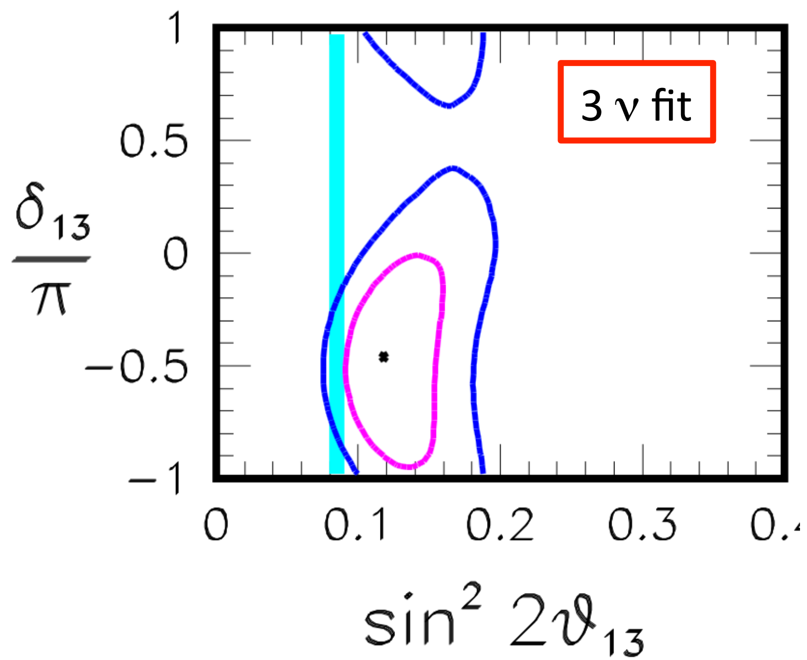
From few % to about 10%,
but with no knowledge
on MO



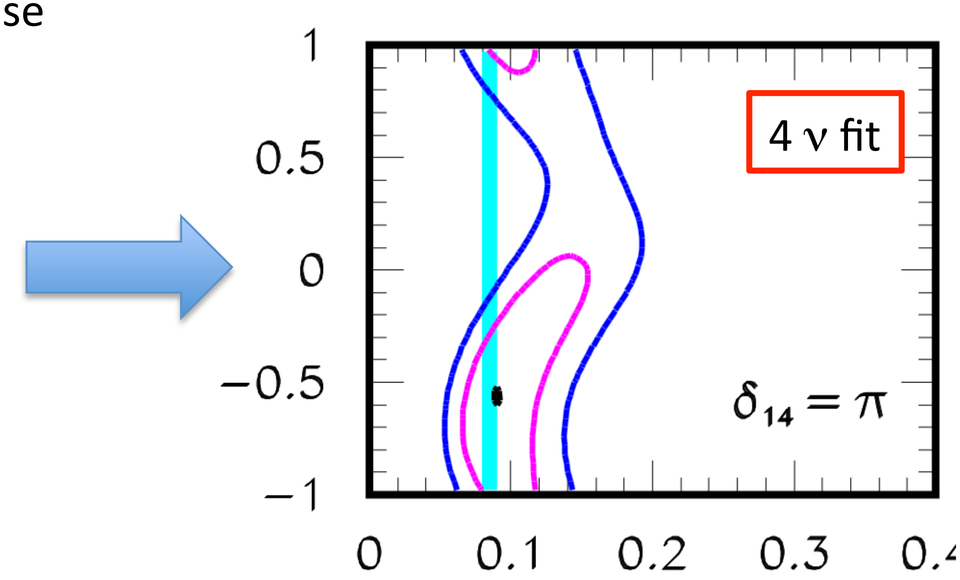
F. Capozzi et al., Nuclear Physics B 908 (2016) 218

How steriles at 1 eV mass scale may wash out results on MH and δ_{CP}

3 ν fit after NOvA and T2K 2015 release



A.Palazzo: arXiv:1509.03148



(**IH**, θ_{23} marginalized, 68% e 90% C.L.)

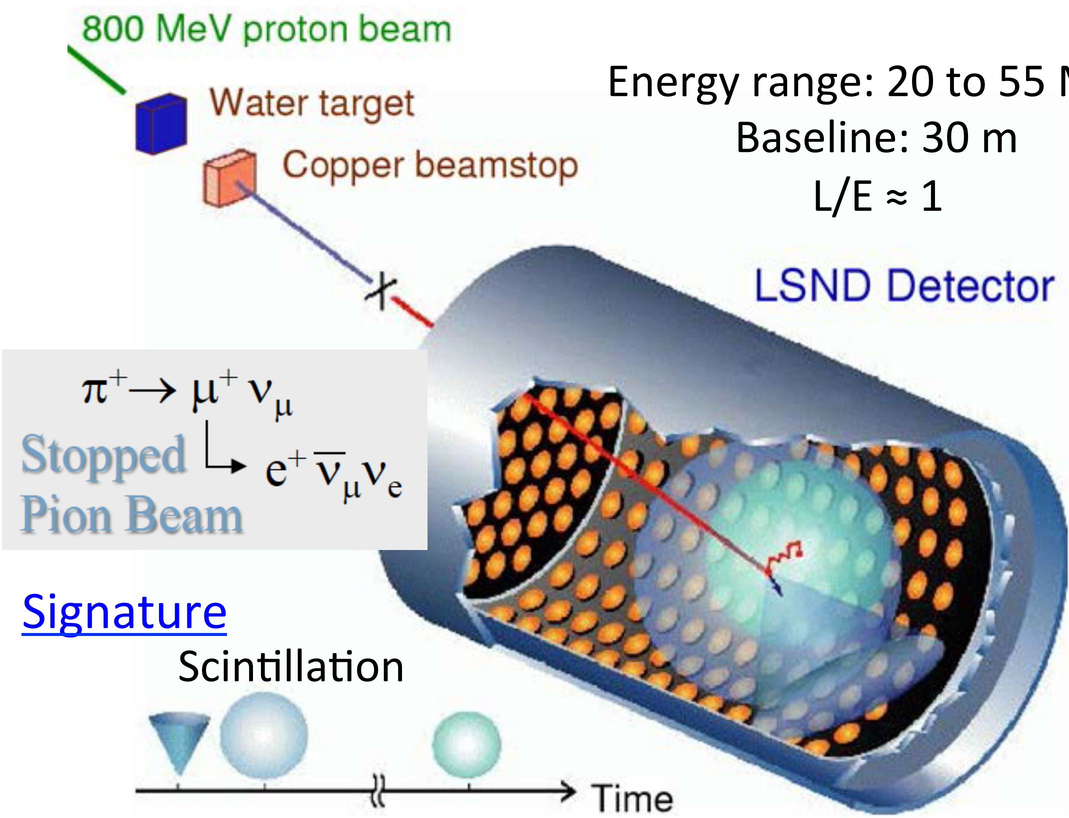
It is MANDATORY to close this SBL sterile story in the *<u>near</u>* future.

The "sterile" issue at eV mass scale

The LSND "story":

PRL 75 (1995) 2650, …, PRD 64 (2001) 112007

Energy range: 20 to 55 MeV
Baseline: 30 m
L/E ≈ 1

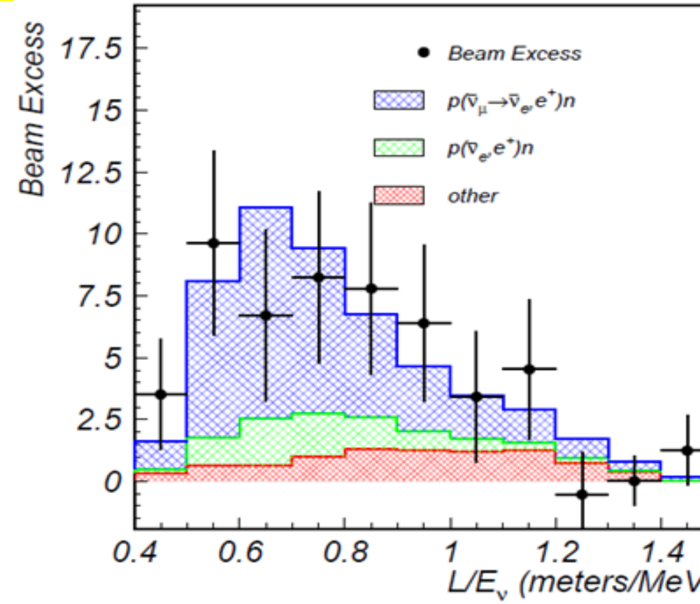


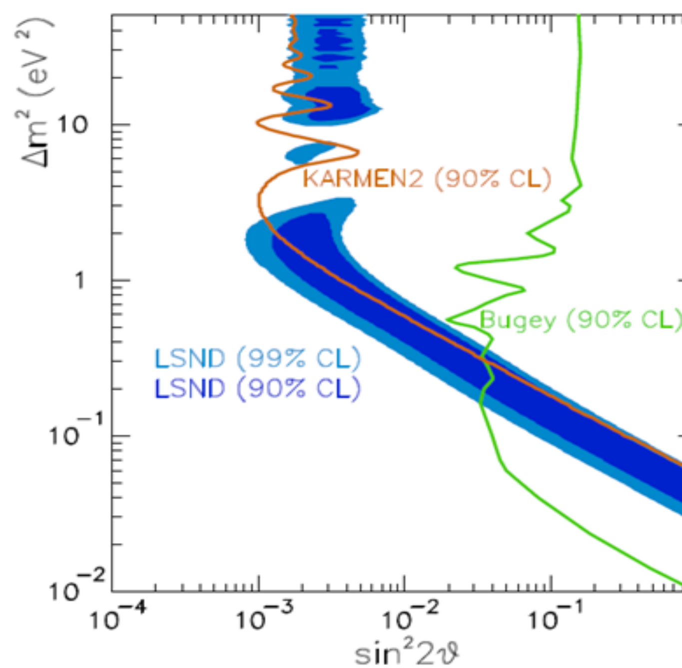
Signature

Scintillation

Cerenkov

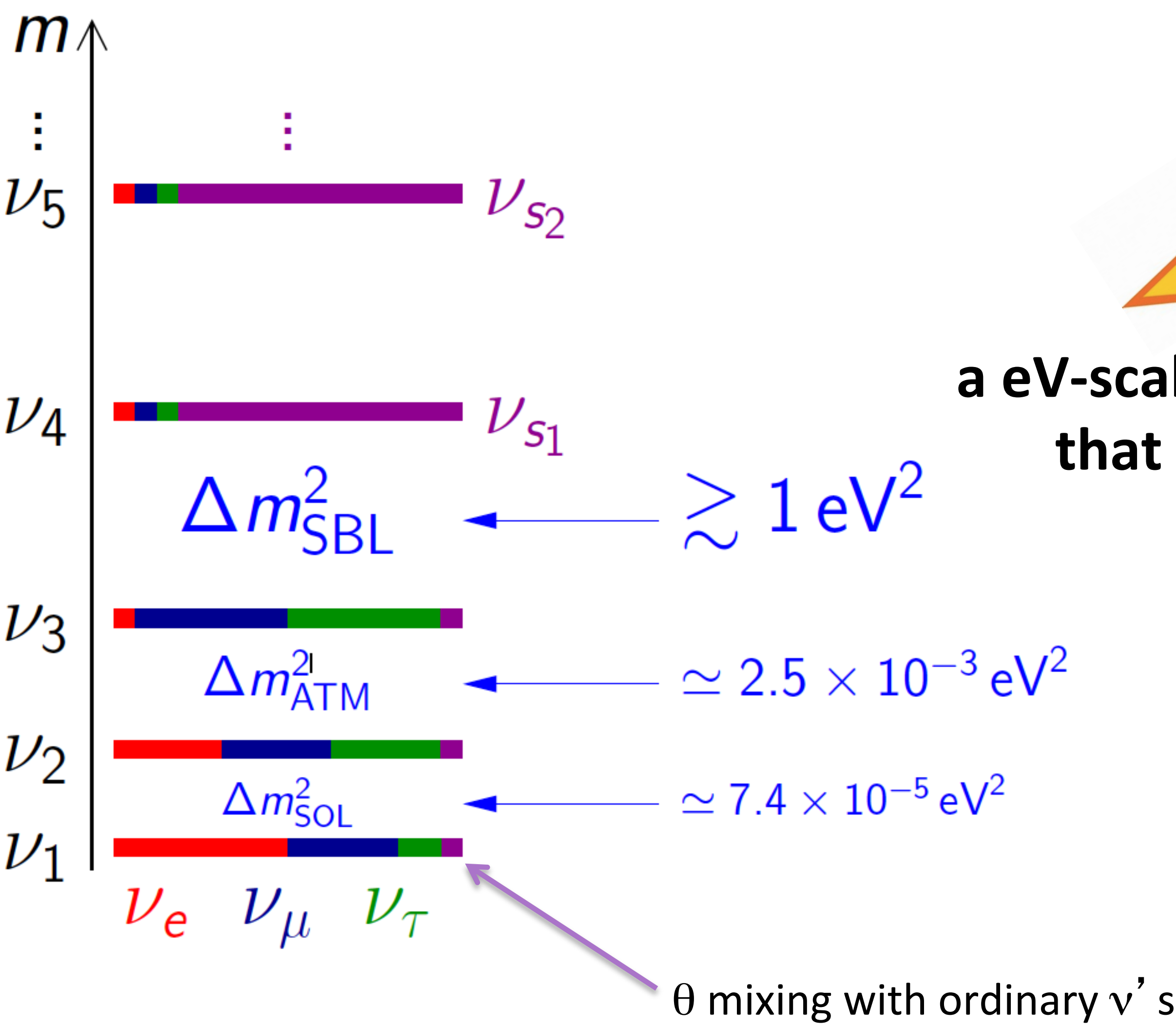
2.2 MeV neutron capture





and the Reactor anomaly: Mention et al, PRD 83 (2011) 073006; upd in WP, arXiv:1204.5379

and the Gallium anomaly: M. Laveder et al., PRC 83 (2011) 065504



a eV-scale massive neutrino that is mainly sterile

The “sterile” issue (cnt.)

The oscillation picture is working wonderfully.
So it should stay whenever extensions are allowed !

Exploit 3+1 or even 3+2 oscillating models, by adding one or more “**sterile**” neutrinos

$$\begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix}$$

$$P(\nu_\alpha \to \nu_\beta) = \sin^2 2\theta_{\alpha\beta} \sin^2\left(\frac{\Delta m_{41}^2 L}{4E}\right)$$

APPEARANCE

$$P(\nu_\alpha \to \nu_\alpha) = 1 - \sin^2 2\theta_{\alpha\alpha} \sin^2\left(\frac{\Delta m_{41}^2 L}{4E}\right)$$

DISAPPEARANCE

when $\Delta m_{21}^2 << \Delta m_{31}^2 << \Delta m_{41}^2$ and $\left|U_{s4}^2\right| \leq 1$

with

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

for **APPEARANCE**

and

$$\sin^2 2\theta_{ee} = 4\left|U_{e4}\right|^2 \left(1 - \left|U_{e4}\right|^2\right)$$

$$\sin^2 2\theta_{\mu\mu} = 4\left|U_{\mu 4}\right|^2 \left(1 - \left|U_{\mu 4}\right|^2\right)$$

for **DISAPPEARANCE**

sterile: *not weakly interacting neutrinos* (B. Pontecorvo, JETP, 53, 1717, 1967)

The "sterile" issue (cnt.)

➔ Experimental hints for more than 3 standard neutrinos, at eV scale
➔ Strong tension with any formal extension of 3x3 mixing matrix

ν_e disappearance

Reactor anomaly ~2.5σ
Re-analisys of data on anti-neutrino flux from reactor short-baseline (L~10-100 m) shows a small deficit of
R=0.943 ±0.023
G.Mention et al, Phys.Rev.D83, 073006 (2011) , A.Mueller et al. Phys.Rev.C **83,** 054615 (2011).

Gallex/SAGE anom[illegible]
Deficit observed by G[illegible]ex in neutrinos coming from a ^{51}Cr and ^{37}Ar sources
***R* = 0.76+0.09 −0.08**
C. Giunti and M. Laveder, Phys.Rev. C83, 065504 (2011), arXiv:1006.3244

ν_e appearance

Accelerator anomaly ~3.8σ
Appearance of anti-ν[illegible] anti-ν_μ beam (LSND). *A.A[illegible]SND Collaboration Ph[illegible]12007 (2001).*

Not [illegible]irmed by miniBooNE (which [illegible]aw appearance of ν_e in a ν_μ [illegible]m) *A.Aguilar et al. (MiniBooNE Collaboration) Phys.Rev.Lett. 110 161801 (2013)*

Anomaly inside the anomalies

No hint so far for
- **ν_μ appearance/disappearance**
- **ν_τ appearance/disappearance**

Tau appearance in the presence of a sterile neutrino (3+1)

$$\Delta_{ij} = \frac{\Delta m^2_{ij} L}{2E}$$

neglect solar driven oscillation $\Delta_{21} \sim 0$

~ standard oscillation

pure exotic oscillation

$$P_{\nu_\mu \to \nu_\tau} = 4|U_{\mu 3}|^2 |U_{\tau 3}|^2 \sin^2 \frac{\Delta_{31}}{2} + 4|U_{\mu 4}|^2 |U_{\tau 4}|^2 \sin^2 \frac{\Delta_{41}}{2}$$

interference terms

$$+ 2\Re[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin \Delta_{31} \sin \Delta_{41}$$
$$- 4\Im[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin^2 \frac{\Delta_{31}}{2} \sin \Delta_{41}$$
$$+ 8\Re[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin^2 \frac{\Delta_{31}}{2} \sin^2 \frac{\Delta_{41}}{2}$$
$$+ 4\Im[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin \Delta_{31} \sin^2 \frac{\Delta_{41}}{2}$$

$$P(Energy) = C^2 \sin^2 \frac{\Delta_{31}}{2} + \sin^2 2\theta_{\mu\tau} \sin^2 \frac{\Delta_{41}}{2}$$
$$+ \frac{1}{2} C \sin 2\theta_{\mu\tau} \cos \phi_{\mu\tau} \sin \Delta_{31} \sin \Delta_{41}$$
$$- C \sin 2\theta_{\mu\tau} \sin \phi_{\mu\tau} \sin^2 \frac{\Delta_{31}}{2} \sin \Delta_{41}$$
$$+ 2 C \sin 2\theta_{\mu\tau} \cos \phi_{\mu\tau} \sin^2 \frac{\Delta_{31}}{2} \sin^2 \frac{\Delta_{41}}{2}$$
$$+ C \sin 2\theta_{\mu\tau} \sin \phi_{\mu\tau} \sin \Delta_{31} \sin^2 \frac{\Delta_{41}}{2}$$

$$C = 2|U_{\mu 3}||U_{\tau 3}|$$
$$\phi = Arg(U^\star_{\mu 3} U^\star_{\tau 3} U^\star_{\mu 4} U^\star_{\tau 4})$$
$$\sin 2\theta_{\mu\tau} = 2|U_{\mu 4}||U_{\tau 4}|$$

(effective mixing)

CP-violating

Mass Hierarchy dependence

At Long-Baselines and eV mass scale:

$$\sin\Delta_{41} \approx 0$$

$$\sin^2\frac{\Delta_{41}}{2} \approx \frac{1}{2}$$

$$P(Energy) = C^2\sin^2\frac{\Delta_{31}}{2} + \frac{1}{2}\sin^2 2\theta_{\mu\tau}$$

$$+ C\sin 2\theta_{\mu\tau}\cos\phi_{\mu\tau}\sin^2\frac{\Delta_{31}}{2}$$

$$+ \frac{1}{2}C\sin 2\theta_{\mu\tau}\sin\phi_{\mu\tau}\sin\Delta_{31}$$

Sensitive to mixing “sterile” angles, MH and phase CP-violation

Separate analyses for NH and IH and maximize Likelihood as $L(\phi_{\mu\tau}, \sin^2\theta_{\mu\tau}, C^2)$

Use $|\Delta m^2_{31}|$=0.00243 eV^2 for NH and 0.00238 eV^2 for IH

effective mixing of sterile with ν_μ and ν_τ

effective mixing of standard $\nu_\mu - \nu_\tau$ oscillation

OPERA search for ν_τ sterile "anomalies"

published in JHEP, 6, 69 (2015) and arXiv:1503.01876, based on 4 taus' candidates

Separate analyses for "high" and low $|\Delta m^2_{41}|$

For $|\Delta m^2_{41}| > 1\ eV^2$ → $\sin^2 2\theta_{\mu\tau} < 0.116$ at 90% C.L.

when integrating over ϕ

(quasi-equal results for NH and IH)

Note: 0.069 obtained if neglect interference terms

OPERA observed a 5th candidate *(PRL 115, 121802, arXiv:1507.01417)*

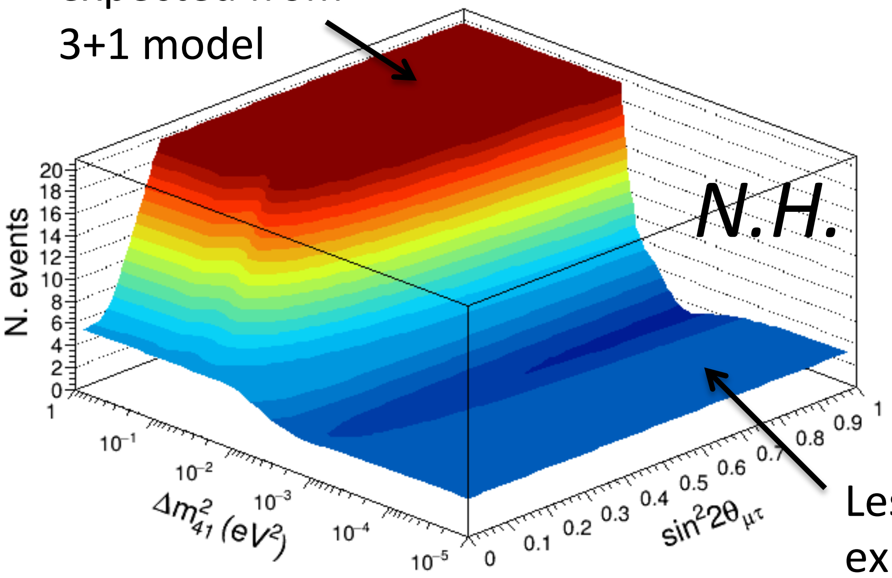
Channel	Expected background				Expected signal	Observed
	Charm	Had. re-interac.	Large μ-scat.	Total		
$\tau \to 1h$	0.017 ± 0.003	0.022 ± 0.006	–	0.04 ± 0.01	0.52 ± 0.10	3
$\tau \to 3h$	0.17 ± 0.03	0.003 ± 0.001	–	0.17 ± 0.03	0.73 ± 0.14	1
$\tau \to \mu$	0.004 ± 0.001	–	0.0002 ± 0.0001	0.004 ± 0.001	0.61 ± 0.12	1
$\tau \to e$	0.03 ± 0.01	–	–	0.03 ± 0.01	0.78 ± 0.16	0
Total	0.22 ± 0.04	0.02 ± 0.01	0.0002 ± 0.0001	0.25 ± 0.05	2.64 ± 0.53	5

Preliminary update of the analysis with 5 ν_τ candidates

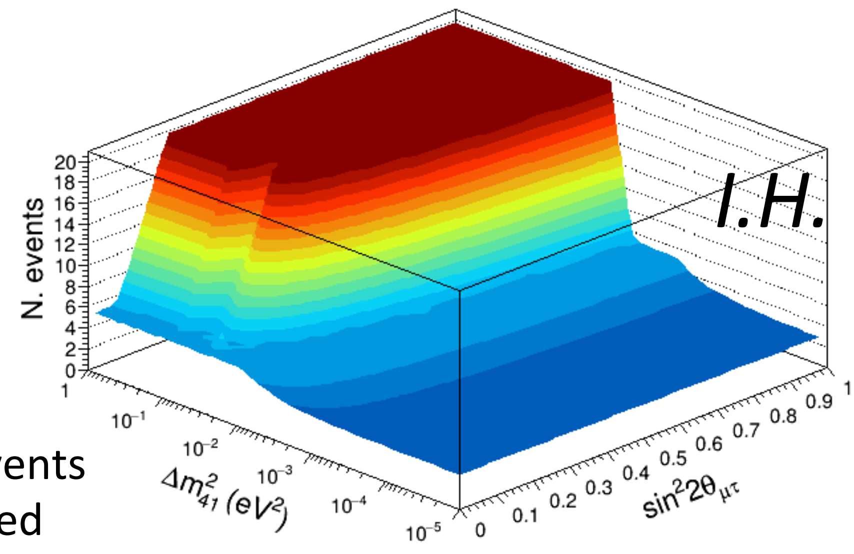
L. Stanco (OPERA) at EPS2015, and arXiv:1510.04151

Interplay of interference

More events expected from 3+1 model

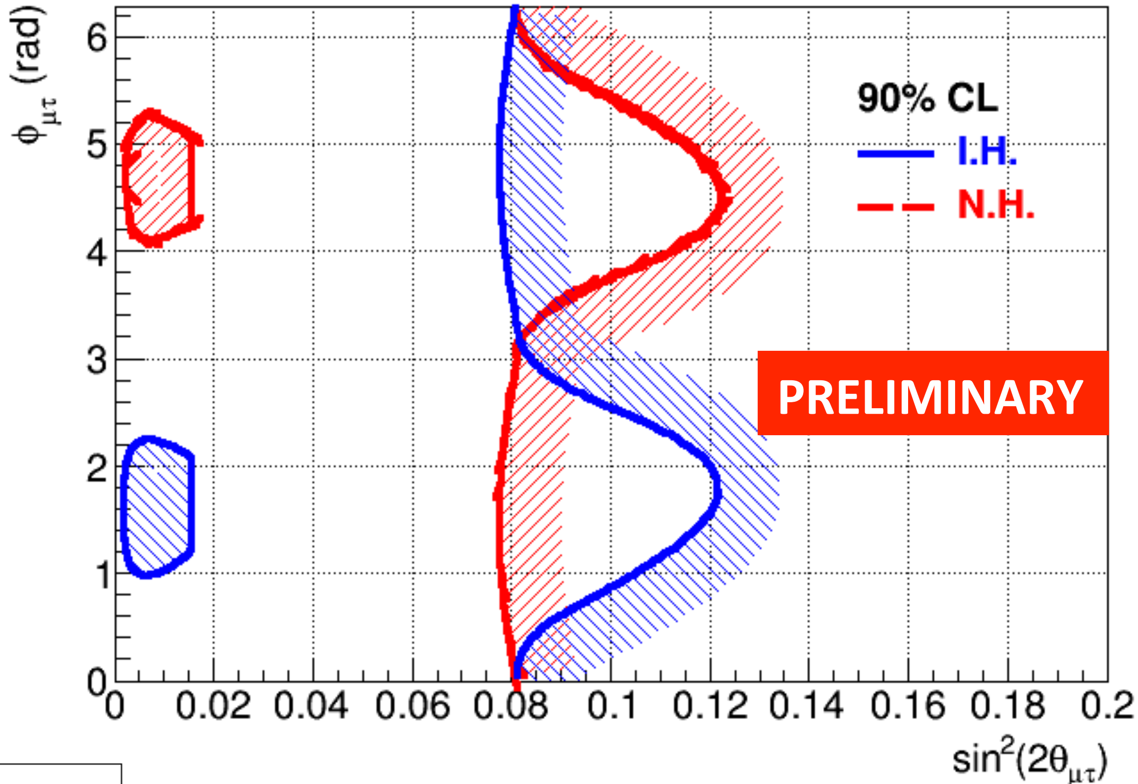


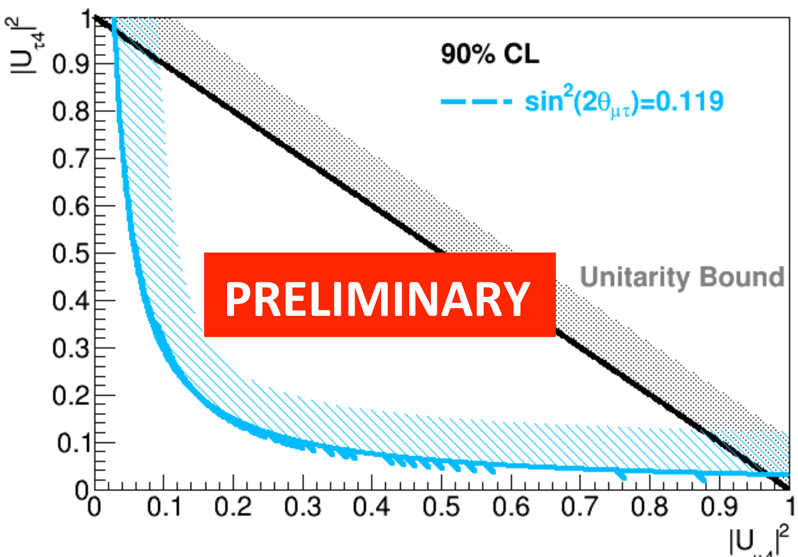
Less events expected



For $|\Delta m^2_{41}| > 1$ eV^2

(Raster-scan à la Feldman&Cousins)





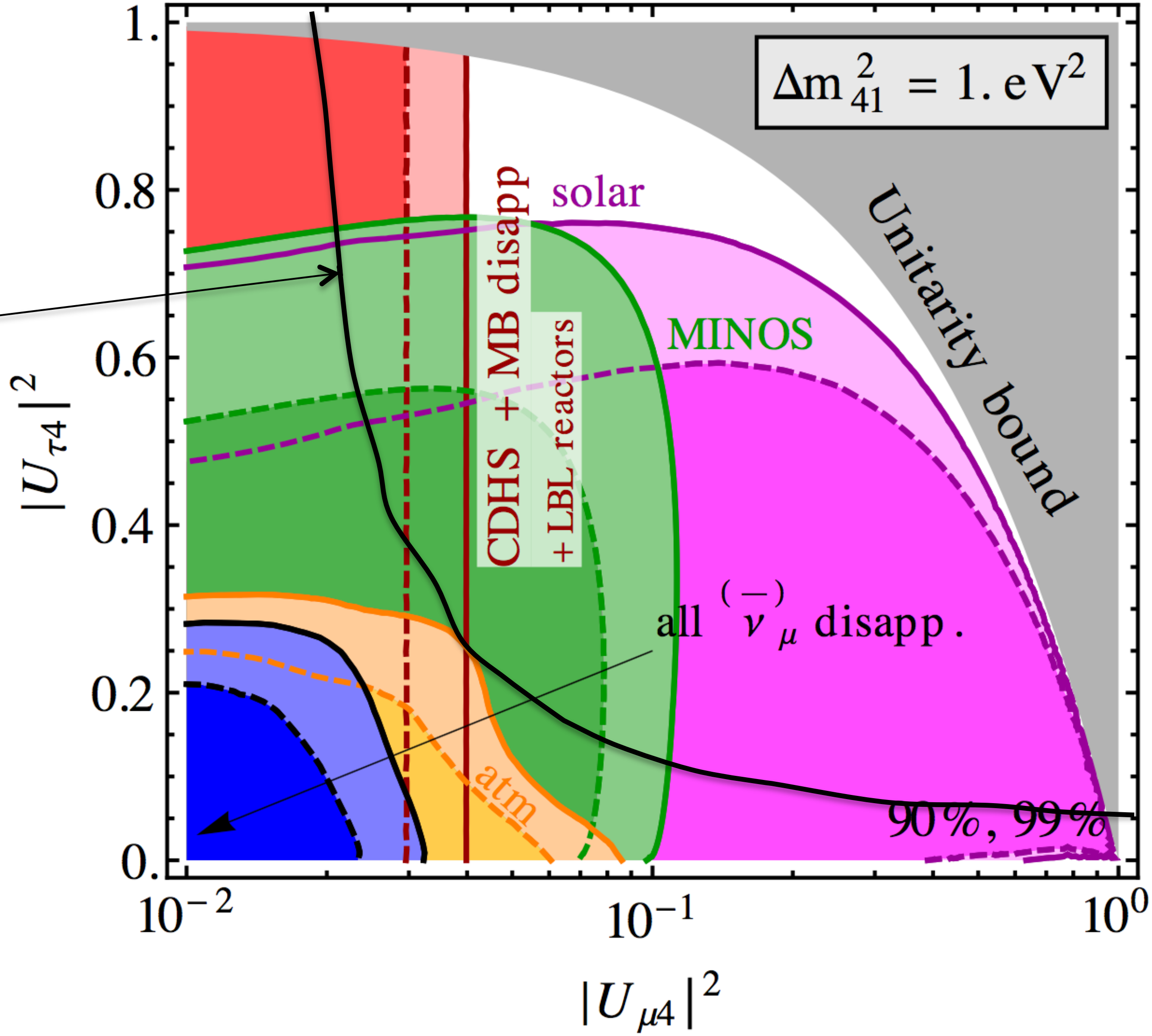
$\sin^2 2\theta_{\mu\tau} < 0.119$ at 90% C.L.
when integrating over ϕ
(quasi-equal results for NH and IH)

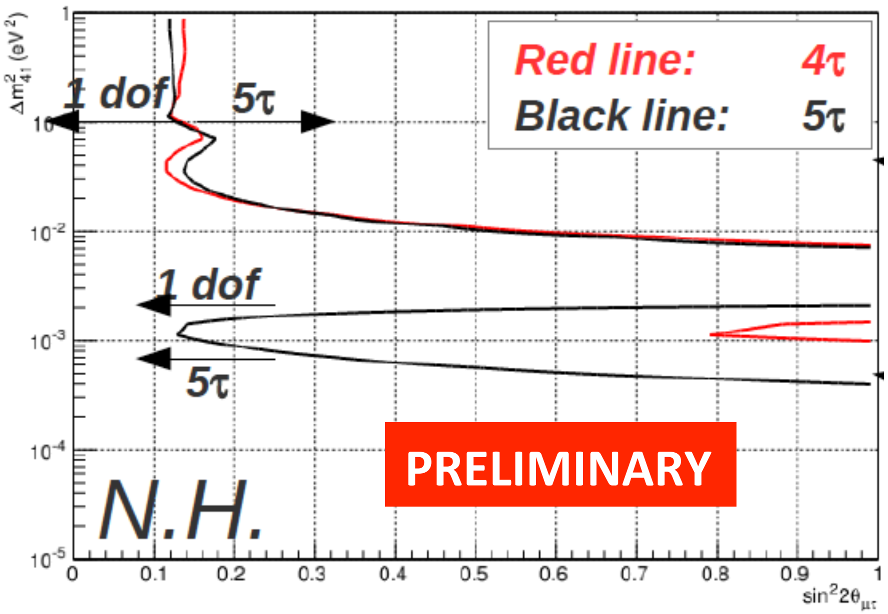
PRELIMINARY

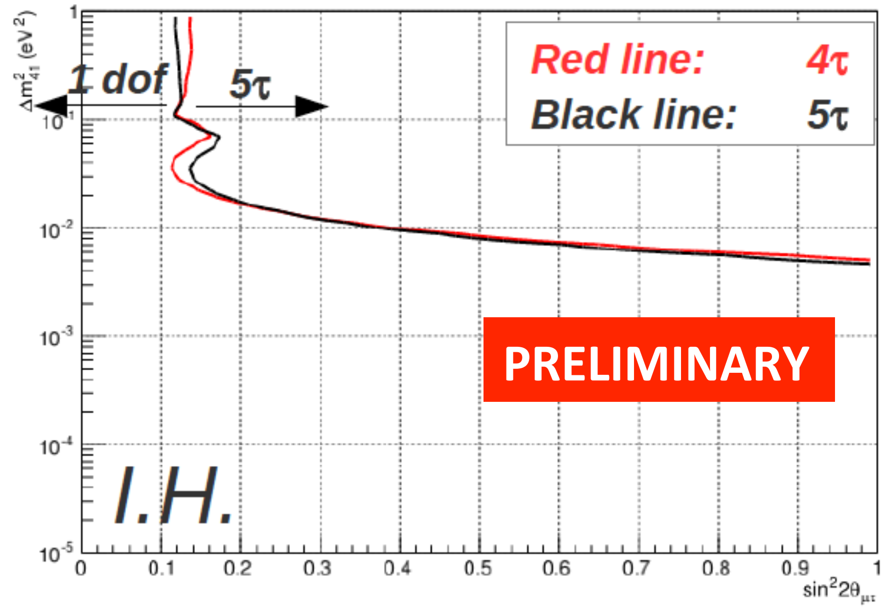
Complementary measurement wrt disappearance experiments

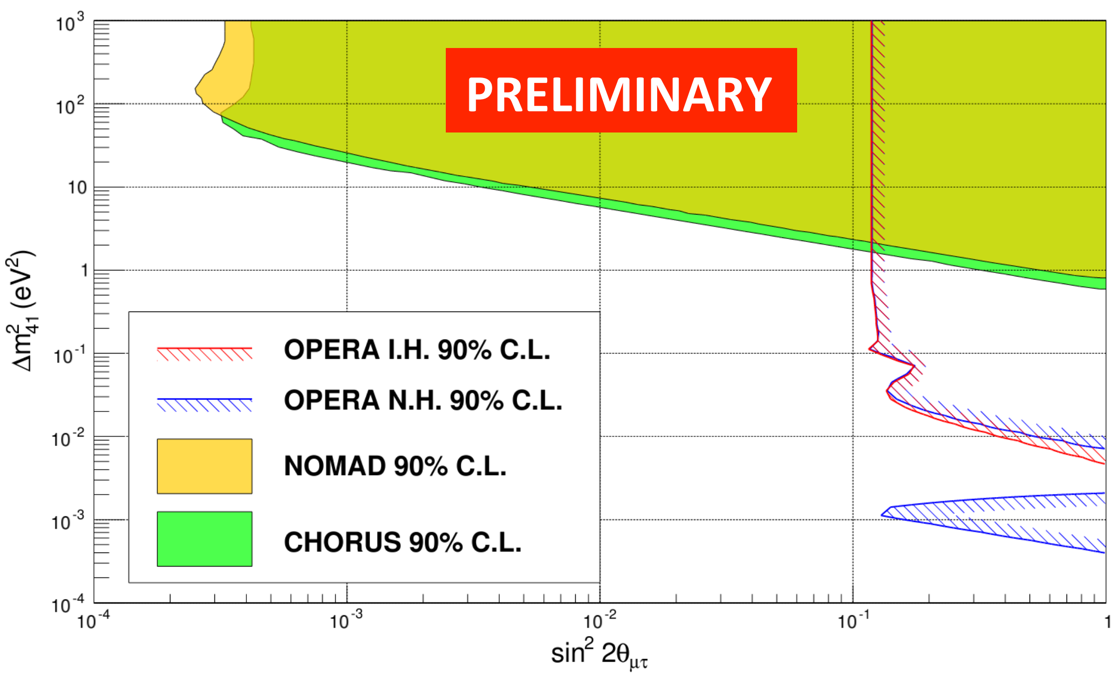
OPERA PRELIMINARY

(just sketched)





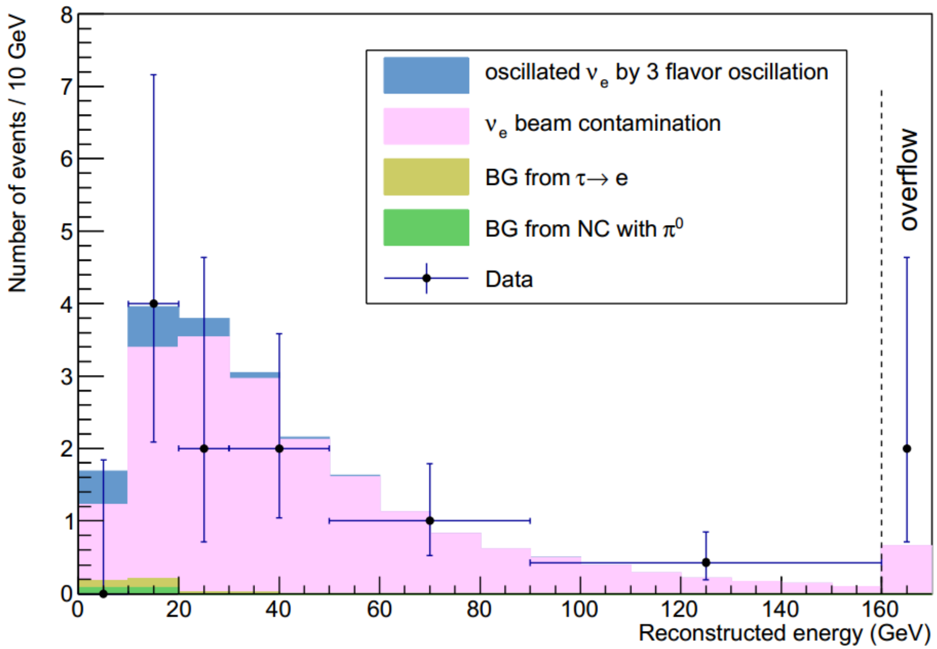




Full analysis with GLOBES (matter effects, Δm^2_{21} included, profiled out on Δm^2_{31})

OPERA can perform similar analysis based on ν_e observation

Old result from 2008+2009 data sample (30% of total): JHEP 4, 1307 (2013) and arXiv:1303.3953



		E<20 GeV
ν_e candidates	19	4
background	19.8±2.8	4.6

Compatible with expectation from intrinsic ν_e component in the CNGS ν_μ beam: 0.9%

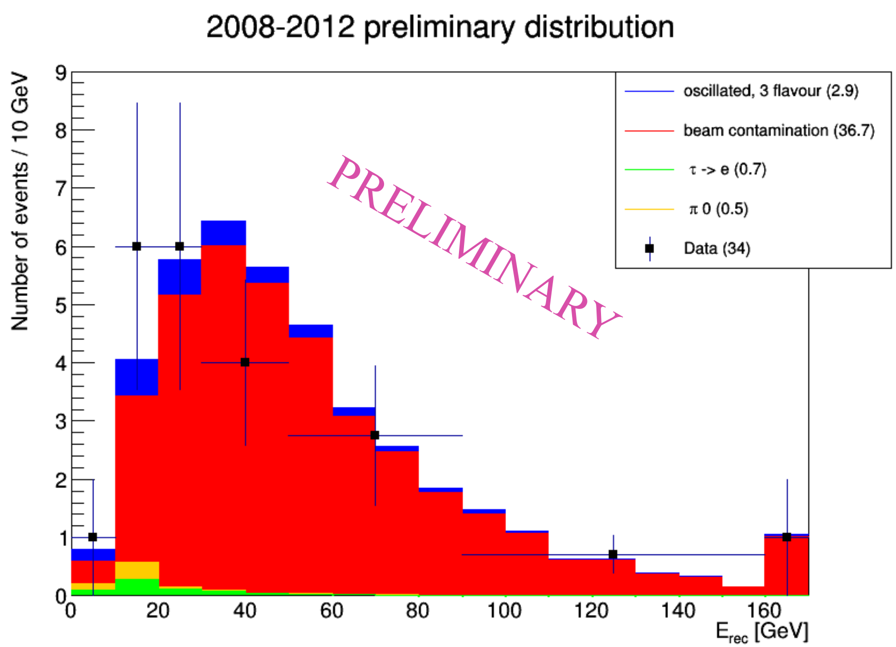
put rough limits to exclude mixing on θ_{14} with a 2 flavour model

Approximate analysis, see OPERA previous result and e.g. A.Palazzo, PRD 91, 91301(R) (2015)

Waiting for the ν_e analysis on the full data sample

(3.5 more statistics)

ν_e candidates selected by Emulsion Analysis → Observed 34 ν_e events



Expected ν_e events :

ν_e beam contamination 36.7 ± 5

Background $\tau \to e$ + mis-id'd π^0 1.2 ± 0.1

From 3-flavour oscillation:

$\nu_\mu \to \nu_e$ 2.9 ± 0.4 evts

($\sin^2(2\theta_{13}) = 0.098$)

Numbers are preliminary.

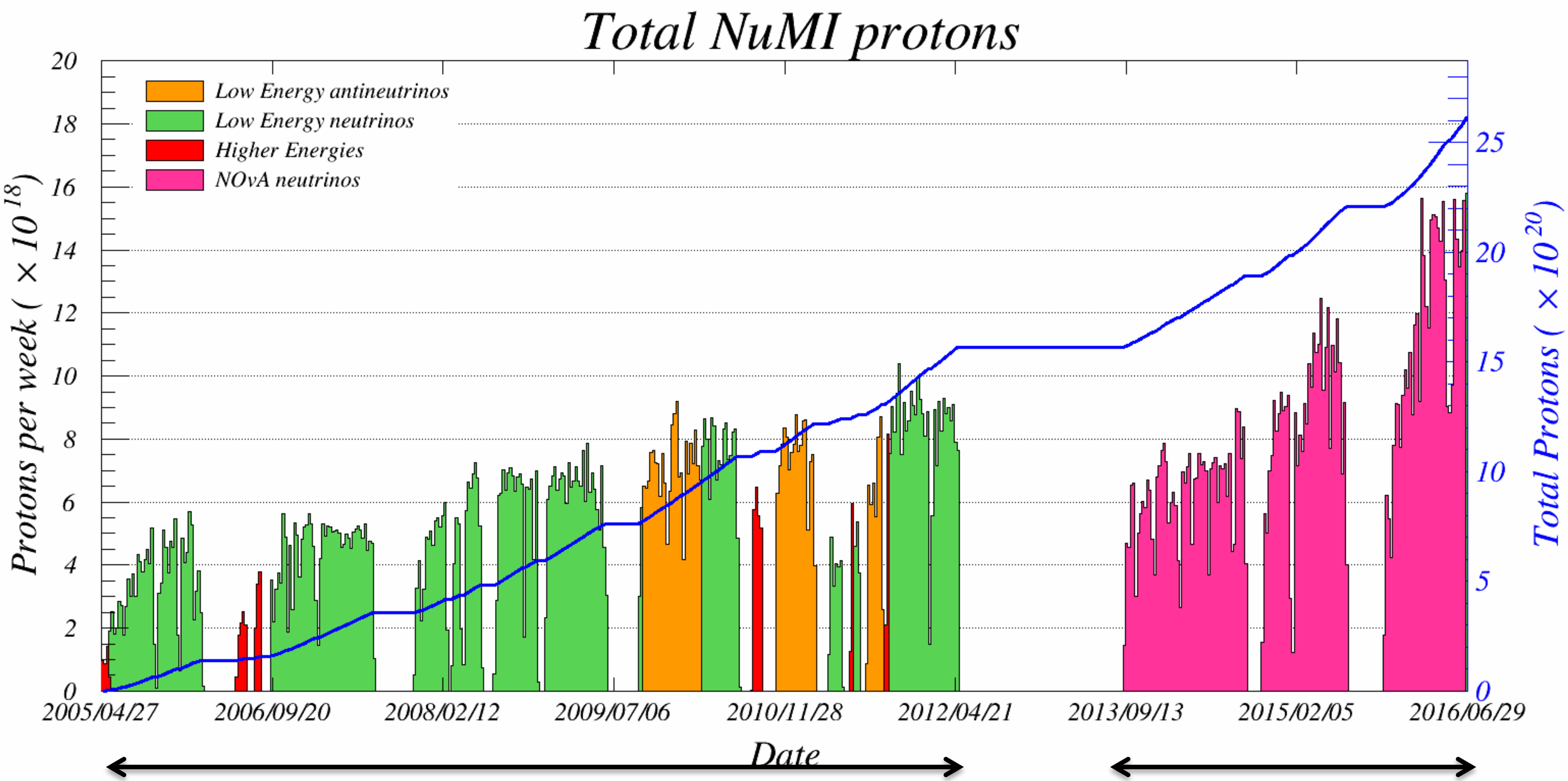
D. Duchesneau@NEUTRINO2016

To increase signal-to-background ratio: E < 30 GeV

13 observed events for

9.2 ± 1 background expected + 1.4 ± 0.2 (from $\nu_\mu \to \nu_e$)

MINOS(+) Analysis on $\nu_\mu \rightarrow \nu_\mu / \nu_e$

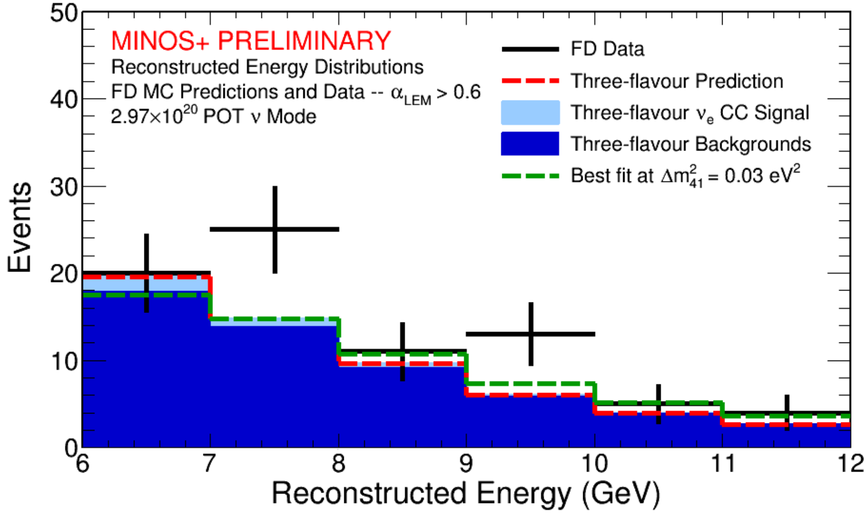


MINOS **MINOS+**

10.56x1020 PoT MINOS neutrino-mode
5.80x1020 PoT MINOS+ neutrino-mode
3.36x1020 PoT MINOS antineutrino-mode

J. Evans @ NEUTRINO2016

MINOS(+) Analysis on $\nu_\mu \rightarrow \nu_e$



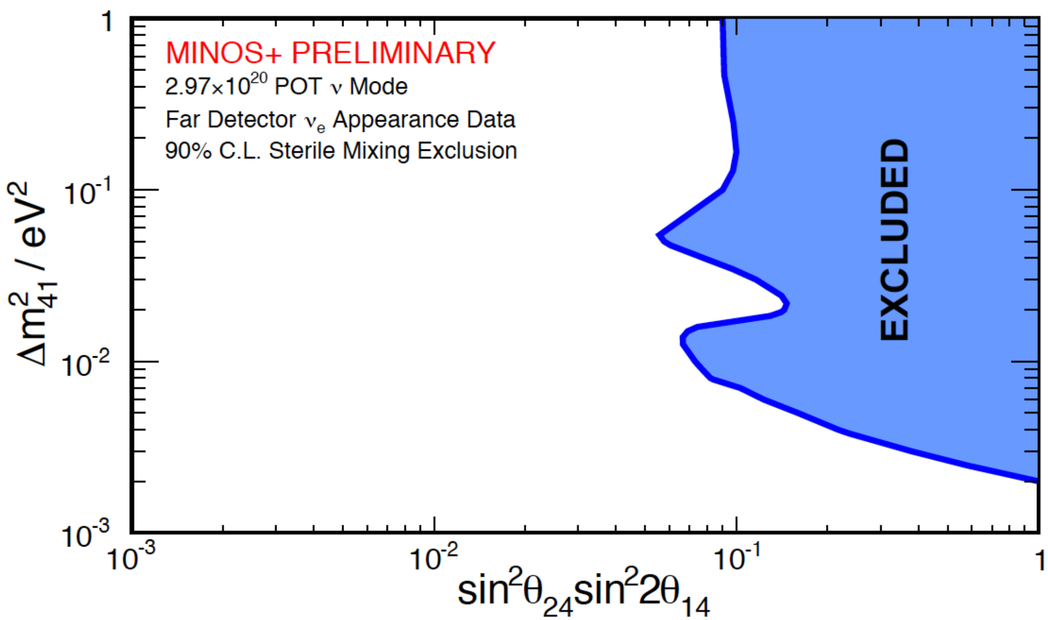
Near detector used to produce a Far Detector prediction

Expect 56.7 events, observe 78

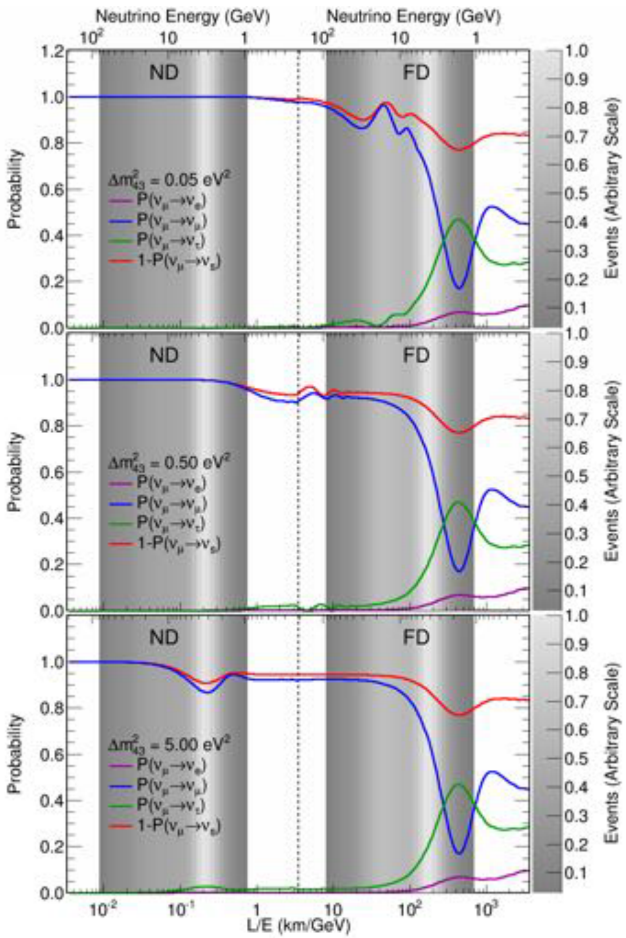
- 2.3σ excess

Three times more data to come

overfluctuation of the data gives a not-so-strong limit

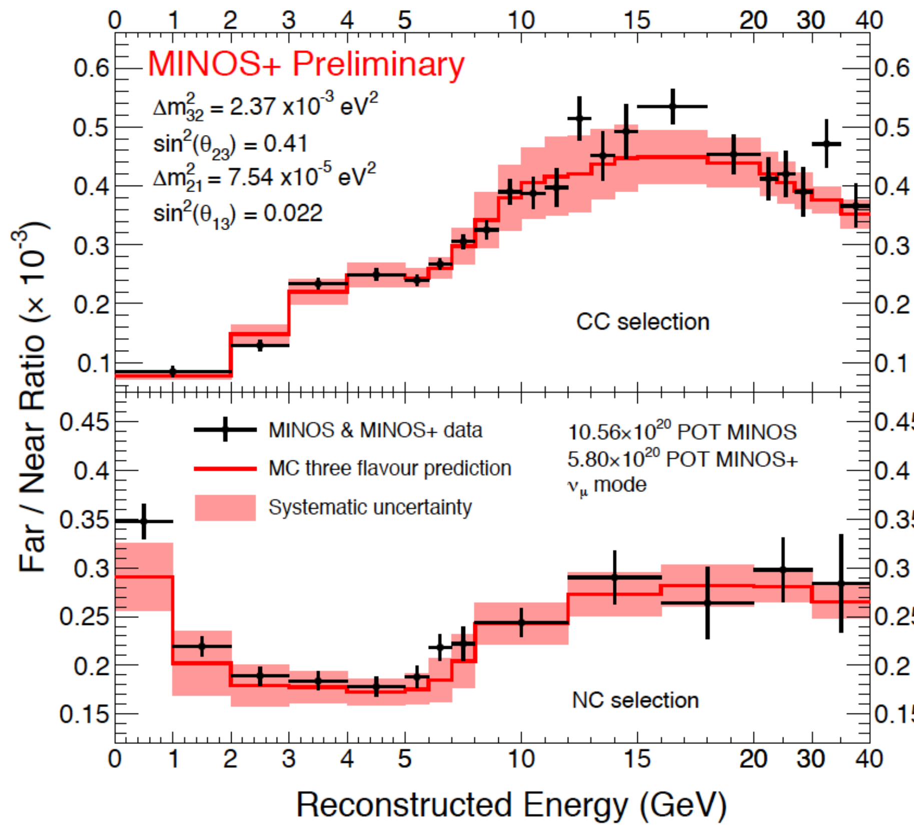


MINOS(+) on ν_μ sterile "anomalies"

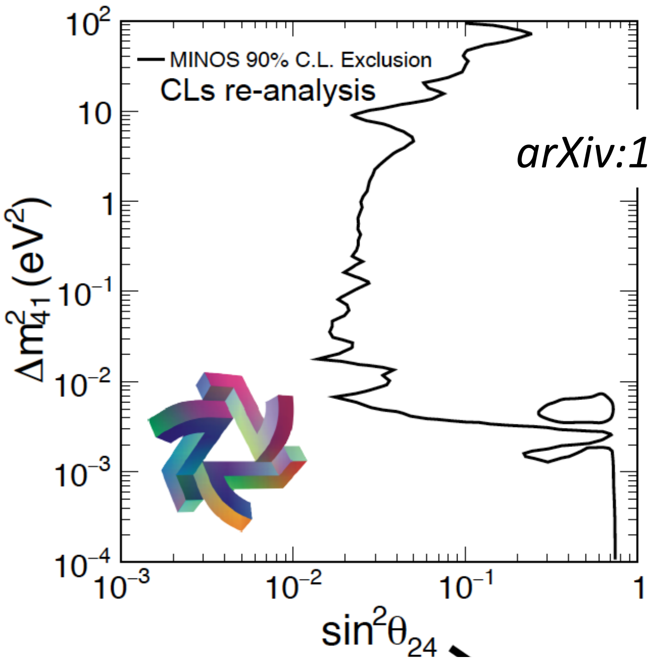


CC and NC searches:

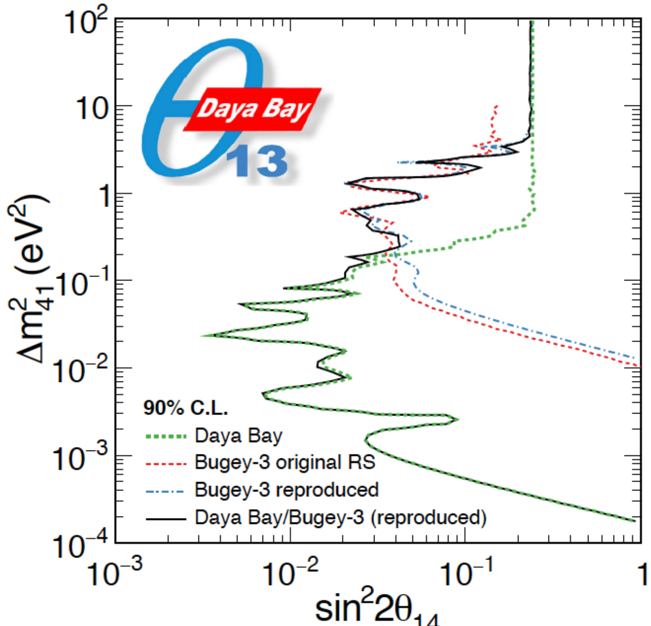
- Excellent agreement with best-fit with 3 flavors
- Extended range in Δm^2 due to large energy span

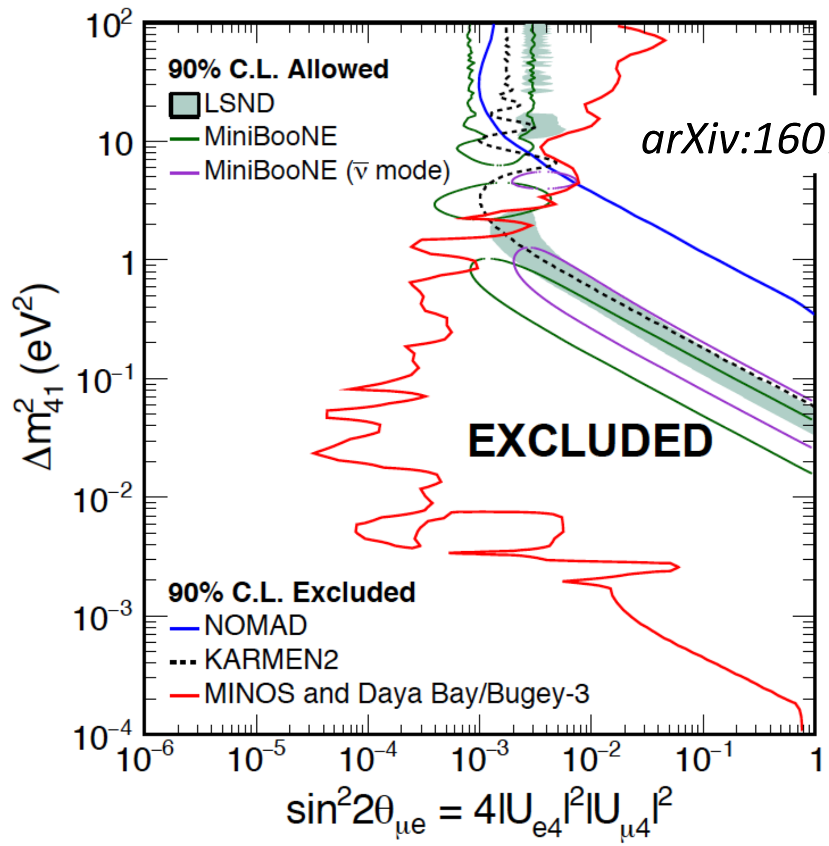


Re-analysis of MINOS and Daya-Bay, including old Bugey-3 data



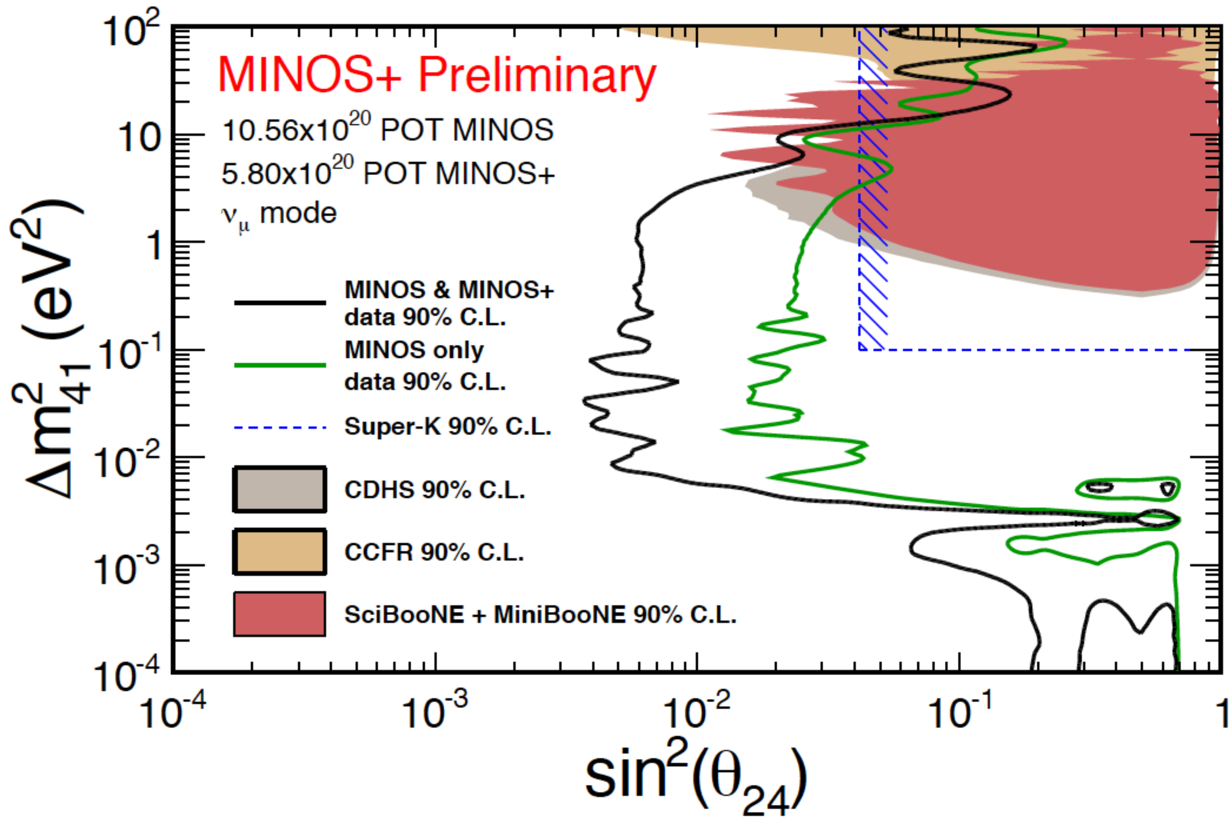
arXiv:1607.01176





arXiv:1607.01177

Adding MINOS+

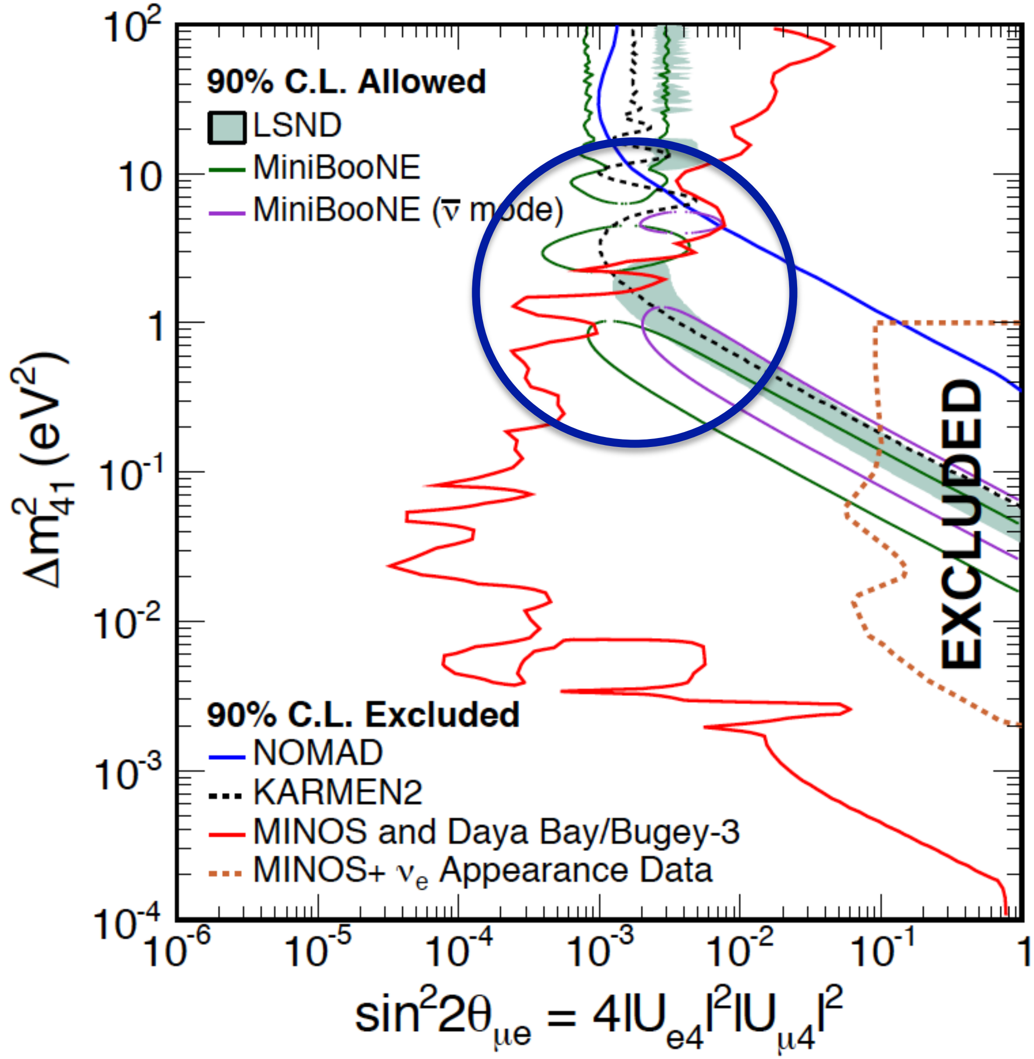


increase tension with ν_e sterile “anomalies”

- possible to double the dataset
- Preliminary result with antineutrino (limit around 0.08)

end of the story ? ➔ comments

Putting all together



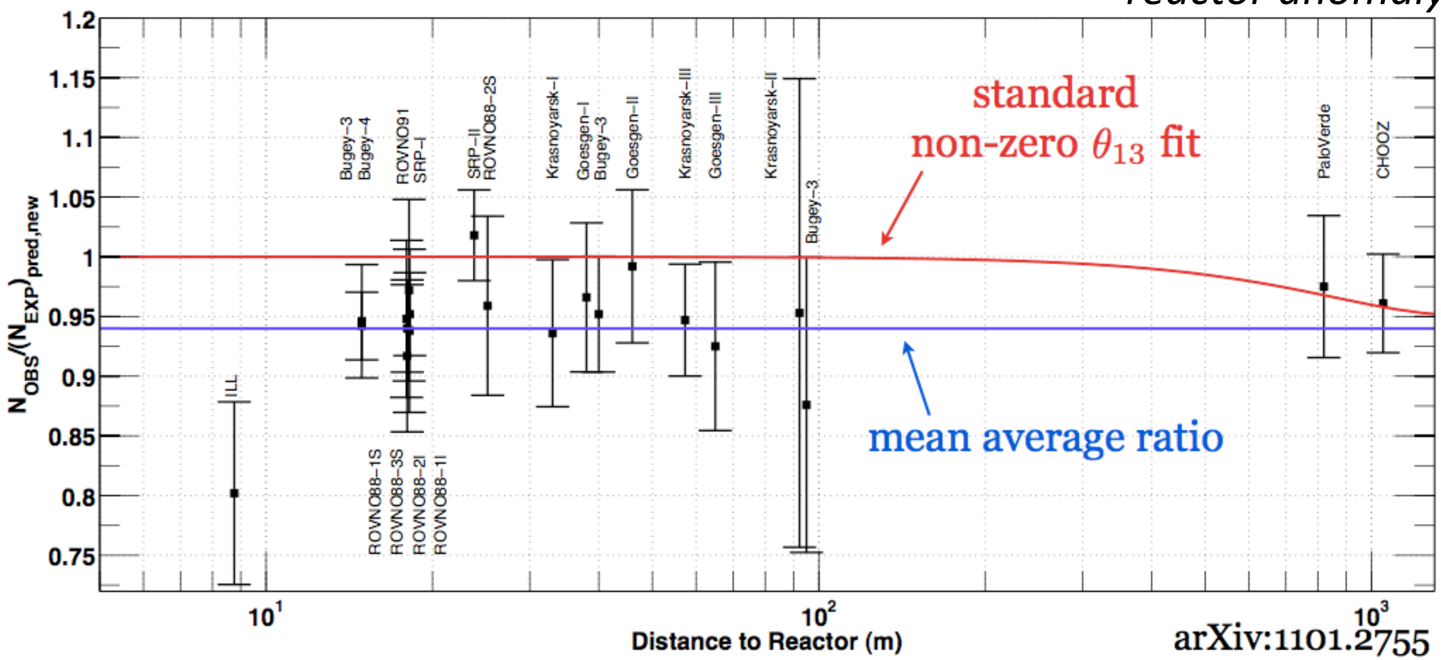
still marginal exclusion,
same for ν_μ disappearance,
same for new Icecube results (see backup slides)

and… 90% C.L. ?? One should use 95% C.L.

Short-Baseline at accelerators

Life is much easier, but choose the right baseline ←→ energy, and the right detectors/system

reactor anomaly



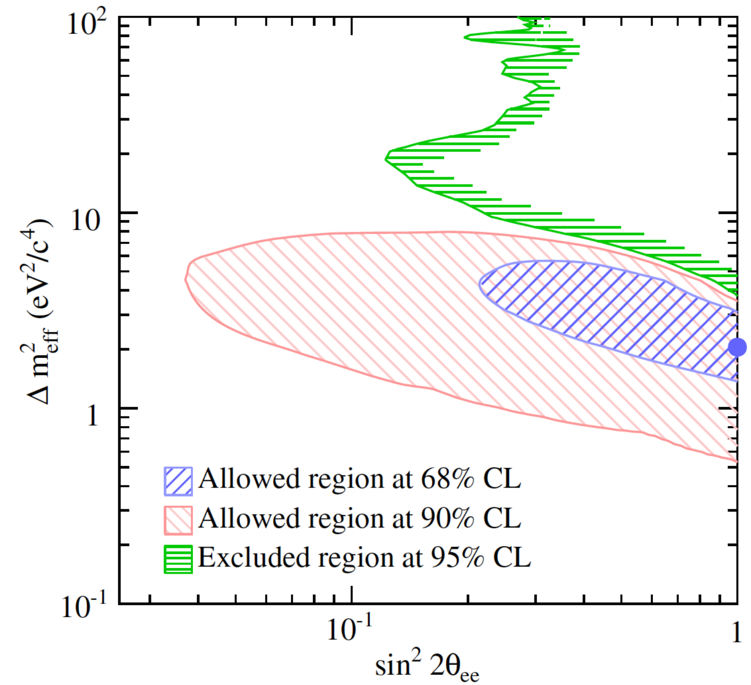
arXiv:1101.2755

Two flavour approximation OK: $P(\nu_\alpha \to \nu_\alpha) = 1 - \sin^2 2\theta_{\alpha\alpha} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$

But contributions from interplayed oscillations can wash out the disentanglement

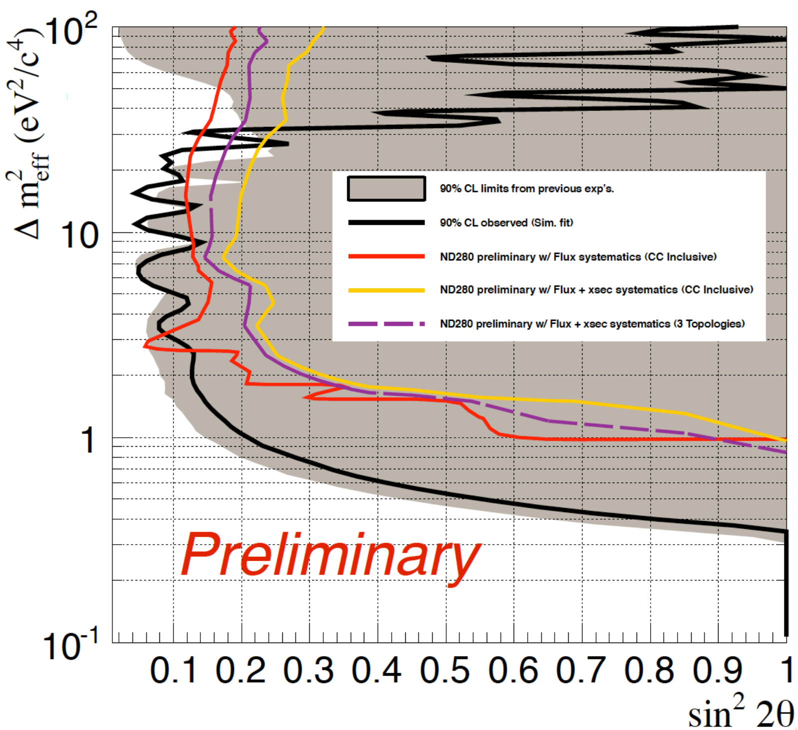
T2K Near (ND280) detector (ν_e disappearance)

T2K, Phys.Rev. D91, 051102(R) (2015), arXiv:1410.8811



Interesting, but assuming $|U_{4\mu}|$=0 and no real exclusion of existing hints.

Still waiting for the promised ν_μ disappearance:



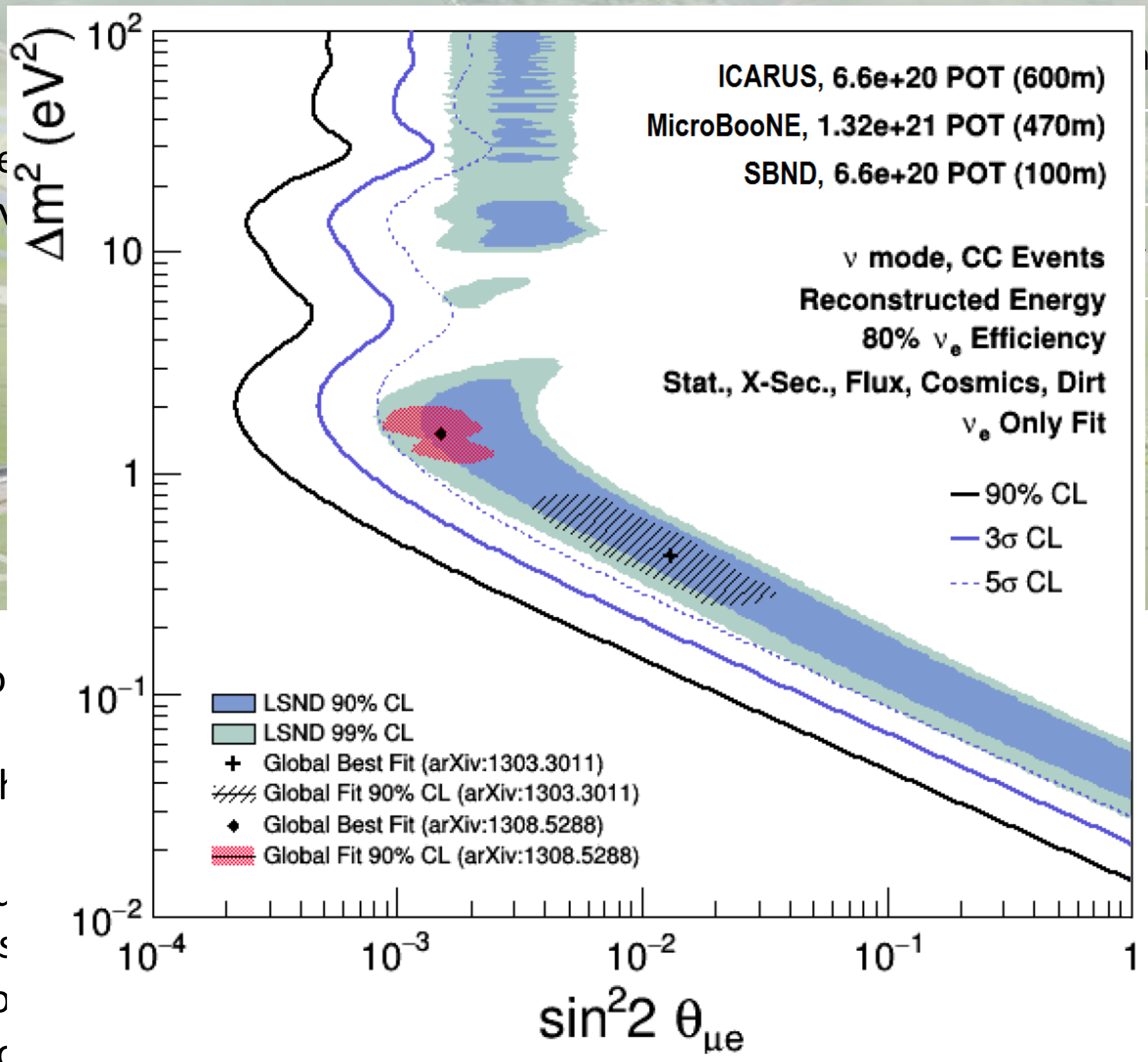
T2K, expected sensitivity, arXiv:1504.08237

The Fermilab Short-Baseline Program

arXiv:1503.01520

They promise
and ν_μ (bar−ν

seline	Mass
10 m	112 t
70 m	89 t
00 m	476 t

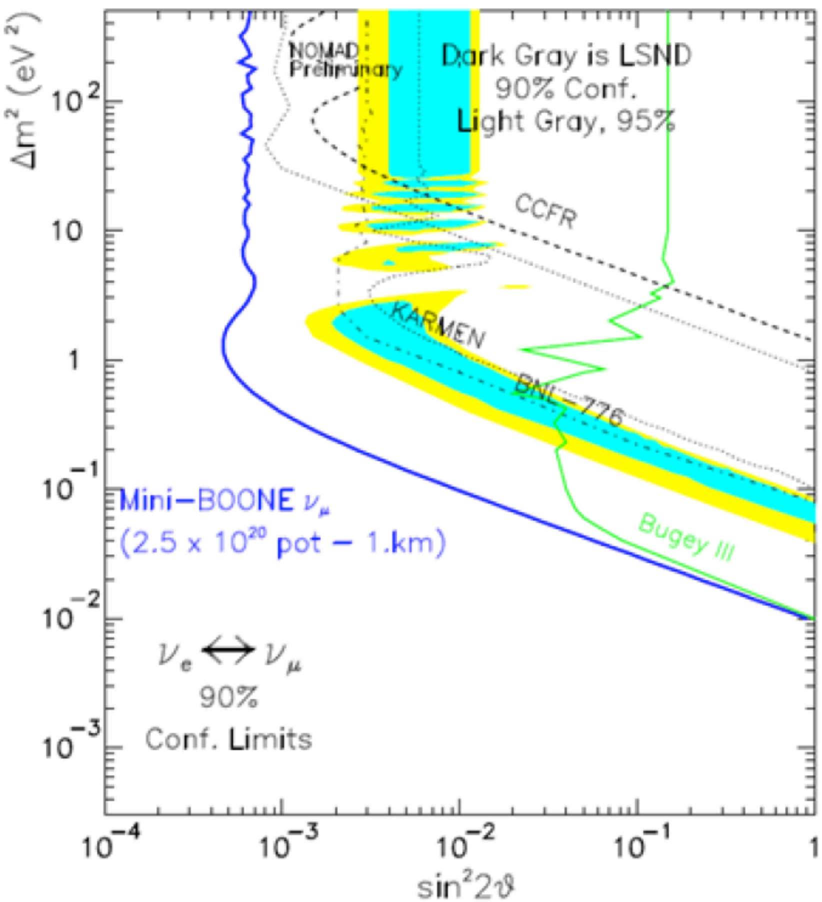


Excellent for cro
Concerns:

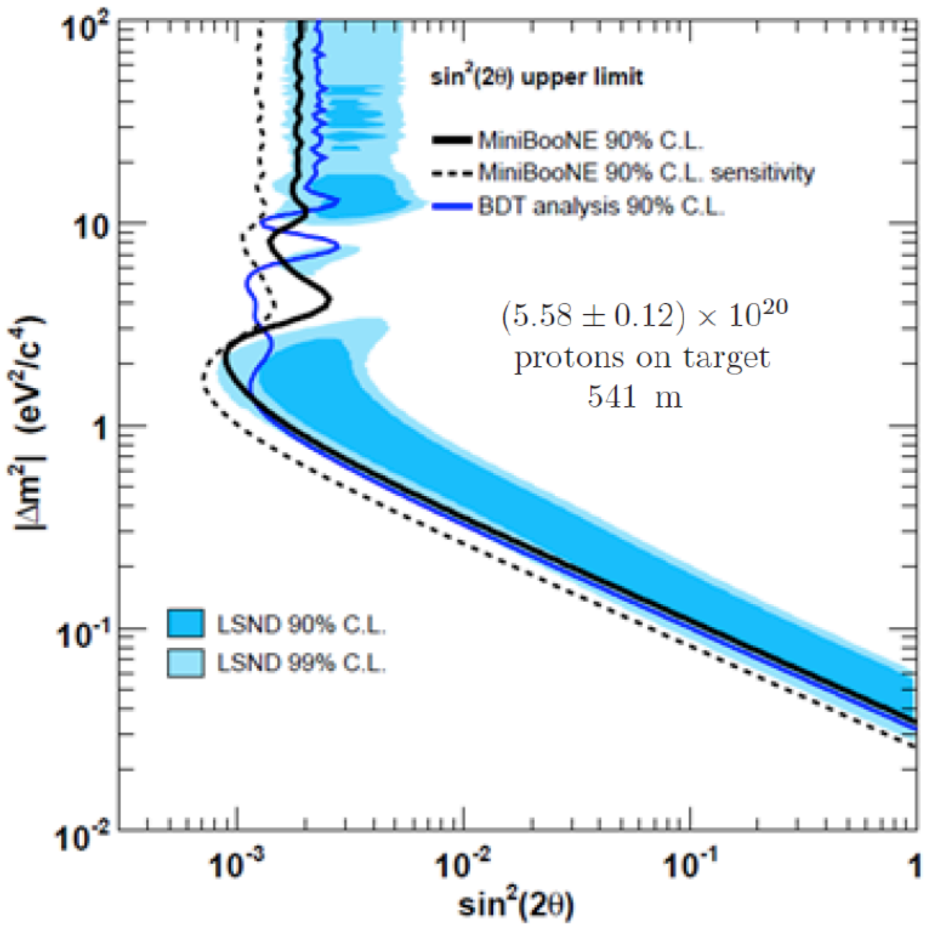
- Excellent tech no extended
- All (only) Liqu mainly for tes
- Not robust fo
- A 5 σ exclusio

Caution on Proposal Sensitivities

MiniBooNE LOI arXiv:nucl-ex/9706011 (1997)



Phys.Rev.Lett. 98,231801 (2007)

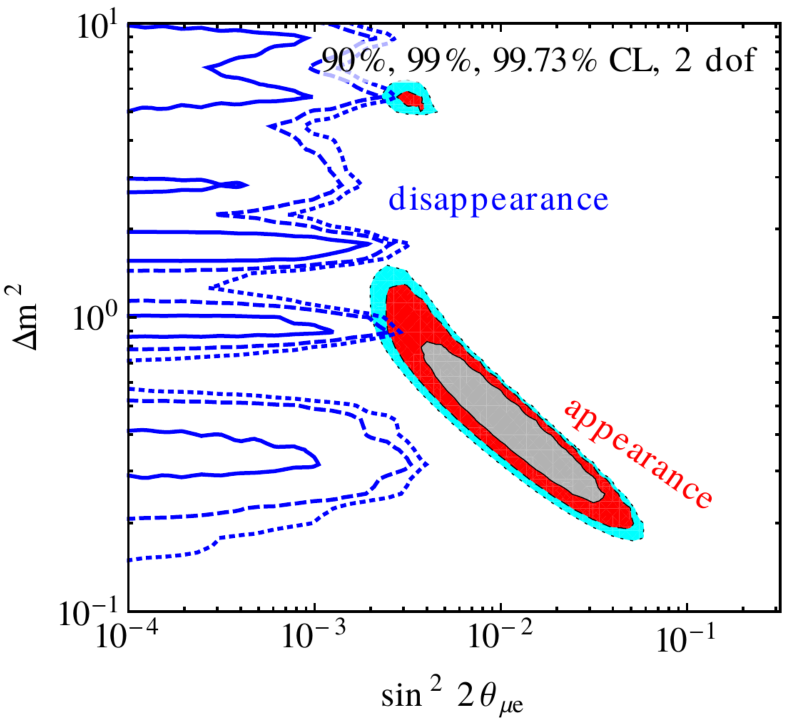


Jonathan Link at TAUP2015

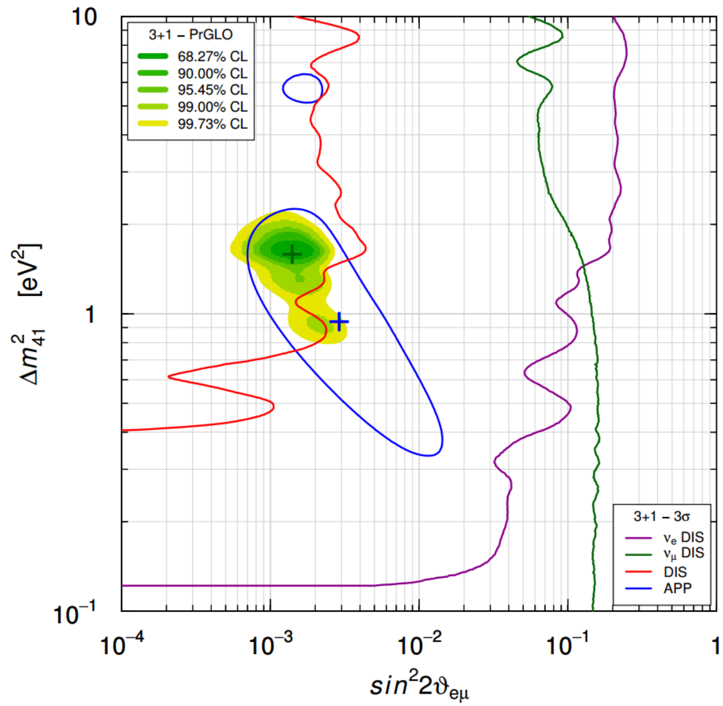
Too optimistics or something present ?

A valid alternative: NESSiE proposal at FNAL *(not approved)*

J. Kopp et al, JHEP 1305 (2013) 050



S. Gariazzo et al, arXiv:1507.08204



Why not directly going to measure the ν_μ disappearance?

Search for sterile neutrinos in the ν_μ disappearance mode at FNAL *arXiv:1503.01876v2*

A conclusive experiment to determine the ν_μ disappearance behaviour at 1 eV mass scale, with spectrometers exploited to provide muon charge assignment and momentum measurement

Key-points for NESSiE

1. **The ν_μ disappearance is mandatory**
   - either in case of null result on electron-neutrino

     the presence of sterile neutrino could be hidden due to interference modes and data mis-interpretation for the interplay between νe appearance/disappearance
   - or in case of positive result on electron-neutrino at SBL

     to address the correct interpretation of sterile neutrino oscillation, see current tension between νe / $\nu\mu$ appearance/disappearance

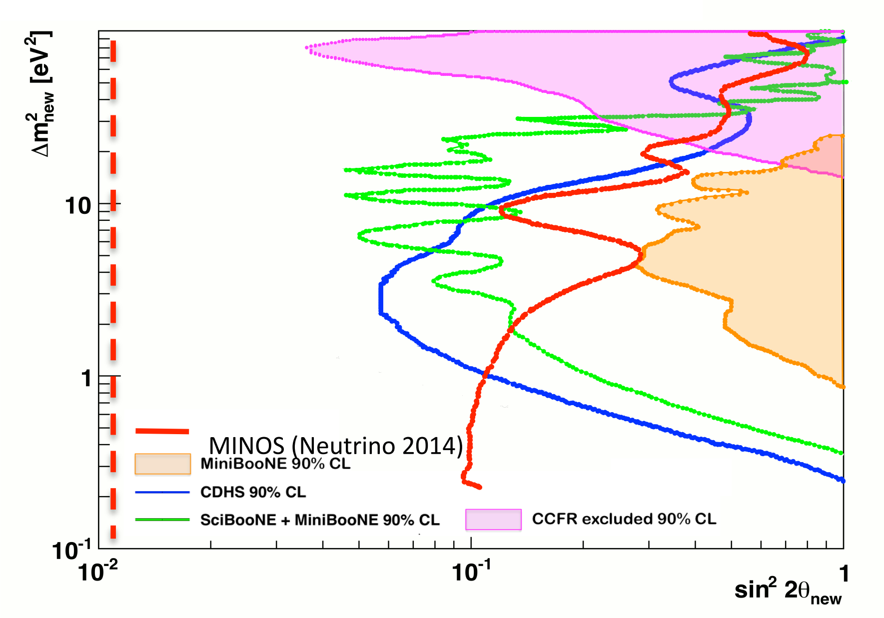
...

5. **No R&D/refurbishing/upgrade: robustness of the program** (technologically, time- and cost-wise
   - 80% of re-used well proven detectors,
   - straightforward extension,
   - low power needed at each site

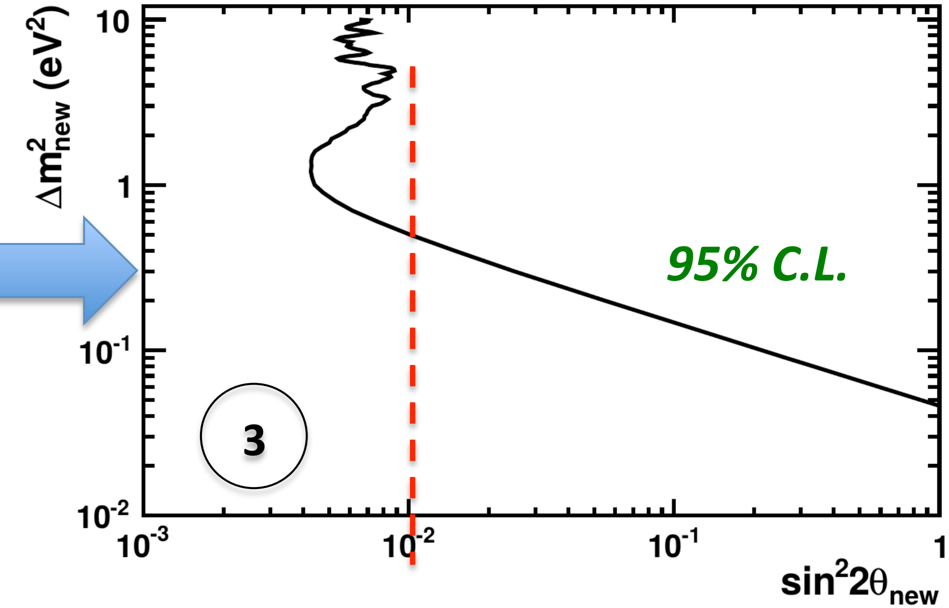
(Two - really cloned - sites with 1 kton of Iron interleaved with RPC muon detectors)

Sensitivity

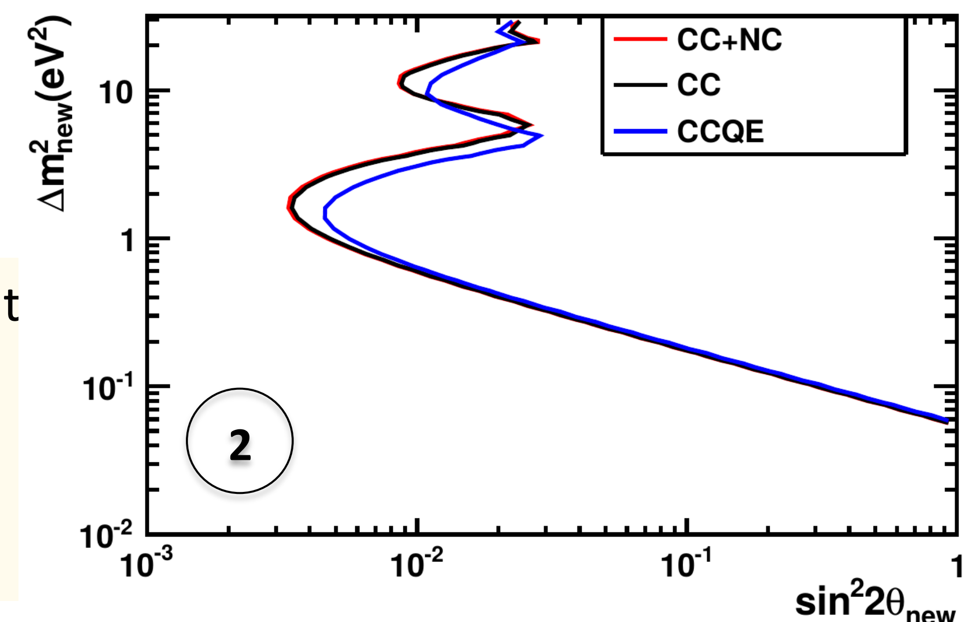
from here (now)



to here (NESSiE)



3 years (6.6 x 10^{20} pot)



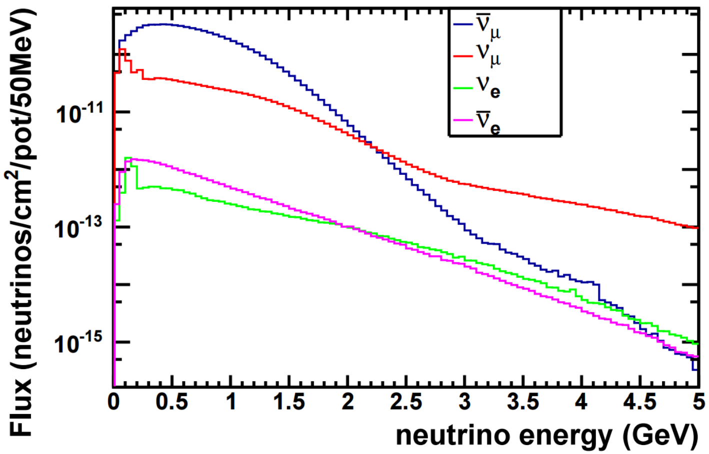
Full simulation and careful treatment of systematics errors

Three **independent** analyses, with different statistical approaches

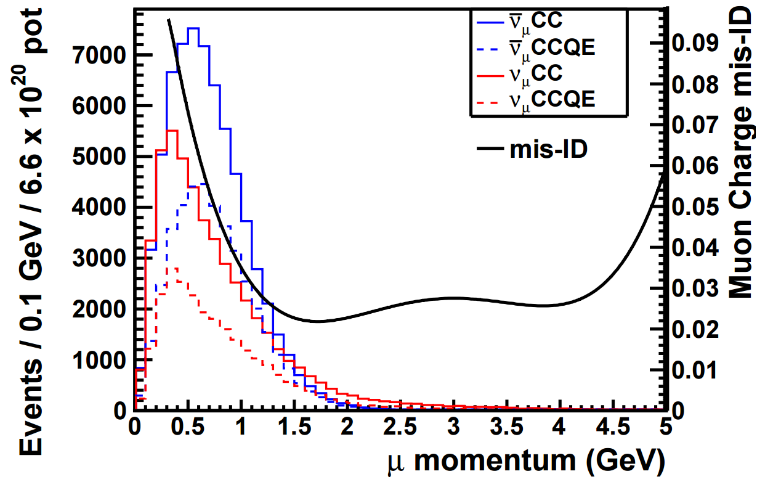
1) Feldman & Cousins
2) $\chi 2$ + Near/Far correlation matrix
3) CLs profile likelihoods

Unique feature of NESSiE for the anti-neutrino mode

In negative-focusing mode the Booster beam contains a large neutrino component

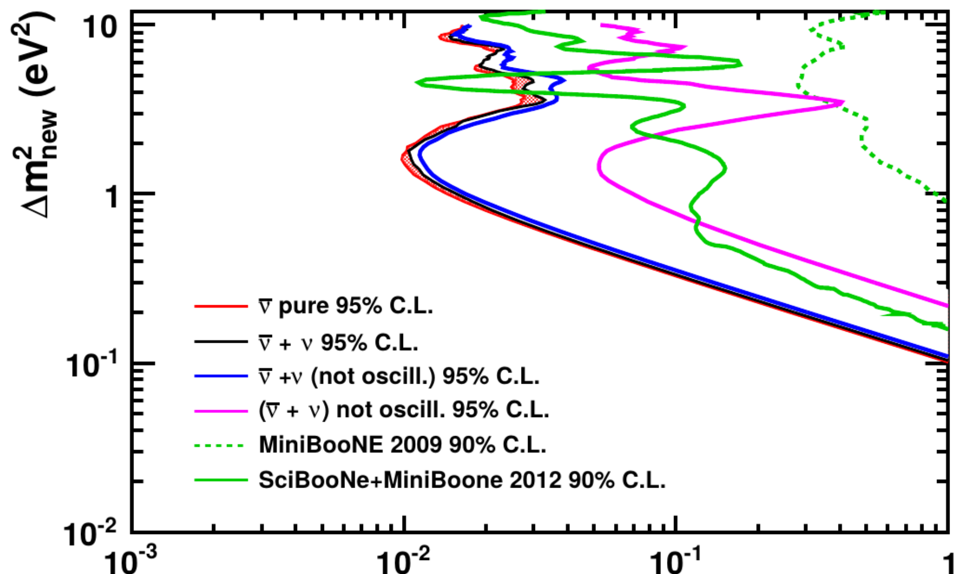


muon mis-ID



Exploiting of charge measurement on event-by-event basis, **anti-ν_μ disappearance is possible**

Four scenario studied:
1) Pure sample of antineutrinos
2) Antineutrinos plus neutrino contamination, both oscillating and identified by the muon charge
3) With neutrino not oscillating
4) Without muon charge identification



3 years (6.6 x 10^{20} pot)

Conclusions and perspectives

- Sterile mixing angle, if it exists, corresponds to low values (order of 1%)

- The sterile issue at eV mass scale can be studied also at **LBL** ν_μ beams
- Many results from OPERA, MINOS, Super-K are already available
- New preliminary result from OPERA on possible ν_τ sterile "anomalies"
  Soon new results (without too restrictive assumptions) from OPERA on ν_e oscillation
- New results from MINOS/MINOS+ on ν_e and ν_μ oscillation

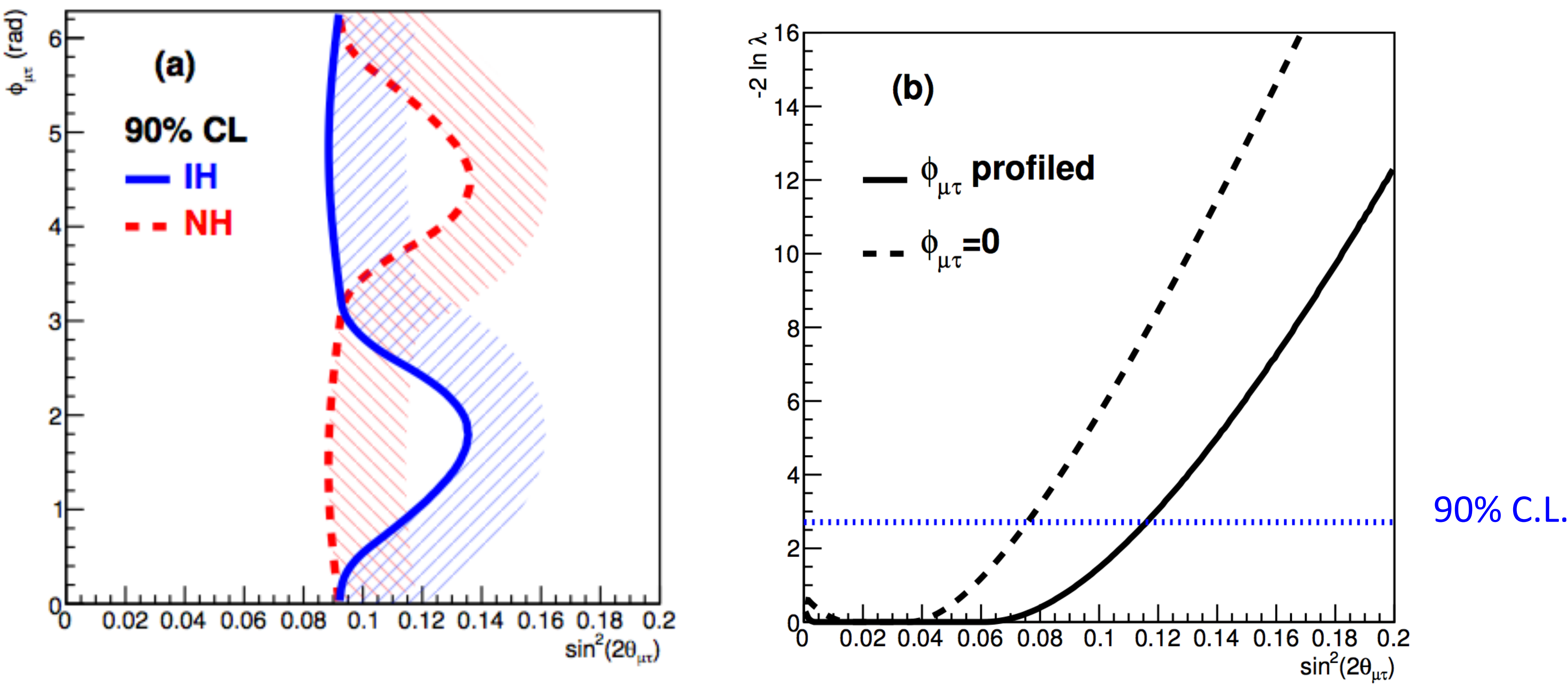
- **SBL** project at FNAL: technologically challenging, physically limited
- Necessary to do an experiment on ν_μ disappearance,
  exploiting high statistics ("brute force") and muon ID

- We urge results in next 2-3 years from on-going projects
- New specific experiments should be settled and approved

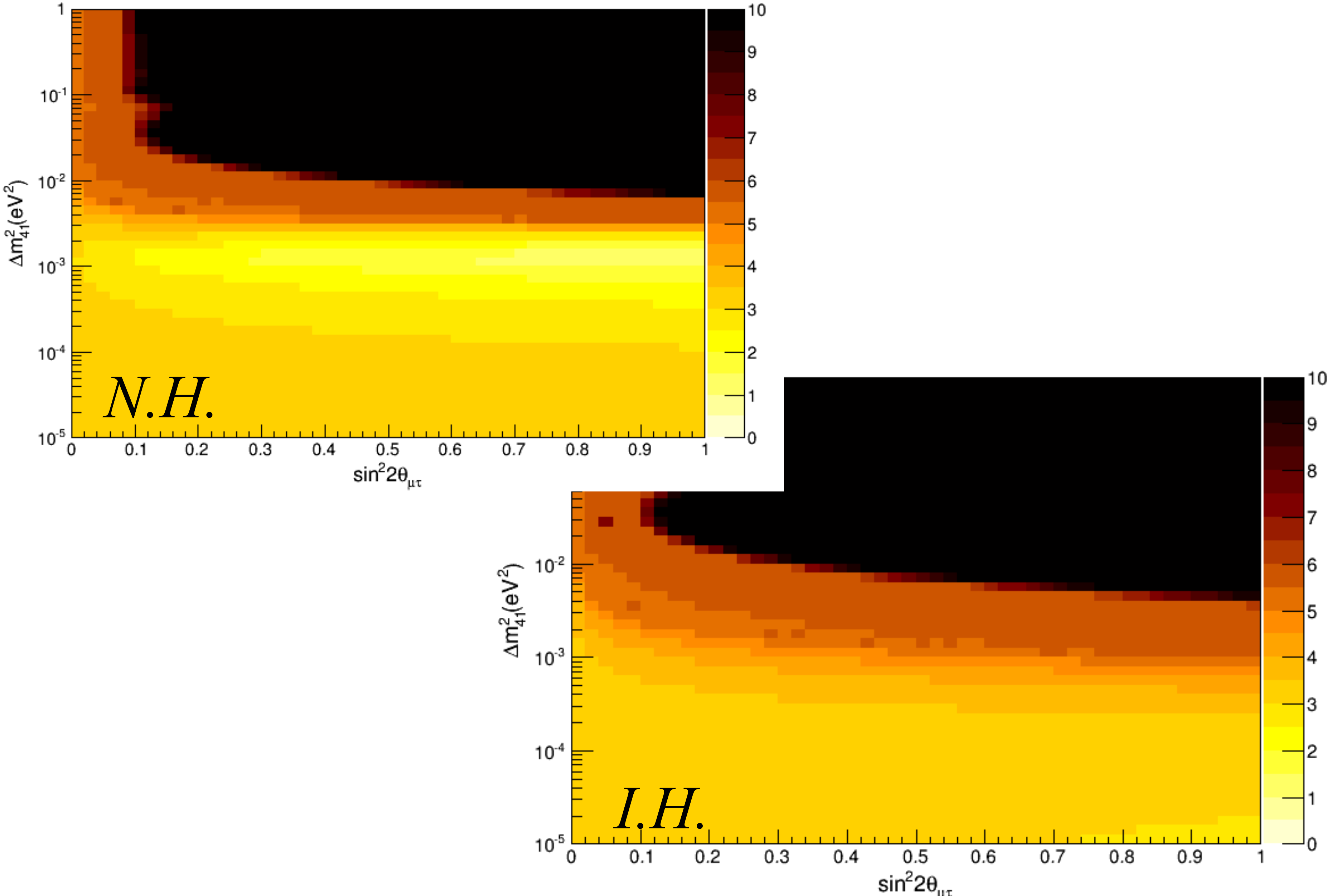
BACKUP

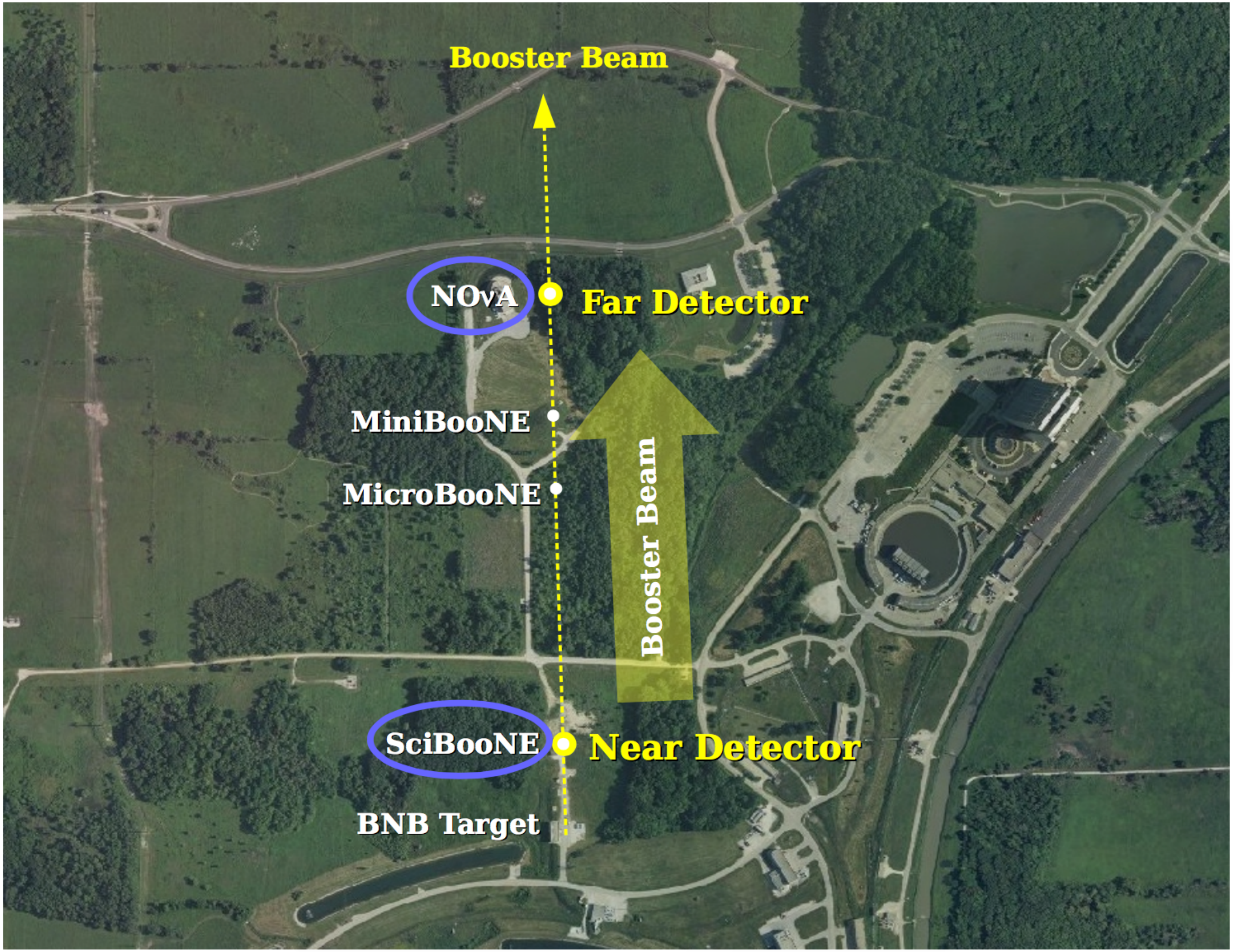
OPERA search for ν_τ sterile "anomalies"

JHEP, 6, 69 (2015) and arXiv:1503.01876, based on 4 taus' candidates



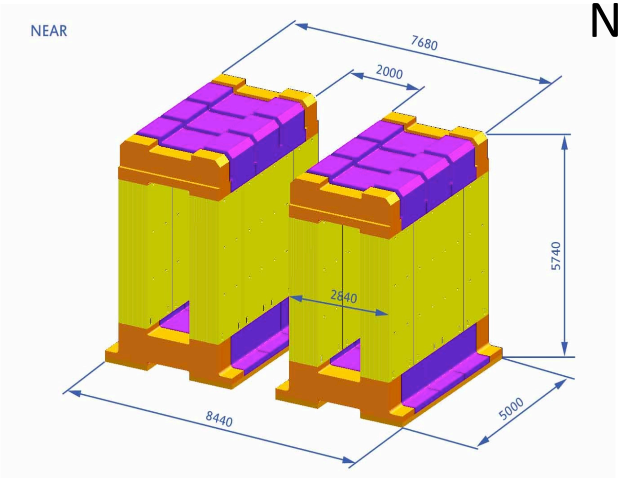
Number of expected ν_τ sterile events

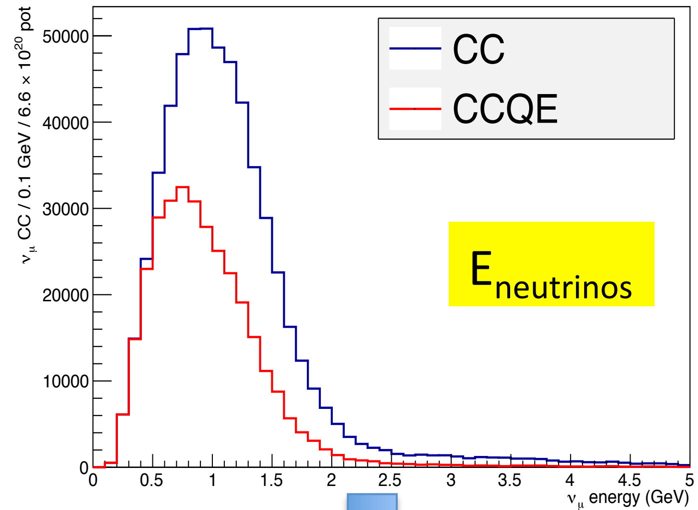




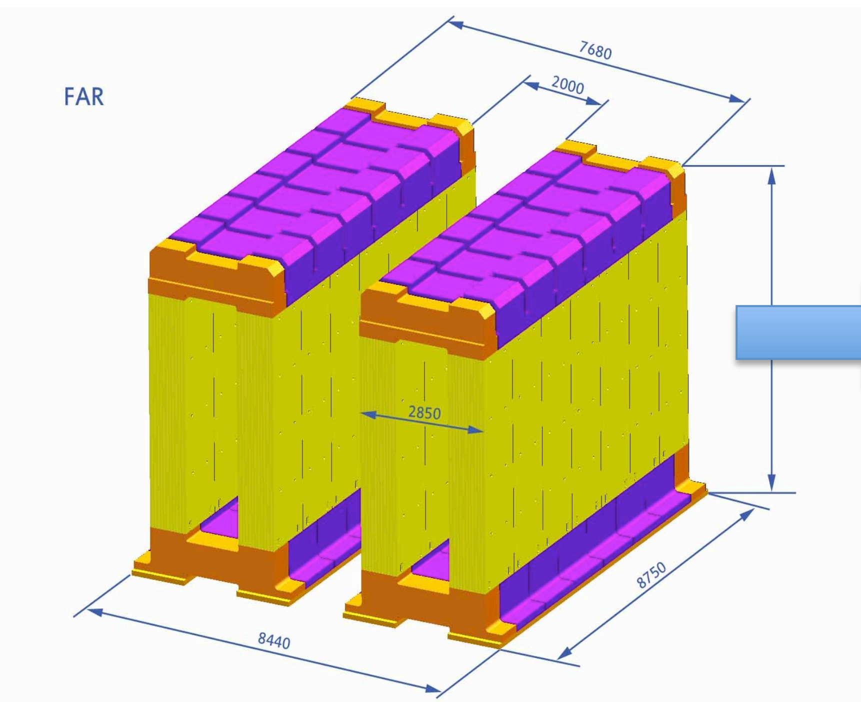
Proposal: **FNAL-P-1057, arXiv:1404.2521, arXiv:1503.07471v2**

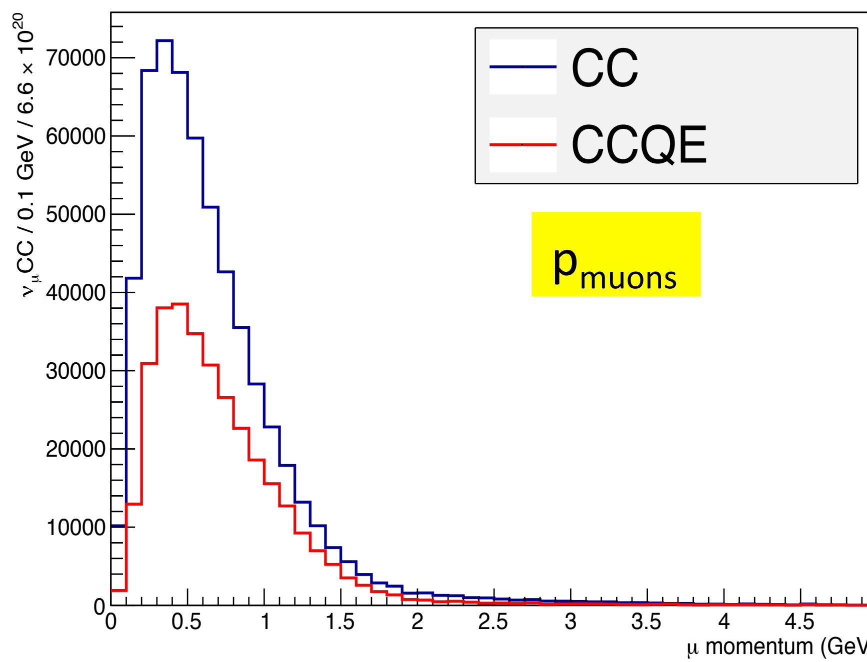
Near site





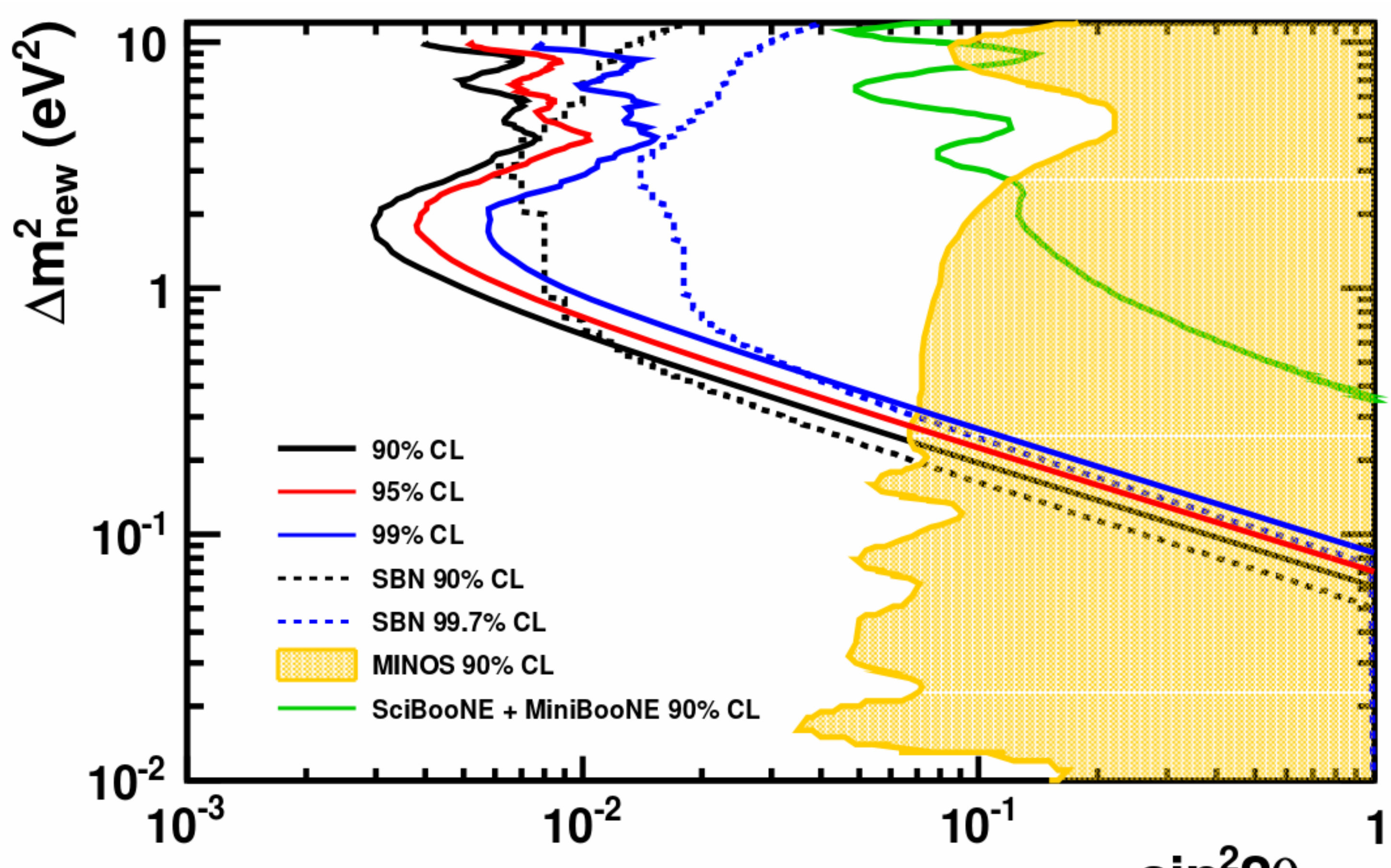
Far site





ABSOLUTE nb. interactions in the FAR fiducial volume, 3 years data taking

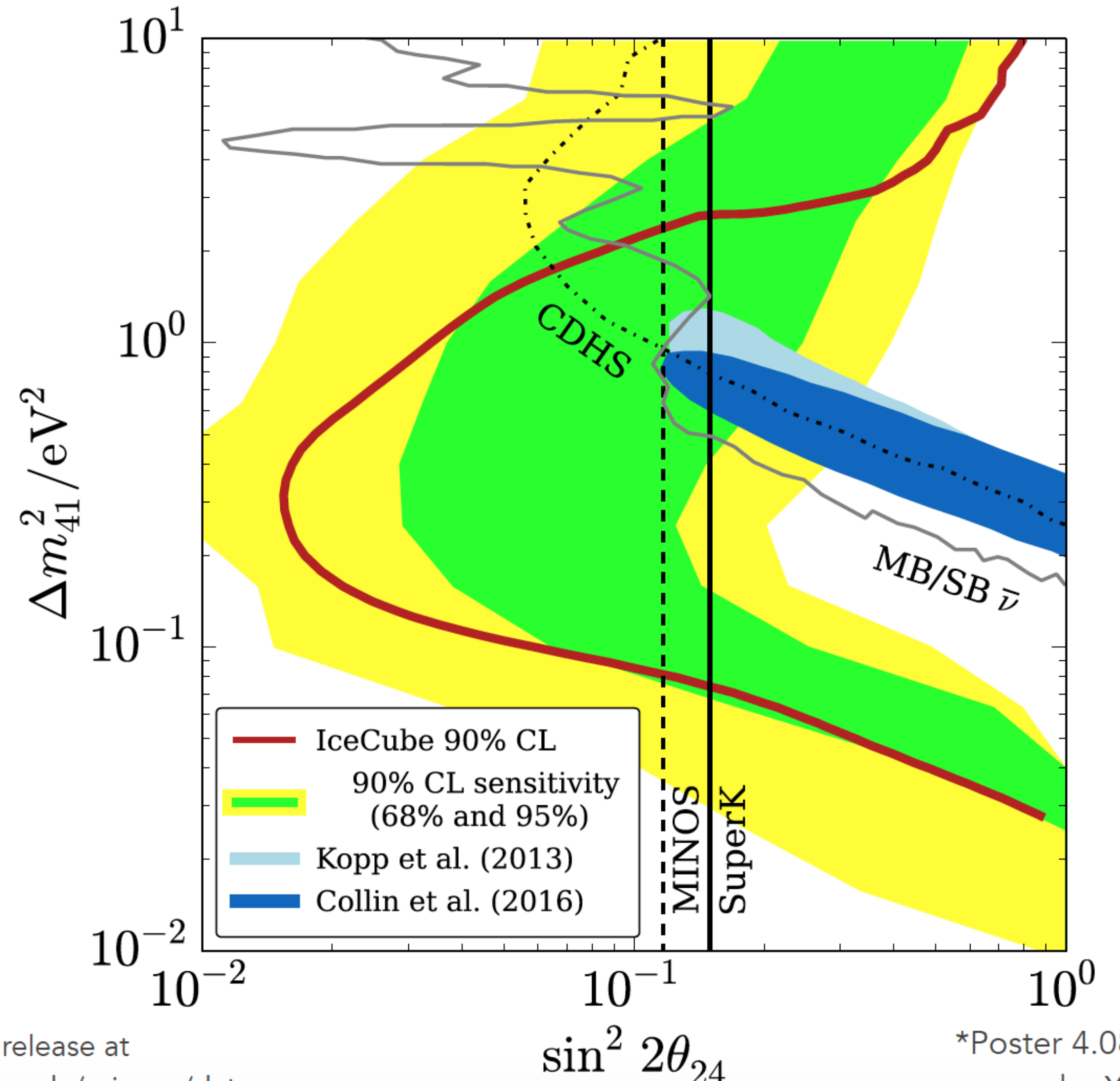
Compare Sensitivities at 90% C.L.



3 years (6.6 x 10^{20} pot)

IceCube new ν Sterile Results

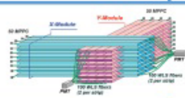
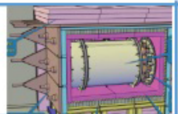
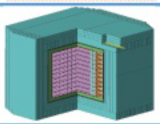
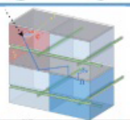
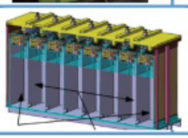
D. Jason Koskinen@Neutrino2016



ıta release at
wisc.edu/science/data

*Poster 4.088
and arXiv

Next generation sterile (reactor/source) experiments are almost ready

Experiment	Reactor Power/Fuel	Overburden (mwe)	Detection Material	Segmentation	Optical Readout	Particle ID Capability
DANSS (Russia) 	3000 MW LEU fuel	~50	Inhomogeneous PS & Gd sheets	2D, ~5mm	WLS fibers.	Topology only
NEOS (South Korea) 	2800 MW LEU fuel	~20	Homogeneous Gd-doped LS	none	Direct double ended PMT	recoil PSD only
nuLat (USA) 	40 MW ^{235}U fuel	few	Homogeneous ^{6}Li doped PS	Quasi-3D, 5cm, 3-axis Opt. Latt	Direct PMT	Topology, recoil & capture PSD
Neutrino4 (Russia) 	100 MW ^{235}U fuel	~10	Homogeneous Gd-doped LS	2D, ~10cm	Direct single ended PMT	Topology only
PROSPECT (USA) 	85 MW ^{235}U fuel	few	Homogeneous ^{6}Li-doped LS	2D, 15cm	Direct double ended PMT	Topology, recoil & capture PSD
SoLid (UK Fr Bel US) 	72 MW ^{235}U fuel	~10	Inhomogeneous ^{6}LiZnS & PS	Quasi-3D, 5cm multiplex	WLS fibers	topology, capture PSD
Chandler (USA) 	72 MW ^{235}U fuel	~10	Inhomogeneous ^{6}LiZnS & PS	Quasi-3D, 5cm, 2-axis Opt. Latt	Direct PMT/ WLS Scint.	topology, capture PSD
Stereo (France) 	57 MW ^{235}U fuel	~15	Homogeneous Gd-doped LS	1D, 25cm	Direct single ended PMT	recoil PSD

e.g. SOX at LNGS (Borexino)