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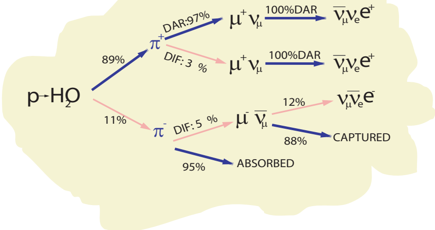
(Light) Sterile Neutrinos

Anomalies
Fits to Steriles
Approved new experiments
Longer term initiatives

LSND at the Los Alamos LAMPF (1993 - 1998)

A 3.8 σ evidence of $\overline{\nu}_e$ appearance in a ν beam produced by pion decays at rest

A naturally $\overline{\nu}_e$ poor beam where backgrounds modelled by MC are not dominant

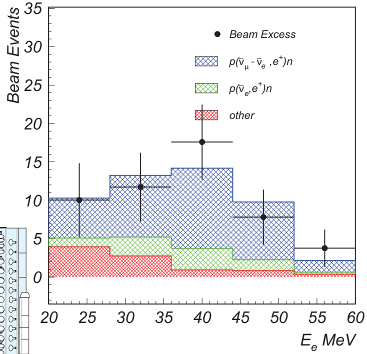


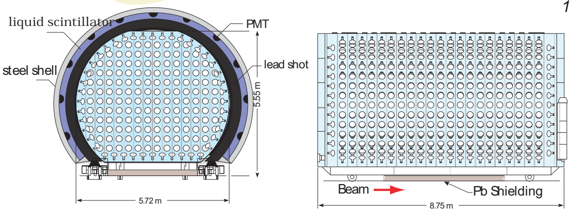
prompt positron signal, energy range.

$\overline{\nu}_e p \quad e^+ n$

$n + p \; \underset{\tau \simeq 186\,\mu s}{-} \; d + \gamma (2.2\ MeV)$

delayed correlated photon.





Checks of LSND

Karmen experiment

Conceptually the same experiment
In the same years
Smaller statistics
Smaller L/E
Better bck control thanks to the beam timing
No $\overline{\nu}_e$ excess detected
A combined analysis of LSND and Karmen doesn't change the LSND signal region
Phys.Rev. D66 (2002) 013001

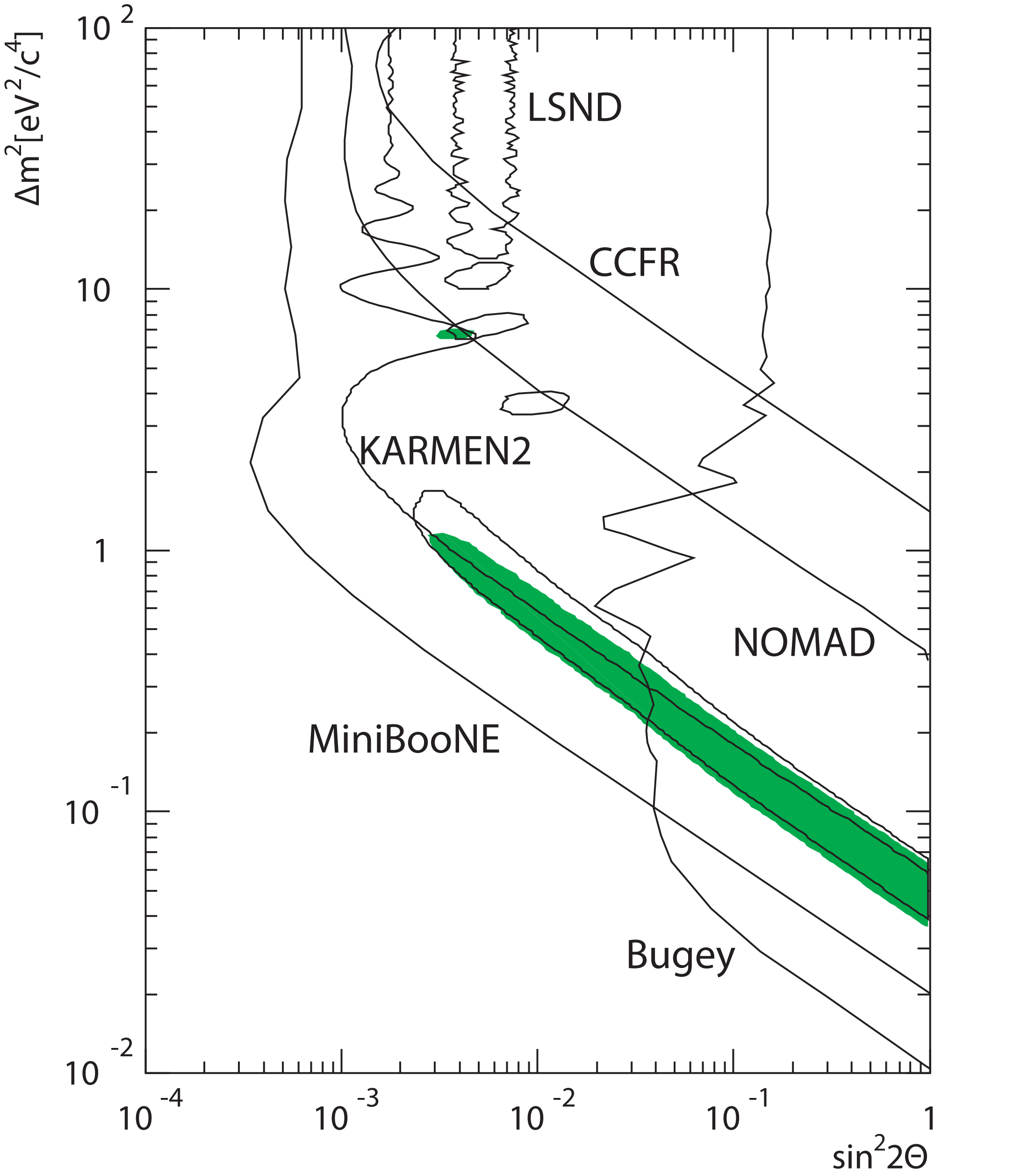
Background re-evaluation

Bolshakova et al., Phys.Rev. D85(2012) 092008

New measure of pion production in water
New evaluation of background processes →

LSND evidence: 3.8σ → 2.3 σ

But have a look to the LSND replica in arXiv:1112.2181

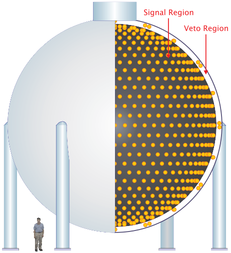


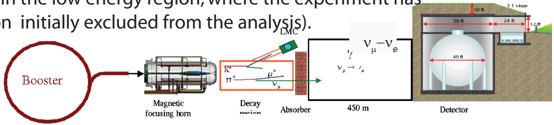
MiniBooNE at FNAL Booster (2002-2013)

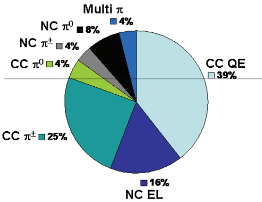
A check of LSND in a conventional neutrino beam. A completely different set of backgrounds and systematics

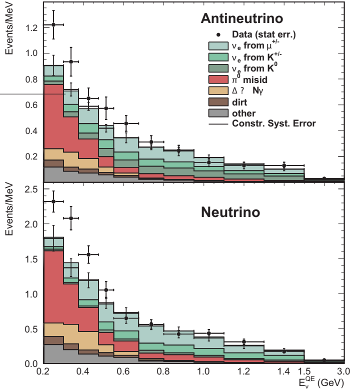
Overall a 3.8 σ excess of events. Mostly in the low energy region, where the experiment has poor control of the backgrounds (region initially excluded from the analysis).

MiniBooNE Detector





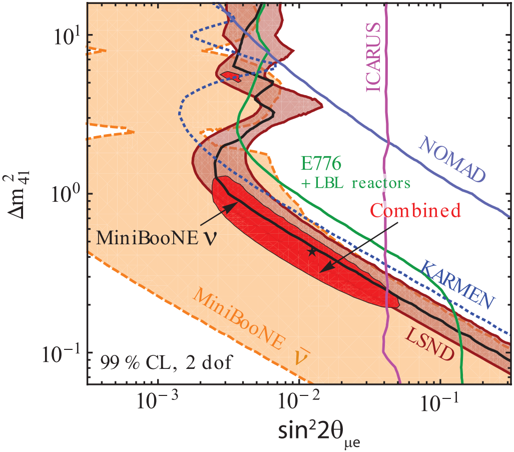




Property	LSND	MiniBooNE
Proton Energy	798 MeV	8000 MeV
Proton Intensity	1000 μA	4 μA
Proton Beam Power	798 kW	32 kW
Protons on Target	28,896 C	284 C
Duty Factor	6×10^{-2}	8×10^{-6}
Total Mass	167 t	806 t
Neutrino Distance	30 m	541 m
Events for 100% $\nu_\mu - \nu_e$ Transmutation	33,300	128,077

Global fits to appearance experiments

Kopp et al., JHEP 1305 (2013) 050 [arXiv:1303.3011]



Note that MiniBooNE ν is not even a signal region
Icarus limit different from the published limit (here is computed in a full 3+1 model)

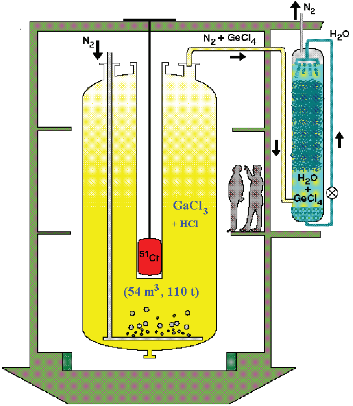
Also Opera published a similar limit

Gallium Anomaly

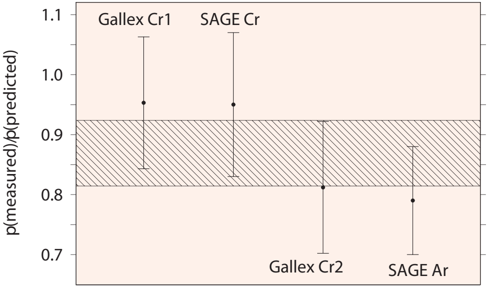
Hampel et al 1998, Kaether et al 2010, Abdurashitov et al 1998, Abdurashitov et al 2005

4 exposures of Gallex and Sage to ^{51}Cr and ^{37}Ar sources
Originally designed and funded as calibration of the detection efficiency

Now interpreted as neutrino disappearance at 2.9 std (assuming perfect calibration)



Giunti, Laveder, Mod. Phys. Lett. A22 (2007)2499



Reactor Neutrino Anomaly

Nuclear reactors: electron spectra from ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu are translated to $\overline{\nu}_e$ flux

Schreckenbach 82, 85

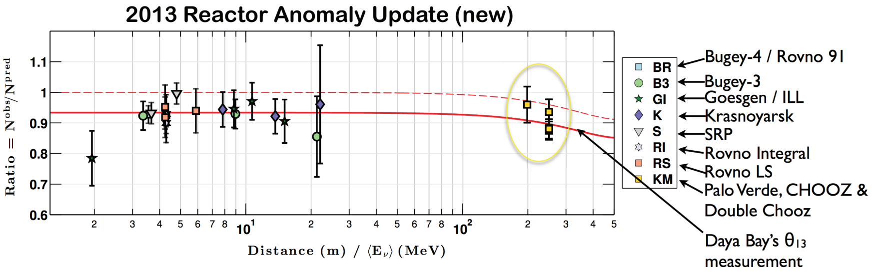
Experiments originally reported no deviations from predictions

A recalculation of fluxes lead to ~ 3% increase -> exp. results reinterpreted as a deficit evidence

Müller et al 2011, Huber 2011

Maybe with ~5% systematic errors

Hayes et al., arXiv 1309.4146

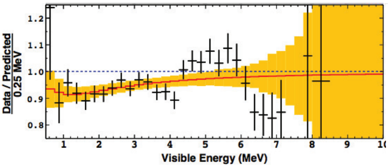


- **2013 result: μ = 0.936 ± 0.024, 2.7σ deviation from unity (T. Lasserre, TAUP 2013)**

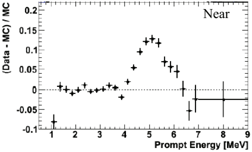
Reactor Anomaly and Systematic Errors

- The significance of reactor experiments heavily depends on the level of systematic errors of the computation of the antineutrino fluxes.
- In the original paper a 2.6% total flux uncertainty was assumed, other groups claimed a 5% error, but also the sharing between correlated and uncorrelated systematic errors can weaken the evidence of $\overline{\nu}_e$ disapperance at reactors.
- A direct measurement is certainly needed
- In the meantime long baseline reactor experiments reported a strong disagreement with predictions in a region where oscillations cannot work

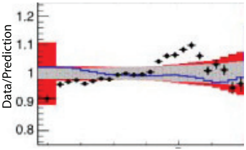
Double Chooz



Reno



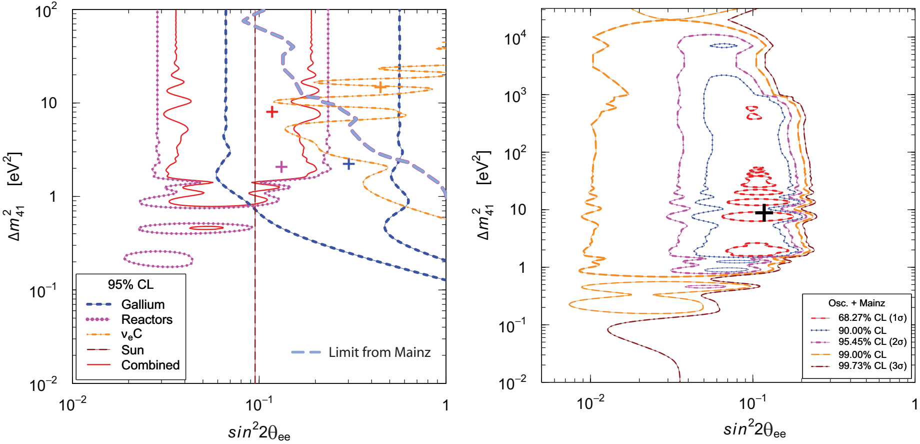
Daya Bay



Prompt positron Energy (MeV)

Global fits to disappearance experiments

Giunti et al., Phys.Rev. D86 (2012) 113014 [arXiv:1210.5715]



Modelling (the 3+1 case)

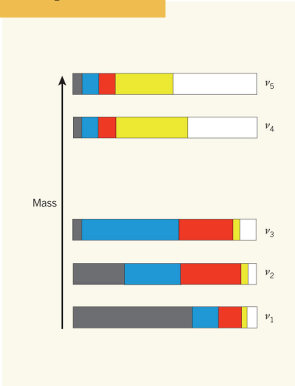
$$P^{SBL}_{\overset{(-)}{\nu}_\alpha \overset{(-)}{\nu}_\beta} = \sin^2 2\theta_{\alpha\beta} \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

$$P^{SBL}_{\overset{(-)}{\nu}_\alpha \overset{(-)}{\nu}_\alpha} = 1 - \sin^2 2\theta_{\alpha\alpha} \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

$$\alpha,\beta = e,\mu,\tau,\ s$$

$$\sin^2 2\theta_{\alpha\beta} = 4|U_{\alpha 4}|^2 |U_{\beta 4}|^2\ ,$$

$$\sin^2 2\theta_{\alpha\alpha} = 4|U_{\alpha 4}|^2\ \ (1-|U_{\alpha 4}|^2$$



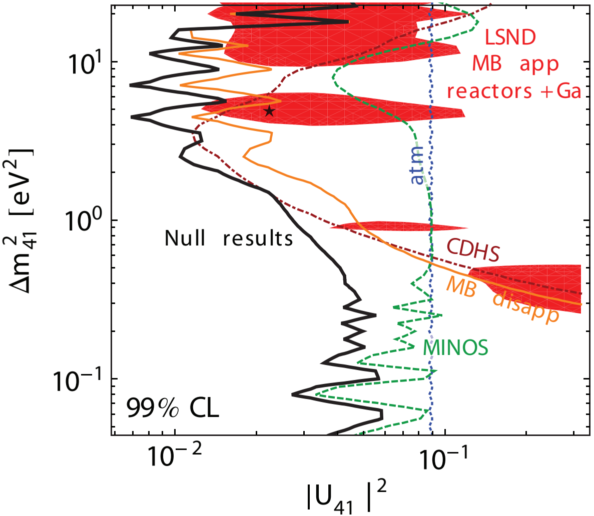
In a 3+1 model, oscillations depend from 2 additional mixing angles and 1 additional Δm^2 (assuming that steriles are much heavier than standard neutrinos)

So ν_e appearance and disappearance are linked by ν_μ disappearance !

What about ν_μ disappearance?

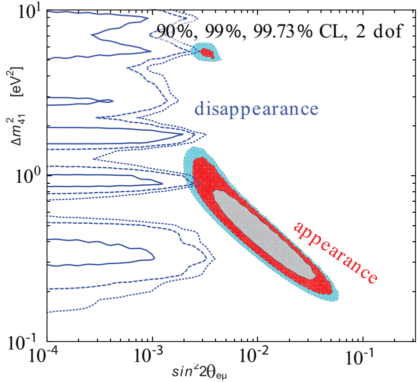
Null results from several different experiments, including atmoshperic neutrinos in SK

Kopp et al., JHEP 1305 (2013) 050 [arXiv:1303.3011]

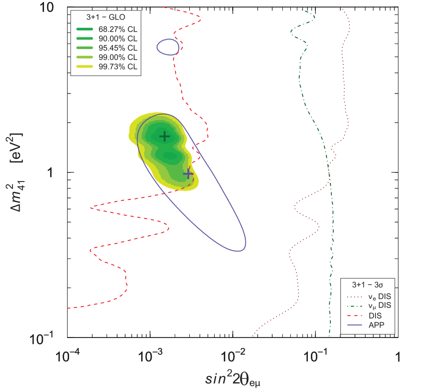


Global fits (3+1)

Kopp et al., JHEP 1305 (2013) 050 [arXiv:1303.3011]



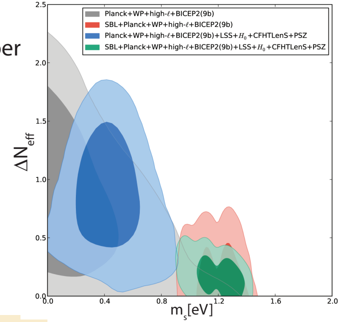
Giunti et al., Phys. Rev. D 88, 073008 (2013) [arXiv:1302.6720]



- Tension between appearance and disappearance results
- The appearance signal region is different in the two fits mainly because Giunti et al. consider MiniBooNE data with $E_\nu > 475$ MeV (M. Laveder, private communication)

Sterile neutrinos and Cosmology

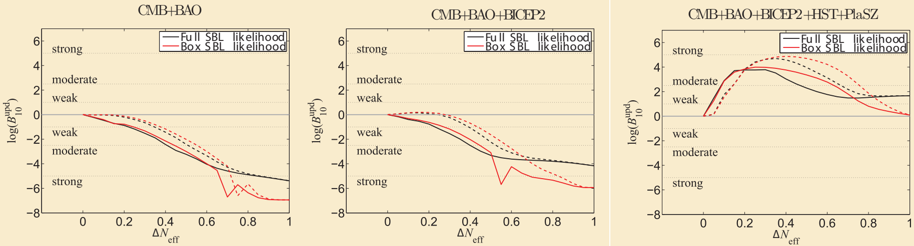
Archidiacono et al, arXiv:1404.1794



Cosmological data are sensitive to the number of neutrino species N_{eff} and to the sum of the masses of neutrinos Σm_i

A combined bayesian fit to short-baseline data and cosmology as function of ΔN_{eff}. Σm_i bounds are taken into account. Three different data sets are used.

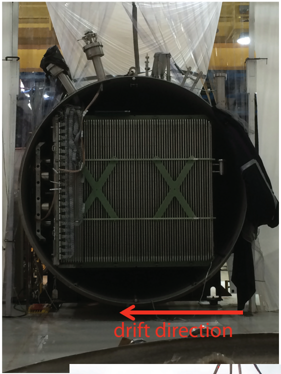
Bergstrom, Gonzalez-Garcia, Niro, Salvado, arXiv:1407.3806



Summarizing the present status

- $\sim 3\sigma$ anomalies in 4 different fields
- None of them is fully convincing by itself.
- They are marginally compatible, but the global picture is not convincing
- Cosmology is not more supporting the existence of a fourth neutrino.
- ... eighteen years after the first LSND paper ...
- ... but several new proposals are now coming to life.

MicroBooNE at FNAL



A 80 ton (fiducial) LAr TPC

At the same position of MiniBoone

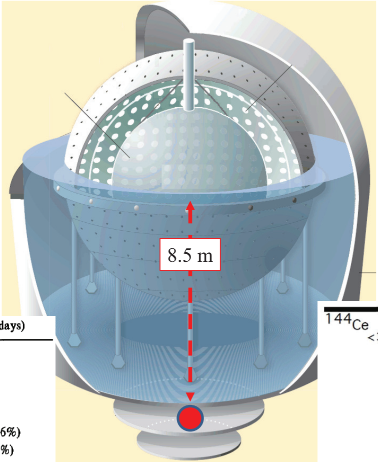
Goals: neutrino cross sections and analysis of the low E events of MiniBooNE (severely limited in statistics for oscillation analysis)

In discussion at FNAL a setup with a close detector at 100 m and Icarus at 600 m in addition to MicroBoone (470 m)

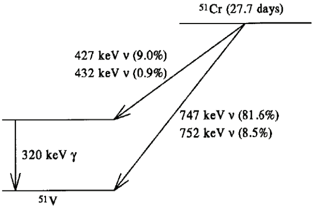
First neutrino interactions expected this winter.

Surface LAr TPCS are in big troubles at those energies :
see C. Rubbia arXiv:1408.6431

SOX (in Borexino)

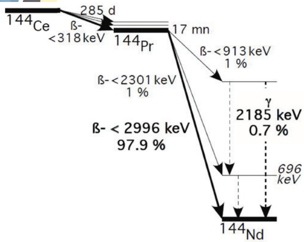


ν: Cr^{51}, 10 MCi



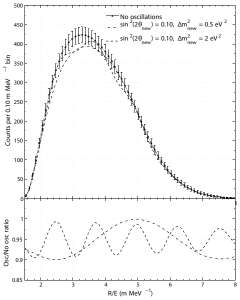
Decay scheme of ^{51}Cr to ^{51}V through electron capture.

$\bar{\nu}$: Ce^{144}, 0.1 MCi

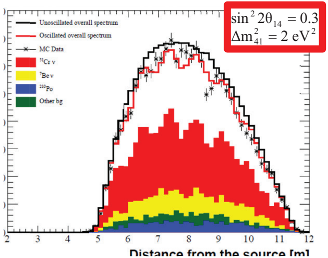


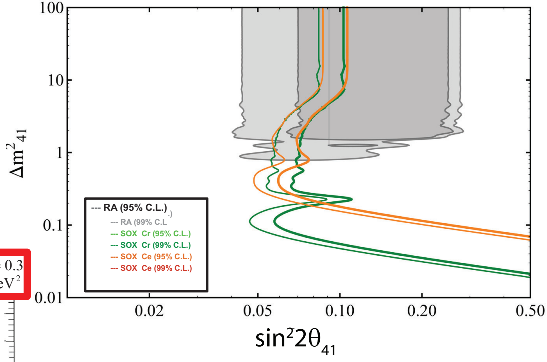
SOX Sensitivities

Cerium source



Cromium source





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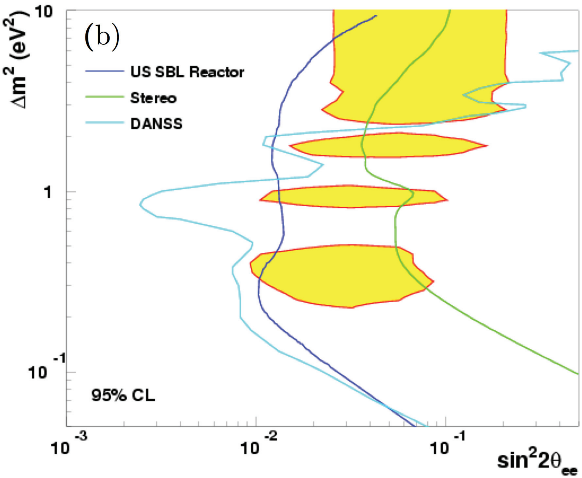
Reactor ν Proposals

Experiment Type	Projects	P_{Th}	M_{det}	L	Depth
Mature Gd-doped LS detector Technology	Nucifer (FRA)	70 MW	0.7 tons	7 m	Few mwe
	Stéréo (FRA)	50 MW	2 tons	[8-11] m	10 mwe
	Neutrino 4 (RU)	100 MW	2 tons	[6-12] m	Surf.
Highly segmented detector for background reduction	DANSS (RU)	1 GW	1 ton	[10-12] m	50 mwe
	SoLid (UK)	45-80 MW	3 tons	8 m	10 m
Enhanced neutron Tagging					
	Hanaro (KO)	30 MW	0.5 t	6 m	Few mwe
2 detector complex or Moving detector	Prospect	85 MW	-	7m & 18m	Surf.
	China project	-			
	DANSS/Neutrino4	Movable detector			

Th. Lasserre – NOW 2014

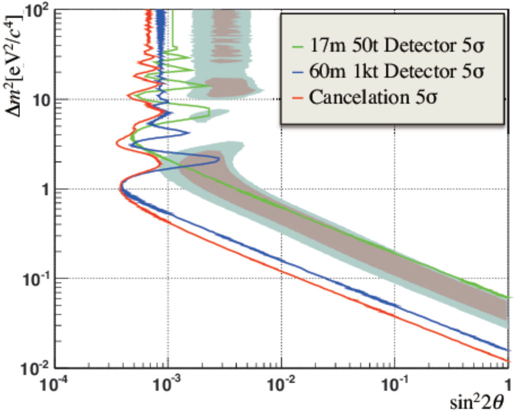
Reactor experiment sensitivity

arXiv:1310.4340

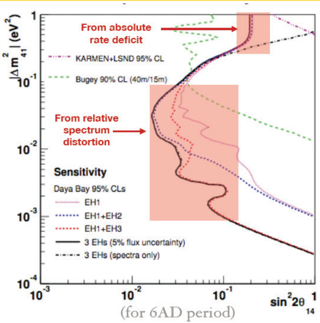


LSND replica at J-PARC MLF

Proposal in arXiv:1310.1437, signed by JPN and Los Alamos
First phase (approved): 25 ton detector at 17 m from the target
Second phase: 1 kton detector at 60 m

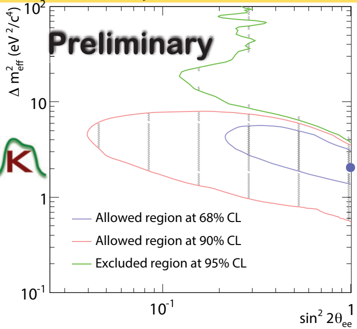


Running Experiments with Sensitivity to Steriles



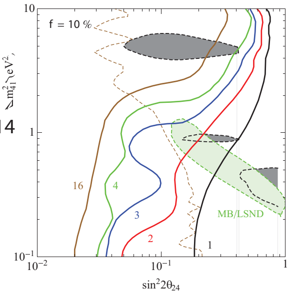
Daya Bay

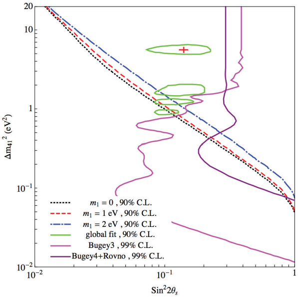
T2K



ICE Cube

Esmaili, Smirnov, JHEP 1312 (2013) 014





Katrin

Expected results from the next generation of experiments

Can falsify the anomalies?
LSND will remain almost unchallenged

Can falsify steriles (3+1)?
A convincing null result in ν_e disppearance, combined with the present null results on ν_μ disappearance, would almost destroy the 3+1 model (the same holds for 3+2 etc.)

Can confirm the anomalies?
Not at 5 σ

Can claim to have discovered steriles? The only convincing signature of sterile neutrinos in this generation of experiments is an oscillation pattern in the source experiments. Which probably will be only partial. And not at 5 σ.

Let's briefly discuss the requirements of an ultimate experiment of steriles under the assumption that steriles exist.

Experimental Goals

- Bring anomalies to evidences or get rid of them definitely.
- Provide a "Smoking Gun" signature of oscillations: close detectors or oscillation pattern
- Demonstrate they are **sterile neutrinos**: NC disappearance.
- Measure in the same experiment all the steriles phenomenology: $\nu_\mu \to \nu_e$ transitions, ν_e disappearance (these two effects could conflict in an accelerator experiment), ν_μ disappearance
- Measure both $\nu_\mu \to \nu_e$ and $\overline{\nu}_\mu$ transitions: this allow to discriminate 3+1 from 3+2 (in other words count the number of sterile neutrinos) and in case measure CP violation

The 3 LAr detectors setup proposed at FNAL has several weak points (and physics doesn't call for a 3 detectors setup): no magnetic field to separate ν_μ from $\overline{\nu}_\mu$ (important for the beam normalization), poor ν_μ momentum reconstruction at the close detector that is too small to range them out or to measure multiple scattering, questionable capacity of providing a clean ν_e sample below 0.5 GeV.
Interesting new technologies:
IsoDAR arXiv:1205.4419.
NuStorm, arXiv:1308.0494.

Conclusions

We are facing four sets of anomalies, they have begun to show up 18 years ago and their case became stronger in the latest years (with a peak in 2011).

None of the hints is convincing by itself.

Nevertheless they can be accommodated by a single model (with some tension).

Would the model be true we had access to outstanding discoveries (new neutrino states beyond the standard model, CP violation)

This makes the physics case very interesting and a new experimental campaign to falsify the anomalies or make the discoveries is both imperative and urgent.

Several different initiatives will be operative in the next years exploring almost all the allowed possibilities and being open to surprises.