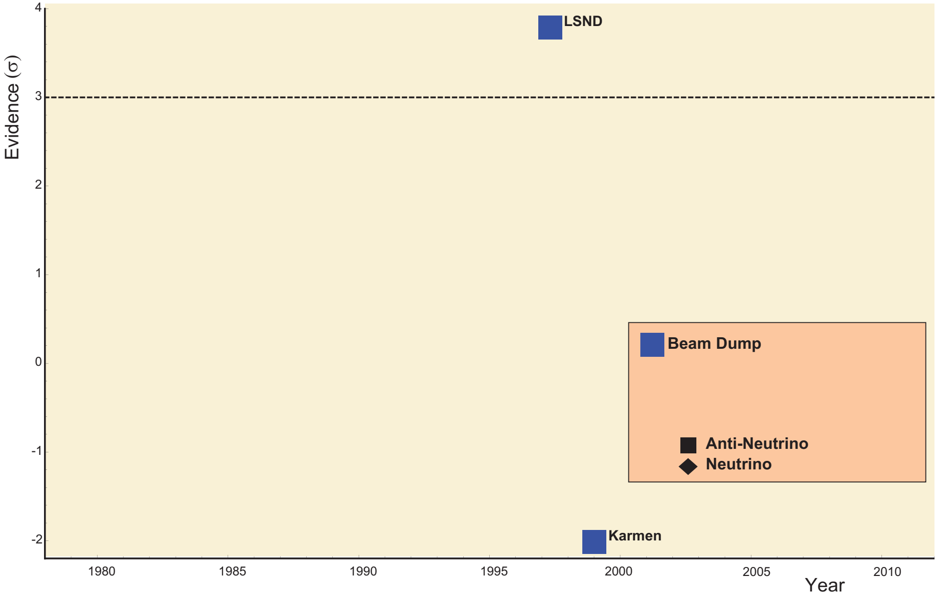
Mauro Mezzetto
Istituto Nazionale di Fisica Nucleare, Sezione di Padova

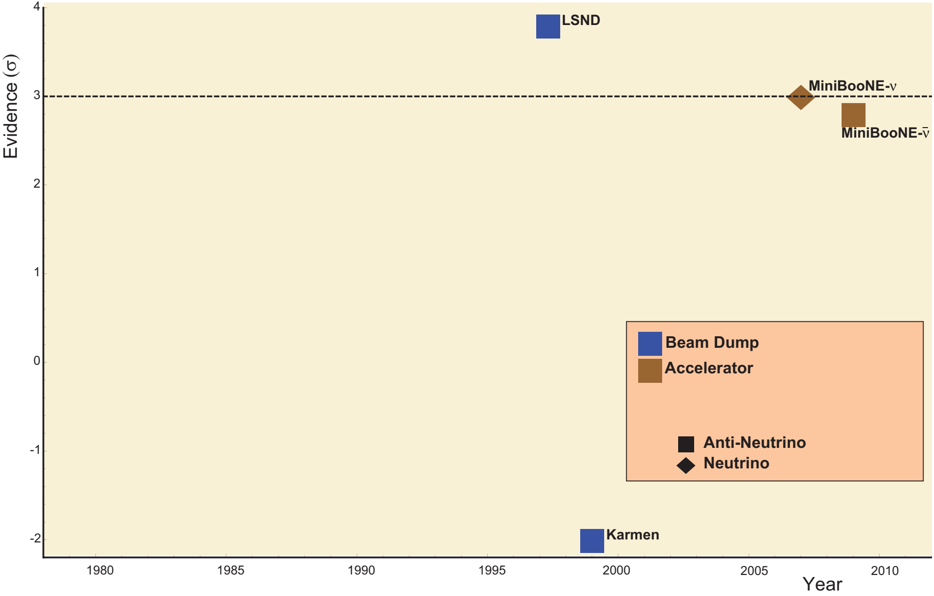
" Summary of Beyond3nu"

A personal point of view rather than a genuine summary, oriented to the "what next" physics program in Europe.

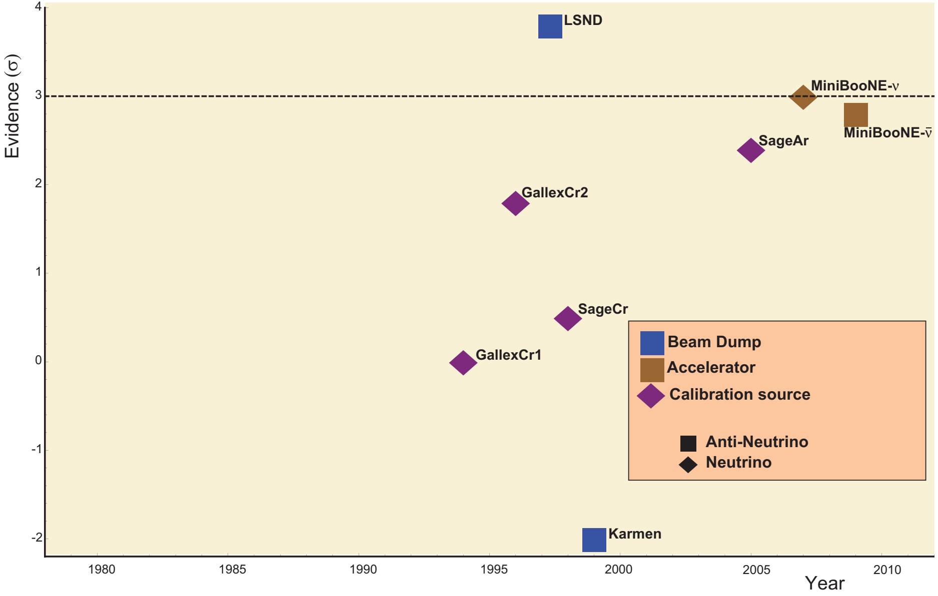
A long standing set of anomalies



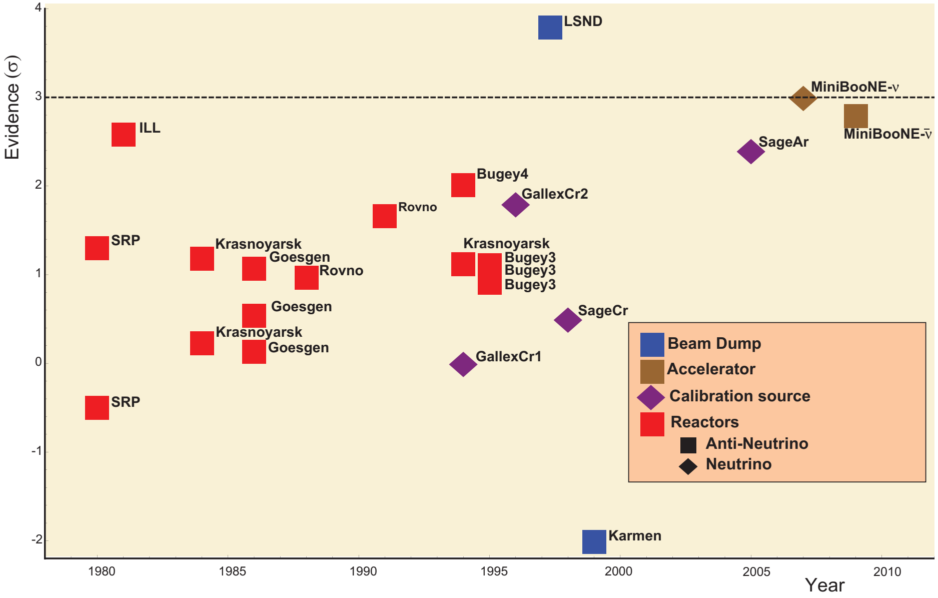
A long standing set of anomalies



A long standing set of anomalies

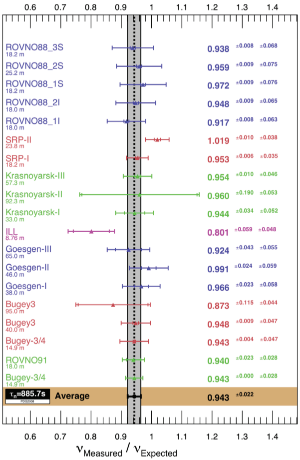


A long standing set of anomalies

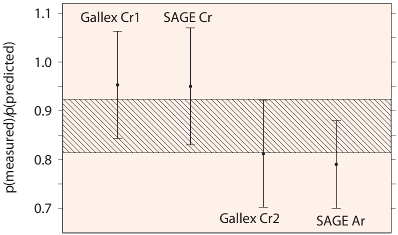


Summarizing

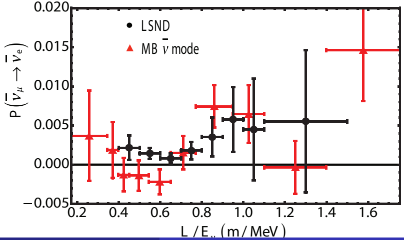
Reactors



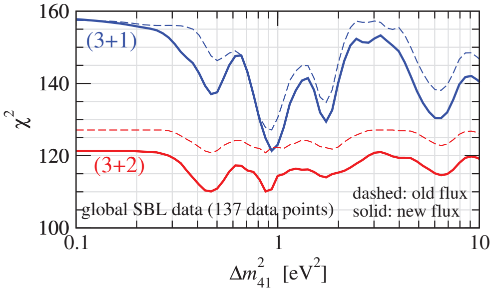
Sources



Accelerators



3+2 global fit



- $\Delta\chi^2_{3+2}$ (old vs new fluxes) = 11.1
- $\Delta\chi^2$ (3+1 vs 3+2) = 11.2 (97.6% CL, 4 dof)
  6.3 for old flux

Kopp, Maltoni, TS, 11

No evidence of steriles whatsoever

- Steriles are not necessary to build up $\nu_\mu \rightarrow \nu_e$ transitions or ν_e disappearance
- They are invoked to accommodate a fourth δm^2 faking the LEP limit on three neutrinos.

Experimental Goals

- Bring anomalies to evidences or get rid of them definitely.
- Demonstrate they are **sterile neutrinos**.
- Confirm the model
    - New neutrinos **are more than one**
    - **CP is violated.**
    - alternatively: NSI (non standard neutrino interactions), CPT violation, quantum decoherence . . . ..

The signature of Steriles

The main signature of steriles is **NC disappearance**

Looked for by SuperKamiokanDE and MINOS, whose limits are going to become interesting.

Possible only at accelerators (look at $P(\nu_\mu \to \nu_\mu)$ in the following)

Requires a detector capable to unambiguously select no-muon events and possibly to tag some NC exclusive topologies and need to be normalized by the ν_μ spectrum.

Mandatory to keep systematics at the 5% level or below

3+2 (3+1+1) models

The only model able to accommodate all the anomalies (plus the null signals from ν_μ ($\overline{\nu}_\mu$) disappearance) is 3+2 (3+1+1). More exotic possibilities are 3+1+NSI or 3+1+CPT.
Take note that even in 3+2 there is tension between appearance and disappearance results.
In the SBL approximation $\Delta m^2_{21} \approx \Delta m^2_{31} \approx 0$ (M.Maltoni, T.Schwetz, Phys. Rev. D76(2007)093005, [arXiv:0705.0107]):

$$P_{\nu_\mu \to \nu_e} = 4\,|U_{e4}|^2 |U_{\mu 4}|^2 \sin^2\phi_{41} + 4\,|U_{e5}|^2 |U_{\mu 5}|^2 \sin^2\phi_{51} + 8\,|U_{e4} U_{\mu 4} U_{e5} U_{\mu 5}| \sin\phi_{41} \sin\phi_{51} \cos(\phi_{54} - \delta)\,, \quad (1)$$

$$P_{\nu_\alpha \to \nu_\alpha} = 1 - 4\left(1 - \sum_{i=4,5} |U_{\alpha i}|^2\right) \sum_{i=4,5} |U_{\alpha i}|^2 \sin^2\phi_{i1} - 4\,|U_{\alpha 4}|^2 |U_{\alpha 5}|^2 \sin^2\phi_{54} \quad (2)$$

with the definitions

$$\phi_{ij} \equiv \frac{\Delta m^2_{ij} L}{4E}\,, \qquad \delta \equiv \arg\left(U^*_{e4} U_{\mu 4} U_{e5} U^*_{\mu 5}\right)\,. \quad (3)$$

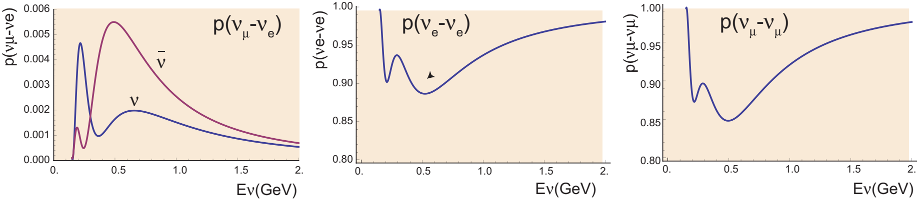
Eq. (1) holds for neutrinos; for anti-neutrinos one has to replace $\delta \to -\delta$.

3+2 best fit

J.Kopp, M.Maltoni, T.Schwetz, arXiv:1103.4570, T. Schwetz talk

Δm^2_{41}	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	Δm^2_{51}	$\lvert U_{e5}\rvert$	$\lvert U_{\mu 5}\rvert$	δ/π	χ^2/dof
0.47	0.128	0.165	0.87	0.1380	0.148	1.64	110.4/130

Baseline: 850 m



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Low energy excess in neutrino mode: effect of the interference term: the steriles are two (at least)! (It doesn't match the MB low energy excess.)

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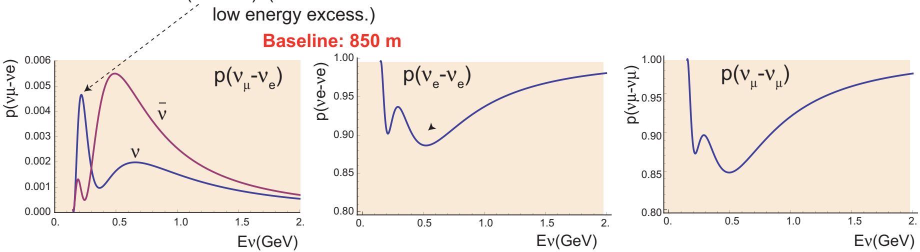

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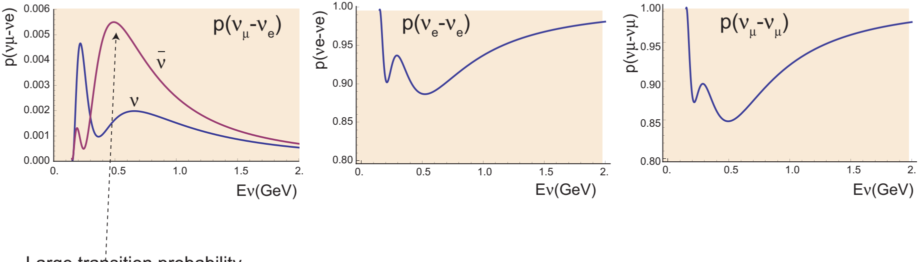

Large transition probability in the antineutrino mode

3+2 best fit

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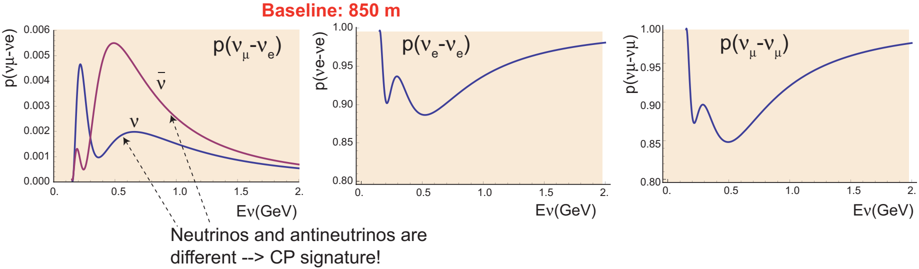

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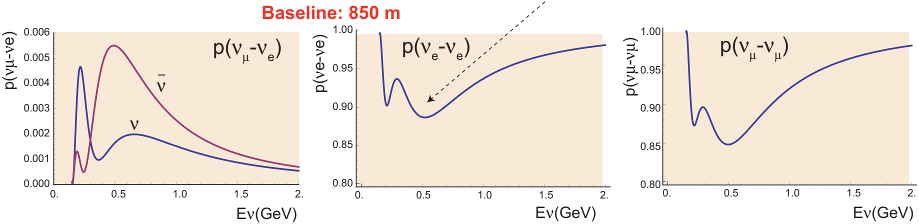
10% disappearance probability: smaller effect than appearance (νμ/νe=200). Very difficult to disentangle disappearance from appearance at accelerators!!



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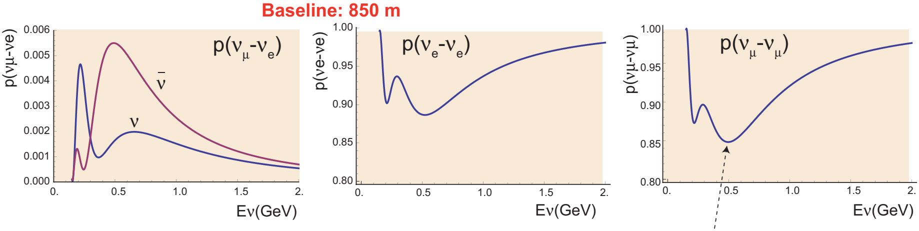

15% probability: spectacular effect once systematics are under control.
A null measurement would kill the model.
The same probability regulates NC disappearance

3+2 best fit

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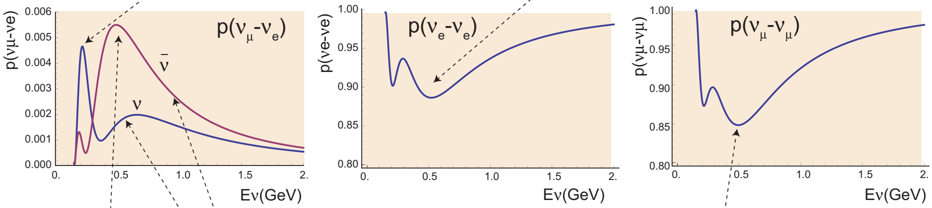


Neutrinos and antineutrinos are different --> CP signature!

Large transition probability in the antineutrino mode

15% probability: spectacular effect once systematics are under control.
A null measurement would kill the model.
The same probability regulates NC disappearance

Options for searches of 3+

Mixing with muon neutrinos at >1%:

Excluded by Matter effects

$$2 \cdot 10^{-3} < \Delta M^2 < 5 \cdot 10^{-3}\ eV^2$$

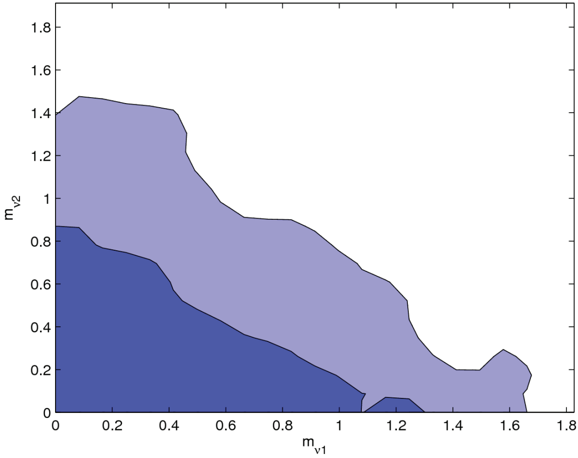
$$0.1 \lesssim \Delta M^2 \lesssim 1\ eV^2$$

SK, IceCUBE, Razaque & Smirnov

$$\sin^2\eta < 0.05$$

From Melchiorri talk

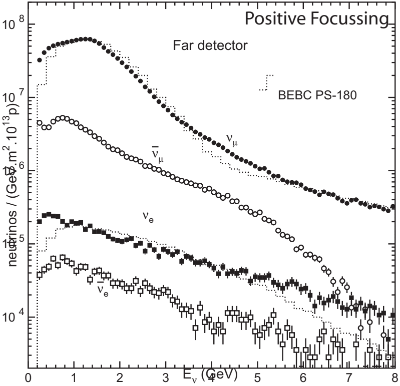
Preliminarly constraints from WMAP7 (only) for N_ν=5 case (3 active massless+2 steriles)



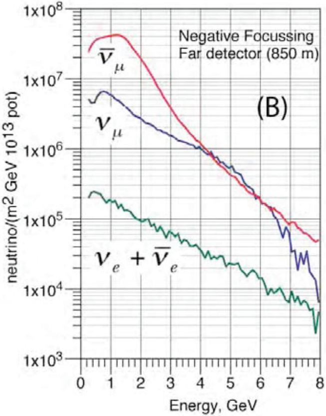
Archidiacono, Fornengo, Giunti, Melchiorri in preparation (2011 ?)

CERN-PS neutrino beam fluxes

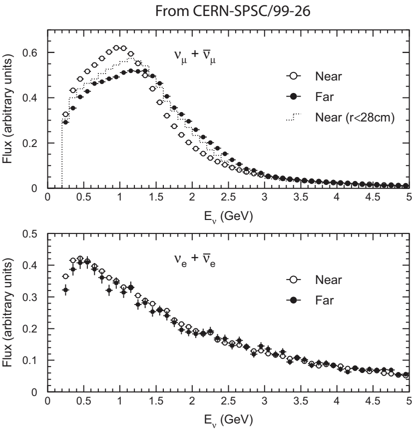
From CERN-SPSC/99-26

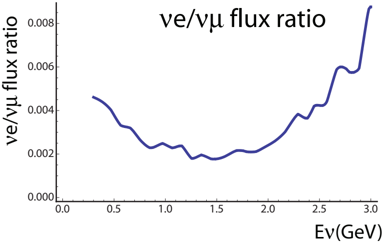


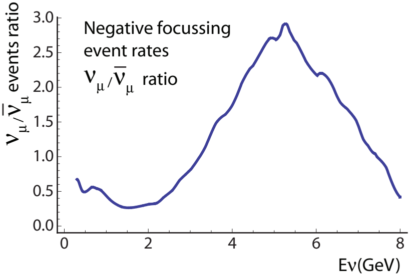
From Icarus Memorandum



CERN-PS neutrino beam ratios





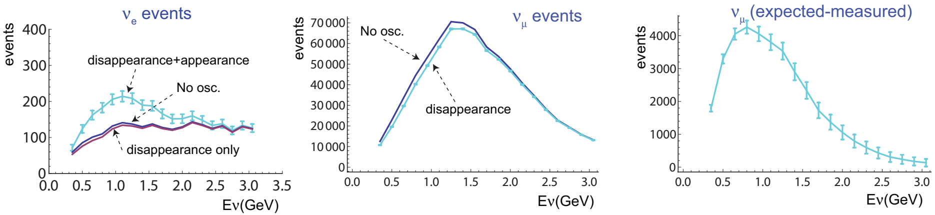


Signals at CERN-PS, neutrino mode

L=850 m, 100% detection efficiency, no backgrounds, no energy resolution smearing, statistical errors only.

$$2.5 \cdot 10^{20} \text{ pot (2 years at 30 kW)}$$

events	no-osc	Disa.	Disa. + App.
ν_e (0-2 GeV)	1294	1226	1877
ν_μ (0-1 GeV)	132503	117472	



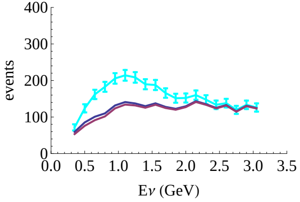
- ν_e excess well visible (ν_e appearance dominates over ν_e disappearance)
- ν_μ disappearance with a good signature
- Low energy ν_e excess missed (no beam below 250 MeV, at least in the simulation)

Effects at CERN-PS, anti-neutrino mode

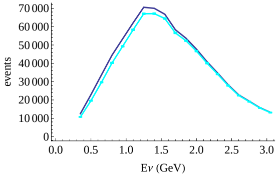
$3.75 \cdot 10^{20}$ pot (3 years at 30 kW)

events	no-osc	Disa.	Disa. + App.
ν_e (0-2 GeV)	1259	1197	1615
ν_μ (0-1 GeV)	111195	98419	

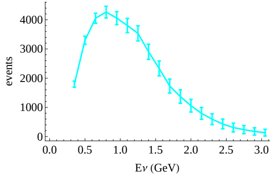
$\nu_e + \overline{\nu}_e$ events



$\nu_\mu + \overline{\nu}_\mu$ events

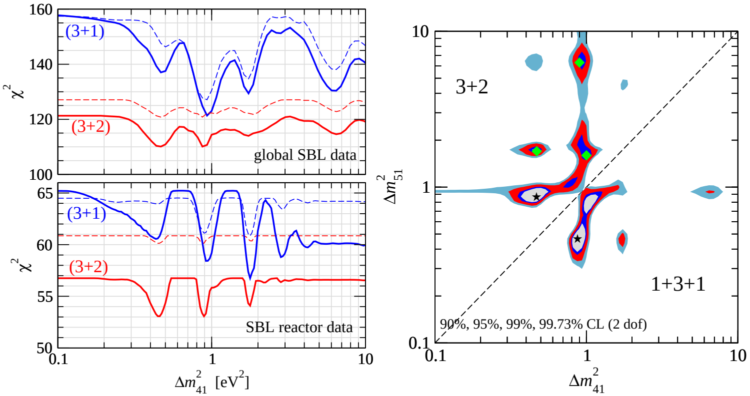


$\nu_\mu + \overline{\nu}_\mu$ (expected-measured)



Other 3+2 best fits

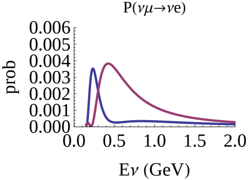
J.Kopp, M.Maltoni, T.Schwetz, arXiv:1103.4570, T. Schwetz talk

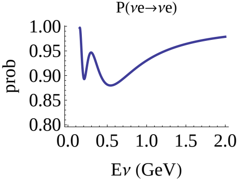


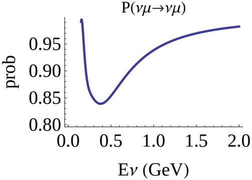
	Δm^2_{41}	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	Δm^2_{51}	$\lvert U_{e5}\rvert$	$\lvert U_{\mu 5}\rvert$	δ/π	χ^2/dof
1)	0.47	0.128	0.165	0.87	0.1380	0.148	1.64π	110.4/130
2)	0.47	0.117	0.201	1.70	0.1150	0.101	1.39	114.4/130
3)	1.00	0.133	0.162	1.60	0.151	0.078	1.48	114.4/130
4)	0.90	0.123	0.163	6.30	0.135	0.091	1.67	115.0/130

3+2 best fit point 2

Δm^2_{41}	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	Δm^2_{51}	$\lvert U_{e5}\rvert$	$\lvert U_{\mu 5}\rvert$	δ/π	χ^2/dof
0.47	0.117	0.201	1.70	0.1150	0.101	1.39	114.4/130

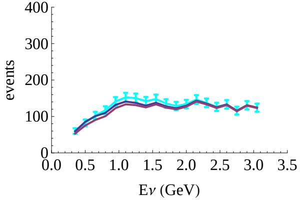




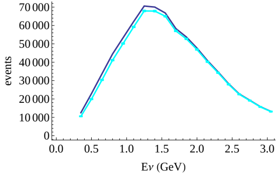


events	no-osc	Disa.	Disa. + App.
ν_e (0-2 GeV)	1294	1229	1375
ν_μ (0-1 GeV)	132503	119434	

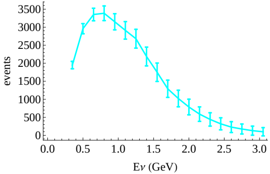
ν_e events



ν_μ events

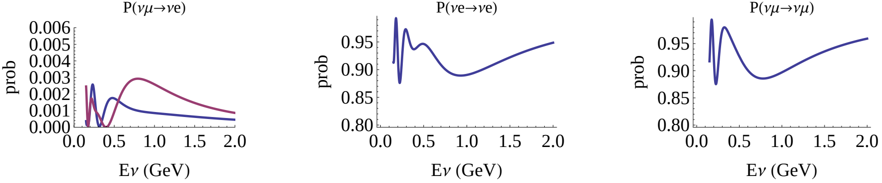


ν_μ expected-measured

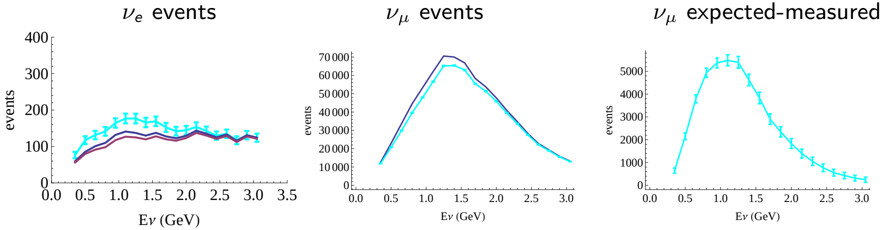


3+2 best fit point 3

Δm^2_{41}	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	Δm^2_{51}	$\lvert U_{e5}\rvert$	$\lvert U_{\mu 5}\rvert$	δ/π	χ^2/dof
1.00	0.133	0.162	1.60	0.151	0.078	1.48	114.4/130

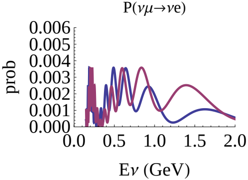


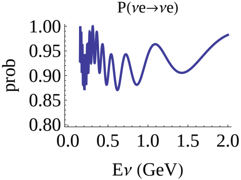
events	no-osc	Disa.	Disa. + App.
ν_e (0-2 GeV)	1294	1188	1625
ν_μ (0-1 GeV)	132503	119174	

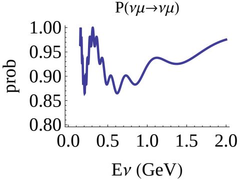


3+2 best fit point 4

Δm^2_{41}	$\|U_{e4}\|$	$\|U_{\mu4}\|$	Δm^2_{51}	$\|U_{e5}\|$	$\|U_{\mu5}\|$	δ/π	χ^2/dof
0.90	0.123	0.163	6.30	0.135	0.091	1.67	115.0/130

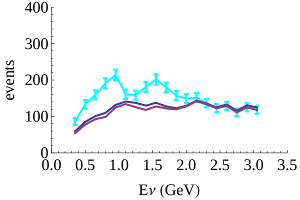




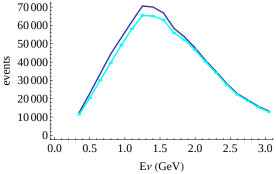


events	no-osc	Disa.	Disa. + App.
ν_e (0-2 GeV)	1294	1206	1835
ν_μ (0-1 GeV)	132503	119032	

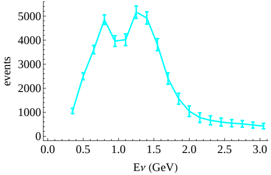
ν_e events



ν_μ events



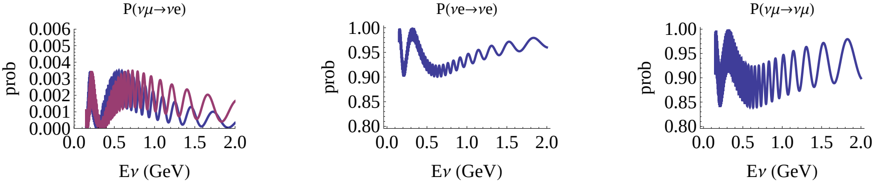
ν_μ expected-measured



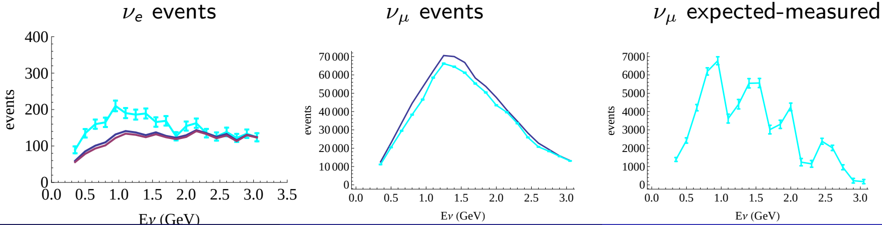
3+2 best fit by Karagiorgi

(Preliminary, talk at Laguna meeting, CERN, March 3-5/2011)

Δm^2_{41}	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	Δm^2_{51}	$\lvert U_{e5}\rvert$	$\lvert U_{\mu 5}\rvert$	δ/π	χ^2/dof
0.92	0.14	0.14	26.60	0.077	0.15	1.7	182.6/192

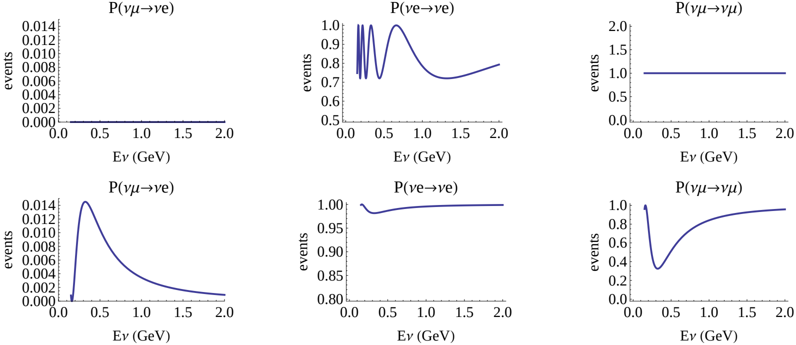


events	no-osc	Disa.	Disa. + App.
ν_e (0-2 GeV)	1294	1226	1797
ν_μ (0-1 GeV)	132503	115994	



3+1+CPT best fit (see C. Giunti talk)

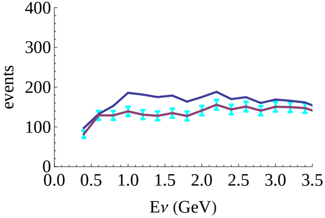
Δm^2_{41}	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	$\overline{\Delta m}^2_{41}$	$\lvert\overline{U}_{e4}\rvert$	$\lvert\overline{U}_{\mu 4}\rvert$
1.92	0.275	0.0	0.47	0.068	0.886



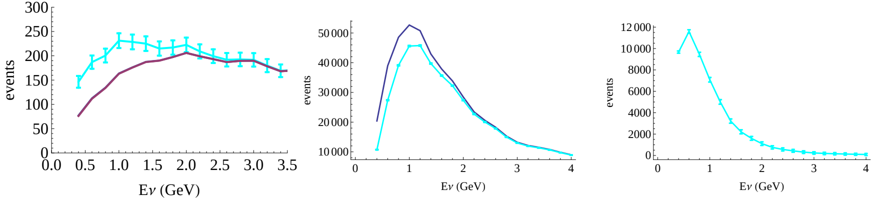
3+1+CPT best fit (see C. Giunti talk)

events		no-osc	Disa.	Disa. + App.
ν mode	ν_e (0-2 GeV)	1294	1024	1024
$\overline{\nu}$ mode	ν_e (0-2 GeV)	1260	1254	1699
$\overline{\nu}$ mode	ν_μ (0-1 GeV)	111195	78322	

Neutrino mode (positive focussing)



Antineutrino mode (negative focussing)



ν_e ($\overline{\nu}_e$) disappearance

At the accelerator ν_e and $\overline{\nu}_e$ disappearance could be canceled or suppressed by $\nu_\mu \rightarrow \nu_e$ ($\overline{\nu}_\mu \rightarrow \overline{\nu}_e$).

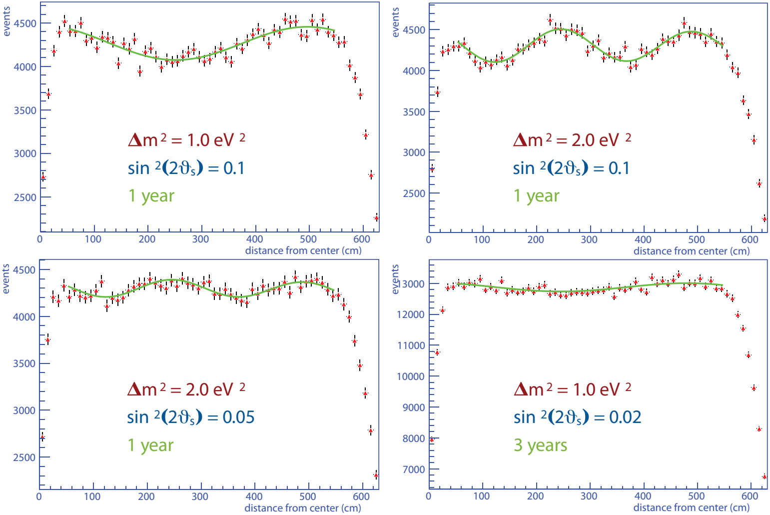
To complete the experimental program an independent measurement is required.

No progress possible with reactors since the errors are already dominated by flux uncertainties (maybe a measurement at L$<$10 m could be of interest anyway).

Strong physics case for the Borexino source.

Borexino Source

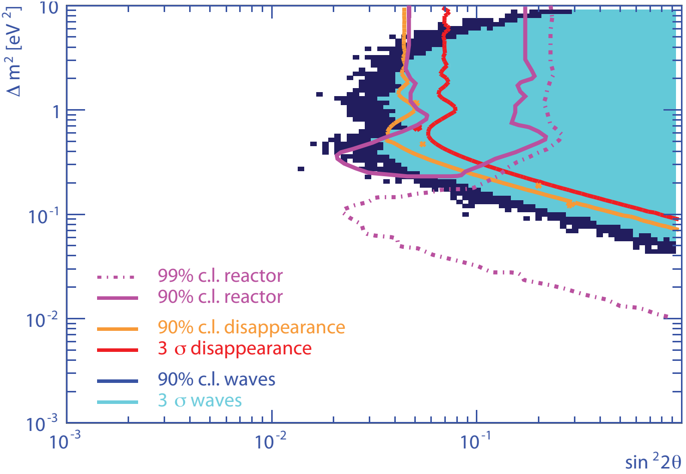
Examples with ^{90}Sr in the center



Borexino Source

^{90}Sr - Total rate and waves - Center

- 1 year, 1 MCi, R=6m, source in the center



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Conclusions (I)

We are facing four sets of anomalies, they have begun to show up 15 years ago and their case became stronger in the latest years.

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 both imperative and urgent.

The physics program must be as general as possible in order to explore all the allowed possibilities and be open to surprises. Indeed we can't trust the model too much and the predictions about the δm^2 are not that sharp.

Conclusions (II)

In Europe we have the extraordinary chance to have two powerful detectors, Icarus and Borexino, already built and running. We just need the neutrino sources, that appear to be not outraugeously expensive.

Their physics program looks genuinely complementary and they have the power to be conclusive.

Oversea competitors have aggressive programs too, a fast schedule (not impossible) is mandatory.

Sterile neutrinos appear to be a very prolific field of physics.