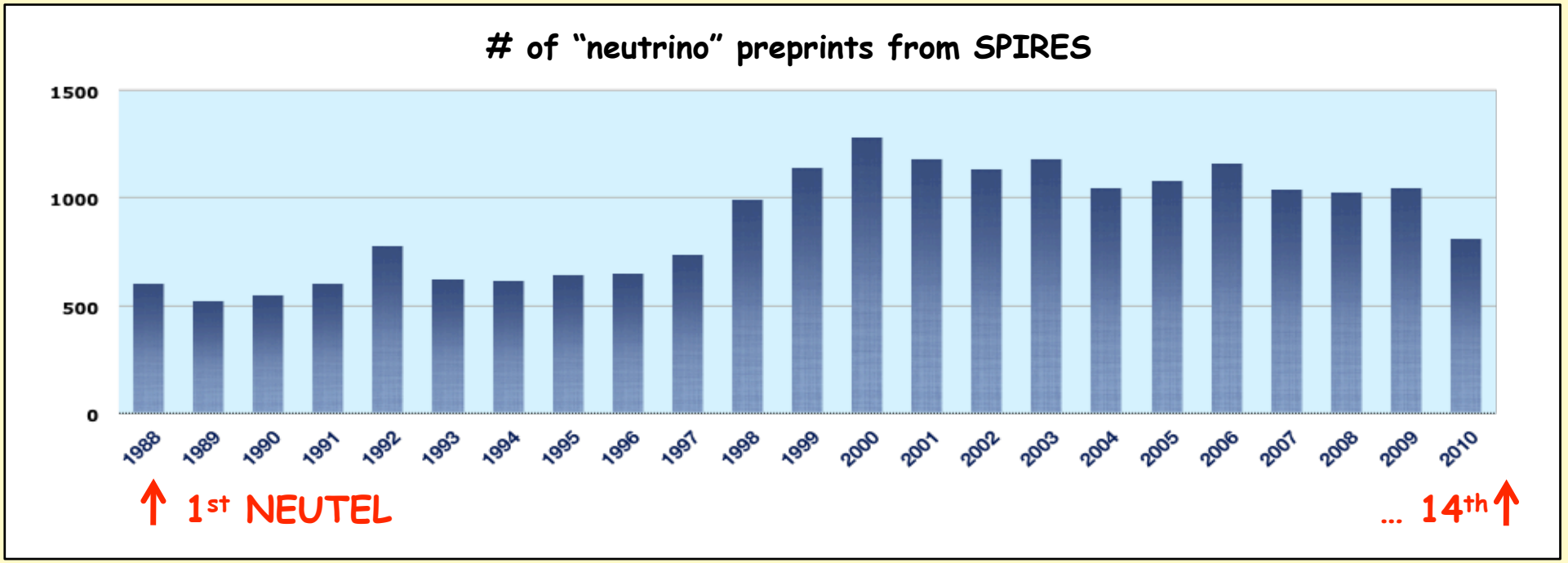
NEUTEL'11: Overview of ν phenomenology

Eligio Lisi
INFN, Bari, Italy

Based in part on work done in collab. with: Fogli, Marrone, Palazzo, Rotunno; Melchiorri et al.; Faessler and Simkovic.

PROLOGUE

In the last 23 years, the NEUTEL workshop series has witnessed great discoveries and tremendous progress in neutrino physics.
But also difficult times for the community – as in Japan, right now.



Beautiful experimental results [previous talk] have generated major **"peaks of interest"** in the field, establishing flavor oscillations at two different frequencies with surprisingly large amplitudes…

Frequency, amplitude

$(\delta m^2,\ \sin^2\theta_{12})$ ⟸ Established

$(\Delta m^2,\ \sin^2\theta_{23})$ ⟸ Established

$(\Delta m^2, \sin^2\theta_{13})$ ⟸ Constrained

⇩

Paradigm of "standard 3ν oscillations"

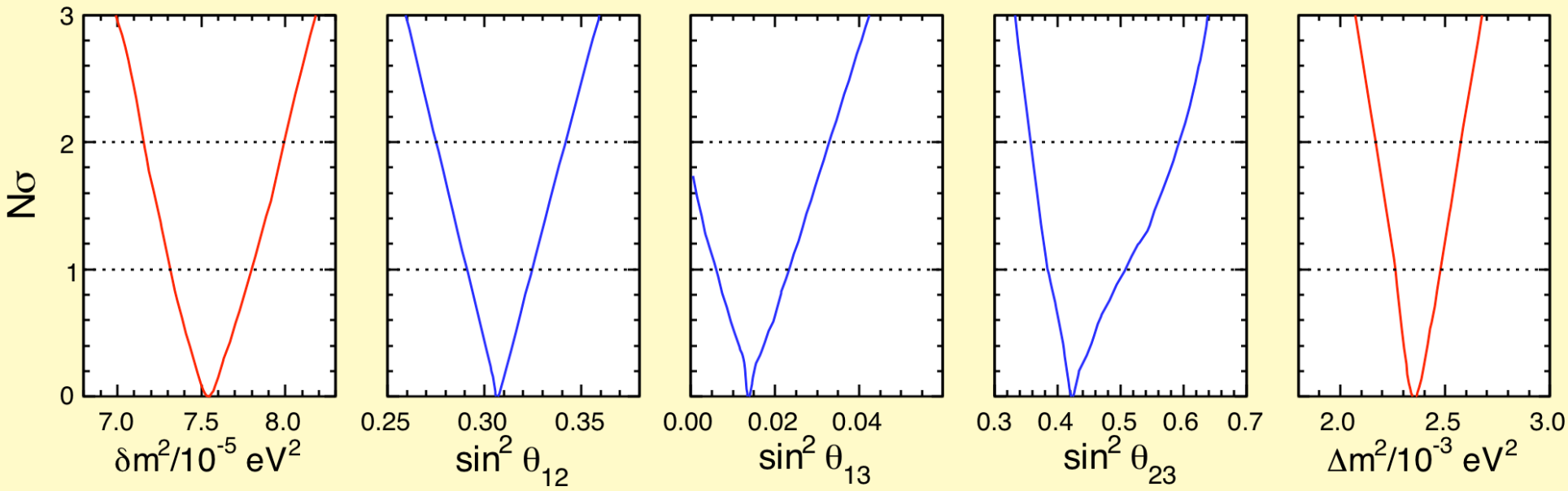
I'll briefly review the status of this paradigm and introduce a few topics/issues, also beyond 3ν, that will be discussed here.

Some of the issues have weak statistical significance or are still controversial, but – who knows…

they might generate the next peaks of interest in our field.

Standard 3ν framework

2011 Status: our update of [Fogli et al. arXiv:0805.2517], in preparation*



Parameter	$\delta m^2/10^{-5}$ eV^2	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	$\Delta m^2/10^{-3}$ eV^2
Best fit	7.54	0.307	0.014	0.42	2.36
1σ range	7.32 – 7.79	0.291 – 0.325	0.006 – 0.023	0.38 – 0.51	2.26 – 2.48
2σ range	7.14 – 7.99	0.275 – 0.342	< 0.033	0.36 – 0.59	2.17 – 2.57
3σ range	6.98 – 8.17	0.259 – 0.360	< 0.042	0.33 – 0.64	2.07 – 2.67

*Includes SK-I+II+III, MINOS app.+disapp., latest KamLAND and solar data.

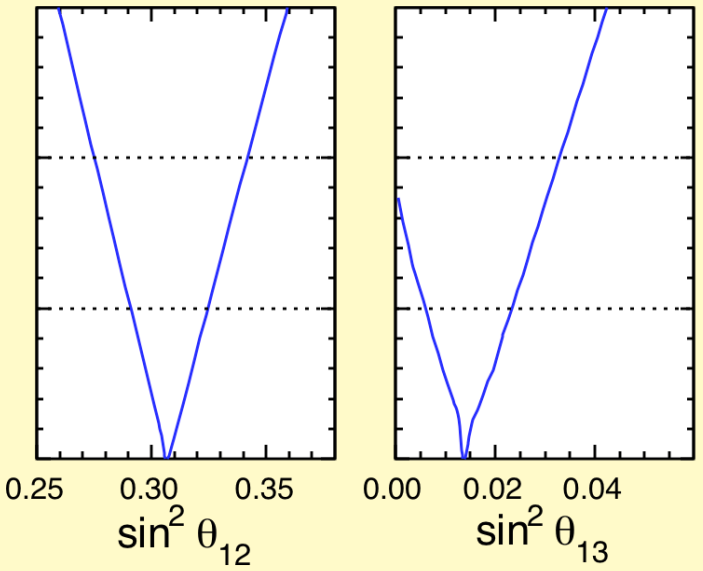
Other recent global analyses: Gonzalez-Garcia et al, arXiv:1006.3795;
Schwetz et al., arXiv:1103.0734 (includes new evaluation of reactor fluxes)

Comment #1: Effect of improved reactor ν fluxes

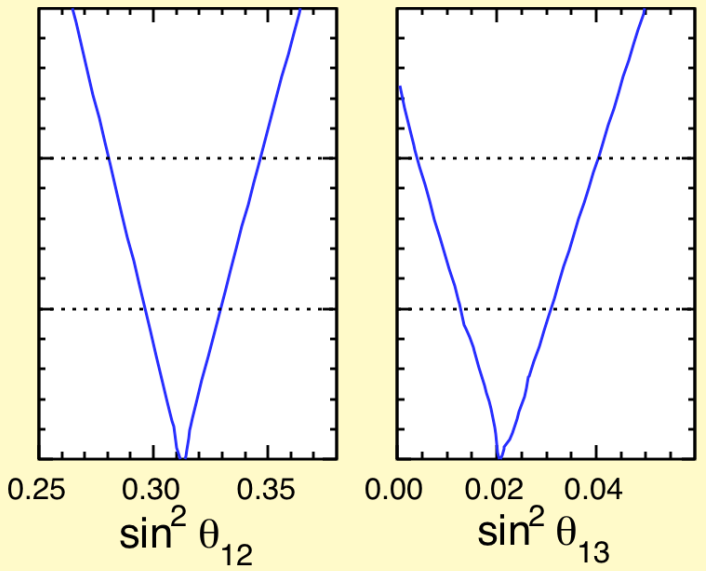
An improved evaluation of reactor fluxes has been recently released: normalization shifted by about +3.5%. [Talk by Lasserre].

Within the 3ν paradigm, it allows "extra ν_e disappearance" in CHOOZ and KamLAND → and thus slightly larger θ_{12} and θ_{13} [Lasserre, Schwetz]. [Other parameters: ~no change.]

We find that both $\sin^2\theta_{12}$ and $\sin^2\theta_{13}$ bounds are shifted by +0.007:



("**old**" fluxes, previous slide)



("**new**" reactor fluxes)

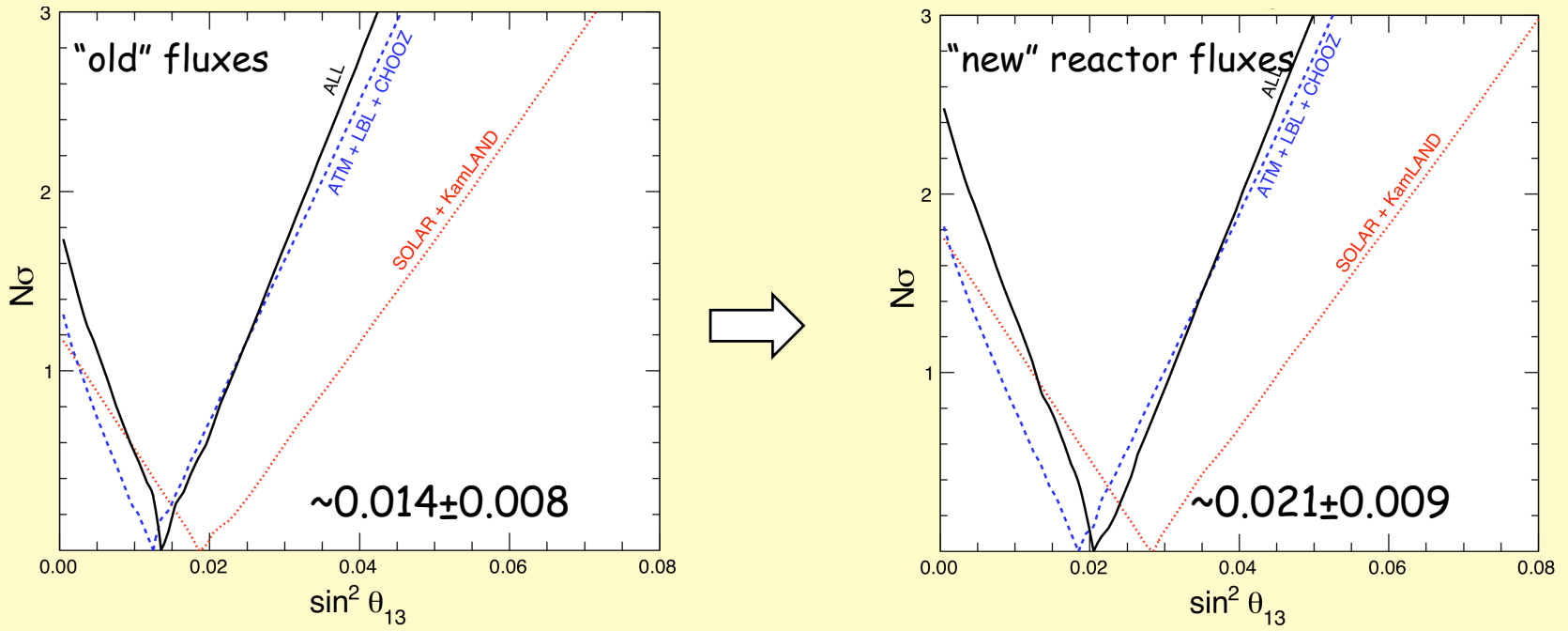
Improved bounds may impact on theoretical models of flavor symmetries [talk by King]

Comment #2: Zooming in on $\sin^2\theta_{13}$ [dedicated talk: Schwetz]

Hints for $\sin^2\theta_{13}>0$ first discussed here [solar+KamLAND "tension"]…
(Fogli @ NO-VE 2008)

Overall significance was ~2σ in 2009 [after MINOS]: **$\sin^2\theta_{13}\sim0.02\pm0.01$**
(Fogli @ NEUTEL 2009).

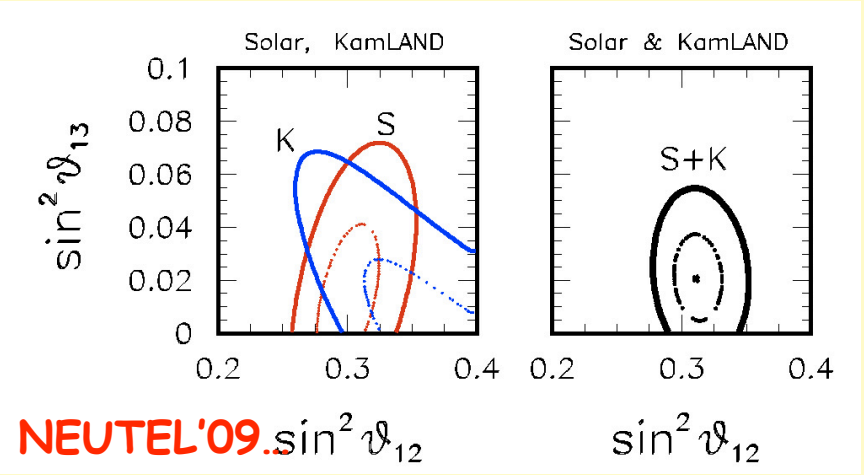
Our update @ NEUTEL 2011:

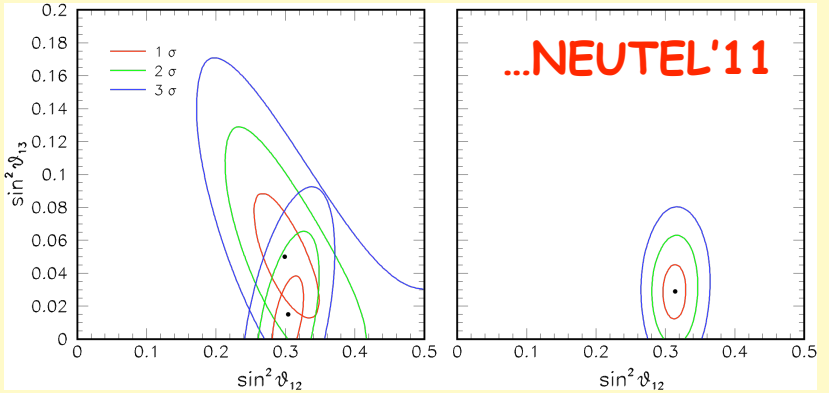


If "in medio stat virtus," then… we are still around 2σ level.

Note: Former solar+KamLAND "tension" has turned into an "agreement"

… but the combination is stable





Expect improvements from current generation of solar ν expts. [talks by Biller, Wilkes, Meroni], from more refined solar models [Serenelli] and from further KamLAND data [Inoue].

Of course, no indirect "hint" can be a substitute for direct searches of $\sin^2\theta_{13}>0$ in accelerator appearance and near/far reactor disapp. searches. The hints just suggest that a θ_{13} discovery might be "around the corner."

Comment #3: Zooming in on δm^2 vs Δm^2

A significant achievement of MINOS (+atm) data:
$\sigma(\Delta m^2) \sim 10^{-4}$ eV^2 is now comparable to $\delta m^2 \sim 0.75 \times 10^{-4}$ eV^2 ! So...

... **Δm^2 conventions must be declared. Ours:** $\Delta m^2 = (\Delta m^2_{31} + \Delta m^2_{32})/2$
(previous results are marginalized over $\pm\Delta m^2$)

... **setting $\delta m^2 \to 0$ should be avoided in LBL data analyses**
(approxim. adopted in current MINOS-disappearance plots [Corwin])

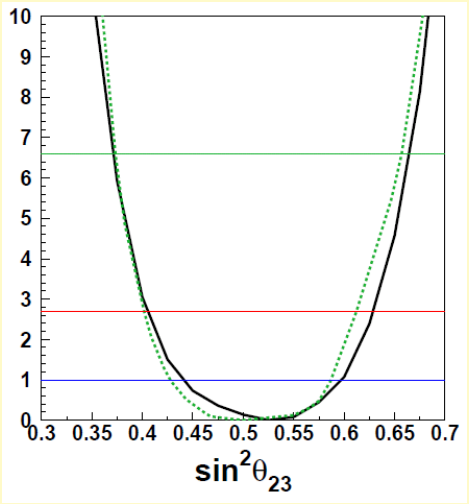
... **setting $\delta m^2 \to 0$ should be avoided in ATM data analyses**
(approximation no longer used in latest SK atm 3ν fits [Wilkes]
but still adopted by [Schwetz] based on older SK χ^2 map)

No real motivation for keeping $\theta_{13} \neq 0$ and $\delta m^2 = 0$: we know that δm^2 is there, and contributes to subleading LBL and ATM effects as well as θ_{13}.

Comment #4: Zooming in on $\sin^2\theta_{23}$ (…reading the fine prints)

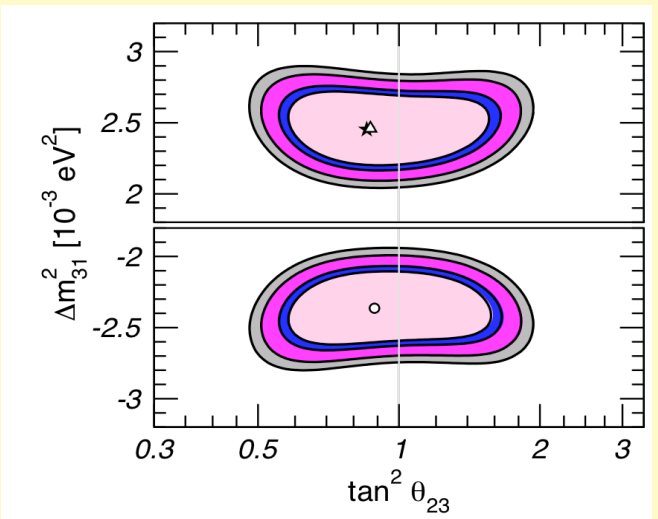
3ν analyses including SK-I+II+III data with both $\theta_{13}\neq 0$ and $\delta m^2\neq 0$:

SK@Neutrino2010



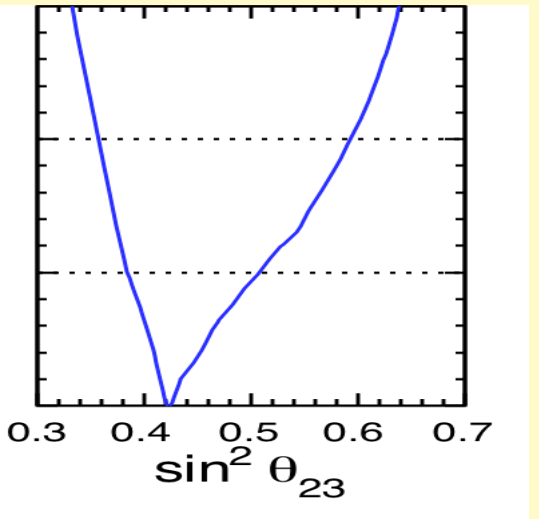
Nearly maximal…

Gonzalez-Garcia et al. 2010



Slightly nonmaximal…

Our update, 2011



Slightly more nonmaximal…

In general, three "signs" appear to be "fragile" in current best fits:
sign($\sin^2\theta_{13}$-1/2), **sign($\pm\Delta m^2$)**, **sign($\cos\delta_{CP}$)**
their effects being comparable to stat/syst errors (approximations ?)

(cont'd): Atm. ν – revisiting some approximations in the future?

Atmospheric ν data are - and will remain – relevant [Maltoni, Choubey].
Their analysis involves calculations of multi-dimensional integrals:

$$\int \ldots \int \text{Flux} \otimes \text{Probability} \otimes \text{Xsection} \otimes \text{Resolution} \otimes \text{Efficiency}$$

Currently, the last two/three terms cannot be reproduced in detail outside the SK collaboration → need approximations and data selection.

On the other hand, the SK collab. evaluates integrals by MonteCarlo, with limited sampling of fast-oscillating probabilities. Approximation:

Probability → some "averaged Probability"

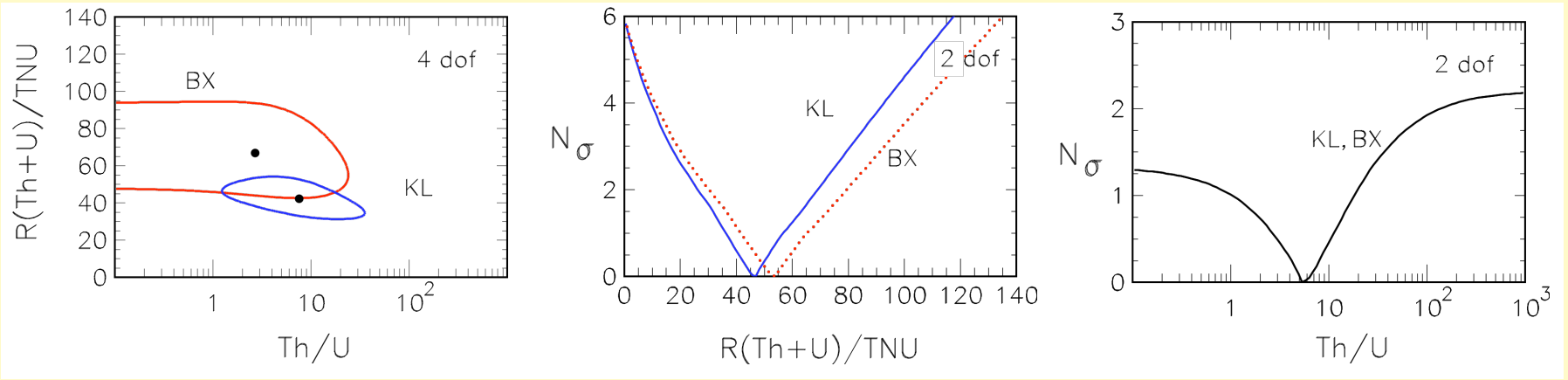
Optimizing averages and assessing their errors is not trivial.
(If averaging not enough → fuzzy C.L. contours; if too much: loose sensitivity)

In order to squeeze "fragile info" from future, high-stat. atm. ν data, it would be useful to revisit and optimize calculations/simulations

Comment #5: Additional pieces of information…

Global analysis not limited to 3ν oscillation parameter estimate.
E.g., a relevant outcome concerns **geo-ν rates** from Th, U decays
[Talks by Fiorentini, Meroni, Inoue]

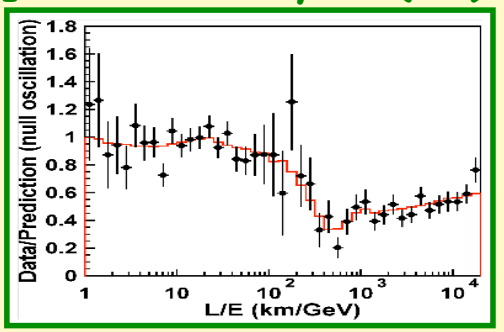
From the latest KamLAND+Borexino data we get*:
Combined 6σ evidence for Th+U flux + some sensitivity to Th/U ratio
[within a factor of two from chondritic value Th/U=3.9]



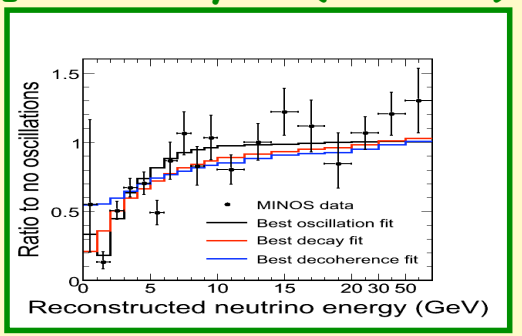
[*Update of Fogli, Lisi, Palazzo, Rotunno, arXiv:1006.1113, in preparation]

Many other pieces of the 3ν paradigm are falling in the right place…

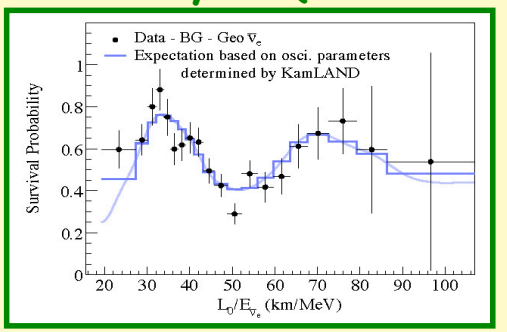
½ oscillation cycle (SK)



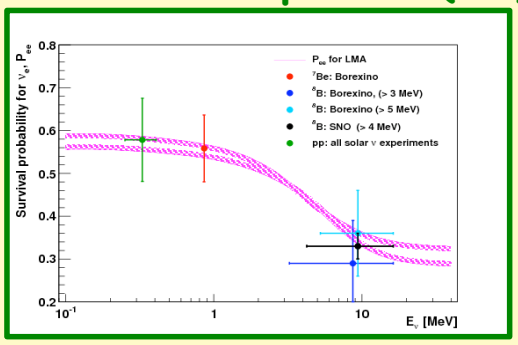
½ oscill. cycle (MINOS)



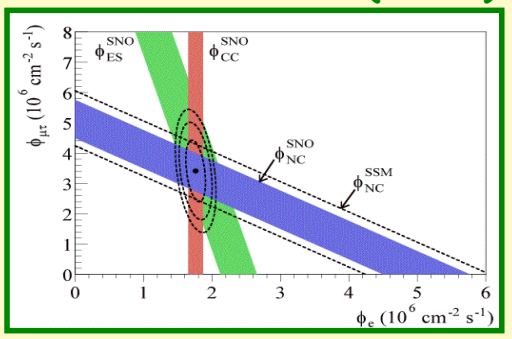
1 oscill.cycle (KamLAND)



MSW adiab. profile (BX)



SSM & CC/NC (SNO)

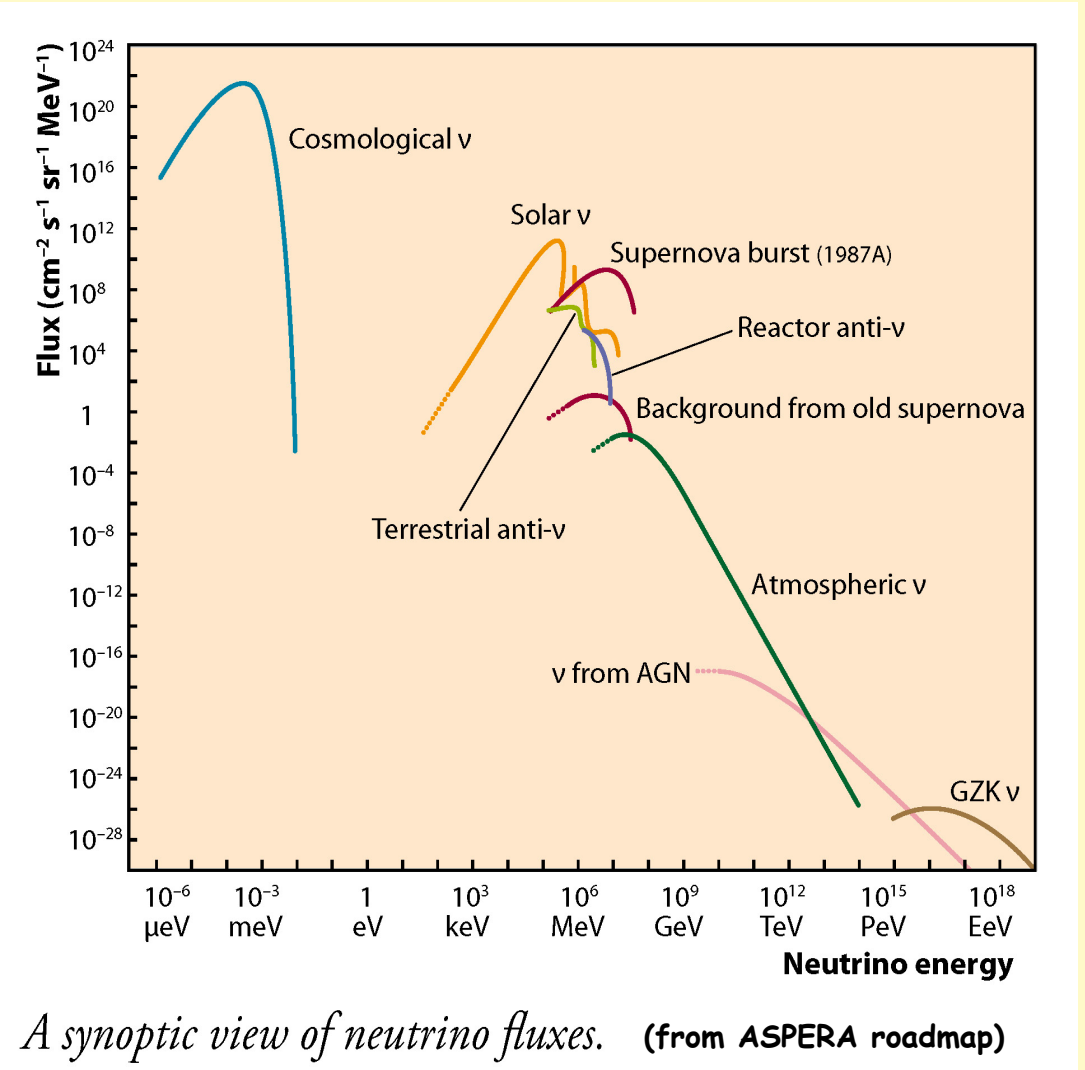


τ event (OPERA)

But several unknowns remain.

Also, a few pieces don't match the picture…

… and vast lands are to be explored: one should be open to unexpected results.



A synoptic view of neutrino fluxes. **(from ASPERA roadmap)**

[Astro ν sources: talks by Volpe, Montaruli, Aharonian, Brunner, Sarkar, Gaisser…]

Unknowns:

θ_{13}, δ_{CP}, sign(Δm^2), m_ν , Majorana ν, …and a deeper understanding of flavor!

[Minos] [Opera] [Icarus]

[T2K]

[NOvA] [SN ν]

[New detectors, new facilities, new beams]

[DChooz] [DayaBay] [RENO]

[Melchiorri] [CUORE] [GERDA] [KL-Zen]

[Iachello] [Gomez-C.]

[King] [Di Bari]

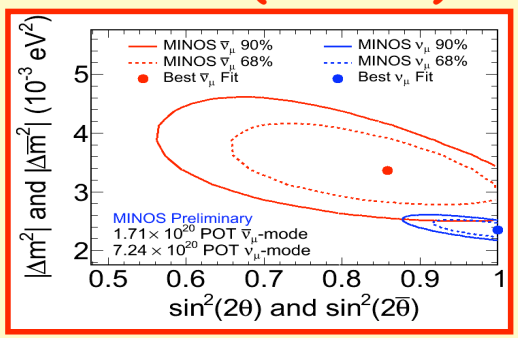
[Paradisi] [MEG]

[Dark Matter] [Astro sources]

Some "mismatches:"

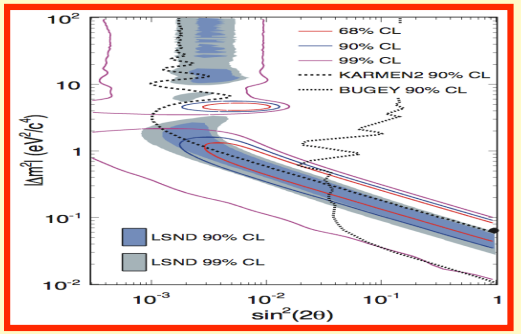
[Corwin] [Maltoni]

ν / anti-ν (MINOS) ?



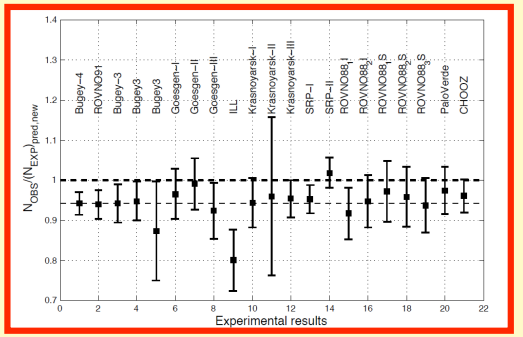
[Mills] [Rubbia] [Giunti] [Lasserre]

LSND/MiniBooNE ?



ν_s?

very SBL reactor disapp.?



The rich NEUTEL 2011 program (talks and posters) reflects an evolving field, open to surprises and challenges, both within and …

…beyond the standard 3ν framework

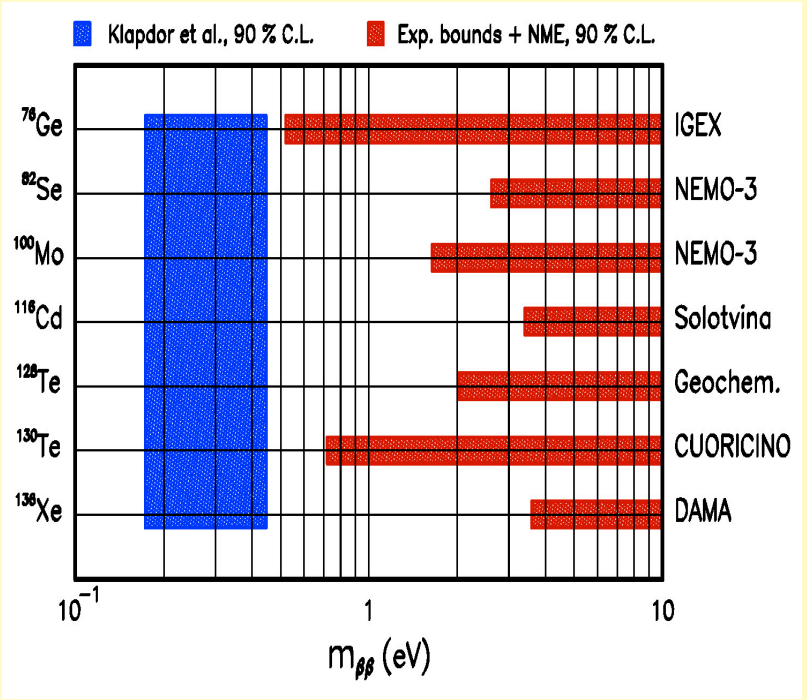
But that's a land with no boundaries…

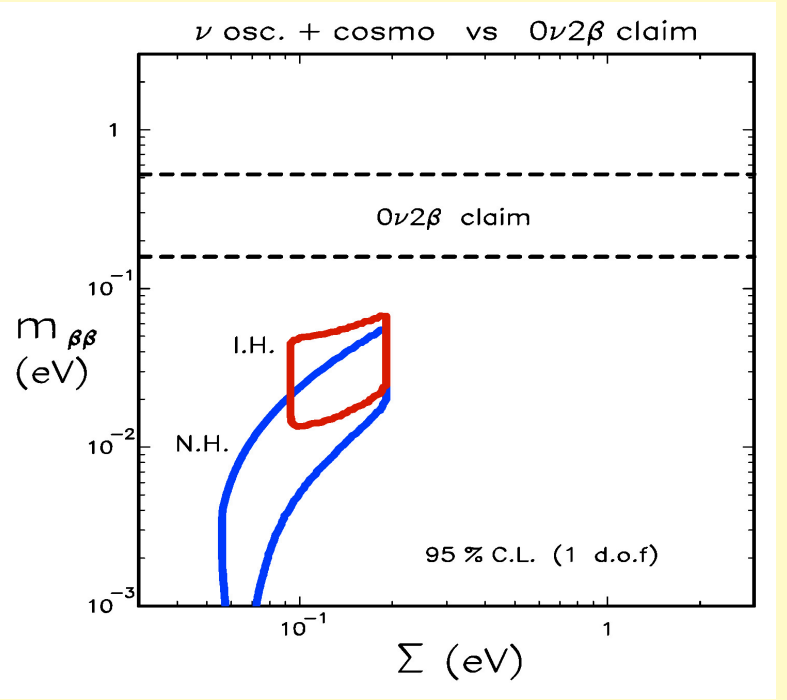
So, let me discuss just two examples of possible **surprises** and **challenges** in ν non-oscillation and oscillation physics

Non-oscillation: Neutrinoless double beta decay

What if Klapdor et al. claim is confirmed by GERDA, CUORE…

… but gets is conflict with stringent cosmological bounds?

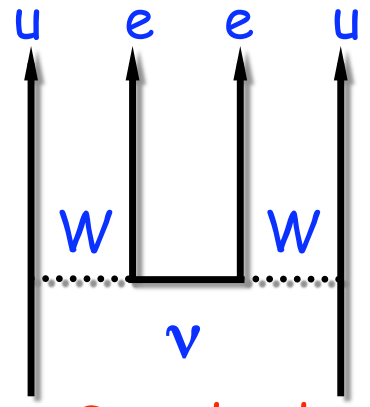




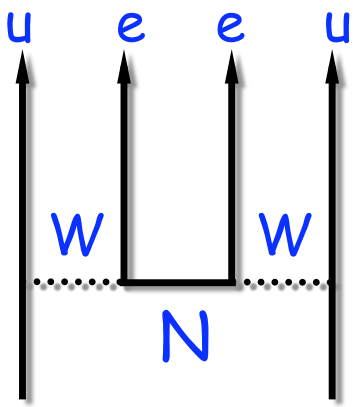
Surprise - Possible solutions:

- Nuclear matrix elements (NME) are wrong
- The standard cosmological model is wrong
- **New physics beyond 3 light Majorana ν**

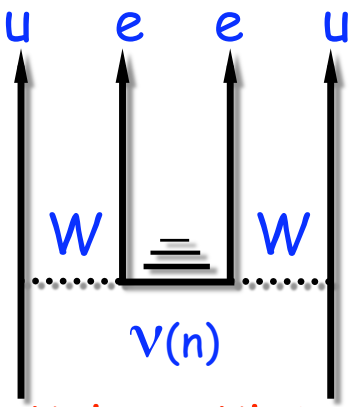
Several nonstandard $0\nu\beta\beta$ decay mechanisms in the latter case...



Standard

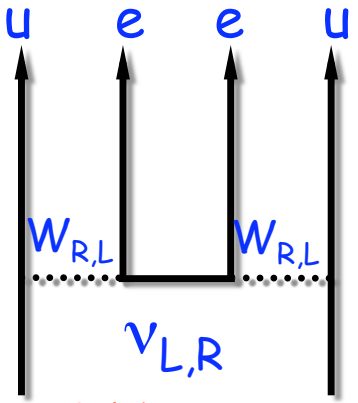


Heavy ν



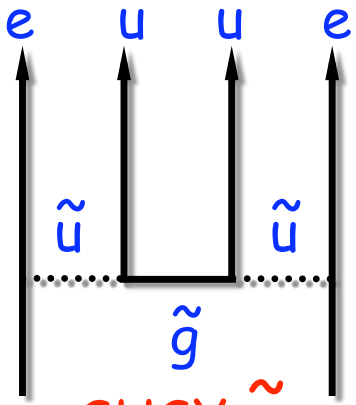
Kaluza-Klein

(KK±1 Brane:a=$10^{\pm1}$/GeV)

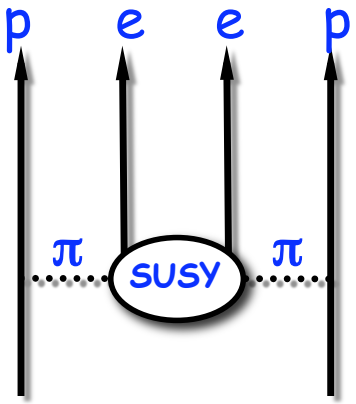


RHC λ,η

λ=RH had, η=LH had

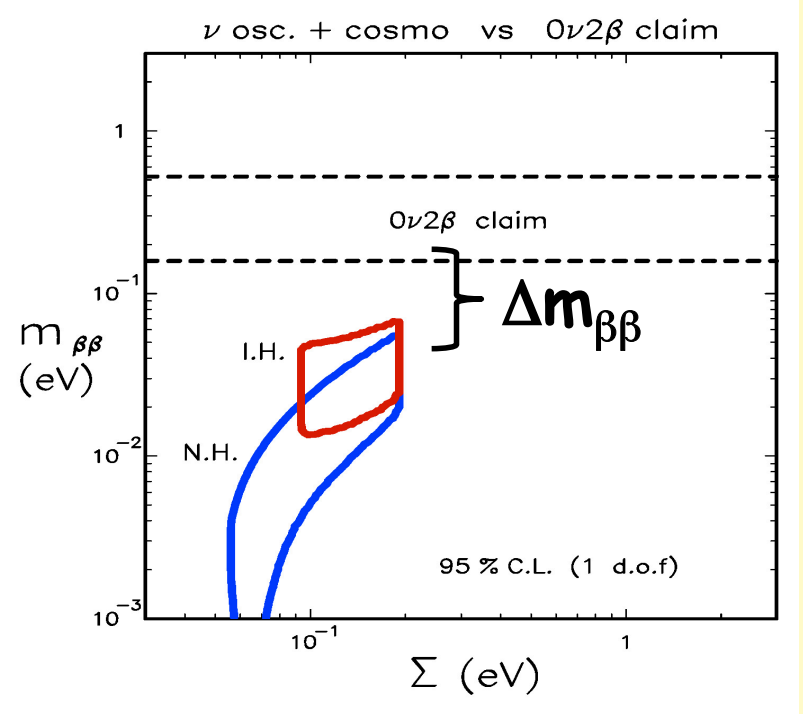


SUSY $\tilde{g}$



SUSY π

A new decay mechanism might provide an extra term $m_{\beta\beta} \rightarrow m_{\beta\beta}+\Delta m_{\beta\beta}$ and solve the "mismatch"



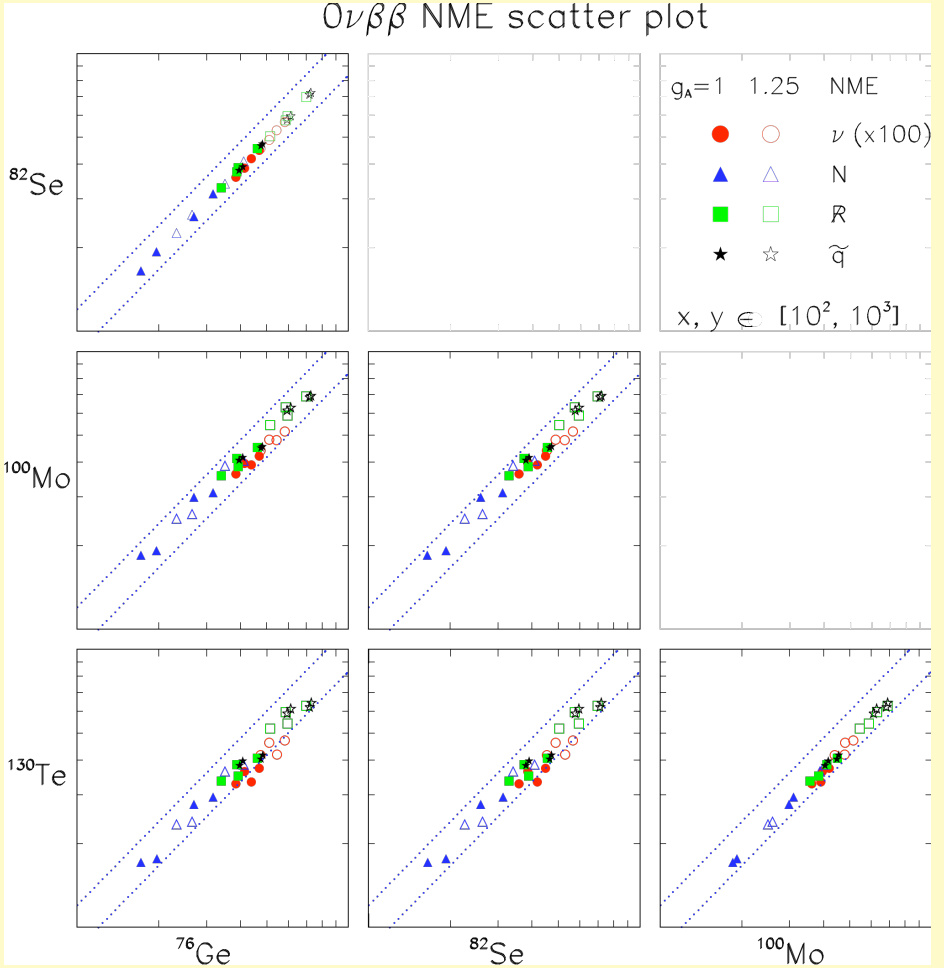
Challenge: Can one tell which mechanism?

In principle – yes, from different $\Delta m_{\beta\beta}$ terms in different nuclei

[See also poster by Aurora Meroni]

But, in practice? It may be very difficult.

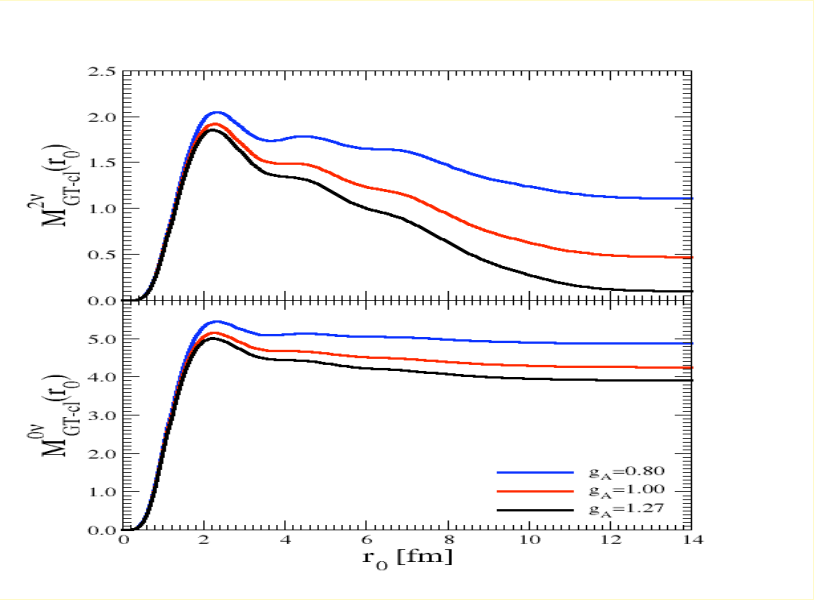
An example: let us consider 4 mechanisms and 4 nuclei in a QRPA model*.
It turns out that the current spread of NME prevents a robust discrimination
→ effective degeneracy of these mechanisms [can't tell which is which].
Need much more accurate NME's (+ very precise data) to break degeneracy.



[*Faessler, Fogli, Lisi, Rotunno, Simkovic – preprint on todays' hep-ph listing]

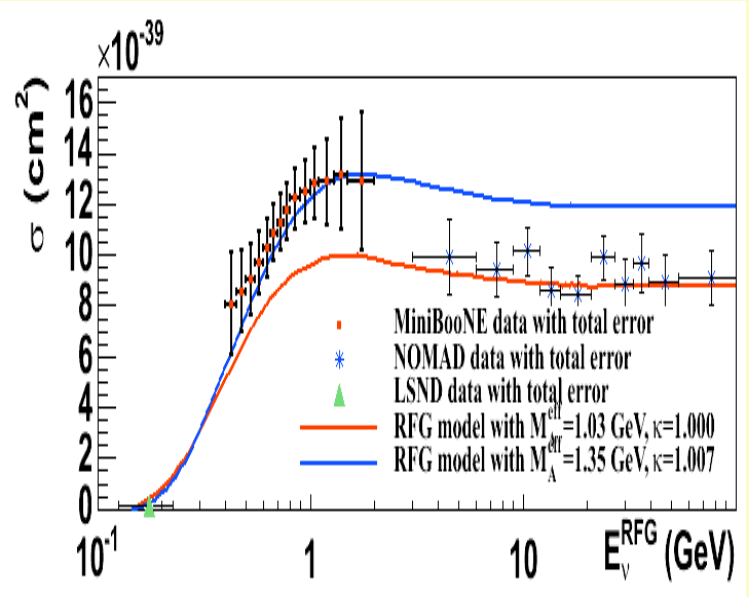
In general, a better understanding of ν-related nuclear processes appears to be a challenging goal, not only for **0νββ decay**, but also for several issues of interest to **ν oscillation experiments**, such as production or scattering cross-sections [Paolone, Popov]. For instance, axial currents not well controlled in magnitude and form factors:

In the context of 0ν2β…



g_A → significant source of error. Interplay with g_{pp} uncertainties once 2νββ data are fitted in QRPA

In the context of QE…



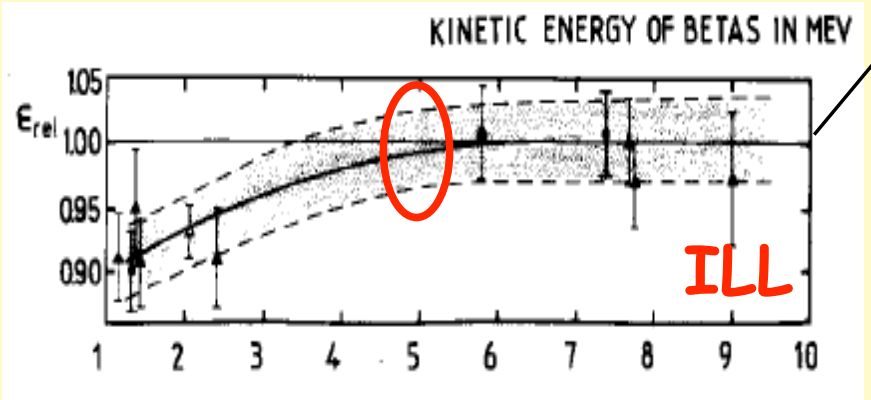
M_A → significant source of error. Interplay with other expt. results once MiniBooNE data are fitted

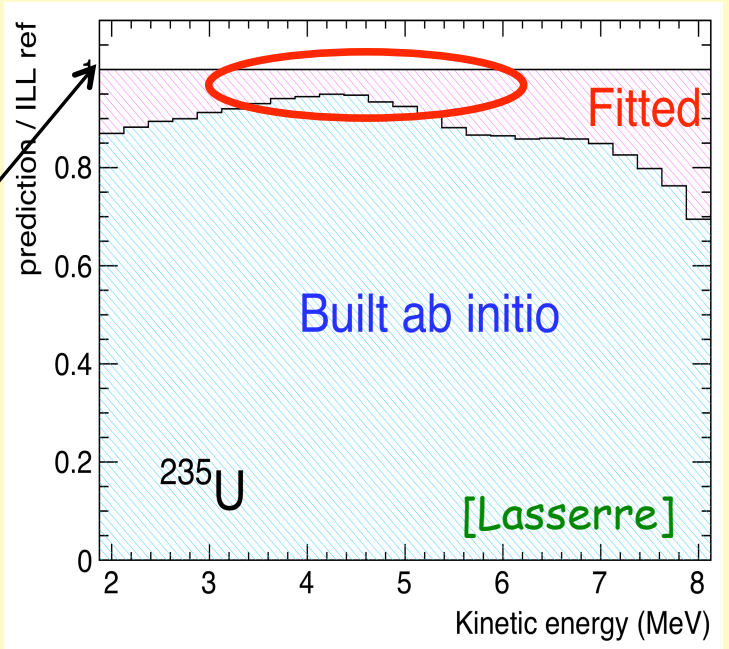
And this brings us to a last example of "surprise and challenge:"

Oscillations and sterile neutrinos

Surprise: theo/expt mismatch of reactor fluxes → sterile ν?
Challenge: (1) Must prove that fission β-decays are under control (nuclear physics again…)

Reactor fluxes anchored to one β-decay experiment (ILL): what about few% deviations from "anchor point" ?…





Challenge: (2) Must consider new degeneracies (say, in 3+1 model)

E.g., θ_{13} and θ_{14} are ~degenerate in solar+KamLAND data…
[A. Palazzo, private communications – talk tomorrow at Moriond]

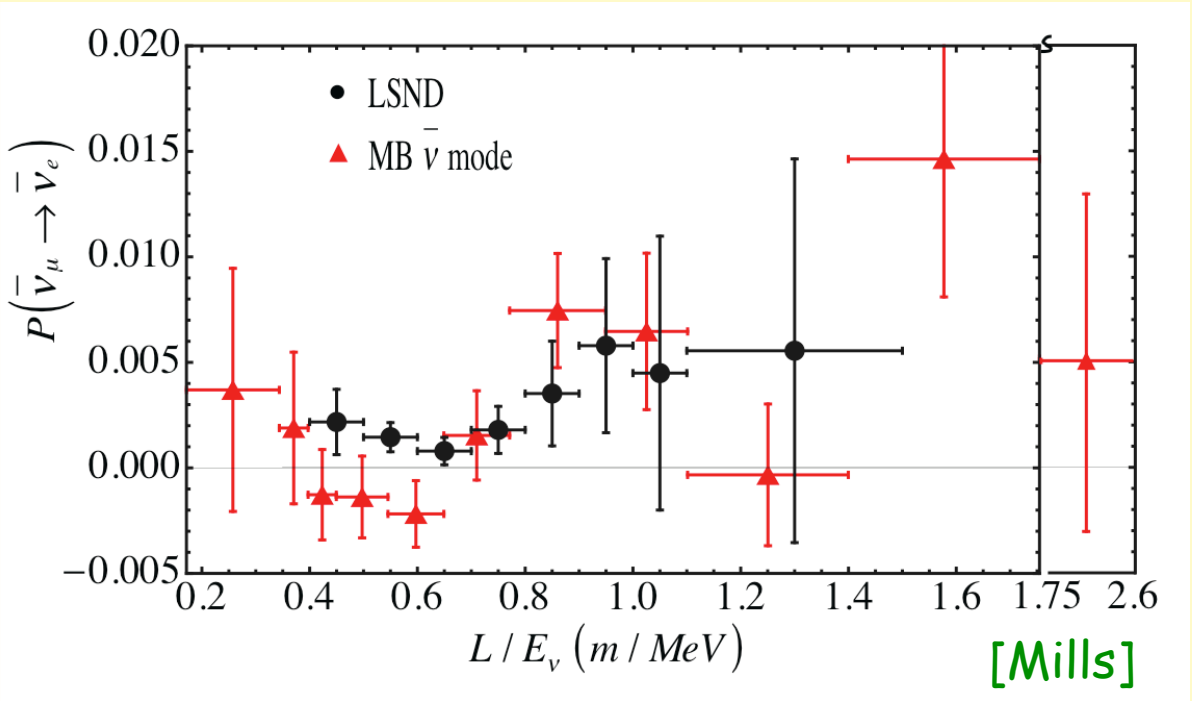
…but θ_{13} and θ_{14} are not degenerate in SBL data
[Talks by Lasserre, Giunti]

If θ_{14} "wins" over θ_{13} in the fit, then $\nu_\mu \to \nu_e$ amplitudes dominated by

$U_{\mu 4}\,(\text{small}) \times U_{e4}\,(\text{small})$ instead of $U_{\mu 3}\,(\text{large}) \times U_{e3}\,(\text{small})$

→ Relatively "large" ν_e appearance in T2K could "rescue" θ_{13}

Challenge: (3) Can we get a coherent picture?
An "L/E ν_s plot" with future data?



NEUTEL'11 is a timely workshop to discuss both "precision 3ν physics" and opportunities/challenges "beyond" standard 3ν oscillations.

EPILOGUE

Three (ν) gondolas are safe in the harbor…
…but that's not what they are made for.
New gondolas might join, and all lead us towards new (physics) horizons

Thank you for your attention