DNP 2014

Status update on 3+n sterile neutrino fits.

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Outline

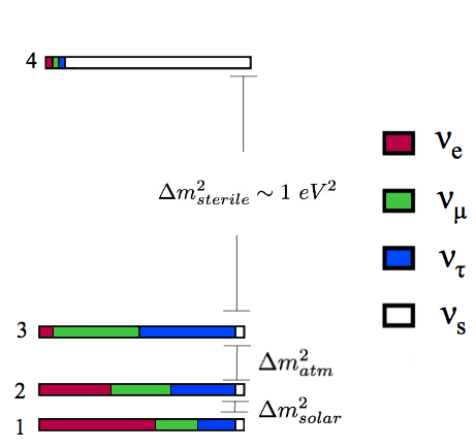
- Introduction to sterile neutrino fits
- Recent issues related to reactor flux
- How reliable is the PG test?

Motivation

- Neutrino detectors have to be designed for a limited range of L/E.
- How do we decide how to design the next generation of neutrino experiments?
- Phenomenology provides a guide.

Sterile neutrino models

- We can test many different models.
  - 3 + n: 3 degenerate active neutrinos + n heavier sterile neutrinos.
- 3+1: Has parameters $\Delta m^2_{41}, |U_{e4}|, |U_{\mu 4}|$



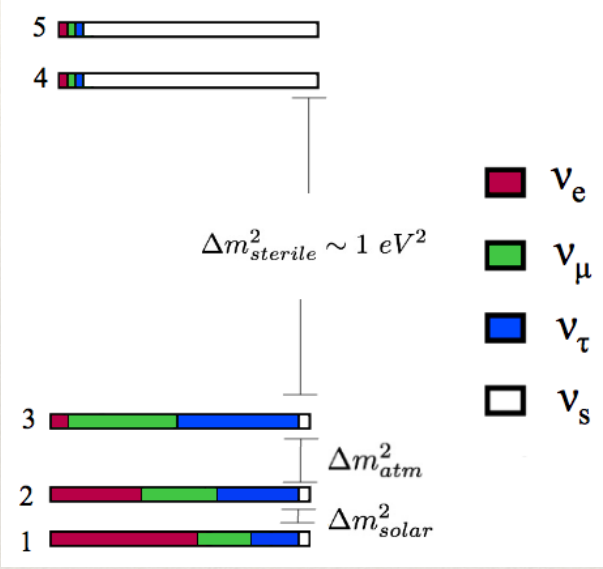
$\sin^2(2\theta_{\mu e})$

$$P(\nu_\alpha \to \nu_\beta) \simeq 4|U_{\alpha 4}|^2|U_{\beta 4}|^2 \sin^2(1.27\Delta m^2_{41} L/E) \ ,$$

$$P(\nu_\alpha \to \nu_\alpha) \simeq 1 - 4(1 - |U_{\alpha 4}|^2)|U_{\alpha 4}|^2 \sin^2(1.27\Delta m^2_{41} L/E) \ .$$

Sterile neutrino models

- 3+2: Has parameters $\Delta m^2_{41}, \Delta m^2_{51}, |U_{e4}|, |U_{\mu 4}|, |U_{e5}|, |U_{\mu 5}|, \Phi_{45}$



CP violation: $\nu \neq \bar{\nu}$

- 3+3: 12 parameters, even more complex.

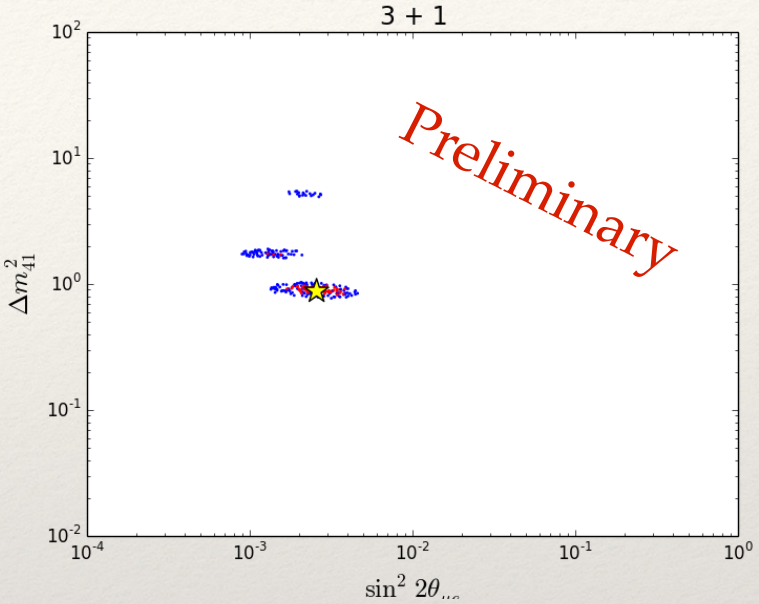
Testing these models

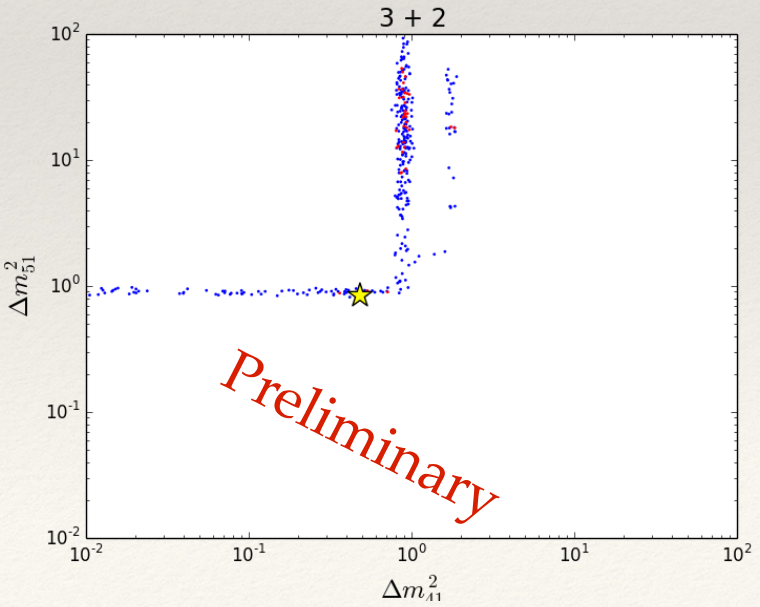
2012 data sets

- Appearance:
  - MiniBooNE-BNB: $\nu_\mu \to \nu_e, \bar{\nu}_\mu \to \bar{\nu}_e$
  - MiniBooNE-NuMI,
  - NOMAD,
  - LSND,
  - KARMEN,
- Disappearance:
  - MiniBooNE-BNB: $\nu_\mu \to \nu_\mu$
  - GALLEX/SAGE,
  - KARMEN/LSND xsec,
  - CCFR84,
  - CDHS,
  - Atmospheric,
  - Bugey,
  - MINOS

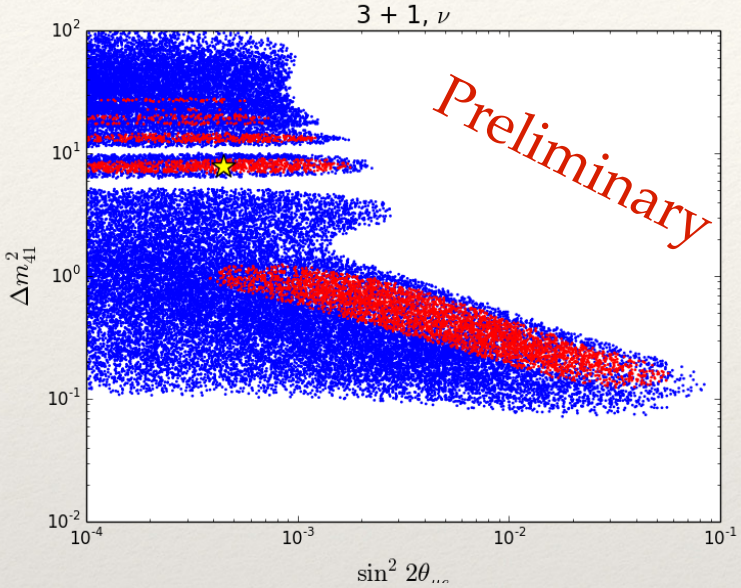
Red: 90% CL
Blue: 99% CL

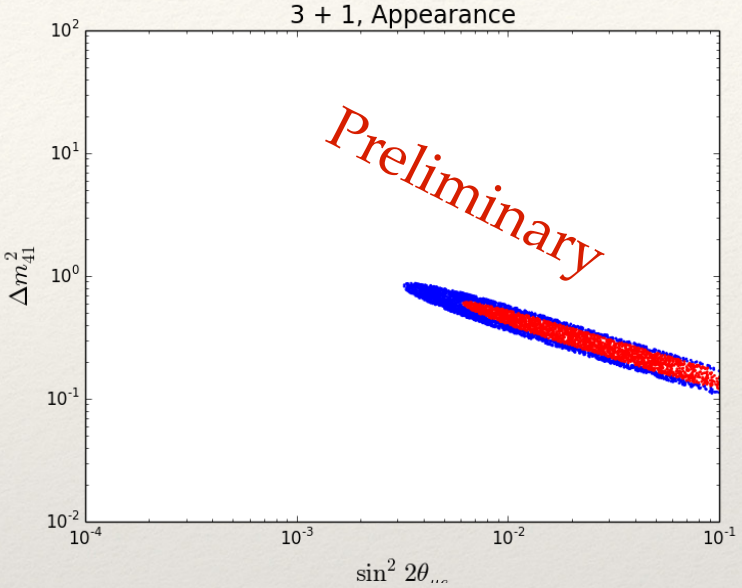
	χ^2_{best}	Pr
Null	290	1.5%
3+1	240	43%
3+2	235	45%

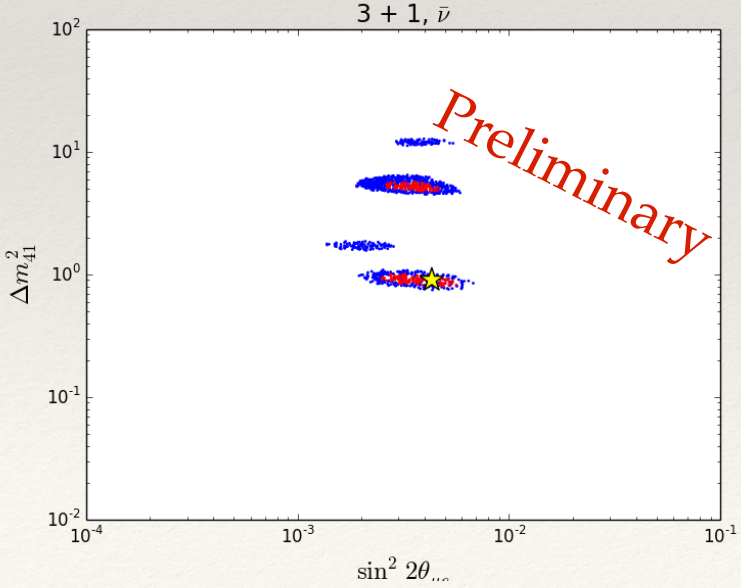


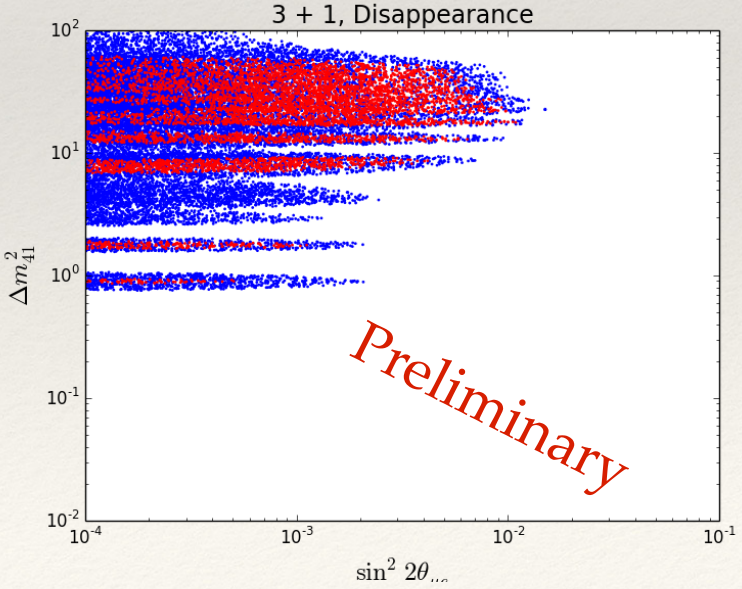


Compare Allowed Regions for Nu/Nubar and Appearance/Disappearance









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- Recent issues related to reactor flux
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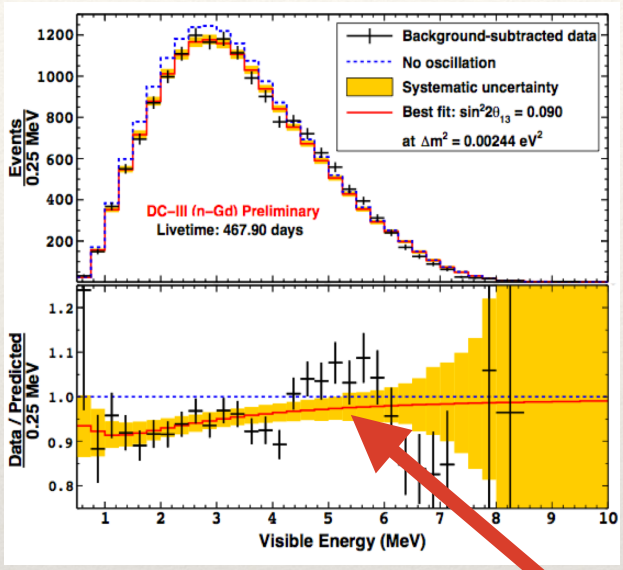
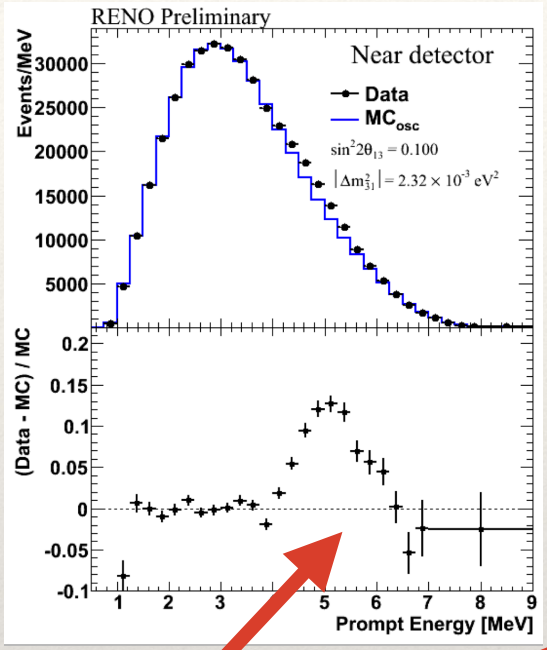
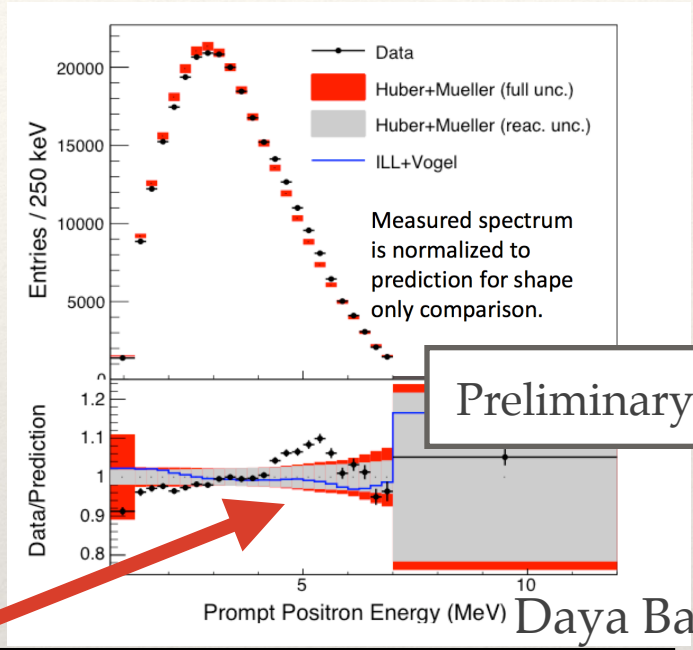
Reactor results from summer conferences



Double CHOOZ



RENO



Daya Bay

- What's that bump?
- Is there additional error on the flux due to forbidden transitions?

3. Examine change in the antineutrino spectrum with respect to the β-spectrum

Examine the function R:

$$R \equiv \sum_i \left[\frac{\partial N_\nu(E_\nu)}{\partial a_i} \right] \Big/ \left[\frac{\partial N_\beta(E_e)}{\partial a_i} \right],$$

$$N_\nu(E_\nu) = \sum_i a_i S(E_\nu, E_{0i}) \;\; ; \;\; N_\beta(E_\beta) = \sum_i a_i S(E_\beta, E_{0i})$$

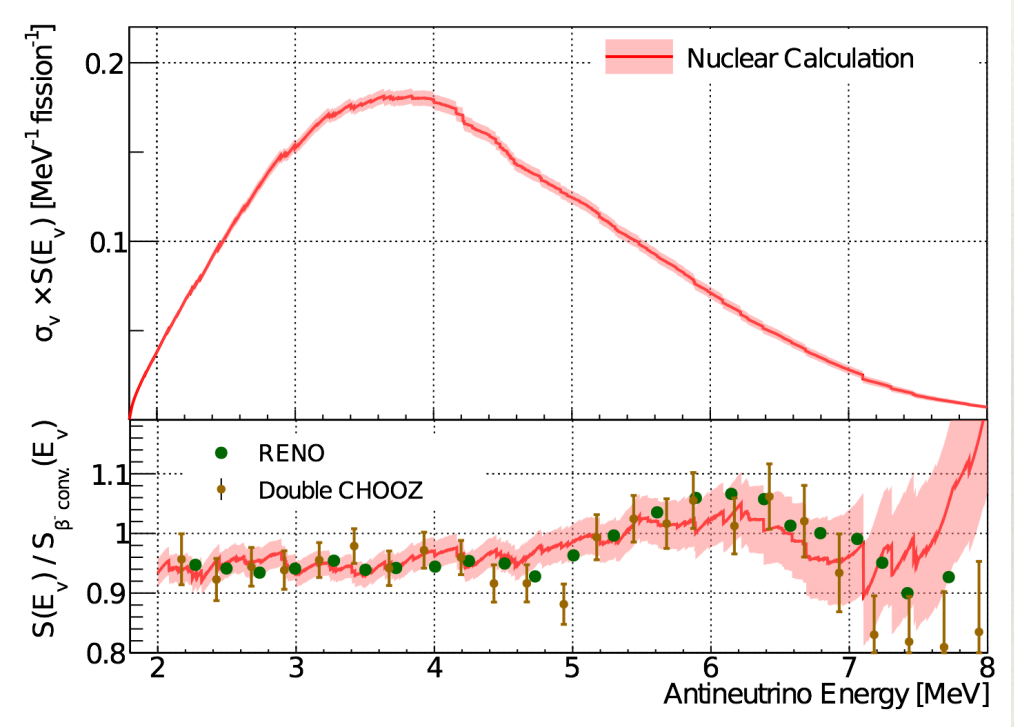
As we changed the operators determining the forbidden transitions there was no path in the (E_e, E_ν) plane such that ***R*** changed by as little as 5%

=> Uncertainty in $N_\nu(E_\nu)$ is ~5%

Gerald Garvey (Neutrino 2014) 17

Try some corrections

- Dwyer and Langford (arXiv:1407.1281) suggest a correction to the predicted flux for reactor experiments.



- Gerald Garvey (Neutrino 2014) suggests an addition of 5% to the normalization error.

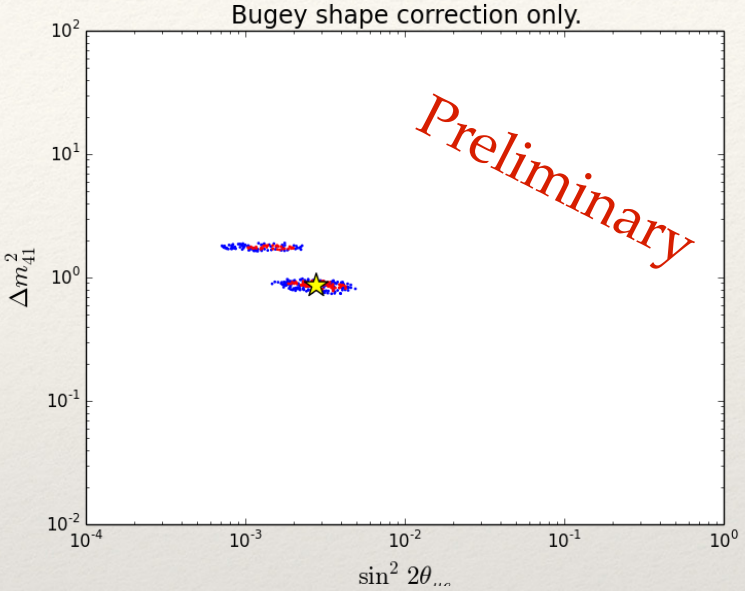
arXiv:1407.1281

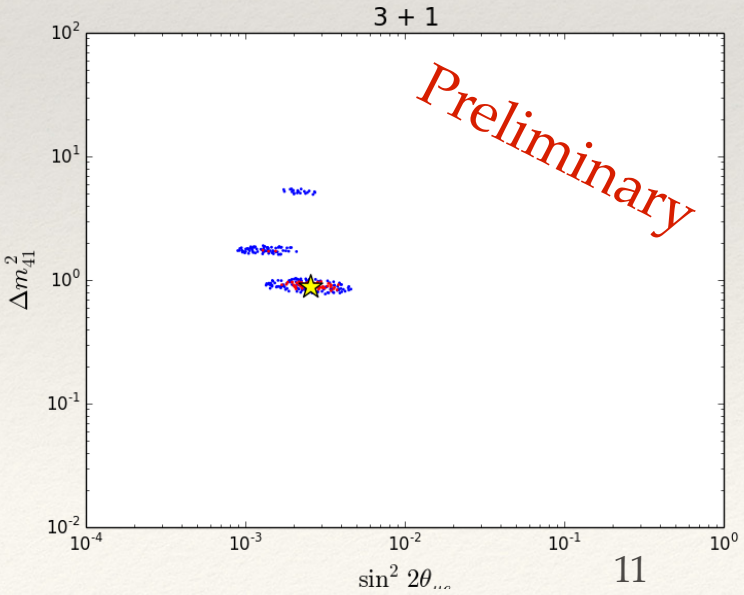
Reactor spectrum correction

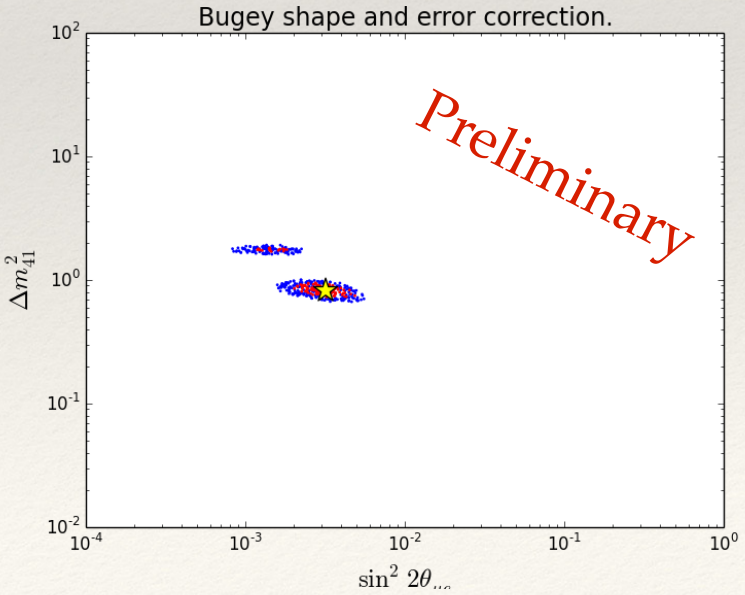
Shape correction slightly changes confidence regions.
Error correction reduces χ^2 slightly.

	χ^2	Δm^2	U_{e4}	$U_{\mu 4}$	χ^2_{null}
Current	240	0.87 eV^2	0.13	0.18	290
Shape only	247	0.86 eV^2	0.14	0.18	302
Shape and error	231	0.82 eV^2	0.15	0.17	285

Bugey $\chi^2 \sim 50.6$







Take-away on reactors

- The Dwyer/Langford changes to the flux shape and the Garvey change to normalization error do not seem to have a large effect on our global fits.

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- Introduction to sterile neutrino fits
- Recent issues related to reactor flux
- How reliable is the PG test?

Motivation for the parameter goodness-of-fit test

arXiv.org > hep-ph > arXiv:hep-ph/0304176

High Energy Physics - Phenomenology

Testing the statistical compatibility of independent data sets

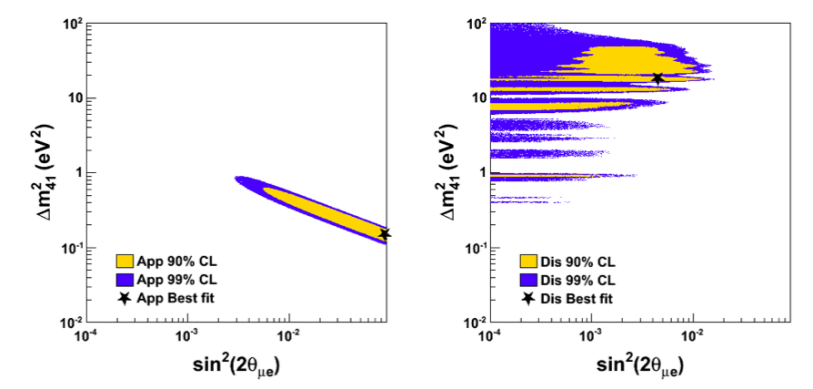
M. Maltoni, T. Schwetz

- Created to address the insensitive bins issue.
- Is interpreted as a test of the compatibility of two data-sets tot he predictions of a neutrino oscillation model.

Based on PG, tensions have been observed.

		χ^2_{PG} (dof)	PG(%)
3+1	ν vs. $\bar{\nu}$	15.6 (3)	0.14%
	App vs. Dis	17.8 (2)	0.013%
3+2	ν vs. $\bar{\nu}$	13.9 (7)	5.3%
	App vs. Dis	23.9 (4)	0.0082%
3+3	ν vs. $\bar{\nu}$	10.9 (12)	53%
	App vs. Dis	27.1 (6)	0.014%

arXiv:1207.4765

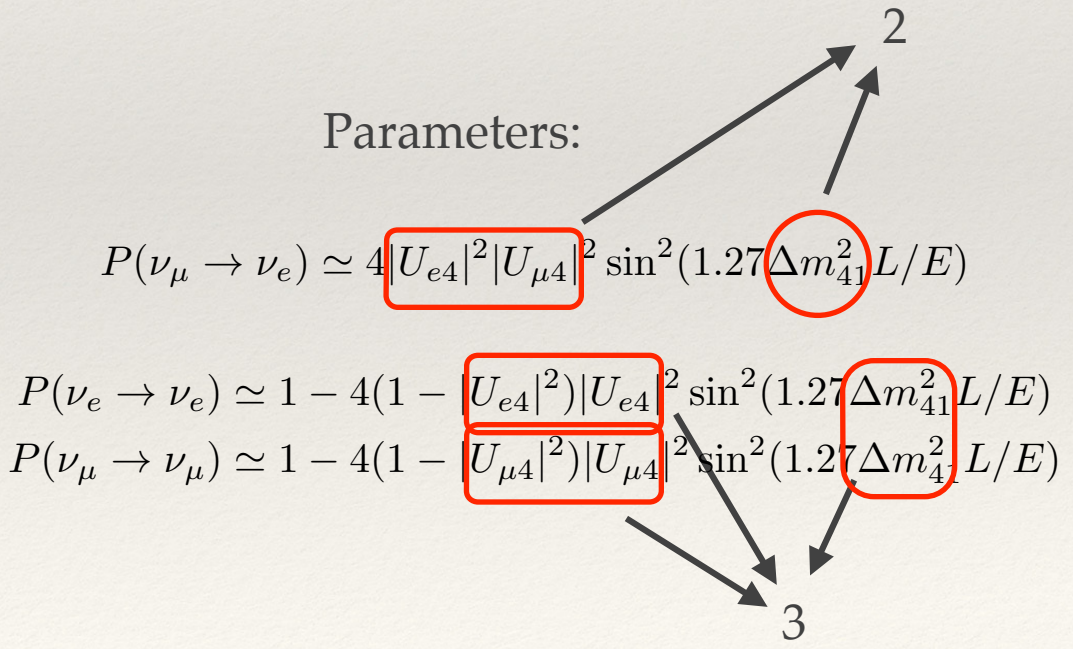


Parameter goodness-of-fit (PG)

$$\chi^2_{PG} = \chi^2_{glob} - (\chi^2_{app} + \chi^2_{dis})$$

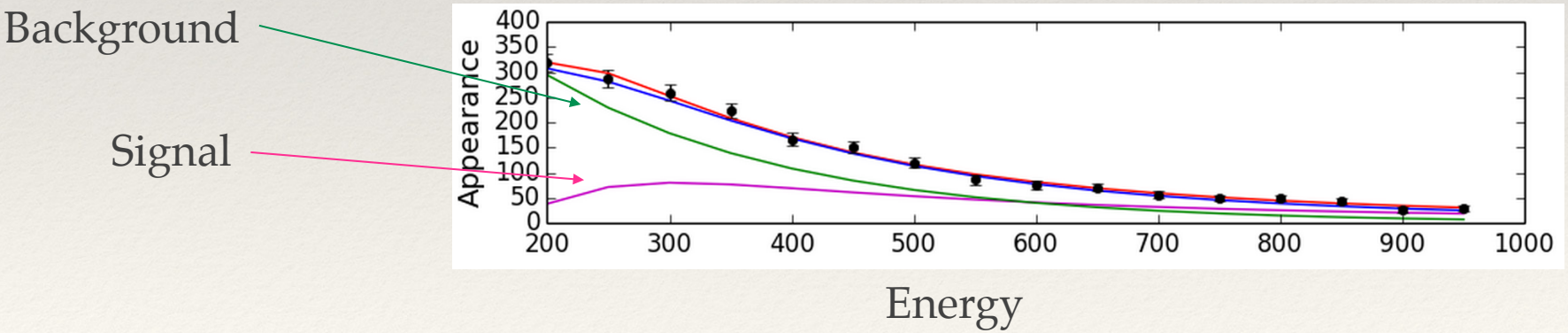
$$N_{PG} = (N_{app} + N_{dis}) - N_{glob}$$
$$= 2 \qquad \text{(for 3+1)}$$

- No. of degrees of freedom is set by the model being tested.
- What is the effect of nuisance parameters on the PG test?



Study nuisance parameter in a toy model

- 3+1 toy model is composed of:
  - Disappearance,
  - Appearance
    - With and without an unexpected background.



Toy model

- Throw many experiments
  - Data points are selected based on random distributions
  - Background is added to data points.
  - Chi^2 fit is performed for Appearance, Disappearance, and Global, with pull parameter (A) for background normalization.
    - For the case of background, $A_{\text{true}} = 0.4, A_{\text{expected}} = 0.0 \pm 0.15 \quad \rightarrow \quad \text{find } A_{\text{fit}}$
  - Calculate the PG
- χ^2 PG for many throws is histogrammed

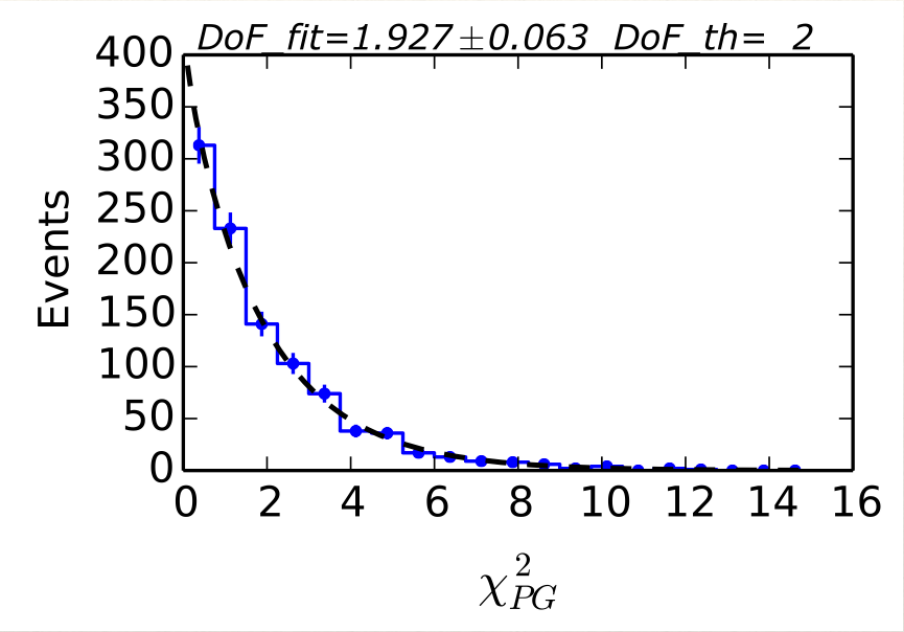
$$\chi^2_{\nu_e app} = \sum_{i=1}^{16} \frac{\left(d_i^{\nu_e app} - \left(osc_i^{\nu_e app} + b_i^{\nu_e app}\left(A_{fit}\right)\right)\right)^2}{\left(\sigma_i^{\nu_e app}\right)^2} + \frac{\left(A_{fit} - A_{exp}\right)^2}{\sigma^2_{A_{exp}}}$$

$$\chi^2_{disapp} = \sum_{i=1}^{16} \frac{\left(d_i^{\nu_\mu disapp} - osc_i^{\nu_\mu disapp}\right)^2}{\left(\sigma_i^{\nu_\mu disapp}\right)^2} + \sum_{i=1}^{16} \frac{\left(d_i^{\nu_e disapp} - osc_i^{\nu_e disapp}\right)^2}{\left(\sigma_i^{\nu_e disapp}\right)^2}$$

$$\chi^2_{global} = \sum_{i=1}^{16} \frac{\left(d_i^{\nu_e app} - \left(osc_i^{\nu_e app} + b_i^{\nu_e app}\left(A_{fit}\right)\right)\right)^2}{\left(\sigma_i^{\nu_e app}\right)^2} + \frac{\left(A_{fit} - A_{exp}\right)^2}{\sigma^2_{A_{exp}}}$$
$$+ \sum_{i=1}^{16} \frac{\left(d_i^{\nu_\mu disapp} - osc_i^{\nu_\mu disapp}\right)^2}{\left(\sigma_i^{\nu_\mu disapp}\right)^2} + \sum_{i=1}^{16} \frac{\left(d_i^{\nu_e disapp} - osc_i^{\nu_e disapp}\right)^2}{\left(\sigma_i^{\nu_e disapp}\right)^2}$$

Toy model, no background

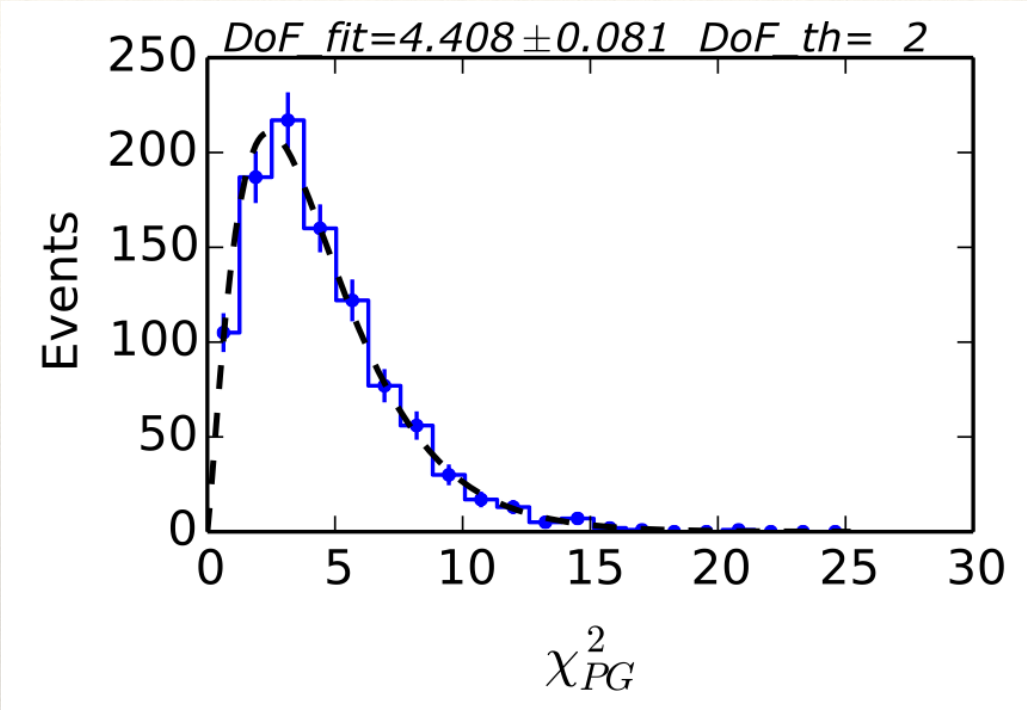
- Background normalization (A_{true}) is set to zero.
- χ^2 PG distribution comes out with expected No. of degrees of freedom.
  - For 3+1, we expected 2.



PG test works in this case

Toy model, with background

- Now,
  - $A_{\text{true}} = 0.4$
  - $A_{\text{expected}} = 0.0 \pm 0.15$
- χ^2 PG distribution now has an incorrect No. of degrees of freedom.



PG test fails in this case

Summary of PG test

- Changing the scaling of the background model changes the d.o.f of the underlying χ^2_{PG} distribution.

- Some experiments (eg: MiniBooNE) have backgrounds that can look like a signal.

Conclusion

- Introduction to sterile neutrino fits
  - We are in the process of updating our 3+n fits.
- Recent issues related to reactor flux
  - Seem to make little difference to global fits.
- How reliable is the PG test?
  - Under certain circumstance there is a problem.
  - We welcome ideas on how to solve this.