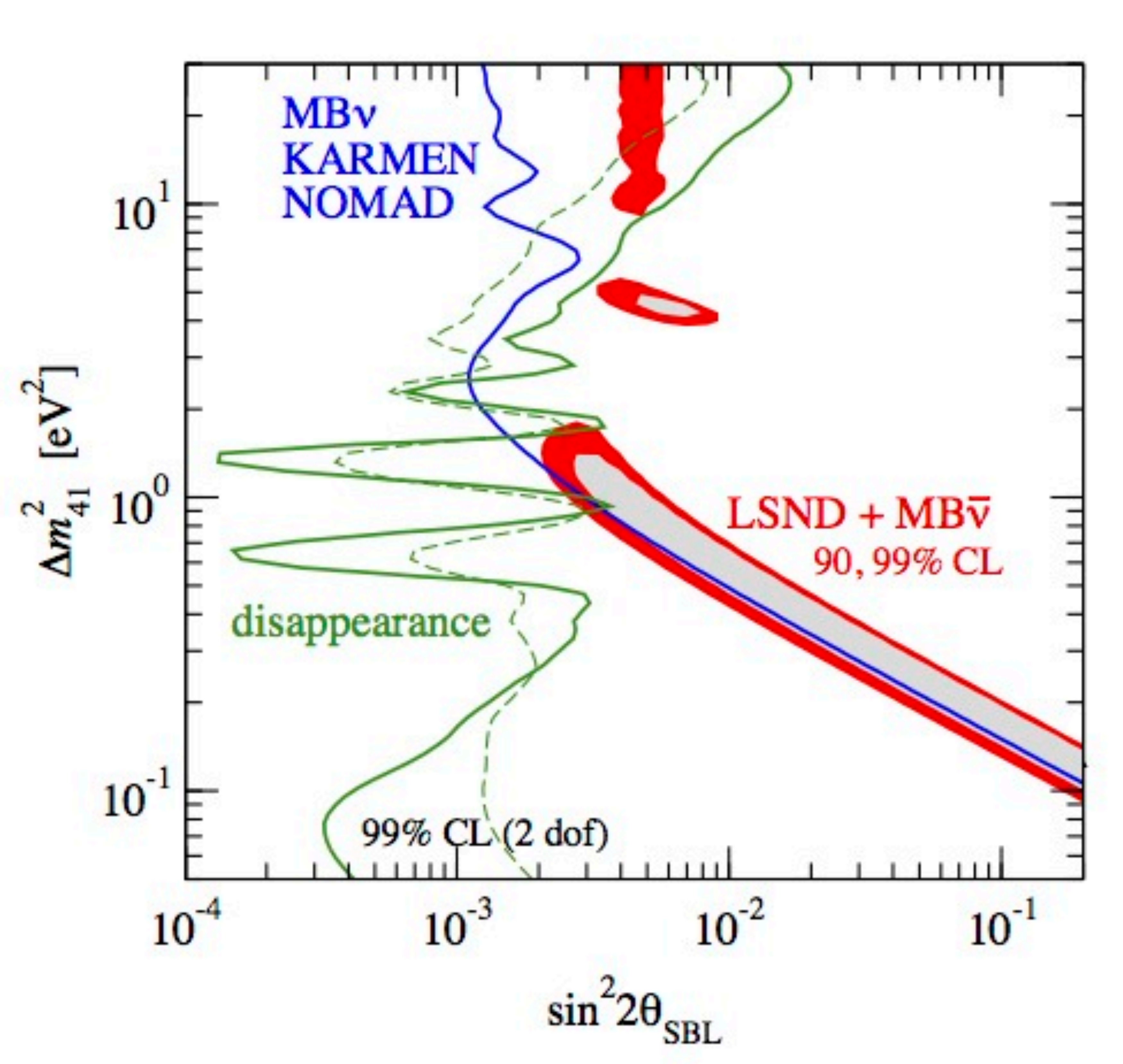
Neutrino Phenomenology in a 3+1+1 Framework

Samuel D. McDermott
with Eric Kuflik and Kathryn M. Zurek
arXiv:(tonight)

MCTP

Motivation

$$\Delta m^2_{41} \sim \mathcal{O}(1\ \mathrm{eV}^2)$$



Kopp, Maltoni, and Schwetz -- arXiv:1103:4570

$$\sin^2 2\theta_{\mathrm{SBL}} \sim \sin^2 2\theta_{e4} \sin^2 2\theta_{\mu 4}/4$$

A single sterile neutrino is disfavored by the data...
but what if we add a second (very heavy) one?

Disappearance probability

The very heavy fifth neutrino has nontrivial effects, even at low energy:

$$1 - P_{\nu_\alpha \to \nu_\alpha} = 4|U_{\alpha 4}|^2 \left(1 - |U_{\alpha 4}|^2 - |U_{\alpha 5}|^2\right) \sin^2 x_{41} + 2|U_{\alpha 5}|^2 \left(1 - \frac{a+1}{2}|U_{\alpha 5}|^2\right).$$

$$\left.\begin{array}{r} a \to 0 \\ x_{41} \to 0 \end{array}\right\} :$$ "Zero distance effect" gives disappearance≠0

(Langacker and London, 1988)

(Four neutrino case is limit $U_{\alpha 5} \to 0$)

Appearance probability

$$P_{\nu_\mu(\bar{\nu}_\mu)\to\nu_e(\bar{\nu}_e)} = 4|U_{\mu 4}|^2|U_{e4}|^2 r\sin^2\left(x_{41}\pm\beta\right) + |U_{\mu 4}|^2\,|U_{e4}|^2\left\{(1-r)^2 + a\left[(1-r)^2 + 4r\sin^2\beta\right]\right\}.$$

(Nelson, 2010)

zero distance effects

r can be greater than 1: $r = \dfrac{|U_{e4}U^*_{\mu 4} + U_{e5}U^*_{\mu 5}|}{|U_{e4}U^*_{\mu 4}|}$

β can reduce sensitivity to specific masses and mixings via CP violation

Plenty of Oscillation Data...

- Many different data sets...
  - positive: LSND and MiniBooNe (2009, 2010, 2011)
  - null: KARMEN, NOMAD, NuTeV, CCFR, E776, E701, MiniBooNe (2007), $\bar{\nu}_e$ disappearance at reactors, ν_μ disappearance at CDHS, CCFR, and Super-Kamiokande

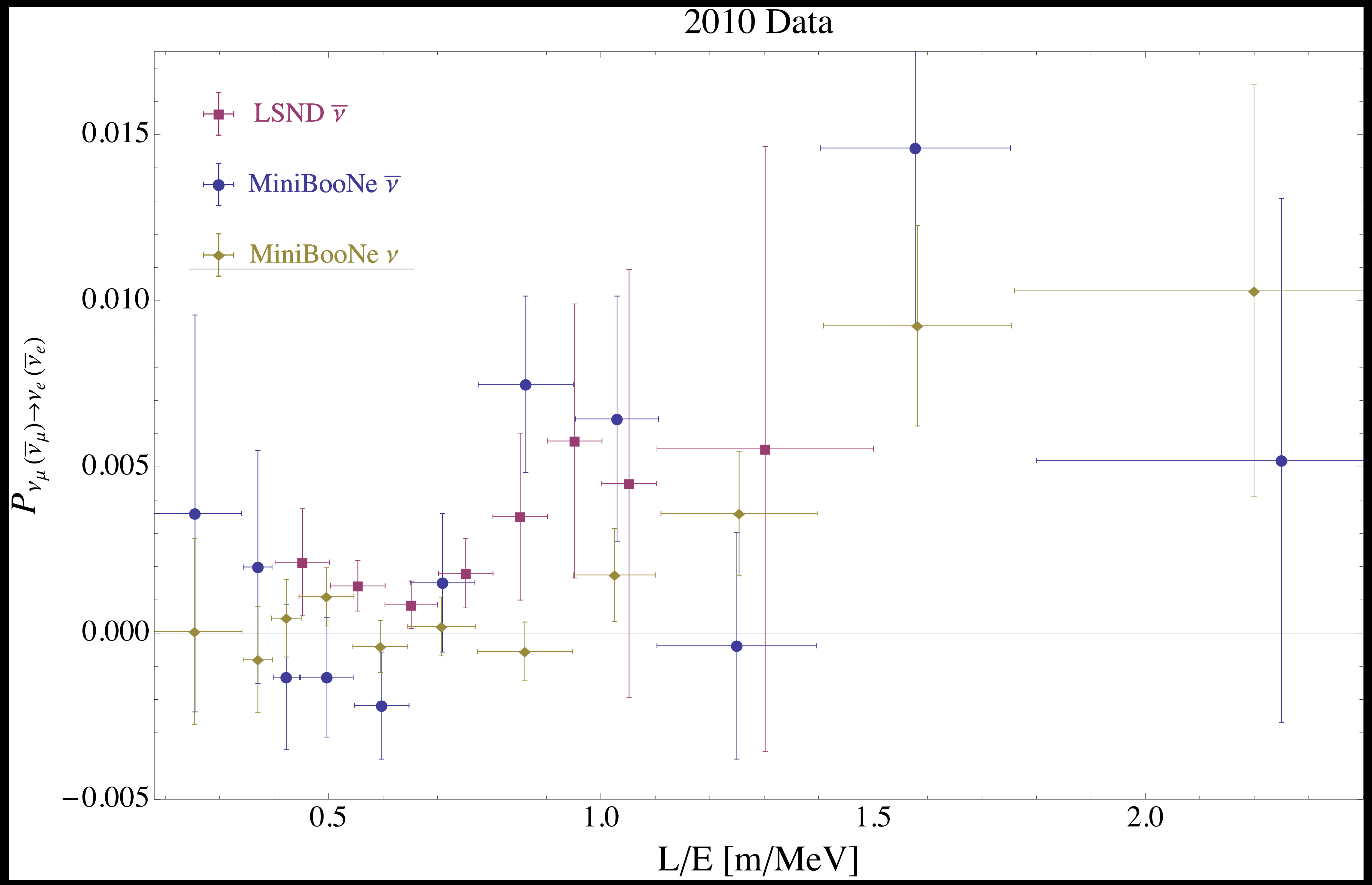
Different experiments are sensitive to different mass splittings (when x~1) and to different mixing angles (by construction)

Appearance Results

Chronologically: LSND, MBnu, then MBantinu, which has been updated (preliminarily)

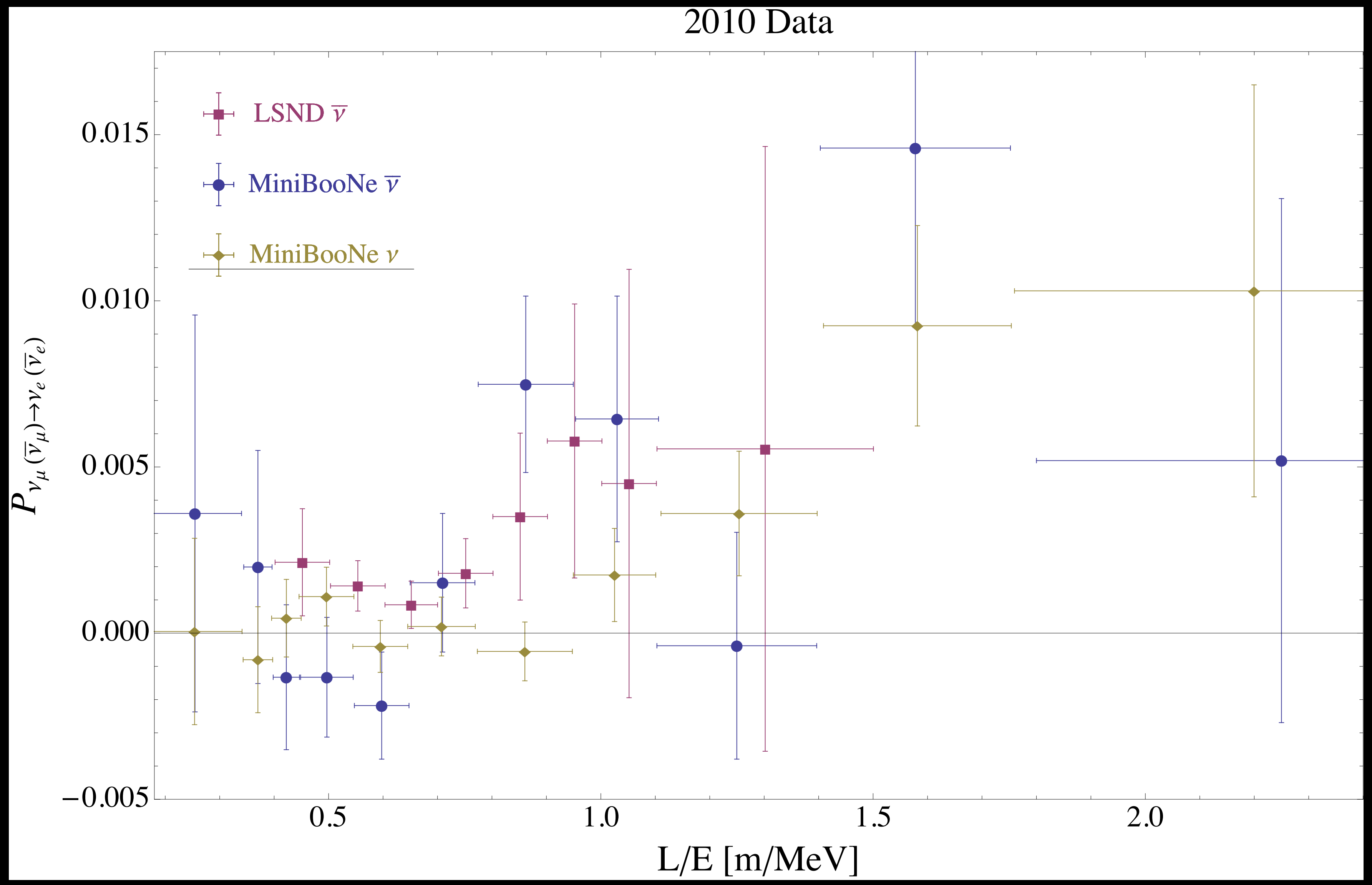
Appearance Results

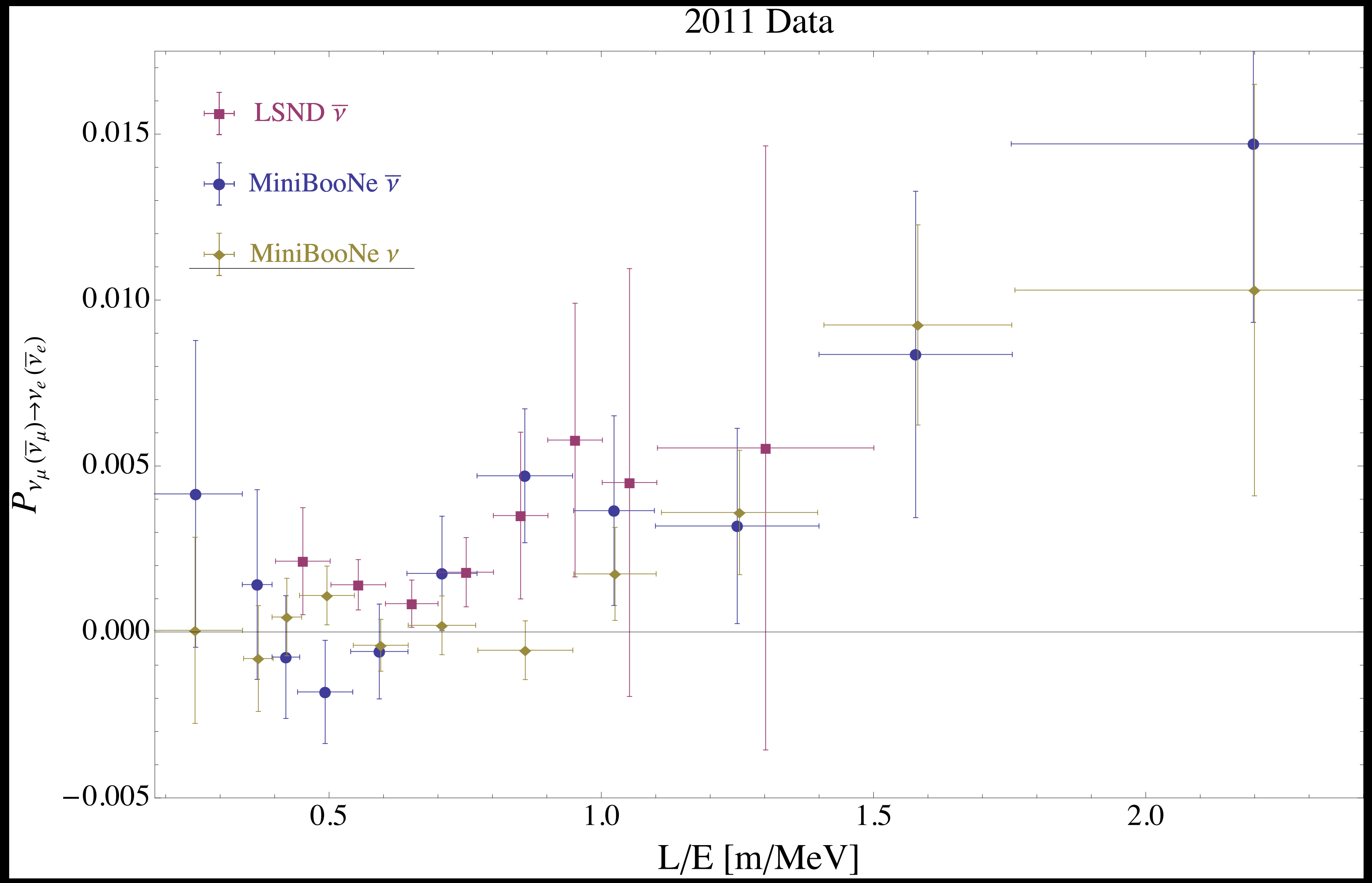
Chronologically: LSND, MBnu, then MBantinu, which has been updated (preliminarily)



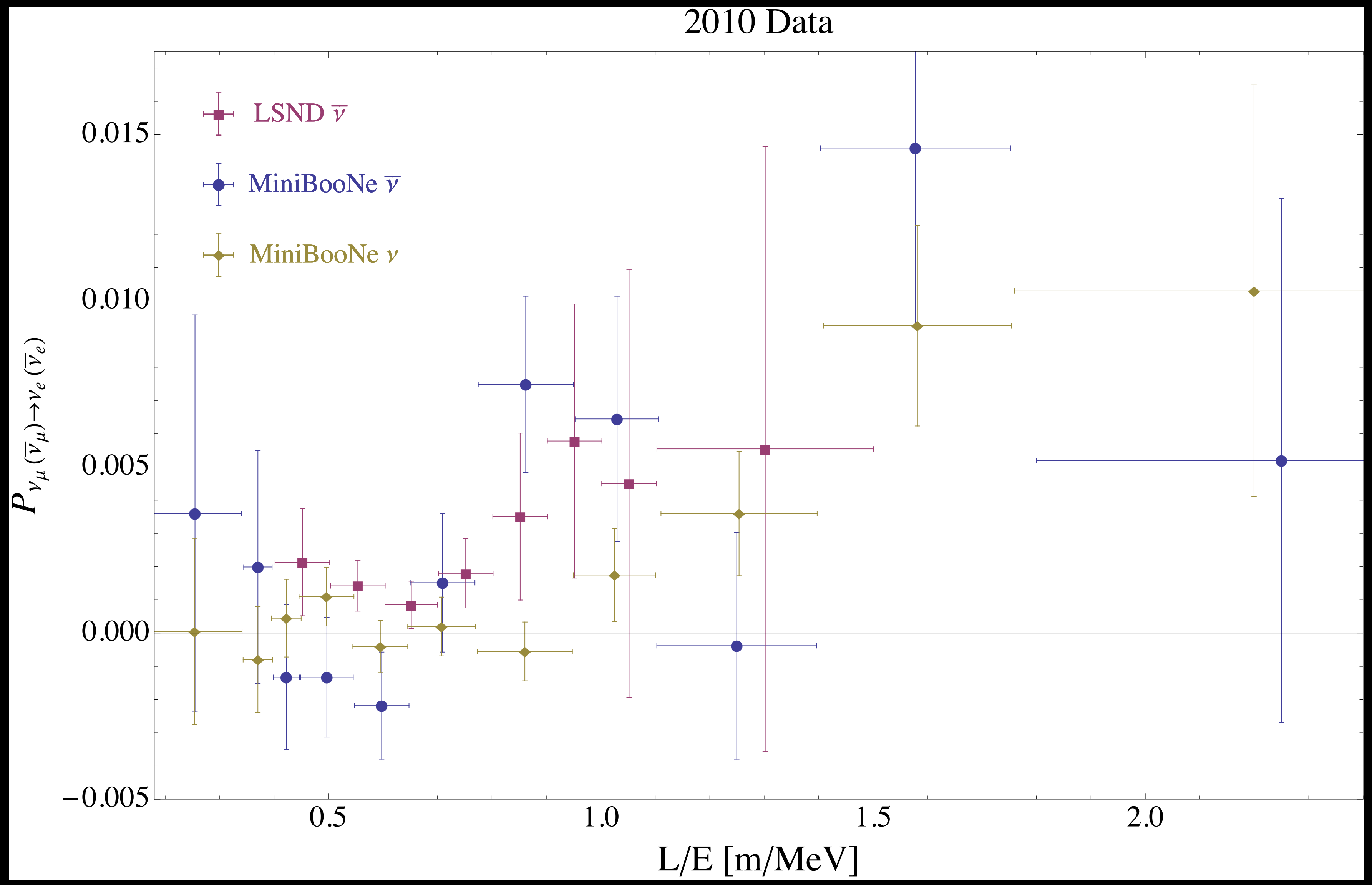
Appearance Results

Chronologically: LSND, MBnu, then MBantinu, which has been updated (preliminarily)

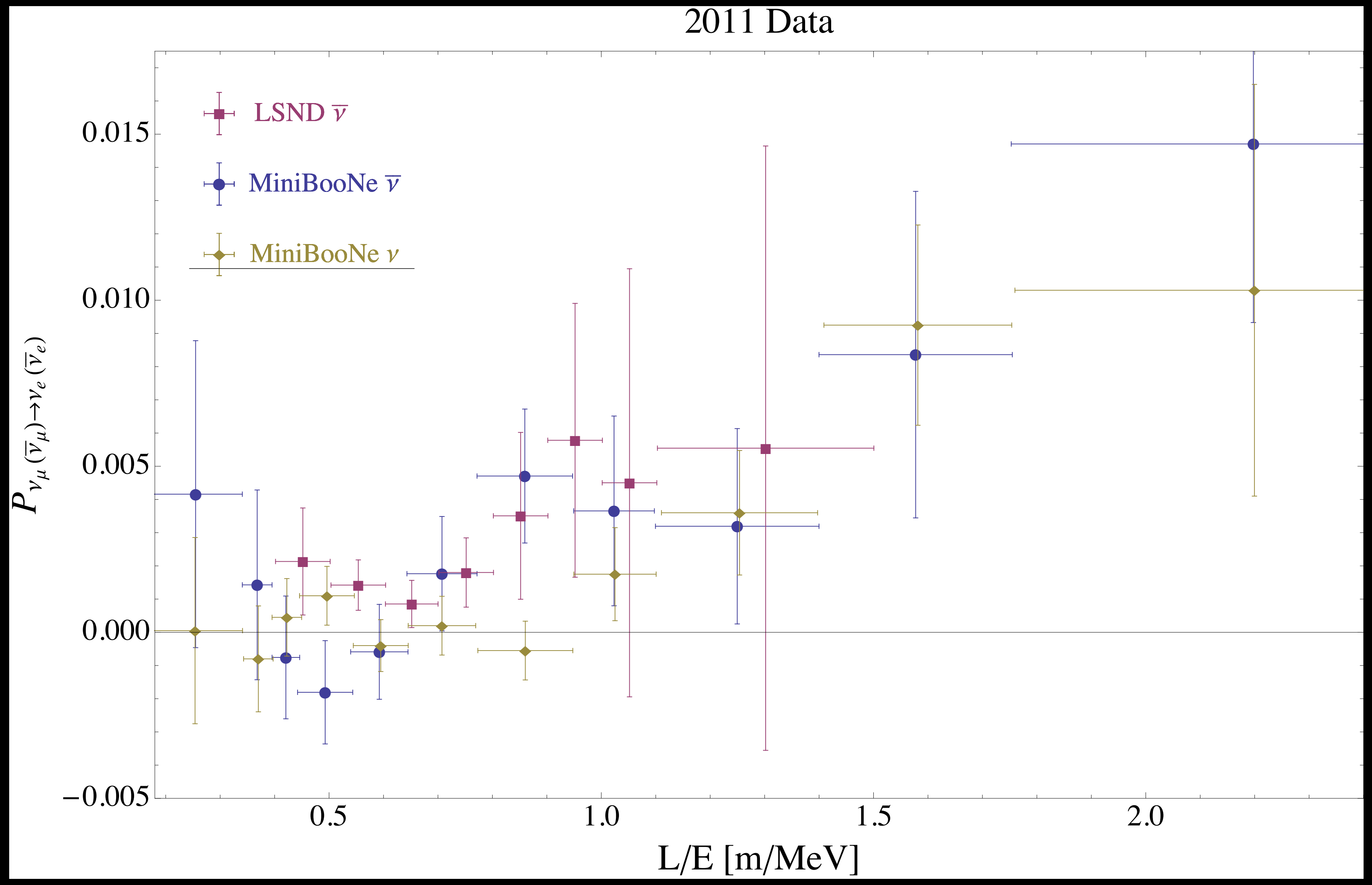




Appearance Results

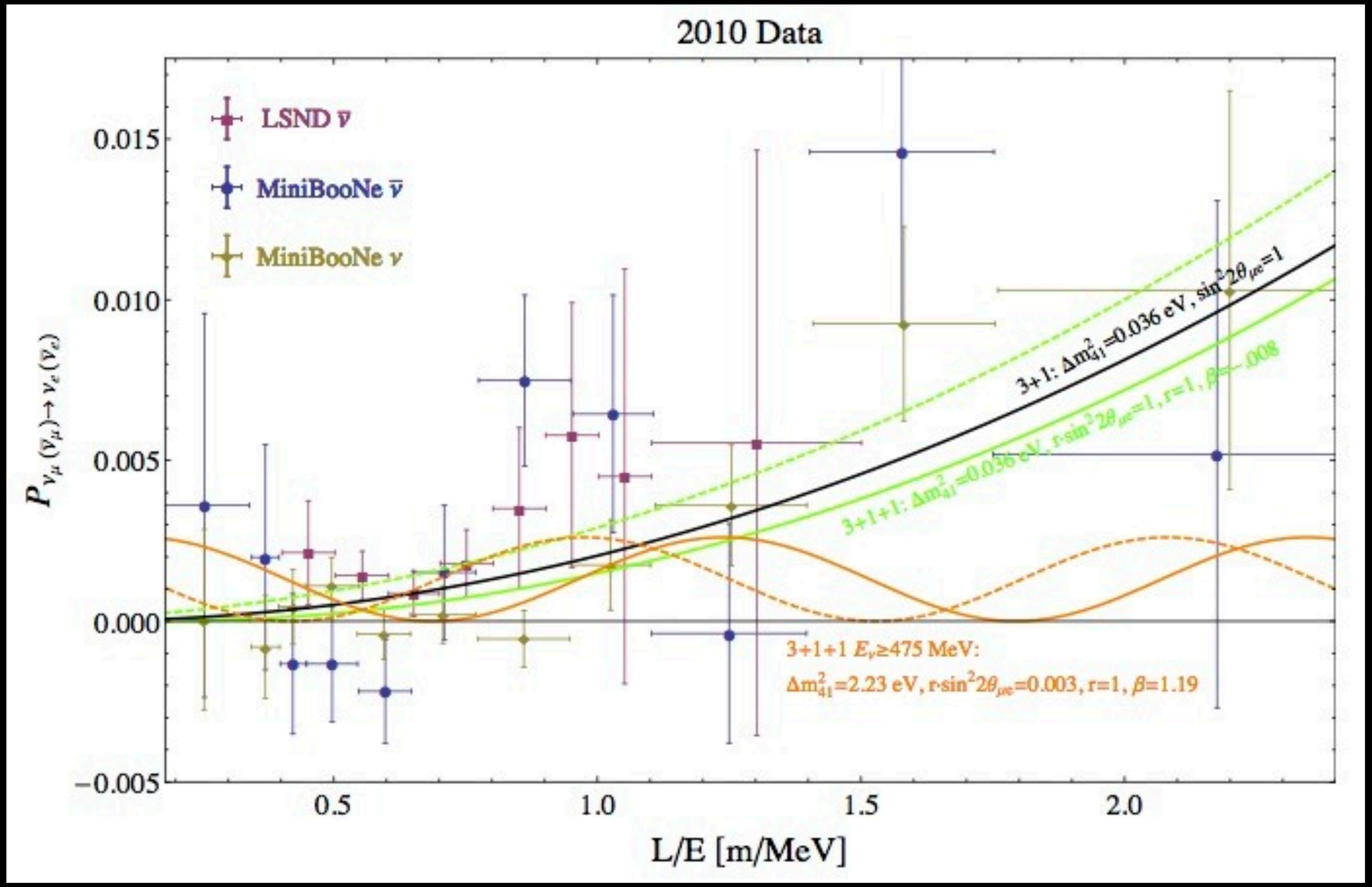


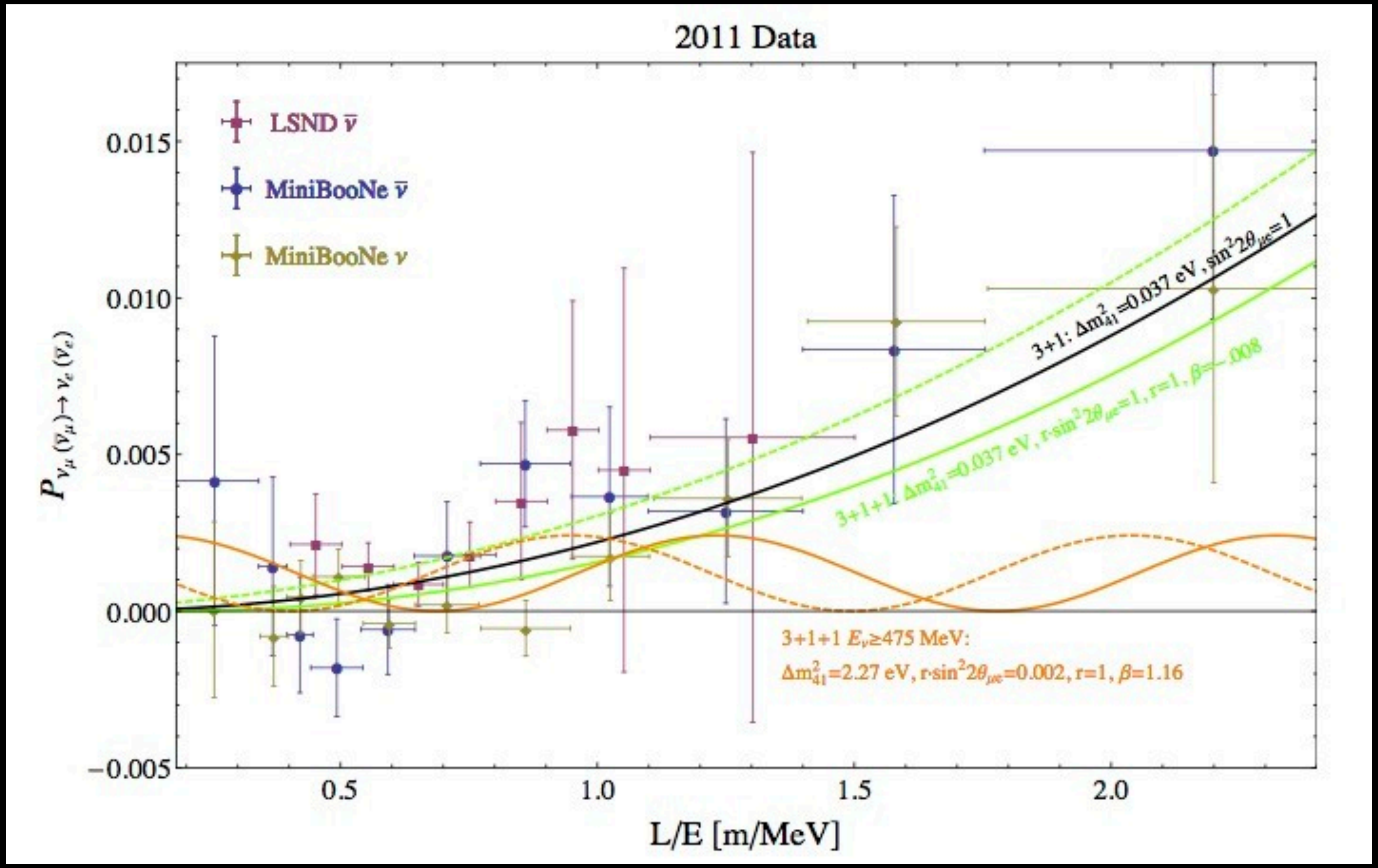
Chronologically: LSND, MBnu, then MBantinu, which has been updated (preliminarily)



Old and new antinu data are fairly different, especially at low energy (high L/E)

Best fits





When dropping low-energy points, CP violation is much more effective

Parameter space of interest

Δm^2_{41} versus $\sin^2 2\theta_{\mu e} = 4|U_{e4}|^2|U_{\mu 4}|^2 r$

In the small mixing, CP-conserving limit, we have

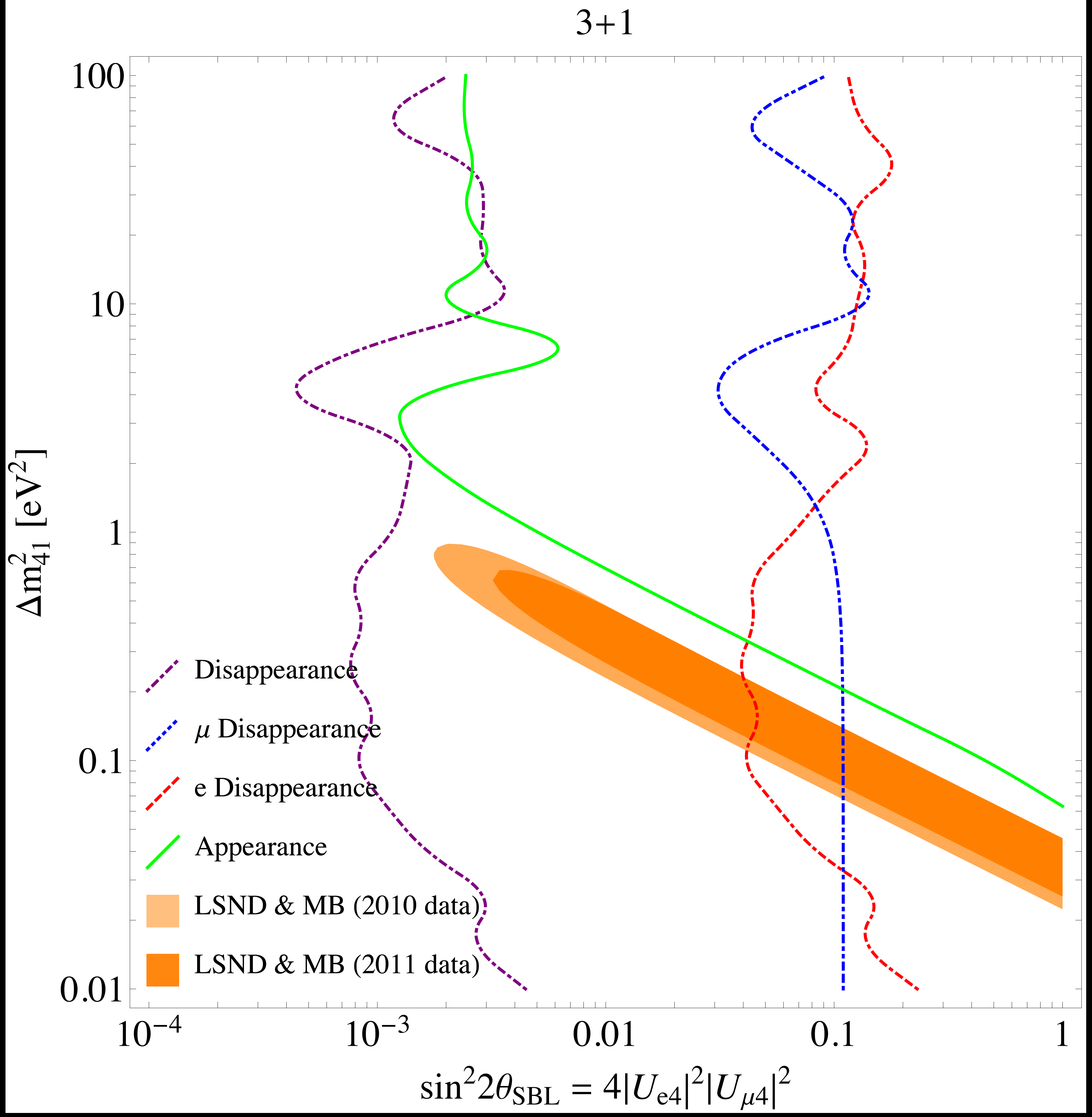
$$\sin^2 2\theta_{\mu e} \approx r \sin^2 2\theta_{\mu 4} \sin^2 2\theta_{e4}/4$$

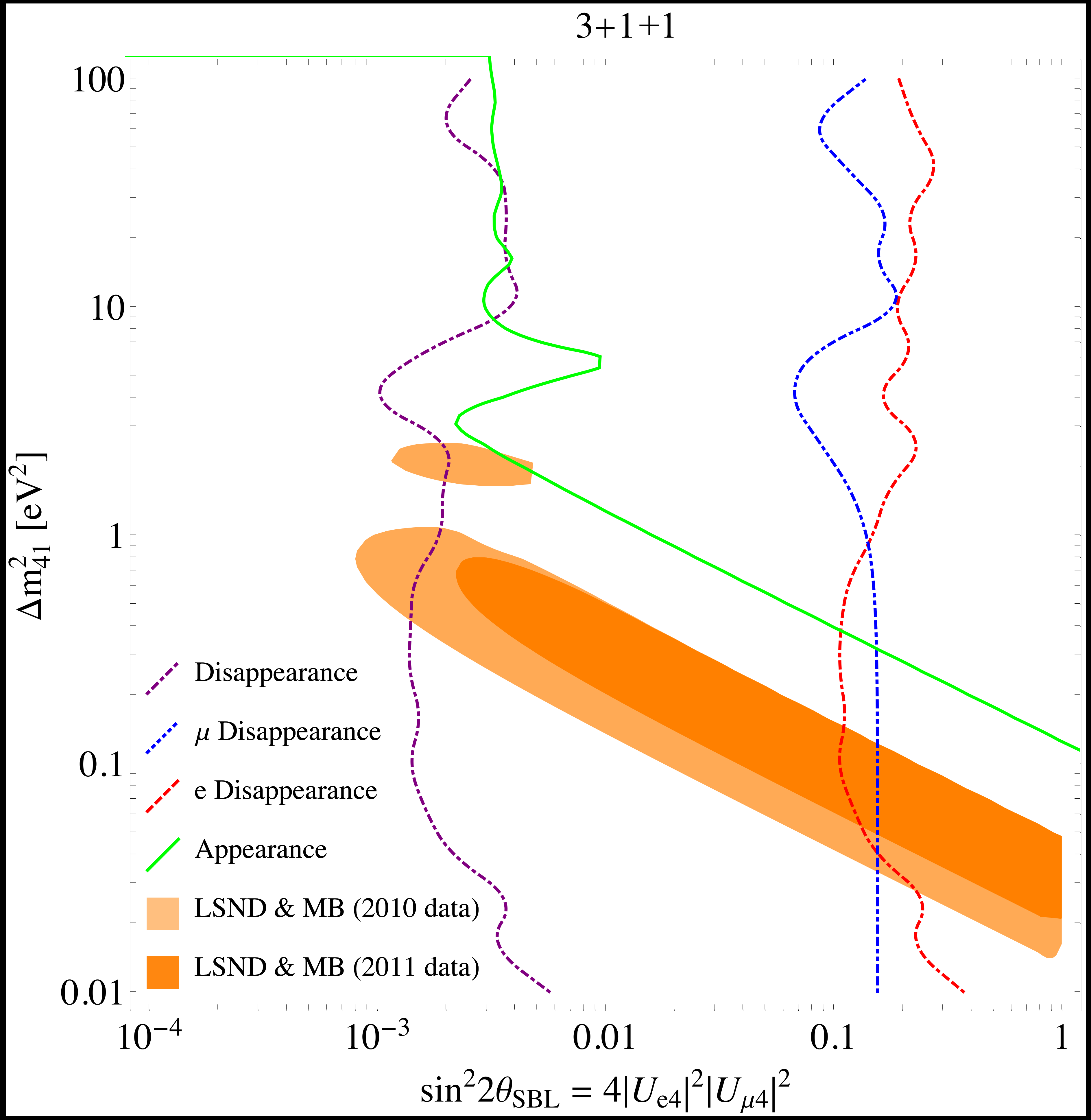
is r>1 allowed?
is CP violation important?

A few objectives...

- Combine disappearance observations to get constraints on appearance mixing angle
- Fit to the data to see how including the MB neutrino data, using the high L/E bins, and taking the new data affect the fit
- Does a very heavy fifth neutrino help us achieve agreement?
- Can the fifth neutrino do anything else (other anomalies)? If so, what parameter space can it live in?

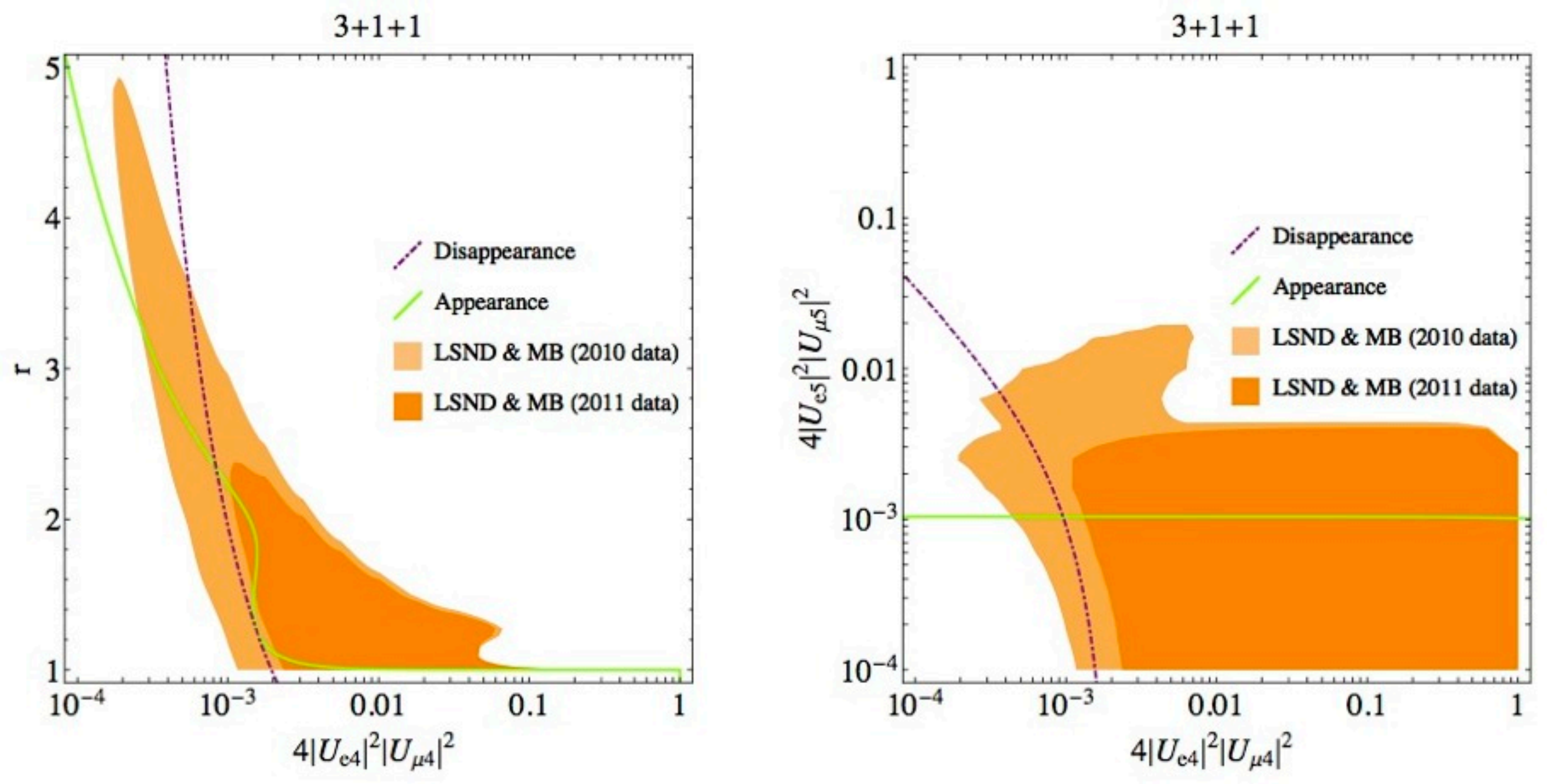
Tension in the data...

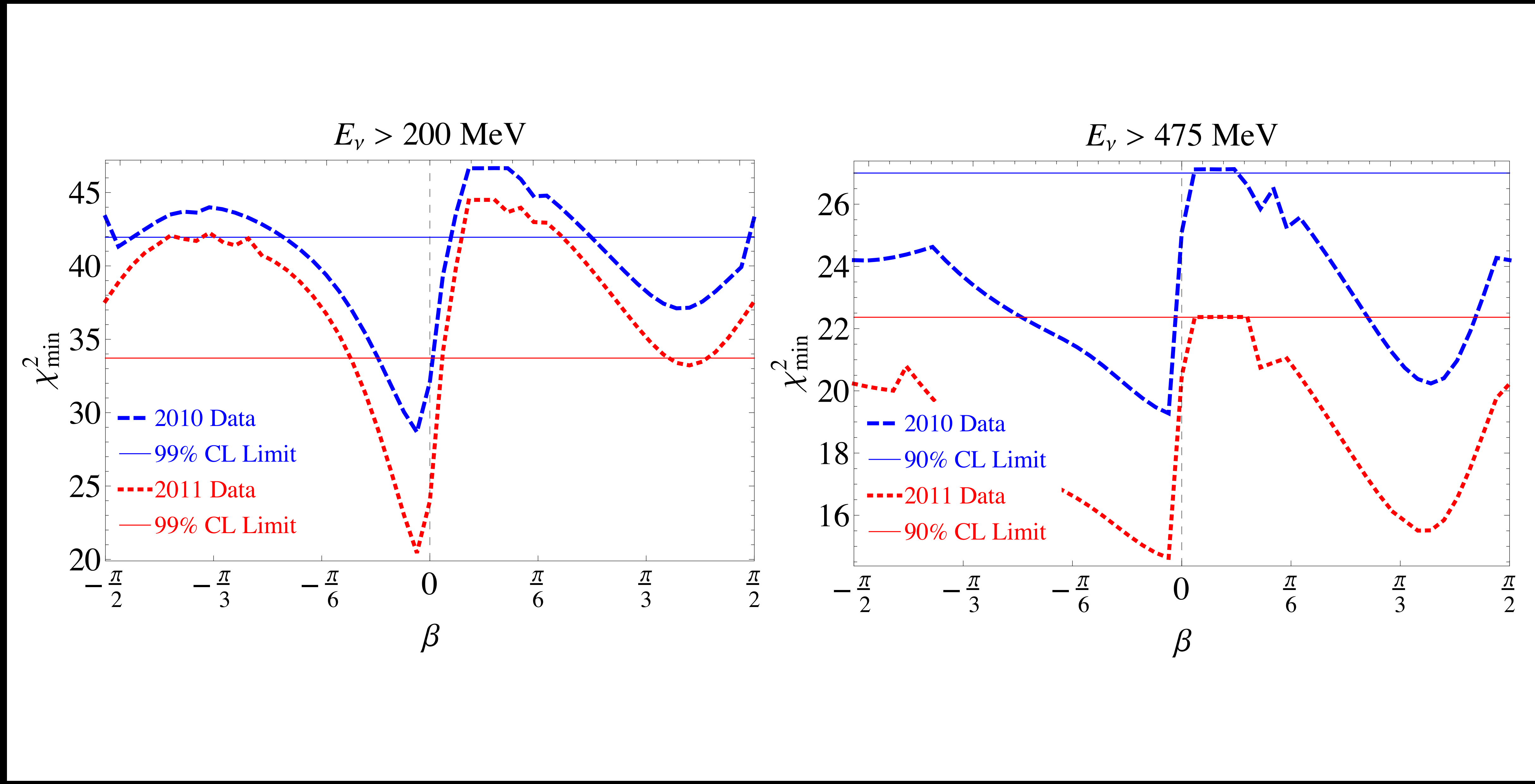




possible handles (r or β) are constrained to be ineffective

r and β

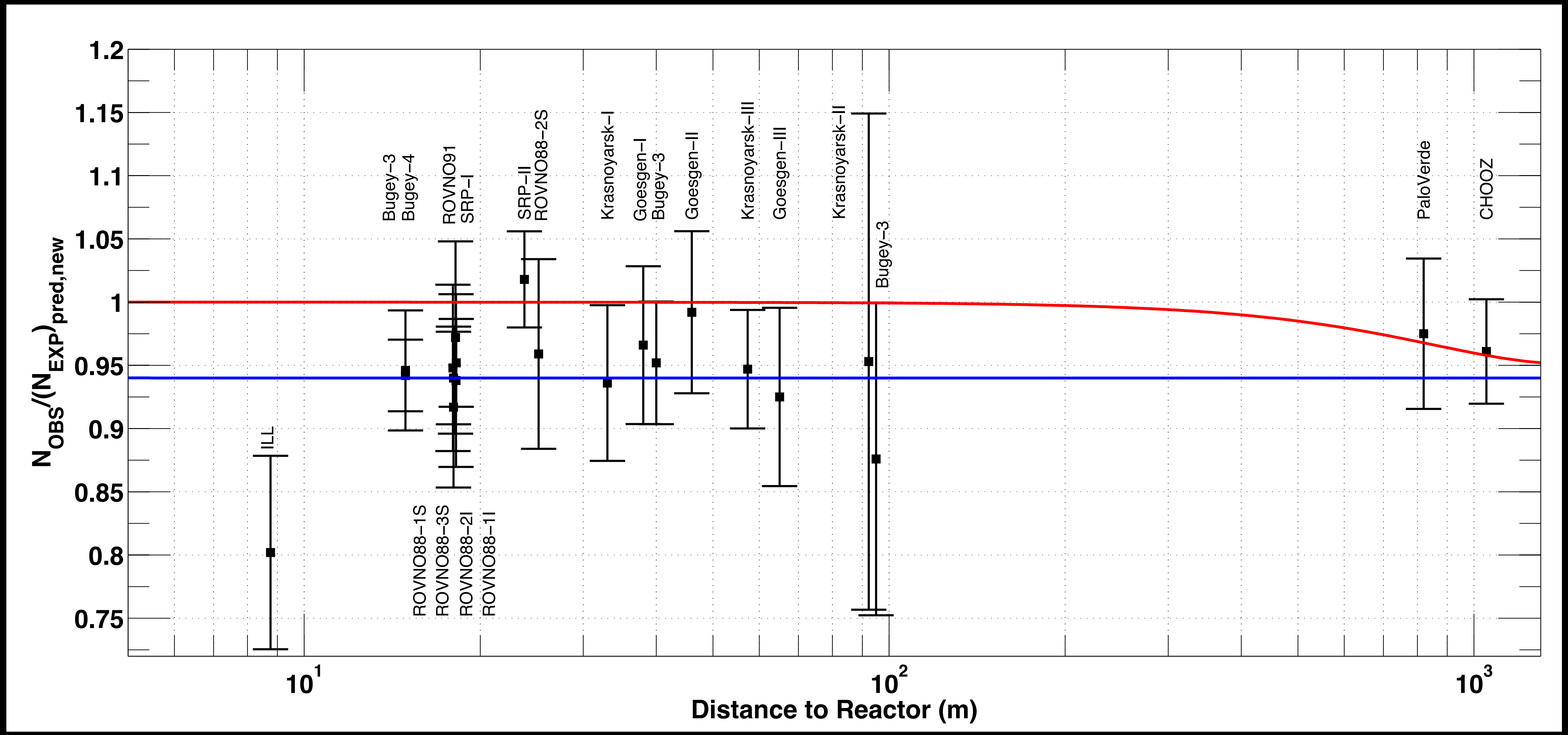




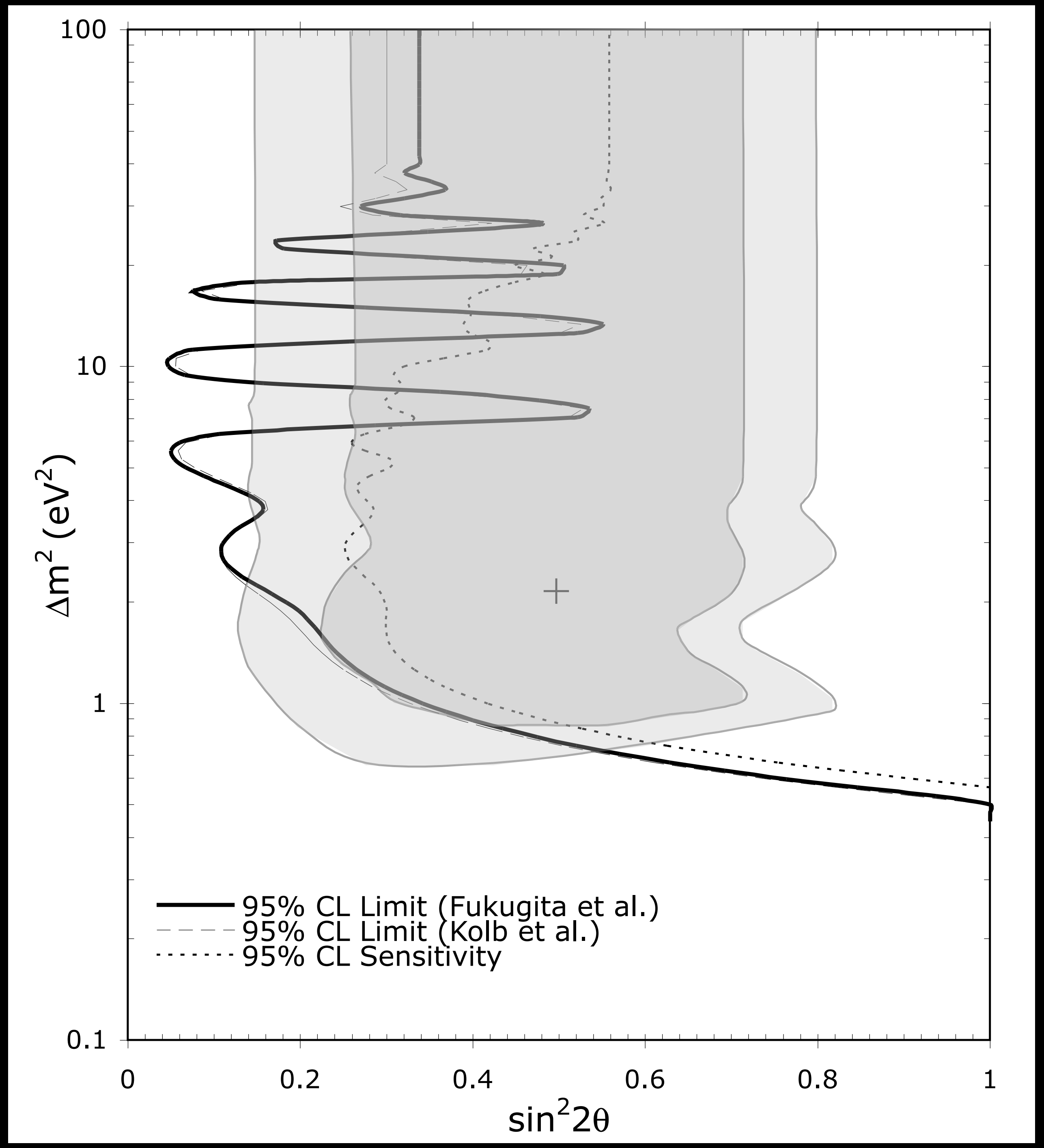
r offers a multiplicative enhancement, but is bound to be very close to one (by zero distance effects)

β offers more parameter freedom, less sensitivity to mass and mixing, but new low-energy data doesn't like CP violation

Flux anomalies



Mention *et al.*, 1101.2755

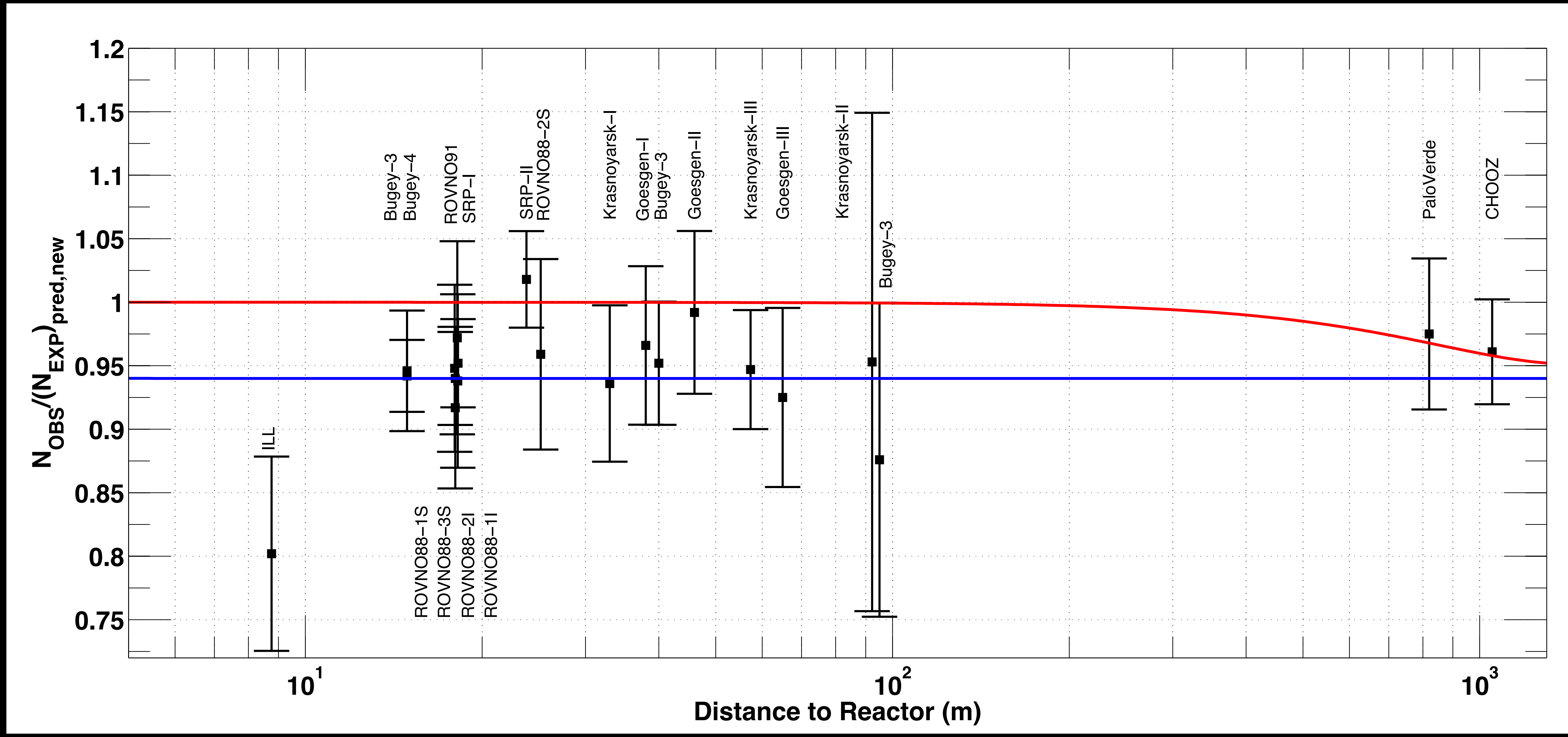


Conrad and Shaevitz, 1106.5552

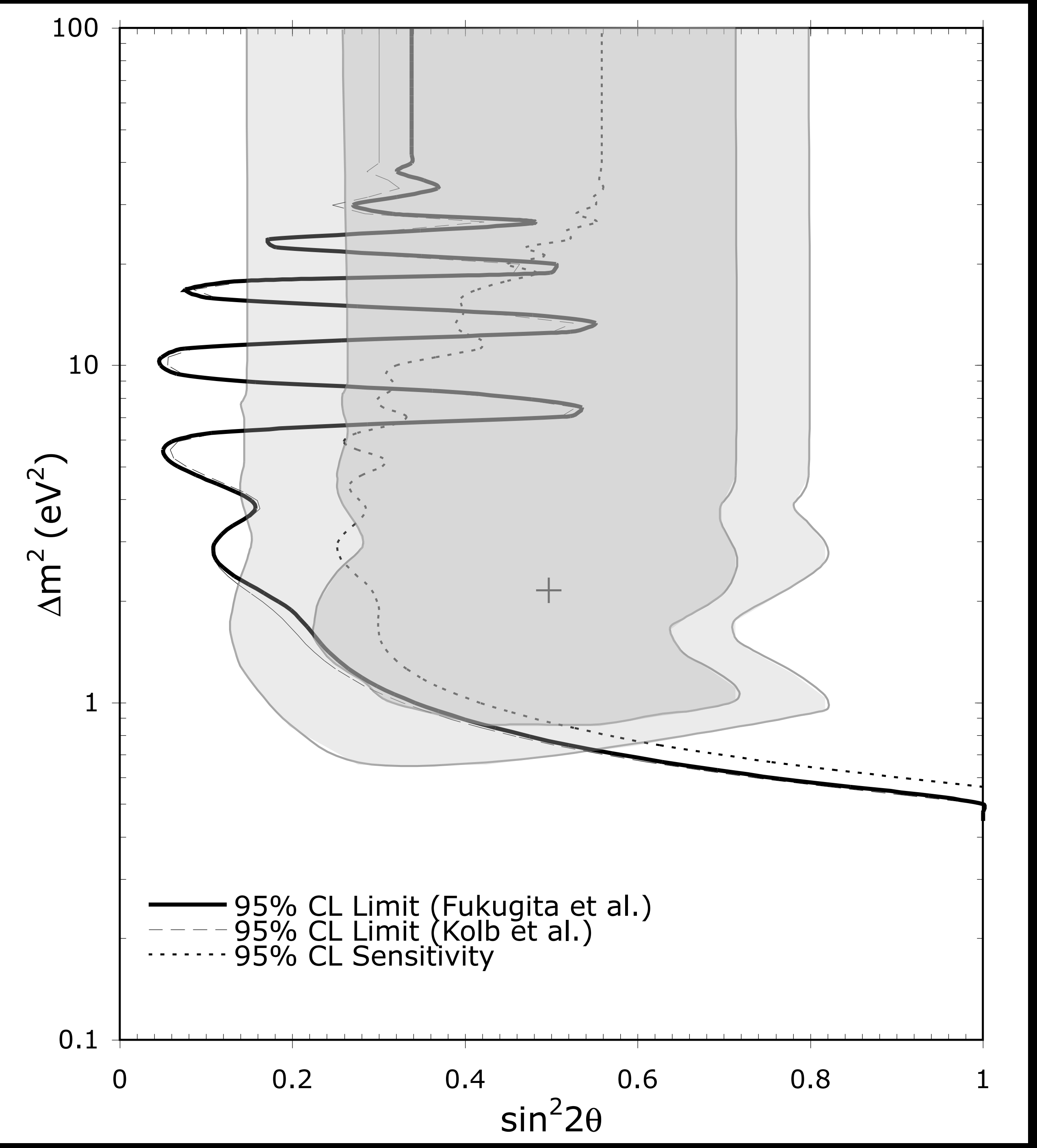
Giunti and Laveder, 1006.3244

- Position- and energy-independent reductions in flux
- Mixing angle is same order of magnitude, and χ^2s happen to be fairly shallow

Flux anomalies



Mention *et al.*, 1101.2755



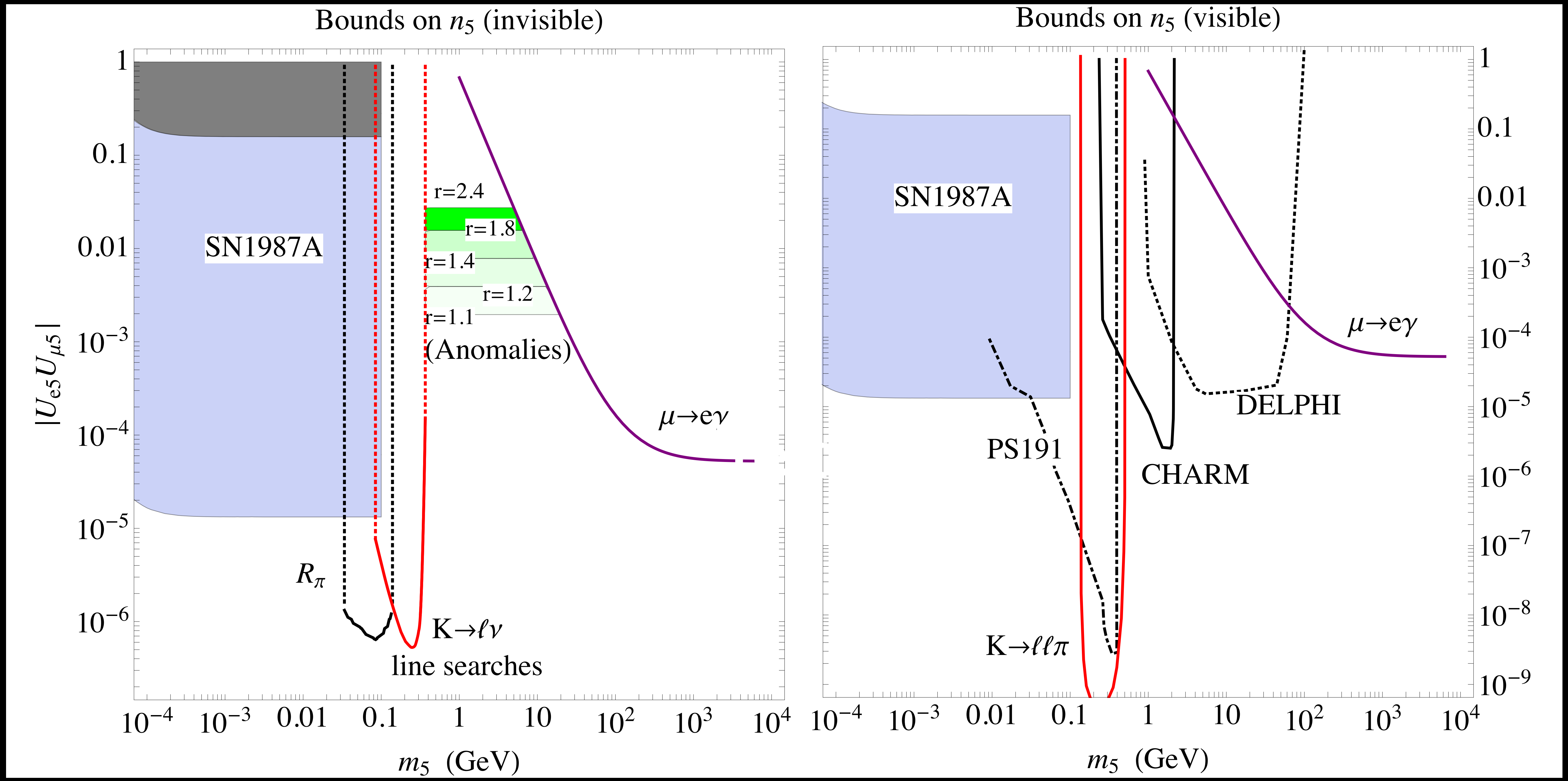
Conrad and Shaevitz, 1106.5552

Giunti and Laveder, 1006.3244

- Position- and energy-independent reductions in flux
- Mixing angle is same order of magnitude, and χ^2s happen to be fairly shallow

$$|U_{e5}|^2 = 0.036 \pm 0.013$$

Constraints on n_5



n_5 must be invisible on collider timescales and can't mix too strongly, but otherwise is allowed to be around 0.3 - 10 GeV

Conclusions

- Neutrino phenomenology is an area with lots of data, puzzling issues, and plenty of good ideas remaining
- Very heavy states can have nontrivial effects on the low-energy physics
- There is parameter space available and there are motivations to put a neutrino there...
- ...but the 3+1+1 framework on its own doesn't seem capable of fully resolving all the tension in the data