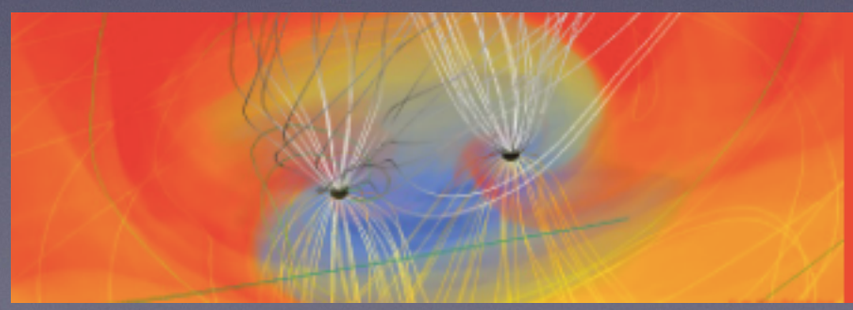
Sterile Neutrinos
with
Altered Dispersion Relations
as an Explanation for
MiniBooNE, LSND, Gallium and Reactor Anomalies

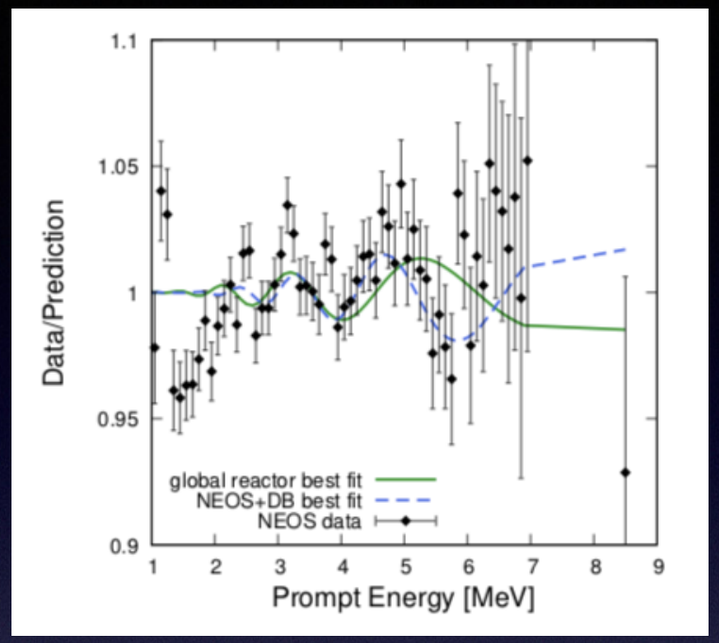
- Heinrich Päs -
tu dortmund



PASCOS 2019
XXV International Symposium

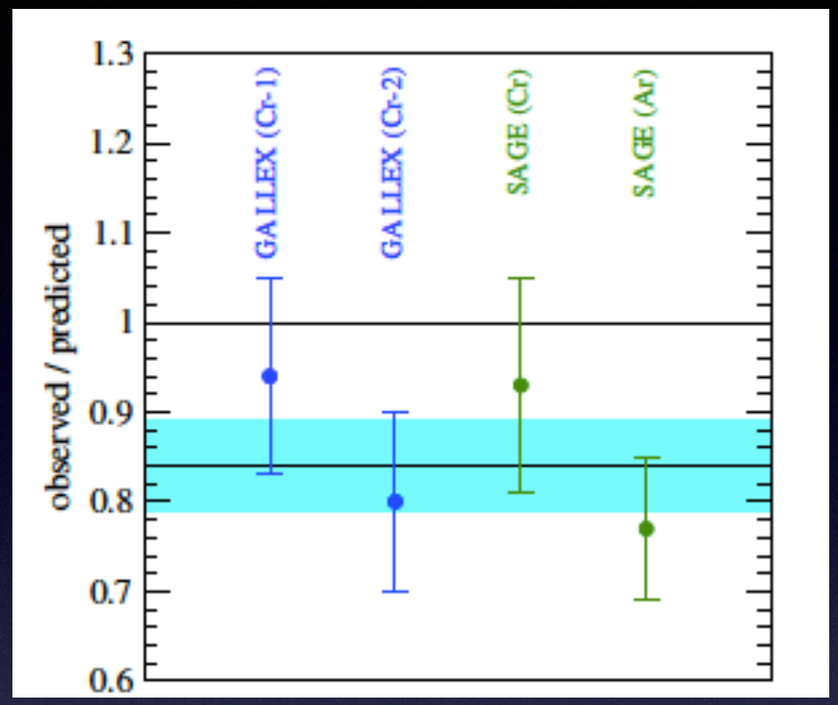
Sterile Neutrinos?

Reactor Anomaly

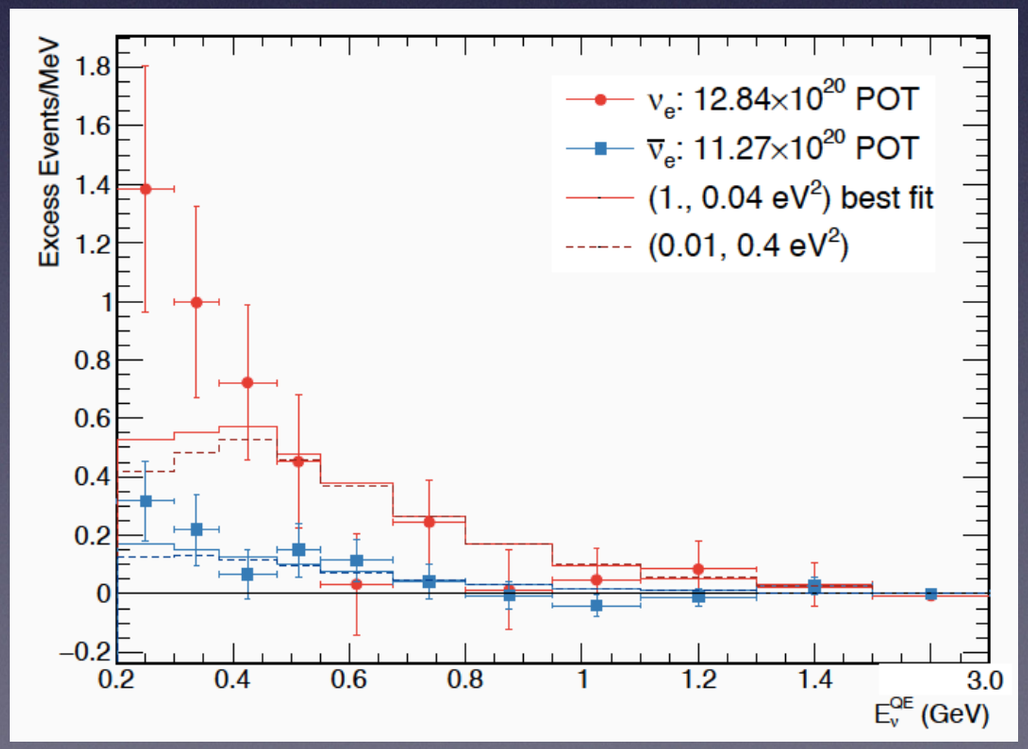


All pointing towards a 1 eV sterile neutrino!

Gallium Anomaly

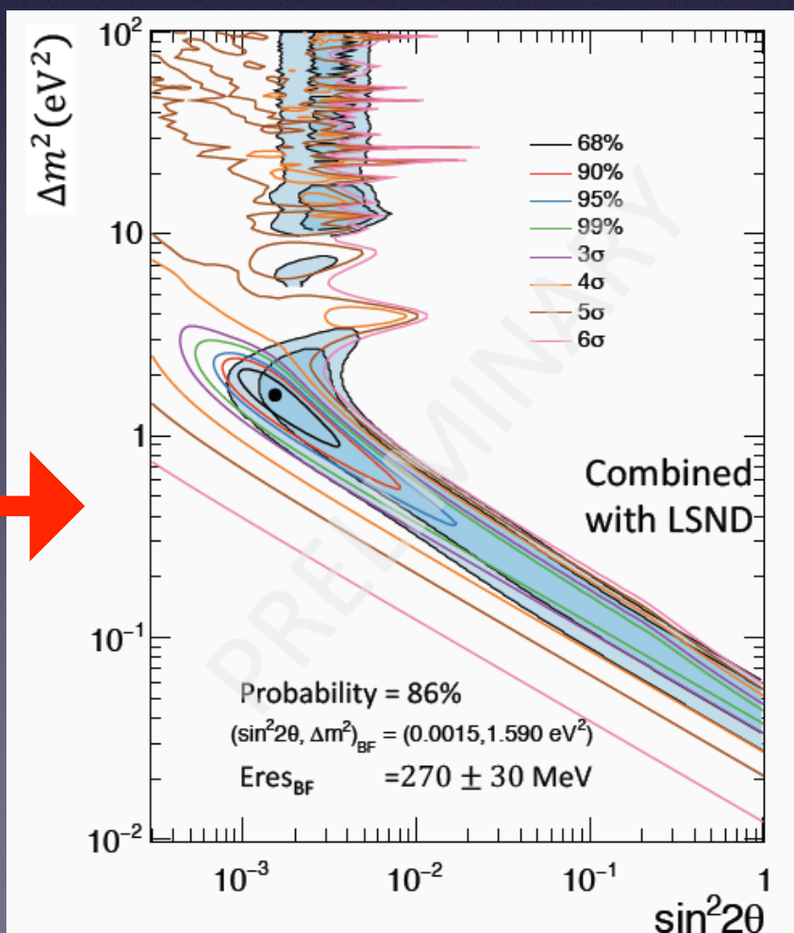


LSND/MiniBooNE Anomaly



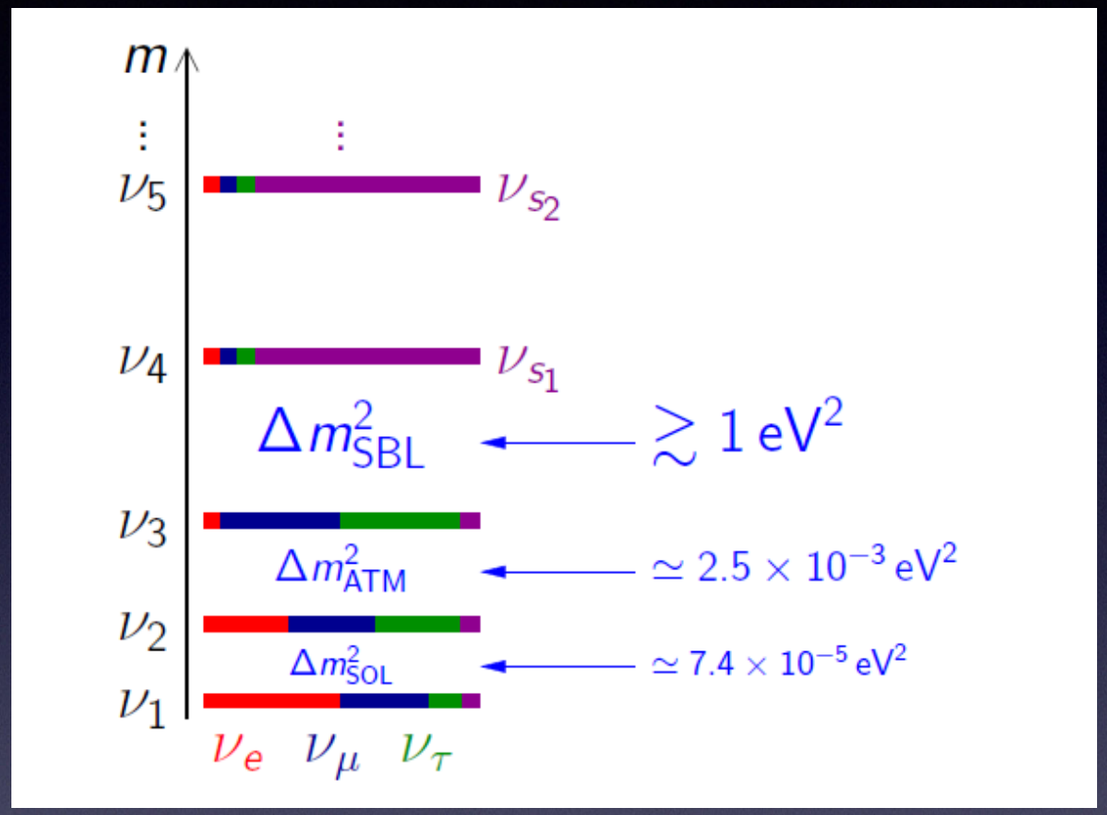
"MSW-like resonance model"

En-Chuan Huang, Talk at Netrino2018



Sterile Neutrinos?

→ Add a sterile neutrino with $\Delta m^2 \sim 1\ eV^2$



Conrad/Shaevitz

To explain LSND/MiniBooNE:

ν_s -mixing with both ν_e and ν_μ :

$$\sin^2 2\theta_{\mu e} = 4\,|U_{\mu 4}|^2 |U_{e4}|^2 = \frac{1}{4}(\sin^2 2\theta_{\mu\mu} + 4\,|U_{\mu\mu}|^4)(\sin^2 2\theta_{ee} + 4\,|U_{ee}|^4)$$
$$\simeq \frac{1}{4}\sin^2 2\theta_{\mu\mu}\sin^2 2\theta_{ee},$$

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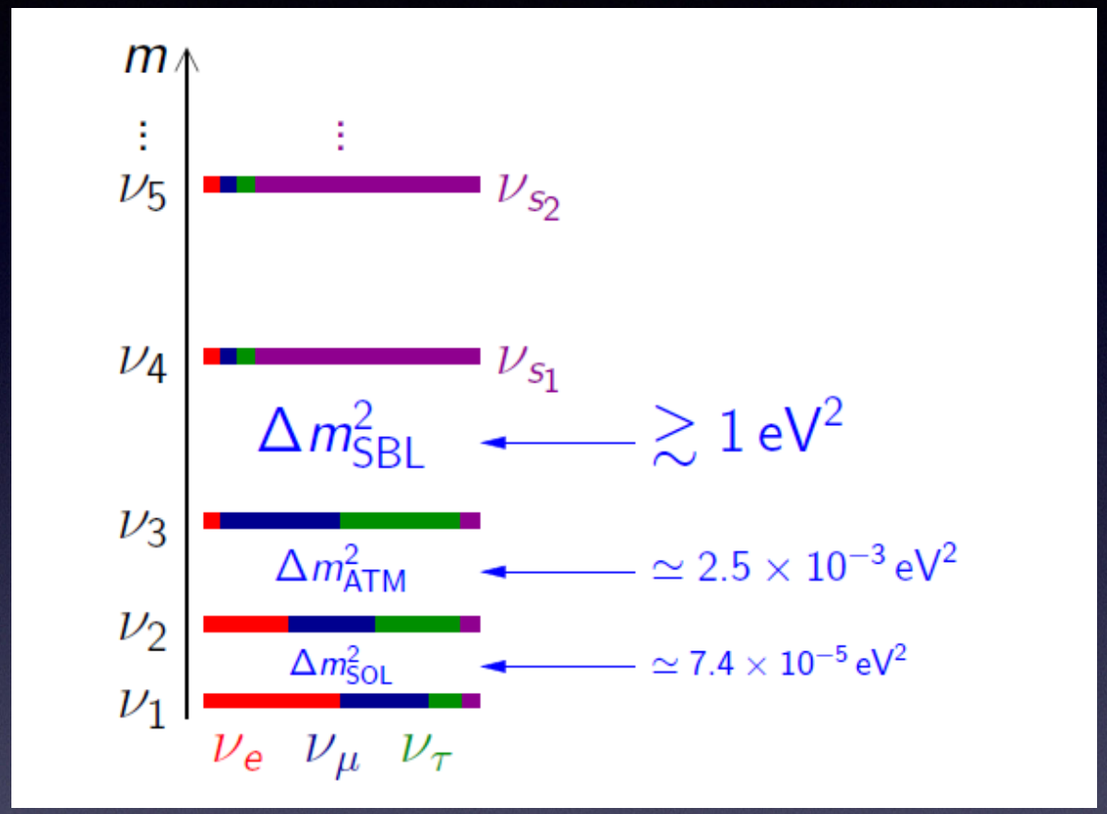

Conrad/Shaevitz

constrained by
ν_μ disappearance

constrained by
νe disappearance

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Giunti, Zavanin, 2015

$$\sin^2 2\theta_{\mu e} = 4\,|U_{\mu 4}|^2 |U_{e4}|^2 = \frac{1}{4}(\sin^2 2\theta_{\mu\mu} + 4\,|U_{\mu\mu}|^4)(\sin^2 2\theta_{ee} + 4\,|U_{ee}|^4)$$
$$\simeq \frac{1}{4}\sin^2 2\theta_{\mu\mu}\sin^2 2\theta_{ee},$$

A 4th sterile neutrino ?

Sterile netrinos can have a very different origin than the SM neutrinos (e.g. superpartners of dilaton, radion or other moduli fields, mirror world fermions, etc...)

There is NO compelling reason to believe that a sterile neutrino should behave just as the SM neutrinos

Sterile neutrino Altered Dispersion Relations

Evidence for light sterile ν is partly conflicting!

- May be wrong!
- May hint towards deviations from the usual oscillation mechanism!
- Sterile neutrinos as messengers of exciting new physics?

Attractive candidate: Altered dispersion relations

$$E = p + m^2/2E + \textit{new terms}$$

→ novel energy dependence!

HP, Pakvasa, Weiler 2005

Altered dispersion relations: vanilla type

Evolution equation in flavor space:

$$i\frac{d}{dt}\begin{pmatrix}\nu_a(t)\\ \nu_s(t)\end{pmatrix} = H_F\begin{pmatrix}\nu_a(t)\\ \nu_s(t)\end{pmatrix}$$

Hamiltonian in the presence of bulk shortcuts:

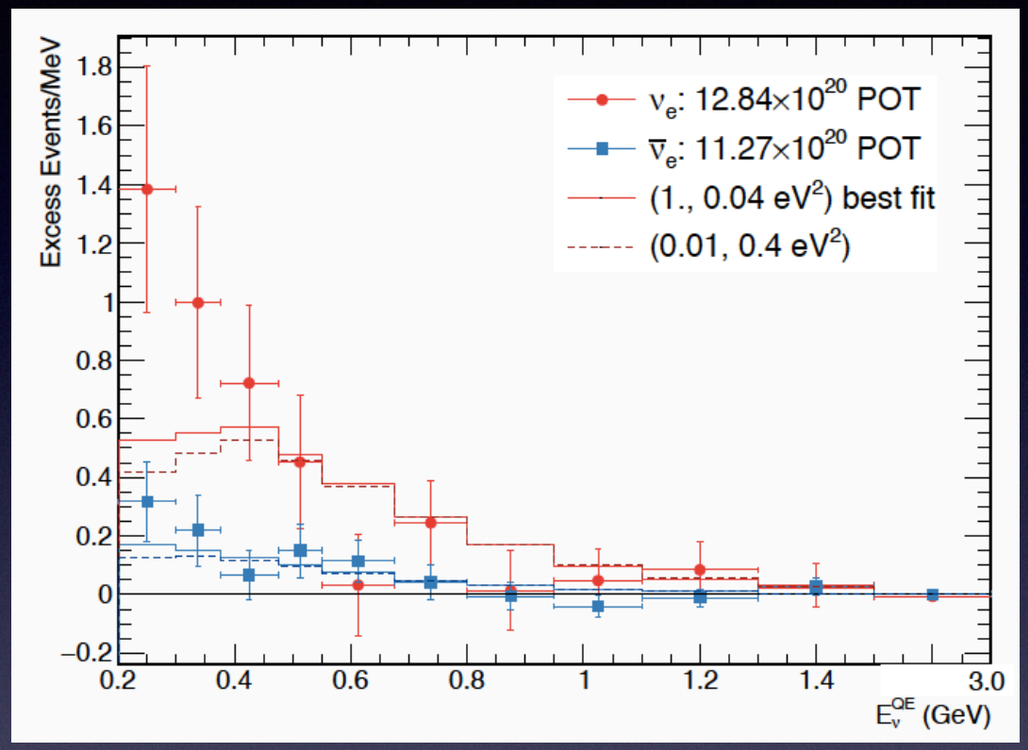
$$H_F = +\frac{\delta m^2}{4E}\begin{pmatrix}\cos 2\theta & -\sin 2\theta\\ -\sin 2\theta & -\cos 2\theta\end{pmatrix} + E\,\frac{\epsilon}{2}\begin{pmatrix}-1 & 0\\ 0 & 1\end{pmatrix}$$

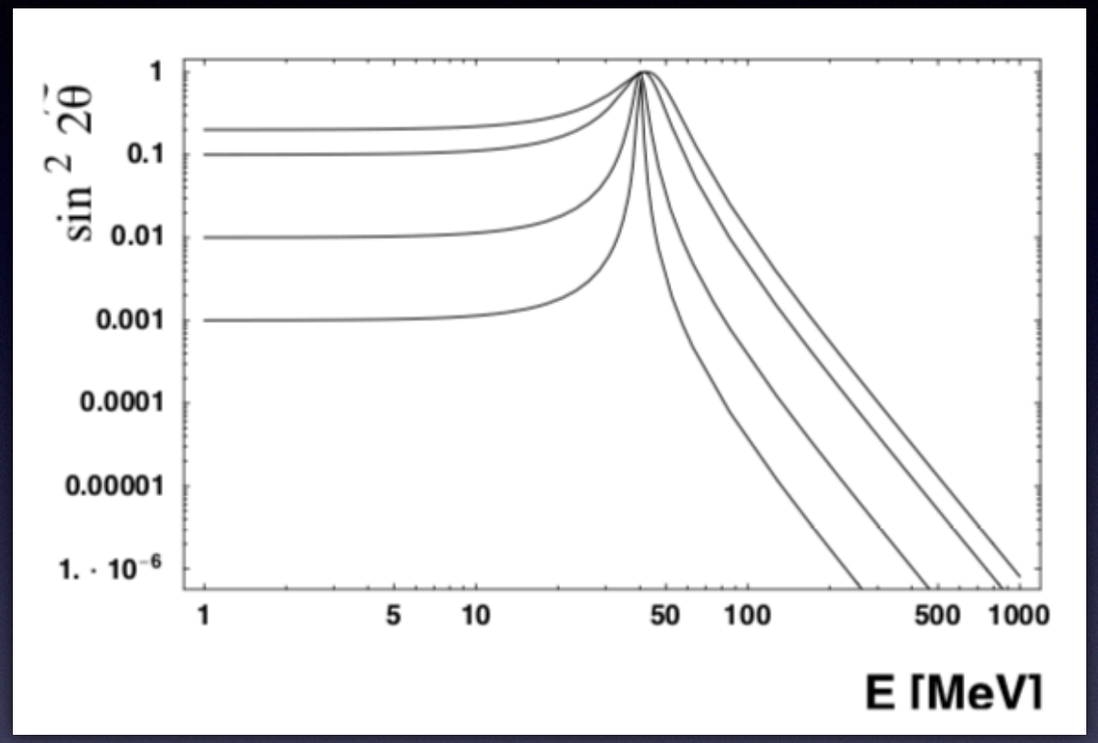
$\Rightarrow$ A Resonance exists at $E_{\rm res} = \sqrt{\frac{\delta m^2\,\cos 2\theta}{2\,\epsilon}}$

$\rightarrow$ choose $E_{\rm res}$=30-400 MeV $\leftrightarrow \epsilon \simeq 10^{-18} - 10^{-16}$

(Päs, Pakvasa, Weiler, 2005)

Altered dispersion relations: vanilla type



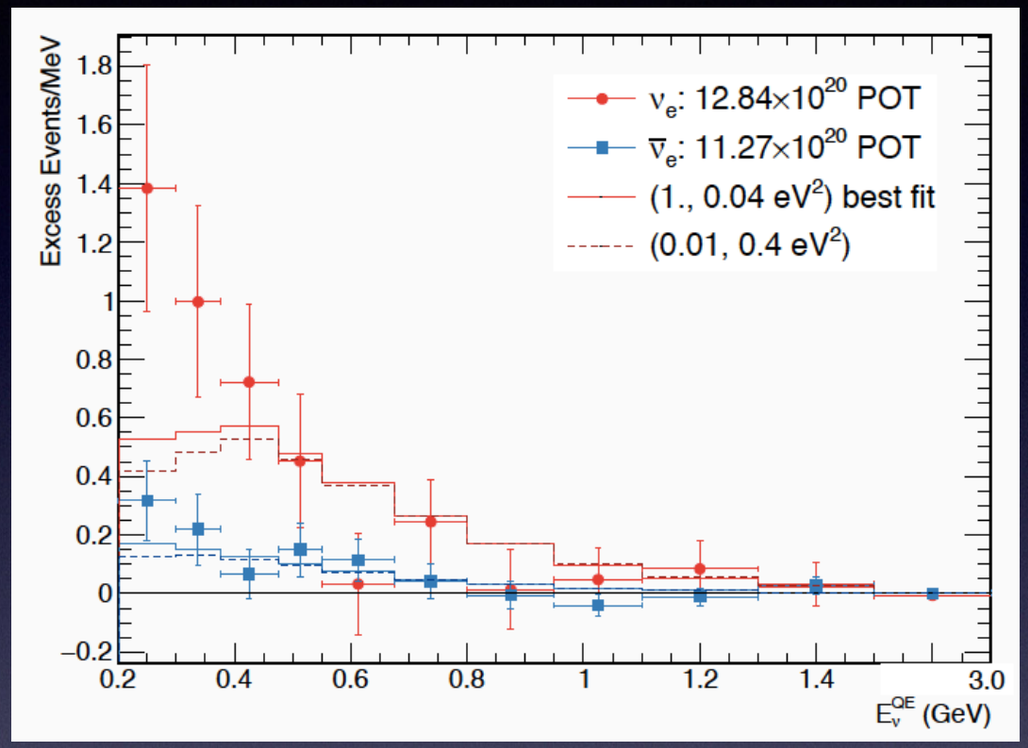


MiniBooNE 2018

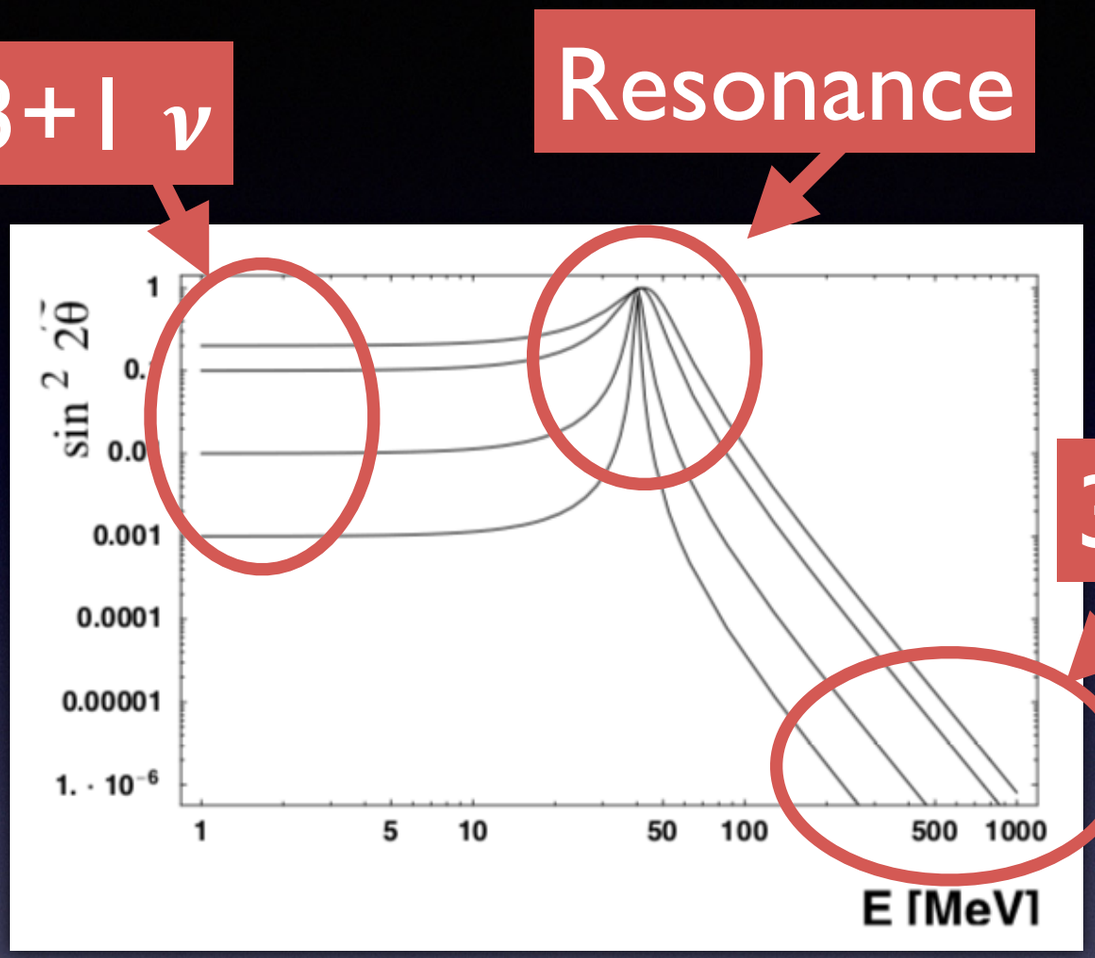
HP, Pakvasa, Weiler 2005

→ resonance-like features!

Altered dispersion relations: vanilla type



MiniBooNE 2018



HP, Pakvasa, Weiler 2005

→ resonance-like features!

[P. Huber, 2007]

Altered dispersion relations: vanilla type

"A nice model -
but unfortunately it doesn't work"

P. Huber

Altered dispersion relations with 3+1 neutrinos

$$\lambda_{4/3} \equiv \lambda_{\pm} = \frac{\Delta}{4E}\left(1 - \cos 2\theta_{34}\left(\frac{E}{E_{\rm R}}\right)^2 \pm \sqrt{\sin^2 2\theta_{34} + \cos^2 2\theta_{34}\left[1 - \left(\frac{E}{E_{\rm R}}\right)^2\right]^2}\right)$$

- 2 mass eigenstates with large effective masses!
- Large Δm^2's
- Fast oscillations:

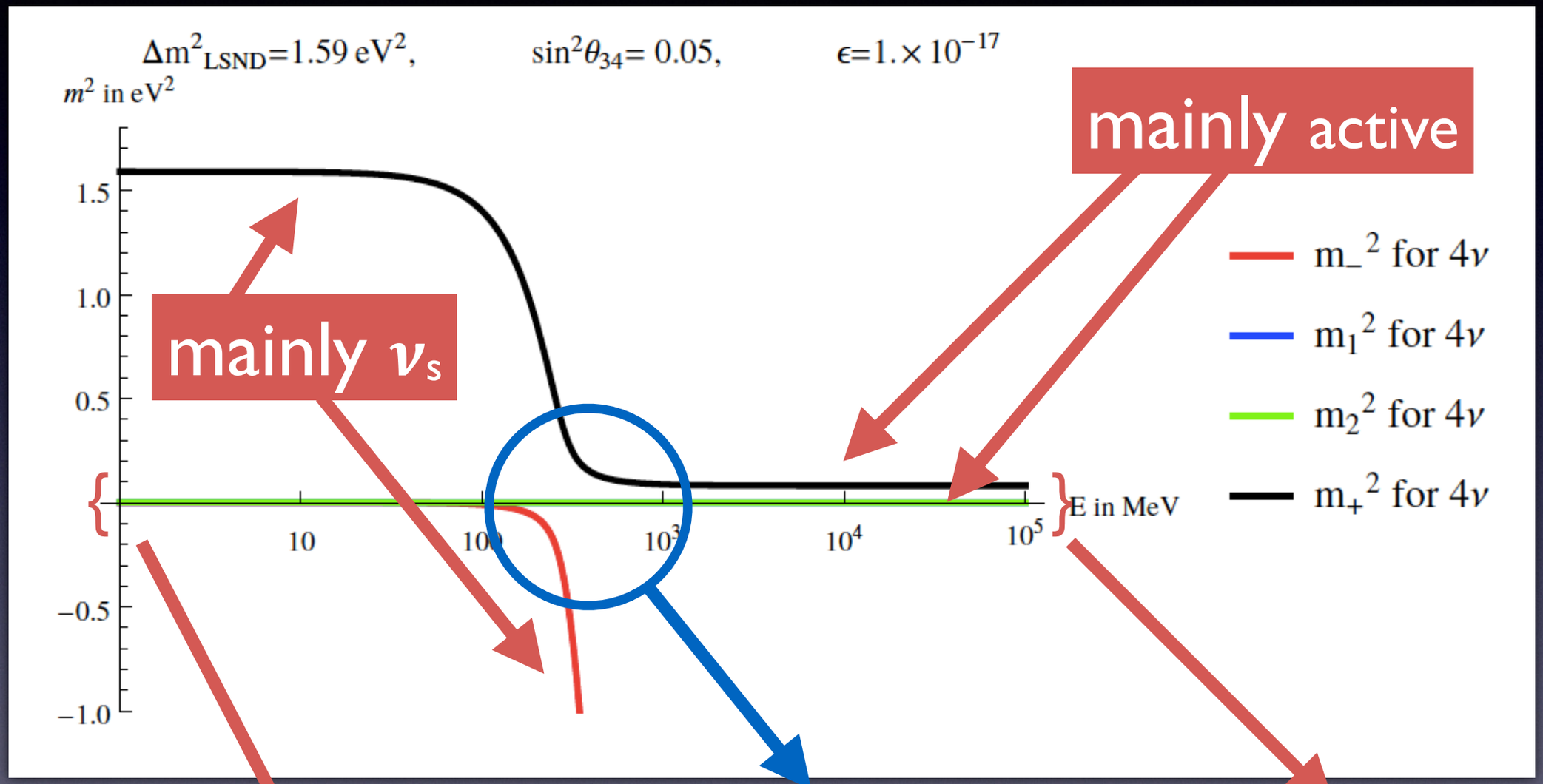
[Marfatia, HP, Pakvasa, Weiler, 2012]

$$P(\nu_a \to \nu_b) = 4\,V_{a3}^2\,V_{b3}^2 \times \begin{cases} -\sin^2\left(\frac{L\,(\lambda_+ - \lambda_-)}{2}\right) & \sin^2\tilde{\theta}\,\cos^2\tilde{\theta} \\ +\sin^2\left(\frac{L\,\lambda_+}{2}\right) & \sin^2\tilde{\theta} \\ +\sin^2\left(\frac{L\,\lambda_-}{2}\right) & \cos^2\tilde{\theta}\,. \end{cases}$$

- Sterile neutrino Lorentz violation excluded by atmospheric ν L/E !!!

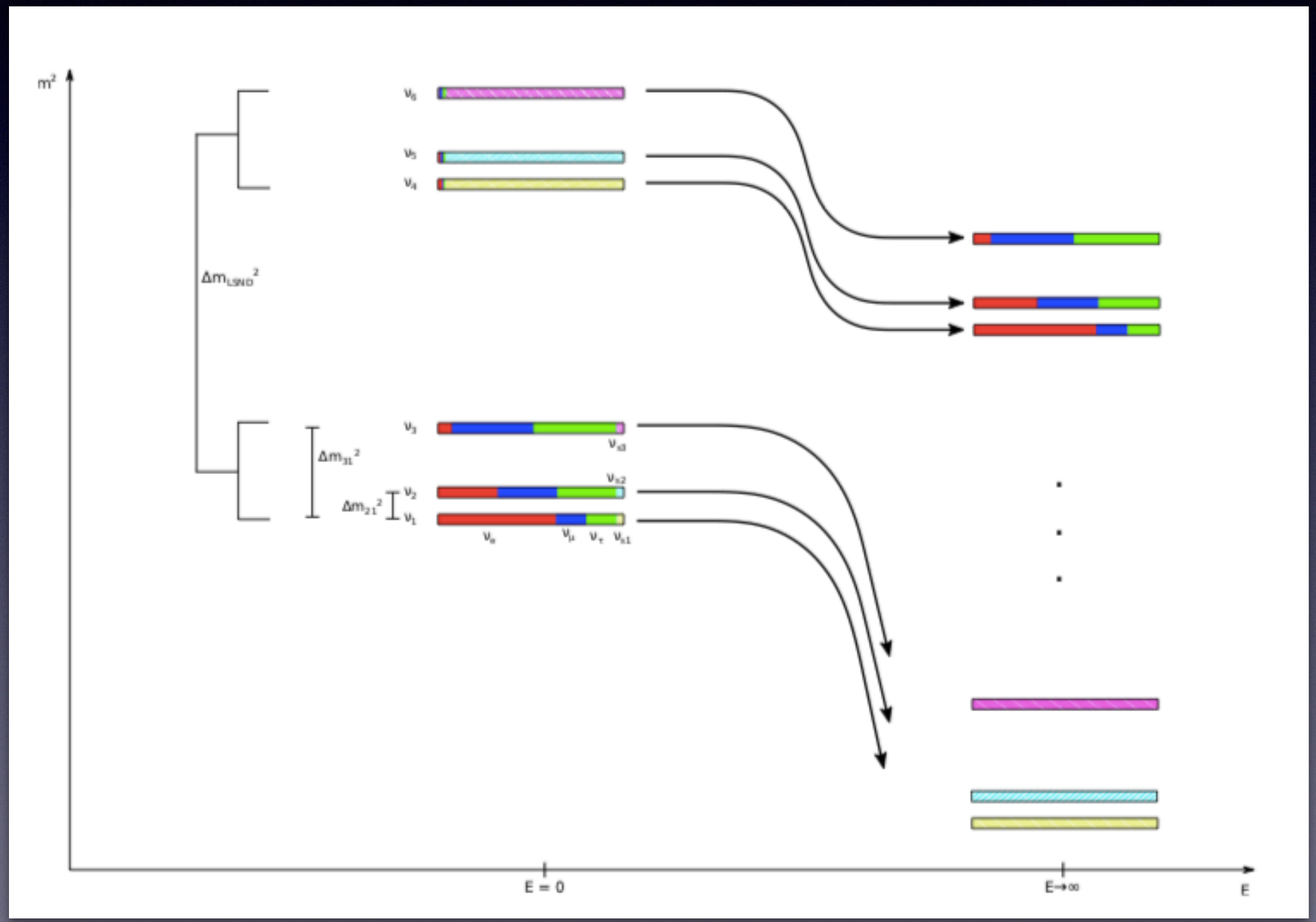
[P. Huber, 2007]

Altered dispersion relations with 3+1 neutrinos



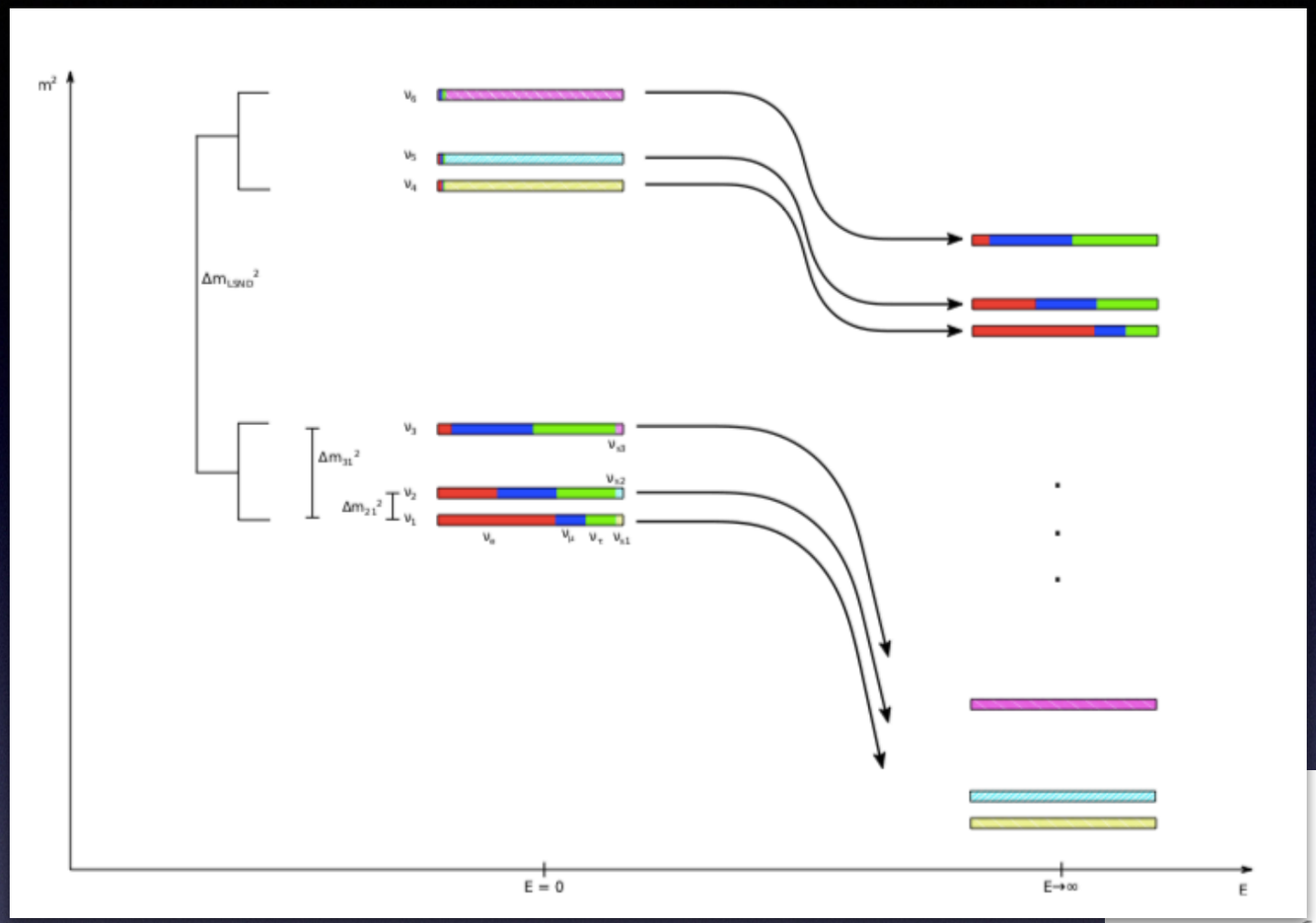
Solution ?

→ Promote the model to 3+3



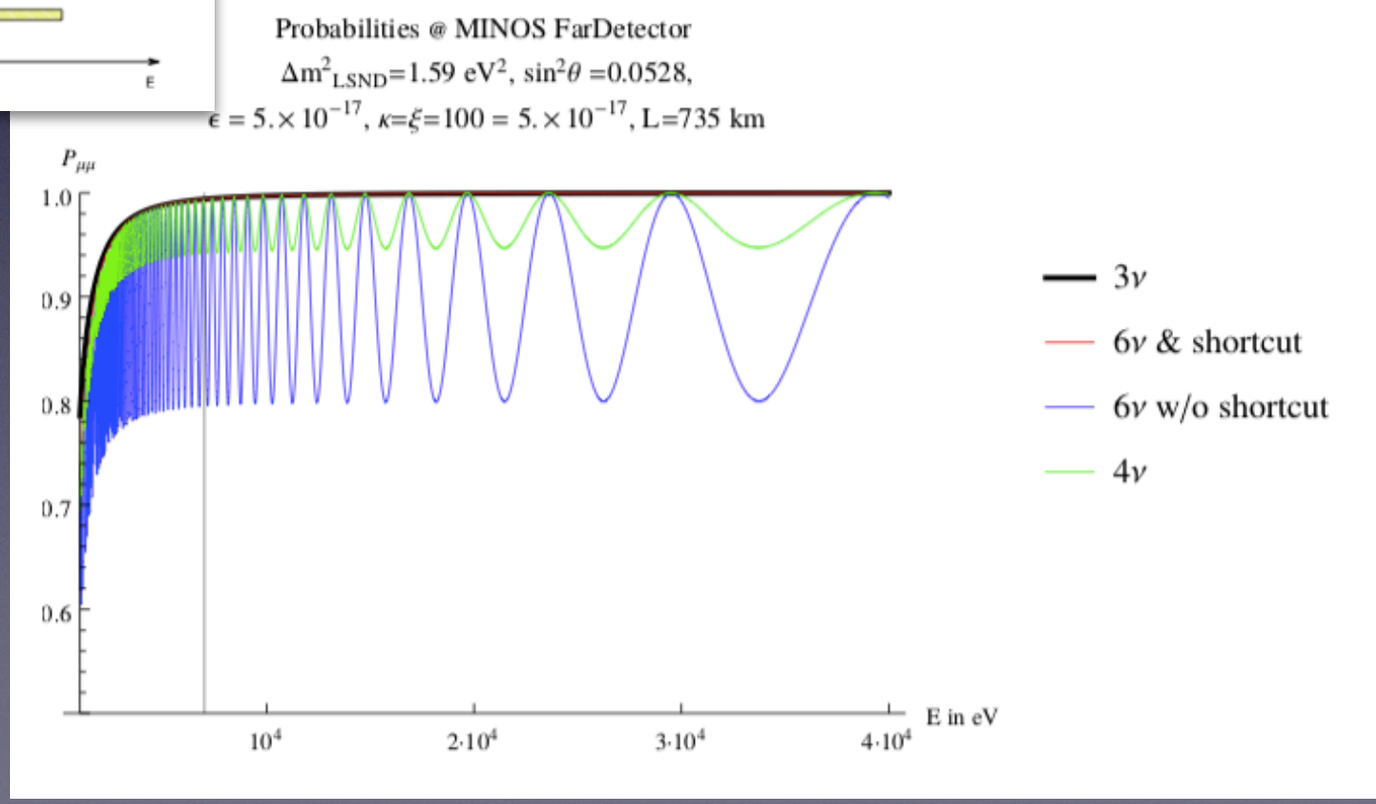
Döring, HP, Sicking, Weiler, arXiv:1808.07460

Sterile Neutrinos?



In a 3+3 model with democratic mixing the sterile neutrino decouples completely at high energies

Döring, HP, Sicking, Weiler, arXiv:1808.07460



Altered dispersion relations with 3+3 neutrinos

Necessary: Different resonance energies for 3 sterile neutrinos to avoid unitarity cancellation!

$$V_{\text{eff}} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \varepsilon E & 0 & 0 \\ 0 & 0 & 0 & 0 & \kappa \cdot \varepsilon E & 0 \\ 0 & 0 & 0 & 0 & 0 & \xi \cdot \varepsilon E \end{pmatrix}.$$

Döring, HP, Sicking, Weiler, arXiv: 1808.07460

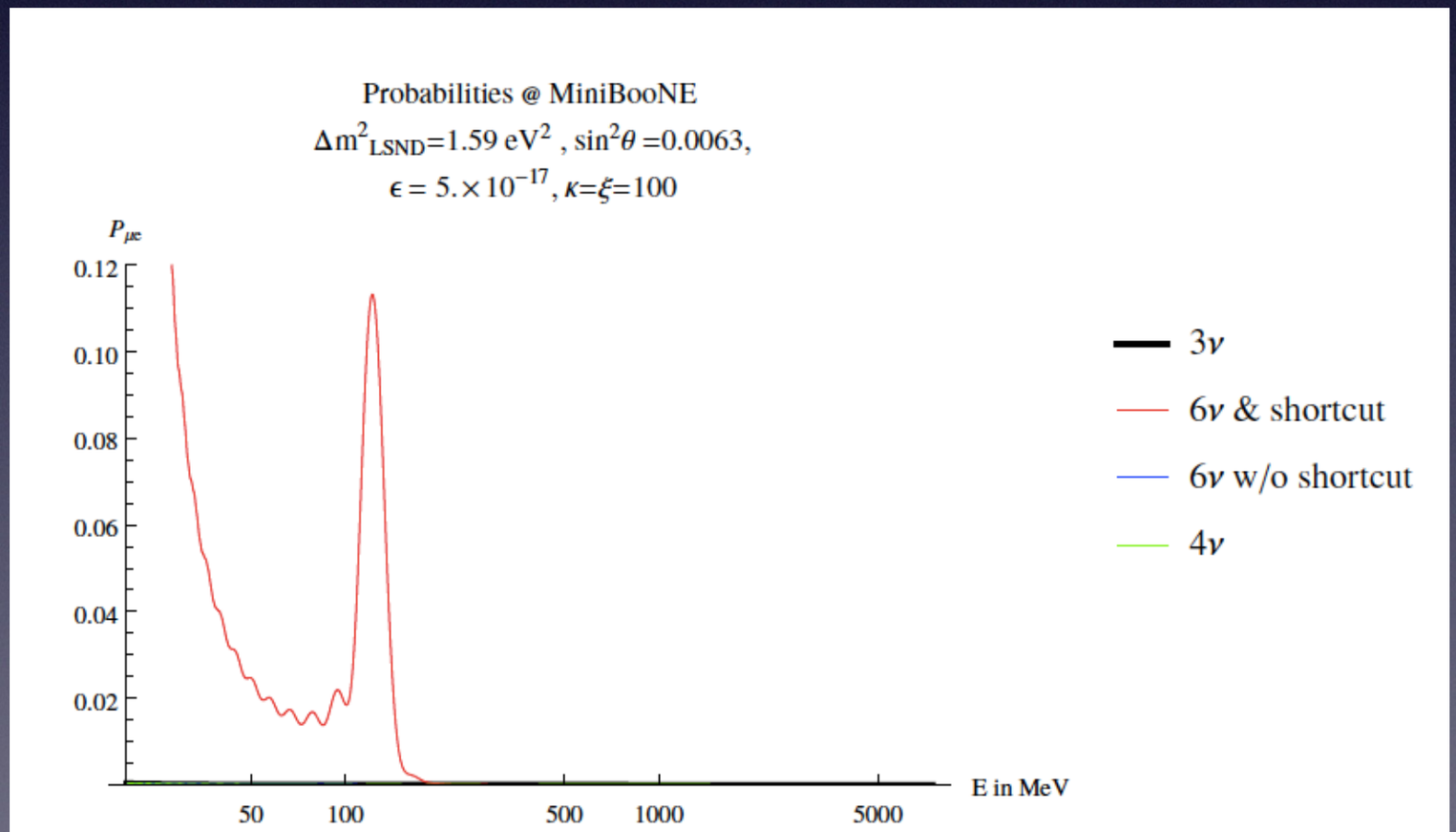
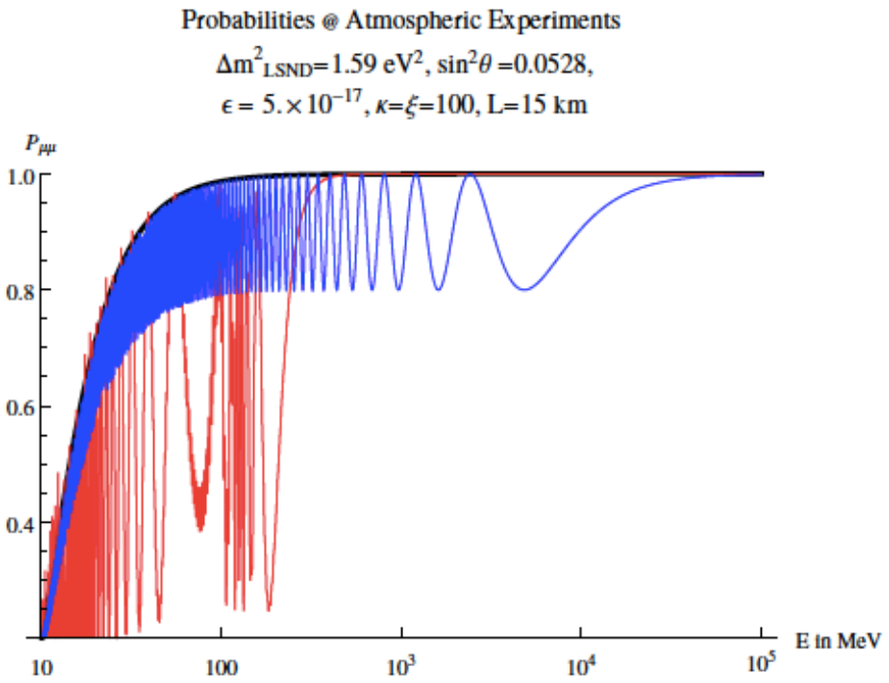
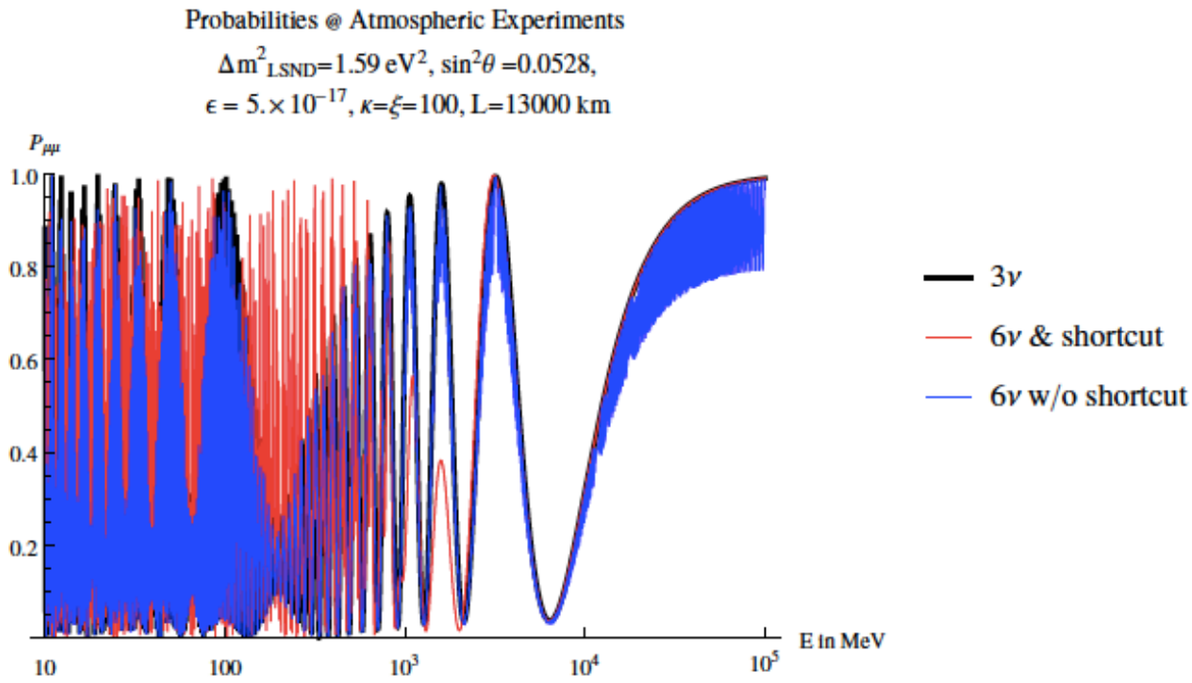


Figure: Probabilities P at MiniBooNE in the $\nu_\mu \to \nu_e$ channel.

sub-GeV Super-K data?

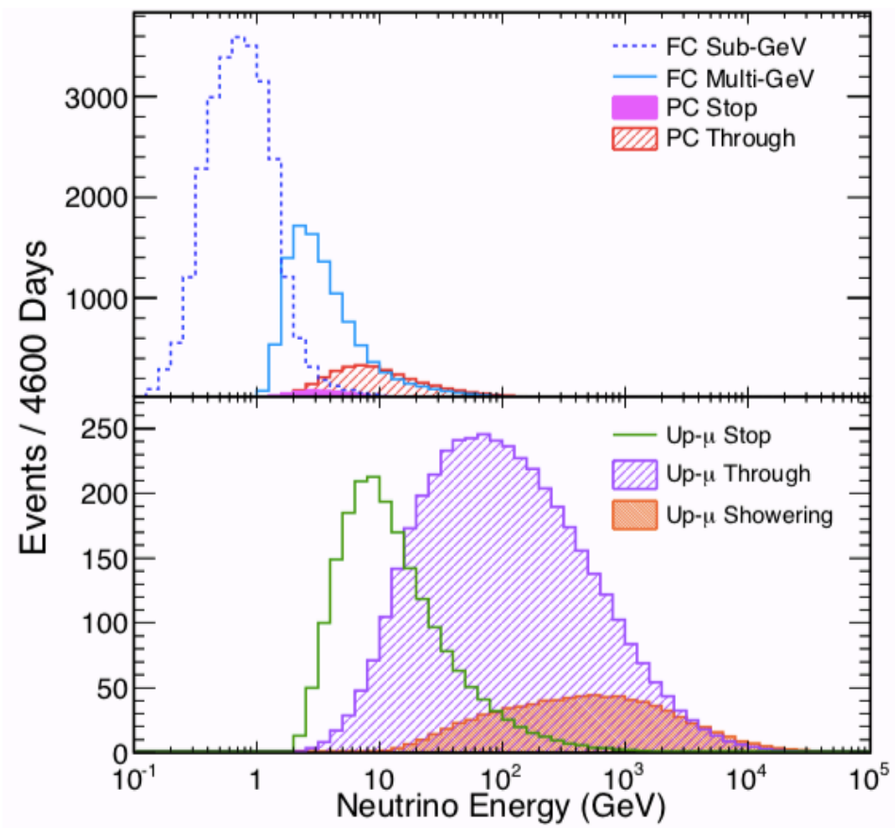




(a)Downward going neutrinos

(b)Upward going neutrinos

Döring, HP, Sicking, Weiler, arXiv:1808.07460



Model Building ?

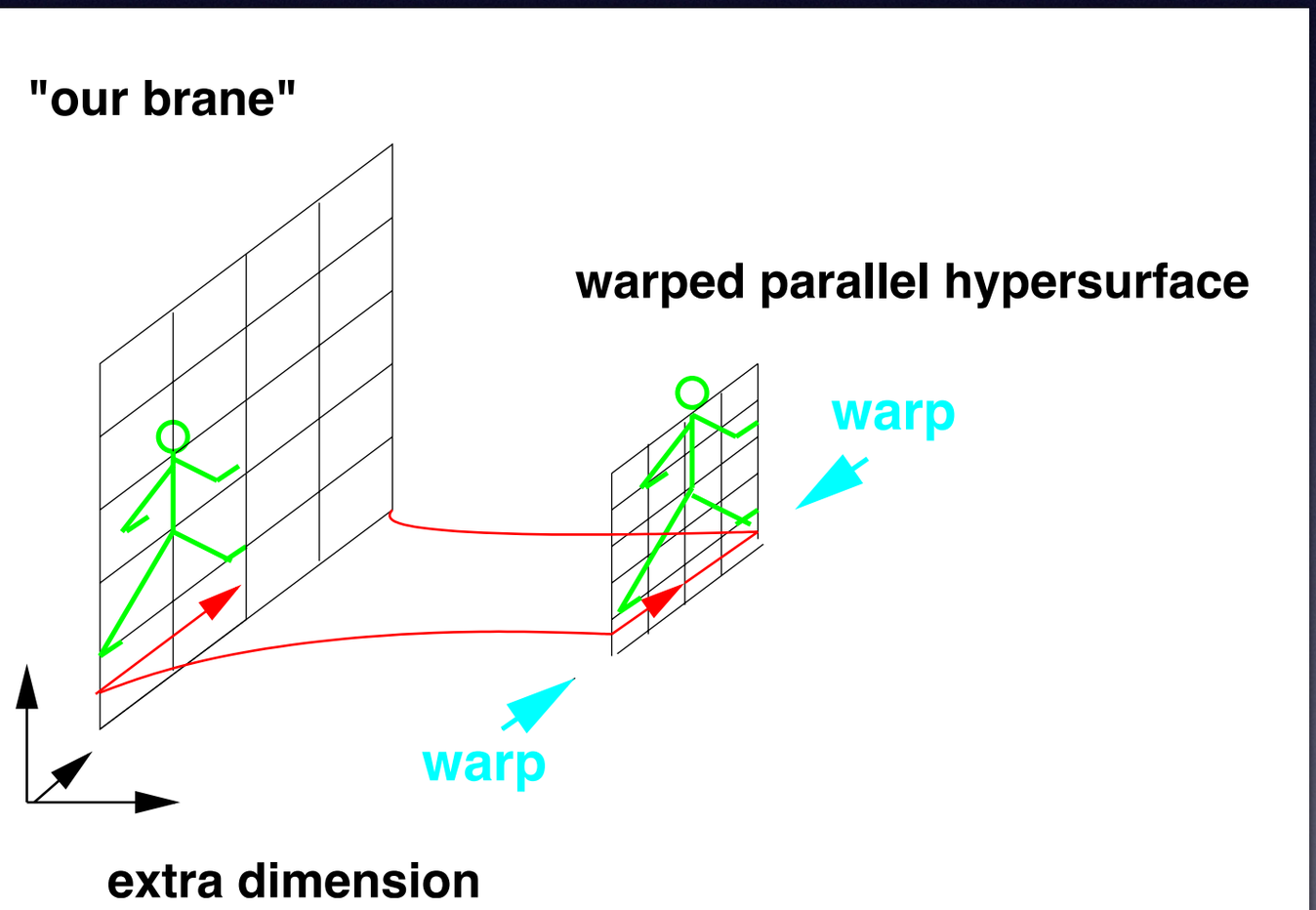
Consider an asymmetrically warped extra dimension with a sterile neutrino in the bulk

$$ds^2 = dt^2 - e^{-2k|u|}dx^2 - du^2$$

Chung, Freese, 1999, 2000
Csaki, Erlich, Grojean, 2001

- Shrinks space parallel to the brane
- Allows for shortcuts in the extra dimension!

[Döring, HP, arXiv:1808.07734



$$p_{\chi/\xi} \approx E - \frac{\kappa^2}{2E} \pm \frac{E^2}{2E}\tilde{I}_{00} + \mathcal{O}(\tilde{I}_{00}^2) + \mathcal{O}(\kappa^2 \tilde{I}_{00})$$

Summary

- Chances are high that MiniBooNE and other anomalies due to backgrounds or systematics
- Partially in conflict with other bounds
- But keep in mind: “1 eV^2 miracle”
- ADR ν oscillations: energy dependence & resonant conversion
- ADR 3+3 ν model seems to explain all data !
- 4D EFT limit of ν mass models in asymmetrically warped extra dimensions
- Potential to alleviate cosmological bounds