Possible Consequences of Density Dependent Neutrino Masses

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based on

V.D. Barger, PH and D. Marfatia, hep-ph/0502xxx.

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Outline

- Motivation

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- Motivation
- Framework

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- Atmospheric neutrinos

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- Solar neutrinos

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- mass varying neutrinos may explain $\Omega_\Lambda \sim \Omega_{\mathrm{matter}}$

R. Fardon, A. E. Nelson and N. Weiner, JCAP **0410** (2004) 005.

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Assuming $m_\nu = m_\nu(\rho)$

What are the consequences for neutrino oscillation?

D. B. Kaplan, A. E. Nelson and N. Weiner, Phys. Rev. Lett. **93**, 091801 (2004).

K. M. Zurek, JHEP **0410** (2004) 058.

Framework

2-flavor case

$$\mathcal{H}_{\mathrm{MVN}} = \frac{1}{2E} U \begin{pmatrix} (m_1 - M_1(r))^2 & M_3(r)^2 \\ M_3(r)^2 & (m_2 - M_2(r))^2 \end{pmatrix} U^\dagger$$

Ordinary matter potential

$$\mathcal{H}_{\mathrm{m}} = \frac{1}{2E} \begin{pmatrix} A(r) & 0 \\ 0 & 0 \end{pmatrix}$$

with

$$A(r) = 2\sqrt{2}\, G_F\, E_\nu\, n_e(r)$$

Framework

General form of M_i

$$M_i = \frac{\lambda_{\nu_i}}{m_\phi^2}\left[\lambda_e n_e + \sum_i \lambda_{\nu_i}\left(n_{\nu_i}^{C\nu B} + \frac{m_{\nu_i}}{E_{\nu_i}} n_{\nu_i}^{\mathrm{rel}}\right)\right]$$

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$m_\phi^2 < 4 \cdot 10^{-8}\,\mathrm{eV}^2$ and $\lambda_e < 0.01\, m_\mathrm{N}/M_\mathrm{Pl} \sim 10^{-21}$

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For pp neutrinos inside the Sun

$$\frac{m_{\nu_i}}{E_{\nu_i}} n_{\nu_i}^{\rm rel} \ll \frac{1\,\mathrm{eV}}{0.3\,\mathrm{MeV}} 7 \cdot 10^{-8}\,\mathrm{eV}^3 = 2.3 \cdot 10^{-13}\,\mathrm{eV}^3$$

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e.g. $\lambda_{\nu_i} \sim 10^{-3}$ and $m_\phi^2 \sim 10^{-11}\,\mathrm{eV}^2$ gives $M_i \sim 10^{-4} - 10^{-2}\,\mathrm{eV}$

Framework

We use following simplifications

$$m_1 = 0,\ M_1 = 0$$

and we assume as density dependence for the M_i

$$M_i(r) = \mu_i \cdot \left(\frac{n_e(r)}{n_e^0} \right)^k$$

where μ_i and k are free parameters

Atmospheric neutrinos

Can MVN replace oscillations?

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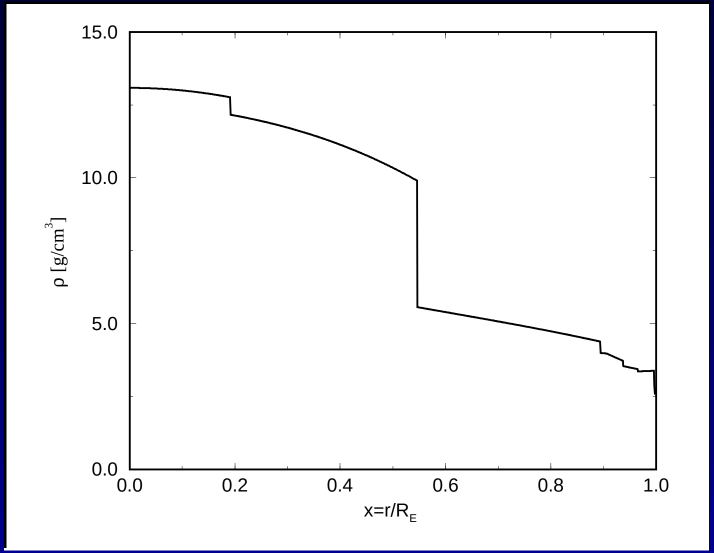

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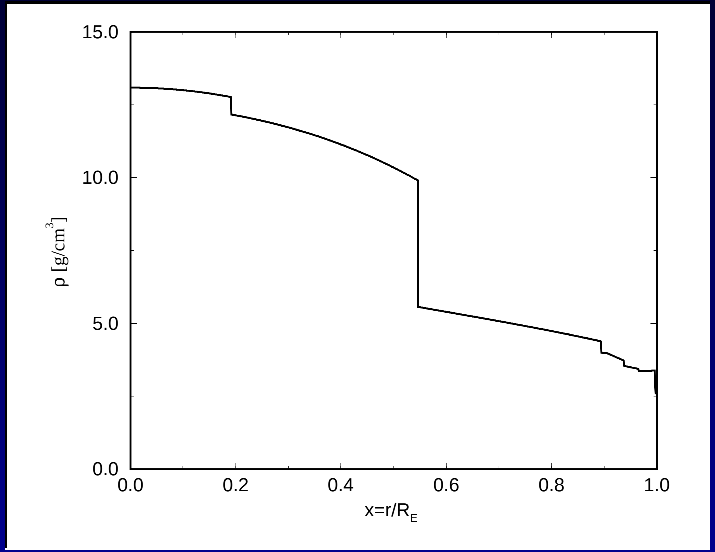

Matching at ρ of K2K:

$$\rho_0 = 2.8\,\mathrm{g\,cm}^{-3}, \quad \Delta m^2 = 2.4 \cdot 10^{-3}\,\mathrm{eV}^2 \quad \theta = \pi/4$$

yields a solution with

$$k = 2, \quad M_3(\rho_0) = 0.034\,\mathrm{eV}, \quad M_2 = 0$$

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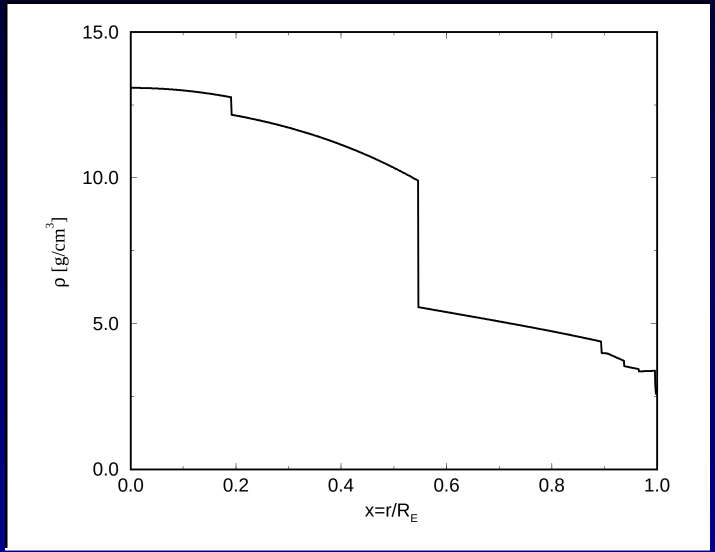

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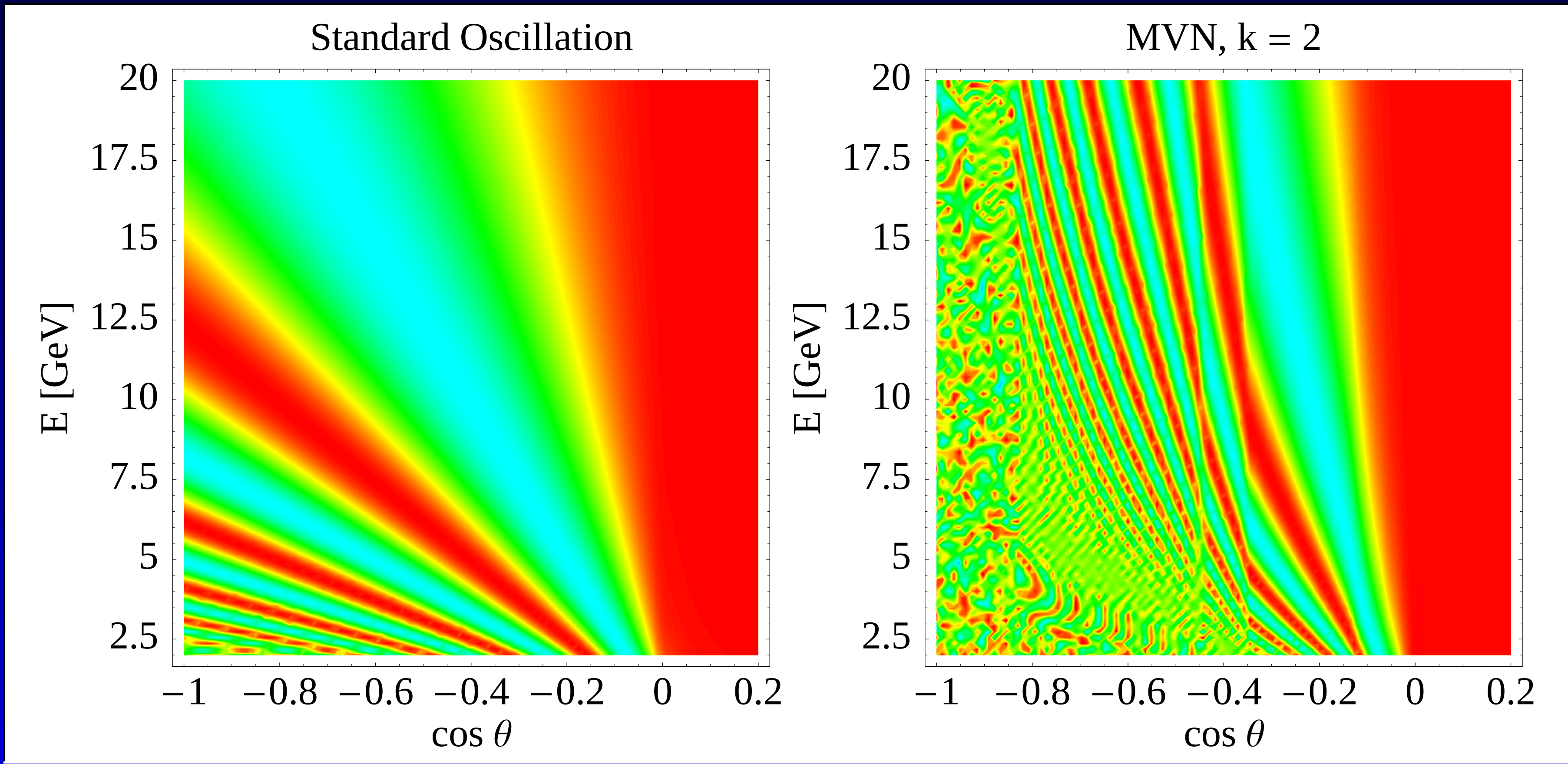
different values for k are equally possible

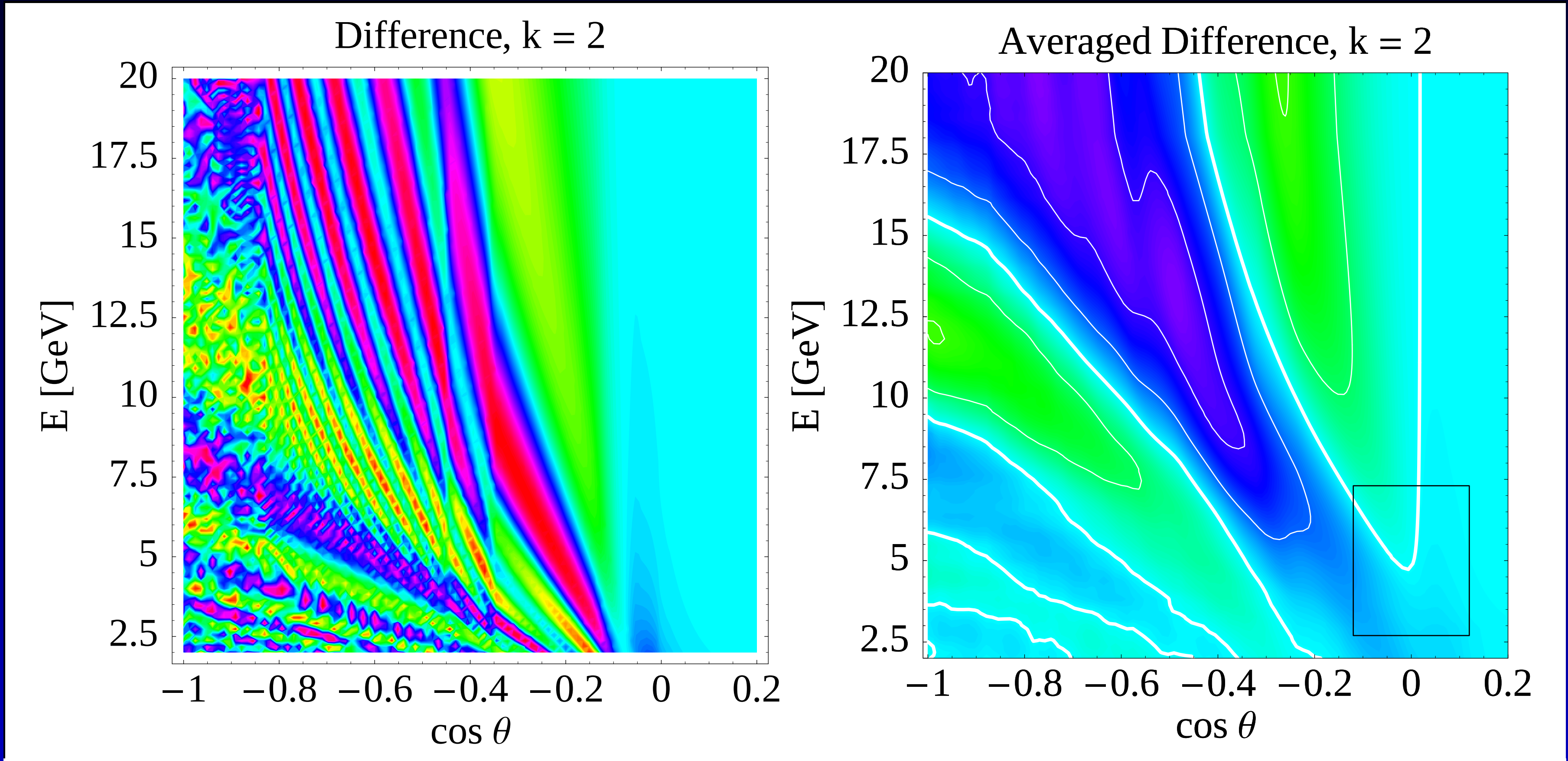
Atmospheric neutrinos

$P_{\mu\mu}$ as a function of $\cos\theta_z$ and E_ν



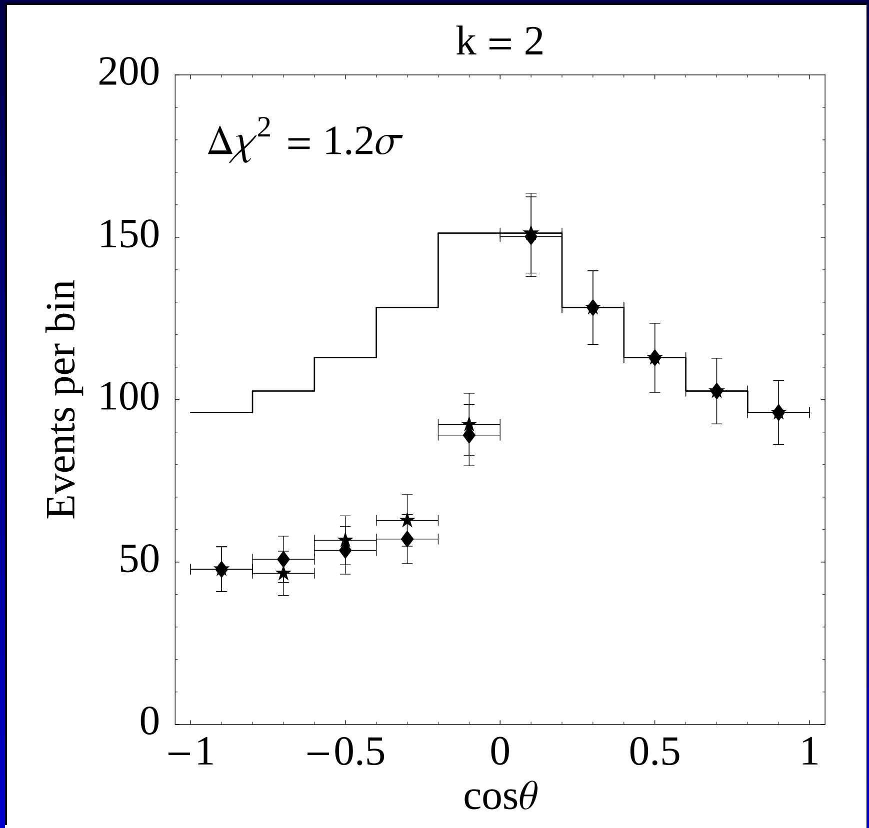
red corresponds to 1 and turquoise to 0

Atmospheric neutrinos



Differences are large, but size of observable effects depends on resolution!

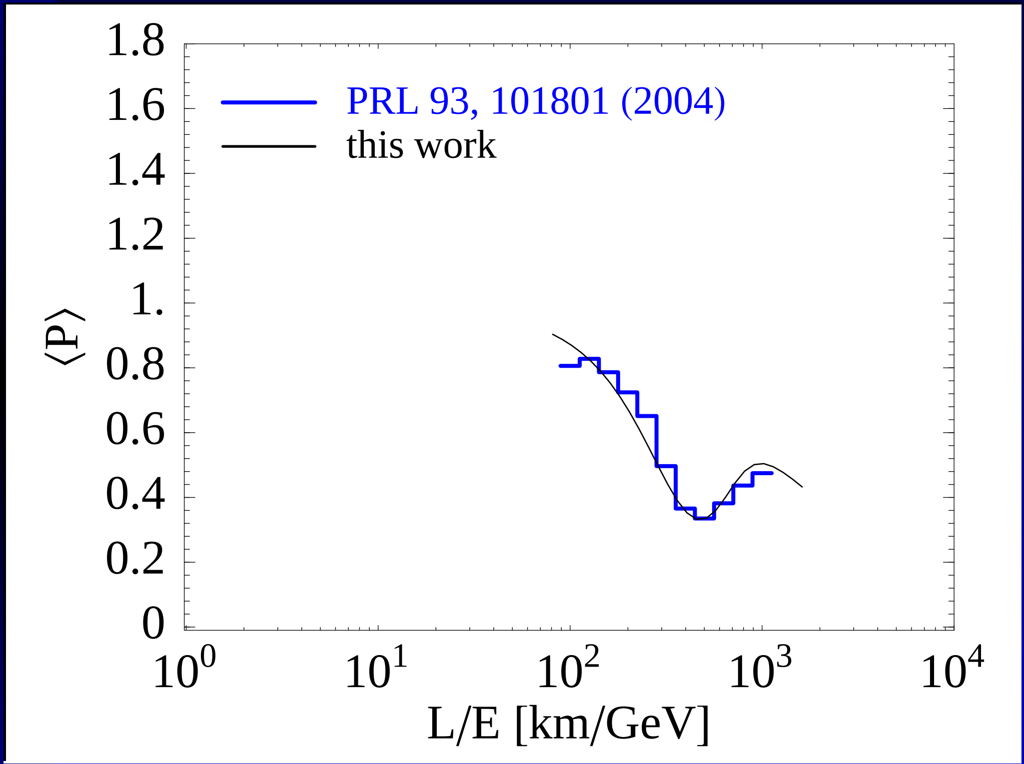
Atmospheric neutrinos



- partially contained events
- ’Mickey Mouse’ event calculation
- much more thorough calculation is needed

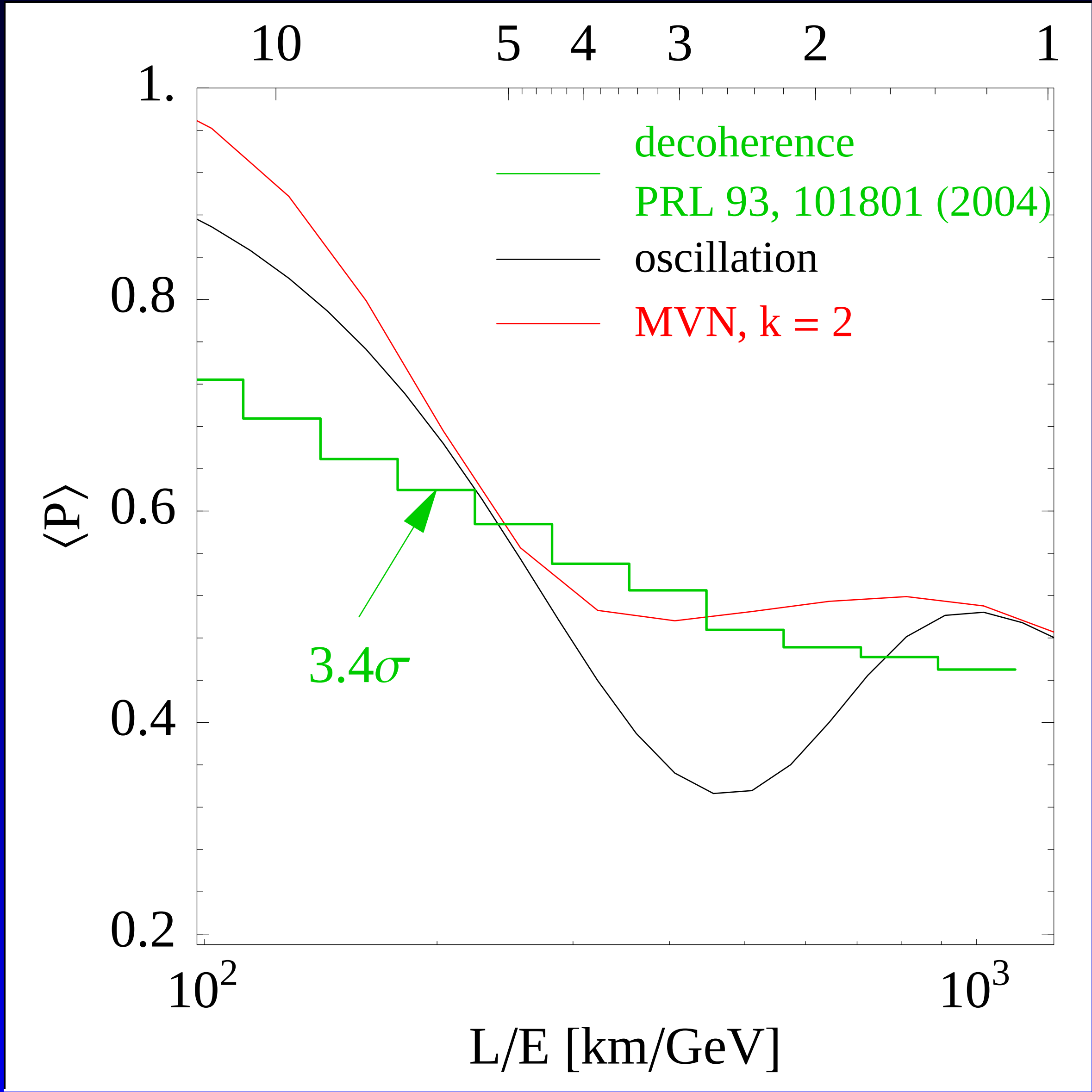
Atmospheric neutrinos

L/E-dependence



- only probabilities
- smearing in L/E of 65%

Atmospheric neutrinos



Solar neutrinos

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is the propagation inside the Sun still adiabatic?

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For the oscillation part the parameters are

$$\Delta m^2 = 7.9 \cdot 10^{-5}\,\text{eV}^2, \quad \tan^2\theta = 0.38$$

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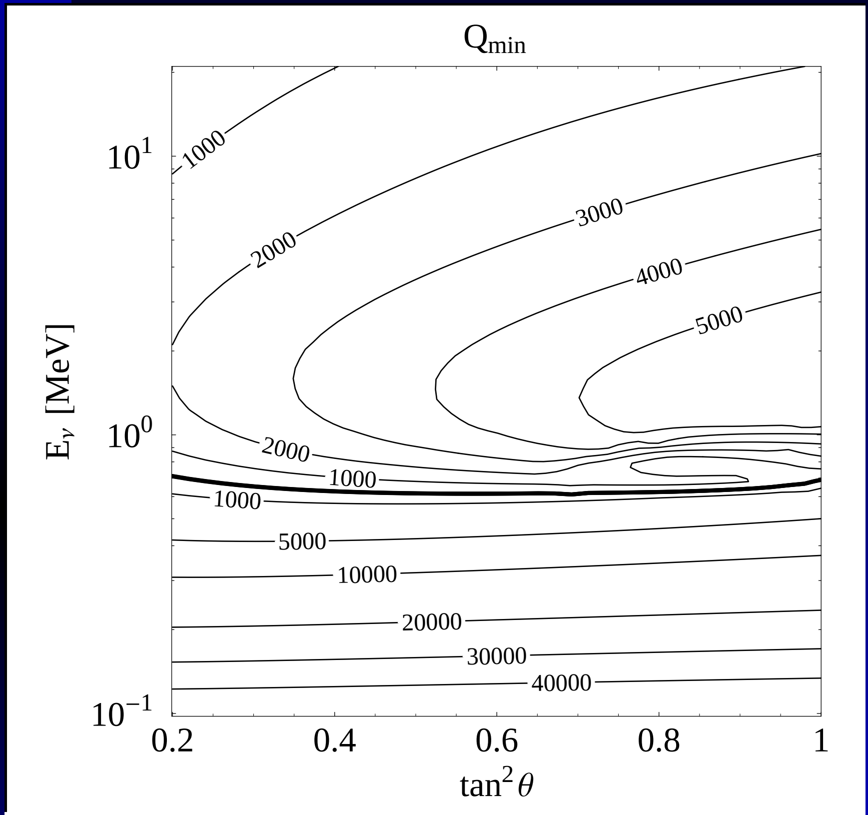

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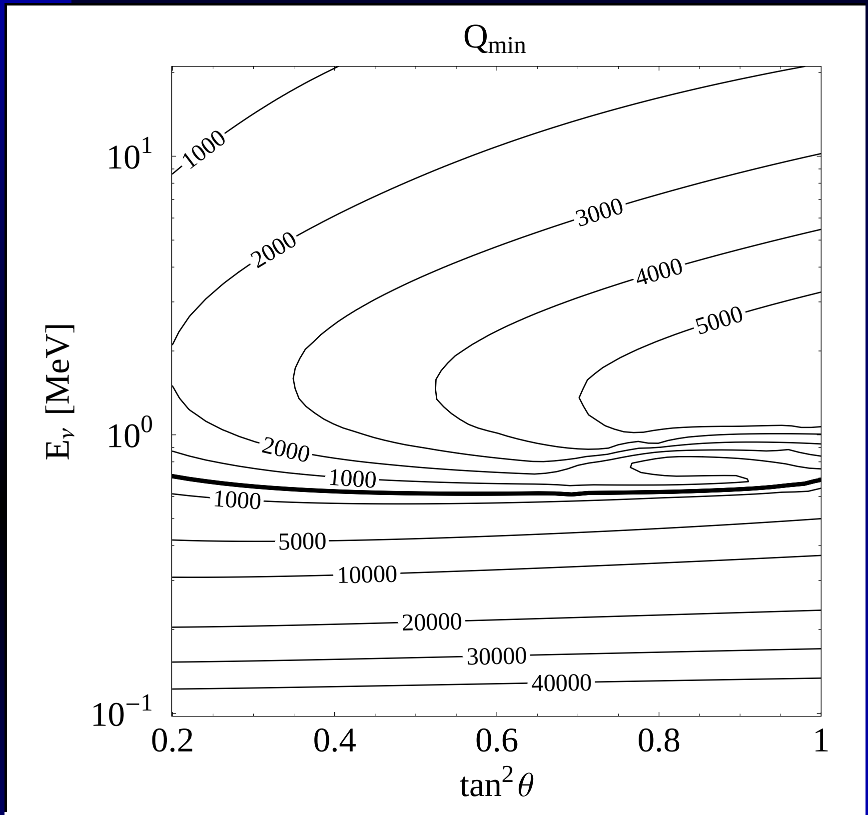

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Everywhere else $Q \gg 1 \Rightarrow$ adiabatic approximation

$$P = \frac{1}{2} + \frac{1}{2}\cos 2\theta_m^0 \cos 2\theta$$

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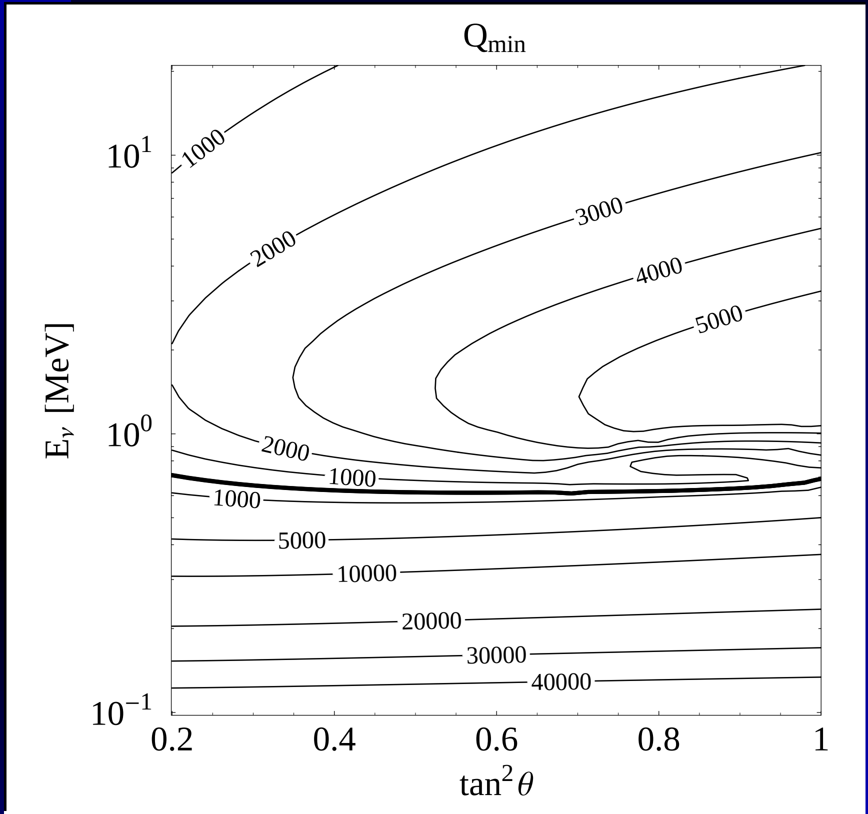

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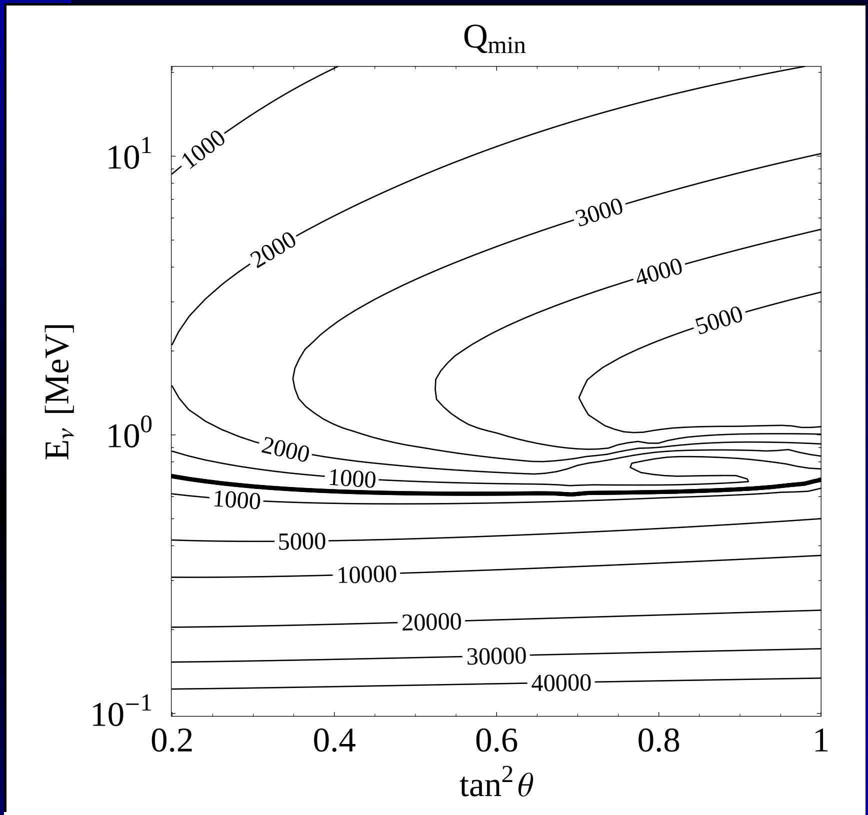
$$\tan 2\theta_m^0 = \frac{(m_2 - \mu_2)^2 \sin 2\theta + 2\mu_3^2 \cos 2\theta}{(m_2 - \mu_2)^2 \cos 2\theta - 2\mu_3^2 \sin 2\theta - A^0}$$

Solar neutrinos



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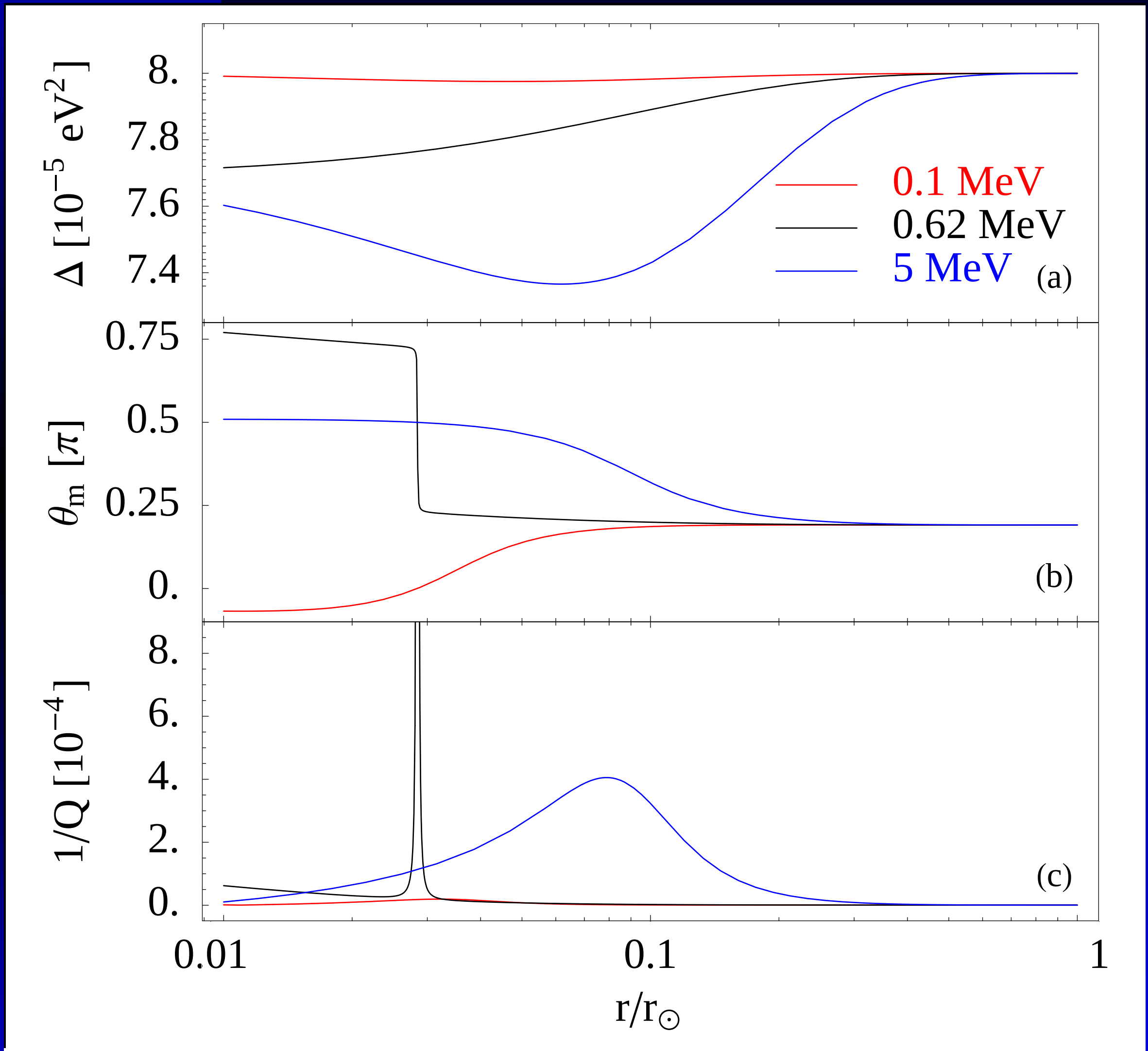
which is independent of k!

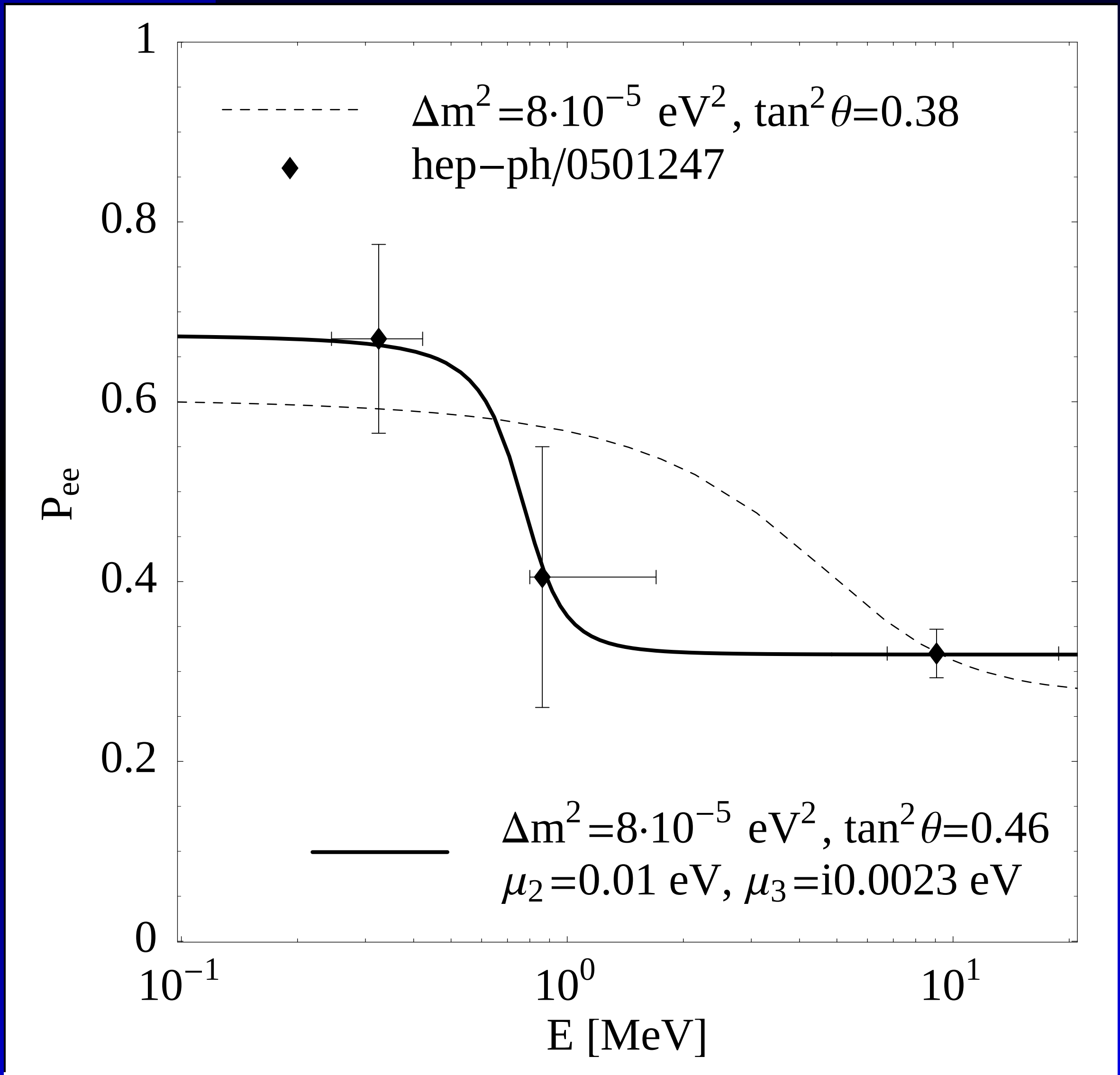
Solar neutrinos



$$Q = 0 \Leftrightarrow \dot{\theta}(r) \longrightarrow \infty$$

this happens if both the numerator and denominator of $\tan 2\theta_m$ become zero for the same value of r

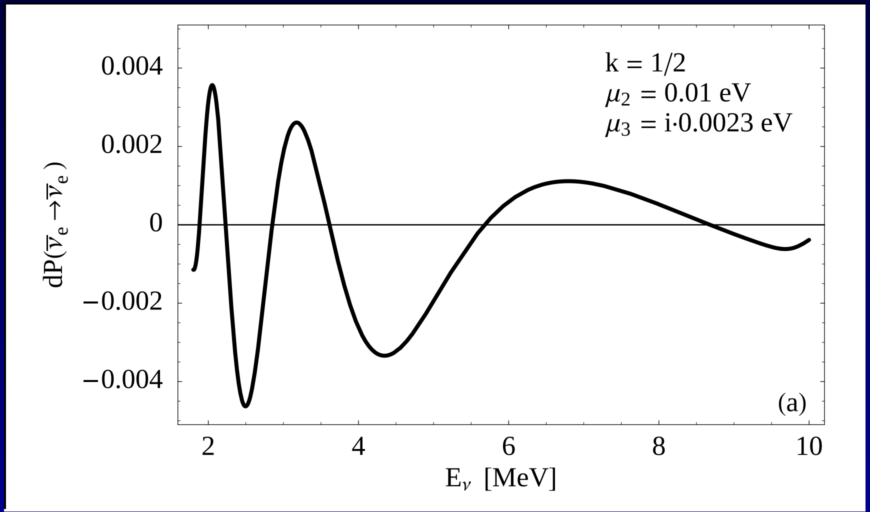
Solar neutrinos



- pure MVN fit not possible
- k-independent
- excellent 'fit'
- flat SK spectrum

Solar neutrinos

Is this in accordance with the KamLAND result?



$$L = 180\,\mathrm{km}$$

$$\Delta P = P_{\bar{e}\bar{e}}^{\mathrm{OSC}} - P_{\bar{e}\bar{e}}^{\mathrm{MVN}}$$

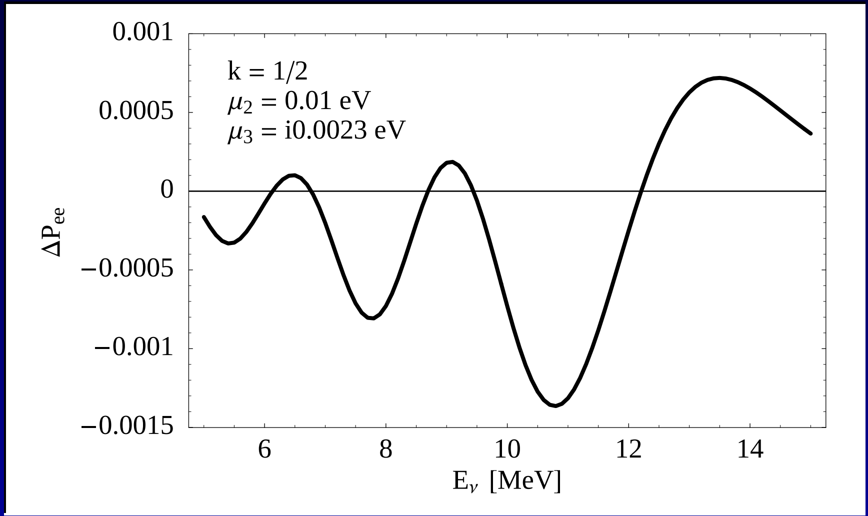
$$\delta E = 7.3\%/\sqrt{E(\mathrm{MeV})}$$

k-dependence

$$\Delta P \propto \left(\frac{\rho_{\mathrm{KamLAND}}}{\rho^0_{\mathrm{Sun}}}\right)^k \simeq 0.015^k$$

Solar neutrinos

Are Day-Night effects okay?



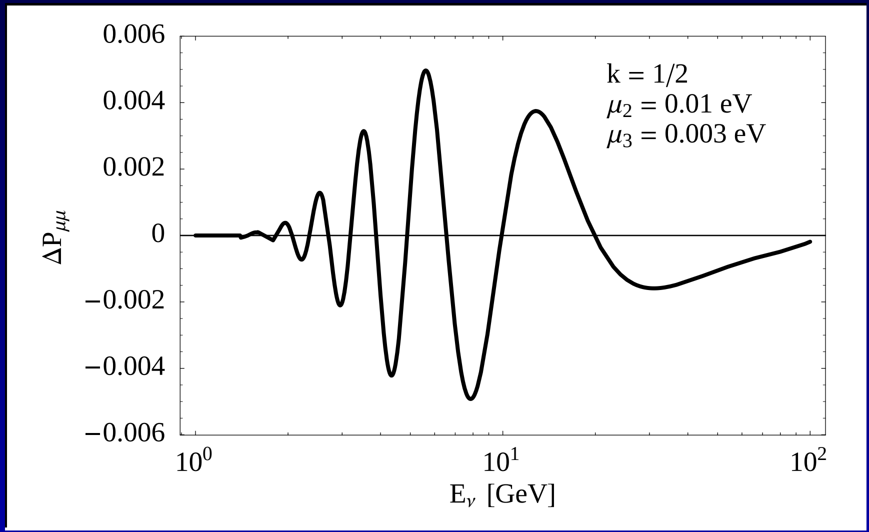
$$cos\theta_z = -1$$

$$\Delta P = P_{ee}^{\mathrm{OSC}} - P_{ee}^{\mathrm{MVN}}$$

$$\delta E = 10\%$$

Solar neutrinos

Would a MVN contribution of the same size be okay in atmospheric neutrinos?



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MVN have a rich phenomenology –
but more precise calculations are needed