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Measuring θ_{13}

- Reactor and LBL experiments

Determining sign(Δm^2_{31})

- LBL (appearance) experiments
- Reactor exp. will help in resolving degeneracies

Can atmospheric neutrinos help?

YES!

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Earth Effect

Mantle interaction

- Constant density ! MSW effect

$$\sin 2\theta_m = \frac{\Delta m^2 \sin 2\theta}{\sqrt{\left(2\,E\,V_e - \Delta m^2 \cos 2\theta\right)^2 + \left(\Delta m^2 \sin 2\theta\right)^2}}$$

$$E_{res} = \frac{\Delta m^2_{31}}{2\sqrt{2}G_F N_e}\cos 2\theta_{13} \cong 10\ \text{GeV}$$

- Thus, $P\left(\nu_e \to \nu_\mu\right)_{MSW} = s^2_{23}\sin^2\left(\frac{\Delta m^2_{31} L}{4\,E_{res}}\sin 2\,\theta_{13}\right)$

$$(L_m)_{Res} = \frac{\pi}{\left(\sqrt{2}G_F N_e \tan 2\theta_{13}\right)}(2k-1) \qquad k = 0,1,2,....$$

$$L_{min} = \frac{(L_m)_{Res}}{\sqrt{2}\cos 2\theta_{13}} \sim 8000\ \text{km}$$

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Water-Cherenkov detectors

- No discrimination of the charge of the produced lepton in an event-by-event basis.
- Measurement of N_μ and N_e events.
- Could we then distinguish the type of mass spectrum with these detectors?

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Water-Cherencov detectors

- N ~ 2/3 N(ν-like events) + 1/3 N($\bar{\nu}$-like events)
- Normal (inverted) hierarchy ! the effect is enhanced for (anti)neutrinos
- Effect larger for normal hierarchy
- Effect larger for larger $\sin^2\theta_{23}$
- Negligible for sub-GeV (r ' 2 and non-resonant)
- Multi-GeV sample: Increase of N_e and decrease of N_μ ! Should consider N_μ/N_e

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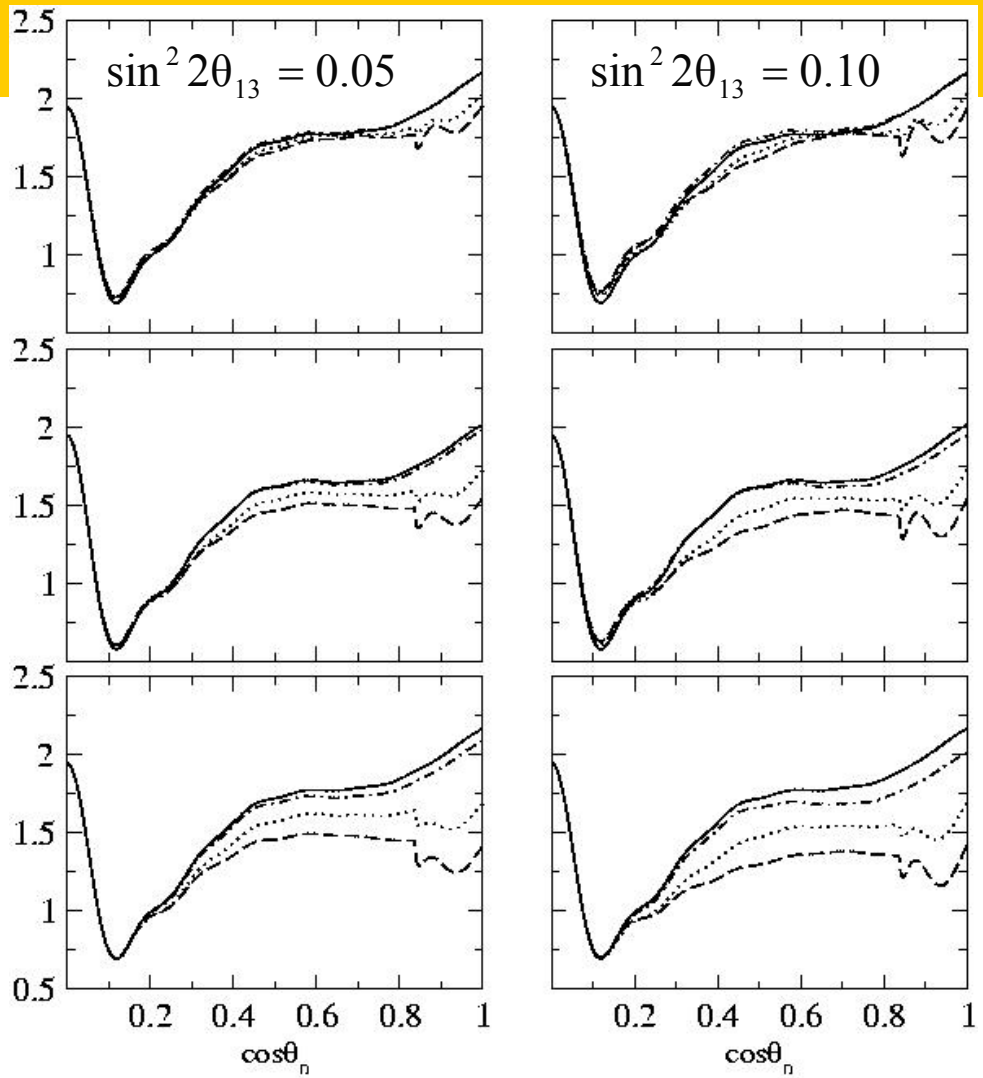
N_μ / N_e

E_ν = [2, 10] GeV



J. Bernabéu, SPR, S. T. Petcov, Nucl. Phys. B669:255,2003

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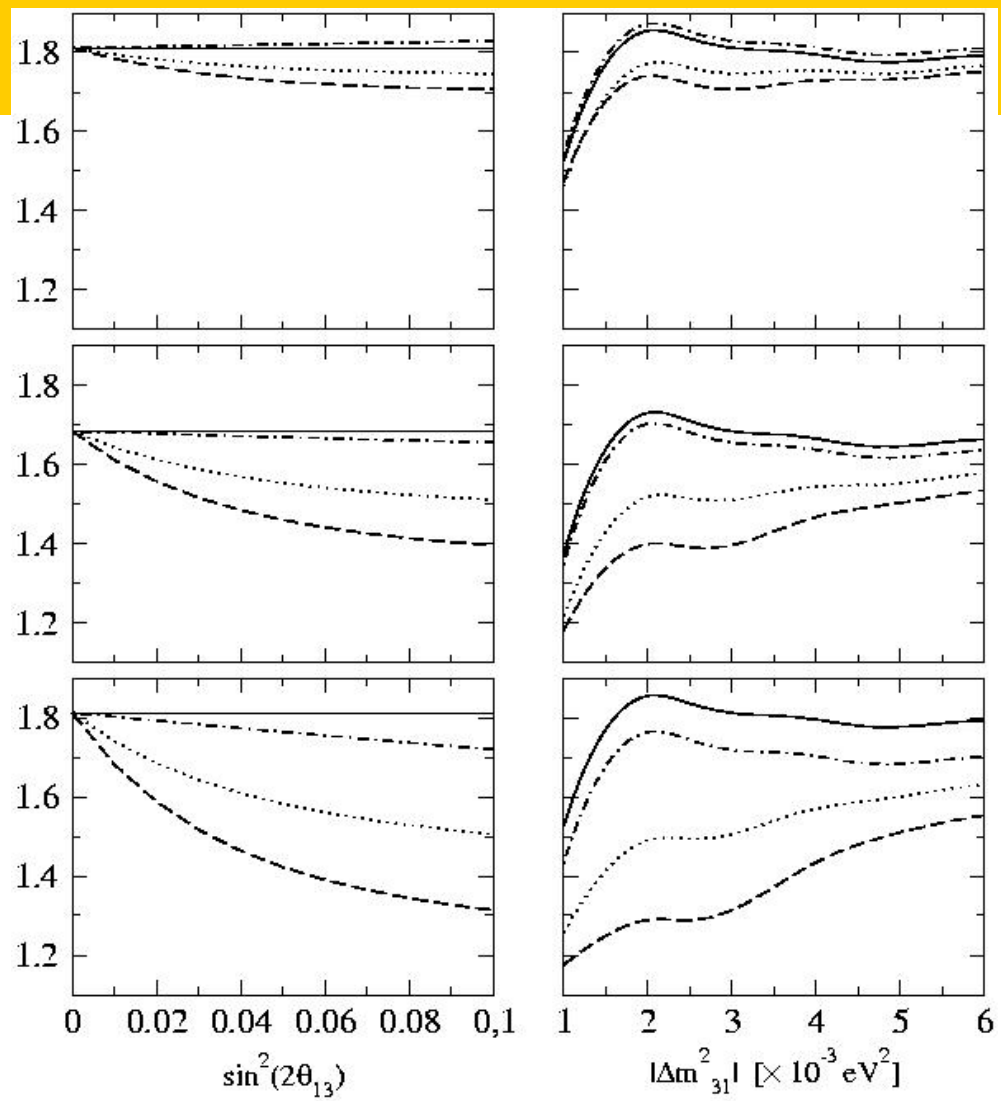
N_μ/N_e

E_ν = [2, 10] GeV

$\cos\theta_n$ = [0.4, 1.0]



$\sin^2\theta_{23} = 0.36$

$\sin^2\theta_{23} = 0.50$

$\sin^2\theta_{23} = 0.64$

J. Bernabéu, SPR, S. T. Petcov, Nucl. Phys. B669:255,2003

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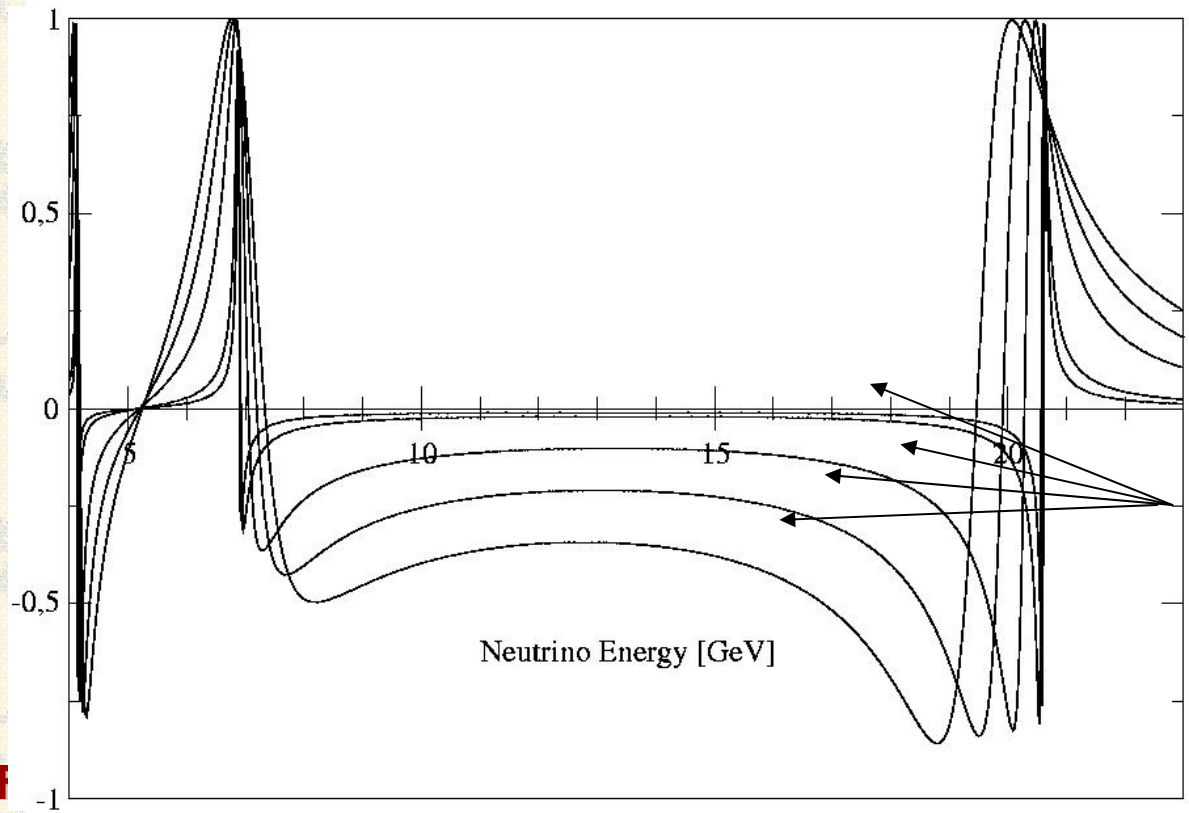
Magnetized detectors

- Discrimination of the charge of the produced lepton.
- Measurement of N_{μ^-} and N_{μ^+} : distinction between neutrinos and antineutrinos
- Neutrino energy determination
- CPT-matter induced asymmetry is measurable

Mantle interaction

$$A_{CPT} = \frac{P(\nu_\mu \to \nu_\mu) - P(\bar{\nu}_\mu \to \bar{\nu}_\mu)}{P(\nu_\mu \to \nu_\mu) + P(\bar{\nu}_\mu \to \bar{\nu}_\mu)}$$



Different θ_{13}

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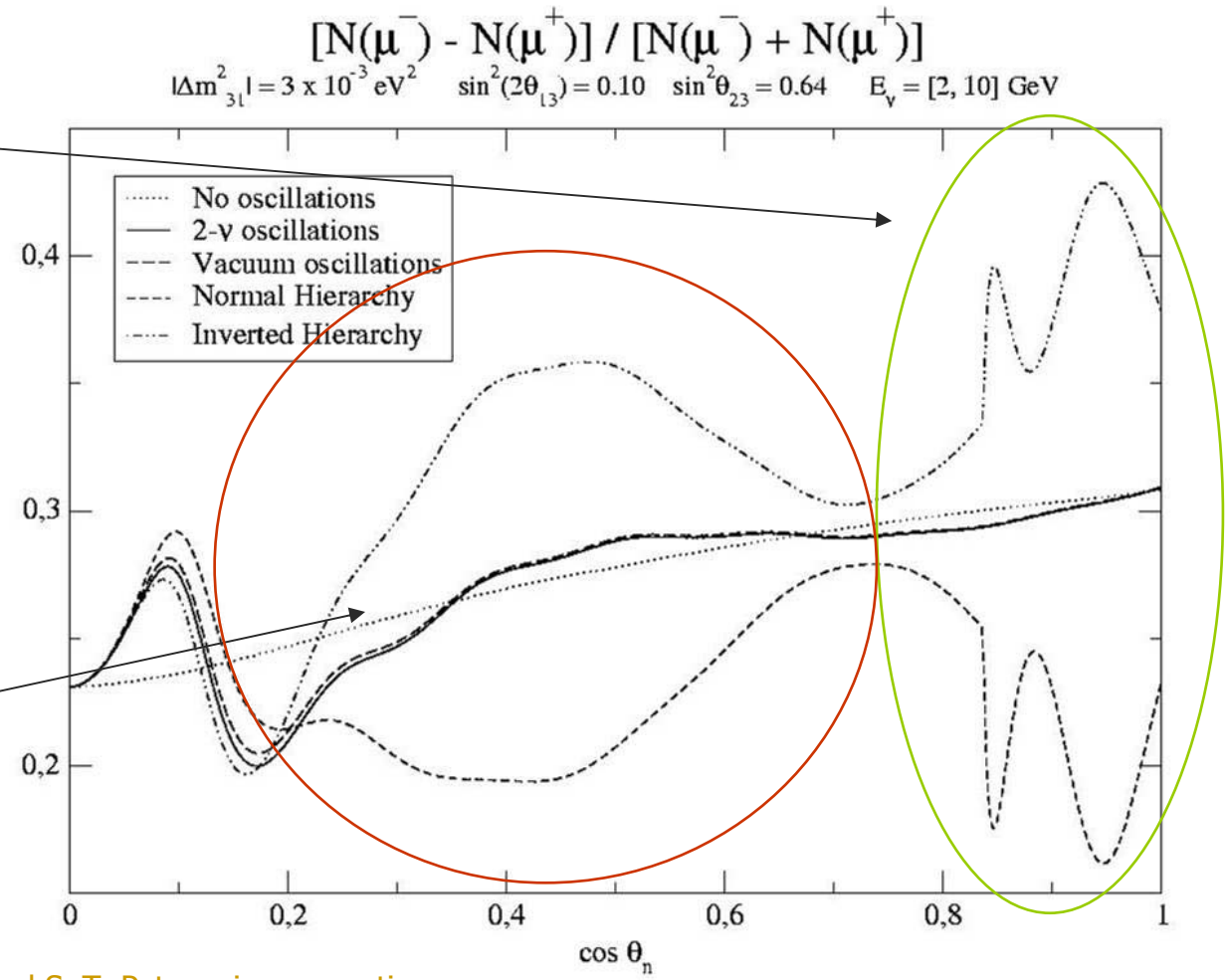
Core-mantle

Mantle



April 24, 2004

Sergio Palomares-Ruiz

SPR and S. T. Petcov, in preparation

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Conclusions

- If $\sin^2\theta_{13} \neq 0$, Earth matter effects can show up in atmospheric neutrinos
- Present in multi-GeV neutrinos crossing deeply the mantle or the mantle and the core, and are larger for Normal Hierarchy, larger $\sin^2\theta_{13}$ and larger $\sin^2\theta_{23}$
- Observable in water-Cherencov (N_μ/N_e) and magnetized detectors (N_{μ^-} - N_{μ^+} asymmetry)
- Constrains on θ_{13} and determination of ν-mass hierarchy could be possible with atmospheric neutrinos

$|U_{e3}|^2$ and β Decay Expts.

$$m^2(\nu_e) = \sum_{i=1}^{3} |U_{ei}|^2 \cdot m_i^2 \quad .$$

$$m_{ee} < m(\nu_e) < \frac{m_{ee}}{||\cos 2\theta_\odot|(1-|U_{e3}|^2) - |U_{e3}|^2|}, \tag{10}$$

The ν_e mixing parameters in (10) can be deduced from the results of oscillation experiments using solar neutrinos (solar mixing angle $\theta_\odot$) and reactor antineutrinos ($|U_{e3}|^2$).