About a Possibility of Measuring the Central Temperature of the Sun through the Regeneration of the ^{7}Be Neutrinos in the Earth

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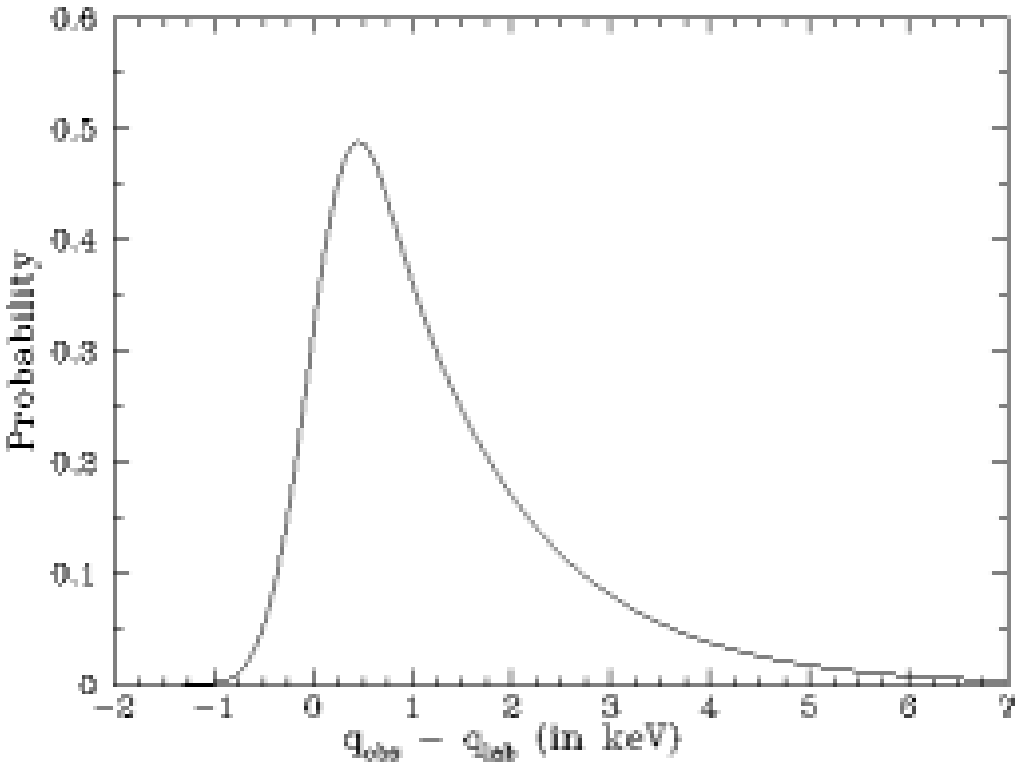
- The solar neutrino's ^{7}Be line ($E_\nu = 0.862$MeV) has a width of an order of the temperature in the center of the Sun ($\sim$ 1keV).
- The regeneration of the electron neutrinos from remote structures of the Earth is suppressed due to the averaging of the effect over the width of the ^{7}Be line (oscillation dyeing effect).
- We discuss a possibility of measuring the width of the beryllium neutrino's line at large liquid scintillator detector (LENA) by measuring the regenerated neutrino flux.



This graph is taken from Bahcall PRL. The energy spectrum of the solar ^{7}Be neutrinos. q_{lab}= 0.86184 MeV.

2 ν mixing

Deviations of θ^m and I_ν^m in medium from their vacuum values

$$\epsilon \equiv \frac{2V_e E}{\Delta m^2} \approx 3.6 \cdot 10^{-3} \left(\frac{\rho}{2.7\mathrm{g/cm}^3}\right) \left(\frac{5 \cdot 10^{-5}\mathrm{eV}^2}{\Delta m^2}\right) \left(\frac{Y_e}{0.5}\right)$$

$$P = P^0 + \Delta P$$

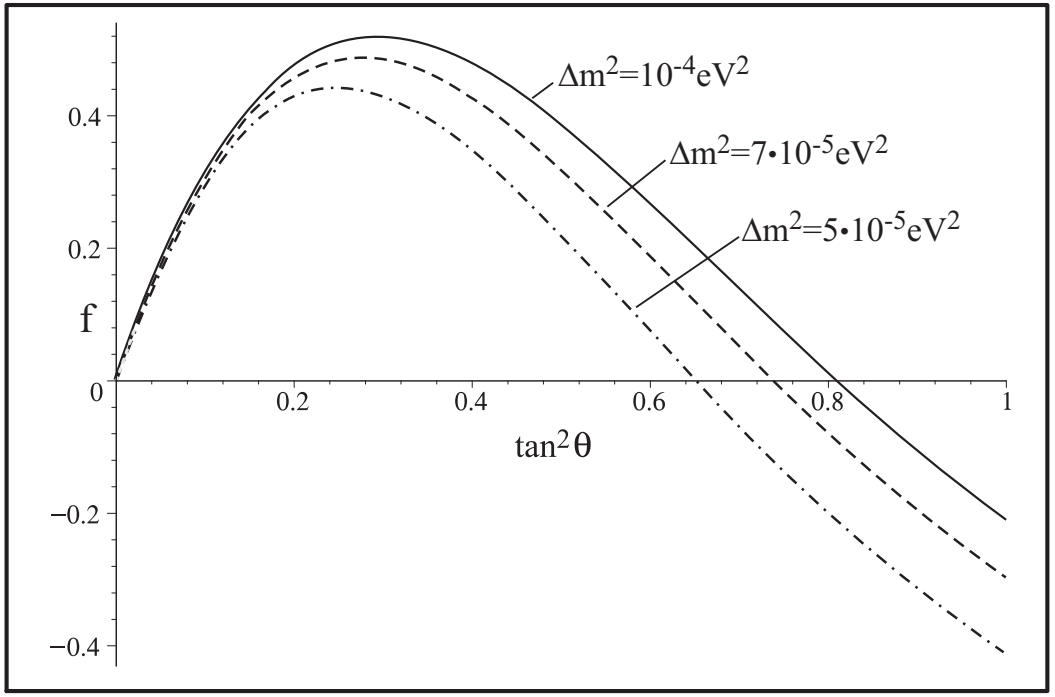
$$P^0 = \frac{1}{2}(1 + \cos 2\bar{\theta}^{\odot} \cos 2\theta)$$

$$\Delta P = \cos 2\bar{\theta}^{\odot} \ (P_{1e} - \cos^2 \theta)$$

P^0 is the probability to find ν_e during the day time and ΔP is the change of the probability due to the Eearth's matter effect during the night time.

$$\frac{\Delta P}{P^0} = -f(\Delta m^2, \theta) \frac{1}{2} \int_{x_0}^{x_f} dx \ V(x) \sin \phi^m_{x \to x_f}$$

$$f(\Delta m^2, \theta) = \frac{2 \ \cos 2\bar{\theta}^{\odot} \ \sin^2 2\theta}{1 + \cos 2\bar{\theta}^{\odot} \cos 2\theta}$$



The dependence of $f(\Delta m^2, \theta)$ on $\tan^2\theta$ for $\Delta m^2 = 5 \cdot 10^{-5}$ eV^2, $7 \cdot 10^{-5}$ eV^2 and 10^{-4}eV^2 (AI and A.Smirnov hep-ph/0201012)

The energy spectrum $g(E', E)$ and perform averaging of the probability folded with g:

$$A_e = \int dE' g(E', E) \frac{\Delta P}{P^0}$$

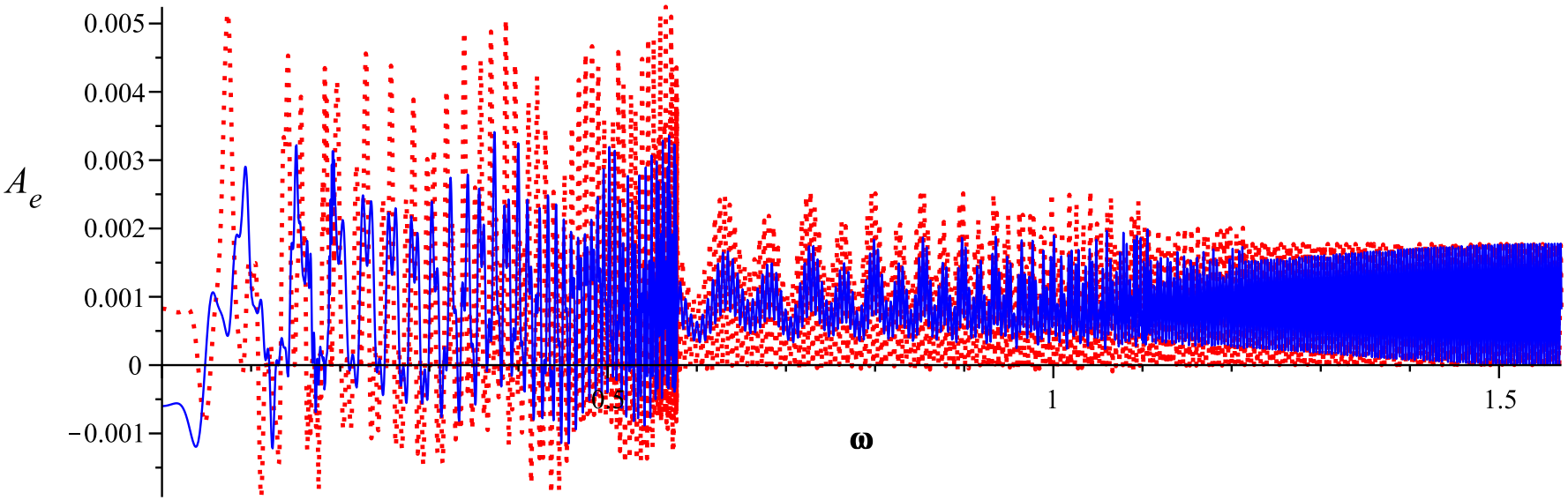
It is convenient to parameterize the effect of integration introducing the *attenuation* factor $F(d)$ in the probability as

$$A_e = -f(\Delta m^2, \theta) \frac{1}{2} \int_{x_0}^{x_f} dx \; V(x) F(x_f - x) \sin \phi^m_{x \to x_f}$$

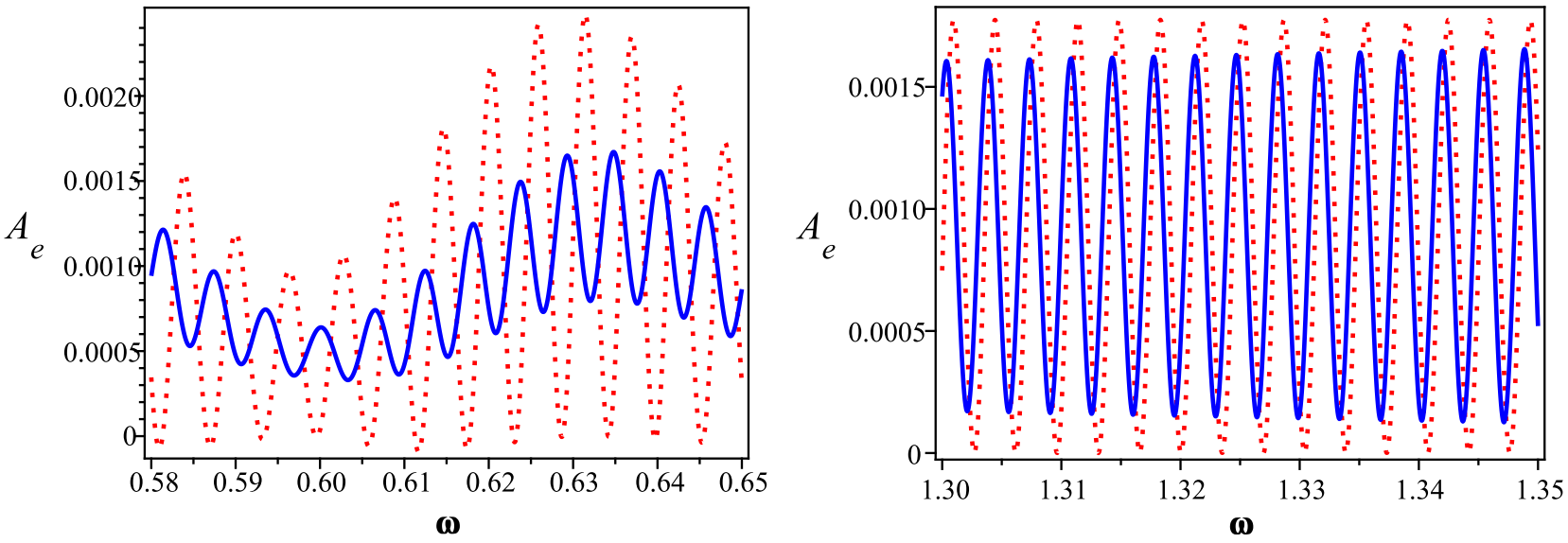
so that in the absence of averaging $F = 1$.

$$g(E, E') = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(E-E')^2}{2\sigma^2}}$$

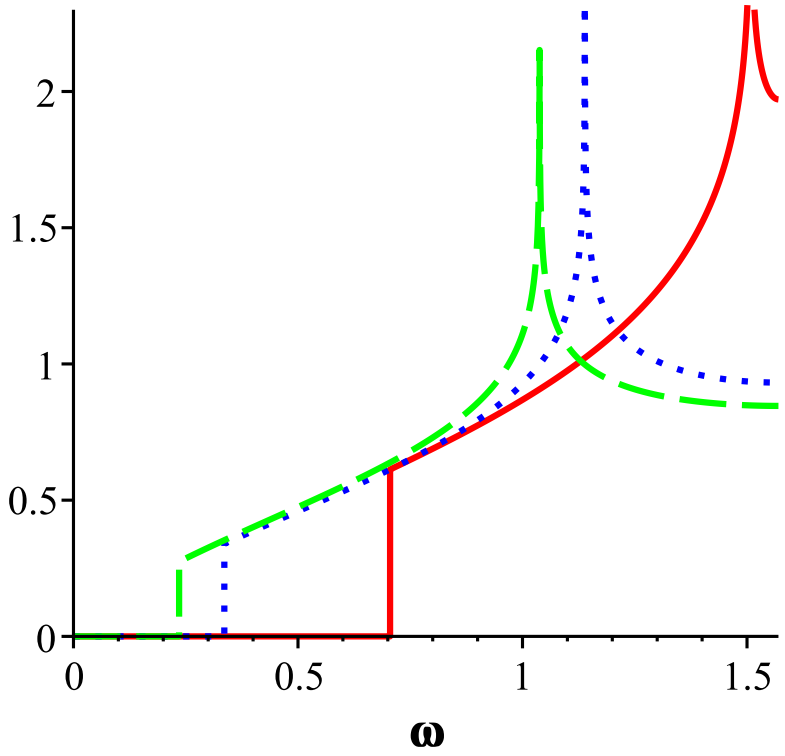
$$F(x - x_f) = e^{-\frac{2\sigma^2 \pi^2 (x - x_f)^2}{E^2 l_\nu^2}}$$



The relative change of the electron neutrino flux ($A_e = \frac{\Delta P_e}{P_e}$) as function of the nadir angle of the neutrino trajectory. Solid line is the averaged effect over the spectrum of the ^{7}Be neutrinos and dotted line without averaging. There is about 300 "oscillations". $\tan^2\theta$=0.3 and $\Delta m^2 = 5 \cdot 10^{-5}$eV^2.



The relative change of the electron neutrino flux for mantle crossing trajectories $\omega = 0.58 \ldots .65$ and $1.3 \ldots 1.35$. Solid line is the averaged effect over the spectrum of the ^{7}Be neutrinos and dotted line without averaging. $\tan^2\theta$=0.3 and $\Delta m^2 = 5 \cdot 10^{-5}\text{eV}^2$.



Dependance of average anual weight function on the nadir angle (ω is in radians) of neutrino trajectory for Pyhäsalmi (solid line), Gran Sasso (dotted line) and Kamioka (dashed line) sites.

The expected rate of events due to the Beryllium neutrino flux at future LENA experimen is :

$$r = few \cdot 10^4 \frac{\text{events}}{\text{day}}$$

$$\Delta N = \kappa \cdot N \cdot A_e$$

here $\kappa \approx \frac{1}{1+1/4P^0} \approx 0.7$ is dumping factor due to the contribution of the neutral interactions (We have taken into account that $\nu_e e^-$ cross section is about 5 times larger than $\nu_\mu e^-$ cross section for ^7Be neutrino scattering with energy transfer (0.25 - 0.664) MeV).

$$N = r \cdot \int W(\omega)\ d\omega$$

$$N > 2 \cdot \beta^2 A_e^{-2} \simeq 10^7$$

$\beta = 3$ ($3\sigma-$level)

Conclusion

LENA may

- precise Δm^2
- determine the width of the ^7Be line- the temperature in the center of the Sun
- to see the core of the Earth