# Terrestrial Matter Effects on Solar Neutrinos

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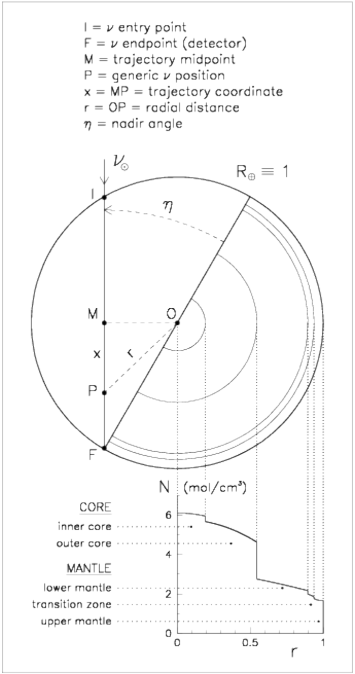


I = ν entry point
F = ν endpoint (detector)
M = trajectory midpoint
P = generic ν position
x = MP = trajectory coordinate
r = OP = radial distance
η = nadir angle
ν⊙
R⊕ ≡ 1
I
η
M
O
x
r
P
F
N (mol/cm³)
CORE
inner core
outer core
MANTLE
lower mantle
transition zone
upper mantle
6
4
2
0
0
0.5
1
r

$$\epsilon \equiv \frac{2VE}{\Delta m^2_{21}} \approx 0.03 \left(\frac{\rho}{3\frac{\mathrm{g}}{\mathrm{cm}^3}}\right)\left(\frac{7.5\cdot 10^{-5}\mathrm{eV}^2}{\Delta m^2_{21}}\right)\left(\frac{E}{10\ \mathrm{MeV}}\right)\left(\frac{Y_e}{0.5}\right)$$

$$l_\nu \approx 330 \left(\frac{7.5\times 10^{-5}\mathrm{eV}^2}{\Delta m^2_{21}}\right)\left(\frac{E}{10\ \mathrm{MeV}}\right)\mathrm{km}$$

$$\phi^m_{x_k\to x_n} \equiv \int_{x_k}^{x_n} dx\ \frac{\Delta m^2_{21}}{2E}\sqrt{(\cos 2\theta_{12} - \epsilon(x))^2 + \sin^2 2\theta_{12}}$$

$$\frac{P_N - P_D}{P_D} = -f(\Delta m^2_{21}, \theta_{12})\frac{1}{2}\int_0^L dx\ V(x)\sin\phi^m_{x\to L}$$

where

$$f(\Delta m^2_{21}, \theta_{12}) = \frac{2\ \cos 2\bar{\theta}^{\odot}_{12}\ \sin^2 2\theta_{12}}{1\ +\ \cos 2\bar{\theta}^{\odot}_{12}\cos 2\theta_{12}} = \frac{(2P_{ee} - 1)}{P_{ee}}\frac{\sin^2 2\theta_{12}}{\cos 2\theta_{12}}$$

$f(\Delta m^2_{21}, \theta_{12}) \simeq -2.3$ for $\tan^2\theta = 0.45$ ( $\theta = 34^0$) and
$\Delta m^2 = 7.5\times 10^{-5}$ eV$^2$ ($P_{ee} \simeq 1/3$))
$V \to V\cdot\cos(\theta_{13})^2 \simeq V\cdot 0.98$

## Averaging over neutrino energy

$$A_e = \int dE' g(E', E) \frac{P_N - P_D}{P_D} \ .$$

$$A_e = -f(\Delta m^2_{21}, \theta_{12}) \frac{1}{2} \int_0^L dx \ V(x) F(L-x) \sin \phi^m_{x \to L},$$

The decrease of $F$ means that contributions from the large distances to the integral are suppressed.

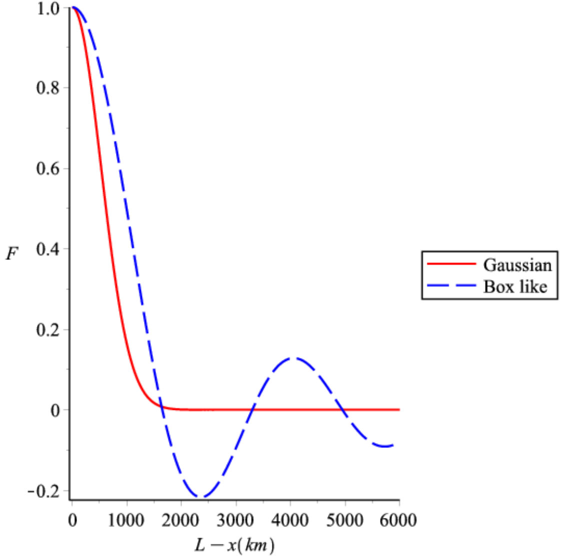
## Gaussian energy resolution function

$$g(E, E') = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(E-E')^2}{2\sigma^2}}, \qquad F(L-x) \simeq e^{-2\left(\frac{\pi\sigma(L-x)}{E \ l_\nu}\right)^2}$$

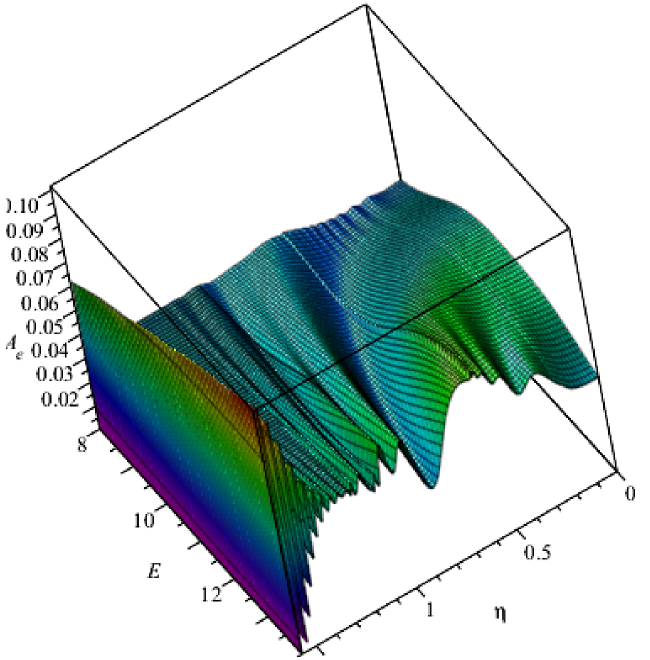
## Box like energy resolution function

$$A_e = \frac{1}{2\sigma} \int_{E-\sigma}^{E+\sigma} dE' \ \frac{P_N - P_D}{P_D}$$

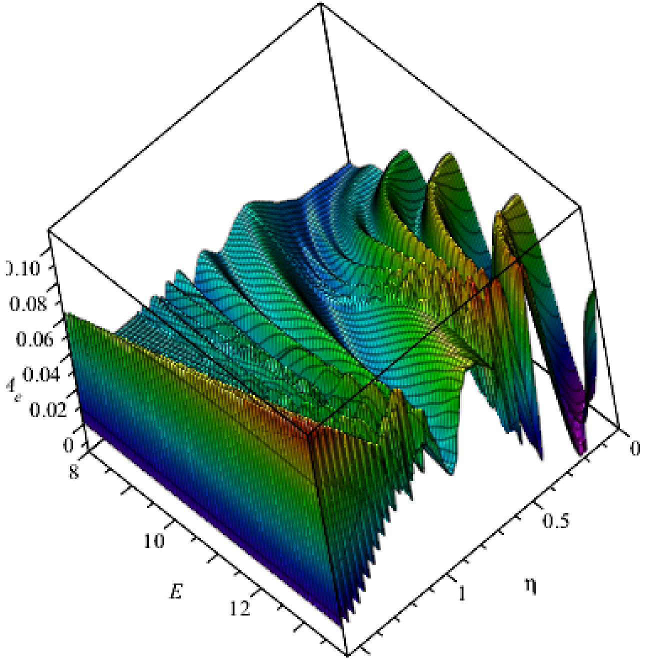
$$F(L-x) \simeq \frac{1}{Q(L-x)} \sin Q(L-x), \qquad Q(L-x) \equiv \frac{2\pi\sigma(L-x)}{E \ l_\nu} \ ,$$




The attenuation factor $F$ as function of $(L-x)$ (distance from detector). $E = 10$ MeV, $\sigma = 1$ MeV, and $\Delta m^2_{21} = 7.5 \cdot 10^{-5}$ eV$^2$.



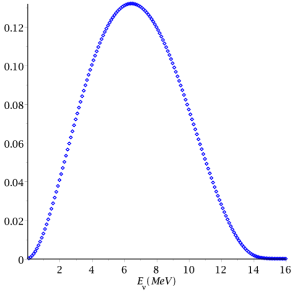
0.10
0.09
0.08
0.07
0.06
0.05
$A_e$ 0.04
0.03
0.02
8
10
E
12
0
0.5
1
η

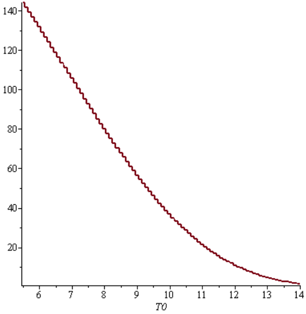

0.08
0.06
0.04
0.02
0
8
10
E
12
0
0.5
1
η

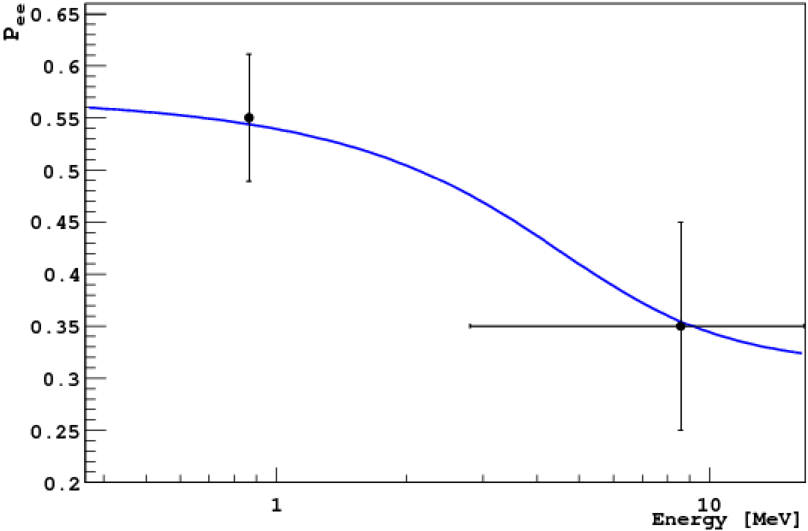
$$A_e(T,\eta) = \frac{\int dT'\ g(T,T') \int_{T+\frac{m_e}{2}} dE\ \Delta P_{ee}(E) j_B(E) (\frac{d\sigma_{\nu_e e}}{dT'} - \frac{d\sigma_{\nu_\alpha e}}{dT'})}{\int dT'\ g(T,T') \int_{T+\frac{m_e}{2}} dE\ j_B(E) (P_{ee}\frac{d\sigma_{\nu_e e}}{dT'} + (1-P_{ee})\frac{d\sigma_{\nu_\alpha e}}{dT'})}$$

$$\Delta P_{ee} = P_N - P_D = (\frac{1}{2} - P_{ee}) \frac{\sin^2 2\theta_{12}}{\cos 2\theta_{12}} \int_0^L dx\ V(x) \sin\phi^m_{x\to L}$$

$\frac{d\sigma_{\nu_e e}}{dT'} / \frac{d\sigma_{\nu_\alpha e}}{dT'} \simeq 6$


0.12
0.10
0.08
0.06
0.04
0.02
0
2 4 6 8 10 12 14 16
$E_\nu\,(MeV)$


140
120
100
80
60
40
20
6 7 8 9 10 11 12 13 14
T0

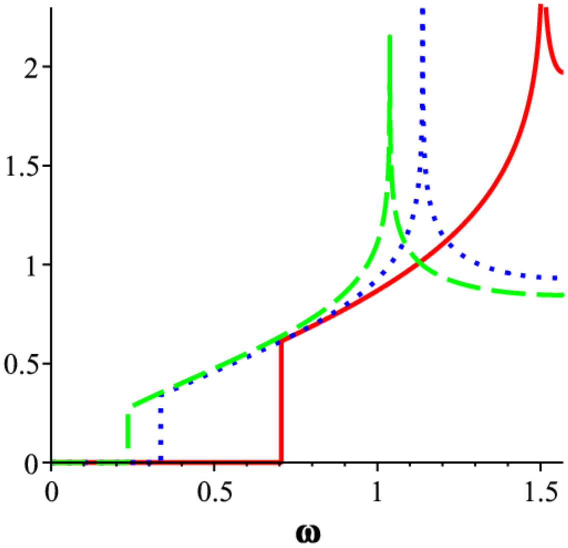



$$P_D \equiv P_{ee} = \frac{1}{2}(1 + \cos 2\bar{\theta}_{12}^{\odot} \cos 2\theta_{12}) + s_{13}^4$$

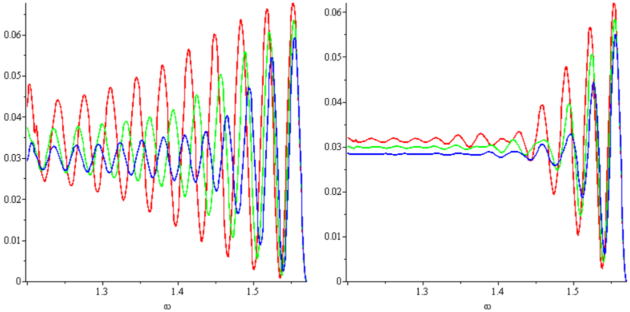
## Averaging over solar neutrino production size

From the Earth $^8B$ neutrino production region in the Sun is seen as a disk where more neutrinos come from the center of the disk. It turns out that that distribution can be appoximated as a normal one with a variance $\delta_\eta \simeq 1.9 \times 10^{-4}$ :

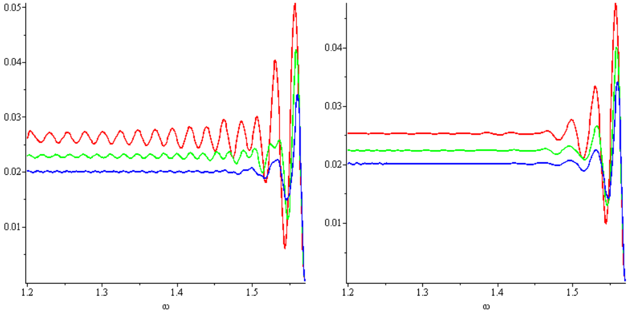
$$f(\eta', \eta) = \frac{1}{\delta_\eta \sqrt{2\pi}} \, e^{-\frac{(\eta-\eta')^2}{2\delta_\eta^2}} = \frac{1}{\delta_\eta \sqrt{2\pi}} \, e^{-\frac{(L-2R_\oplus \cos\eta)^2}{8\delta_\eta^2 R_\oplus^2 \sin^2\eta}}$$



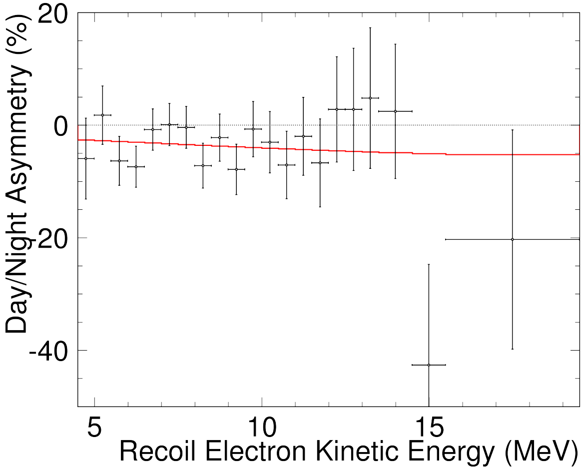

Dependance of average annual weight function on the nadir angle of neutrino trajectory($\omega$ is in radians). Outer core is "visable" at Kamioka site about 4.4 hours per day . Kamioka, SD, Finland




$T_e = 13, 12, 11$ MeV




$T_e = 9, 7, 5$ MeV

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the change of the solar neutrino flux due to the eccentricity of the Earth orbit ($\pm 3\%$) must be taken into account.

SK recent result A= $3.2 \pm 1.1 \pm 0.5$ and they use $\Delta m^2 \simeq$ 5 $10^{-5}$ $eV^2$

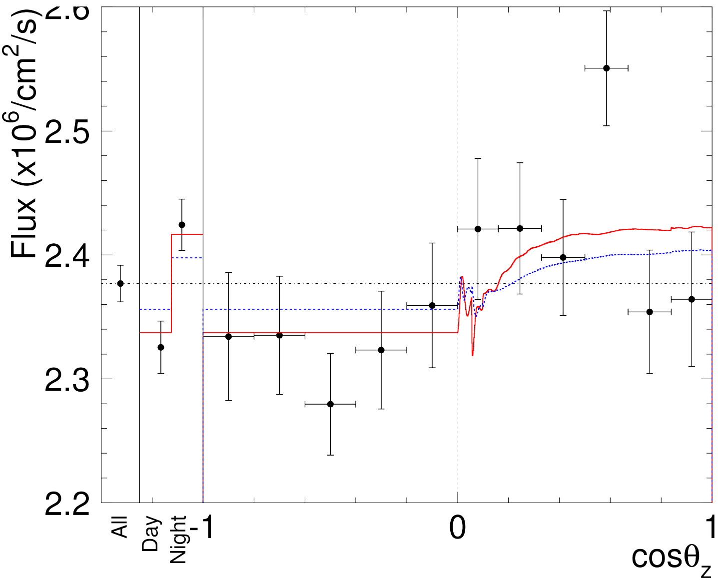
FULL 3D analise of the data

fit with Kamland $\Delta m^2$=7.5 $10^{-5}$ $eV^2$

make use "periodograms"

look to the high energy edge of the spectrum

THANK YOU

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