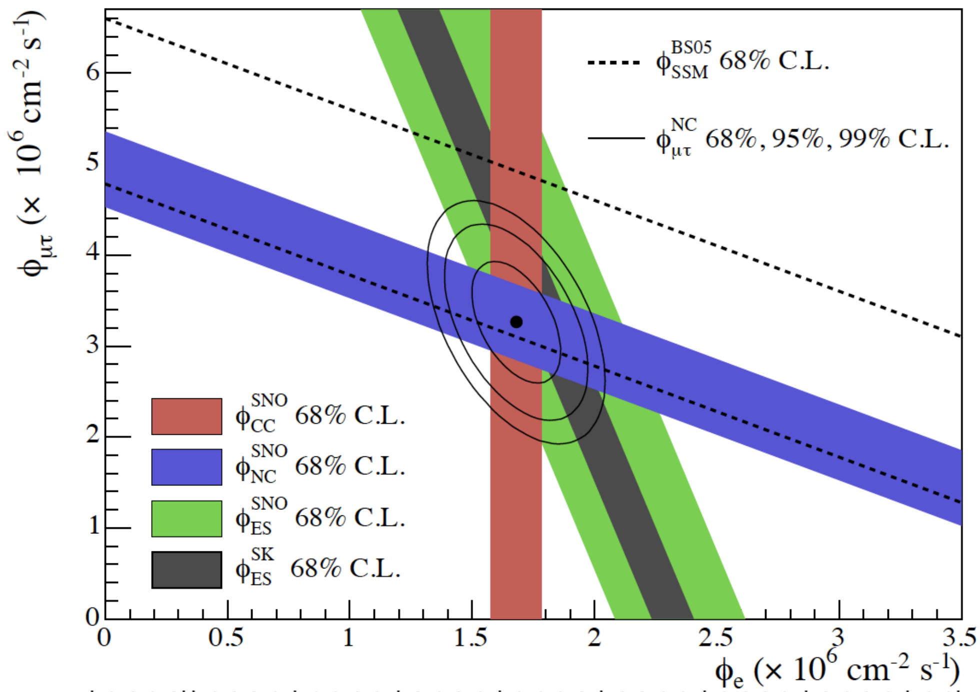
STATUS QUO AND FUTURE EVOLUTION OF THETA-12 AND DELTA M2-12

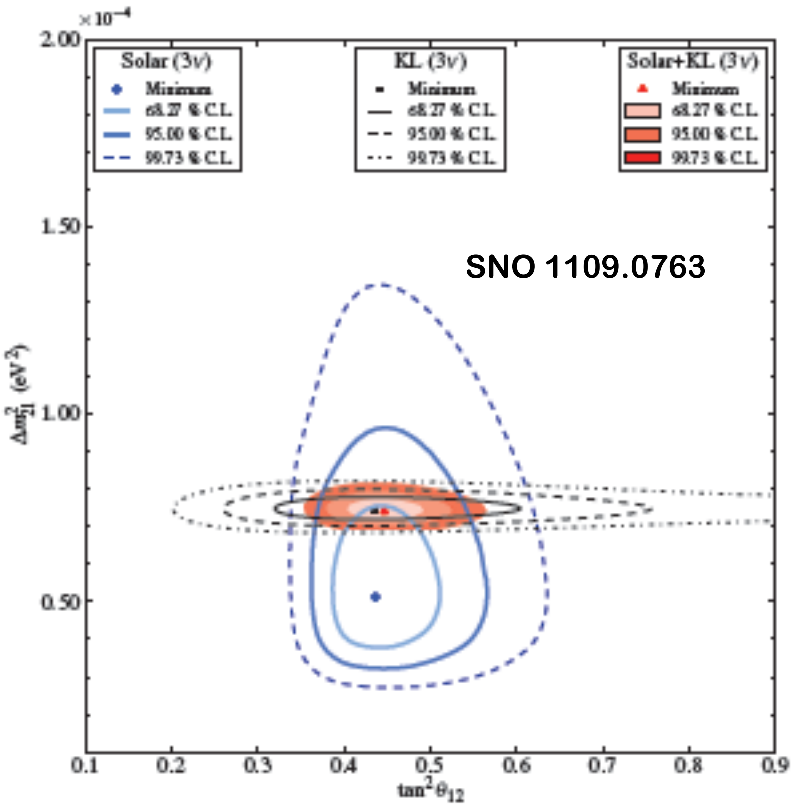
INTENSITY FRONTIER NEUTRINO WORKSHOP, SLAC, MARCH 6, 2013

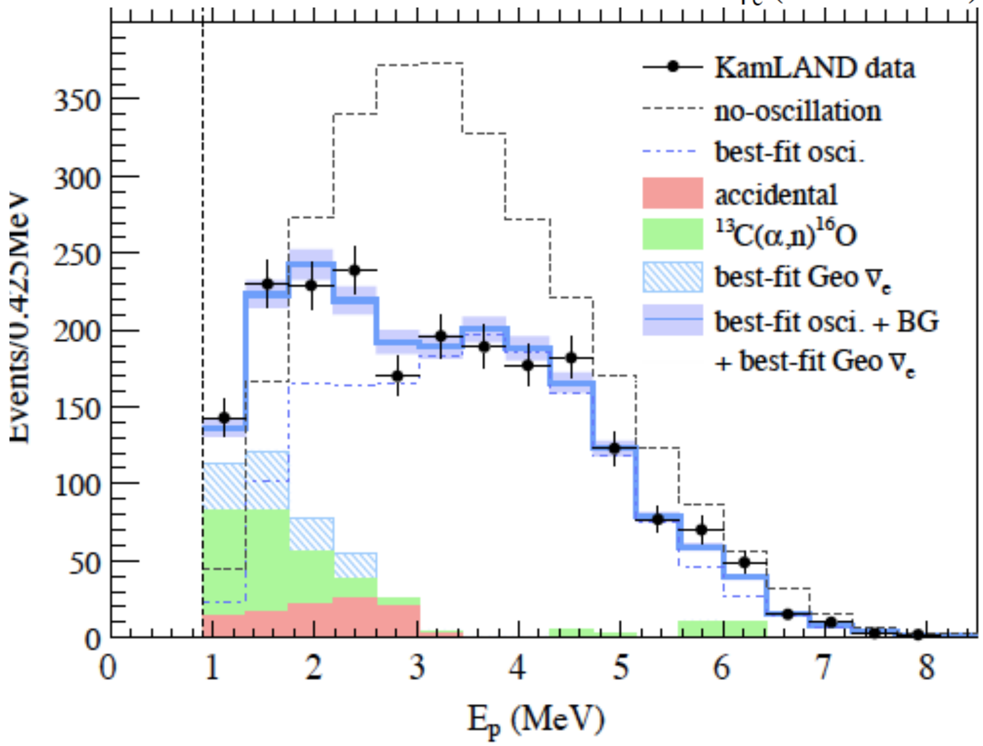
Hamish Robertson, University of Washington

STATUS

Known as the “solar” parameters determined mainly from solar neutrino experiments Super-Kamiokande and SNO, and the KamLAND reactor experiment.







STATUS

Known as the "solar" parameters, determined mainly from solar neutrino experiments Super-Kamiokande and SNO, and the KamLAND reactor experiment.

Δm_{21}^2	$7.50^{+0.18}_{-0.19} \times 10^{-5}$ eV^2	Gonzalez-Garcia et al. 1209.3023v3
θ_{12}	$33.4^{+0.8}_{-0.8}$ deg	"

Marginalized 1-D 1-σ uncertainties.

See also Fogli et al. 1205.5254

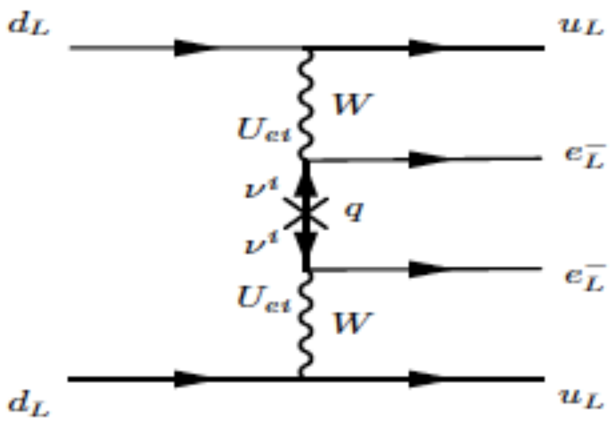
DO WE NEED MORE ACCURACY?

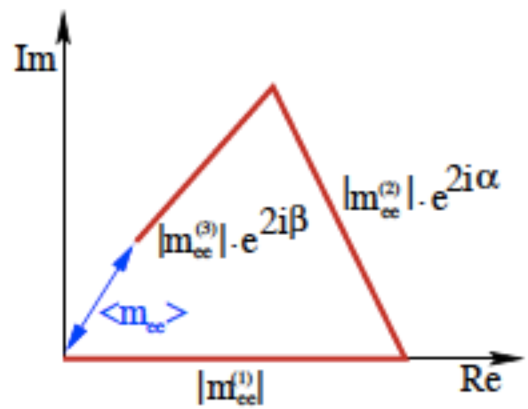
The precision on Δm^2 is probably sufficient for foreseeable applications. However there are a number of reasons for improving the precision on θ_{12}.

1. **Neutrinoless Double Beta Decay**
2. **Solar neutrinos**
3. **Sterile neutrinos**
4. **Theory**
5. **CP violation experiments**

NEUTRINOLESS DOUBLE BETA DECAY

Are neutrinos their own antiparticles? Is lepton number conserved?





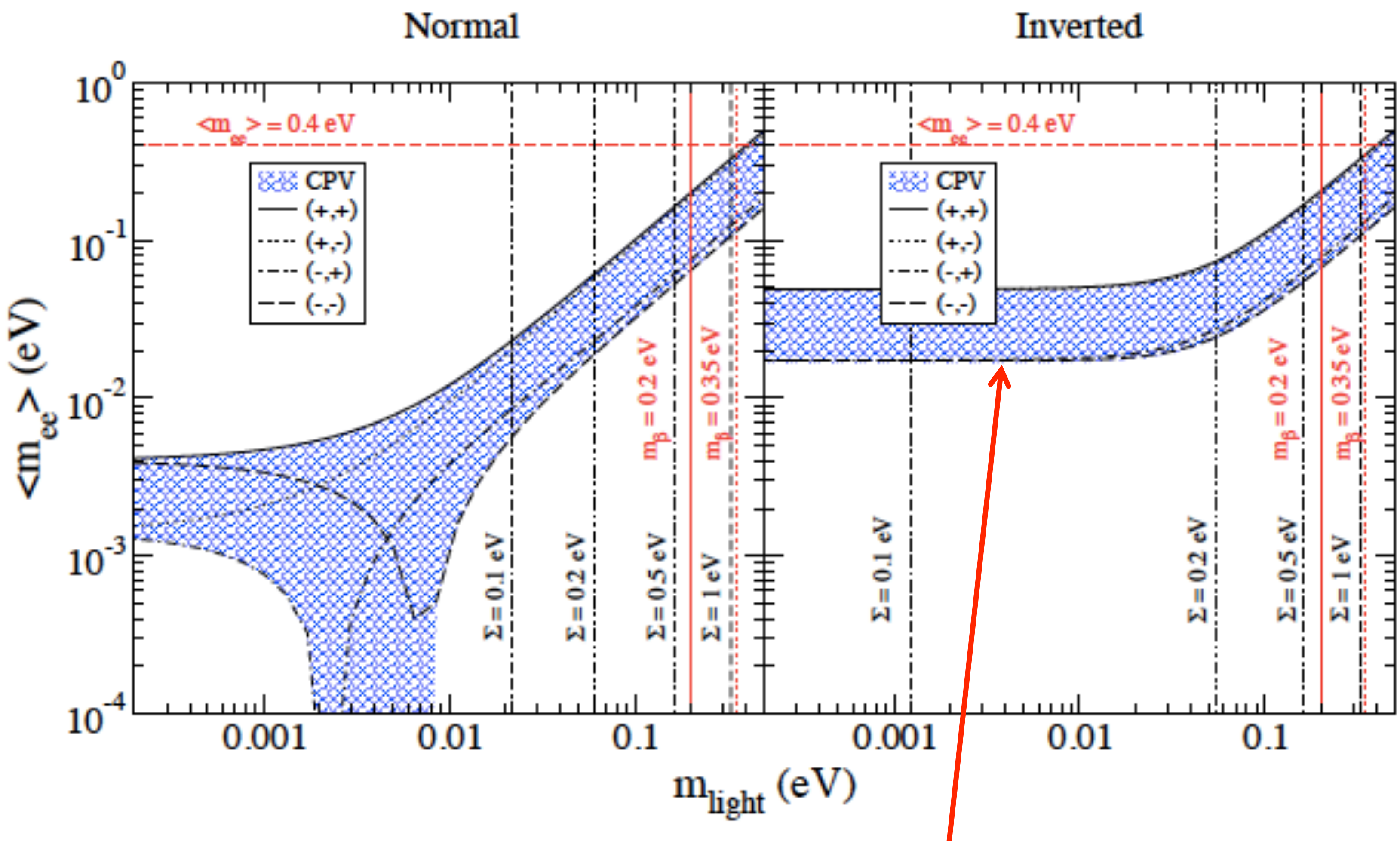
W. Rodejohann, 1206.2560

Decay rate per unit mass of isotope:

$$\lambda_{0\nu}\frac{N}{M} = \frac{N_A}{Am_e^2}G_{0\nu}^{(0)}g_A^4\,|M_{0\nu}|^2\,|\langle m_{ee}\rangle|^2$$

$$\equiv \Gamma_{0\nu}\,|M_{0\nu}|^2\,|\langle m_{ee}\rangle|^2$$

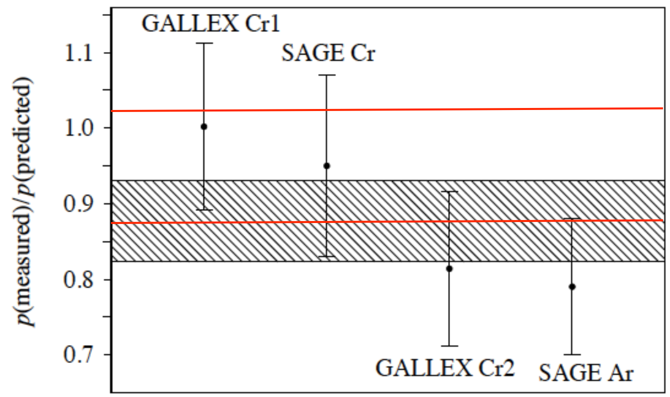
$$\langle m_{ee}\rangle = \left|U_{e1}^2 m_1 + U_{e2}^2 m_2 e^{i\alpha} + U_{e3}^2 m_3 e^{i\beta}\right|$$



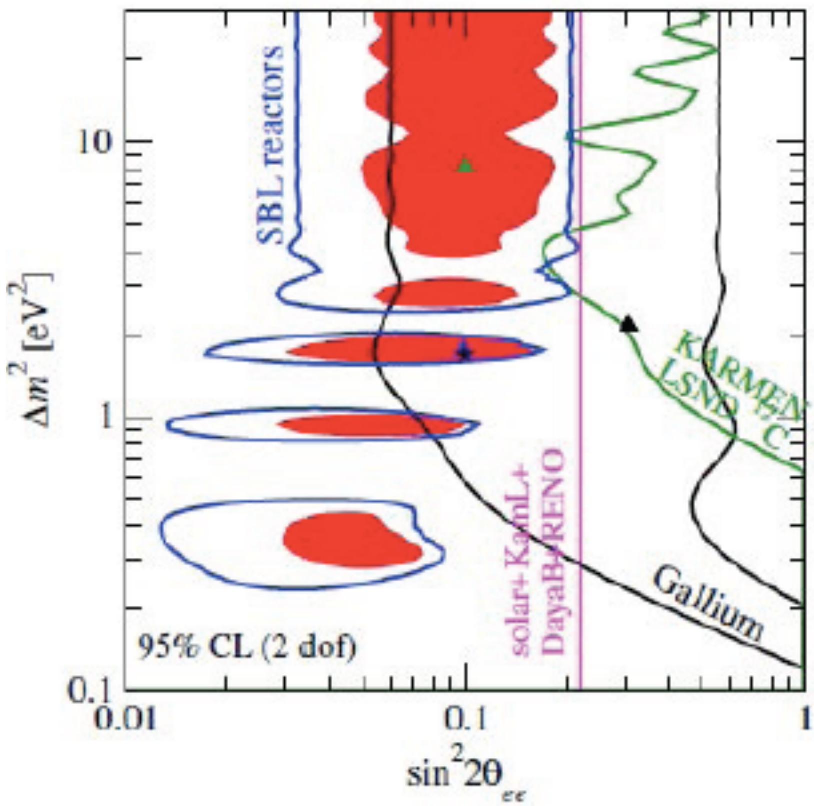
$$\langle m_{ee} \rangle_{\min}^{IH} = c_{13}^2 \sqrt{m_A^2} \cos 2\theta_{12}$$

1 deg in θ_{12}
corresponds to 20% in decay rate

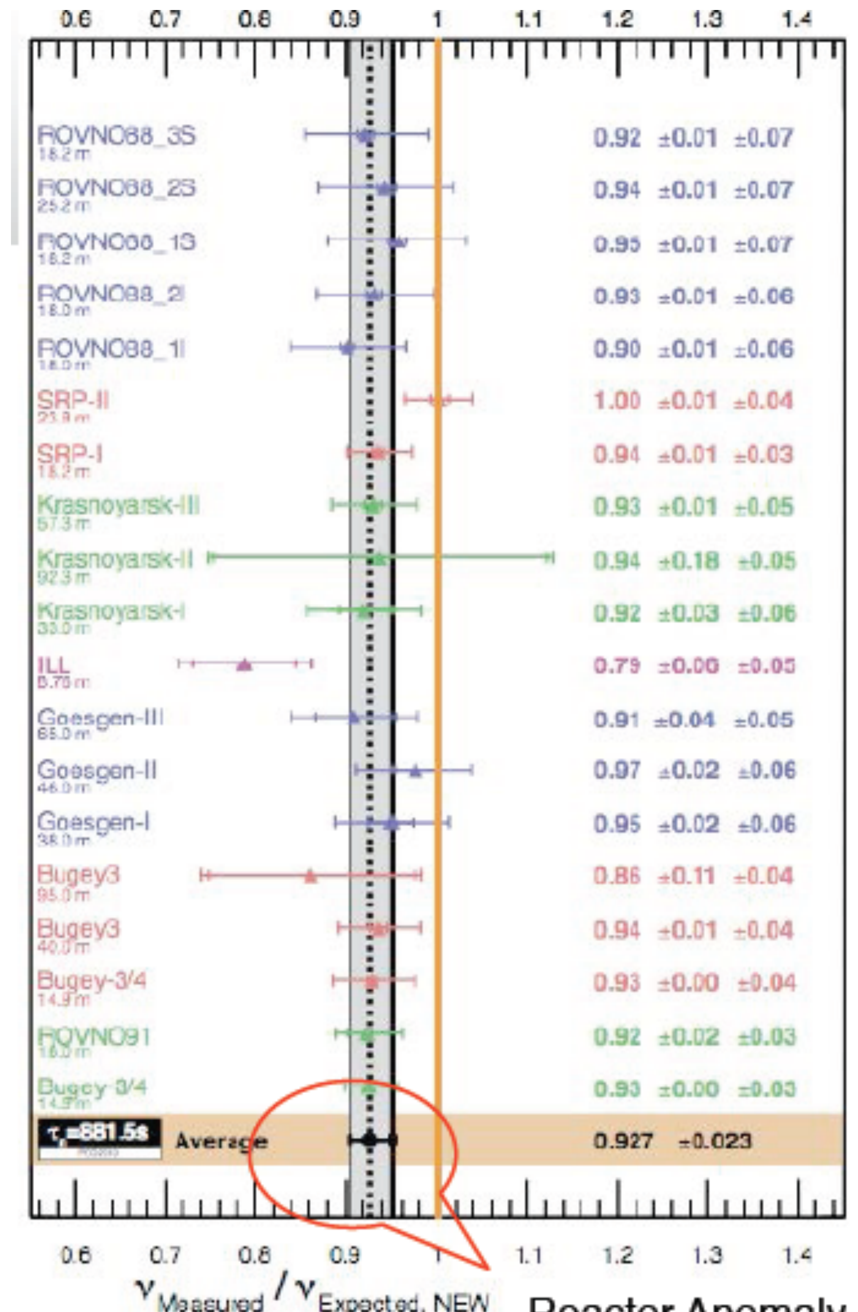
THE ANOMALIES



~3 σ



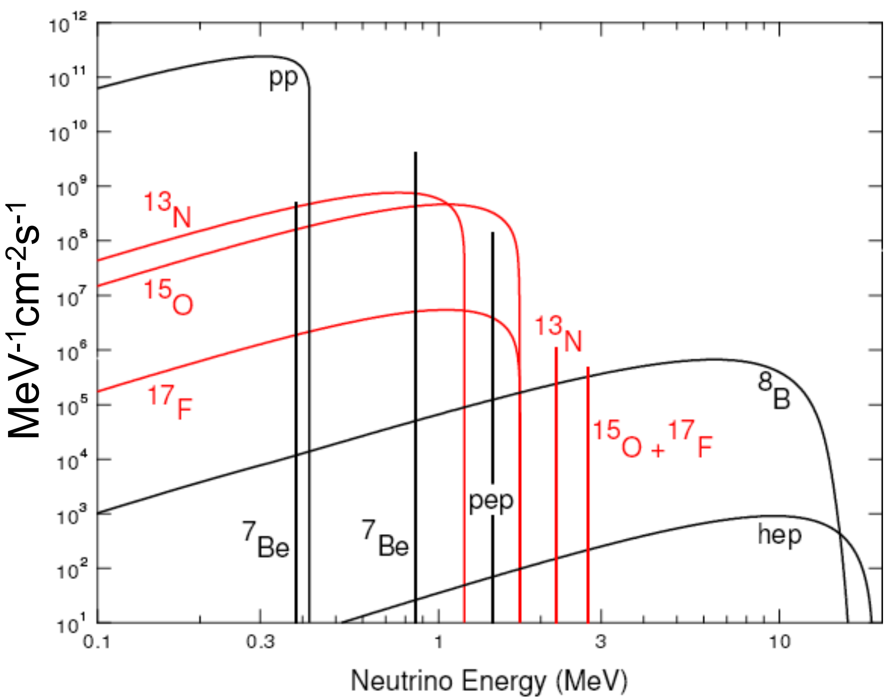
K. Heeger



Reactor Anomaly

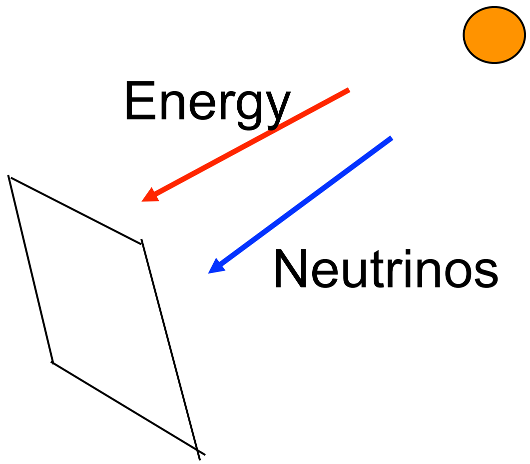
Ref: Mention et al, 1101.2755 (2012 upd)

A REACTOR WE REALLY UNDERSTAND



Our challenge is a 1% measurement of the TOTAL neutrino luminosity. Comparison with the electromagnetic luminosity will test for sterile neutrinos.

SIMPLICITY OF THE LUMINOSITY TEST:



Energy from Hydrogen Burning:

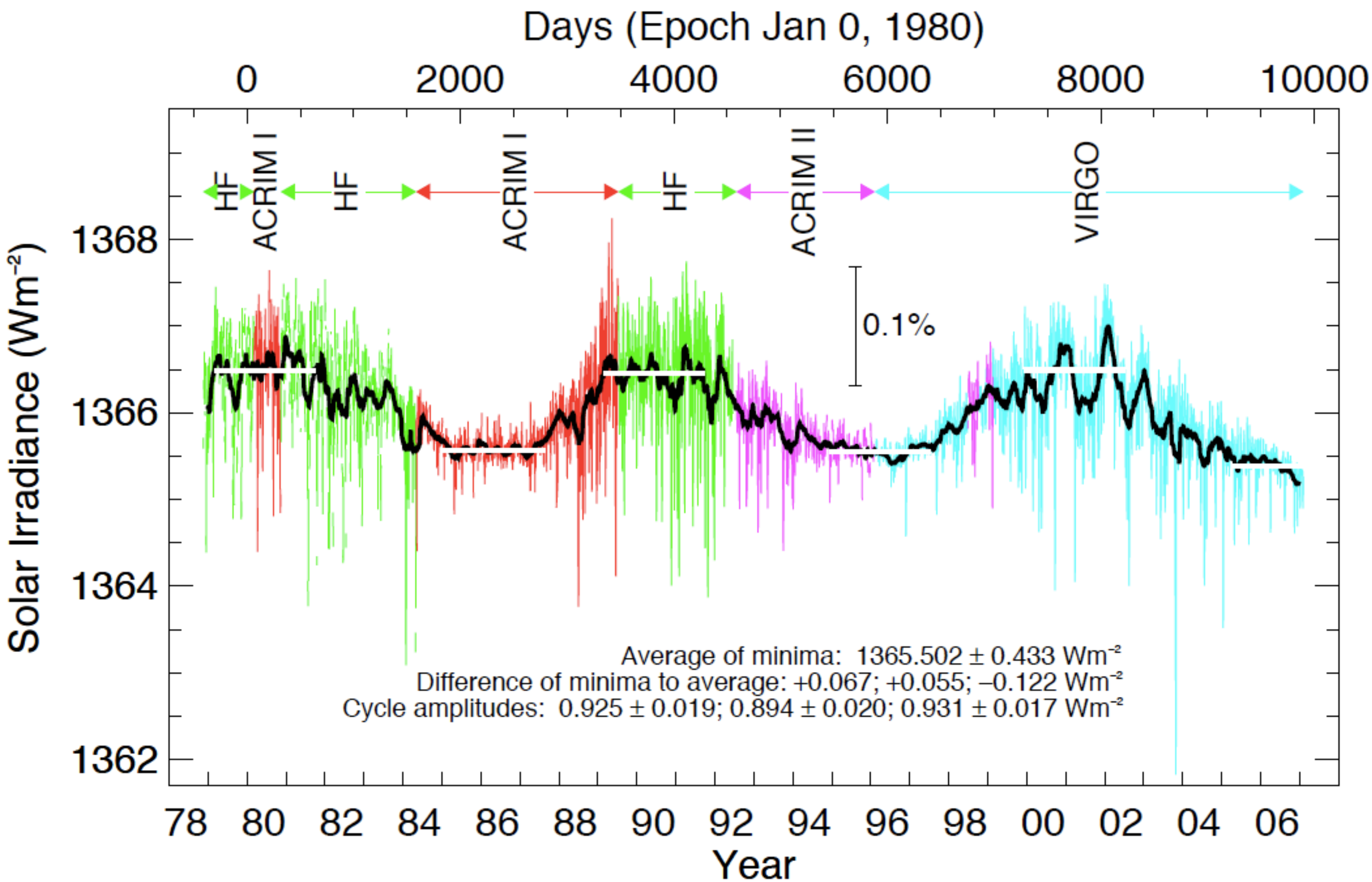
$4\ p + 2\ e^- \rightarrow {}^4He + 2\nu_e + 26.731\ MeV$

Measured power reaching Earth:

$137\ mW\ cm^{-2} = 8.53 \times 10^{11}\ MeV\ cm^{-2}\ s^{-1}$

So… the neutrino flux is

$$\frac{2 \times 8.53 \times 10^{11}}{26.731} = \mathbf{6.38 \times 10^{10}}\ \nu_e\ cm^{-2}\ s^{-1}$$


Days (Epoch Jan 0, 1980)
0
2000
4000
6000
8000
10000
HF
ACRIM I
HF
ACRIM I
HF
ACRIM II
VIRGO
0.1%
Solar Irradiance (Wm⁻²)
1368
1366
1364
1362
Average of minima: 1365.502 ± 0.433 Wm⁻²
Difference of minima to average: +0.067; +0.055; –0.122 Wm⁻²
Cycle amplitudes: 0.925 ± 0.019; 0.894 ± 0.020; 0.931 ± 0.017 Wm⁻²
78 80 82 84 86 88 90 92 94 96 98 00 02 04 06
Year

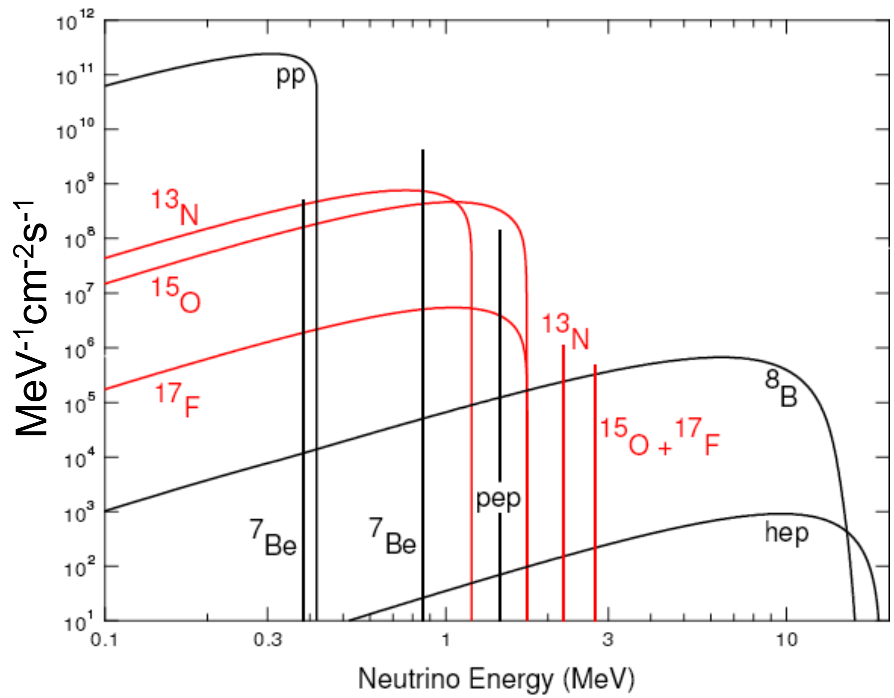
THE NEUTRINO LUMINOSITY

Some corrections and assumptions:--

Residual heat from formation (gravitation, deuterium burning) <<1%

Quasi-static burning (^{3}He, CNO)

The practical problem →



The Luminosity Constraint:

$$\sum_i \eta_i \Phi_i = \frac{2I}{Q}$$

I = 85.31(34) x 10^{10} MeV cm^{-2} s^{-1} (solar irradiance)

DETERMINATION OF THE NEUTRINO LUMINOSITY

Gonzalez-Garcia et al. 0910.4584v4:

$$\frac{L_\odot(\text{neutrino-inferred})}{L_\odot} = 1.00 \pm 0.14 \, \left[{}^{+0.37}_{-0.34}\right] .$$

(before recent Borexino data)

WHAT DO WE NEED?

Source	η_i
pp	0.9799
pep	0.8917
^{7}Be	0.9352
^{8}B	0.4979
CNO (^{13}N + ^{15}O)	0.9363
hep	0.7609

DATA:

SAGE, Gallex/GNO:

Borexino: 1.6(3) x 10^8 cm^{-2}s^{-1}

Borexino: 4.89(24) x 10^9 cm^{-2}s^{-1}

SNO: 5.25(19) x 10^6 cm^{-2}s^{-1}

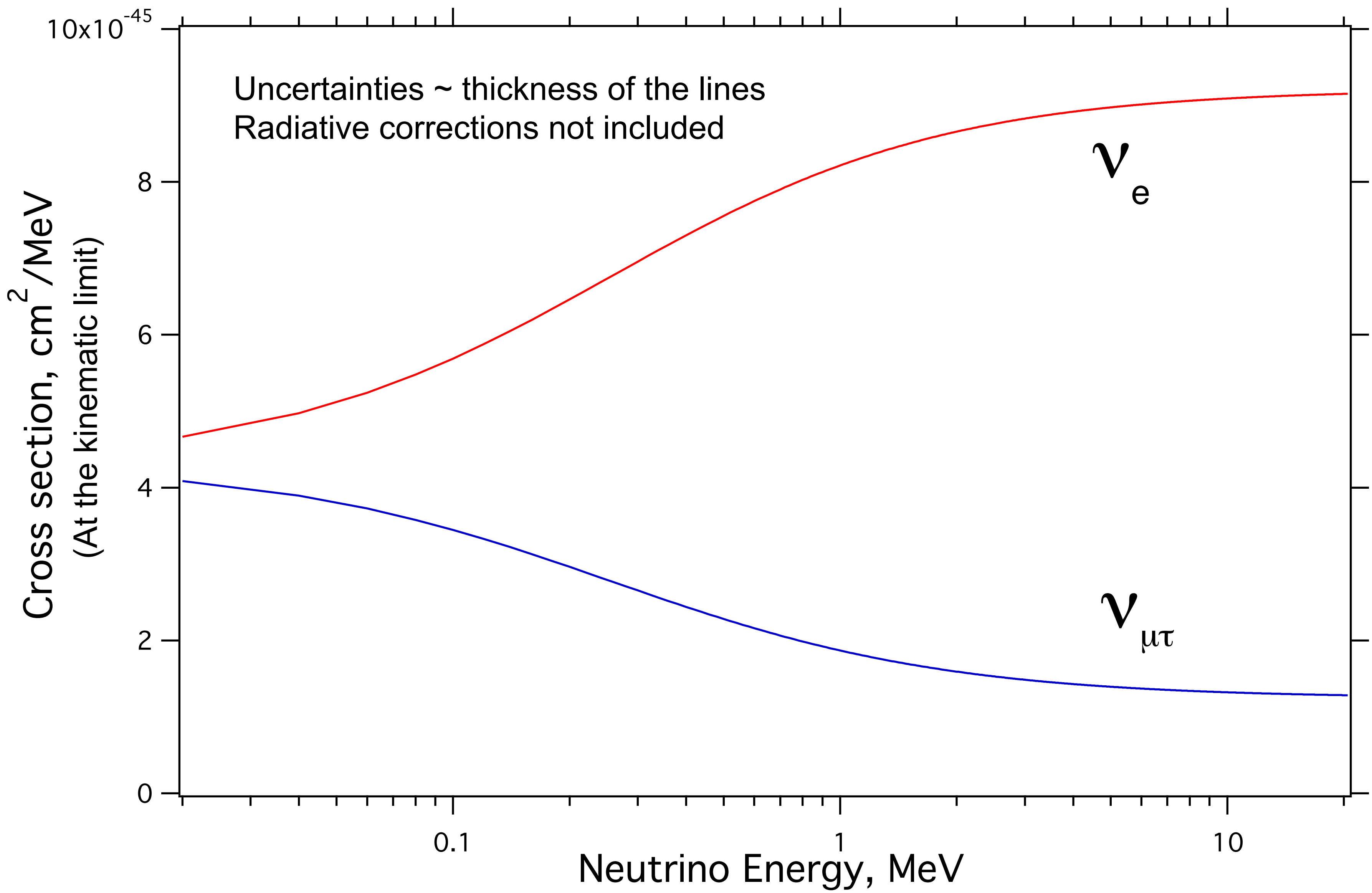
Borexino: <3.7 x 10^8 cm^{-2}s^{-1}

SNO: <2 x 10^4 cm^{-2}s^{-1}

θ_{12} SNO, SK, KamLAND

θ_{13} D-Chooz, Daya Bay, RENO

NEUTRINO – ELECTRON SCATTERING



ES DEPENDENCE ON Θ_{12}

$$P_{ee} = (1 - \sin^2\theta_{13})^2(1 - 2\sin^2\theta_{12} + 2\sin^4\theta_{12}) + \sin^4\theta_{13}$$
$$\equiv (1 - S_{13})(1 - 2S_{12} + 2S_{12}^2) + S_{13}^2$$

The survival probability depends on the oscillation parameters as follows:

$$\frac{dP_{ee}}{P_{ee}} = \frac{-2S_{12} + 4S_{12}^2}{P_{ee}}\frac{dS_{12}}{S_{12}}$$
$$\frac{dP_{ee}}{P_{ee}} = \frac{-S_{13}(1 - 2S_{12} + 2S_{12}^2) + 2S_{13}^2}{P_{ee}}\frac{dS_{13}}{S_{13}}$$

With the current best-fit values, $S_{12} = 0.307(17)$ and $S_{13} = 0.0245(32)$, the logarithmic derivative ratios are,

$$\frac{dP_{ee}}{P_{ee}} = -0.422\frac{dS_{12}}{S_{12}}$$
$$\frac{dP_{ee}}{P_{ee}} = -0.028\frac{dS_{13}}{S_{13}}$$

Flux	E_ν MeV	Flux Uncert. %
pp	0.42	1.22
^{7}Be	0.86	1.45
pep	1.44	1.54

2x better uncertainty on θ_{12} gets us below 1% !

THEORY

The large mixing angles invite theoretical interpretation.

The original Harrison-Perkins-Scott tribimaximal mixing predicts vanishing θ_{13} but can be rescued with "corrections".

In 2004 Minkata and Smirnov proposed "Quark-Lepton Complementarity" (hep-ph/0405088). **One of 6 scenarios is:**

$$U_{MNS} = V^{CKM\dagger}\Gamma_\delta R_{23}^m R_{12}^m = R_{12}^{CKM\dagger} R_{13}^{CKM\dagger} R_{23}^{CKM\dagger}\Gamma_\delta R_{23}^m R_{12}^m,$$

$$\sin\theta_{sun} = \sin\left(\frac{\pi}{4} - \theta_C\right) + \frac{\sin\theta_C}{2}(\sqrt{2} - 1 - V_{cb}\cos\delta)$$

$$\theta_{sun} = 35.4^\circ \pm 0.3^\circ, \qquad \sin^2\theta_{sun} = 0.335 \pm 0.005,$$

$$\sin^2\theta_{13} = 0.026 \pm 0.008$$

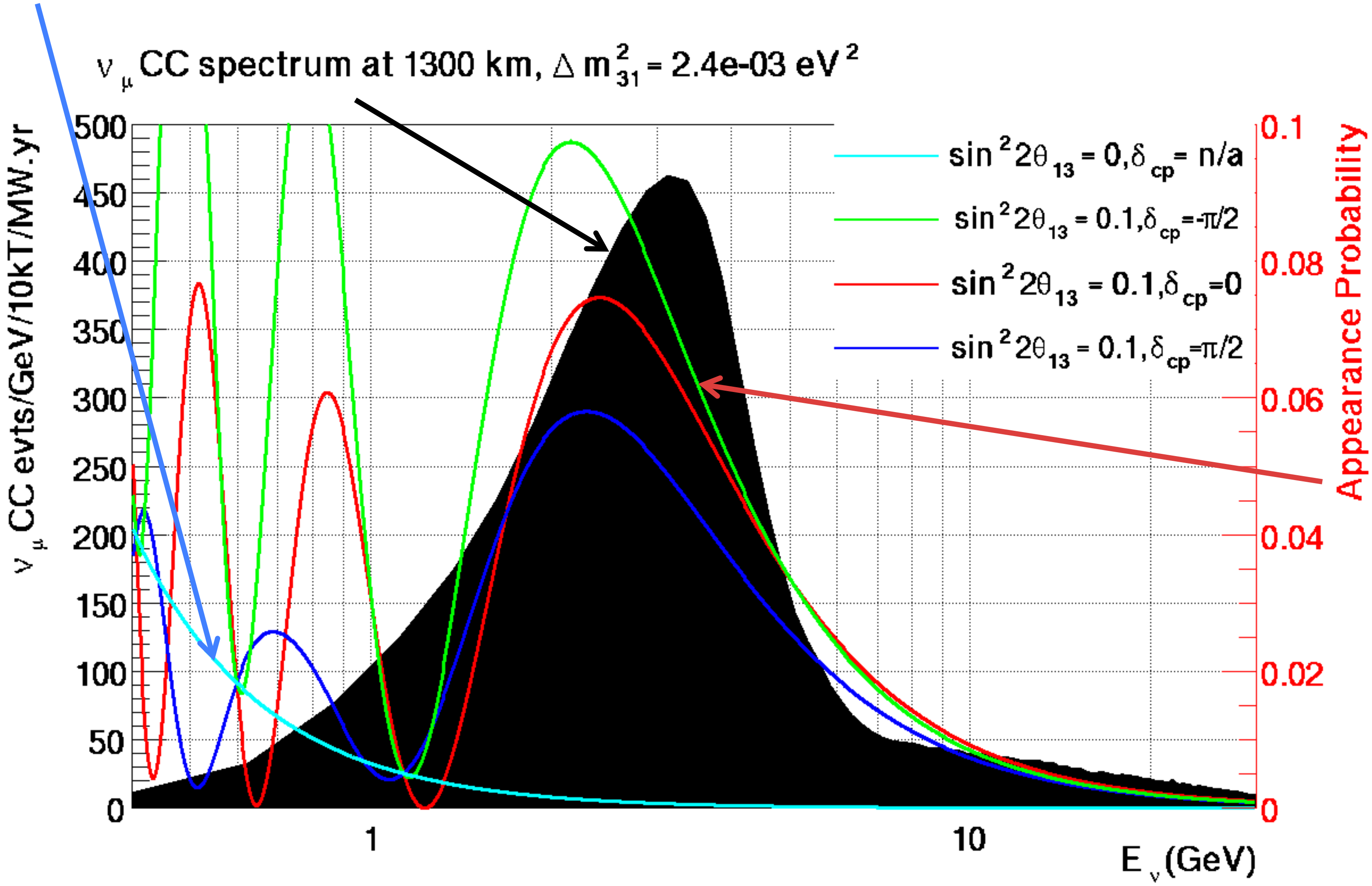
(wow!)

0.0227 +/- 0.0023

LBNE SPECTRUM

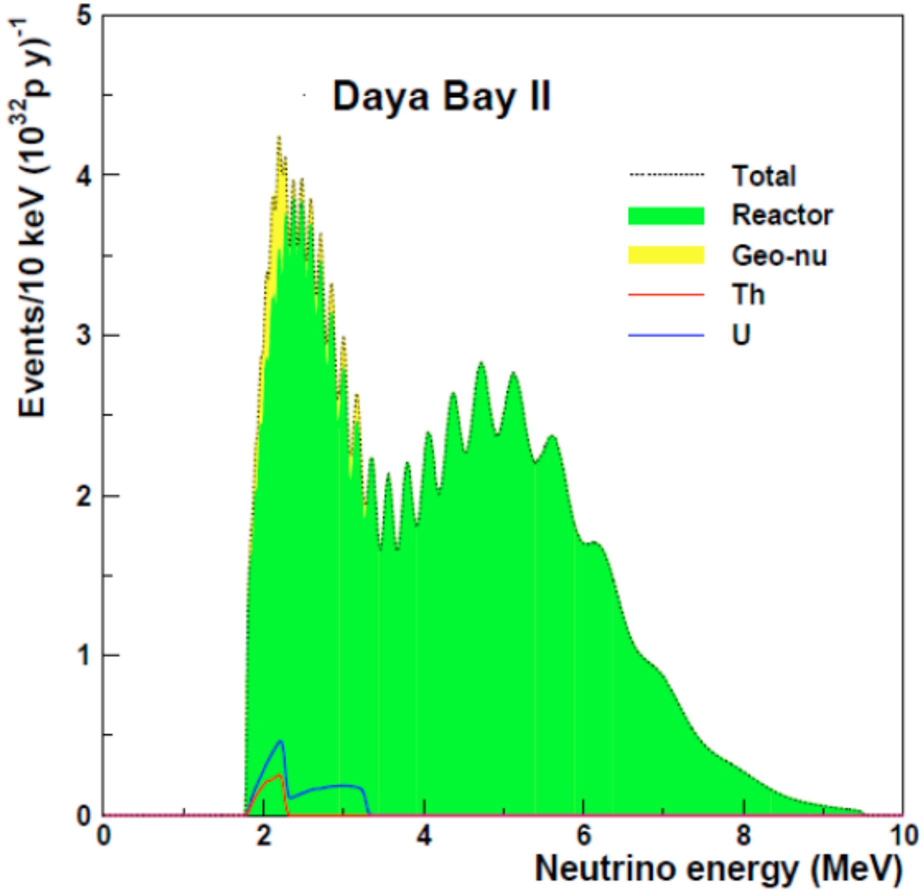
M.Bishai

Homework problem! How does the solar term affect searches at the second minimum?



DAYA BAY II

A fine prospect for improving the precision on θ_{12}.



	Current	Daya Bay II
Δm^2_{12}	3%	0.6%
Δm^2_{23}	5%	0.6%
$\sin^2\theta_{12}$	6%	0.7%
$\sin^2\theta_{23}$	20%	N/A
$\sin^2\theta_{13}$	14% ➔ 4%	~ 15%

Y. Wang

SUMMARY

An improvement of a factor of 2 to 3 in the precision on θ_{12} would have a beneficial impact in several areas of physics:

1. **Search for neutrinoless double beta decay and lepton-number violation.**
2. **Use of the sun as a standard candle for sterile neutrino admixture searches.**
3. **Tests of theory, particularly quark-lepton complementarity.**
4. **Design of LBNE searches for CP violation.**