“Neutrino Physics from New Measurements”

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Introduction:

Compelling evidence for neutrino flavor conversion
Solar neutrinos primarily change to an other active flavor

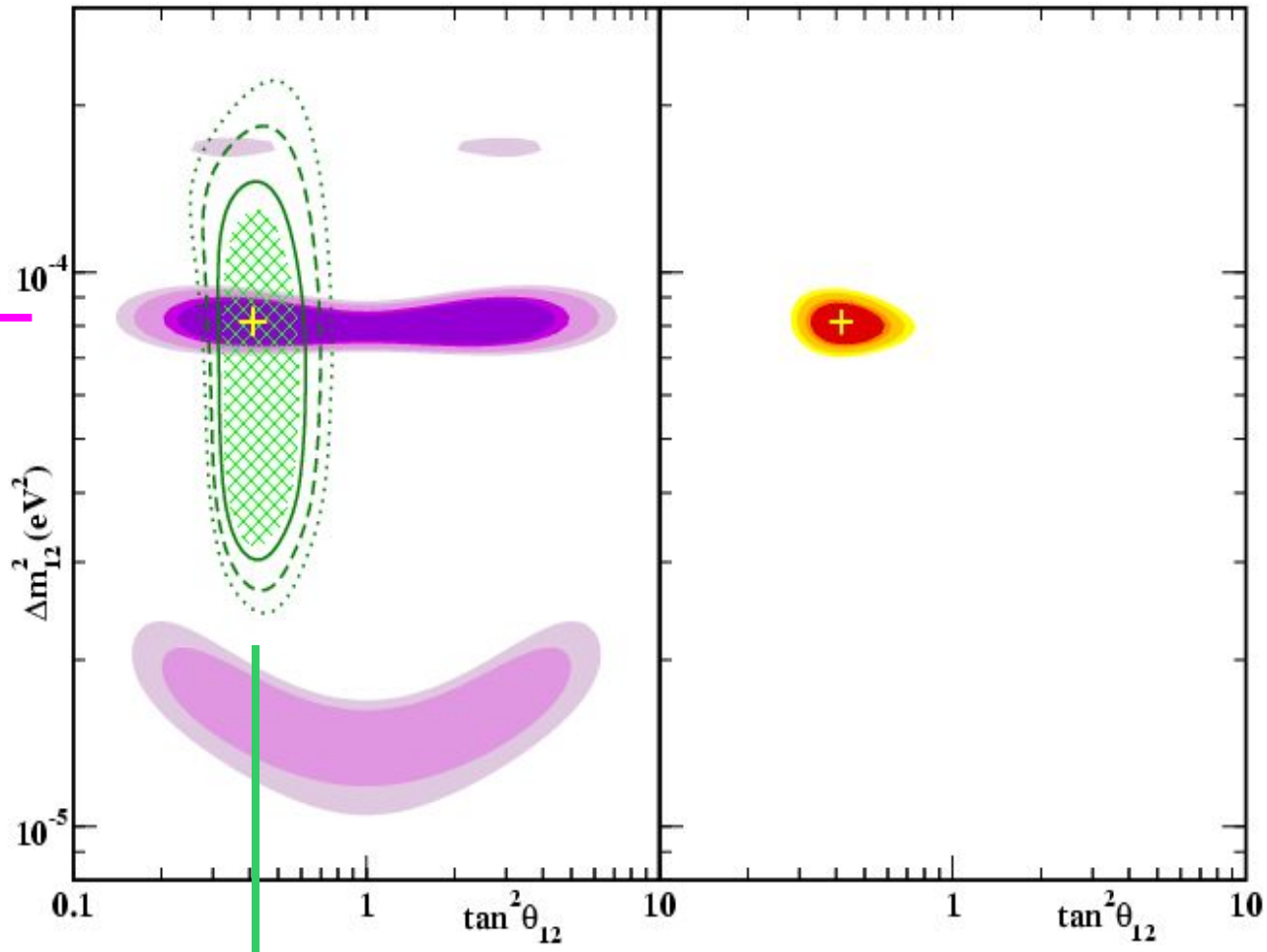
In framework of oscillations, mass and mixing:

- matter probably has an effect in transformation
- mixing angle θ_{12} is large but not maximal
- mixing angle θ_{13} is large or even maximal

What is likely to be the possible outcomes of the future measurements of SNO and KamLAND:

- How much determination of mixing parameters can be improved?
- Can we improve bounds on θ_{13} before specific experiments for this measurement starts?
- Can we determine or limit the sterile fraction of solar neutrino flux and/or sterile mixing angle?

Allowed Regions after latest KamLAND Results:



$$\tan^2(\theta_{12}) = .40^{+0.09}_{-0.07}$$

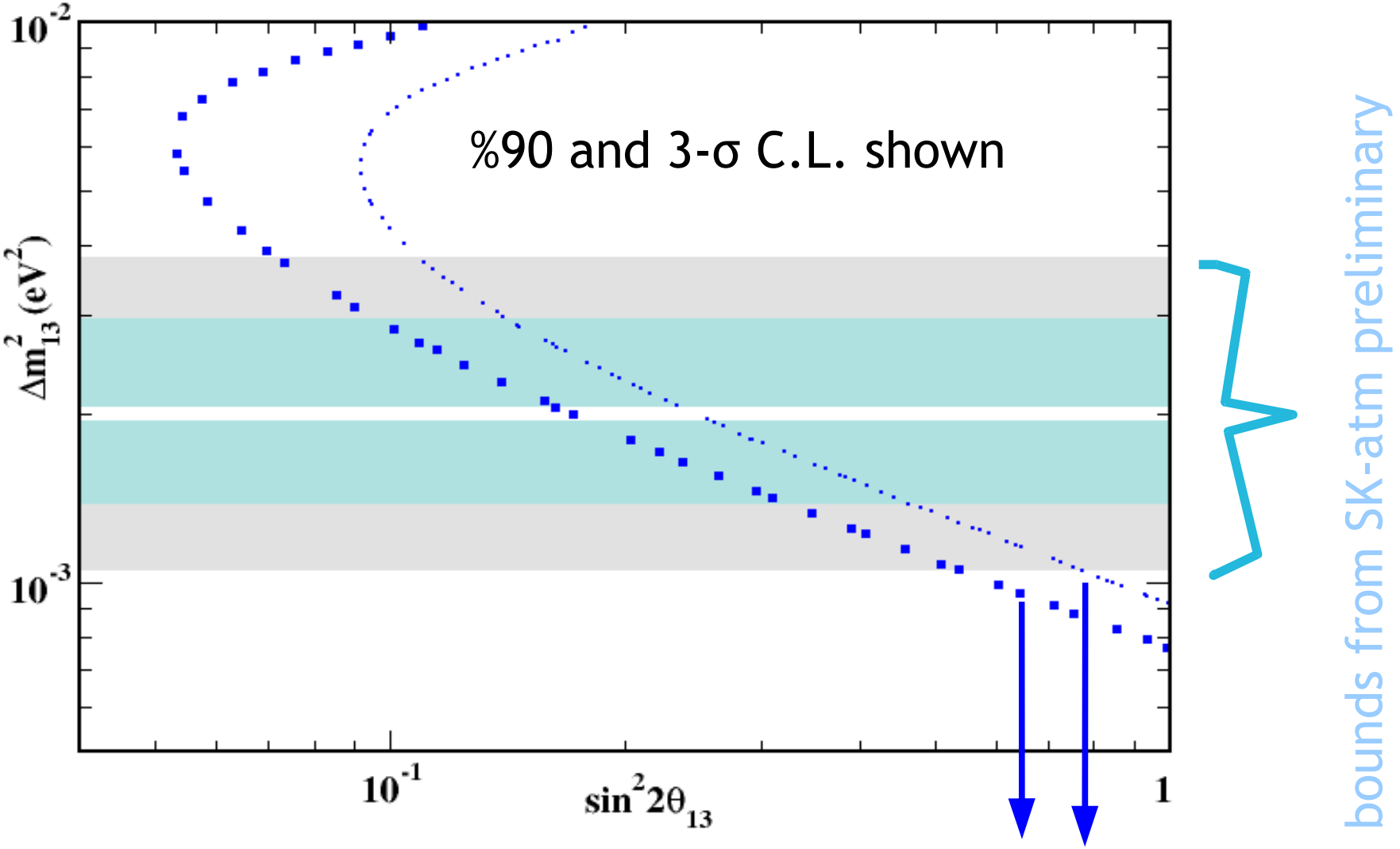
$$\delta m^2_{12} = 8.2^{+0.6}_{-0.5} \times 10^{-5}\,\mathrm{eV}^2$$

- Homestake
- SAGE
- GALLEX/GNO
- SK
- SNO

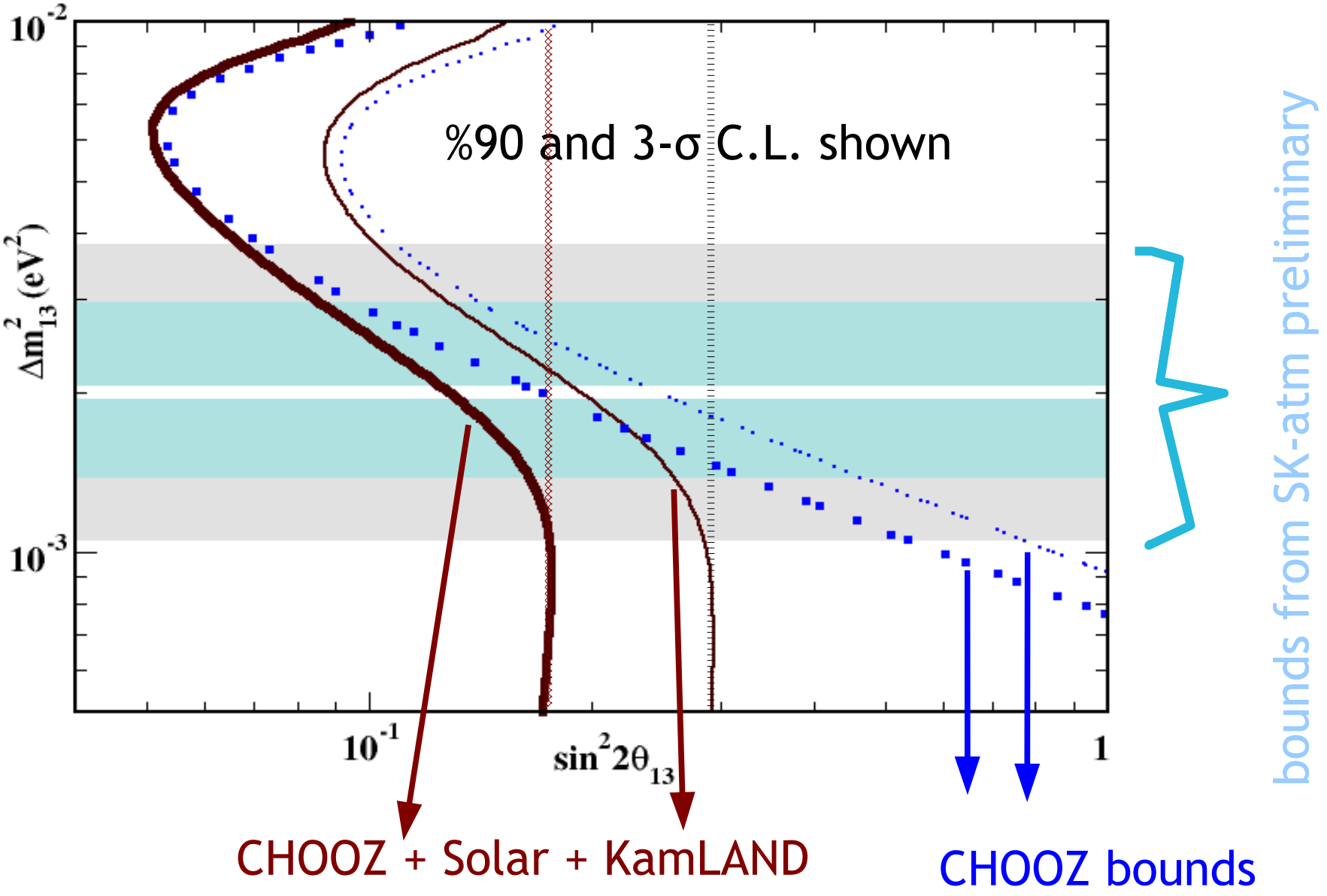
- KamLAND

θ_{13} Bounds from Reactor and Atmospheric Neutrinos::

- Best limit on θ_{13} is coming from combined reactor experiments (*Chooz, Polo Verde, etc.), atmospheric neutrino experiments (SK, etc.) and K2K long baseline experiment*

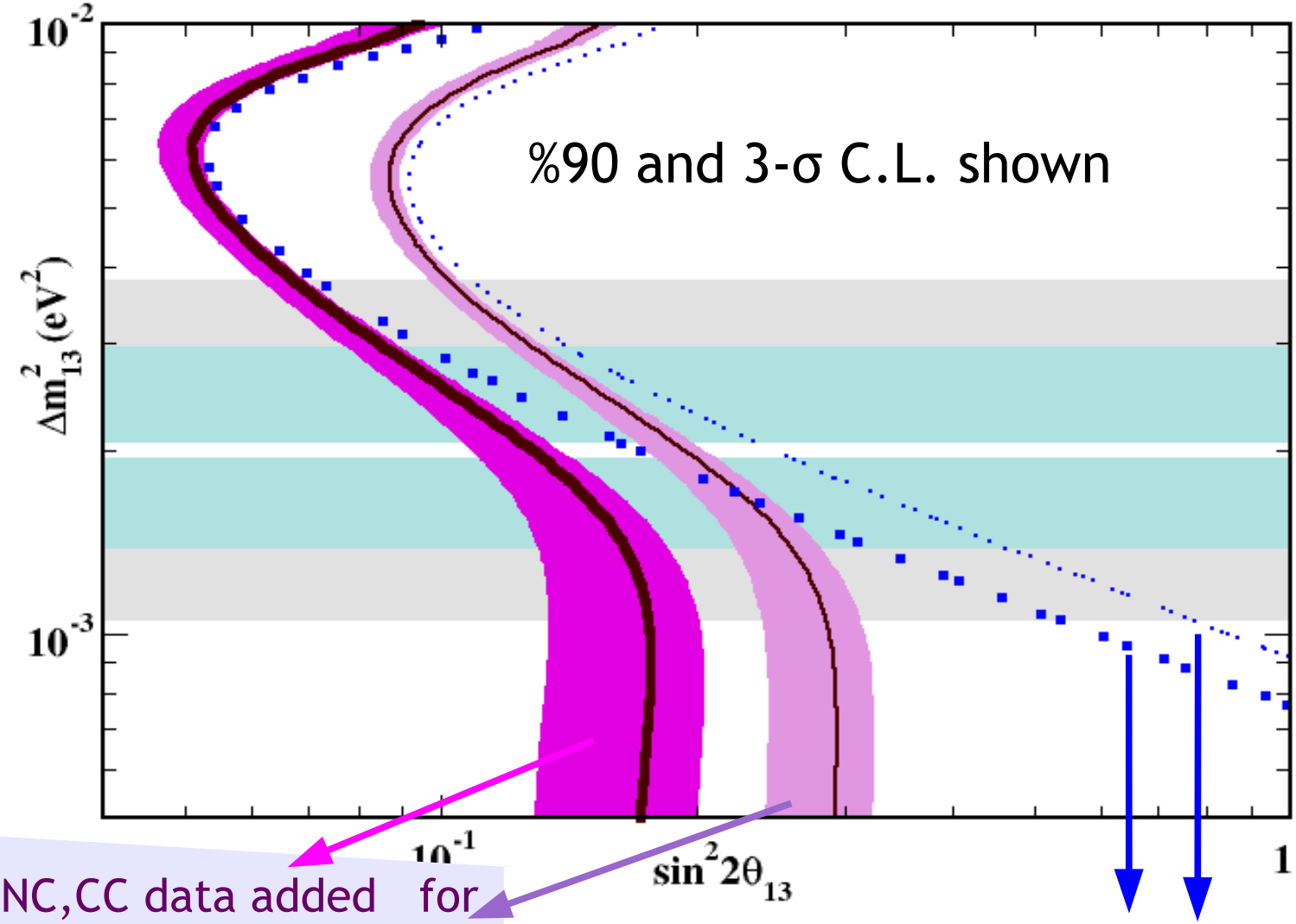


θ_{13} Bounds When Solar and KamLAND Data Added:



θ_{13} Bounds and Possible Impact of NC,CC from SNO NCD Phase:

$$\frac{\sigma_{NC}}{NC} = \%6.4 \qquad \frac{\sigma_{CC}}{CC} = \%5.5$$



bounds from SK-atm preliminary

Simulated NC,CC data added for SNO NCD-phase (varied by 1-σ around SNO salt-phase values)

CHOOZ bounds

"in simple 4-neutrino mixing scenarios, electron neutrino changes into some linear combination of an another active flavor and a sterile neutrino"

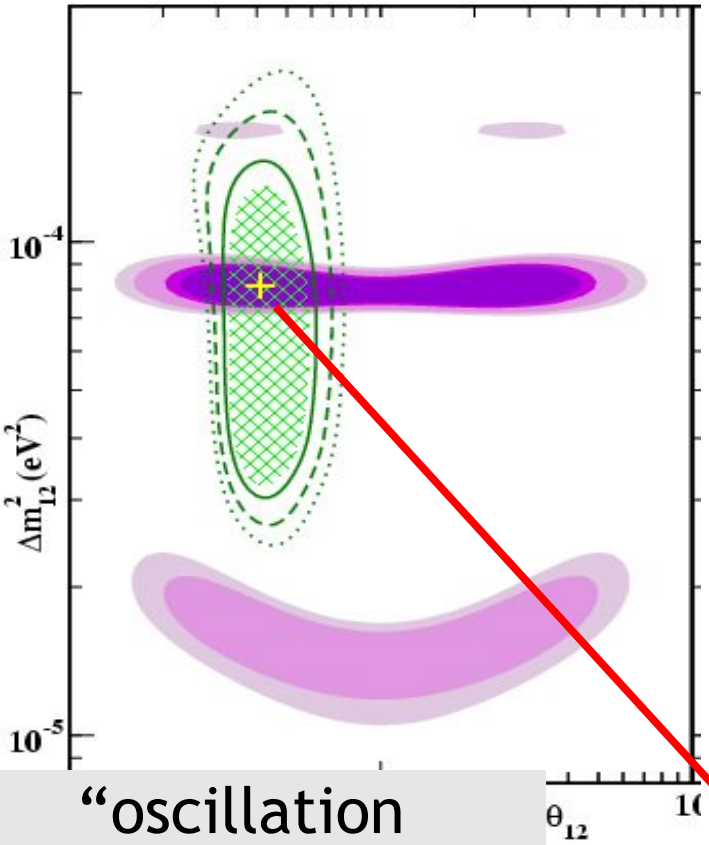
$$\nu_e \rightarrow \sqrt{\eta}\,\nu_s + \sqrt{1-\eta}\,\nu_{\mu,\tau}$$

sterile mixing angle:

$\eta = \cos^2(\alpha)$ fraction of the oscillating neutrinos changing into sterile neutrinos

$1-\eta = \sin^2(\alpha)$ fraction of the oscillating neutrinos changing into active neutrinos

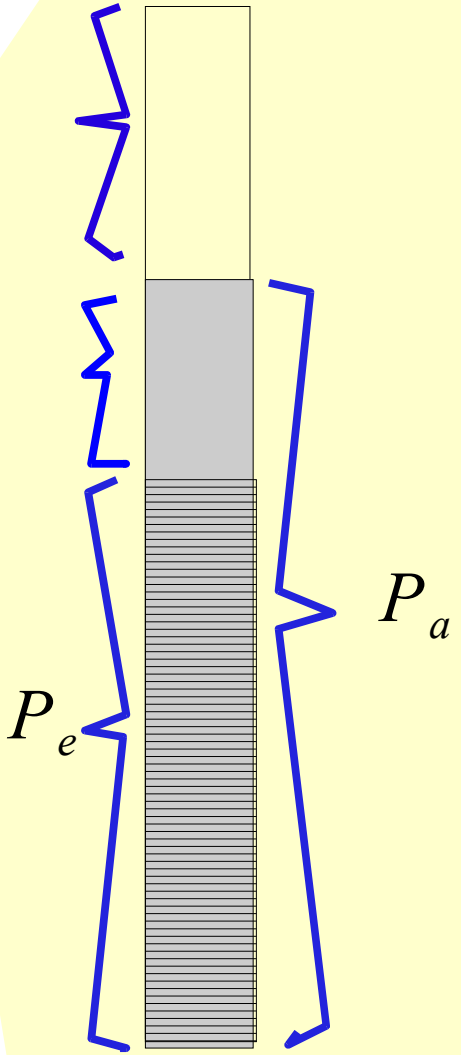
P_e can be calculated (almost model independently) as:



"oscillation parameters from KamLAND measurement"

$$P_s = \cos^2(\alpha)(1-P_e)$$

$$\sin^2(\alpha)(1-P_e)$$



$$P_e = \frac{\int \lambda(E_\nu)\sigma^{SNO}_{CC}(E_\nu)P_{e\to e}(E_\nu,\delta m^2_{12},\theta_{12})dE_\nu}{\int \lambda(E_\nu)\sigma^{SNO}_{CC}(E_\nu)dE_\nu}$$

$$P_s + P_a = 1$$

Sterile Fraction in Solar Flux:

$$CC \sim P_e \phi_{^8B}$$
$$NC \sim P_a \phi_{^8B}$$

$$P_a \sim P_e \frac{NC}{CC}$$

"P_a from SNO measurements"

$$\frac{\sigma_{P_a}}{P_a} \sim \sqrt{\left(\frac{\sigma_{P_e}}{P_e}\right)^2 + \left(\frac{\sigma_{NC}}{NC}\right)^2 + \left(\frac{\sigma_{CC}}{CC}\right)^2} \sim \%11$$

$\%7$ $\%6.4$ $\%5.5$

$$P_s + P_a = 1$$

$$\sigma_{P_s} \sim \sigma_{P_a} \sim Pe \frac{NC}{CC} \times 11\% \sim \%11$$

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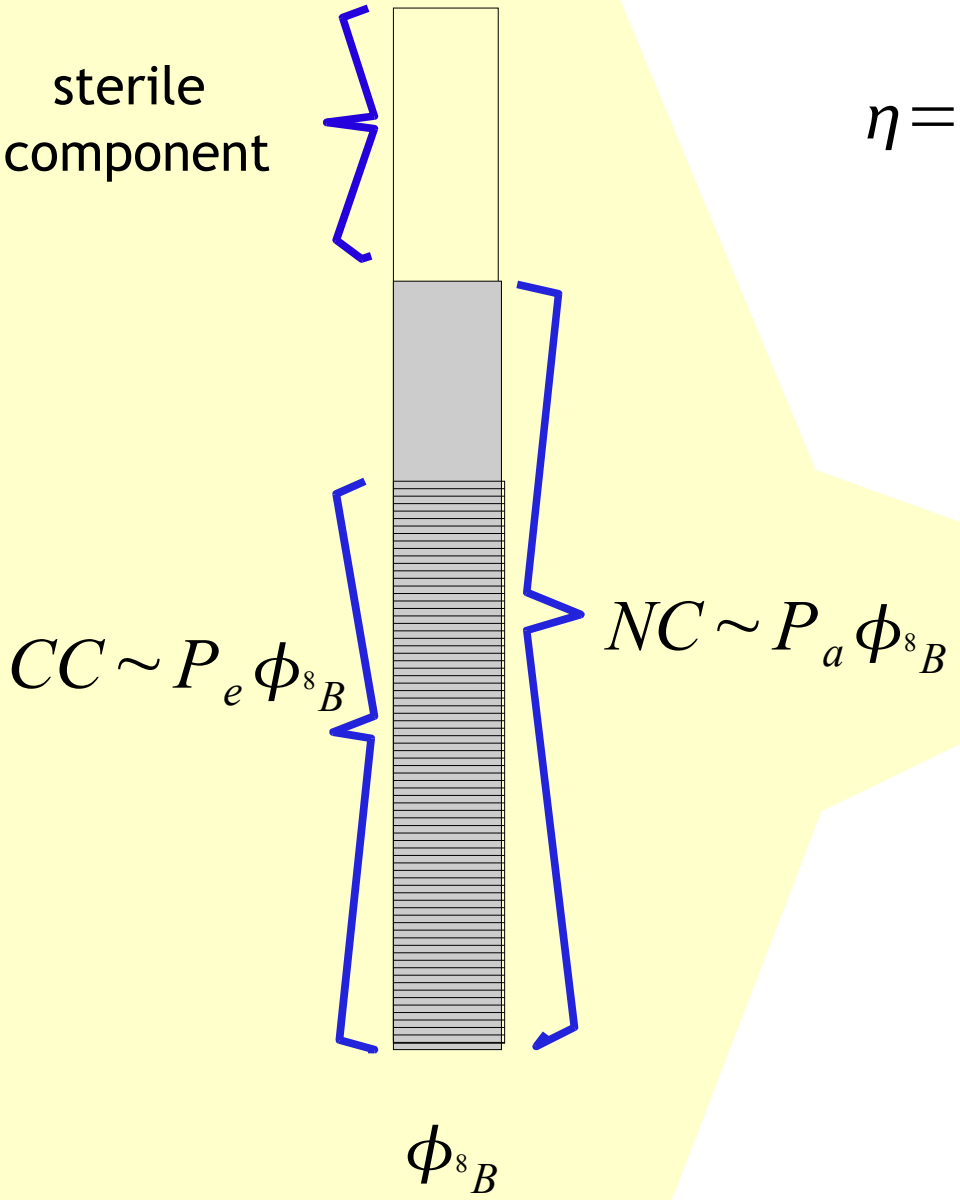
Limits on Sterile Mixing Angle:



sterile component

$$\eta = \cos^2(\alpha) \sim \frac{1-P_a}{1-P_e} = \frac{\phi_{^8B} - NC}{\phi_{^8B} - CC}$$

non-electron flavor component

fraction of oscillating neutrinos changing to active neutrinos:

$$\sin^2(\alpha) \sim 1 - \frac{\phi_{^8B} - NC}{\phi_{^8B} - CC} = \frac{NC - CC}{\phi_{^8B} - CC}$$

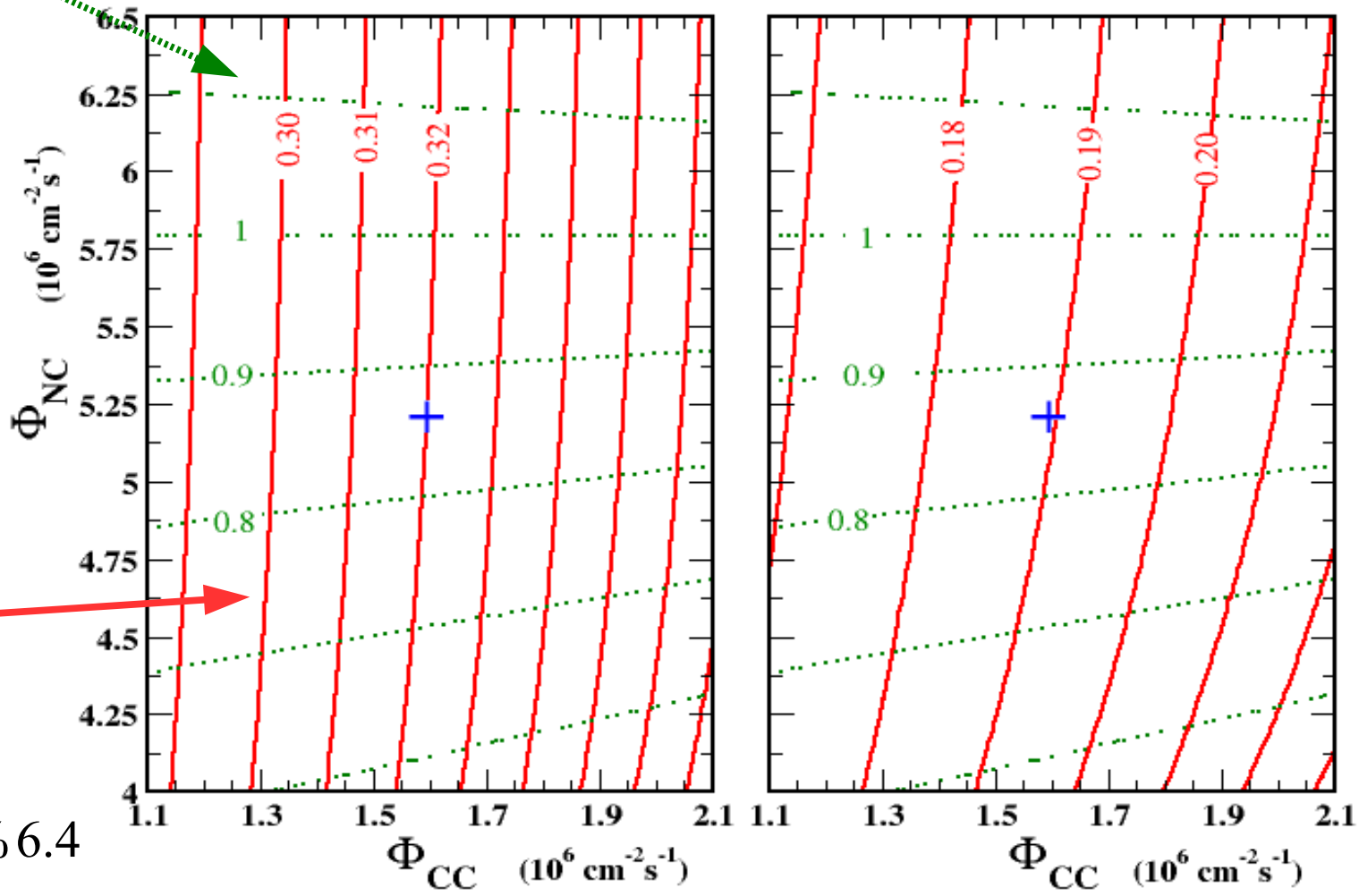
$$\frac{\sigma_{\sin^2(\alpha)}}{\sin^2(\alpha)} = ?$$

Limits on Sterile Mixing Angle (with SSM):

$$\sin^2(\alpha) \sim \frac{NC - CC}{\phi_{^8B} - CC}$$

$$\phi_{^8B} = \phi_{^8B_{SSM}}$$

$$\frac{\sigma_{\phi_{^8B_{SSM}}}}{\phi_{^8B_{SSM}}} \sim \%21, \%12$$



$$\frac{\sigma_{\sin^2(\alpha)}}{\sin^2(\alpha)}$$

$$\frac{\sigma_{CC}}{CC} = \%5.5 \quad \frac{\sigma_{NC}}{NC} = \%6.4$$

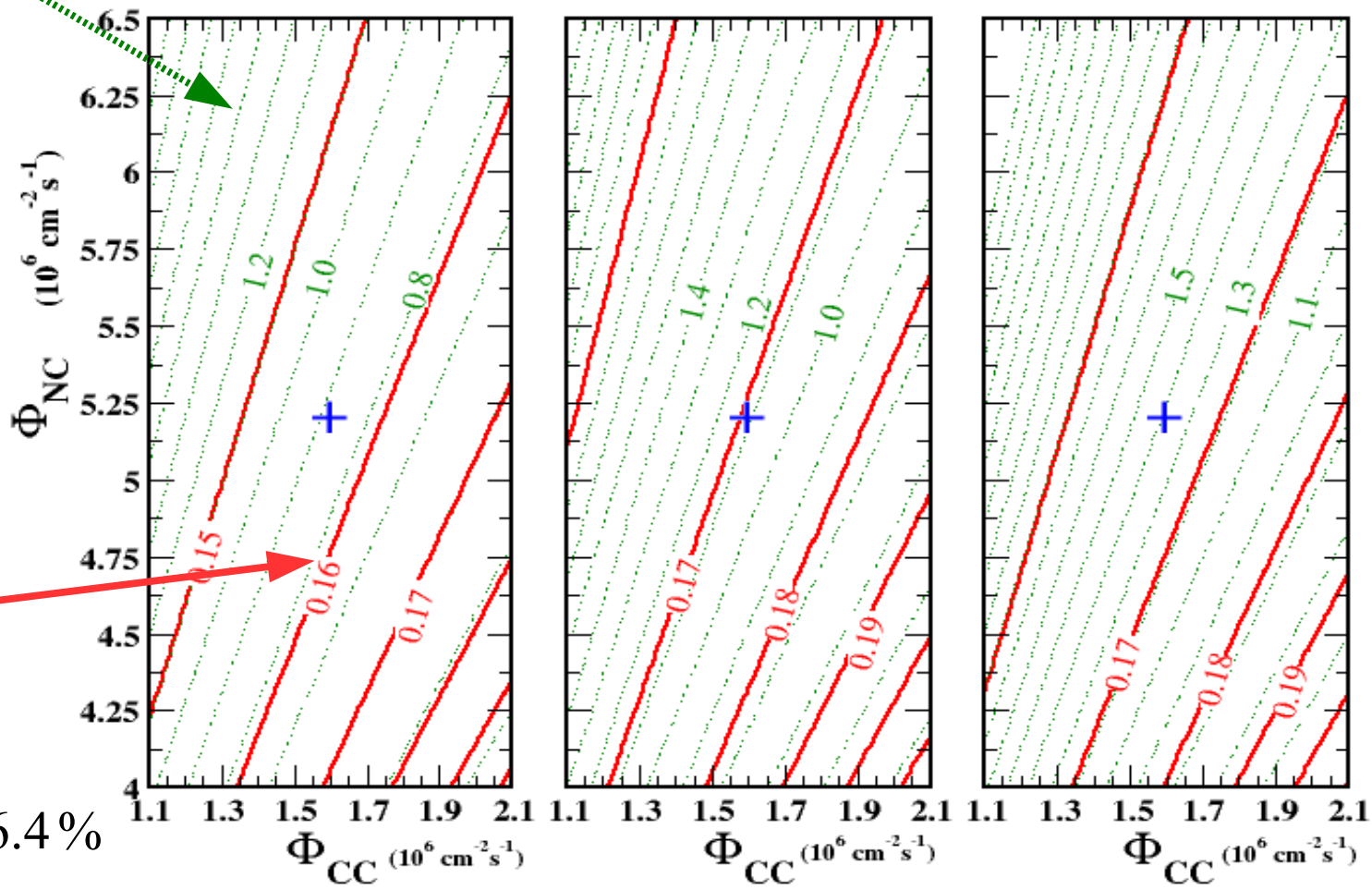
Limits on Sterile Mixing Angle (model independent):

$$\sin^2(\alpha) \sim \frac{NC - CC}{\phi_{^8B} - CC}$$

$$\phi_{^8B} \sim \frac{CC}{P_e}$$

$$\frac{\sigma_{P_e}}{P_e} \sim \%7$$

$$P_e \sim 0.28, 0.33, 0.38$$



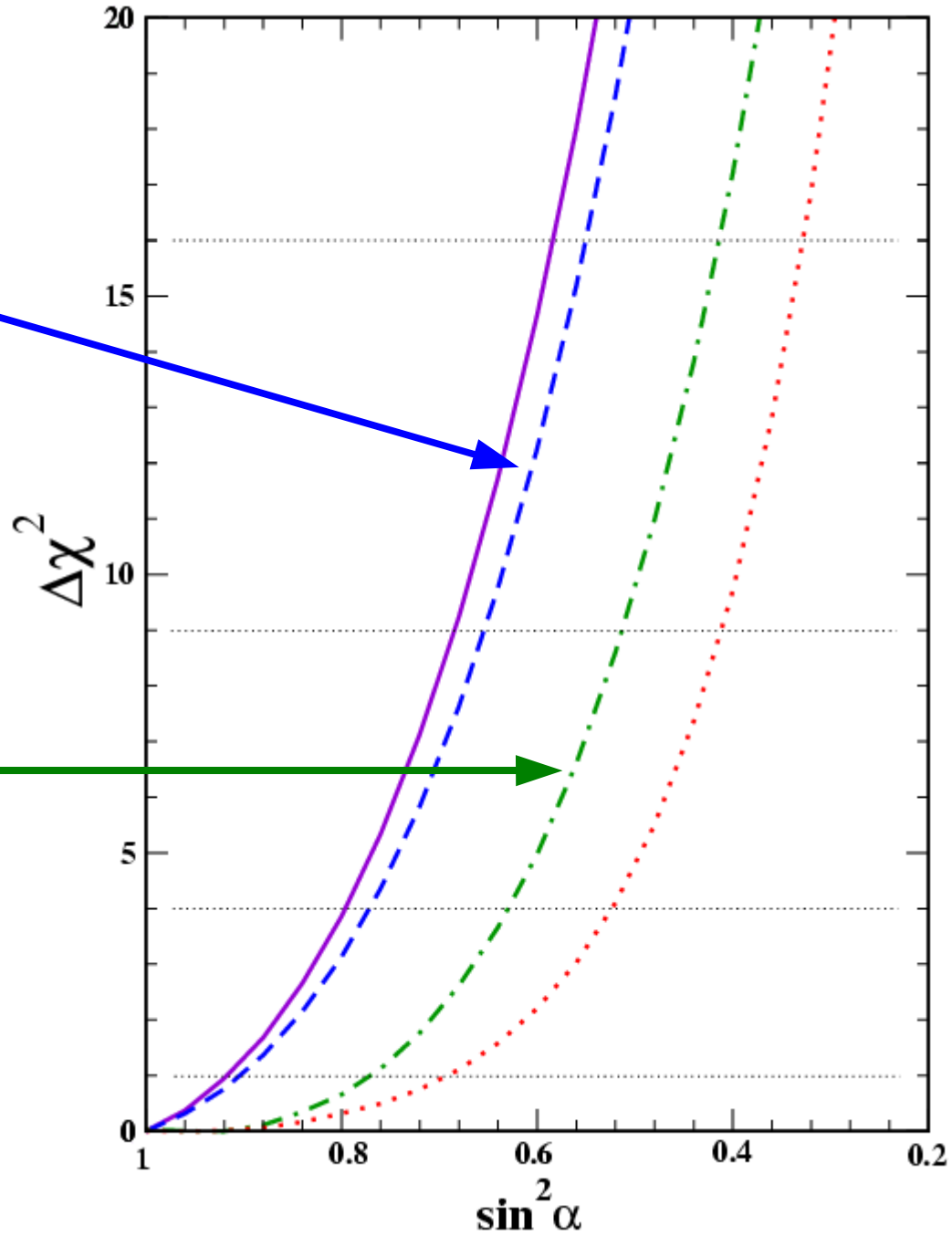
$$\frac{\sigma_{\sin^2(\alpha)}}{\sin^2(\alpha)}$$

$$\frac{\sigma_{CC}}{CC} = 5.5\% \quad \frac{\sigma_{NC}}{NC} = 6.4\%$$

Limits on Sterile Mixing Angle (by global analysis):

"All Solar + KamLAND data with free ^{8}B"

"Only SNO + KamLAND data with free ^{8}B"



Conclusions:

- Combined KamLAND and Solar data provides better limits on θ_{13} as well as other mixing parameters
- Future measurements by SNO and KamLAND could provide significant improvement in the limits of θ_{13} on the low-end of dm^2_{13} region allowed by atmospheric measurements
- Oscillations into pure sterile neutrinos are disfavored but non-negligible sterile component will remain a possibility
- SNO NC and CC measurements combined with determination of P_e by KamLAND provides strong limits on the value and error of sterile mixing angle (almost) in a model independent way
- In the long run, solar model independent measurements are the preferred way for determining the sterile neutrino fraction/sterile mixing angle