Global Fits to Solar and Atmospheric Neutrino Data

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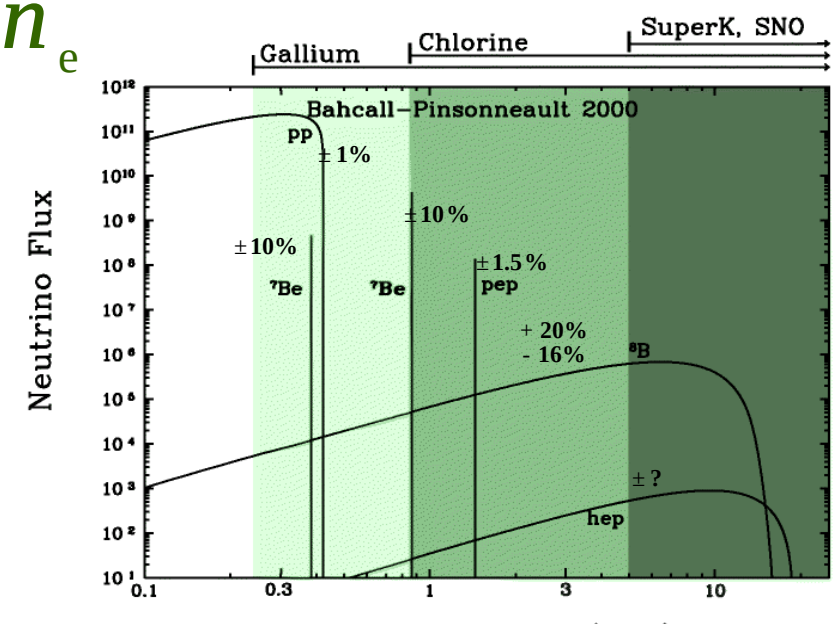
Outline

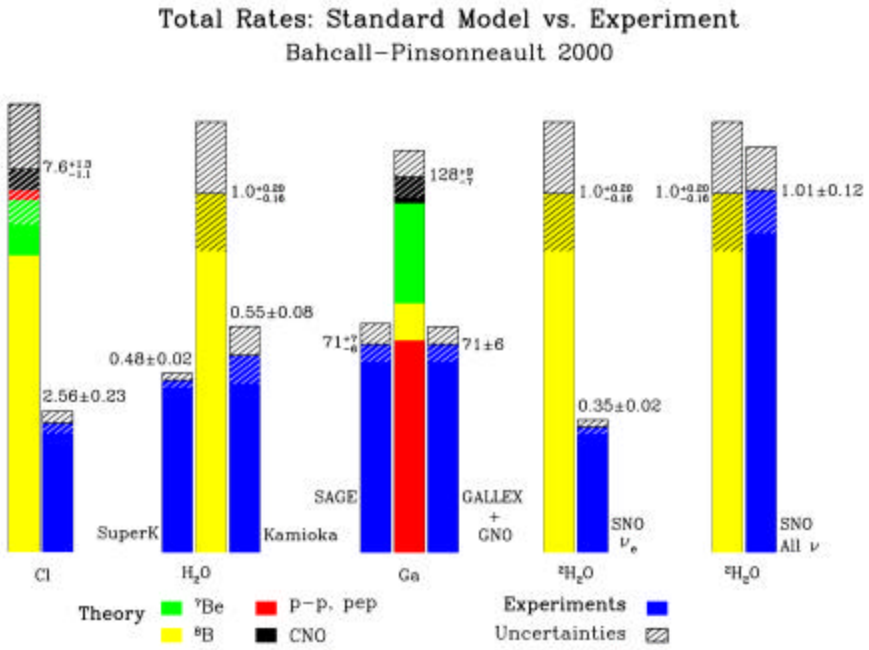
- 2ν : **Leading osc. pattern**
- 3ν : **The role of** q_{13}
- 4ν : **The role of** n_s

Talk based on:

Bahcall, Gonzalez-Garcia, P-G, JHEP207, 2002
Bahcall, Gonzalez-Garcia, P-G, PRC66, 2002
Gonzalez-Garcia, Maltoni, P-G, PRD64, 2001
Gonzalez-Garcia, Maltoni, P-G, Valle, PRD63, 2001

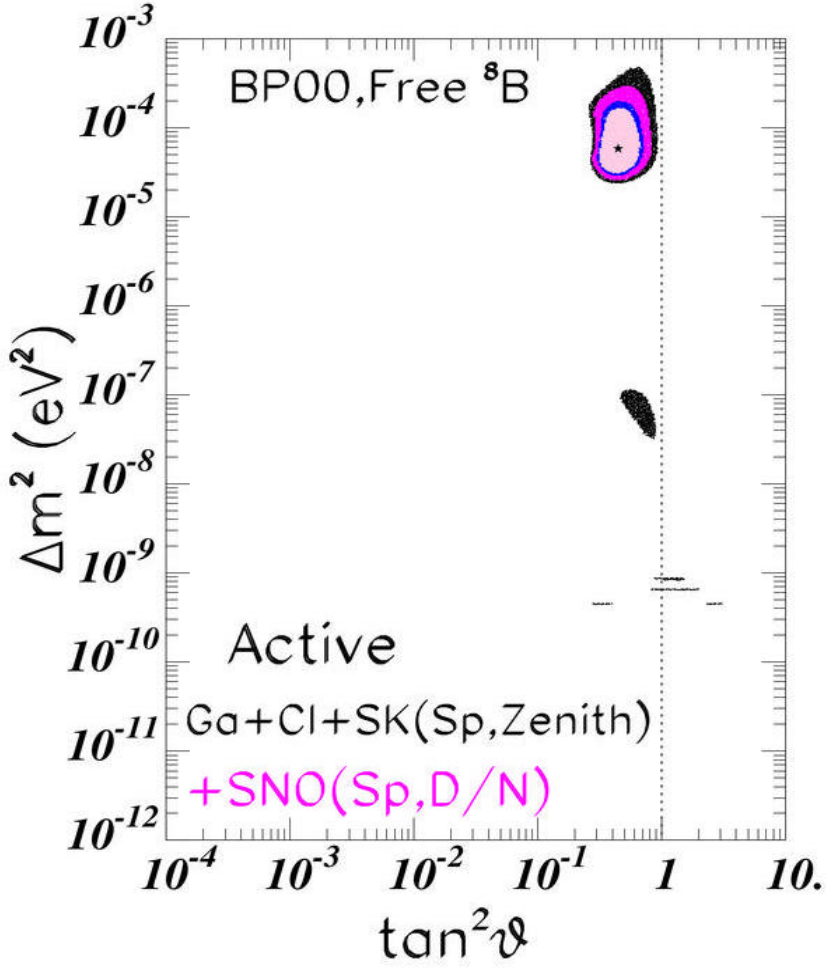
ν_e

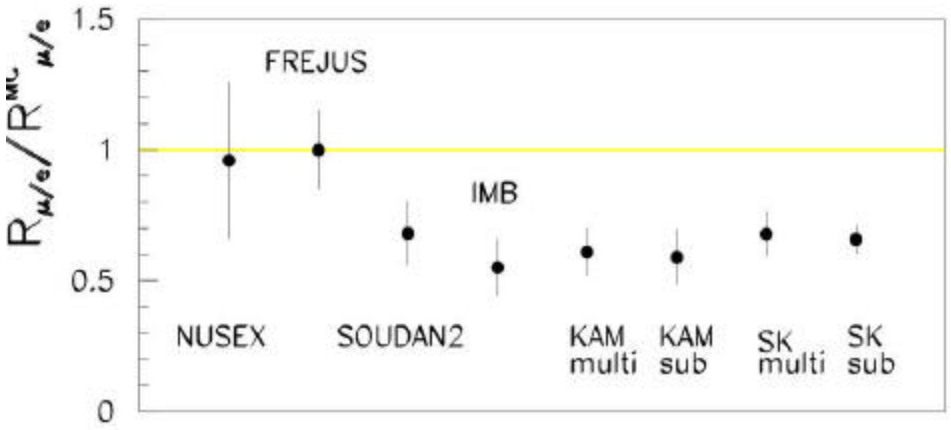




Solar 2ν

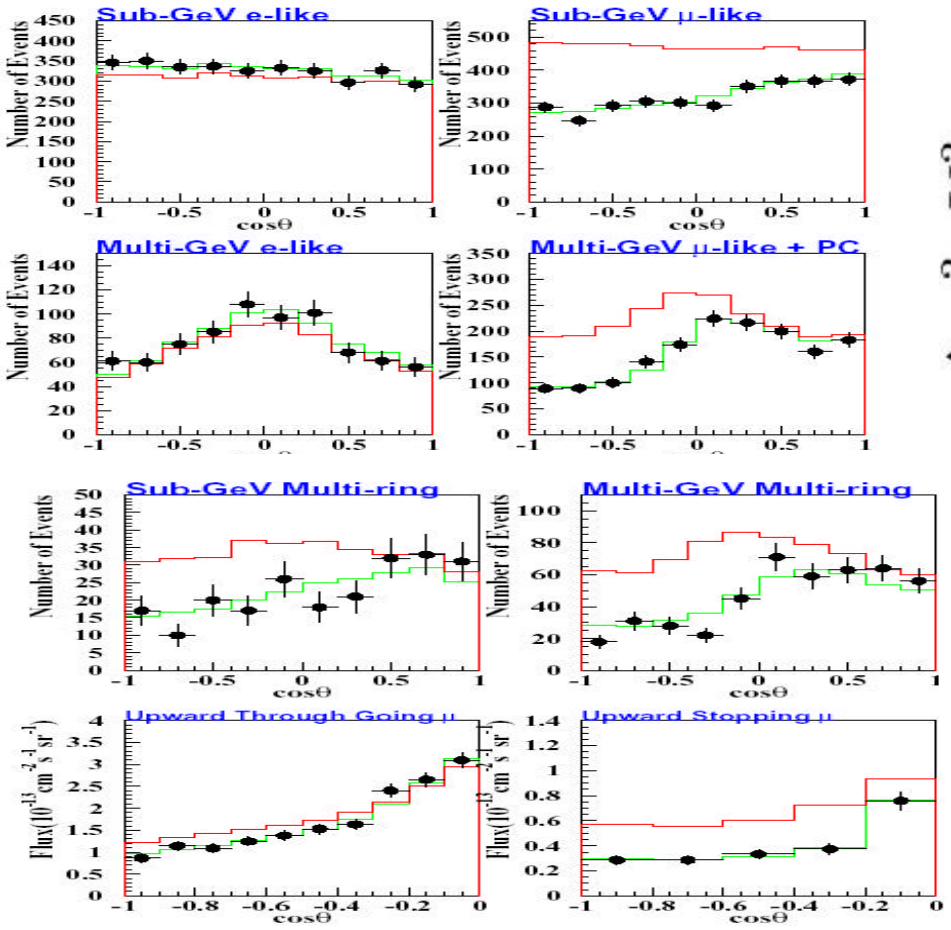
$$P(\nu_e \rightarrow \nu_a) = P(\Delta m^2_{sol}, \theta_{sol})$$

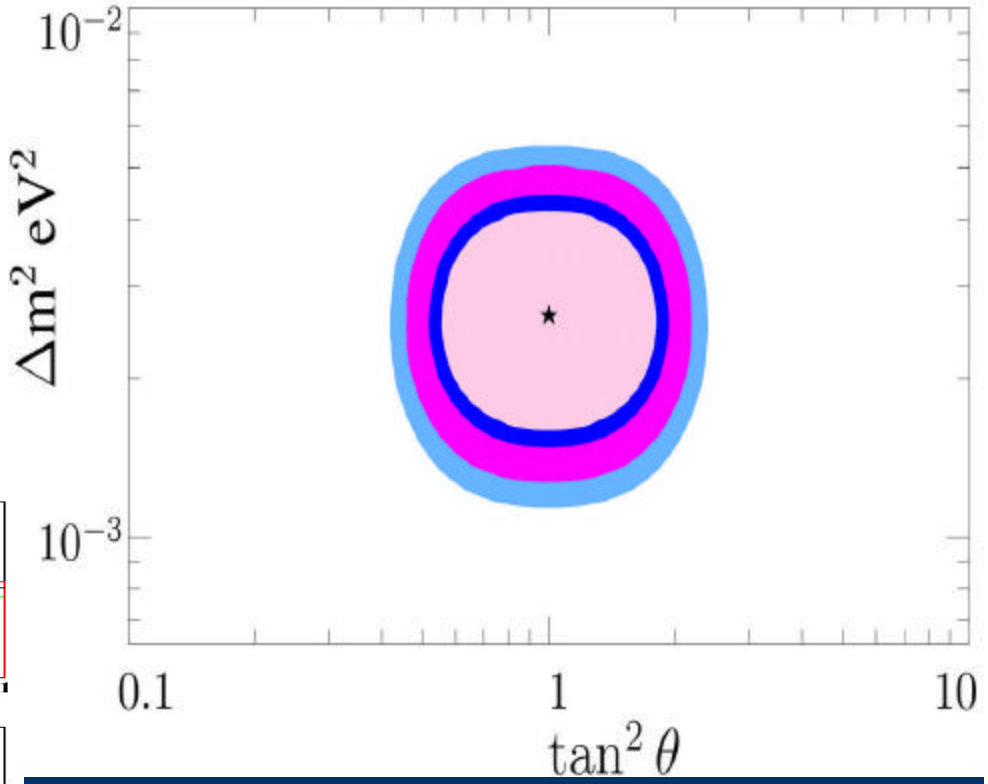




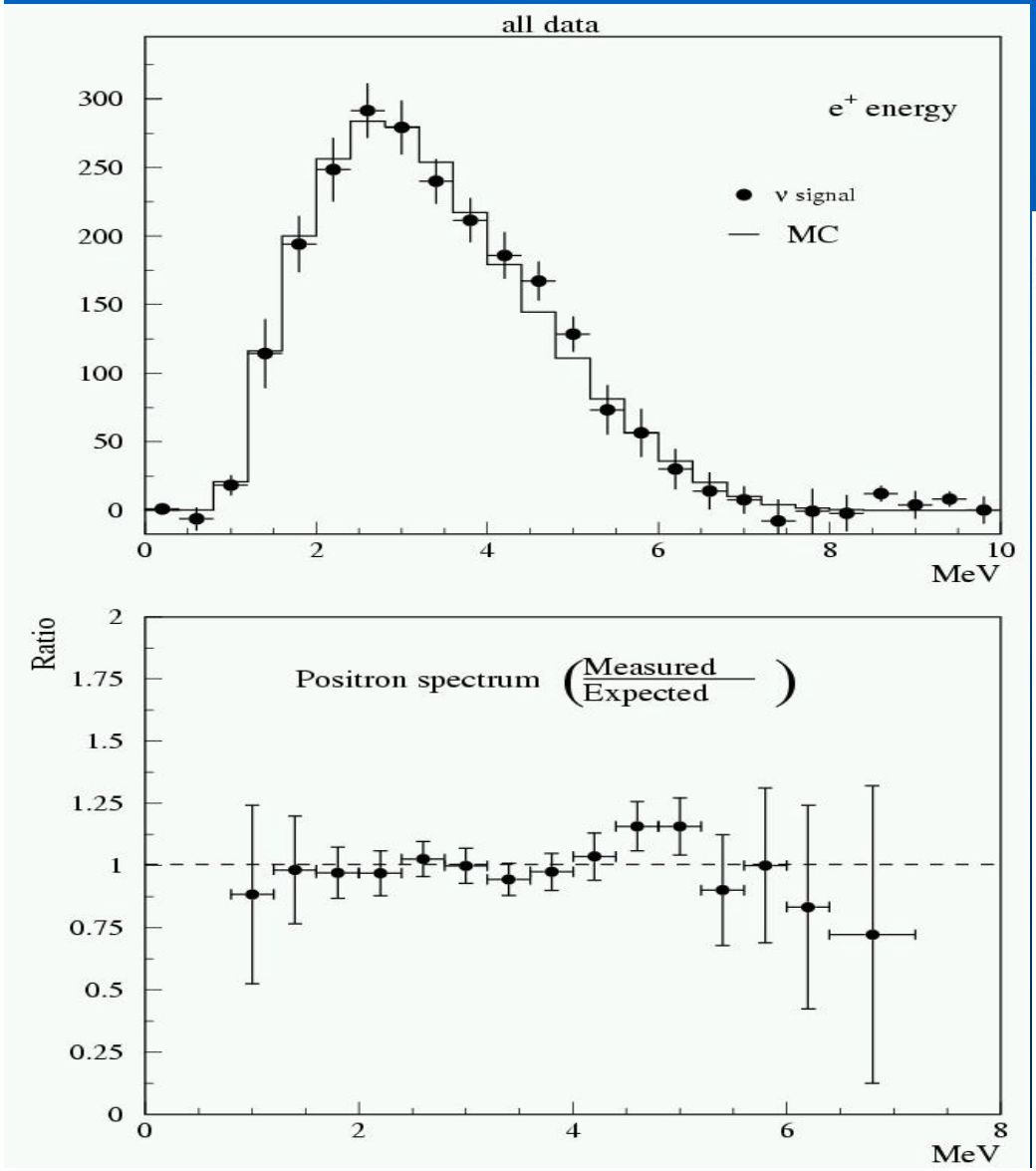
Atmospheric 2*n*

$$P(n_m \rightarrow n_t) = P(\Delta M^2_{ATM}, q_{ATM})$$



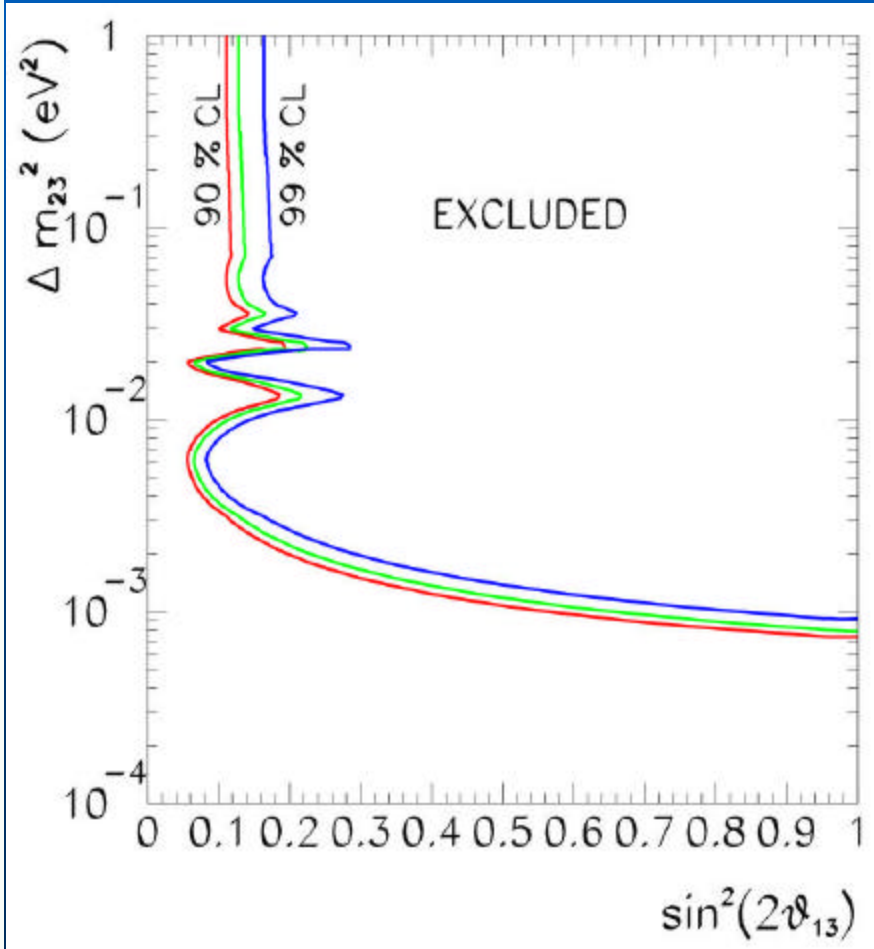


Reactor : Chooz/Palo Verde 2n



$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = P(\Delta M^2_{atm}, q_{chooz})$$

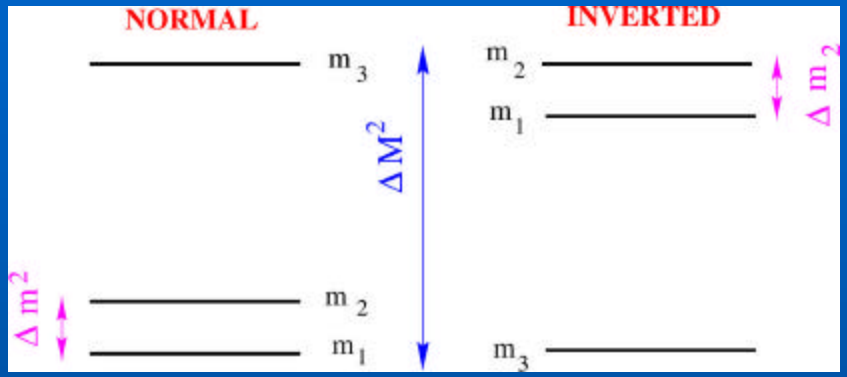
$$R = 1.01 \pm 2.8\% \pm 2.7\%$$



Three Neutrinos

Δm^2

ΔM^2



$$U_{ai} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{t1} & U_{t2} & U_{t3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-id} \end{pmatrix} \cdot \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Three Neutrinos

$\Delta m^2 \quad (\Delta m^2_{sol})$

$\Delta M^2 \quad (\Delta M^2_{atm})$

$$U_{ai} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{t1} & U_{t2} & U_{t3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-id} \end{pmatrix} \cdot \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Searched by :

atmospheric **reactor** **solar**

Three Neutrinos

$\Delta m^2 \quad (\Delta m^2_{sol})$

$\Delta M^2 \quad (\Delta M^2_{atm})$

$$U_{ai} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{t1} & U_{t2} & U_{t3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-id} \end{pmatrix} \cdot \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Searched by :

atmospheric **reactor** **solar**

Three Neutrinos

If $\Delta m^2 << \Delta M^2$

Solar $P_{3n}(n_e \to n_e) = P(\Delta m^2, q_{12}, q_{13})$

$$P_{3n}(n_e \to n_e) = \cos^4 q_{13} P_{2n}(n_e \to n_e) + \sin^4 q_{13}$$

Atmospheric $P_{3n}(n_{a=e,m} \to n_{b=e,m}) = P(\Delta M^2, q_{23}, q_{13})$

$$P_{3n}(n_e \to n_m) = \sin^2 2q_{13,m} \sin^2 q_{23} \sin^2(\Delta M^2 L / 4E)$$

Reactor $P_{3n}(\bar{n}_e \to \bar{n}_e) = P(\Delta M^2, \Delta m^2, q_{12}, q_{13})$

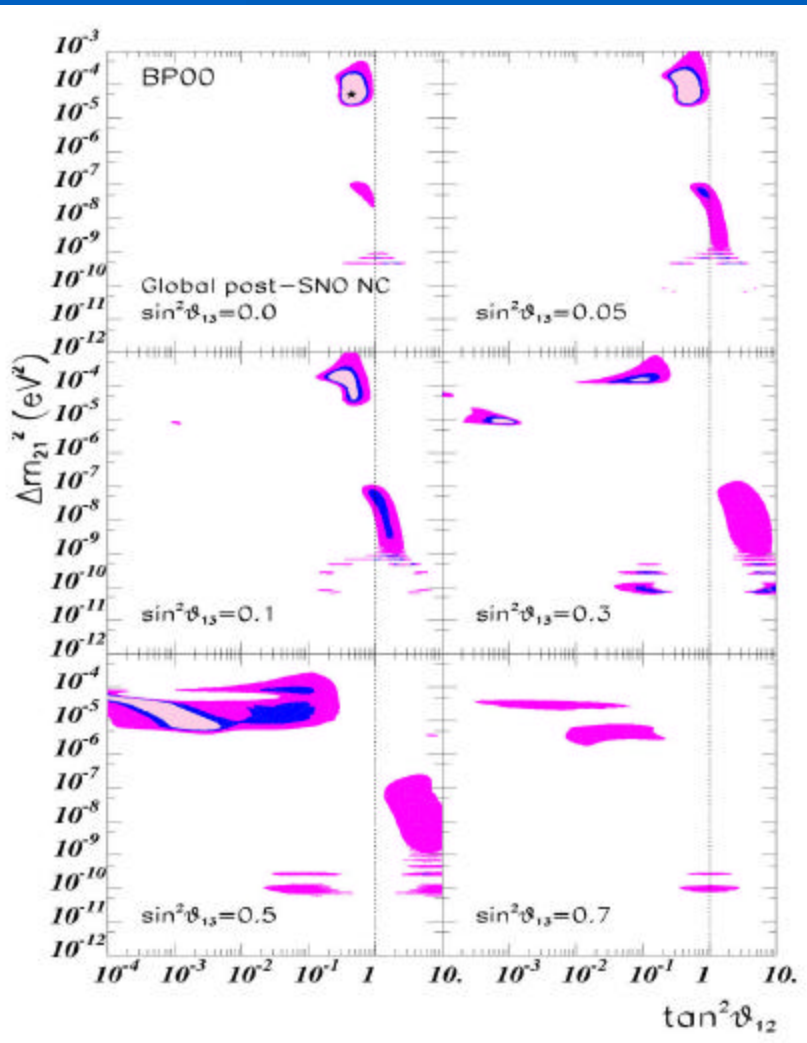
Two scales

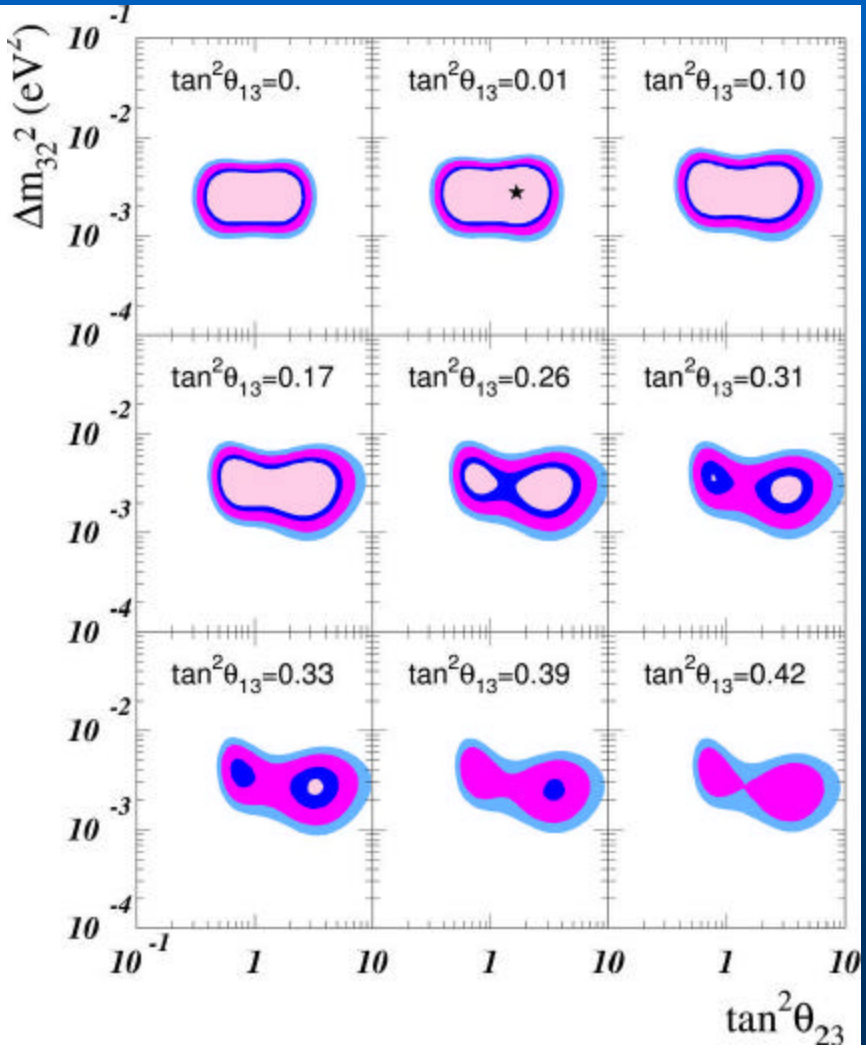
Gonzalez-Garcia, Maltoni, hep-ph/0202218
Fogli, Lisi, Palazzo, PRD65, 2002
Gonzalez-Garcia, Maltoni, P-G, Valle, PRD63, 2001
Bilenky, Nicolo, Petcov, PLB538, 2002
Mocioiu, Shrock, JHEP0111, 2001

Three Neutrinos

Weak bound on q_{13}

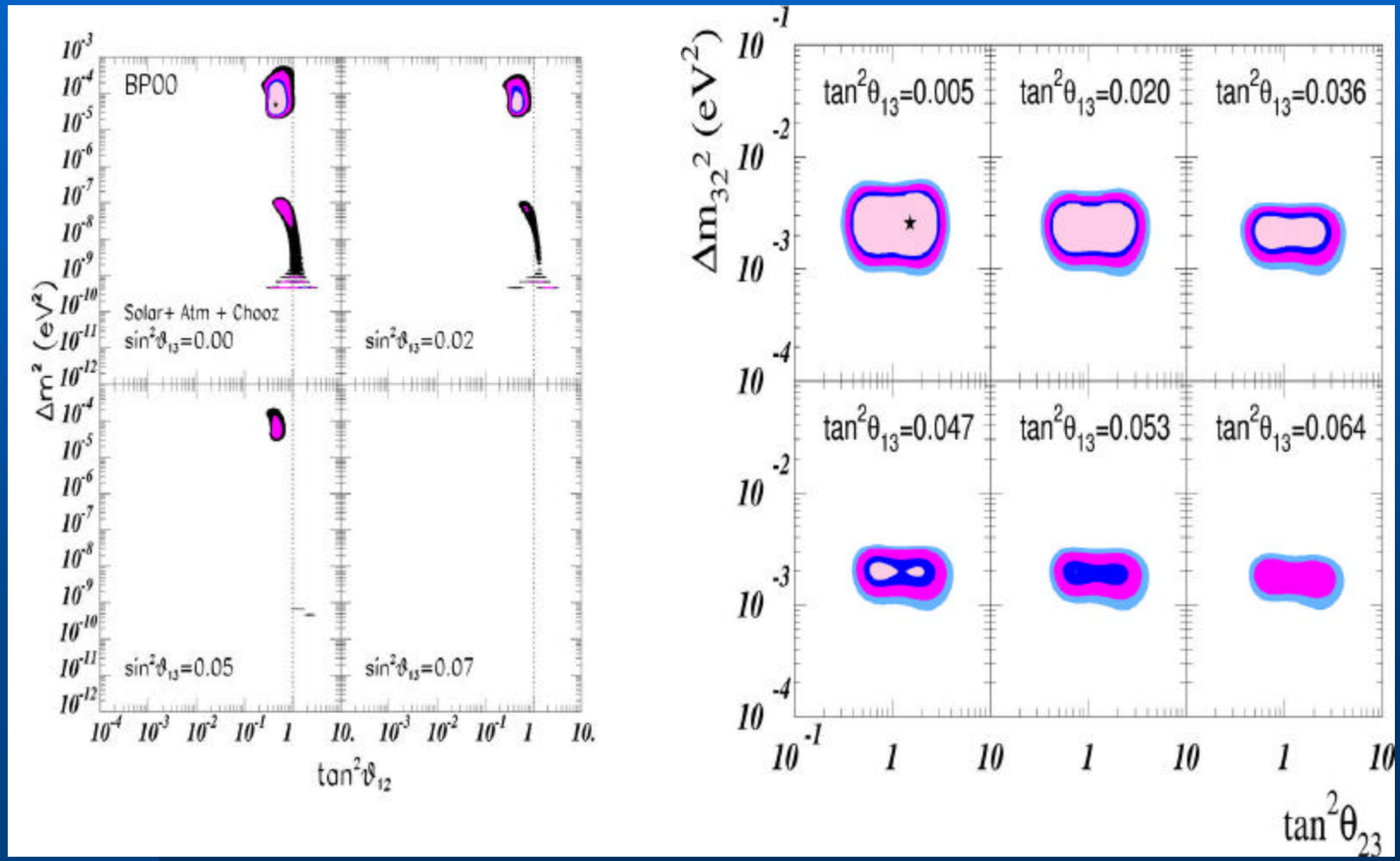
Small $q_{13}^{\ 2}$ value preferred: 0.00, 0.01





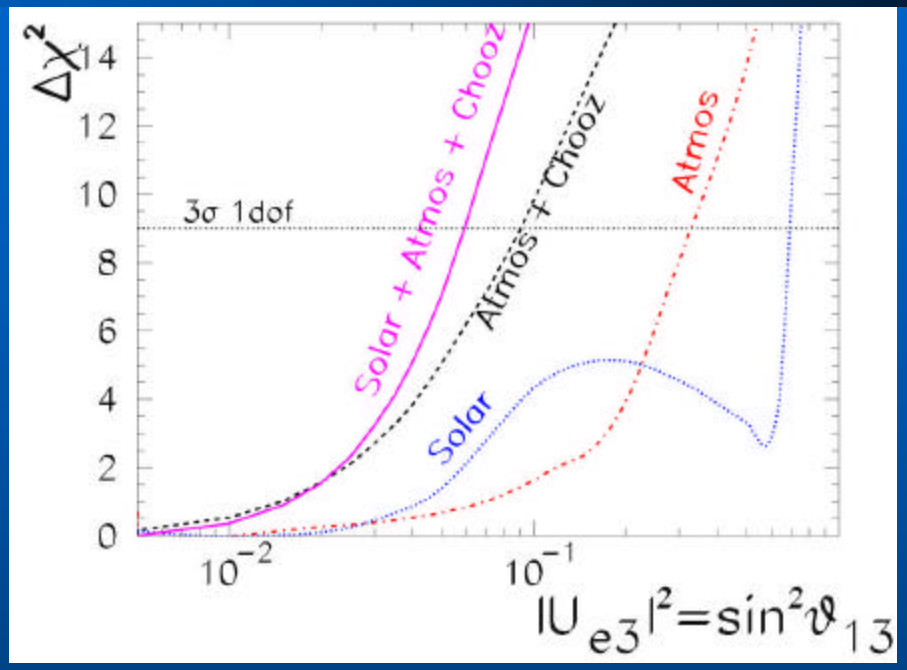
Three Neutrinos

Including reactor (Chooz) data:



Three Neutrinos: q_{13}

Bound on q_{13} :



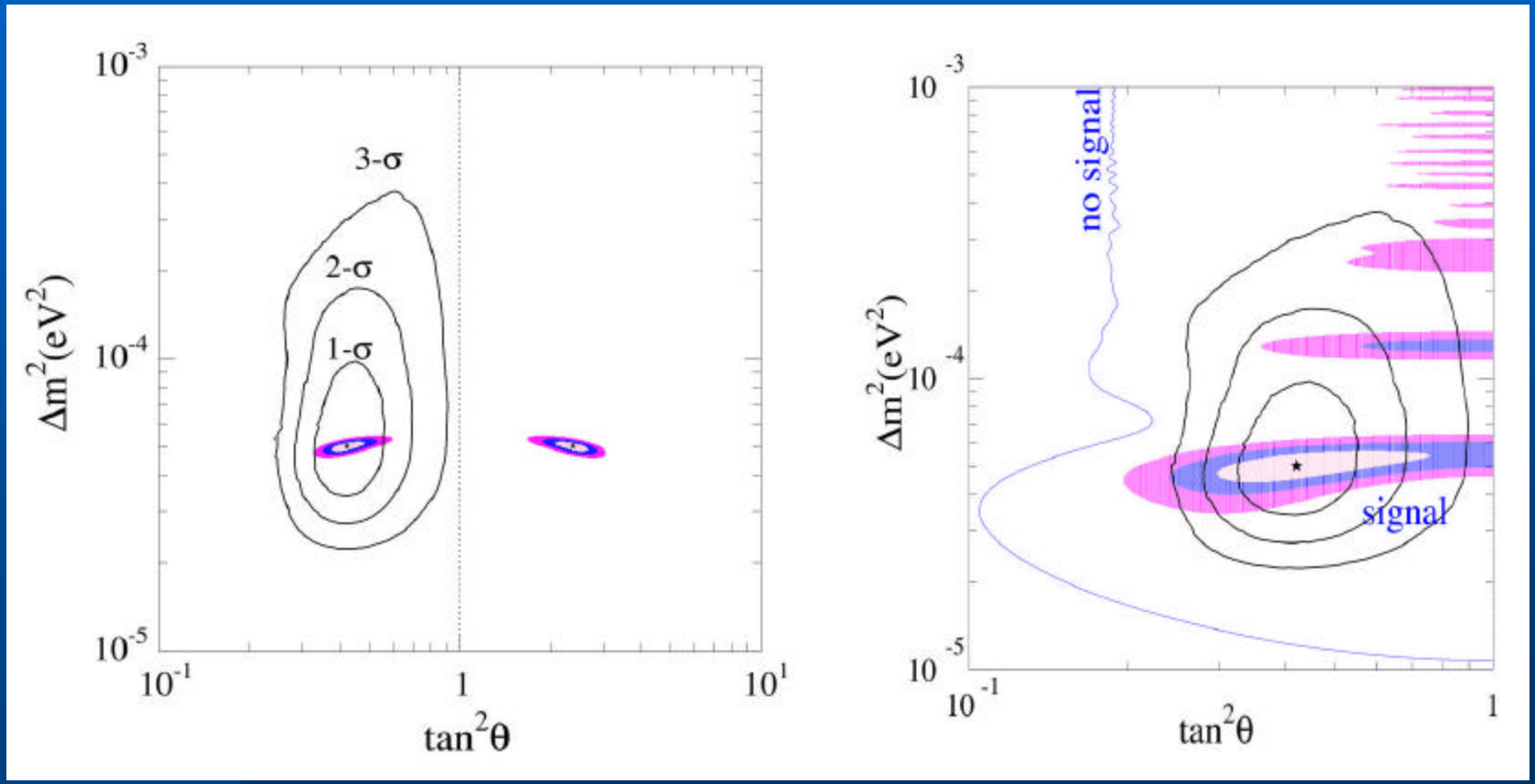
$3s$ ranges:

$$2.4\times10^{-5} < \Delta m^2(eV^2) < 2.4\times10^{-4} eV^2 \qquad 1.4\times10^{-3} < \Delta M^2(eV^2) < 6.0\times10^{-3}$$

$$|U_{ai}| = \begin{pmatrix} 0.73\text{–}0.89 & 0.44\text{–}0.66 & <0.24 \\ 0.23\text{–}0.66 & 0.24\text{–}0.75 & 0.51\text{–}0.87 \\ 0.06\text{–}0.57 & 0.40\text{–}0.82 & 0.48\text{–}0.85 \end{pmatrix}$$

KamLAND reactor data:

- **Matter effects negligible**
- **CC detection**



Bahcall, Gonzalez-Garcia, P-G, PRC66, 2002

3 years **3 months**

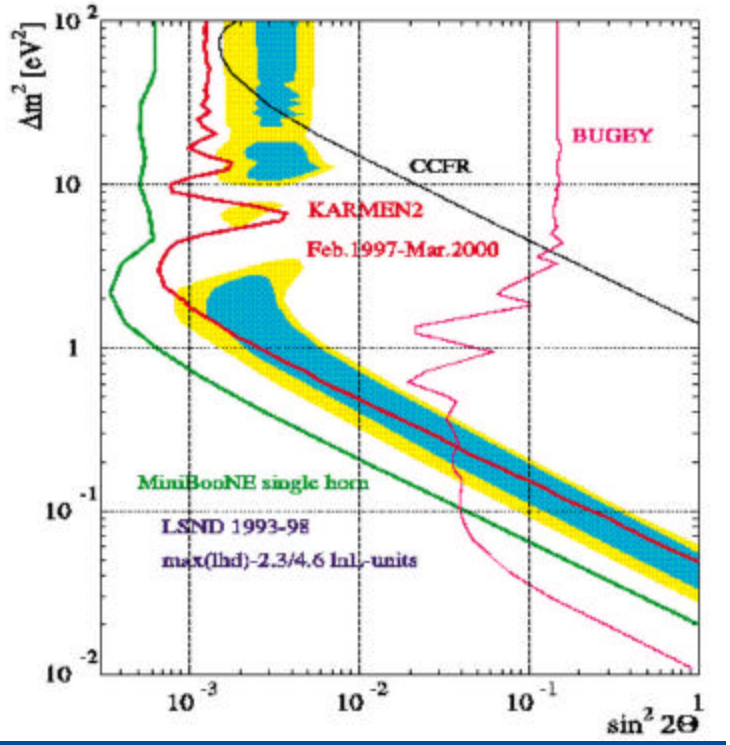
LSND, Miniboone

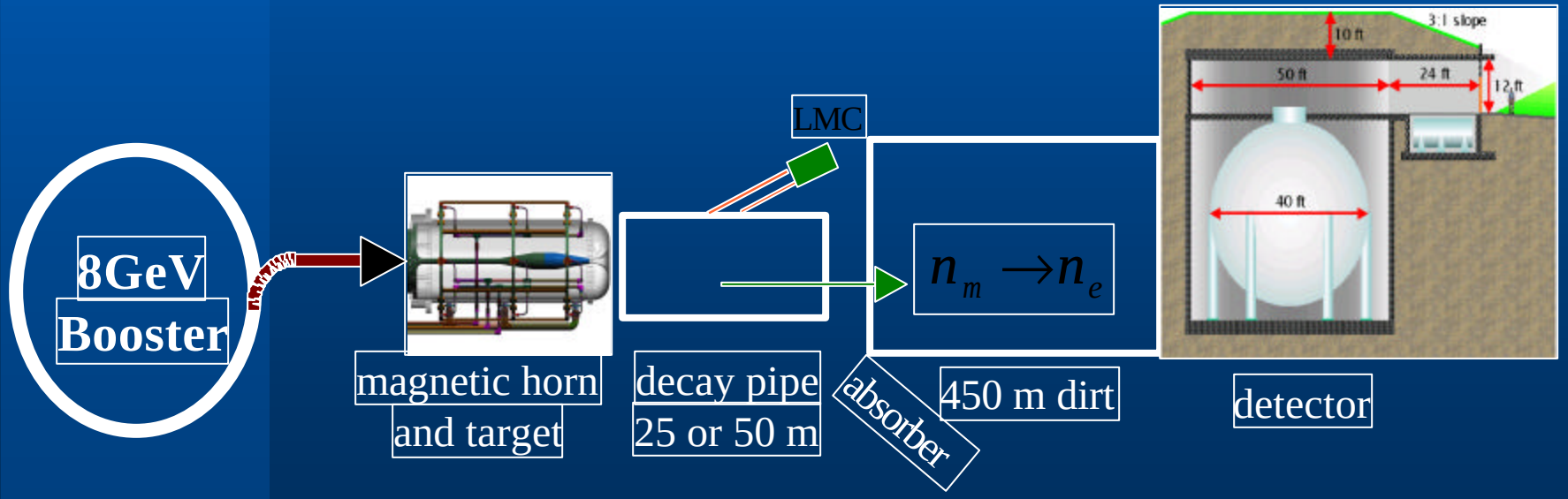
$\bar{n}_m \rightarrow \bar{n}_e$

Proton beam producing p^+

$N(\bar{n}_e) = 87.9 \pm 22.4 \pm 6.0$

$d = 30m \quad 20MeV < E < 60MeV$





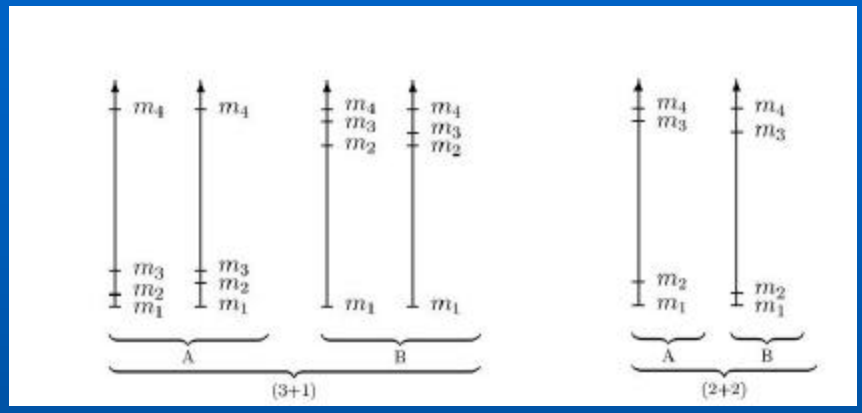
$0.5GeV < E < 1GeV \quad d = 500m$

Four Neutrinos: n_s

3 scales (Solar, atmosp., LSND)

LEP data $\Rightarrow 3n_a \quad m \le 50\,GeV$

$\rightarrow n_s$ **4th state?**



$$U = U_{24}U_{23}U_{14}U_{13}U_{34}U_{12}$$

Solar $n_e \rightarrow n_a = c_{23}c_{24}n_s + \sqrt{1 - c_{23}^2 c_{24}^2}\, n_a$

Atmospheric (2+2) $n_b = s_{23}c_{24}n_s + c_{23}n_m - s_{23}s_{24}n_s \rightarrow n_g = s_{24}n_s + c_{24}n_t$

Where : $\sin^2 h \equiv c_{23}^2 c_{24}^2 = U_{s1}^2 + U_{s2}^2$

$s_{23}^2 = U_{m1}^2 + U_{m2}^2$

If $q_{23} = 0$ { **Sol** $n_e \rightarrow n_a = \sin h\ n_s + \cos h\ n_a$

Atm $n_m \rightarrow n_b = \cos h\ n_s + \sin h\ n_a$

Four Neutrinos: n_s

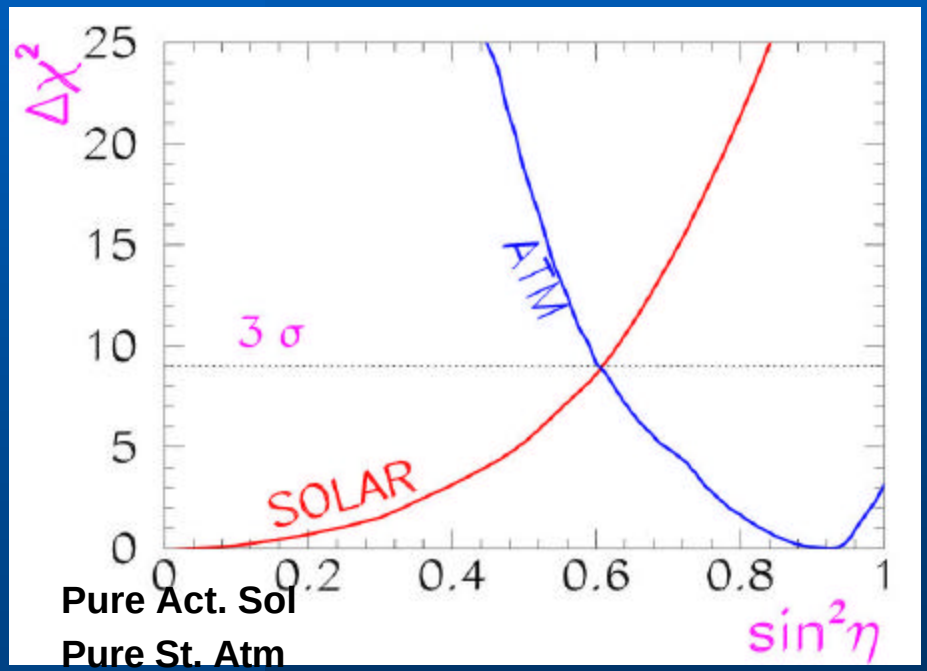
2+2 : Solar and Atmospheric compatibility?

$$s_{23} = 0 \Rightarrow P_{n_s}^{sun} + P_{n_s}^{atm} = 1$$

Peres, Smirnov, NPB599, 2001

$$s_{23} \neq 0 \Rightarrow P_{n_s}^{sun} + P_{n_s}^{atm} > 0.9$$

Gonzalez-Garcia, Maltoni, P-G, PRD64, 2001



Pure Act. Sol

Pure St. Atm

Bahcall, Gonzalez-Garcia, P-G, PRC66, 2002

Maltoni, Schwetz, Tortola, Valle, hep-ph/0207227

$$s_{13} \neq 0, s_{14} \neq 0 \Rightarrow P_{n_s}^{sun} + P_{n_s}^{atm} \geq 0.3 - 0.4$$

Pas, Song, Weiler, hep-ph/0209373

Volunteers wanted !!!

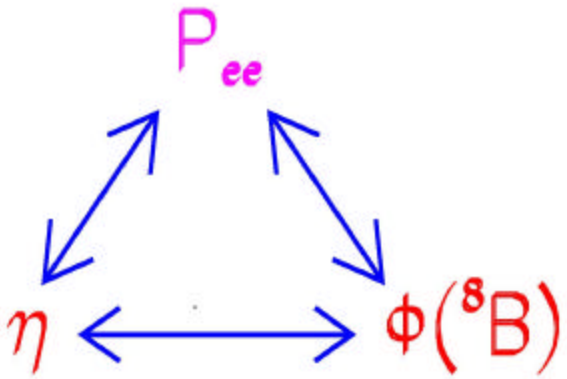
Four Neutrinos: n_s

Sterile limit weaker if free ^{8}B:

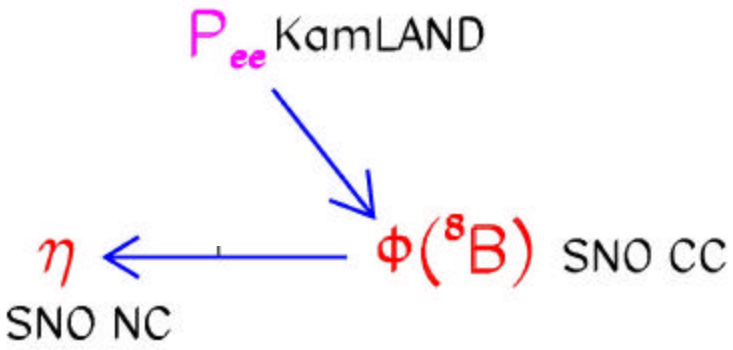
$$\Phi(^8B) = \Phi(\nu_e) + \Phi(\nu_{\mu\tau}) + \Phi(\nu_s) = \Phi(\nu_e) + (1 + \tan^2\eta)\Phi(\nu_{\mu\tau})$$

In other way (Barger et al., PRL88, 2002):

$$\Phi(CC) = \Phi(^8B) \cdot < P_{ee} >$$
$$\Phi(NC) = \Phi(^8B) \cdot (< P_{ee} > + \cos^2\eta(1 - < P_{ee} >))$$



Sterile content: Improvement with Solar + KamLAND :



KamLAND $\Rightarrow < P_{ee} >$ at $\sim 7\%$

+ SNO CC $\Rightarrow \Phi(^8B)$ at $\sim 10\%$

+ SNO NC $\Rightarrow \Phi(\nu_s)$ at $\sim 12\%$ ($\sin^2 h < 0.16$)

Bahcall, Gonzalez-Garcia, P-G, PRC66, 2002