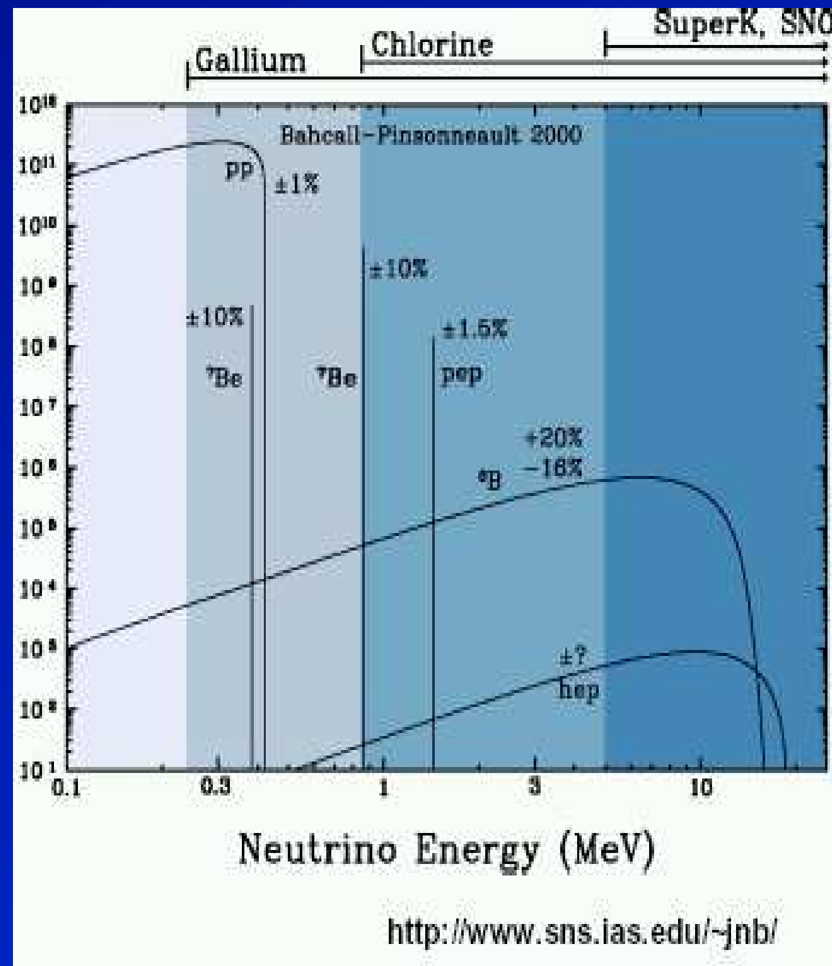
Neutrino physics:

present experimental status

1 – Solar neutrinos and KamLAND

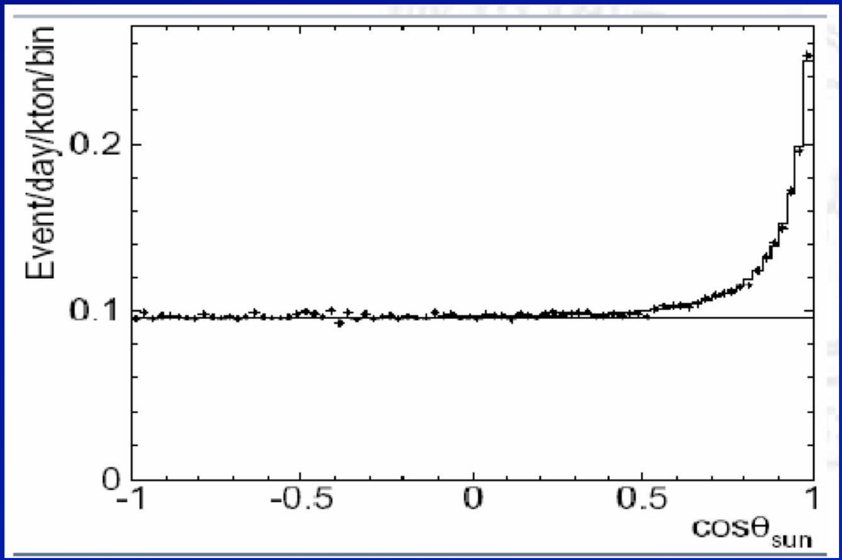
In the Sun a large flux of ν_e's is produced in nuclear reactions.

Reaction	Termination (%)	Neutrino Energy (MeV)	Nomenclature
$p+p \to {}^2\mathrm{H}+e^+ + \nu_e$	99.96	< 0.423	*pp*-neutrinos
$p+e^- + p \to {}^2\mathrm{H}+\nu_e$	0.044	1.445	*pep*-neutrinos
${}^2\mathrm{H}+p \to {}^3\mathrm{He}+\gamma$	100	–	–
${}^3\mathrm{He}+{}^3\mathrm{He} \to {}^4\mathrm{He}+p+p$	85	–	–
${}^3\mathrm{He}+{}^4\mathrm{He} \to {}^7\mathrm{Be}+\gamma$	15	–	–
${}^7\mathrm{Be}+e^- \to {}^7\mathrm{Li}+\nu_e$	15	0.863(90%) 0.386(10%)	^{7}Be-neutrinos
${}^7\mathrm{Li}+p \to {}^4\mathrm{He}+{}^4\mathrm{He}$		–	–
${}^7\mathrm{Be}+p \to {}^8\mathrm{B}+\gamma$	0.02	–	–
${}^8\mathrm{B} \to {}^8\mathrm{Be}^* + e^+ + \nu_e$		< 15	^{8}B-neutrinos
${}^8\mathrm{Be} \to {}^4\mathrm{He}+{}^4\mathrm{He}$		–	–
${}^3\mathrm{He}+p \to {}^4\mathrm{He}+e^+ + \nu_e$	0.00003	< 18.8	*hep*-neutrinos



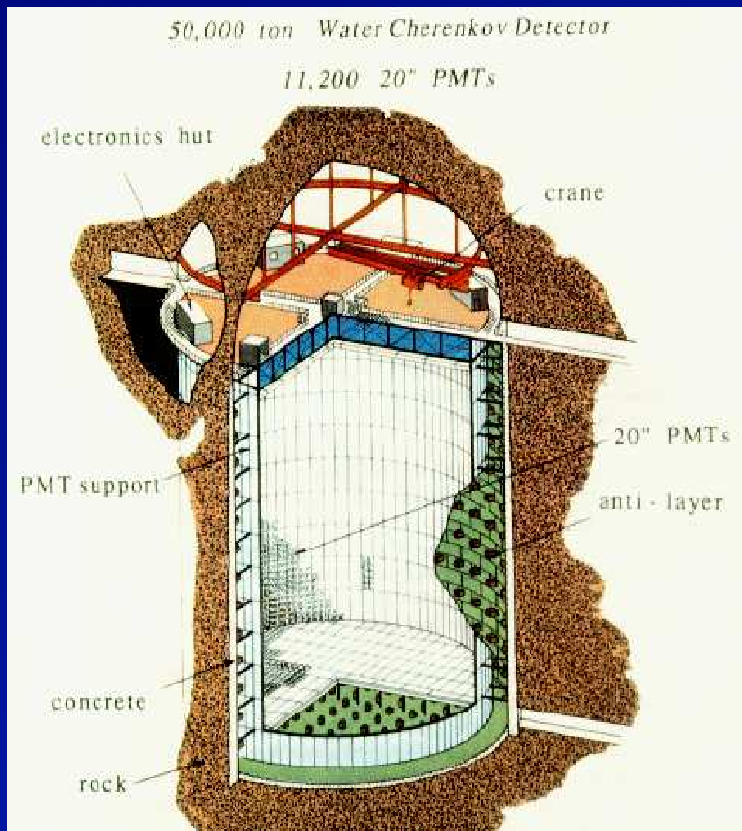
In the Sun a large flux of ν_e's is produced in nuclear reactions.

Homestake, Kamiokande, SAGE, GALLEX/GNO, SuperK, SNO provide evidence of a depletion of the expected ν_e-flux.

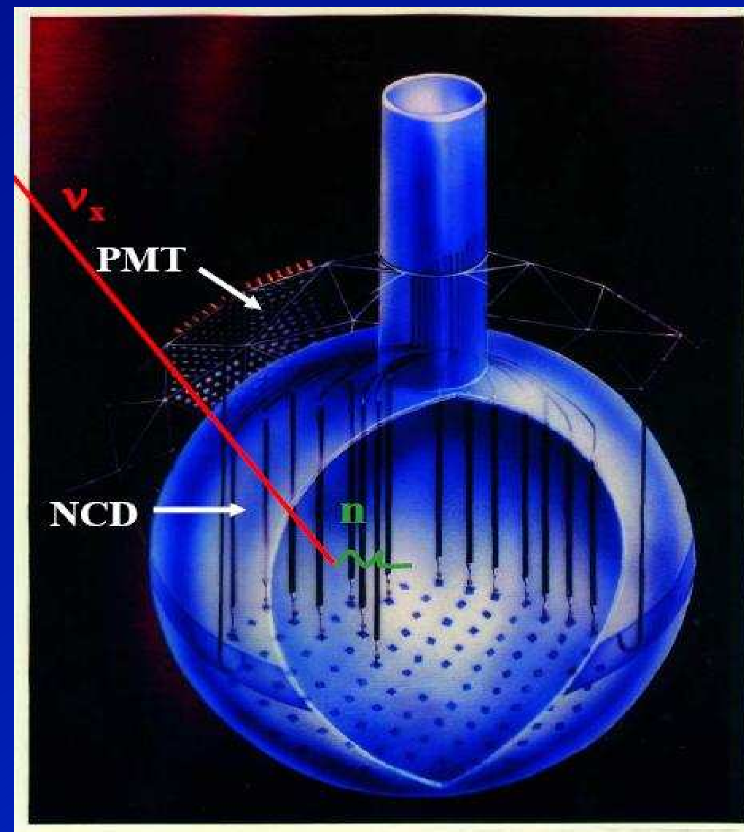


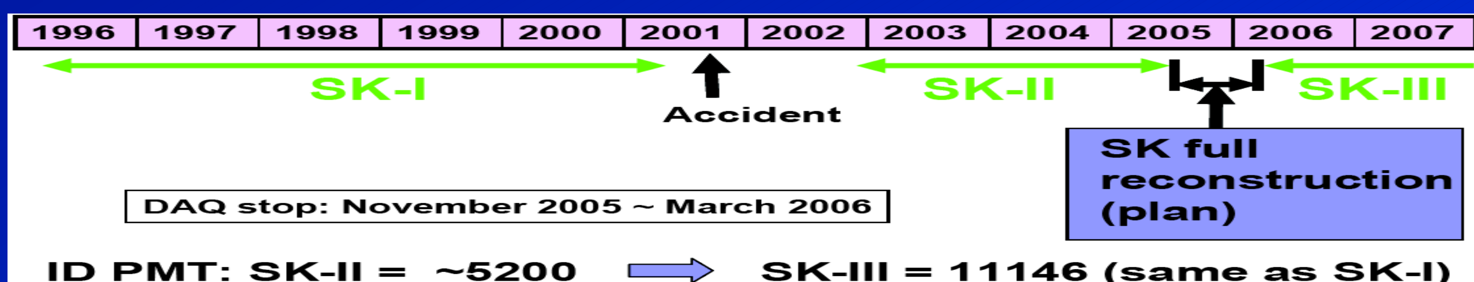
For pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos, Raymond Davis Jr. with the Homestake Chlorine exp, (together with M. Koshiba) co-won the 2002 Nobel Prize in Physics.

Super-Kamiokande



SNO





Super-Kamiokande provided strong confirmation of the $\bar{\nu}_e$ depletion with respect to the standard solar model.

SNO is a heavy water detector:

- $\nu_e + H \longrightarrow p + p + e^-$, CC current
- $\nu_{e(\mu,\tau)} + e^- \longrightarrow \nu_{e(\mu,\tau)} + e^-$, elastic scattering
- $\nu + H \longrightarrow \nu + p + n$, NC current

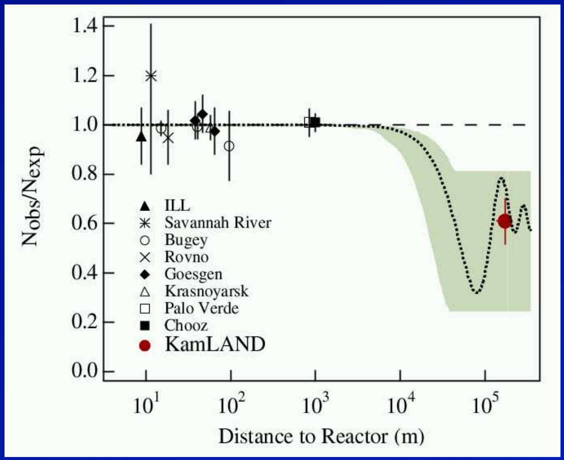
In 2002, it provided the first indirect measurement of the total neutrino flux and confirmed the oscillation of $\nu_e \longrightarrow \nu_{\mu,\tau}$.

The KamLAND experiment,

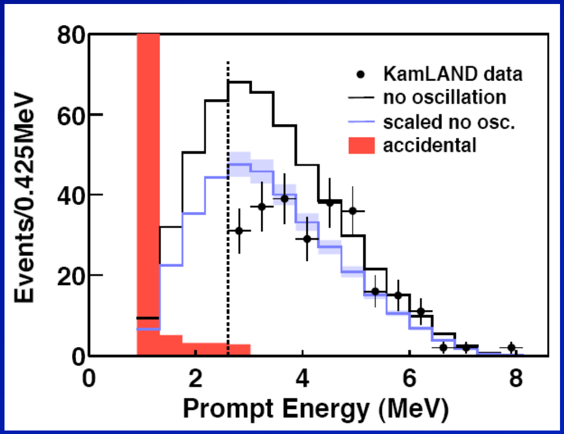
using reactor $\bar{\nu}_e$,

confirmed the disappearance

of anti-neutrinos.



[KamLAND Coll, PRL 90 (2003) 021802]



The latest results

show a spectrum dependence,

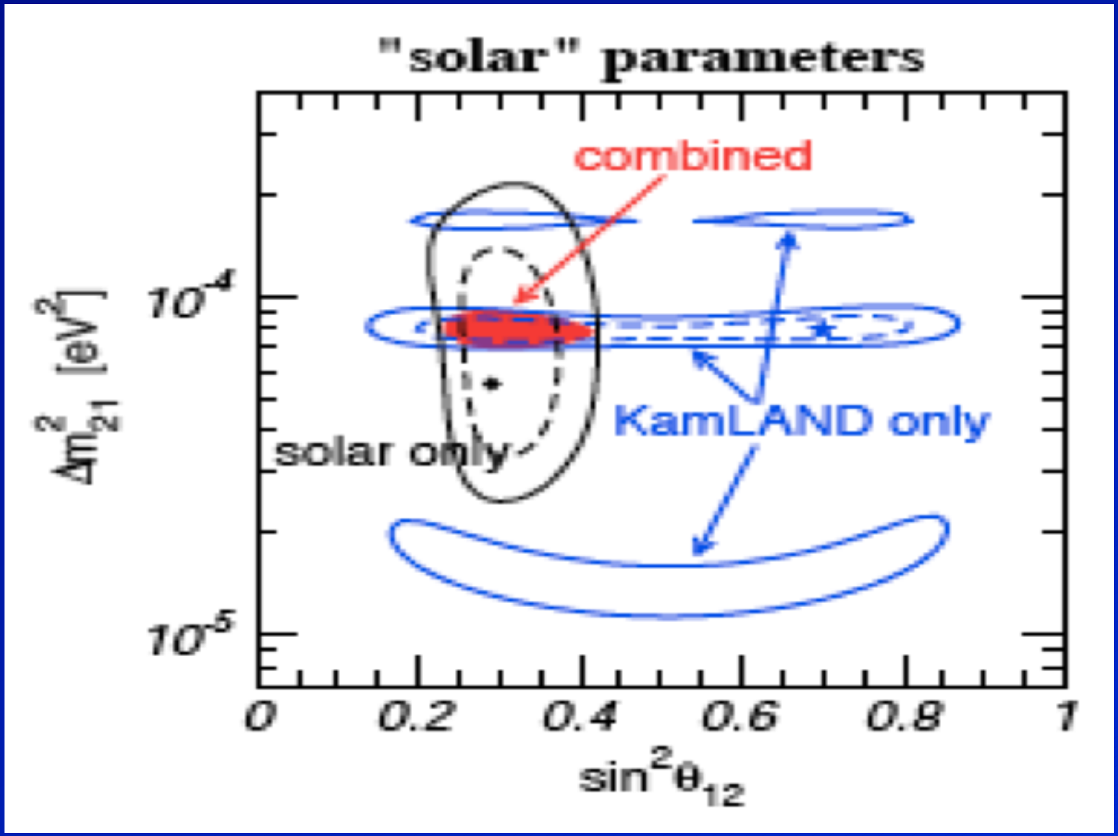
a hint of neutrino oscillations.

[KamLAND Coll., PRL 94 (2005) 081801]

The solar ν_e and reactor $\bar{\nu}_e$ flux depletion can be explained in terms of

$\nu_e \leftrightarrow \nu_{\mu,\tau}$ oscillations.

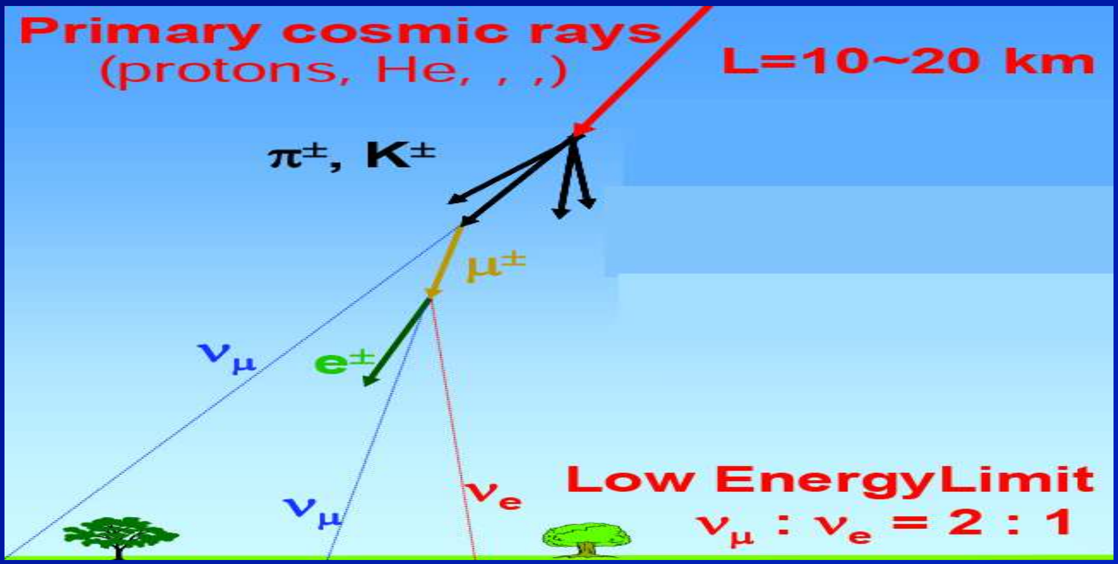
Solar + KamLAND data



[T. Schwetz, hep-ph/0606060]

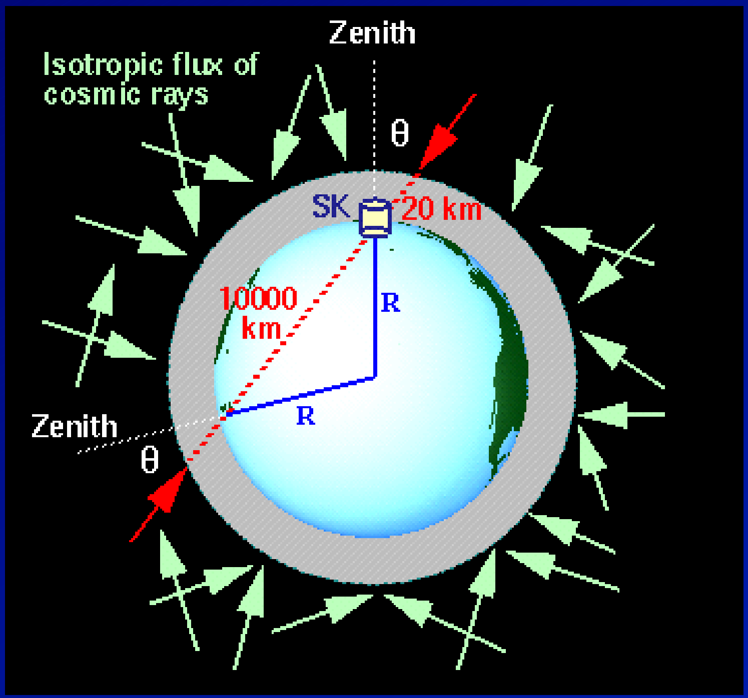
• Atmospheric neutrinos

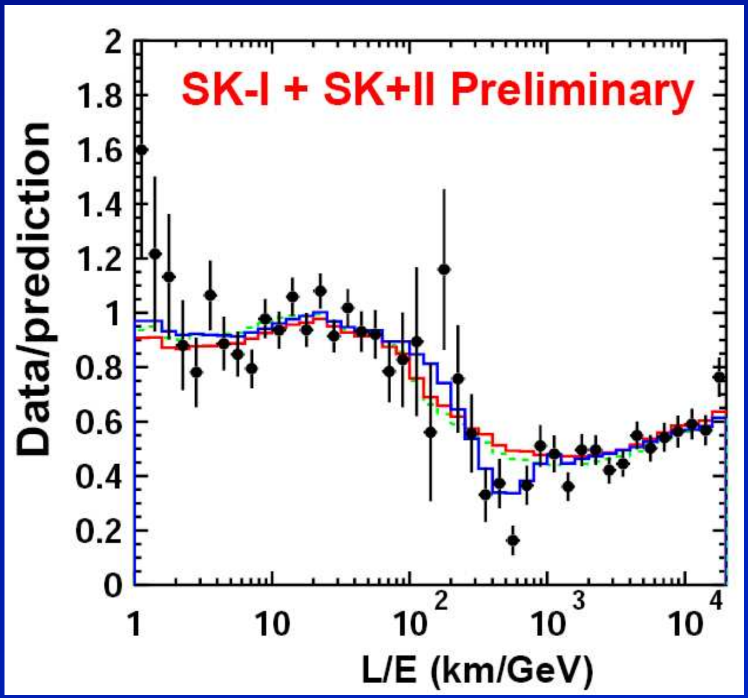
Neutrinos are produced in the atmosphere by cosmic rays interactions (π and μ decays).



[Thanks to Y. Suzuki @ Taup2005]

The SuperKamiokande (IMB, Kamiokande, MACRO, Soudan2) experiment observes an up-down asymmetry and zenith-angle dependence in the rate of μ-like events.



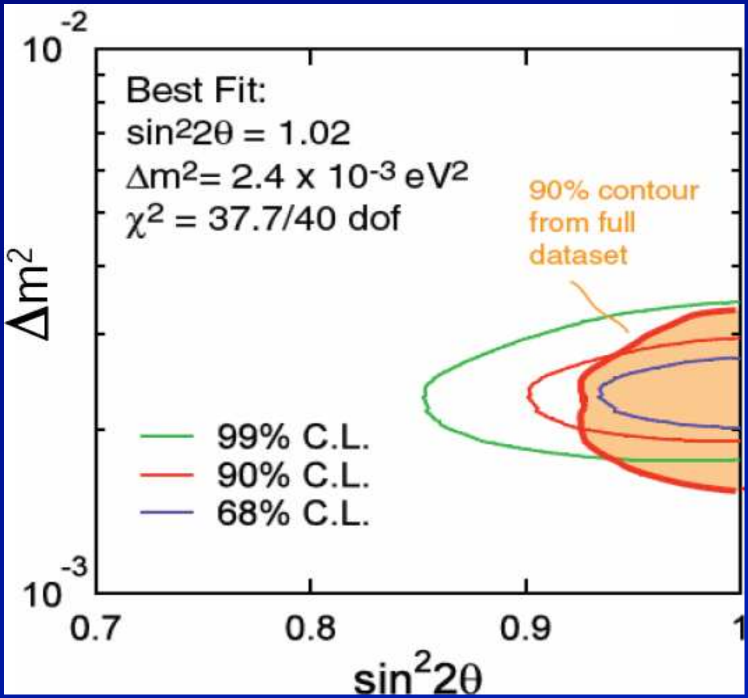


[Preliminary, Y. Suzuki @ Taup2005]

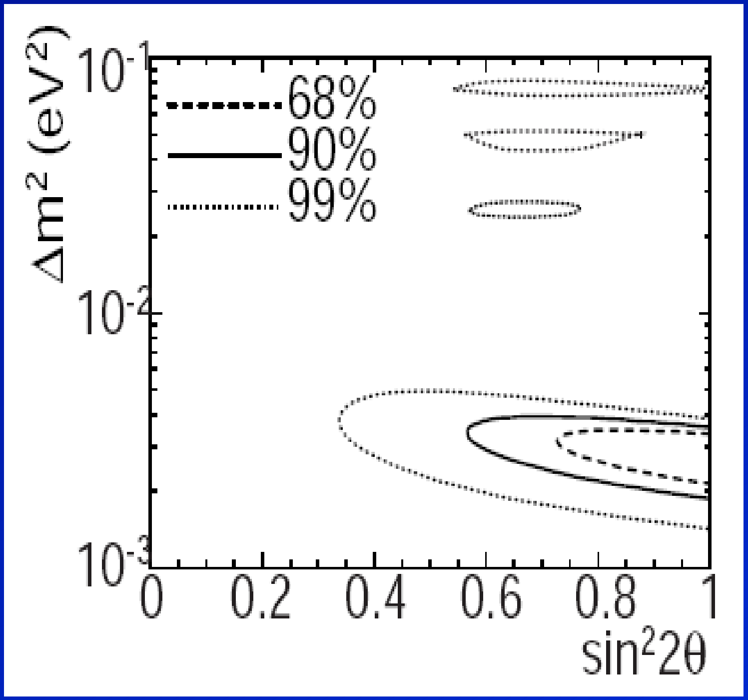
The first evidence of neutrino oscillations has been reported.

$\nu_\mu \leftrightarrow \nu_\tau$ oscillations

The **K2K** long-baseline neutrino experiment confirmed ν_μ disappearance.

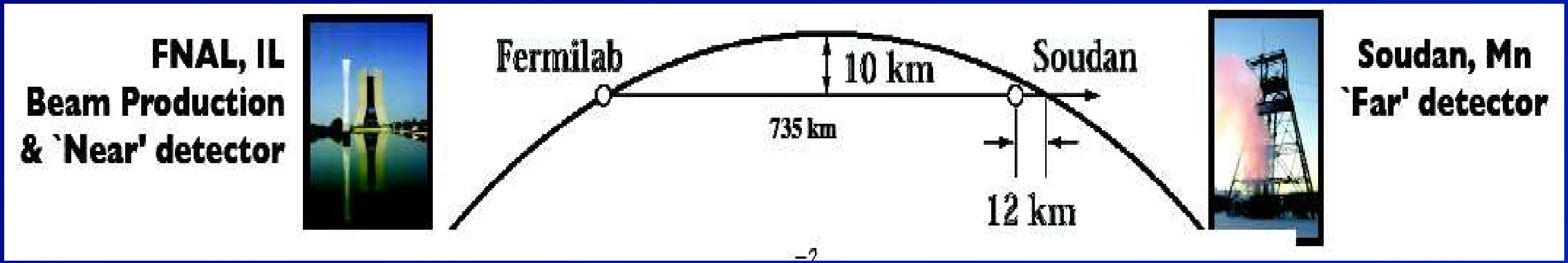


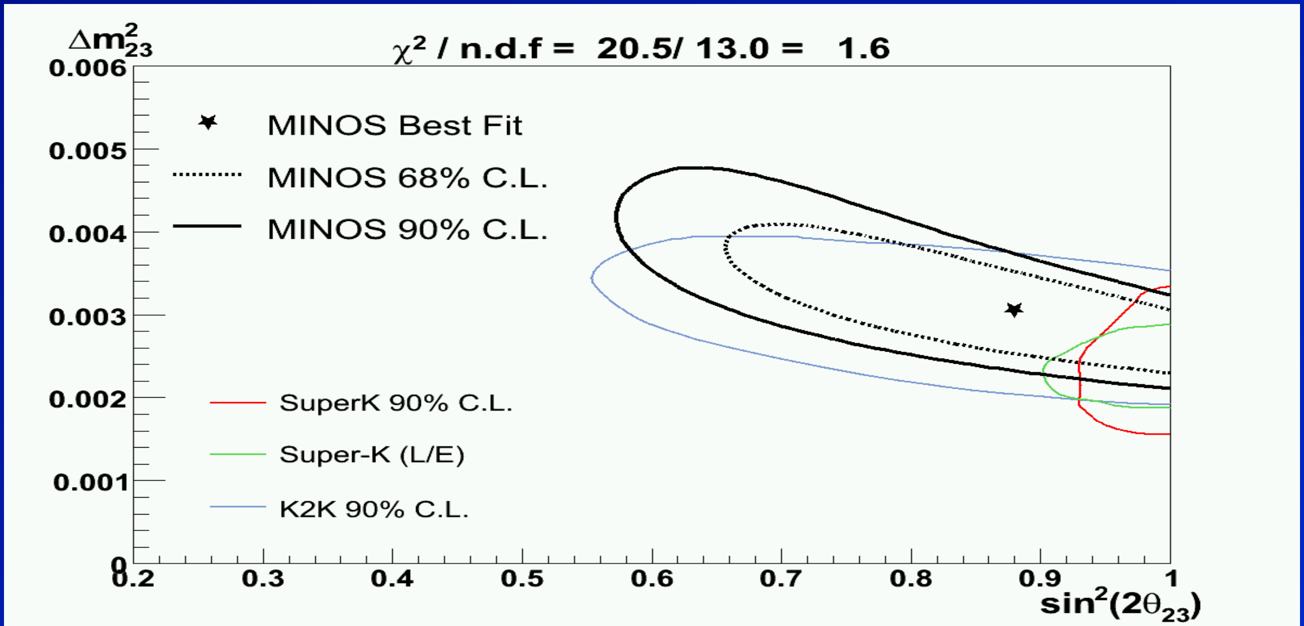
[Preliminary, Y. Suzuki @ Taup2005]



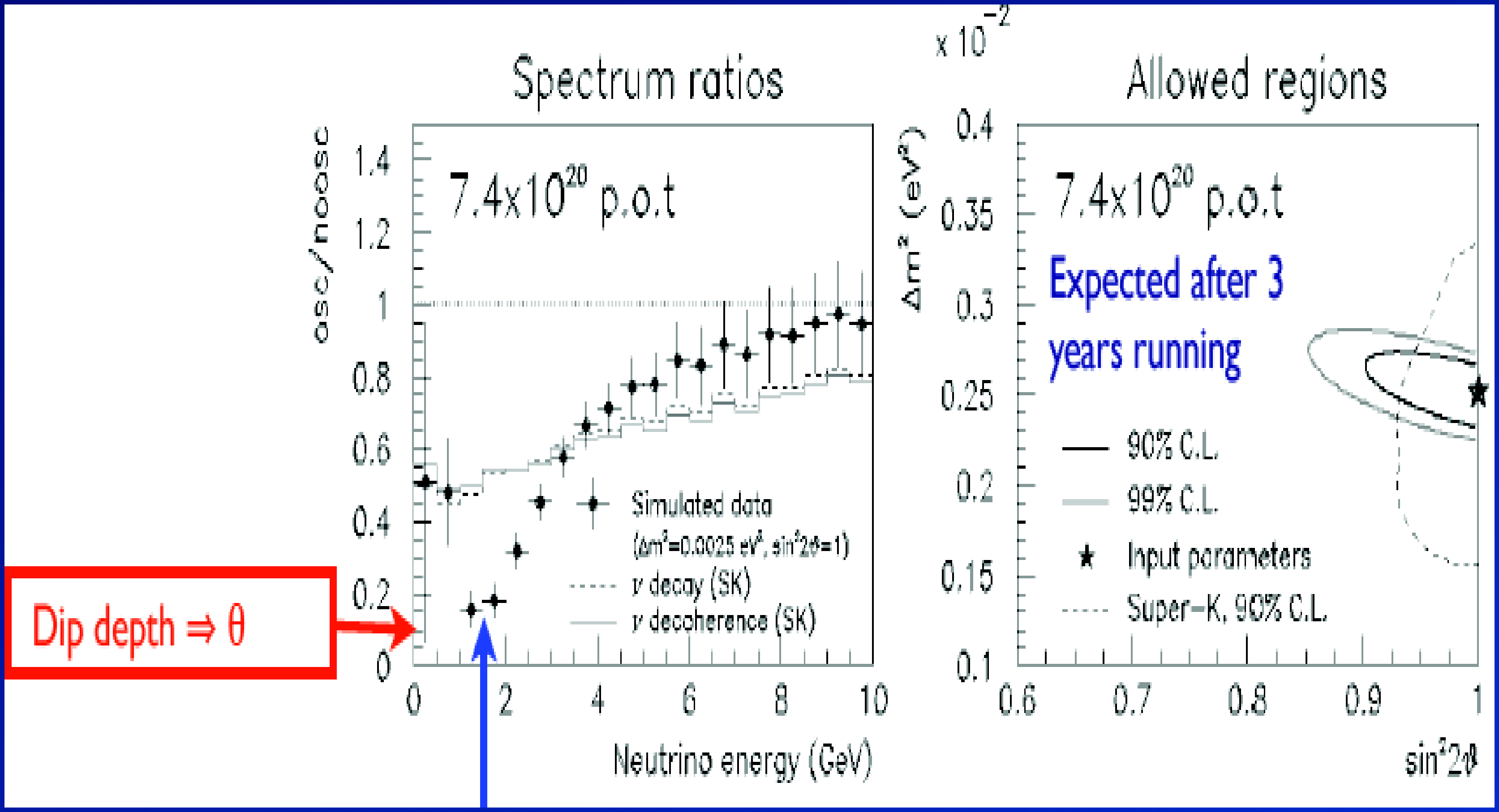
[K2K Coll., PRL 94 (2005) 081802]

MINOS, (first data publication March 2006) confirmed the oscillation hypothesis via ν_μ disappearance.

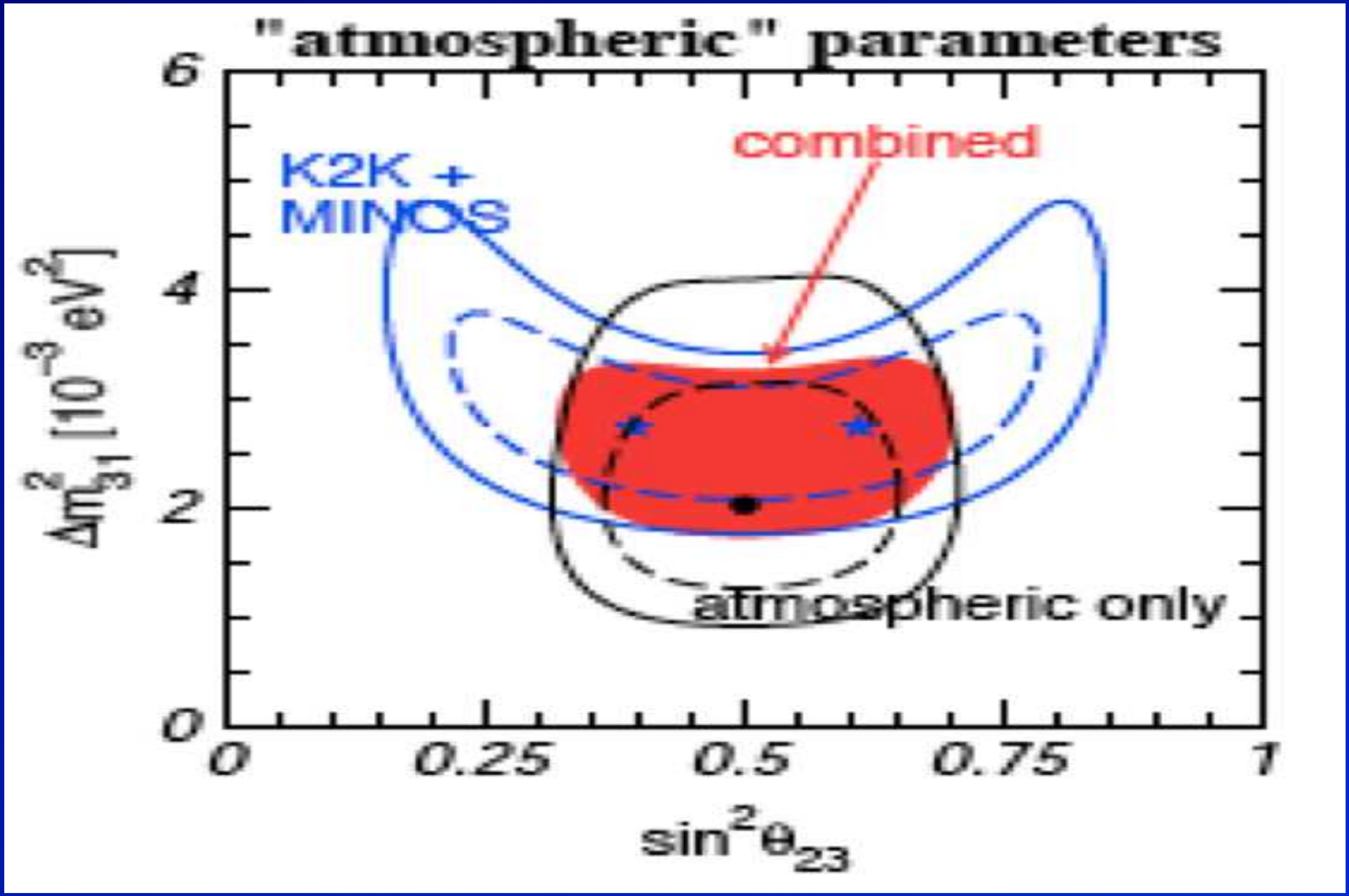




OPERA (started data collection 1 year ago) will search for $\nu_\mu \longrightarrow \nu_\tau$ appearance.



[http://www-numi.fnal.gov; NUMI Note NUMI-L-930]

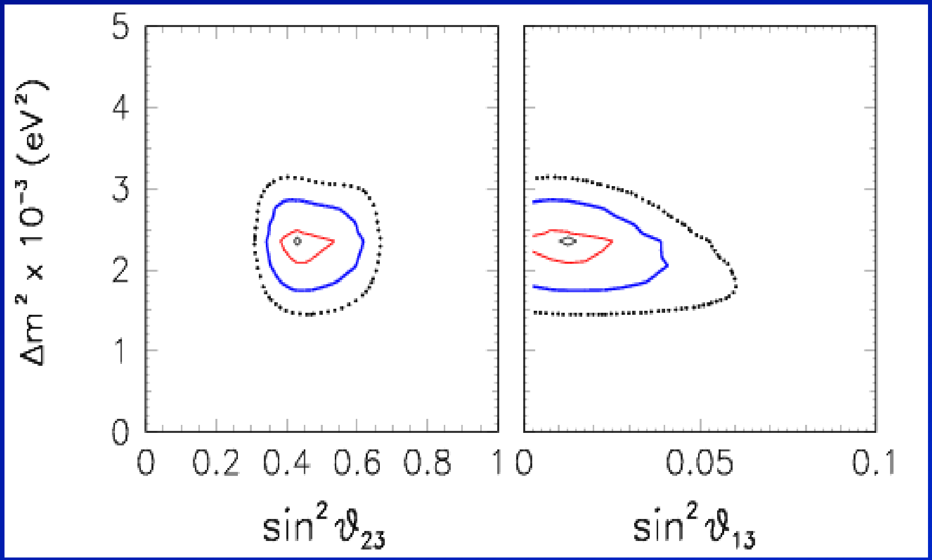


[T. Schwetz, hep-ph/0606060]

- Reactor neutrinos

Reactor $\bar{\nu}_e$ disappearance was searched for in CHOOZ and Palo Verde experiments but no positive signal was found.

Bound on the third mixing angle, θ_{13}:



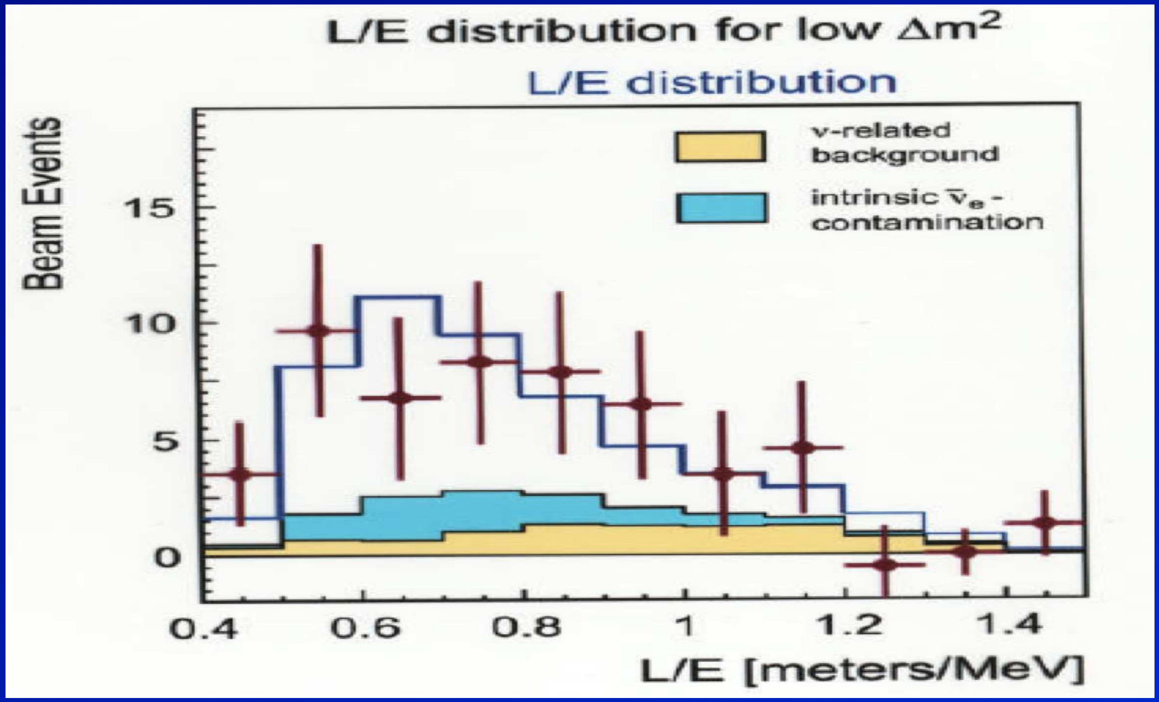
[Fogli et al., hep-ph/0506083]

New experiments with 2 detectors (D-CHOOZ, Kaska, Braidwood, Daya Bay) will improve this limit to $\sin^2 2\theta_{13} \sim 0.01 - 0.02$.

- LSND

The LSND exp took data from 1993 to 1998.

Accelerator neutrinos, ν_μ, ν_e and $\bar{\nu}_\mu$, were produced in π^+ and μ^+ decays. The LSND detector was located at a distance of 30 m. $\bar{\nu}_e$ were reveled.

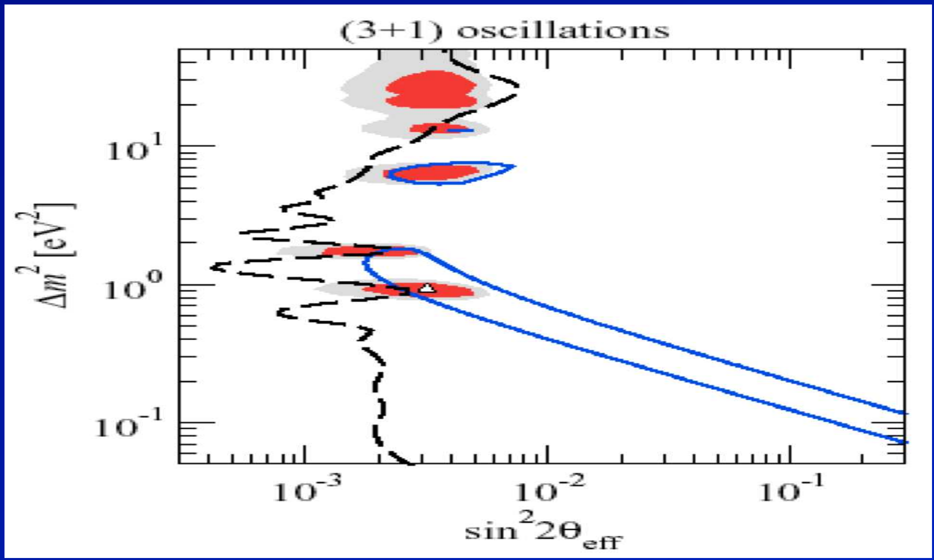


[LSND Coll., PRL 81 (1998) 1774]

The KARMEN experiment tested the LSND result but without founding any positive result.

At first, the LSND data was explained in terms of $\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$ oscillations, in a 4-neutrino mixing scheme.

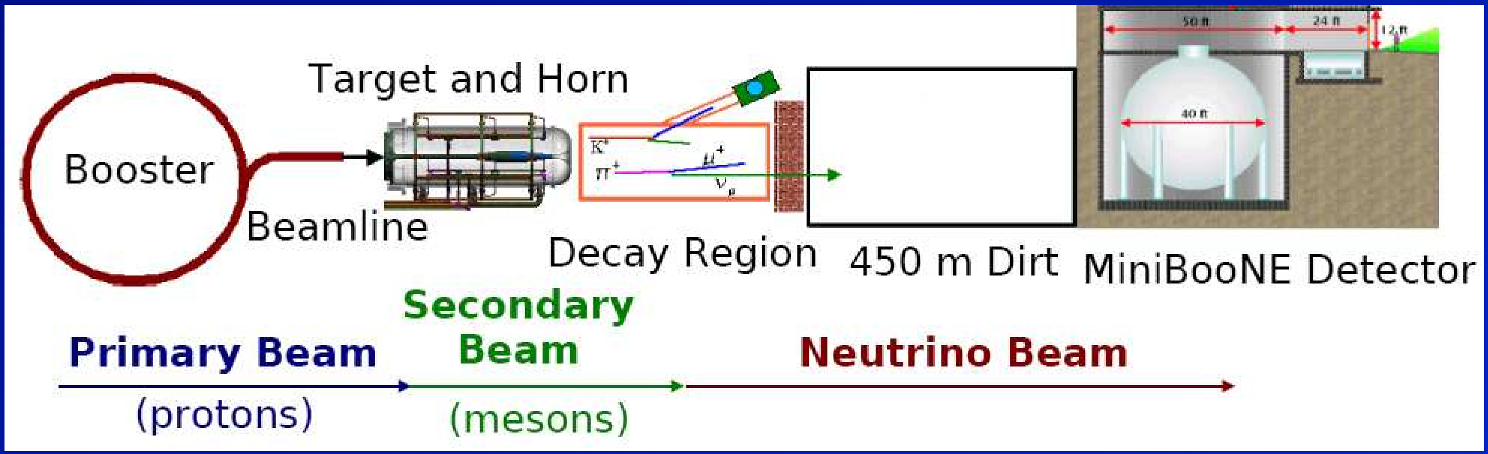
SBL disappearance experiments constrain the LSND mixing angle. A global analysis of all oscillation data is required.



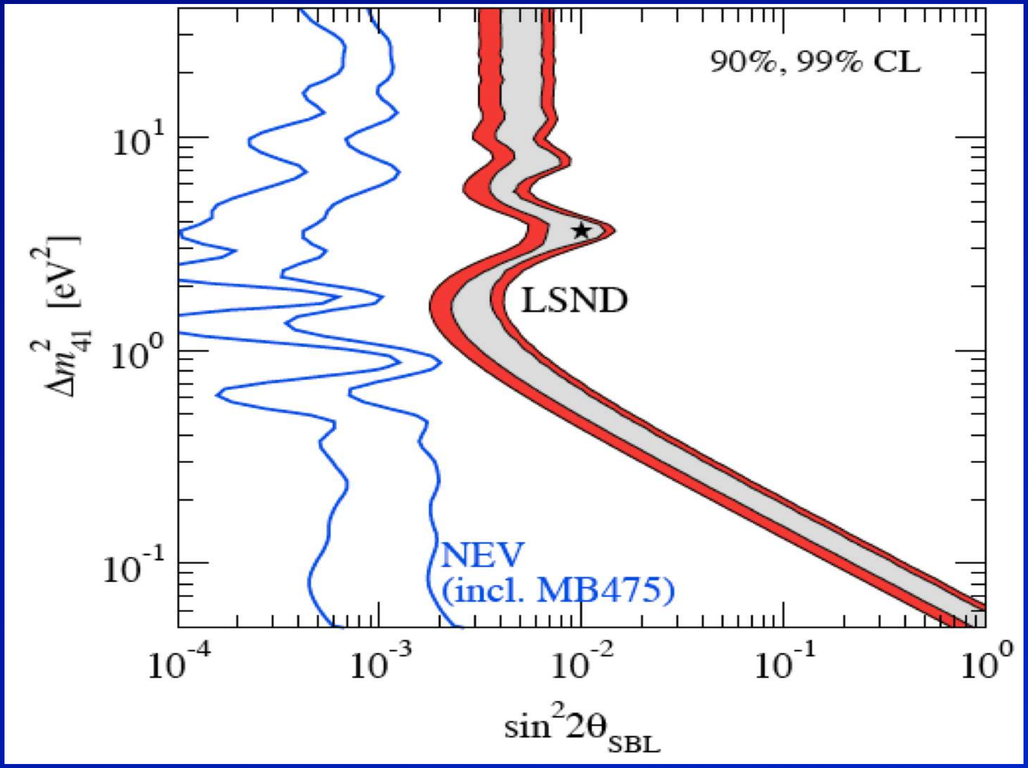
[Palomares-Ruiz, S.P., Schwetz, JHEP 0509 (2005) 048]

The parameter space required by LSND data is disfavored by SBL experiments. The LSND signal requires the existence of sterile neutrinos and maybe new interactions.

The **MiniBOONE** exp. tested the result without confirming the LSND signal.



[http://www-boone.fnal.gov]


90%, 99% CL
LSND
NEV
(incl. MB475)
10^{1}
10^{0}
10^{-1}
Δm^2_{41} [eV^2]
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
$\sin^2 2\theta_{SBL}$

2 – Summary of present status of oscillation data

parameter	bf$\pm 1\sigma$	1σ acc.	2σ range	3σ range
$\Delta m^2_{21}\ [10^{-5}\mathrm{eV}^2]$	7.9 ± 0.3	4%	$7.3 - 8.5$	$7.1 - 8.9$
$\lvert\Delta m^2_{31}\rvert\ [10^{-3}\mathrm{eV}^2]$	$2.5^{+0.20}_{-0.25}$	10%	$2.1 - 3.0$	$1.9 - 3.2$
$\sin^2\theta_{12}$	$0.30^{+0.02}_{-0.03}$	9%	$0.26 - 0.36$	$0.24 - 0.40$
$\sin^2\theta_{23}$	$0.50^{+0.08}_{-0.07}$	16%	$0.38 - 0.64$	$0.34 - 0.68$
$\sin^2\theta_{13}$	–	–	≤ 0.025	≤ 0.041

[T. Schwetz, hep-ph/0606060]