Sommario della situazione

Neutrini solari

Convincente evidenza di consistenza tra flusso totale $(\nu_e+\nu_\mu+\nu_\tau)$
predetto ed osservato (esperimento SNO)

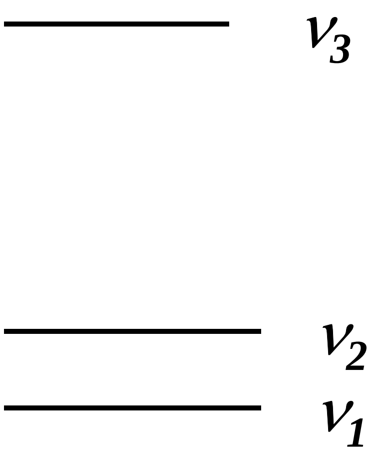
Convincente evidenza per soppressione dei ν_e
(esperimenti radiochimici+SK+SNO)

Soluzione (MSW) per δm^2 e $\sin^2 2\theta$:

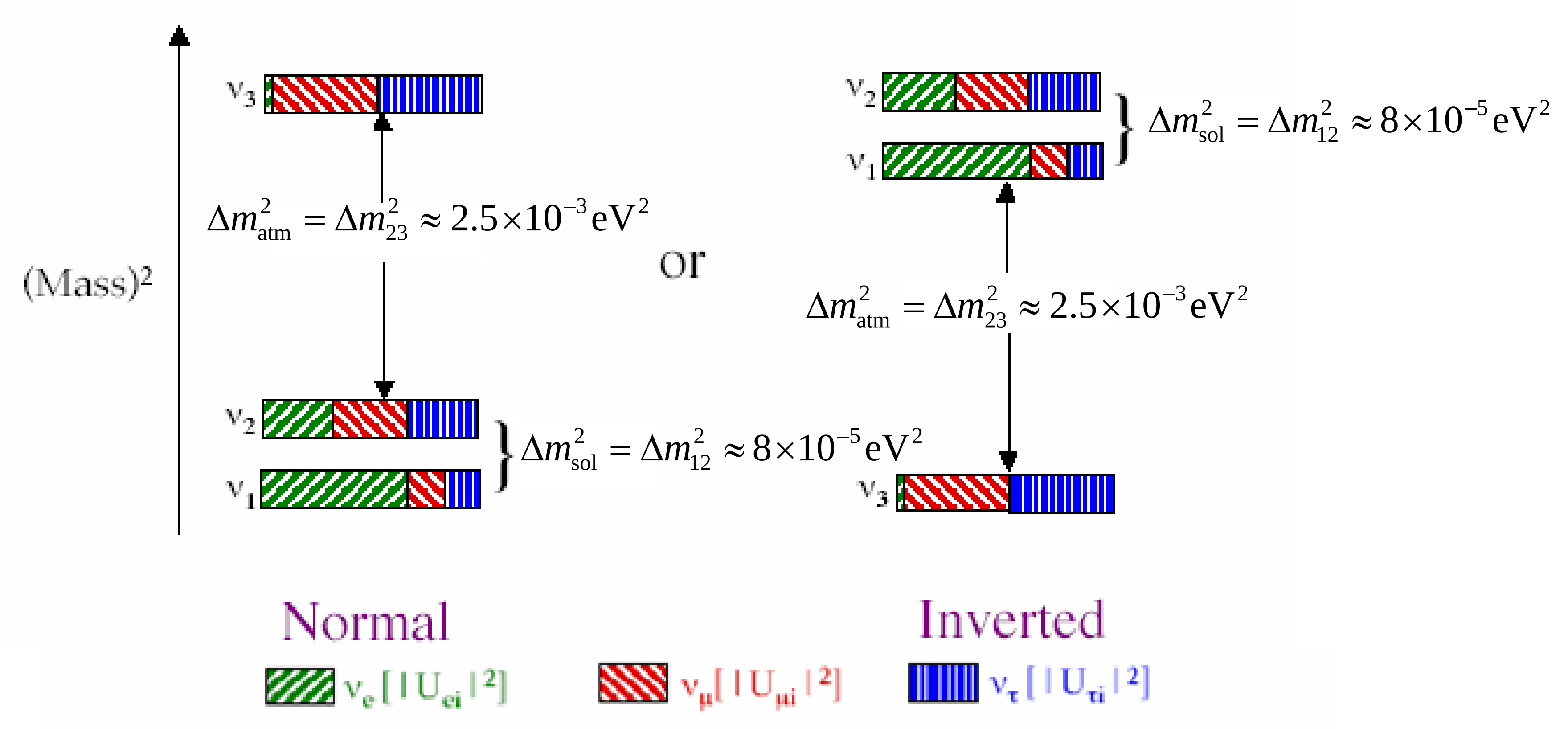
$\delta m^2 = 6.5\ 10^{-5}$
$\tan^2 2\theta = 0.40 \rightarrow \sin^2 2\theta = 0.28$

Consistente con oscillazioni $\nu_e \rightarrow \nu_\mu$ o $\nu_e \rightarrow \nu_\tau$

Autostati di massa:



Mass Eigenstates



Don't know yet absolute offset for m:

Sommario della situazione

Neutrini atmosferici

Convincente evidenza di scomparsa di ν_μ

(esperimenti Kamioka+SK+MACRO+SOUDAN+IMB)

Flusso dei ν_e in accordo con quello atteso

Soluzione per δm^2 e $\sin^2 2\theta$:

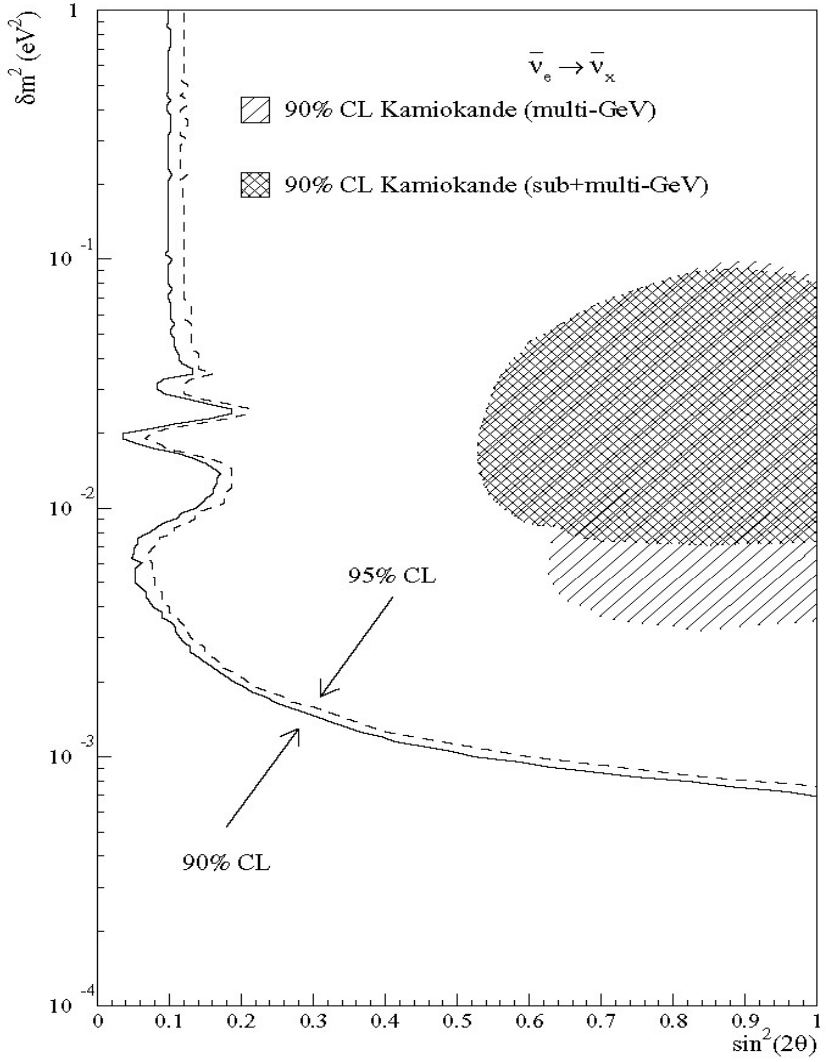
$$1.9\ 10^{-3}\ eV^2 < \delta m^2 < 3.0\ 10^{-3}\ eV^2\ ; \quad \sin^2 2\theta > 0.90$$

Inoltre assenza di oscillazioni di antineutrini elettronici in questa regione dei parametri (esperimento Chooz)

→ Risultati consistenti con oscillazioni $\nu_\mu \rightarrow \nu_\tau$

Chooz

$$\mathcal{P}(\nu_\alpha \to \nu_\alpha) = \mathcal{P}(\bar{\nu}_\alpha \to \bar{\nu}_\alpha) \qquad \text{(CPT conserved).}$$



La regione permessa da SK per $\nu_\mu \rightarrow \nu_e$ o $\nu_\mu \rightarrow \nu_\tau$ e' esclusa da Chooz per $\nu^{(bar)}_e \rightarrow \nu^{(bar)}_x$

Figure 9: Exclusion plot for the oscillation parameters based on the absolute comparison of measured vs. expected positron yields.

Evidenza dell'oscillazione (superK)

Physical Rev. Lett.
24 Giugno 2004

Flusso dei ν_μ
in funzione di *L/E*
e
confronto con previsioni Montecarlo

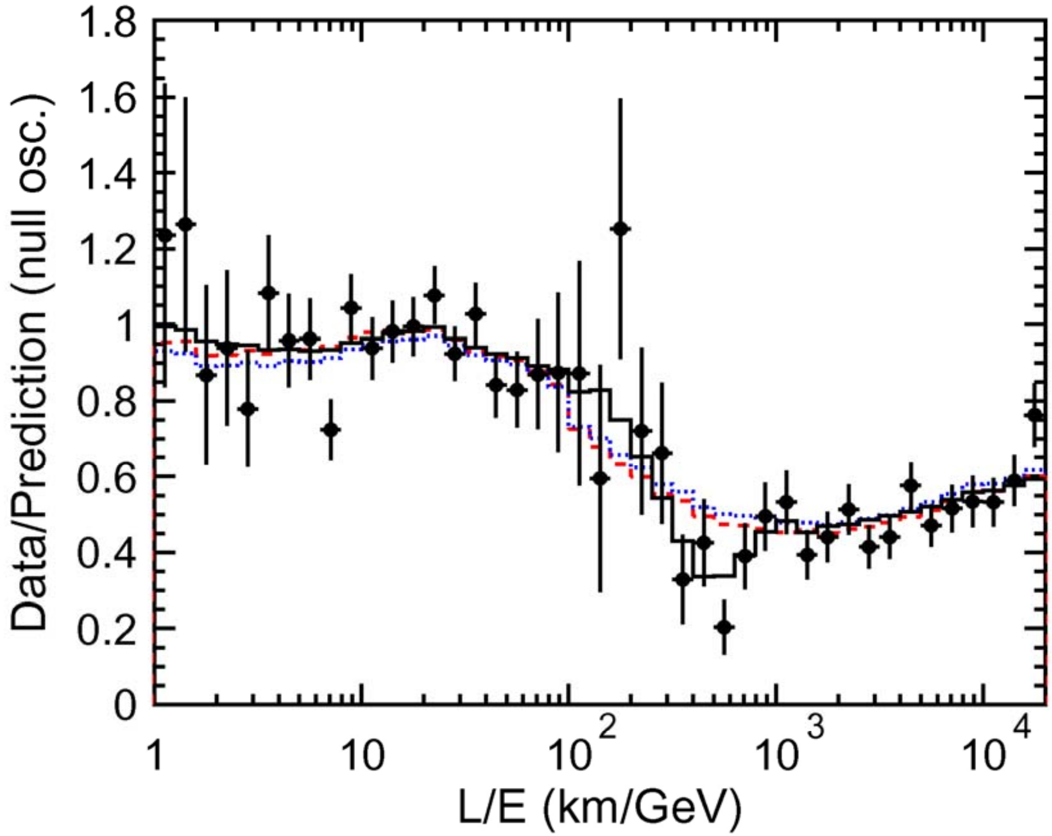
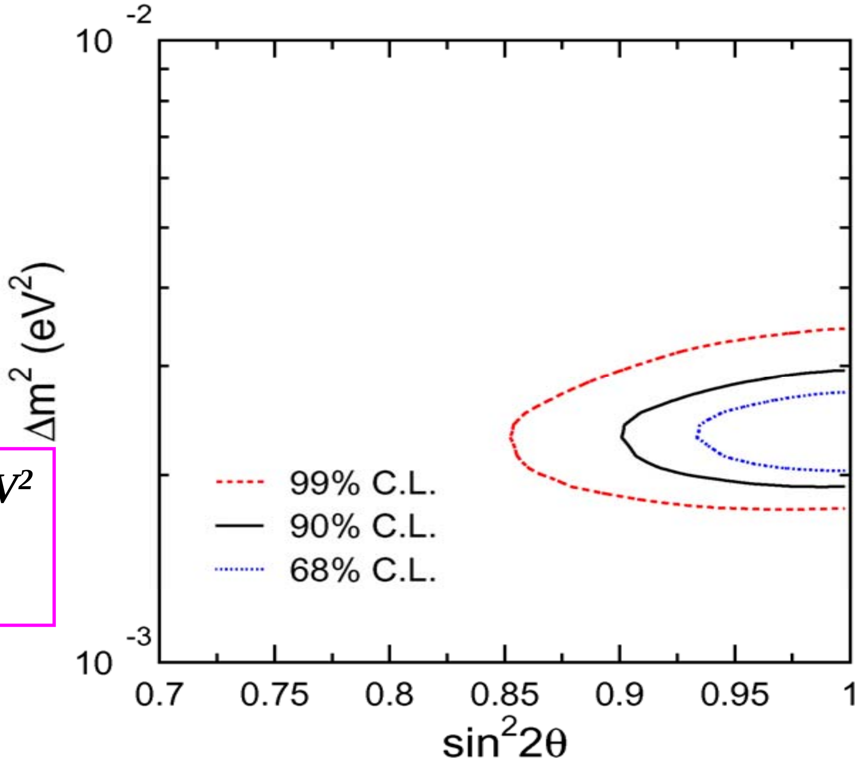


FIG. 4: Ratio of the data to the MC events without neutrino oscillation (points) as a function of the reconstructed L/E together with the best-fit expectation for 2-flavor $\nu_\mu \leftrightarrow \nu_\tau$ oscillations (solid line). The error bars are statistical only. Also shown are the best-fit expectation for neutrino decay (dashed line) and neutrino decoherence (dotted line).

Evidenza dell'oscillazione (superK)

SuperK.
Physical Rev. Lett.
24 Giugno 2004



$1.9\ 10^{-3}\ eV^2 < \Delta m^2 < 3.0\ 10^{-3}\ eV^2$
$\sin^2 2\theta > 0.90$
90% CL

FIG. 5: 68, 90 and 99% C.L. allowed oscillation parameter regions for 2-flavor $\nu_\mu \leftrightarrow \nu_\tau$ oscillations obtained by the present analysis.

Man-made neutrinos ?

(1) Antineutrini (elettronici) da reattori

(2) Neutrini (mu) da acceleratori

$$p + p \rightarrow \text{nucleoni} + \text{molti } \pi$$

…………………

Esperimento Kamland

***Antineutrini* prodotti da un gran numero *(53)* di reattori nucleari in Gappone (e Corea)**

Distanza della piu' gran parte dei reattori dal rivelatore:

138-214 km

Distanza media: ***180 km***

Energia media degli antineutrini ~ 4 MeV

$\rightarrow$ ***E/L ~ 2 10^{-5}***

$\rightarrow$ ***sensibilita' a valori di δm^2 di questo stesso ordine di grandezza***

Risultati di SNO (neutrini!): δm^2 ~ (5-7) 10^{-5}

Rivelatore Kamland

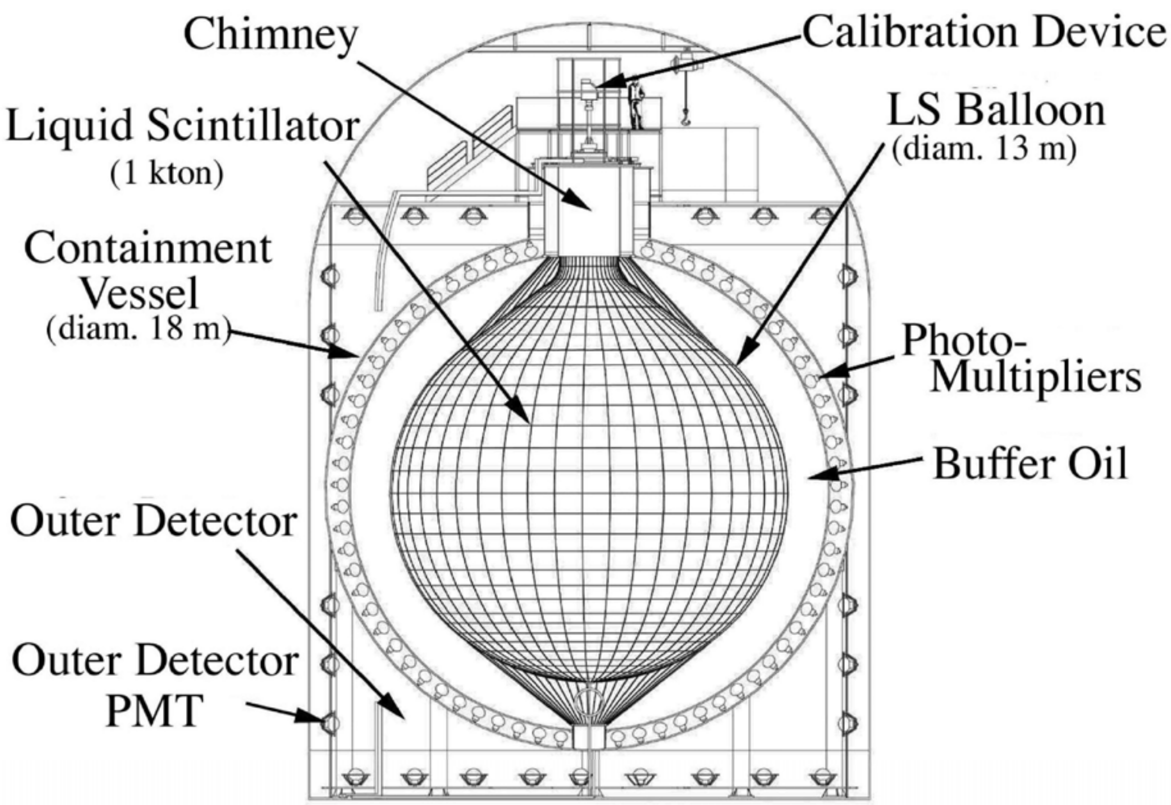


FIG. 1: Schematic diagram of the KamLAND detector.

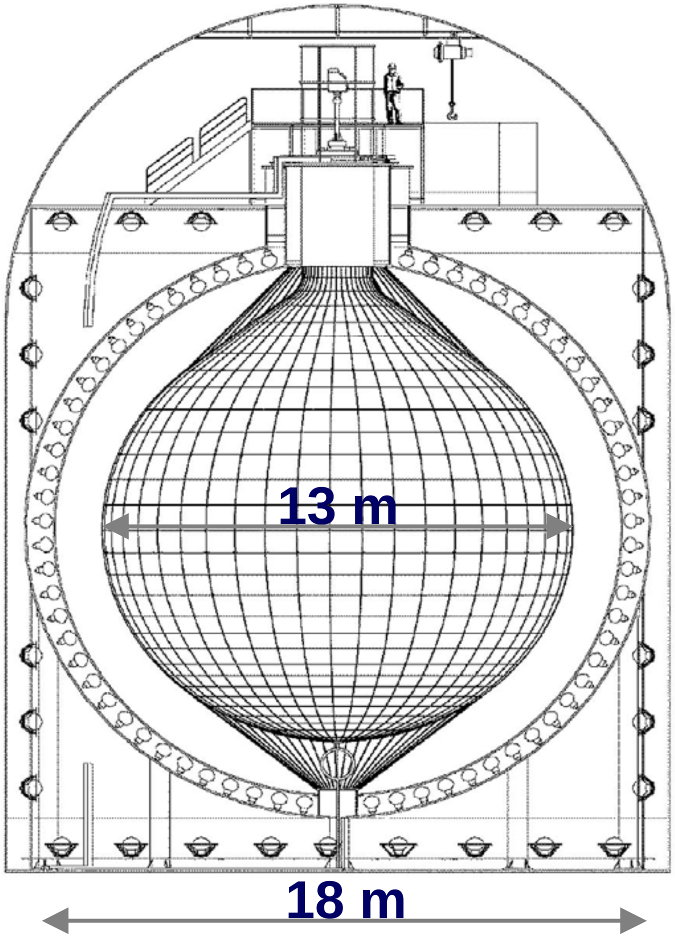
1879 PMT "interni"

Copertura 22% → 34%

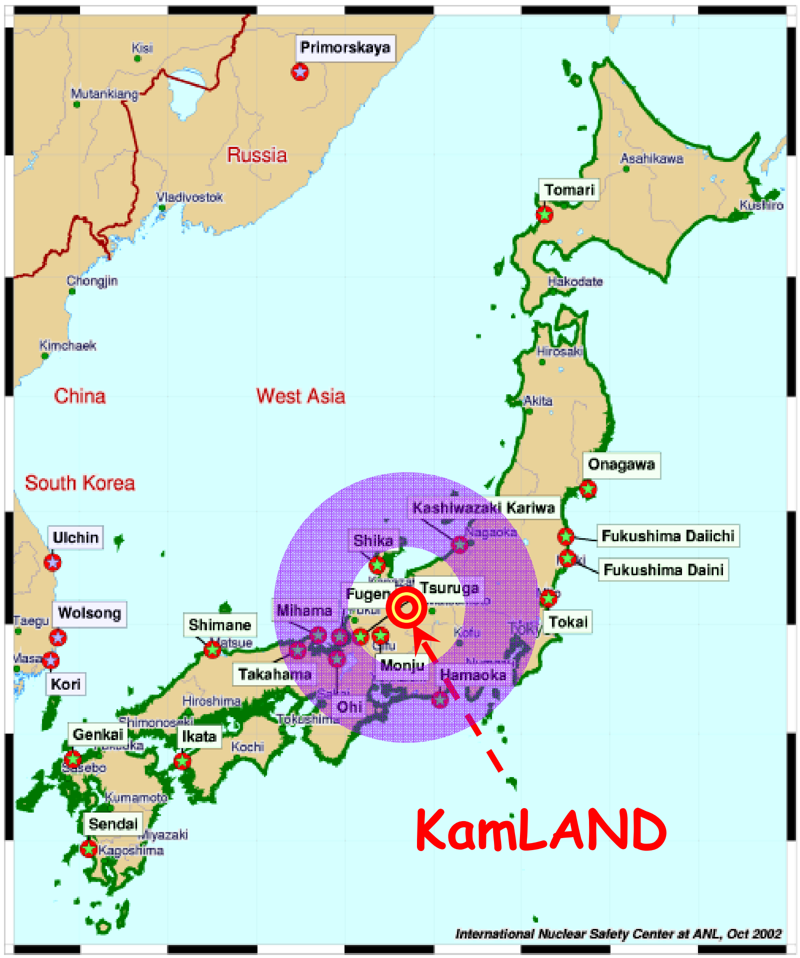
oltre a 225 PMT "esterni"
(veto Cerenkov)

Recent Solar Sector Measurements

➢ KamLAND—`Long' Baseline Reactor Antineutrinos



1000 tons of liquid scintillator



$\bar{\nu}_e + p \rightarrow e^+ + n$

~ $5 \times 10^6\ \bar{\nu}_e$ / cm2 / sec

Few evts/day detected

Reazione utilizzata

$$\bar{\nu}_e + p \rightarrow e^+ + n \quad ; \quad seguita\ da:$$

$$cattura\ del\ neutrone\ da\ parte\ di\ un\ protone \quad (0.5\,\mu s \le \Delta T \le 660\,\mu s)$$

$$con\ emissione\ di\ un\ \gamma\ di\ 2.2\ MeV$$

$$E_{prompt} = E_{\bar{\nu}} - \overline{E}_n - 0.8\ MeV$$

Soglia utilizzata nel trigger: 0.7 MeV (200 PMT)
Soglia effettiva sull’energia del neutrino: 1.8 MeV

Energia ritardata vs prompt

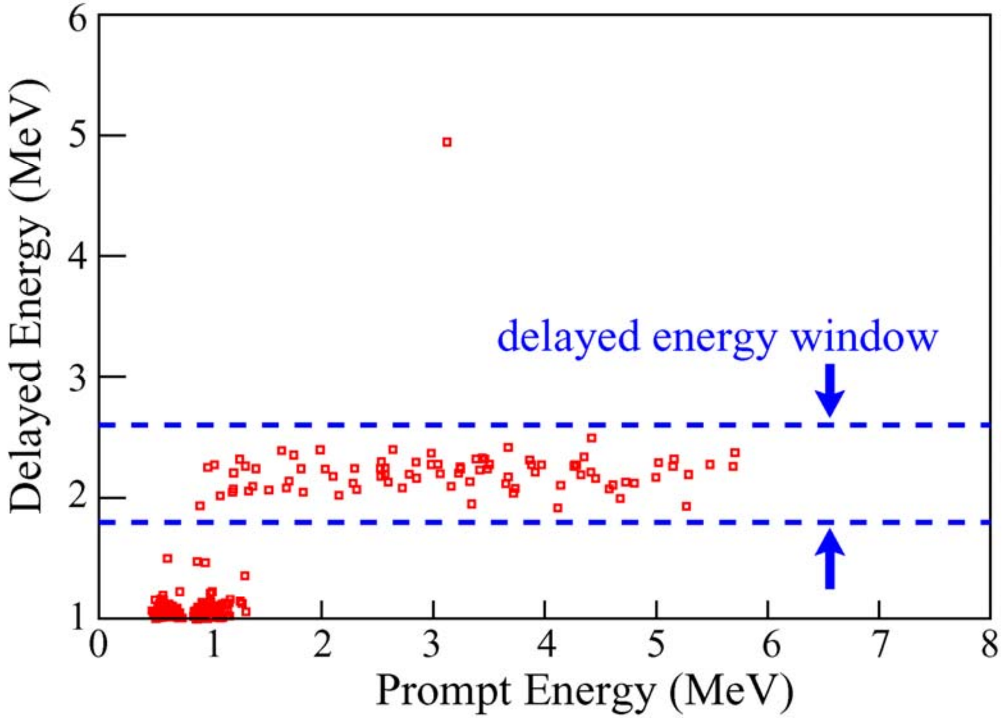
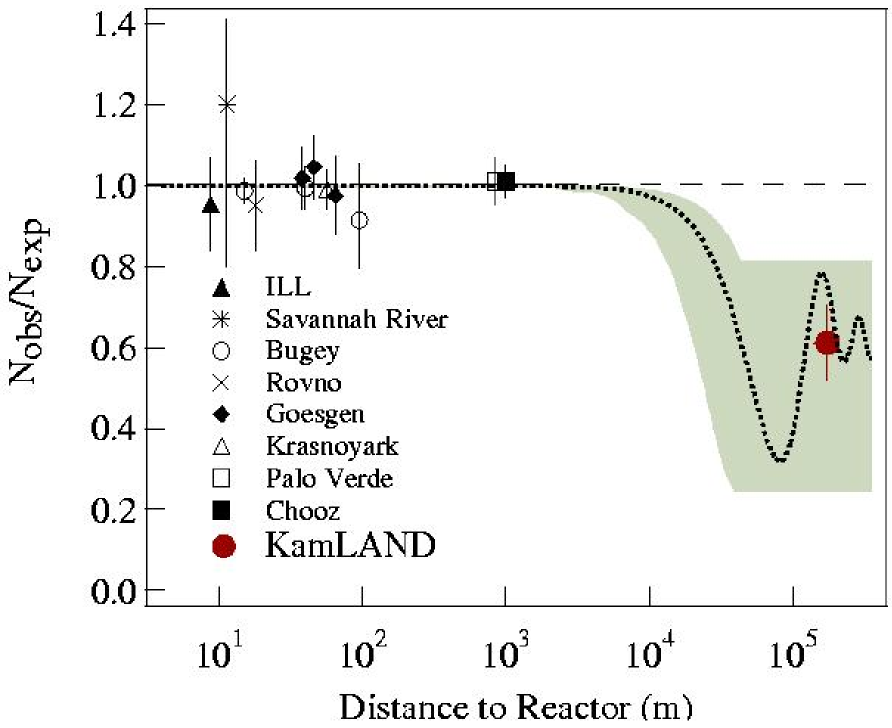


FIG. 3: Distribution of $\bar{\nu}_e$ candidates with fiducial volume cut, time, vertex correlation, and spallation cuts applied. The prompt energy corresponds to the positron and the delayed energy to the captured neutron. The events within the horizontal lines bracketing the delayed energy of 2.2 MeV are due to thermal neutron capture on protons. The events with prompt energy below ~0.7 MeV are obtained from the delayed trigger. The one event with delayed energy near 4.95 MeV is consistent with theexpected 0.54% fraction from $^{12}C(n,\gamma)$.

Nuovi risultati di Kamland (2004)

- Copertura con PMT portata al 34%
- Risoluzione in energia migliorata
- 365.2 +/- 23.7 eventi attesi al di sopra di 3.4 MeV
- 258 eventi osservati
- Analizzato il rapporto tra # di eventi osservati/predetti
  in funzione di L/E (oscillazione)

Ratio vs Distance



KamLAND, PRL 90, 2003

Event numbers for 766 ton-years of data:

Expected (no oscillation)=365.2 ± 23.7

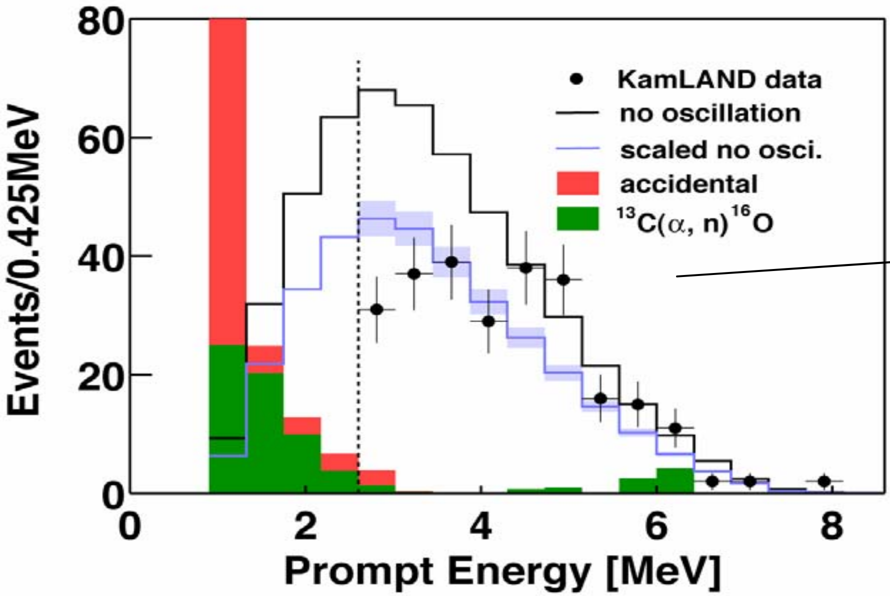
Expected background =17.8 ± 7.3

Observed =258

Disappearance with significance of 99.998%

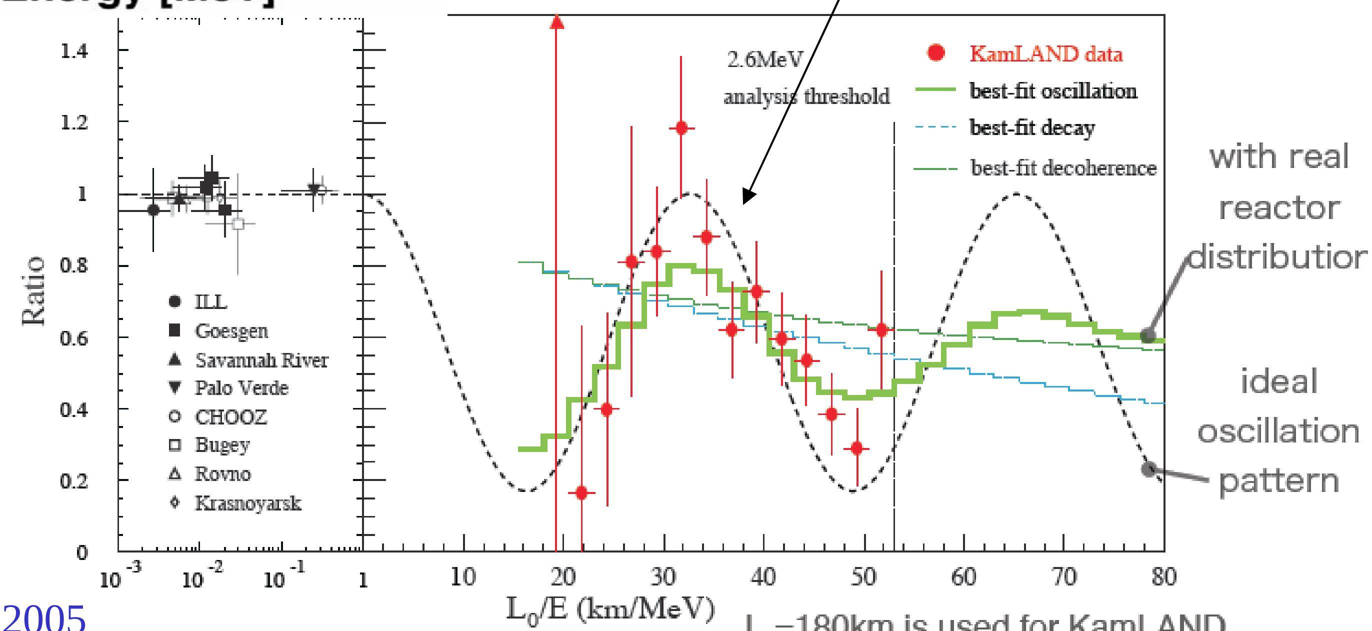
Recent Solar Sector Measurements

➢ KamLAND: Testing the Model with L/E Behavior



• Rate + Shape: Oscillations at 99.999995% C.L.

$$P_{\upsilon_e \to \upsilon_e} = 1 - \sin^2 2\theta_{12} \sin^2\left(\frac{1.27\Delta m_{12}{}^2 L}{E}\right)$$

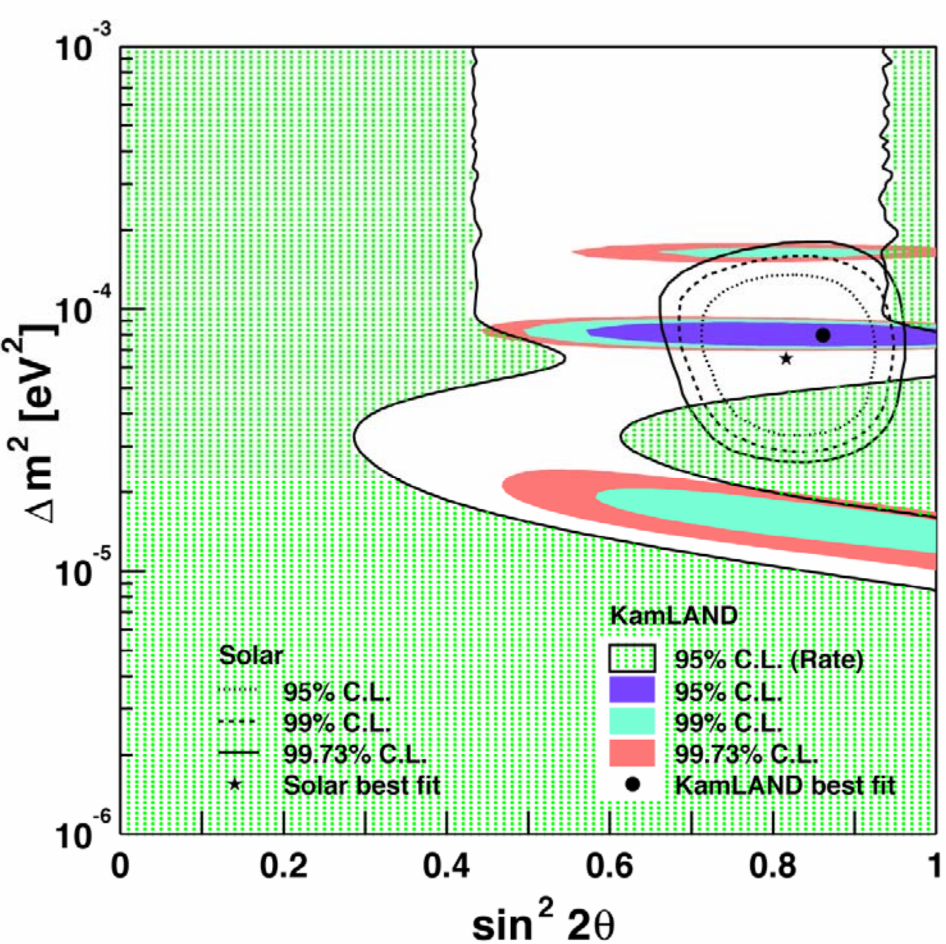


L_0=180km is used for KamLAND

KamLAND, PRL 94, 2005

Recent Solar Sector Measurements

➢ KamLAND+SNO: Testing the Model



	Reactor	Solar
E	2-10 MeV	0.1-15 MeV
L	150 km	1.5 x 10^8 km
MSW	No	Yes
ν	**Anti-ν_e**	ν_e

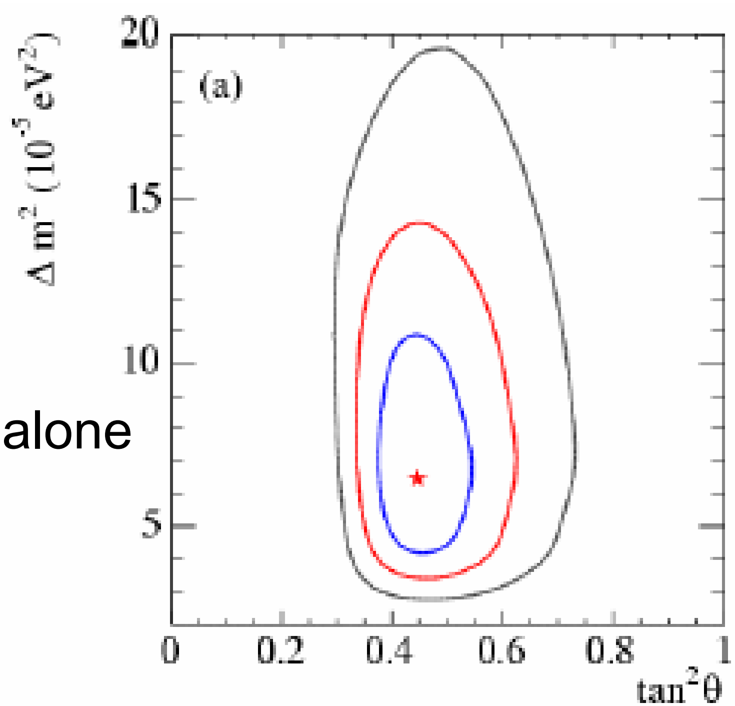
KamLAND, PRL 94, 2005

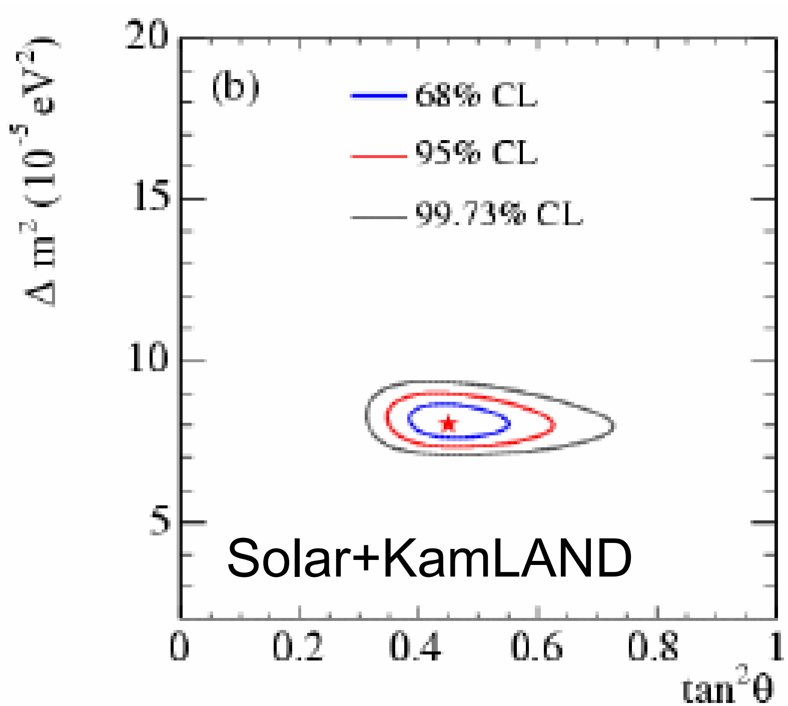
Only(?) ν Standard Model predicts these 2 experimental regimes see the same effect

Recent Solar Sector Measurements

- KamLAND+Solar: Measuring $\nu(1,2)$ Parameters

Solar alone





(Maximal mixing excluded at >5 σ)

KamLAND best-fit (rate + shape)

$$\Delta m^2 = 7.9\times10^{-5}\ \mathrm{eV}^2,\quad \tan^2\theta = 0.46$$

Solar

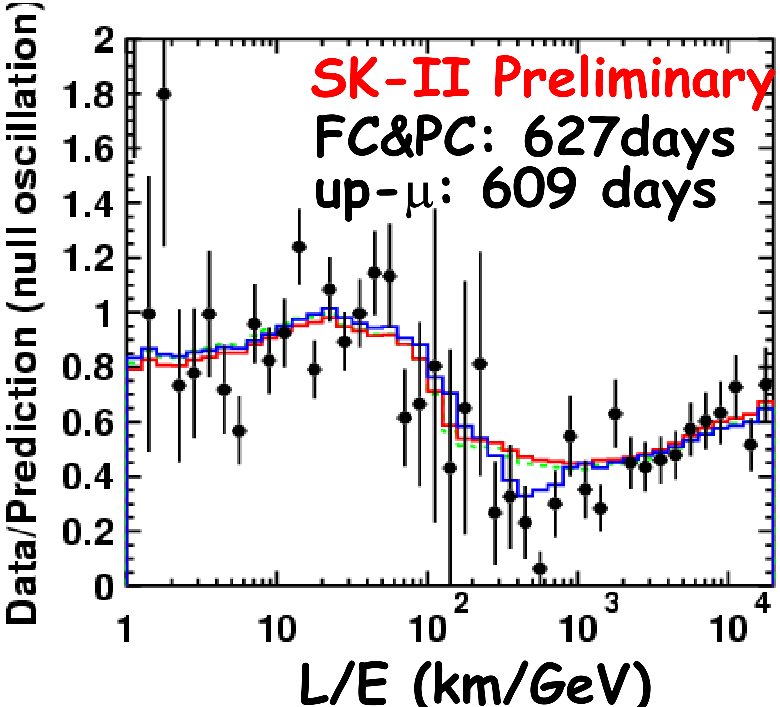
$$\Delta m^2 = 6.5^{+4.4}_{-2.3}\times10^{-5}\ \mathrm{eV}^2,\quad \tan^2\theta = 0.45^{+0.09}_{-0.08}$$

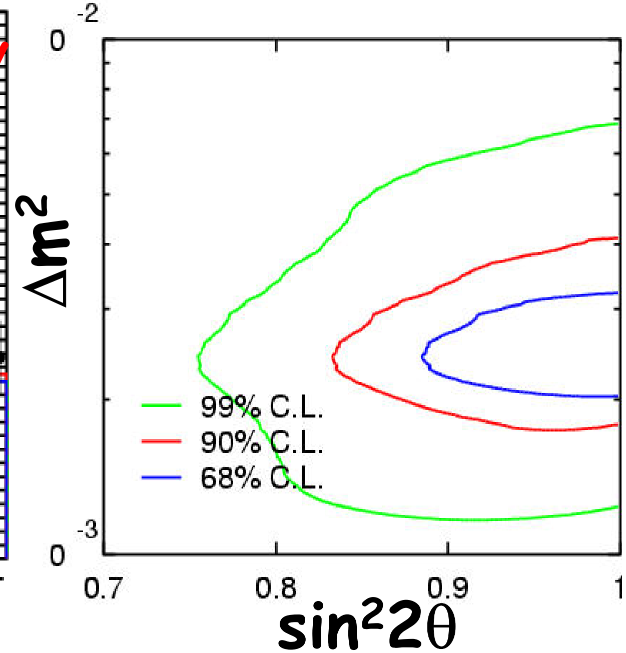
KamLAND + Solar

$$\Delta m^2 = 7.9^{+0.6}_{-0.5}\times10^{-5}\ \mathrm{eV}^2,\quad \tan^2\theta = 0.40^{+0.10}_{-0.07}$$

Verifica delle oscillazioni dei neutrini atmosferici

- Esperimento K2K (KEK to Kamioka)
- Fascio di ν_μ di circa 1 GeV dall'acceleratore KEK verso Superkamiokande (distanza ~ 250 Km)
- $\rightarrow$ $E/L \sim 4\ 10^{-3}$ $\rightarrow$ $\delta m^2 \sim 10^{-3}$



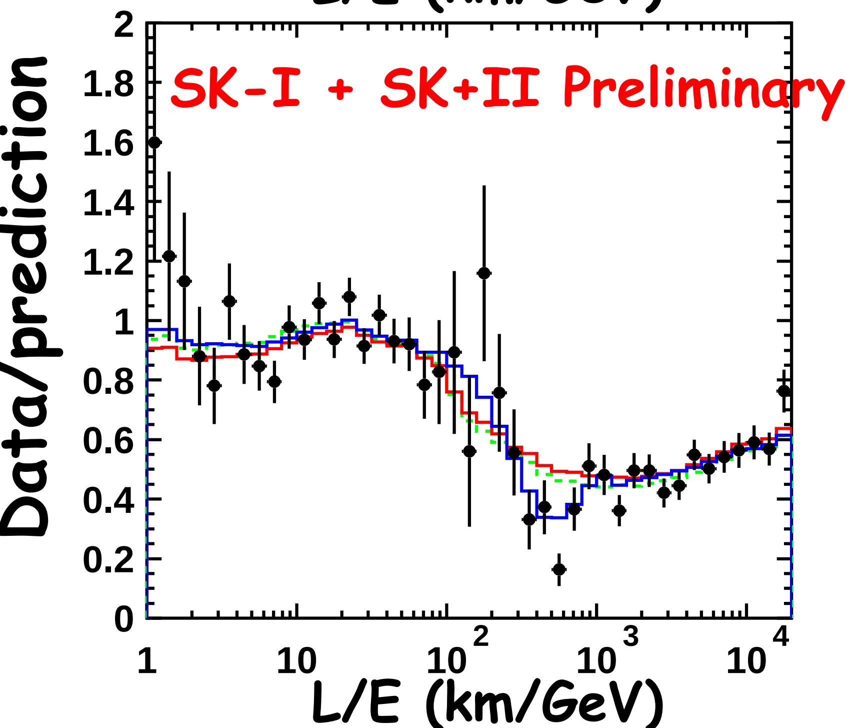


Best Fit Results: (physical region)

$\Delta m^2 = 2.6 \times 10^{-3}$ eV^2

$\sin^2 2\theta = 1.0$

$\chi^2_{min} = 54.8/40$ d.o.f.

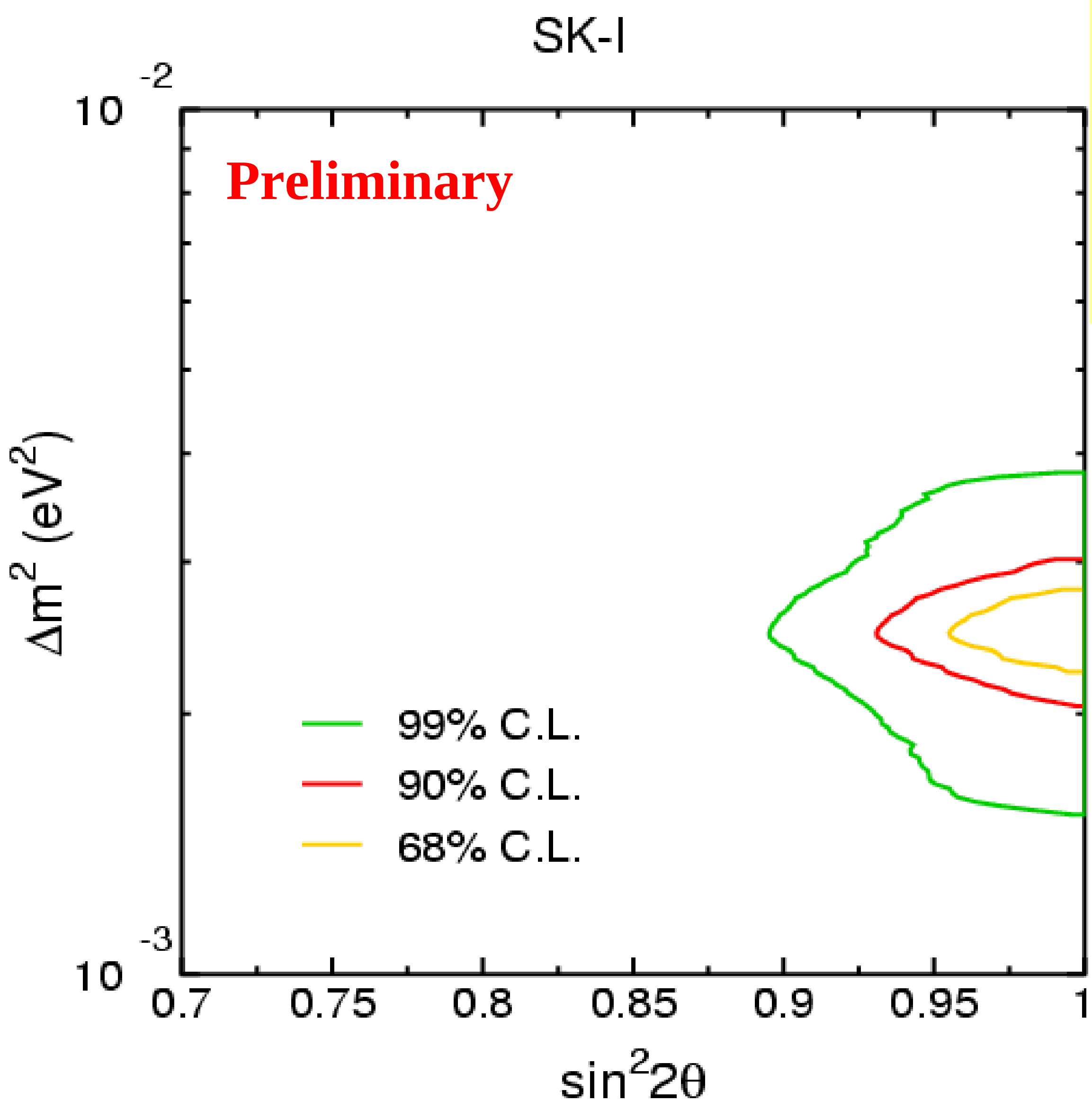


Combined results from SK-I and SK-II will be shown.

Need correct treatment of different systematics of SK-I and II .

Recent Atmospheric Sector Measurements

➢ Mixing Parameters



Best Fit Results:

$\Delta m^2 = 2.5 \times 10^{-3}\ eV^2$

$\sin^2(2\theta) = 1.0$

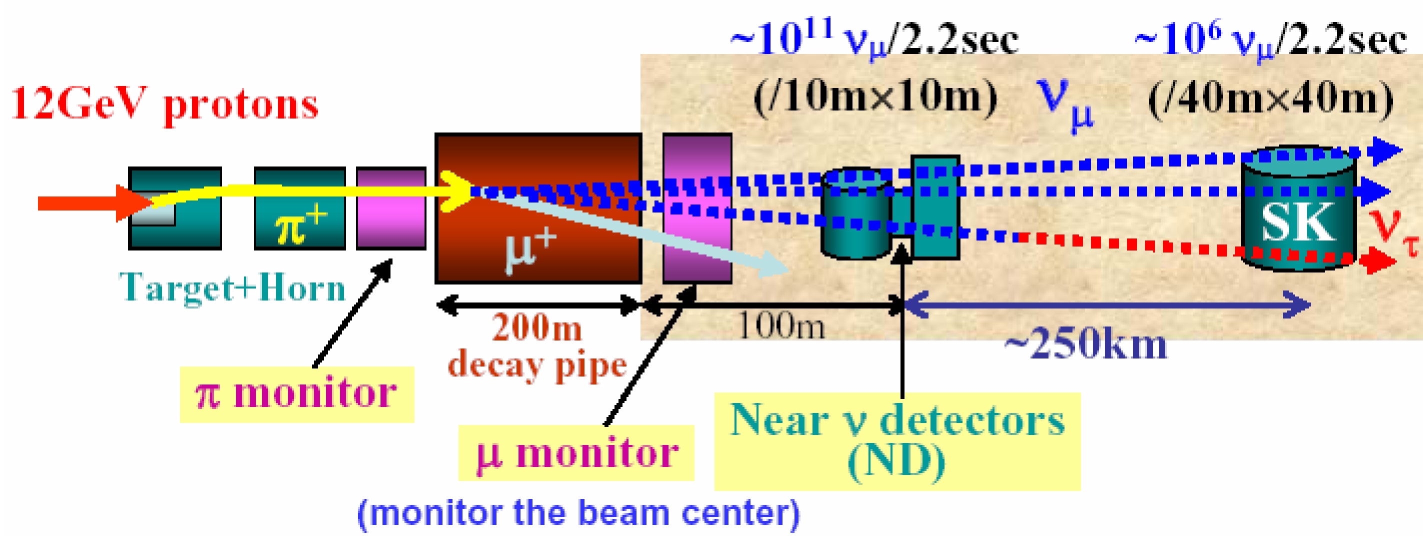
(constrained to physical region)

χ^2_{min}= 375.2/367 DOF

K. Scholberg, WIN05

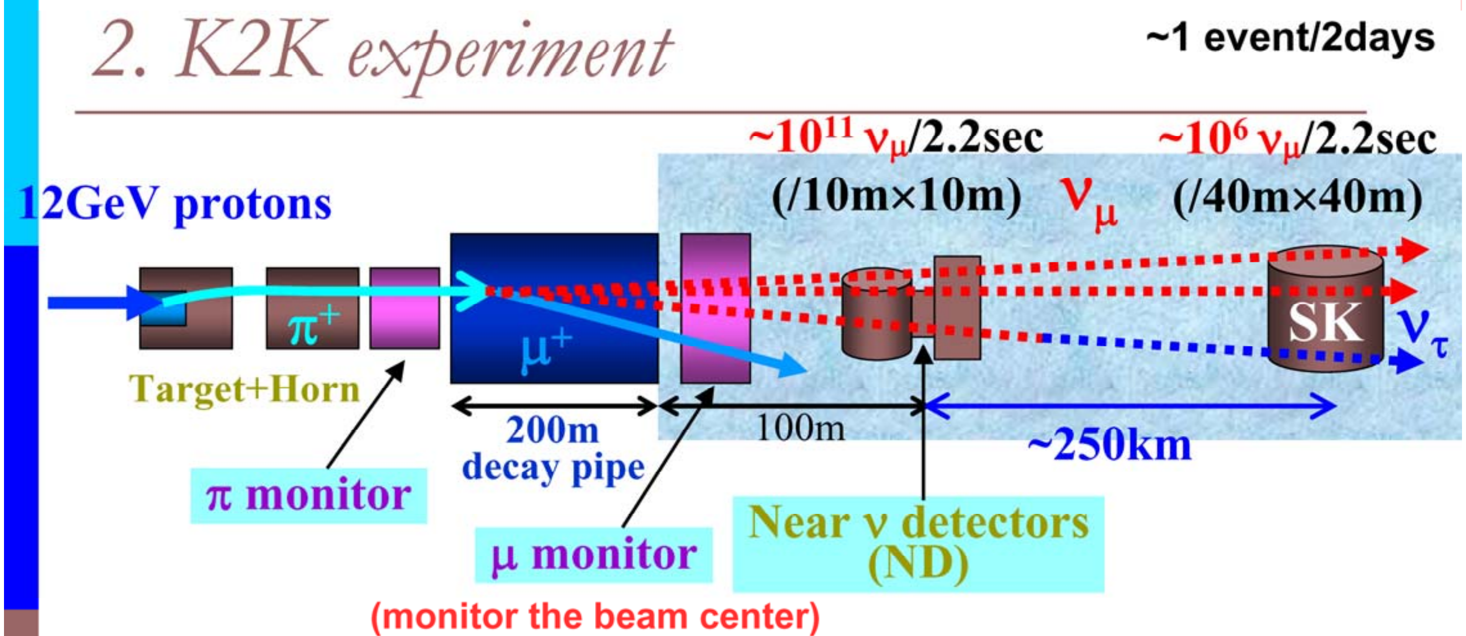
Recent Atmospheric Sector Measurements

- K2K Long Baseline Accelerator (KEK to Kamioka)



First long baseline accelerator experiment

K2K setup

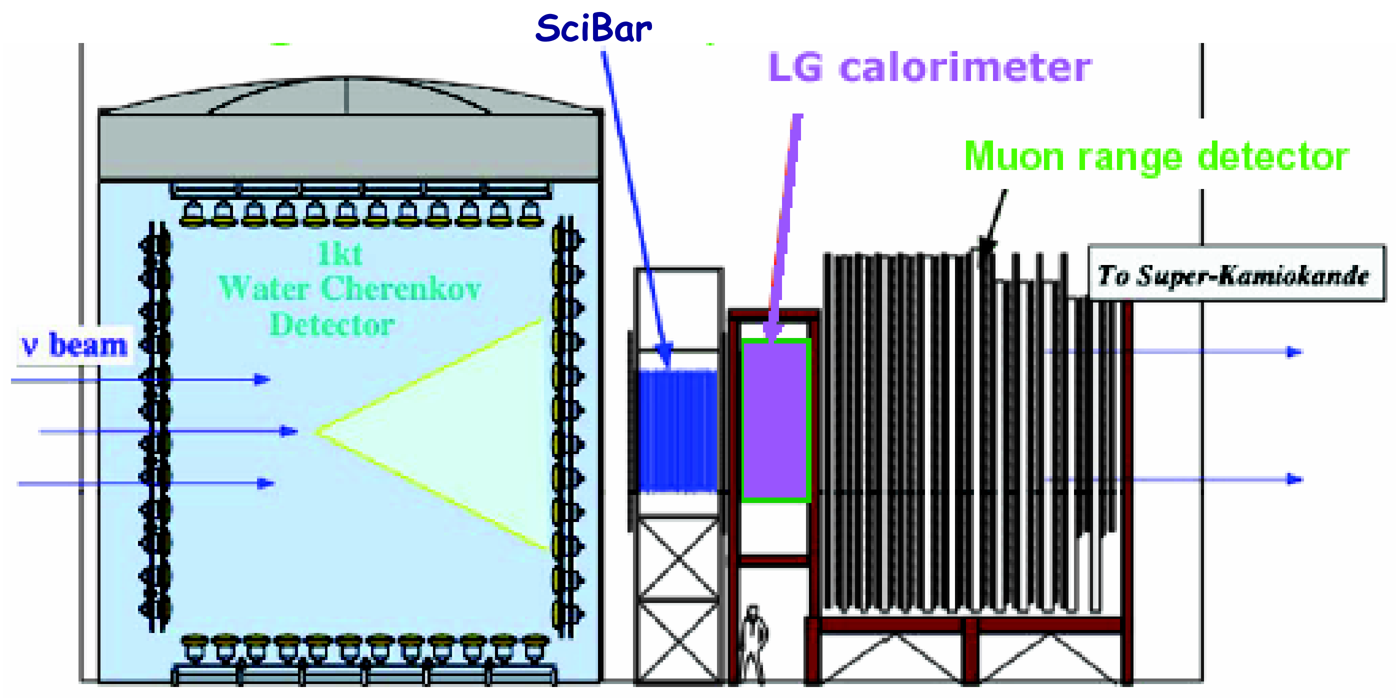


Signal of ν oscillation at K2K
- Reduction of ν_μ events
- Distortion of ν_μ energy spectrum

Recent Atmospheric Sector Measurements

- K2K Long Baseline Accelerator (KEK to Kamioka)

Near Detector:



Critical to both measure flux <u>and</u> allow extrapolation to Super-K

Misura dell’energia del neutrino

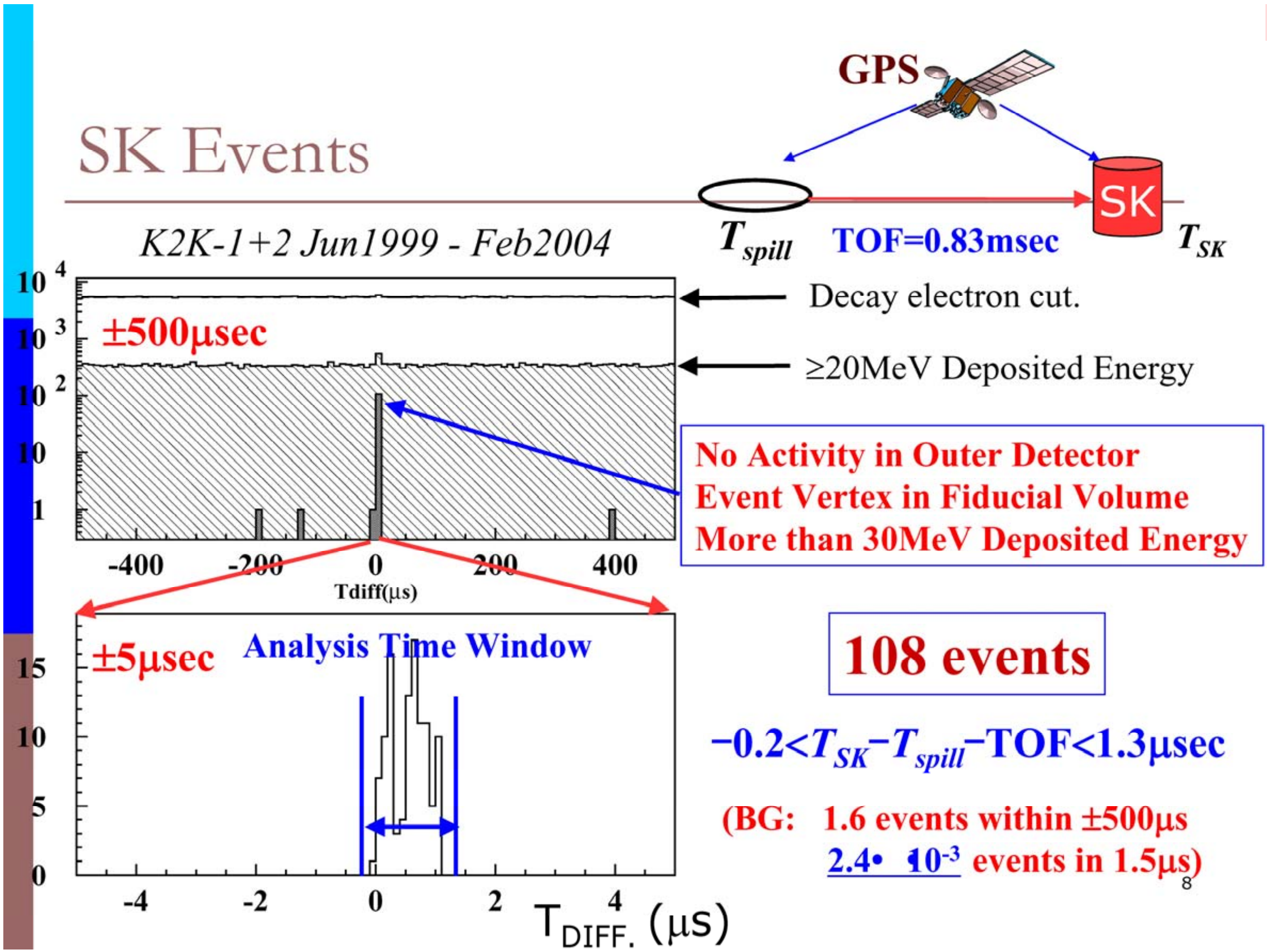
$$\nu_\mu + n \to \mu^- + p \qquad [reazione\ quasi\ elastica \quad (QE)]$$

$$E_\nu + m_n = E_p + E_\mu$$

$$P_\nu = P_p^{//} + P_\mu^{//}$$

$$E_\nu = \frac{m_N E_\mu - m_\mu^2 / 2}{m_N - E_\mu + P_\mu \cos\vartheta_\mu}$$

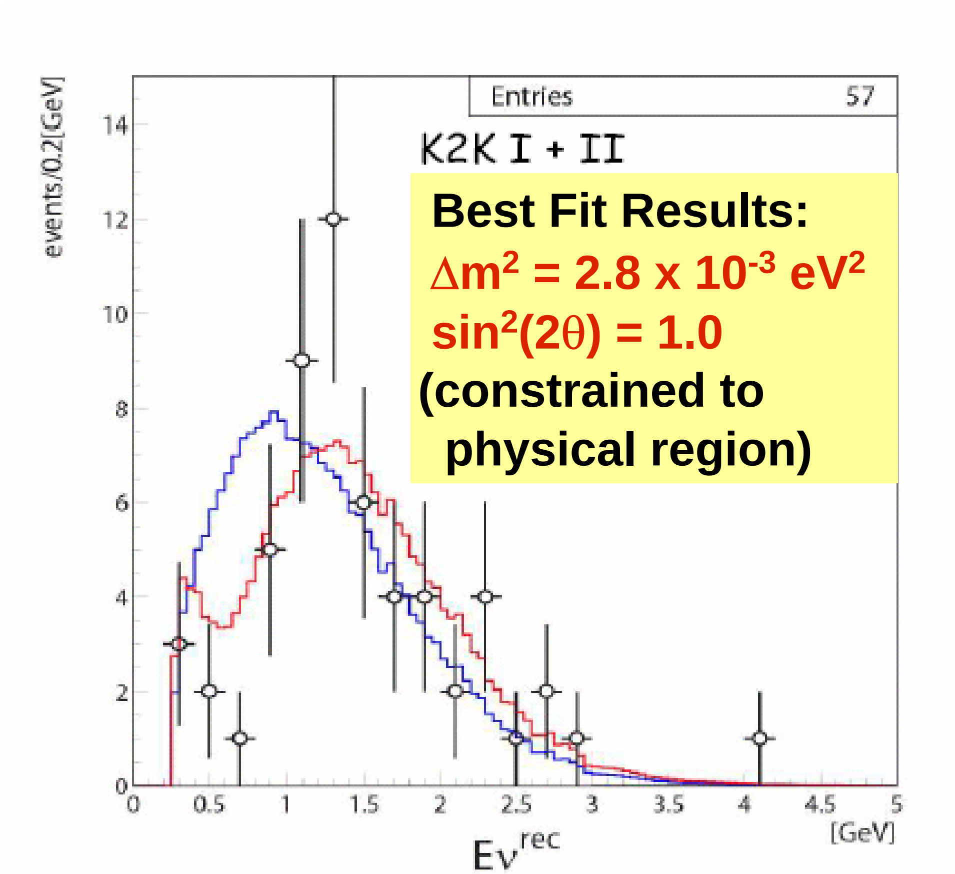
K2K timing

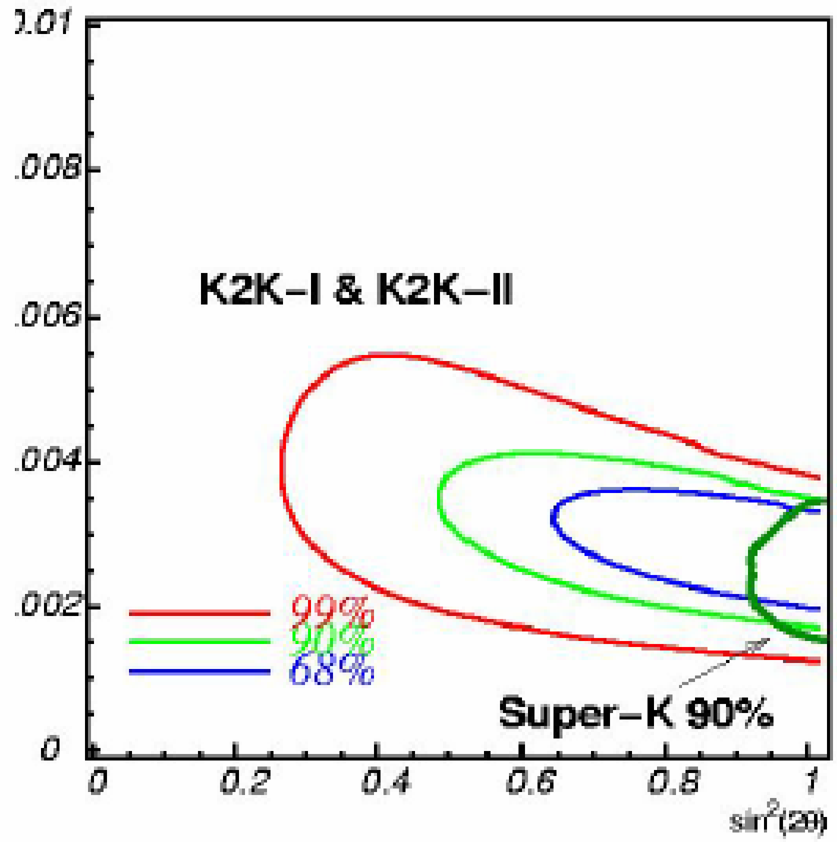


GPS
SK Events
SK
K2K-1+2 Jun1999 - Feb2004
T spill
TOF=0.83msec
T SK
Decay electron cut.
≥20MeV Deposited Energy
±500μsec
No Activity in Outer Detector
Event Vertex in Fiducial Volume
More than 30MeV Deposited Energy
Tdiff(μs)
±5μsec
Analysis Time Window
108 events
−0.2<T SK −T spill −TOF<1.3μsec
(BG: 1.6 events within ±500μs
2.4• 10-3 events in 1.5μs)
T DIFF. (μs)
8

Recent Atmospheric Sector Measurements

➢ K2K Long Baseline Accelerator (KEK to Kamioka)





Single-ring μ-like events

Total 107 beam events observed; expect 149.7

K. Scholberg, WIN05

No-oscillation excluded at $>4\sigma$

Consistent with SK atmospheric ν's

1 Kt flux measurements

4.1 1KT Flux measurement

- The same detector technology as Super-K.
- Sensitive to low energy neutrinos.

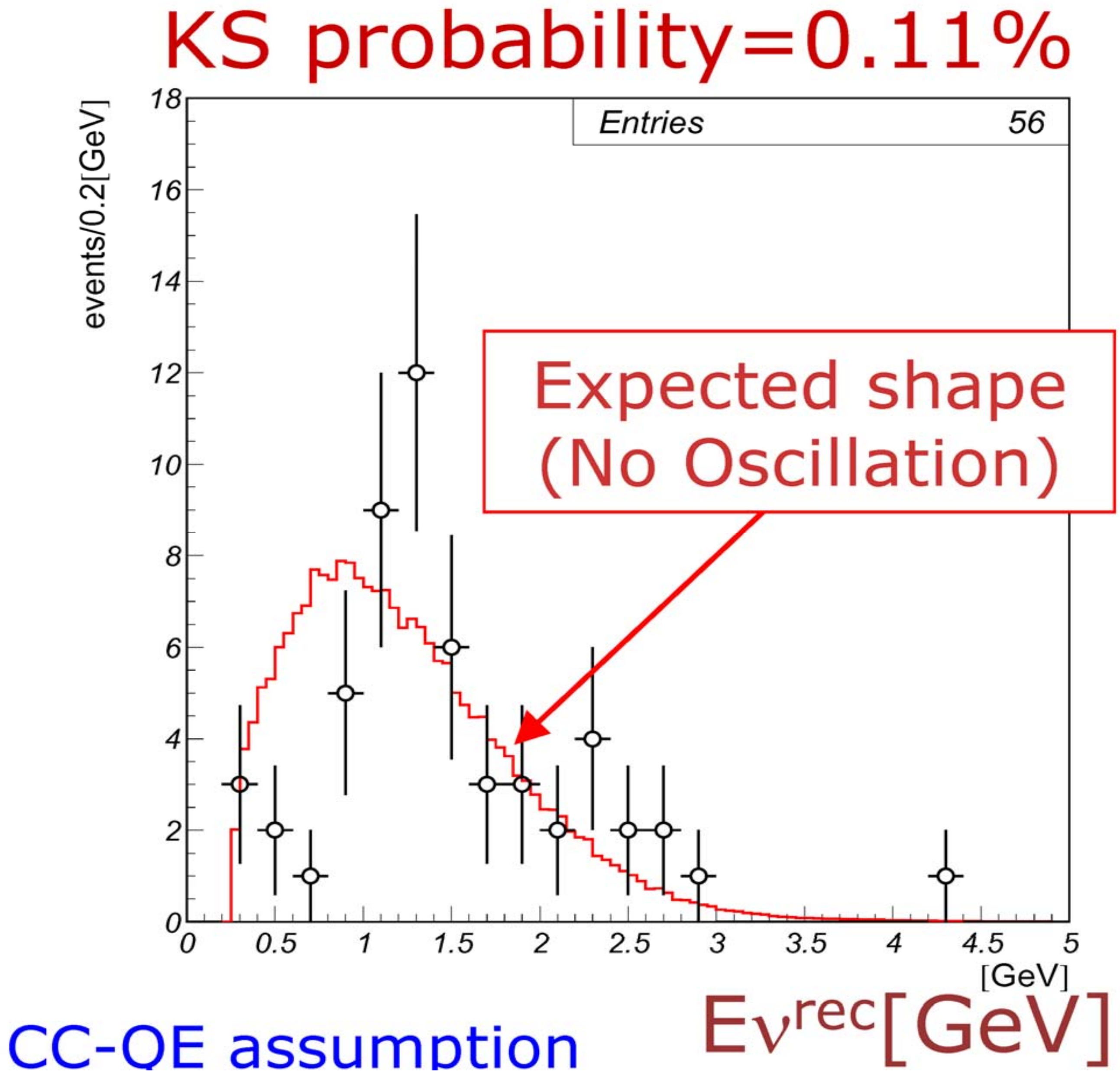
$$N_{SK}^{\exp} = N_{KT}^{obs} \bullet \boxed{\frac{\int \Phi_{SK}(E_\nu)\sigma(E_\nu)dE_\nu}{\int \Phi_{KT}(E_\nu)\sigma(E_\nu)dE_\nu}} \bullet \frac{M_{SK}}{M_{KT}} \bullet \frac{\varepsilon_{SK}}{\varepsilon_{KT}}$$

$\equiv$Far/Near Ratio (by MC)~1×10^{-6}

M: Fiducial mass M_{SK}=22,500ton, M_{KT}=25ton
ε: efficiency $\varepsilon_{SK\text{-}I(II)}$=77.0(78.2)%, ε_{KT}=74.5%

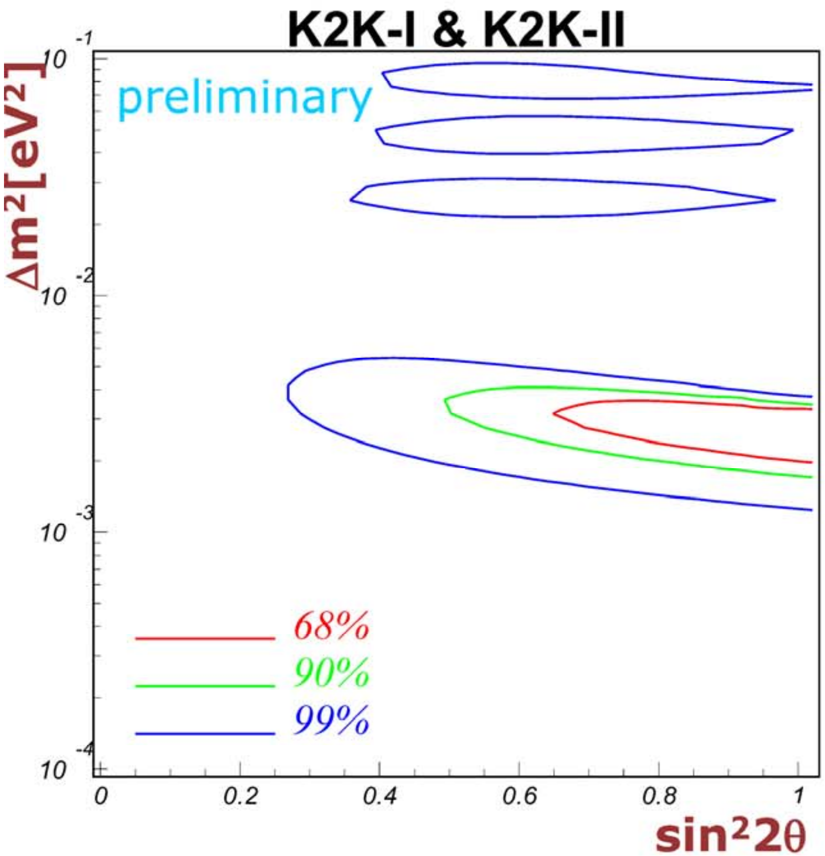
$\boxed{N_{SK}^{exp}=150.9^{+11.6}_{-10.0}}$ ⟺ $\boxed{N_{SK}^{obs}=108}$

K2K spectrum



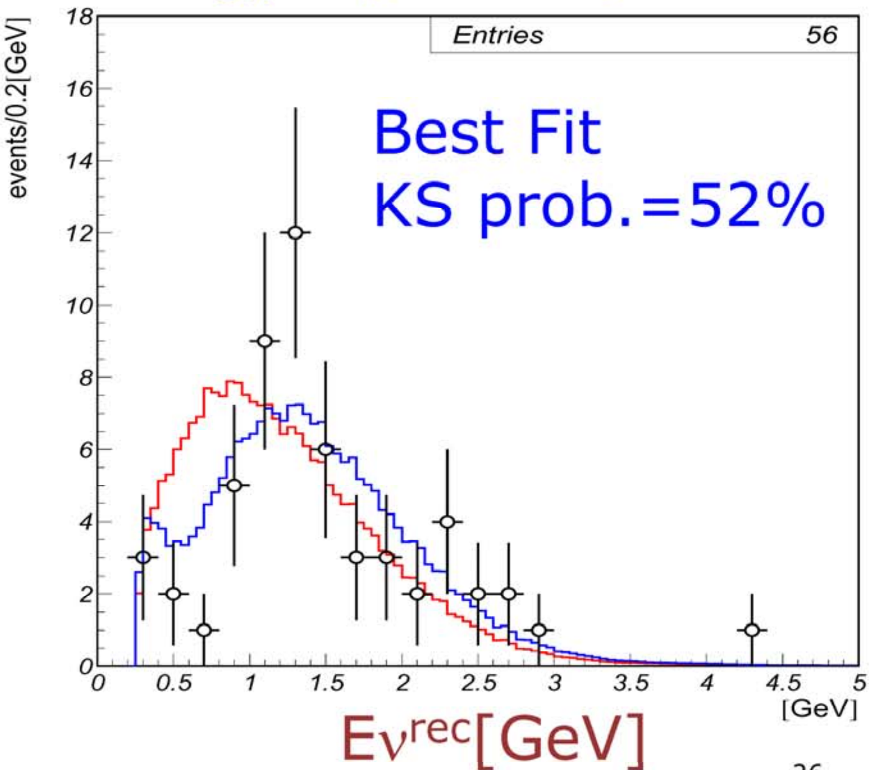
K2K results

Data are consistent with the oscillation.



Based on ΔlnL

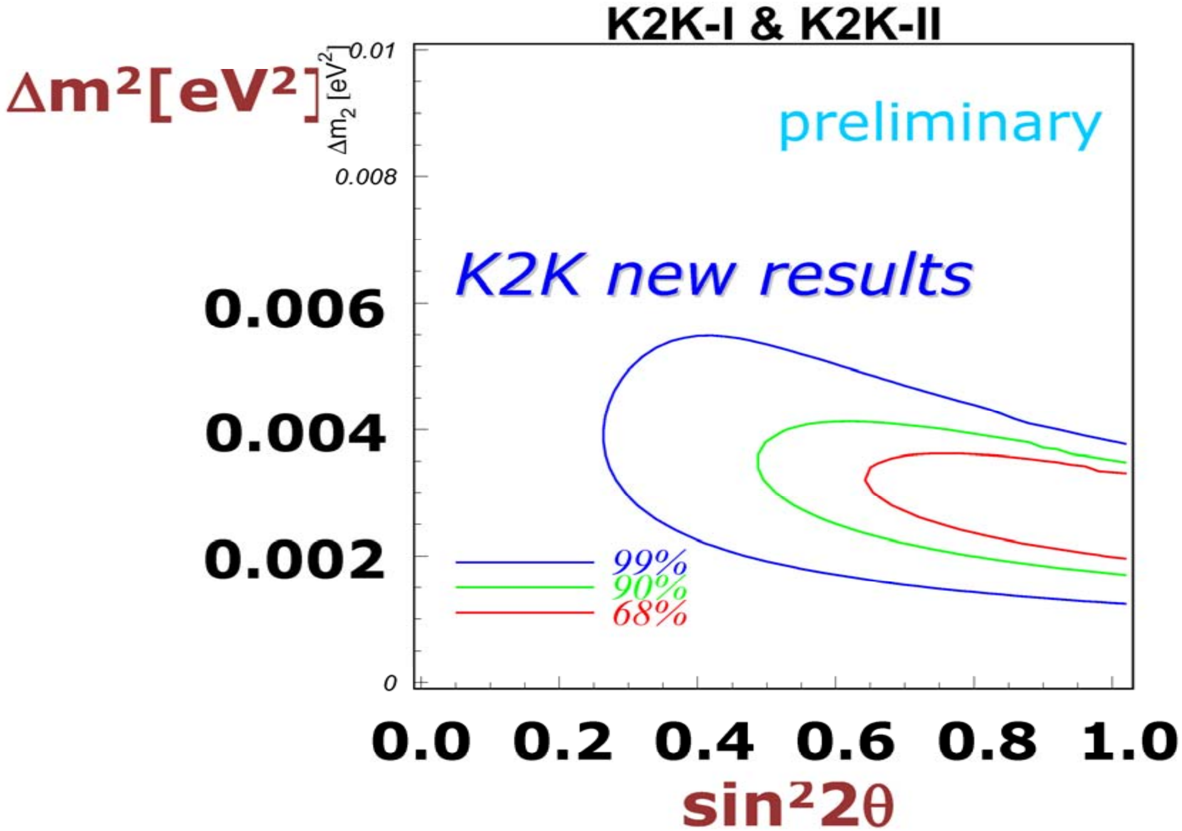
- $N_{SK}^{obs}=108$
- N_{SK}^{exp} (best fit)=104.8



K2K conclusions

With 8.9×10^{19} POT, K2K *has confirmed* neutrino oscillations at **3.9σ**.

- Disappearance of ν_μ **2.9σ**
- Distortion of E_ν spectrum **2.5σ**



Risultati di K2K per δm^2 e $\sin^2 2\theta$

$\delta m^2 \sim (1.5\text{-}3.9)\ 10^{-3}\ eV^2$

$\sin^2 2\theta$ consistente con il valore 1

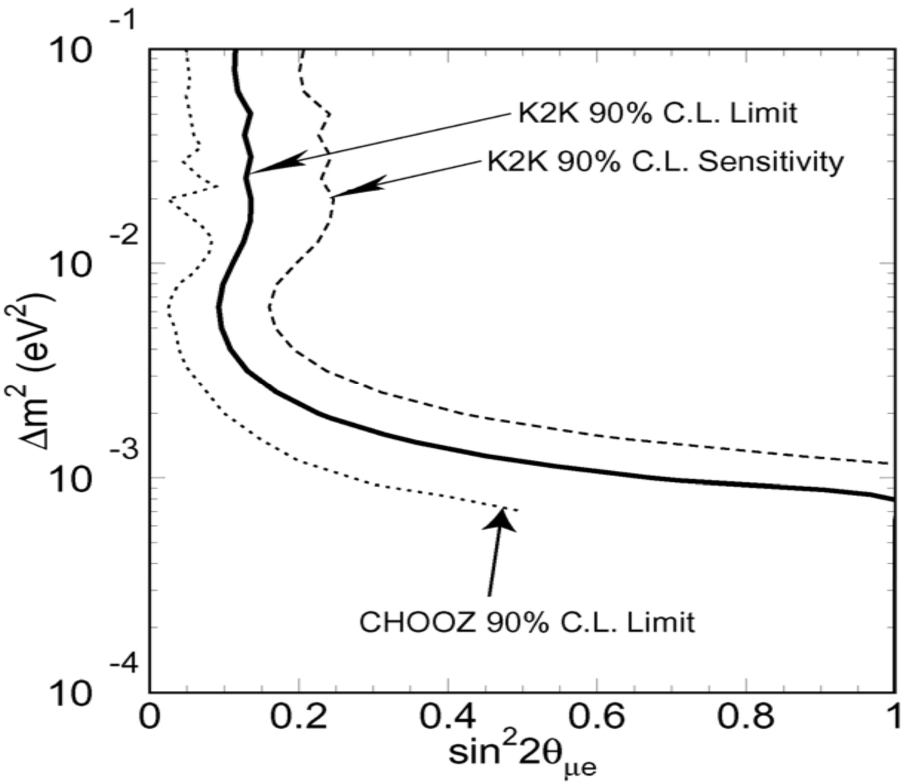


FIG. 2: The confidence interval for $\nu_\mu \rightarrow \nu_e$ oscillations as a function of the effective $\Delta m^2_{\mu e}$ at 90% C.L. (solid line). Dashed line indicates 90% C.L. sensitivity of the experiment for the current statistics. The area to the right of each curve is excluded. Dotted line shows the limit at 90% C.L. by CHOOZ assuming $\sin^2 2\theta_{\mu e} = \frac{1}{2} \sin^2 2\theta_{13}$.