Precision Measurement of Neutrino Oscillation Parameters with KamLAND

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for the KamLAND Collaboration

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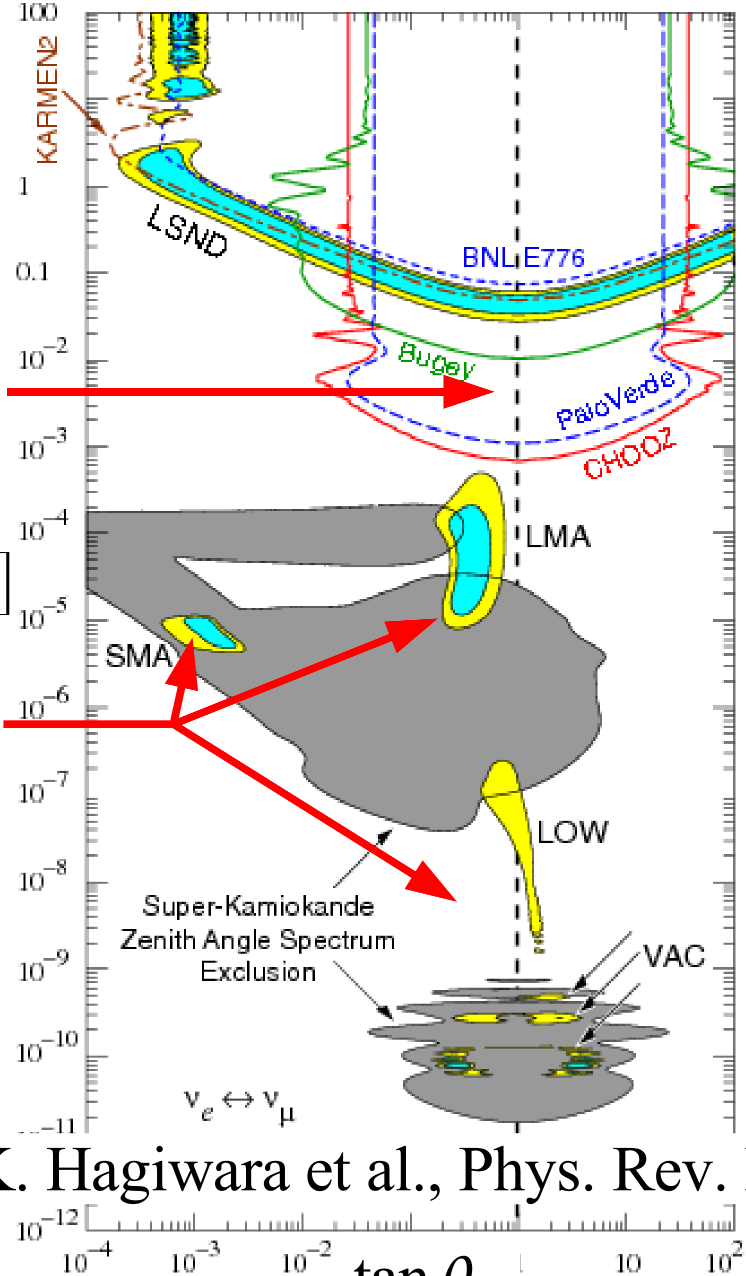
Motivation for KamLAND

Probe Solar LMA using reactor $\bar{\nu}_e$

Excluded by reactor $\bar{\nu}_e \rightarrow \bar{\nu}_e$ experiments

Allowed by solar $\nu_e \rightarrow \nu_e$ experiments

$\Delta m^2_{21} [eV^2]$



$\tan \theta_{12}$

K. Hagiwara et al., Phys. Rev. D66, 010001 (2002)

- Reactor source is known
- Independent of solar physics

KamLAND Collaboration

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- **Louisiana State University:** S.Dazeley
- **Stanford University**: K.Downum, G.Gratta, K.Tolich
- **University of Tennessee**: W.Bugg, Y.Efremenko, Y.Kamyshkov, O.Perevozchikov
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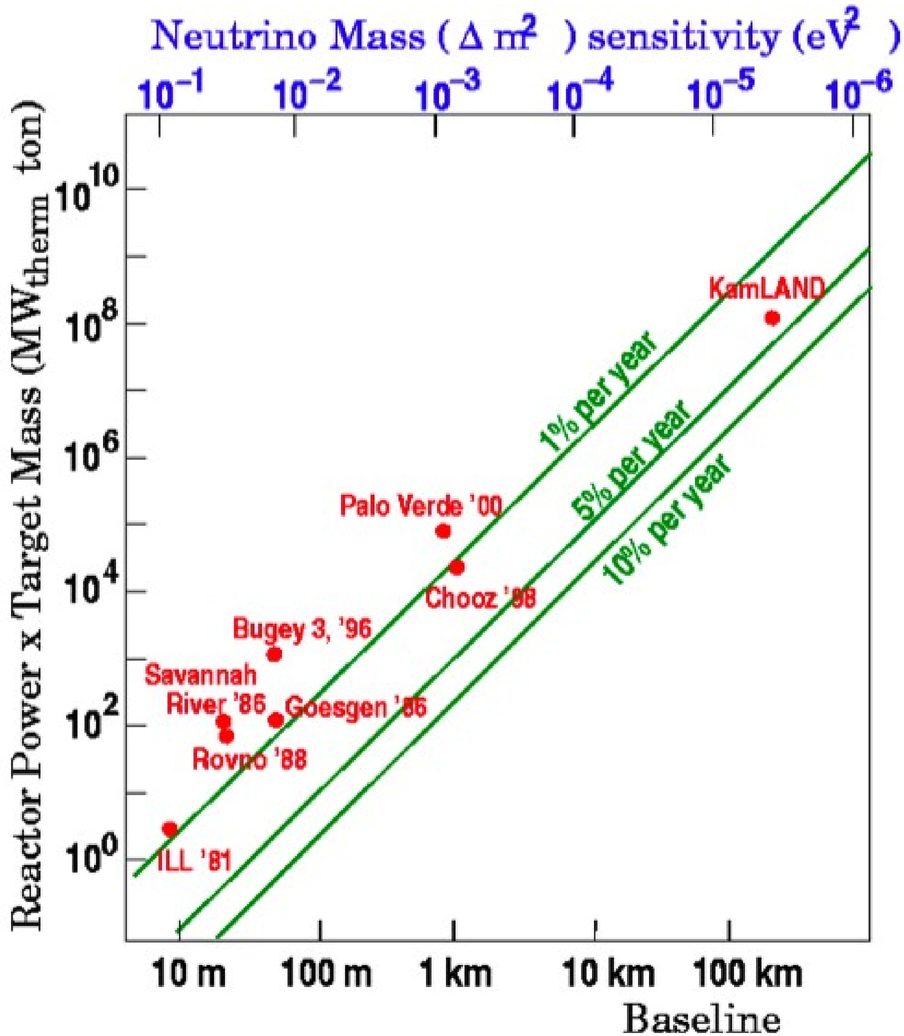
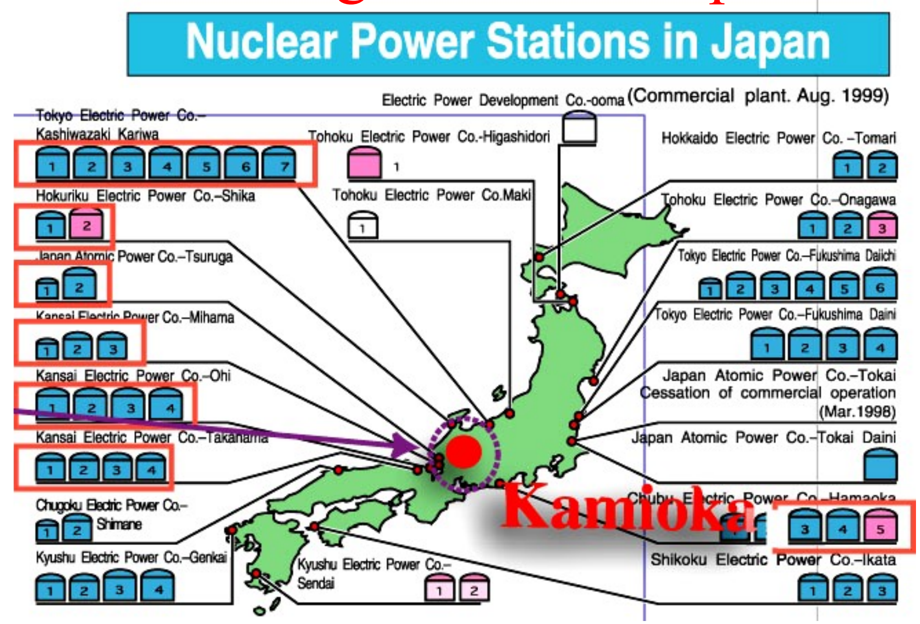
- **CEN Bordeaux-Gradignan:** F.Piquemal, J.-S.Ricol

Requirements

$$L_{osc} \sim \frac{E(MeV)}{\Delta m^2_{LMA}(eV^2)} \sim 100\,km$$



~12% of global nuclear power



Baseline: ~180 km average

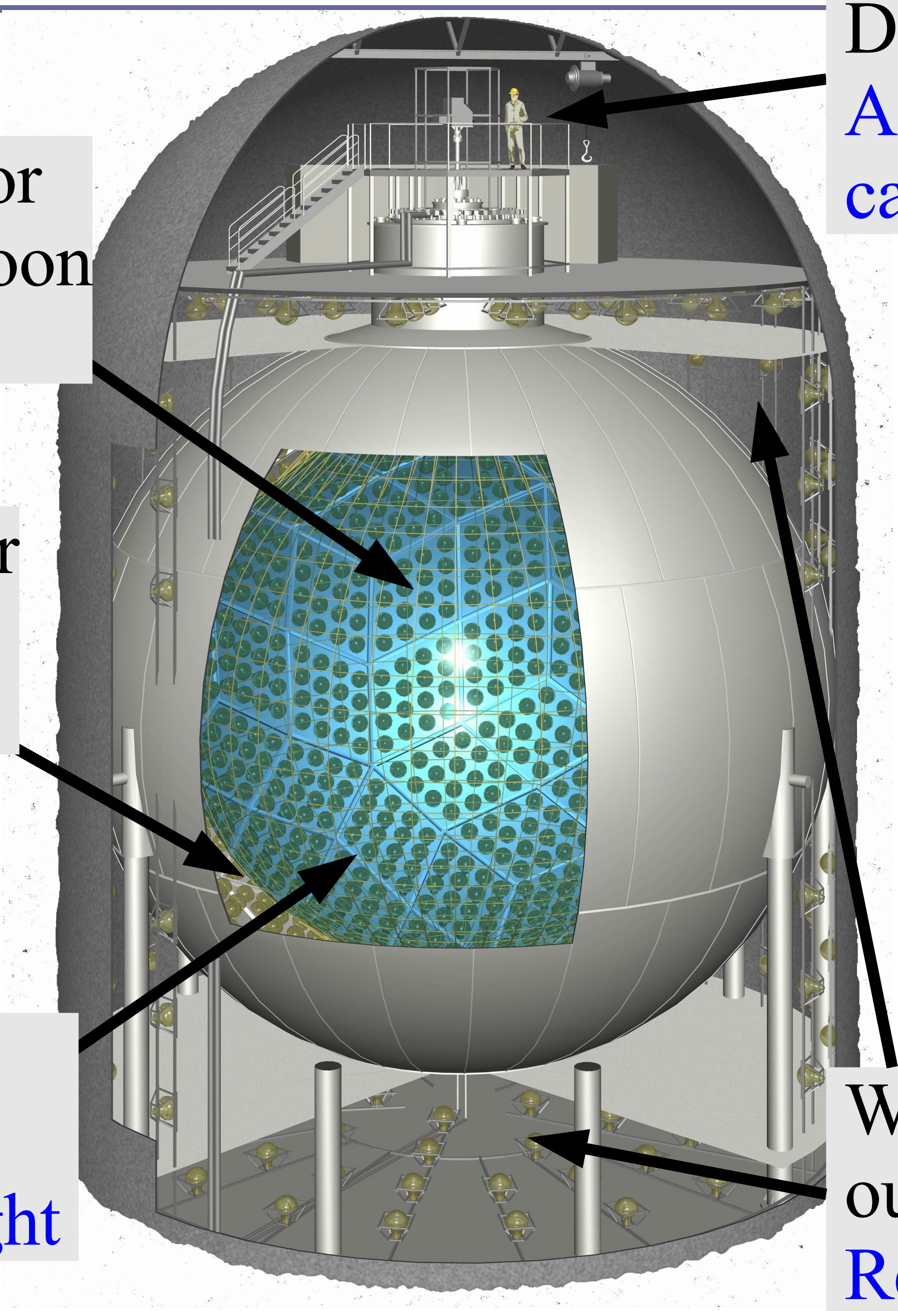
Target Mass: 1 kiloton

KamLAND Detector

1 kton liquid scintillator inside transparent balloon
Active target

2.5m mineral oil buffer outside balloon
Shields scintillator

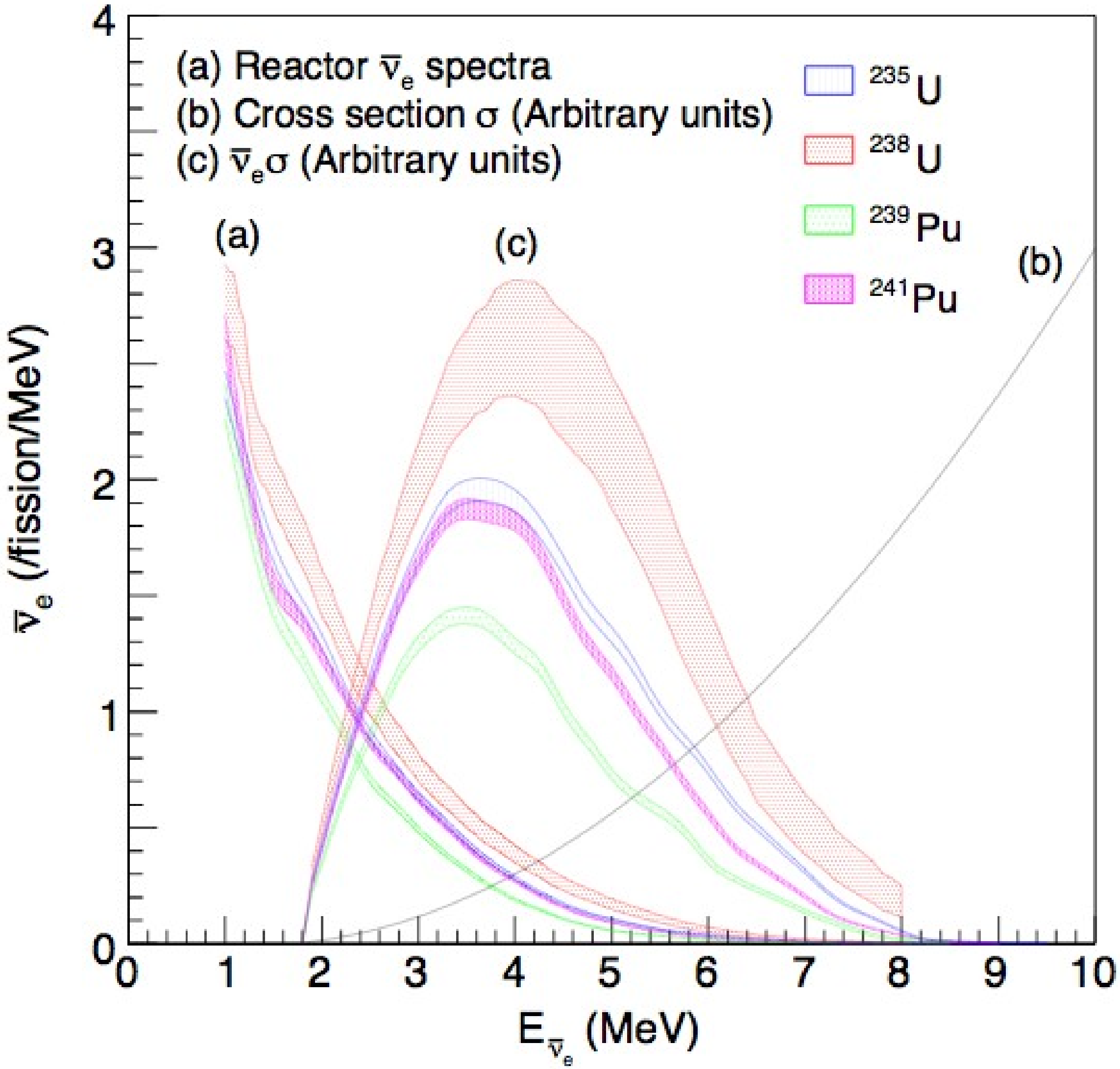
1879 Photomultipliers mounted on sphere
Detect scintillation light



Dome area
Access detector for calibration

Water Cherenkov outer detector
Rejects cosmic rays

Reactor Antineutrino Detection



Reaction Process: inverse β-decay

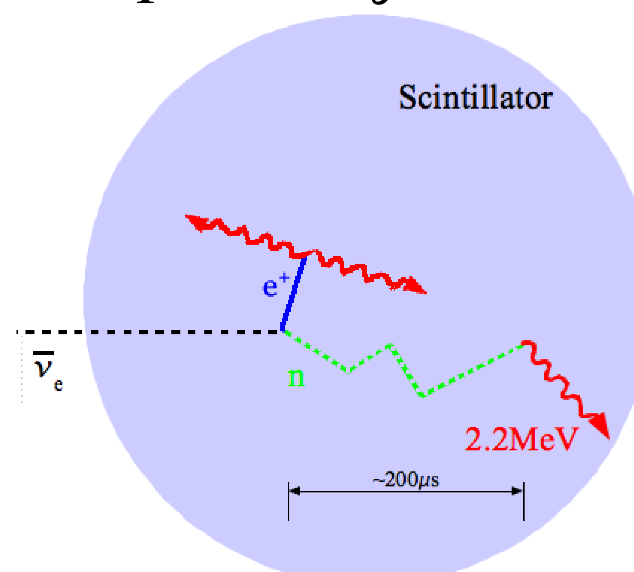
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Threshold: 1.8 MeV

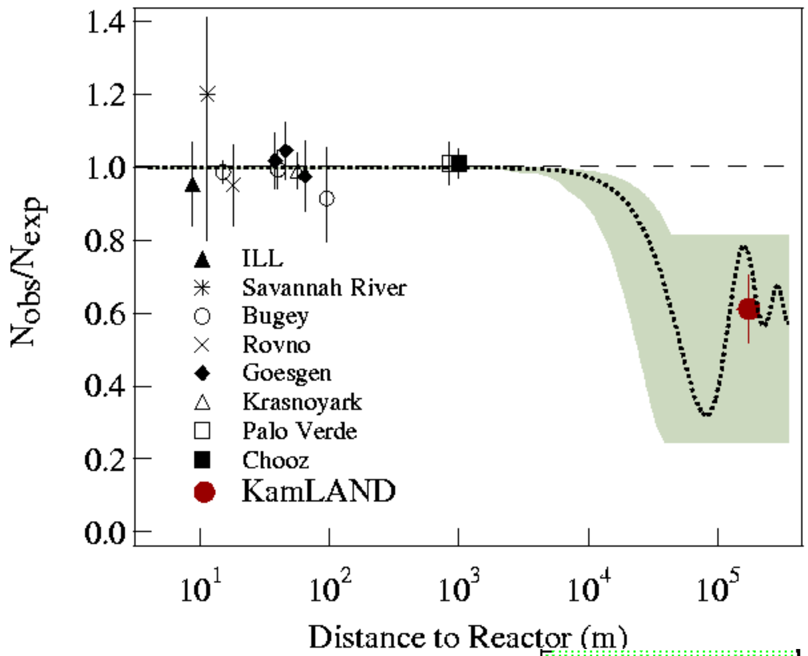
$$E_{e^+} \approx E_\nu - 0.8\ MeV$$

Delayed neutron capture (~200us)

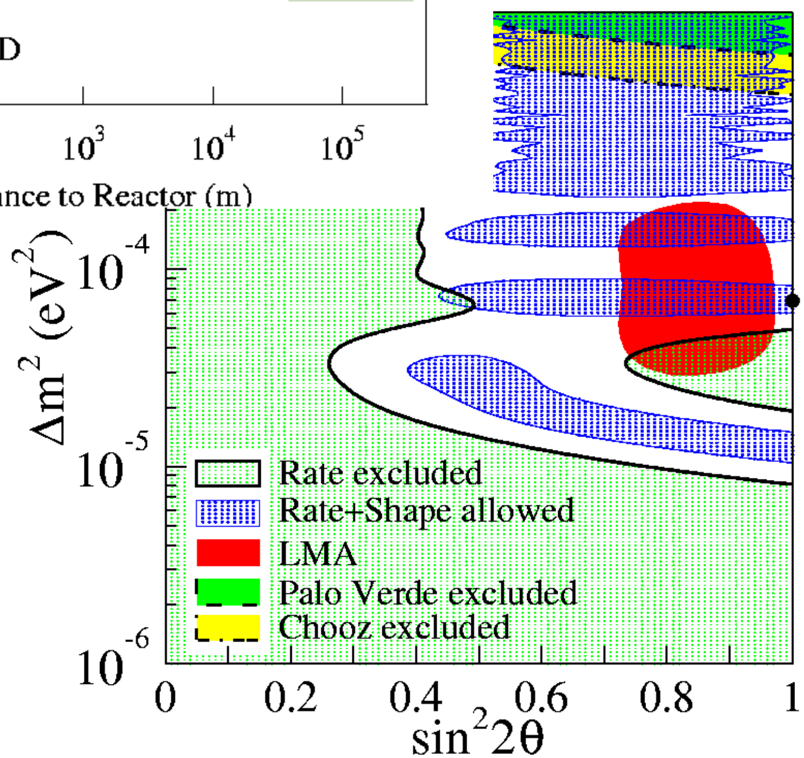
$$n + p \rightarrow d + \gamma$$



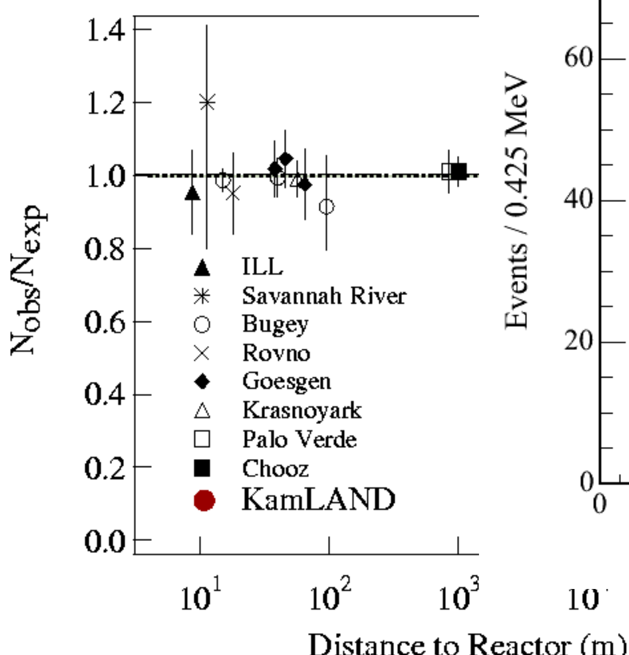
Past Results

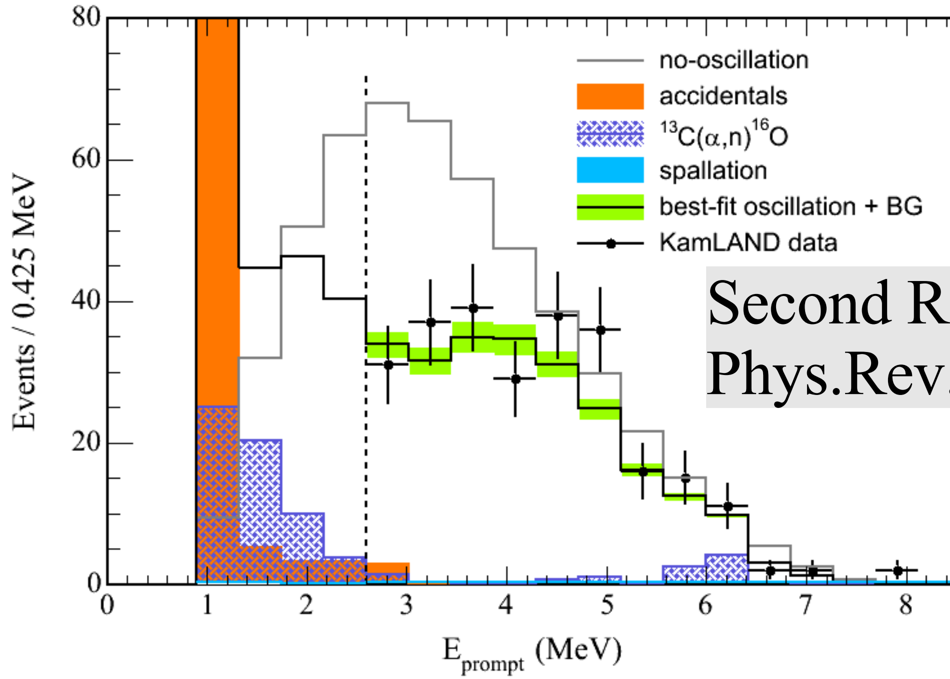


First Reactor Results,
Phys.Rev.Lett. 90, 021802 (2003)

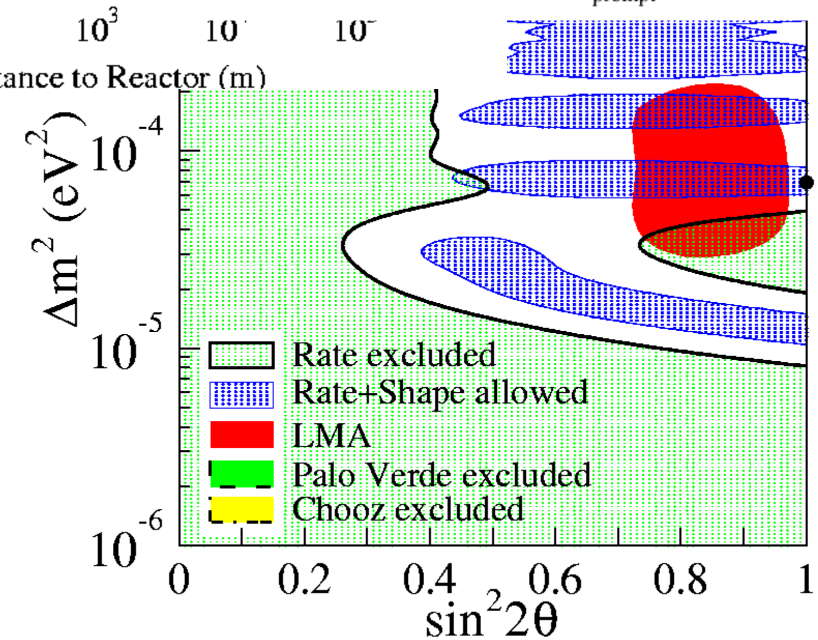


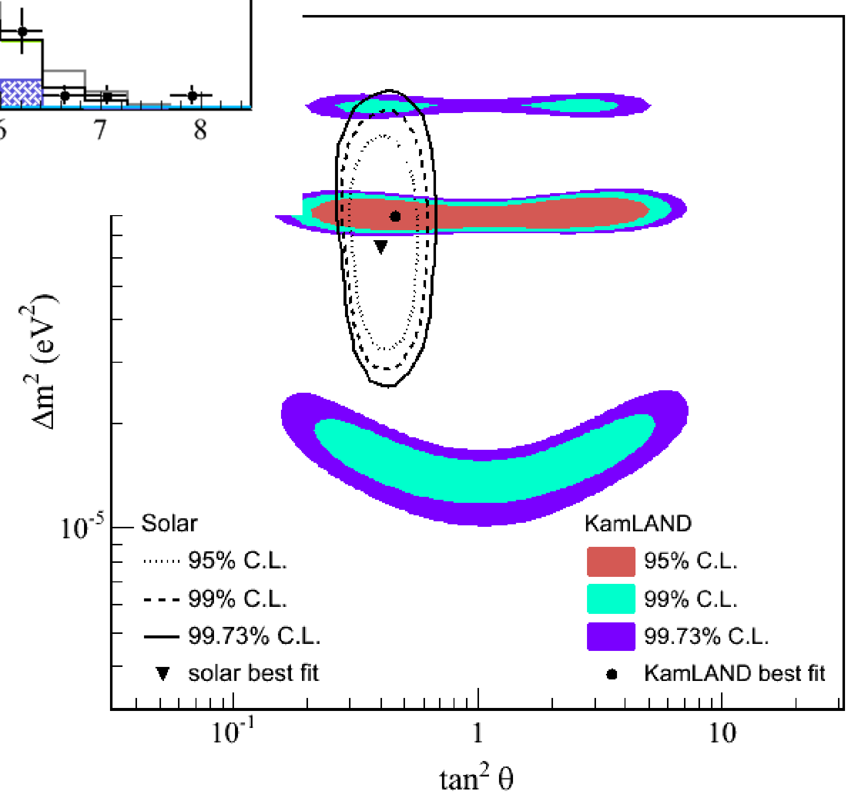
Past Results





Second Reactor Results,
Phys.Rev.Lett. 94, 081801 (2005)

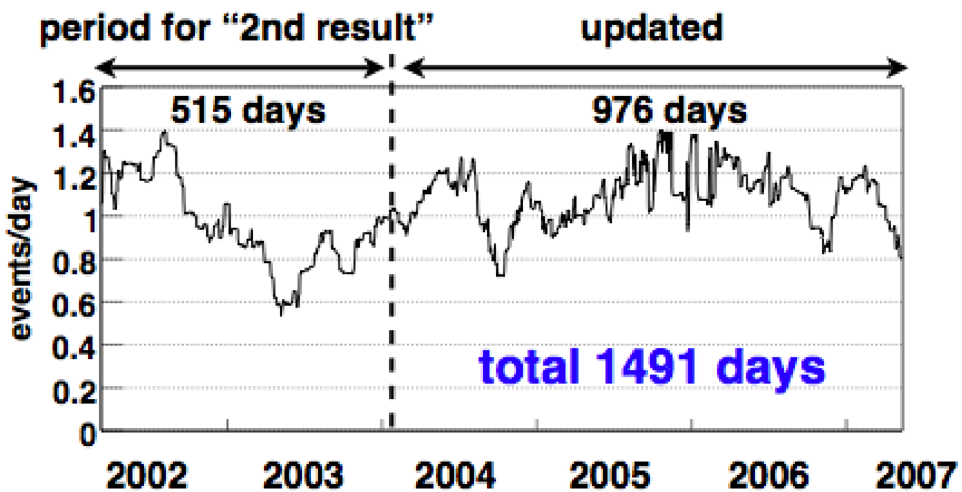




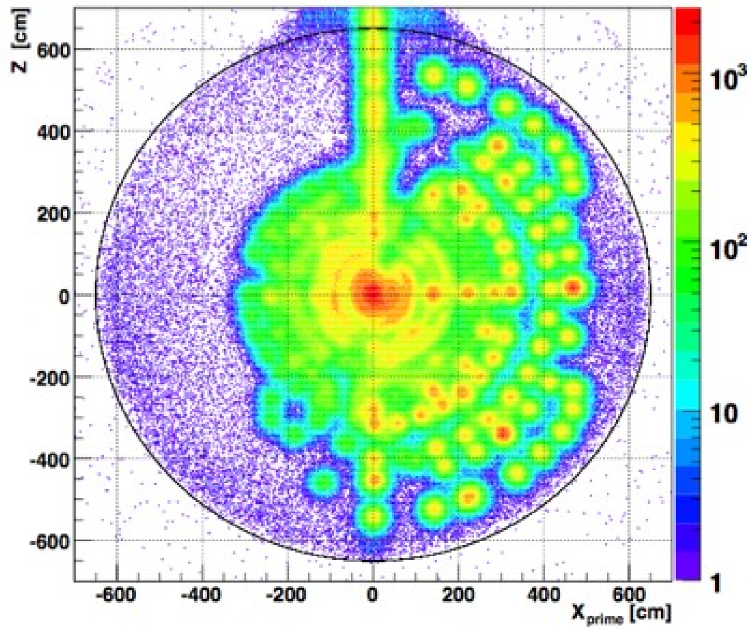
New Results

Improvements

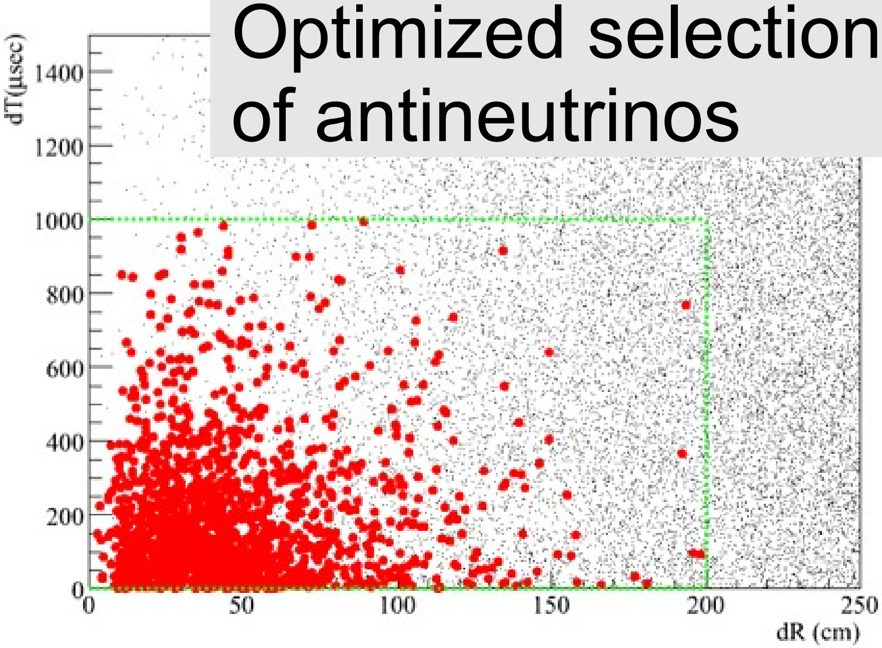
3x previous runtime



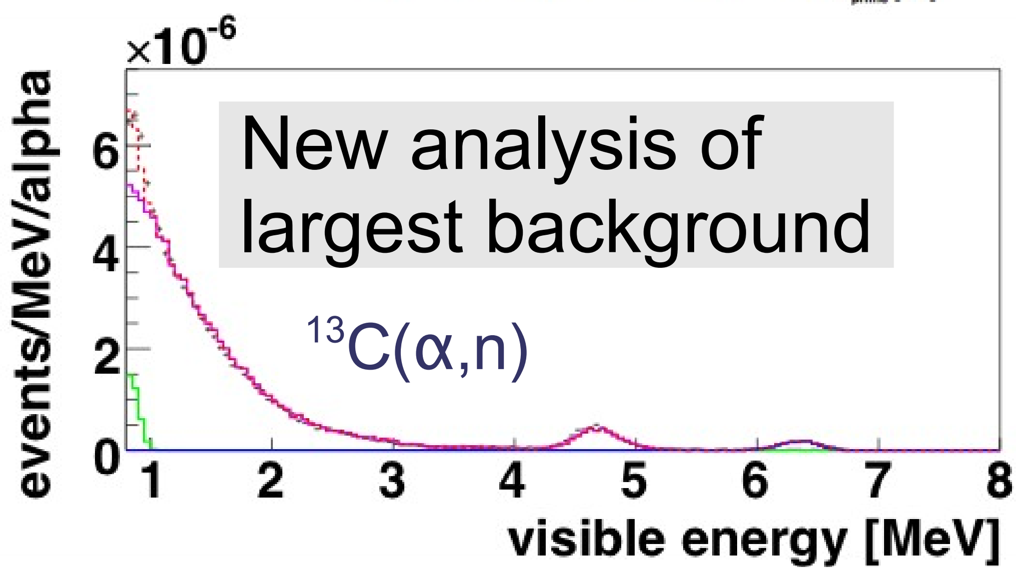
New calibration system



Optimized selection of antineutrinos



New analysis of largest background



Systematic Uncertainties

	Detector-related (%)		Reactor-related (%)	
Δm^2_{21}	Energy scale	1.9	$\overline{\nu}_e$-spectra [7]	0.6
Event rate	Fiducial volume	1.8	$\overline{\nu}_e$-spectra	2.4
	Energy threshold	1.5	Reactor power	2.1
	Efficiency	0.6	Fuel composition	1.0
	Cross section	0.2	Long-lived nuclei	0.3

Total Systematic Uncertainty:

Δm^2_{21}: 2.0% Event rate: 4.1%

Signal and Background Summary

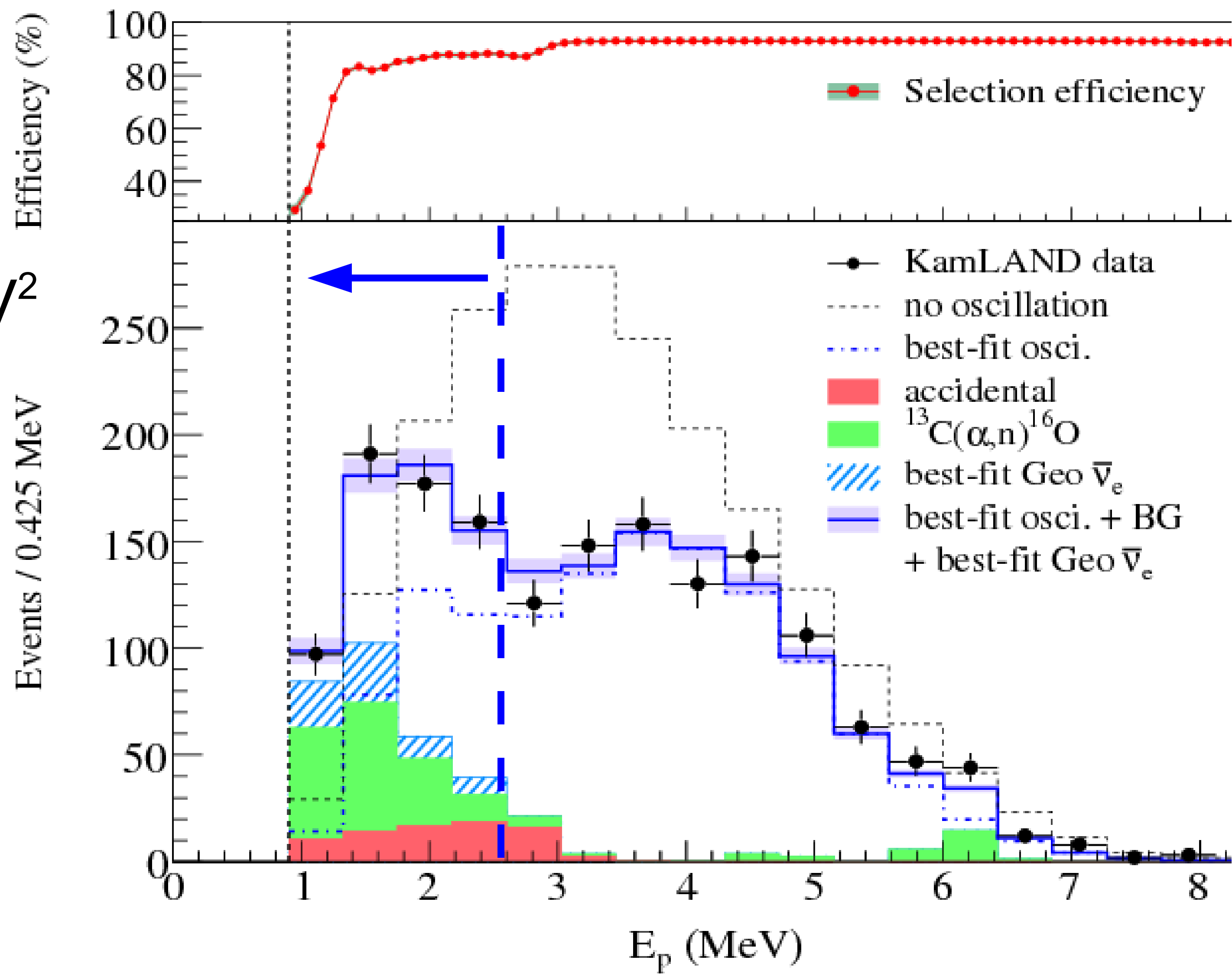
Background	Contribution
Accidentals	80.5 ± 0.1
^{9}Li/^{8}He	13.6 ± 1.0
Fast neutron & Atmospheric ν	<9.0
^{13}C(α,n)^{16}O G.S.	157.2 ± 17.3
^{13}C(α,n)^{16}O ^{12}C(n,nγ)^{12}C (4.4 MeV γ)	6.1 ± 0.7
^{13}C(α,n)^{16}O 1st exc. state (6.05 MeV e^+e^-)	15.2 ± 3.5
^{13}C(α,n)^{16}O 2nd exc. state (6.13 MeV γ)	3.5 ± 0.2
Total	276.1 ± 23.5

According to reactor flux:

Expected events (no oscillation): 2179 ± 89

Detected events: 1609

Full Spectral Analysis



Best Fit:

$\Delta m^2 = 7.58 \times 10^{-5}\ eV^2$

$\tan^2\theta = 0.56$

Geo-neutrinos:

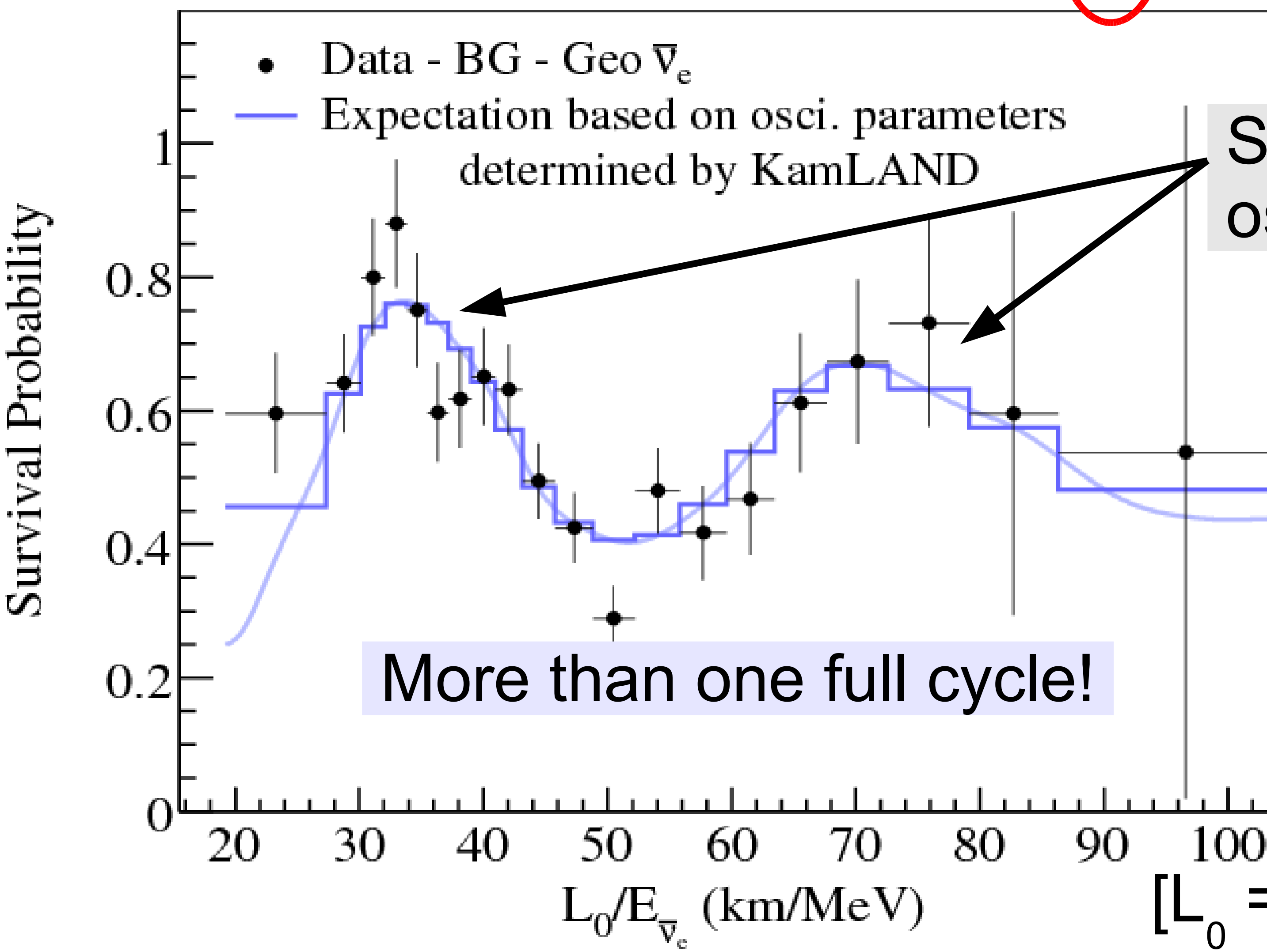
73 ± 27 events

Threshold moved to 0.9 MeV

Each energy bin an oscillation measurement!

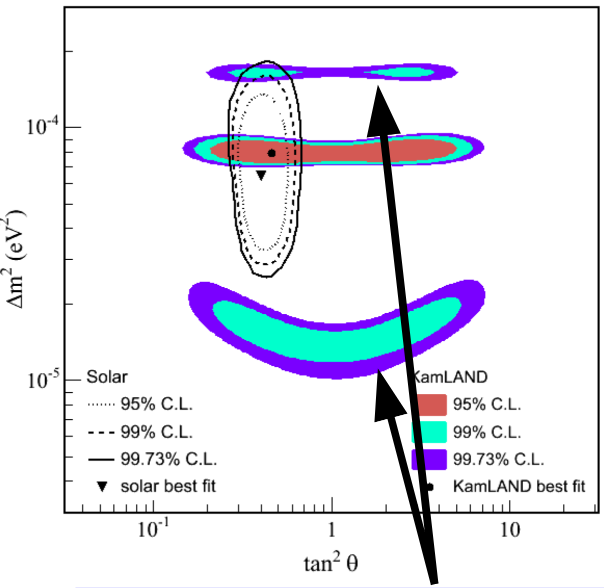
Neutrino Oscillation

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2(2\theta_{12}) \sin^2 \frac{\Delta m^2_{21} L}{4E}$$



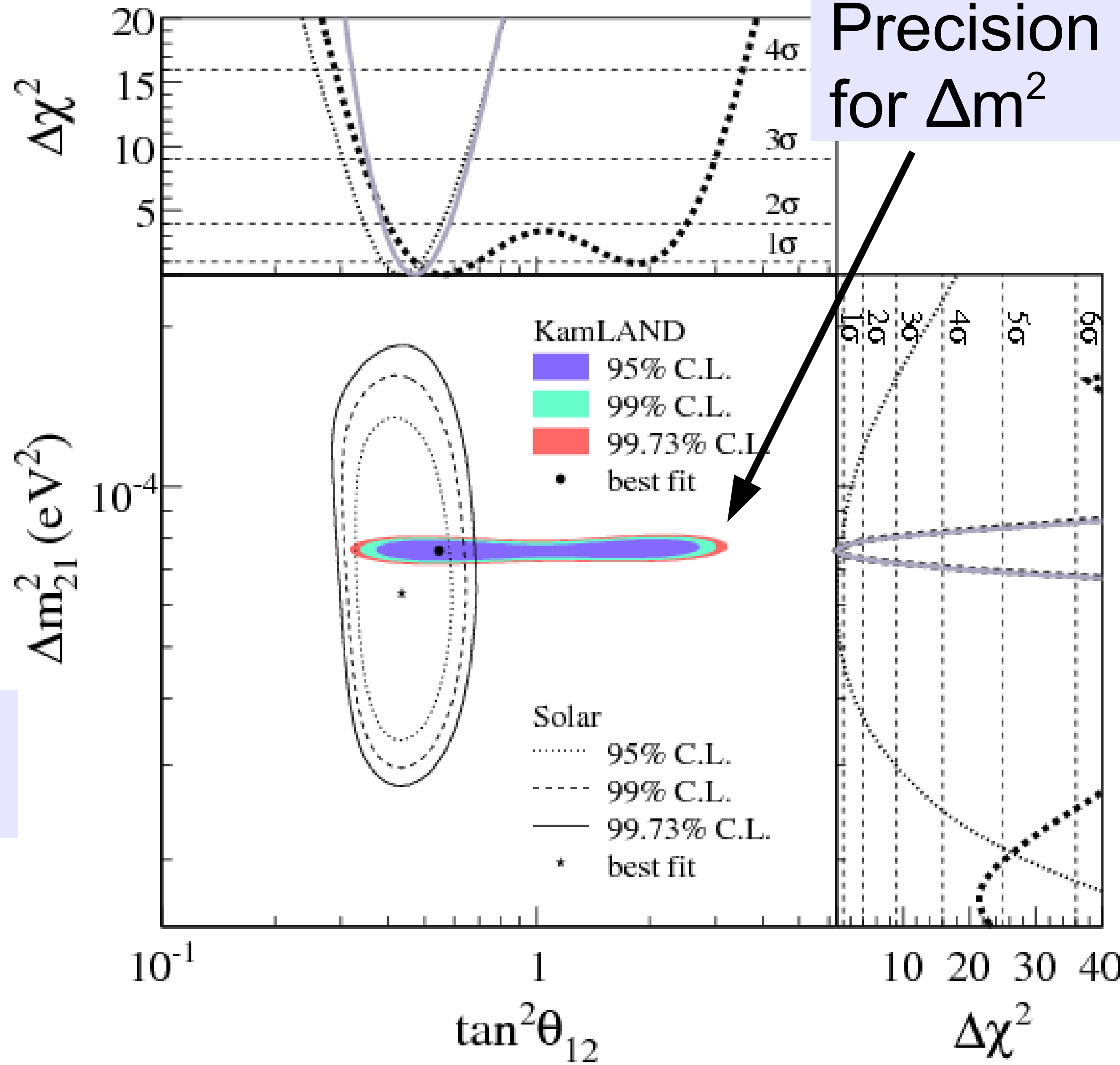
[L_0 = 180 km]

Oscillation Parameters



Previous regions now excluded

Precision value for Δm^2



$\tan^2\theta = 0.56^{+0.14}_{-0.09}$ $\Delta m^2 = 7.58^{+0.21}_{-0.20} \times 10^{-5}$ eV^2

KamLAND Future

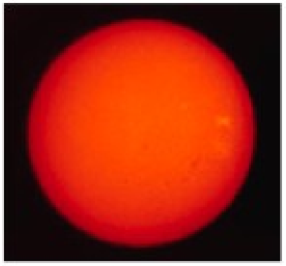
Purification: remove radioactive backgrounds

0.4 — 1.0 — 2.6 — 8.5 — Visible energy [MeV]

neutrino electron elastic scattering
$\nu + e^- \rightarrow \nu + e^-$

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

^{7}Be solar neutrino



Neutrino Astrophysics

Verification of SSM

geo-neutrino

Neutrino Geophysics

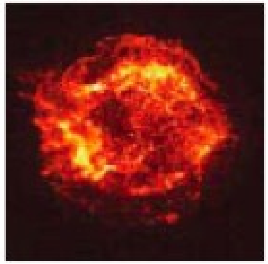
Study of earth heat model

reactor neutrino

Neutrino Physics

Precision measurement of oscillation parameters

supernova, relic neutrino, solar anti-neutrinos etc.



Neutrino Cosmology

Verification of universe evolution, SSM

If backgrounds reduced to 10^{-6}

Purification will improve

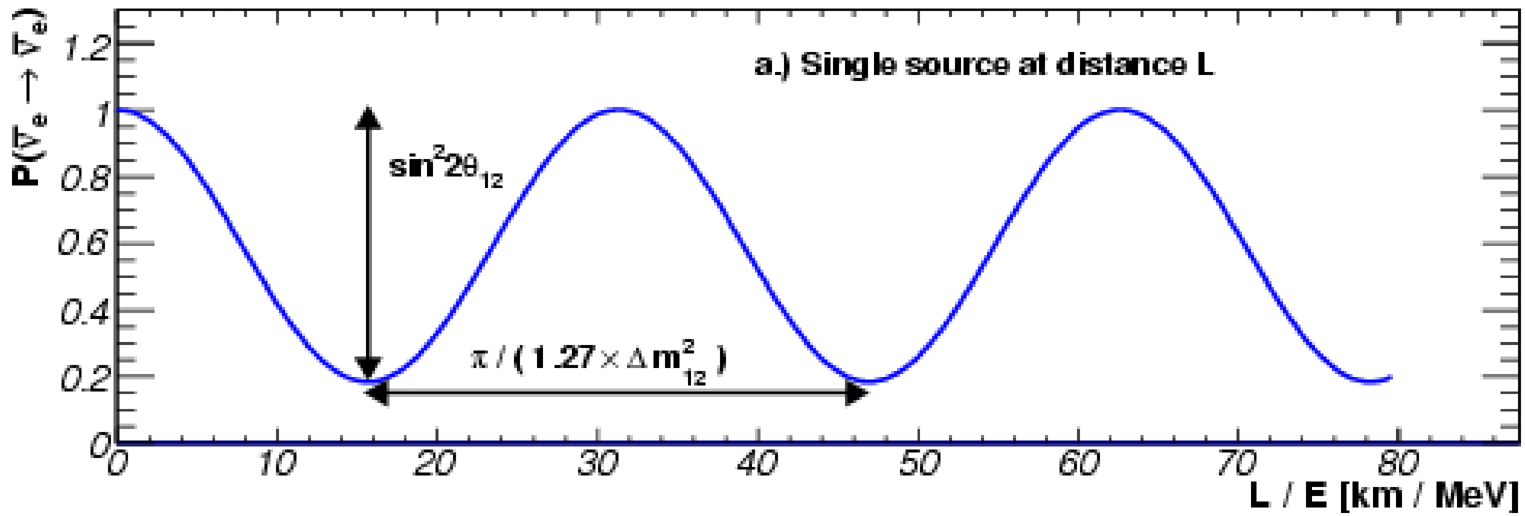
Thank You!

Additional Slides

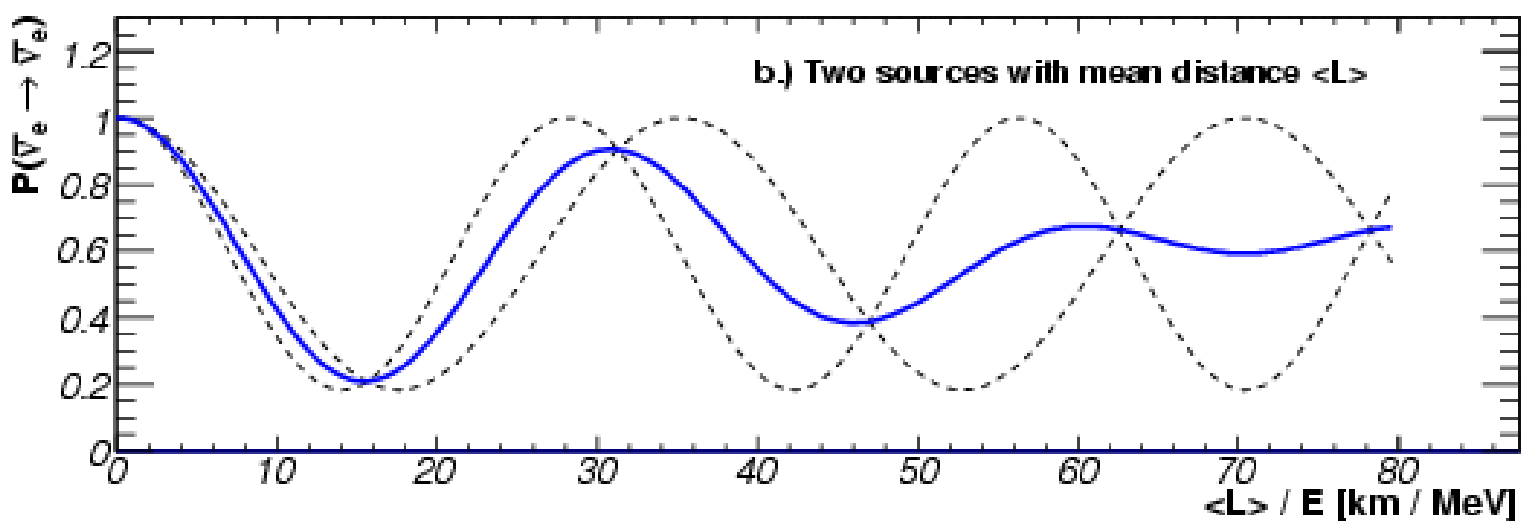
Oscillation Signature

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2(2\theta_{12}) \sin^2 \frac{\Delta m_{21}^2 L}{4E}$$

Single source oscillation in L/E



Distortion from multiple sources



Geoneutrinos