Prospects of Measuring Reactor Antineutrino Anomaly with 3-16 m

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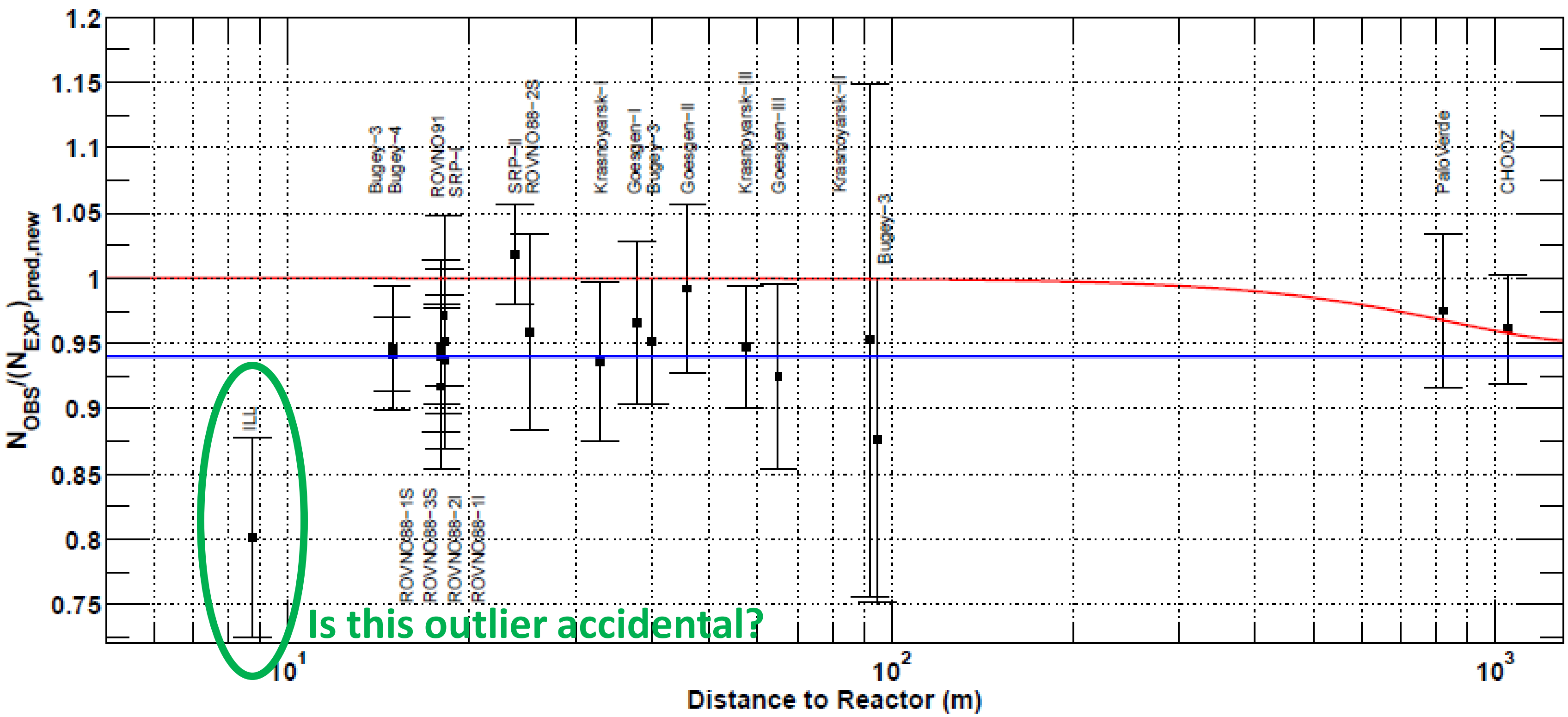
ICHEP 2012, July 6th 2012

Outline

- Motivation: reactor antineutrino anomaly status
- Approaches:
  - Measure reactor spectrum from compact reactor core with close by detector
  - Use very high activity antineutrino source
- PBq source outside of large liquid scintillator detector
- KamLAND detector and its features
- Neutrino rates and spectrum in KamLAND
- Backgrounds
- Sensitivity
- Conclusion

Reactor Antineutrino Anomaly Indication

- Recent calculation of reactor antineutrino spectra showed 3% flux increase → resulted in 98.6% C.L. deviation from unity for reactor antineutrino survival probability for all detectors with < 100 m baseline.
- Possible indication of the 4th neutrino flavor with short oscillation baseline < 10m.
- It became known as a reactor antineutrino anomaly (*arXiv:1101:2755v4*)
- Fortified by results from MiniBOONE and radiochemical neutrino experiments.
- *Some uncertainties in the flux calculation may lead to the same effect (SNAC2011)*



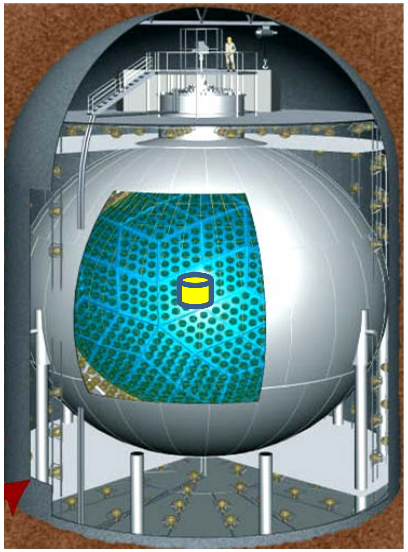
Resolving Reactor Antineutrino Anomaly

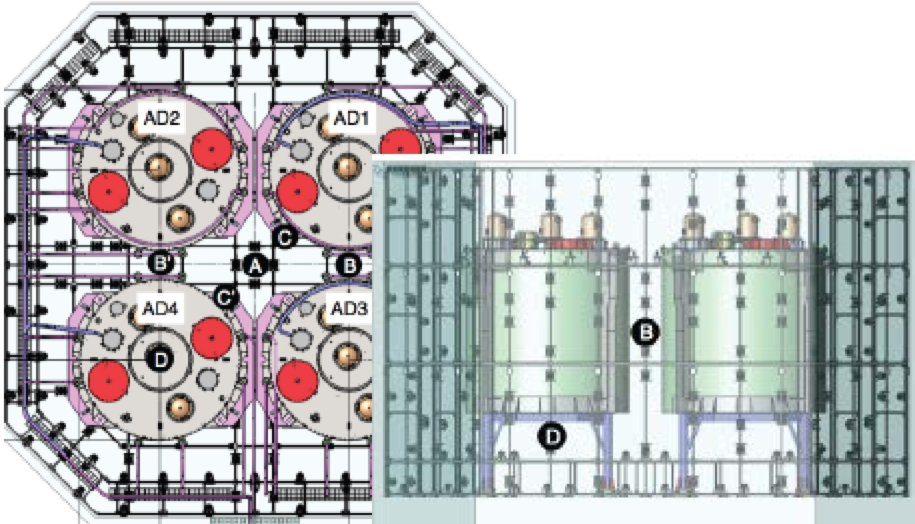
- Need to confirm oscillation pattern with < 10m baseline

- Two proposed ways to confirm or refute reactor antineutrino anomaly:
  - Place detector close to compact reactor core (SCRAAM, NUCIFER, …)
  - **Make a very strong neutrino or antineutrino radioactive source and place it inside or outside of the antineutrino detector**

Proposed Studies so far

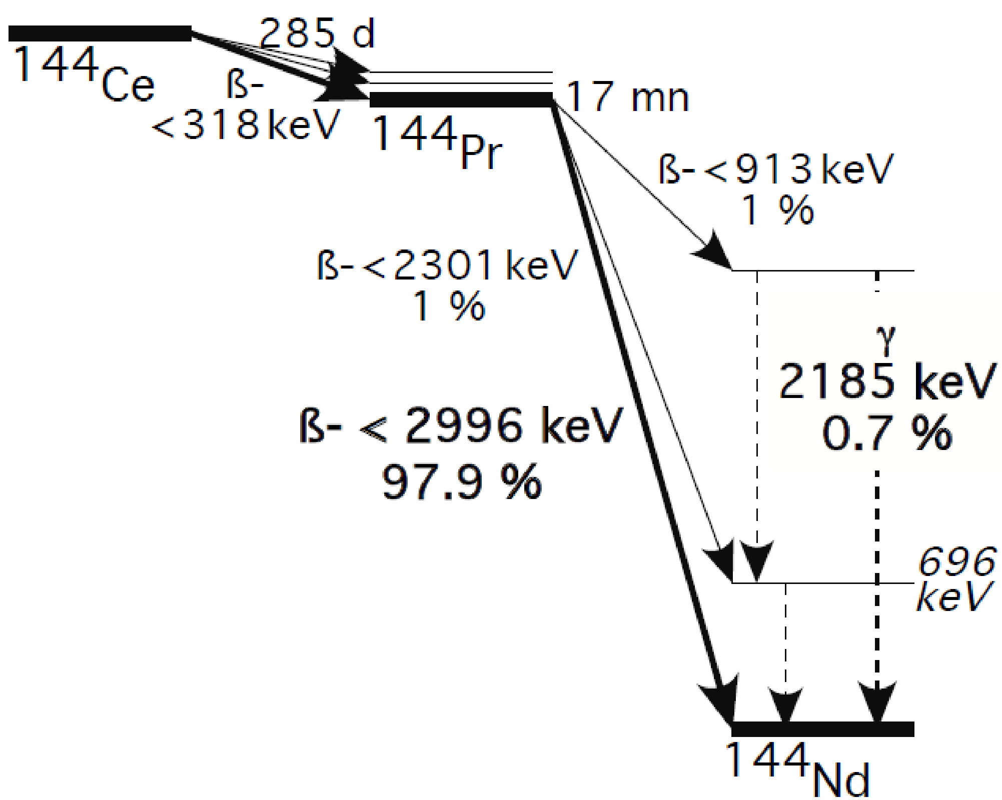
- MCi neutrino source in/or outside Borexino – low energy, monoenergetic
- PBq source in the center of a large liquid scintillator detector such as Borexino, KamLAND or SNO; baseline: 1.5 – 6 m (arXiv: 1107.2335v2)
  - Advantages: 4π coverage; Disadvantage: risk and chimney modifications needed
- 10 PBq source in the veto region of Daya Bay antineutrino detectors; baseline: 1.3-8.5 m (arXiv:1109.6036v1)
  - Advantage: simple deployment; Disadvantage; only fraction of produced neutrinos used





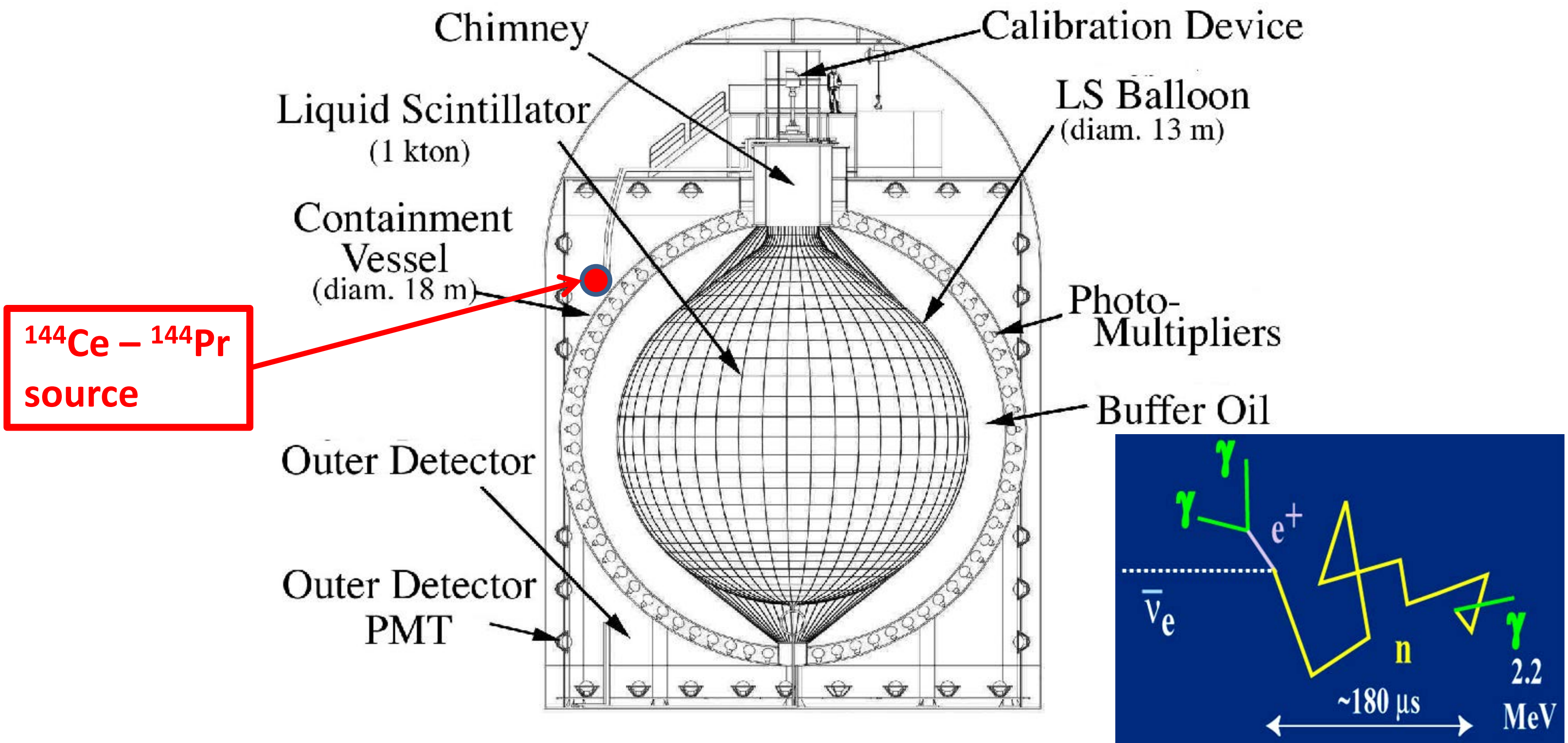
Antineutrino Source

- Must have Q_β > 1.8 MeV and lifetime > several months
- Candidate: ^{144}Ce-^{144}Pr ($t_{1/2}$ = 285 days and Q_β = 2.996 MeV) is contained in SNF and can be extracted by reprocessing (proposed by V. Kornoukhov, ITEP, 1994).
- Extremely challenging process, but possible with sufficient resources
- 250 KCi source ^{144}Ce needs about 70 gr of ^{144}Ce and can be contained within 7cmx7cmx7cm (or 7.5 kg of Ce element)

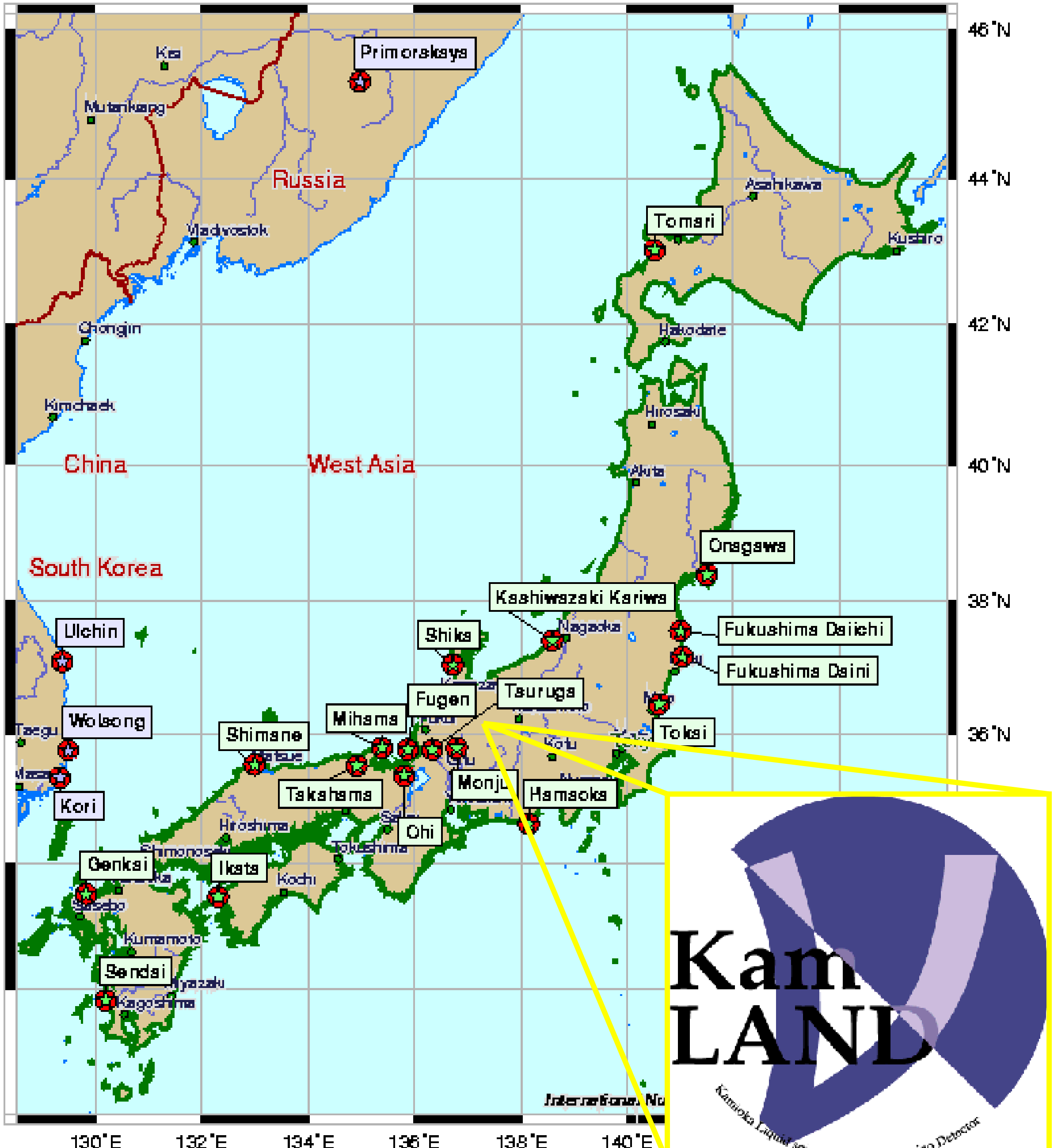


Antineutrino Source Outside KamLAND

- Advantages: safe, relatively simple to deploy through the access hatch of the veto detector, baseline 3.3 – 15.3 m, excellent shielding by 2.5 m thick layer of buffer oil; easier cooling; deployed in water as opposed to flammable scintillator
- Disadvantages: lot of neutrinos lost due to partial solid angle coverage



KamLAND Location



Backgrounds to ^{144}Pr Signal

- As suggested in arXiv: 1107.2335v2, 33 cm thick wolfram and 2 cm thick Cu shielding attenuates energetic gamma rays and bremsstrahlung photons.
- Radioactivity from wolfram itself is sufficiently shielded by 1.5 m thick layer of oil.
- Accidental and correlated backgrounds can mimic double, time correlated anti-neutrino detection signature (accidentals, 8He/9Li, fast neutrons, but the rates in KL are low: ~20 nus/year
- Reactor neutrino rate was 1-2 neutrinos/day when all Japanese reactors were operational, but is negligible now.
- Geoneutrino rate ~18 nus/year

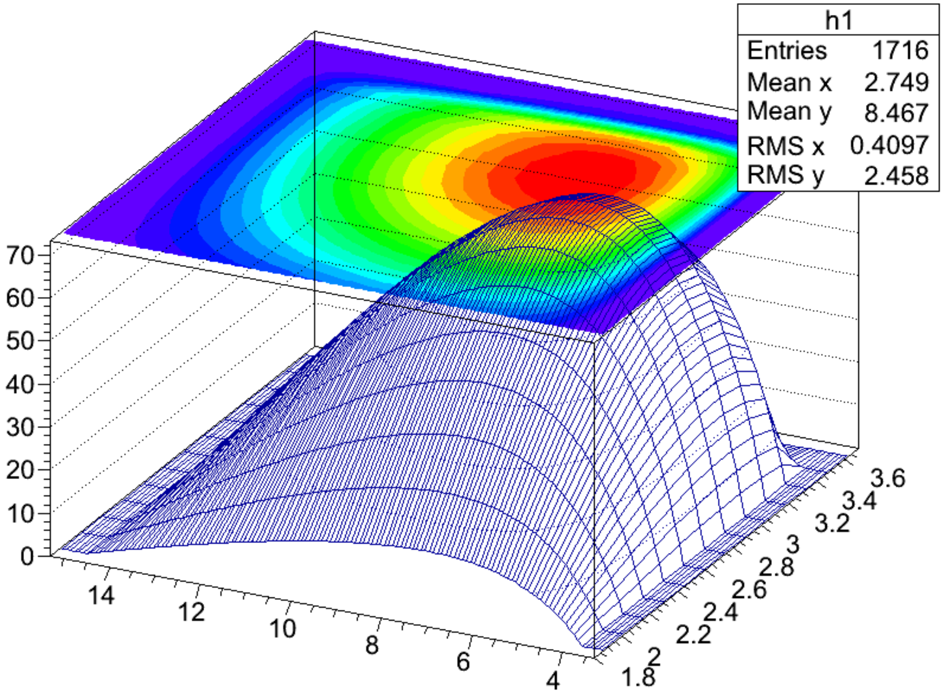
Expected Neutrino Interaction Rate from ^{144}Pr Source

- Use proton density of 5.3×10^{22} cm^{-3}
- Use 100 keV energy bins and 10 cm position bins (different flux due to different solid angle at different positions)
- 250 kCi source for 1 year and $t_{1/2}$ = 285 days for ^{144}Ce
- Vertex resolution ~15 cm
- Energy resolution ~5%
- ~42,000 interactions in no oscillation scenario
- Using $$P = 1 - sin^2(2\theta_{new}) \cdot sin^2(\frac{1.27\Delta m^2_{new} L[m]}{E[MeV]})$$
- We get ~40,000 interactions for

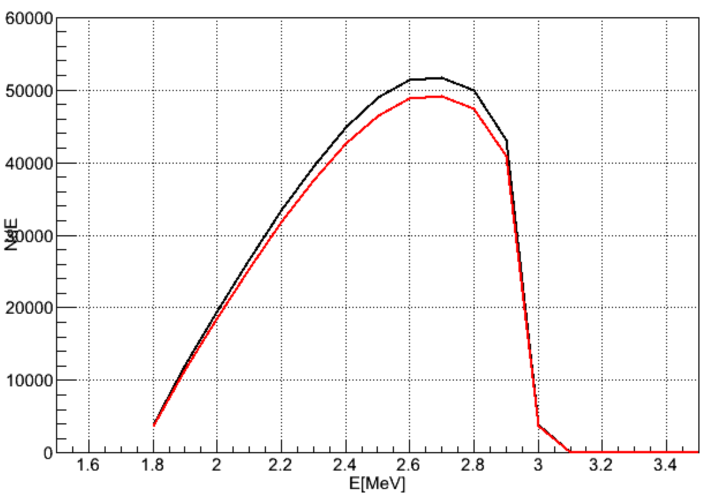
$$sin^2 2\theta_{new} = 0.1$$
$$\Delta m^2_{new} = 2 \text{ eV}$$

Neutrino Event Rate Distribution

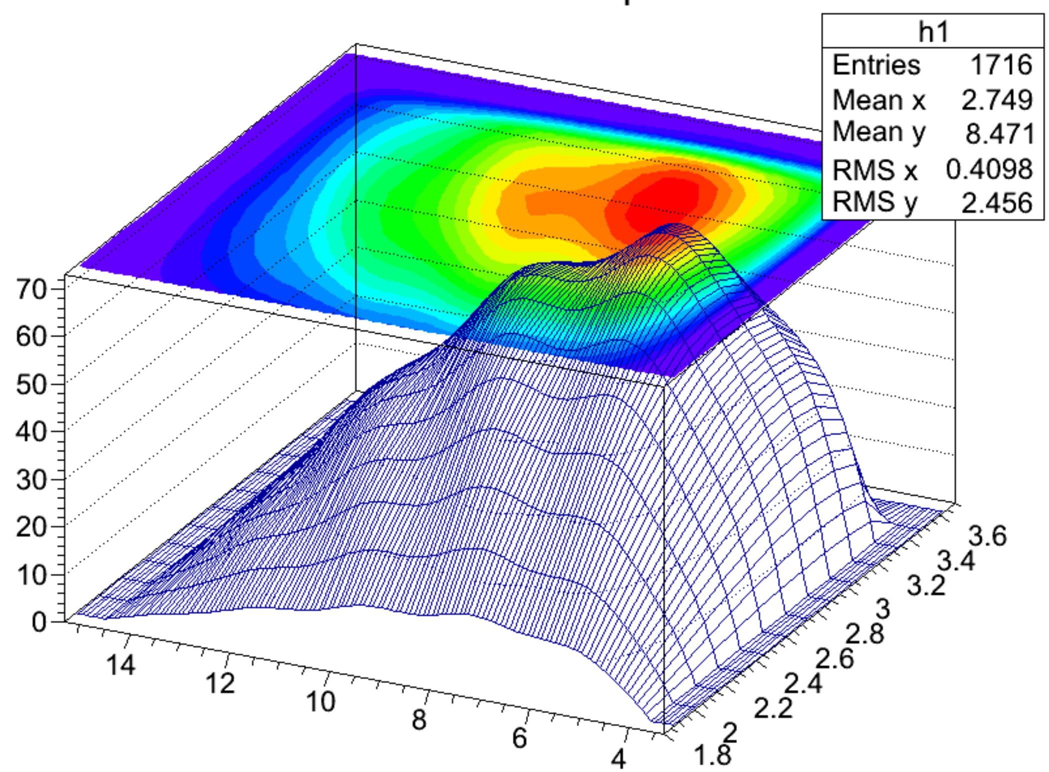
Unoscillated Neutrino Spectrum



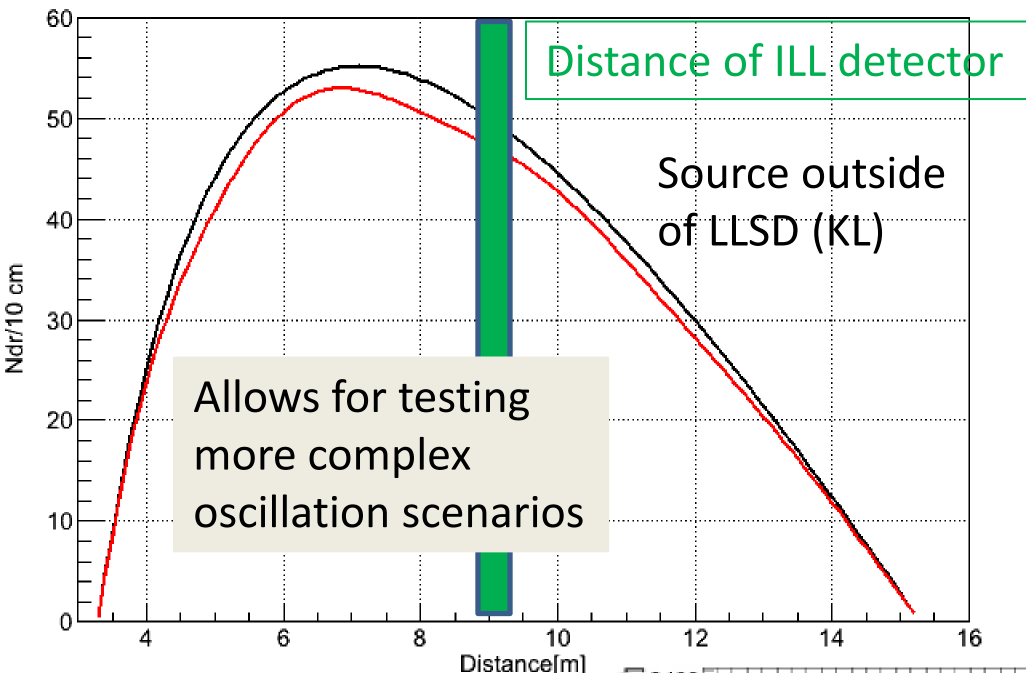
Cumulative event rate vs. energy

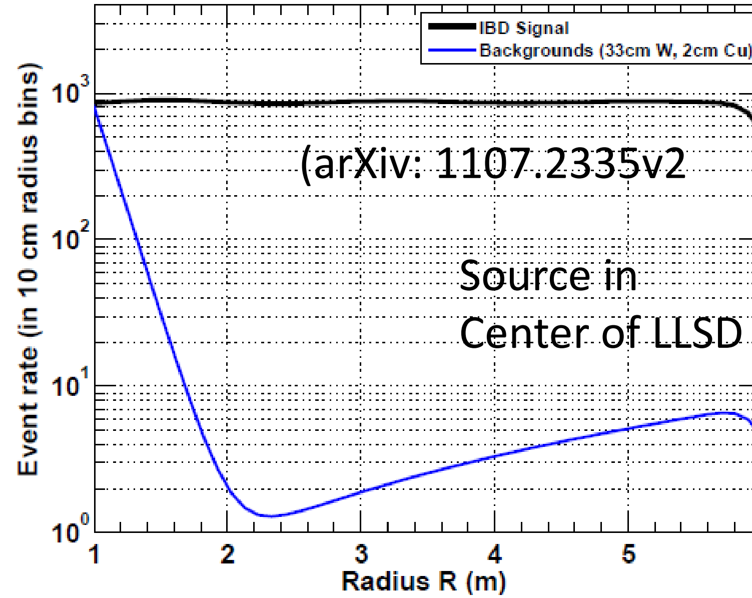


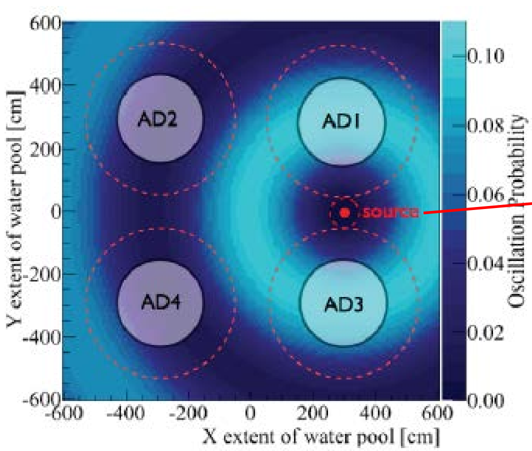
Oscillated Neutrino Spectrum

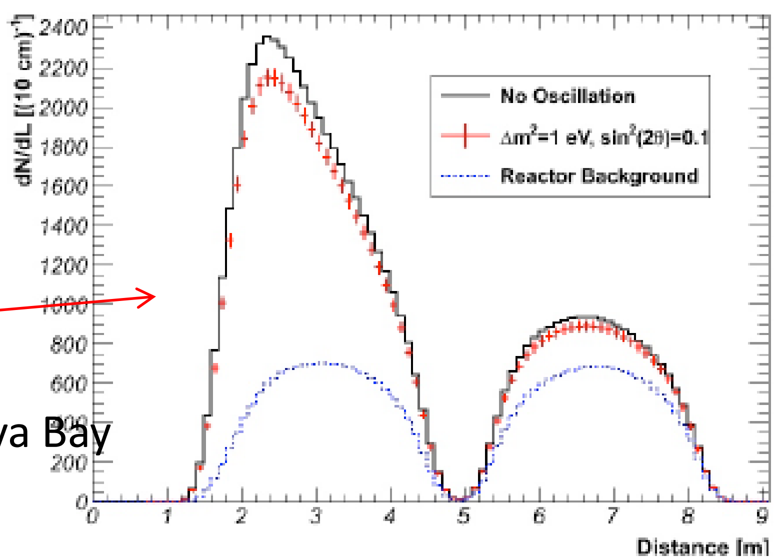


Rate as a function of energy and distance





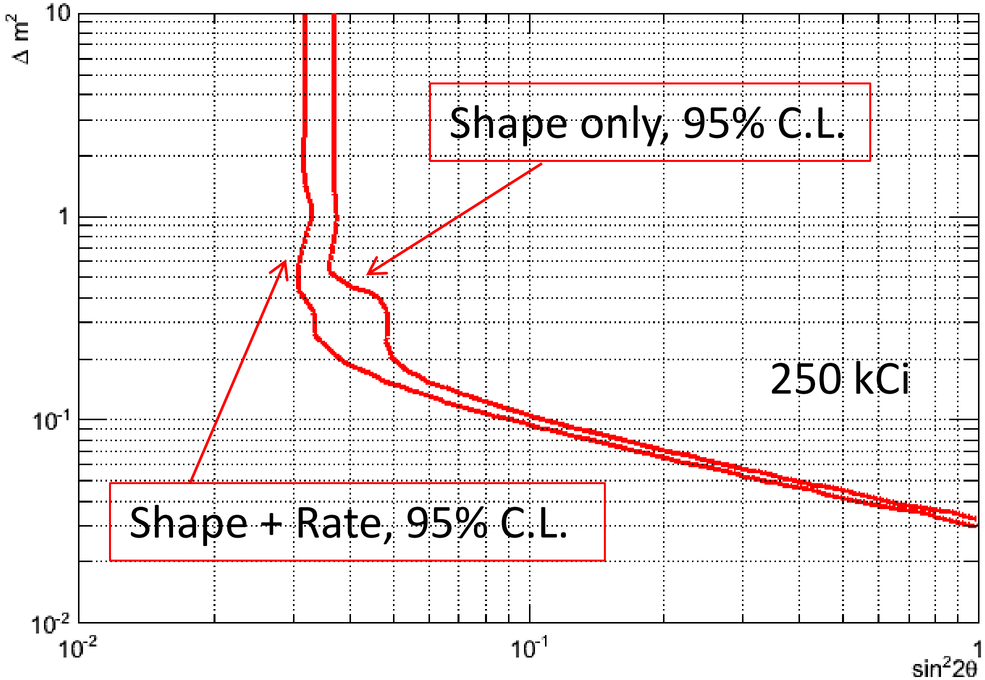


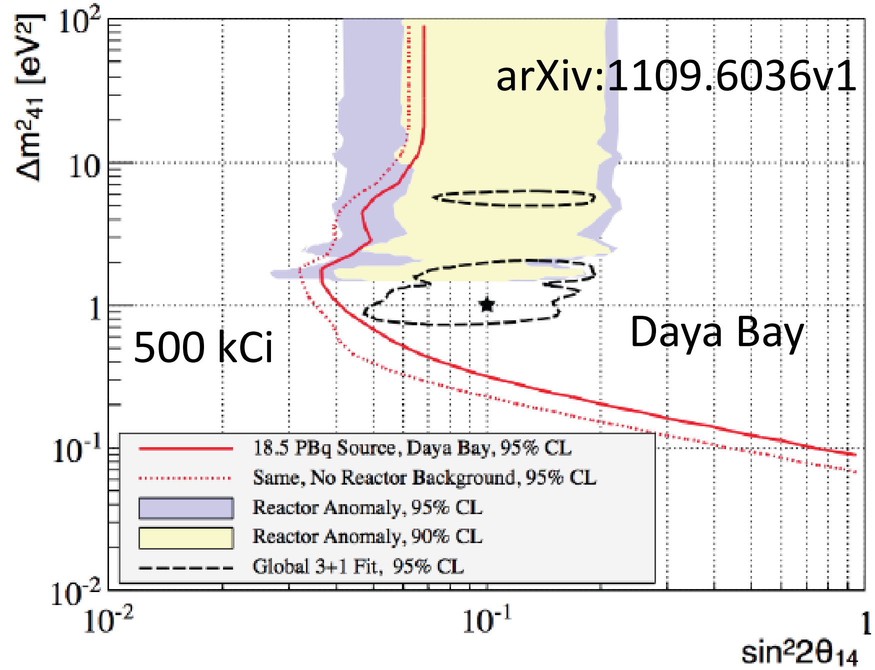


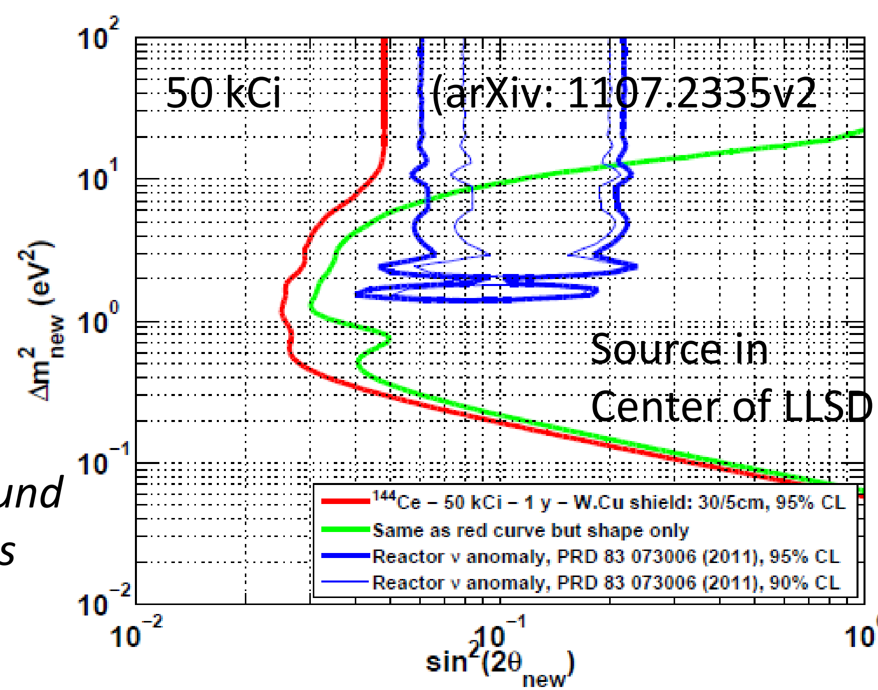
Daya Bay

arXiv:1109.6036v1

Sensitivity, t = 1 year







$$\chi^2 = \sum_i \sum_j \frac{\left(N^{i,j}_{\rm obs} - (1+\alpha)N^{i,j}_{\rm exp}\right)^2}{N^{i,j}_{\rm exp}(1+\sigma_b^2 N^{i,j}_{\rm exp})} + \left(\frac{\alpha}{\sigma_N}\right)^2$$

$$\sigma_b = 2\%$$

$$\sigma_N = 1\%$$

Absence of reactor background extends range to lower mass and angle.

Summary

- Strong antineutrino sources have excellent potential to test reactor antineutrino anomaly below 10 eV
- Production of the source represents technical challenge
- Several different approaches under consideration
- Placing the source outside KamLAND carries several advantages:
  - Easier to deploy and cool; longer baseline range, overlapping with ILL detector; test more complex oscillation scenarios; extends sensitivity range at lower Δm^2.

The most direct and simplest approach for detecting sterile neutrinos in this parameter space.