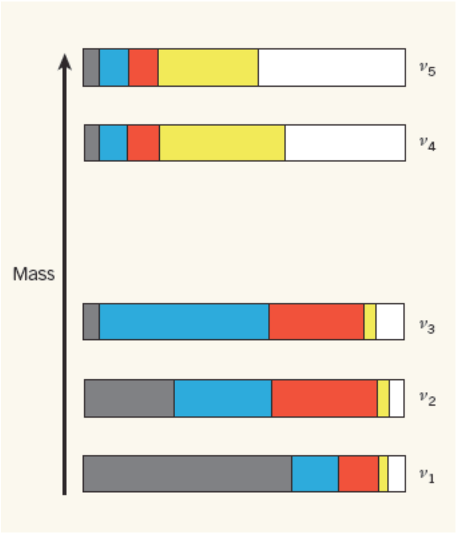
Source and Reactor Experiments to Search for Sterile Neutrinos

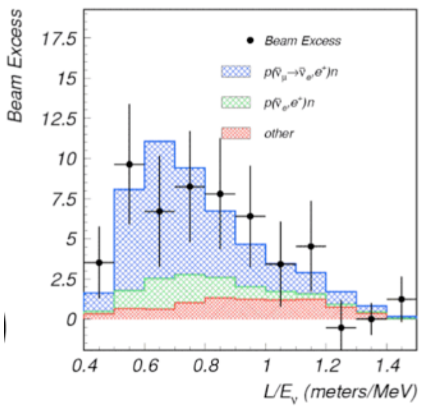


Karsten Heeger
University of Wisconsin

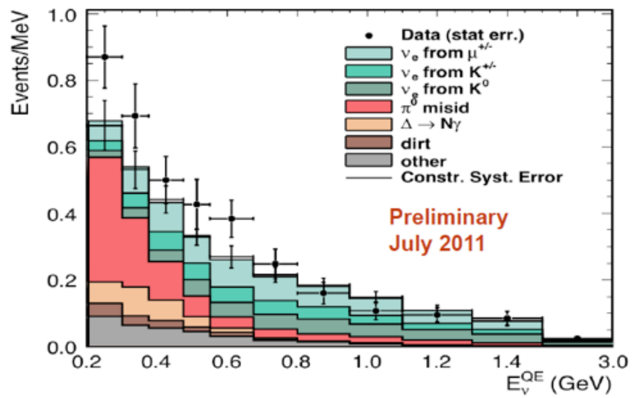
figure from Nature, Oct 2011

Neutrino Anomalies & Sterile ν Hypothesis

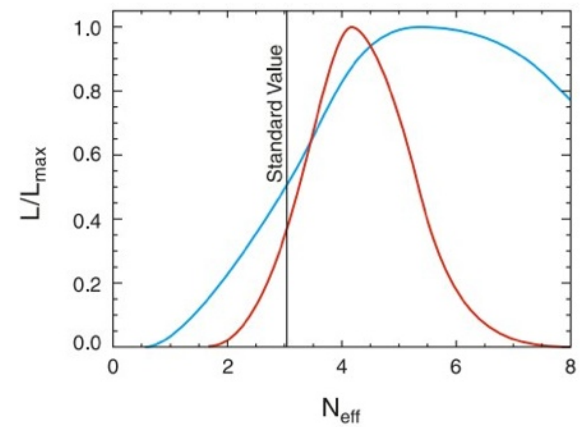
LSND



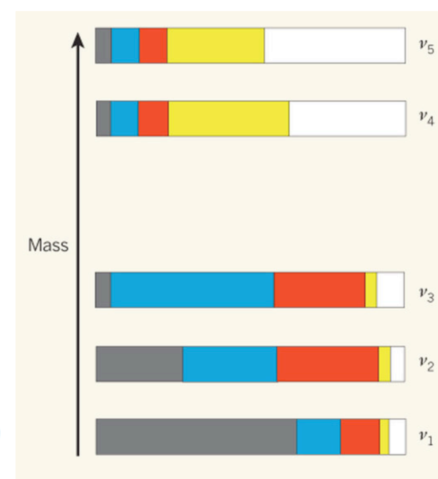
MiniBoone



Cosmology WMAP 7-year



- Experiments at odds with the standard **3-neutrino interpretation** of global neutrino oscillation data:
  - LSND ($\bar{\nu}_e$ appearance)
  - MiniBooNE anti-neutrinos ($\bar{\nu}_e$ appearance)
  - Short baseline reactor experiments (re-evaluation of neutrino fluxes) ($\bar{\nu}_e$ disappearance)



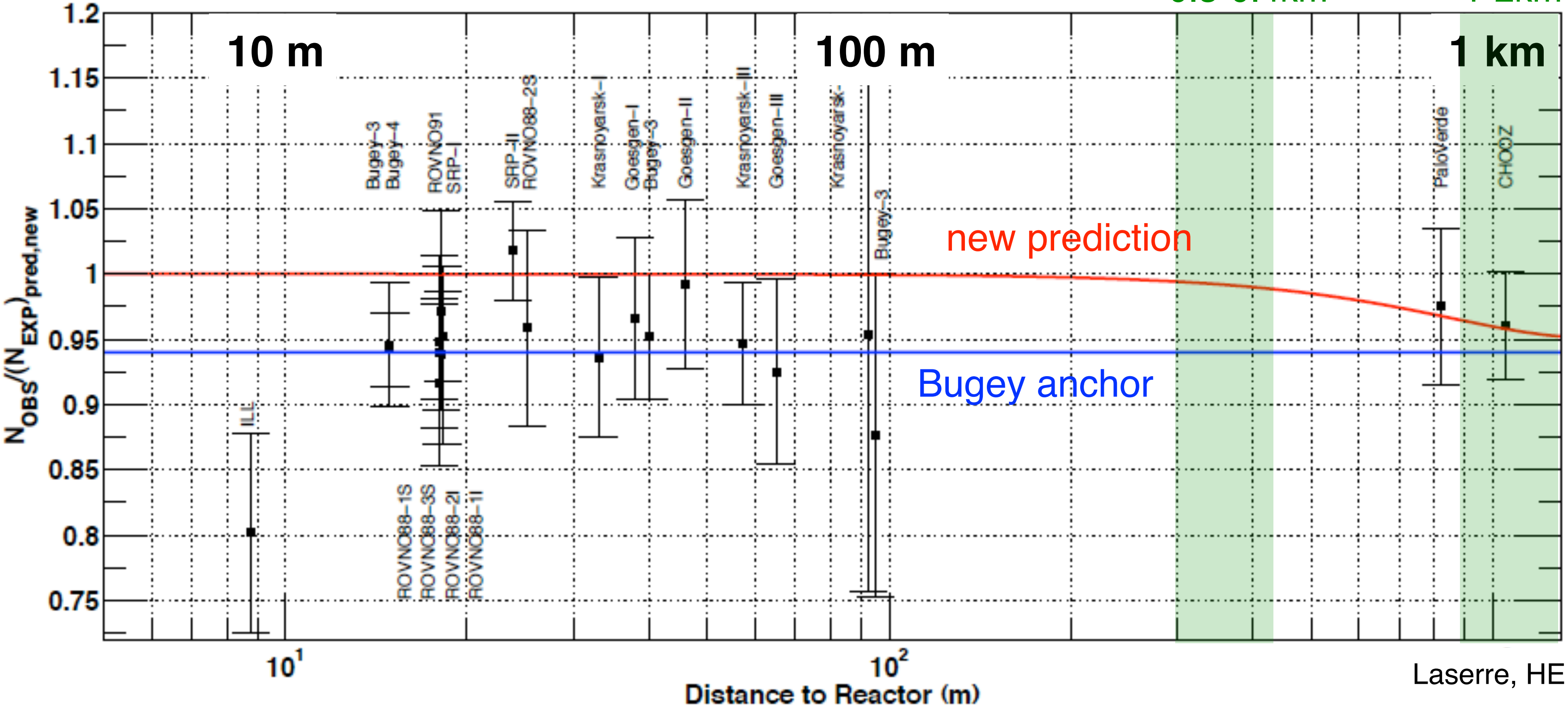
- If interpreted as oscillation signals → a 4th (or more) **sterile neutrino** with $\Delta m^2 \sim O(1\ eV^2)$ and $\sin^2 2\theta > 10^{-3}$.

Reactor Anomaly

Reactor flux measurements vs distance

reactor θ_{13} near detector 0.3-0.4km

reactor θ_{13} far detector 1-2km



Laserre, HEP2011

updates in 2011

- new reactor antineutrino spectra
- re-analysis of 21 reactor results
- neutron lifetime correction, off-equilibrium effects

net 3% upward shift in energy averaged fluxes

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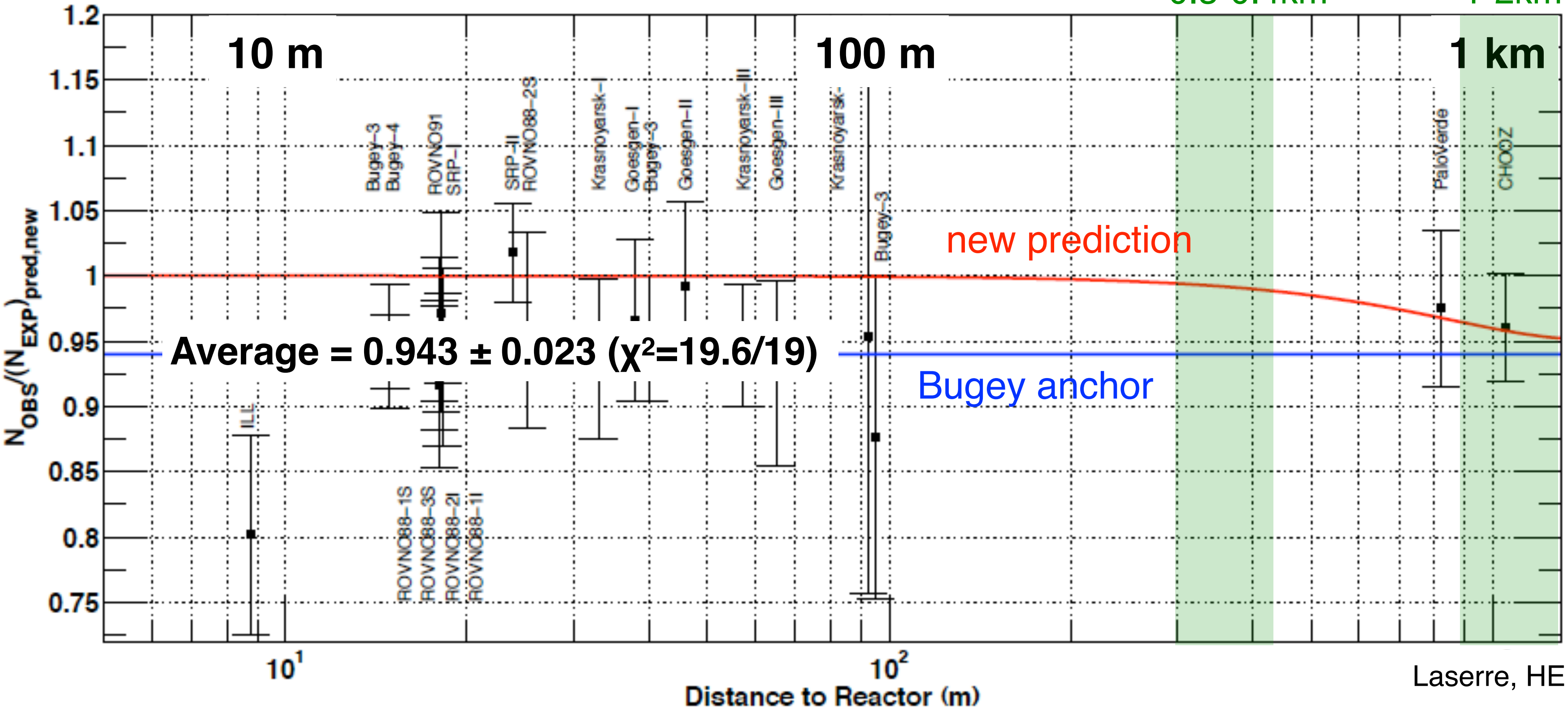

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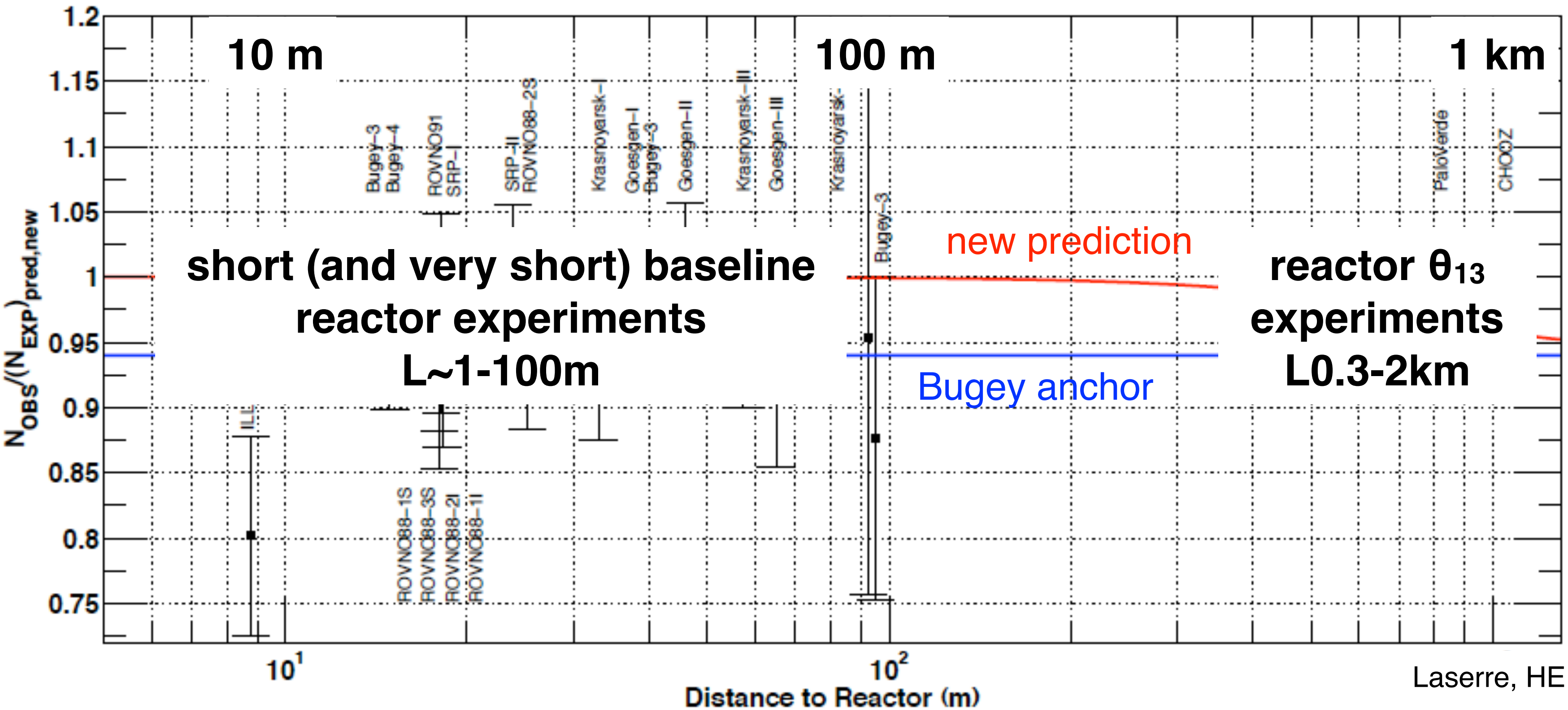


Laserre, HEP2011

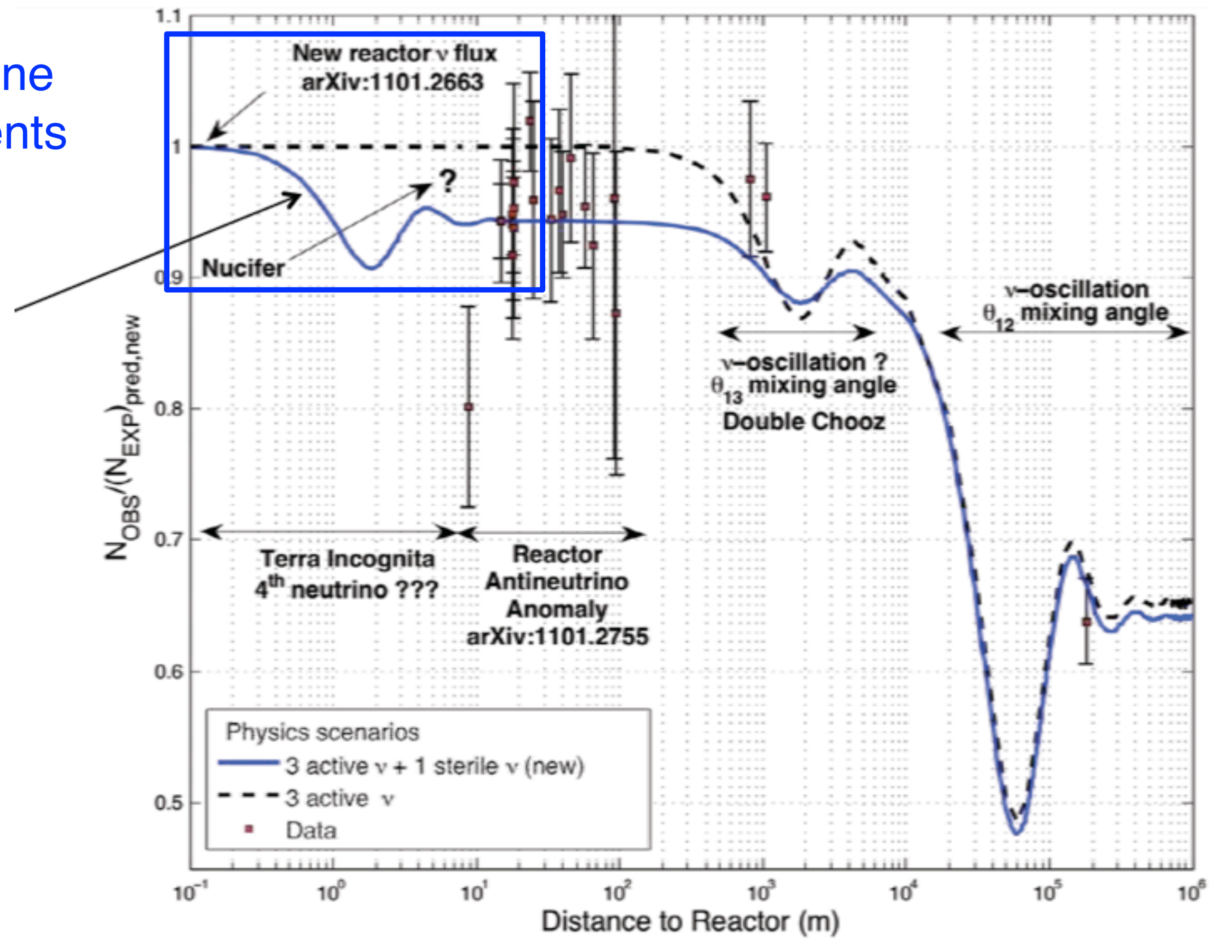
oscillation length of interest for sterile neutrino search: 2-3 m

reactor θ_{13} experiments may help with understanding reactor flux normalization and spectrum but cannot provide proof/evidence of sterile ν

Sterile ν Searches with Very Short Baselines: Reactors

Very short-baseline reactor experiments require L~1-10m

see Nathaniel's Bowden talk

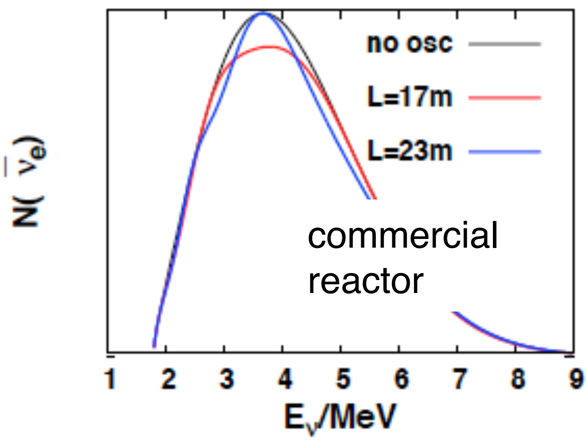


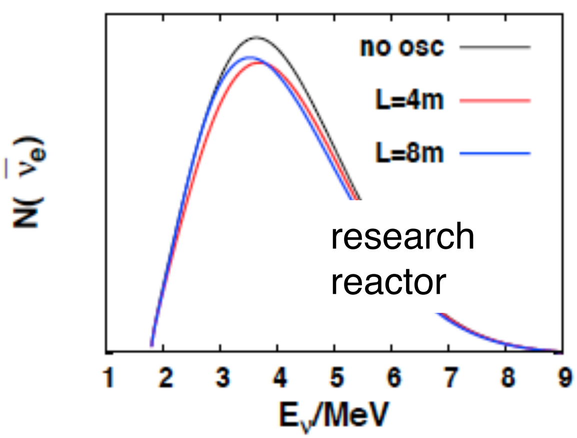
Challenges:
- getting close to reactor core
- operating neutrino detector in high-background environment (typically very little overburden near reactor core, large gamma and neutron backgrounds)

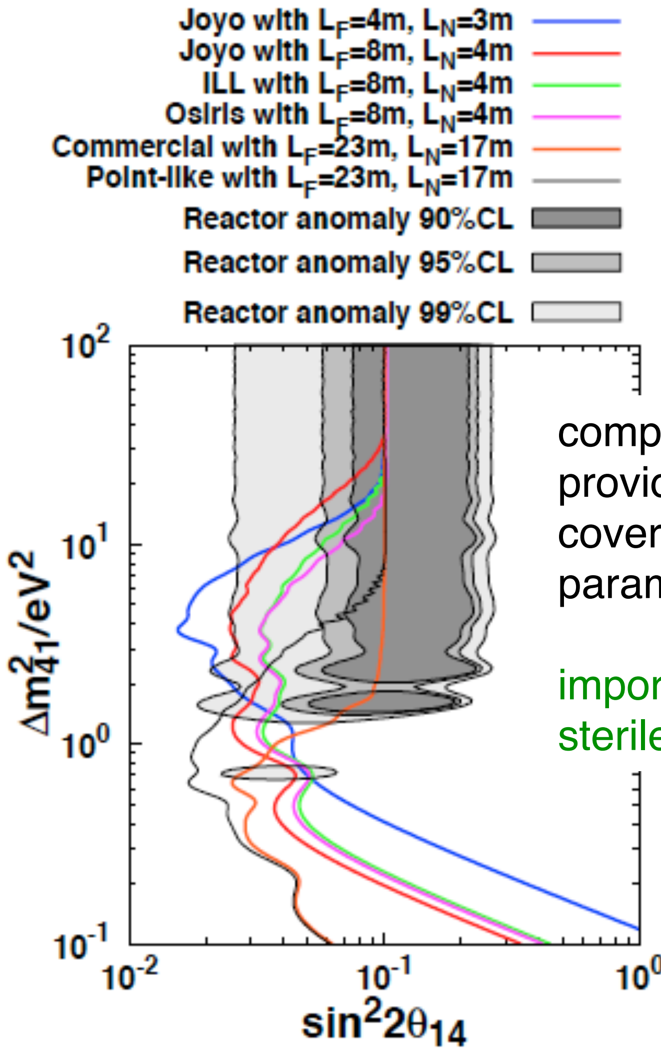
Sterile ν Searches with Very Short Baselines: Reactors

Research vs commercial reactors and compact cores for very short-baseline reactor experiments at L~1-10m

Energy spectrum w/ and w/out oscillation







compact research reactors provide generally better coverage of anomaly parameter space

important for definitive sterile nu experiment

Yasuda,
arXive: 1110.2579

Sterile ν Searches with Very Short Baselines: Sources

Alternative Approach: Place source near or inside detector and search for ν_e or $\bar{\nu}_e$ disappearance.

Advantages

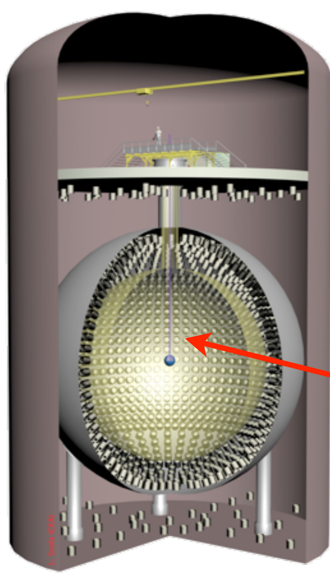
- baseline can be as short as needed
- detectors can be underground to minimize backgrounds
- potential for oscillometry (i.e. demonstrate oscillation signature vs baseline and energy)
- may be able to re-use existing, well-characterized detectors

Challenges

- construct suitable, intense radioactive source
- regulatory and licensing requirements for radioactive source

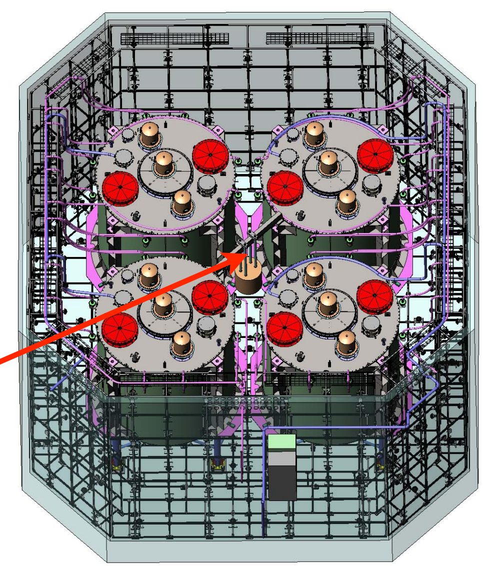
source inside detector

e.g. Ce-LAND



source next to detector

e.g. Daya Bay



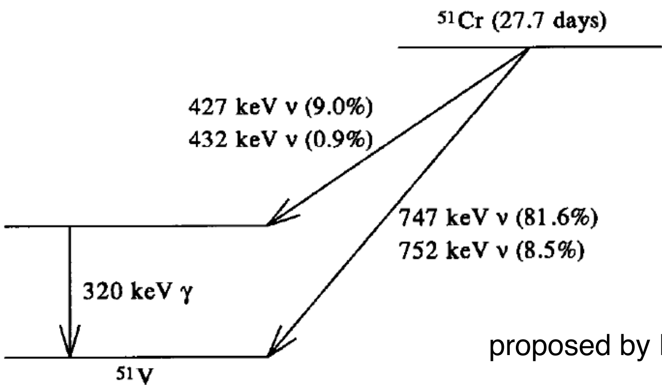
source

Sterile ν Searches with Very Short Baselines: Sources

A Variety of Sources and Detectors Are Feasible

Sources based on EC
(^{65}Zn, ^{51}Cr, ^{152}Eu, ^{37}Ar)

e.g. ^{51}Cr, <u>mono-energetic</u>, ν_e, 750 keV

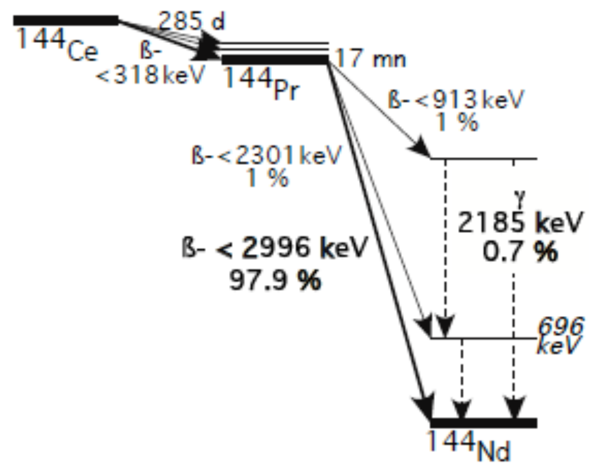


Decay scheme of ^{51}Cr to ^{51}V through electron capture.

proposed by Raghavan

Sources based on beta-decays

e.g. ^{144}Ce-^{144}Pr, $\overline{\nu}_e$, <u>continuous spectrum</u>



arxiv:1107.2335
Cribier et al

Detection Channels & Proposed Experiments

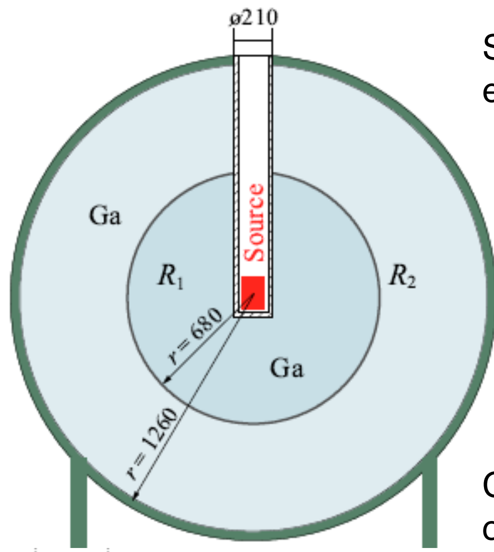
Elastic Scattering:	Borexino, SNO+Cr
Charged Current:	LENS-Sterile, Baksan, Ce-LAND, Borexino, Daya Bay
Neutral Current:	RICOCHET

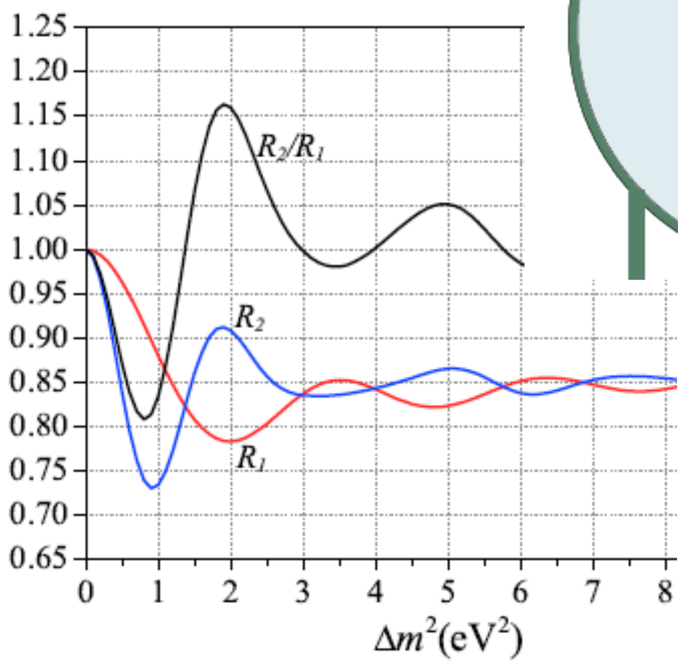
see following examples

Short Baseline Search with Ga Target

^{51}Cr Source inside Dual Metallic Ga Target

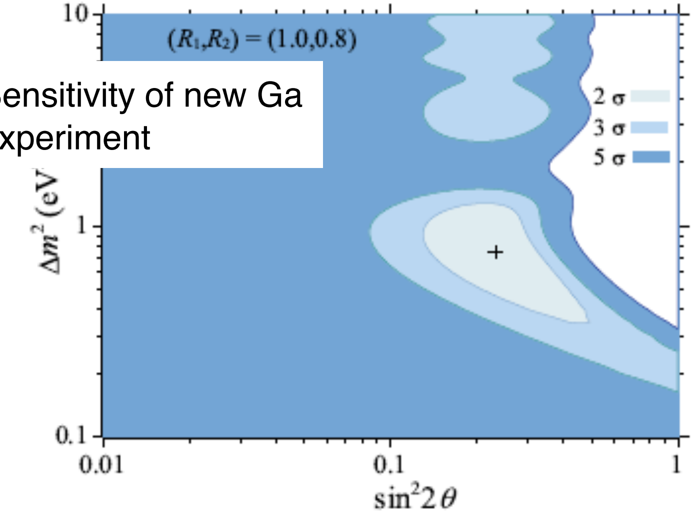
measure ratio of capture rates in R_1 and R_2



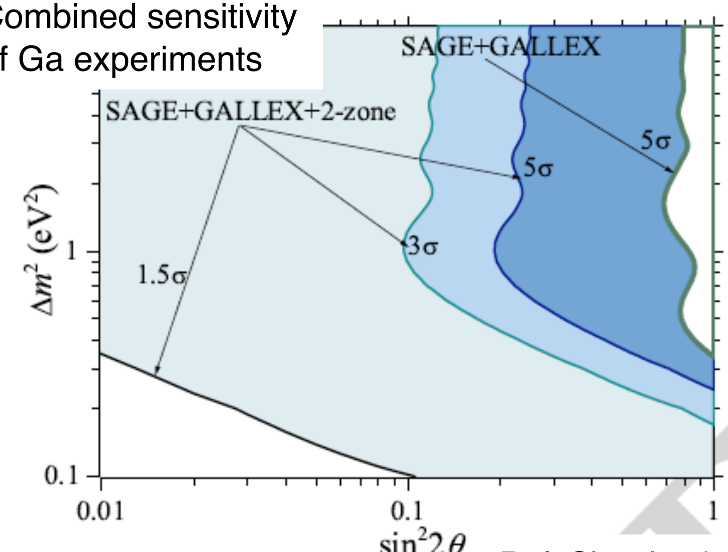


ratio of measured capture rates to predicted rate in inner and outer zones and their ratio R_2/R_1

Sensitivity of new Ga experiment

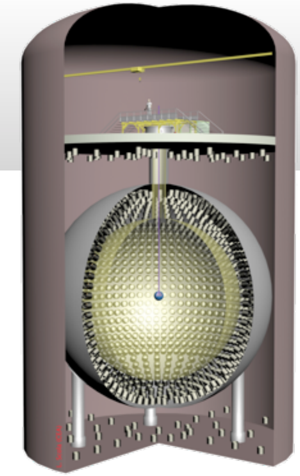


Combined sensitivity of Ga experiments

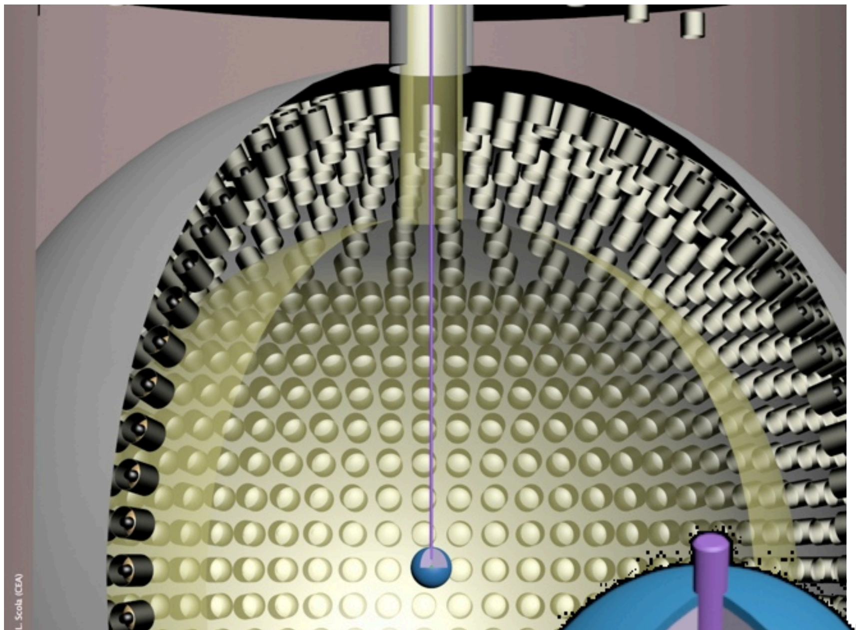


Ref: Cleveland et al.

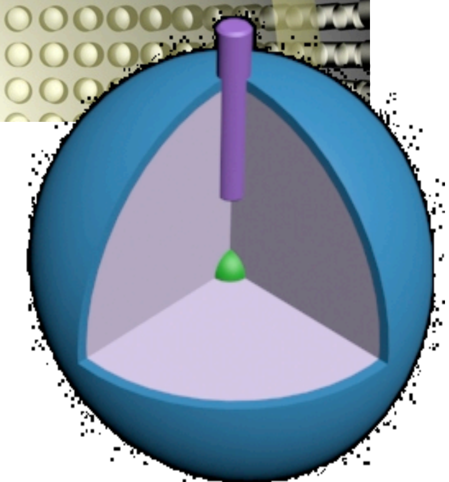
Ce-LAND



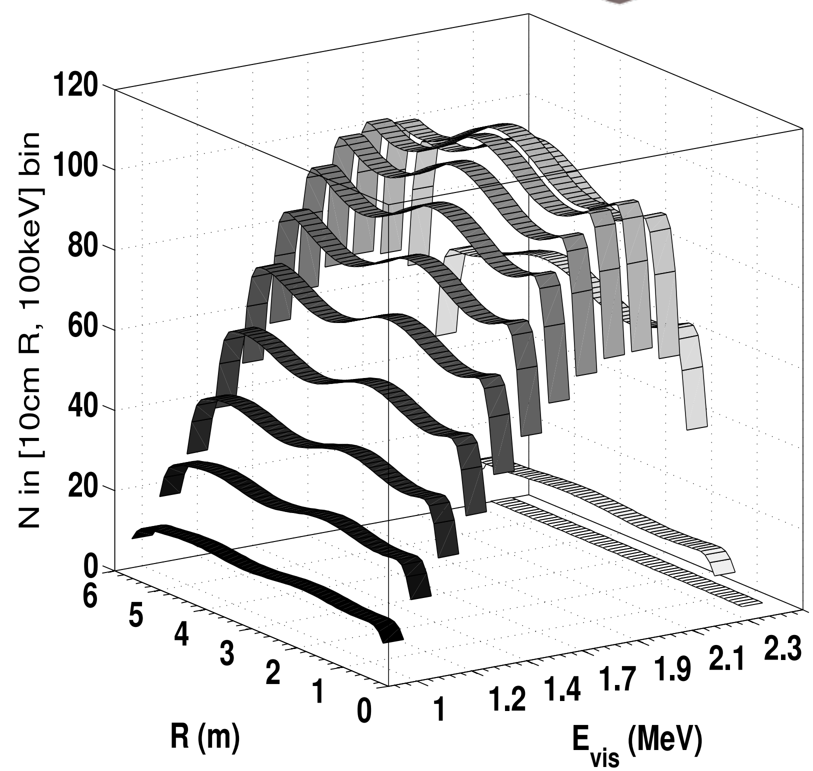
^{144}Ce source inside Liquid Scintillator Detector



map oscillation effect in R and E

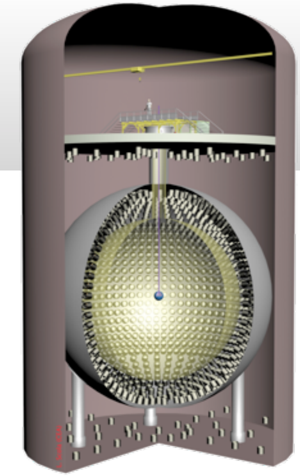


Holder & cold finger
R=8cm, 1.5 kg of Ce
R=37 cm, Tungsten
mass= 5 tons,
diameter 82 cm
teflon coating?



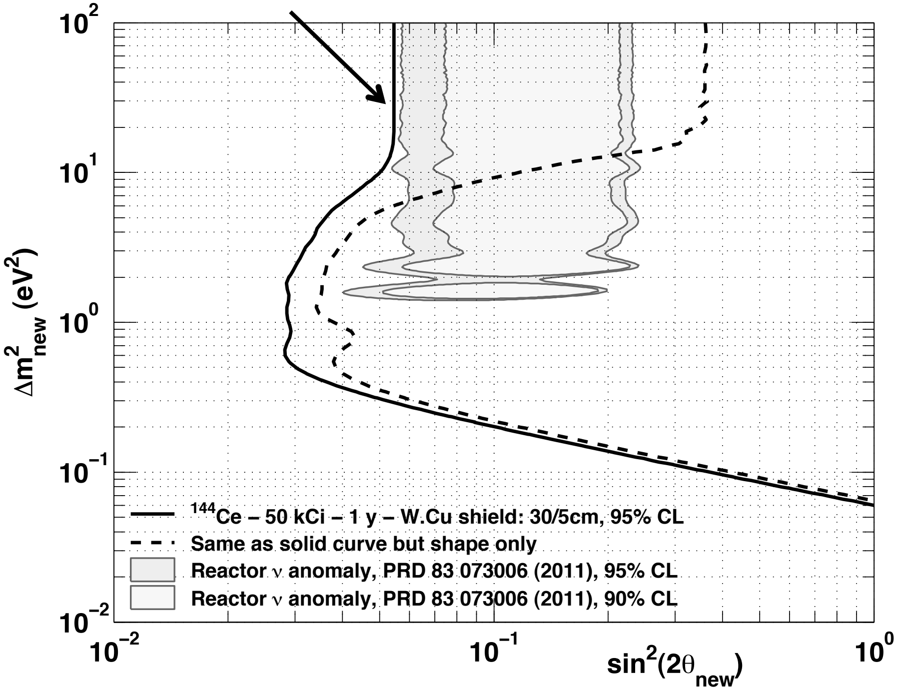
Ref: Lasserre

Ce-LAND

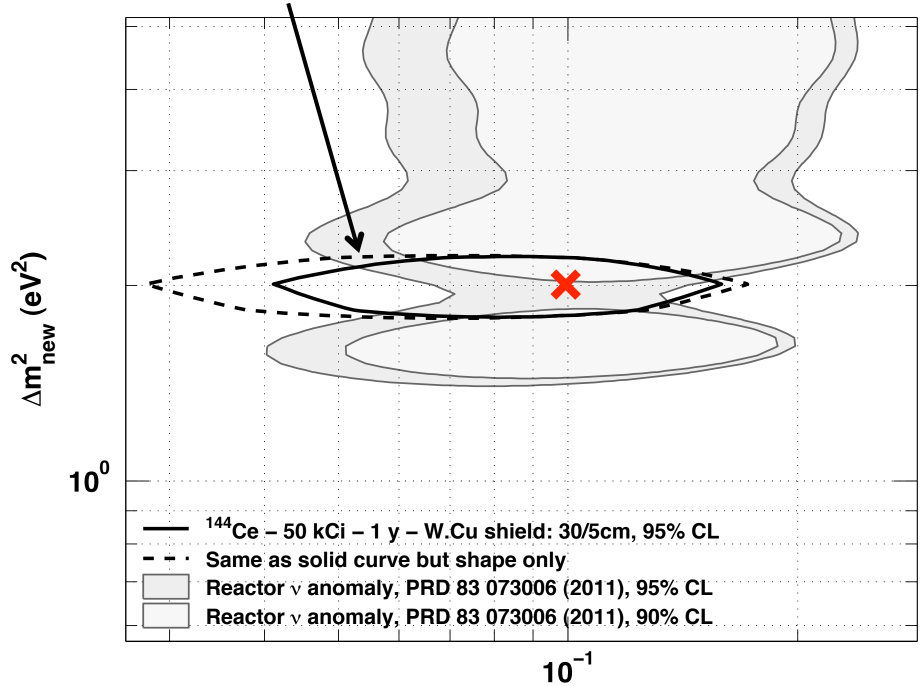


Sensitivity and Discovery Potential

1 y – 50 kCi
^{144}Ce-^{144}Pr
95%CL



1 y – 50 kCi
^{144}Ce-^{144}Pr
5σ contours



$\sin^2 2\theta = 0.1$ & $\Delta m^2 = 2$ eV^2 tagged at 5σ

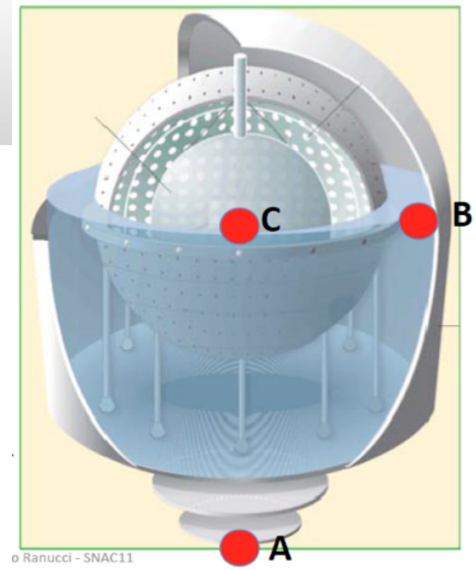
Ref: Lasserre

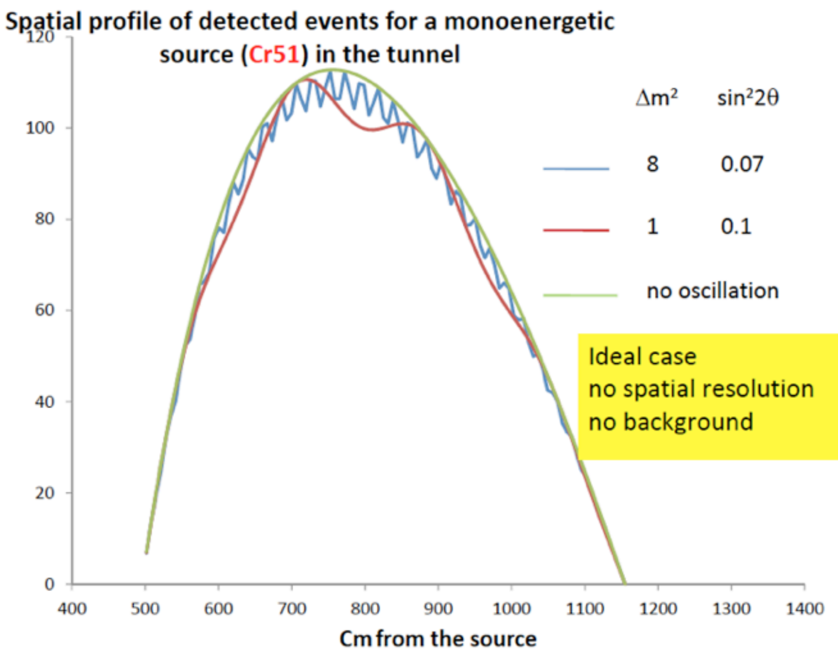
Borexino Source Experiment

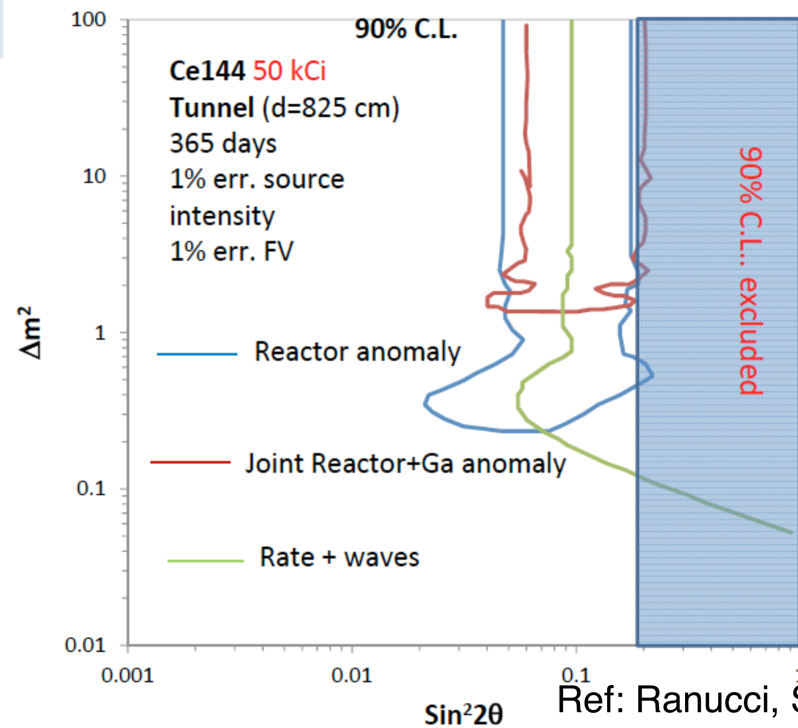
Source	decay	τ [days]	Energy [MeV]	Kg/MCi	W/kCi
^{51}Cr	e-capture (E_γ=0.32 MeV 10%)	40	0.746 81%	0.011	0.19
^{90}Sr-^{90}Y	Fission product β^-	15160	<2.28 MeV 100%	7.25	6.7
^{144}Ce-^{144}Pr	Fission product β^-	411	<2.9975 MeV 97.9%	0.314	7.6

different sources and locations under consideration

inside and outside detector





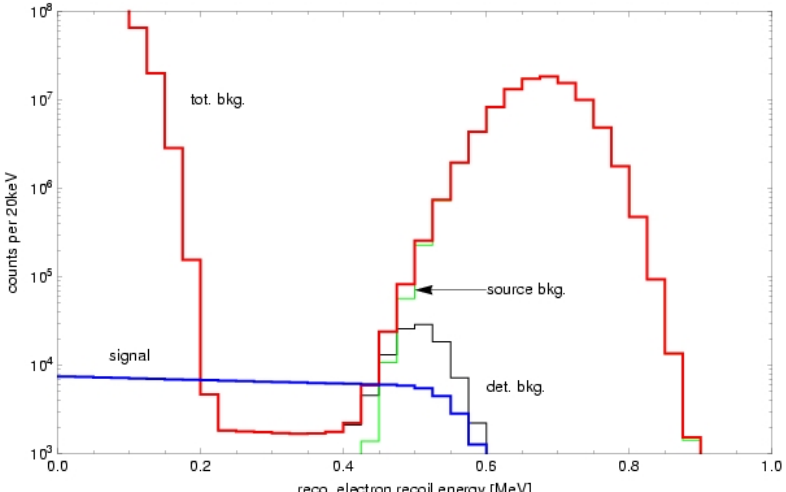


Ref: Ranucci, SNAC

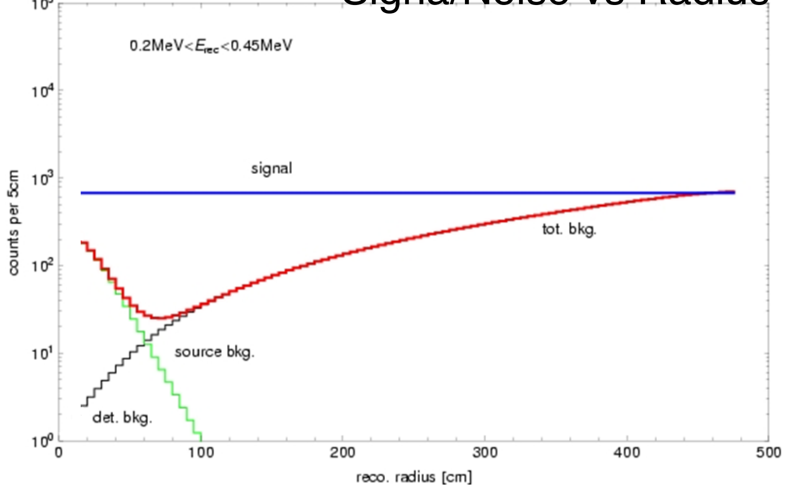
SNO-Cr

^{51}Cr source inside SNO+

Central Source Location in SNO+

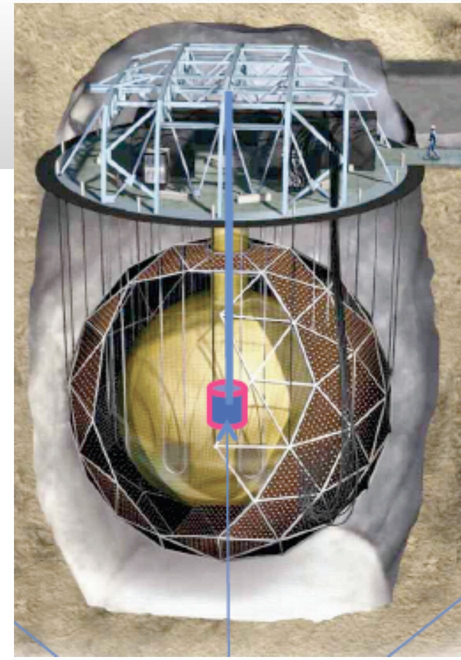


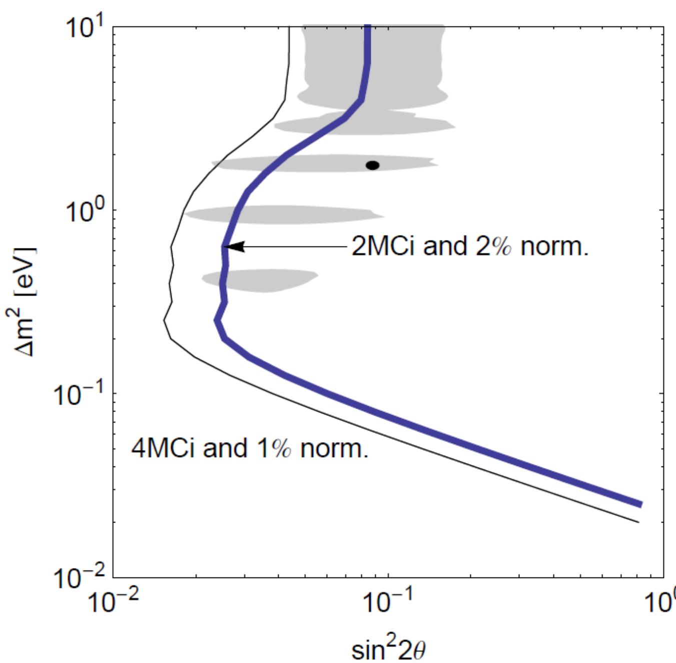
Signa/Noise vs Radius



SNO has widest neck/ chimney of all liquid scintillator detectors

may be able to produce ^{51}Cr source in US at High Flux isotope reactor at ORNL





Ref: Link, Huber

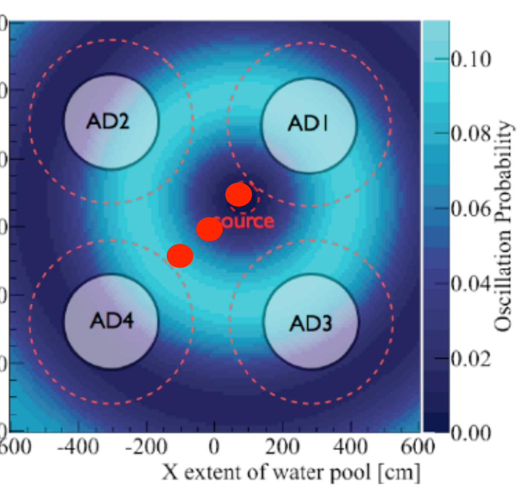
Daya Bay Sterile Neutrino Search

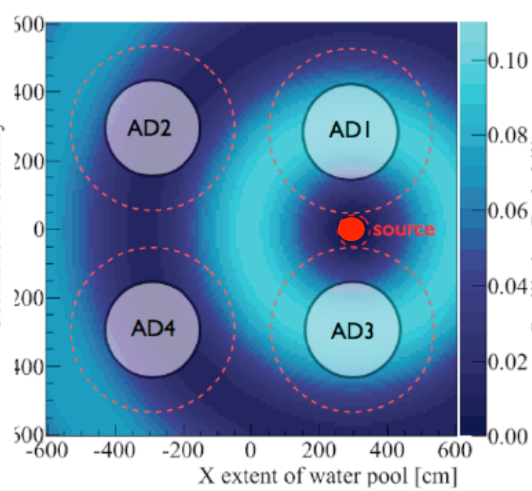
18 PBq ^{144}Ce source at the Daya Bay far site

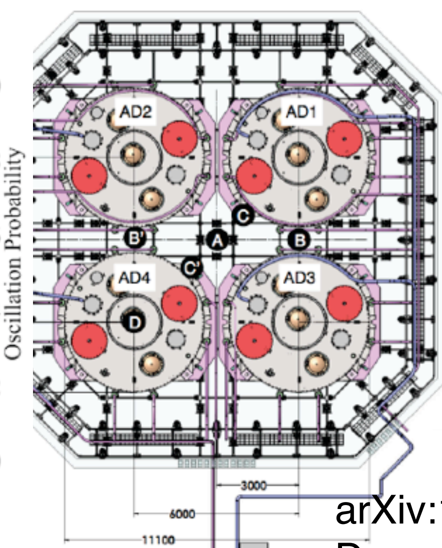
<u>Signal</u>

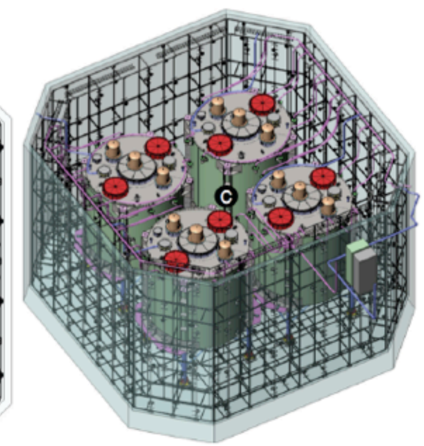
- baseline range: ~1.5 - 8 m
- ν energy range: 1.8 - 3 MeV
- 30k - 40k inverse beta-decay (IBD) events/per year

- Probing baselines from 1.5-8 m with an antineutrino source in the water pool of the Daya Bay Far Hall
- Advantageous to place source outside detectors in water pool.
- Multiple detectors allow for control of systematics.







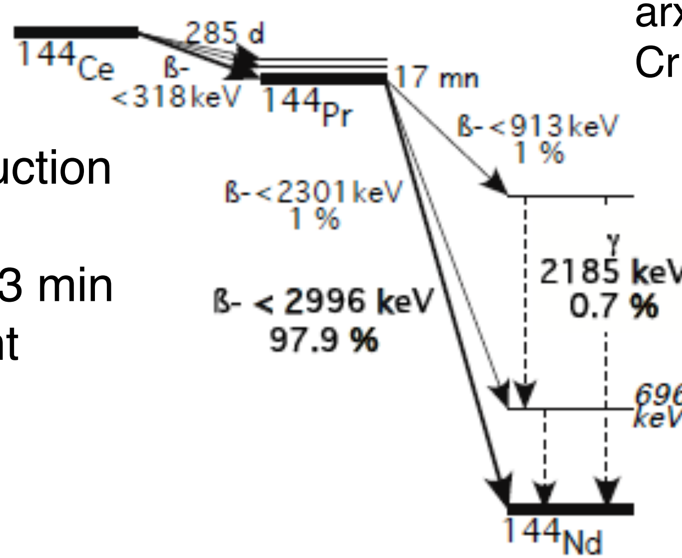


arXiv:1109.6036
Dwyer, Littlejohn, Vogel, KMH

Daya Bay Sterile Neutrino Search

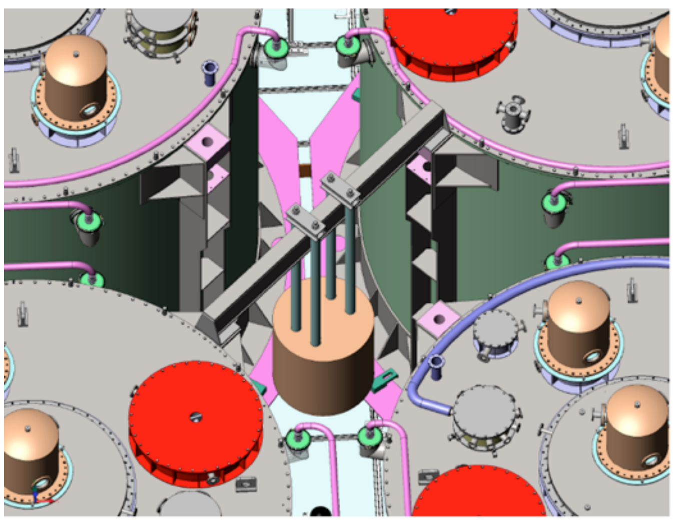
^{144}Ce-^{144}Pr Antineutrino Source

- Q_β> 1.8 MeV (IBD threshold)
- lifetime long enough to allow for production and transport
- $T_{1/2}$ (^{144}Ce)=285 days, $T_{1/2}$ (^{144}Pr)=17.3 min
- contained in fission fragments of spent nuclear fuel



arxiv:1107.2335
Cribier et al

Ce-144 source with W shielding



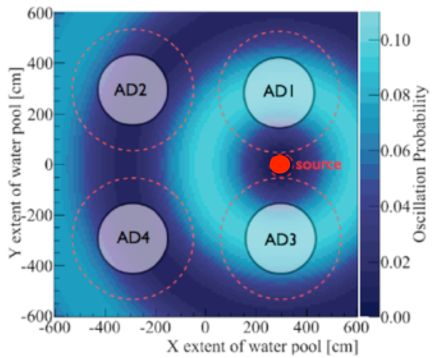
Littlejohn, KMH

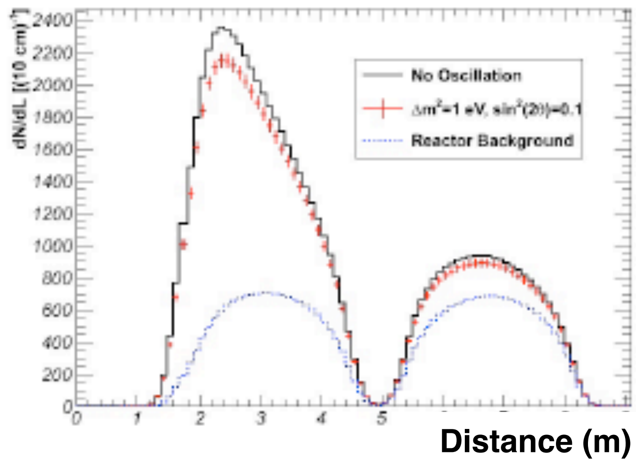
Background

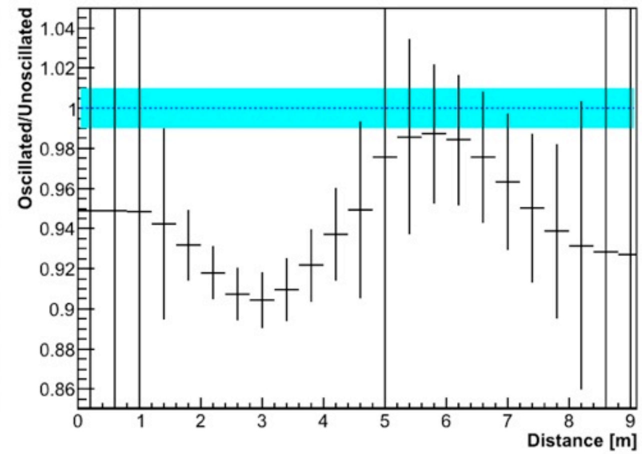
- ~0.5 m thick shielding makes source gammas negligible
- Water pool also shields, cools source outside detector
- Reactor neutrino 'background' well-known to <1% from near detectors

Daya Bay Sterile Neutrino Search

Signal and Event Distributions







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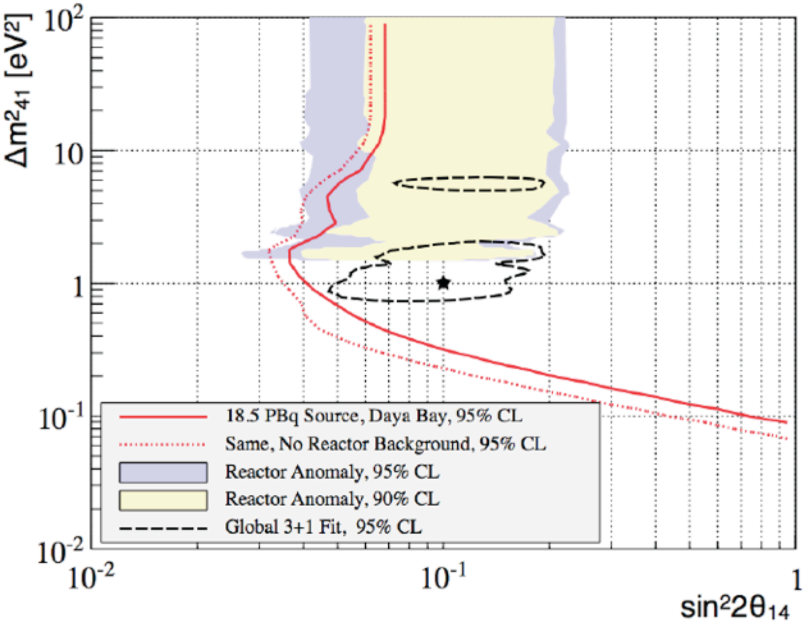

Sterile neutrino oscillations with mass > 1eV can be tested using ^{144}Ce source in the Far Hall of the Daya Bay experiment after θ_{13} measurement.

Summary and Conclusions

- Reactor and source experiments provide a complimentary way to search for sterile neutrinos.
- Proposed experiments build on decades of experience with low-energy neutrino experiments, and systematics are different from accelerator-based short-baseline experiments.
- Energy and baseline-dependent signatures are critical for an unambiguous resolution of the current anomalies. Proposals need optimization to cover the entire region of anomaly parameter space.
- Regulatory constraints for source production and logistics at reactors will likely constrain the number of feasible proposals.
- There is no “fast” way to resolve the current anomalies. Experiments need to be designed with sufficient systematic control, background mitigation, and physics reach to enable a $>5\sigma$ discovery or exclusion

More information in SNAC white paper: http://cnp.phys.vt.edu/white_paper/