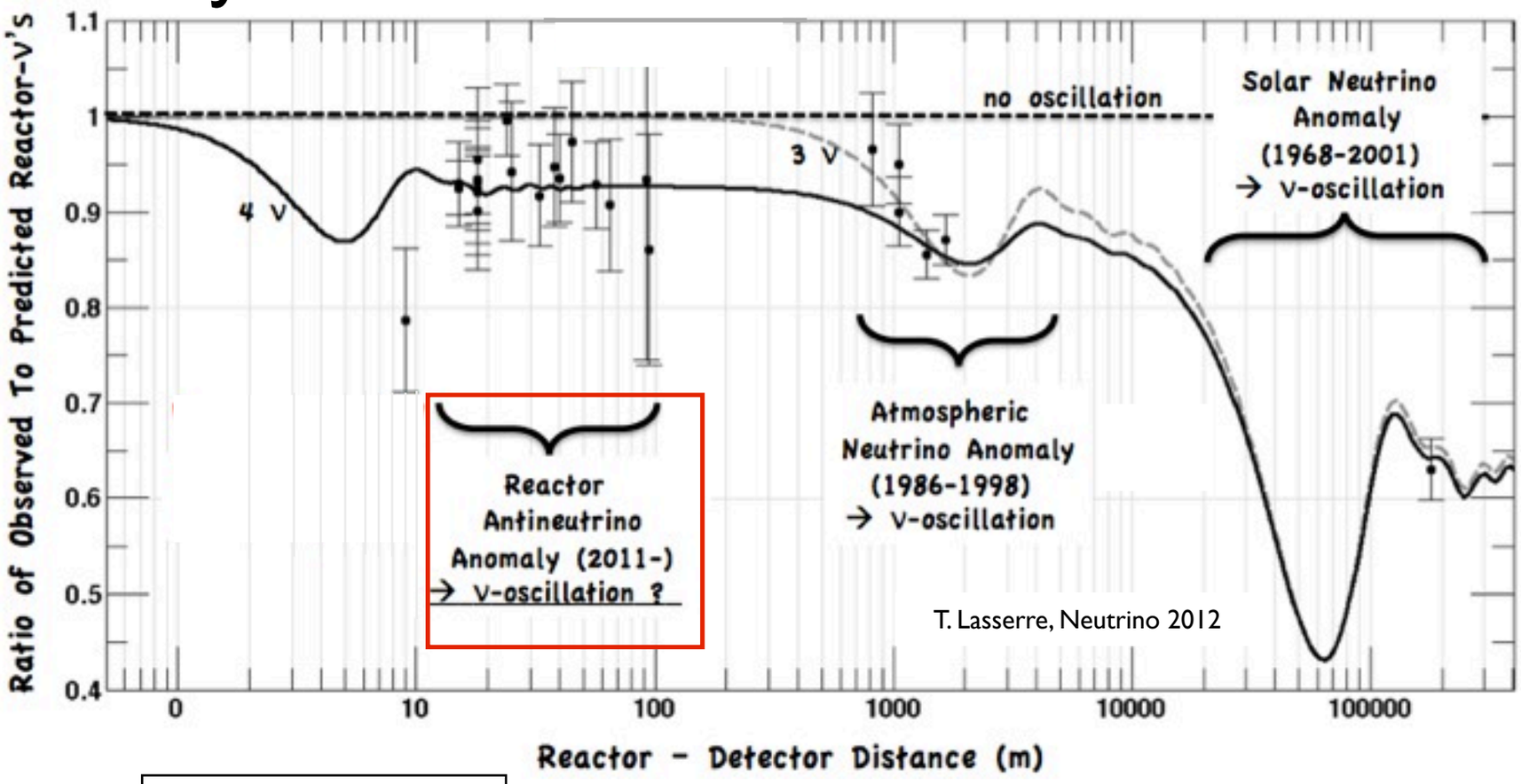
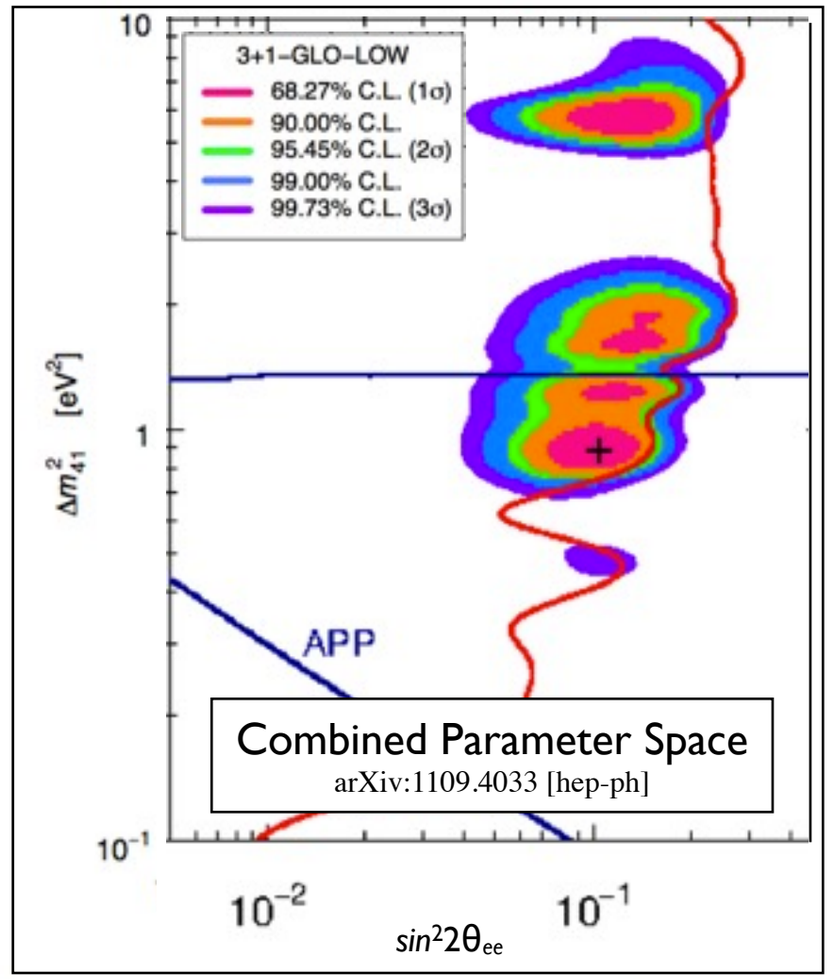
Worldwide Initiatives Toward Very Short-Baseline Oscillation Searches

Bryce Littlejohn
University of Cincinnati

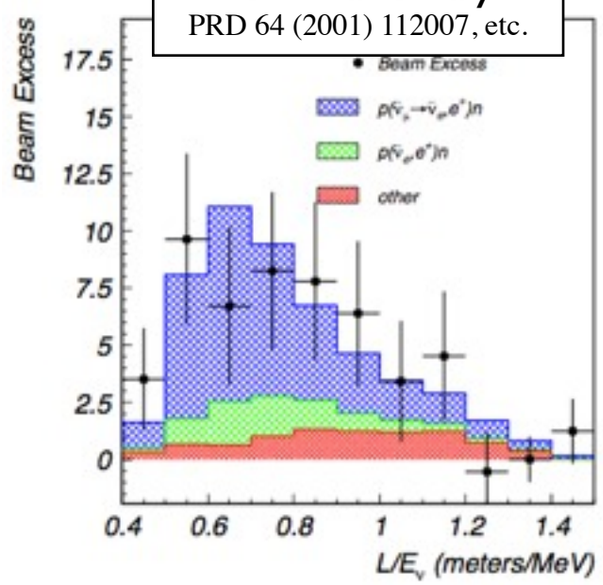
New Physics: Sterile Neutrinos

- Many anomalies in ν physics can be collectively explained by existence of eV-scale sterile ν:

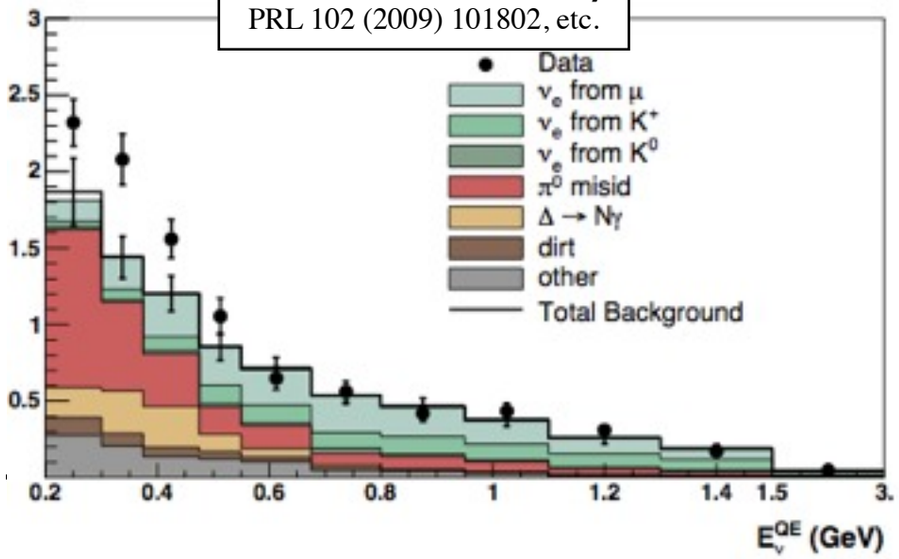




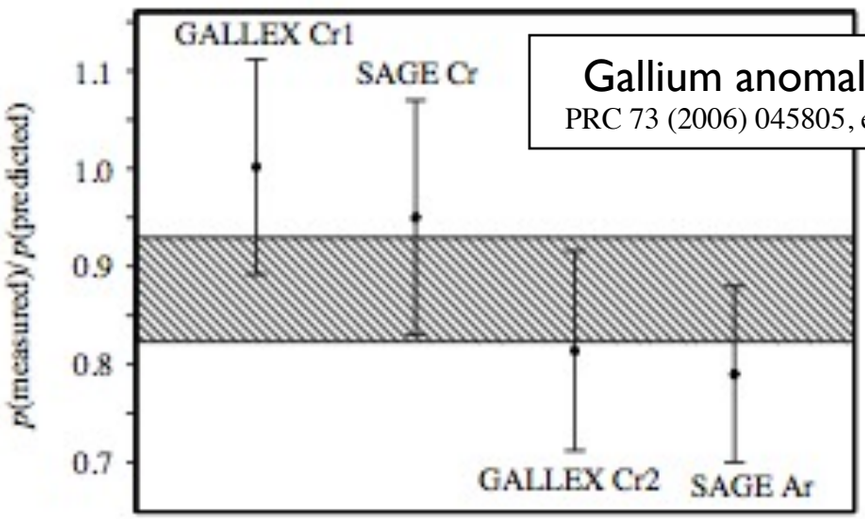
LSND anomaly
PRD 64 (2001) 112007, etc.



MiniBooNE anomaly
PRL 102 (2009) 101802, etc.



Gallium anomaly
PRC 73 (2006) 045805, etc.



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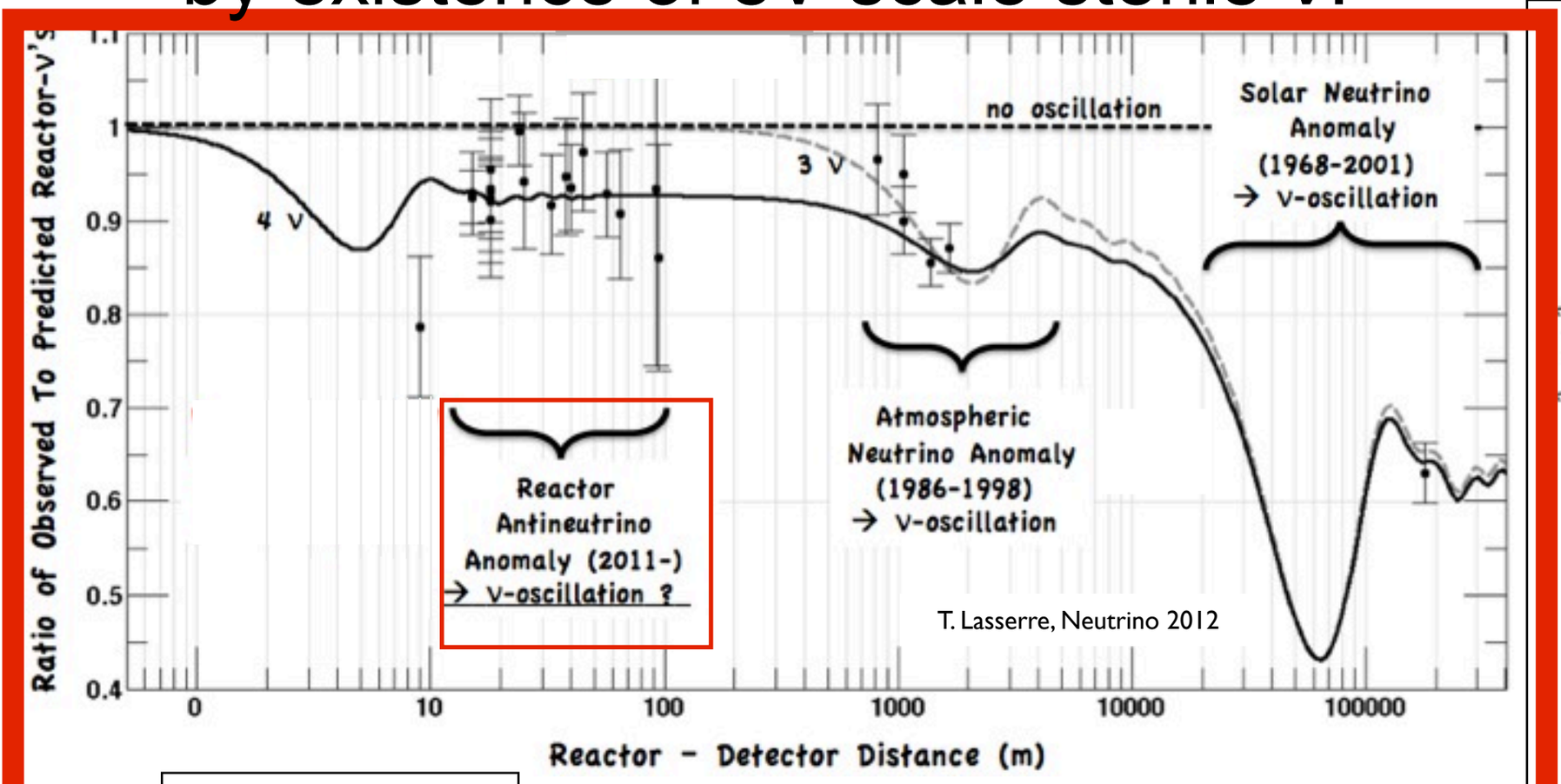

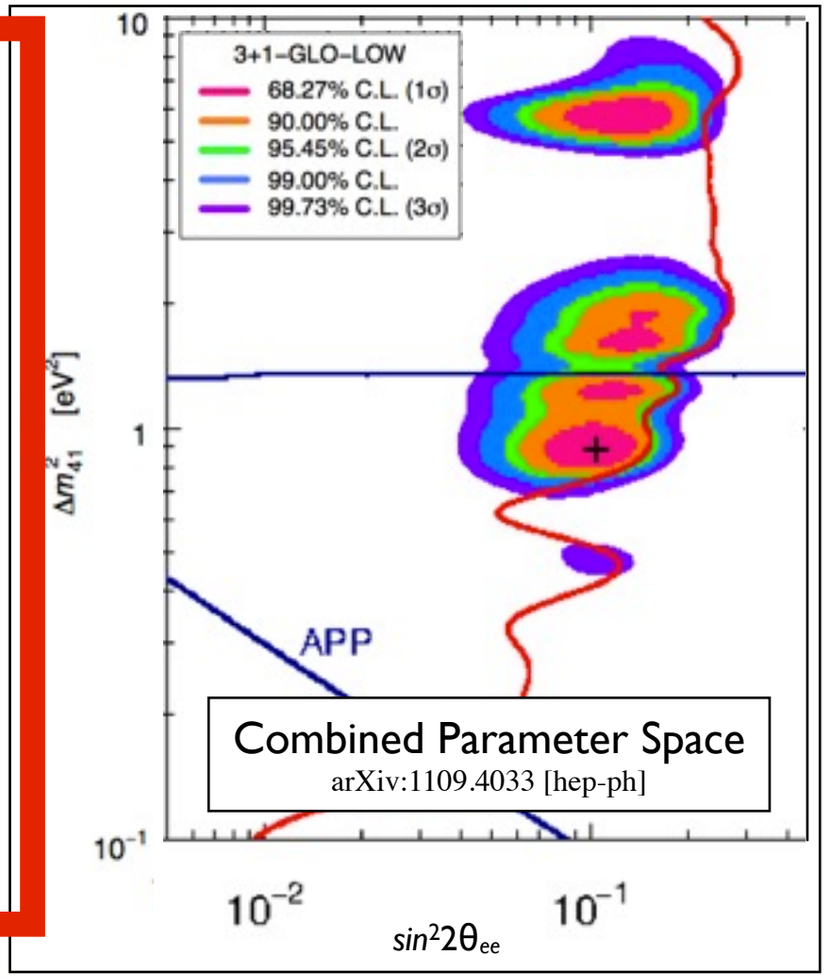

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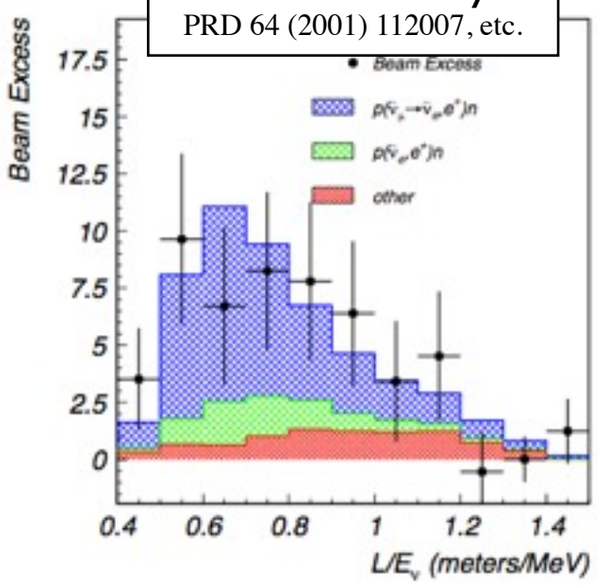

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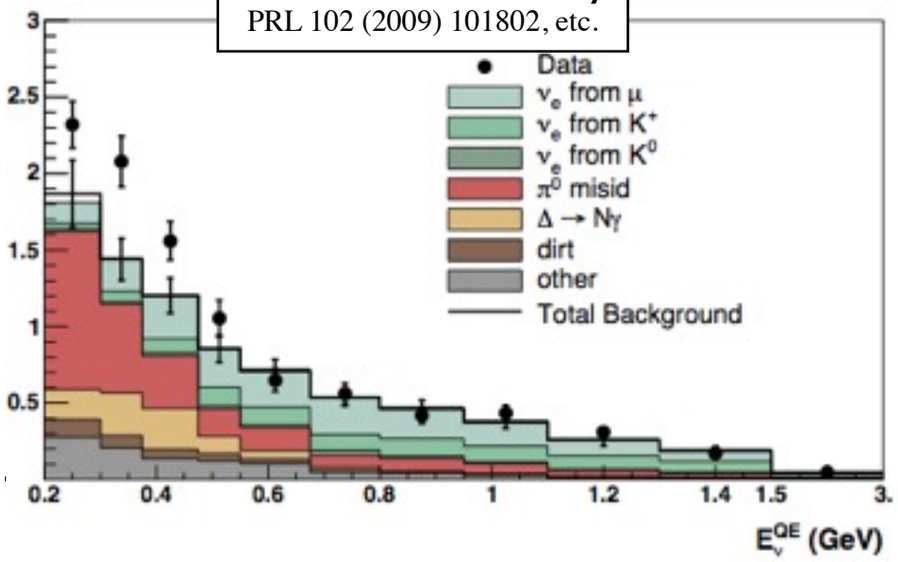

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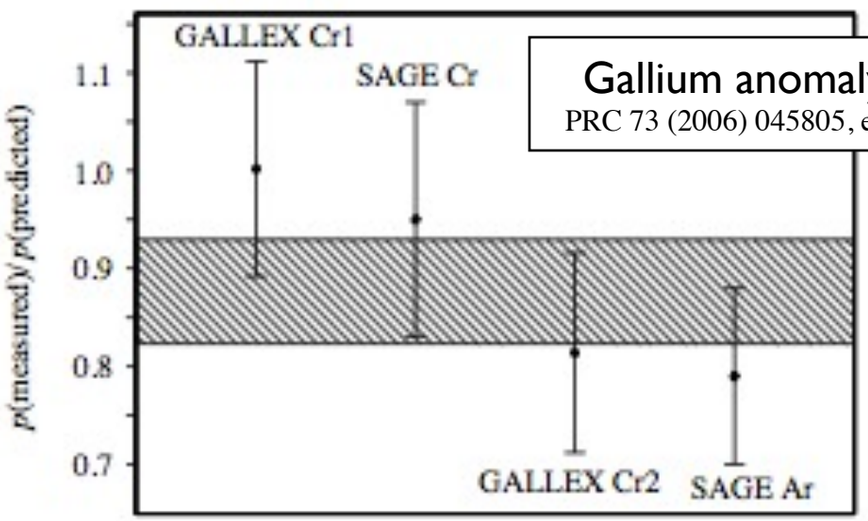
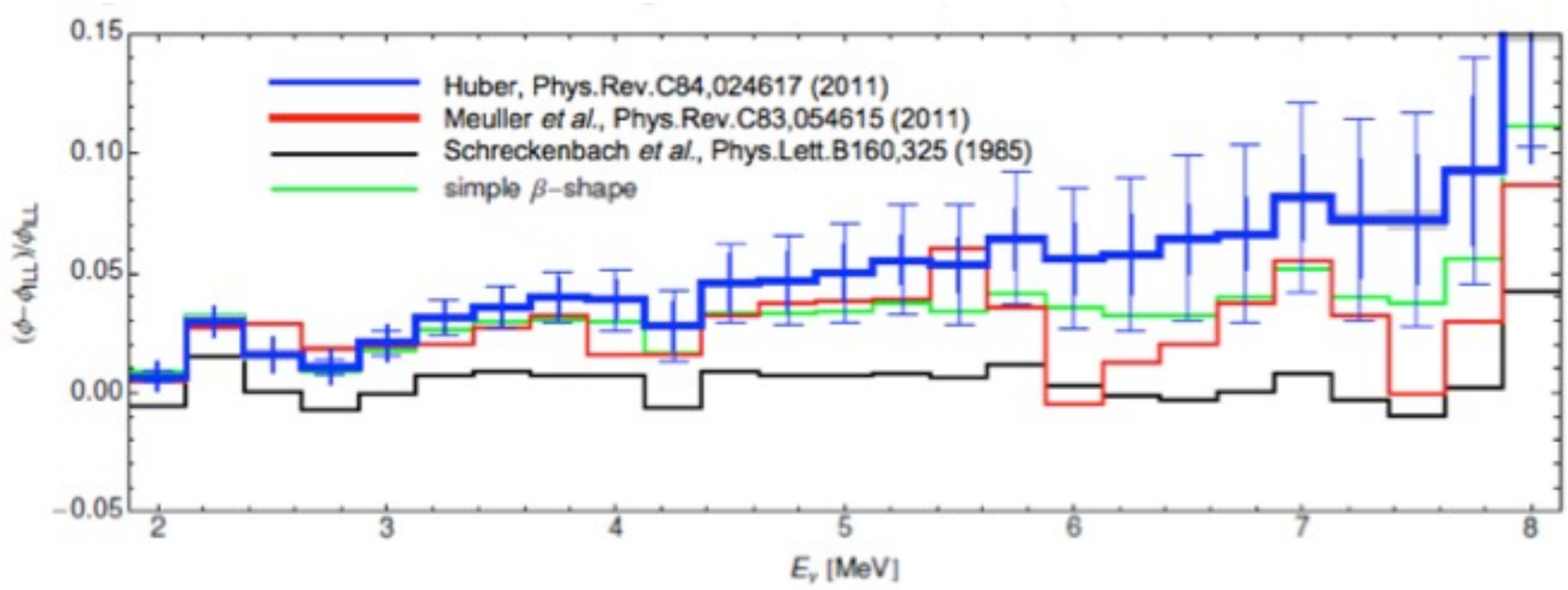


The Reactor Antineutrino Anomaly

- Main impetus: re-calculation of reactor flux predictions
  - Flux prediction increased by 3.5%

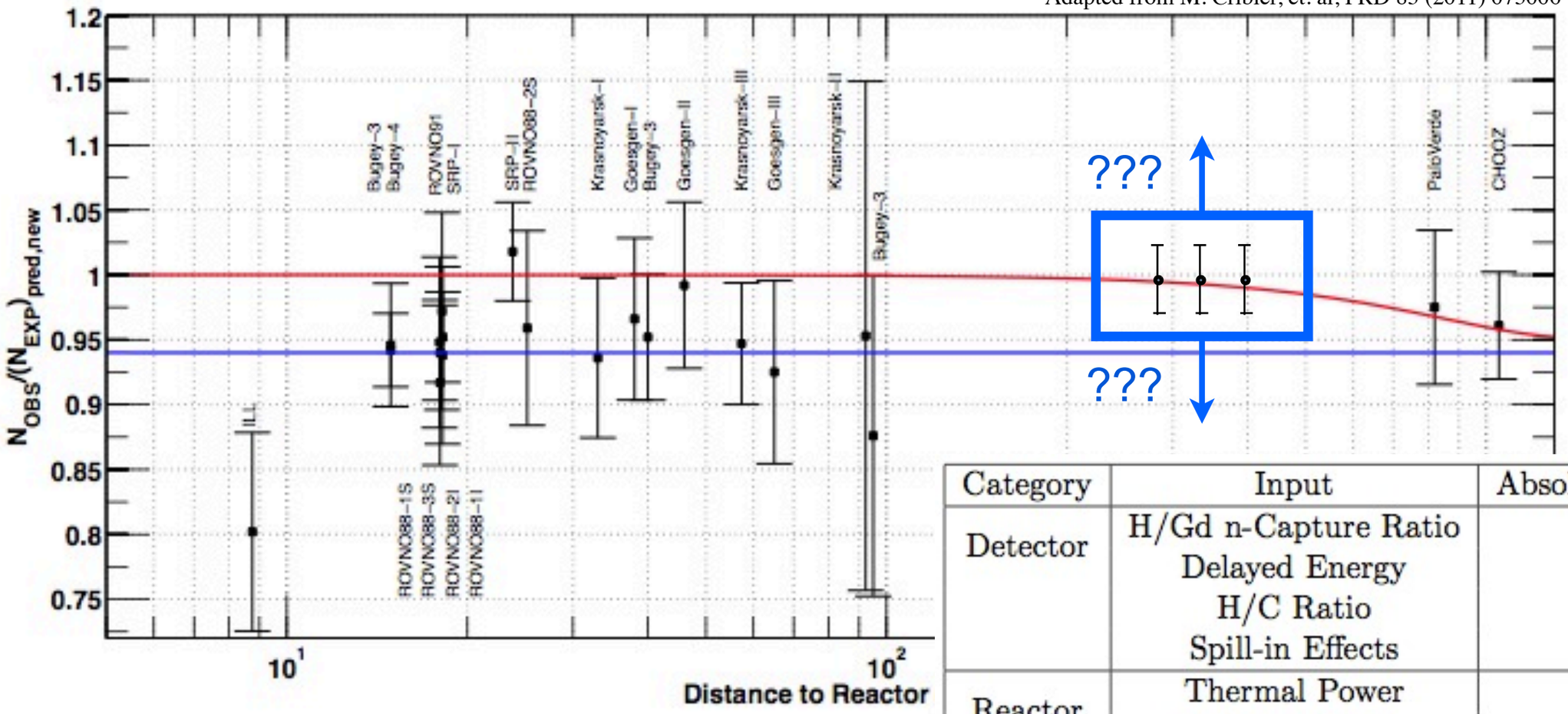


- Other smaller corrections increase prediction:
  - New neutron lifetime measurement (+1%)
  - Proper treatment of non-equilibrium reactor isotopes (+1%)
- Near-agreement between measurements, prediction becomes 5.7% measurement deficit!
- How to double-check this deficit?

θ_{13} Experiments: Absolute Flux

- Upcoming absolute checks on reactor anomaly from Daya Bay and RENO (soon), Double Chooz (later)

Adapted from M. Cribier, et. al, PRD 83 (2011) 073006



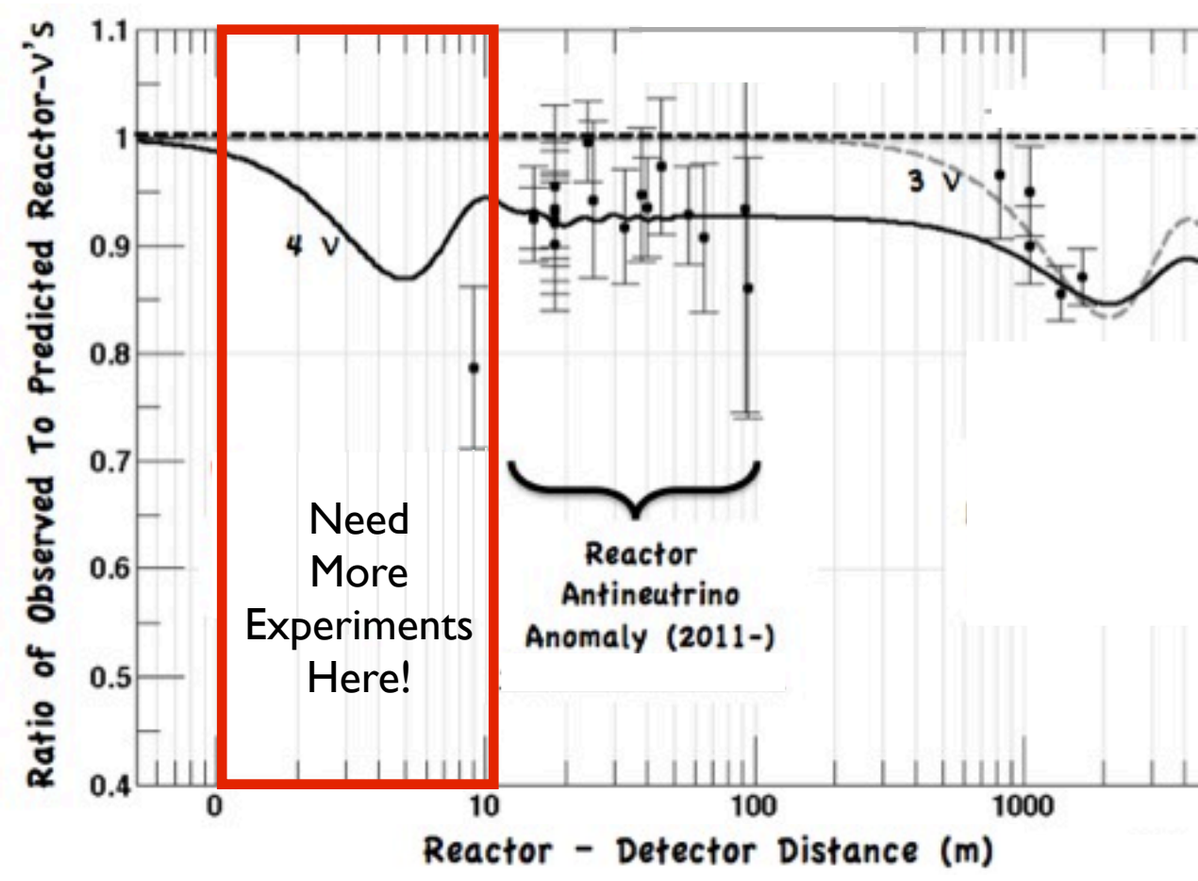
Category	Input	Absolute Unc. (%)	Goal (%)
Detector	H/Gd n-Capture Ratio	0.5	0.2
	Delayed Energy	0.6	0.3
	H/C Ratio	0.47	0.3
	Spill-in Effects	1.5	0.3
Reactor	Thermal Power	0.5	0.5
	Fission Fraction	0.6	0.6
Total		1.9	0.96

Adapted from PhD Thesis, B. Littlejohn

- Better statistics and systematics than previous SBL exps.
  - O(1%) level uncertainty, aside from 2.7% reactor flux prediction uncertainty

Oscillimetry: A Smoking Gun

- Need a definitive MeV-scale short-basline (SBL) test
  - Absolute reactor flux checks are nice, but not good enough
- Want experiments at sterile oscillation length: meter-scale
  - Best: see oscillations in position and energy
    - Impact of spectral shape uncertainties are minimized with multiple baselines
    - Impact of position-dependent efficiency uncertainties minimized by wide energy range
    - A very distinct signature!



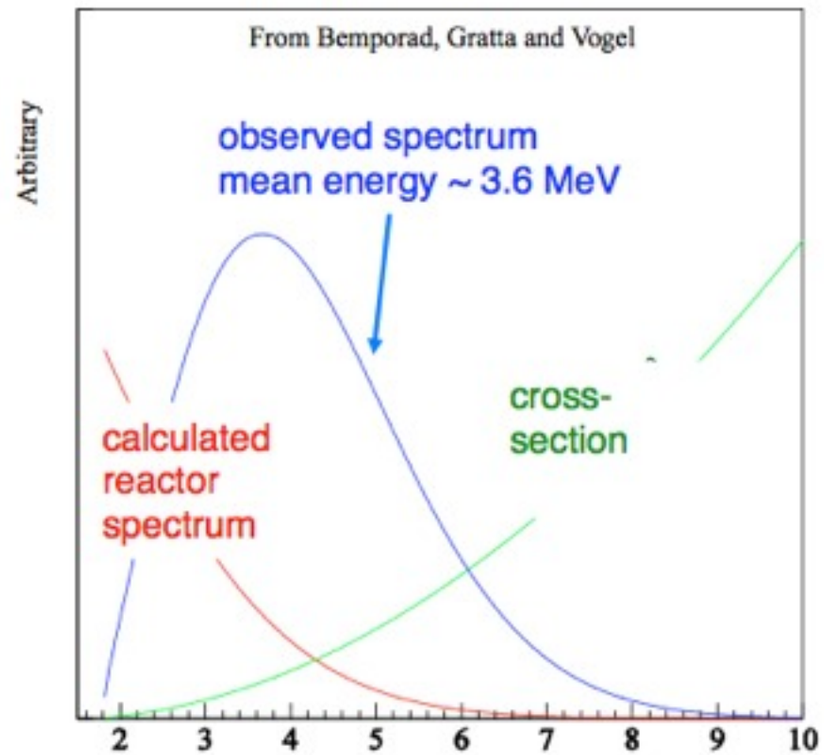
- MeV experiments can we can carry out at short baselines:
  - Reactor experiments
  - Antineutrino source experiments
  - Neutrino source experiments
- This talk will explain these options, specific proposals

Reactor Sterile Searches

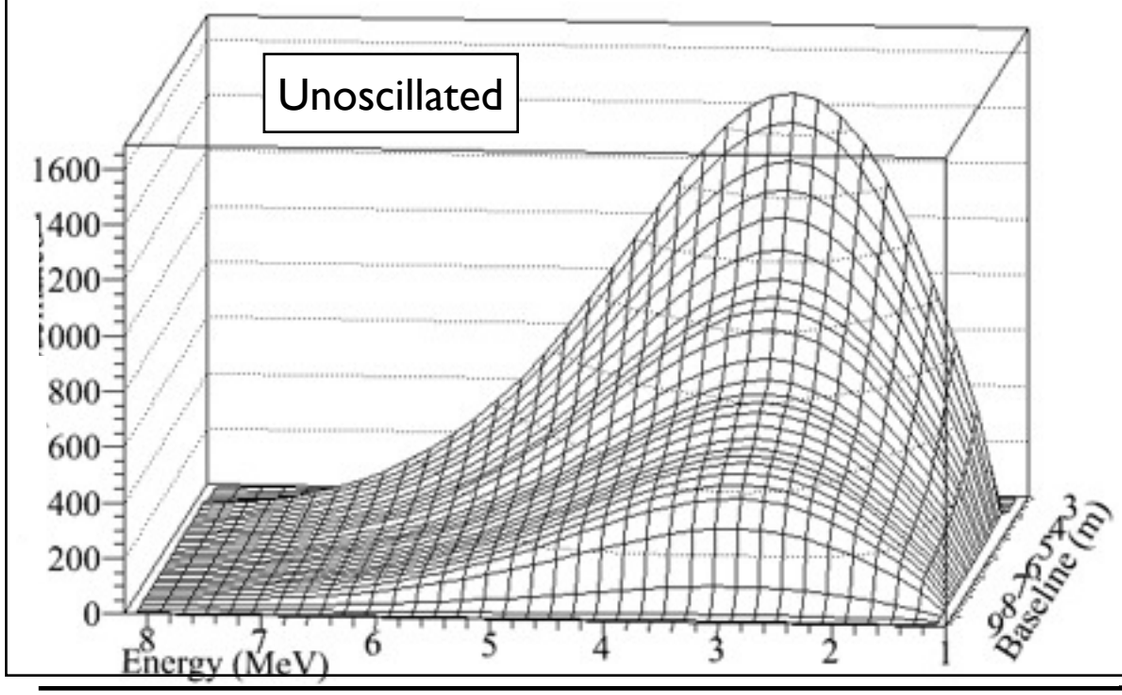
* My apologies to experiments I didn't have time to mention: see backup slides!

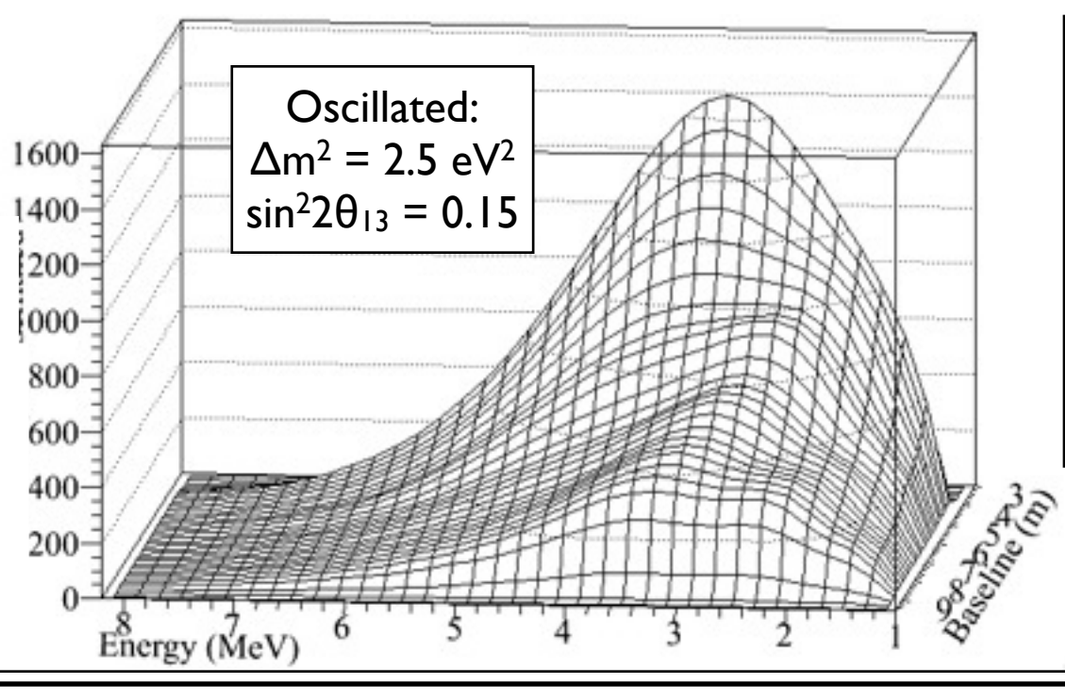
Sterile Searches at Reactors

- Detect reactor neutrino flux via inverse beta decay interaction
  - Highly enriched uranium reactors: << $1GW_{th}$, 20+% U-235
  - Conventional reactors: >1 GW, 4-6% U-235
- Look for deficits in rate, energy, position, or some combination



5x1x1 m^3 detector, $1m^3$ 20 MW HEU core, 4m closest distance





30% Efficiency

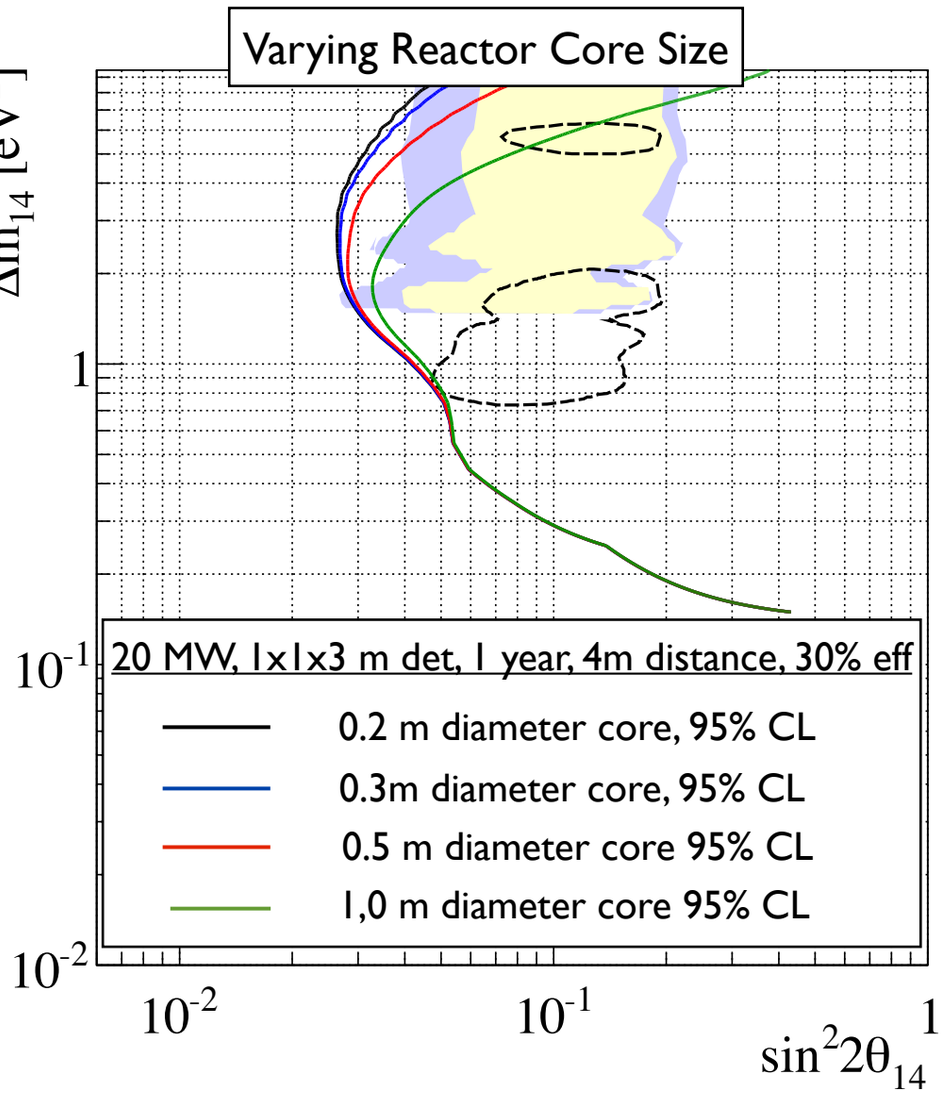
15cm position resolution

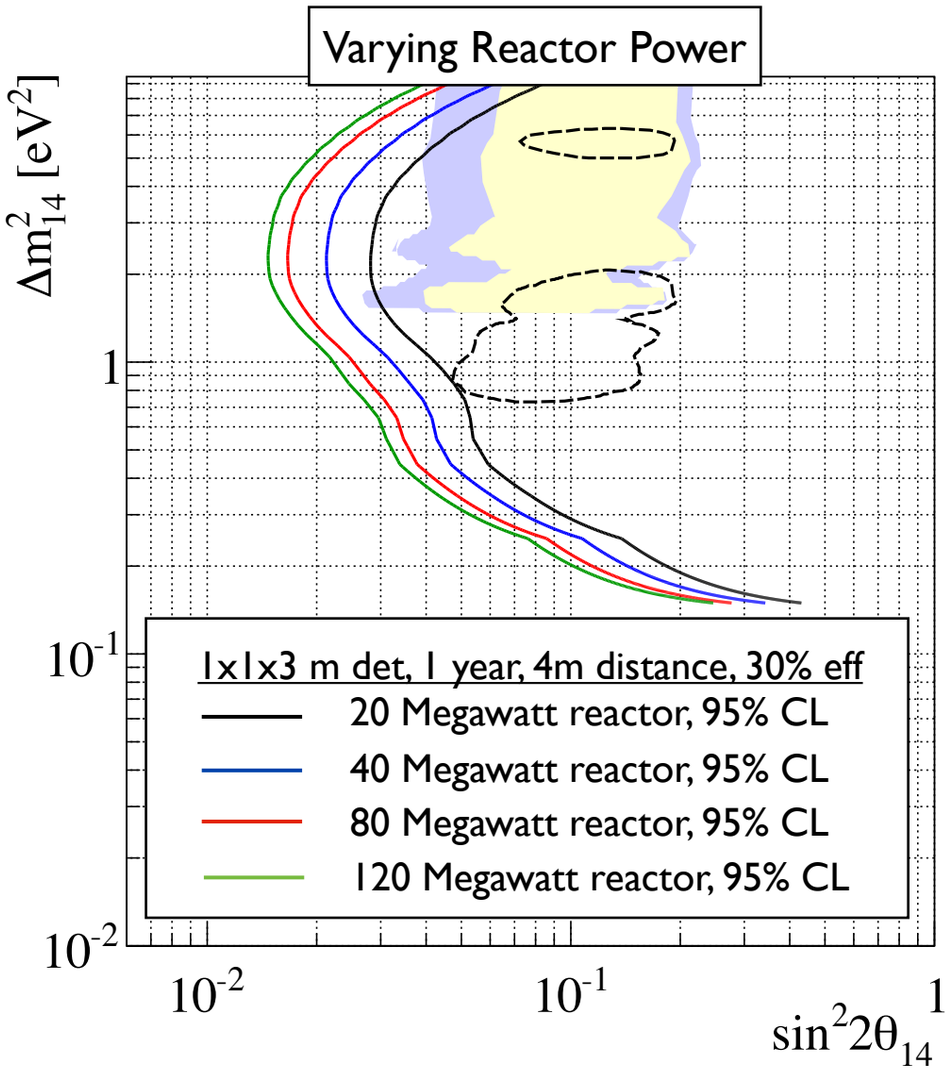
10%/Sqrt(E) Energy Resolution

SBL Reactor Experimental Variables

- Sensitivity of candidate experiment dependent on some main variables:
  - Core size
  - Core power
  - Baseline ranges
  - Detector eff, volume
  - Backgrounds

Heeger, Littlejohn, Mumm, et. al.
Upcoming Publication





- The following projects have necessary variables to cover large portions of 90% CL anomaly parameter space at 95% CL.
  - Too many experiments to show each sensitivity plot individually...

Worldwide Reactor Efforts

Location	Experiment	Reactor Power (MW)	Baselines (m)	Measures Oscillation Via:	Status
USA	SCRAAM	3000	24	Energy	Proposal
	ATR	110	7,12	Energy + Baseline	Proposal
	HFIR	85	7-10		
	NIST	20	4-13		
France	Nucifer	70	7	Rate, Energy	Built; Upgrading
	Stereo	50	7-9	Energy + Baseline	Proposal
Russia	Neutrino-4	18; 100	5-10	Energy + Baseline	Proposal
	DANSS	3000	9,12,18	Rate, Energy at multiple positions	Construction
Korea	Hanaro-4	30	6	Rate, Energy	Prototype

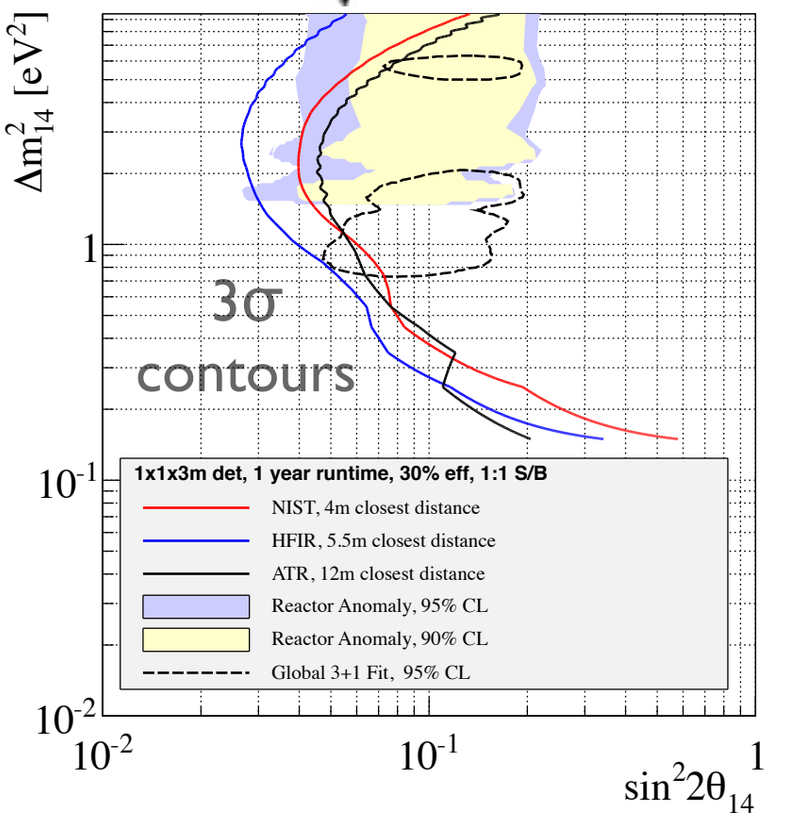
- Segmented detector allows oscillation versus baseline analysis
- Many scintillator options: Gd-doped LS, Li-doped LS, plastic scintillators

Worldwide Reactor Efforts: USA

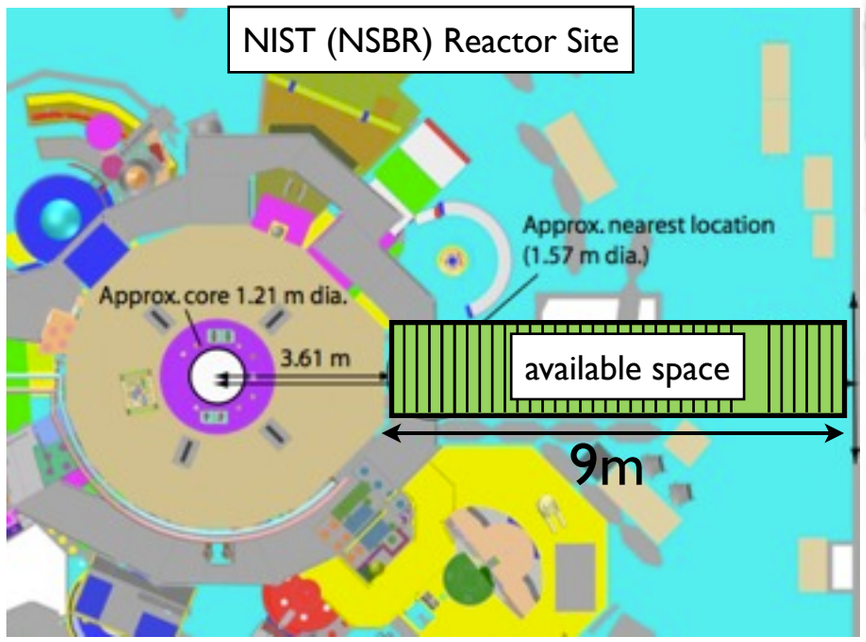
- Gaining consensus on one US-based effort
  - Some sites have better available baseline: NIST
  - Some sites have better thermal power: ATR
  - Some site have smaller core size: HFIR

Heeger, Littlejohn, Mumm, et. al.
See poster here at NNN12!

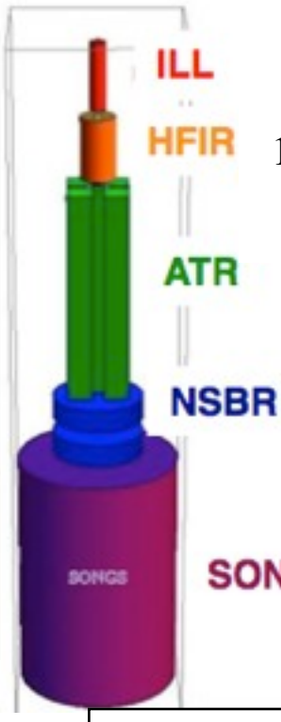
- US groups have significant experience building detectors for non-proliferation
  - Also significant oscillation analysis experience

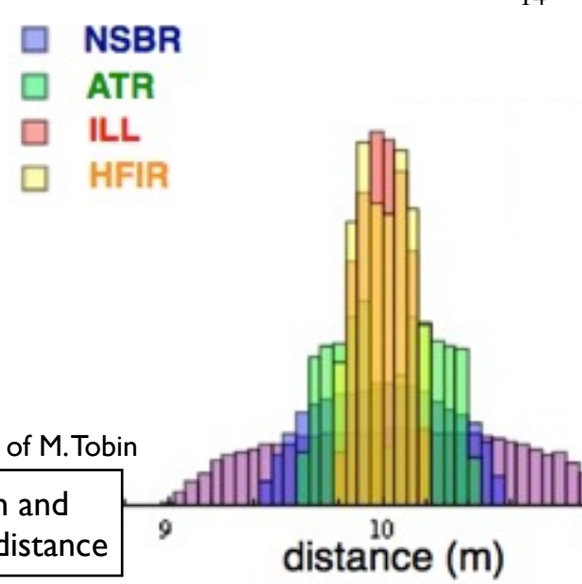


N. Bowden, SNAC 2011, Virginia Tech



Courtesy of P. Mumm





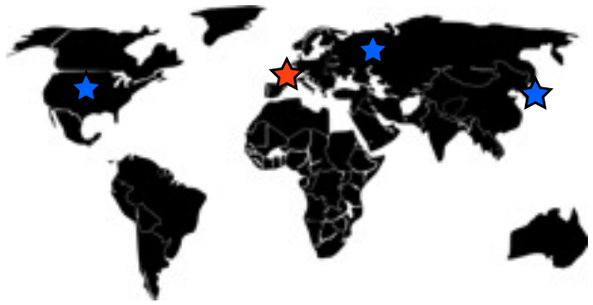
Courtesy of M. Tobin

Core size comparison and baseline spread at 10m distance

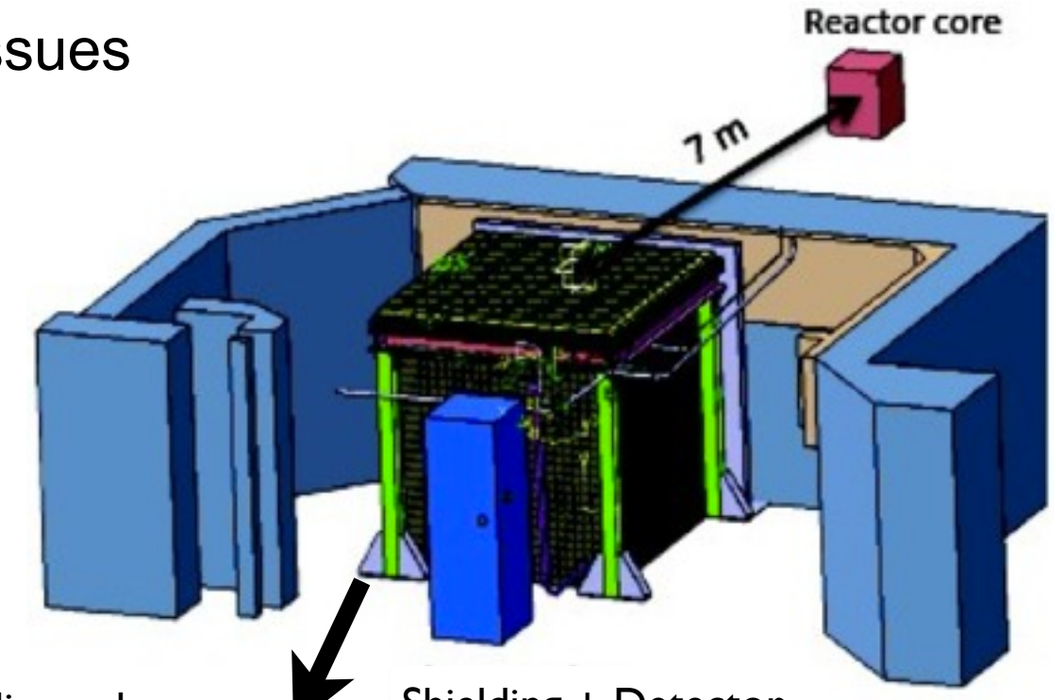
Worldwide Reactor Efforts: France

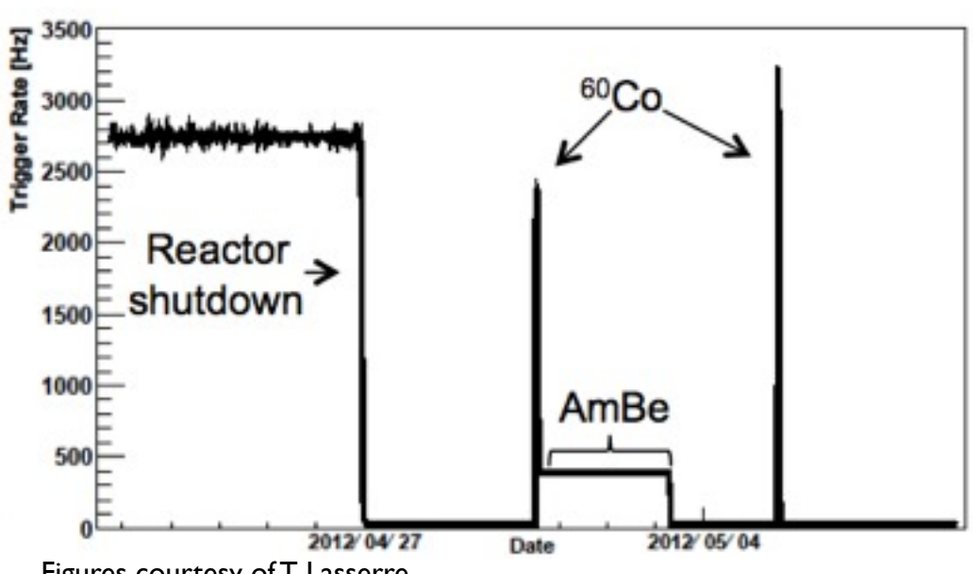
- Nucifer

A.S. Cucoanes for Nucifer, TAUP 2011, Munich



  - Measure energy spectrum distortion at one baseline
  - Detector built, has taken test data in 2012
  - Addressing gamma shielding and GdLS issues
  - Start oscillation data-taking in 2013
  - STEREO: Proposal for segmented detector at ILL





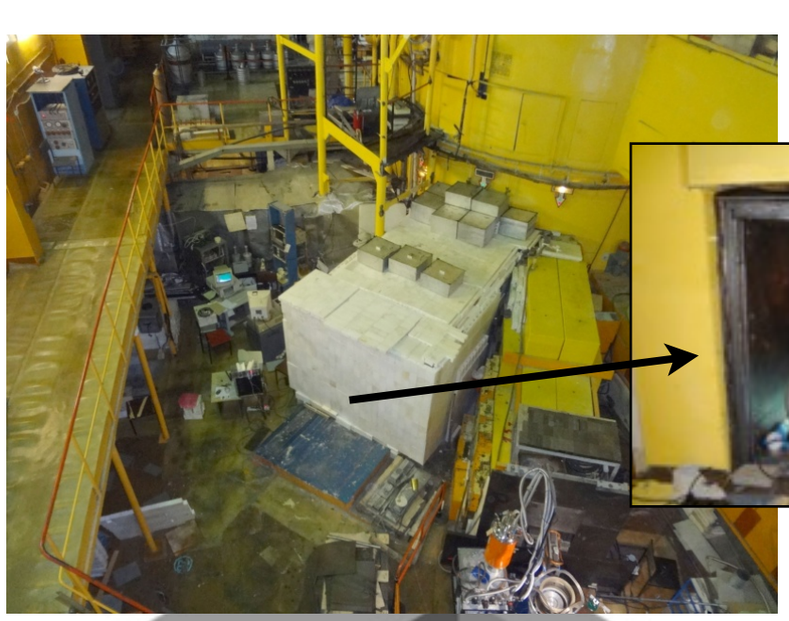
Figures courtesy of T. Lasserre

Shielding only

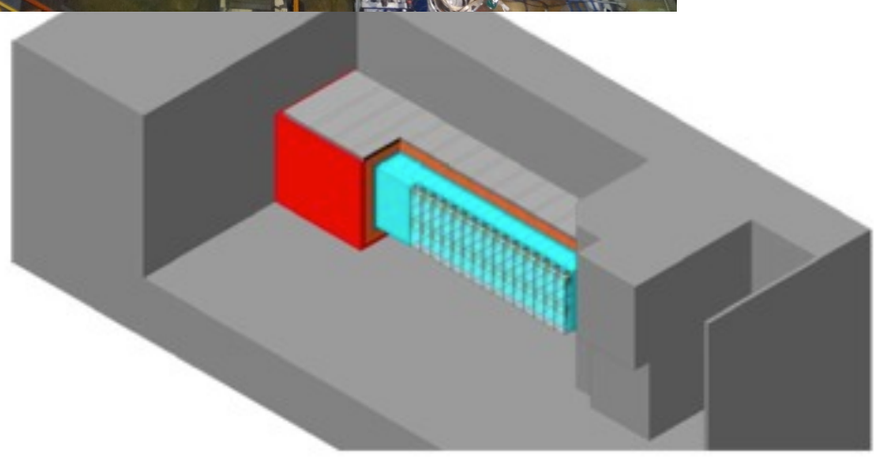
Shielding + Detector

Worldwide Reactor Efforts: Russia

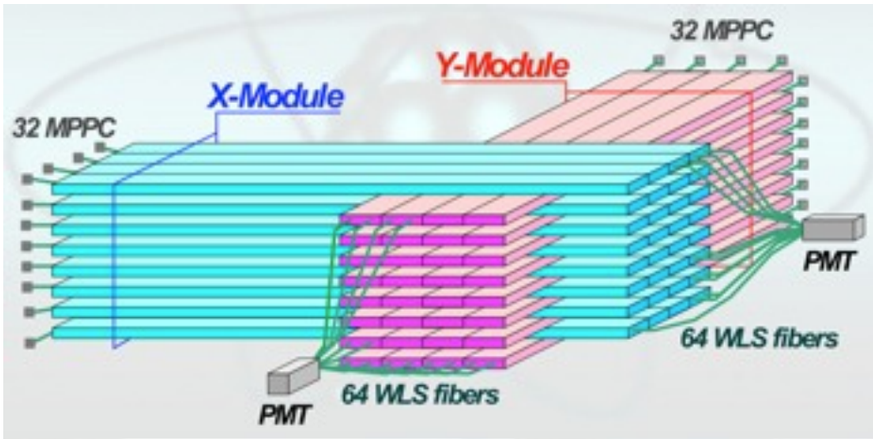
- Neutrino-4 — A. Serberov, et. al. arXiv:1205.2955
  - Long, segmented detector, active shielding proposed
  - Passive shielding built, characterized at 18 MW reactor
  - Move to 100 MW reactor?

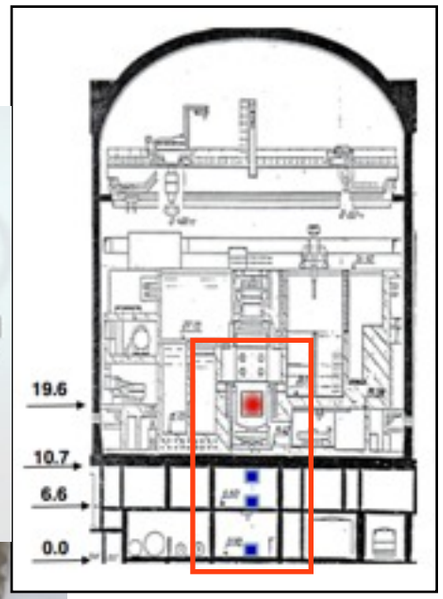


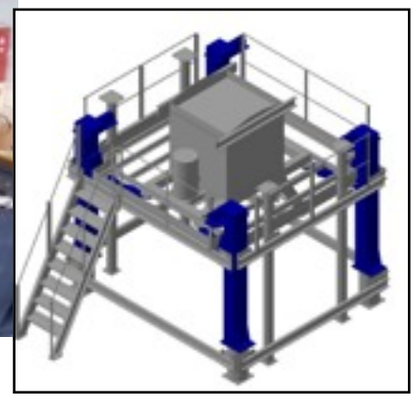
Courtesy of A. Serebrov



- DANSS — V. Egorov, TAUP2011
  - At 3GW Commercial reactor
  - Highly segmented solid scint detector being constructed - finish in 2012?
  - Propose to use lift to move detector to different baselines





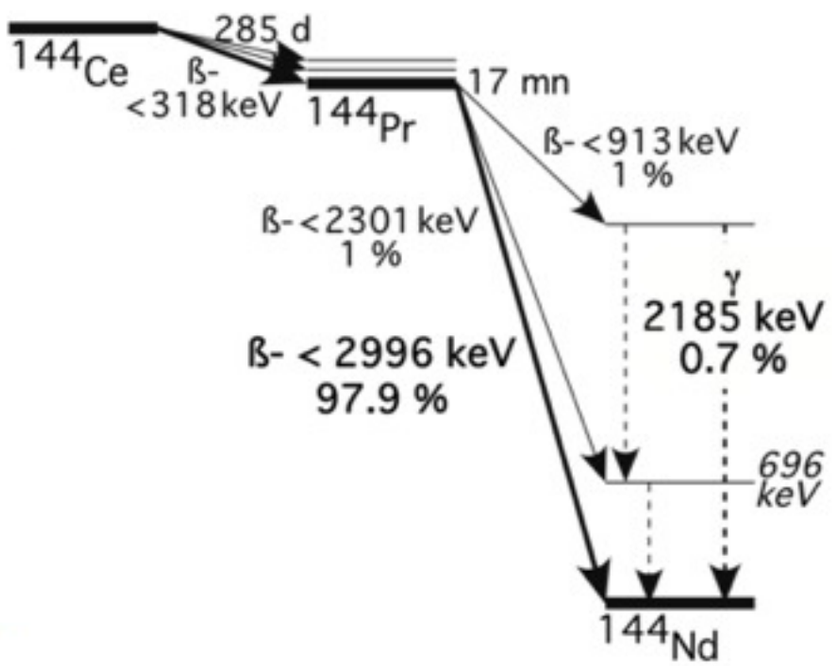


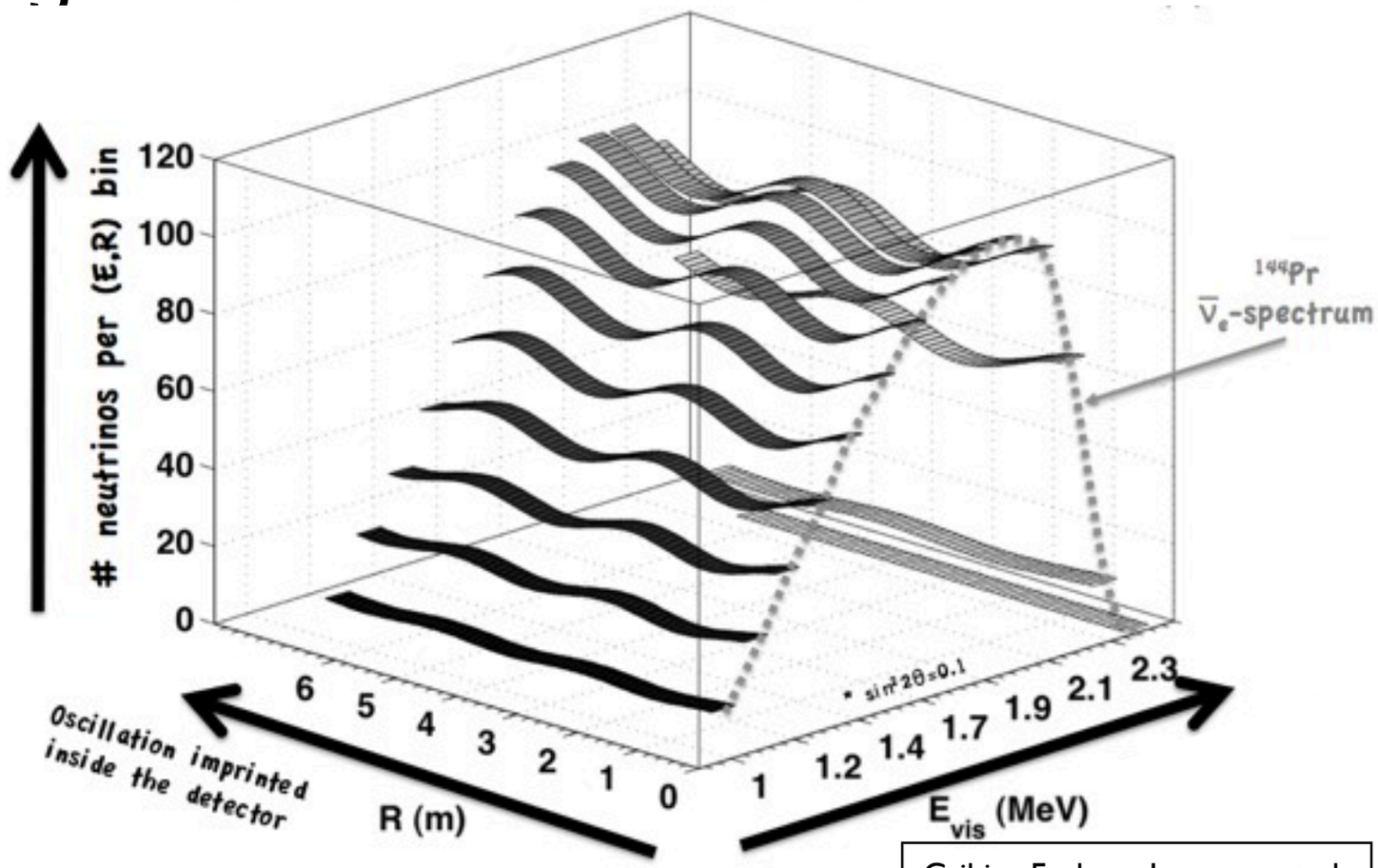
ν / ν̄ Source Sterile Searches

* My apologies to experiments I didn't have time to mention: see backup slides!

Antineutrino Sources: ^{144}Ce-^{144}Pr

- Concentrated source of long-lived ^{144}Ce beta emitter
  - ^{144}Ce is long lived, daughter ^{144}Pr short-lived, high Q-value above IBD threshhold
- Detect ^{144}Pr decays via inverse beta decay
  - Low background coincidence signature
- Detect oscillation through distortion with baseline
  - Energy spectrum too narrow to exhibit much oscillation

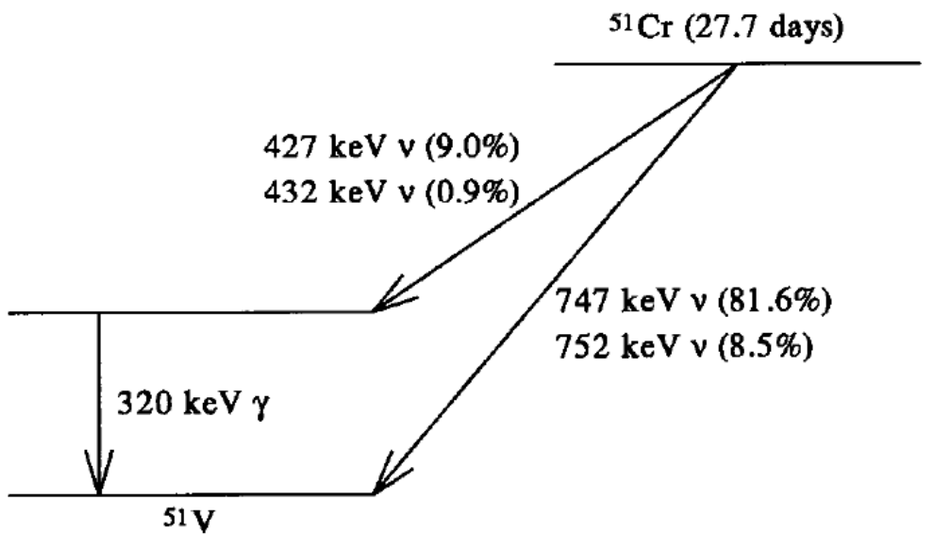




Cribier, Fechner, Lasserre, et. al., PRL 107 201801 (2011)

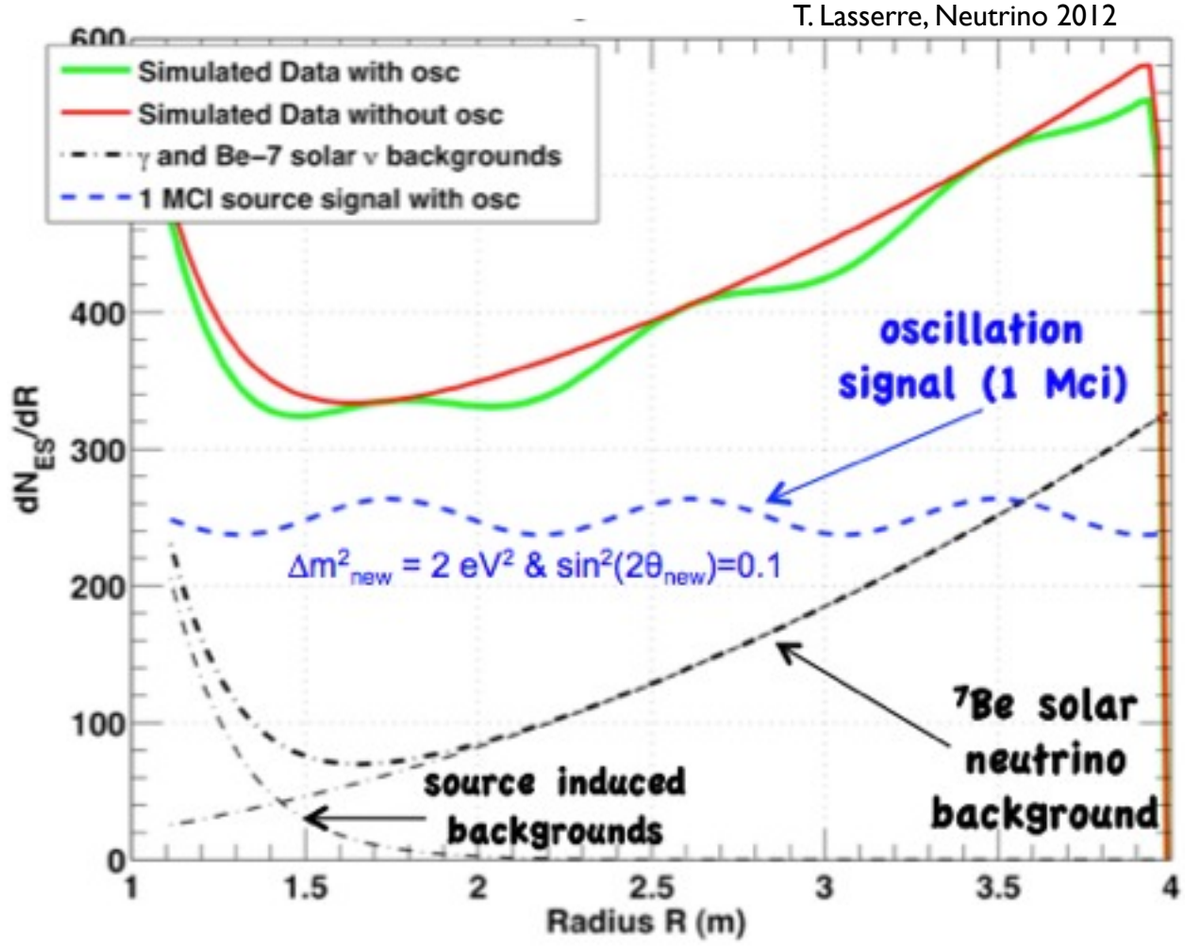
Neutrino Sources: ^{51}Cr

- ^{51}Cr electron capture source
  - Nearly mono-energetic 1-body decay, so oscillation doesn't drop off with distance!
- Detect via elastic scattering off electrons
  - Clean, low-threshhold detectors required
- Detect oscillation through distortion with baseline



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

T. Lasserre, Neutrino 2012

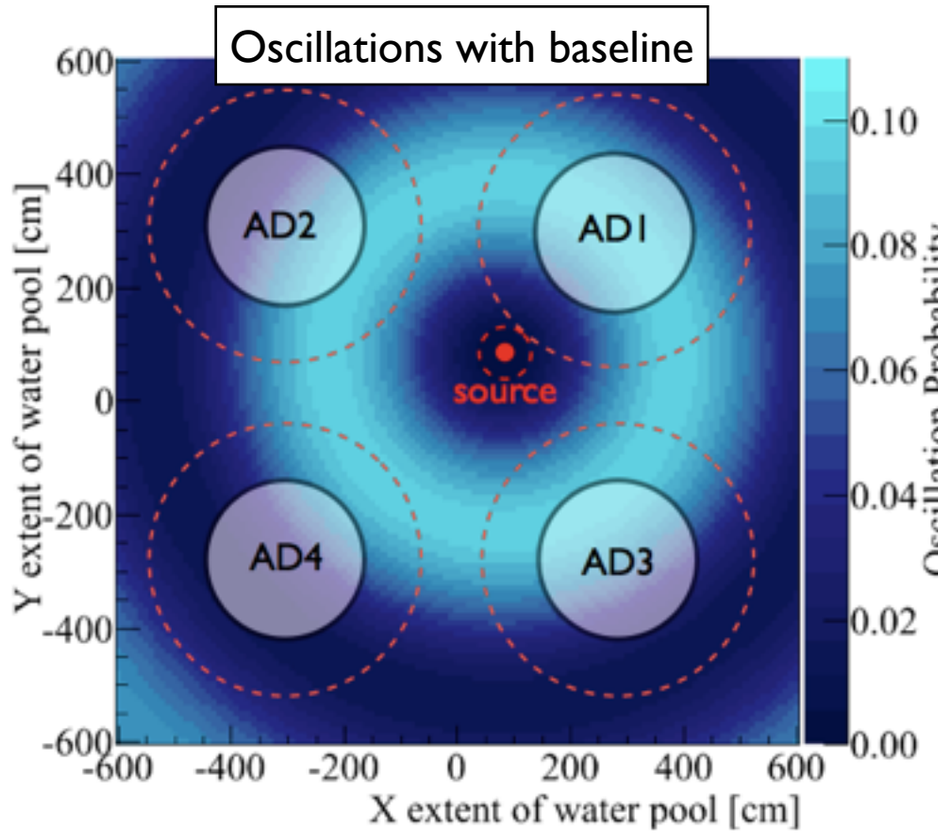


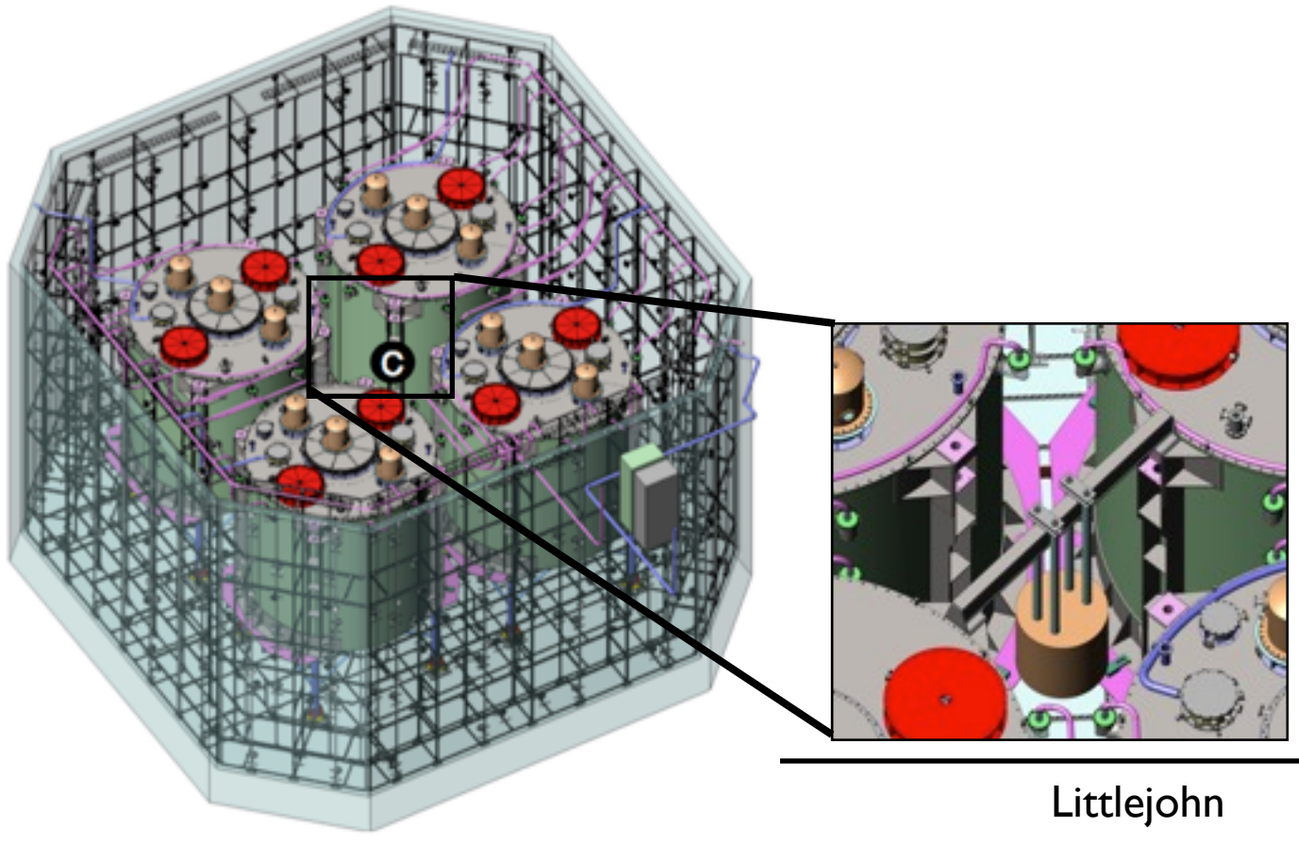
Daya Bay Source Experiment

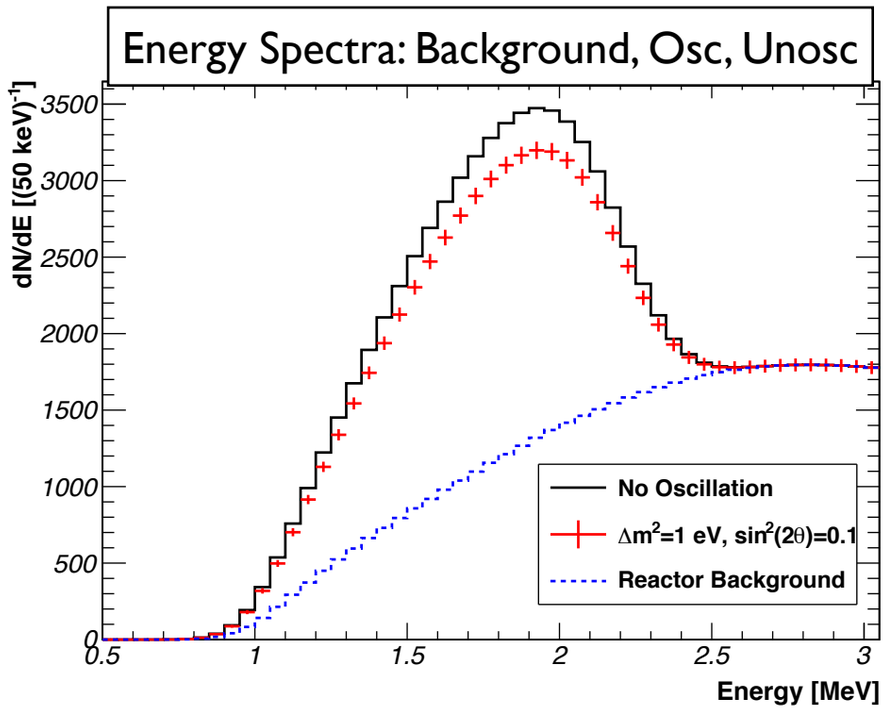
- 0.5 MCi ^{144}Ce source
  - 35,000 events/year
  - 35 cm tungsten shielding

Dwyer, Heeger, Littlejohn, Vogel
arXiv:1109.6036 [hep-ex]

- ‘Easy’ deployment in far hall water pool: detectors undisturbed
  - Multiple source locations to check osc behavior
- Could install after θ_{13} measurement





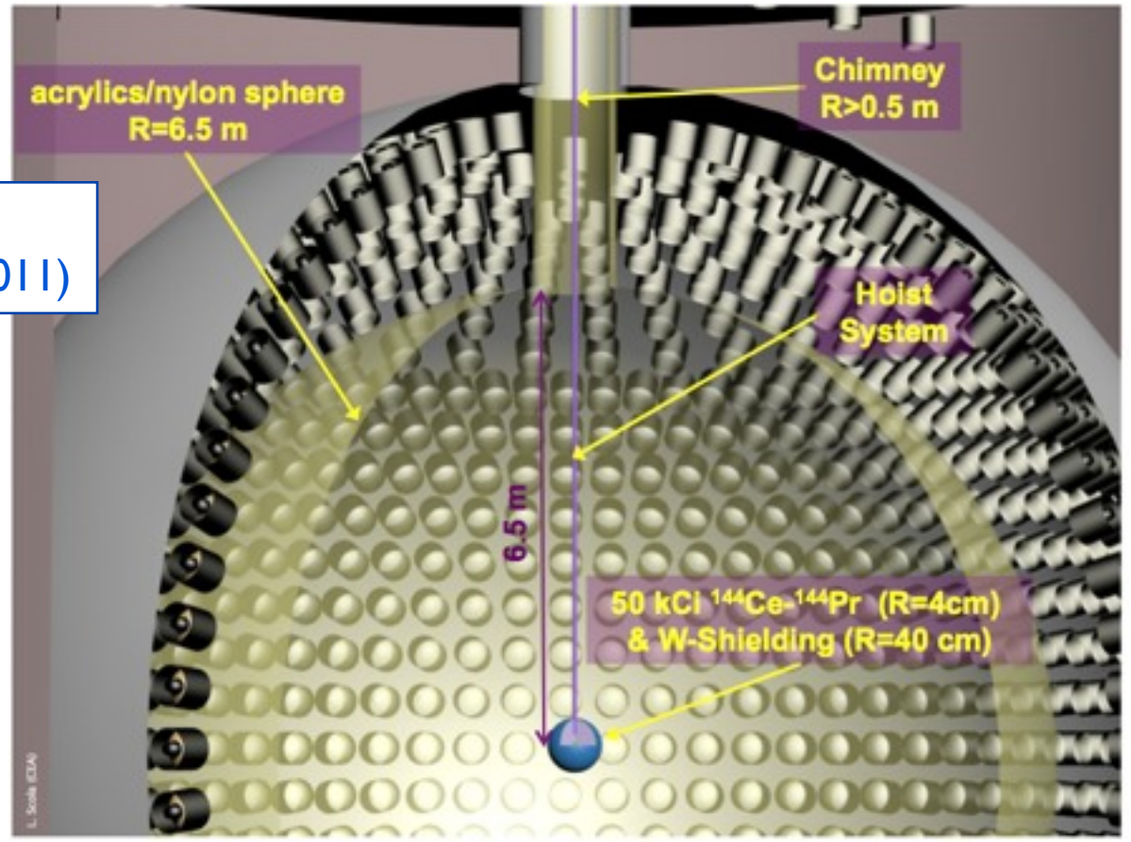


CeLAND

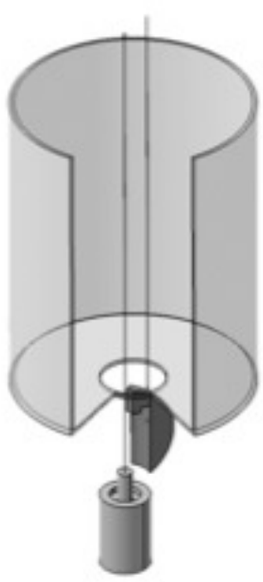
- 0.05 MCi ^{144}Ce source
  - 40,000 events/year
  - 40 cm tungsten shielding

Cribier, et. al.,
PRL 107 201801 (2011)

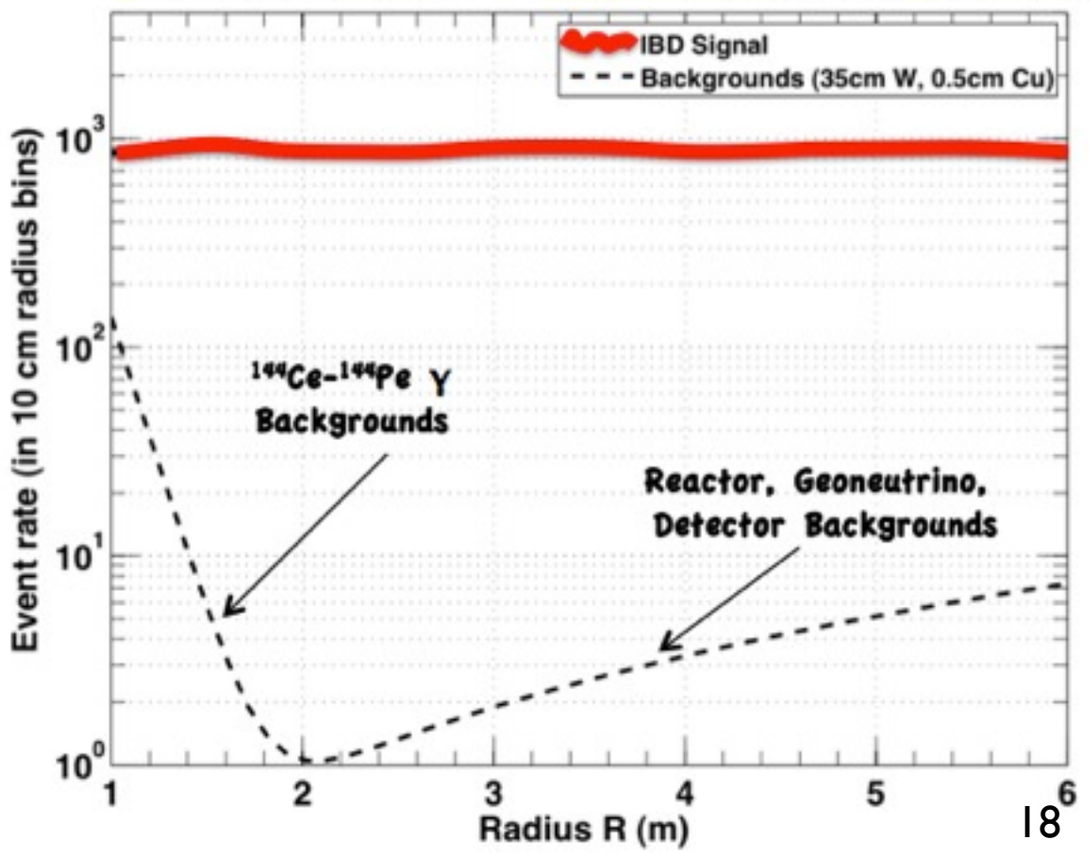
- Deployed inside detector
  - Shield and source combined in-situ to fit down chimney
  - See many oscillation periods



- Conflicts with KamLAND-Zen
  - Schedule after 2015 will be clearer after October collaboration meeting

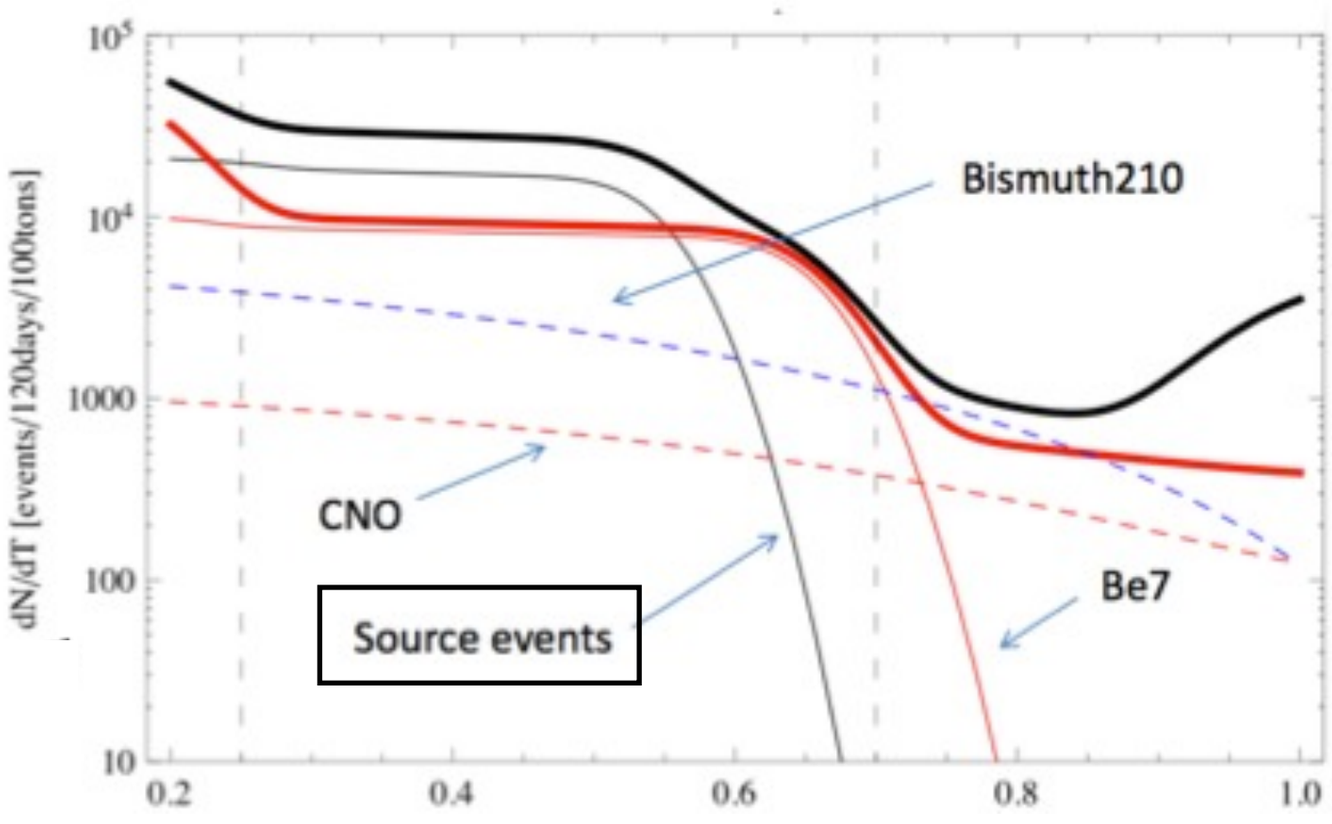


Source - shielding Deployment

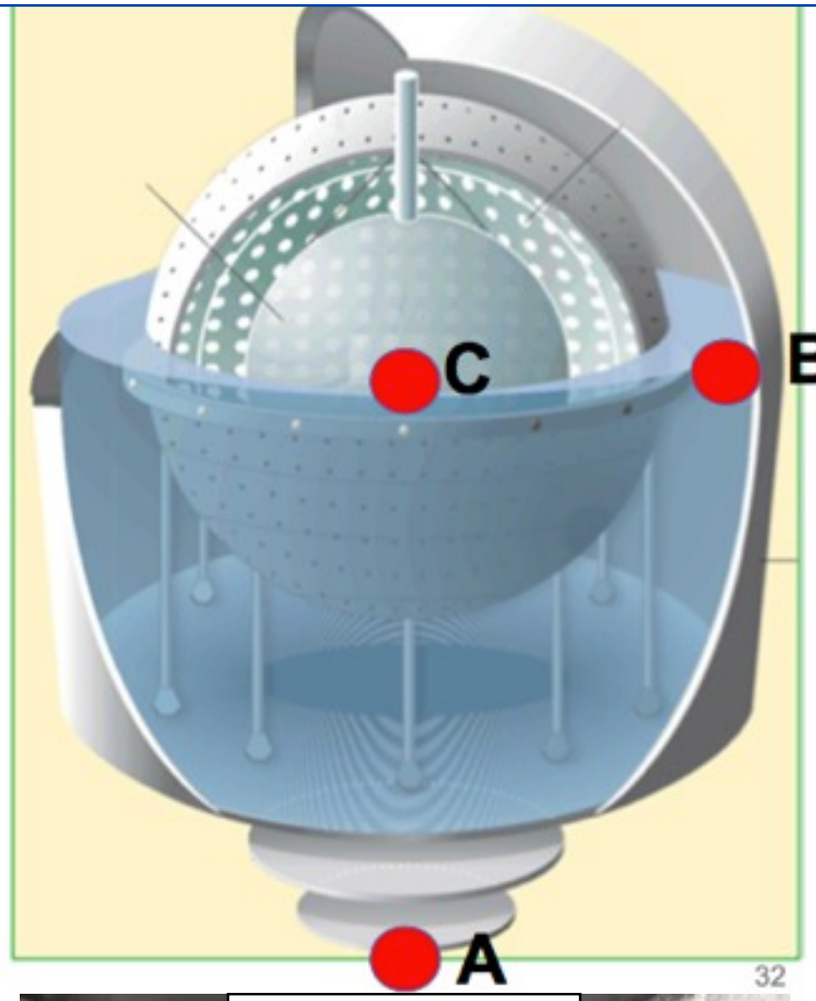


Borexino

- 0.05 MCi ^{144}Ce source at center
  - Like CeLAND; not until after 2015
- ~10 MCi ^{51}Cr source below detector
  - Absolute rate measurement - no oscillimetry
  - Must measure source activity to <1%
  - Possible before 2015



See Borexino Collab in Sterile Nu White Paper

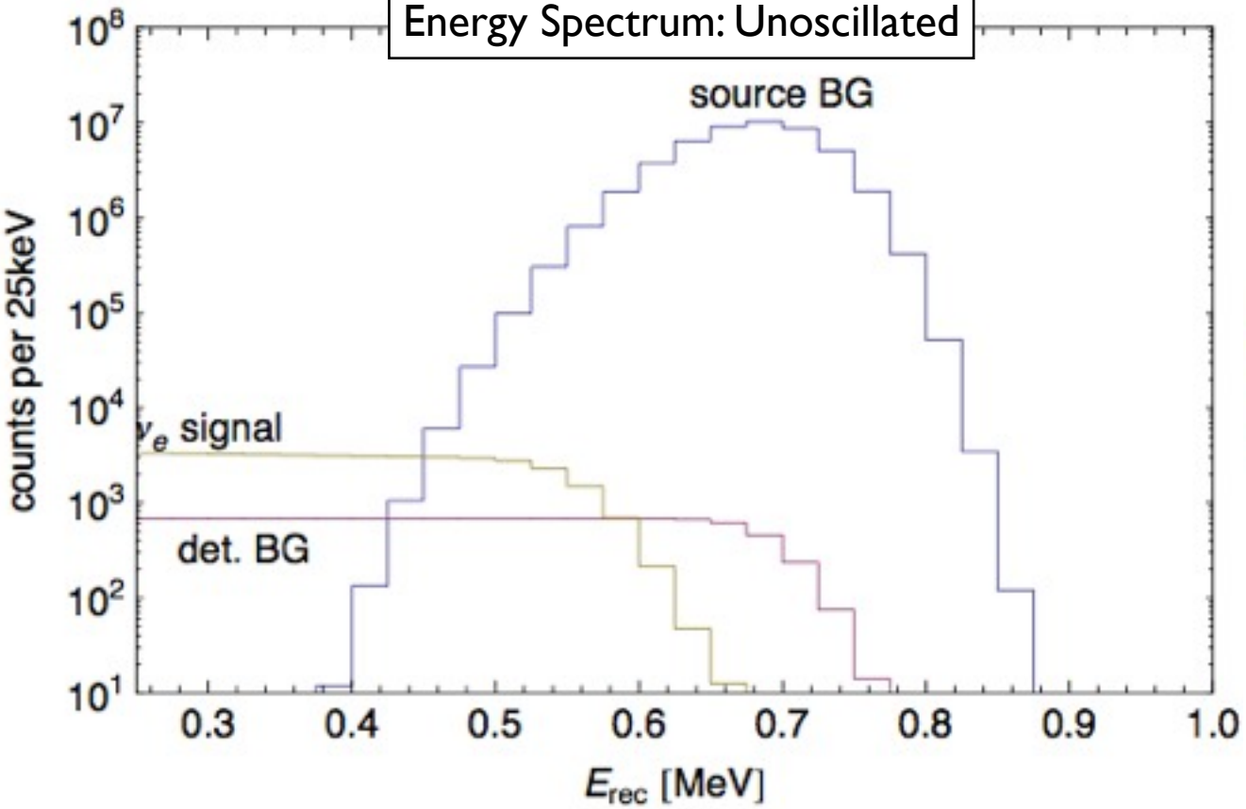


SNO+ Sterile

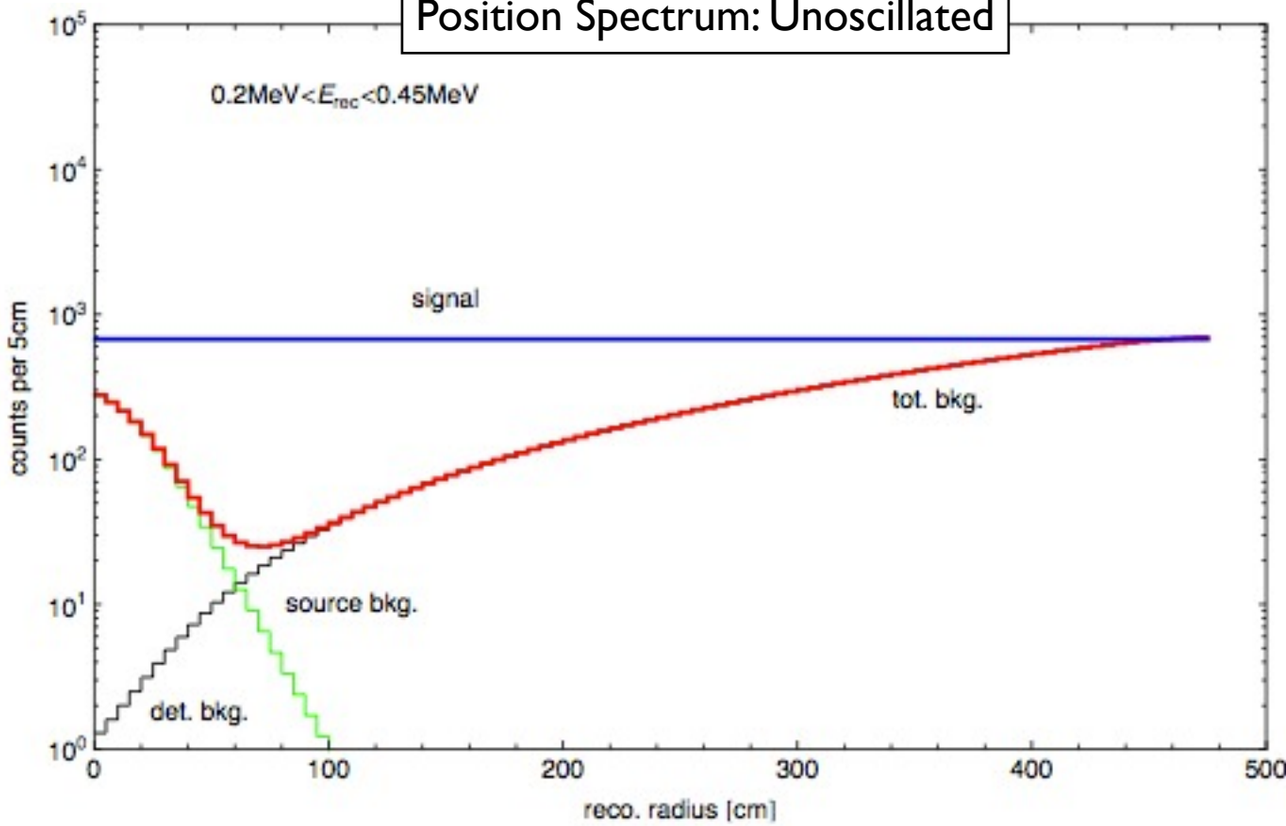
- 1+ MCi ^{51}Cr source inside SNO+
  - Oscillation with baseline
  - Deployment is easy with wide SNO chimney
  - Must have high-purity Tungsten shield
- Conflicts w/ SNO+ Nd phase: 2014
  - Deploy after multi-year Nd phase?

See J. Link, P. Huber in Sterile Nu White Paper

Energy Spectrum: Unoscillated

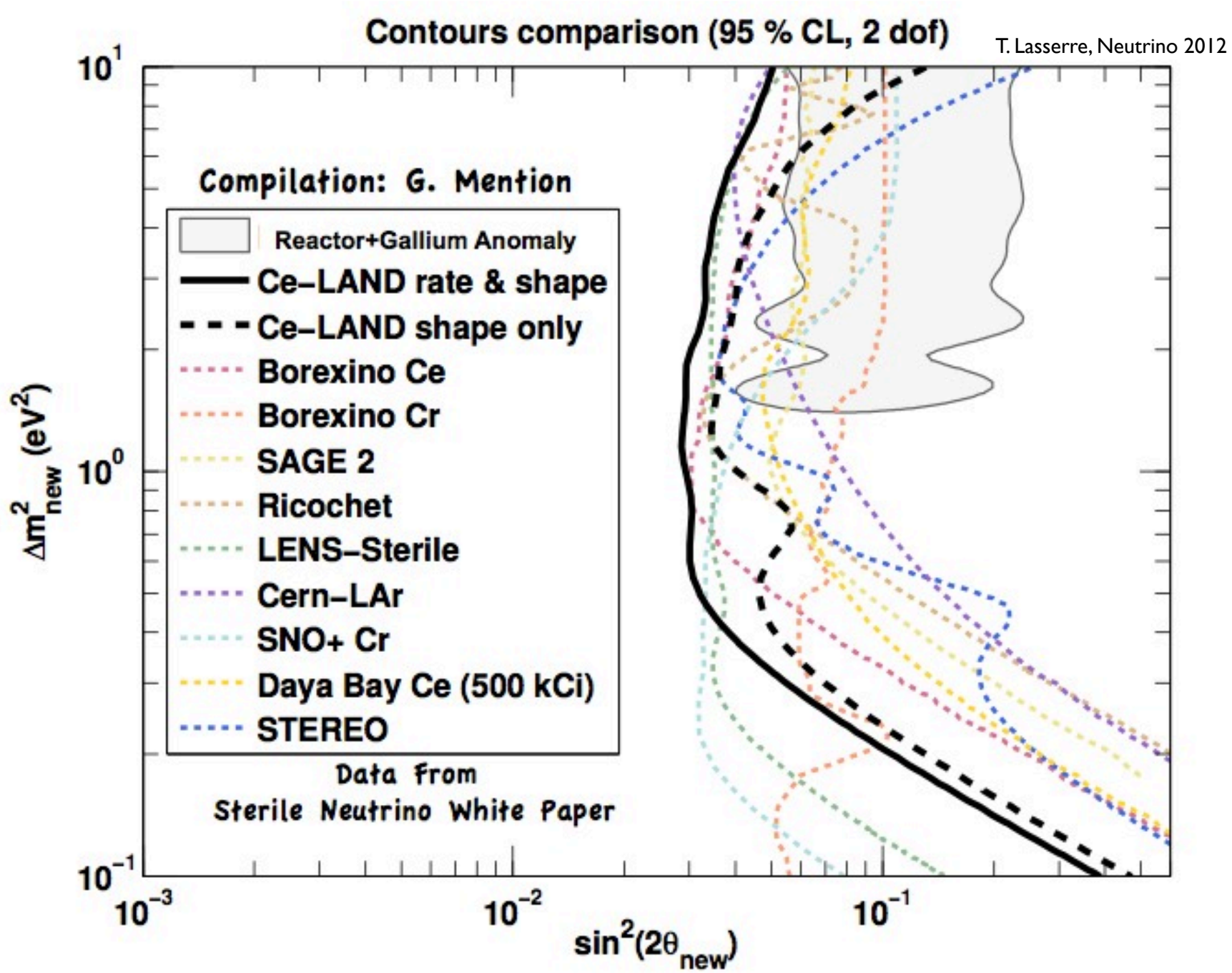


Position Spectrum: Unoscillated



Neutrino Sources: Sensitivity

- Sensitivity to sterile neutrinos vary from experiment to experiment, but most rule out anomaly to 95% CL



Sterile Searches: Feasible Timelines

****NOTE** - All dates are estimates - most proposals have no funding yet!**

	Experiment	2013	2014	2015	2016	2017+
Reactor	US Reactor	???	→	→	→	→
	Nucifer	→	→	→	→	→
	Stereo	???	→	→	→	→
	Neutrino-4	???	→	→	→	→
	DANSS	???	→	→	→	→
	Hanaro-4	???	→	→	→	→
	Ricochet	Not sure... 'new' technology, so much R&D remaining				
Antinu Source	Daya Bay Sterile	xxx θ_{13} running xxx	→	→	→	→
	CeLAND	xxx KamLAND-Zen running xxx		???	→	→
	Borexino ^{144}Ce	xxx Solar nu running xxx		???	→	→
Nu Source	SNO+ ^{51}Cr		xxx Nd phase running xxx		???	→
	LENS Sterile	Not sure... 'new' technology, so much R&D remaining				
	Borexino ^{51}Cr	???	→	→	→	→

Energy + Baseline + Rate Signature

Baseline + Rate Signature

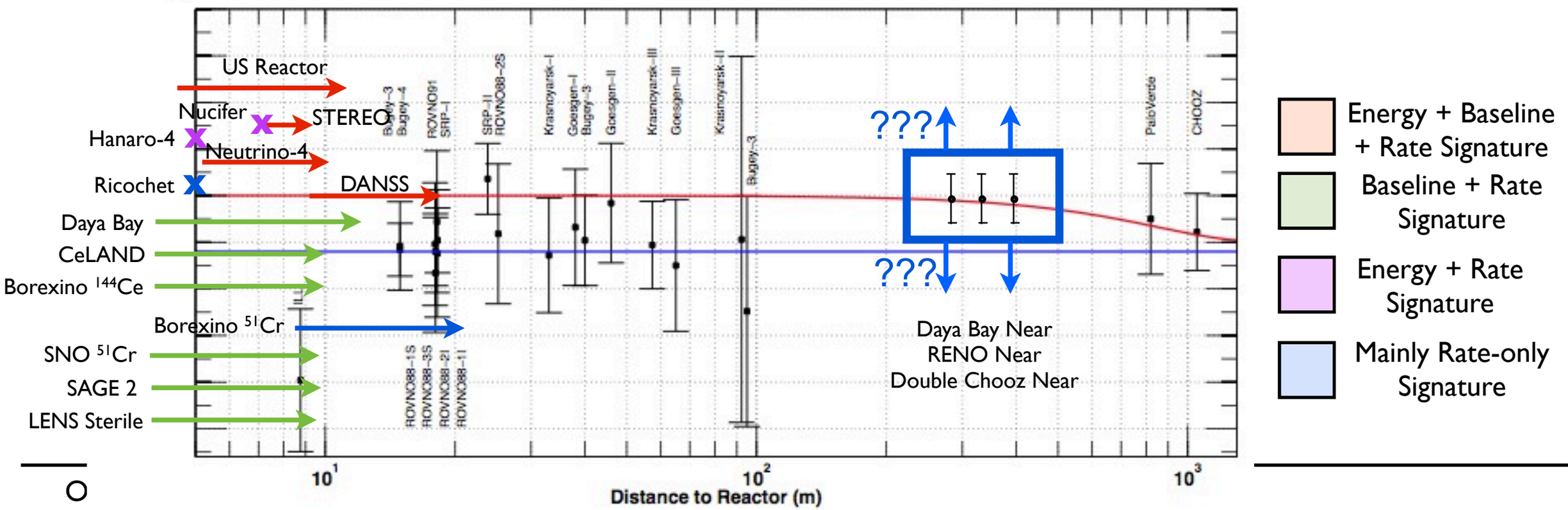
Energy + Rate Signature

Mainly Rate-only Signature

- Reactors appear to lead the way in terms of schedule
- Source experiments limited in time by competing detector uses

Summary: Beating SBL ν to Death

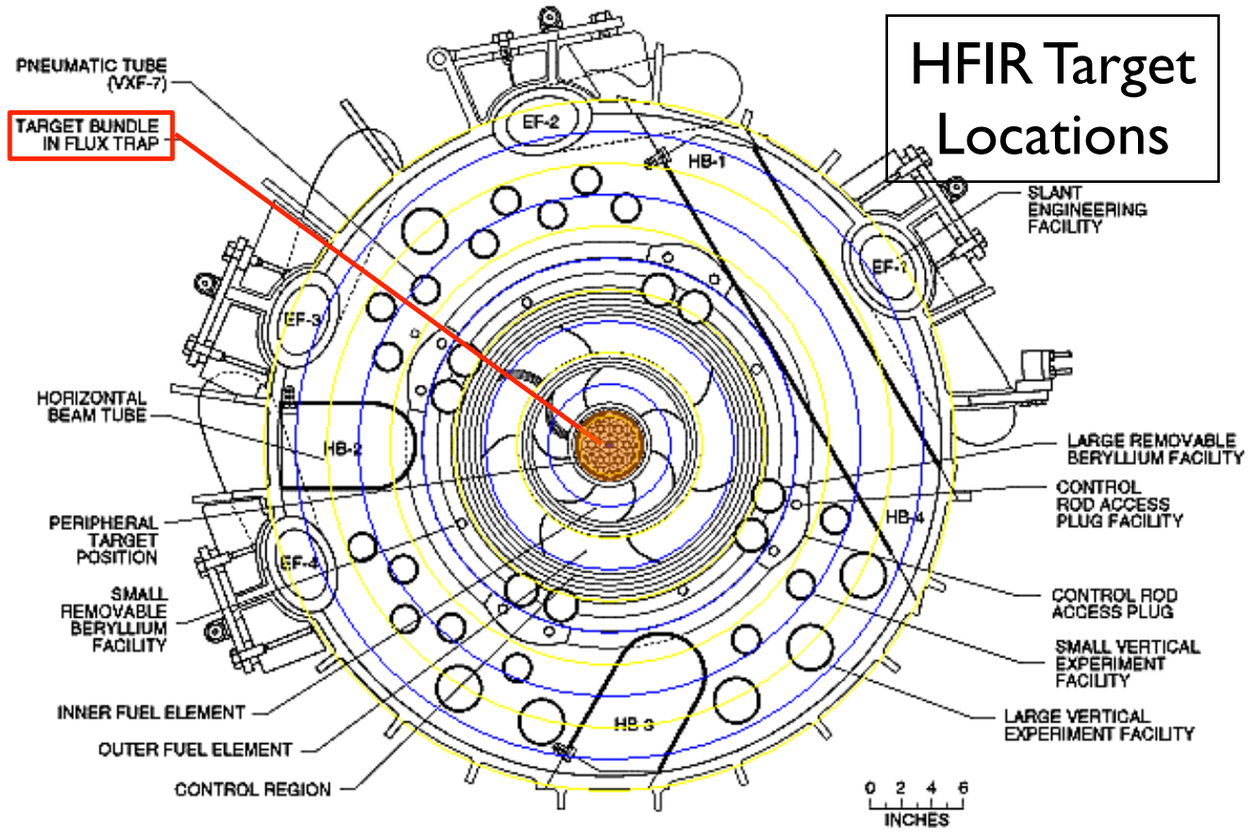
- Significant new information on SBL neutrino oscillations within a few years, more after ~5 years
- Many complimentary searches:
  - Rate measurements
  - Energy spectrum distortions
  - Baseline spectrum distortions
  - Multiple source types: reactors versus nu sources versus antinu sources
- Hopefully we can put the sterile neutrino question to rest!



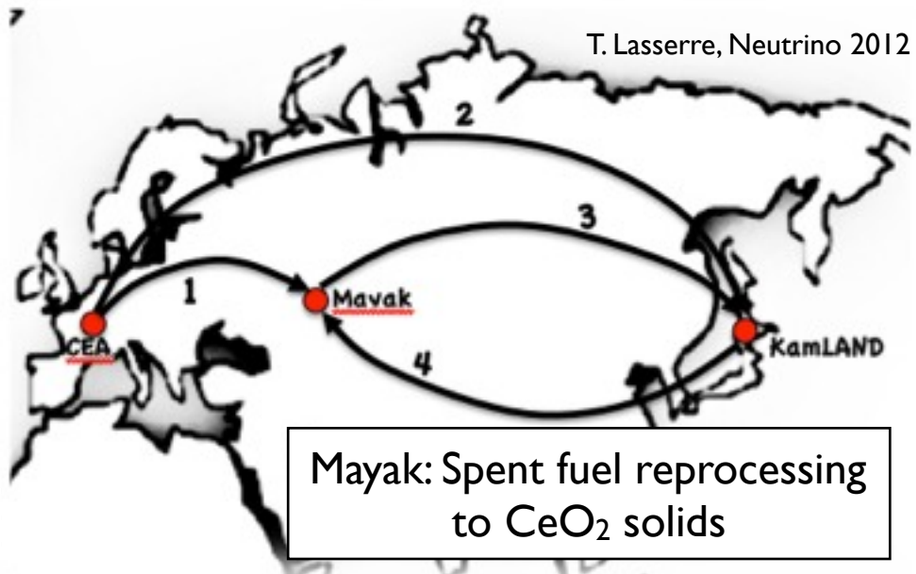
Backup

Source Production

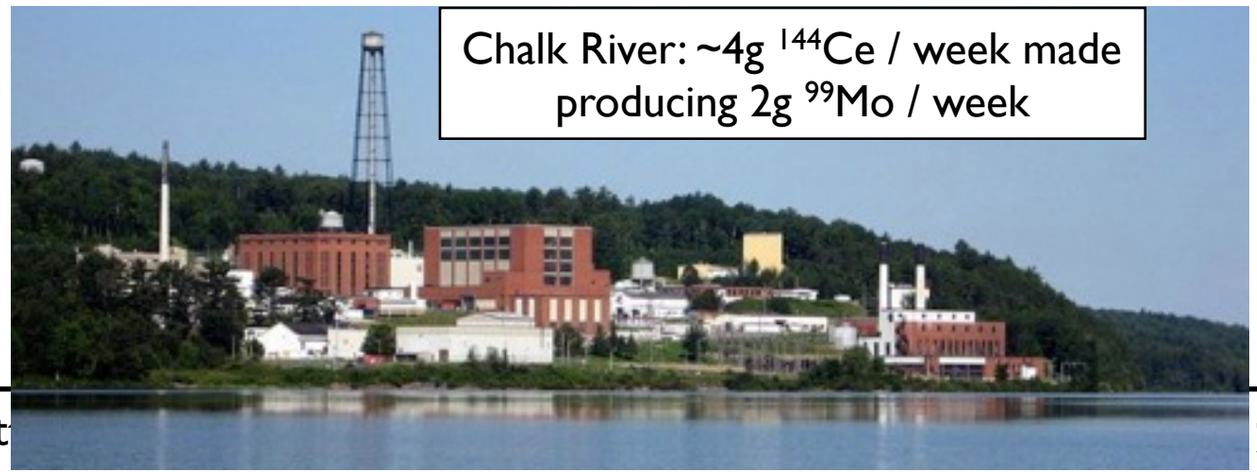
- Besides schedules, main barrier to realizing experiments
- ^{51}Cr: Neutron irradiation of ^{50}Cr in research reactor
  - Have been made before
  - Sites in Russia, USA are identified
- ^{144}Ce: less well-defined
  - Reprocess spent nuclear fuel
  - Reprocess neutron-irradiated actinide target
  - Reprocess ^{99}Mo/^{99}Tc prod. waste
  - Following leads in Russia, USA and Canada



Cross section of reactor core at horizontal midplane



Mayak: Spent fuel reprocessing to CeO_2 solids



Chalk River: ~4g ^{144}Ce / week made producing 2g ^{99}Mo / week

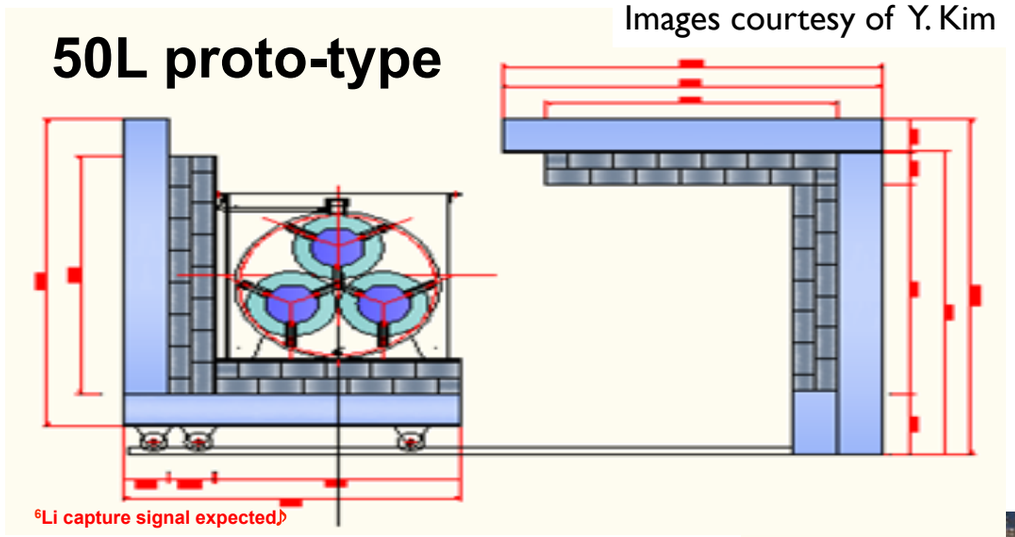
Other Worldwide Reactor Efforts

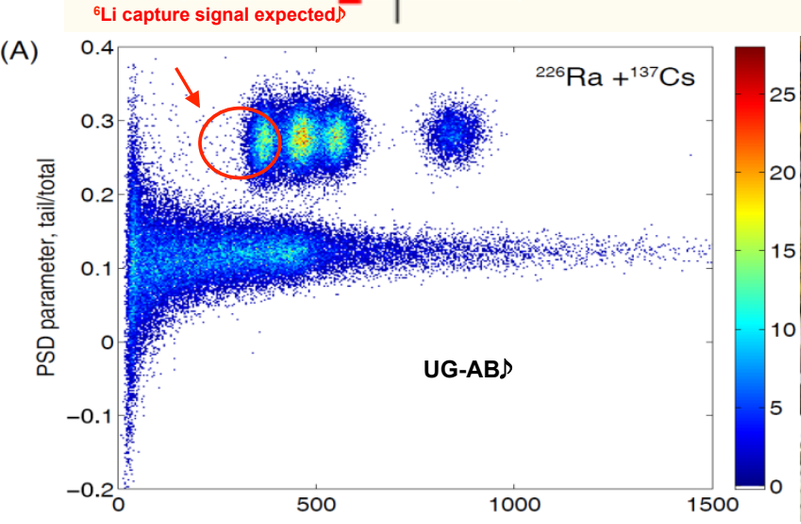
- Hanaro-4
  - 500L final detector
  - 50L prototype in production
  - Testing Li-doped scintillator
  - Localized neutron capture signal

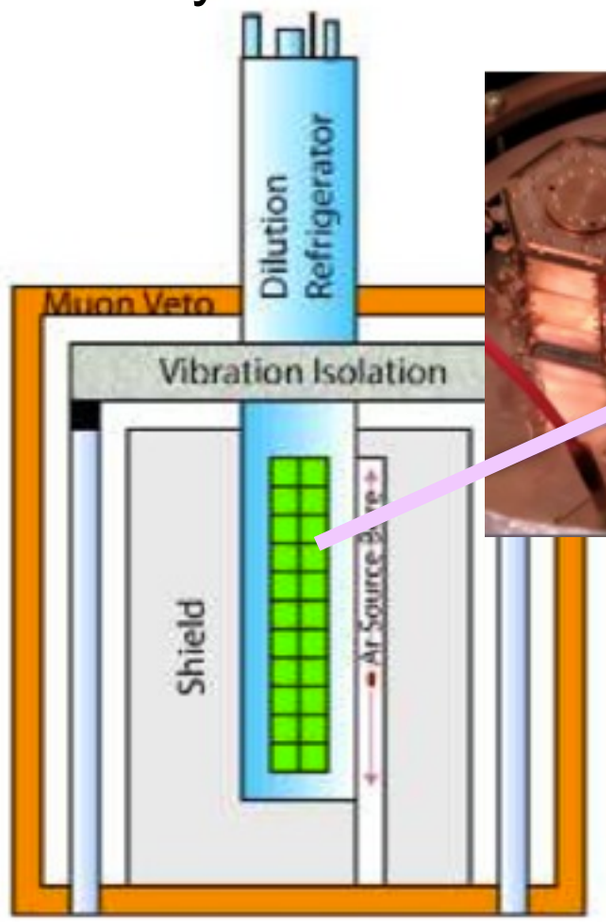
- RICOCHET
  - Coherent neutrino scattering detection: not yet observed
  - Utilize CDMS-like detectors with very low threshholds
  - First testing at MIT reactor: 5MW

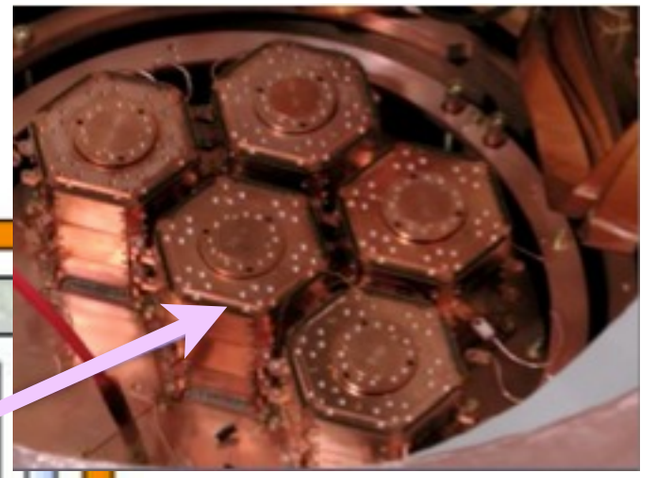
  - 500 kg array w/ 5MCi source has sensitivity to sterile neutrinos

Images courtesy of Y. Kim









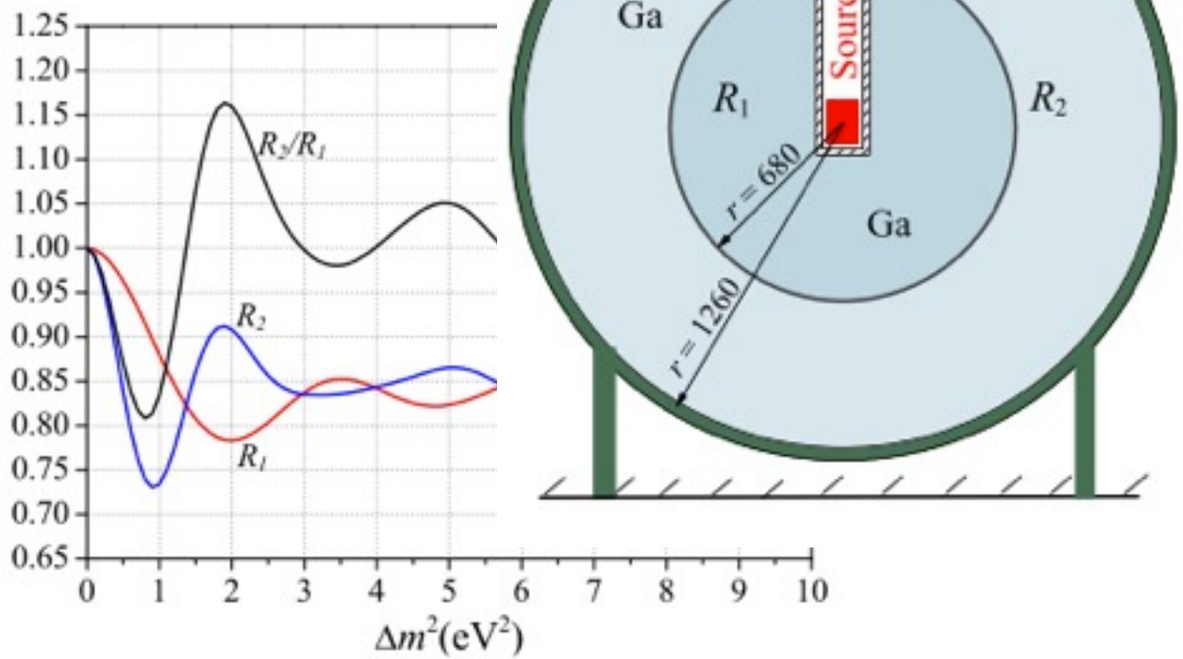
K. Scholberg, et. al
Sterile Nu White Paper:
arXiv:1204.5379 [hep-ph]

Other Worldwide Reactor Efforts

- SAGE 2

See B. Cleveland, et al. in Sterile Nu White Paper

  - Re-do SAGE ^{51}Cr calibration with a 2-zone detector
  - 3 MCi source
  - Measure relative rate differences between zones
  - Significant funding issues



- LENS Sterile

See LENS Collab. in Sterile Nu White Paper

  - 10 MCi ^{51}Cr next inside LENS detector
  - Time coincidence: nu capture on Indium
  - Nearly background-free measurement
  - 1/2000 prototype exists: MicroLENS presented at APS 2012 meeting
  - Much prototyping, R&D left to do