Sterile Neutrino Oscillation Sensitivity at Very Short Reactor Baselines

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Introduction

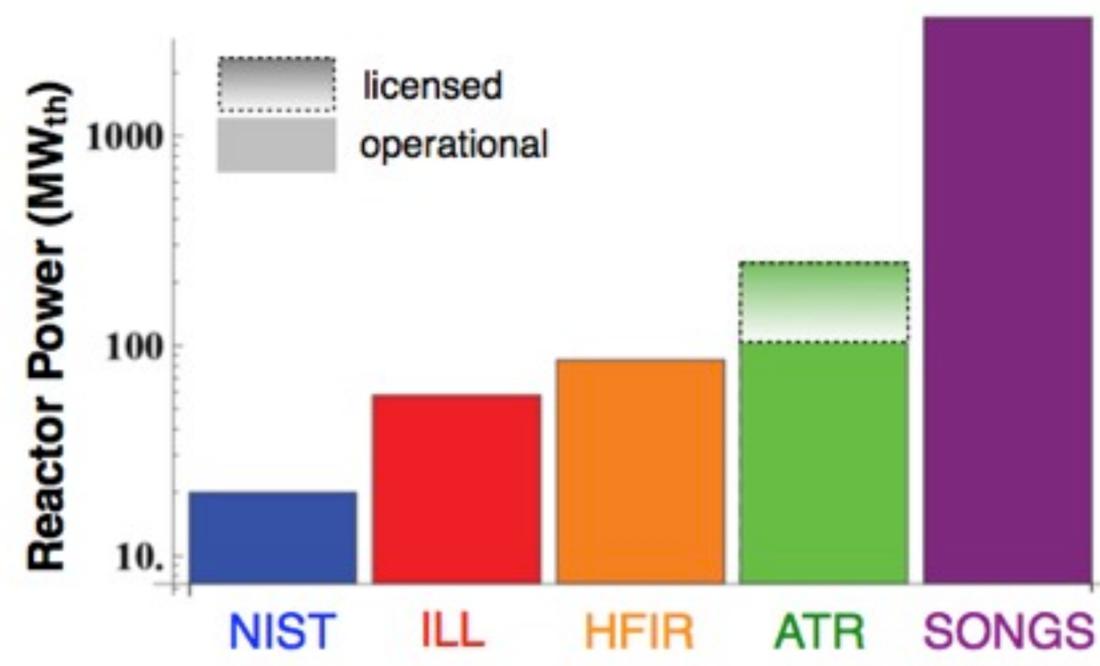
- We want to know what it takes to build a ‘definitive’ experiment to address reactor anomaly:

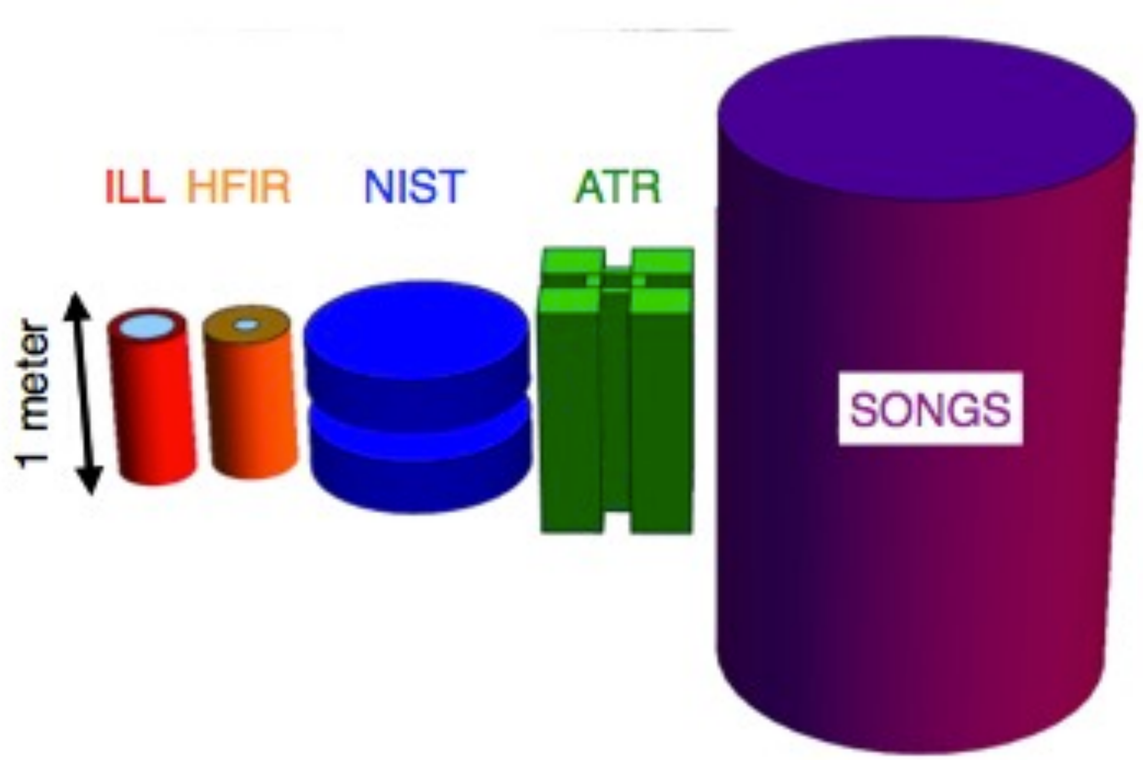
- Is it possible?
- What experimental variables are important?
- What values are necessary for a definitive experiment?

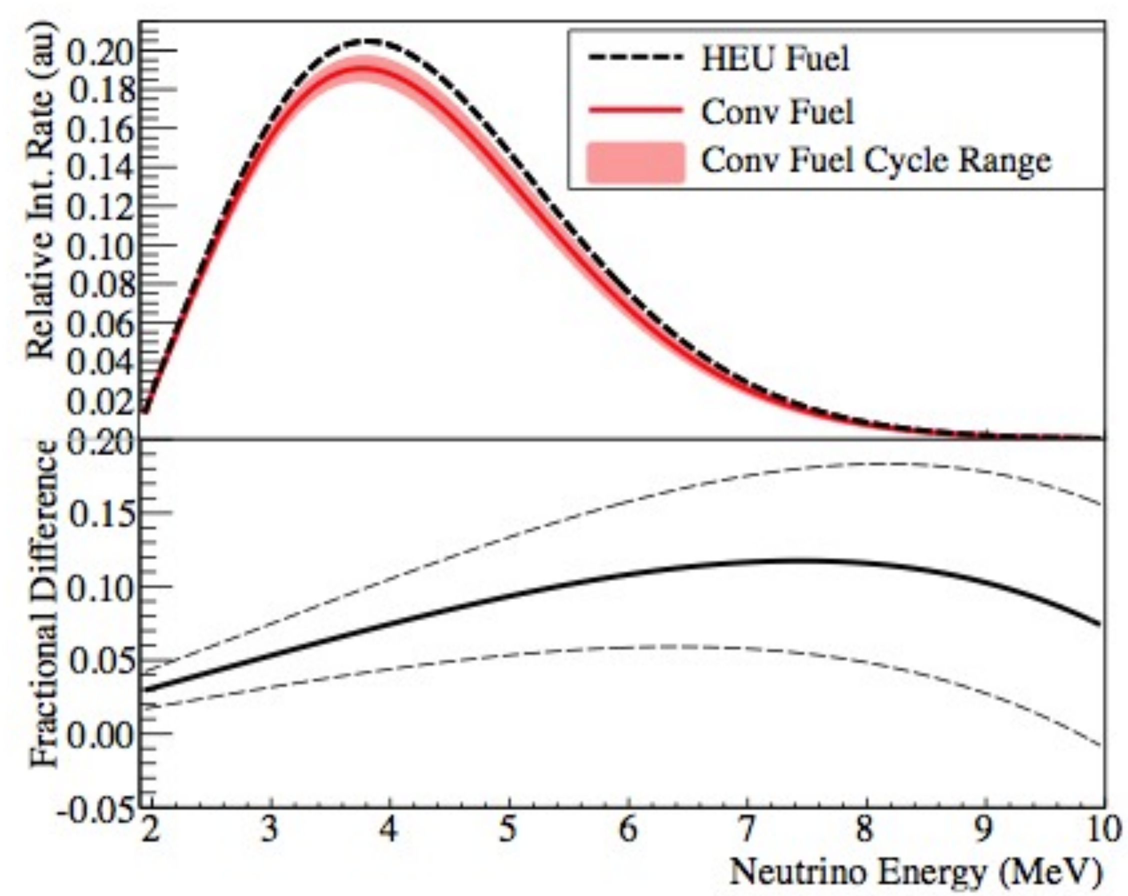
- Heeger, Littlejohn, Mumm, Tobin:
- Addresses and provides (hopefully) definitive and complete answers to these questions

Experimental Parameters

- Reactor
  - Power: MW_{th}
  - Duty cycle: Refueling periods, etc.
  - Fuel: HEU, LEU, etc.
  - Shape: cube, cylinder, etc.
  - Size: height, width, etc.

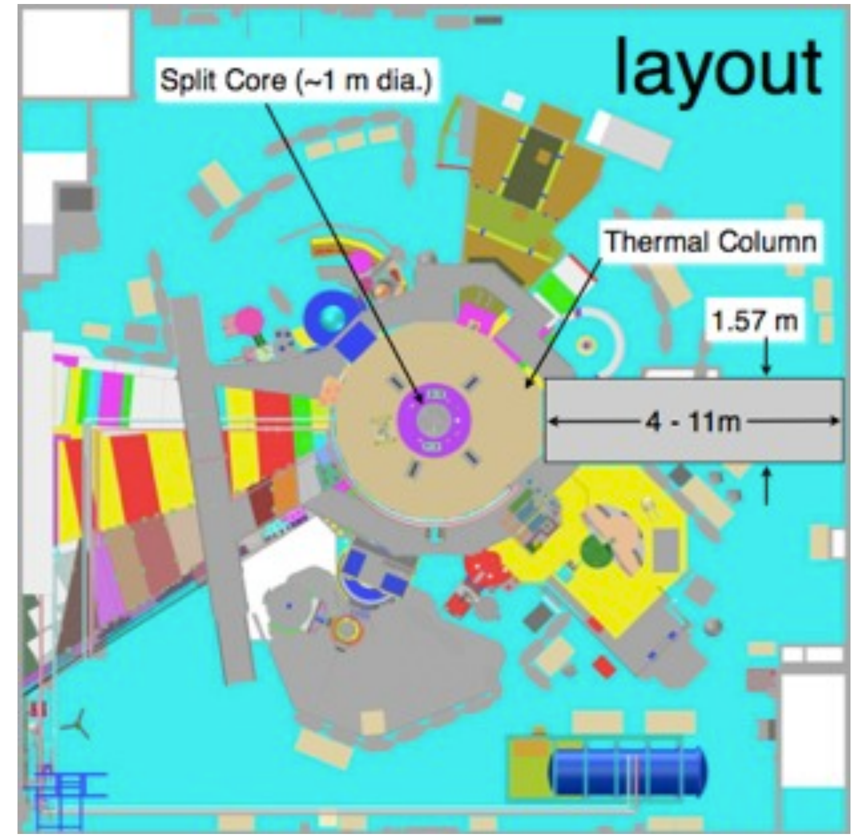


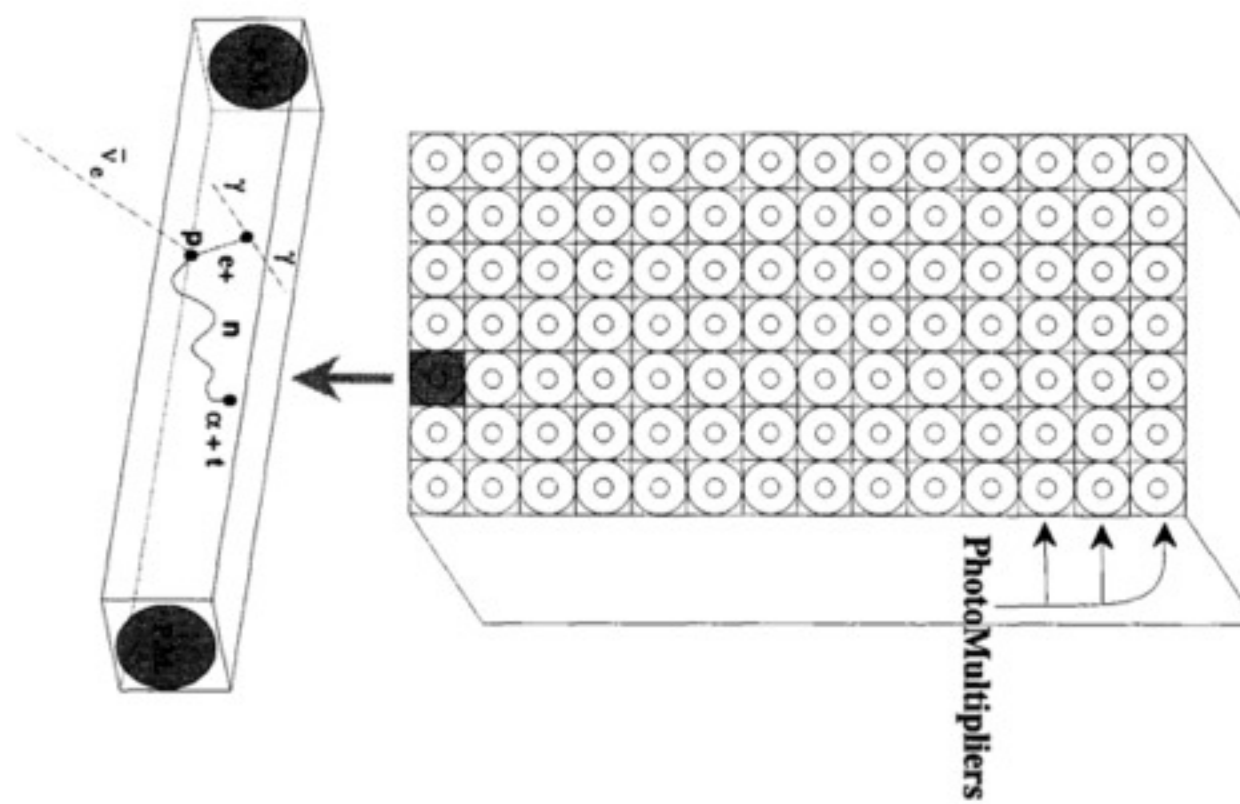


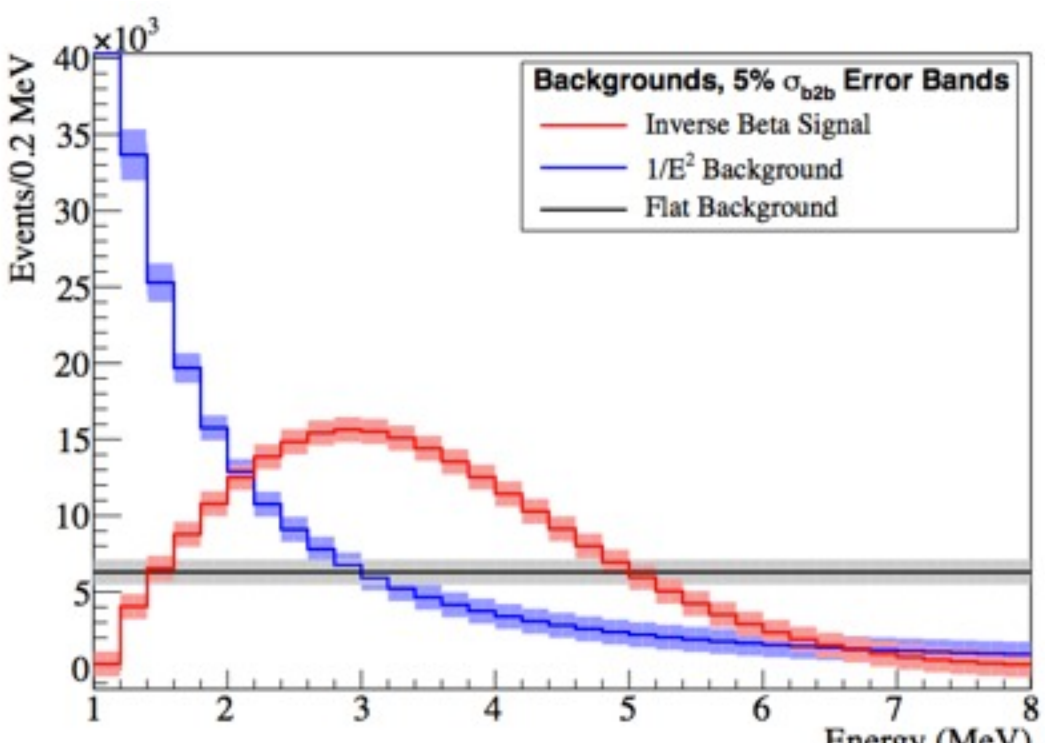


Experimental Parameters, Con't

- Facility
  - Experimental space
  - Nearest distance to core
- Detector
  - Efficiency
  - Position, energy resolution
- Background
  - Overall Signal-to-background
  - Position and energy spectrum







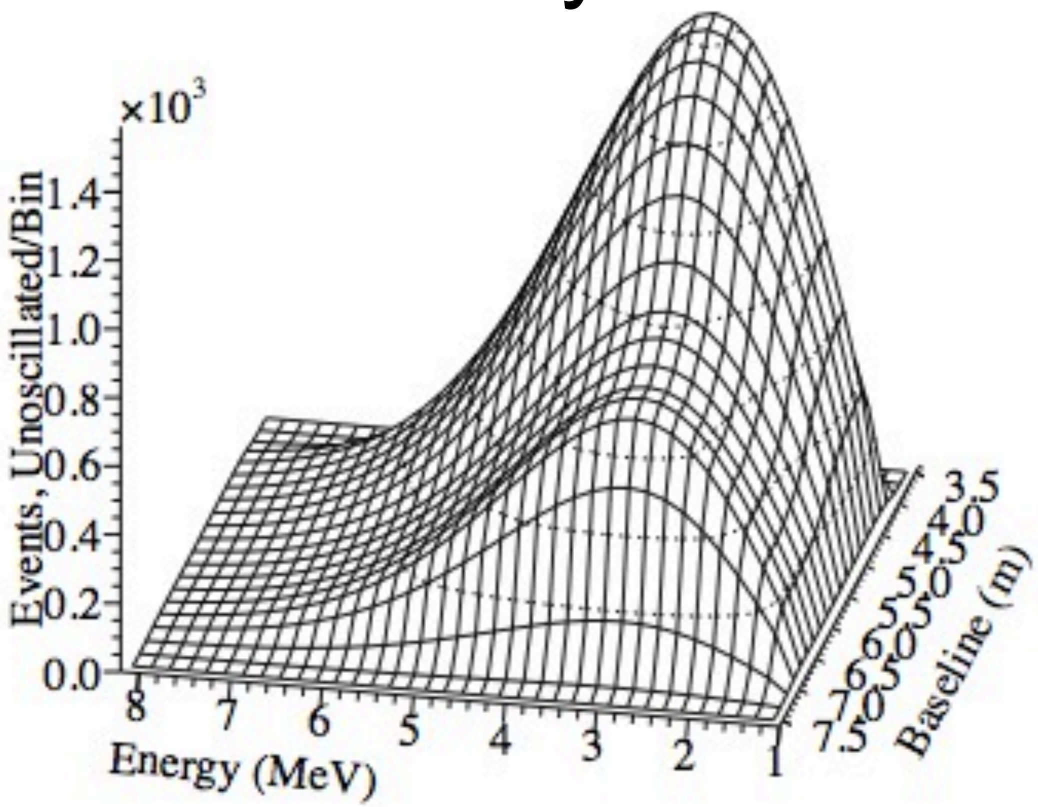
Experimental Parameters, Con't

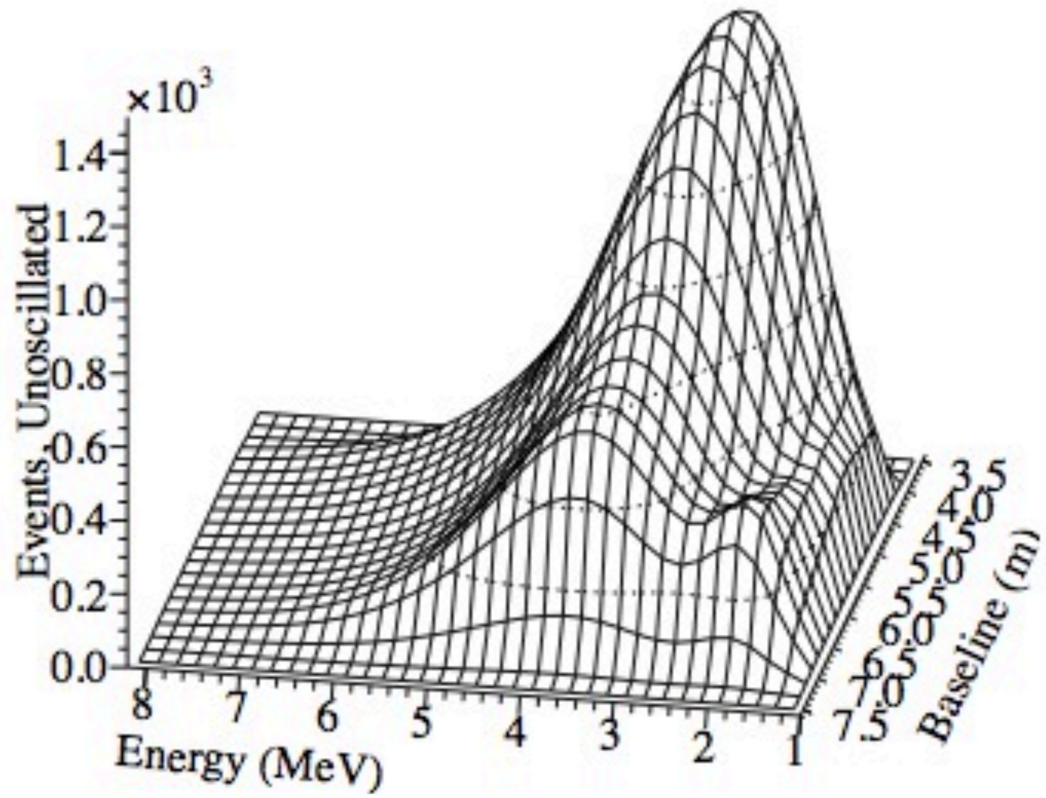
- Default values used in this study:

	Parameter	Value	Comment	Reference
Reactor	Power	20 MW	NIST-like	[31]
	Shape	cylindrical	NIST-like	[31]
	Size	0.5 m radius, half-height	NIST-like	[31]
	Fuel	HEU	Research reactor fuel type	[31–33]
Detector	Dimensions	$1\times1\times3$ m	3 meters of available baseline	-
	Efficiency	30%	In range of SBL exps. (10-50%)	[25, 28, 29]
	Proton density	$6.39\times10^{28}\ \frac{p}{m^3}$	From Daya Bay GdLS	[34]
	Position resolution	15 cm	Daya Bay-like	[27]
	Energy resolution	$10\%/\sqrt{E}$	Daya Bay-like	[35]
Other	Run Time	1 year live-time	-	-
	Closest distance	4 m	NIST-like	-
	S:B ratio	1:1	In range of SBL exps. (1-25)	[22, 25, 28]
	Background shape	$1/E^2$	Similar to SBL experiments	[22, 25, 27]

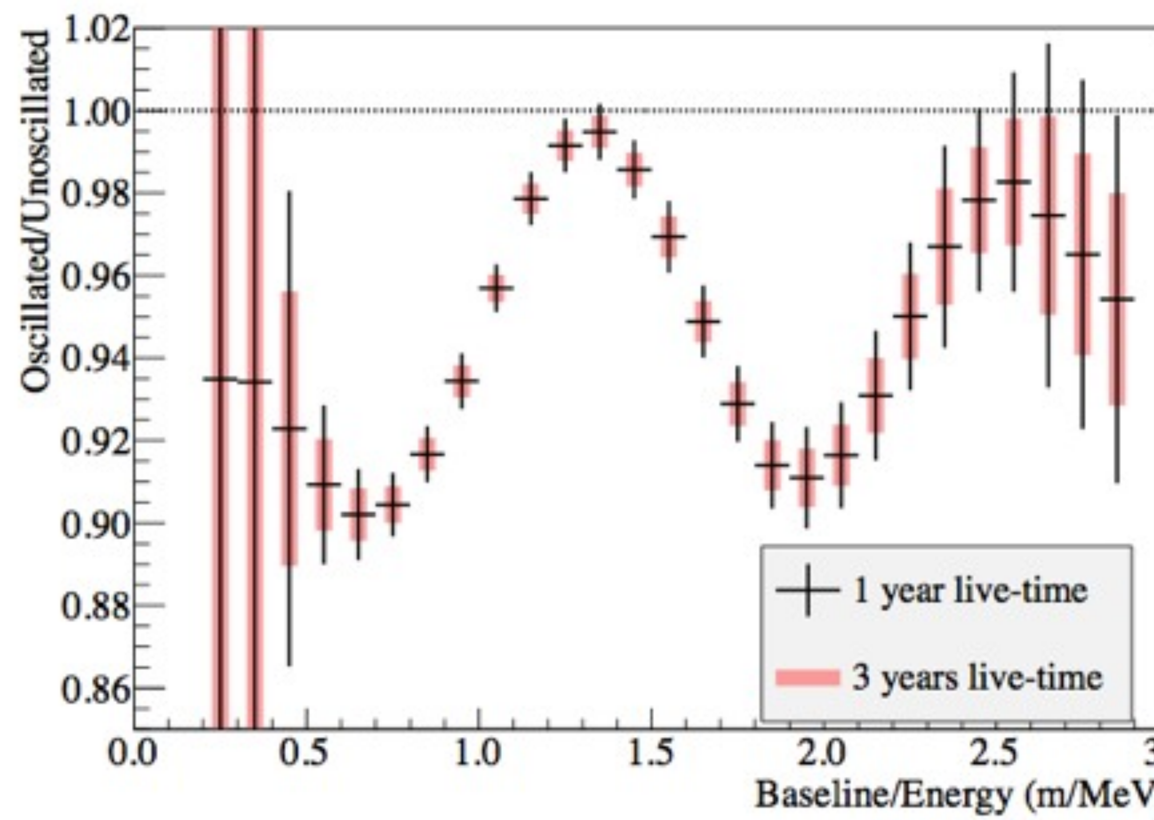
Very Short Baseline Oscillations

- What will they look like in our detector?





$$P_{sur}(E,\vec{L}) \simeq 1 - \sin^2 2\theta_{ee} \sin^2\left(\frac{1.27\Delta m^2_{41}|\vec{L}-\vec{r}|}{E}\right)$$



X^2 Analysis Method

- Compare calculated 'detected' spectra, oscillated and unoscillated, with a pulls-approach X^2:

$$\chi^2 = \sum_{i,j} \frac{\left[M_{ij} - (\alpha + \alpha_e^i + \alpha_r^j)T_{ij} - (1+\alpha_b)B_{ij}\right]^2}{T_{ij} + (\sigma_{b2b}B_{ij})^2} + \frac{\alpha^2}{\sigma^2} + \sum_j \left(\frac{\alpha_r^j}{\sigma_r}\right)^2 + \sum_i \left(\frac{\alpha_e^i}{\sigma_e^i}\right)^2 + \frac{\alpha_b^2}{\sigma_b^2}$$

X^2 Analysis Method

- Compare calculated 'detected' spectra, oscillated and unoscillated, with a pulls-approach X^2:
  - Your standard X^2 stuff

Oscillated, unoscillated events in energy bin i, position bin j

Background events in bin i,j

$$\chi^2 = \sum_{i,j} \frac{[M_{ij} - (\alpha + \alpha_e^i + \alpha_r^j) T_{ij} - (1 + \alpha_b) B_{ij}]^2}{T_{ij} + (\sigma_{b2b} B_{ij})^2} + \frac{\alpha^2}{\sigma^2} + \sum_j \left(\frac{\alpha_r^j}{\sigma_r}\right)^2 + \sum_i \left(\frac{\alpha_e^i}{\sigma_e^i}\right)^2 + \frac{\alpha_b^2}{\sigma_b^2}$$

stat. uncertainty in bin i,j

X^2 Analysis Method

- Compare calculated 'detected' spectra, oscillated and unoscillated, with a pulls-approach X^2:
  - Your standard X^2 stuff
  - Accounting for experimental systematics: minimization parameters $\vec{\alpha}$, associated systematic uncertainties $\vec{\sigma}$

Oscillated, unoscillated events in energy bin i, position bin j

Background events in bin i,j

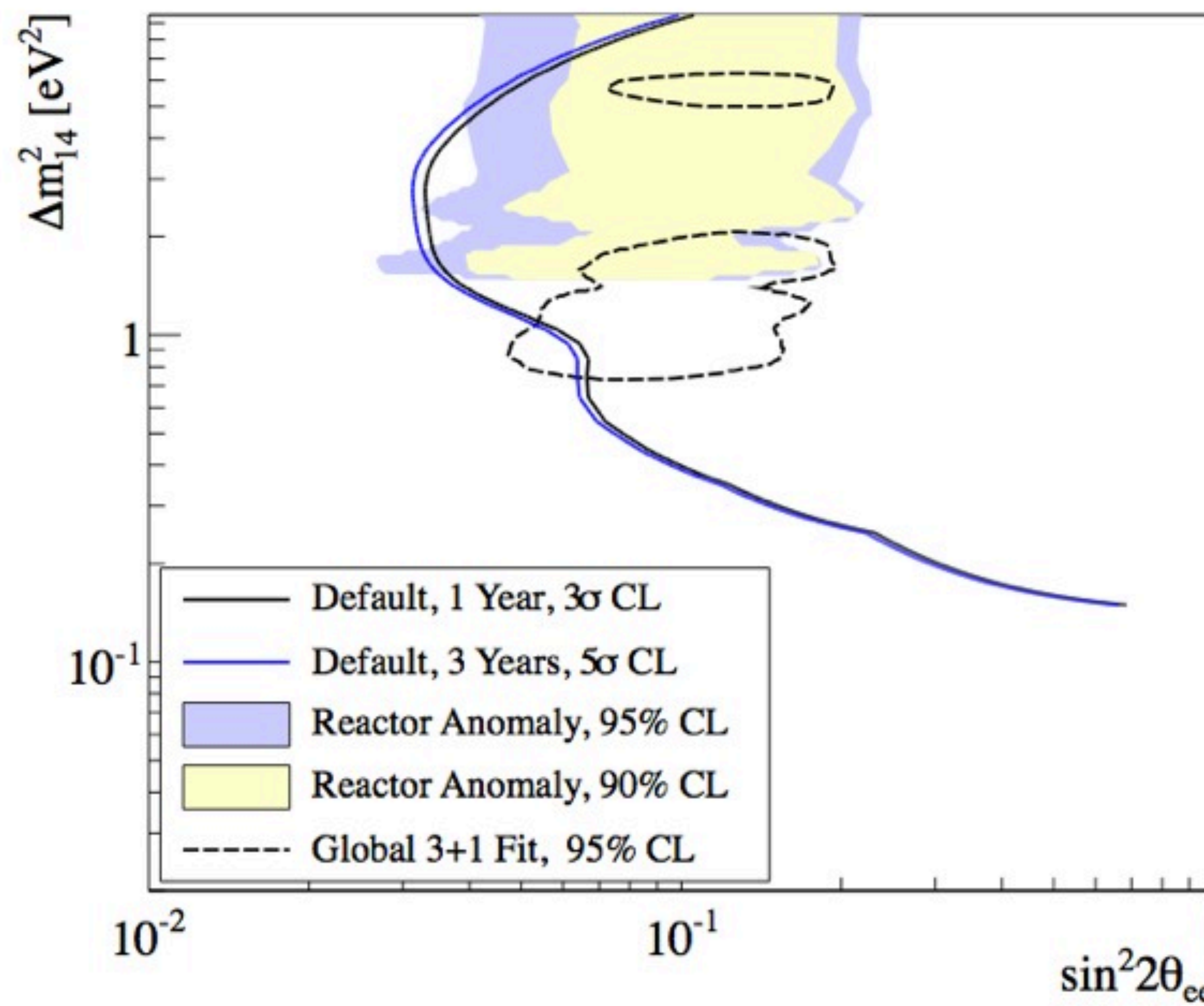
$$\chi^2 = \sum_{i,j} \frac{[M_{ij} - (\alpha + \alpha_e^i + \alpha_r^j) T_{ij} - (1+\alpha_b) B_{ij}]^2}{T_{ij} + (\sigma_{b2b} B_{ij})^2} + \frac{\alpha^2}{\sigma^2} + \sum_j \left(\frac{\alpha_r^j}{\sigma_r}\right)^2 + \sum_i \left(\frac{\alpha_e^i}{\sigma_e^i}\right)^2 + \frac{\alpha_b^2}{\sigma_b^2}$$

stat. uncertainty in bin i,j

- α - normalization uncertainty;
  σ: 100%
- α_e^i - energy spectrum uncertainty;
  σ_e^i: given by PH:
- α_r^j - baseline spectrum uncertainty;
  σ_r: 0.5%
- α_b - background normalization;
  σ_b: 10%
- σ_{b2b}: background shape uncertainty;
  shape and position uncorrelated: 0.5%

Sensitivity of Default Experiment

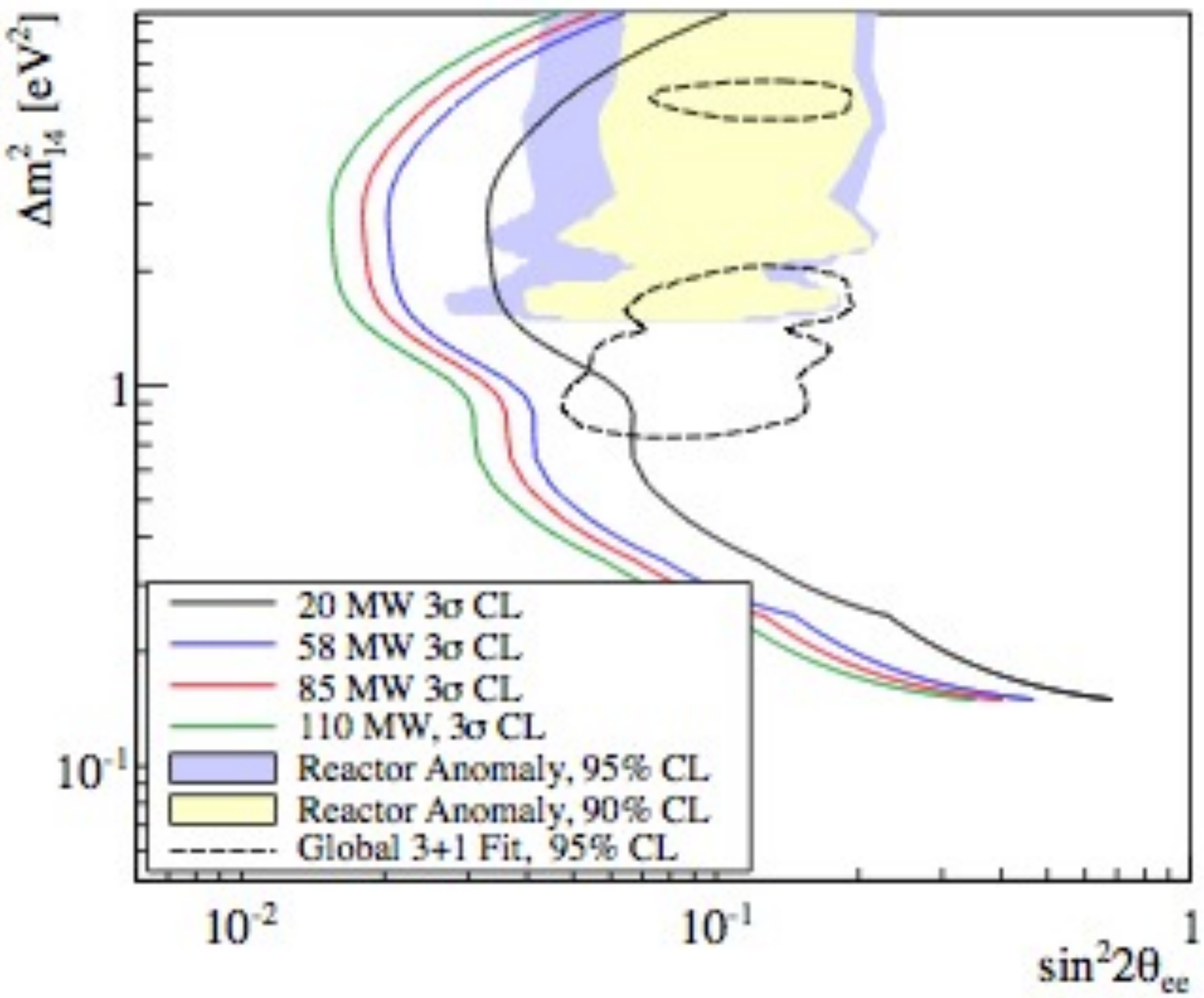
- Get 5σ with three years of data-taking, even with relatively modest parameter values:
  - 30% efficiency
  - 1:1 S:B
  - 20 MW
  - ~m^3 reactor volume
  - 3m detector length



Reactor Parameters

Reactor Power

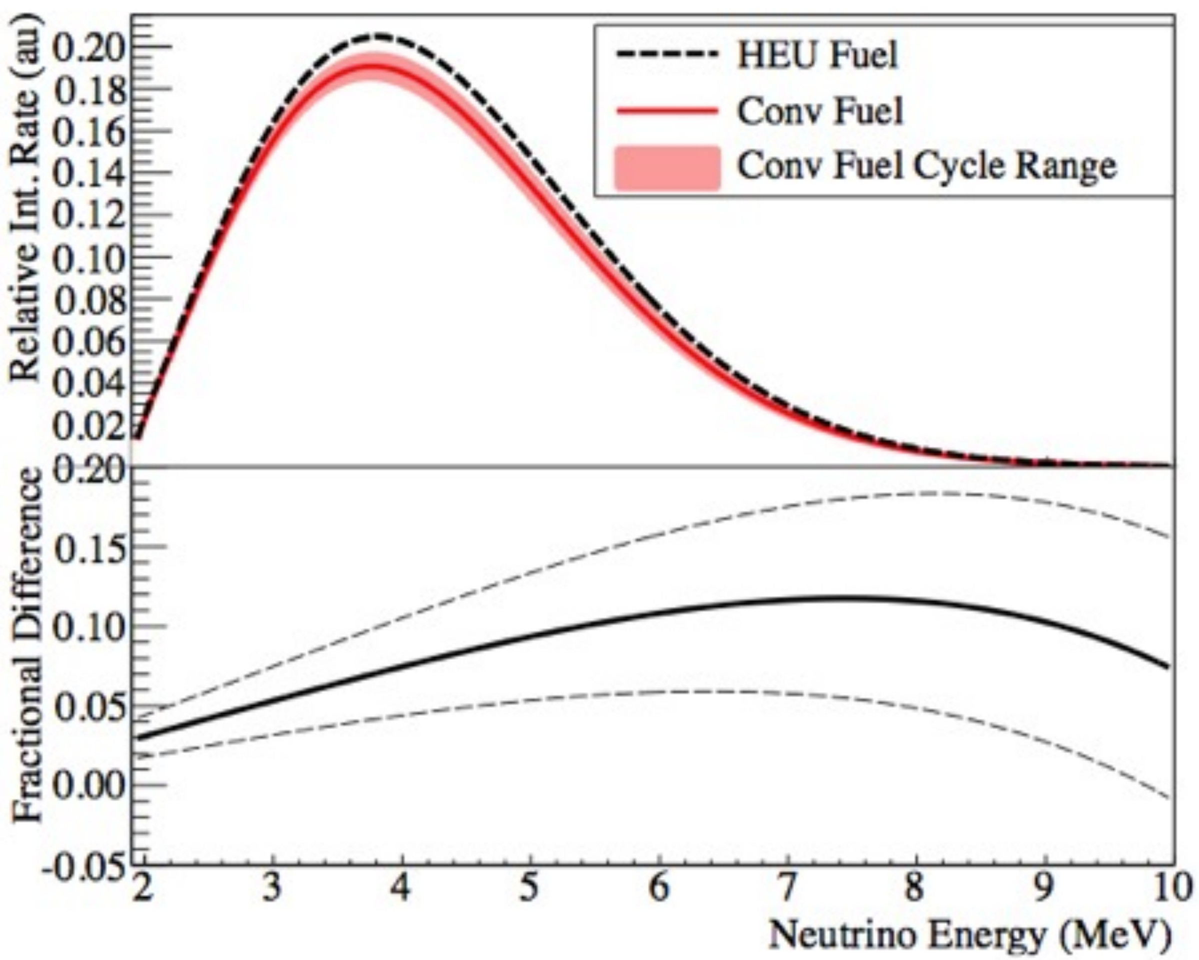
- Reactor power matters a LOT, at all dm2
- 20 MW is about the limit if we want to keep 3σ for 1 year of data
- Also fold in duty cycle...

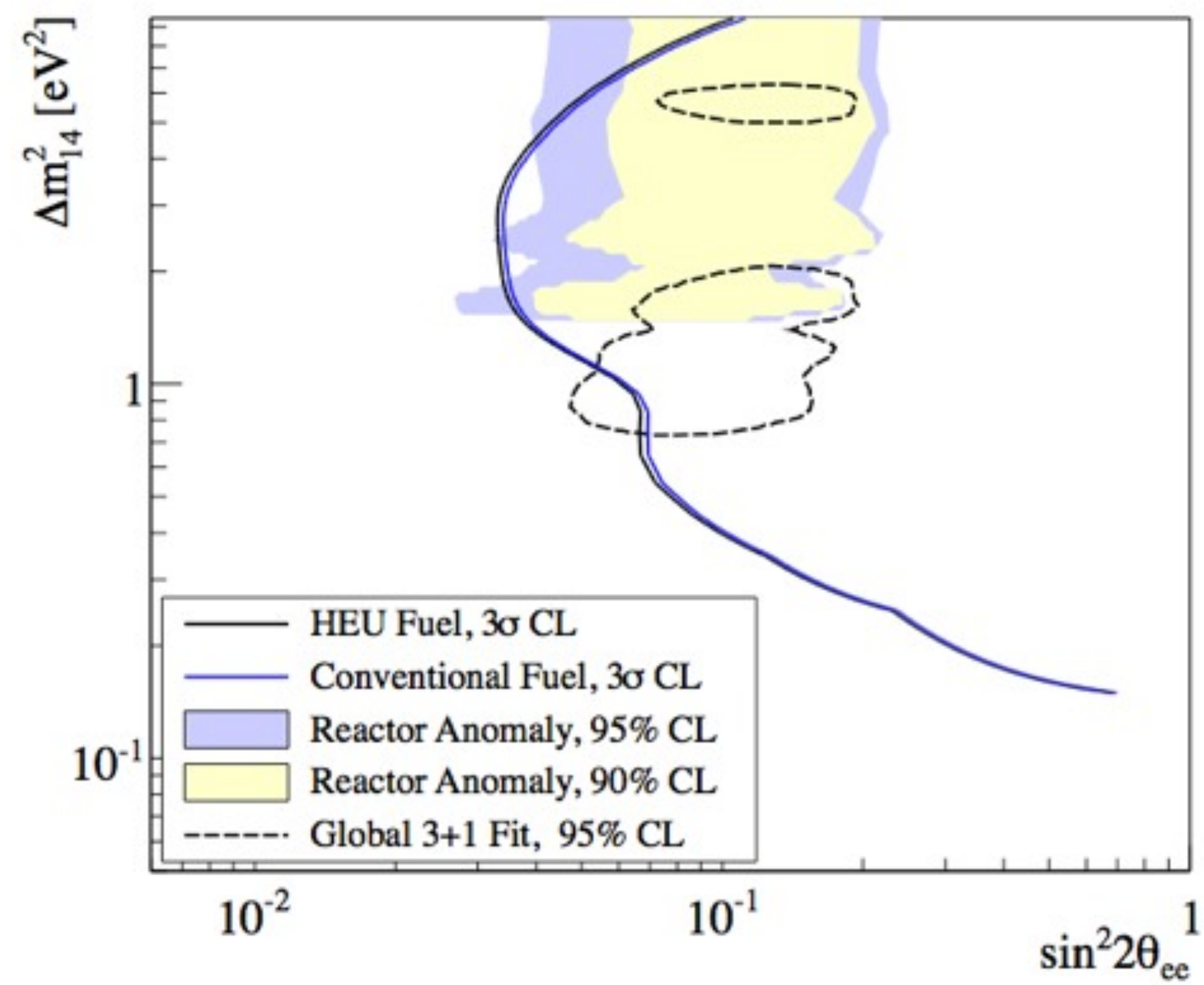


Reactor	Power (MW_{th})	Baselines (m)	Reactor On (Days)	Reactor Off (Days)	Down-Time	Ref.
NIST	20	4-13	42	10	~32%	[31]
HFIR	85	6-8	24	18	~50%	[32]
ATR	250 (licensed) 110 (operational)	7-8 (restricted) 12-20 (full access)	48-56	14-21	~27%	[33]
ILL	58	7-9	50	41	~45%	[40]
SONGS	3438	24	639	60	8.6%	[38, 39]

Fuel Type

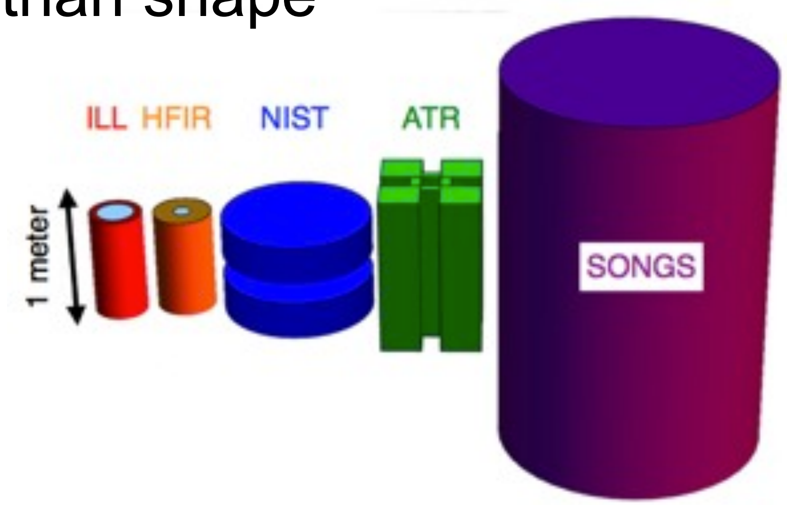
- Not much difference here...

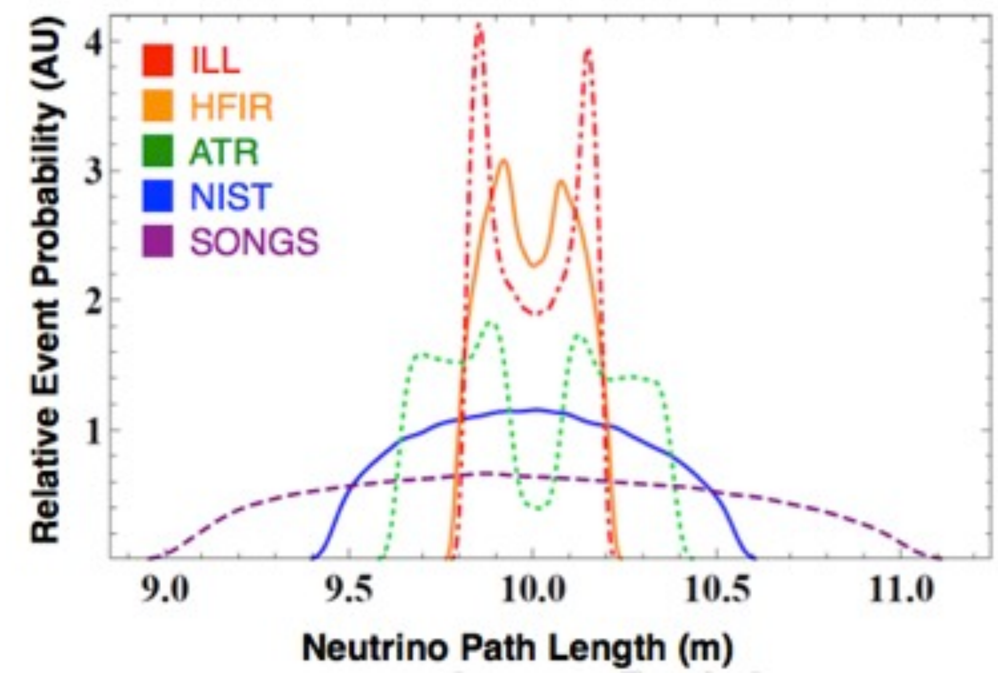


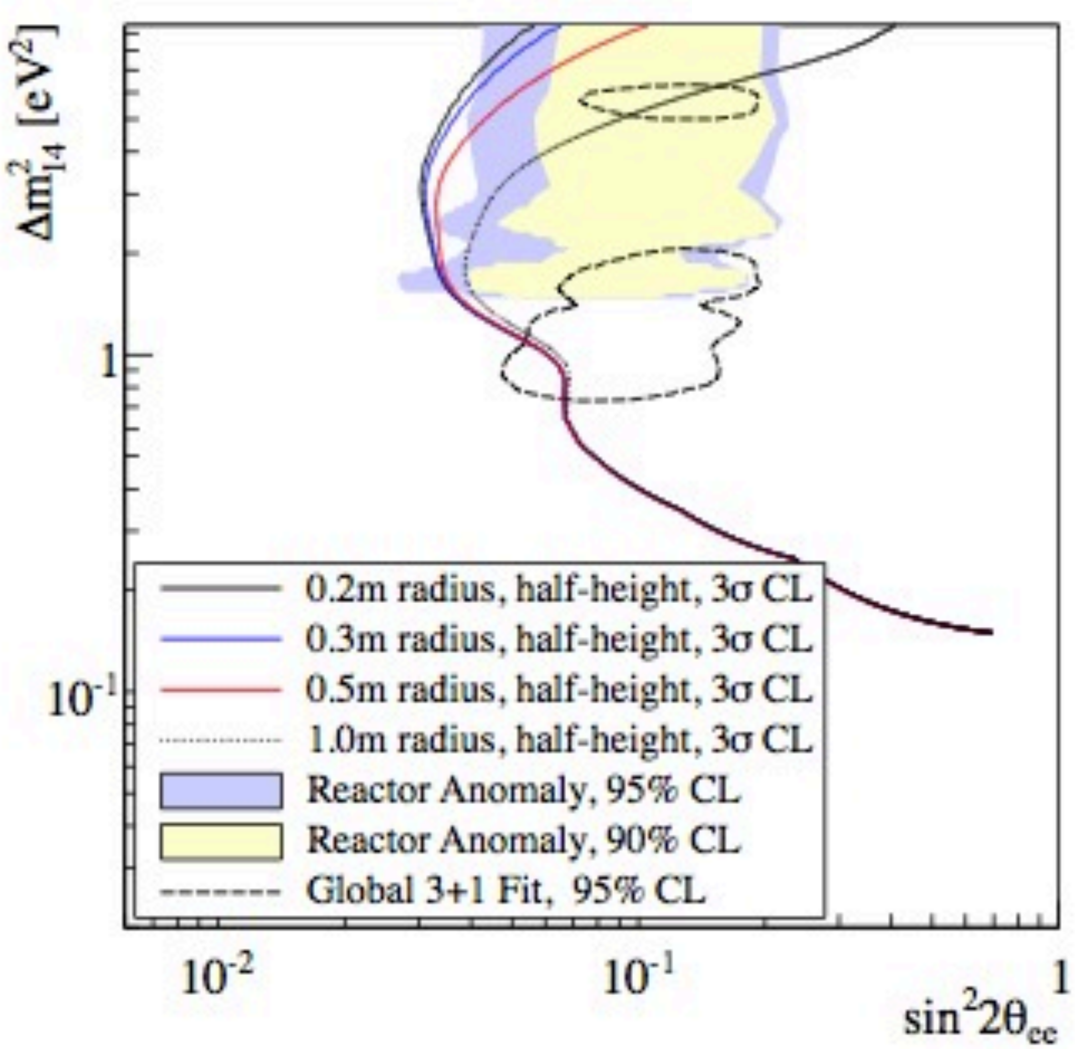


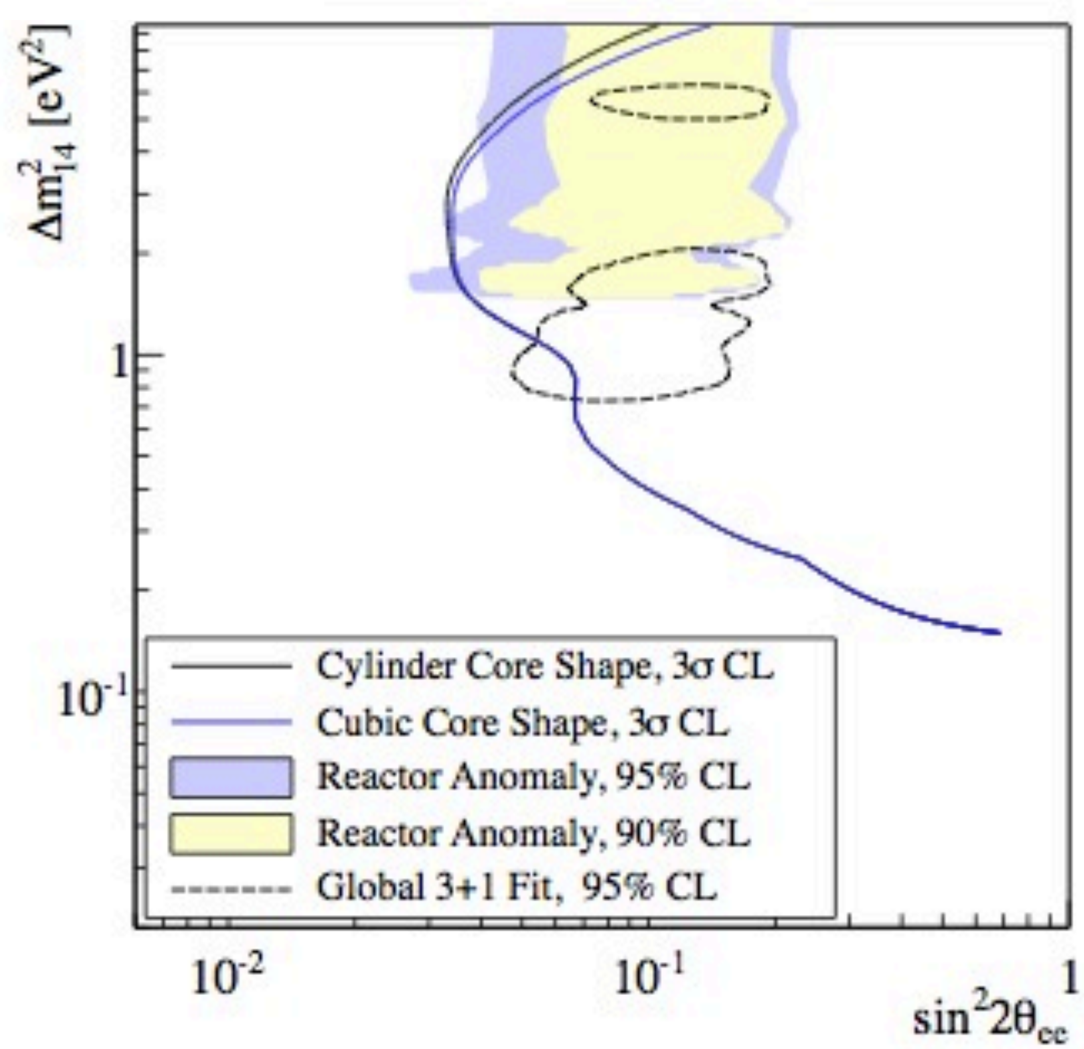
Reactor Shape/Size

- Matters particularly at high dm2
  - Size matters more than shape
  - Baseline spread set mainly by reactor width, not much by exact shape





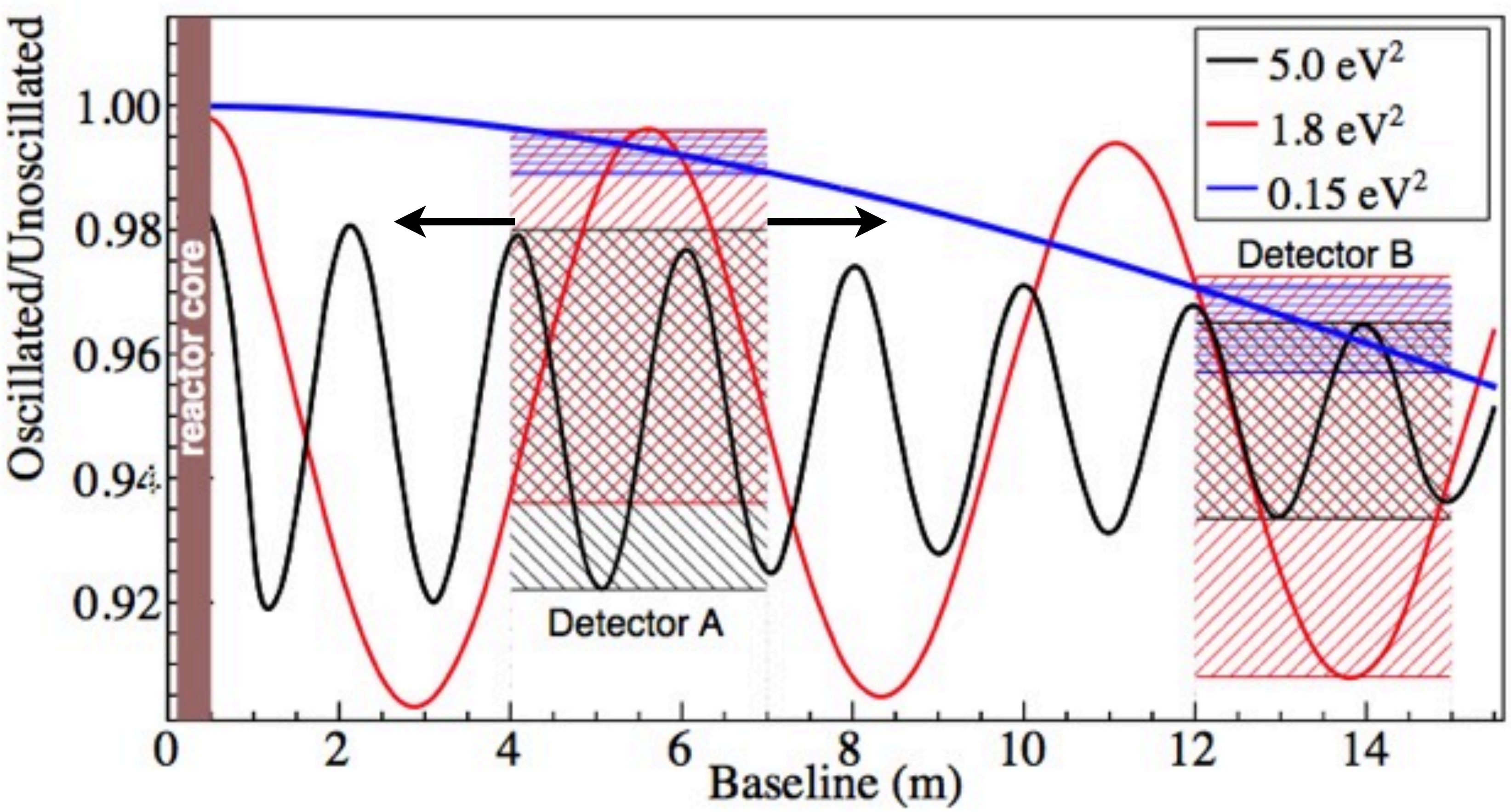


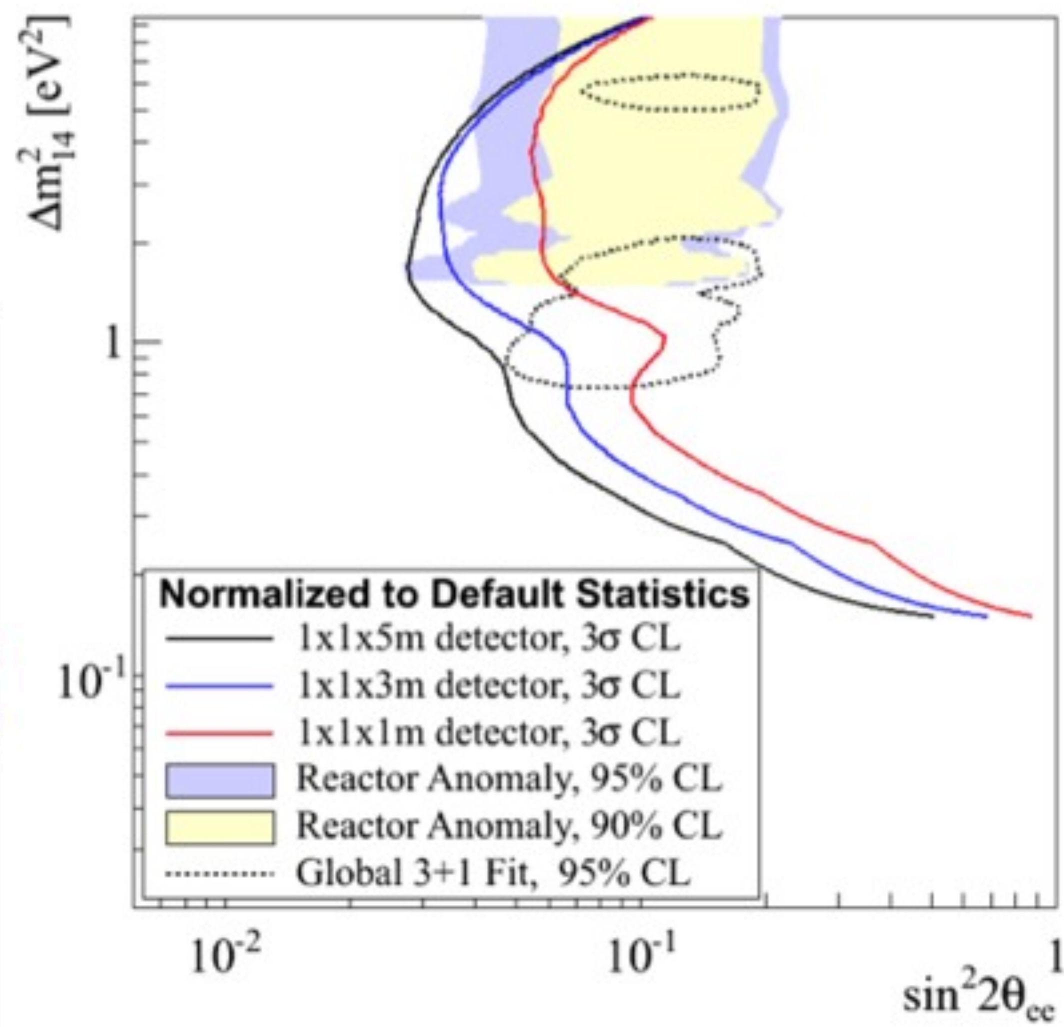


Facility Parameters

Experimental Area and Detector Volume

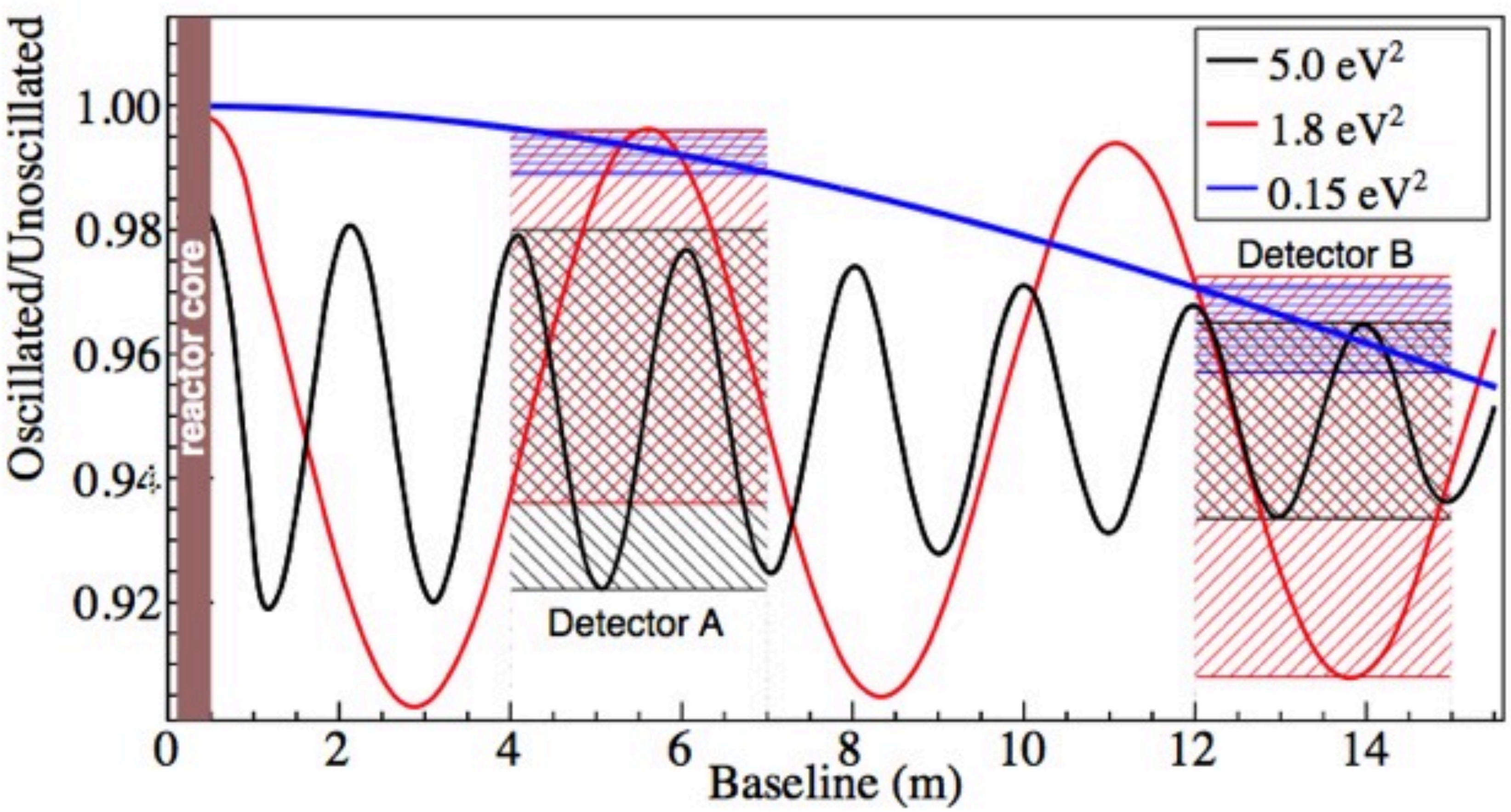
- Detector can only be as long as facility allows
- Longer detector greatly improves sensitivity
  - Particularly at low dm2
  - Also demonstrates value of multiple detectors

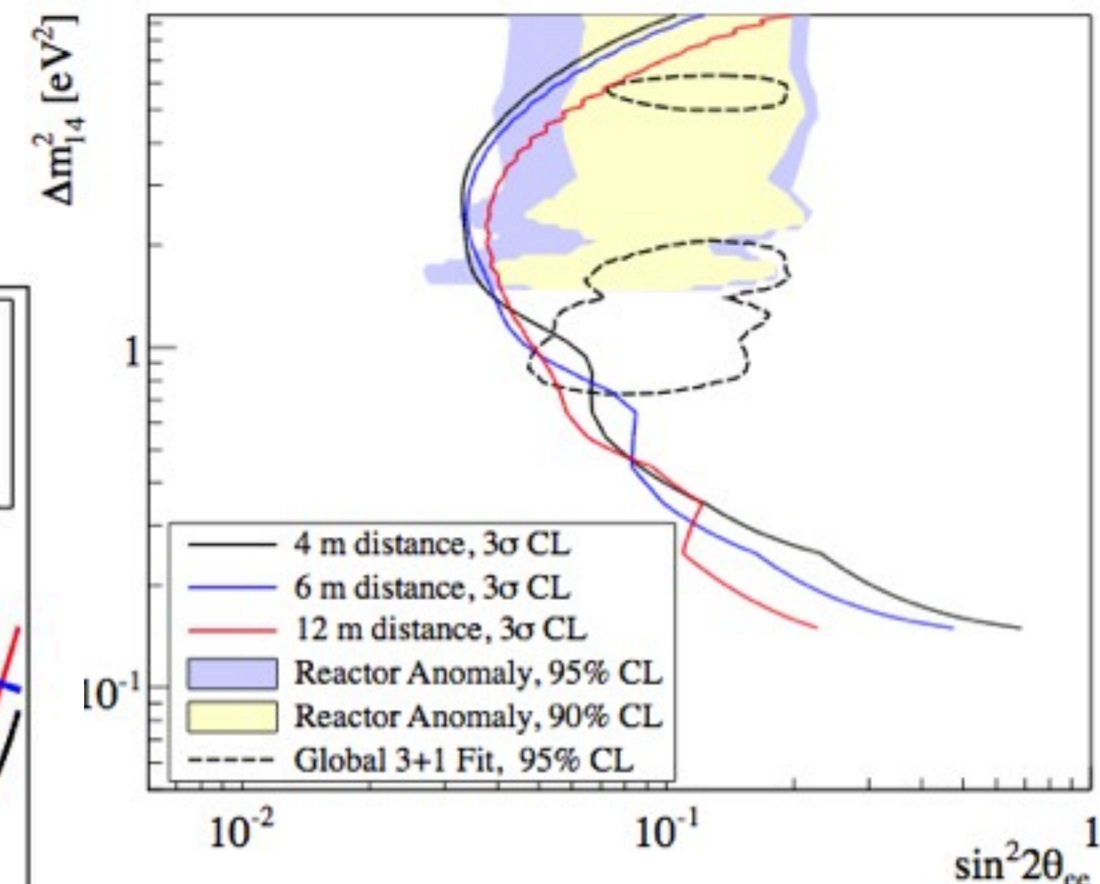




Reactor-Detector Distance

- The closer the detector and reactor, the higher in dm2 the sensitivity moves
  - High dm2: both detectors see full wavelength, but more smeared out at further distance
  - Low dm2: larger change over far detector, but neither detector contains all that much of a wavelength...

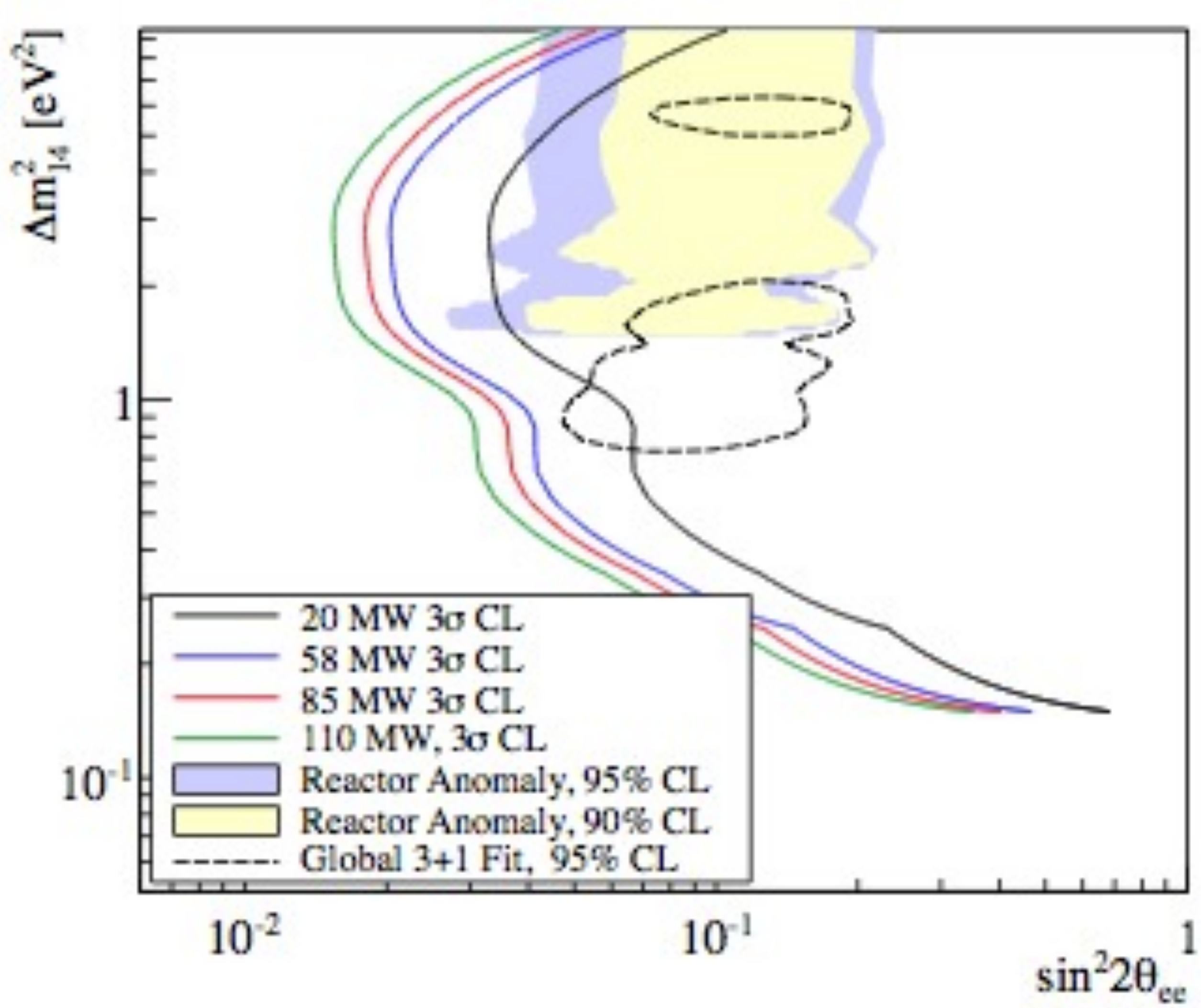




Detector Parameters

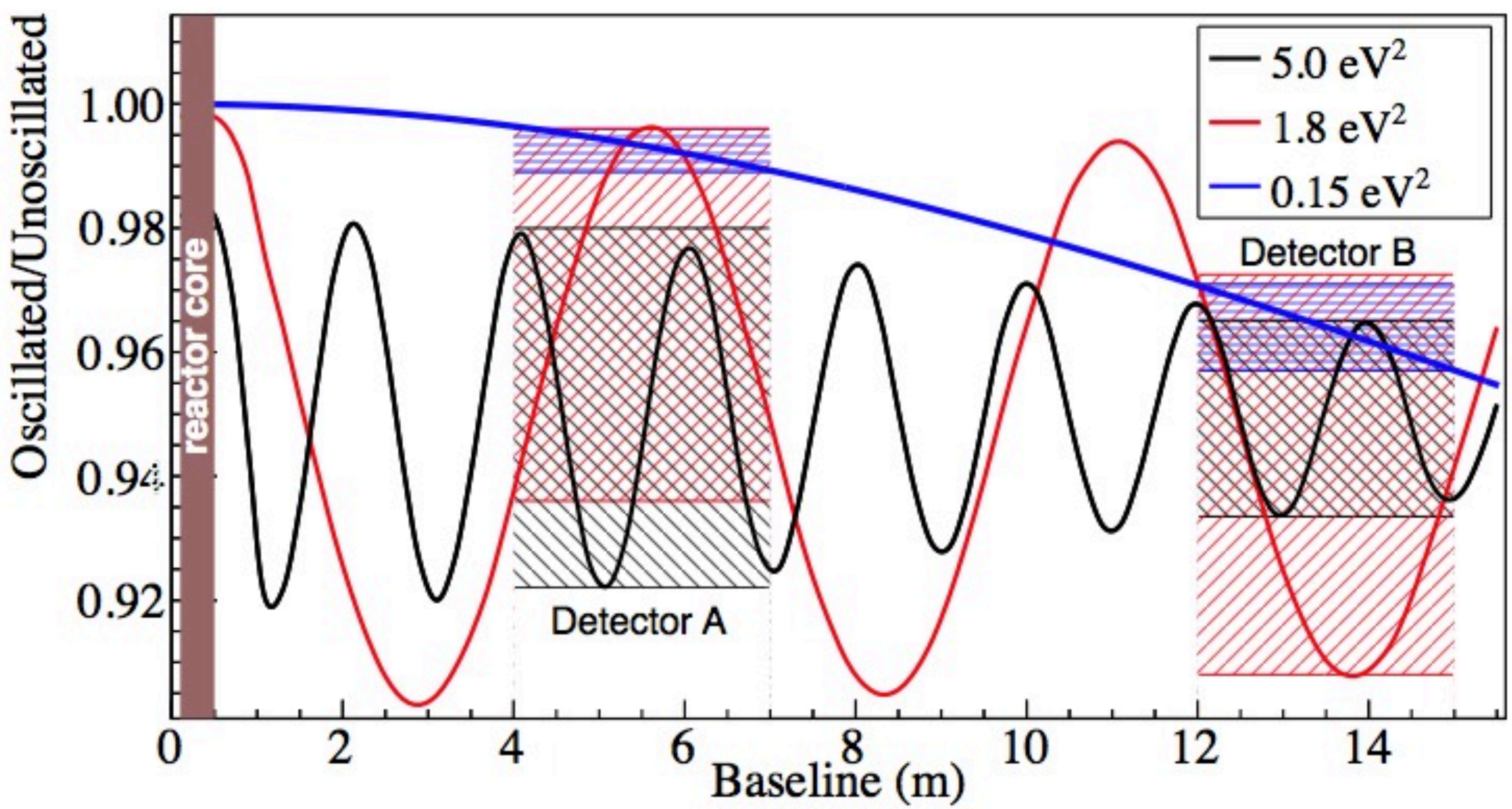
Detector Parameters

- Detector efficiency, target mass (x-section, length) impact total statistics
- Same effect as changing reactor power



Resolution

- Lower energy resolution: oscillation amplitude will drop off with distance faster
- Lower position resolution: oscillation with baseline automatically smeared out



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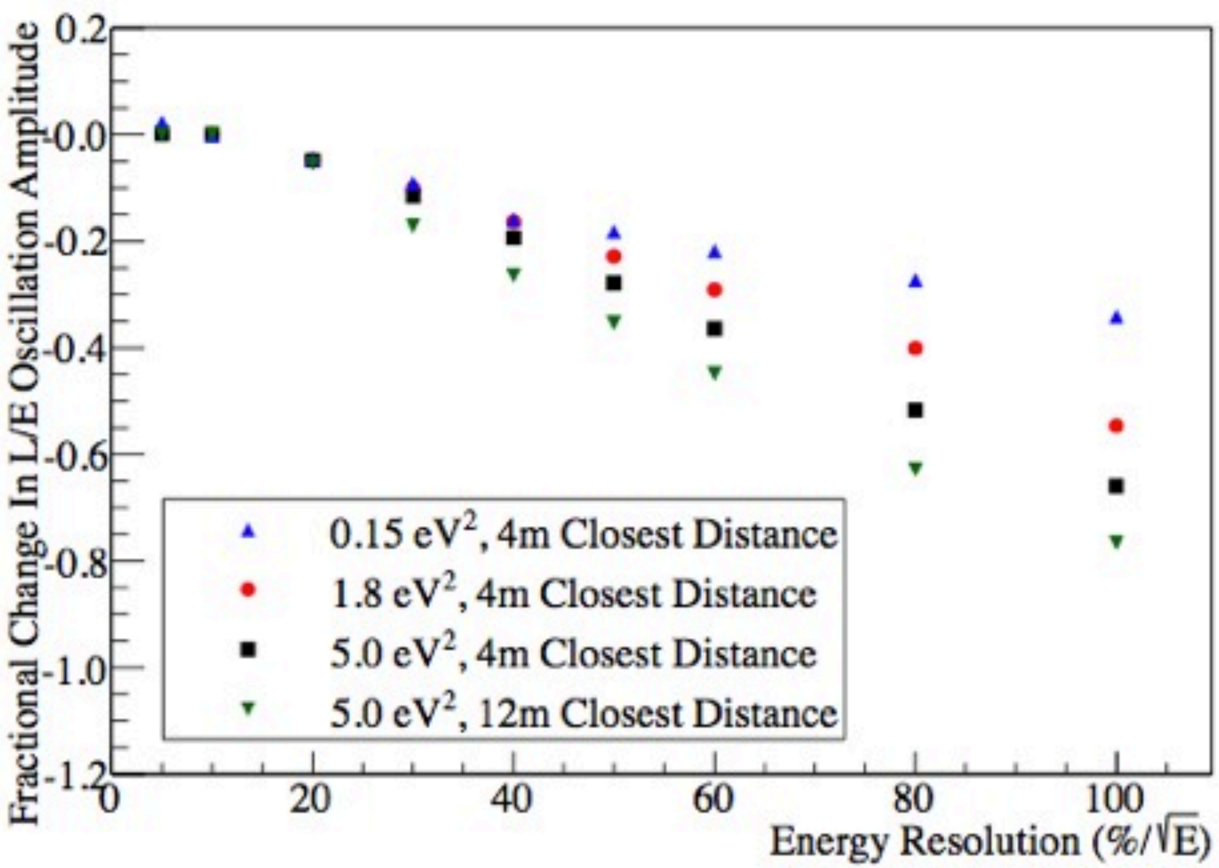
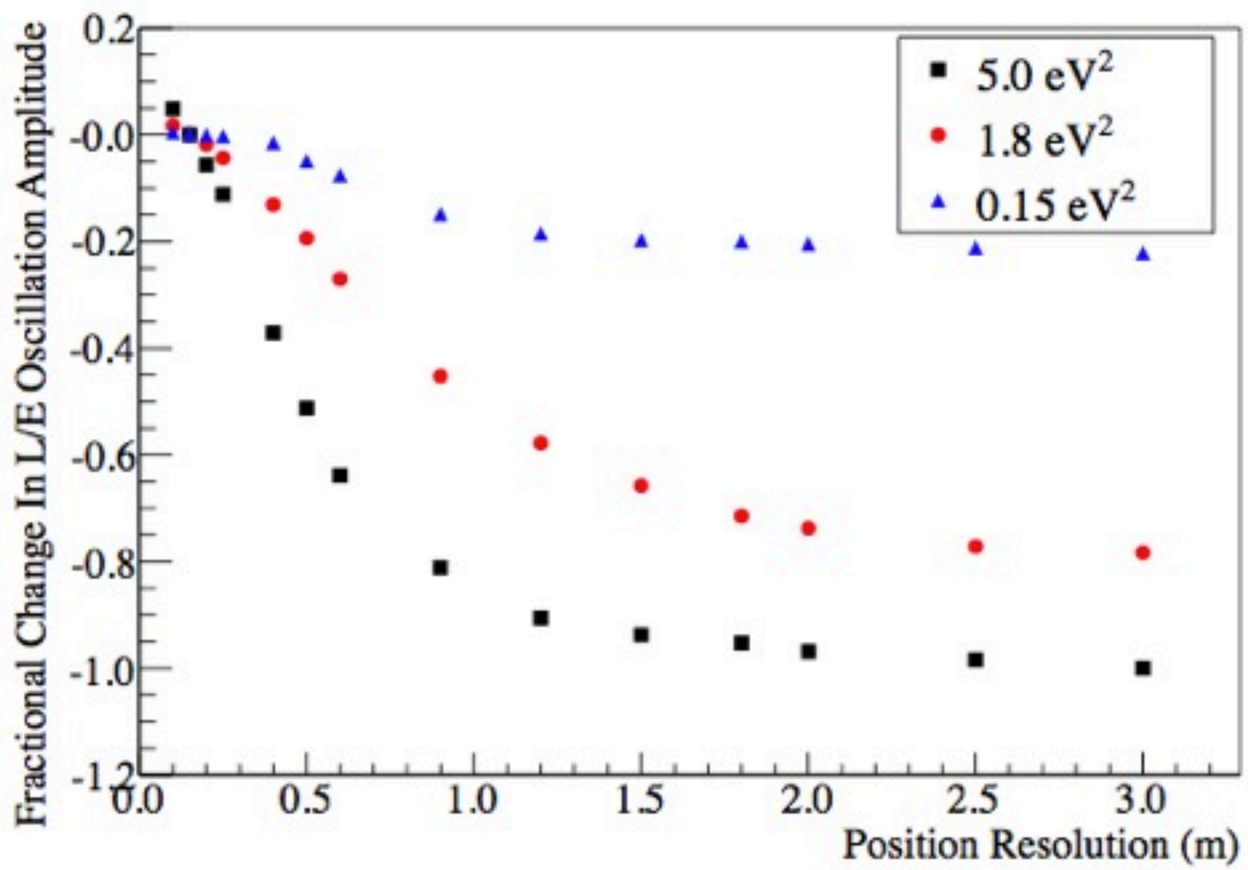
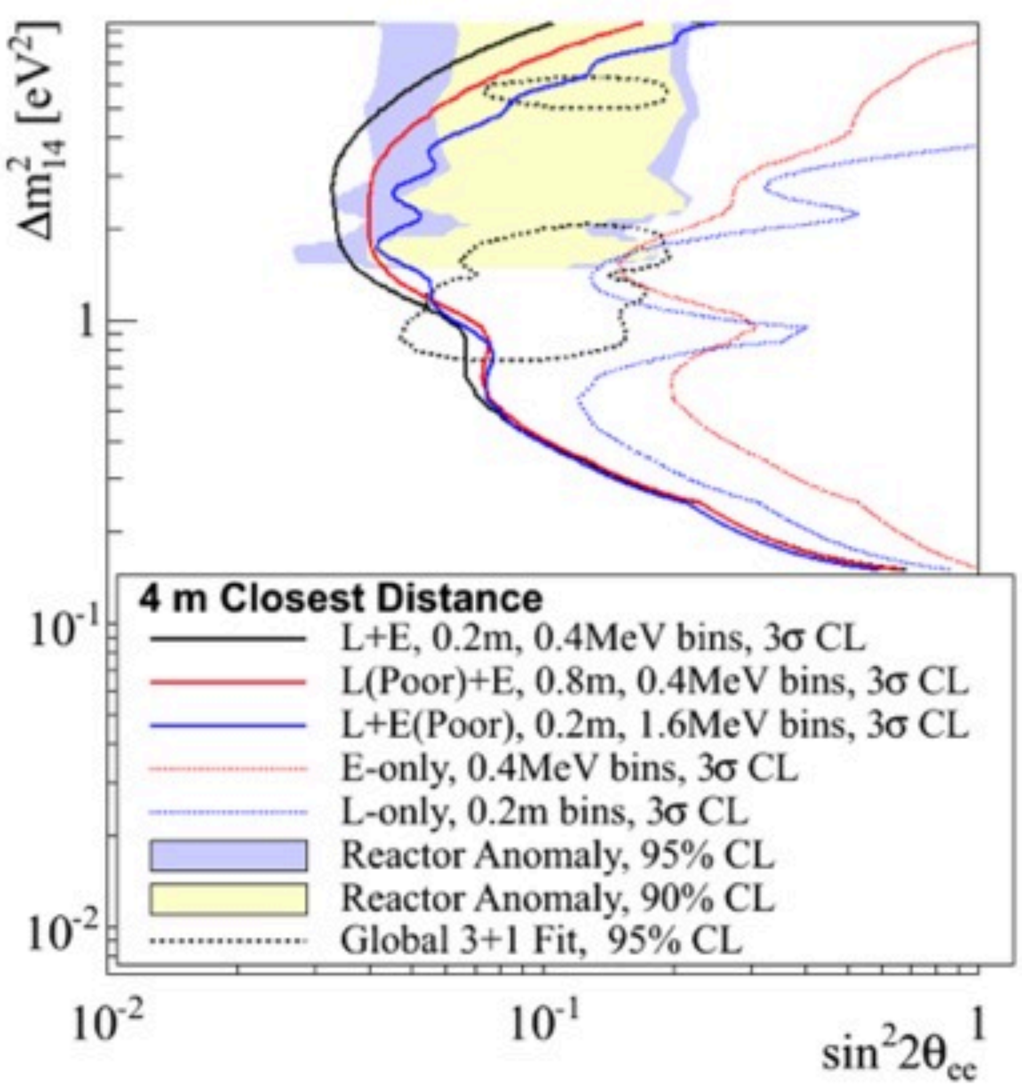
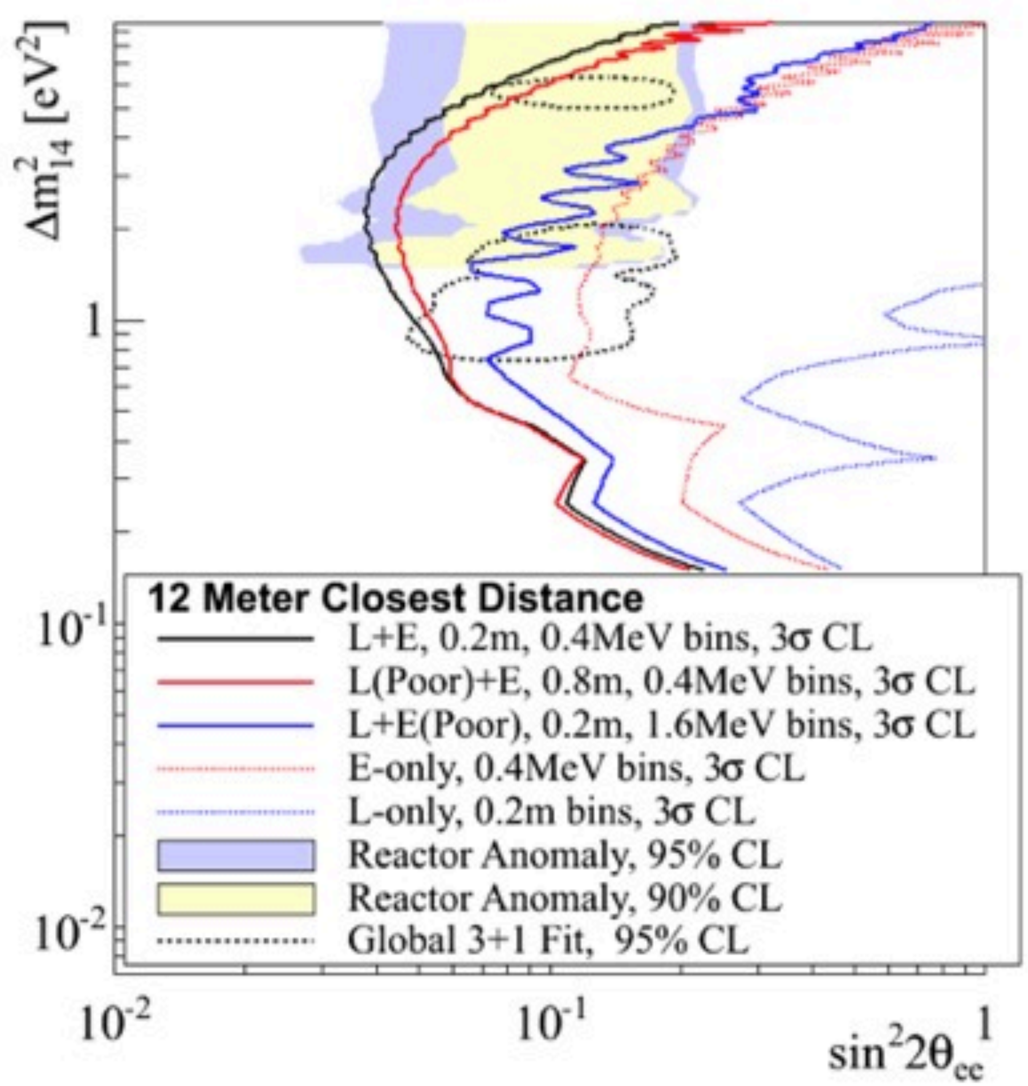




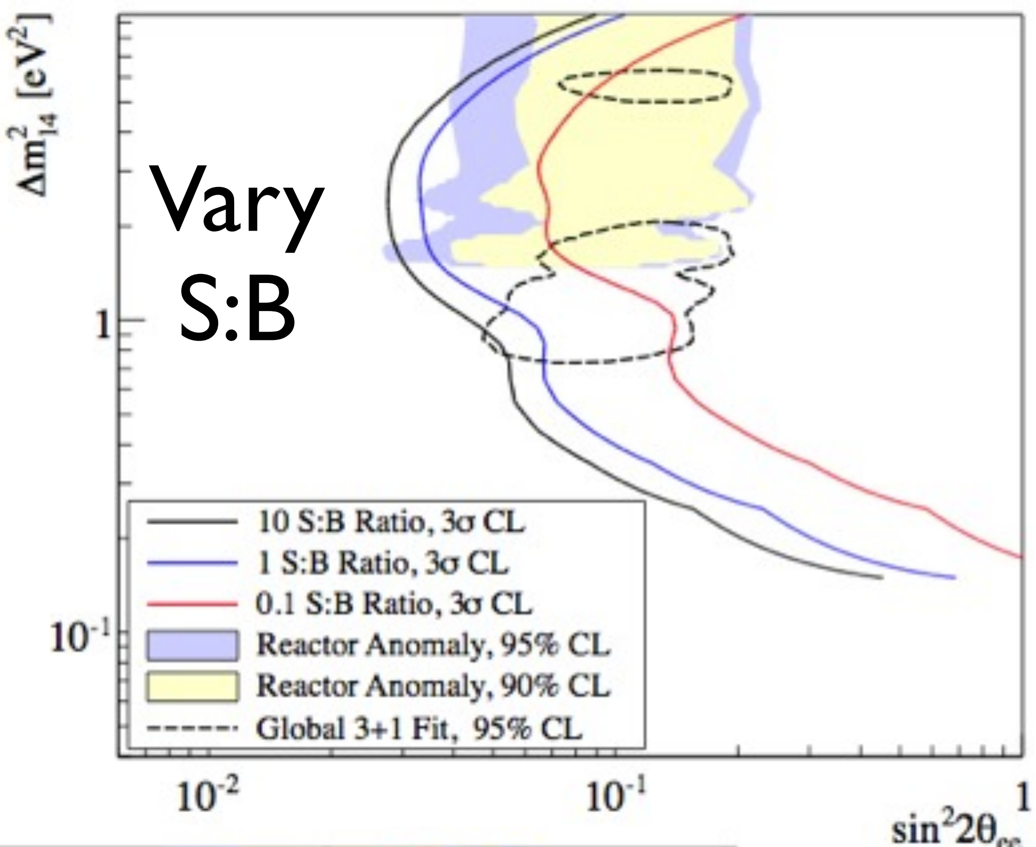
Resolution

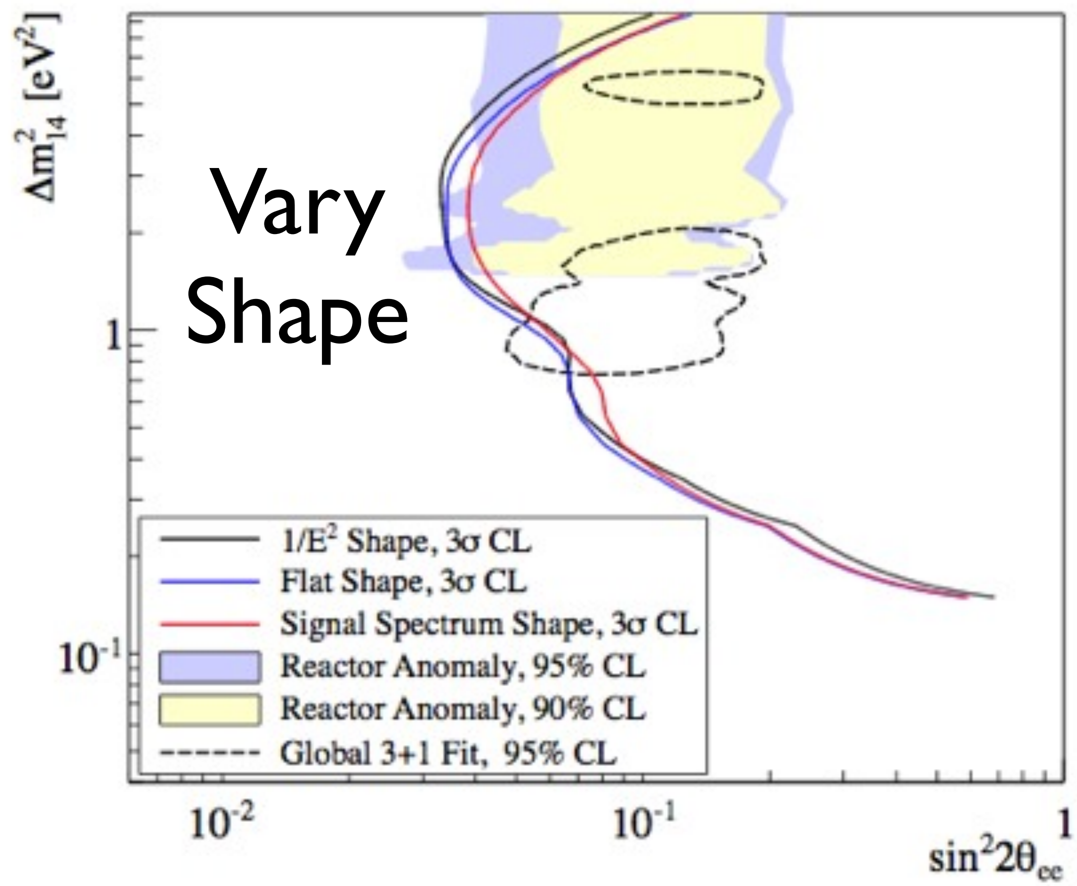
- So, naturally, sensitivity reduced with resolution loss
  - Particularly important at high dm2.
- Importance of resolution (information) in position, energy depends on baselines, detector lengths
  - Clearly some interplay that needs to be sorted out for particular sites

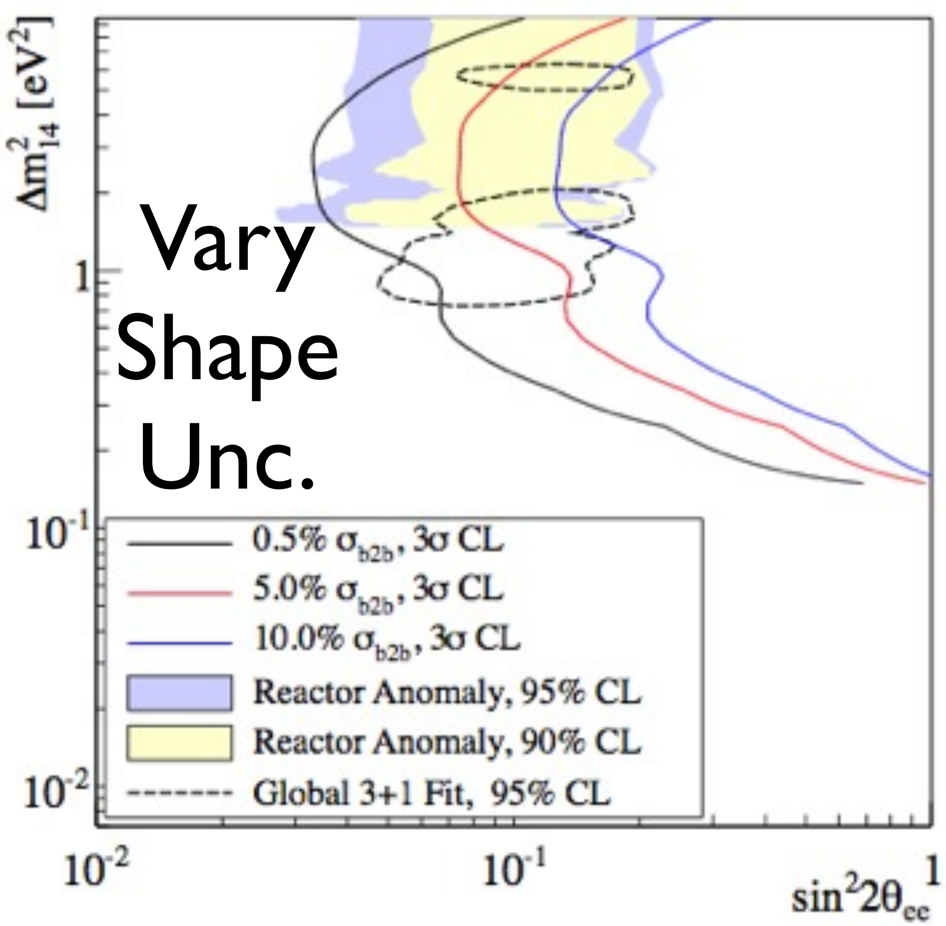


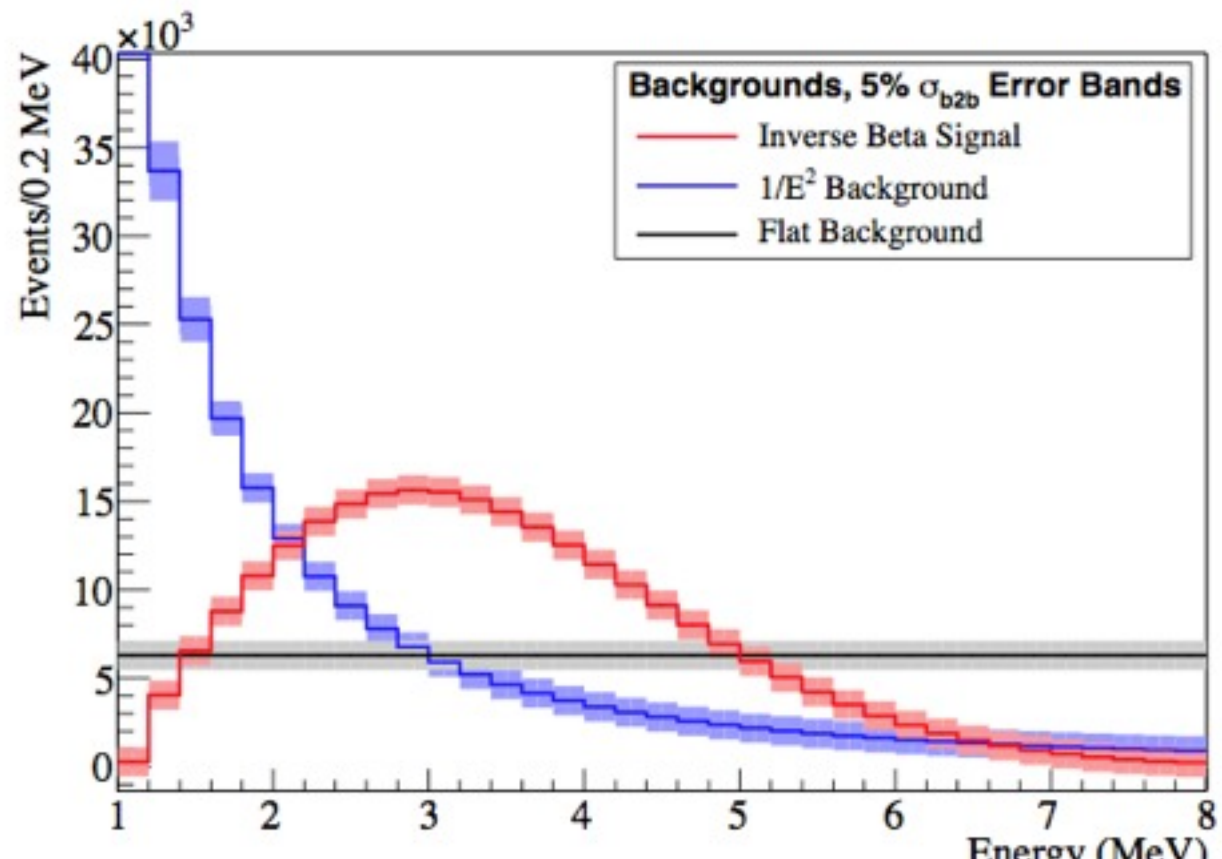


Background Parameters









Conclusions

- Very short baseline experiments can probe reactor anomaly to 5σ
- Critical Parameters:
  - Reactor power and detector efficiency
  - Reactor size
  - Detector length and distance to reactor
  - Resolution
  - Signal:Background
  - Understanding background energy/position distribution
- Secondary concerns:
  - Reactor shape, fuel type
  - Background shape

Conclusions

- Very short baseline experiments WE ARE CONSIDERING can probe reactor anomaly to 5σ
- We should work on exact sensitivities for each site
  - Need to have exact parameters available at each site
    - Exact baseline ranges
    - Exact detector sizes
  - Need to know the backgrounds at each site, baseline