DayaBay Reactor Neutrino Experiment

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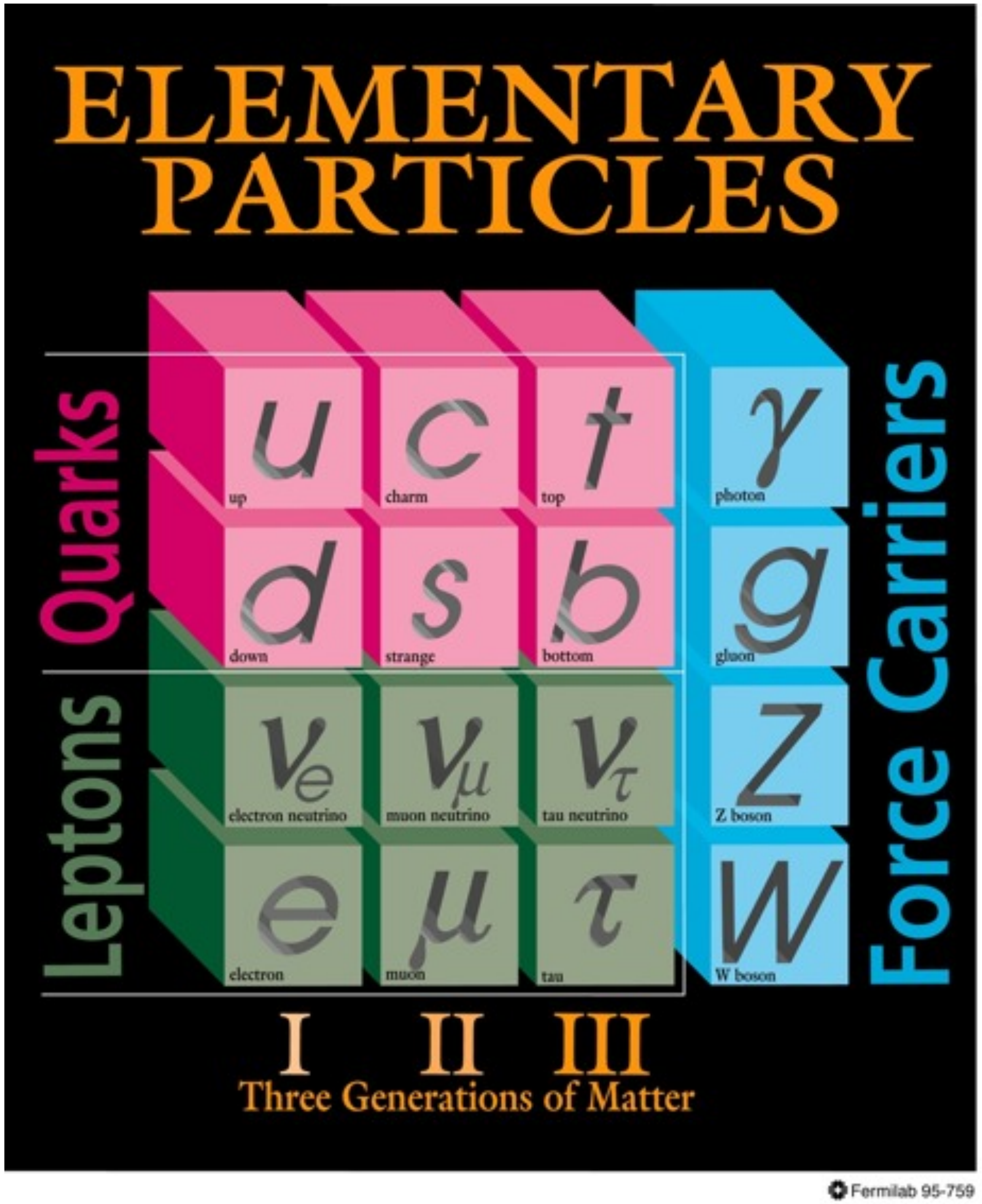
Outline

- Neutrinos
  - Flavors and Masses
  - Oscillation
- DayaBay
  - Experiment Goals
  - Short Term Physics Potentials
    - Predicting the Reactor Anti Neutrino Flux
    - “4 Month Sensitivities”

Neutrinos

What is a neutrino?



- No "electric" charge (electro-magnetic force)
- No "color" charge (strong force)
- They do have "flavor" charge (weak force)
- They do have some mass (gravity)

- Relic neutrinos – 100/cm^3 @ 2K
- Influence nucleo-synthesis and CMB
- Required to explain SN explosions
- Neutrino astronomy is a growing field
- Matter-Antimatter asymmetry
- They are one of the fundamental particles

Definition of Flavor States

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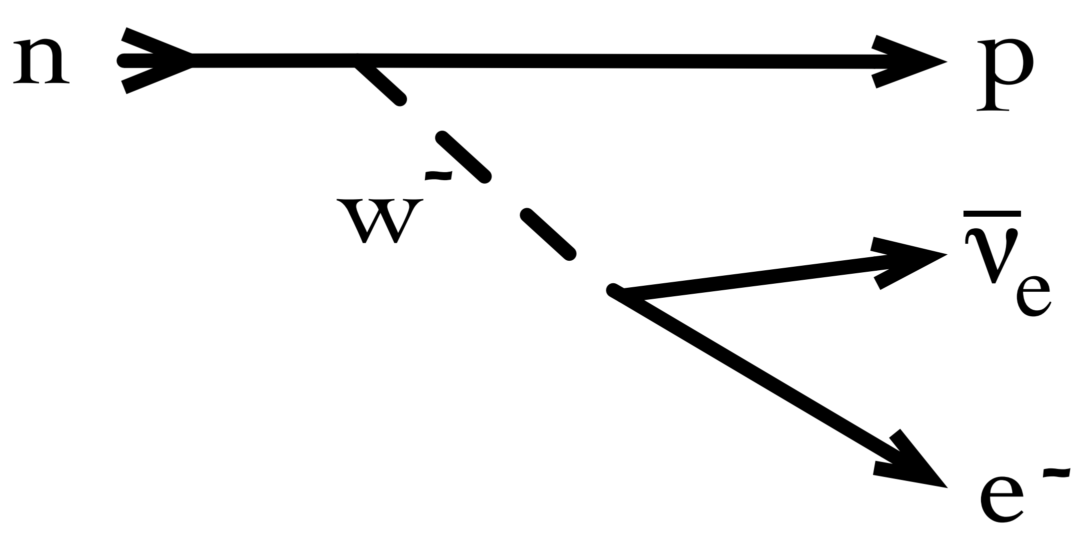
By Definition:

An electron flavored neutrino is what is created alongside an electron flavored lepton



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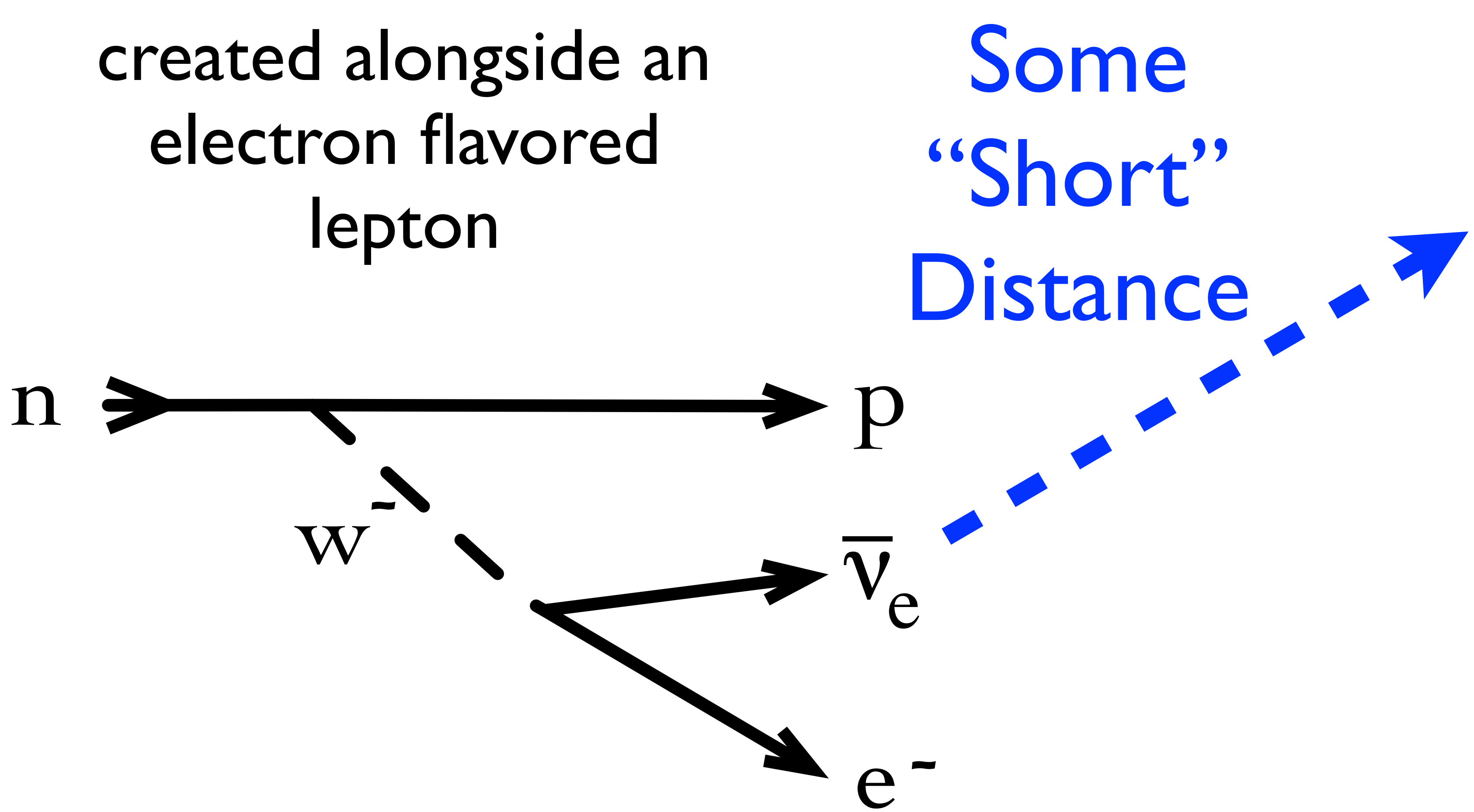

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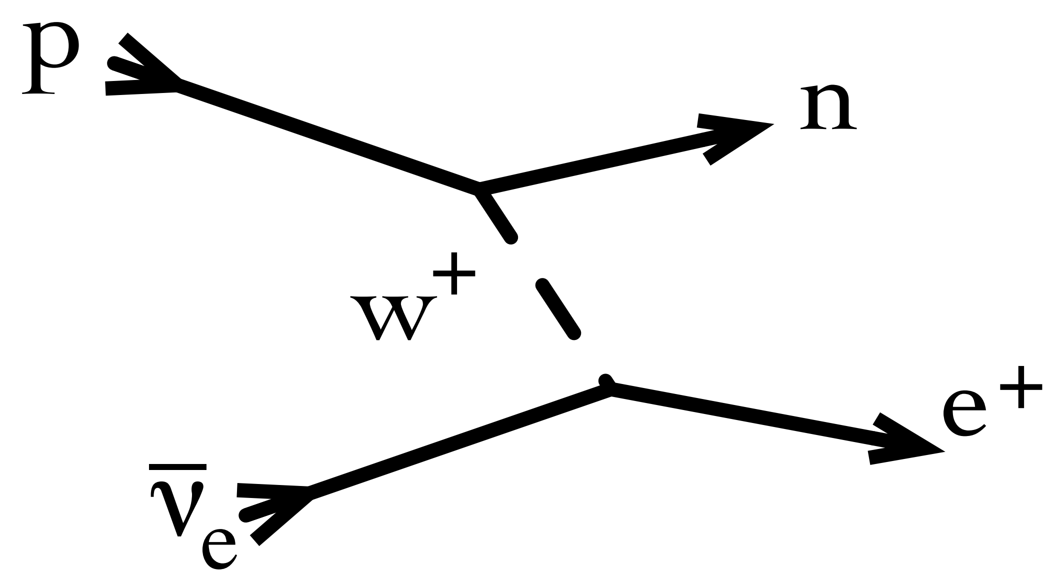
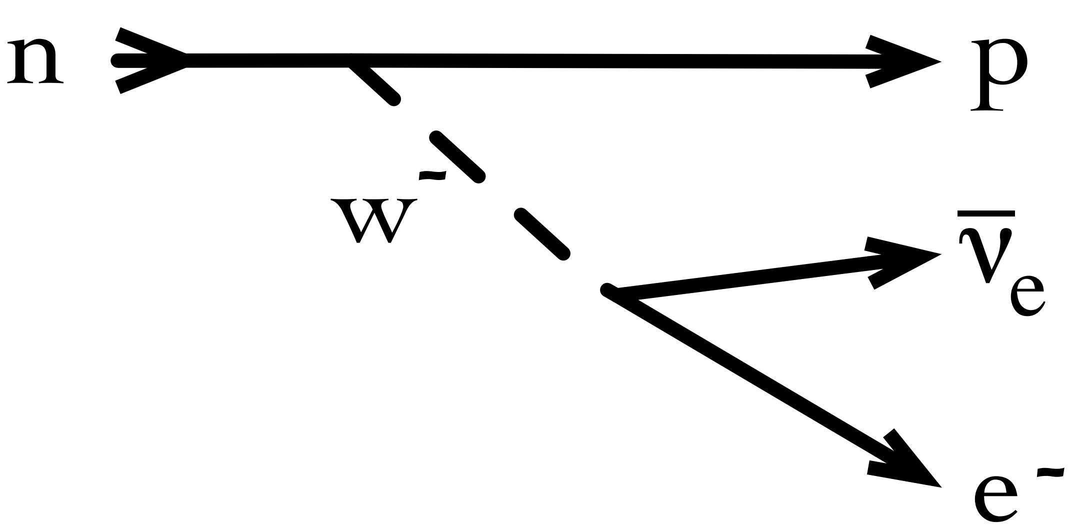


Some "Short" Distance



By Definition:
An electron flavored neutrino was captured to produce an electron flavored lepton

Relation to Mass States

Flavor and Mass states are related by a unitary mixing matrix.

$$|\nu_\alpha\rangle = \sum_{\mathrm{i}} \mathrm{U}^*_{\alpha \mathrm{i}} |\nu_{\mathrm{i}}\rangle \qquad |\nu_{\mathrm{i}}\rangle = \sum_{\alpha} \mathrm{U}_{\alpha \mathrm{i}} |\nu_\alpha\rangle$$

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For the 3 flavor case:

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

PMNS Matrix (3 flavor case)

Pontecorvo, Maki, Nakagawa, Sakata

$$U_{PMNS} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} = \begin{bmatrix} 0.8 & 0.5 & U_{e3} \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{bmatrix}$$

?

6 Free parameters:
3 real mixing angles , 3 complex phases

$c_{23} \equiv \cos(\theta_{23})$

$$U = \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix}}_{\text{atmospheric mixing}} \underbrace{\begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix}}_{\text{cross mixing}} \underbrace{\begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{\text{solar mixing}} \underbrace{\begin{bmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{\text{majorana phases}}$$

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Current Knowledge

$$\sin^2(2\theta_{12}) = 0.87 \pm 0.03$$

$$\Delta m^2_{21} = (7.59 \pm 0.20) \times 10^{-5} \quad \mathrm{eV}^2$$

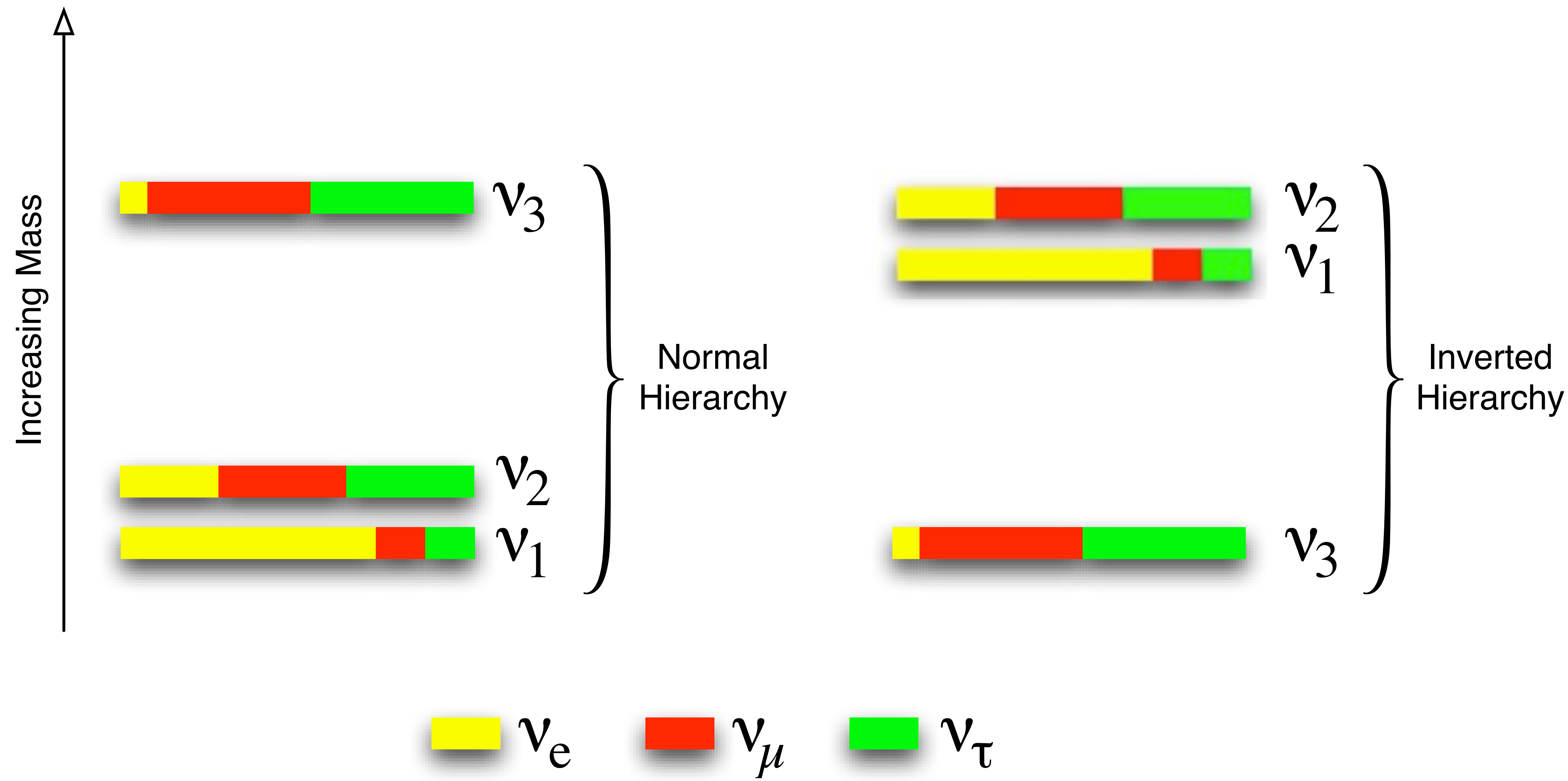
$$\sin^2(2\theta_{23}) > 0.92$$

$$\left|\Delta m^2_{32}\right| = (2.43 \pm 0.13) \times 10^{-3} \quad \mathrm{eV}^2$$

$$\sin^2(2\theta_{13}) < 0.15, \mathrm{CL} = 90\%$$

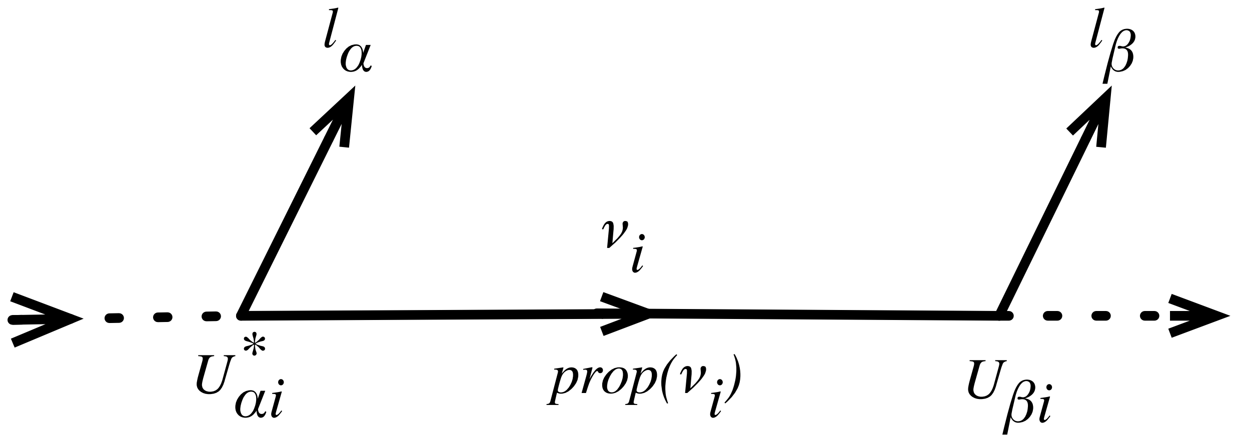
2010 PDG

Picture Version



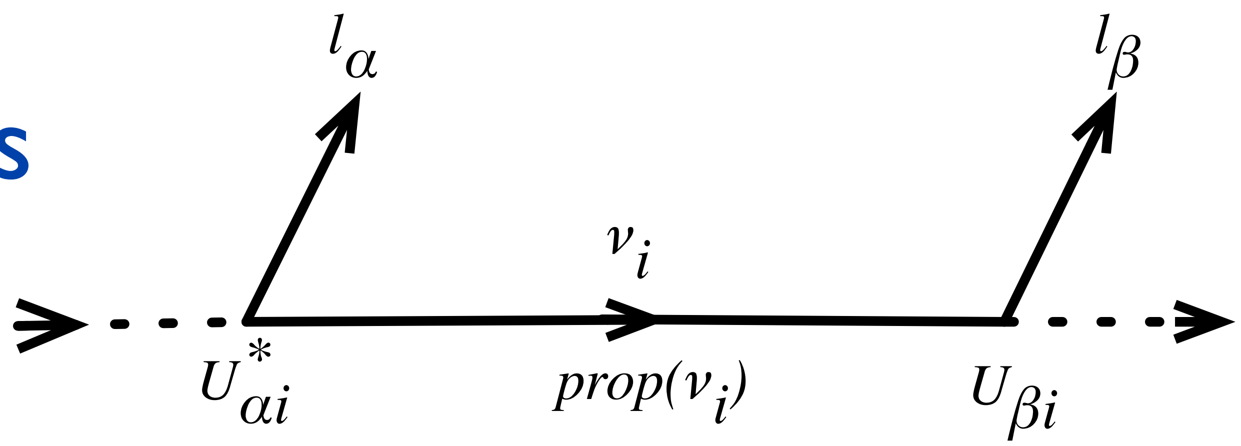
Neutrino Oscillation

What does this mean?



What does this mean?

A neutrino produced as flavor α



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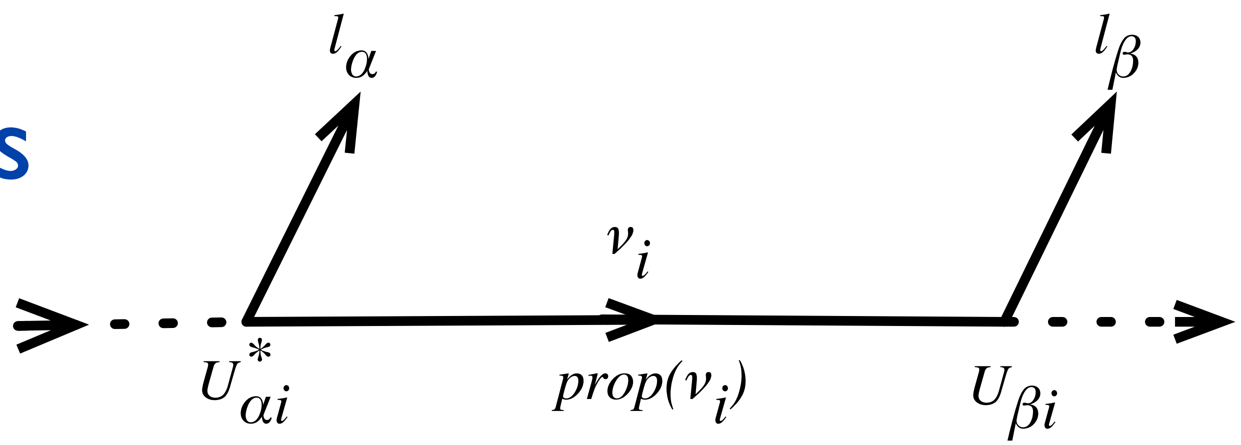

Is Detected as flavor β

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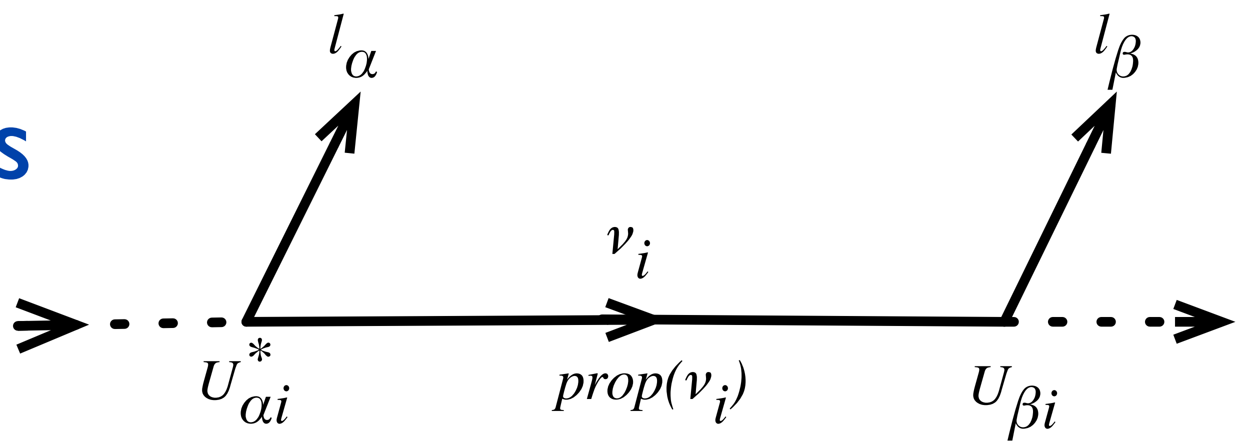
A neutrino produced as flavor α

Propagates with mass state i

Is Detected as flavor β



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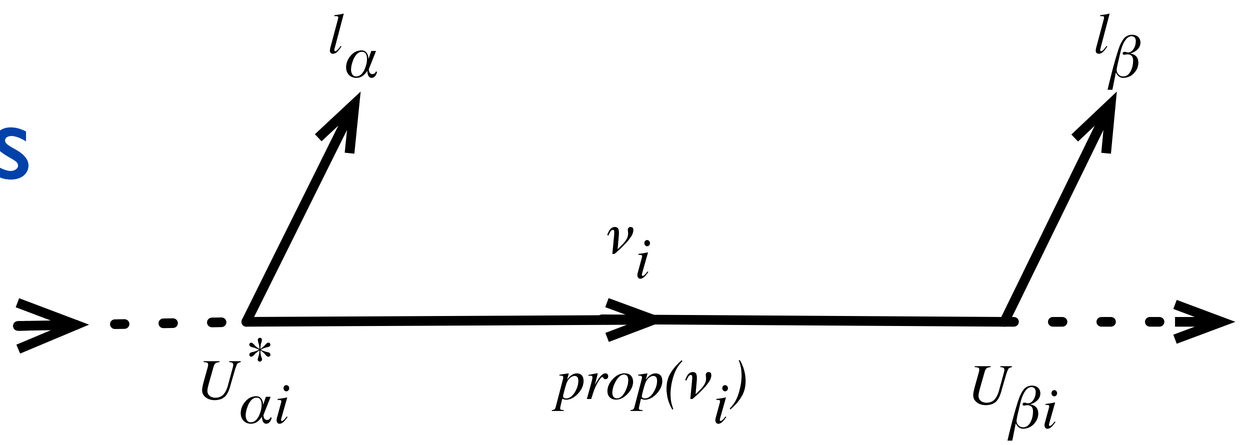

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According to Quantum Mechanics...

What does this mean?

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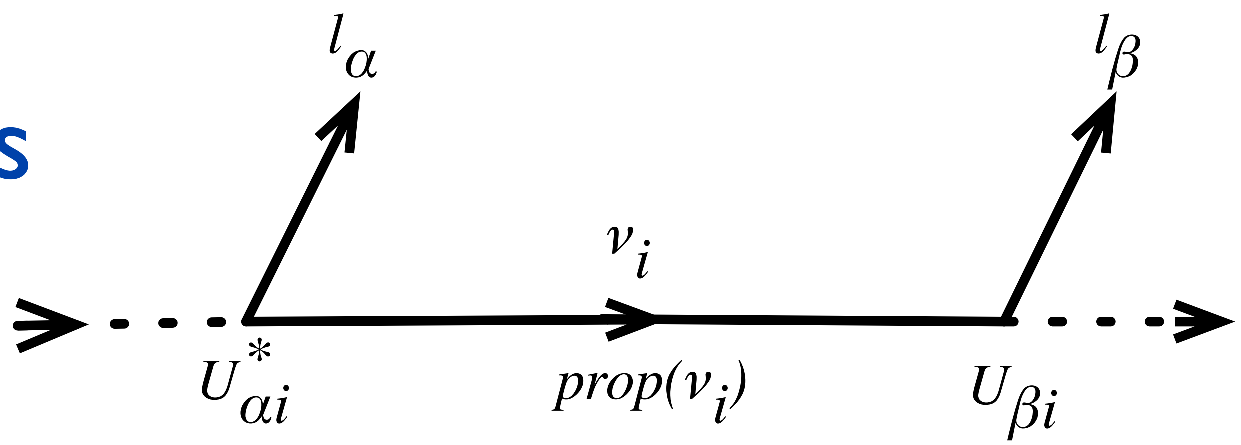
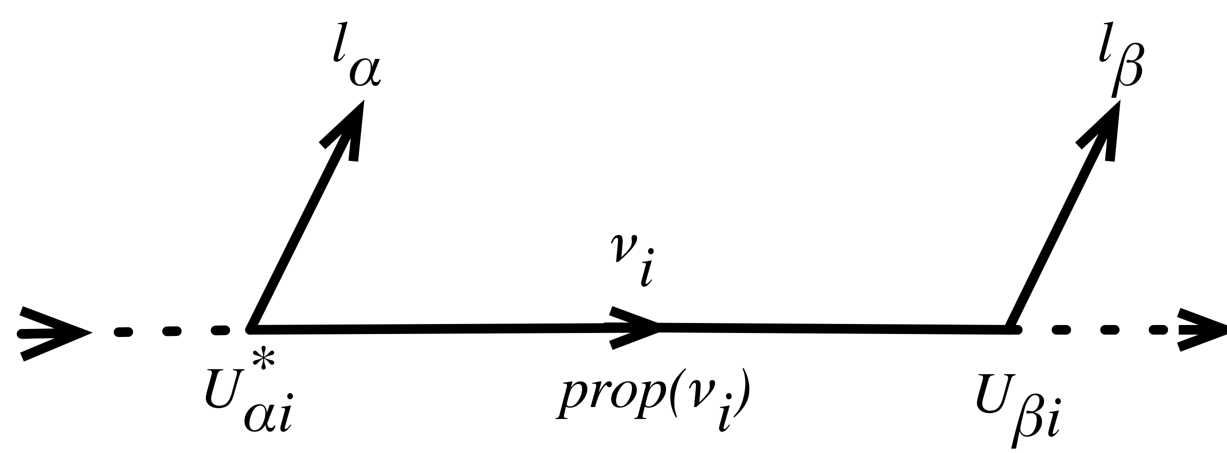


Is Detected as flavor β

According to Quantum Mechanics...

$$\mathrm{Amp}(\nu_\alpha \rightarrow \nu_\beta) = \sum_i \mathrm{Amp}\Bigg[$$



$$\Bigg]$$

Propagation of Mass

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In the rest frame of the neutrino:

$$-i\frac{\partial}{\partial t}\left|\nu_i(\tau_i)\right\rangle = m_i\left|\nu_i(\tau_i)\right\rangle$$

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$$\left|\nu_i(\tau_i)\right\rangle = e^{-im_i\tau_i}\left|\nu_i(0)\right\rangle$$

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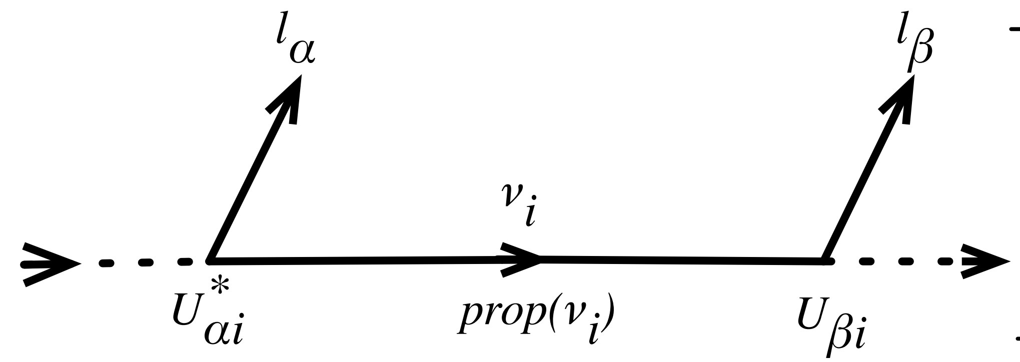
Which can be rewritten:

$$\left|\nu_i(\tau_i)\right\rangle = e^{-i\frac{m_i^2 L}{2E}}\left|\nu_i(0)\right\rangle$$

Oscillation Probability

$$\mathrm{Amp}(\nu_\alpha \to \nu_\beta) = \sum_i \mathrm{Amp}\Big[\ \cdots\ \Big]$$



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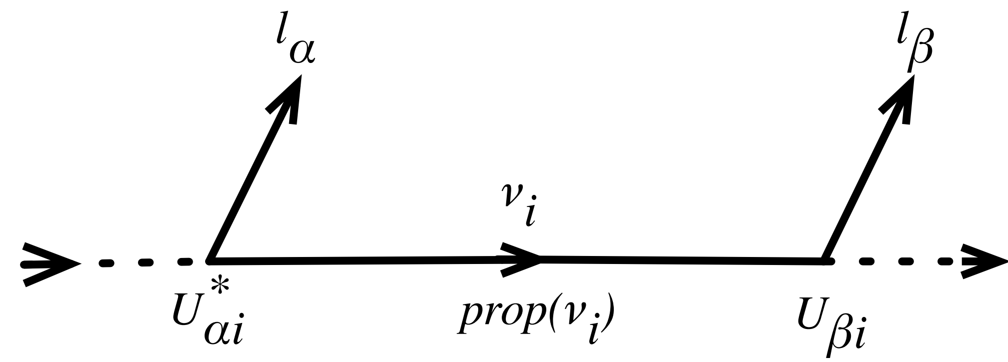

$$P(\nu_\alpha \to \nu_\beta) = \left|\mathrm{Amp}(\nu_\alpha \to \nu_\beta)\right|^2 = \left(\sum_i U^*_{\alpha i} e^{-i m_i^2 \frac{L}{2E}} U_{\beta i}\right)\left(\sum_j U_{\alpha j} e^{i m_j^2 \frac{L}{2E}} U^*_{\beta j}\right)$$

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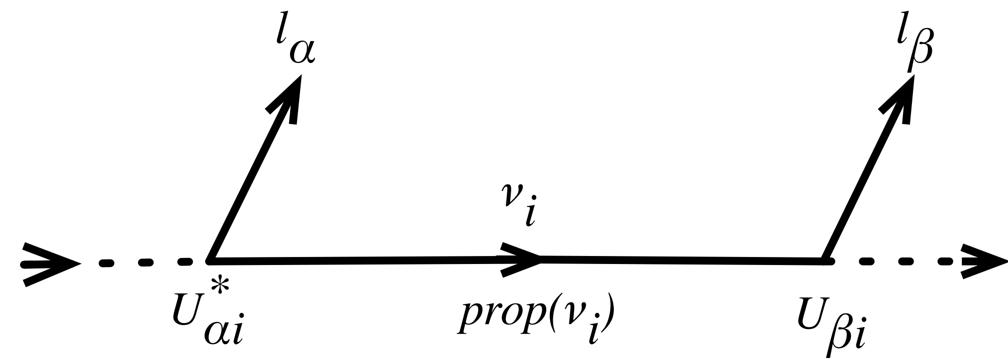

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$$P(\nu_\alpha \to \nu_\beta) = \delta_{\alpha\beta} - 4\sum_{i>j} \Re\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) \sin^2\left(\Delta m^2_{ij} \frac{L}{4E}\right) + 2\Im \sum_{i>j} \left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) \sin\left(\Delta m^2_{ij} \frac{L}{2E}\right)$$

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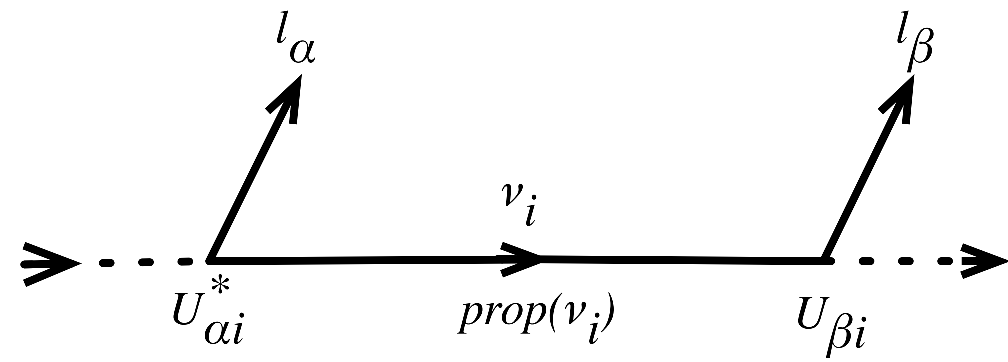

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Oscillation Probability

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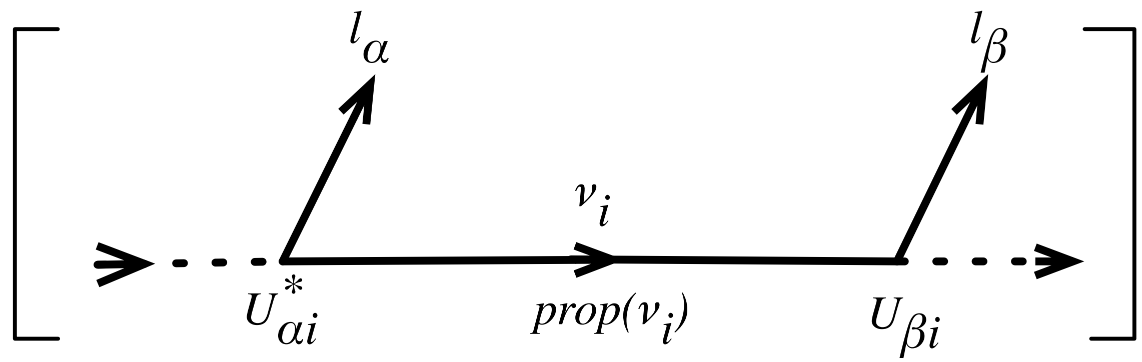

$$P(\nu_\alpha \to \nu_\beta) = \left|\mathrm{Amp}(\nu_\alpha \to \nu_\beta)\right|^2 = \left(\sum_i U^*_{\alpha i} e^{-im_i^2 \frac{L}{2E}} U_{\beta i}\right)\left(\sum_j U_{\alpha j} e^{im_j^2 \frac{L}{2E}} U^*_{\beta j}\right)$$

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CP Violating Term If U is imaginary!

$$P(\overline{\nu_\alpha} \to \overline{\nu_\beta}) \overset{CPT}{=} P(\nu_\beta \to \nu_\alpha) = P(\nu_\alpha \to \nu_\beta, U \to U^*)$$

$$P(\overline{\nu_\alpha} \to \overline{\nu_\beta}) = \delta_{\alpha\beta} - 4\sum_{i>j} \Re\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right)\sin^2\left(\Delta m^2_{ij}\frac{L}{4E}\right) - 2\Im\sum_{i>j}\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right)\sin\left(\Delta m^2_{ij}\frac{L}{2E}\right)$$

3 Neutrino Case

In The 3 neutrino case we have an explicit representation of U

$$U = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & -c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

$$P\left(\nu_\alpha \to \nu_\beta\right) = \left| e^{-im_1^2 \frac{L}{2E}} \mathrm{Amp}^*\left(\nu_\alpha \to \nu_\beta\right) \right|^2 = \left| \sum_i e^{-i\Delta m_1^2 \frac{L}{2E}} U_{\alpha j} e^{i\Delta m_i^2 \frac{L}{2E}} U^*_{\beta j} \right|^2$$

General 3x3 Oscillation Result

$$P\left(\nu_\alpha \to \nu_\beta\right) = 4\left[\left|U_{\alpha 2}U_{\beta 2}\right|^2 \sin^2\left(\Delta m_{21}^2 \frac{L}{4E}\right) + \left|U_{\alpha 3}U_{\beta 3}\right|^2 \sin^2\left(\Delta m_{31}^2 \frac{L}{4E}\right)\right.$$
$$\left. +2\left|U_{\alpha 2}U_{\beta 2}U_{\alpha 3}U_{\beta 3}\right| \sin\left(\Delta m_{21}^2 \frac{L}{4E}\right) \sin\left(\Delta m_{31}^2 \frac{L}{4E}\right) \cos\left(\Delta m_{32}^2 \frac{L}{4E} + \delta_{32}\right)\right]$$

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$$\left. +2\left|U_{\alpha 2}U_{\beta 2}U_{\alpha 3}U_{\beta 3}\right| \sin\left(\Delta m^2_{21}\frac{L}{4E}\right)\sin\left(\Delta m^2_{31}\frac{L}{4E}\right)\cos\left(\Delta m^2_{32}\frac{L}{4E} + \delta_{32}\right)\right]$$

$$P\left(\overline{\nu_\alpha} \to \overline{\nu_\beta}\right) = 4\left[\left|U_{\alpha 2}U_{\beta 2}\right|^2 \sin^2\left(\Delta m^2_{21}\frac{L}{4E}\right) + \left|U_{\alpha 3}U_{\beta 3}\right|^2 \sin^2\left(\Delta m^2_{31}\frac{L}{4E}\right)\right.$$

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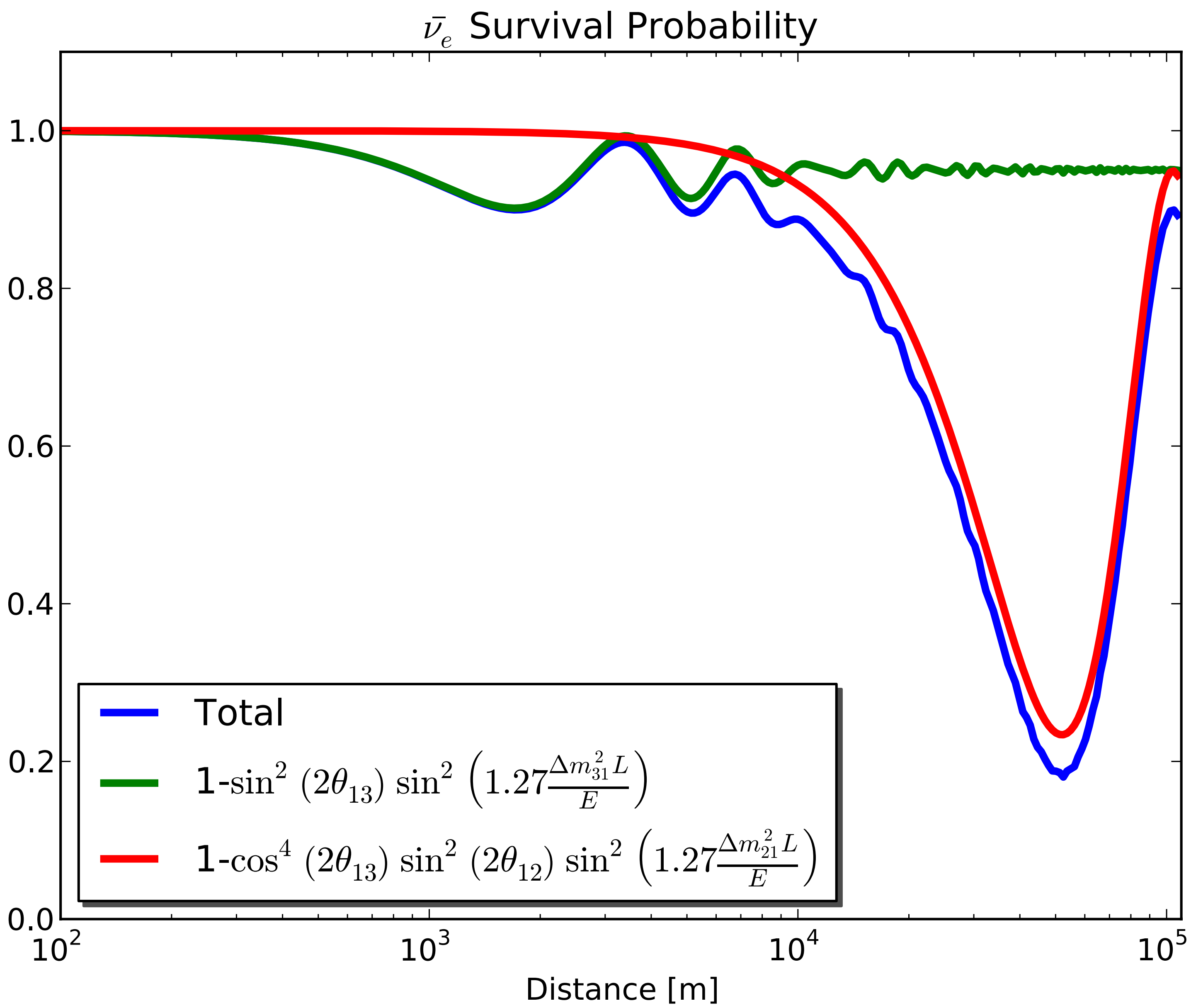
$$\left. +2\left|U_{\alpha 2}U_{\beta 2}U_{\alpha 3}U_{\beta 3}\right|\sin\left(\Delta m^2_{21}\frac{L}{4E}\right)\sin\left(\Delta m^2_{31}\frac{L}{4E}\right)\cos\left(\Delta m^2_{32}\frac{L}{4E}+\delta_{32}\right)\right]$$

CP Violating Phase

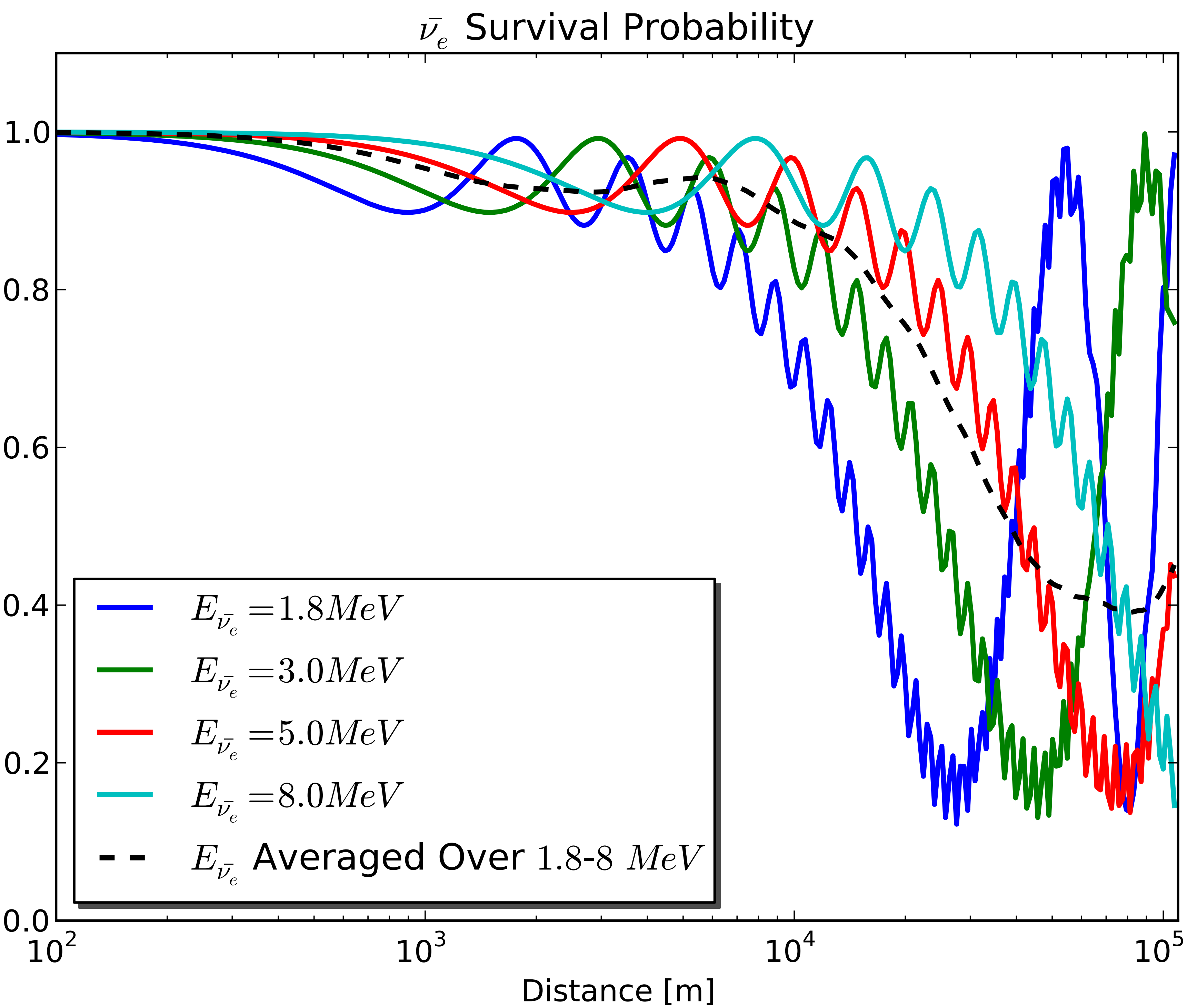
$$P\left(\overline{\nu_\alpha} \to \overline{\nu_\beta}\right) = 4\left[\left|U_{\alpha 2}U_{\beta 2}\right|^2 \sin^2\left(\Delta m^2_{21}\frac{L}{4E}\right) + \left|U_{\alpha 3}U_{\beta 3}\right|^2 \sin^2\left(\Delta m^2_{31}\frac{L}{4E}\right)\right.$$
$$\left. +2\left|U_{\alpha 2}U_{\beta 2}U_{\alpha 3}U_{\beta 3}\right|\sin\left(\Delta m^2_{21}\frac{L}{4E}\right)\sin\left(\Delta m^2_{31}\frac{L}{4E}\right)\cos\left(\Delta m^2_{32}\frac{L}{4E}-\delta_{32}\right)\right]$$

Survival Probability

$$P\left(\overline{\nu_e} \rightarrow \overline{\nu_e}\right) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}^2 L}{4E}\right)$$

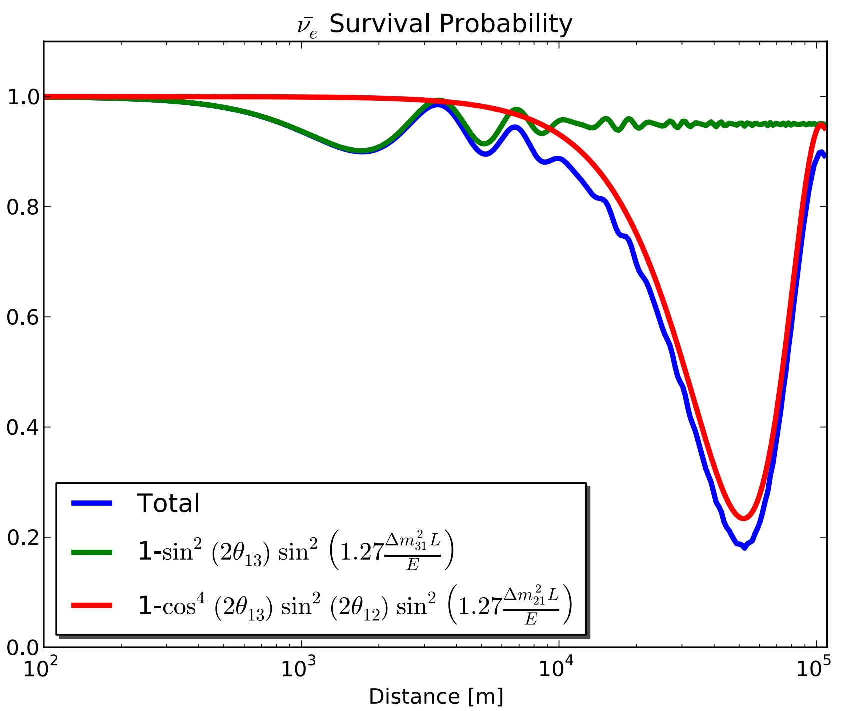


Survival Probability (E dependent)

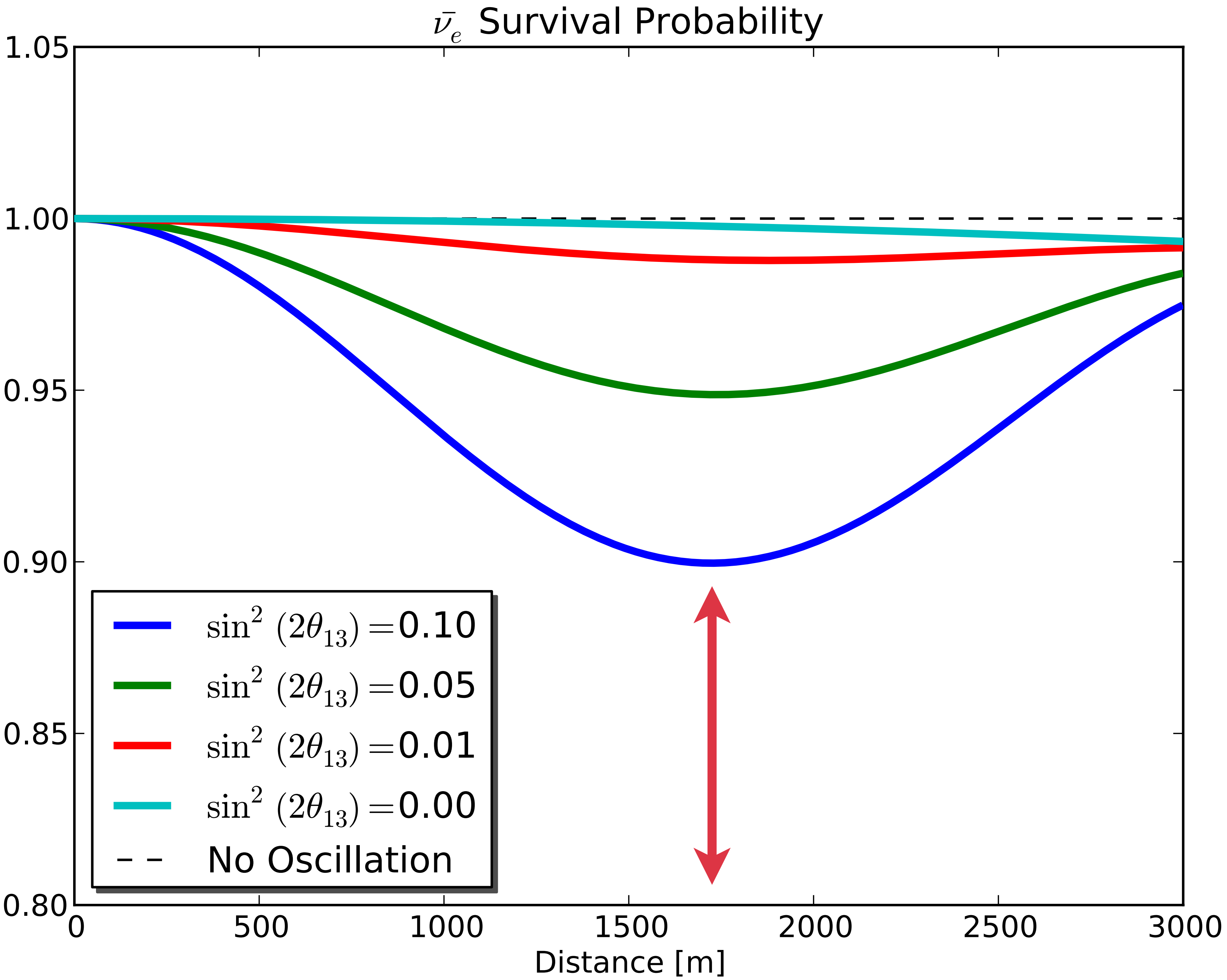


Previous plot averaged over energies.

Each energy bin has a slightly different survival probability



Signal Size

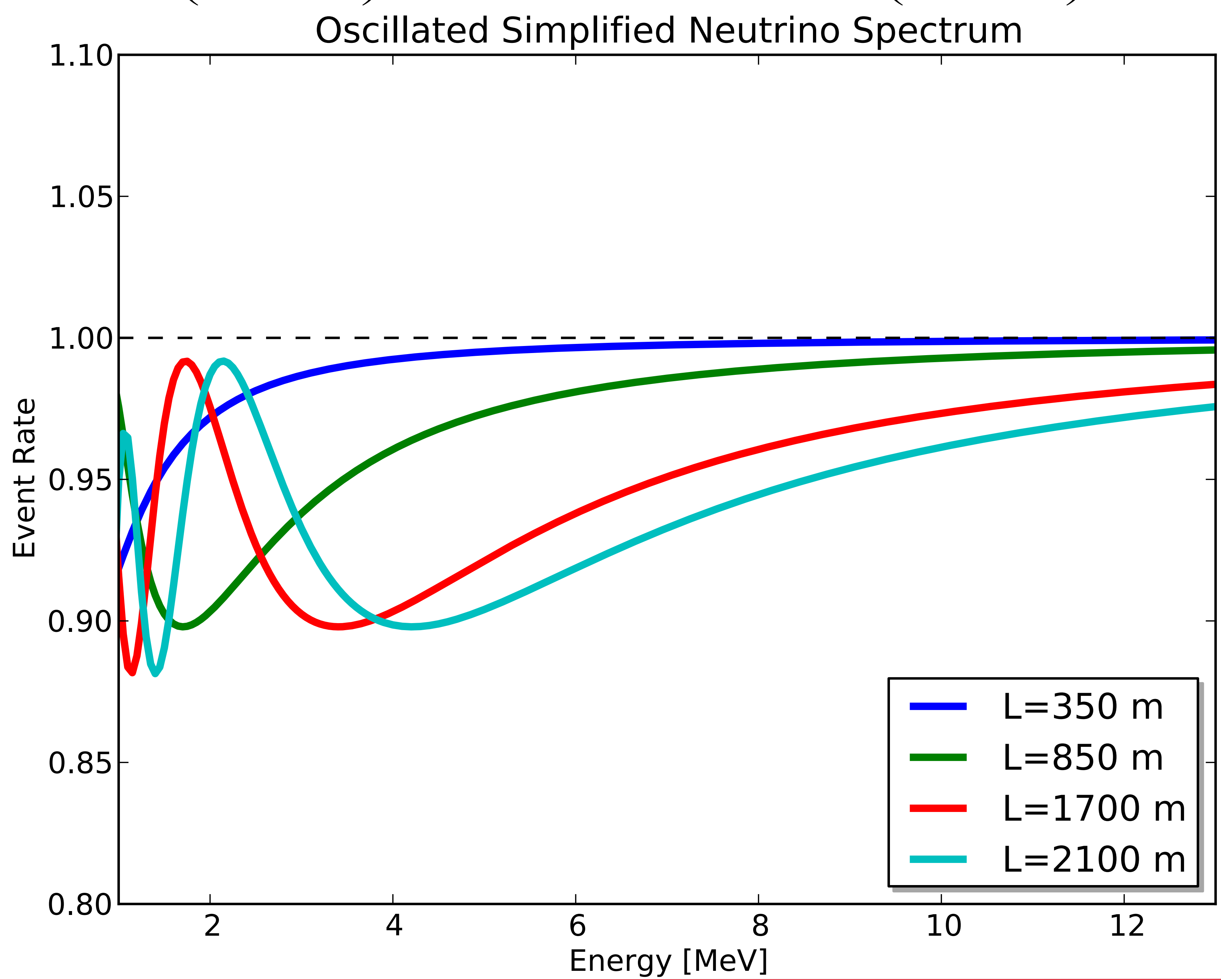


For antineutrinos with 3-4 MeV of Energy, the optimal distance to measure θ_{13} is around 1700m

Spectral Distortion

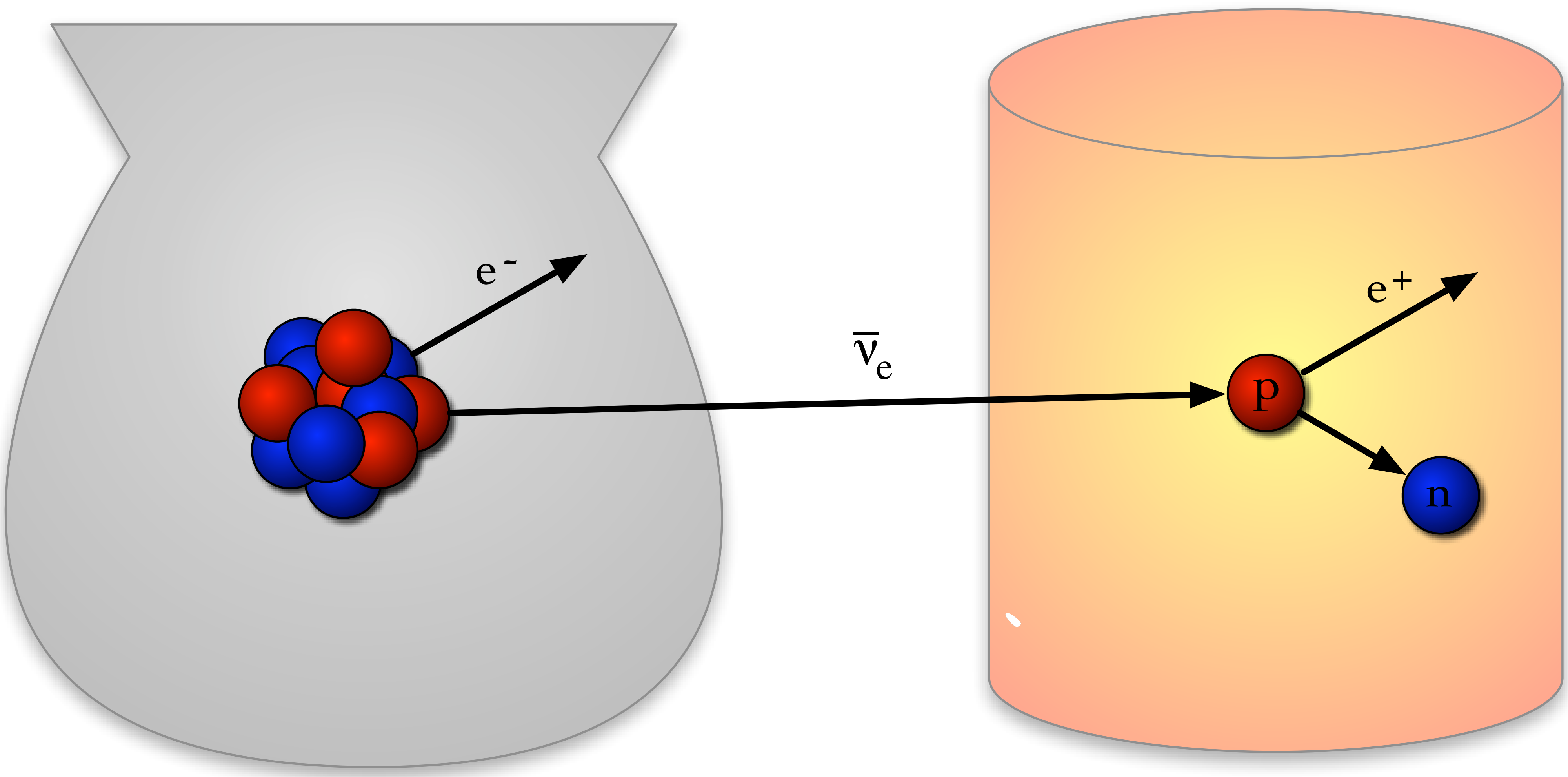
$$P\left(\overline{\nu_e} \rightarrow \overline{\nu_e}\right) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}^2 L}{4E}\right)$$

In addition to a deficit of events, the energy spectrum also changes.



Previous Reactor Experiments

$$P\left(\overline{\nu}_e \rightarrow \overline{\nu}_e\right) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)$$



Look for a deficit of anti-neutrino events by predicting the expected flux.

DayaBay

Location


55 km
Gangkou Liedao
Xi Zhou
Mabian
Chi Zhou
DAYA WAN
Dalajia
Dapeng
Nan'ao
867
QINIANG SHAN
Dasanmen
Xiaosanmen Dao
Shiyan
Pingshan
Fuyong
587
Longhua
Henggang
Kuichong
444
547
214
Buji
YANTIAN
Meisha
Yantian Port
MIRS BAY
SHENZHEN
LUOHU
FUTIAN
944
WUTONG SHAN
SHATOUJIAO
Sha Tau Kok
Man Kam To
Crooked Island
Crescent Island
Double Island
Xixiang
BAO'AN
Xiaochan Dao
NANSHAN
Dachan Dao
Shekou Port
Shekou
Mawan Port
Chiwan Port
DEEP BAY
LO WU
Lok Ma Chau
FANLING
639
TIN SHUI WAI
572
566
TAI PO
Plover Cove Reservoir
TOLO HARBOUR
YUEN LONG
HONG KONG
957
TAI MO SHAN
702
MA ON SHAN
468
Neilingding Dao
Lung Kwu Chau
URMSTON ROAD
583
TUEN MUN
CASTLE PEAK
YANG
The Brothers
Ma Wan
TSUEN WAN
SHA TIN
SAI KUNG
High Island Reservoir
Kau Sai Chau
602
KOWLOON PEAK
Town Island
ANG
Chek Lap Kok
Tsing Yi
Kwai Chung Port
KOWLOON
VICTORIA HARBOUR
TSEUNG KWAN O
Jin Island
Basalt Island
TUNG CHUNG
Lantau Island
Peng Chau
552
VICTORIA PEAK
Hong Kong Island
869
934
Tai O
LANTAU PEAK
Mui Wo
Hei Ling Chau
Aberdeen
Ninepin Group
Tung Lung Chau
TATHONG CHANNEL
EAST LAMMA CHANNEL
WEST LAMMA CHANNEL
LANTAU CHANNEL
Niutou Dao
Siu A Chau
Shek Kwu Chau
Cheung Chau
Soko Islands
Tai A Chau
Lamma Island
Stanley
Beaufort Island
Sung Kong
Waglan Island
Po Toi
Po Toi Islands
Boundary of Special Administrative Region
Guishan
Dazhi Zhou
Xiaozhi Zhou
Guishan Dao
LEGEND
Railway
Main road
Secondary road
Built-up area / Cultivation
Airport / Major port
Power station
Peak (in metres)
Contours
Sea depth in metres
Series AR/18/IRS
Edition 7 2002
Survey and Mapping Office, Lands Department
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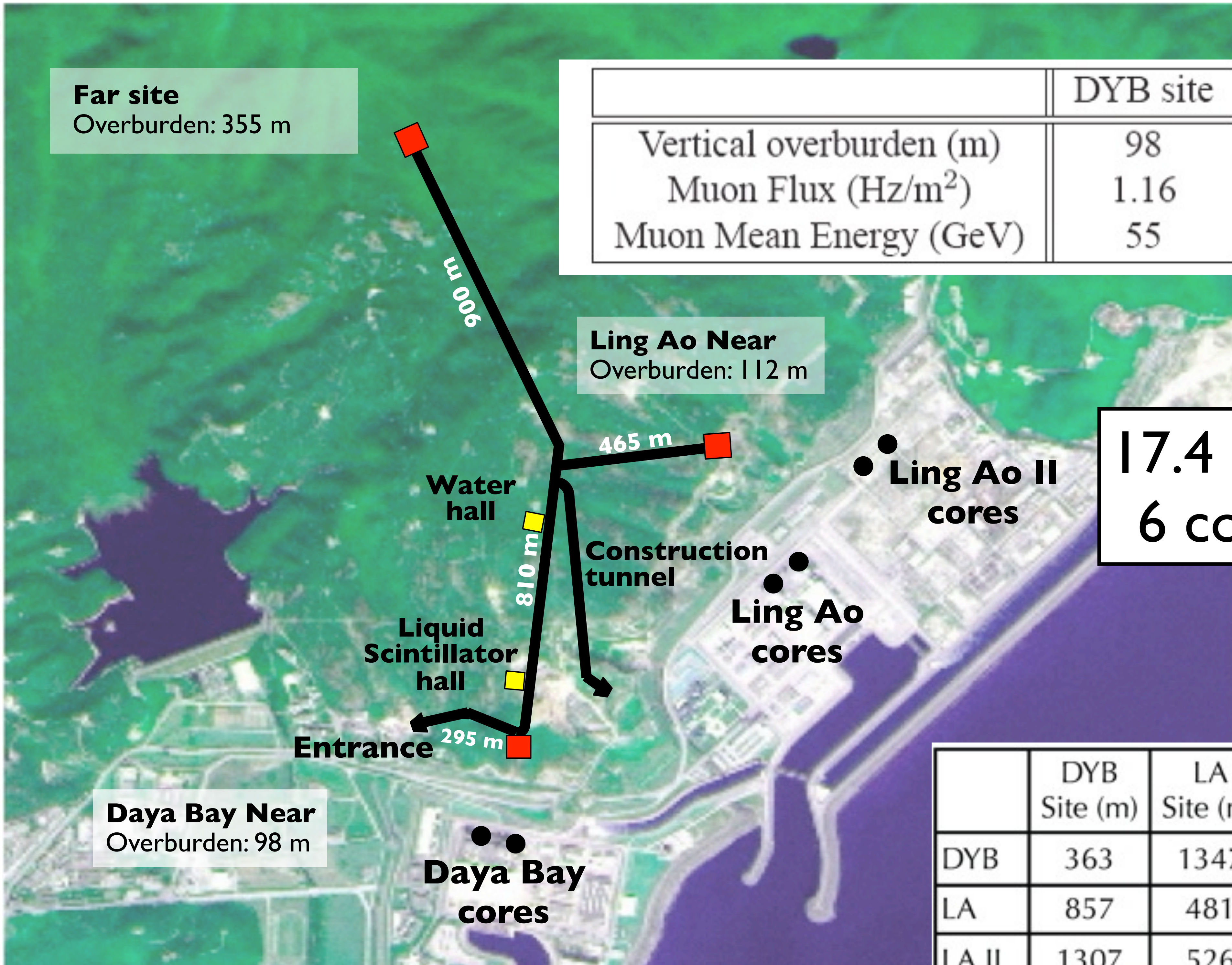
Experimental Halls

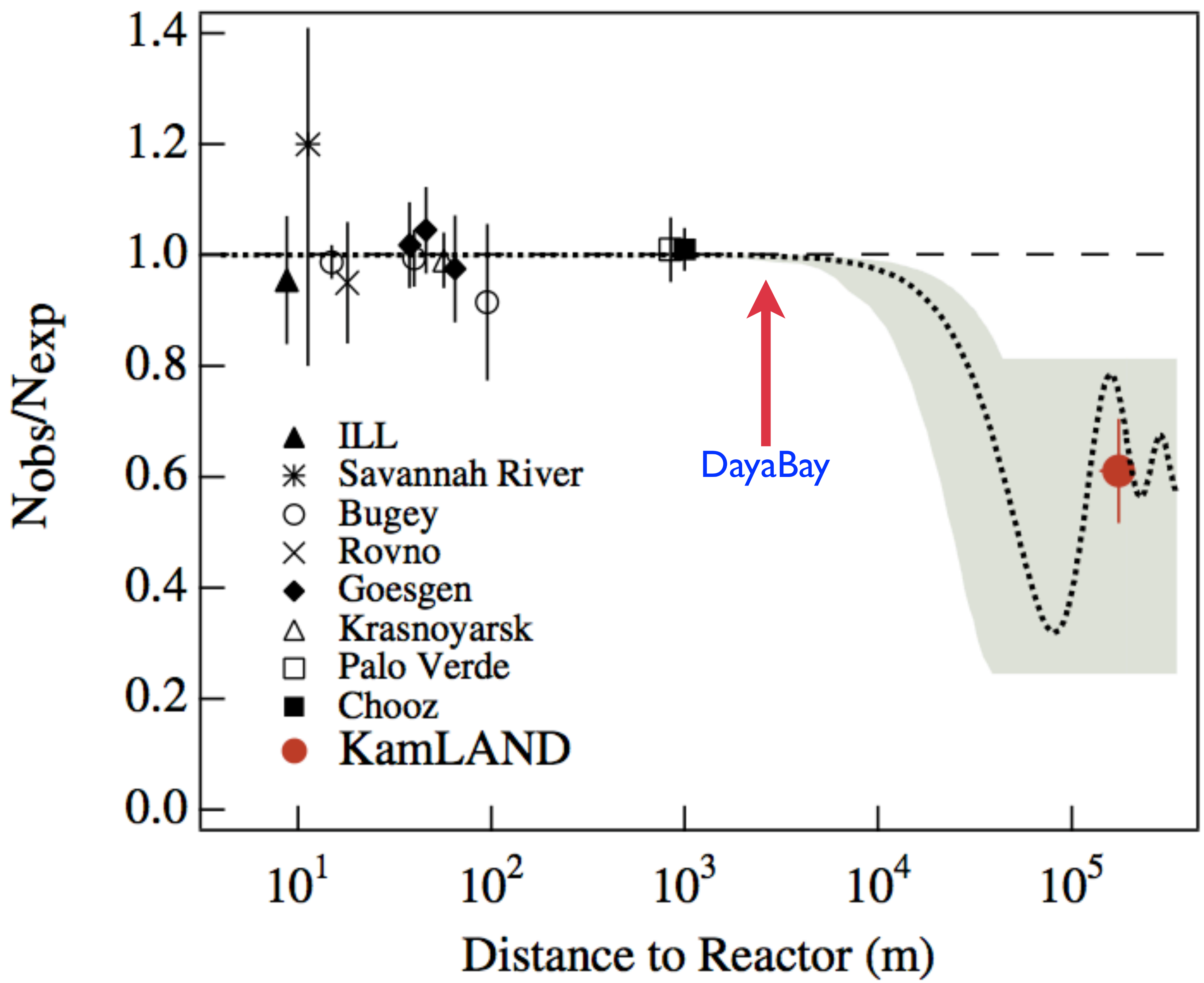


	DYB site	LA site	Far site
Vertical overburden (m)	98	112	355
Muon Flux (Hz/m^2)	1.16	0.73	0.041
Muon Mean Energy (GeV)	55	60	138

17.4 GW_{th} When all 6 cores are online

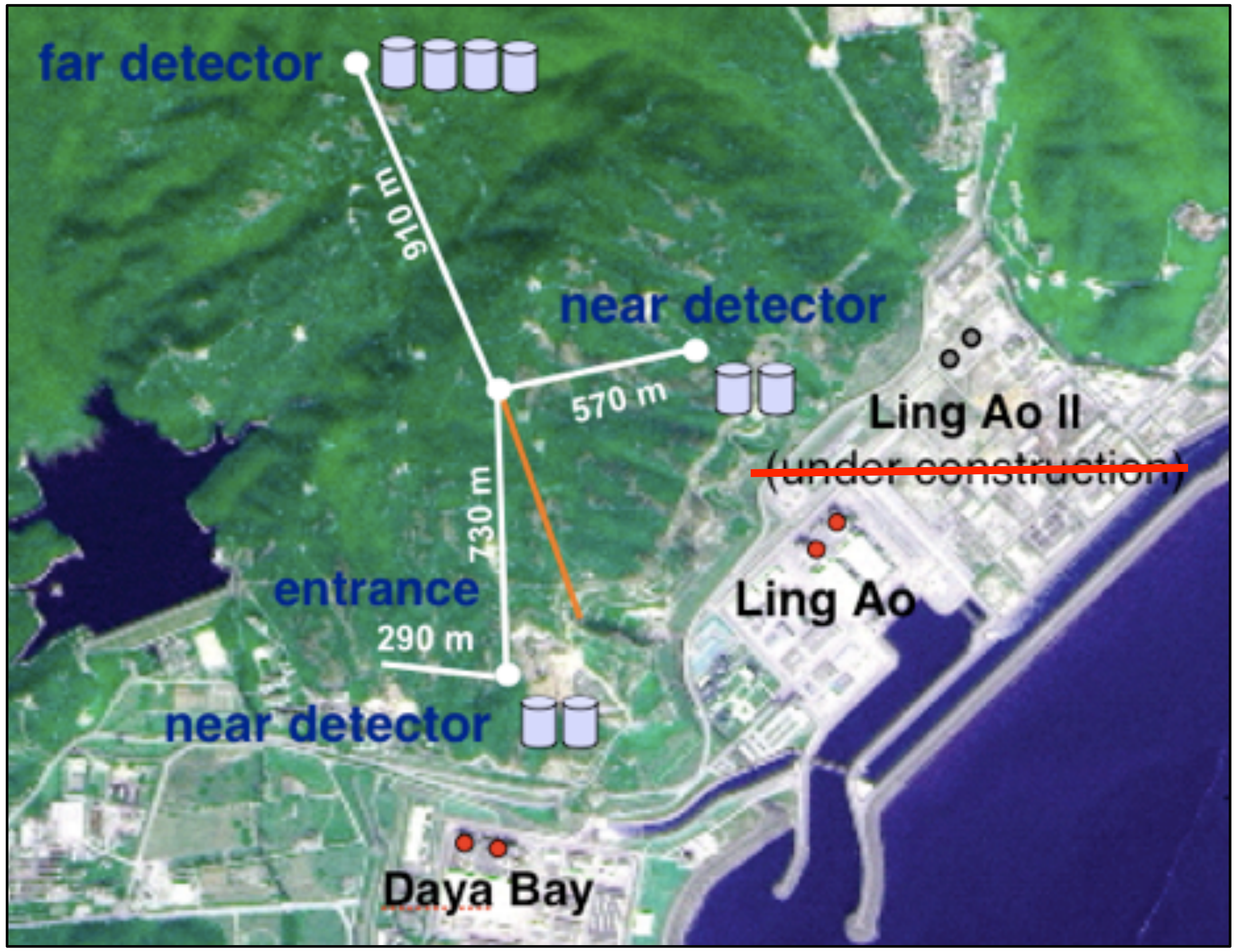
	DYB Site (m)	LA Site (m)	Far Site (m)
DYB	363	1347	1985
LA	857	481	1618
LA II	1307	526	1613

Where Does DayaBay Fit In?

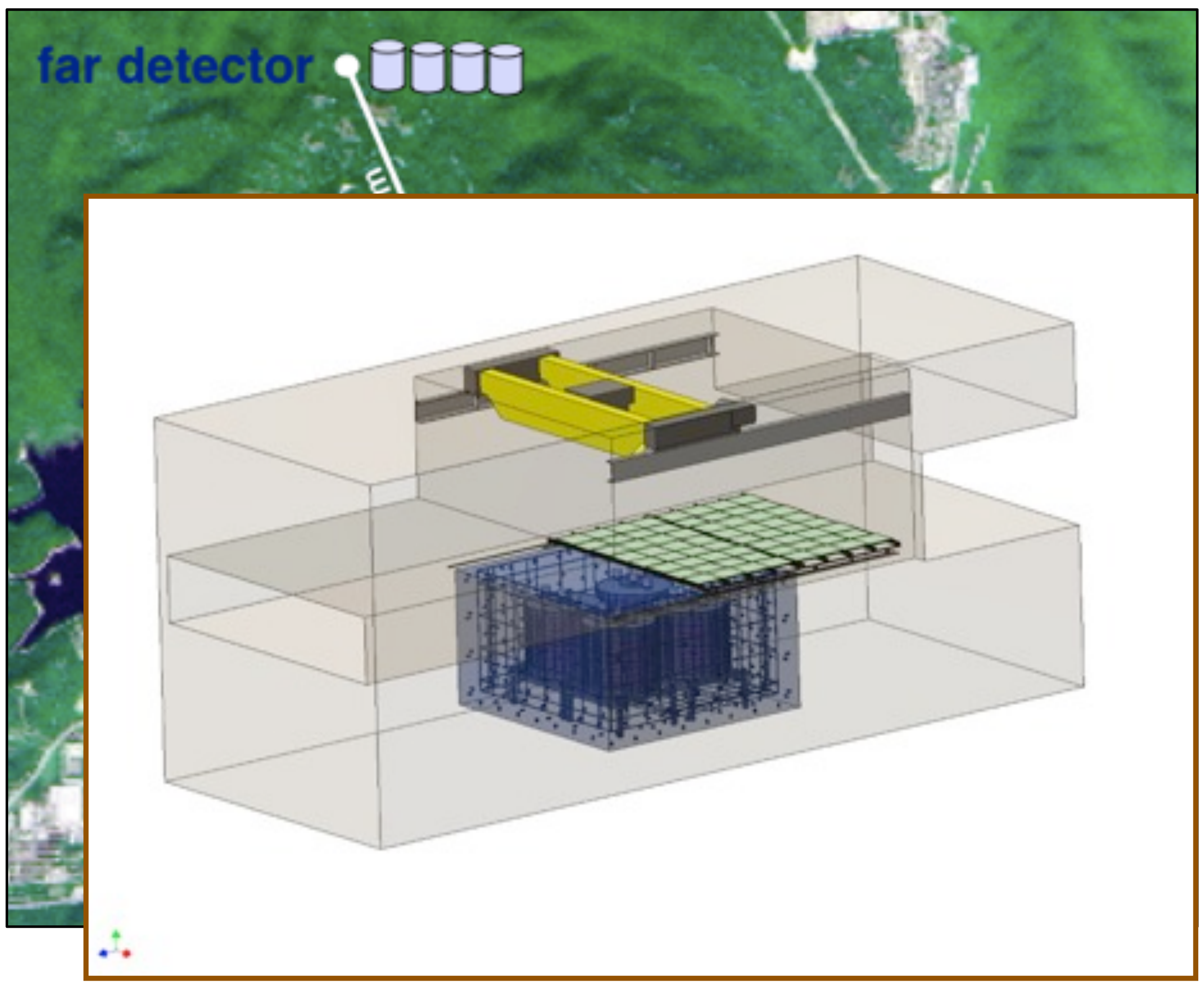


KamLAND Collaboration et al. First Results from KamLAND: Evidence for Reactor Antineutrino Disappearance. Physical Review Letters (2003) vol. 90 (2) pp. 021802

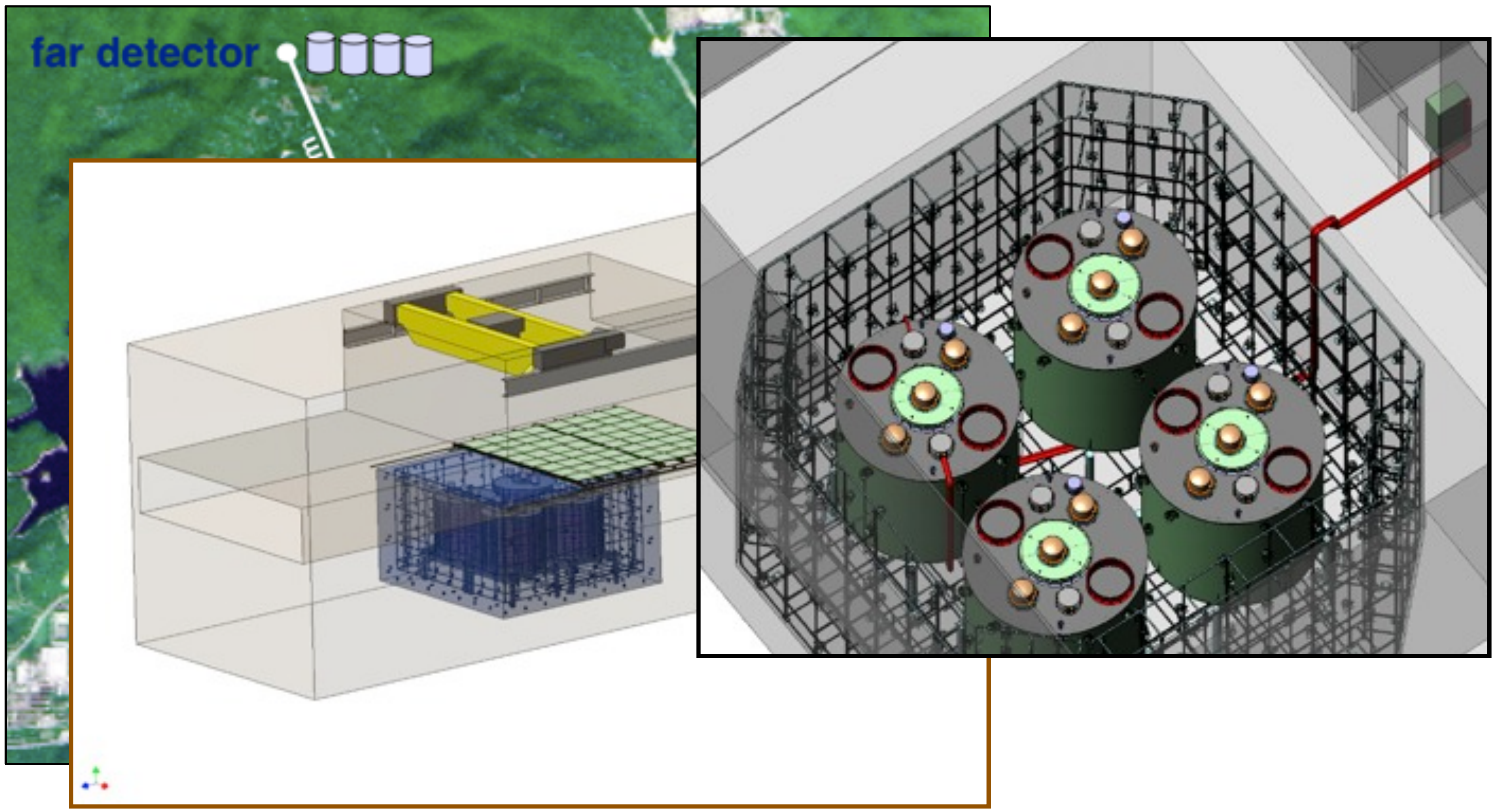
Overview


far detector
910 m
near detector
570 m
Ling Ao II
~~(under construction)~~
730 m
entrance
290 m
Ling Ao
near detector
Daya Bay

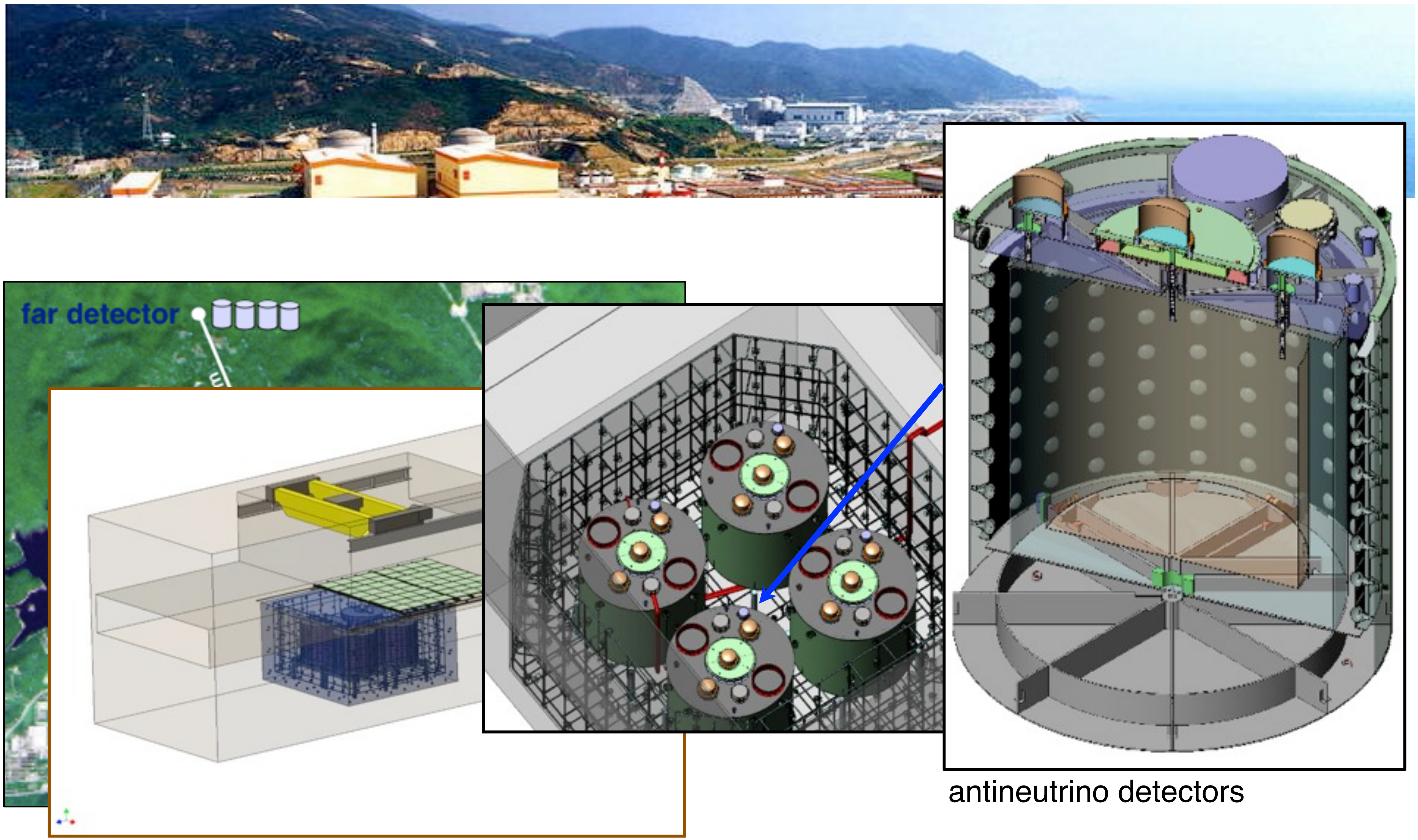
Overview



Overview

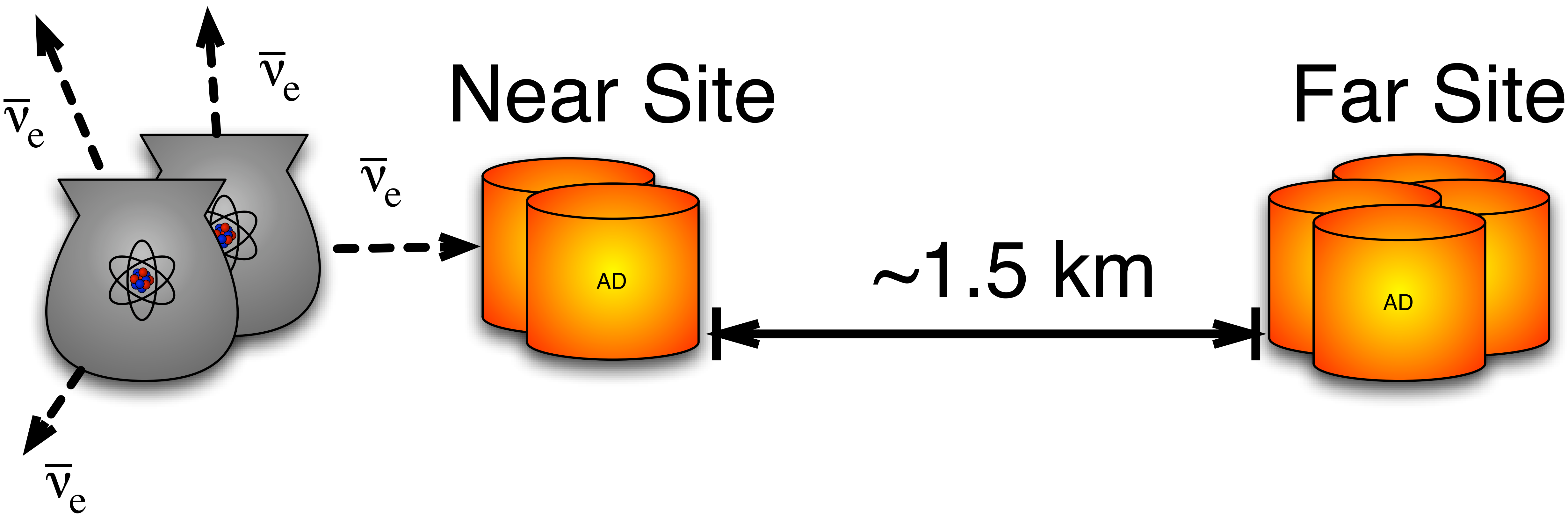


Overview

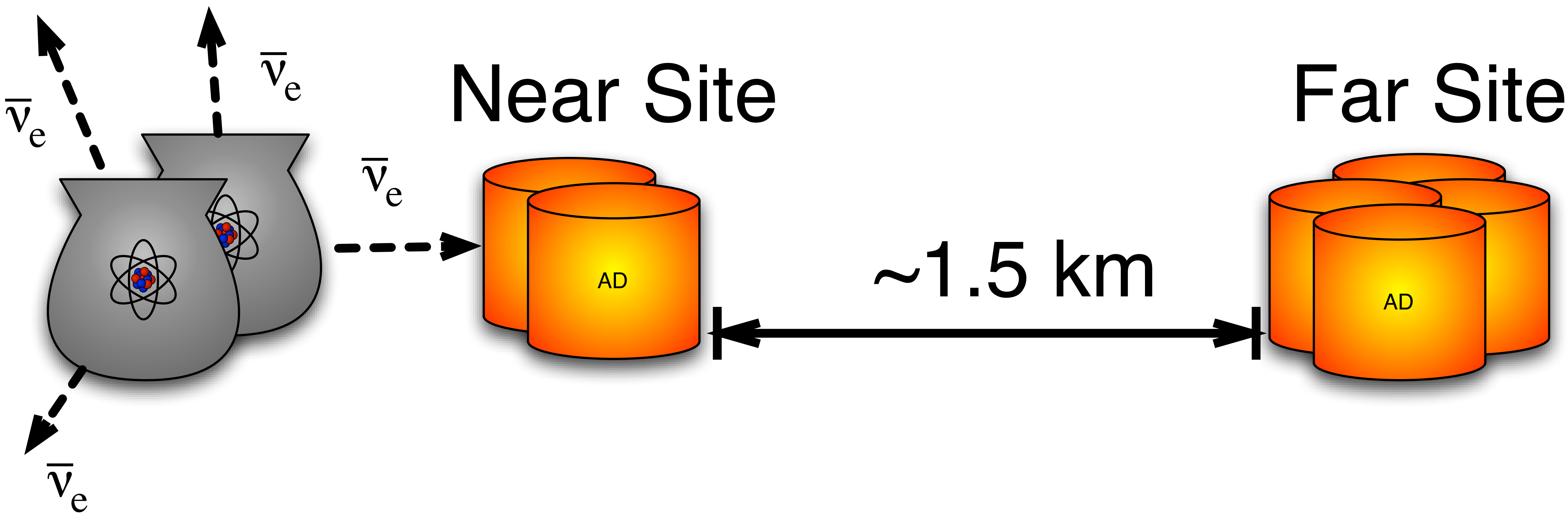


antineutrino detectors

Experimental Setup

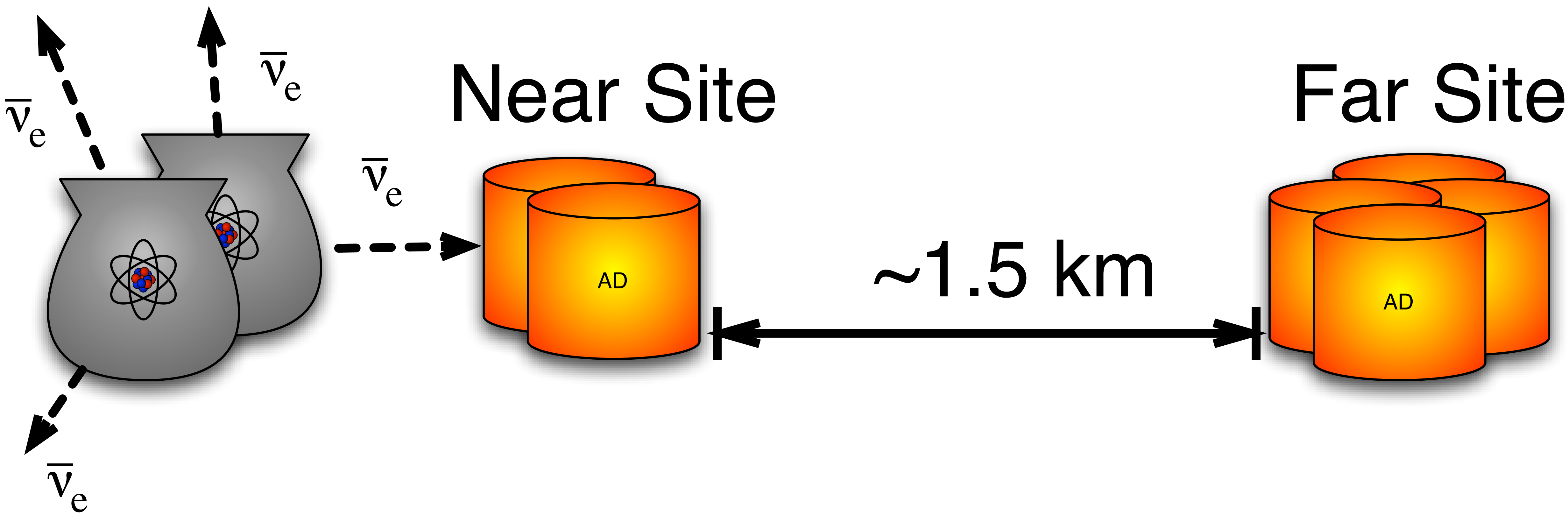


Experimental Setup



$$N_{\text{neutrinos,far}} \propto \Phi_{\overline{\nu}_e} N_{\text{protons,far}} \left(\frac{1}{L_{\text{far}}} \right)^2 \varepsilon_{\text{far}} \left[P_{ee}\left(E, L_{\text{far}} \right) \right]$$

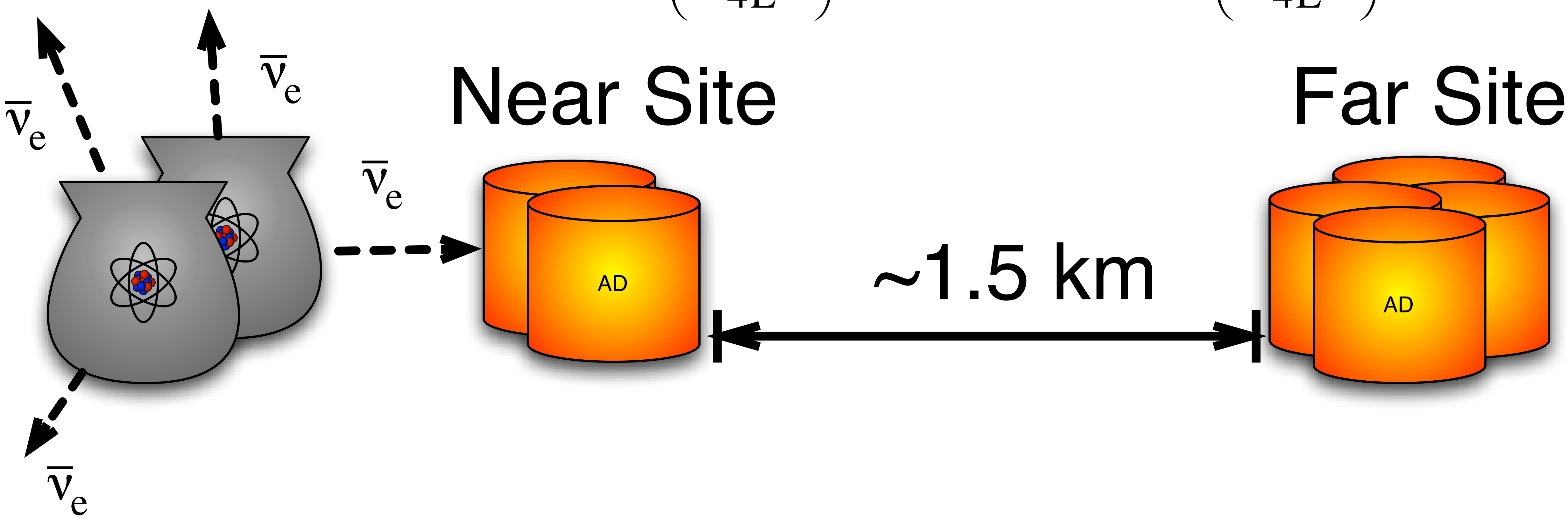
Experimental Setup



$$\frac{N_{neutrinos,far}}{N_{neutrinos,near}} = \left(\frac{N_{protons,far}}{N_{protons,near}}\right)\left(\frac{L_{near}}{L_{far}}\right)^2\left(\frac{\varepsilon_{far}}{\varepsilon_{near}}\right)\left(\frac{P_{ee}(E,L_{far})}{P_{ee}(E,L_{near})}\right)$$

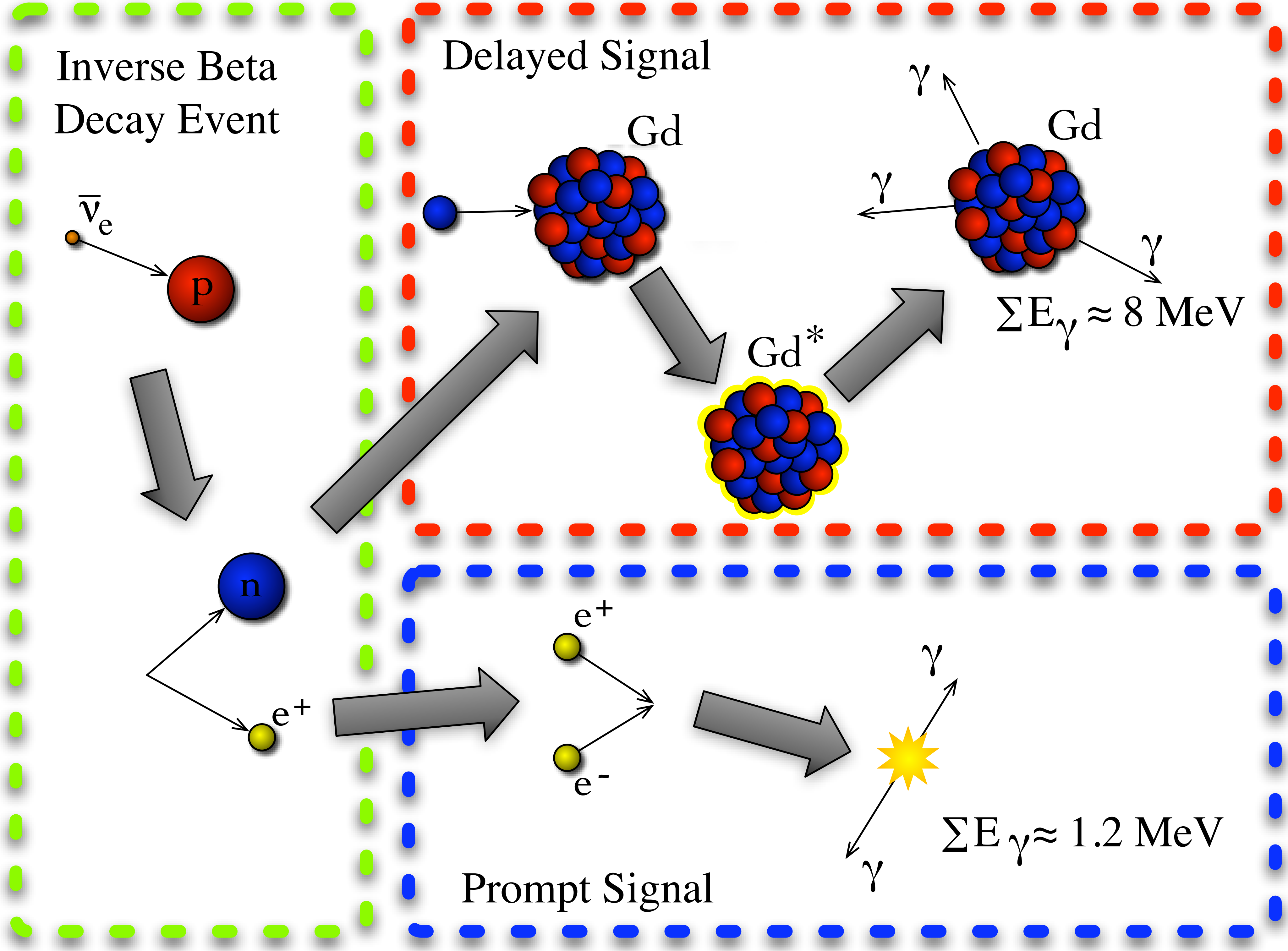
Experimental Setup

$$P\left(\overline{\nu_e} \to \overline{\nu_e}\right) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)$$

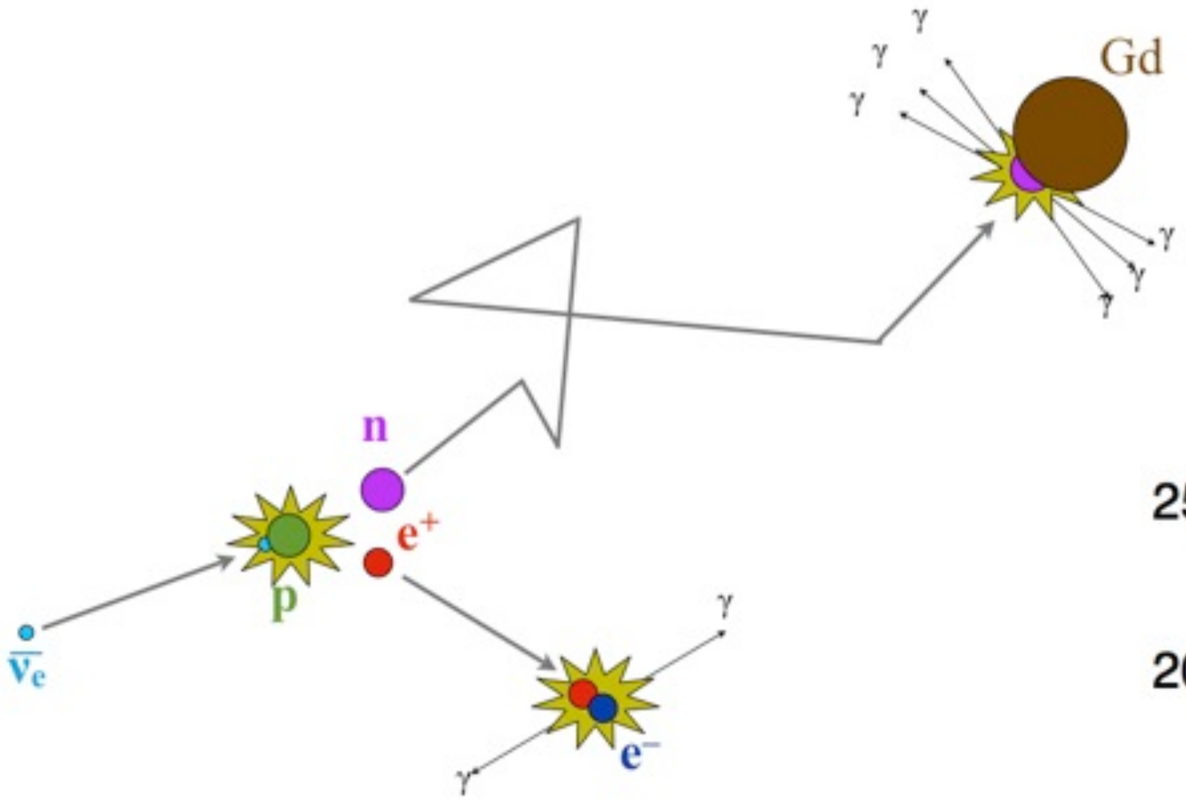


$$\frac{N_{neutrinos,far}}{N_{neutrinos,near}} = \left(\frac{N_{protons,far}}{N_{protons,near}}\right)\left(\frac{L_{near}}{L_{far}}\right)^2\left(\frac{\varepsilon_{far}}{\varepsilon_{near}}\right)\left(\frac{P_{ee}\left(E,L_{far}\right)}{P_{ee}\left(E,L_{near}\right)}\right)$$

Coincidence Method



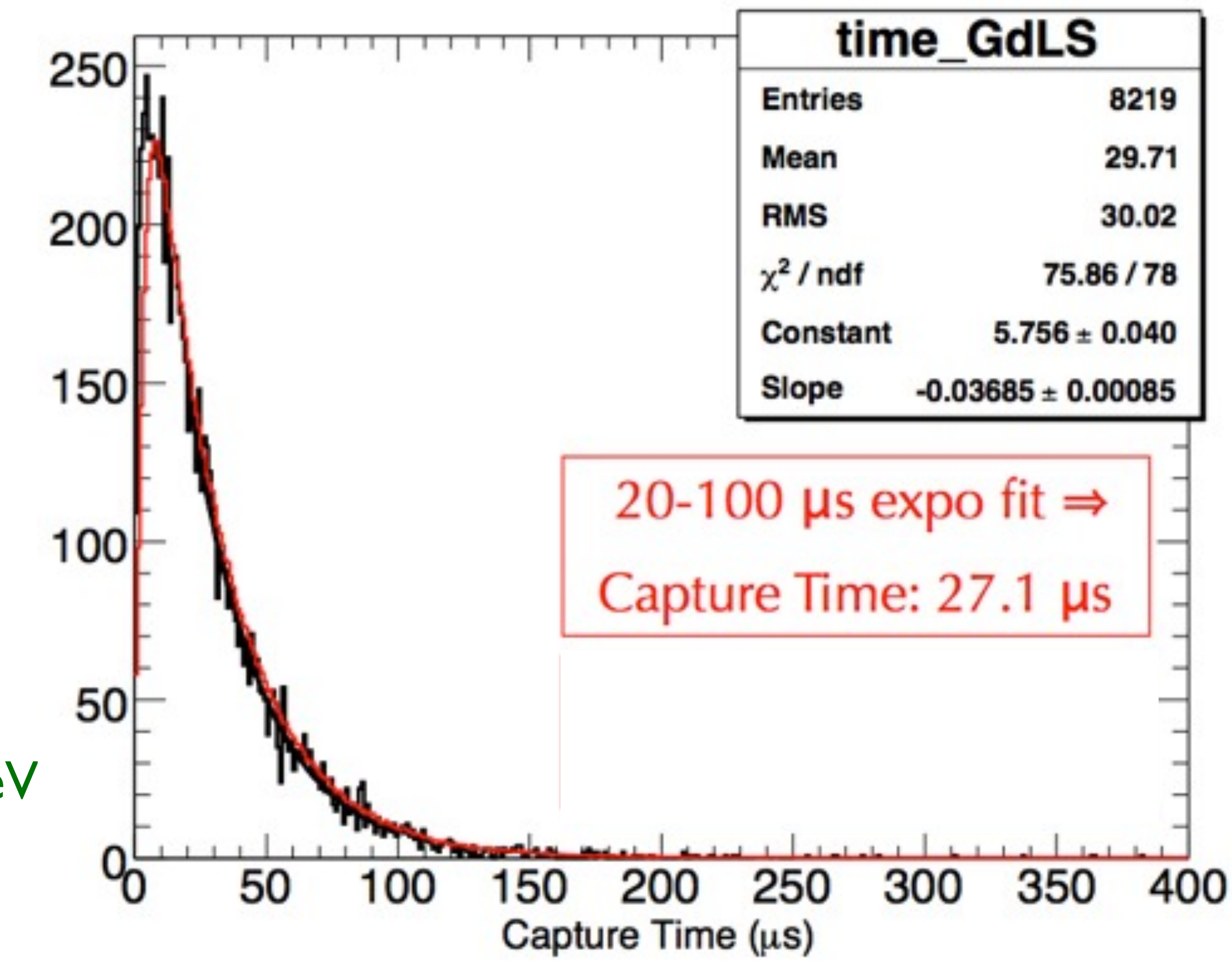
Neutron Capture + Coincidence Signal



$\nu_e + p \rightarrow e^+ + n$ (prompt)

0.3b ↳ $+ p \rightarrow D + \gamma(2.2\ \text{MeV})$ (delayed)

50,000b ↳ $+ Gd \rightarrow Gd^* \rightarrow Gd + \gamma' s(8\ \text{MeV})$ (delayed)



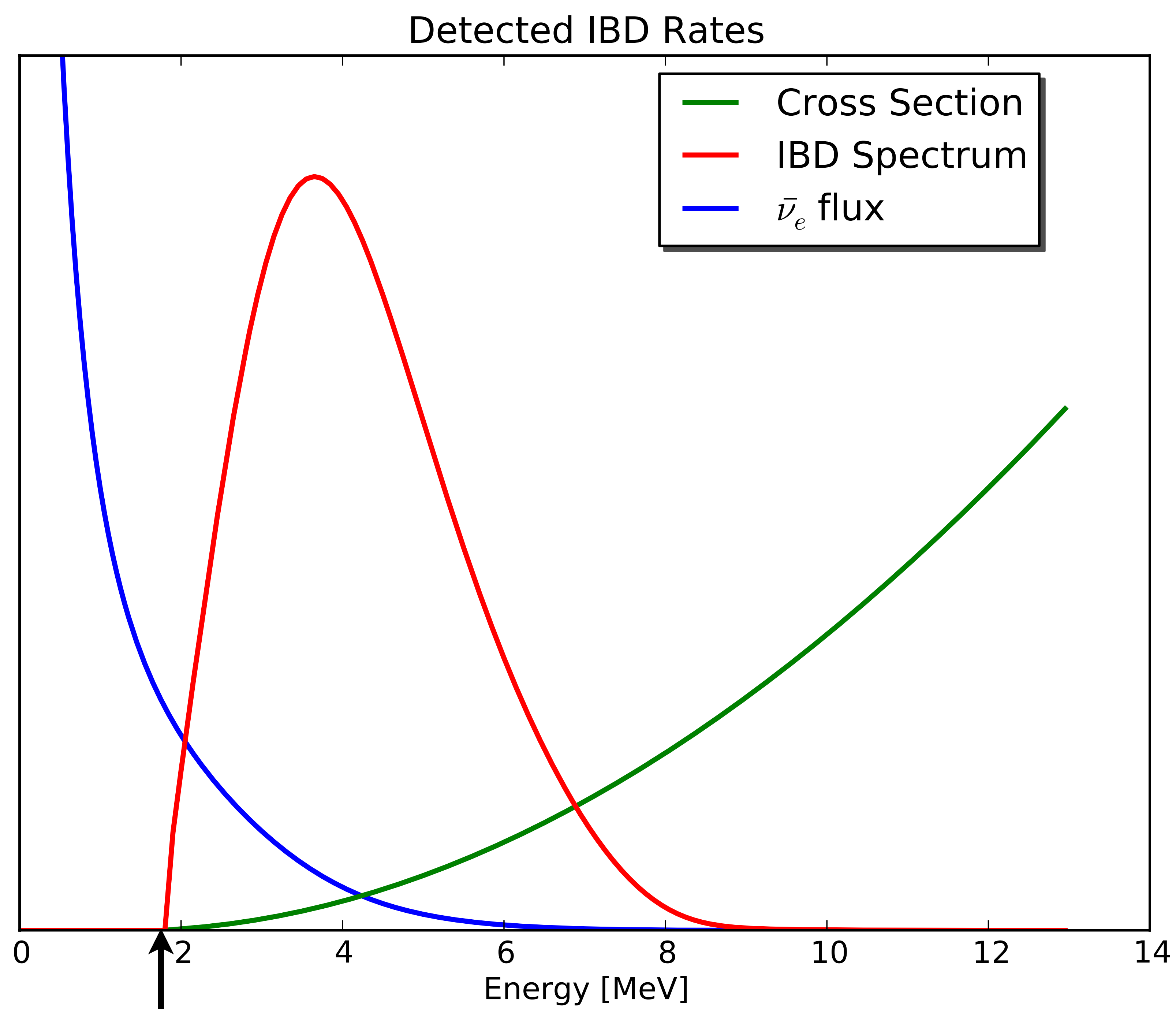
- Energy of ν_e is given by:

$$E_\nu \approx T_{e+} + T_n + (m_n - m_p) + m_{e+} \approx T_{e+} + 1.8\ \text{MeV}$$

10-40 keV

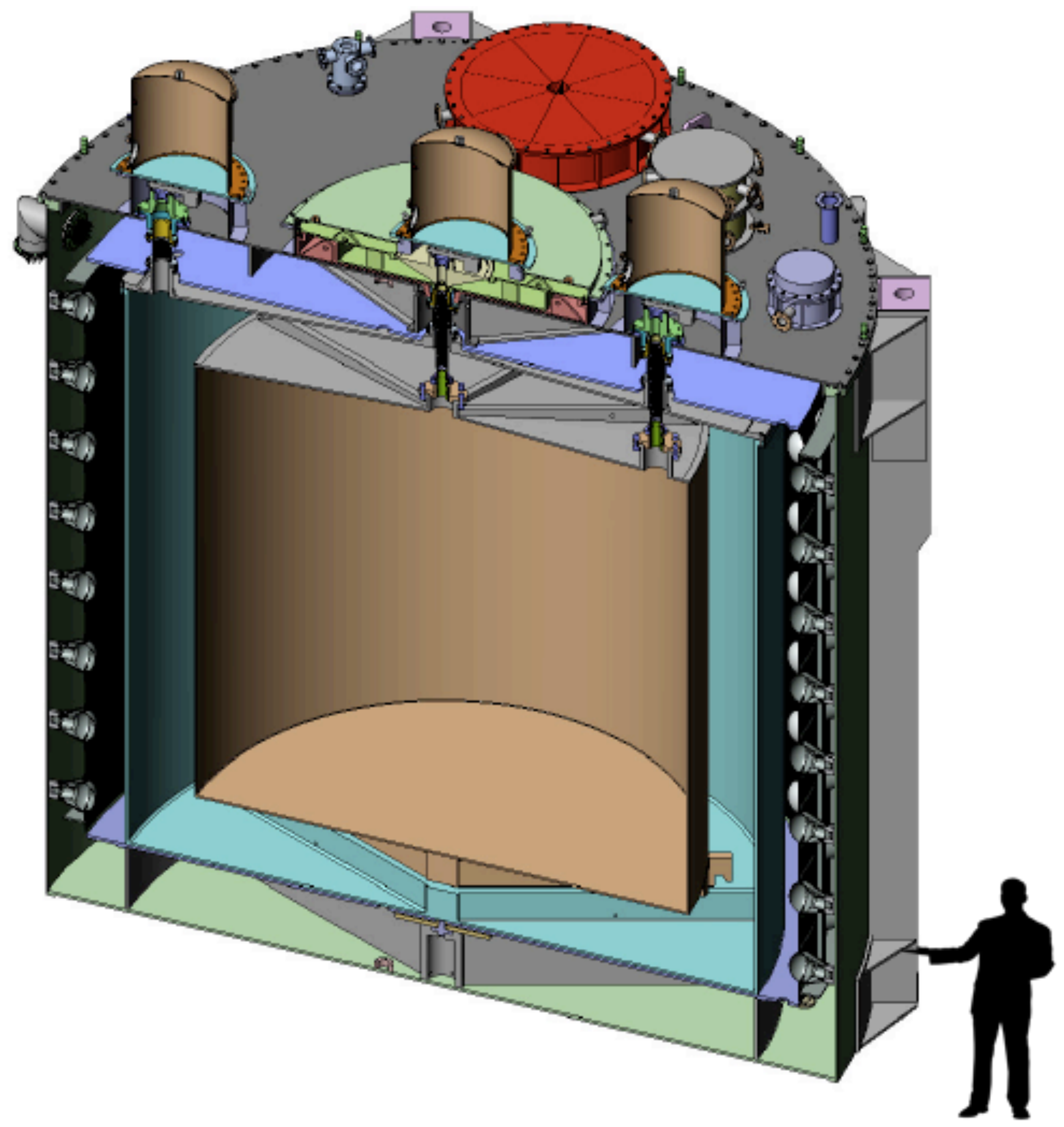
Measured IBD Spectrum

The Measured Spectrum is the convolution of the Incoming Flux and IBD Cross Section.

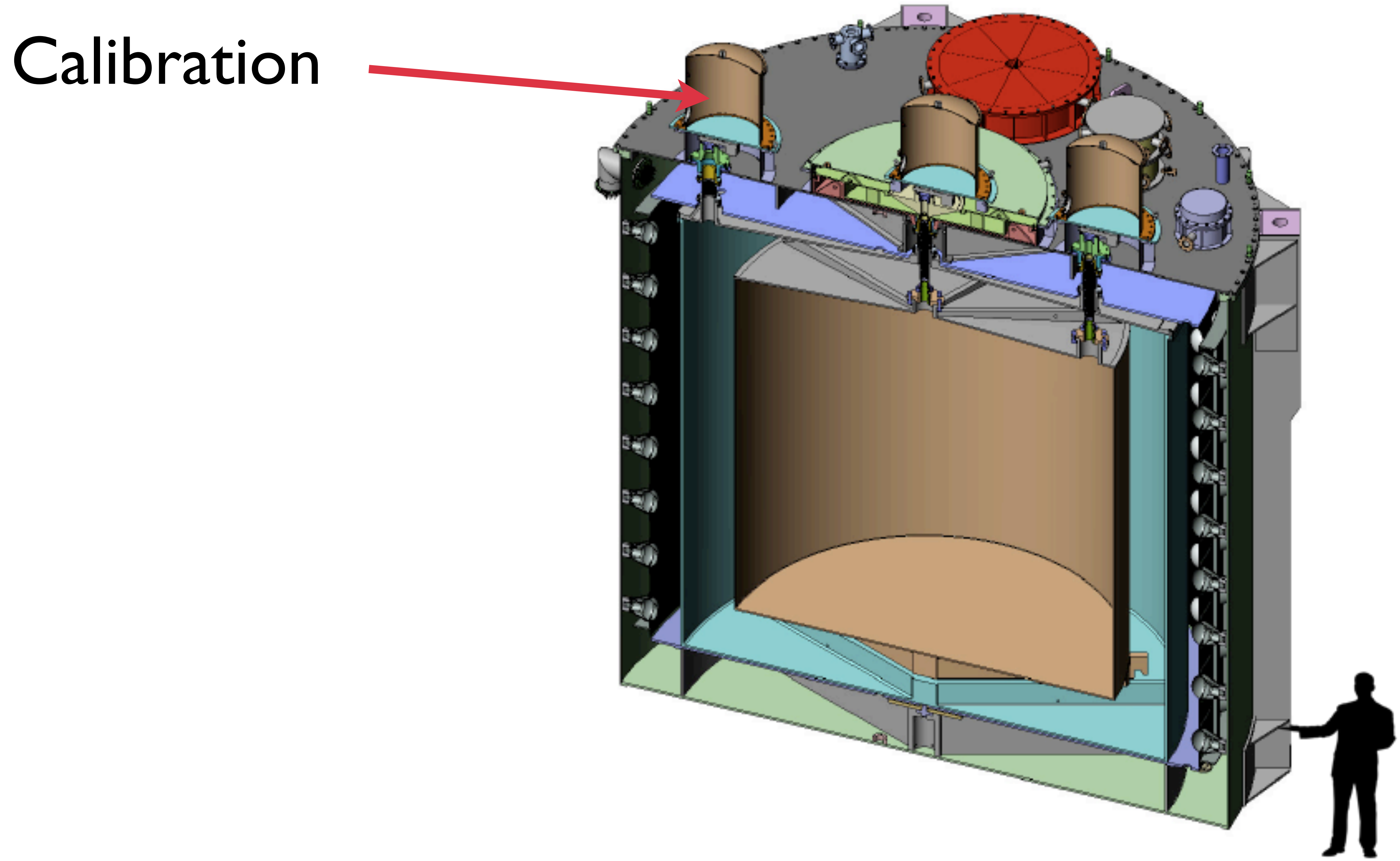


1.8 MeV Threshold

3 Zone Detector



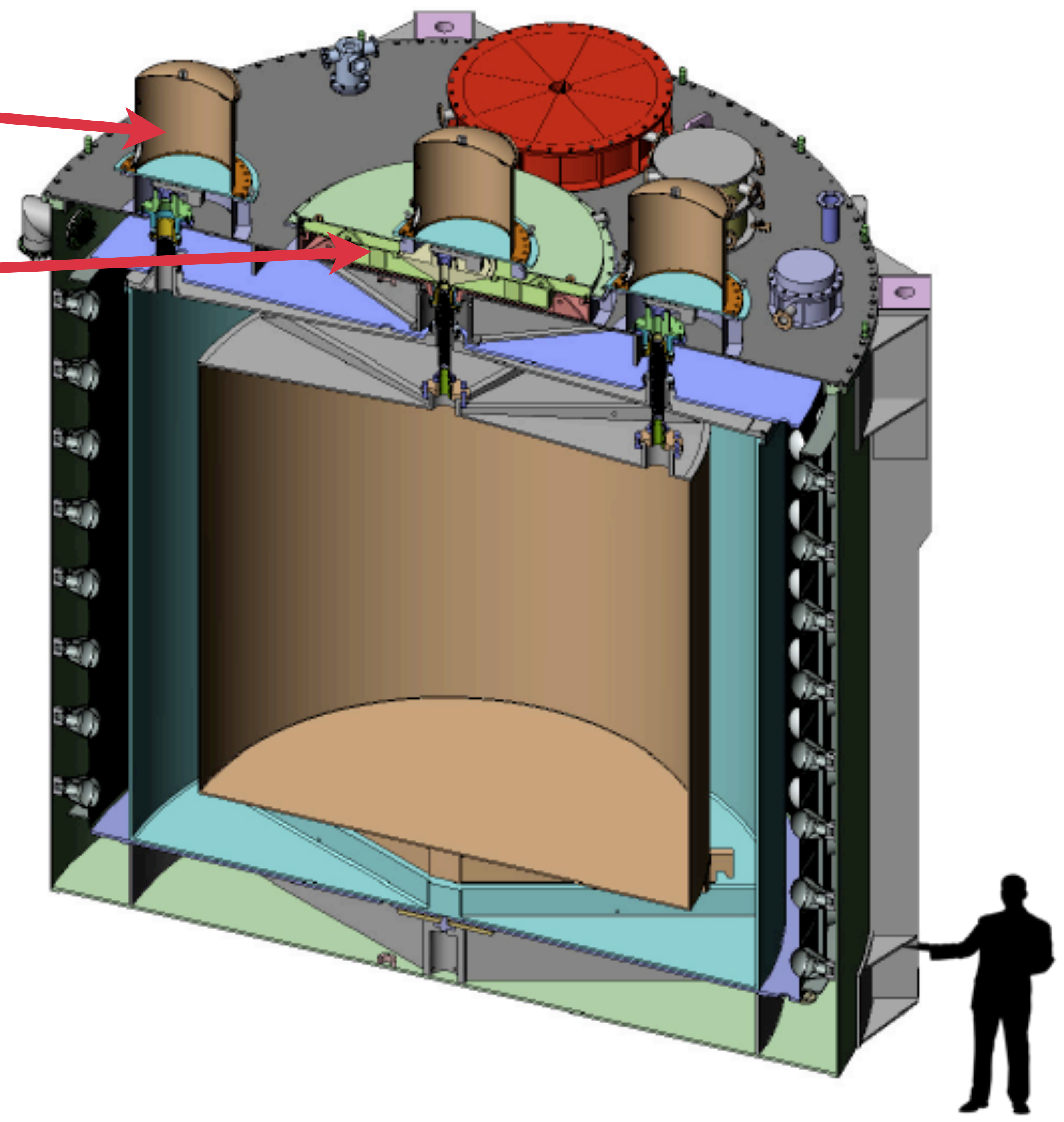
3 Zone Detector



3 Zone Detector

Calibration

Overflow
(Target Mass Monitoring)

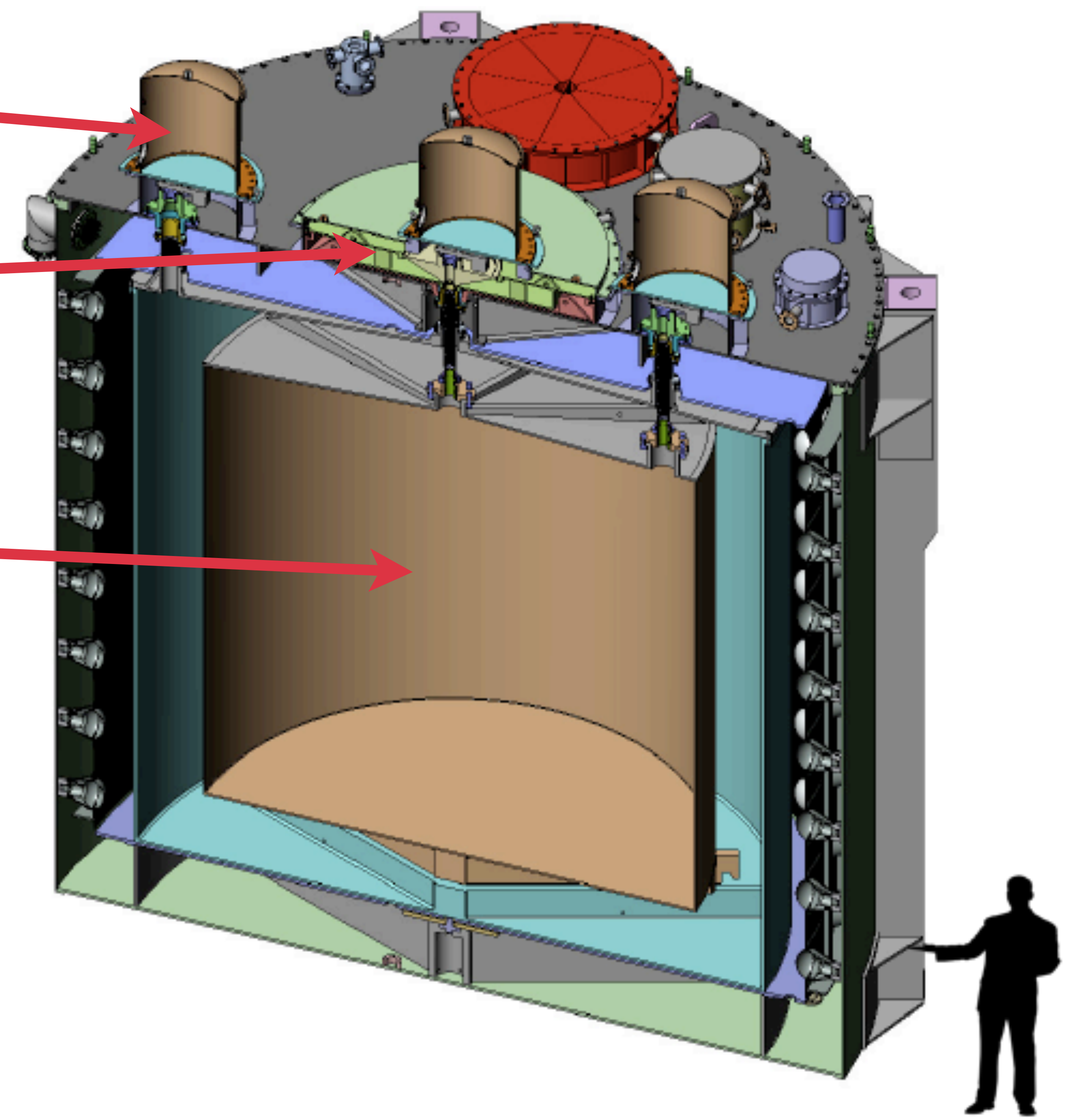


3 Zone Detector

Calibration

Overflow
(Target Mass Monitoring)

Target Region (GDLS)



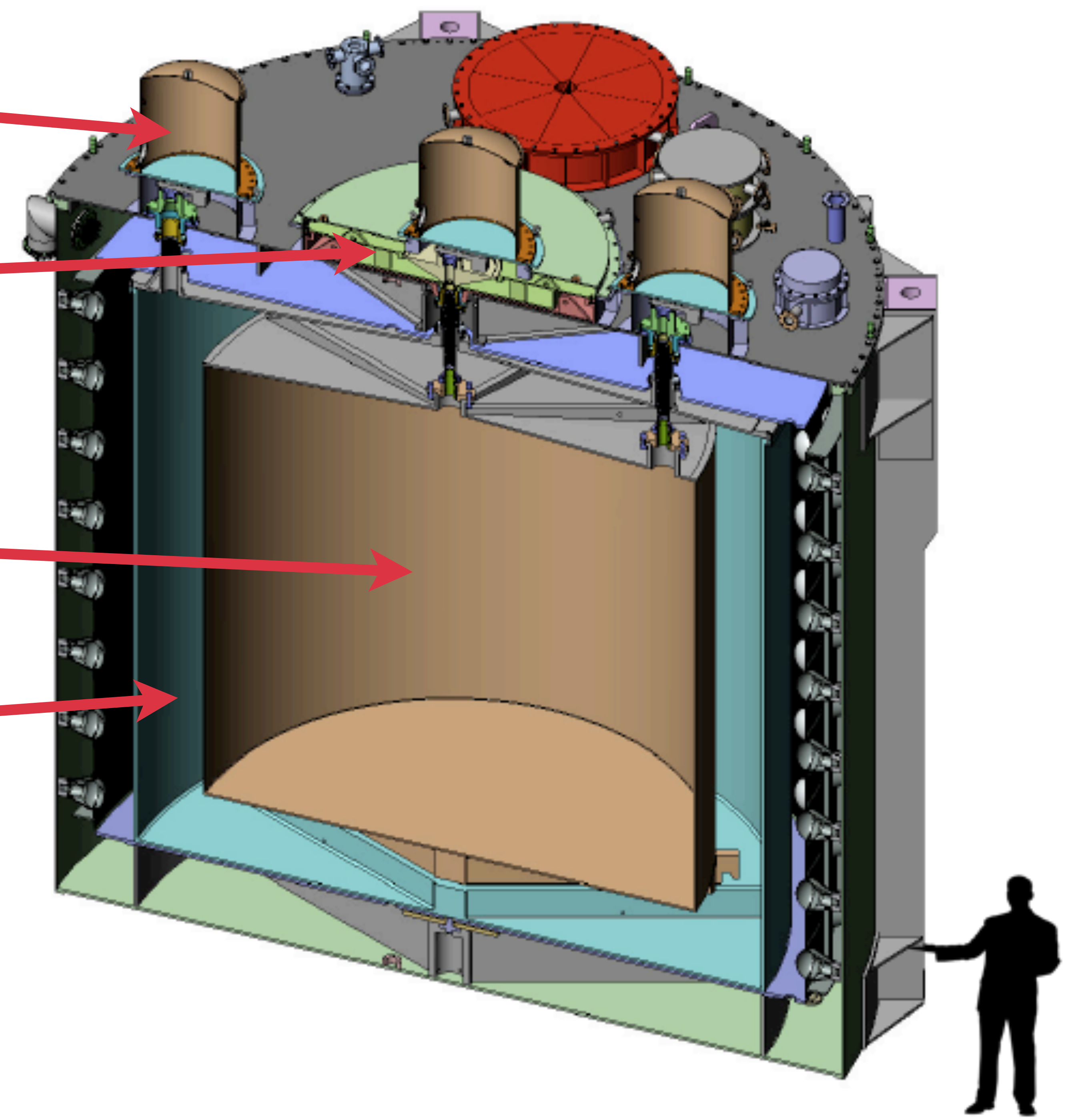
3 Zone Detector

Calibration

Overflow
(Target Mass Monitoring)

Target Region (GDLS)

Gamma Catcher (LS)



3 Zone Detector

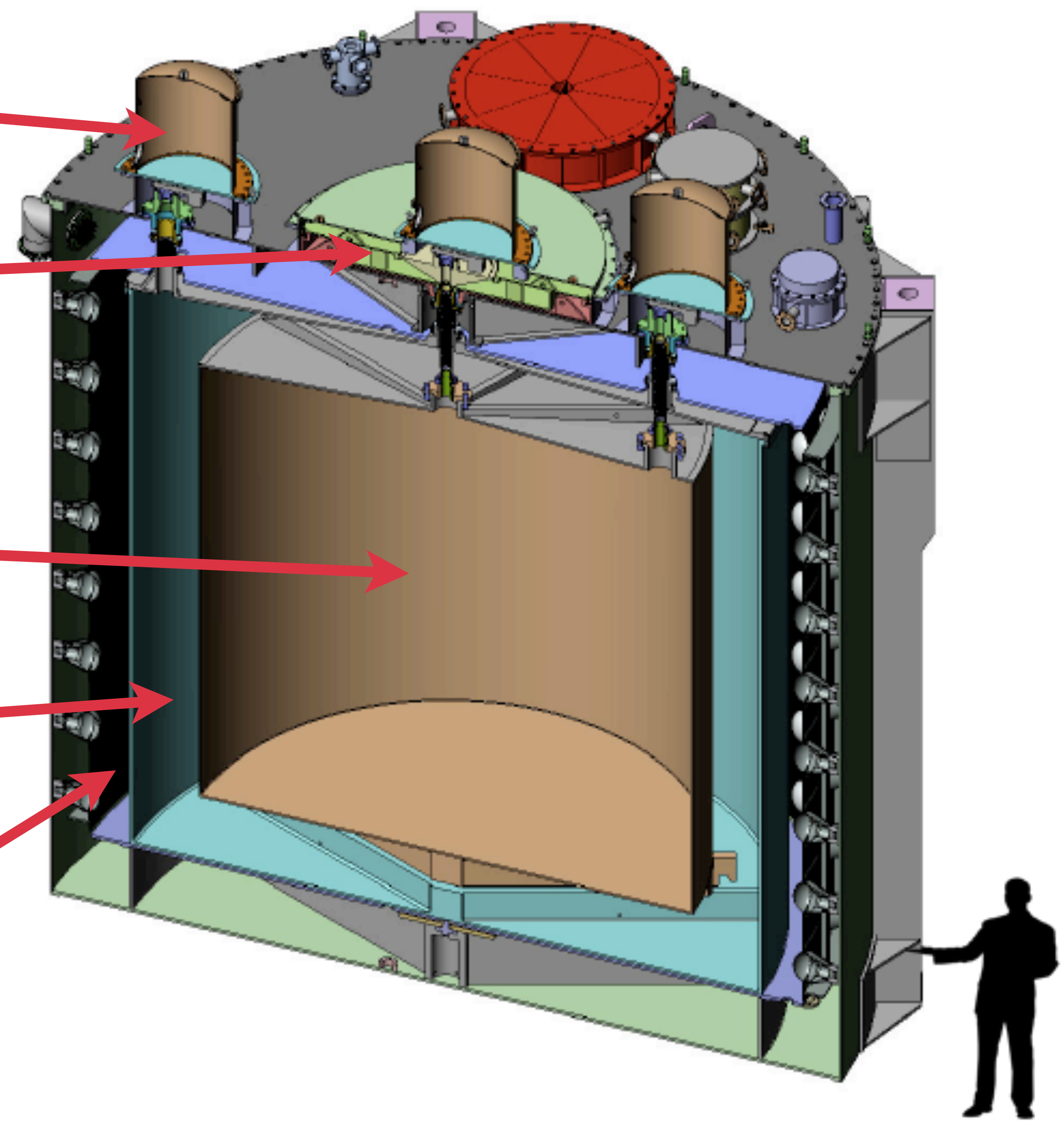
Calibration

Overflow
(Target Mass Monitoring)

Target Region (GDLS)

Gamma Catcher (LS)

Oil Buffer (MO)



3 Zone Detector

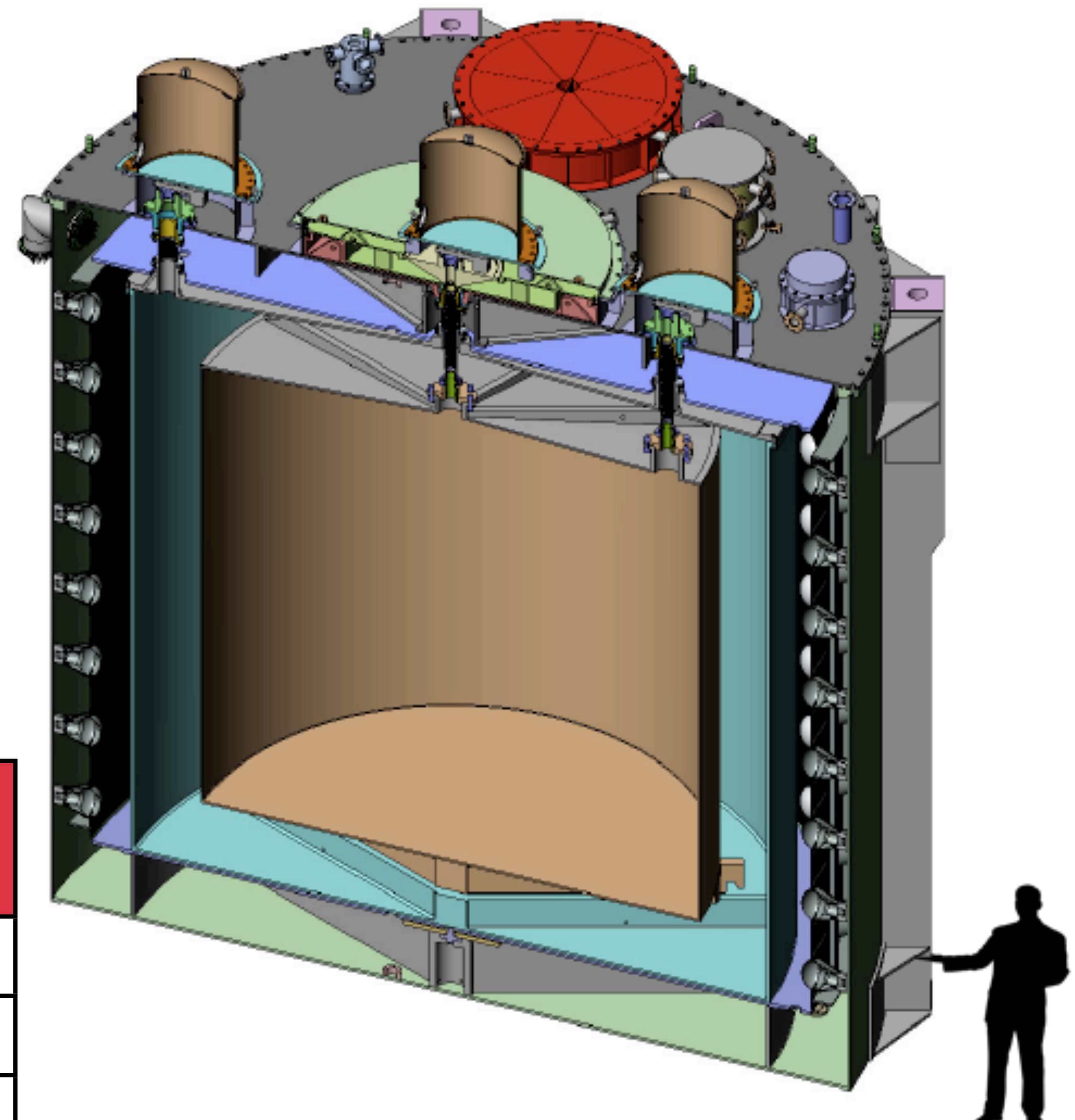
Target Mass:

20t per Detector

Detector Mass: ~110t

192 (+8 calibration) PMTS

Energy Resolution 12%/√E

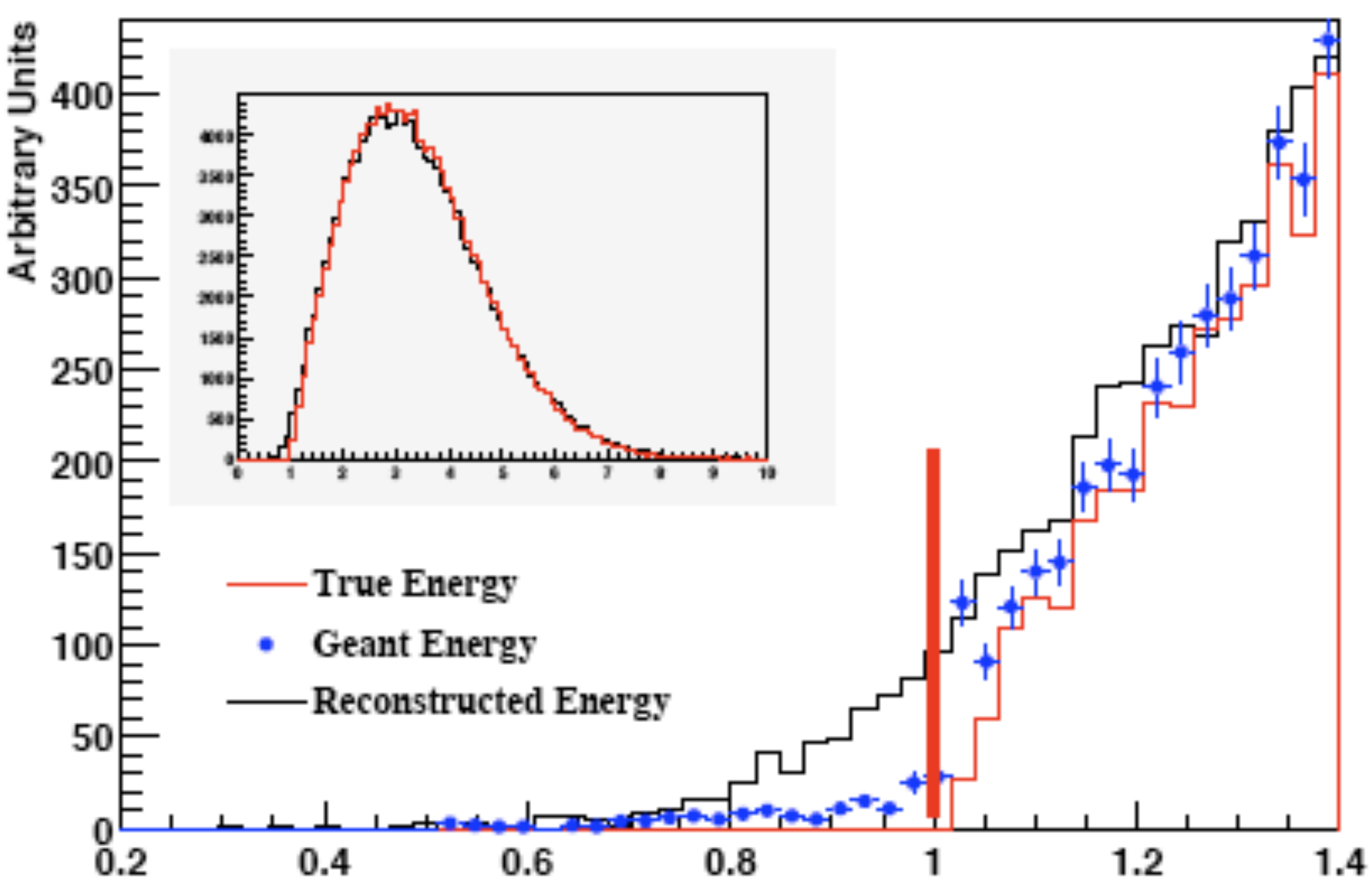


Site	Rate (per AD per Day)	AD's
DBNear	840	2 (40 ton)
LANear	760	2 (40 ton)
Far	90	4 (80 ton)

Detection Efficiency

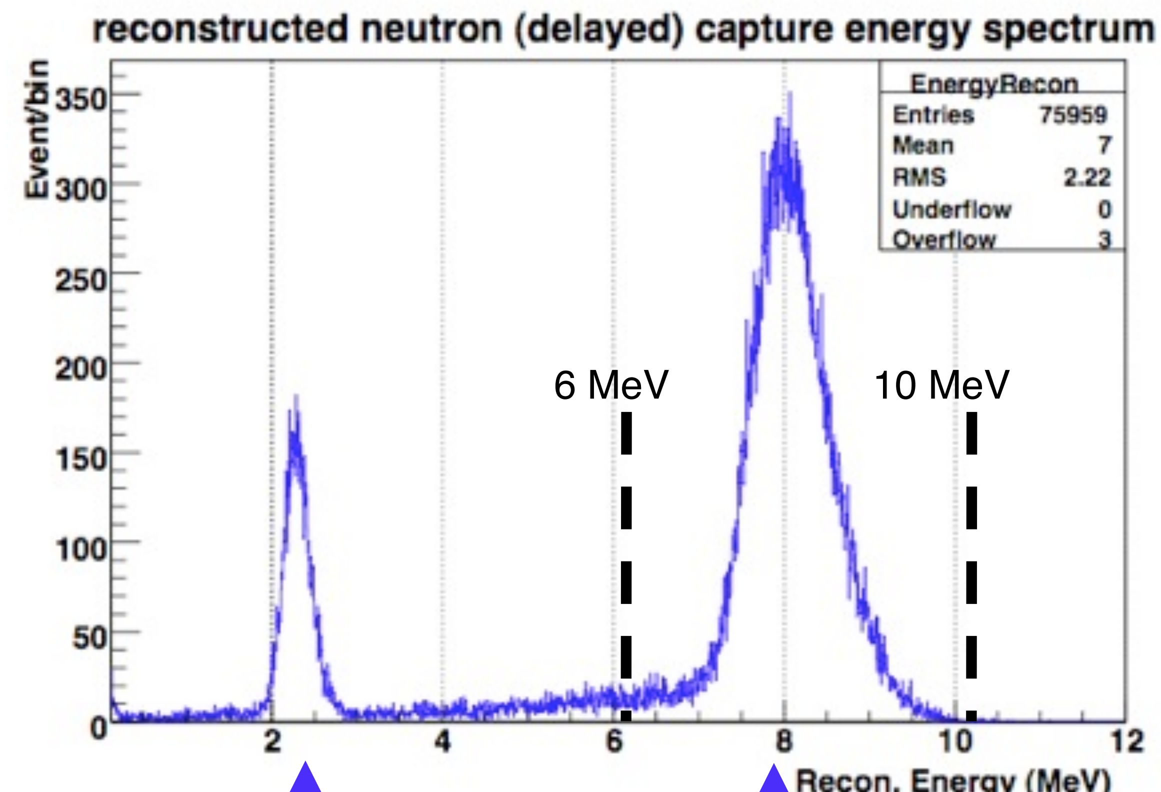
Prompt e$^+$ Signal

1 MeV cut for prompt positrons: >99%, uncertainty negligible



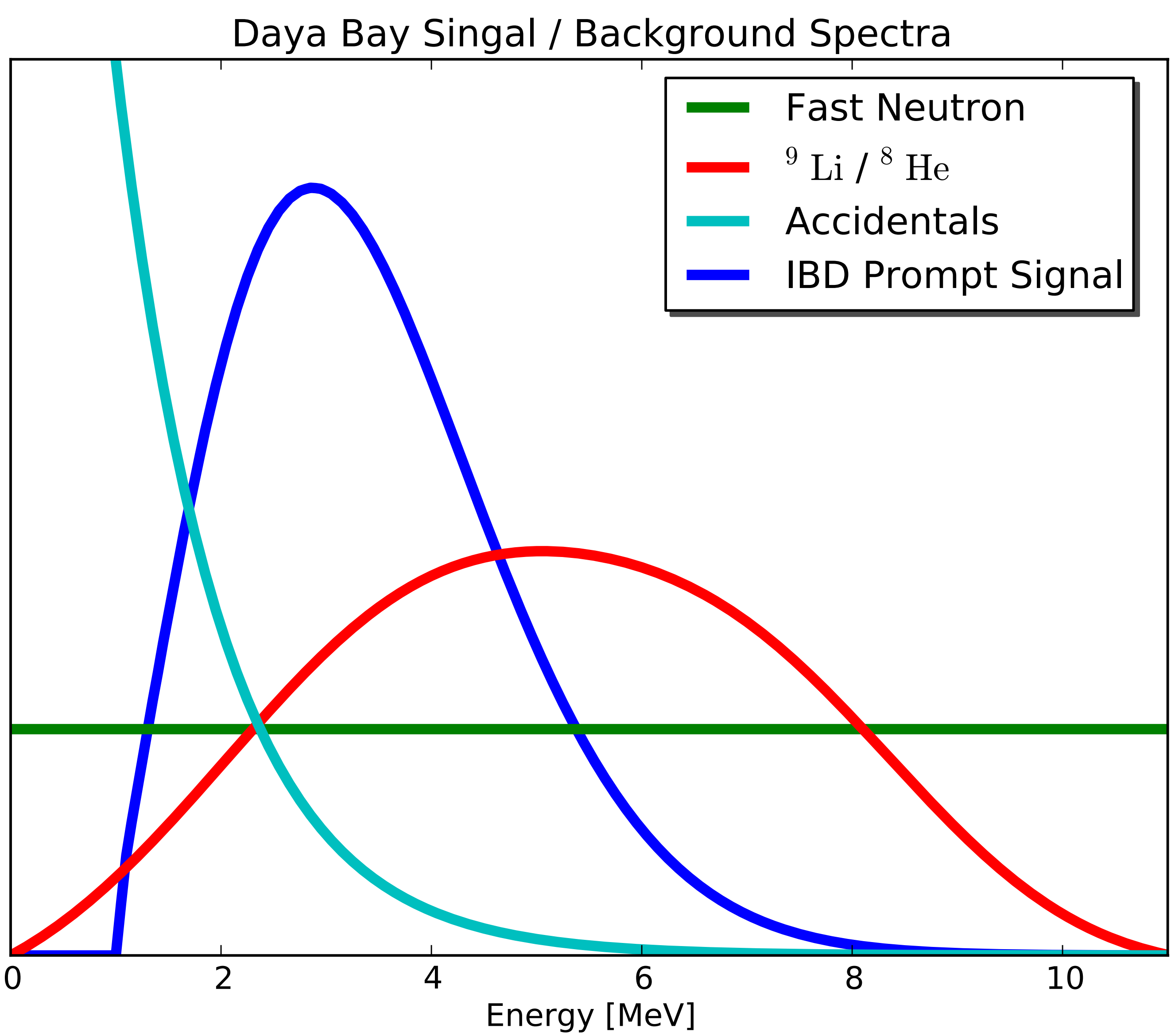
Delayed n Signal

6 MeV cut for delayed neutrons: 91.5%, uncertainty 0.22% assuming 1% energy uncertainty



H Capture Gd Capture

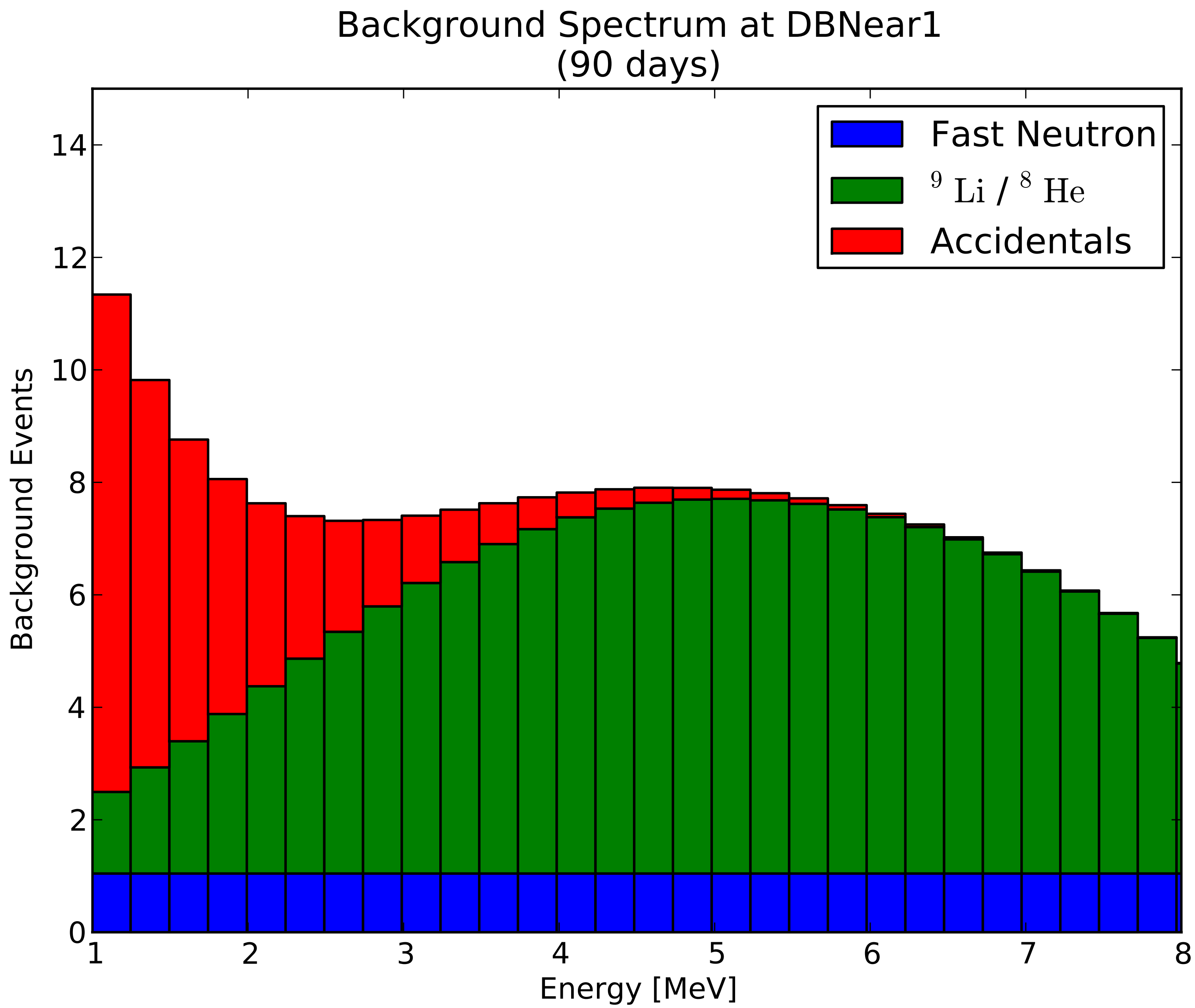
Backgrounds



(Normalized to area)

- Fast Neutron
  - Proton recoil + neutron capture.
- $^9Li/^8He$
  - 49.5% / 16% branching fraction for beta decay followed by neutron emission.
- Accidental
  - Natural Radiation + neutron Capture.

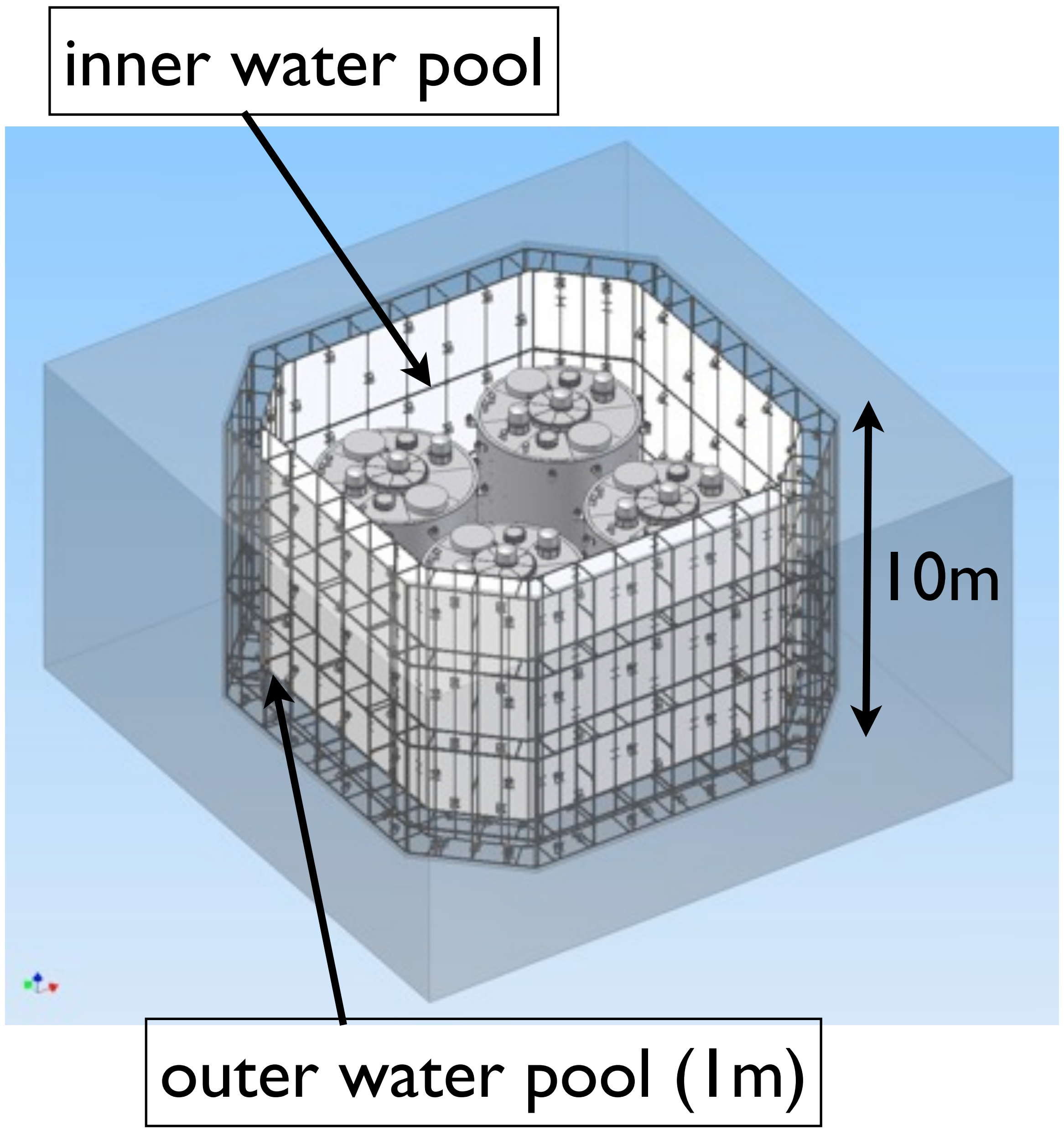
Near Site Background Rate



With background to signal ratio of 0.3%

Muon System

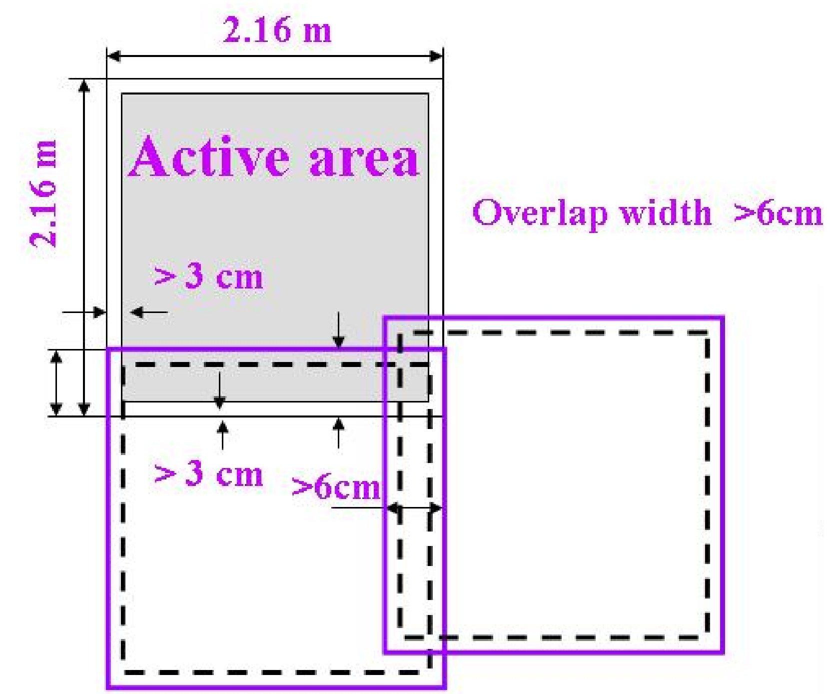
The water pools are the first of two systems to veto muons and help suppress backgrounds



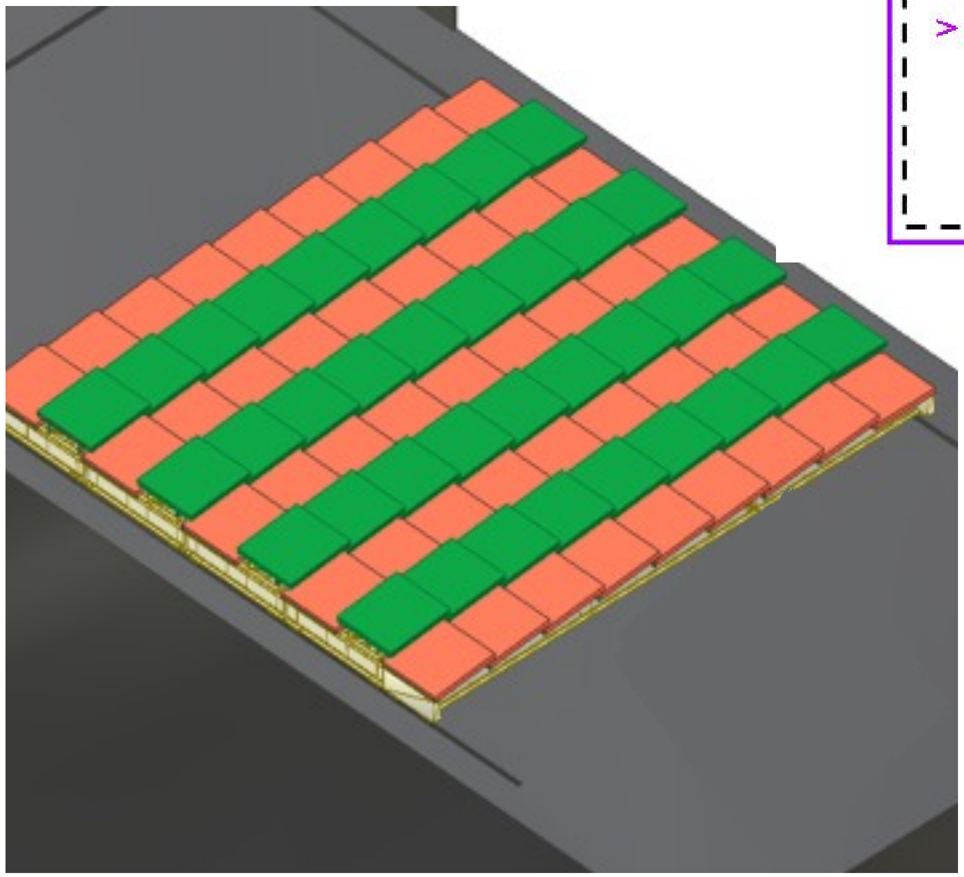
- Water Cherenkov detector
  - ~1000 total pmt's
  - 1PMT/8m^2 (inner)
  - 1PMT/6-7m^2 (outer)
- Divided into 2 optically separated regions
  - 2 region design provides independent triggers
  - When combined give a 98% muon efficiency

Resistive Plate Chambers

The second system consists of 4 layers of RPC’s that cover the entire water pool



- 1512 RPC’s
  - 189 modules (8 RPC’s per module)
  - Modules overlap to eliminate dead space
- 6048 readout strips
  - 4 readout strips per RPC
  - Each strip is 2m x 25cm
  - Zigzag design (6cm pitch)
- 4 layer structure
  - Trigger on 3 of 4 layers hit
  - Alternate direction
  - 0.5m spatial resolution



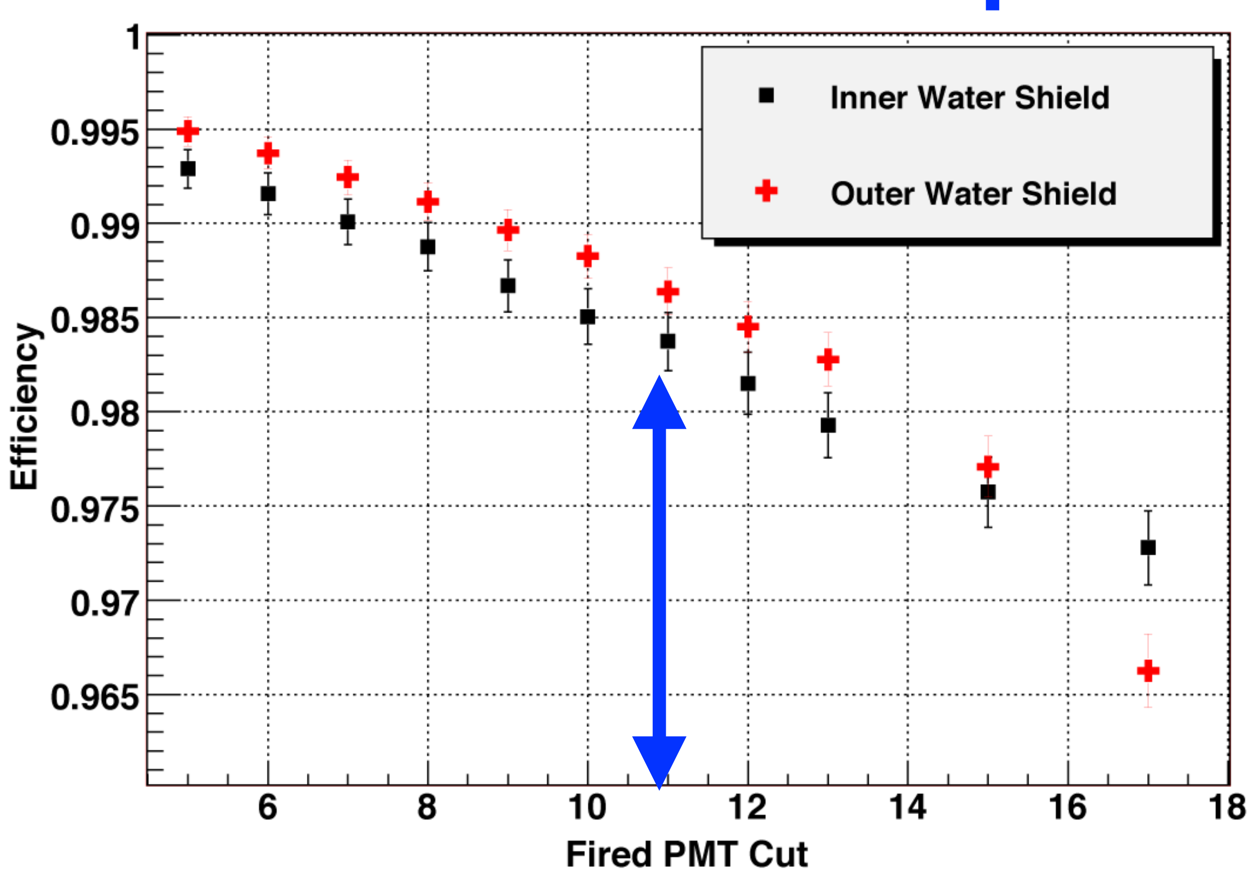
Muon Detection Efficiency

RPC

Trigger Threshold

	Layer	≥1	≥2	≥3	≥4
Total Planes	1	95%			
	2	99.75%	90.25%		
	3	99.987%	99.275%	85.74%	
	4	99.999%	99.952%	98.598%	81.45%

Water Pool

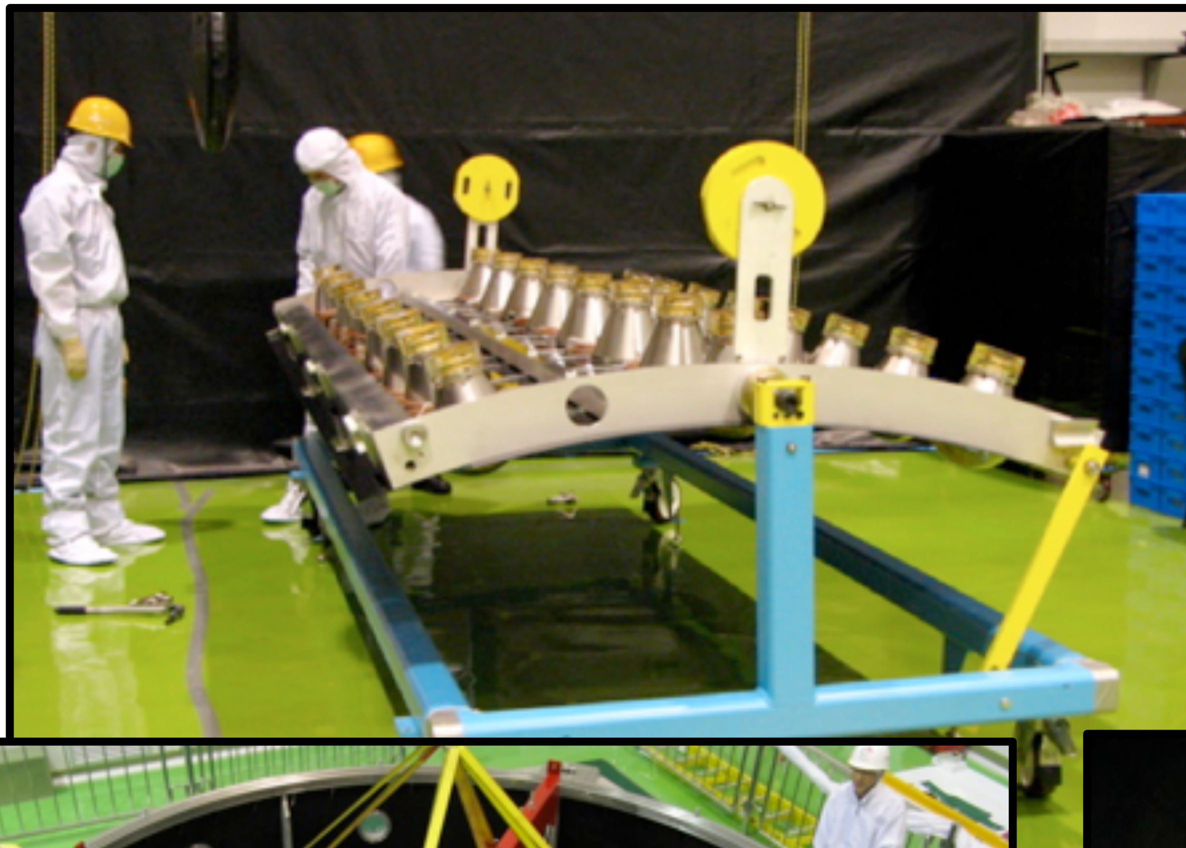


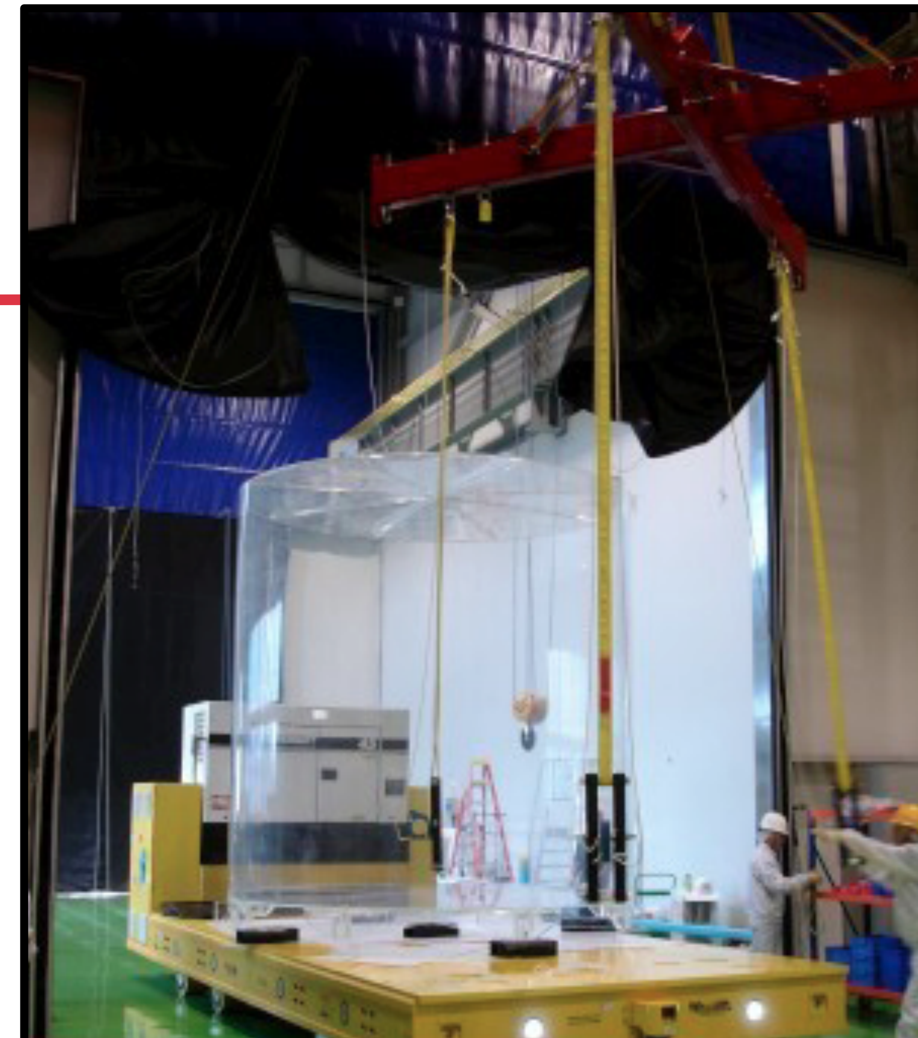
Using an 11 pmt multiplicity trigger in the water pool and requiring 3 of 4 RPC layers register a hit gives a combined muon detection efficiency of over 99%

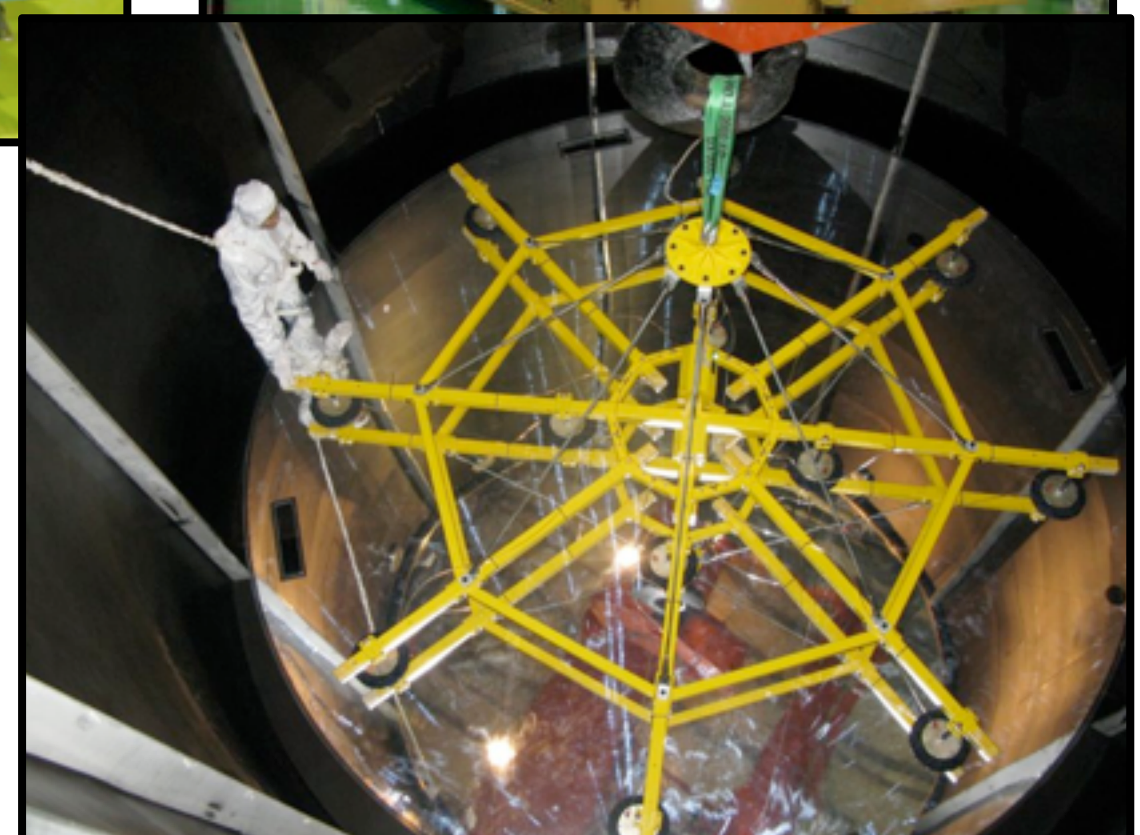
Water Pool + RPC

	Pool Only	Pool+RPC
Near	98.85±0.12%	99.43±0.09%
Far	98.81±0.12%	99.44±0.08%

DayaBay -- Tour

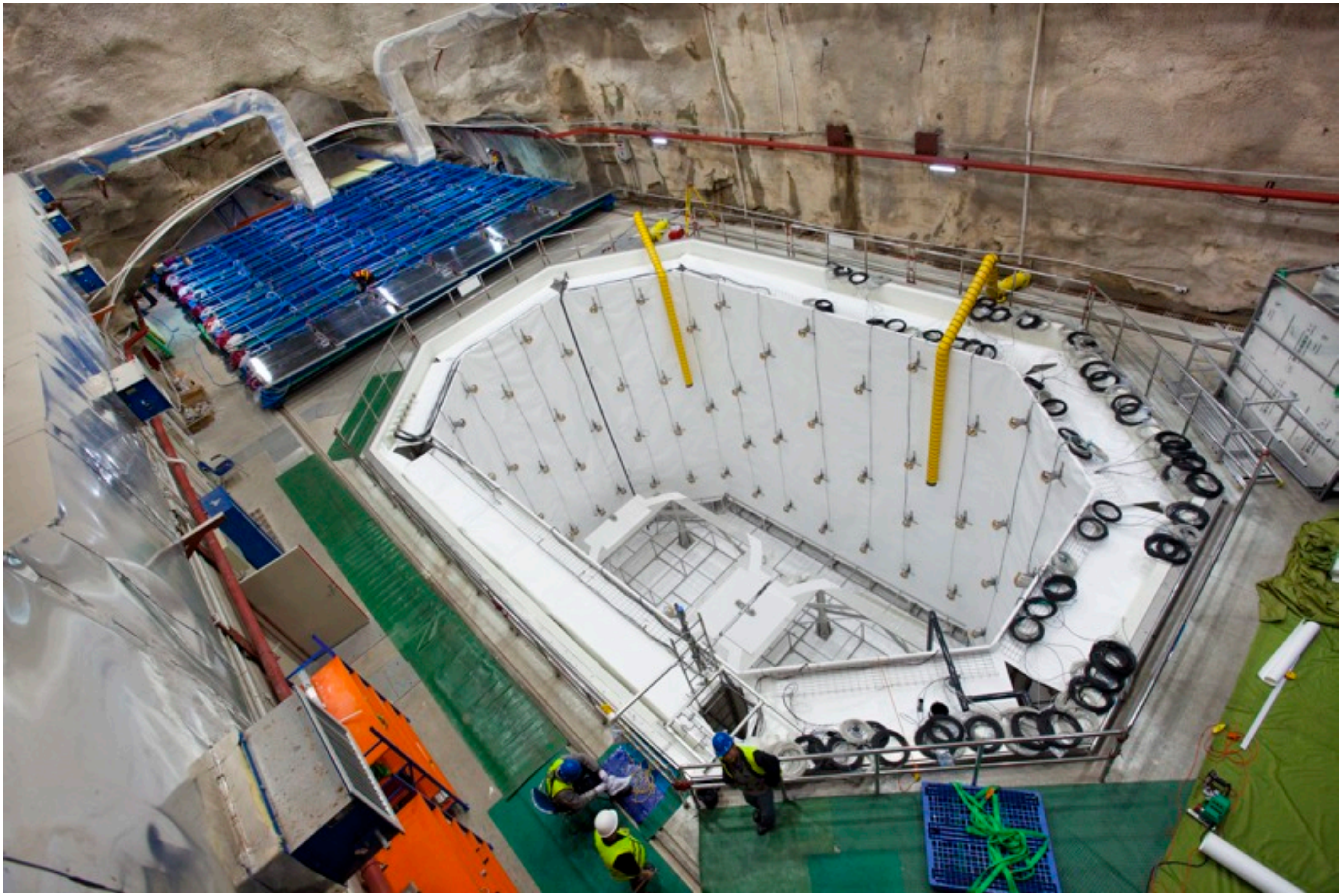




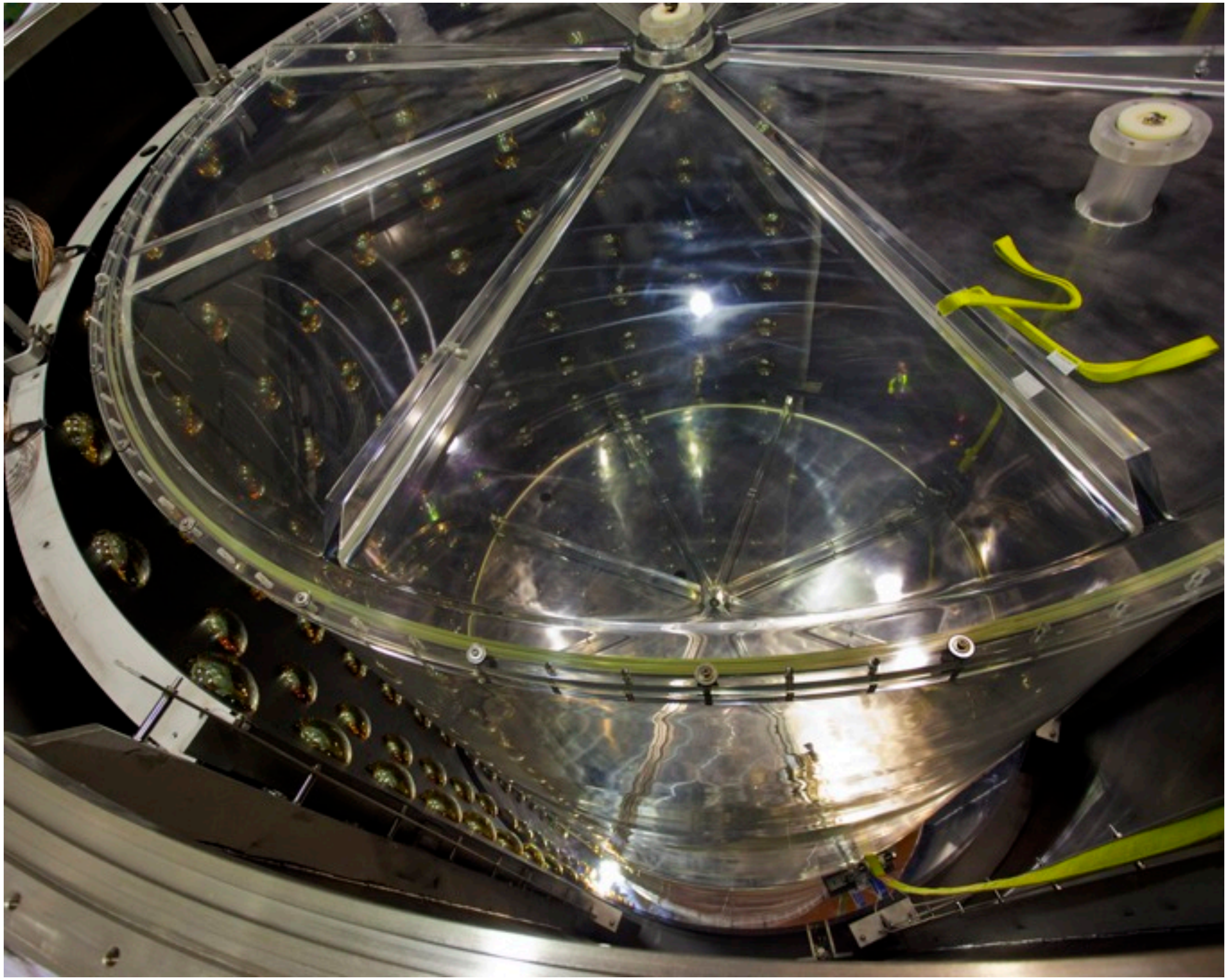


DayaBay -- Tour

DayaBay -- Tour



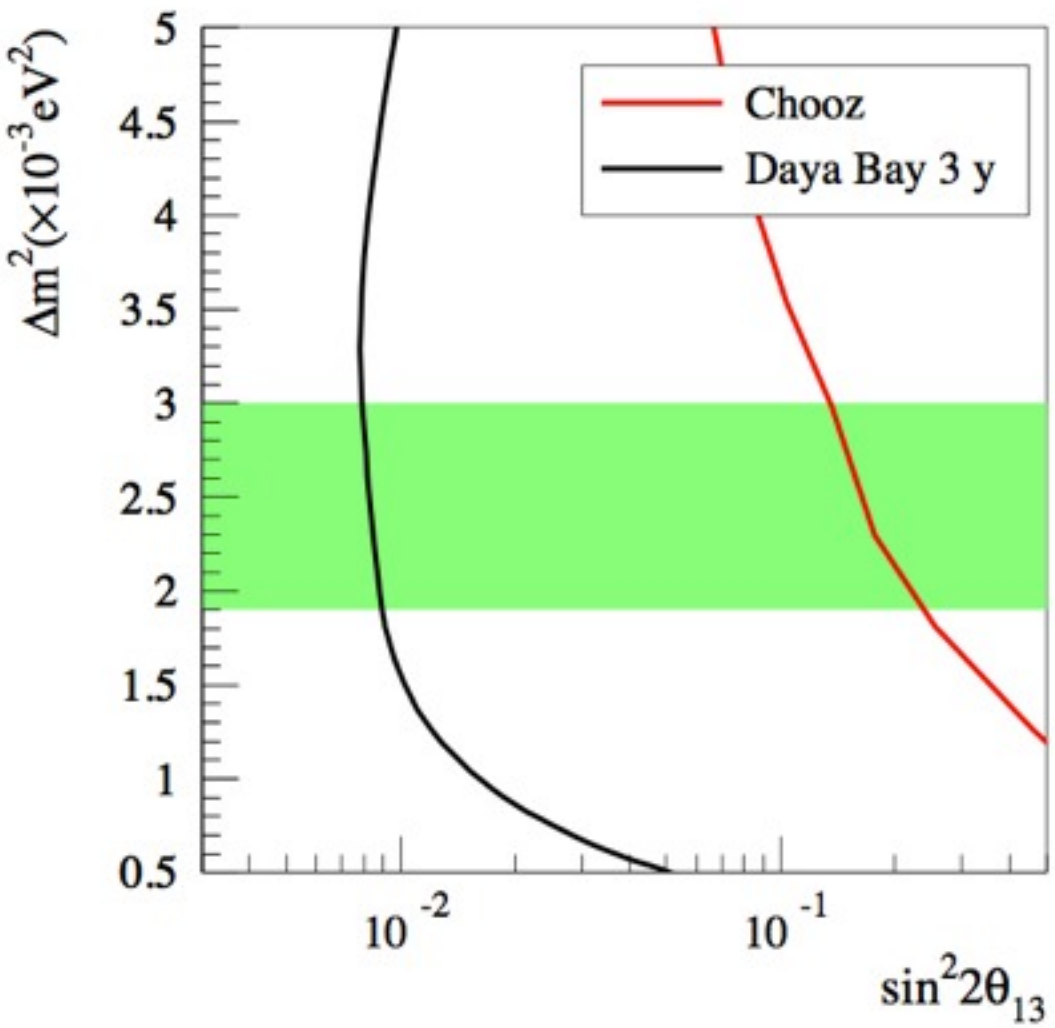
DayaBay -- Tour

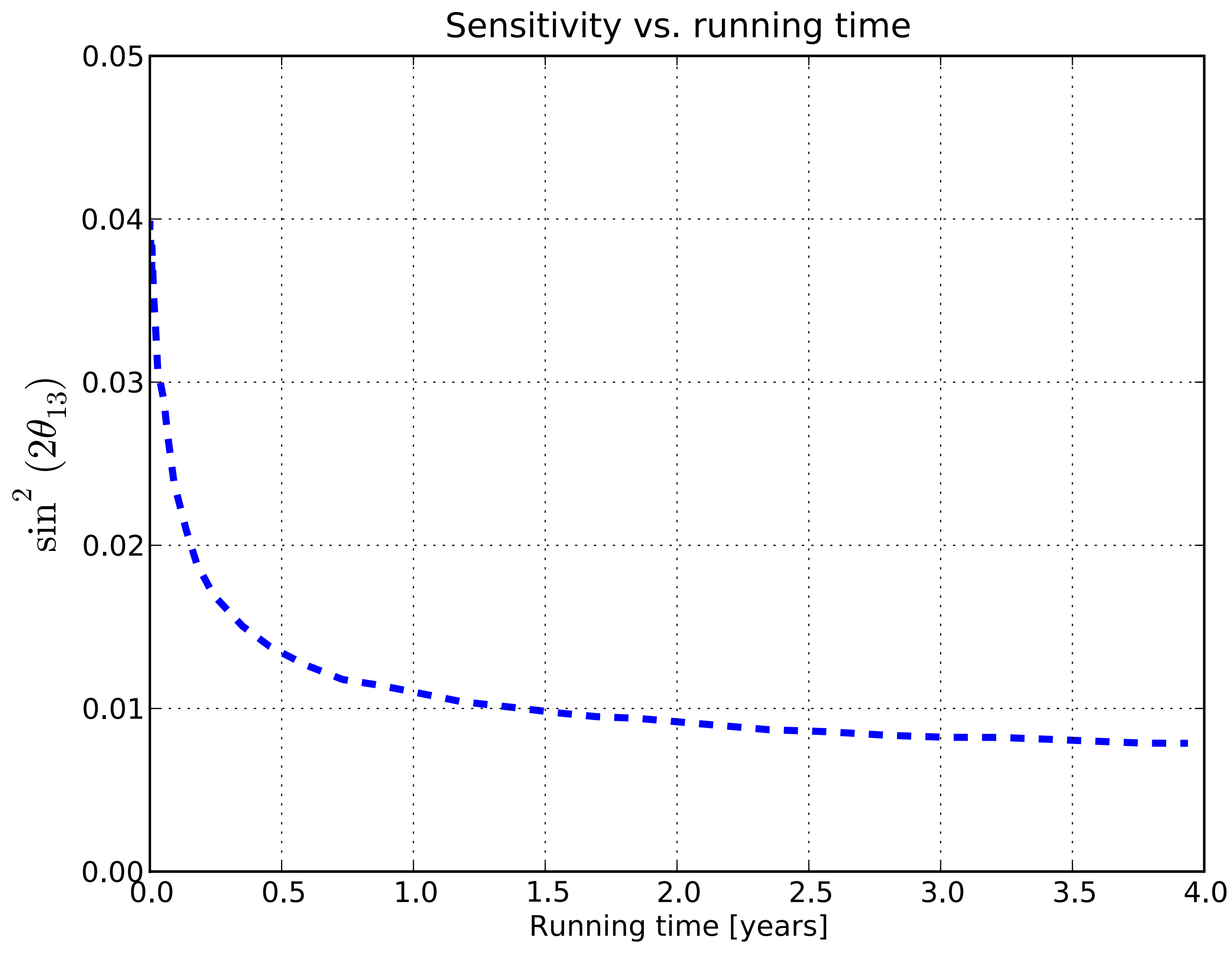


Sensitivity / Schedule

Upcoming Milestones

- Summer 2011: Daya Bay near hall physics ready
- Fall 2012: all near/far halls physics ready





Near Site Physics

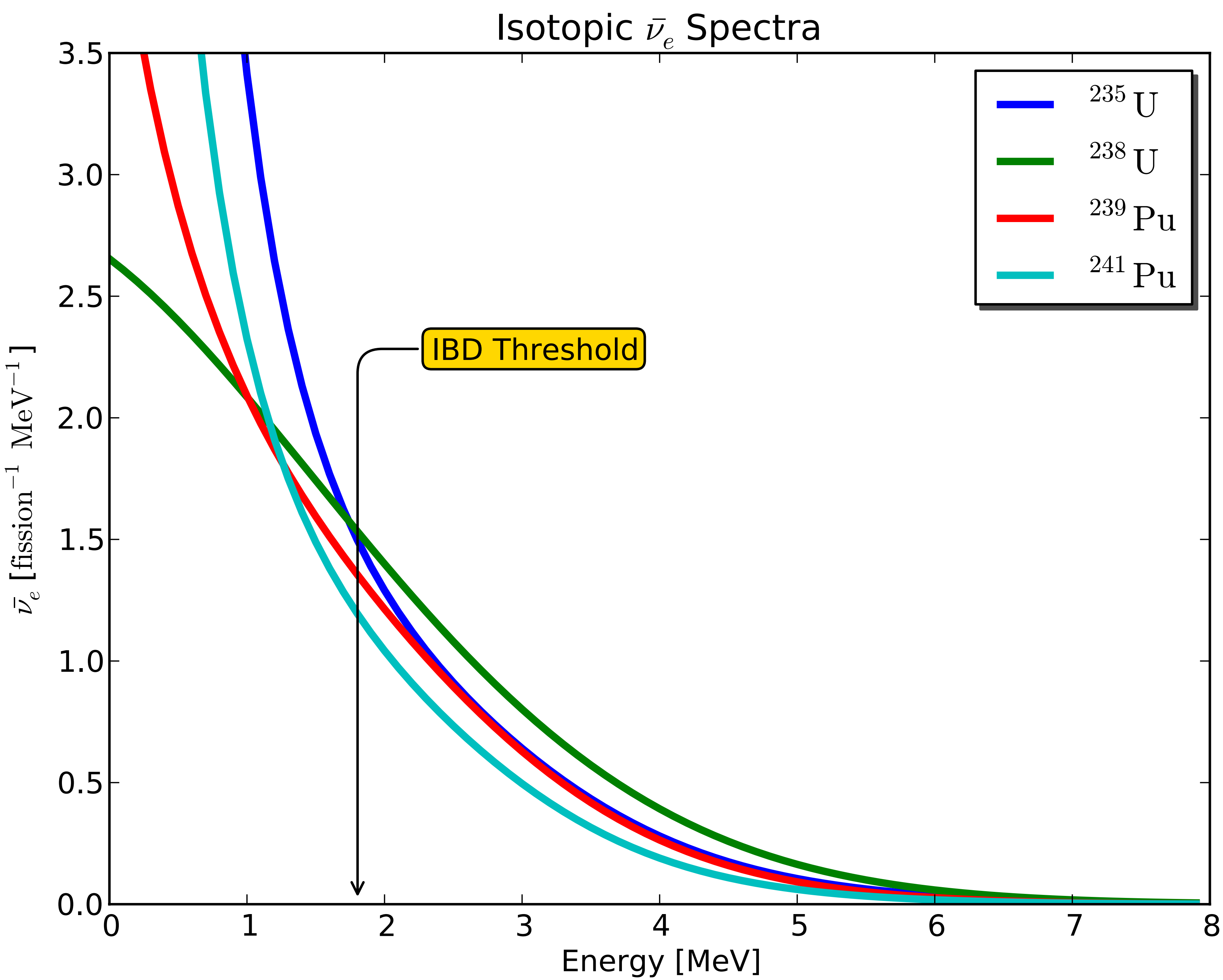
Near Site Physics

- Data is available soon because we will take DBNear site data while commissioning the other two halls.
- High event rate (840 / module / day)
- No Near/Far Cancellation, need a very good understanding of Reactor Flux.
- Non-optimal Baseline.

Potential Topics

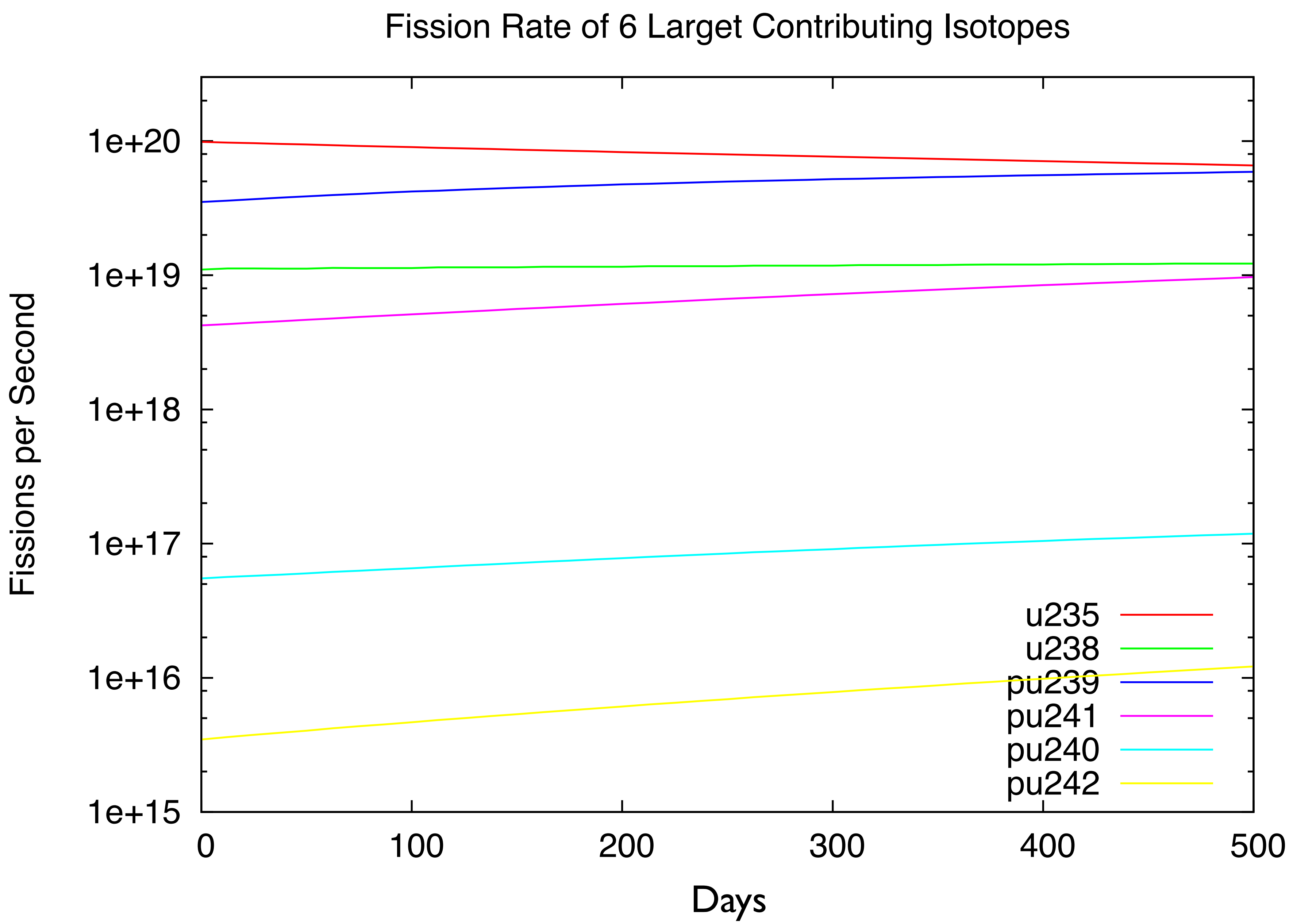
- First "real" chance to test identicalness.
- Observe reactors:
  - Burn-up
  - Shutdowns
  - Power Fluctuations
- Single site Theta13 Measurement.

Flux Predictions

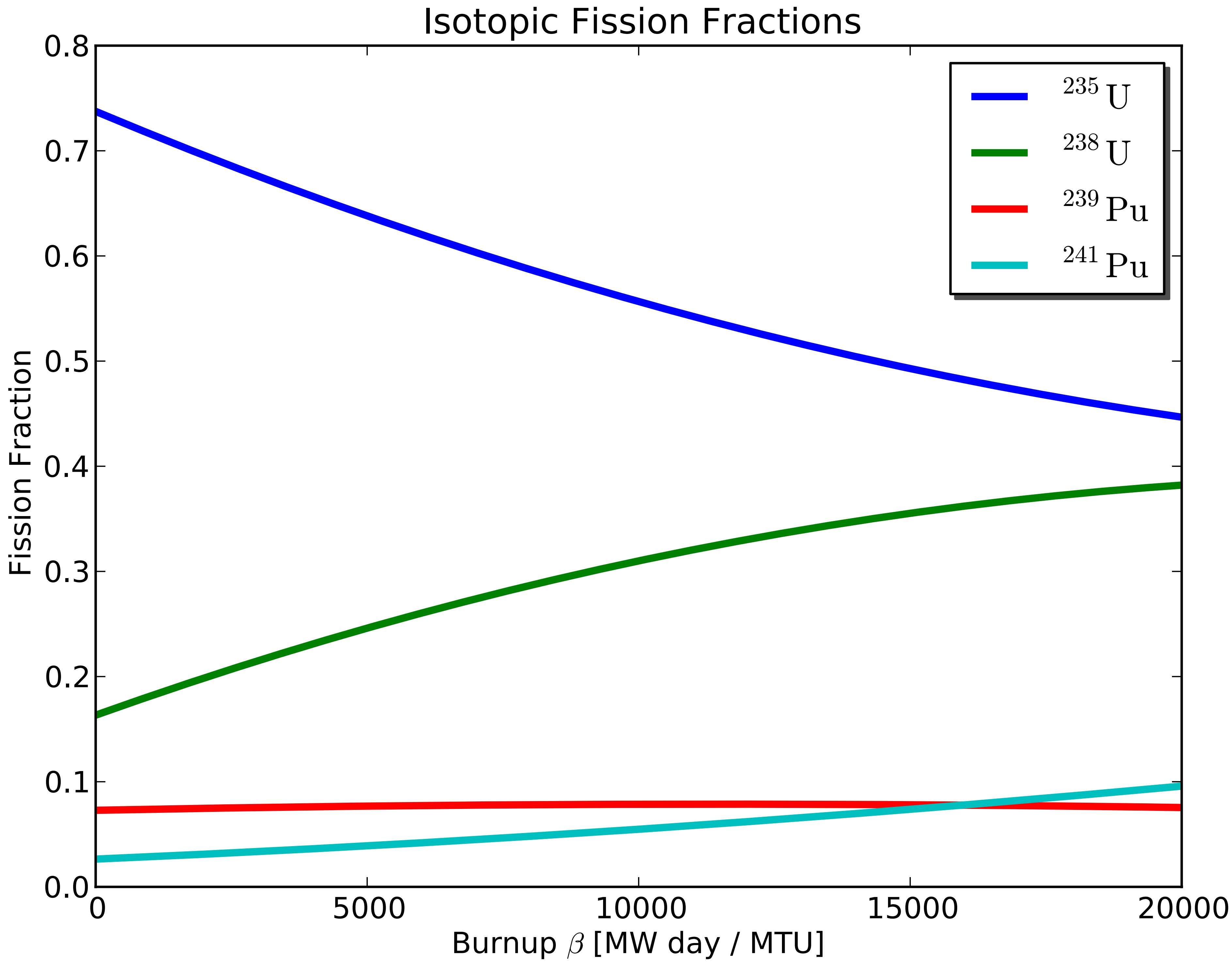


Huber and Schwetz. Precision spectroscopy with reactor antineutrinos. Phys. Rev. D (2004)

Fission Rates

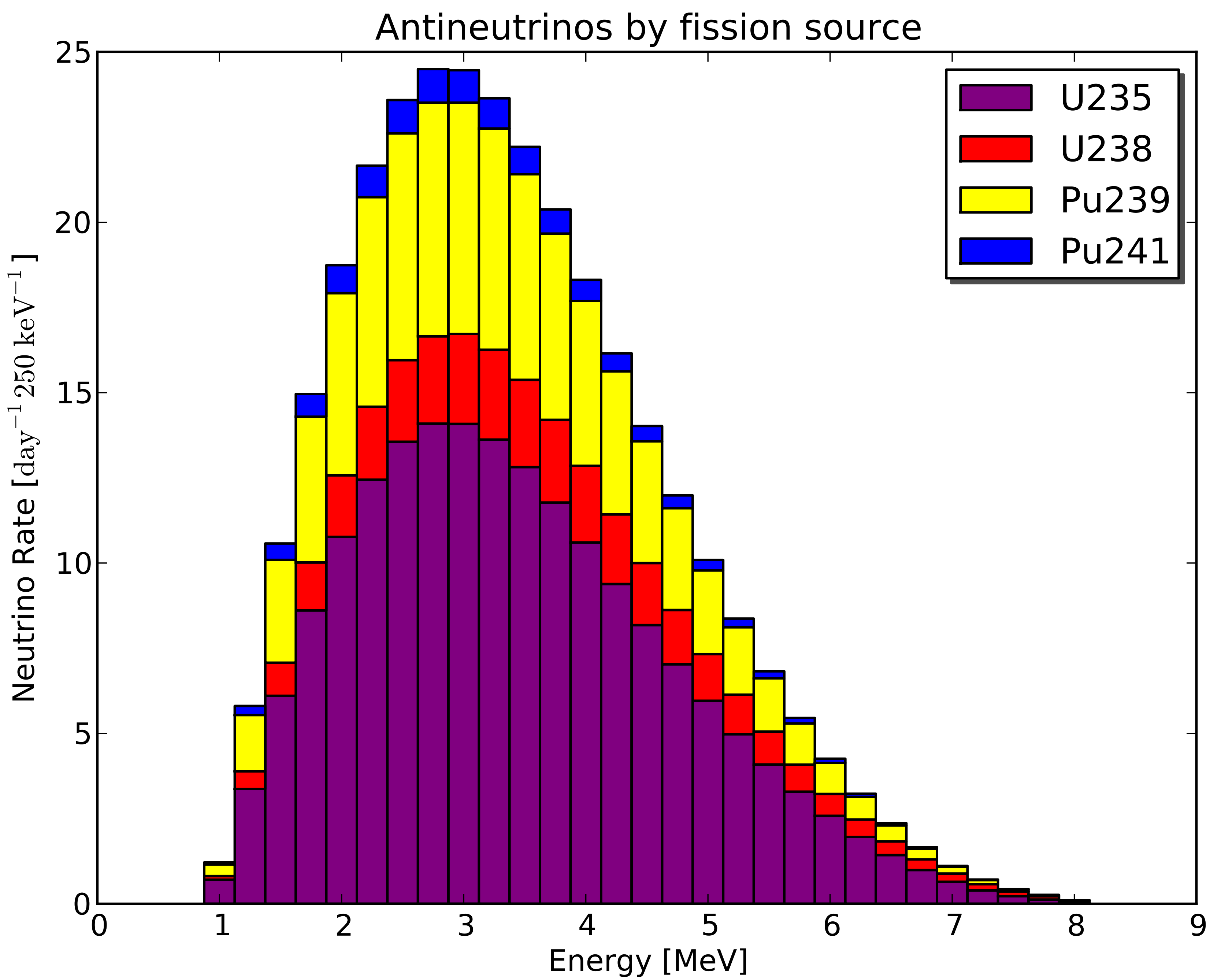


Fission Fractions

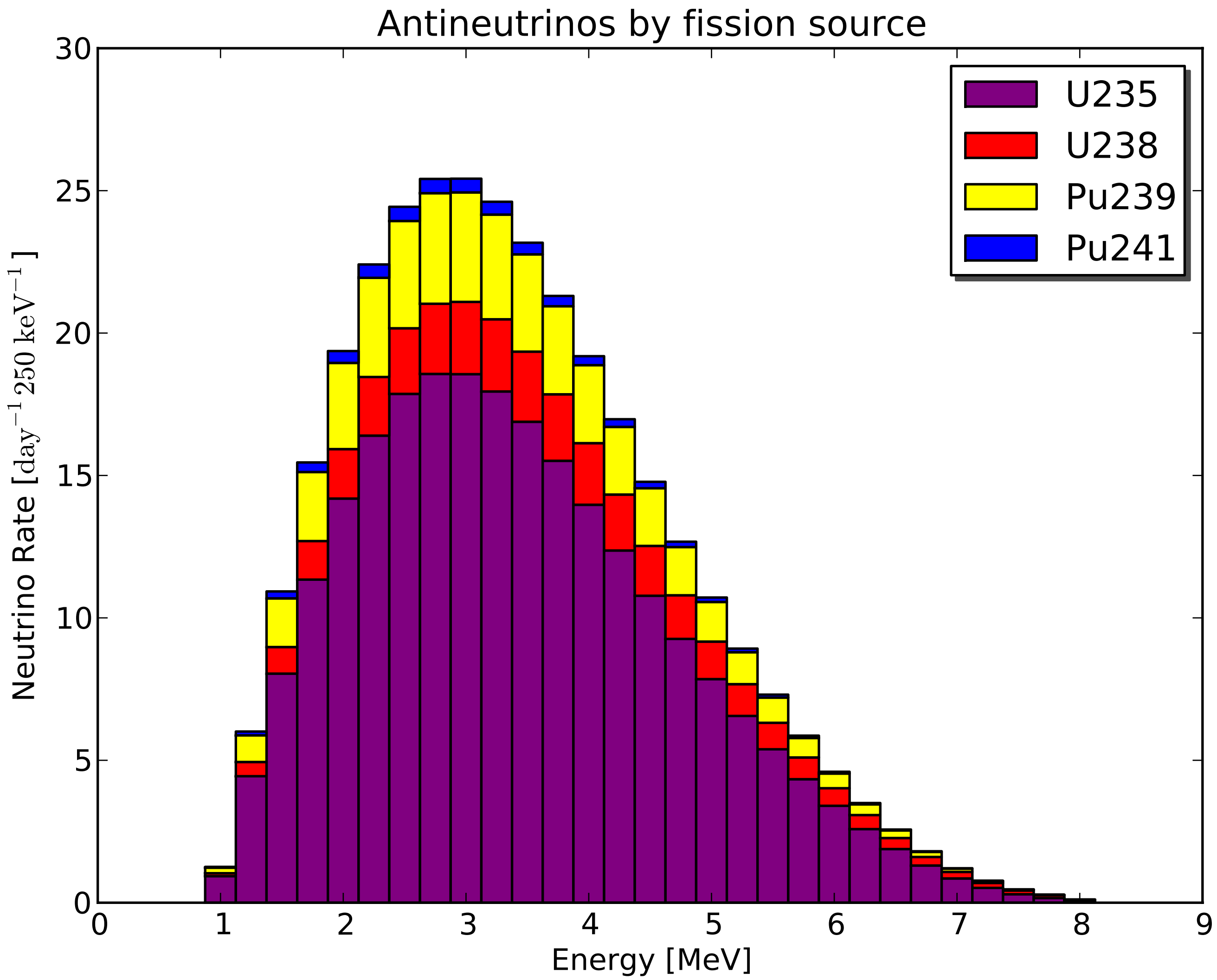


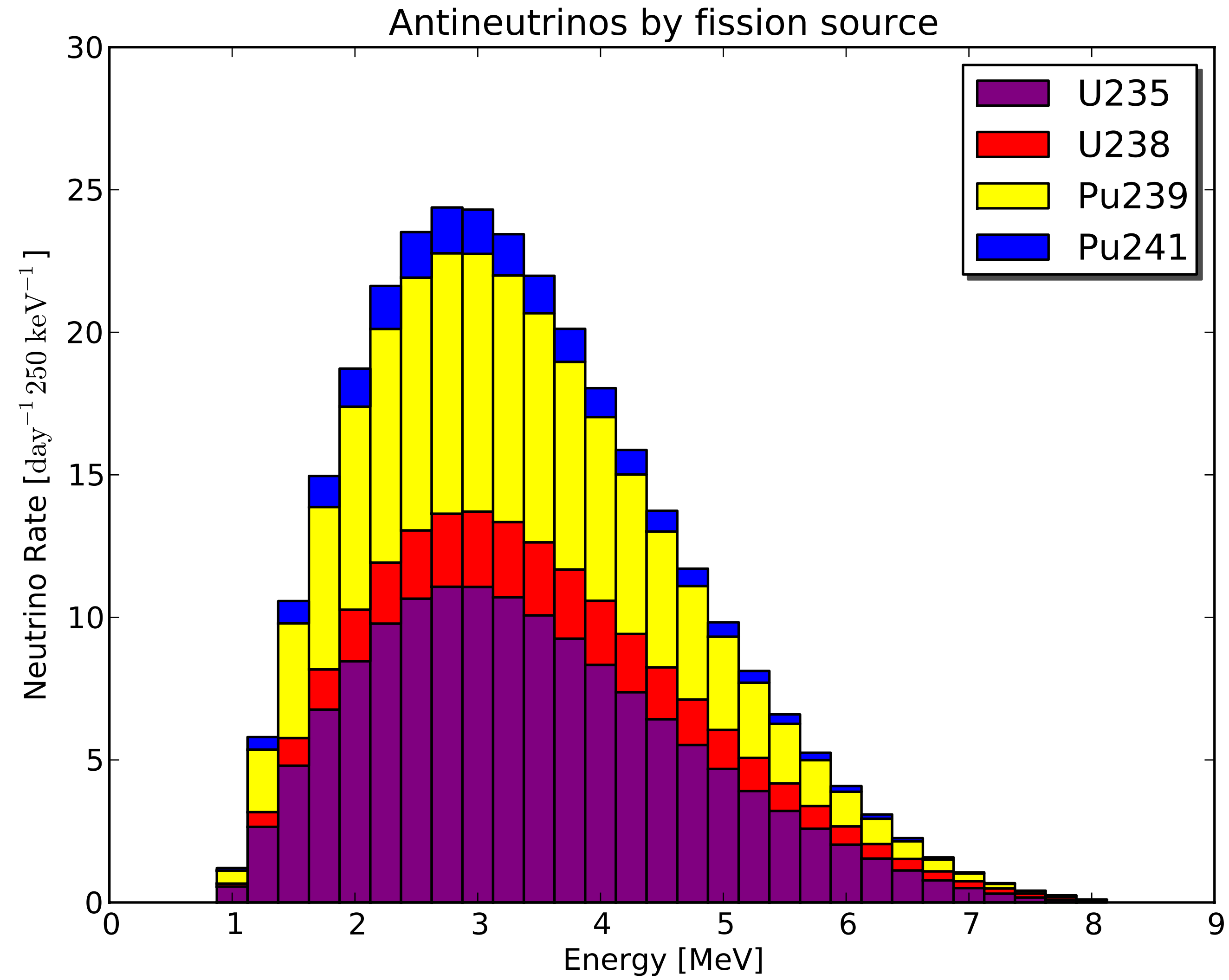
Rate by Isotope

Using a “standard” core: [0.570:0.078:0.295:0.057]



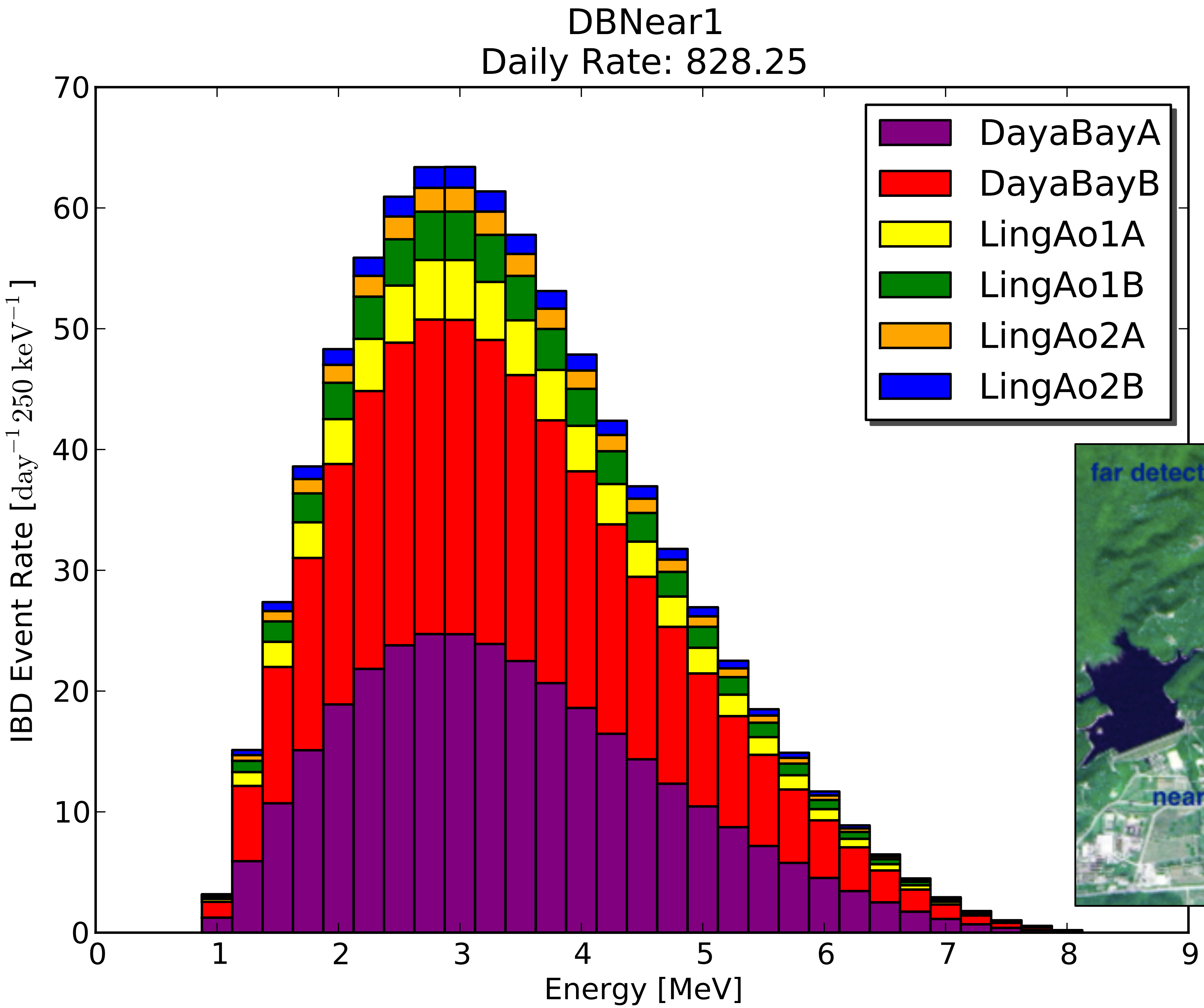
Fuel Cycle





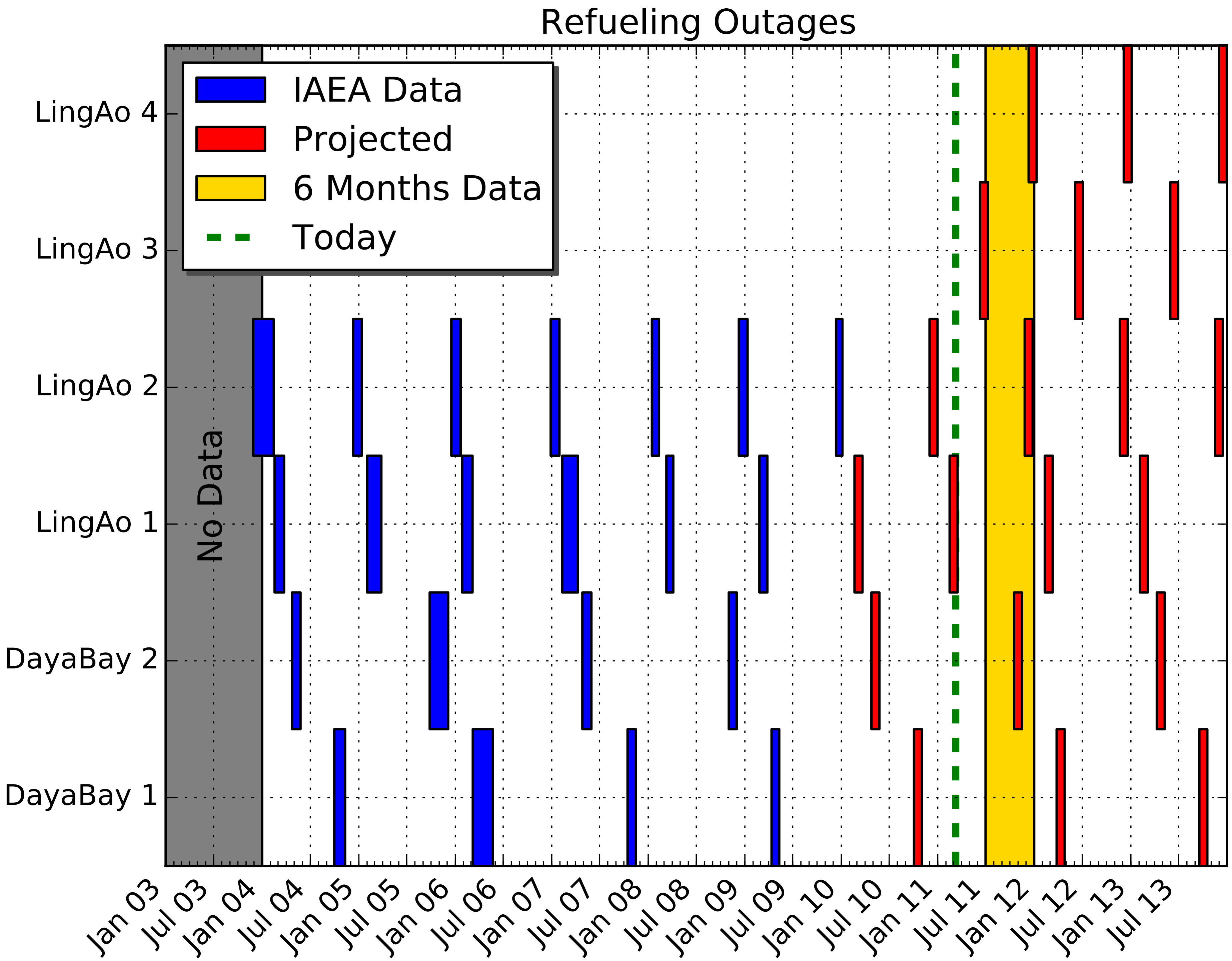
Beginning of Fuel Cycle → End of Fuel Cycle

IBD Rate


DBNear1
Daily Rate: 828.25
DayaBayA
DayaBayB
LingAo1A
LingAo1B
LingAo2A
LingAo2B
IBD Event Rate [day^{-1} 250 keV^{-1}]
Energy [MeV]
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9

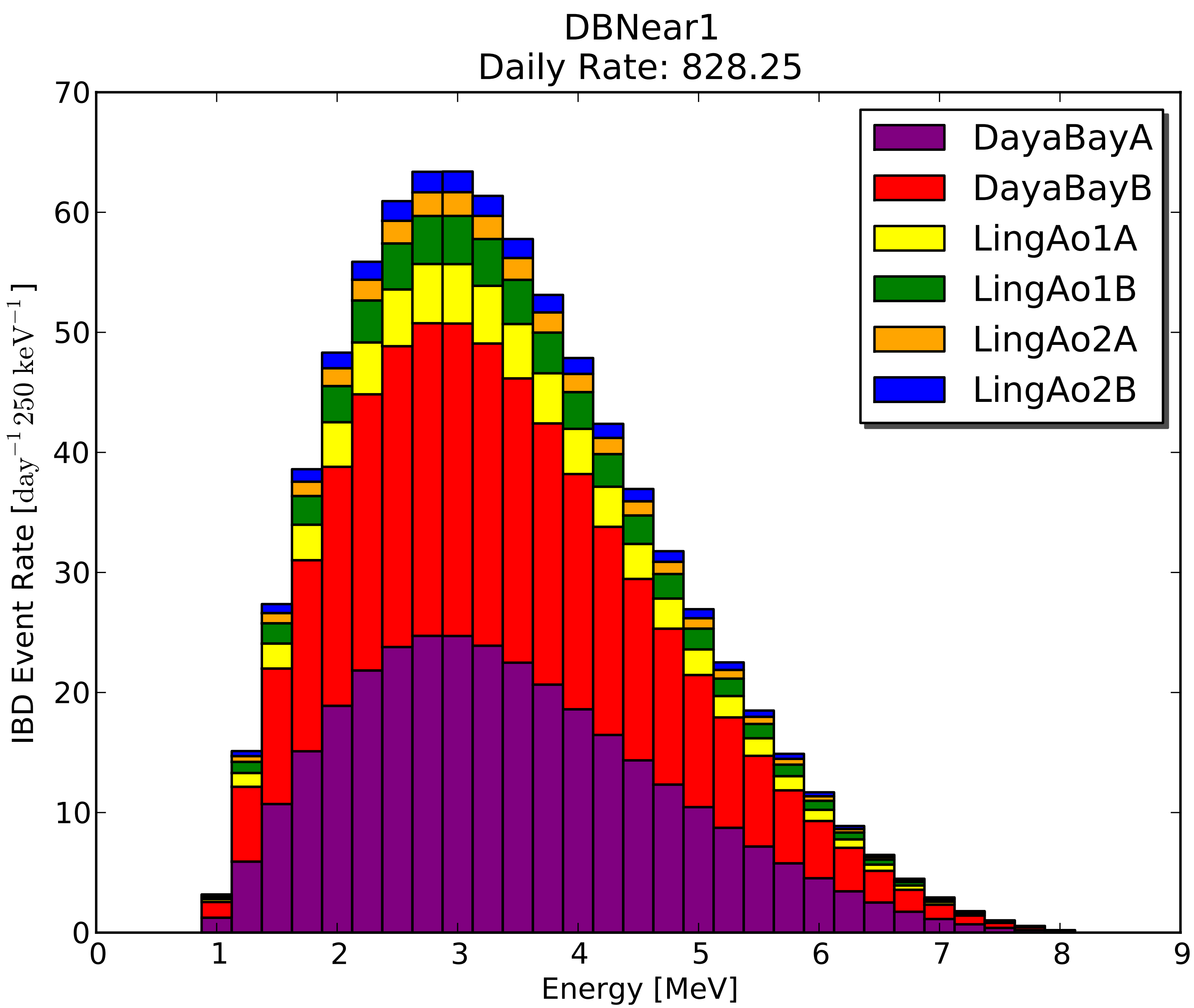

far detector
910 m
near detector
570 m
Ling Ao II
(under construction)
730 m
entrance
290 m
near detector
Ling Ao
Daya Bay

Reactor Shutdowns

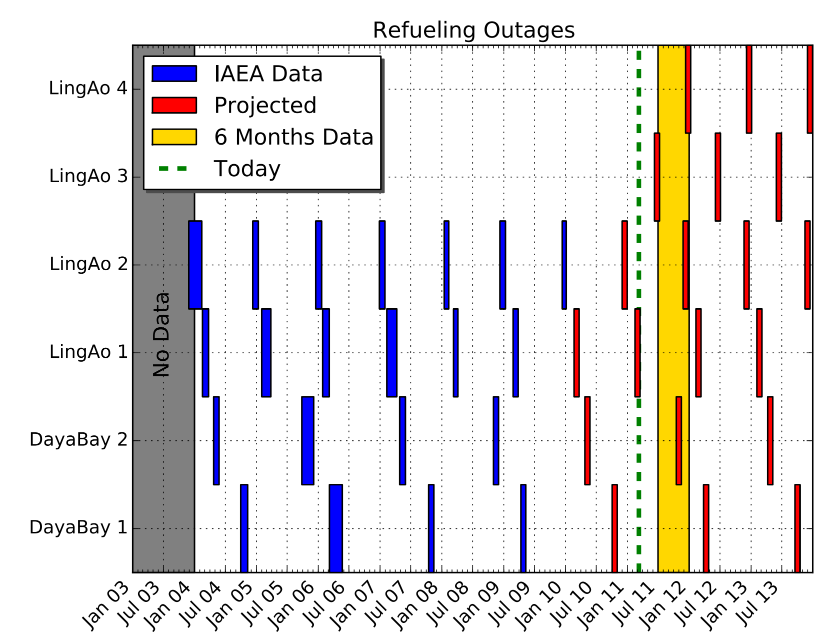


IAEA: OPERATING EXPERIENCE WITH NUCLEAR POWER STATIONS IN MEMBER STATES IN 2004-2009

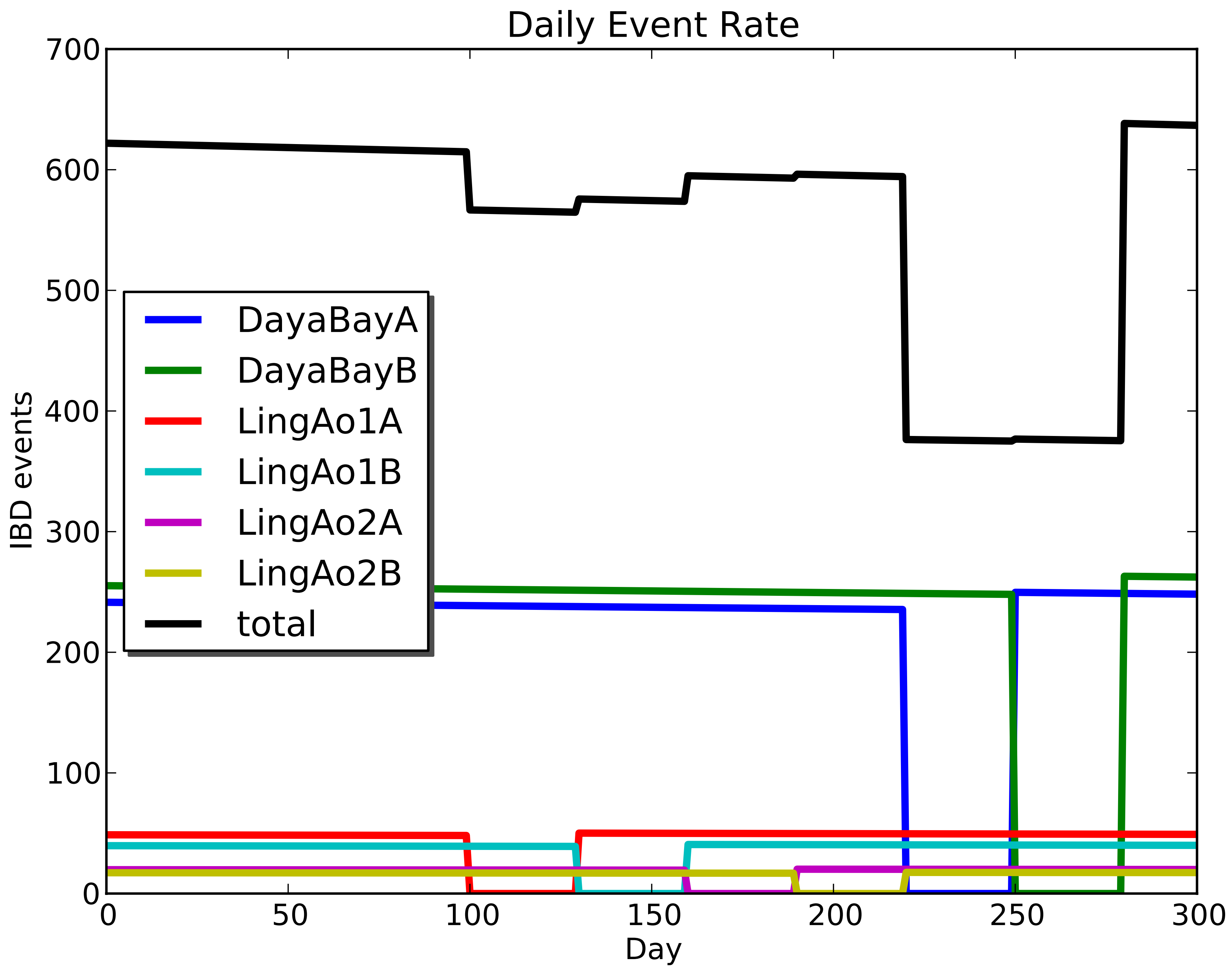
Shutdown Observation



As various cores are shutdown, we will observe a corresponding drop in flux.

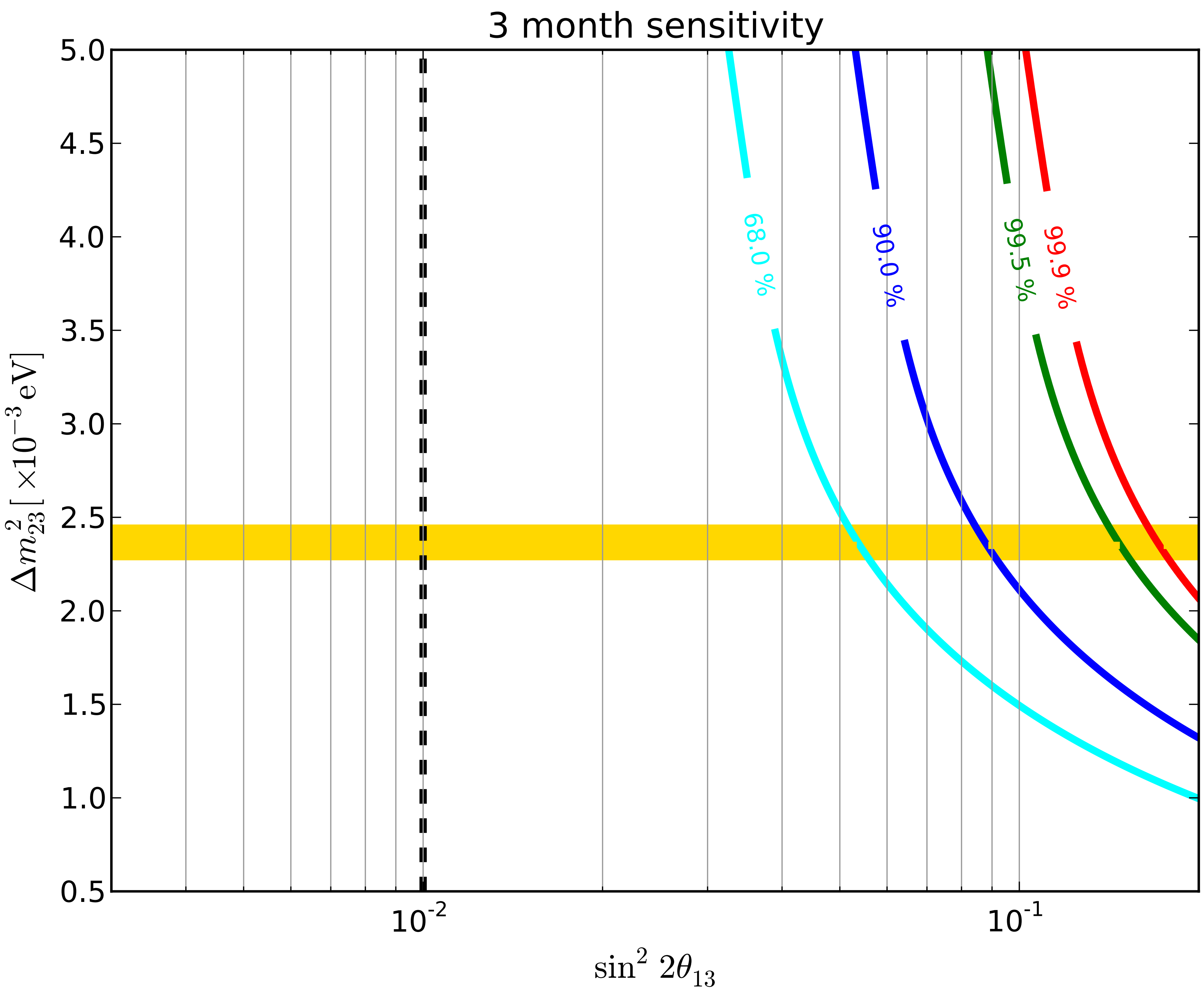


Shutdown



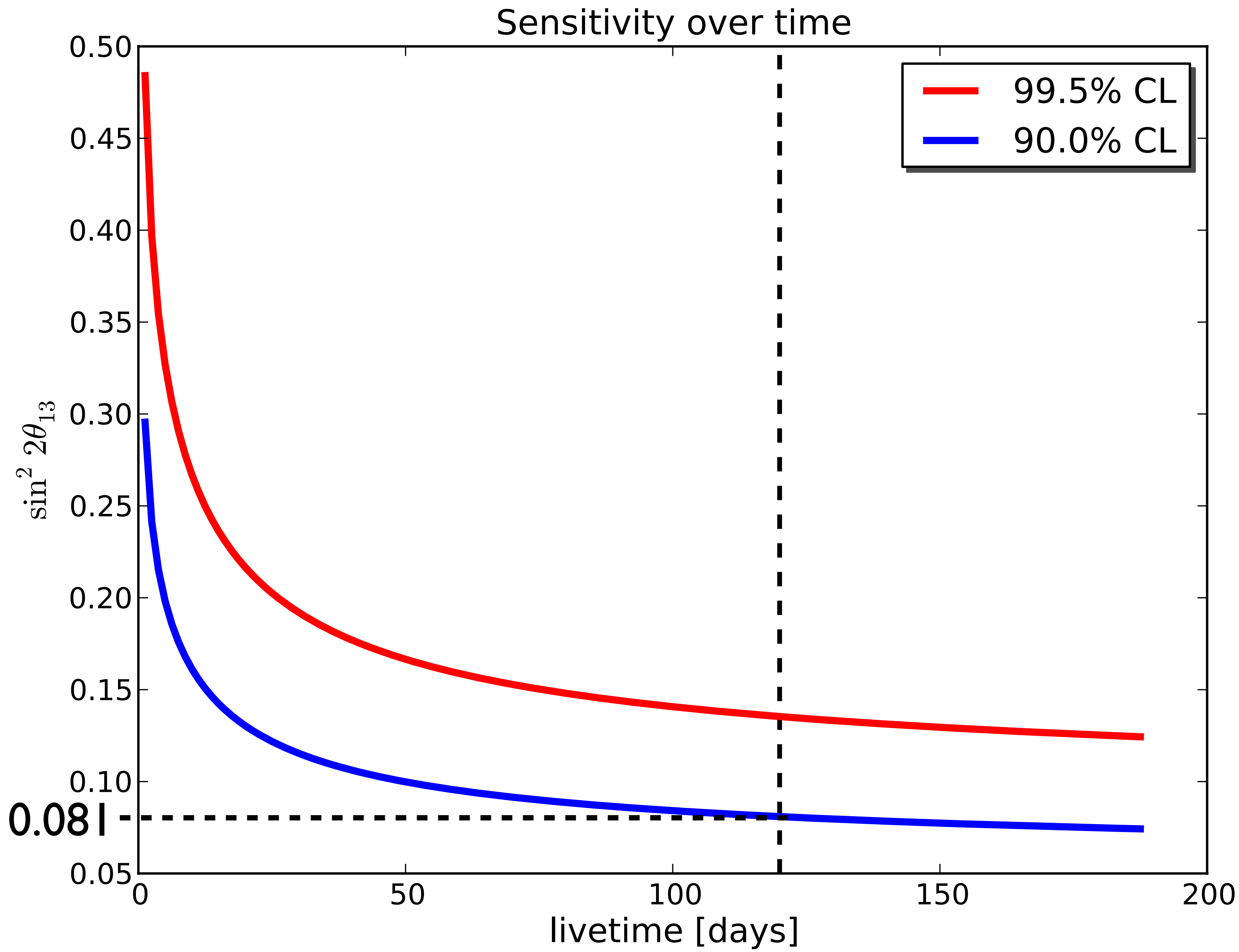
Daily Event Rate
IBD events
Day
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
DayaBayA
DayaBayB
LingAo1A
LingAo1B
LingAo2A
LingAo2B
total

Theta 13 Sensitivity



Live time

Live time takes into account 80% uptime



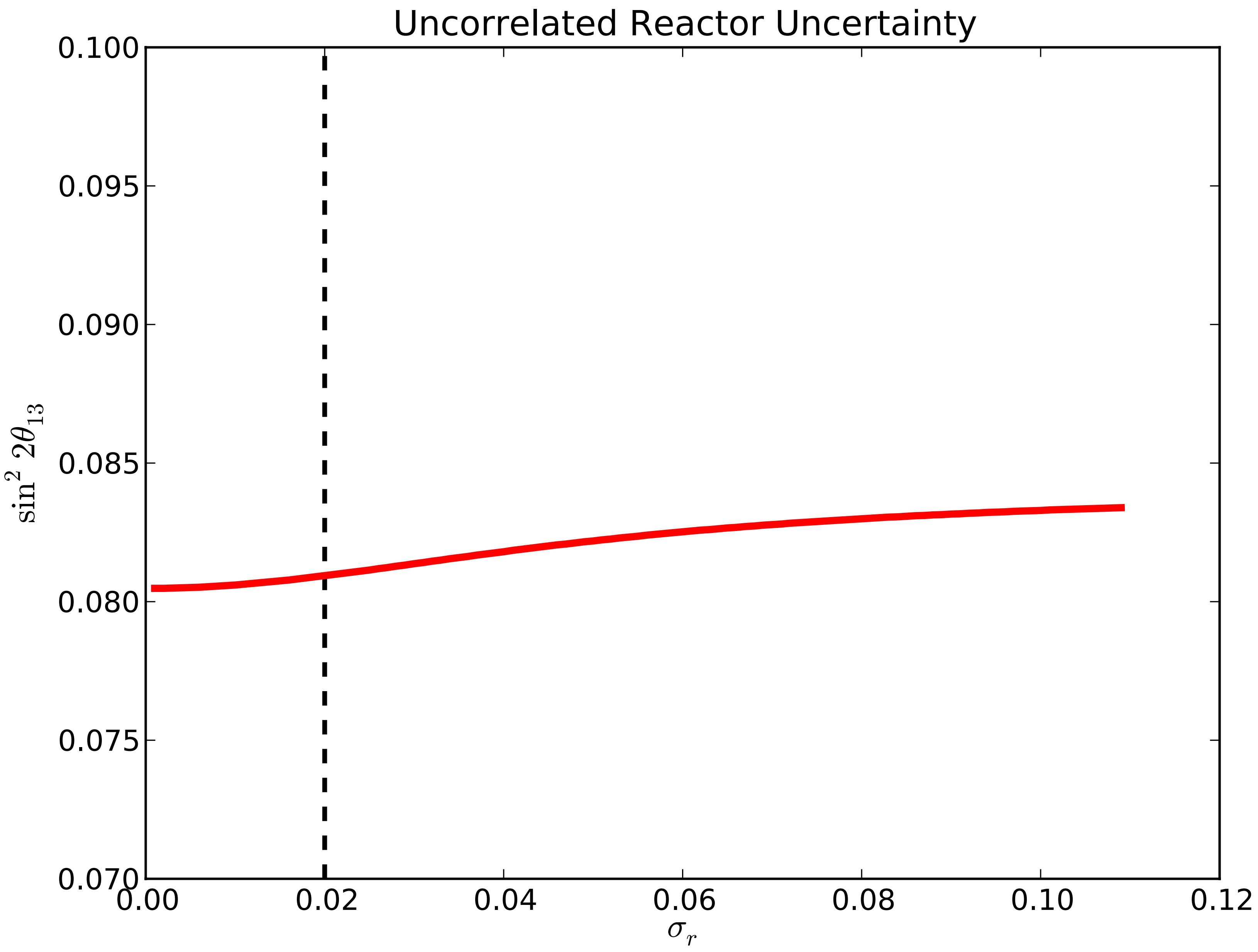
Global Chi Squared

$$\chi^2 = \min_{\gamma} \sum_{A=1}^{N_{\text{det}}} \sum_{i=1}^{N_{\text{bins}}} \frac{\left[M_i^A - T_i^A \left(1 + \alpha_c + \sum_{r=0}^{N_{\text{cores}}} \omega_r^A \alpha_r + \beta_i + \varepsilon_D + \varepsilon_d^A \right) - \eta_f^A F_i^A - \eta_n^A N_i^A - \eta_s^A S_i^A \right]^2}{T_i^A + \left(\sigma_{\text{b2b}} T_i^A \right)^2}$$

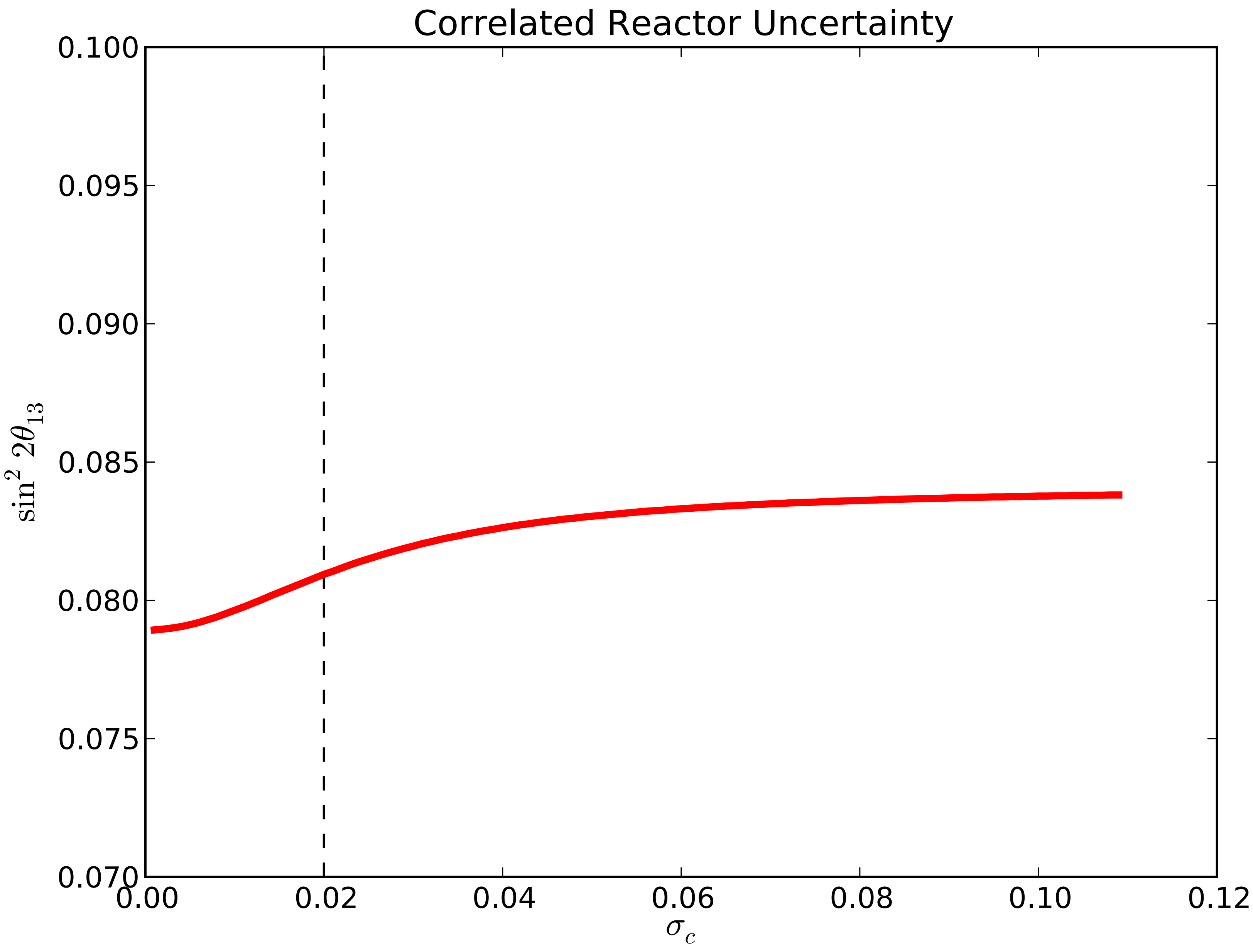
$$+ \frac{\alpha_c^2}{\sigma_c^2} + \sum_{r=0}^{N_{\text{cores}}} \frac{\alpha_r^2}{\sigma_r^2} + \sum_{i=0}^{N_{\text{bins}}} \frac{\beta_i^2}{\sigma_{shp}^2} + \frac{\varepsilon_D^2}{\sigma_D^2} + \sum_{A=0}^{N_{\text{dets}}} \left[\left(\frac{\varepsilon_d^A}{\sigma_d} \right)^2 + \left(\frac{\eta_f^A}{\sigma_f^A} \right)^2 + \left(\frac{\eta_n^A}{\sigma_n^A} \right)^2 + \left(\frac{\eta_s^A}{\sigma_s^A} \right)^2 \right]$$

Parameter	Uncertainty Desctiption	Value
σ_{b2b}	Bin to bin uncorrelated	0.003
σ_c	Reactor correlated	0.02
σ_r	Reactor uncorrelated	0.02
σ_{shp}	Reactor flux shape	0.02
σ_D	Detector Correlated	0.02
σ_d	Detector uncorrelated	0.0038
σ_f	Fast Neutron	1.0
σ_n	Accidental	1.0
σ_s	^{8}He/^{9}Li	0.003

Reactor Uncorrelated

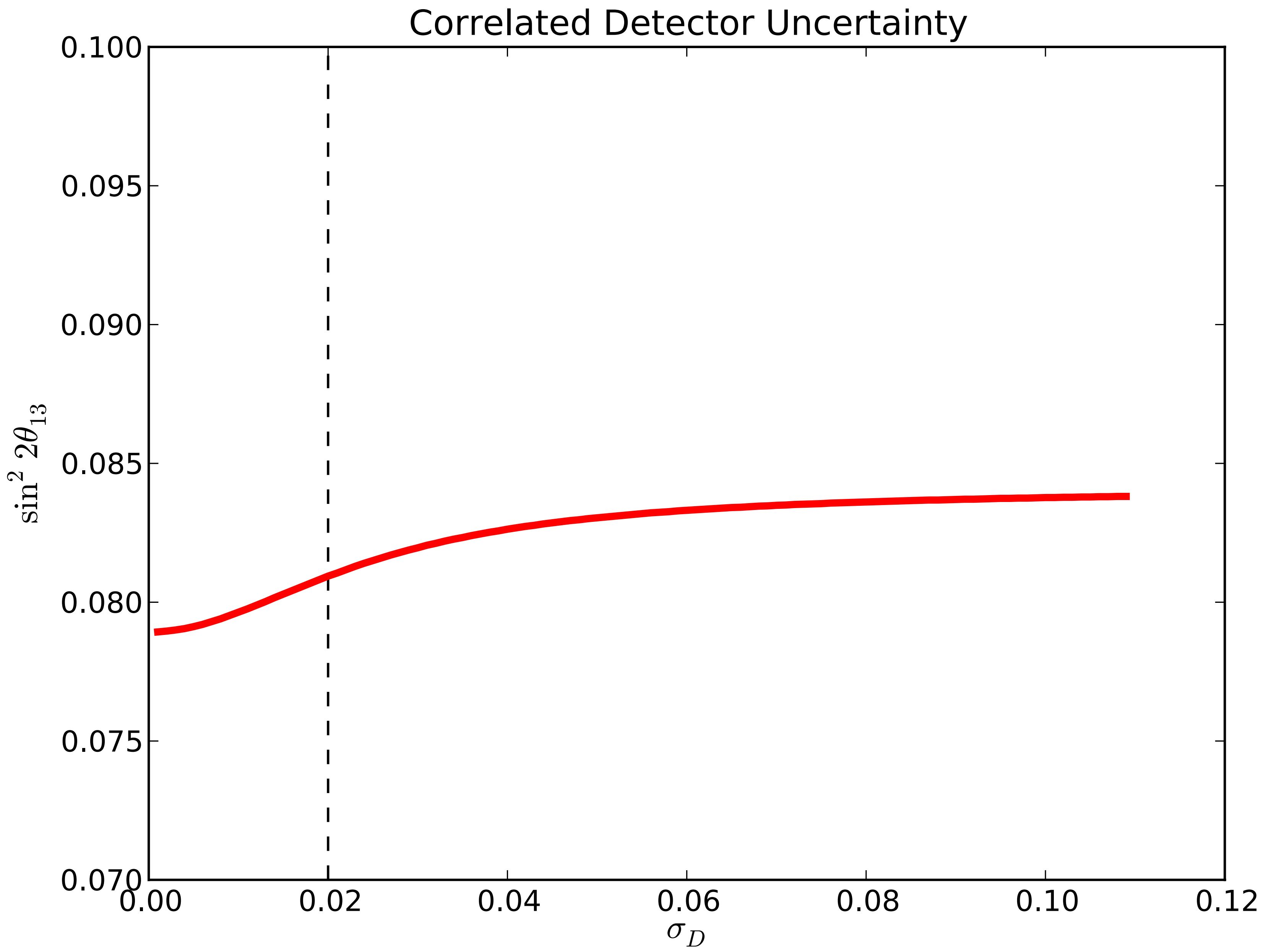


Reactor Correlated

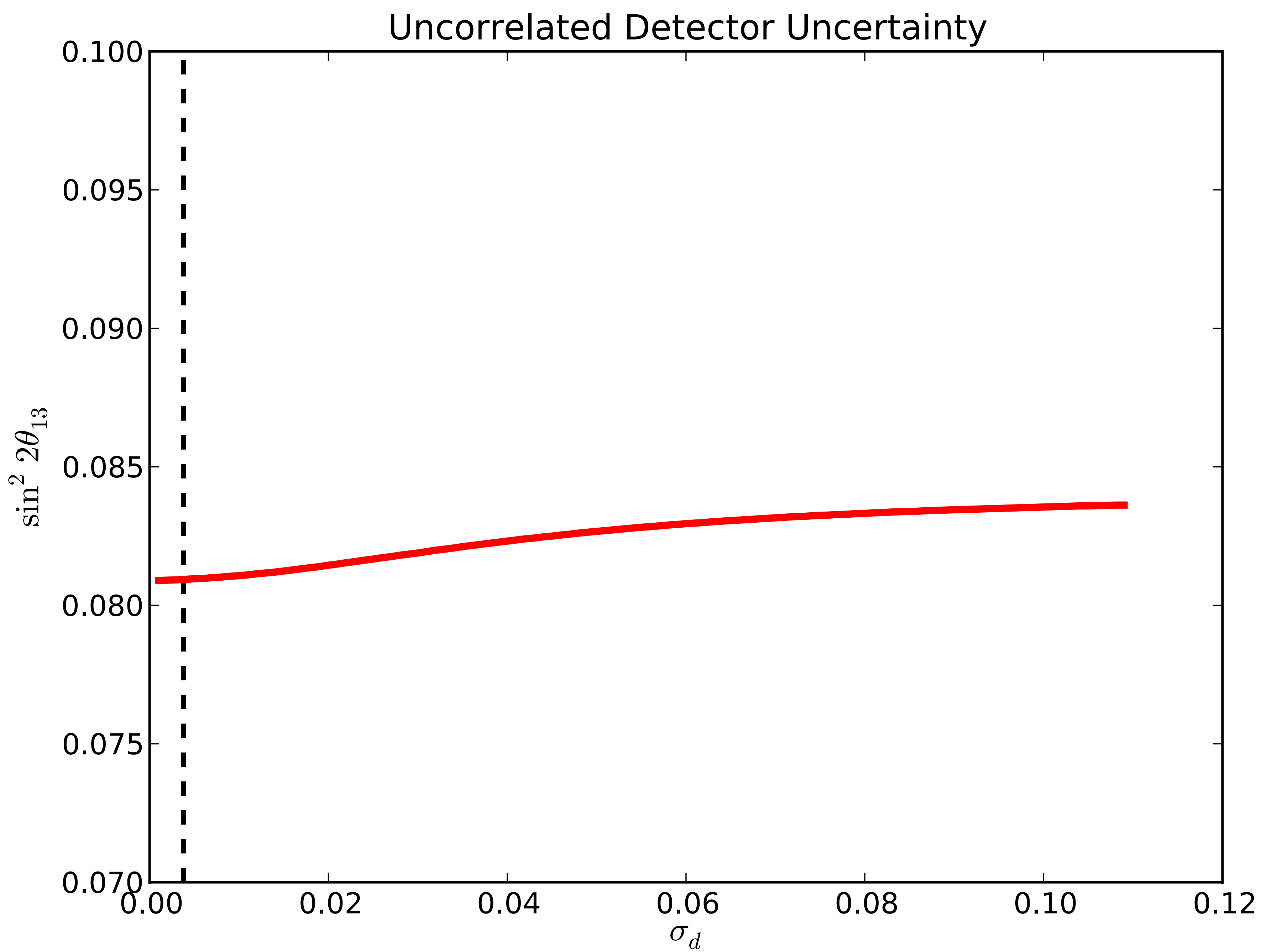


Detector Correlated

Examples: H/Gd ratio, H/C ratio, neutron capture time, spill in / spill out



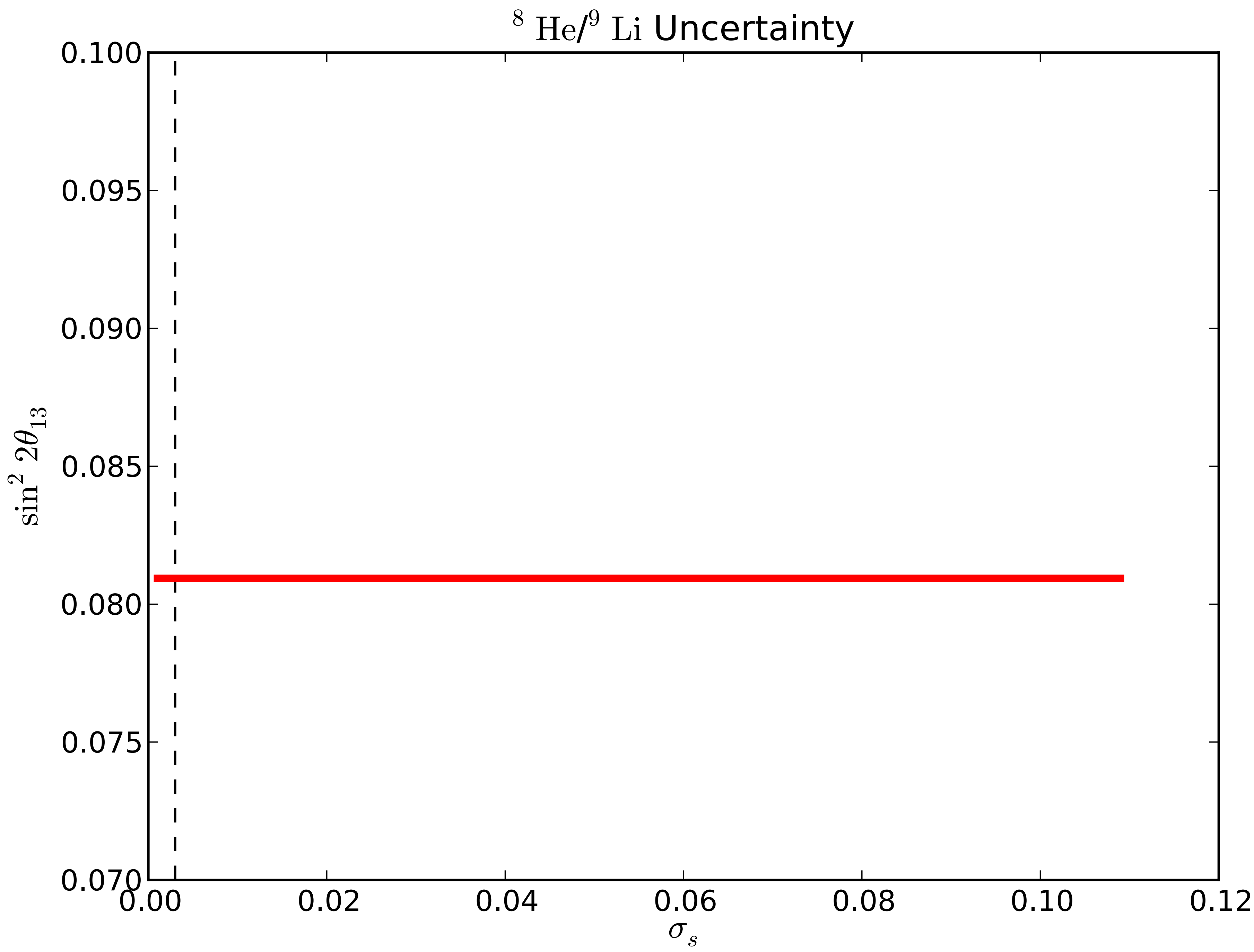
Detector Uncorrelated



Detector Uncertainty

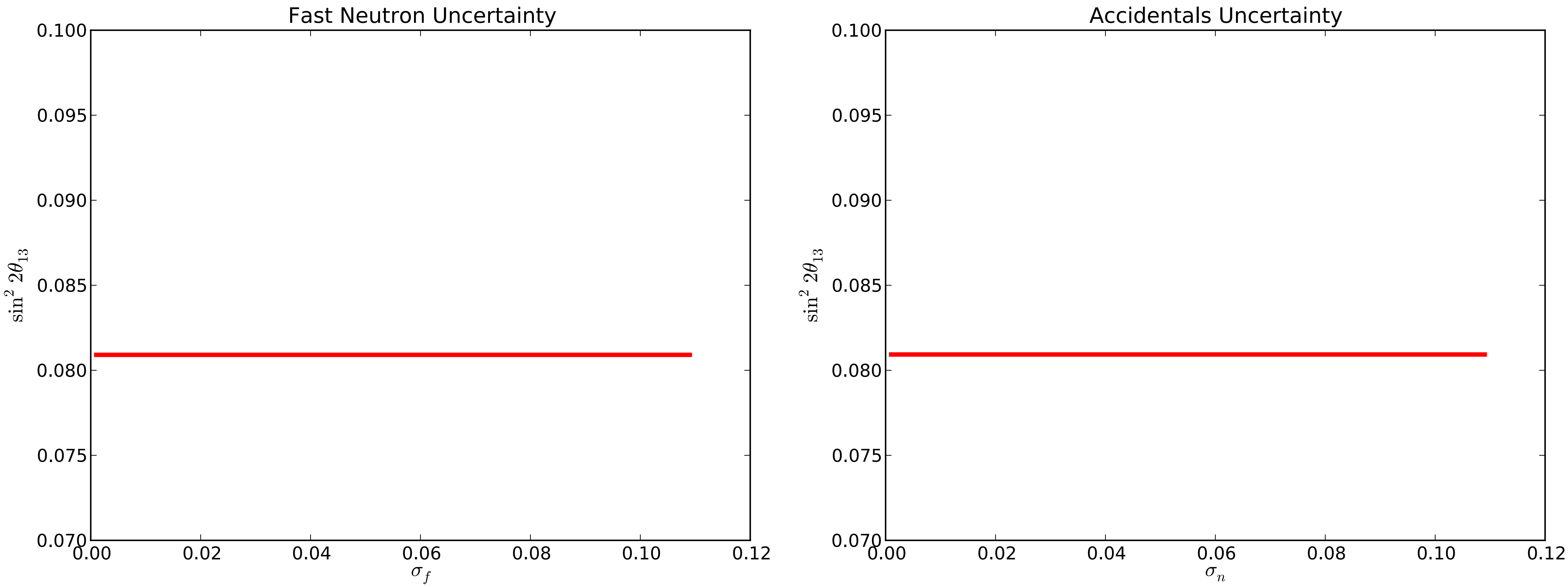
Source of uncertainty		Chooz (*absolute*)	Daya Bay (*relative*) Baseline	Goal	Goal w/Swapping
# protons		0.8	0.3	0.1	0.006
Detector Efficiency	Energy cuts	0.8	0.2	0.1	0.1
	Position cuts	0.32	0.0	0.0	0.0
	Time cuts	0.4	0.1	0.03	0.03
	H/Gd ratio	1.0	0.1	0.1	0.0
	n multiplicity	0.5	0.05	0.05	0.05
	Trigger	0	0.01	0.01	0.01
	Live time	0	<0.01	<0.01	<0.01
Total detector-related uncertainty		1.7%	0.38%	0.18%	0.12%

9Li / 8He

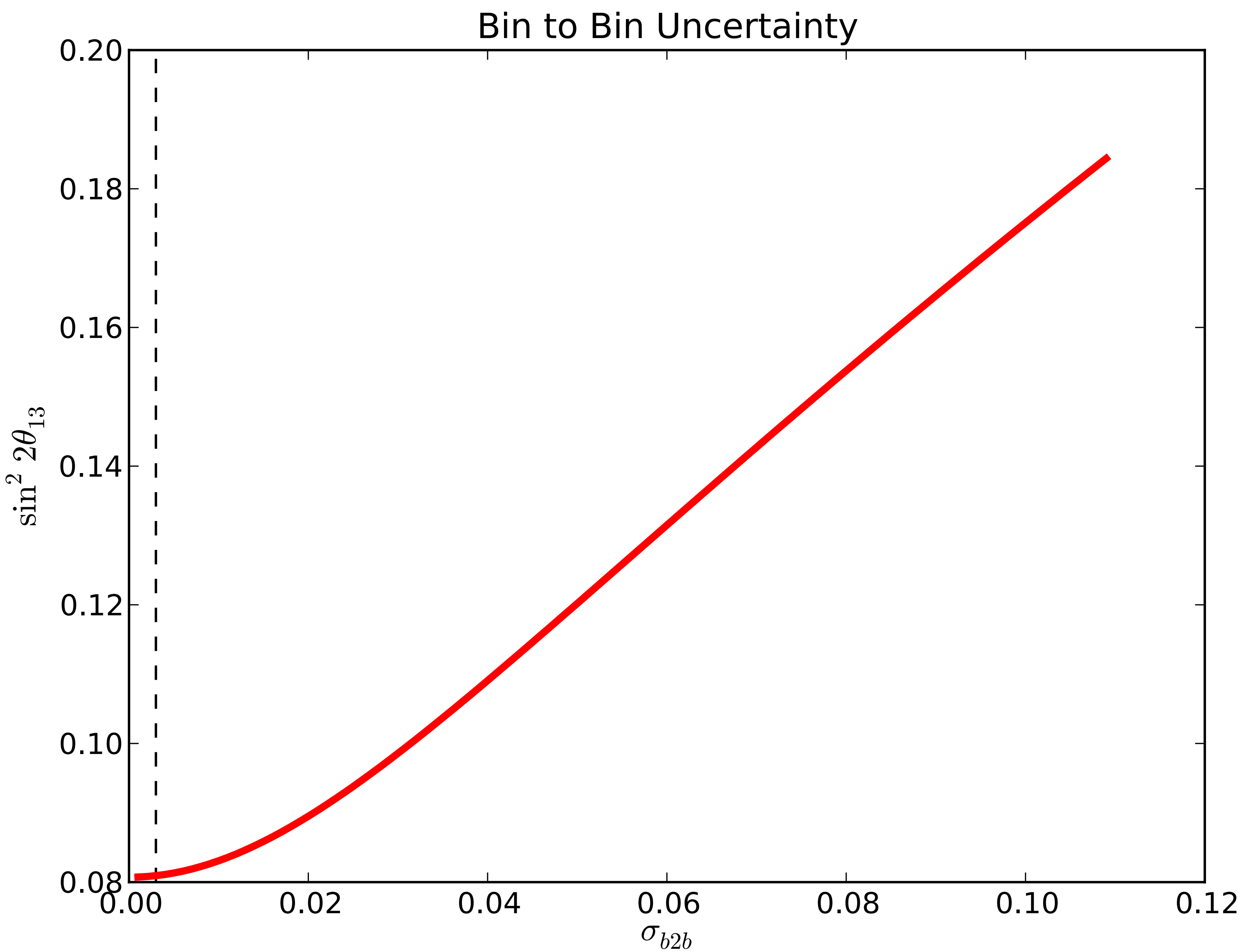


^{8} He/^{9} Li Uncertainty
0.100
0.095
0.090
0.085
0.080
0.075
0.070
$\sin^2 2\theta_{13}$
0.00
0.02
0.04
0.06
0.08
0.10
0.12
σ_s

Other Backgrounds

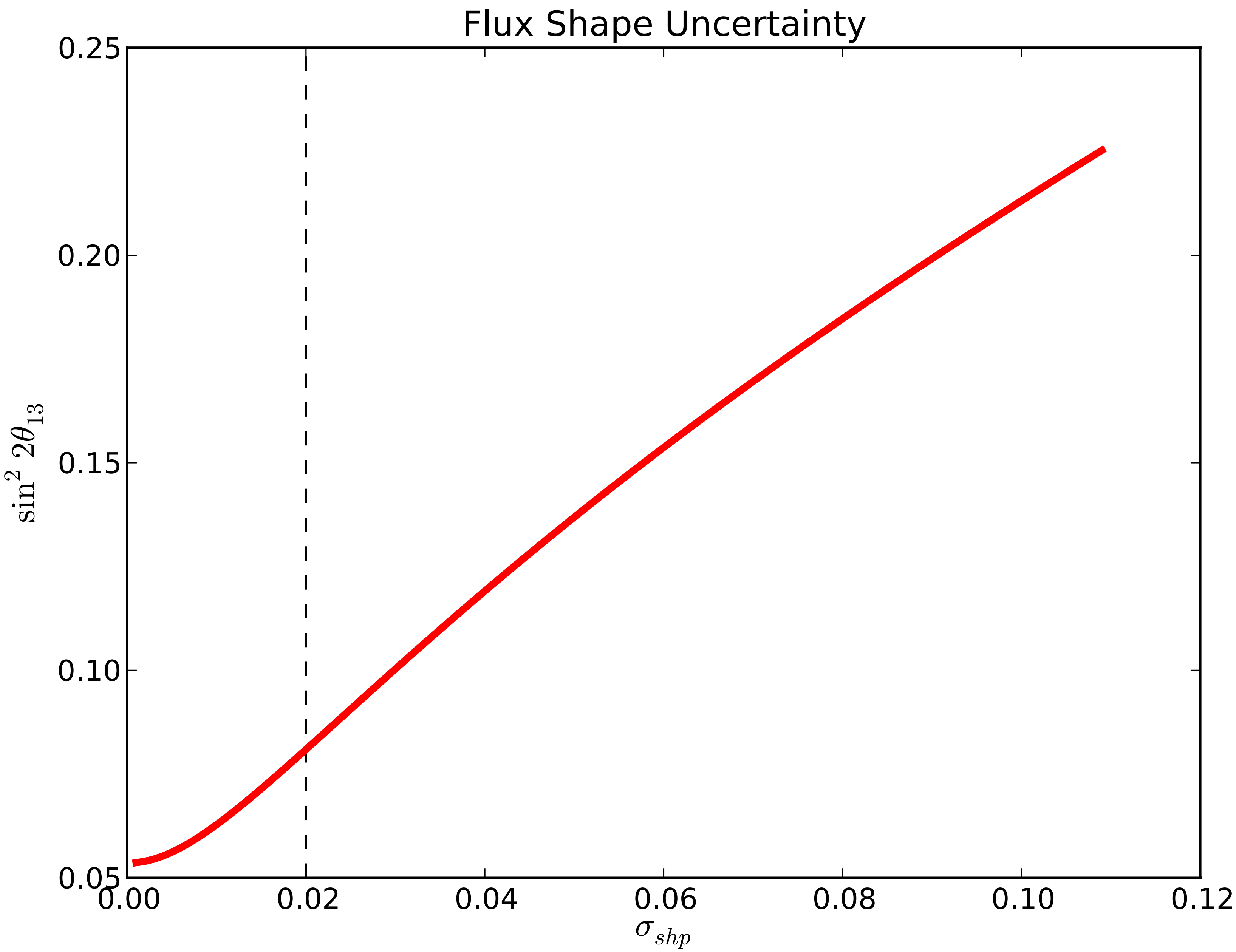


Bin-to-bin

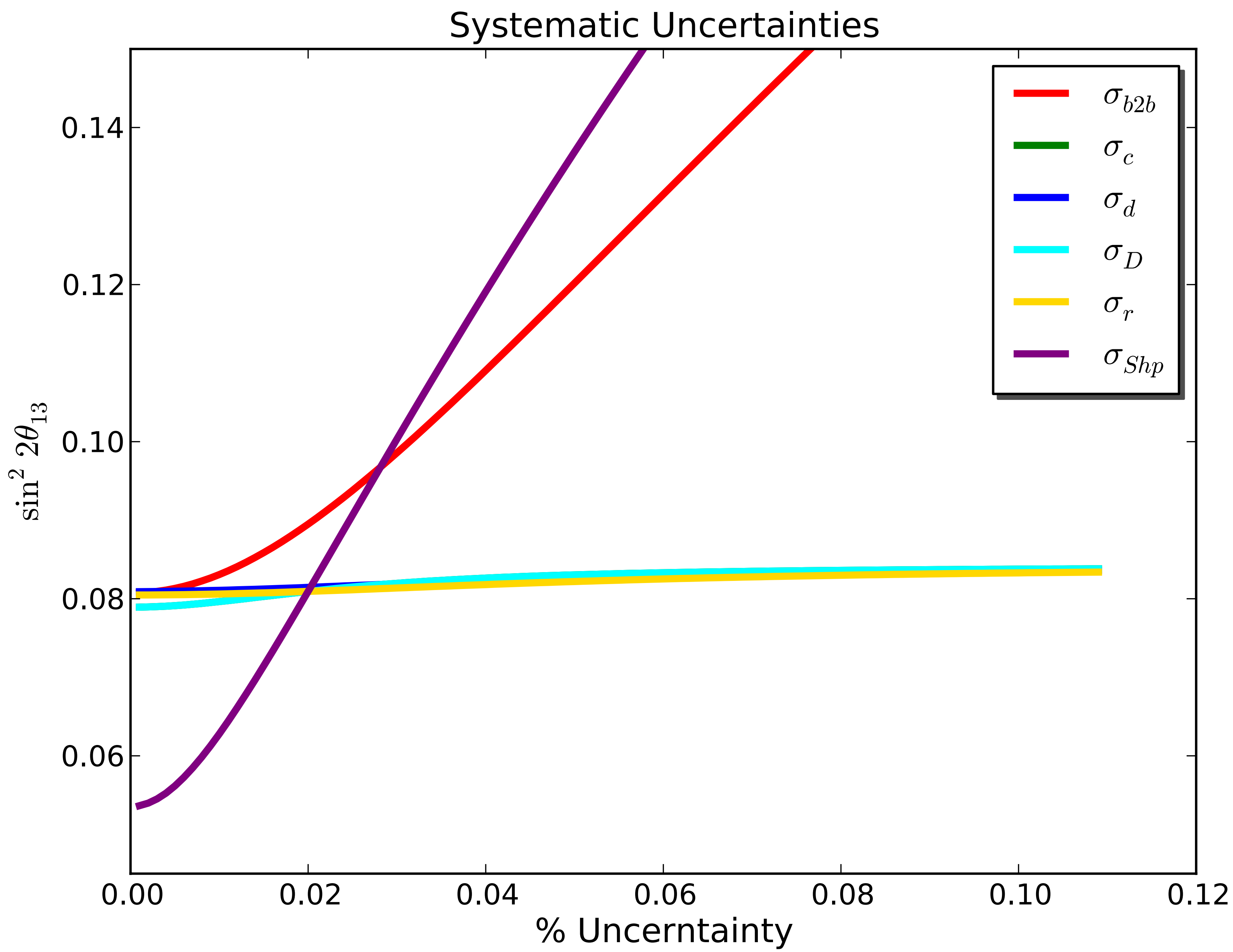

Bin to Bin Uncertainty
0.20
0.18
0.16
0.14
0.12
0.10
0.08
$\sin^2 2\theta_{13}$
0.00
0.02
0.04
0.06
0.08
0.10
0.12
σ_{b2b}

Reactor Flux Shape

In Full running this has a much lower impact because the nearsites will "measure" the flux much better than 2 %



Uncertainty Summary



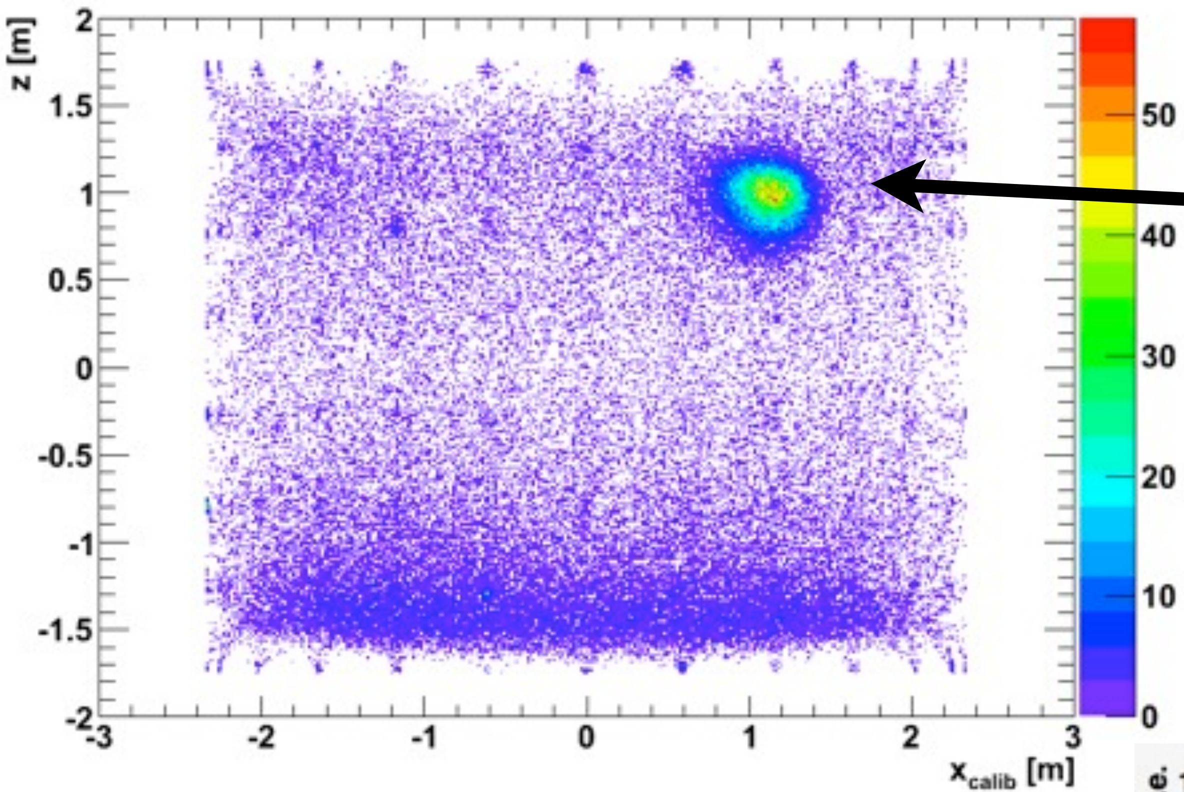
Summary

- Oscillation experiments give a unique handle on weakly interacting neutrinos.
- With full running scheduled for Fall 2012 the goal sensitivity can be reached as early as 2014.
- In the near term, interesting physics measurements can be made using near site data taken during commissioning of the remaining sights.

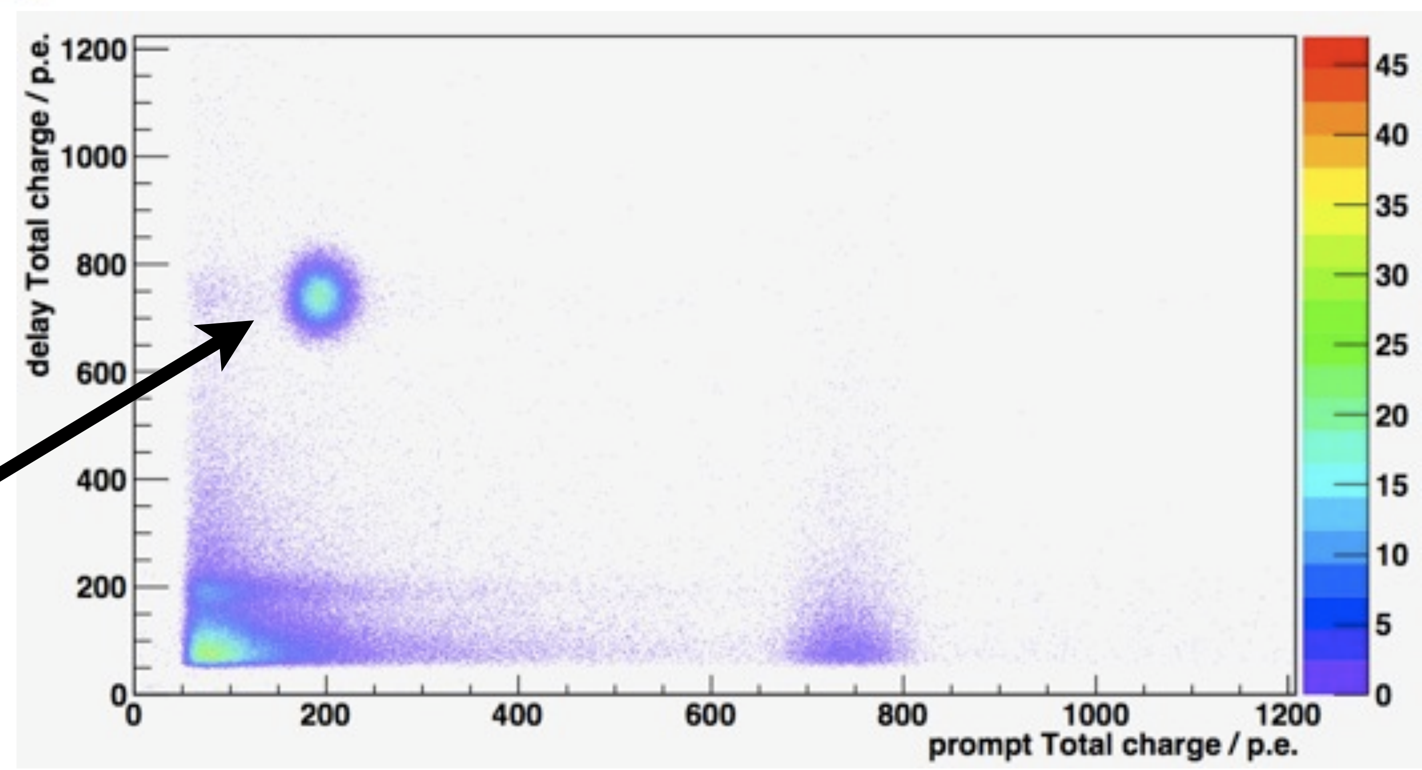
Thank You

Backup

Dry-Run Results



Single LED with simple charge center of mass reconstruction



Two LED's in succession simulating IBD prompt and delayed signal.

Propagator

Rest frame

$P_i = (m_i, 0)$

$x = (\tau_i, 0)$

$P_i = (E_i, \overrightarrow{p_i})$

$x = (t, \vec{x})$

Lab frame

$$\boxed{m_i \tau_i = Et - p_i L}$$

Phase Difference: $\delta\phi = (p_1 - p_2)L - (E_1 - E_2)t$

Average Velocity: $\bar{v} = \dfrac{p_1 + p_2}{E_1 - E_2}$

$$\delta\phi = (p_1 - p_2)L - \frac{(E_1^2 - E_2^2)}{(p_1 + p_2)}L - (E_1 - E_2)\delta t \implies \delta\phi = \frac{\Delta m_{21}^2 L}{2E}$$

$$\boxed{\text{prop}(\nu_i) = e^{-i\frac{m_i^2 L}{2E}}}$$

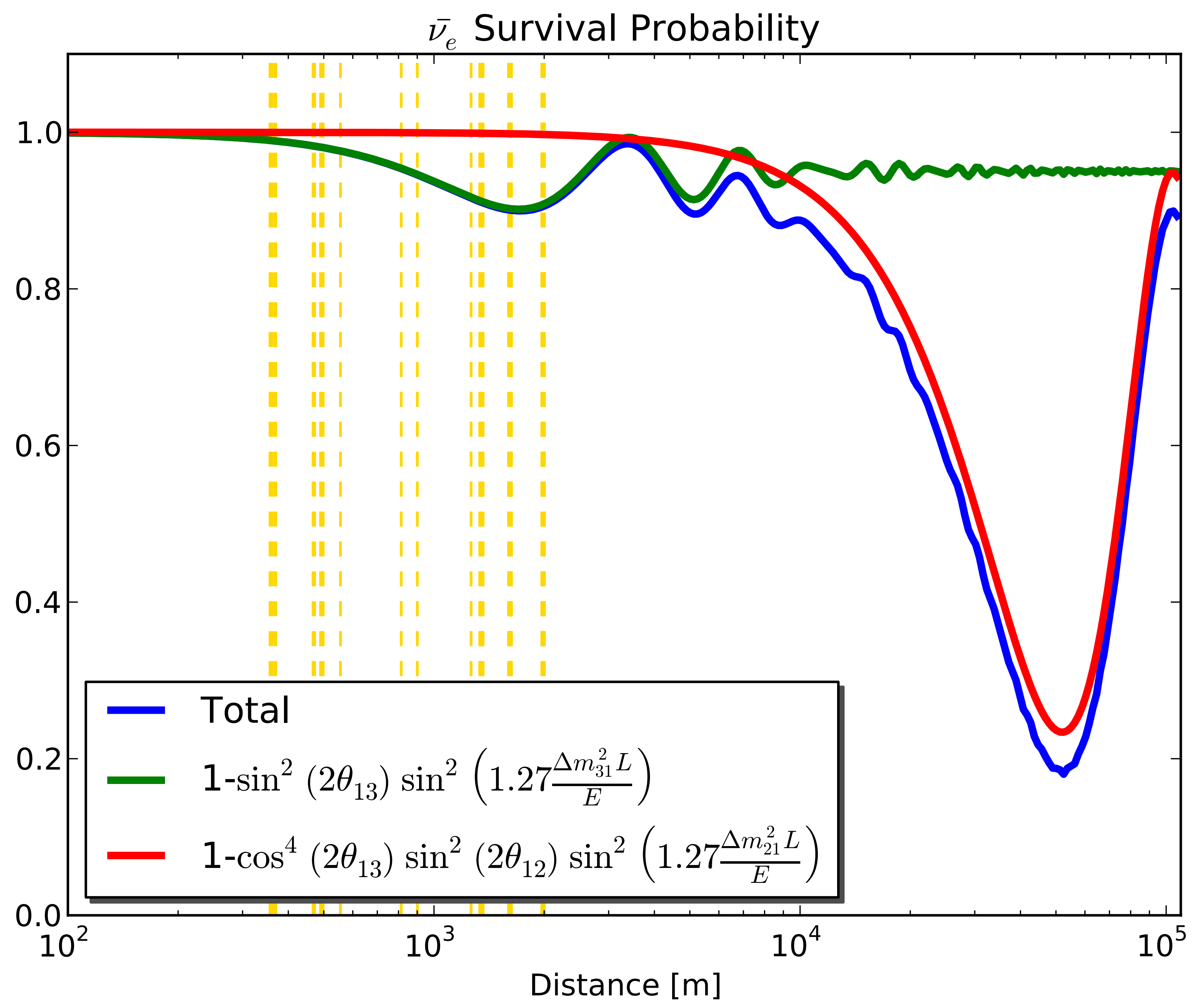
3 Neutrino Mixing

In General: $$\mathrm{Amp}(\nu_\alpha \to \nu_\beta) = \sum_i U^*_{\alpha i} e^{-i m_i^2 \frac{L}{2E}} U_{\beta i}$$

$$P(\nu_\alpha \to \nu_\beta) = \left| e^{-i m_1^2 \frac{L}{2E}} \mathrm{Amp}^*(\nu_\alpha \to \nu_\beta) \right|^2 = \left| \sum_i e^{-i\Delta m_{i1}^2 \frac{L}{2E}} U_{\alpha j} e^{i\Delta m_{i1}^2 \frac{L}{2E}} U^*_{\beta j} \right|^2$$

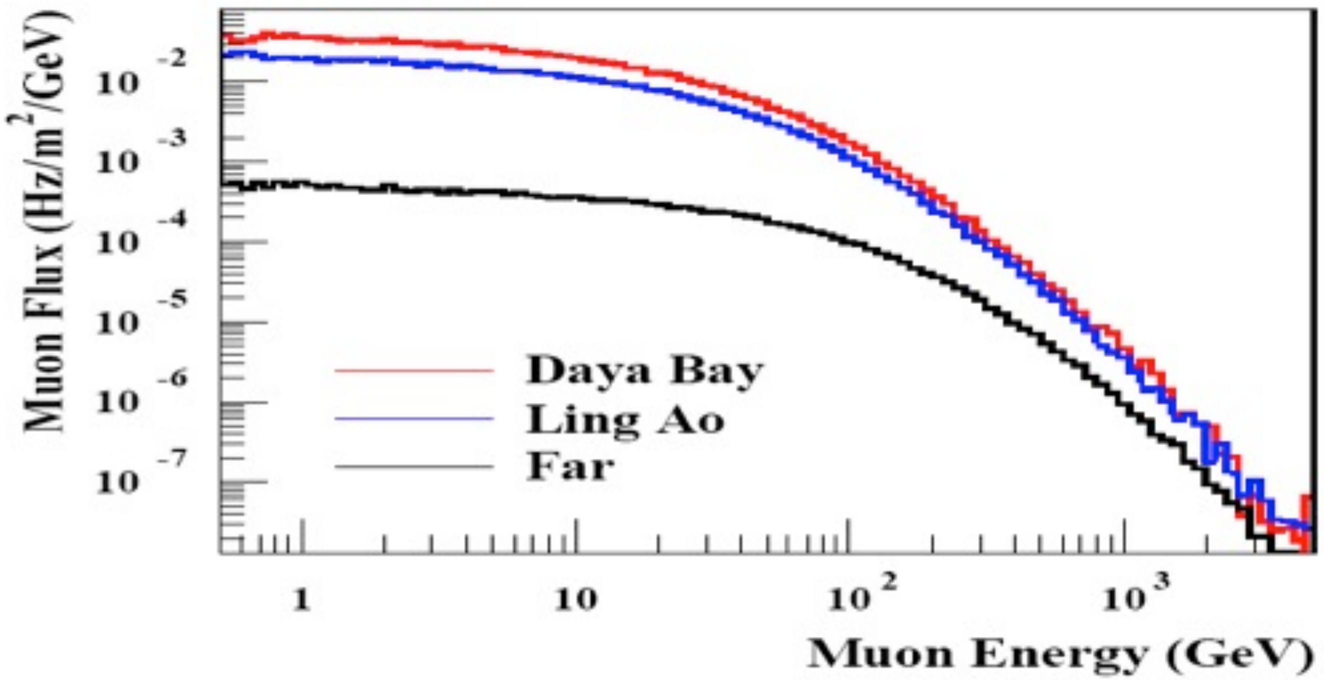
$$P(\nu_\alpha \to \nu_\beta) = \delta_{\alpha\beta} - 4\sum_{i>j} \Re\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) \sin^2\left(\Delta m_{ij}^2 \frac{L}{4E}\right) + 2\Im \sum_{i>j}\left(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}\right) \sin\left(\Delta m_{ij}^2 \frac{L}{2E}\right)$$

Coverage From DayaBay



Muon Rate

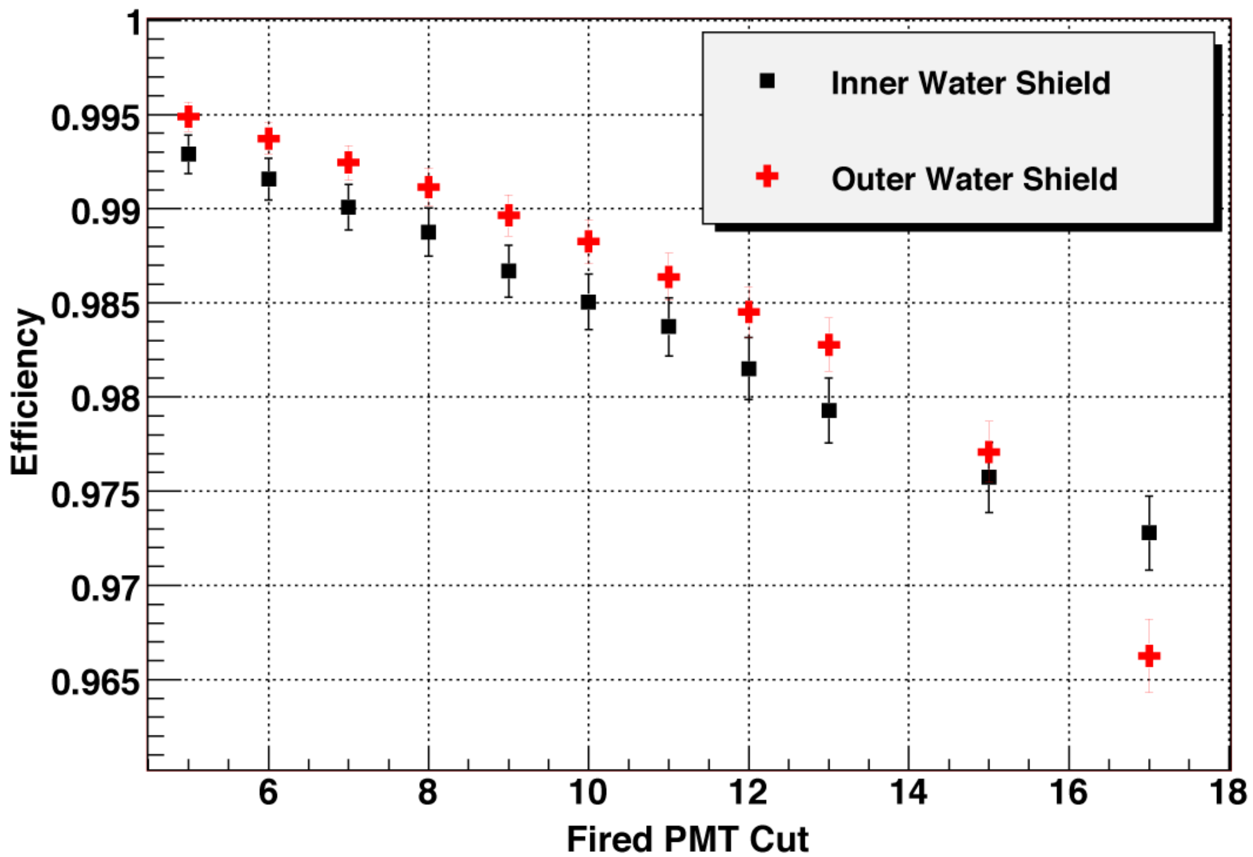
Detailed topo map, modified Gaisser formula, and MUSIC



Expected Muon Flux from Simulation.

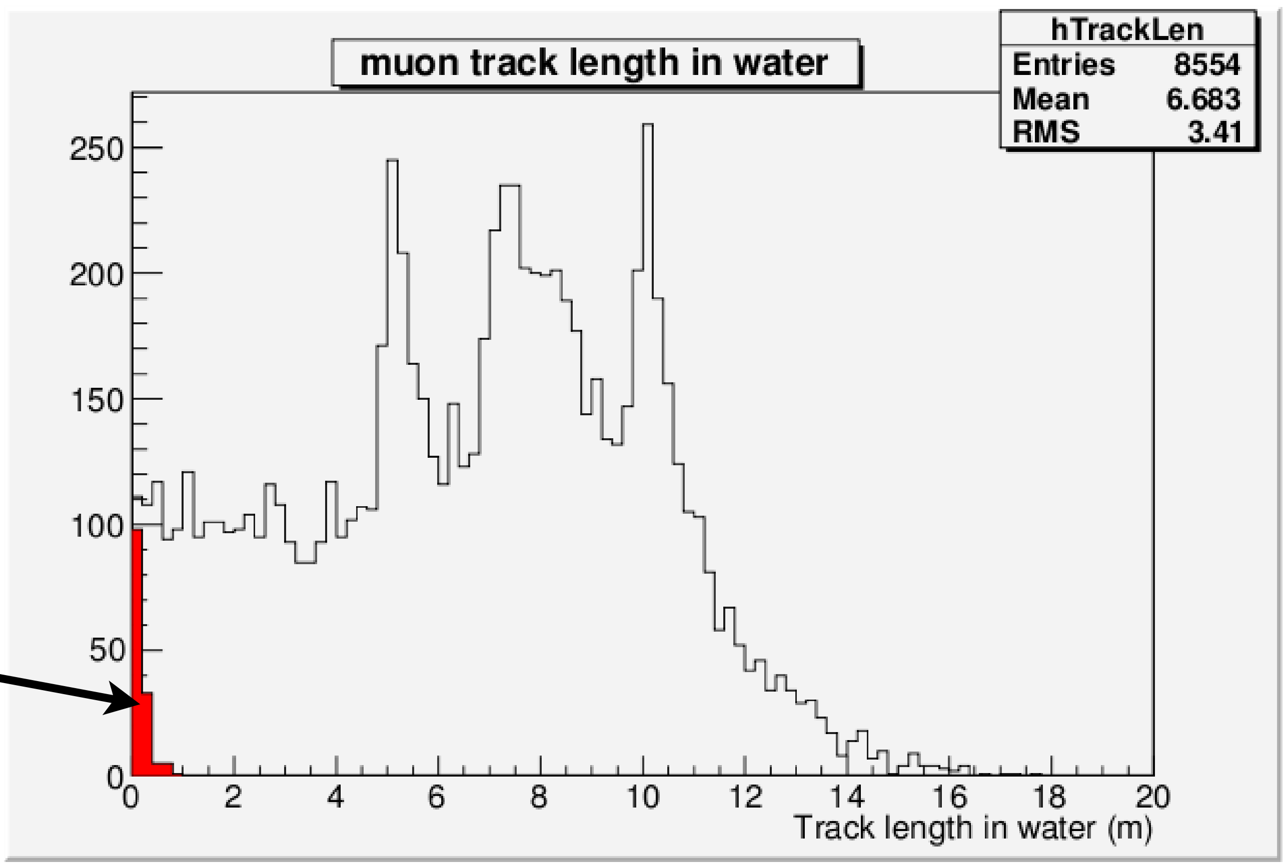
	DYB site	LA site	Far site
Vertical overburden (m)	98	112	355
Muon Flux (Hz/m^2)	1.16	0.73	0.041
Muon Mean Energy (GeV)	55	60	138

Water Pool Efficiency

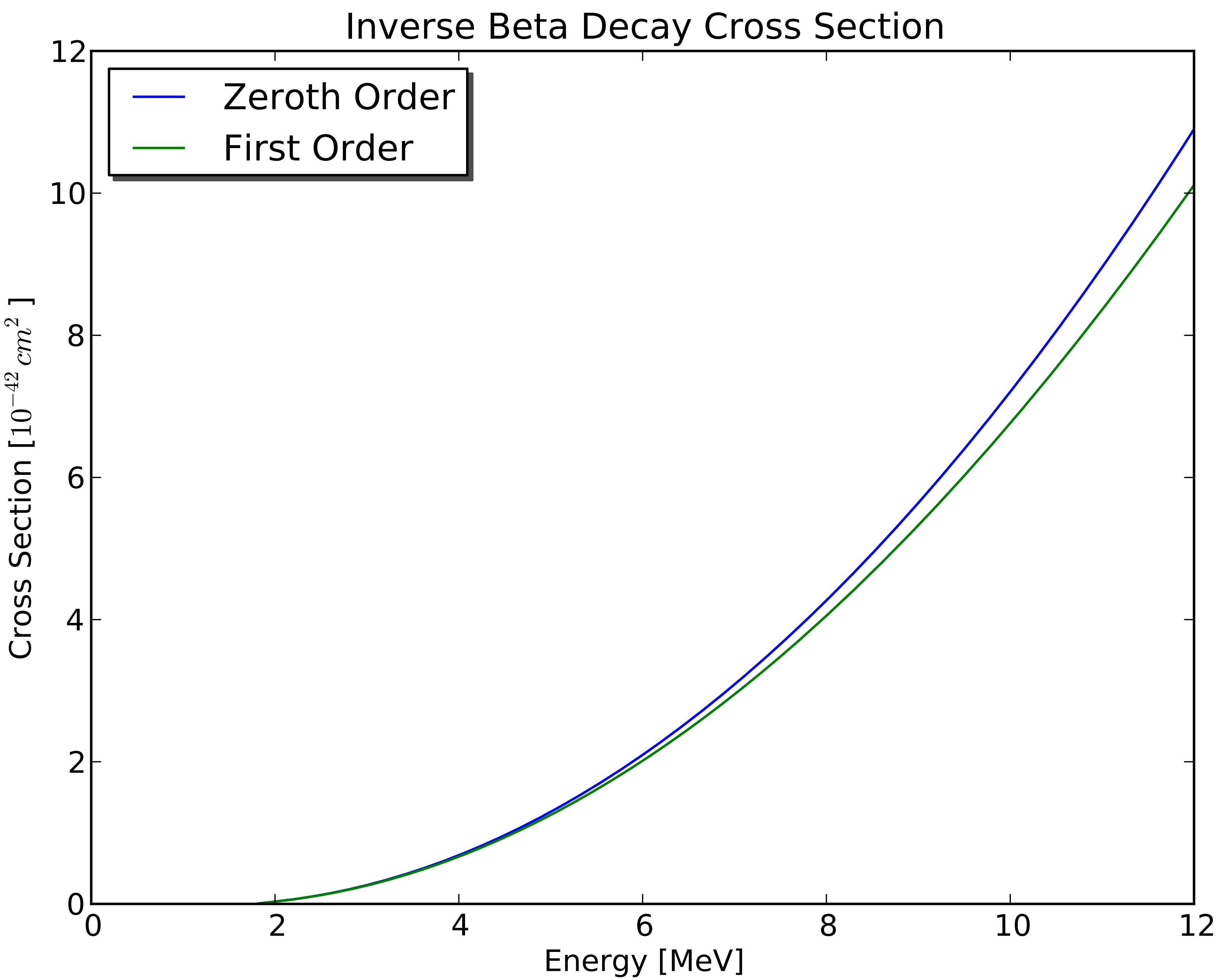


11 Fired PMT cut gives >98% efficiency in both inner and outer water shields.

Inefficient muons (red) are typically short tracks in the outer water shield.



IBD Cross Section



Fuel Cycles

$$^{238}U(n,\gamma)^{239}U$$

$$^{239}U \xrightarrow[E_{\nu}^{max}=1.26\,\mathrm{MeV}]{T_{1/2}=23\,\mathrm{min}} {}^{239}Np$$

$$^{239}Np \xrightarrow[E_{\nu}^{max}=0.71\ \mathrm{MeV}]{T_{1/2}=2.4\ \mathrm{days}} {}^{239}Pu$$

$$^{U}N\Big|_{E>1.8\ \mathrm{MeV}} = 0$$

Isotope Yields

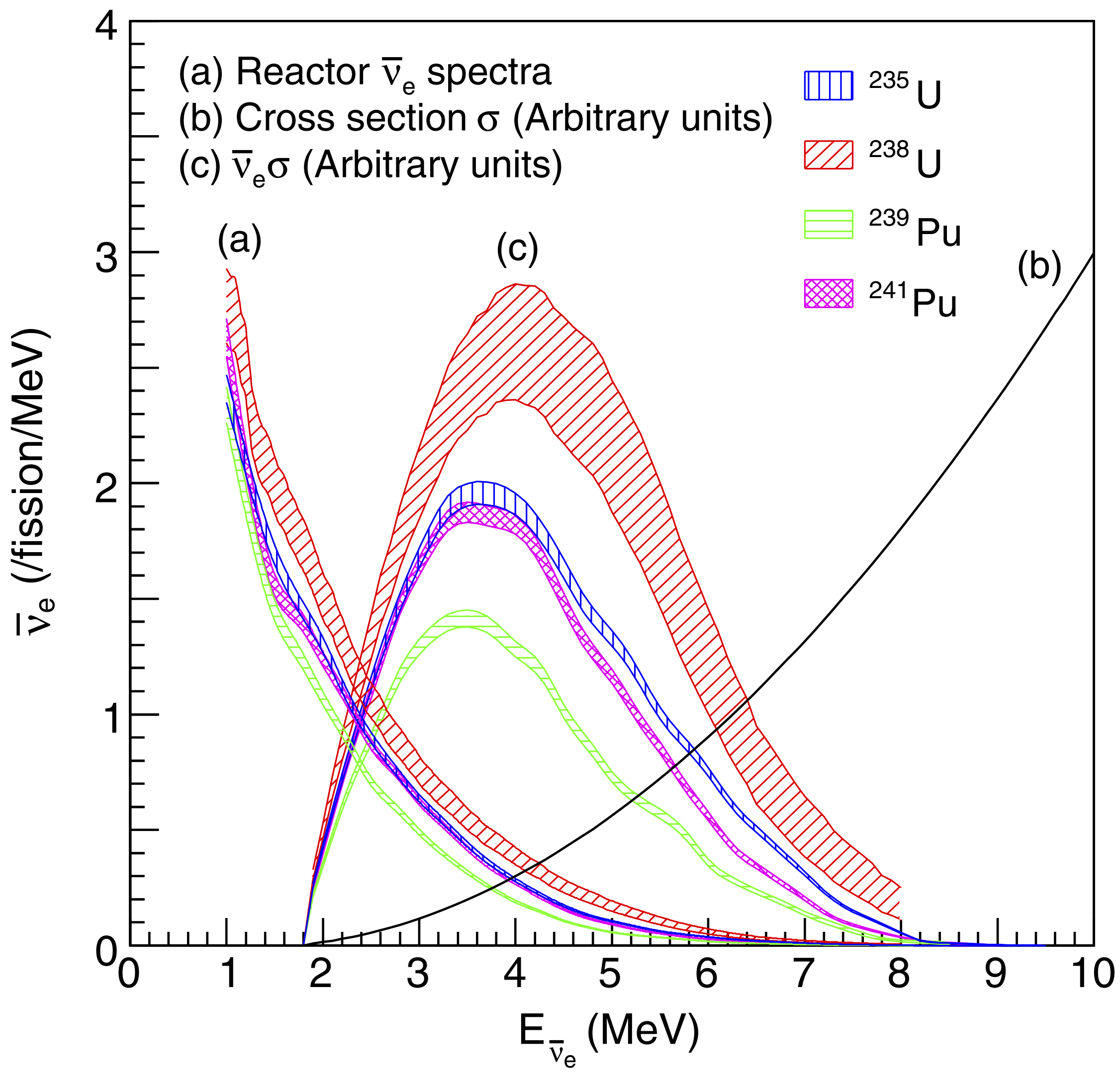
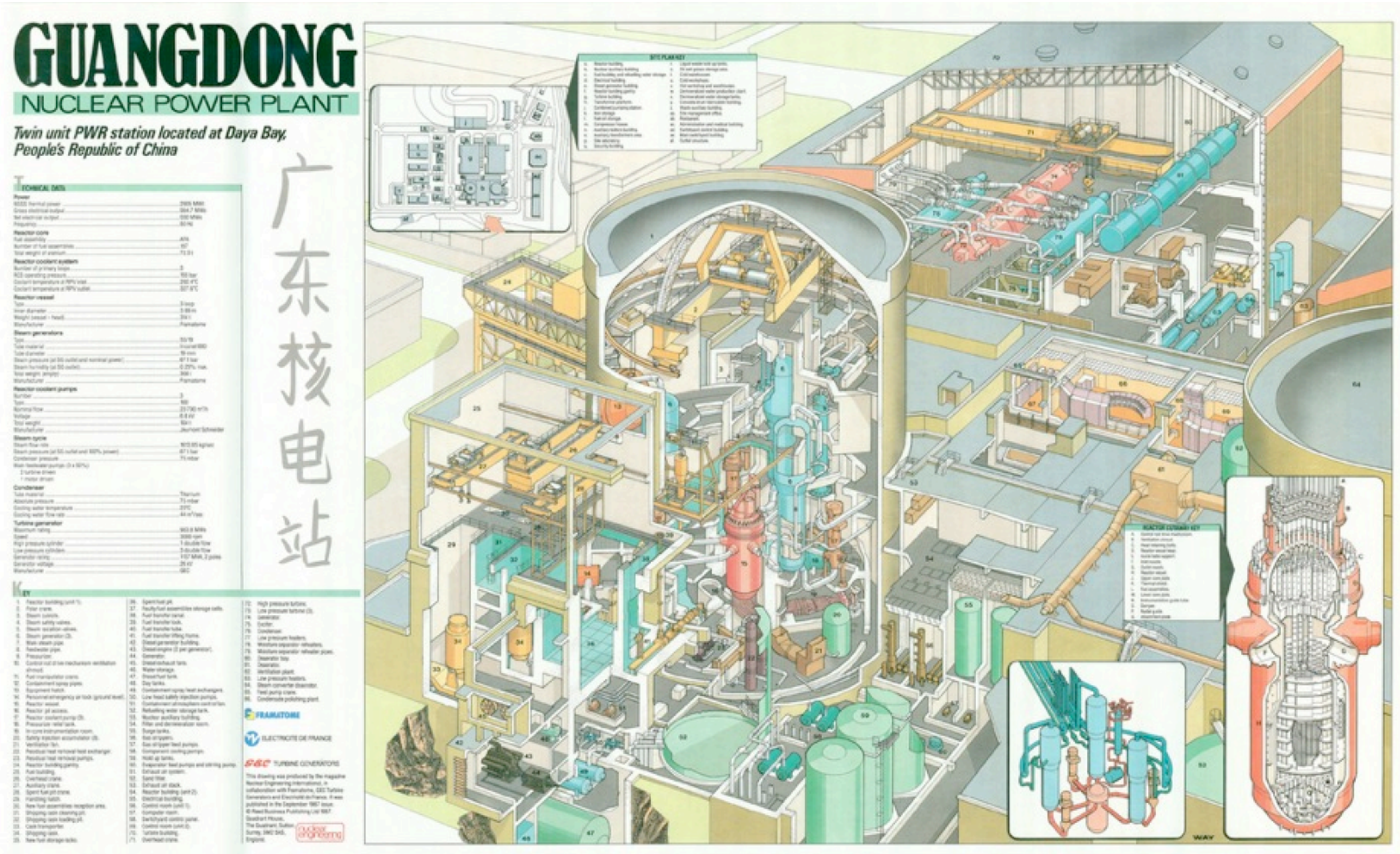


Fig. 1. (a) Reactor $\bar{\nu}_e$ energy spectra for four main fissile isotopes [5]. The shaded region for the isotopes gives the uncertainty in the spectrum. (b) Cross-section of the inverse β-decay reaction [4]. (c) $\bar{\nu}_e$ observed no-oscillation spectrum for each fissile isotope; this is a convolution of (a) and (b).

Nakajima et al. Nuclear Inst. and Methods in Physics Research (2006)

Reactor


GUANGDONG
NUCLEAR POWER PLANT
Twin unit PWR station located at Daya Bay, People's Republic of China
广东核电站

Core Data

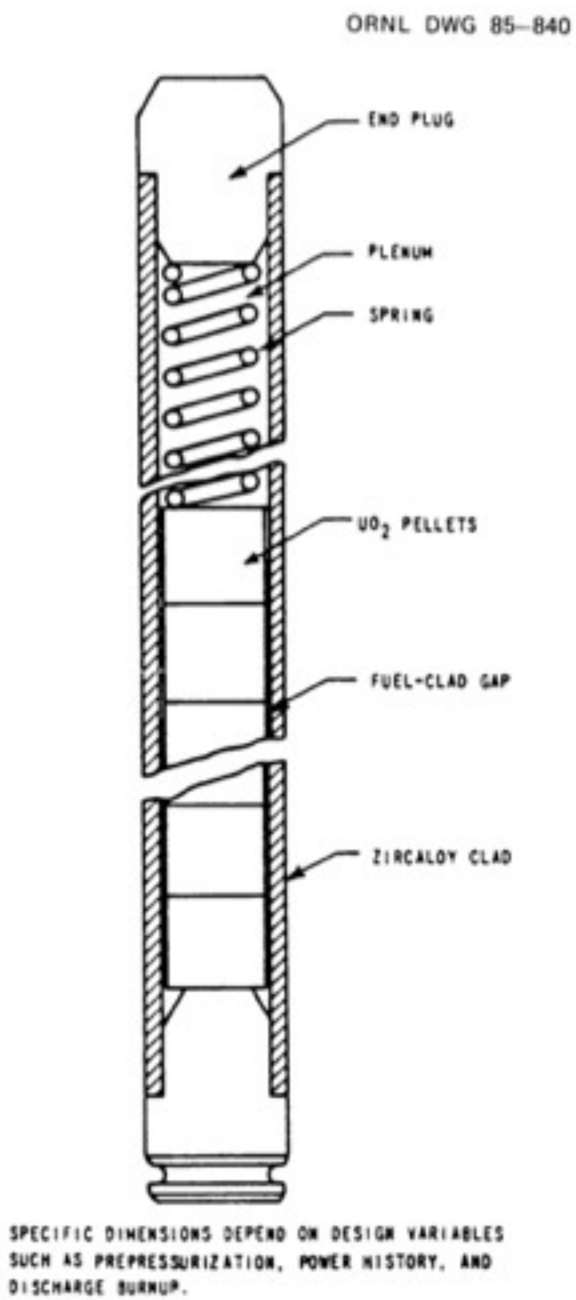
2 - TECHNICAL DESCRIPTION

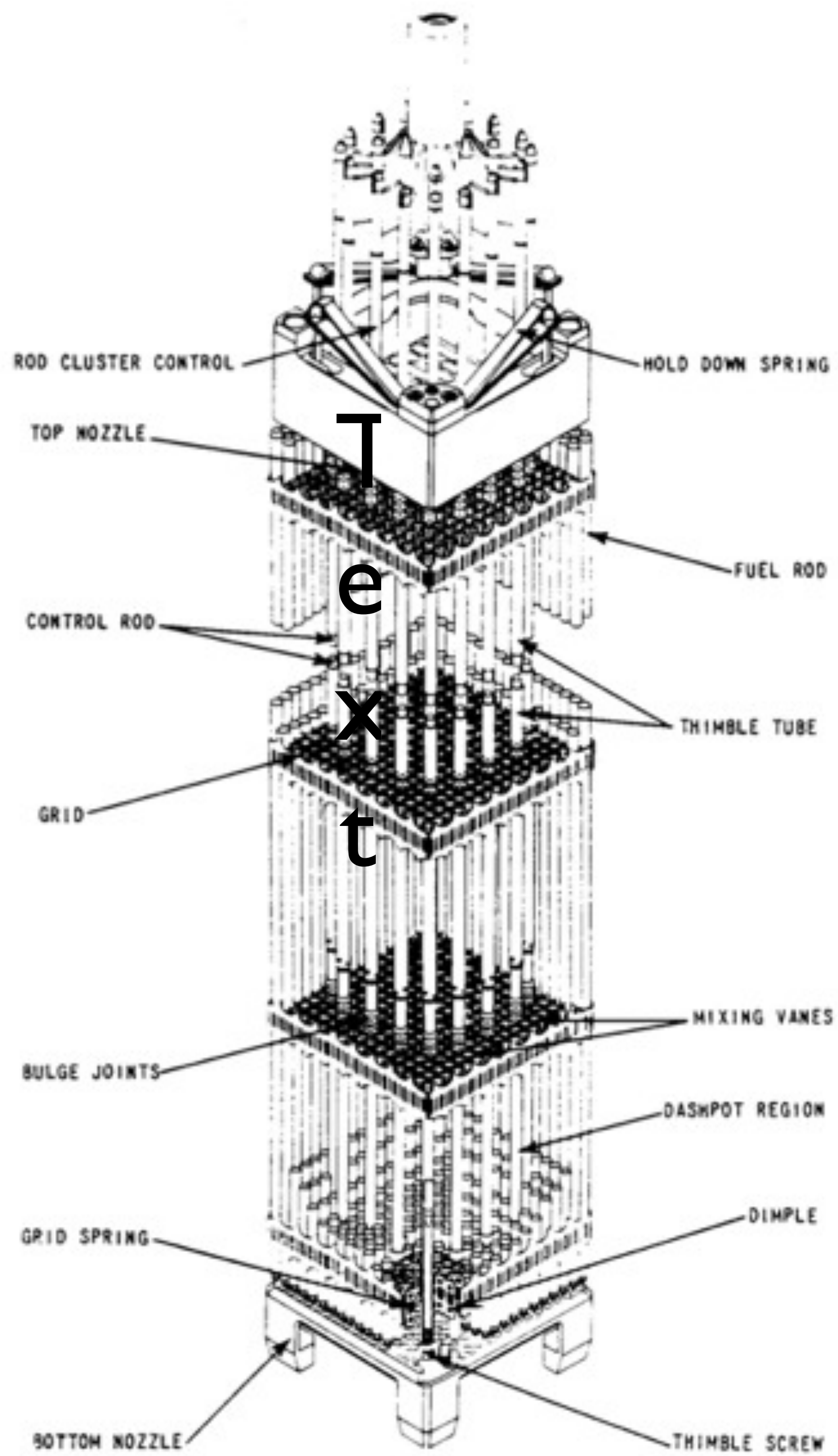
TECHNICAL DATA

Power	
NSSS rated thermal output	2905 MWth
Gross electrical output	990 Mwe
Reactor Containment	
Type	Single Containment Prestressed concrete + steel liner
Inside diameter	37 m
Wall thickness	0.90 m
Overall height (from ground level)	59.4 m
Overall internal volume	60000 m^3
Overall internal free volume	50000 m^3
Reactor Core	
Core rated thermal output	2895 MWth
Core damage frequency	5 x 10^{-6} reactor-year
Number of fuel assemblies	157
Total weight of Uranium	72.5 t
Rod cluster control available locations (equipped with CRDMs)	61
Main Primary System	
Number of reactor coolant loops	3
Number of CRDMs	61
Reactor coolant system operating pressure	155 bar
Reactor coolant temperature at RPV inlet	292.4°C
Reactor coolant temperature at RPV outlet	327.6°C
Steam generator tube material	Inconel 690
Steam pressure at SG outlet at nominal power	≥ 67.1 bar
Steam flow rate	1614 kg/s
Steam humidity at SG outlet	< 0.25%
Reactor coolant pump type	Model 100
Reactor coolant pump nominal flow	23790 m^3/h

Areva Press Release

Fuel Pin and Assembly





ORNL TM-9591

Event Rated

	Daya Bay Near	Ling Ao Near	Far Hall
Baseline (m)	363	481 from Ling Ao 526 from Ling Ao II	1985 from Daya Bay 1615 from Ling Ao
Overburden (m)	98	112	350
Radioactivity (Hz)	<50	<50	<50
Muon rate (Hz)	36	22	1.2
Antineutrino Signal (events/day)	840	740	90
Accidental Background/Signal (%)	<0.2	<0.2	<0.1
Fast neutron Background/Signal (%)	0.1	0.1	0.1
^{8}He+^{9}Li Background/Signal (%)	0.3	0.2	0.2