Measurement of the Absolute $\overline{\nu}_e$ Flux at Daya Bay

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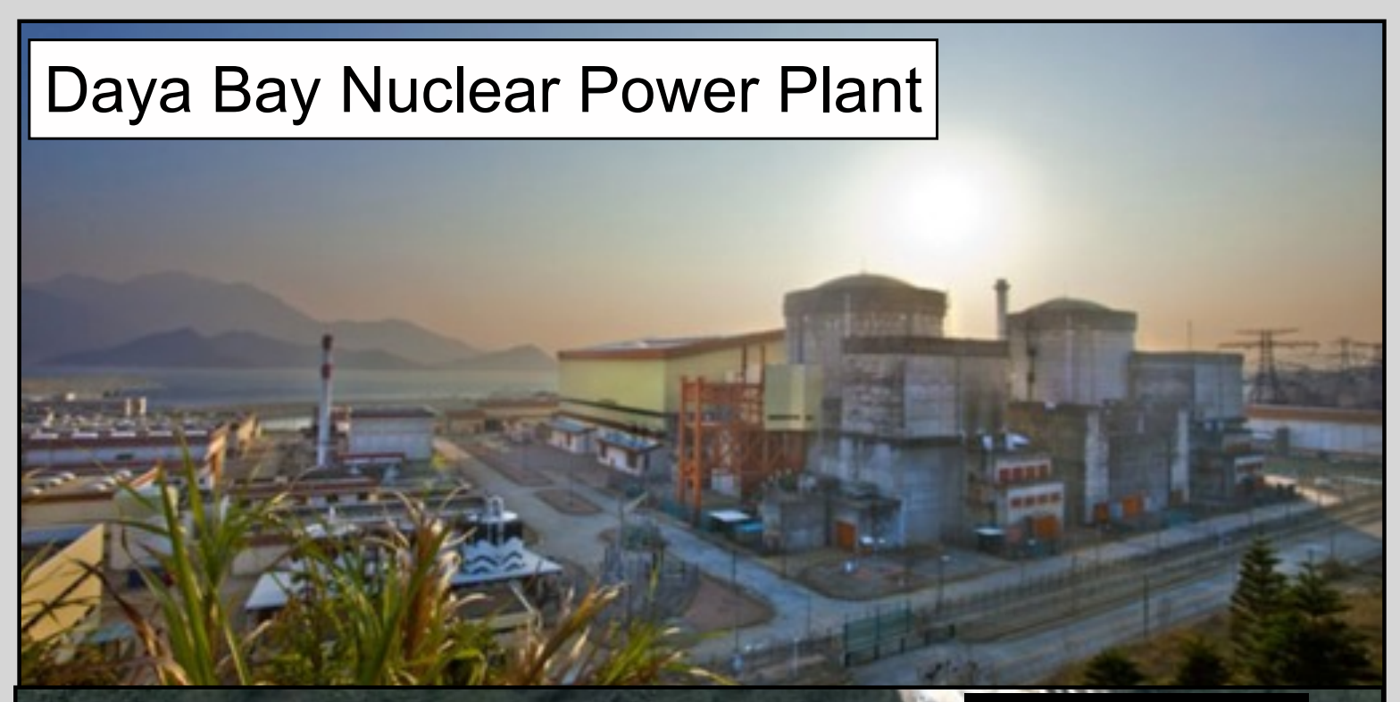
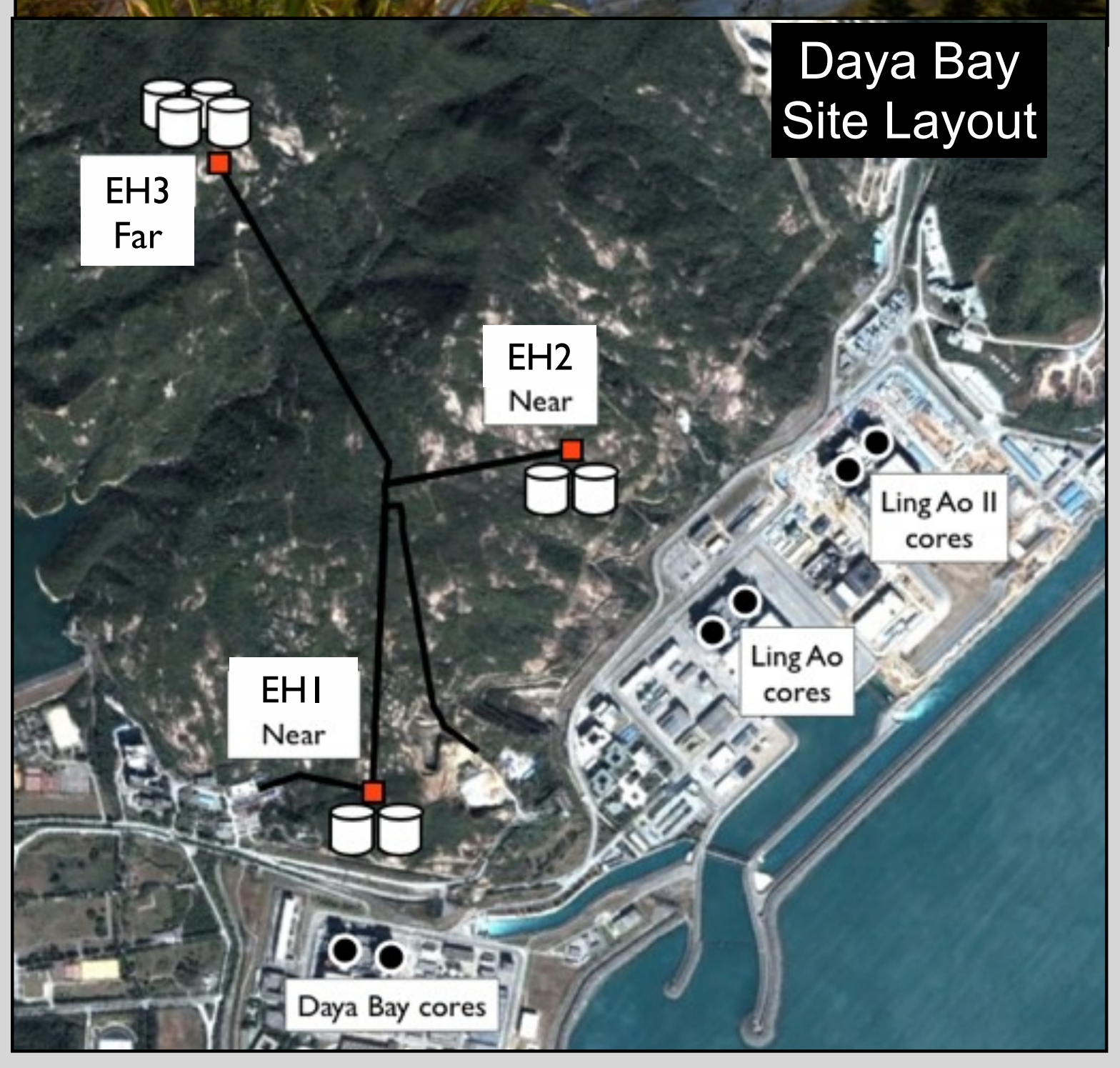
The Daya Bay reactor $\overline{\nu}_e$ experiment has provided the most sensitive measurement of the neutrino mixing parameter θ_{13} by measuring relative differences in reactor $\overline{\nu}_e$ interaction rates between detectors at long and short baselines. In addition, the Daya Bay experiment can make a high-statistics measurement of the absolute reactor $\overline{\nu}_e$ flux and spectrum. Daya Bay's first absolute flux measurements are presented in this poster along with comparisons to previous experiments and existing reactor models. The absolute spectrum analysis and its value in understanding existing reactor models will also be discussed.

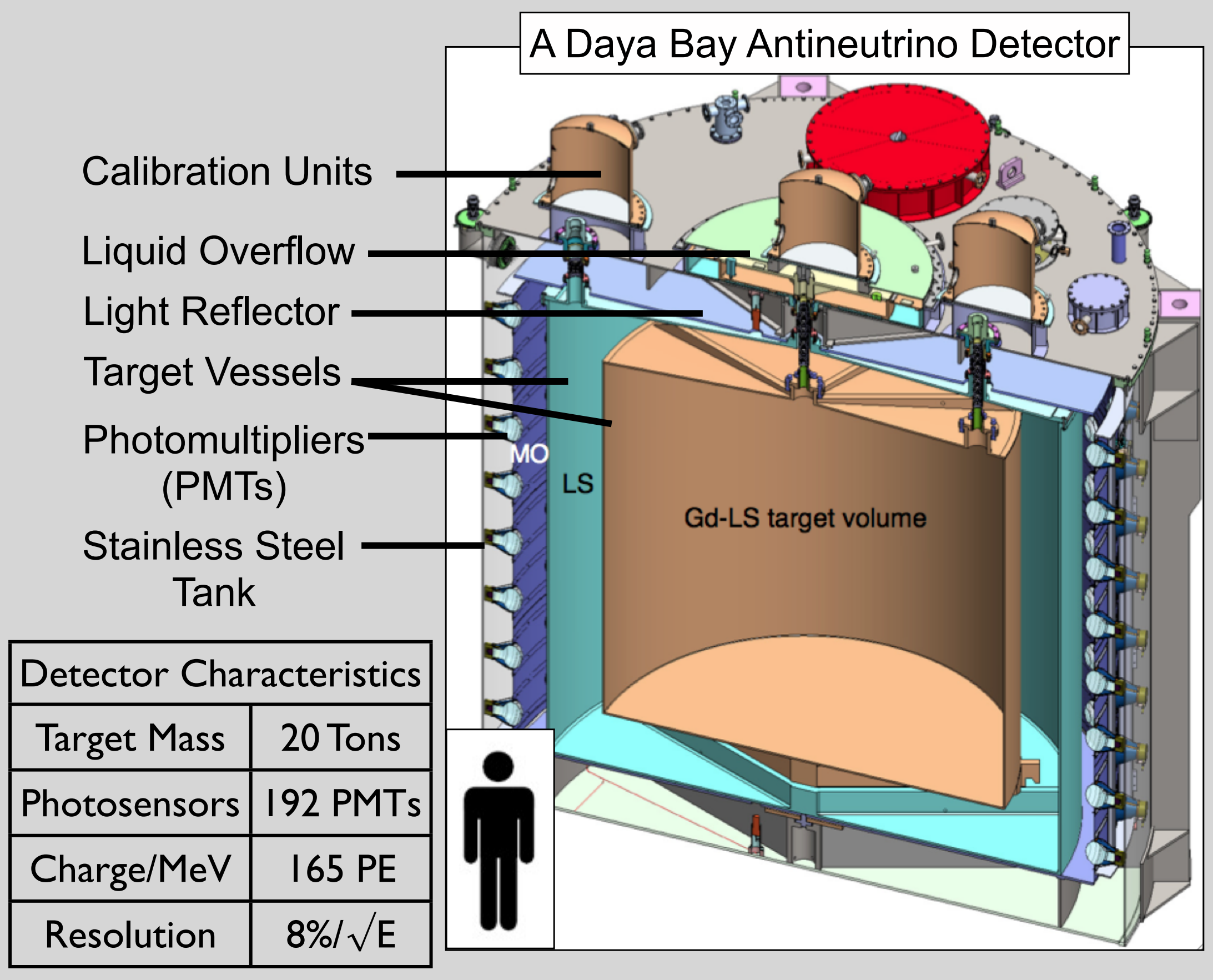
The Daya Bay Experiment

- Six 2.95 GW_{th} nuclear reactors; six liquid scintillator detectors, three sites


Daya Bay Nuclear Power Plant


Daya Bay Site Layout

- Detect $\overline{\nu}_e$ via inverse beta decay (IBD)
- Relative flux+spectrum comparison between near/far sites gives world's best measurement of θ_{13} [1]


A Daya Bay Antineutrino Detector

Detector Characteristics	
Target Mass	20 Tons
Photosensors	192 PMTs
Charge/MeV	165 PE
Resolution	8%/√E

Analysis

- Blind analysis: Sequester true reactor powers and fission fractions
- Utilized two differing analysis methods
- Fit oscillation and flux simultaneously using the Daya Bay rate-only X² [4] with an additional normalization fitting parameter

$$\chi^2 = \sum_{d=1}^{6} \frac{\left[M_d - \underset{\theta_{13}\text{ included here}}{\boxed{T_d}}\left(1 + \underset{\text{normalization}}{\boxed{\varepsilon_R}} + \varepsilon_D + \sum_r \omega_r^d \alpha_r + \varepsilon_d\right) + \eta_d\right]^2}{M_d + B_d} + \chi^2_{\text{penalty}}$$

- Calculate flux directly in multiple ways using nominal inputs
- Use either one common model with differing thermal power for all cores, or use reactor-specific modeling of fission fractions and other corrections

$$Y_c = Y_0 + \delta Y_c$$

Common to all cores

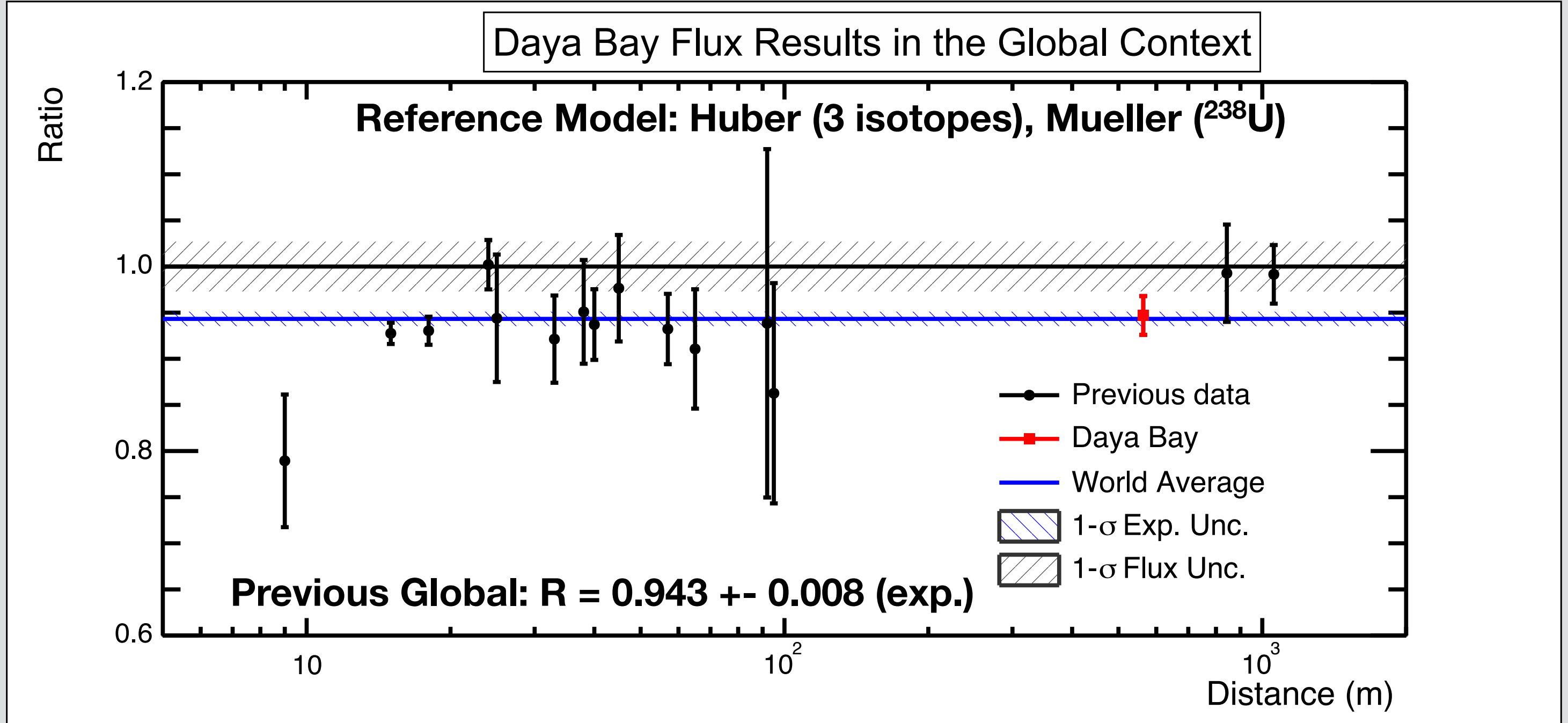
$$Y_0^{\text{obs}} = \frac{N_d^{\text{obs}} - N_d^{\text{bkg}}}{\epsilon_d T_d n_d \sum_c \frac{W_c}{4\pi L_{dc}^2}\langle p_{dc}\rangle} \approx Y_c$$

Differing between cores: fission fraction, etc.

$$\phi_c(E) = \sum_i \frac{f_i}{\sum_j f_j e_j} \times S_i(E) + \text{corrections}$$

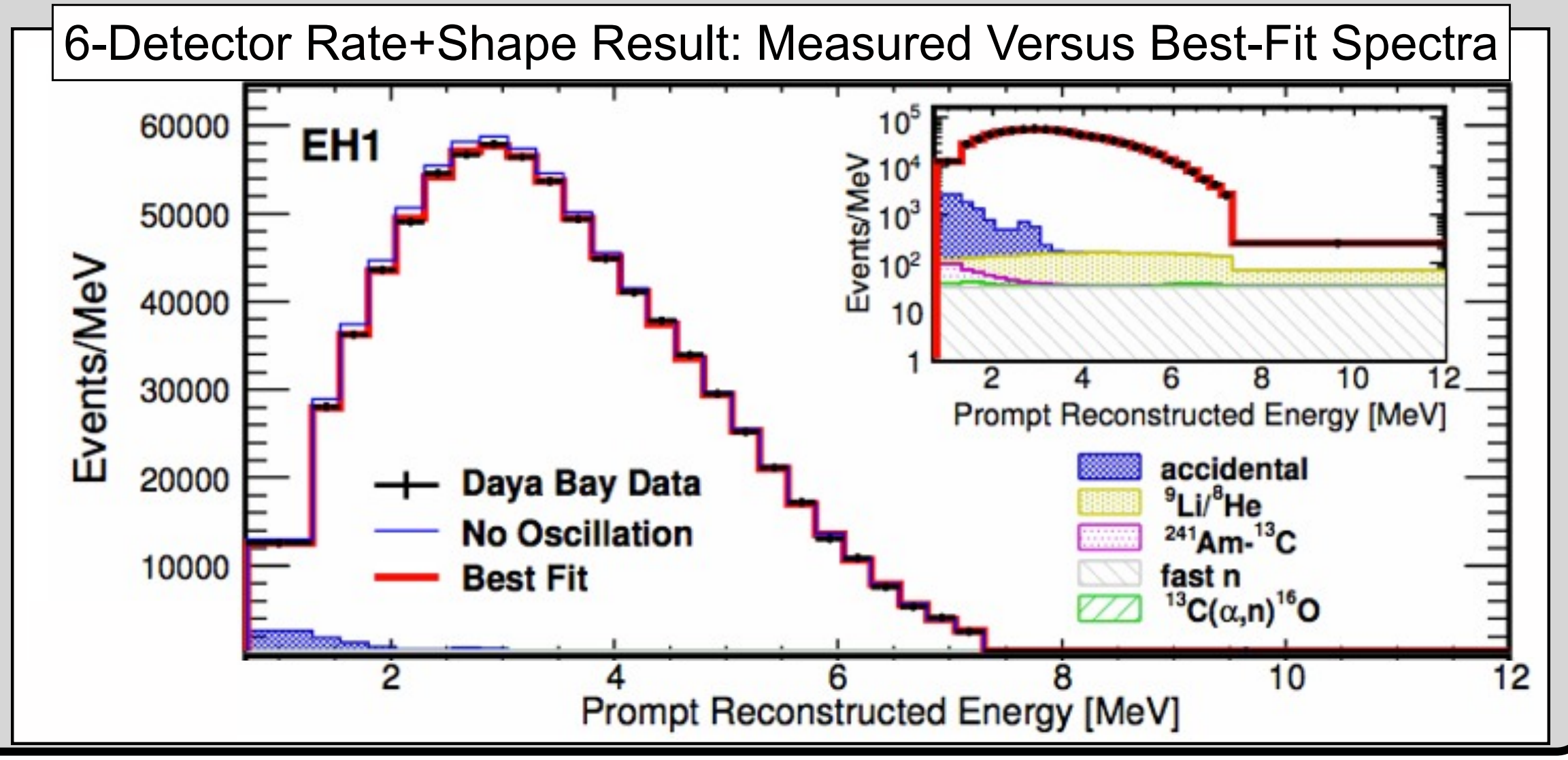
Global Context

- Re-calculated average measured flux of previous experiments utilizing consistent inputs (\l$_{\text{neutron}}$ = 880.1 s [5], non-zero θ_{13})
- Daya Bay measurement is completely consistent with global average flux
- See the same 'reactor anomaly' as indicated by previous global fit


Daya Bay Flux Results in the Global Context

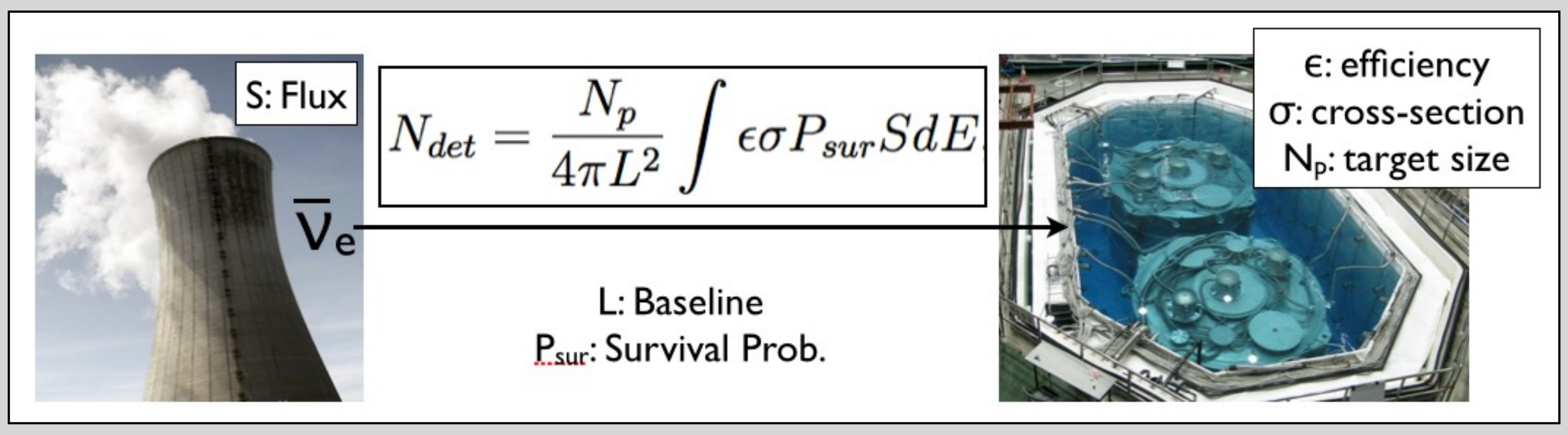
Absolute Spectrum Measurement

- Current rate+shape osc. fit largely insensitive to underlying spectrum model
- **Working to provide a comparison of nominal to measured spectrum**
- Will provide insight on nature of the disagreement with modeled reactor flux
- Spectral features: May indicate improperly modeled reactor physics [6]
- Flat: Could arise from either improperly modeled reactor physics and/or large-Δm^2 oscillations to sterile neutrinos


6-Detector Rate+Shape Result: Measured Versus Best-Fit Spectra

Measuring Absolute Reactor Flux

- **How many neutrinos are coming out of nuclear reactors per fission?**
- Daya Bay flux measurement can provide high-statistics check of existing models/measurements and test for existence of the 'reactor anomaly' [2,3]

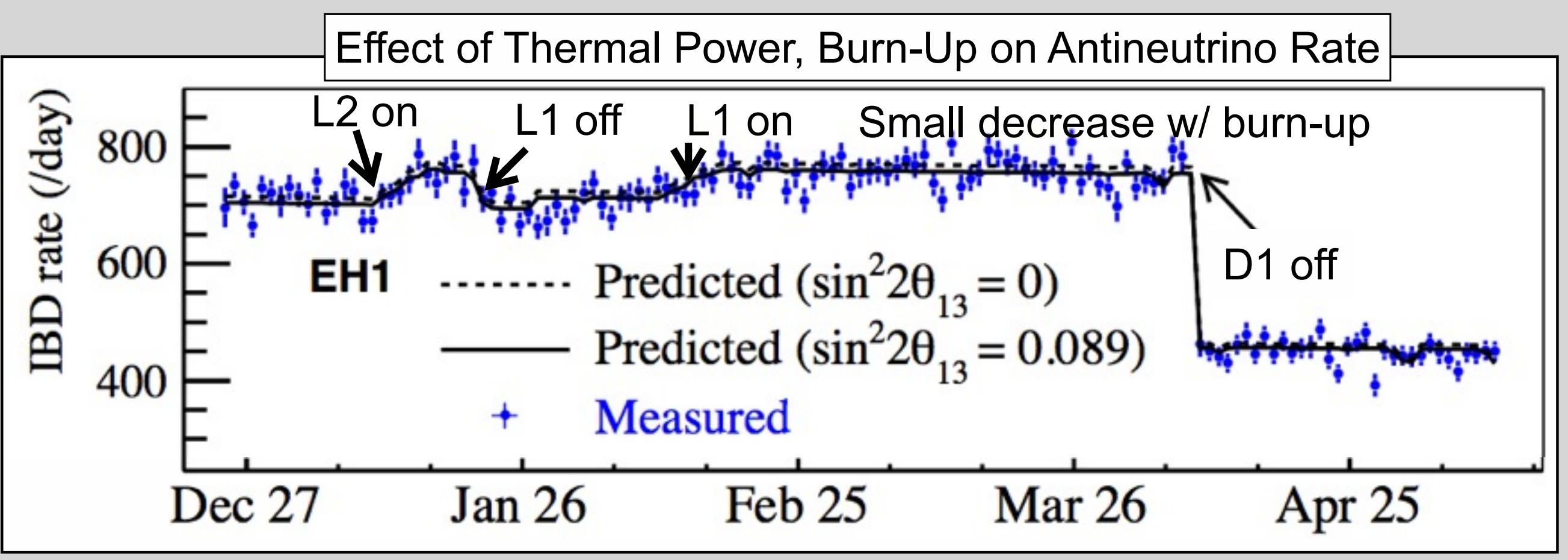


$$N_{det} = \frac{N_p}{4\pi L^2}\int \epsilon\sigma P_{sur} S dE$$

- Different metrics can be used to describe same flux measurement ∫SdE:
  - Y_0: Rate, cm²/(p·GW·d): relies on thermal power input from power plant
  - σ_f: Cross section, cm²/fission: common in literature, requires burn-up info
- Key Inputs:
  - Detector: Target protons (LS chemistry, target mass), absolute detection efficiency (Analysis in G. Cao's poster)
  - Baselines (GPS, metrological measurements)
  - Inverse beta decay cross section (Theory, other exp's)
  - Neutrino oscillation from three-neutrino mixing
  - Reactor: Thermal powers, burn-up and fission fractions for each core; data provided by power company (See X. Ma's poster for details)

Target Masses

AD	GdLS mass/20t
1	0.99705
2	0.9983
3	0.99455
4	0.99565
5	0.99955
6	0.9946

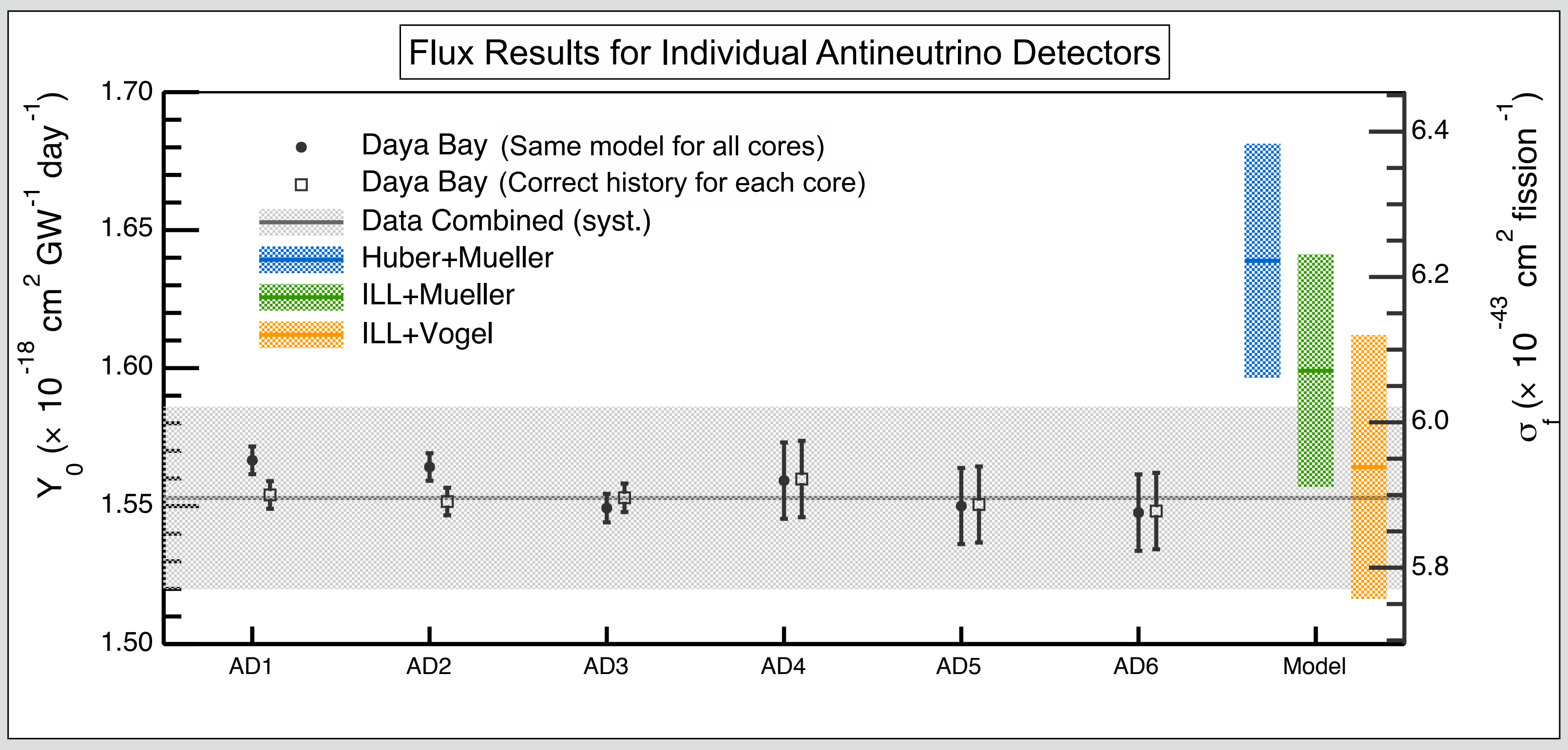

Effect of Thermal Power, Burn-Up on Antineutrino Rate

Detector Uncertainties

Input	ϵ	$\delta\epsilon/\epsilon$
Target protons	-	0.47%
Flasher cut	99.98%	0.01%
Muon veto cut	-	0.02%
Multiplicity cut	-	0.02%
Capture time cut	98.70%	0.12%
Prompt energy cut	99.81%	0.10%
Gd capture ratio	84.2%	0.95%
nGd detection efficiency	92.7%	0.97%
Spill-in correction	104.9%	1.50%
Combined	80.6%	2.08%

Results

- High degree of consistency in measured Y_0, σ_f between reactor cores
- Clear discrepancy between measurement and newest reactor models

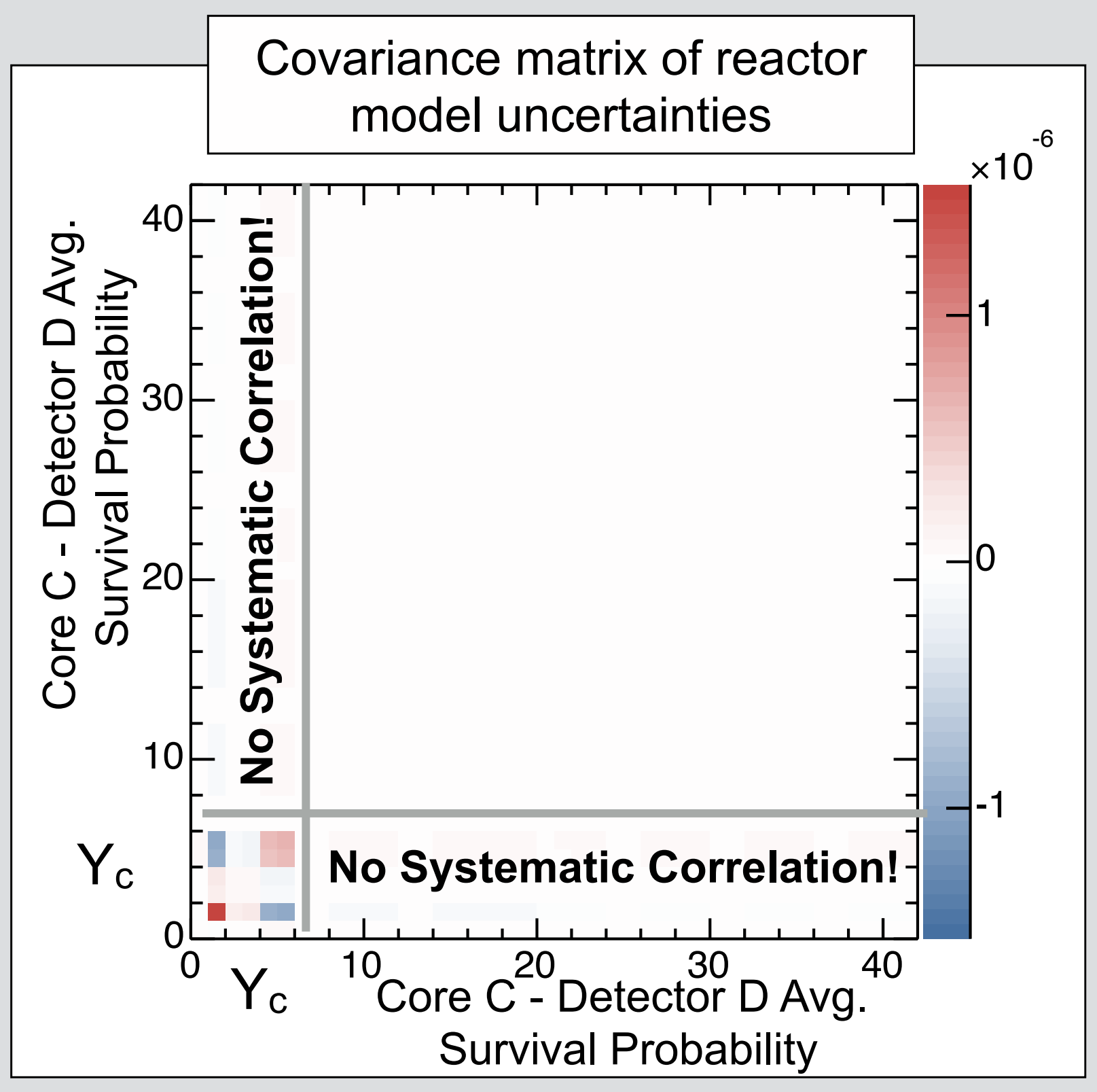

Flux Results for Individual Antineutrino Detectors

- Detection efficiency uncertainty dominates flux systematics
- Statistical uncertainty is completely negligible from high statistics: >300,000 IBD detected
- Flux measurement is relatively insensitive to precise reactor history
- Very little correlation between flux and survival probability

data/model [2,3]	0.0947 +/- 0.021
σ_f	5.934 x 10^{-43} cm² / fission
Y_0	1.553 x 10^{-18} cm² / (p·GW·d)
^{235}U : ^{238}U : ^{239}Pu : ^{241}Pu	0.586 : 0.076 : 0.288 : 0.050
Effective Baseline	573 m

Systematics Breakdown

Systematic	**δϕ/ϕ (%)**
Detection Efficiency	2.0
Target protons	0.5
Thermal power	0.5
Fission Fractions	0.6
Oscillation	0.2
Statistics	0.2
Total	2.3


Covariance matrix of reactor model uncertainties

References:

- [1] Daya Bay Collab., PRL 112 061801 (2014)
- [2] T. Mueller, et. al, PRC 83 054615 (2011)
- [3] P. Huber PRC 84 024617 (2011)
- [4] Daya Bay Collab. PRL 108, 171803 (2012)
- [5] Particle Data Group, PRD 86 010001 (2012)
- [6] A. C. Hayes, *et. al,* PRL 112 202501 (2014)