The Daya Bay Calibration System — Key to θ_{13}

Jianglai Liu
Caltech, for the Daya Bay Collaboration

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Requirement on Systematic Uncertainty

$$\frac{N_{\mathrm{f}}}{N_{\mathrm{n}}} = \left(\frac{N_{\mathrm{p,f}}}{N_{\mathrm{p,n}}}\right)\left(\frac{L_{\mathrm{n}}}{L_{\mathrm{f}}}\right)^2\left(\frac{\epsilon_{\mathrm{f}}}{\epsilon_{\mathrm{n}}}\right)\left[\frac{P_{\mathrm{sur}}(E, L_{\mathrm{f}})}{P_{\mathrm{sur}}(E, L_{\mathrm{n}})}\right]$$

Measured Ratio of Rates

Number of Proton Ratio

Detector Efficiency Ratio

$\sin^2 2\theta_{13}$

Goal:

<1% to $\sin^2 2\theta_{13}$

0.3%

0.2%

Key requirement of the calibration program

Calibration of Detector Efficiency

- Geometry (edge effects, spill in/out)

  cancel in ratio for identical detectors

- Positron detection

  energy cuts at 1, 8 MeV

- Neutron detection

  energy threshold at 6 MeV

  delayed timing cuts [0.3, 200] μs

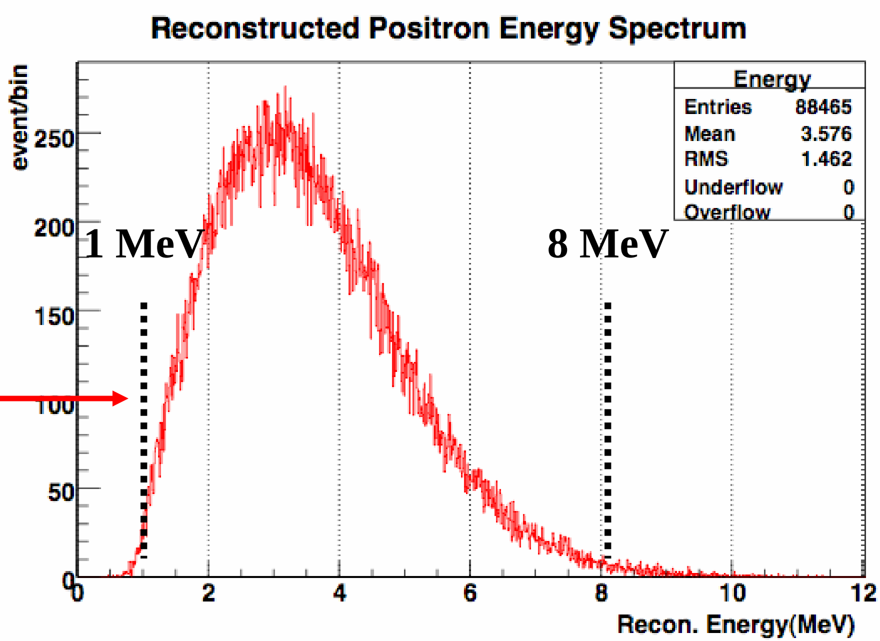
  Gd/H cancels in near/far ratio when filling in pair

Calibration Program

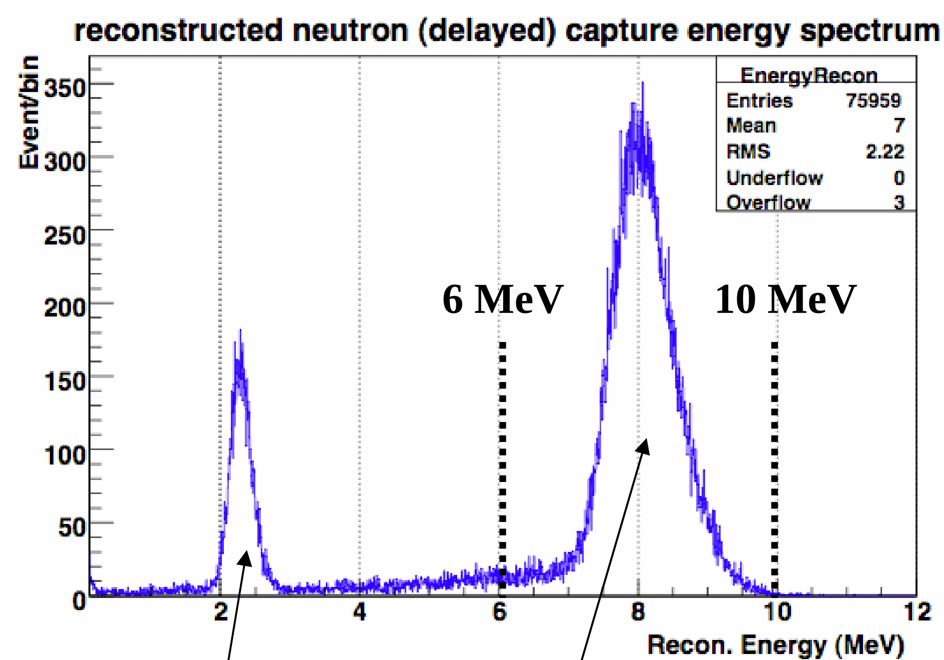
- Routine (weekly) deployment of sources
- Radioactive sources = fixed energy, LED light source = fixed time
- Tagged cosmogenic background (free) = fixed energy & time

Energy Cuts

Prompt Energy Signal (Simulation)



Delayed Energy Signal (Simulation)



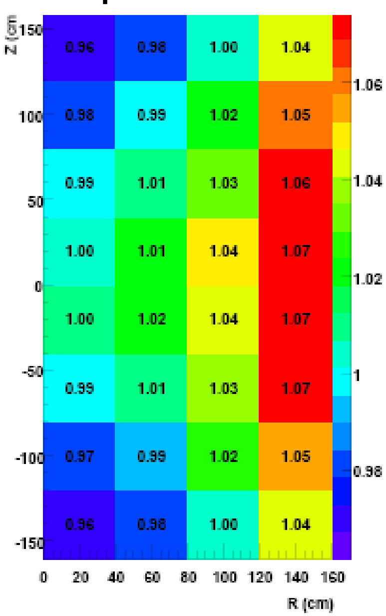
- Stopped positron signal using ^{68}Ge source (2 x 0.511 MeV) ⇒ e^+ threshold
- Neutron (n source, spallation) capture signal
  - 2.2 MeV ⇒ e^+ energy scale
  - 8 MeV ⇒ neutron threshold at 6 MeV

Major Issue: Neutron Threshold

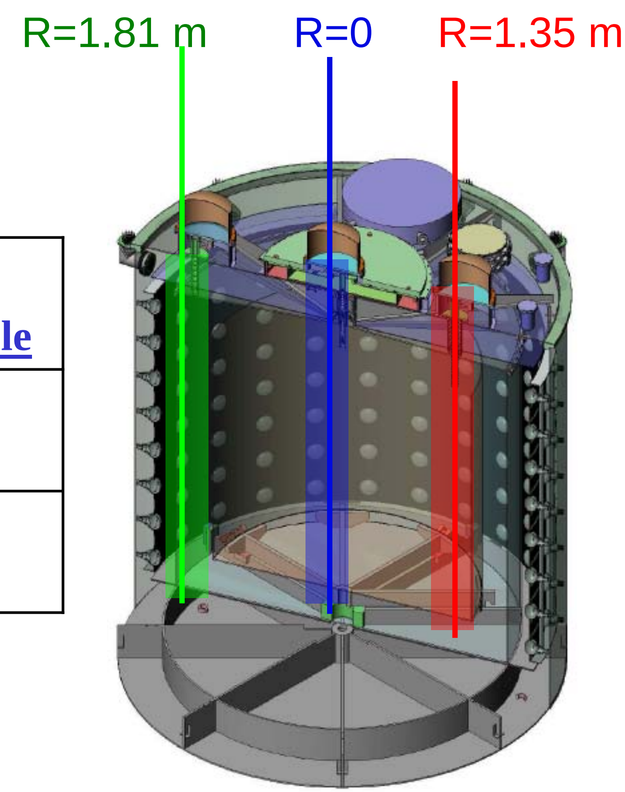
Simulation: 0.2% on detector efficiency ⇔ knowing positron threshold to 2% (easy), relative neutron threshold to 1% (more difficult)

Strategy: use position reconstructed spallation n-Gd capture signals (full fiducial volume) + weekly deployment of neutron sources (3 vertical axes)

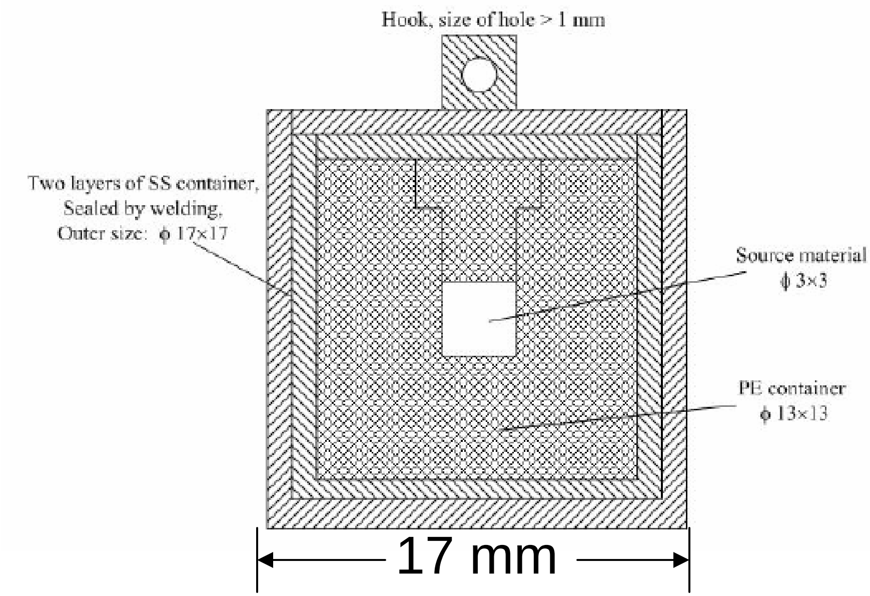
100 pixel/detector



	Near /day/module	**Far /day/module**
Spallation Neutrons	13500	1100
σ/E=0.5% per pixel	1 day	10 days



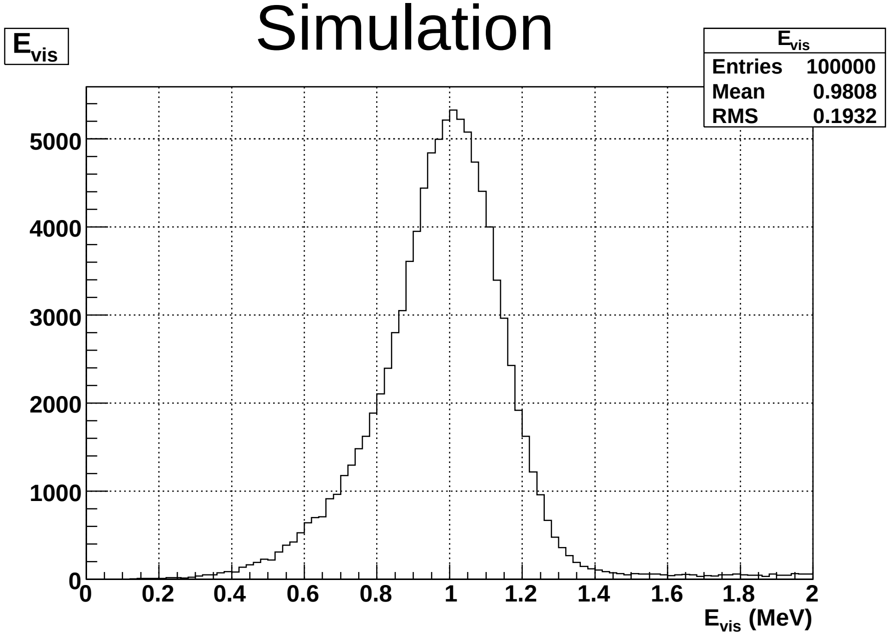
^{68}Ge Source: Stopped e^+



$$^{68}Ge \xrightarrow{EC} {}^{68}Ga \xrightarrow{\beta^+} {}^{68}Zn$$

Rate: 100 Bq ($T_{1/2}$ = 270 days)

Simulation

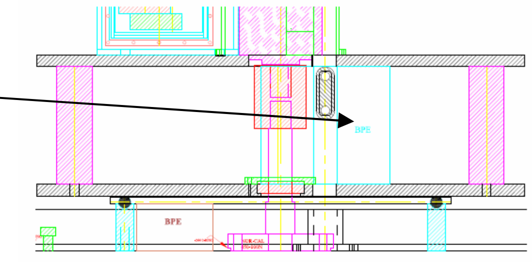


Simulation:

- 3% of positrons hitting the stainless steel capsule. Others annihilated in plastic
- Net energy escaped via Bremsstrahlung ~ 0.17%

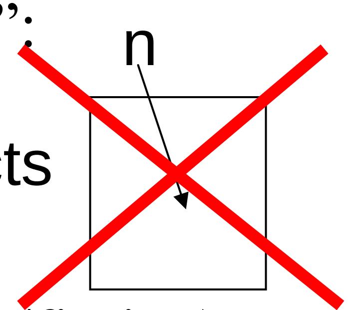
Neutron Source

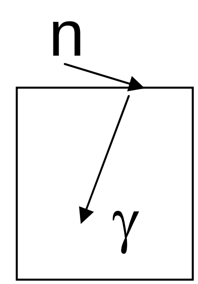
- Source “parked” above detector during normal running with borated polyethylene shielding



- Neutron “leakage”:

Directs
small





Captures on steel
“Neutron-like”!

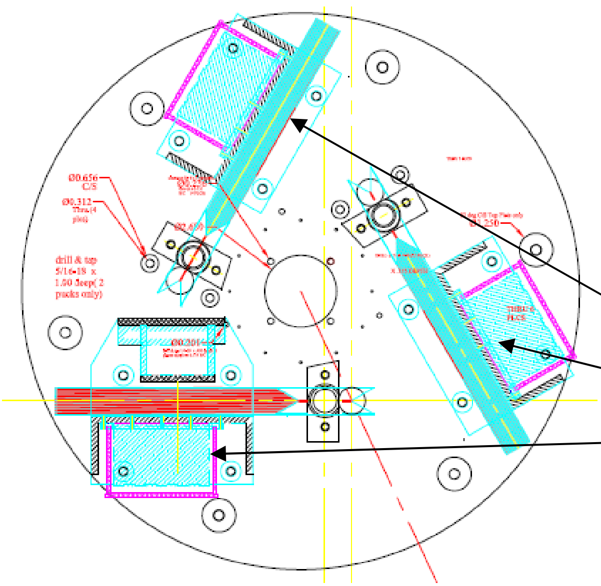
- ^{252}Cf (3-4 neutrons/fission) or Am-Be (4.4 MeV gammas): coincidence (dangerous) background level too high

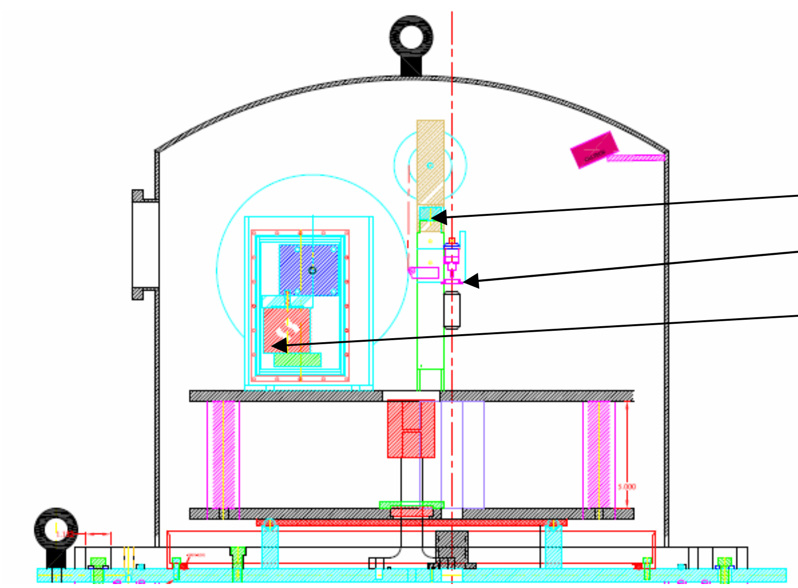
Solution:

- Limit neutron rate to 0.5 Hz
- Use ^{241}Am (alpha) + ^{13}C $\Rightarrow$ n + ^{16}O
- Attenuate alpha energy with Au foil to <4.5 MeV to suppress ^{16}O in excited state (6.15 MeV gamma)

} <0.1% background contamination at the far site

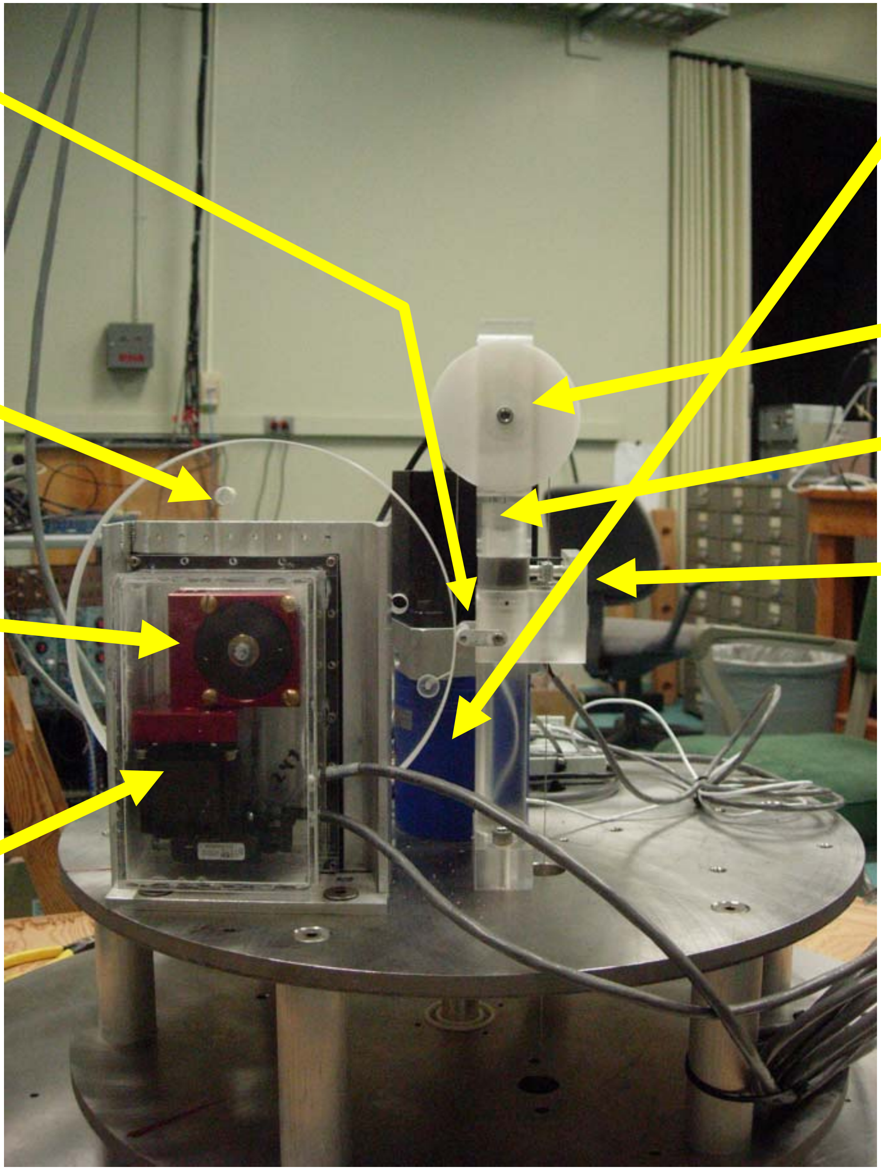
Design of Calibration Unit





- Three units per detector (3 z axes)
- Each unit contains three stepper motor systems on a turntable, capable of deploying three sources: ^{68}Ge, neutron, and LED along a given vertical axis
- 100% automated remote control/monitoring software
- Position encoder, limit switch, load cell to ensure a fail safe system
- Selection of materials: Stainless steel, Teflon, Viton and Acrylic

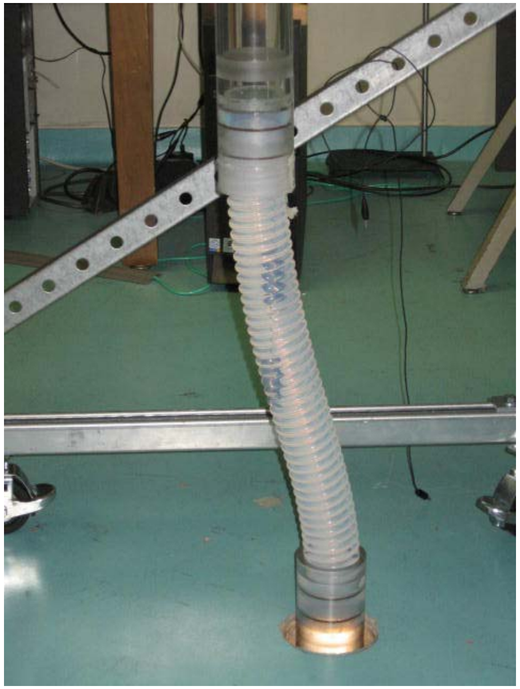
Full Size Prototype

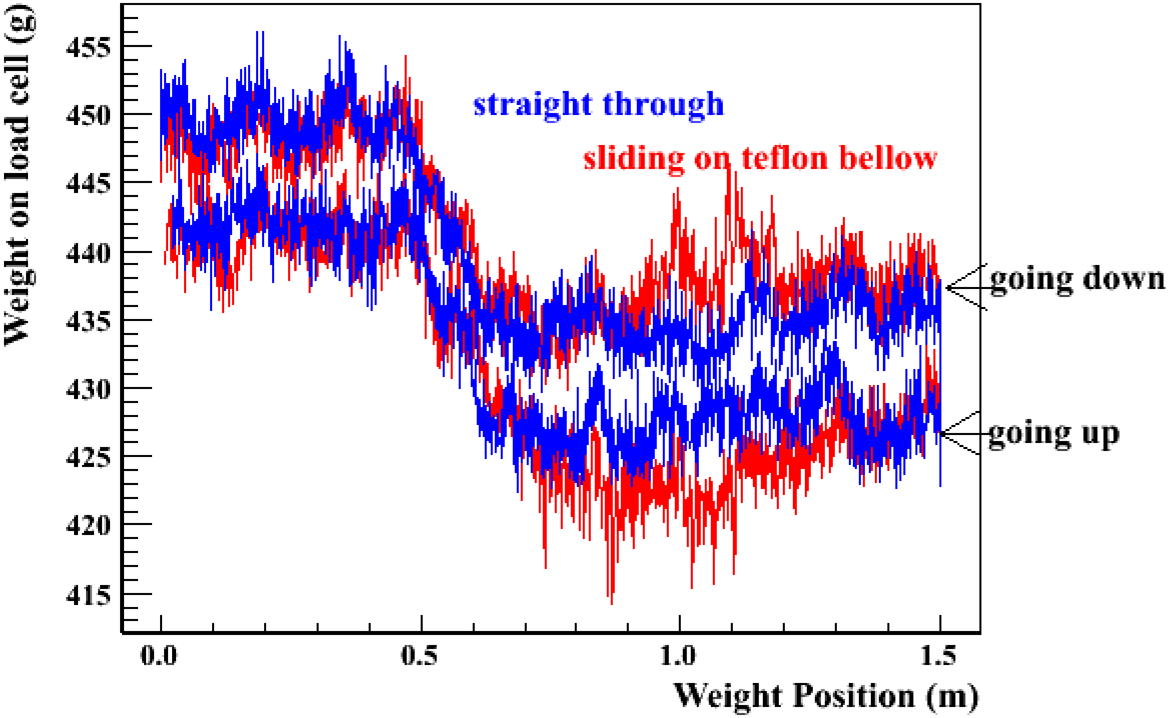


2-floor down

Tested in lab >20-year worth of deployment!

Dragging Along Teflon Bellows





Status

• Mechanical/electronics design finished. Performed many prototype tests

• Fabrication in progress. On schedule to ship 3 units to Daya Bay Dec. 08

Turn-table plate out-of the shop

Assembly area at Caltech

Backups

Experimental Principle of Daya Bay