The Daya Bay Calibration System

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on behalf of the Daya Bay Collaboration

Caltech

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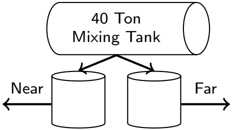
Outline

1. Systematic Uncertainties
2. Automated Calibration Units
3. Simulations of Calibration Sources
4. Concluding Remarks

Requirements on Systematic Uncertainties

$$\underbrace{\frac{R_f}{R_n}}_{\text{Measured Ratio of Rates}} = \underbrace{\left(\frac{N_{p,f}}{N_{p,n}}\right)}_{\text{Proton Number Ratio}} \left(\frac{L_n}{L_f}\right)^2 \underbrace{\left(\frac{\epsilon_f}{\epsilon_n}\right)}_{\text{Detector Efficiency Ratio}} \frac{\mathcal{P}_{sur}(E, L_f; \sin^2 2\theta_{13})}{\mathcal{P}_{sur}(E, L_n; \sin^2 2\theta_{13})}$$

- Sensitivity goal: $\sin^2 2\theta_{13} < 0.01$
- N_p relative uncertainty: 0.3%
  Attained using load cells and Coriolis mass and volume flow meters
- ϵ relative uncertainty: 0.2%
  Key requirement of calibration program

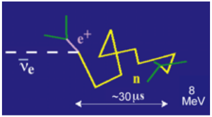


IBD Detection

Detect $\bar{\nu}$s via inverse beta-decay in 20 tons of 0.1% Gd-doped LS:

IBD threshold: $E_{\bar{\nu}}^{thr} = 1.806$ MeV

$\bar{\nu}_e + p \rightarrow e^+ + n$

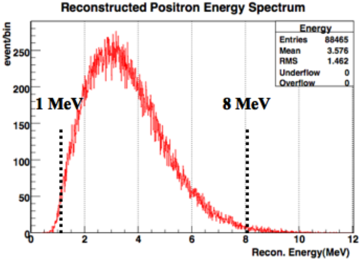


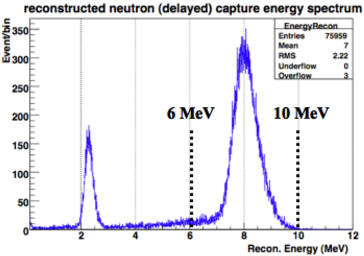
Prompt Signal: $e^+ + e^- \rightarrow 2\gamma$

Delayed Signal:

$n + \text{Gd} \rightarrow \text{Gd} + \gamma$ ($\sim$8 MeV) [$\sim$50,000 barns]

$n + p \rightarrow d + \gamma$ (2.2 MeV) [0.3 barns]





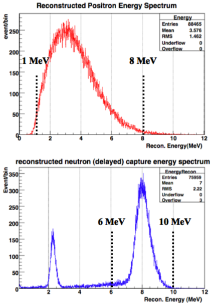
Detector Efficiency Calibration

Positron detection:

- Energy cuts at 1 and 8 MeV

Neutron detection:

- Energy cuts at 6 and 10 MeV
- Delayed timing cuts [0.3 μs, 200 μs]
- Gd/H ratio



To achieve 0.2% on detector efficiency, need to know e^+ relative threshold to 2% (easy) and relative n threshold to 1% (more difficult).

Calibration program:

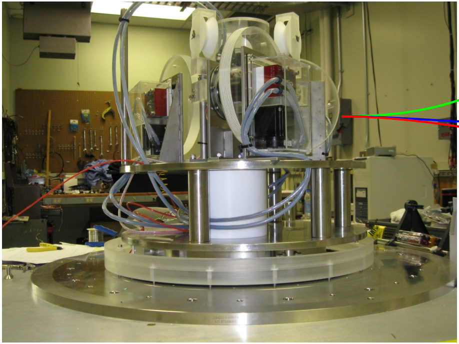
◇ Routine (weekly) deployment of calibration sources

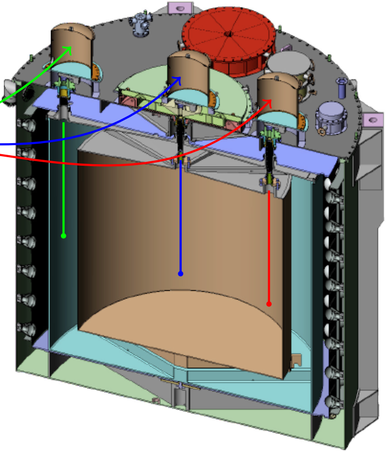
◇ Radioactive sources → fixed energy
LED light source → fixed time

◇ Tagged cosmogenic background

Outline

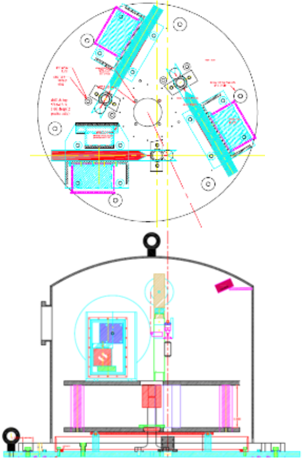
Automated Calibration Units (ACU)





3 ACUs: LS and on-/off-axis GdLS

Automated Calibration Units



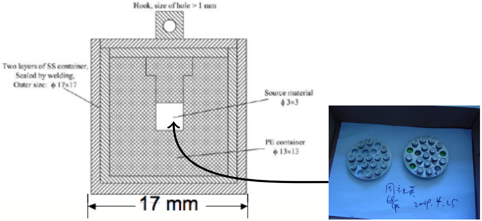
Source deployment (speed $\times 5$):

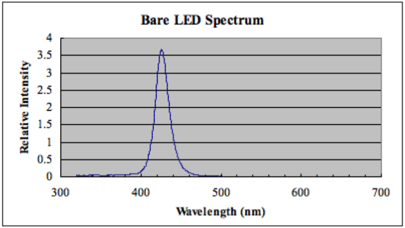
Loading...

Calibration Sources

- Positron source:
  $^{68}\text{Ge} \xrightarrow{\text{EC}} {}^{68}\text{Ga} \xrightarrow{\beta^+} {}^{68}\text{Zn}$
  Rate: 100 Bq ($T_{1/2}$=270 days)
  ⇒ Positron threshold
  ⇒ Relative PMT quantum efficiencies

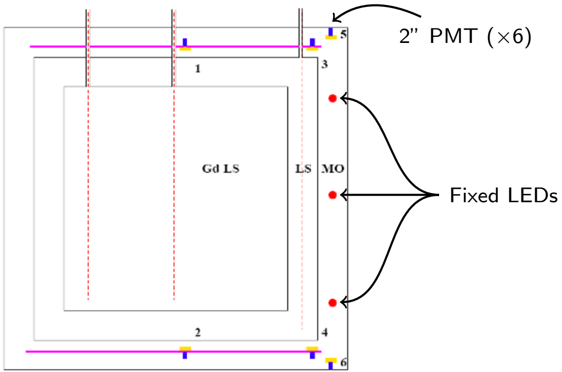
- LED source (deployed):
  430 nm LED in 3/4” nylon diffuser ball
  ⇒ PMT timing, gain
  ⇒ Optical properties





Calibration Sources

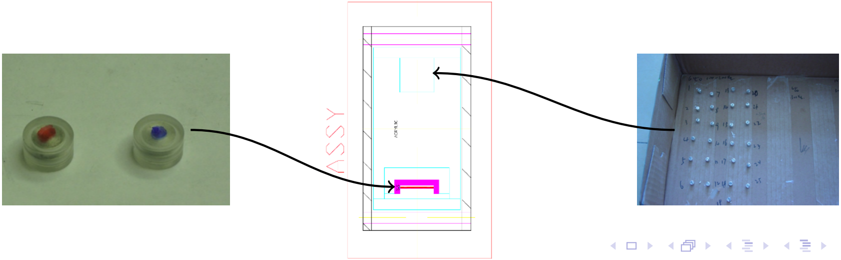
Fixed LEDs in mineral oil to monitor reflectors and attenuation length.



Calibration Sources

- Neutron source:
  ^{241}Am $(\alpha) + {}^{13}$C $\rightarrow n + {}^{16}$O
  Rate: 0.5 Hz
  Attenuate α to < 4.5 MeV with Au foil to suppress excited ^{16}O (6.13 MeV)
  $\Rightarrow$ Neutron energy scale
  $\Rightarrow$ e^{+} threshold

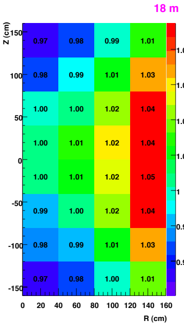
- Gamma source:
  ^{60}Co $\rightarrow 1.173 + 1.333$ MeV
  Rate: 150 Bq
  $\Rightarrow$ Energy calibration
  $\Rightarrow$ Monitor light yield/attenuation

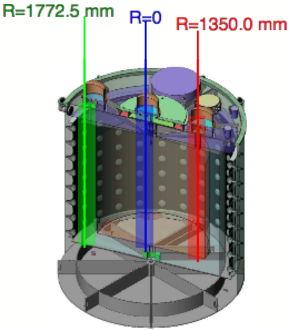


Spallation from Cosmogenic Muons

Use spallation neutrons to determine stability of detectors.

	Near	Far
Neutrons ^{12}B	13500/day/AD 300/day/AD	1100/day/AD 28/day/AD
$\sigma_E/E = 0.5\%$ per pixel	1 day/AD	10 days/AD

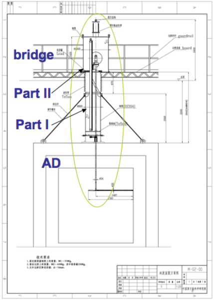


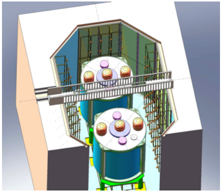


- Spallation products uniformly distributed
- 100 pixels/detector
- Energy stability (relevant to neutron capture ϵ): $\sigma_E/E \sim 0.5\%$
- ^{12}B β-decay: $T_{1/2} = 20.2$ ms and $Q = 13.4$ MeV

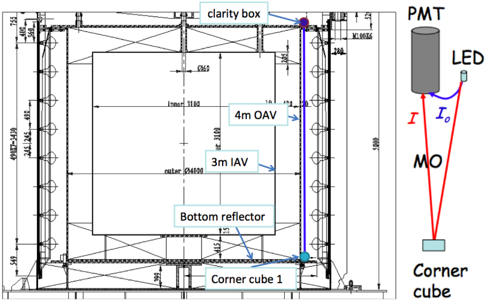
Additional Calibration Systems

Manual calibration: CIAE





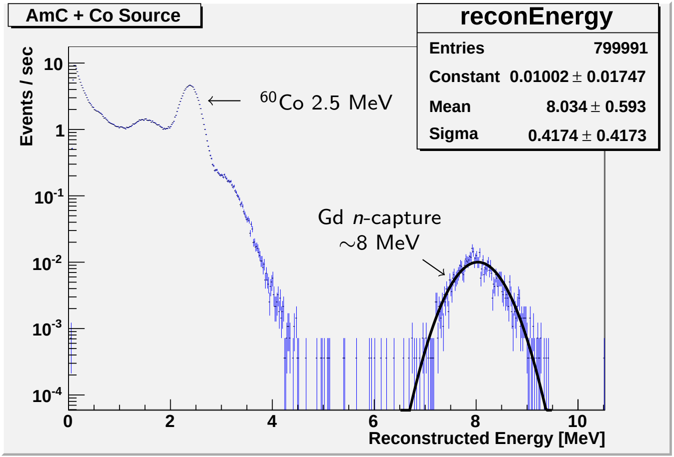
MO clarity: CUHK and HKU



Outline

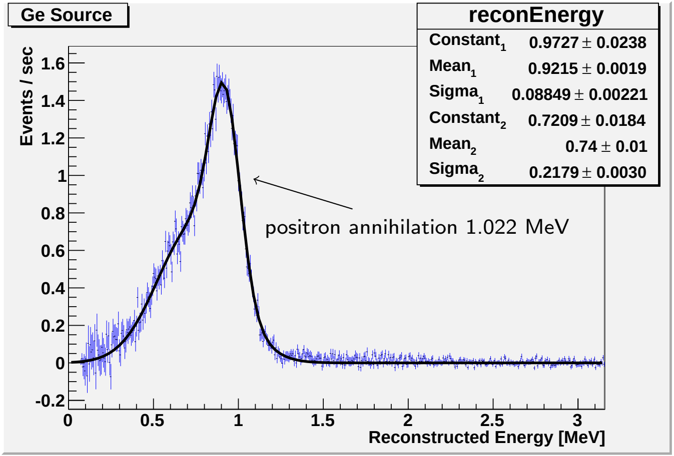
Deployed Neutron Source

Energy spectrum of AmC + ^{60}Co source at center of AD with backgrounds from stainless steel tank and PMTs:



Deployed Positron Source

Energy spectrum of ^{68}Ge source at center of AD with backgrounds subtracted:



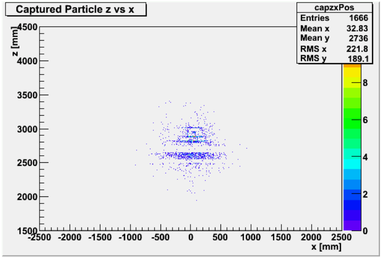
Outline

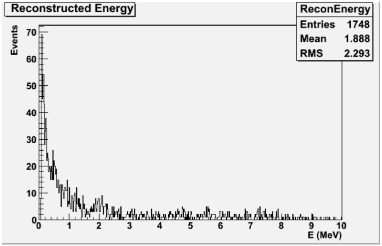
Status Report

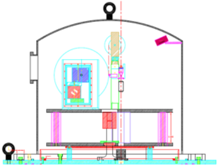
- Fabrication of first 2 ACUs complete - delivered in August
- Longevity tests performed (4 years worth of deployment)
- Software complete and undergoing testing
- Test during AD dry run
- Ge source: Ready
  Co source: Ready
  AmC source: Prototyped, developing protocol for assembly and shipment

Backup Slides

Background from Neutron Source in ACU







Limit neutron source to 0.5 Hz

$\sim$ 1-2% of neutrons from AmC source in ACU create signal in AD

Accidental bkg rate (event/day/AD)	1.20
(DB) Acc/IBD event rate (%)	0.19
(LA) Acc/IBD event rate (%)	0.18
(Far) Acc/IBD event rate (%)	1.33

Investigating correlated background rate

IBD Detection Efficiency

Positron Detection Efficiency

- Low-energy cut: ^{68}Ge source (two 511 keV γs)
- High-energy cut: nGd capture (8 MeV)

Neutron Detection Efficiency $\epsilon_n = P_{\mathrm{Gd}}\epsilon_E\epsilon_t$

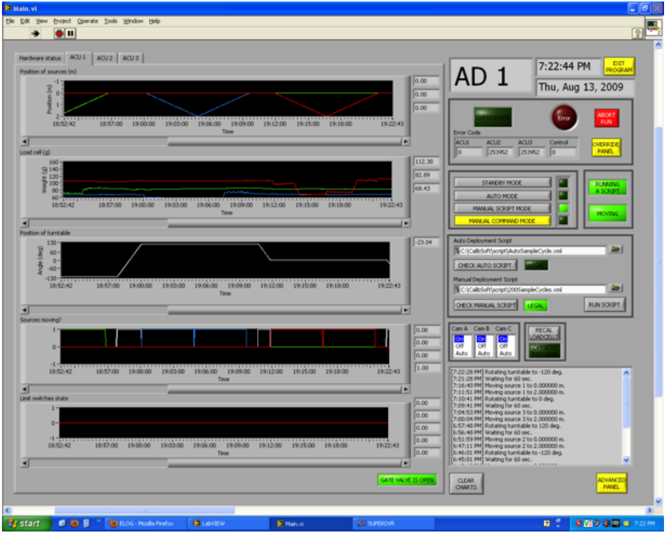
- $P_{\mathrm{Gd}} = 1/(1+\Gamma_H/\Gamma_{\mathrm{Gd}})$
  Measure $\tau = 1/\Gamma$ to 0.5% $\Rightarrow$ provide relative value of P_{Gd} to 0.1% uncertainty
- ϵ_E energy cut efficiency:
  - 1% energy scale uncertainty leads to 0.2% uncertainty in ϵ_E
  - Negligible uncertainty due to high-energy cut
- ϵ_t time cut efficiency:
  Event window [0.3 μs,200 μs] can be determined to $\sim$10 ns precision by using common master clock for all electronics

Reducing Systematic Uncertainties

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

All numbers are in percent.
Chooz has a one-detector absolute uncertainty.
Daya Bay will have a two-detector relative uncertainty.

LabVIEW Software



LabVIEW Software