Automated Calibration System for the Daya Bay Experiment

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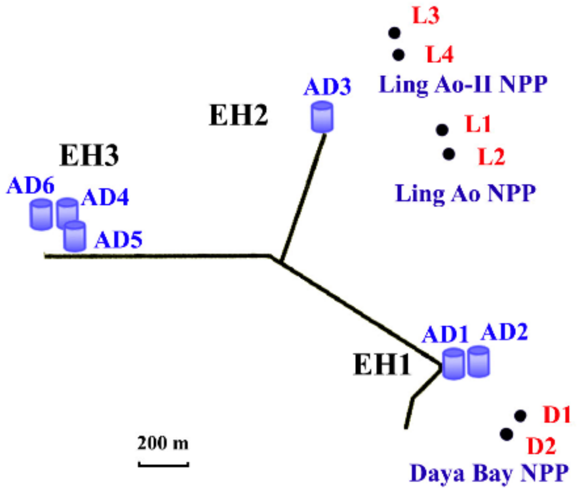
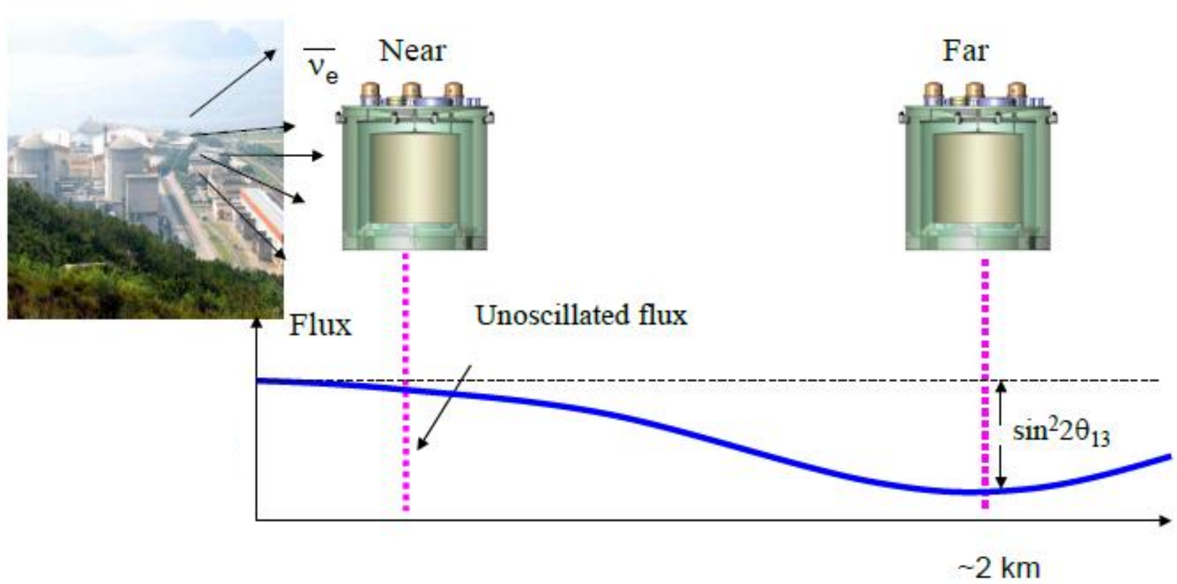
On behalf of the Daya Bay Collaboration

Daya Bay experiment overview

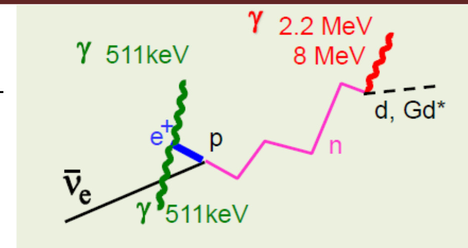


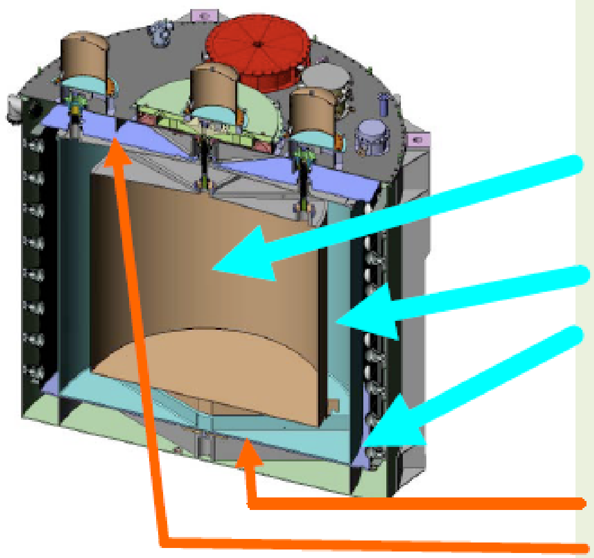
To first order



Anti-neutrino detector (AD)

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





Cylindrical 3-zone Structure
Separated By Acrylic Vessels:

I. Target: 0.1% Gd-loaded liquid scintillator, 20 ton

II. Gamma-catcher: liquid scintillator,

III. Buffer shielding: mineral oil

Acyrlic vessel thickness: 1.5 cm (outer) and 1 cm (inner)

192 8" PMT's on circumference and reflective reflectors on top and bottom.

6 'functionally identical' detectors:
Reduce systematic uncertainties

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

Design principle of the automated calibration system

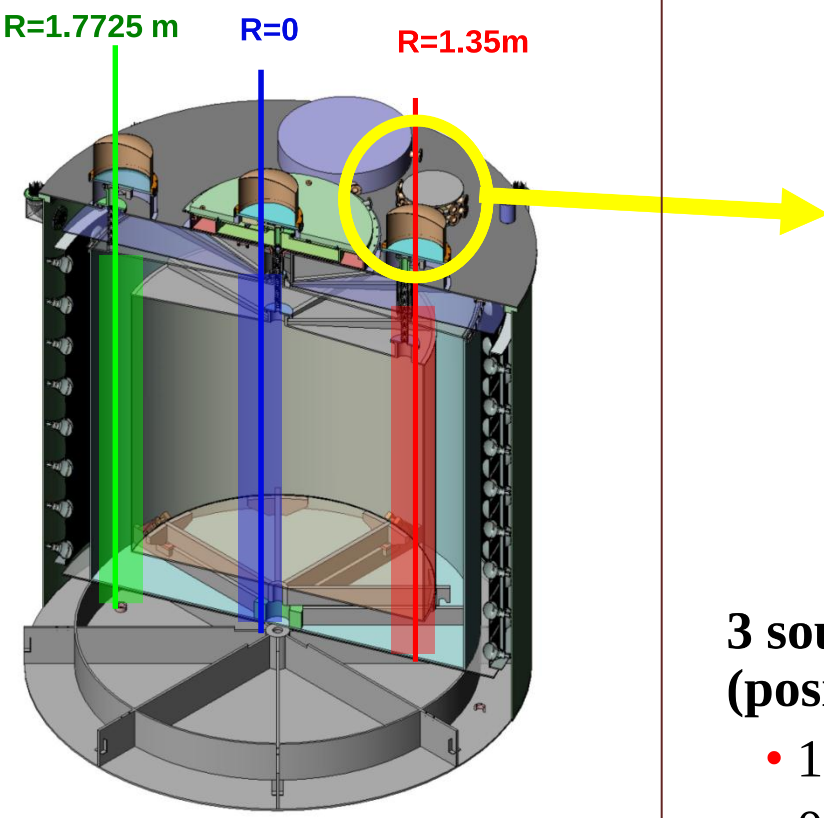
1   **1? Key target of the calibration program**

$$\frac{N_f}{N_n} = \left(\frac{N_{p,f}}{N_{p,n}}\right)\left(\frac{L_n}{L_f}\right)^2\left(\frac{\varepsilon_f}{\varepsilon_n}\right)\frac{P_{survival}(E,L_f)}{P_{survival}(E,L_n)}$$

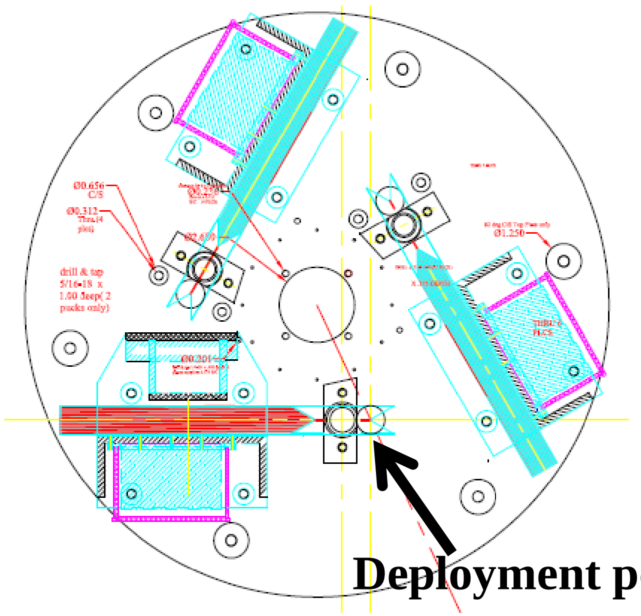
→ $\sin^2 2\theta_{13}$

Routine (weekly) deployment of sources →	Automated calibration unit
No introduction of Rn background →	ACU stays with AD
Simple, robust, and minimize material in liquid →	z scan only
Sample target and gamma catcher region →	Multiple unit on each AD
LED light = fix time →	Timing and gain calibration
Radioactive source = fix energy →	e^+ and neutron sources for energy and efficiency calibration

Overview



Three axes: center, edge of target, middle of gamma catcher



3 sources for each z axis on a turntable (position accuracy < 5 mm):

- 10 Hz ^{68}Ge
- 0.5 Hz ^{241}Am-^{13}C neutron source + 100 Hz ^{60}Co gamma source
- LED diffuser ball (500 Hz)

Mechanical construction

Neutron source (Am-C)
+ Gamma source (Co-60)

Limit switch: Limits the range of source motion

Gamma source (Ge-68)

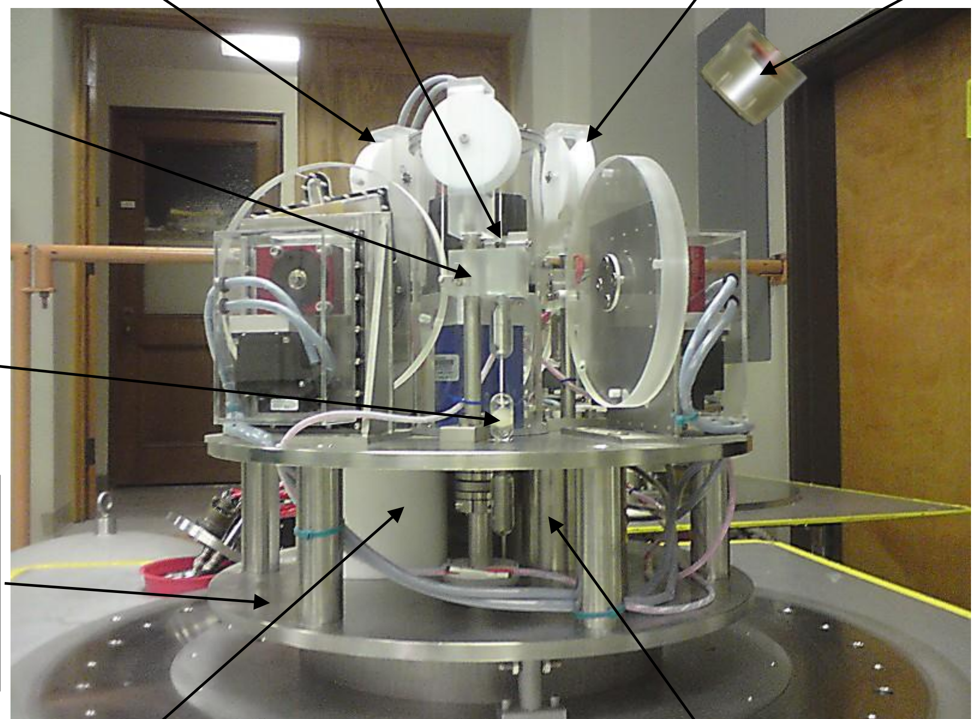
Camera with IR LEDs: mounted on the inside of the bell jar

Load cell: Monitors tension in the cable

Stepper motor with worm gear box

LED (~430 nm) with diffuser ball

Turntable
- For source selection
- Equipped with forward and reverse limit switches



SS Bell Jar: enclosing ACU

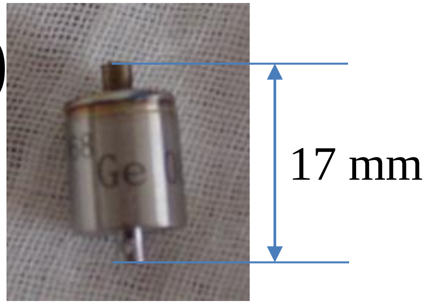
Borated-Polyethylene neutron shield

Stainless gamma shield

Compatibility with LAB-based scintilator: teflon, acrylic (enclosed), stainless steel

Gamma sources

- Ge-68 (Rate: 10 Bq, $T_{1/2}$: 270 days)



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

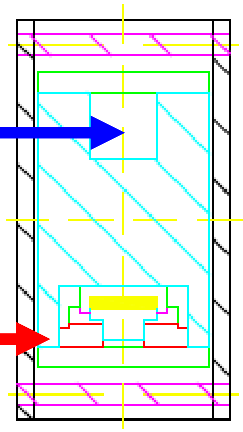
  - Positron threshold
  - Relative PMT detecting efficiency

- Co-60 (Rate: 150 Bq, $T_{1/2}$: 1925 days)

$$^{60}Co \longrightarrow 1.173 + 1.333\ \text{MeV}$$

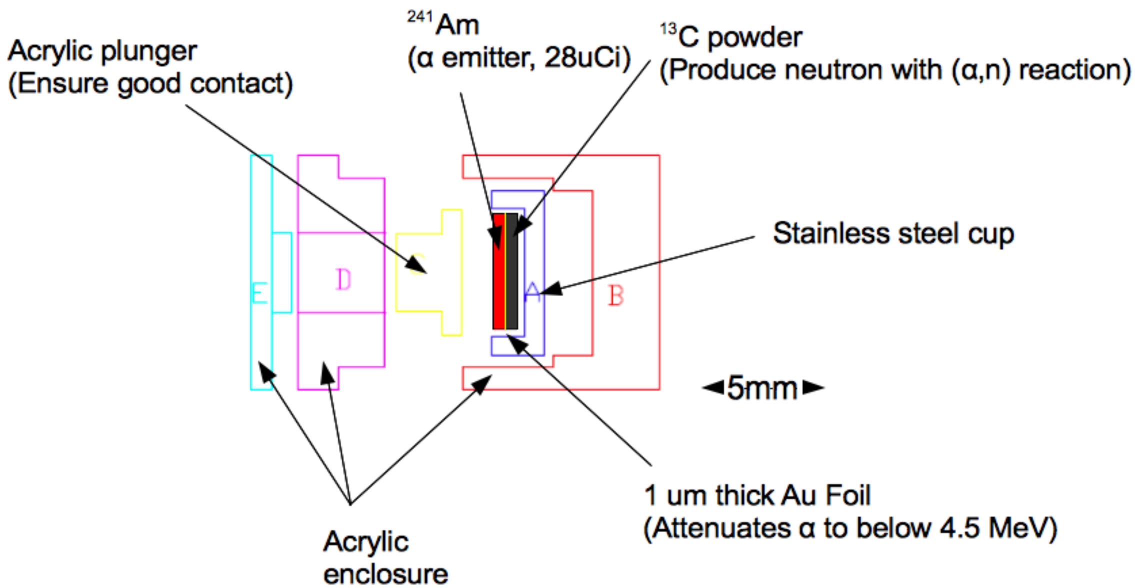
  - Energy calibration
  - Monitor light yield/attenuation

5 x 5 mm



Neutron source: AmC
(Next slide)

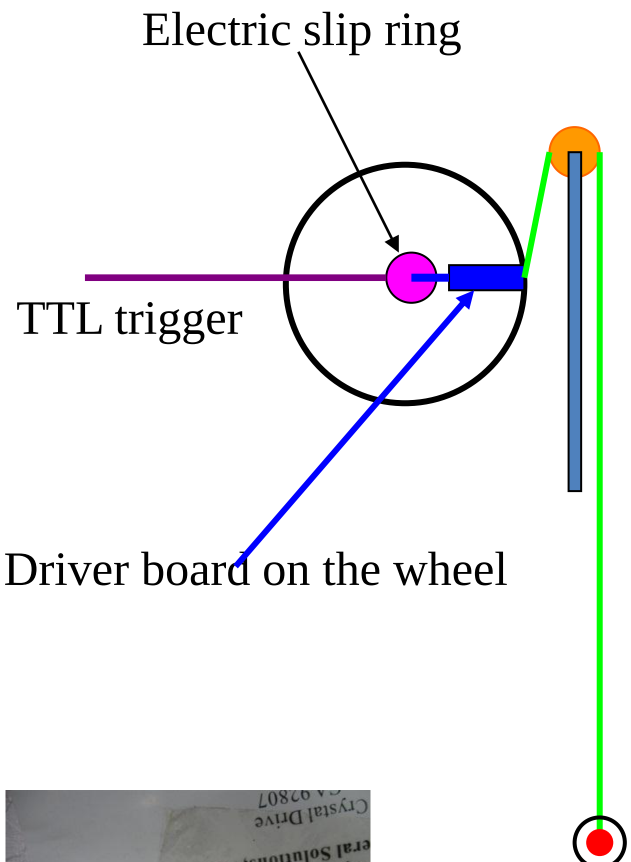
Neutron source

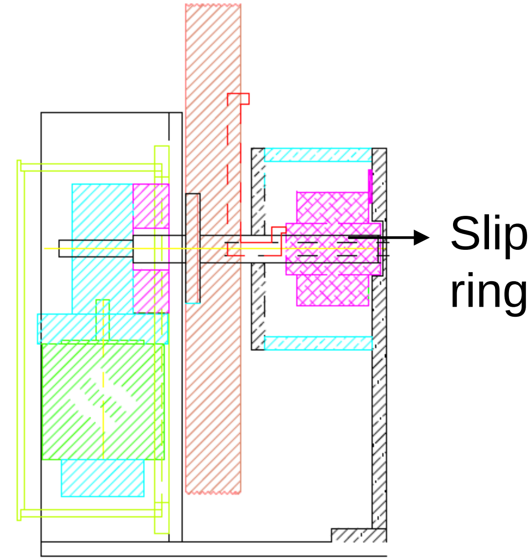


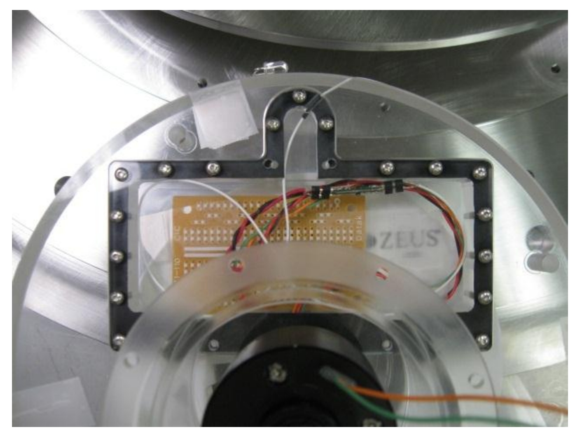
^{241}Am-^{13}C (Rate: 0.5 Hz)

- ^{13}C (α, n) ^{16}O
- Au foil attentuate α to < 4.5 MeV, hence suppressing 6.13 MeV gamma from excited state of ^{16}O.
- Neutron energy scale

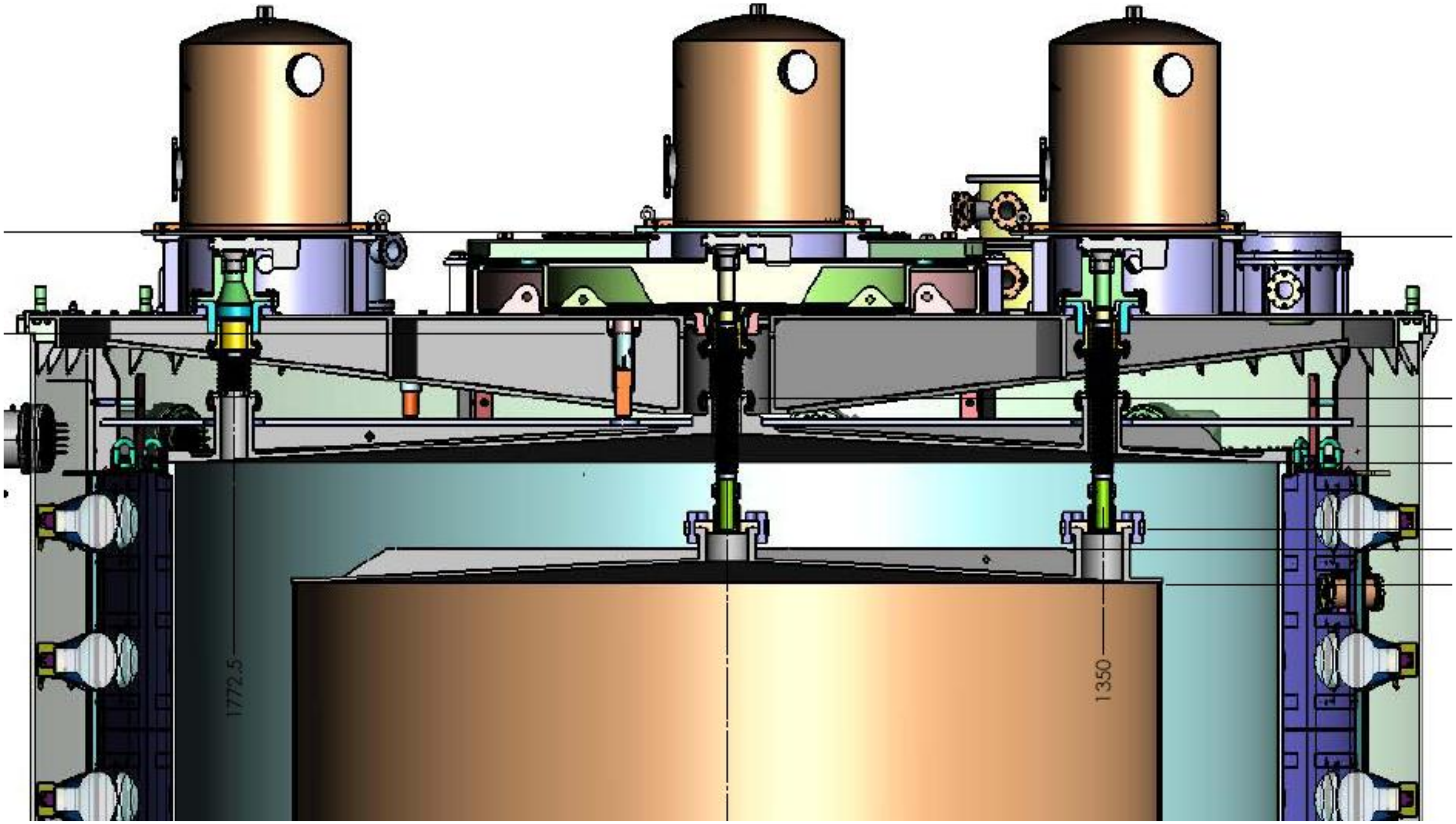
Light source







Interface with the AD

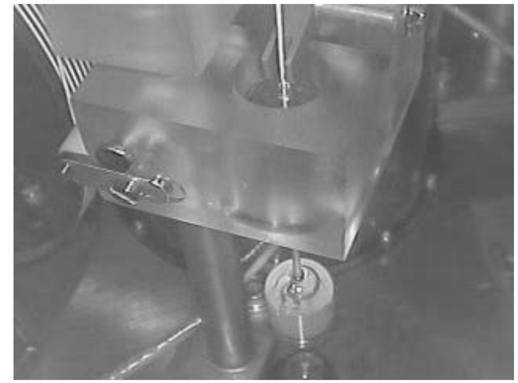


- Source port in ACU aligned with acrylic vessel penetrations
- Source deploy through the penetration by gravity
- Absolute position accuracy – 5 mm

Control and software

- Control software written with LabVIEW.
- Handshake between control software and DAQ → complete automated calibration and synchronized data taking

40x speed



Operate ACU

```
<DeploymentScript>
  <ActivateACU AcuNumber="1"/>
  <Move Depth="2" MovementType="MO" SourceNumber="1"/>
  <PulseLED Frequency="500" Handshake="True" LTBMode="Fals
  <Move Depth="1.9" MovementType="MO" SourceNumber="1"/>
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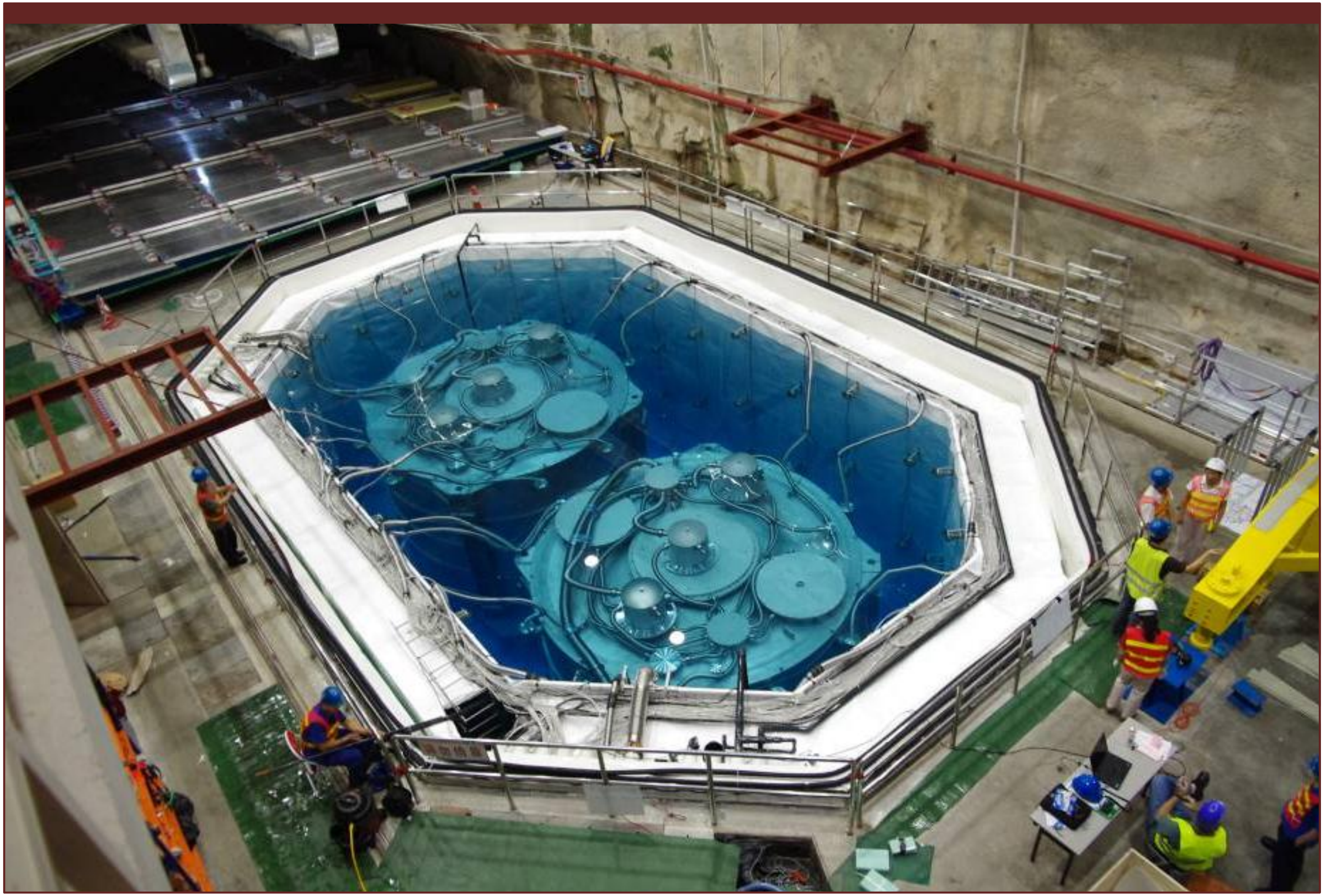
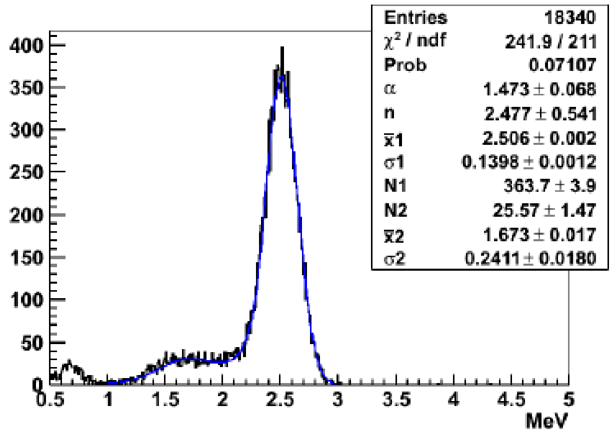
Input XML script

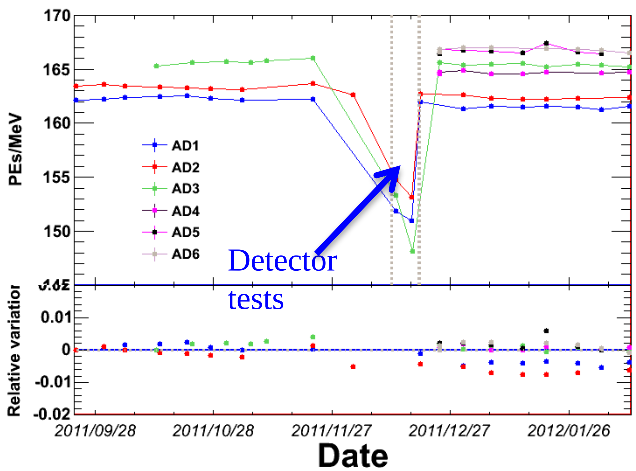
Calibration system in experimental halls



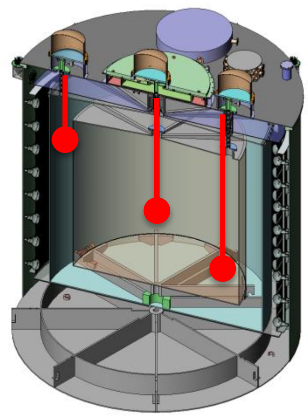
Example analysis: energy calibration

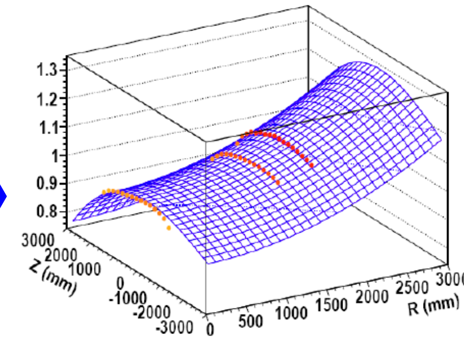
Weekly deployments of ^{60}Co at detector center: Monitor photoelectrons collected per MeV

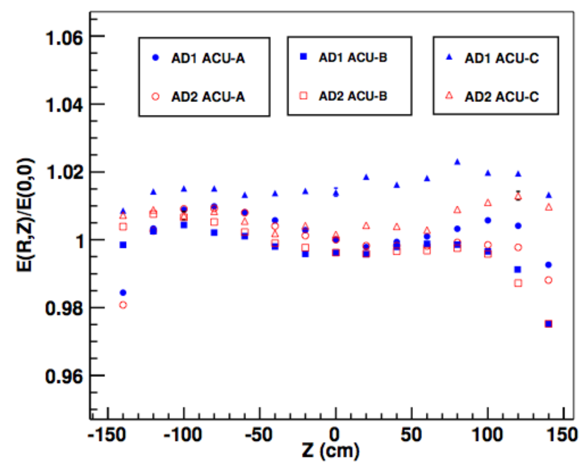




3 sources along 3 axes







Summary of features

- Completely automated
- Three movable units per detector, stayed on the detector lid, accessing three vertical axis in the detector
- LED, gamma, and neutron sources in each unit
- Stringent material selection and cleanliness requirement met
- Under smooth operation since the start of data taking (Dec. 2011).

All design goals fulfilled