The JUNO Calibration Strategy and Simulation

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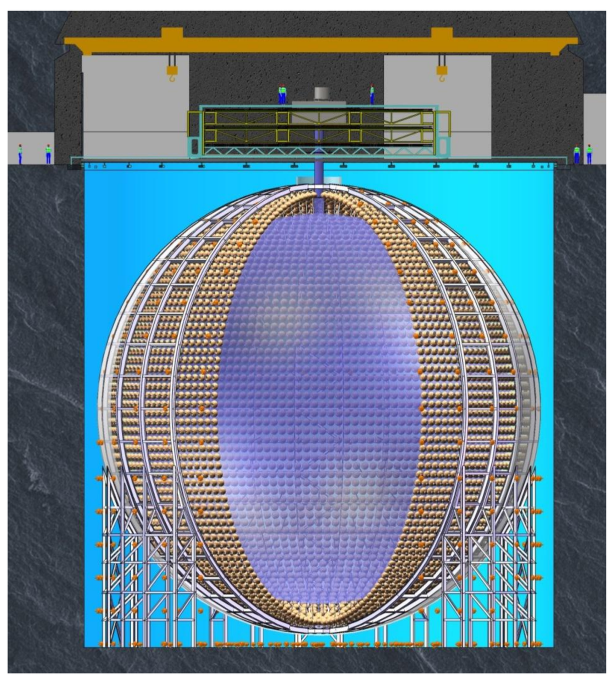
1. Introduction of JUNO

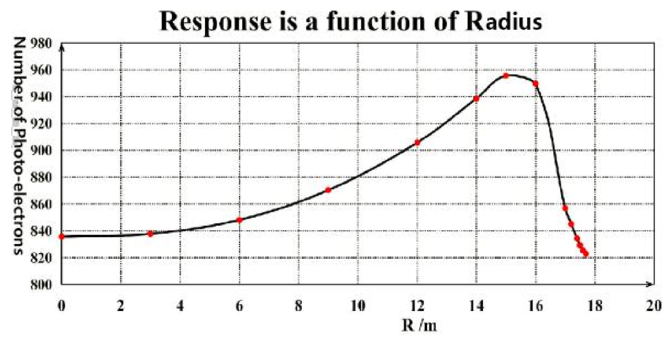
- The Jiangmen Underground Neutrino Observatory (JUNO) , which will be constructed at Kaiping, Jiangmen in South China, is a multi-purpose experiment, including neutrino mass ordering determination, neutrino oscillation parameter measurement, solar neutrino detection and so on.
- JUNO central detector (CD) which is an **acrylic sphere with a diameter of 35.4 m,** is filled with liquid scintillator(LS) and equipped with ~ **43 k photomultipliers (PMTs)** in total to measure the energy of neutrinos.
- A better than 1% linear energy scale and a superior effective energy resolution of 3%/sqrt(E) to determine Mass Ordering (MO) in **3σ in 6 years**, so the calibration complex is very critical and has been designed.



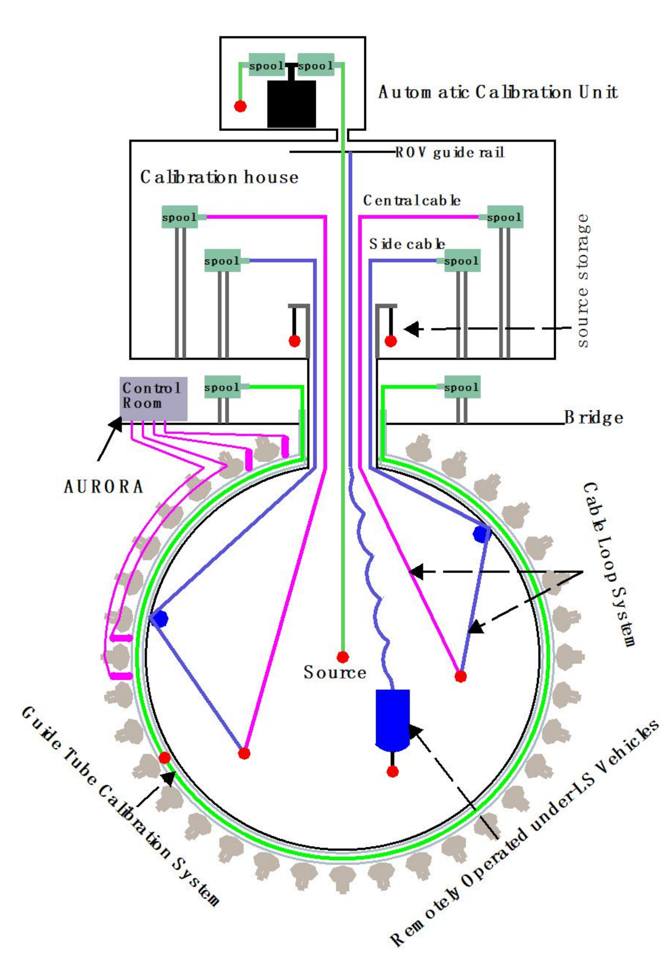
2. Calibration Complex

JUNO energy response is strongly position-dependant due to the detector structure and dimension

Response is a function of Radius



Calibration System of the JUNO Experiment



Requirements

Overall energy resolution: $3\%/\sqrt{E}$

Energy nonlinearity: < 1%

Calibration Sources

Source	Type	Radiation
^{137}Cs	γ	0.662 MeV
^{54}Mn	γ	0.835 MeV
^{60}Co	γ	1.173 + 1.333 MeV
^{40}K	γ	1.461 MeV
^{68}Ge	e^+	annil 0.511 + 0.511 MeV
^{241}Am-Be	n, γ	neutron + 4.43 MeV
^{241}Am-^{13}C	n, γ	neutron + 6.13 MeV
(n,γ)p	γ	2.22 MeV
(n,γ)^{12}C	γ	4.94 MeV or 3.68 + 1.26 MeV

Subsystems for Full-volume Coverage

1-D: Automatic Calibration Unit (**ACU**) for central axis scan

2-D: Cable Loop System (**CLS**) for one vertical plane scan + Guide Tube Calibration System(**GTCS**) for CD outer surface

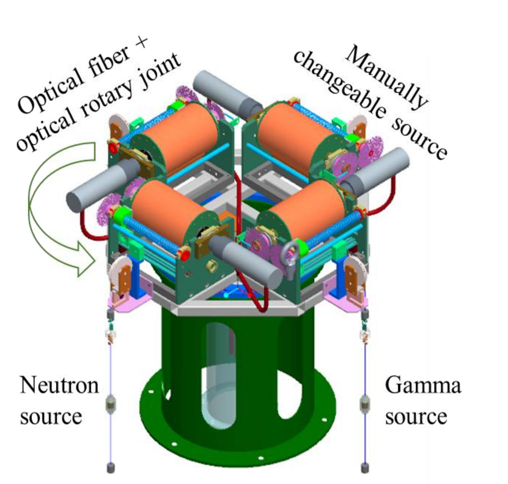
3-D: Remotely Operated under-liquid-scintillator Vehicles (**ROV**) for whole CD scan

* Ultrasonic sensor system (**USS**) and **CCD** for ROV and CLS positioning purpose

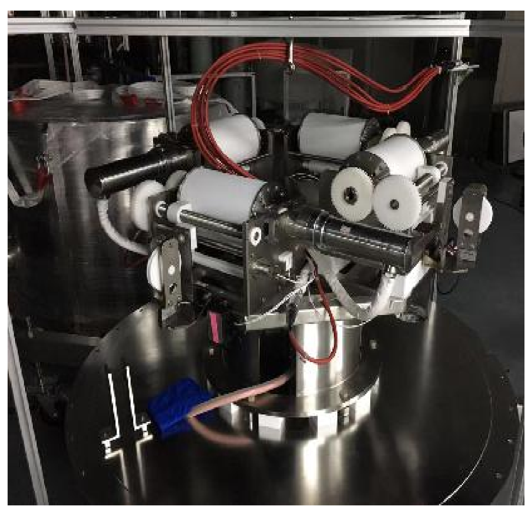
System	Frequency	Positioning	Position Control	Source change	Others
ACU	Weekly	Rope Length	Spool drive (steel wire coated with Teflon Φ1.0 mm) +Tension Control	Manual	All are critical, have to be combined
CLS	Monthly	Rope Length, CCD and USS		Automatic	
GTCS	Monthly	Rope Length Metal Sensor		Manual	
ROV	When needed, seasonally or annually	CCD and USS	Remotely Operated Vehicle	Manual	Redundancy

3. Introduction of Calibration Subsystems

Automatic Calibration Unit (ACU)



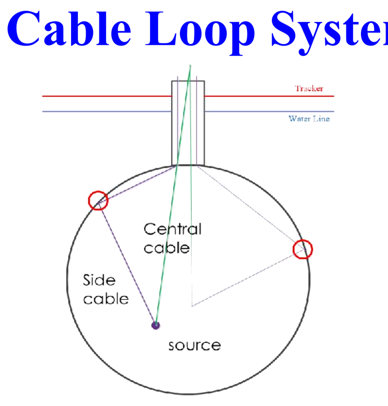
ACU layout : JUNO detector central axis



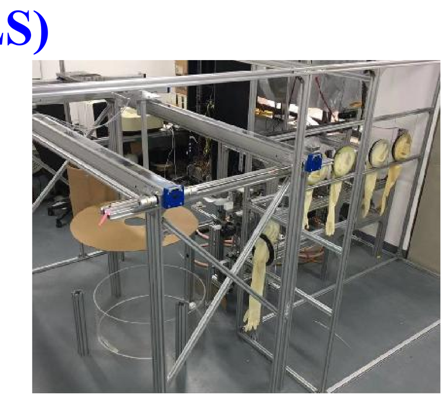
ACU prototype

- ACU is used for calibration along central axis (1-D).
- It supports γ/neutron/laser/positron sources.
- Source positioning precision is 10 mm.
- It provides an access for manually changing calibration sources. The schema is important for non-linearity correction.

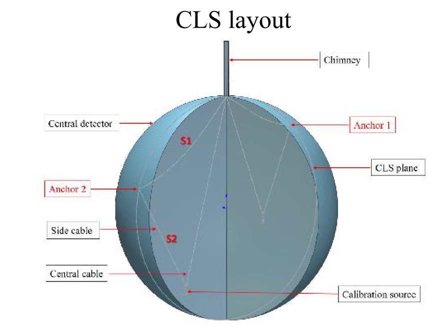
Cable Loop System (CLS)



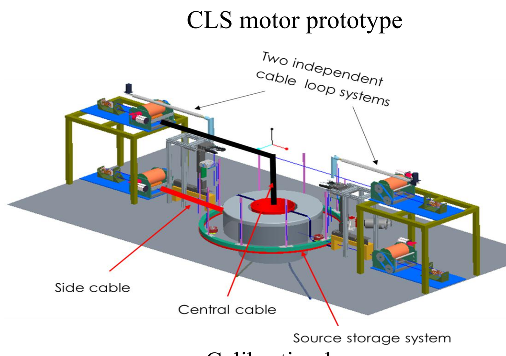
CLS layout



CLS motor prototype



2D CLS layout

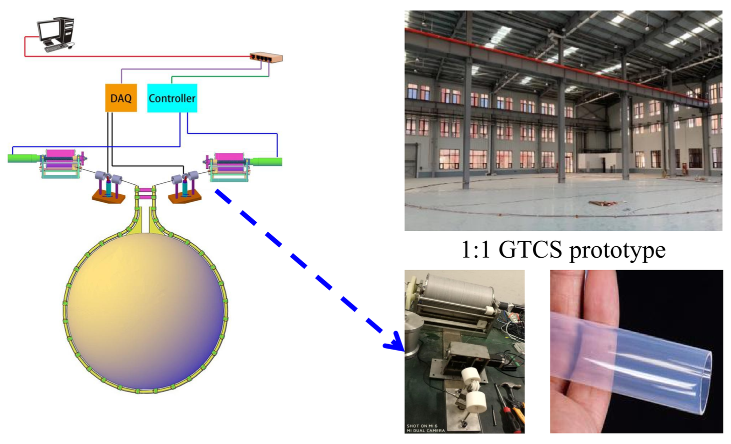


Calibration house

- Two cable loops will be assembled on both semisphere, source position is controlled by spools with Teflon-coated steel cables.
- Source can reach 79% areas on one plane:one vertical plane scan(2-D).
- Source position precision is designed less than 3cm.
- Independent ultrasonic system is used for the source positioning with an ultrasonic emitter is attached to the radioactive source fixture.
- Calibration house: Source storage, motors to control CLS , ROV , etc.

Guide Tube Calibration System (GTCS)

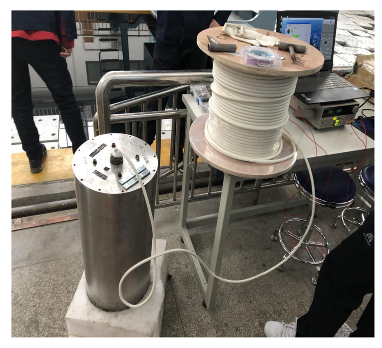
- GTCS is used for calibration along boundary area and provides boundary condition for correction map (2-D).
- Source delivery is controlled by servomotors, Teflon tube and Teflon-coated steel cable are used to minimize friction.
- Source position inaccuracy is < 10 cm.



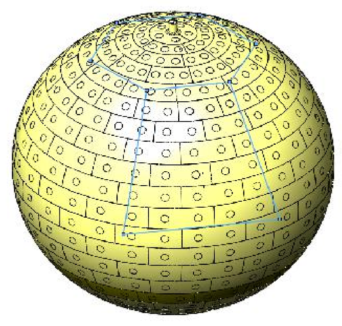
1:1 GTCS prototype

Winding machine system Tube

Remotely Operated Vehicle (ROV)



ROV



USS layout

- A self-driven vehicle (Φ300 × H700 mm) .
- The body is coated with PTFE.
- Four ultrasonics emitters are attached with ROV for positioning and motion feedback. 8 ultrasonic receivers will monitor ROV`s position (3-D).
- Positioning accuracy is designed < 3 cm, and ROV is designed to be stable in 5 minutes.

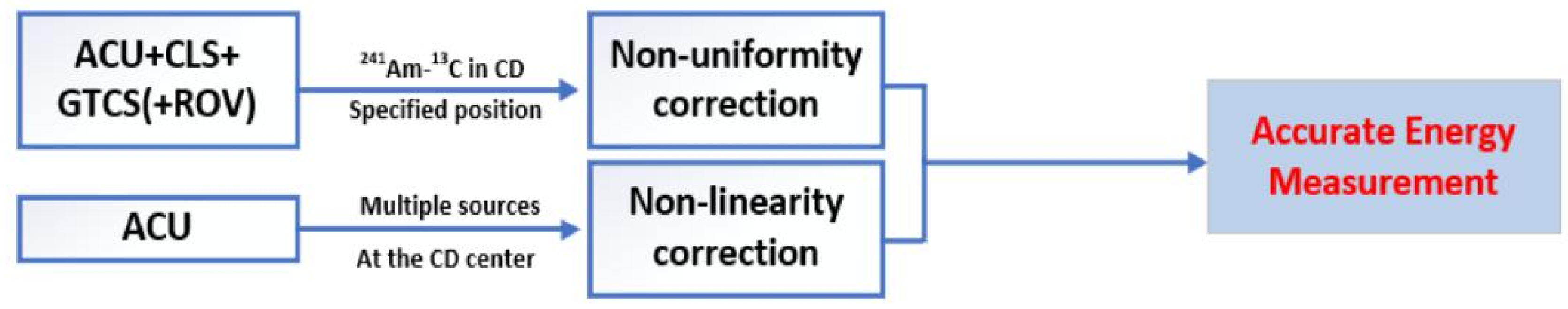
Ultrasonic sensor system (USS) and CCD

USS

CCD prototype

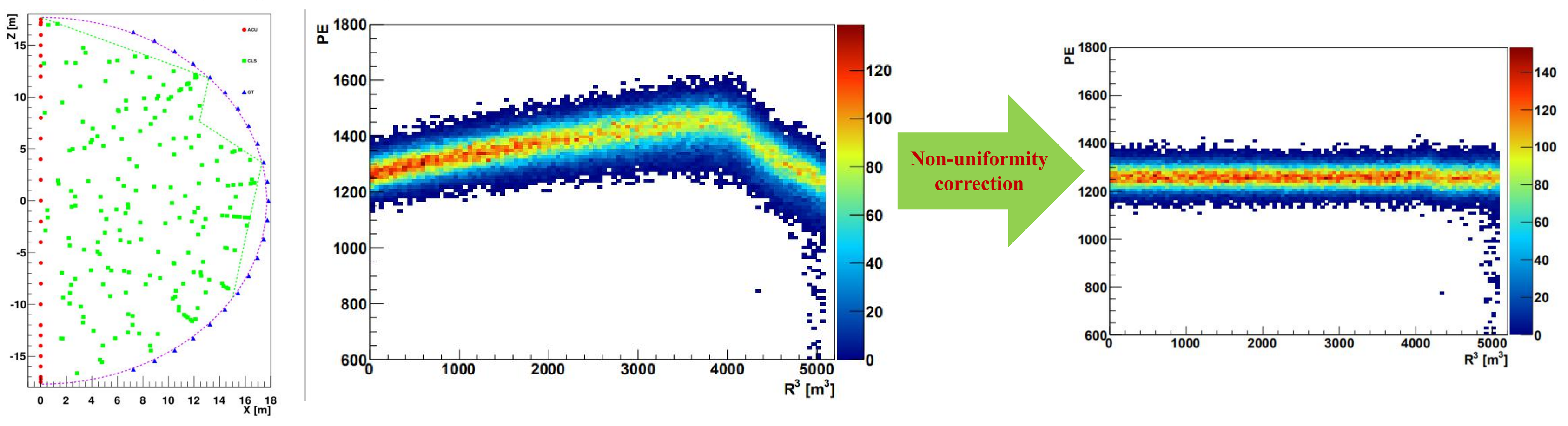
- Positioning ROV and CLS

4. Simulation of Calibration Strategy



4.1 Non-uniformity Correction

- Calibrate JUNO energy response by using the data from the given calibration points.
- A simple spline function is used to predict the "blank" region.
- The energy response uniformity would be corrected with the correction function.
- Effective energy resolution is **3.02%**, with the nominal JUNO detector parameters, satisfying the physics needs, bias of the mean value is ~0.1%.



250 calibration points with Am-C from ACU/CLS/GTCS.

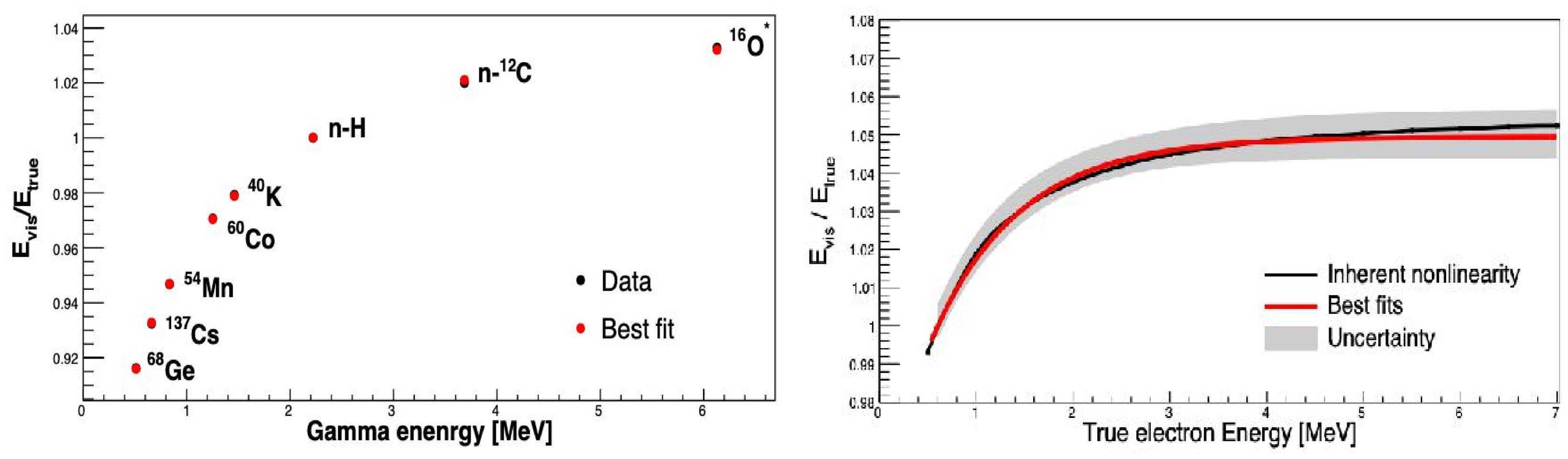
Before Correction Resolution is 7%

After Correction Resolution is 3.02%

Resolution is improved by correction

4.2 Non-Linearity Correction

- Energy linearity is investigated by placing various sources at CD center.
- **8 gamma sources** are used to study the detector non-linearity.
- The bias in the reconstructed energy is expected to be less than **1%.**



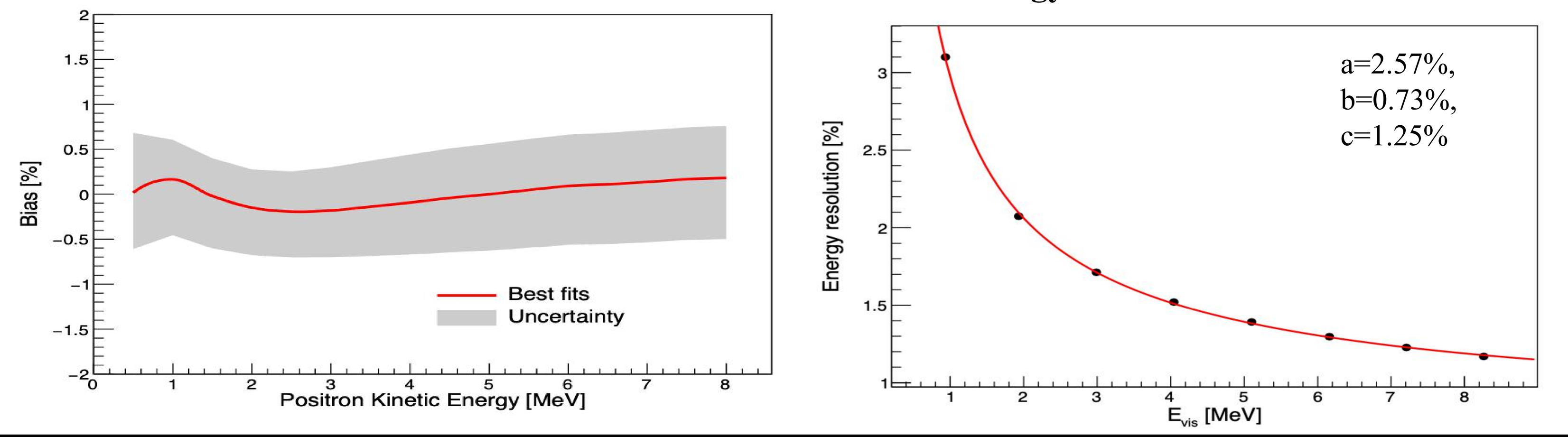
4.3 Overall Energy Resolution

➢The simulated mono-energy e^+ events are uniformly distributed in the CD and the non-uniformity correction (response is obtained with ^{241}Am-^{13}C) is applied .

➢**The bias < 0.1% and the energy resolution < 3.0%.**

Mean bias after correction

Energy resolution after correction



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