Calibration system of the JUNO experiment

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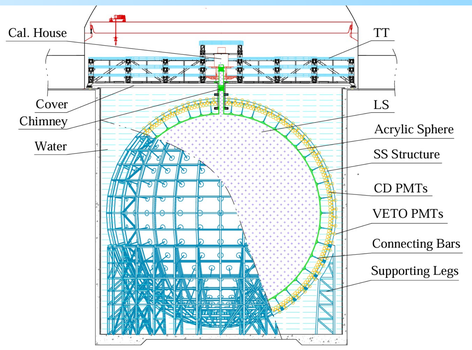
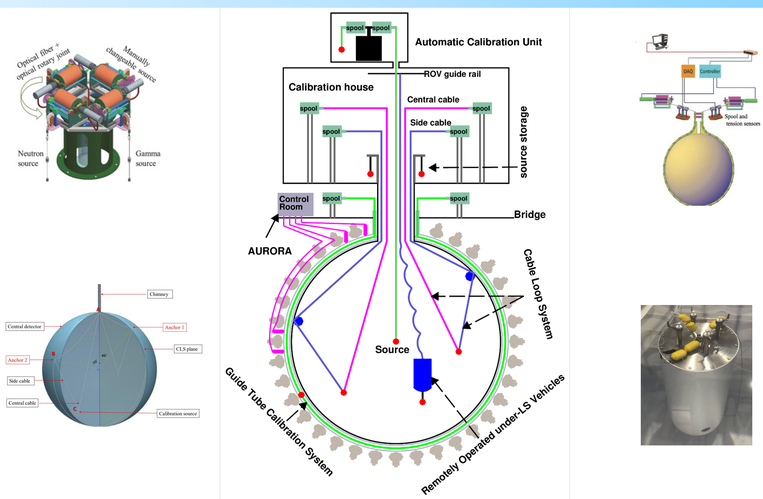
JUNO Experiment



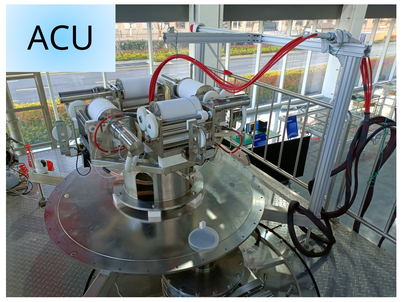
- 20 kton liquid scintillator neutrino detector
- 35.4 m inner-diameter acrylic sphere
- 17,596 20-inch and 25,600 3-inch PMTs in central detector
- Calibration Challenges
  - Precise detector response calibration across full volume
  - Energy resolution: ~3% at 1 MeV
  - Energy scale uncertainty: < 1%

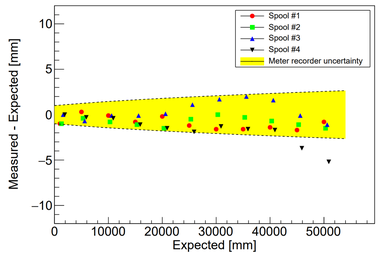
Calibration System



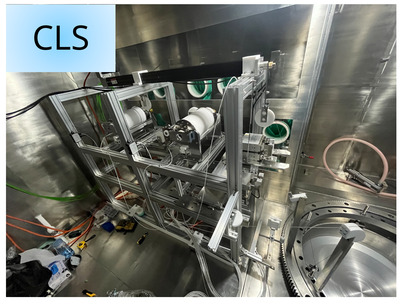
- 1D central axis scan - Automatic Calibration Unit (ACU)
- 2D plane scan - Cable Loop System (CLS)
- 2D boundary scan - Guide Tube Calibration System (GTCS)
- 3D scan - Remotely Operated Vehicle (ROV)

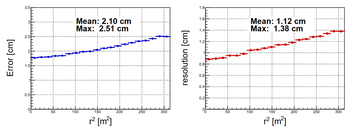
Calibration Subsystems

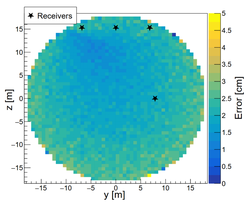




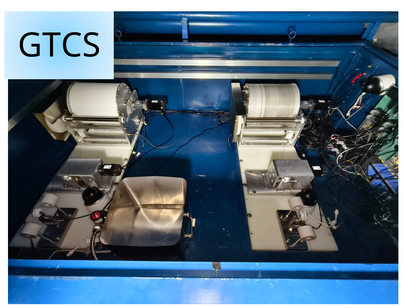
- 4 spools for radioactive source and laser
- Turntable for source selection
- ACU positioning accuracy < 7 mm (requirement: 30 mm)

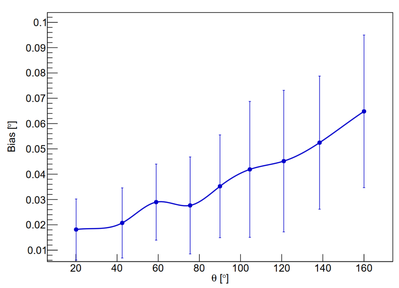






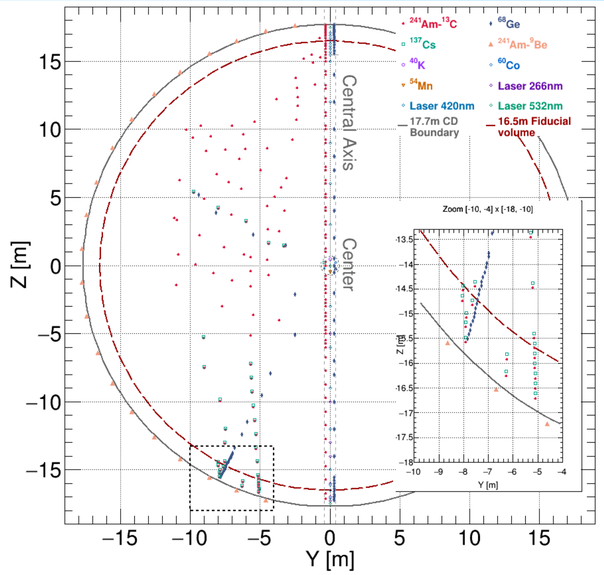
- 2 spools for radioactive source deployment
- Automated source change mechanism
- CLS positioning accuracy < 30 mm (requirement: 30 mm)





- 2 spools for radioactive source deployment
- PTFE tube for source moving
- GTCS positioning accuracy (including cable elongation, not shown in upper plot) < 0.1° (requirement: 0.2°)

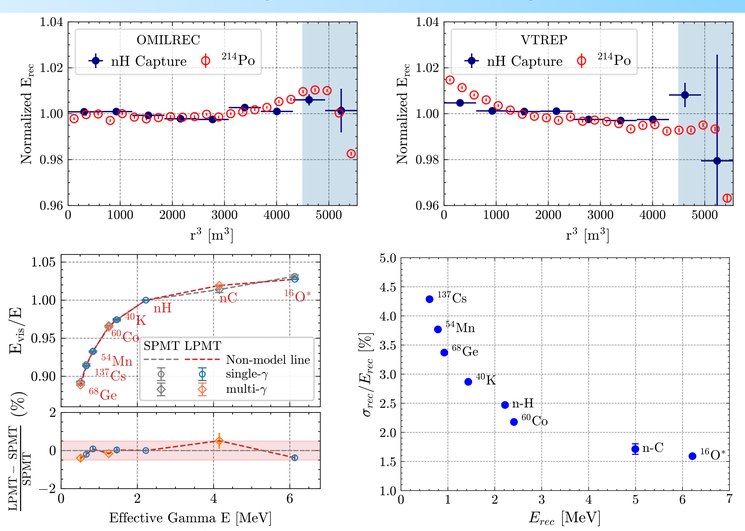
Onsite Calibration - Points and Sources



Sources/Processes	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^+	annihilation 0.511 + 0.511 MeV
^{241}Am-^{9}Be	n, γ	neutron + 4.43 MeV (^{12}C*)

Sources/Processes	Type	Radiation
^{241}Am-^{13}C	n, γ	neutron + 6.13 MeV (^{16}O*)
(n,γ)p	γ	2.22 MeV
(n,γ)^{12}C	γ	4.94 MeV or 3.68 + 1.26 MeV
266 nm laser	photon	266 nm
420 nm laser	photon	420 nm
532 nm laser	photon	532 nm

Non-uniformity Non-linearity Resolution



References: ACU-JINST16T08008, CLS-NIMA988 64867 (2021), GTCS-JINST14T09005 (2019), ROV-JINST13T12001 (2018), Calibration strategy-JHEP20214 (2021), Initial performance-CPC 50 4 043001 (2026)