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Dual Calorimetry Calibration in the JUNO experiment

Jiajun LI [1], Roberto MANDUJANO [2] On behalf of the JUNO collaboration

1. Sun Yat-sen University, Guangzhou, China lijj295@mail2.sysu.edu.cn
2. University of California, Irvine, USA rcmanduj@uci.edu

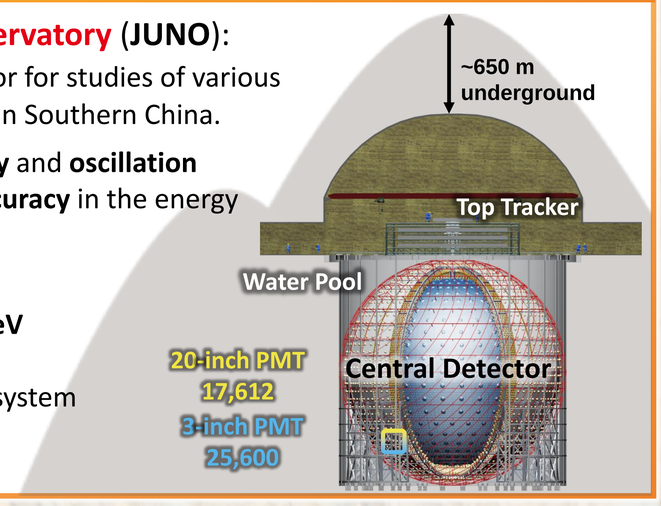
JUNO: State-of-the-art liquid scintillator detector

Jiangmen Underground Neutrino Observatory (JUNO):

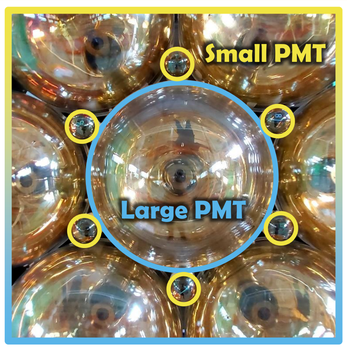
A 20-kiloton liquid scintillator (LS) detector for studies of various neutrino physics topics. Under construction in Southern China.

Measurement of **neutrino mass hierarchy** and **oscillation parameters** demands **high precision and accuracy** in the energy measurement.

- The world's **largest** LS detector
- Excellent energy resolution: **3% @ 1MeV**
- 1% energy scale uncertainty
- **~650m overburden** and a muon veto system to control backgrounds



Dual Calorimetry: Stringent systematics control in energy



Primarily calorimetry — **Large (20-inch) PMT system**

- Primarily in **charge integration (CI) mode**
- Waveform solution, various systematic effects in **CI** mode

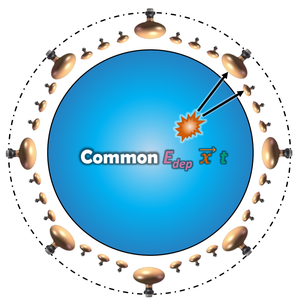
Secondary calorimetry — **Small (3-inch) PMT system**

- Primarily in **photon counting (PC) mode**
- Minimal systematics in **PC** mode. As a robust **linear charge reference** for LPMT

LPMT and **SPMT** always view the **same events**, i.e. **common** deposited energy, **event vertex** and **time**.

JUNO Calorimetry Response (R):

R_{LSNL} liquid scintillator non-linearity
R_{NU} non-uniformity
R_{NS} non-stability
R_{QNL} charge non-linearity



Degeneracy breakdown [3]

$$R^{LPMT} = R^{L}_{LSNL} \cdot R^{L}_{NU} \cdot R^{L}_{NS} \cdot R^{L}_{QNL}$$
$$R^{SPMT} = R^{S}_{LSNL} \cdot R^{S}_{NU} \cdot R^{S}_{NS} \cdot R^{S}_{QNL}$$

Cancellation | Isolation

Correlated | Uncorrelated

Independent response control after DCC

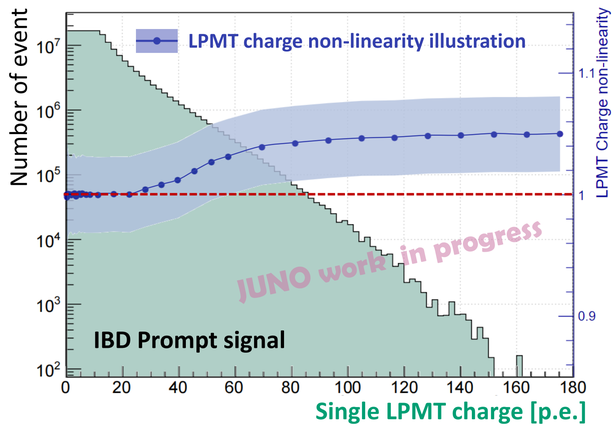
Direct correction with DCC

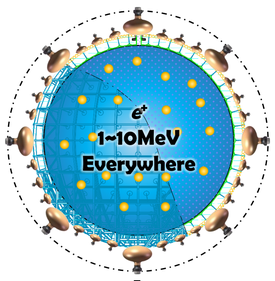
Response Degeneracy:

- Systematics in CI → R_{QNL}
- R_{QNL} degenerates with: R^{L}_{LSNL}, R^{L}_{NU}, R^{L}_{NS}

Dual Calorimetry Calibration (DCC)

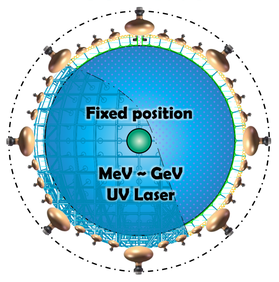
- **DCC Interest: Inverse Beta Decay (IBD)** e^+ signal in 1~10 MeV in a full volume
  → 0~150 p.e. for single LPMT charge range
- **DCC goal:** calibrate the potential **charge non-linearity (QNL) of each LPMT channel**, with the aid of the **UV laser source** and **radioactive sources**.



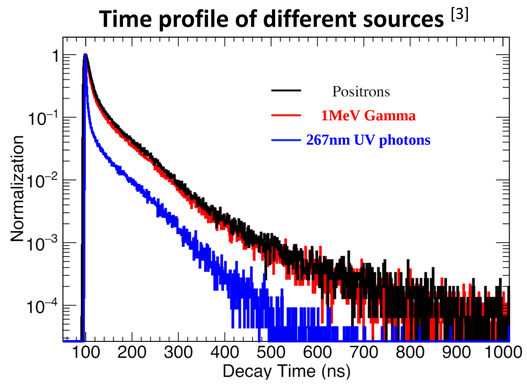


Complementary Comprehensive Combined

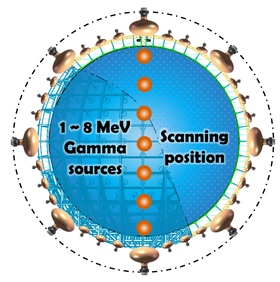
DCC - Laser



Time profile of different sources [3]



DCC - Gamma



Wide range of the laser intensity

- Cover the **full charge detection range** of IBD signals for **every LPMT**

One calibration position:

- **Perfect isolation** of the QNL

Difficult to match the IBD time profile

Radioactive sources match IBD time profile

- IBD signal induced **QNL can be calibrated**

Difficult to calibrate every LPMT;
IBD charge detection range cannot be fully covered.

DCC - Laser

I. Strategy: Varying UV laser intensity @ detector center #

II. Response comparison:

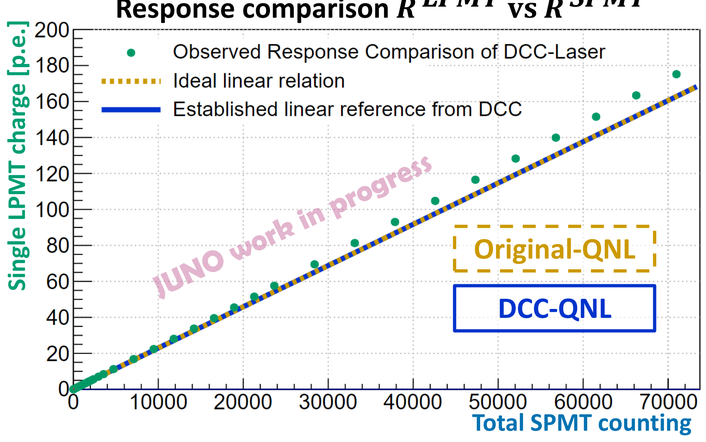
R^{SPMT}_{QNL} : ~ 0.1%

- photon counting + correction based on **Poisson law**

R^{LPMT} vs R^{SPMT} → R^{LPMT}_{QNL}

- **SPMT** as a linear reference

Response comparison R^{LPMT} vs R^{SPMT}

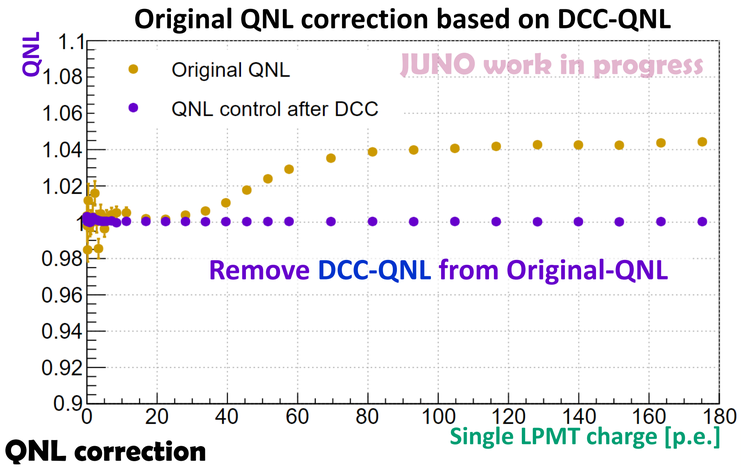


III. Correction:
based on diagnosed DCC-QNL

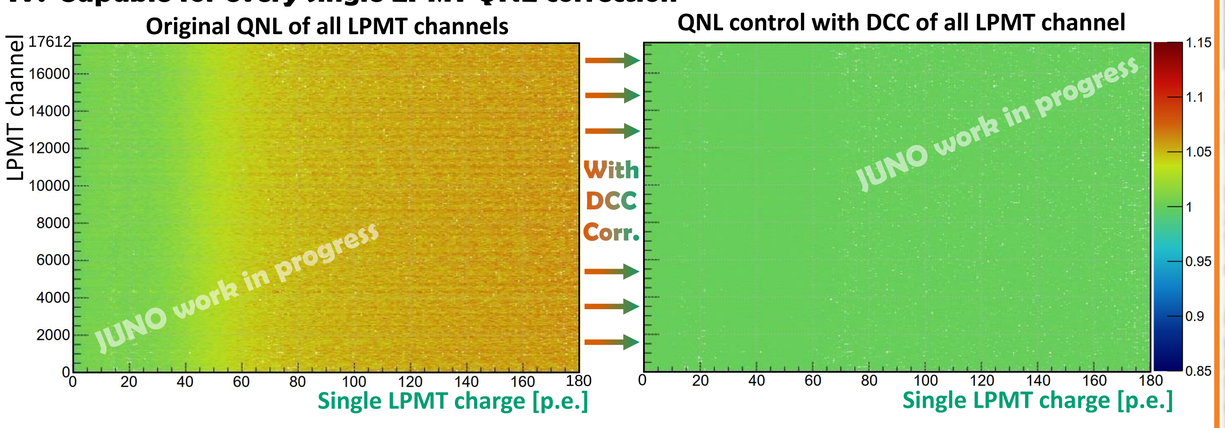
Correct Original-QNL with DCC to ~ 0.5% for this LPMT

Expand to every LPMT channel

Original QNL correction based on DCC-QNL



IV. Capable for every single LPMT QNL correction



- **All LPMT channels' QNL can be corrected with DCC–Laser**

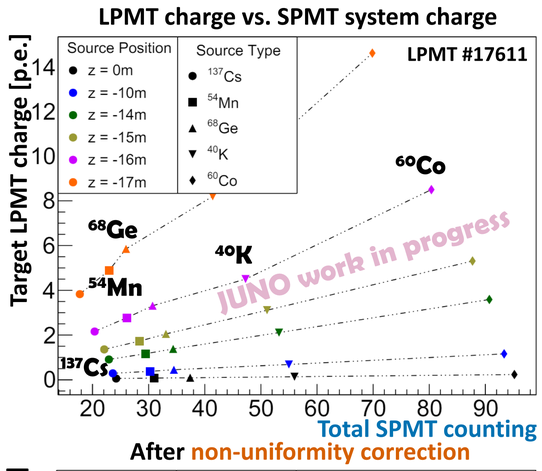
UV Laser source: at the center of the detector, intensity from 5,000 to 30 million photons, wavelength: 267nm
Above analysis are based on JUNO offline software's data from detector, electronic simulation, waveform reconstruction.

DCC - Gamma

I. Strategy: Various gamma sources scanning multiple positions *

- **Position scan:**
  - → SPMT non-uniformity correction
  - → LPMT solid-angle correction
  - → Response comparison between LPMT and SPMT.

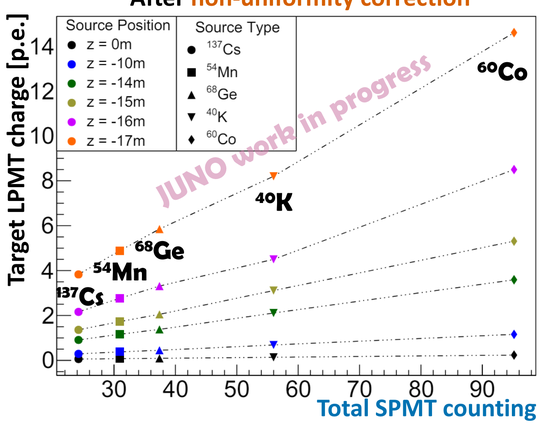
LPMT charge vs. SPMT system charge



II. Correction of SPMT non-uniformity

- **Calibrate SPMT response to detector center illumination**

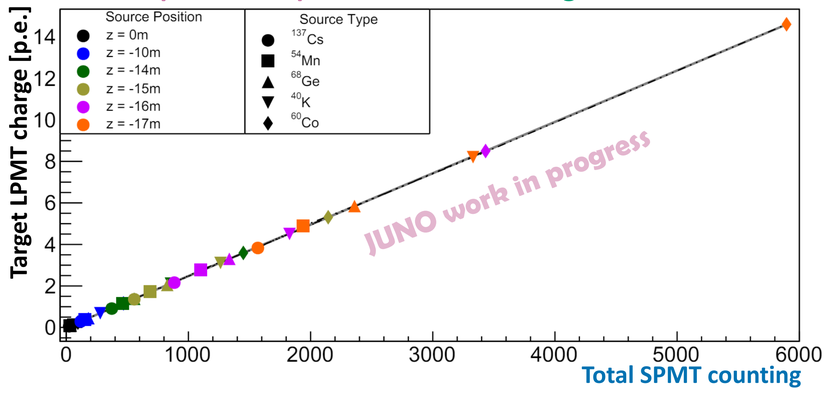
After non-uniformity correction



III. Correction LPMT solid angle on SPMT

- Correct SPMT response by applying **"LPMT solid angle factor"**
- **"Thread"** all curves into single line
- QNL calibration relation established with hit-level simulation.
  More work ongoing with electronic simulation.

Response comparison after solid angle corrections



IV. Expectation:

QNL can be diagnosed with gamma sources for several channels, and then calibrated with DCC-gamma, which is complementary to DCC-laser

* 20k events of ^{54}Mn, ^{68}Ge, ^{40}K and ^{60}Co simulated at 0, 10, 14, 15, 16, and 17 meters from detector center towards target LPMT

Reference

[1] JUNO Collaboration, "JUNO Physics and Status", PPNP, 123 (2022), 103927
[2] JUNO Collaboration, Mass Testing and Characterization of 20-inch PMTs for JUNO, 2022
[3] Yang Han. Dual Calorimetry for High Precision Neutrino Oscillation Measurement at JUNO Experiment. Physics. Université Paris Cité, 2020

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