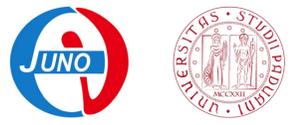




JUNO Calibration: hardware and strategy



A. Serafini^{a, +} on behalf of the JUNO collaboration

^a Department of Physics and Astronomy, University of Padua and INFN, 35131 Padua, Italy

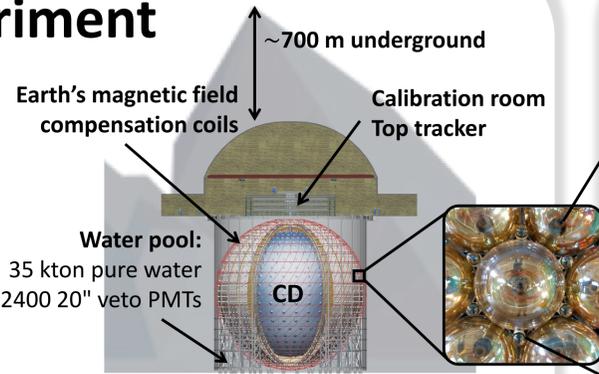
⁺ Correspondence: andrea.serafini@infn.it



15th Pisa Meeting on Advanced Detectors, La Biodola, Isola d'Elba, May 22-28, 2022

The JUNO experiment

The Jiangmen Underground Neutrino Observatory (JUNO) is a **neutrino medium baseline** experiment with an expected unprecedented energy resolution of 3% at 1 MeV, under construction in China [1, 2].



Extensive **neutrino physics and astrophysics program:**

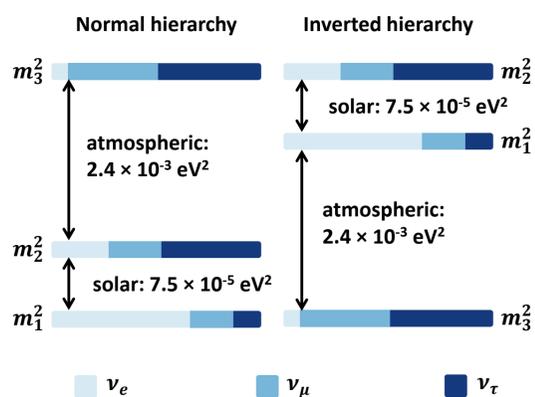
- Reactor $\bar{\nu}_e$: 60 IBD/day
- Supernovae burst: 5000 IBD + 2300 ES in 10 s (@ 10 kpc)
- DSNB: 2-4 IBD/yr
- Solar ν : $O(10^3)$ /yr
- Atmospheric ν : $O(10^2)$ /yr
- Geo- ν : ~400/yr

Main physics goals:

- **neutrino mass hierarchy** determination @ 3σ in 6yr
- measurement of three **oscillation parameters** with sub-percent precision

Central detector (CD): 20 kton liquid scintillator inside an acrylic vessel (\varnothing 35.4 m), supported by a stainless-steel latticed shell

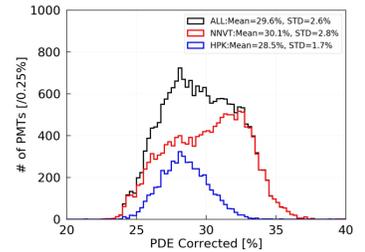
PMT system: 17612 20" Large-PMTs, 25600 3" Small-PMTs, photocoverage > 75%



Dual calorimetry system

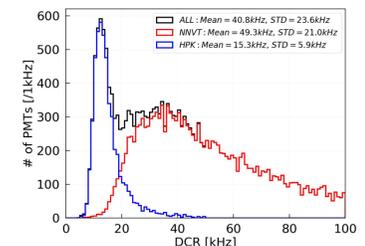
20" Large-PMT (L-PMT) system:

- Photocathode coverage of 75.2%
- High photon detection efficiency (PDE) [4]
 - Hamamatsu dynode PMTs: 28.5%
 - NNTV Micro Channel Plate PMTs: 30.1%
- Low dark count rate (DCR)
- High dynamic range: 0 - 1000 PE
- Waveform acquisition and charge reconstruction



3" Small-PMT (S-PMT) system:

- Photocathode coverage of 2.7%
- High dynamic range: 0 - $O(10^2)$ PE
- Photon-counting regime for $E < 10$ MeV



JUNO employs the dual calorimetry system to correct electronics non-linearity

Sources of non-linear response:

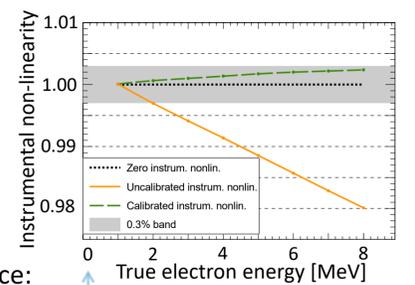
- Non-uniformity (NU)
- Liquid scintillator non-linearity (LSNL)
- Charge non-linearity (QNL) of L-PMTs

Simulations with extreme channel-level non-linearity of 50% over 100 PE show that L-PMT response (R) non-linearity can be corrected using S-PMT as calibration reference:

$$R^{L-PMT} = R_{LSNL} \cdot R_{NU}^{L-PMT} \cdot R_{QNL}^{L-PMT}$$

$$R^{S-PMT} = R_{LSNL} \cdot R_{NU}^{S-PMT} \cdot R_{QNL}^{S-PMT}$$

$$\frac{R^{L-PMT}}{R^{S-PMT}} = \frac{R_{QNL}^{L-PMT}}{R_{QNL}^{S-PMT}} \quad [5]$$



Calibration strategy

JUNO's main requirements for reaching its physics goals are:

- 3% energy resolution at 1 MeV
- energy-scale systematics below 1%

In order to accurately characterize the detector response, a **multiple-source campaign** relying on a specifically designed **calibration system** has been developed [6].

*calibration strategy study not updated to latest PDEs published in [4]

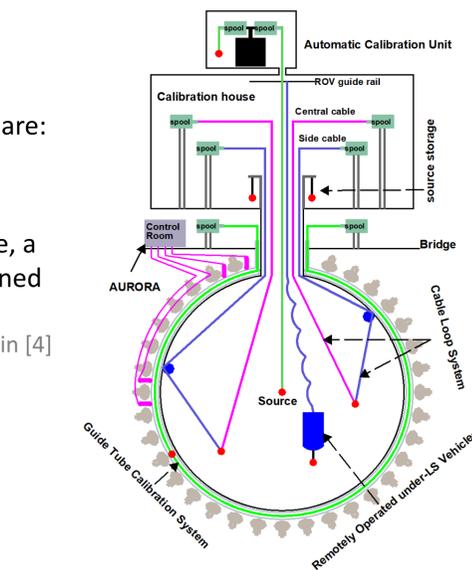
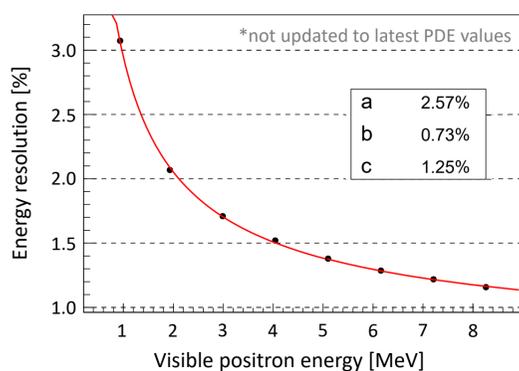
Energy resolution

A key aspect in JUNO is energy resolution for the IBD positron signals. This can be written as:

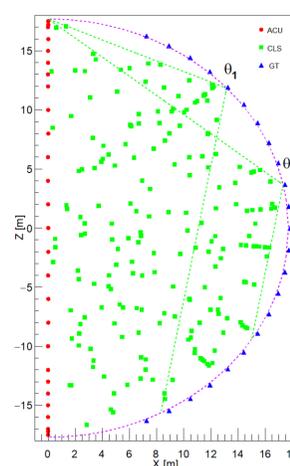
$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{a}{\sqrt{E}}\right)^2 + b^2 + \left(\frac{c}{E}\right)^2}$$

statistical term position non-uniformity PMT dark noise

In case of ideal non-uniformity correction:



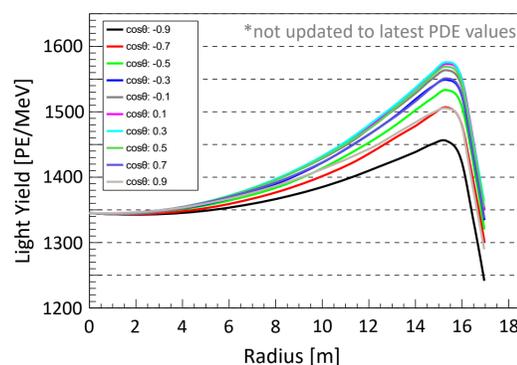
250 calibration points



Sources/Processes	Type
^{137}Cs	γ
^{54}Mn	γ
^{60}Co	γ
^{40}K	γ
^{68}Ge	e^+
$^{241}\text{Am-Be}$	n, γ
$^{241}\text{Am-13C}$	n, γ
$(n, \gamma)p$	γ
$(n, \gamma)^{12}\text{C}$	γ

Detector non-uniformity

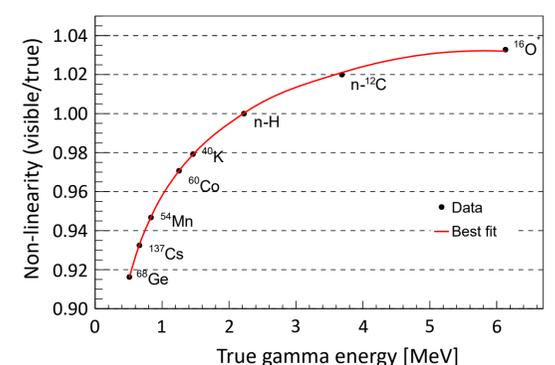
The detector response to the same charge deposition depends on the position at which the event occurs and needs to be properly characterized.



Liquid scintillator non-linearity

Light emission has an intrinsic non-linearity because of:

- Birks' quenching effect in scintillation photon yield;
- Velocity-dependent Cherenkov emission.



The a and c parameters depend on the liquid scintillator and PMT properties, respectively, and cannot be reduced by better comprehending the detector response. The b parameter can instead be studied and reduced by **characterizing the detector non-uniformity**.

From the perspective of calibration this can be achieved **deploying radioactive sources to fixed locations** and by studying uniformly distributed background events, (e.g., spallation neutrons).

References:

- [1] JUNO Collaboration, *JUNO Physics and Detector*, Prog. Part. Nucl. Phys. 123, 2022
- [2] JUNO Collaboration, *Neutrino Physics with JUNO*, J. Phys. G43, 3, 2016
- [3] JUNO Collaboration, *JUNO Conceptual Design Report*, 2015
- [4] JUNO Collaboration, *Mass Testing and Characterization of 20-inch PMTs for JUNO*, 2022
- [5] Yang Han. *Dual Calorimetry for High Precision Neutrino Oscillation Measurement at JUNO Experiment*. Physics. Université Paris Cité, 2020
- [6] JUNO Collaboration, *Calibration strategy of the JUNO experiment*, J. High Energy. Phys. 4, 2021