Double Calorimetry System of the JUNO experiment

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JUNO: an unprecedented Liquid Scintillator Detector

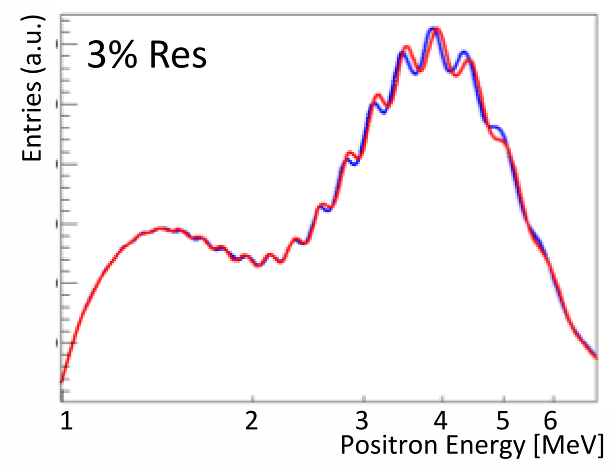
Determination of the neutrino mass hierarchy requires a precision measurement of reactor antineutrinos with 3% energy resolution at 1 MeV and a calibration error lower than 1% over a huge detector.

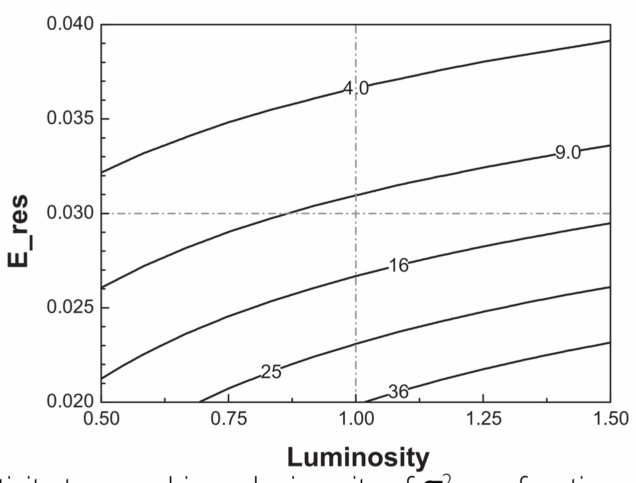
3% resolution at 1 MeV is pivotal

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

a - stochastic term → *Maximise the detected light* → *Large photo-coverage, Transparent scintillator, High QE*

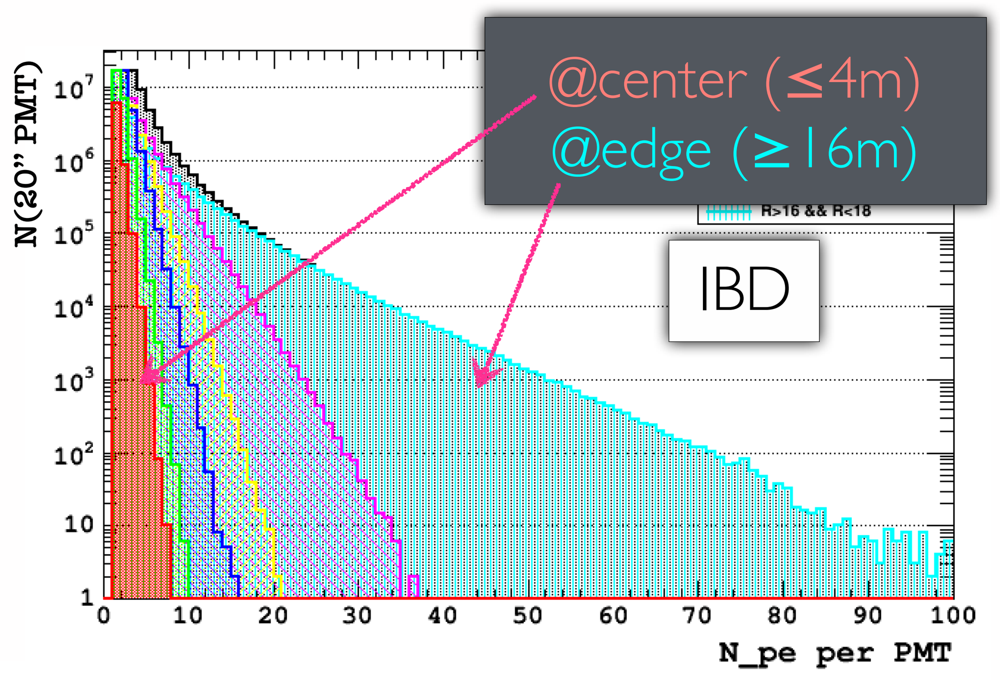
b,c - non stochastic terms → *Control systematics* → *Challenge over huge detector*

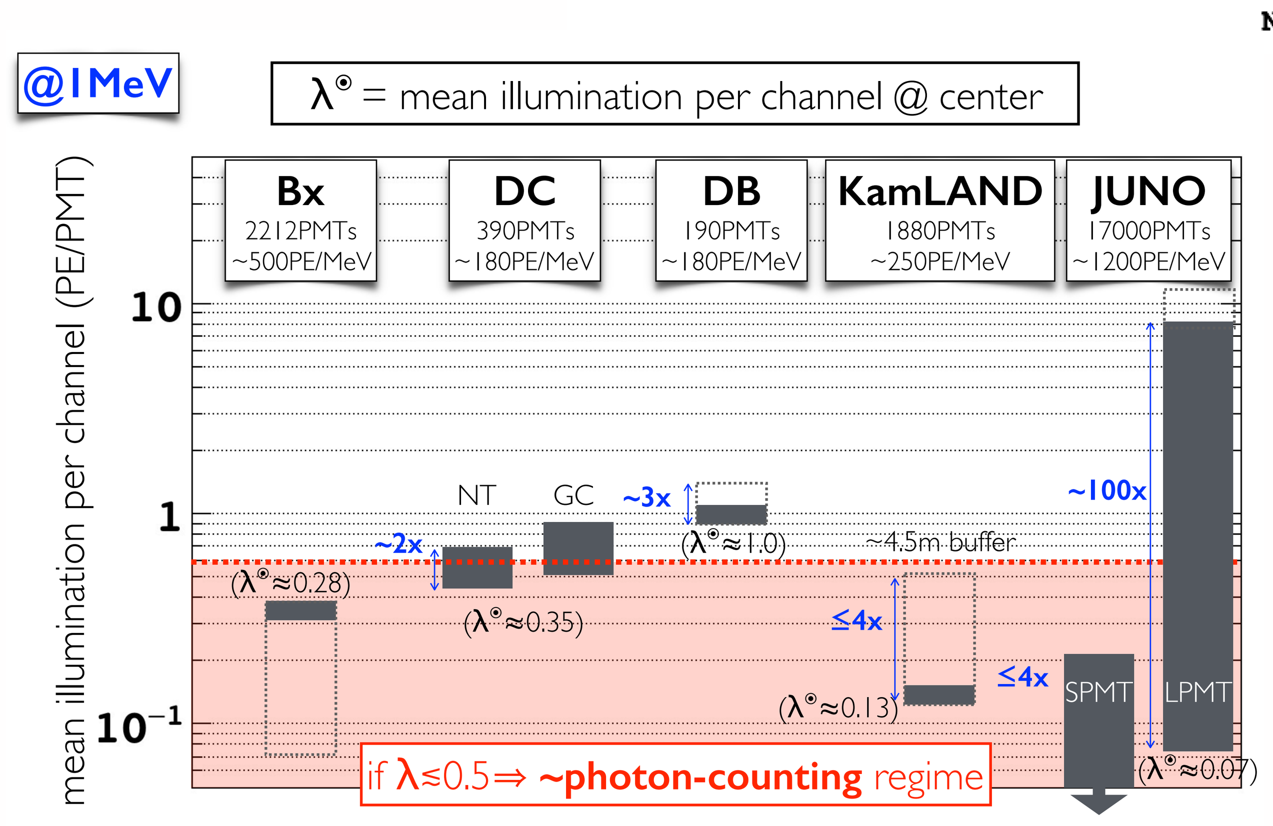




Sensitivity to mass hierarchy in units of σ^2 as a function of energy resolution and years (1.00=6 yrs)

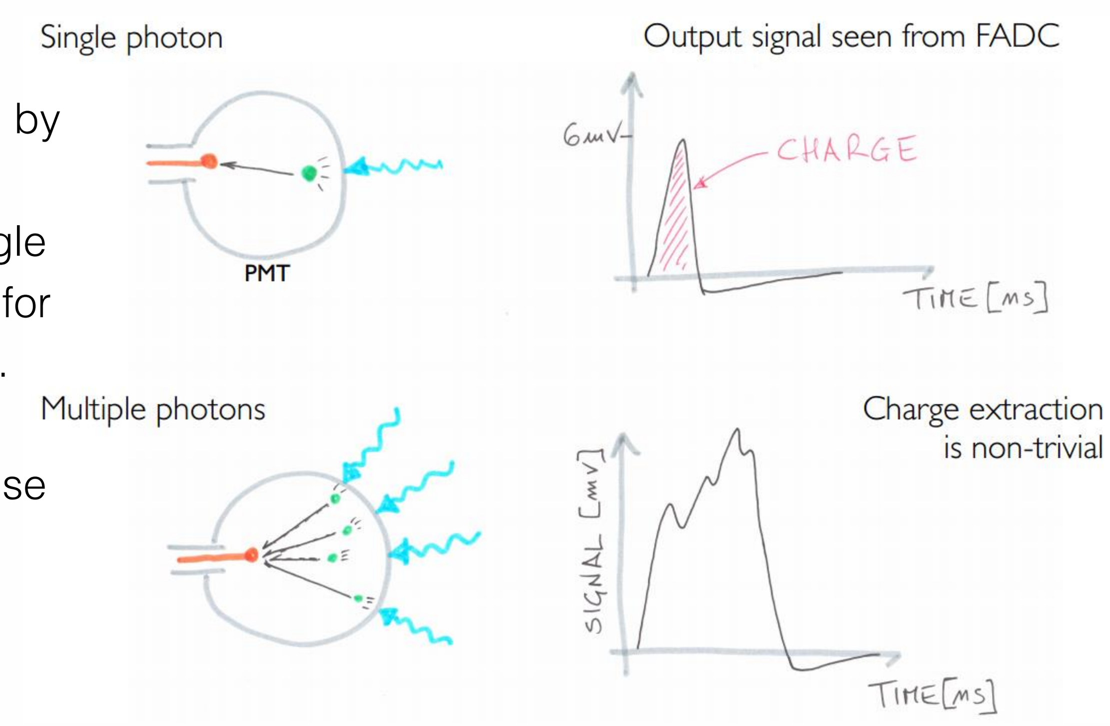
The large Liquid Scintillator (LS) volume and the large (20") PMT's surface imply an unprecedented PMT dynamical range which represents a challenge for the control of the systematic uncertainties.





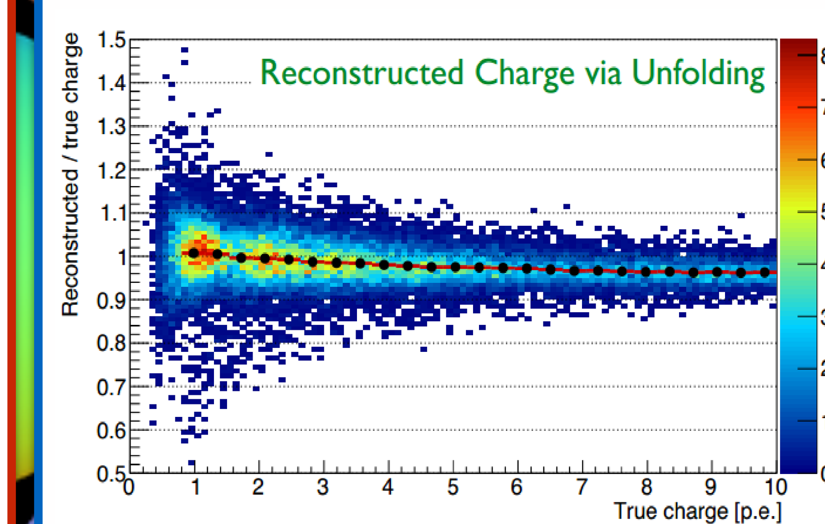
Charge measurement of single channel

Optical photons are detected by photomultiplier tubes (PMTs). The charge extraction for single photon is straightforward but for multiple photons is non-trivial. Noise and overshoot can introduce a non linear response in the measurement of the charge in case of multiple photons.

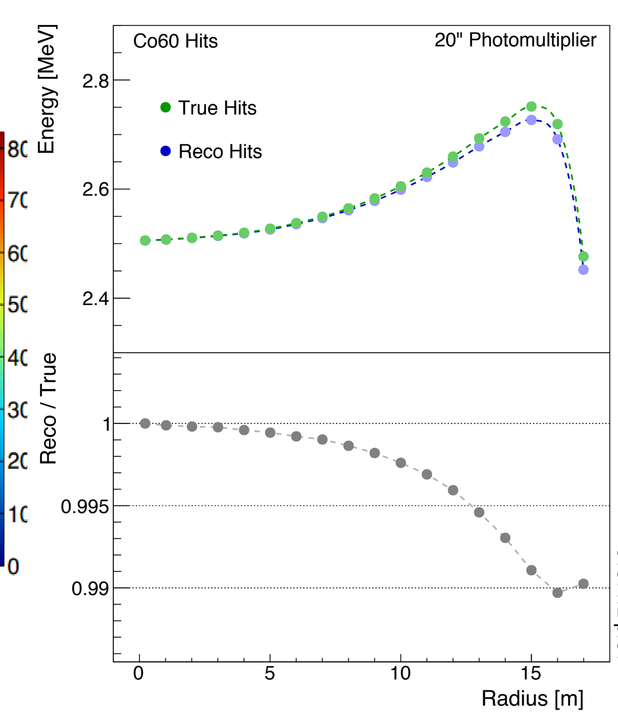


Three ways have been tested to reconstruct the PMT charge based on the sampled waveform with overshoot and noise simulated

1) charge integration
2) waveform fitting
3) waveform deconvolution

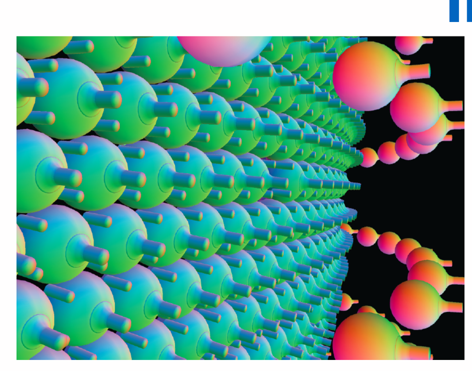


Even with sophisticated wave form analysis, it is very difficult to reduce the non-linearity below a few percent.



non linearity (channel-wise)
↓
non uniformity (position-wise)
↓
worse resolution (position-wise)

Implementation for JUNO



- The physics concept of Double Calorimetry was approved by the JUNO collaboration in July 2015.
- The project design was approved in January 2016.
- The final number of SPMT and their positions in the detector depend on physics optimisations (on-going)

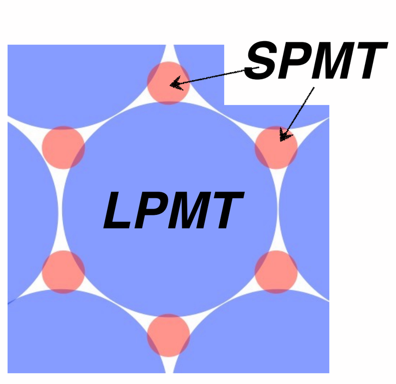
Investigation of PMTs from different suppliers

Current baseline design

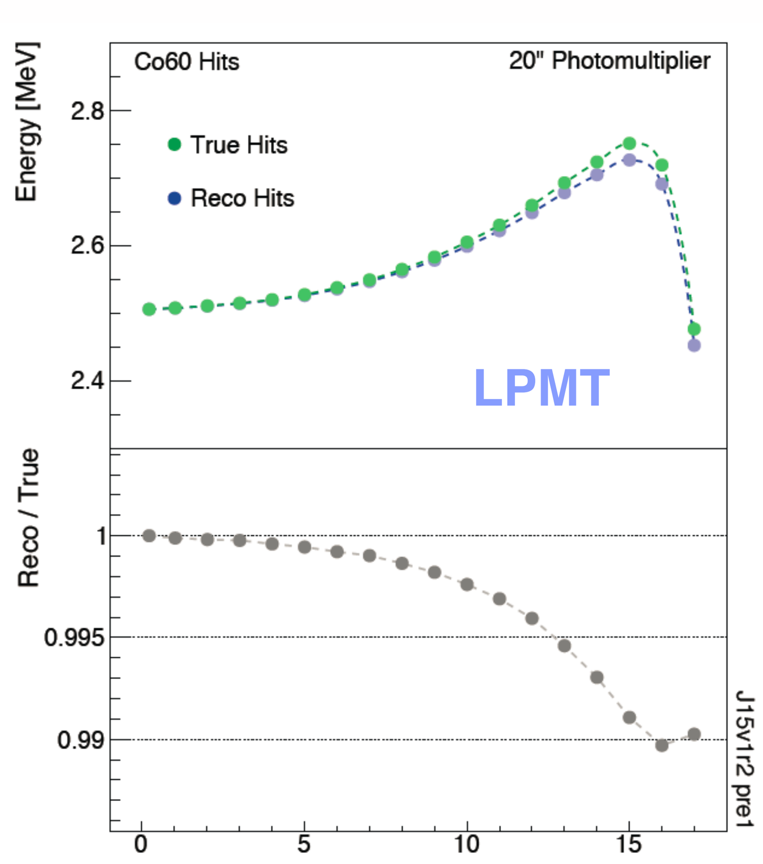
- ~18,000 20-inch PMTs
- ~36,000 3-inch PMTs

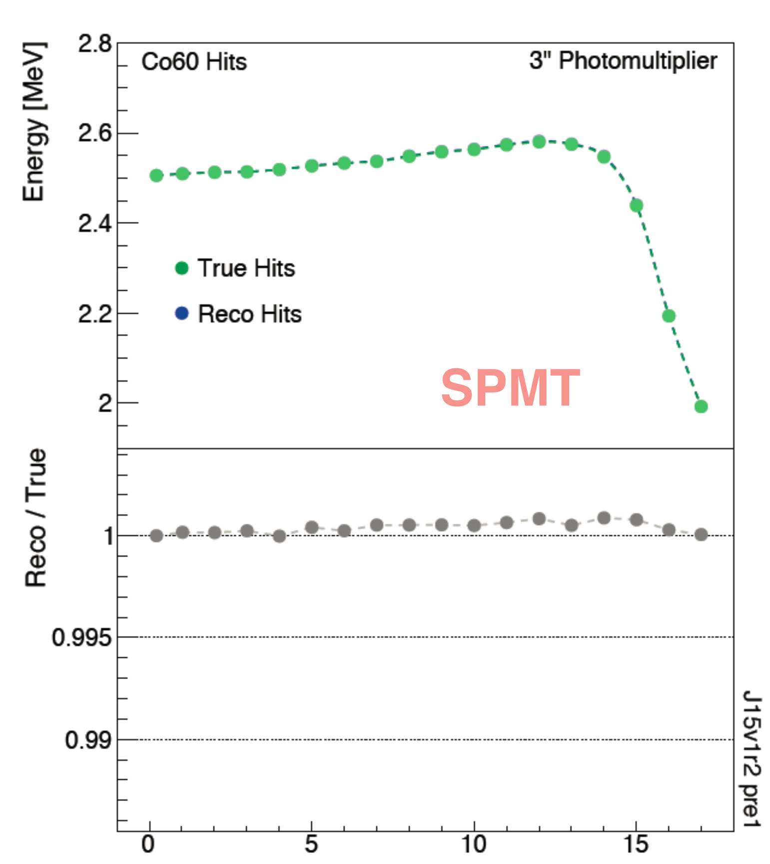
A new concept of double calorimetry

To disentangle the non-linear effects in the calibration from the non-uniform response of the detector we have introduced a second set of small PMT (SPMT) whose mean illumination is such that they operate mainly in photon counting regime.



- Large-PMT (LPMT): measure energy via "charge integration", increase photon statistics ⇒ stochastic effect
- Small-PMT (SPMT): measure energy via "photon counting", control systematics ⇒ non-stochastic effects

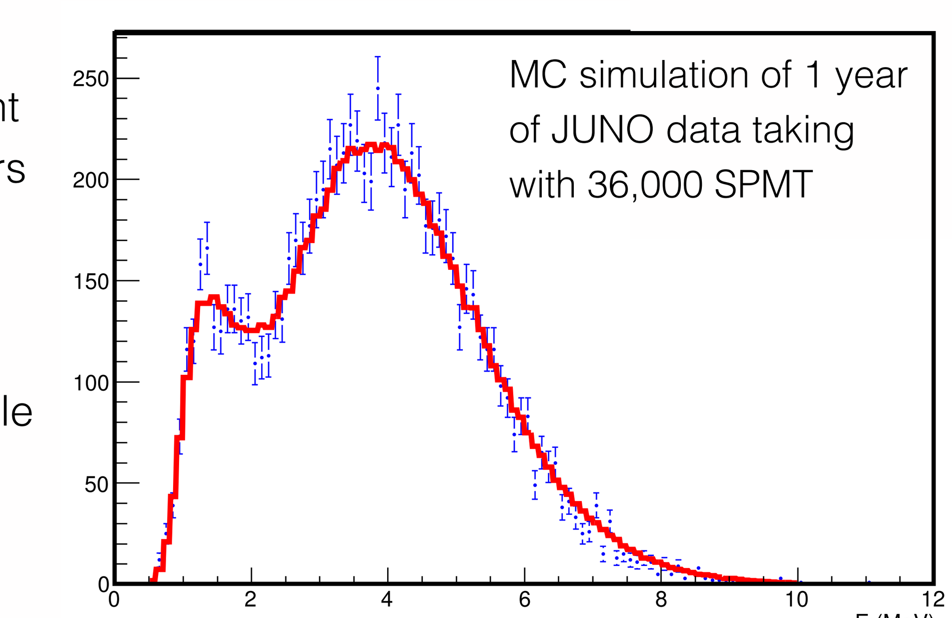




Simulated ^{60}Co calibration campaign at different radii. The reconstructed energy with LPMT is biased compared to MC, while the bias can be corrected by the SPMT measurement.

Other benefits from SPMT

- Provide an independent measurement of solar neutrino oscillation parameters with similar resolution and time frame as LPMT measurement. We can use the solar neutrino oscillation parameters to cross check for possible systematics on the energy reconstruction.



- Extend the dynamical range beyond the region where LPMT are no longer linear or even saturated.
- Improve time and vertex resolution due to the lower TTS of the small PMTs.
- Improve muon tracking with better timing and higher granularity to control $^9Li/^8He$ backgrounds.
- Improve the supernovae neutrino detection with less pile-up compared to LPMT.