Dual Calorimetry at JUNO Experiment

NEUTRINO 2020

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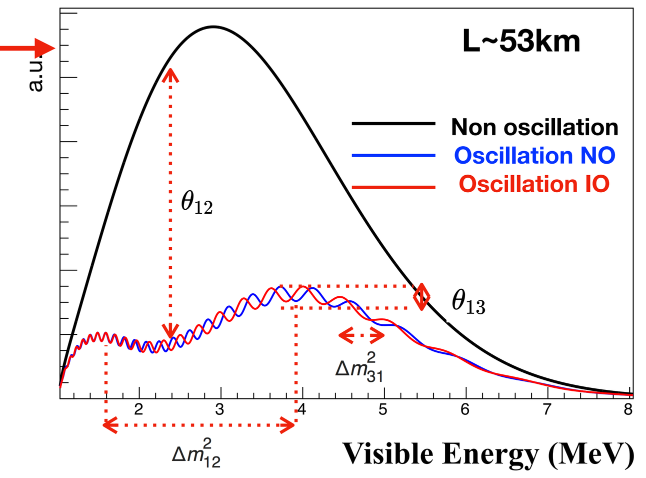
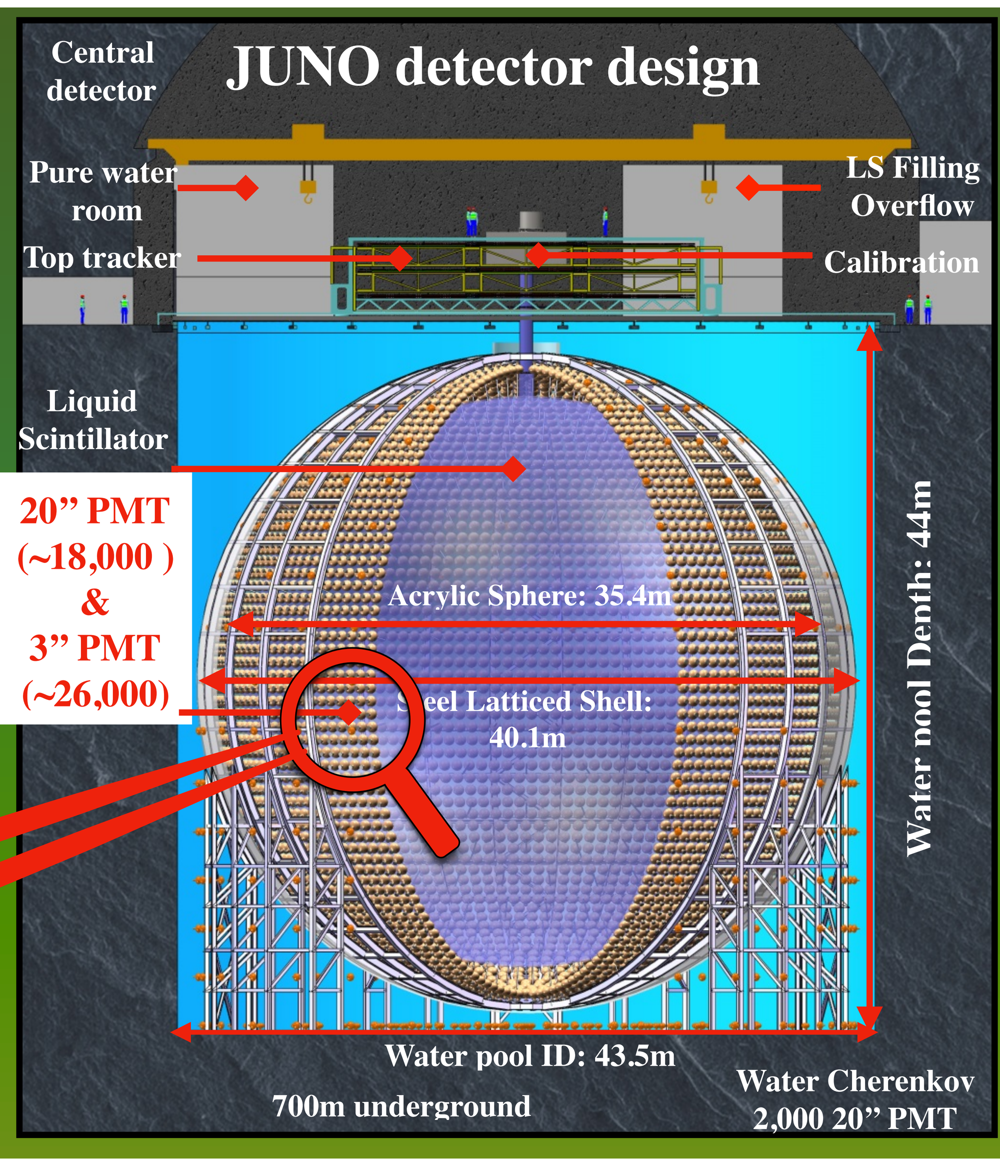
Jiangmen Underground Neutrino Observatory

Primary physics: neutrino mass ordering (νMO) determination and sub-percent precision measurement of Δm^2_{31}, Δm^2_{21}, θ_{12} through reactor neutrinos.

Other physics potentials: supernova neutrino, solar neutrino, geo-neutrino, proton decay search, etc.



JUNO detector design



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

design driven by neutrino mass ordering determination

	Daya Bay	BOREXINO	KamLAND	JUNO
Target Mass	~20 t	~300 t	~1 kt	~20 kt
Photo-coverage	~12%	~34%	~34%	~78%
Light Yield (PE/MeV)	~160	~500	~250	~1200
Energy Resolution@1MeV	~8%	~5%	~6%	3 %
Energy scale precision	<1%	~1%	~1.4%	<1%

Critical requirements:

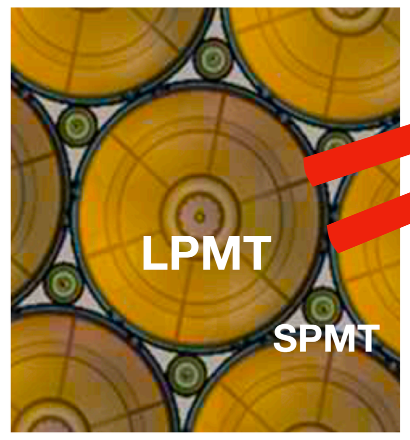
3% energy resolution at 1 MeV with non-stochastic terms <1% and energy scale precision better than 1%.

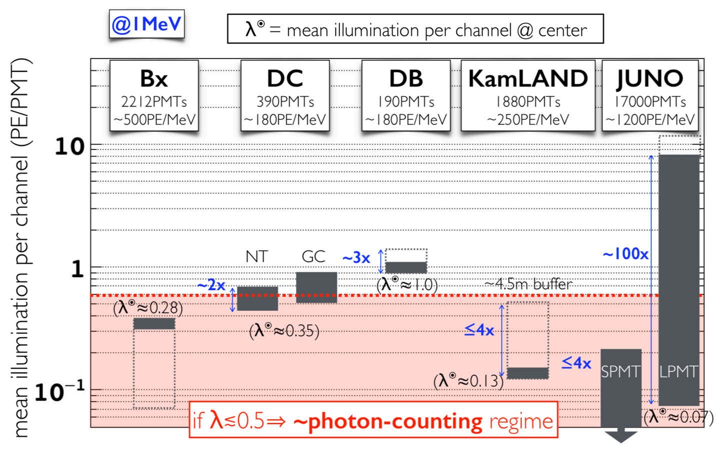
$$\frac{\sigma(E)}{E} = \sqrt{\underbrace{\left[\frac{a}{\sqrt{E}}\right]^2}_{\text{Stochastic term}} + \underbrace{[b(E)]^2}_{\text{Non-stochastic terms}}}$$

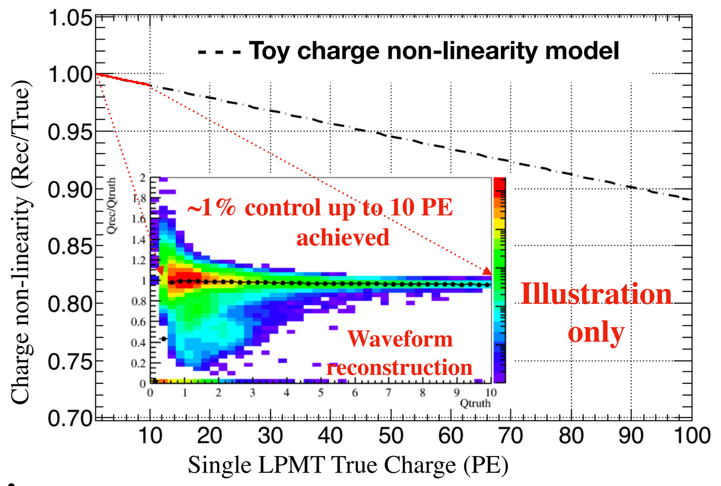
Dual Calorimetry

Motivation: The JUNO 20-inch PMT (LPMT) needs to handle the unprecedented charge dynamical range in liquid scintillator neutrino experiment history. Because of this vast dynamic range, the LPMT readout response control is expected to be a big challenge.

The charge non-linearity at readout level could degenerate with the non-uniformity, the liquid scintillator non-linearity and the stability. Thus, the control of charge non-linearity is critical to understand the whole detector response and achieve the sub-percent calorimetry systematics control.







Concept&Design: The 3-inch PMT (SPMT) is introduced as the charge linear reference for the LPMT. Due to its small size, the charge detection of the SPMT is based on the robust photoelectron counting, thus being linear by design. The LPMT and the SPMT are linked through the common exposure to the same energy deposition, constituting the Dual Calorimetry design. This design allows the direct charge response comparison between the two systems. It provides some unique insights for the calorimetry systematics control through e.g. direct charge non-linearity calibration.

Response comparison
(written in multiplication for illustration only)

$$R^L = R_{LS} \cdot R^L_X \cdot R^L_T \cdot \boxed{R^L_Q}$$
$$R^S = R_{LS} \cdot R^S_X \cdot R^S_T \cdot \boxed{R^S_Q}$$

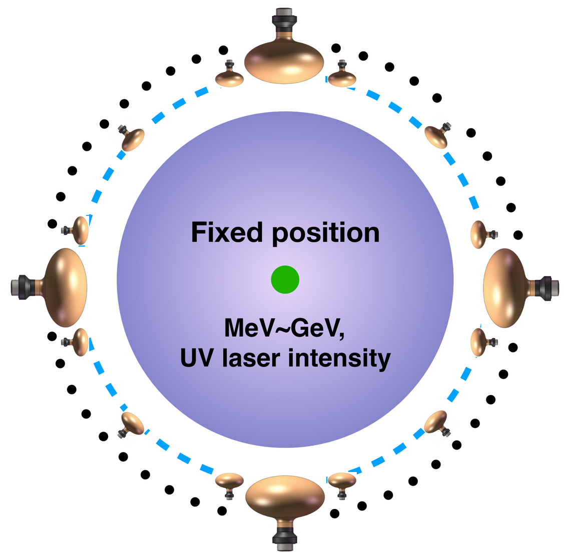
Liquid scintillator — Position — Time (stability) — Charge

Charge response isolation

Implementation(channel-wise):

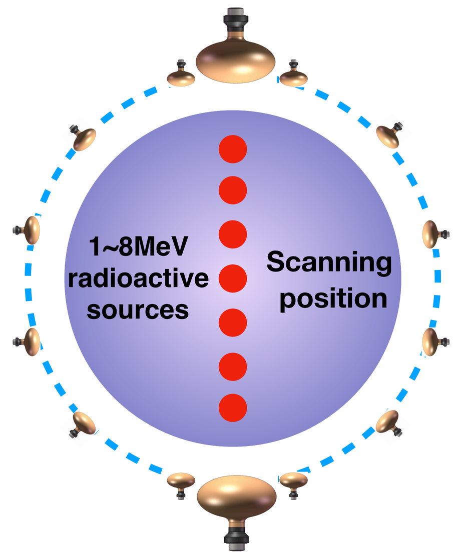
Dual Calorimetry Calibration (DCC) aims to calibrate the potential nonlinear charge response of every channel of LPMT. With the aid of the UV laser source and the radioactive source, a two stages calibration strategy can be implemented to correct the potential LPMT charge non-linearity.

DCC-laser:
UV laser source
position@detector center



Advantage: Covering all channels, Covering large dynamic range
Challenge: Laser≠ Reactor neutrino IBD signal (positron)

DCC-gamma:
Radioactive source (mainly gamma)
scanning position (1D)



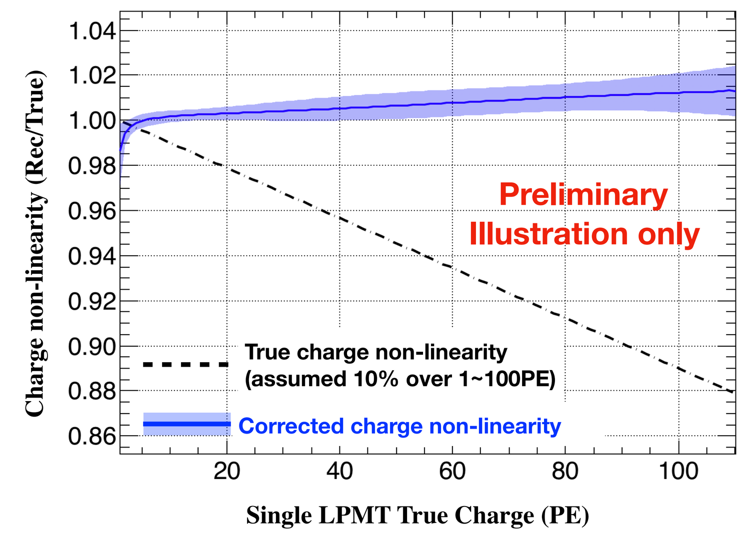
Advantage: Radioactive source (gamma) ~ Reactor neutrino IBD signal (positron)
Challenge: Not covering all channels

DCC performance

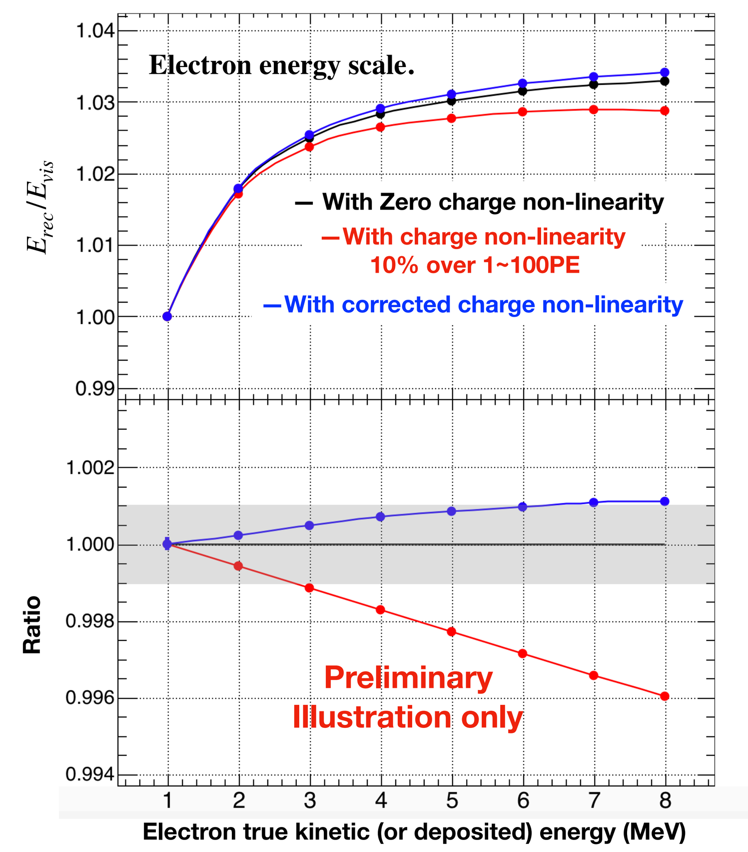
DCC can significantly correct the potential nonlinear charge response of the LPMT. Through this calibration, the potential energy scale bias, as well as the potential energy resolution reduction caused by the charge non-linearity can be largely corrected. DCC can aid the overall JUNO calorimetry systematics control, hence the physics measurement.

Other possible implementations of Dual Calorimetry, e.g. through cosmogenic signals or neutrino oscillation, could allow further scrutiny of the calorimetry systematics.

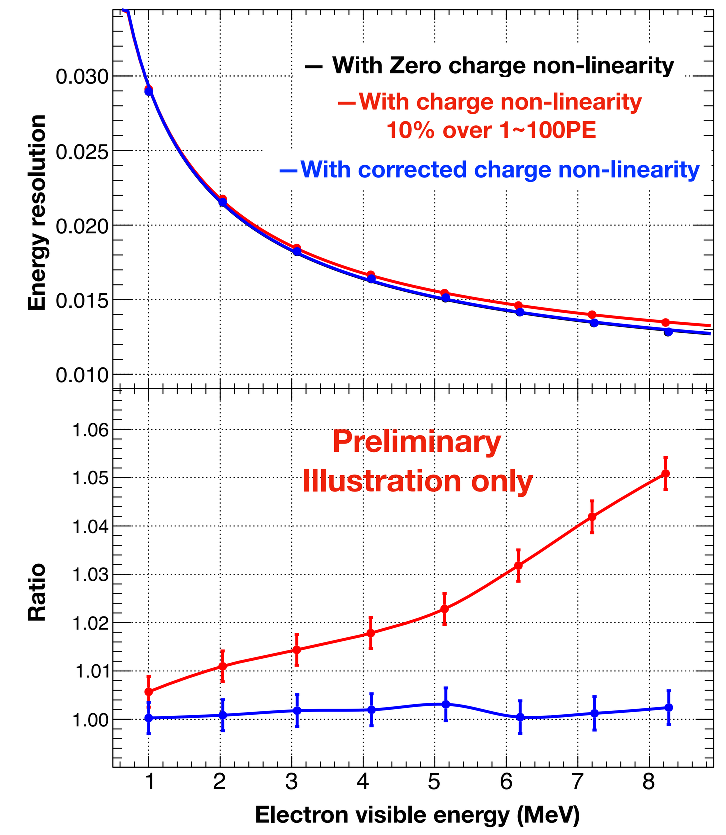
Direct channel-wise charge non-linearity control:



Energy scale control:

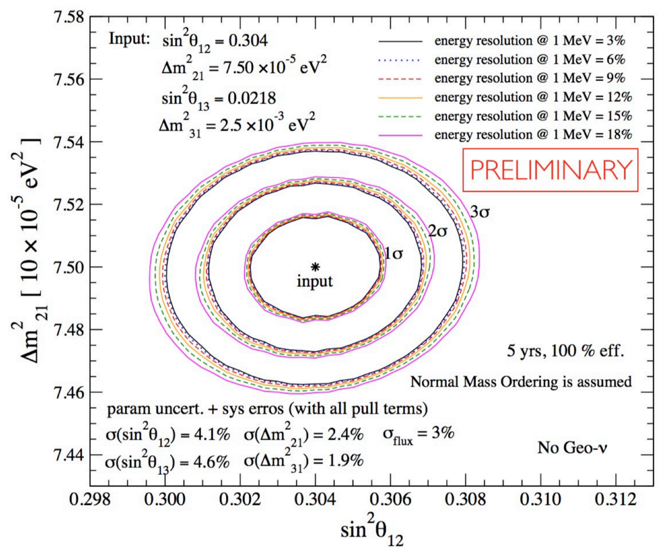


Energy resolution control:



"Solar" Oscillation Parameters

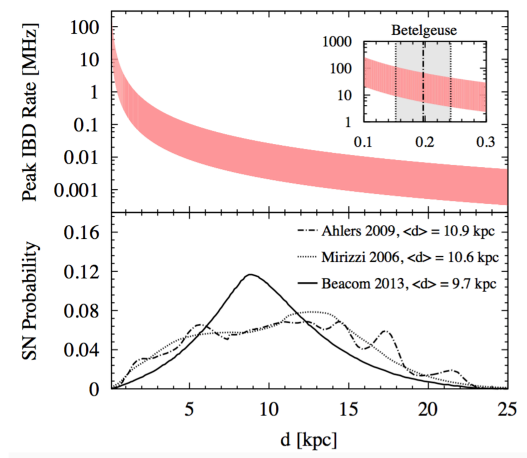
The SPMT system is an independent photo detection system to determine the "solar" oscillation parameters: Δm^2_{21} and θ_{12} with similar sensitivity compared to the LPMT system. It provides a cross check to LPMT system measurement. It could shed light on the potential charge response issues.



Other physics potentials with the SPMT System

Supernova Neutrino

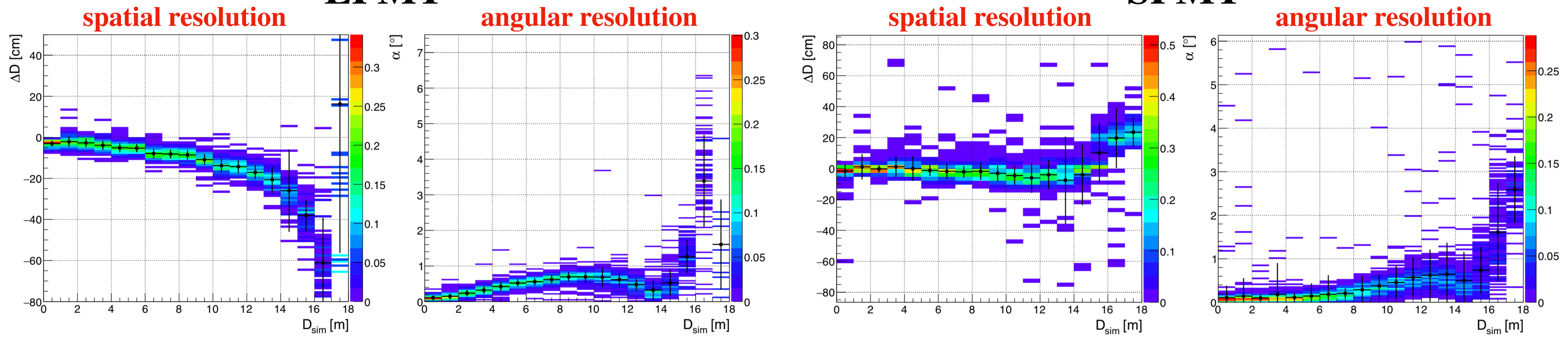
During a SN burst, ~99% of the energy will be released through neutrinos and antineutrinos of all flavours. The challenge for the SN neutrino detection is the pile-up of events since most of them arrive in the time window less than a second. The lower light level and the fast readout of SPMTs are expected to provide additional analysis control for maximal physics extraction during supernova core collapse observation.



Maximum IBD rate at JUNO as a function of the distance to a galactic SN

Reconstruction of Cosmic-ray Muons

The cosmic-ray muons are one of the main source of the backgrounds in JUNO. Compared to the LPMT, the SPMT system has better time resolution and avoidance of saturation. It can handle large energy deposition to provide valuable inputs for precise studies of muons.



Source: C. Genster et al. *Muon reconstruction with a geometrical model in JUNO*, JINST 13 (2018) T03003.