# Stereo Calorimetry in JUNO

## Physics Motivation and Instrumentation


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**on behalf of JUNO collaboration**

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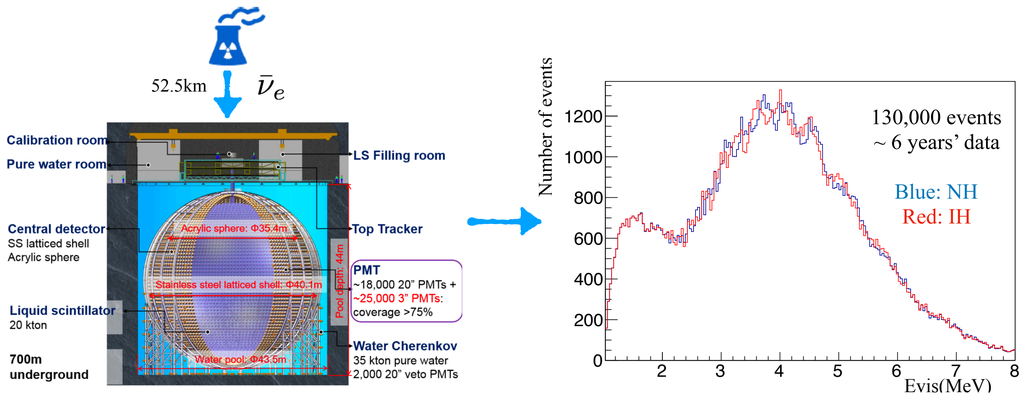
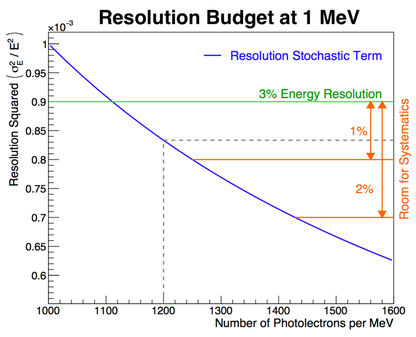
## Jiangmen Underground Neutrino Observatory

✤ JUNO: a multipurpose experiment designed primarily to determine the neutrino mass hierarchy by precisely measuring the medium baseline reactor neutrino energy spectrum.



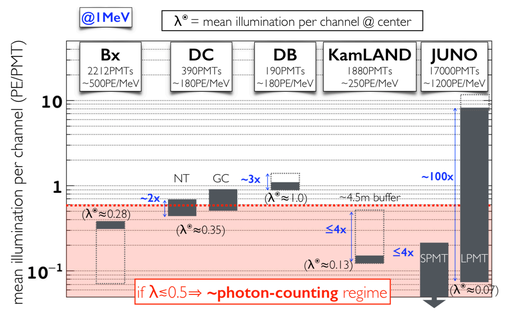

✤ Requirements of JUNO detector: 3% energy resolution at 1 MeV and calibration error lower than 1%.




$$\frac{\sigma(E)}{E} = \sqrt{\left[\frac{a}{\sqrt{E}}\right]^2 + [b(E)]^2}$$

Stochastic term ~ 1200 p.e./MeV (~ Light yield, Transparency Photo-coverage, QE…)

Non stochastic terms (~ control of systemics)

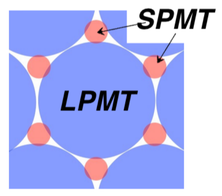


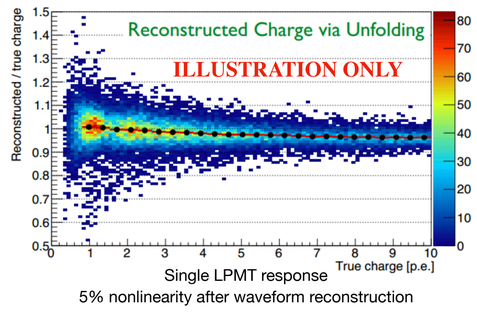

✤ For JUNO large PMT(20-inch) system it is a challenge to control systematics because of the unprecedented PMT dynamical range. A SPMT system is introduced as a calibration gauge for the LPMTs.

## Stereo Calorimetry for JUNO

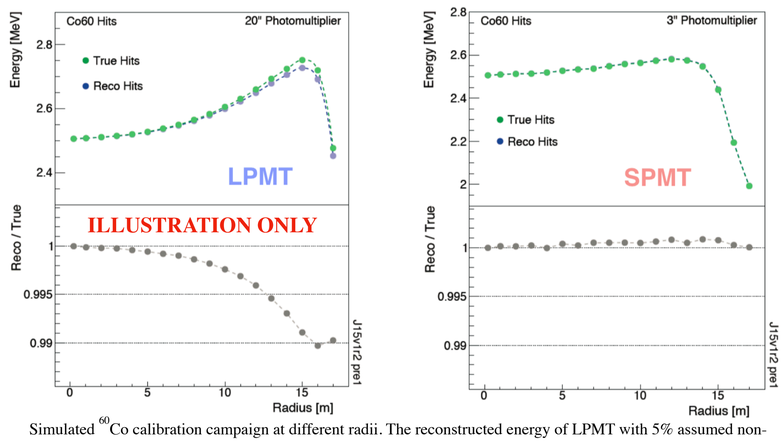
✤ The stereo calorimetry consists of two Photo Multiplier Tube systems:

- 18,000 large (20-inch) PMT system which will record and reconstruct the individual LPMT waveforms
- 25,000 small (3-inch) PMT system which is based on "photon counting" and expected to have almost zero-dynamic range, hence virtually no non-linearity, thus providing a linear reference to LPMT.




✤ The majority physics goals of JUNO are supposed to be achieved by LPMT system. However, because of the large dynamical range of LPMT, response non-linearities are expected to be the biggest challenge. A priori corrected non-stability and non-uniformity effects could, additionally, correlated into apparent non-linearities. The SPMT system is expected to provide an additional set of information with reduced and well understood systematics by recording the same events as LPMTs.

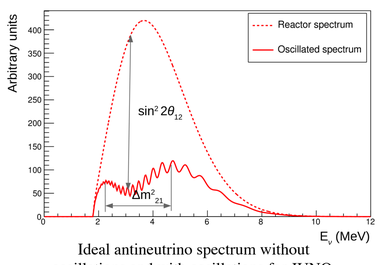



Simulated $^{60}$Co calibration campaign at different radii. The reconstructed energy of LPMT with 5% assumed non-linearity is biased compared to MC, while the bias can be corrected by the SPMT measurement

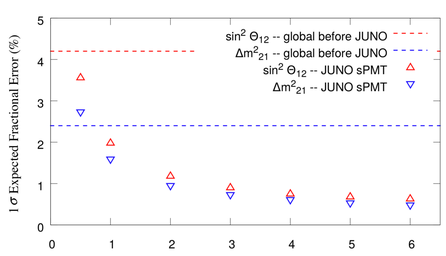
## Enhanced Physics Capabilities with SPMT System

### Solar Oscillation Parameters

✤ The SPMT system can serve for an independent photo detection system to determine the solar oscillation parameters: $\Delta m^2_{12}$ and $\theta_{12}$ with a precision comparable to LPMT system.




Ideal antineutrino spectrum without oscillations and with oscillations for JUNO



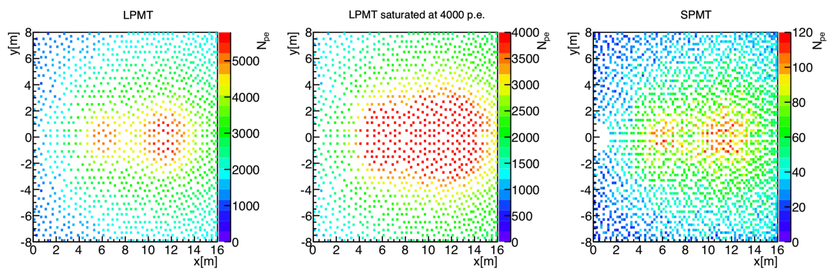

Sensitivity to $\Delta m^2_{12}$ and $\theta_{12}$

✤ The solar oscillation parameters do not depend on the fast oscillation pattern.
✤ It will surpass the current precision in one year with SPMTs.
✤ Cross-check of the LPMT system measurement.

### Reconstruction of Cosmic-ray Muon

✤ The cosmic-ray muons are one of the main source of the backgrounds in JUNO. The LPMTs are limited in muon track (and muon bundles) reconstruction, because of (1) the saturation with large energy deposits and (2) generally worse time resolution.

✤ SPMT system has better time resolution and avoidance of saturation. It can handle large energy deposits to provide valuable inputs for precise studies of muon tracks.

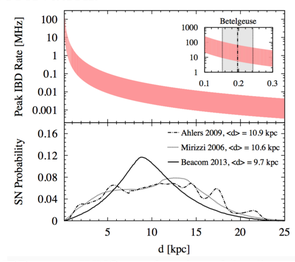



Example of double muon hit pattern seen by LPMTs without saturation, LPMTs saturated at 4000 p.e. and SPMTs

### Supernova Neutrino

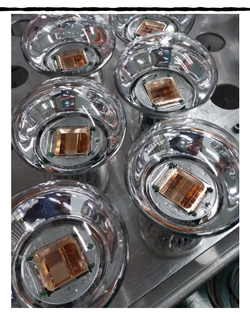
✤ During a SN burst, about 99% of the energy will be released through neutrinos and antineutrinos of all flavours. Detection of supernovae neutrinos can help us understand neutrino properties, gravitational core collapse and nucleosynthesis r-process…

✤ The challenge for the SN neutrino detection is the pile-up of events since most of them arrives in the time window less than a second. The lower light level, fast and dead-time-less 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

## Instrumentation of SPMT System



| Parameters | HZC XP72B22 Performance |
|---|---|
| Photon detection efficiency@420 nm | 24% |
| TTS (FWHM) of single photoelectron | <5 ns |
| P/V ratio of single photoelectron | 3 |
| Single photoelectron resolution | 35% |
| Dark rate @ 0.25 p.e. | 1,000 Hz |
| Quantum efficiency uniformity | <30% in Φ60 mm |
| Pre/after pulse charge ratio | <5%/<15% |
| Nonlinearity | <10%@1-100 p.e. |
| Radioactivity | $^{238}$U<400 ppb, $^{232}$Th<400 ppb, $^{40}$K<200 ppb |

### SPMT

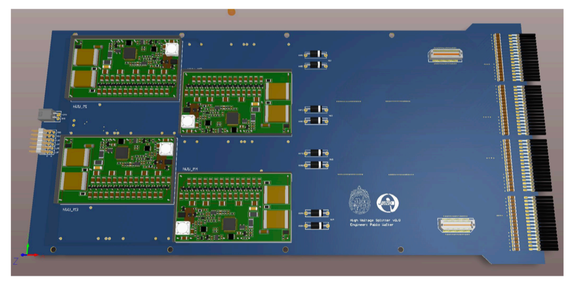
✤ The SPMTs (XP72B22) are supplied by HZC photonics after co-developement with JUNO-SPMT collaboration.

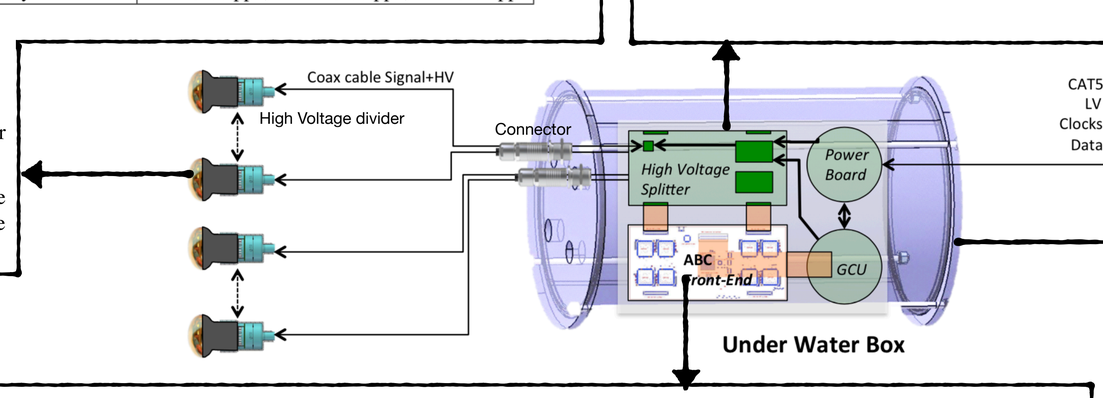
✤ The SPMTs are required to have excellent resolution for single photoelectron (SPE), high quantum efficiency, good transit time spread and low dark rate.

### High Voltage Splitter

✤ Two HV splitter boards are placed above and below the ABC board with desired output range 800~1600V.

✤ Each board has 8 HV units. One HV unit will power 16 SPMTs, while there is a back-up unit for each HV unit.

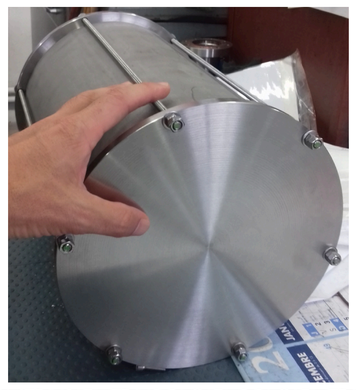


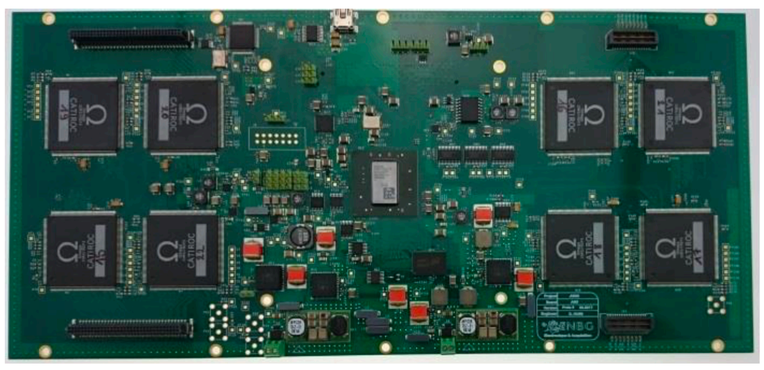



### Under Water Box

✤ The SPMT readout electronics will be located underwater in the UWBs in order to reduce the costs associated with the cabling and to avoid transmission losses in the long distance to the surface.

✤ Each UWB will serve 128 SPMT channels and withstand pressures up to 50 m depth for more than 20 years





### Readout Electronics

✤ The signal will be read by an ABC (ASIC Battery Card) board housing 8 CATIROC (Charge And Time Integrated Read Out Chip) chips and sent via the Global Control Unit (GCU) to the Data Acquisition (DAQ) system placed on the surface

✤ The front-end ABC board consisting of two key elements.

- Eight 16-channels CATIROC ASICs provide a trigger-less, by-channel accurate measurement of the integrated charge and time of each input.
- A high-performance Kintex-7 Field Programmable Gate Array (FPGA) responsible for the communication with the slow control, as well as data capture, processing and further packaging.