3-inch PMT System and Double Calorimetry at JUNO

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On behalf of the JUNO collaboration

Baksan-50

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JUNO: Jiangmen Underground Neutrino Observatory

- **Source:** 10 reactor cores (2 NPPs)
- **Baseline:** 52.5 km
- **Overburden:** 700 m
- **Detection channel:** $\bar{\nu}_e + p \rightarrow e^+ + n$
  - Time coincident signal
- **Liquid Scintillator Target (LAB):**
  - mass of 20 kt
  - IBD statistics $\sim 10^5$ events in 6 yrs
  - $\sim 12000$ photons/MeV, high transparency
  - 1200 p.e./MeV
- **Light detection:**
  - $17k$ 20" PMTs + $25k$ 3" PMTs
  - $>75\%$ photo-coverage
  - 2 independent PMT systems
  - energy resolution 3% @ 1 MeV
Physics @ JUNO

Main goals:

Mass Hierarchy

\[ \sin^2 2\theta_{12}, \Delta m^2_{12} \text{ and } \Delta m^2_{ee} \text{ to } < 1\% \text{ uncertainty} \]

Key requirements for PMT:

- Energy resolution:
  - Photo coverage
  - Detection efficiency: CE x QE

- Systematics under control:
  - Calibration
  - Minimization/correction of non-linearities
We can look at the same event with two independent and complimentary instruments.

**Large & Small PMT Systems**

**LPMT (17k x 20")**
- NNVT MCP-PMT
- Hamamatsu R12860 dynode PMT
- High photo-electron statistics =>
- Good energy resolution

**sPMT (25k x 3")**
- HZC XP72B22
- Single-photon mode =>
- Non-linearity free
Charge Integration

Single photon

Output signal seen from FADC

Multiple photons

Charge extraction is non-trivial
Co-60 Calibration (simulation)

Non-linearity (single channel)  Non-uniformity (position dependent)  resolution deterioration (full detector)

LPMT

sPMT

Much better!

Can help to correct
Dynamical Range

<table>
<thead>
<tr>
<th>Experiment</th>
<th>PMTs</th>
<th>Mean Illumination per Channel (PE/PMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bx</td>
<td>2212</td>
<td>500PE/MeV</td>
</tr>
<tr>
<td>DC</td>
<td>390</td>
<td>180PE/MeV</td>
</tr>
<tr>
<td>DB</td>
<td>190</td>
<td>180PE/MeV</td>
</tr>
<tr>
<td>KamLAND</td>
<td>1880</td>
<td>250PE/MeV</td>
</tr>
<tr>
<td>JUNO</td>
<td>17000</td>
<td>1200PE/MeV</td>
</tr>
</tbody>
</table>

If $\lambda \leq 0.5$ ⇒ ~photon-counting regime

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Additional benefits from sPMTs

- Better time characteristics
- Help when LPMTs became saturated
  - Muon reconstruction (for $^{12}$B / $^9$Li / $^8$He tagging/vetoing)
  - Multi-muon events
  - Near supernova burst
  - ...

In addition sPMT can cross-check LPMT measurement of $\sin^2 2\theta_{12}$ and $\Delta m^2_{12}$ (no need for high resolution)
Summary

- JUNO will have a double calorimetry system:
  - 17k 20" PMTs
  - 25k 3" PMTs

looking with two independent and complimentary instruments on the same events

- LPMT: energy resolution 3% @ 1MeV
- sPMT: control of systematics
- LPMT+sPMT: huge dynamical range