Neural Network-Based Waveform Reconstruction in JUNO

Data-driven PMT waveform reconstruction improves detector energy resolution

Zhangming Chen on behalf of JUNO collaboration| Shanghai Jiao Tong University | Neutrino 2026

87% -> 27%
MCP SPE resolution

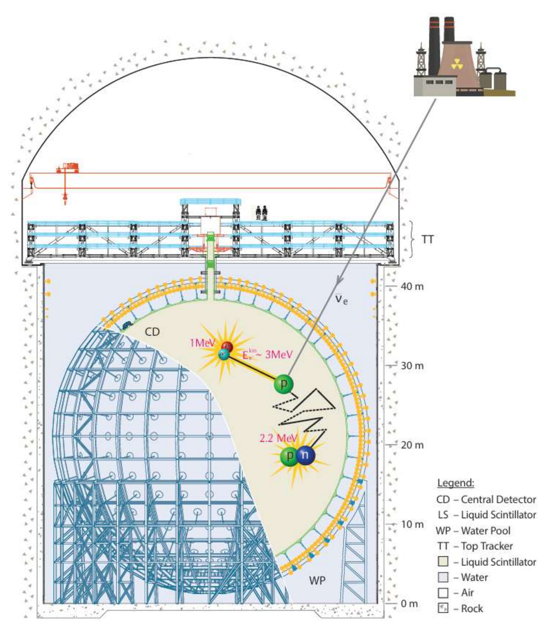
43% -> 23%
Dynode SPE resolution

~4%
Energy resolution improvement

+/-0.5%
Energy non-uniformity

Use single photoelectron (SPE) pulses from data to assemble fake waveforms of any number of photoelectrons (NPE); these training samples produce a convolutional neural network (CNN) model.

JUNO Experiment



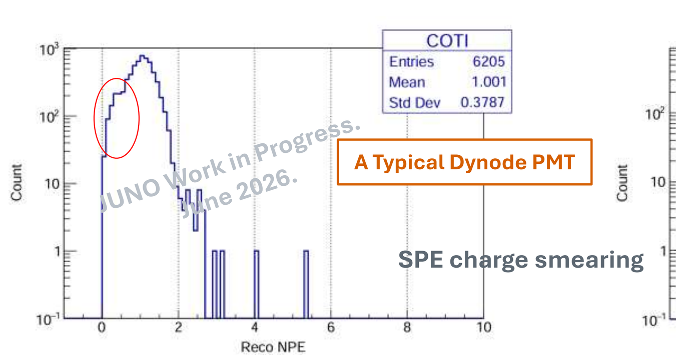
- 20 kton liquid-scintillator detector, located at southern China.
- Designed to determine the neutrino mass ordering by measuring reactor antineutrinos.
- Data taking began on 26 August 2025; precision solar oscillation results followed in November 2025 [1].

JUNO PMTs

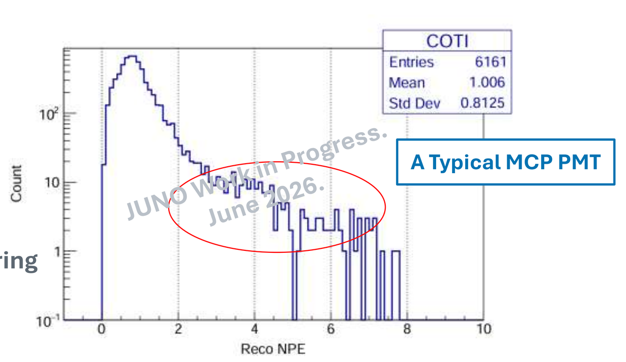
- 17,596 20-inch PMTs and 25,587 3-inch PMTs.
- 78% photocathode coverage.
- Large PMTs: 12,657 MCP PMTs and 4,939 Dynode PMTs.

Baseline: Continuous Over Threshold Integral (COTI) algorithm, a simple waveform-integration method. It is used for comparison in this poster

SPE spectrum generated by COTI algorithm



Dynode: small shoulder



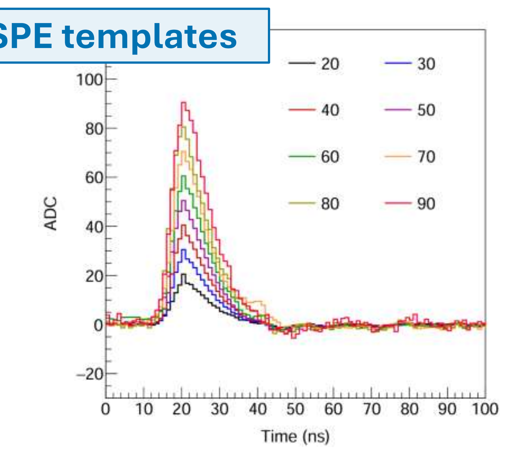
MCP: long tail

Charge smearing motivates a new waveform reconstruction method

Fake Waveform Construction

Build fake waveforms based on calibration data

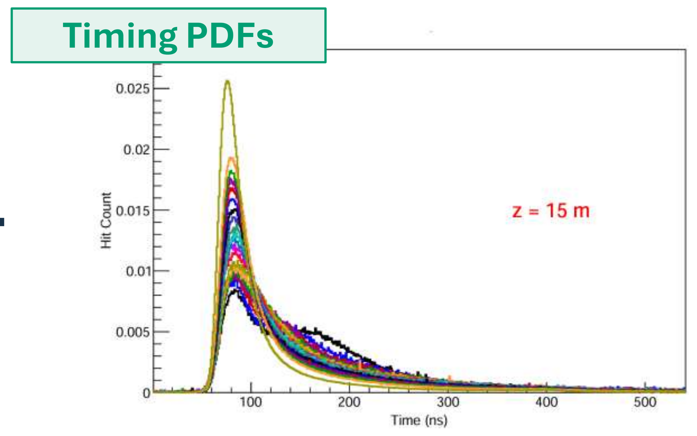
SPE templates



137Cs at detector center: low-energy events provide clean SPE pulse templates.

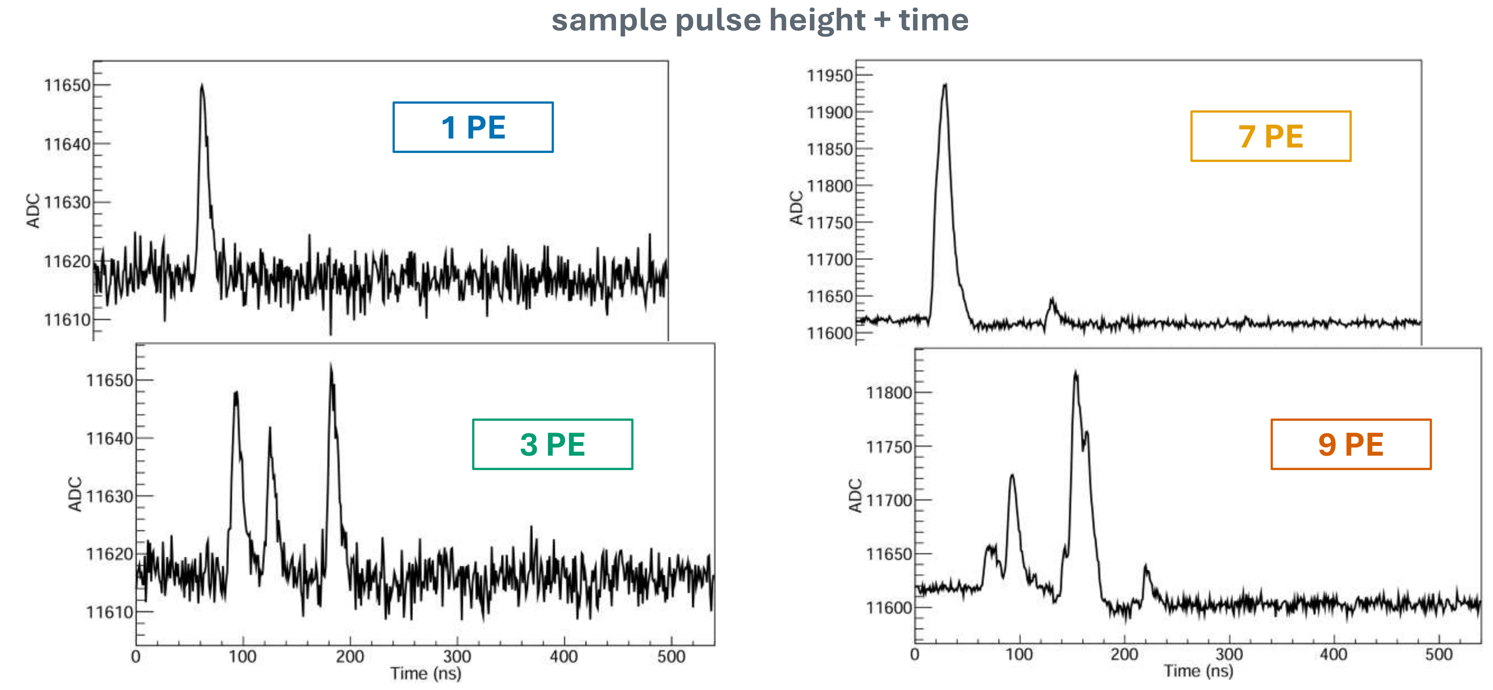
+

Timing PDFs



68Ge along the z-axis at different z positions: covers different source-PMT relative geometries.

sample pulse height + time

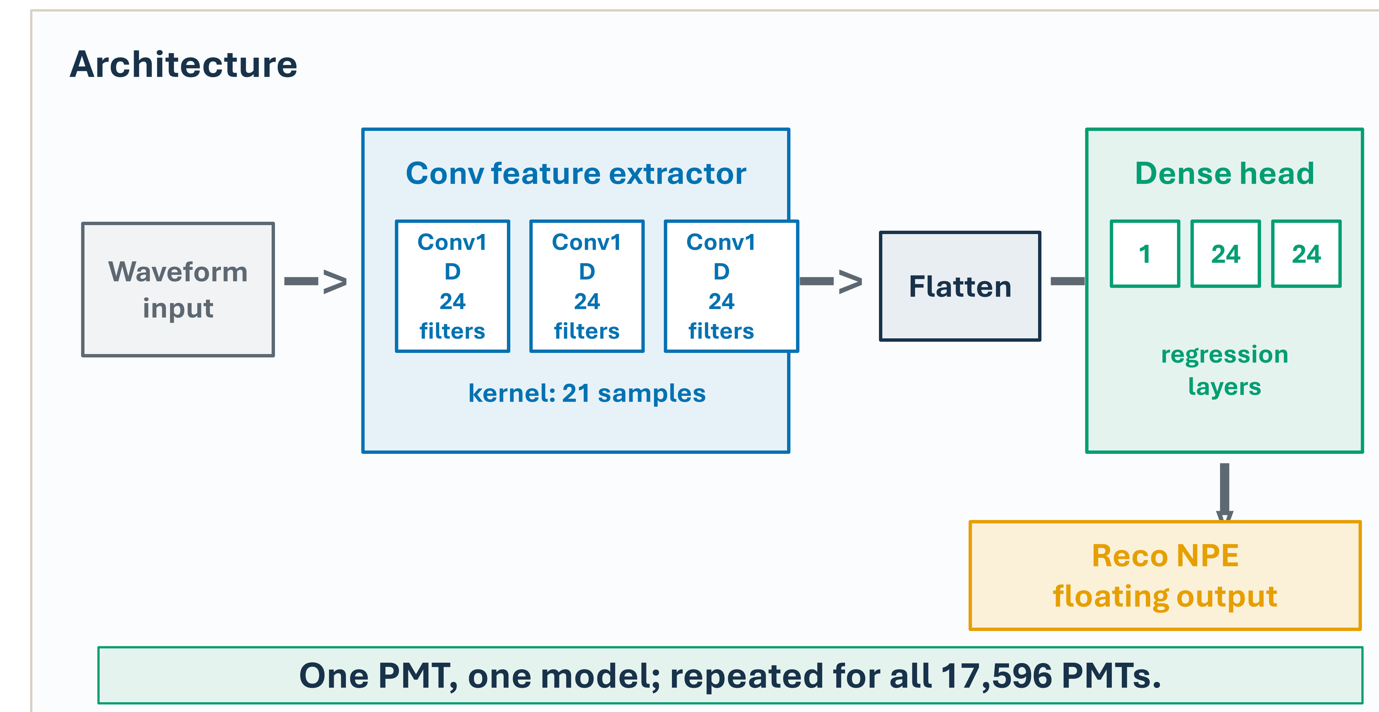


Fake waveforms with known NPE

Data-driven method. Known NPE labels enable supervised CNN training.

CNN Waveform Reconstruction Model

Fake waveforms train a compact 1D CNN to regress reconstructed NPE.



- Training input: fake waveform.
- Training target: known NPE used to assemble the waveform.
- Evaluation target: reduced SPE charge smearing and improved energy resolution.

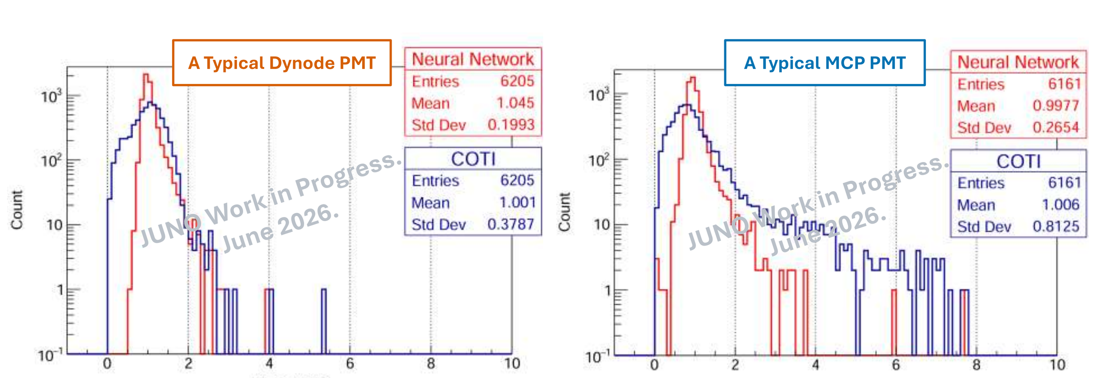
Key benefit
The CNN learns from the full waveform shape and the full SPE charge spectrum, instead of relying on only the mean charge.

Energy-Resolution Improvement

The CNN model improves energy resolution relative to COTI baseline, with good energy non-uniformity.

1 | SPE resolution improves

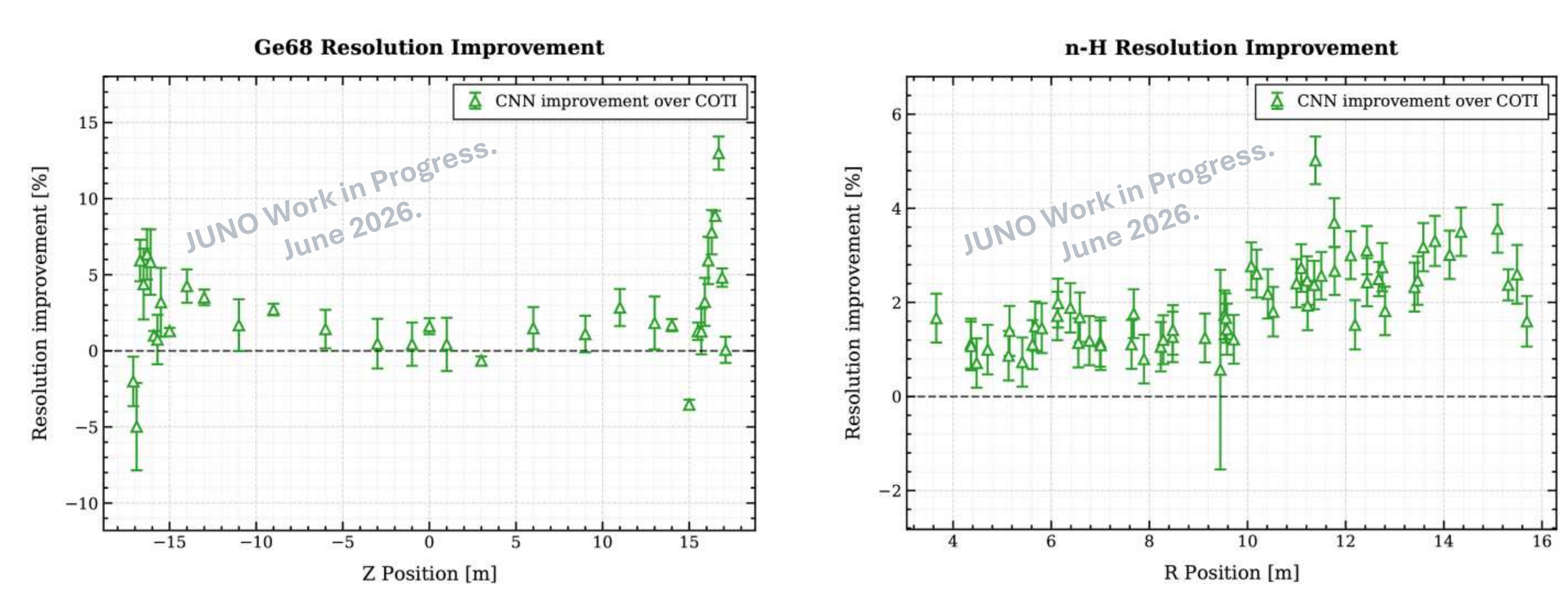
Test with real waveforms from data.
SPE charge smearing is significantly reduced by CNN model.



Overview of All PMTs
MCP 87% -> 27%
Dynode 43% -> 23%

2 | Energy resolution

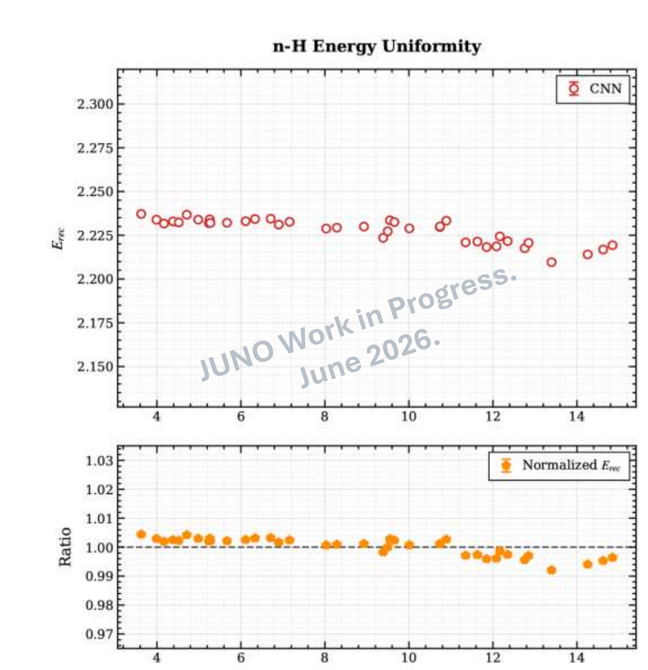
68Ge along z-axis and n-H in different R positions show consistent resolution improvement.



~4% improvement

3 | Energy non-uniformity

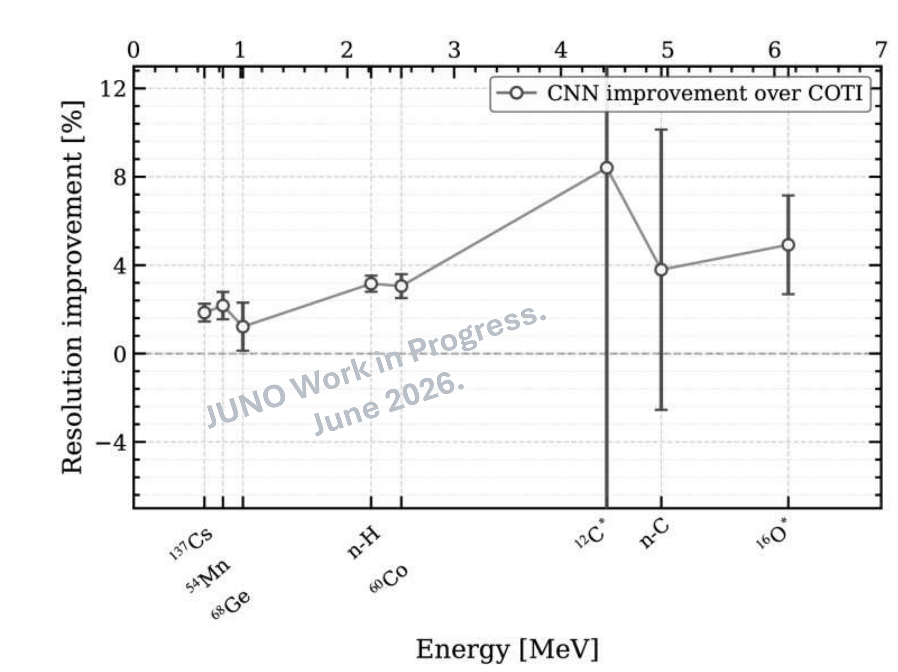
n-H across R positions show good energy non-uniformity.



uniformity +/-0.5%

4 | Resolution curve

Improvements cover the energy range of interest.



[1] The JUNO Collaboration. Measurement of reactor neutrino oscillation with the first JUNO data. Nature 654, 343–348 (2026).

SPE templates + timing PDFs -> fake waveforms -> CNN model -> improved energy resolution