The JUNO Experiment: Towards Data-Taking

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Outline

- Introduction to JUNO
- Physics Goals
- Timeline
- Summary
- US Participation in JUNO
The Jiangmen Underground Neutrino Observatory (JUNO) is a large liquid scintillator neutrino detector under construction in China.

At 20 kton, it will be the largest detector of its kind ever built.

Multi-purpose experiment with rich physics portfolio.

Main physics goals are neutrino mass ordering (NMO) determination and precision measurement of neutrino oscillation parameters.
35.4 m diameter acrylic sphere filled with 20 kton of liquid scintillator (LS)

17,612 20” PMTs (LPMT) and 25,600 3” PMTs (SPMT)

- >75% photo-coverage
- ~30% detection efficiency (LPMT)

Instrumented outer water tank and top scintillator panels serve as muon background veto, reconstruct muon tracks, and provide shielding from natural radiation

JUNO LS has high light yield and low attenuation length, tested in decommissioned Daya Bay detector

Unprecedented 3% energy resolution at 1 MeV
Neutrinos from Near and Far

- **Solar ν’s**
  - Hundreds/day
- **Atmospheric ν’s**
  - Several/day
- **Geo-ν’s**
  - 1-2/day
- **26.6 GWth, 53 km**
  - reactor ν’s
  - ~ 60/day
- **~700 m**
- **Supernova ν’s**
  - 5000 IBDs for CCSN @10 kpc
- **Cosmic muons**
  - ~ 250k/day
- **R. Mandujano - UCI**
Reactor $\bar{\nu}_e$ Detection

- Reactor $\bar{\nu}_e$ detected through Inverse Beta Decay reaction
  - $\bar{\nu}_e + p \rightarrow e^+ + n$
  - Positron (prompt) signal followed by slower neutron (delayed)
  - Coincidence of prompt and delayed signals (with no background events inside a time window) is a reactor neutrino signal
- Maximum matter effect correction of $\sim 4\%$ at 3 MeV

Event Type

<table>
<thead>
<tr>
<th>Event Type</th>
<th>Reactor IBD</th>
<th>Geo-$\nu$</th>
<th>Accidentals</th>
<th>Fast-$n$</th>
<th>9Li/8He</th>
<th>Alpha-$n$</th>
<th>Global Reactor</th>
<th>Atm.-$\nu$</th>
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<tbody>
<tr>
<td>Rate [per day]</td>
<td>47</td>
<td>1.2</td>
<td>0.8</td>
<td>0.1</td>
<td>0.8</td>
<td>0.05</td>
<td>1</td>
<td>0.16</td>
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</tbody>
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arXiv: 2204.13249
Calibration

- Comprehensive calibration strategy
  - Gamma/neutron sources, cosmogenic $^{12}$B and UV laser
  - Multi-positional source deployment

- SPMTs serve as linear reference for LPMT non-linearity
  - Operate in photon-counting mode for $\sim$1-10 MeV

- Dual Calorimetry Calibration compares LPMT charge to SPMT charge under same source
  - Channel-wise LPMT charge vs. total SPMT charge
  - UV laser energies span region of interest
  - Gamma sources match time profile of neutrino (positron) signal
  - Absolute energy scale uncertainty $<$1%
JUNO-TAO (Taishan Antineutrino Detector) will be a satellite detector

- 35 m from 4.6 GW$_{th}$ reactor
- ~1 ton GdLS fiducial volume
- Instrumented with SiPM providing <2% at 1 MeV energy resolution

**Measure reactor antineutrino energy spectrum** with excellent resolution

- Reference spectrum for JUNO, removing possible model dependence from NMO measurement
- Search for sterile neutrinos
- Decomposition into isotopic spectra

Reactor $\bar{\nu}_e$ : Oscillations Program

- Determination of NMO through interference effects in fine structure of oscillated spectrum (allowed by large $\theta_{13}$)
  - JUNO-TAO energy spectrum provides precise reference of un-oscillated JUNO energy spectrum
  - Independent of $\delta_{cp}$, octant of $\theta_{23}$
  - Complementary to accelerator measurement (different baseline and technology)

- Observation of $\theta_{12}, \theta_{13}, \Delta m_{21}^2,$ and $\Delta m_{32}^2$ driven oscillations
~3σ NMO sensitivity in 6 years

- Independent of $\delta_{cp}$, octant of $\theta_{23}$
- Complementary to accelerator measurement (different baseline and technology)

Measurement of $\sin^2\theta_{12}$, $\Delta m^2_{21}$ and $\Delta m^2_{31}$ to sub-percent precision

- About an order of magnitude improvement in precision over existing constraints
- Precision tests of neutrino oscillations and $U_{PMNS}$ unitarity (1%)
Geoneutrinos and Atmospherics

- Geoneutrinos $\bar{\nu}_e$ from $^{238}\text{U}/^{232}\text{Th}$ in Earth’s crust and mantle
  - Development of local crust model underway

- 400-500 geoneutrino events a year:
  - $\sim$5% precision on flux (fixed U/Th ratio) in 10 years
  - Will supersede combined KamLAND and Borexino statistics in less than a year

- Atmospheric Neutrinos: Independent constraint of NMO through matter effect
Study of flavor composition, time evolution, and energy spectrum of supernova (SN) burst neutrinos

- Low detection threshold (sub-MeV)
- 5000 detected IBDs for SN @ 10 kpc

Diffuse Supernova Neutrino Background

- Expected detection significance of $\sim 3\sigma$ after 10 years
- Measurement of $^8\text{B}$ and $^7\text{Be}$ neutrino fluxes
- Background a challenge for this analysis: aiming for $10^{-17}$ g/g U/Th isotopes
- $\Delta m^2_{21}$ measurement with reactor and solar neutrinos in one detector
- Explore solar metallicity problem
- Observe $\nu_e$ regeneration through MSW effect caused by solar neutrino propagation through Earth at night
Will exploit triple coincidence in $p \rightarrow \bar{\nu} + K^+ \rightarrow \nu_\mu + \mu^+ \rightarrow \bar{\nu}_\mu + \nu_e + e^+$ channel.

Nanosecond time discrimination of first two signals allowed by 3-inch PMT system.

Good sensitivity: $8.34 \times 10^{33}$ s 90% CL in 10 years for $p \rightarrow \bar{\nu} + K^+$ channel.
Construction Progress

Installation Platform finished (May 2022)

Steel Support Structure finished (June 2022)
Construction Progress (cont.)

Liquid Scintillator Hall under construction

Electronics produced and undergoing testing

Large PMTs potted and tested

Acrylic panels finished
Timeline

- **2014**: Collaboration formed
- **2015**: Civil construction started
- **2016**: PMT production and testing started
- **2018**: Testing PMTs Central Detector 1:12 prototype
- **2019**: LPMT potting started
- **2020**: PMT preparation ends
- **2021**: PMT installation begins
- **2022 - Now**: Installation and Construction
- **2023**: Detector Completion

Detected Completion Expected in 2023
US Participation in JUNO

- University of California, Irvine
  - SPMT system hardware: HV system, underwater boxes, commissioning, etc.
  - Measurement of Oscillation Parameters
  - Double Calorimetry Calibration (Large + Small PMT)

- University of Maryland, College Park
  - Characterization of the global and local geoneutrino signal
Summary

- JUNO is a multi-purpose experiment with a rich portfolio in neutrino, astroparticle, and exotic physics

- JUNO is pushing the envelope of liquid scintillation detection technology, with innovative ideas in calibration and design to take it to unprecedented sensitivity and results

- Much progress has been done, with detector construction to finalize in 2023

- Stay tuned for our exciting results!
Independent constraint of NMO through matter effect

Measurement of low energy atmospheric neutrino spectra (100 MeV - 10 GeV)

Combined reactor + atmospheric NMO analysis in progress
Backup: Atmospheric Fluxes

$E^2 \phi [\text{GeV} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$

$\log_{10}(E_v / \text{GeV})$

- HKKM14 $v_\mu$ Flux (w/o osc.)
- HKKM14 $v_\mu$ Flux (w/ osc.)
- HKKM14 $v_e$ Flux (w/o osc.)
- HKKM14 $v_e$ Flux (w/ osc.)

$E^2 \phi [\text{GeV} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$

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$\text{Reco/MC}$

$\log_{10}(E_v / \text{GeV})$

$\text{Reco/MC}$
Backup: Neutrino-less Double Beta

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