# JUNO POTENTIAL IN NON-OSCILLATION PHYSICS

## EPS-HEP2021 conference

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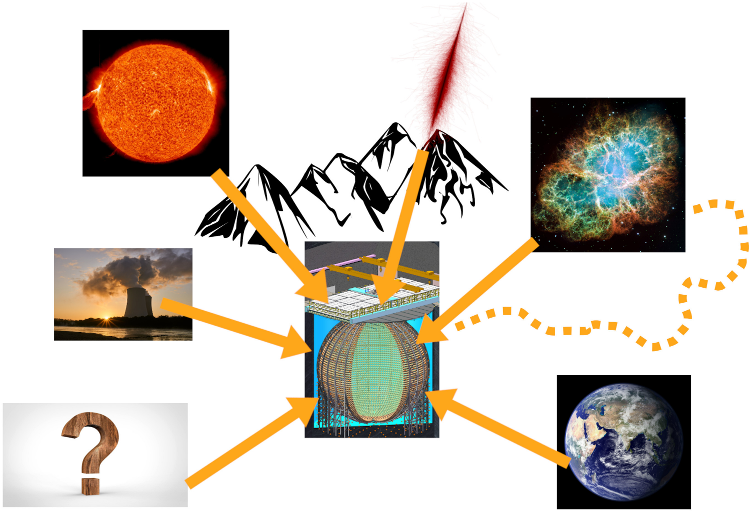
# The Jiangmen Underground Neutrino Observatory

## A multi-purpose 20 kt liquid scintillator neutrino experiment in China



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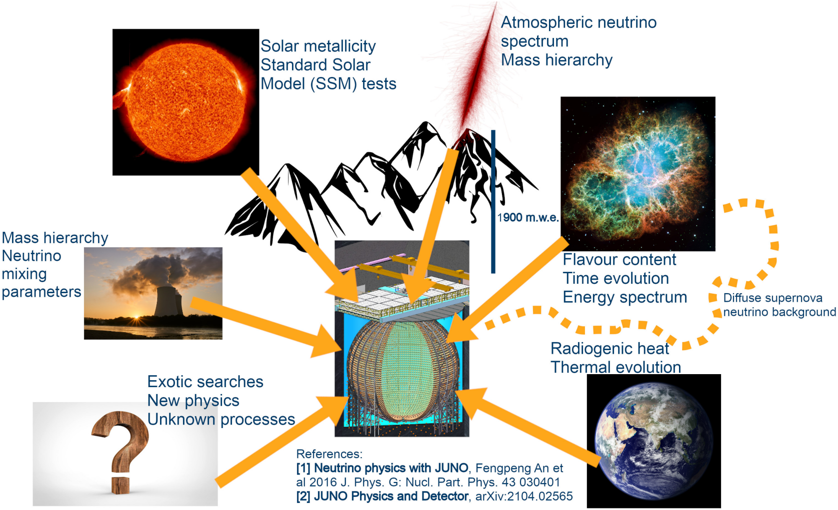
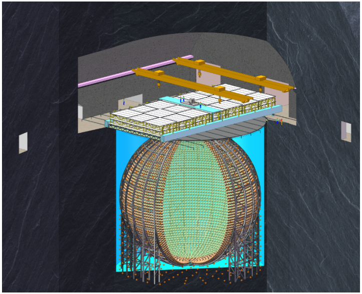


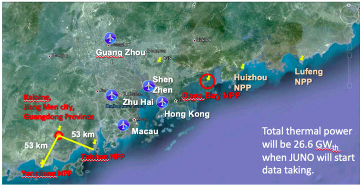

References:
[1] **Neutrino physics with JUNO**, Fengpeng An et al 2016 J. Phys. G: Nucl. Part. Phys. 43 030401
[2] **JUNO Physics and Detector**, arXiv:2104.02565

# JUNO

## The detector

- Under construction in Guangdong Province, China
- 20 kt of LAB-based liquid scintillator (LS) in a 35.4 m diameter acrylic vessel
- Water buffer
- Top muon veto
- $\approx$40k PMTs in dual calorimetry: 20” + 3” PMTs
- 3% energy resolution @1 MeV
- $<$ 1% energy scale uncertainty
- Satellite experiment: TAO
- Multi-Messenger trigger with $\mathcal{O}$(10 keV) threshold

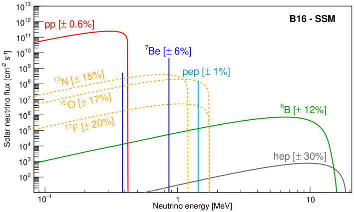




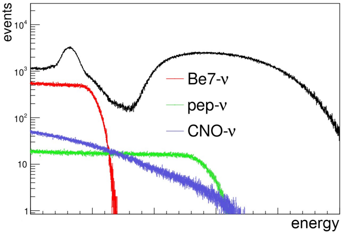
# Solar neutrinos

## Low/intermediate-E: *pp* and $^7$Be neutrinos

Solar neutrino spectra




(Toy)Example JUNO signal



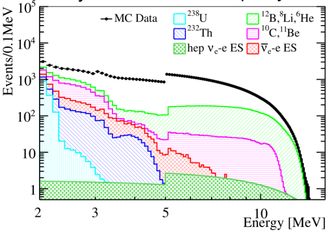

- Immense statistics compared to previous experiments: $\mathcal{O}(10^4)$ ev/day for $^7$Be neutrinos, $\mathcal{O}(500)$ for *pp*-neutrinos
- Large target mass allows stringent fiducial volume cut
- Potential to measure $^7$Be neutrinos, maybe *pp* neutrinos
- Strong dependence on internal radioactivity

# Solar neutrinos

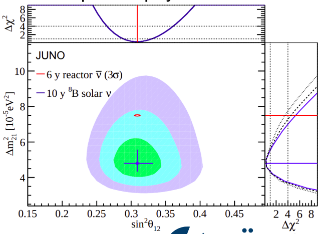
## High-E: $^8$B neutrinos. [3] doi:10.1103/PhysRevD.103.053002

- Neutrino-Electron elastic scattering
- 2 MeV threshold
- Background reduction strategies
- Expect 60,000 signal and 30,000 background events
- Day-night asymmetry + upturn
- Possible measurement: $\Delta m^2_{21} = 7.5^{+1.6}_{-1.2} \cdot 10^{-5}\mathrm{eV}^2$
- Flux measurement can help discriminate between solar metallicity models
- Can add 9.000 signal events by using neutrino-$^{13}$C NC/CC interactions

10 years with $10^{-17}$ radiopurity




Expected physics results



# Geo-neutrinos

## Answering questions about Earth's formation.

$$^{238}\text{U} \rightarrow ^{206}\text{Pb} + 8\alpha + 6e^{-} + 6\bar{\nu}_e$$

$$^{232}\text{Th} \rightarrow ^{208}\text{Pb} + 6\alpha + 4e^{-} + 4\bar{\nu}_e$$

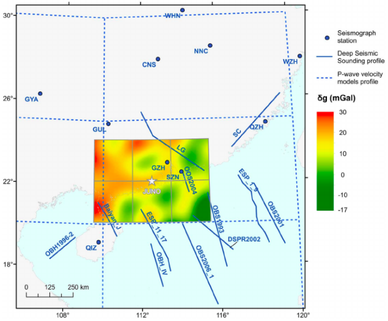
- 1.8 MeV IBD threshold: measure $^{238}$U- and $^{232}$Th-chain neutrinos
- Expect ≈400 events per year (40 TNU) [4]

→ 5% uncertainty (2 TNU) in 6 years

( 1 TNU: ≈ 1 $ev/kton/yr$ for IBDs in LS)

- KamLAND measured about 169 geoneutrinos in 6 years and Borexino 53 in 9 [5, 6]
- Study radiogenic contribution to terrestrial heat production
- Measure Th/U mass ratio - important parameter to understand Earth's formation
- Local geological studies ongoing to tackle largest uncertainty source [7, 8]

Inputs to local 3-d models [5]

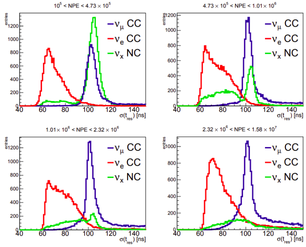



[4] doi:10.1088/1674-1137/40/3/033003
[5] doi:10.5281/zenodo.3959690
[6] doi:10.1103/PhysRevD.101.012009
[7] doi:10.1029/2018JB016681
[8] doi:10.1016/j.pepi.2019.106409

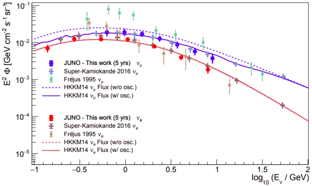
# Atmospheric neutrinos

[6] **arXiv:2103.09908**

$\nu_e/\nu_\mu$ discrimination




Unfolded fluxes in comparison



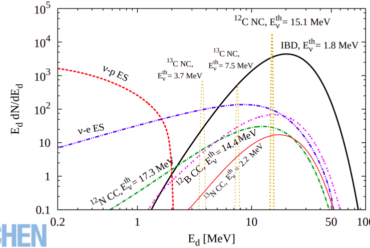

- Use time-information to discriminate $\nu_e/\nu_\mu$ [6]
- Reconstruct spectrum between 0.1 GeV to 10 GeV
- First sub-GeV measurement using liquid scintillator
- Complementary sensitivity to mass hierarchy through MSW effect
- Sensitivity to $\sin^2\theta_{23}$ and $\delta_{CP}$ ($< 2\sigma$) [1]

# Core-Collapse supernova (CCSN)

## $\mathcal{O}(10^4)$ events in 10 s, expect 1-3 per century

- Dedicated trigger scheme with 100 keV threshold
- Typical 10 kpc SN: 5000 IBD + 2000 $\nu$pES + 300 $\nu$eES + 500 $\nu^{12}$C events in 10 s ($\bar{\nu}_e, \nu_e, \nu_x$)
- Measure flavour content, time evolution, flux, energy spectrum
- Study star parameters, SN physics, late-stage stellar evolution
- Constrain absolute neutrino mass $m_\nu < (0.83 \pm 0.24)$ eV (95% CL) @10 kpc

10 kpc SN expected signals in JUNO:

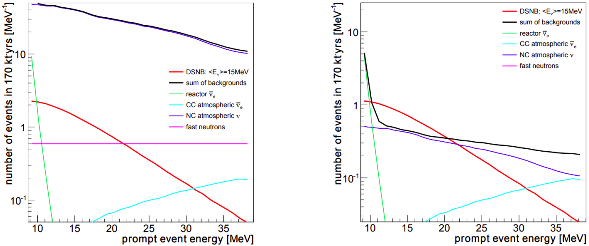


# Diffuse supernova neutrino background

## Integrated flux of all (past) supernovæ in the galaxy

- Not yet observed!
- Main signal and background: Supernova-induced IBD and atmospheric NC $\nu-^{12}$C reactions, all energies above the reactor spectrum
- Study star & black hole formation rate, CCSNs
- $3\sigma$ discovery in 10 years for $\overline{E_{\bar{\nu}_e}} \gtrsim 15\,\text{MeV}$

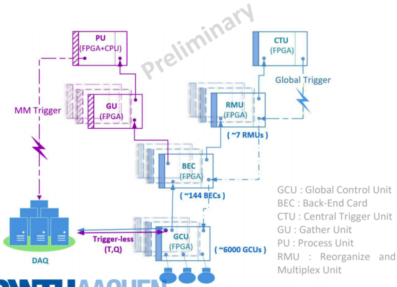
Expected IBD prompt energy spectrum without and with pulse shape discrimination cut



# Multi-Messenger astronomy

## JUNO as a transient sky monitor

- Ultra low-E MM trigger under development $\mathcal{O}(10\,\text{keV})$ threshold
- Hardware+Firmware solution: filter dark noise on FPGA
- JUNO could become a major player in the SuperNova Early Warning System [9] (SNEWS 2.0 - arXiv:2011.00035)
- Communication with world telescopes



# Exotic searches and new physics

## Nucleon decay

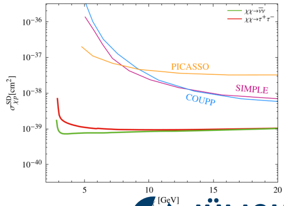
Two proton decay modes: $\begin{cases} p \to \pi^0 + e^+ & \textbf{SUSY} \\ p \to K^+ + \nu & \textbf{GUT} \end{cases}$

- Three-fold coincidence in $p \to \bar{\nu} K^+ \to \mu^+ + \nu_\mu \to e^+ + \nu_e + \bar{\nu_\mu}$
- Sensitivity: $8.34 \cdot 10^{33}$ years (90%CL) in ten years of data-taking
- $n \to 3\nu$ and $p \to \mu^+\mu^+\mu^-$ channels under investigation

## Dark matter

- Indirect search $\chi \to \tau\tau$, $\chi \to \nu\bar{\nu}$ for DM annihilation in the Sun
- Best limits for cold dark matter
- Improve current best limit (Super-K) on primordial black holes by an order of magnitude via antineutrinos

JUNO limits on spin-dependent DM-nucleon interactions



# Exotic searches and new physics

## Non-standard interactions

- JUNO-TAO will test the neutrino reactor anomaly
- Light sterile neutrinos: leading limits on $\delta m^2$ from $1 \times 10^{-5}$ eV$^2$ to $1 \times 10^{-3}$ eV$^2$
- Additional limits on physics beyond the three-flavour framework
- Exotic particles competitive limits from $1 \times 10^{13}$ GeV to $1 \times 10^{15}$ GeV for nuclearites
- Probe Lorentz invariance violation via sidereal modulation of reactor antineutrino rates

# Questions?

**Thank you for your attention!**

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See previous talk by **M. Gonchar**: *“Neutrino oscillation physics in JUNO”*

See poster by **M. Vollbrecht**: *“OSIRIS – An online scintillator radiopurity monitor for the JUNO experiment”*

**JUNO Collaboration**: 663 members from 18 countries


# Backup

# Taishan Antineutrino Observatory (TAO)

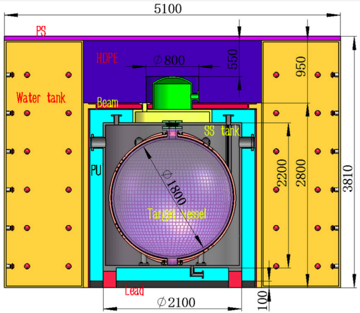
30 m **from the reactor core!**

## Cold Gd-doped liquid-scintillator detector

- Operated at $-50^{\circ}$C
- 99% coverage with SiPMs
- Results in 4500 nPE/MeV
- 1.7% resolution at 1 MeV

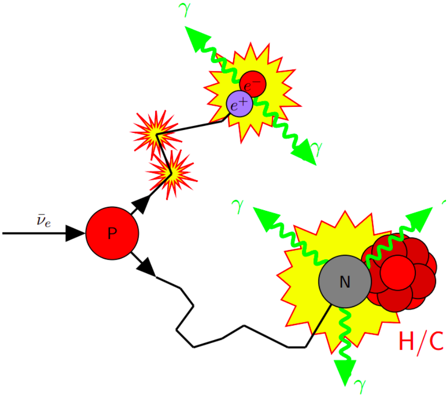
## High-resolution low-baseline anti-neutrino spectrum

- Model-independent reference for JUNO
- Cancel systematics in reactor shape
- Also measure and test reactor shape
- Analyse neutrino reactor anomaly at 5 MeV



# Neutrino interactions

Inverse beta decay $\bar{\nu}_e + p \to e^+ + n$
1.8 MeV interaction threshold
250 µs delayed neutron signal




Elastic scattering - off electrons or nuclei
NC: all flavours, CC: only electron neutrinos in our energy regions