Supernova's neutrino detection at the Jiangmen Underground Neutrino Observatory

12th Cosmic Ray International Seminar
Naples, Italy, September 12 -16, 2022

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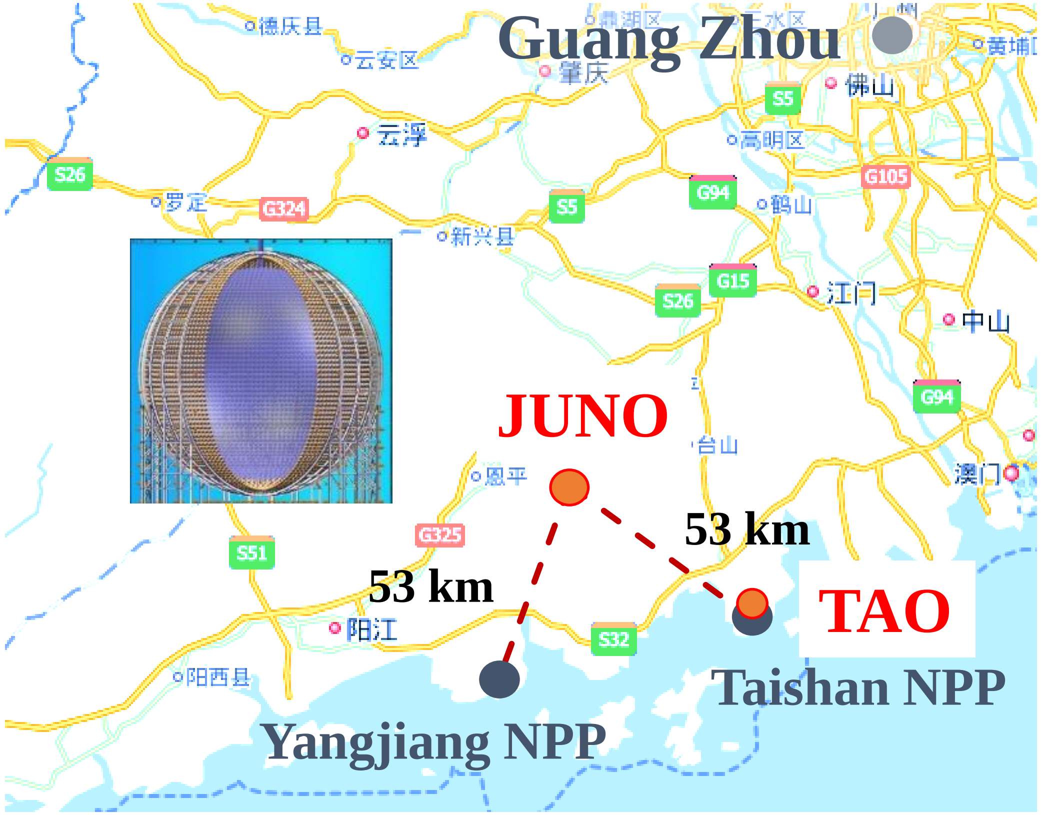
Jiangmen Underground Neutrino Observatory

- JUNO is a medium baseline (53 km) reactor neutrino experiment, located in China and 650 m overburden.
- JUNO measures the neutrino flux from 8 reactor cores dispatched in two nuclear power plants (combined thermal power of 26.6 GW).
- In addition to the main detector JUNO will also have a second detector called JUNO-TAO placed near one of the reactor cores.
- JUNO is also sensitive to other neutrino sources.



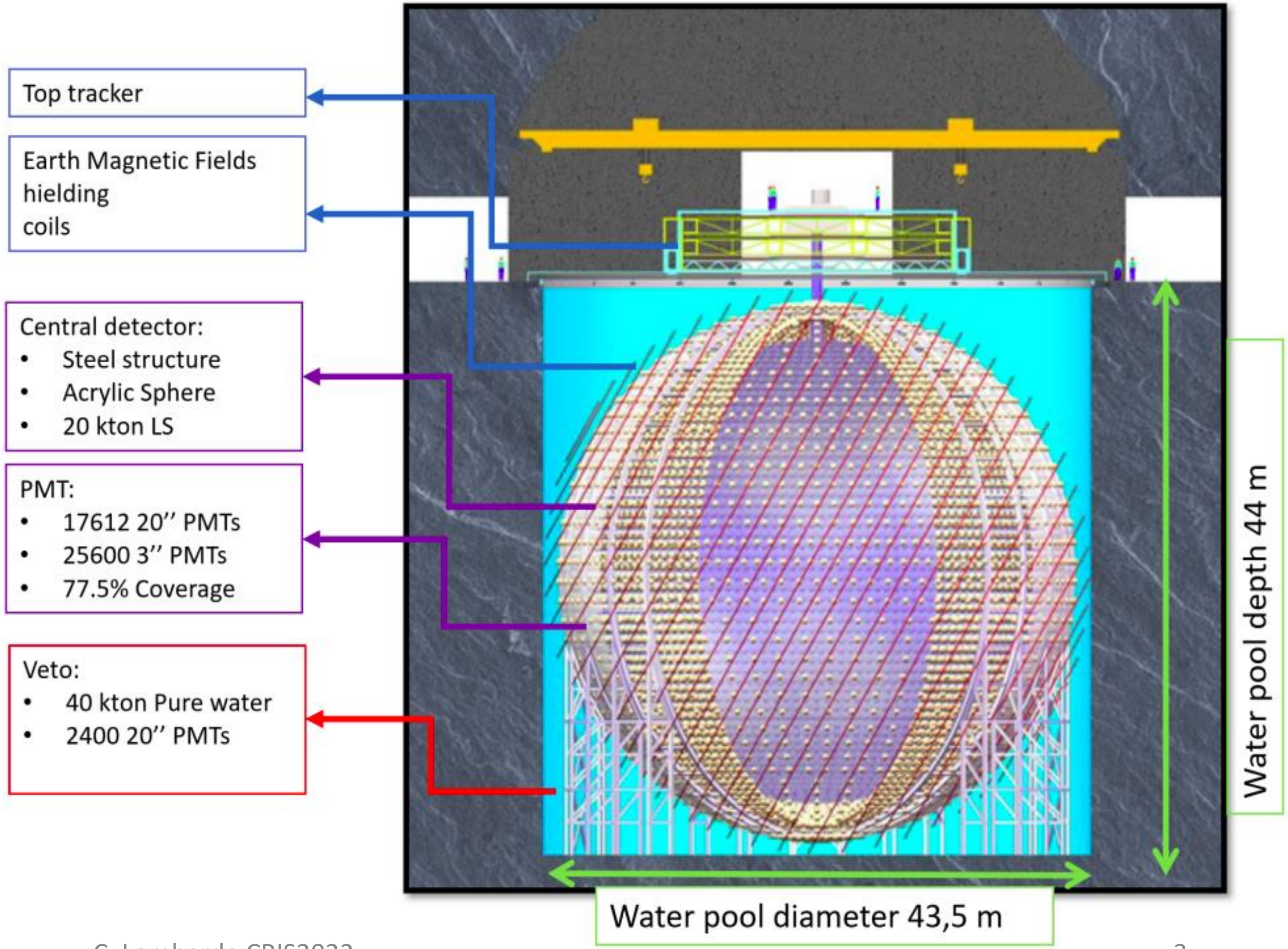
JUNO:Central Detector

- 20 kt of liquid scintillator based on LAB inside a 35.4 m acrylic vessel
- Surrounded by a water Cherenkov tank and a top muon tracker as veto
- 17612 20-inch PMTs + 25600 3-inch PMTs for dual calorimetry
- Primary goals: precise measurement of reactor neutrino oscillation parameters and Neutrino Mass Ordering (NMO) determination

Requirements:

- High statistics ($\sim 10^5$ events in 6 yr)
- Energy resolution: $\sim 3\%$@1MeV
- Energy scale uncertainty < 1%

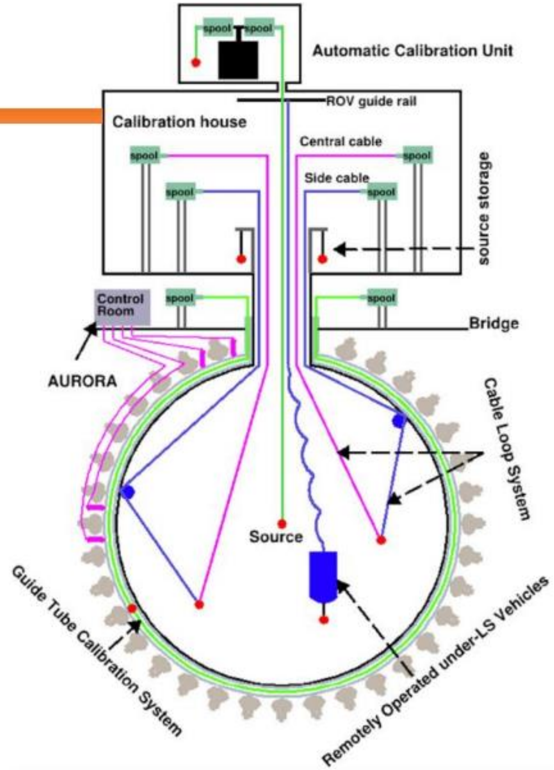
arXiv:2104.02565



JUNO: Calibration

Crucial to understand detector response non-uniformity and achieve: <1% energy scale uncertainty + 3% at 1MeV energy resolution
Four complementary sub-systems: 1D, 2D and 3D scan with multiple calibration sources

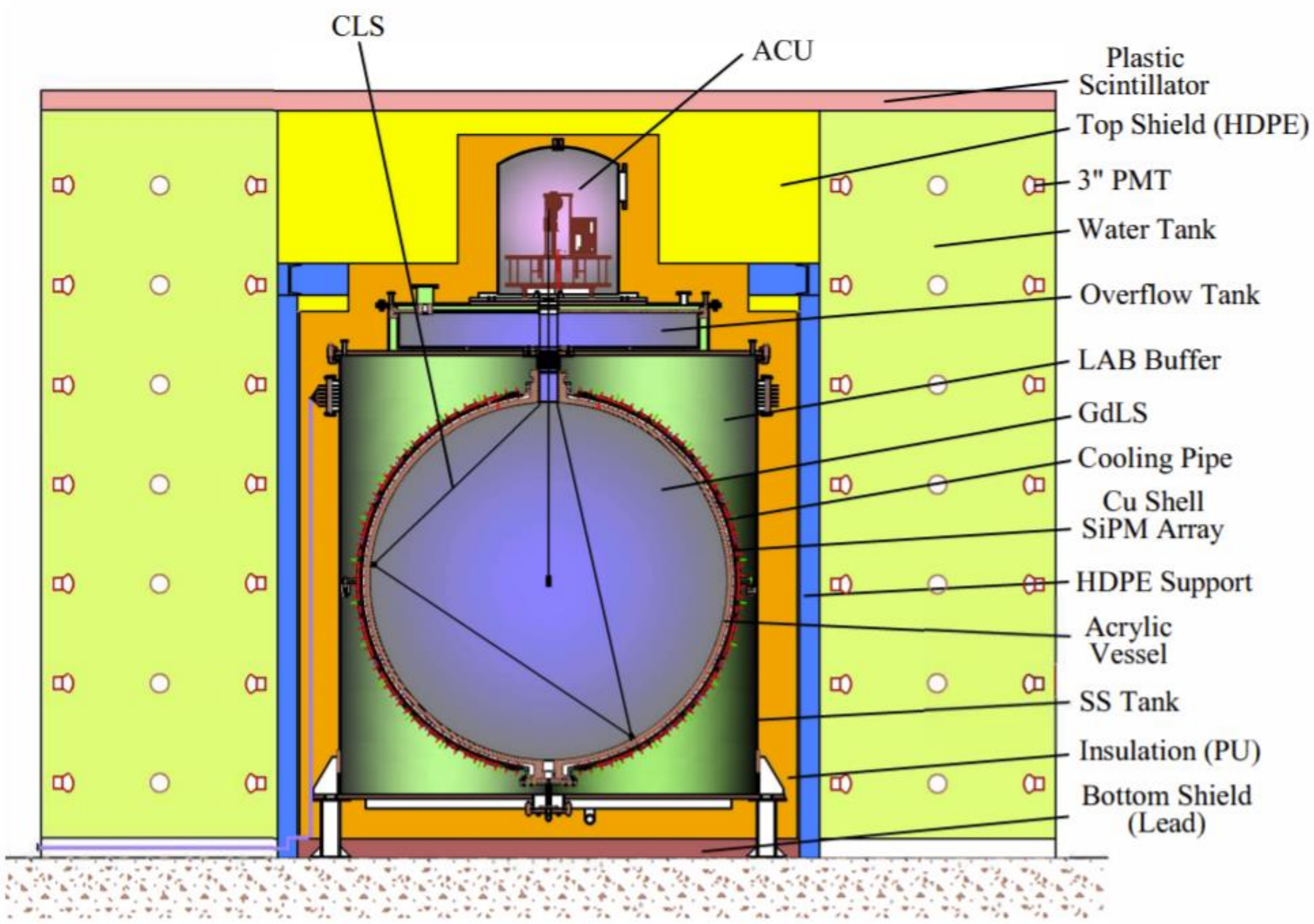
Cable system finished prototype test



Angel, Abusleme, et al. "Calibration strategy of the JUNO experiment." *Journal of High Energy Physics* 2021.3 (2021).

JUNO:TAO detector

- 2.8 ton of Liquid Scintillator doped with Gadolinium (GdLS) in a spherical vessel with 1.8 m diameter
- Expected 4000 IBD/Day (2000 with 1-ton fiducial volume)
- $\sim 10\ m^2$ of SiPMs (more than 4000 4 x 8 SiPMs arrays)
- Operate at -50 °C to reduce SiPM dark noise
- From the center to the outside: GdLS → Acrilic vessel → SiPMs and support → LAB Buffer → Criogenic system → water and HDPE shield → muon veto
- High energy resolution : $\sim$1.5%@1MeV
- Prototype under construction in China



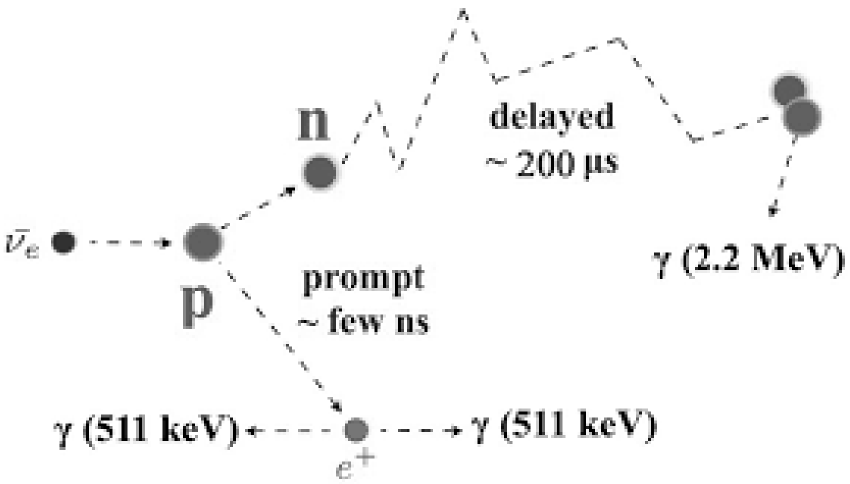
JUNO: Neutrino Detection

(Anti-)neutrinos are observed by:

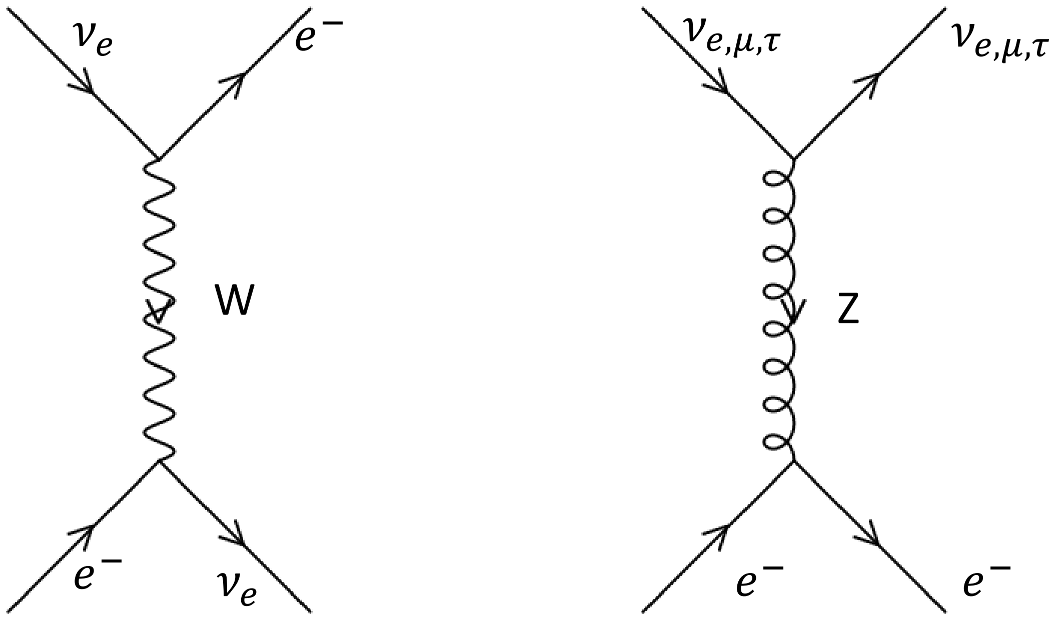
- **Inverse Beta Decay (IBD)** via the positron signal (1) and the following neutron capture (2):

$$\overline{\nu}_e + p \rightarrow e^+ + n \qquad (1)$$

$$n + p \rightarrow d + \gamma \qquad (2)$$



- **Elastic scattering (ES)** on e⁻ **,** CC and NC interactions:



Current Status

Current Status: Central Detector

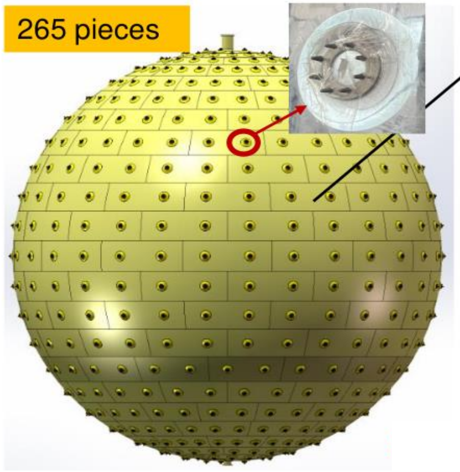
Acrylic sphere (LS container)

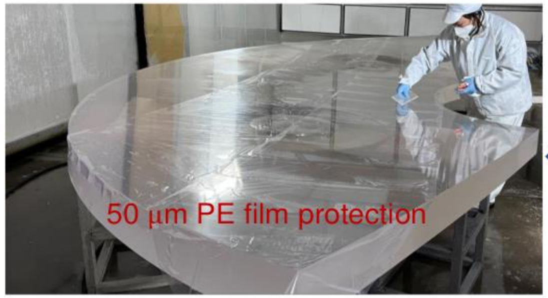
Inner diameter: 35.40±0.04 m

Thickness: 124±4 mm

Light transparency > 96% @ LS

Radiopurity: U/Th/K < 1 ppt





- All pieces ready on site
- Installation just started

Supported by **Stainless Steel (SS) Structure**:

- Installation completed

Current Status: Liquid Scintillator

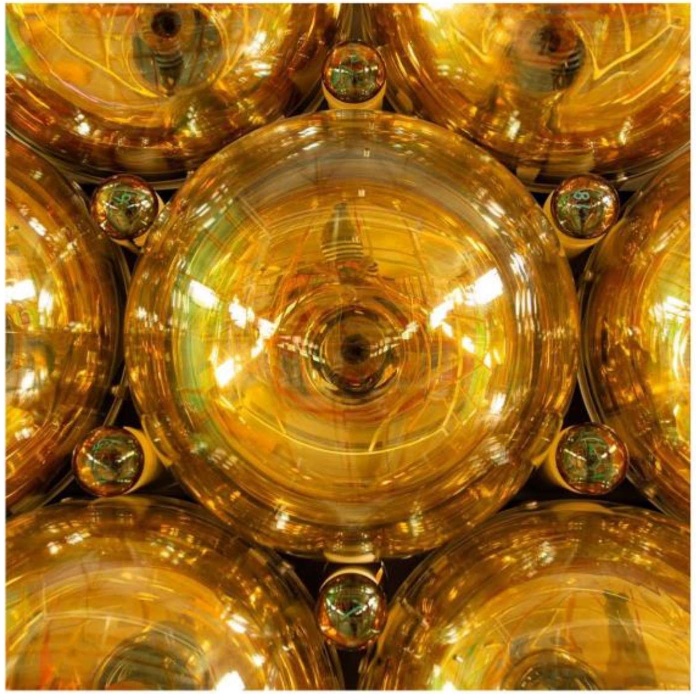
Four purification plants to achieve target radio-purity 10^{-17} g/g U/Th and 20 m attenuation length at 430 nm.

Liquid scintillator:

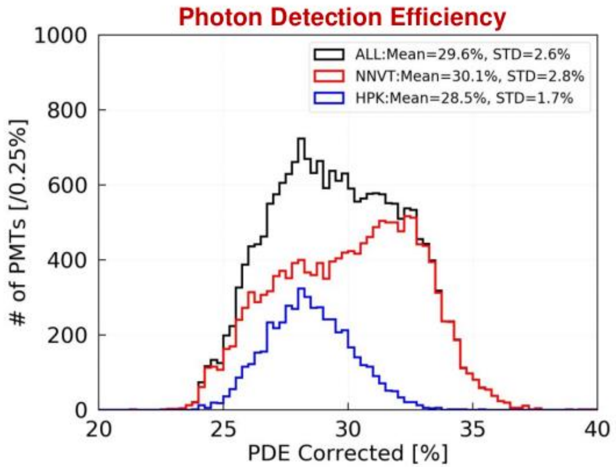
LS mixing + purification systems are almost ready →will start commissioning after summer

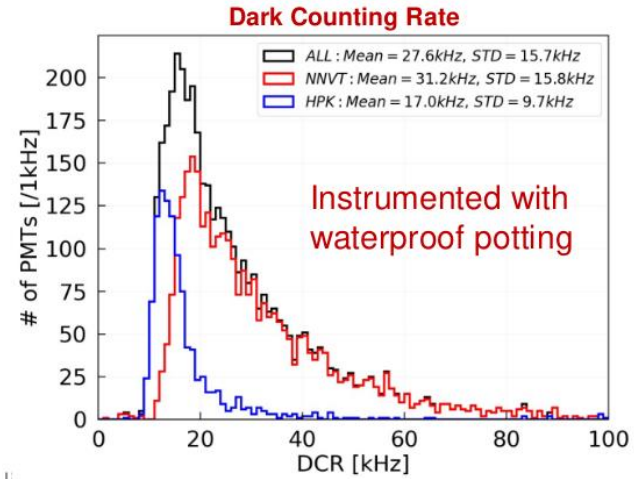
Current Status: Electronics + PMT

Synergetic 20-inch and 3-inch PMT systems to ensure energy resolution and charge linearity



Clearance between PMTs: 3 mm → **Assembly precision: < 1 mm**





Electronics:

- All PMTs produced, tested*, and instrumented with waterproof potting
- Assembly finished and connections being tested → Installation in October

* arXiv:2205.08629

Current Status: Veto detector

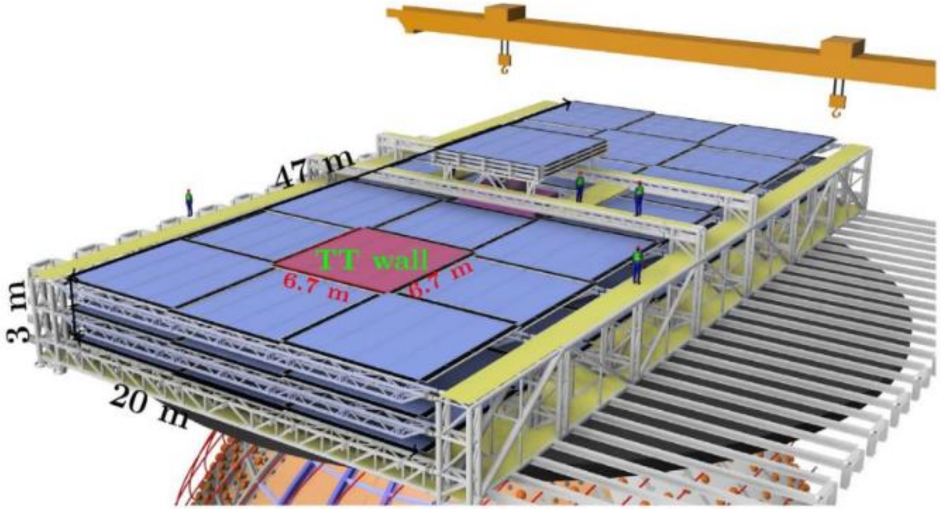
Water pool:

- 35 kton of ultrapure water cherenkov detector
- Will act as passive shield and veto for cosmic muons (> 99.5% efficiency, 2400 20' PMTs)

- Water pool liner construction finished
- Water pipes and extraction system: installations done → will provide clean water underground soon

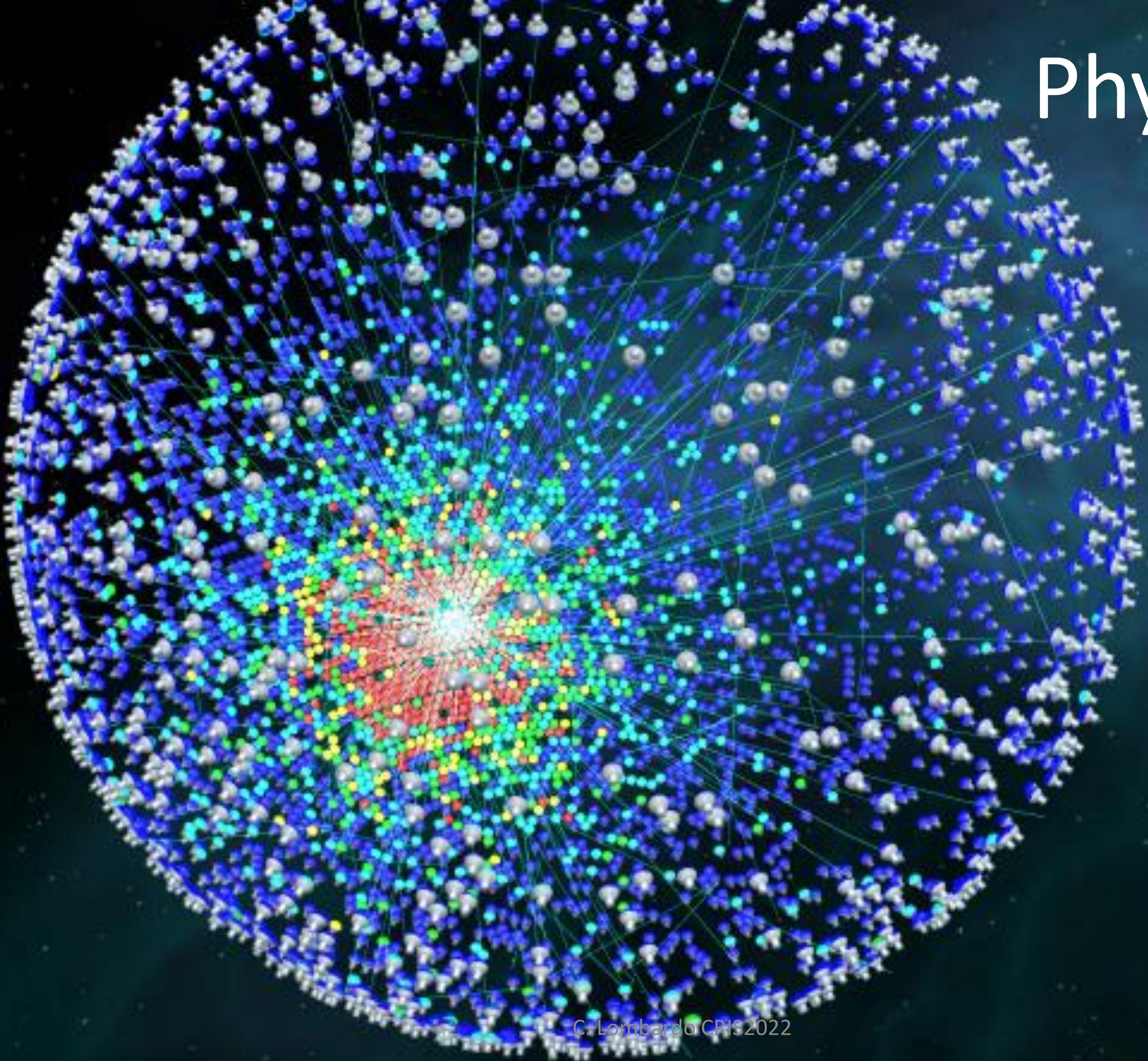
Top tracker:

- Built from OPERA's tracker layers
- Goal: study and veto cosmogenic backgrounds and atmospheric muons

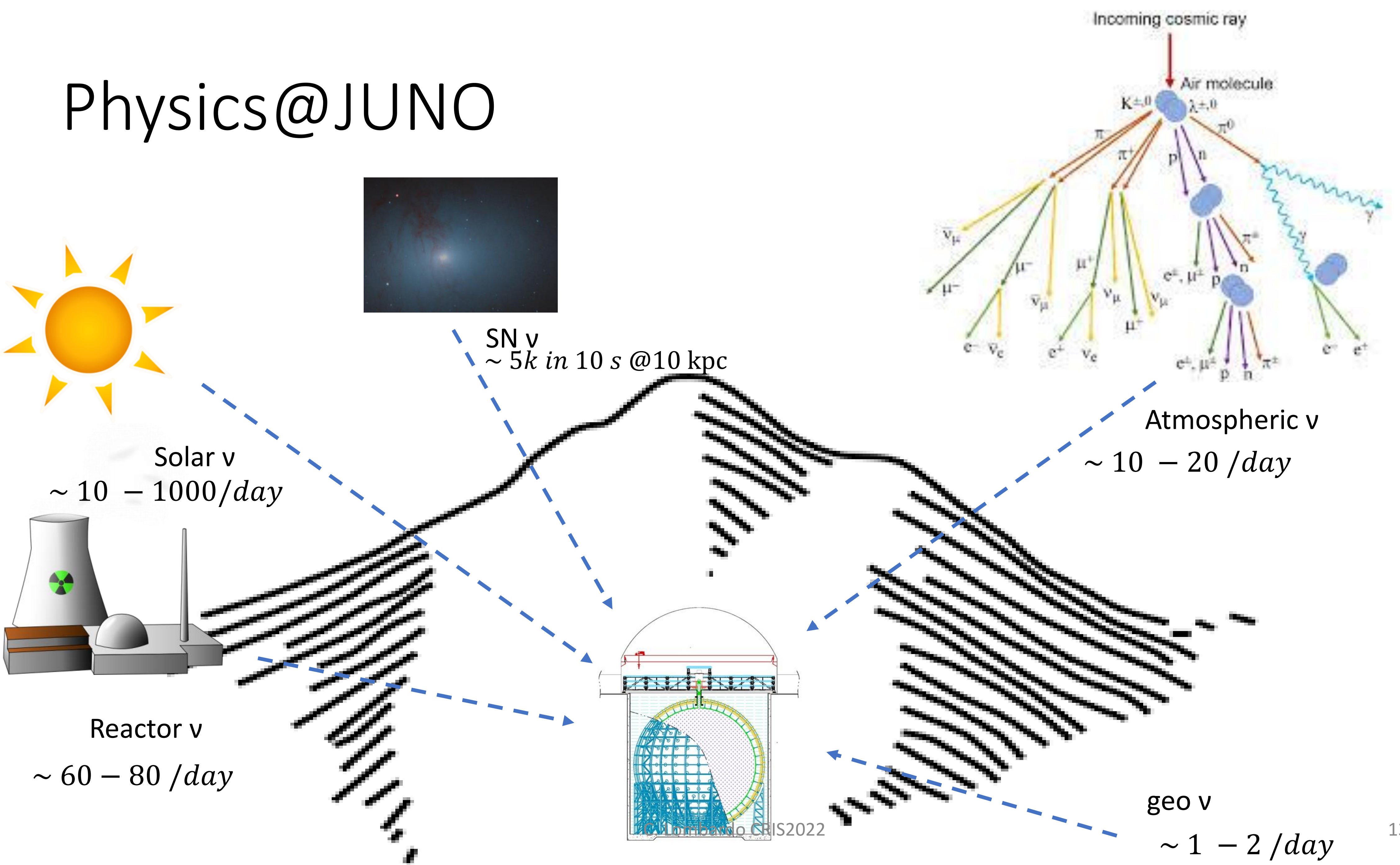


- Prototype working
- Modules already at JUNO site
- Mechanical structure design done
- Electronic design done
- → To be produced and tested this year

Physics@JUNO



Physics@JUNO



Physics@JUNO

- Reactor Neutrino Oscillations
  - Sub-percent precision measurement of the oscillation parameters (arXiv: 2204.13249 accepted by Chin. Phys. C)
  - Determination of the neutrino mass ordering
- Solar Neutrinos
  - Sensitivity of ^{7}Be, ^{8}B, pep, and CNO neutrinos (Chin. Phys. *C* **45** 023004)
- Diffused SuperNova Background (arXiv:2205.08830)
- Atmospheric Neutrinos
  - independent measurements and systematics to boost NMO sensitivity
  - Flux measurements (EPJ-C 81 (2021))
- Geoneutrinos
  - $\bar{\nu}_e$ from ^{238}U and ^{232}Th decay chains in Earth (Chin. Phys. C 40 (2016).)

CCSN@JUNO

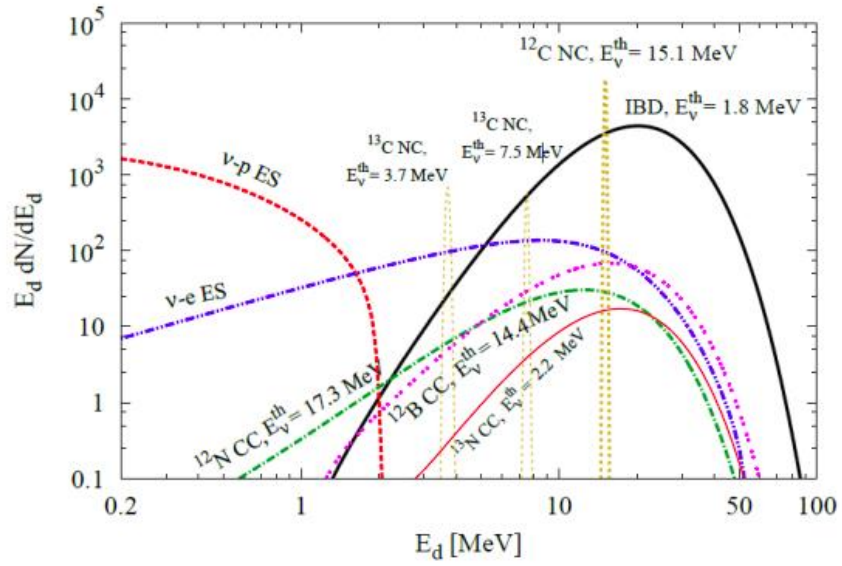
- If there is a Galactic CCSN, JUNO will be able to detect the CCSN flux with high statistics
- High signal rate → almost background free observation
- Possibility to detect Pre-SN neutrinos for close-by sources ($\sim<$ 1kpc)

CCSN@JUNO

- If there is a Galactic CCSN, JUNO will be able to detect the CCSN flux with high statistics
- The multi-channel detection of CCSN enables JUNO to get spectra of all neutrino flavours
- Dominant detection channels: IBD, ν-p ES, and ν-e ES

Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \rightarrow e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \rightarrow \nu + p$	NC	0.6×10^3	1.2×10^3	2.0×10^3
$\nu + e \rightarrow \nu + e$	ES	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$	NC	1.7×10^2	3.2×10^2	5.2×10^2
$\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N$	CC	0.5×10^2	0.9×10^2	1.6×10^2
$\overline{\nu}_e + {}^{12}C \rightarrow e^+ + {}^{12}B$	CC	0.6×10^2	1.1×10^2	1.6×10^2

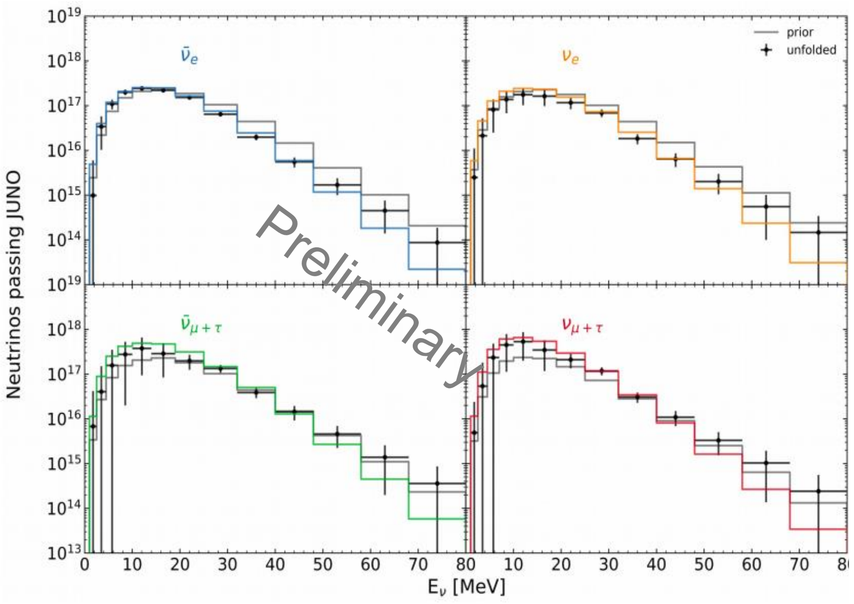
Fengpeng An et al 2016 J. Phys. G: Nucl. Part. Phys. 43 030401



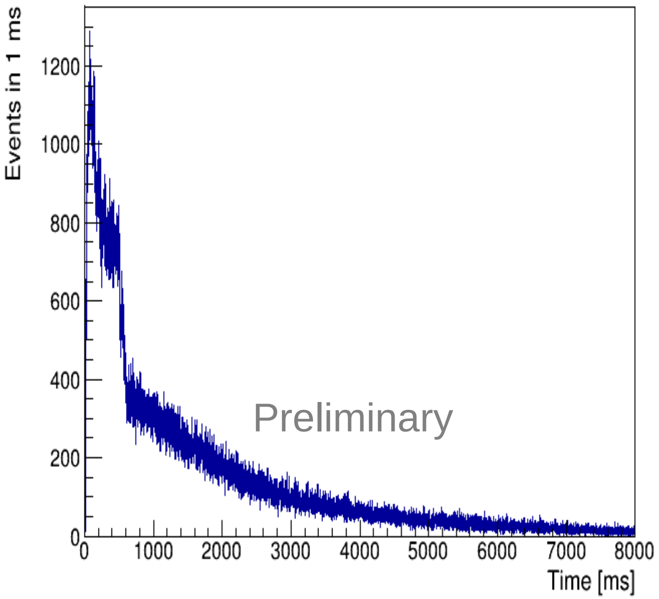
Visible energy distribution in JUNO of a typical SN at 10 kpc

CCSN@JUNO

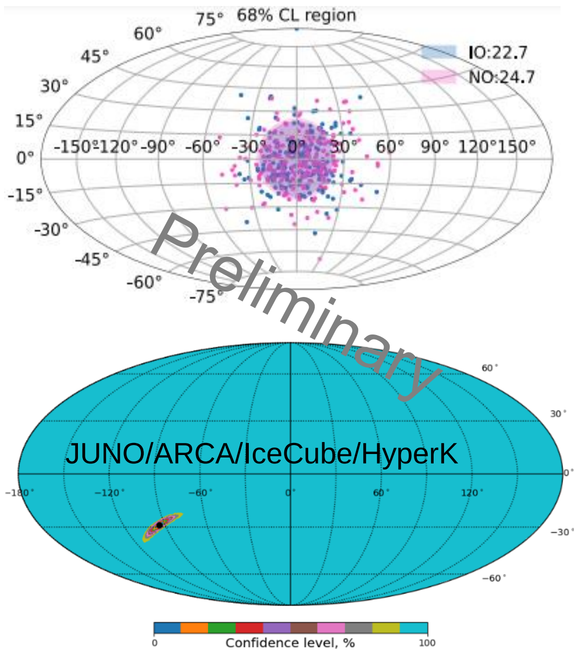
Good energy and time resolution + flavor classification allow JUNO to measure:



Flavor dependent energy spectrum



Light curve



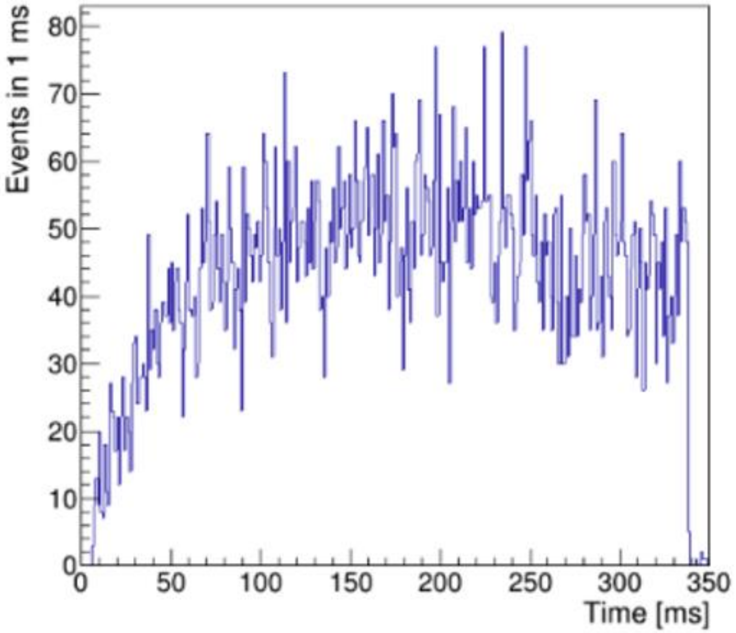
Direction

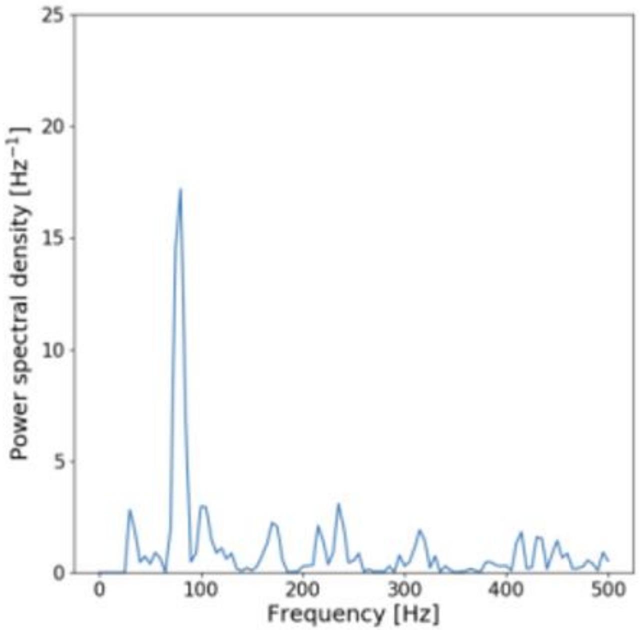
Eur. Phys. J. C 80, 856 (2020)

CCSN@JUNO

Can JUNO detect SASI (Standing Accretion Shock Instability)?
Fast time variations of the detected rates, oscillating with a characteristic frequency → Spectral Analysis of the neutrino data

Observed Light Curve → Fourier Transform → Power Spectrum





Currently under investigation!

CCSN@JUNO

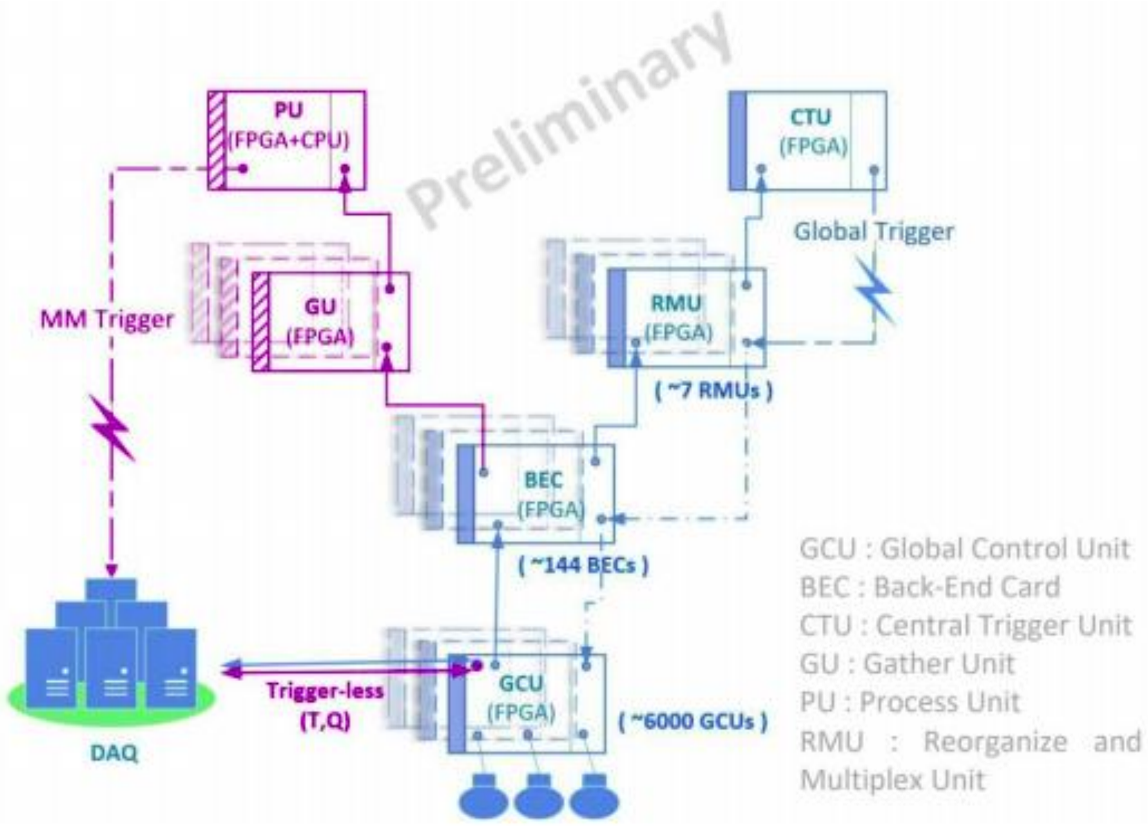
Two strategies to trigger a transient event:

- Prompt Real-time Monitor:
    - Higher energy threshold (∼1MeV)
    - Increase sensitivity horizon
- Multi-messenger (MM) trigger:
    - Lower energy threshold (∼20 keV)
    - Increase signal statistics

Real-time monitoring based on:

- Sliding window: compare number of candidates in time window with a pre-defined threshold
- Bayesian blocks algorithm: divide the timeline into blocks with candidates uniformly distributed to search for event rate change

If transient astrophysical signal triggered:
→ All (triggerless) data are stored to increase the physical data obtained



⟶ JUNO as a powerful neutrino telescope for transient MM observations

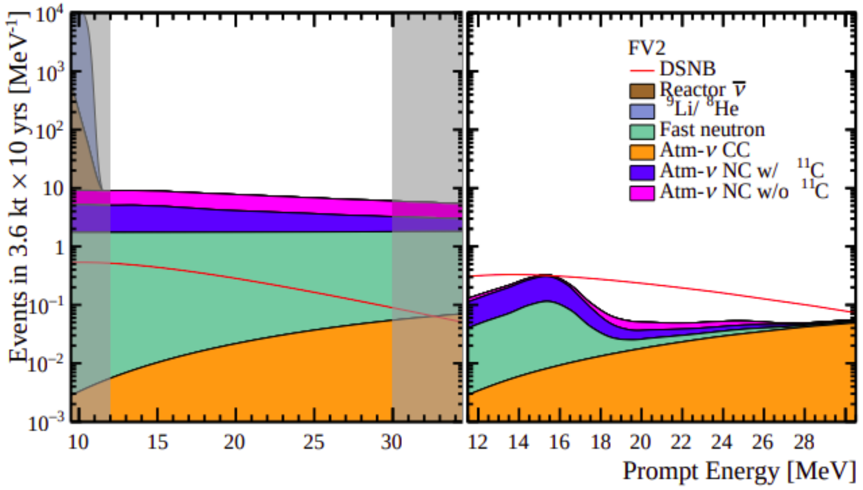
⟶ Major role in the next-generation Supernova Early Warning System (SNEWS 2.0)

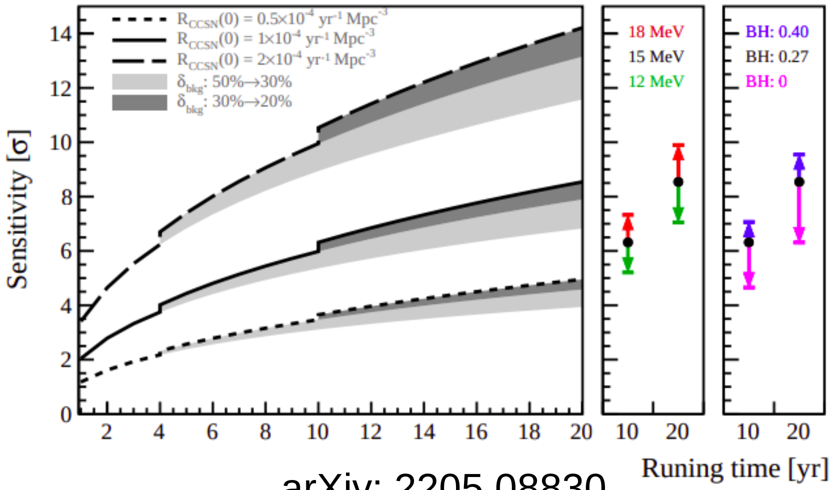
Diffused Neutrino Supernova Background@JUNO

Diffused Supernova Neutrino Background (DSNB) = superposition of neutrino signals from all past supernova explosions, yet to be observed

- Discovery of DSNB signal will provide important information on astrophysics and cosmology
- Detection in JUNO via IBD, with main background from NC atmospheric neutrinos → few events/year
- Selection: [12-30] MeV + fiducial volume + PSD (pulse shape discrimination, signal vs background)

before cuts → after cuts (PSD)

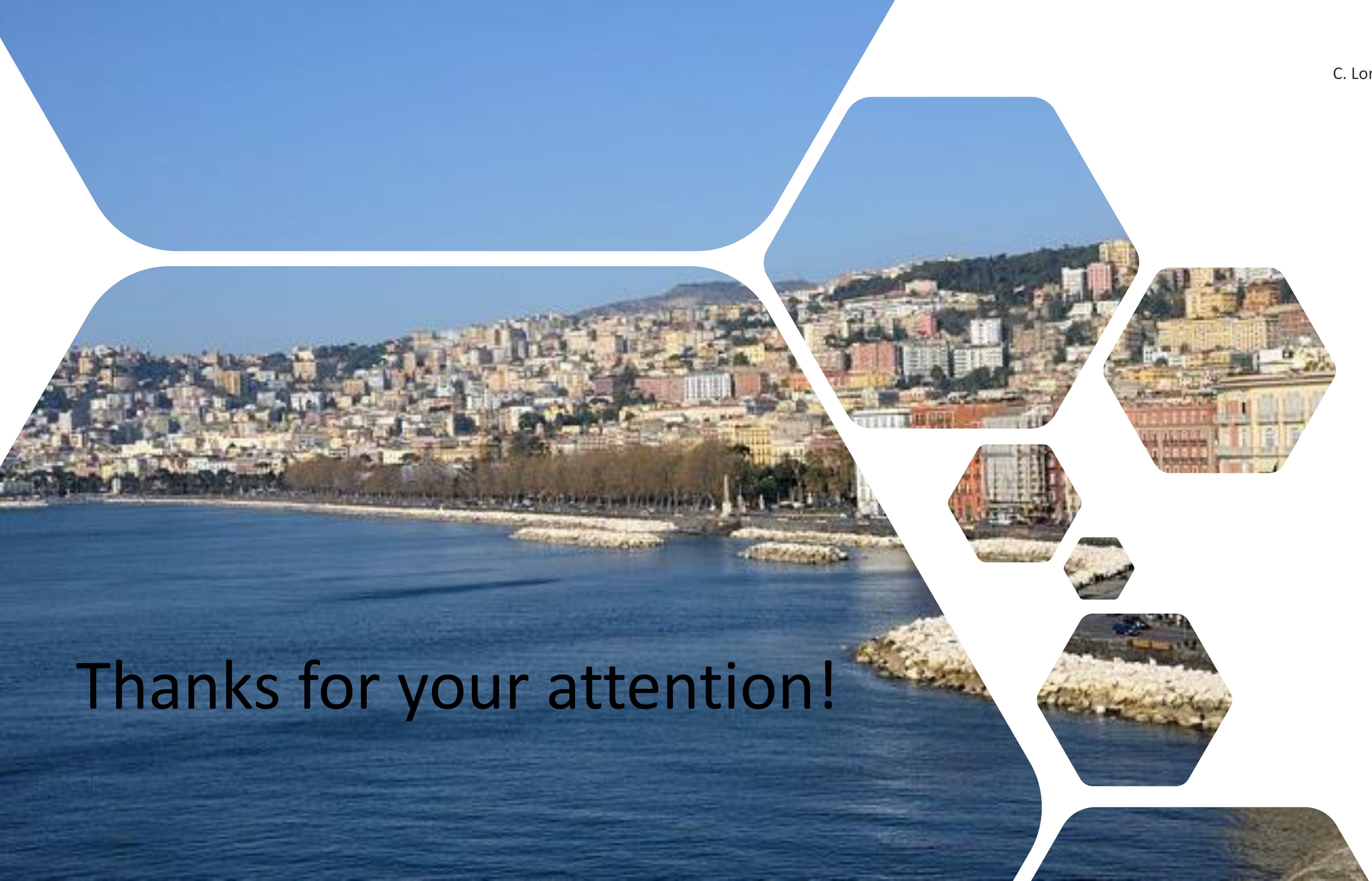




arXiv: 2205.08830

Conclusions

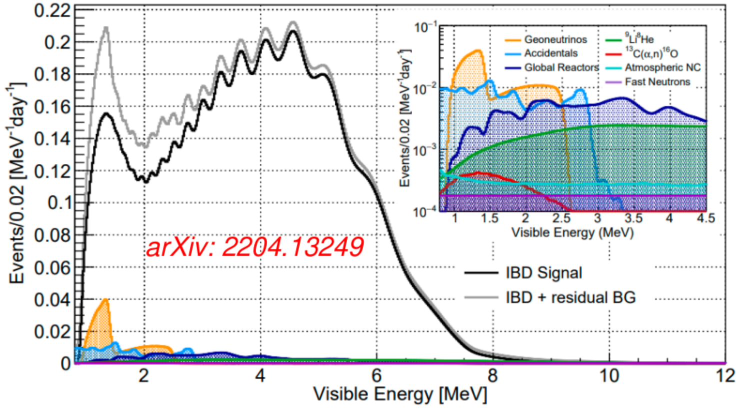
- JUNO is a powerful observatory for neutrinos coming from different sources
- JUNO has different physics goals: NMO, oscill. parameters, solar neutrinos, geoneutrino
- It will play an important role in Multi-messenger Astrophysics, with different possible measurements:
  - CCSN all flavour lightcurves;
  - CCSN direction;
  - CCSN flavor-dependent spectrum;
  - Diffused SN background.



Thanks for your attention!

Back up

Reactor Neutrino Oscillations

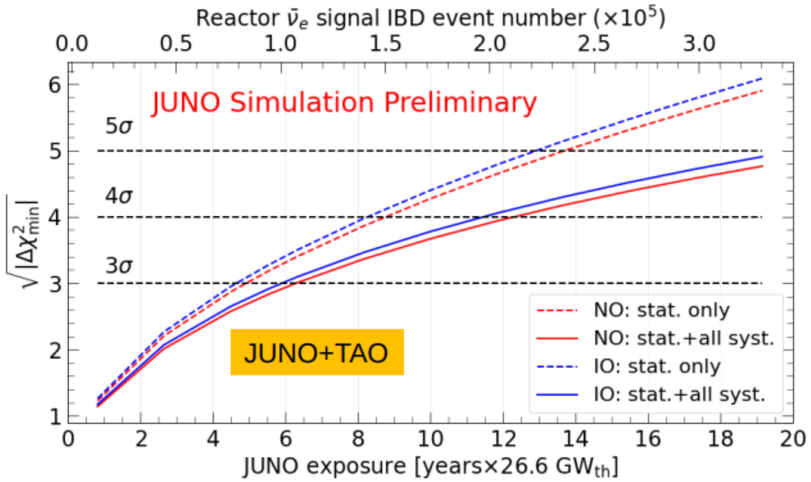


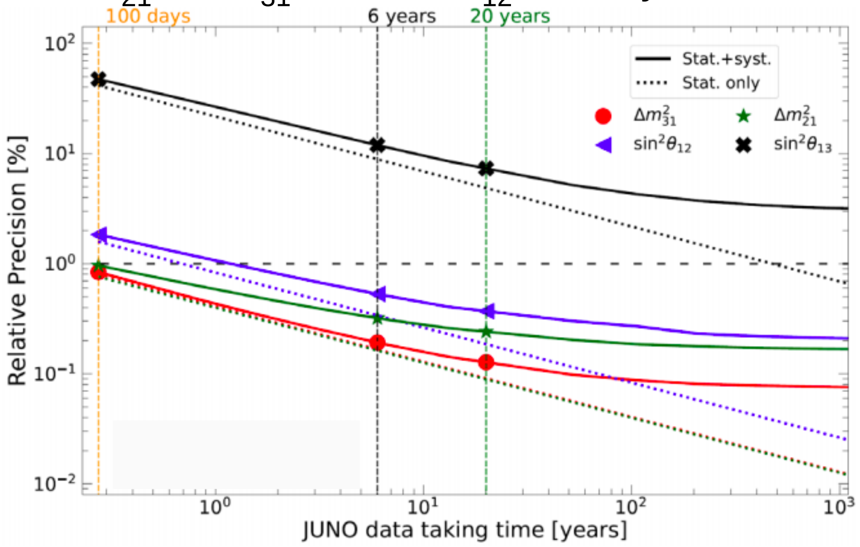
Sub-percent precision measurement of the oscillation parameters (arXiv: 2204.13249)

- Profit from spectrum precise measurement to extract oscillation parameters with <1% precision
- Probe simultaneously Δm^2_{21} and $\Delta m^2_{32}/\Delta m^2_{31}$ driven oscillations

→ JUNO will reach sub-percent precision level on Δm^2_{21} , Δm^2_{31} and $\sin^2\theta_{12}$ in 1-2 years

Determination of the neutrino mass ordering





Atmospheric Neutrinos

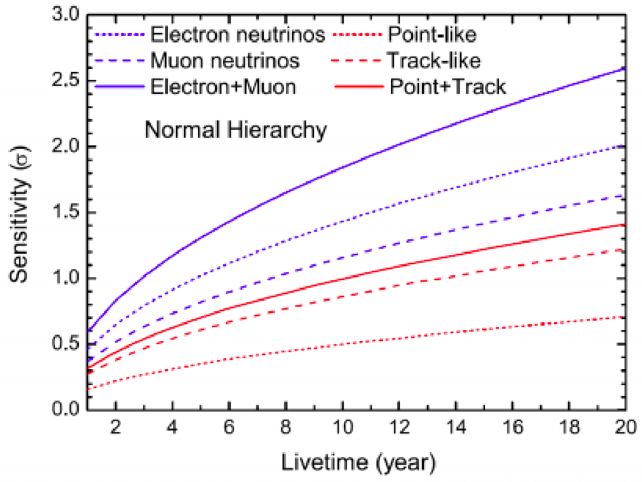
→ **Neutrino oscillations and NMO can also be assessed using atmospheric neutrinos**

Why atmospheric neutrinos?

- Complementary detection channels: independent measurements and systematics
- **Boost of NMO sensitivity using both channels:**

→ NMO determination at 3σ faster!

- Exploit matter effects on oscillations
- Additional parameters: $\sin^2\theta_{23}$ and δ_{CP}



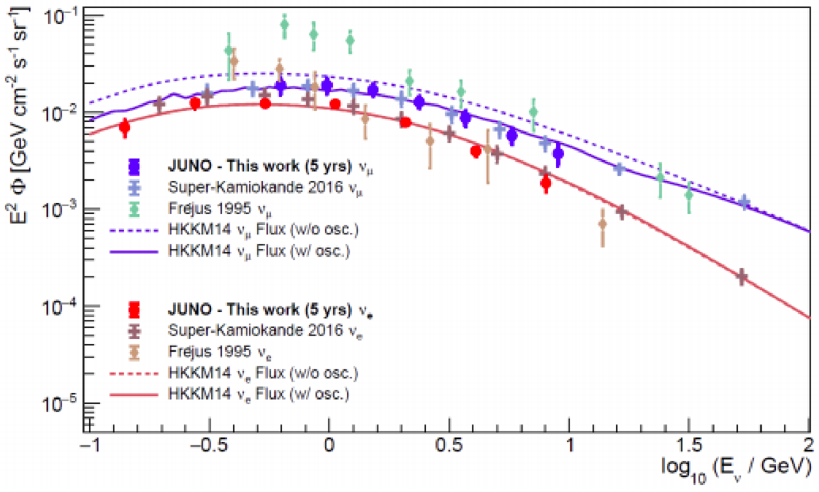
Ongoing analysis!

→ Flavor - dependent energy spectrum can be measured in the (0.1 - 10) GeV energy range

→ ν_e/ν_μ discrimination based on time pattern of scintillation light possible

→ Promising potential for GeV neutrino physics

Results published in Eur. Phys. J. C (2021) 81:887

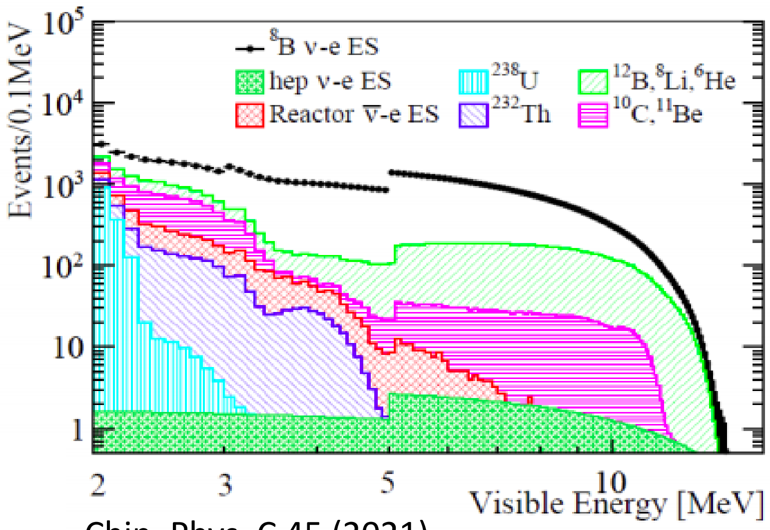


Solar Neutrinos

- Main detection channel → ν_e elastic scattering (ES)
- JUNO can benefit of its enormous statistics
- Different fluxes could be detected:
  - ^{7}Be
  - ^{8}B
  - Pep
  - CNO

Solar Neutrinos

- In particular, High energy (^8B neutrinos):
  - Possibility to use CC and NC interactions on ^{13}C
  - Unprecedented detection threshold at 2 MeV
  - More precision: contribute to solve metallicity puzzle
  - Spectral shape: study day/night asymmetry



Chin. Phys. C 45 (2021)