First Results of the JUNO Experiment

Benoit VIAUD

On behalf of the JUNO collaboration

IRN Neutrino, June 2 2026

Introduction

Motivations of the JUNO Experiment

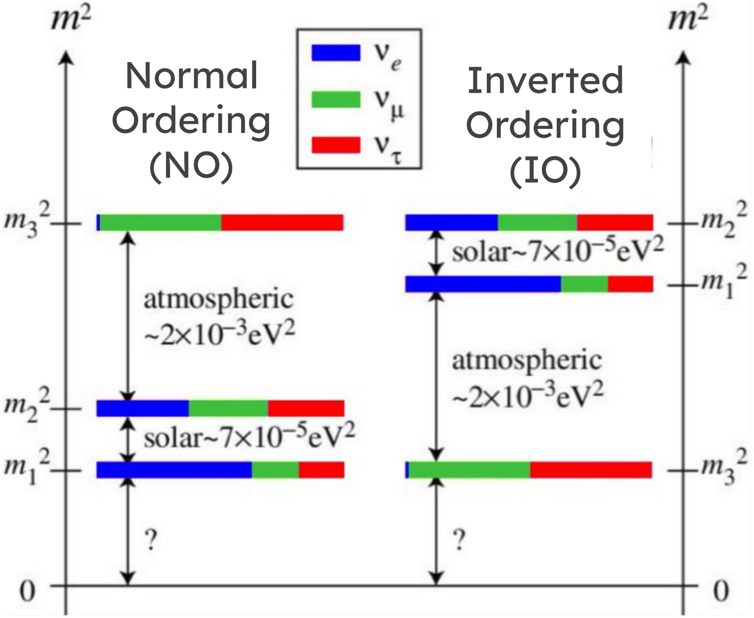
- **Neutrino Mass Ordering (NMO)**

  + To better understand the mechanisms at play to generate flavor & mass.

- **Precision measur't of Flavor Mixing in lepton sector**

$$\Delta m^2_{31},\ \Delta m^2_{21},\ \sin^2\theta_{12}$$

  + Challenge the 3-ν model to explore beyond the SM (unitarity, non-standard int., …)



- **Rich physics possibilities**

  *+ Beyond **reactor** neutrinos:* *solar neutrinos, atmospheric neutrinos.*

  + Beyond neutrino physics: *neutrinos as probes for astrophysics (SN) or geology (geo-ν's)*

Measuring the NMO

$$\mathcal{P}(\overline{\nu}_e \to \overline{\nu}_e) = 1 - \sin^2 2\theta_{12} c_{13}^4 \sin^2 \Delta_{21} - \frac{1}{2}\sin^2 2\theta_{13}\left(\sin^2 \Delta_{31} + \sin^2 \Delta_{32}\right) - \frac{1}{2}\cos 2\theta_{12} \sin^2 2\theta_{13} \sin \Delta_{21} \sin(\Delta_{31} + \Delta_{32})$$

- **Measure the interference between solar and atmospheric oscillations.**

  + Makes the $\overline{\nu}_e$ disappearance probability depend on the sign of $\Delta_{31} \propto \Delta m^2_{31}$

- **JUNO must be able to measure very precisely the E spectrum to tell NO from IO**

- **Ingredients:**

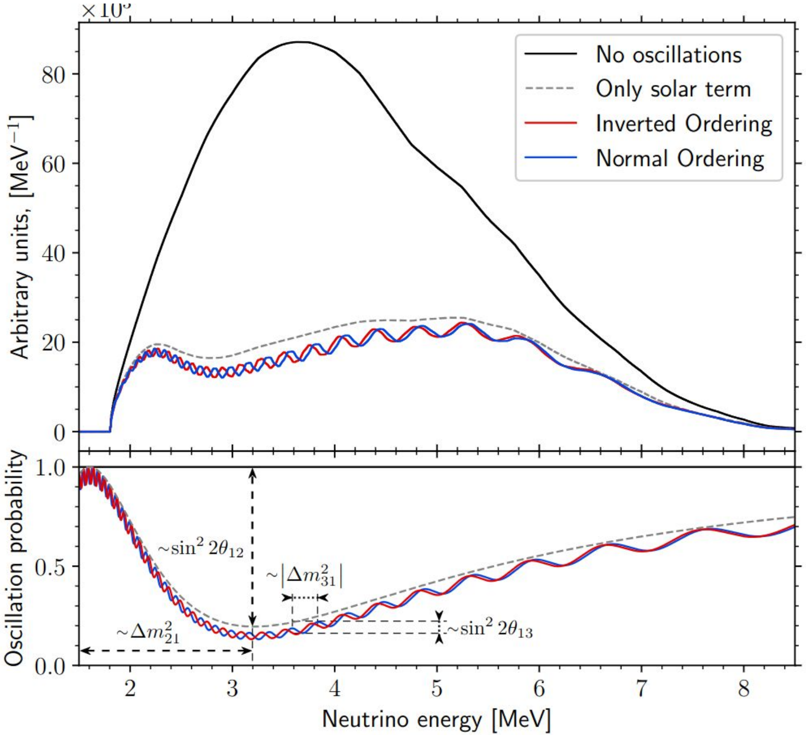
  + Presence of this peculiar oscillation pattern

  + High statistics

  + A favorable detection channel.

  + Minimal backgrounds

  + Very precise and well understood E reconstruction



Measuring the NMO

Ingredients:

+ Presence of this peculiar oscillation pattern

-> detector ~50km from a O(1) MeV neutrino source.

+ High statistics

-> Many reactors + Large detector.

+ A favorable detection channel (IBD).

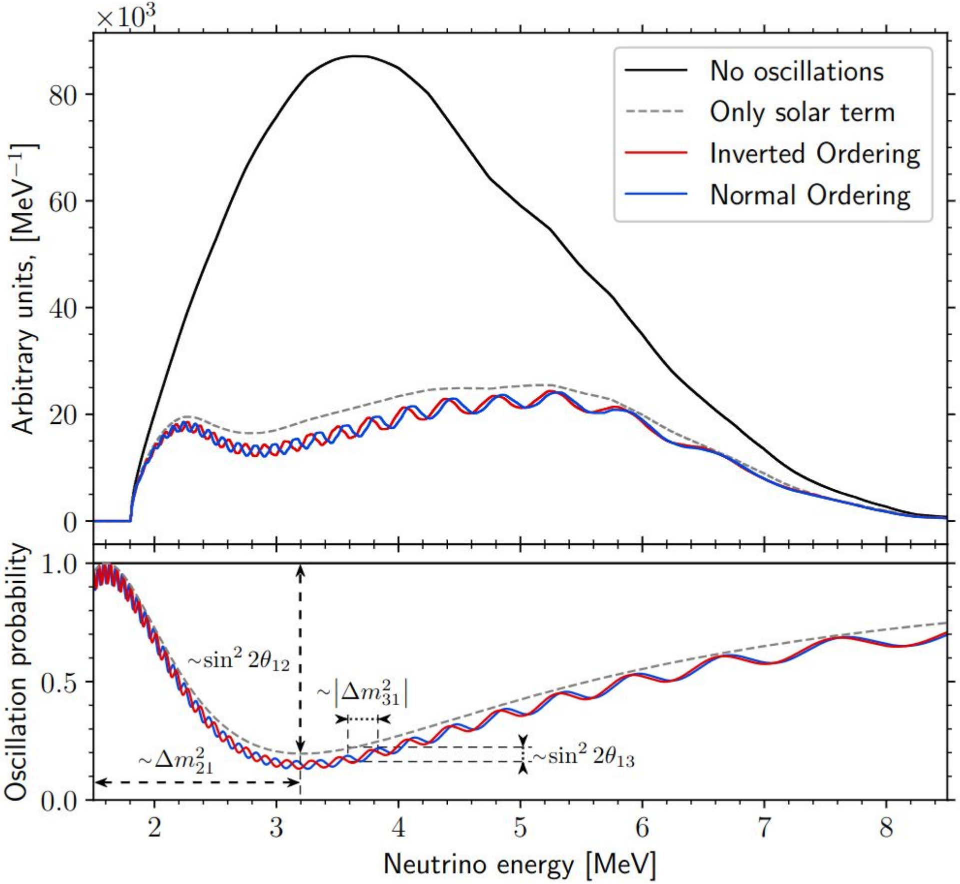
$$\bar{\nu}_e + \mathbf{p} \rightarrow \mathbf{e^+} + \mathbf{n}$$

+ Minimal backgrounds

-> Deep underground detector,
segmented for vetoes.

+ Very precise and well understood E reconstruction

-> Optimized liquid scintillator
-> Sophisticated reconstruction
-> Instrumental redundancy.



JUNO COLLABORATION

- established in 2014
- 74 institutions
- 750 collaborators
- 17 countries and regions

Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	Wu Yi U.	Italy	INFN di Frascati
Belgium	Universite Libre de Bruxelles	China	Wuhan U.	Italy	INFN-Ferrara
Brazil	PUC	China	Xi'an JT U.	Italy	INFN-Milano
Brazil	UEL	China	Xiamen University	Italy	INFN-Milano Bicocca
Chile	SAPHIR	China	Zhengzhou U.	Italy	INFN-Padova
Chile	UNAB	China	NUDT	Italy	INFN-Perugia
China	BISEE	China	CUG-Beijing	Italy	INFN-Roma 3
China	CAGS	China	ECUT-Nanchang City	Pakistan	PINSTECH (PAEC)
China	ChongQing University	China	CDUT-Chengdu	Russia	INR Moscow
China	DGUT	China	SUSTech-Shenzhen	Russia	JINR
China	Guangxi U.	China	KNRC	Russia	MSU
China	Harbin Institute of Technology	Czech	Charles U.	Slovakia	FMPICU
China	IHEP	Finland	University of Jyvaskyla	Taiwan-China	National Chiao-Tung U.
China	Jinan U.	France	IJCLab Orsay	Taiwan-China	National Taiwan U.
China	Nanjing U.	France	LP2i Bordeaux	Taiwan-China	National United U.
China	Nankai U.	France	CPPM Marseille	Taiwan-China	NKNU
China	NCEPU	France	IPHC Strasbourg	Taiwan-China	NTUT
China	Shandong U.	France	Subatech Nantes	Thailand	NARIT
China	Shanghai JT U.	Germany	RWTH Aachen U.	Thailand	PPRLCU
China	IGG-Beijing	Germany	TUM	Thailand	SUT
China	SYSU	Germany	U. Hamburg	U.K.	U. Liverpool
China	Tsinghua U.	Germany	GSI	U.K.	U. Warwick
China	UCAS	Germany	U. Mainz	USA	UMD-G
China	U. of South China	Germany	U. Tuebingen	USA	UC Irvine
China	IMP	Italy	INFN Catania		

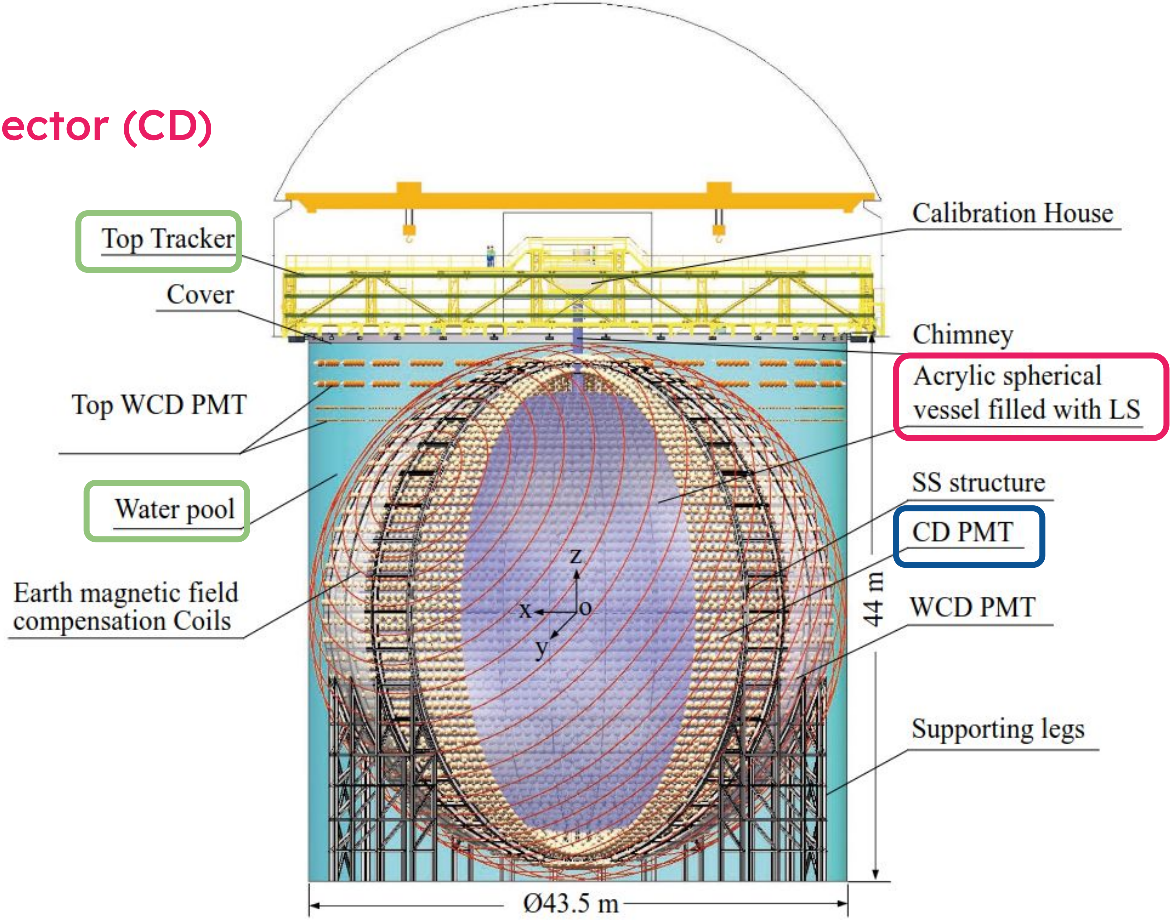
+Observers: USTC, Pekin Uni., Jilin Uni., Beijing Normal Uni., CIAE (China)

Design overview

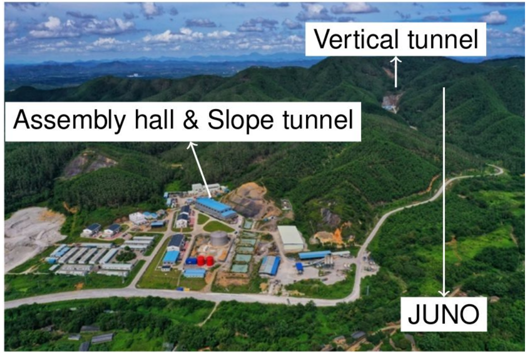
- Optimized LS in the Central Detector (CD)
- Muon veto
- Redundant PMT systems

  + 17612 20-inch PMTs (LPMTs)

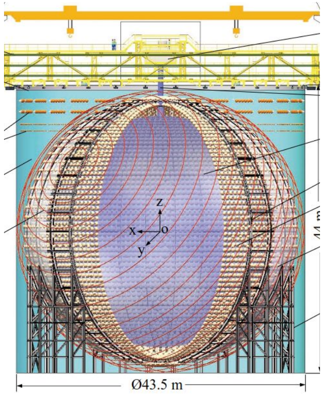
  + 25600 3-inch PMTs (SPMTs)



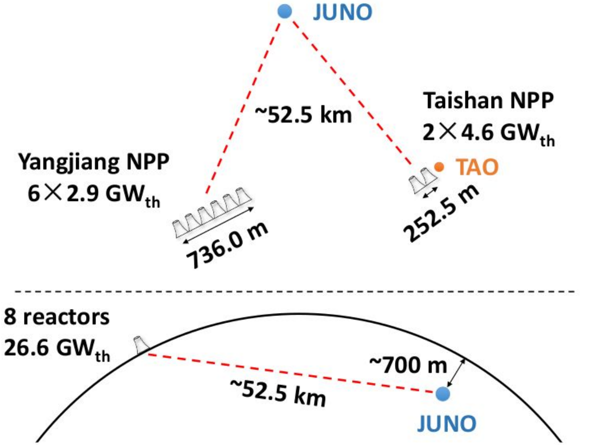
The Jiangmen Underground Neutrino Observatory



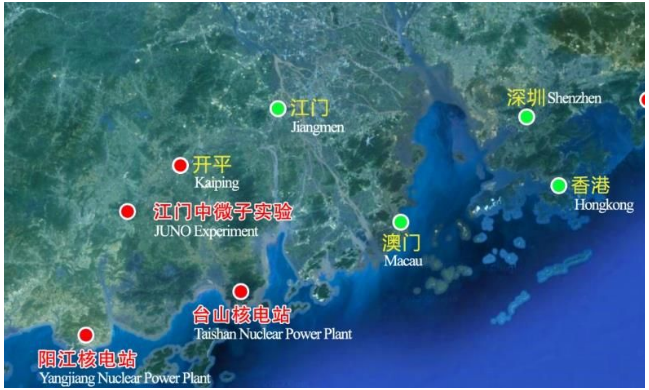
Underground lab (700 m), located in China.



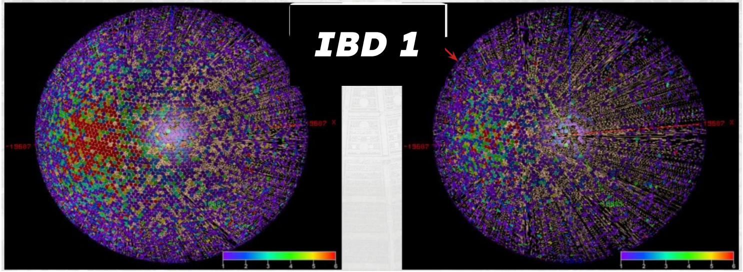
A 35 m diameter sphere: 20kton of LS Surrounded by a Cerenkov detector



~52.5 km from 2 nuclear complexes: ~27 GW_{th} in total



Site and detector built from 2015 to Dec. 2024

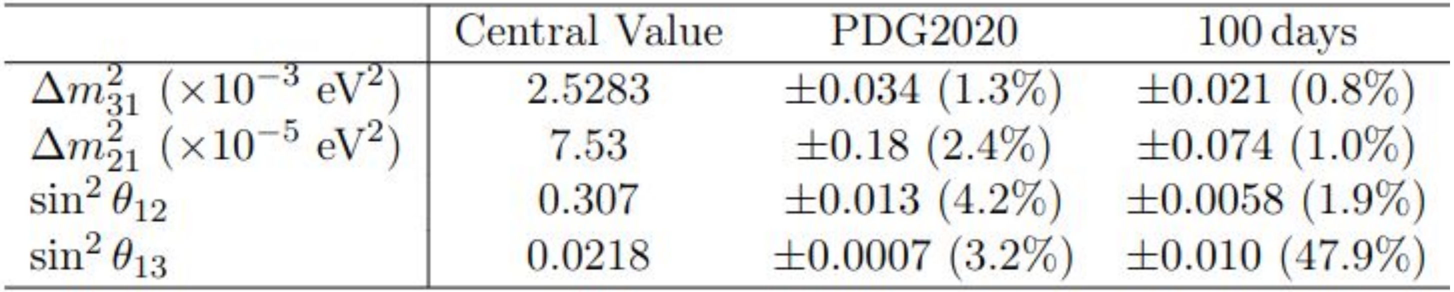


Physics operations started in Aug. 2025.

Engines on !

- After years of design & construction, JUNO's now taking data (physics: since Aug. 25)
- Sensitivity studies suggested world leading solar parameters with early data.

From *Chin.Phys.C* 46 (2022) 12, 123001, arXiv:2204.13249



	Central Value	PDG2020	100 days
Δm^2_{31} ($\times 10^{-3}$ eV^2)	2.5283	± 0.034 (1.3%)	± 0.021 (0.8%)
Δm^2_{21} ($\times 10^{-5}$ eV^2)	7.53	± 0.18 (2.4%)	± 0.074 (1.0%)
$\sin^2\theta_{12}$	0.307	± 0.013 (4.2%)	± 0.0058 (1.9%)
$\sin^2\theta_{13}$	0.0218	± 0.0007 (3.2%)	± 0.010 (47.9%)

How up to this first challenge we've been is presented today.

Engines on !

- After years of design & construction, JUNO's now taking data (physics: since Aug. 25)
- Sensitivity studies suggested world leading solar parameters with early data.

- Above all, the first years of operations are a learning phase, to design methods to…

  + Characterise and calibrate detector effects.

  + Reconstruct events

  + Identify & reject backgrounds, determine the shape and rates of what remains.

  + Interpret statistically the IBD e^+ energy spectrum to extract oscillation physics, via a model that incorporates :

    -> Initial antineutrino spectrum, inclusion of reactor information
    -> Energy model (resolution and non linearity)
    -> Systematic uncertainties (dozens of nuisance parameter).

…with enough precision and robustness to eventually be able to measure the NMO, and oscillation parameters at the subpercent level.

Reconstruction and Calibration

See Arxiv:2511.14590

Initial performance results of the JUNO detector*

JUNO Collaboration • Angel Abusleme (Chile U., Catolica) Show All(1138)

Nov 18, 2025

38 pages

Published in: *Chin.Phys.C* 50 (2026) 4, 043001

Energy and position reconstruction

$$\frac{\sigma_{E^{\mathrm{rec}}}}{E^{\mathrm{vis}}} = \sqrt{\left(\frac{a}{\sqrt{E^{\mathrm{vis}}}}\right)^2 + b^2 + \left(\frac{c}{E^{\mathrm{vis}}}\right)^2}$$

- Needed for the NMO : σE/E = 3% @ 1 MeV & E-scale understood @ < 1%.
- 2 key ingredients (>1600 PE @ 1 MeV + 78% PMT coverage) do not suffice !
  => A sophisticated reconstruction is also essential essential.
- Main E & vertex reconstruction methods maximize likelihoods. Ex:

$$L(E_{\mathrm{rec}}) = \prod_{j}^{\text{Unhit LPMTs}} P_j(\mathrm{unhit}|\mu_{j,\mathrm{exp}}) \times \prod_{i}^{\text{Hit LPMTs}} P_i(Q_{i,\mathrm{obs}}|\mu_{i,\mathrm{exp}})$$

+ Based on the Charge and Hit time PDFs expected in each PMT, as a function of the value and position of the E deposit.

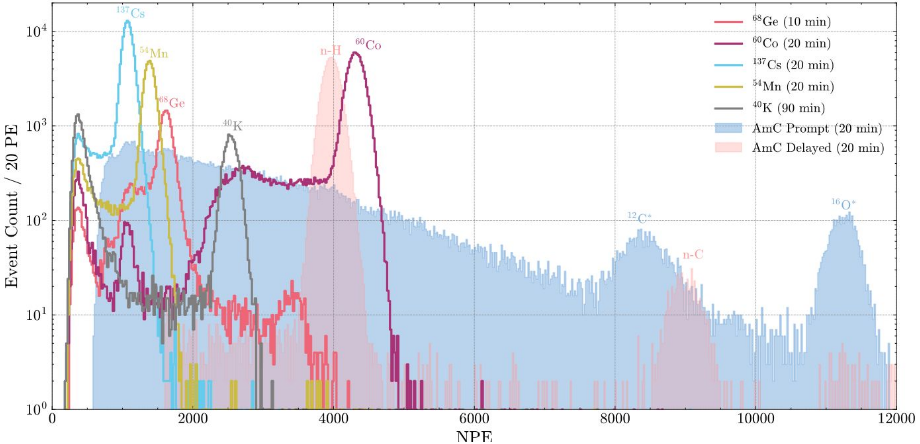
+ Determining these PDFs: a precision work. Relies on : calibration sources, 214Po decays, laser sources, …

+ Impacted by: spatial & time variation of gains, of LS state, transparency, radiopurity, WF recons., ….

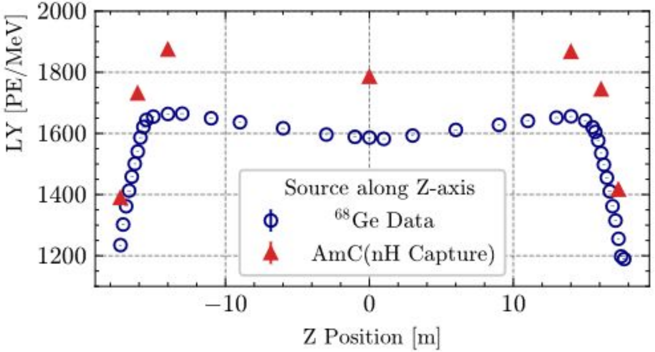
=> Long work with calibration & control samples, progressively reach design perf.

JUNO's calibration

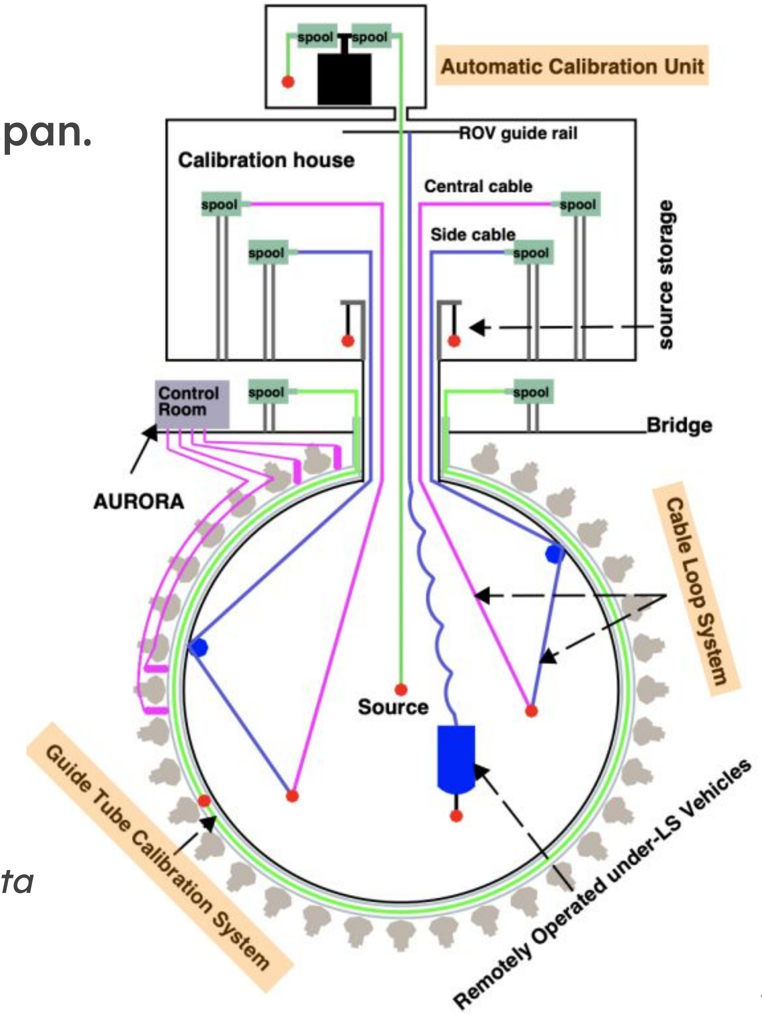
- 5 γ and 2 neutron sources: characterise a large E span.



- Confirms the Light Yield (above expectancies)



68Ge (1.022 MeV)
and AmC (2.2 MeV) data



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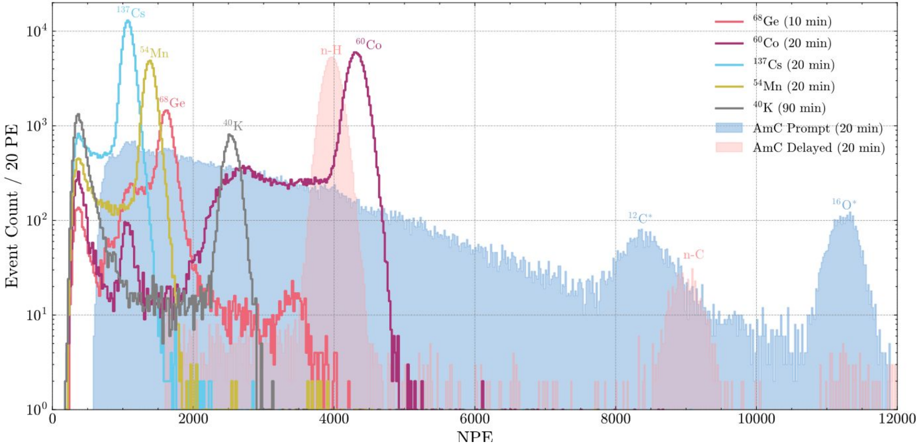

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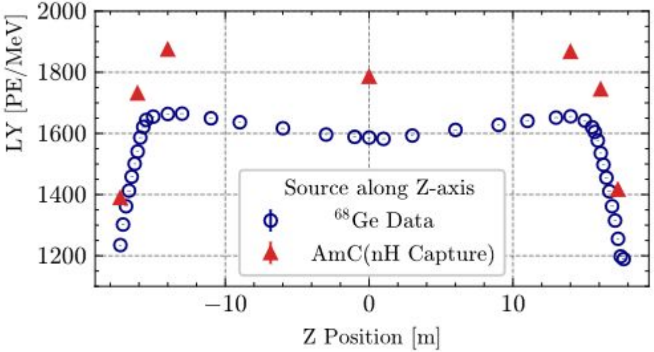

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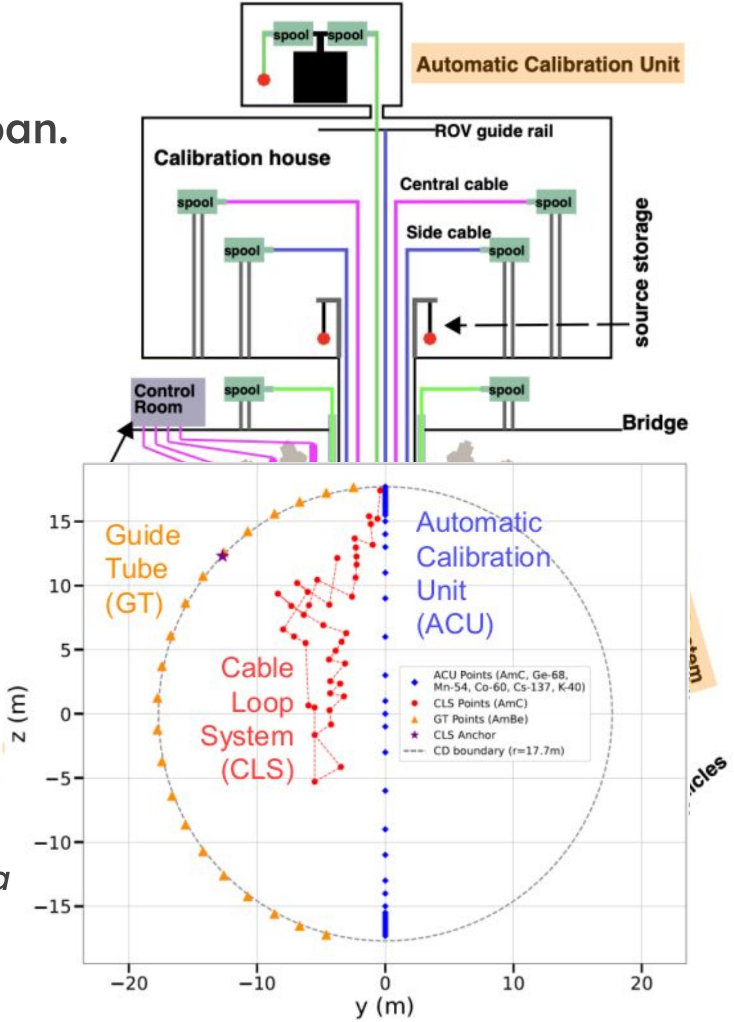
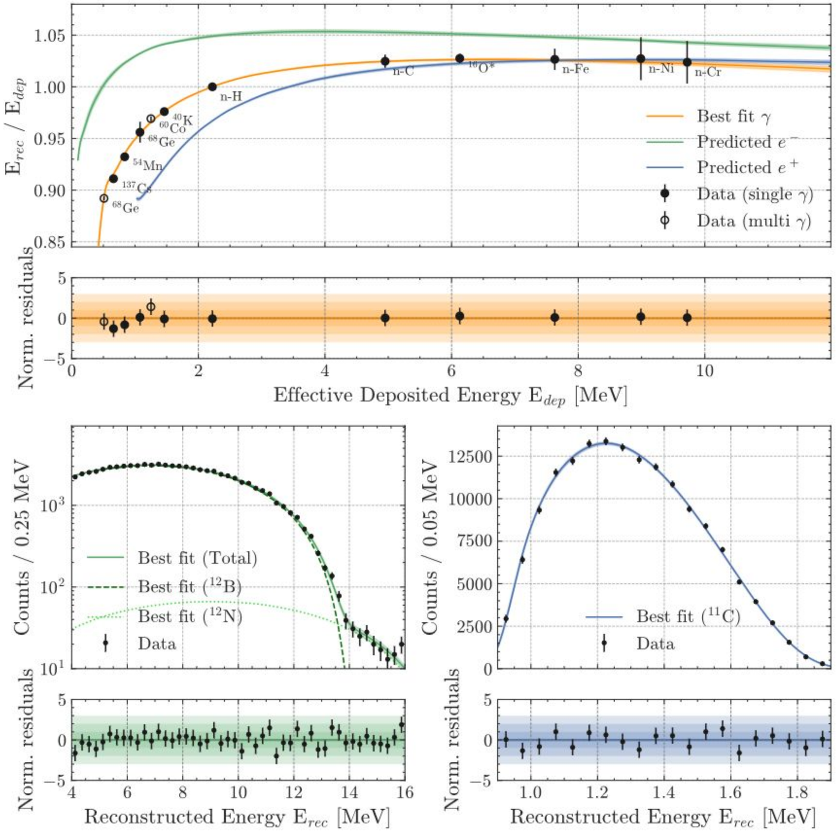
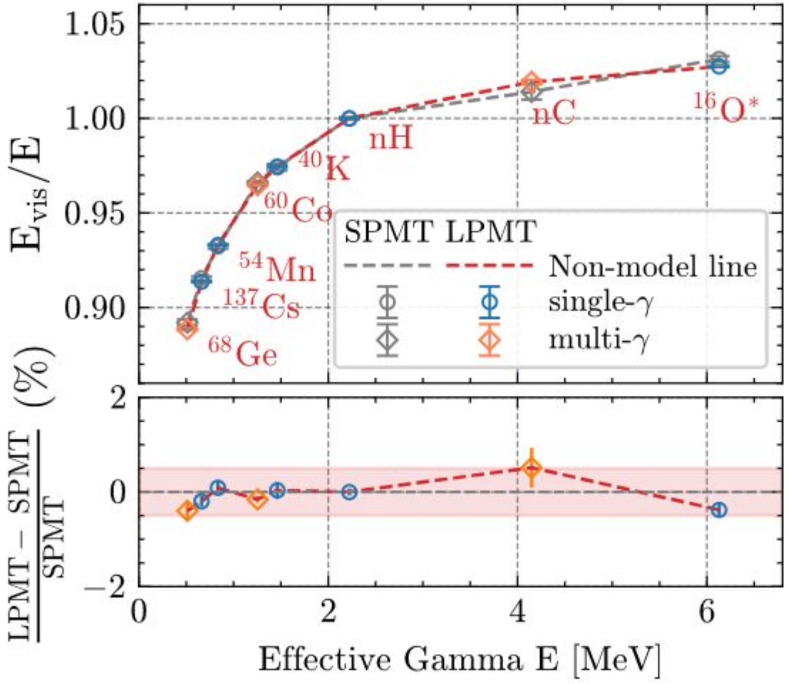


JUNO's calibration

- Non linearity known @ 1 %

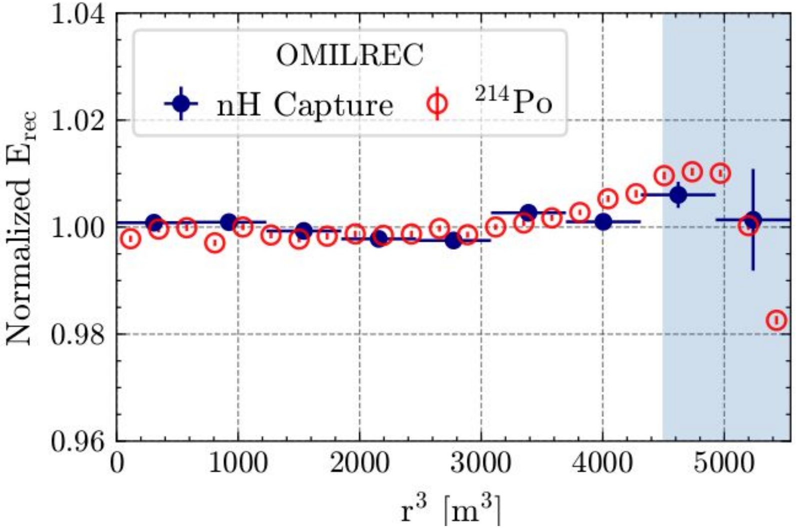


Role of the SPMT system



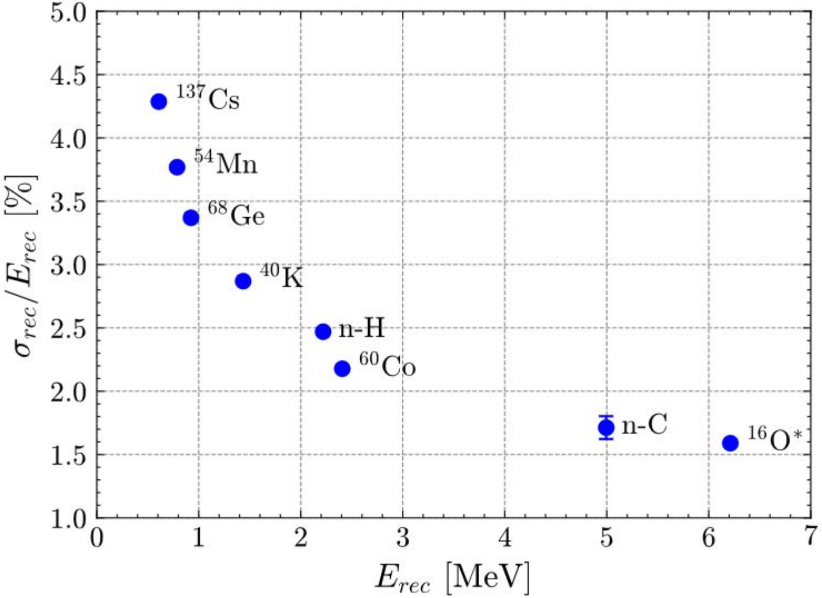
JUNO's calibration

▌Energy scale uniformity



+ *Uniformity better than ±1% within R < 16.5 m (FV)*
  214-Po visible E ~0.9 MeV

▌Energy resolution

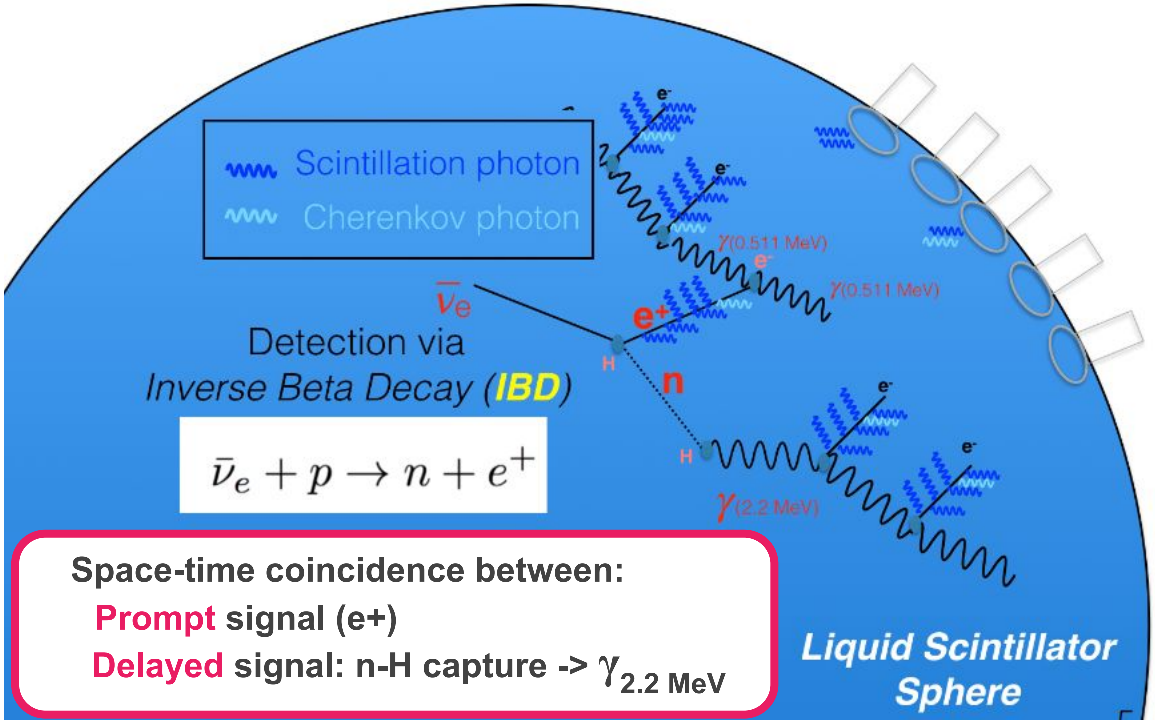


+ *3.4% @ 1 MeV @ detector center*
  Stochastic term @ 3.3%

IBD sample selection

Selecting the antineutrino sample

- Main signal detection principle



$$\bar{\nu}_e + p \rightarrow n + e^+$$

Space-time coincidence between:

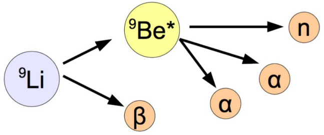
Prompt signal (e+)

Delayed signal: n-H capture -> $\gamma_{2.2\ \mathrm{MeV}}$

- The final selection needs more complex criteria to mitigate backgrounds which mimic this coincidence.

Cosmogenics (muon-induced)

^{9}Li ^{8}He



Spallation neutrons.

Natural radioactivity

^{214}Bi-^{214}Po

^{13}C(α-n)^{16}O

Accidentals

Other neutrinos

Atmospheric neutrinos

IBDs: Geoneutrinos, World Reactors

- Muon veto

  Removes all events <5 ms after a muon seen in the CD or WP.

  Cuts short lived spallation products

- Spatial & temporal veto around spallation neutrons

  Removes all events <4 m from a spallation neutron, for 1.2 s after this neutron.

  Cuts long lived spallation products like ^{9}Li ^{8}He

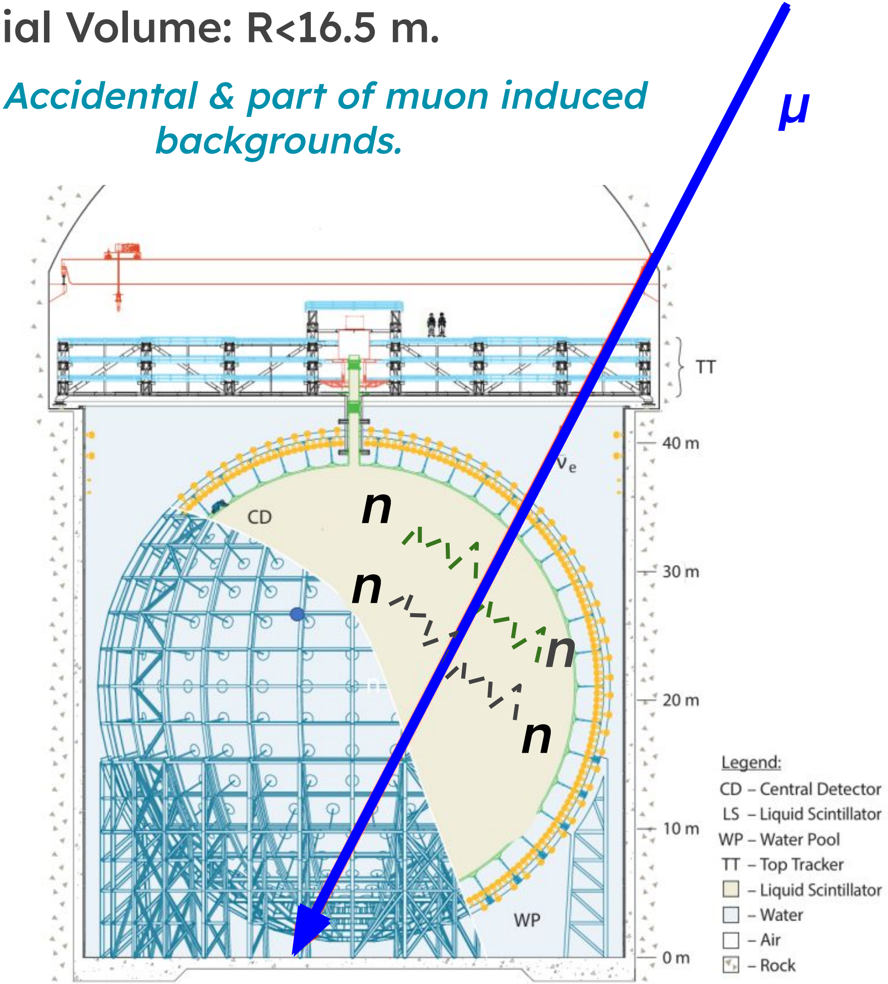
- Finally form pairs of prompt+delayed events

  Keep pairs with $\Delta t < 1$ ms and $\Delta d < 1.5$ m

  Multiplicity cut: no additional events in $[t_{delayed} - 2\text{ms} ; t_{delayed} + 1\text{ ms}]$

- Fiducial Volume: R<16.5 m.

  Cuts Accidental & part of muon induced backgrounds.

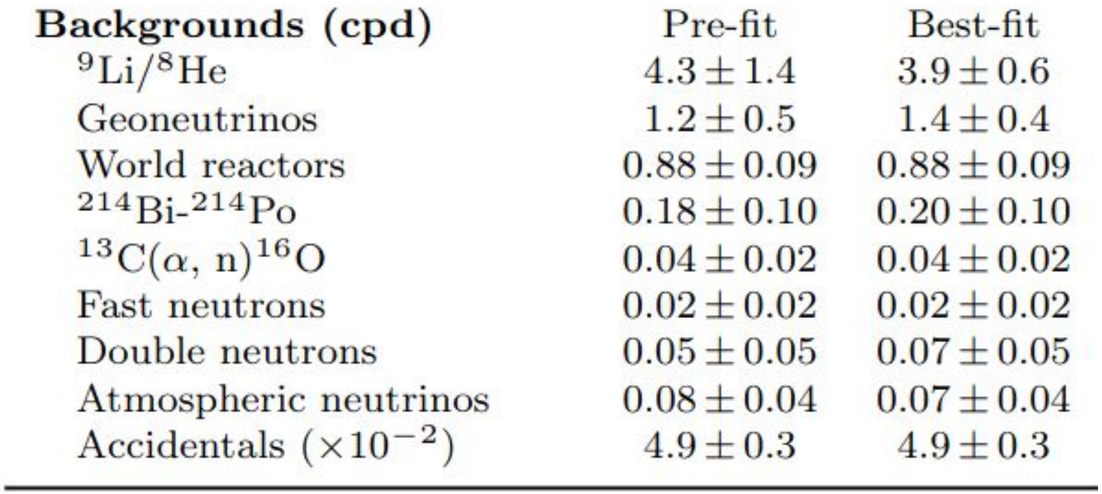


- 2379 $\overline{\nu}_e$ candidates in 59.1 days.

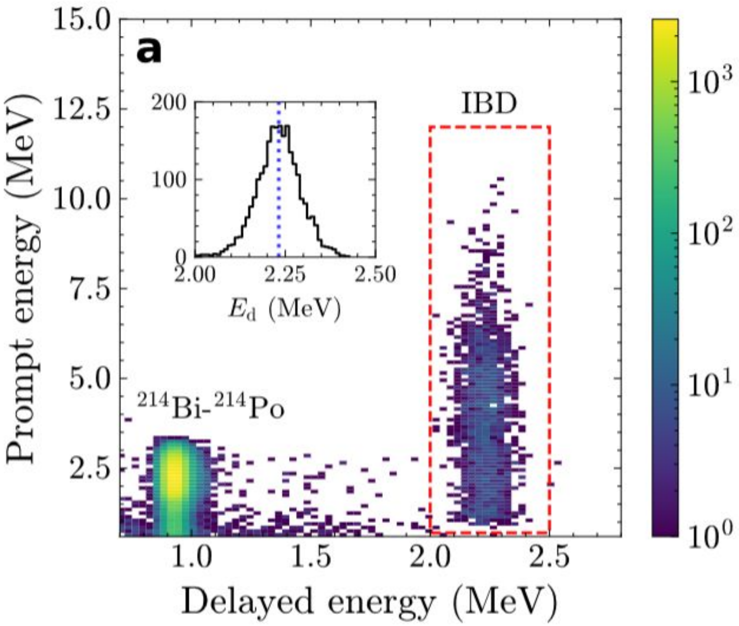
37 true IBDs / day

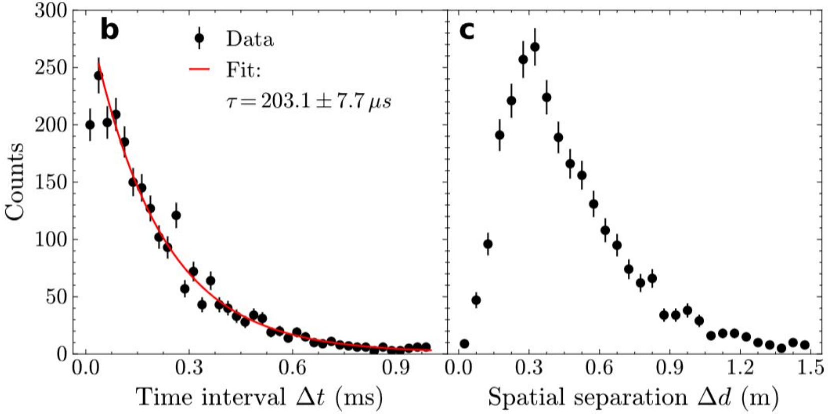
Signal efficiency: ~ 70%

Purity: 86 %



Backgrounds (cpd)	Pre-fit	Best-fit
^{9}Li/^{8}He	4.3 ± 1.4	3.9 ± 0.6
Geoneutrinos	1.2 ± 0.5	1.4 ± 0.4
World reactors	0.88 ± 0.09	0.88 ± 0.09
^{214}Bi-^{214}Po	0.18 ± 0.10	0.20 ± 0.10
^{13}C(α, n)^{16}O	0.04 ± 0.02	0.04 ± 0.02
Fast neutrons	0.02 ± 0.02	0.02 ± 0.02
Double neutrons	0.05 ± 0.05	0.07 ± 0.05
Atmospheric neutrinos	0.08 ± 0.04	0.07 ± 0.04
Accidentals ($\times 10^{-2}$)	4.9 ± 0.3	4.9 ± 0.3





Constructing the Fit Model

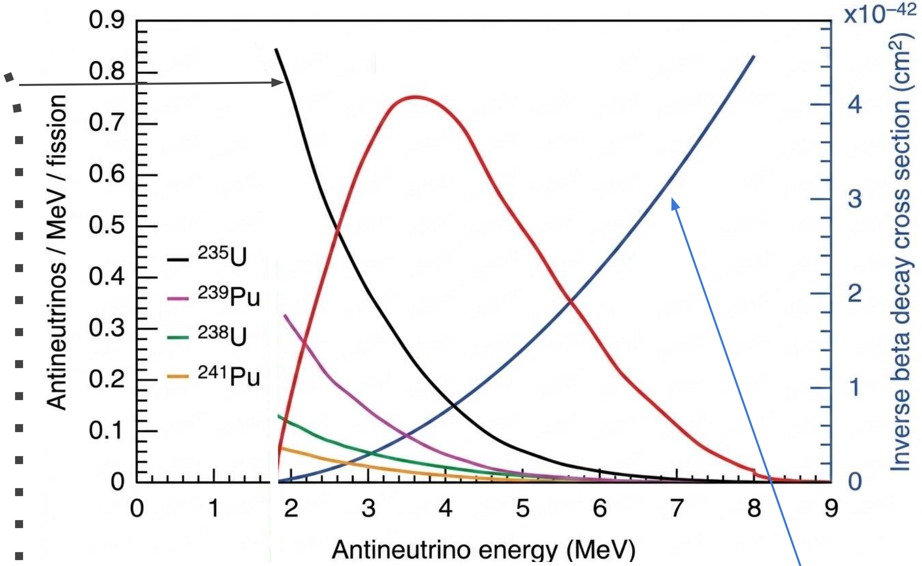
1. True non-oscillated spectrum of detected $\bar{\nu}_e$

- Start from Huber-Mueller prediction
- Elementary brick of a combination of
  - *+ 4 isotopes (^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu)*
  - *+ 4 fission fractions*
  - *+ 4 values of the E released per fission*
  - *+ 1 Reactor Thermal Power*

  Repeated over 10 reactors
- Add Non-equilibrium & Spent Fuel corr.
- Split in 21 segments to apply additional shape corrections.

  + Constrained by a simultaneous fit to Daya Bay's near detectors data.

=> ~75 fitted nuisance parameters (not counting DYB's)



- Multiply by the IBD X-section $\frac{d\,\sigma}{d\,\cos\theta}(E_{\bar{\nu}_e}, \cos\theta)$

2. Oscillation

- Apply the oscillation probability

$$\mathcal{P}(\overline{\nu}_e \rightarrow \overline{\nu}_e) \simeq -\sin^2 2\theta_{12} c_{13}^4 \sin^2 \Delta_{21} - \frac{1}{2}\sin^2 2\theta_{13}\left(\sin^2 \Delta_{31} + \sin^2 \Delta_{32}\right) - \frac{1}{2}\cos 2\theta_{12} \sin^2 2\theta_{13} \sin \Delta_{21} \sin(\Delta_{31} + \Delta_{32})$$

=> 5 fitted parameters

(oscillation params + Matter density)

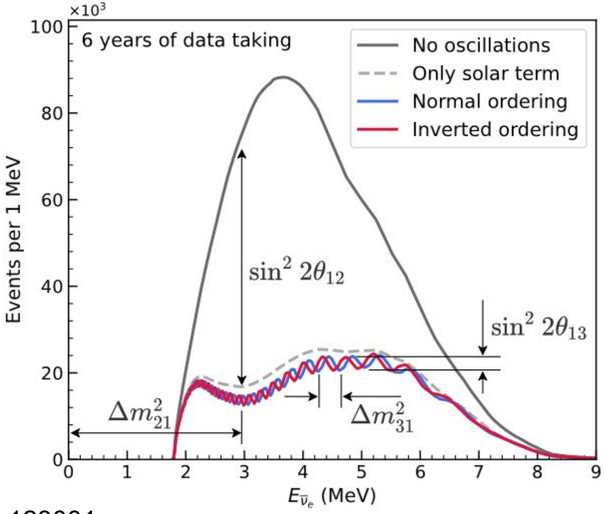


Illustration from *Chin.Phys.C* 46 (2022) 12, 123001

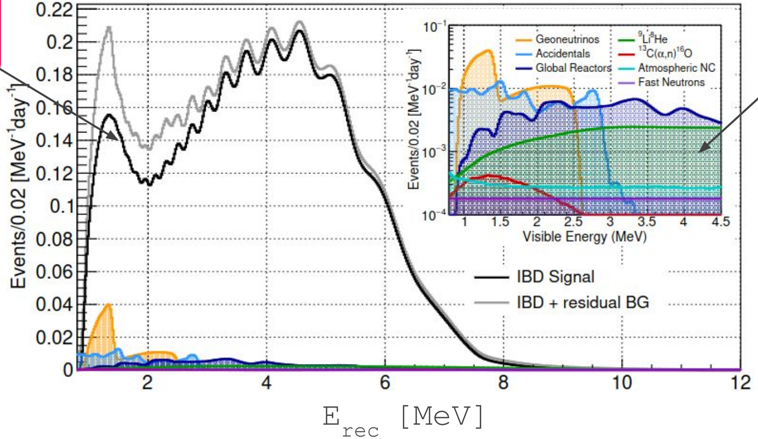
3. Detect. effects

- From $E(\overline{\nu}_e)$ to E_{vis} to E_{rec}

  + Non linearity model

  + Resolution model

=> 7 nuisance parameters



4. Backgrounds

- Rate & Shapes:

  + Mostly data driven

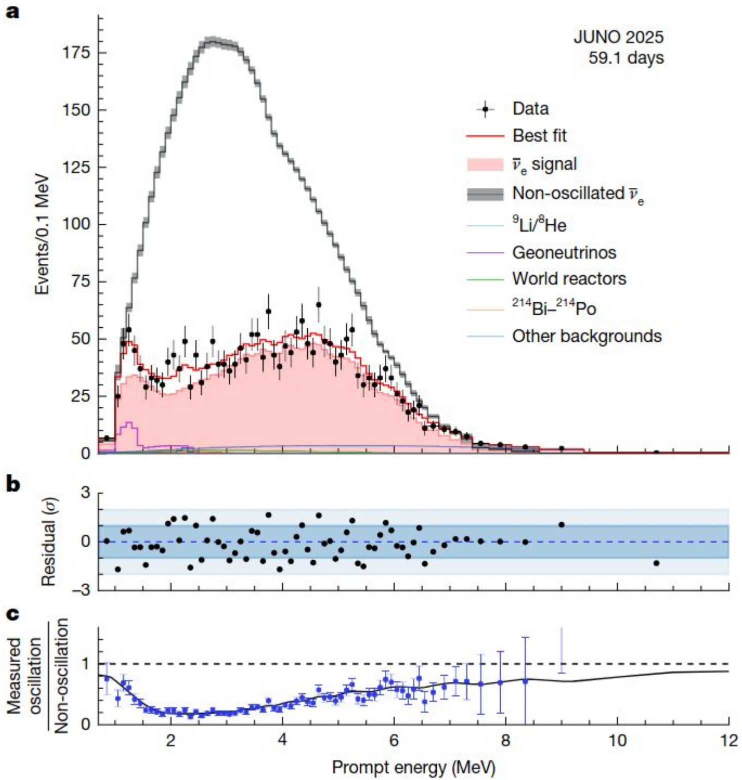
  + Complemented with MC

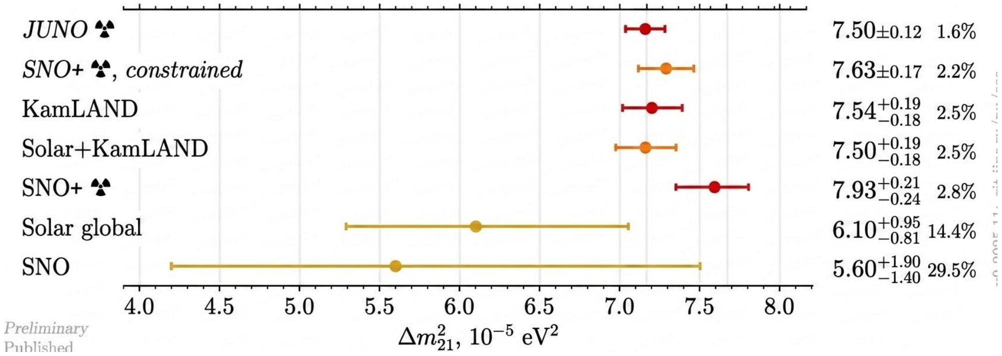
- Selection eff.

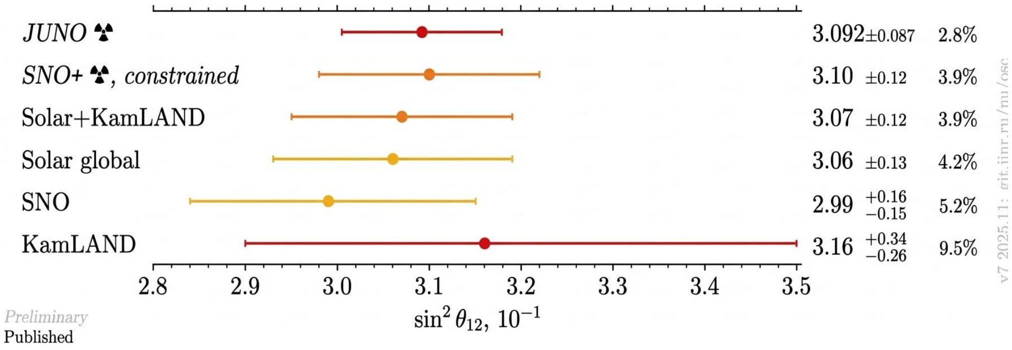
=> >10 nuisance parameters

Results

World best solar oscillation parameters measurement.







$$\sin^2\theta_{12} = 0.3092 \pm 0.0087\,,$$
$$\Delta m^2_{21} = (7.50 \pm 0.12)\times 10^{-5}\ \mathrm{eV}^2\,.$$

Uncertainties

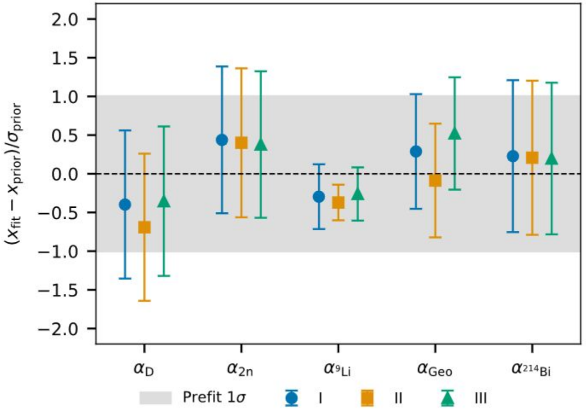
	PDG 2025	JUNO (59.1 days)
Δm^2_{21}	2.5%	1.6%
$sin^2\theta_{12}$	3.9%	2.8%

- σ(stat) ~ ¾ of total uncertainty.
- Main systematic uncertainties:
  - + *Backgrounds*
  - + *Energy response model*
  - + *Detector efficiency*
  - + *Reactor info*
  - + *More marginal:* $\overline{\nu}_e$ *spectrum shape*

=> Mostly treated via > 100 nuisance parameters

Robustness

- Essential to precision physics
- JUNO's bias killing policy based on
  - + *Thorough comparison of 3 distincts analysis groups.*



  - + *Blinding strategy that conceals the oscillation parameters and reactor info until the analysis design is frozen.*

Looking forward

- **59.1 days: not enough for a precise Δm^2_{31}**

  + Requires a sophisticated statistical treatment (e.g. à la Feldman-Cousins)

- **A continuous hard work to progress on the path to precision physics (crucial for NMO!)**

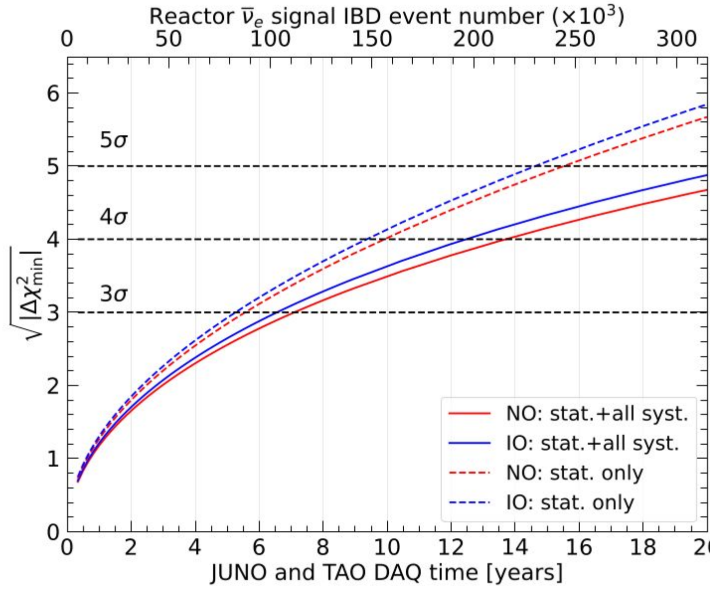
  + Improved Energy resolution and Energy model

  + TAO data available for future analyses.

  + Improved understanding of backgrounds.

- **Hints at the NMO may arrive earlier thanks to synergies with experiments exploiting Accelerators or Atmospheric neutrinos.**

JUNO-only sensitivity in years to come

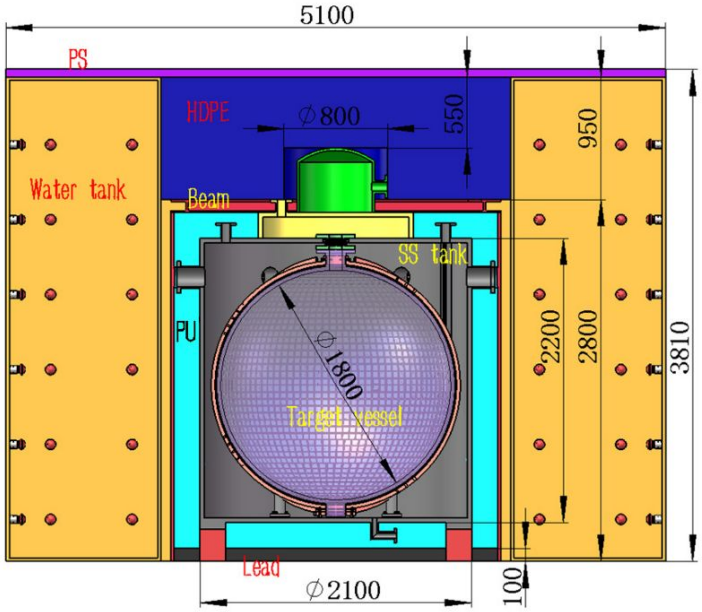


The Taishan Antineutrino Observatory (TAO)

- **Will constrain the unoscillated $\overline{\nu}_e$ spectrum shape**
  - *+ Relies on very high statistics and exceptional energy resolution (design: ~2 % @ 1 MeV)*

- **1-ton fiducial volume of Gd-dopped LS**
  - *+ 40 m from one of Taïshan's cores (4.6 GWth)*
  - *+ IBD rate: 30*JUNO*
  - *+ Photon detection yield : 4500 PE/MeV !!*

- **Detection: 10 m2 of SiPM**
  - *+ Photon detection efficiency : 50%*
  - *+ Photo coverage: 95%*



Started physics data taking in Feb' 26

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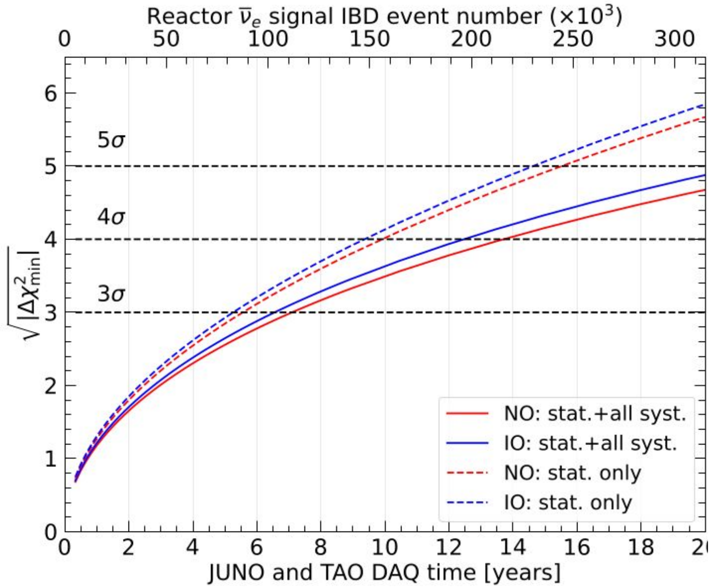
  + Improved Energy resolution and Energy model

  + TAO data available for future analyses.

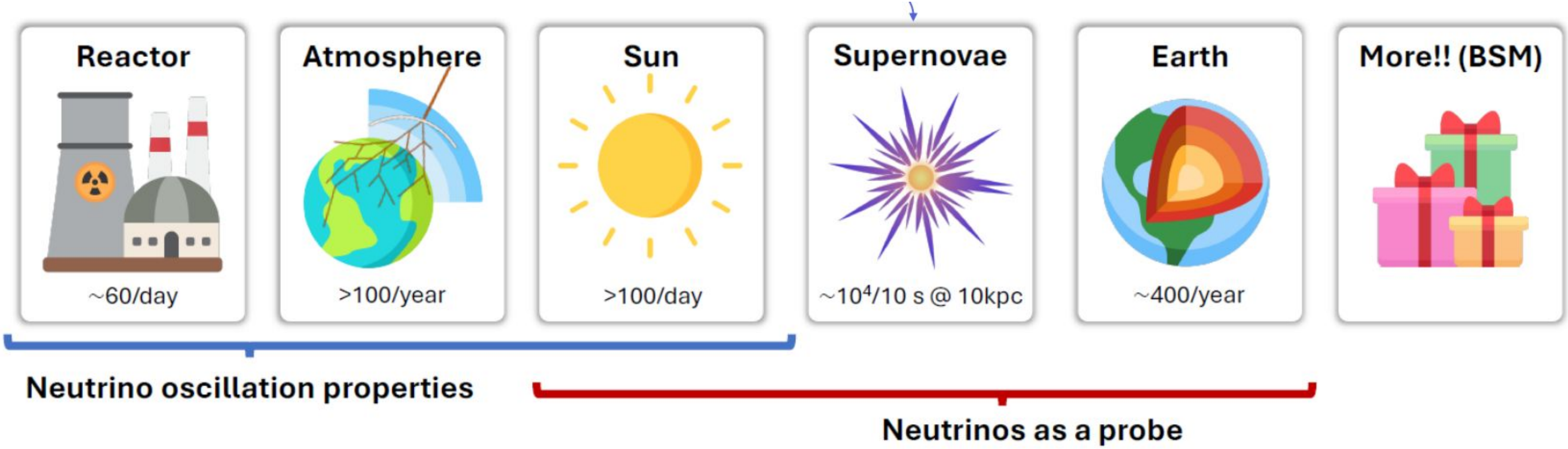
  + Improved understanding of backgrounds.

- **Hints at the NMO may arrive earlier thanks to synergies with experiments exploiting Accelerators or Atmospheric neutrinos.**

JUNO-only sensitivity in years to come



Looking forward (II): JUNO's wide scientific spectrum



Reactor

~60/day

Atmosphere

>100/year

Sun

>100/day

Supernovae

~10^4/10 s @ 10kpc

Earth

~400/year

More!! (BSM)

Neutrino oscillation properties

Neutrinos as a probe

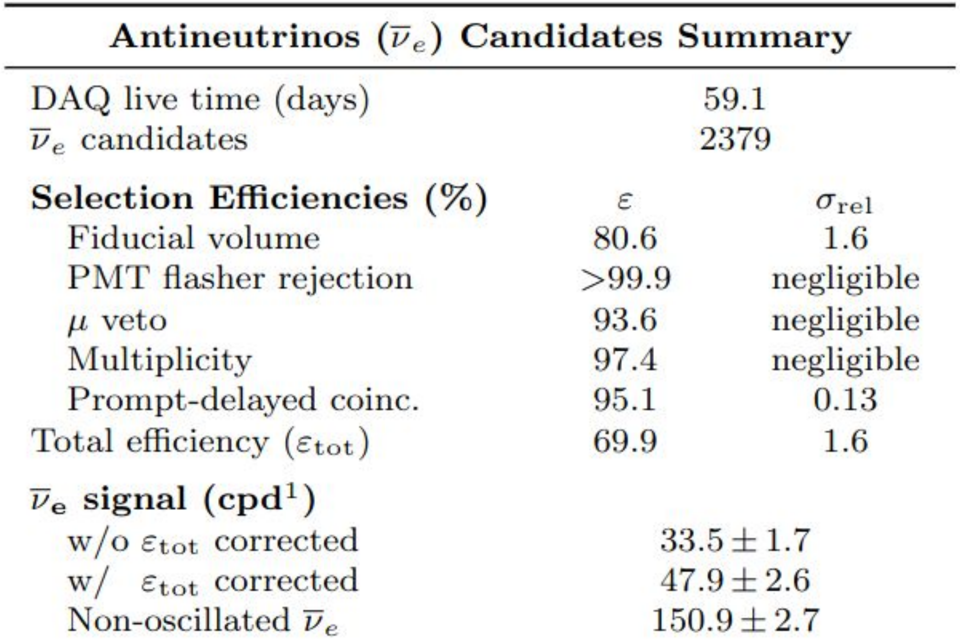
Summary

- **JUNO has successfully started to take data and produce physics results.**
- **A successful first campaign showing that the global measurement chain – detection, reconstruction, calibration, selection, robust statistical procedure – is already in a good shape**
  - *Proven by measuring solar parameters better than the World average, as expected.*
  - *A remarkable achievement for a detector of this scale, after only a few months of commissioning and physics operation.*

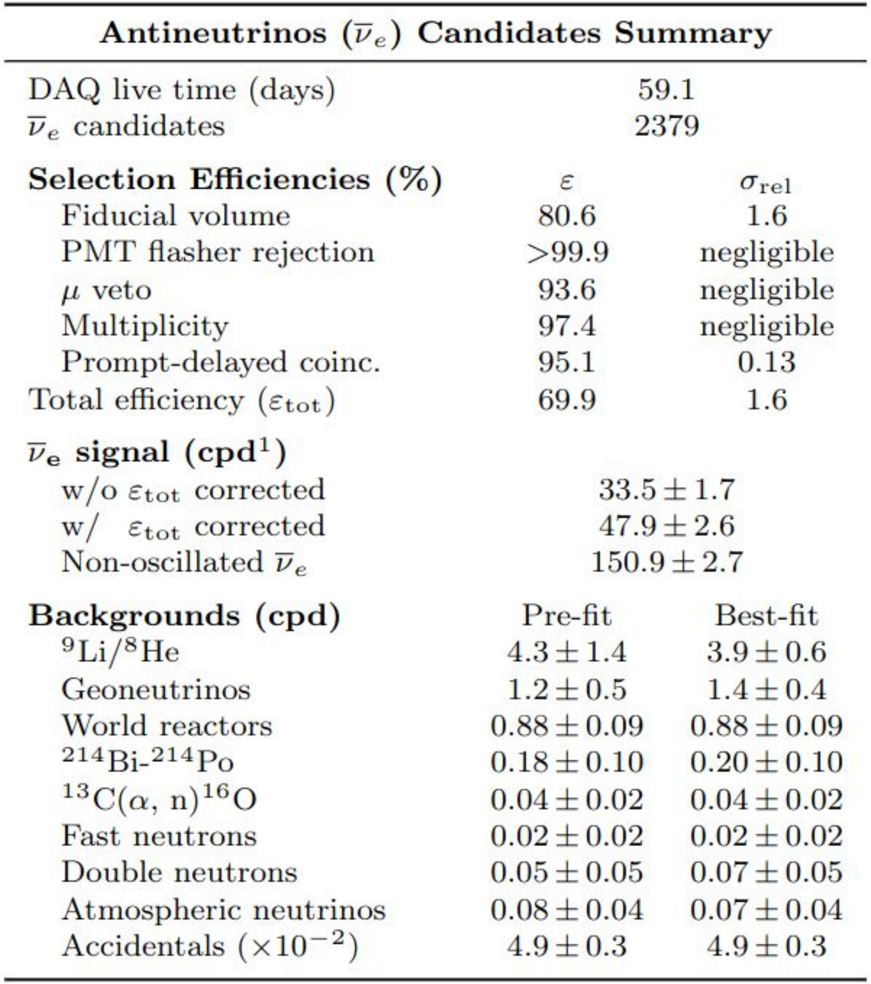
	PDG 2025	JUNO (59.1 days)
Δm^2_{21}	2.5%	1.6%
$sin^2\theta_{12}$	3.9%	2.8%

- **We're now sharpening our tools to be ready for precision physics (Δm^2_{31} , NMO)**
- **Stay tuned !**
  - *Short term: summer conferences*
  - *Longer term: JUNO's wide physics program.*

Backup slides



Antineutrinos ($\overline{\nu}_e$) Candidates Summary		
DAQ live time (days)	59.1	
$\overline{\nu}_e$ candidates	2379	
Selection Efficiencies (%)	ε	$\sigma_{\rm rel}$
Fiducial volume	80.6	1.6
PMT flasher rejection	>99.9	negligible
μ veto	93.6	negligible
Multiplicity	97.4	negligible
Prompt-delayed coinc.	95.1	0.13
Total efficiency ($\varepsilon_{\rm tot}$)	69.9	1.6
$\overline{\nu}_{\rm e}$ signal (cpd[1])		
w/o $\varepsilon_{\rm tot}$ corrected	33.5 ± 1.7	
w/ $\varepsilon_{\rm tot}$ corrected	47.9 ± 2.6	
Non-oscillated $\overline{\nu}_e$	150.9 ± 2.7	



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Backgrounds (cpd)	Pre-fit	Best-fit
^{9}Li/^{8}He	4.3 ± 1.4	3.9 ± 0.6
Geoneutrinos	1.2 ± 0.5	1.4 ± 0.4
World reactors	0.88 ± 0.09	0.88 ± 0.09
^{214}Bi-^{214}Po	0.18 ± 0.10	0.20 ± 0.10
^{13}C(α, n)^{16}O	0.04 ± 0.02	0.04 ± 0.02
Fast neutrons	0.02 ± 0.02	0.02 ± 0.02
Double neutrons	0.05 ± 0.05	0.07 ± 0.05
Atmospheric neutrinos	0.08 ± 0.04	0.07 ± 0.04
Accidentals ($\times 10^{-2}$)	4.9 ± 0.3	4.9 ± 0.3

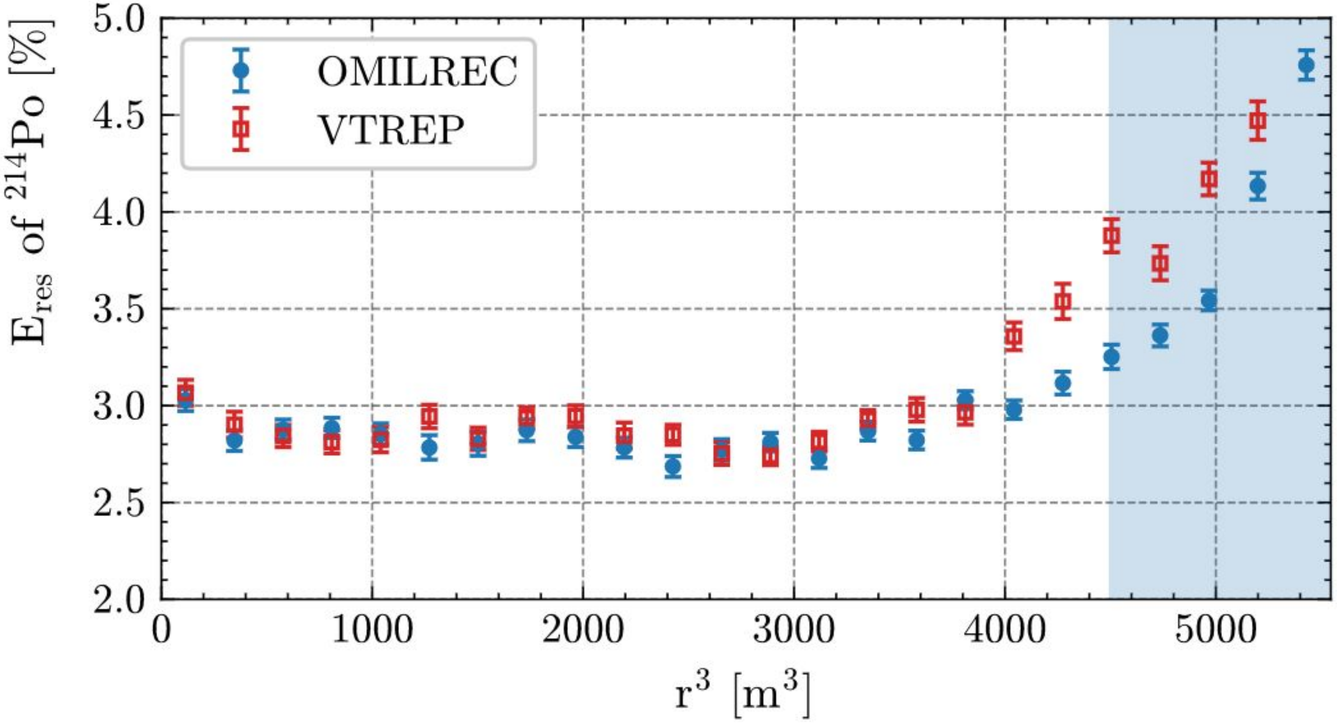
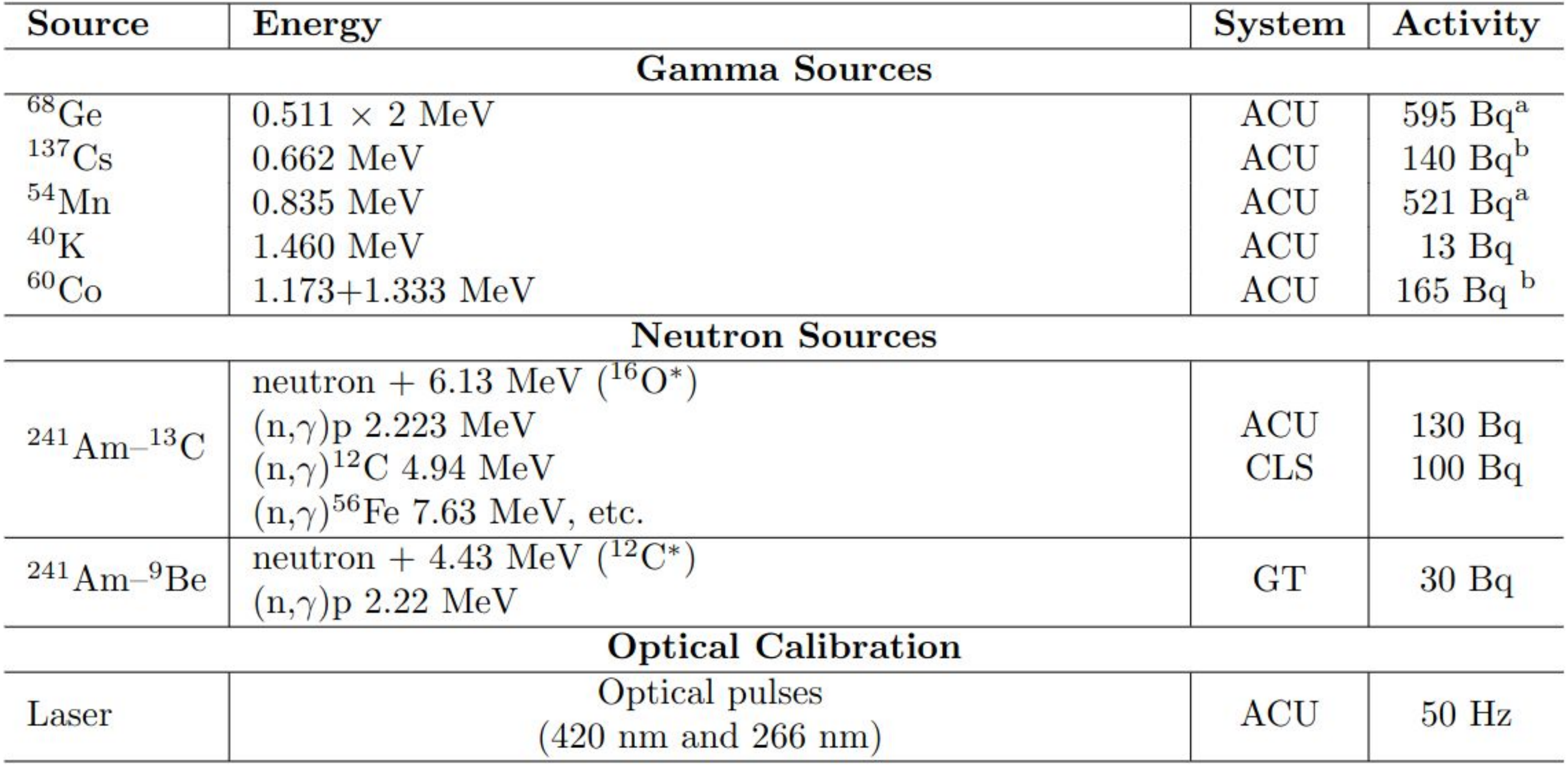


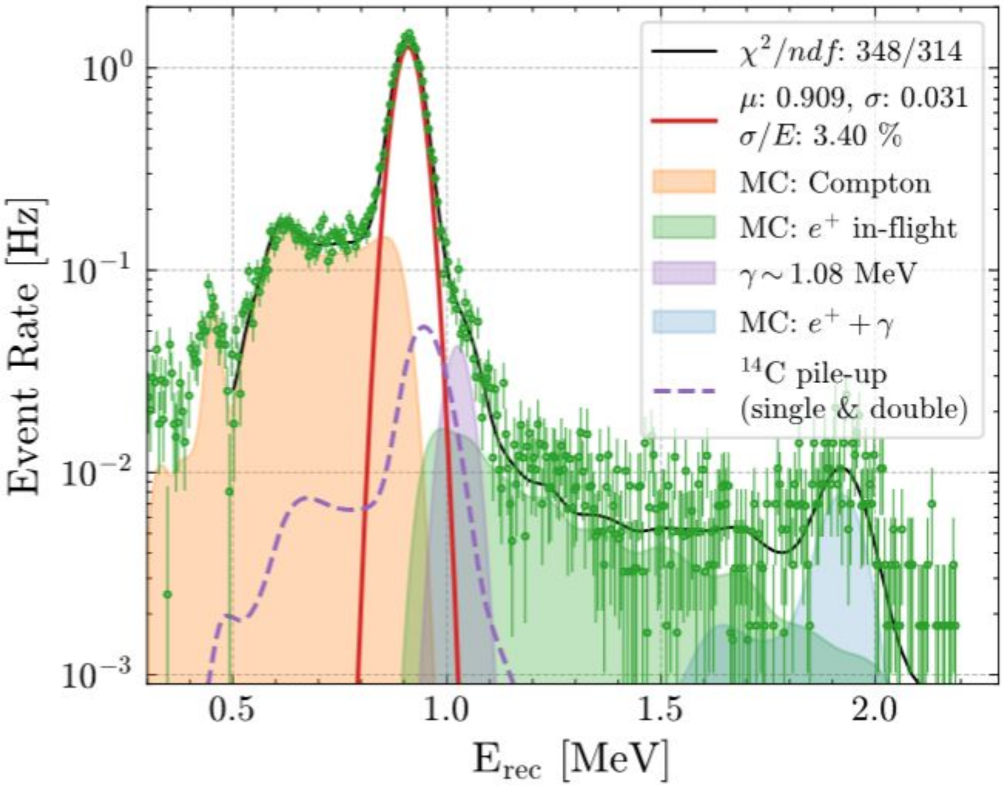
Figure 19: Energy resolution versus R^3 evaluated using ^{214}Po with a reconstructed energy of about 0.93 MeV.

Calibration sources

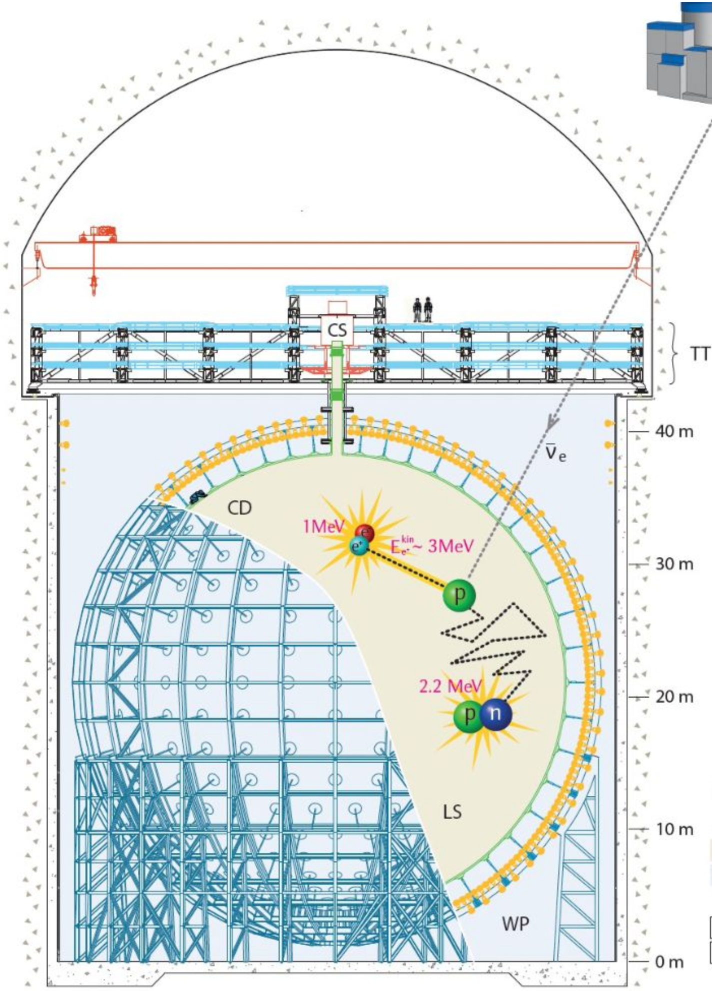


Source	Energy	System	Activity
Gamma Sources			
^{68}Ge	0.511 × 2 MeV	ACU	595 Bq[a]
^{137}Cs	0.662 MeV	ACU	140 Bq[b]
^{54}Mn	0.835 MeV	ACU	521 Bq[a]
^{40}K	1.460 MeV	ACU	13 Bq
^{60}Co	1.173+1.333 MeV	ACU	165 Bq [b]
Neutron Sources			
^{241}Am–^{13}C	neutron + 6.13 MeV (^{16}O*) (n,γ)p 2.223 MeV (n,γ)^{12}C 4.94 MeV (n,γ)^{56}Fe 7.63 MeV, etc.	ACU CLS	130 Bq 100 Bq
^{241}Am–^{9}Be	neutron + 4.43 MeV (^{12}C*) (n,γ)p 2.22 MeV	GT	30 Bq
Optical Calibration			
Laser	Optical pulses (420 nm and 266 nm)	ACU	50 Hz

68-Ge peak


χ^2/ndf: 348/314
μ: 0.909, σ: 0.031
σ/E: 3.40 %
MC: Compton
MC: e^+ in-flight
$\gamma\sim$1.08 MeV
MC: $e^+ + \gamma$
^{14}C pile-up
(single & double)
Event Rate [Hz]
10^0
10^{-1}
10^{-2}
10^{-3}
0.5
1.0
1.5
2.0
E_{rec} [MeV]

X-section


CS
TT
40 m
30 m
20 m
10 m
0 m
$\bar{\nu}_e$
CD
1MeV
e^+
e^-
$E_{e^+}^{kin}$ ~ 3MeV
p
2.2 MeV
p
n
LS
WP