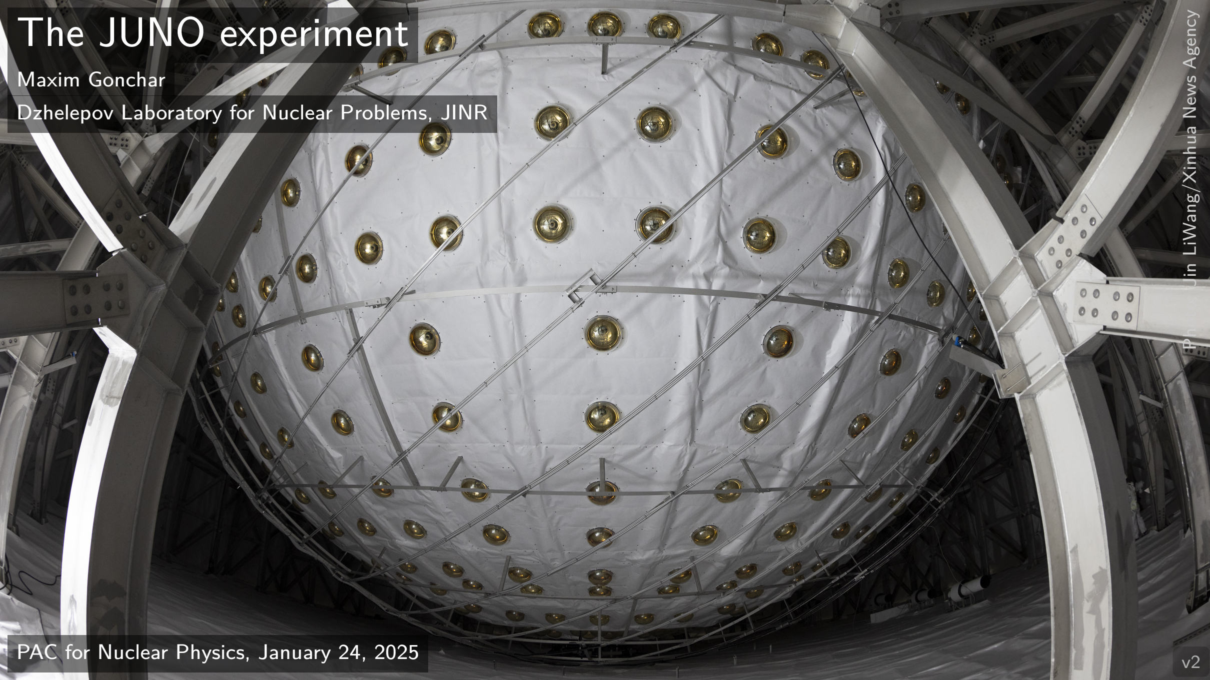
The JUNO experiment

Maxim Gonchar

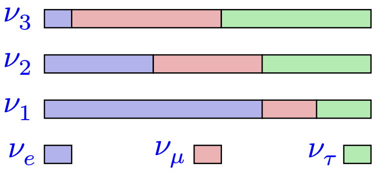
Dzhelepov Laboratory for Nuclear Problems, JINR



PAC for Nuclear Physics, January 24, 2025

v2

Mandatory slide I: Neutrino mixing



Weak and mass eigenstates differ:

$$|\nu_\alpha\rangle = \sum U^*_{\alpha i} |\nu_i\rangle$$

α — flavor states

i — mass states

Mixing parametrized by:

- three mixing angles: $\theta_{12}, \theta_{23}, \theta_{13}$,
- CP-violating phase: δ_{CP}.

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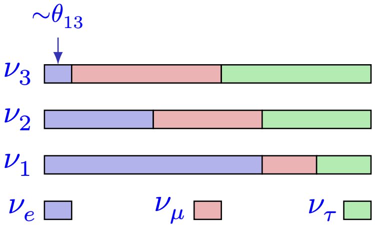

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Pontecorvo-Maki-Nakagawa-Sakata (PMNS) mixing matrix:

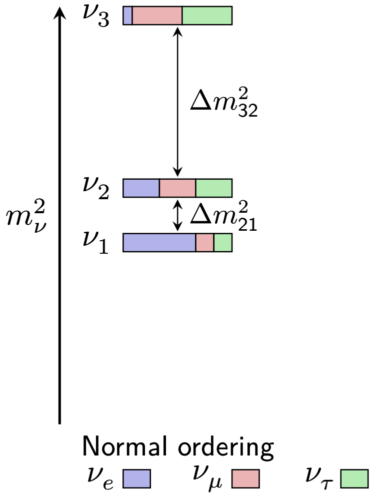
✓ $\theta_{23} \approx 45^\circ$ established through atmospheric and accelerator experiments: possibly maximal.

✓ $\theta_{12} \approx 34^\circ$ established through solar experiments and KamLAND: large, but not maximal.

✓ $\theta_{13} \approx 8^\circ$ established by reactor: **Daya Bay**, RENO, Double Chooz.

- δ_{CP} unknown: NOvA and T2K.

Mandatory slide II: Neutrino mass and ordering



Mass splitting: oscillations PDG2020

- $\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5}$ eV^2
- $\left|\Delta m^2_{32}\right|_{\text{NO}} = (2.453 \pm 0.033) \times 10^{-3}$ eV^2
- $\left|\Delta m^2_{32}\right| / \Delta m^2_{21} \sim 31$

Numbers updated: 2022.06.10

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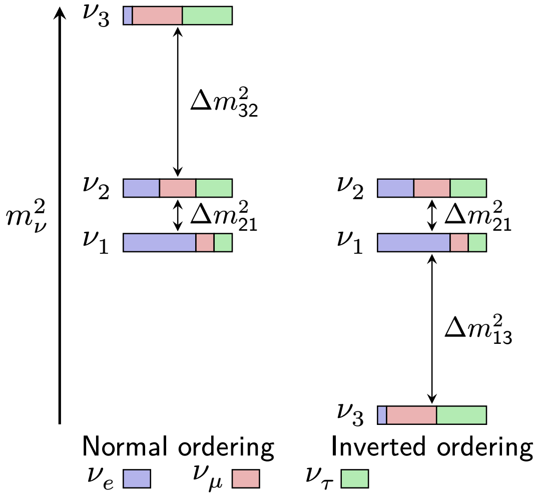

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- Mass ordering: is ν_1 lighter than ν_3?

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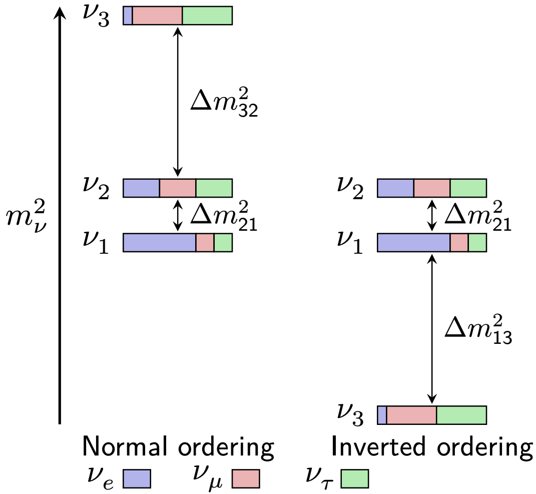

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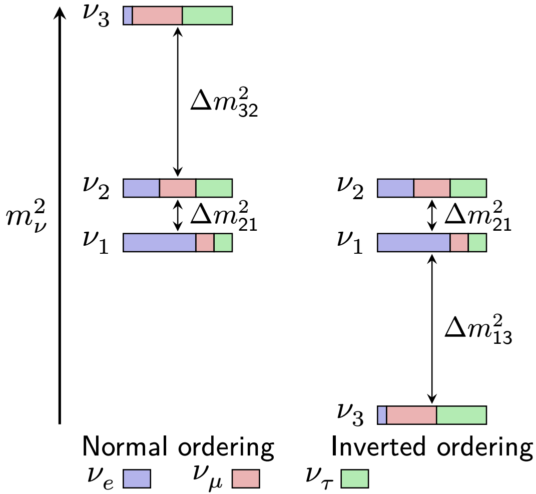
Neutrino mass

- Mass limits, meV:

$m_2, m_3 >$	0	oscillations	
$\sum m_i \gtrsim$	60	oscillations	
$\sum m_i \lesssim$	120	cosmology	Planck
$m_\beta <$	900	direct	KATRIN [2105.08533]
$\langle m_{\beta\beta} \rangle <$	156	$0\nu\beta\beta$	Kamland-ZEN
$m_{\text{light}} \lesssim$	500	$0\nu\beta\beta$	[2203.02139]

Numbers updated: 2022.06.10

Mandatory slide II: Neutrino mass and ordering



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Neutrino mass

- Mas

$m_2,$

$\sum$

$\sum$

$$m_\beta = \sqrt{\sum_i m_i^2 \left|U_{ei}\right|^2}$$

$$m_{\beta\beta} = \left|\sum_i m_i U_{ei}^2\right|$$

m_β<900	direct	KATRIN [2105.08533]
$\langle m_{\beta\beta}\rangle$<156	$0\nu\beta\beta$	Kamland-ZEN
$m_{\text{light}}\lesssim$500		[2203.02139]

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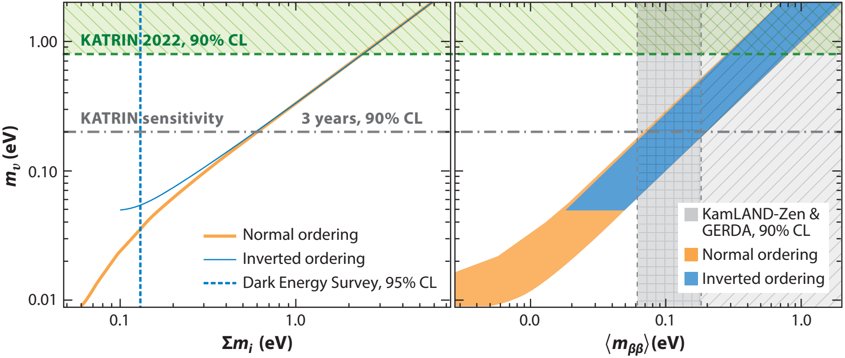
Neutrino Mass Ordering (NMO): why bother?

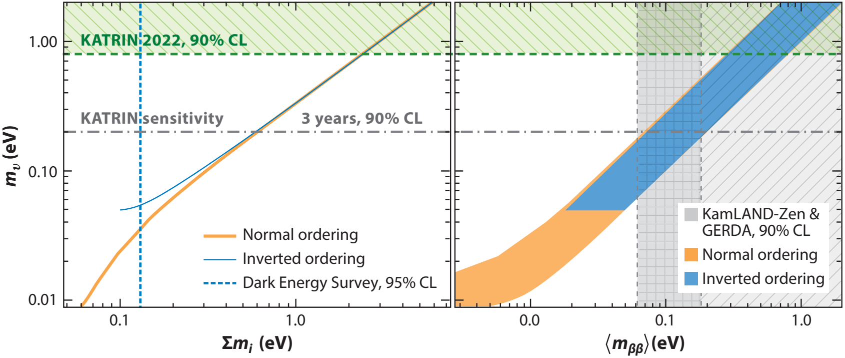
- Absolute neutrino mass scale
  neutrino masses m_1, m_2 and m_3 may be measured only via effective masses and Δm^2_{21}, Δm^2_{31} (including NMO).
- Neutrinoless double decay
  effective masses $\langle m_{\beta\beta}\rangle$ depend on NMO.



Lokhov et al. Ann.Rev.Nucl.Part.Sci. 72 (2022)

Neutrino Mass Ordering (NMO): why bother?

- Absolute neutrino mass scale
- Neutrinoless double decay
- Core collapse Supernovae:
  - Neutrinos contribute to the collapse process: collective neutrino oscillations
  - NMO especially important at pre-collapse stage ∼day before
  - Nucleosynthesis



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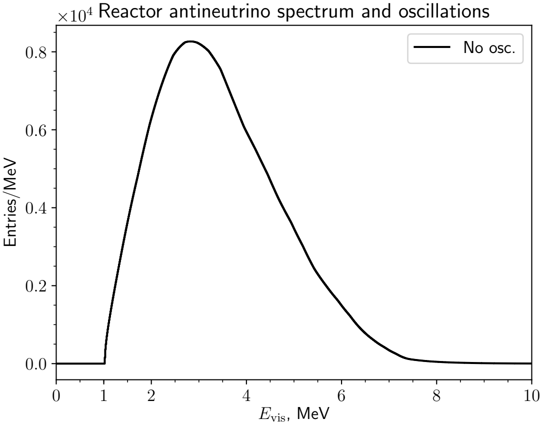
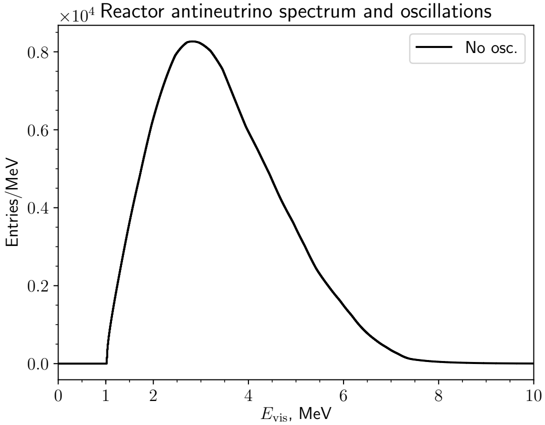


$E_{\text{vis}} \approx E_\nu - 0.78\,\text{MeV}$

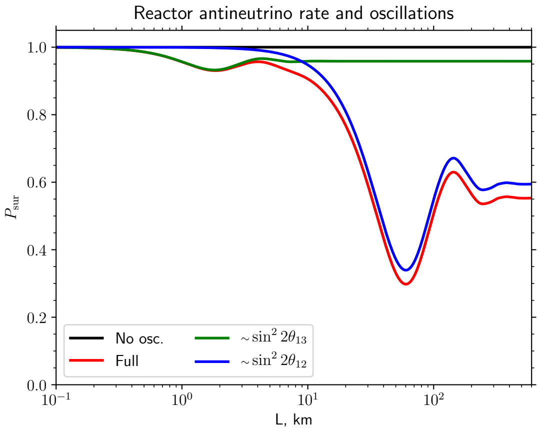


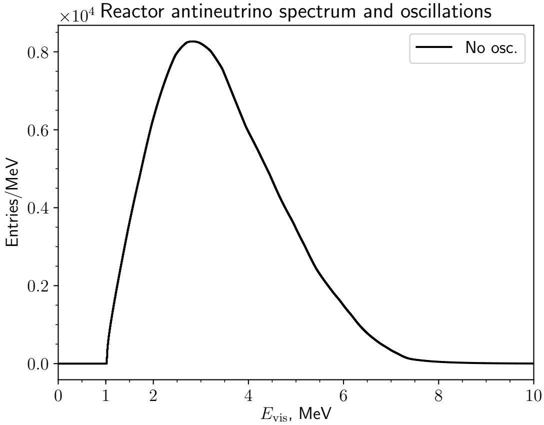
$$1 - P_{\overline{\nu}_e \to \overline{\nu}_e} = \sin^2 2\theta_{13} \left(\sin^2\theta_{12} \sin^2 \frac{\Delta m^2_{32} L}{4E} + \cos^2\theta_{12} \sin^2 \frac{\Delta m^2_{31} L}{4E} \right) + \sin^2 2\theta_{12} \cos^4\theta_{13} \sin^2 \frac{\Delta m^2_{21} L}{4E}$$

~~δ_{CP}, θ_{23}~~

$E_{\mathrm{vis}} \approx E_\nu - 0.78$ MeV

Integrated with reactor $\overline{\nu}_e$ spectrum





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~~$\delta_{\rm CP}$, θ_{23}~~

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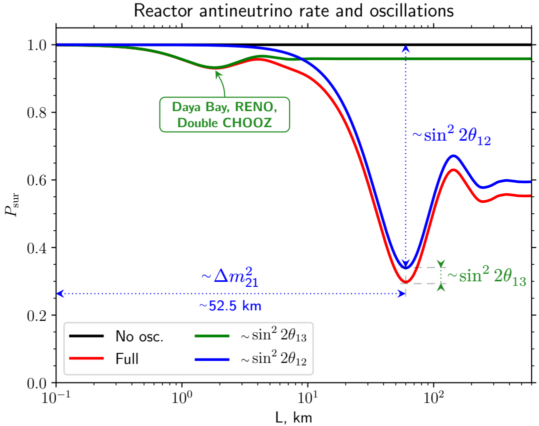

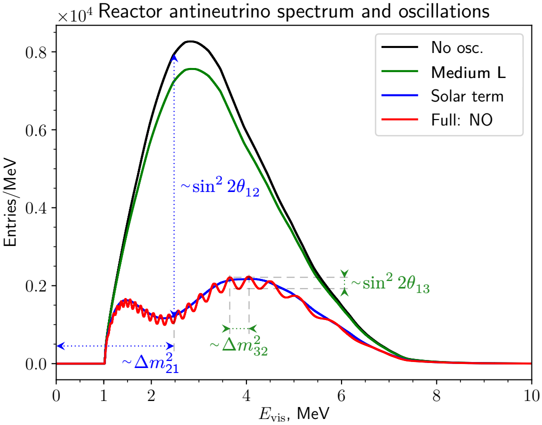

deficit value — minimum location — minimum location

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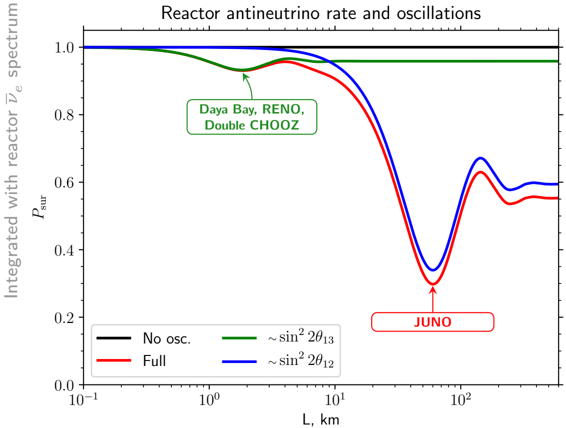

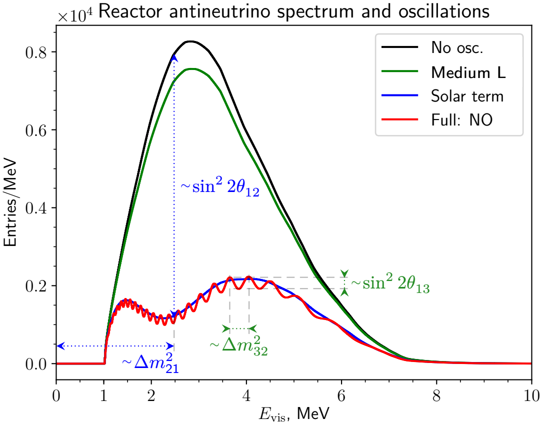

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~~$\delta_{\mathrm{CP}}, \theta_{23}$~~

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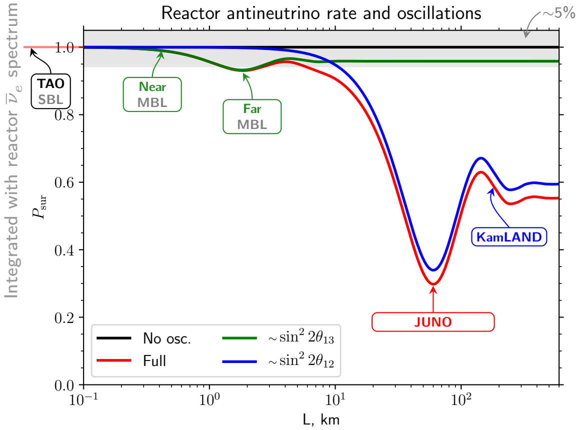
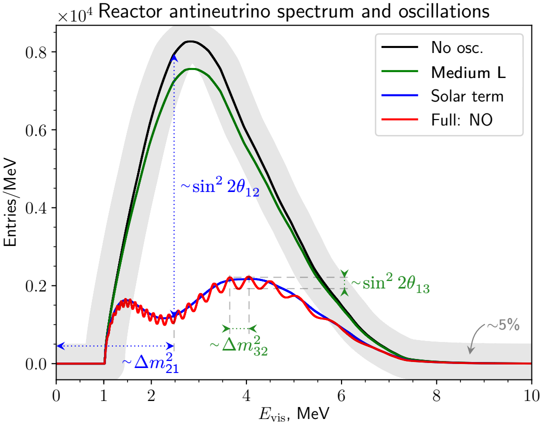


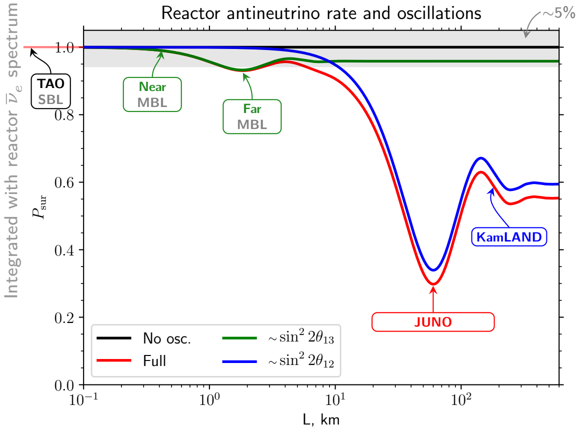


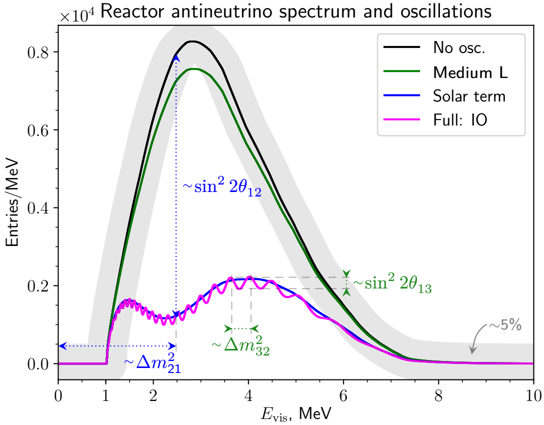
Challenges

- Unreliable antineutrino spectrum model: ↪ measure reference spectrum
- Energy resolution of the detector $\sigma < 3\%$ at 1 MeV: ↪ resolve the peaks
- Energy scale of the detector (uncertainty $< 1\%$): ↪ ensure the peak positions

$E_{\text{vis}} \approx E_\nu - 0.78\,\text{MeV}$

SBL/MBL — short/medium baseline





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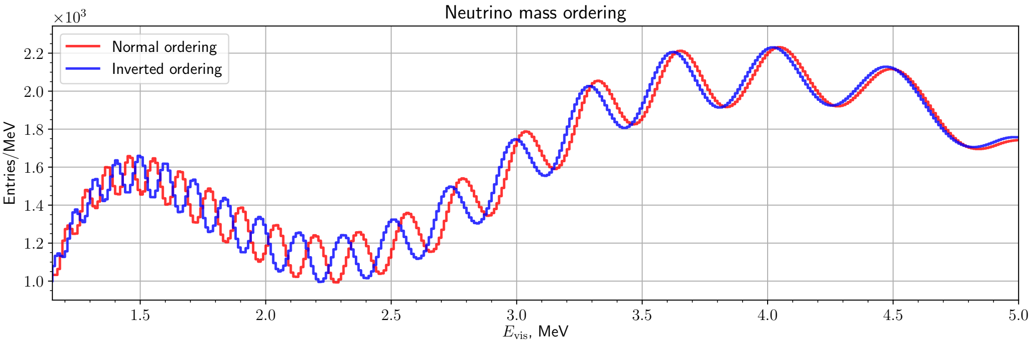
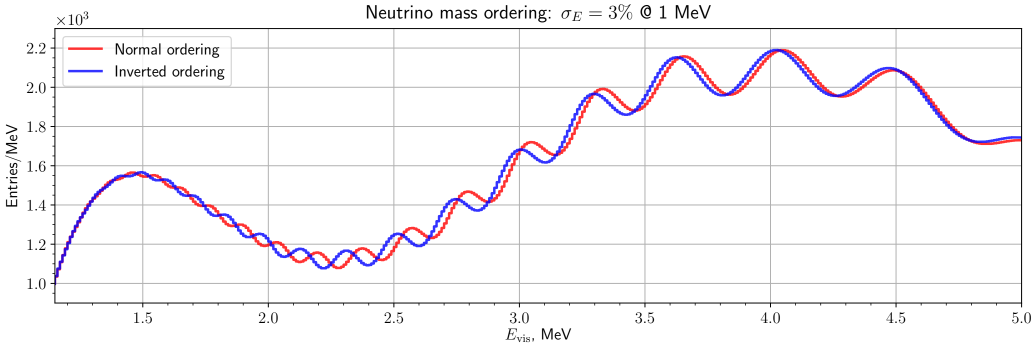
SBL/MBL — short/medium baseline

(plot: same Δm^2_{ee})



- Change of oscillation period with ordering $\ll$ energy resolution
- Cumulative effect across most of the energy range

$E_{\text{vis}} \approx E_\nu - 0.78\,\text{MeV}$



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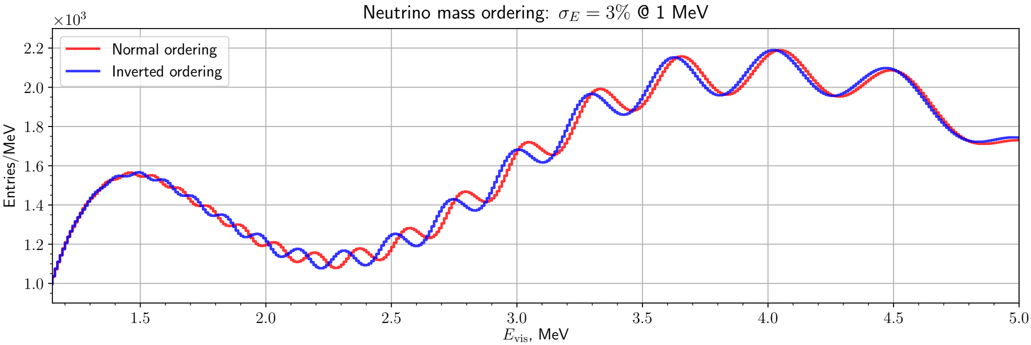
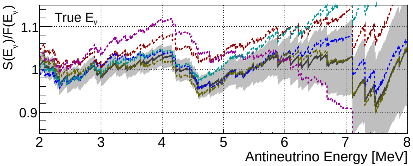


- Change of oscillation period with ordering $\ll$ energy resolution
- Cumulative effect across most of the energy range
- Possible impact: fine structure in reactor $\overline{\nu}_e$ spectrum

need a reference measurement!

$E_{\text{vis}} \approx E_\nu - 0.78\,\text{MeV}$



(plot: same Δm^2_{ee})

Dwyer&Langford [1407.1281], PRL114

Experimental setup

JUNO and TAO location

- JUNO — Jiangmen Underground Neutrino Observatory
- TAO — Taishan Antineutrino Observatory

	Yangjian (YJ)	Taishan (TS)
Thermal power, GW	2.9×6	4.6×2
Total, GW	26.6	
	signal	

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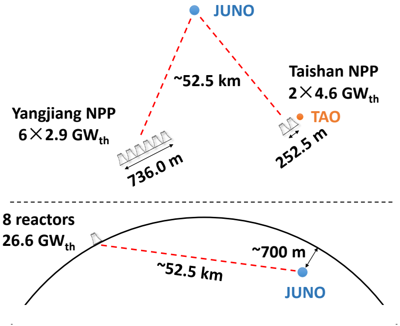

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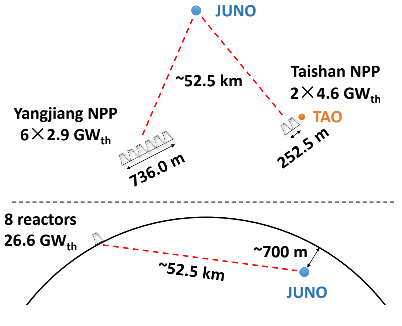
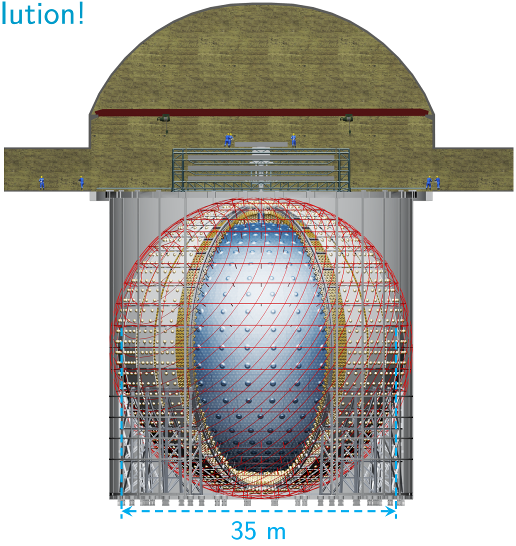


	Yangjian (YJ)	Taishan (TS)	Daya Bay/Ling Ao	World
Thermal power, GW	2.9×6	4.6×2	2.9×6	
Total, GW	26.6		17.4	...
	signal		background	

JUNO DETECTOR

More light → better resolution!
More statistics!



JUNO DETECTOR

More light → better resolution!
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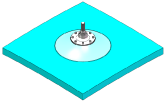
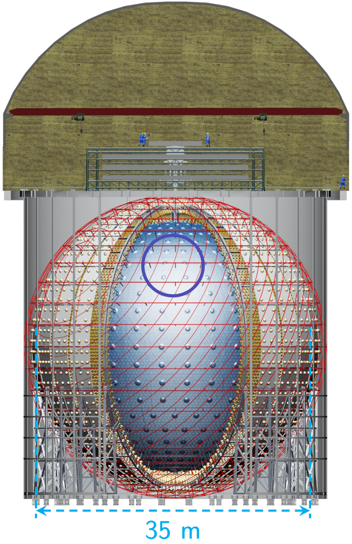
LS — Liquid Scintillator
LY — Light Yield

Target

- 20 kt LS
- Optimized LY
- Acrylic sphere





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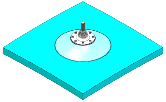

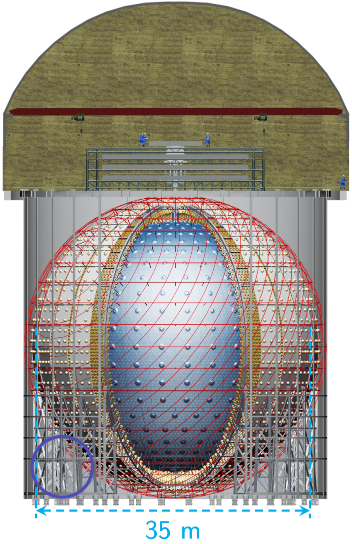

Support

- Stainless steel structure

JUNO DETECTOR

More light → better resolution!
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LS — Liquid Scintillator
LY — Light Yield
PMT — PhotoMultiplier Tube
QE — Quantum Efficiency
p.e. — photo-electron

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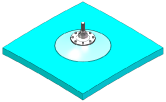

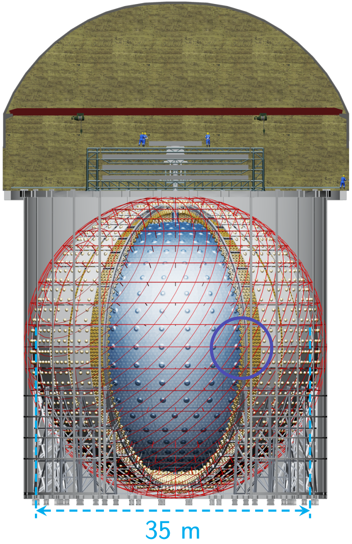

Support

- Stainless steel structure

Light collection

- 18k 20” PMTs
- High QE: 29.6%
- 1665 p.e./MeV
- +26k 3” PMTs

JUNO DETECTOR

More light → better resolution!
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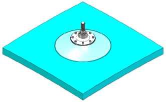
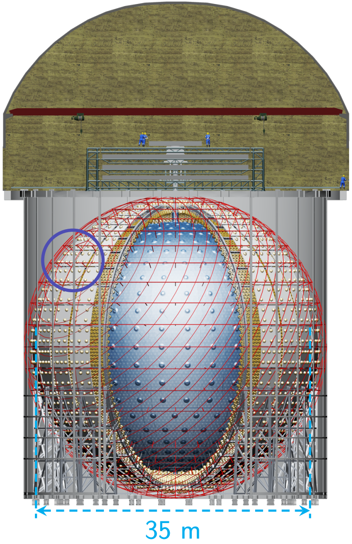


Coils

- Compensation of the Earth Magnetic Field

Support

- Stainless steel structure



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Light collection

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JUNO detector

More light → better resolution!
More statistics!

Target

- 20 kt LS
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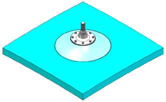
- Acrylic sphere



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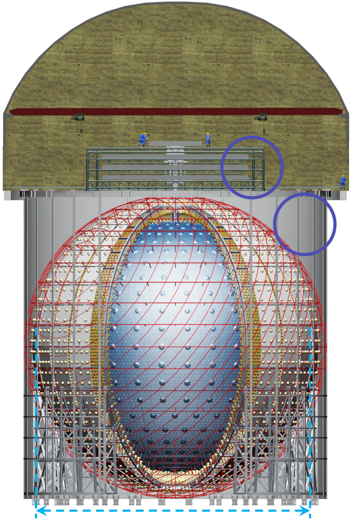


LS — Liquid Scintillator
LY — Light Yield
PMT — PhotoMultiplier Tube
QE — Quantum Efficiency
p.e. — photo-electron
PS — Plastic Scintillator

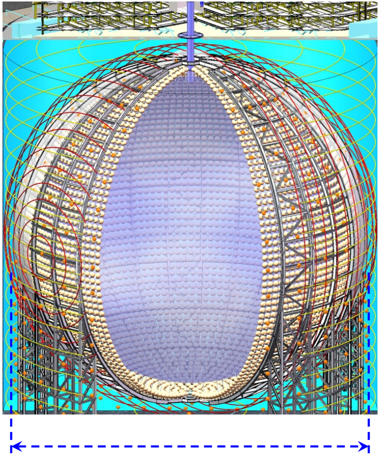
Muon veto

- Top Tracker: 3 layers PS
- Water pool

Light collection

- 18k 20” PMTs
- High QE: 29.6%
- 1665 p.e./MeV
- +26k 3” PMTs

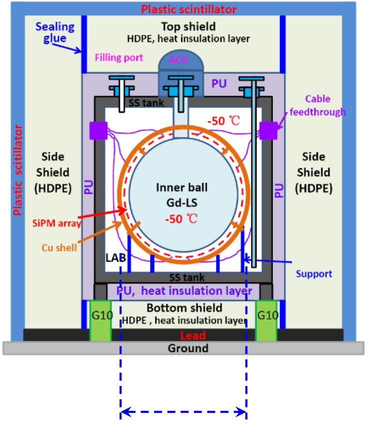
JUNO and TAO detectors



35 m / 20 kt LS

	JUNO
Attention	**Energy resolution $\sigma \searrow$**
Method	**Light collection $\nearrow$**
Scintillator	**LS**
PMTs	**18k 20"** **+26k 3"**
Coverage, %	**78**
Light col. p.e./MeV	**1665**
σ_E at 1 MeV, %	**2.9**
Thermal power, GW	**26.6**
Baseline	**52.5 km**
IBD/day	**47**

JUNO and TAO detectors

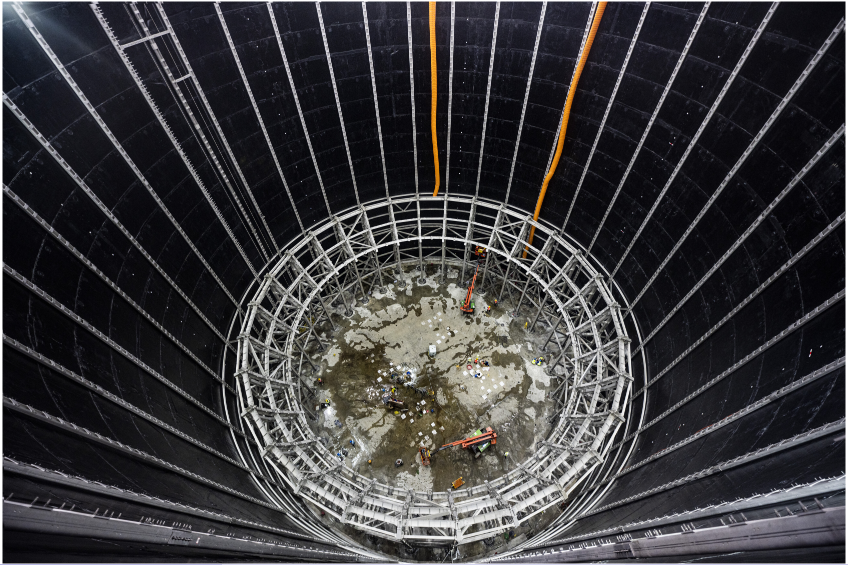


1.8 m / 2.8 t GdLS, 1 t in FV

	TAO	JUNO
Attention	**Energy resolution $\sigma \searrow$**	
Method	**Light collection $\nearrow$** **Dark noise $\searrow$**	
Scintillator	**GdLS @ -50°C**	LS
PMTs	**SiPM** **1.5M 5 mm**	18k 20" +26k 3"
Coverage, %	**94**	78
Light col. p.e./MeV	**4500**	1665
σ_E at 1 MeV, %	**2**	2.9
Thermal power, GW	**4.6**	26.6
Baseline	**44 m**	52.5 km
IBD/day	**1000**	47

Status

Central detector assembly



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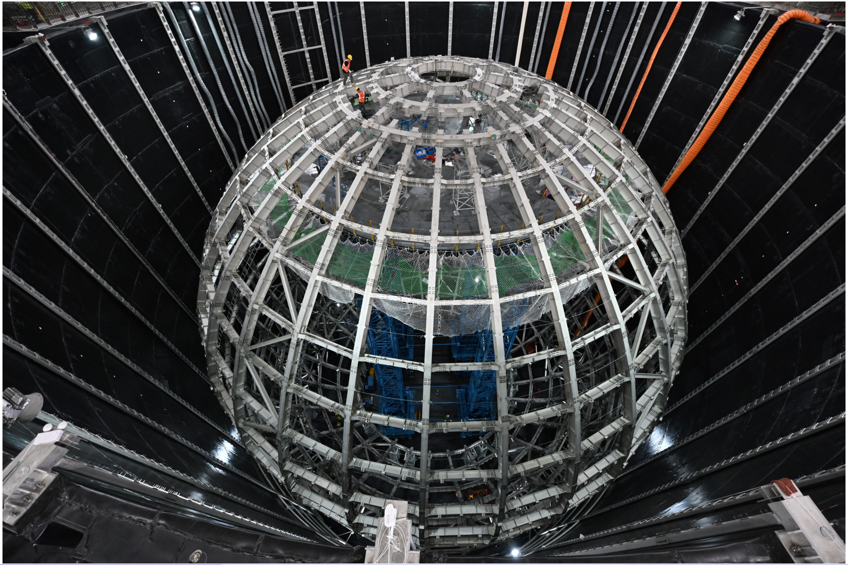

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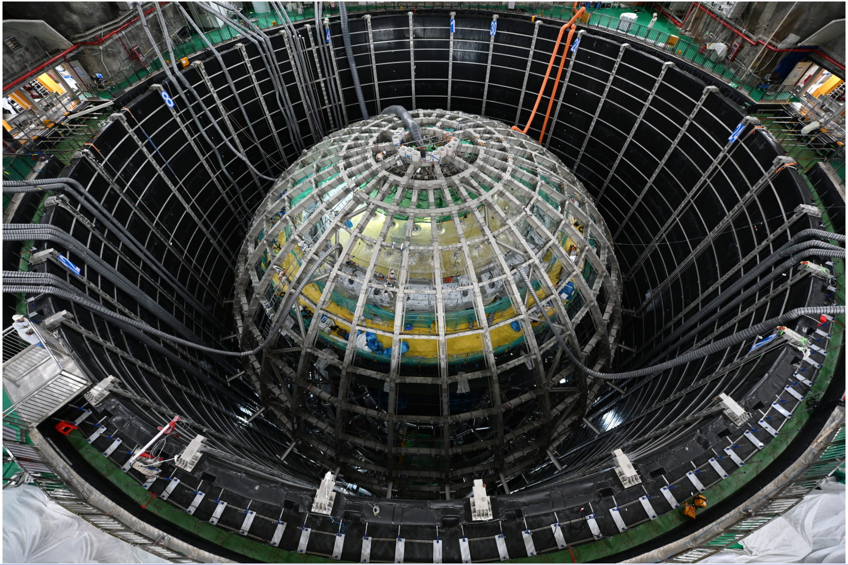

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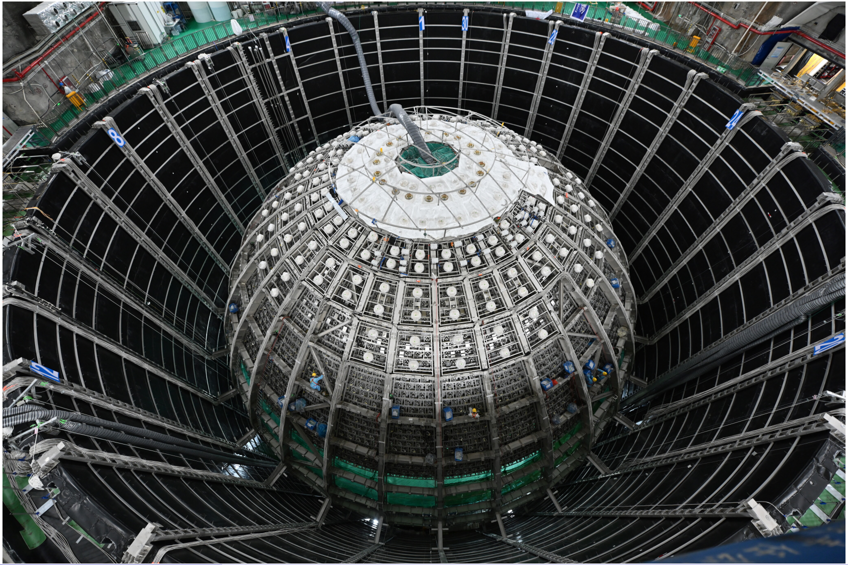

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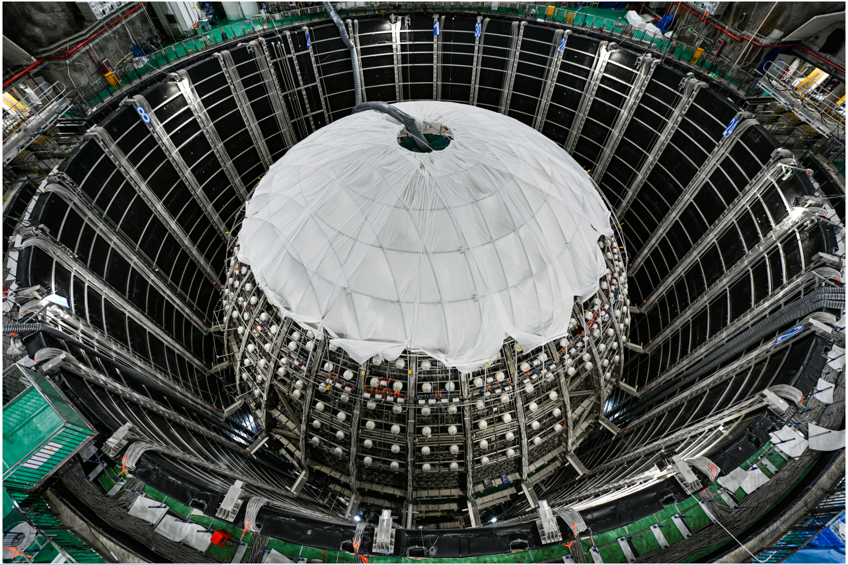

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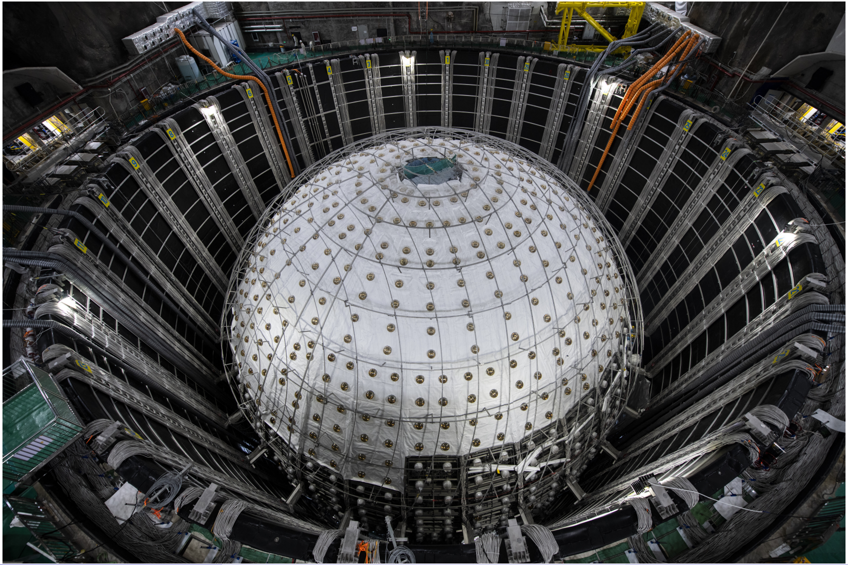

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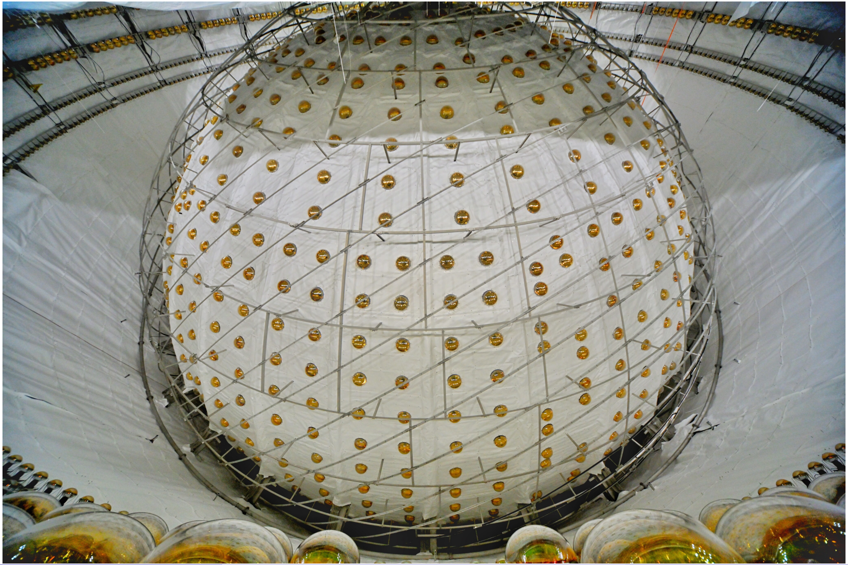

Central detector assembly

JUNO water pool and detector filling

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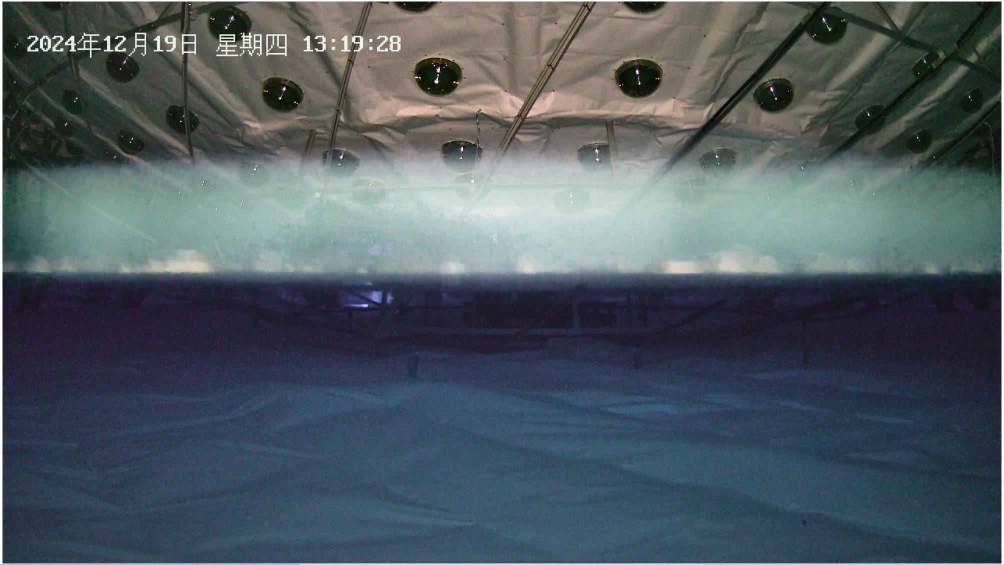

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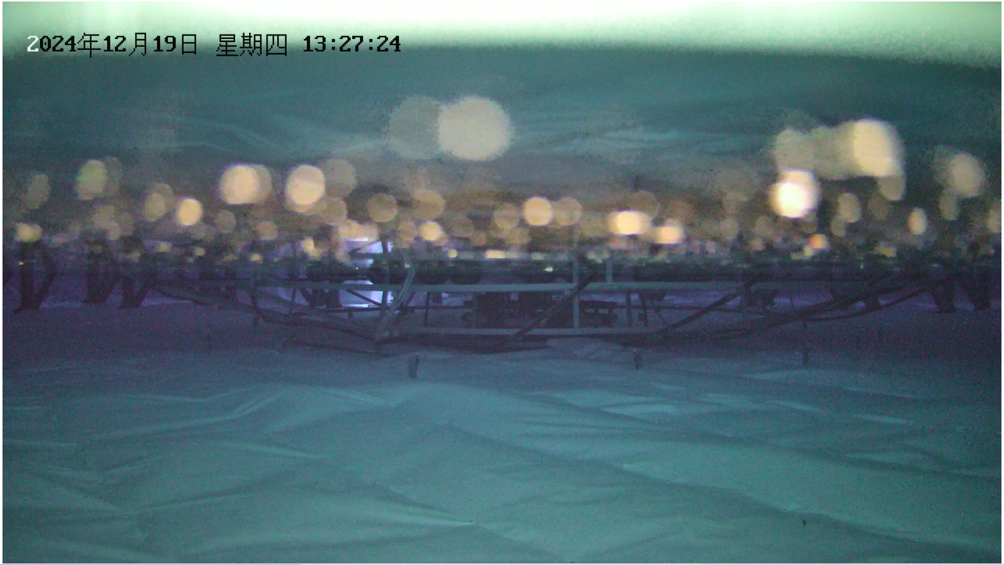

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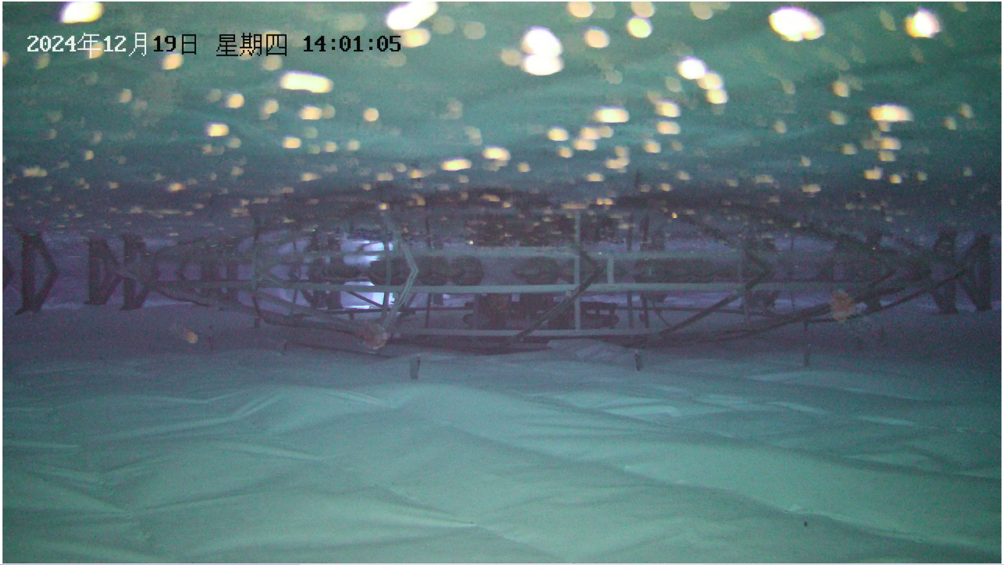

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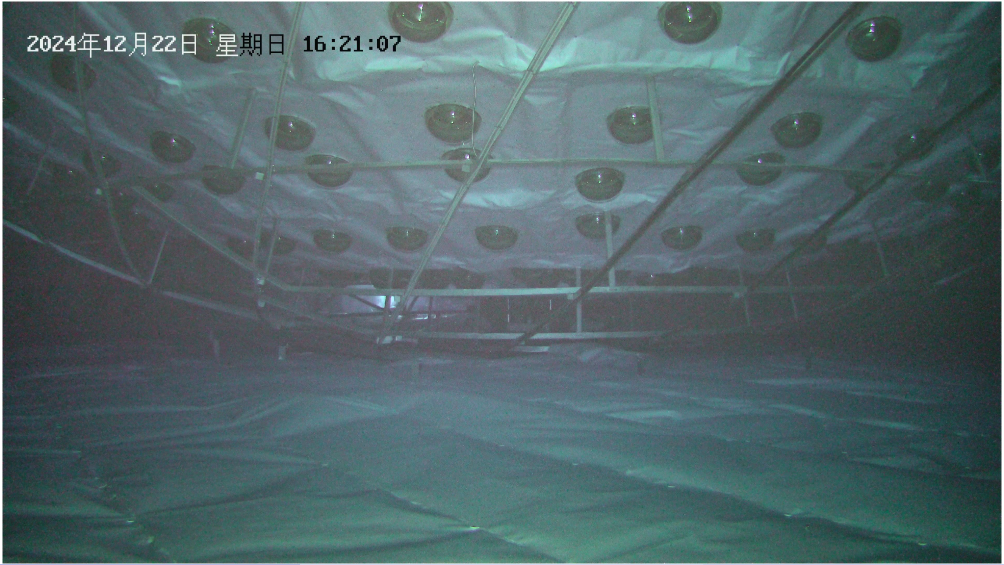

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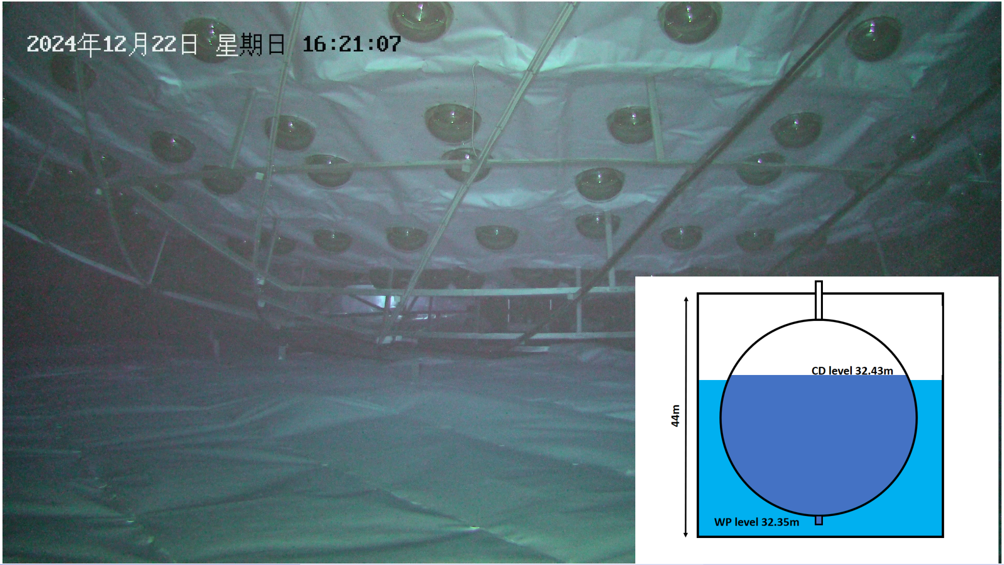
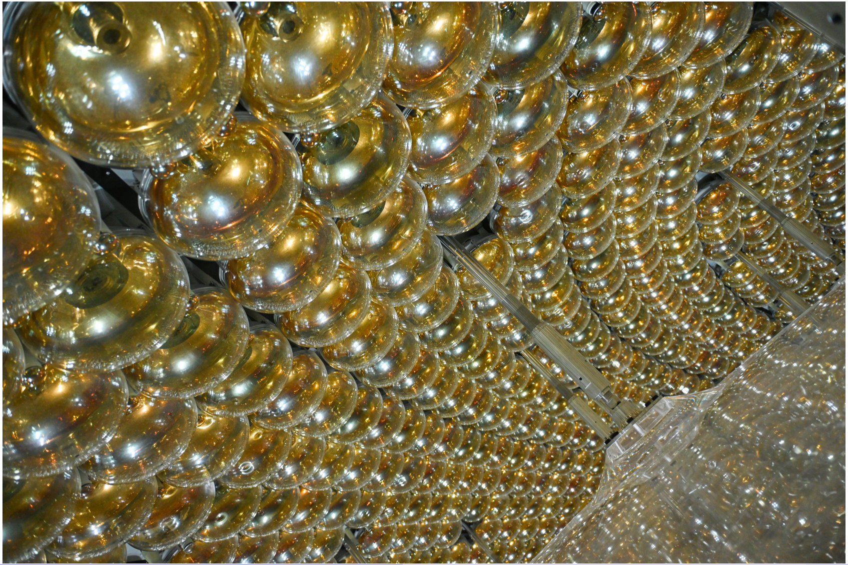


Photomultipliers and electronics



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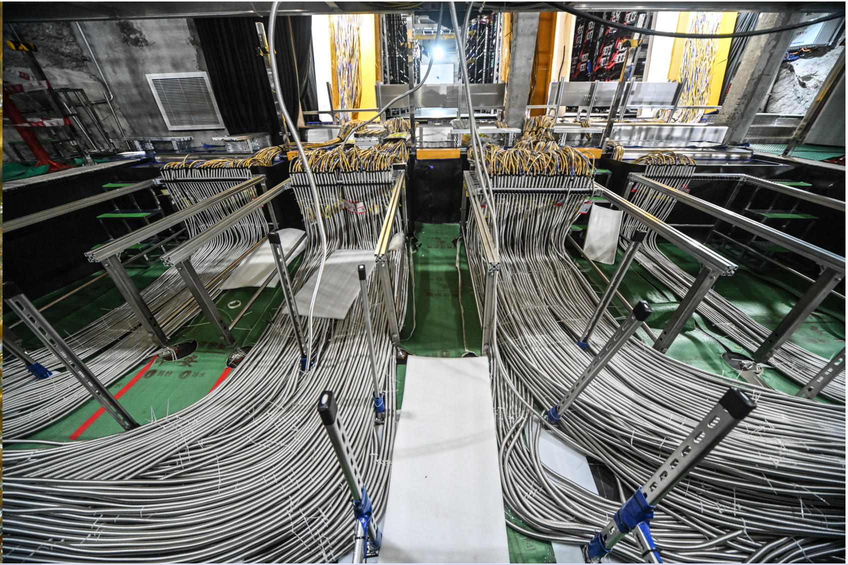

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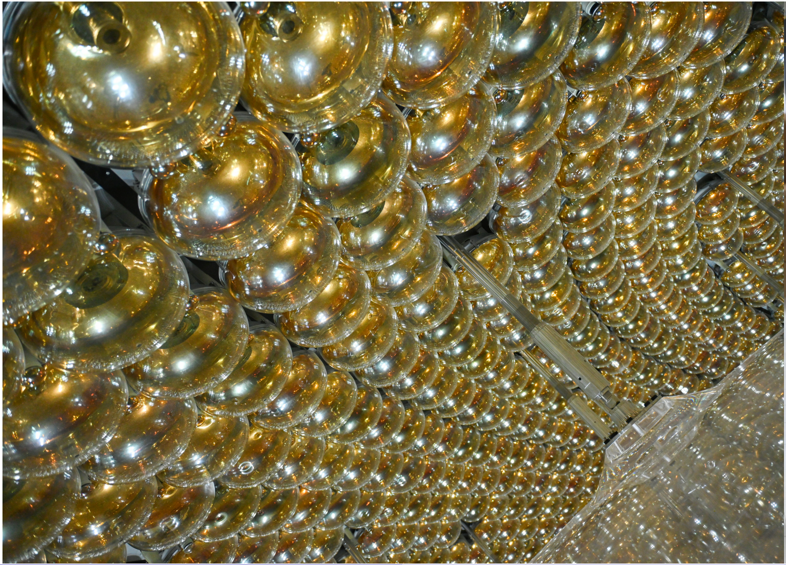
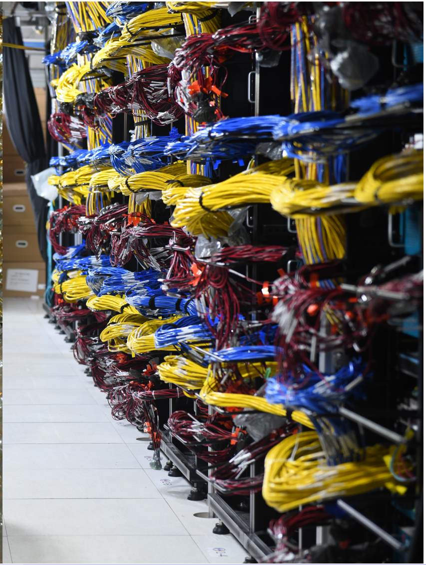
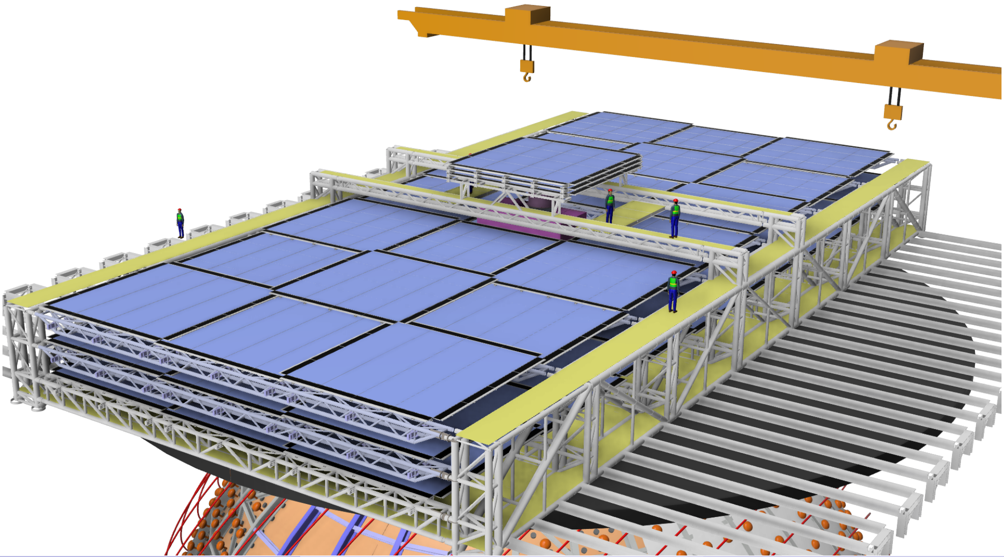




Top Tracker muon veto installation



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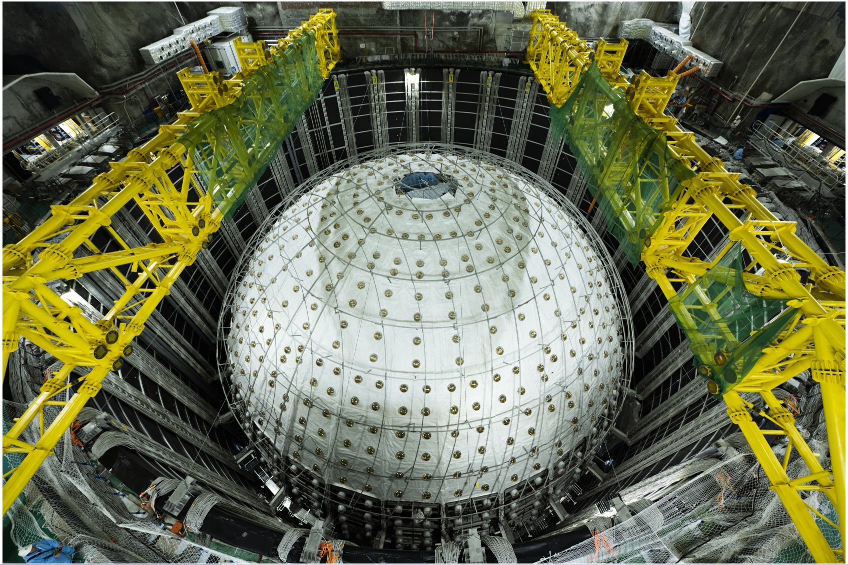

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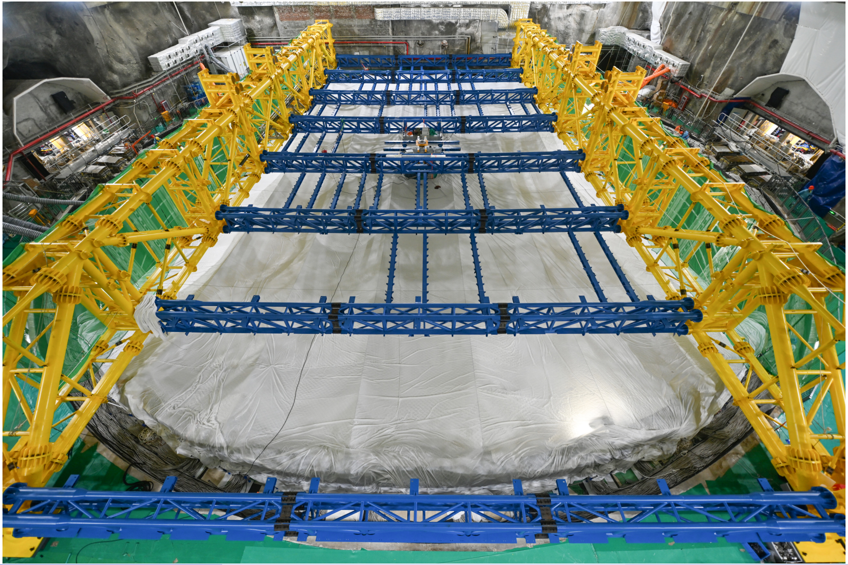

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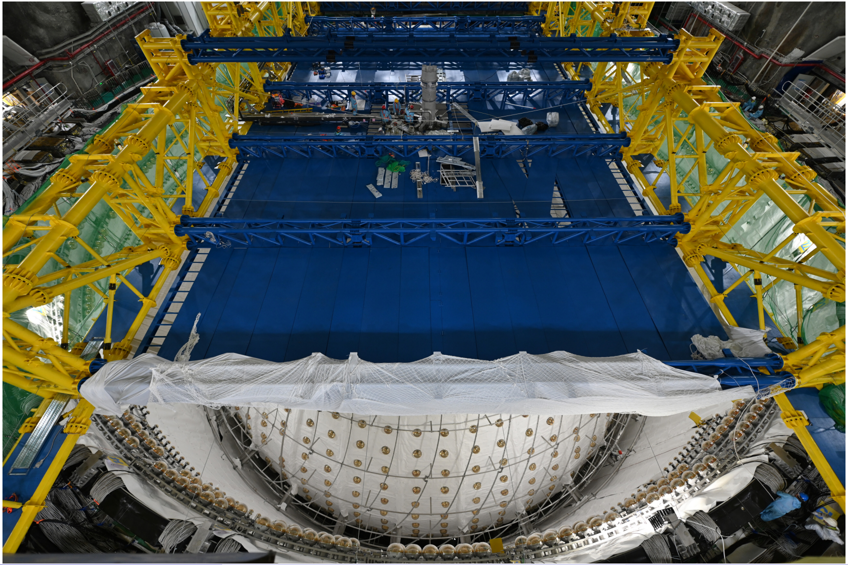

Top Tracker muon veto installation

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TAO construction

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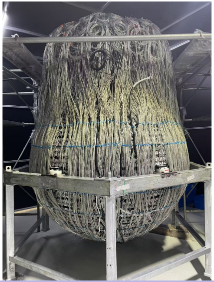

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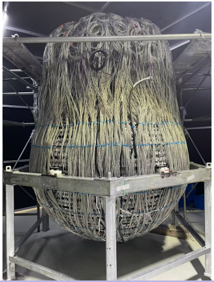
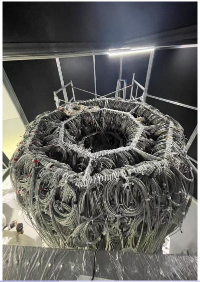

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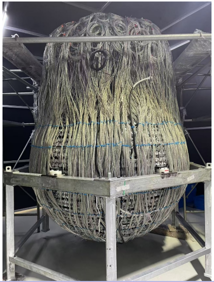
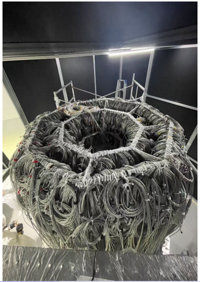
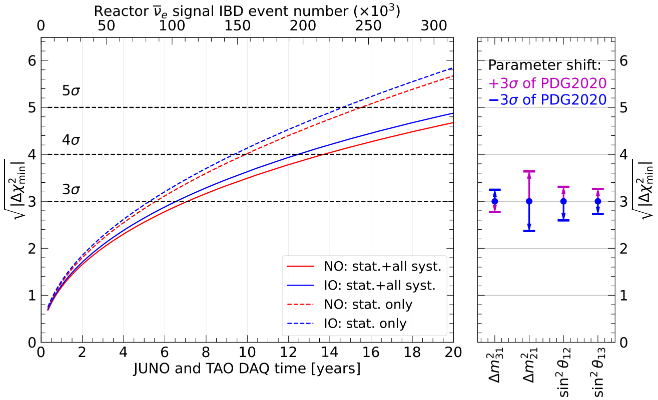




Physics of neutrino

Sensitivity to Neutrino Mass Ordering



Signal and background

- Inverse beta decay:
  $\overline{\nu}_e + p \to e^+ + n$
  ↪ double coincidence
- Signal: 47 $\overline{\nu}_e$/day, bkg 9%

✓ JUNO+TAO, 7.1 years×26.6 GW exposure: $\sim 3\sigma$

✓ +1% external constrain on Δm^2_{32}: $> 4\sigma$

✓ combined with accelerator/atmospheric experiment: $> 5\sigma$

↪ sensitivity boost due to tension for wrong ordering

JUNO NMO, CPC (2025) [2405.18008]
JUNO+accelerator [2008.11280]
JUNO+IceCube [1911.06745]

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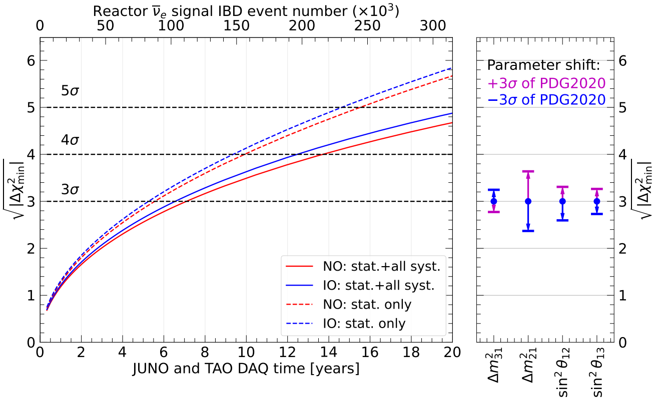

Impact of systematics:

	$\Delta\chi^2_{\rm min}$
Statistics	11.3
Stat.+Flux error	-0.6
Stat.+Backgrounds	-1.4
Stat.+Nonlinearity	-0.4
Stat.+Others	< -0.05
Total	9.0

JUNO Simulation Preliminary

- ✓ JUNO+TAO, 7.1 years×26.6 GW exposure: $\sim 3\sigma$
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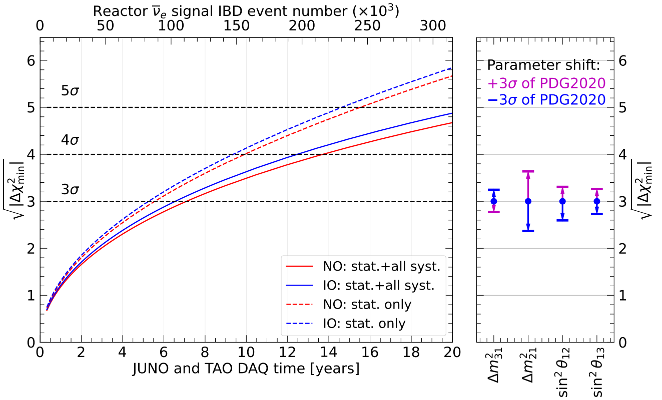

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- Combination of reactor and atmospheric channels within JUNO is investigated.

JUNO NMO, CPC (2025) [2405.18008]
JUNO+accelerator [2008.11280]
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JUNO and neutrino oscillation parameters

[2204.13249]

- Percent precision for $\Delta m^2_{21}/\Delta m^2_{31}$: 100 days
- Few permille level for $\Delta m^2_{21}/\Delta m^2_{31}/\sin^2 2\theta_{12}$: 6 years

✓ Order of magnitude improvement over existing constraints.

JUNO AND NEUTRINO OSCILLATION PARAMETERS

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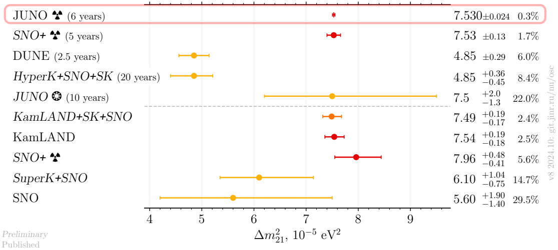

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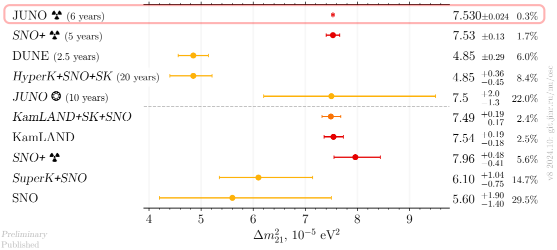

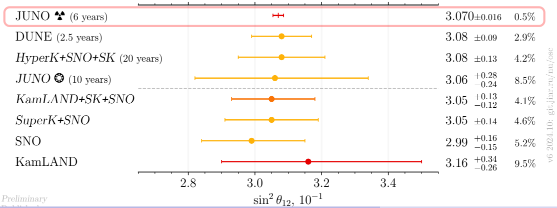

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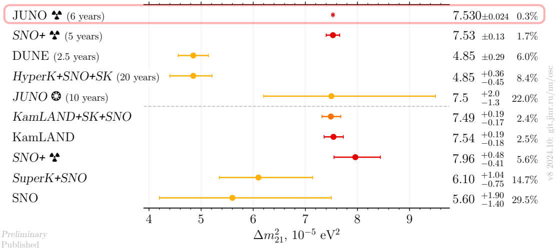

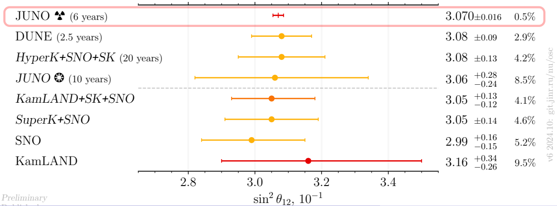

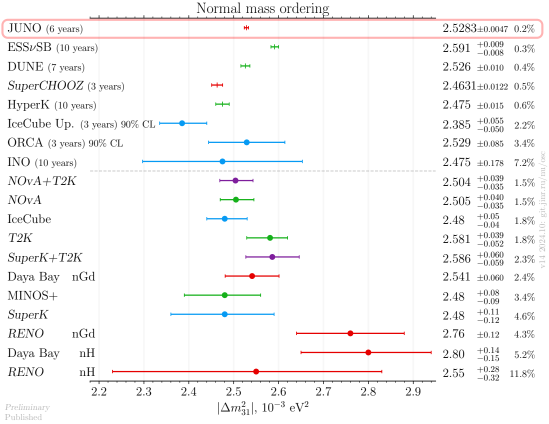

✓ Negligible correlation between measured parameters.

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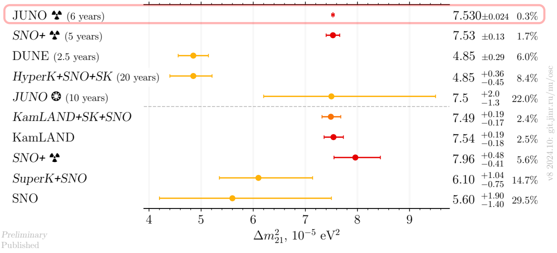

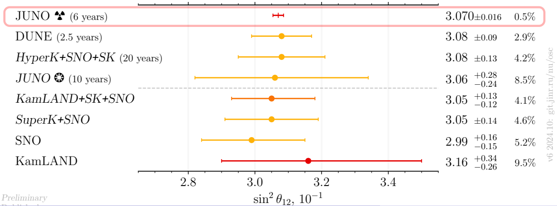

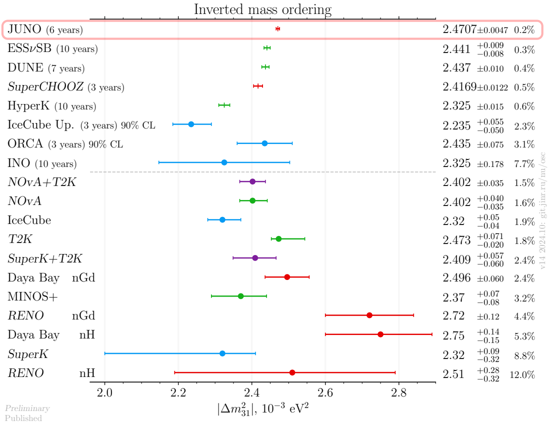

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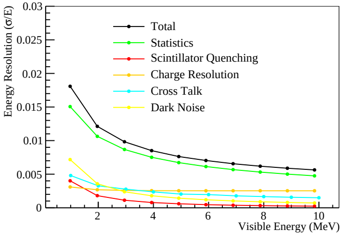
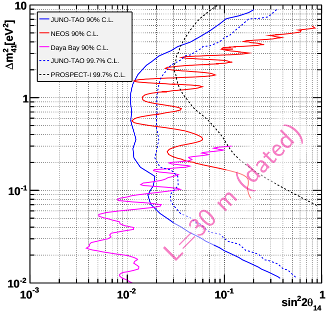
Sterile neutrino search with TAO





Primary goal

TAO CDR [2005.08745]

- Reference reactor $\overline{\nu}_e$ spectrum with $\sigma = 2\%$ at 1 MeV.

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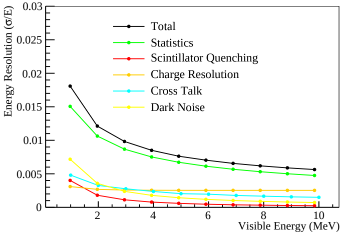

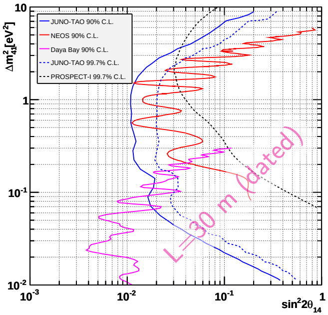

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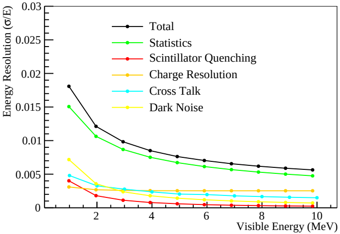
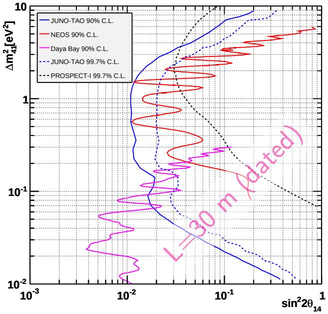
Oscillations: reactor at 44 m

- Relevant range: $0.03\,\text{eV}^2 \lesssim \Delta m^2_{41} \lesssim 3\,\text{eV}^2$
- ∼large L counterbalanced with high energy resolution

Sterile neutrino search with TAO





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- Inverse beta decay with nGd tag
- Expected rate: $\sim$1000 $\overline{\nu}_e$/day

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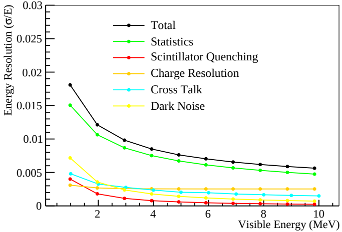

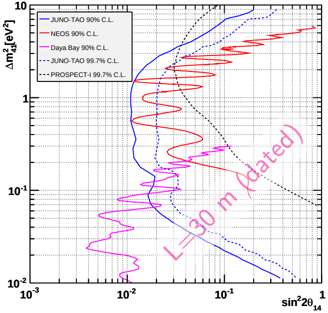

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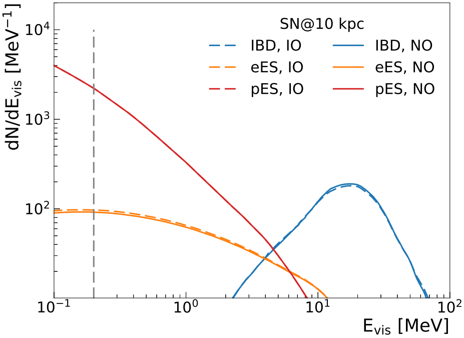
Data and analysis

- Events, finely binned vs energy
- Simultaneous fit: TAO's 4 virtual subdetectors

Physics with neutrino

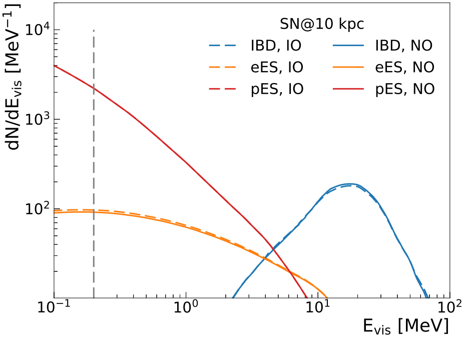
Core collapse SuperNova explosion



- Expect a few SuperNova explosions per century
- $\sim 10^4$ events in 10 s

[2104.02565] [2309.07109]

Core collapse SuperNova explosion



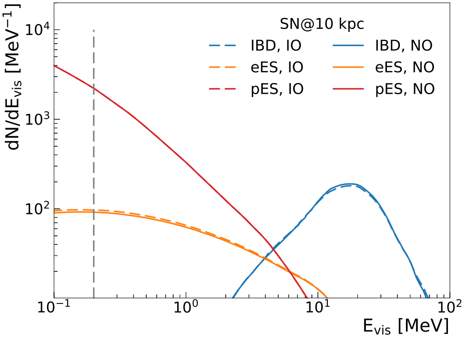
- Expect a few SuperNova explosions per century
- $\sim 10^4$ events in 10 s

Detection

- Dedicated trigger: 100 keV threshold
- Expected statistics at 10 kpc:
  - $2000 - 5000$ IBD
  - 2000 ES off proton
  - 300 ES off electron
  - 300 ν^{12}C NC
  - 200 ν^{12}C CC
- Expected pre-SuperNova statistics at 0.2 kpc:
  - $200 - 1200$ IBD
- Negligible background

[2104.02565] [2309.07109]

Core collapse SuperNova explosion



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Detection

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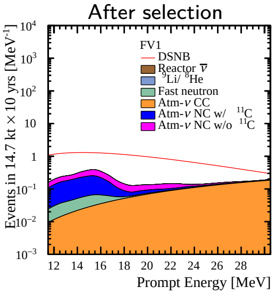
Goals

- Measure: flavor content, time evolution, flux, energy spectrum
- Study: stellar parameters, SN physics, late stage stellar evolution
- Constrain: [1412.7418]
  $m_\nu < (0.83 \pm 0.24)$ eV @90% CL @10 kpc
- Multi-messenger trigger

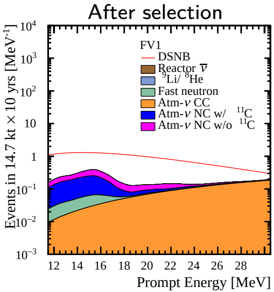
[2104.02565] [2309.07109]

Diffuse SuperNova neutrino background



[2205.08830]

Diffuse SuperNova neutrino background



DSNB

- Integrated signal of all the SuperNova explosions in the universe
- Not yet observed

Detection

- Signal: inverse beta decay
- Expected rate: 2–4 $\overline{\nu}_e$/year
- Energies: E>12 MeV, above reactor IBD

[2205.08830]

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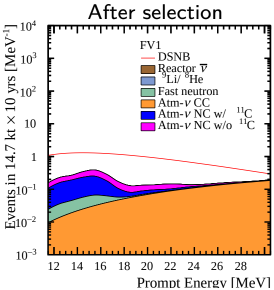

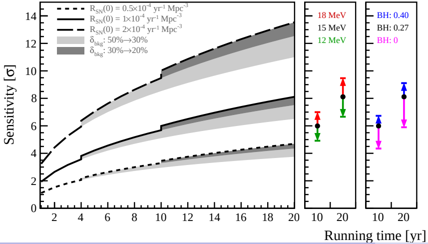

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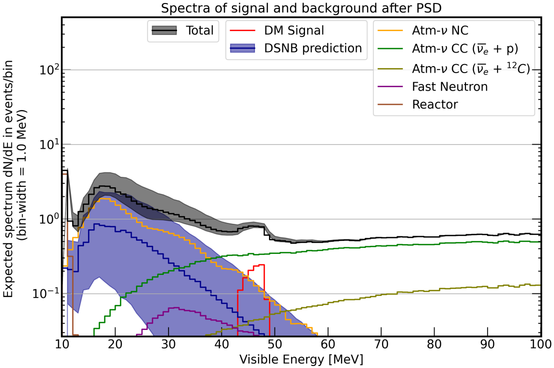
Discovery potential

- 5σ in 10 years
- 3σ in 3 years

[2205.08830]

MeV scale dark matter

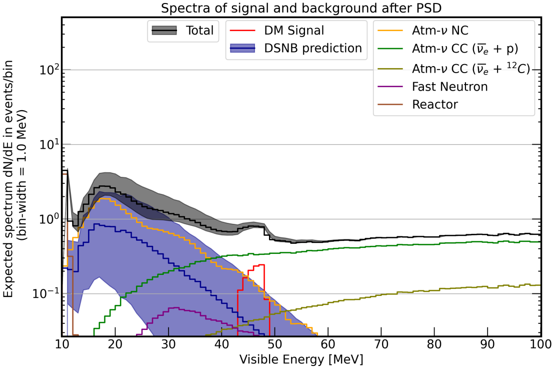


Source

- Dark matter annihilation to $\nu_e + \overline{\nu}_e$ in Milky Way.
- Masses: 15 MeV to 100 MeV.

JCAP 09 [2306.09567]

MeV scale dark matter



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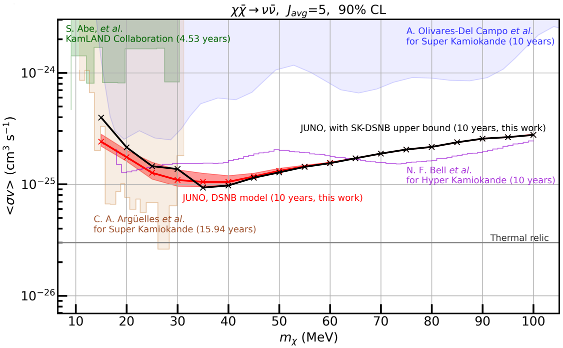
Data

- Inverse beta decay with E> that of $\overline{\nu}_e$.
- Major backgrounds: atmospheric $\overline{\nu}_e$ and atmospheric ν via NC, DSNB, fast neutrons.
- Use PSD to suppress backgrounds.

JCAP 09 [2306.09567]

MeV scale dark matter



Source

- Dark matter annihilation to $\nu_e + \overline{\nu}_e$ in Milky Way.
- Masses: 15 MeV to 100 MeV.

Data

- Inverse beta decay with E> that of $\overline{\nu}_e$.
- Major backgrounds: atmospheric $\overline{\nu}_e$ and atmospheric ν via NC, DSNB, fast neutrons.
- Use PSD to suppress backgrounds.

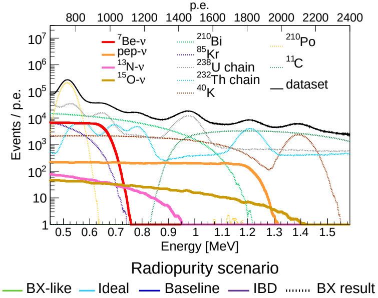
Sensitivity

- Competitive limits in 10 years.

JCAP 09 [2306.09567]

Intermediate energy solar neutrinos: ^{7}Be, pep, CNO

[2303.03910]



Detection

- Signal: ν_e elastic scattering off e^-
- Expected rate:
  - ^{7}Be ~ 130 ES/day
  - pep ~ 17 ES/day
  - CNO ~ 16 ES/day
- Limiting factors: LS purity, cosmic ray related background
- Baseline ^{238}U/^{232}Th contamination: 10^{-16} g/g

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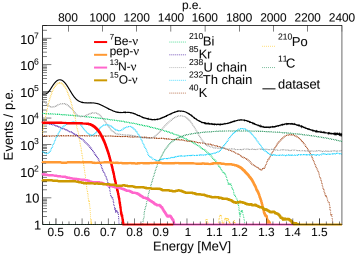
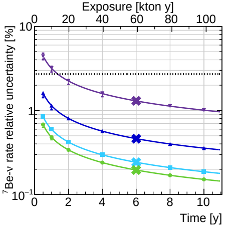


Radiopurity scenario

BX-like — Ideal — Baseline — IBD — BX result



[2303.03910]

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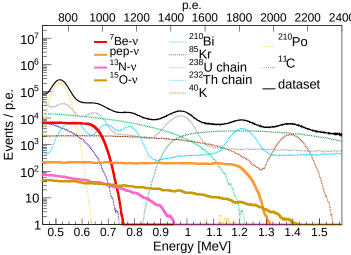
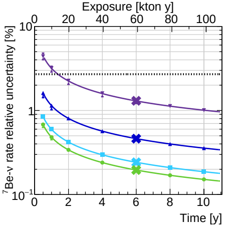


Radiopurity scenario
BX-like, Ideal, Baseline, IBD, BX result



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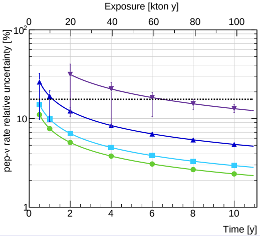

Intermediate energy solar neutrinos: ^{7}Be, pep, CNO

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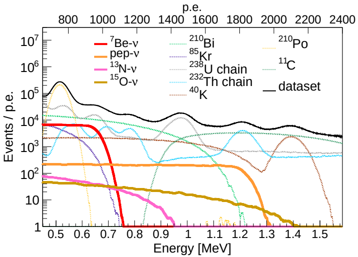

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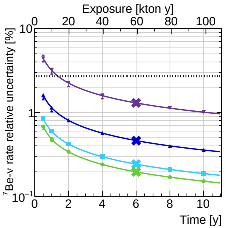
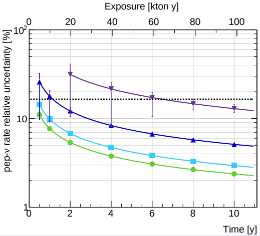
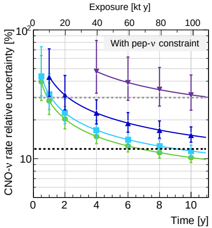
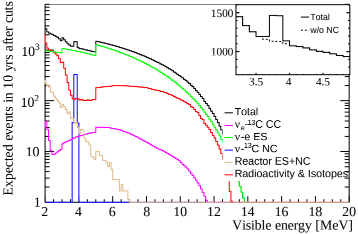
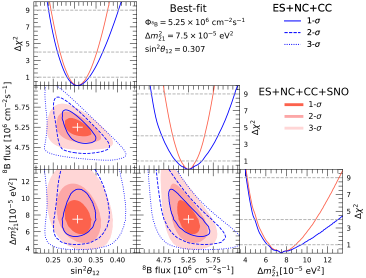






Oscillation physics with solar ^8B ν_e

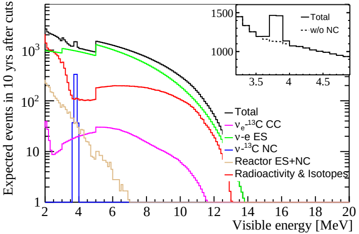


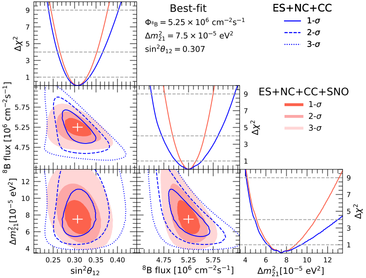


Oscillations

- ^8B ν_e are sensitive to the matter effect: Day/Night asymmetry

Oscillation physics with solar $^{8}\mathrm{B}\ \nu_e$





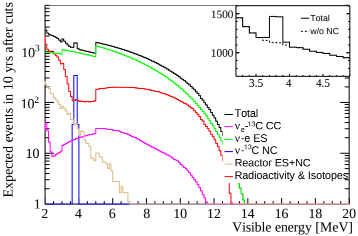
Oscillations

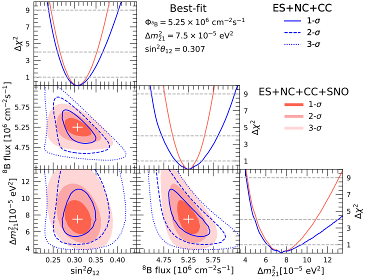
- $^{8}\mathrm{B}\ \nu_e$ are sensitive to the matter effect: Day/Night asymmetry

Detection

- Elastic scattering off e^- — $\sim$16 ν_e/day
- Neutral current on $^{13}\mathrm{C}$ — $\sim$73.8 ν_e/year
- Charged current on $^{13}\mathrm{C}$ — $\sim$64.7 ν_e/year
- Limiting factors: LS purity, cosmic ray related background
- Baseline $^{238}\mathrm{U}/^{232}\mathrm{Th}$ contamination: 10^{-16} g/g

Oscillation physics with solar ^{8}B ν_e





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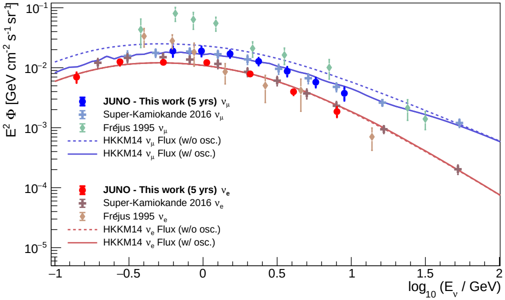
Data and analysis

- Events binned vs zenith angle $\cos\theta_z$ and ν_e energy
- 5%, $\sim 8\%$ and $\sim 20\%$ sensitivity to ^{8}B flux, $\sin^2 2\theta_{12}$ and Δm^2_{21}.

Oscillation physics with atmospheric $\nu_\mu/\overline{\nu}_\mu$

[2103.09908][2104.02565]

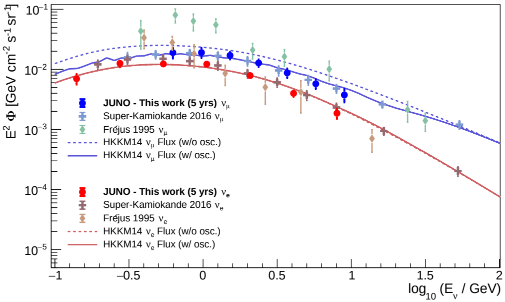


Oscillations

- Matter effect: θ_z dependence

Oscillation physics with atmospheric $\nu_\mu/\overline{\nu}_\mu$

[2103.09908][2104.02565]



Oscillations

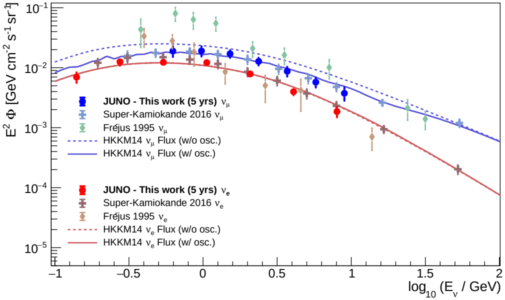
- Matter effect: θ_z dependence

Detection

- Primary channel: $\nu_\mu/\overline{\nu}_\mu$ CC
- Expected statistics, 200 kton-years: 1233/1035 events
- Limiting factors: angular resolution / PID purity

Oscillation physics with atmospheric $\nu_\mu/\overline{\nu}_\mu$

[2103.09908][2104.02565]



Oscillations

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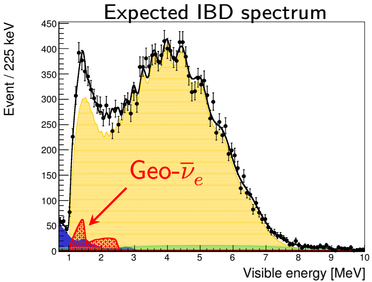
Detection

- Primary channel: $\nu_\mu/\overline{\nu}_\mu$ CC
- Expected statistics, 200 kton-years: 1233/1035 events
- Limiting factors: angular resolution / PID purity

Data and analysis

- Events binned vs zenith angle $\cos\theta_z$ (fine) and ν energy (coarse)
- $\sim 1\sigma$ sensitivity to ordering in 10 years
- Potential: combination with reactor analysis

Geo-neutrinos

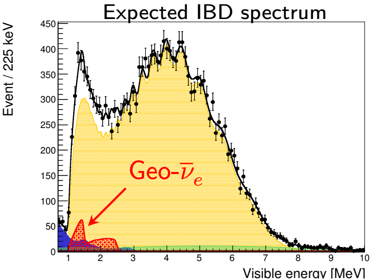


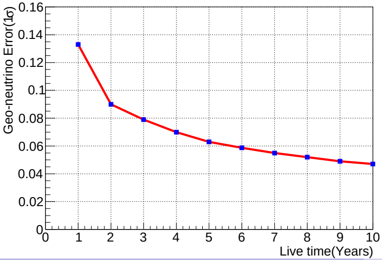
Source: ^{238}U/^{232}Th from Earth's crust and mantle

- $^{238}\mathrm{U} \to {}^{206}\mathrm{Pb} + 8\alpha + 6e^- + 6\overline{\nu}_e$
- $^{232}\mathrm{Th} \to {}^{208}\mathrm{Pb} + 6\alpha + 4e^- + 4\overline{\nu}_e$
- there is also ^{40}K, which is below IBD threshold of 1.8 MeV
- 500 km of crust around JUNO contributes $> 50\%$ of signal
- Local geological studies: [1901.01945] [1903.11871]

[2104.02565]

Geo-neutrinos





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- 500 km of crust around JUNO contributes $> 50\%$ of signal
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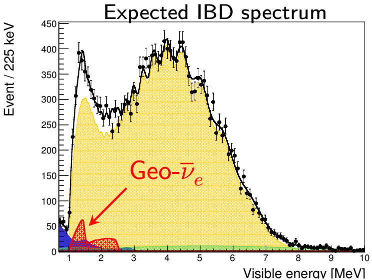
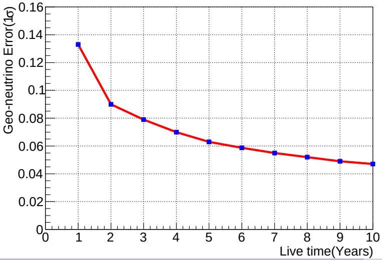
Data

- KamLAND: 175 $\overline{\nu}_e$ in 8 years [2205.14934]
- Borexino: 53 $\overline{\nu}_e$ in 9 years [1909.02257]
- JUNO: 400 $\overline{\nu}_e$/year (40 TNU/year)

[2104.02565]

Geo-neutrinos





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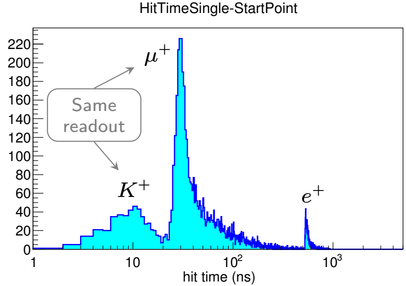
Goals

- 5% geo-$\overline{\nu}_e$ measurement in 10 years
- Measure: Th/U mass ratio
- Study: radiogenic heat production

[2104.02565]

Physics with no neutrino

Proton decay

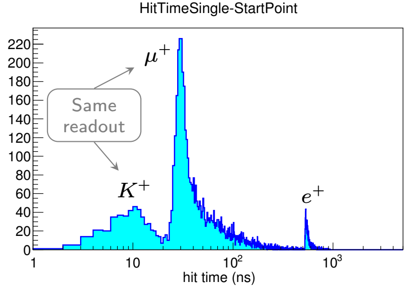


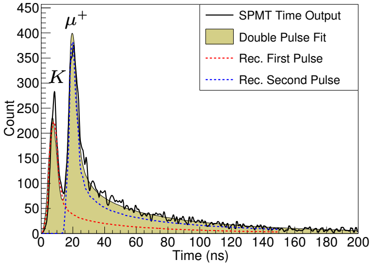
Signature

- $p \to \nu + K^+ \to \nu_\mu + \mu^+ \to \overline{\nu}_\mu + \nu_e + e^+$ GUT
- $p \to \nu + \pi^+ \to \nu_\mu + \mu^+ \to \overline{\nu}_\mu + \nu_e + e^+$ SUSY
- $p \to \mu^+\mu^+\mu^-$ under investigation

[2104.02565]

Proton decay





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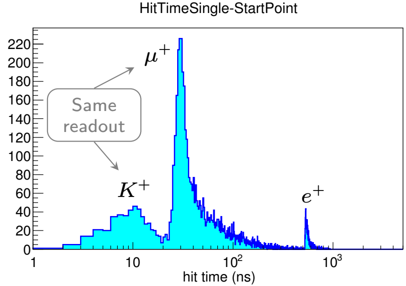
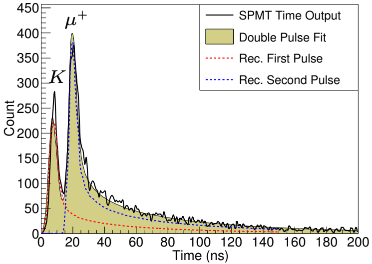
Data

- Signal: three-fold coincidence
- Backgrounds: atmospheric neutrinos, cosmic muons

[2104.02565]

Proton decay





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Data

- Signal: three-fold coincidence
- Backgrounds: atmospheric neutrinos, cosmic muons

Sensitivity

- 8.34×10^{33} years 90% CL in 10 years

[2104.02565]

Invisible mode of neutron decay

Signature

Decay of 1 or 2 bound neutrons in ^{12}C:

- $^{11}\mathrm{C}^* \to n +^{10}\mathrm{C}$ B=3.0%
- $^{11}\mathrm{C}^* \to n + \gamma +^{10}\mathrm{C}$ B=2.8%
- $^{10}\mathrm{C}^* \to n +^{9}\mathrm{C}$ B=6.2%
- $^{10}\mathrm{C}^* \to n + p +^{8}\mathrm{B}$ B=6.0%
- Triple signal:
  np scattering, nH capture, daughter decay.

EPJC85 [2405.17792]

Invisible mode of neutron decay

Signature

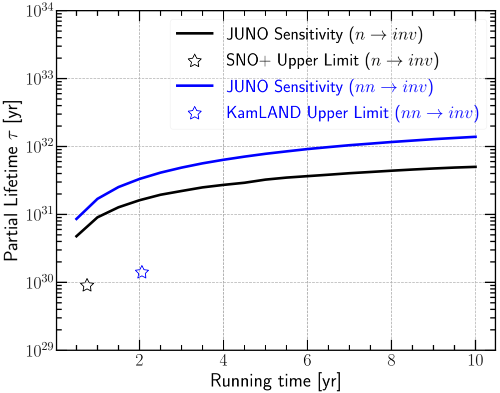
Decay of 1 or 2 bound neutrons in $^{12}\mathrm{C}$.

Data

- Triple signal:
  np scattering, nH capture, daughter decay.
- Backgrounds: IBD+single, atmospheric ν.
- Difficulties: long coincidence window, $<$100 s for n and $<$3 s for nn. Require PSD to suppress background.

EPJC85 [2405.17792]

Invisible mode of neutron decay



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- Backgrounds: IBD+single, atmospheric ν.
- Difficulties: long coincidence window, <100 s for n and <3 s for nn. Require PSD to suppress background.

Sensitivity @90%C.L.

- $\tau / B(n \to inv) > 5.0 \times 10^{31}$ years.
- $\tau / B(nn \to inv) > 1.4 \times 10^{32}$ years.

EPJC85 [2405.17792]

Neutrinoless double beta decay

Conclusions

JUNO HIGHLIGHTS

JUNO and physics

- Largest liquid scintillator detector.
- 3σ on neutrino mass ordering in 7.1 years.
- Complementary with reactor and atmospheric measurements.
- Permille level precision on neutrino oscillation parameters: Δm^2_{31}, Δm^2_{21}, $\sin^2 2\theta_{12}$.
- Rich physics programme including solar, geo-, atmospheric, supernovae neutrinos.

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Status and prospects

- JUNO filling goes full speed and will finish by Autumn.
- Part of the detector already in operation.
- First physics results in early 2026.

JUNO highlights

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Status and prospects

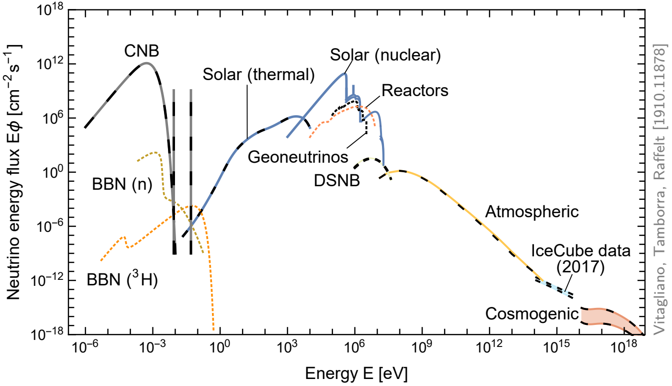
- JUNO filling goes full speed and will finish by Autumn.
- Part of the detector already in operation.
- First physics results in early 2026.
- Exciting times, stay tuned.

Thank you for your attention!
Спасибо за внимание!

Spare slides:

- Neutrino flux
- Reactor antineutrino
- Calibration
- Energy resolution
- LS
- OSIRIS
- IBD selection

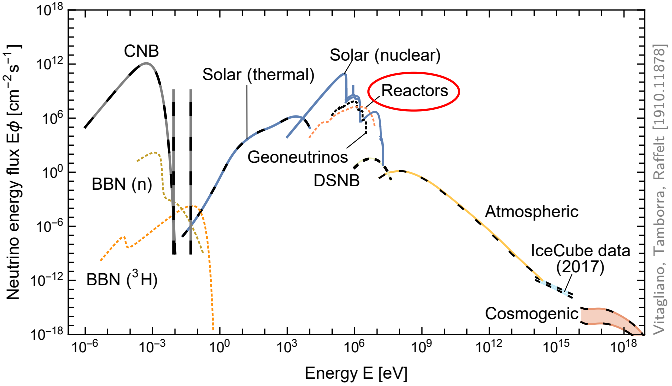
Physics with JUNO: neutrinos and more...



DSNB — Diffuse SuperNova Background
* Rates after selection

Physics with JUNO: neutrinos and more...

Osc. [2204.13249], TAO [2005.08745]

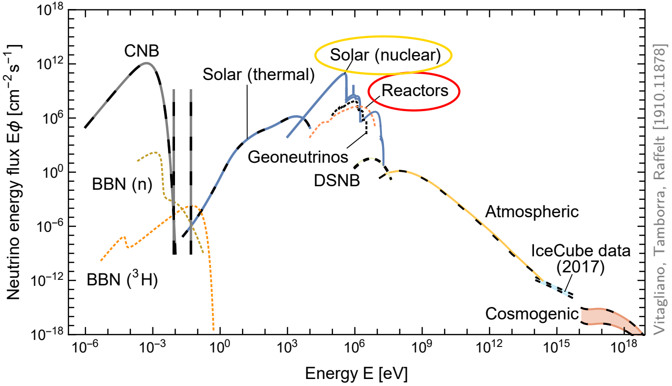


Neutrino physics

- Reactor
  - **Long baseline** ∼**47 IBD/day**
  - Short baseline @TAO ∼2000 IBD/day

DSNB — Diffuse SuperNova Background
IBD — Inverse Beta Decay
* Rates after selection

Physics with JUNO: neutrinos and more...



^{8}B [2006.11760], OSIRIS-Serappis [2109.10782], JUNO [2104.02565]

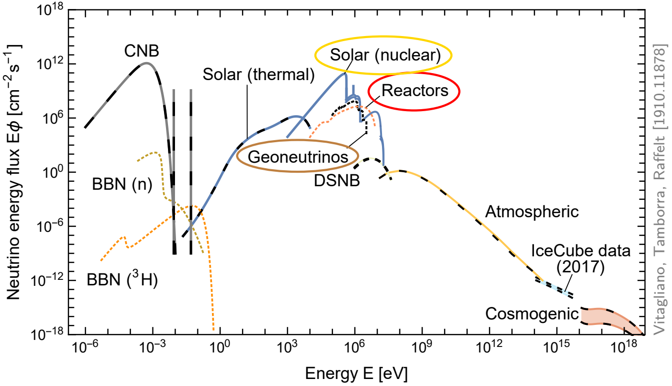
Neutrino physics

- Reactor ~47 IBD/day
- Solar
  - ^{7}Be ~130 ES/day
  - pep ~17 ES/day
  - CNO ~16 ES/day
  - ^{8}B (high E) ~16 ES/day
  - pp @OSIRIS ~ 16 ES/day
  - ^{7}Be @OSIRIS ~ 4.5 ES/day

DSNB — Diffuse SuperNova Background
IBD — Inverse Beta Decay
ES — Elastic Scattering
* Rates after selection

Physics with JUNO: neutrinos and more...

JUNO [2104.02565]



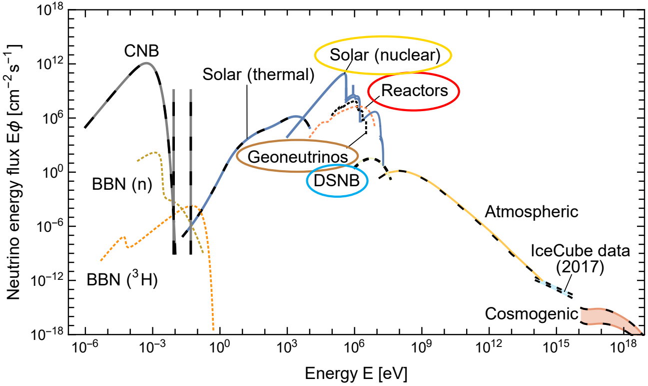
Neutrino physics

- Reactor ∼47 IBD/day
- Solar
- Geo-neutrino ∼400 IBD/year

DSNB — Diffuse SuperNova Background
IBD — Inverse Beta Decay
ES — Elastic Scattering
* Rates after selection

PHYSICS WITH JUNO: NEUTRINOS AND MORE...

DSNB [2205.08830]



Vitagliano, Tamborra, Raffelt [1910.11878]

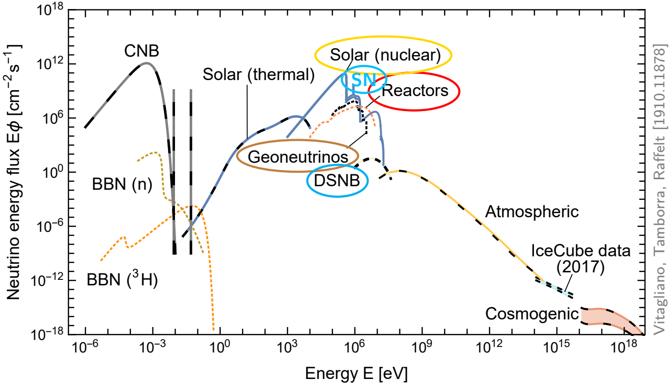
Neutrino physics

- Reactor $\sim$47 IBD/day
- Solar
- Geo-neutrino $\sim$400 IBD/year
- DSNB $2-4$ IBD/year

DSNB — Diffuse SuperNova Background
IBD — Inverse Beta Decay
ES — Elastic Scattering
* Rates after selection

Physics with JUNO: neutrinos and more...

JUNO [2104.02565]



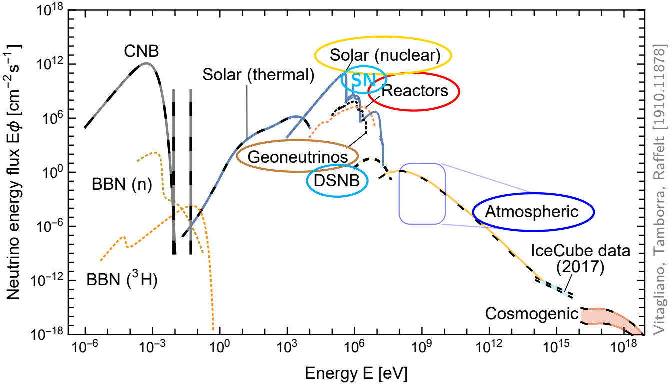
Neutrino physics

- Reactor ∼47 IBD/day
- Solar
- Geo-neutrino ∼400 IBD/year
- DSNB $2-4$ IBD/year
- SuperNova 5000 IBD/2300 ES@10 kpc

DSNB — Diffuse SuperNova Background
IBD — Inverse Beta Decay
ES — Elastic Scattering
* Rates after selection

Physics with JUNO: neutrinos and more...

Atmospheric [2103.09908], JUNO [2104.02565]



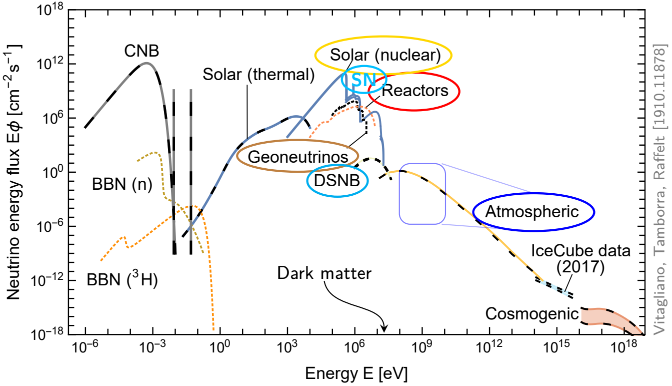
Neutrino physics

- Reactor $\sim$47 IBD/day
- Solar
- Geo-neutrino $\sim$400 IBD/year
- DSNB $2-4$ IBD/year
- SuperNova 5000 IBD/2300 ES@10 kpc
- Atmospheric $\mathcal{O}$(100) CC/year

DSNB — Diffuse SuperNova Background
IBD — Inverse Beta Decay
ES — Elastic Scattering
CC — Charged Current
* Rates after selection

Physics with JUNO: neutrinos and more...

DM JCAP 09 [2306.09567], JUNO [2104.02565]



Neutrino physics

- Reactor ~47 IBD/day
- Solar
- Geo-neutrino ~400 IBD/year
- DSNB $2-4$ IBD/year
- SuperNova 5000 IBD/2300 ES@10 kpc
- Atmospheric $\mathcal{O}(100)$ CC/year
- MeV Dark matter

DSNB — Diffuse SuperNova Background
IBD — Inverse Beta Decay
ES — Elastic Scattering
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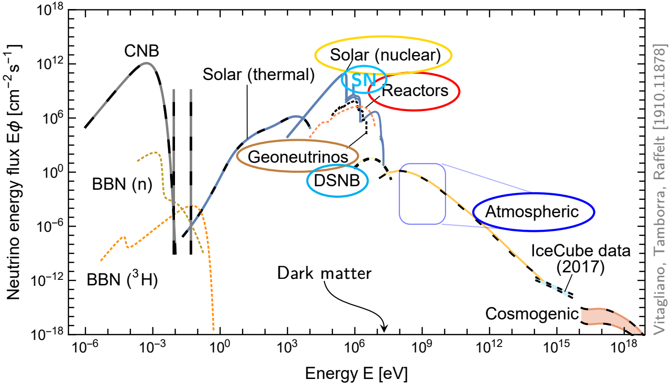
Physics with JUNO: neutrinos and more...

JUNO [2104.02565]



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Non-neutrino physics

- Proton decay
- Invisible bound neutron decay
- Future: $0\nu\beta\beta$ decay

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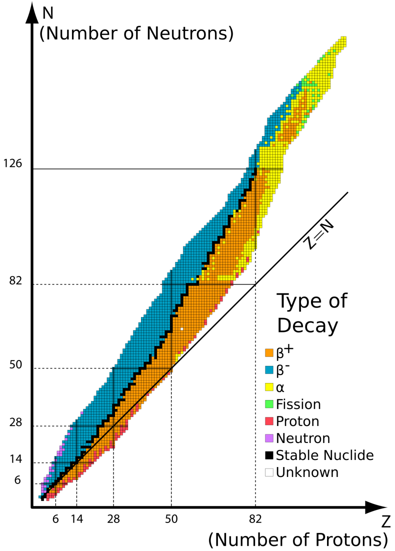
Reactor $\overline{\nu}_e$ production and detection



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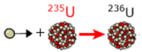
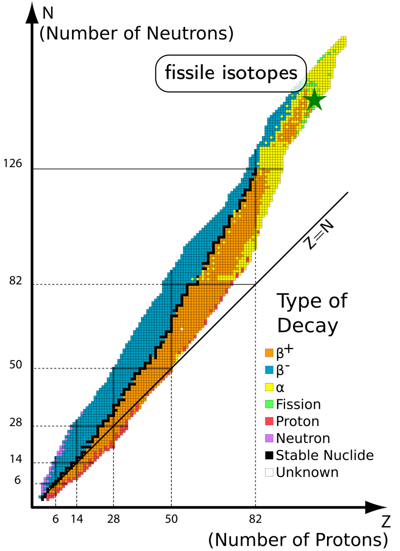
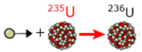
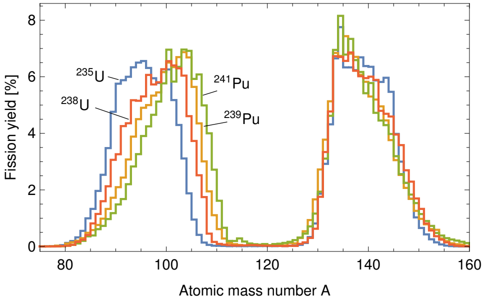
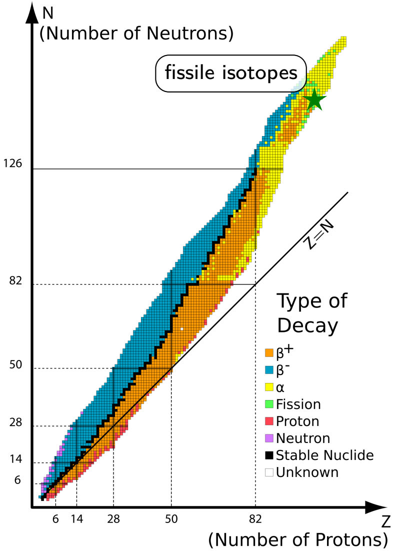




Reactor $\bar{\nu}_e$ production and detection







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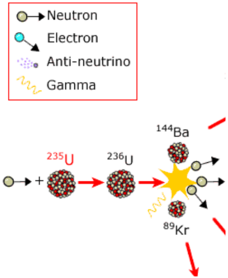

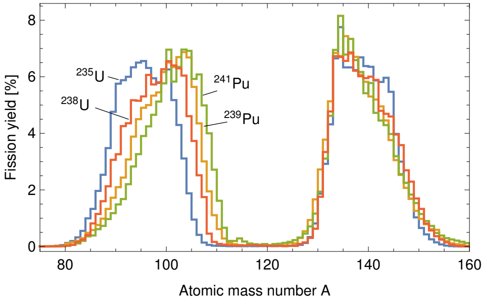

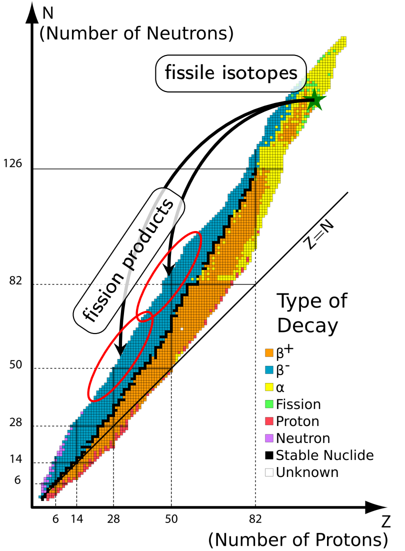

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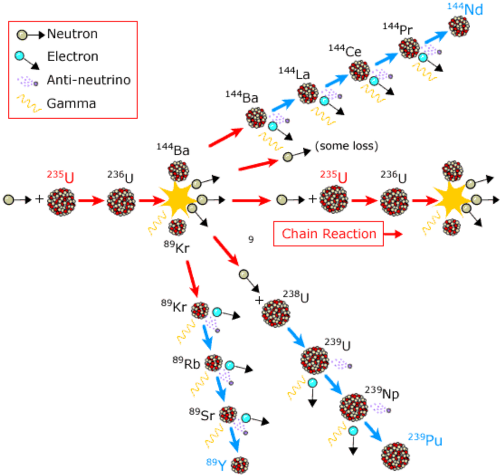

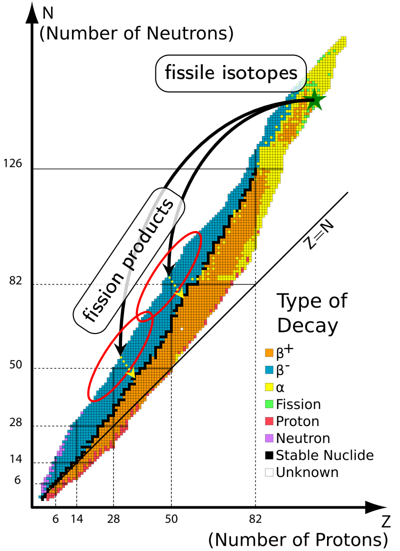

Reactor $\overline{\nu}_e$ production and detection

Reactor $\overline{\nu}_e$ production

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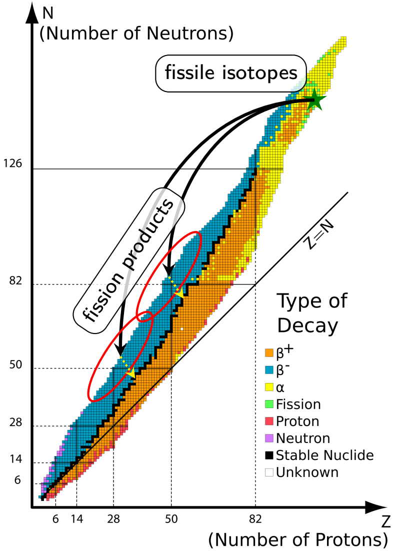

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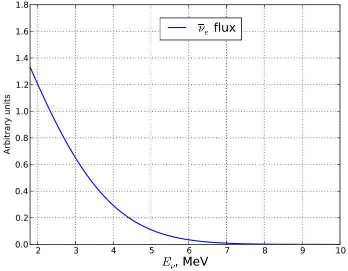

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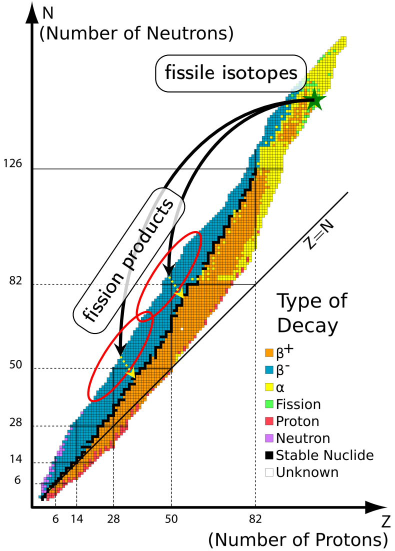

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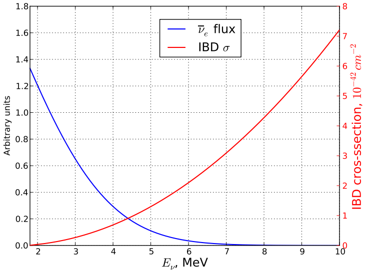

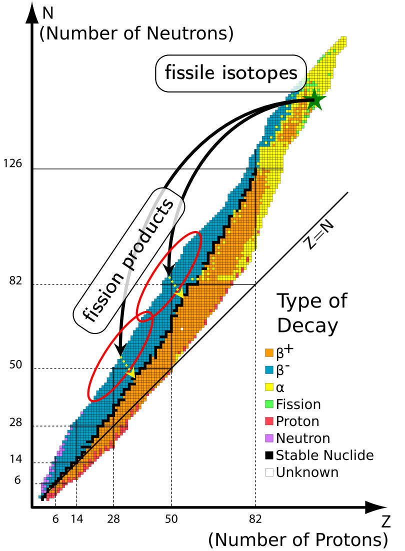

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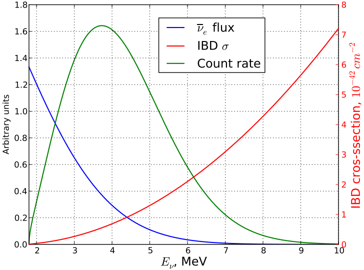
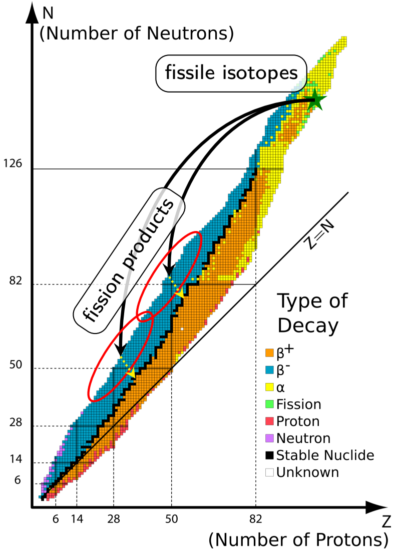
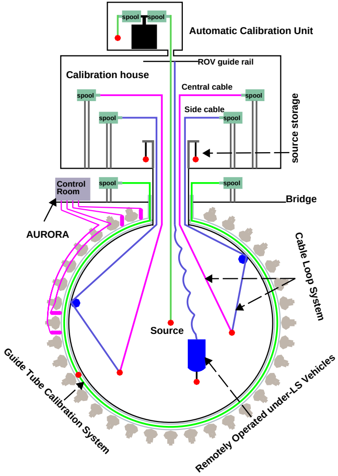
- Threshold: 1.8 MeV





Calibration

[2011.06405]



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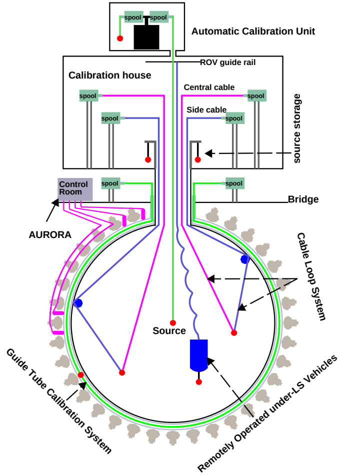

Goals

- Energy scale uncertainty $<1\%$
- Reaching desired $\sigma_E = 3\%$ at 1 MeV

Methods

- Cable Loop System, CLS 2d
- Guide Tube, GT 1d
- Remotely Operated under-LS Vehicle, ROV 3d

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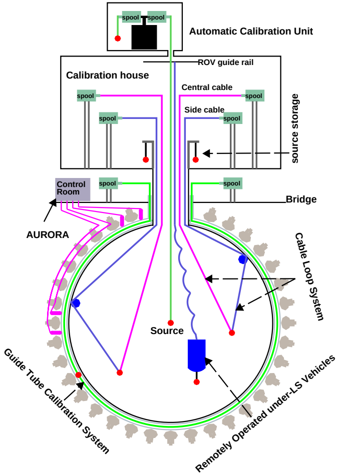

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- Multiple sources
- Multiple coatings:
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- Cross calibration with small PMTs

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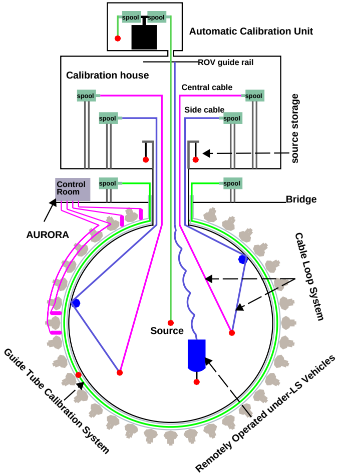

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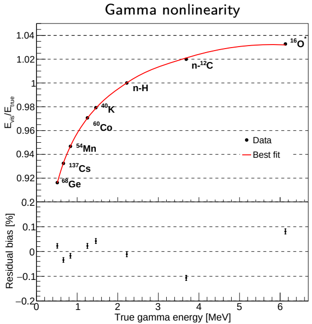
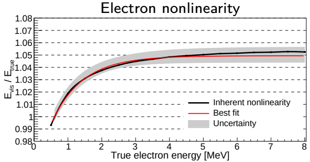




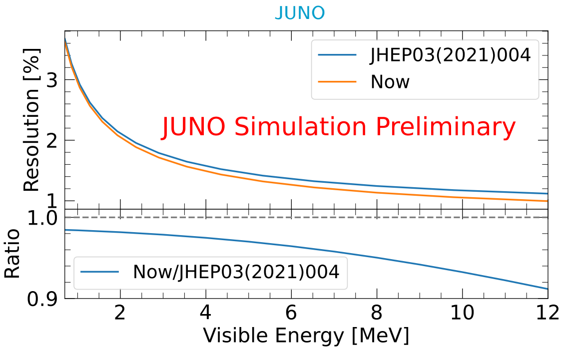
Energy resolution

Parametrization

(illustrative)

$$\frac{\sigma}{E_{\text{vis}}} = \sqrt{\frac{a^2}{E_{\text{vis}}} + \frac{b^2}{1} + \frac{c^2}{E_{\text{vis}}^2}},$$

- Parameter a — photon statistics
- Parameter b:
  - Scintillation quenching
  - Contribution of Cherenkov light
  - Non-uniformity and reconstruction
- Parameter c:
  - γs related to annihilation
  - PMT Dark Noise



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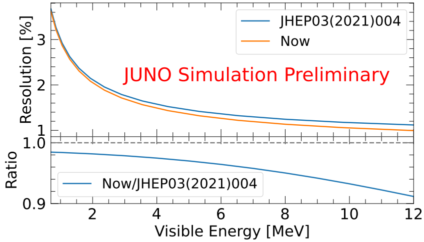
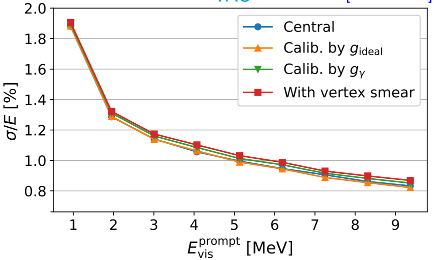
Estimation

- JUNO resolution: 2.9% at 1 MeV
- TAO: 1.9% at 1 MeV
- Goal: combined analysis of JUNO+TAO data

JUNO



TAO [2204.03256]



Liquid scintillator

[2007.00314]

5000 m^3 LAB tank

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Al_2O_3: remove particles

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Distillation:
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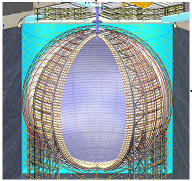
85%

15%

single run

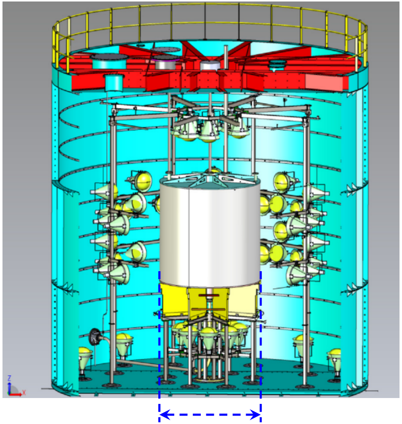
OSIRIS:
LS qualification



JUNO:
no recirculation

OSIRIS: Online Scintillator Internal Radioactivity Investigation System

[2103.16900]



3×3 m

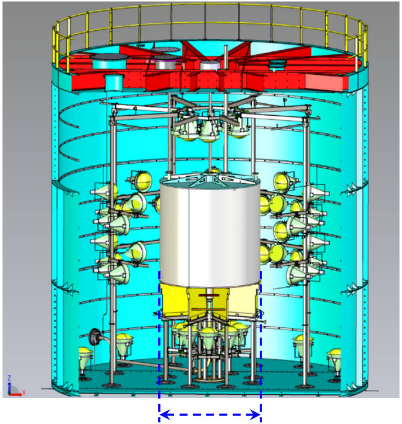
18 t LS, flow-through

OSIRIS: Online Scintillator Internal Radioactivity Investigation System

[2103.16900]

Goals

- Monitor LS during the filling of JUNO — 15% LS
- U/Th via tagging Bi-Po chains
  - Reactor baseline: 10^{-15} g/g — $\sim$ few days
  - Solar baseline: 10^{-17} g/g — $\sim$ 2-3 weeks
- Other isotopes measurement: ^{14}C, ^{210}Po, ^{85}Kr.



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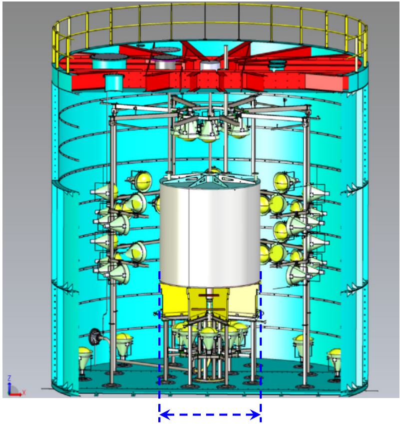
Detector

- 64 20-inch PMTs: — coverage 9%
- $\sigma_E = 6\%$ at 1 MeV: — 280 p.e./MeV



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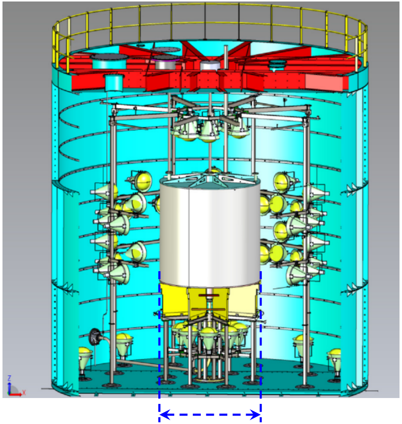
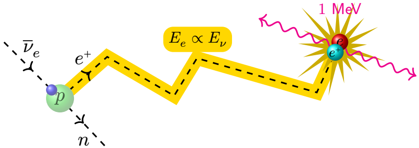
Status

- Expect to start commissioning in July.
- Possible upgrade to Serappis:
  measurement of solar pp neutrinos with 3.5% precision in 5 years



Inverse beta decay and selection criteria



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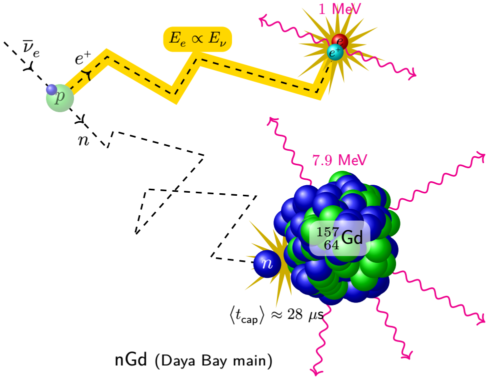
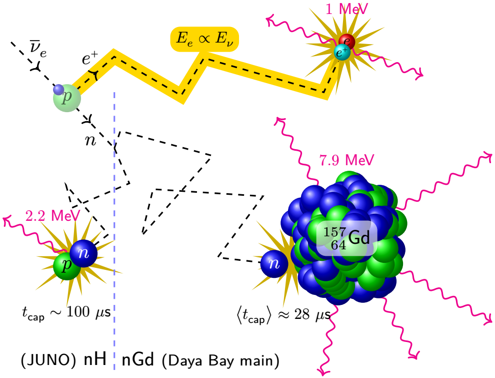


nGd (Daya Bay main)

Inverse beta decay and selection criteria



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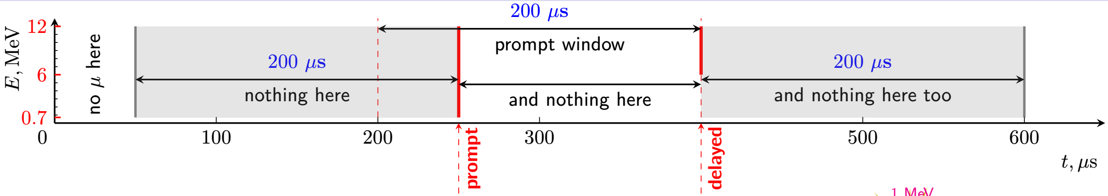
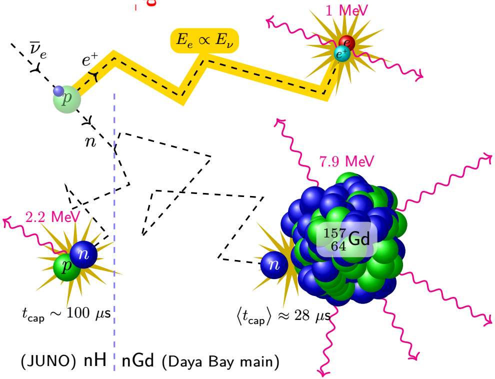
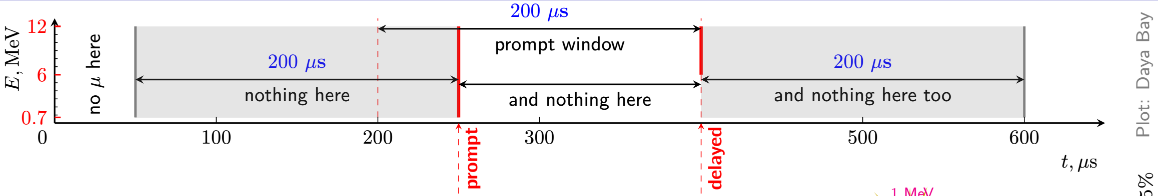


Plot: Daya Bay



Cherenkov: < 5%

Inverse beta decay and selection criteria



Tagged antineutrino signal

- Great background suppression
- Control over tag cross section and energy
- More complicated event selection procedure