XIX International Conference on Topics in Astroparticle and Underground Physics

Physics potential of detecting solar neutrinos at JUNO

Marco Beretta
on behalf of the JUNO collaboration

Solar neutrinos

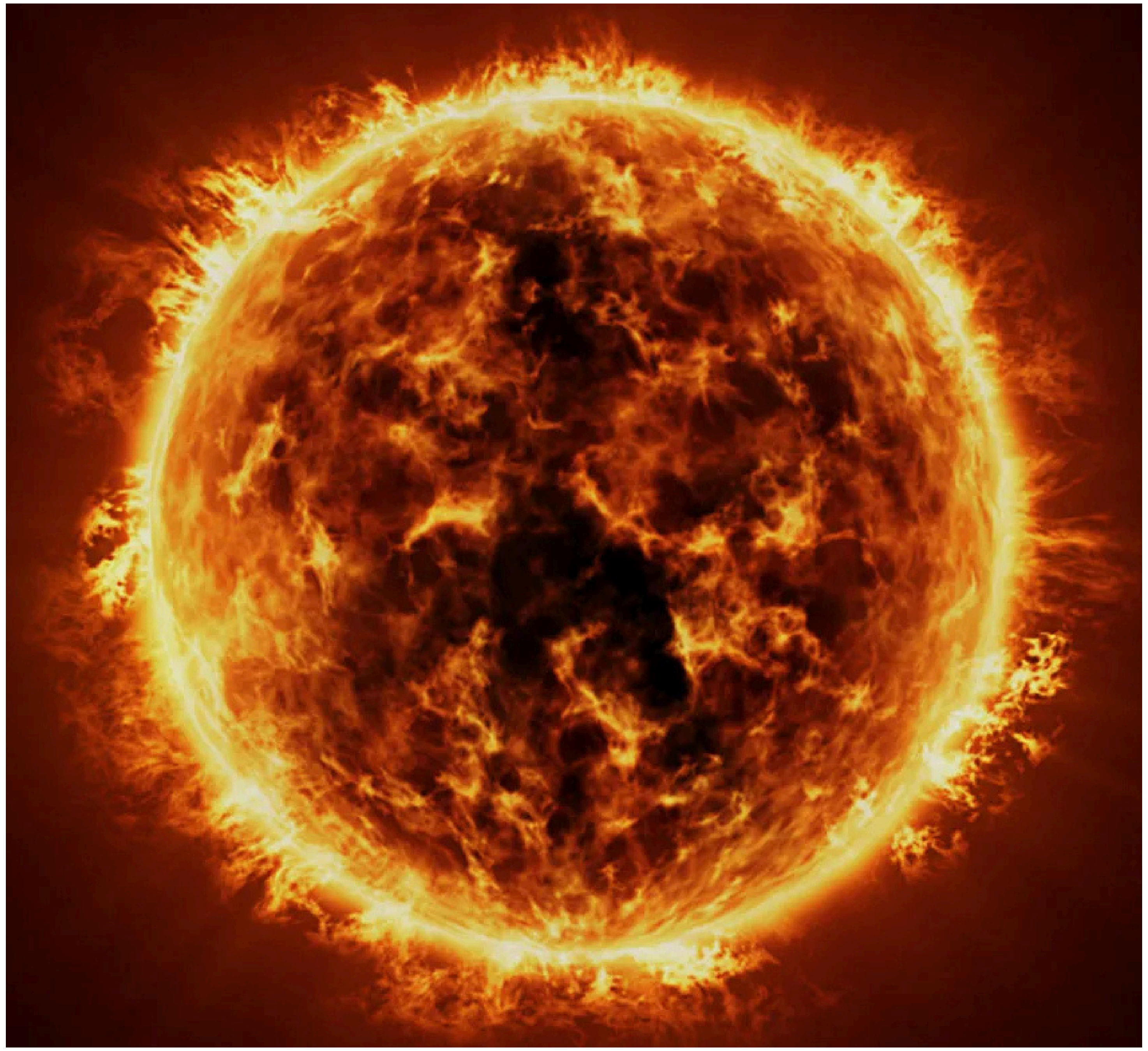
Solar neutrinos are produced in the Sun through the reactions:

$$4p \to \alpha + 2e^{+} + 2\nu_e$$

Neutrinos interact through the weak-interaction only:

$$\sigma \sim 10^{-44}\,\mathrm{cm}^2 \text{ @ } 1\,\mathrm{MeV}$$

Photons take about 100 000 years to reach our star surface. Instead, neutrinos only take about 8 minutes to travel from their production site to the Earth.



Solar neutrinos

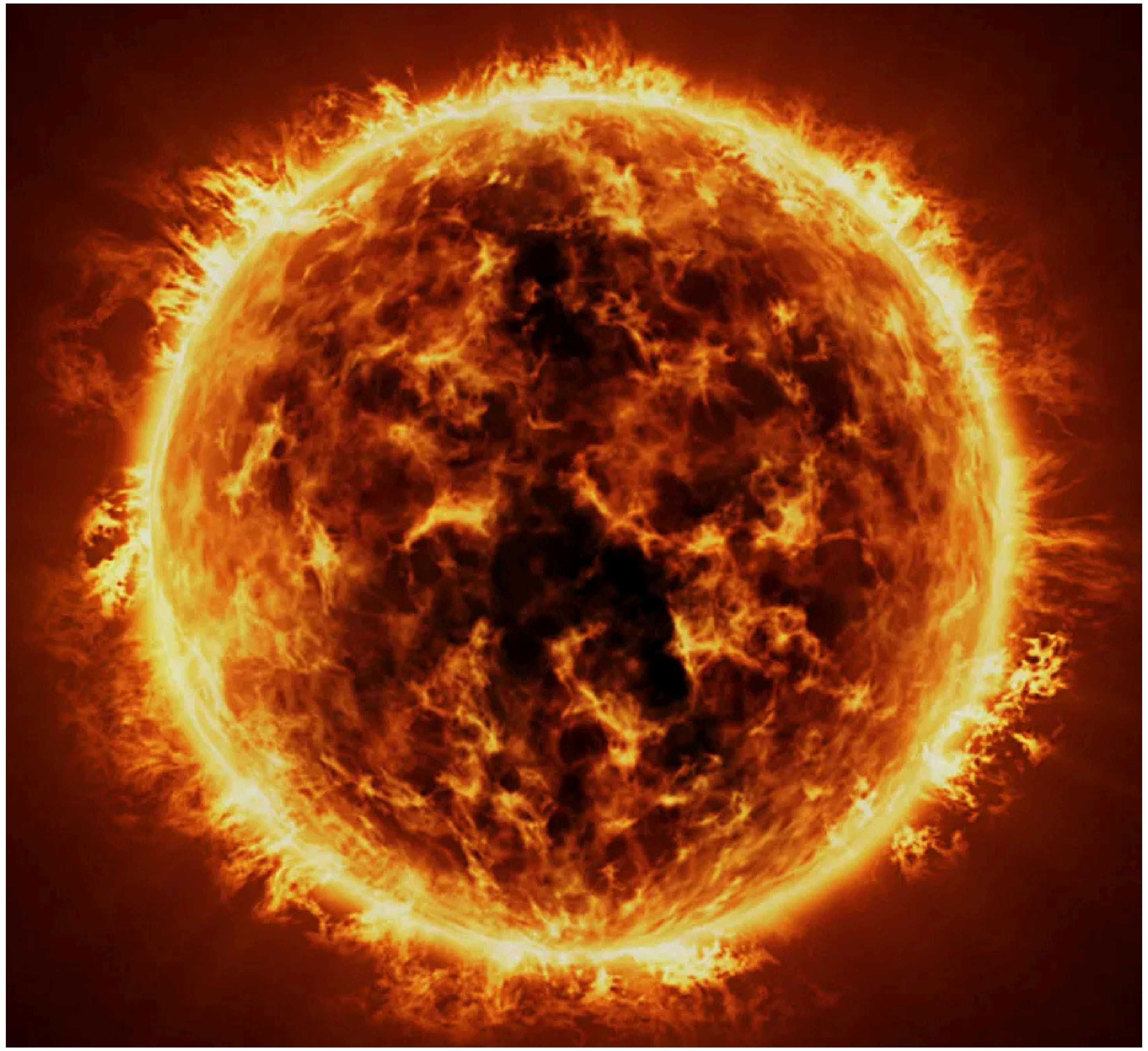
Solar neutrinos were historically important for particle physics:

→ Solving the "solar neutrino deficit" introduce **neutrino oscillation** and neutrino masses in particle physics

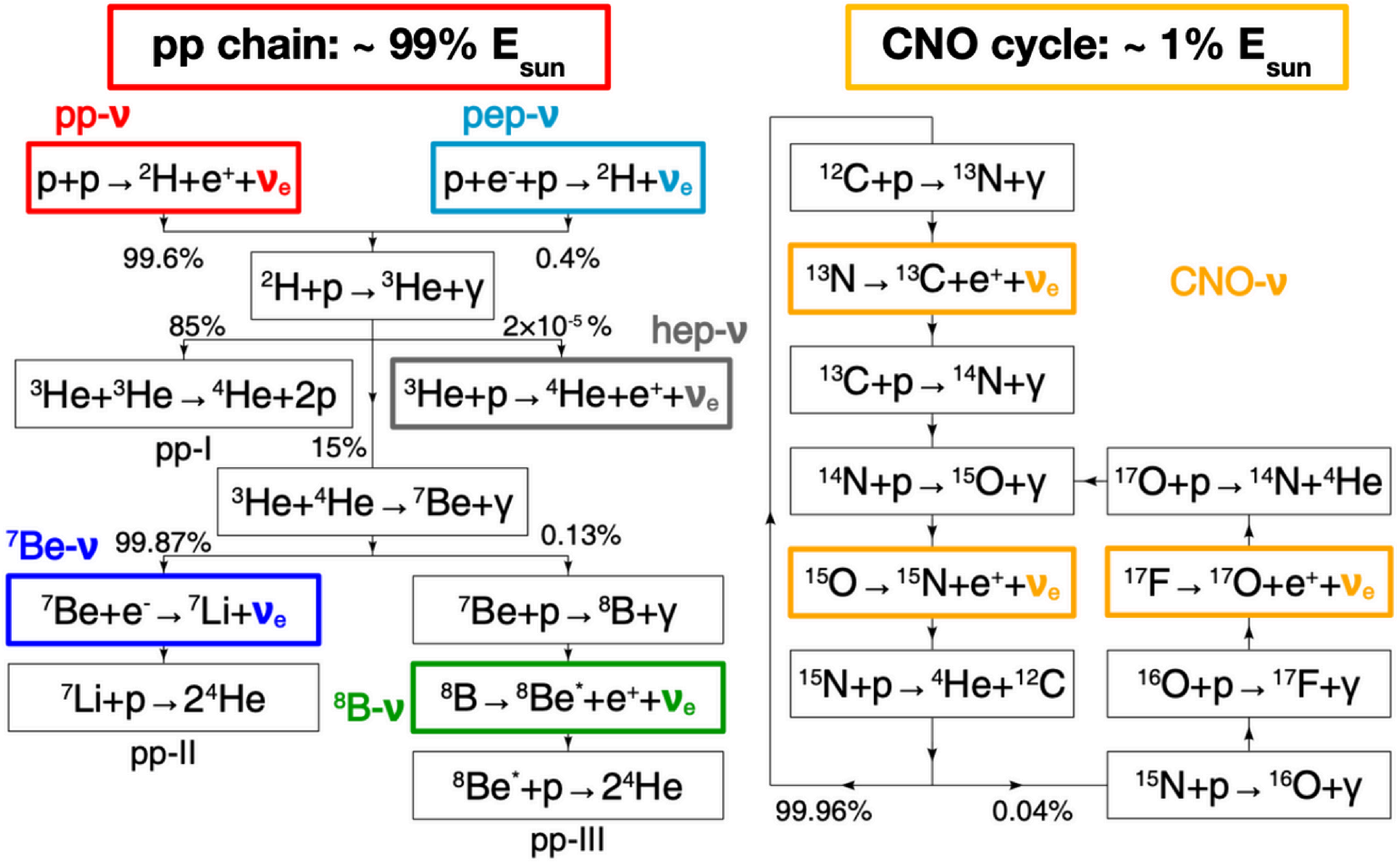
Two important roles:

→ **probe for Sun propertie**s: solar model, luminosity, metallicity problem, etc.

→ **Well known neutrino source**: neutrino oscillation, matter effect, NSI



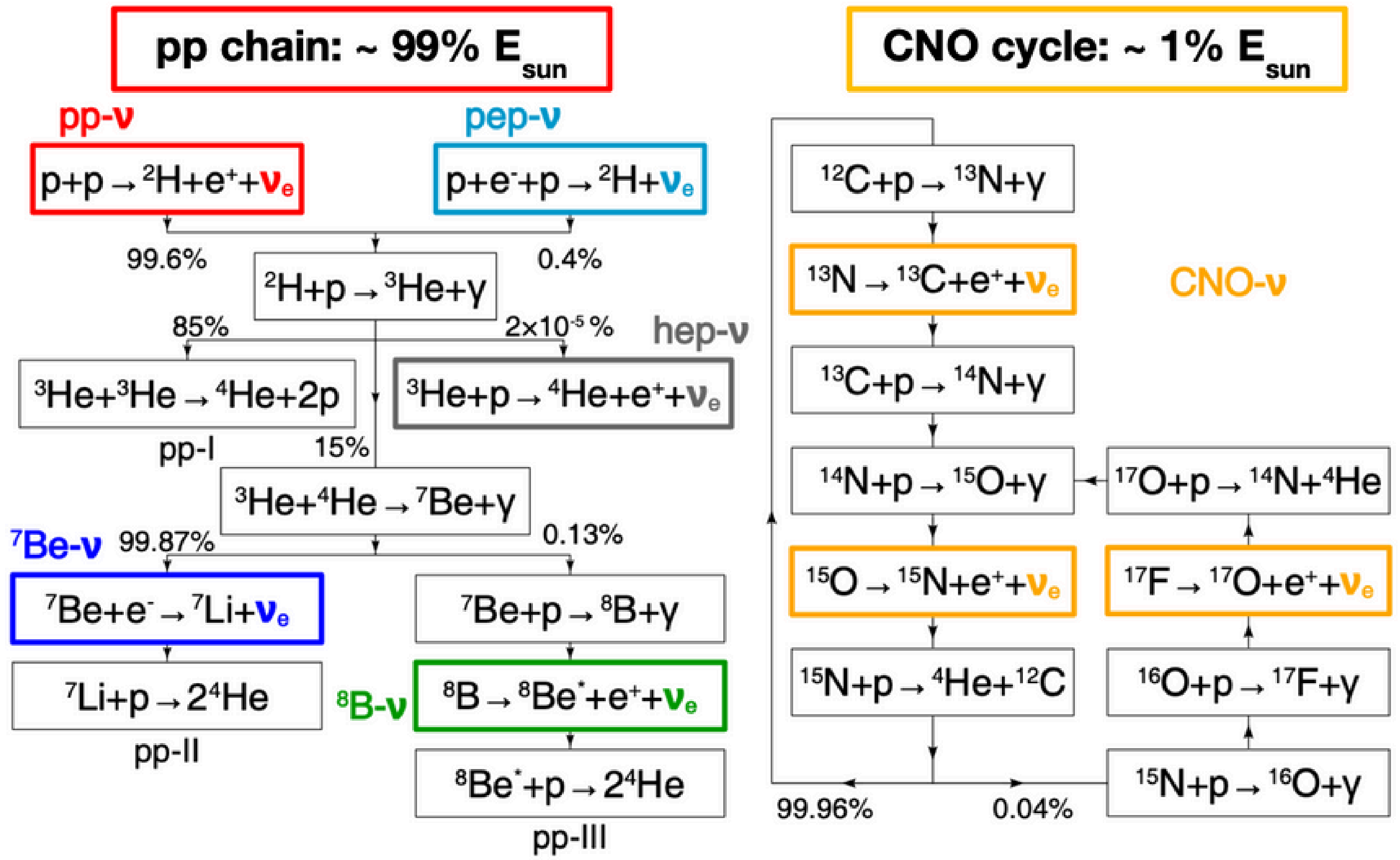
Solar neutrinos

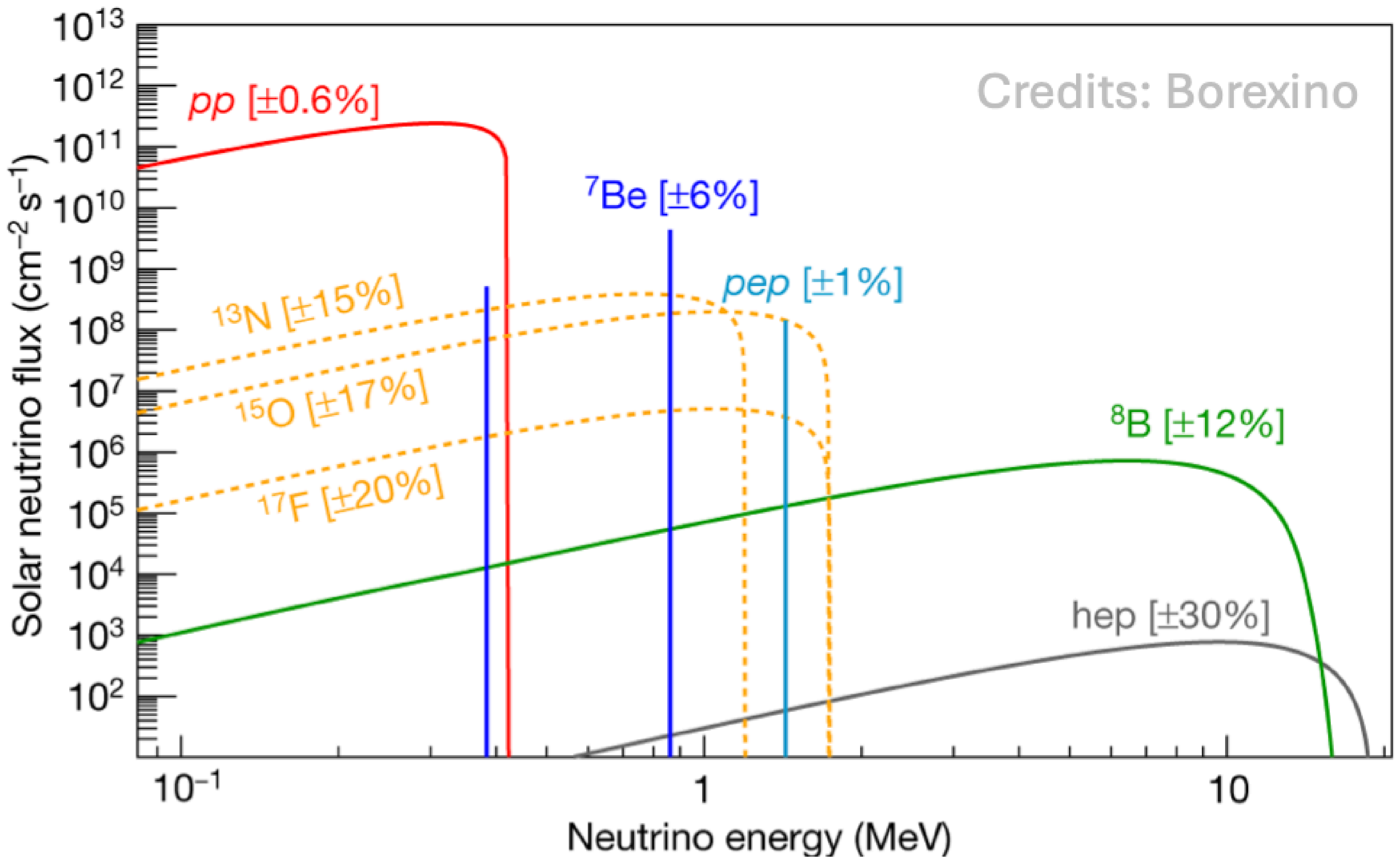


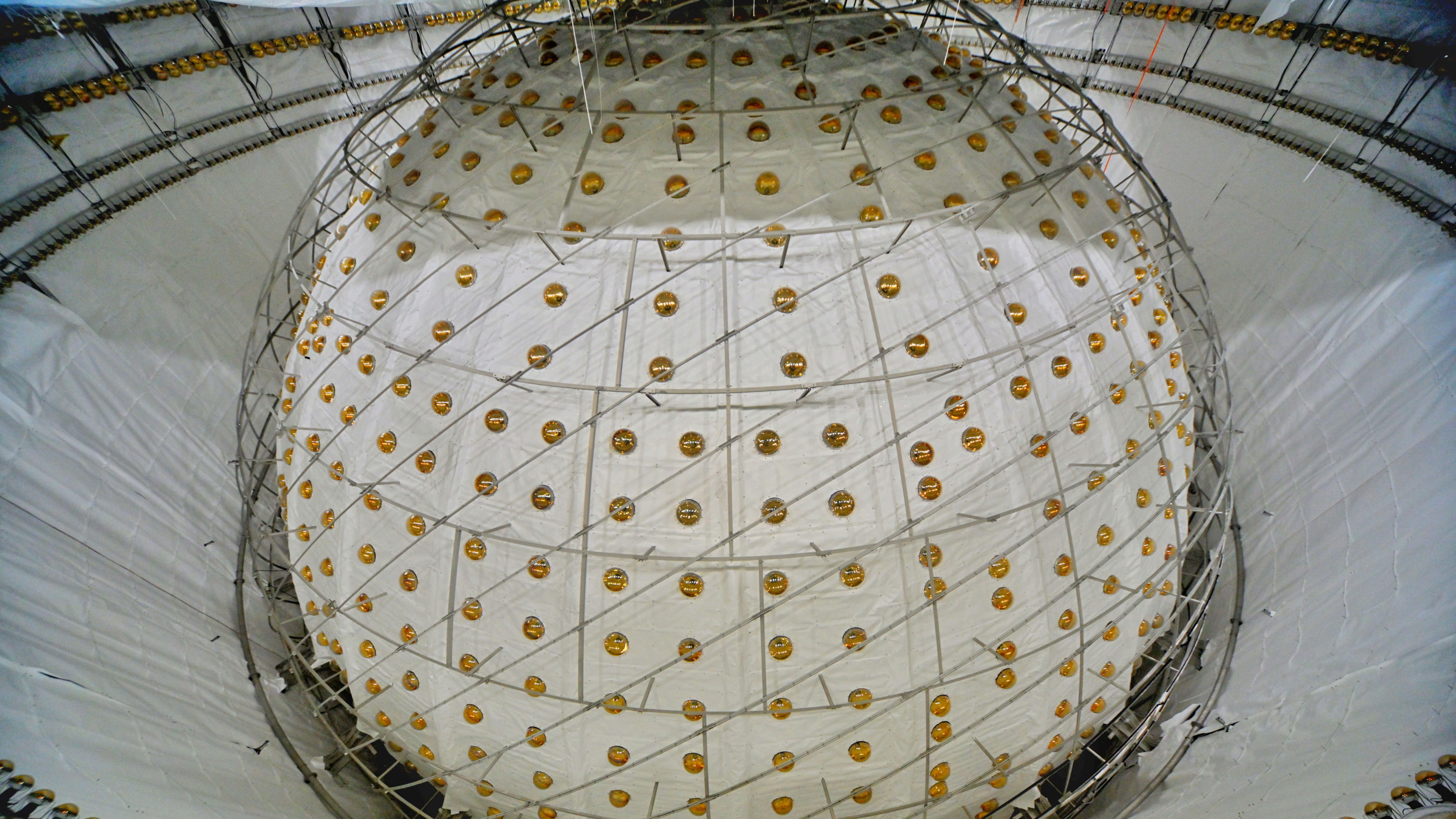
Solar neutrinos

Produced in the two primary nuclear fusion processes in the Sun

The energy range extends from **fraction of MeV to ~10 MeV**

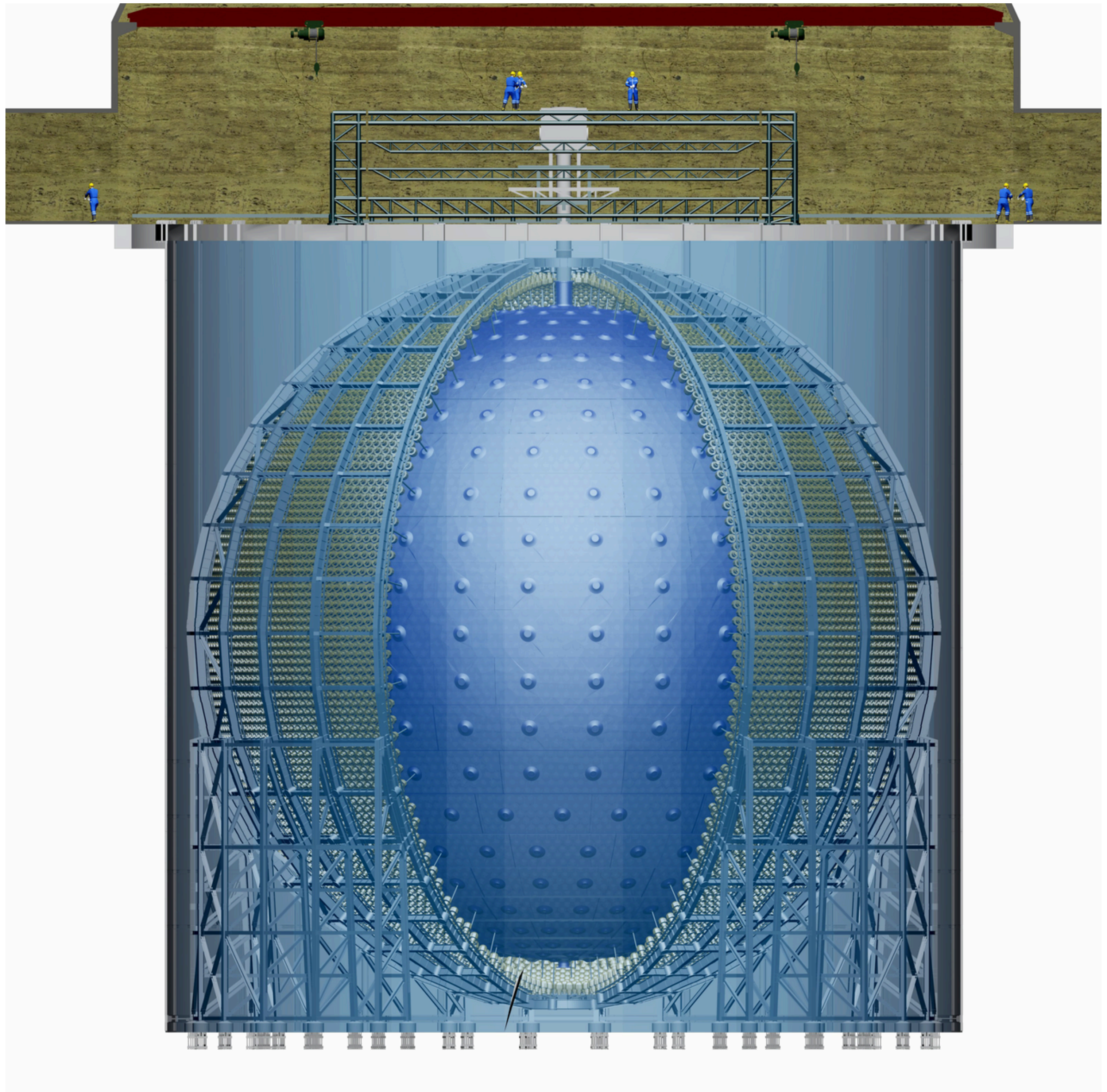






JUNO detector

The Central Detector of the JUNO experiment is a gigantic sphere of 40 m of diameter which support all the parts of the detector:



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→ More then 42000 Photo-Multiplier Tubes divided in two systems (20" and 3"), reaching 78% optical coverage

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→ An acrylic sphere ~ 35.4 m of diameter needed to contain the liquid scintillator

→ 20 000 tons of an organic liquid scintillator: LAB + 2.5 g/l PPO + 3 mg/l bis-MSB

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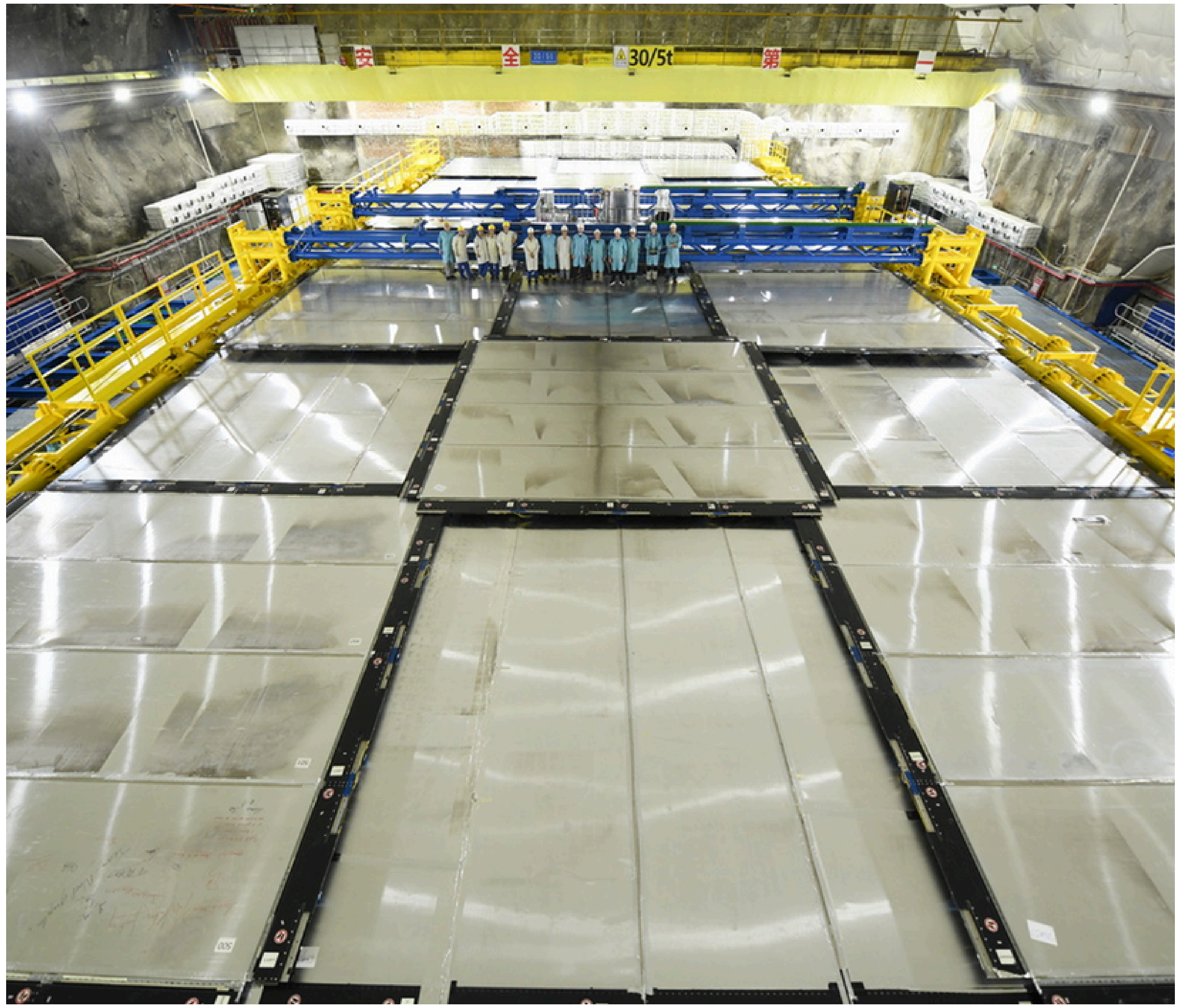
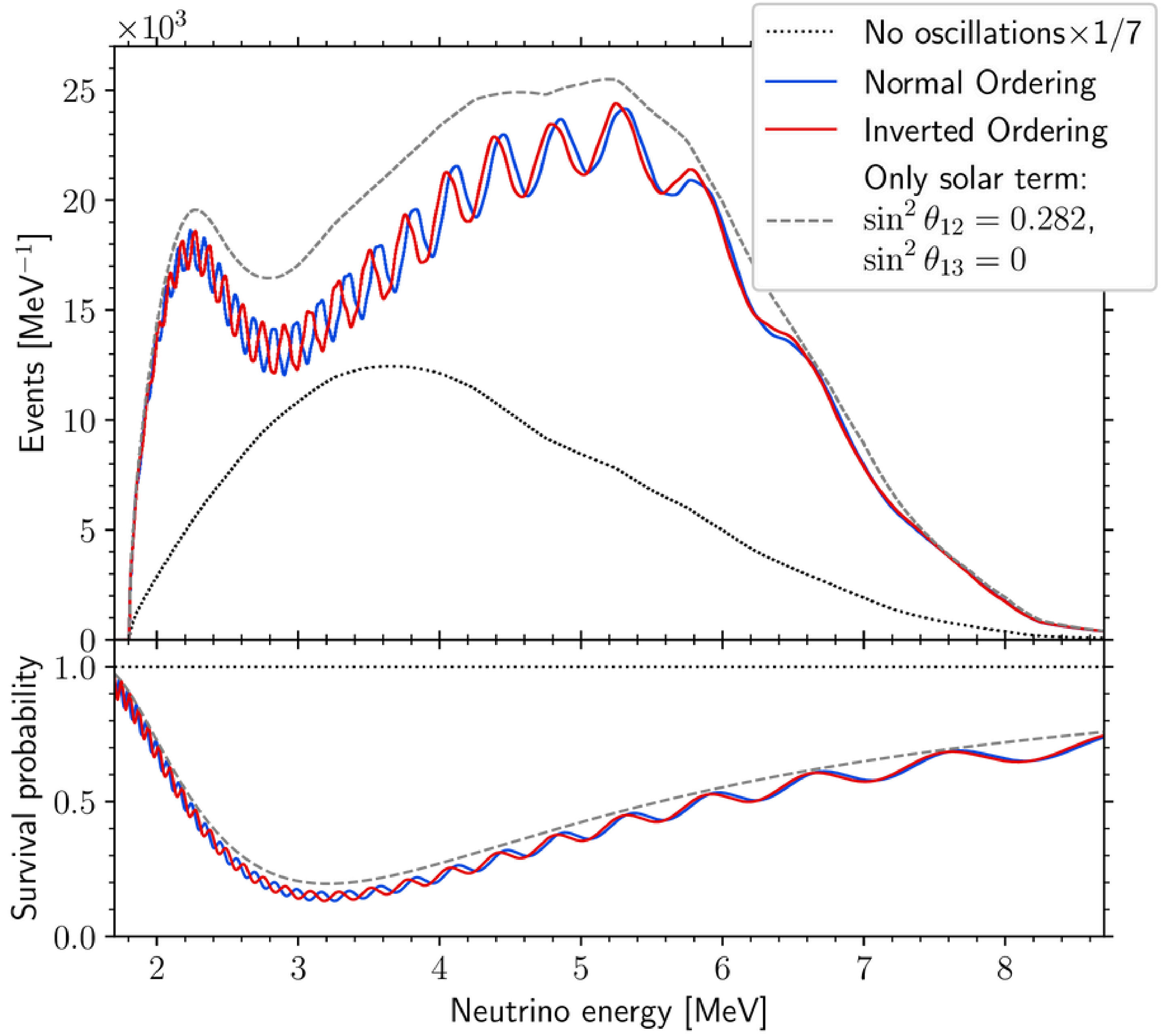
All submerged in ultra-pure water and cover by a plastic scintillator tracker for muon veto



JUNO detector: physics

The main goal is the determiation of the neutrino mass ordering by detecting anti-neutrinos from 2 NPP at 52.5 km away

The expected sensitivity is ~ 3 sigma in 6 years of data taking having ~3 % of energy resolution at 1 MeV



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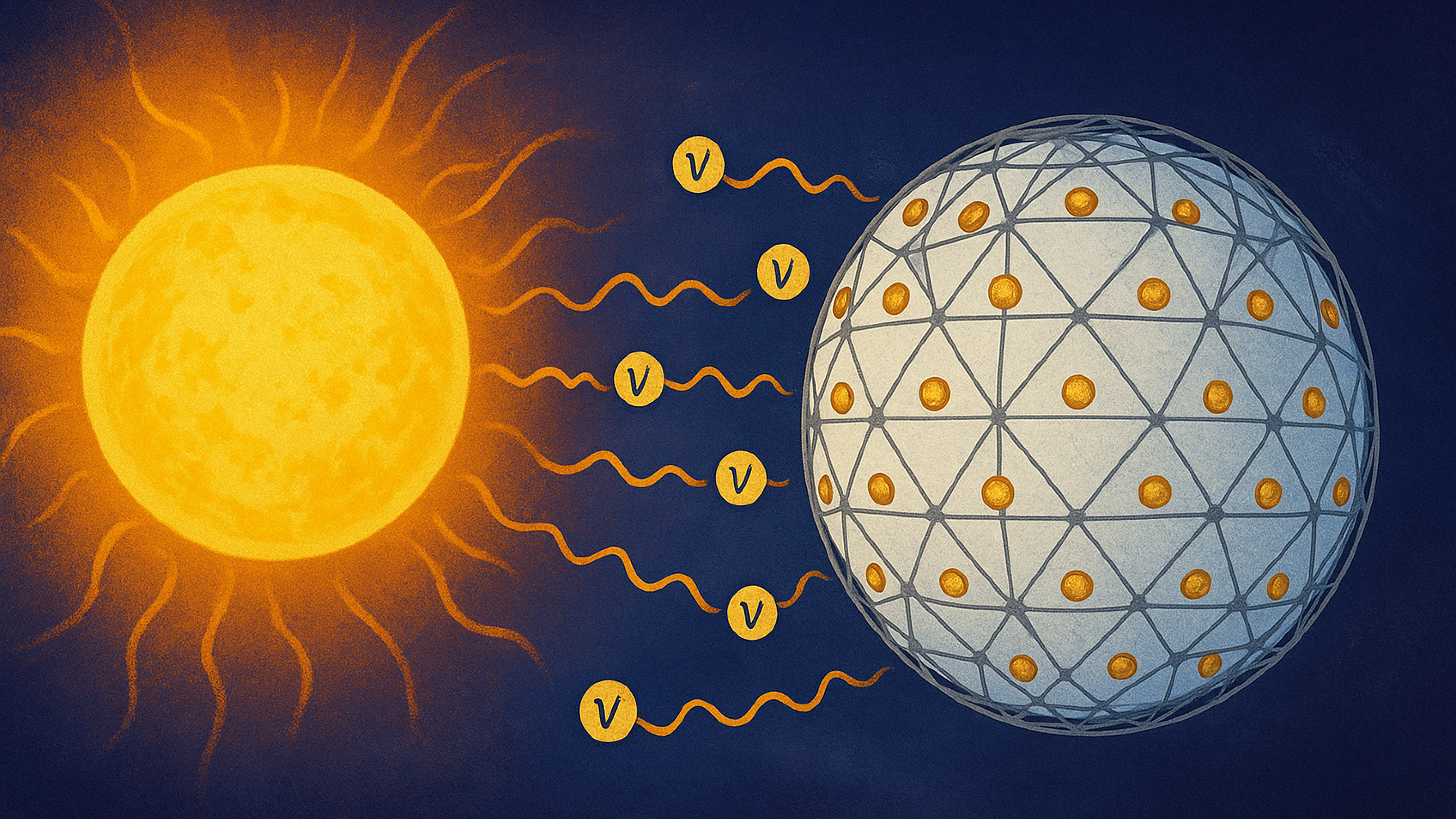
Thanks to its huge mass and the good internal radiopurity it will be a great detector for natural source physics:
_ Geoneutrinos
_ Supernova
_ Atmospheric
_ **Solar**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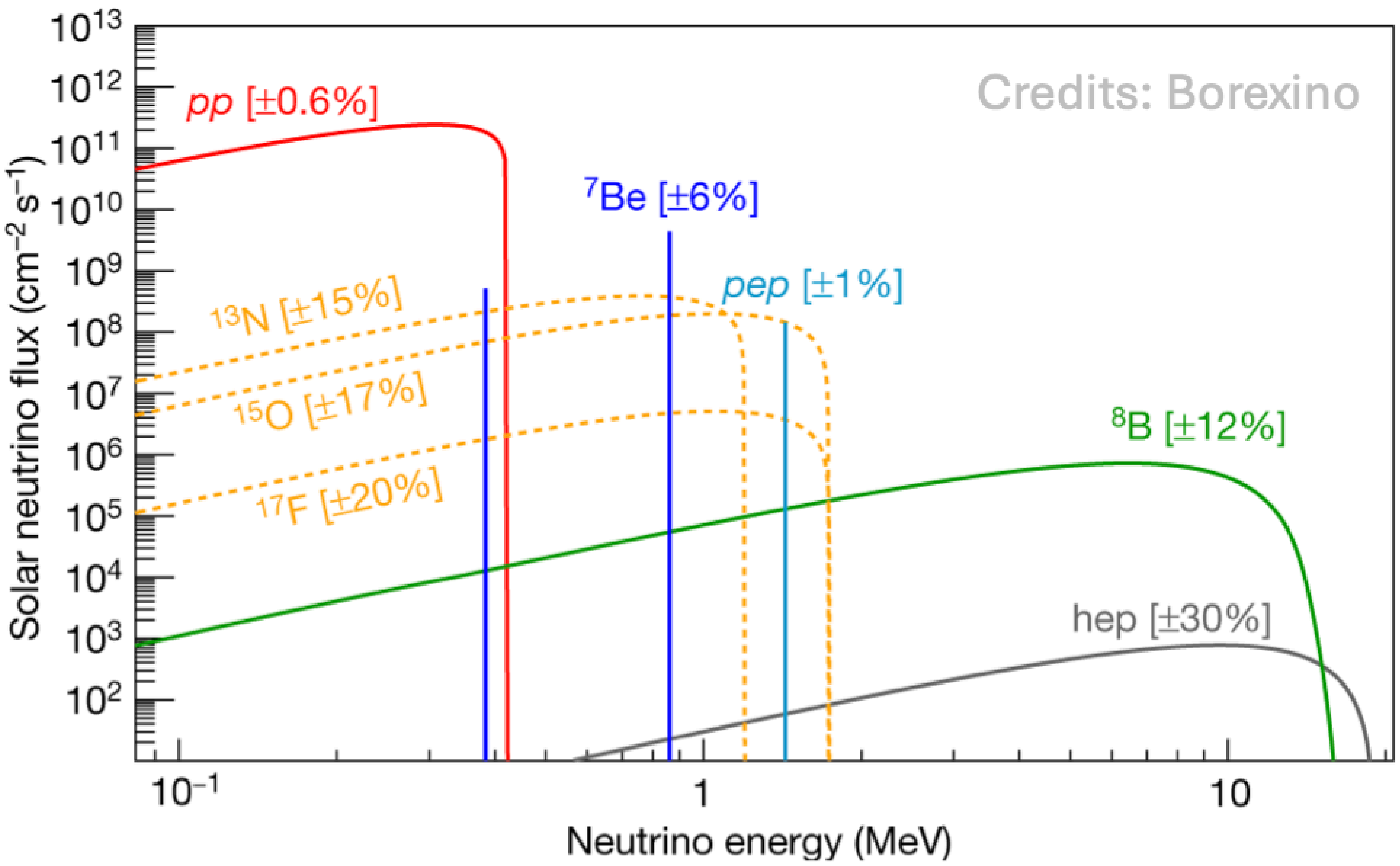
JUNO sensitivity to solar neutrino



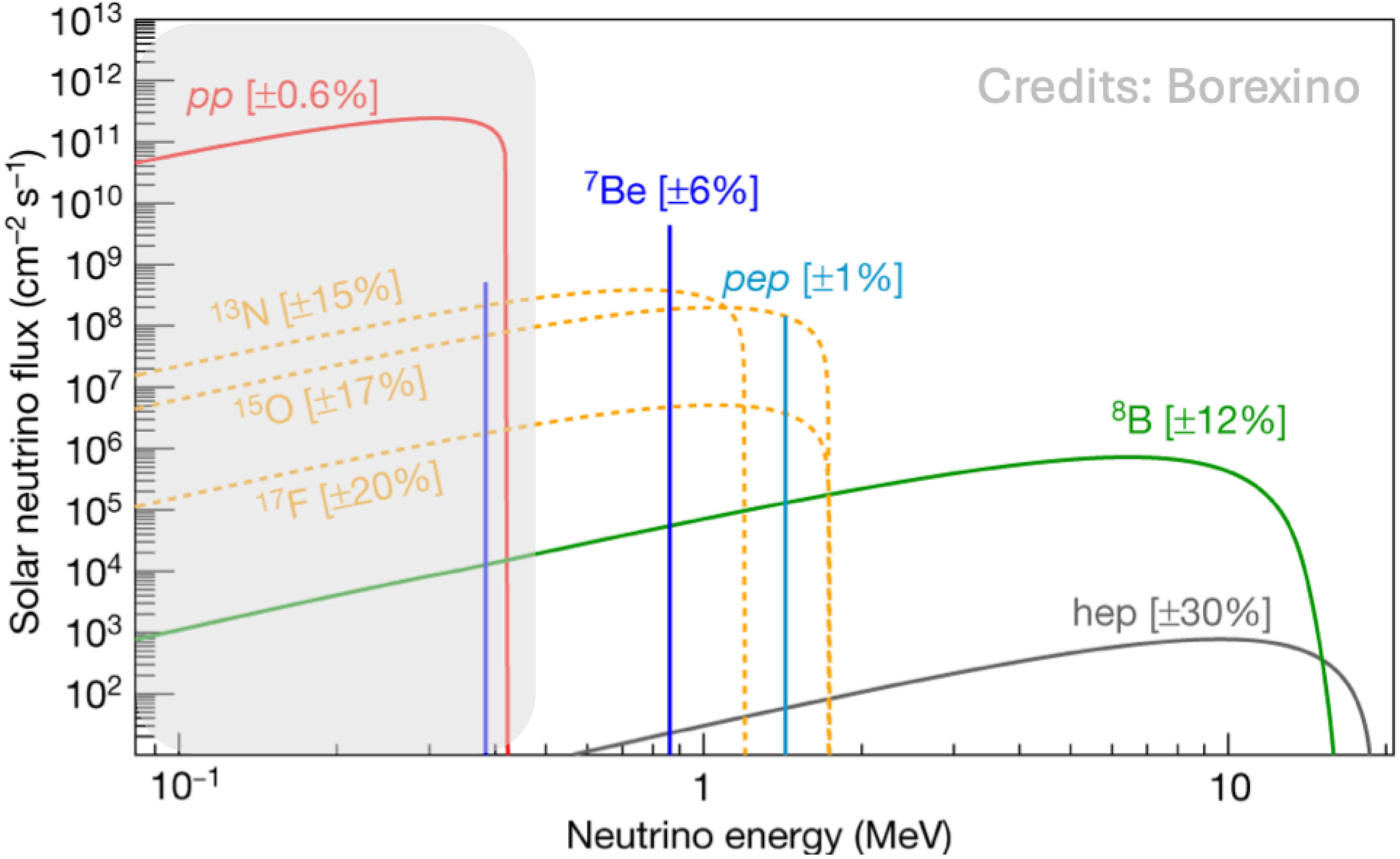
JUNO sensitivity to solar neutrino

Low energy:

- 0.2 - 0.4 MeV
- mostly ***pp***

Main backgrounds:

- **14C** and pile-up
- **85Kr**
- **238U** and **232Th** chains



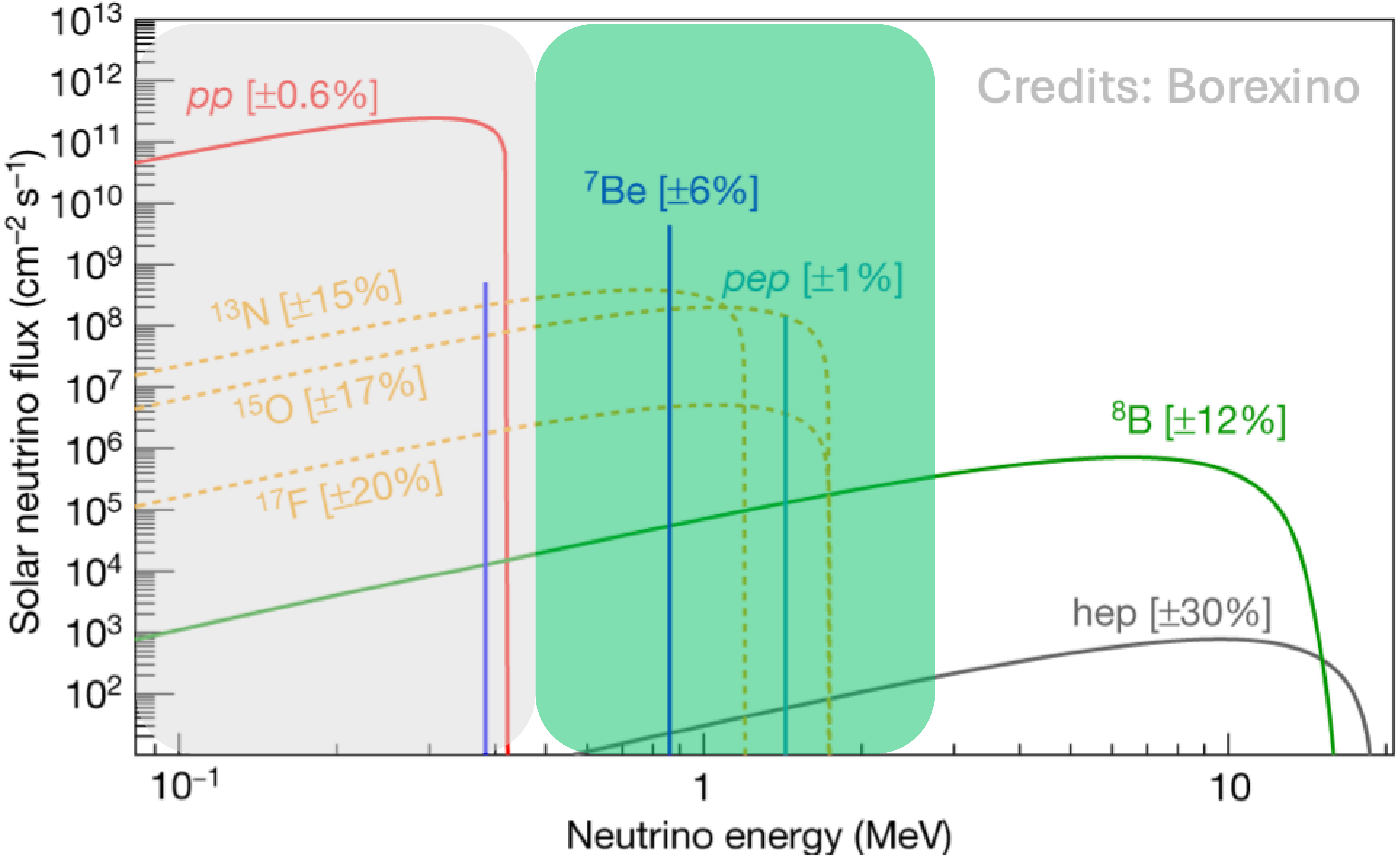
JUNO sensitivity to solar neutrino

Intermediate energy:

- 0.4 - 2.0 MeV
- **7Be, pep, CNO**

Main backgrounds:

- **85Kr**
- **238U** and **232Th** chains
- **210Po - 210Bi**
- **210Pb** chain
- **11C** (cosmogenic)

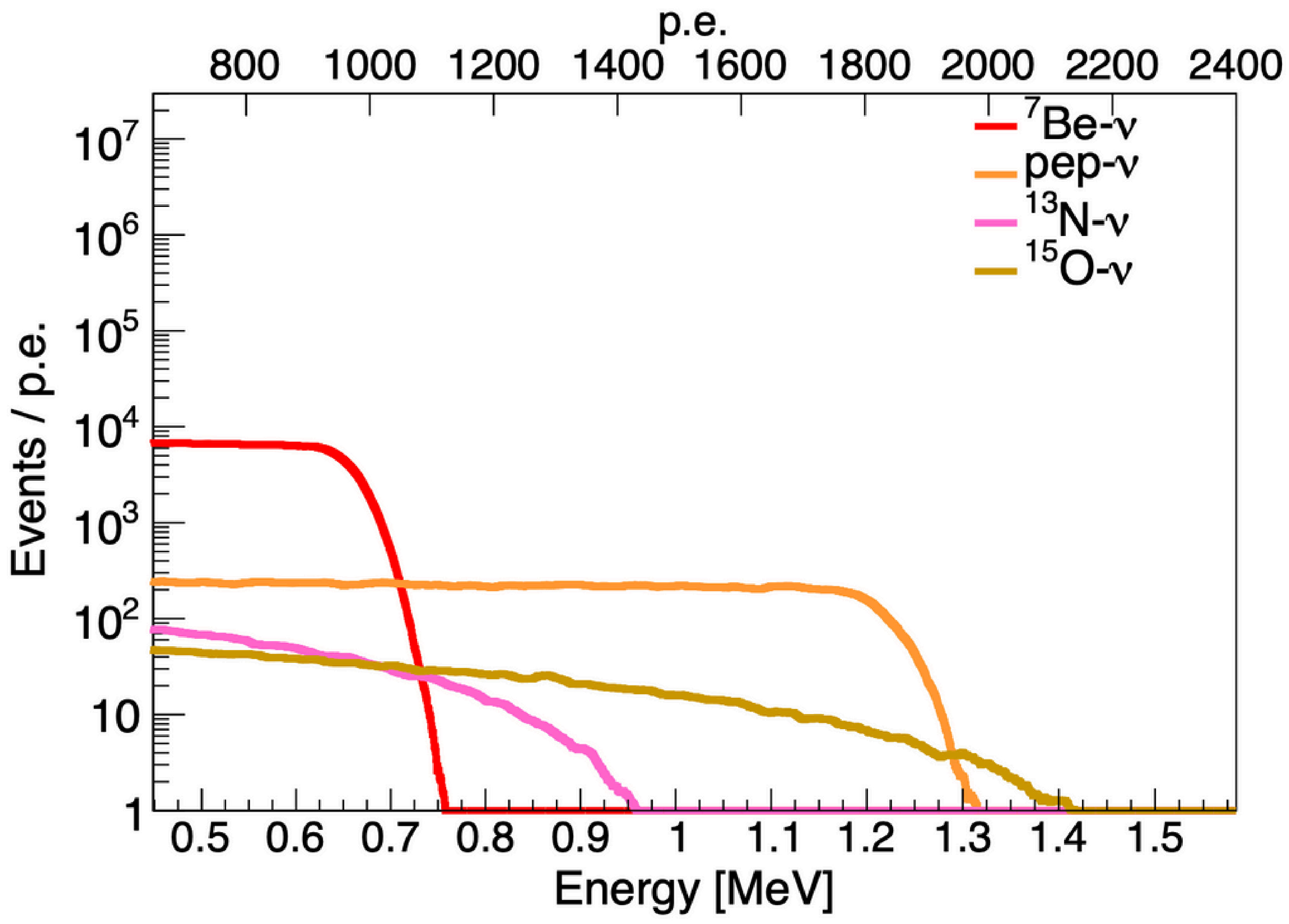


Intermediate energy: 7Be, pep, CNO

The main interaction channel is elastic scattering the electrons of the medium:

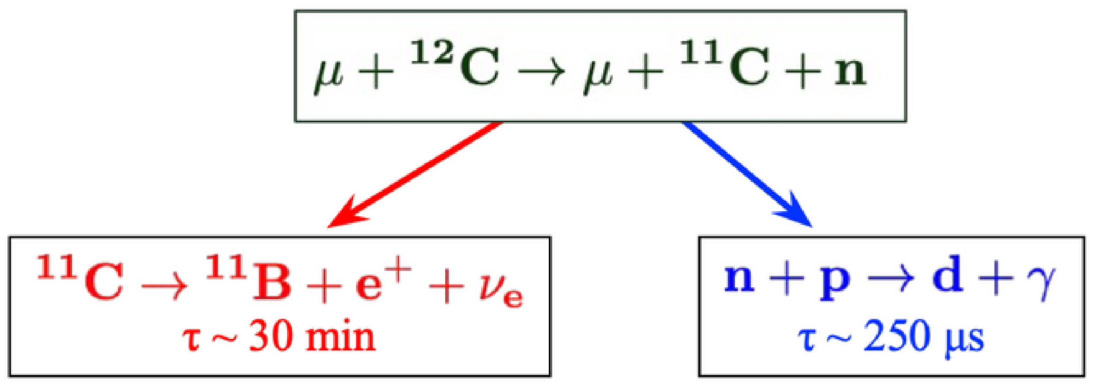
$$\nu_x + e^- \rightarrow \nu_x + e^-$$

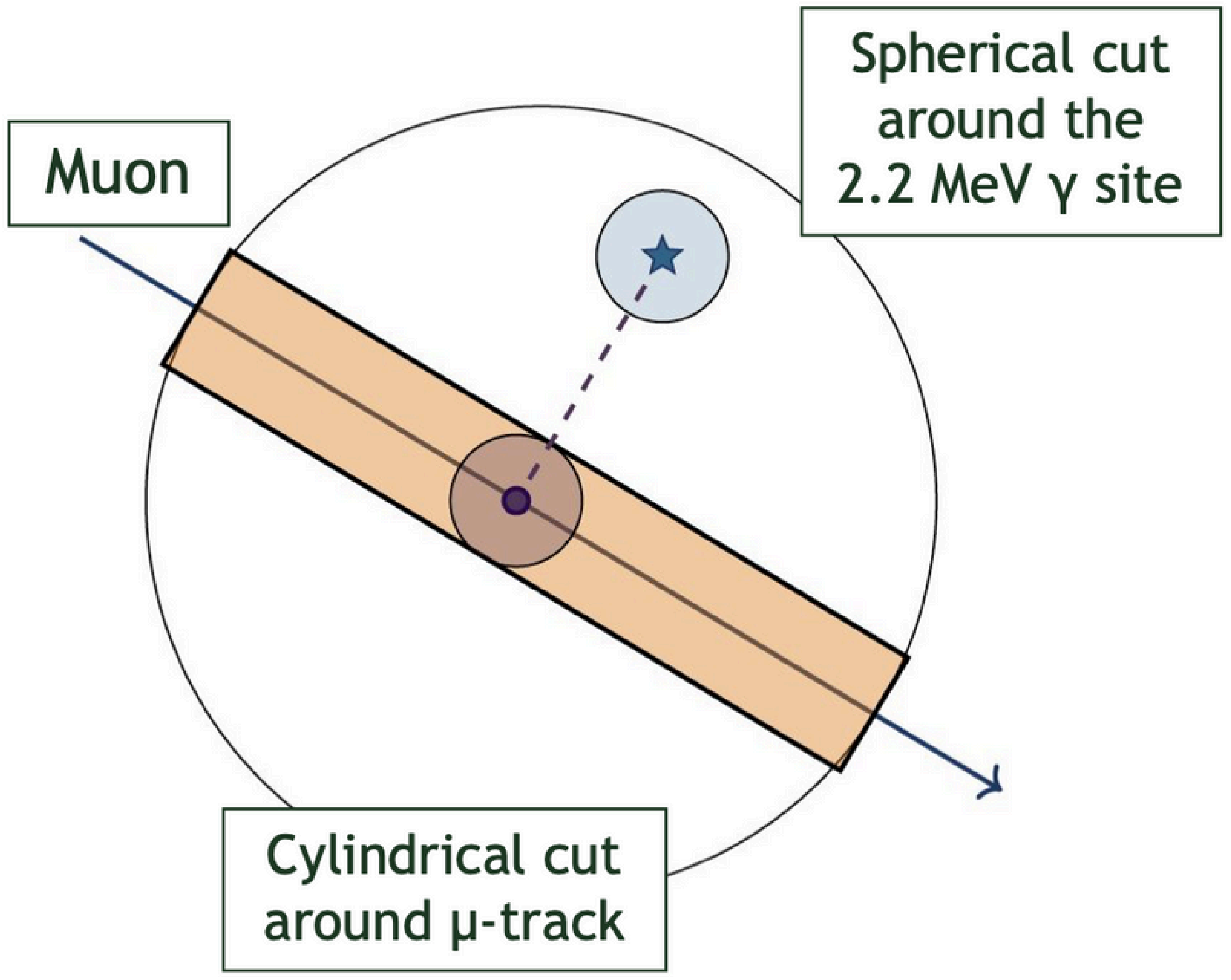
Backgrounds control is one of the key challenge for measure intermediate energy which mimics neutrino signal



Intermediate energy: Cosmogenic backgrounds

Using a technique called Three-Fold Coincidence (TFC) it is possible to tag the production of a 11C isotope in a cylindrical volume along the track of the particle.

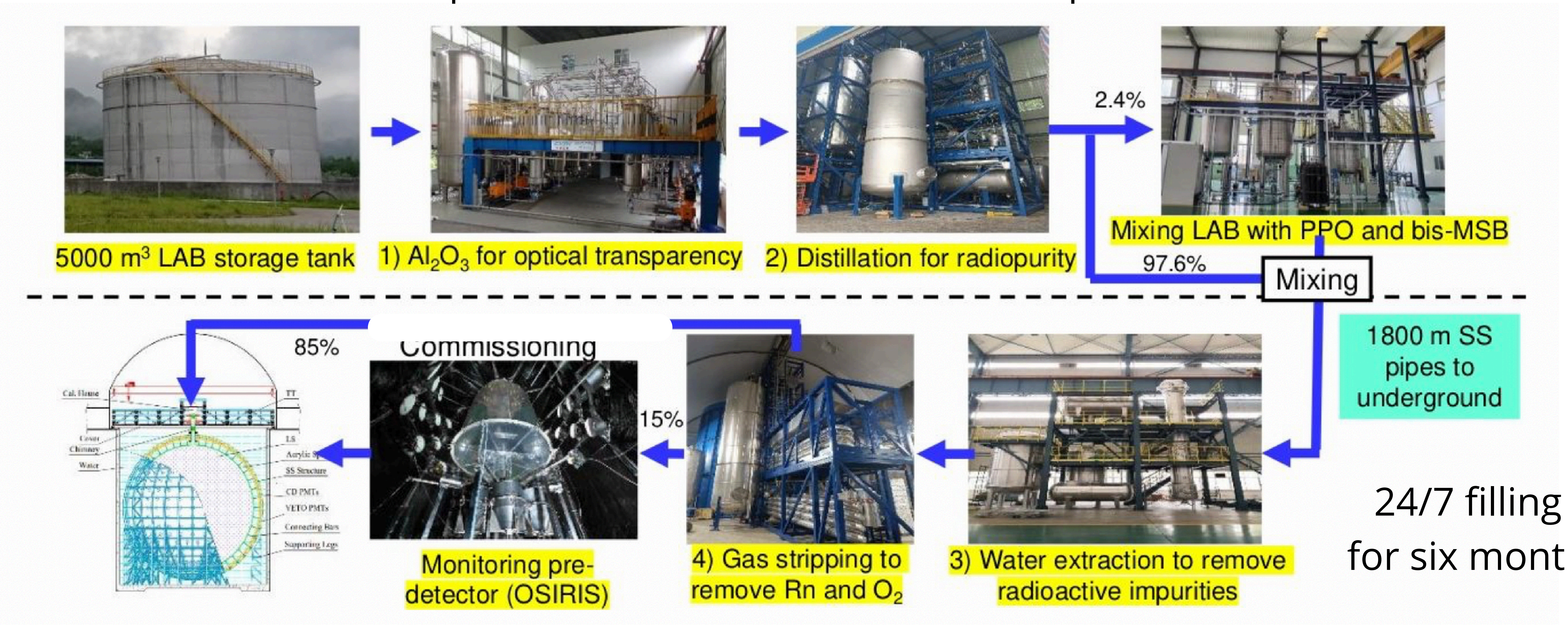




This allows to identify about 90% of the 11C events reducing this background

Intermediate energy: Internal backgrounds

Five purification plants to produce and purify the liquid scintillator going into JUNO
Plus a continuos control in production and cleanness of each part of the detector



24/7 filling
for six month

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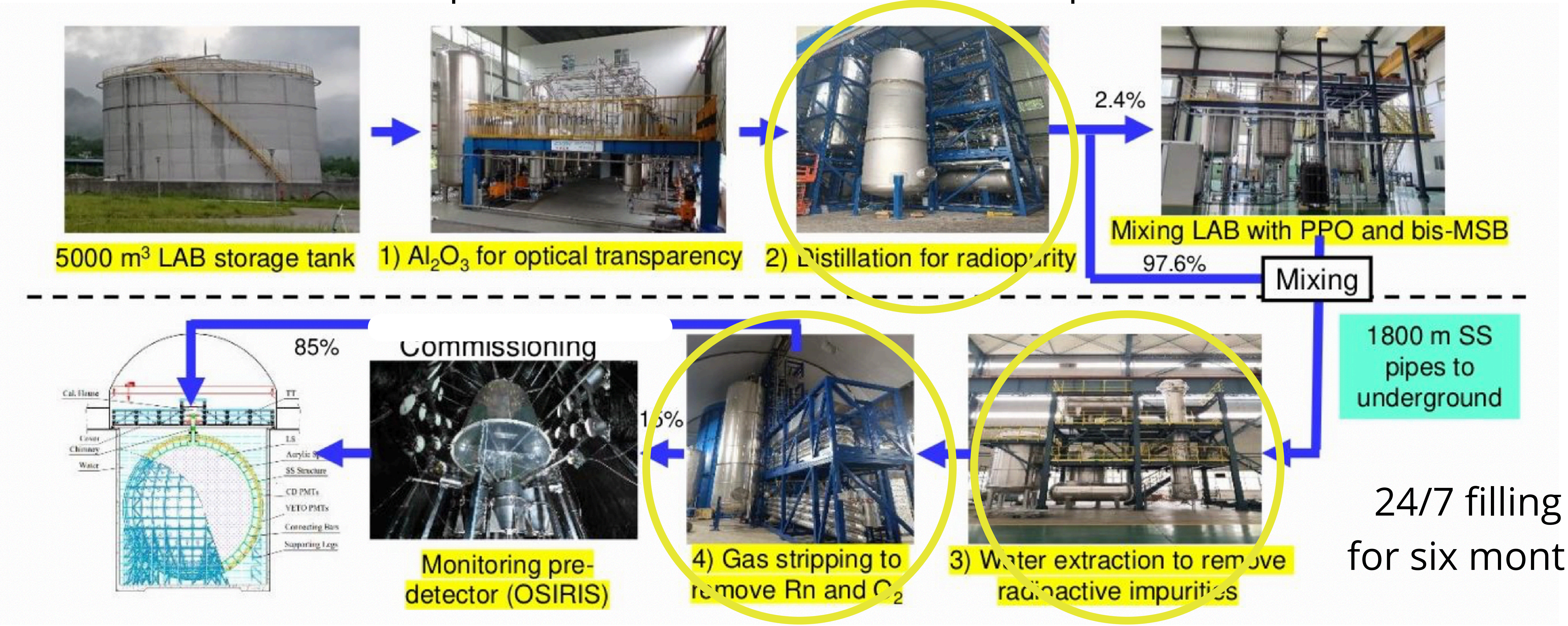

24/7 filling
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The main interaction channel is elastic scattering the electrons of the medium:

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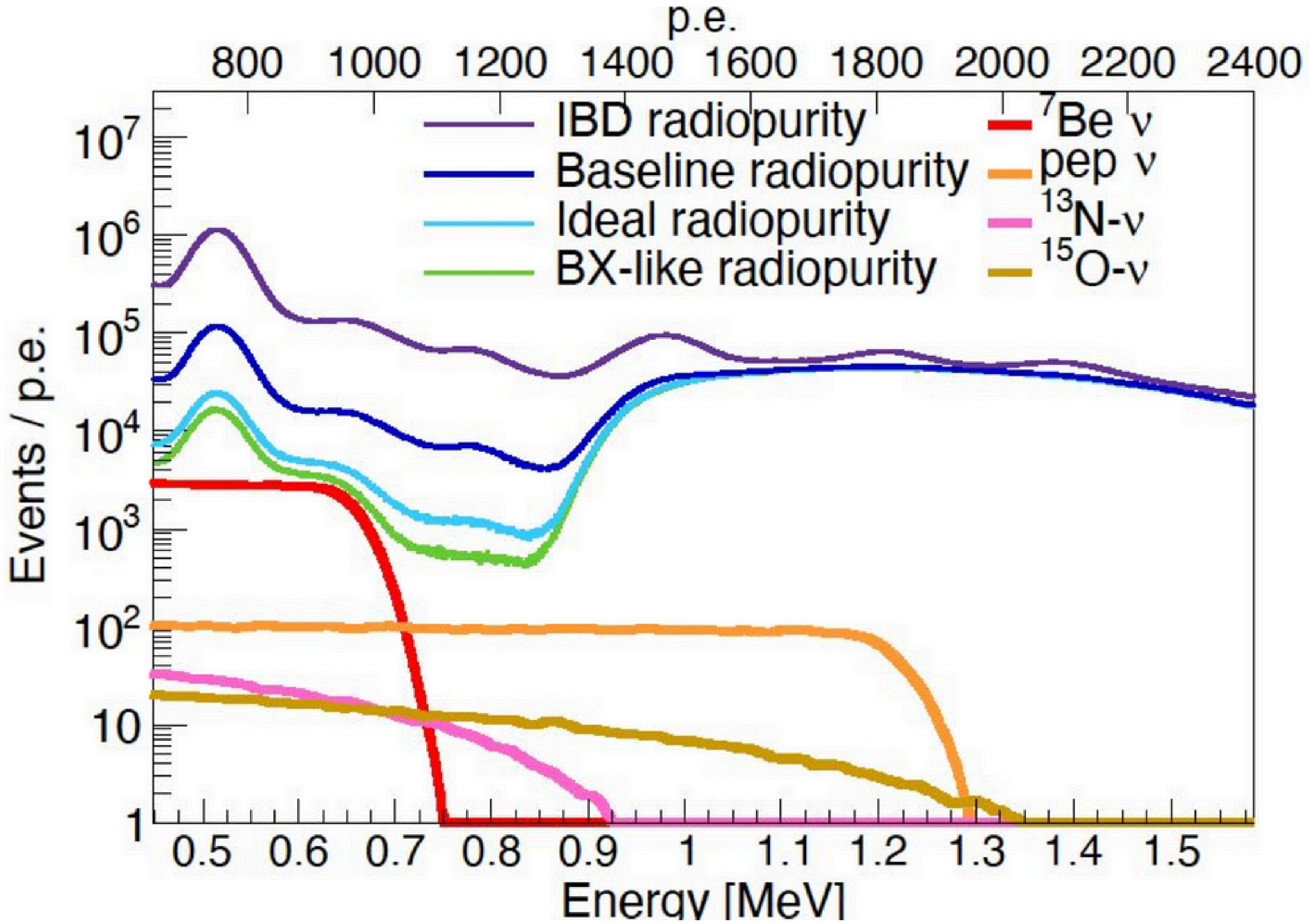
We evaluated three different radiopurity scenarios:

Borexino-like	**~10^{-19} g/g** (U/Th)
Ideal	**10^{-17} g/g** (U/Th)
Baseline	**10^{-16} g/g** (U/Th)
Minimal (IBD)	**10^{-15} g/g** (U/Th)



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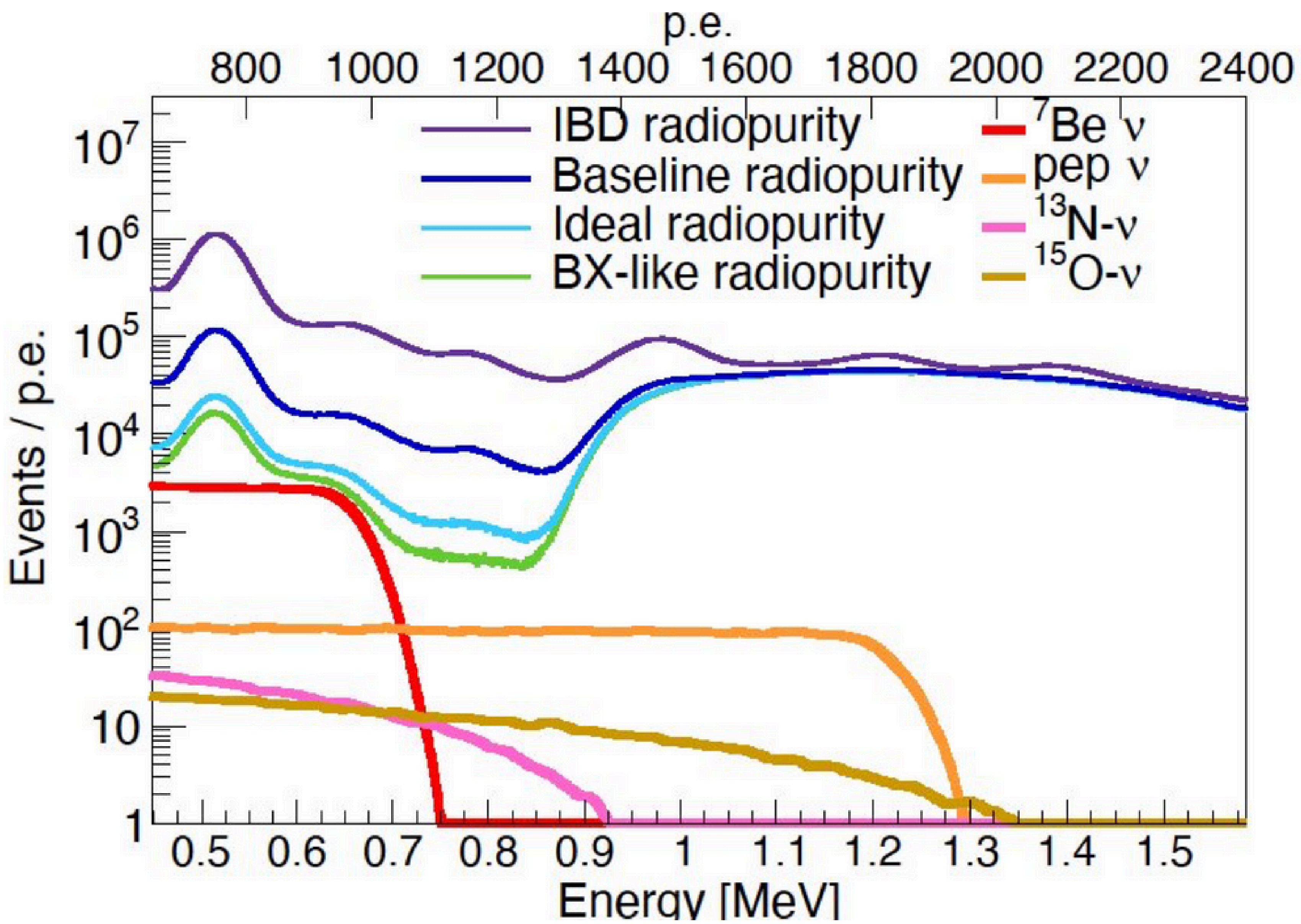


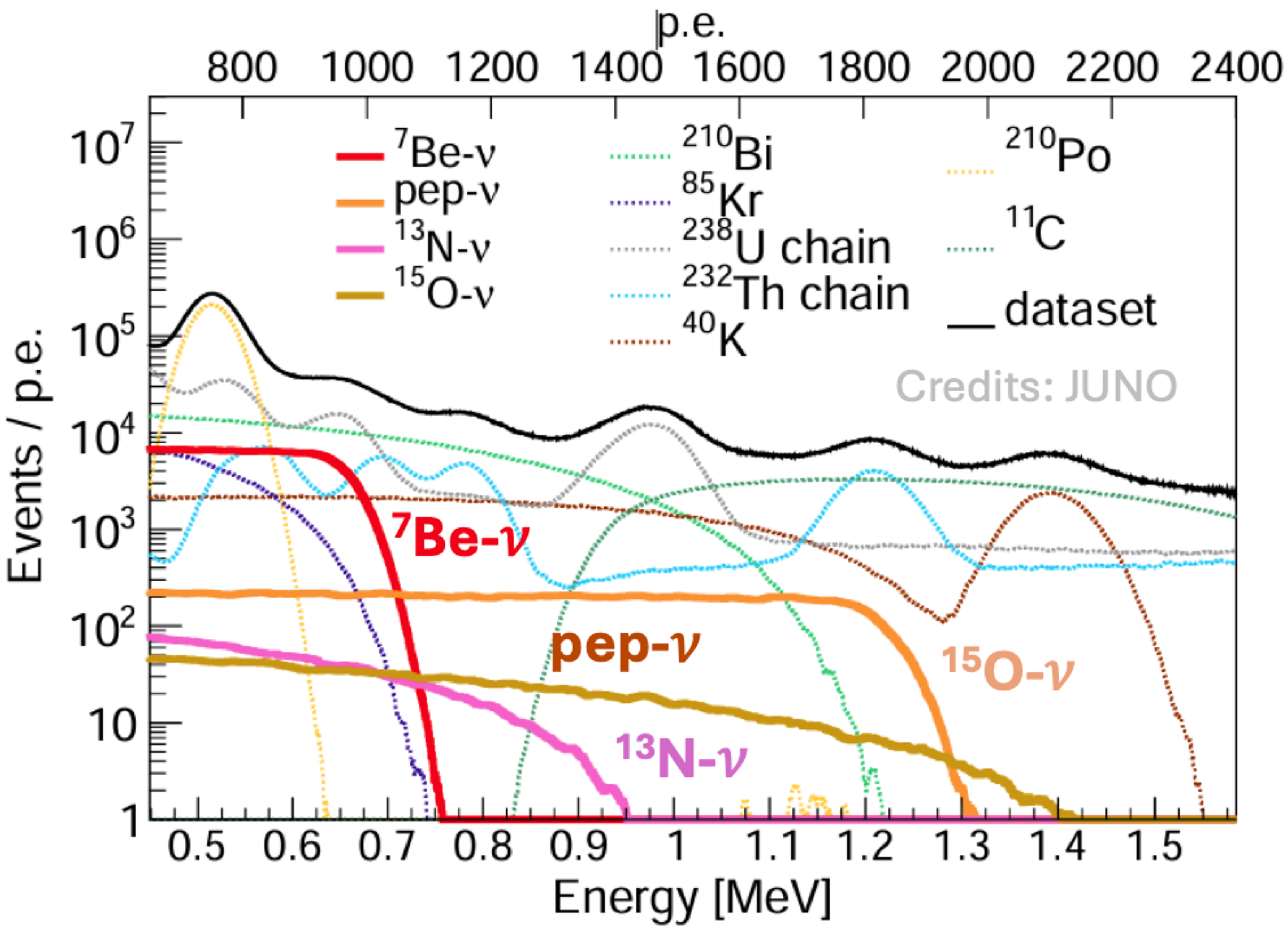
Intermediate energy: 7Be, pep, CNO

As it has been done by the Borexino collaboration, using a **Monte Carlo based fitter** it is possible to separate all the contributions in this energy spectrum

We need to have a very robust Monte Carlo tune on calibration data

From this fit, we extracted relative uncertainty on **solar neutrino rates in the four radiopurity scenarios** in function of the acquisition time

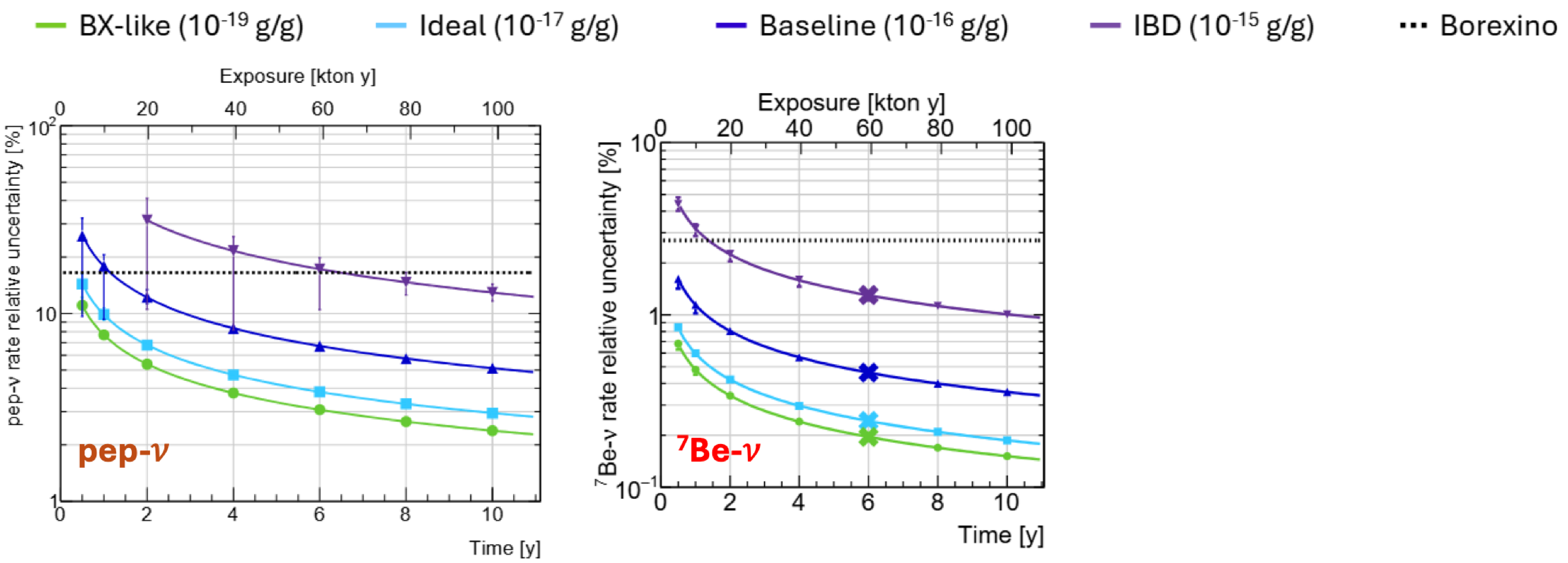
10^-16 g/g scenario



Intermediate energy: 7Be, pep, CNO

Improve current measurements: (with bkg ≤ 10^-16 g/g)

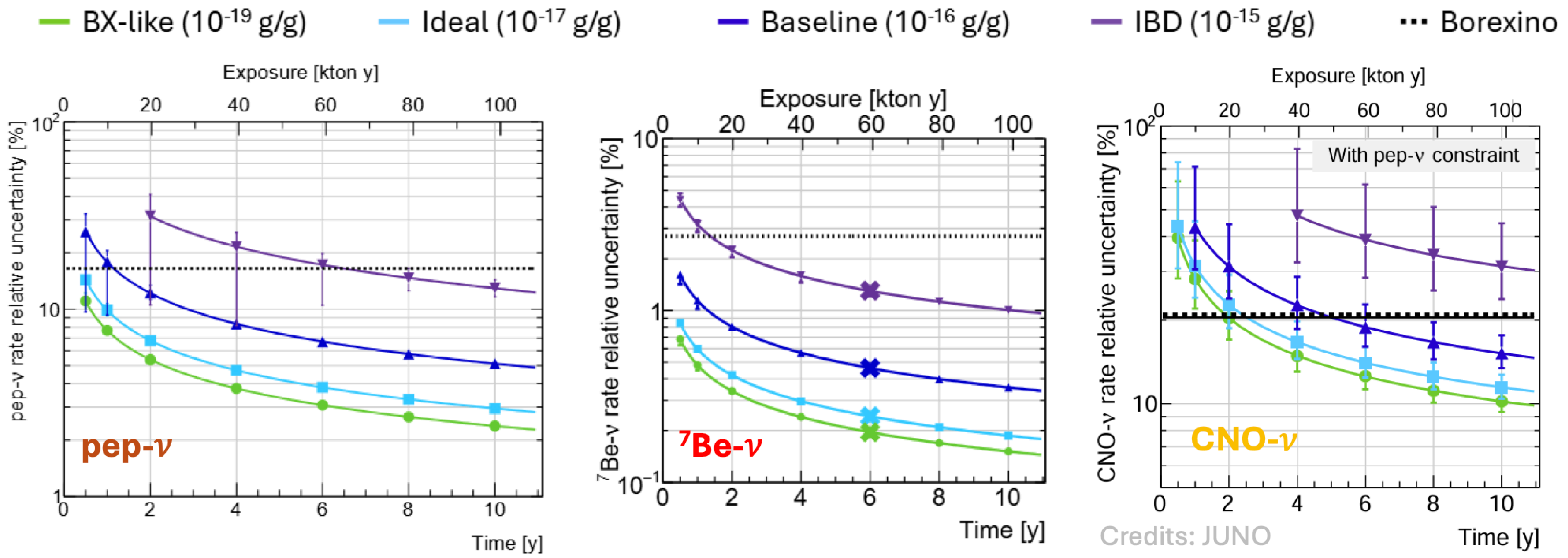
- **pep** and **7Be** better than Borexino in ~2y



Intermediate energy: 7Be, pep, CNO

Improve current measurements: (with bkg ≤ 10^-16 g/g)

- **pep** and **7Be** better than Borexino in ~2y
- **CNO** better than Borexino in ~6y (with no constraint on 210Bi)



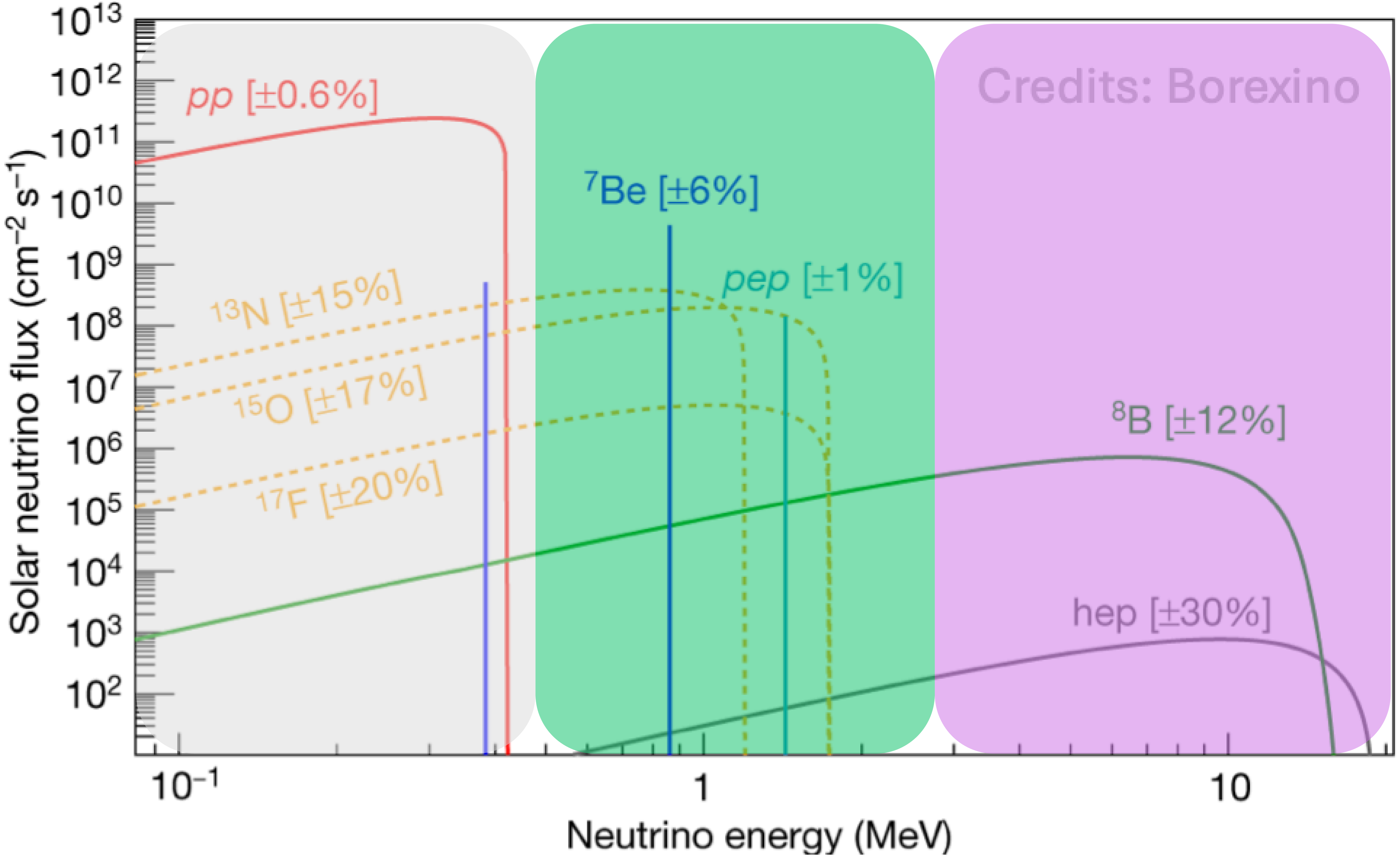
JUNO sensitivity to solar neutrino

High energy:

- > 3 MeV
- mostly **8B** (hep)

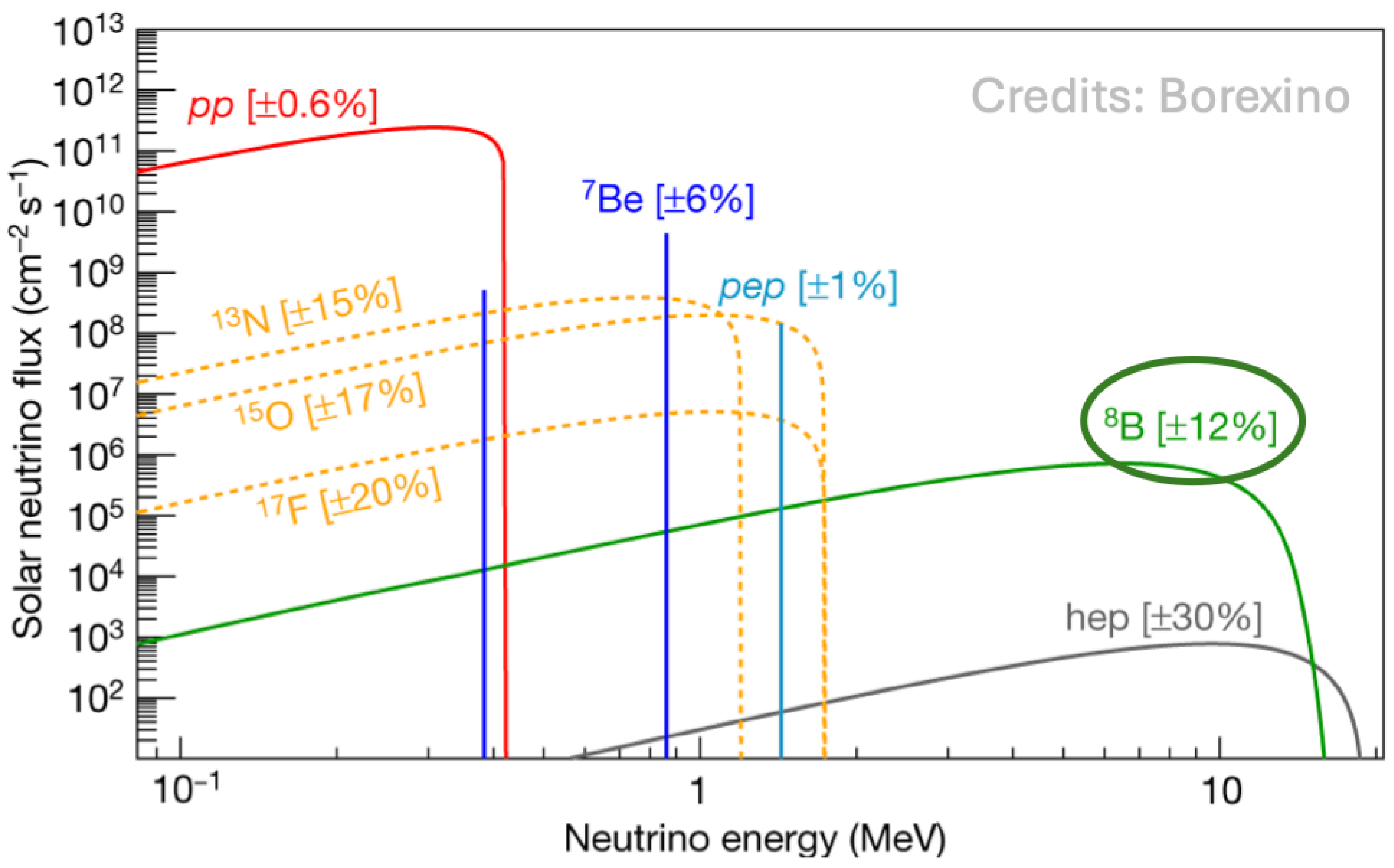
Main backgrounds:

- **Cosmogenics**
- External
- **Accidental** for (CC)



High energy: 8B

JUNO can detect **8B solar neutrinos** by looking to different interaction channels:



ES: $\nu_x + e^- \rightarrow \nu_x + e^-$

- No threshold
- All flavours & $\sigma(\nu_{\mu,\tau}) / \sigma(\nu_e) = 1/6$
- Single events - continuous spectrum

CC: $\nu_e + {}^{13}C \rightarrow e^- + {}^{13}N$

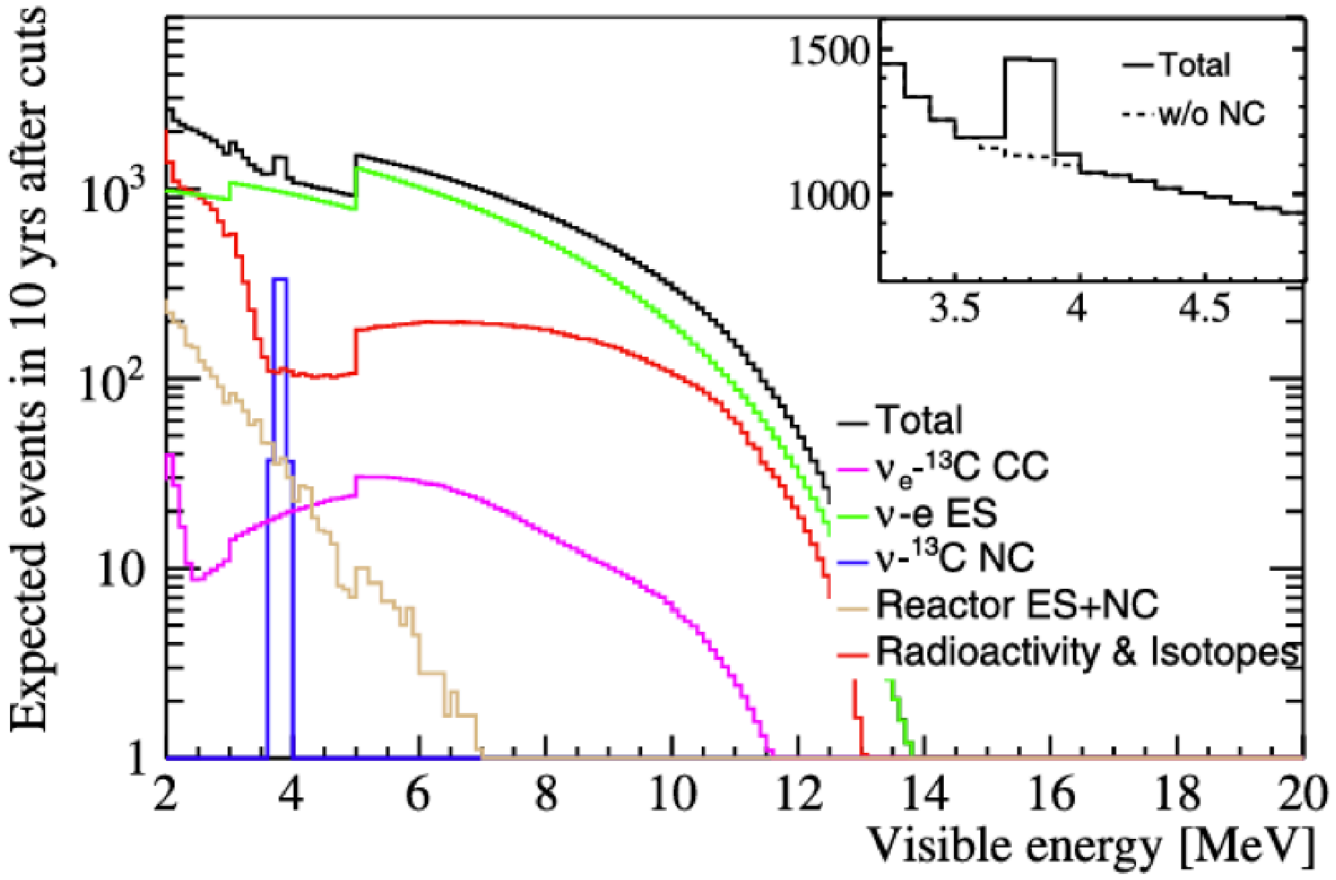
- $E_{thr} = 2.2$ MeV
- Possible only with ν_e
- Prompt: e^-; Delayed: ^{13}N decay

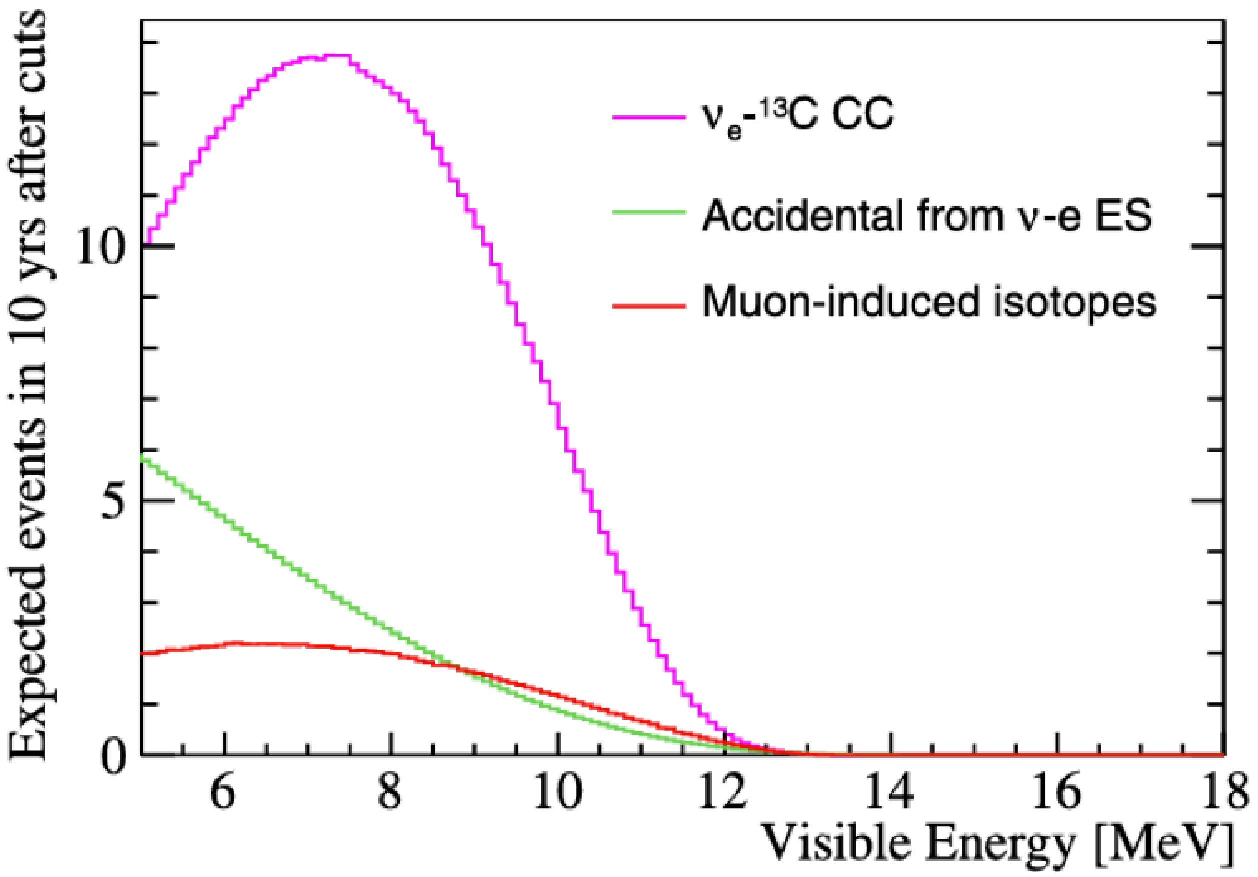
NC: $\nu_x + {}^{13}C \rightarrow \nu_x + {}^{13}C^*$

- $E_{thr} = 3.685$ MeV
- All flavors & equal σ
- Single events - monochromatic γ

High energy: 8B

- ES: $\nu_x + e^- \rightarrow \nu_x + e^-, with\ x = e, \mu, \tau$
  - **no energy threshold**
  - **continuous** energy spectrum
  - all flavors with $\sigma(\nu_{\mu,\tau})$ / $\sigma(\nu_e)$ = 1/6
- CC: $\nu_e + {}^{13}C \rightarrow e^- + {}^{13}N$
  - **threshold of 2.2 MeV**
  - **prompt-delayed** coincidence
  - only ν_e
- NC: $\nu_x + {}^{13}C \rightarrow \nu_x + {}^{13}C^*$
  - **threshold of 3.685 MeV**
  - **mono-energetic** gamma
  - all flavors



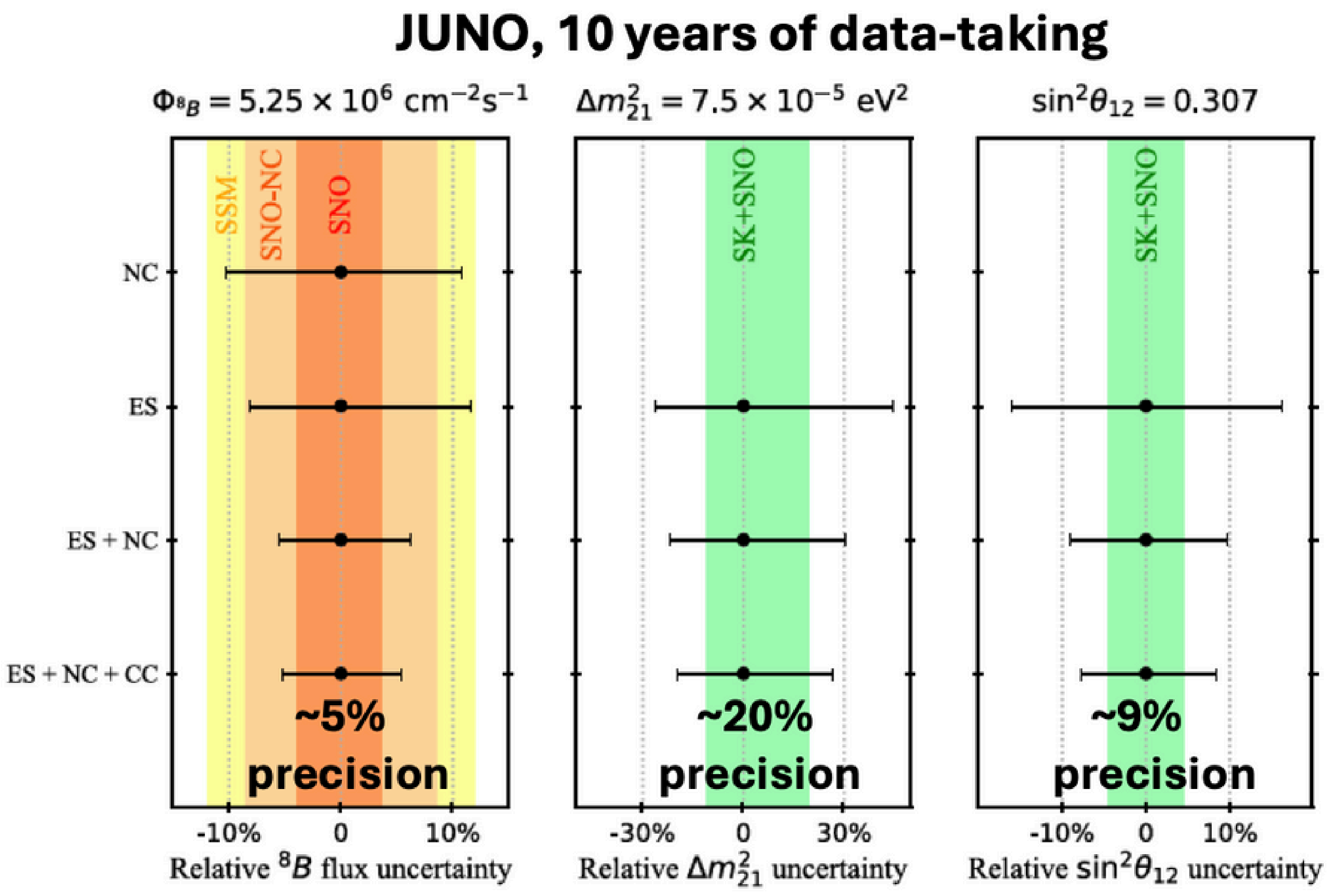


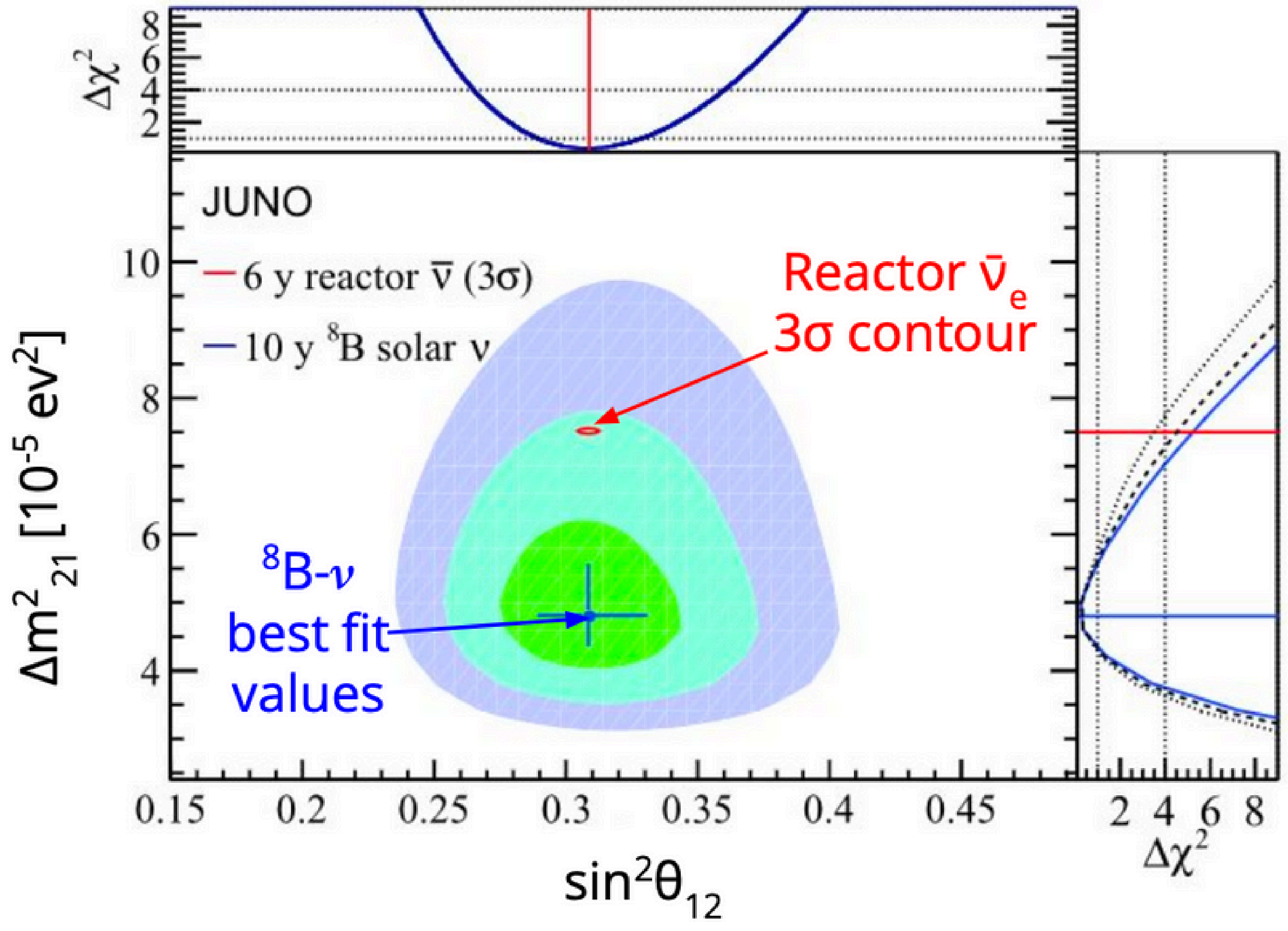
High energy: 8B

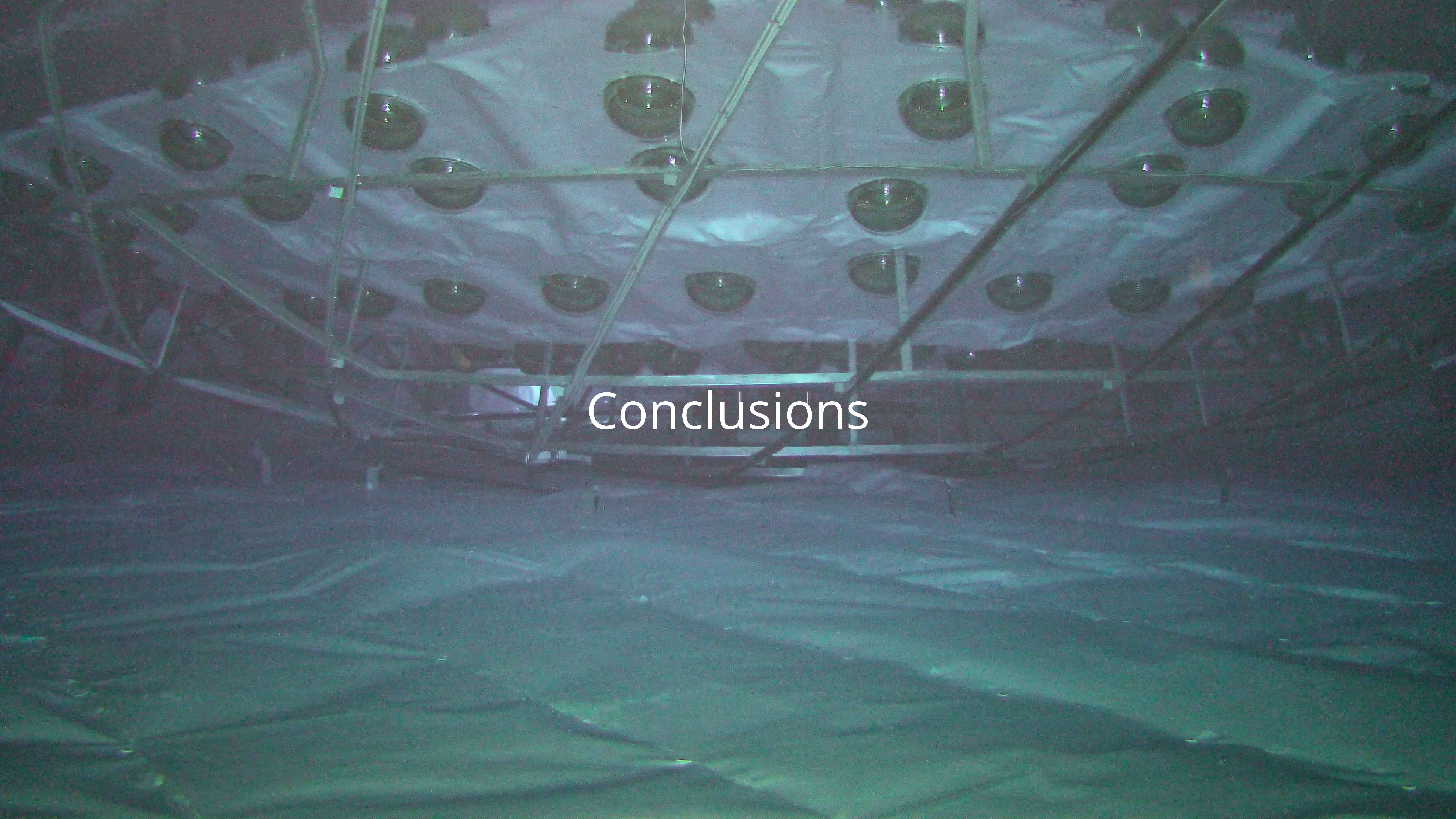
CC & ES: their event rate depends on the **neutrino flux** and on the ν **survival probability**

NC: it will allow a model **independent measurement of** $\Phi(^8B)$, first after SNO

Simultaneous measurement of $\Phi(^8B),\ \Delta m^2_{21}, sin^2(\theta_{12})$





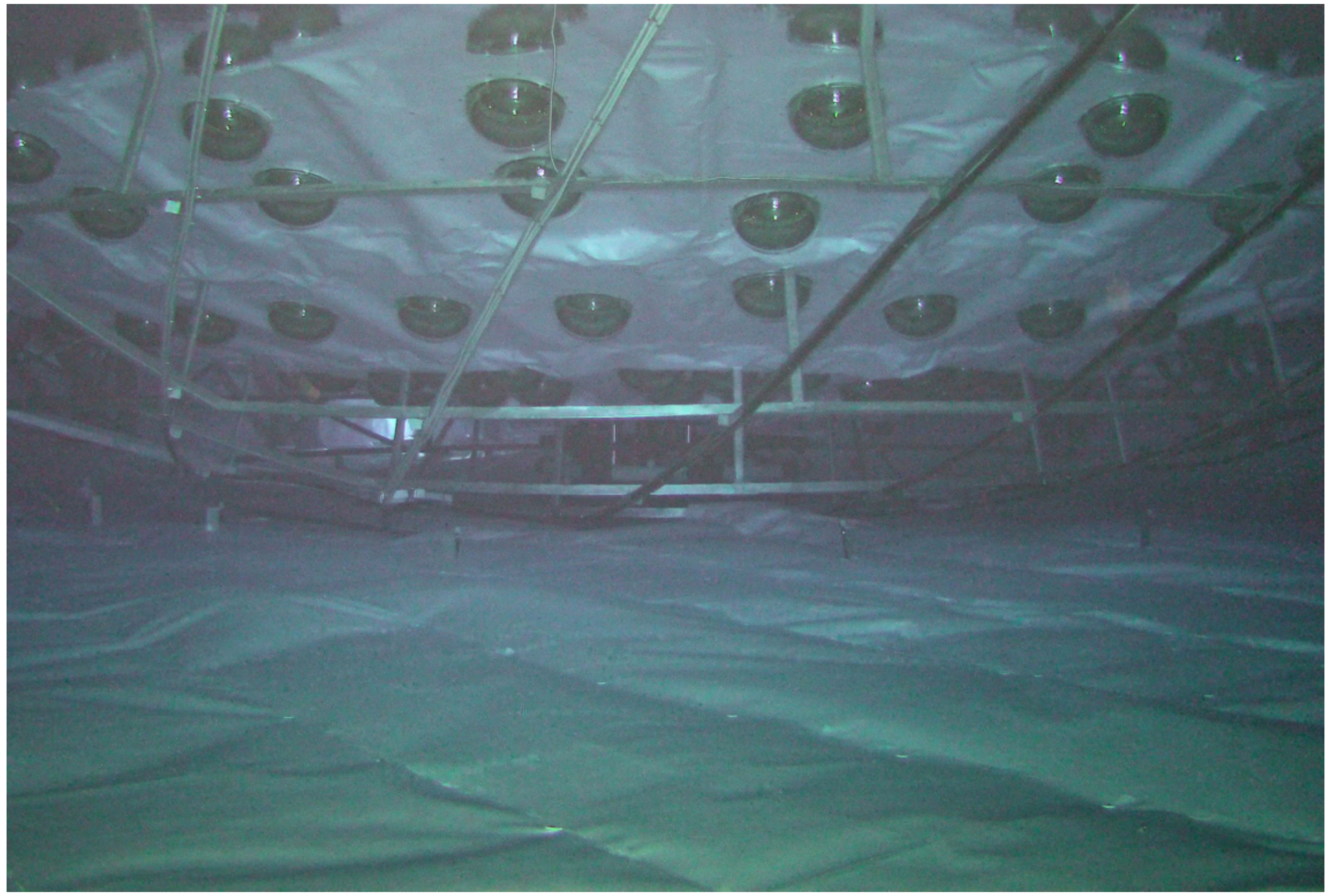


Conclusions

Conclusions

JUNO will perform important solar neutrino measurements, such as:

- **8B** flux with **5% precision** after 10 years
- Solar **oscillation parameters** independently from reactor
- **7Be and pep fluxes better than Borexino** in few years
- **CNO flux solar for metallicity problem**



JUNO data taking is going to start

Current level of radiopurity is < 10^{-16} g/g U/Th


Backup

Intermediate energy: 7Be, pep, CNO

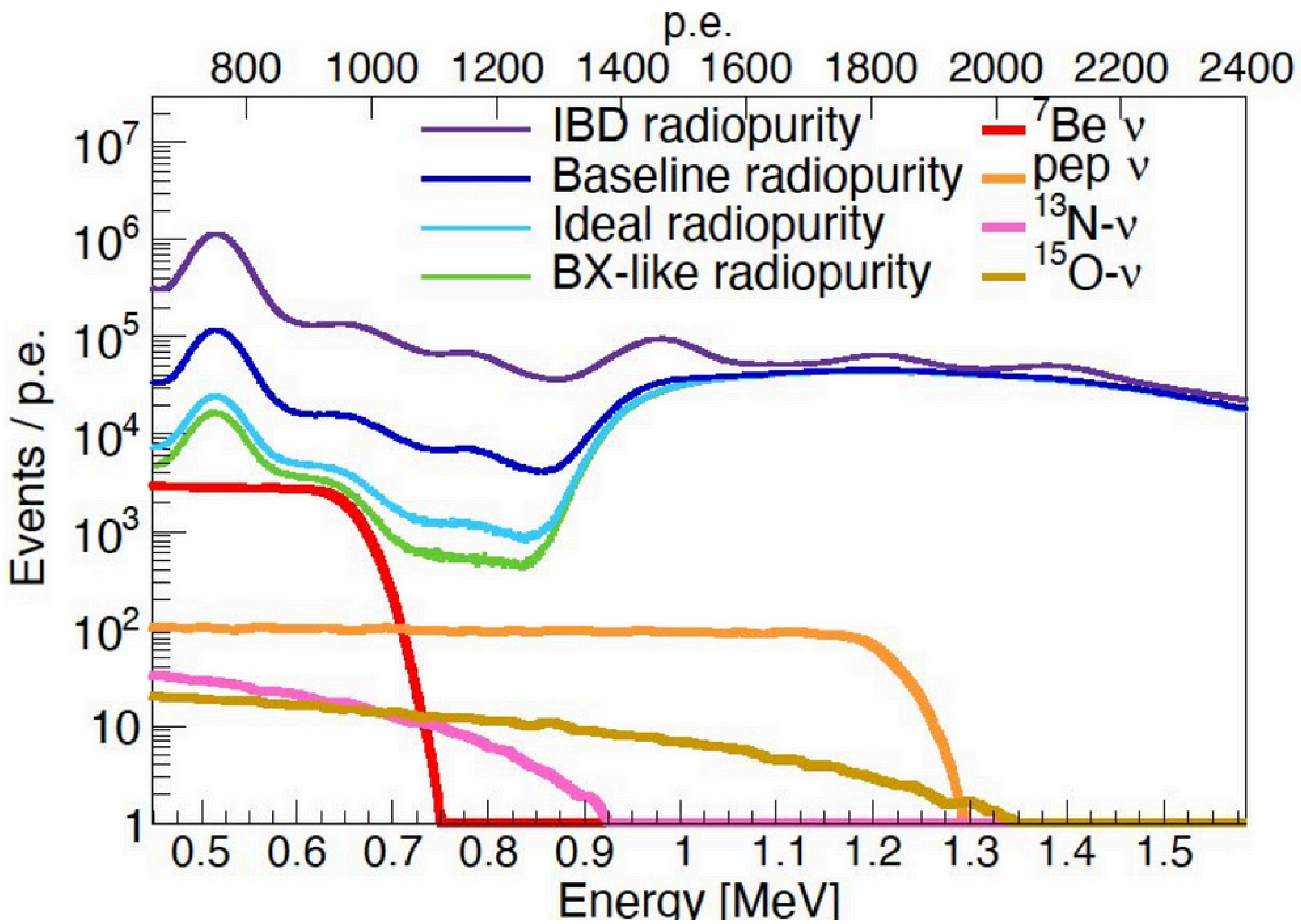
The main interaction channel is elastic scattering the electrons of the medium:

$$\nu_x + e^- \rightarrow \nu_x + e^-$$

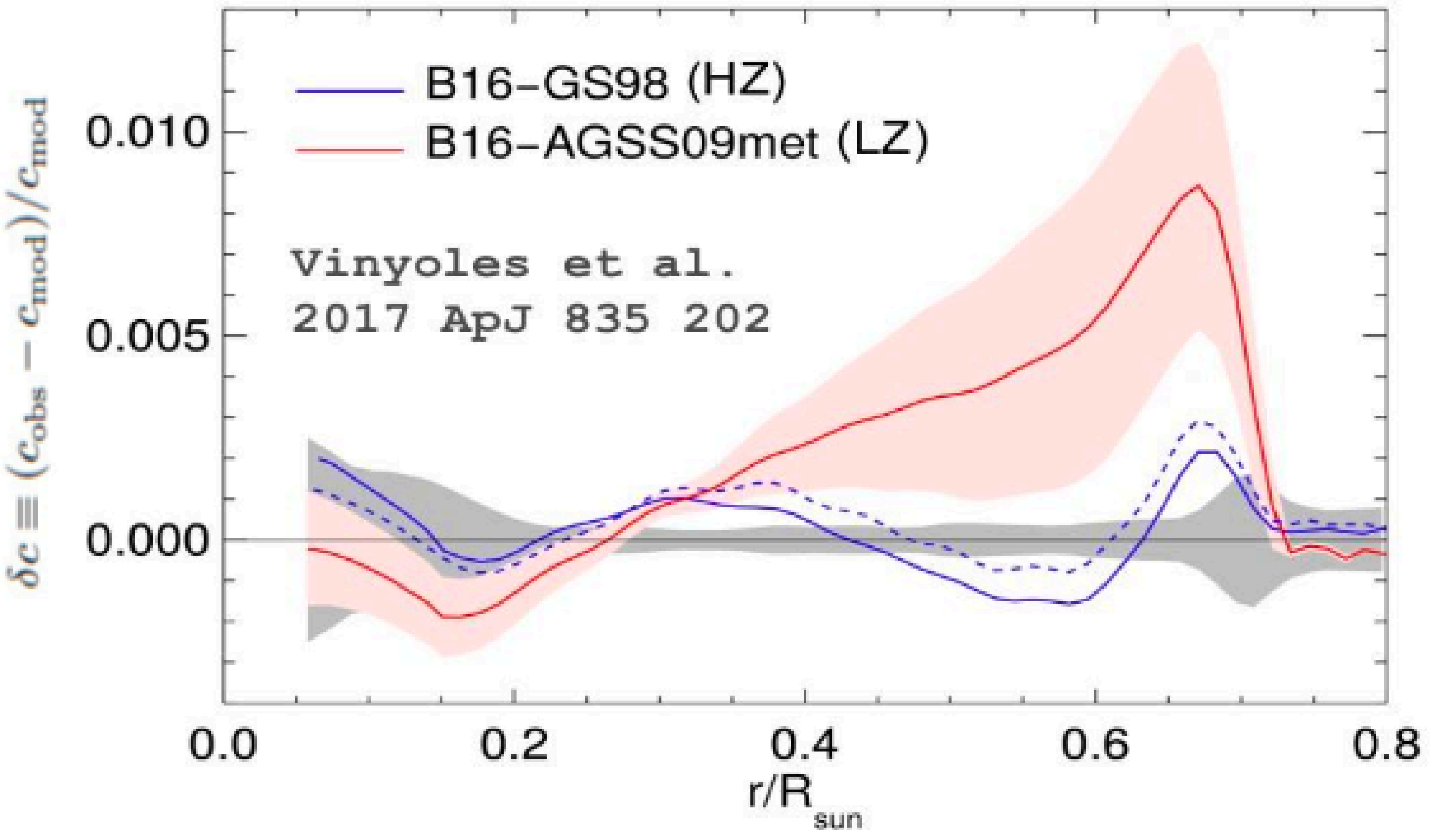
Backgrounds control is one of the key challenge for measure intermediate energy which mimics neutrino signal

We evaluated three different radiopurity scenarios:

	U [g/g]	Th [g/g]	K [g/g]	Kr [g/g]
IBD	1×10^{-15}	1×10^{-15}	1×10^{-16}	4×10^{-24}
Baseline	1×10^{-16}	1×10^{-16}	1×10^{-17}	4×10^{-25}
Ideal	1×10^{-17}	1×10^{-17}	1×10^{-18}	8×10^{-26}
BX-like	5.7×10^{-19}	9.4×10^{-20}	2×10^{-19}	8×10^{-26}



Intermediate energy: solar metallicity



	Solar ν	^{7}Be	*pep*	CNO
HZ-SSM	$\Phi\ [10^8\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}]$	49.3(1±0.06)	1.44(1 ± 0.009)	4.88(1 ± 0.11)
	R [cpd/kton]	489 ± 29	28.0 ± 0.4	50.3 ± 8.0
	R^{ROI} [cpd/kton]	142.5 ± 8.3	17.1 ± 0.2	16.6 ± 2.6
LZ-SSM	$\Phi\ [10^8\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}]$	45.0(1±0.06)	1.46(1 ± 0.009)	3.51(1 ± 0.10)
	R [cpd/kton]	447 ± 26	28.4 ± 0.4	36.0 ± 5.3
	R^{ROI} [cpd/kton]	130.0 ± 7.5	17.3 ± 0.2	11.9 ± 1.8

Intermediate energy: solar metallicity

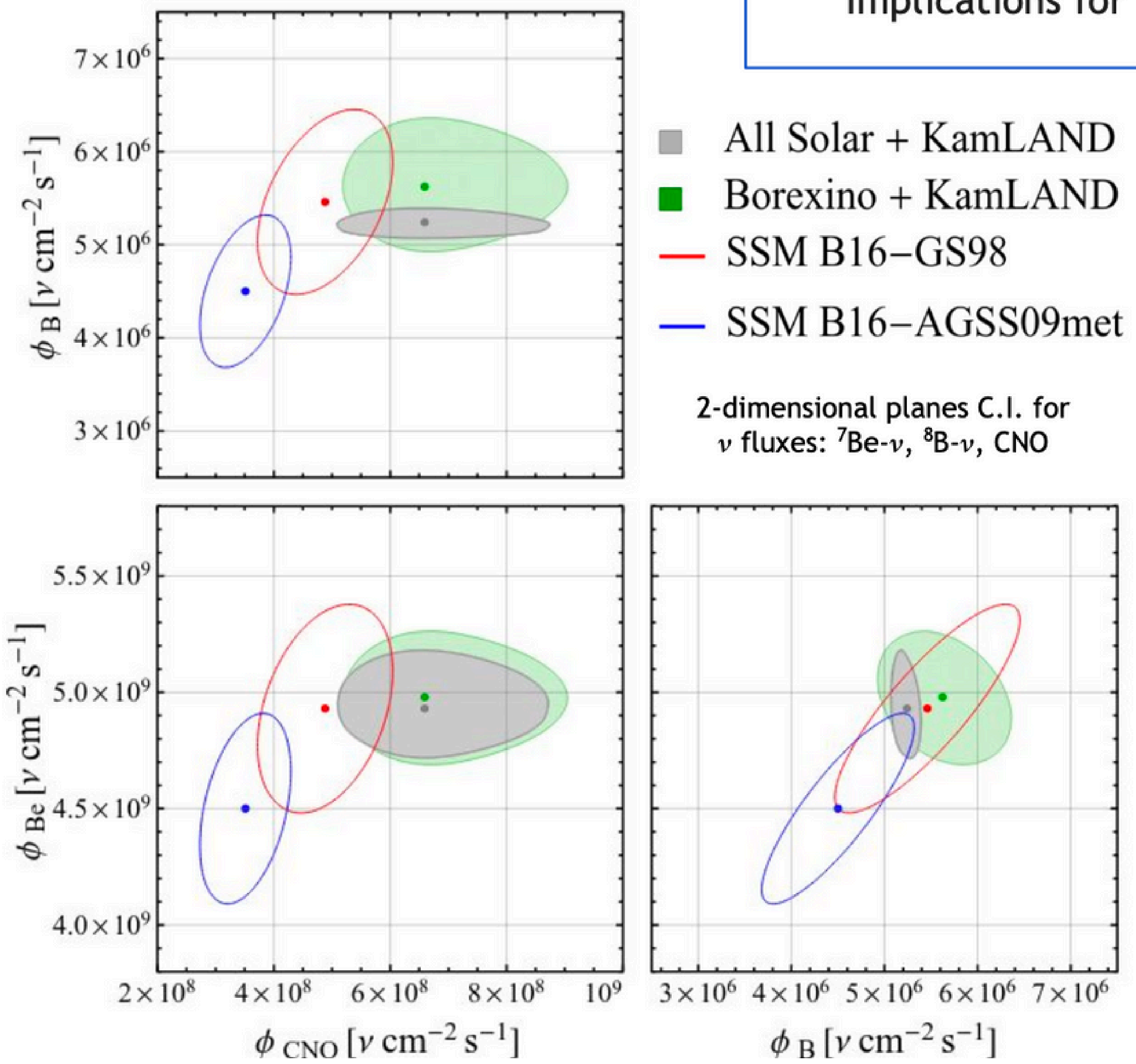
PRL 129 (2022) 252701
"Improved Measurement of Solar Neutrinos from CNO cycle and Its Implications for the SSM".

Global analysis of solar ν fluxes

- General agreement with SSM-HZ scenario
- Binary hypothesis test: HZ vs LZ

Assuming SSM-HZ, Borexino results on ^{7}Be-ν + ^{8}B-ν + CNO-ν,

→ **the SSM-LZ scenario is disfavored at ~3.1σ level**



2-dimensional planes C.I. for ν fluxes: ^{7}Be-ν, ^{8}B-ν, CNO