The JUNO experiment at IIHE

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On behalf of the JUNO IIHE group

JUNO

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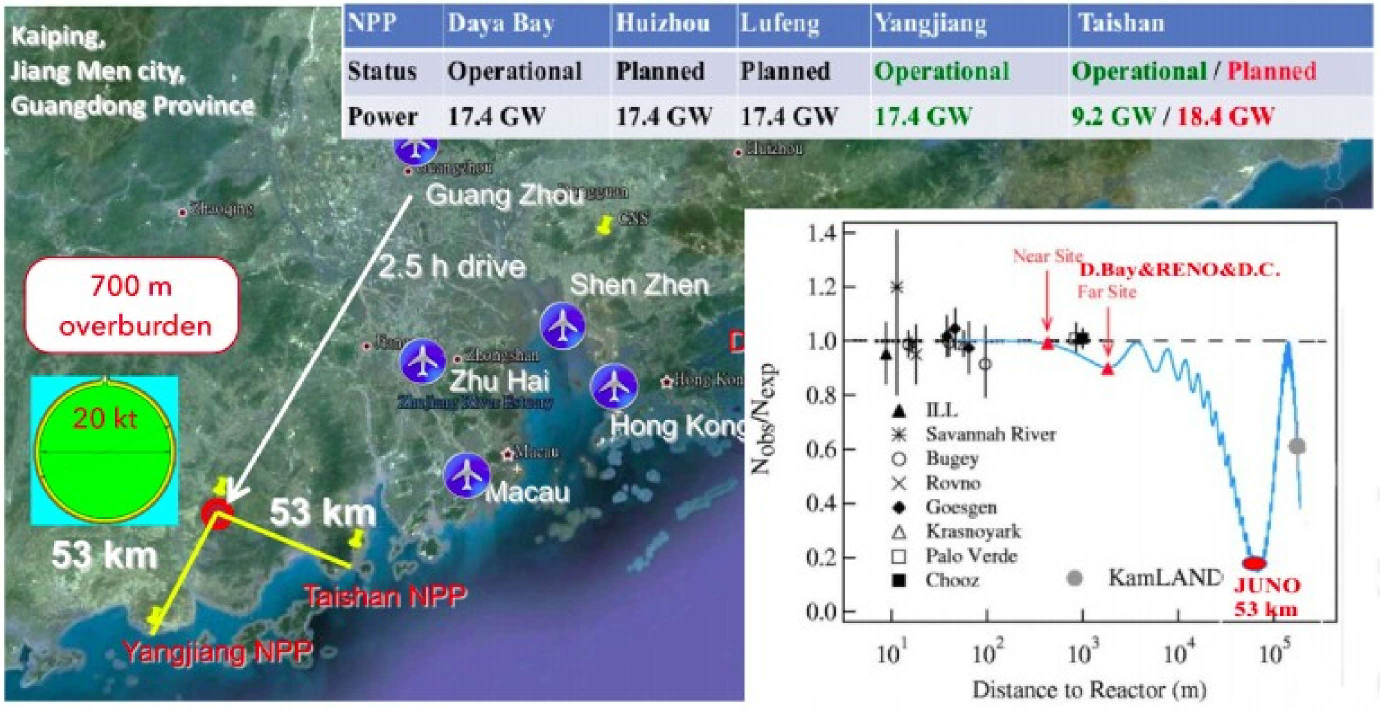
An overview of JUNO

The JUNO detector

- JUNO (Jiangmen Underground Neutrino Observatory) is a medium baseline (53 km) reactor neutrino experiment, located 700 m underground.
- JUNO measures the neutrino flux from 8 reactor cores dispatched in two nuclear power plants (combined thermal power of 26.6 GW).

Why is JUNO a particular experiment?
→ Largest ever liquid scintillator (LS) detector with impressive PMT coverage (>40k PMTs)



NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Operational	Operational / Planned
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	9.2 GW / 18.4 GW

The JUNO detector

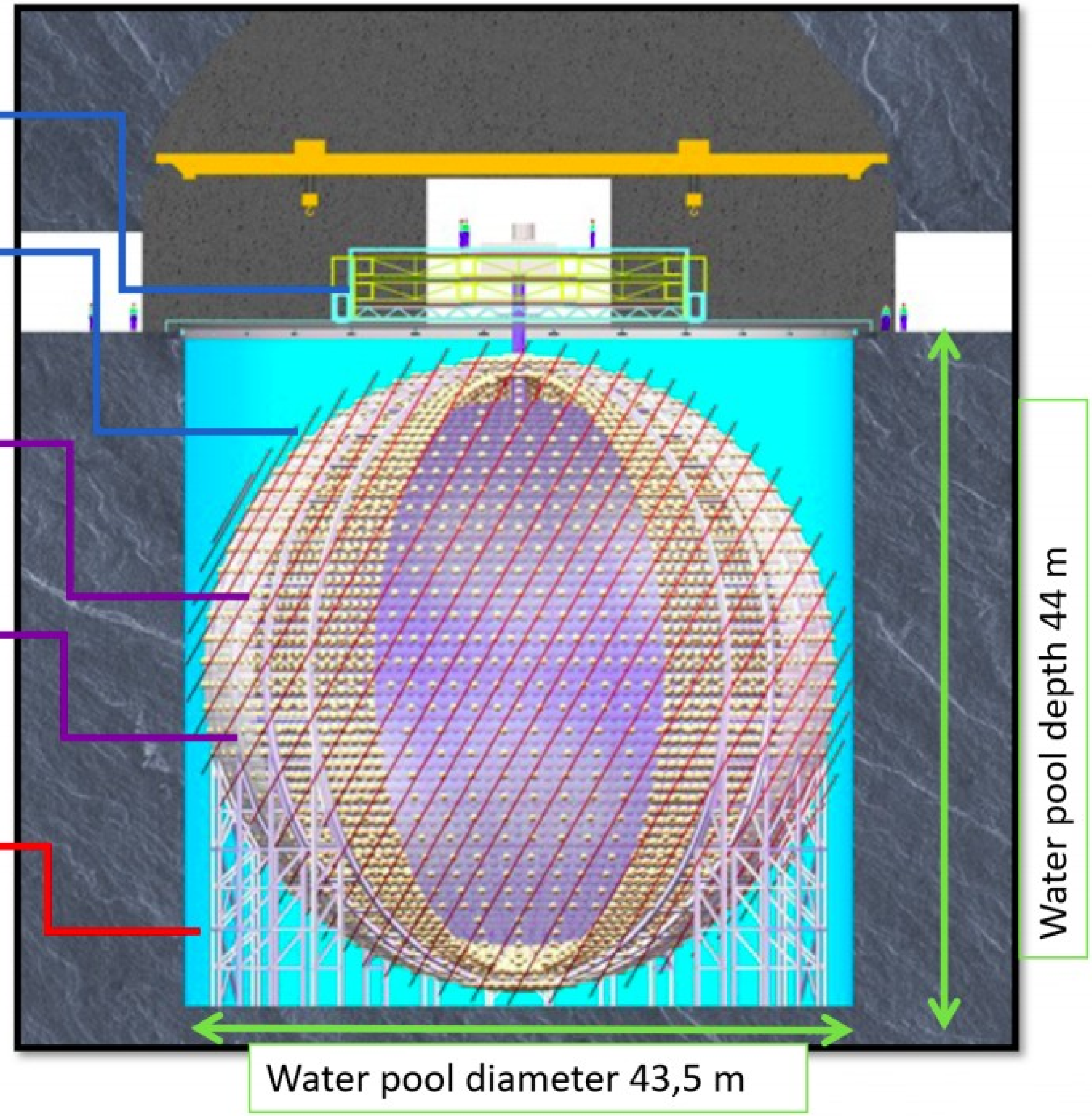
Top tracker

Earth Magnetic Fields
hielding
coils

Central detector:
- Steel structure
- Acrylic Sphere
- 20 kton LS

PMT:
- 17612 20'' PMTs
- 25600 3'' PMTs
- 77.5% Coverage

Veto:
- 40 kton Pure water
- 2400 20'' PMTs

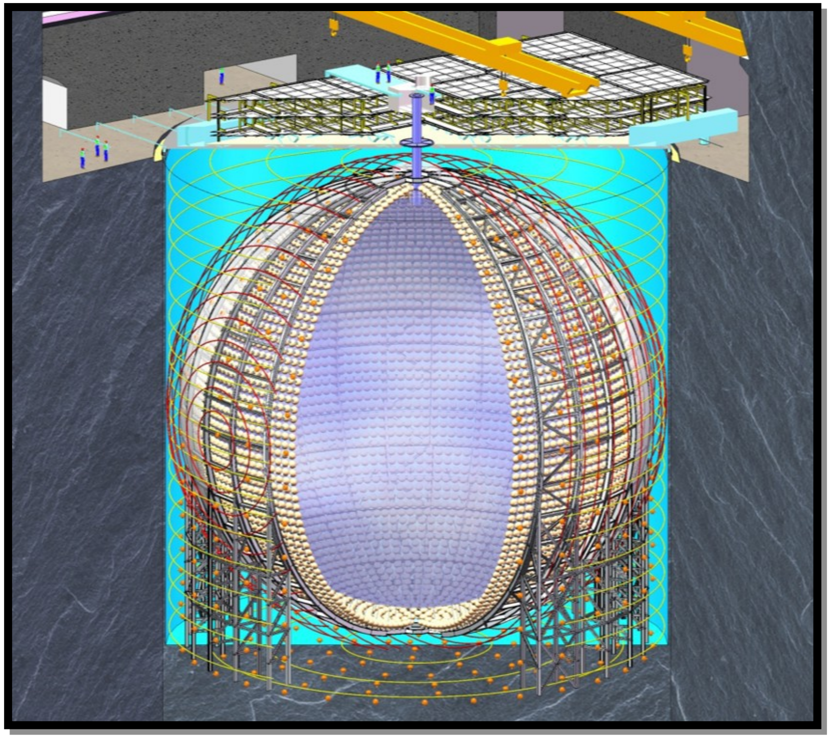


The JUNO detector

Goal: determination of the neutrino mass ordering (3σ level) in 6 years

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

How?
- Large LS volume (20 kton)
- High LS light yield & transparency
- High PMT coverage and efficiency
- Double (stereo-)calorimetry
- Complementary calibration systems



Experiment	Daya Bay	Borexino	KamLAND	JUNO
LS mass	20/detector t	~300 t	~1000 t	~20 000 t
Photon collection	~160/MeV	~500/MeV	~250/MeV	~1200MeV
Energy resolution	~7.5%@ 1 MeV	~5%@ 1 MeV	~6%@ 1 MeV	~3% @ 1 MeV
PMT number	192 8-in.	2212 8-in.	1325 20-in. & 554 17-in.	17612 20-in. & 25600 3-in

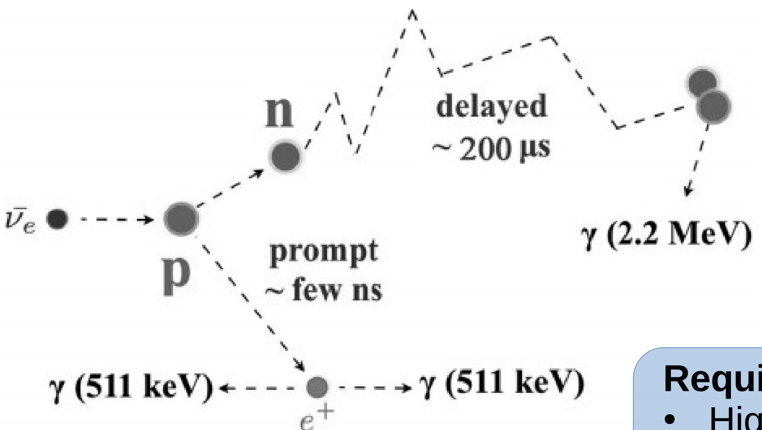
Neutrino physics in JUNO

- Reactor electron anti-neutrinos are observed by Inverse Beta Decay (IBD, 1) and the following neutron capture (2):

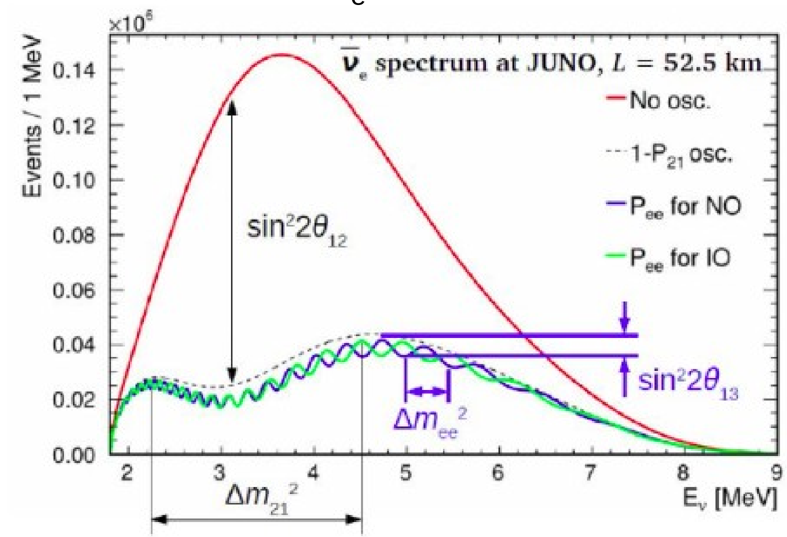
$$\overline{\nu}_e + p \rightarrow e^+ + n \qquad (1)$$

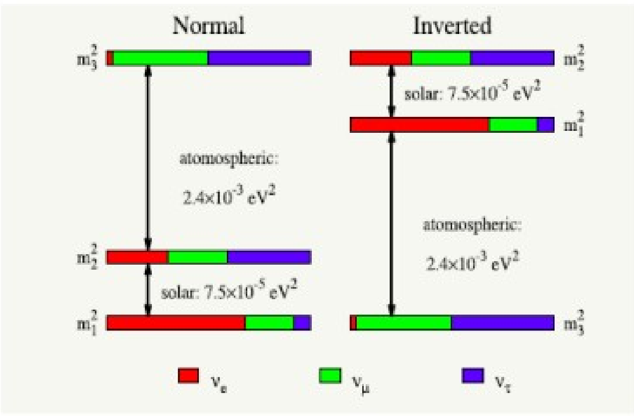
$$n + p \rightarrow d + \gamma \qquad (2)$$

- Very clear signal: prompt + delay coincidence in energy range [2,8] MeV:



Sensitive to $\overline{\nu}_e$ survival probability:

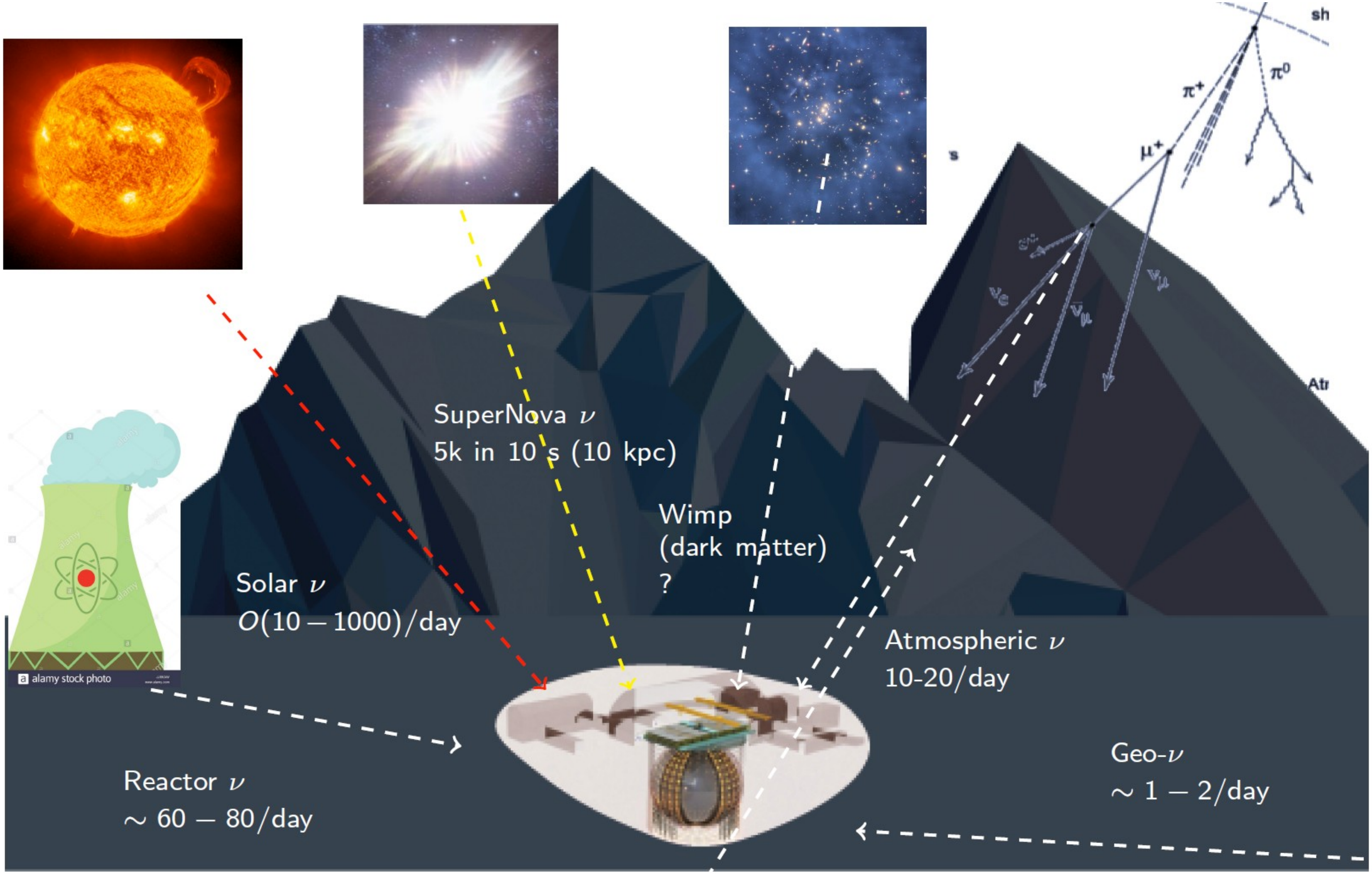




Requirements (KEY):
- High statistics
- Energy resolution: ~3% @1MeV
- Energy scale uncertainty < 1%

Main final physics goals:
- Determination of the NMO within 6 years of data taking
- Best precision measurement of oscillation parameters

JUNO physics program



JUNO activities at IIHE

The JUNO group at IIHE

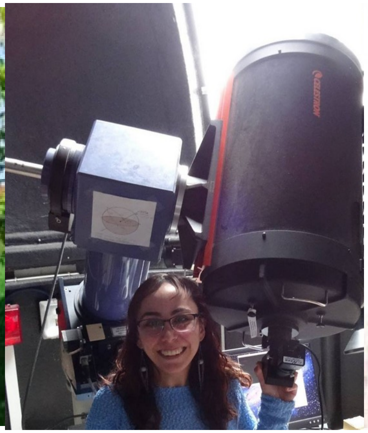
Staff : - **Barbara Clerbaux** (Physicist - Prof. Dr.)
- **Yifan Yang** (Engineer in electronics, Dr.)

PostDoc : - **Marta Colomer** - started in 10/2020
- **Jaydeep Datta** - started in 09/2021 <- new !

PhD st. : - **Pierre-Alexandre Petitjean** (teatching Assistant, Ing.) started a PhD in 01/10/2018

MA st. : - **Daniel Gomez De Gracia** - defended in June 2021

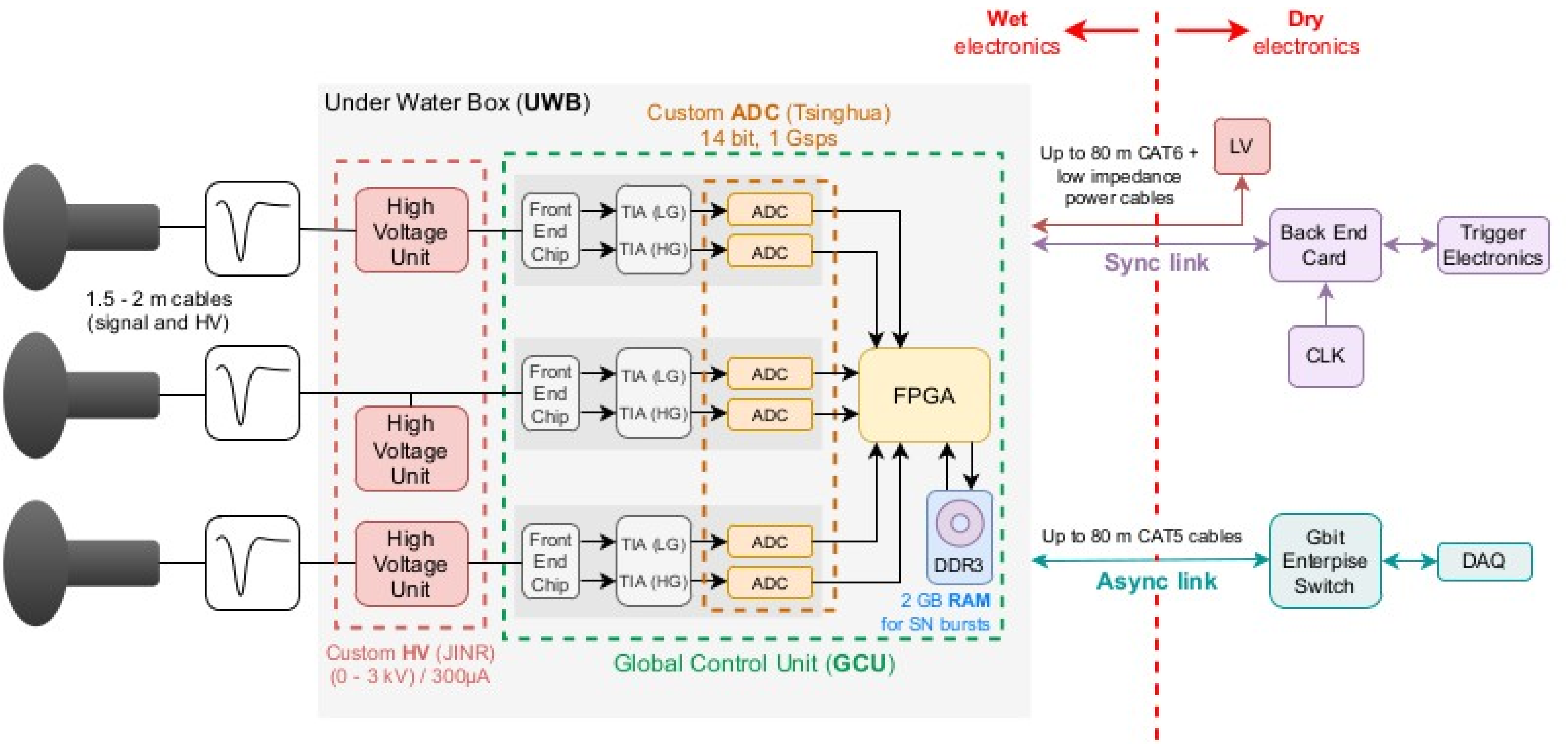





I) On the electronics hardware

Barbara, Yifan, Pierre-Alexandre, Daniel, Marta

JUNO electronics:



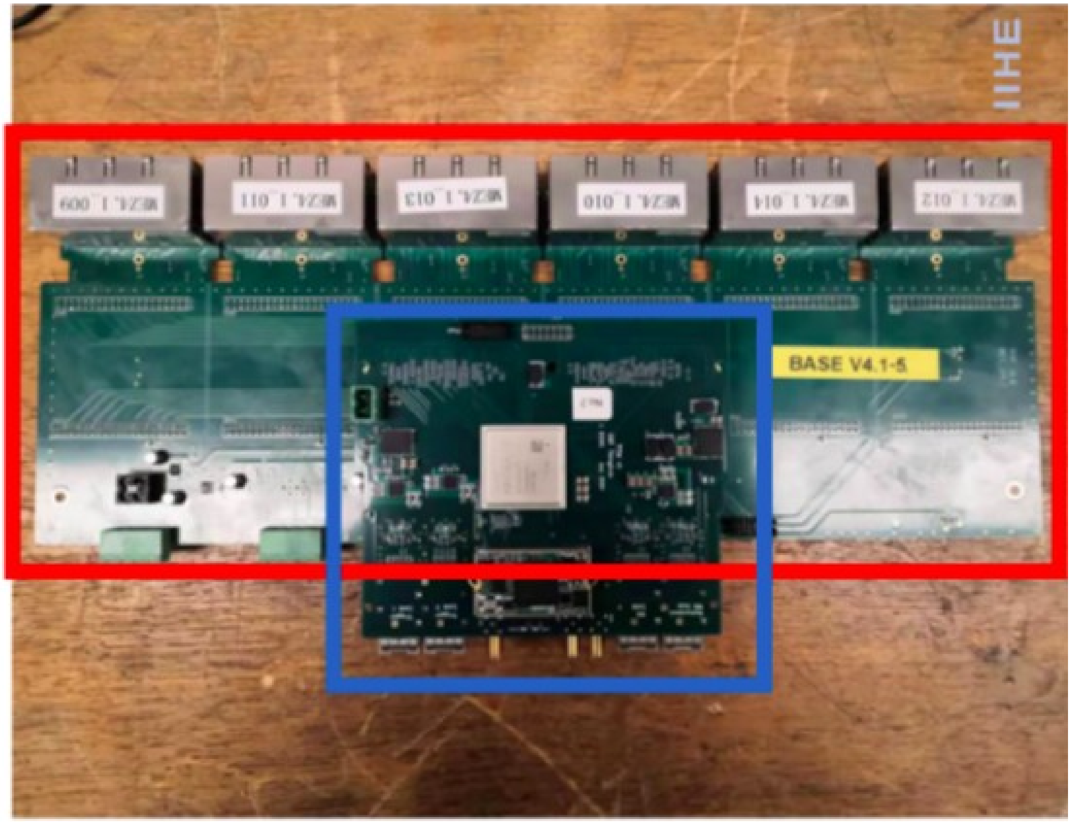
Backend (dry) electronics:

The backend electronics make the connections between the Global Control Units and the dry electronics.

Two main components:
- red box: the backend card (BEC)
- blue box: the Trigger/Timing interface mezzanine (TTIM)

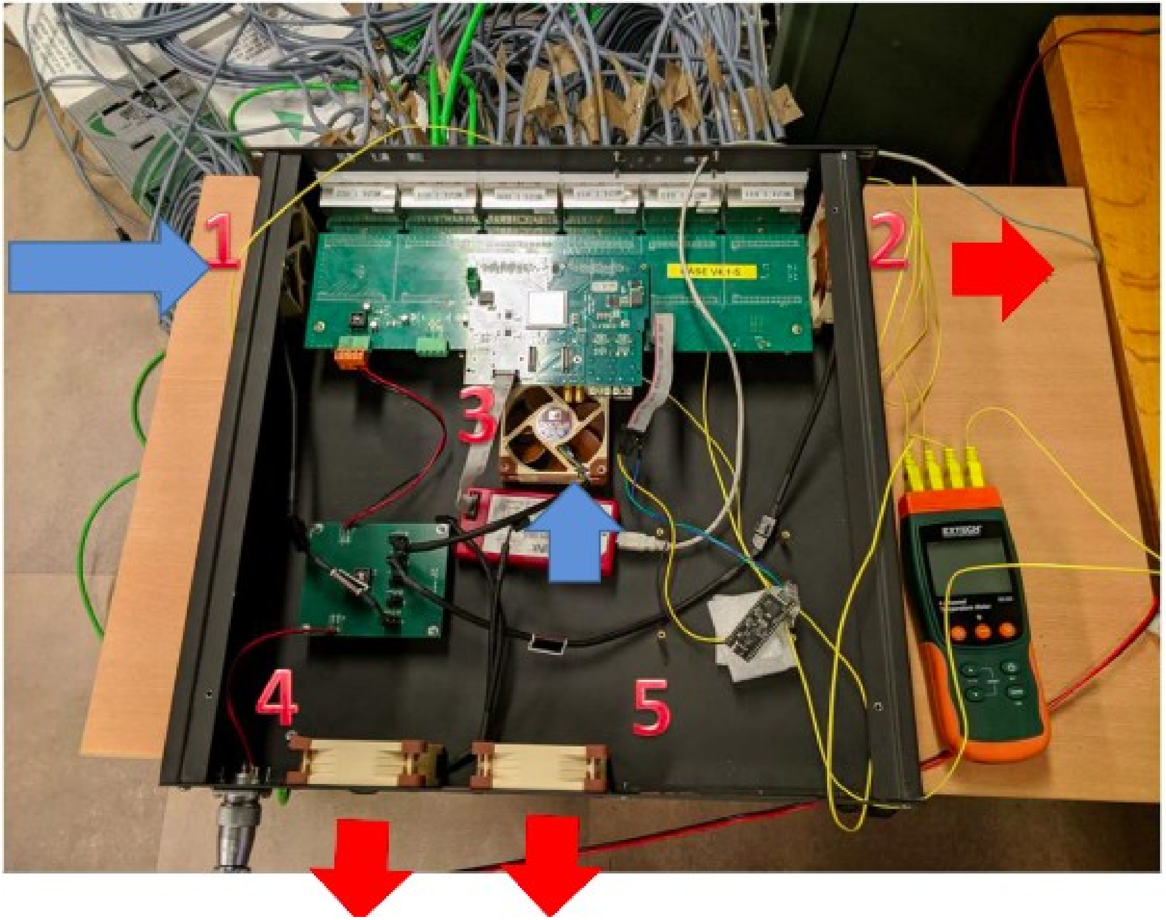
Final production will consist of:
- 180 BECs (20% spare)
- 44 GCUs connected to one BEC by a ~100 m cable

Each BEC is composed of:
- 1 Base board (180 in total)
- 6 Mezzanines (1080 in total)



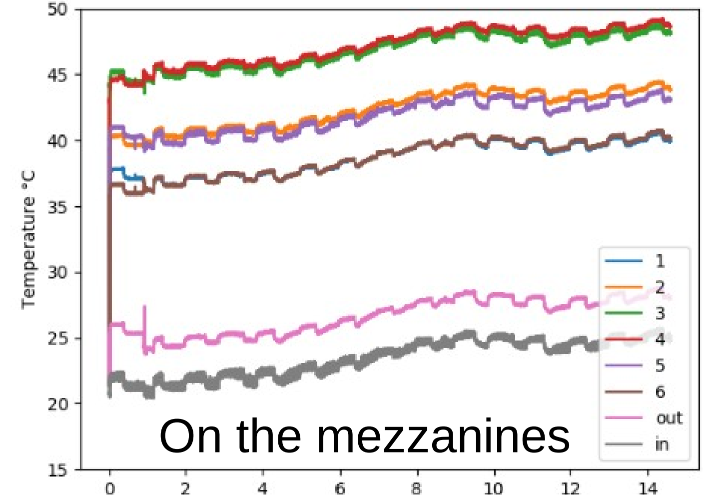
Electronics activities:

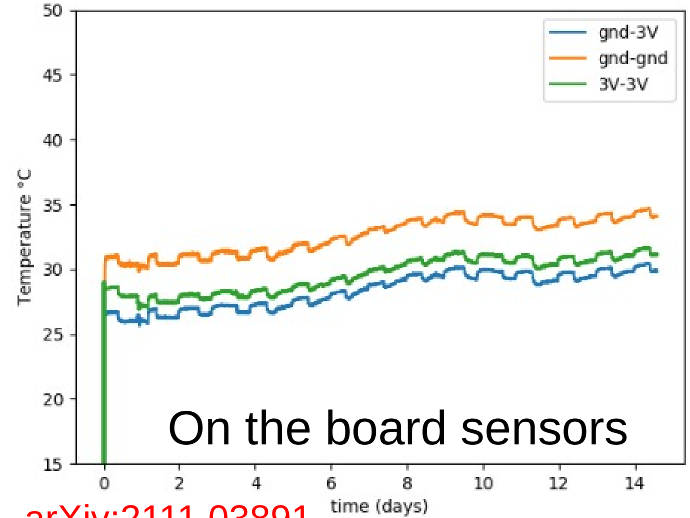
→ IIHE group responsible of the design, tests, mass production and installation of the BEC and the box



arXiv:2011.06823

→ First temperature tests performed at IIHE

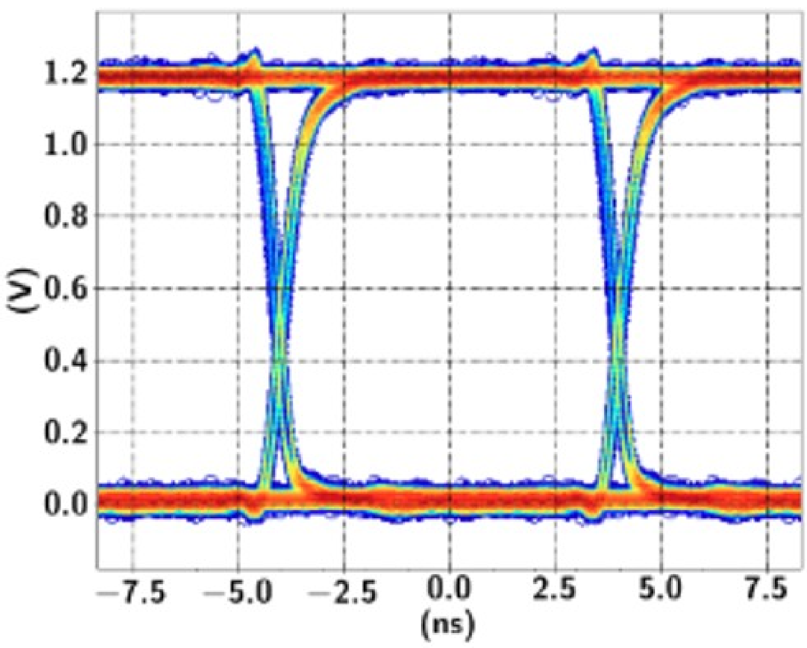




arXiv:2111.03891

Electronics activities:

→ Eye diagram from tests at IIHE shows very good performance (low error rate from noisy channels)



Status of the production and tests:

- All the base boards and mezzanines have been produced and are currently under assembling in Huizhou. Then, will be fully tested in Tsinghua.
- After the tests, they will be assembled with the box in Daxing, and tested again before being sent to Kunshan for the final combined test.
- Once the aging test is passed in Kunshan with the GCU, the box will be sent to JUNO site.
- We are participating to the whole procedure remotely (main activity now and for ~6 months)

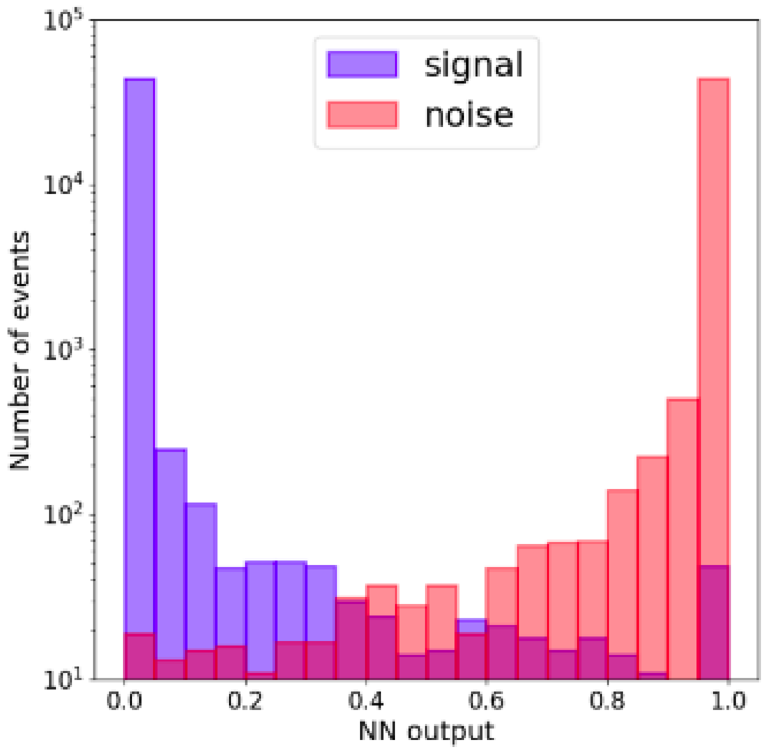
L1 trigger based on NN

- Motivations :
  - L1 trigger based on a Neural Network (firmware implemented) will need less logic resources than the current L1 trigger developed for JUNO
  - Potential bonus: L1 trigger based on a Neural Network which could perform better at low-energies (below 100 keV) than the current trigger (same motivation as for the MM trigger low-energy threshold, see later)
- Requirements:
  - Final trigger rate has to be low enough to be handled by the DAQ
  - It has to be hardware implementable (into an FPGA)

- Why machine learning?
  - → L1 trigger decision can be seen as a binary classification problem
- Which model of neural network?
  - → Multi-Layer Perceptron (MLP): simple, with basic structure, but robust and with good performance
- Why FPGA?
  - → No other choice for a synchronised trigger running at desired bandwidth
  - → Allows for: full control to ns precision, fixed and low latency, and high parallelism

L1 trigger based on NN

Simulation results:



Results on the FPGA (Kintex7) implementation:

Blue: periodical enable signal for 512 times inferences
Pink: one of the output

Oscilloscope running at infinite persistence mode
Firmware running at 125 MHz

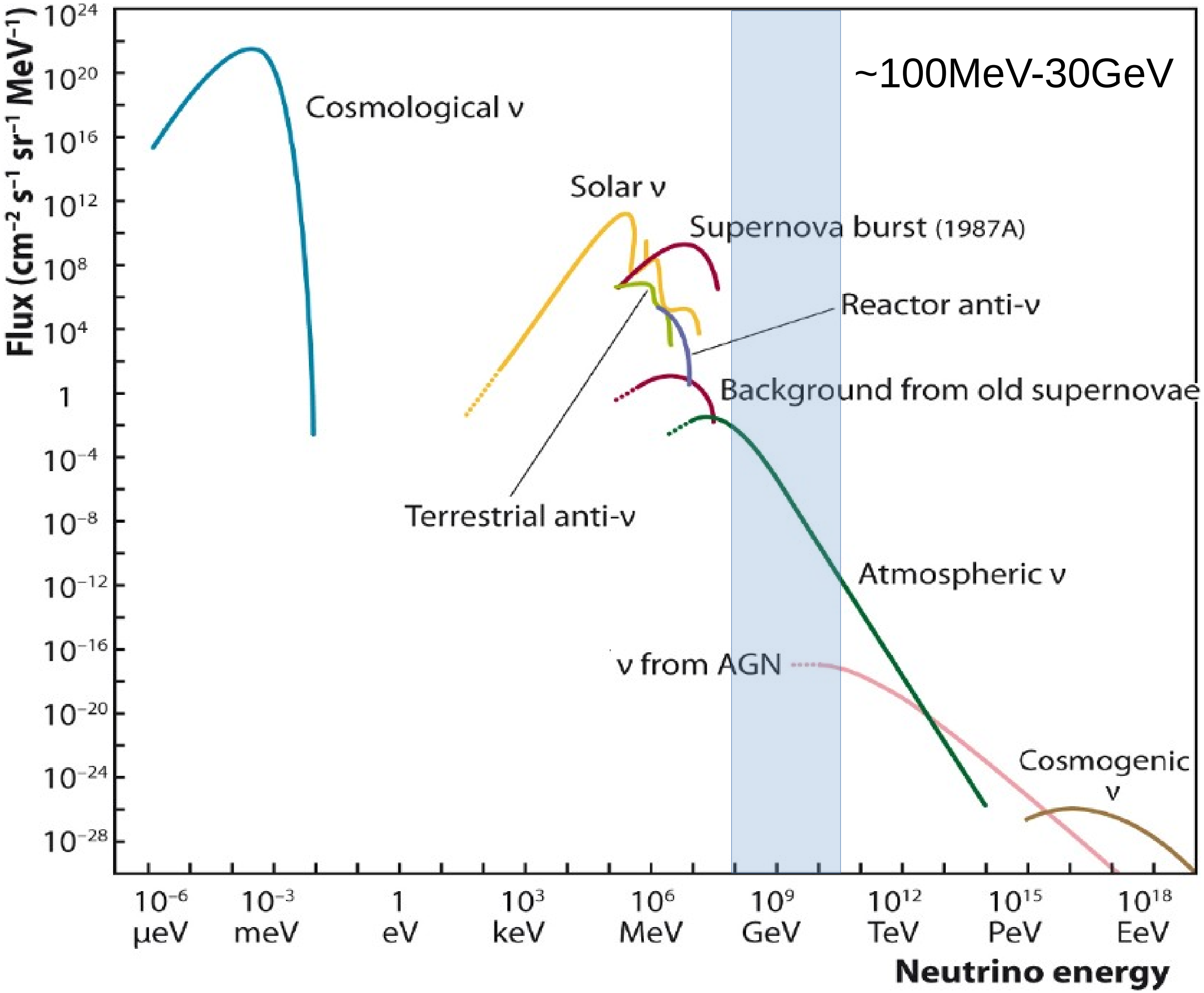
→ Good performance with simple NN model after implemented into an FPGA expected

IEEE TNS 68 (2021) 8

II) On physics analyses/software

Barbara, Marta, Pierre-Alexandre, Jaydeep

Atmospheric neutrinos



Atmospheric neutrinos

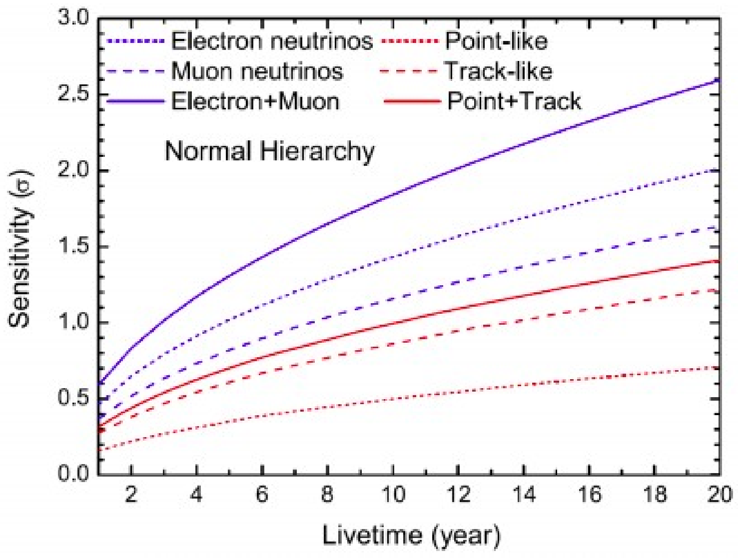
→ **Neutrino oscillations and NMO can also be assessed using atmospheric neutrinos**

Why atmospheric neutrinos?

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

→ **NMO determination at 3σ ~2 years faster!**

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



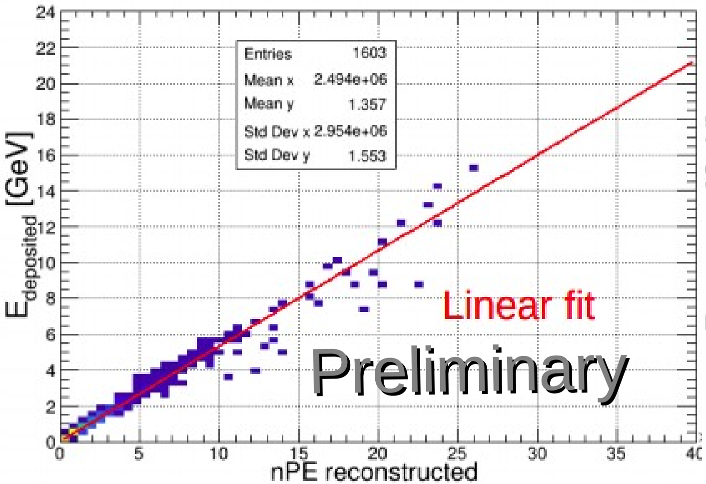
Measuring atmospheric neutrino oscillations effects (NMO) requires:

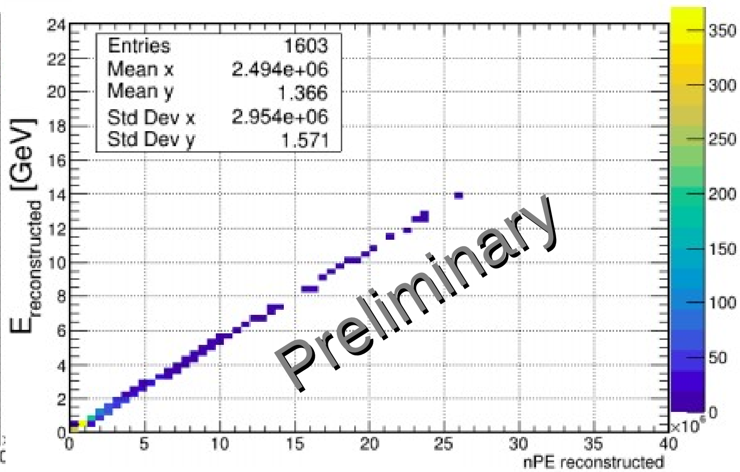
- Good energy (~10%) and direction (~6 deg) reconstruction performance
- Discriminate between electron and muon neutrino + neutrino VS antineutrino

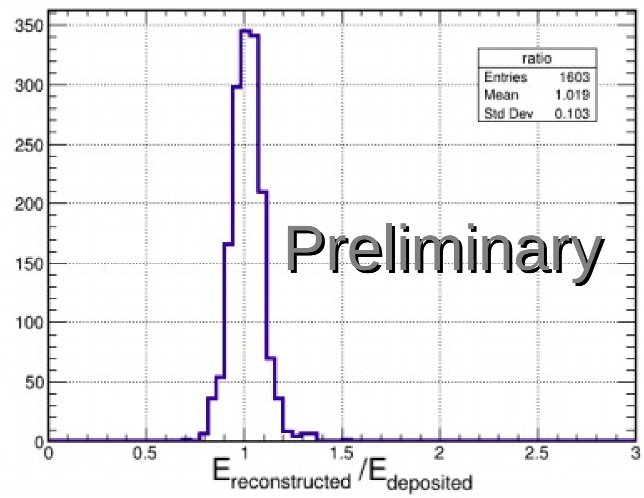
IIHE group involved in development of reconstruction and PID algorithms in JUNO

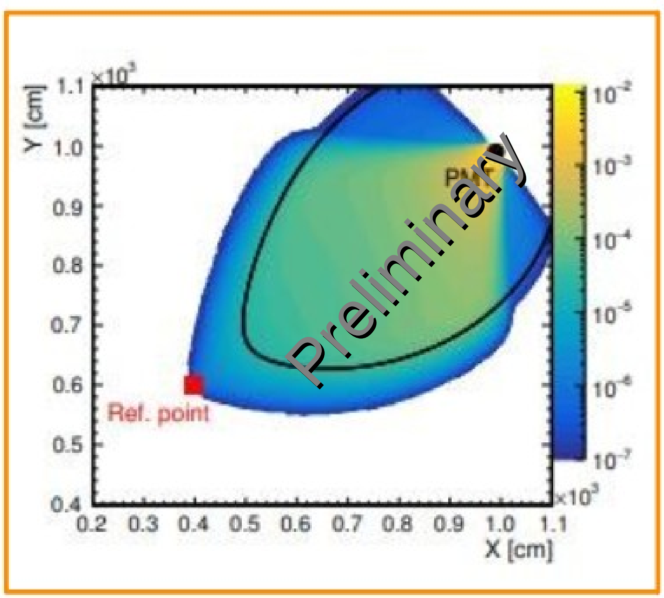
Atmospheric neutrinos

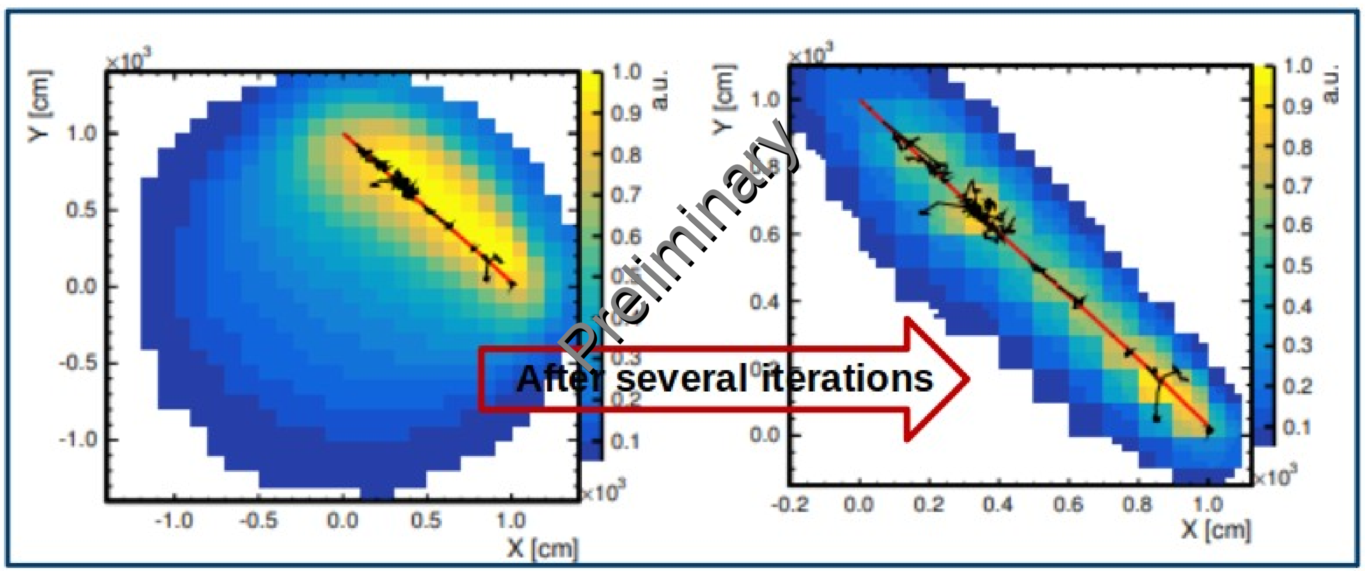
Energy and direction reconstruction:



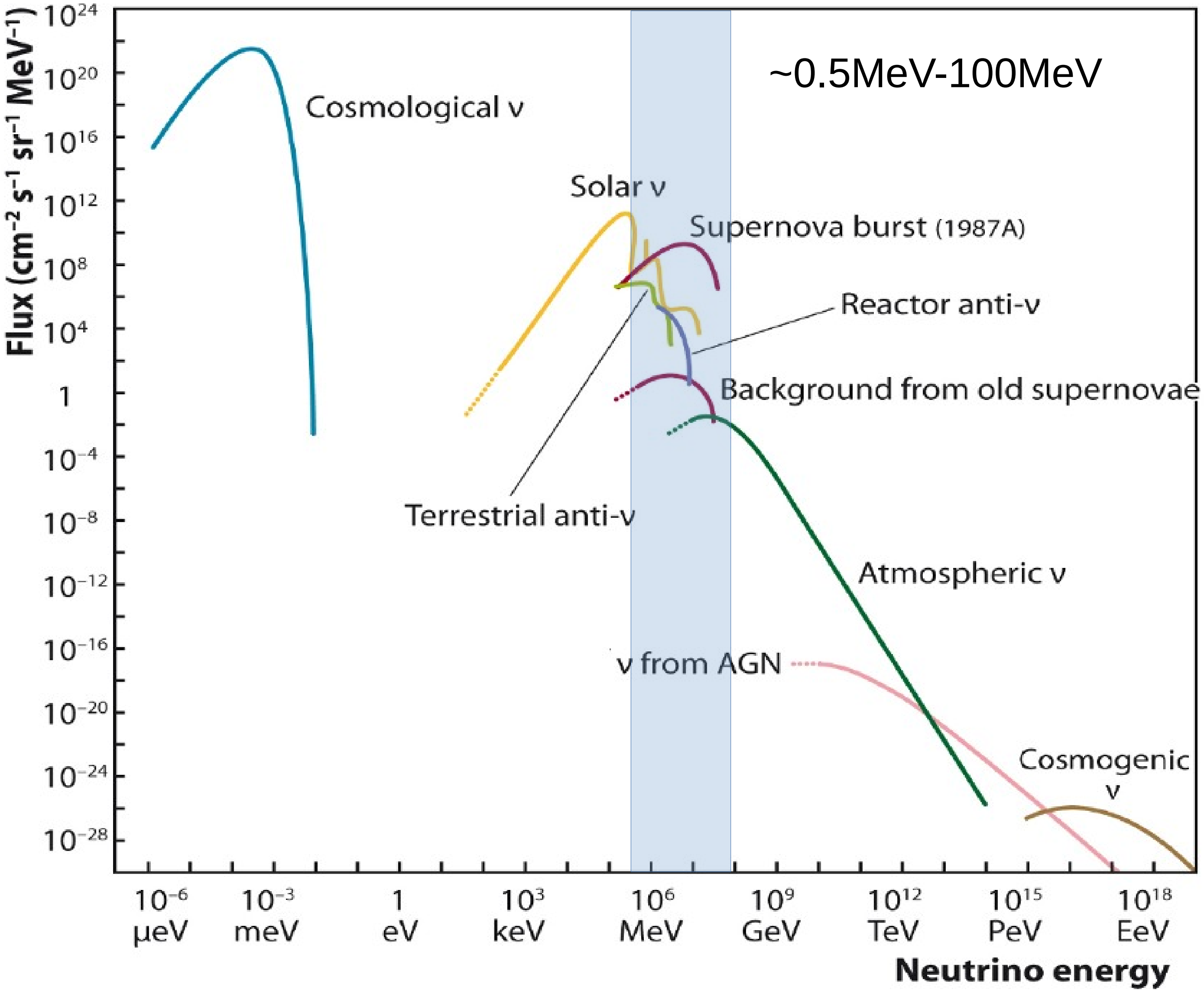






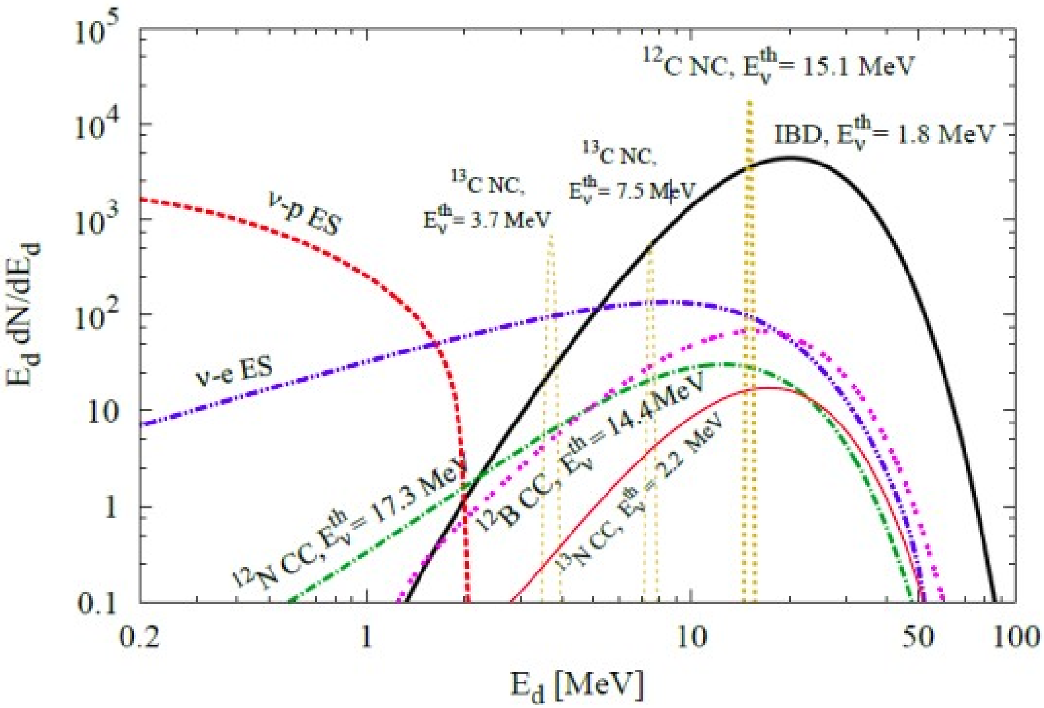


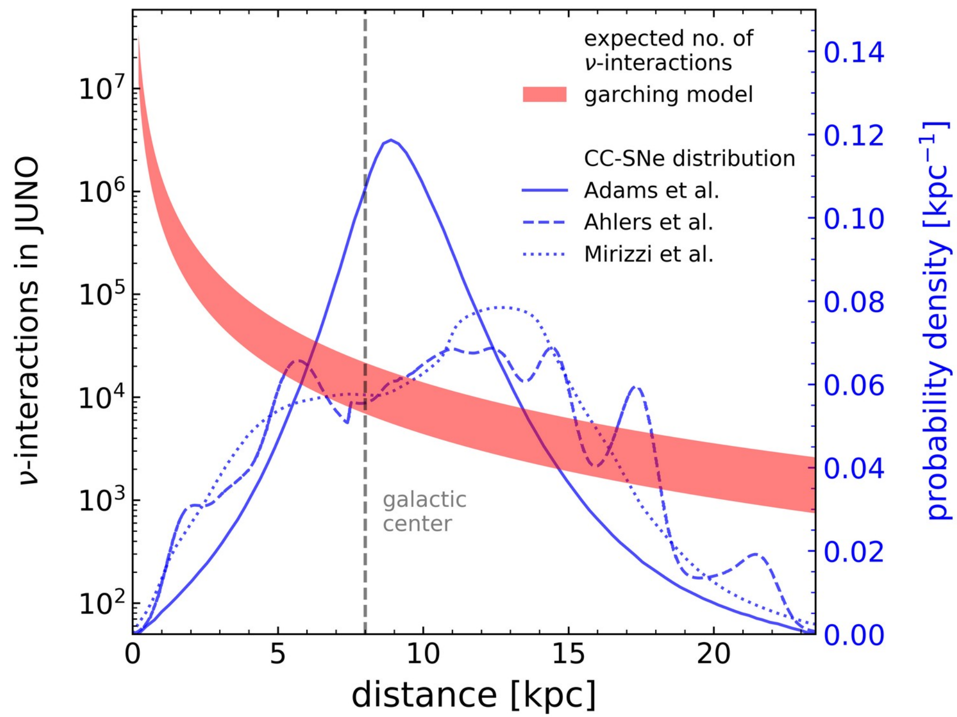
Supernova burst neutrinos



Supernova burst neutrinos

- JUNO will be able to detect the CCSN flux from all neutrino flavors with high statistics
- Dominant detection channels: IBD, ν-p ES, and ν-e ES
- High signal rate → almost background free observation





- Only one observation made via neutrinos (24 events from SN1987A) → need more data
- Only 1-2 CCSN per century in our Galaxy expected → need to be prepared for it

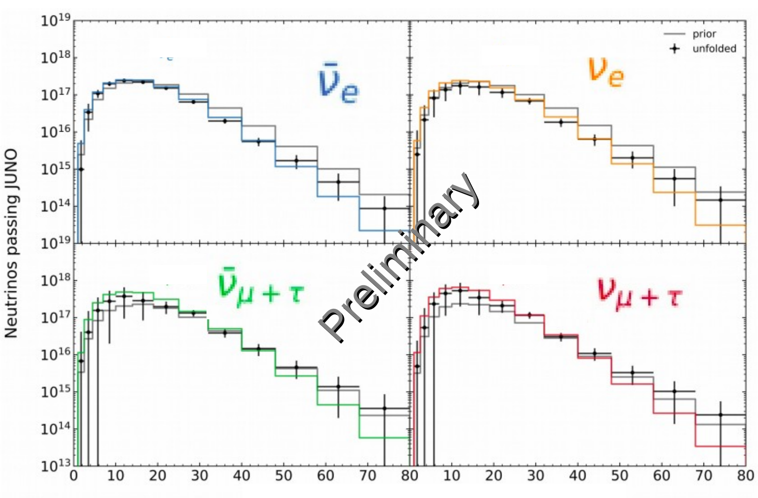
Supernova burst neutrinos

What can we learn from the next explosion?

Good energy and time resolution + flavor classification → JUNO will measure:

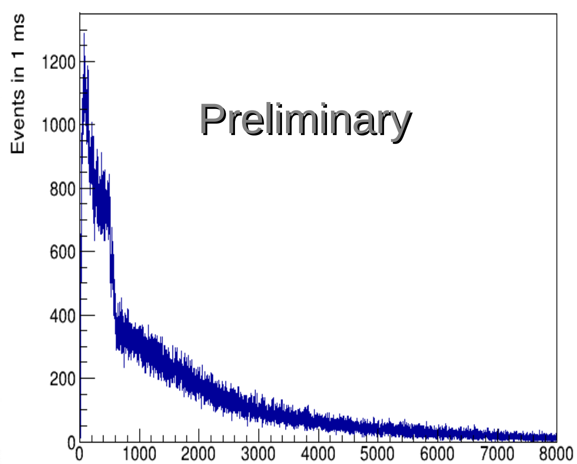
Constrain CCSN physics!

Flavor dependent energy spectrum



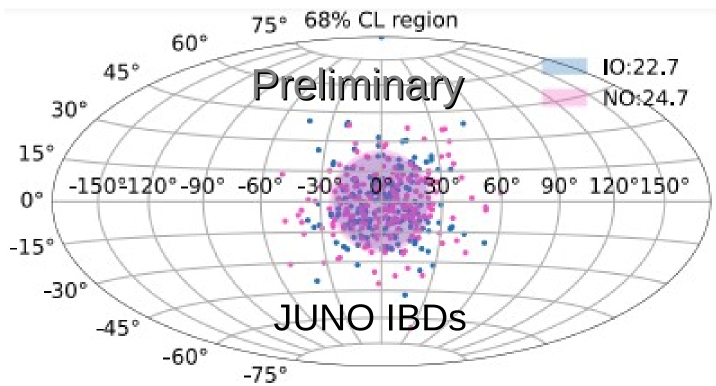
Energy [MeV]

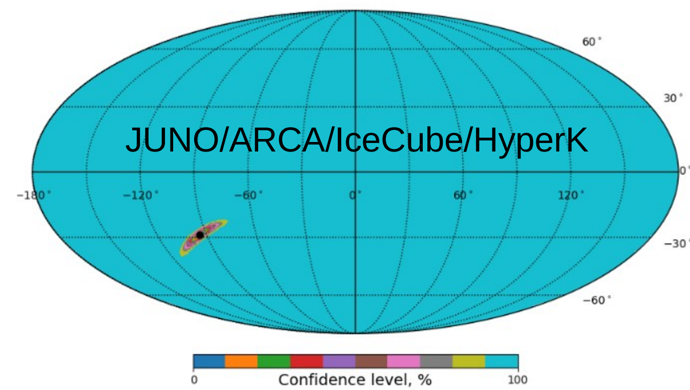
Lightcurve (time profile)



Time [ms]

Direction:





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

CCSN lightcurve studies

Why?

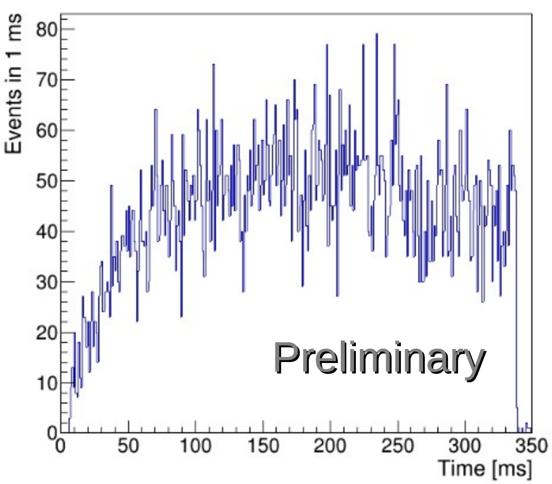
The observed neutrino lightcurve gives information about:
- CCSN physics: hydrodynamical instabilities, neutrino flavor conversion, etc
- CCSN progenitor: mass, distance, rotation, etc

Constrain CCSN physics!

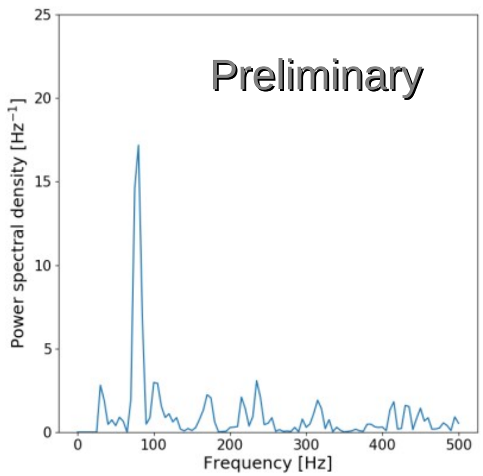
arXiv:2109.08188

Ongoing analyses at IIHE:

Detection of oscillation patterns:



OBSERVED LIGHT-CURVE → (Fourier Transform) → POWER SPECTRUM



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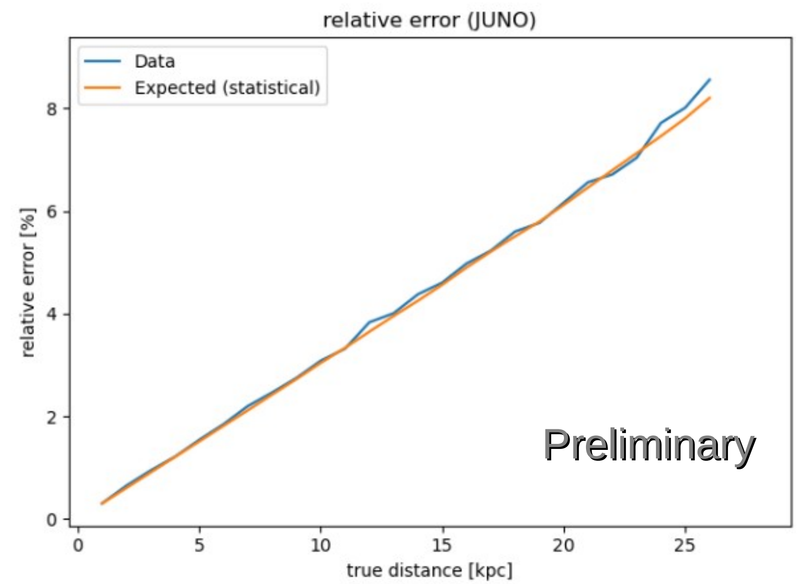
DETECTION SENSITIVITY

Source distance estimate:

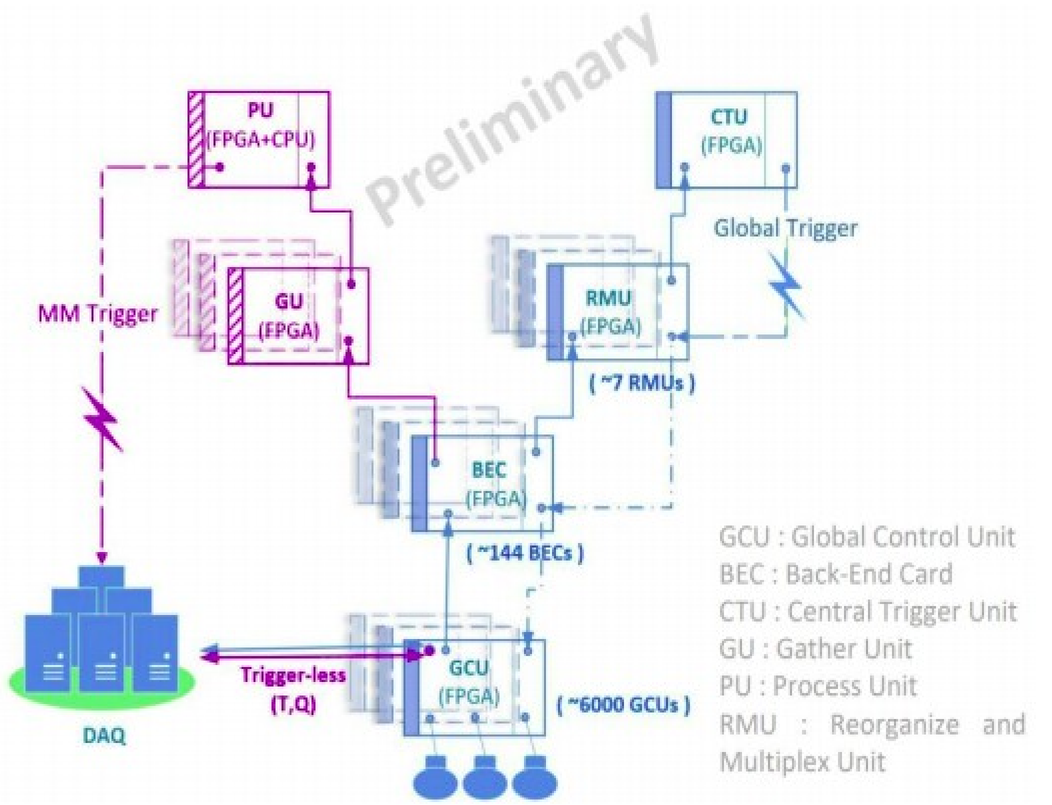


Multi-messenger astronomy

Two strategies to trigger a transient event:

- Prompt Real-time Monitor:
  - Higher energy threshold (≥1000 hits) to reduce atmospheric background
  - High significance trigger, lower stats
  - Based on sliding window method
- Multi-messenger (MM) trigger:
  - Lower energy threshold (~20 keV) possible: larger background
  - Filter pure dark noise events on FPGAs
  - Based on Bayesian Blocks algorithm

If transient astrophysical signal triggered:
→ All (triggerless) data are stored to obtain the most physics reach in offline analysis



- ➔ JUNO as a powerful neutrino telescope for transient MM observations
- ➔ Major role in the next-generation Supernova Early Warning System (SNEWS 2.0)

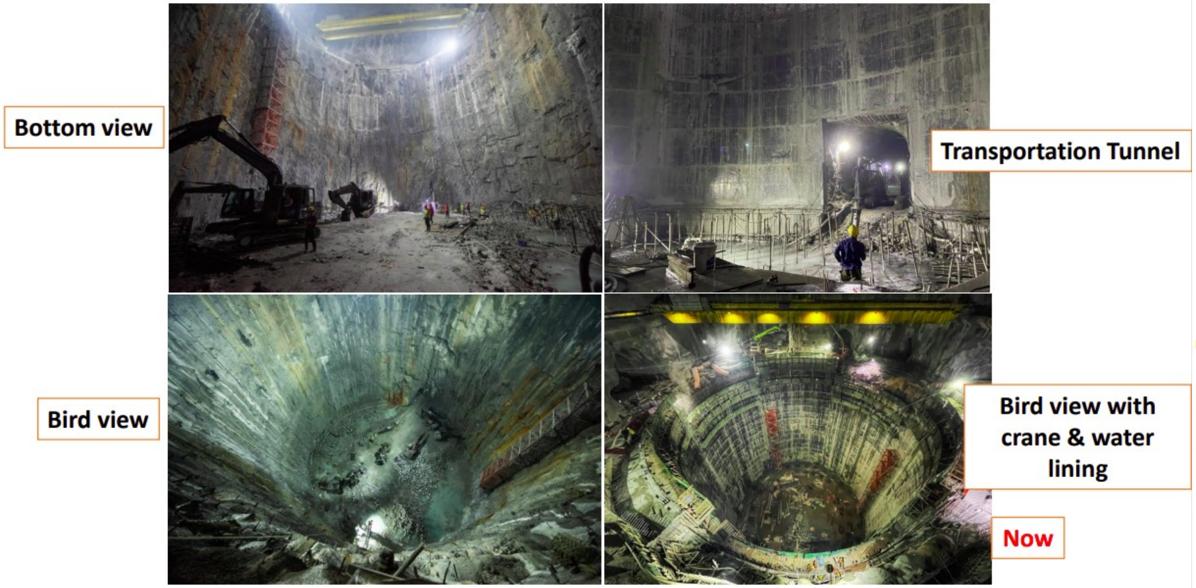
IIHE contribution to SNEWS: co-convener of detector response WG

New J. Phys. 23 031201 (2021)

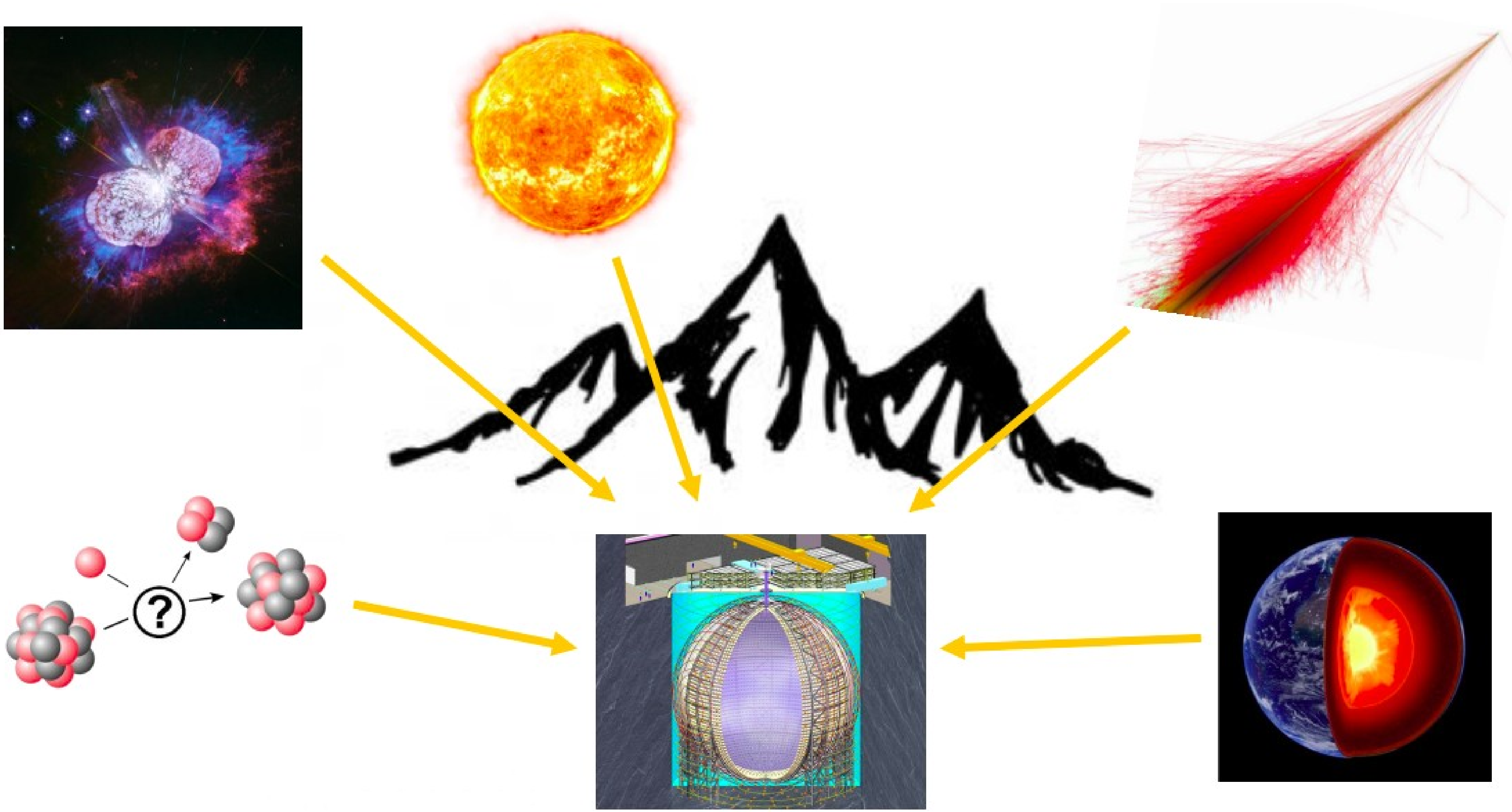
Status of JUNO experiment

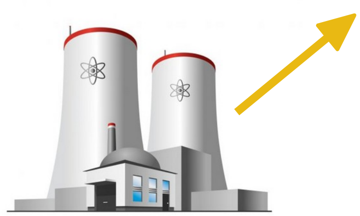
Status of JUNO experiment

- Civil construction finished: experimental cavern dug ready for detector installation.
- Power supply equipment already in position
- 20-inch LPMTs ans 3-inch sPMTs: produced, potted and tested.
- Acrylic sphere + stainless steel structure: production and pre-assembly finished
- All detector components produced or in the production stage, in time for the installation.
- Detector installation and commissioning will happen next year
- JUNO data taking will start in 2023.



JUNO – AN INSTRUMENT WITH AN INCREDIBLE PHYSICS POTENTIAL!





and data are coming soon...