The JUNO experiment and its electronics readout system

PLAN :

- Introduction
- The JUNO detector
- The JUNO electronics readout

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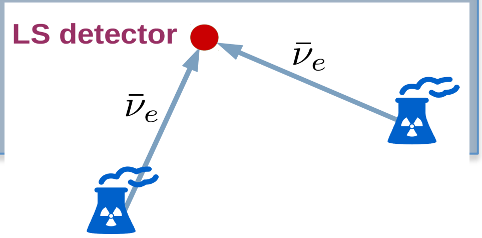
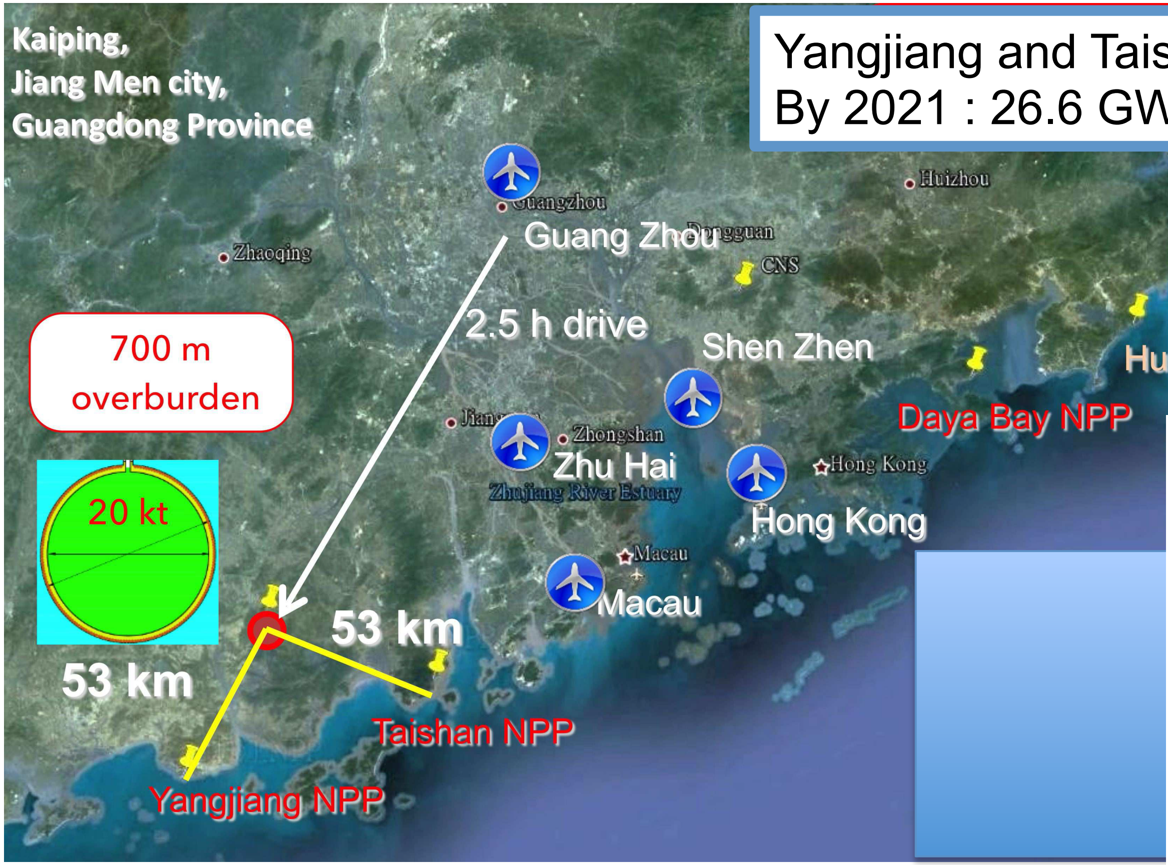
What is JUNO ?

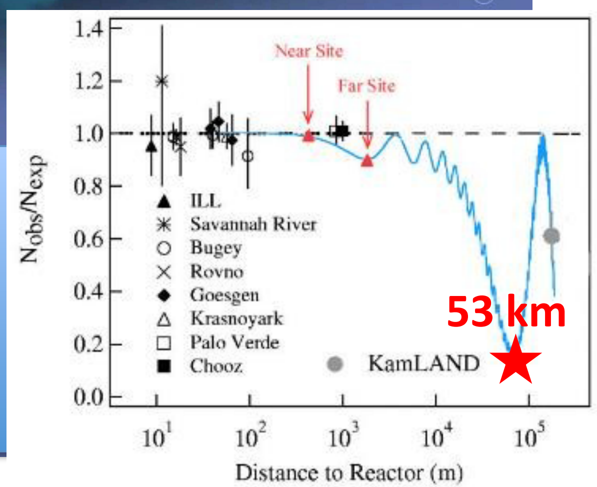


JUNO = Jiangmen Underground Neutrino Observatory

- JUNO is a "medium-baseline" (53km) reactor neutrino experiment located in China, under construction (data taking foreseen in 2021)
- JUNO will be the largest Liquid Scintillator detector ever built (20kt)
- Goals : Measurement of the neutrino mass hierarchy (NMH) and oscillation parameters + astroparticle and rare processes



Yangjiang and Taishan under construction
By 2021 : 26.6 GW



Neutrino Mass Hierarchy

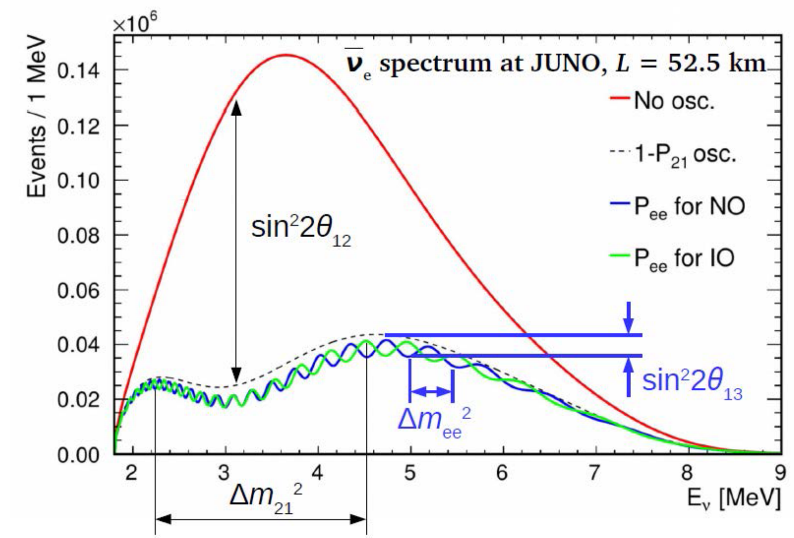
- **Neutrinos are observed via**
  Inverse Beta Decay (IBD) :

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

$$\tau \simeq 200\mu\text{sec} \quad \longrightarrow \quad n + p \to d + \gamma$$

→ Very clean signature

E range : 2 to 8 MeV



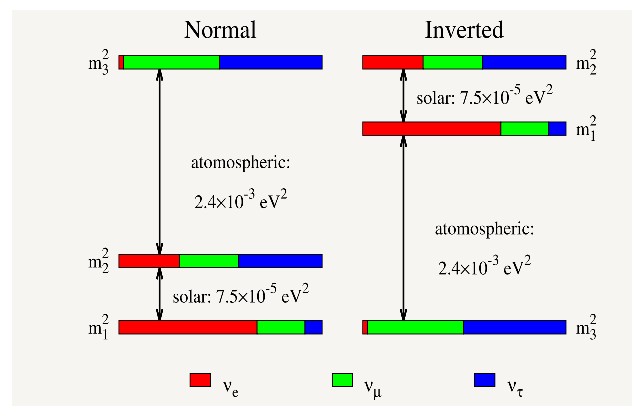
- **Neutrino energy spectrum:**

The Pee survival probability in vacuum :

$$\begin{aligned} P_{ee}(L/E) &= 1 - P_{21} - P_{31} - P_{32} \\ P_{21} &= \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21}) \\ P_{31} &= \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31}) \\ P_{32} &= \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32}) \end{aligned}$$

$$\Delta_{ij} = 1.27\Delta m^2_{ij} L/E$$

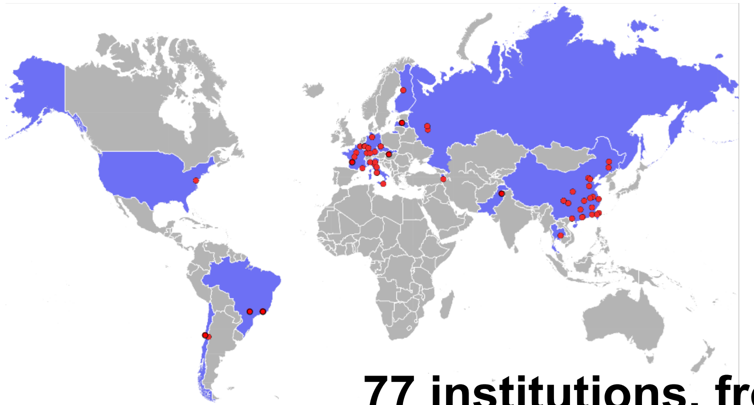
$$\begin{aligned} \Delta m^2_{31} &= \Delta m^2_{32} + \Delta m^2_{21} \\ \text{NH}: \ |\Delta m^2_{31}| &= |\Delta m^2_{32}| + |\Delta m^2_{21}| \qquad \omega P_{31} > \omega P_{32} \\ \text{IH}: \ |\Delta m^2_{31}| &= |\Delta m^2_{32}| - |\Delta m^2_{21}| \qquad \omega P_{31} < \omega P_{32} \end{aligned}$$

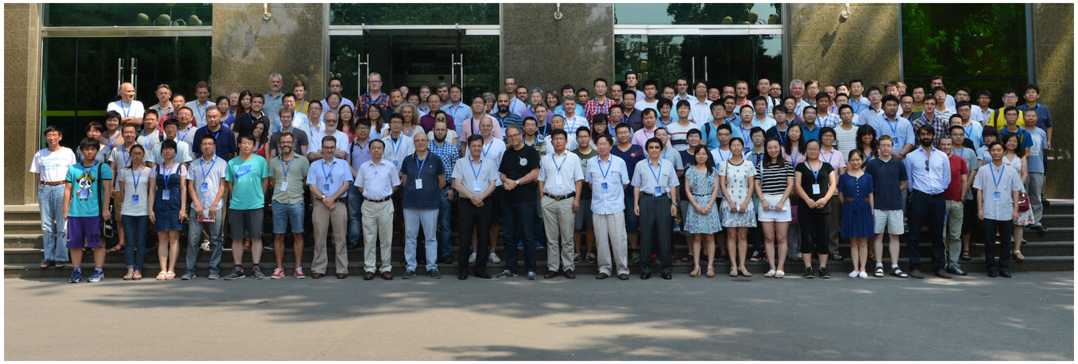


Key issues :

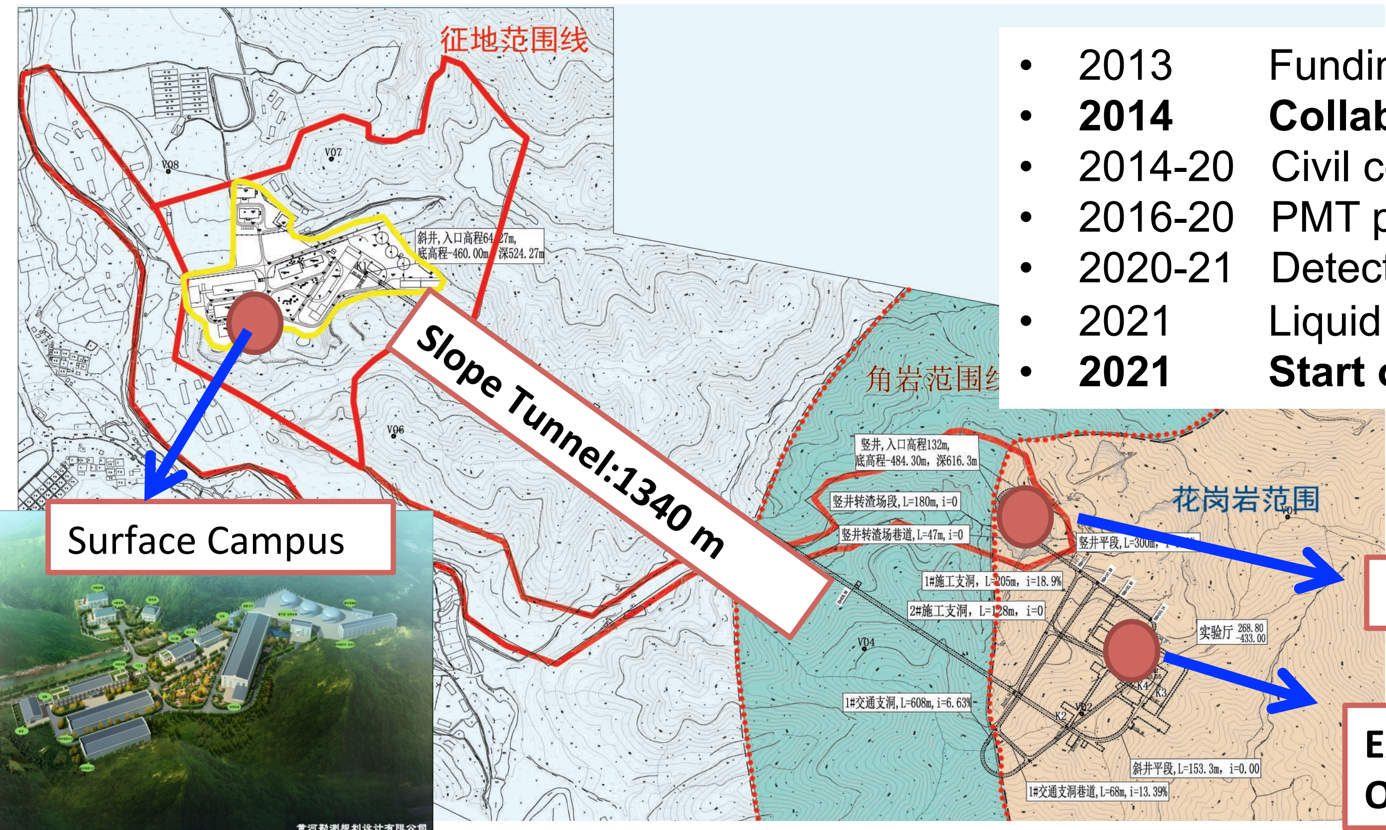
- **Energy resolution and scale**
- **Statistics**

JUNO Collaboration and timescale





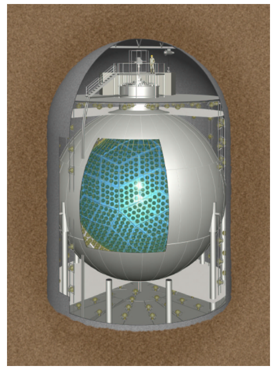
77 institutions, from 17 countries, more than 600 scientists



- 2013 Funding approved
- **2014 Collaboration officially formed**
- 2014-20 Civil construction
- 2016-20 PMT production
- 2020-21 Detector assembly & installation
- 2021 Liquid scintillator filling
- **2021 Start of data taking**

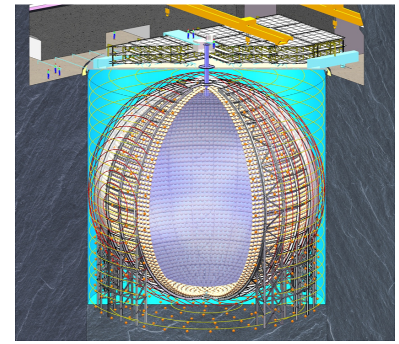
The JUNO detector

Detector performance goals :



KAMLAND

JUNO



Energy Resolution	6% @ 1MeV	**3% @ 1MeV**
LS mass	~1 kt	**20 kt**
LS Attenuation/Diameter	15m / 16m	**>20m / 35m**
Photocathode Coverage	32%	**75%**
QE x CE	25% x 60%	**40% x 60%**
Photon collection	250 p.e./MeV	**1200 p.e./MeV**

→ An unprecedented LS detector !

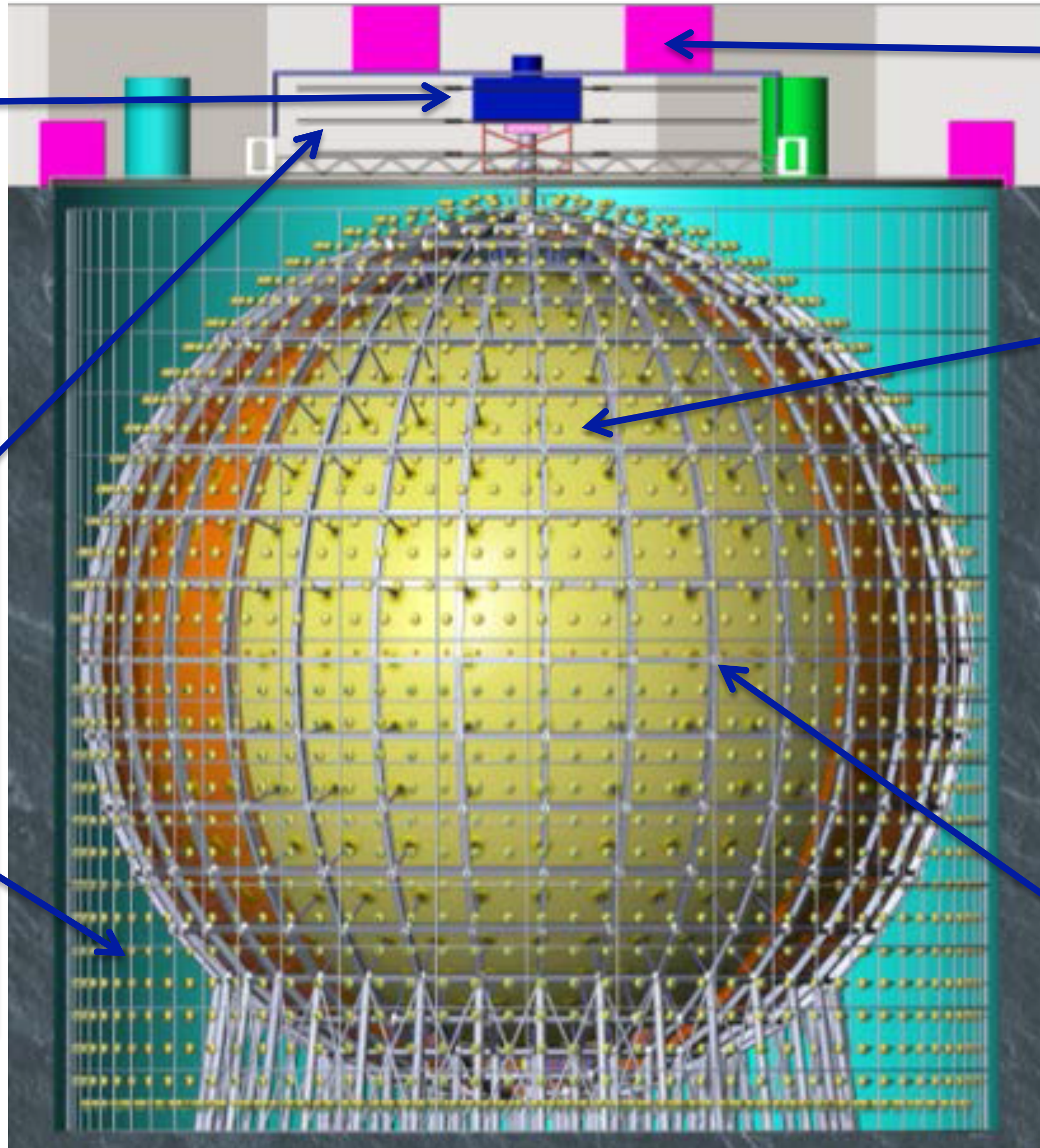
Detector main components

Calibration
4-complementary Calibration systems

Muon veto :

Top Tracker

Water Cherenkov Veto
20kt ultrapure water and 2000 20’’ PMTs



Electronics

Central detector :

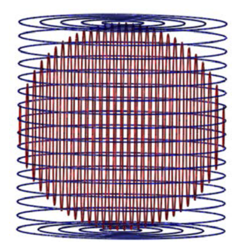
Acrylic sphere (35.4 m diameter)

Filled with 20kt LAB LS

18000 20’’ PMTs and 25600 3’’ PMTs

Stainless steel

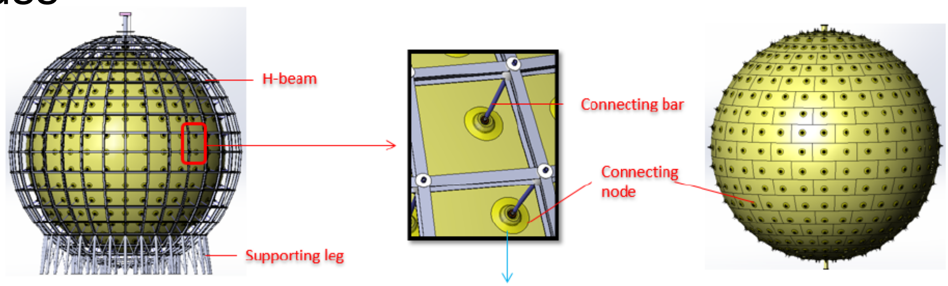
Magnetic Field Compensating Coil



Detector main components

CDR http://arxiv.org/abs/1508.07166

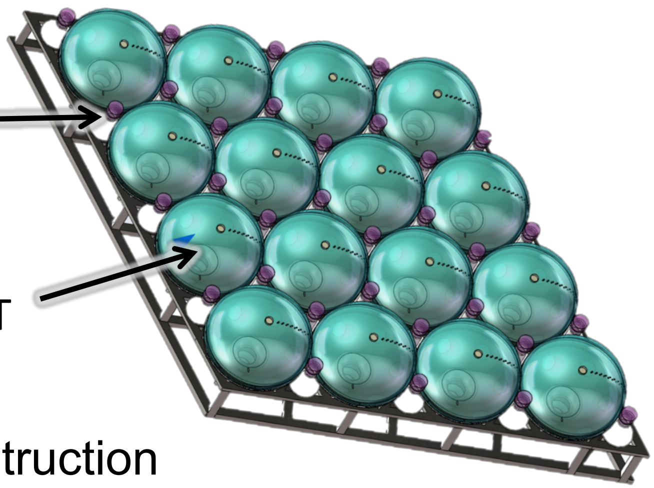
- **Central detector :**
  Acrylic sphere and stainless steel truss
  Liquid Scintillator (LS) large volume
  → for the statistics



  Double calorimetry :

  → 18000 large PMTs (20'') → 75%
  → 25600 small PMTs (3'') → 2.5%

  High light coverage (78%)
  and double calorimetry system
  → for the energy resolution



- **Muon veto** : TT : use OPERA tracker layers
  Reject 50% of the muons
  Provide tagged muon sample to study muon reconstruction and bg contamination with the central detector

- **Calibration** : 4-complementary systems : Automatic calibration unit (1D- central axis scan), Cable loop system and guide tube calibration system (2D), remote operated vehicules (3D) – radiative sources (photon, positrons, neutrons)

JUNO electronics specifications

What we need :

- Excellent energy resolution, especially at low energy (for NMH)
- Excellent photons arrival time measurement (for good vertexing)
- A large dynamic range (for atm-, geo-, and supernova neutrinos)
- A negligible deadtime (for supernova events lasting up to few seconds)

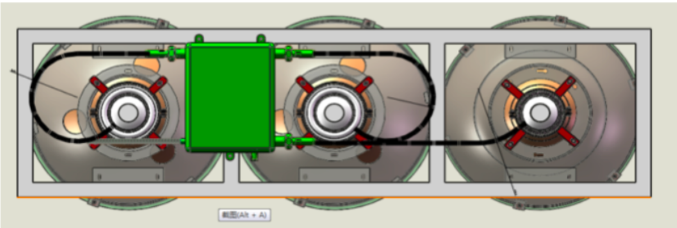
Specifiations :

- Provide full waveform digitization with high speed (1 Gsample/s), high resolution (12 bits) ADC
- Measure photon pulses with high resolution (full dynamic range: 1-4000 pe)

Main concern :

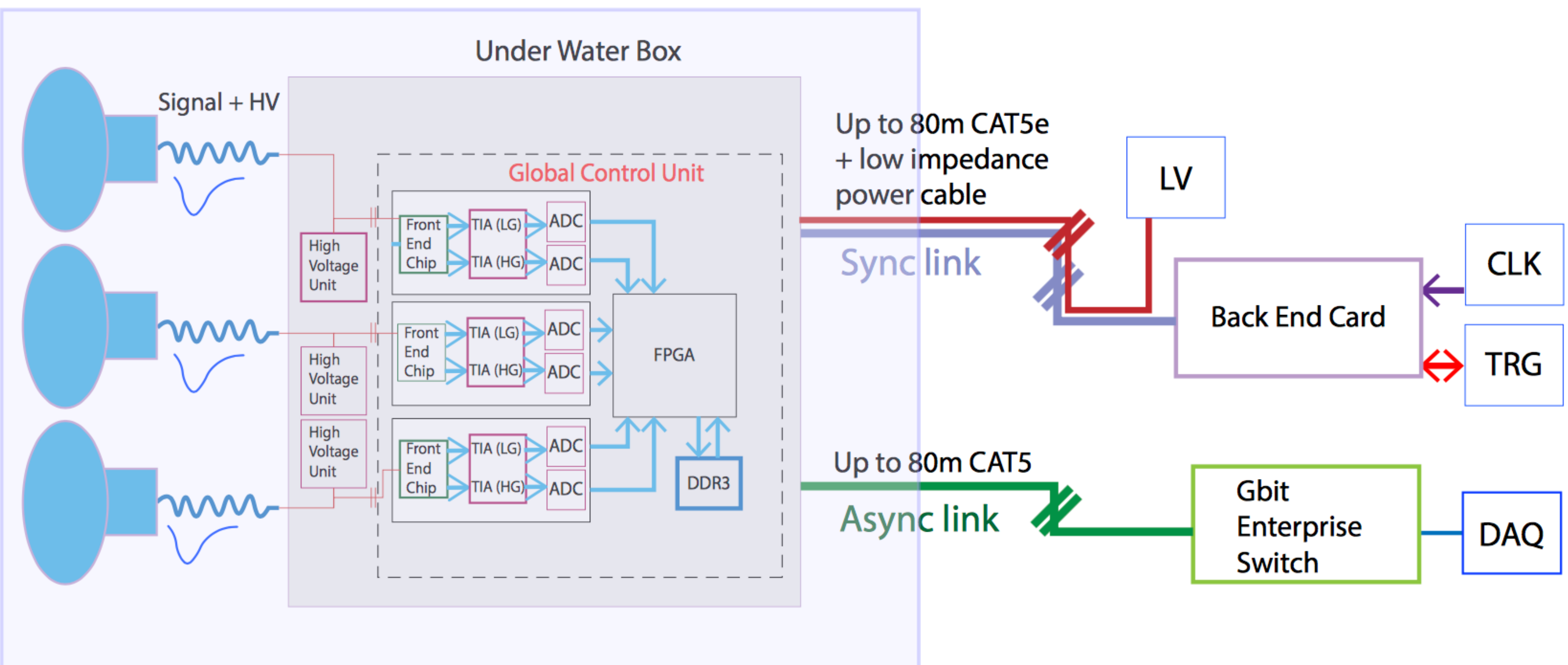
Reliability of Under Water (UW) electronics (not accessible after installation)
→ goal : less than 1% PMT + underwater electronics failure over 6 years
(calculation + laboratory reliability/aging tests + redundancy)

Readout of the 20” PMTs

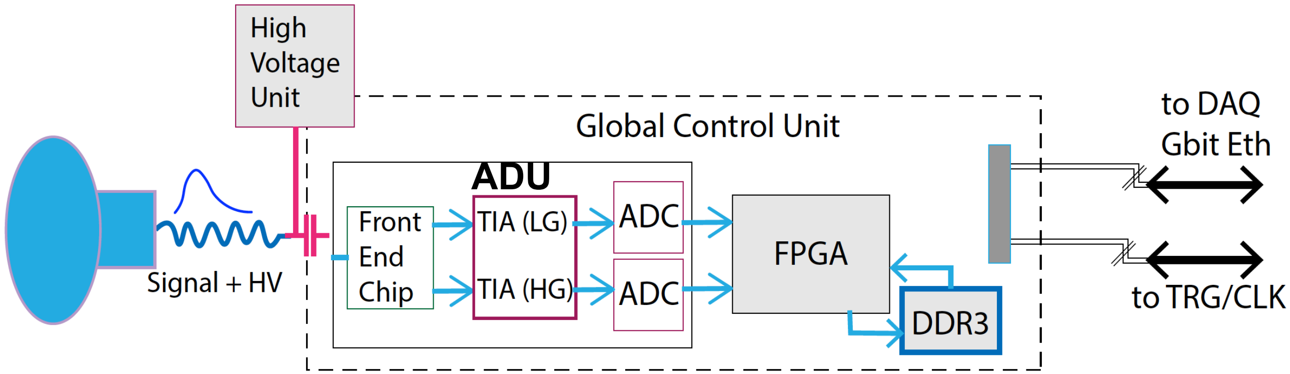


Under Water Electronics

Dry Electronics



Global Control Unit (GCU)

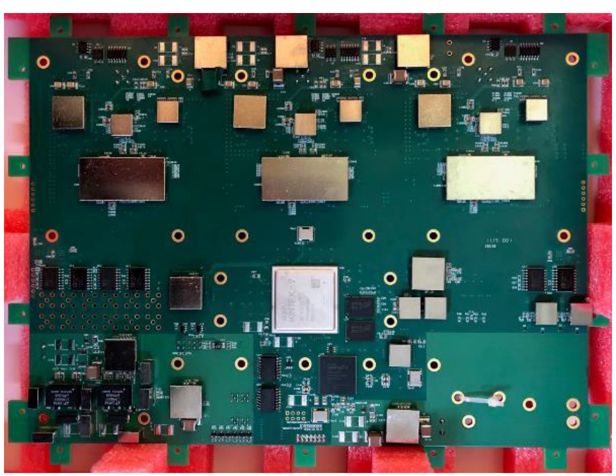


ADU (Analog to Digital Unit)
PMT current signal is conditioned, duplicated in two streams and converted to voltage (low-gain and high-gain TIAs) :

- Low gain (8:1) 0-1000 pe
- High Gain (1:1) 1-128 pe

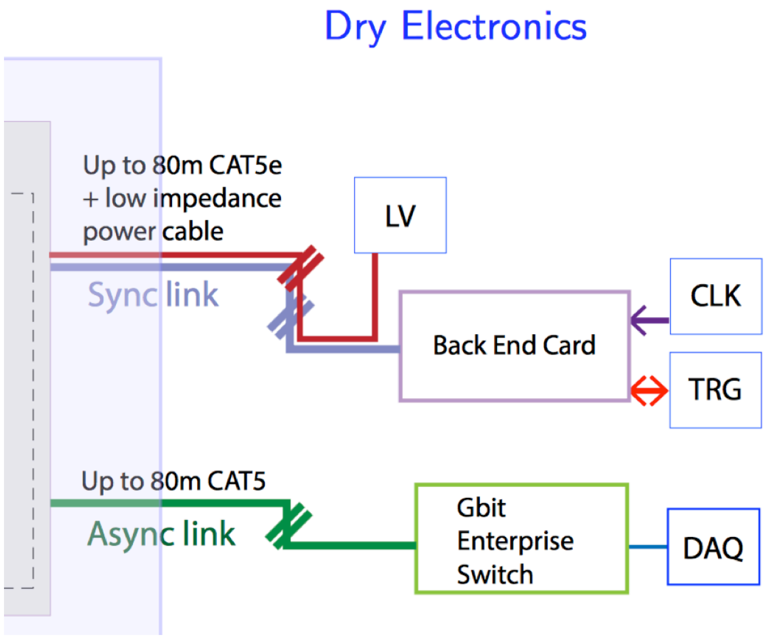
Each stream is digitized with a 12-bit 1 Gsample/s custom designed ADC

Digital signal is then processed in **FPGA (Xilink kintex7)** : reconstructed (timestamp, charge) and the digitized waveform is stored locally (2 GB **DDR** RAM)
All GCU (about 6000) synchronised < 16 ns window



- in **'Global-Trigger'** running mode, a local TRG signal is sent to the Global Trigger and, if validated, data are transferred to DAQ through Ethernet
- in **'Auto-Trigger'** mode, fixed window waveform (300 ns) are sent to the DAQ every time a local trigger is issued

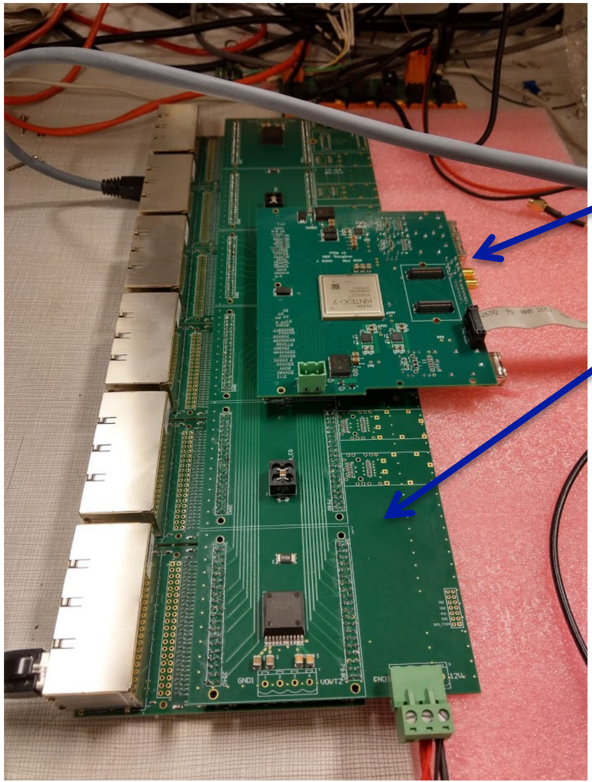
Outside water electronics



Up to 80 meter CAT5 cables :

- **Asynchronous Link :** variable latency ethernet link
  Data readout and slow control
  Protocol : IPBUS - Nominal link speed : 1Gbps

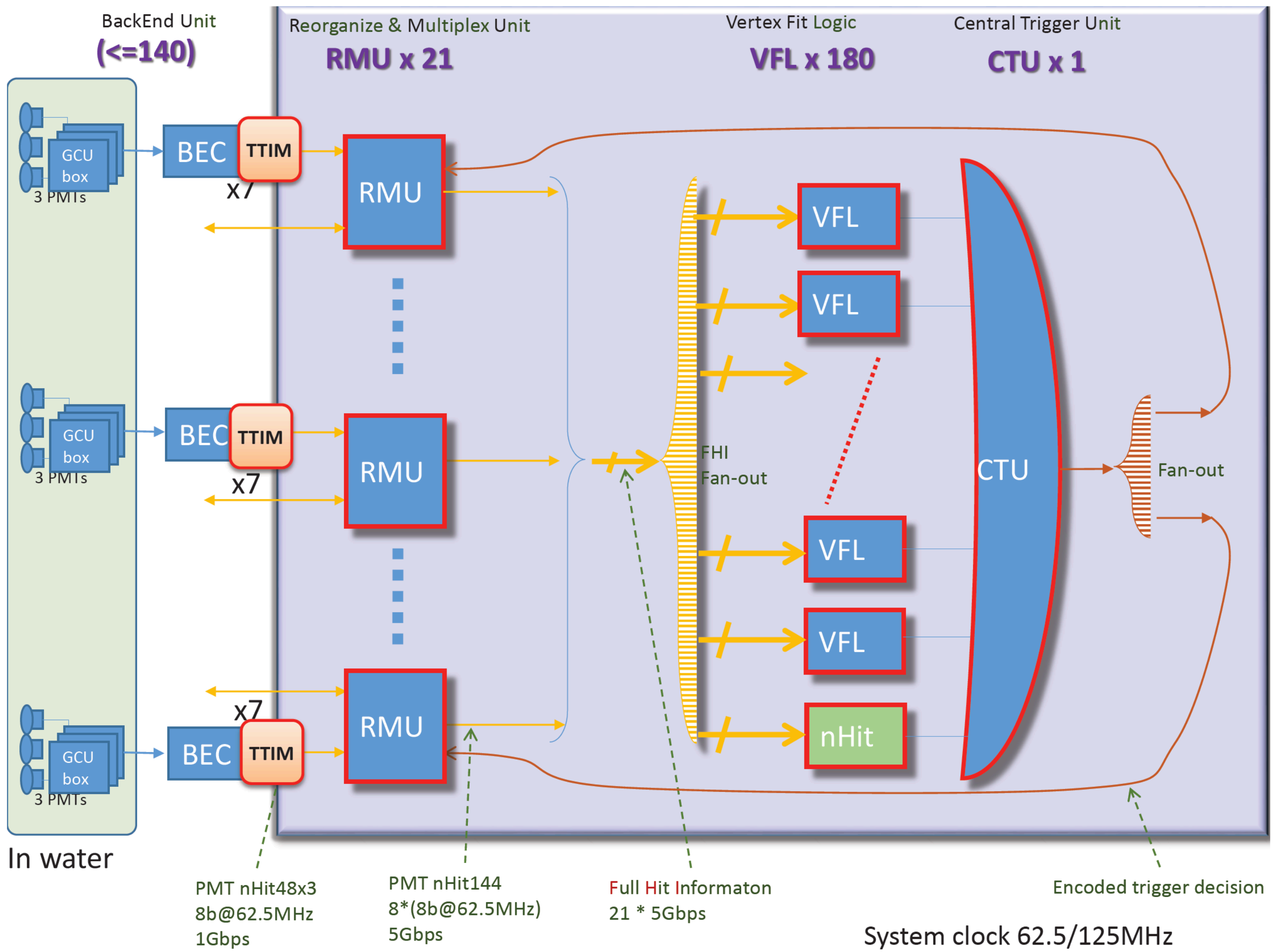
- **Synchronous link :** fixed latency link
  Timing Trigger and Control (TTC) protocol



TTIM (Trigger/Timing interface mezzanine)

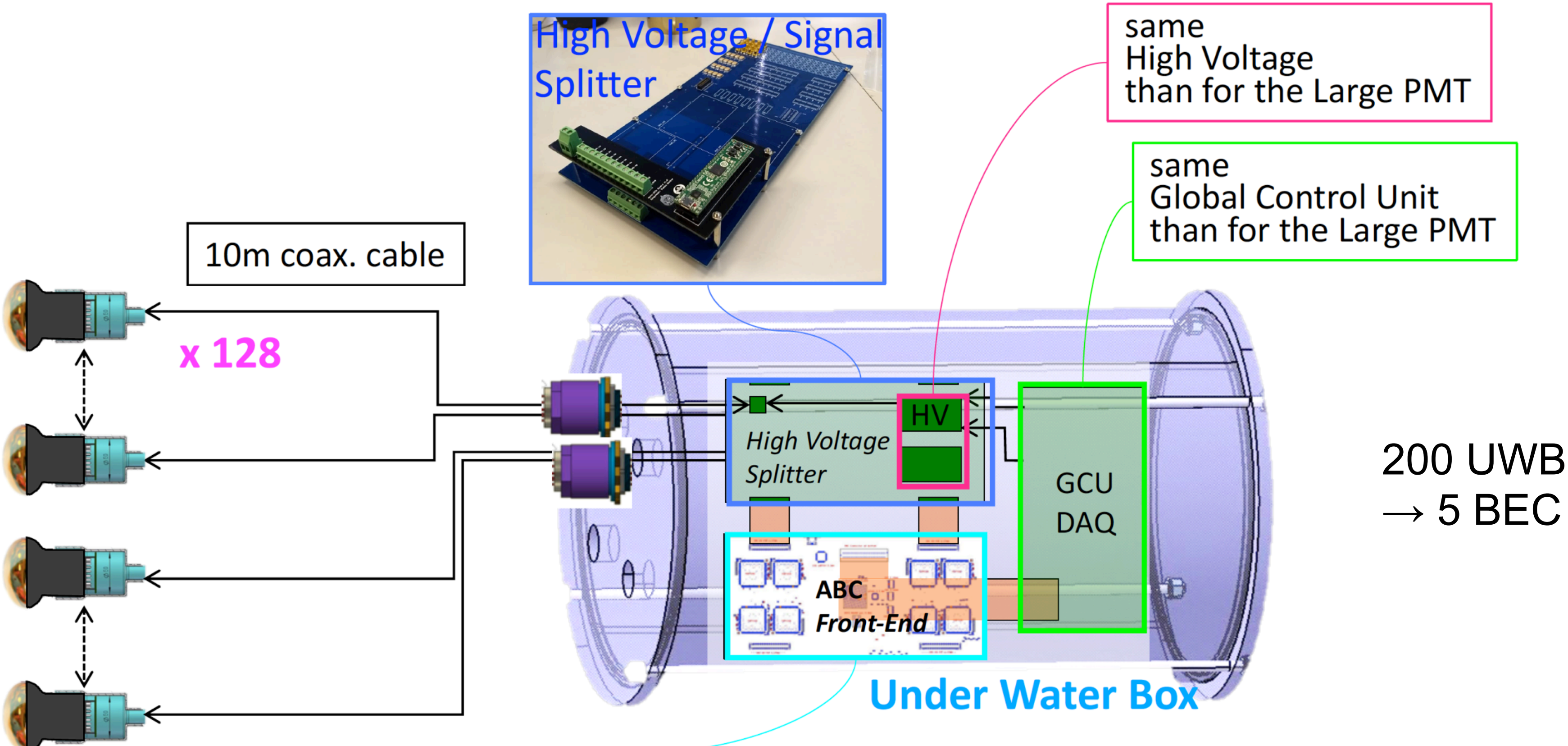
BEC (Backend Card)
Receive 48 Ethernet cables from the underwater boxes
Distributes CLK signal to GCUs
Transfers TRG signal between Global Trigger and GCUs

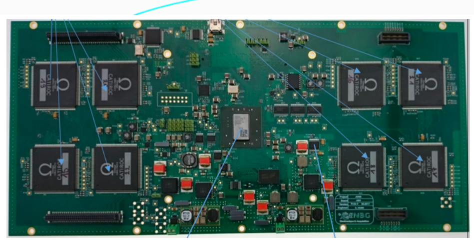
Global trigger scheme



- Design completed for most of the components
- Validation and integration tests are being carried on

Readout of the small PMTs



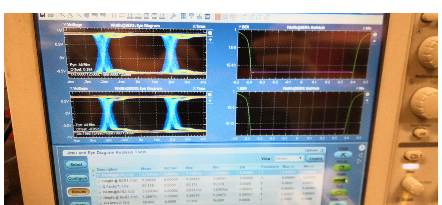


ABC front-end card
with CATIROC ASIC

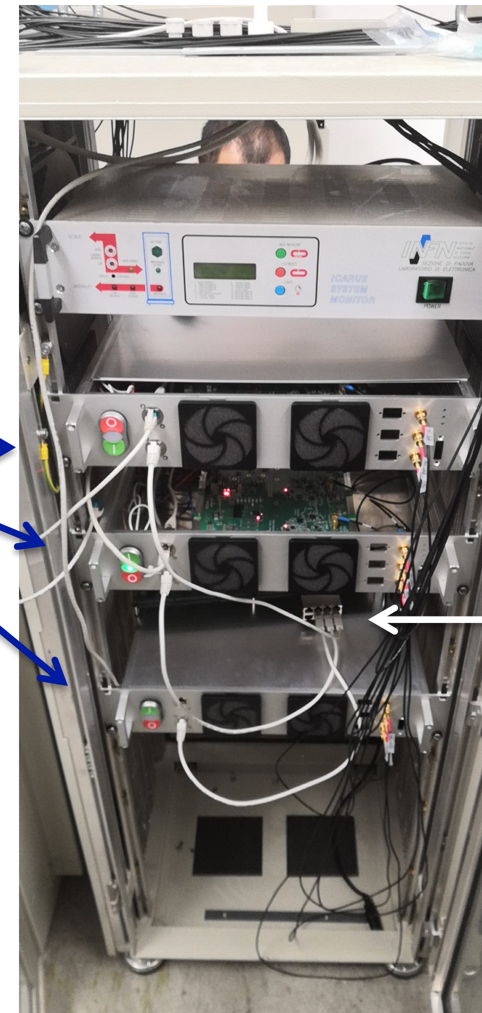
Conclusions

- JUNO is an unprecedented liquid scintillator detector (size & resolution)
- Required to reach 3% energy resolution at 1MeV
- The design of the electronics is almost completed, all the different components have been validated and a full integration test is being performed
- Production of the individual parts will follow

Combined test in Padova →



GCU



BEC +TTIM

OTHER JUNO TALKS/ POSTERS at EPSHEP2019

See Talks:

- *JUNO potential for neutrino oscillation physics*, Marco Grassi, Neutrino session
- *Atmospheric neutrino spectrum reconstruction with JUNO,* Giulio Settanta, Astroparticle session

See Posters :

- *Detection of supernova neutrinos with JUNO*, Mario Buscemi
- *Reactor Neutrino Spectrum Uncertainty and Mass Hierarchy Determination*, Emilio Ciuffoli
- *Current status of JUNO Top Tracker*, Qinhua Huang
- *Study on HQ-LAB for the JUNO experiment*, QI Ming
- *Water Cherenkov detector of the JUNO Veto system*, Ruiguang Wang
- *The electronics readout system of the JUNO experiment,* Pierre-Alexandre Petitjean

BACKUP

JUNO TAO

TAO = Taishan Anti-neutrino Observatory
TAO will measure the anti-neutrino spectrum at % level, to provide:

- a model-independent reference spectrum for JUNO
- a benchmark for investigation of the nuclear database

Detector concept :
2.6 t Gd-loaded LS @-50°C+ SiPM
700k/year @ 40m from Taishan
20x JUNO 6-year data in 3 year
Energy resolution: 1.5%/√E

Status:
Design and R&D on the way:

- LS works in -50°C
- SiPM & its readout electronics
- Mechanical design
- Measured onsite muon/neutron flux
- Prototype a low temperature LS detector