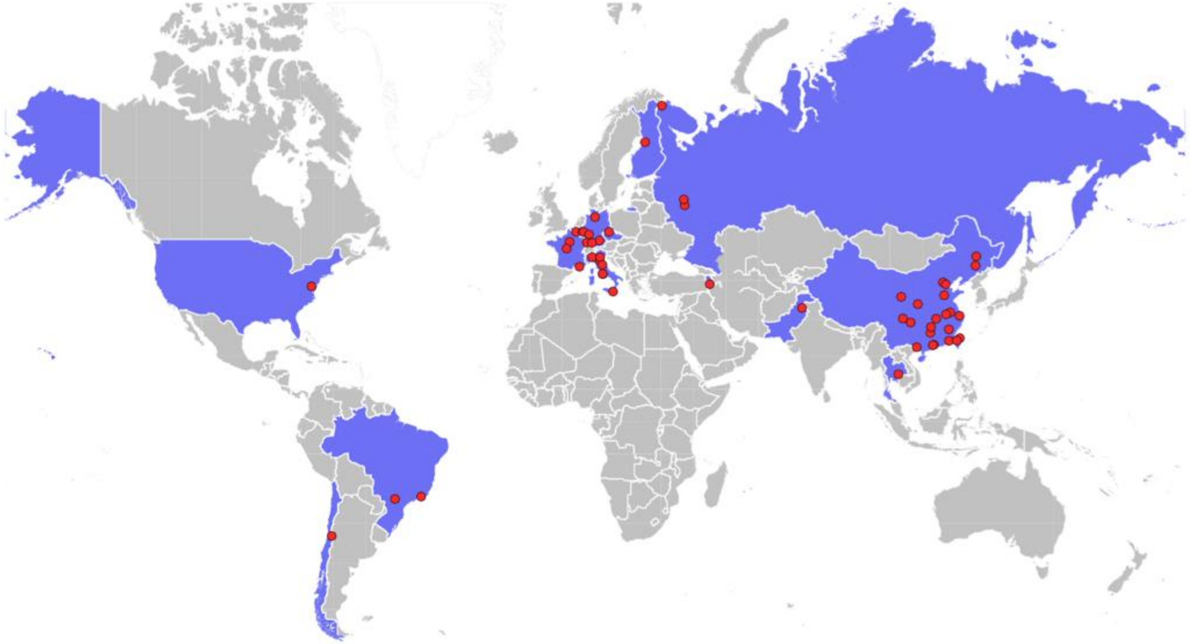
Status of JUNO

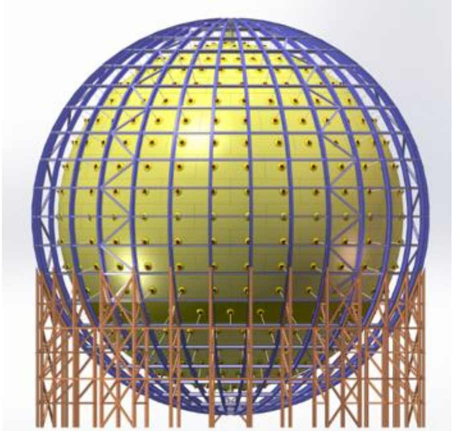
Wladyslaw H. Trzaska on behalf of JUNO Collaboration

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Jiangmen Underground Neutrino Observatory

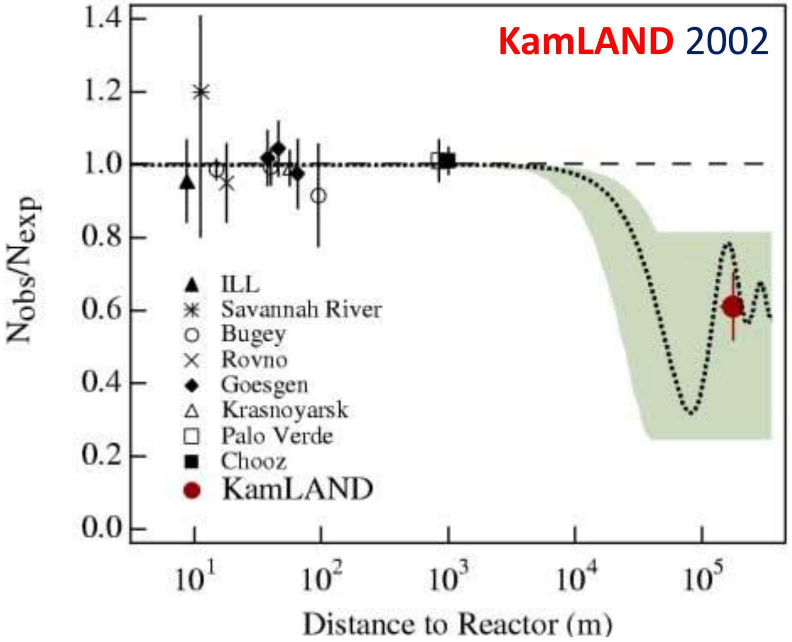


Multipurpose
Neutrino
Experiment
Utilizing 20 kton of LS

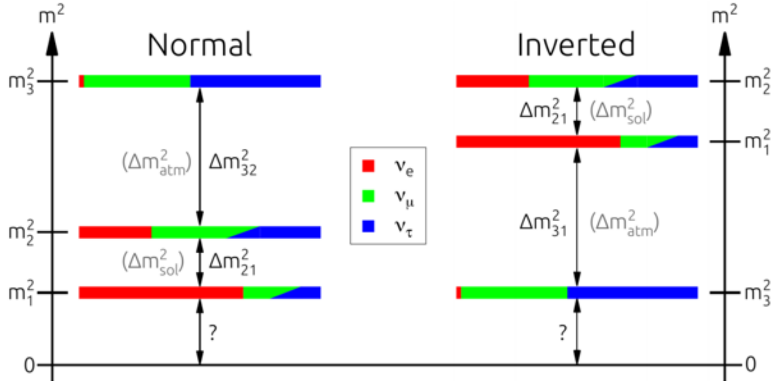


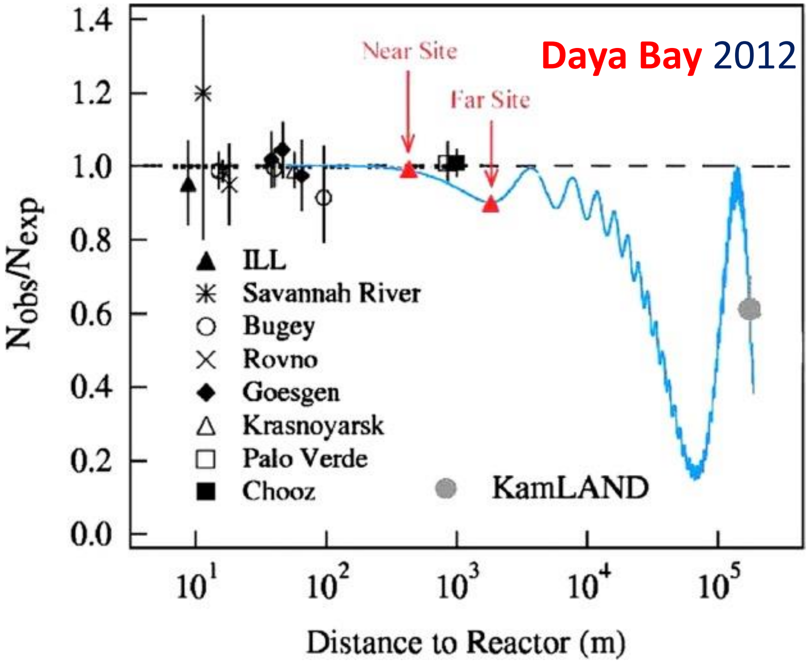
~550 participants from 72 institutions in 17 countries

Rapid progress over the past 2 decades in Liquid Scintillator neutrino detectors



JUNO 2022 →

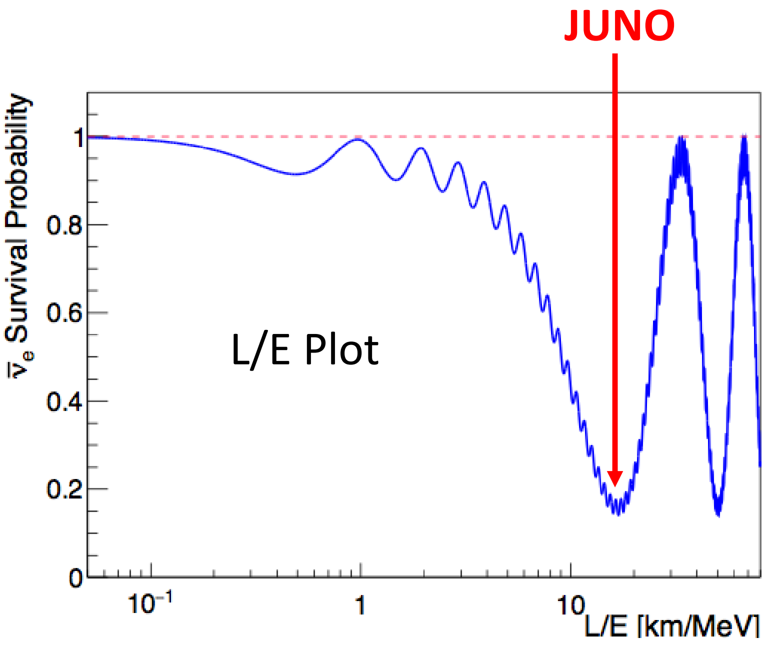


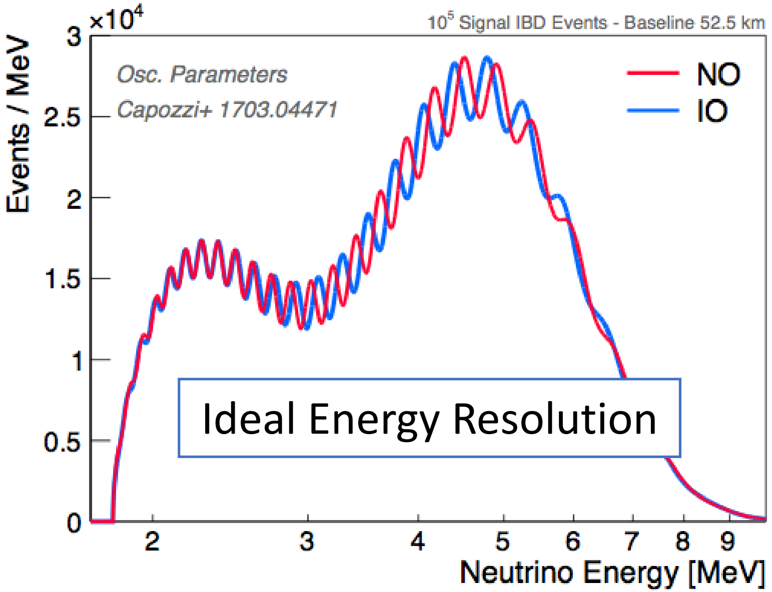


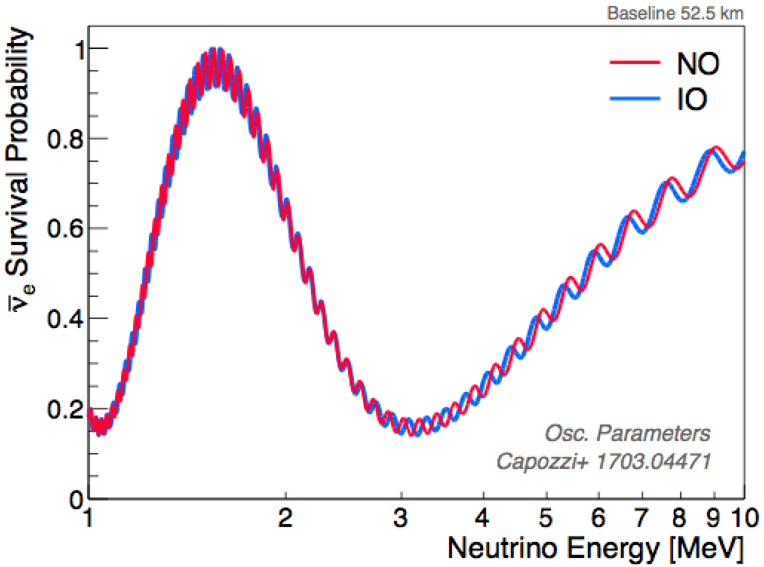
Main goal of JUNO: Mass Hierarchy

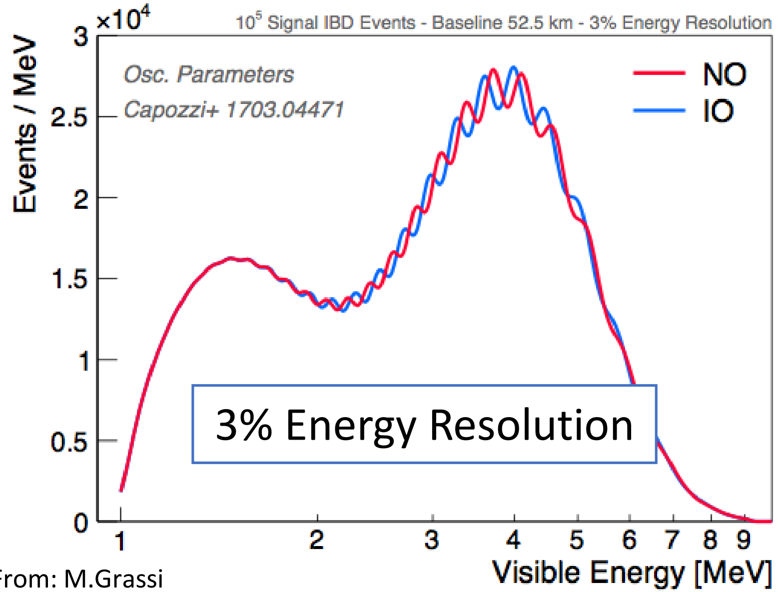
Essential requirements:

- Energy **resolution** ~3%/$\sqrt{E}$
- Energy **scale** uncertainty <1%
- Large **statistics**
  - ~30 GW_{th} reactor power
  - 20 kton of liquid scintillator
    - ~60 events/day
  - Overburden & μ-tracking
- Reactor baseline **spread** < 1% (<0.5 km @ 50 km)





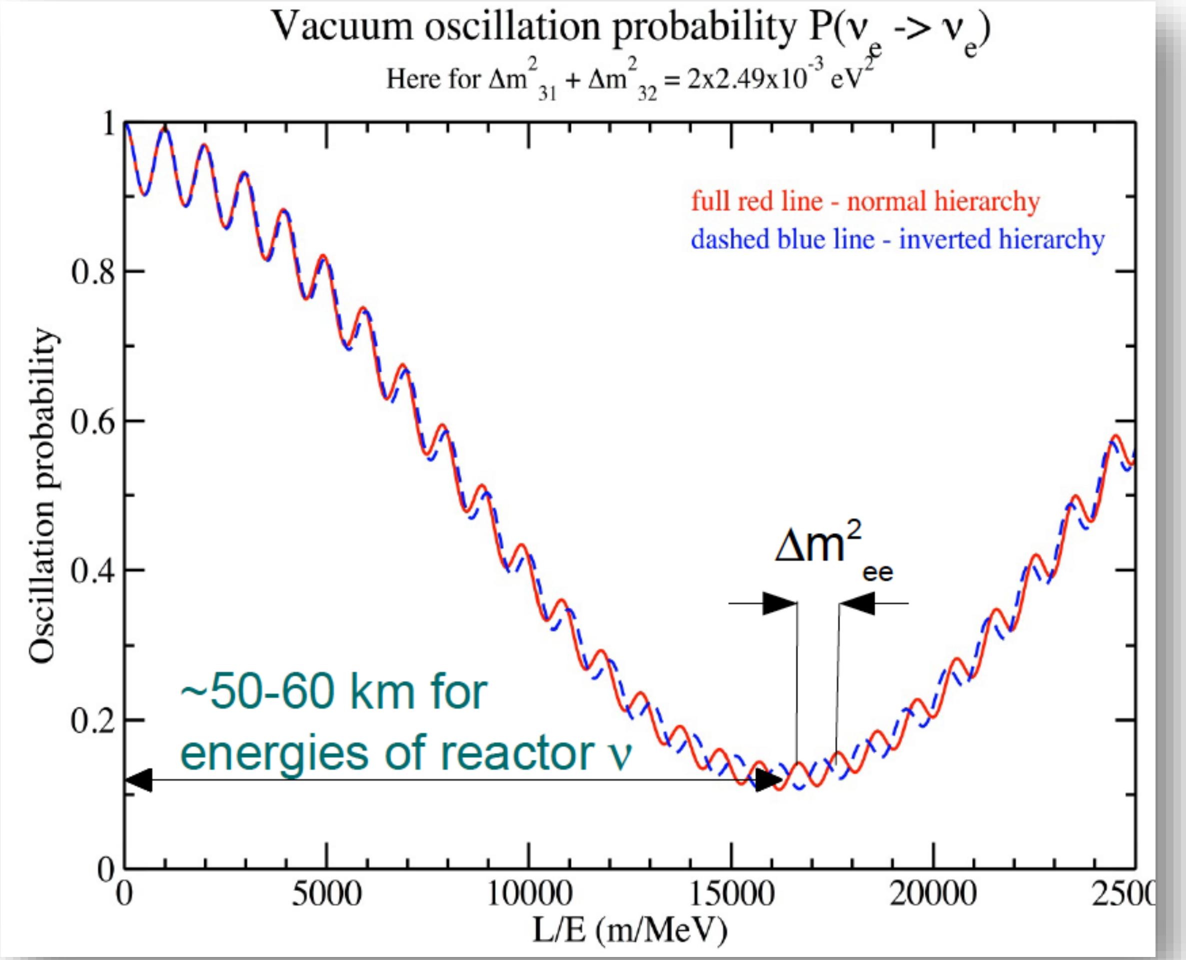




From: M.Grassi

Mass Hierarchy Determination Sensitivity

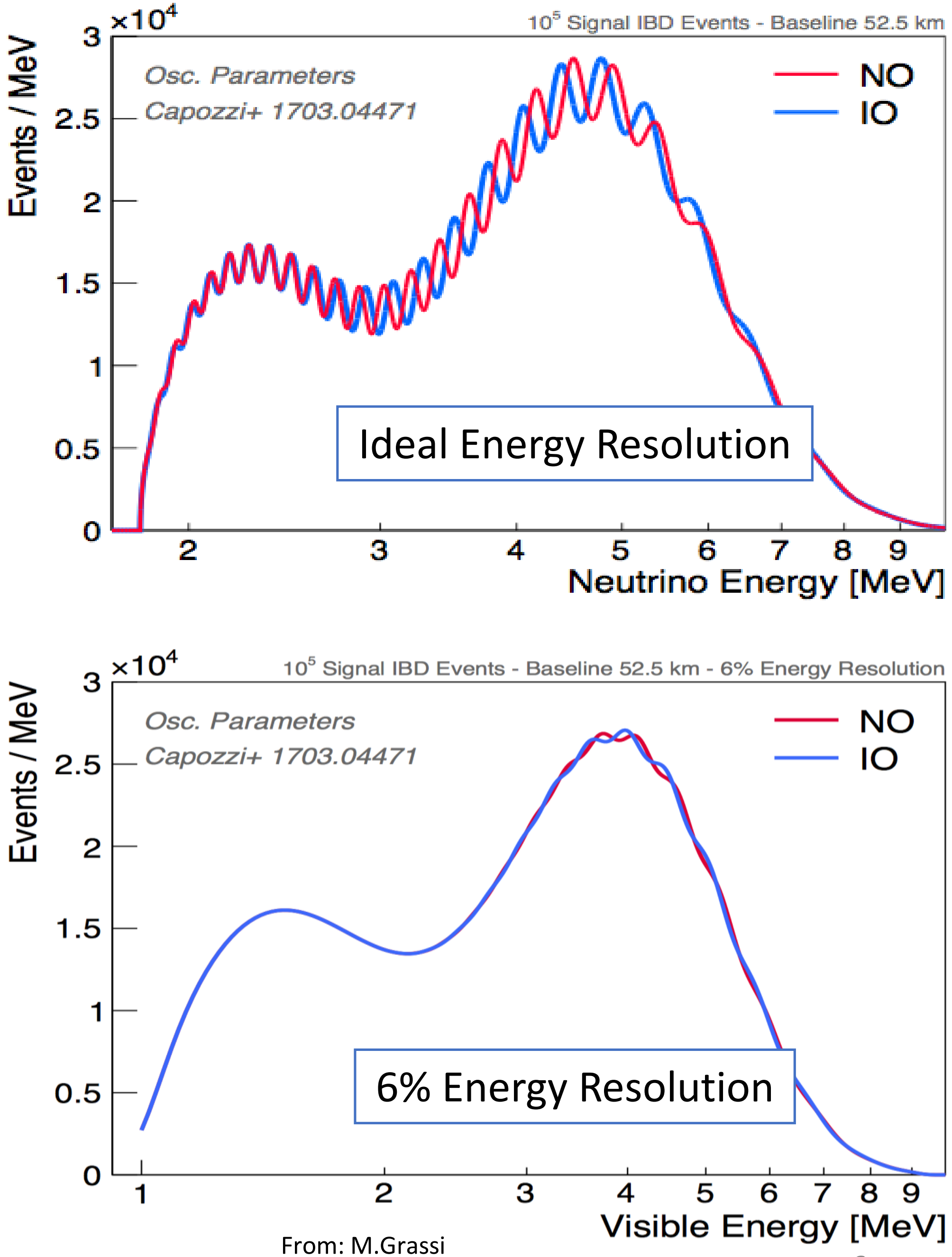
- **6 years** of running with **20 kton detector** at 52 km from **36 GW** reactor complex should yield 100 k Inverse Beta Decay events
- **3σ** would be reached with the current oscillation parameters
- **4σ** assuming improved estimate of Δm^2_{ee} (~1%) from T2K and NOvA experiments



$$\Delta m^2_{ee} = \cos^2\theta_{12}\Delta m^2_{31} + \sin^2\theta_{12}\Delta m^2_{32}$$

Energy resolution is crucial

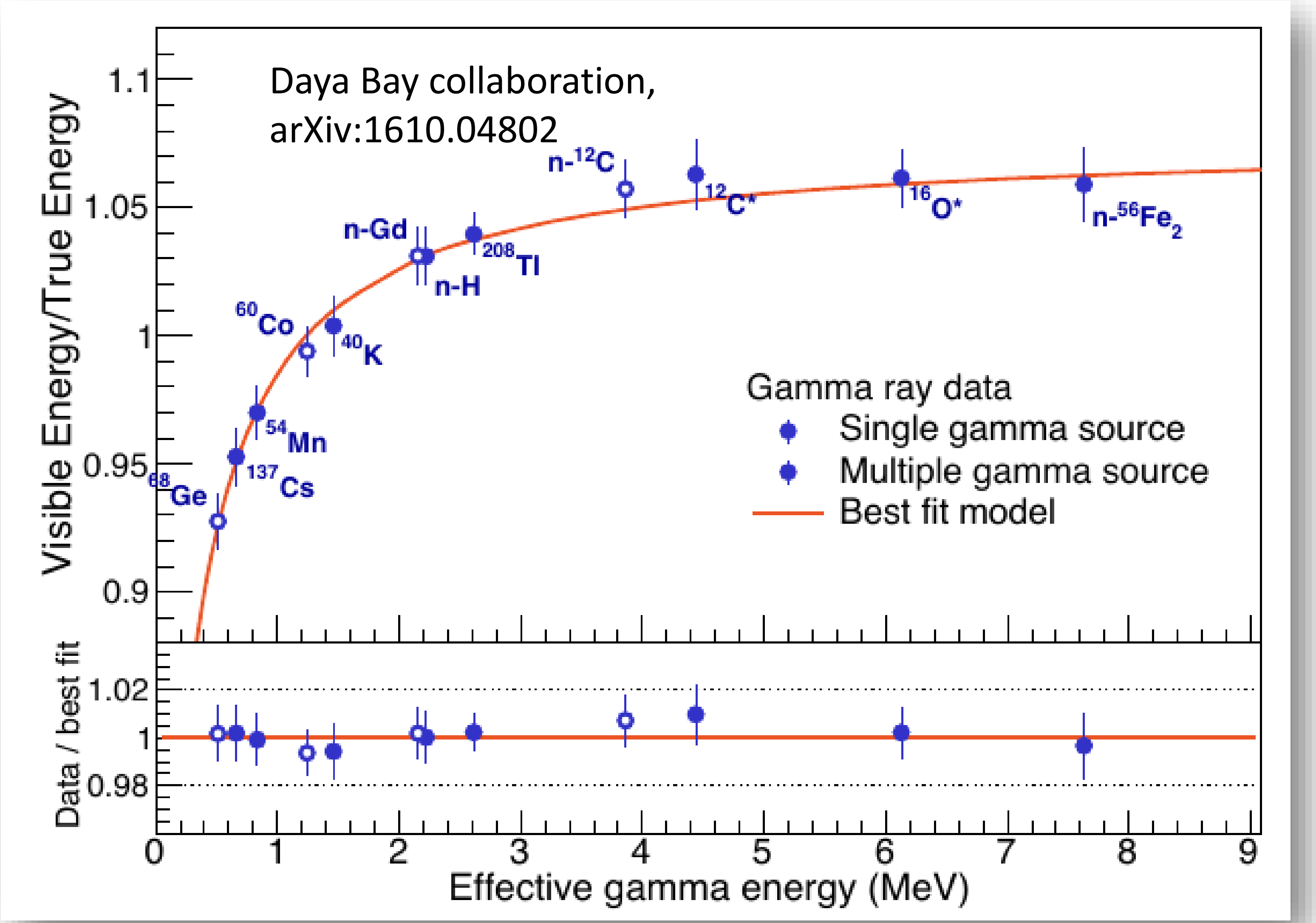
- Determination of MH would be challenging even with perfect energy resolution
- With a 6% energy resolution the signal is already completely smeared out



From: M.Grassi

Is it possible to reach 1% uncertainty in energy scale?

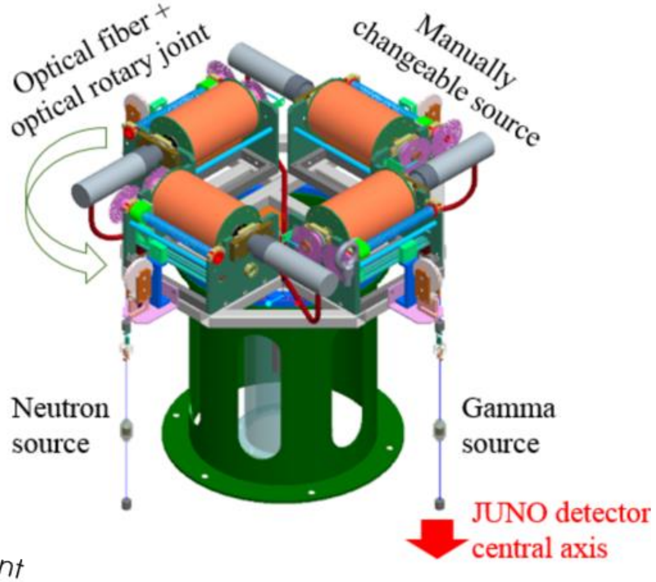
- It has been done before
  - Double Chooz 0.74%
  - Daya Bay ~1%
  - Borexino <1% (at low energies)
  - KamLAND 1.4%
- Requires painstaking multiple-source calibration procedures

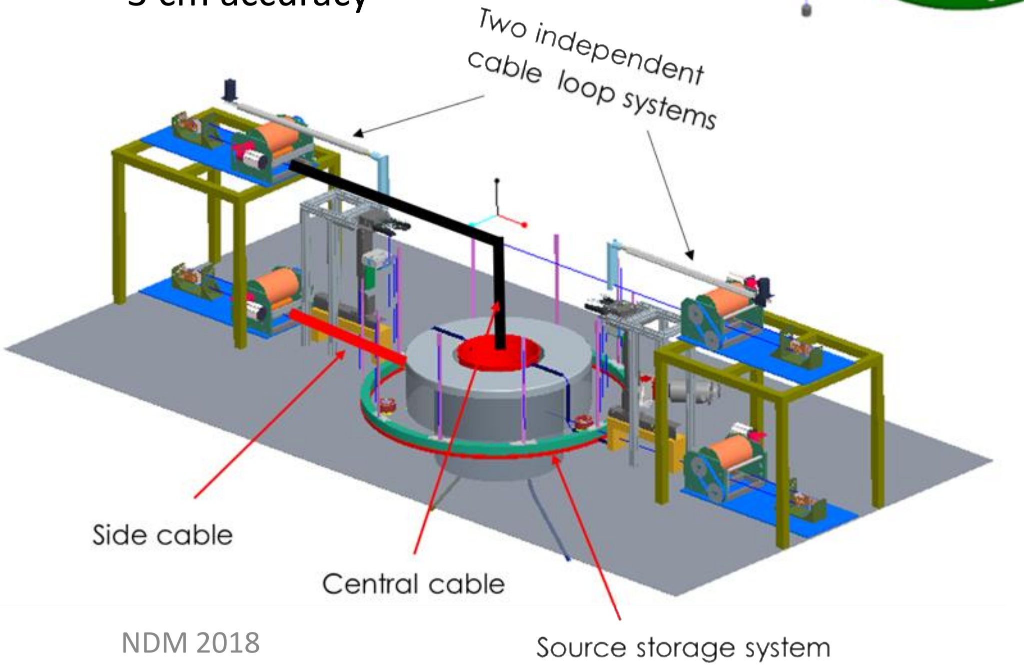


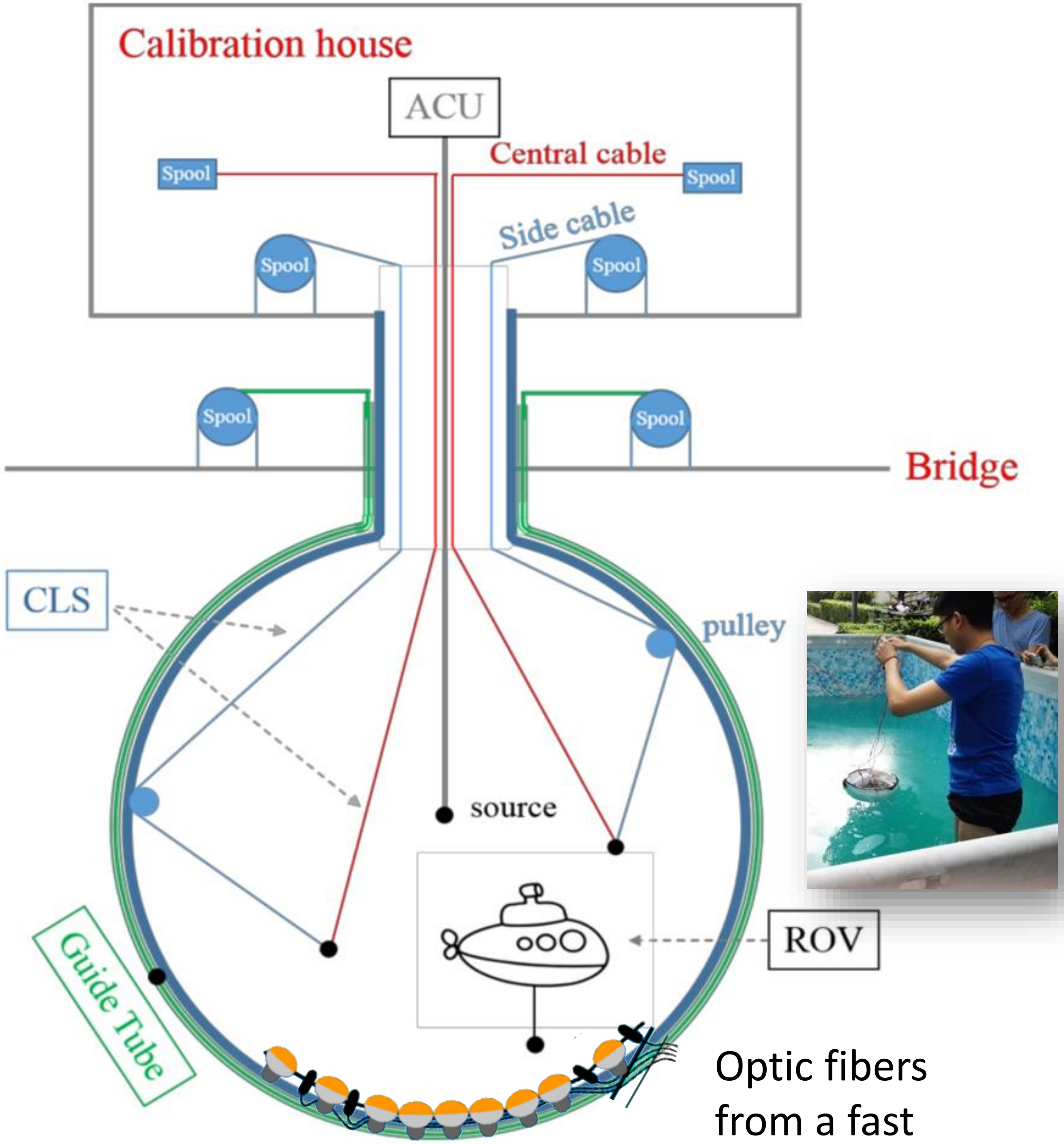
R&D on calibration systems

- Automatic Calibration Unit
- Cable Loop System
- Guide Tube System
- Remotely Operated Vehicle

- Ultrasonic positioning
  - 3 cm accuracy

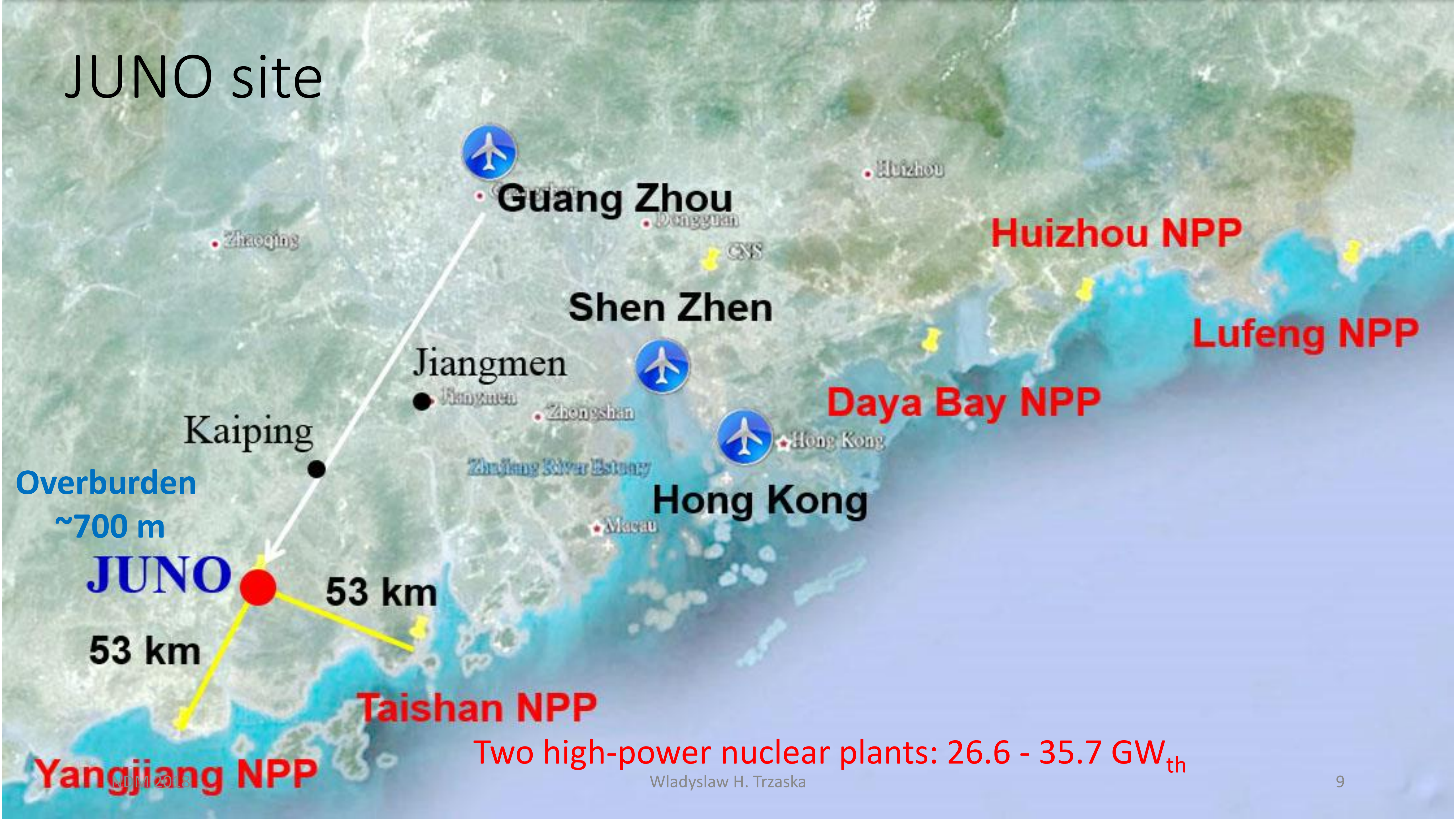






Optic fibers
from a fast
UV LASER

JUNO site

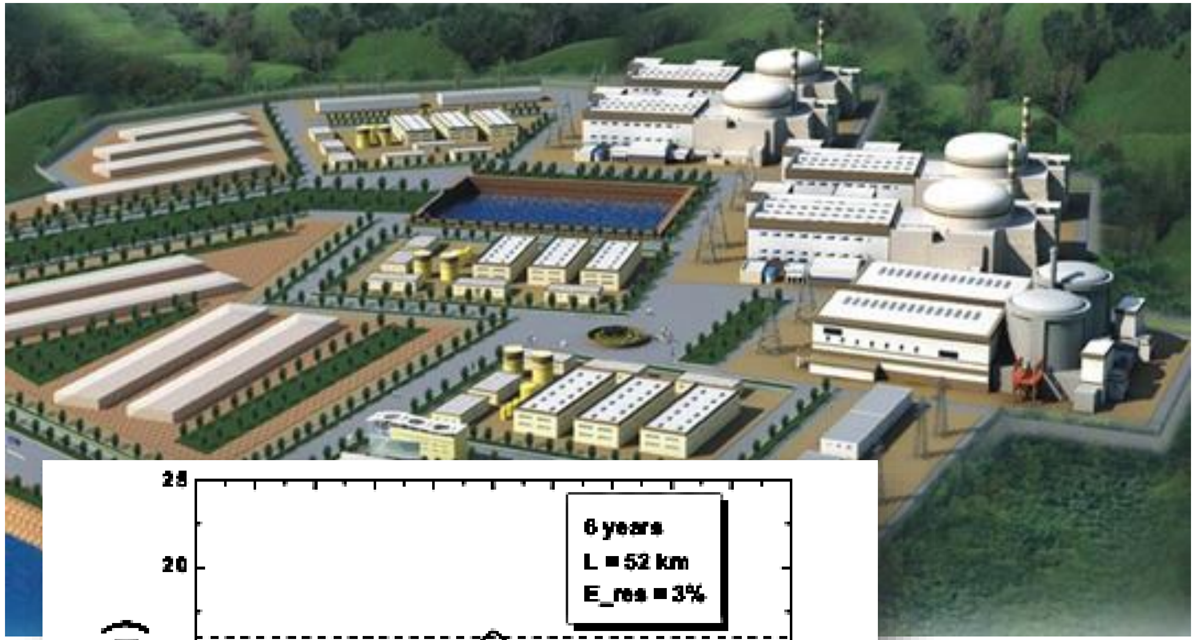


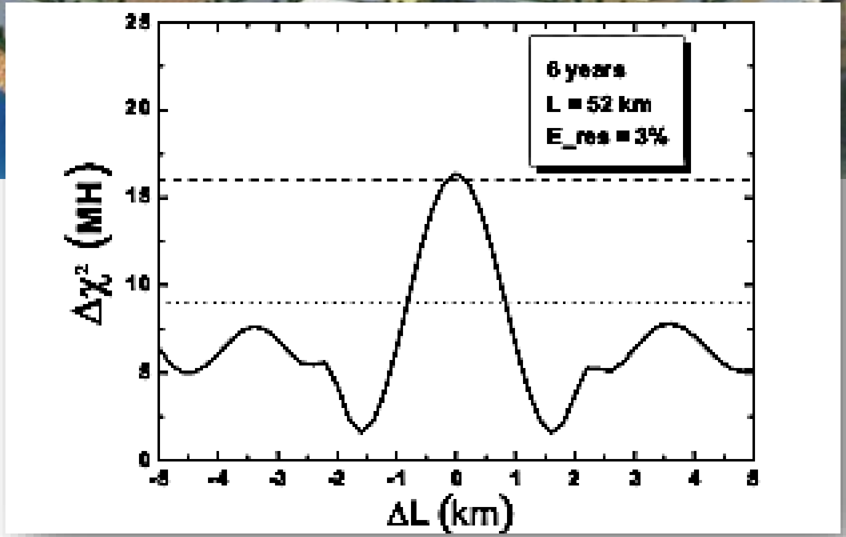
Two high-power nuclear plants: 26.6 - 35.7 GW_{th}

Baseline between JUNO Central Detector and neighboring nuclear power plants

Cores	YJ-C1	YJ-C2	YJ-C3	YJ-C4	YJ-C5	YJ-C6
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9
Baseline(km)	52.75	52.84	52.42	52.51	52.12	52.21

Cores	TS-C1	TS-C2	TS-C3	TS-C4	DYB	HZ
Power (GW)	4.6	4.6	4.6	4.6	17.4	17.4
Baseline(km)	52.76	52.63	52.32	52.20	215	265



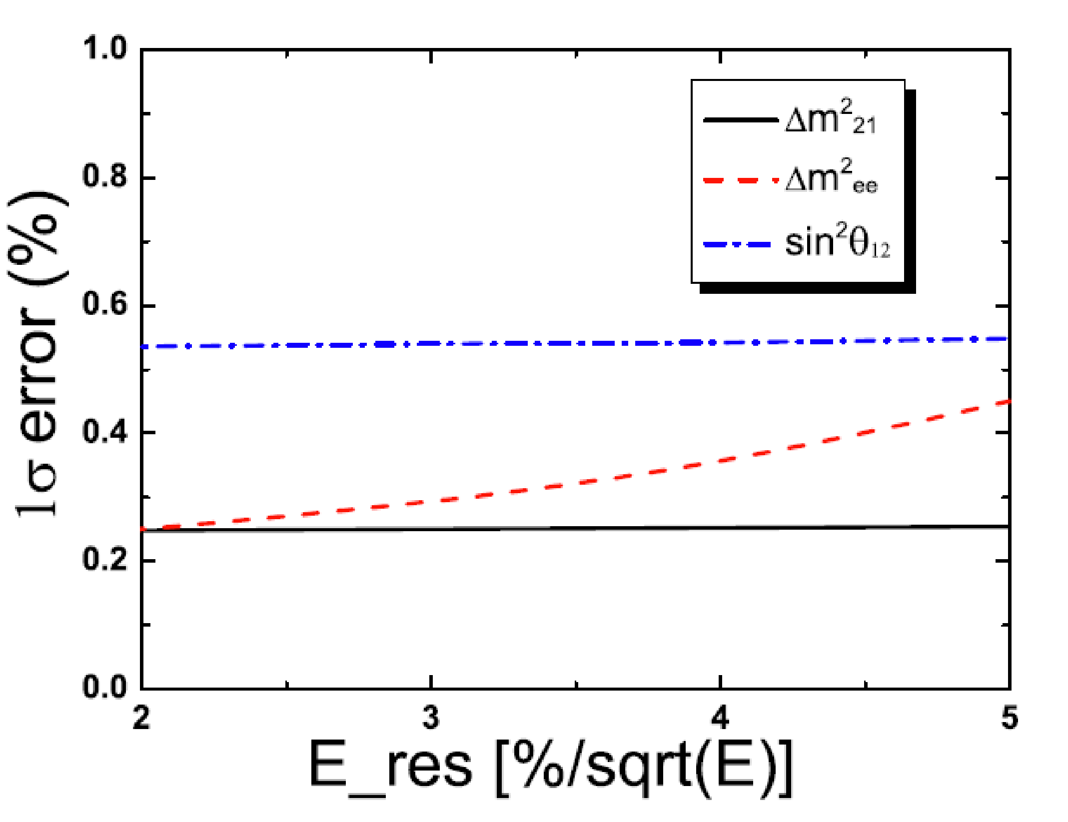


Taishan

https://arxiv.org/abs/1507.05613v2

Oscillation Parameter Accuracy Expected from JUNO Data

- **0.6% for Δm^2_{21}**
  (2.4% KamLAND; 2.2% Global)
- **0.4% for $|\Delta m^2_{31}|$**
  (3.2% T2K; 1.2% Global)
  - Depends on the energy resolution
- **0.7% for $\sin^2\theta_{12}$**
  (6.7% SNO; 3.9% Global)
- **JUNO complements** the parameters extracted from LBNO measurements: **Δm^2_{31}, θ_{13} , θ_{23}**

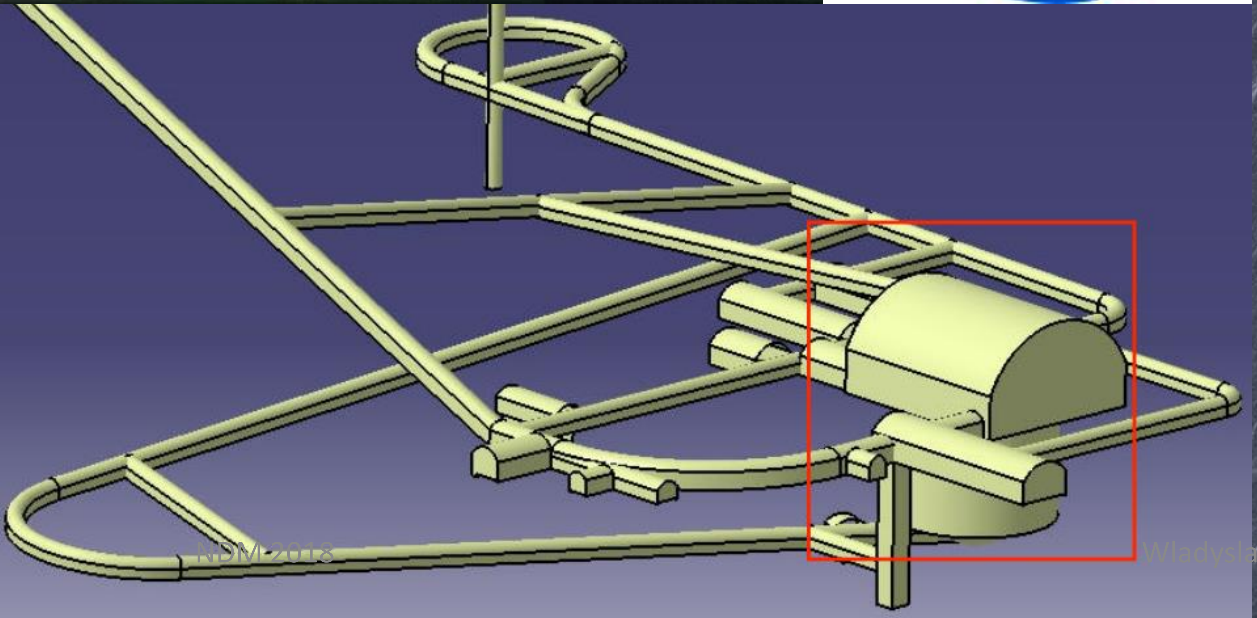


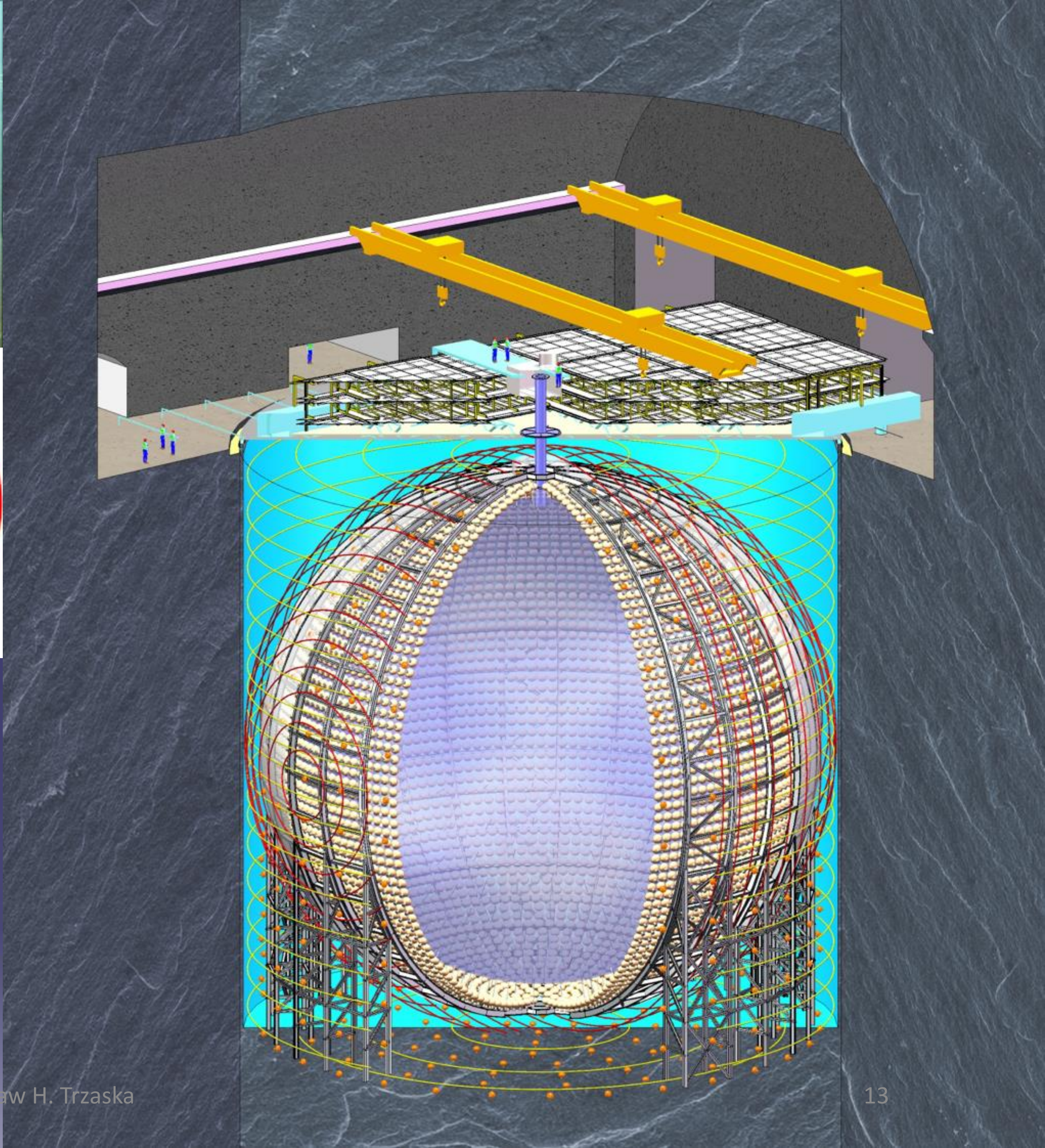
$$\Delta m^2_{ee} = \cos^2\theta_{12}\Delta m^2_{31} + \sin^2\theta_{12}\Delta m^2_{32}$$

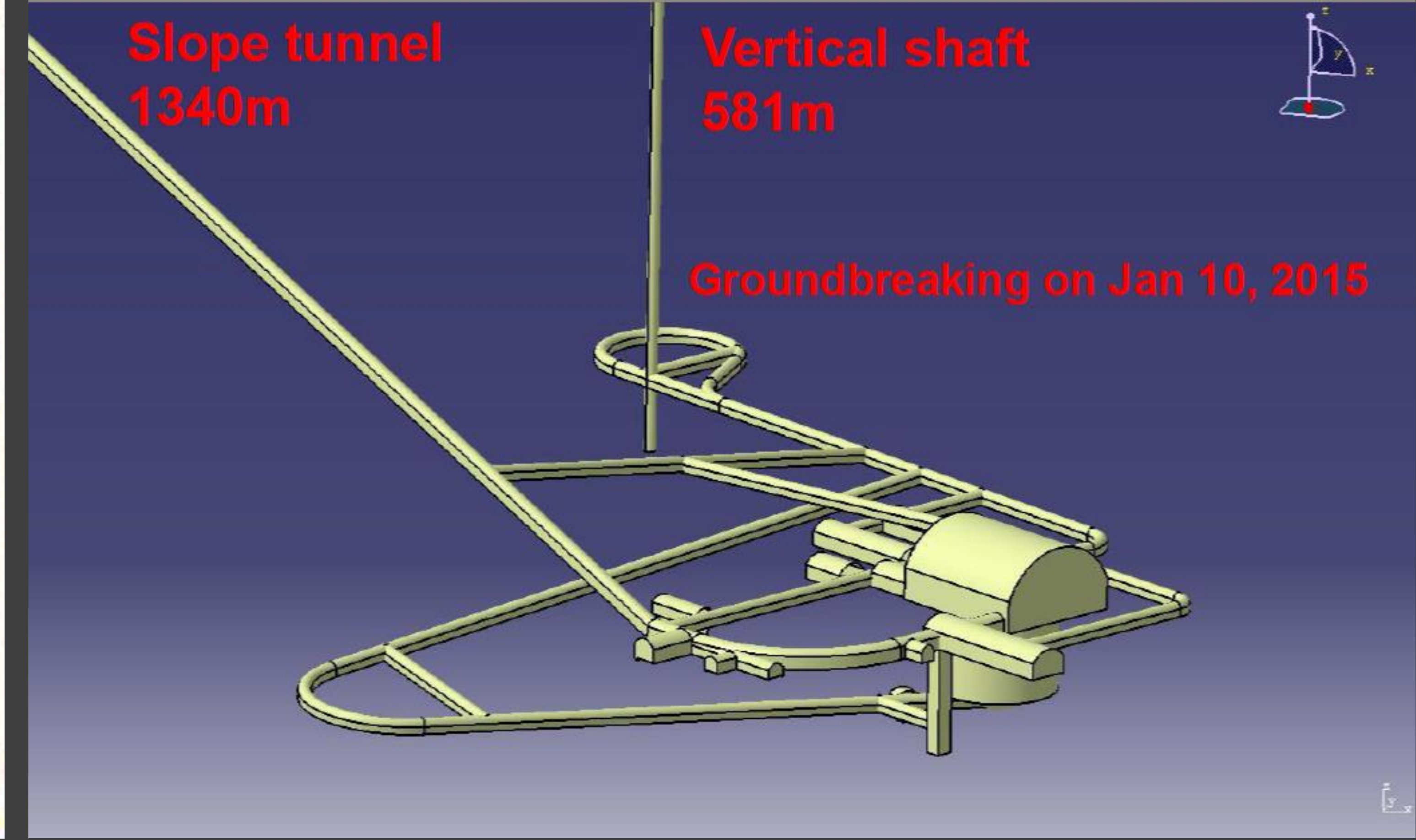
Other research goals for JUNO

For in-depth review of the physics case see:
https://arxiv.org/abs/1507.05613v2

- Supernova neutrinos
- Diffuse Supernova Neutrino Background
- Solar neutrinos
- Atmospheric neutrinos
- Geoneutrinos
- Sterile neutrinos
- Nucleon decay
- Neutrinos from Dark Matter

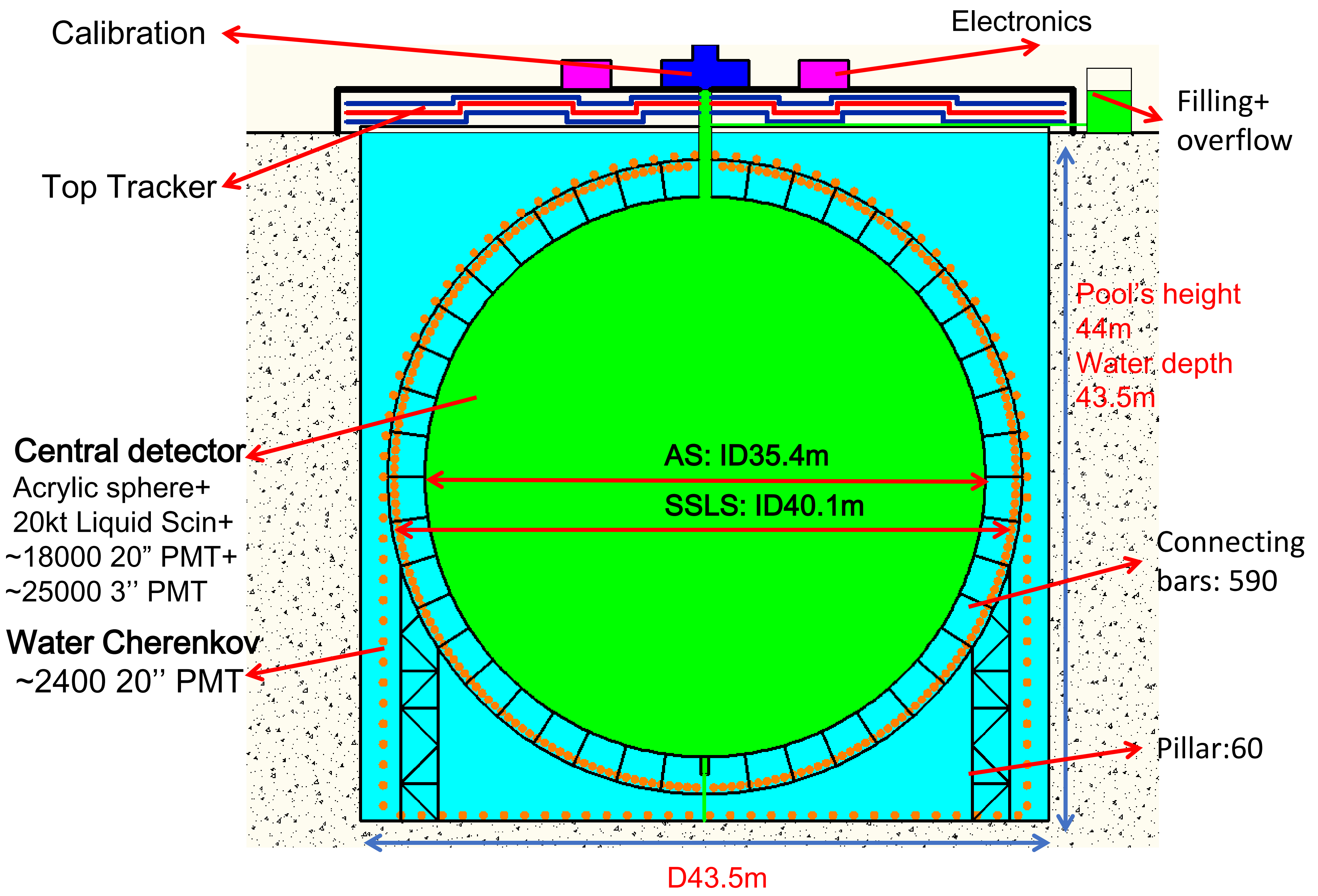






Civil construction

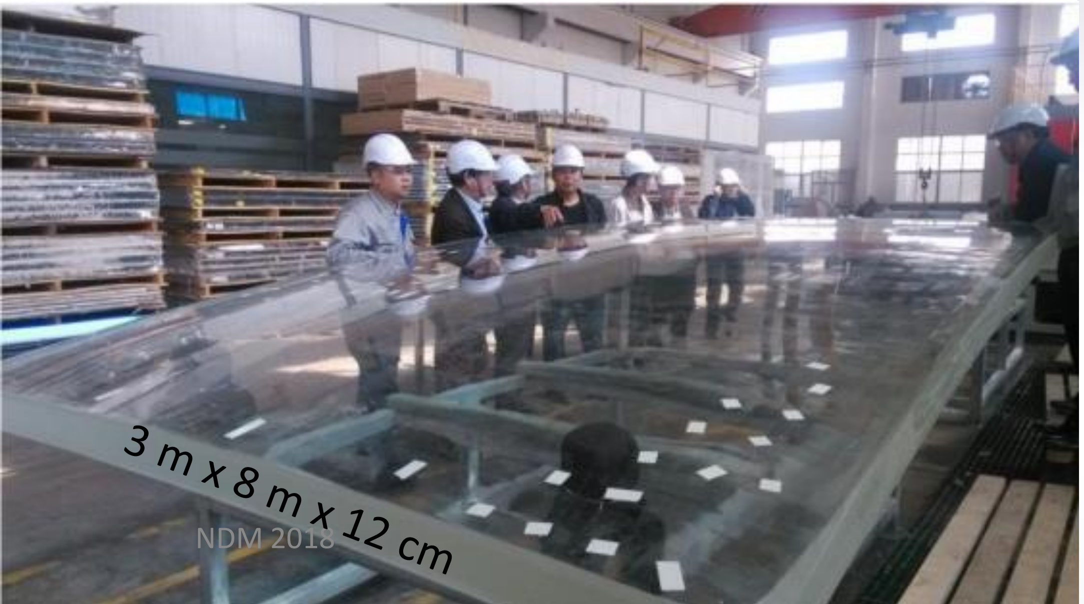
Central Detector

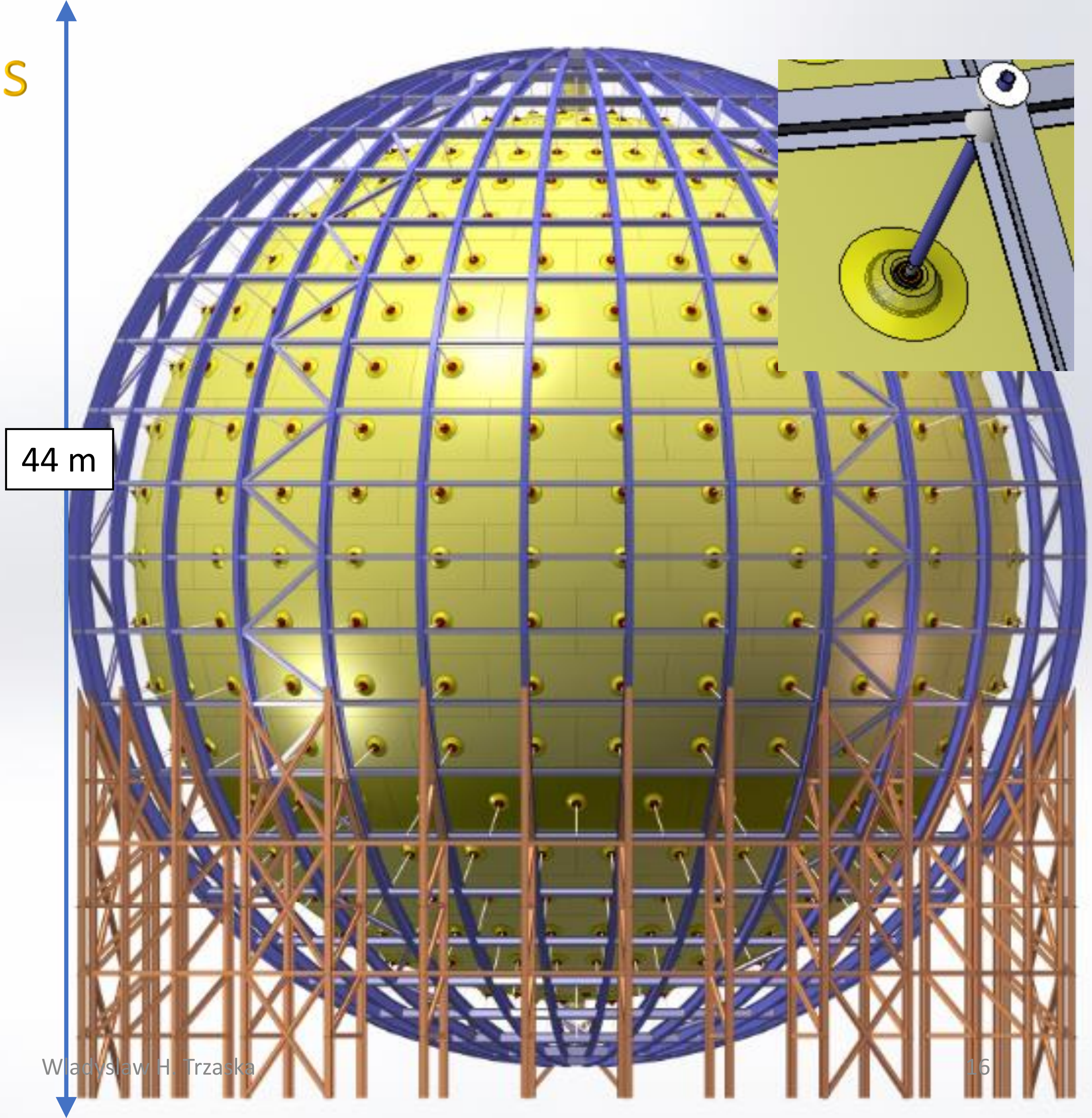


AS: Acrylic sphere; SSLS: stainless steel latticed shell

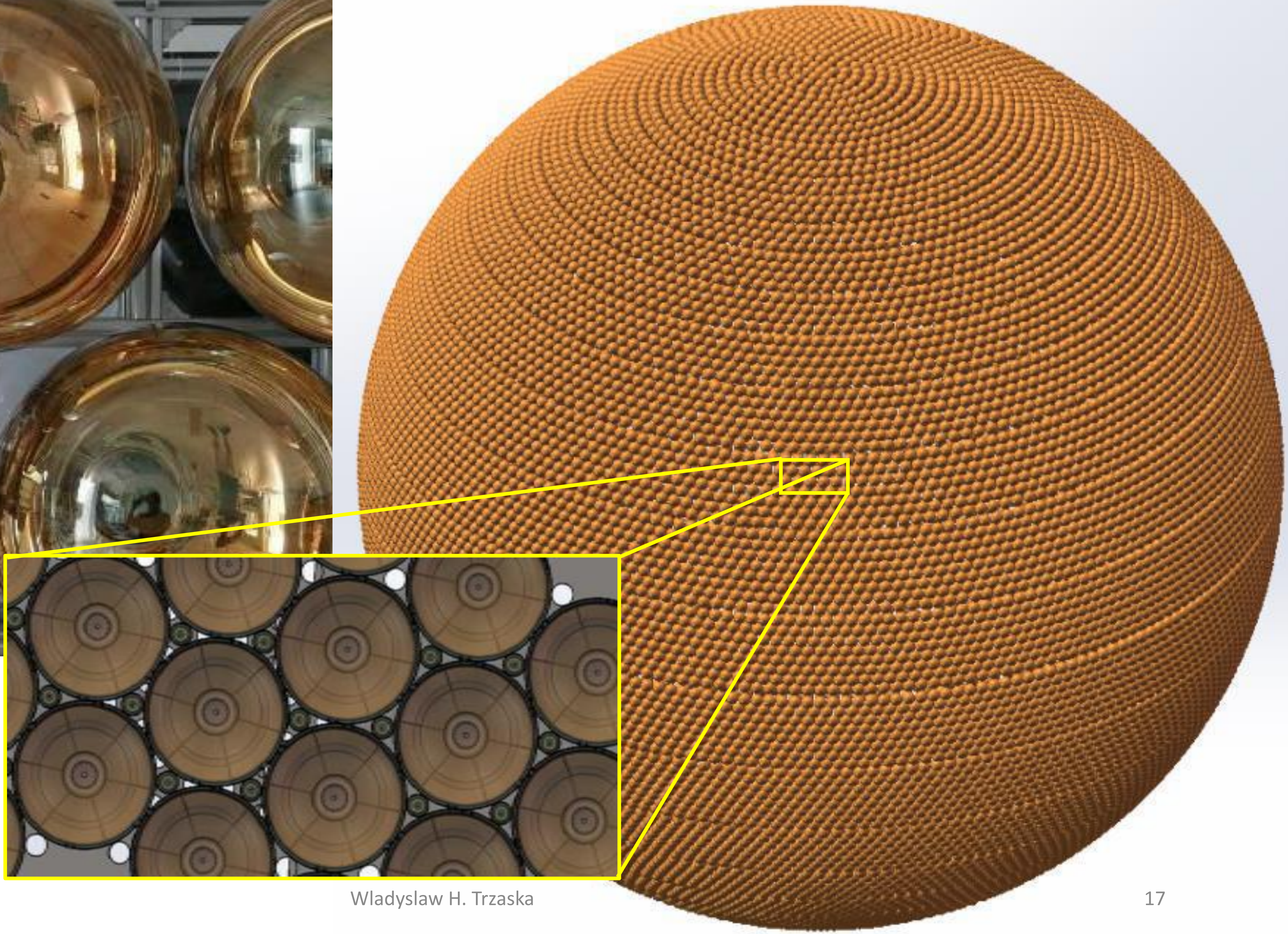
Acrylic Sphere on Steel Truss

- 1,200 tons of acrylic from Donchamp
- 35.4 m diameter; 12 cm thick; made of 265 sheets
  - Polymerization in water
  - Thermal bending
- ~600 support nodes
- Load ~3,000 tons (buoyancy)
- Radioactivity control



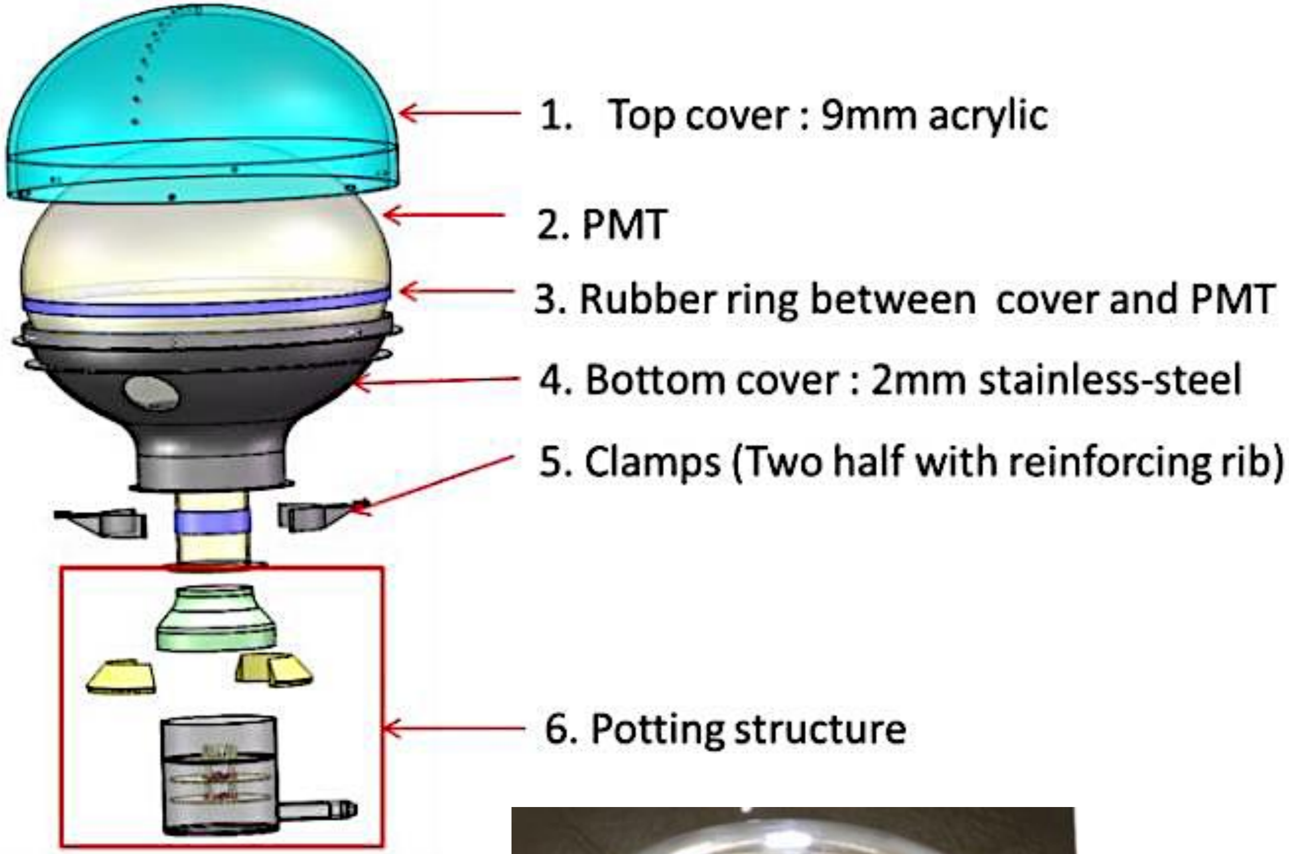


PMTs



JUNO PMT strategy

- Two sizes of PMTs will be used
  - 20” Large PMT; ~20,000 units
  - 3” Small PMT; ~25,000 units
  - Optical coverage ~ 78%
    75% LPMT; 2.5% SPMT
- Implosion protection
- Waterproof potting
- Custom-made dividers
  & electronics
- Stringent quality control



Large PMT

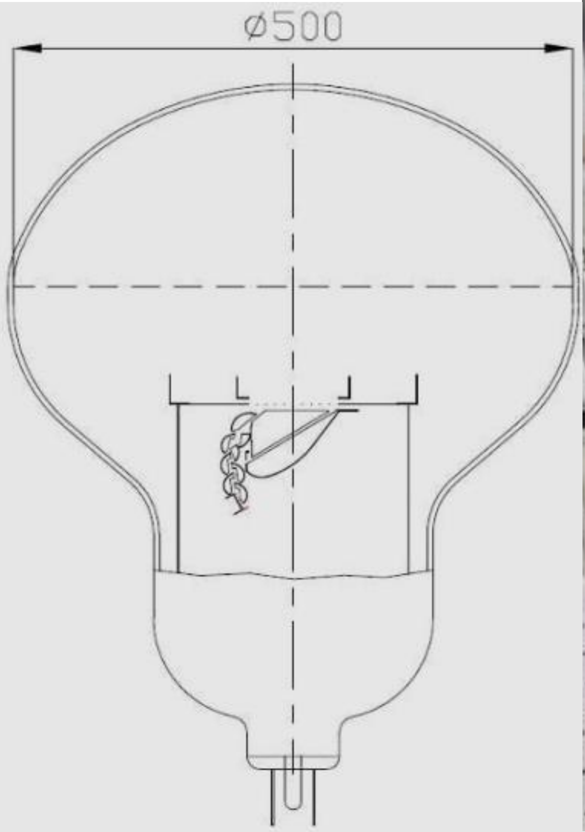
Two types of 20'' PMTs will be used:

- 15,000 MCP PMTs (NNVT)
- 5,000 Dynode PMTs (Hamamatsu)

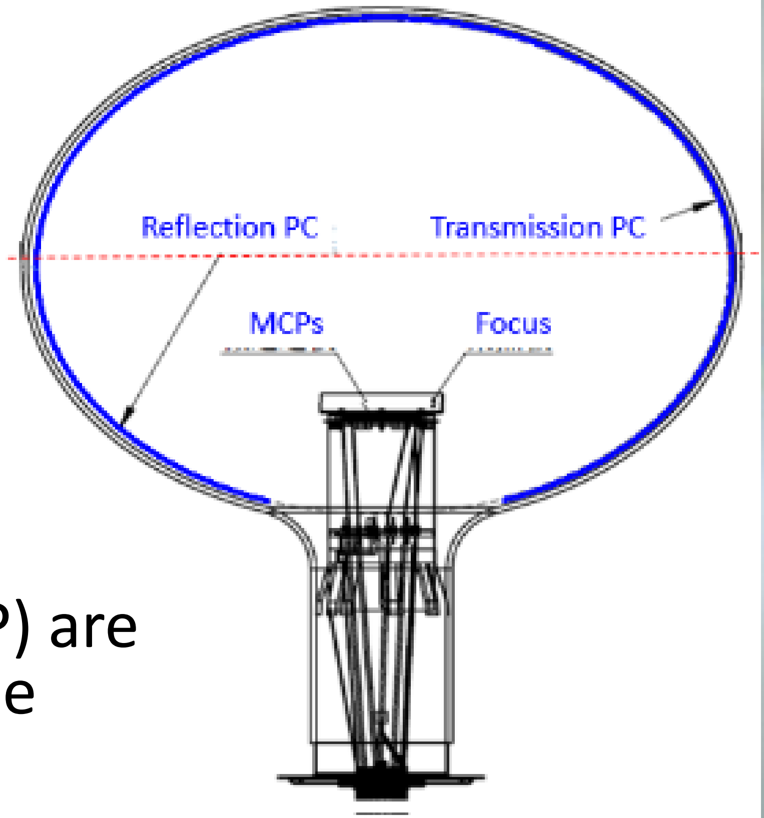
Dynode LPMT

HAMAMATSU
PHOTON IS OUR BUSINESS

- Hamamatsu R12860HQE
- 5000 units ordered
- 3500 already received
- Tests are ongoing
- Average Detection Efficiency > 27%



MCP-based LPMT

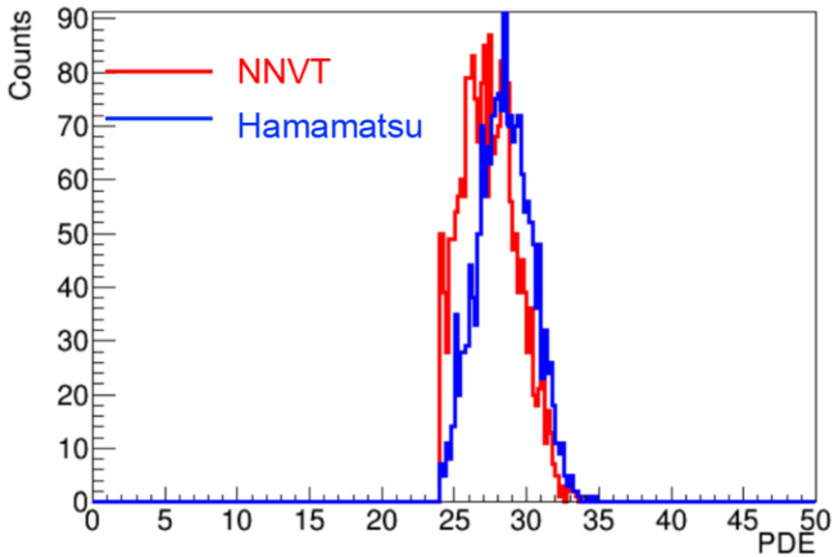


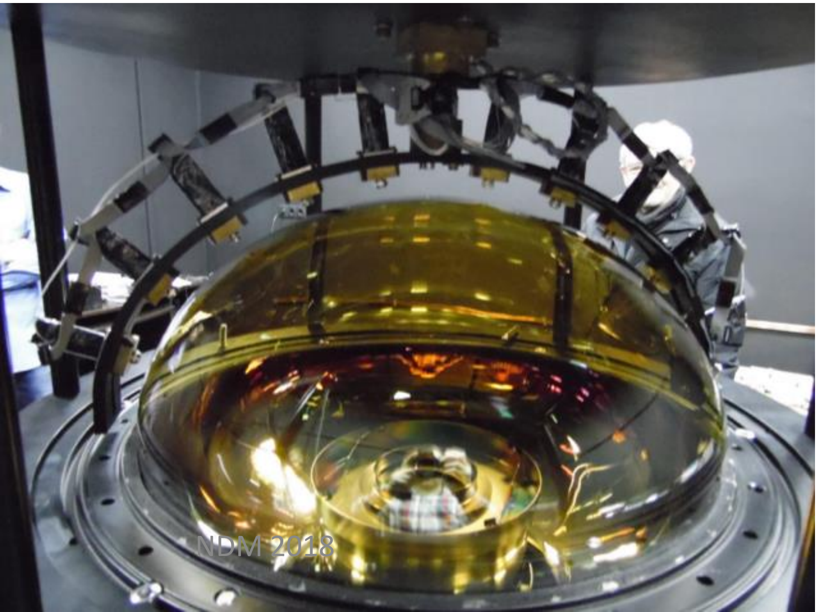
NVT | NIGHT VISION TECHNOLOGY

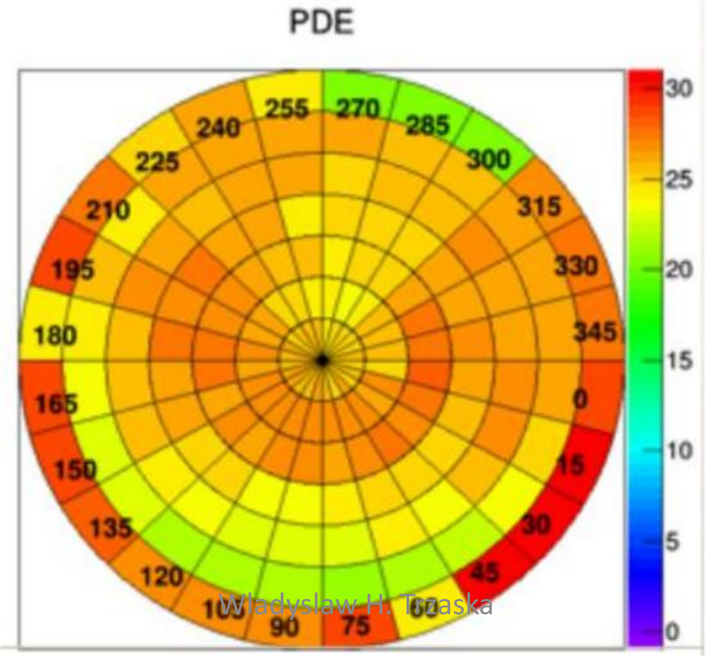
- Custom designed and manufactured for JUNO
- Microchannel plates (MCP) are used instead of the dynode chain
- Dual photocathode:
  - Transmission (front hemisphere)
  - Reflection (back hemisphere)
- 15,000 units ordered from Northern Night Vision Technology

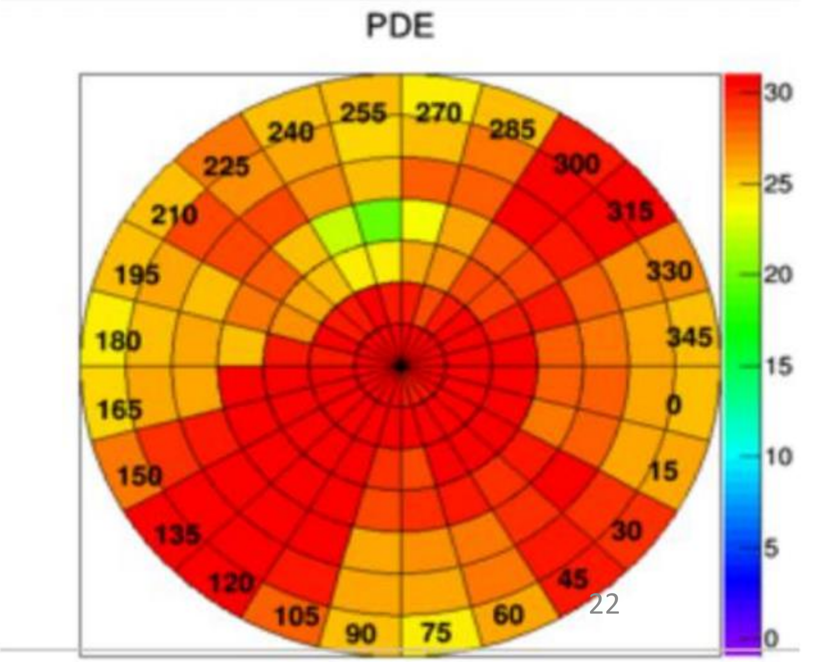
MCP-PMT vs. R1286

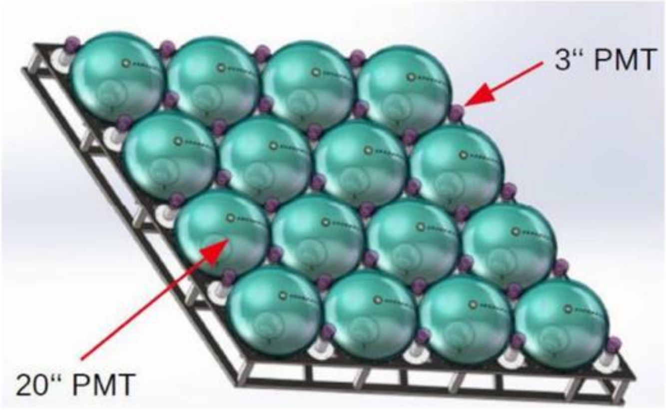
Characteristics	unit	MCP-PMT (NNVT)	R12860 (Hamamatsu)
Detection Efficiency (QE*CE)	%	27%	27%
P/V of SPE		3.5, > 2.8	3, > 2.5
TTS on the top point	ns	~12, < 15	2.7, < 3.5
Rise time/ Fall time	ns	R~2, F~12	R~5,F~9
Anode Dark Count	Hz	20K, < 30K	10K, < 50K
After Pulse Rate	%	1, <2	10, < 15
Radioactivity of glass	ppb	238U:50 232Th:50 40K: 20	238U:400 232Th:400 40K: 40



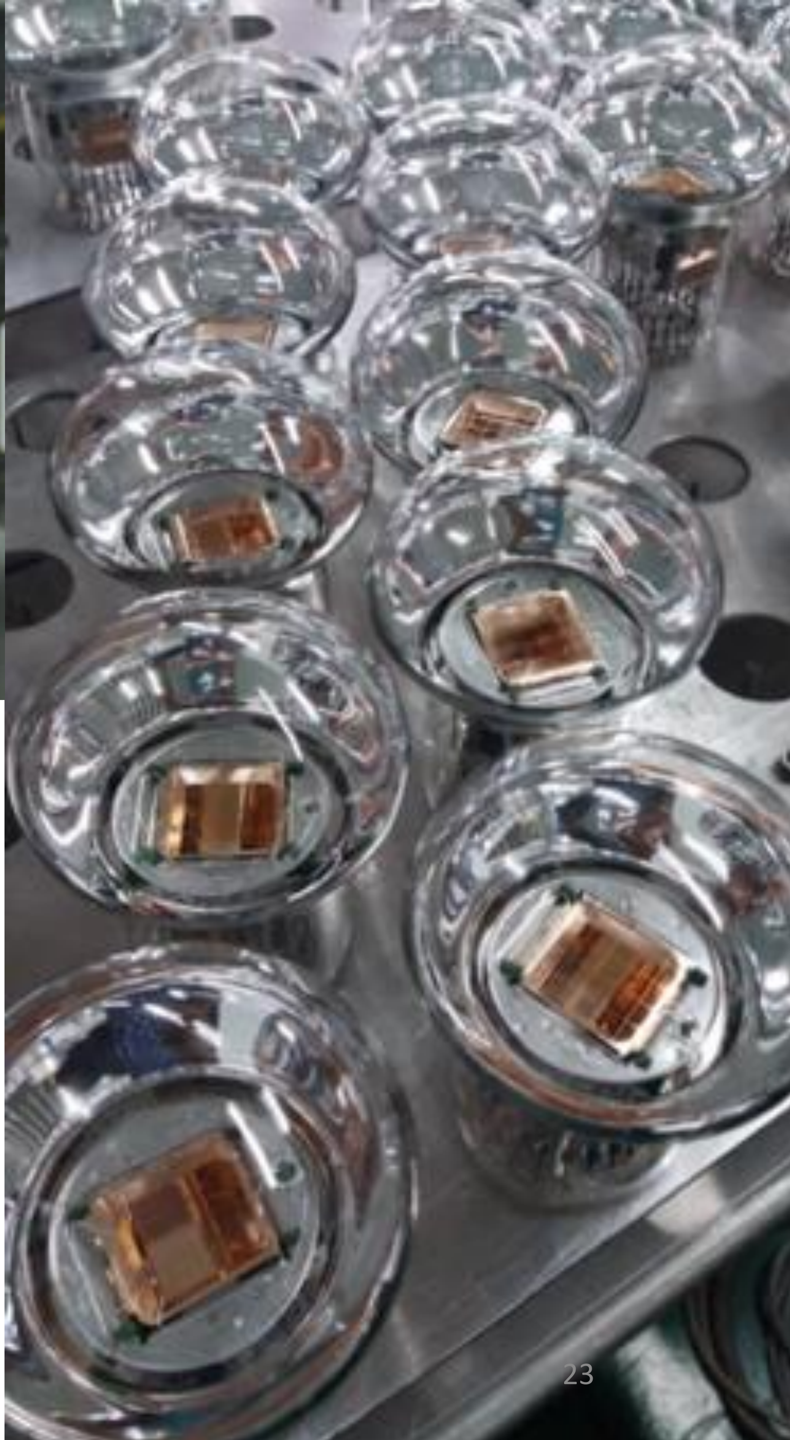








Small PMT



- JUNO custom design XP72B22
  - QE 24%, P/V 3.0, SPE res. 30%; 2-5 ns
- 25000 PMTs contracted to HZC
- 6000 produced, 3000 tested and accepted
- Increased coverage
- Increased dynamic range
  - muons, supernova
- Better control of systematics
- Help in calibration of LPMTs
  - non-linear response of LPMTs

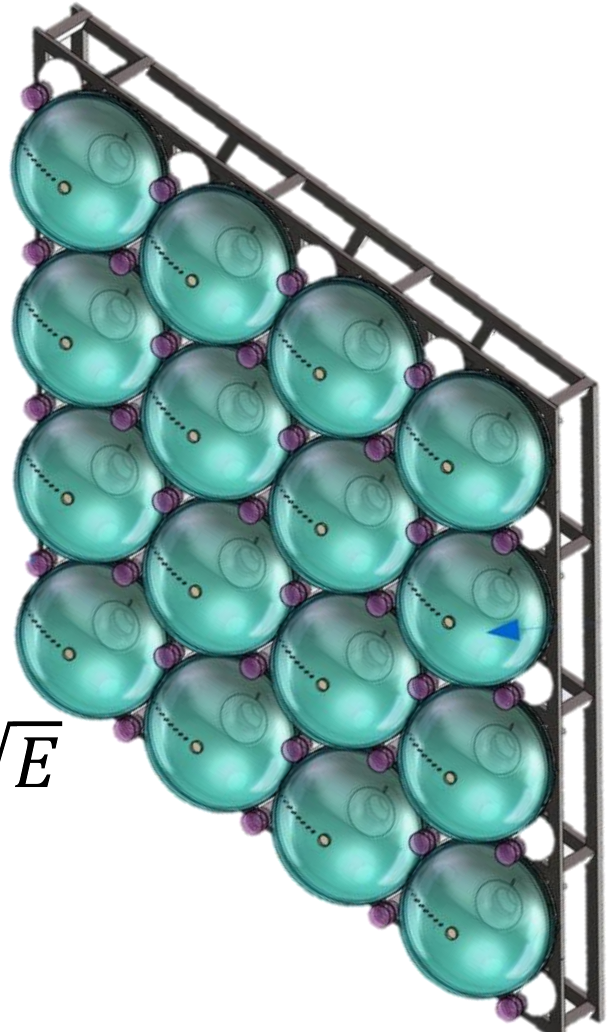
Double Calorimetry: LPMT & SPMT

20” LPMT

- 20,000 units
- 75% optical coverage
- ~1200 p.e./MeV
- Stochastic term: $3\%/\sqrt{E}$
- Large dark noise
- Relatively slow

3” SPMT

- 25,000 units
- 2.5% optical coverage
- ~36 p.e./MeV
- Stochastic term: $16.6\%/\sqrt{E}$
- Small dark noise
- Fast



Benefits: extended dynamic range (for muons), improved time and vertex resolution, muon reconstruction, capability of detecting high events rates (SN)

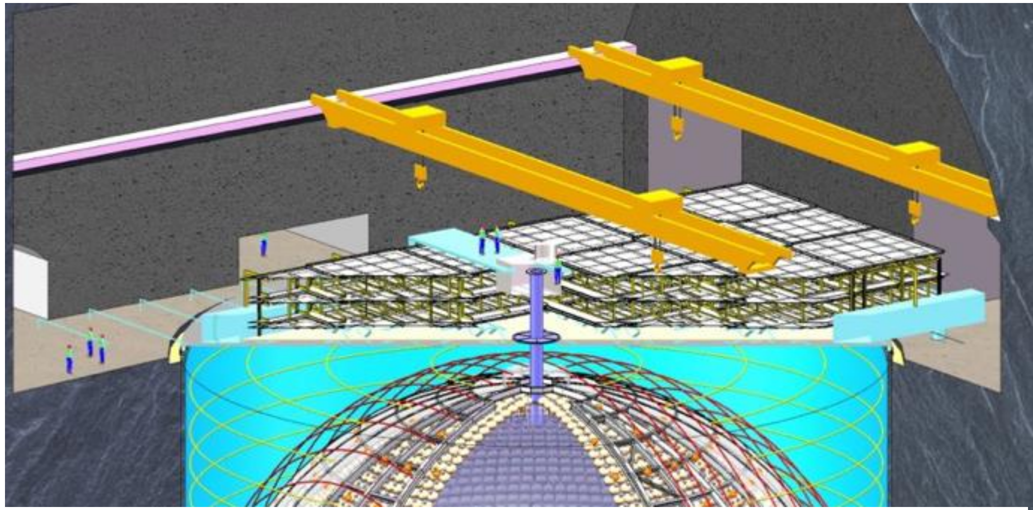
PMT potting

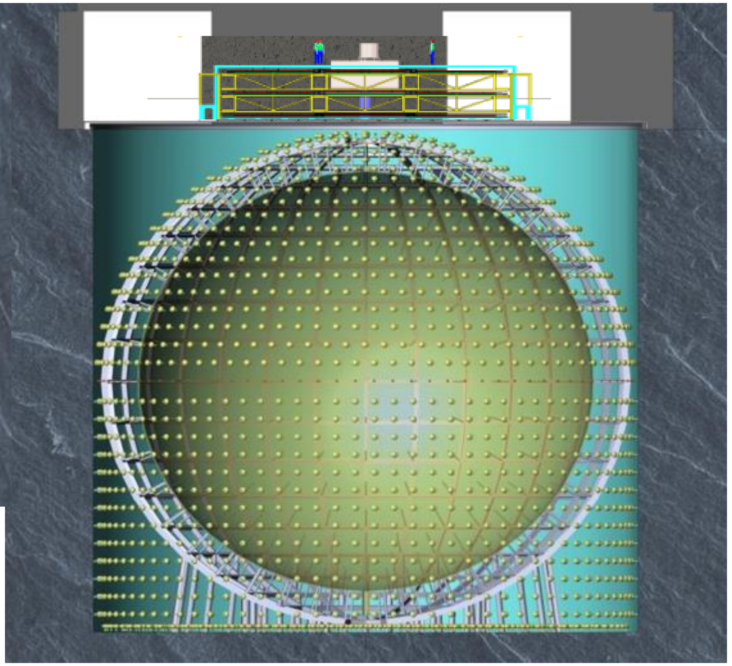
20" MCP-PMT

20" Dynode-PMT

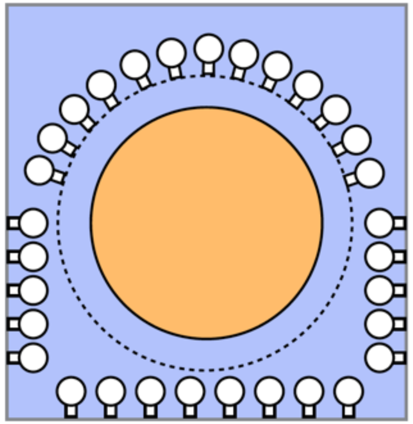
3" SPMT

Muon Veto & Tracking

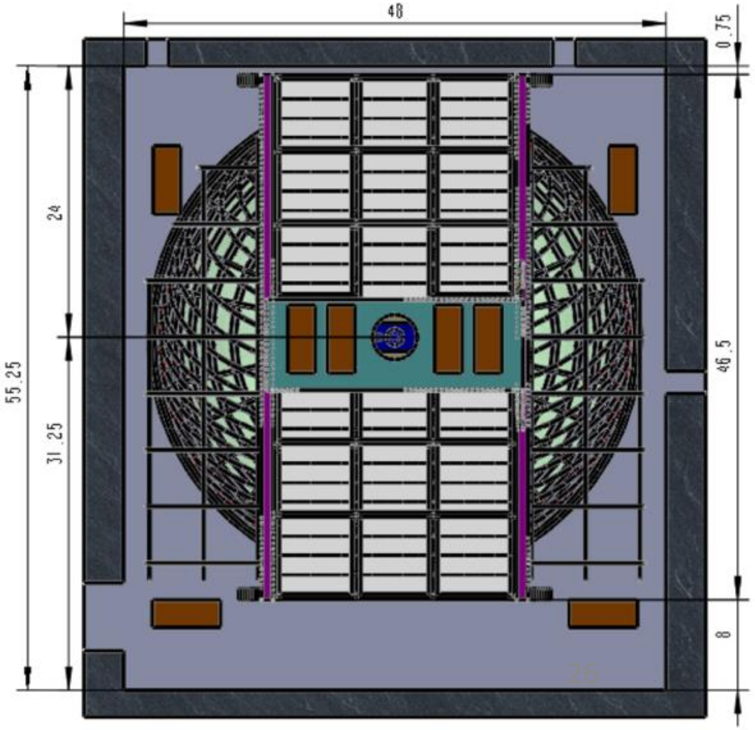




- Water Cherenkov Veto
  - ~25 kton of ultra-pure water
  - 2400 20” PMTs
  - ~95% efficiency

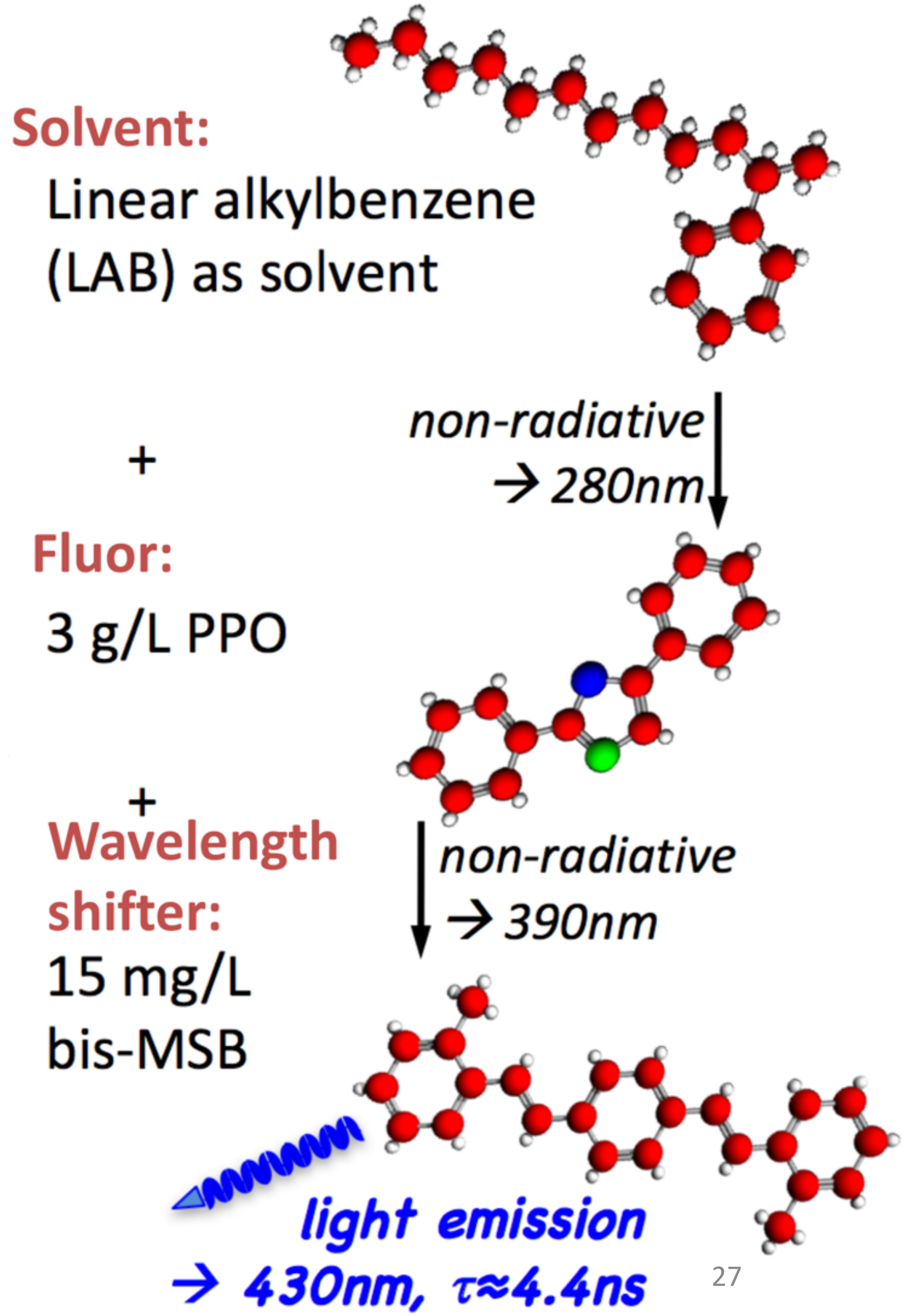


- Top Tracker
  - Reused OPERA plastic scintillators ($49 m^2$/module)
  - 3-layer configuration for good tracking
  - Covers 50% of water pool



Liquid scintillator: LAB →

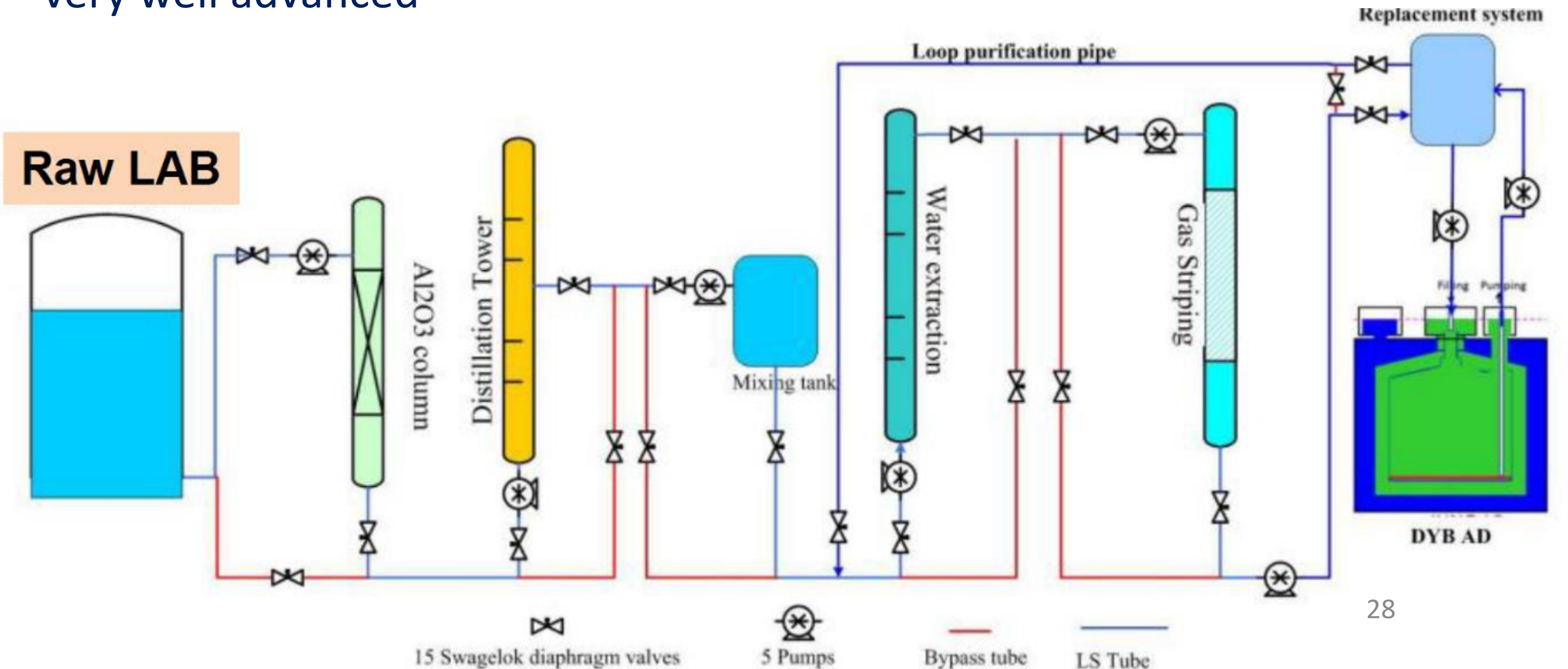
- To reach the required energy resolution several conditions must be fulfilled
  - High light-yield (10^4 photons/MeV)
  - Large Attenuation Length (>20 m @ 430 nm)
- Optimized composition
- Controll over the key processes
  - Production, transportation and storage
  - Purification
    - Destillation, Al_2O_3 column purification, water extraction, removal of dissolved gases, etc.



←Purification Pilot Plant

in operation at Daya Bay

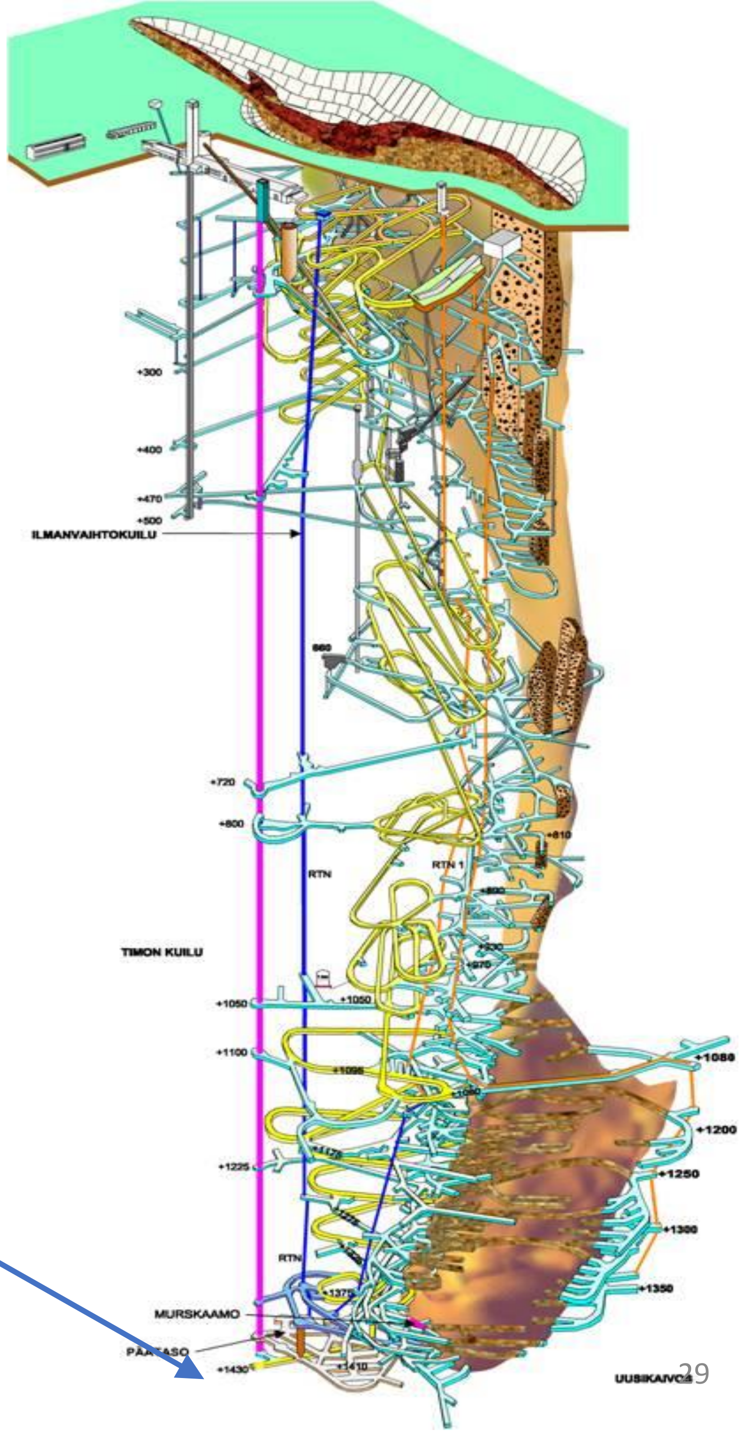
- LS formula determined: PPO 2.5g/l, BisMSB 1 mg/l
- Vendors of raw components selected
- Optimization of the purification process is nearly completed
- Design of on-site purification system, pipes, storage tanks is very well advanced



Finnish contribution to JUNO: LS C14 contamination measurements

CallioLAB2

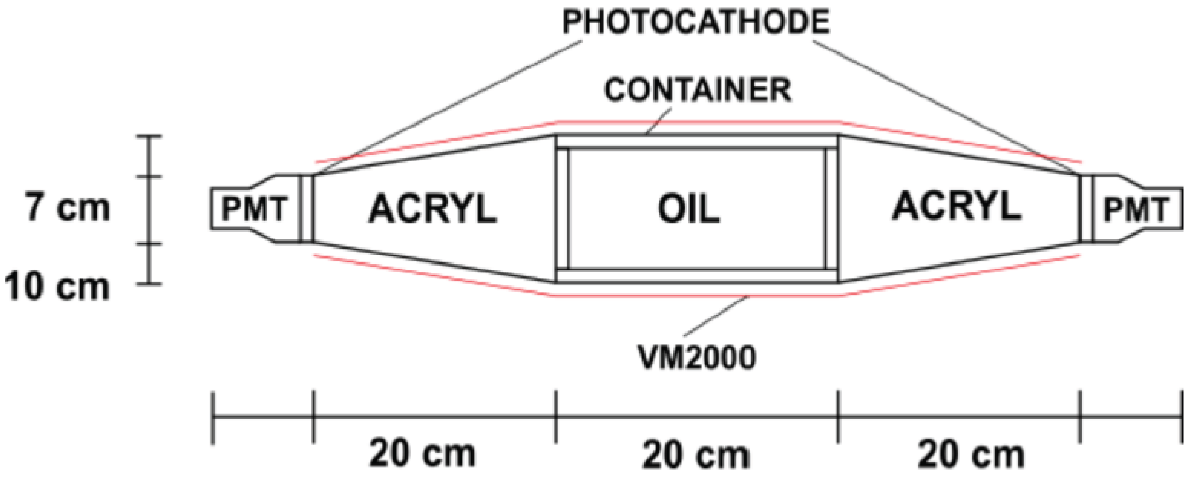
low-background laboratory @1430 m (4100 m.w.e.) in the Pyhäsalmi mine

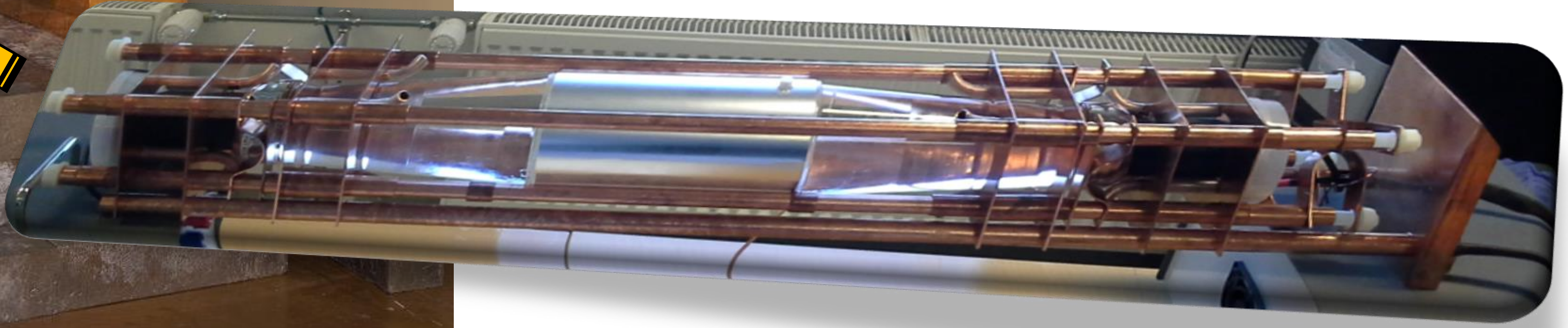


Liquid Scintillator collaboration meeting in Finland
October 2015

This area has now been converted into CallioLAB 2

April 2016: CallioLAB 2 ready

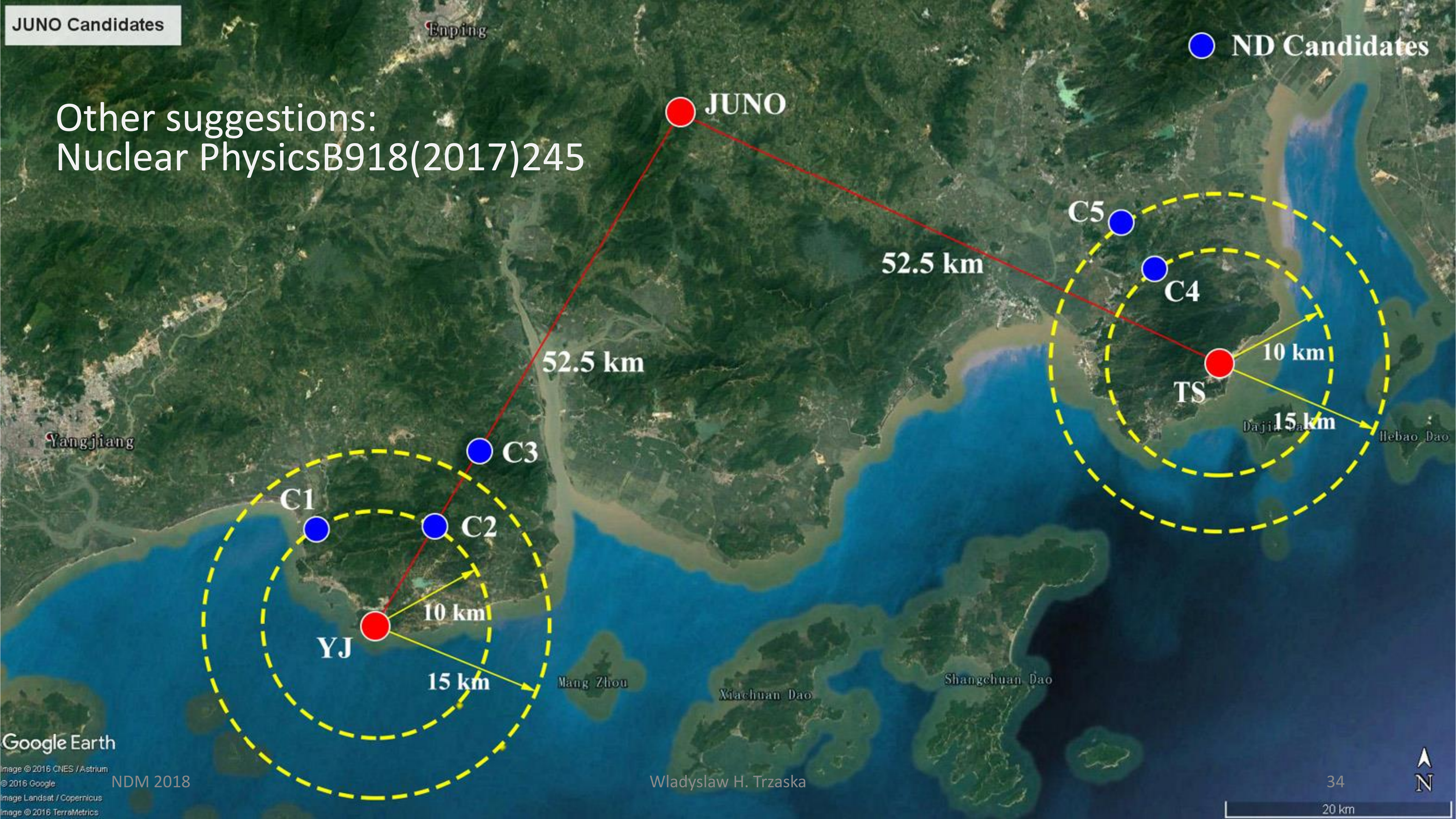

PHOTOCATHODE
CONTAINER
7 cm
10 cm
PMT
ACRYL
OIL
ACRYL
PMT
VM2000
20 cm
20 cm
20 cm



Near Detector proposal

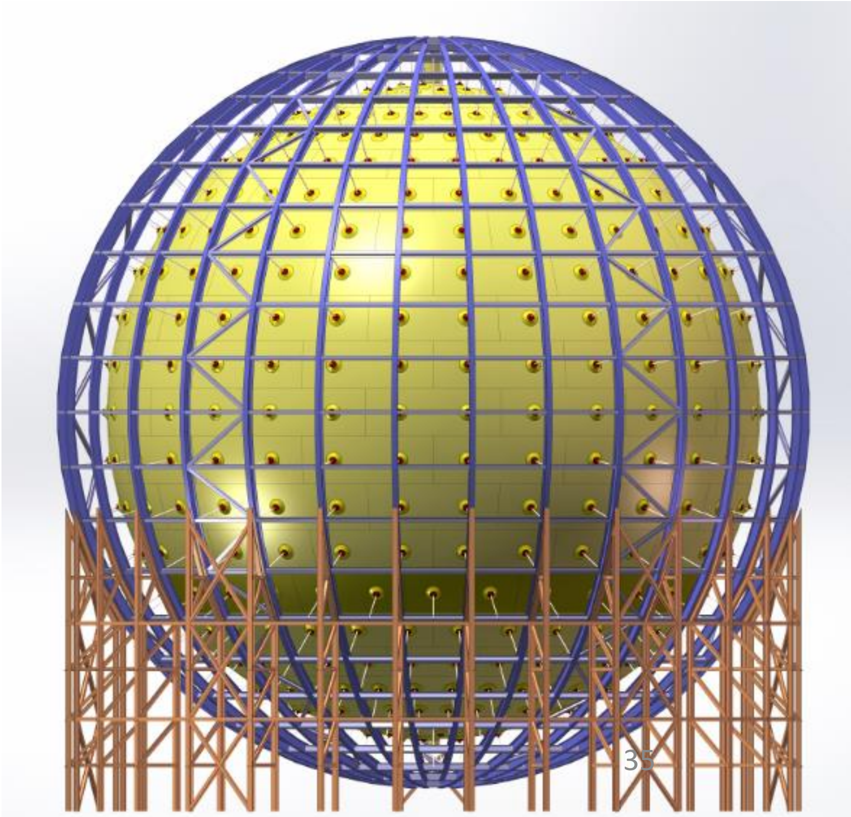
- Rationale (arXiv:1710.07378) → Reduction of systematic errors
  - Statistics from a 3 ton ND @ 35 m would be ~10 x larger than CD@52 km
  - Antineutrino reactor fluxes have a micro-structure at the 50 keV level which is similar to the mass hierarchy signal in experiments like JUNO.
  - Reference measurement of the antineutrino spectrum with an energy resolution very similar to the far detector is needed to exclude any sensitivity reduction due to the unknown micro-structure of the antineutrino flux
- Considered solution: 2.9 ton Gd-LS in a spherical acrylic vessel
- Proposed photosensors
  - SiPM (cooled down to -50C would yield 1.4% energy resolution; expensive)
  - 2300 3.5” PMTs → 2.5% energy resolution

Other suggestions:
Nuclear PhysicsB918(2017)245



Summary

- JUNO is a 20 kton LS multi-purpose neutrino experiment
- Physics program is very broad
- The main emphasis is on Mass Hierarchy and oscillation parameters
- JUNO construction is in a full swing
  - Bold new technological solutions implemented
- The first data expected in 2021
- R&D on the near detector has been initiated



Thank you for your attention!