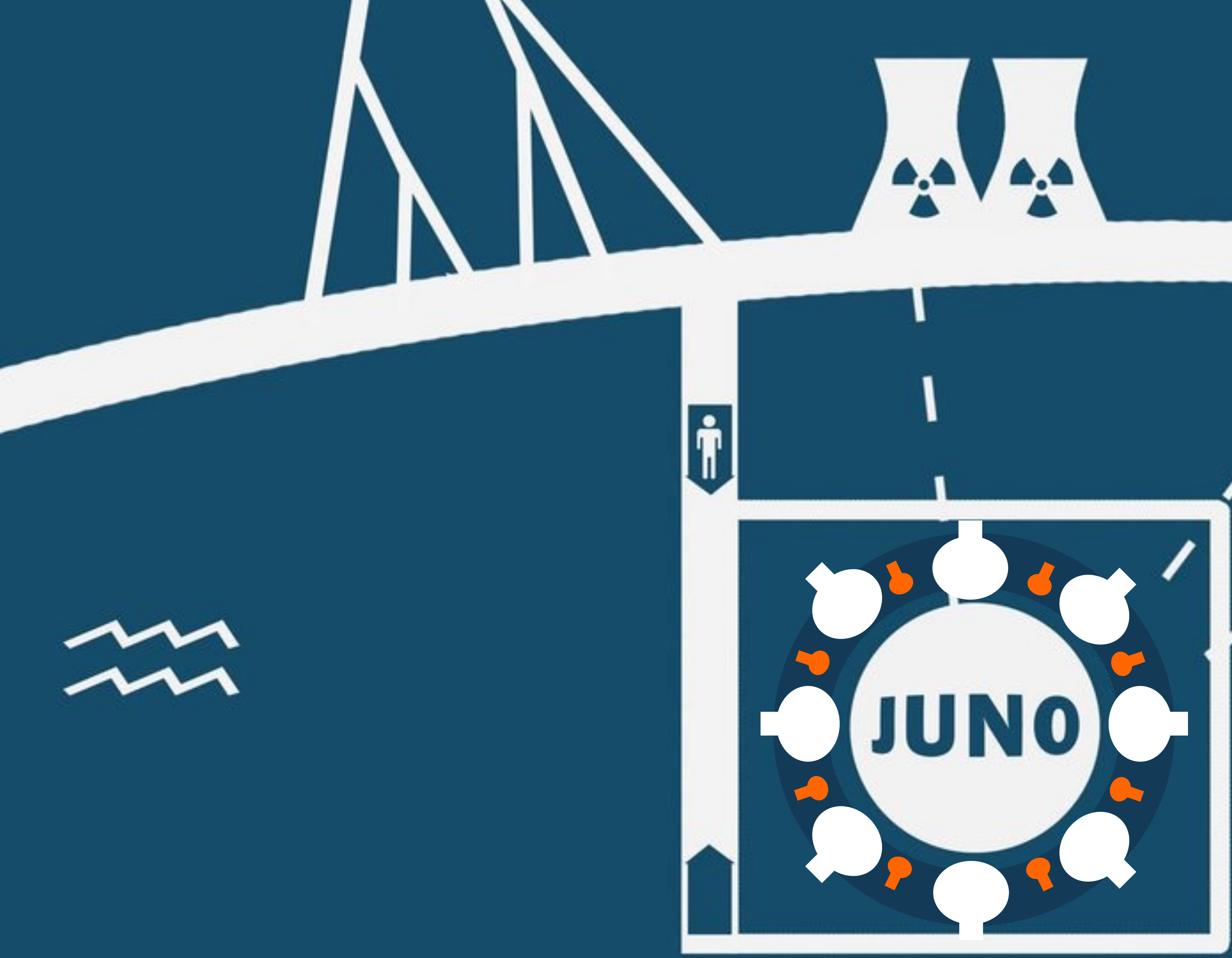
JUNO:
Design and Progress



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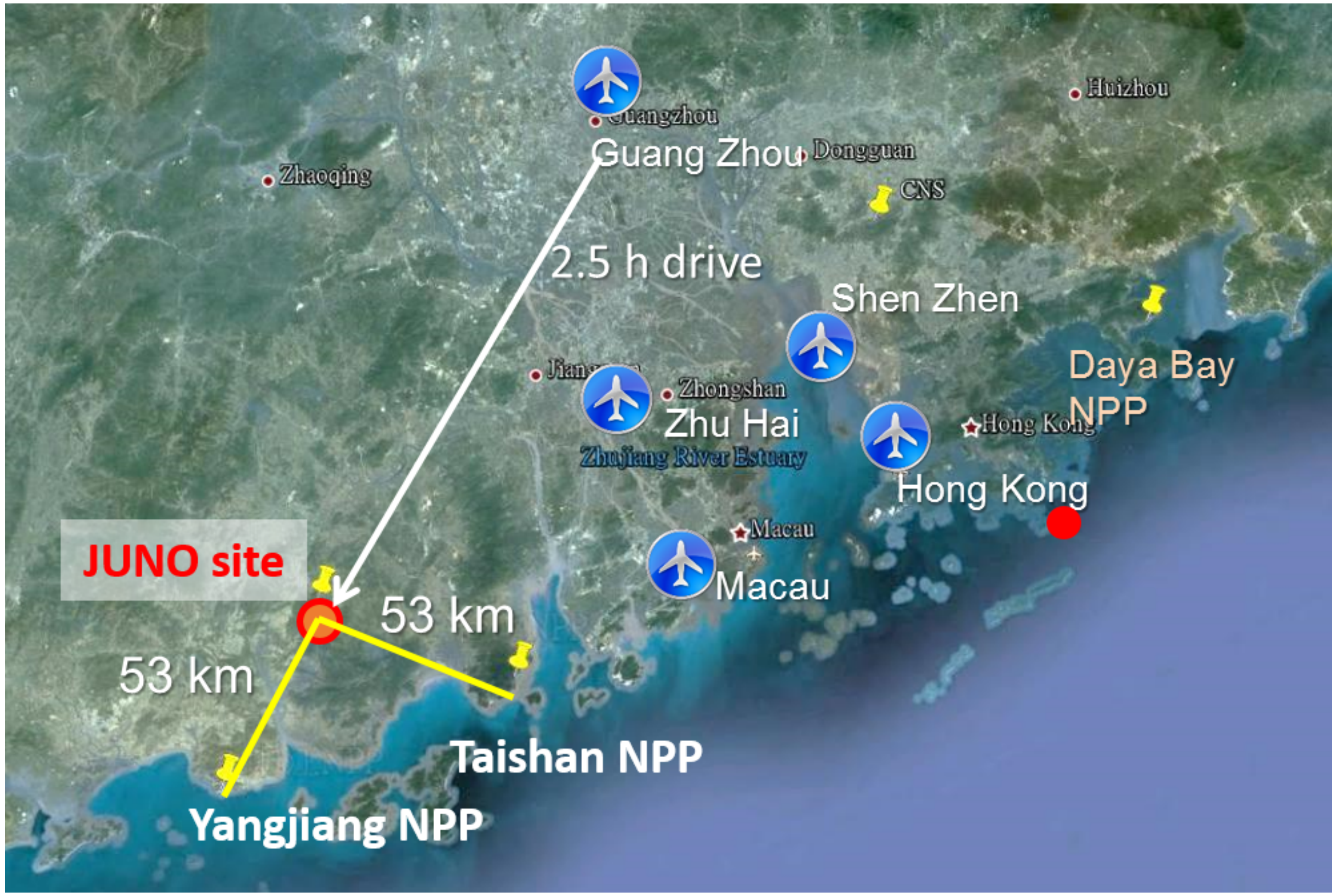
on behalf of the JUNO collaboration

JUNO Basics

- The **J**iangmen **U**nderground **N**eutrino **O**bservatory (**JUNO**) is a large experiment under construction in China:

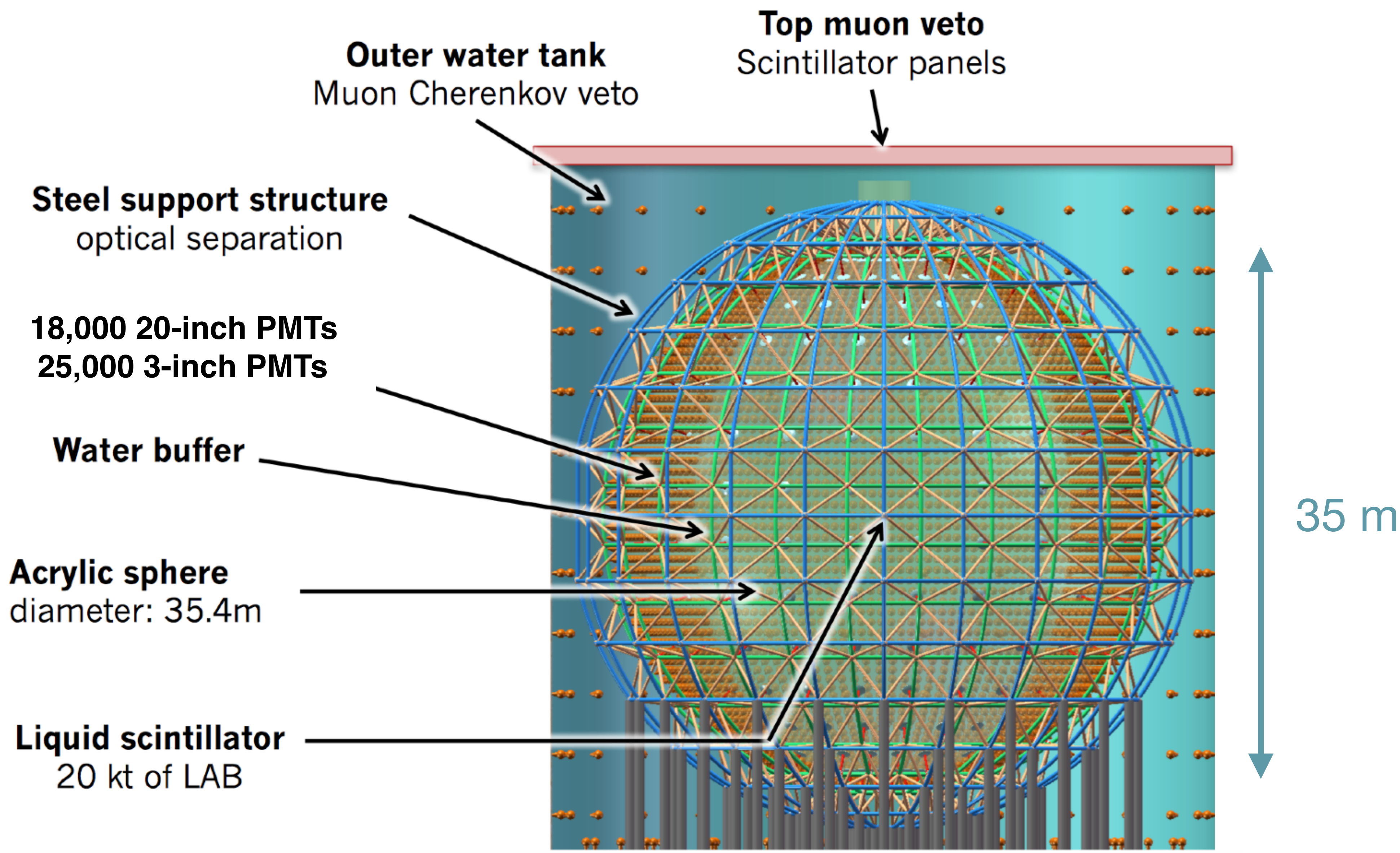
53 km from two major nuclear power plants



Power Plant	Yangjiang	Taishan
Status	Operational	Operational
Power	**17.4 GW$_{th}$**	**9.2 GW$_{th}$**

Detector Overview

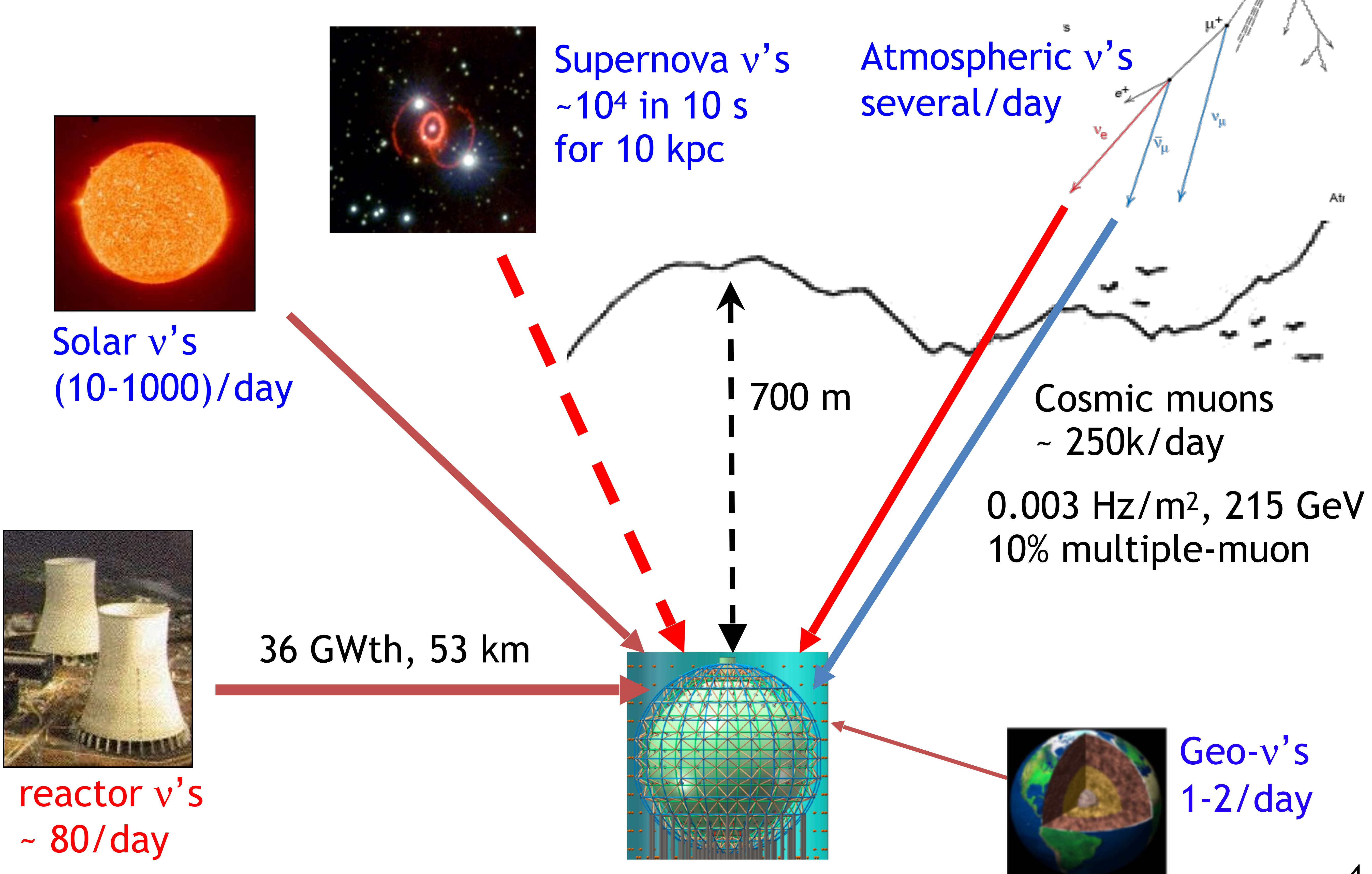
- JUNO is a monolithic liquid scintillator (LS) detector:



Much **LARGER** and **MORE PRECISE** than any other LS detector before

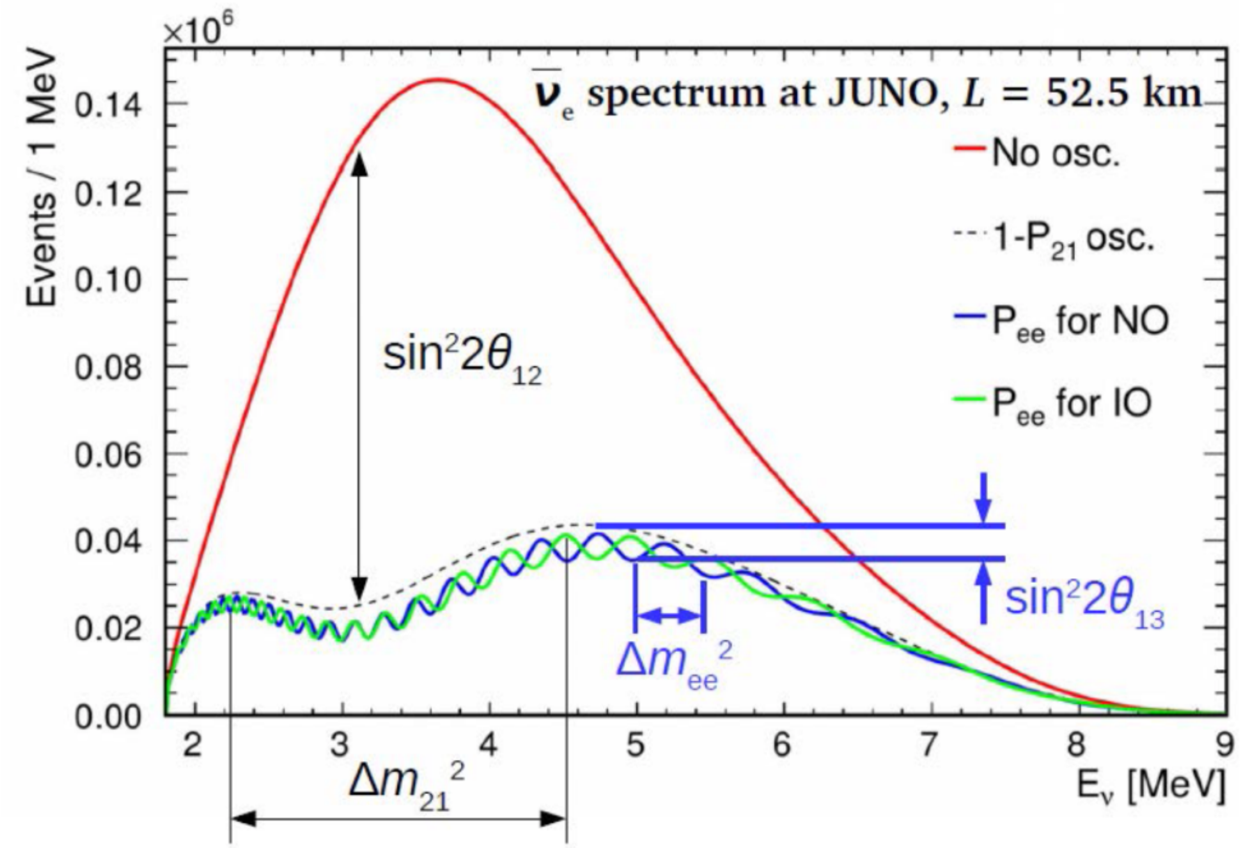
LS Detectors	Daya Bay	Borexino	KamLAND	JUNO
Target Mass	**20 t x 8**	**300 t**	**1 kt**	**20 kt**

A Multipurpose Neutrino Observatory

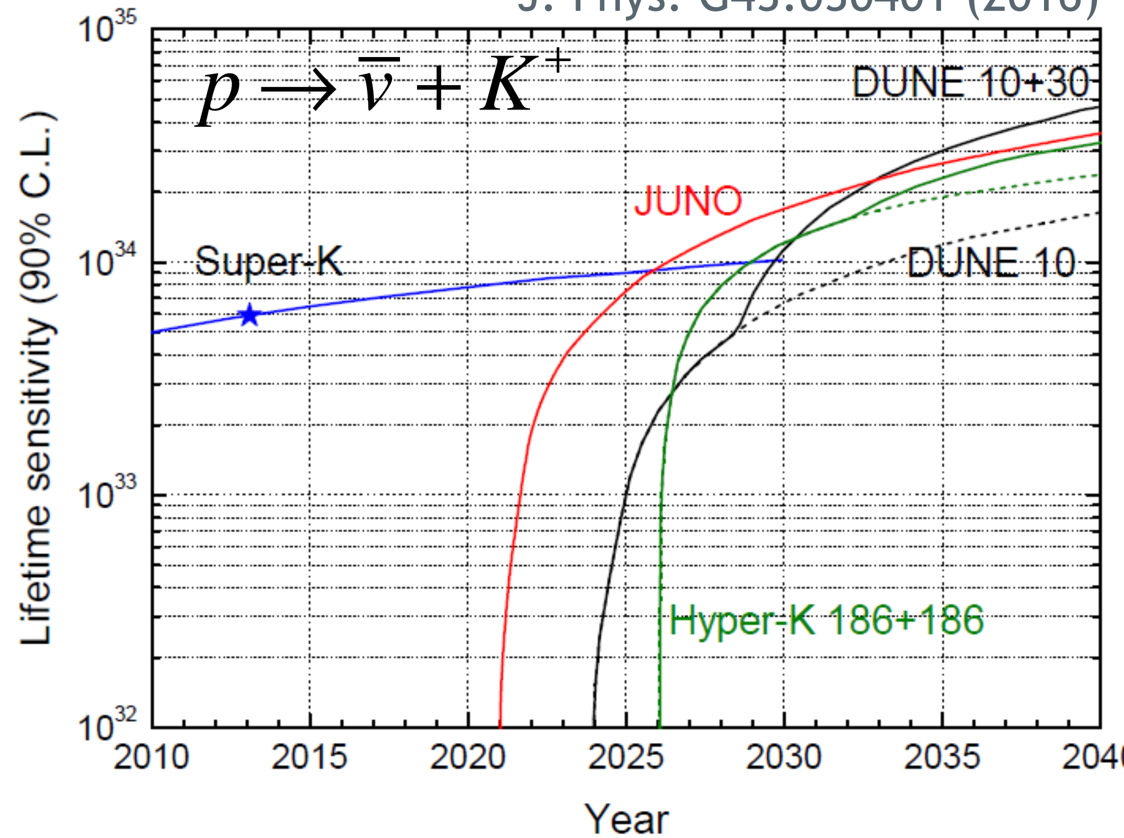


JUNO Physics

- Determination of the neutrino mass ordering (NMO)
- Measurement of $\sin^2 2\theta_{12}$, Δm^2_{21} and Δm^2_{31} to better than 0.7%
- Supernova neutrinos:
  - 10^4 detected events (5000 IBDs) for SN@10kpc
  - Leading sensitivity to Diffuse Supernova Neutrino Background
- Measurement of geoneutrino flux to ~5% in 10 years
- Search for proton decay and other new physics
- Atmospheric and solar neutrinos



J. Phys. G43:030401 (2016)



Energy resolution

- With 3% @ 1 MeV, JUNO will be the LS detector with the best energy resolution in history

$$\frac{\sigma(E)}{E} = \sqrt{\frac{\sigma^2_{STOCH}}{E} + \sigma^2_{NON-STOCH}}$$

stochastic term: depends on photostatistics

non-stochastic term: residual issues (stability, uniformity, linearity) after calibration

- Most obvious (although not unique) requirement for achieving this resolution: **seeing enough photons**
  - No approach that can singlehandedly provide all the light needed:

	KamLAND	JUNO	Relative Gain
Total light level	**250 p.e. / MeV**	**1200 p.e. / MeV**	**5**
Photocathode coverage	34%	75%	~2
Light yield	1.5 g/l PPO	2.5 g/l PPO	~1.5
Attenuation length / ⌀	15 m / 16 m	20 m / 35 m	~0.8
PMT QE×CE	20%×60% ~ 12%	~30%	~2

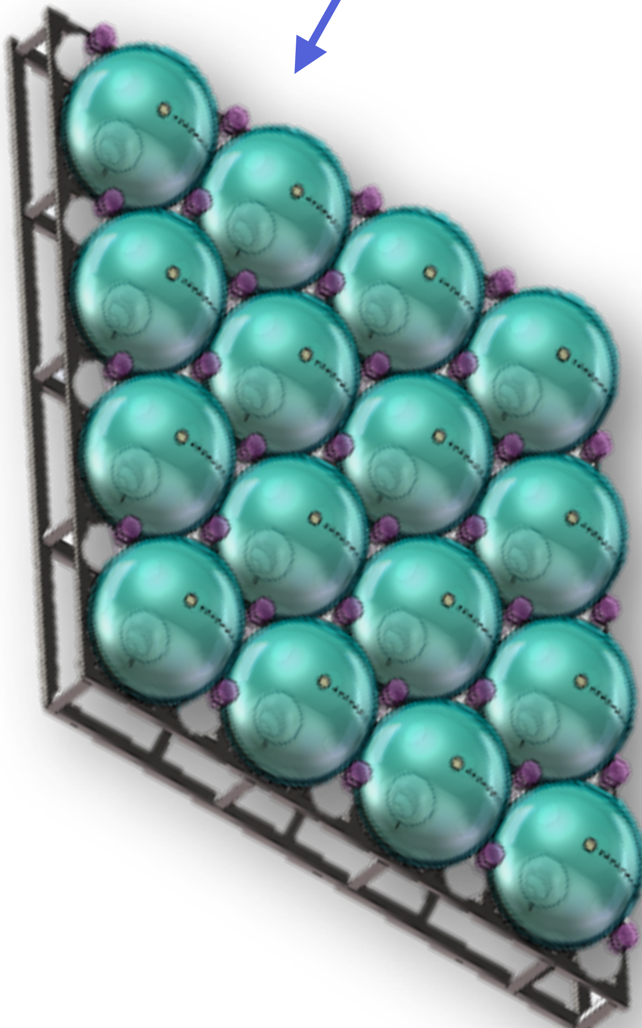
KamLAND used for comparison (→ Relative Gain)

goal (→ 5)

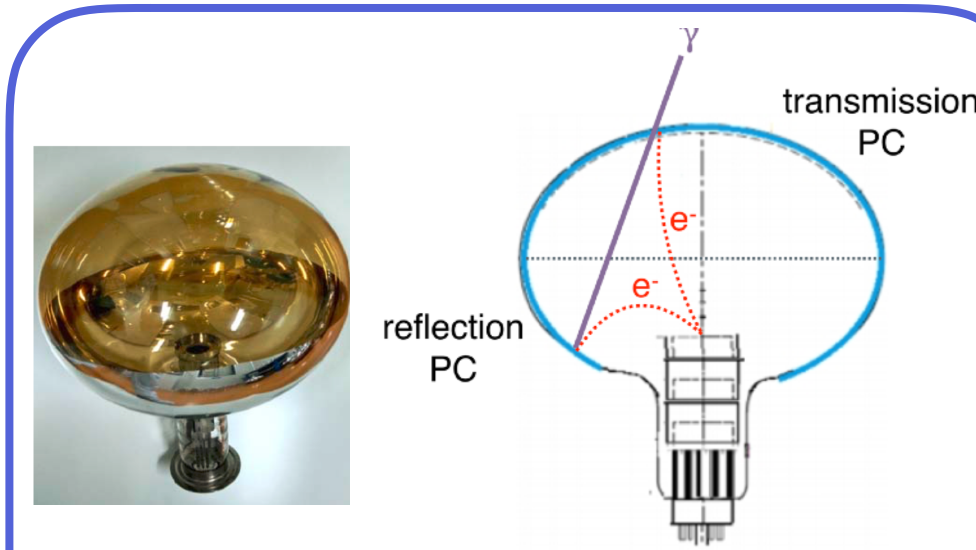
Large PMT system

- JUNO will use large 20-inch PMTs as its main light-detection device

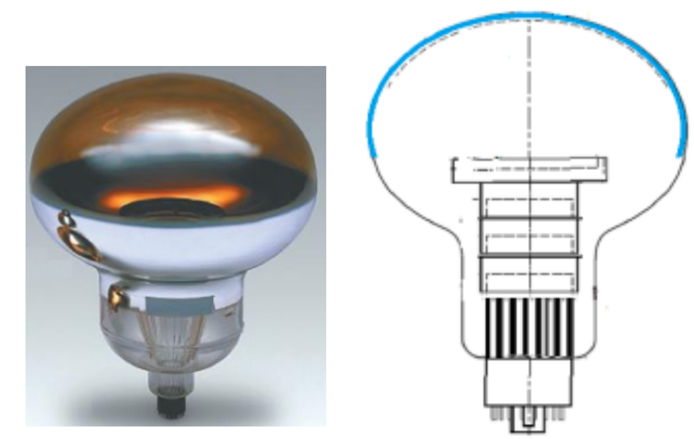
Arranged as tightly as possible (~75% coverage)



2 complementary (and new!) technologies:



Microchannel plate (MCP)-PMTs



Dynode-PMTs

- Developed for/by JUNO, mass-produced by NNVT (China)
- Use of transmission + reflection cathodes to increase QE

- R12860 from Hamamatsu
- New type of bialkali photocathode

Both reach QE x CE ~ 30%!

JUNO's central detector will use 13,000 MCP-PMTs and 5,000 Dynode-PMTs

Large PMT system

- We have already received all dynode PMTs and over 10,000 MCP PMTs:

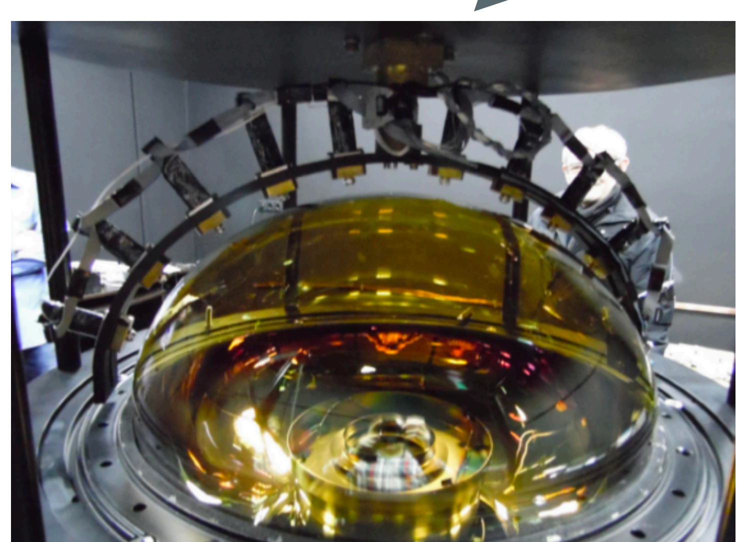
Have a very large storage, testing and potting facility near the JUNO site

Acceptance & characterization tests ongoing at full speed

Industrial container mass testing system

Photocathode uniformity scanning system

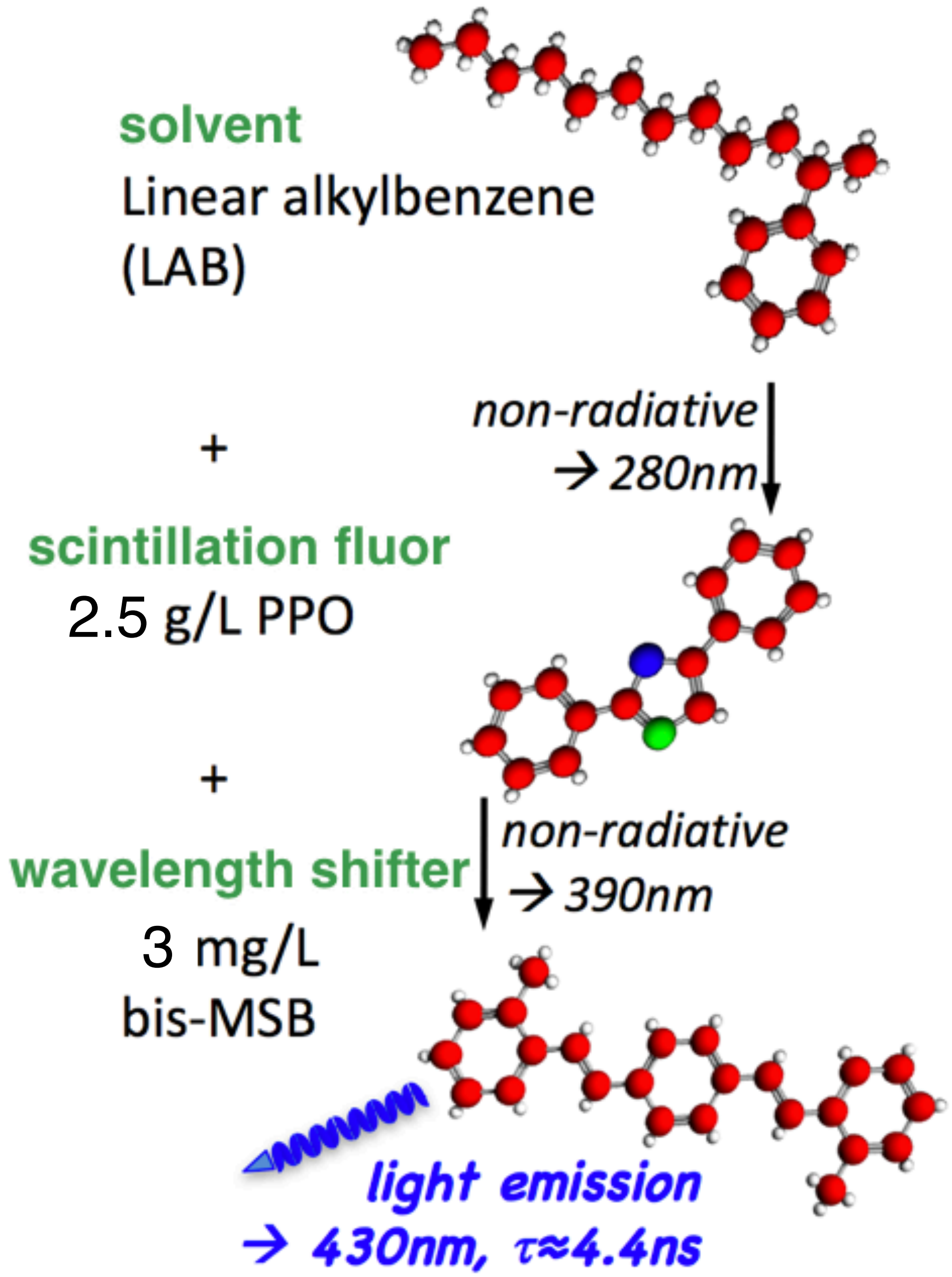
Potting lab



An industrial process!

Liquid Scintillator

- Using a recipe inspired from Daya Bay's experience



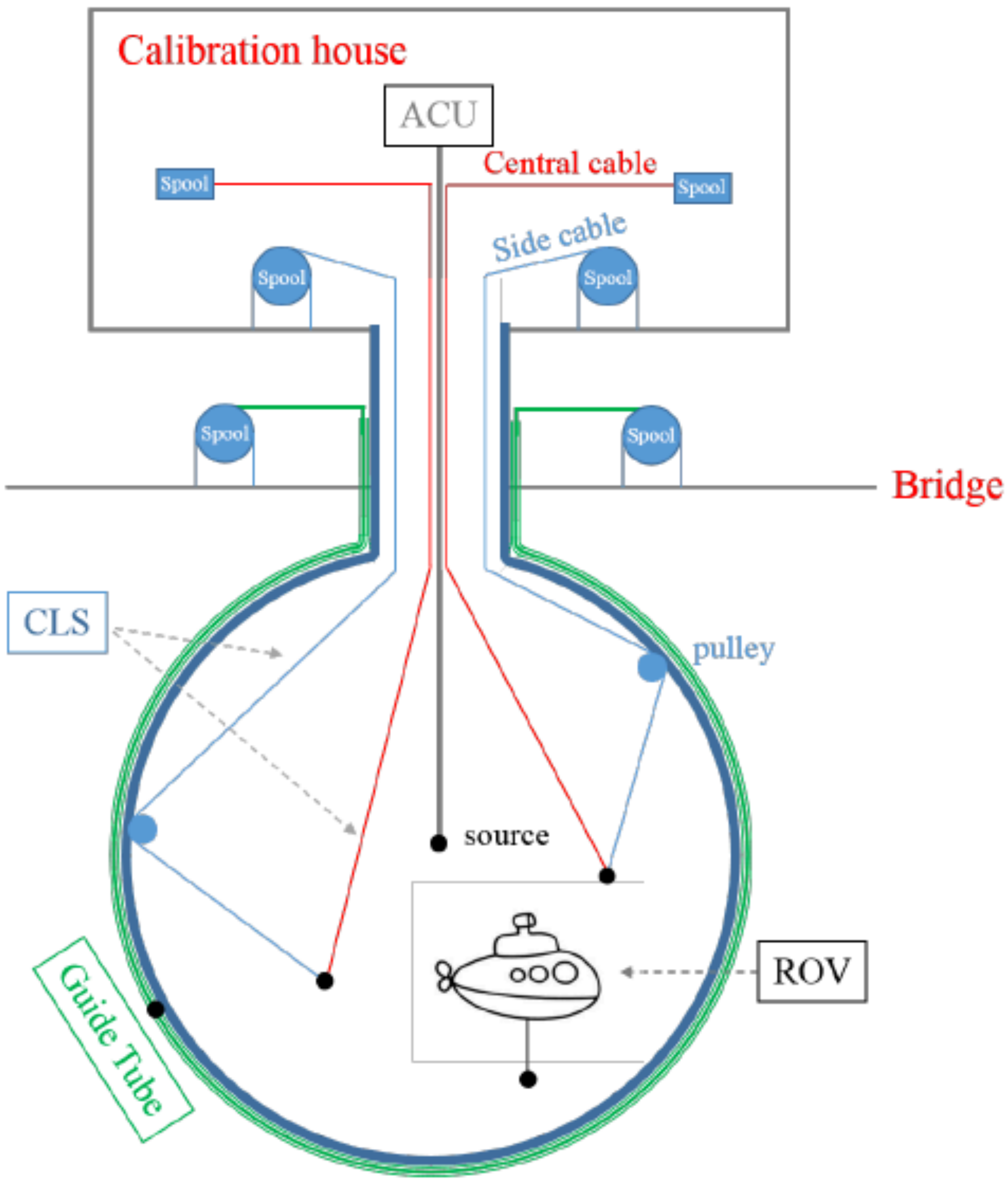
In early 2017 one of the eight Daya Bay detectors was taken down permanently and its Gd-LS replaced with JUNO LS

Invaluable experience to study different recipes and purification methods

- No doping, large fluor concentration, Al_2O_3 column purification, vacuum distillation

Calibration System

- Achieving a light level of 1200 p.e. / MeV is not enough. Also have to **keep the systematics under control**



- Aggressive calibration program with **4 complementary systems**:
  - **1D**: Automated Calibration Unit (ACU) deploys radioactive and laser (1 ns, keV-TeV range) sources along the central axis
  - **2D**: Cable Loop System (CLS) to scan vertical planes
  - **2D**: Guide Tube to scan outer surface of the central detector
  - **3D**: Remotely Operated Vehicle (ROV) operating inside the LS

Goal is to keep the energy scale uncertainty < 1%

Small PMT System

- JUNO will also have to keep the non-stochastic term of the resolution under control (≲1%)

$$\frac{\sigma(E)}{E} = \sqrt{\frac{\sigma^2_{STOCH}}{E} + \sigma^2_{NON-STOCH}}$$

< 1% never achieved before!

- 25,000 3-inch PMTs will operate predominantly in photon-counting mode:

Basic principle: look at the same events with two sets of "eyes" that have different systematics
(e.g. nonlinearity)

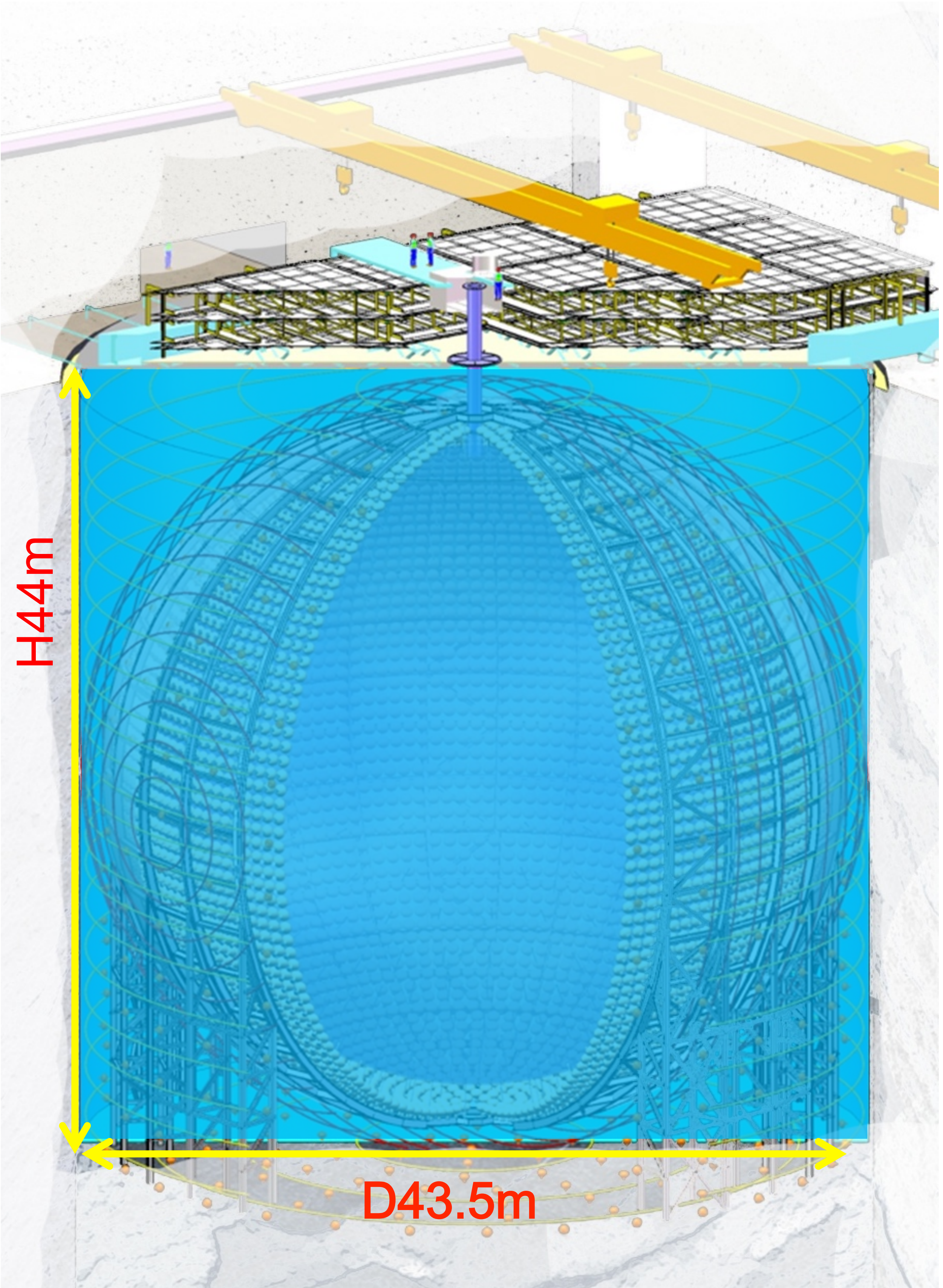
- The small PMTs also bring other nice benefits to the table:
  - Independent physics
  - Aid to position reconstruction and muon track reconstruction
  - Aid to supernova neutrino measurement
  - Others (a little extra light, larger dynamic range… etc).

HZC PHOTONICS

XP72B22

A custom design for JUNO!

Muon Veto System



- The LS acrylic sphere will be immersed in water:
  - 35 kton ultrapure water pool with a circulation system

Double-purpose:
- Shield central detector
- Veto cosmic-ray muons

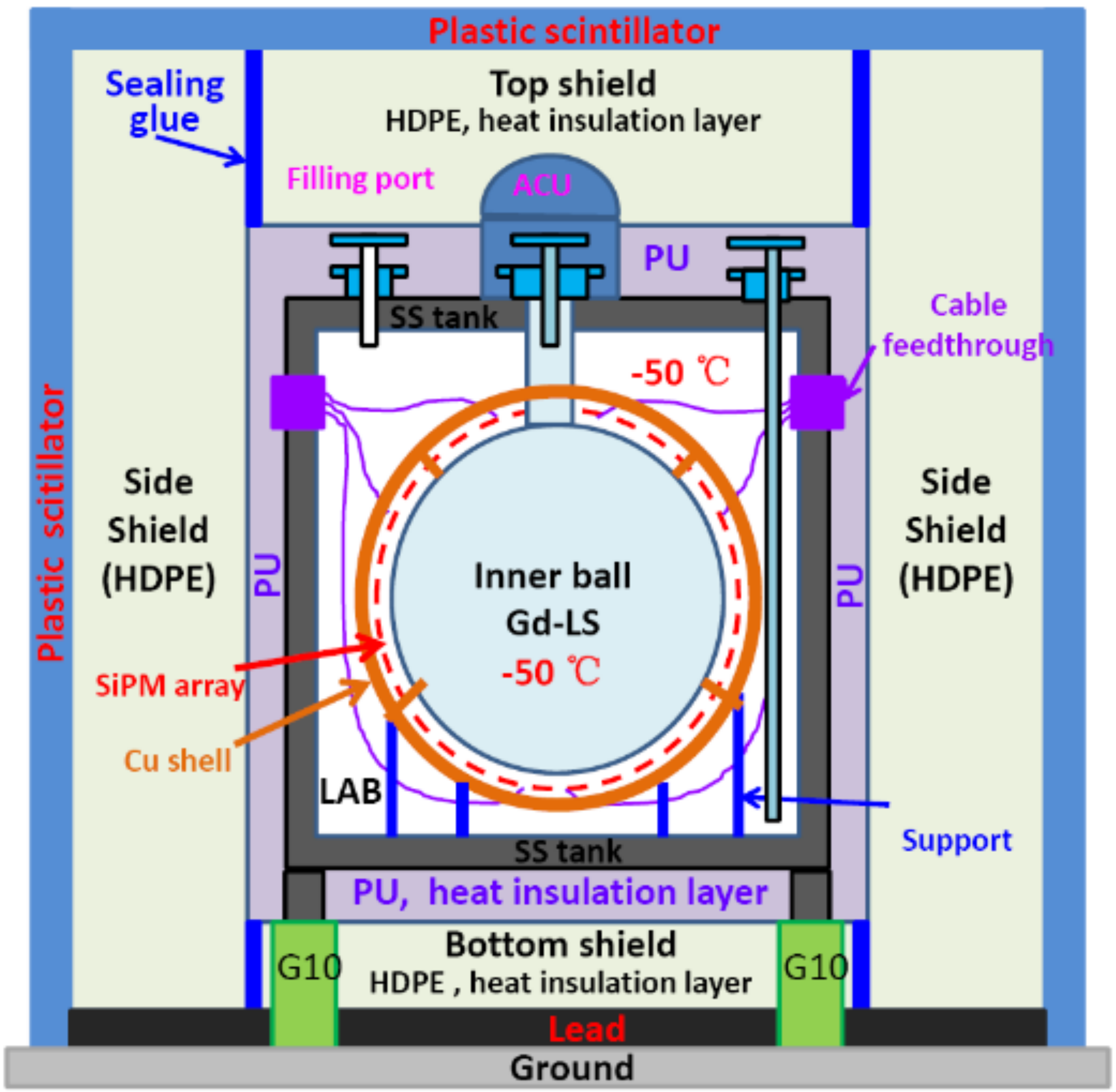
- Additional systems:
  - 3 layers of plastic scintillators at the top with partial coverage
  - Magnetic field (EMF) shielding system

JUNO-TAO

- JUNO will also deploy a satellite detector called **TAO** (Taishan Antineutrino Observatory)
  - ~35 m from a 4.6 GW_{th} reactor
  - 1 ton fiducial Gd-LS volume
  - SiPM and Gd-LS at -50°C
  - < 2% @ 1 MeV energy resolution

Main goal: measure the reactor antineutrino spectrum with unprecedented resolution

- See fine structure due to Coulomb corrections
- Serve as benchmark for JUNO, other experiments, and nuclear databases
- Search for sterile neutrinos
- Study flux and shape change with fuel evolution & decompose isotope spectra



- R&D well underway and prototype under development

Timeline

- **2014**: Conceptual design completed. International collaboration established
- **2015**: Start of civil construction. Setup of PMT production line
- **2016**: Bidding of detector components
- **2017**: Start PMT mass production. Electronics prototypes delivered
- **2018**: PMT mass production & testing
- **2019**: Start PMT Potting
- **2020**: End of civil construction. Electronics mass production.
- **2021**: PMT Installation in central detector & veto. End of detector construction

Summary & Conclusions

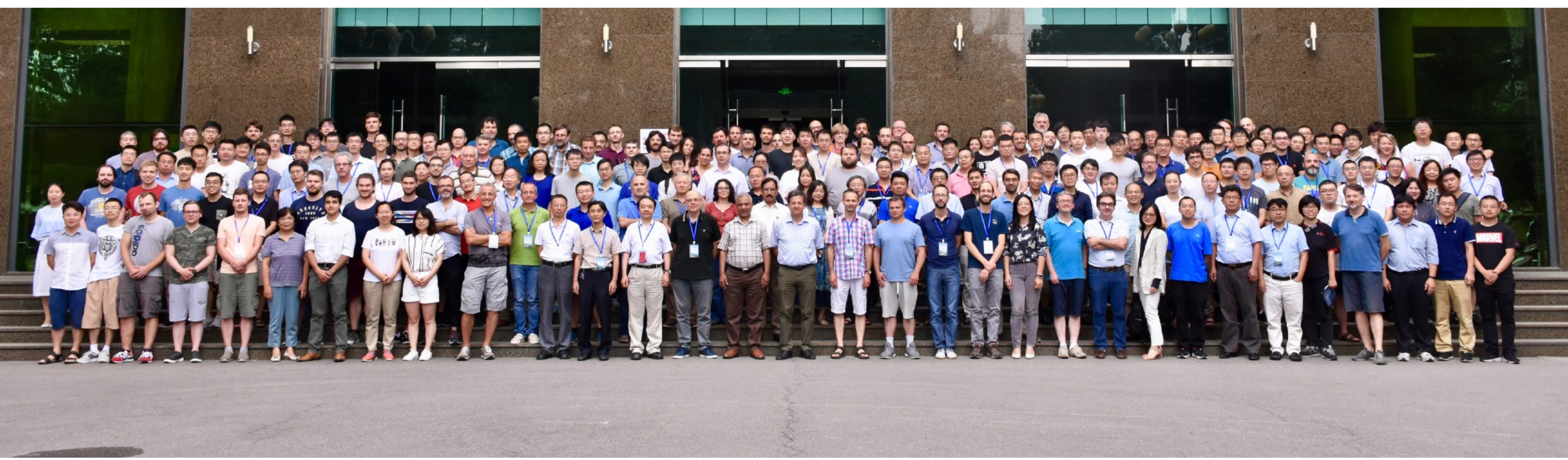
- JUNO is a multipurpose neutrino observatory with a rich program in neutrino physics and astrophysics
- JUNO is pushing the limits in liquid scintillator detection technology
  - New solutions in terms of PMT technology, liquid scintillator properties and detector construction
  - Developing some unique approaches to calibration and to the reduction of systematic uncertainties
- Progress is well underway, and expect to complete the construction of the detector by 2021
- Anticipate some exciting results (and maybe some surprises?)

Stay tuned!

JUNO

The JUNO Collaboration: 77 institutions from over 15 countries

Thank you for your attention!

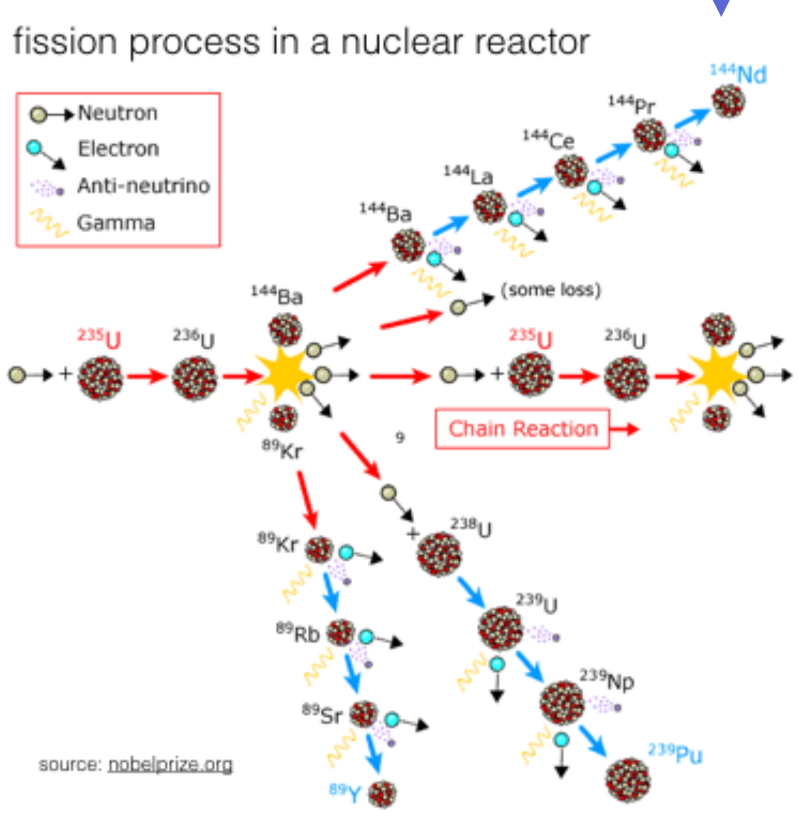


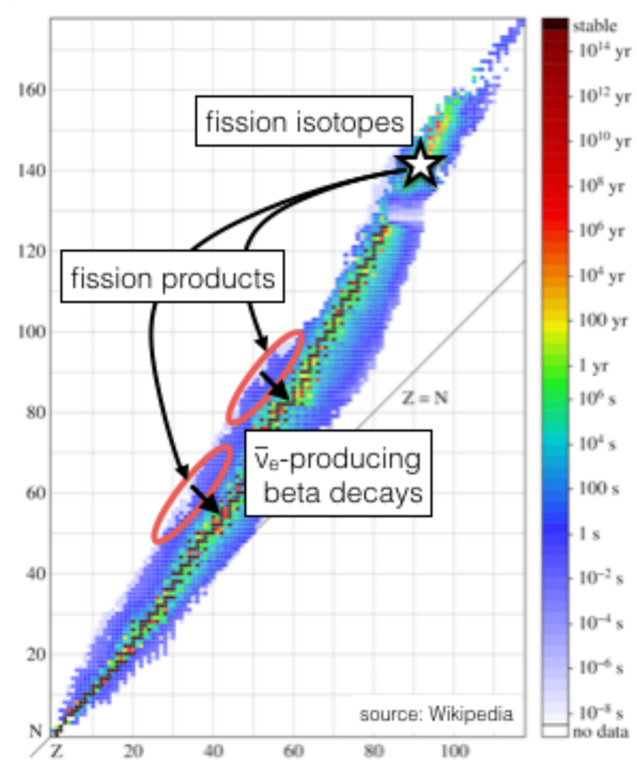
Backup

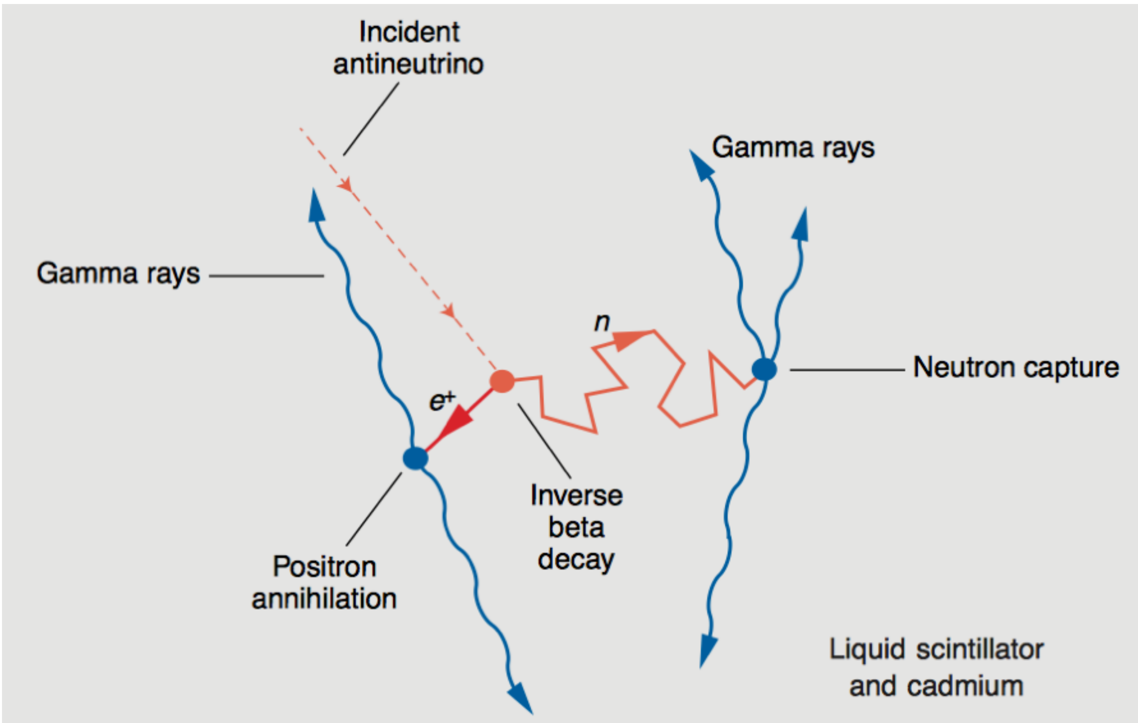
Reactor Neutrino Refresher

Nuclear reactors are a bountiful and well-understood source of electron antineutrinos

The primary detection channel is the inverse beta decay (IBD) reaction







Beta decay: $n \to p + e^- + \bar{\nu}_e$

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

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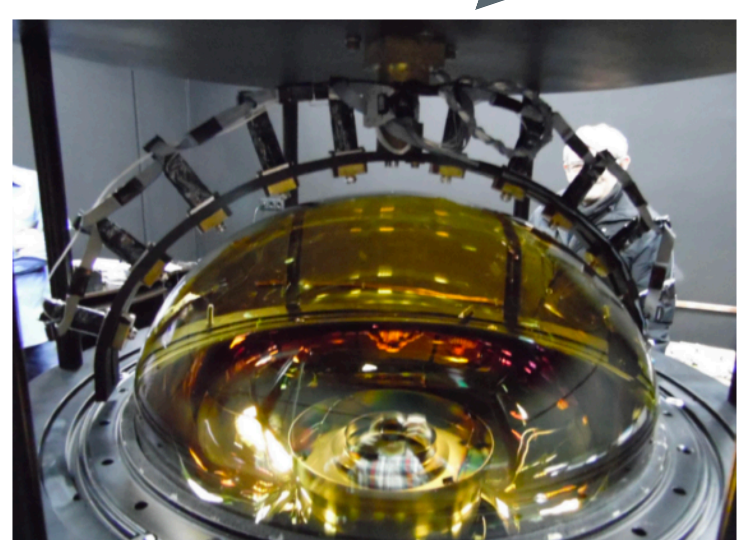

An industrial process!

Civil Construction

- A new underground laboratory with a 700 m overburden and infrastructure at the surface is under construction since late 2014
- Expect to finish by summer 2020

Vertical shaft

Slope Tunnel