STATUS OF THE JIANGMEN UNDERGROUND NEUTRINO OBSERVATORY

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On behalf of the JUNO Collaboration

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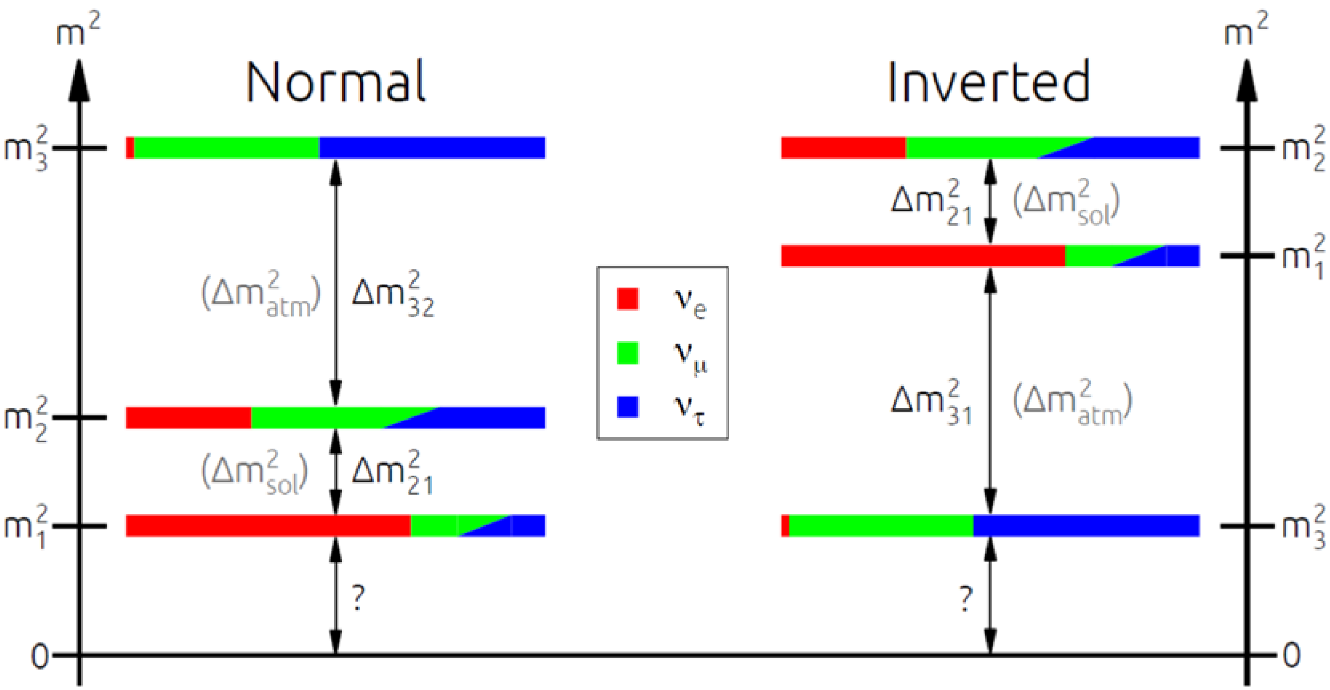
Mitglied der Helmholtz-Gemeinschaft

JÜLICH Forschungszentrum

OUTLINE

- Physics Motivation
- The JUNO Collaboration
- The JUNO Experiment
- Extended Physics Program

MOTIVATION: NEUTRINO MASS HIERARCHY



$m_1 < m_2 < m_3$

$m_3 < m_1 < m_2$

$\Delta m^2_{21} = 7.5\cdot10^{-5}\ eV^2$
$|\Delta m^2_{ee}| = 2.4\cdot10^{-3}\ eV^2$

Sign and absolute value of Δm^2_{31} depend on MH

The neutrino mass hierarchy (MH) gives access to:

- CP violating phase δ_{CP}
- Octant of Θ_{23}
- Parameter space for $0\nu\beta\beta$

MOTIVATION: NEUTRINO MASS HIERARCHY

Neutrino oscillations of reactor antineutrinos $\bar{\nu}_e$ depend on the mass hierarchy:

$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2 2\Theta_{13} \left(\underbrace{\sin^2 \Theta_{12} \sin^2 \Delta_{32} + \cos^2 \Theta_{12} \sin^2 \Delta_{31}}_{\Delta sin^2 \Delta_{ee}} \right) - \sin^2 2\Theta_{12} \cos^4 \Theta_{13} \sin^2 \Delta_{21}$$

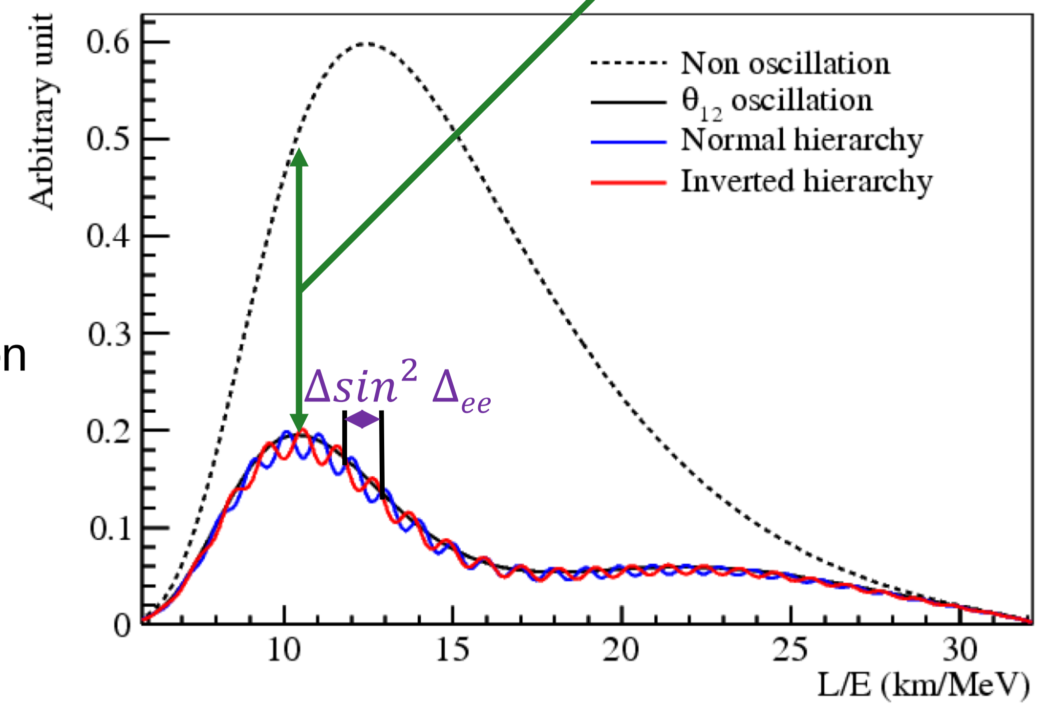
with

$$\Delta_{ij} = \frac{\Delta m_{ij}^2 \, L}{4 \, E}$$

E: neutrino energy
L: baseline

- ΔX^2 is measured for discrimination between NH and IH
- Expected sensitivity:

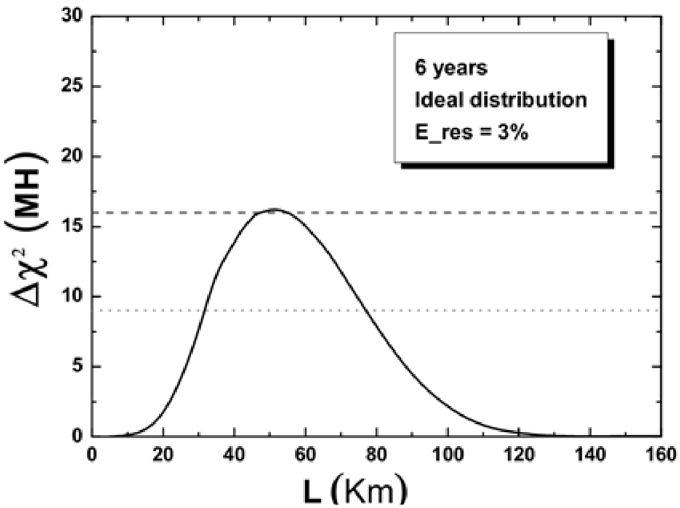
  3 – 4 σ
  → $\Delta X^2 = 9 - 16$

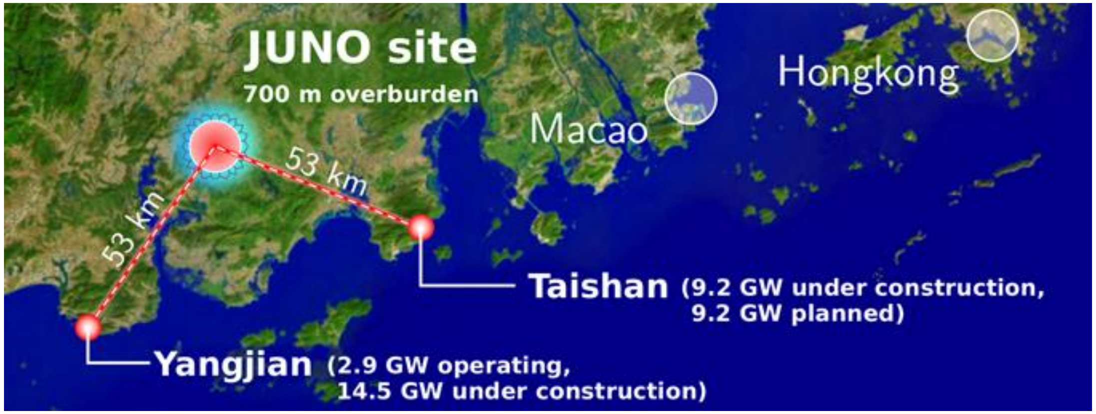


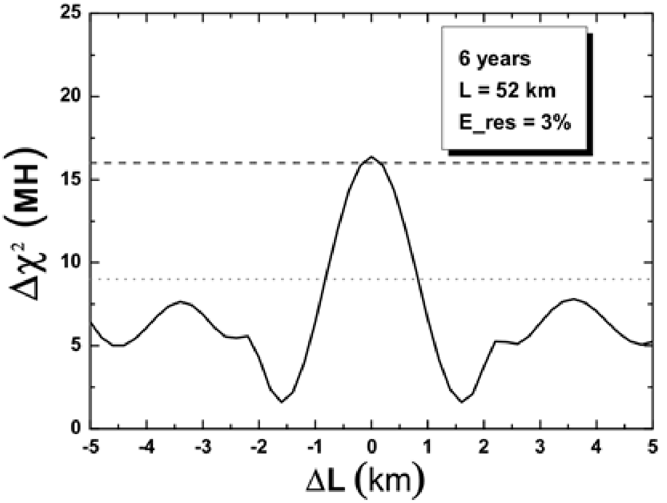
THE JUNO COLLABORATION

Country	Institute	Country	Institute	Country	Institute		
Armenia	Yerevan Physics Institute	China	NCEPU	China	ECUT-Nanchang City	Italy	INFN-Milano Bicocca
Belgium	Universite libre de Bruxelles	China	Pekin U.	Czech R.	Charles University	Italy	INFN-Padova
Brazil	PUC	China	Shandong U.	Finland	University of Jyvaskyla	Italy	INFN-Perugia
Brazil	UEL	China	Shanghai JT U.	France	LAL Orsay	Italy	INFN-Roma 3
Chile	PCUC	China	IGG-Beijing	France	CENBG Bordeaux	Latvia	IECS
Chile	UTFSM	China	IGG-Wuhan	France	CPPM Marseille	Pakistan	PINSTECH (PAEC)
China	BISEE	China	IMP-CAS	France	IPHC Strasbourg	Russia	INR Moscow
China	Beijing Normal U.	China	SYSU	France	Subatech Nantes	Russia	JINR
China	CAGS	China	Tsinghua U.	Germany	FZJ-ZEA	Russia	MSU
China	ChongQing University	China	UCAS	Germany	RWTH Aachen U.	Slovakia	FMPICU
China	CIAE	China	USTC	Germany	TUM	Taiwan-China	National Chiao-Tung U.
China	DGUT	China	U. of South China	Germany	U. Hamburg	Taiwan-China	National Taiwan U.
China	ECUST	China	Wu Yi U.	Germany	FZJ-IKP	Taiwan-China	National United U.
China	Guangxi U.	China	Wuhan U.	Germany	U. Mainz	Thailand	NARIT
China	Harbin Institute of Technology	China	Xi'an JT U.	Germany	U. Tuebingen	Thailand	PPRLCU
China	IHEP	China	Xiamen University	Italy	INFN Catania	Thailand	SUT
China	Jilin U.	China	Zhengzhou U.	Italy	INFN di Frascati	USA	UMD1
China	Jinan U.	China	NUDT	Italy	INFN-Ferrara	USA	UMD2
China	Nanjing U.	China	CUG-Beijing	Italy	INFN-Milano	USA	UC Irvine
China	Nankai U.						

JUNO – THE EXPERIMENTAL SITE





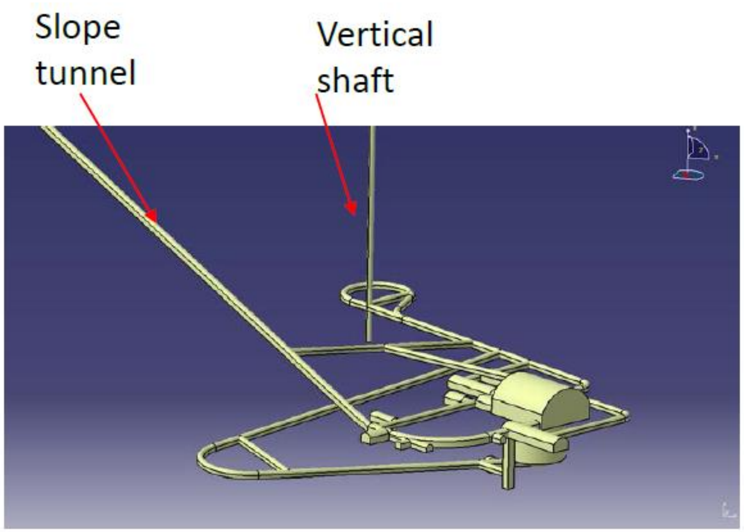


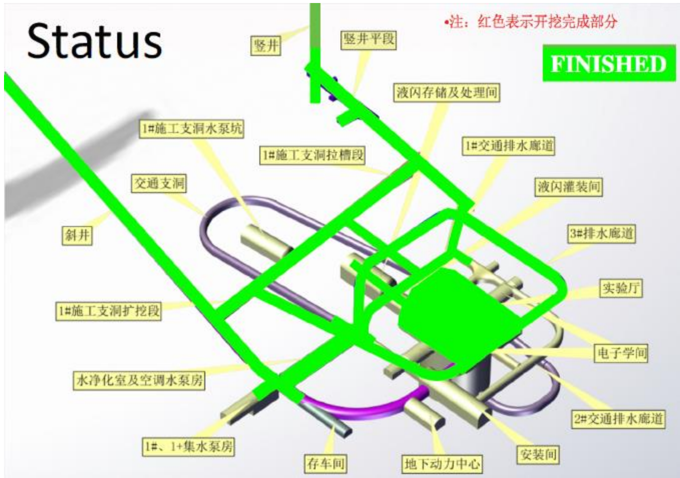
- Located in China close to Jiangmen
- Baseline of 53 km
- Nearby power plants Taishan and Yangjian with final total thermal power 35.8 GW_{th}

$\sqrt{\Delta X^2} \rightarrow$ significance σ

JUNO – CIVIL CONSTRUCTION STATUS

- 2 access tunnels are finished
- Main hall under construction
- Surface buildings under construction



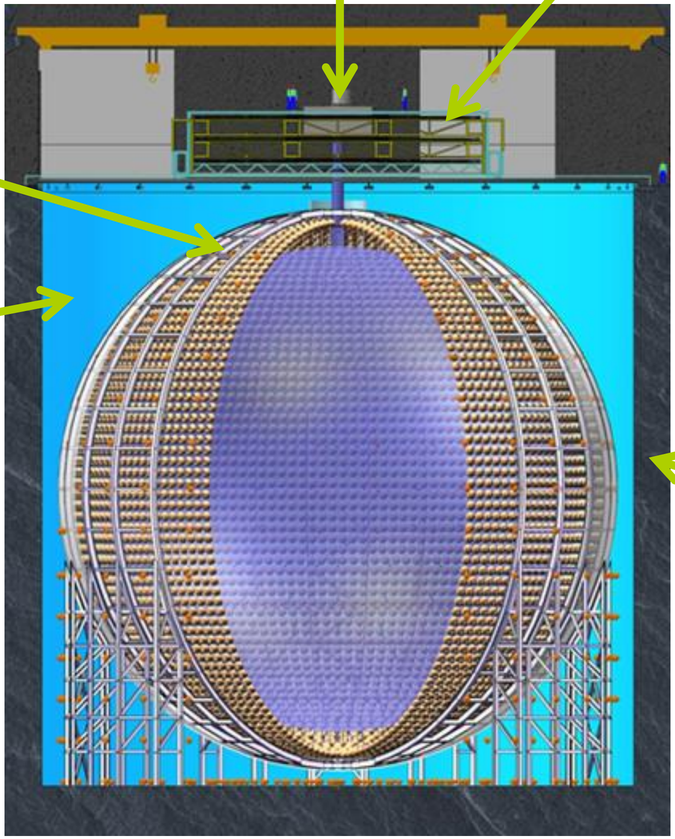


THE JUNO DETECTOR

Central detector:
- 20 kton liquid scintillator
- 35.4 m diameter acrylic sphere

Calibration

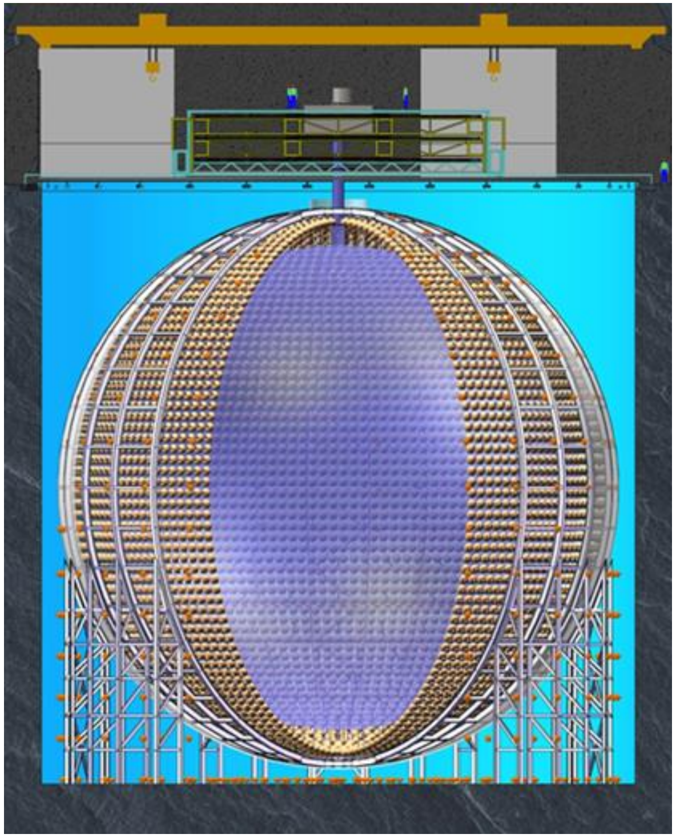
Top tracker:
- Former Opera experiment
- Scintillator panels



Water pool:
- Muon veto

650 m underground

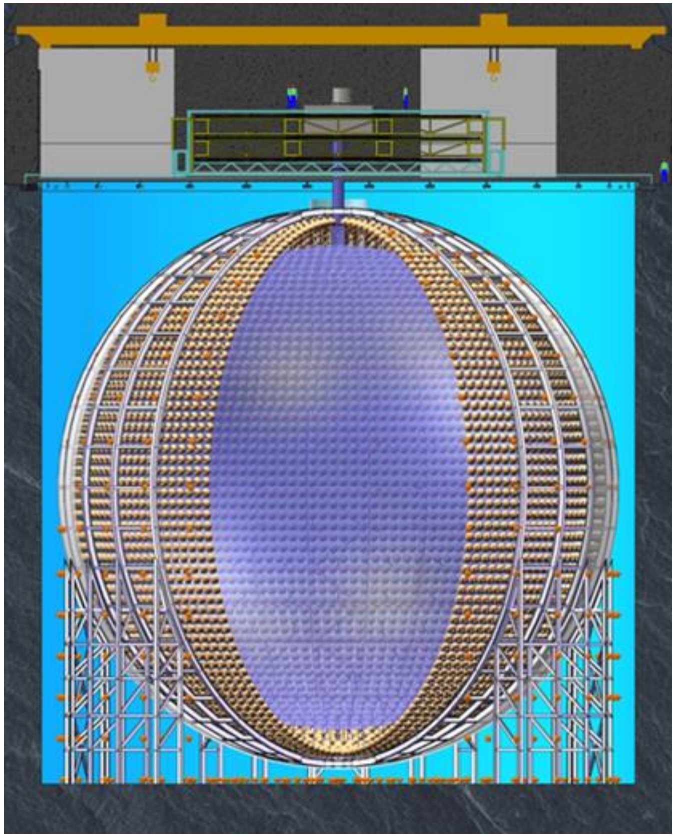
THE JUNO DETECTOR



Milestones for JUNO:

- **High $\bar{\nu}_e$ detection:** 100,000 events
  - Nominal measurement time: 6 years with full reactor power of 35.8 GW_{th}
  - High $\bar{\nu}_e$ flux at detector: ~ $2.6 \cdot 10^8$ / cm^2s
  - 20 kton liquid scintillator → will be the largest scintillator detector ever built
- **Unprecedented energy resolution** of 3% / $\sqrt{E(MeV)}$:
  - Collected NPE / MeV: 1200
- **Energy scale uncertainty** < 1%

THE JUNO DETECTOR



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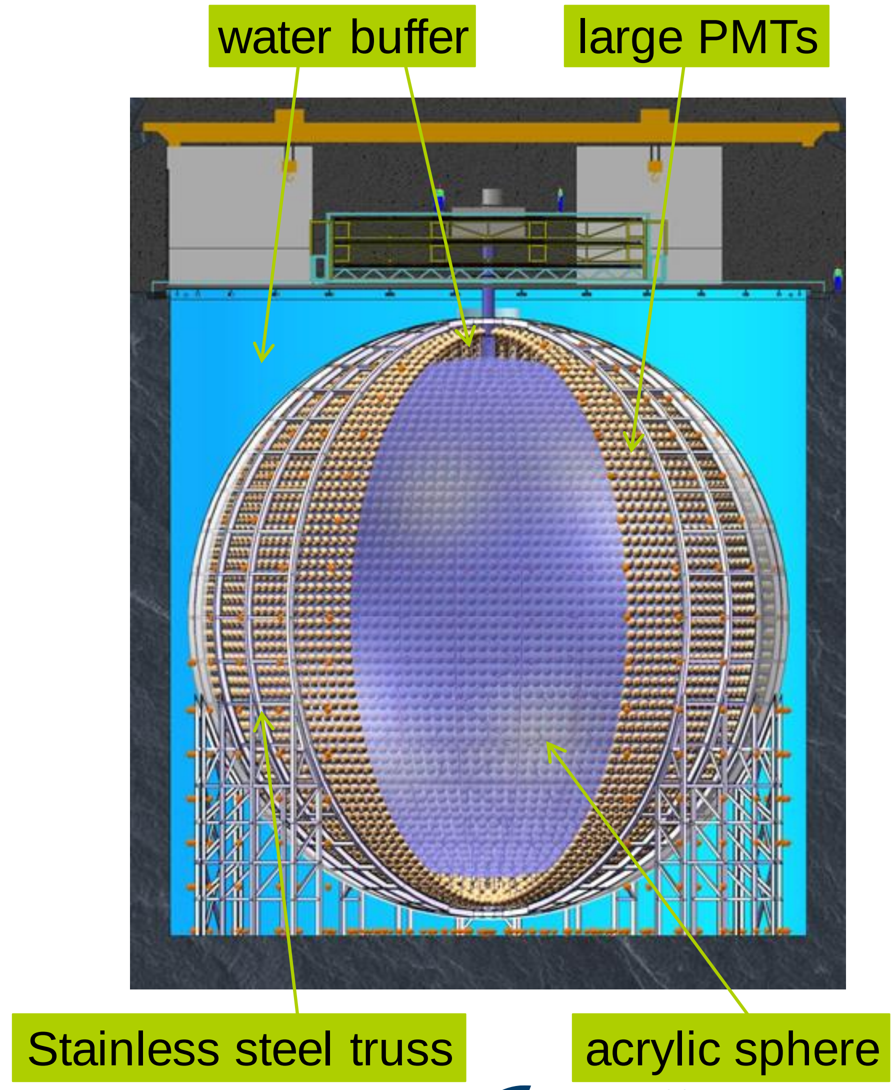
Experiment	Daya Bay	BOREXINO	KamLAND	JUNO
Collected NPE/MeV	~ 160	~ 500	~ 250	~ 1200
LS mass	20 ton	~ 300 ton	~ 1 kton	20 kton
Energy resolution	~ 7.5% / $\sqrt{E(MeV)}$	~ 5% / $\sqrt{E(MeV)}$	~ 6% / $\sqrt{E(MeV)}$	~ 3% / $\sqrt{E(MeV)}$

CENTRAL DETECTOR (CD)

- 20 kton liquid scintillator
- 35.4 m diameter acrylic sphere
- PMT system:
  - 18,000 large PMTs (20 inch)
  - 25,000 small PMTs (3 inch)
- PMTs in water buffer on stainless steel truss
- 78% PMT coverage

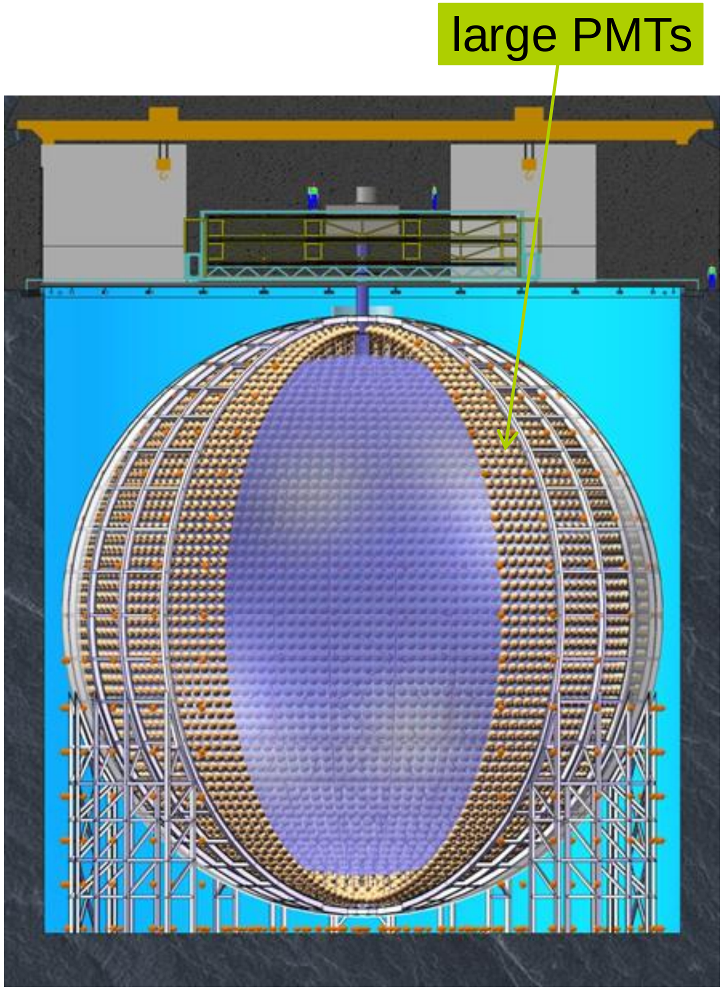
→ **unprecedented energy resolution of 3% /** $\sqrt{E(MeV)}$



PMT SYSTEM IN CD

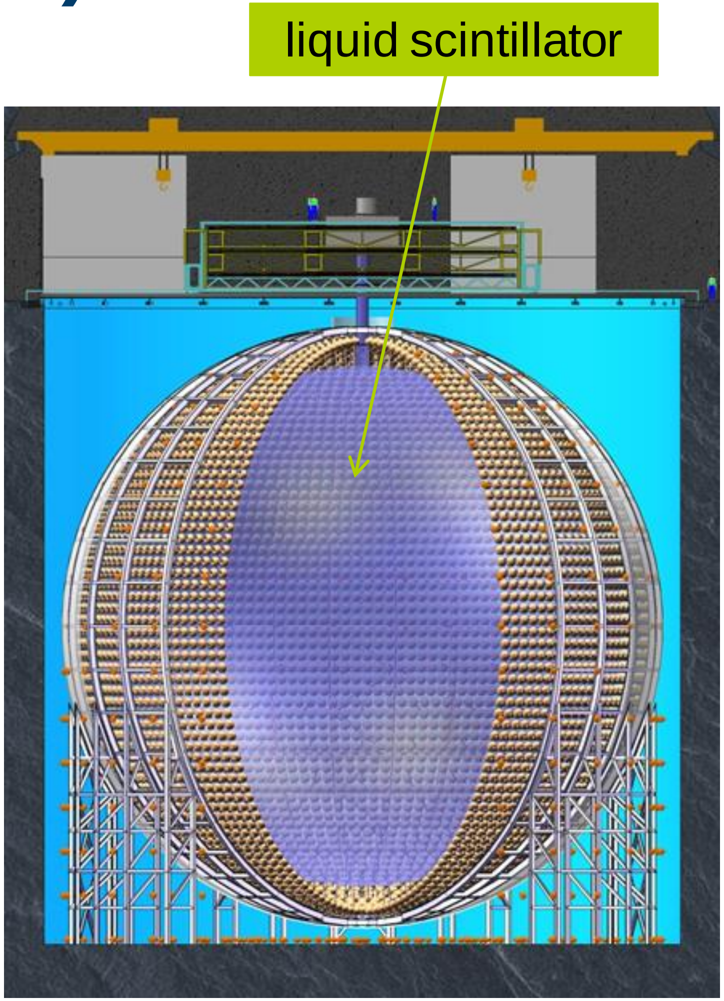
- Light yield of 1200 NPE / MeV deposited energy
- Double calometry:
  - 18,000 large PMTs (LPMTs) of 20 inch
  - 25,000 small PMTs (SPMTs) of 3 inch
- LPMTs:
  - 5,000 dynode PMTs by Hamamatsu
  - 13,000 MCP PMTs by NNVT
- 78% total coverage
- High QE: ~ 30%
- Earth magnetic field compensation by coils

→ unprecedented energy resolution of 3% / $\sqrt{E(MeV)}$



LIQUID SCINTILLATOR (LS)

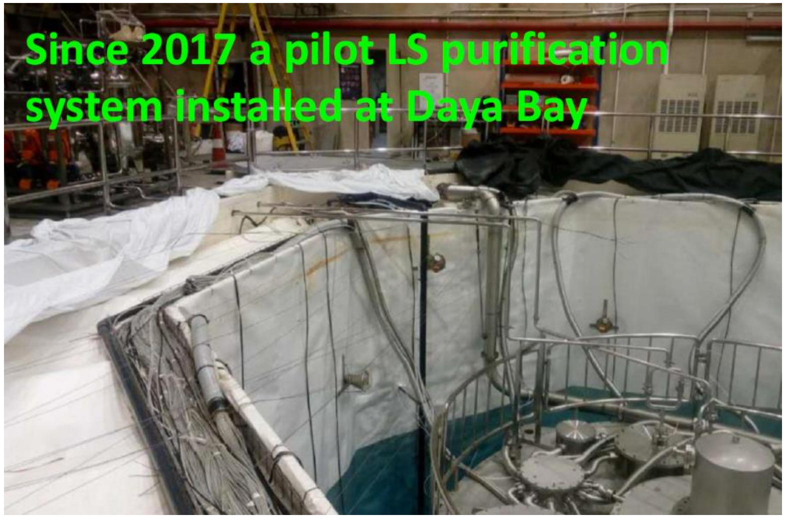
- 20 kton LAB + PPO + bis-MSB
- High intrinsic light yield of LS: ~10^4 / MeV
- High transparency: attenuation length L_{att} > 20 m @ 430 nm
- Development of highly precise measurement of L_{att} and quenching
- Online monitoring of transparency with laser system
- Low radioactivity < 10^{-15} g/g (U/Th)



→ unprecedented energy resolution of 3% / $\sqrt{E(MeV)}$

→ energy scale uncertainty < 1%

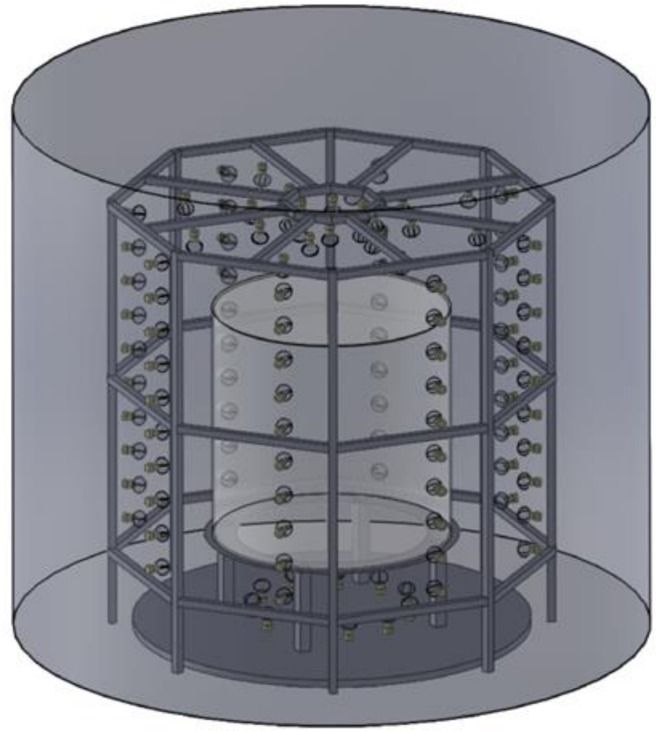
LS: PURIFICATION & FILLING



- Mixing of LS components and online purification
- Pilot LS purification system tested at Daya Bay
- Filling 100 t per day
- Online monitoring of gas pressure, attenuation length and filling levels
- Gaseous nitrogen prevents radon contamination and contact with oxygen

LS: OSIRIS

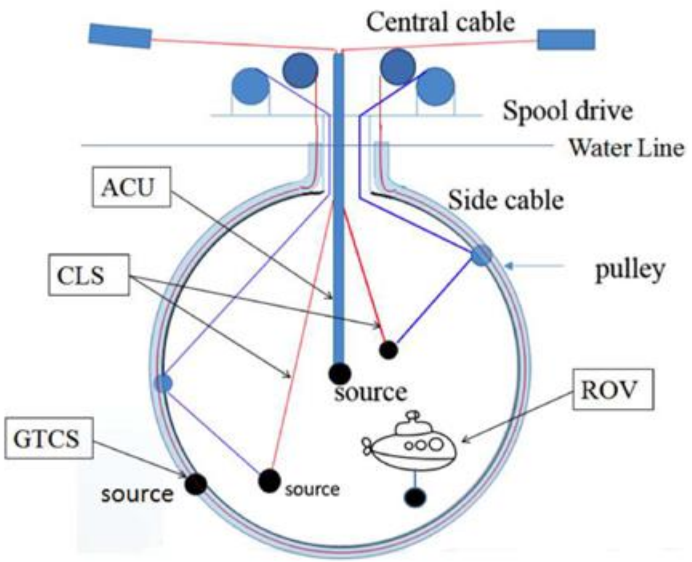
- **O**nline **S**cintillator **I**nternal **R**adioactivity **I**nvestigation **S**ystem (OSIRIS)
- Measures the radioactive contamination of the LS before filling into JUNO up to 10^{-16} g/g (U/Th) (→ 24 / 8 mBq in JUNO by U/Th)
- Challenge:
  - Measure ~ 18 t / day
  - Reach target sensitivity in 24 h
- Acrylic tank with 18 t LS:
  - 3 m diameter and height
  - ~ 2.5 m water shielding
  - Readout with 80 intelligent PMTs

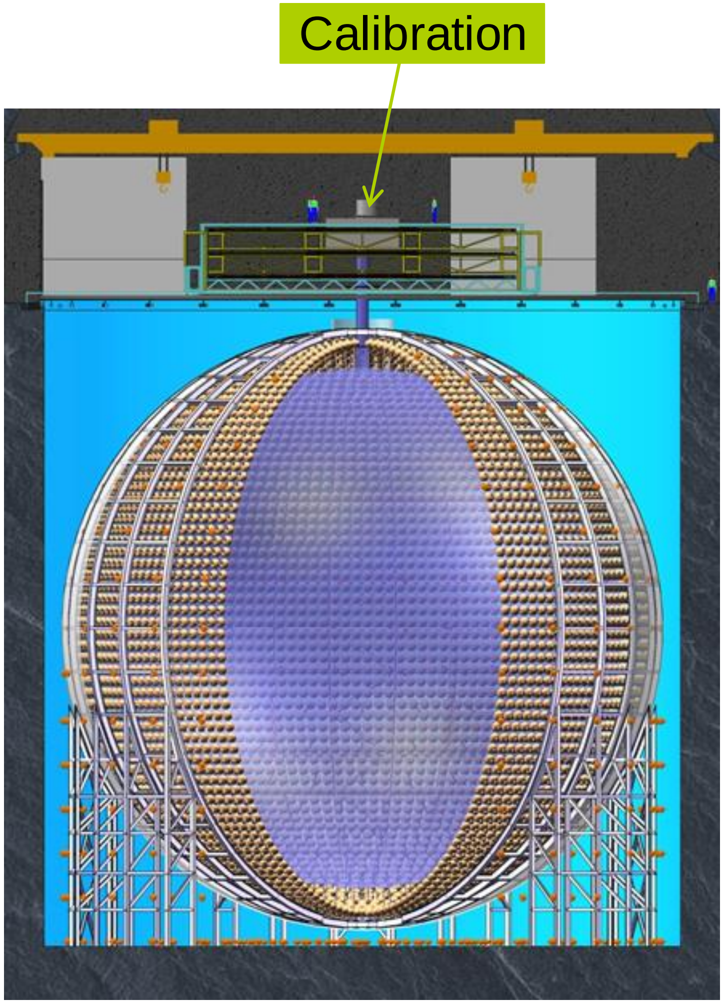


Gefördert durch
DFG Deutsche Forschungsgemeinschaft

CALIBRATION SYSTEM

- PMT charge and timing calibration
- Comprehensive calibration strategy with radioactive sources:
  - **1D:** Automated Calibration Unit **(ACU)**
  - **2D:** Cable Loop System **(CLS)**, Guide Tube Calibration System **(GTCS)**
  - **3D:** Remotely Operated Vehicle **(ROV)**

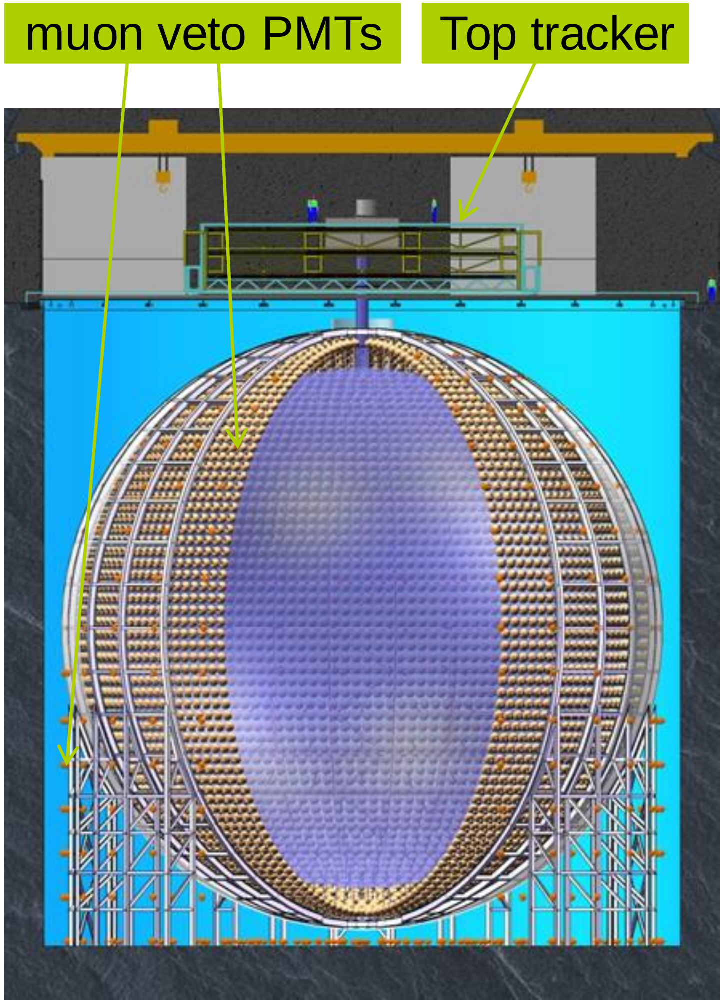




→ **energy scale uncertainty < 1%**

MUON VETO

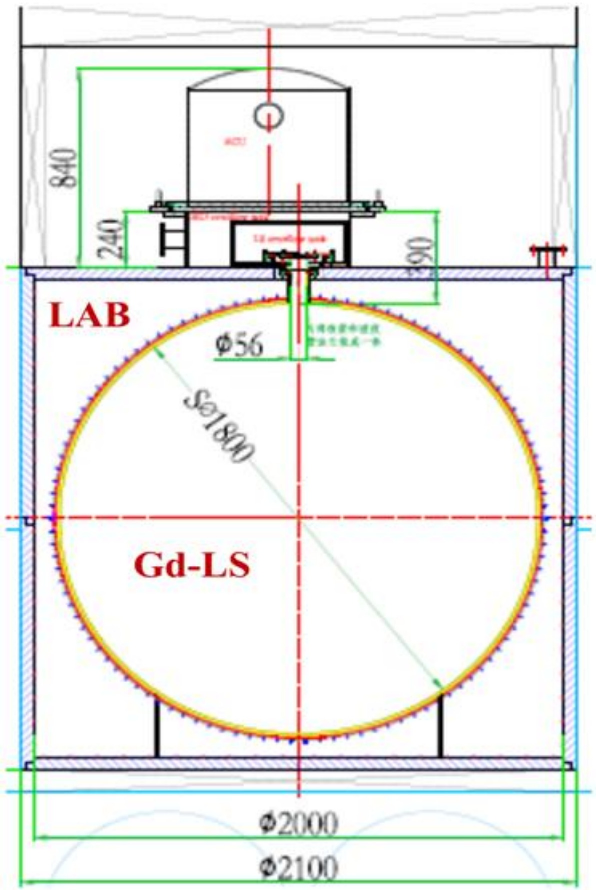
- Cosmic muon flux:
  - Cosmic muon rate: ~ 3.5 Hz
  - Average muon energy: 215 GeV
- Water Cherenkov Detector:
  - 40 kton pure water
  - 4 m water shielding
  - 2000 large PMTs
- Top tracker:
  - Muon track reconstruction
  - From former Opera experiment
  - Plastic scintillator panels

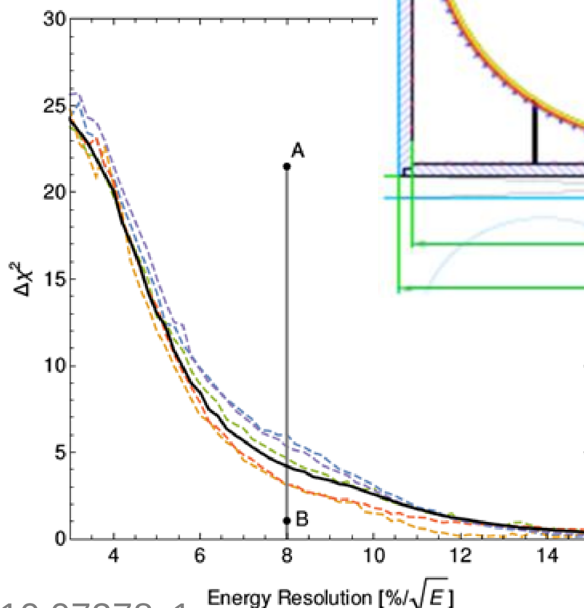


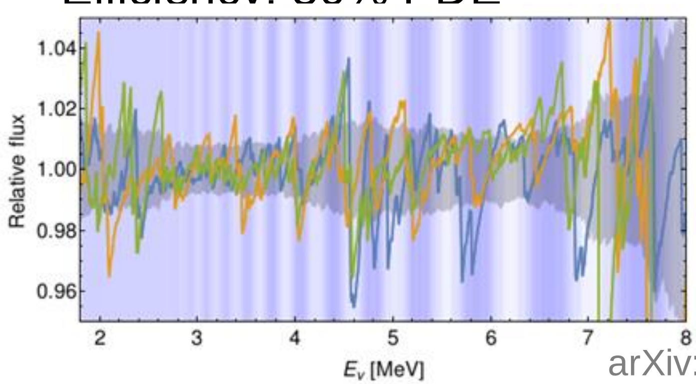
TAO

- **T**aishan **A**ntineutrino **O**bservatory (TAO)
- Goal: measure fine structure of reactor spectrum
- Location: 30 m distance to Taishan powerplant core
- Rate: 30 · JUNO rate
- Energy resolution: 1.7% / $\sqrt{E(MeV)}$

- Setup:
  - 1 t fiducial mass
  - 10 m^2 silicon photomultiplier:
    - Full coverage
    - Efficiency: 50% PDE





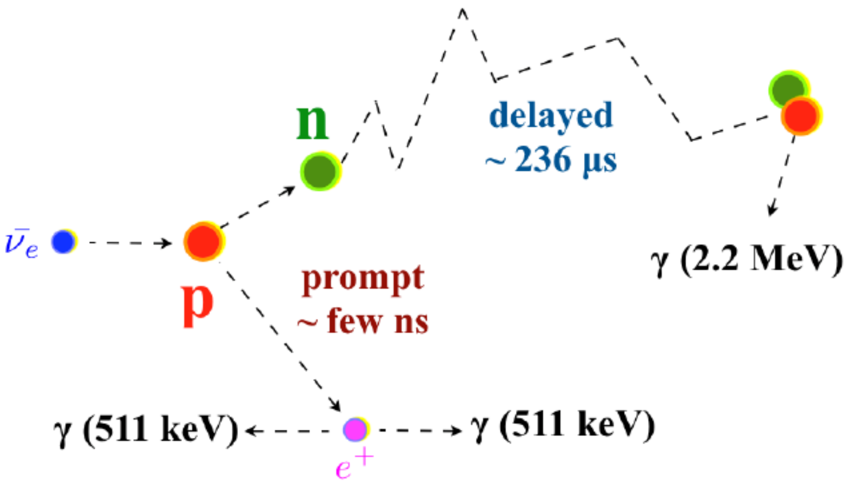


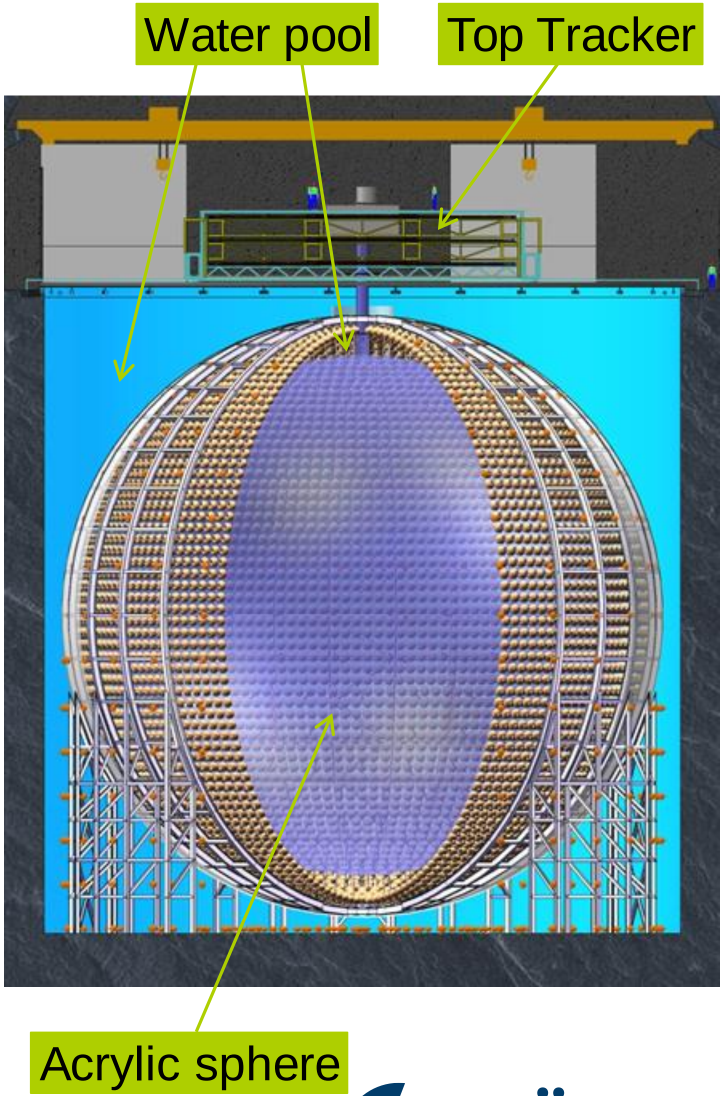
arXiv: 1710.07378v1

SIGNAL AND BACKGROUND IN JUNO

Signal:

- Reactor $\bar{\nu}_e$ are detected via the Inverse Beta Decay (IBD): $\bar{\nu}_e + p \rightarrow e^+ + n$
- Coincidence between prompt positron and delayed neutron capture
- Rate: ~ 60/day





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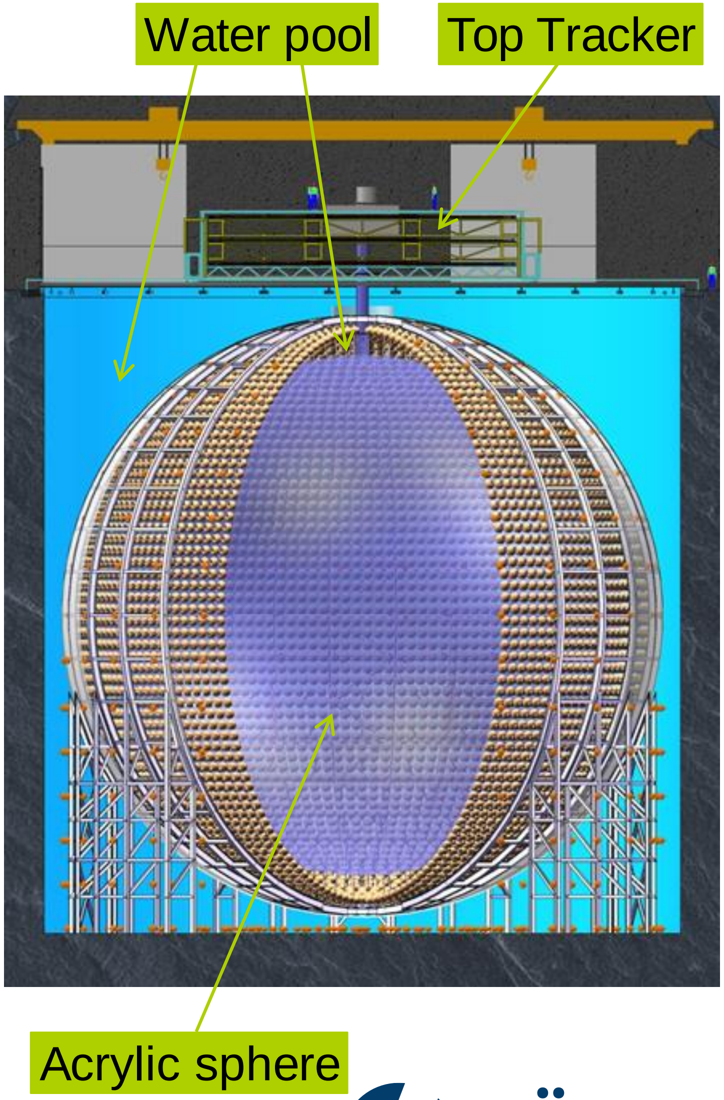
Background:

- Muons:
  - Main background with 3.5 Hz in CD
  - 650 m overburden (≙ 1750 m.w.e.)
  - (β^-+n)-decay of ^{9}Li and ^{8}He mimic delayed IBD coincidence (rate before veto ~ 84/day)
  - Partial volume veto: 17% exposure loss
  - Rate after veto: ~ 1.6/day
- Geo-neutrinos (~ 1.1/day)
- Fast neutrons (~ 0.1/day)
- (α, n)-decays (~ 0.05/day)



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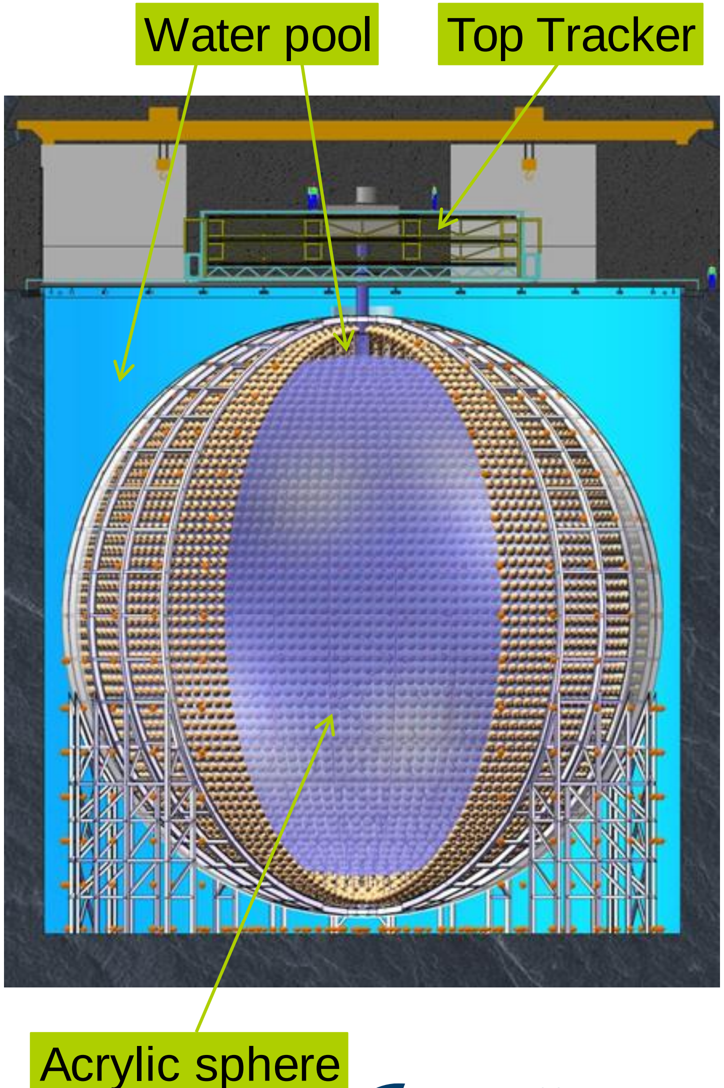
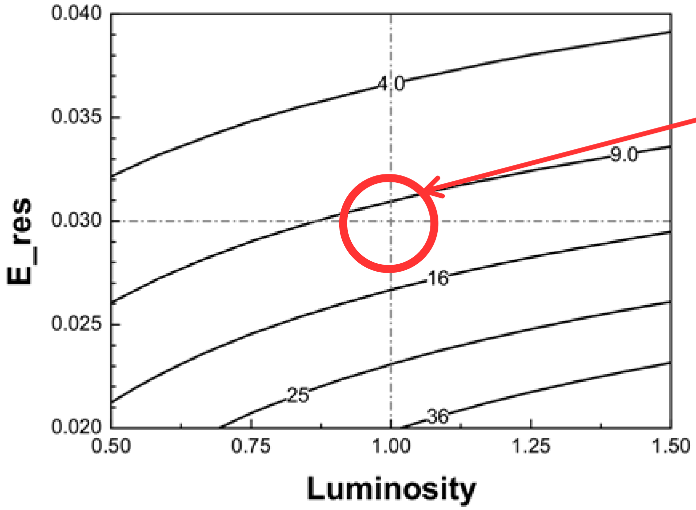
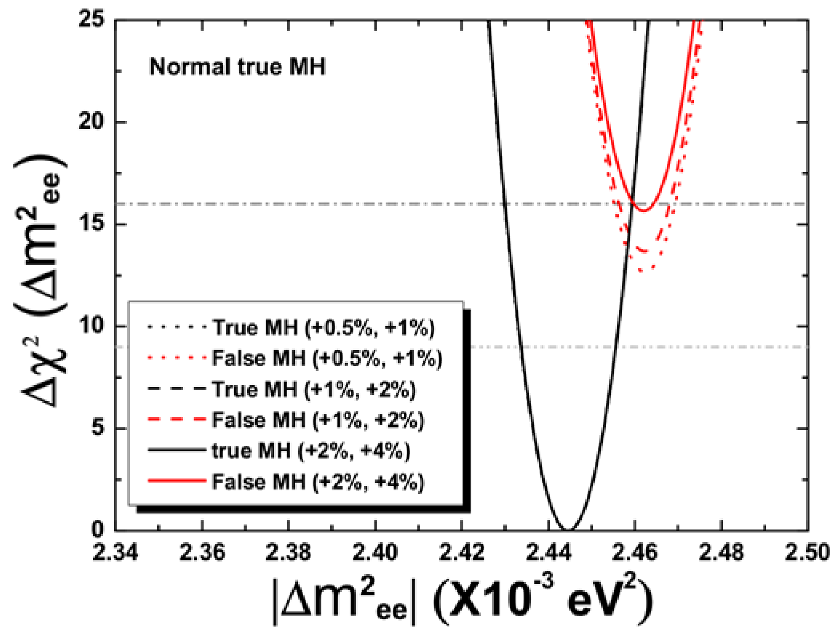
→ after all cuts: 60 IBD / 3.8 background per day



SENSITITVITY ON MASS HIERARCHY AND OSCILLATION PARAMETERS



Nominal exposure = 100k IBD events
$\widehat{=}$ *6 years · 20 kt LS · 36GW$_{th}$*



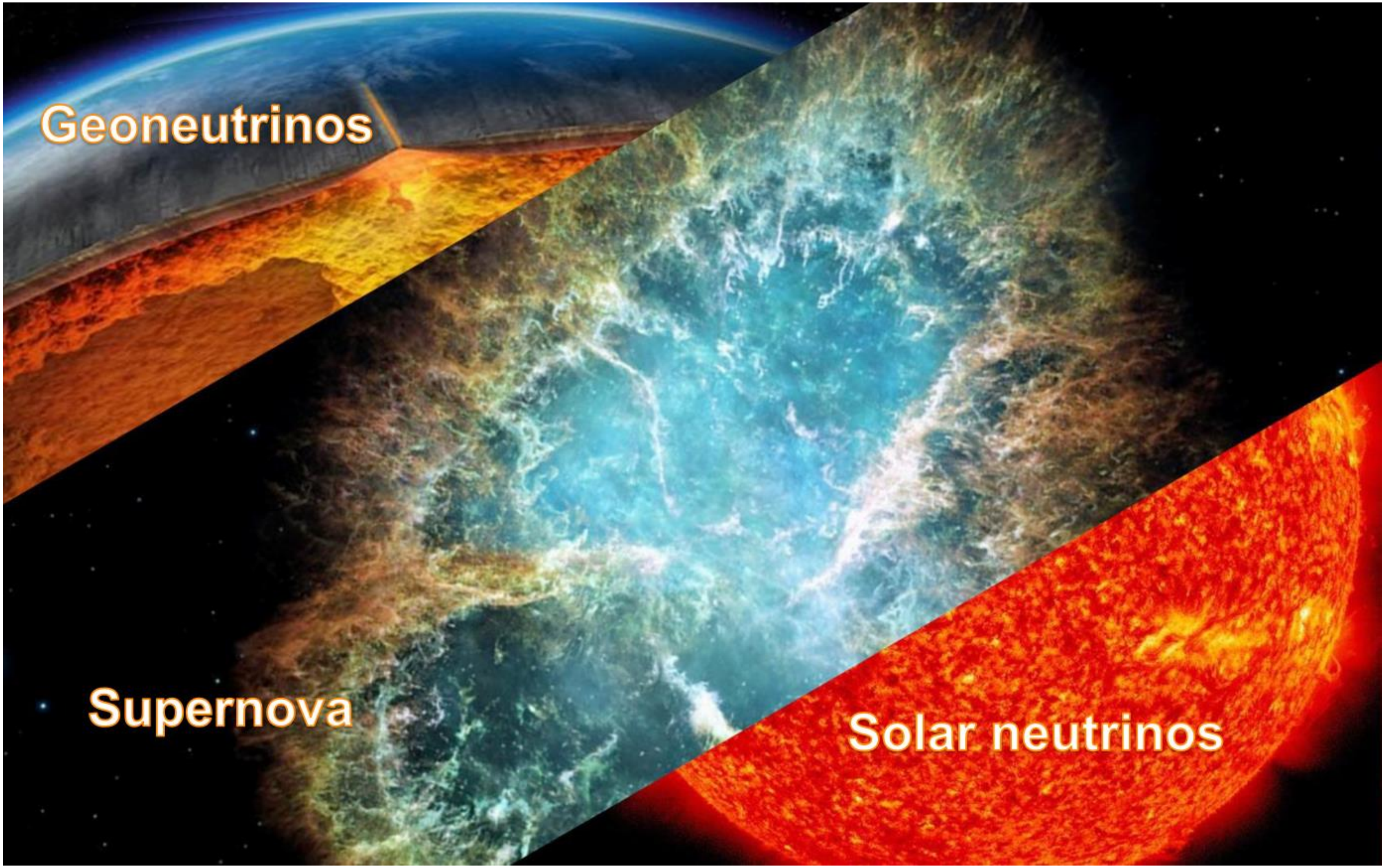
Sensitivity on MH with nominal exposure and energy resolution:

- ~ 3σ JUNO alone
- 4σ combined with NOvA and T2K

Precision on oscillation parameters:

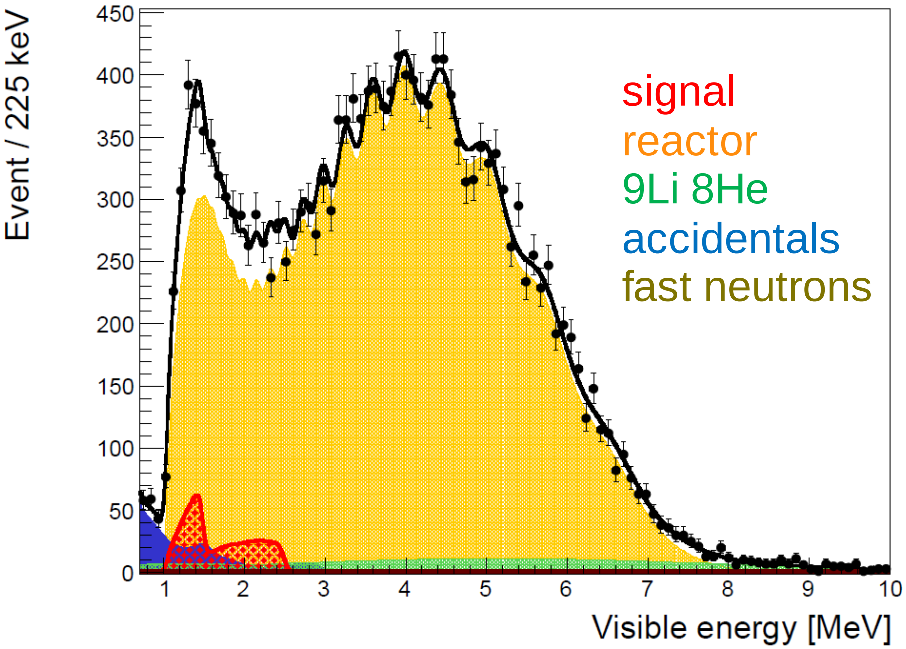
Parameter	$\sin^2\theta_{12}$	Δm^2_{21}	$\lvert\Delta m^2_{ee}\rvert$
Precision (Current)	4.1%	2.6%	1.9%
Precision (JUNO)	0.67%	0.50%	0.44%

EXTENDED PHYSICS PROGRAMM



GEONEUTRINOS

- Detect $\bar{\nu}_e$ from the ^{238}U and ^{232}Th chain from the Earth mantle and crust
- Study the composition of the Earth and its radiogenic heat production
- Expected rate: 400 events / year → world‘s largest sample of geoneutrinos in less than one year
- Challenge: large background from reactor $\bar{\nu}_e$

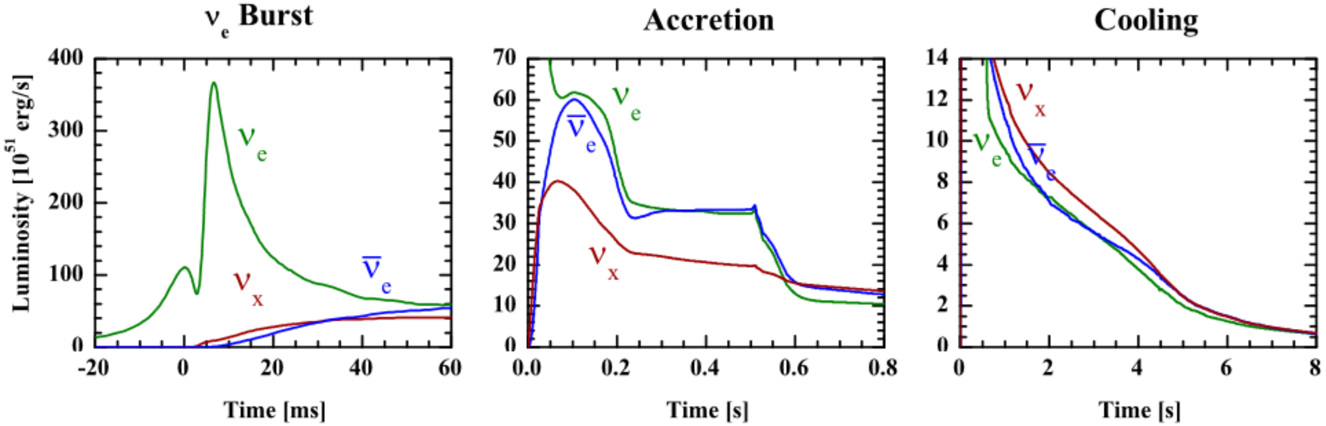


arXiv:1507.05613

CORE-COLLAPSE SUPERNOVA

- DAQ of a high statistics sample in case of a core collapse SN at distance ~ 10 kpc:
  - 5,000 IBD events from $\bar{\nu}_e$
  - 2,000 elastic p scatterings within 10 s
- Separation of $\bar{\nu}_e$, ν_e and ν_x
- Probe SN models:
  - Time evolution
  - Energy spectra
  - Flavor mixing

Channel	Type	Events for $\langle E_\nu \rangle = 14$ MeV
$\bar{\nu}_e + p \rightarrow e^+ + n$	CC	5.0×10^3
$\nu_x + p \rightarrow \nu_x + p$	NC	1.2×10^3
$\nu_x + e \rightarrow \nu_x + e$	ES	3.6×10^2
$\nu_x + {}^{12}\mathrm{C} \rightarrow \nu_x + {}^{12}\mathrm{C}^*$	NC	3.2×10^2
$\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$	CC	0.9×10^2
$\bar{\nu}_e + {}^{12}\mathrm{C} \rightarrow e^+ + {}^{12}\mathrm{B}$	CC	1.1×10^2

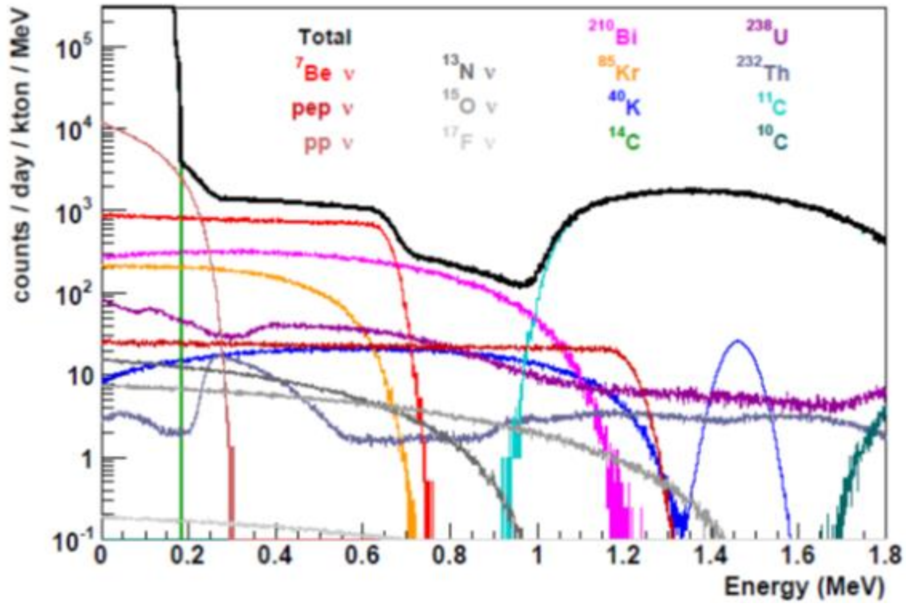


arXiv:1507.05613

3 phases of core-collapse supernova

SOLAR NEUTRINOS

- Sun emits MeV electron neutrinos
- LS detector well suited due to low detection threshold and high energy resolution
- JUNO can measure neutrinos from the ^{7}Be (10^{4} / year) and ^{8}B (~ 10 / year) chain
- Measured by scattering of electrons
- Study of the
  - MSW effect: transition between vacuum and matter
  - Solar metallicity



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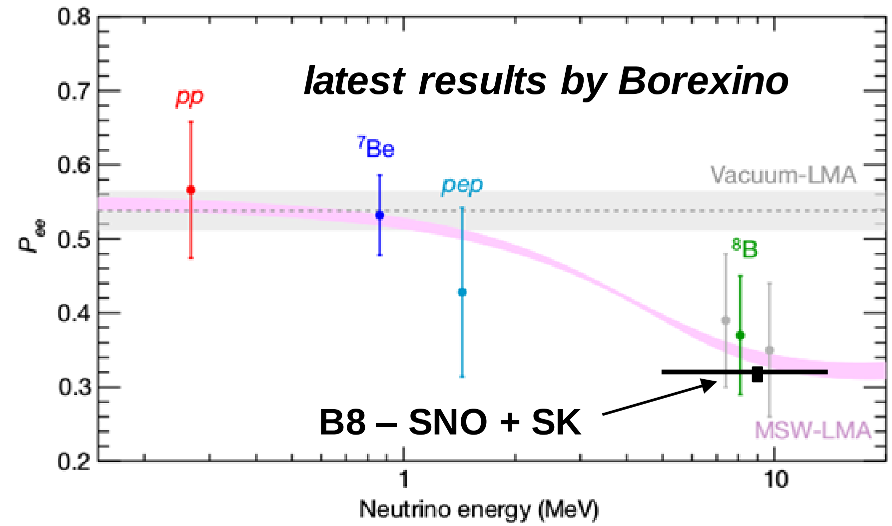


arXiv:1810.12967

MILESTONES & SCHEDULE

2014:

- International collaboration established
- Start civil construction

2015:

- PMT production line setup
- CD parts R&D

2016:

- Start PMT production
- Start CD parts production

2017:

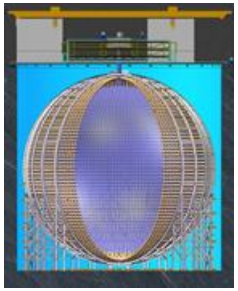
- Start PMT testing
- TT arrived

2018:

- PMT potting
- Start delivery of surface buildings
- Start production of acrylic sphere

2019-2020:

- Electronics production starts
- Civil work and lab preparation completed
- Detector construction



2021:

Detector ready for data taking!

SUMMARY & OUTLOOK

- 20 kton liquid scintillator detector with
  - 3% energy resolution
  - 1% energy scale uncertainty
- Will determine the neutrino mass hierarchy based on reactor $\bar{\nu}_e$
  - 3σ significance after 6 years of data taking with 35.8 GW_{th}
- Extended physics program with terrestrial and astrophysical neutrinos
  - Will determine the oscillation parameters $\sin^2\Theta_{12}$, Δm^2_{12}, and $|\Delta m^2_{ee}|$ with subpercentage precision
- Collaboration of 77 institutes from 16 countries
- Funded and under construction in China
- Data taking expected to start in 2021