Проект JUNO: измерение иерархии масс нейтрино

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Outline

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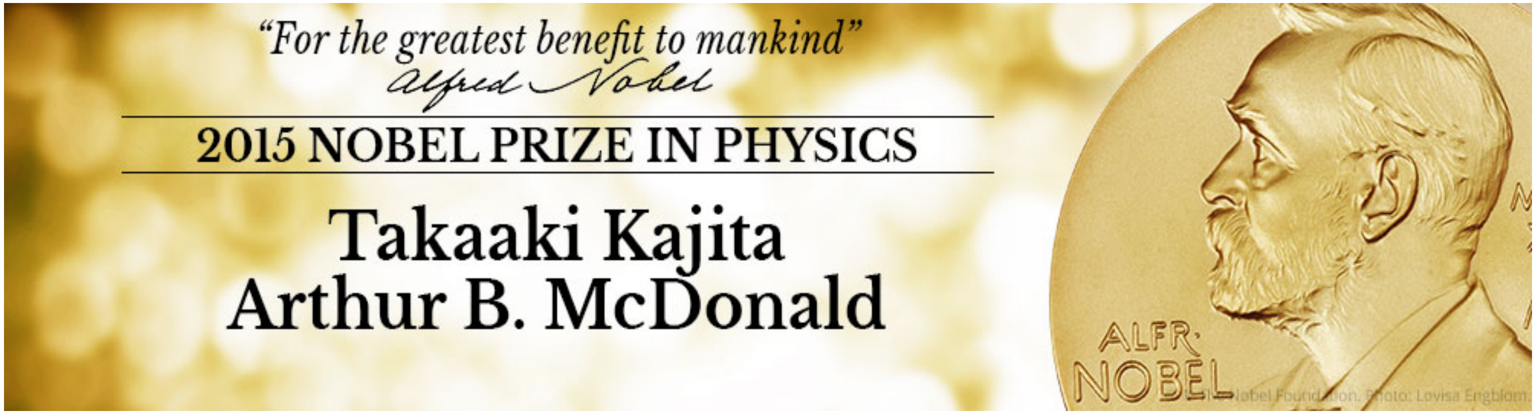
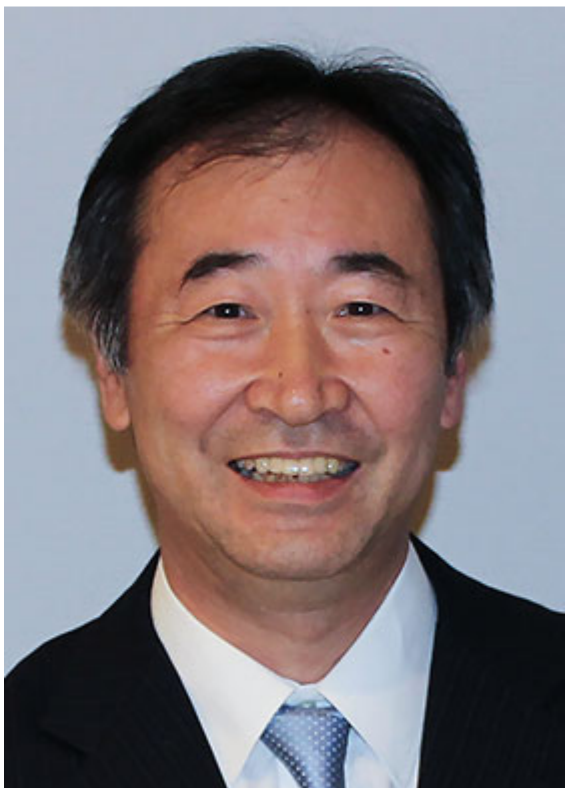
- JUNO Experimental Goals and Strategy
- JUNO collaboration
- Location
- Neutrino Detection
- Experimental Layout
- JUNO at JINR and MSU
- JUNO Overall Schedule
- Summary





for the discovery of ***neutrino oscillations,*** *which shows that neutrinos have mass*

PMNS today
What We Know

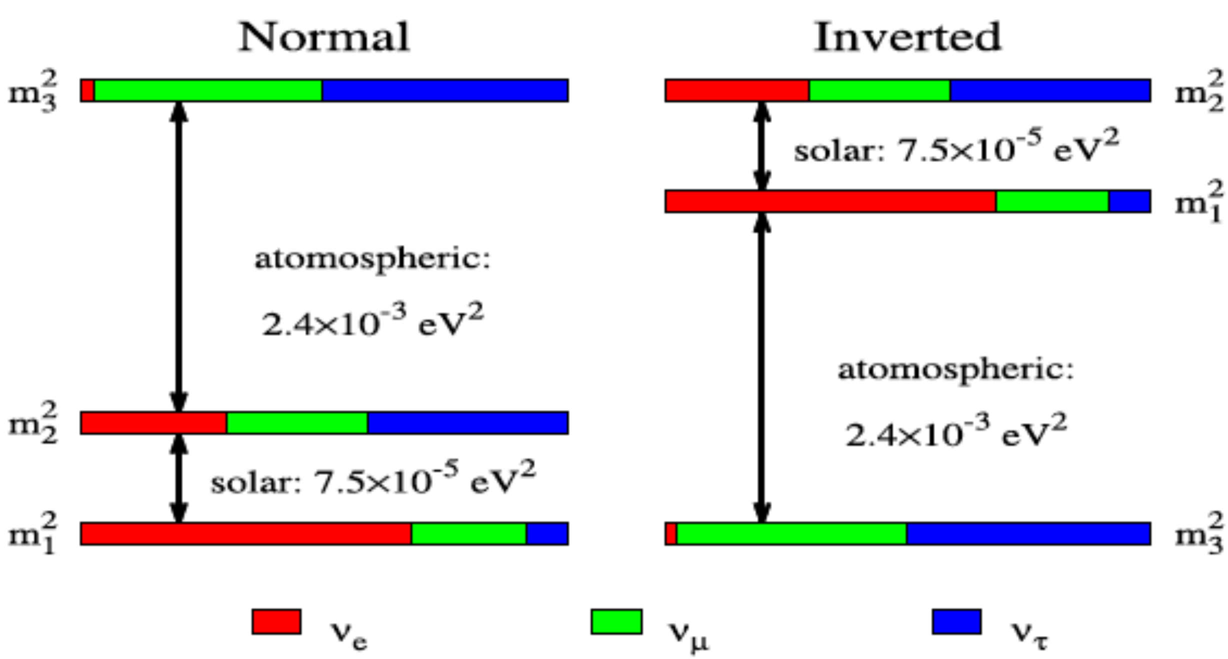
atmospheric, accelerator ν_μ | short baseline reactor, accelerator ν_e | solar, long baseline reactor

Flavor

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass

$\theta_{23} \approx 45^\circ$ $\theta_{13} \approx 9^\circ$ $\theta_{12} \approx 34^\circ$



PMNS today

What We Know

atmospheric accelerator ν_μ	short baseline reactor accelerator ν_e	solar long baseline reactor

Flavor

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}=\begin{pmatrix}1&0&0\\0&c_{23}&s_{23}\\0&-s_{23}&c_{23}\end{pmatrix}\begin{pmatrix}c_{13}&0&s_{13}e^{-i\delta}\\0&1&0\\-s_{13}e^{i\delta}&0&c_{13}\end{pmatrix}\begin{pmatrix}c_{12}&s_{12}&0\\-s_{12}&c_{12}&0\\0&0&1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Mass

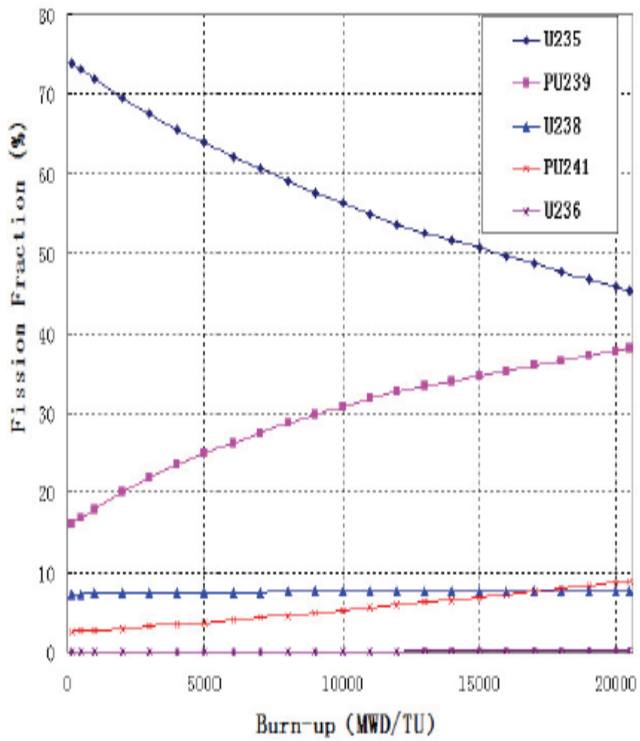
$\theta_{23}\approx 45^\circ$ $\theta_{13}\approx 9^\circ$ $\theta_{12}\approx 34^\circ$

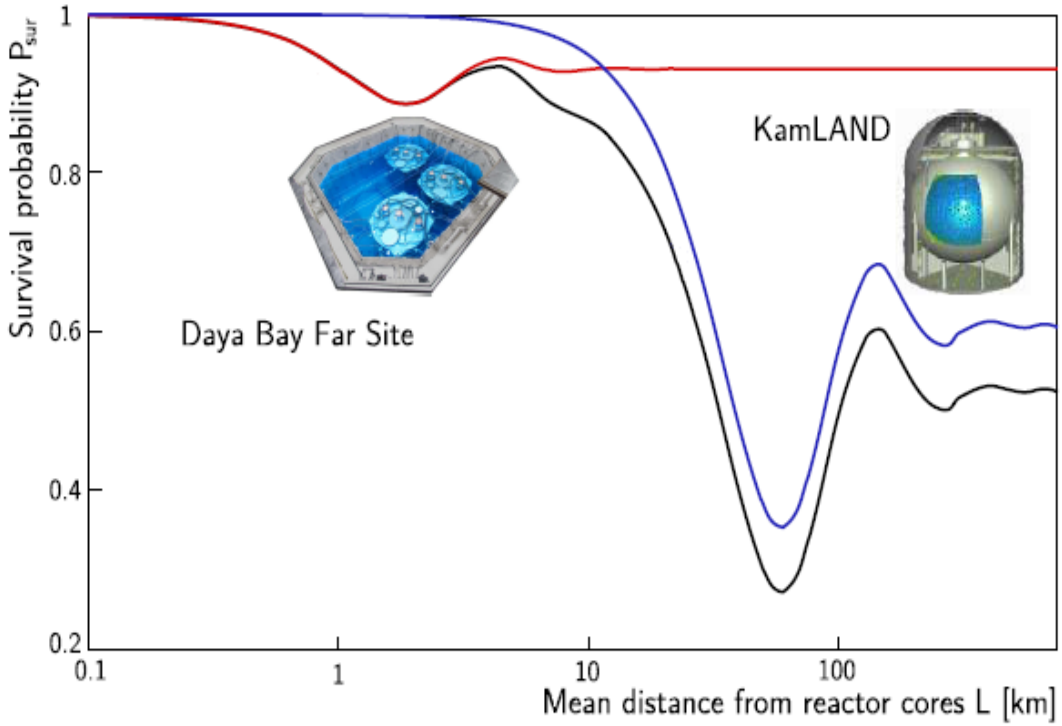
	Best Fit		Global 1 σ
	NO	IO	
$\Delta m^2_{21}\ (eV^2)$	7.37×10^{-5}		~2.3 %
$\Delta m^2\ (eV^2)$	2.525×10^{-3}	2.505×10^{-3}	~1.6 %, sign is unknown
$sin^2\theta_{12}$	2.97×10^{-1}		~4-6%
$sin^2\theta_{13}$	2.15×10^{-2}	2.16×10^{-2}	4%
$sin^2\theta_{23}$	4.25×10^{-1}	5.89×10^{-1}	octant is unknown
δ/π	1.38	1.31	~50%

Reactor Antineutrino Experiments with 1-2 km baselines are sensitive to θ_{13} ,

$$P_{sur} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\Delta m^2_{32} \frac{L}{4E}\right) - \sin^2 2\theta_{12} \cos^4 2\theta_{13} \sin^2\left(\Delta m^2_{21} \frac{L}{4E}\right)$$

Isotope fission rates vs. reactor burn-up





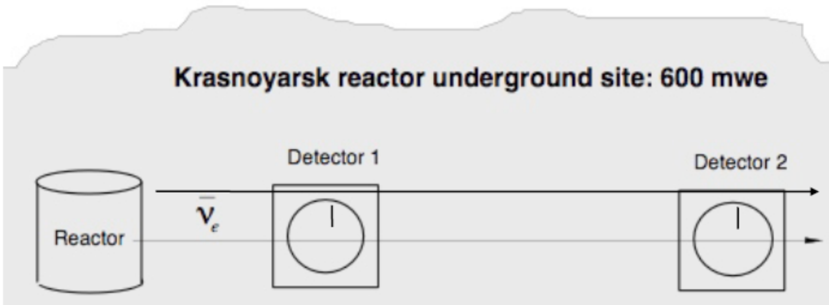
but have significant neutrino flux normalization uncertainty

Absolute Reactor Flux:
Largest uncertainty in previous measurements

Relative Measurement:
Multiple detectors removes absolute uncertainty

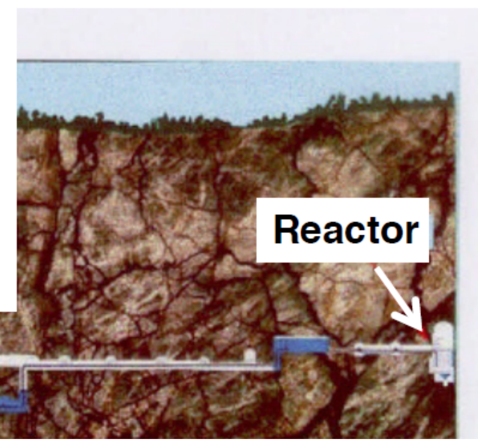
Relative Measurement: A 2-Detector Experiment

Krasnoyarsk, Russia
first proposed at Neutrino2000



Krasnoyarsk
- underground reactor
- detector locations determined by infrastructure

	115 m	1000 m
Target:	46 t	46 t
Rate:	~1.5 x 10^6 ev/year	~20000 ev/year
S:B	>>1	~ 10:1

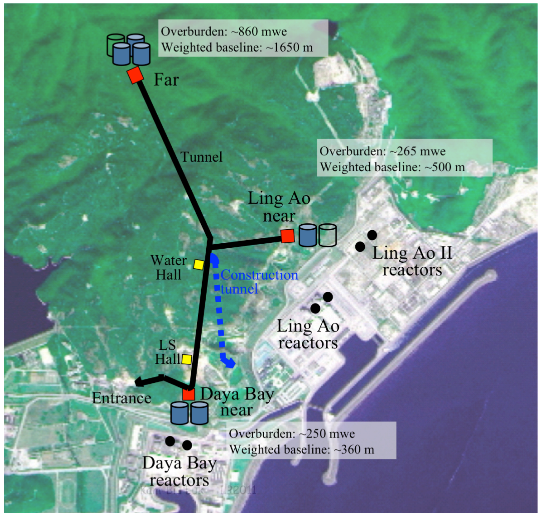


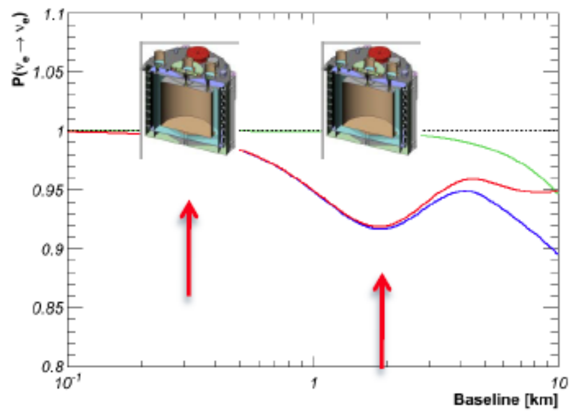
ex/0211(

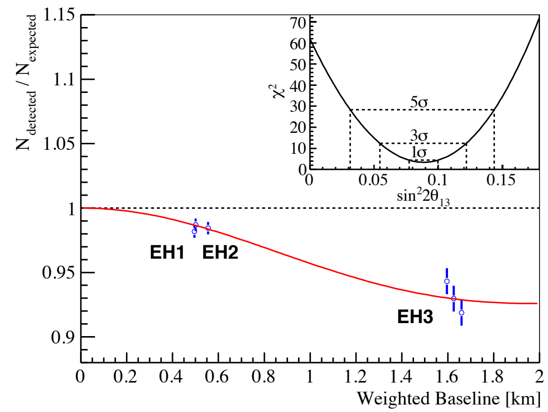
Ref: Marteyamov et al, hep-ex/0211070

First proposed by L. A. Mikaelyan et al., Phys. Atomic Nucl. 63 1002 (2000)

Измерение угла смешивания θ_{13} в эксперименте Daya Bay

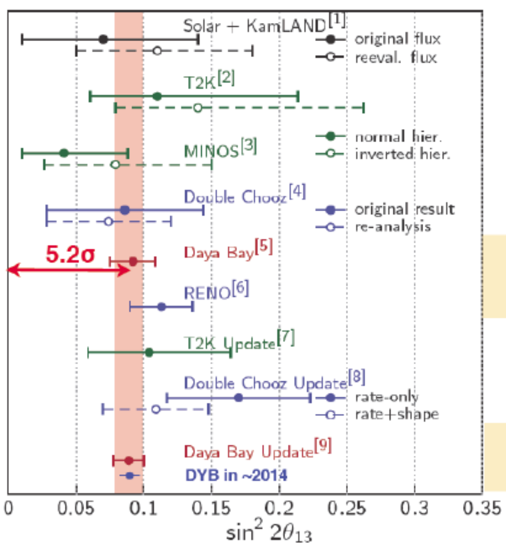






Global θ_{13} Measurements

2011/2012 -The year of θ_{13}



JINR contribution to Daya Bay experiment:

- Detector Construction and Running
- Data and Background Handling
- Oscillation Analysis

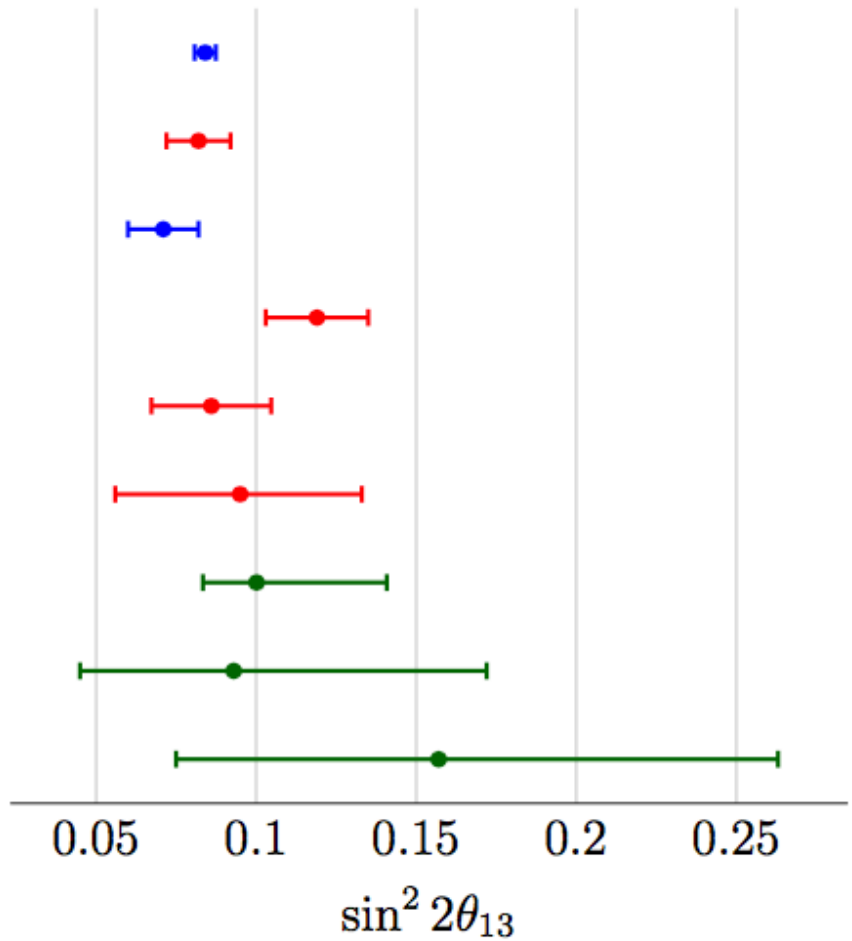
$$\sin^2 2\theta_{13} = 0.089 \pm 0.010\ (\text{stat}) \pm 0.005\ (\text{syst})$$

Breakthrough of the Year, 2012, by Science Magazine

The Laureates from JINR are: M.O. Gonchar, Yu.A. Gornushkin, D.V. Naumov, I.B. Nemchenok, A.G. Olshevski (all from Daya Bay), E.A. Yakushev (KamLAND), V.A. Matveev and B.A. Popov (T2K).

Современный статус измерения угла смешивания θ_{13}

Experiment		Value
Daya Bay	nGd	0.0841 ± 0.0033
RENO	nGd	0.082 ± 0.010
Daya Bay	nH	0.071 ± 0.011
D-CHOOZ	nGd+nH	0.119 ± 0.016
RENO	nH	0.086 ± 0.019
D-CHOOZ	nH	$0.095^{+0.038}_{-0.039}$
T2K		$0.100^{+0.041}_{-0.017}$
NOνA	NH	$0.093^{+0.079}_{-0.048}$
	IH	$0.157^{+0.106}_{-0.082}$



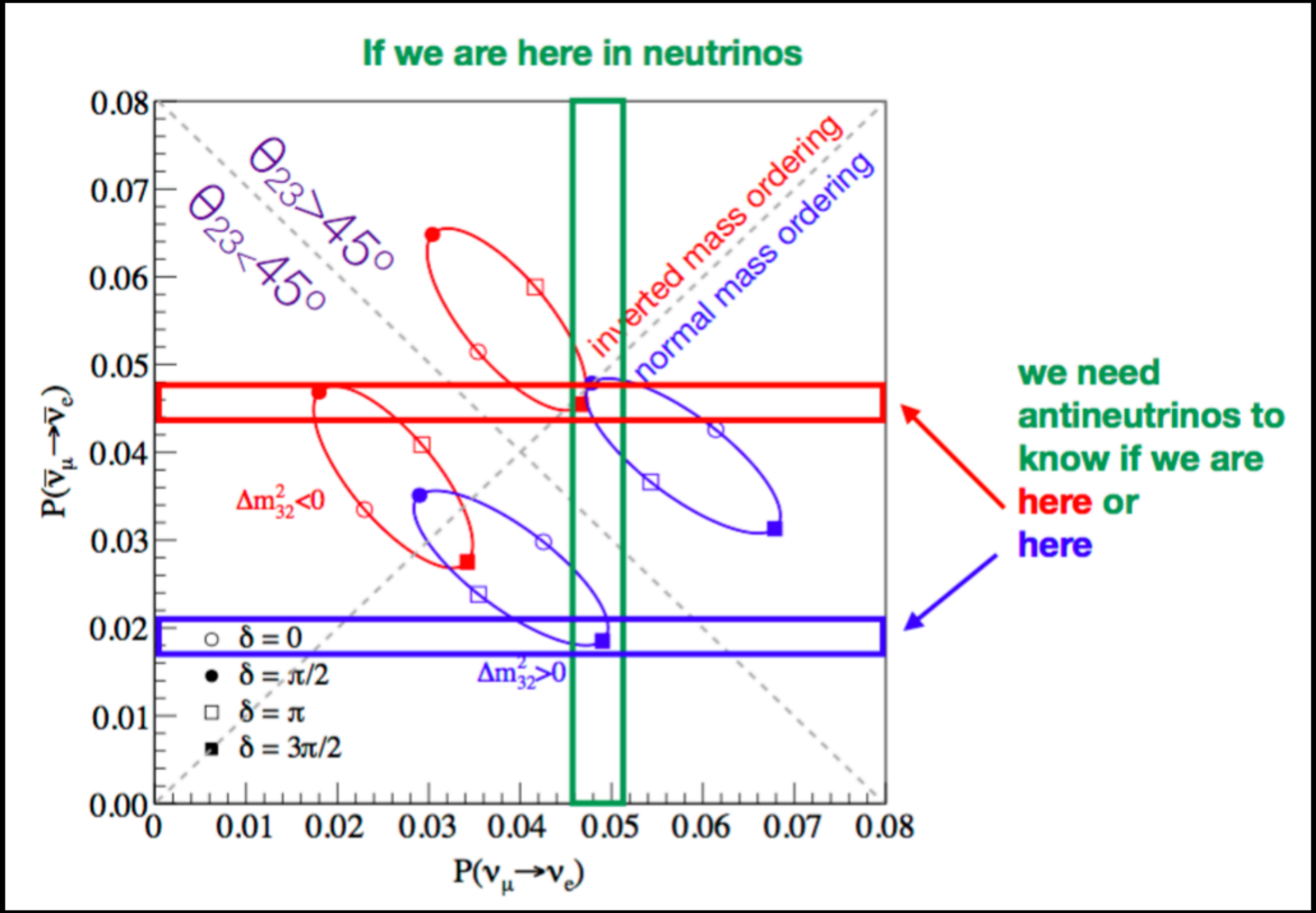
Предложения по измерению иерархии масс

Project	ν source	Detector	Goal	Challenges
NOVA	LBL (810 km)	14 kt tracking calorimeter	2σ (2020)	Parameter degeneracy
JUNO	Reactor (53 km)	20 kt LS	$(3-4)\sigma$ (2026)	Energy resolution
PINGU/ORCA	Atmosphere	(1-10) Mt of ice	$(3-5)\sigma$ (unknown)	Energy resolution, systematics
INO	Atmosphere	50 kt magnetized calorimeter	3σ (2030)	Low statistics (10 years)
T2HK	LBL (295 km)	1Mt of water	3σ (2030)	Parameter degeneracy
DUNE	LBL (1300 km)	1kt of liquid argon	$(3-5)\sigma$ (2030)	Parameter degeneracy
Cosmology	Early Universe	CMB-S4 bolometers	4σ (>2023)	Dependence on cosmological models

Comparison of expected median sensitivities to neutrino mass hierarchy determination of various accelerator, atmospheric, reactor and cosmological experiments.

Использование эффекта вещества

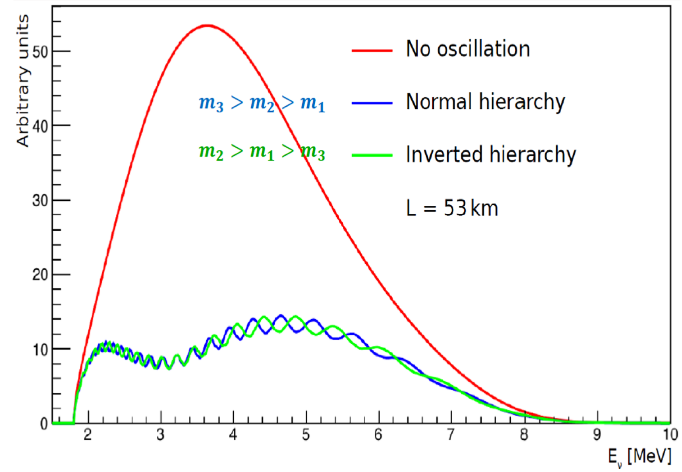
Neutrino. The big picture and NOvA



• Neutrino mass hierarchy • CP violating phase • Precise measurements of θ_{23}

Strategy: The spectral distortion contains the MH information.

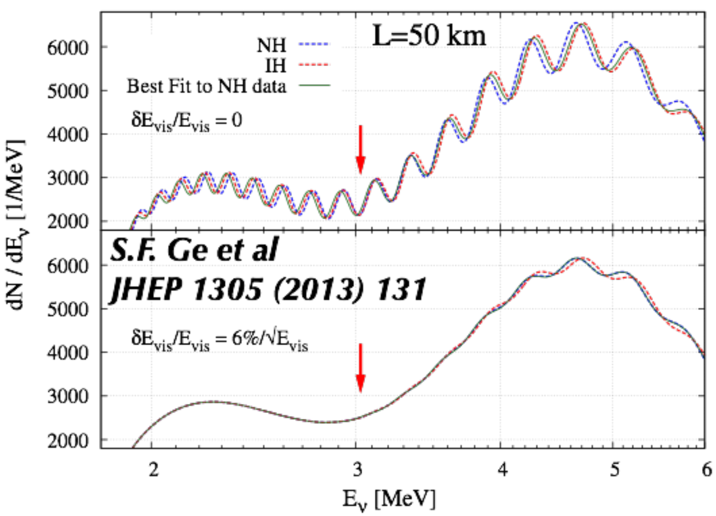
- Reactor power: 36 GW
- 6 years data with 20 kt LS
- Energy resolution: 3%
- Detector eff. :73%



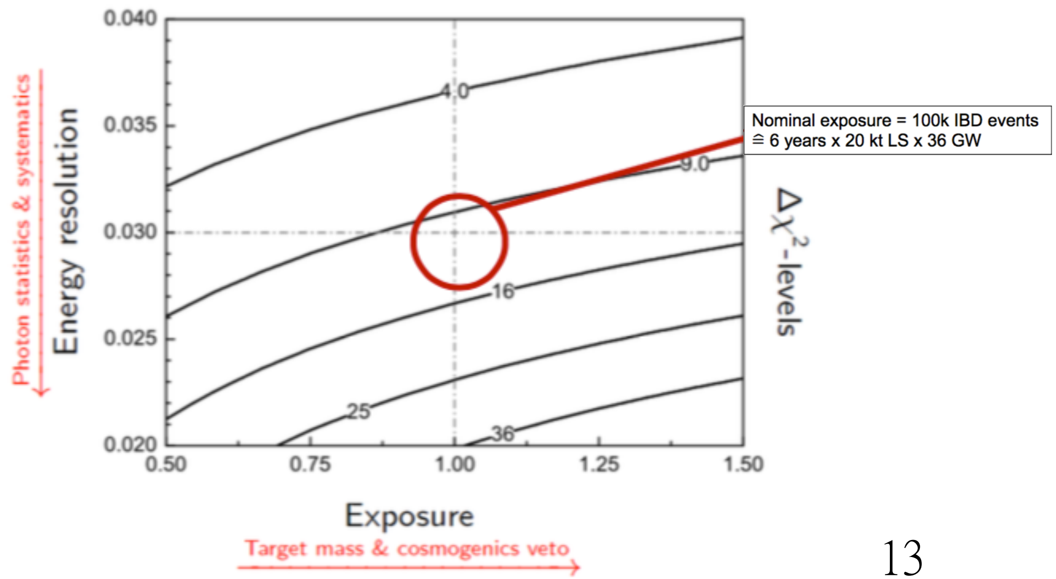
➢ **Baseline optimization: 53±0.5 *km***

➢ **Excellent energy resolution: $3\%/\sqrt{E[MeV]}$**

If not, the MH signal practically disappears!



MH Discriminator: $\Delta\chi^2_{MH} = [\chi^2_{MIN}(NH) - \chi^2_{MIN}(IH)]$



JUNO Collaboration

71 institutions, ~500 collaborators

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

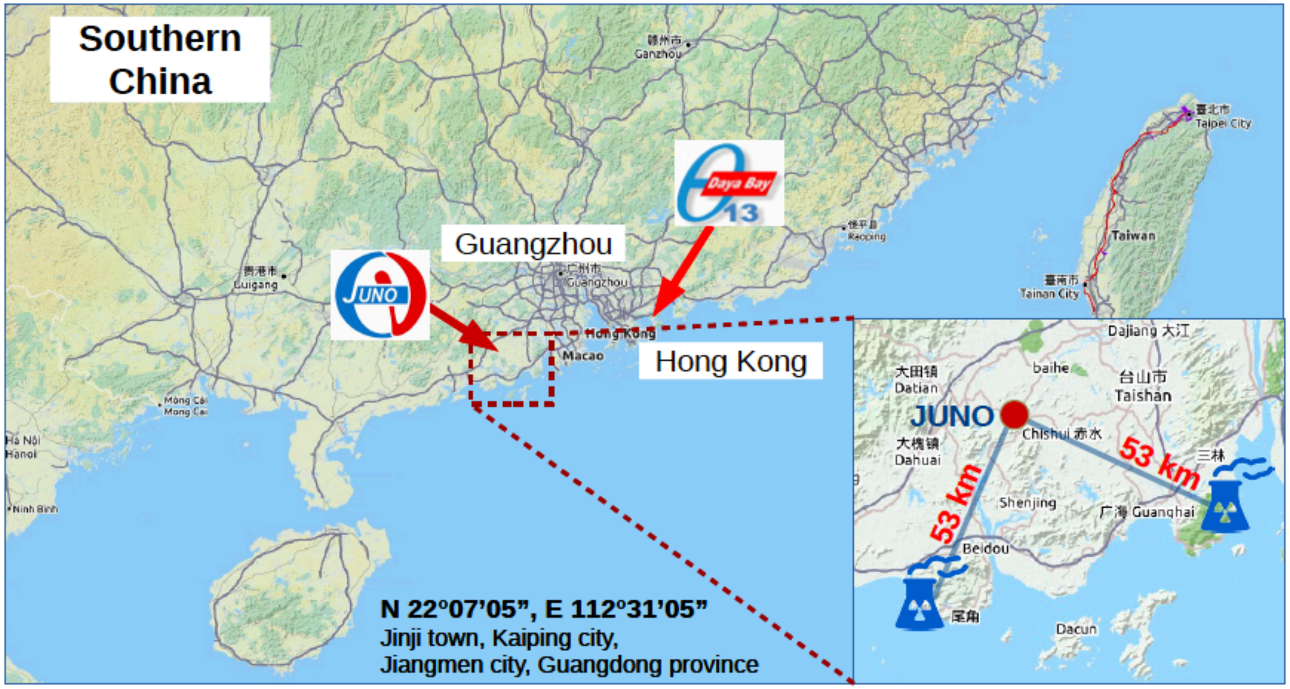
Observers

1. Department of Physics, Jyvaskyla University, Finland
2. Institute of Electronics and Computer Science, Riga, Latvia

Location

➢ Civil construction for underground site started early 2015

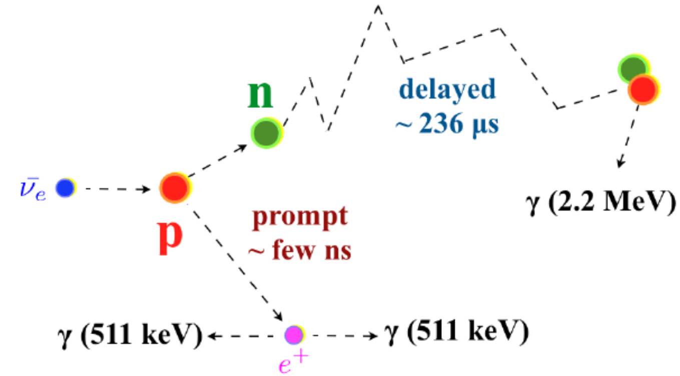
- **Powerful source**: **Yangjiang and Taishan power plants**
  26.6 GWth in 2020, later 35.7 GWth
- **Ideal baseline**: 53 km
- **Shielding**: 700 m underground



Neutrino Detection

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

$$E_\nu \approx E_{prompt} + 0.8(MeV)$$

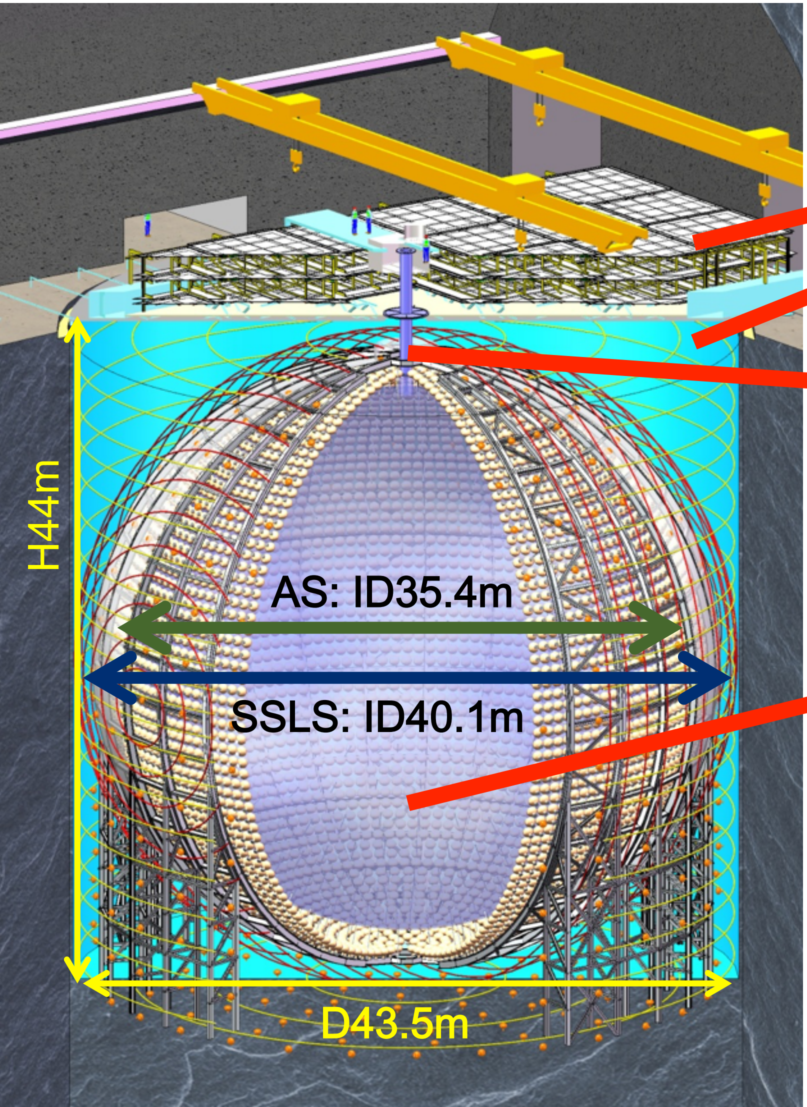


- Prompt signal: annihilation process
- Delayed signal: neutron capture
- Prompt + Delayed coincidence signal provides IBD signal

Cornerstones for succesful MH measurement:

- ✓ ~53km baseline to two NPP with 35.8 GW_{th} (26GW by 2020)
- ✓ 100k events in 6 years
- ✓ 1200 p.e. per MeV $\Delta E/E = 3\%/\sqrt{E(MeV)}$
- ✓ 20 kt liquid scintillator
- ✓ Energy scale uncertainty < 1%

Experimental Layout



Veto System

- Top tracker (Solid scintillator)
- Water Cherenkov veto pool with 2k 20” PMTs

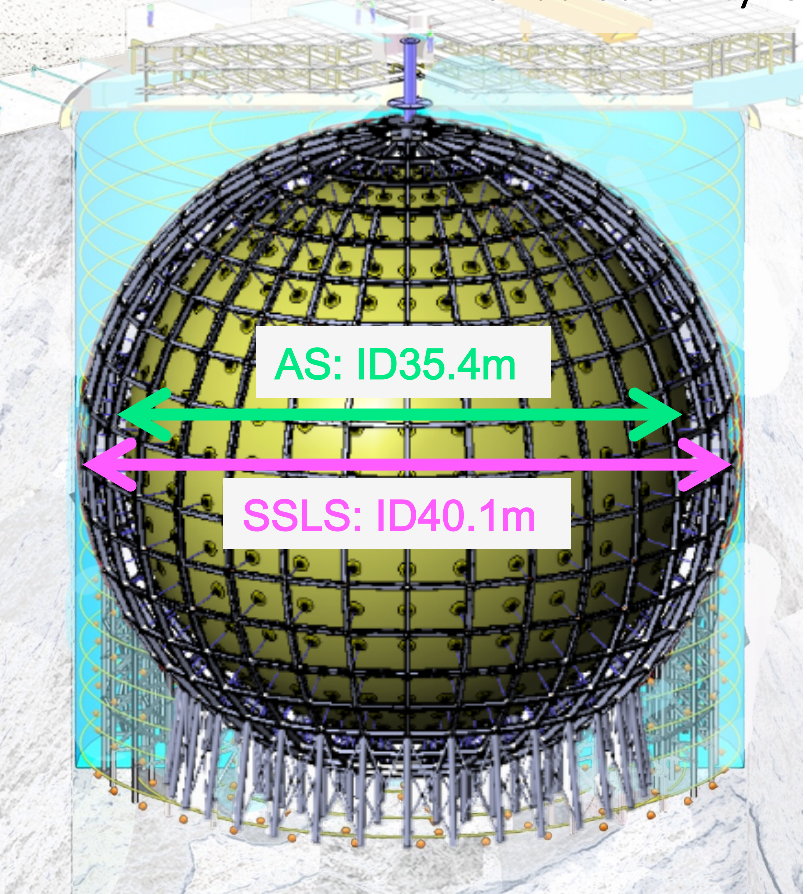
Calibration system

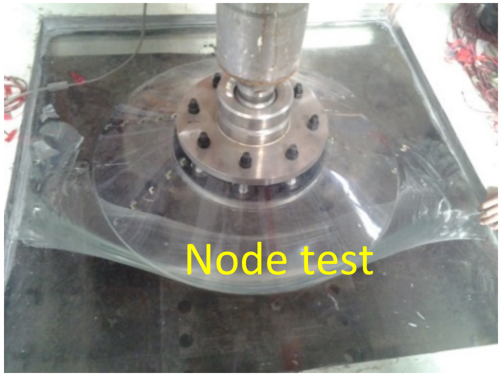
Central detector (CD)

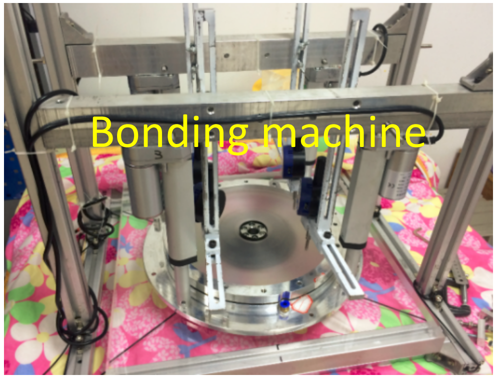
- 20 kton *Liquid Scintillator (LS)*
- Optical separation: *Acrylic sphere (AS)*
- Stainless Steel Latticed Shell (SSLS)
- *PMTs*: ~75% coverage with 18k 20'' PMTs + 25k 3'' PMTs

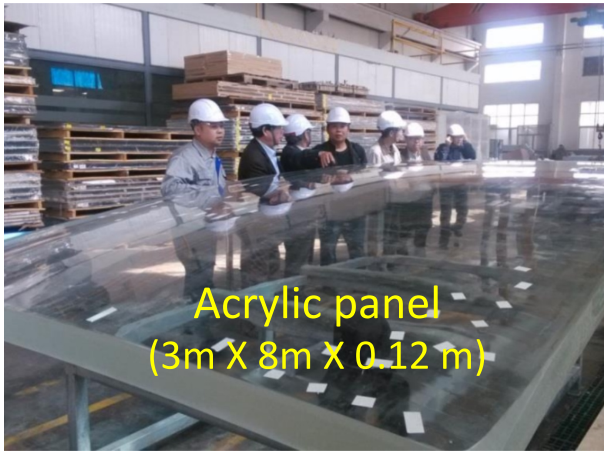
Central detector (CD)

- **Acrylic Sphere + Stainless Steel Latticed Shell**
  - ✓ ~260 acrylic panels of 12 cm thickness
  - ✓ Total weight: ~600 t of acrylic and ~600 t of steel
  - ✓ The problems of shrinkage and shape variation were resolved
  - ✓ The radioactivity level of panels were checked and under control



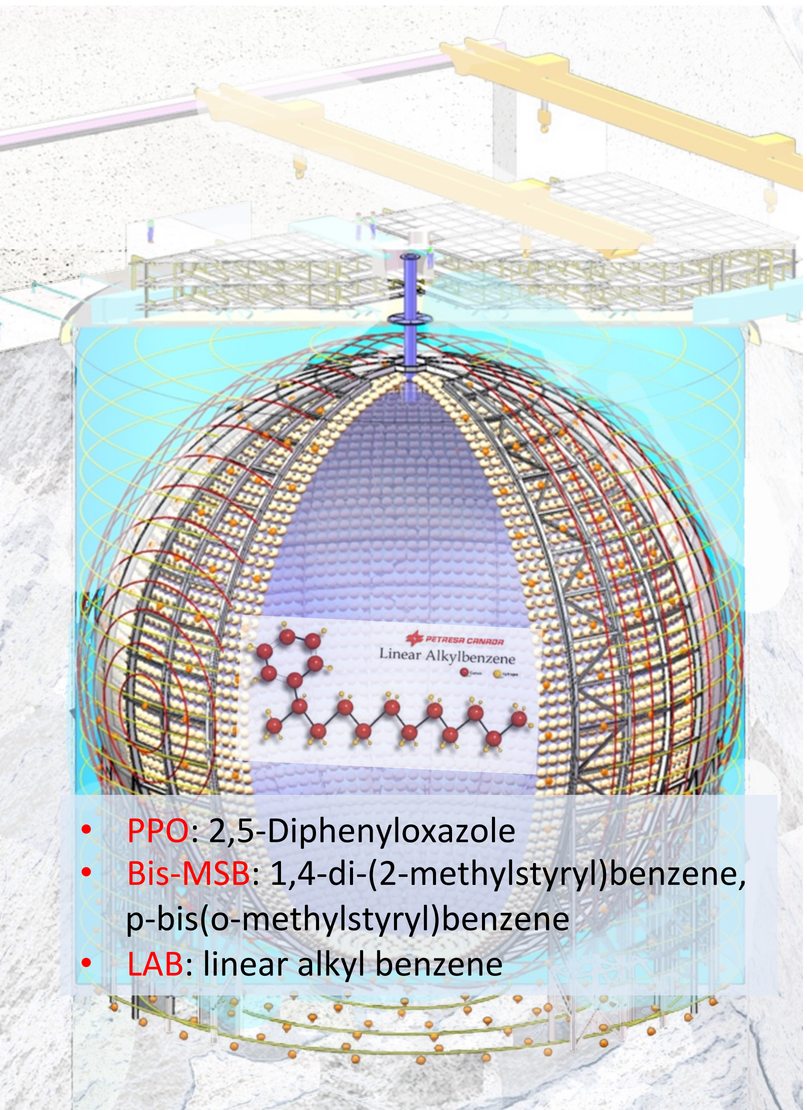






Central detector (CD)

➢ **LS in acrylic (35.4 m diam.)**



- PPO: 2,5-Diphenyloxazole
- Bis-MSB: 1,4-di-(2-methylstyryl)benzene, p-bis(o-methylstyryl)benzene
- LAB: linear alkyl benzene

■ Requirements for JUNO LS

- Lower background for physics: $^{238}U<10^{-15}$g/g, $^{232}Th<10^{-15}$g/g, $^{40}K<10^{-17}$g/g
- High light yield: ~1200 p.e./MeV
  concentration of flour need to be optimized
- Long attenuation length: >20m@430nm

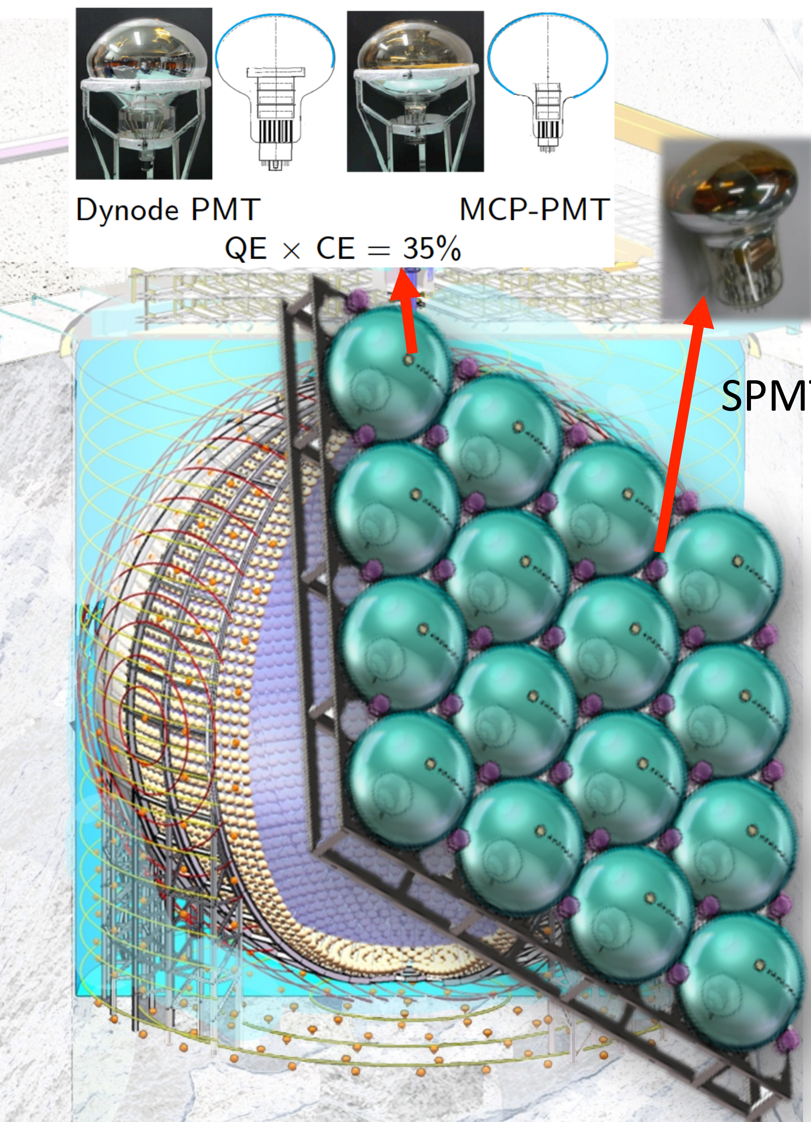
■ Preliminary LS recipe (based on DYB experiment)

20 kt **LS** : 3 g/l **PPO** .... *Scintillation flour*
+15 mg/l **bis-MSB** ..... *Wavelength-shifter*
+ **LAB** .... *Solvent*

Overall LAB5 view at Daya Bay

Central detector (CD)

➢ Two independent Double Calorimetry System: LPMT+SPMT



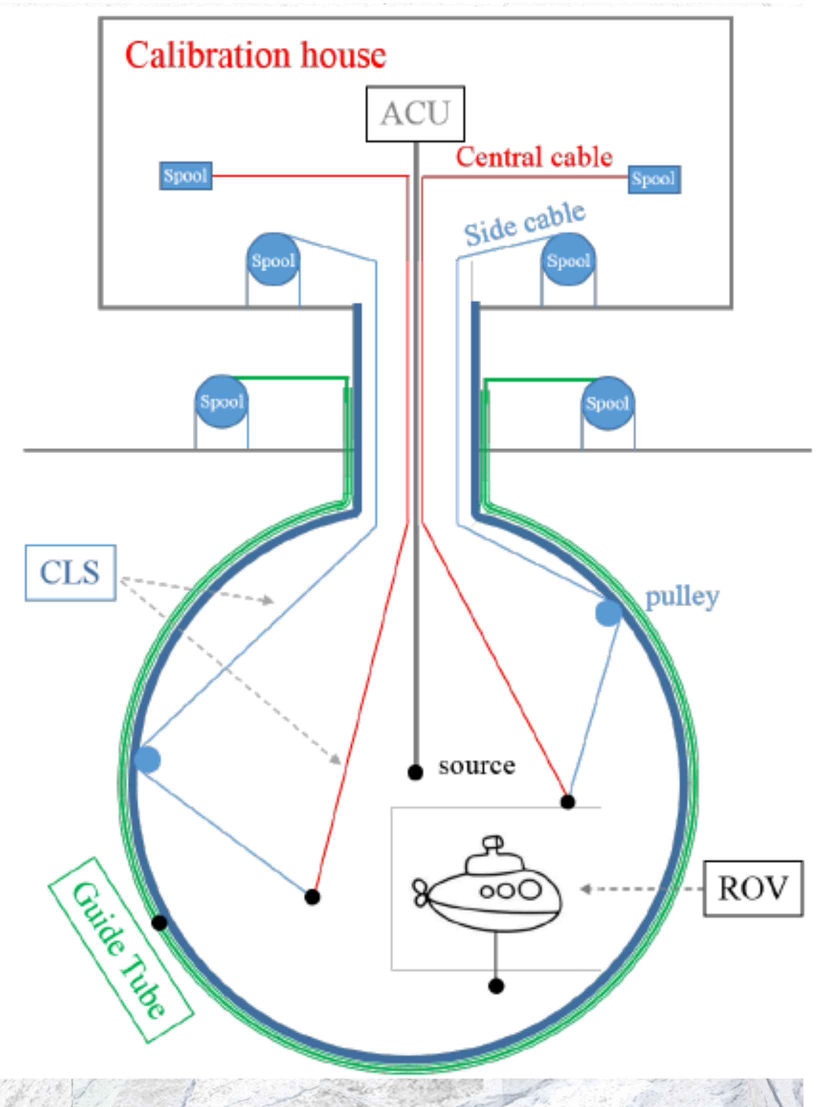
Requirements
- High optical coverage
- High photon detection efficiency
- Acceptable noise/radio purity levels
- Acceptable time resolution
- Broad dynamic range

SPMTs are in the gap between LPMTs

	20" PMT (LPMT)	3" PMT (SPMT)
Number	18k	25k
Coverage	75%	3%
Energy resolution (Stochastic term)	3%@1 MeV	14%@1 MeV
p.e. resolution	Worse (slower)	Better (faster)
Dark noise	high	low

Central detector (CD)

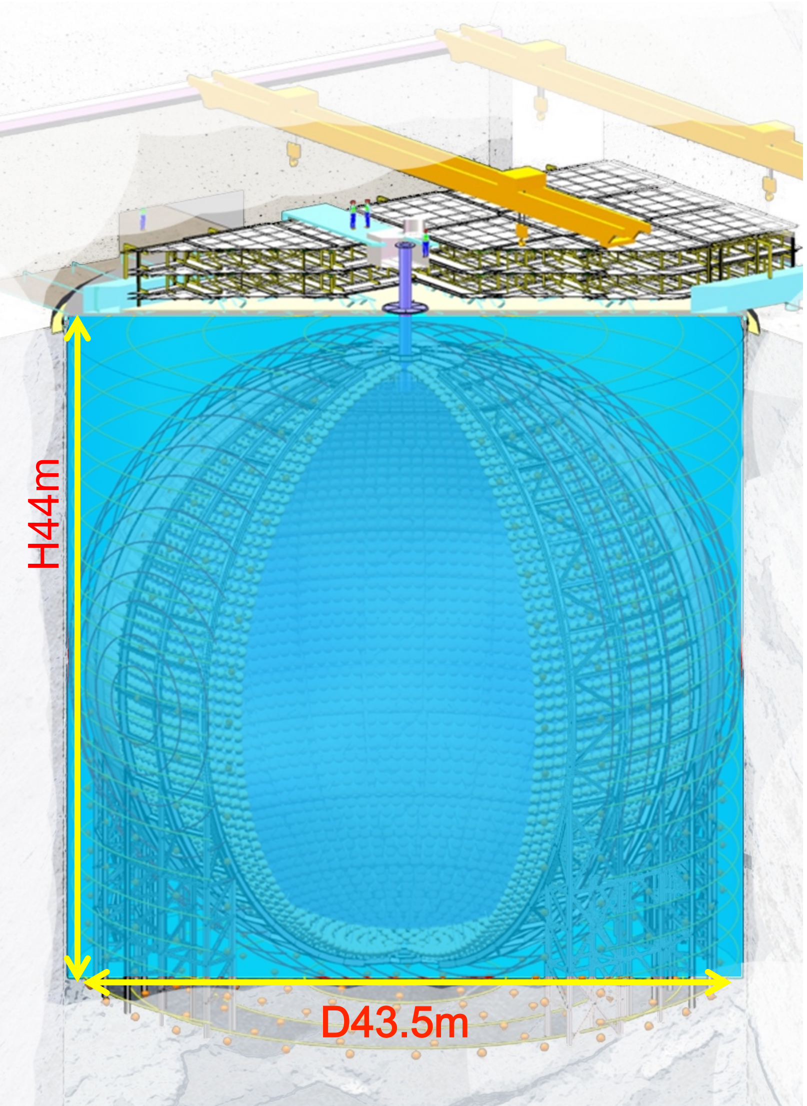
➢ Calibration system



- **The challenge:**
  - Overall energy resolution: ≤ 3% / Sqrt(E)
  - Energy scale uncertainty: <1%

- **Four complementary calibration systems**
  - **1D**: Automatic Calibration Unit (ACU)
    → central axis scan
  - **2D**: Cable Loop System (CLS)
    → scan vertical planes
    Guide Tube Calibration System (GTCS)
    → CD outer surface scan
  - **3D**: Remotely Operated under-LS Vehicle (ROV)
    → whole detector scan

Veto System



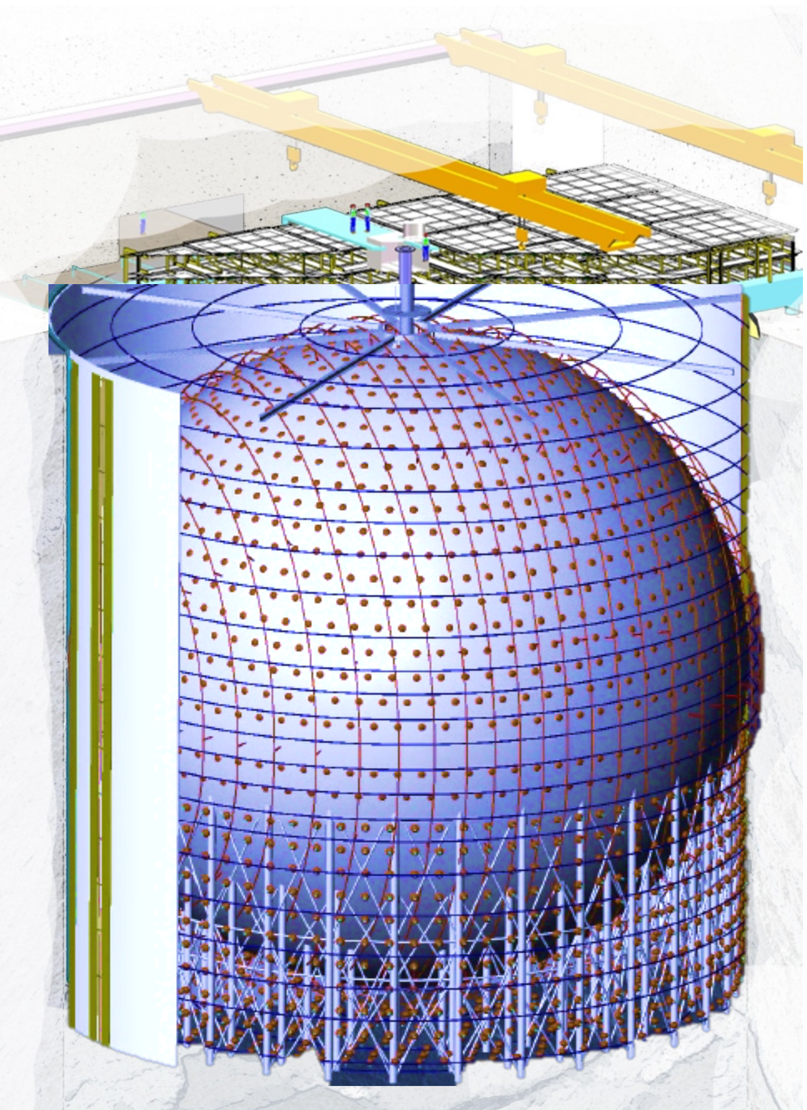
➢ Goals of veto

- Fast neutron background rejection
- Help muon tracking and cosmogenic isotopes study
- Gamma background passive shielding
- Earth magnetic field shielding

➢ Top tracker

- Using the **OPERA's** Target Tracker
  (plastic scintillator, $49m^2$/module)
  - Three layers to ensure good muon tracking
  - Partial coverage due to available modules
- Cover half of the top area

Veto System



➢Water cherenkov detector

- ~2000 20" PMT
- 35 kton ultrapure water with a circulation system
- Detector efficiency is expected to be > 95%
- Fast neutron background ~0.1/day.

Mechanical structure

– A "bird cage" structure was designed for support veto PMTs, tyvek films, cables and water pipes.

Earth magnetic field (EMF) shielding system

– Use double coils system for EMF shielding。

– The theoretically calculation and prototype data are consist with each other. It's a good validation for compensation coils design of JUNO.

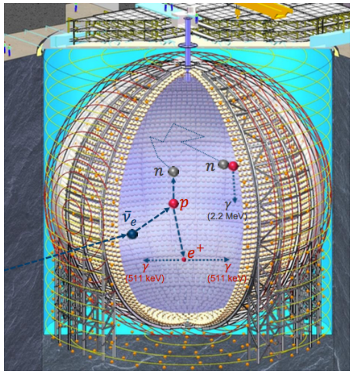
Signal and background in JUNO

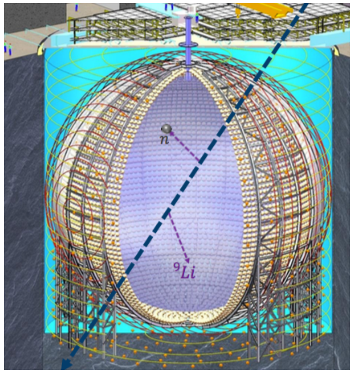
- Reactor $\bar{\nu}_e$ are detected via Inverse Beta Decay (IBD)

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

- Delayed coincidence between prompt positron annihilation and delayed neutron capture
- Rate: ~83/day
- Muons create main background:
  - 700 m overburden (≙ 1900 m.w.e.)
  - 3.5 Hz in central detector
  - Decay of ^9Li and ^8He mimic delayed IBD coincidence
  - ~84/day
- Top Tracker (former OPERA)
- Water bufferwith 2000 20-inch PMTs
- Reconstruction in Central Detector
- Other backgrounds include geo-ν (1.5/day), fast neutrons (0.1/day) and (α, n)-decays (0.05/day)
- After all cuts:

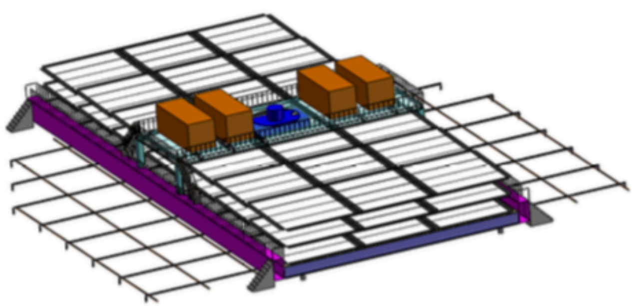
  60 IBD / 3.8 background
  events per day

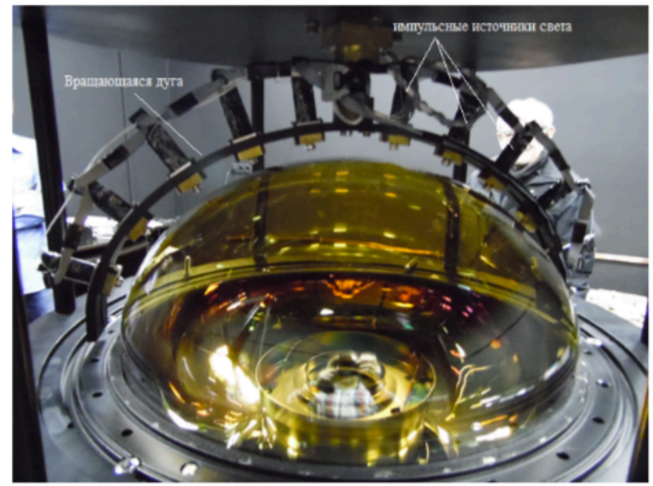




JUNO at JINR and MSU

- Powering JUNO: PMT high voltage R&D
- Top Tracker: precise μ detector
- Earth Magnetic Field: PMT protection R&D
- PMT testing: brand new precise scanners + mass testing
- Liquid scintillator: purification methods and measurements
- Experiment sensitivity estimation
- MC and data analysis:
  - Hierarchy and oscillations
  - Solar and geo- neutrinos
  - Rare processes



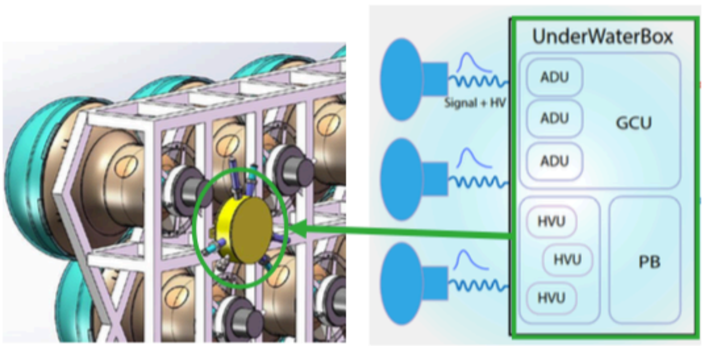


JUNO at JINR and MSU

- HV for 20 000 LPMT and 25 000 sPMT
  - Design, Production, Tests
- Top Tracker.
  - maintenance, installation, DAQ, design, production and delivery of mechanical support, and simulation and reconstruction software.
- PMT tests
  - Precision scanners, LED for containers, scanning techniques and acceptance criteria
- PMT protection against the EMF.
- Software development
  - Detector simulation
  - Reconstruction
  - Background
  - Statistical analysis (GNA)
  - Methodology for solar neutrinos

JUNO at JINR and MSU

Technical developments – Readout Electronics



JUNO HV Unit design and production

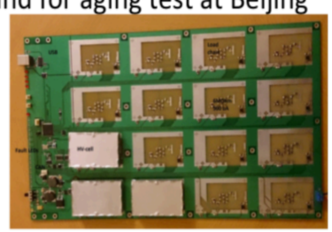
is the JINR responsibility.

But this work is performed in collaboration with with MSU (and MARATHON)

A.S.Chepurnov et al.

HV Unit Test Production Status

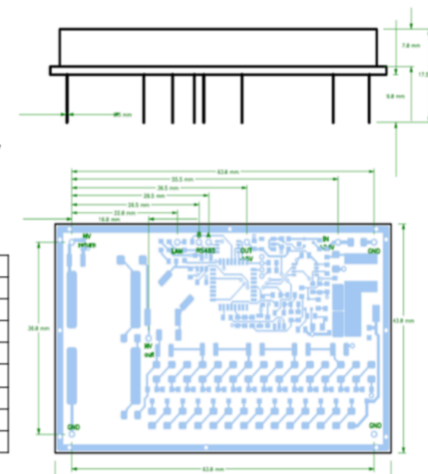
- Production of 200 units:
  - (20+180) provided to different groups and for aging test at Beijing
  - Additional test boards were designed and produced by MSU (MARATHON) as their own contribution to JUNO.
  - Full assembly with 12 test boards, connecting cables, 180 units, CAN-USB converter and software was transported to Beijing and installed at temperature accelerated test laboratory.



HVU Dimensions

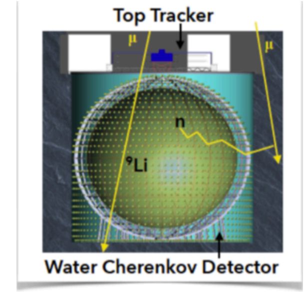
The design and prototyping of HVU resulted in the dimensions and input/output pin layout presented at this slide.

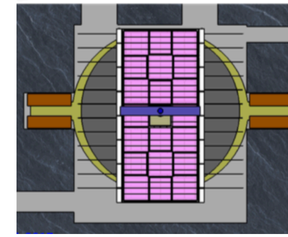
Pin Name	Pin Description
IN +24V	Power supply input pin (+24V/100 mA max)
OUT +5V	Auxilary power supply output pin (+5V/5 mA max)
GND	Power ground pins
HV out	HV output pin (Up to +3000 Vdc/300 mkA max)
HV return	HV output ground pin (Analog ground)
LAM	Look At Me signal
A RS-485	RS-485 transceiver Noninverting input/output
B RS-485	RS-485 transceiver inverting input/output



JUNO at JINR: Top Tracker

Main issue: $^{9}Li/^{8}He$ background.



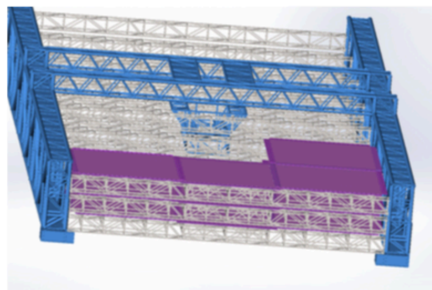


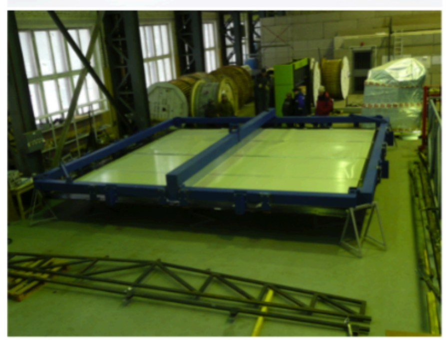
JINR is responsible for

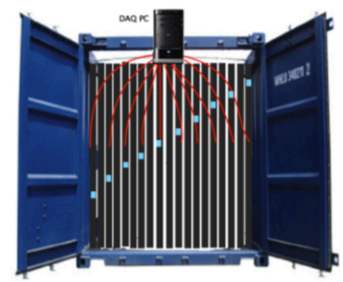
- the design, fabrication and construction of the mechanical support of the TT detector;
- monitoring of performance of the TT modules during the period of their storage;

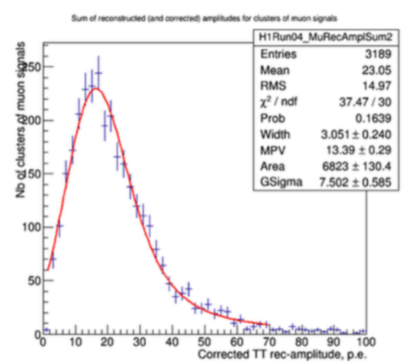
JINR takes part

- in development of the data acquisition system software;
- in the offline software development for the analysis of the TT data.









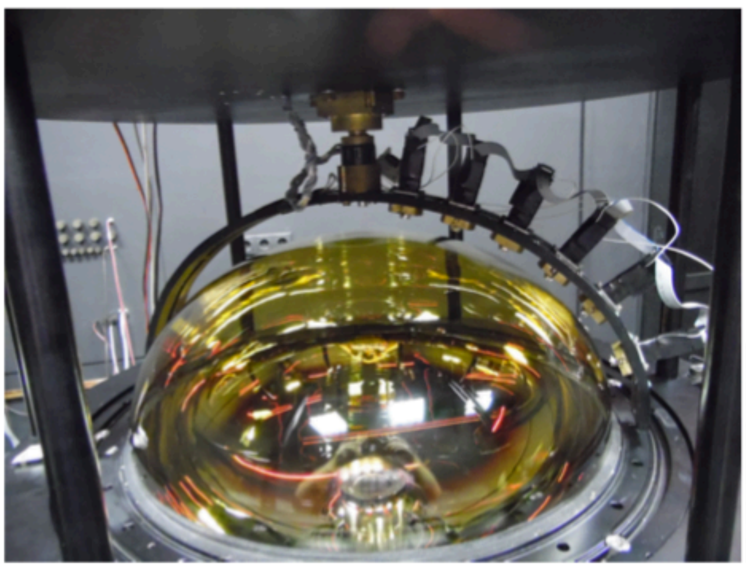
JUNO at JINR: PMT tests

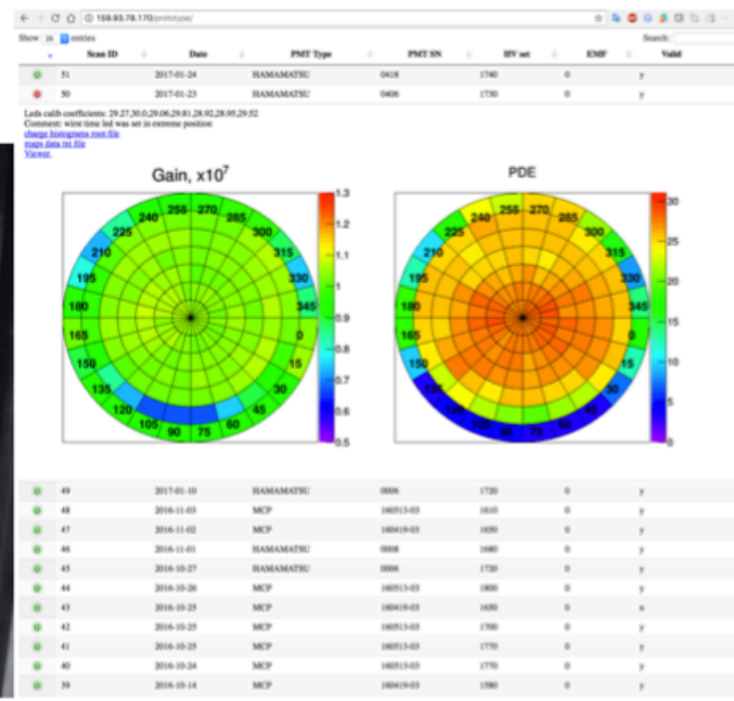
Test of 20’000 (5’000 Hamamatsu and 15’000 NNVT) 20” PMTs are performed at a special facility in China,

for which:

JINR

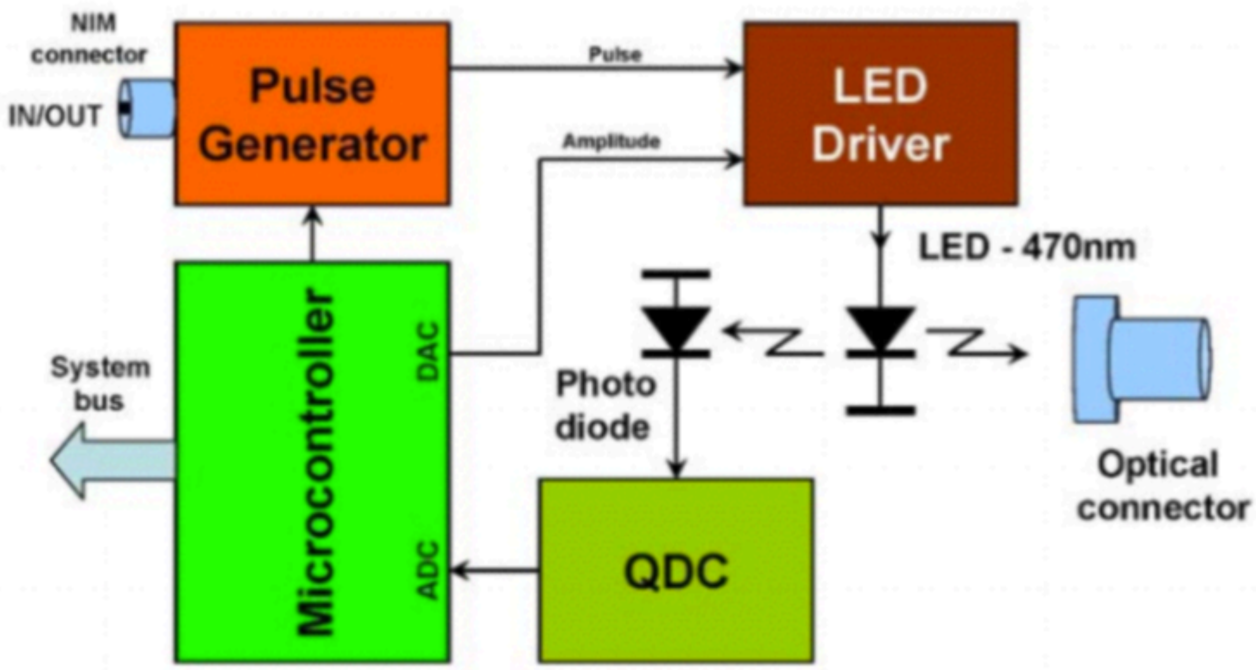
- constructed a laboratory with dark room and EMF compensation
- developed a brand-new PMT scanner
- will deliver onsite 4 scanners with software (three already built)





JUNO at JINR: PMT tests

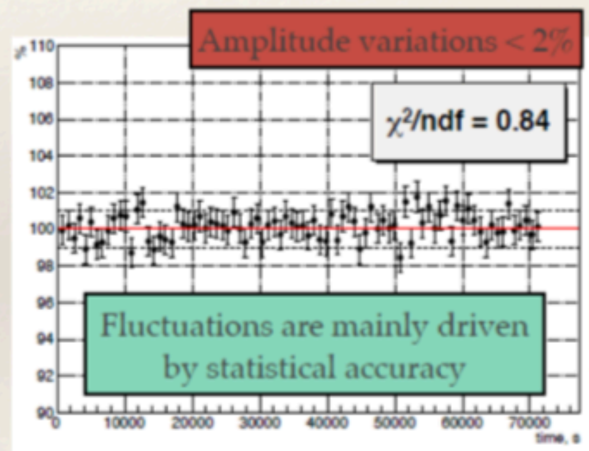
LED source stability



Block diagram of the LED source operation principle

http://hvsys.ru/images/data/news/10_small_1368803142.pdf

Low light intensity ≈ 1.75 ph.e



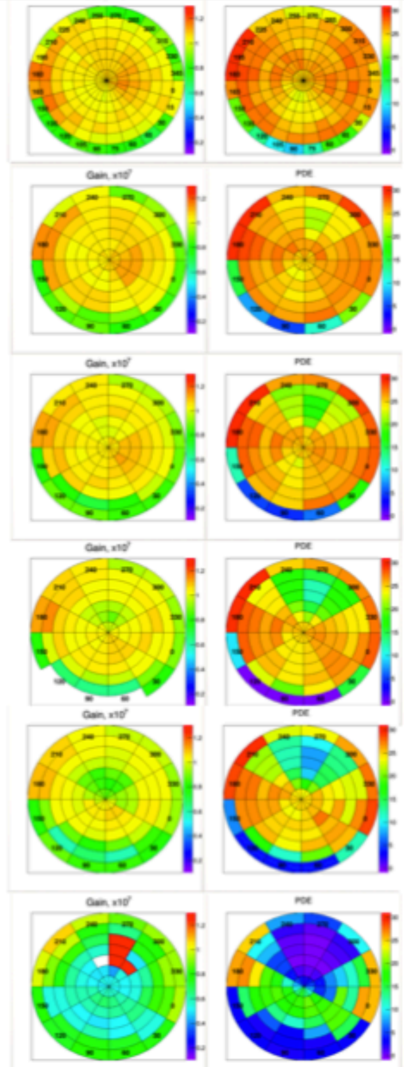
LED source stability measured by
20" Hamamatsu 12860 HQE PMT in a single point

JUNO at JINR: PMT sensitivity to EMF

EMF Sensitivity

Measured at Scanning Station changing EMF compensating coils current

Hamamatsu R12860-50 A1578 U=1980V G=107



% of EMF	PDE	Non-Uniformity
0%	27.8%	5.3%
10%	27.3%	6.0%
20%	26.4%	9.7%
30%	24.8%	17.4%
40%	22.7%	27.7%
100%	10.7%	78.3%

JUNO at JINR: Software and Physics

Already at Daya Bay Experiment the JINR:

- Developed a Dubna IBD selection
- Estimated backgrounds to IBD candidates.
- Performed an oscillation analysis of Daya Bay data based on 1230 days of collected statistics.
  - official analysis of Daya Bay Collaboration
  - Paper Editors
- Wave packet impact on neutrino oscillations using the Daya Bay data.
  - Analysis
  - Paper writing
- The reactor antineutrino flux measurement
  - cross-check the official analysis
  - Review the Daya Bay paper.
- Conducted a research on measurement of reactor antineutrino energy spectra due to different isotopes.
  - Initial idea
  - Review the Daya Bay paper.
- Search for sterile neutrino.
  - Review analyses.
  - Paper writing.

JUNO at JINR: Software and Physics

JINR team develops

- Global Neutrino Analysis Framework (GNA): statistical data analyses of neutrino experiments.

The following studies are performed:

- Impact of $^{9}Li/^{8}He$ background on mass hierarchy determination (GNA).
- Impact of ^{14}C contamination in liquid scintillator on mass hierarchy determination (GNA).
- Simulation of optical properties of photomultiplier in various media

GNA is a good framework for extension of the JINR and MSU collaboration in software and physics, in particular, this applies to the group of A.I.Studenikin - also a member of JUNO project

JUNO: Civil Construction

JUNO: Overall Schedule

Task	JINR	Start	End
Underground lab construction		2015.1.1	2019.6.30
Water pool cleaning and CD construction preparation		2019.7.1	2019.7.5
CD and water pull equipment installation		2019.7.6	2020.7.5
PMT base, HV and electronics prototypes ready	•	2017.3.1	2017.3.1
PMT base, HV and electronics design finalized	•	2018.4.30	2018.4.30
PMT base, HV and electronics production and aging tests	•	2018.5.1	2019.10.30
sPMT bidding		2017.1.1	2017.4.30
PMT mass production		2017.3.1	2019.6.30
PMT testing	•	2017.3.1	2020.1.31
PMT potting and testing		2018.10.1	2020.4.30
CD and VETO PMT installation		2019.10.1	2020.7.31
CD and water pool cleaning		2020.8.1	2020.8.31
Water pool cover is placed		2020.9.1	2020.9.7
TTS supporting structure installation	•	2020.9.8	2020.9.30
TTS installation	•	2020.10.1	2021.4.30
AD and VETO water filling		2020.9.8	2020.10.30
LS filling/commissioning		2020.11.1	2021.4.30
Test run	•	2021.5.1	2021.5.4

Keys to Precise Measurement

To achieve:

- **Baseline optimization**: $\mathbf{53 \pm 0.5}$ $\boldsymbol{km}$
- **Excellent energy resolution:** $\mathbf{3}\%/\sqrt{\boldsymbol{E}[\boldsymbol{MeV}}$

We should have

- ✓ **Powerful source**: 10 nuclear reactors (26.6 GWth in 2020, later 35.7 GWth)
- ✓ **Ideal baseline:** ~53 km (distance between target and reactor core)
- ✓ **Shielding**: 700 m underground
- ✓ **Huge target mass**:
  Single 20 kt LS detector ~10^5 events in 6 years detected via IBD
- ✓ **Superb energy resolution**: 3%@1 MeV
  - High-yield scintillator
  - 75% photo coverage
- ✓ **Systematics suppression**:
  - Unique combination of two sets of PMTs: 18k 20-inch PMTs + 25k 3-inch PMTs

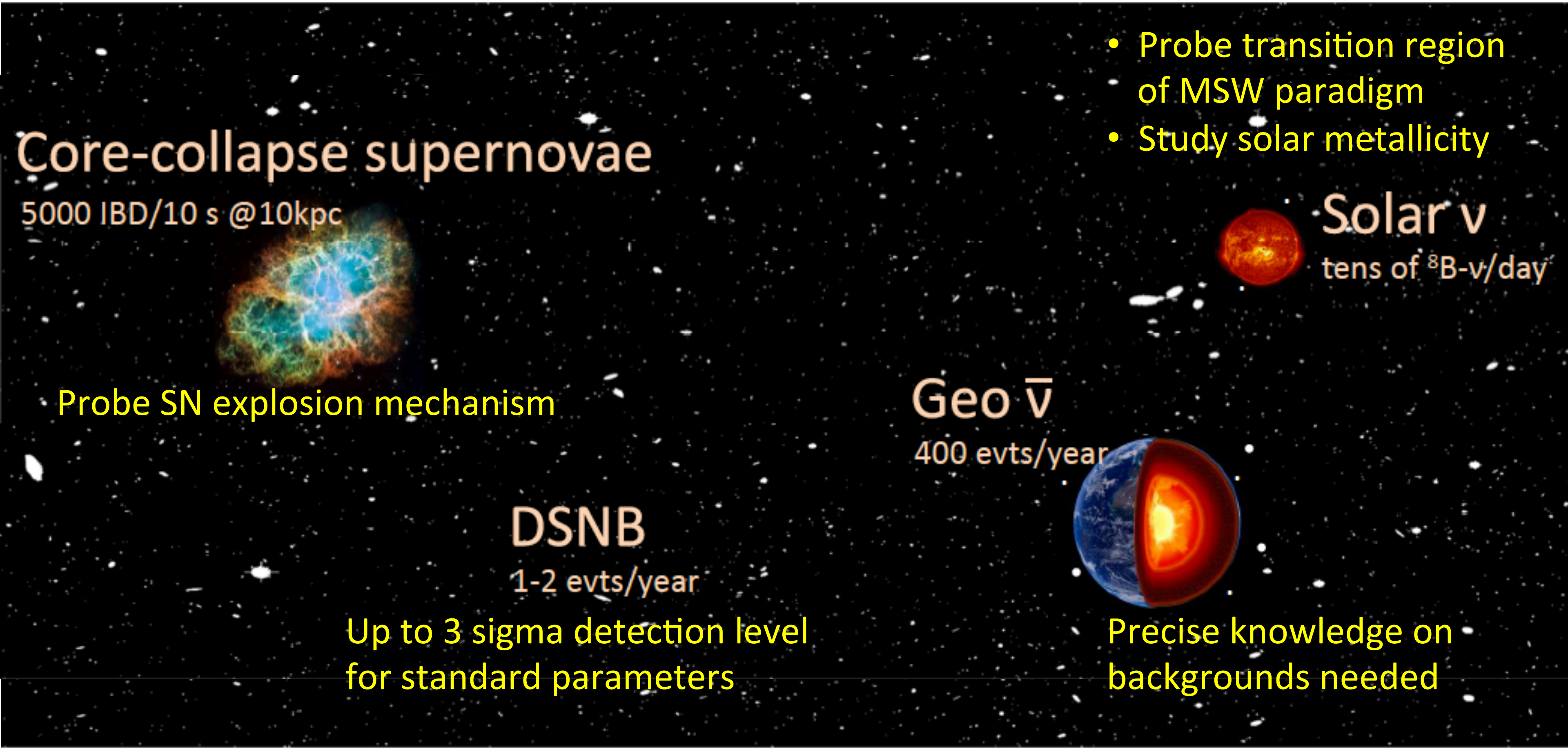
Extended Physics Program

- neutrino mass hierarchy determination with expected sensitivity corresponding to $(3-4)\sigma$,
- precision measurement of Δm^2_{21}, Δm^2_{32}, θ_{12} with accuracy better than 1%,
- possible observation of SuperNova neutrinos,
- detection of geo-neutrinos with a factor ten larger statistics than currently available,
- detection of diffuse SuperNova neutrinos,
- detection of solar neutrinos,
- detection of atmospheric neutrinos,
- study of sterile neutrino,
- indirect dark matter search,
- non-standard interaction study,
- probes of new physics.

Thank you

Backup slides

Other Physics

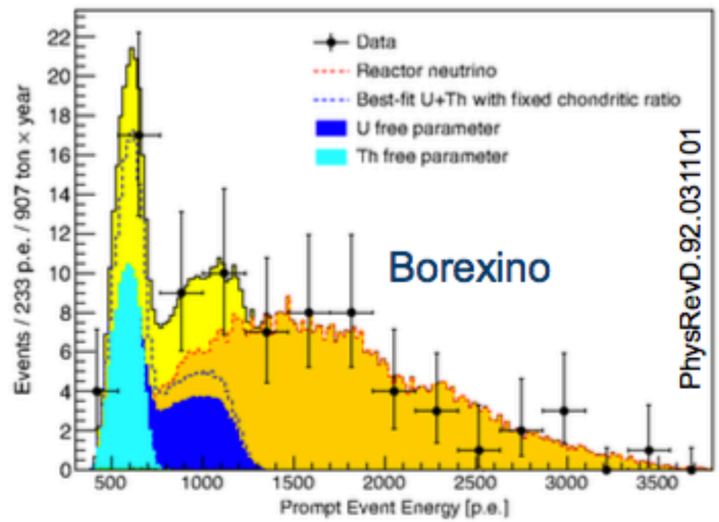


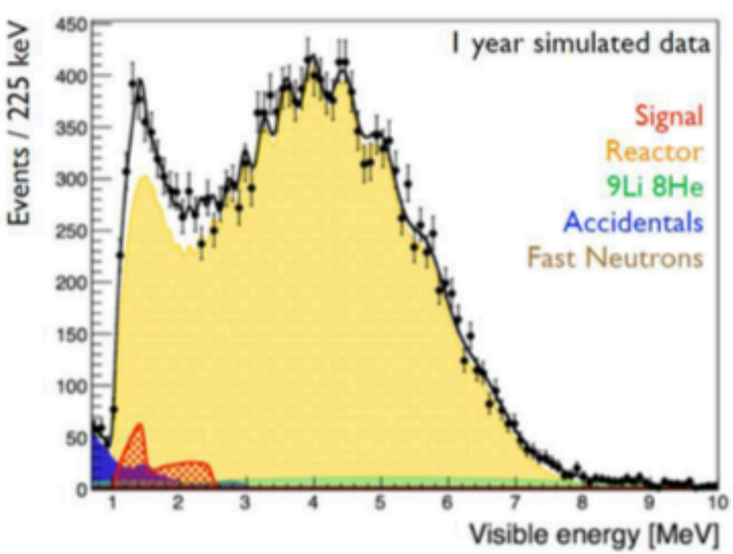
DSNB: Diffuse Supernova Neutrino Background

Extended Physics Program

Geoneutrinos

- $\bar{\nu}_e$ neutrinos from U- and Th-chains in the earth mantle and crust
- Used to study the composition of the Earth & its radiogenic heat production
- Currently only measured by Borexino and KamLAND



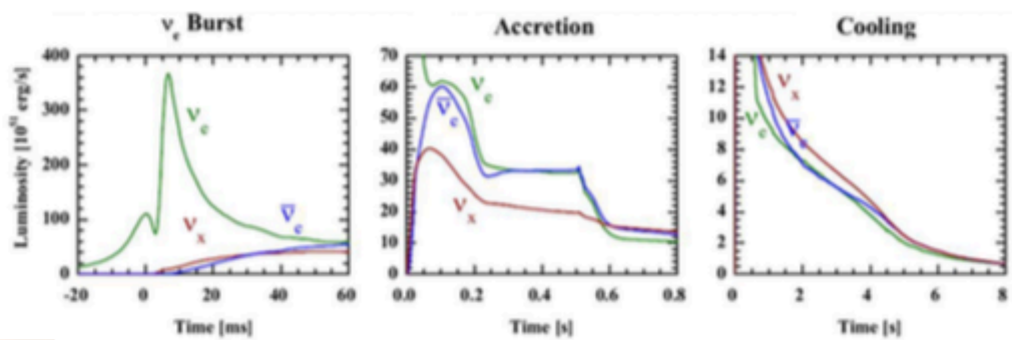


- Expected rate of 400 events/year could match present world sample in less than 1 year
- Challenge: large background from reactor $\bar{\nu}_e$

Extended Physics Program

Core-collapse supernova

- JUNO will be equipped to record a high statistics sample in case of a core collapse SN at d ~10 kpc:
  - 5000 IBD from $\bar{\nu}_e$ & 2000 elastic ν_x-p scatterings within 10 sec
- Separate detection 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
$\bar{\nu}_e + p \to e^+ + n$	CC	5.0×10^3
$\nu_x + p \to \nu_x + p$	NC	1.2×10^3
$\nu_x + e \to \nu_x + e$	ES	3.6×10^2
$\nu_x + {}^{12}\mathrm{C} \to \nu_x + {}^{12}\mathrm{C}^*$	NC	3.2×10^2
$\nu_e + {}^{12}\mathrm{C} \to e^- + {}^{12}\mathrm{N}$	CC	0.9×10^2
$\bar{\nu}_e + {}^{12}\mathrm{C} \to e^+ + {}^{12}\mathrm{B}$	CC	1.1×10^2

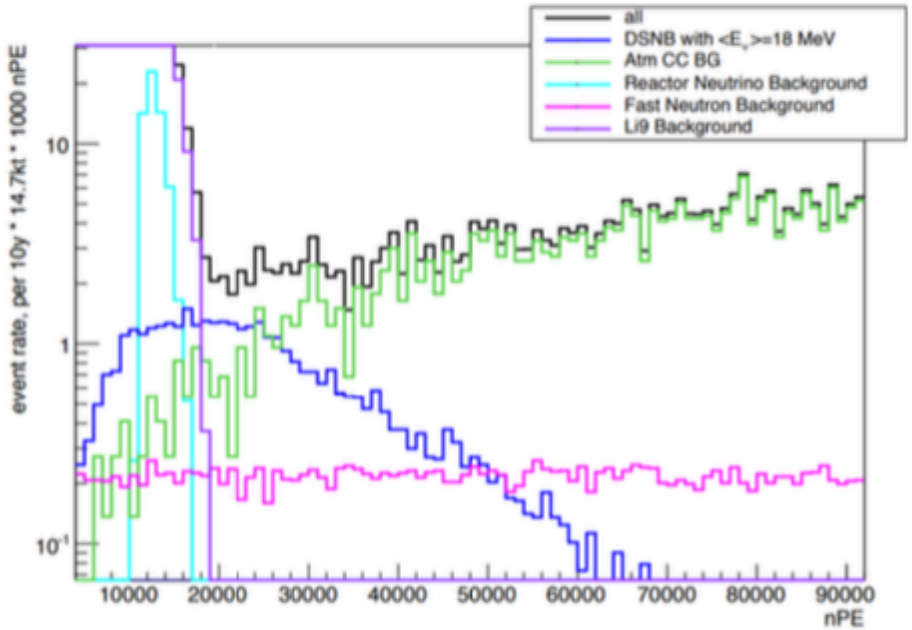
- T 32.9 „*Thermonuclear Supernova Neutrino Signals in JUNO*“ by J. Schulte
- T 93.7 „*Neutrinos from Supernovae collapsing into Black Holes in JUNO*” by M. Büsken

Extended Physics Program

Diffuse supernova background

DSNB is made up of the cumulative neutrino emission of core-collapse SN throughout the universe

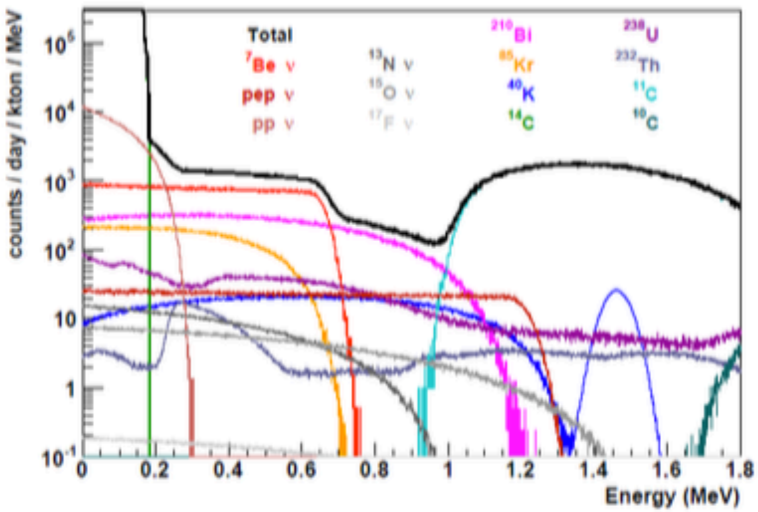
- Detected via IBD channel
- Expected rate 1-4 events per year
- Strong background from atmospheric ν
- Up to 3σ detection level for 10 year measurement
- Improvement of limits even for non-detection

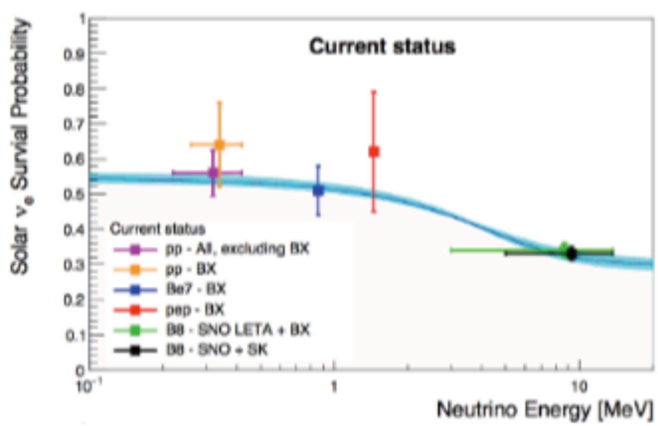


- T 32.10 „*Detection Potential for the Diffuse Supernova Neutrino Background in the Large Liquid Scintillator Detector JUNO*" by J. Sawatzki

Extended Physics Program

Solar neutrinos





arXiv 1602.01733

- The sun is a large source for MeV neutrinos
- LS detector well suited due to low threshold and high energy resolution
- JUNO can measure ^{7}Be and ^{8}B neutrinos
- Elastic scattering possible for all neutrino flavors
- Expected rate O(10) ^{8}B events and O(10^4) ^{7}Be events per day
- Study of the MSW effect and the solar metallicity