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JÜLICH FORSCHUNGSZENTRUM

JUNO

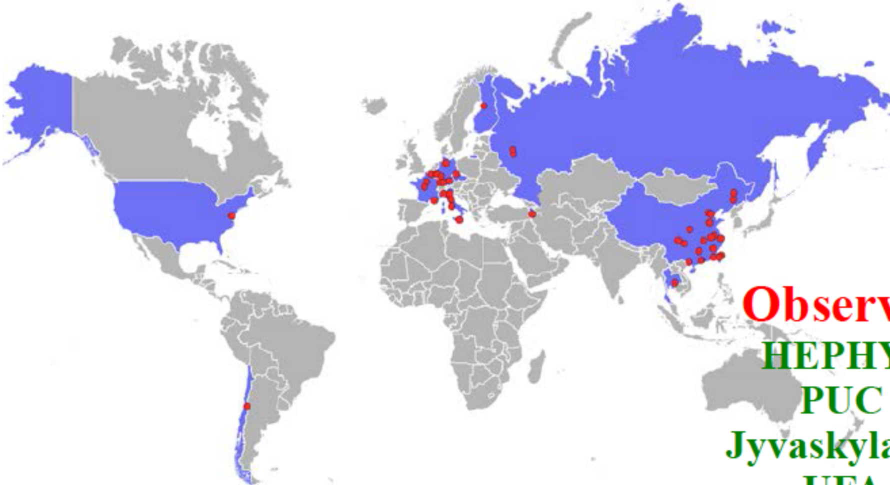
Livia Ludhova
for the JUNO collaboration

FroST – Topical Workshop for THEIA, 22 – 24 October, JGU Mainz, Germany

Jiangmen Underground Neutrino Observatory

the first multi-kton liquid scintillator detector ever

JUNO Collaboration



Asia (31)

BNU
CAGS
CQ U
CIAE
DGUT
ECUST
Guangxi U
HIT
IHEP
Jilin U
Jinan U.
Nanjing U
Nankai U
Natl. CT U
Natl. Taiwan U
Natl. United U
NCEPU
Pekin U
Shandong U
Shanghai JTU
Sichuan U
SUT
SYSU
Tsinghua
UCAS
USTC
U. of S. China
Wuhan U
Wuyi U
Xiamen U
Xi'an JTU

Observers (7):

HEPHY Vienna
PUC Brazil
Jyvaskyla U. Finlan
UFA Brazil
CENBG France
UTFSM Chile
IMP CAS China

Europe (27)

France (5)
APC Paris
CPPM Marseille
IPHC Strasbourg
LLR Paris
Subatech Nantes
Finland (1)
U Oulu
Czech (1)
Charles U

Italy (8)
INFN Catania
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INFN-Ferrara
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INFN-Padova
INFN-Perugia
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Russia (3)
JINR
INR Moscow
MSU

Germany (7)
FZ Julich
RWTH Aachen
TUM
U Hamburg
IKP FZI Jülich
U Mainz
U Tuebingen
Belgium (1)
ULB
Amenia (1)
YPI

America (4)

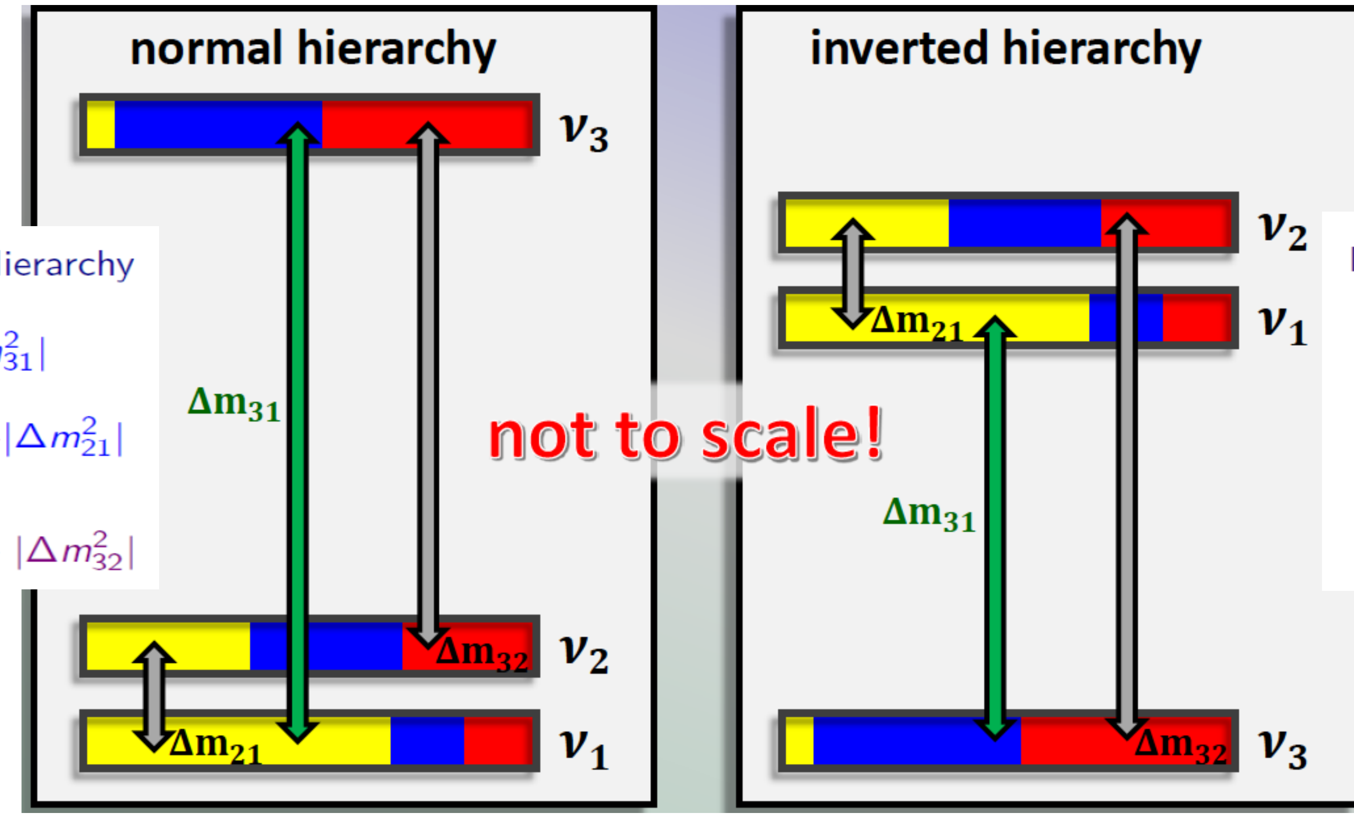
PCUC – BISEE Chile
Maryland U.- 2 groups

Neutrino mass hierarchy

Normal Hierarchy

$|\Delta m^2_{31}|$ = $|\Delta m^2_{32}| + |\Delta m^2_{21}|$

$|\Delta m^2_{31}| > |\Delta m^2_{32}|$



Inverted Hierarchy

$|\Delta m^2_{31}|$ = $|\Delta m^2_{32}| - |\Delta m^2_{21}|$

$|\Delta m^2_{31}| < |\Delta m^2_{32}|$

$$\Delta m_{31,\text{normal}} > \Delta m_{31,\text{inverted}}$$

+

$|\Delta m^2_{31}|$ *$= m^2_3 - m^2_1$ has opposite signs in the two hierarchies!*

-

Oscillation interference

Method from Petcov and Piai, Physics Letters B 553, 94-106 (2002)

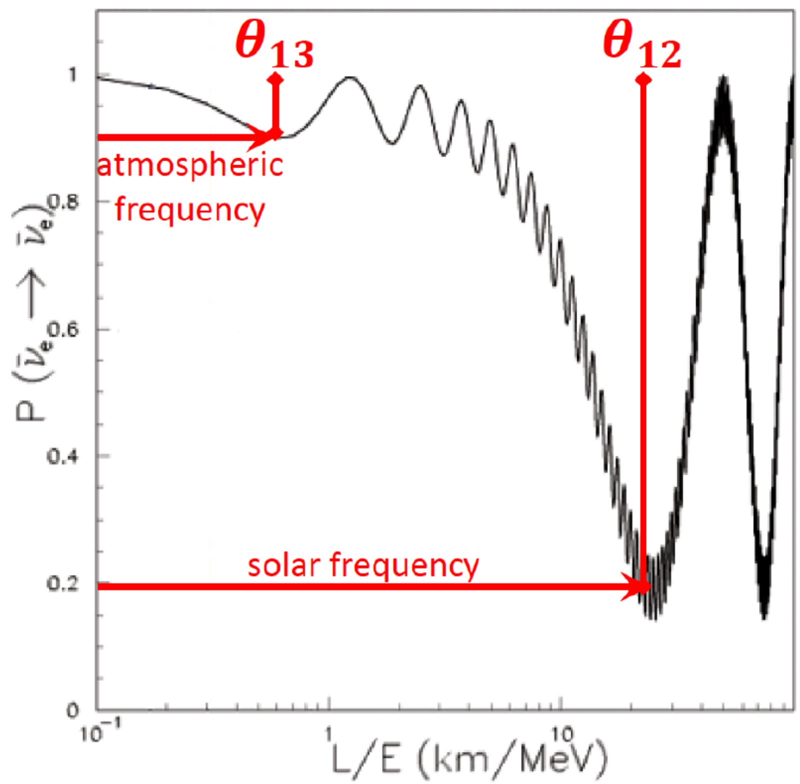
$$\Delta_{ij} = \frac{\Delta m^2_{ij} L}{4E}$$

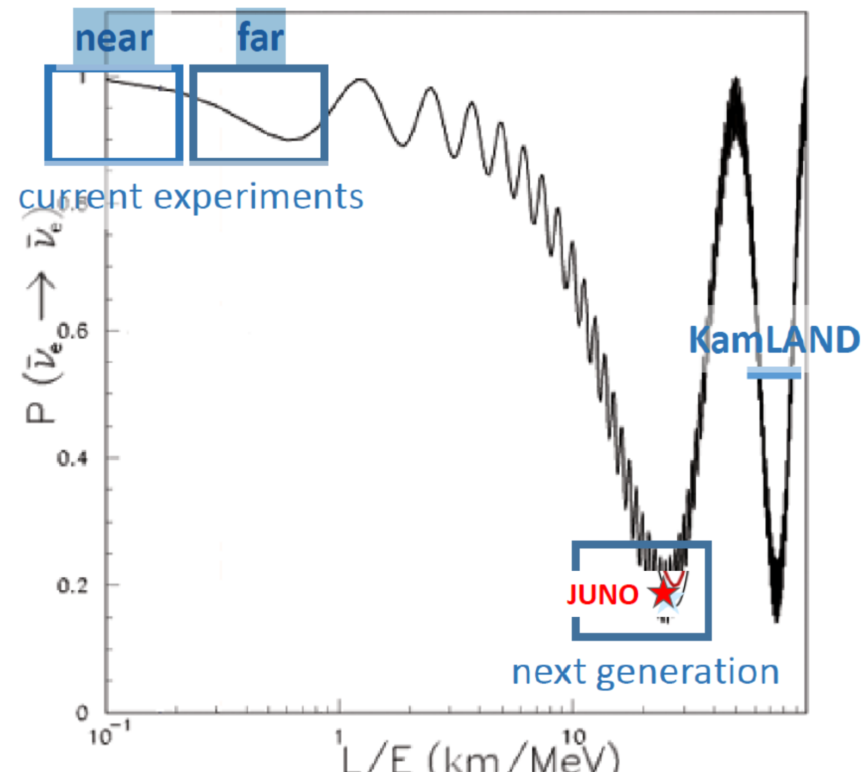
Full oscillation probability

Large value of θ_{13} crucial!

$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2 2\vartheta_{13} \left(\cos^2\vartheta_{12} \sin^2\Delta_{31} + \sin^2\vartheta_{12} \sin^2\Delta_{32} \right) \quad \text{FAST } \Delta m^2_{ATM}$$

$$- \sin^2 2\vartheta_{12} \cos^4\vartheta_{13} \sin^2\Delta_{21} \quad \text{SLOW } \Delta m^2_{SOL}$$





Interference term

Survival probability

$$P_{\bar\nu_e\to\bar\nu_e} = 1 - \sin^2 2\theta_{13}\left(\cos^2\theta_{12}\sin^2\Delta_{31} + \sin^2\theta_{12}\sin^2\Delta_{32}\right) - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21}$$

Fast oscillations with the two similar mass splittings

slow solar oscillations

$$\Delta_{ij} \equiv \Delta m^2_{ij} L/4E,$$

$$= 1 - \frac{1}{2}\sin^2 2\theta_{13}\left[1 - \sqrt{1 - \sin^2 2\theta_{12}\sin^2\Delta_{21}}\cos\left(2|\Delta_{ee}| \pm \phi\right)\right] - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21},$$

NH: +
IH: -

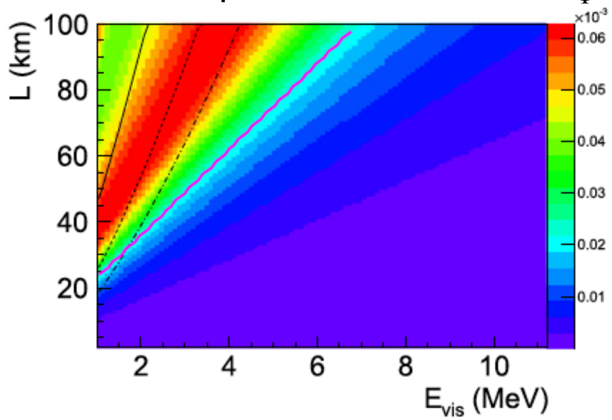
$$\Delta m^2_{ee} = \cos^2\theta_{12}\Delta m^2_{31} + \sin^2\theta_{12}\Delta m^2_{32}.$$

$$\sin\phi = \frac{c^2_{12}\sin\left(2s^2_{12}\Delta_{21}\right) - s^2_{12}\sin\left(2c^2_{12}\Delta_{21}\right)}{\sqrt{1 - \sin^2 2\theta_{12}\sin^2\Delta_{21}}},$$

$$\cos\phi = \frac{c^2_{12}\cos\left(2s^2_{12}\Delta_{21}\right) + s^2_{12}\cos\left(2c^2_{12}\Delta_{21}\right)}{\sqrt{1 - \sin^2 2\theta_{12}\sin^2\Delta_{21}}},$$

$$\Delta m^2_{\phi} = 4E\phi/L.$$

Can be looked at as an extra effective mass-squared difference $\Delta m^2_{\Phi} = f(E,L)$

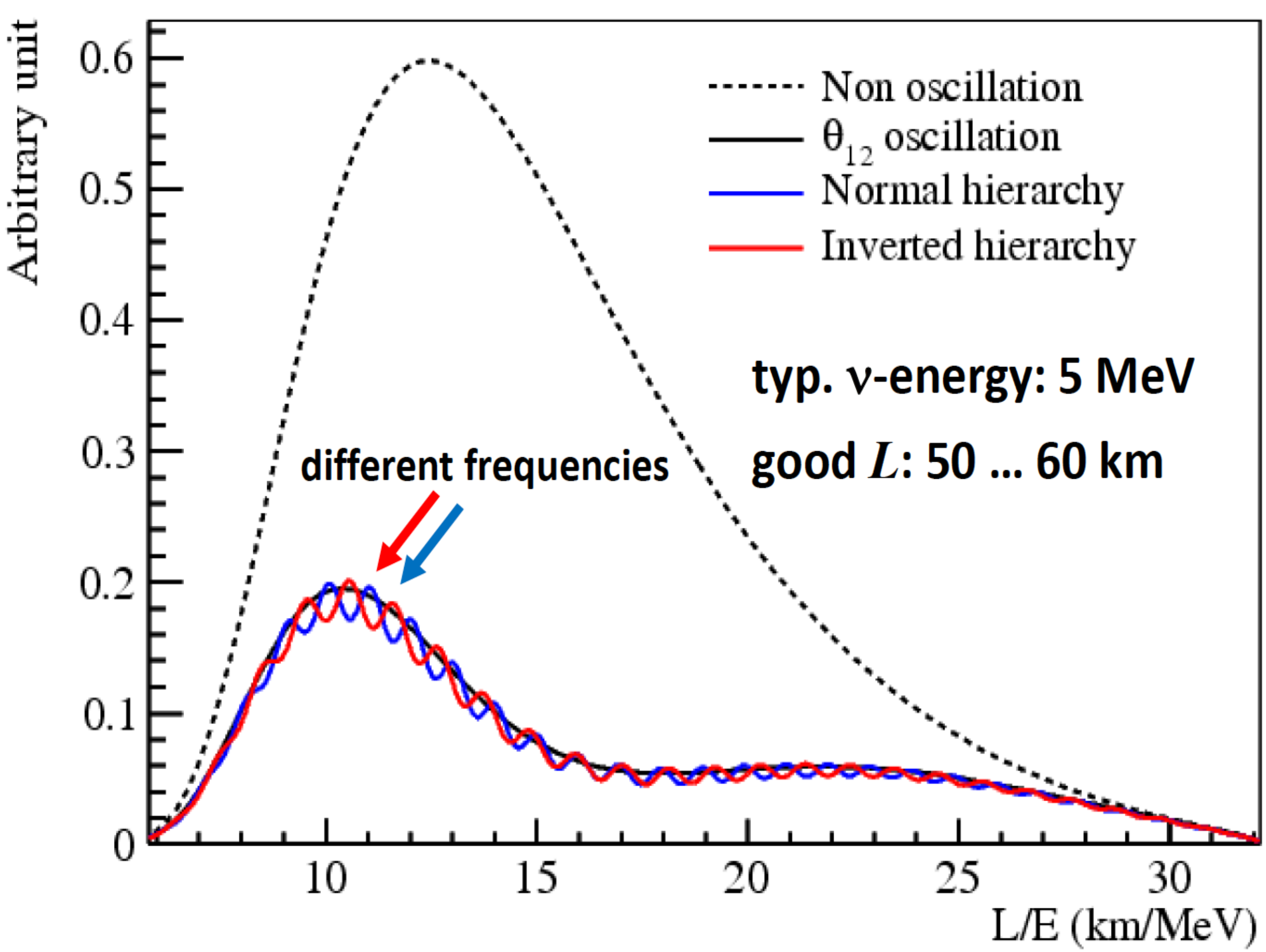


Effective mass-squared difference

NH: $2|\Delta m^2_{ee}| + \Delta m^2_{\Phi}$ and increases with energy

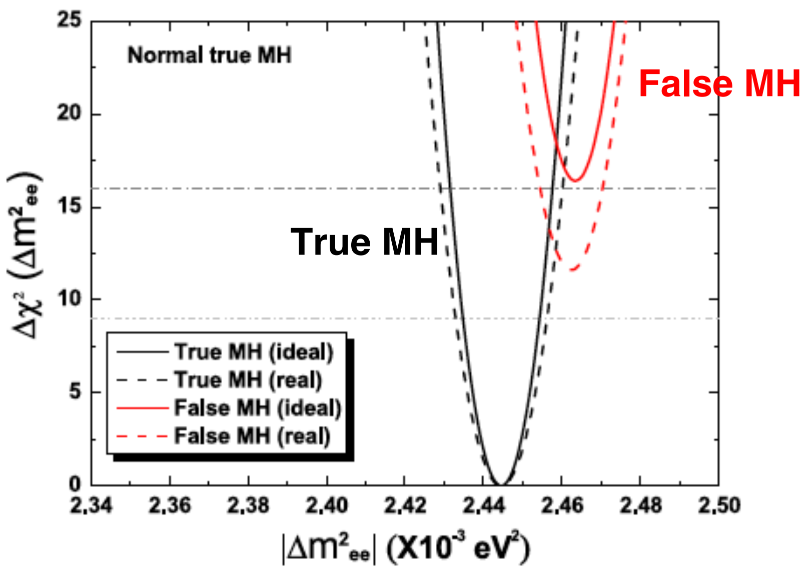
IH: $2|\Delta m^2_{ee}| - \Delta m^2_{\Phi}$ and decreases with energy

Oscillation pattern for JUNO



$\Delta\chi^2$ as the standard statistics in a nutshell

Spectra generated with NH and fit with both hypothesis



$$\chi^2_{\mathrm{REA}} = \sum_{i=1}^{N_{\mathrm{bin}}} \frac{\left[M_i - T_i\left(1 + \sum_k \alpha_{ik}\epsilon_k\right)\right]^2}{M_i} + \sum_k \frac{\epsilon_k^2}{\sigma_k^2},$$

First, we have the observed spectrum of measurements.

Second, fit the (pseudo-)data with both hypotheses (normal and inverted hierarchies).

Third, define $\Delta\chi^2$ as our standard statistics.

Finally, use $\Delta\chi^2$ as the discriminator for experimental design and optimization.

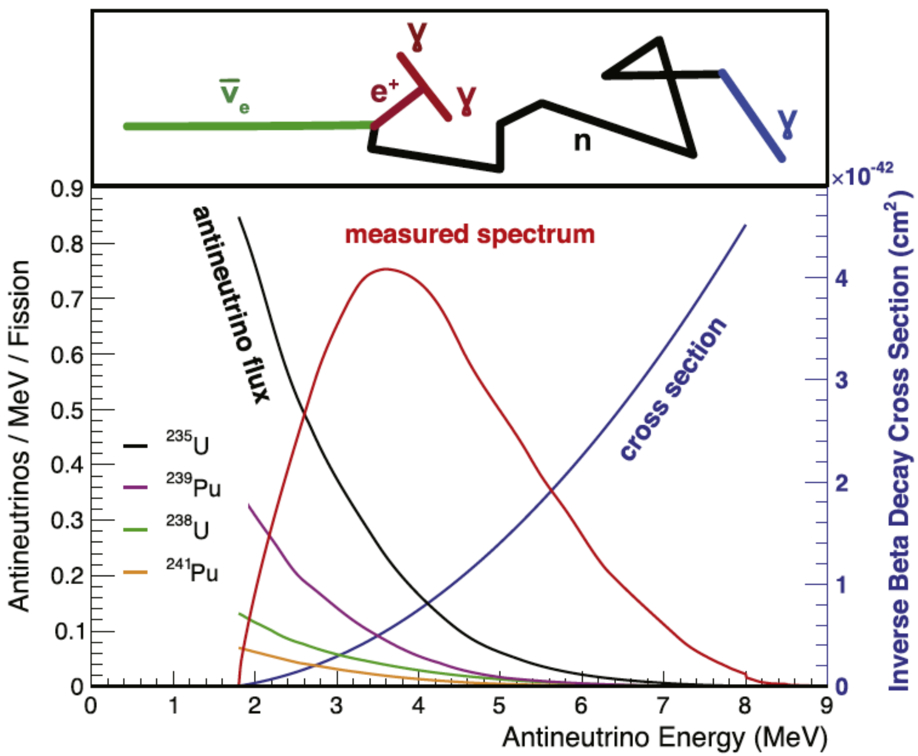
$$\Delta\chi^2_{\mathrm{MH}} = |\chi^2_{\mathrm{min}}\ (\mathrm{N}) - \chi^2_{\mathrm{min}}\ (\mathrm{I})|,$$

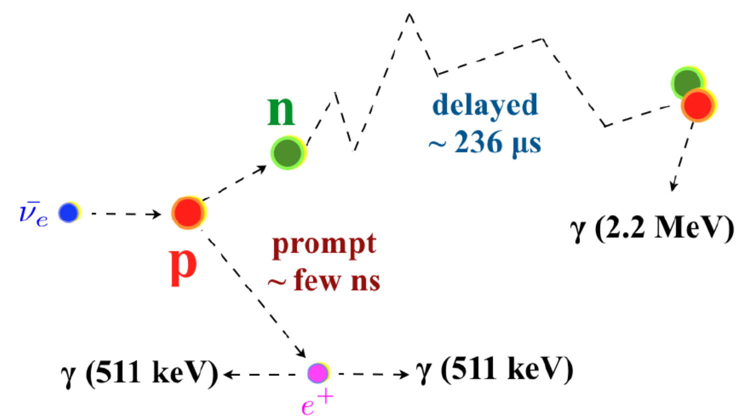
Systematic effects

	Ideal	Core distr.	Shape	B/S (stat.)	B/S (shape)	$\lvert\Delta m^2_{\mu\mu}\rvert$
Size	52.5 km	Real	1%	4.5%	0.3%	1%
$\Delta\chi^2_{\mathrm{MH}}$	+16	−4	−1	−0.5	−0.1	+8

Spectrum, an experimental challenge

- Detection of few MeV electron flavour antineutrinos from reactor: **liquid scintillator detector**
- **I**nverse **B**eta **D**ecay interaction (**IBD**)





Spectrum, an experimental challenge

Resolving signature wiggles in the L/E spectrum

- excellent **energy resolution 3%/sqrt(E)**
- better than **1% understanding of the energy scale**

Large statistics (O(100k) = **large mass (20 kton)**

Backgrounds: radio-purity and rock overburden of ~700 m

Stochastic terms (photon statistics)

- **High light yield**
- **Good transparency**
- **PMT geometrical coverage**
- **PMT collection efficiency**
- **PMT quantum efficiency**

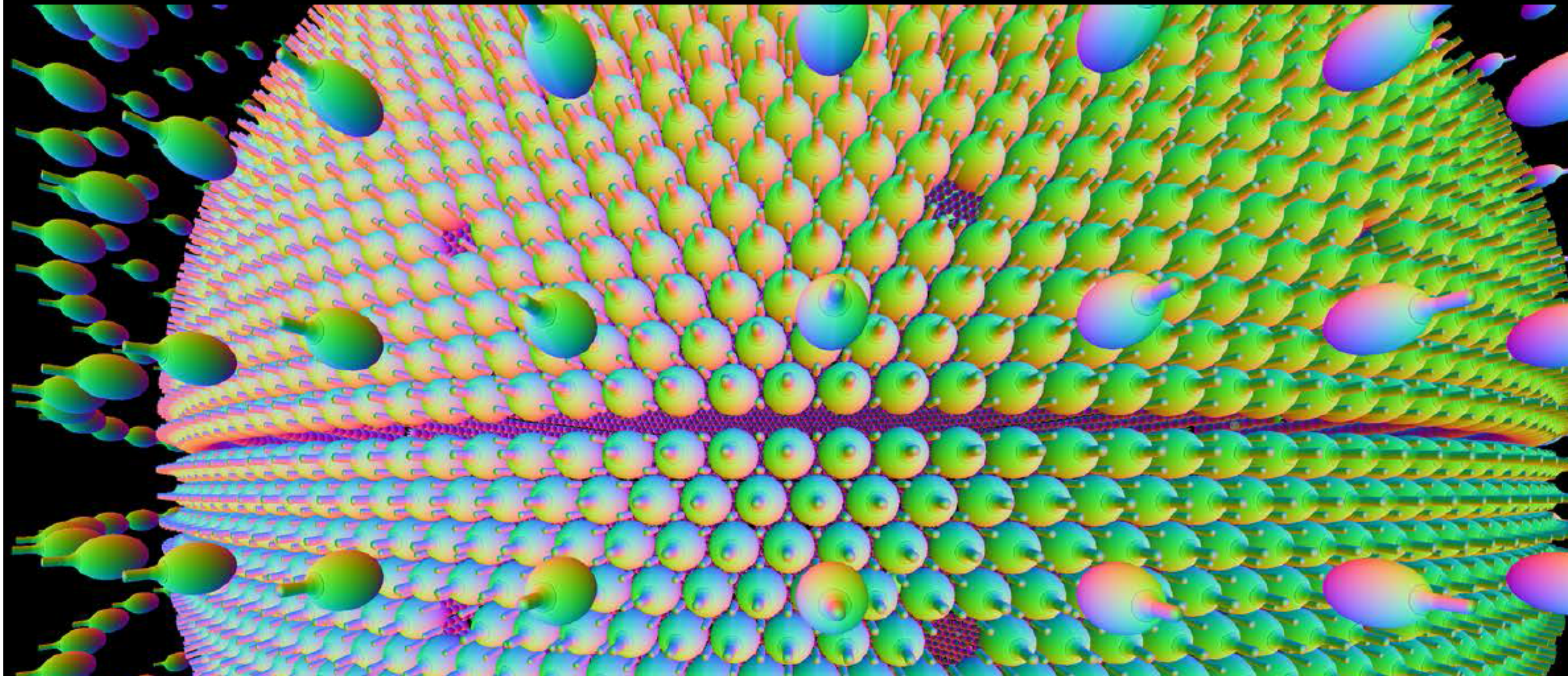
Systematic effects

- **Calibration**

✓ $\alpha/\beta/\gamma$ sources
✓ Light pulses
✓ UV-laser

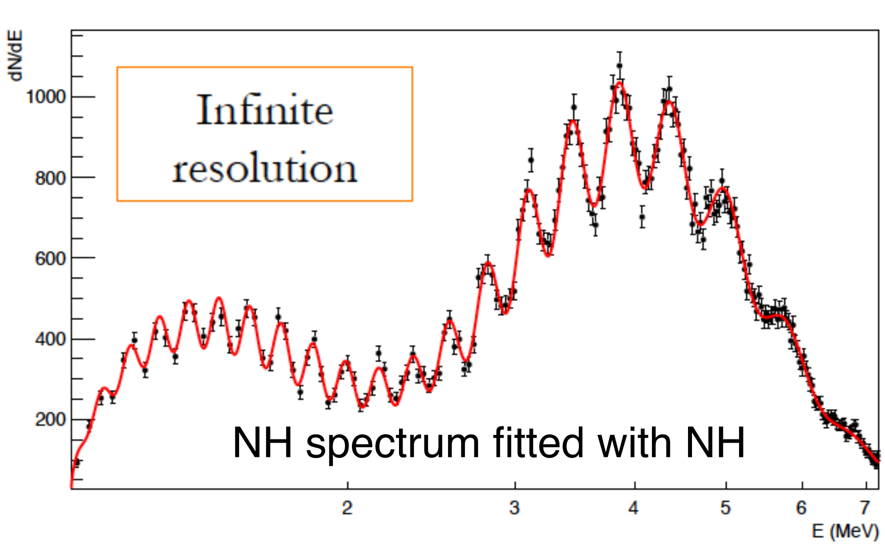
- **Double calorimetry concept** (large and small PMTs)

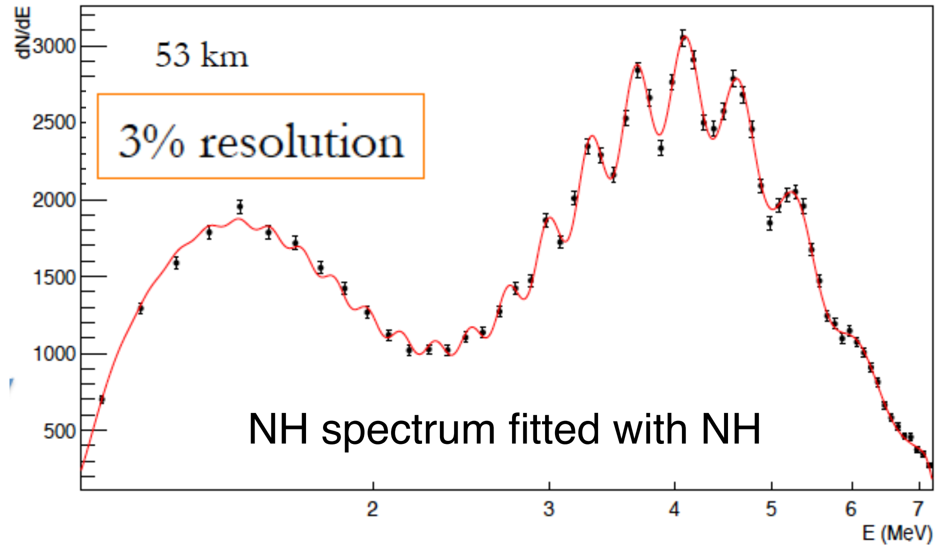
JUNO detector challenges

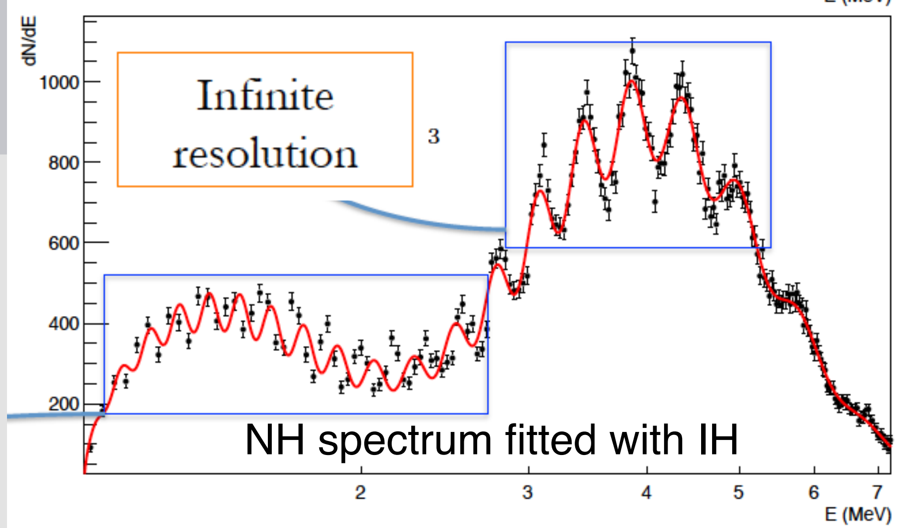


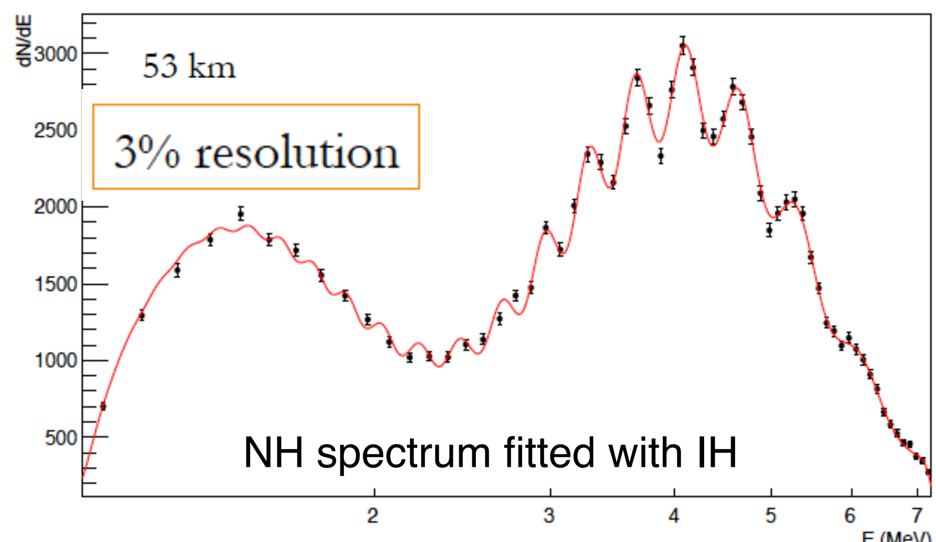
Experiment	Daya Bay	BOREXINO	KamLAND	JUNO
LS mass	20 ton	~300 ton	~1 kton	20 kton
Coverage	~12%	~34%	~34%	~80%
Energy resolution	~7.5%/$\sqrt{E}$	~5%/$\sqrt{E}$	~6%/$\sqrt{E}$	~3%/$\sqrt{E}$
Light yield	~ 160 p.e. / MeV	~ 500 p.e. / MeV	~ 250 p.e. / MeV	~ 1200 p.e. / MeV

Fit with both hypothesis: NH and IH









From: Bachelot thesiis of Luigi Pertoldi, Uni Padova, Italy

Other physics goals of JUNO

Precision measurement of the oscillation parameters

	Δm^2_{21}	$\lvert\Delta m^2_{31}\rvert$	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
Dominant Exps.	KamLAND	MINOS	SNO	Daya Bay	SK/T2K
Individual 1σ	2.7% [20]	4.1% [25]	6.7% [6]	10% [21]	14% [23, 24]
Global 1σ	2.6%	2.7%	4.1%	8.6%	11%

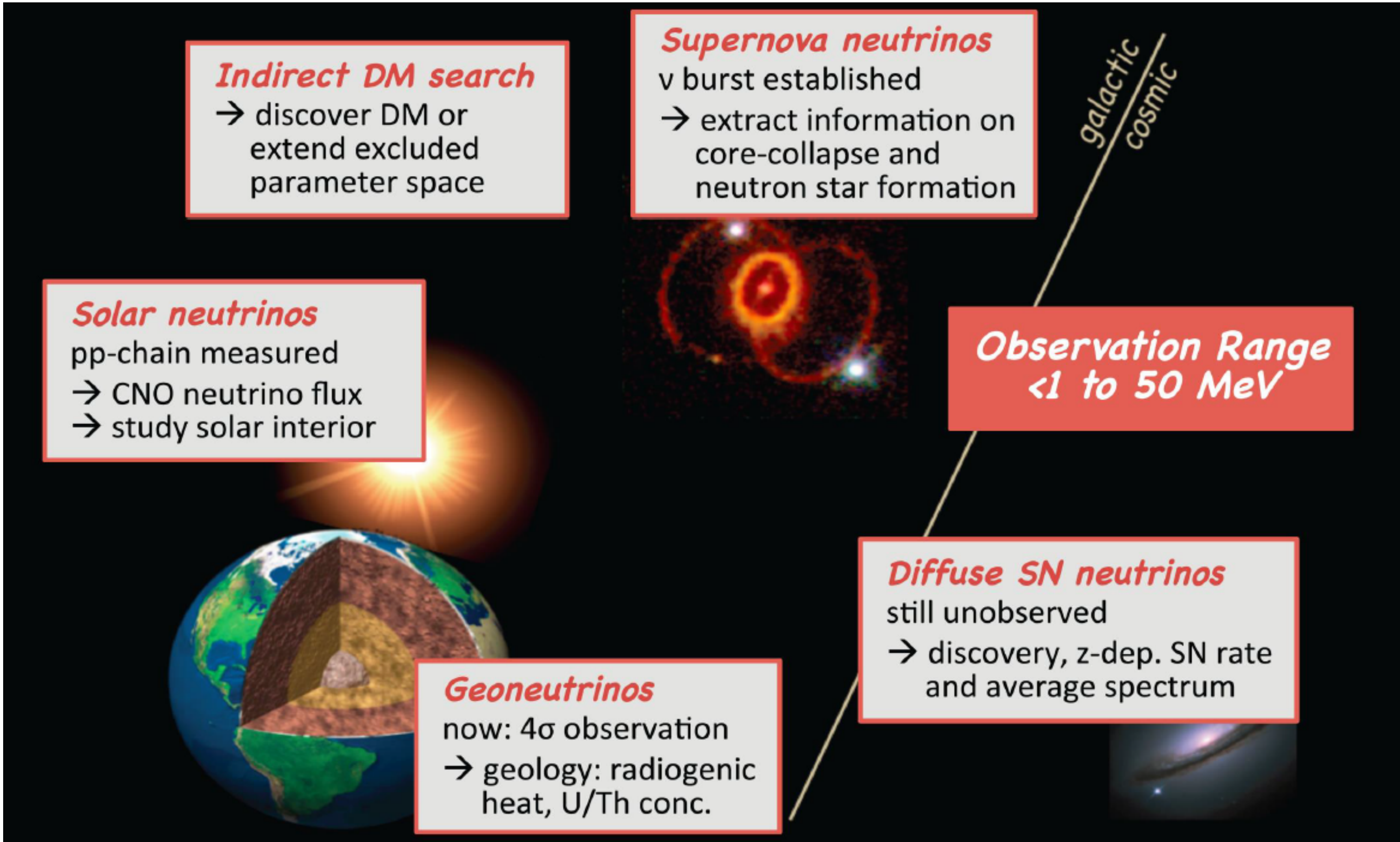
Probing the unitarity of U_{PMNS} to ~1%
more precise than CKM matrix elements !

	Statistics	**+BG +1% b2b +1% EScale +1% EnonL**
$\sin^2\theta_{12}$	0.54%	0.67%
Δm^2_{21}	0.24%	0.59%
Δm^2_{ee}	0.27%	0.44%

New physics tests in low-energy oscillation phenomena:

- Light sterile neutrinos 1405.6540
- Non-standard neutrino interactions 1310.5917, 1408.6301
- Lorentz and CPT violation 1409.6970

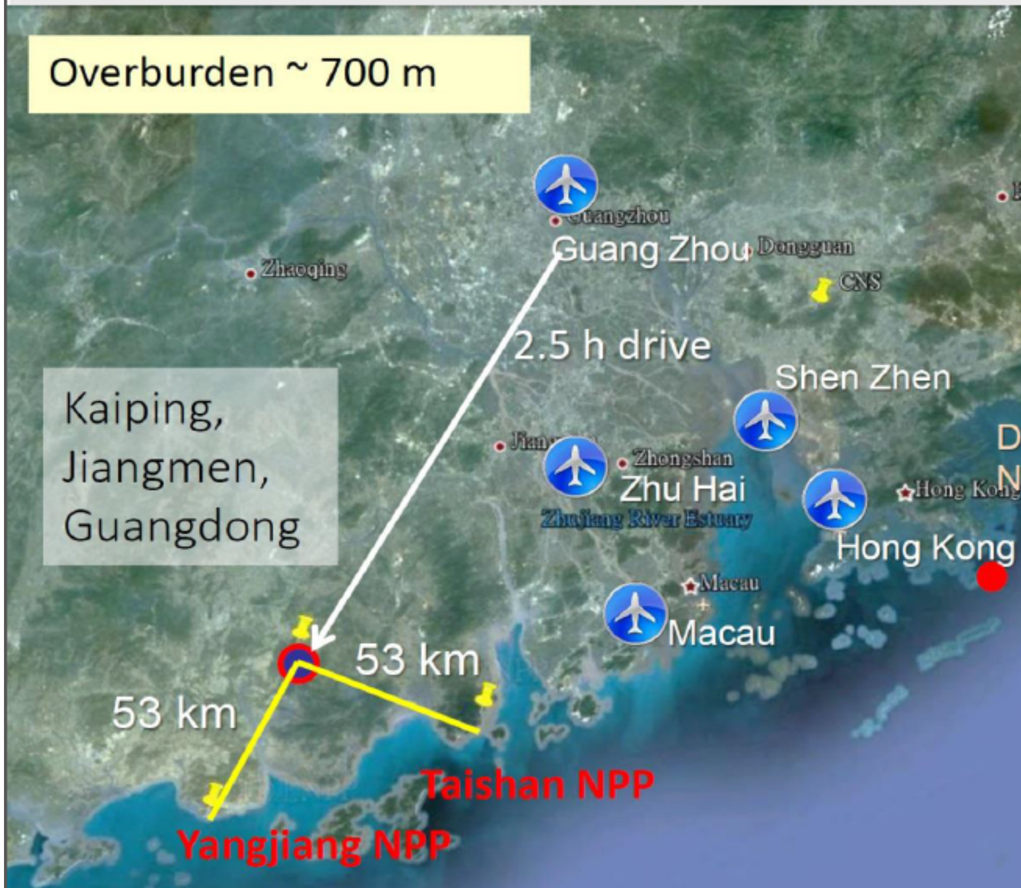
Observatory for astrophysical neutrinos

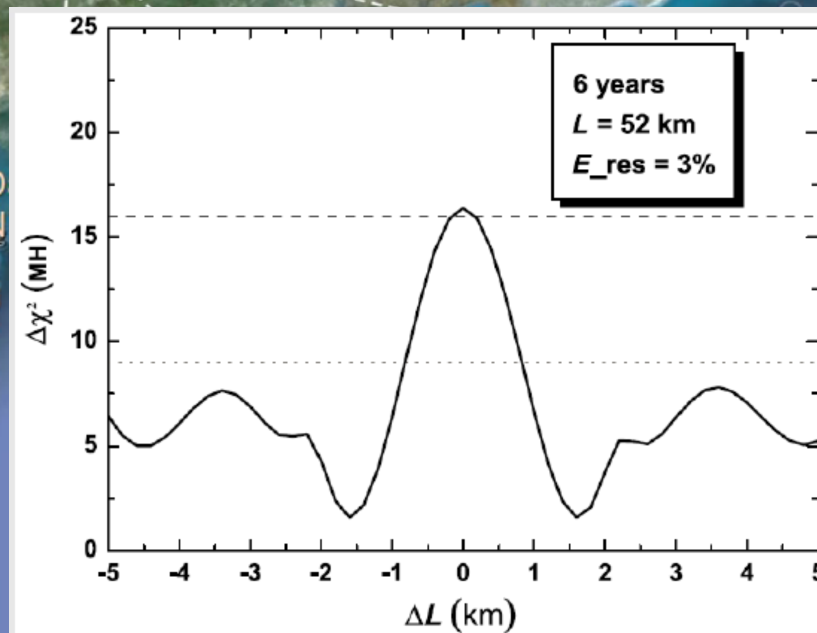


Detector design

Experimental site and baseline optimization

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW





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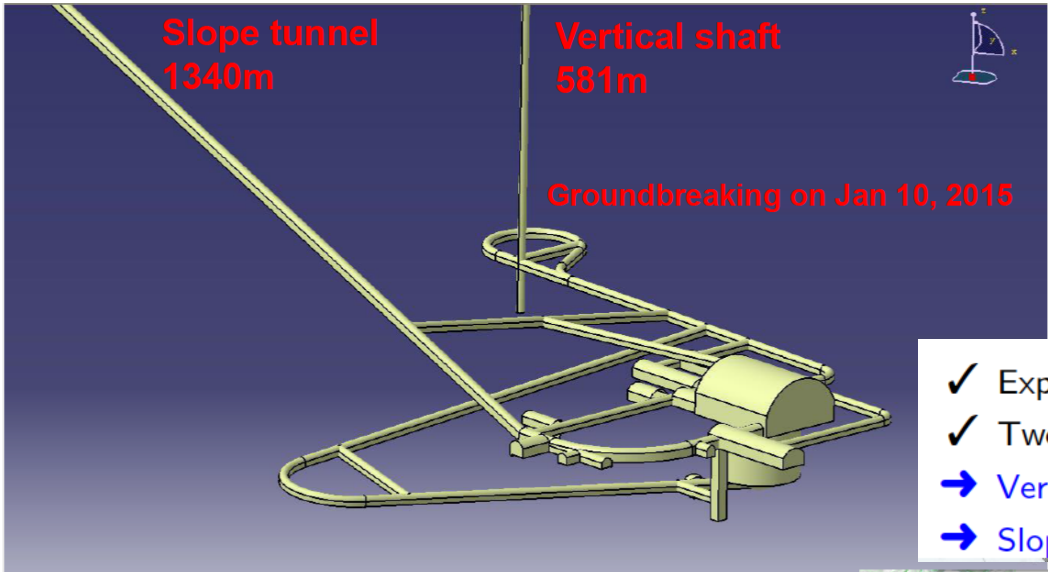
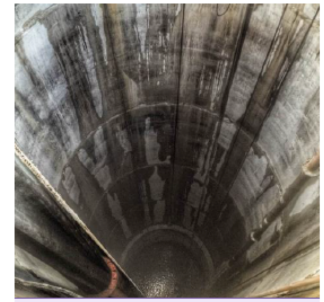
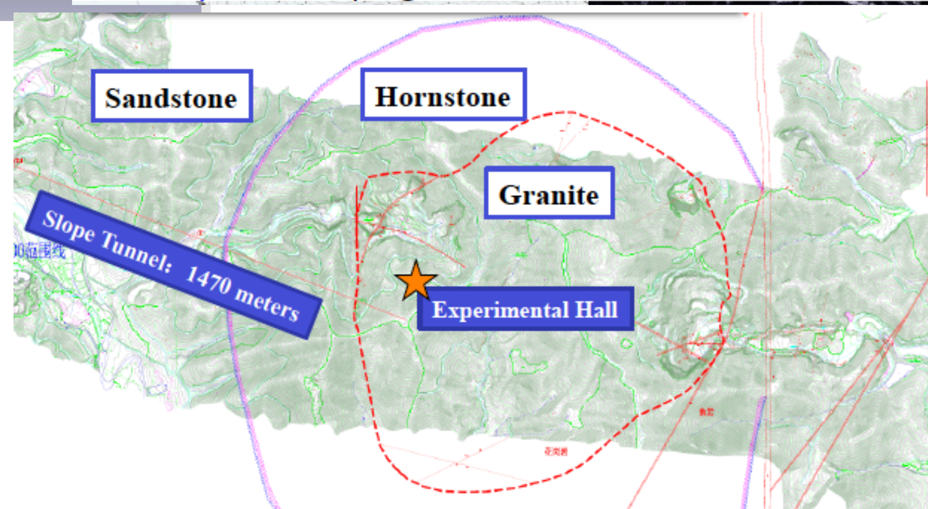
Going 720 m underground





Vertical Tunnel: 611 meters

- ✓ Experimental Hall overburden: 720 m (1900 mwe)
- ✓ Two access to experimental Hall
- ➜ Vertical shaft progress : 330 m out of 611 m
- ➜ Slope tunnel progress : 900 m out of 1340 m



JUNO detector design

Calibration

Top muon veto
Scintillator panels

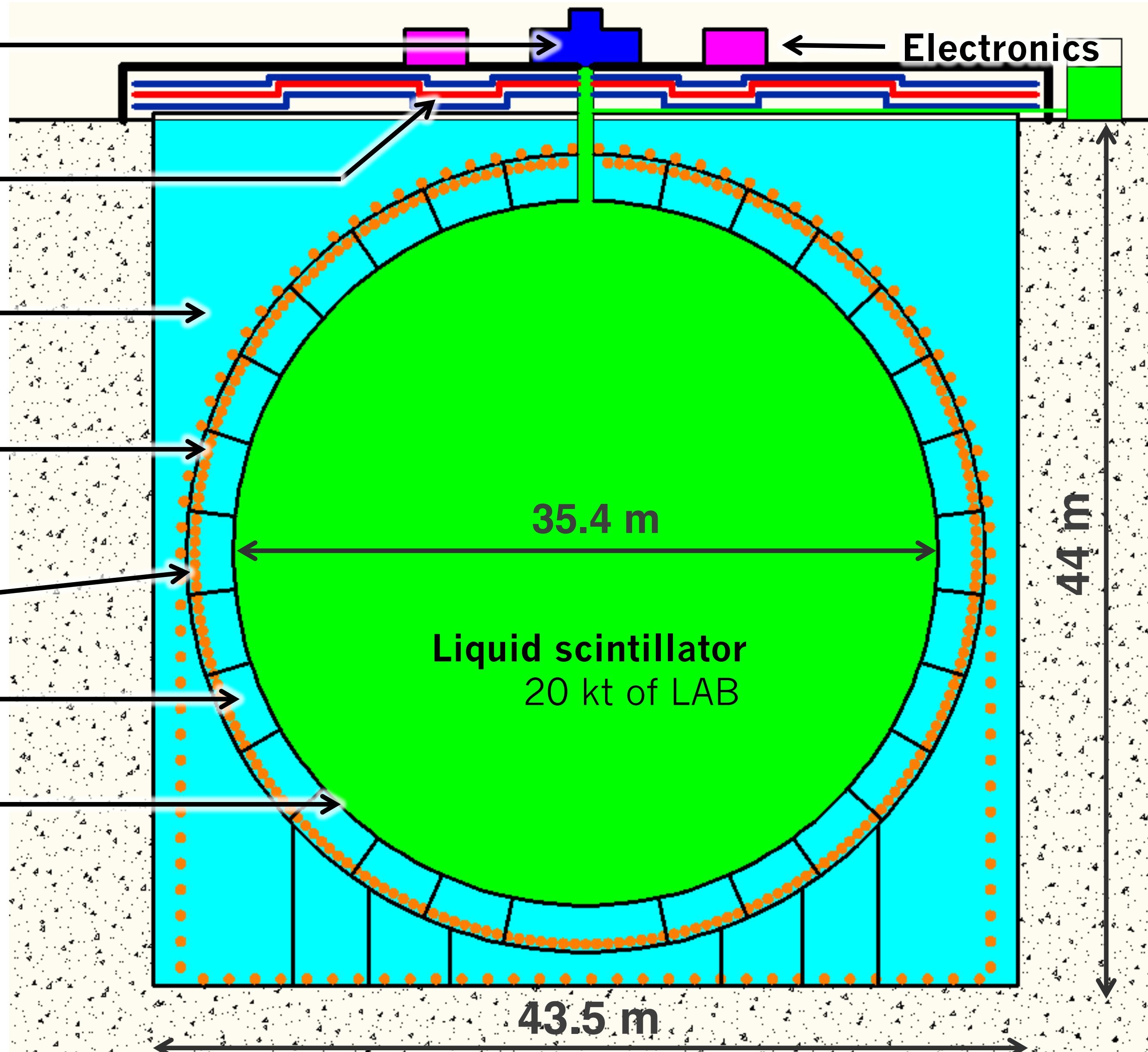
Outer water tank
Muon Cherenkov veto

Steel support structure
optical separation

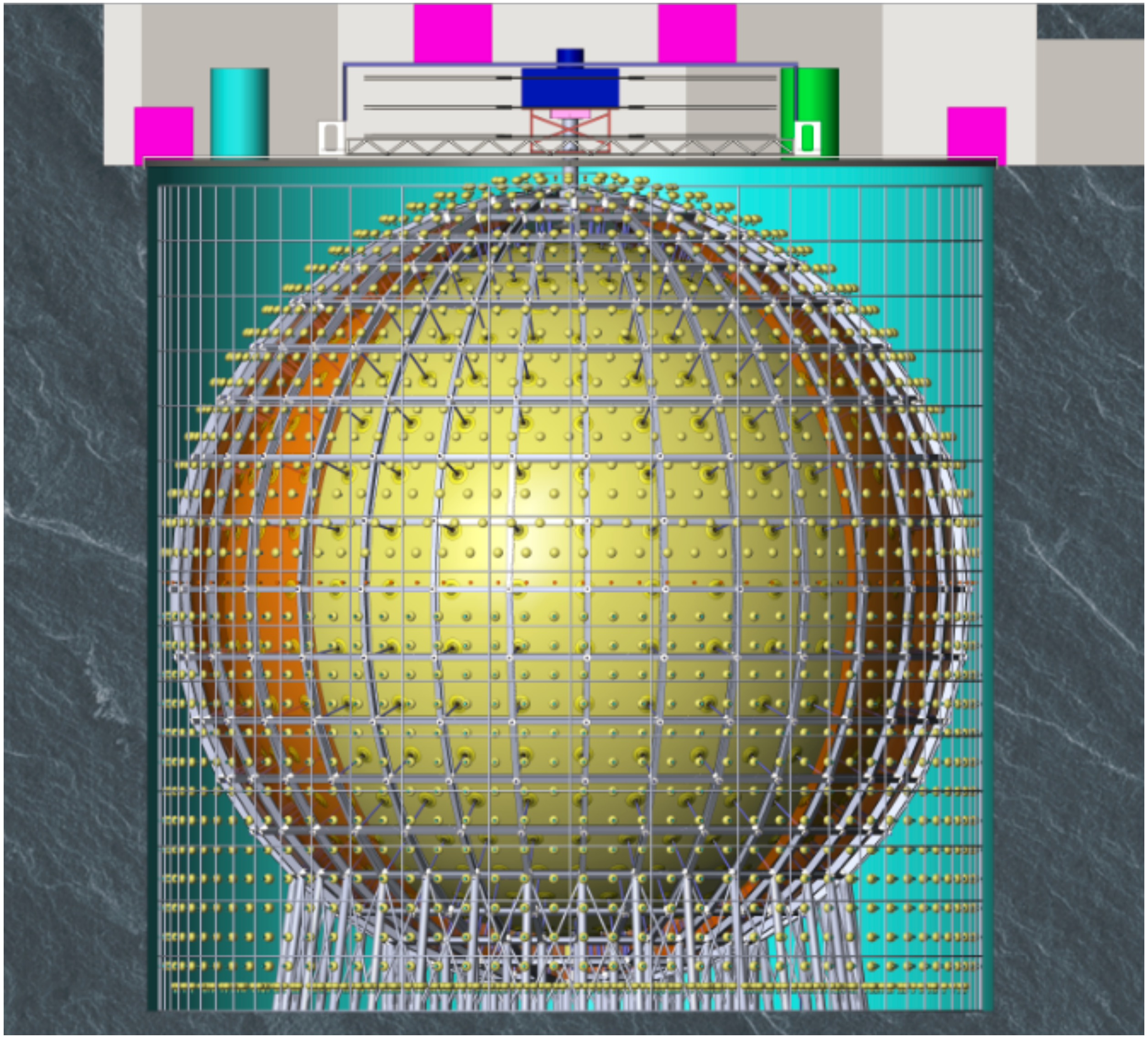
18,000 PMTs (20‘‘)
36,000 PMTs (3‘‘)

water buffer (2m)

Acrylic sphere
diameter: 35.4m



JUNO detector design



JUNO expected background

Geo:1.8%

Acc: 1.5%

^{9}Li/^{8}He: 2.7%

Selection	IBD efficiency	IBD	Geo-νs	Accidental	^{9}Li/^{8}He	Fast n	(α, n)
-	-	83	1.5	$\sim 5.7 \times 10^4$	84	-	-
Fiducial volume	91.8%	76	1.4	410	77	0.1	0.05
Energy cut	97.8%	73	1.3		71		
Time cut	99.1%						
Vertex cut	98.7%			1.1			
Muon veto	83%	60	1.1	0.9	1.6		
Combined	73%	60	3.8				

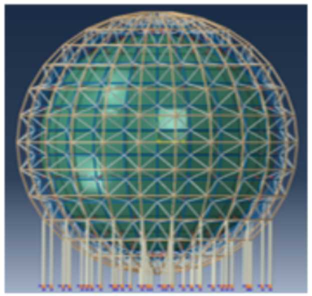
Expected upper limit for each material (Preliminary)

Material	Mass	Upper limit					Singles(Hz)	
		^{238}U	^{232}Th	^{40}K	^{222}Rn	^{60}Co	All volume	Fiducial volume
LS ★	20kt	10^{-6}ppb	10^{-6}ppb	10^{-7}ppb	1.4×10^{-13}ppb		2.39	2.2
Acrylic ★	561t	1ppt	1ppt	1ppt			6.92	0.36
Oxygen-free copper	10t	0.099ppb	0.1ppb	0.14ppt		1.8mBq/kg	2.44	0.2
Dust							1	0.1
Pulley and Ultrasonic receiver Array							1	0.1
SS tank	350t	0.097ppb	1.97ppb	0.05ppb		2.0mBq/kg	0.89	0.087
PMT glass ★	156t	400ppb	400ppb	40ppb	Hamamastu PMT		17.93	2.42
		50ppb	50ppb	20ppb	NNVT PMT			
PMT potting sealant	6.6t	12ppb	26ppb	25ppb			1	0.1
PMT protection cover	177.5t	10ppt	10ppt	10ppt				0.01
PMT potting shell	177.5t	10ppt	10ppt	10ppt				
Cable								0.01
CUU								
Radon in water ★	35kt					$0.2Bq/m^3$	16	1.3
Rock		10ppm	30ppm	5ppm			7.4	0.984
						Sum	57.0	7.9

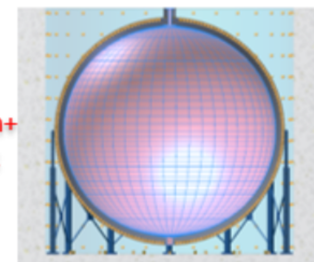
➤ The most critical materials are shown with "stars" in the material column.

JUNO Central Detector

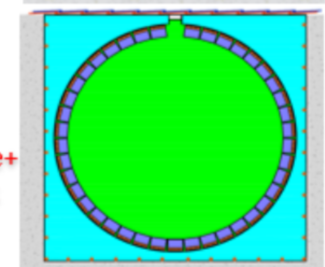
Acrylic sphere+ SS truss



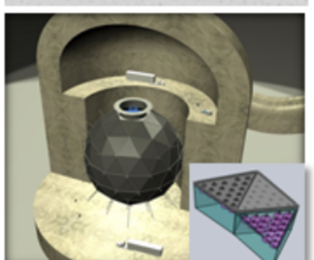
Balloon+ SS tank



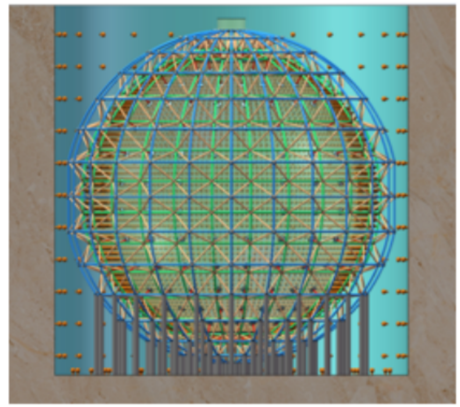
Acrylic module+ SS tank



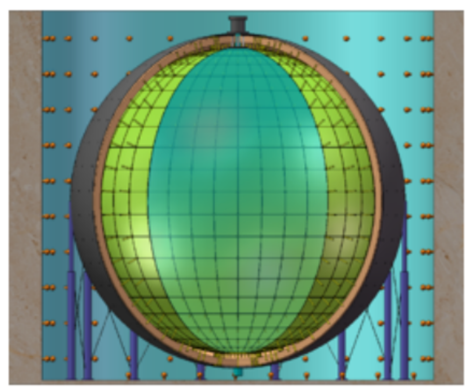
Acrylic sphere+ SS tank



March, 2014

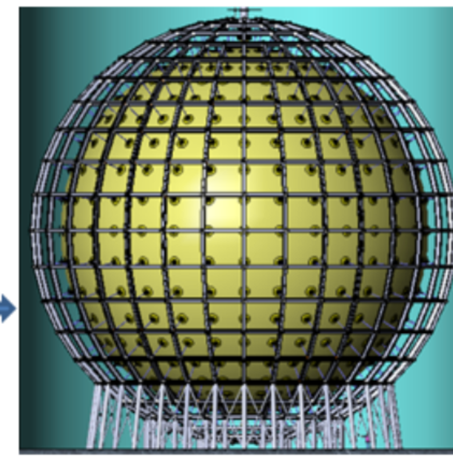


SS truss+ Acrylic sphere



Balloon + Acrylic support+ SS tank

July, 2015

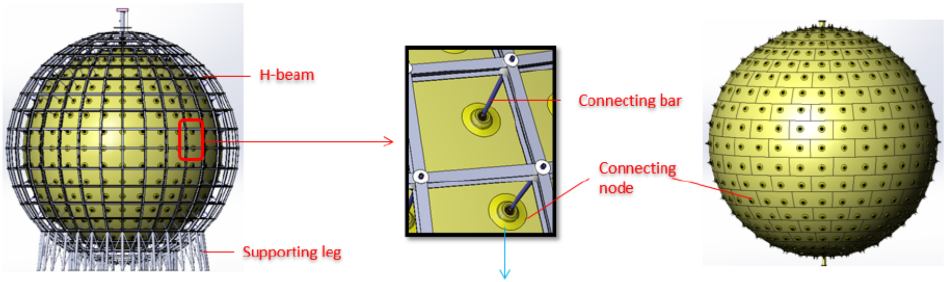


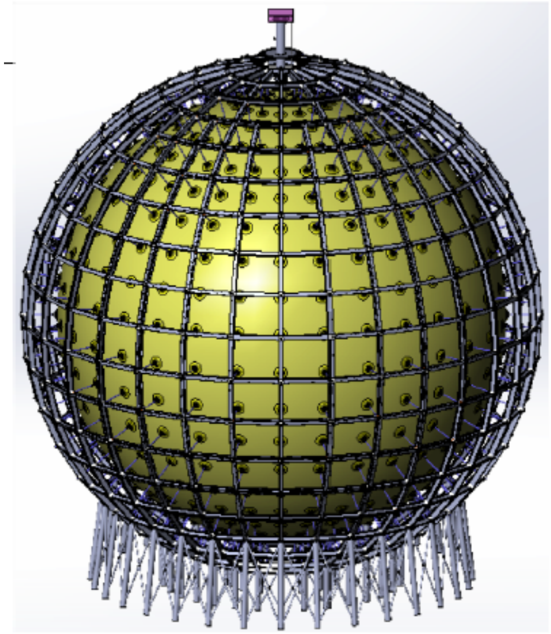
Final decision:
Acrylic sphere + SS truss

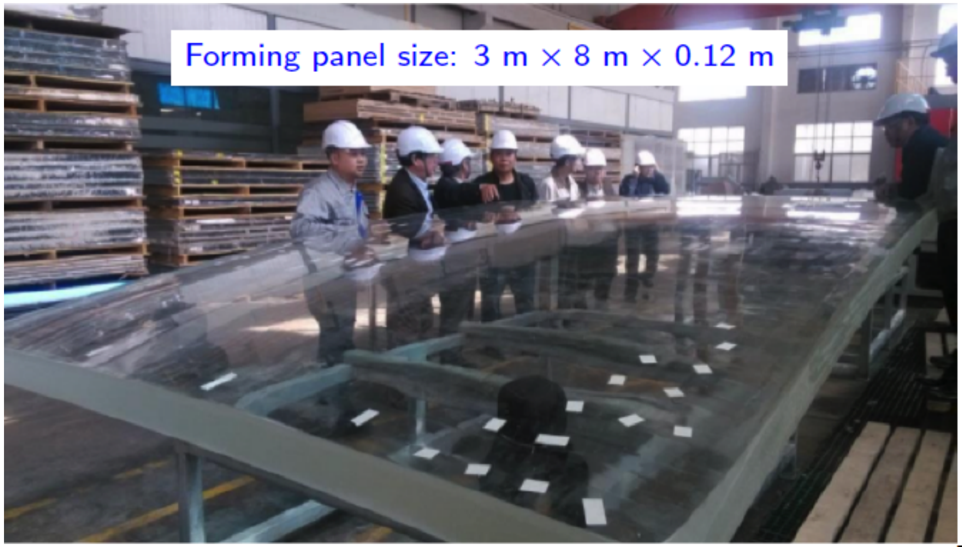
JUNO Central Detector

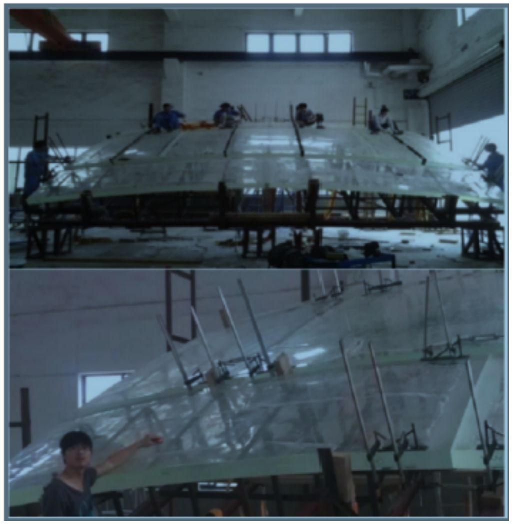
Acrylic Sphere and Stainless Steel truss

- ✓ safety was given a priority
- ✓ 260 acrylic panels of 120 mm thickness
- ✓ Total weight: ~600 t of acrylic and ~600 t of steel



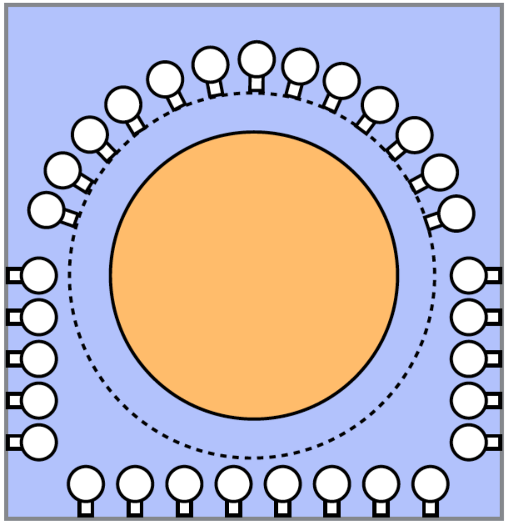






Worst stress case: the total vertical load is ~2600t up, ~560 connecting nodes will carry it

JUNO Muon Veto



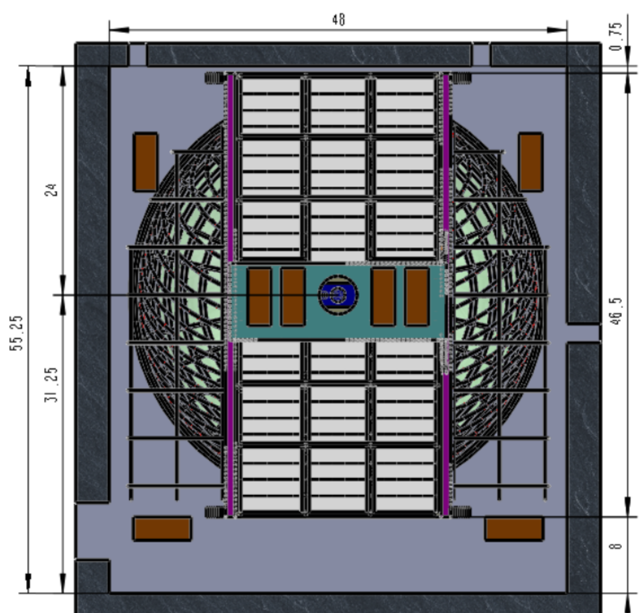
Water Cherenkov

20~30kt ultra-pure water

Water acting as moderator &
pool instrumented to detect Cherenkov light

2000 20'' PMTs located as in the picture

Maximise detection efficiency of Cherenkov light



Top Tracker

Using **OPERA** plastic scintillator (49m^2/module)

Three layers to ensure good muon tracking

Partial coverage due to available modules

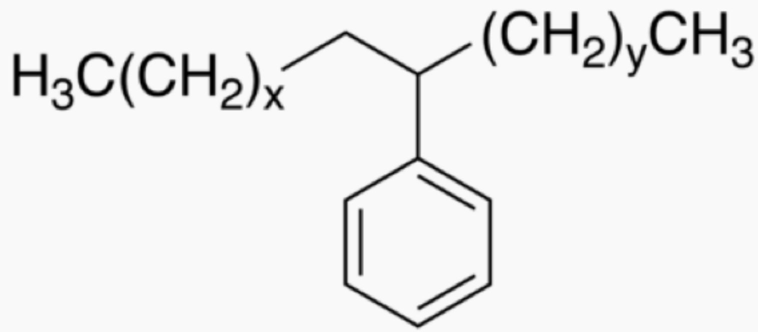
- **Reject ~50% muons**
- Provide tagged muon sample to study reconstruction and background contamination with central detector

JUNO Liquid Scintillator

LAB solvent

linear-alkylbenzene

- Developed by SNO+
- Used in Daya Bay
- Planned for JUNO



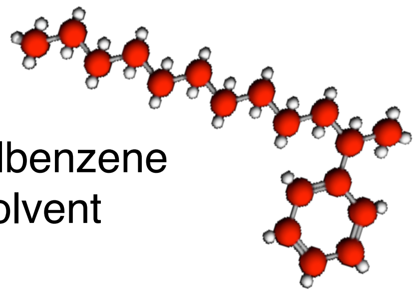
Compared to pseudocumene:

- Non toxic
- High flash point
- Cheap
- Compatible with acrylic
- Excellent transparency
- Worse particle discrimination

JUNO Liquid Scintillator cocktail

Liquid scintillator composition

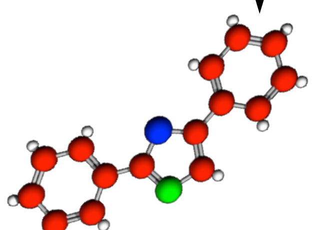
Linear alkylbenzene (LAB) as solvent



\+

non-radiative → 280nm

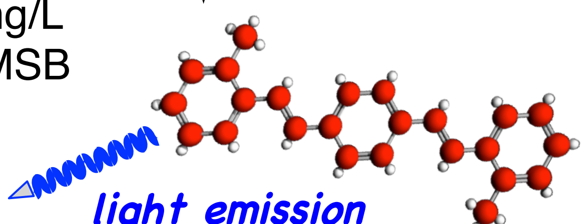
3 g/L PPO



\+

non-radiative → 390nm

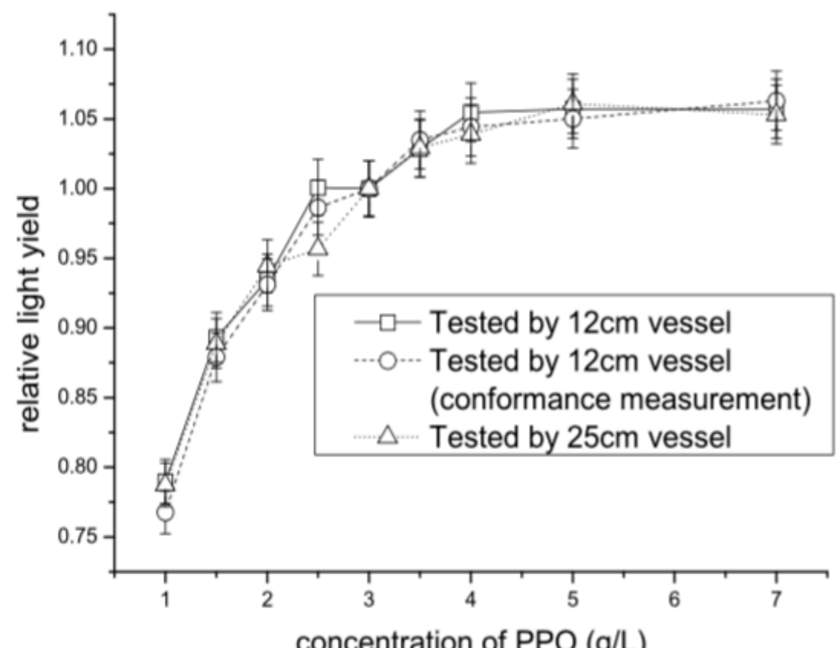
15 mg/L bis-MSB



light emission → 430nm, τ≈4.4ns

Required properties:

- **High light yield**: ~10^4 ph/MeV
  → pure organic solvent
  → high fluor (PPO) concentration
- **High transparency: ~**20m
  → choose transparent solvent → **LAB**
  → the producer matters!
- → shift light to long wavelength → **bisMSB**



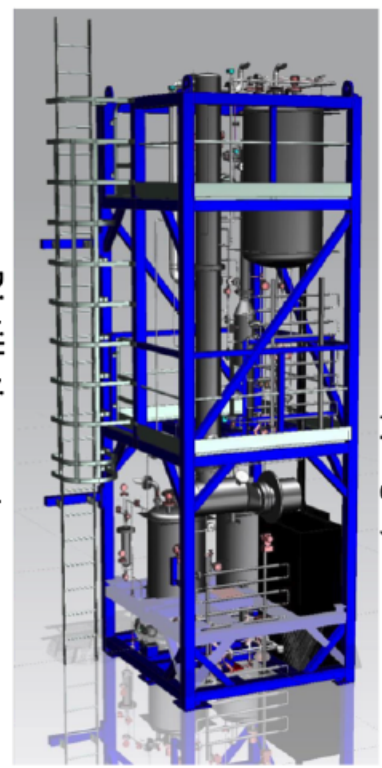
JUNO Liquid Scintillator Pilot Plant

Goals

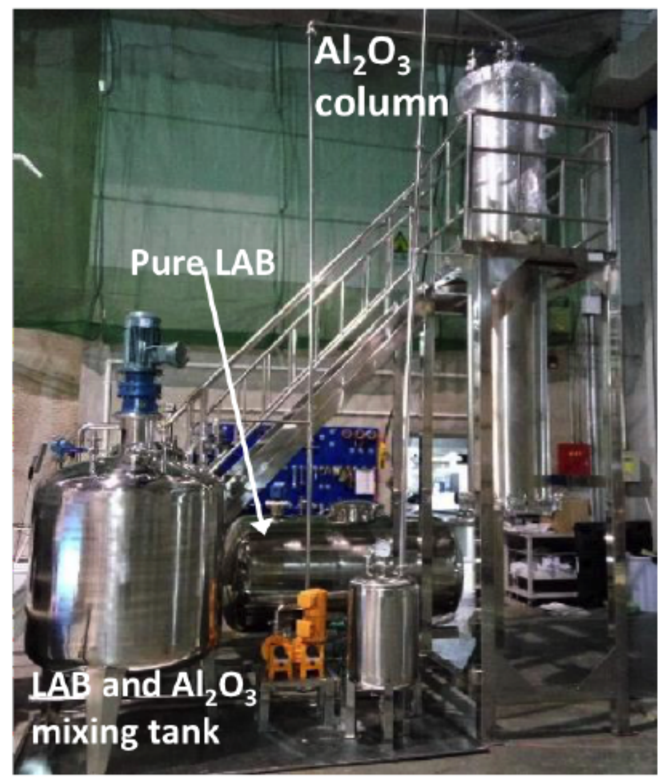
- ✓ Purify 20 t LAB to test the overall design and operation at Daya Bay.
  Replace the target LS in one detector.
- ✓ Quantify the subsystems effectiveness:
  - ➜ optical : > 20 m at 430 nm
  - ➜ radio-purity : 10^{-15} g/g (U, Th)
- ✓ Allow to select the best sub-system
  - ➜ Al_2O_3 column, distillation, gas stripping, water extraction

Distillation and steam stripping
Installed at Daya Bay

Distillation system

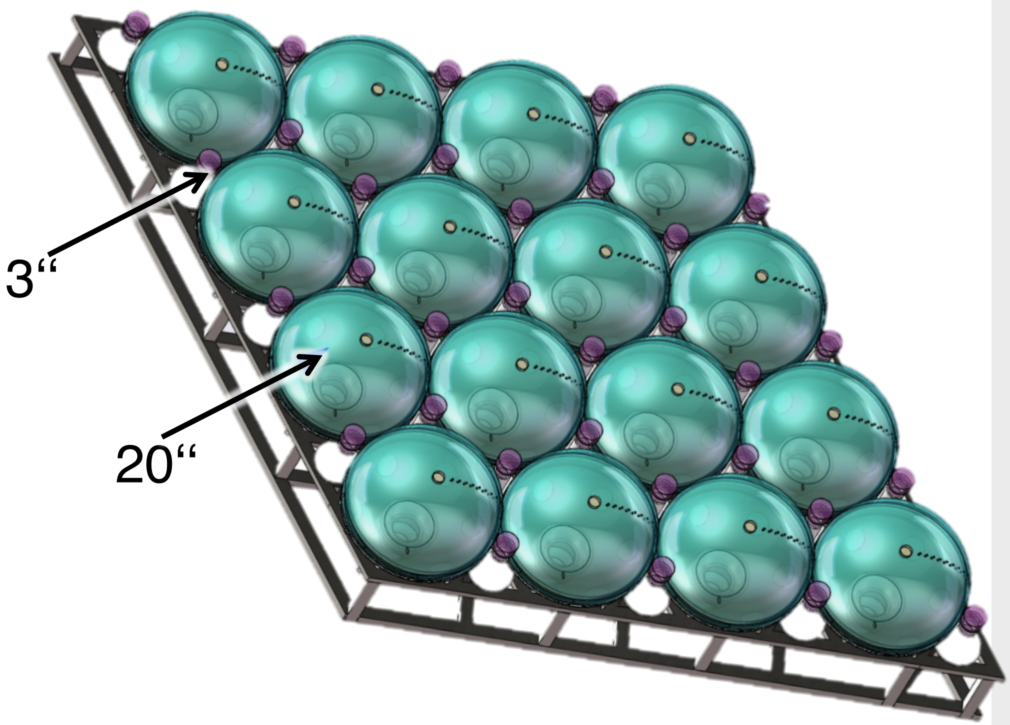


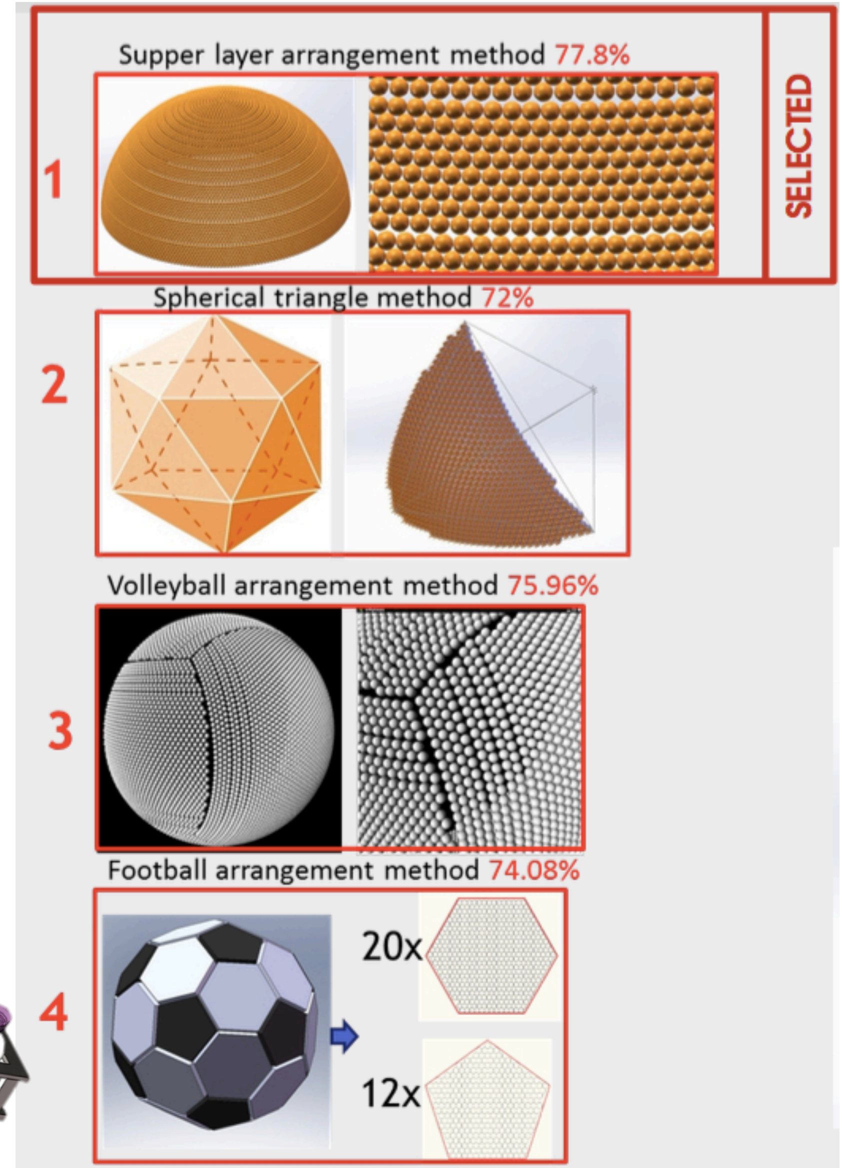
Steam stripping system



Optimizing light collection

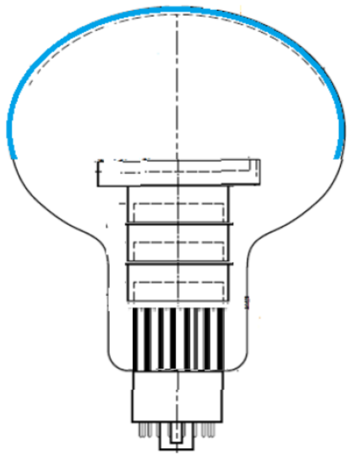
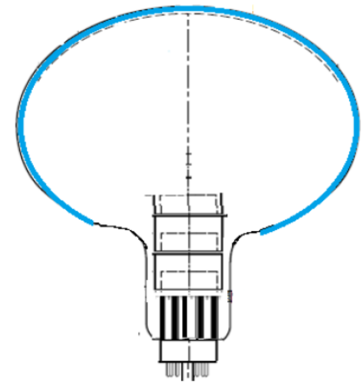
- **optical coverage: 78%**
  → 18,000 large PMTs (20“) → 75%
  → 36,000 small PMTs (3“) → 3%
  (double calorimetry + timing)





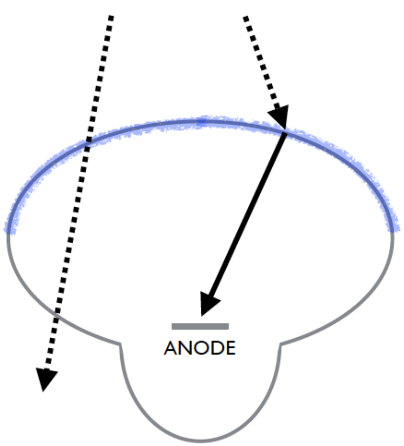
JUNO Large 20-inch PMTs

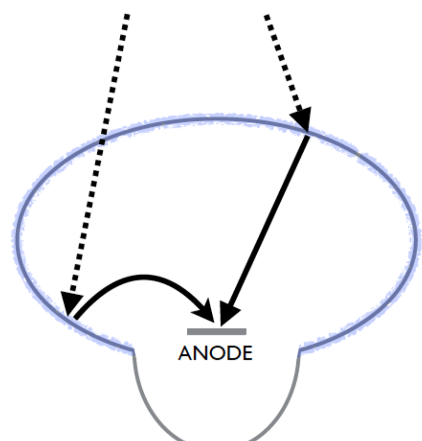
JÜLICH FORSCHUNGSZENTRUM

20-inch Hamamatus PMT-Dynode Ellipsoidal Glass	20-inch IHEP-MCP-PMT-Ellipsoidal Glass
 	 

TRANSMISSION

TRANSMISSION + REFLECTION





JUNO Large PMTs

Optimize light collection:

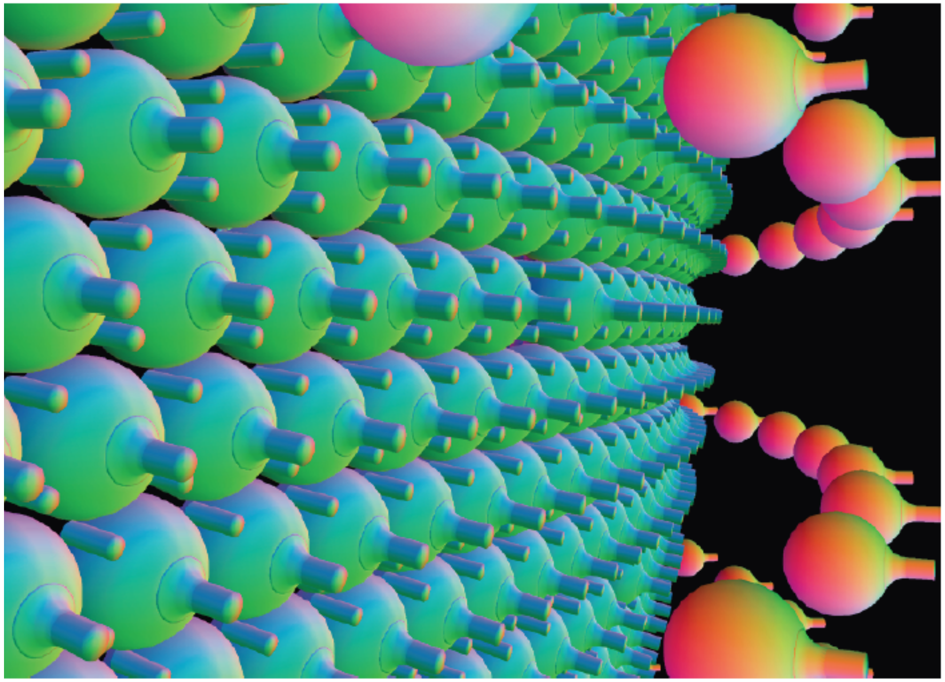
- optical coverage: 75%
- quantum efficiency QE x collection efficiency CE = 35%

→ photons detected: ~26%

More in the talk of Sen Qian on Sunday @ 11:15!

Parameter	**Dynode-PMT R12860** Hamamatsu Japan **5000 units**	**MCP-PMT** NNCV – IHEP China **15000 units**
Photocathode	transmission	transmission + reflection
QE (400nm)	30%(T)	26%(T) + 4%(R)
relative CE	100%	110%
peak-to-valley ratio	>3	>3
transit time spread	~3 ns	~12 ns
dark rate	~30 kHz	~30 kHz
afterpulsing	10%	3%

JUNO Double Calorimetry



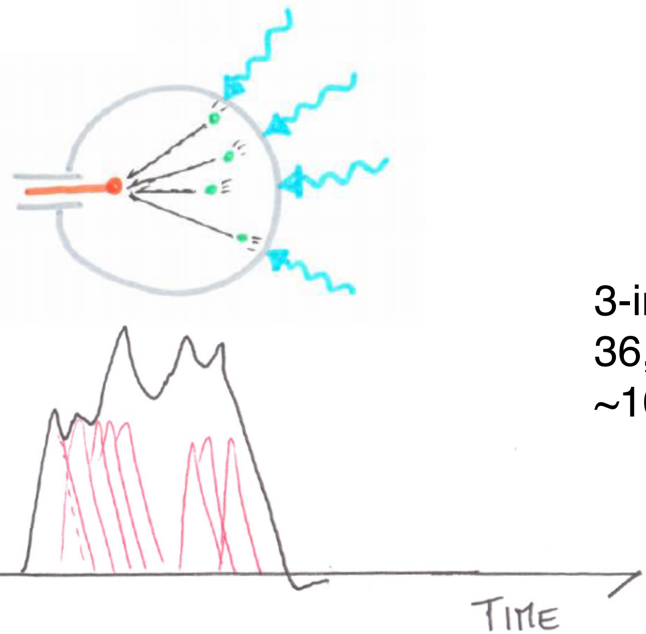
- 2 independent read-put systems
  18,000 20-inch Large PMTs (LPMTs)
  36,000 3-inch Small PMTs (SPMTs)

- Concept approved in July 2015
- Optimization of the final number ongoing

Investigation of PMTs from different suppliers

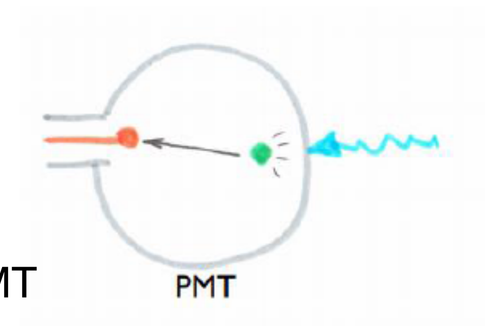
Current baseline design
- ~18,000 20-inch PMTs
- ~36,000 3-inch PMTs

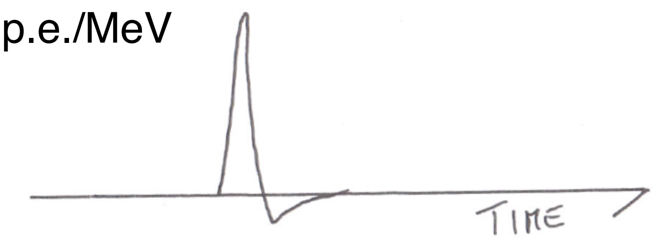
JUNO Double Calorimetry



20-inch LPMT
18,000
1,200 p.e./MeV

3-inch SPMT
36,000
~100 p.e./MeV





- 75% photo-covergae
- Stochastic term: 3%/sqrt(E)
- Slower and worse p.e. resolution
- Large dark noise

- 3% photo-covergae
- Stochastic term: 10%/sqrt(E)
- Faster and better p.e. resolution
- Small dark noise

- Reducing non-stochastic terms in the energy resolution dependence
- Extending the dynamical range
- Improving time and vertex resolution, muon reconstruction
- Importance in high-rate SN detection

Integrated PMT-redout Chip

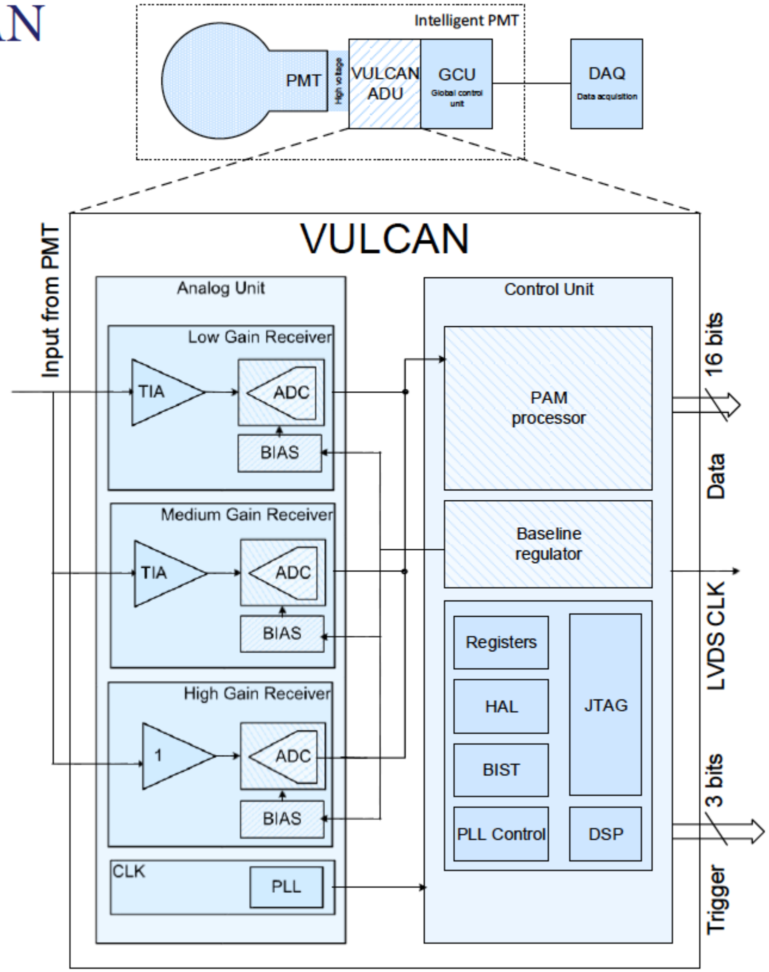
Developed at ZEA FZJ, Germany

JÜLICH FORSCHUNGSZENTRUM

Key features of VULCAN

Sampling rate	1 GHz
Bandwidth	500 MHz
Input impedance	<10 Ω
Dynamic range	$\frac{1}{16}$ - 2000 p.e.
ADC resolution	8 bit [3 ×]
High gain	0.06 p.e./bit
Medium gain	0.4 p.e./bit
Low gain	8 p.e./bit
Power	1 W
Area	22.09 mm^2

- Data processing for signal reconstruction
- Fast trigger generation parallel to signal data
- Three large dynamic range ADCs
- Highly configurable alternative operating modes
- Optional compensation for signal overshoot



Selection of gain mode (best precision & not saturated)

Data reduction: 3 GB/s → 1 GB/s

Analog Unit

- Transimpedance amplifier (TIA)
- Phase locked loop (PLL)
- Analog to digital converter (ADC)

Digital Unit

- Programmable adaptive memory (PAM)
- Digital signal processor (DSP) for trigger
- Configuration Interface (JTAG)
- Built-in self test (BIST)
- Head of assigned liabilities for start up control (HAL)

JUNO calibration system

Goals

- ✓ Overall energy resolution : $3\%/\sqrt{E}$
- ✓ Energy scale, non linearities : $< 1\%$

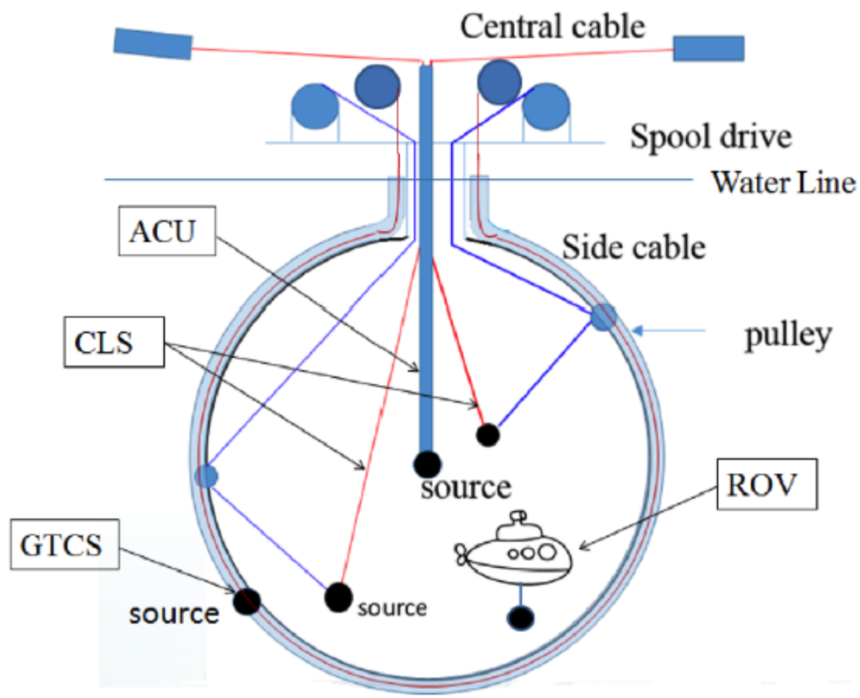
Four Complementary Systems

- ✓ 1D : Automatic Calibration Unit ACU for central axis scan
- ✓ 2D : Cable Loop System CLS for vertical planes scan and Guide Tube Calibration System GTCS for CD outer surface
- ✓ 3D : Remotely Operated under-liquid-scintillator Vehicles ROV for whole CD scan

Method	System
Rope Length Calculation	CLS, ACU and GTCS
Ultrasonic receiver	ROV, CLS
CCD(Independent)	ROV, CLS

Radioactive Sources

- ✓ photons : ^{40}K, ^{54}Mn, ^{60}Co, ^{137}Cs
- ✓ positrons : ^{22}Na, ^{68}Ge
- ✓ neutrons : ^{241}Am-Be, ^{241}Am-^{13}C, ^{241}Pu-^{13}C, ^{252}Cf



JUNO schedule

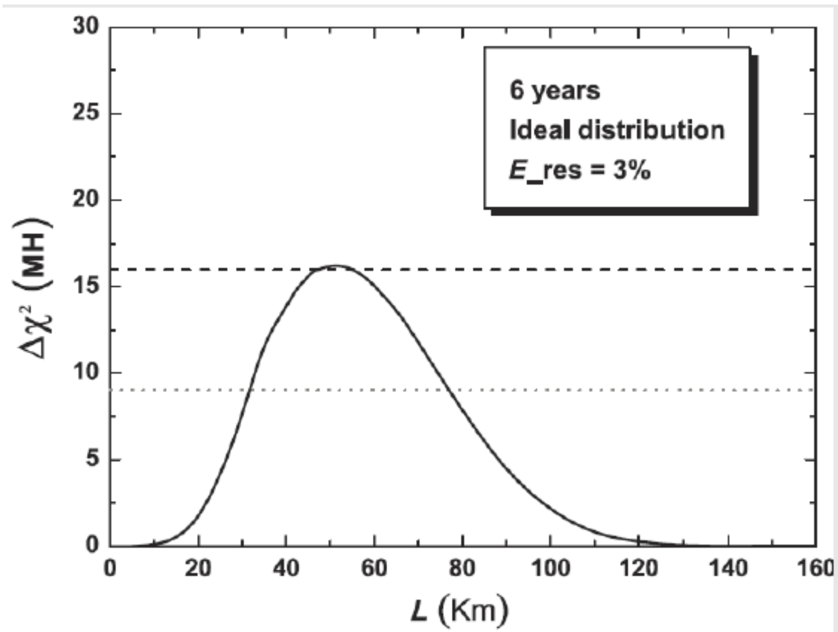
2013 ▶ 2014 ▶ 2015 ▶ 2016 ▶ 2017 ▶ 2018 ▶ 2019 ▶ 2020

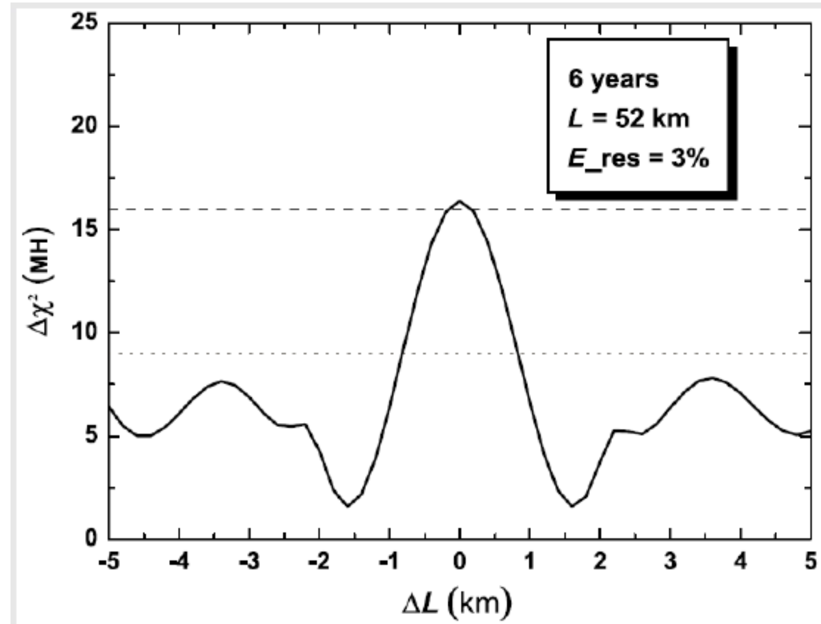
- **2013**: Complete conceptual design. Complete civil design and bidding
- **2014**: Start civil construction. Complete prototyping (PMT & detector). International collaboration established
- **2015**: PMT production line manufacturing
- **2016**: Start PMT production. Start detector production or bidding
- **2017**: Complete civil construction. Start detector construction and assembly
- **2018**: Start LS production
- **2019**: Complete detector assembly, installation and LS filling
- **2020**: Start data taking

Thank you!

BACKUP SLIDES

Baseline optimization





Optimal baseline is at L = 50-60 km, at the oscillation maximum of Δm^2_{12}

In case of multiple reactors, minimize the spread of L

Choice of the experimental site

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

Step 3, 4: $\Delta\chi^2$ definition and MH discrimination

$$\chi^2_{REA} = \sum_{i=1}^{N_{bin}} \frac{\left[M_i - T_i\left(1 + \sum_k \alpha_{ik}\,\epsilon_k\right)\right]^2}{M_i} + \sum_k \frac{\epsilon_k^2}{\sigma_k^2}$$

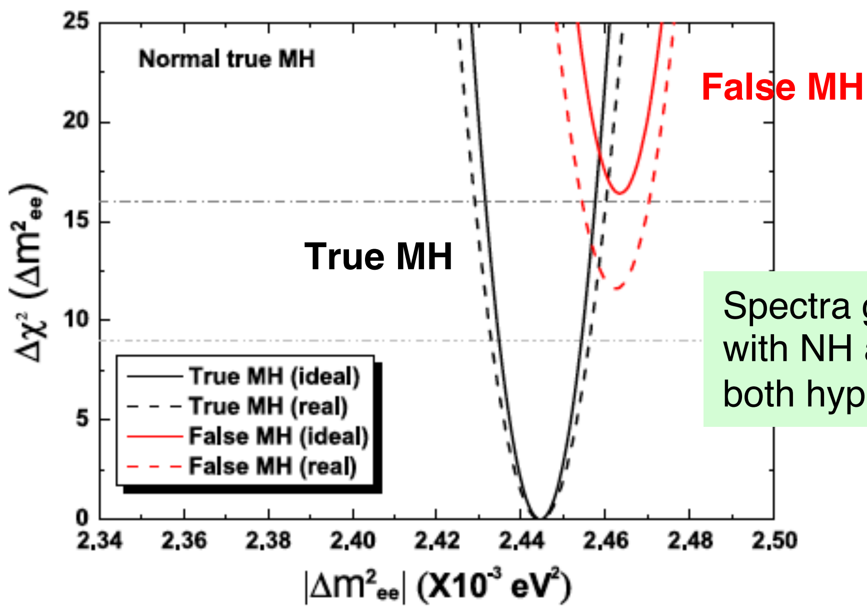
$$\Delta\chi^2_{MH} = |\chi^2_{min}(N) - \chi^2_{min}(I)|$$

fit with NH assumption — fit with IH assumption

M_i = number of measured IBD events in the i^{th} bin (200 bins between 1.8 – 8 MeV)
T_i = number of expected IBD events in the i^{th} bin after oscillation $f(MH;\, E,\, L,\, \sin^2\theta_{12},\, \sin^2\theta_{13},\, \Delta m^2_{12},\, \Delta m^2_{ee})$

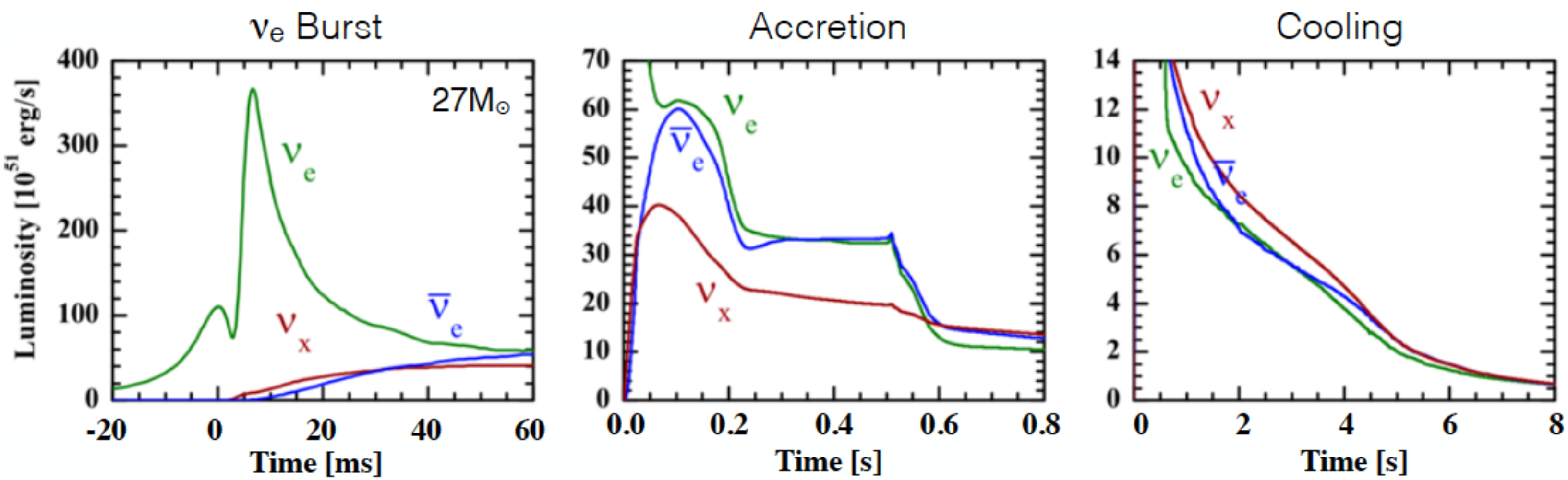
T_i for NH and IH is considered separately, two separate minimizations

ε_k = pull parameters for reactor and detector-related systematic effects
σ_k = uncertainty of the parameters used in pull terms
α_{ik} = fraction of neutrino event contribution of the i^{th} pull parameter to the i^{th} energy bin



Spectra generated with NH and fit with both hypothesis

Supernova (SN) burst neutrinos



- Huge amount of energy (3×10^{53}erg) emitted in neutrinos (~$0.2 M_\odot$) over long time range
- 3 phases equally important ▶ 3 experiments teaching us about astro- and particle-physics

Process	Type	Events ⟨E_ν⟩=14MeV
$\bar{\nu}_e + p \rightarrow e^+ + n$	CC	5.0×10^3
$\nu + p \rightarrow \nu + p$	NC	1.2×10^3
$\nu + e \rightarrow \nu + e$	ES	3.6×10^2
$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$	NC	3.2×10^2
$\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N$	CC	0.9×10^2
$\bar{\nu}_e + {}^{12}C \rightarrow e^+ + {}^{12}B$	CC	1.1×10^2
NB Other ⟨E_ν⟩ values need to be considered to get complete picture.		

Expected events in JUNO for a typical SN distance of 10kpc

We try to be able to handle Betelgeuse (d~0.2kpc) resulting in ~10MHz trigger rate

J.Phys. G43 (2016) no.3, 030401

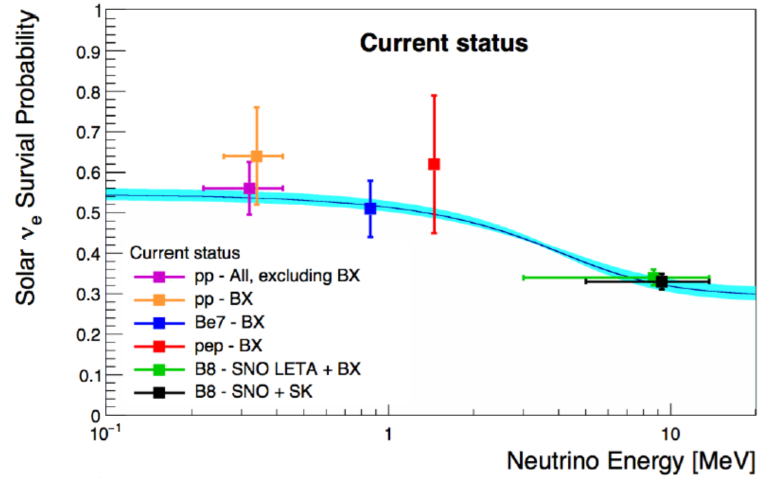
Solar neutrinos

Fusion reactions in solar core: powerful source of electron neutrinos O(1 MeV)

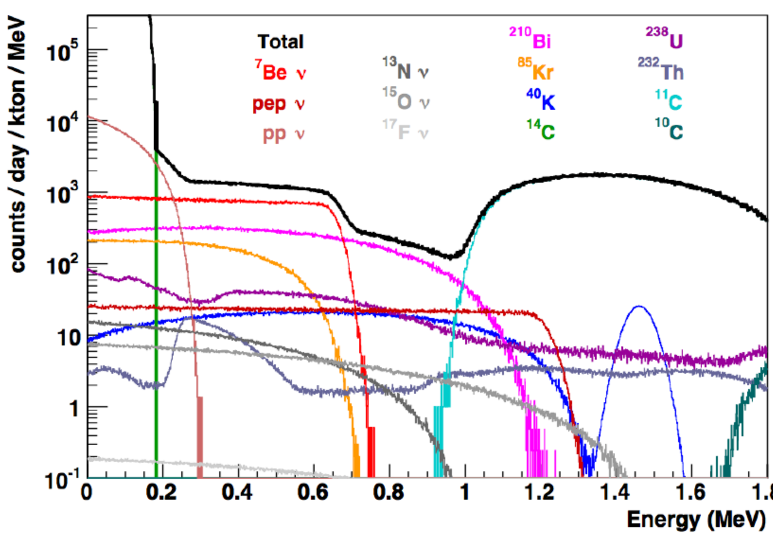
JUNO: neutrinos from ^{7}Be and ^{8}B chains

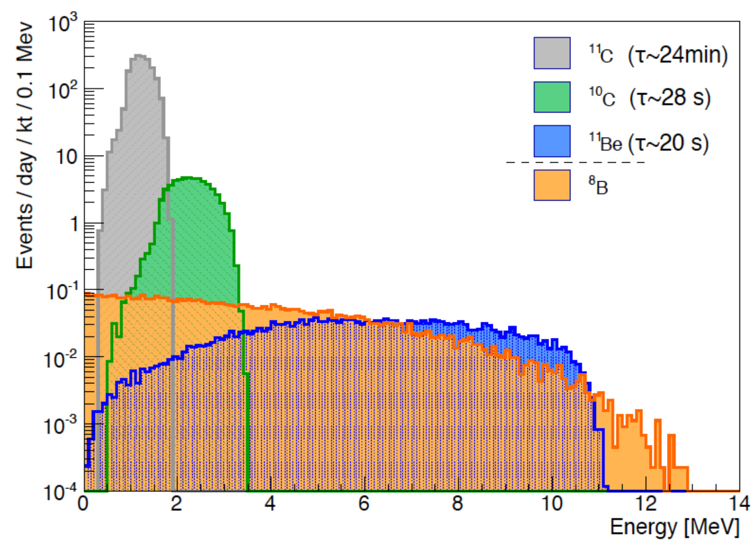
Investigate MSW effect: Transition between vacuum and matter dominated regimes

Constrain Solar Metallicity Problem: Neutrinos as proxy for Sun composition



arXiv 1602.01733





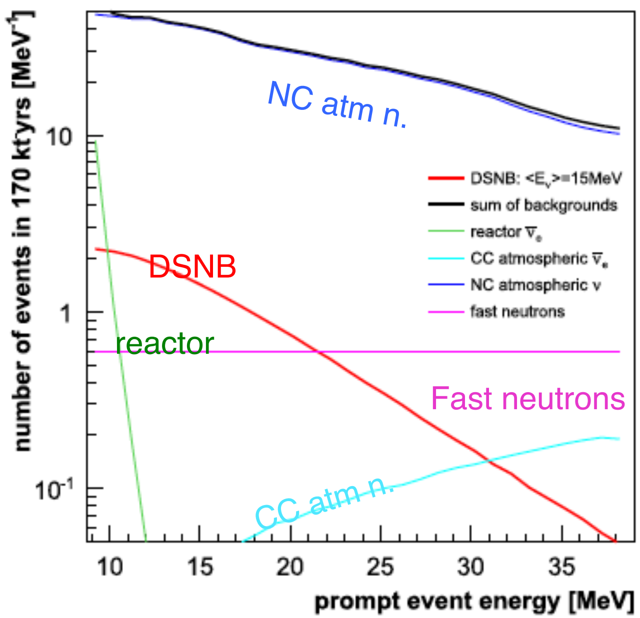
J.Phys. G43 (2016) no.3, 030401

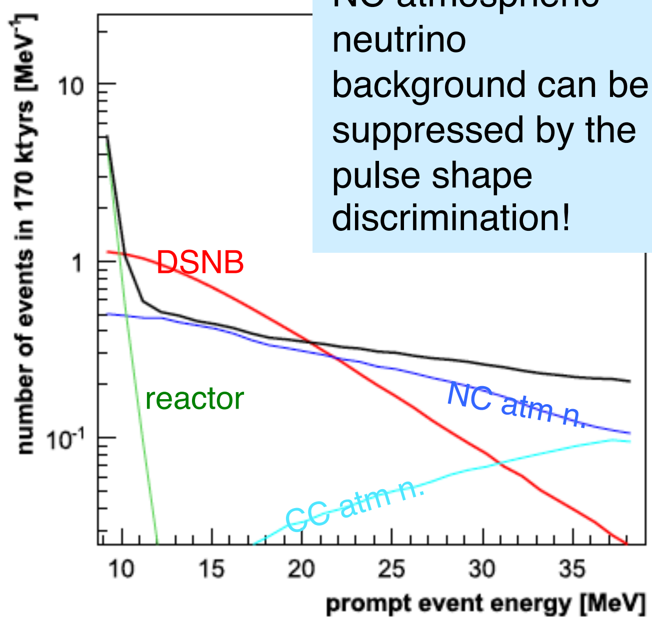
Diffuse SN Neutrino Background

10^8SN per year
average flux

DSNB spectrum
averaged SN spectrum
redshifted by
cosmic expansion
$\bar{\nu}_e$ flux: 20 $cm^{-2}s^{-1}$

Problem: NC events with prompt energy deposition plus neutron knock-out from ^{12}C mimick IBD events





Possible solution:
NC atmospheric neutrino background can be suppressed by the pulse shape discrimination!

Never observed yet!

10 Years' sensitivity

Syst. uncertainty BG	5 %		20 %	
$\langle E_{\bar{\nu}_e} \rangle$	rate only	spectral fit	rate only	spectral fit
12 MeV	1.7 σ	1.9 σ	1.5 σ	1.7 σ
15 MeV	3.3 σ	3.5 σ	3.0 σ	3.2 σ
18 MeV	5.1 σ	5.4 σ	4.6 σ	4.7 σ
21 MeV	6.9 σ	7.3 σ	6.2 σ	6.4 σ

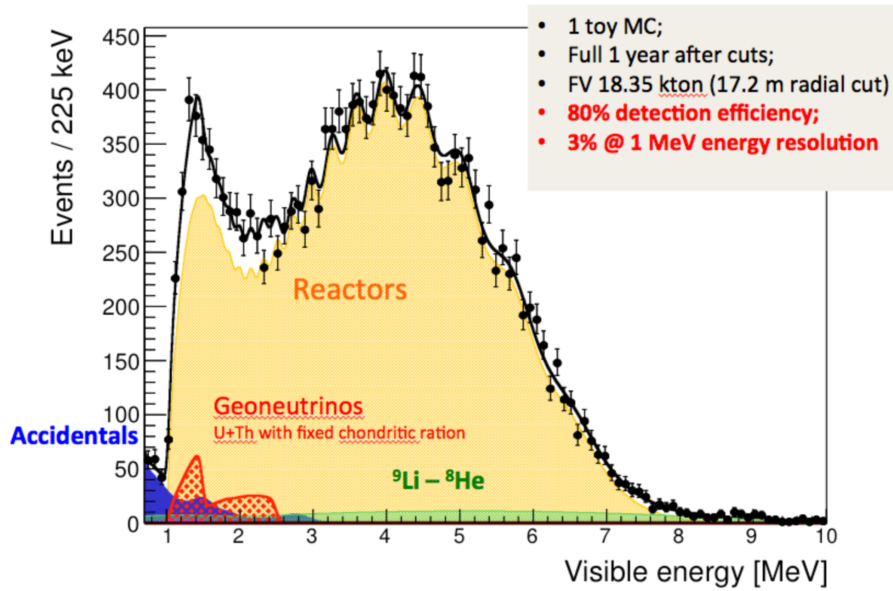
Geoneutrinos

Big advantage:
- ✓ Big volume and thus high statistics!

Main limitations:
- ✓ Huge reactor neutrino background;
- ✓ Relatively shallow depth – cosmogenic background;

Critical:
- ✓ Keep other backgrounds (^{210}Po contamination!) at low level and under control;

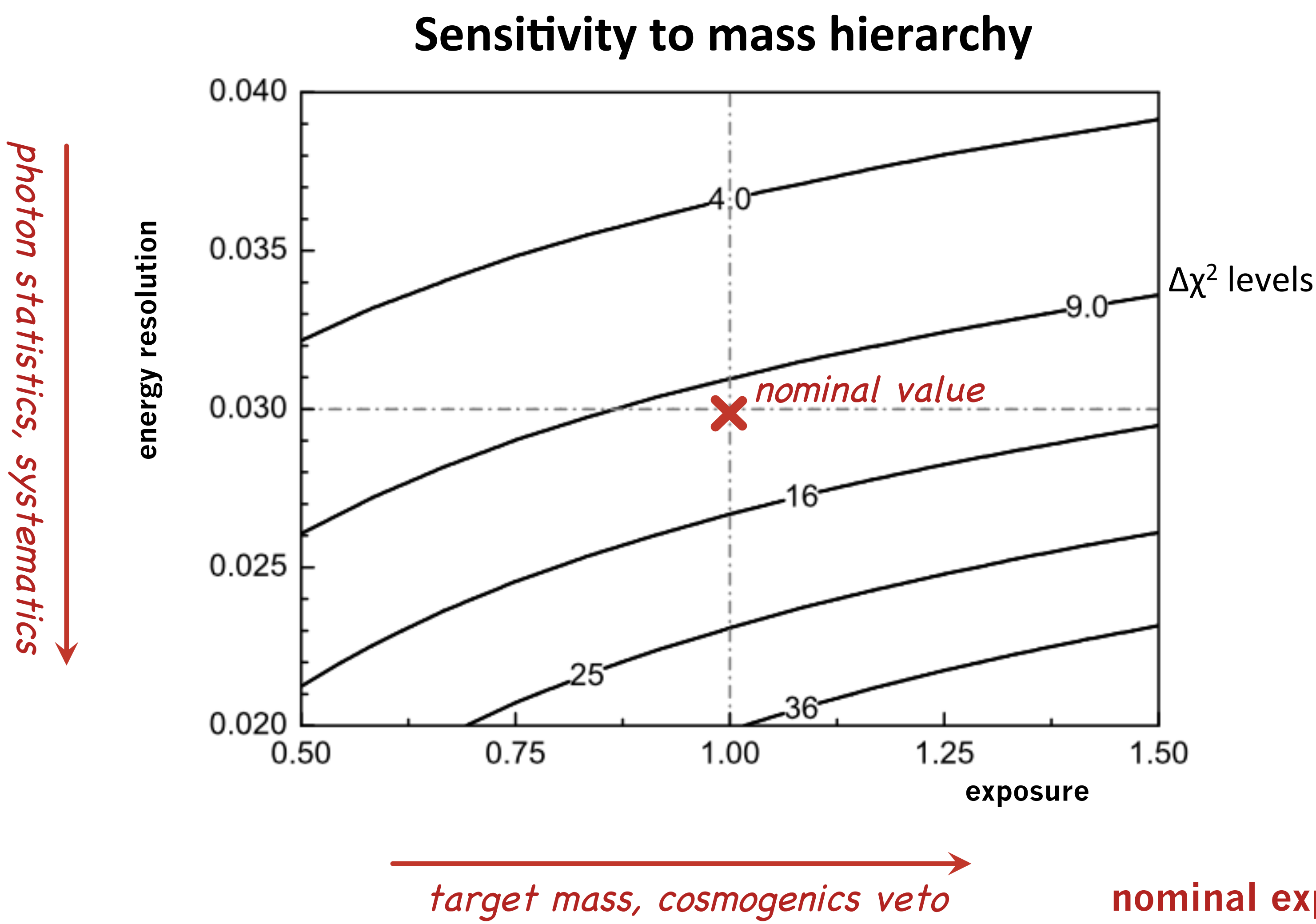
Simulated JUNO antineutrino spectrum (prompt energy) and the best fit



Source	Events/year
Geoneutrinos	408 ± 60
U chain	311 ± 55
Th chain	92 ± 37
Reactors	16100 ± 900
Fast neutrons	3.65 ± 3.65
^{9}Li - ^{8}He	657 ± 130
$^{13}C(\alpha, n)^{16}O$	18.2 ± 9.1
Accidental coincidences	401 ± 4

- Current (Borexino and KamLAND) precision on geoneutrino flux is ~25%
- JUNO can reach 17% precision within the first year and 6% after 10 years
- Geological study of the local crust: separate mantle contribution

Sensitivity: Energy resolution & exposure



nominal exposure

- 36 GW x 6 years x 20kt
- 80% IBD efficiency

Detector Resolution Requirement

parametrization for the detector energy resolution is defined as

$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{a}{\sqrt{E}}\right)^2 + b^2 + \left(\frac{c}{E}\right)^2} \,, \tag{2.12}$$

where the visible energy E is in the unit of MeV.

Based on the numerical calculation of sensitivity studies in terms of $\Delta\chi^2_{\mathrm{MH}}$, we find the approximate relation for the effects of non-stochastic terms (i.e., b, c) using the a term as,

$$\sqrt{\left(\frac{a}{\sqrt{E}}\right)^2 + b^2 + \left(\frac{c}{E}\right)^2} \simeq \sqrt{\left(\frac{a}{\sqrt{E}}\right)^2 + \left(\frac{1.6\,b}{\sqrt{E}}\right)^2 + \left(\frac{c}{1.6\,\sqrt{E}}\right)^2} \,, \tag{2.13}$$

which demonstrates that the effect of b is 1.6 times larger than the a term, and the non-trivial c term is less significant than a by a factor of 1.6. Therefore, a requirement for the resolution of $a/\sqrt{E}$ better than 3% is equivalent the following requirement,

$$\sqrt{(a)^2 + (1.6 \times b)^2 + \left(\frac{c}{1.6}\right)^2} \leq 3\% \,. \tag{2.14}$$