

JUNO Experiment

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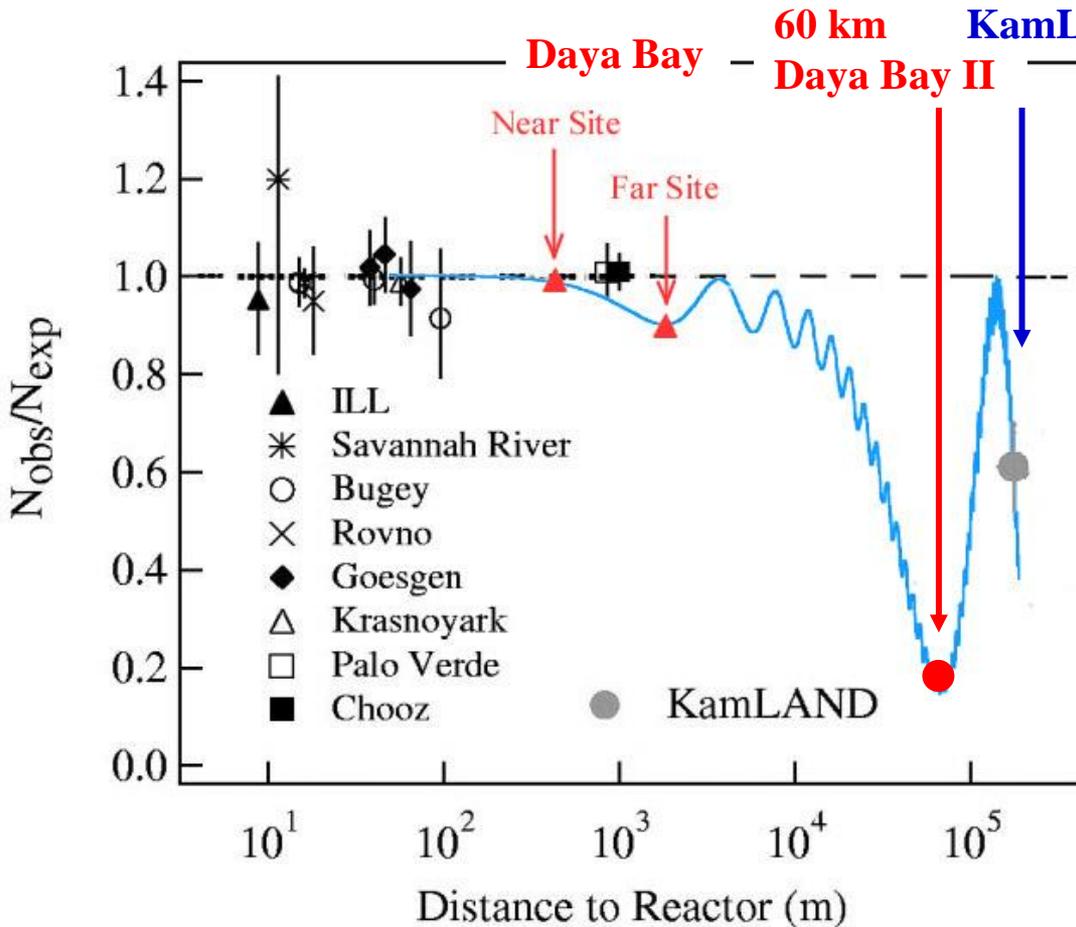
Paris, June 23, 2014

- ◆ **Q1. (Theoretical relevance) What is according to you the theoretical relative urgency of the determination of the**
 - ⇒ **Neutrino mass hierarchy,**
 - ⇒ **PMNS CP violating phase δ ,**
 - ⇒ **θ_{23} octant**
 - ⇒ **existence of sterile neutrinos**
 - ⇒ **Dirac vs Majorana nature of the neutrino**

Compare, if relevant, to other attempts of measurement direct or indirect (e.g. in cosmology). Describe also synergies with other topics of science e.g. proton decay or neutrino astrophysics (supernova burst and relic, solar neutrinos,...).

- ◆ **Answer: All, but we can only do mass hierarchy. Probably a little bit on sterile neutrinos. See next slides.**

The JUNO Experiment



- ◆ 20 kton LS detector
- ◆ 3% energy resolution
- ◆ Rich physics possibilities
 - ⇒ Mass hierarchy
 - ⇒ Precision measurement of 4 mixing parameters
 - ⇒ Supernovae neutrinos
 - ⇒ Geoneutrinos
 - ⇒ Sterile neutrinos
 - ⇒ Atmospheric neutrinos
 - ⇒ Exotic searches

Talk by Y.F. Wang at ICFA seminar 2008, Neutel 2011; by J. Cao at Nutel 2009, NuTurn 2012 ;
 Paper by L. Zhan, Y.F. Wang, J. Cao, L.J. Wen, PRD78:111103,2008; PRD79:073007,2009

Location of JUNO

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

Overburden ~ 700 m

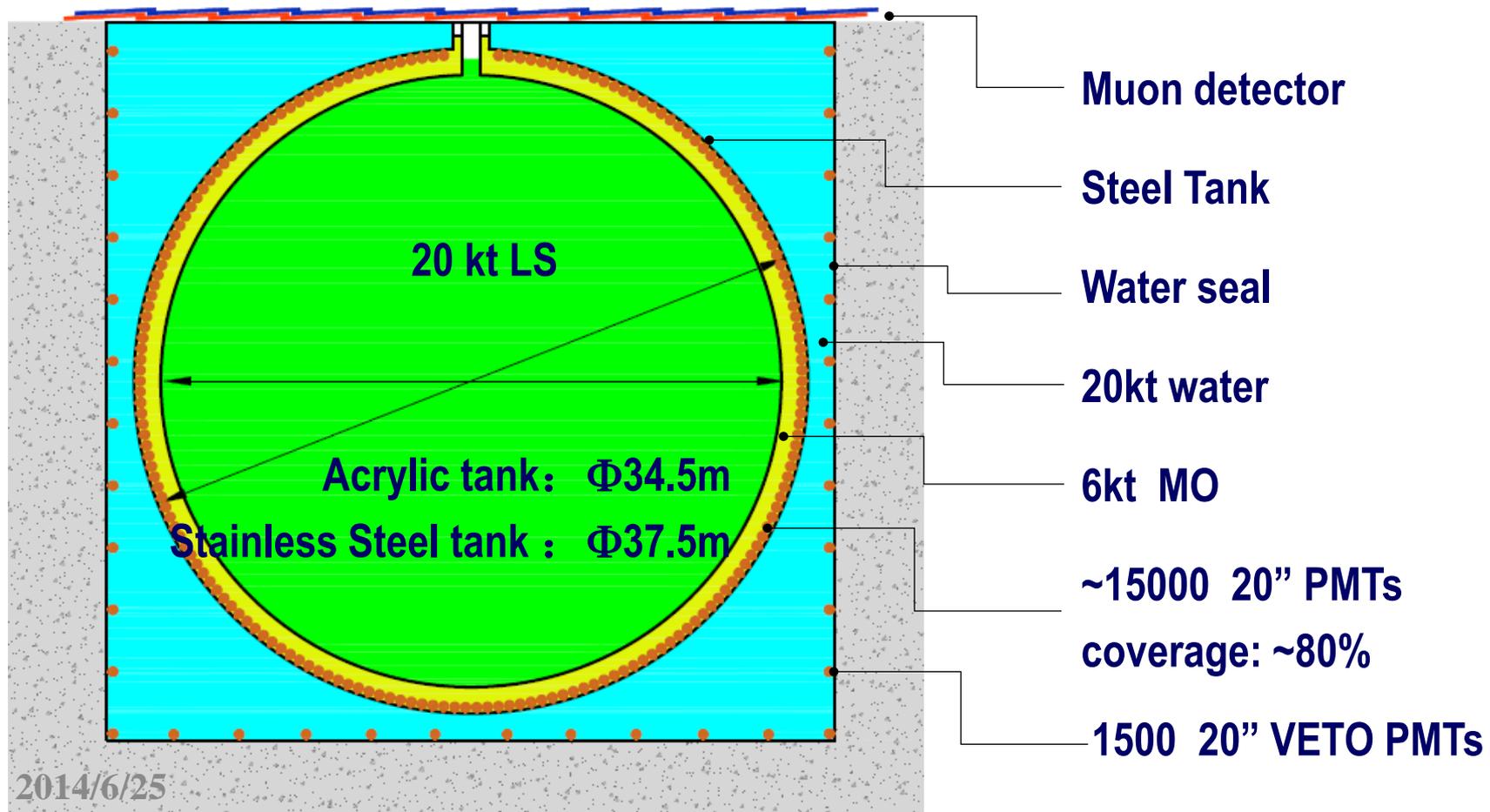


- ◆ **Q4. (Site issues)** What are the optimisation criteria for the site you propose? What is the regional support for the site you propose? Is your proposal site specific? Could the same or better performances be obtained in another site in the same continent or some other region?
- ◆ **Answer:** The Juno site is the best one, at least in China, thanks to the huge power of reactors, the mountain and good rock at the right place. We also get very good support from the local government.

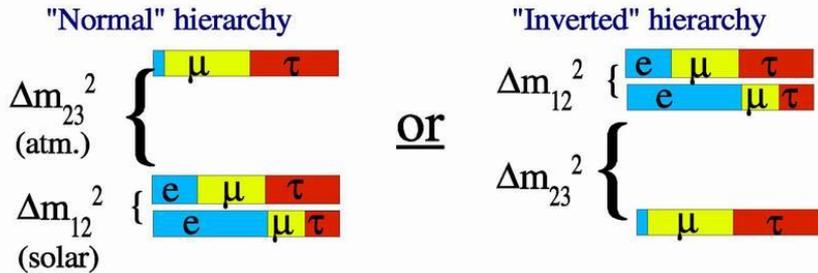
- ◆ **Q2. (Experimental Strategy)** What is according to you the experimental strategy that needs to be deployed worldwide in order to answer the above questions? And in particular, how many experiments should there be worldwide, what complementarities or double check features should they exhibit? In this world-wide context describe the phases of your project, its timeline and the expected statistical significance per phase. Discuss the relevant systematics, how well you know them and in particular do you need any supporting measurements to further determine them?
- ◆ **Answer: See next slides**

The plan: a large LS detector

- LS volume: $\times 20 \rightarrow$ for more statistics (40 events/day)
- light(PE) $\times 5 \rightarrow$ for better resolution ($\Delta M^2_{12} / \Delta M^2_{23} \sim 3\%$)



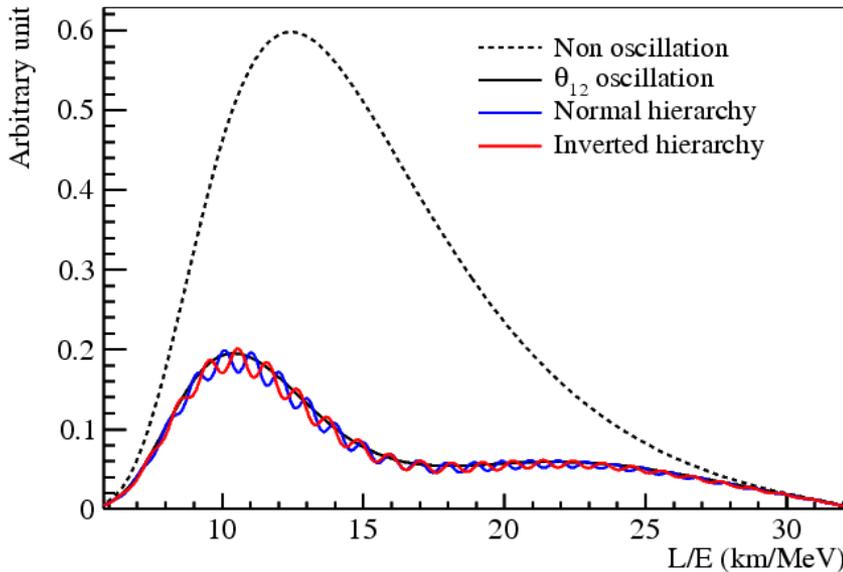
Mass Hierarchy at Reactors



$$\Delta m_{31}^2 = \Delta m_{32}^2 + \Delta m_{21}^2$$

NH : $|\Delta m_{31}^2| = |\Delta m_{32}^2| + |\Delta m_{21}^2|$

IH : $|\Delta m_{31}^2| = |\Delta m_{32}^2| - |\Delta m_{21}^2|$

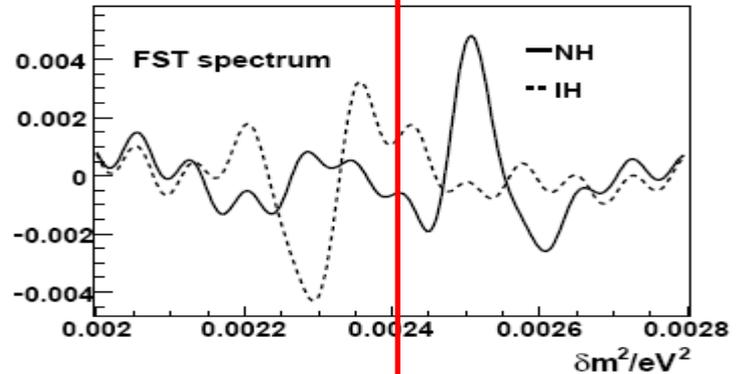
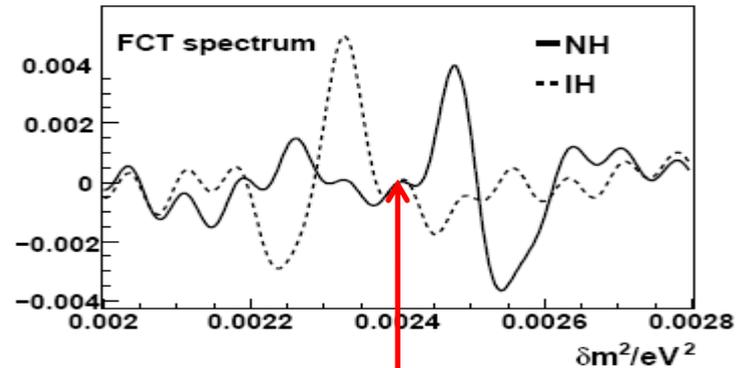


$$P_{ee}(L/E) = 1 - P_{21} - P_{31} - P_{32}$$

$$P_{21} = \cos^4(\theta_{13}) \sin^2(2\theta_{12}) \sin^2(\Delta_{21})$$

$$P_{31} = \cos^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{31})$$

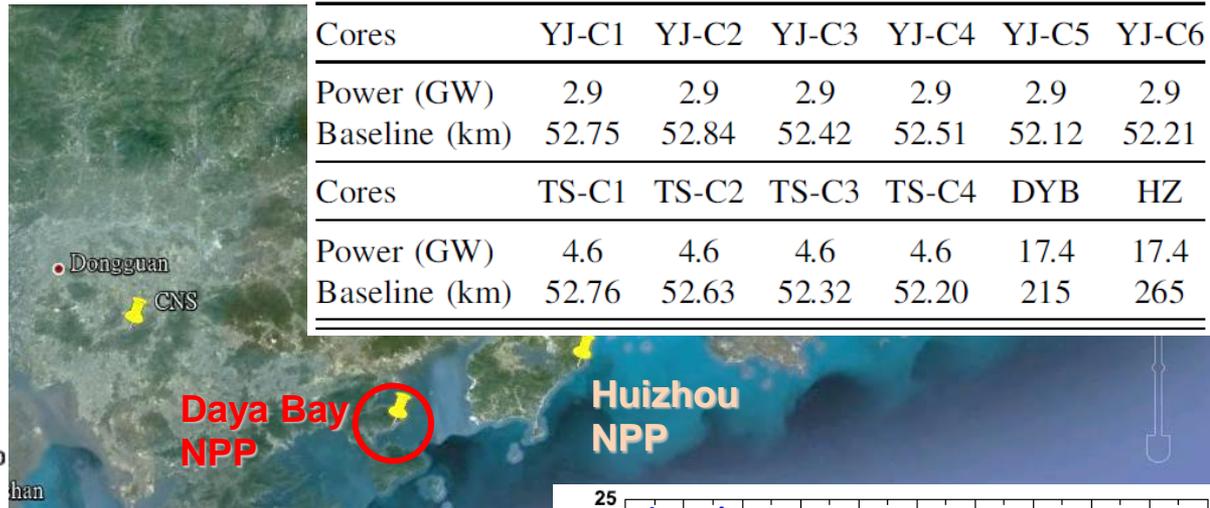
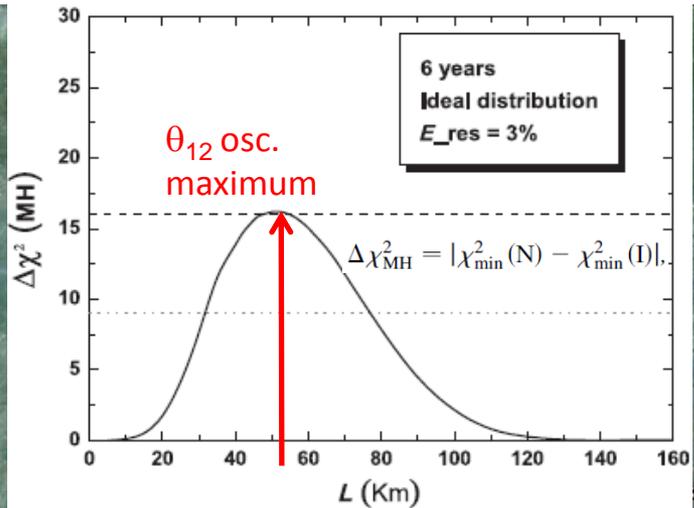
$$P_{32} = \sin^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{32})$$



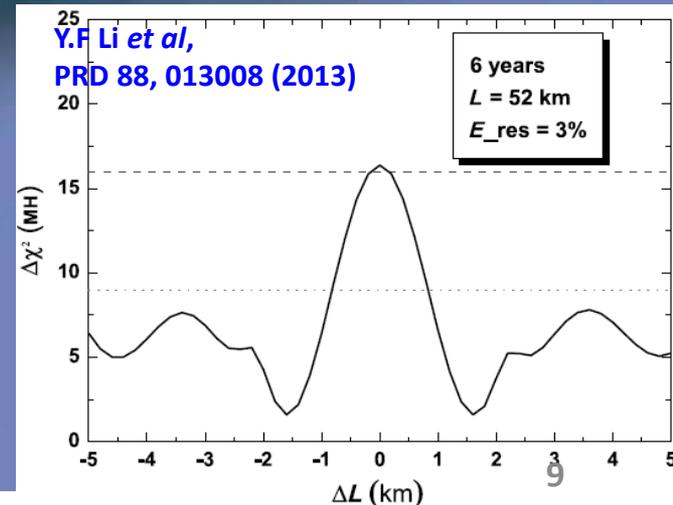
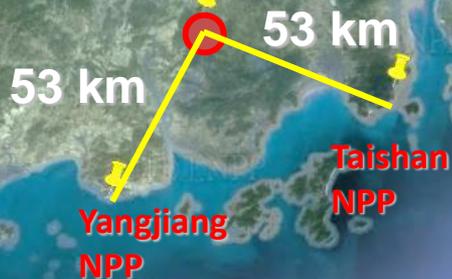
ΔM_{23}^2

Optimum baseline for MH

- Optimum at the oscillation maximum of θ_{12}
- Multiple reactors may cancel the oscillation structure
 - Baseline difference cannot be more than 500 m



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



Energy scale can be self-calibrated

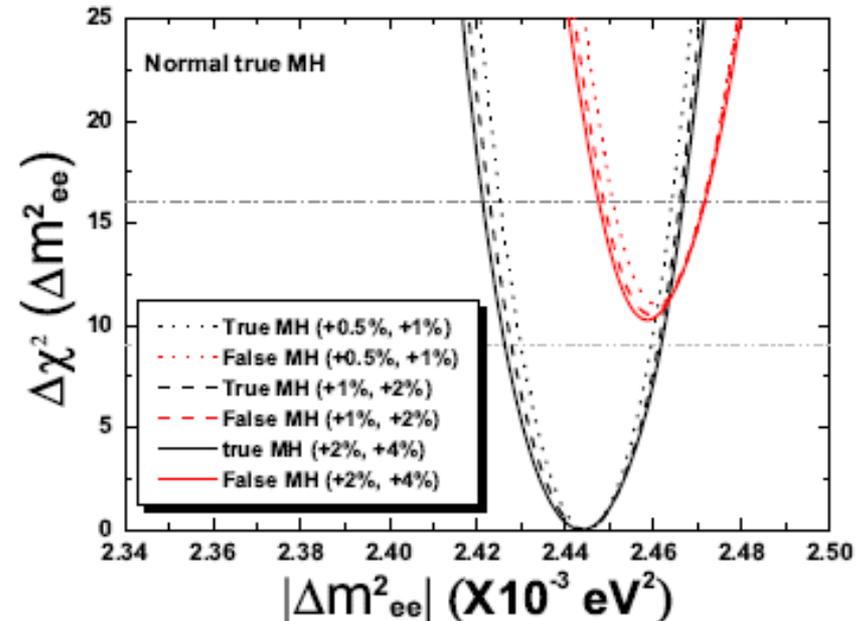
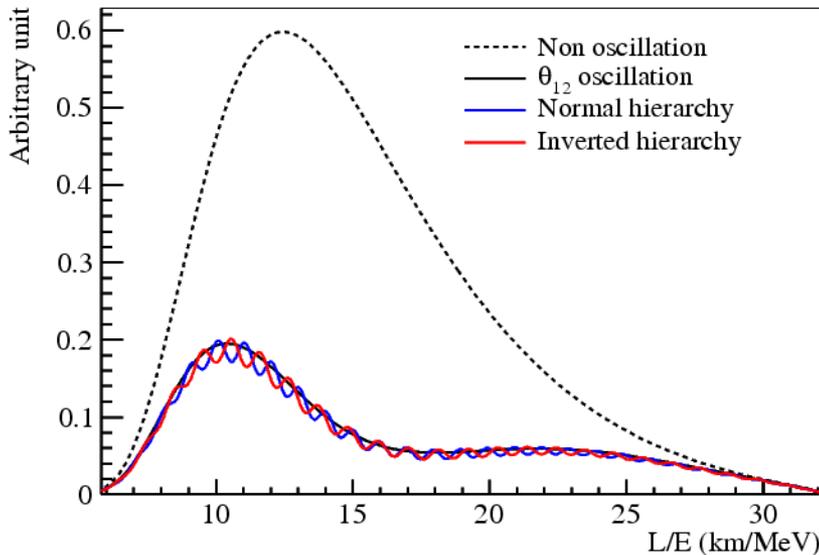
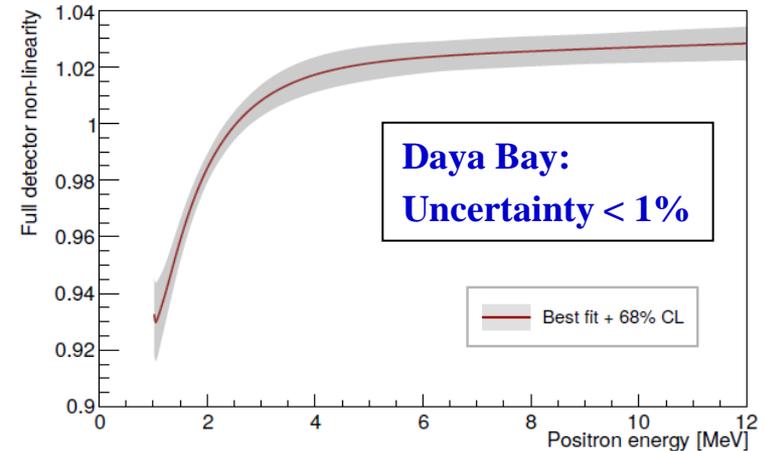
If we have a residual non-linearity:

$$\frac{E_{\text{rec}}}{E_{\text{true}}} \simeq 1 + q_0 + q_1 E_{\text{true}} + q_2 E_{\text{true}}^2,$$

by introduce a self-calibration (based on ΔM^2_{ee} peaks):

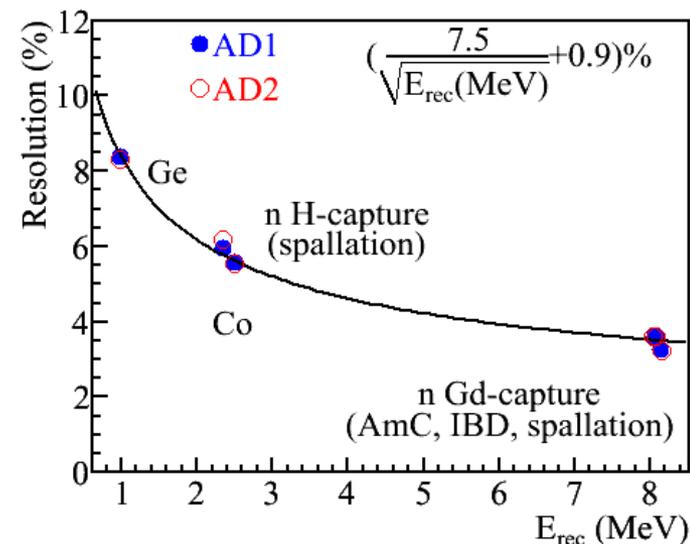
$$\chi^2_{\text{NL}} = \sum_{i=0}^2 q_i^2 / (\delta q_i)^2$$

effects can be corrected and sensitivity is un-affected

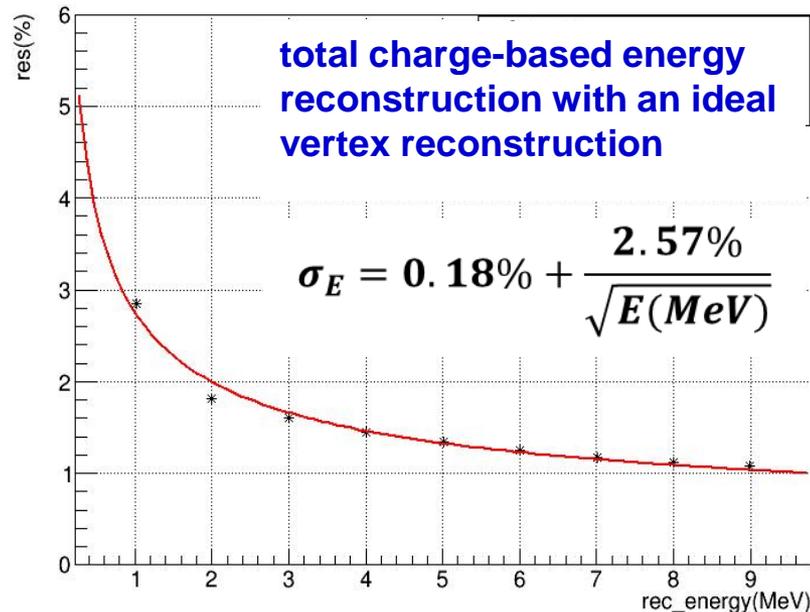
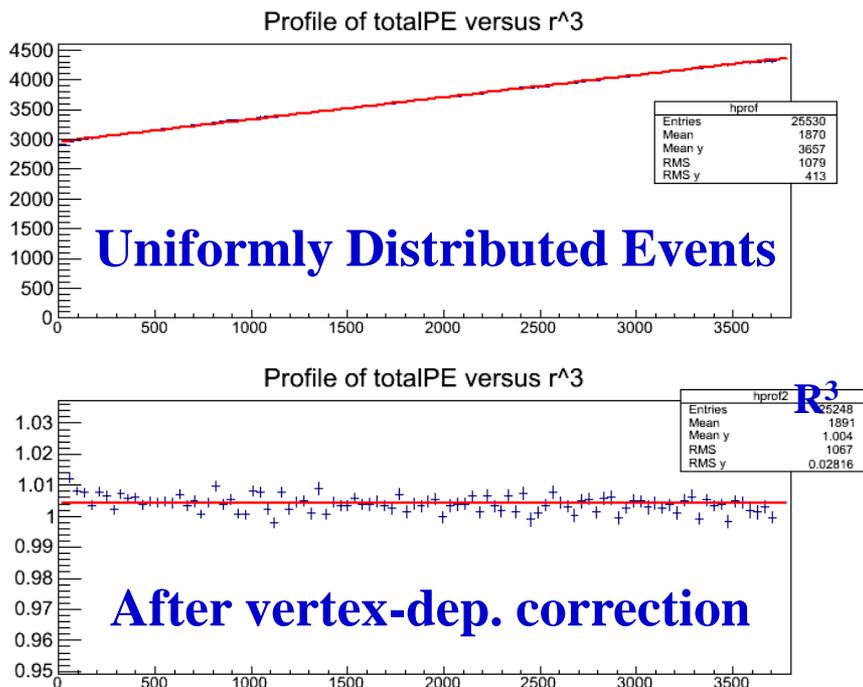


MC example: Energy Resolution

- ◆ Based on DYB MC (tuned to data), except
 - ⇒ JUNO Geometry and 80% photocathode coverage
 - ⇒ PMT QE from 25% → 35%
 - ⇒ Attenuation length (1m-tube measurement@430nm)
 - ✓ from 15m = abs. 30 m + Rayleigh scatt. 30 m
 - ✓ to 20 m = abs. 60 m + Rayleigh scatt. 30m



energy resolution vs rec_energy



Signals & Backgrounds

◆ Estimated IBD signal event rate: ~40/day

◆ LS without Gd-loading for

$\tau \sim 200 \mu\text{s}$

⇒ Better attenuation length → better resolution

⇒ Lower irreducible accidental backgrounds from LS, important for a larger detector:

✓ With Gd: $\sim 10^{-12}$ g/g → 50,000 Hz

✓ Without Gd: $\sim 10^{-16}$ g/g → 5 Hz

◆ Backgrounds

Overburden 700m:

$E_\mu \sim 211$ GeV, $R_\mu \sim 3.8$ Hz

Single rates:

5 Hz by LS and 5Hz by PMT

Good muon tracking

muon efficiency $\sim 99.5\%$

	B/S @ DYB EH1	B/S @ JUNO	Techniques to be used by JUNO
Accidentals	~1.4%	~10%	Low PMT radioactivity; LS purification; prompt-delayed distance cut
Fast neutron	~0.1%	~0.4%	High muon detection efficiency (similar as DYB)
${}^9\text{Li}/{}^8\text{He}$	~0.4%	~0.8%	Muon tracking; If good track, distance to muon track <5m and veto 2s; If shower muon, full volume veto 2s

Physics Reach

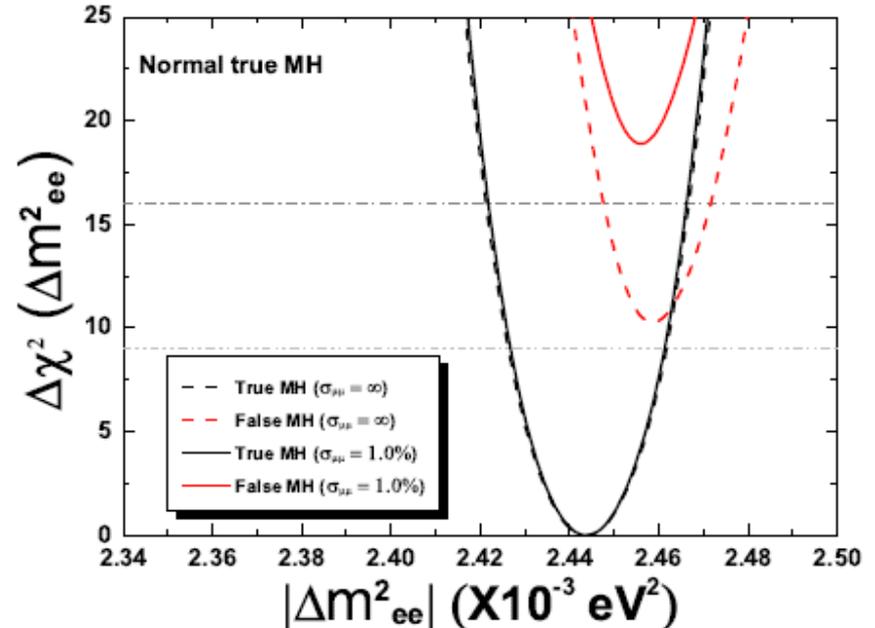
Thanks to a large θ_{13}

For 6 years,

◆ Ideally, The relative measurement can reach a sensitivity of 4σ , while the absolute measurement (with the help of $\Delta m^2_{\mu\mu} \sim 1\%$) can reach 5σ

◆ Due to reactor core distributions, relative measurement can reach a sensitivity of 3σ , while the absolute measurement can reach 4σ

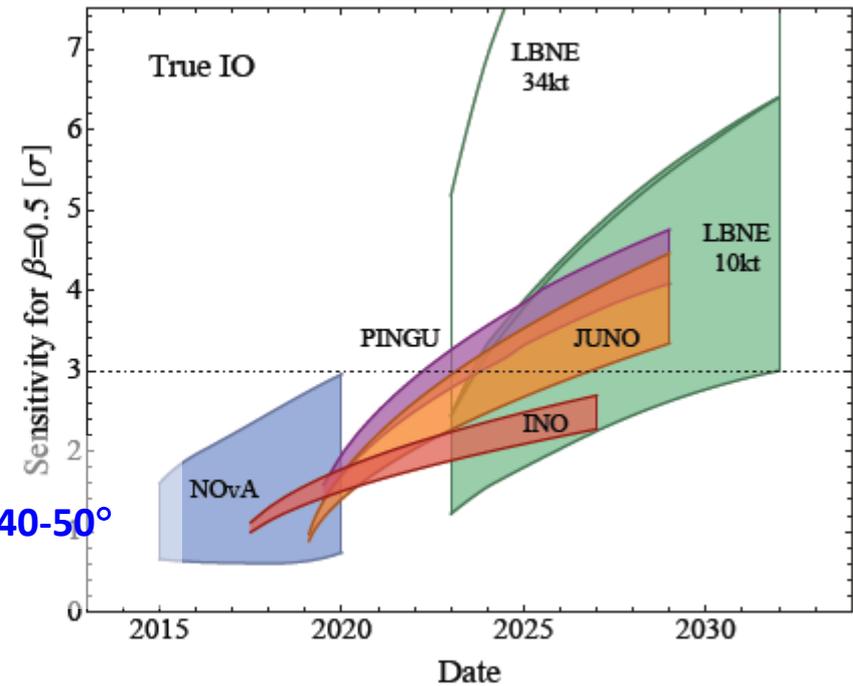
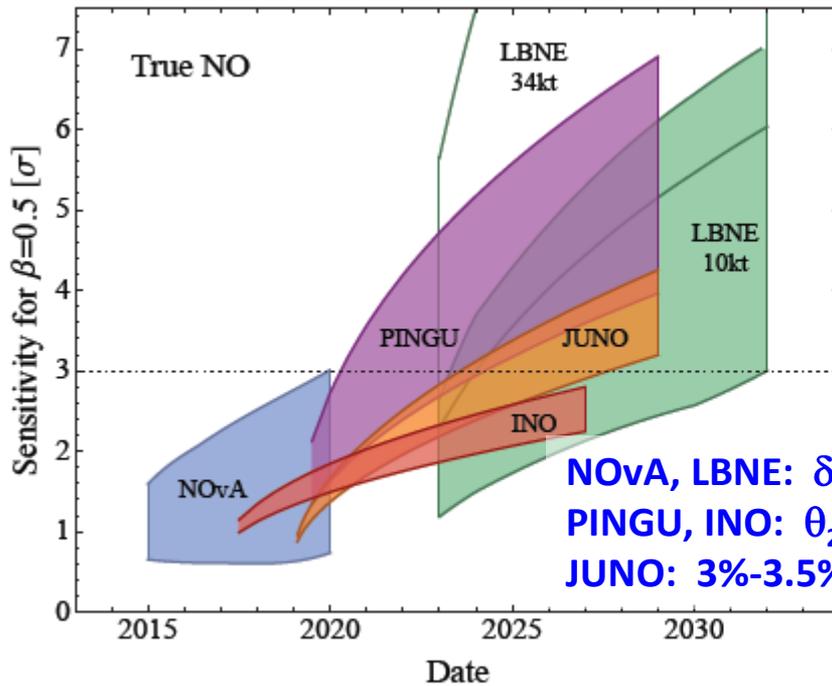
Detector size: 20kt LS
Energy resolution: $3\%/\sqrt{E}$
Thermal power: 36 GW



Y.F. Li et al., arXiv:1303.6733

Comparison with Other Experiments

M. Blennow et al., JHEP 1403 (2014) 028



- **JUNO is unique for measuring MH using reactor neutrinos**
 - Independent of the CP phase and free from the matter effect: complementary to accelerator-based experiments
 - competitive in time
- **Many other science goals:**

Precision Measurement of Mixing Parameters

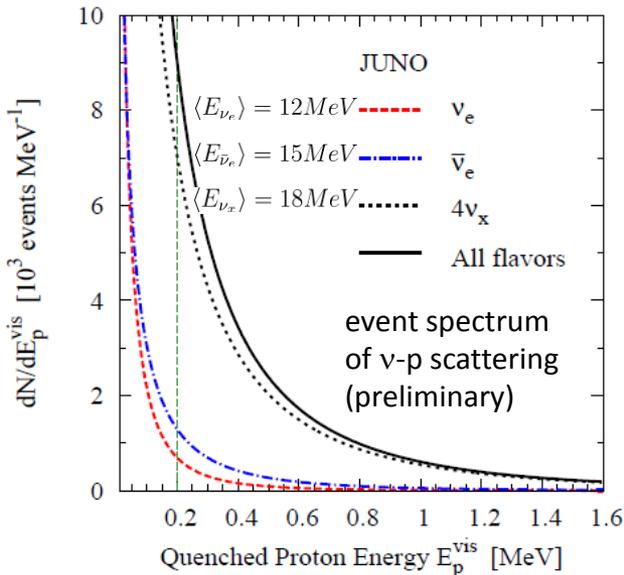
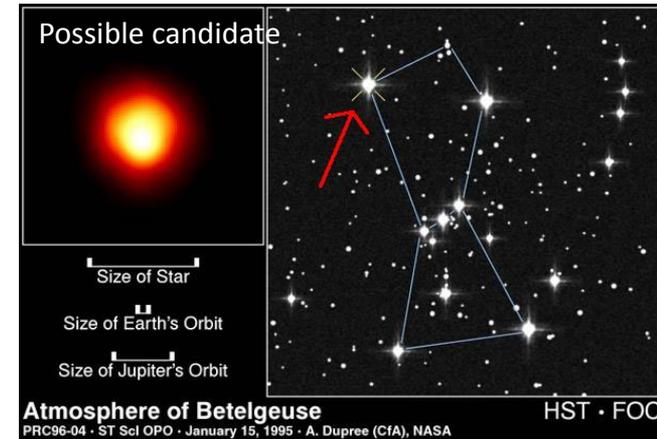
- ◆ **Fundamental to the Standard Model and beyond**
- ◆ **Probing the unitarity of U_{PMNS} to $\sim 1\%$ level !**
 - ⇒ **Uncertainty from other oscillation parameters and systematic errors, mainly energy scale, are included**

	Current	Daya Bay II
Δm^2_{12}	3%	0.6%
Δm^2_{23}	5%	0.6%
$\sin^2\theta_{12}$	6%	0.7%
$\sin^2\theta_{23}$	14%	N/A
$\sin^2\theta_{13}$	10% → 4%	~ 15%

Will be more precise than CKM matrix elements !

Supernova neutrinos in Giant LS detector

- Less than 20 events observed so far
- Assumptions:
 - Distance: 10 kpc (our Galaxy center)
 - Energy: 3×10^{53} erg
 - L_ν the same for all types



Estimated numbers of neutrino events in JUNO (preliminary)

Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\bar{\nu}_e + p \rightarrow e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \rightarrow \nu + p$	NC	6.0×10^2	1.2×10^3	2.0×10^3
$\nu + e \rightarrow \nu + e$	NC	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}\text{C} \rightarrow \nu + {}^{12}\text{C}^*$	NC	1.7×10^2	3.2×10^2	5.2×10^2
$\nu_e + {}^{12}\text{C} \rightarrow e^- + {}^{12}\text{N}$	CC	4.7×10^1	9.4×10^1	1.6×10^2
$\bar{\nu}_e + {}^{12}\text{C} \rightarrow e^+ + {}^{12}\text{B}$	CC	6.0×10^1	1.1×10^2	1.6×10^2

LS detector vs. Water Cerenkov detectors:
much better detection to these correlated events

→ Measure energy spectra & fluxes of almost all types of neutrinos

Other Physics with Giant LS detector

- **Geo-neutrinos**

- **Current results:**

- KamLAND: 30 ± 7 TNU (*PRD 88 (2013) 033001*)**

- Borexino: 38.8 ± 12.0 TNU (*PLB 722 (2013) 295*)**

- **Desire to reach an error of 3 TNU:
statistically dominant**

- **JUNO:**

- **$\times 10$ statistics**
 - **Huge reactor neutrino backgrounds**
 - **Expectation: $? \pm 10\% \pm 10\%$**

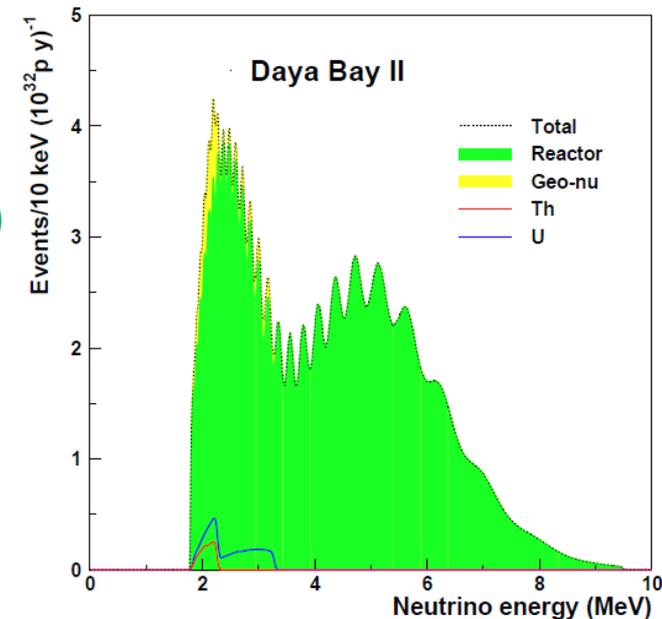
- **Solar neutrinos**

- **need LS purification, low threshold**
 - **background handling (radioactivity, cosmogenic)**

- **Atmosphere neutrinos**

- **Nucleon Decay**

- **Sterile neutrinos**

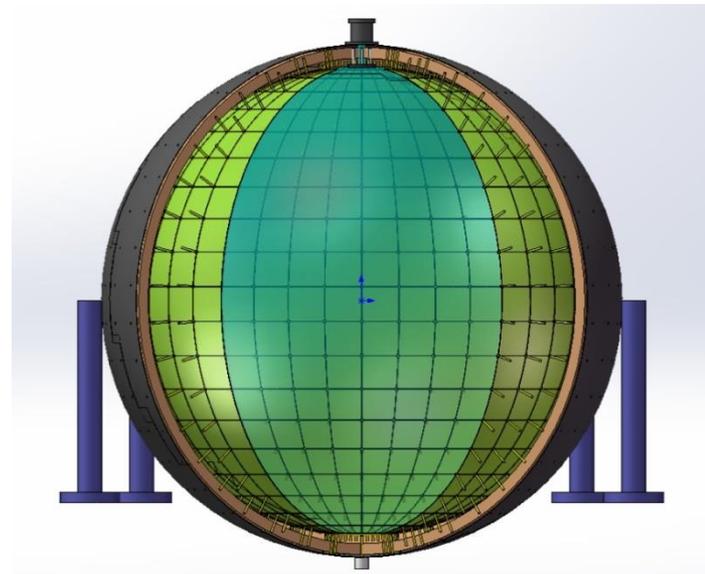
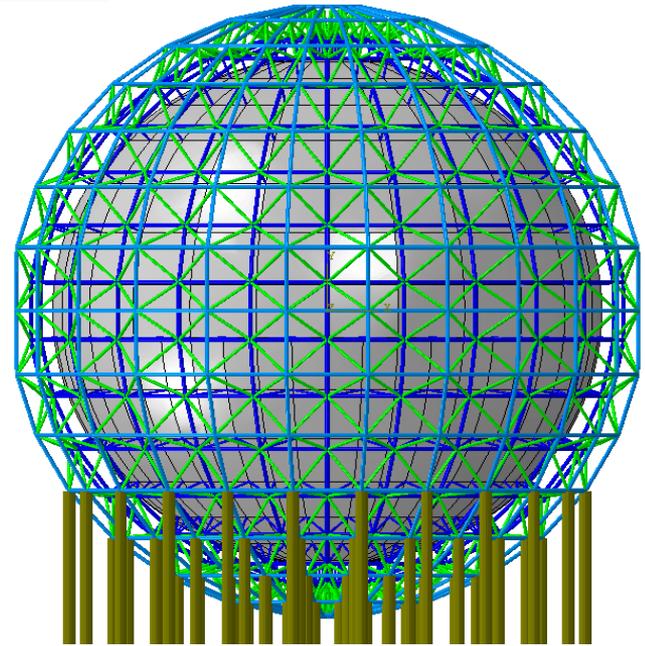


Stephen Dye @Neutrino 2012

- ◆ **Q3. (Experimental readiness)** Evaluate the readiness of the technology you are planning to use. Describe the phases (or R&D) towards its final validation. What are the risks associated. Is there place for global sharing and coordination of the R&D or validation effort? Are there industrial issues e.g. in procurement?
- ◆ **Answer: See next slides**

Central Detector

- ◆ **A huge detector in the water pool:**
 - ⇒ Mechanics, optics, chemistry, ...
 - ⇒ How to keep it clean during and after the assembly ?
 - ⇒ Possibility of assembly within 2 years
- ◆ **Current design:**
 - ⇒ **Default: acrylic tank(D~35m) + SS structure**
 - ✓ **Acrylic bonding, creeping, stress, steel support at acrylic, deformation, event reconstruction with total refraction, ...**
 - ⇒ **Backup: SS tank(D~38m) + acrylic panel + balloon**
 - ✓ **Balloon materials, cleanness, leaks, deployment, ...**
- ◆ **R&D and prototyping underway**



Liquid Scintillator

◆ **Current Choice: LAB+PPO+BisMSB**

◆ **Requirements & works:**

⇒ **Long attenuation length: 15m → 30m**

- ✓ **Improve raw materials**
- ✓ **Improve the production process**
- ✓ **Purification**
 - **Distillation, Filtration, Water extraction, Nitrogen stripping...**

⇒ **High light yield: Optimization of PPO & BisMSB concentration**

◆ **Other works:**

⇒ **Rayleigh scattering length**

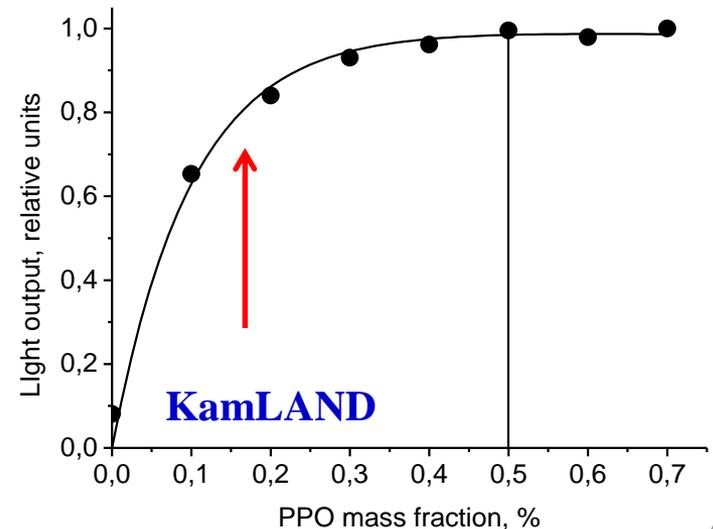
⇒ **Energy non-linearity**

⇒ **Aging**

⇒ **Engineering issues: equipment & handling for 20kt**

⇒ **Raw material selection: BKG & purity issues**

Linear Alky Benzene	Atte. L(m) @ 430 nm
RAW	14.2
Vacuum distillation	19.5
SiO₂ coloum	18.6
Al₂O₃ coloum	22.3
LAB from Nanjing, Raw	20
Al₂O₃ coloum	25



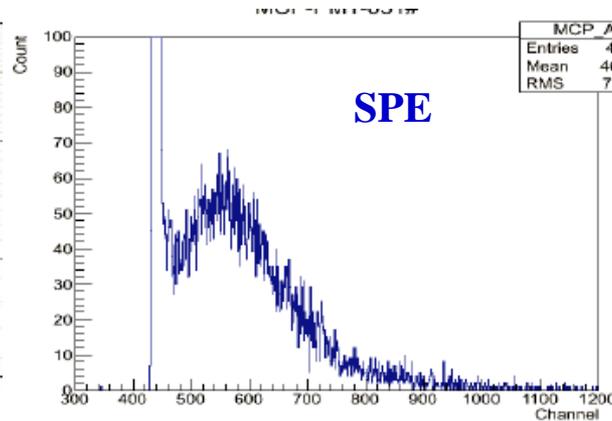
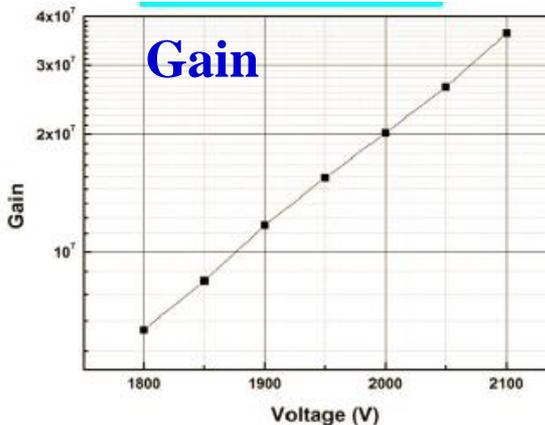
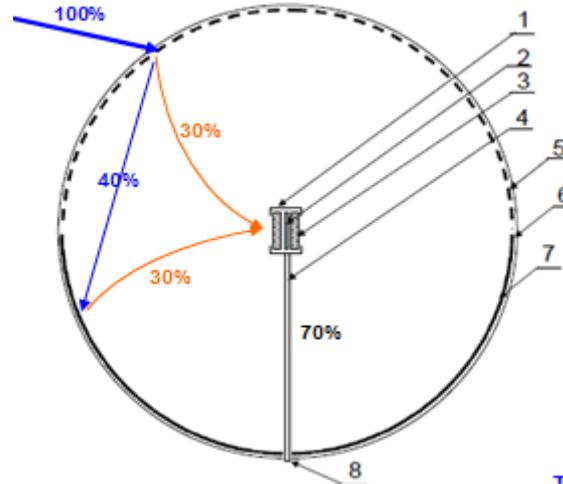
High QE PMT

◆ Three types of high QE 20” PMTs under development:

- ⇒ New MCP-PMT: 4π collection
- ⇒ Hamamatsu R5912-100 with SBA photocathode
- ⇒ Photonics-type PMT

◆ MCP-PMT by Chinese industry:

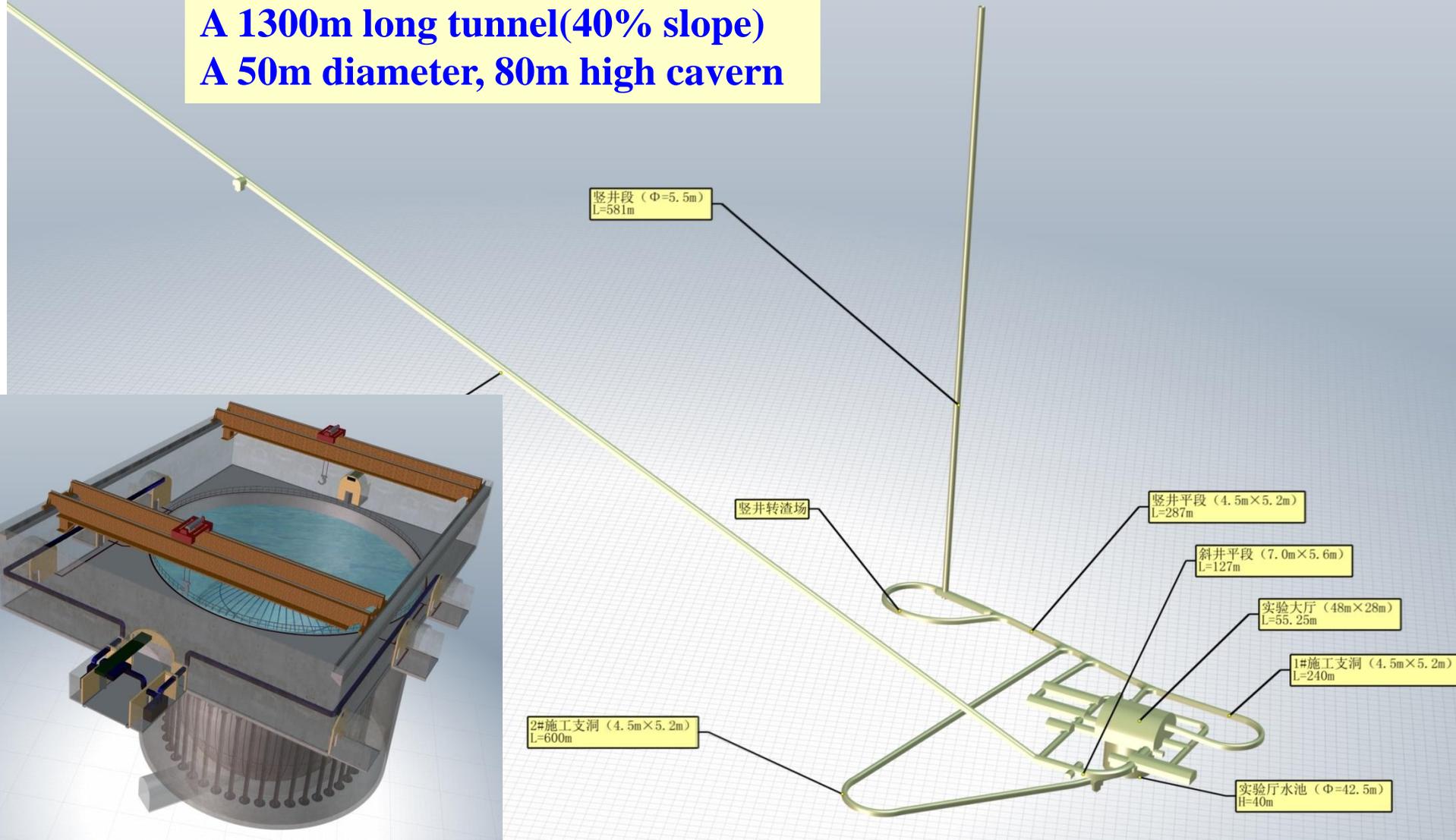
- ⇒ Technical issues mostly resolved
- ⇒ Successful 8” prototypes
- ⇒ A few 20” prototypes



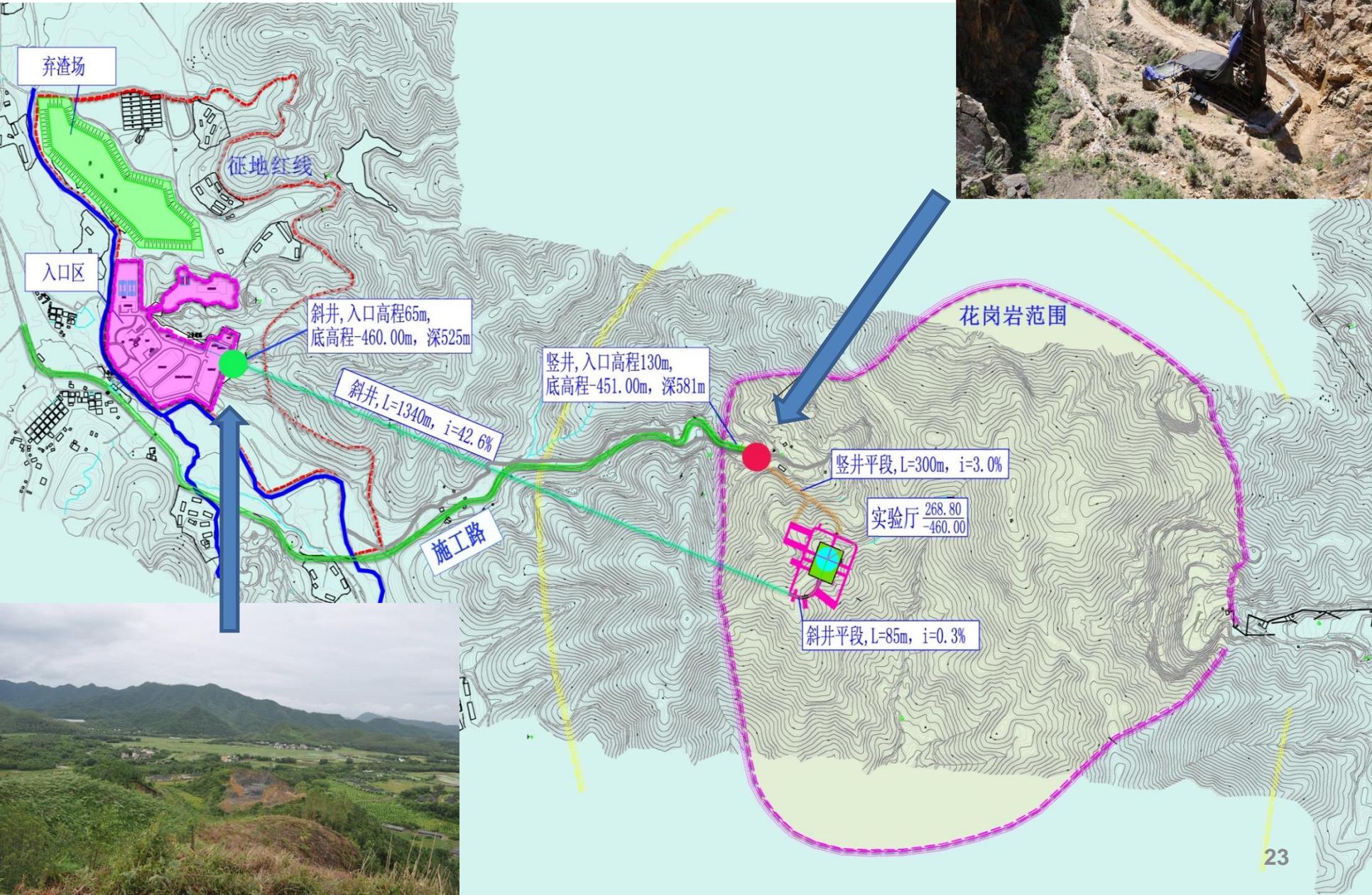
	R5912	R5912-100	MCP-PMT
QE@410nm	25%	>30%	25-30%
Rise time	3 ns	3.4ns	5ns
SPE Amp.	17mV	18mV	17mV
P/V of SPE	>2.5	>2.5	~ 2
TTS	5.5ns	1.5 ns	3.5 ns

Civil Construction

A 600m vertical shaft
A 1300m long tunnel(40% slope)
A 50m diameter, 80m high cavern



Layout



Current Design: Surface Buildings



Dorm

**Office &
control
room**

**LS storage,
mixing &
purification**

Dorm

**Tunnel entrance,
Assembly →
exhibition**

Storage

Current Status & Brief Schedule

- ◆ Project approved by CAS for R&D and design
- ◆ Geological survey completed
 - ⇒ Granite rock, tem. ~ 31 °C, little water
- ◆ EPC contract signed:
 - ⇒ Engineering design by July
 - ⇒ Construction work by Nov.
- ◆ Paper work towards the construction:
 - ⇒ Land, environment, safety, ...

Schedule:

Civil preparation: 2013-2014

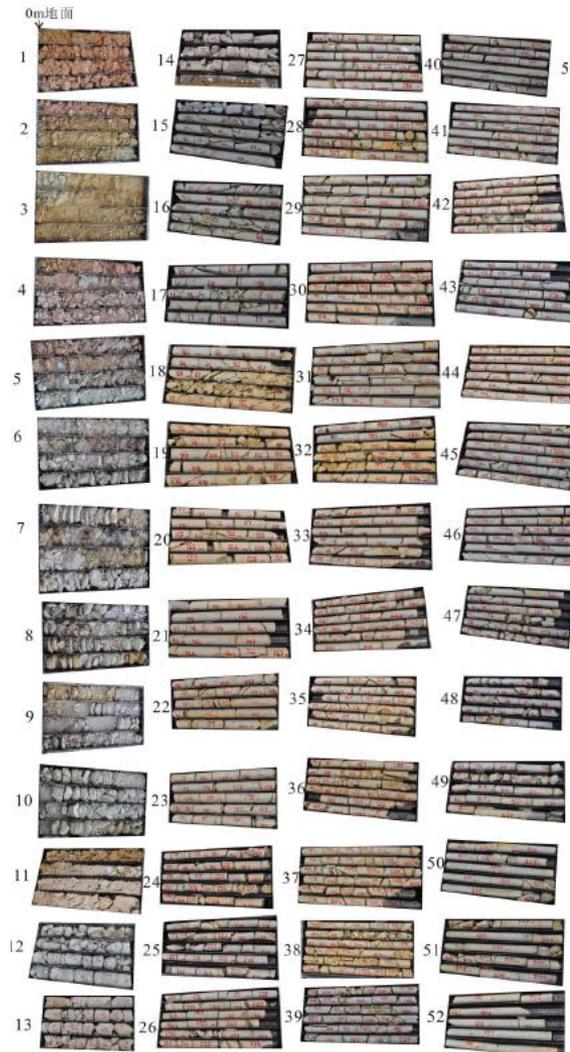
Civil construction: 2014-2017

Detector component production: 2016-2017

PMT production: 2016-2019

Detector assembly & installation: 2018-2019

Filling & data taking: 2020



◆ **Q5. (Financial and internationalisation issues)** What is the cost of the experimental configuration (beam where relevant and detector)? What is your financial plan? What is the current level of international participation and what level of participation would be necessary to move to a construction decision? What models would you propose for international participation and at which parts of the beam or detectors? What would be the parts of the configuration whose leadership you would be willing to negotiate in exchange of international participation ?

◆ **Answer:**

- ⇒ The experiment costs in total of ~ 300 M\$. It will be funded mostly by CAS via a special program (2010-2020).
- ⇒ International participation is warmly welcome. Contribution is hoped to exceed ~ 20%.
 - ✓ Civil: 1/4, China
 - ✓ Detector: 2/4 China, 1/4 International

International collaboration

- ◆ **Proto-collaboration since 2013, meeting every 6 months**
 - Czech, Italy, France, Germany, Russia, US, ...
 - Double Chooz, Borexino, LENA, Daya Bay, Hanohano, OPERA, ...
- ◆ **Formal collaboration this summer**
- ◆ **Welcome more collaborators**



Welcome to Kaiping

