JUNO Experiment

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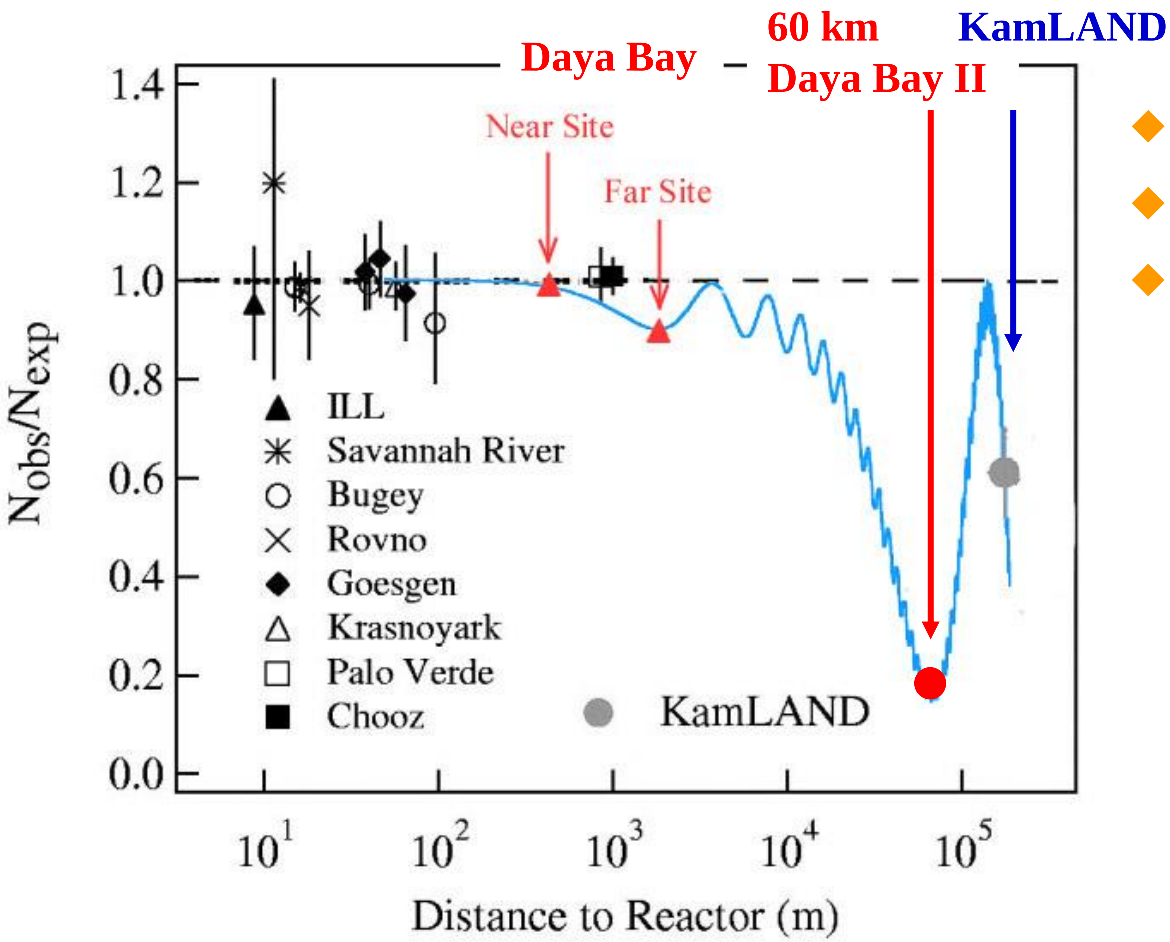
- **Q1. (Theoretical relevance) What is according to you the theoretical relative urgency of the determination of the**
  - **Neutrino mass hierarchy,**
  - **PMNS CP violating phase δ,**
  - **θ_{23} octant**
  - **existence of sterile neutrinos**
  - **Dirac vs Majorana nature of the neutrino**

  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

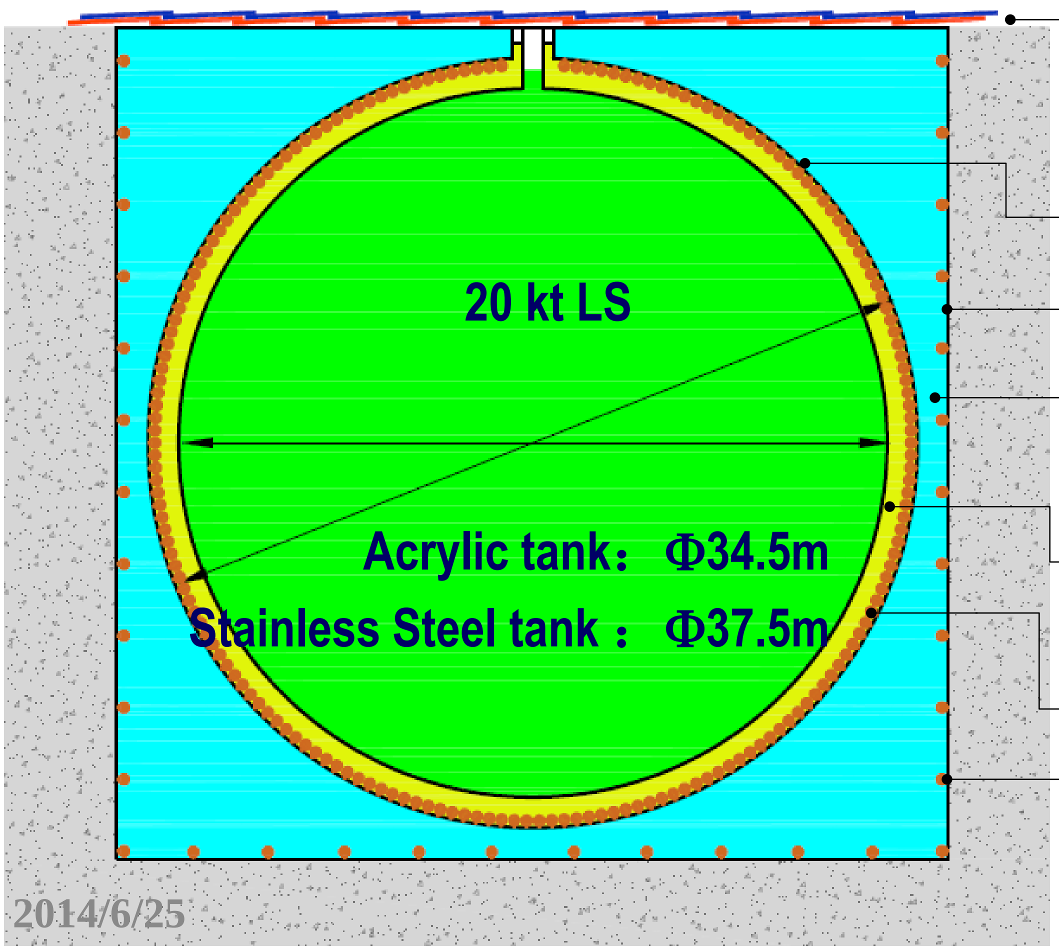
NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW

- **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.**

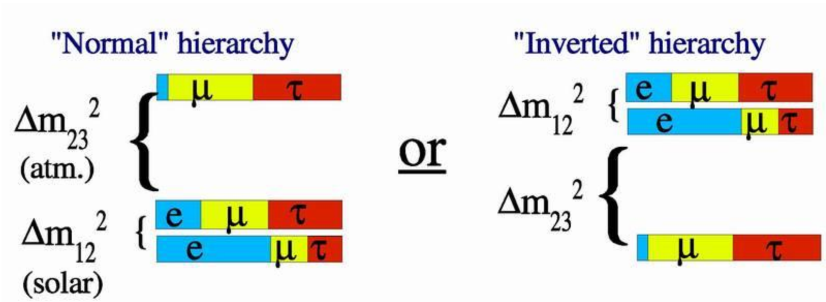
- **Q2. (Experimental Strategy) What is according to you the experimental strategy that needs to be deployed worldwide in order to answer the above questions? And in particular, how many experiments should there be worldwide, what complementarities or double check features should they exhibit? In this 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

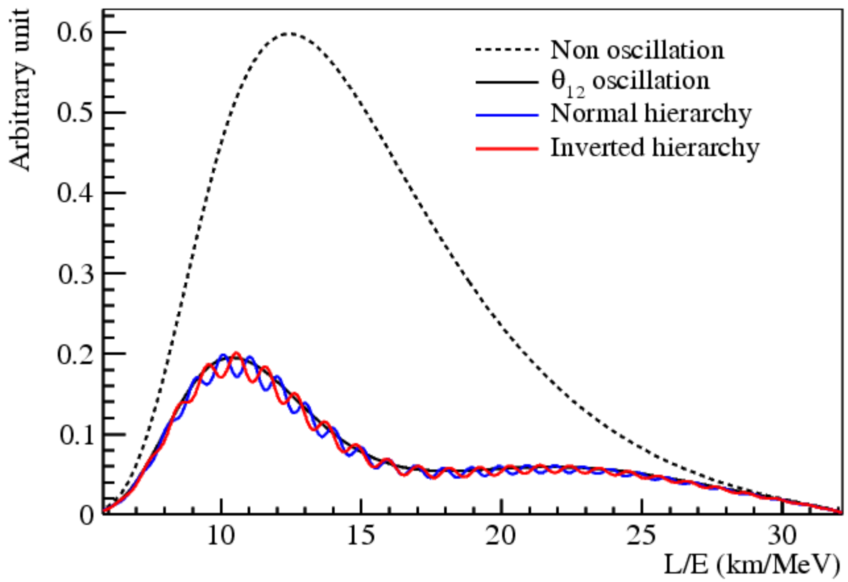
- LS volume: × 20 ➔ for more statistics (40 events/day)
- light(PE) × 5 ➔ for better resolution ($\Delta M^2_{12} / \Delta M^2_{23}$ ~ 3%)

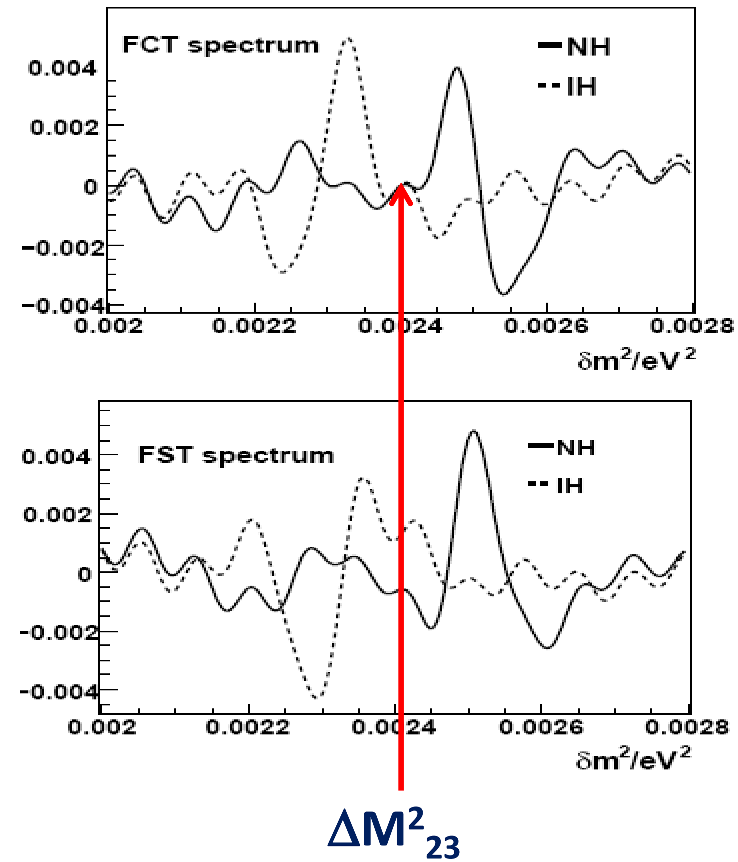


Mass Hierarchy at Reactors



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



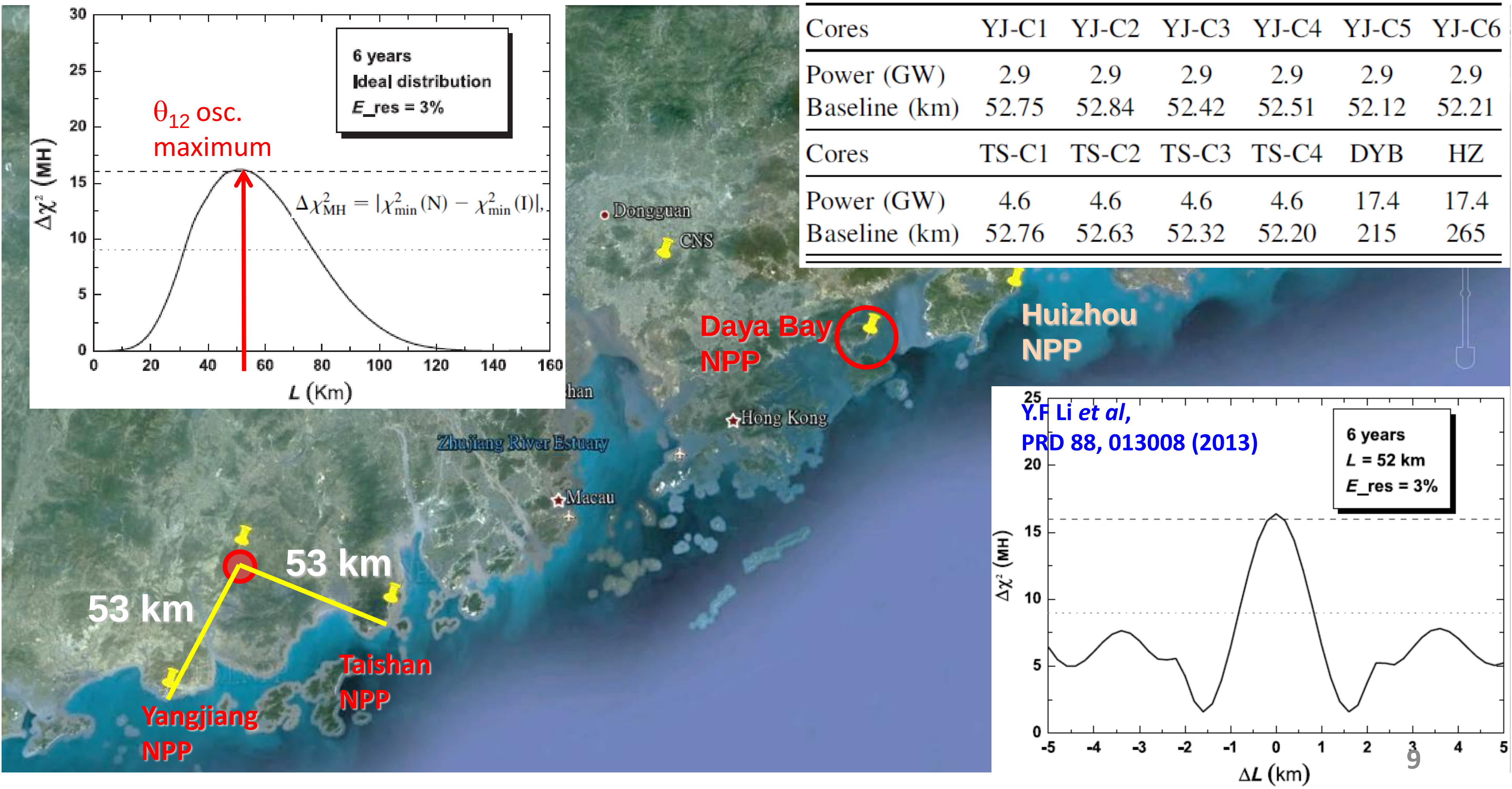


$$P_{ee}(L/E) = 1 - P_{21} - P_{31} - P_{32}$$
$$P_{21} = \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21})$$
$$P_{31} = \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31})$$
$$P_{32} = \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32})$$

L. Zhan et al., PRD78:111103,2008; PRD79:073007,2009

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

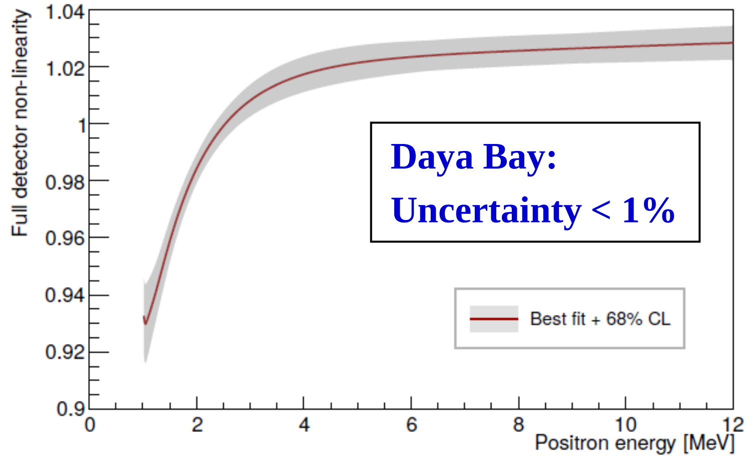
If we have a residual non-linearity:

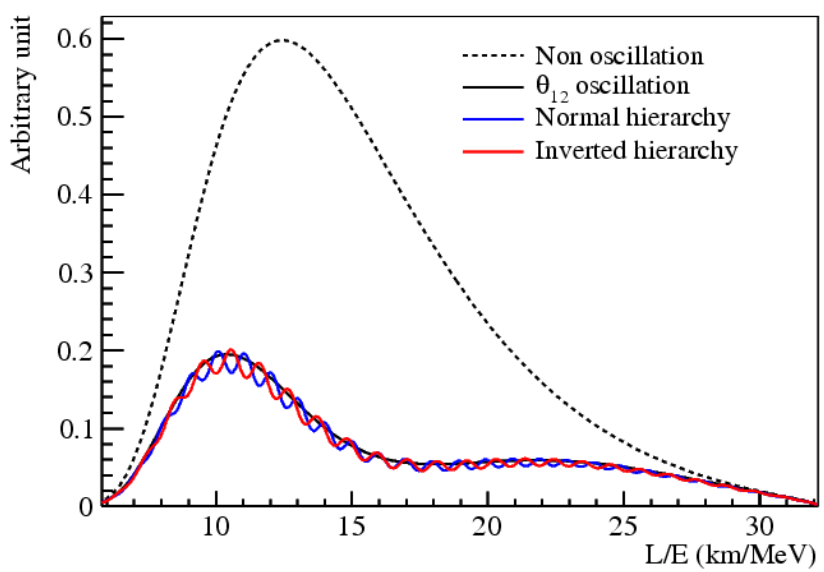
$$\frac{E_{\rm rec}}{E_{\rm true}} \simeq 1 + q_0 + q_1 E_{\rm true} + q_2 E_{\rm true}^2 \,,$$

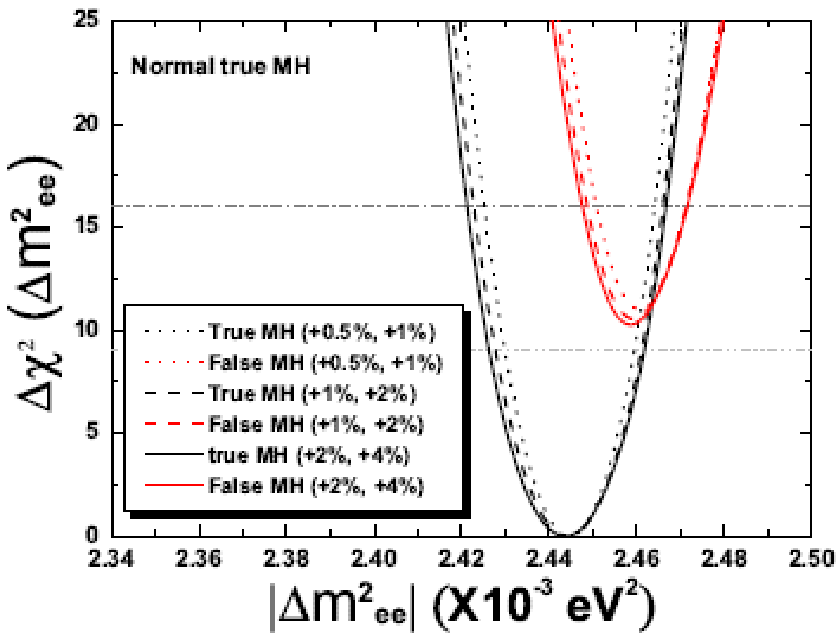
by introduce a self-calibration(based on ΔM^2_{ee} peaks):

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

effects can be corrected and sensitivity is un-affected

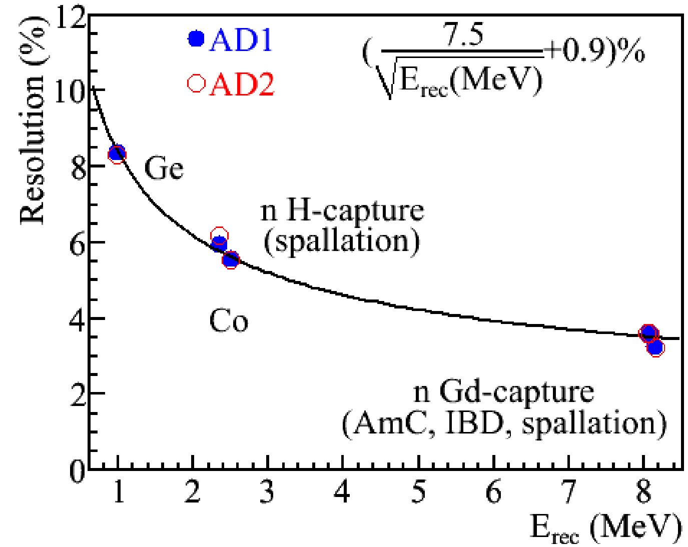


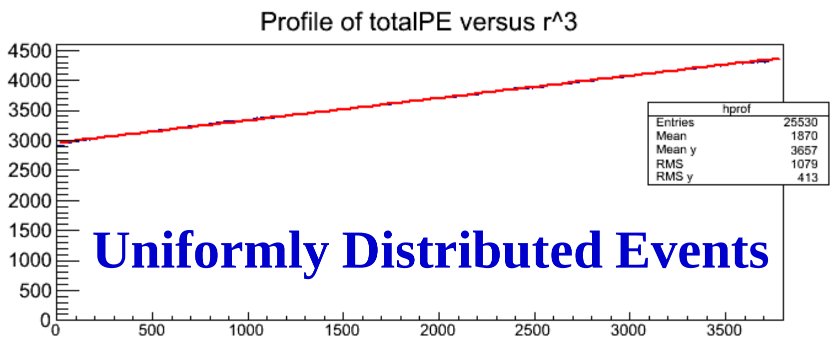


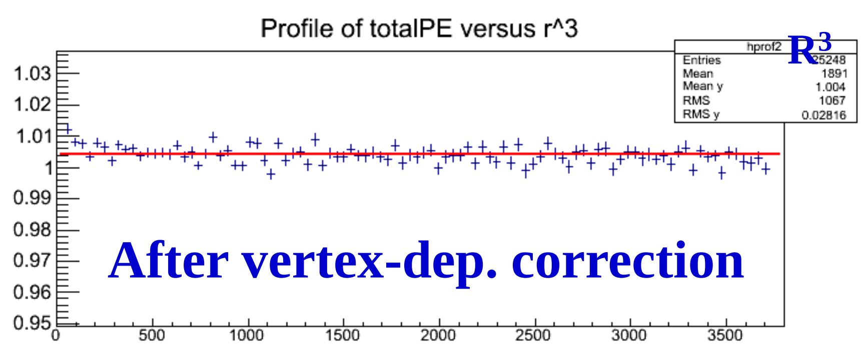


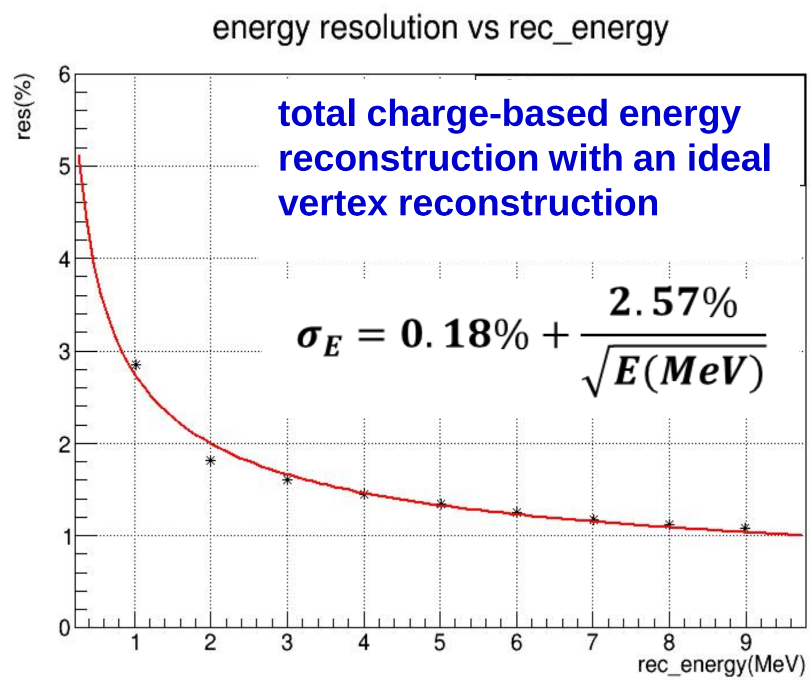
MC example： Energy Resolution

- 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









Signals & Backgrounds

- **Estimated IBD signal event rate: ~40/day**
- **LS without Gd-loading for**
  - Better attenuation length ➔ better resolution
  - Lower irreducible accidental backgrounds from LS, important for a larger detector:
    - ✓ With Gd: ~ 10^{-12} g/g ➔ 50,000 Hz
    - ✓ Without Gd: ~ 10^{-16} g/g ➔ 5 Hz
- **Backgrounds**

$\tau \sim 200\ \mu s$

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 ~ 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)
$^{9}Li/^{8}He$	~0.4%	~0.8%	Muon tracking; If good track, distance to muon track <5m and veto 2s; If shower muon, full volume veto 2s

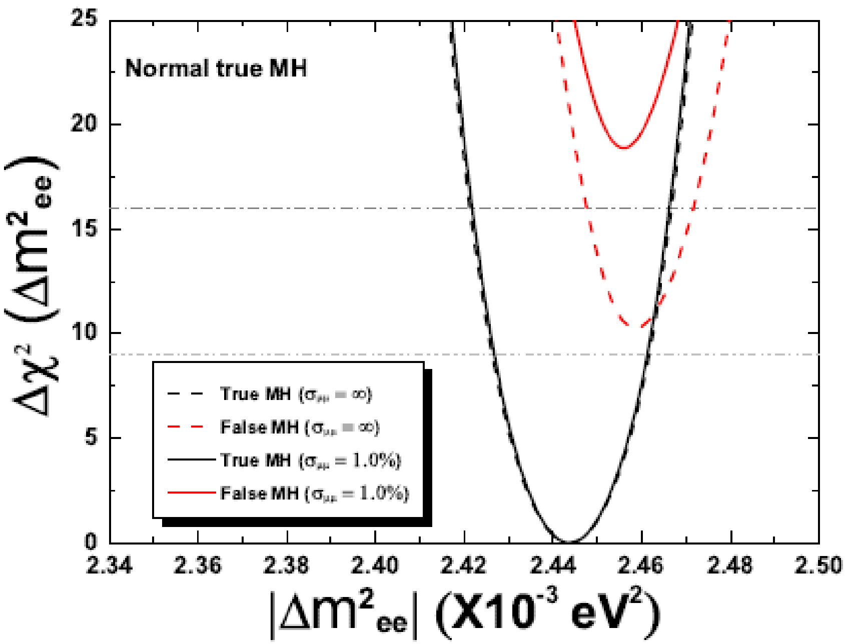
Physics Reach

Thanks to a large θ_{13}

Detector size: 20kt LS
Energy resolution: 3%/√E
Thermal power: 36 GW

For 6 years,

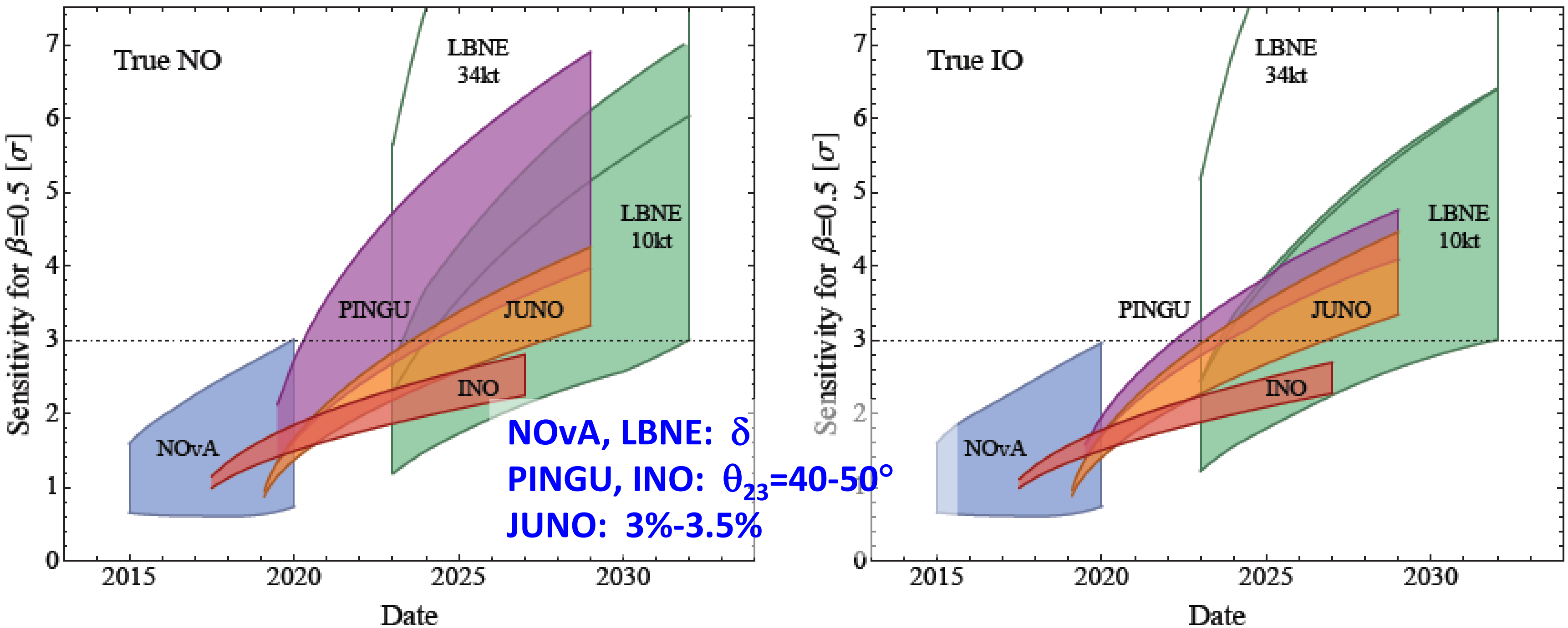
- **Ideally , The relative measurement can reach a sensitivity of 4σ , while the absolute measurement (with the help of $\Delta m^2_{\mu\mu}$ ~ 1%) can reach 5σ**
- **Due to reactor core distributions, relative measurement can reach a sensitivity of 3σ, while the absolute measurement can reach 4σ**



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

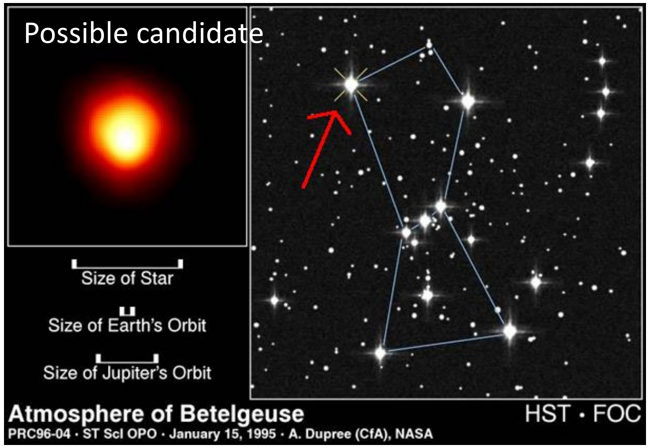
- Fundamental to the Standard Model and beyond
- Probing the unitarity of U_{PMNS} to ~1% level !
  - ⇨ Uncertainty from other oscillation parameters and systematic errors, mainly energy scale, are included

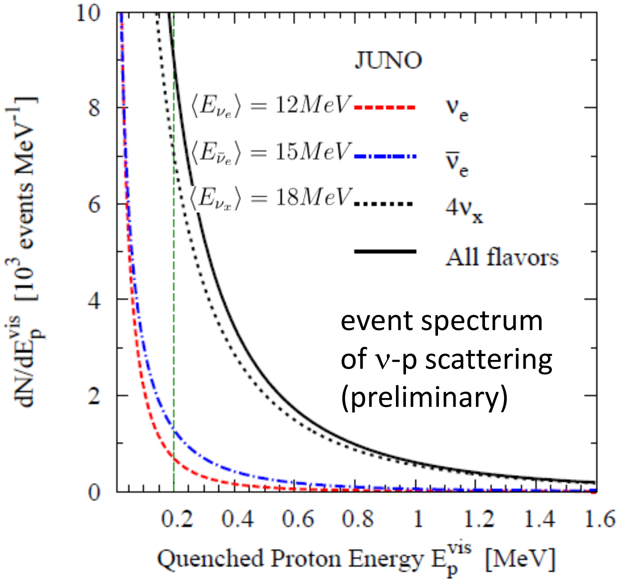
	Current	Daya Bay II
Δm^2_{12}	3%	0.6%
Δm^2_{23}	5%	0.6%
$\sin^2\theta_{12}$	6%	0.7%
$\sin^2\theta_{23}$	14%	N/A
$\sin^2\theta_{13}$	10% → 4%	~ 15%

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)

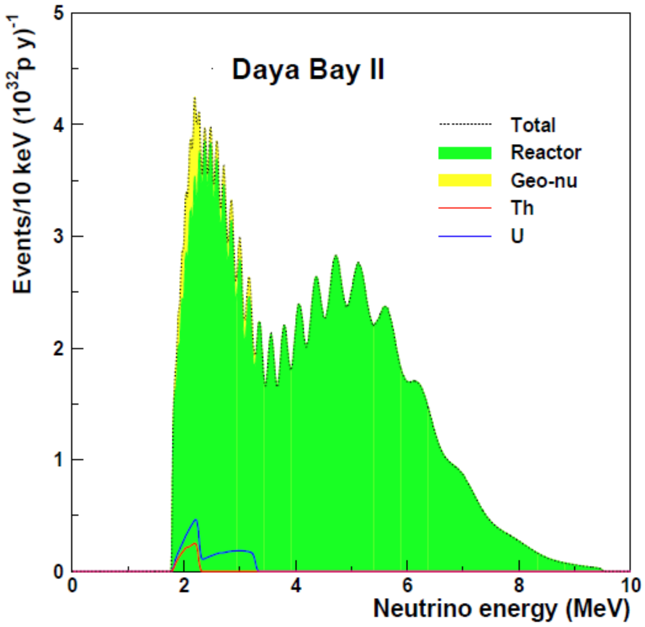
Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \to e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \to \nu + p$	NC	6.0×10^2	1.2×10^3	2.0×10^3
$\nu + e \to \nu + e$	NC	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}C \to \nu + {}^{12}C^*$	NC	1.7×10^2	3.2×10^2	5.2×10^2
$\nu_e + {}^{12}C \to e^- + {}^{12}N$	CC	4.7×10^1	9.4×10^1	1.6×10^2
$\overline{\nu}_e + {}^{12}C \to e^+ + {}^{12}B$	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:**
    - ×10 statistics
    - Huge reactor neutrino backgrounds
    - Expectation: ? ±10%±10%



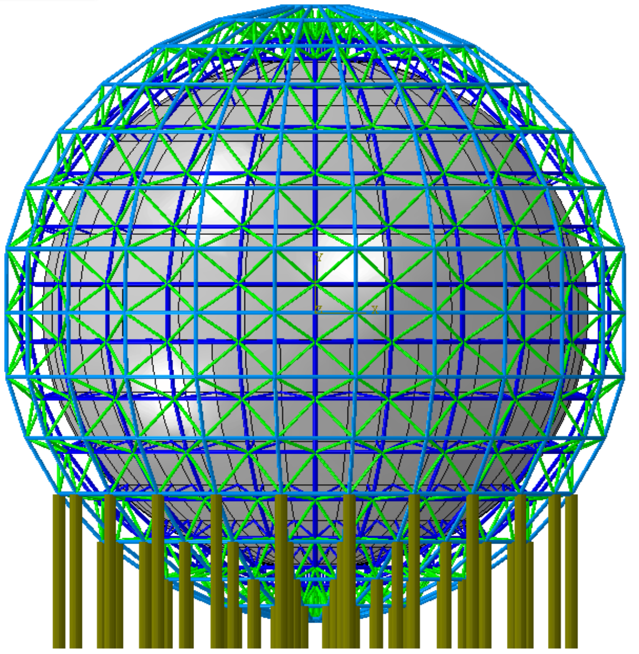
Stephen Dye @Neutrino 2012

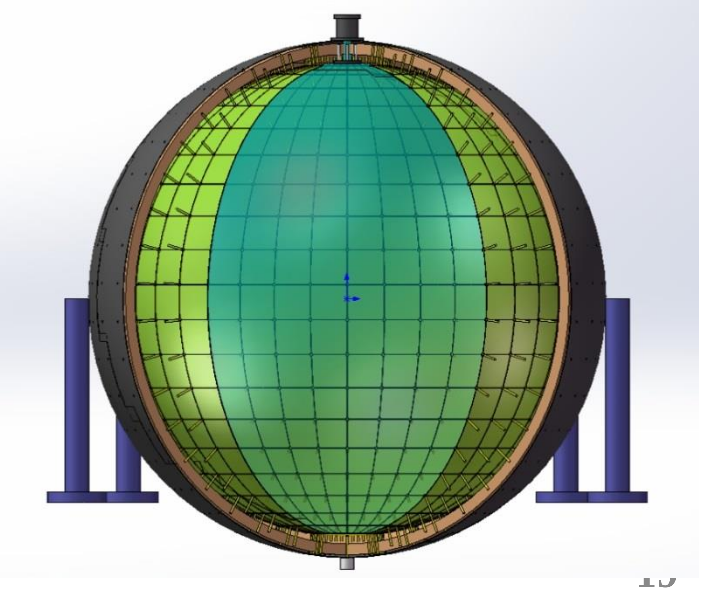
- **Solar neutrinos**
  - need LS purification, low threshold
  - background handling (radioactivity, cosmogenic)
- **Atmosphere neutrinos**
- **Nucleon Decay**
- **Sterile neutrinos**

- **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 refection, …**
  - ⇨ **Backup: SS tank(D~38m) + acrylic panel + balloon**
    - ✓ **Balloon materials, cleanness, leaks, deployment, …**
- **R&D and prototyping underway**

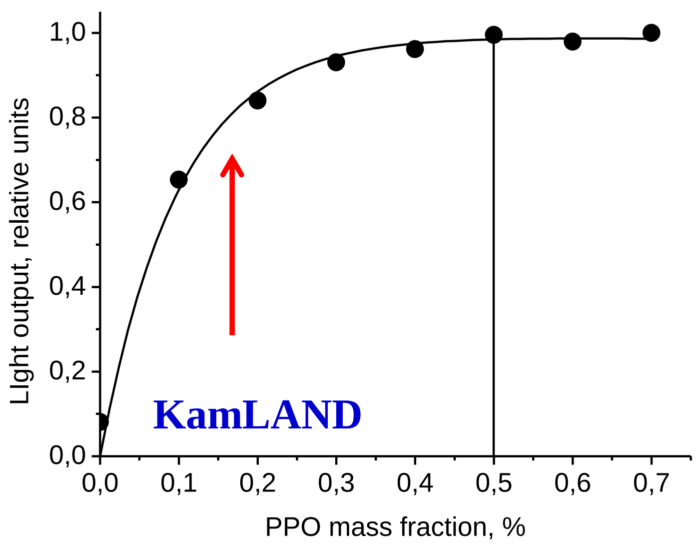




Liquid Scintillator

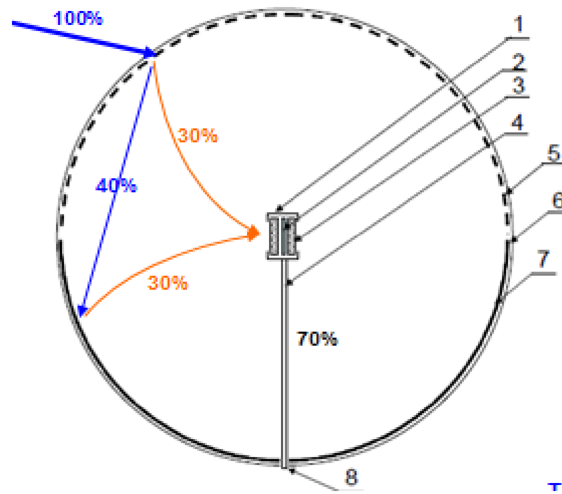
- **Current Choice: LAB+PPO+BisMSB**
- **Requirements & works:**
- ⇨ **Long attenuation length: 15m ➔ 30m**
  - ✓ **Improve raw materials**
  - ✓ **Improve the production process**
  - ✓ **Purification**
    - – **Distillation, Filtration, Water extraction, Nitrogen stripping…**
- ⇨ **High light yield: 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**

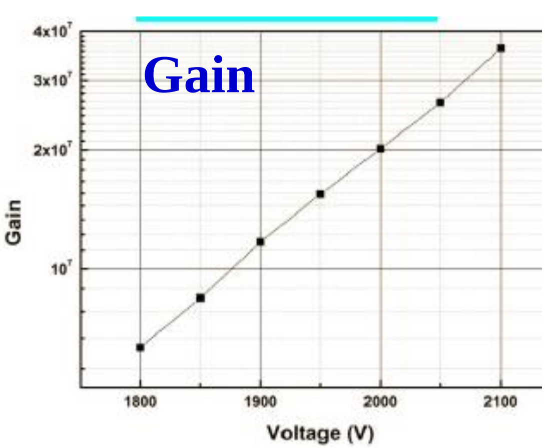
Linear Alky Benzene	Atte. L(m) @ 430 nm
RAW	14.2
Vacuum distillation	19.5
SiO_2 coloum	18.6
Al_2O_3 coloum	22.3
LAB from Nanjing, Raw	20
Al_2O_3 coloum	25

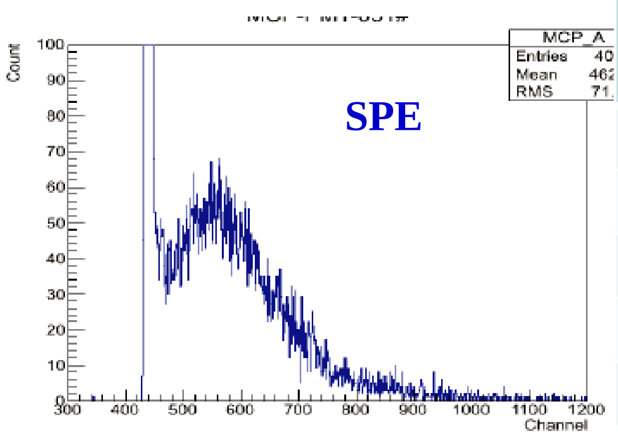


High QE PMT

- **Three types of high QE 20" PMTs under development:**
  - ⇨ New MCP-PMT: 4π collection
  - ⇨ Hammamatzu R5912-100 with SBA photocathode
  - ⇨ Photonics-type PMT
- **MCP-PMT by Chinese industry:**
  - ⇨ Technical issues mostly resolved
  - ⇨ Successful 8" prototypes
  - ⇨ A few 20" prototypes



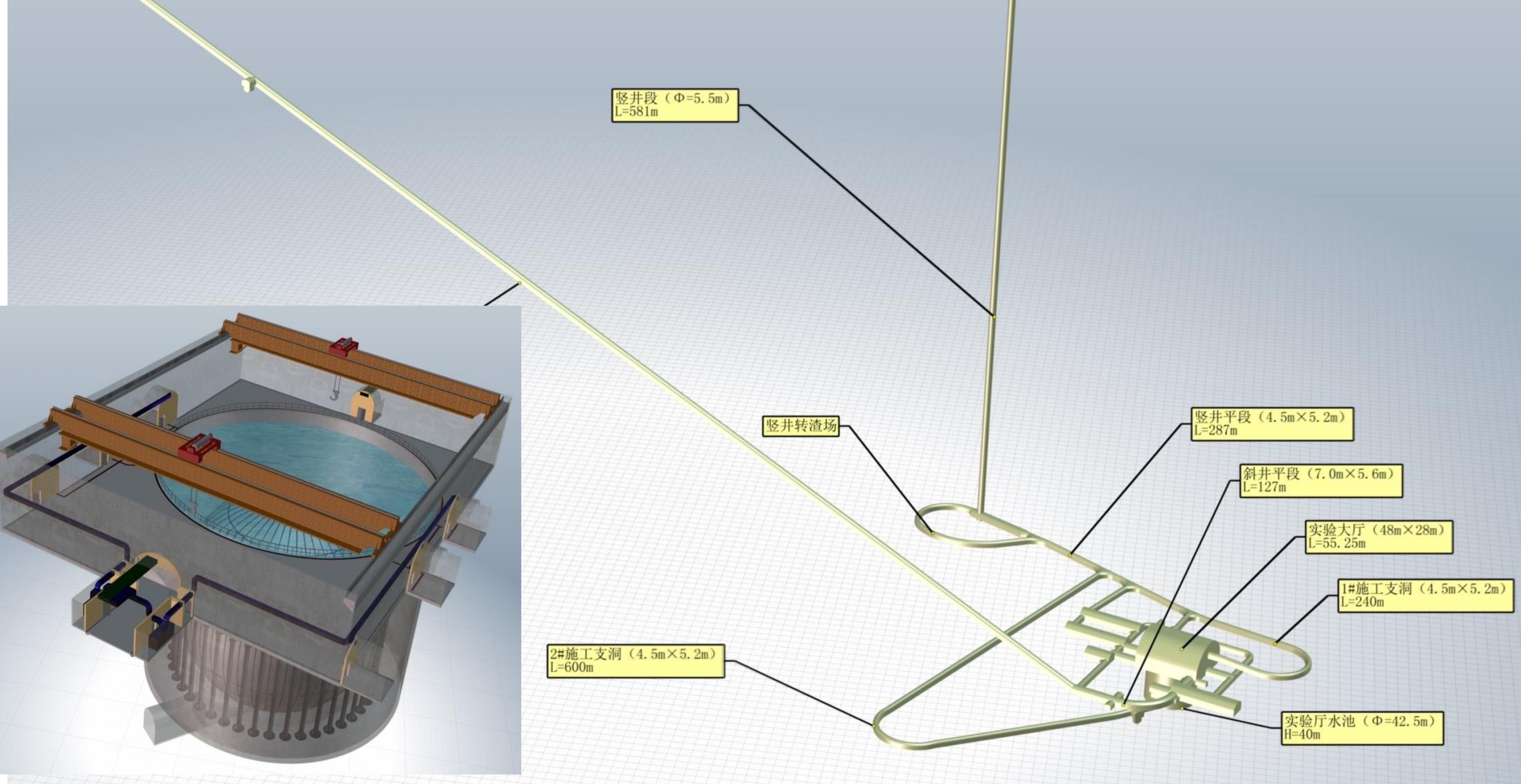




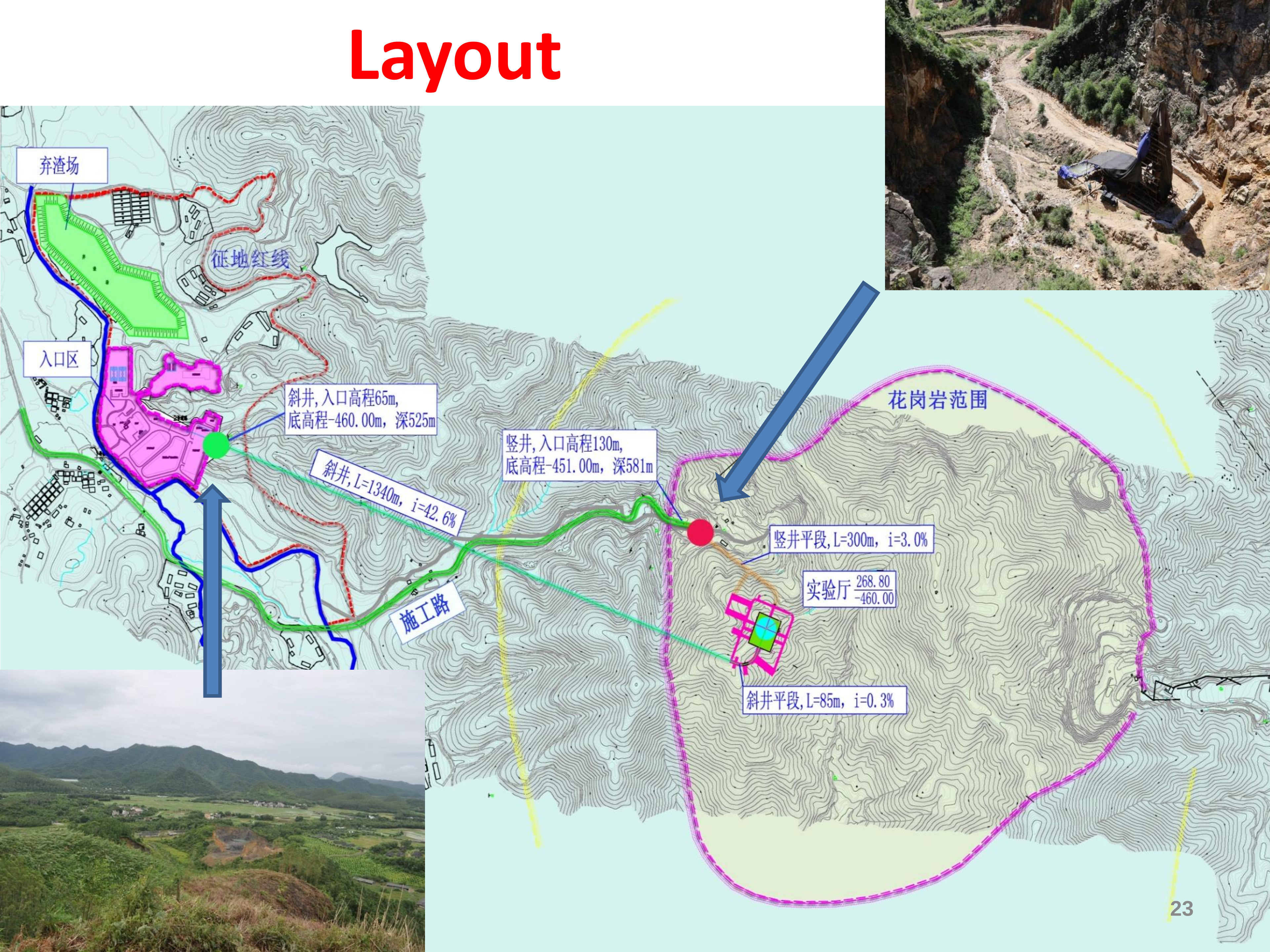
	R5912	R5912 -100	MCP-PMT
QE@410nm	25%	>30%	25-30%
Rise time	3 ns	3.4ns	5ns
SPE Amp.	17mV	18mV	17mV
P/V of SPE	>2.5	>2.5	~ 2
TTS	5.5ns	1.5 ns	3.5 ns

Civil Construction

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



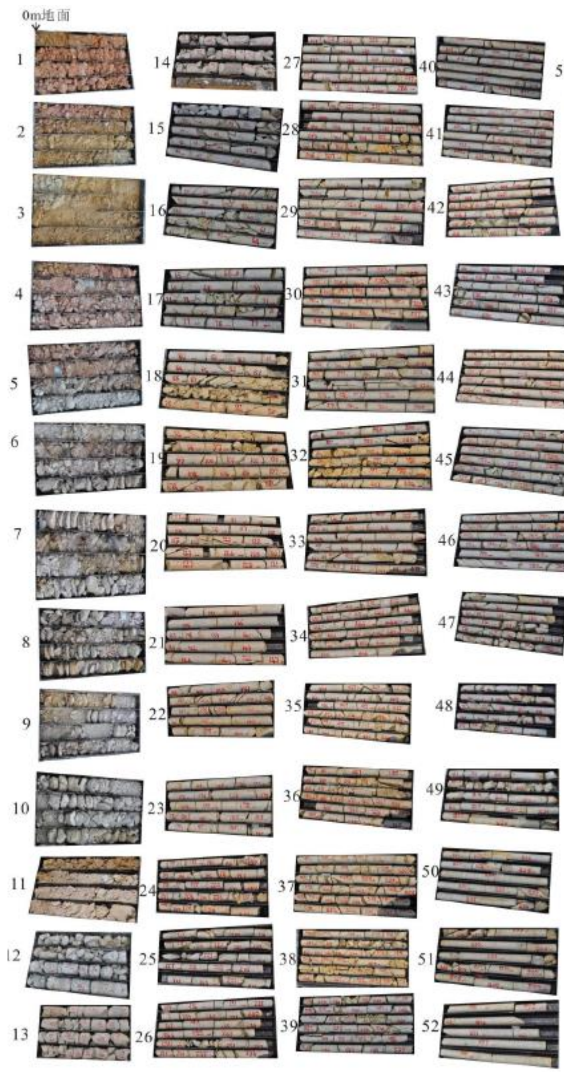
Layout


弃渣场
征地红线
入口区
斜井,入口高程65m,
底高程-460.00m，深525m
竖井,入口高程130m,
底高程-451.00m，深581m
斜井,L=1340m，i=42.6%
施工路
花岗岩范围
竖井平段,L=300m，i=3.0%
实验厅 268.80
-460.00
斜井平段,L=85m，i=0.3%

Current Design: Surface Buildings

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