Daya Bay II：A multi-purpose LS-based experiment

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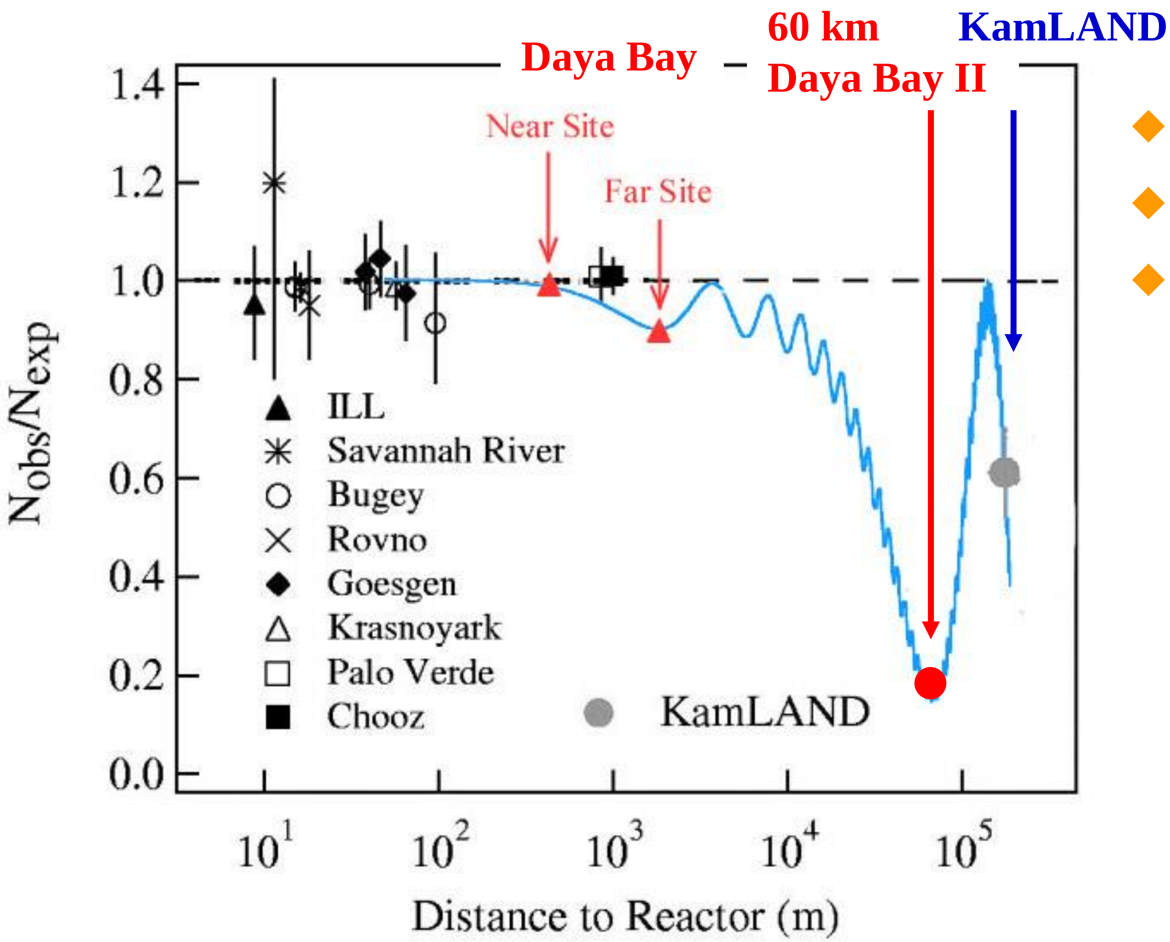
What is next after θ_{13} determined ?

- Neutrino oscillation
  - ⇨ What is the neutrino mass hierarchy ?
  - ⇨ Are there CPV in neutrinos ?
  - ⇨ Is the neutrino mixing angle θ_{23} maximized ?
  - ⇨ Is the neutrino mixing matrix unitary ?
- What are the absolute mass of neutrinos ?
- Are neutrinos their anti-particles ?
- Are there sterile neutrinos ?
- Are there fourth generation neutrinos ?
- How to detect relic neutrinos ?

Idea of the Daya Bay-II Experiment

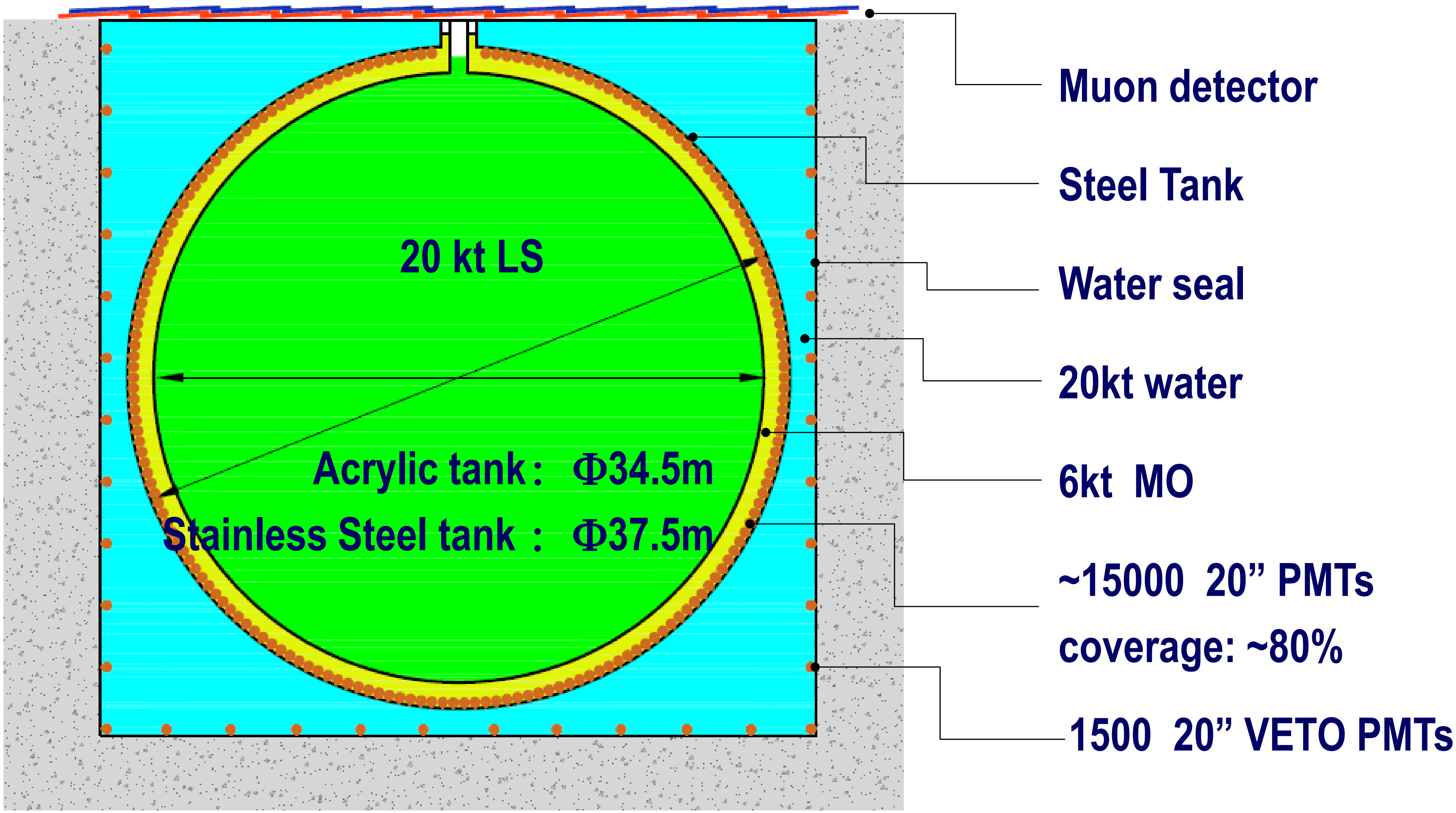


- 20 kton LS detector
- 3% energy resolution
- Rich physics possibilities
  - ⇨ Mass hierarchy
  - ⇨ Precision measurement of 4 mixing parameters
  - ⇨ Supernovae neutrinos
  - ⇨ Geoneutrinos
  - ⇨ Sterile neutrinos
  - ⇨ Atmospheric neutrinos
  - ⇨ Exotic searches

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

The plan: a large LS detector

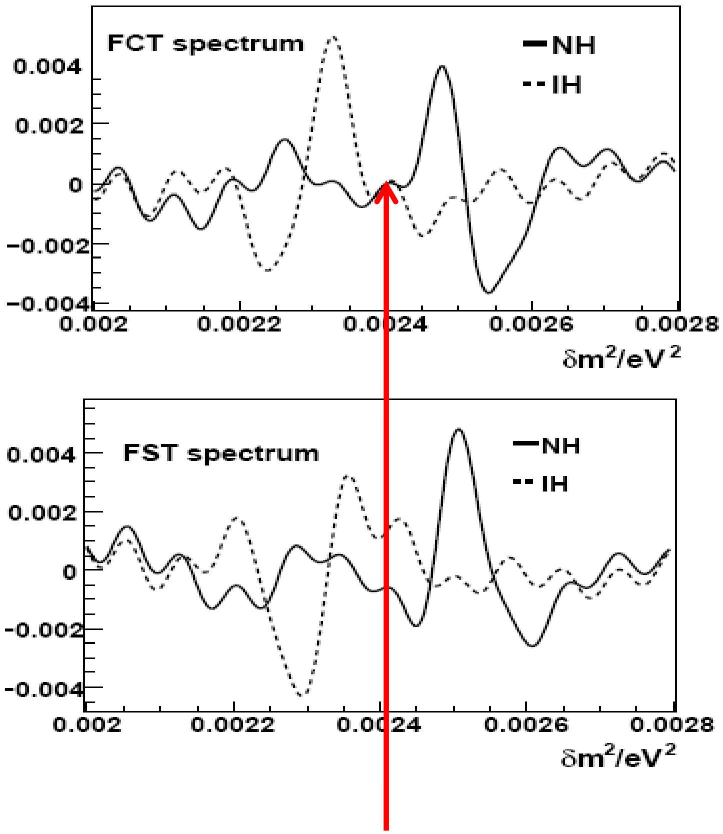
- LS volume: × 20 ➔ for more mass & statistics
- light(PE) × 5 ➔ for resolution



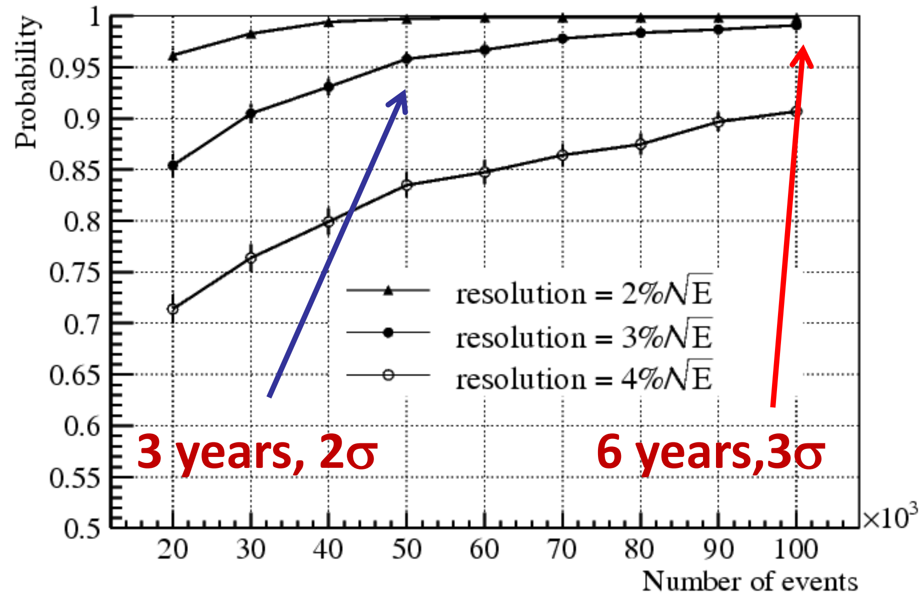
Mass hierarchy： sensitivity

- **Thanks to a large θ_{13}**

Fourier transformation:



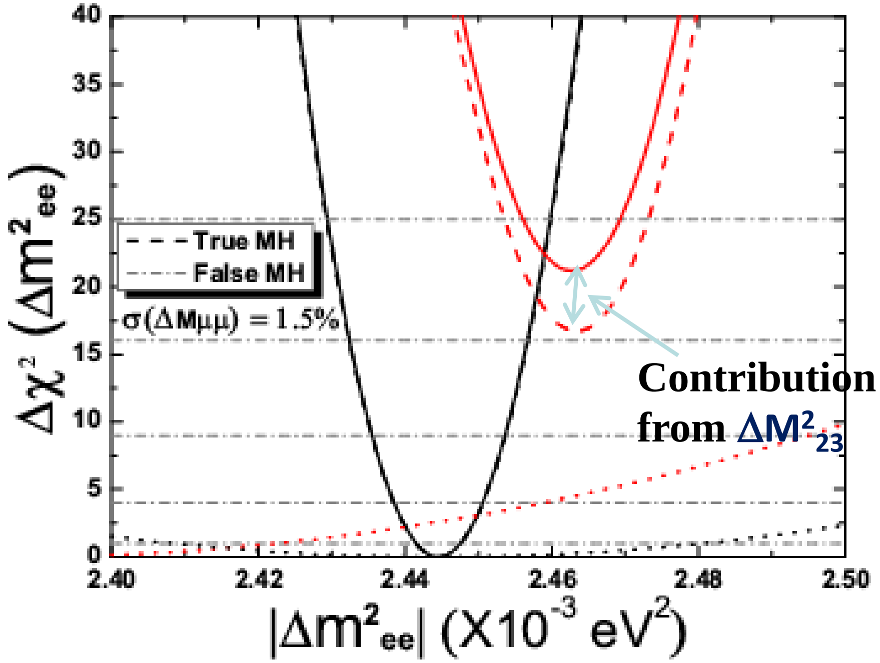
ΔM^2_{23}



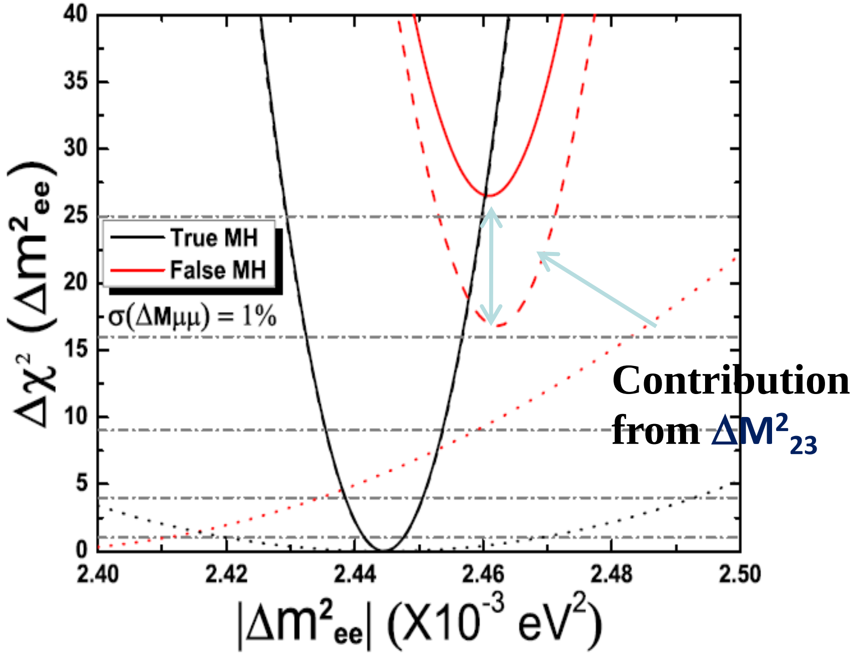
Detector size: 20kt
Energy resolution: 3%/√E
Thermal power: 36 GW
Baseline 58 km

Taking into account ΔM^2_{23}

- A χ^2 method by taking into account ΔM^2_{23} from T2K and Nova in the future：



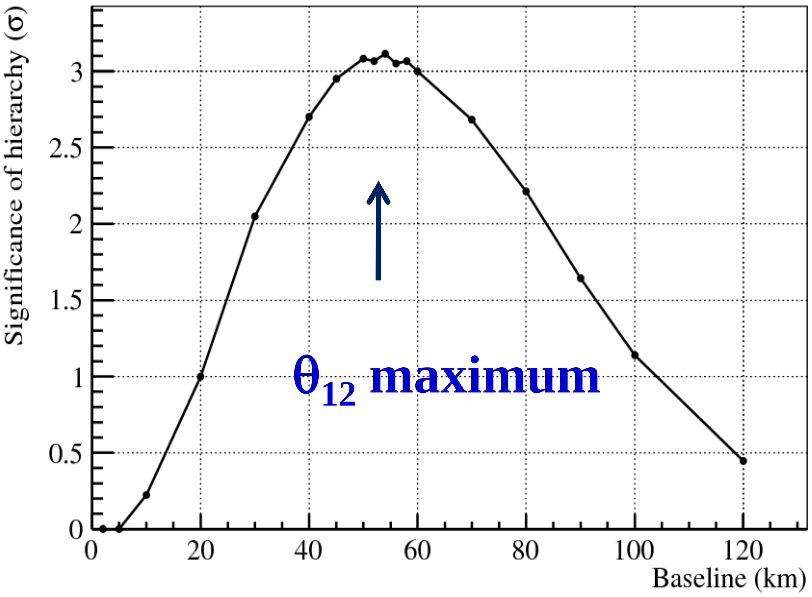
If $\Delta M^2_{\mu\mu}$ at 1.5% precision， mass hierarchy can be determined to ~4.5σ in 6 years

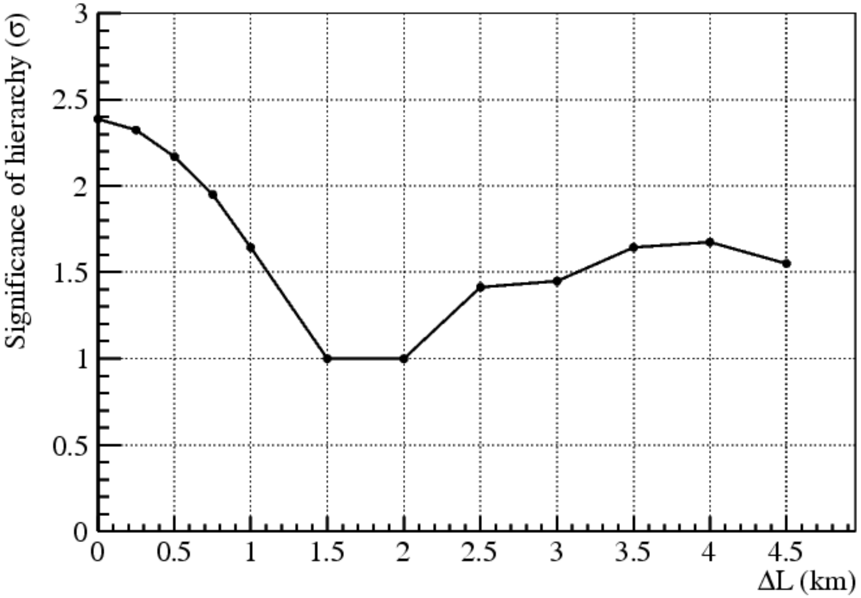


If $\Delta M^2_{\mu\mu}$ at 1% precision， mass hierarchy can be determine to ~5σ in 6 years

Optimum baseline

- Optimum at the oscillation maximum of θ_{12}
- Multiple reactors may cancel the oscillation structure
  - ⇨ Baseline difference should be controlled to be less than 500 m





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%**
$\sin^2\theta_{23}$	**20%**	**N/A**
$\sin^2\theta_{13}$	**14% ➔ 4%**	**~ 15%**

Will be more precise than CKM matrix elements !

Supernova neutrinos

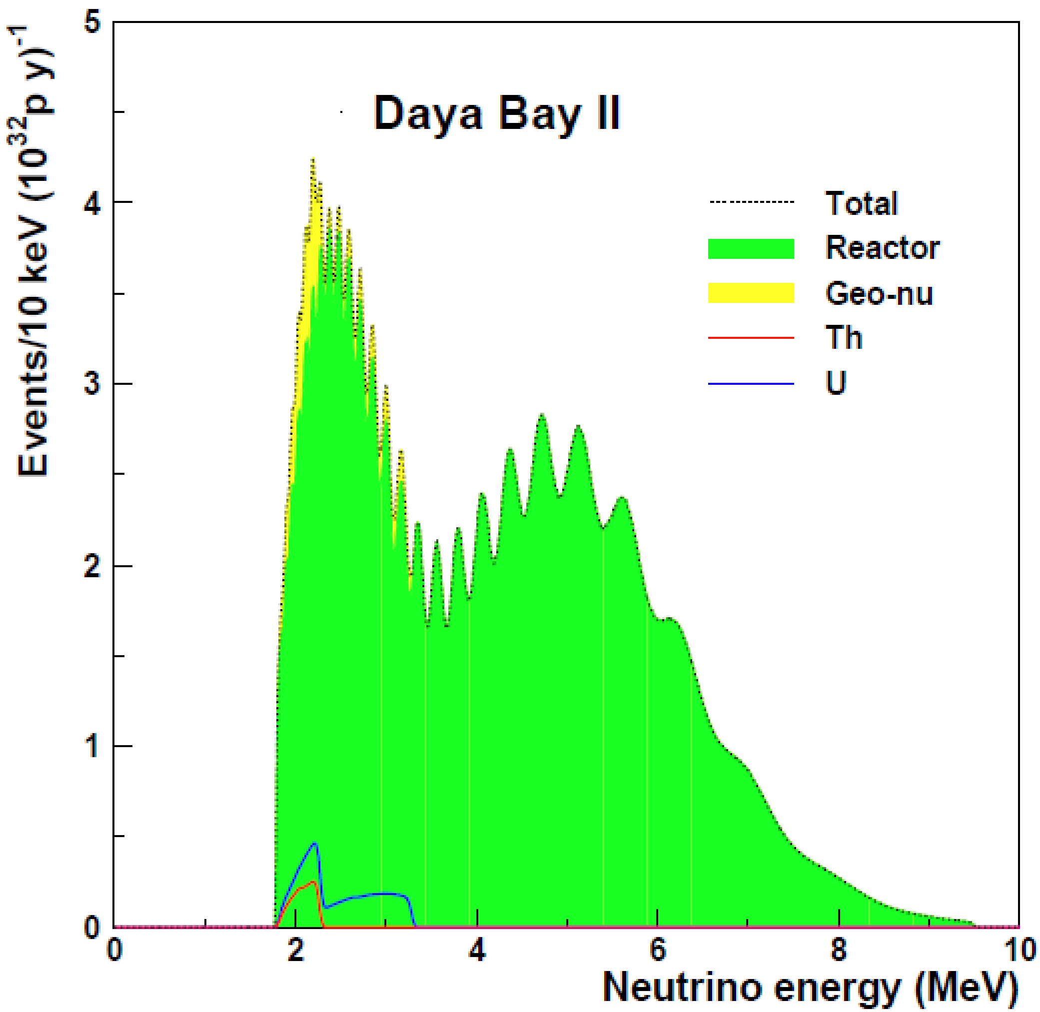
- Less than 20 events observed so far
- Assumptions:
  - Distance: 10 kpc (our Galaxy center)
  - Energy: 3×10^{53} erg
  - L_ν the same for all types
  - Tem. & energy
    $T(\underline{\nu}_e) = 3.5$ MeV, $\langle E(\underline{\nu}_e)\rangle = 11$ MeV
    $T(\nu_e) = 5$ MeV, $\langle E(\nu_e)\rangle = 16$ MeV
    $T(\nu_x) = 8$ MeV, $\langle E(\nu_x)\rangle = 25$ MeV
- Many types of events:
  - $\bar{\nu}_e + p \rightarrow n + e^+$, ~ 3000 correlated events
  - $\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B^* + e^+$, ~ 10-100 correlated events
  - $\nu_e + {}^{12}C \rightarrow {}^{12}N^* + e^-$, ~ 10-100 correlated events
  - $\nu_x + {}^{12}C \rightarrow \nu_x + {}^{12}C^*$, ~ 600 correlated events
  - $\nu_x + p \rightarrow \nu_x + p$, single events
  - $\nu_e + e^- \rightarrow \nu_e + e^-$, single events
  - $\nu_x + e^- \rightarrow \nu_x + e^-$, single events

Water Cerenkov detectors can not see these correlated events

Energy spectra & fluxes of all types of neutrinos

Geoneutrinos

- **Current results:**
  - **KamLAND:** **40.0±10.5±11.5 TNU**
  - **Borexino:** **64±25±2 TNU**
- **Desire to reach an error of 3 TNU: statistically dominant**
- **Daya Bay II: >×10 statistics, but difficult on systematics**
- **Background to reactor neutrinos**



From Stephen Dye

Challenges

- **Large detector: 20 kt LS ➔ ϕ ~ 38m**
- **Energy resolution: < 3%/$\sqrt{E}$ ➔ 1200 p.e./MeV**
  - ⇨ **To generate more light**
  - ⇨ **To detect more light**

	KamLAND	Daya Bay II
LS mass	**~1 kt**	**20 kt**
Energy Resolution	**6%/$\sqrt{E}$**	**3%/$\sqrt{E}$**
Light yield	**250 p.e./MeV**	**1200 p.e./MeV**

More photons, how and how many ?

- **Highly transparent LS:**
  - ⇨ **Attenuation length/D: 15m/16m → 30m/34m ×0.9**
- **High light yield LS:**
  - ⇨ **KamLAND: 1.5g/l PPO → 5g/l PPO**

    Light Yield: 30%→ 45%; × 1.5
- **Photocathode coverage :**
  - ⇨ **KamLAND: 34% → ~ 80% × 2.3**
- **High QE "PMT":**
  - ⇨ **20" SBA PMT QE: 25% → 35% × 1.4**

    or New PMT QE: 25% → 40% × 1.6

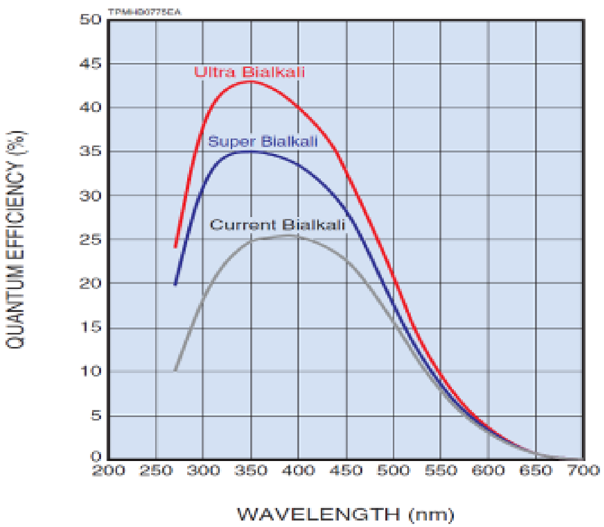
    Both: 25% → 50% × 2.0

4.3 – 5.0 → (3.0 – 2.5)% /√E

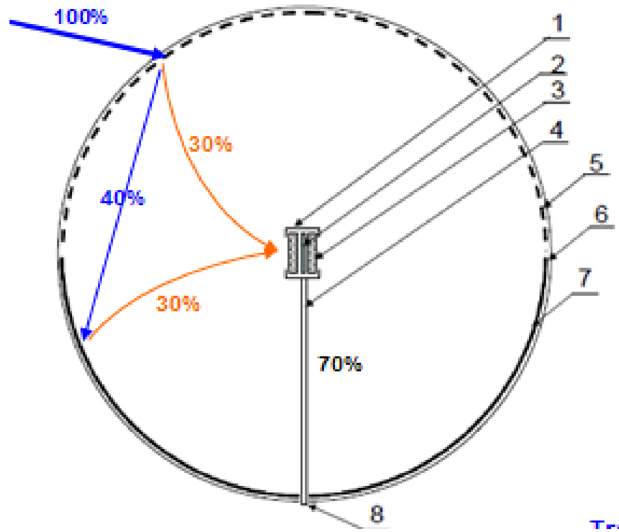
Other contributions: 0.5% constant term & 0.5% neutron recoil uncertainty

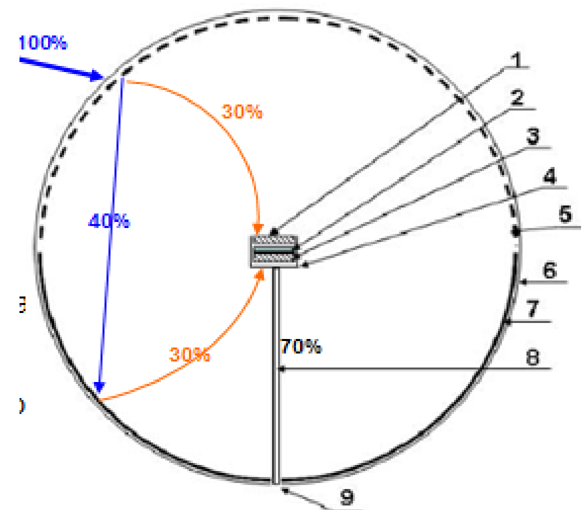
More Photoelectrons-- PMT

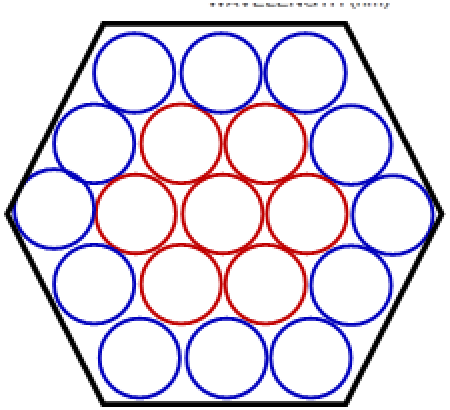
SBA photocatode



New type of PMT: MCP-PMT





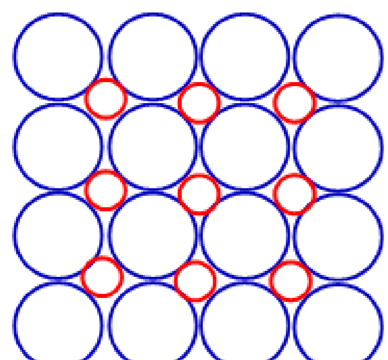


No clearance:

coverage 86.5%

1cm clearance:

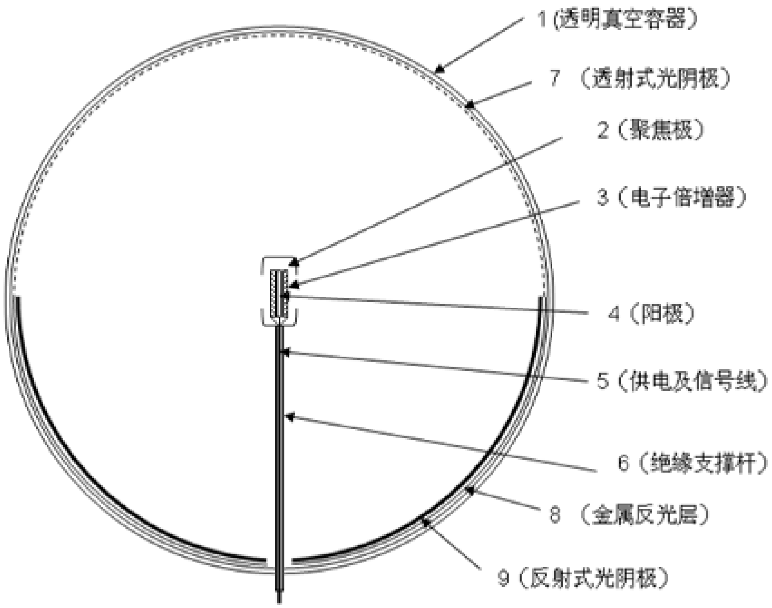
coverage: 83%

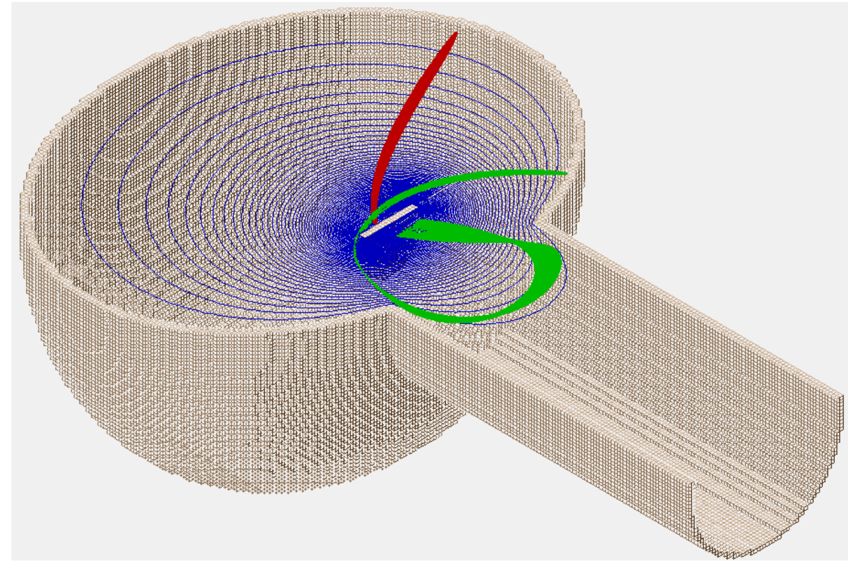


20" + 8" PMT

8" PMT for better timing(vertex)

A new type of PMT: higher photon detection eff.





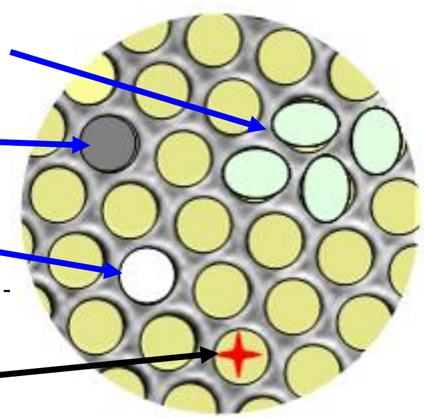
- Top: transmitted photocathode
- Bottom: reflective photocathode

  additional QE: ~ 80%*40%
- MCP to replace Dynodes ➔ no blocking of photons

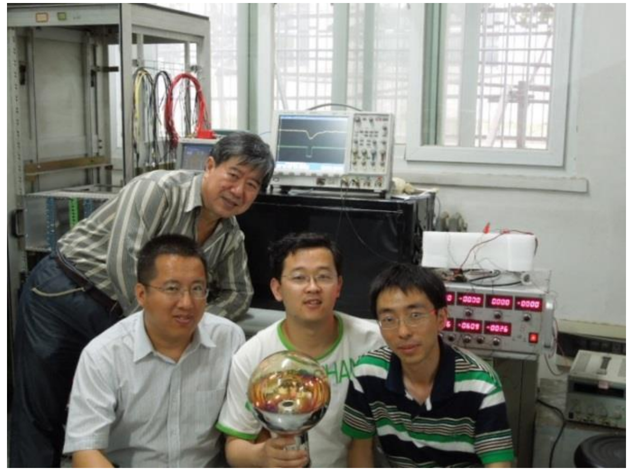
~ ×2 improvement

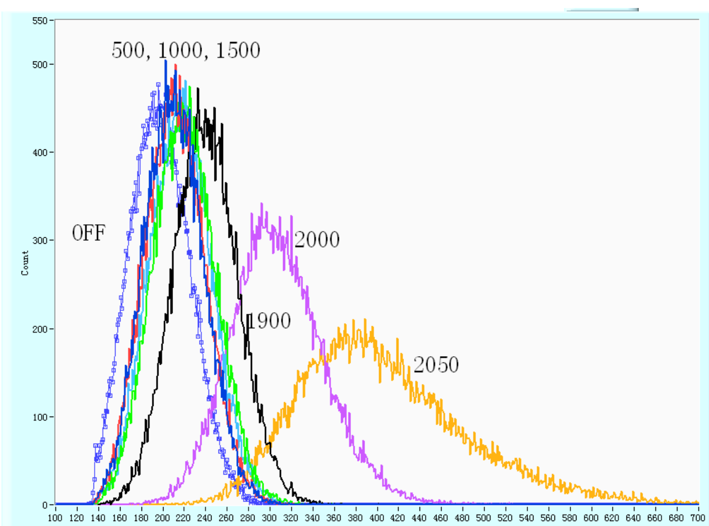
Low cost MCP by accepting the following:

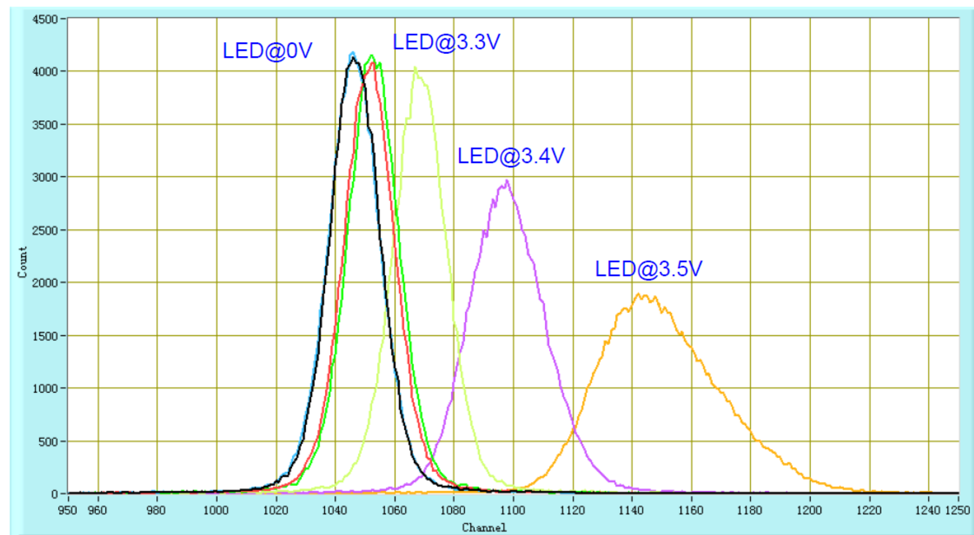
1. asymmetric surface;
2. Blind channels;
3. Non-uniform gains
4. Flashing channels



Prototypes







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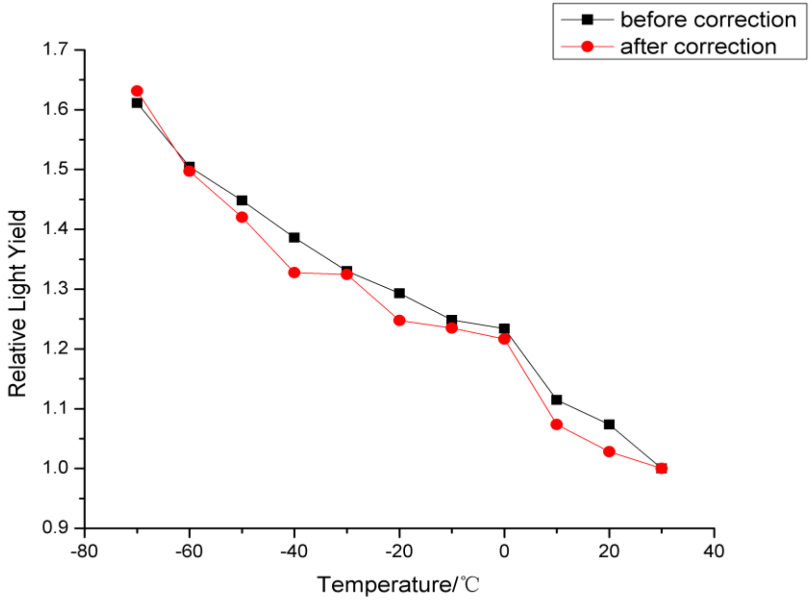
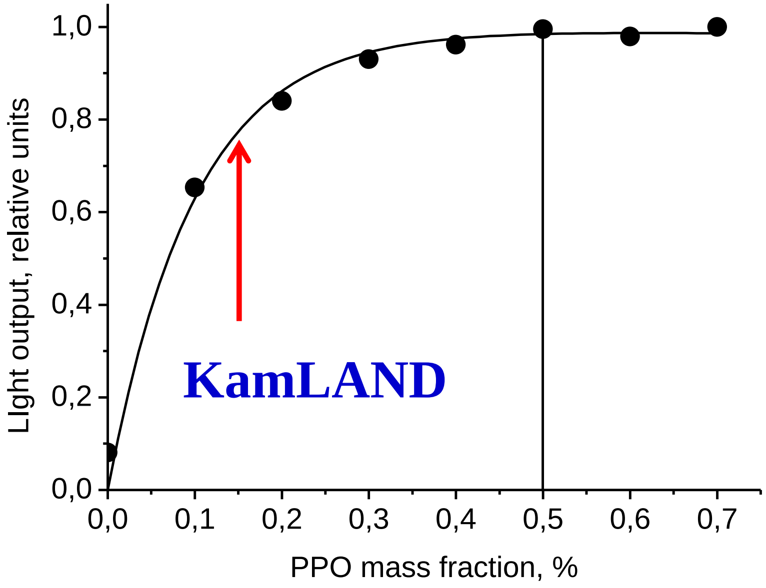
海南展创光电技术有限公司 HZC PHOTONICS
中核（北京）核仪器厂 CNNC Beijing Nuclear Instrument Factory

More Photoelectrons-- LS

- **Longer attenuation length**
  - Improve raw materials (using Dodecane instead of MO for LAB production）
  - Improve the production process
  - Purification
- **Higher light yield**
  - Lower temperature
  - fluor concentration optimization
  - Wave length shifter

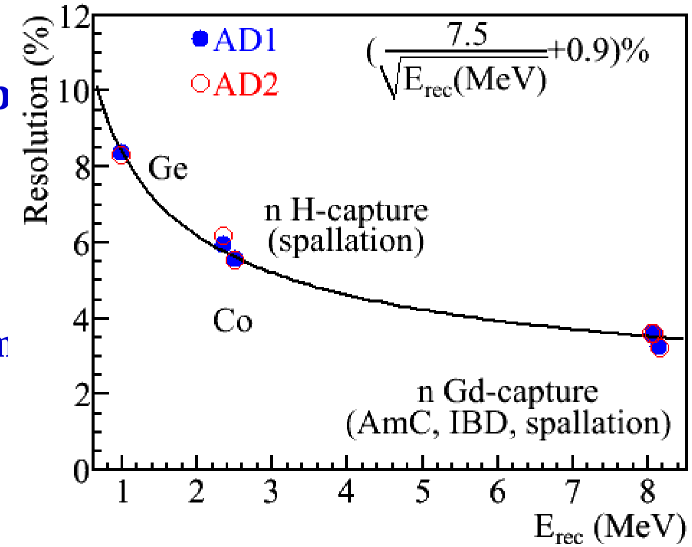
Linear Alky Benzene	Atte. Length @ 430 nm
RAW	14.2 m
Vacuum distillation	19.5 m
SiO_2 coloum	18.6 m
Al_2O_3 coloum	22.3 m

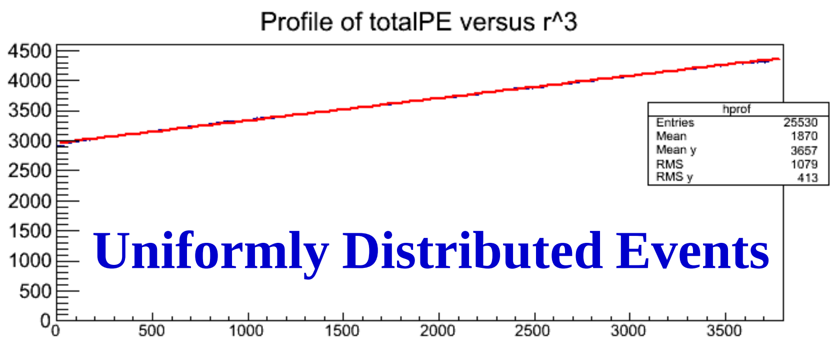


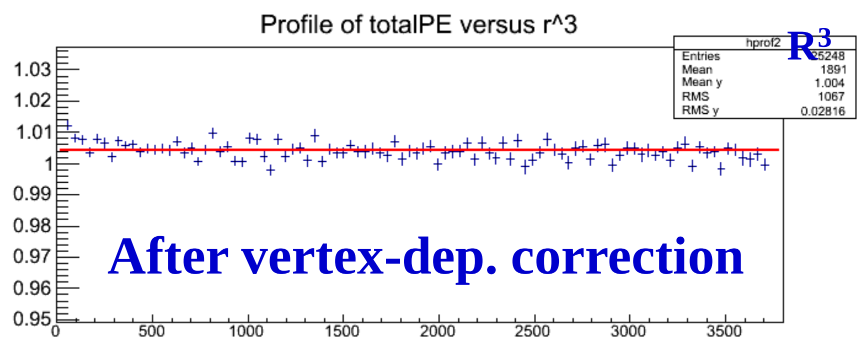


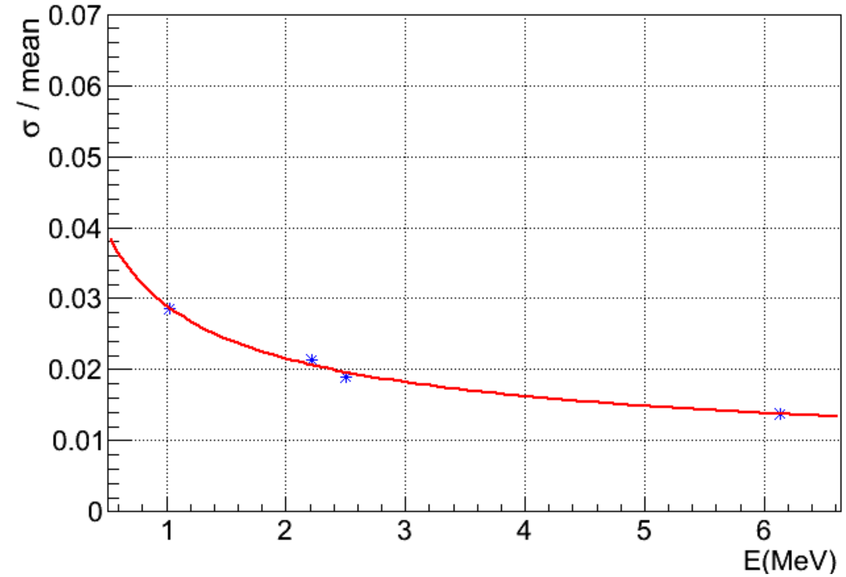
MC example： Energy Resolution

- DYBII MC, based on DYB MC (tuned to data), excep
  - DYBII Geometry and 80% photocathode coverage
  - SBA PMT: maxQE from 25% -> 35%
  - Lower detector temperature to 4 degree (+13% light)
  - LS attenuation length (1m-tube measurement@430nm
    - ✓ from 15m = absoption 24m + Raylay scattering 40 m
    - ✓ to 20 m = absorption 40 m + Raylay scattering 40m









$3.0\%/\sqrt{E}$, or $(2.6/\sqrt{E} + 0.3)\%$

IBD Signal

- **Signal:**

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

Estimated IBD rate: ~40/day

$$n + p \rightarrow d + \gamma\ (2.2\ \mathrm{MeV})$$

$\tau \sim 200\ \mu s$

- **LS without Gd-loading for**
  - ⇨ Better attenuation length ➔ resolution
  - ⇨ Lower irreducible accidental backgrounds from LS, important for a larger detector:
    - ✓ With Gd: $\sim 10^{-12}$ g/g
    - ✓ Without Gd: $\sim 10^{-16}$ g/g
  - ⇨ Less risk
- **Longer capture time & lower energy the capture signal ➔ more accidental backgrounds**

Backgrounds Summary

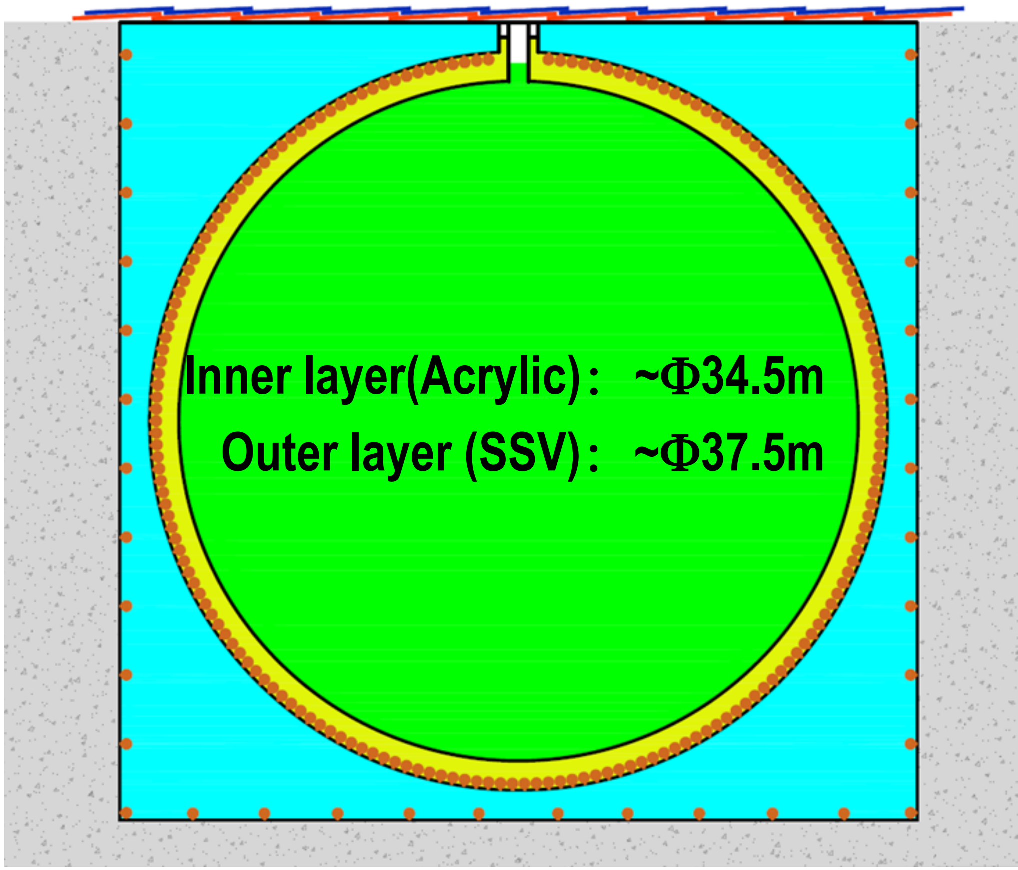
- **Assumptions**
  - Overburden is 700m
    - ✓ E_μ ~ 211 GeV, R_μ ~ 3.8 Hz
  - Single rates from LS and PMT are 5Hz, respectively
  - Good muon tracking
  - Similar muon efficiency as DYB

	Daya Bay	Daya Bay II
Mass (ton)	20	20,000
E_μ (GeV)	~57	~211
L_μ (m)	~1.3	~ 23
R_μ (Hz)	~21	~3.8
$R_{singles}$ (Hz)	~50	~10

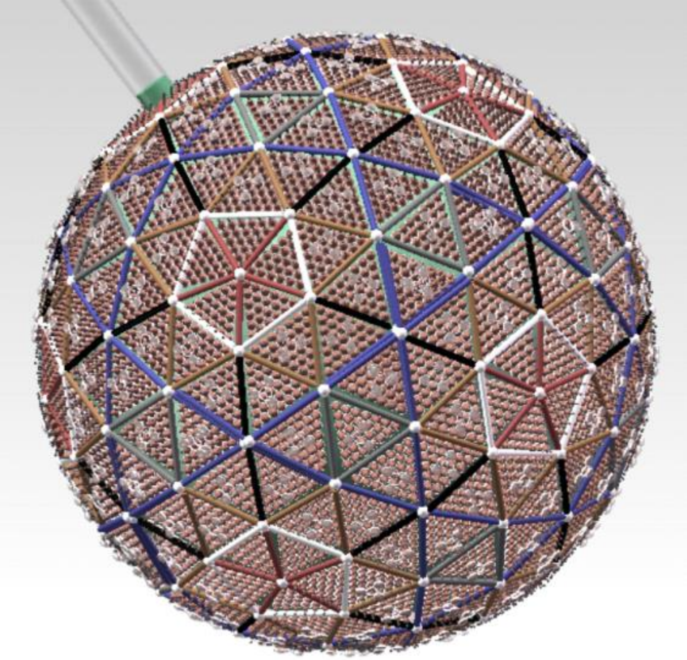
	B/S @ DYB EH1	B/S @ DYB II	Techniques used for DYB II detector
Accidentals	~1.4%	~10%	Low PMT radioactivity; LS purification; prompt-delayed distance cut
Fast neutron	~0.1%	~0.4%	High muon detection efficiency (similar as DYB)
$^9Li/^8He$	~0.4%	~0.8%	Muon tracking; If good track, distance to muon track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

Detector design

- Extremely difficult to build both the stainless steel tank and the acrylic tank
- Options:
  - No steel tank, only acrylic tank
  - Steel tank +
    - Acrylic box/wall
    - Balloon
    - nothing

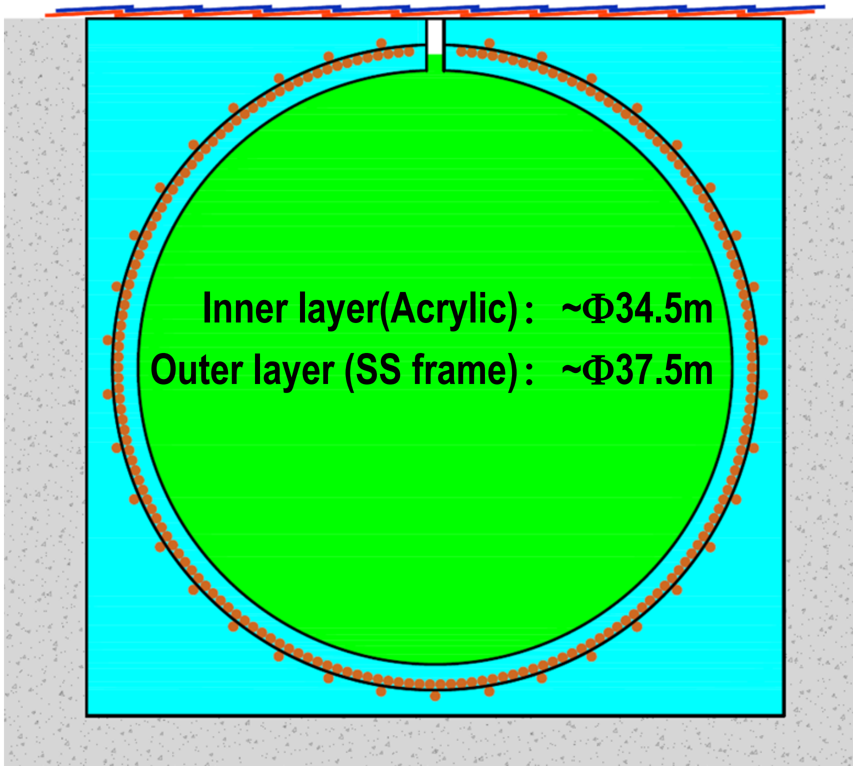


Option 1: no steel tank

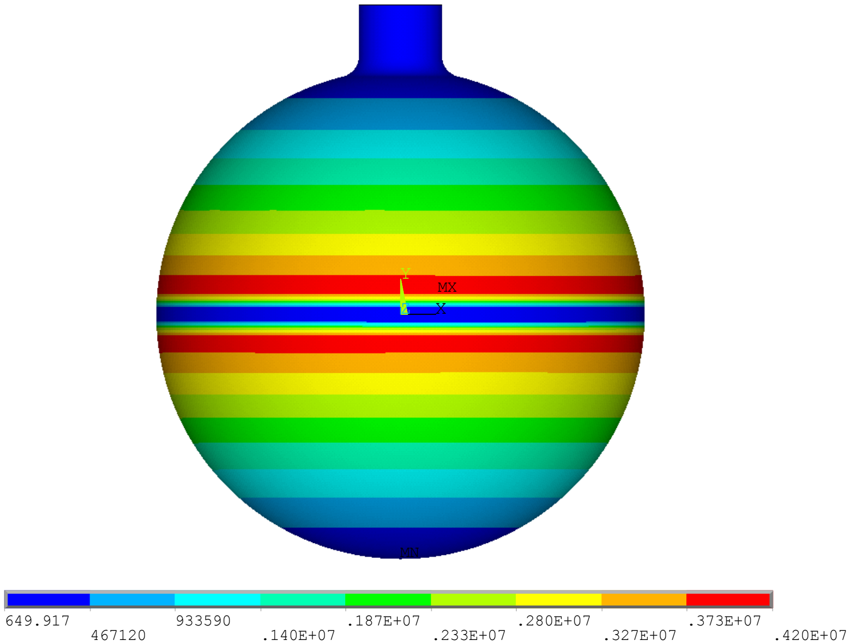


- No more interference
- "Easy" for PMT holding
- Water buffer ➔ cheap
- Difficulties:
  - ⇨ Larger pressure difference for the acrylic tank

15% density difference leads to a maximum pressure of ~6m in air ➔ A normal aquarium ➔ Not a major problem



- **Stress calculation shows that a 12cm thick acrylic tank is feasible but in really…**



- **SNO 1kt: a 10-person team for two years**
- **20kt ???**

A variation：acrylic wall

- Mature technology
- Quick installation
- Good for PMT explosion protection
- But
  - ⇨ Light loss，5% ?
  - ⇨ Sealing, compatibility，…

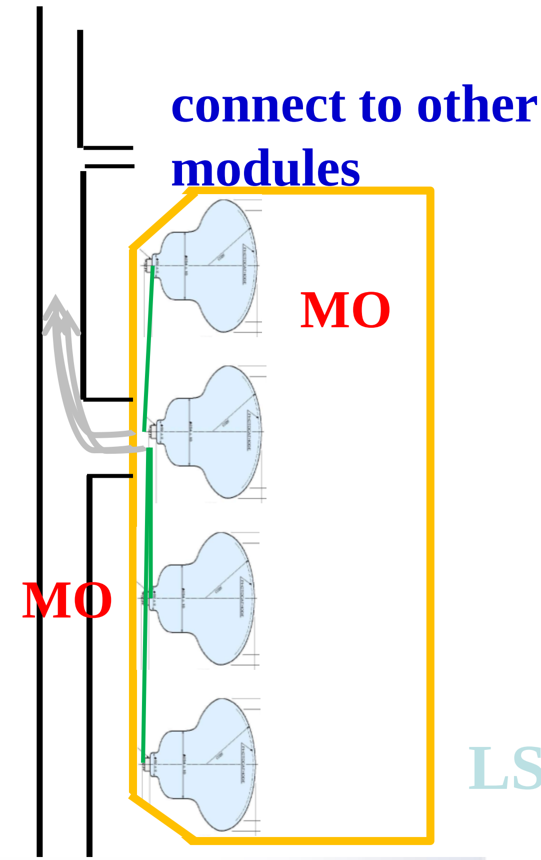
Airport

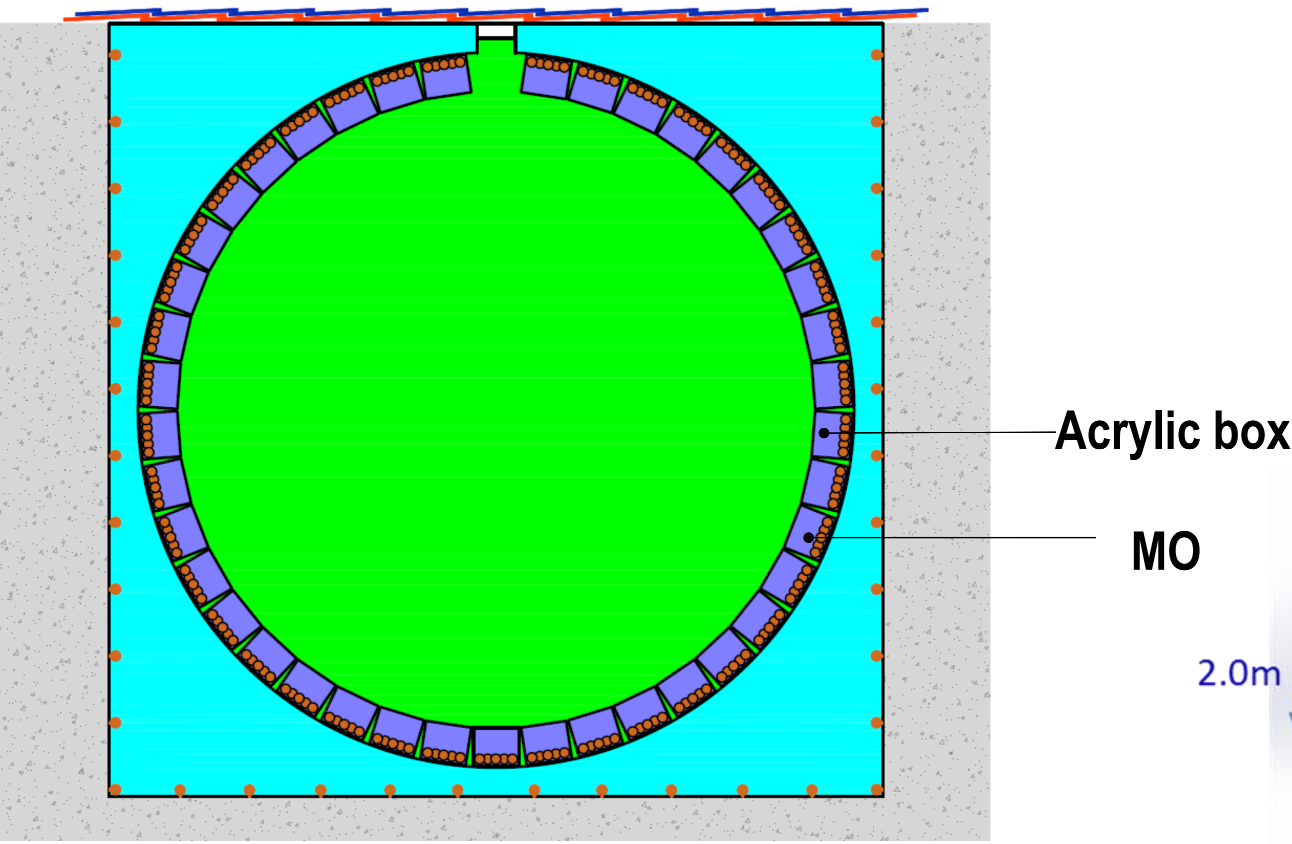
Zhujiang City Building
Ball conference : 39 m

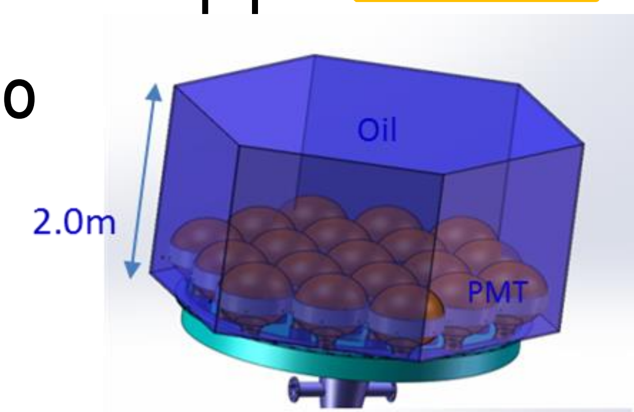
Expo 2010, Shanghai
Sunshine Valley

Option 2: Acrylic box

- Mineral oil in optical modules.
- Pipes for MO filling and cabling
- Concerns
  - ⇨ Leakage through cables



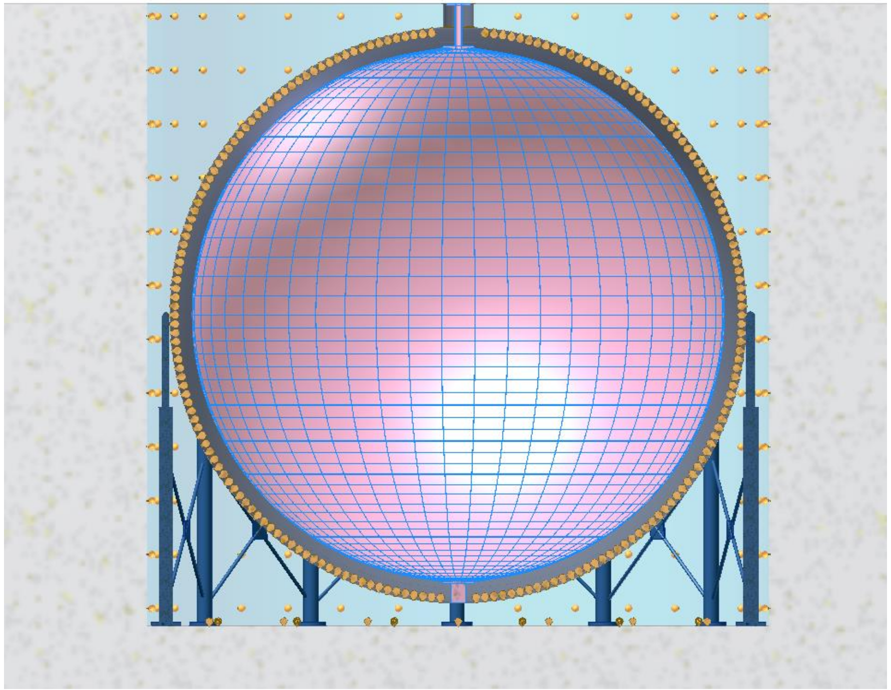




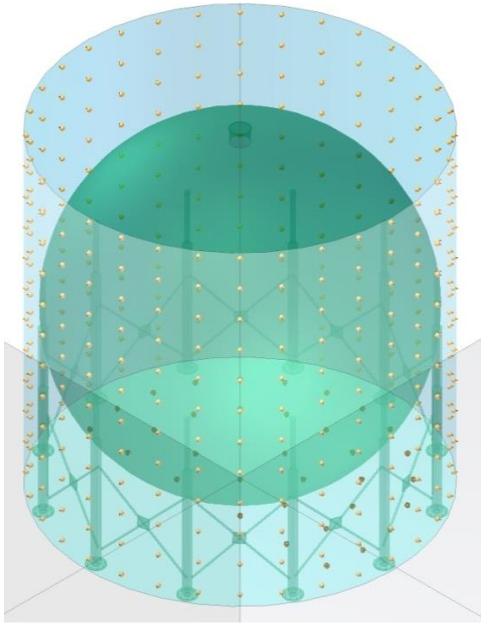
Option 3: Balloon

- "Cheap" for construction & quick for installation
- Experience from Borexino (0.5kt) & KamLAND (1kt)
- Need to consider film materials(mechanics, transparency, compatibility, welding technique, radon permeability, …) , cleanness, leak check, deployment, backup plan if fails, …

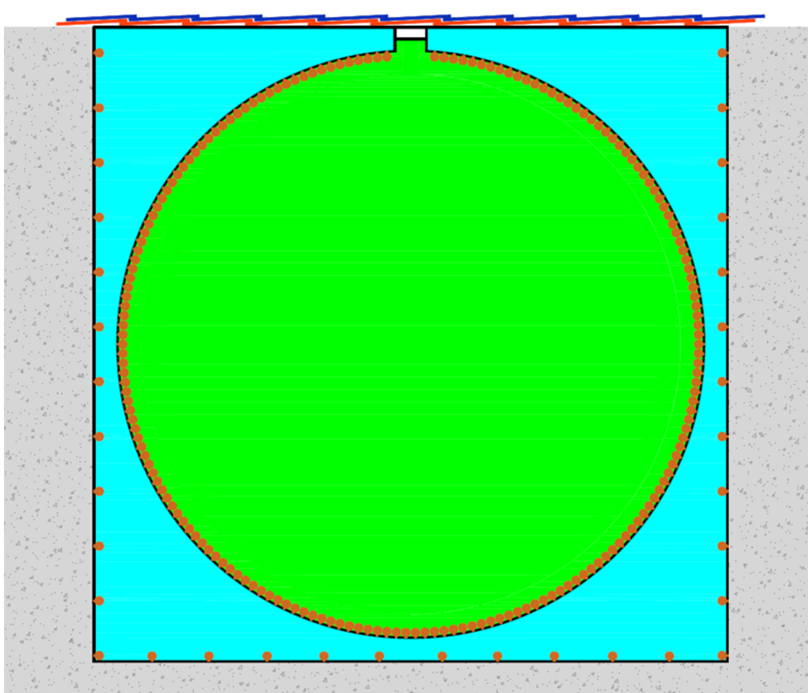
Not new to IHEP



Option 4: Steel tank only



- No problem for construction
- A fall back plan of the balloon option
- But
  - PMT protection
  - Trigger rate by backgrounds
  - Resolution affected by pile-up of background events

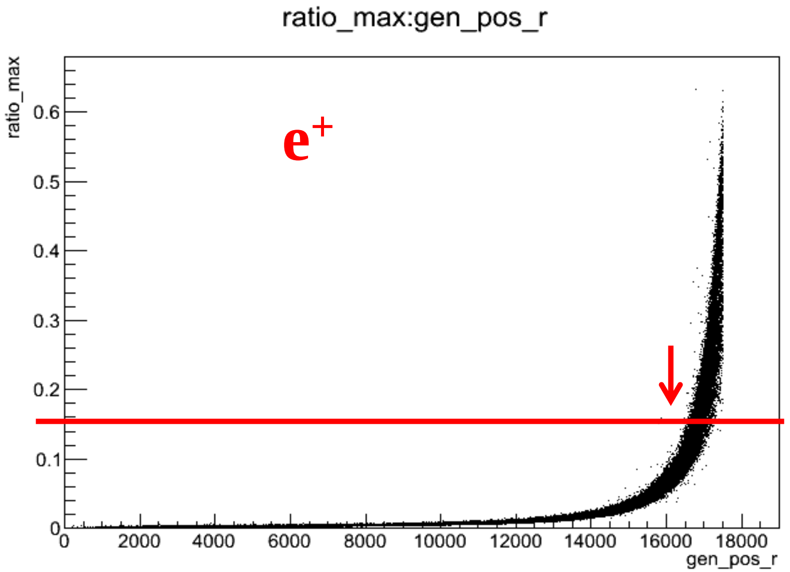


If the PMT glass is the same as Daya Bay, radioactivity will be 44 Bq/PMT, or 3.3 MHz in total

If better glass is used, it may be reduced to 0.5-1 MHz

Online background suppression

- **Divide PMTs to 1476 regions**
- **Look at the charge ratio Q_i/Q_{total} (i: the region ID)**
  - ⇨ Cut charge ratio < 0.16
  - ⇨ Cut $N_{p.e.}$ > 500(~0.4 MeV)
- **Event rates can be reduced to 0.6kHz**



Resolution is affected:

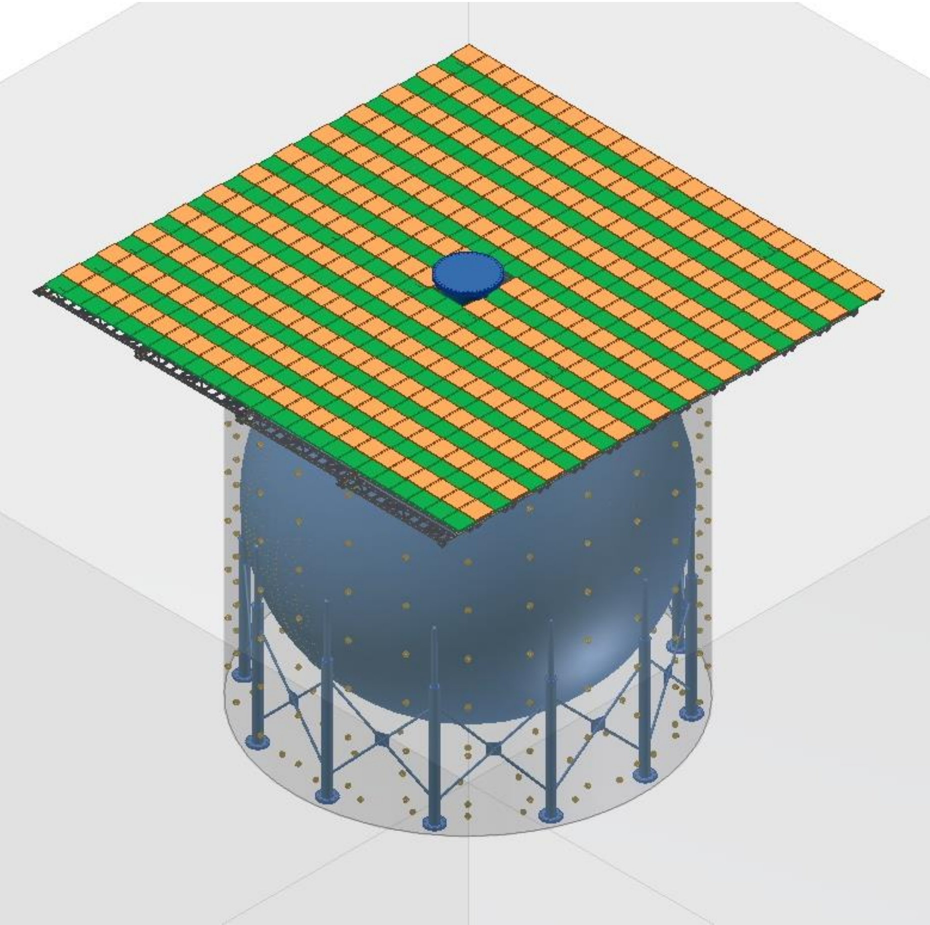
Energy(MeV)	No Background (vertex corrected)		Mix Background(1MHz, 500ns) (vertex corrected)	
	sigma	mean	sigma	mean
2*0.511	0.030	1	0.035	0.94
2.22	0.024	1	0.027	0.97
1.173+1.333	0.021	1	0.024	0.97
6.13	0.016	1	0.017	0.99

Prototyping plan

- **One or a few of the following:**
  - **Φ2m acrylic ball**
  - **Φ2m steel ball**
  - **Φ35m balloon**
  - **Acrylic box**
- **To understand the following:**
  - **Design and manufacturing technologies**
  - **Assembly and installation issues**
  - **Background suppression capabilities**

VETO

- **Water**
  - **A MC simulation show that ~ 2m water, 1500 20" PMT is good enough**
- **Top VETO**
  - **Fully or partially covered**
  - **Options:**
    - ✓ **RPC**
    - ✓ **Plastic scintillator**
    - ✓ **Liquid scintillator**



New site：Kaiping county, Jiangmen city

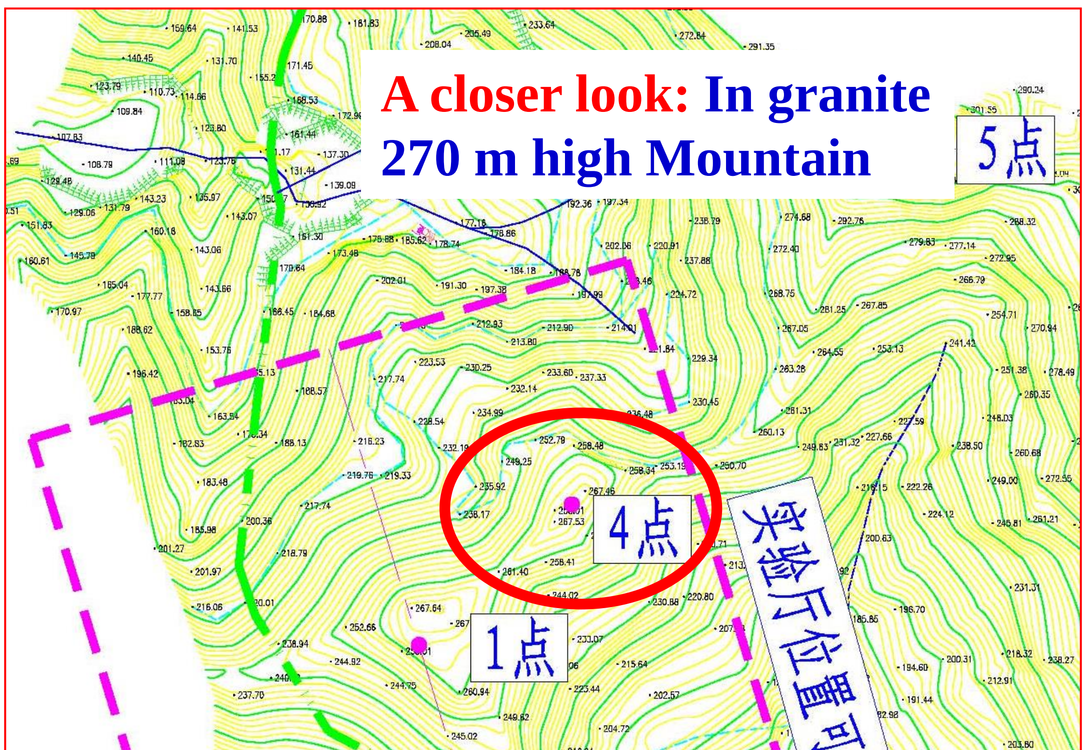
	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	running	planned	approved	Construction	construction
power/GW	17.4	17.4	17.4	17.4	18.4

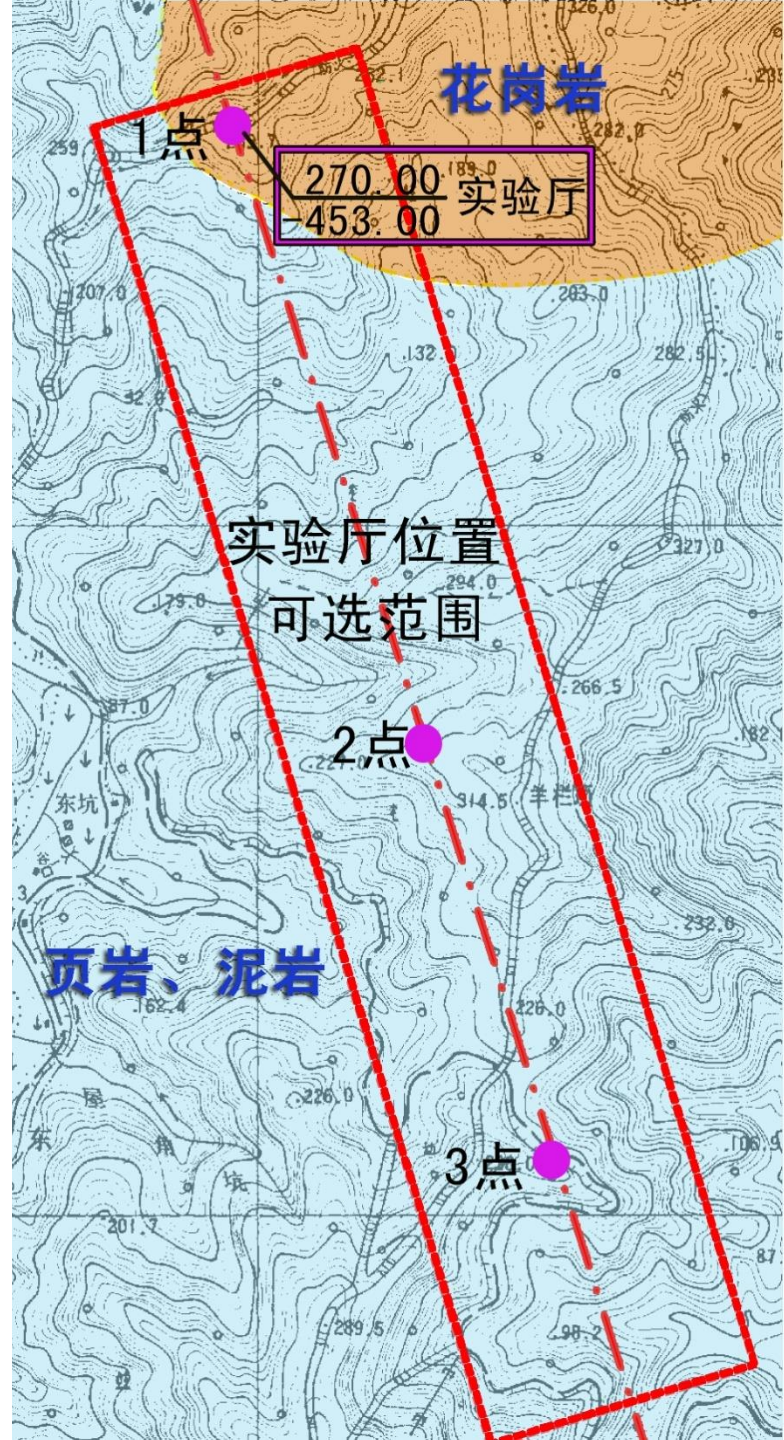
Kaiping county, Jiangmen city

广东省江门市开平市金鸡镇、赤水镇一带

Site selection

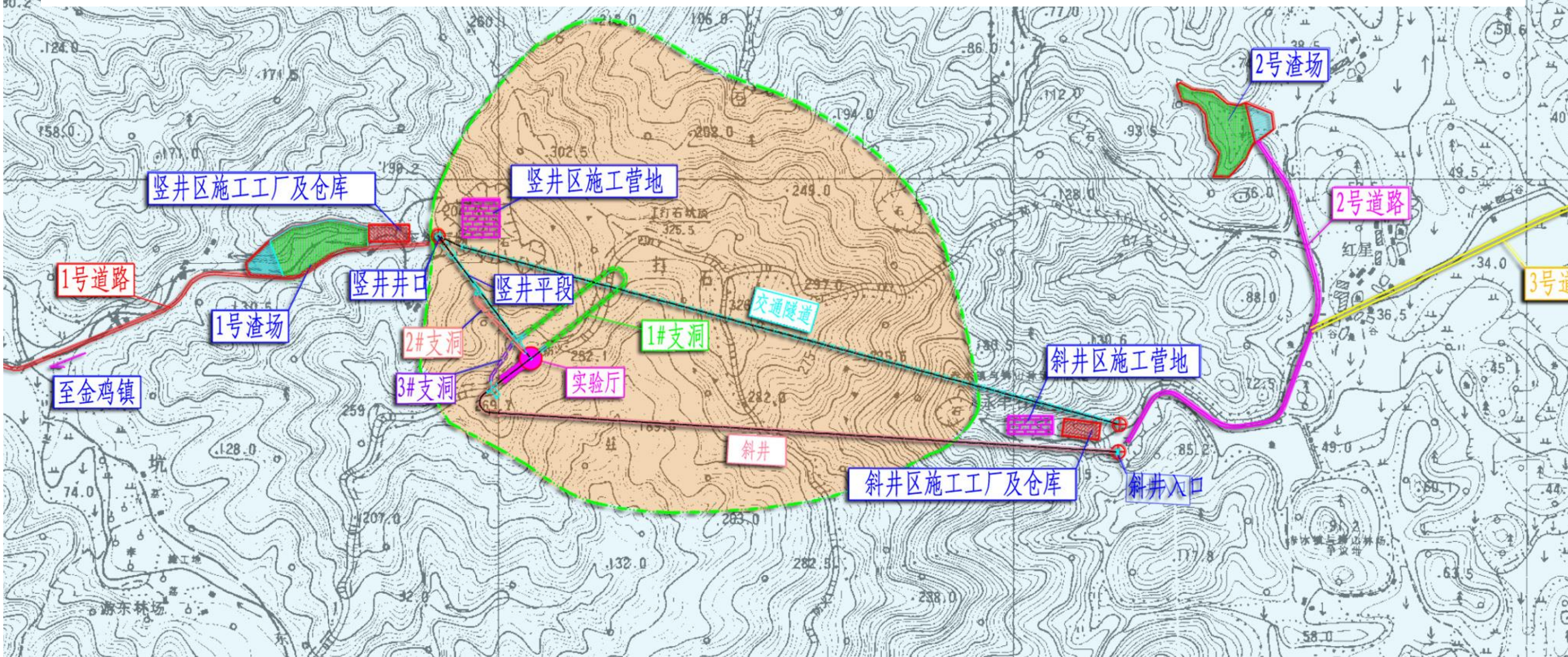
- Experimental hall selected
- Preliminary geological survey:
  - ⇨ Review held on Dec. 17, 2012
  - ⇨ No show-stoppers
- Detailed geological survey to be started this month



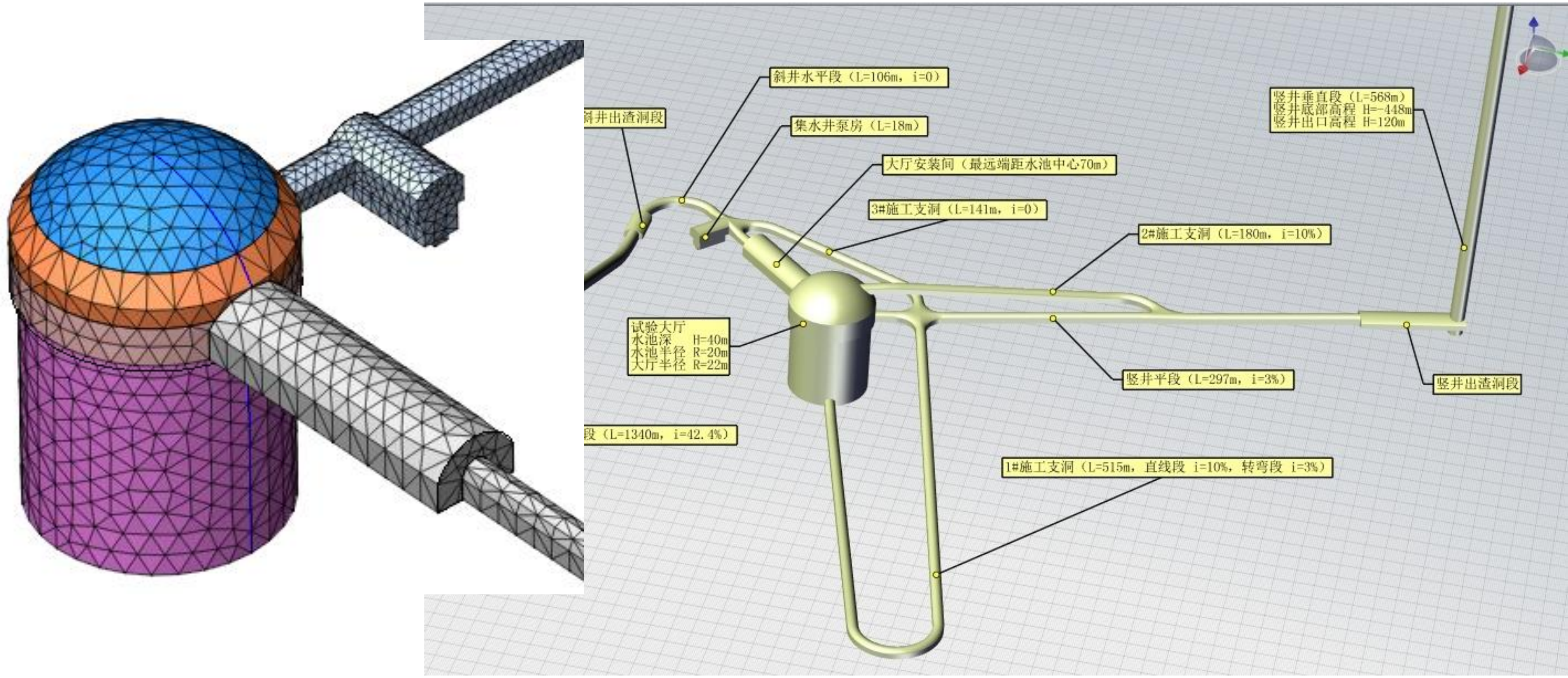


Construction plans

- **Two options considered**
  - Rails(40%, 1100m) + vertical shaft(600m)
  - Rails(40%, 1100m) + horizontal tunnel(6600m)
- **Conceptual design completed. Review held on Dec.17, 2012.**
  - Rails+vertical shaft is chosen for cost and schedule reasons
  - No show-stoppers



Experimental hall



- **Preliminary study shows that:**
  - **Stability of the hall is not a problem**
  - **Total time needed for the civil construction is 3 years**

Brief schedule

- **Civil preparation：2013-2014**
- **Civil construction：2014-2017**
- **Detector R&D：2013-2016**
- **Detector component production：2016-2017**
- **PMT production：2016-2019**
- **Detector assembly & installation：2018-2019**
- **Filling & data taking：2020**

After a number of reviews, we are approved by the CAS(~ CD1)

Summary

- **"Daya Bay II" is a project with a very rich and interesting physics program**
- **Although challenging, initial study shows that it is not impossible**
- **A few R&D efforts already started, more will come**
- **Detector design and civil design has been started**
- **Good support from the local government & the Chinese funding agencies**

Welcome collaborators