Perspectives for the measurement of mass hierarchy with the Daya Bay II experiment

Changgen Yang

Institute of High Energy Physics, Beijing

Colloquium Towards CP Violation in Neutrino Physics

Charles University in Prague, 23-24 May 2013

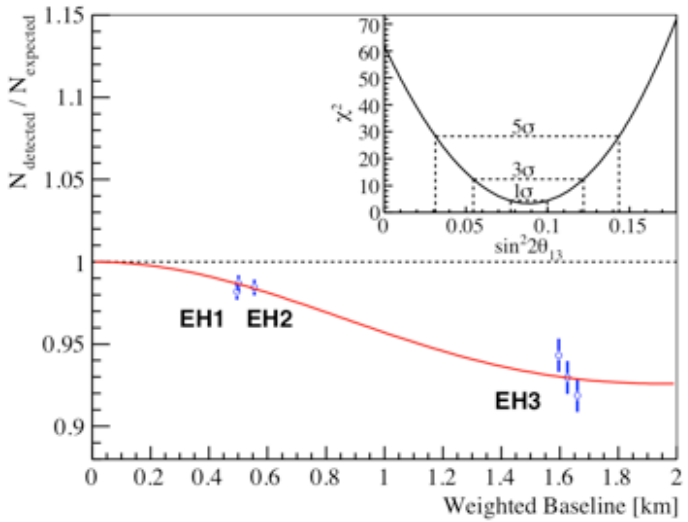
Outline

- Physics
- Plan and Challenges
- Signal & Backgrounds
- Detector concepts
- Site survey & civil
- Cost & Schedule
- Summary

The large θ_{13} era

Daya Bay, Dec 24, 2011 - May 11, 2012

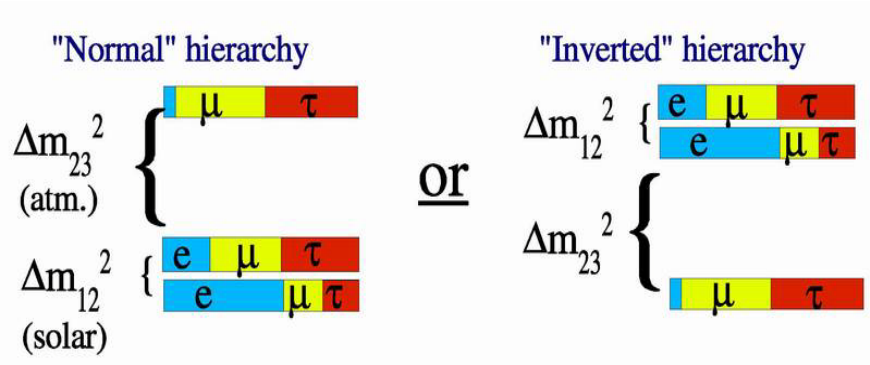
$\sin^2 2\theta_{13} = 0.089 \pm 0.010(\text{stat}) \pm 0.005(\text{sys})$

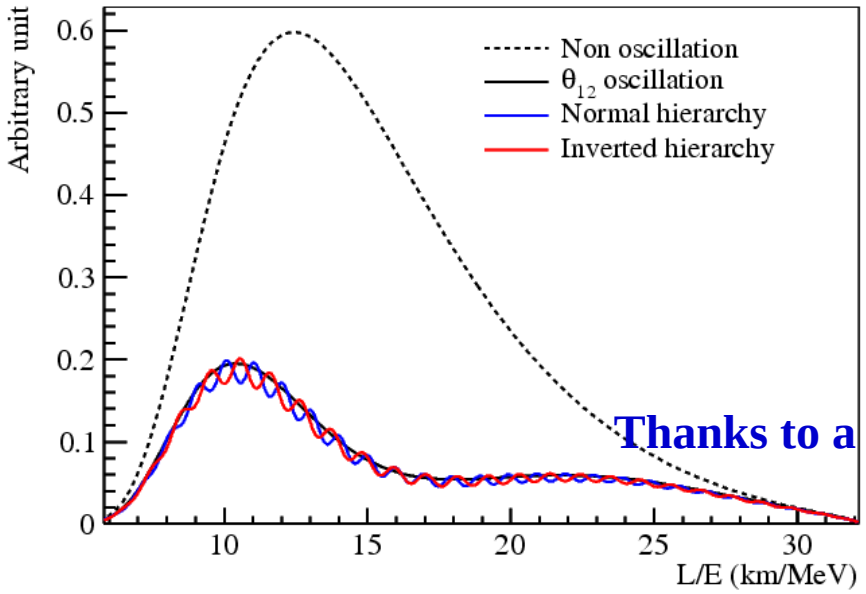


- **Non-zero and large θ_{13} observed and the $\sin^2 2\theta_{13}$ precision can reach to 4-5% by Daya Bay in 5 years.**
- **Mass hierarchy and CP phase are the main focus of next generation neutrino experiments.**
- **A medium baseline reactor neutrino experiment can measure mass hierarchy independent of CP phase.**

Reactor neutrino to determine MH

$$
\begin{aligned}
P_{ee}(L/E) &= 1 - P_{21} - P_{31} - P_{32} \\
P_{21} &= \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21}) \\
P_{31} &= \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31}) \\
P_{32} &= \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32}) \\
\Delta m^2_{31} &= \Delta m^2_{32} + \Delta m^2_{21} \\
\text{NH}: \ |\Delta m^2_{31}| &= |\Delta m^2_{32}| + |\Delta m^2_{21}| \\
\text{IH}: \ |\Delta m^2_{31}| &= |\Delta m^2_{32}| - |\Delta m^2_{21}|
\end{aligned}
$$

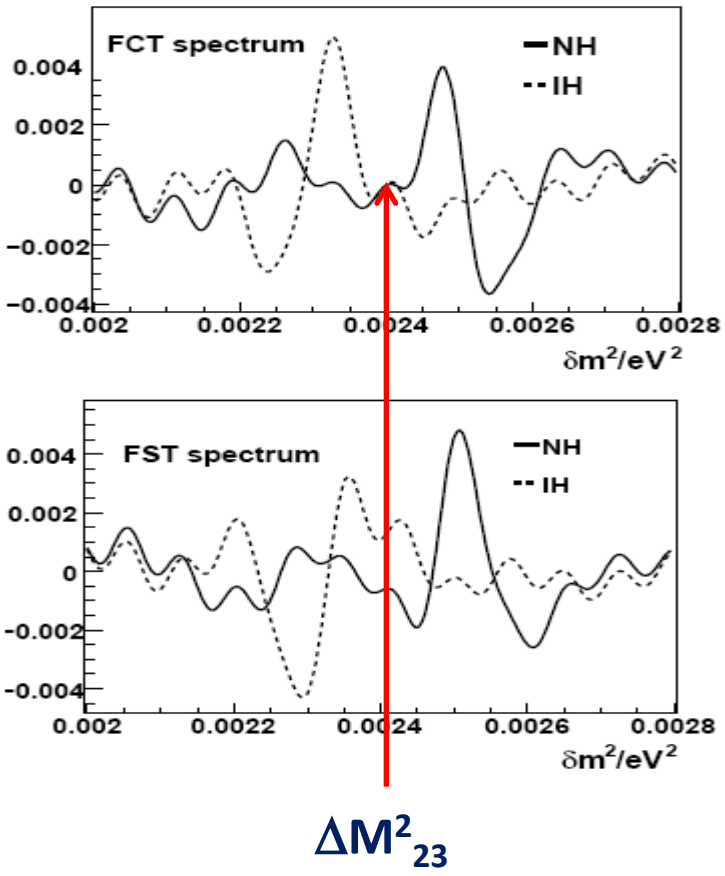




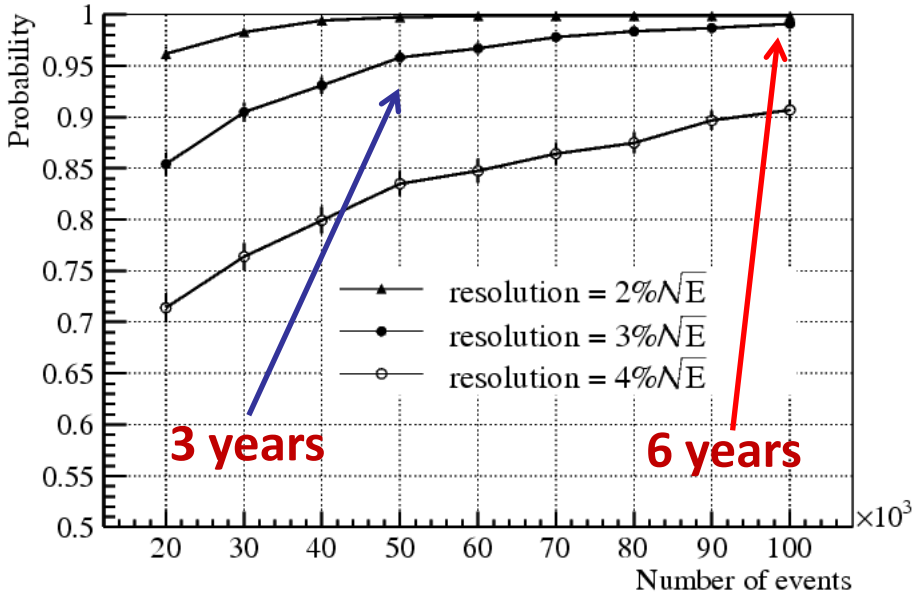
Thanks to a large θ_{13}

Mass hierarchy：sensitivity

Fourier transformation



ΔM^2_{23}



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

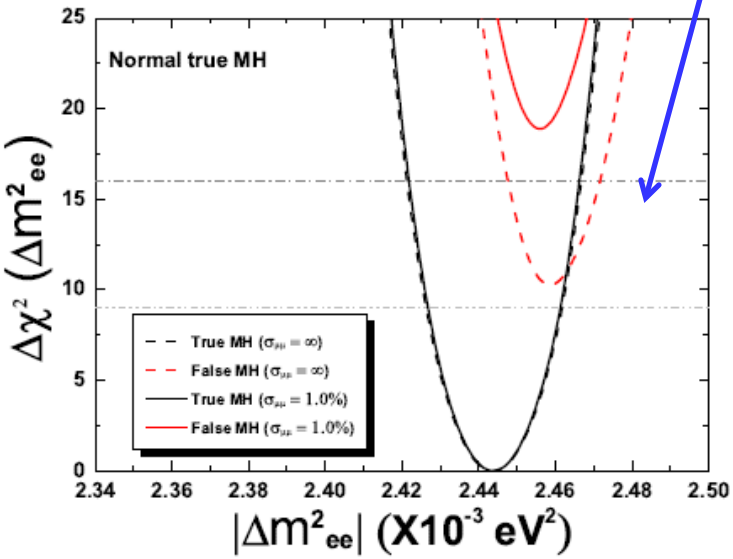
Calculations and Considerations

S.T. Petcov et al., PLB533(2002)94
S.Choubey et al., PRD68(2003)113006 J. Learned et al., hep-ex/0612022 L.

Zhan, Y. Wang, J. Cao, L. Wen, PRD78:111103, 2008

PRD79:073007, 2009

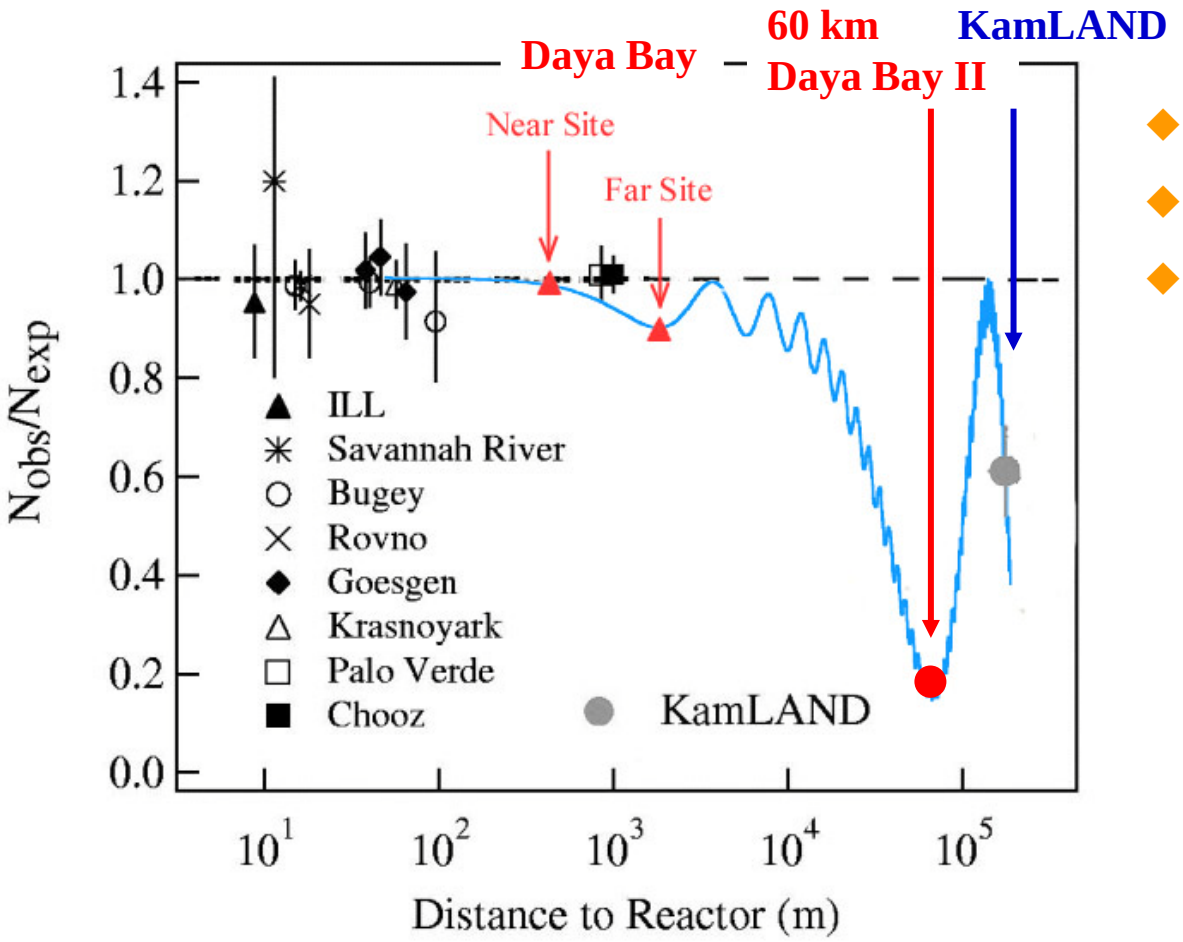
Talk by Y.F. Wang at ICFA seminar 2008...NuFact 2012; by J. Cao at Nutel 2009...NPB 2012 (ShenZhen)



arXiv:1303.6733

- Improve MH sensitivity with χ^2 method by taking into account ΔM^2_{23} from T2K and Nova in the future;
- Reactor interference effects with different baselines;
- Study of nonlinear energy response to the mass hierarchy determination;
- Peak location with 2 detectors
- The oscillation frequencies with 2 identical detectors at 2 distinct baselines; etc

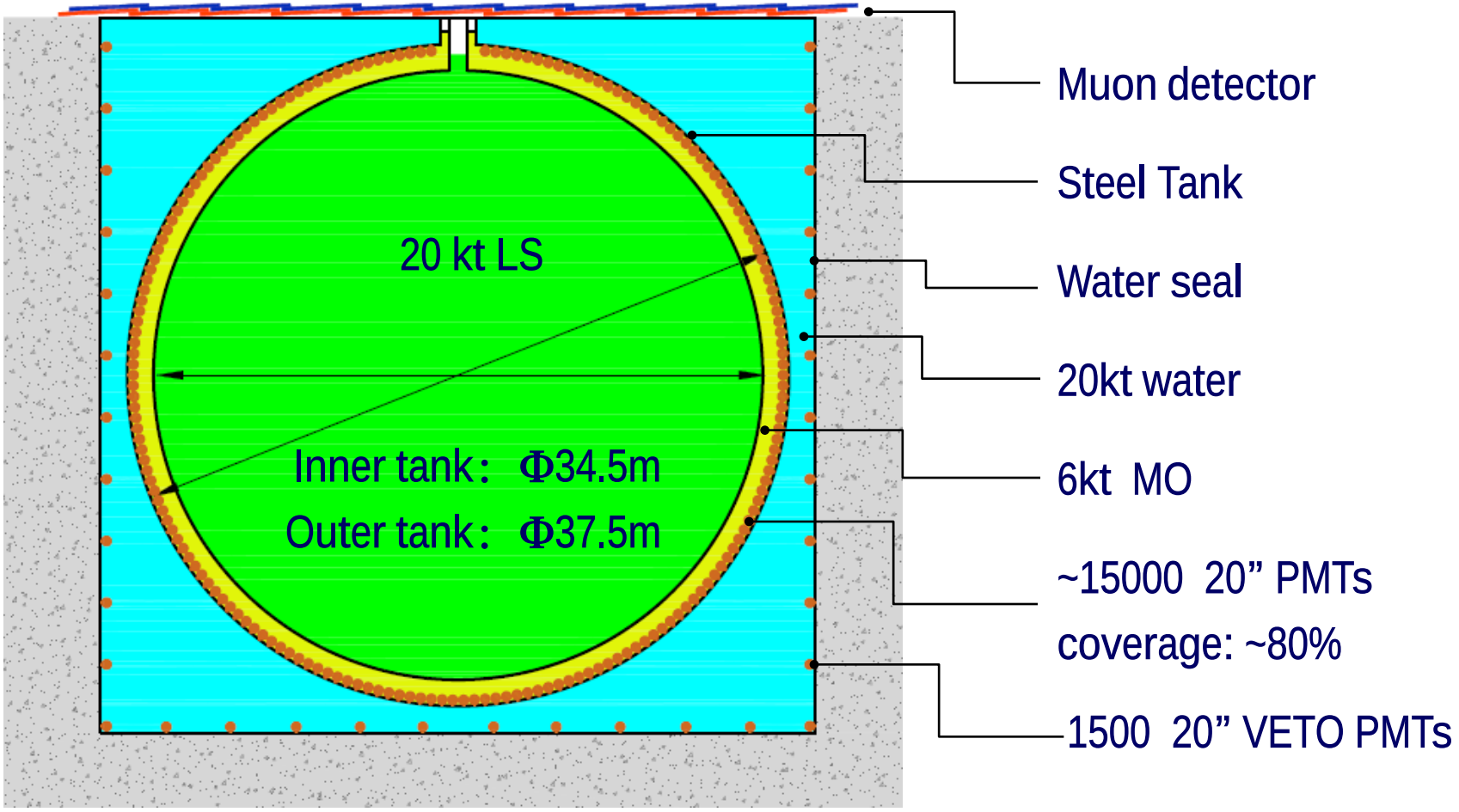
Daya Bay-II Experiment



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

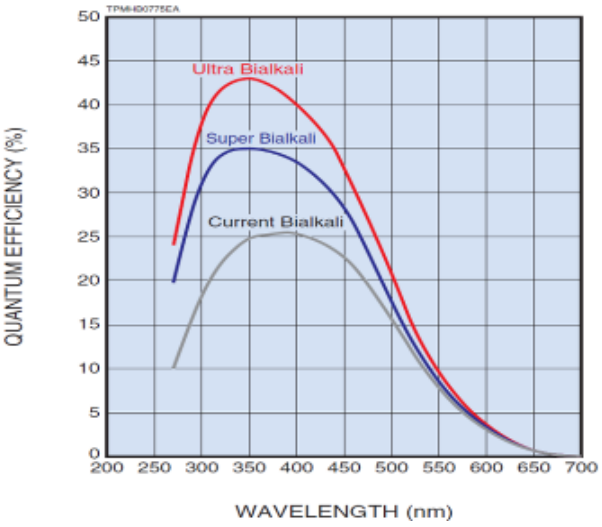
The plan and Challenges: a large LS detector

	Daya Bay II	What to do?
LS mass	**20 kt**	**Increase Mass**
Energy Resolution	**3%/√E**	**More photons,**
Light yield	**1200 p.e./MeV**	**And more photons**

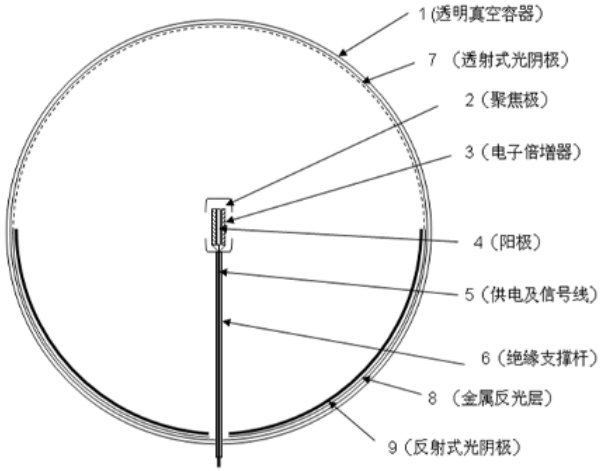


More Photons-- PMT

SBA photocatode

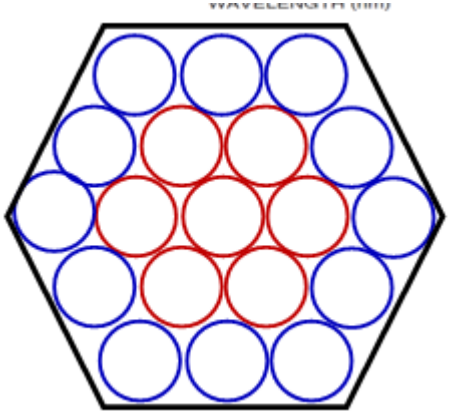


New type of PMT: MCP-PMT

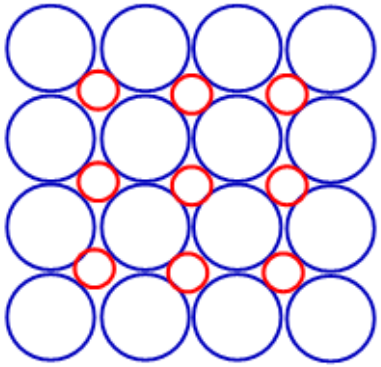


- Top: transmitted photocathode
- Bottom: reflective photocathode

~ ×2 improvement

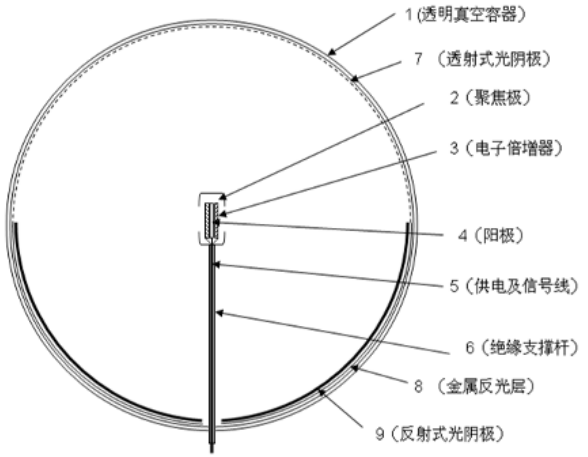


No clearance:
coverage 86.5%
1cm clearance:
coverage: 83%



20" + 8" PMT
8" PMT for better timing(vertex)

A PMT R&D collaboration



Institute of High Energy Physics Chinese Academy of Sciences

XIAN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CA

北方夜视技术股份有限公司
NORTH NIGHT VISION TECHNOLOGY CO.,LTD

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

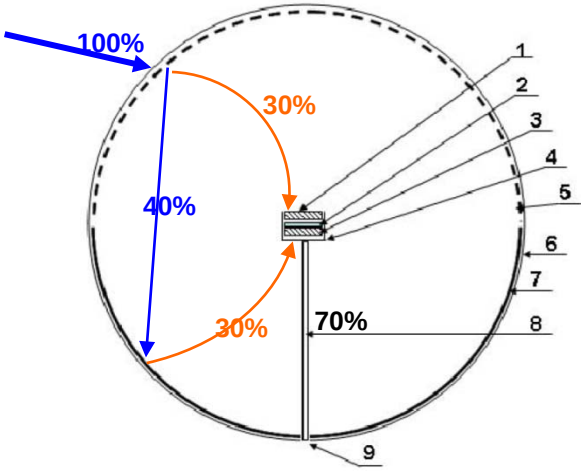
宝光股份
BAOGUANG

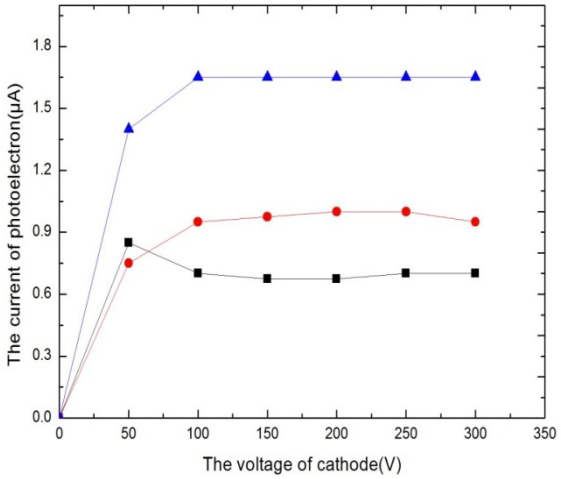
南京大學

Patent serial number：
200910147915.4（China）
US13/259,861（US）

- Started in 2008
- Big progress in last year
- Single p.e. measured with 8” PMT
- Goal：35-50%QE, 20" MCP-PMT

PMT: a number of new prototypes

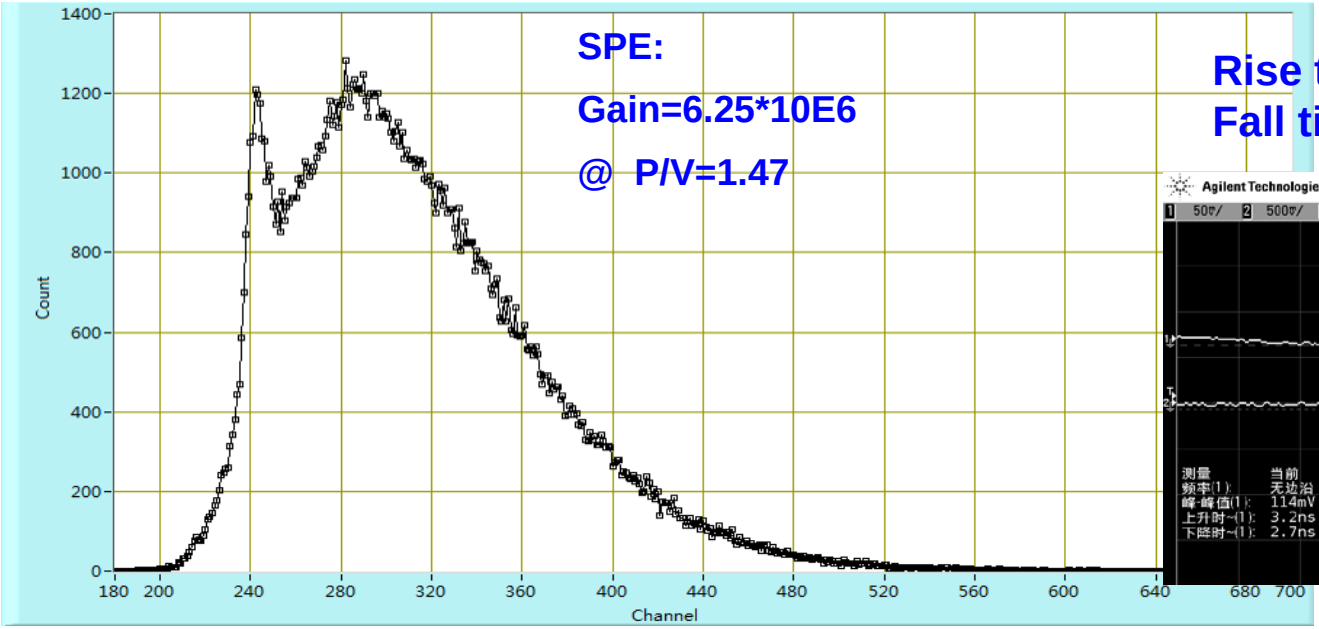




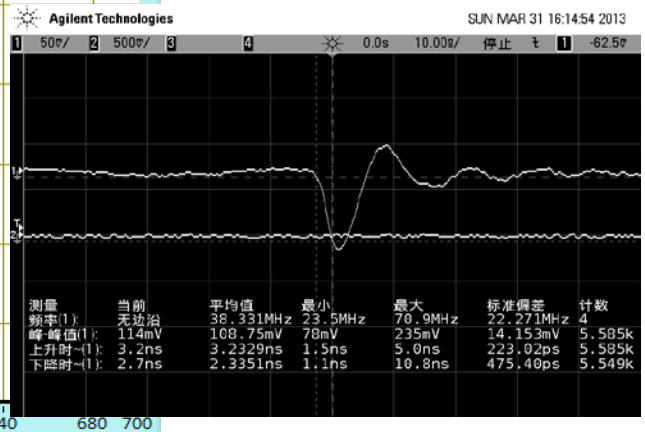
Sum

Reflective photocathode

Transmitted photocathode



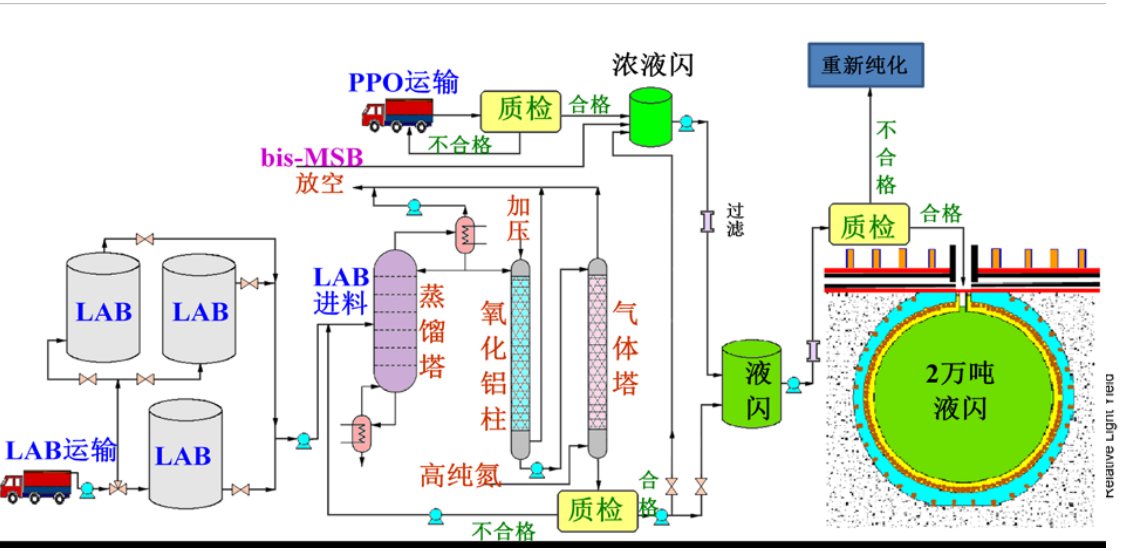
Rise time： 2.7ns；
Fall time： 3.2ns

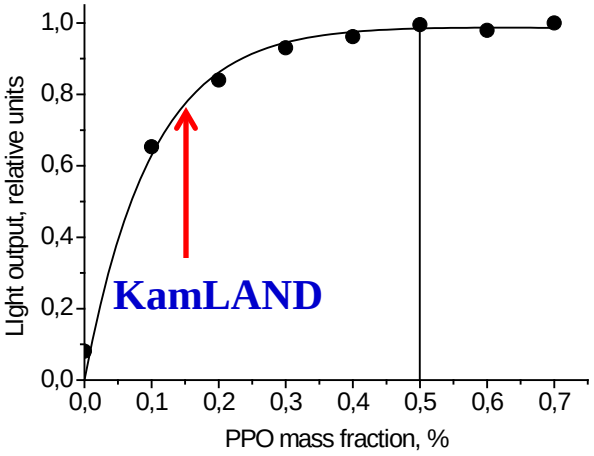


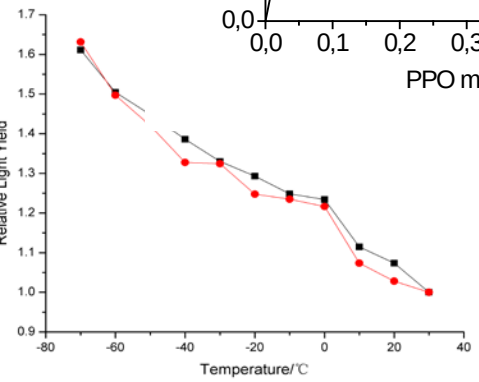
More Photons-- LS

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

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

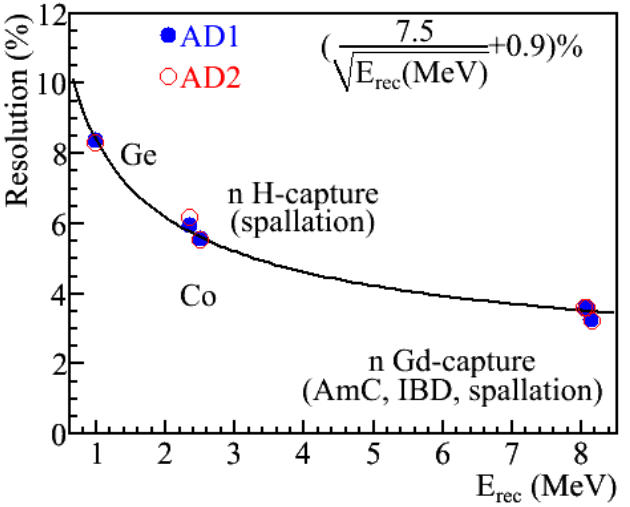


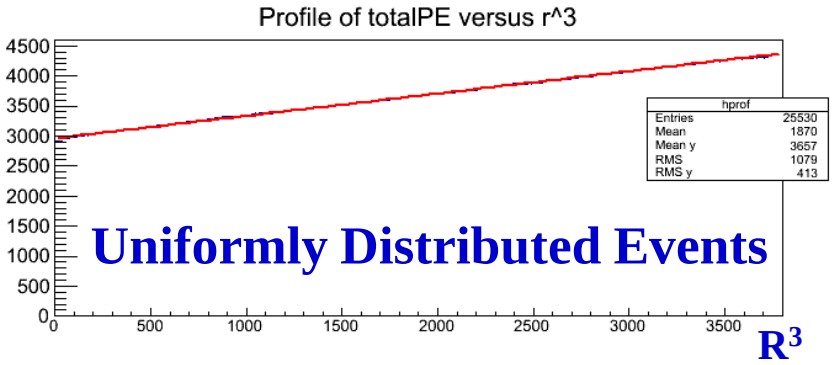


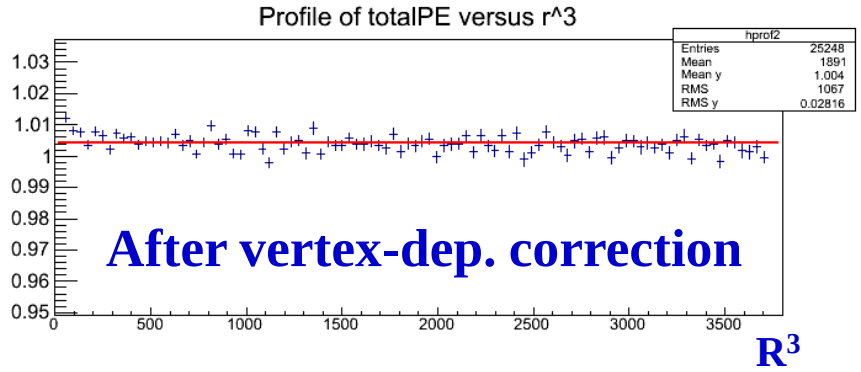


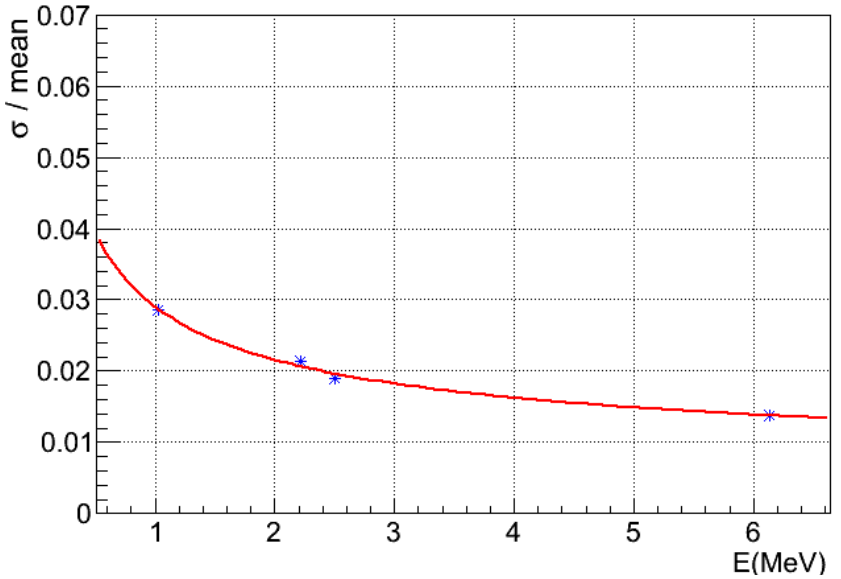
Energy Resolution(MC)

- **DYBII MC, based on DYB MC (tuned to data), except**
  - ⇨ **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:**

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

Estimated IBD rate: ~40/day

$$\mathrm{n + p \rightarrow d + \gamma\ (2.2\ MeV)} \qquad \tau \sim 200\ \mu s$$

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

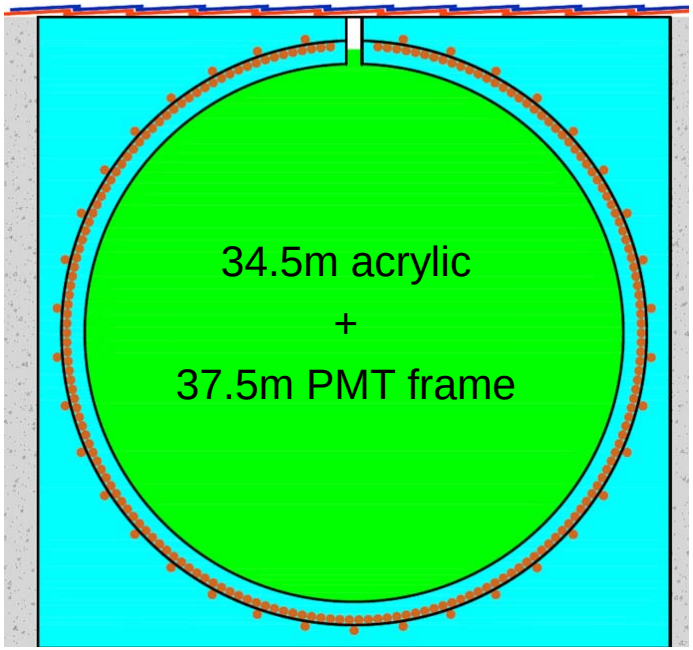
Backgrounds Summary

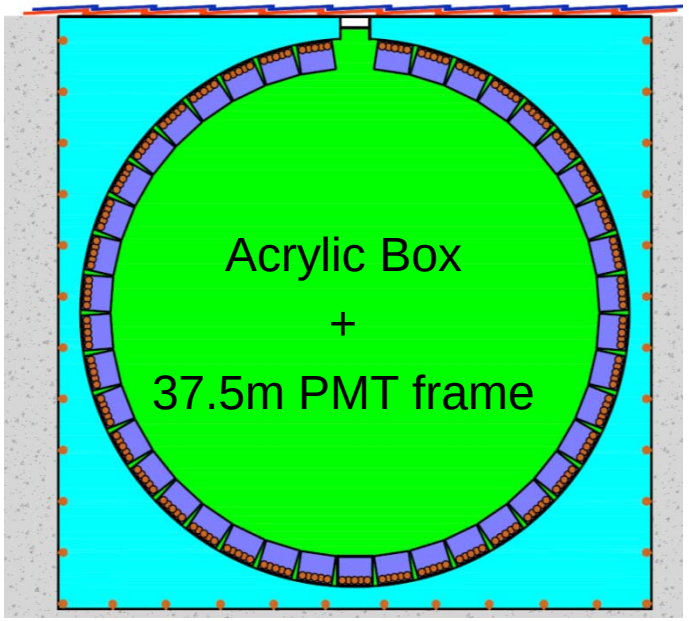
- **Assumptions**
  - ⇨ **Overburden is 700m**
    - ✓ E_μ ~ 211 GeV, R_μ ~ 3.8 Hz
  - ⇨ **Single rates from LS and PMT are 5Hz, respectively**
  - ⇨ **Good muon tracking**
  - ⇨ **Similar muon efficiency as DYB**

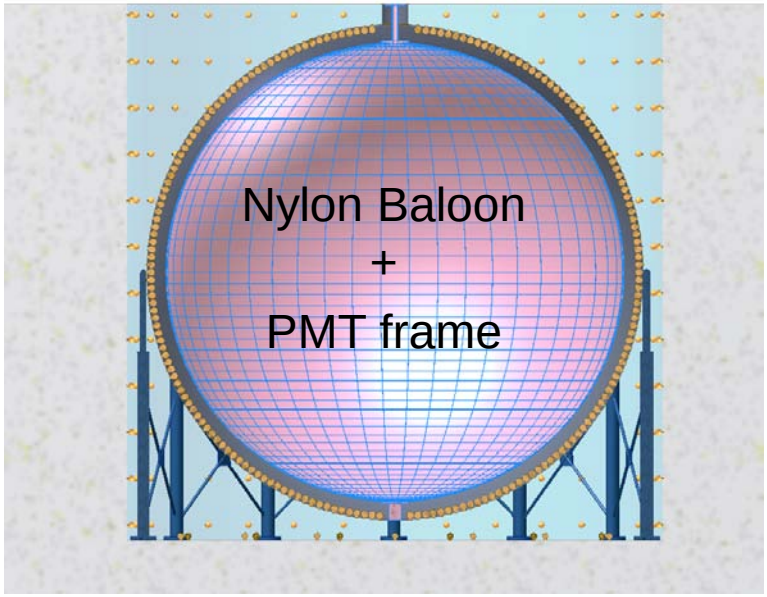
	Daya Bay	Daya Bay II
Mass (ton)	20	20,000
E_μ (GeV)	~57	~211
R_μ (Hz)	~21	~3.8
$R_{singles}$ (Hz)	~50	~40

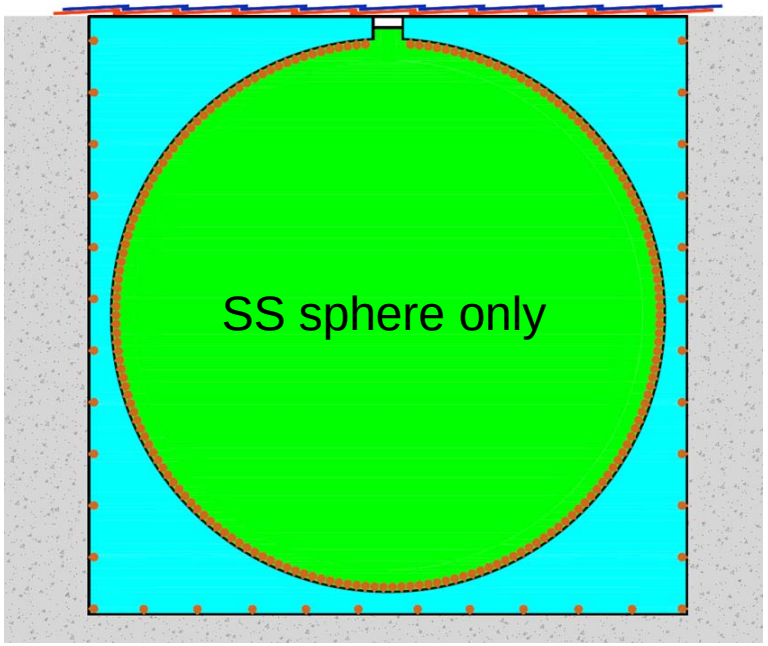
	B/S @ DYB EH1	B/S @ DYB II	Techniques used for DYB II detector
Accidentals	~1.4%	~10%	Low PMT radioactivity; LS purification; prompt-delayed distance cut
Fast neutron	~0.1%	~0.4%	High muon detection efficiency (similar as DYB)
^{9}Li/^{8}He	~0.4%	~0.8%	Muon tracking; If good track, distance to muon track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

Central Detector Concept



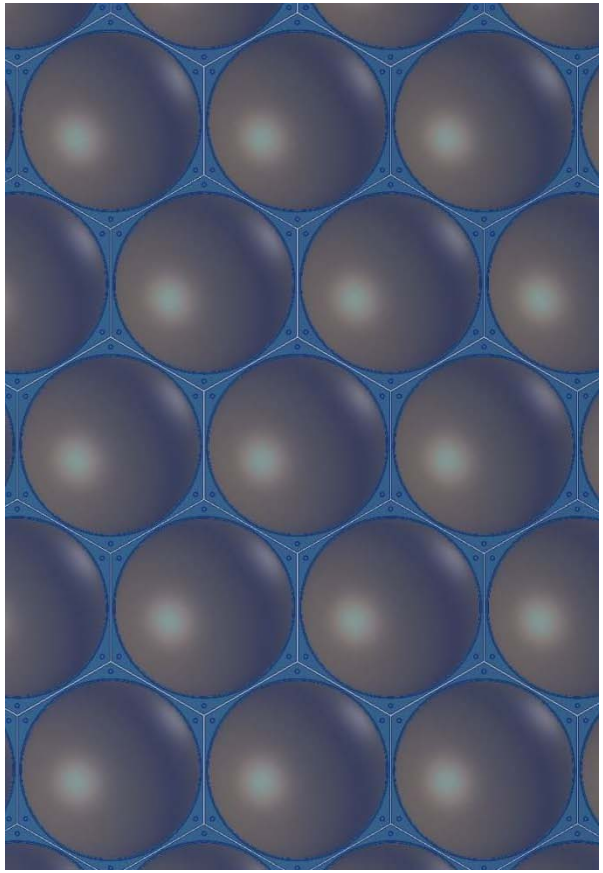


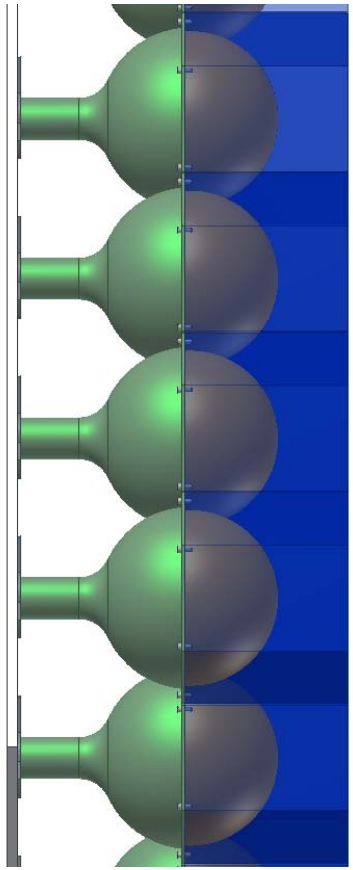


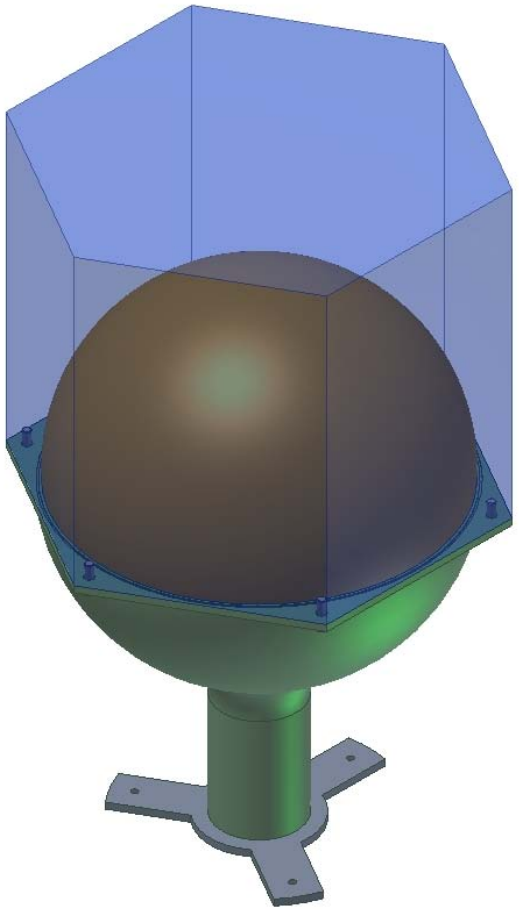


Detector option: no one is eliminated, more is coming

- Acrylic blocks individually mounted

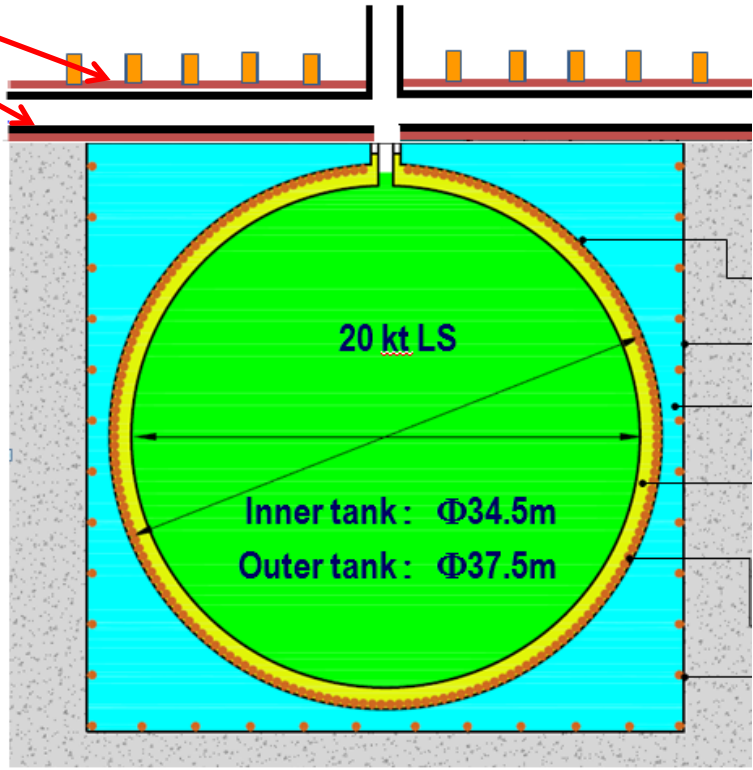






VETO Detector Concept

- **Water Cerenkov**
  - ⇨ **A MC simulation show that ~ 3m water, 1500 20” PMT is good enough**
- **Top VETO: 2 Hyper layers of tracker (to have better track resolution)**
  - ⇨ **Options:**
    - ✓ **Glass or bakelite RPC(6 layers)**
    - ✓ **Liquid scintillator + WLS fiber**
- **R&D started**

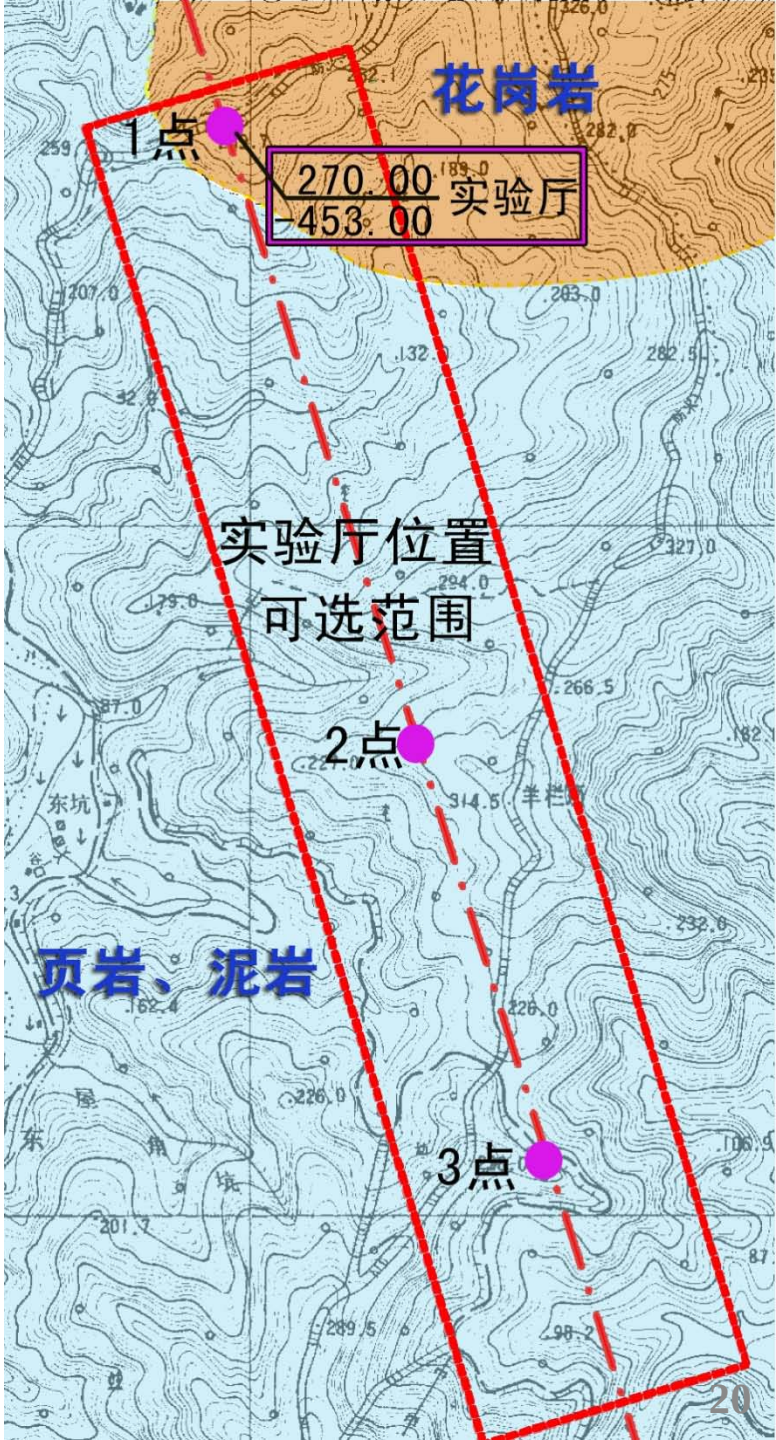


New site：Kaiping county, Jiangmen city

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

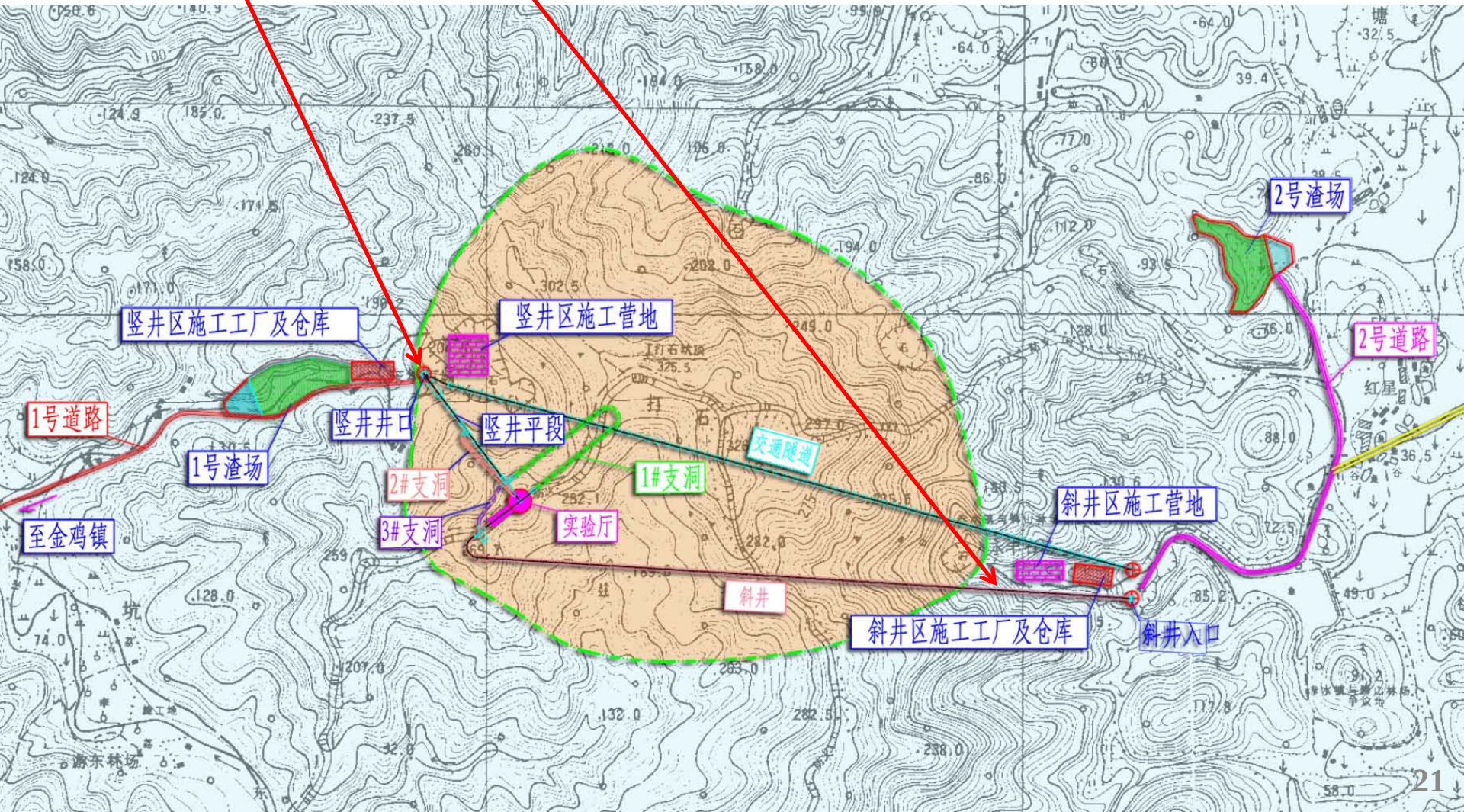
Site selection

- Allowed region determined
- Experimental hall selected:
  - ⇨ In granite
  - ⇨ Mountain height: 270 m
- Preliminary geological survey completed:
  - ⇨ Review held on Dec. 17, 2012
  - ⇨ No show-stoppers
- Detailed geological survey started
- Contacts with local government established, good support



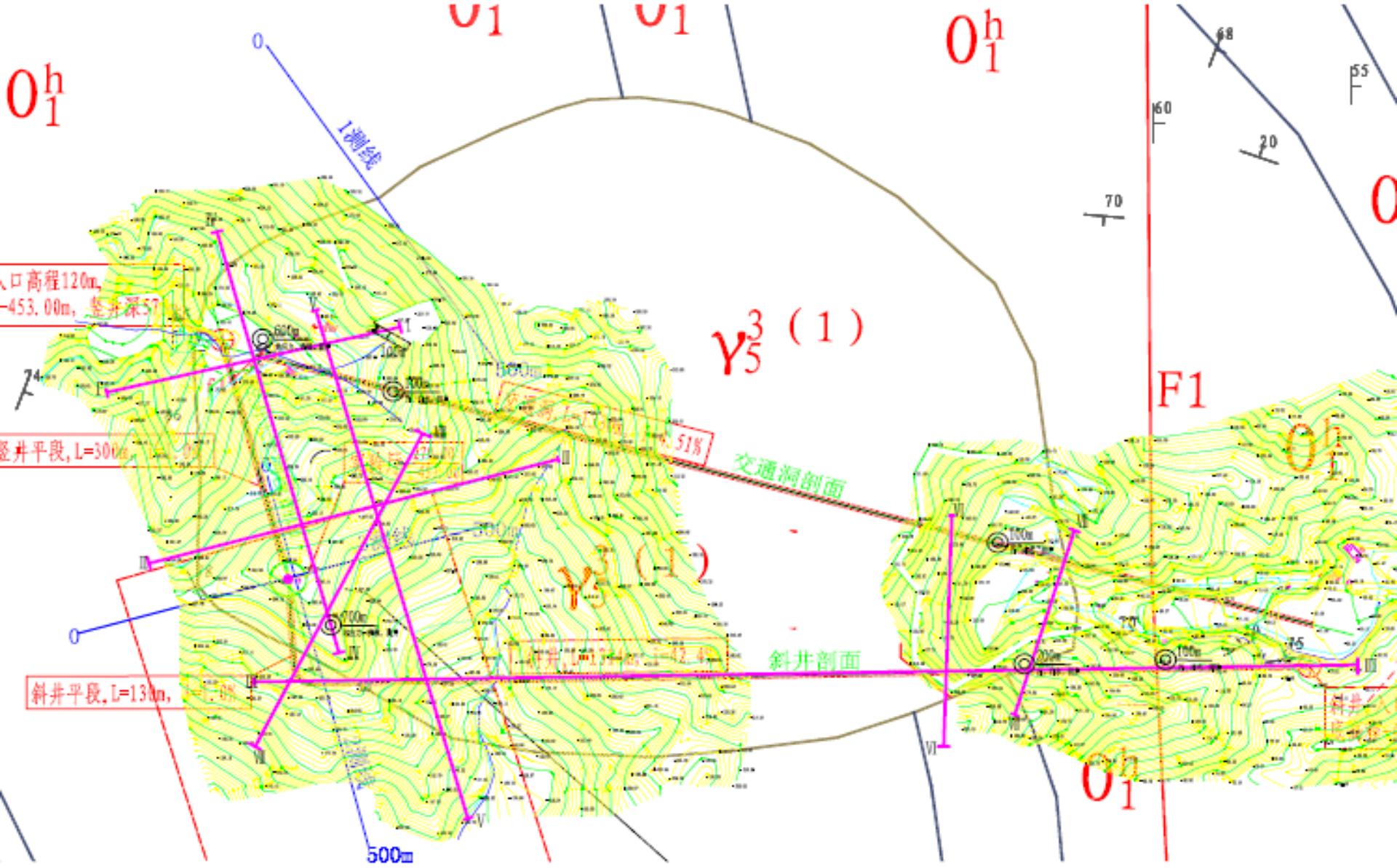
Construction plan

- **Conceptual design completed.**
  - ⇨ Vertical shaft + Rail is chosen for cost and schedule reasons
  - ⇨ A tunnel to connect them

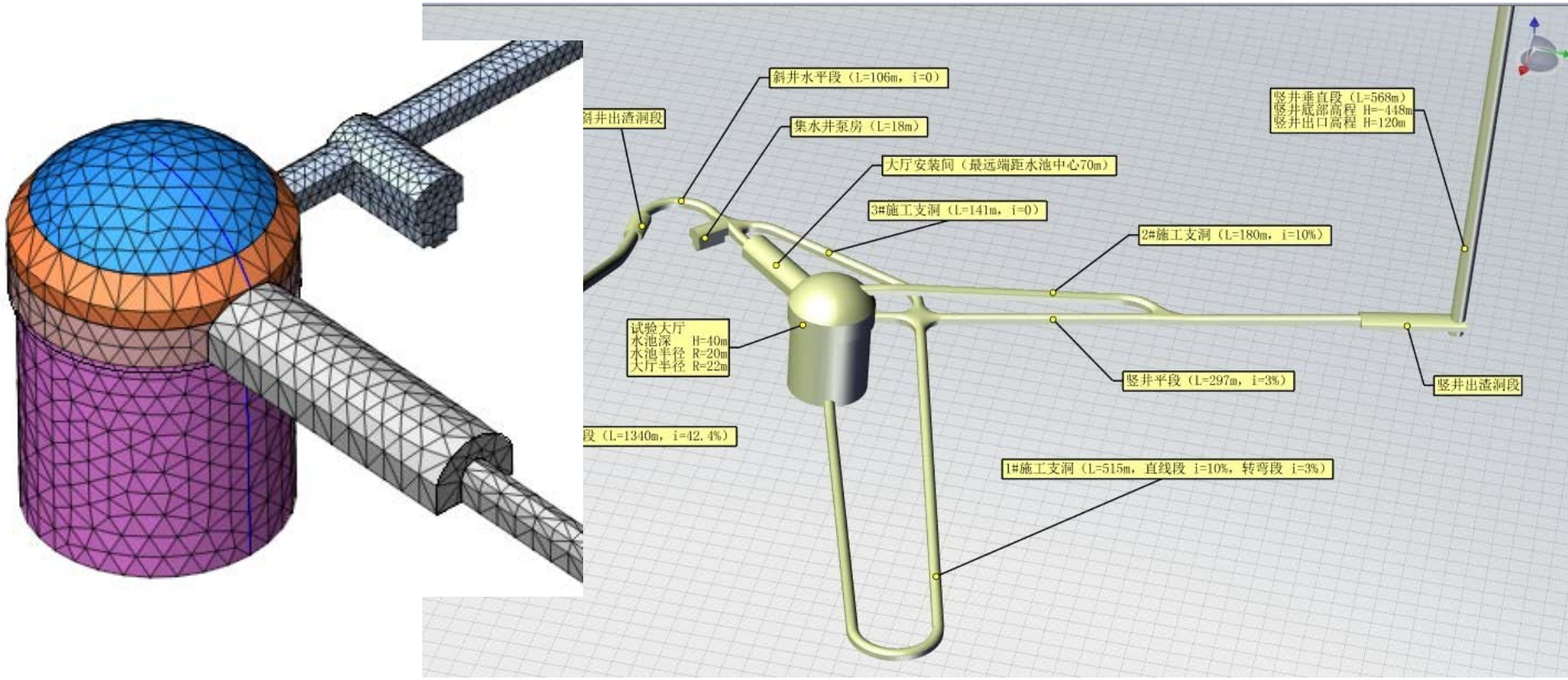


Detailed geological survey started

Expect to finish in a few months, include 200m and 700m bore holes.



Experimental hall



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

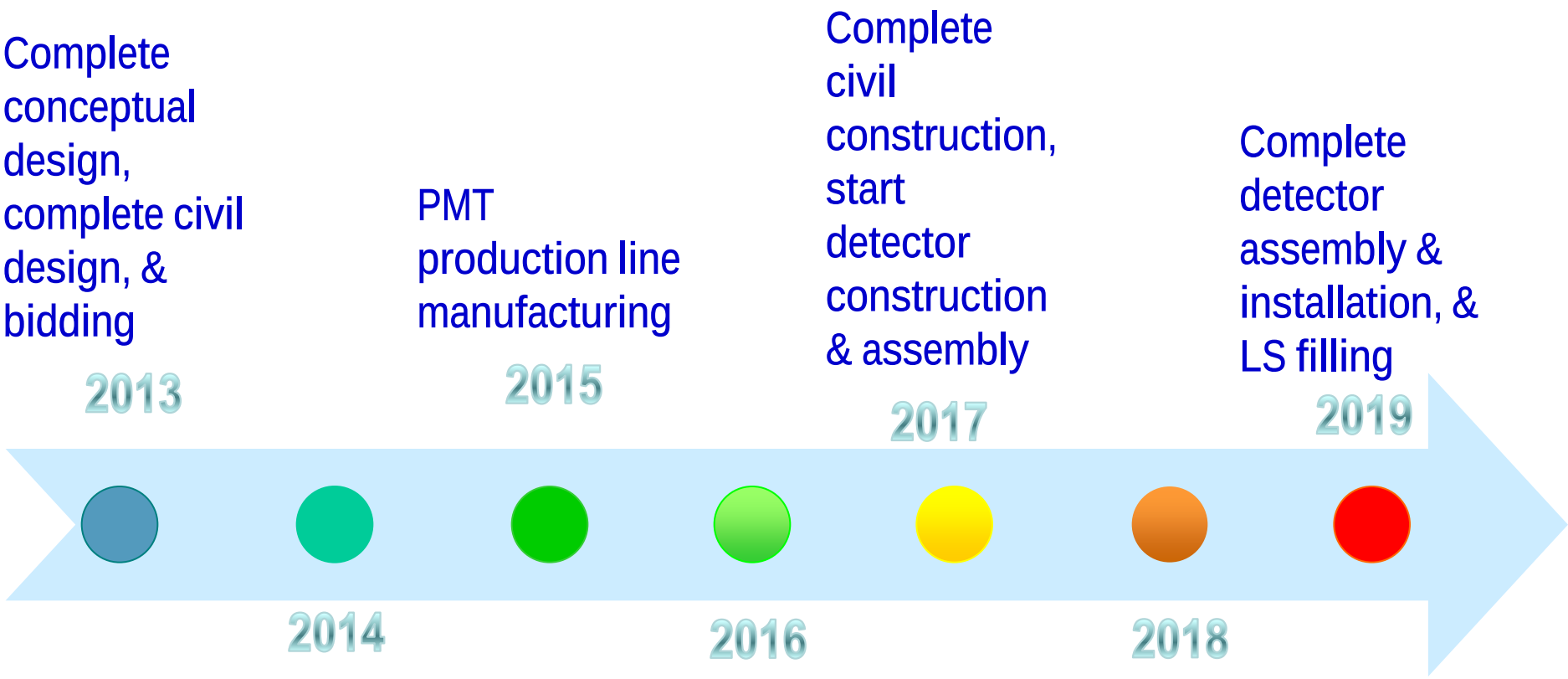
Cost estimate

	Unit price ($)	quantity	Cost (M$)
R&D			10
Civil & utilities			70
Central Detector			30
PMT	3000	20000	60
HV, electronics,trigger,DAQ,	1000	20000	20
LS & equipment	3000	20000 t	60
VETO			10
Assembly & installation			10
Contingency			30
total			300

We already passed all reviews and get support from CAS:

“Special fund for advancement”

Overall Schedule



Jiangmen(Kaiping): a tourist site with no industry

- **Famous for its architecture: mixture of east & west**

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
- R&D efforts already started
- Detector design and civil design has been started
- Good support from the local government
- Get funding from CAS “Special fund for advancement”
- Need more collaborators, more support from the community and funding agencies

Welcome to join us, mail to: liwd@ihep.ac.cn, Thanks