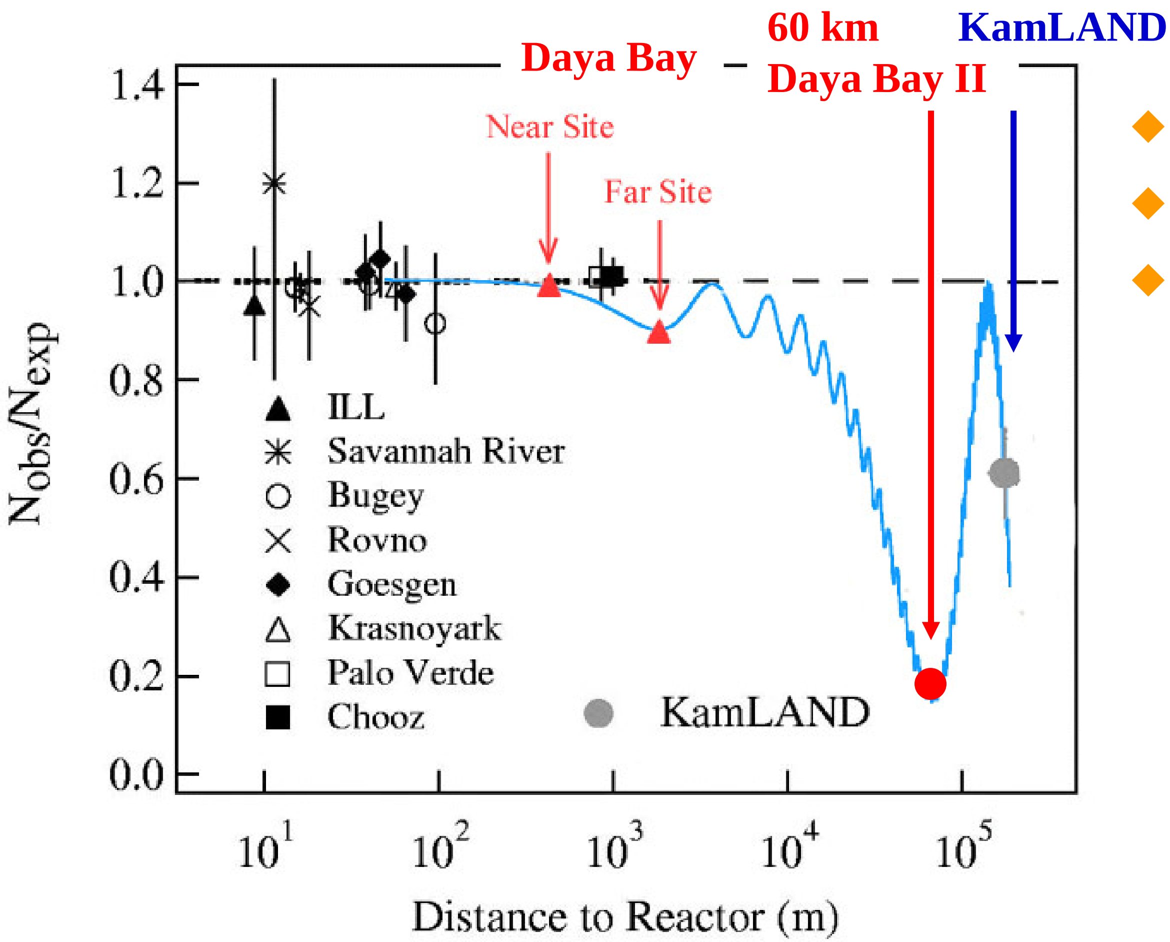
General features of the JUNO experiment

The JUNO Experiment

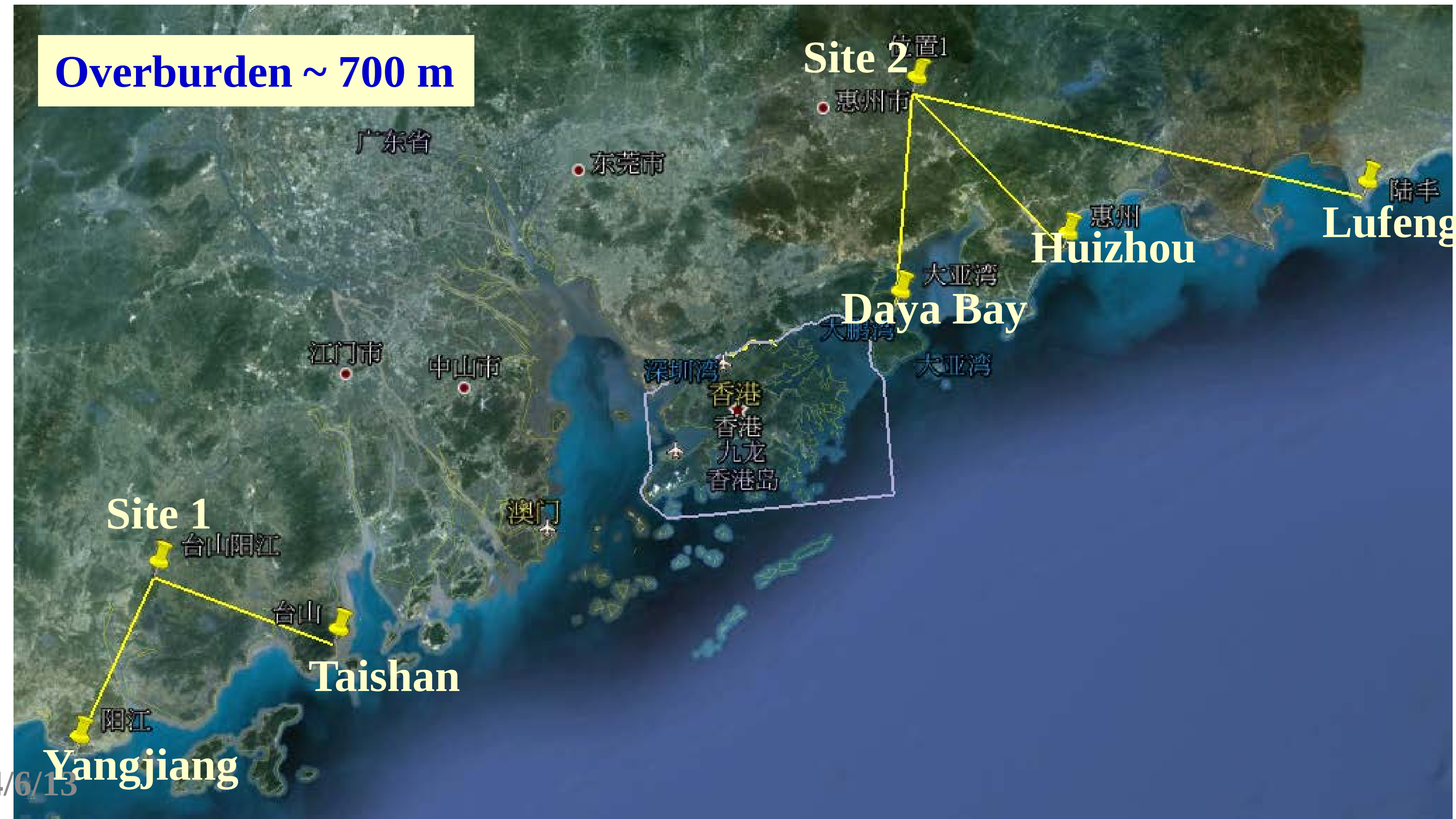


- **20 kton LS detector**
- **3% energy resolution**
- **Rich physics possibilities**
  - ⇨ **Mass hierarchy**
  - ⇨ **Precision measurement of 4 mixing parameters**
  - ⇨ **Supernovae neutrinos**
  - ⇨ **Geoneutrinos**
  - ⇨ **Sterile neutrinos**
  - ⇨ **Atmospheric neutrinos**
  - ⇨ **Exotic searches**

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

The Site

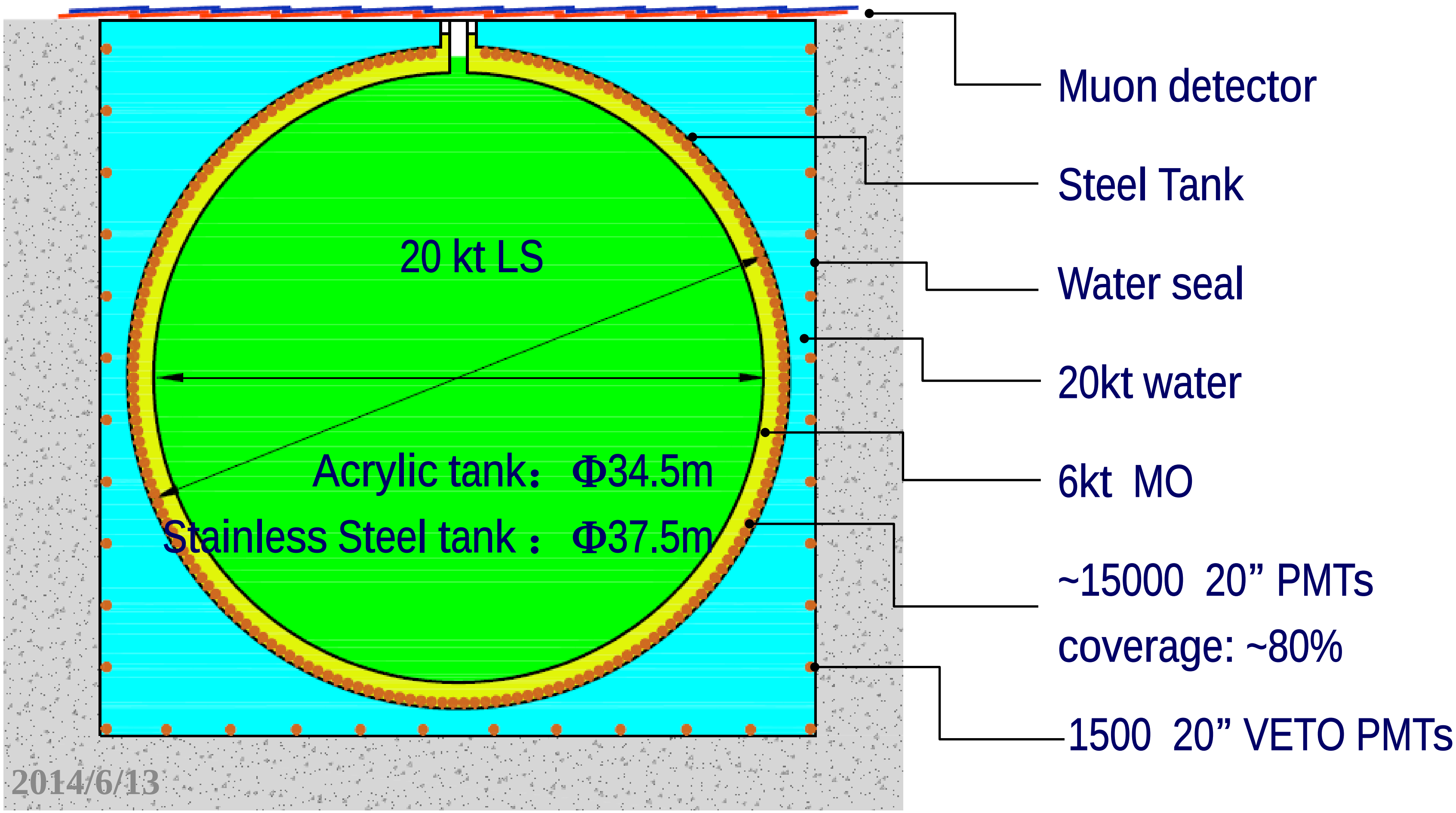
	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW，9.2 by 2020



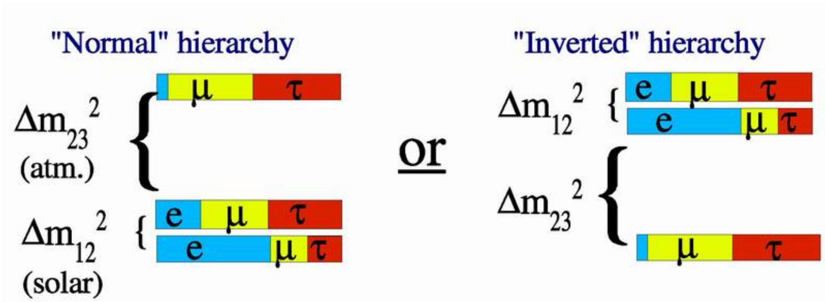
The plan: a large LS detector

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

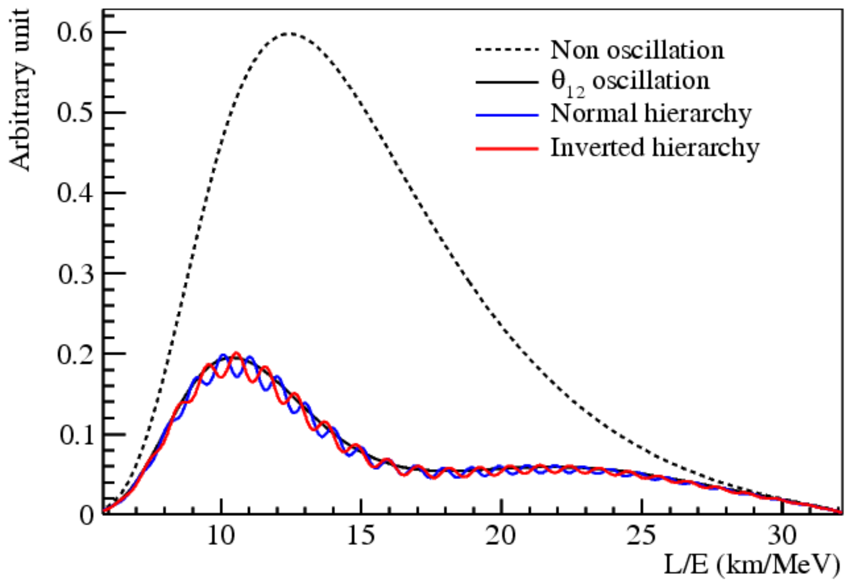
40 events/day

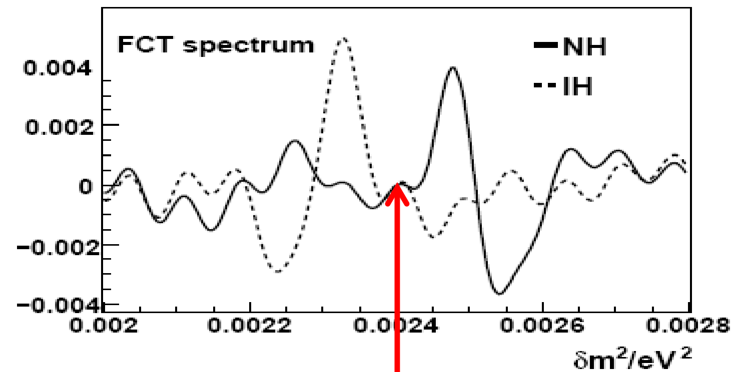


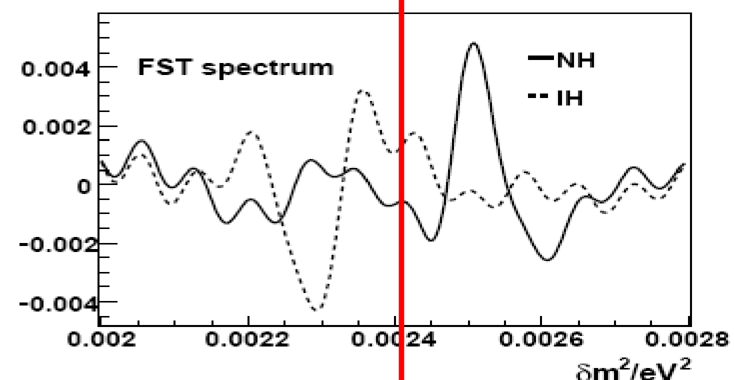
Mass Hierarchy at Reactors



$$\begin{aligned} \Delta m^2_{31} &= \Delta m^2_{32} + \Delta m^2_{21} \\ \mathrm{NH}: \quad |\Delta m^2_{31}| &= |\Delta m^2_{32}| + |\Delta m^2_{21}| \\ \mathrm{IH}: \quad |\Delta m^2_{31}| &= |\Delta m^2_{32}| - |\Delta m^2_{21}| \end{aligned}$$







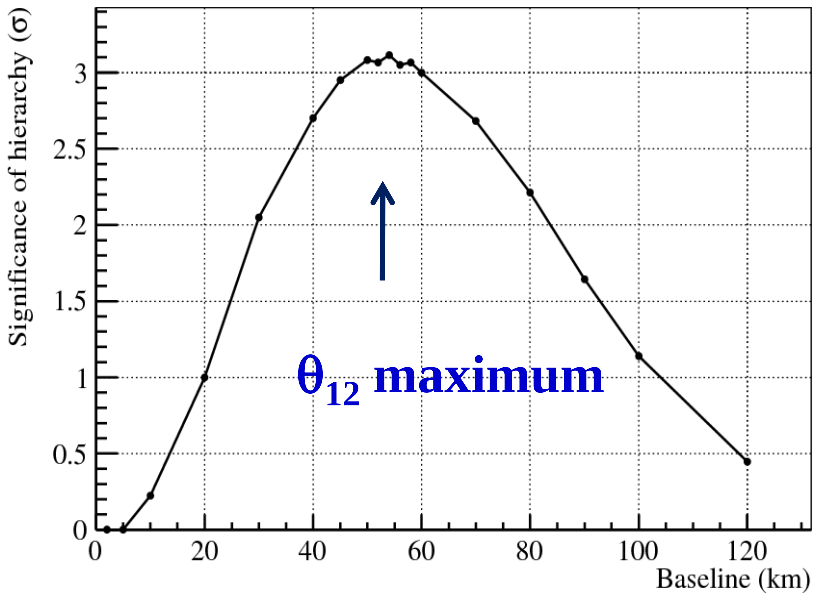
$$\begin{aligned} P_{ee}(L/E) &= 1 - P_{21} - P_{31} - P_{32} \\ P_{21} &= \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21}) \\ P_{31} &= \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31}) \\ P_{32} &= \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32}) \end{aligned}$$

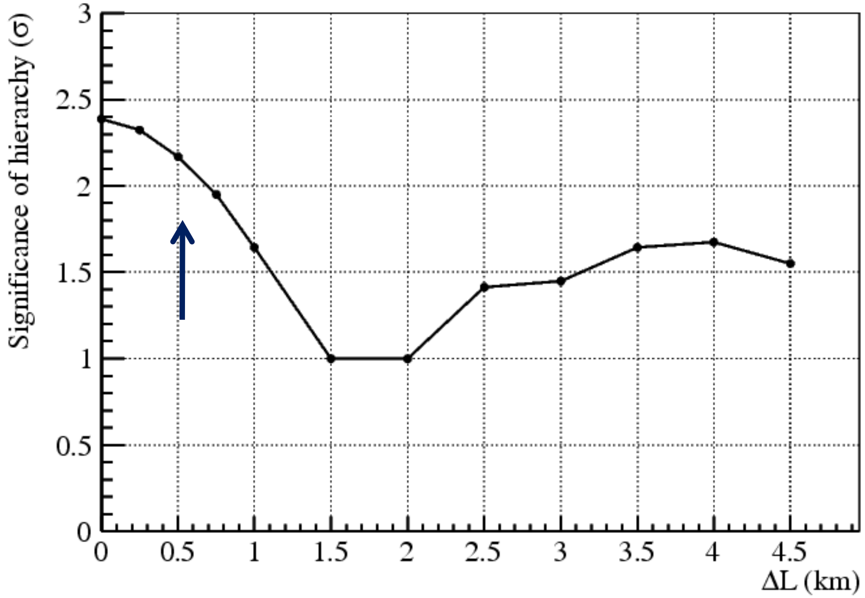
ΔM^2_{23}

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

Optimum baseline

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





Energy scale can be self-calibrated

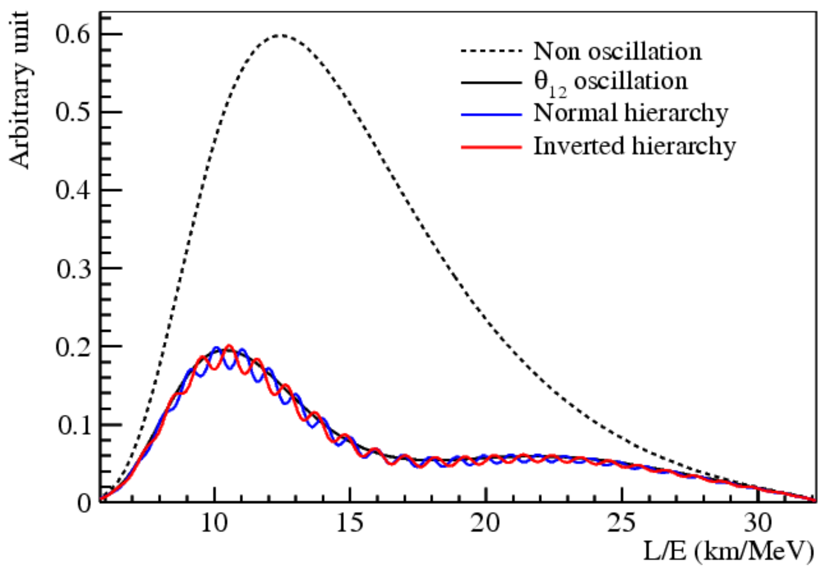
If we have a residual non-linearity:

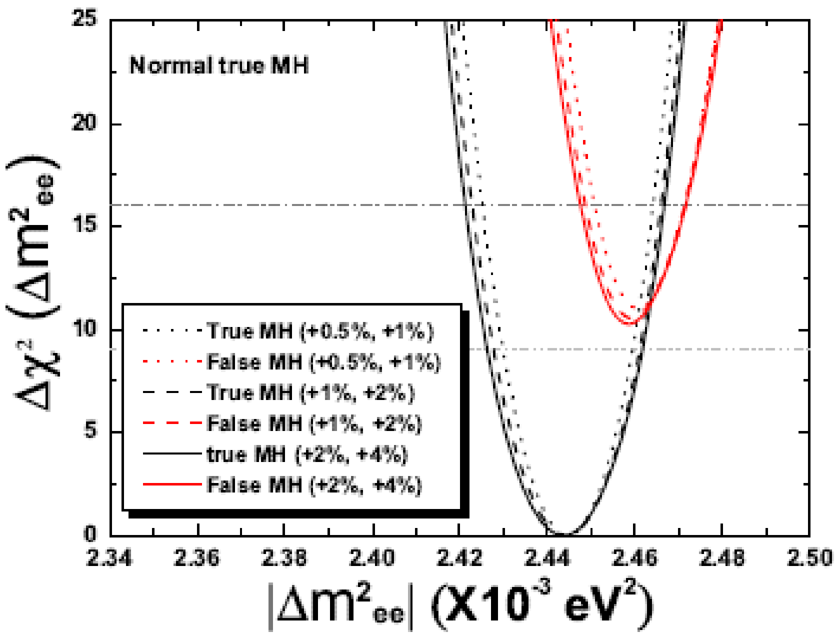
$$\frac{E_{\rm rec}}{E_{\rm true}} \simeq 1 + q_0 + q_1 E_{\rm true} + q_2 E_{\rm true}^2 \,,$$

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





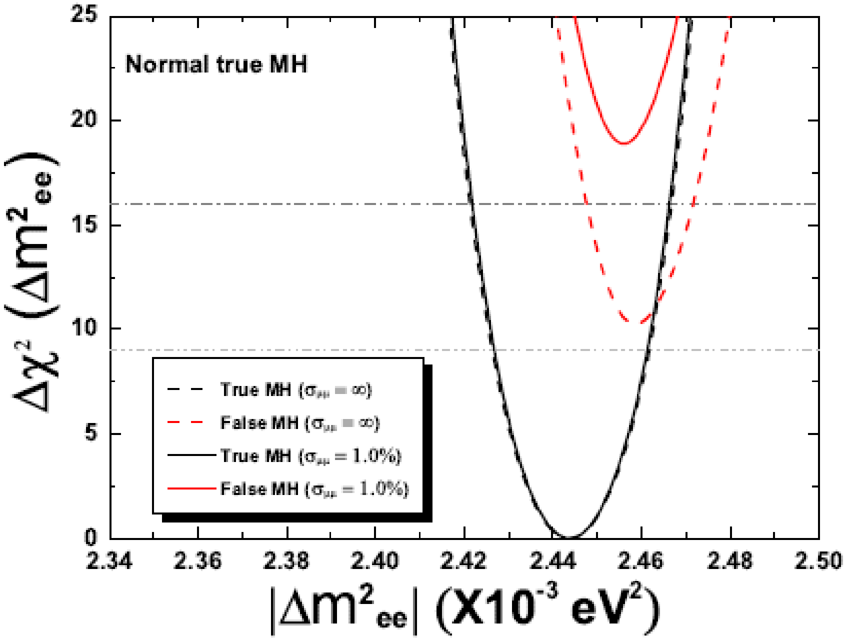
Physics Reach

Thanks to a large θ_{13}

Detector size: 20kt
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

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

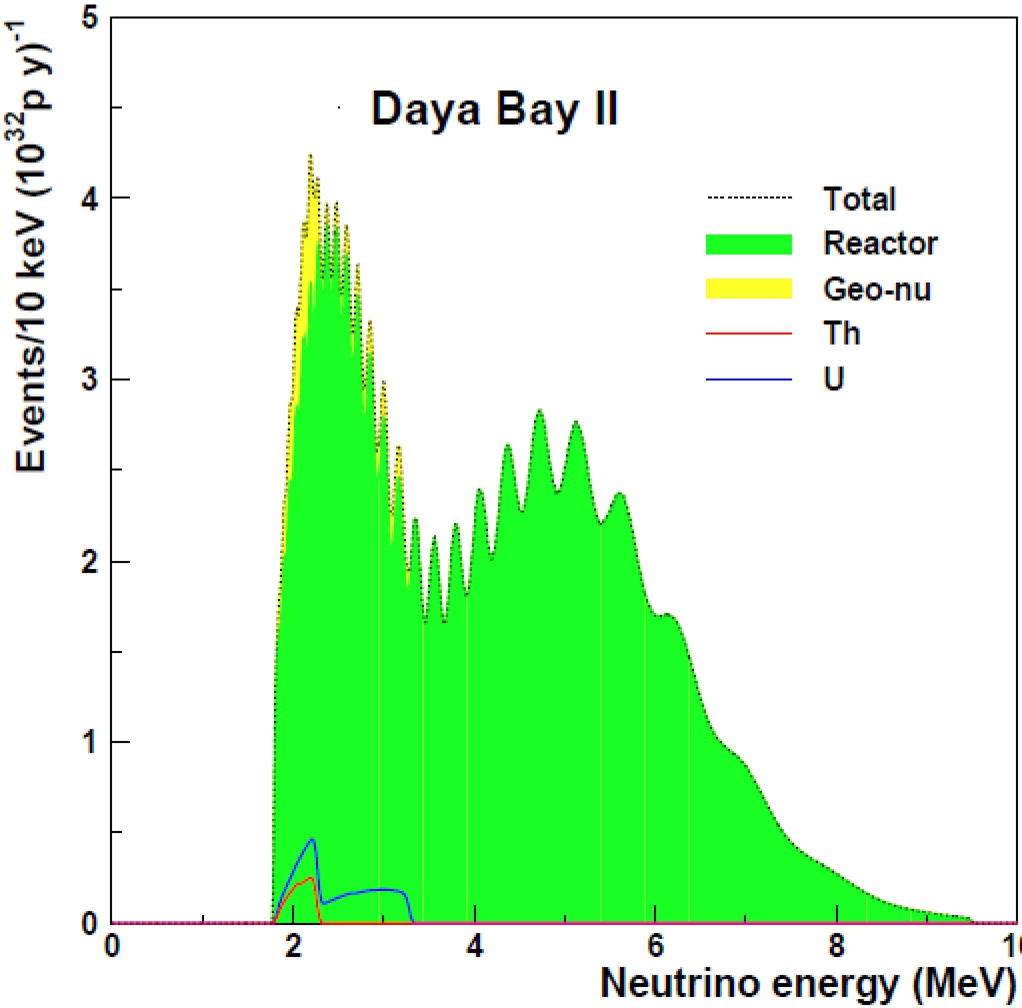
- Many types of events:
  - ⇨ $\bar{\nu}_e + p \rightarrow n + e^+$, ~ 3000 correlated events
  - ⇨ $\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B^* + e^+$, ~ 10-100 correlated events
  - ⇨ $\nu_e + {}^{12}C \rightarrow {}^{12}N^* + e^-$, ~ 10-100 correlated events
  - ⇨ $\nu_x + {}^{12}C \rightarrow \nu_x + {}^{12}C^*$, ~ 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

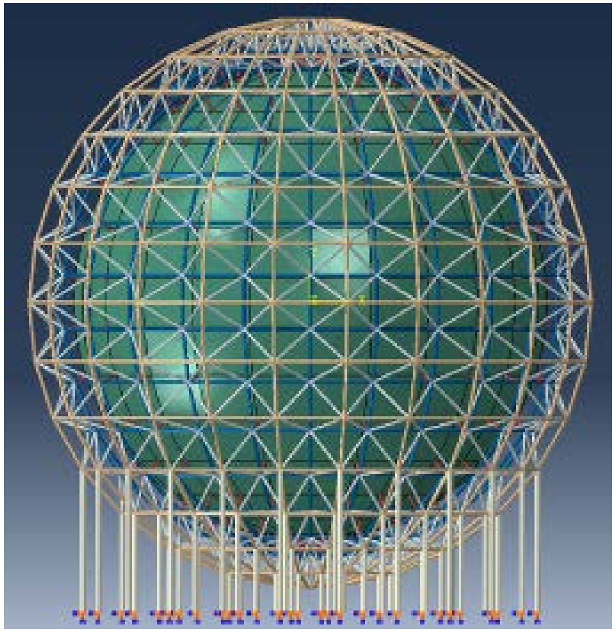
- Current results:
  - KamLAND: 40.0±10.5±11.5 TNU
  - Borexino: 64±25±2 TNU
- Desire to reach an error of 3 TNU: statistically dominant
- Daya Bay II: >×10 statistics, but difficult on systematics
- Background to reactor neutrinos

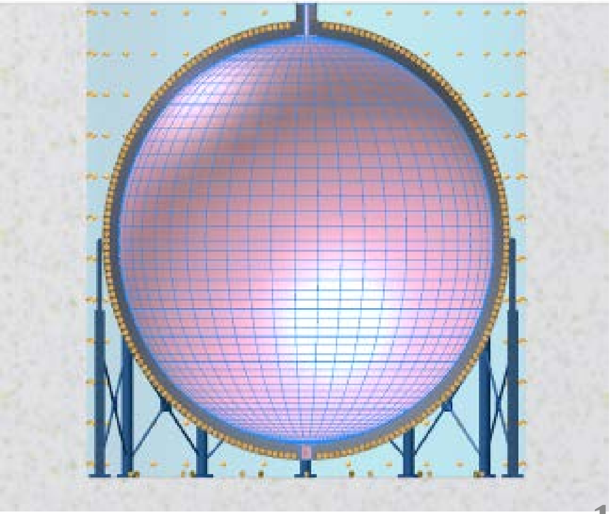


From Stephen Dye

Central Detector

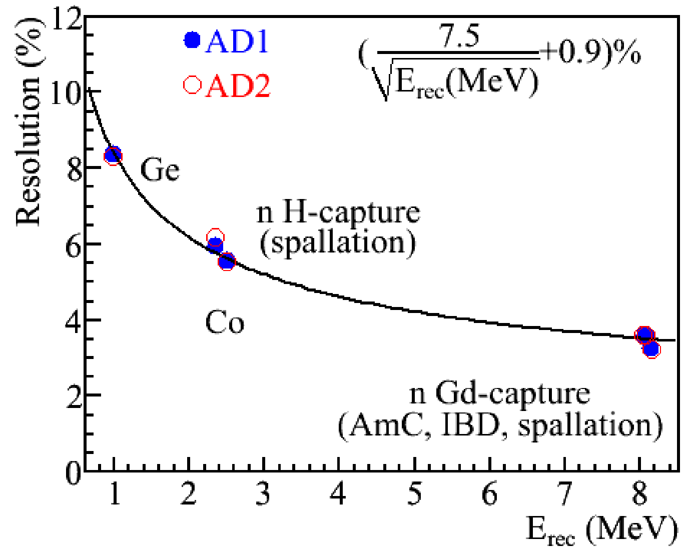
- **Some basic numbers:**
  - ⇨ **20 kt liquid scintillator as the target**
  - ⇨ **Signal event rate: 40/day**
  - ⇨ **Backgrounds with 700 m overburden:**
    - ✓ **Accidentals(~10%), ^{9}Li/^{8}He(<1%), fast neutros(<1%)**
- **A huge detector in a water pool:**
  - ⇨ **Default option: acrylic tank(D~35m) + SS structure**
  - ⇨ **Backup option: SS tank(D~38m) + acrylic structure + balloon**
- **Issues:**
  - ⇨ **Engineering: mechanics, safety, lifetime, …**
  - ⇨ **Physics: cleanness, light collection, …**
  - ⇨ **Assembly & installation**
- **Design & prototyping underway**

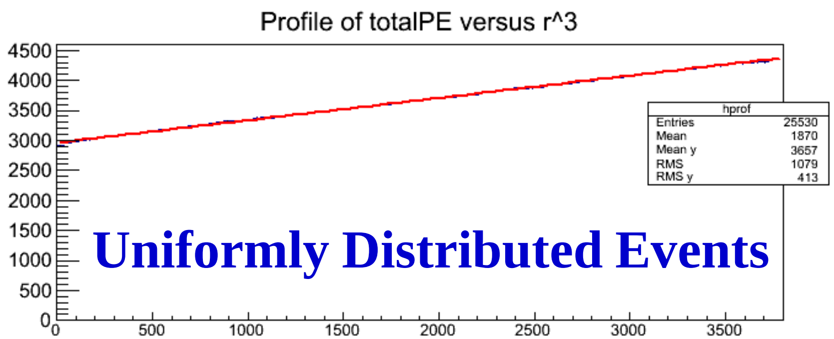


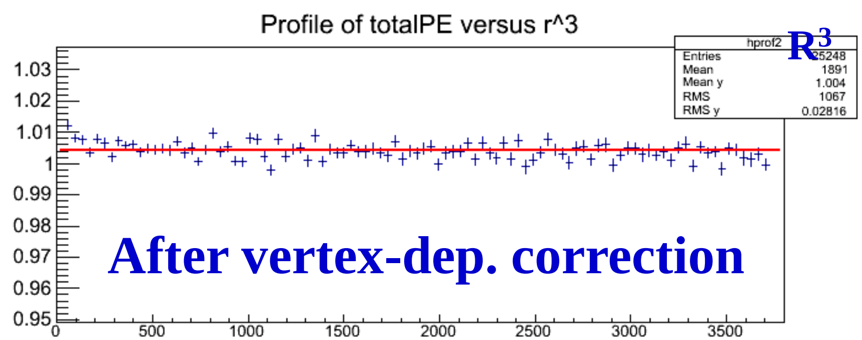


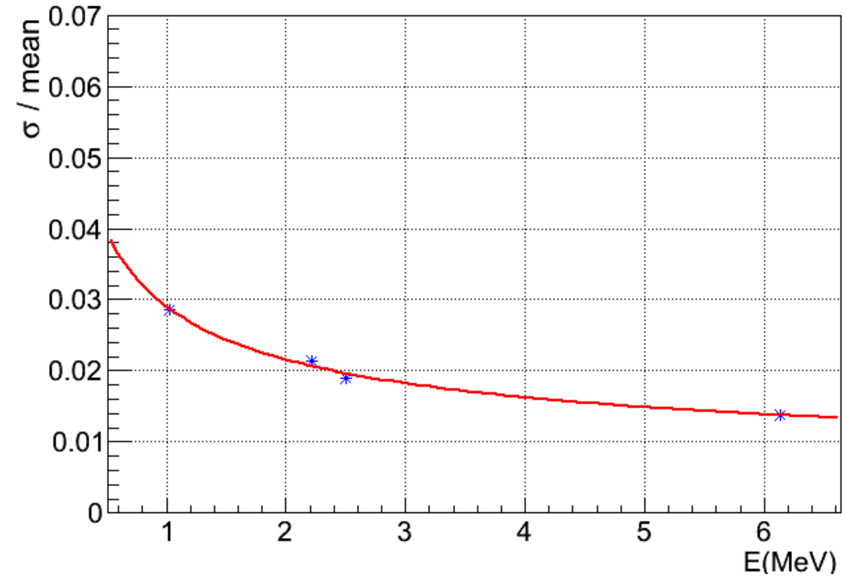
MC example: Energy Resolution

- 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 + Raylay scatt. 30 m
    - ✓ to 20 m = abs. 60 m + Raylay scatt. 30m





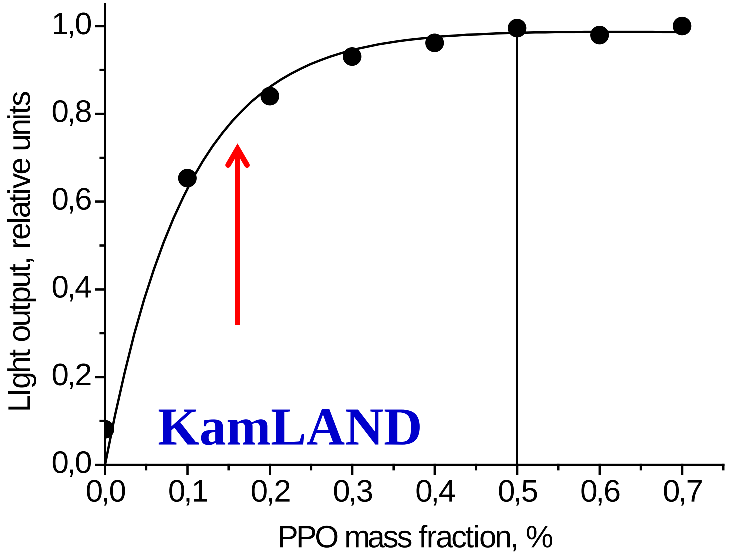




$3.0\%/\sqrt{E}$, or $(2.6/\sqrt{E} + 0.3)\%$

Liquid Scintillator

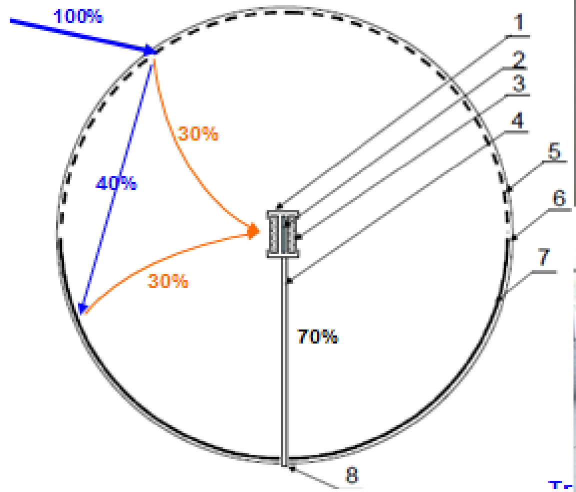
- **Requirements:**
  - Low background: ➔ No Gd-loading
  - Long attenuation length: 15m ➔ 30m
    - ✓ Improve raw materials
    - ✓ Improve the production process
    - ✓ Purification
  - High light yield: optimize fluor concentration
- **Current Choice: LAB+PPO+BisMSB**

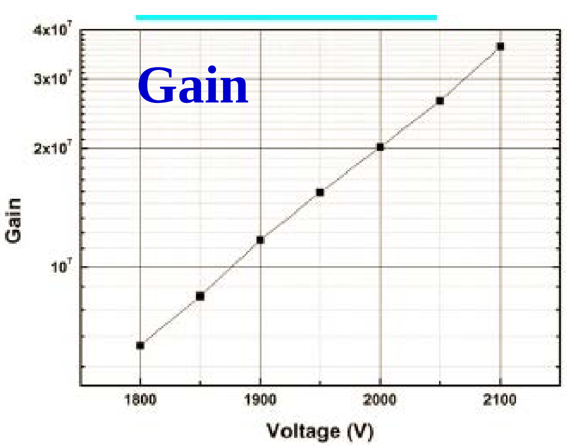


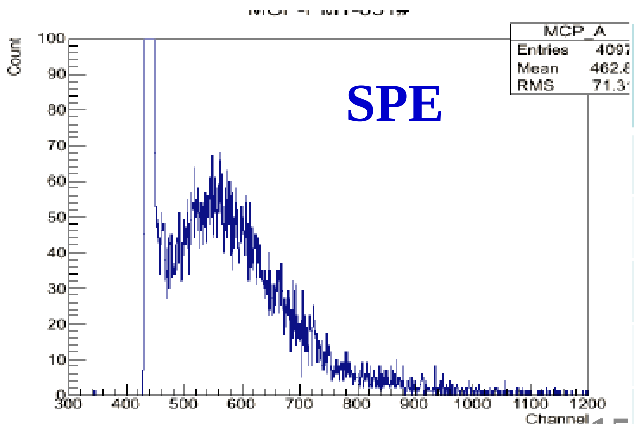
Linear Alky Benzene	Atte. L(m) @ 430 nm
RAW	14.2
Vacuum distillation	19.5
SiO_2 coloum	18.6
Al_2O_3 coloum	22.3
LAB from Nanjing, Raw	20
Al_2O_3 coloum, fourth time	27
Al_2O_3 coloum, second time	25
Al_2O_3 coloum, 8^{th} time	24

High QE PMT

- Two types of high QE 20” PMTs under development:
  - ⇨ Hammamatzu R5912-100 with SBA photocathode
  - ⇨ A new design using MCP: 4π collection
- MCP-PMT development:
  - ⇨ Technical issues mostly resolved
  - ⇨ Successful 8” prototypes
  - ⇨ 20” prototypes done



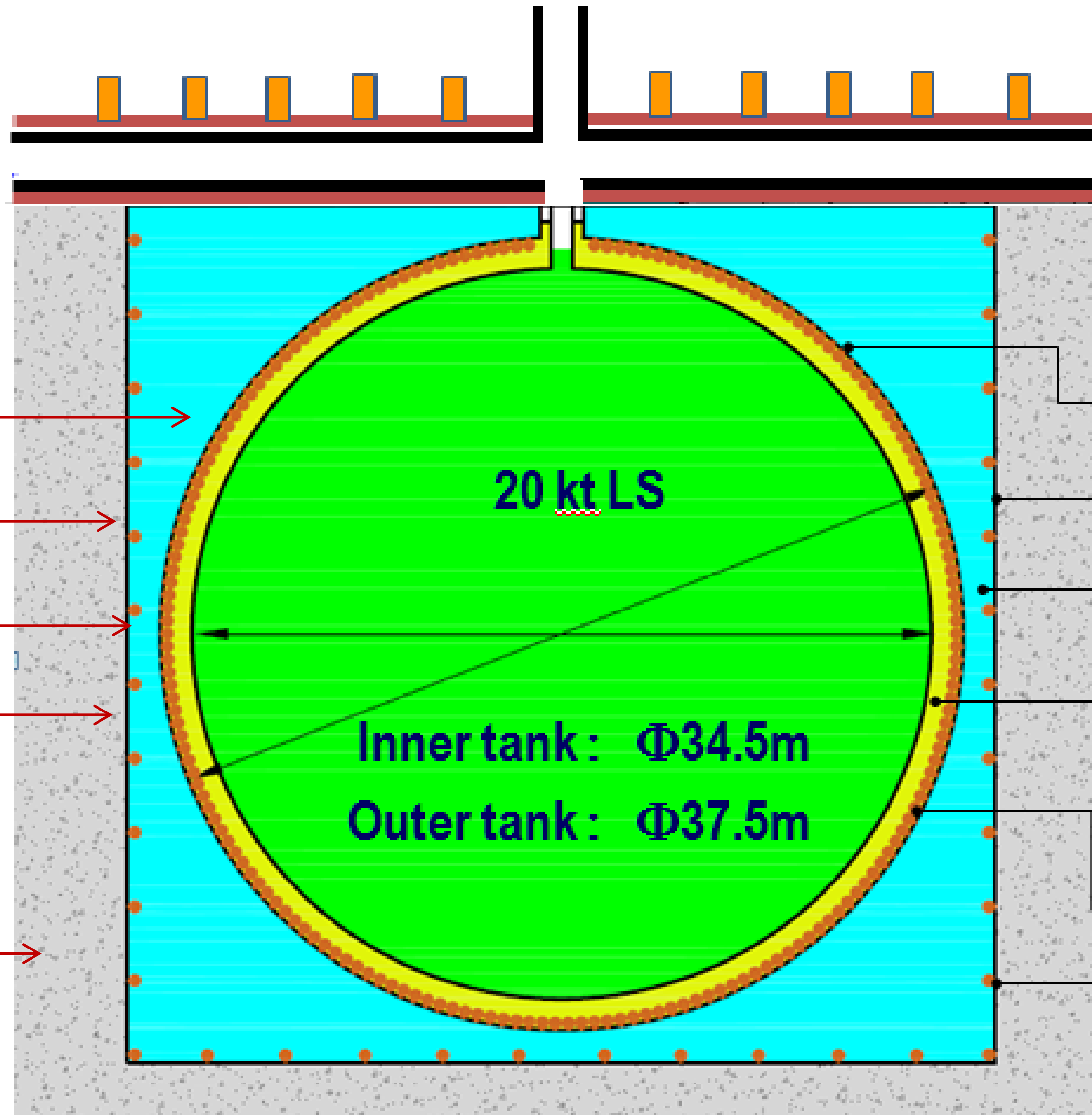




	R5912	R5912-100	MCP-PMT
QE@410nm	25%	35%	25%
Rise time	3 ns	3.4ns	5ns
SPE Amp.	17mV	18mV	17mV
P/V of SPE	>2.5	>2.5	`2
TTS	5.5ns	1.5 ns	3.5 ns

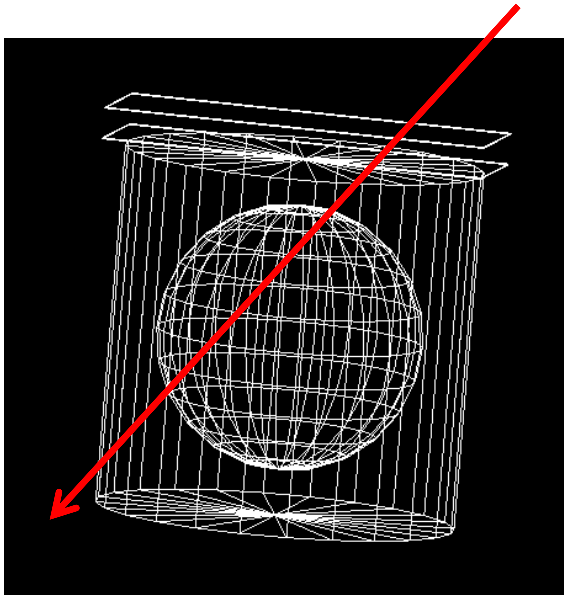
Muon VETO detector

- Top tracker
- Tracker support
- Water system
- Tyvek
- PMT support
- Water pool liner
- Earth magnetic shielding



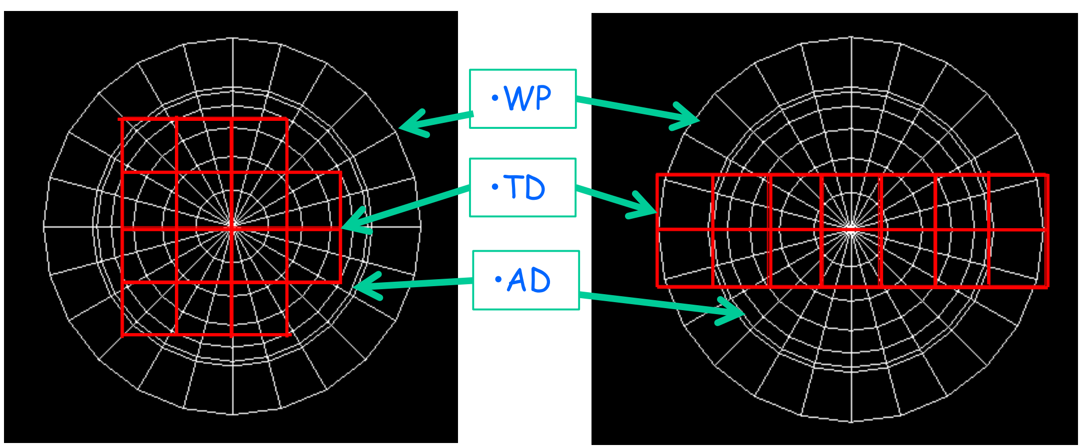
OPERA Target Tracker for the Top Tracker

- 56 x-y walls (6.7m × 6.7m each)
- 14 TT stations, 4 walls each.
- each station is composed of 2 layers of 2 TT walls separated by 4 m distance.
- Distance of lowest and upper wall: 4 m
- Distance of lowest plane from water pool: 1 m.
- Different configurations (Middle, Rectangle, Around)
- Covered area is about 630m^2.

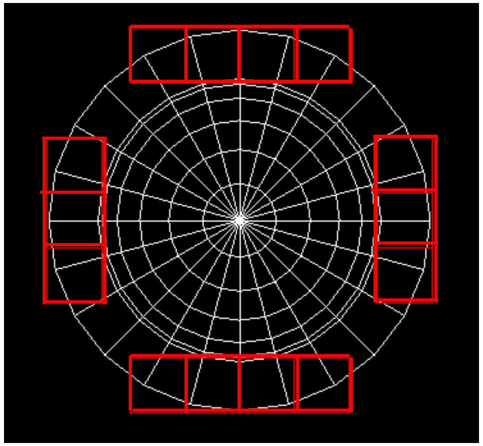


•4XY Middle (Mid)
•(3 × 4+2 modules)

•4XY Rectangle(Rtg)
•(2 × 7 modules)



•4XY Around("O")
•(2 × 4+2 × 3 modules)



Dismounting schedule

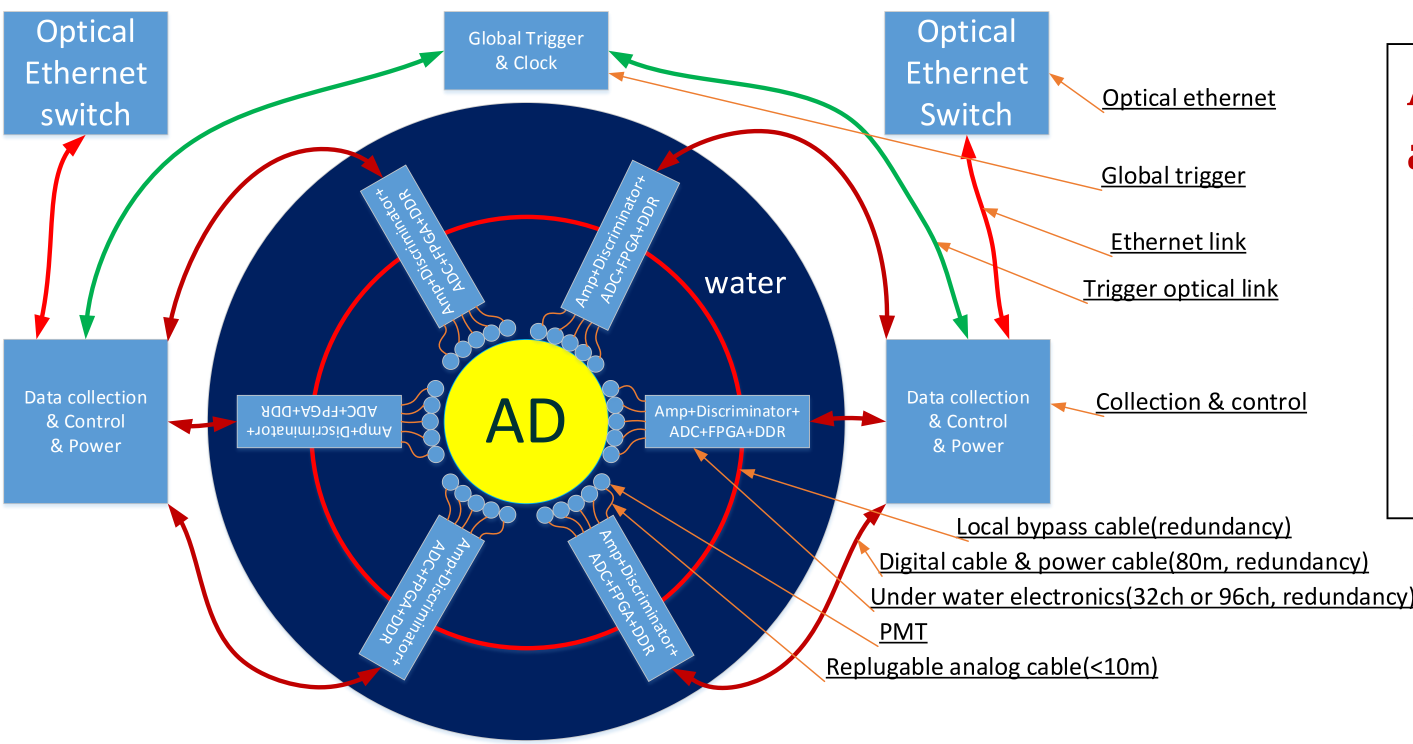
- Dismounting schedule:
  - mid-2015: first OPERA super module (31 TT walls, 248 modules)
  - beginning 2016: second OPERA super module (31 TT walls, 248 modules)
  - storage of all TT modules in Gran Sasso in containers up to the moment all dismounting is finished
  - send all TT containers (10) to Kaiping ~Spring 2016 if storage buildings already available
- Mounting in JUNO: ~2019

Readout Electronics and Trigger

- **Charge and timing info. from 1 GHz FADC**

Total No. channel	20,000
Event rate	~ 50 KHz
Charge precision	1 – 100 PE: 0.1 – 1 PE; 100-4000PE: 1-40PE
Noise	0.1 PE
Timing	0-2us: ~ 100 ps

- **Main Choice to be made: in water or on surface**

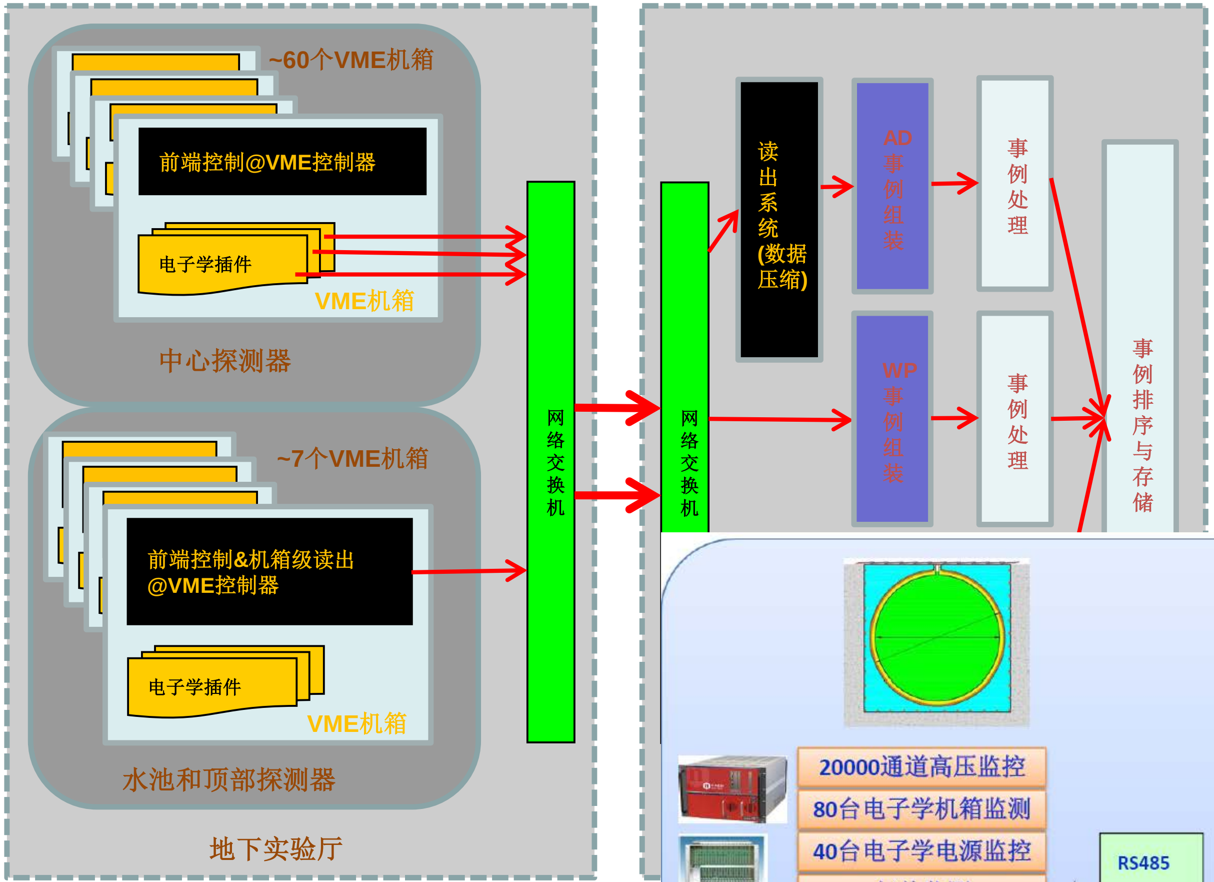


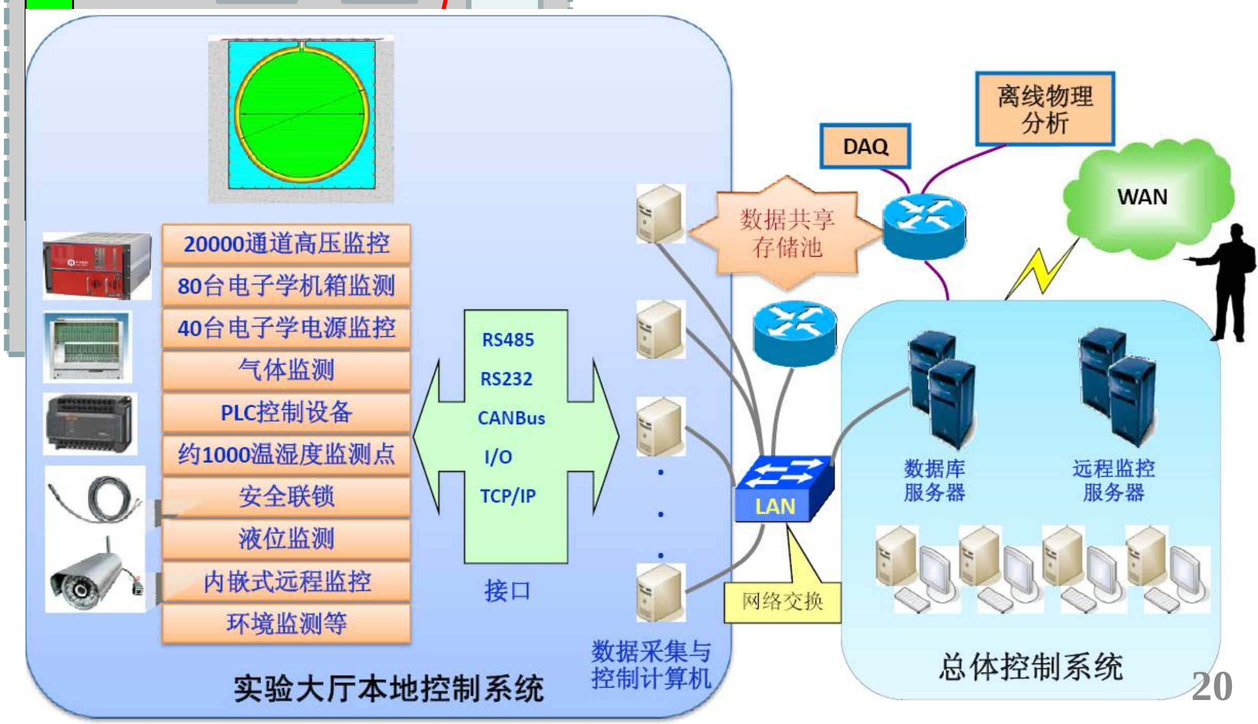
An option to have a box in water:

- **~100 ch. per box**
- **Changeable in water**
- **Global trigger on surface**

DAQ and Detector Monitoring

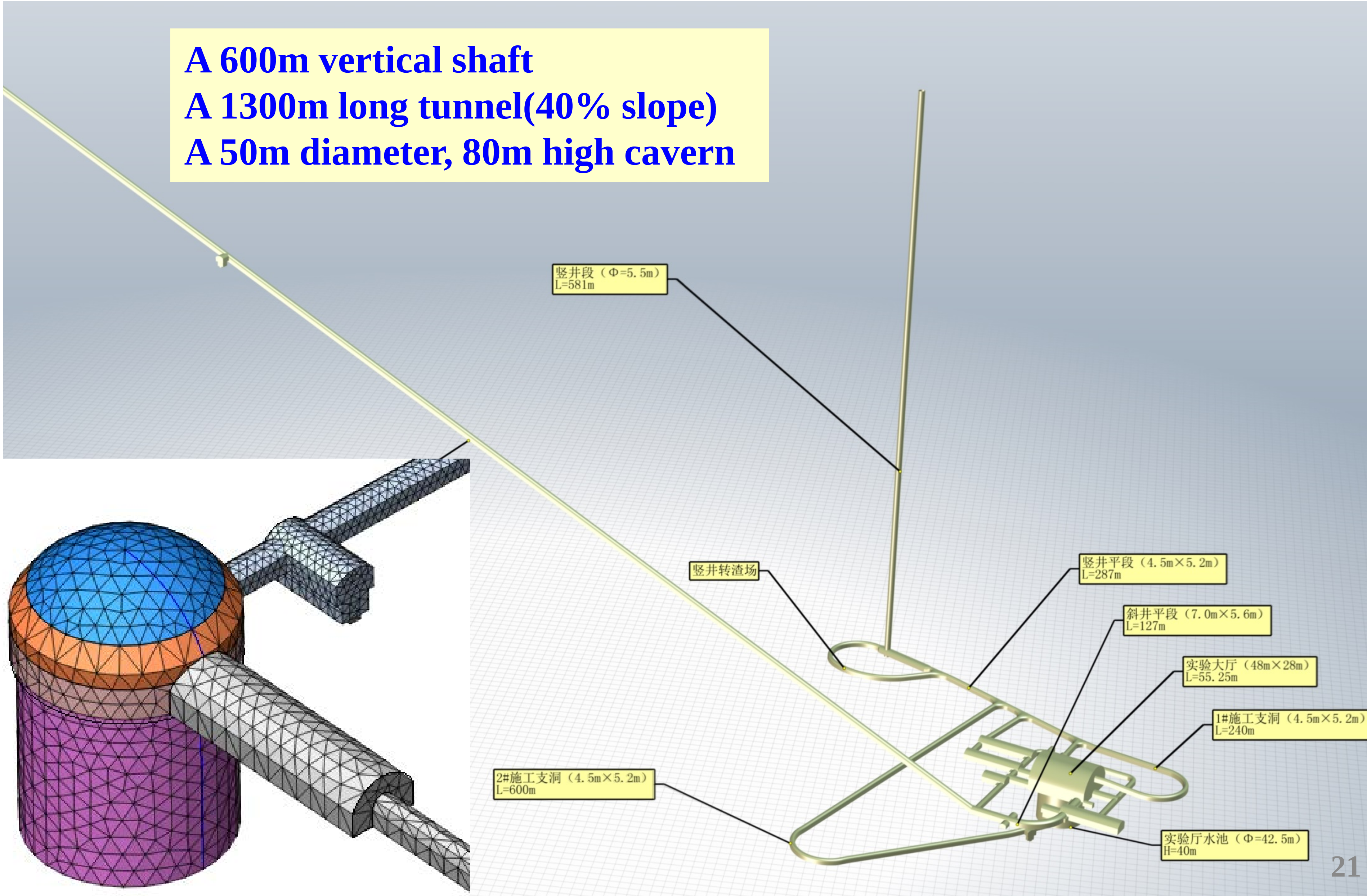
Readout:2GB/s,
Storage:200MB/s



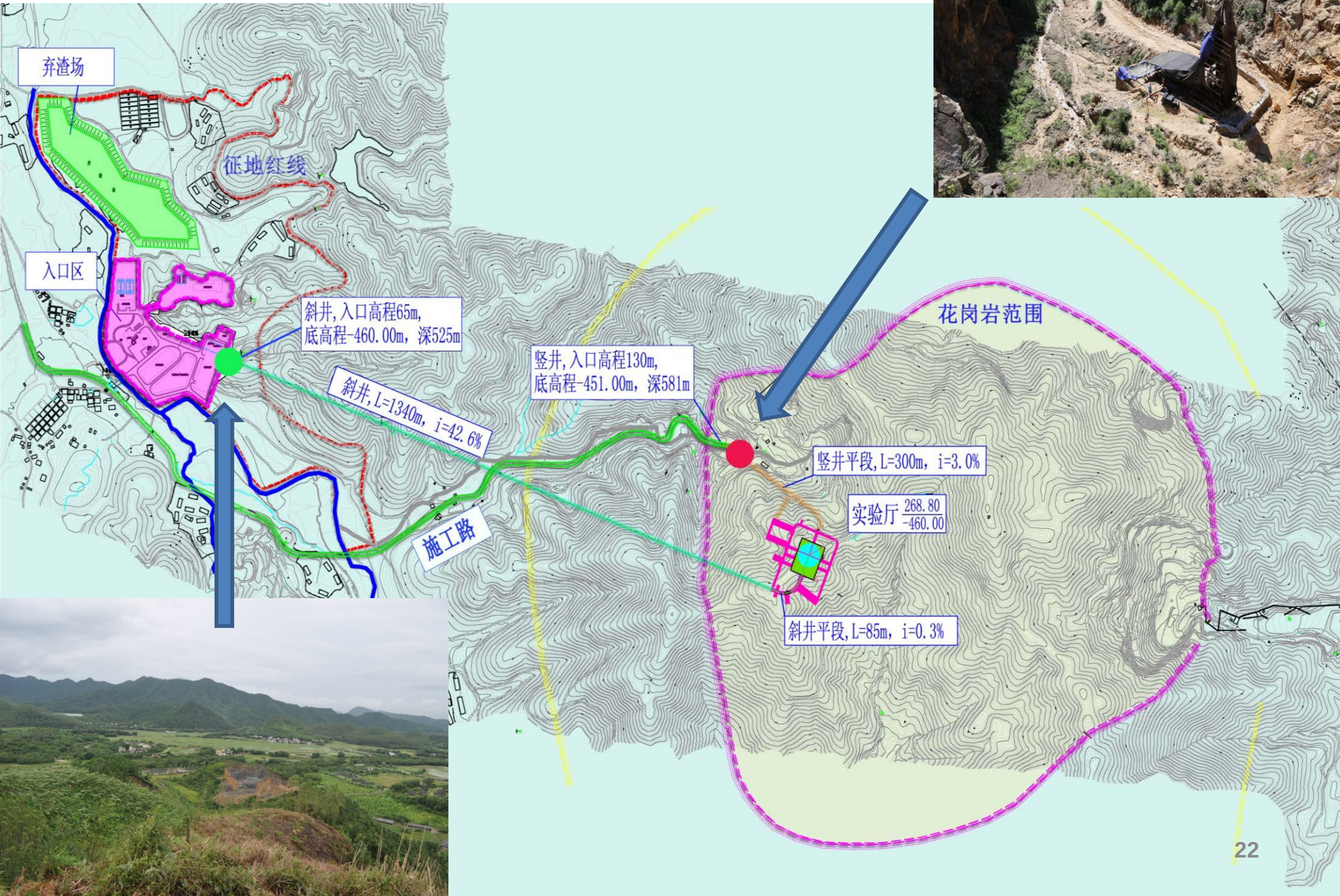


Civil Construction

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

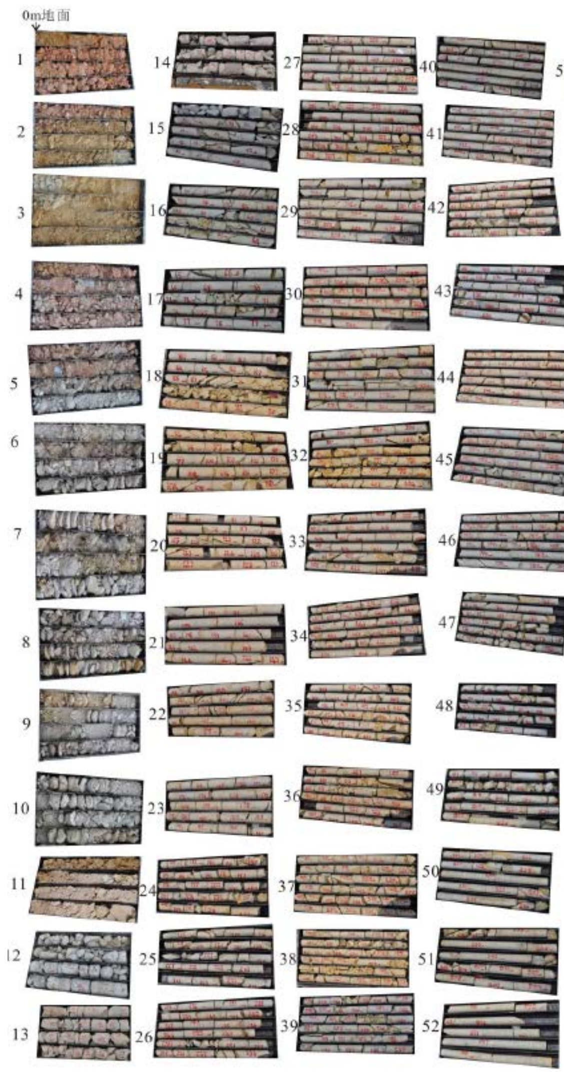


Layout


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

Current Status & Brief Schedule

- **Project approved by CAS for R&D and design**
- **Geological survey completed**
  - ⇨ Granite rock, tem. ~ 31 ^{o}C, little water
- **Engineering design underway, contract signed**
- **Land is acquired, civil construction approval underway**



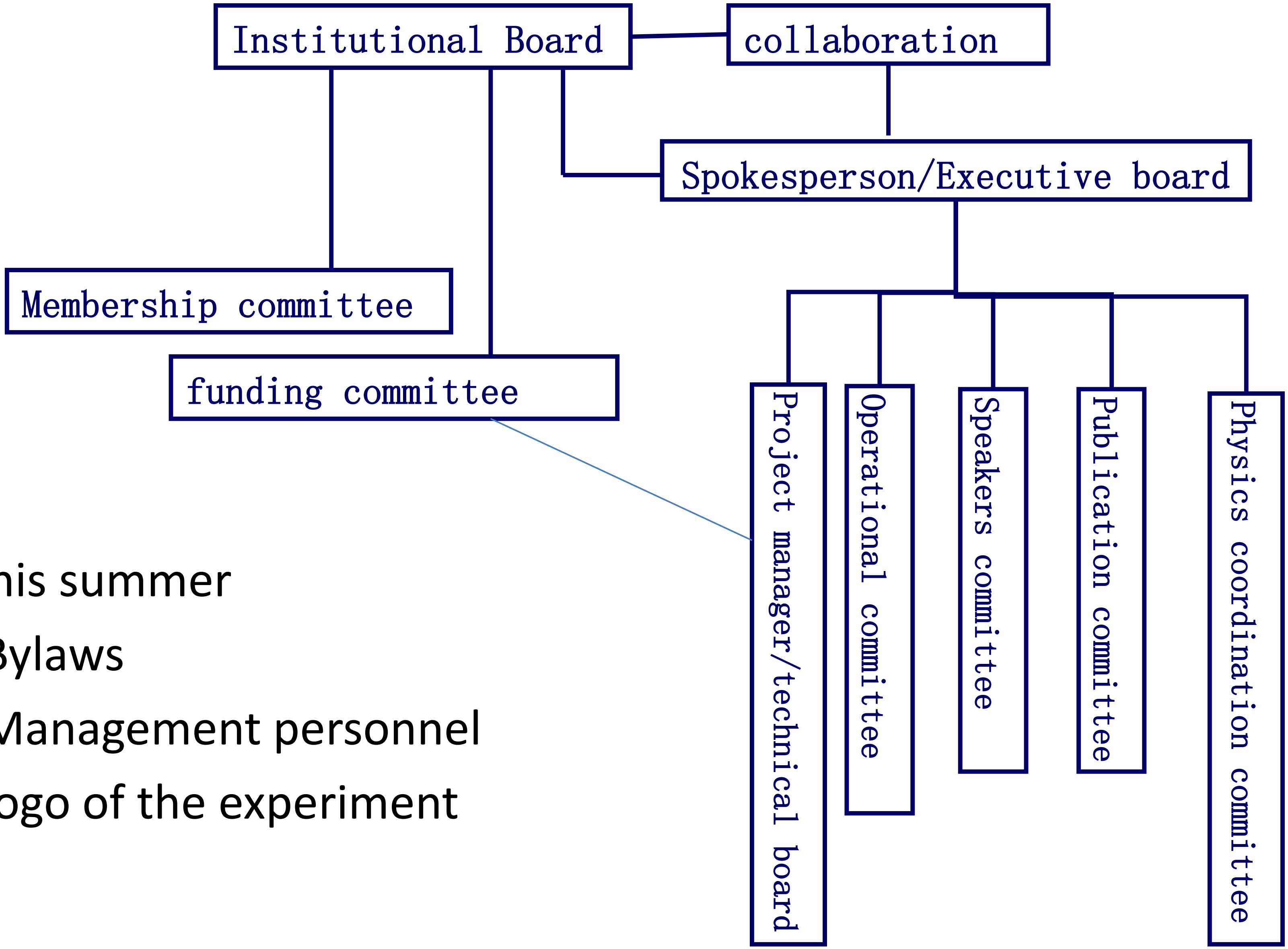
Schedule:

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

International collaboration

- Status of each country
  - Italy: committed
    - Milan, Frascati, Perugia, Padova… ➔ Liquid Scintillator, PMT, …
  - Germany: almost committed,
    - Munich, Aachen, Tubingen, … ➔ Electronics, …
  - France: almost committed
    - Paris, Strasburg,… ➔ VETO， electronics
  - Russia: almost committed,
    - Dubna ➔ PMT HV
  - US: waiting for P5
    - DYB + Hawaii, Washington, Maryland, … ➔ calibration…
- Proto-collaboration since 2013, meeting every 6 months
- Formal collaboration this summer

Collaboration organization: to be approved



This summer

- Bylaws
- Management personnel
- logo of the experiment

Next plan

- By end of this year before the civil construction, we will have a major review in China to answer the question: "Can we start ?"
  - A yellow book of JUNO physics
  - A CDR of JUNO detector
- They are useful for everyone to get funding
- Task sharing by end of this year:
  - For funding estimate

Welcome to Kaiping

2014/6/13

JUNO : INFN perspectives

Framework of INFN involvement in JUNO

Main Motivations

Scientific continuity $\rightarrow$ Neutrino oscillation study and astroparticle program in JUNO natural evolution of the INFN activities in both fields and may represent one of the pillars of the INFN participation to the next round of “gigantic” neutrino oscillation experiments worldwide

Technological continuity $\rightarrow$ broad expertise acquired throughout the Borexino program in PMT’s, scintillator, purification and low background techniques can be profitably reused within the JUNO project

Added later in the course of the on-going discussions $\rightarrow$ option to reuse the OPERA plastic scintillator tracker (40% INFN funded for PMTs) for the JUNO top muon tracker

Framework of INFN involvement in JUNO

First contact triggered by the President in occasion of the 2012 **INFN-IHEP Bilateral Meeting** held in Rome at the INFN headquarters on May 19th, 2012

The general features of our possible involvement were discussed during the **NPB 2012** workshop at Shenzhen on September 2012 – Antonio, Roberto and Rinaldo were part of the discussion

After that, in a series of participation to general (Beijing January 2013, Beijing July 2013, Kaiping January 2014) and restricted (LNGS September 2013) meetings, we have **initially** shaped the guidelines of our participation by identifying two major items of interest:

- ✓ Scintillator
- ✓ PMT's

Now the Opera tracker issue has emerged as the third main element of this cooperative effort

Scintillator

- Scintillator optical measurements (very wide and deep experience gained within the Borexino R&D)

- Procurement of LAB from European suppliers and check of the properties to compare with the LAB from China. A LAB supplier has been found in Italy, at Augusta $\rightarrow$ breakthrough also for the possible future of initiatives at Gran Sasso. Other two suppliers in Germany and Spain. Exchange of samples (solvents and scintillator cocktails)

- Conceptual definition, design and construction of the **distillation column** and of the associate **N_2 stripping column** for scintillator purification. Possibility to do the pre- assembly here in Italy and send the pre-assembled skid to China. Potential industrial partner, located close to Milano, already identified

The Perugia and Milano Borexino groups are those involved in the scintillator activity

Note: studies for alternative novel LS solvents initiated before the JUNO effort

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ELSEVIER

Decay time and pulse shape discrimination of liquid scintillators based on novel solvents

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Di-isopropylnaphthalene

ABSTRACT

Over the past few years the liquid scintillation technique employed for particle detection applications has undergone a significant technological breakthrough with the introduction of novel solvents tailored to address the concerns about toxicity, flammability and disposal problems associated with the scintillators of traditional formulation.

The increasing popularity of the new solvents in the realization of experimental set-ups of various degrees of size and complexity implies the need of a thorough study and characterization of the features of the corresponding scintillation mixtures, with the aim to approach eventually a level of understanding similar to that, very accurate, achieved throughout many years of research for the scintillators realized with conventional solvents.

In this general context, aim of this work is to illustrate the results of the fluorescence decay time and pulse shape discrimination measurements carried out on a set of scintillation mixtures realized using two of such novel solvents, i.e., linear alkylbenzene (LAB) and di-isopropylnaphthalene (DIN). The measurements have been performed either under particle or UV excitation of the scintillating solutions, which permitted to unravel the features both of the fast component and of the long tail forming the entire scintillation pulse.

Moreover, the particle characterization via β or α excitation allows also predicting the α/β pulse shape discrimination capability of the mixtures, a property of paramount significance for applications focused on the increasingly important field of low background detectors.

1. Introduction

Liquid scintillation technology [1] is a well-established method used to realize a great variety of devices for particle detection, with size ranging from small table-top set-ups intended for laboratory measurements, to massive detectors focused on the search of very rare events. The latter application implies very often the deployment in underground caves of large experiments, employing hundreds or even thousands tons of liquid scintillator. Examples of experiments of this kind, running since several years, are the Borexino [2] solar neutrino experiment located at the Gran Sasso Laboratory, the supernova observatory LVD [3], again at Gran Sasso, and the KamLAND [4] detector in the Kamioka mine. The more recent Double Chooz [5] and Reno [6] near and far detectors, as well as the Day Bay [7] multiple detectors complex, are specific implementations of the liquid scintillation method for the detection of anti-neutrinos from reactor (the main, but not unique goal of KamLAND, too), while the imminent start-up of the SNO+ [8] experiment, the successor of SNO+ that will replace the heavy water with liquid scintillator, is expected within 2013. The largest liquid scintillator detector currently under construction is NOvA [9], which will employ 13 kt of liquid organic scintillator to catch neutrinos in an accelerator beam from Fermilab. Looking far in the future, the possibility of the gigantic detector LENA [10], based on 50–100 kt of liquid scintillator, is actively pursued with the perspective to be installed in the Pyhäsalmi mine in Finland.

Therefore this mature technique, born in the 1950s, is still an important tool in the particle physics arena, as witnessed not only by the numerous experiments under operation or installation, but also by its crucial role in the recent assessment of the neutrino oscillation phenomenon [11,4] through the measurements, among others, of Borexino and KamLAND.

Most of the technical foundations in this field were established in the 1950s and 1960s, when the organic, aromatic compounds Xylene, Toluene and Pseudocumene were identified as the best suited choices for the solvent, i.e., the basis for any scintillator formulation.

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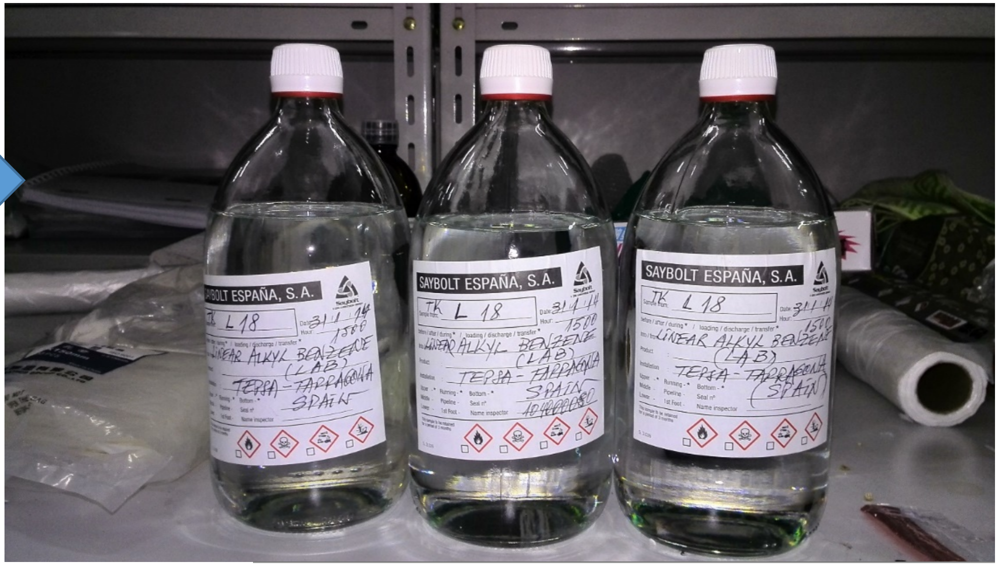
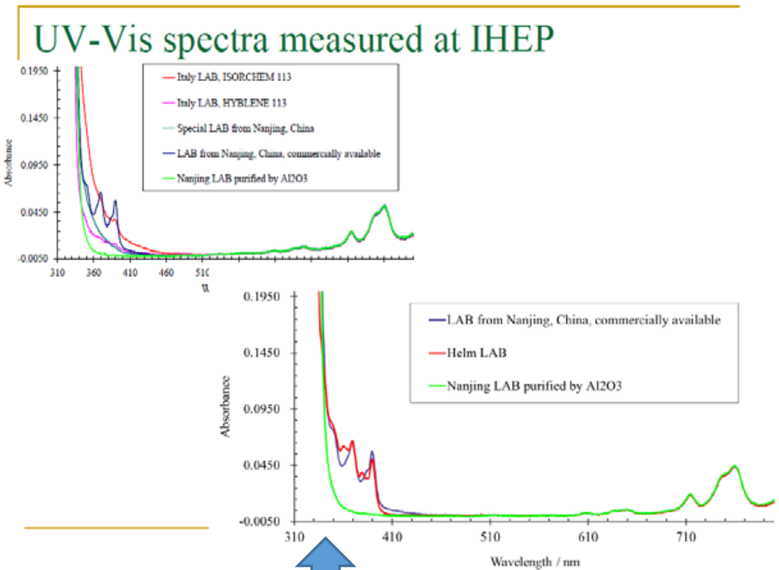
Joint measurements effort well in progress

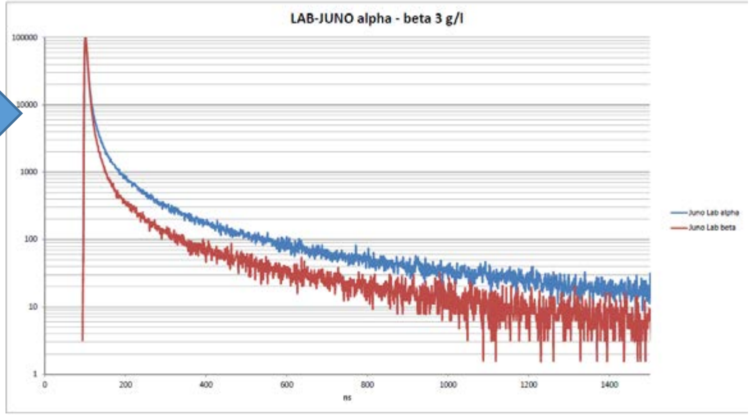
Samples from a European company to IHEP





Absorbance and attenuation length measures at IHEP of our European samples

Our own measurements on a scintillator sample from IHEP



From the talk of Paolo Lombardi @ the last proto-collaboration meeting at Kaiping

Introduction

In Milano we have started a research activity for a possible LAB scintillator purification plant starting from our past long term experience in this field.
The conceptual idea is to adopt, with a proper scaling, the successful purification technique, sequence and construction specifications developed for Borexino experiment @ Gran Sasso .

Borexino plant was designed and by a NJ company (Koch Modular Process System).

We have searched for a reliable European company and we found one in Milano

Polaris engineering http://www.polarisengineering.com

The company already worked with us for a design upgrade of the cryogenic distillation column at Fermilab for the underground Ar gas purification of DarkSide experiment

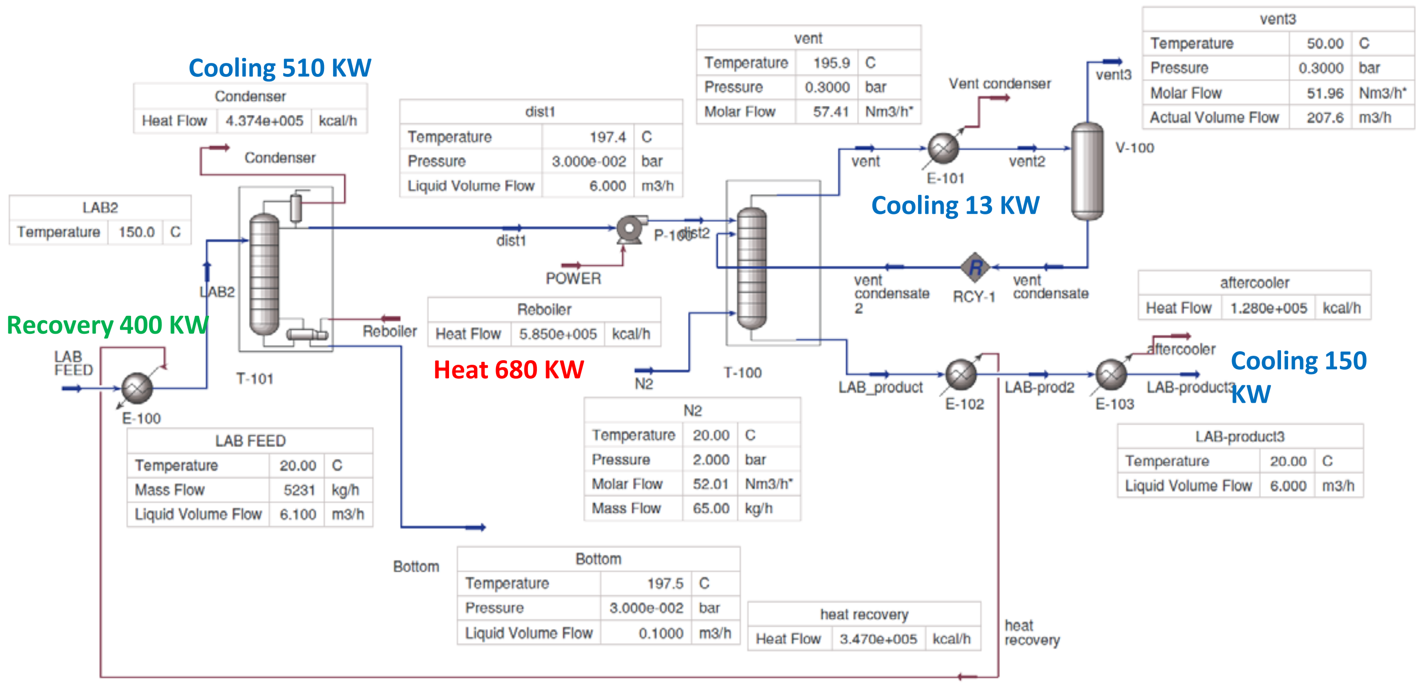
Preliminary mass and energy flow chart

From the talk of Paolo Lombardi @ the last proto-collaboration meeting at Kaiping

Reboiler Heat power: 680 KW

Condensers Cooling power: 673 KW

Inlet-Outlet Energy recovery: 400 KW



Space requirements

From the talk of Paolo Lombardi @ the last proto-collaboration meeting at Kaiping

Concept:

We have considered to divide the LAB purification plant in 3 separate skids to be prepared in Italy and shipped and installed at JUNO site

Item	Footprint	Height	Weight
Distillation skid	3,0 m x 4,0 m	12,0 m	15 tons
Stripping skid	3,0 m x 4,0 m	12,0 m	11 tons
Accessories skid (vacuum pumps, heat recovery, etc.)	3,0 m x 4,0 m	6,0 m	7 tons

To be further discussed

PMT's

Our broad experience with phototubes makes it natural for us to be involved somehow also in this area.

MCP-PMTs prototype

Test of prototypes

- The Chinese group has started since several time an effort leaded by Yifang for the development of innovative MCP-PMTs with North Night Vision Technology : we recently received two 8" spherical prototypes$\rightarrow$ testing already started - stemmed useful suggestions for the divider to improve the shape of the signal

- Move of the Philips Photonix to China completed $\rightarrow$ **HZC Photonics**. Contacts established with the CEO Dr. Maggie Wang. Also received two 8" spherical devices XP1805, testing commenced

- Hamamatsu "path" : new 20" device based on the 3600 Super-Kamiokande type $\rightarrow$ High SBA QE . Next meeting with the Company **middle of July** . We will receive further improved prototypes as far as they will be available

- The amount of possible further works and commitments will depend on the final composition and strength of the group (realization of divider and ancillary parts, participation to installation)





Other possible areas of contribution

Linked to the joining of other groups

Very concrete plans of participation : Padova, Frascati, Ferrara ……..

- ✓ Top Tracker

  → see the previous exhaustive description of Yifang concerning the solid option to re-use of the Opera tracker based on plastic scintillators **Yesterday meeting in Frascati between IHEP and Opera groups (Frascati, Padova, Strasbourg, Dubna)**

- ✓ Electronics & DAQ

  → contacts being taken with the Chinese colleagues and in coordination with the other European groups

- ✓ General simulation of the detector

  → Other potential groups could join in this Marco Grassi from Roma-La Sapienza, co-funded by INFN and IHEP post-doc

- ✓ Development of analysis tools

Scenario for a broad European participation

Stemming from previous joint efforts

- Strasbourg, Dubna, Hamburg : Opera
- Paris APC , Munich, Tubingen&Mainz, Dubna, Hamburg : Borexino (Paris and Munich cooperating in Double Chooz)

But not only

- Aachen
- Prague (already in Daya Bay)

Perspectives for a strong European Collaboration, in sizable fraction coming from Borexino and Opera, suitable to put in a broader context our role in the experiment

Meetings in Milano before the next Collaboration meeting:

Italian component $\rightarrow$ May 22
European meeting $\rightarrow$ JUNE/JULY to be finalized

Conclusion

The vast potential physics reach of JUNO - MH determination and beyond - makes the experiment very attractive for Italian as well as European groups

The perspectives for an INFN participation of significant impact are very promising, solidly grounded on previous expertise and well positioned in a larger European framework