Jiangmen Underground Neutrino Observatory (JUNO)

Miao He

Institute of High Energy Physics, Beijing

On behalf of the JUNO collaboration

Neutrino Oscillation Workshop

Conca Specchiulla (Otranto, Lecce, Italy)

September 7-14, 2014

JUNO Collaboration Established (2014.7)

Europe (20)*

APC Paris
Charles U.
CPPM Marseille
FZ Julich
INFN-Frascati
INFN-Ferrara
INFN-Milano
INFN-Padova
INFN-Perugia
INFN-Roma 3
IPHC Strasbourg
JINR
LLR Paris
RWTH Aachen U.
Subatech Nantes
TUM
U.Hamburg
U.Mainz
U.Oulu
U.Tuebingen
U. libre de Bruxelles (Observer)

US*

BNL, UIUC, Houston,
Observers on behalf of US institutions

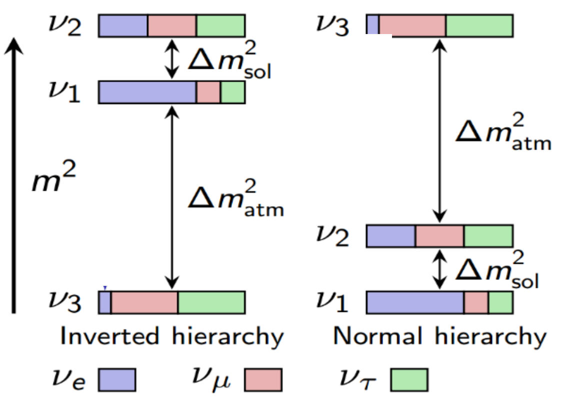
Asia (25)

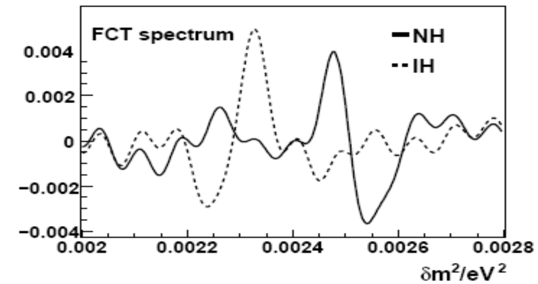
Beijing Normal U.
CAGS,
CIAE
DGUT
ECUST
Guangxi U.
IHEP
Jilin U.
Nanjing U.
Nankai U.
Natl. Chiao-Tung U.
Natl. Taiwan U.
Natl. United U.
NCEPU
Pekin U.
Shandong U.
Shanghai JT U.
Sichuan U.
SYSU
Tsinghua U.
UCAS
USTC
Wuhan U.
Wuyi U.
Xi'an JT U.

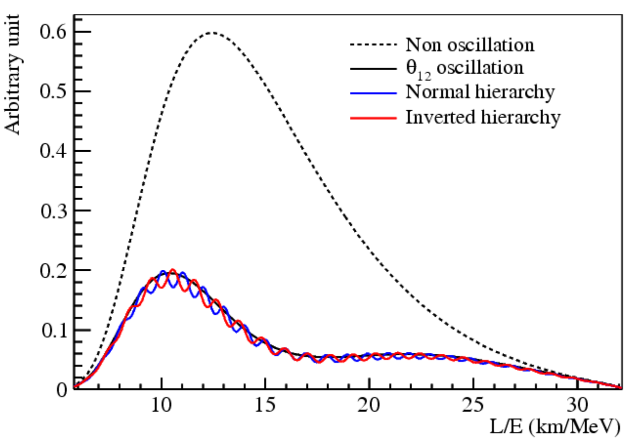
*Subject to funding agency approval

Neutrino Mass Hierarchy

- Next generation neutrino experiments focus on mass hierarchy and CP violation
- Mass hierarchy determination
  - Matter effects in the atmospheric (PINGU，INO，HyperK）and accelerator (LBNE, LBNO, T2HK) neutrinos oscillation
  - Disappearance of reactor electron antineutrino: interference between Δm^2_{31} and Δm^2_{32} (JUNO, RENO50)





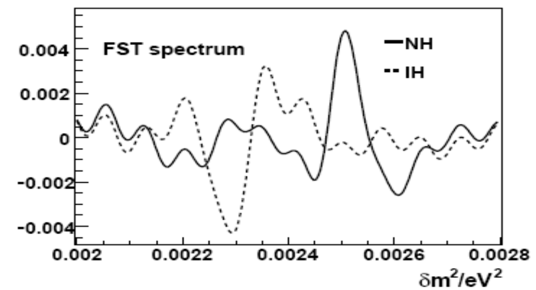


$$
\begin{aligned}
P_{ee}(L/E) &= 1 - P_{21} - P_{31} - P_{32} \\
P_{21} &= \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21}) \\
P_{31} &= \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31}) \\
P_{32} &= \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32})
\end{aligned}
$$

The Fourier Transformation

$$FCT(\omega) = \int_{t_{min}}^{t_{max}} F(t)\cos(\omega t)\mathrm{d}t$$

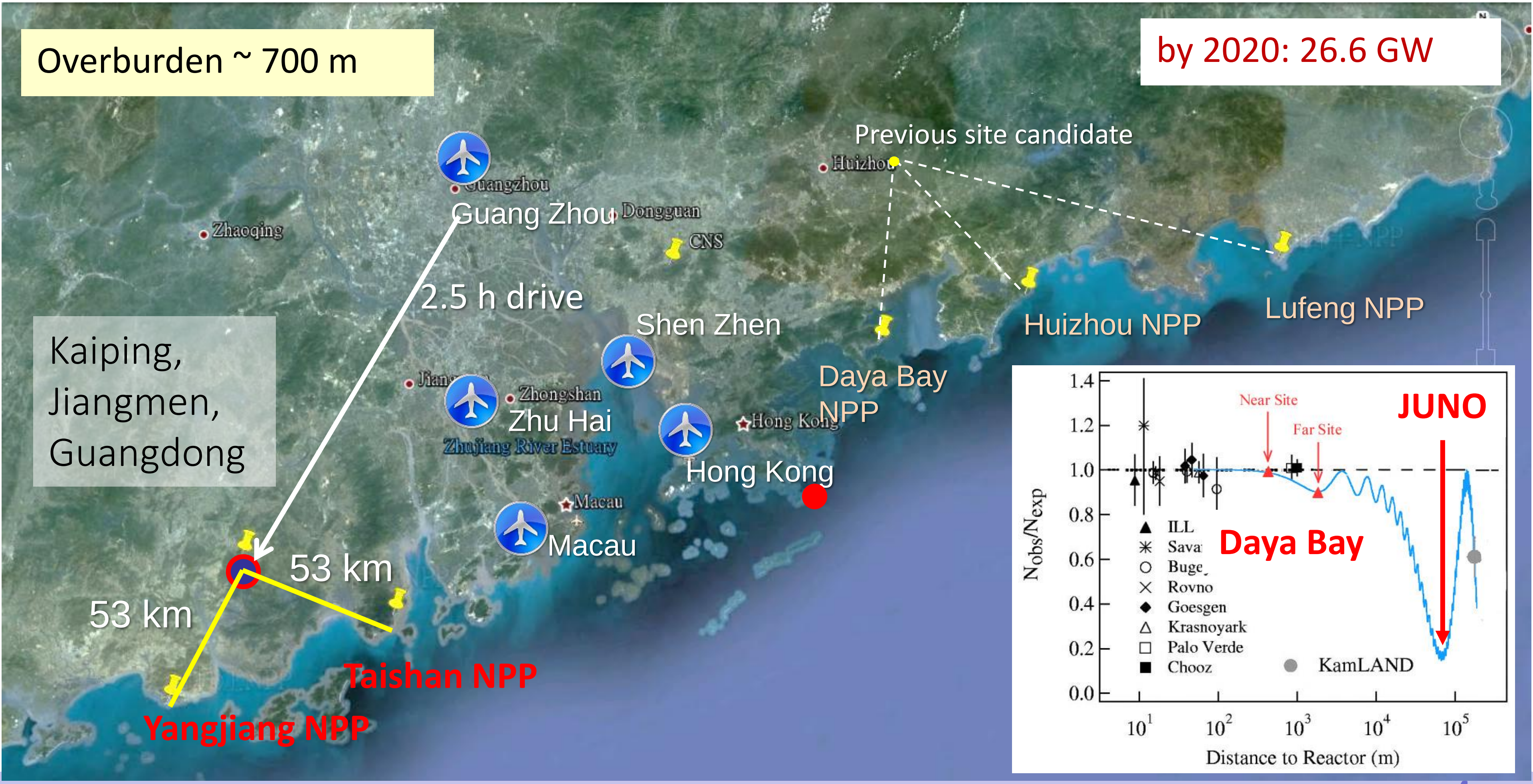
$$FST(\omega) = \int_{t_{min}}^{t_{max}} F(t)\sin(\omega t)\mathrm{d}t$$



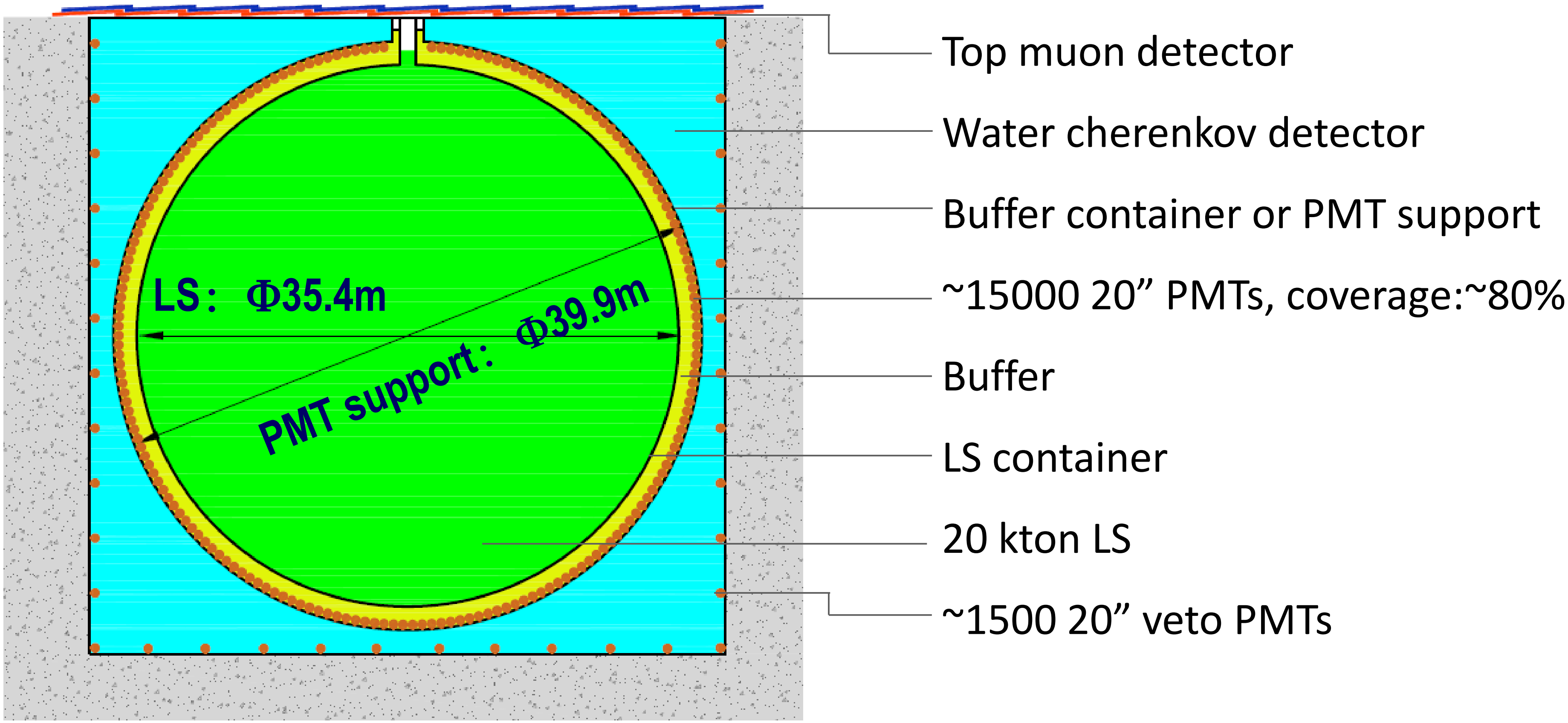
L. Zhan, Y. Wang, J. Cao, L. Wen, PRD78:111103, 2008, PRD79:073007, 2009

The JUNO experiment

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



Detector Concept: a Large LS Detector



- LS volume: ×20 → more statistics
- Light (PE): ×5 → better resolution

Signal and background of reactor antineutrinos

- **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: $\sim 10^{-12}$ g/g ➔ 50,000 Hz
    - ✓ Without Gd: $\sim 10^{-16}$ g/g ➔ 5 Hz

$\tau \sim 200\ \mu s$

Overburden 700m:
$E_\mu \sim 211$ GeV, $R_\mu \sim 3.8$ Hz
Single rates:
5 Hz by LS and 5Hz by PMT
muon efficiency ~ 99.5%

- **Backgrounds**

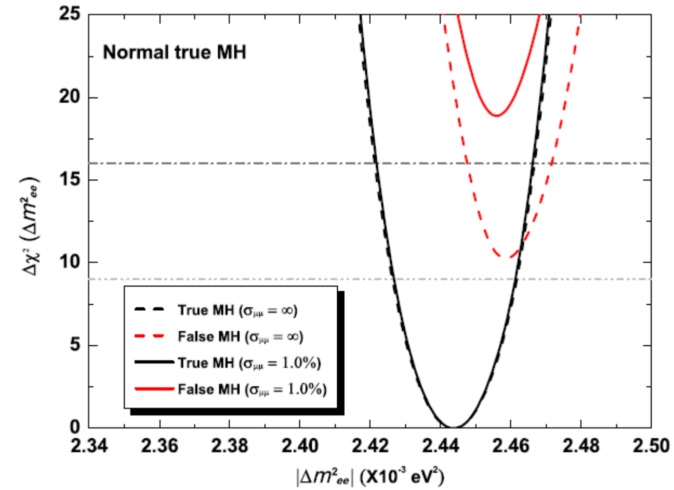
Preliminary

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

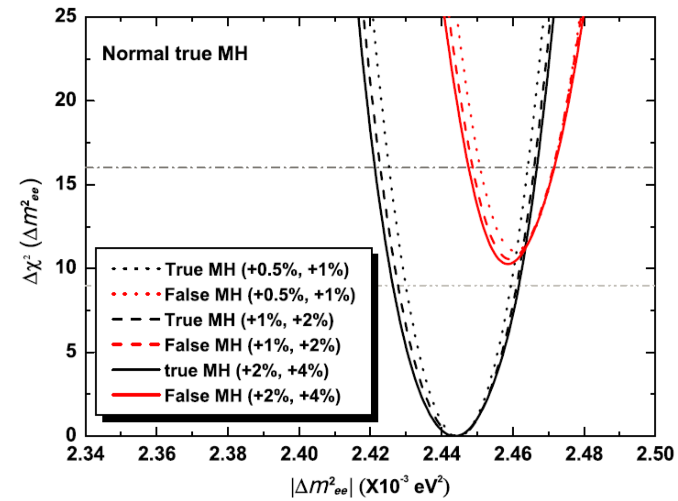
JUNO Physics: Mass Hierarchy

- Relative measurement (no pre-condition of Δm^2_{32})
- Absolute measurement (constrain of Δm^2_{32} from external experiments)
- Baseline optimization: ~53km
- Baseline differences to reactor cores: <500m
- Requirement to energy resolution: $3\%/\sqrt{E}$
- Energy scale determination: self calibration
  - Based on Δm^2_{ee} periodic peaks
  - Relatively insensitive to continuous backgrounds, non-periodic structures
- Sensitivity (6 years, 100k IBDs)
  - Relative measurement : $\Delta\chi^2>9$
  - Absolute measurement : $\Delta\chi^2>16$

Y.F.Li et al., PRD.88.013008



Relative and absolute meas.



Self-calibration

Other Physics in JUNO

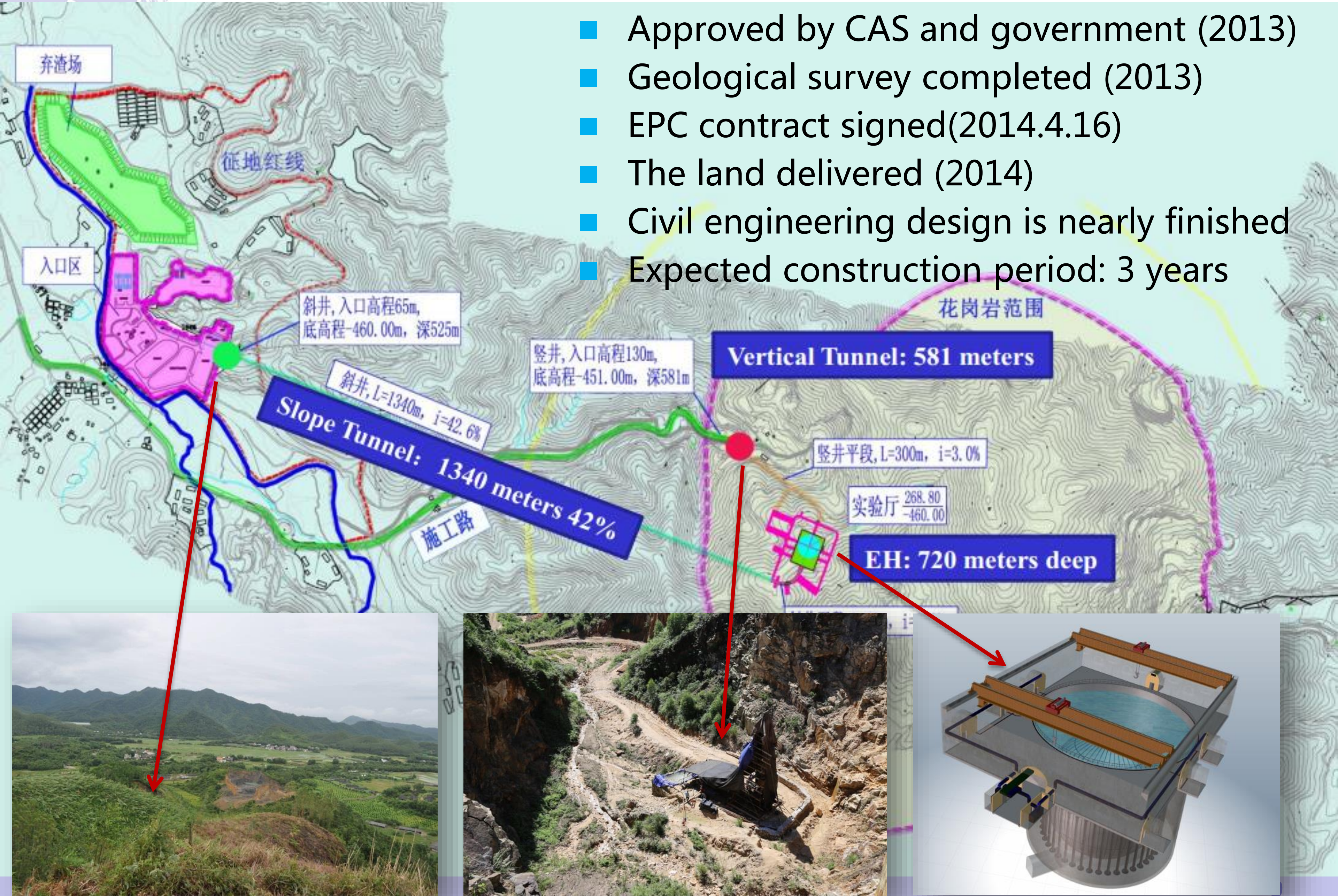
- Precision measurements of mixing parameters

	Nominal	+B2B(1%)	+BG	+1.0% (EL)	+1.0% NL
$\sin^2\theta_{12}$	0.54%	0.60%	0.62%	0.64%	0.67%
Δm^2_{21}	0.24%	0.27%	0.29%	0.44%	0.59%
Δm^2_{ee}	0.27%	0.31%	0.31%	0.35%	0.44%

- Supernova neutrinos
  - Expected events (10kpc):
    IBD ~5000, other CC+NC+ES ~2000
- Geoneutrinos
  - Expected event rate: 37TNU
  - Main background: reactor antineutrinos
- Solar neutrinos, atmospheric neutrinos, sterile neutrinos, proton decay, exotics

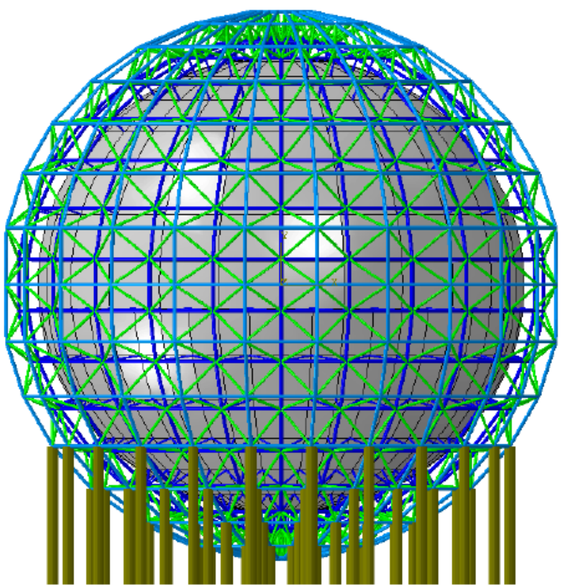
Civil Construction

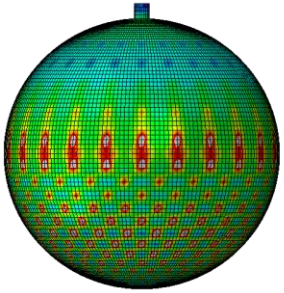
- Approved by CAS and government (2013)
- Geological survey completed (2013)
- EPC contract signed(2014.4.16)
- The land delivered (2014)
- Civil engineering design is nearly finished
- Expected construction period: 3 years



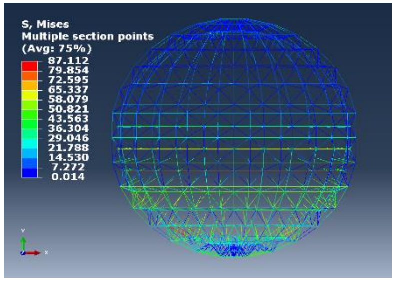
Central Detector (1)

- A large (D>35m) detector in the water pool
  - Mechanics, optics, chemistry, cleanness, assembly, …
- Default option: acrylic sphere + stainless steel truss
  - Independent designs from multiple groups
  - Acrylic performances research: strength, bonding, aging, creep
  - Connecting point R&D, making a part of sphere

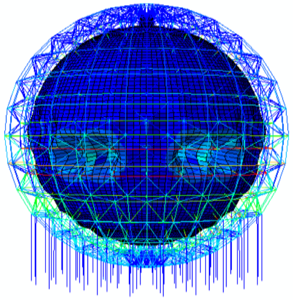




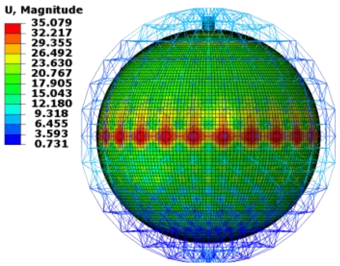
Stress analysis



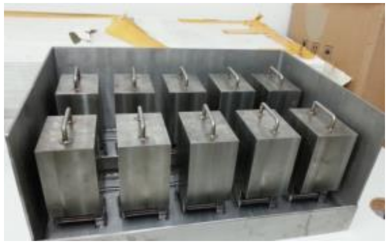
0.1g seismic load



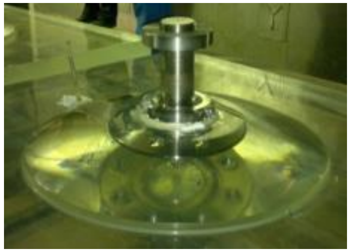
Double nonlinearity



Deflection analysis



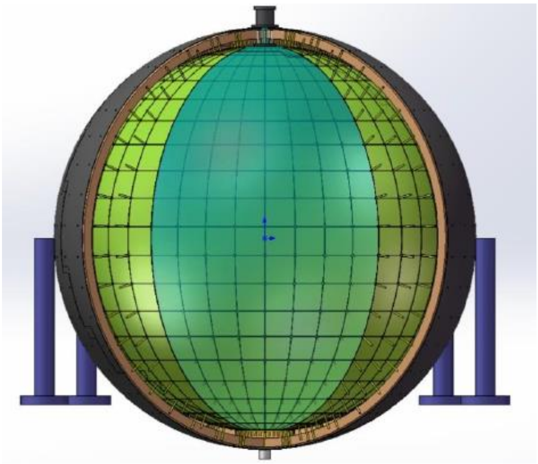
Aging test



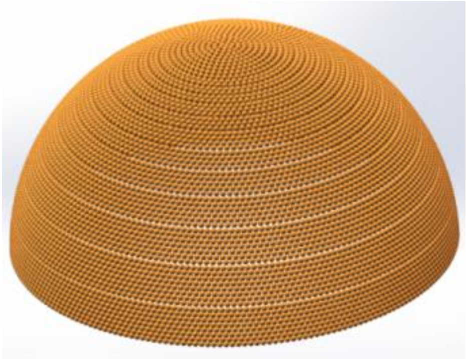
Connecting point test

Central Detector (2)

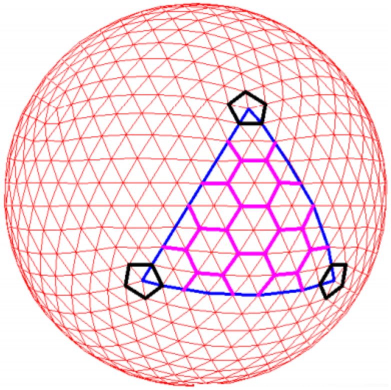
- Backup option : stainless steel tank + acrylic panel + balloon
  - Stainless steel tank design is in progress
  - Film material: ETFE/FEP/PEPA
  - Requirements to leakage and dust
  - 12 m prototype design is underway



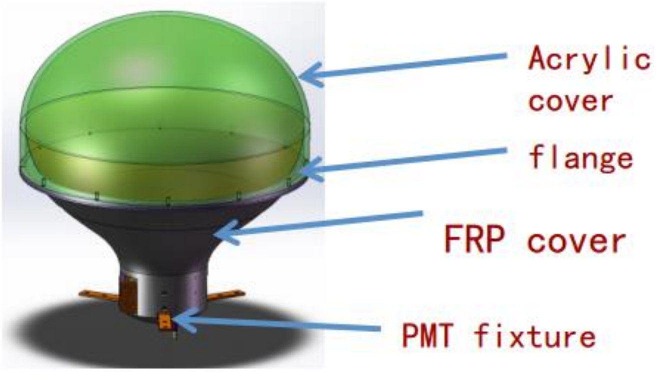
- PMT related
  - PMT coverage, implosion-proof, HV, sample test



Superlayer layout in latitude: >75%



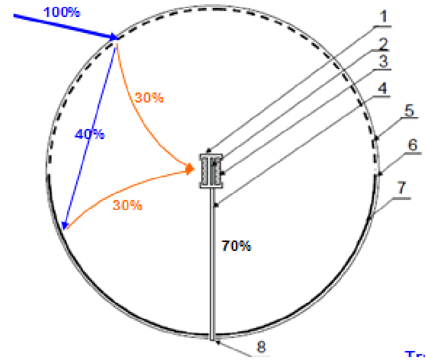
Module layout: >75%



Possible implosion-proof structure

High QE PMT

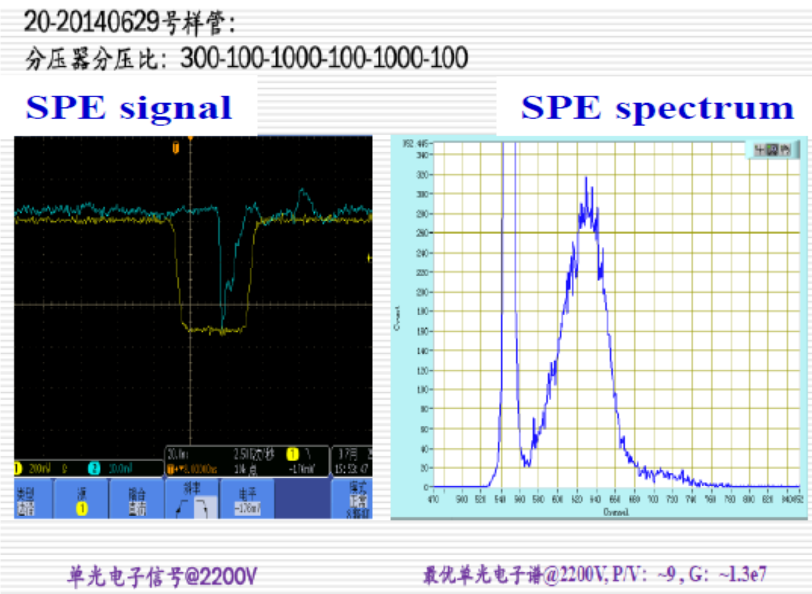
- 20" PMTs under discussion:
  - MCP-PMT with Chinese Industry
  - Photonics-type PMT: 8"→12"→20"
  - Hammamatzu R5912-100 (SBA)
- MCP-PMT development:
  - Technical issues mostly resolved
  - Successful 8" prototypes
  - A few 20" prototypes



Photon detection efficiency: ~30%

20" MCP-PMT

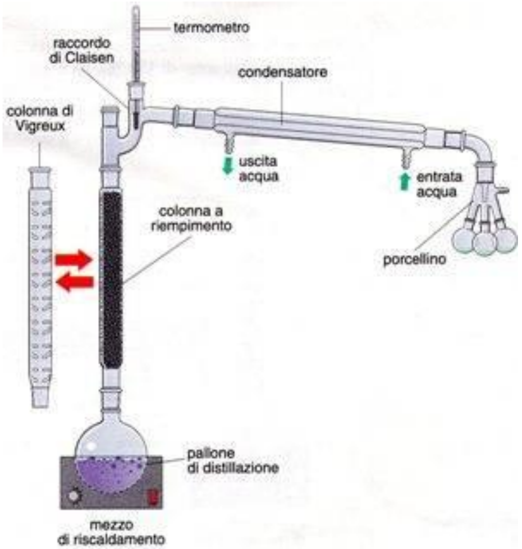
	R5912	R5912-100	MCP-PMT
QE@410nm	25%	35%	25%
Rise time	3 ns	3.4ns	5ns
SPE Amp.	17mV	18mV	17mV
P/V of SPE	>2.5	>2.5	>2.5
TTS	5.5ns	1.5 ns	3.5 ns



Liquid Scintillator

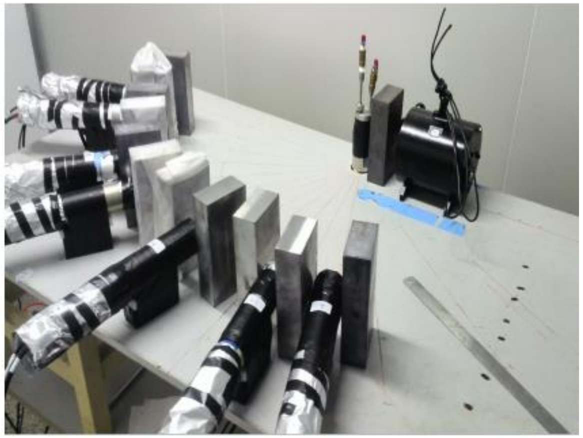
- JUNO LS: LAB+PPO+BisMSB
  - No Gd doping: lower radioactivity
  - Attenuation: 15m (DYB) -> 30m
- R&D efforts:
  - Improve raw materials
  - Improve the production process
  - Purification
    - Column purification (IHEP&TUM)
    - Purification by charcoal (IHEP&JINR)
    - Vacuum distillation (IHEP&Perugia)

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

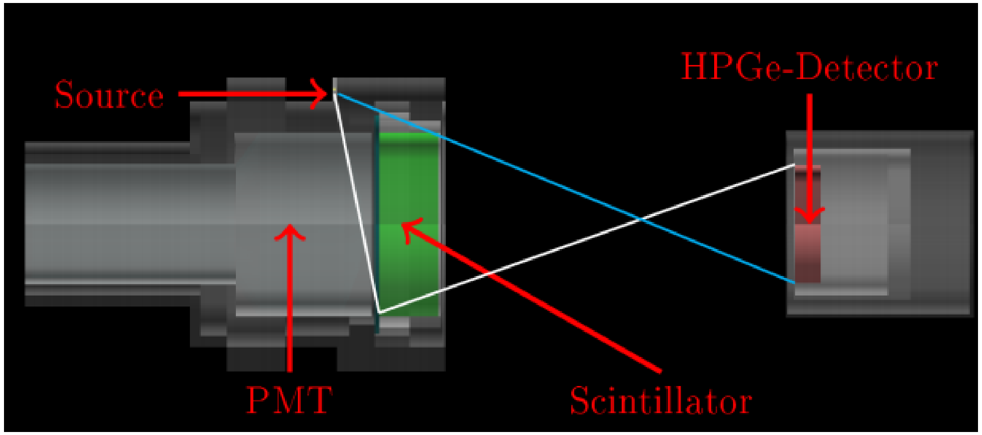


LAB/LS Characterization

- Ongoing measurements
  - Attenuation length
  - Light yield (Optimize concentration of PPO and bis-MSB)
  - Impurity
  - Rayleigh scattering
  - $^{14}C/^{12}C$
- LS energy response measurements

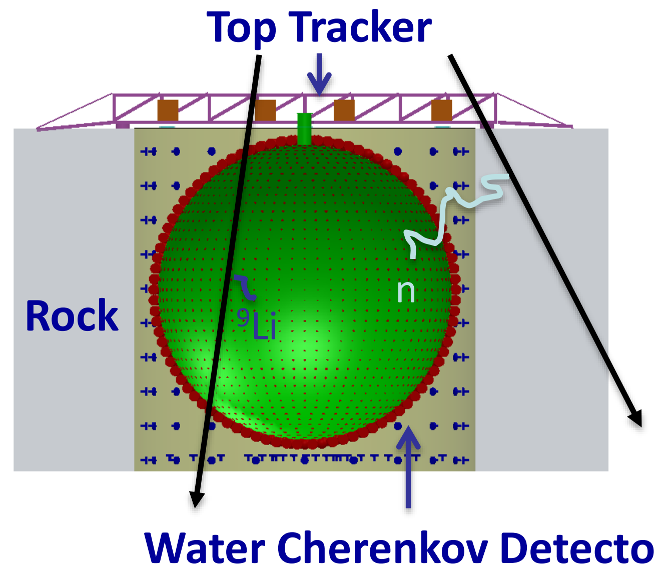


Setup at IHEP: multiple angular measurements



Setup at TUM: HPGe measurements

Veto System



Goals of veto

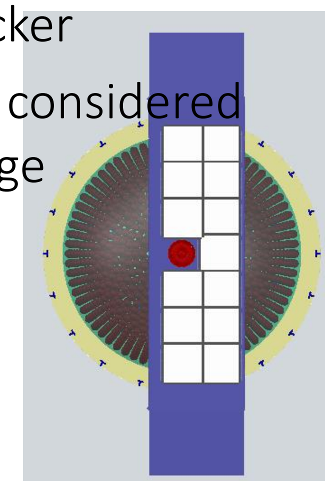
- Cosmogenic isotopes rejection
- Neutron background rejection
- Gamma background passive shielding
- …

Water cherenkov detector

- ~1500 20” PMT
- 20~30 kton ultrapure water with a circulation system
- Earth magnetic field shielding
- Tyvek reflector film
- PMT support frame
- Water pool sealing

Top tracker

- Use OPERA Target Tracker
- Additional options are considered to increase the coverage



Readout Electronics and Trigger

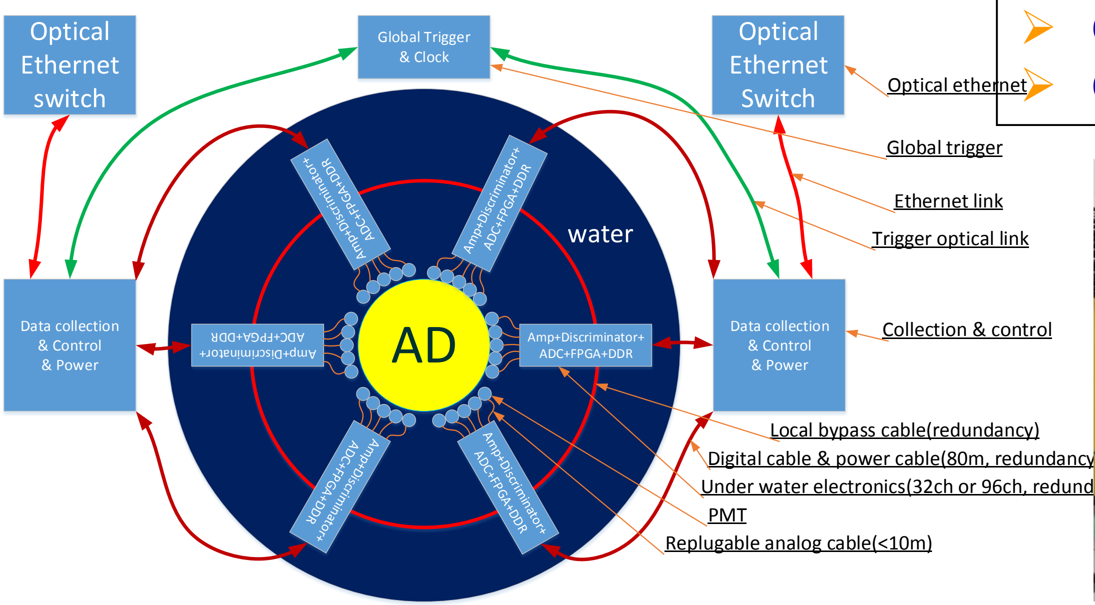
- Charge and timing info. from 1 GHz FADC

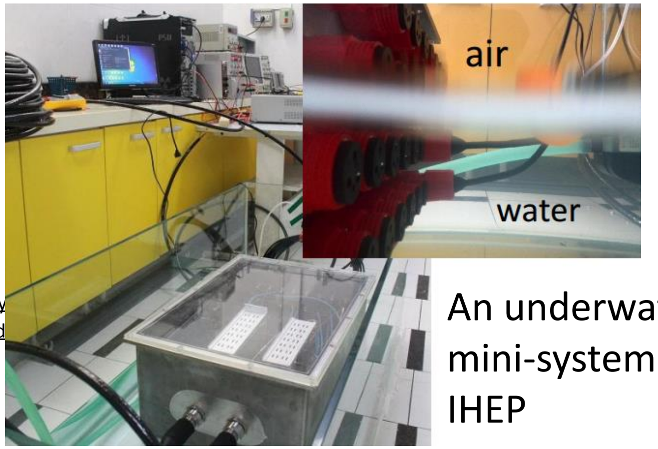
Total No. channel	**20,000**
Event rate	**~ 50 KHz**
Charge precision	**1 – 100 PE: 0.1 – 1 PE; 100-4000PE: 1-40PE**
Noise	**0.1 PE**
Timing	**0-2us: ~ 100 ps**

- 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

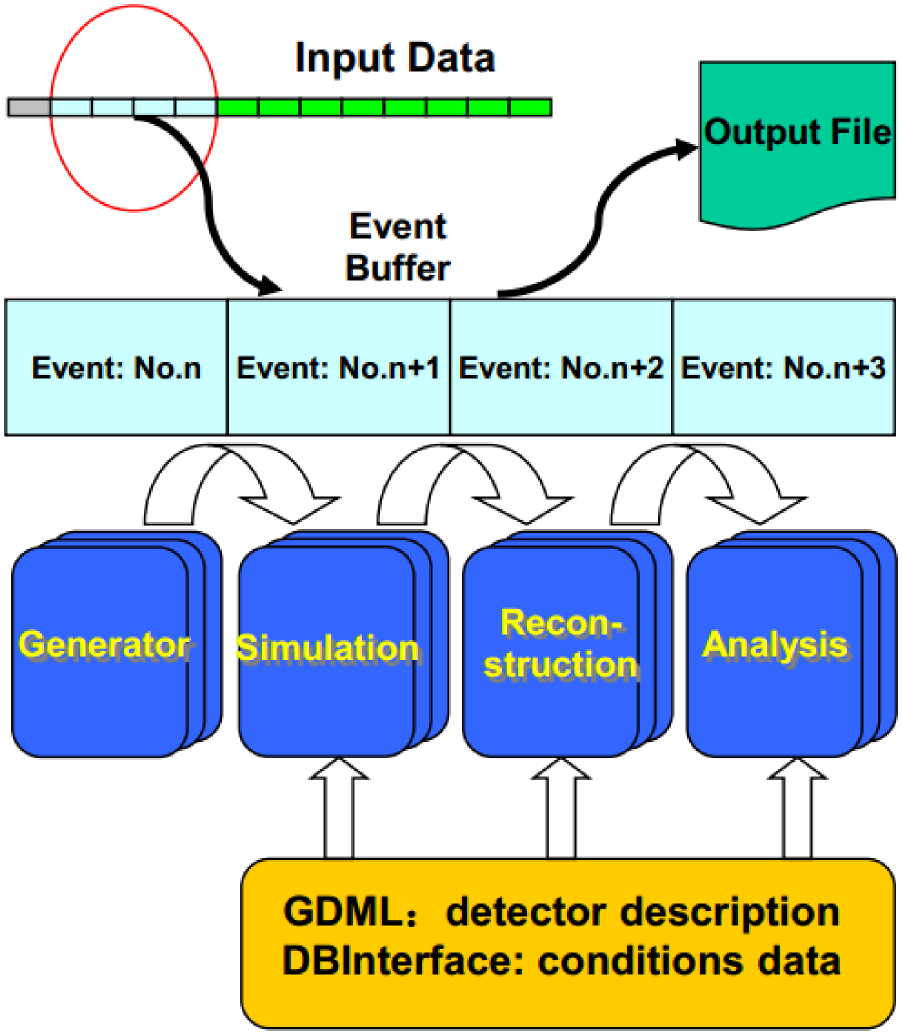




An underwater mini-system at IHEP

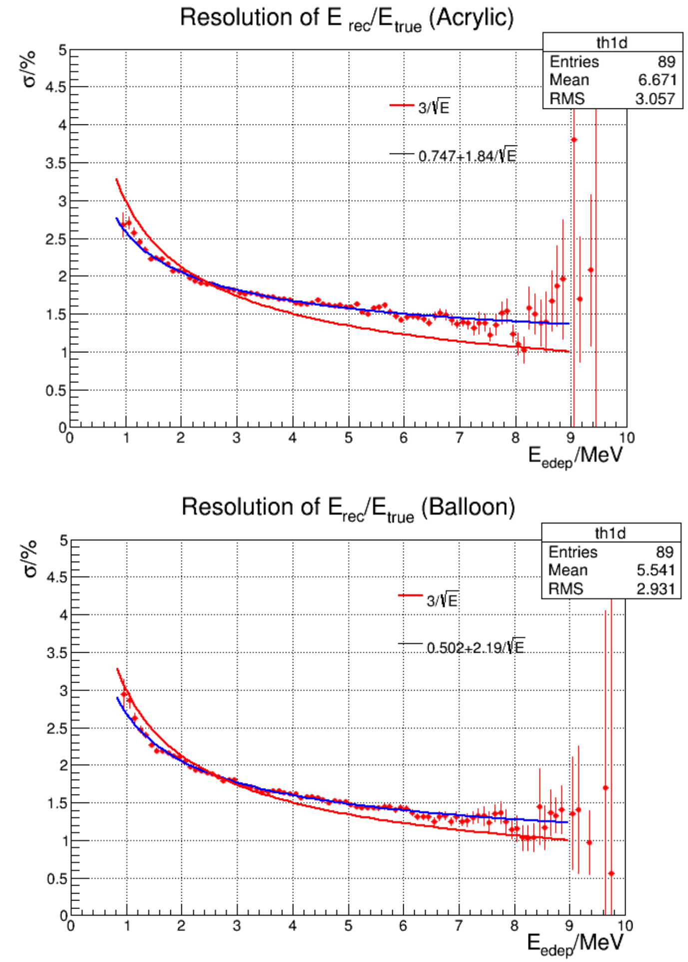
Offline Software

- Software framework: SNiPER
  - Designed for Noncollider Physics ExpeRiments)
  - Flexible event buffer
  - Cascade data model
  - Minimal external lib required
- Detector simulation
  - Geant4 based simulation
  - Geometry description of different detector options
  - Readout electronics simulation
  - Background mixing
- Event reconstruction
  - PMT waveform fitting
  - Vertex and energy reconstruction
  - Cosmic muon tracking



MC Studies

- Optical model
  - Based on DYB (tuned to data), except:
  - **PMT QE:** 25%→ 35%
  - **LS light yield:** 10400 photons/MeV
  - **LS attenuation length:** 20 m @430 nm
    - **Absorption** 60m
    - **Rayleigh scattering** 30 m
- Detector performance studies
  - Vertex and energy resolution: σ_E/E~3%@1MeV
  - Effect of steel struts, PMT proof, film transparency, dark noise …
  - Buffer thickness: reduce PMT background
  - Optimize fiducial volume
  - Muon efficiency in water pool: 99.5%



Energy resolution of two detector options: similar performances

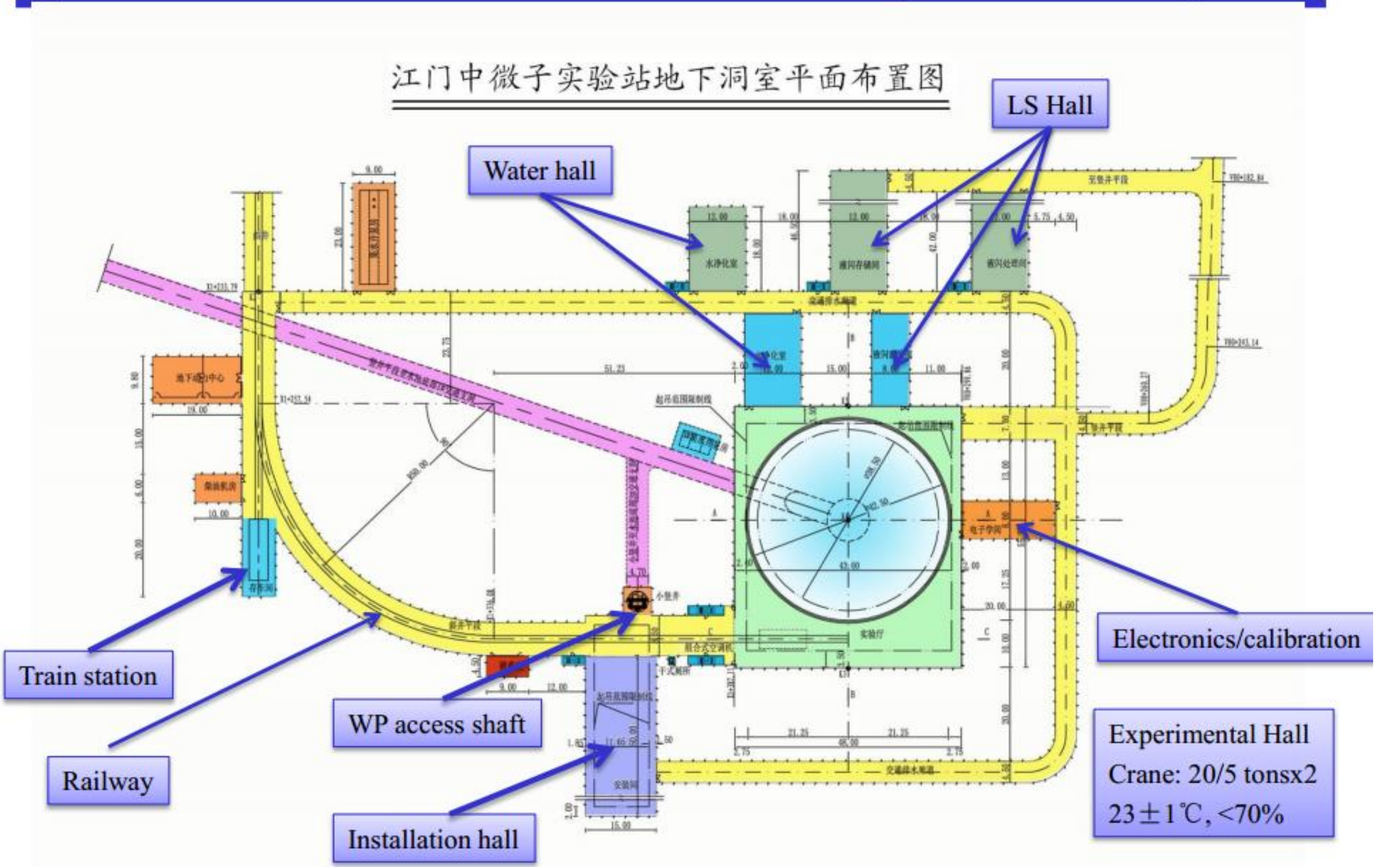
Schedule

- 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

backup

Surface Building

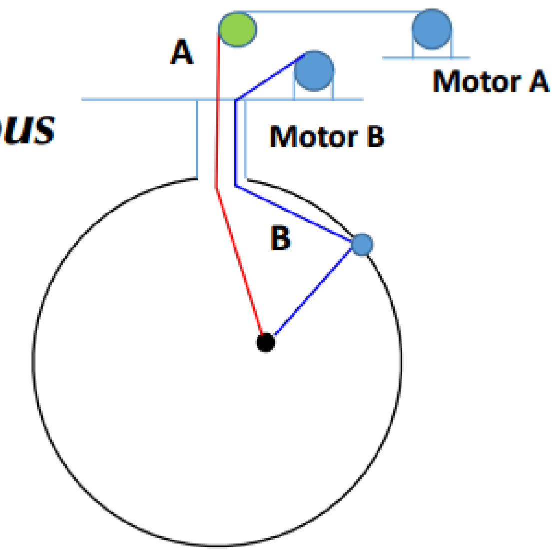
Underground Layout



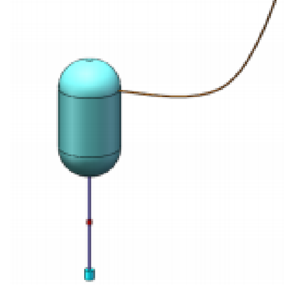
Calibration System Conceptual Designs

- Point radioactive source calibration systems
  - A automatic rope system is the most primary source delivery system
  - Considering a ROV to be more versatile
  - Considering a guide tube system to cover the boundaries and near boundary regions
- Also considering a short-lived diffusive radioactive sources
- A UV laser system being considered to calibrate the LS responses

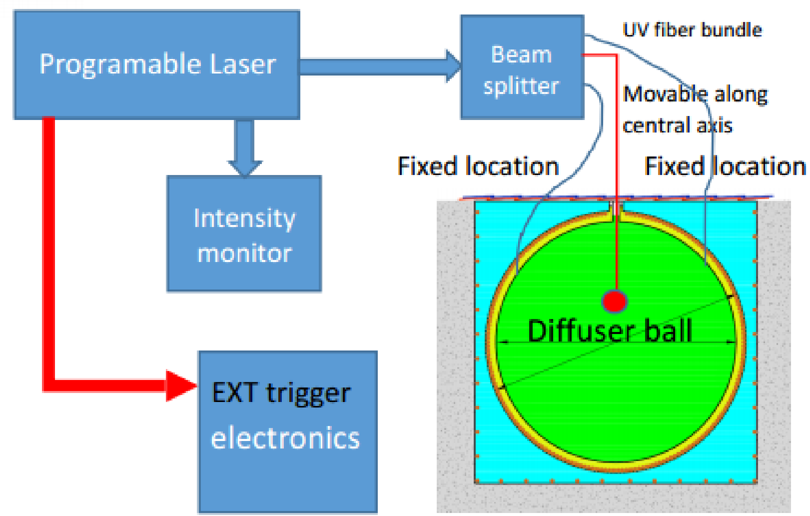
A-B rope synchronous motion

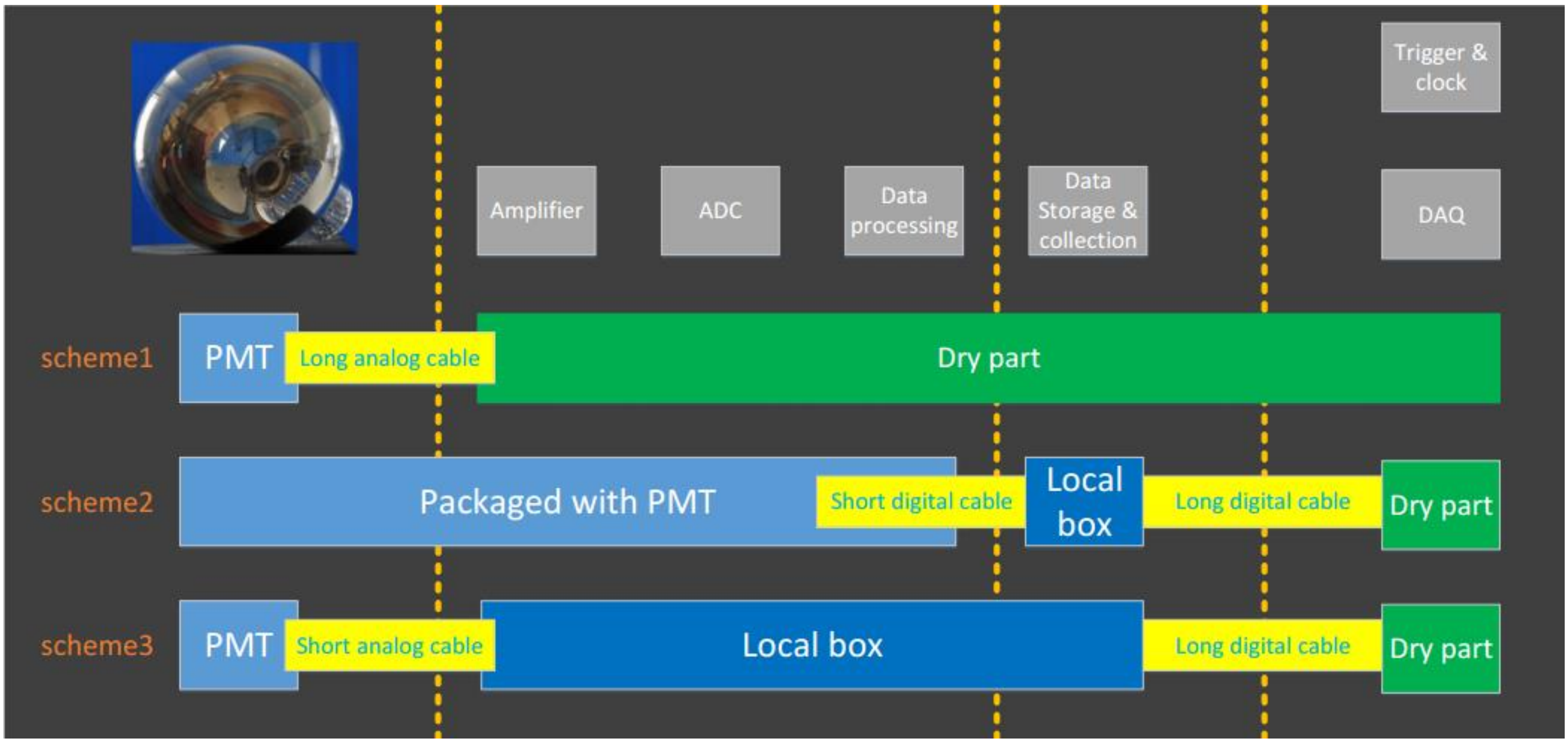


All-in-one ROV



sources




Trigger & clock
Amplifier
ADC
Data processing
Data Storage & collection
DAQ
scheme1
PMT
Long analog cable
Dry part
scheme2
Packaged with PMT
Short digital cable
Local box
Long digital cable
Dry part
scheme3
PMT
Short analog cable
Local box
Long digital cable
Dry part