# Astrophysics in China

**Yifang Wang**

**Institute of High Energy Physics**

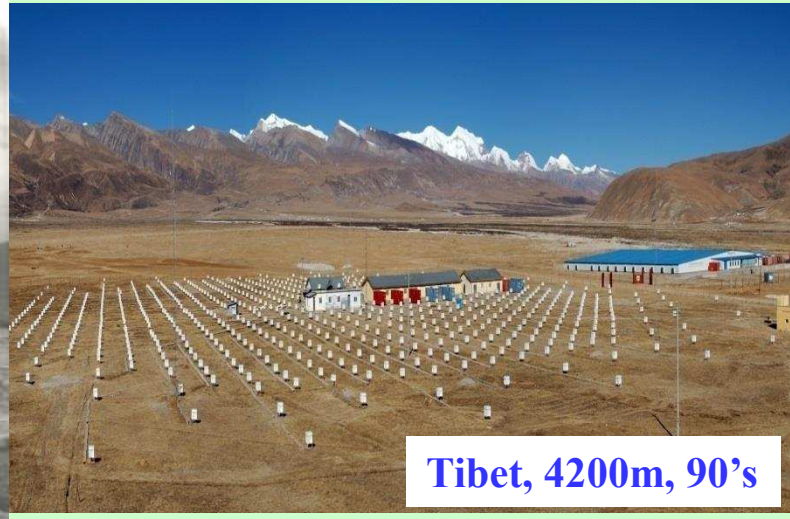
**Vulcano, May 23, 2016**

# Astrophysics in China Since 50's

Yunnan, 3200m, 50's

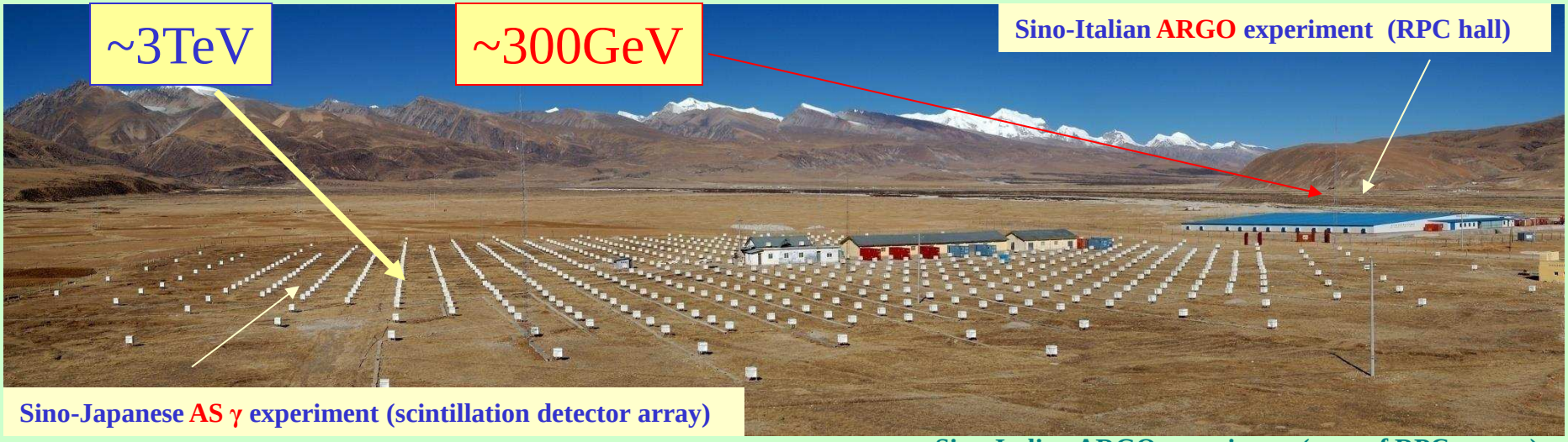
Cloud chamber, 60's

Tibet, 5500m, 70's

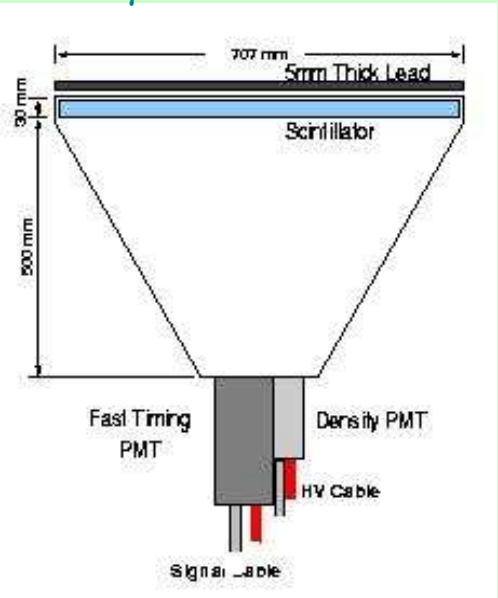


Tibet, 4200m, 90's

# Yangbajing Cosmic-ray Observatory: ASγ & ARGO experiment




ASγ scintillation detector



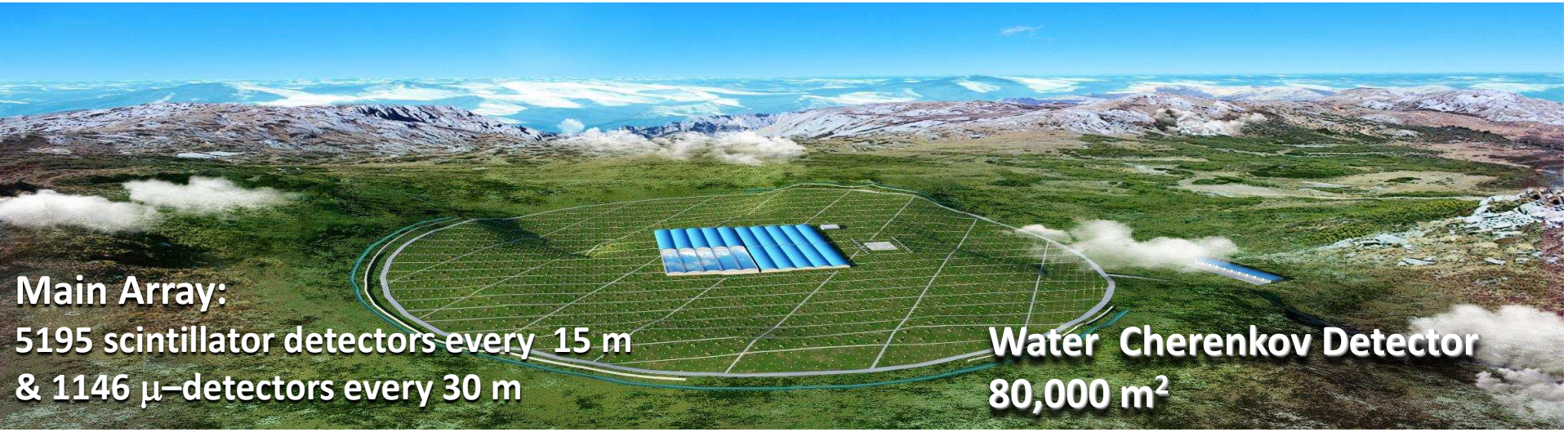

Sino-Italian ARGO experiment (part of RPC carpet)

# A new Phase: LHAASO

## —— Large High Altitude Air Shower Observatory

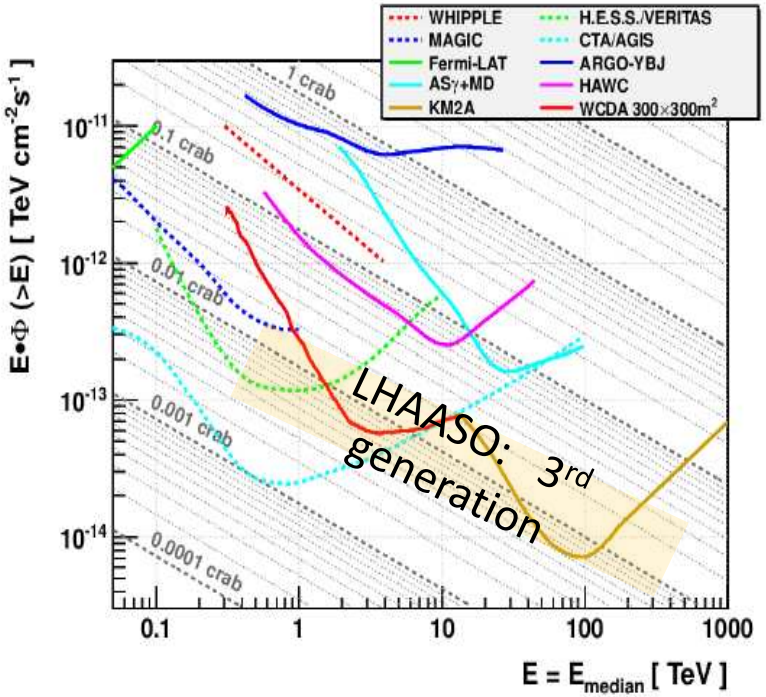

**Sichuan, 4300 m a.s.l.**

# LHAASO Detector Setup



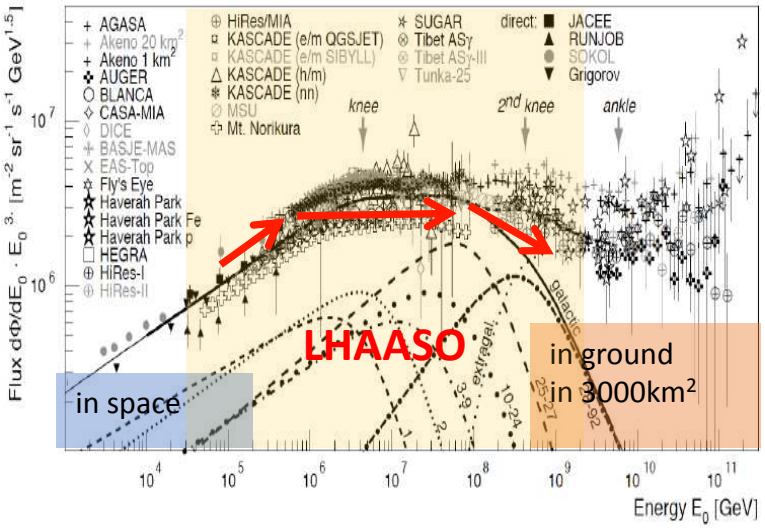

# Science at LHAASO

- Unique for 10 TeV γ astronomy with the highest sensitivity in the world
- Window for discovering the hadronic origins of cosmic rays
- Crucial CR data covering a very wide energy region of knees
- Exploring for new physics, such as DM or quantum gravity



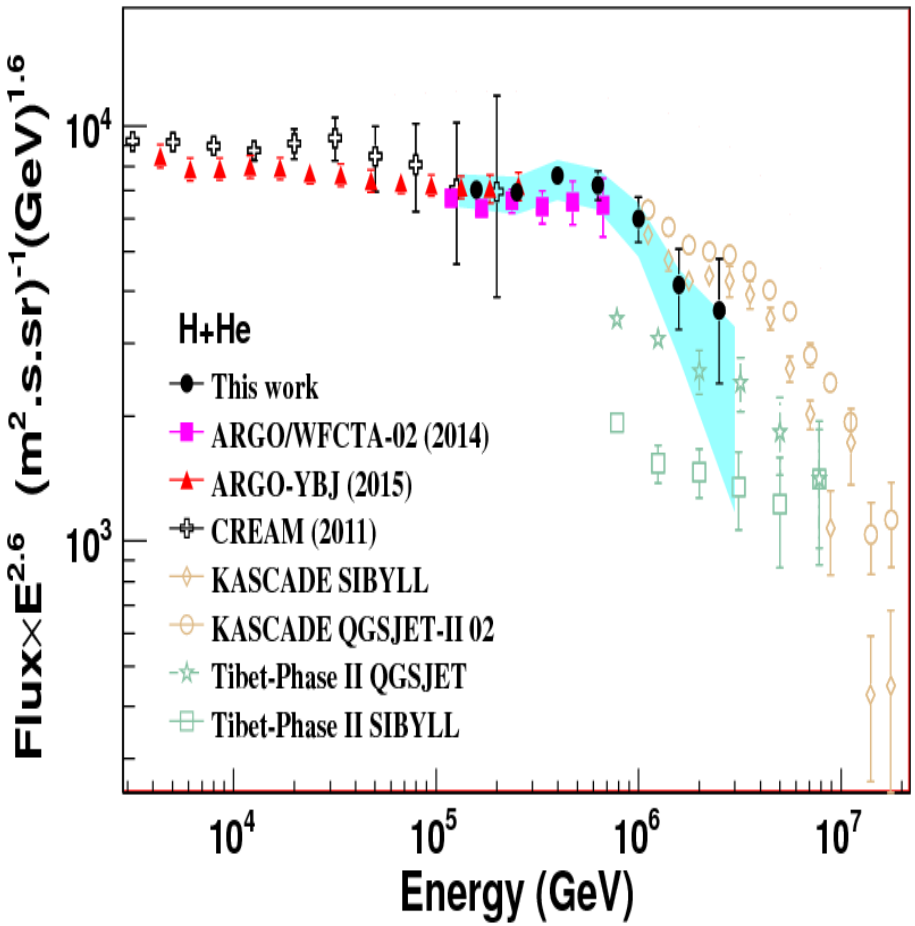

## Complementary to CTA:

- All the time
- All the sky
- Time-variant sources
- Extended sources
- Fast indication for CTA



# Current Status

- LHAASO is funded for 2016-2020
- Sichuan province provides land & infrastructure
- Construction starts by the end of this year
- **The 1st Result with LHAASO prototype & ARGO-YBJ**
  - **H & He (70% purity)**
  - **A knee @700 TeV**

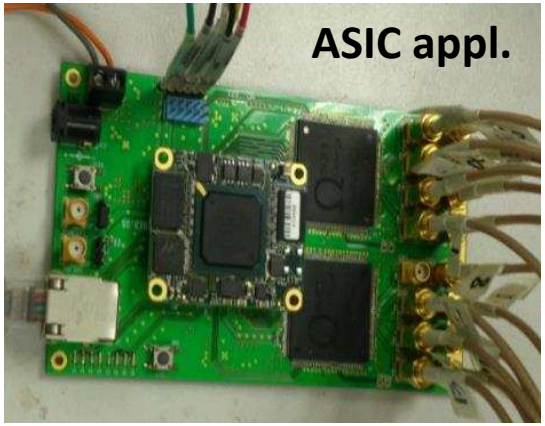



**Phys.Rev. D92 (2015) 9, 092005**

- The knee at 700±230±70 TeV is found
- Spectral index: $\beta_1$=-2.56 ± 0.05 below the knee;
  $\beta_2$=-3.24 ± 0.36 above the knee;

# International Collaboration

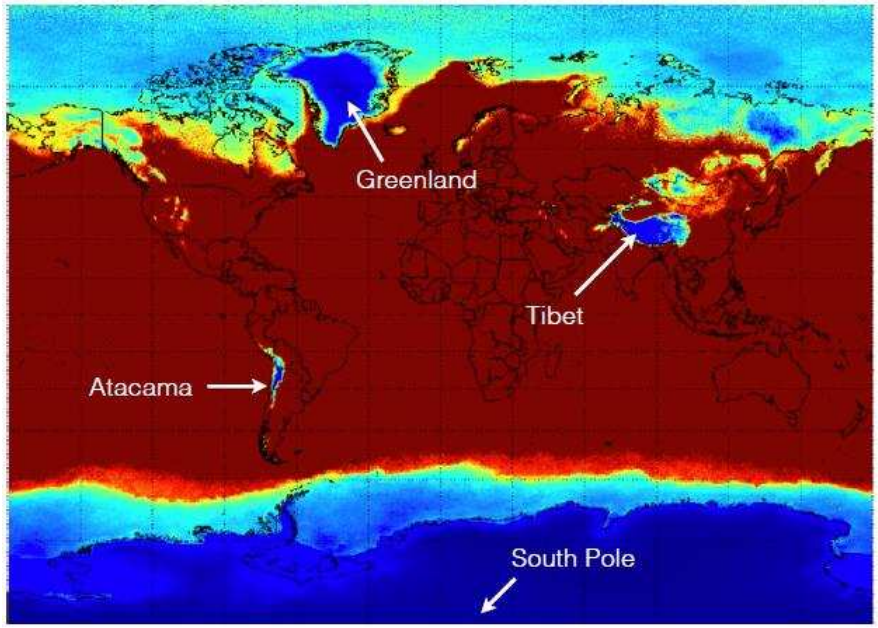
- **Italy**
  - **INFN approved the LHAASO proposal in Oct. 2015, for one year**
  - **Torino: gamma ray astronomy, gamma ray burst search, CR spectrum**
  - **Rome-II: DM search, CRs**
  - **Natural evolution of 20+yr collaboration (ARGO-YBJ) in HEP between IHEP and INFN**
  - **The longest & important scientific collaboration between Italy and China**
- **Switzerland**
  - **Geneva Univ. joined LHAASO as an associated member for collaboration on the SiPM based C-telescope camera**
  - **They are developing Winston cones for SiPM pixels**
- **France**
  - **IPN-Orsay and OMEGA group for micro-electronics**
- **Russian**
  - **neutron detectors**
- **Thailand**
  - **solar CR group**



# CMB at Tibet： Ali/BICEPx

- Ali(5100m) is the best observatory in the north hemisphere
  - Moisture in winter: 1.0 mm
  - Nearby(~6000m): 0.5 mm
    - Comparable or even better than South Pole/Chile
  - Existing infrastructure
  - Good sky coverage
- Collaboration with BICEPx:
  - China participate BICEPx & G4 planning at Chile/South pole
  - US & China establish a new site in Tibet

**Thanks to LIGO, Funding suddenly arrived**

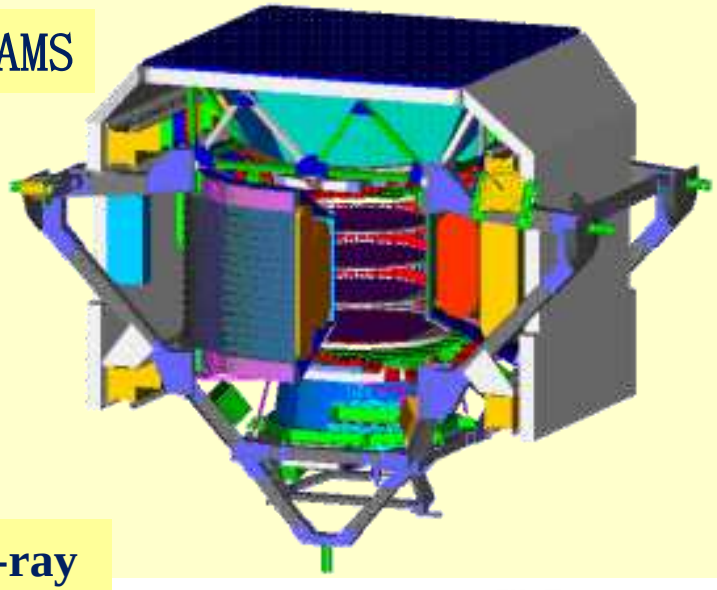



# Particle & Astro-Particle Physics at IHEP

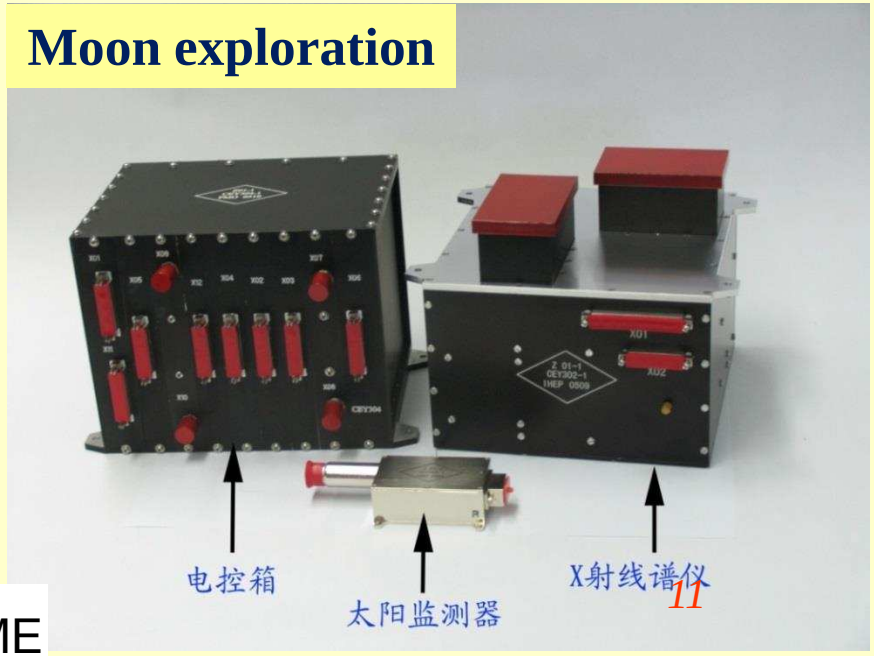
| | | Current | Future |
|---|---|---|---|
| Accelerator-based | Precision frontier | BESIII | International: ILC<br>CEPC ➔ SppC |
| | | International projects: Belle II、PANDA、COMET | |
| | Energy frontier | CMS、ATLAS | |
| Non-accelerator-based | underground | Daya Bay | JUNO |
| | | EXO | |
| | Surface | ARGO/ASγ | LHASSO |
| | | | Ali/BICEPx |
| | Space | AMS | HERD<br>XTP |
| | | HXMT | |

# Space Projects

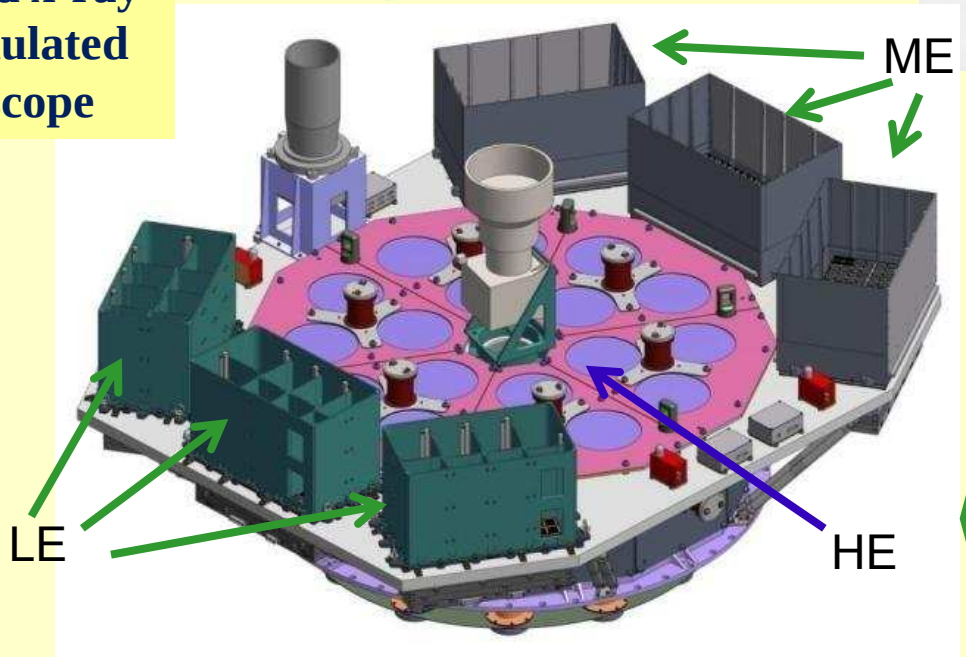
AMS



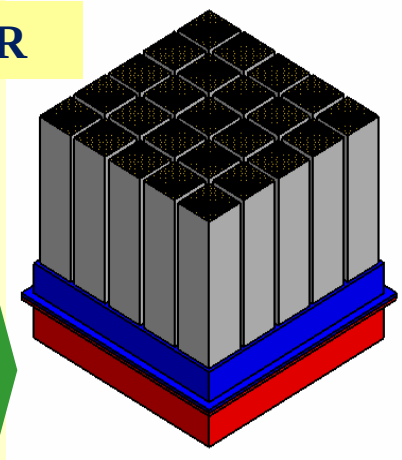
Moon exploration




Hard x-ray modulated telescope



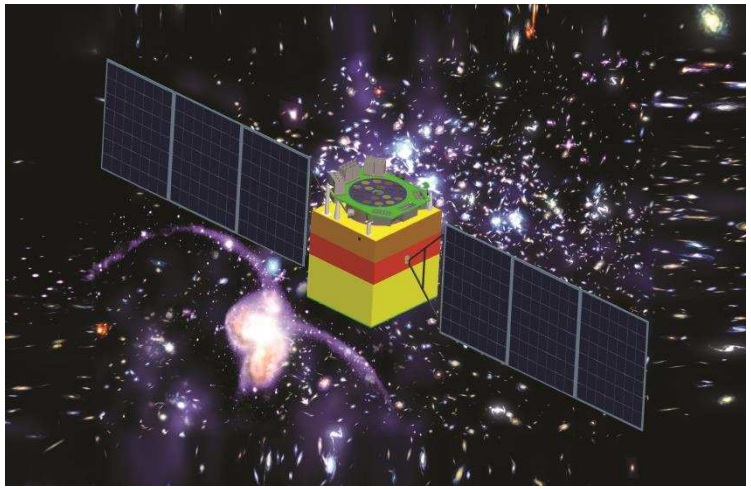

POLAR



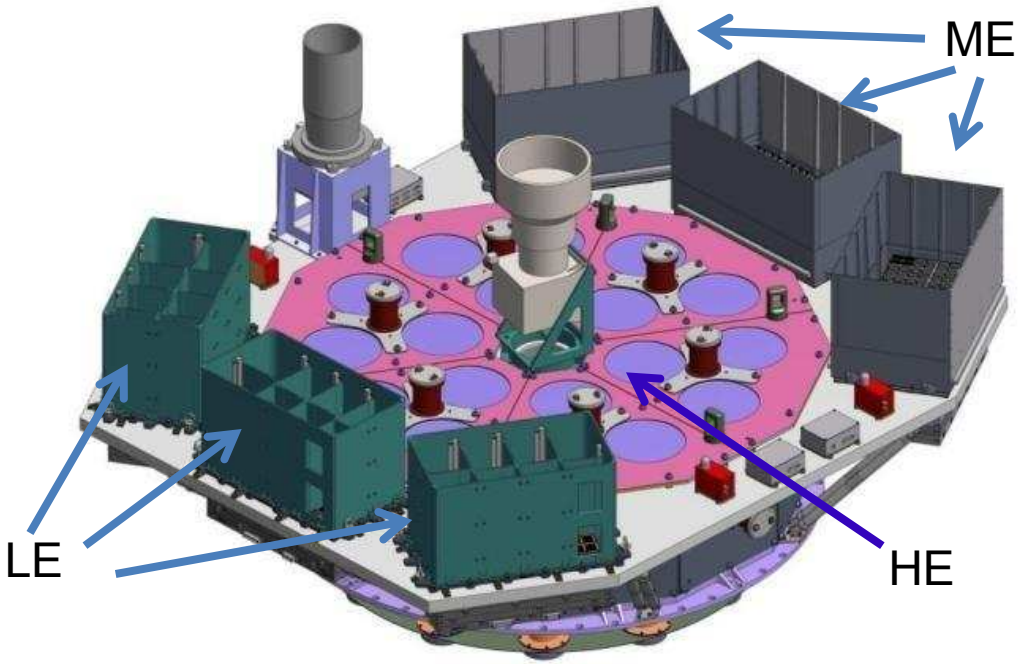
To be launched this year

# Hard X-ray modulated telescope ( HXMT )

- Full sky survey with good angular resolution and sensitivity
- First satellite for astronomy & astrophysics in china
- Construction completed, under final testing
- To be lunched around Oct.-Nov., 2016

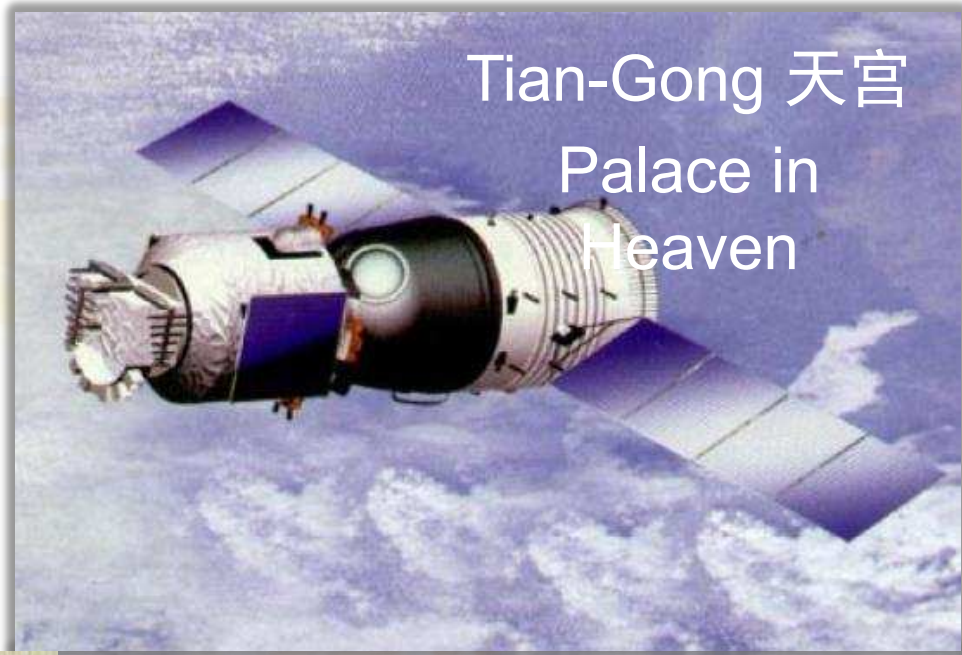


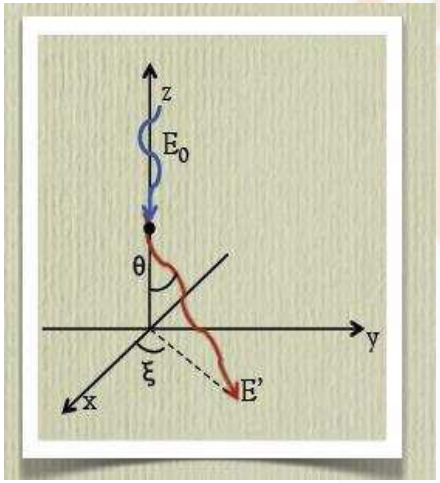
Total mass： 1021kg
signal： 1881 Ch.
Power： 350W



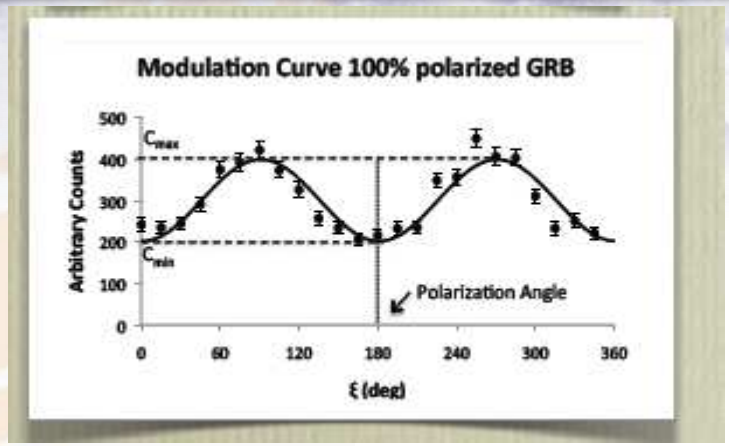
# Gamma-ray burst polarization experiment onboard China's Spacelab: POLAR

- Onboard China's spacelab TG-2: launch time ~2016
- An international collaboration (Switzerland, France, Poland)
- FOV of POLAR: ~½ sky





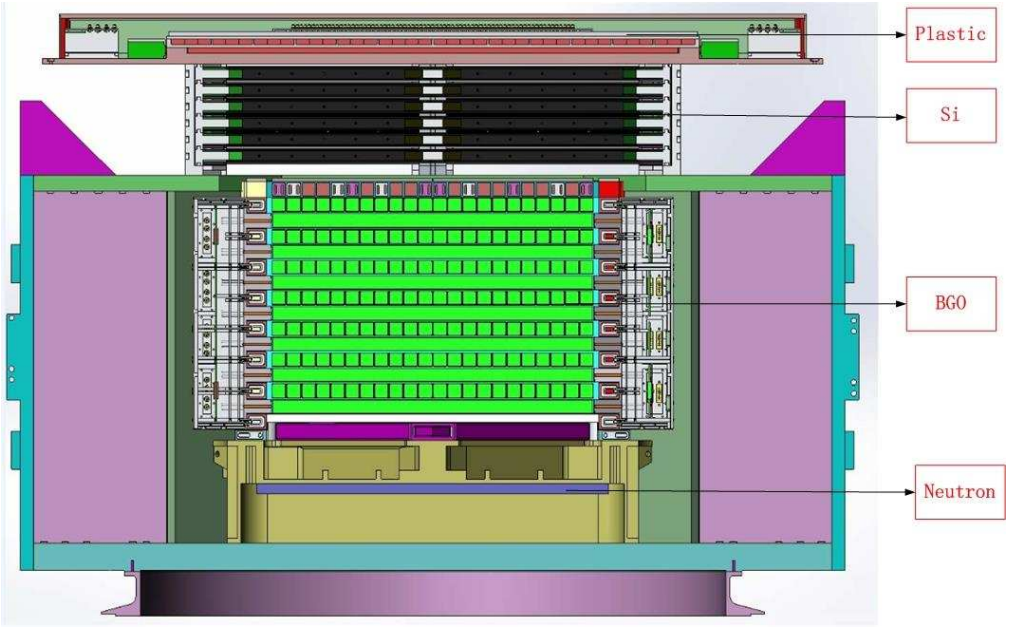



Instrument concept proposed by N. Produit, et al., NIM (2005)

# DArk Matter Particle Explorer (DAMPE) satellite

**Energy range: 1 GeV-10 TeV**
**Particle type: electron, γ-ray, heavy ions**
**Energy resolution: 1.5%@800GeV**
**Spatial resolution: 0.1degree@500GeV**
**Background level: 1%@800GeV**
**p/e separation: <1%**
**GF: 0.5m$^2$.sr**

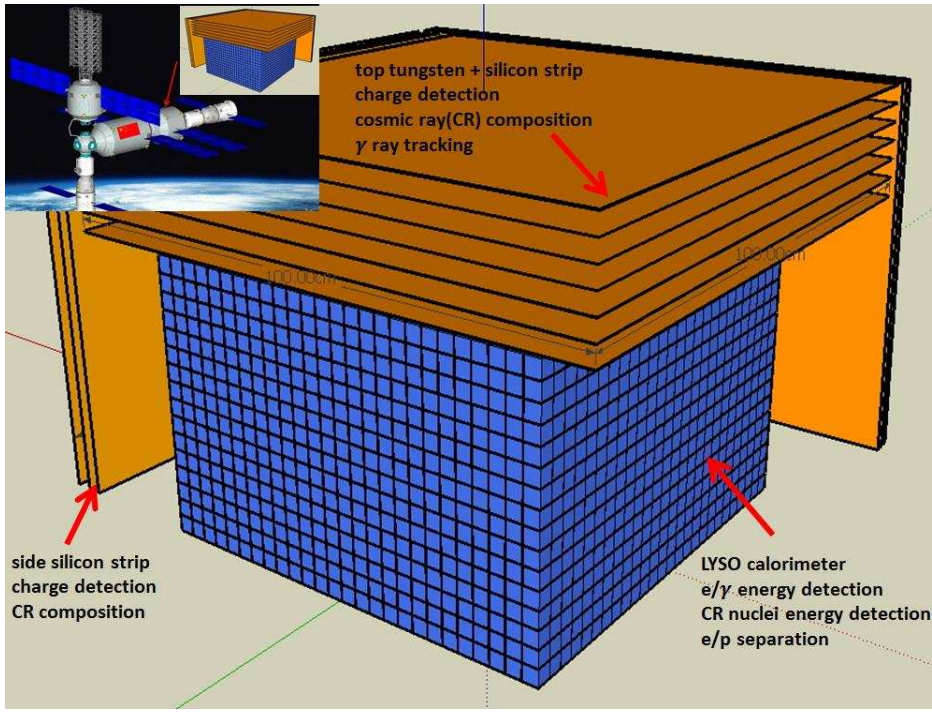
**Top scintillators**
**Si tracker (5 layers)**
**BGO calorimeter**
**Neutron detector**




- **Satellite ~ 1900 kg**
- **Payload ~1340kg**
- **Power: 840W**
- **Lifetime > 3 years**
- **Launched successful on Dec. 18, 2015**

# HERD @ the China's Space Station

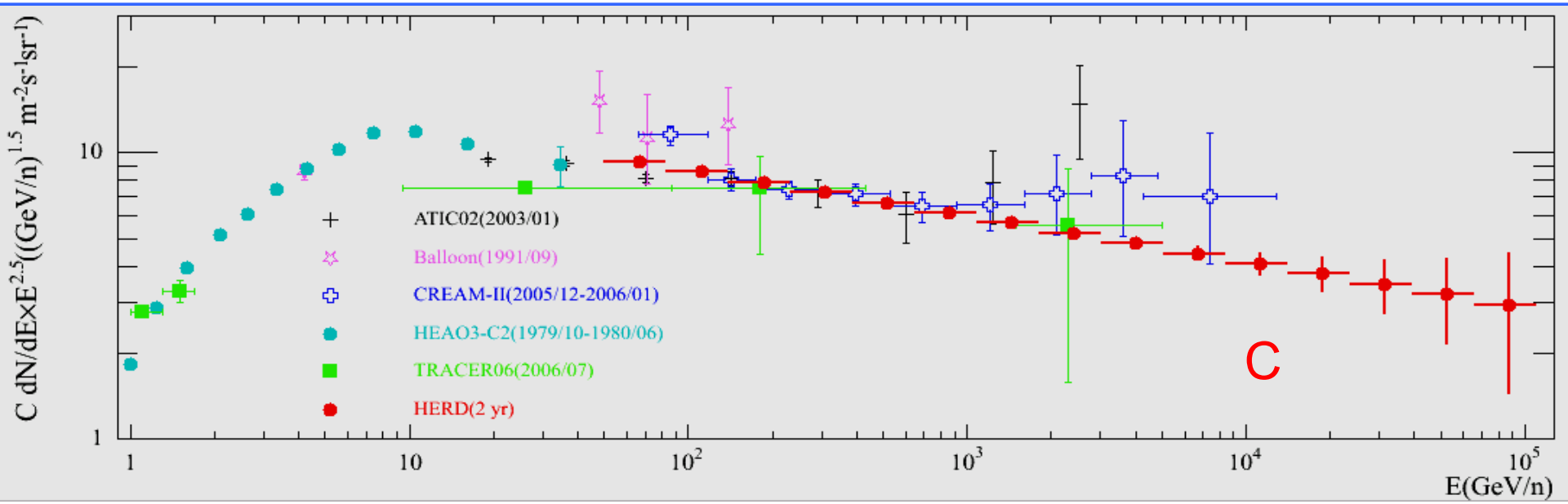
- Science
  - Dark matter search: γ from 100 – 10,000 GeV
  - γ-ray astronomy: GRBs, microquasars, Blazars and other transients down to 100 MeV
  - Spectral and composition measurements of CRs between 300 GeV to PeV with a large geometrical factor
  - Complementary to LHAASO: directly measured composition & spectrum in space
- Status
  - Groups from China, Italy, Switzerland, Sweden,…
  - Launch in ~2023

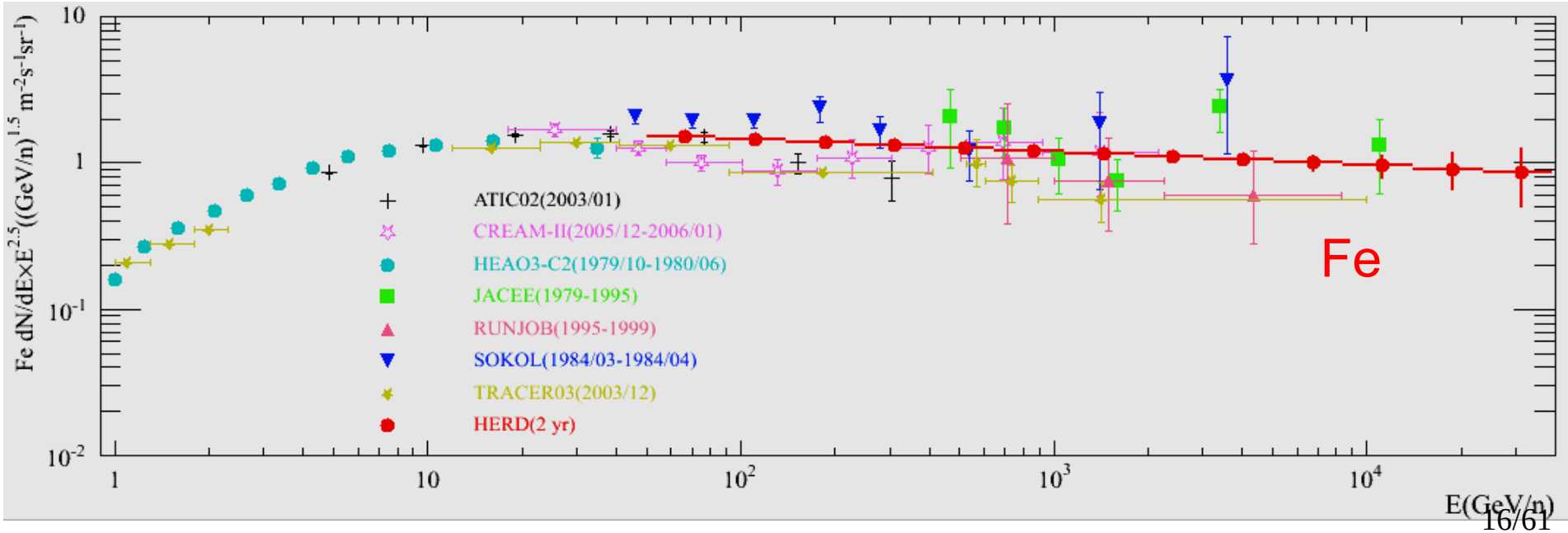



| | X0(λ) | ΔE/E for e | e/p sep | e GF $m^2sr$@ 200GeV | p GF $m^2sr$@100TeV |
|---|---|---|---|---|---|
| HERD (2020) | 55(3) | 1% | $10^{-6}$ | 3.1 | 2.3 |
| Fermi (2008) | 10 | 12% | $10^{-3}$ | 0.9 | -- |
| AMS02 (2011) | 17 | 2% | $10^{-6}$ | 0.12 | -- |
| DAMPE (2015) | 31 | 1% | $10^{-4}$ | 0.3 | -- |
| CREAM (2015) | 20(1.5) | -- | -- | -- | 0.2 |

Acceptance & H-energy > 10X all others

# Expected HERD Spectra of C and Fe



# HERD beam test @ SPS H4 2015/11

China (hardware+data analysis)

- 1 LYSO array
  - 5*5*10 crystals
- Fibers: 2 ICCD + 2 PMT

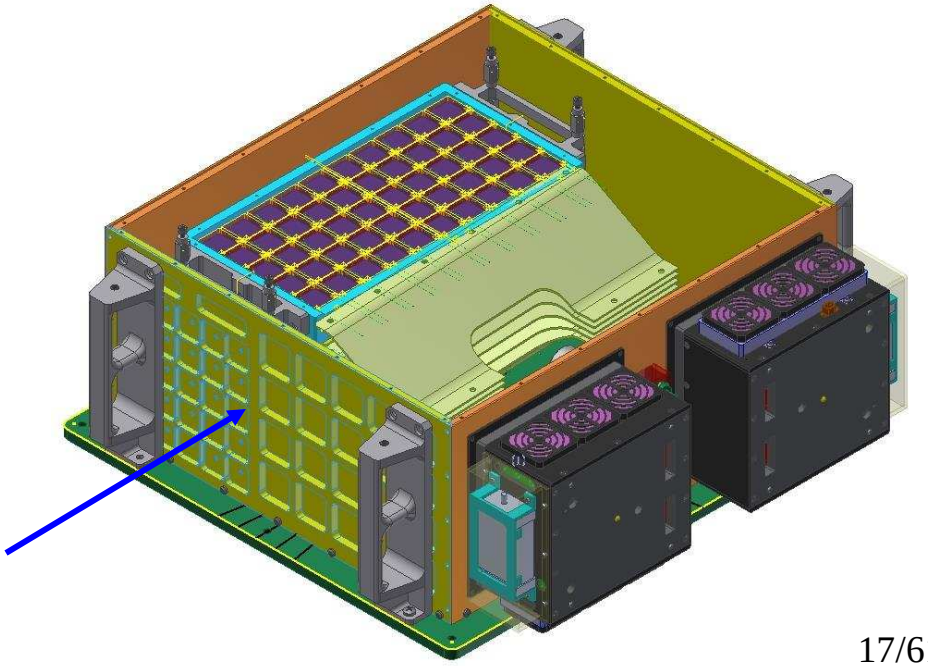
Geneva: beam ccordination

Italy (hardware+data analysis)

- Silicon microstrip tracker
- Plastic scintillator trigger

## Conclusion: success

- ICCD performance: OK
- Energy resolution: OK
- Dynamic range: ~OK
- Improved design started

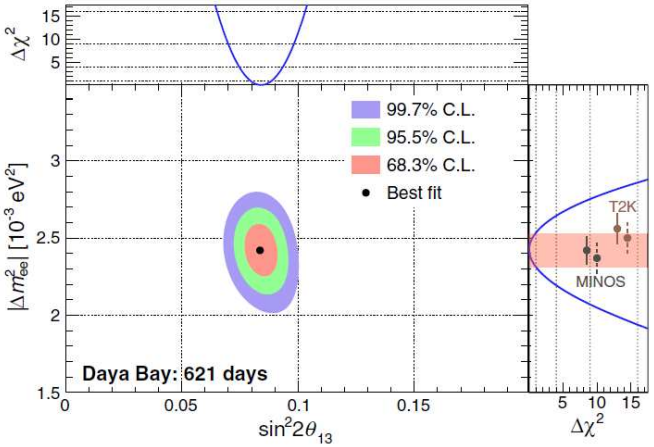
# 3rd HERD Workshop Xi'An 2016/1/18-21


Current team:

- China: IHEP, PMO, USTC, XIOPM
- Swizerland: Geneva
- Italy: Pisa, Florence, IAPS/INAF, Perugia,Trento,
- Sweden: KTH,

# Neutrinos: A lot of Progress but still a Lot of Unknowns

- **Neutrino oscillation:**
  - ⇨ **Neutrino mass hierarchy ?**
  - ⇨ **Unitarity of neutrino mixing matrix ?**
  - ⇨ **$\Theta_{23}$ is maximized ?**
  - ⇨ **CP phase ?**
- **Absolute neutrino mass ?**
- **Dirac or Majorana ?**
- **Sterile neutrinos?**
- **Magnetic moments ?**
- **Relic neutrinos ?**

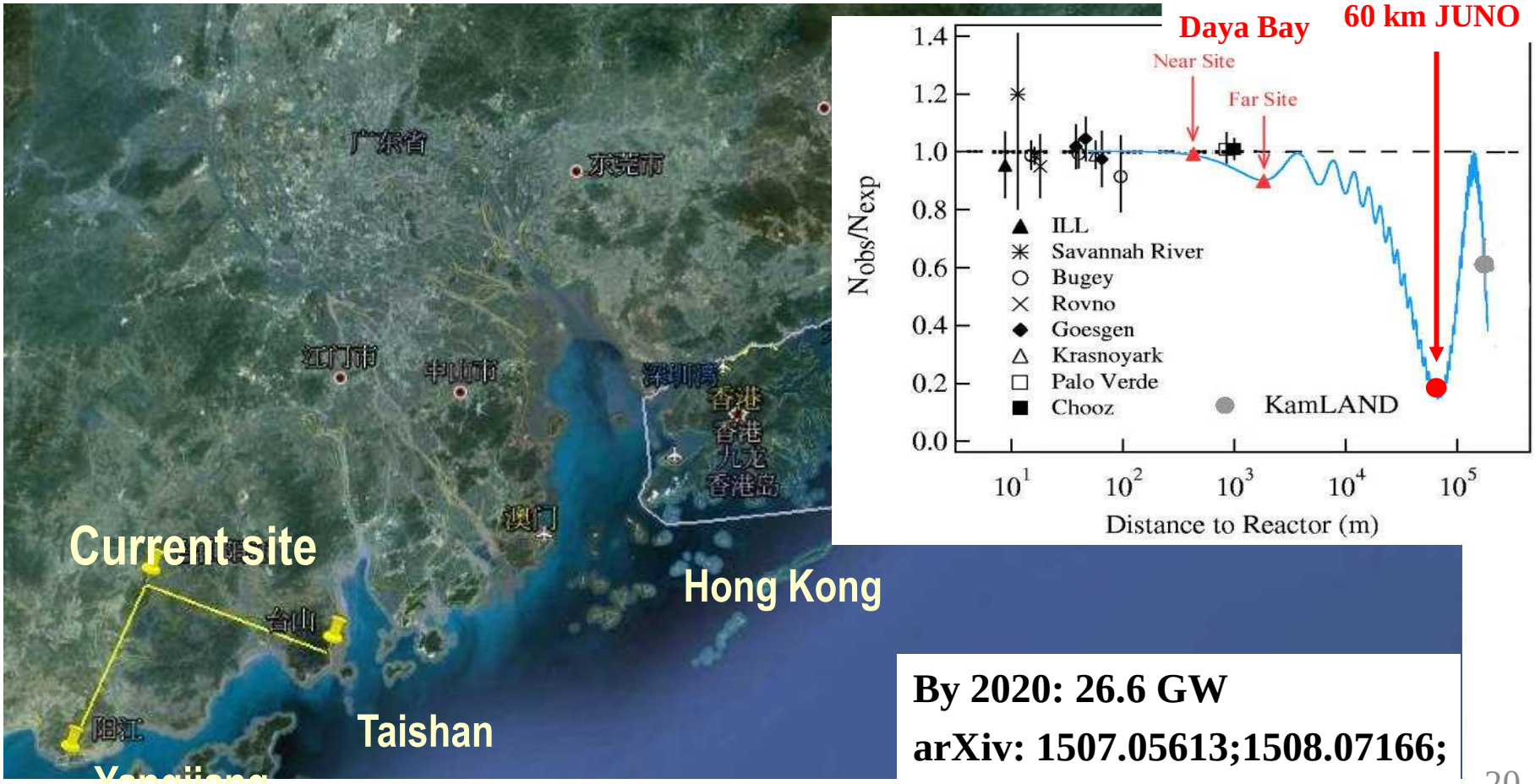



$\sin^2 2\theta_{13} = 0.084 \pm 0.005$
$|\Delta M^2_{ee}| = (2.42 \pm 0.11) \times 10^{-3}$ eV$^2$

arXiv: 1505.03456; 1603.03549

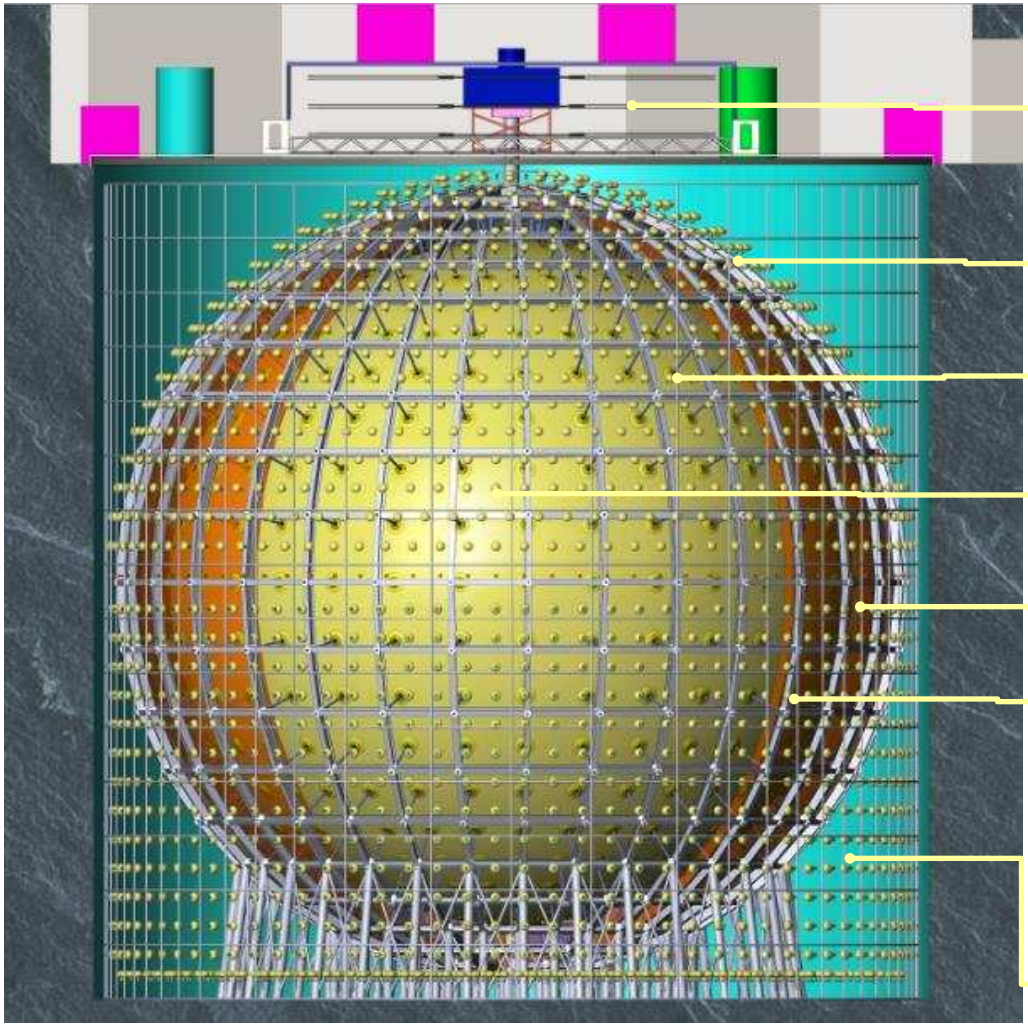
# JUNO

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



# Largest 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%)



Muon detector

Stainless Steel Structure

Φ35m Acrylic tank

20 kt LS($A_L$> 25 m)

40kt pure water($A_L$> 50 m)

~18000 20" PMTs, ~75% coverage; ~36000 3" PMTs; 3% coverage

2000 20" VETO PMTs

# Physics Reach

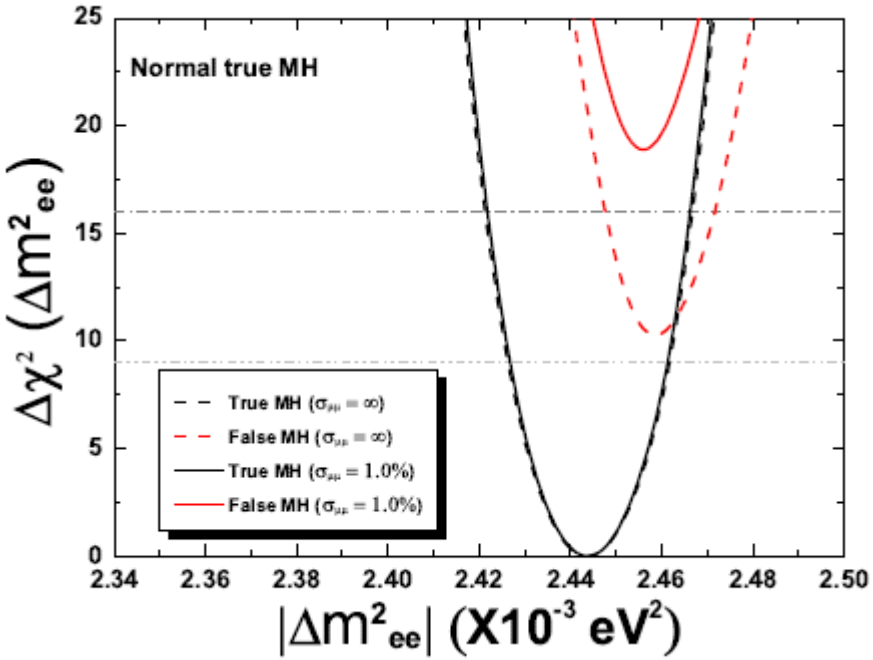
## Thanks to a large $\theta_{13}$

- **Mass hierarchy**
- Precision measurement of mixing parameters
- Supernova neutrinos
- Geoneutrinos
- Sterile neutrinos
- ……

| | Current | JUNO |
|---|---|---|
| $\Delta m^2_{12}$ | 4% | 0.6% |
| $\Delta m^2_{23}$ | 4% | 0.6% |
| $\sin^2\theta_{12}$ | 6% | 0.7% |
| $\sin^2\theta_{23}$ | 10% | N/A |
| $\sin^2\theta_{13}$ | 6% ➔ 4% | ~ 15% |

## MH sensitivity with 6 years' data:

| *Ref: Y.F Li et al, PRD 88, 013008 (2013)* | Relative Meas. | [a]Use absolute $\Delta m^2$ |
|---|---|---|
| Ideal case | 4σ | 5σ |
| [b]Realistic case | 3σ | 4σ |

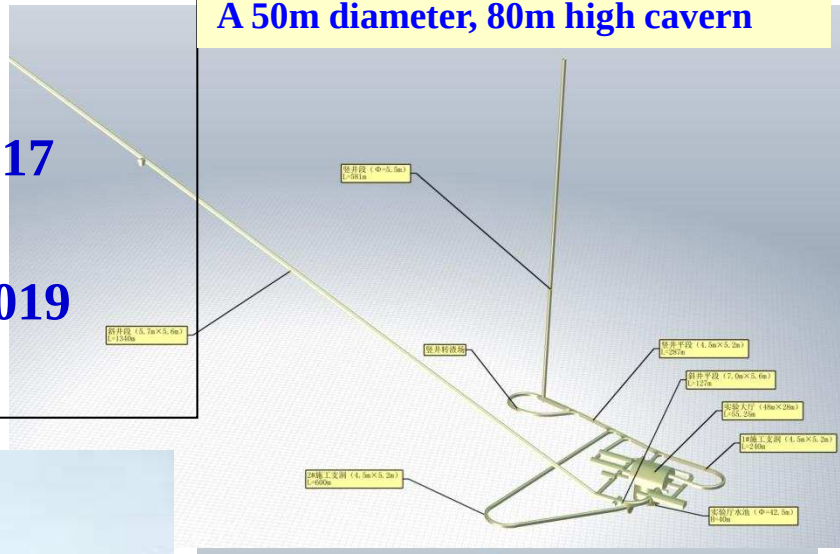


# Schedule & Current Status

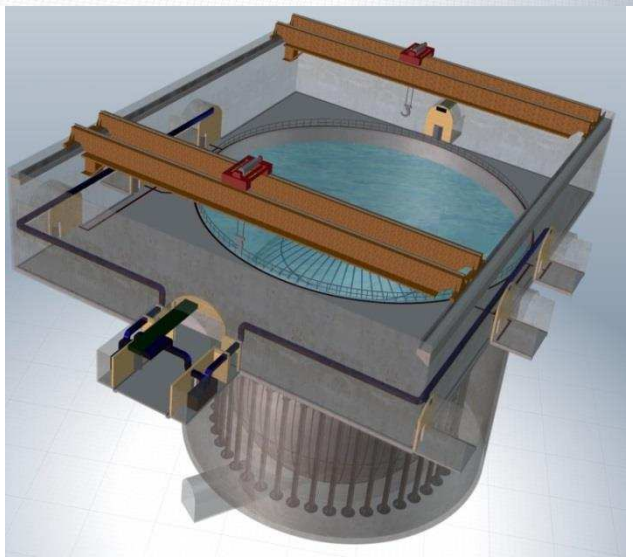
**Schedule:**

- 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

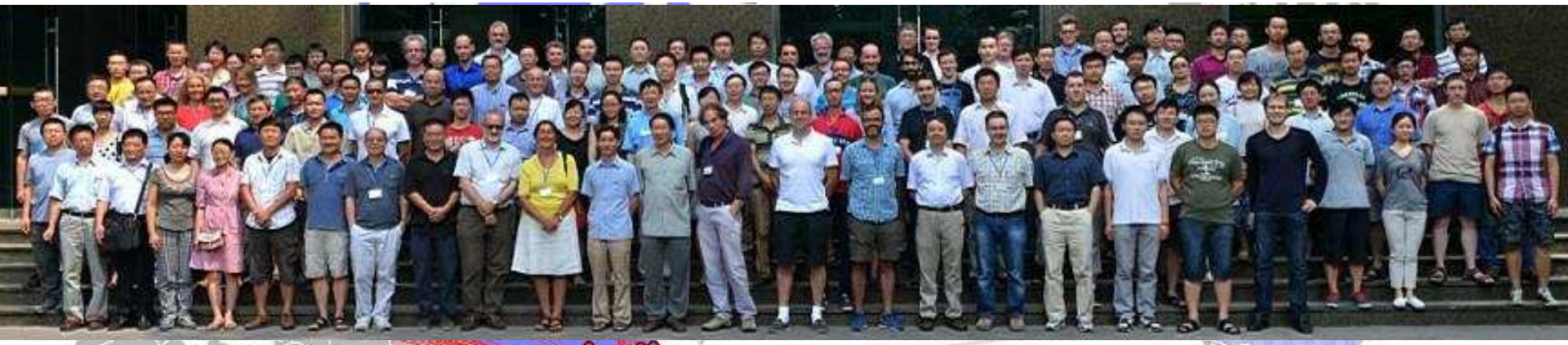
A 600m vertical shaft
A 1300m long tunnel(40% slope)
A 50m diameter, 80m high cavern



Grounding breaking on Jan. 10, 2015

# JUNO collaboration established



## Europe (27)

**Armenia(1)**
Yerevan Phys. Inst

**Belgium(1)**
ULB

**Czech(1)**
Charles U

**France(5)**
APC Paris
CPPM Marseille
IPHC Strasbourg
LLR Paris
Subatech Nantes

**Finland(1)**
U.Oulu

**Italy(8)**
INFN-Catania
INFN-Frascati
INFN-Ferrara
INFN-Milano
INFN-Mi-Bicocca
INFN-Padova
INFN-Perugia
INFN-Roma 3

**Germany(7)**
FZ Jülich
RWTH Aachen
TUM
U.Hamburg
IKP FZI Jülich
U.Mainz
U.Tuebingen

**Russia(3)**
INR Moscow
JINR
MSU

## America(4)

**US(2)**
UMD
UMD-Geo

**Chile(2)**
Catholic Univ. of Chile
BISEE

**Thailand(1)**
SUT

## Asia (31)

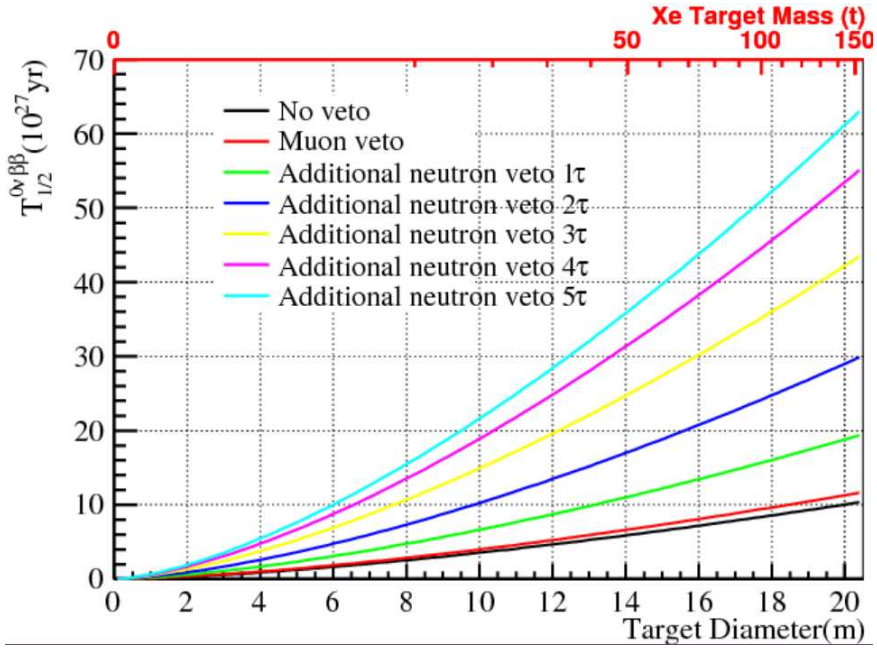
BJ Nor. U.
CAGS
Chongqing U.
CIAE
DGUT
ECUST
Guangxi U.
HIT
IHEP
Jilin U.
Ninan U.
Nanjing U.
Natl. Chiao-Tung U.
Natl. Taiwan U.
Natl. United U.
Nankai U.
NCEPU
Pekin U.
Shandong U.
Shanghai JT U.
Sichuan U.
SYSU
Tsinghua U.
UCAS
USTC
U. Of South China
Wuhan U.
Wuyi U.
Xi'an JT U.
Xiamen U.

# Future of JUNO ?

- Insert a Balloon into the JUNO detector, and fill the balloon with $^{136}$Xe-loaded LS
- Benefit from great experience of KamLAND-Zen
- Benefit from good energy resolution of JUNO
- Too shallow ? Cut active volume around the muon track

| | Isotopes | Mass(t) | $\langle m_\nu \rangle$,meV |
|---|---|---|---|
| nEXO | $^{136}$Xe | 5 | 10-50 |
| GERDA | $^{76}$Ge | 1 | 10-40 |
| Majorana | $^{76}$Ge | 1 | 10-40 |
| SNO+ | $^{130}$Te | 8 | 20-60 |
| KamLAND-Zen | $^{136}$Xe | 1 | 30-80 |
| JUNO-bb | $^{136}$Xe | 50 | 4-13 |

Very preliminary !




Muon tracking is important !

# Particle & Astro-Particle Physics at IHEP

| | | Current | Future |
|---|---|---|---|
| Accelerator-based | Precision frontier | BESIII | International: ILC<br>CEPC ➔ SppC |
| | | International projects: Belle II、PANDA、COMET | |
| | Energy frontier | CMS、ATLAS | |
| Non-accelerator-based | underground | Daya Bay | JUNO ➔ ββ decay |
| | | EXO | |
| | Surface | ARGO/ASγ | LHASSO |
| | | | Ali/BICEPx |
| | Space | AMS | HERD<br>XTP |
| | | HXMT | |