Status of the LHAASO Experiment

Zhiguo Yao
IHEP, Beijing

Vulcano Workshop, 20-26/05/2018

LHAASO

- Abbreviation of

  "**L**arge **H**igh **A**ltitude **A**ir **S**hower **O**bservatory".

- It is supported in China as one of the "National Major Science and Technology Infrastructure".

- Trivia:
  - It is supported on the last day of 2015 (last day of 12th five-year);
  - The project name in Chinese actually means "High Altitude Cosmic Ray Observatory";
  - And very probably, after the construction, it will be given another Chinese "nickname" for the public.
    - like "Wukong" for DUMPE, "Tianyan" for FAST, "Guoshoujing" for LAMOST, "Huiyan" for HXMT, "Zhangheng" for CSES.

Primary Goals

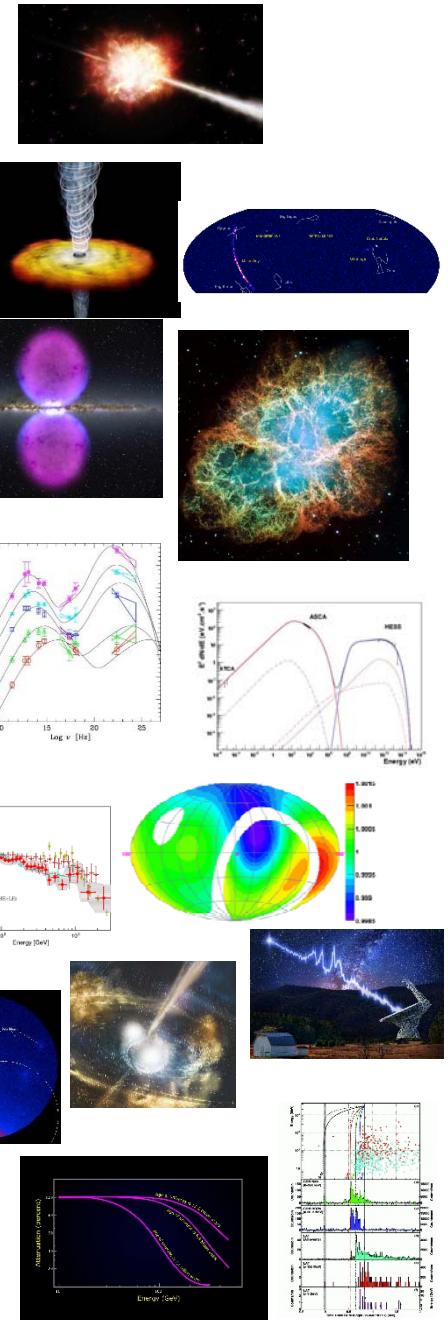
- Complimentary to IACTs, survey the sky for detecting & monitoring VHE gamma ray sources:
  - with not so-bad sensitivity (~10% of cotemporary IACTs);
  - sources can be stable, variable, transient, extended, diffused, ...
  - a successor to Tibet ASγ and ARGO-YBJ experiments in China.

- Better sensitivity above 100 TeV:
  - to challenge the mystery of origin of cosmic rays.

- Precisely measure UHE cosmic ray components & spectra:
  - with hybrid detector design;
  - and with the high altitude privileges.

Physics

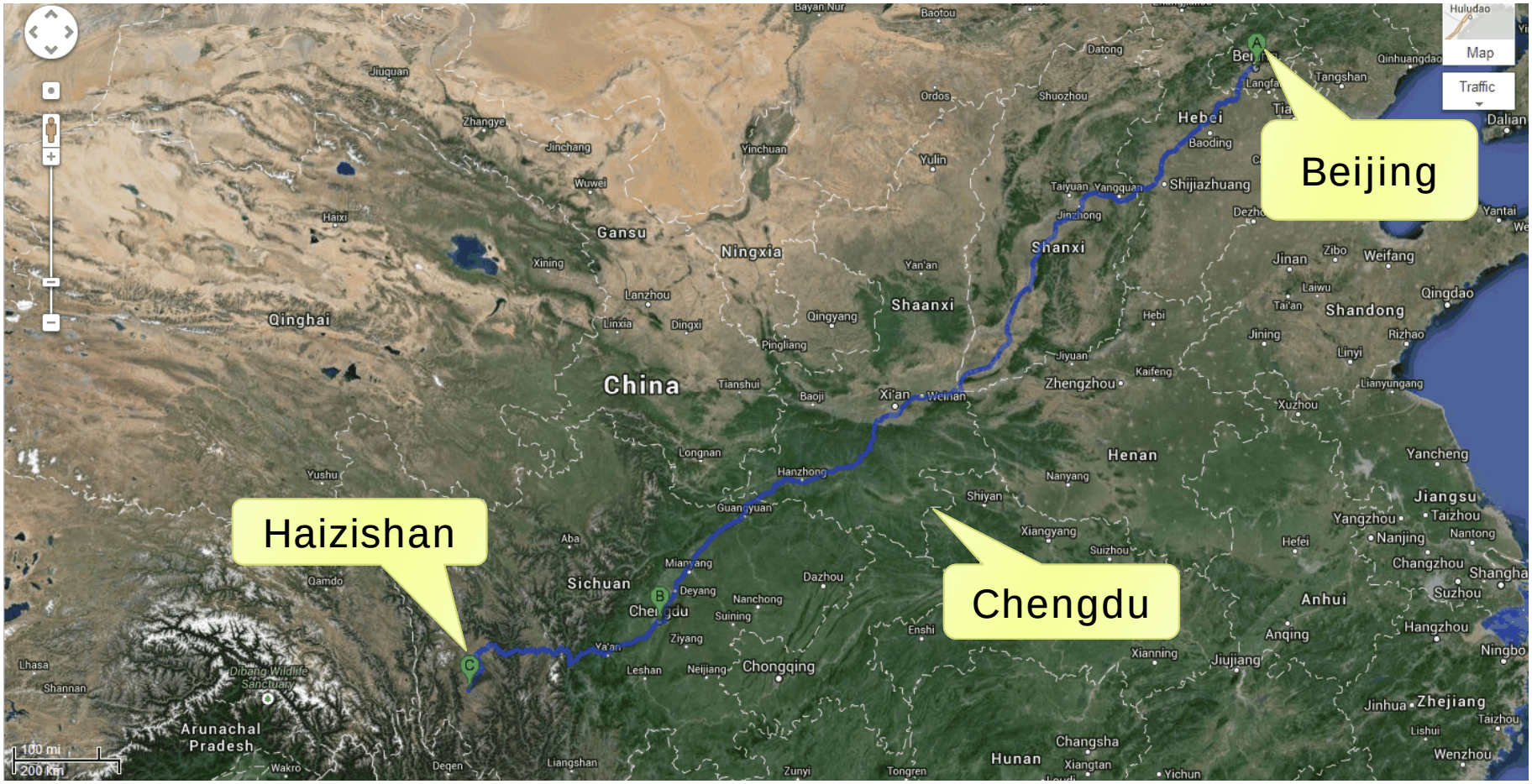
- VHE gamma sky survey & Monitor (100 GeV-1 PeV):
  - Galactic sources;
  - Extragalactic sources & flares;
  - VHE emission from GRBs;
  - Diffused Gamma rays.
- Gamma ray spectrum measurement:
  - Mechanisms of the acceleration, escape and transport;
  - Origin of cosmic rays – 100 years' mystery.
- Cosmic rays (10 TeV-10 PeV):
  - Components and spectrums;
  - Anisotropy of VHE cosmic rays.
- Miscellaneous:
  - Dark matter;
  - Counterparts of neutrinos, GWs, FRBs, …
  - Sun storm & IMF;
  - Particle physics;
  - …



LHAASO Site


RUSSIA
KAZAKHSTAN
MONGOLIA
Harbin
Ürümqi
KYRGYZSTAN
Shenyang
Qinhuangdao
N.KOREA
CHINA
BEIJING
Tianjin
Dalian
S.KOREA
Qingdao
Lanzhou
Zhengzhou
Yellow Sea
Xi'an
Nanjing
Shanghai
Chengdu
Wuhan
Shigatse
Lhasa
NEPAL
Chongqing
Yangtze
Ningbo
East China Sea
LHAASO
BHUTAN
Taipei
BANGLA-DESH
Guangzhou
INDIA
Macau
Hong Kong
BURMA
VIETNAM
PACIFIC OCEAN
Bay of Bengal
LAOS
THAILAND
Hainan Dao

Location: Haizishan (“Lakes Mountain”)



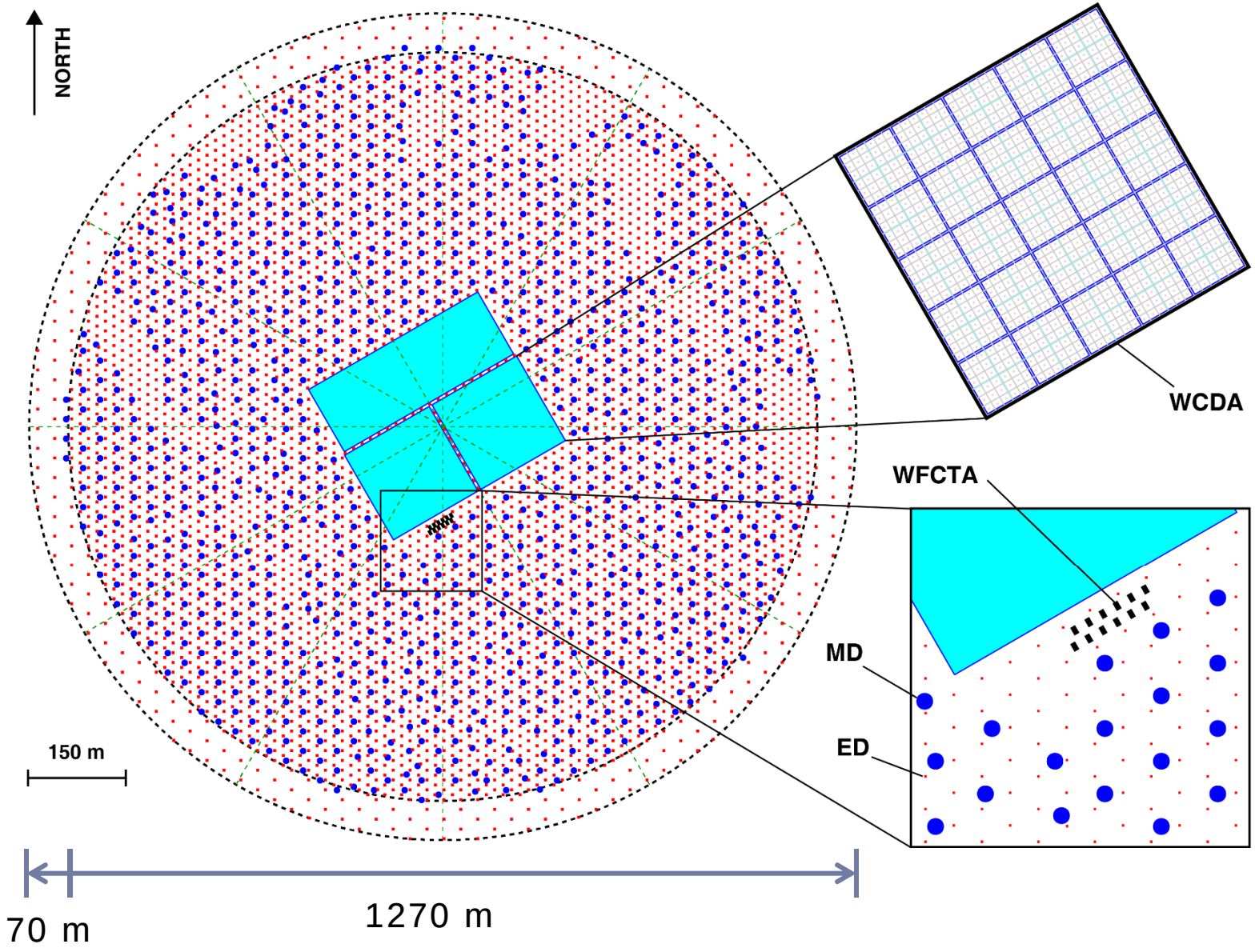
- Location: 29°21’27.6”N, 100°08’19.7”E, 4400 m a.s.l;
- 8 km to Daocheng-Yading Airport (4411 m a.s.l.);
- 50 km to Daocheng City, Sichuan Province.

Detector Components

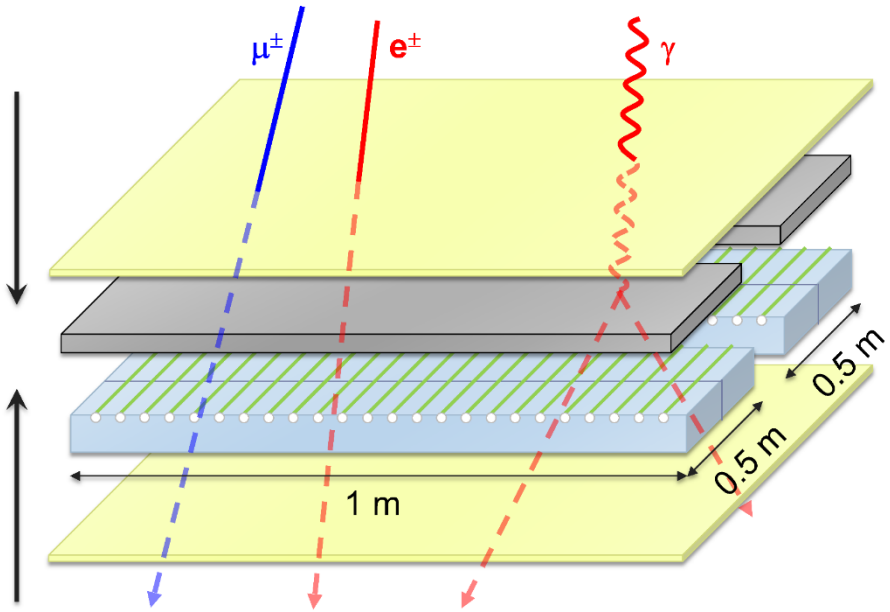
- **EDA** – **E**lectron (**E**lectromagnetic particle) **D**etector **A**rray
  - 5195 cassettes
  - Each with effective area 1 m^2
  - Plastic scintillator + wavelength shift fibers
- **MDA** - **M**uon **D**etector **A**rray
  - 1171 tanks
  - Each with effective area 36 m^2
  - Water Cherenkov
- **WCDA** - Water **C**herenkov **D**etector **A**rray
  - 3120 cells
  - Each with effective area 25 m^2
  - Water Cherenkov
- **WFCTA** - **W**ide **F**ield-of-view **C**herenkov **T**elescope **A**rray
  - 18 telescopes
  - Each (the mirror) with effective area 5 m^2
  - Air Cherenkov (+ Air fluorescence)

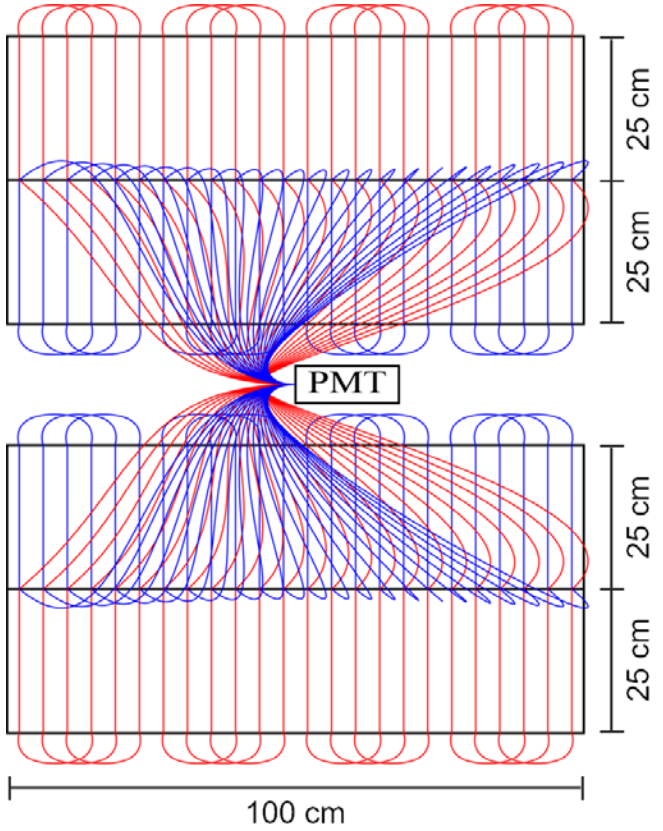
KM2A

Layout of LHAASO Detectors



ED

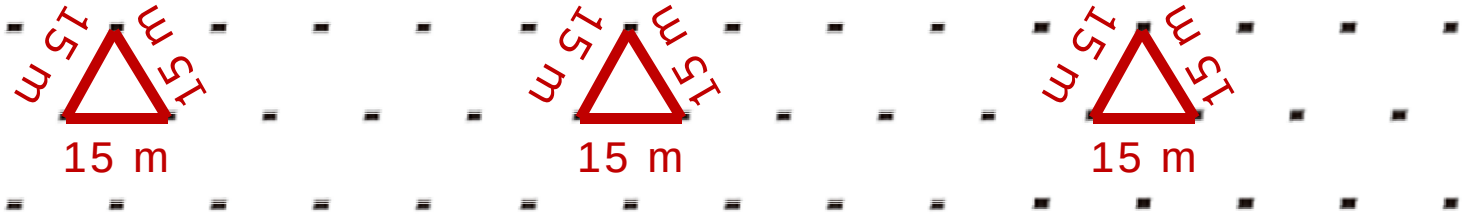




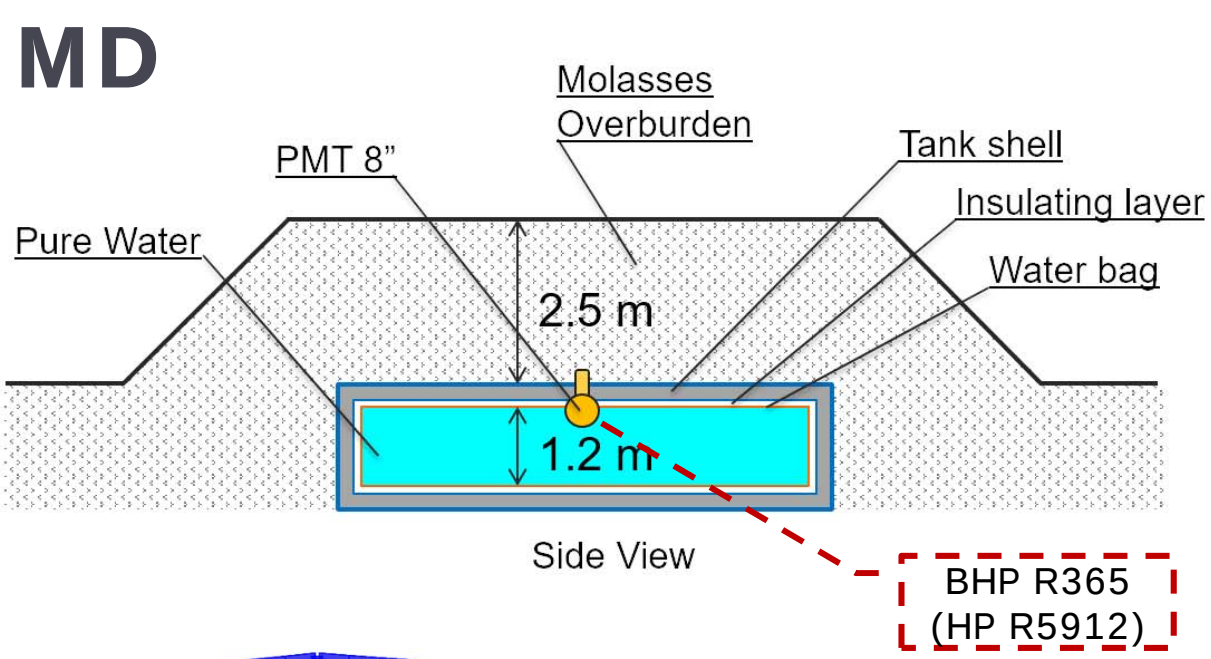
- Scintillator (SGC BC408): 1 cm thickness, 4 tiles (1 m × 0.25 m)
- 24 fibers (SGC BCF92) for each tile
- One 1.5-in PMT (HZC XP3960)
- Lead: 0.5 cm
- Iron case: 0.1 cm
- Electronics (IHEP) & power supply: in the case

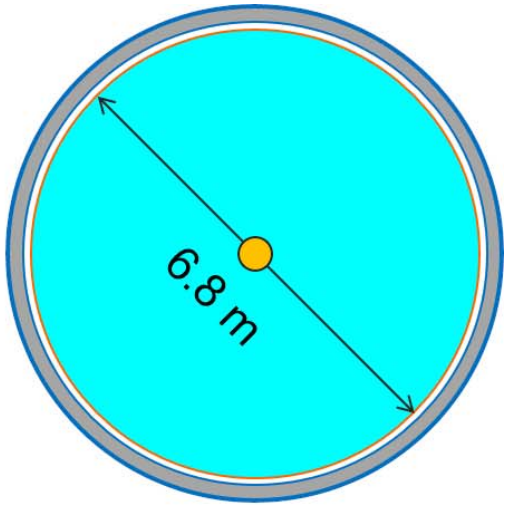
EDA Specifications

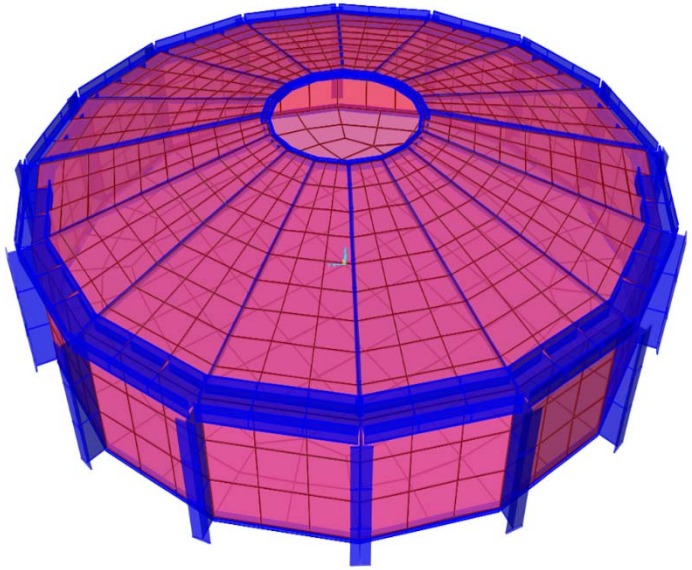
Item	Value
Effective area	1 m^2
Thickness of tiles	1 cm
Number of WLS fibers	24/tile×4 tile
Detection efficiency (> 5 MeV)	>95%
Dynamic range	1-10,000 particles
Time resolution	<2 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	<20% (over 10 years)
Spacing	15 m
Total number of detectors	5195

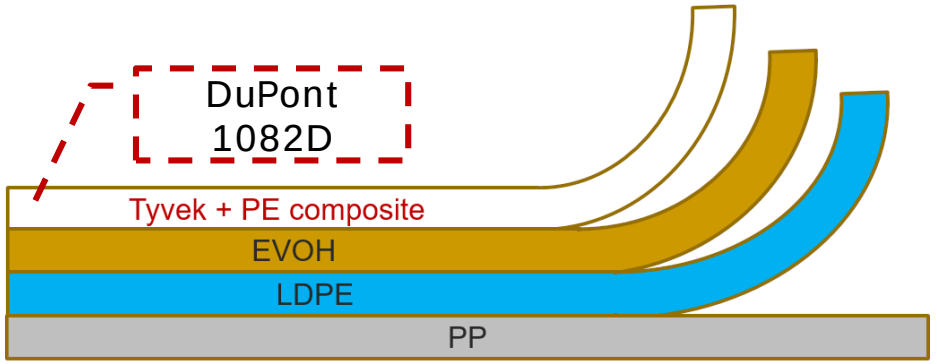


MD


Molasses
Overburden
PMT 8”
Tank shell
Insulating layer
Pure Water
Water bag
2.5 m
1.2 m
Side View
BHP R365
(HP R5912)

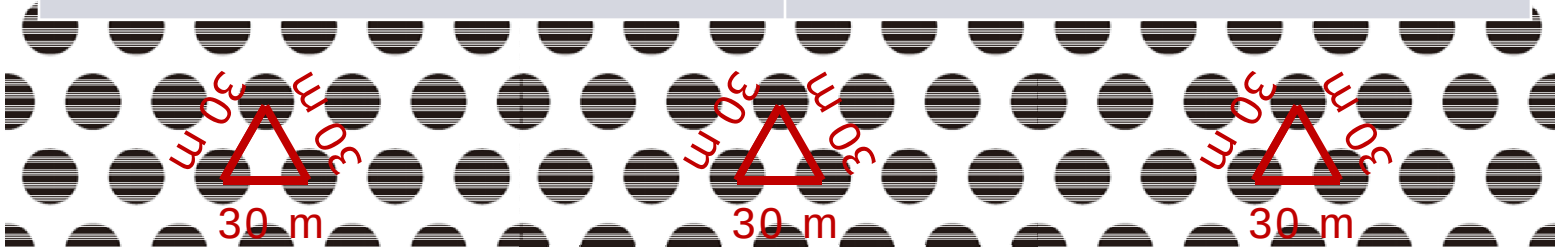

6.8 m
Top view



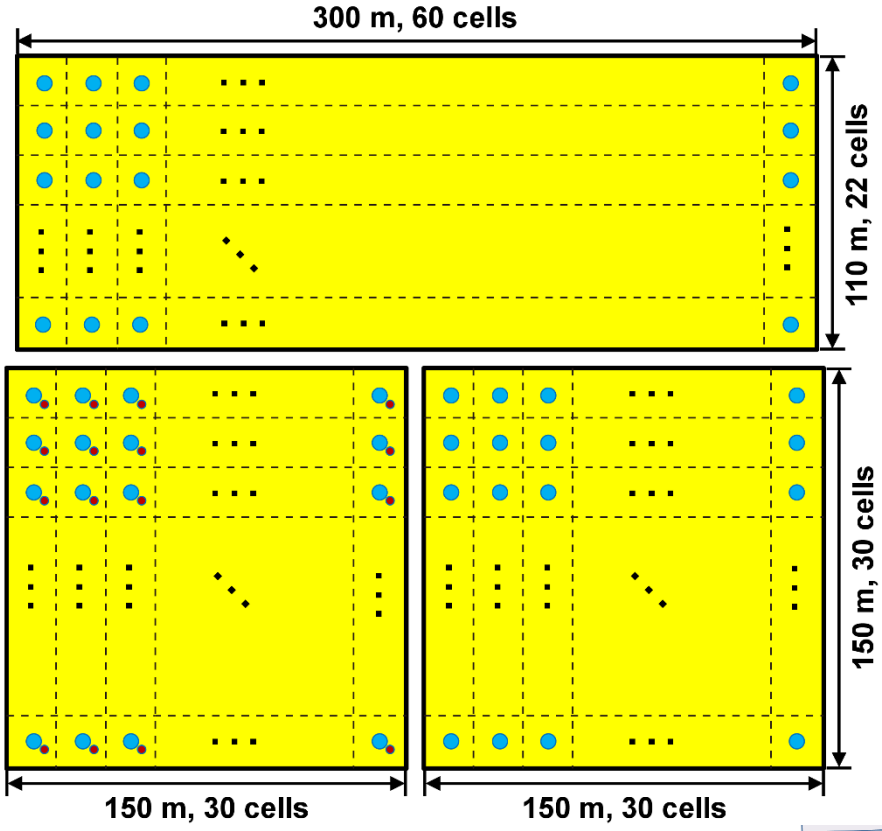

DuPont
1082D
Tyvek + PE composite
EVOH
LDPE
PP

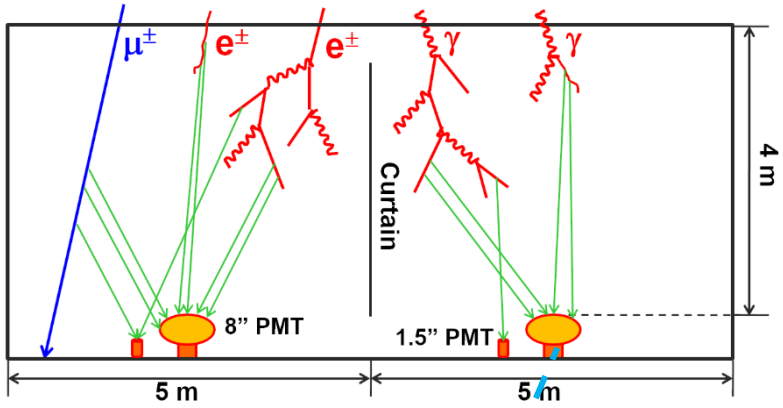
MDA Specifications

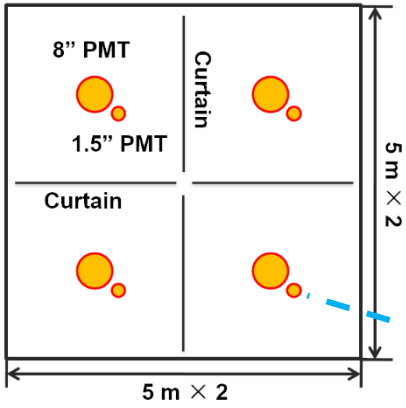
Item	Value
Area	36 m^2
Depth	1.2 m
Molasses overburden	2.5 m
Water transparency (att. len.)	> 30 m (400 nm)
Reflection coefficient	>95%
Time resolution	<10 ns
Dynamic range	1 – 10,000 particles
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Lifetime	>20 years
Spacing	30 m
Total number of detectors	1171



WCD



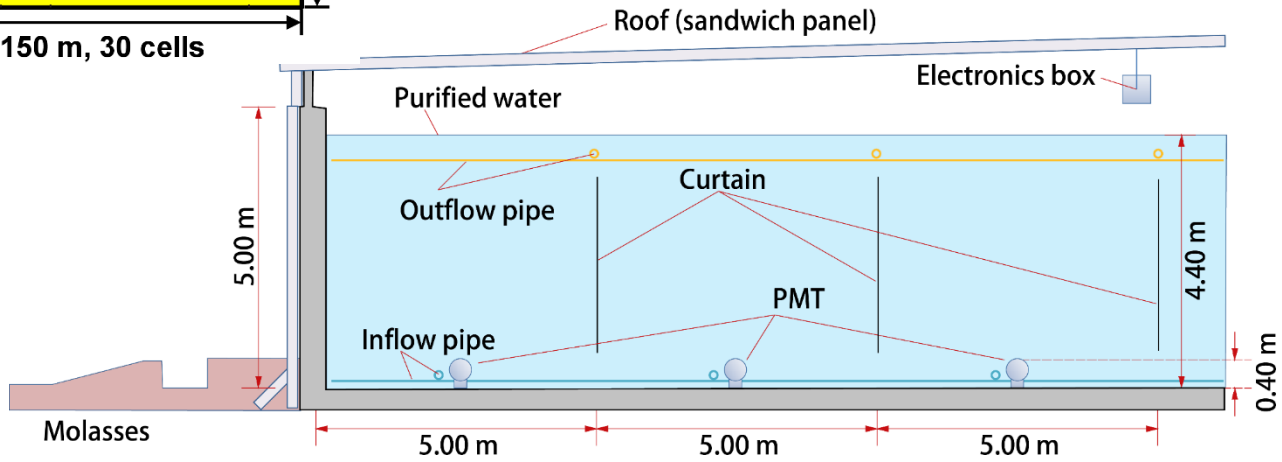




BHP R365
(HP R5912)

HZC XP3960

Electronics:
USTC + SCU

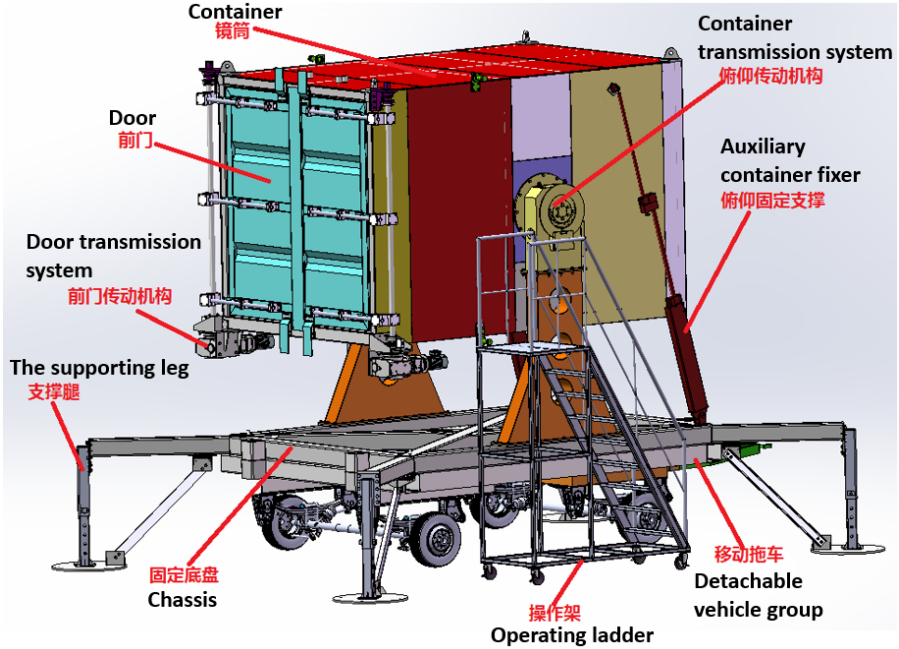


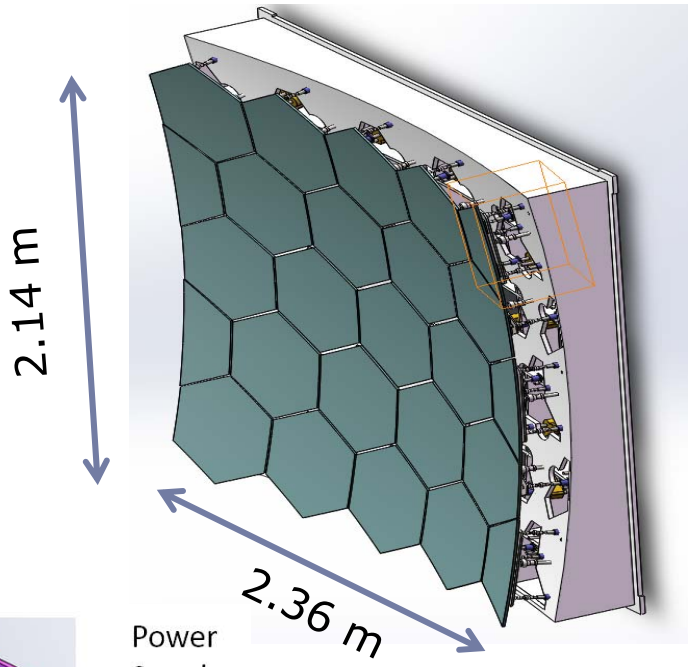
WCDA Specifications

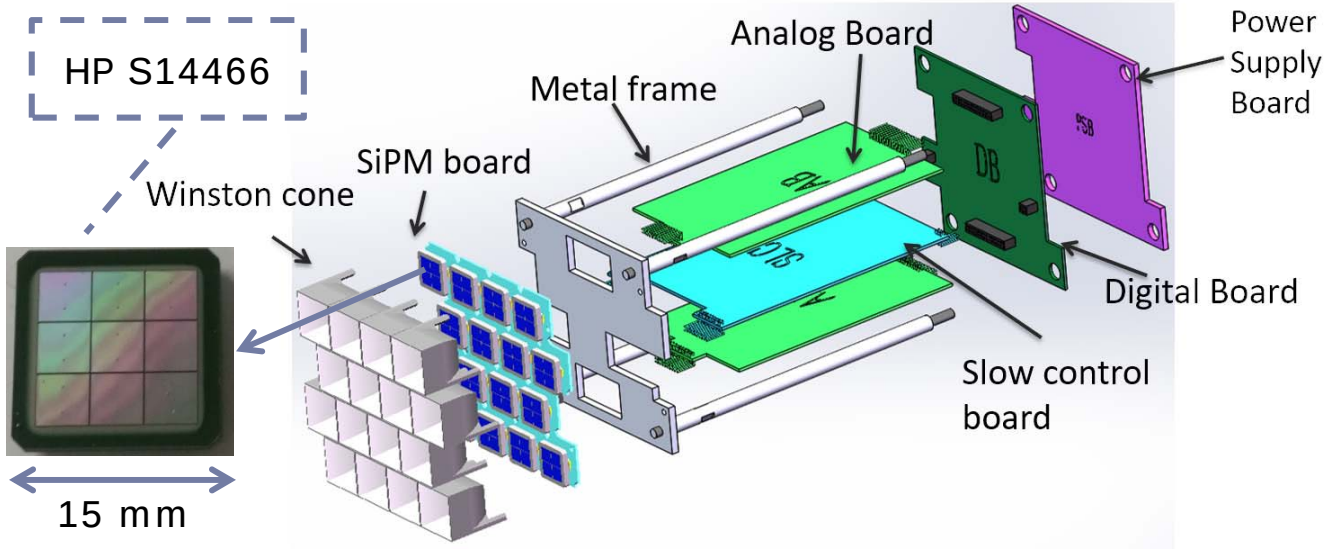
Item	Value
Cell area	25 m^2
Effective water depth	4 m
Water transparency	> 20 m (400 nm)
Precision of time measurement	0.5 ns
Dynamic range	1-4000 PEs
Time resolution	<2 ns
Charge resolution	40% @ 1 PE 5% @ 4000 PEs
Accuracy of charge calibration	<2%
Accuracy of time calibration	<0.2 ns
Total area	78,000 m^2
Total cells	3120

WFCT

Hexagonal mirror side length: 219.1 mm
Curvature radius: 5800 mm
Focal length: 2780 mm







1/64 (a sub-cluster) of the camera

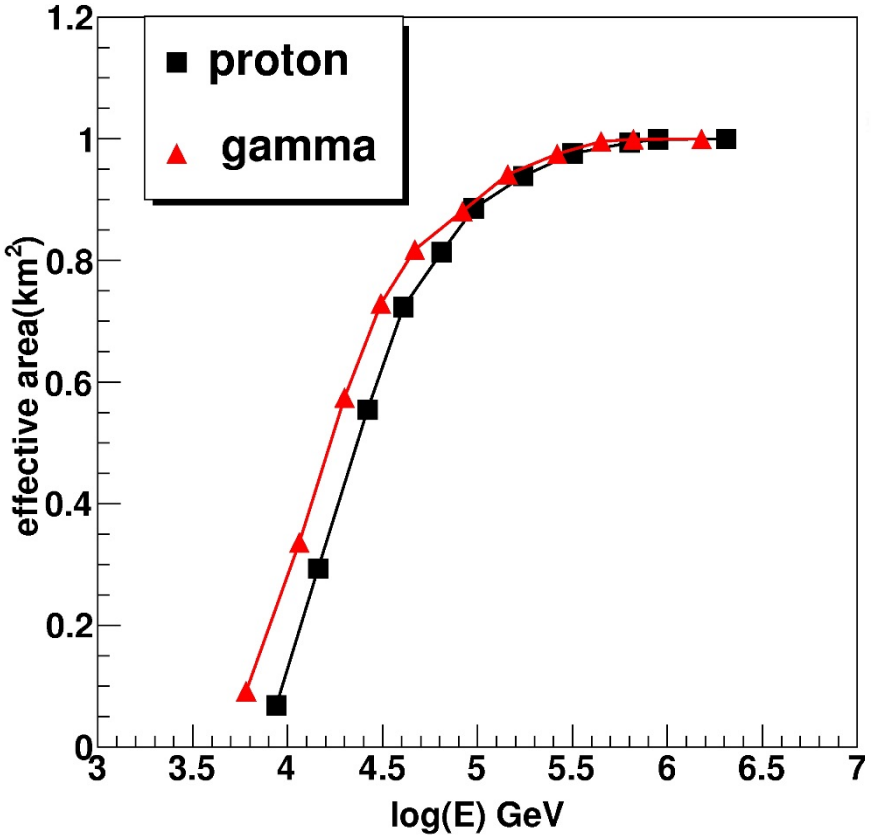
Electronics: SCU

WFCTA Specifications

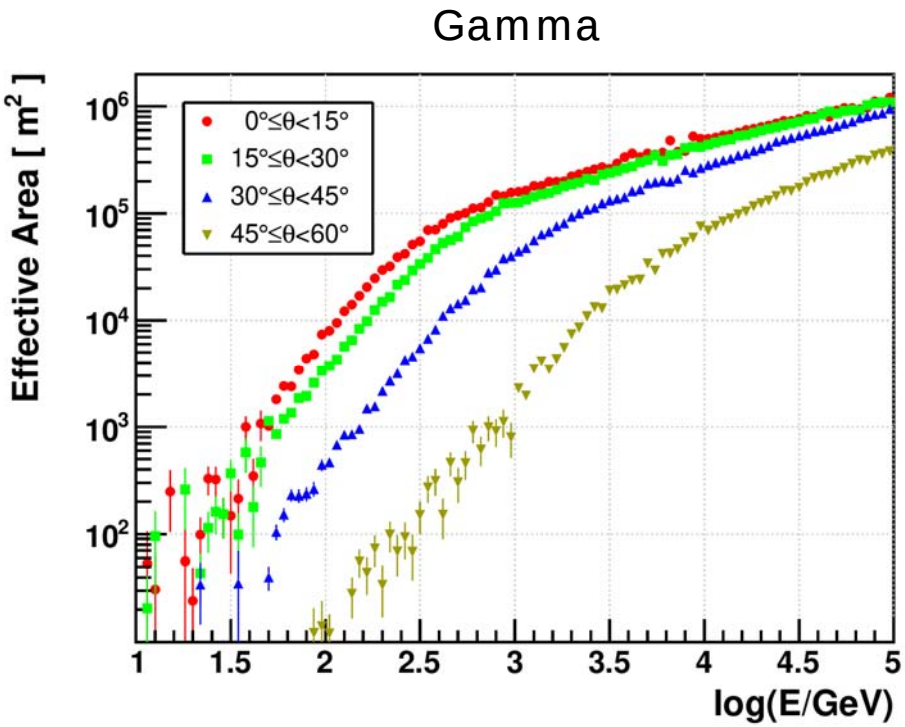
Item	Value
Mirror size	5 m^2 / telescope
Pixel size	0.5°
Number of Pixels	1024 / telescope
FOV / telescope	14°×16° / telescope
Dynamic range	10-32000 PE / pixel (<10% nonlinearity)
Photo detection efficiency	>28%@400 nm, >22%@350 nm, >17%@310 nm
Time resolution	<10 ns
Charge resolution	<50%@10 PE <5%@>1000 PE
Accuracy of charge calibration	<8%
Pointing accuracy	<0.1°
Number of telescopes	16 (18)

Effective Area

Note: Most of the plots are quite old.
Not updated yet since 2014.

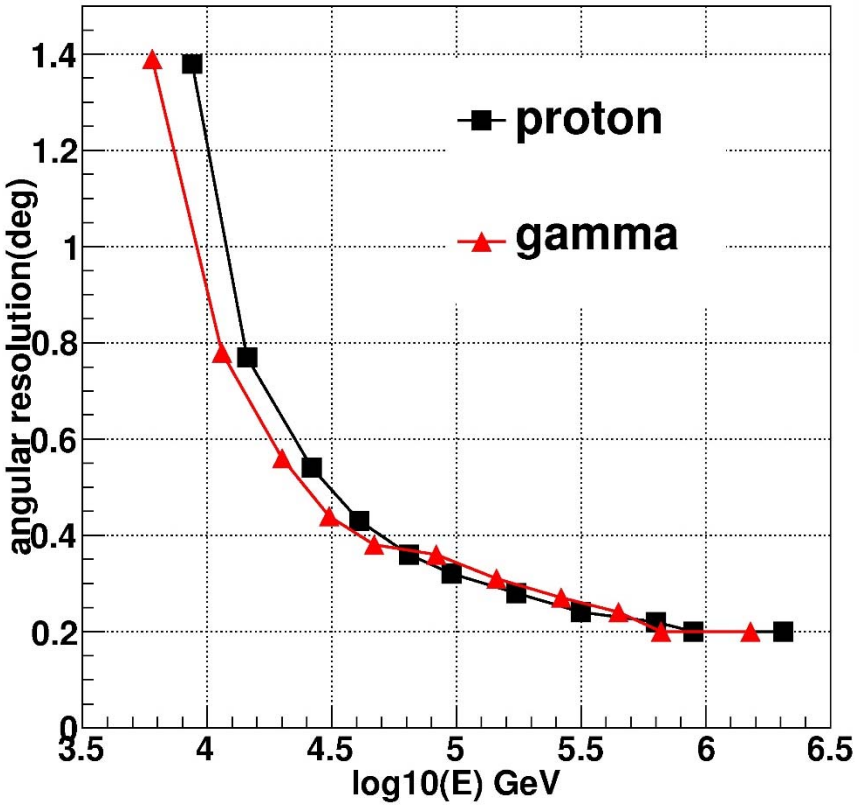


KM2A

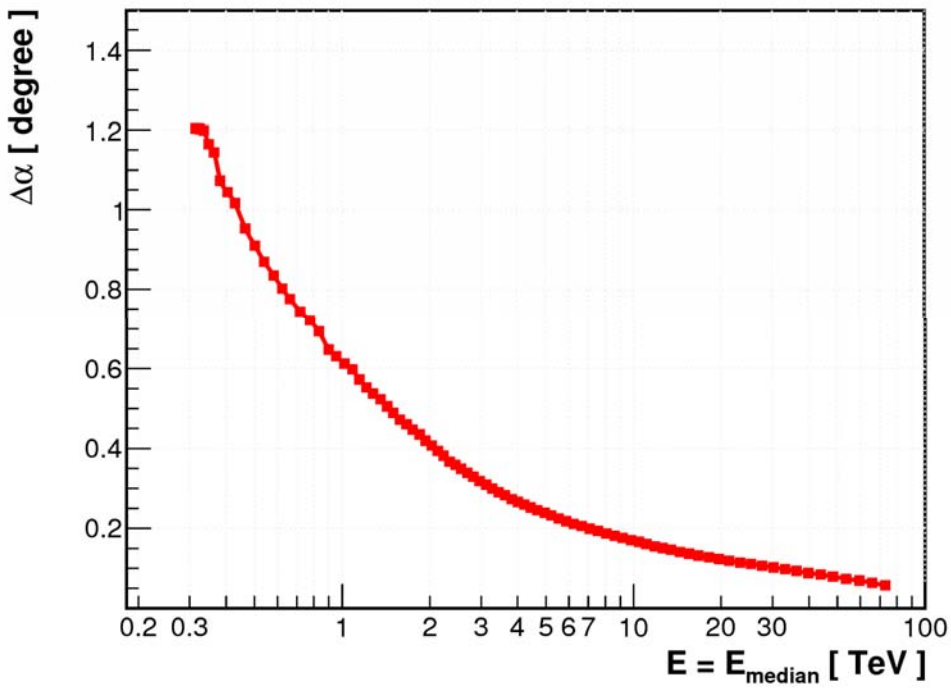


WCDA

Angular Resolution

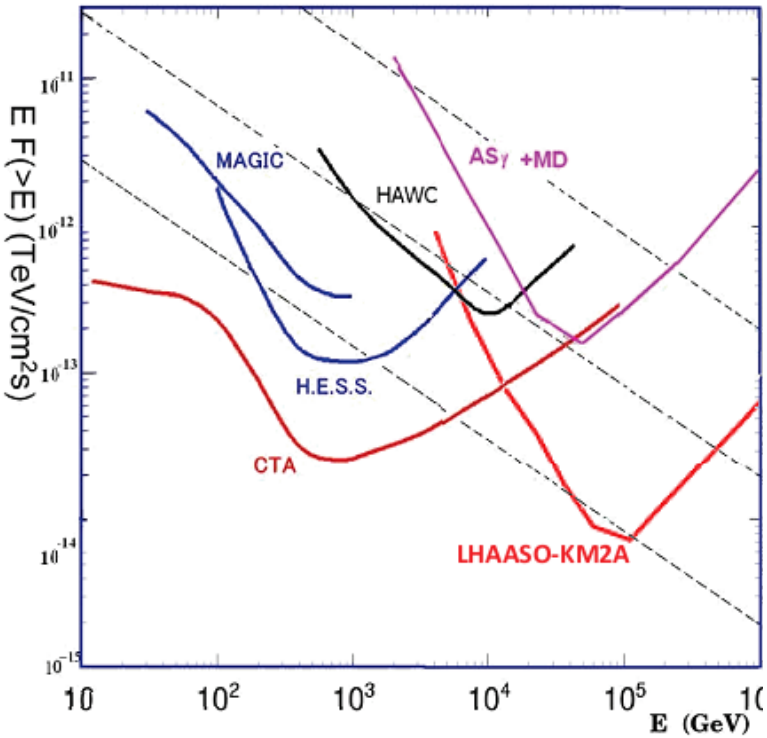


KM2A

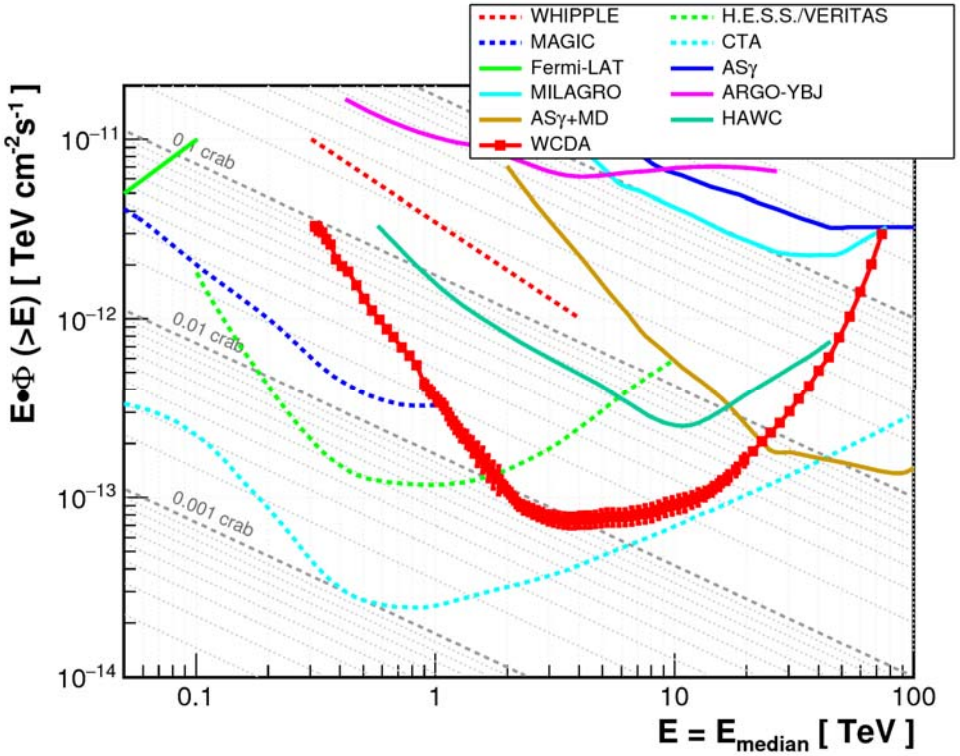


WCDA

Integral Sensitivity

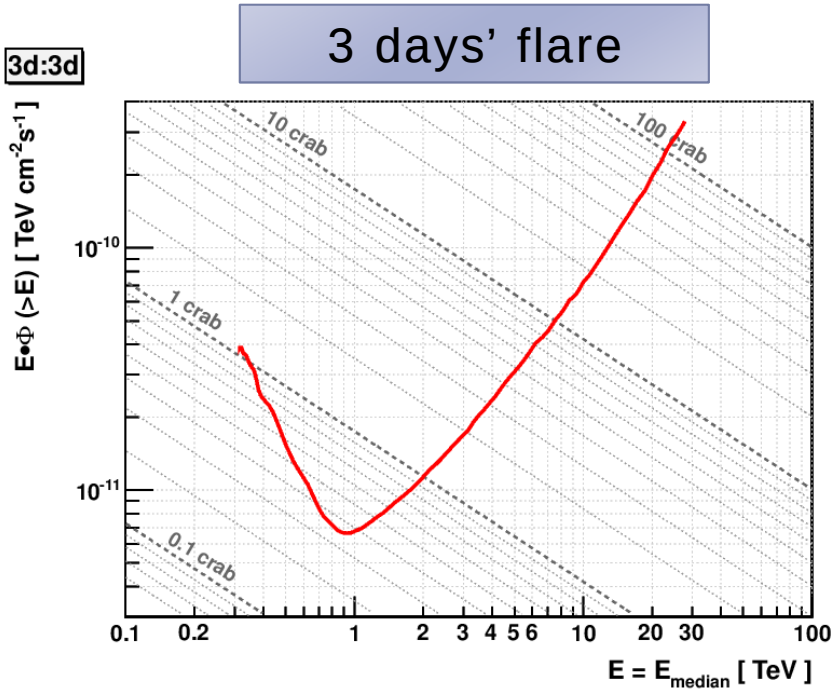


KM2A



WCDA

Sensitivity to Flares - WCDA



- Requirements & assumptions:
  - 30 events;
  - 5 s.d.;
  - Crab location & spectrum.
- Values for short time: limited by statistics (large area or low energy threshold is crucial)!

Duration	Sensitivity (Crab)
1 year	0.0066
6 months	0.0094
3 months	0.013
1 month	0.039
10 days	0.10
3 days	0.36
1 day	1.0
2 hours	3.5
1 hour	5.4
30 minutes	13
10 minutes	67
3 minutes	410
1 minute	2100

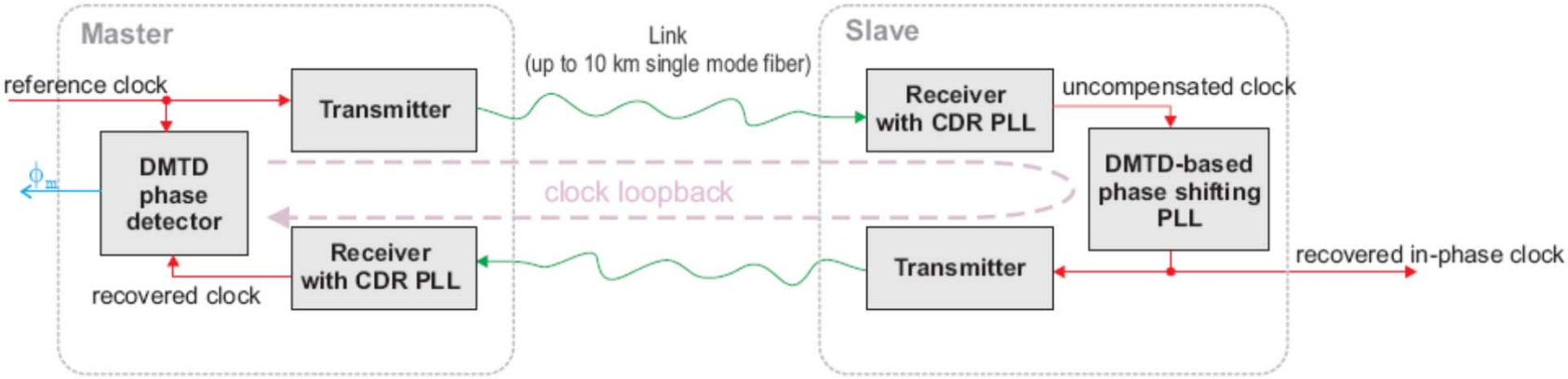
Supplementary Systems

- Time distribution & synchronization
- DAQ
- Slow control
- Data storage & processing
- Offline software framework

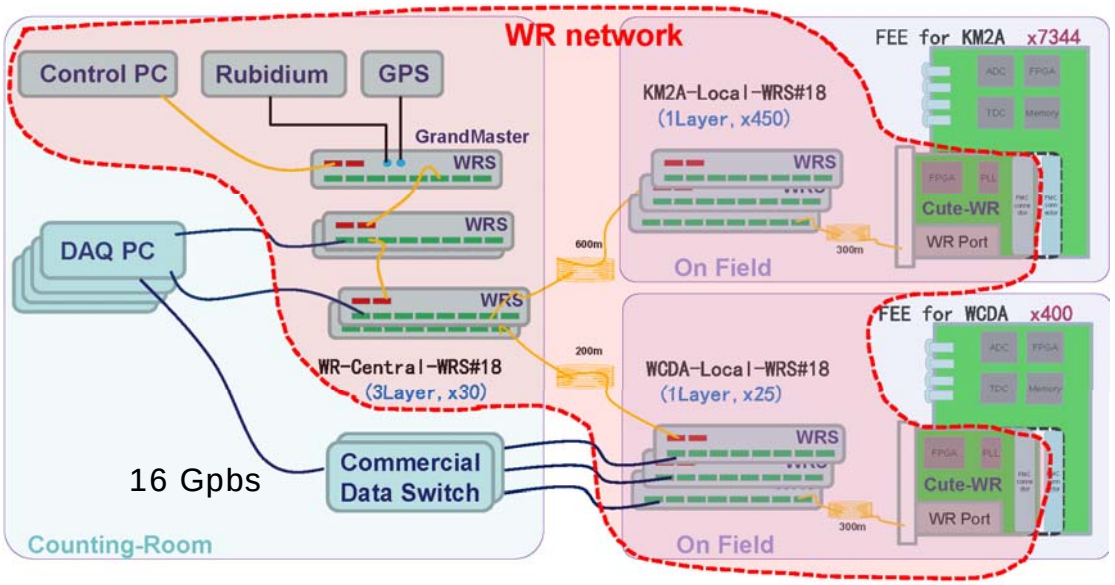
- Water supply
  - for MDA (purified water) & WCDA (cleaned water, circulating during operation).
- Electricity supply
  - Cables run to every detector.

- Civil construction
  - field, road, building, electricity power, ...

Time Distribution & Synchronization

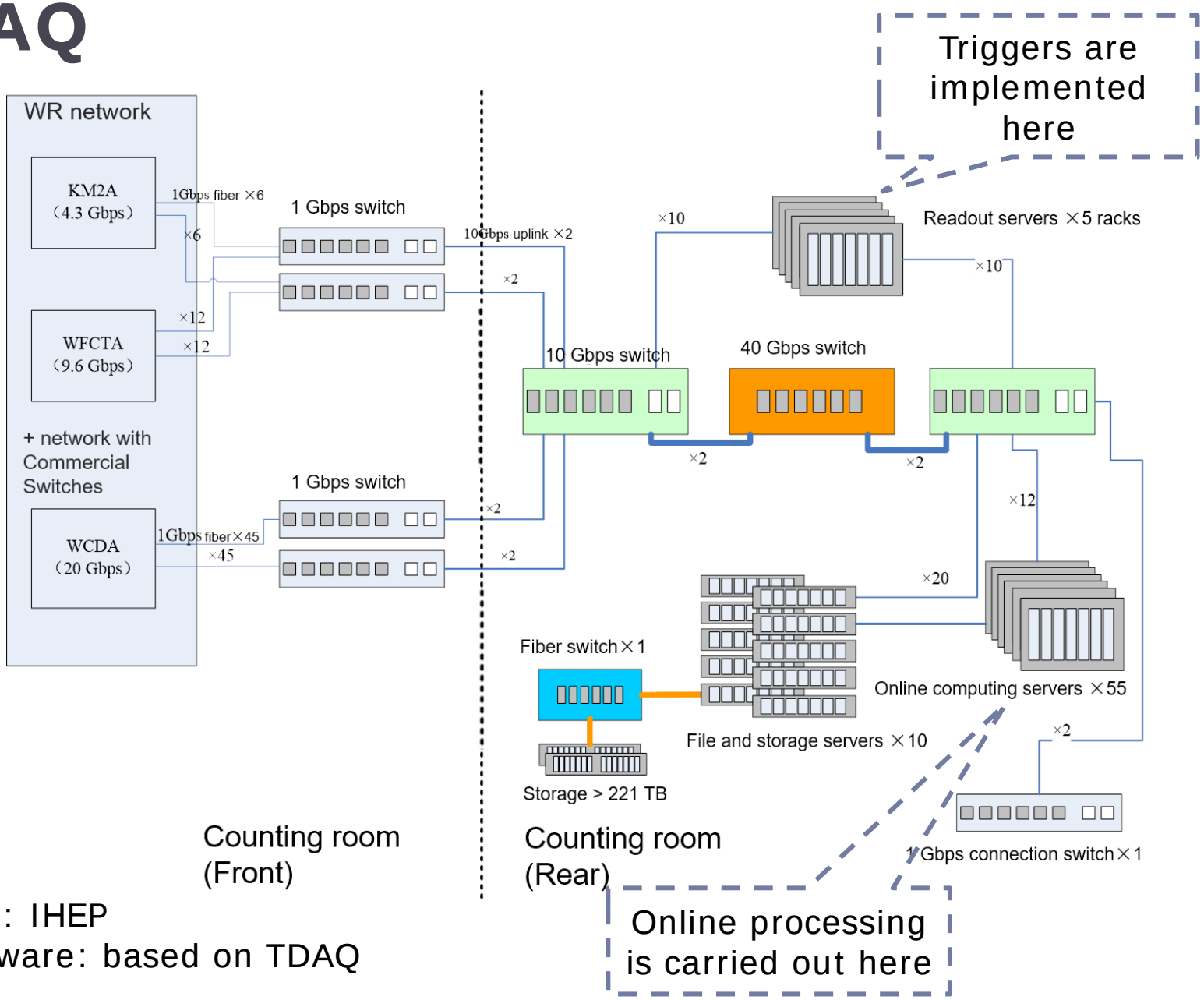


- **White Rabbit PTP:** switches and fiber connections employed for clock distribution and data transferring.
- Precise synchronization (<0.3 ns) for all FEEs in the distance of at least >1 km;
- Every hit can be tagged with the absolute time.



WR switch + WR CUTEDP: U. Tsinghua

DAQ

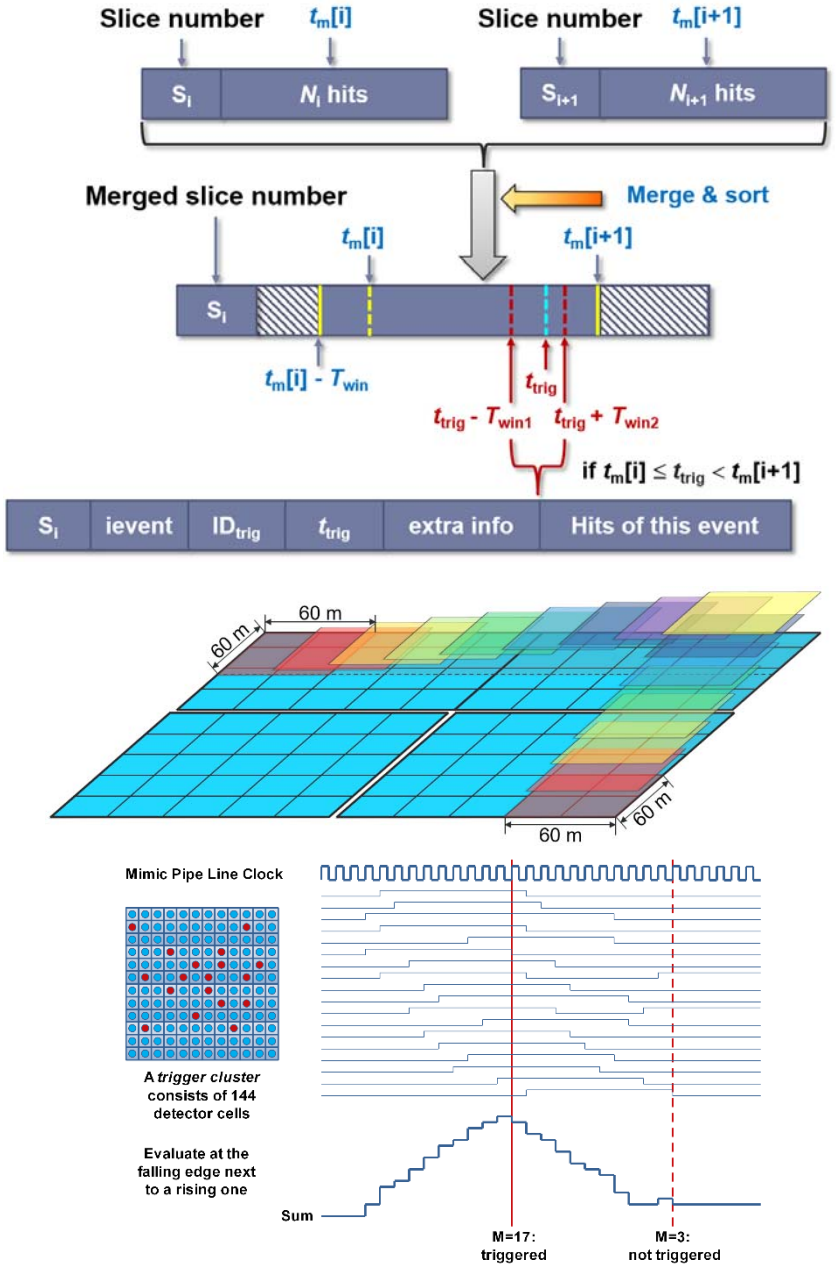


DAQ: IHEP

Software: based on TDAQ

Soft Trigger

- Implemented on a computing cluster:
  - Soft trigger.
- Basic triggers:
  - KM2A (EDA + MDA), WCDA and WFCTA (own has hardware trigger), independently;
  - 3 parallel data streams;
  - for every stream, other detector hits in a time window are collected and stored.
- Special triggers & streams:
  - Histograms;
  - Calibration;
  - Specially collected physics goals.

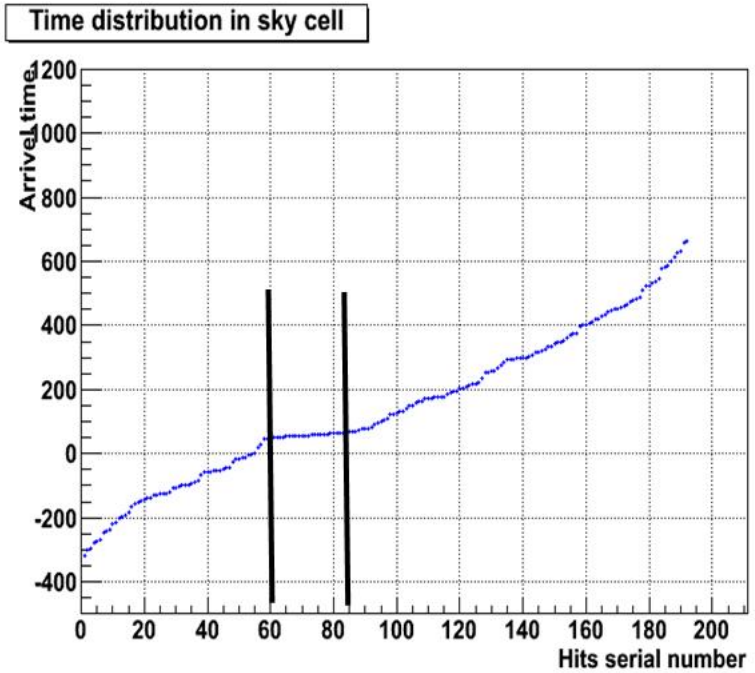


Trigger logic of WCDA

Triggerless Scheme

- All single counting signals are recorded (with precision lost):
  - charge: 3 bits
  - time: 15 bits
  - WCDA only: 1/7 original data size.
- Cached in site for up to 2 weeks:
  - Storing at the site temporarily, no bandwidth for transferring the data.
- For follow-up observations at very low energy threshold:
  - AGNs, GRBs, and counterparts for neutrino, GW, FRB, etc.

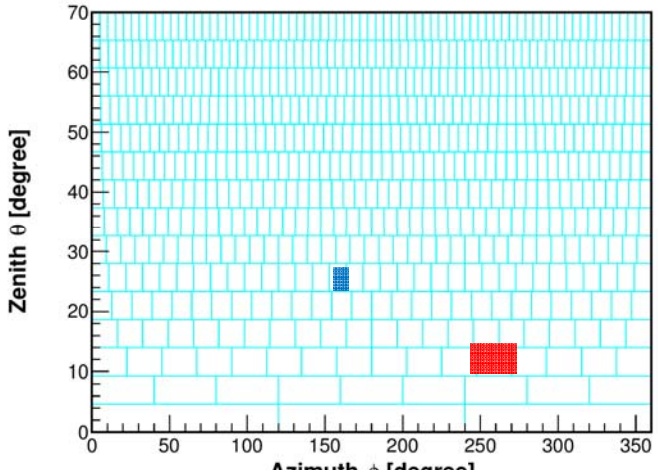
Analyses can be carried out as, for example …

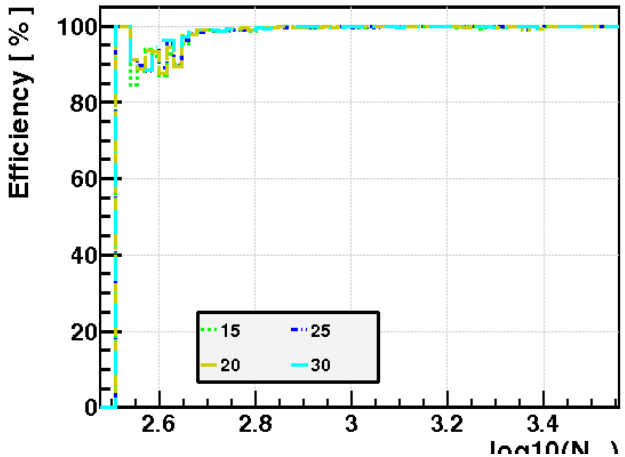


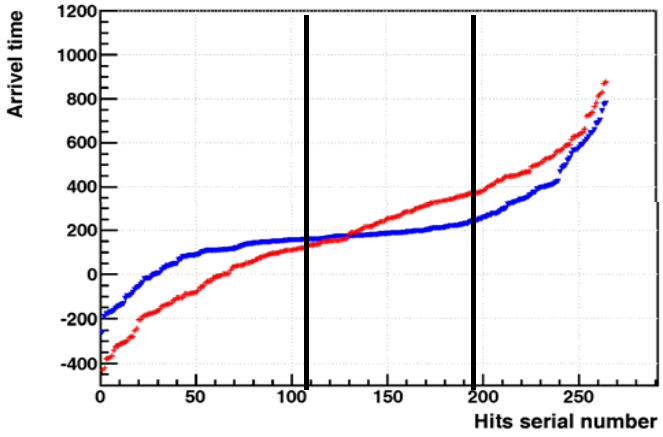
A simulated shower (50 GeV gamma).

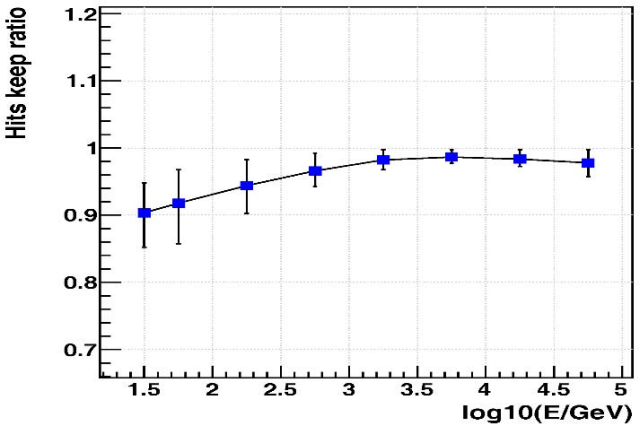
Online Processing

Filtering of background noise for WCDA (~31 kHz/PMT)









Raw data
1.5 Gpbs

Triggered
3.0 Gpbs

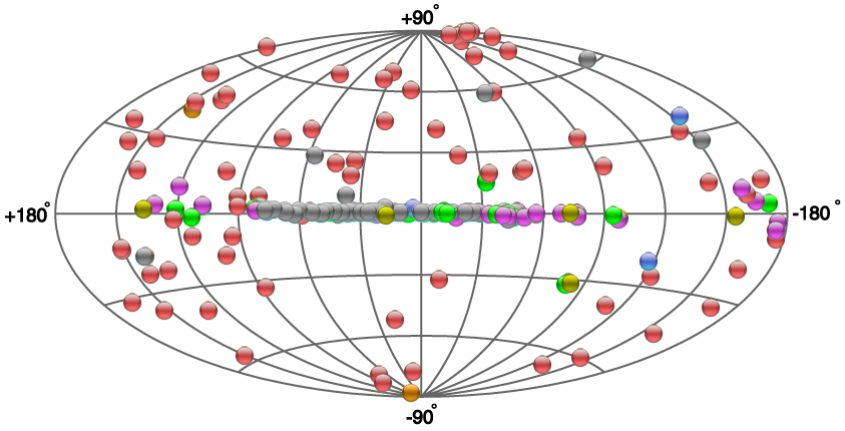
Online filtered
0.8 Gpbs

Compressed
0.4 Gpbs

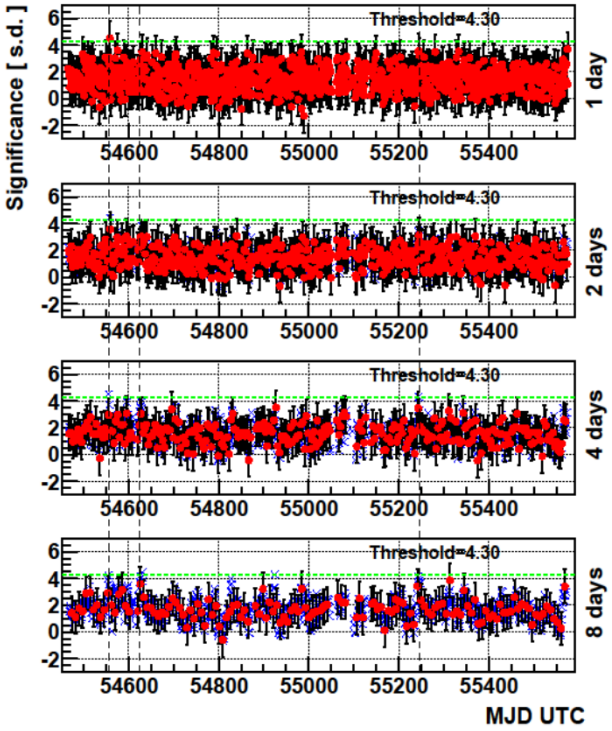
~90% single counting noises can be filtered out

Online Processing

- Real time monitoring & alerting of handful of candidate sources (as what we have done for ARGO-YBJ)

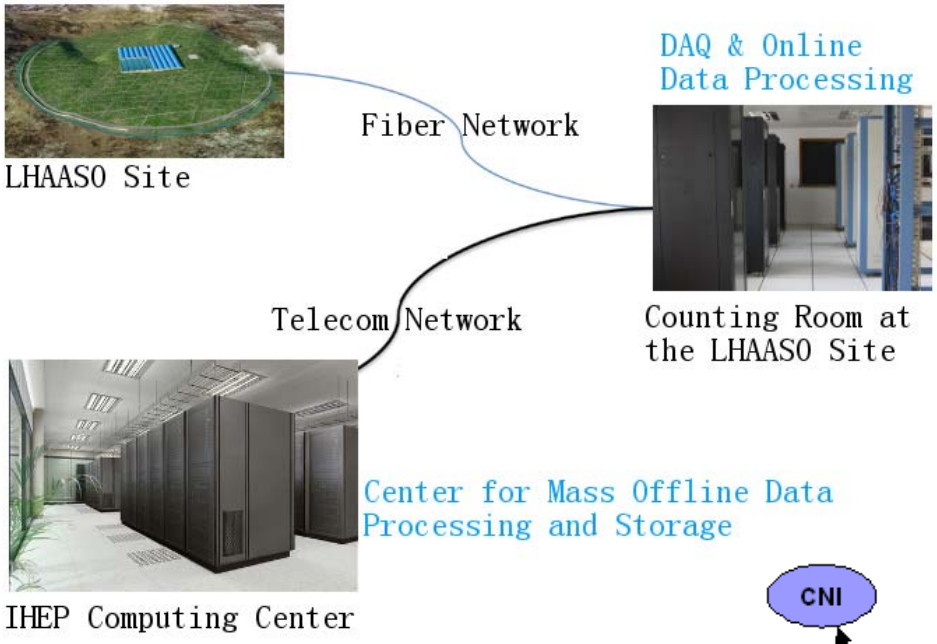


Day: sidereal day / transit.



Our ultimately goal is to implement calibration, reconstruction and data analysis online – to real time monitor every piece of the sky.

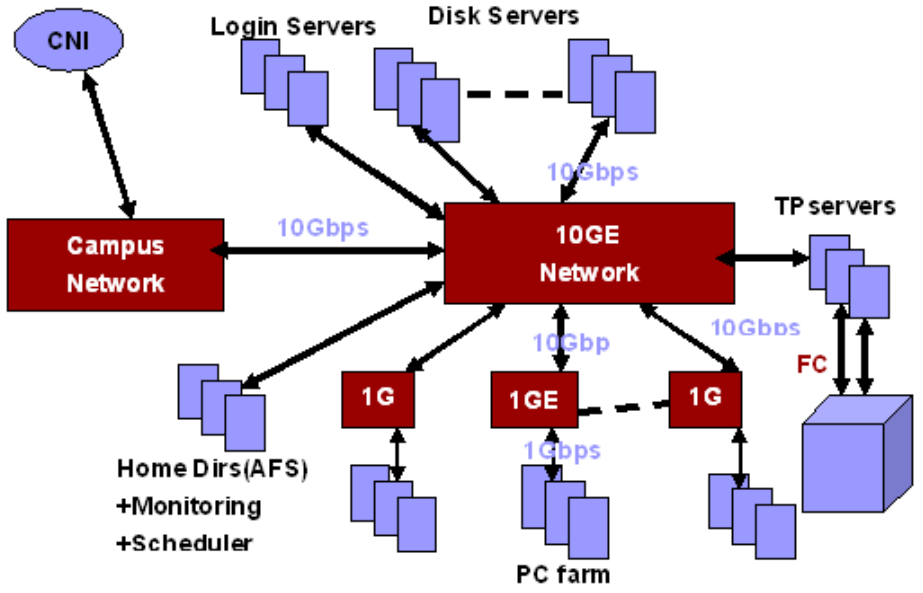
Data Storage & Computing



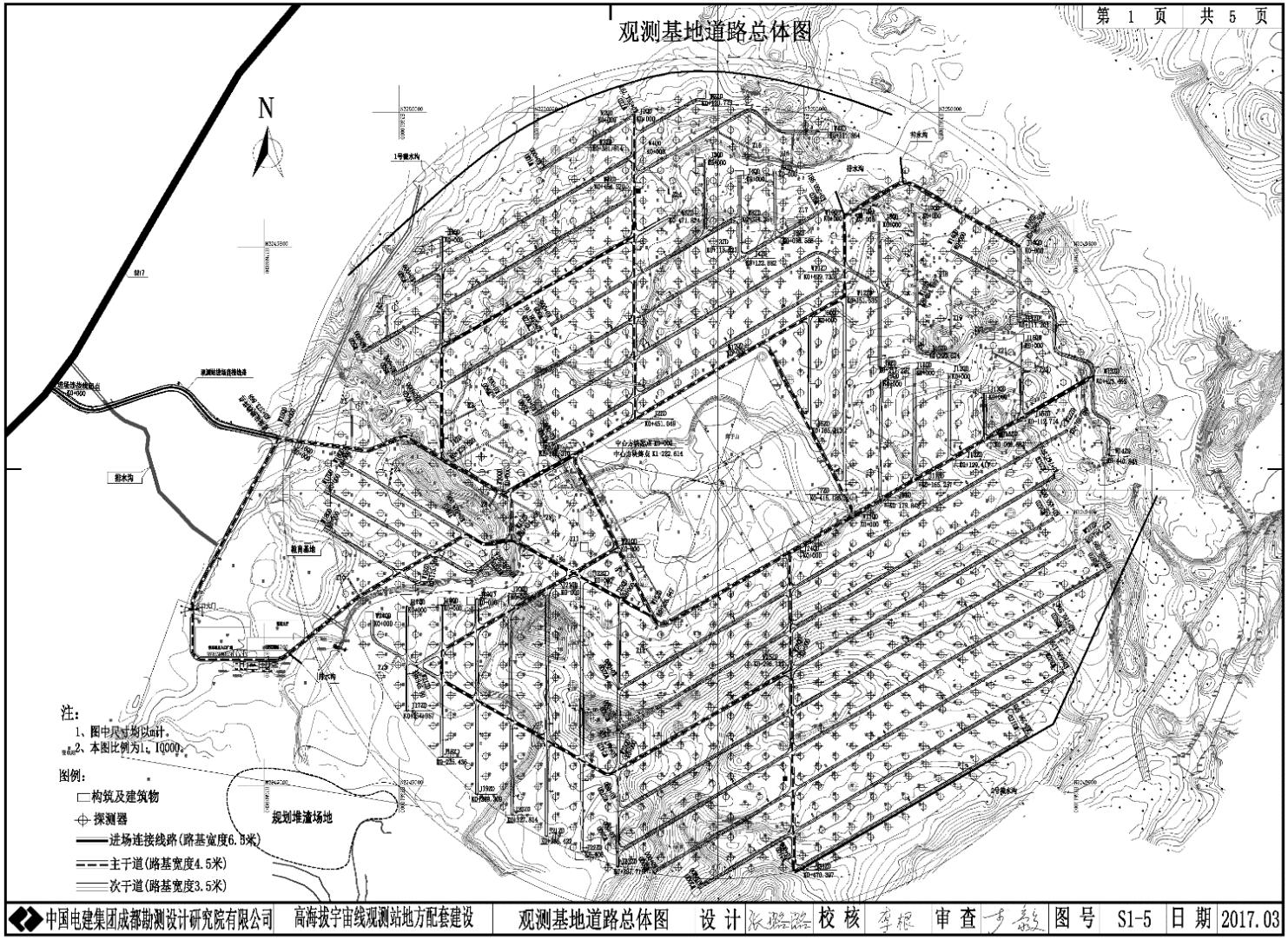
- Data:
  - transferred to a computing center at IHEP (or other site) via commercial network links, and stored in disk & tape.
  - can be accessed and processed in IHEP or other sites.

- Control:
  - The detectors can be monitored and controlled at Daocheng and other remote sites.

CERN-style storage management

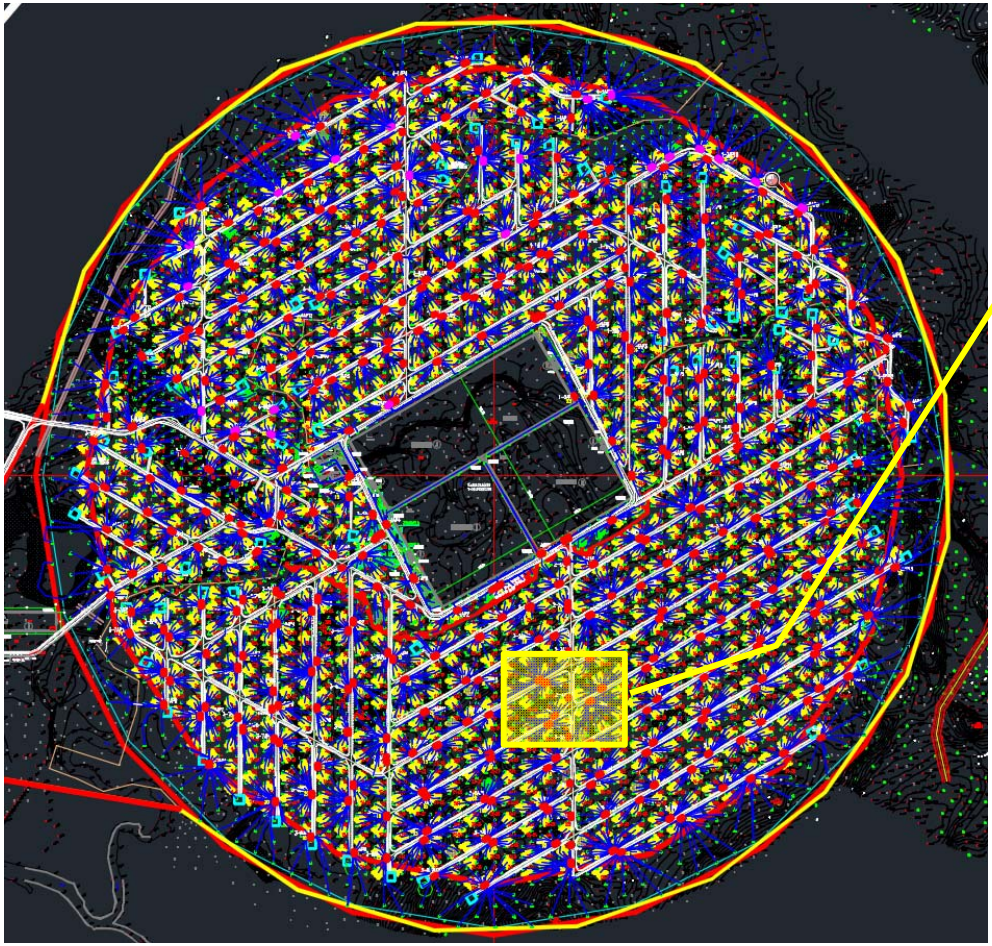


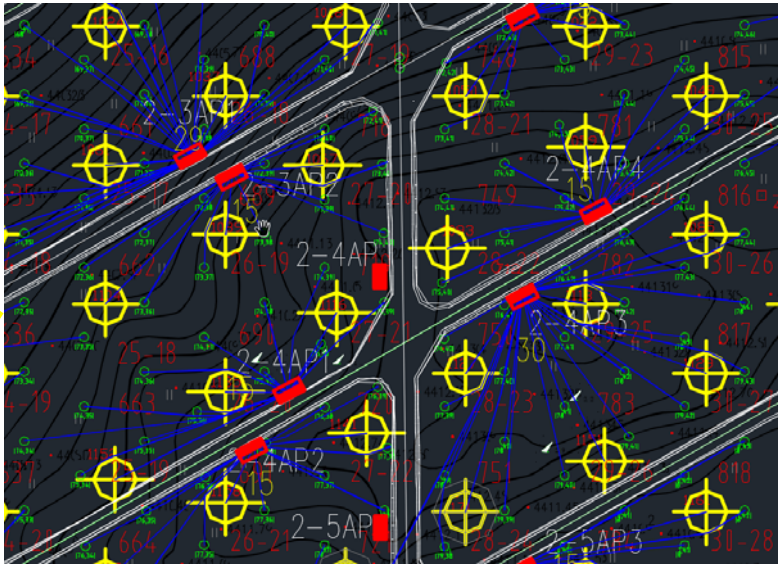
Roads



Total length of roads in the site: ~21.5 km

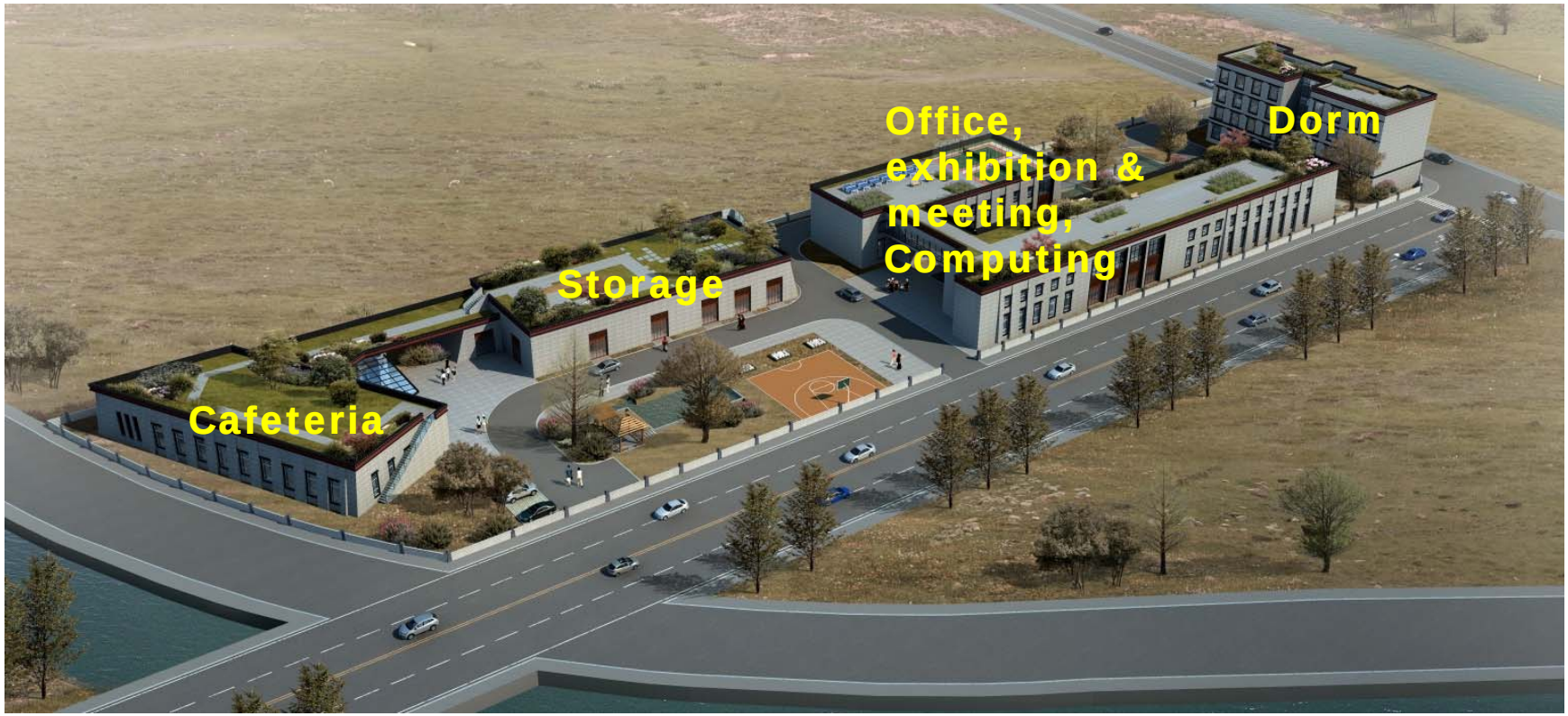
Electricity & WR Network Cables





- Photoelectric composite cable (armored): 195 km;
- Optical cable (armored): 155 km;
- Huge laying effort.

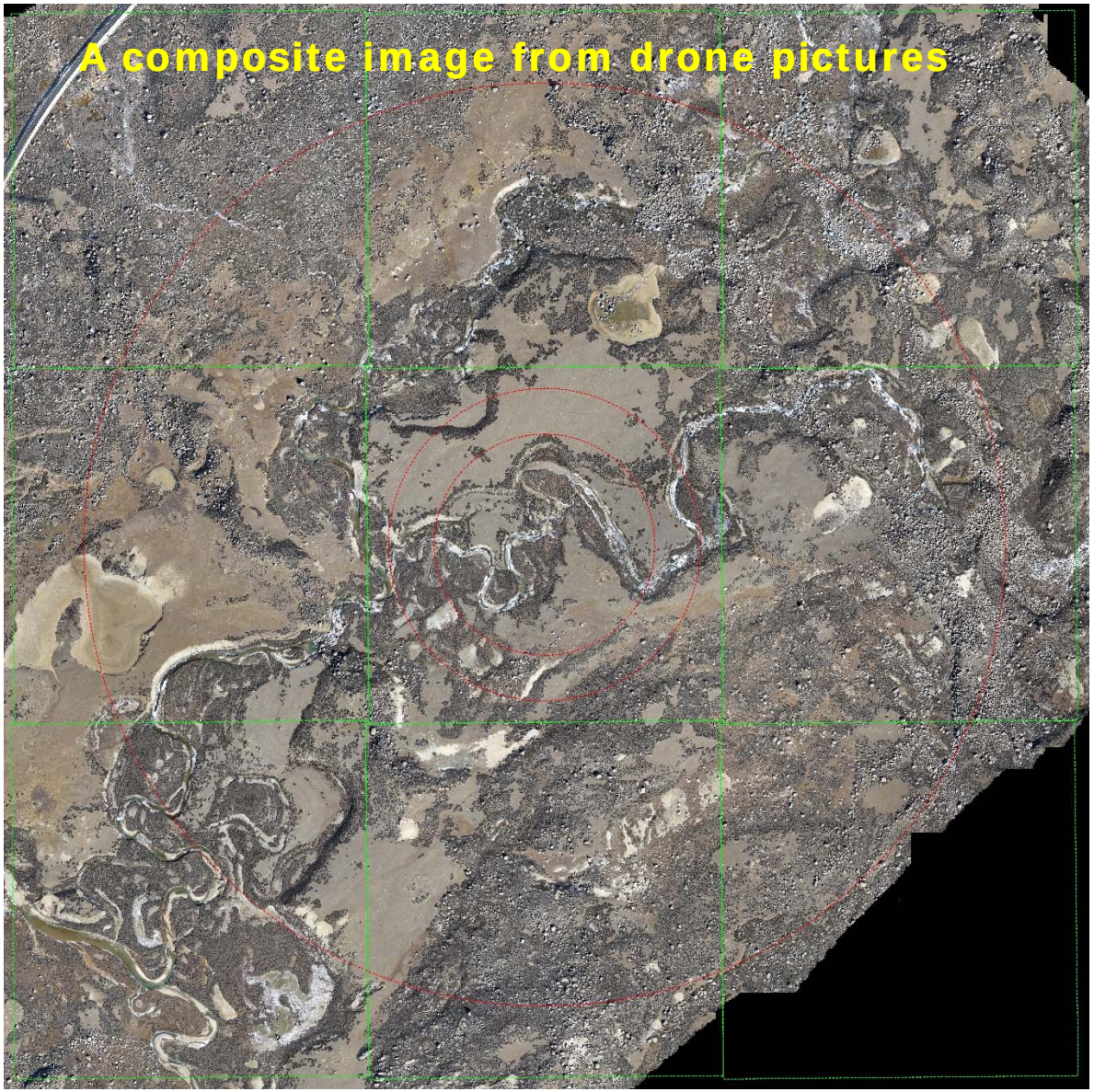
Home Base in Daocheng (Sketch)



Commissioning Status

- Field & infrastructure
  - Supported by the local government, and executed via a construction agent.
  - Including:
    - land lease, field preparation, ecological protection, ditches for flood control, roads led to every muon detector, long distance power supply, home base construction in Daocheng city (lower altitude), …
  - Started from May 2016;
  - Most of the work has completed until December 2017.

Field: Oct. 2013 (Before Any Construction)

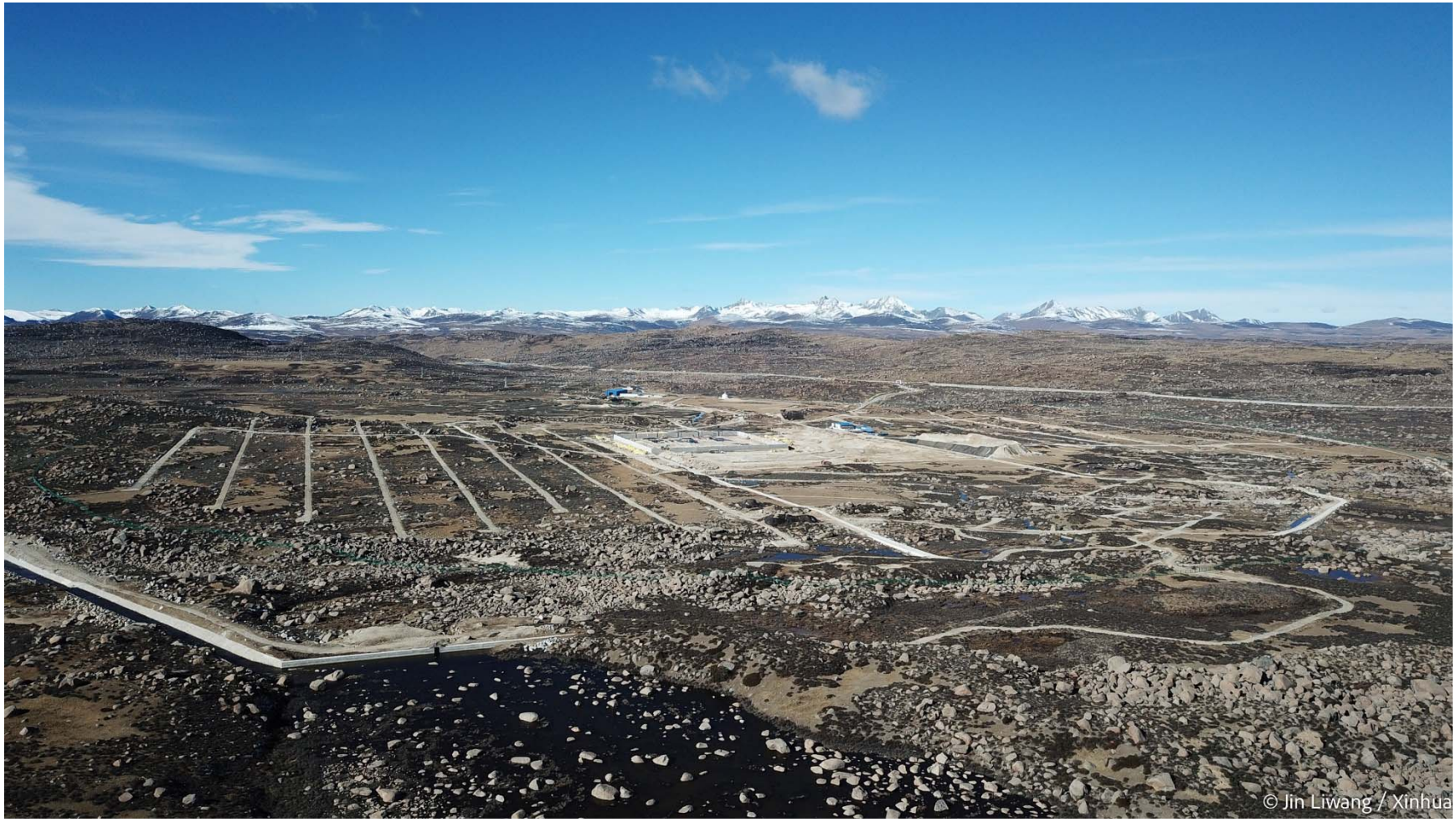


Typical Landscapes

- Sand & gravel
- Grass & bush (partly alpine azalea)
- Boulders
- Rivers & marshland
- Hills & ridges

July 2017 (Since May 2017)

November 2017



Power Supply

35 kV power transmission line
from around 30 km away.
Powered on since August 2017.

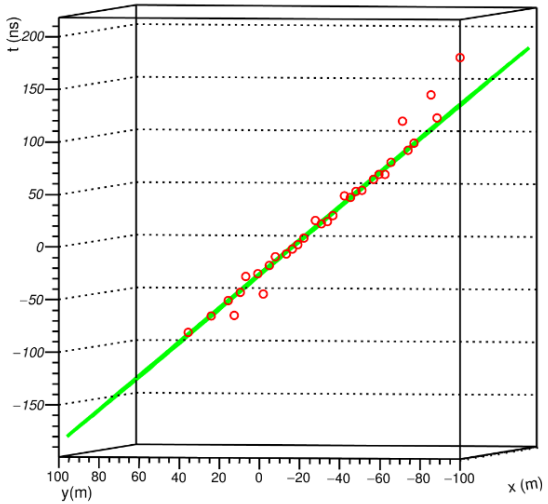
Detector Production (1 year later)

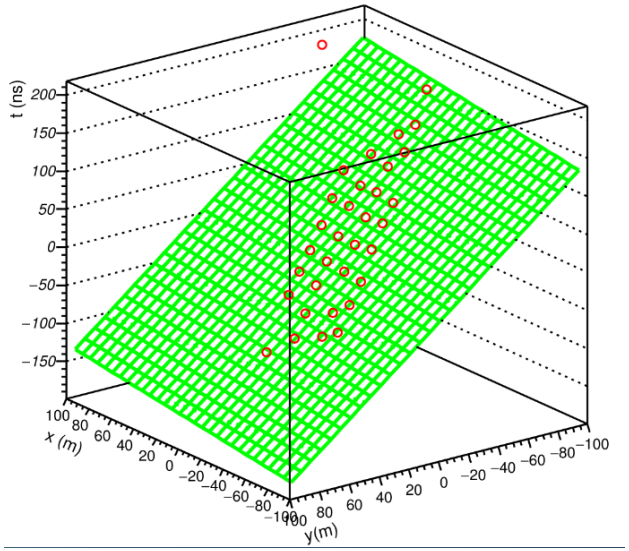
- Tasks assignment:
  - including manufacturing, assembling, testing, transporting, installing the detectors, …
  - Via a **biding** procedure, govern by the government procurement law;
  - more than 50 contracts have been signed with universities, corporations, companies and factories;
  - e.g., 6 parties for PMTs, 3 parties for electronics, 3 parties for power supplies, 6 parties for mechanics, …
  - The products will be examined and accepted in a well-designed manner.

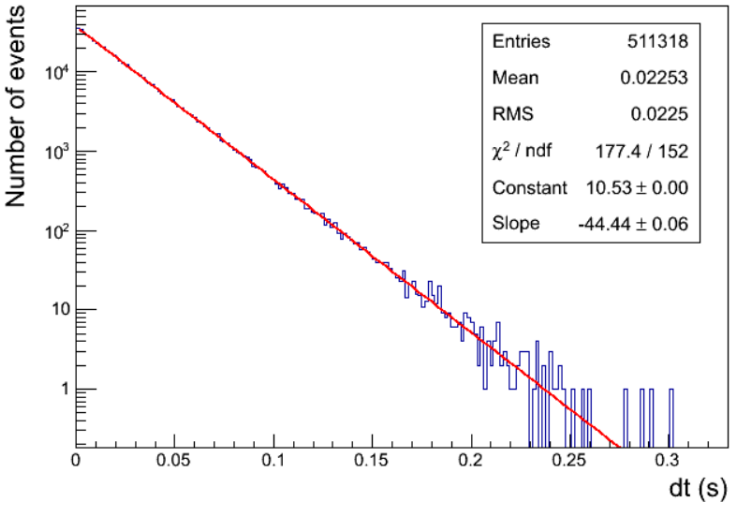
EDA

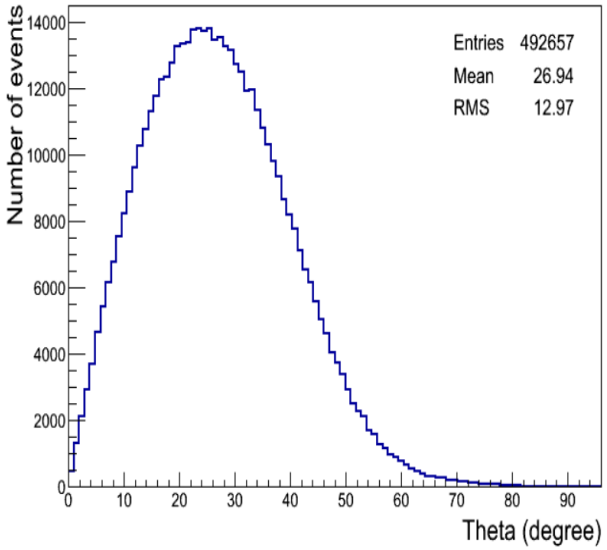
- 33 detectors has been installed in the site by Feb. 3, 2018.

Data-taking Started









MD Water Container

MD Tank

WCDA Pond (Since June 2017)

August 2017

September 2017

October 2017

December 2017

WCDA Pond

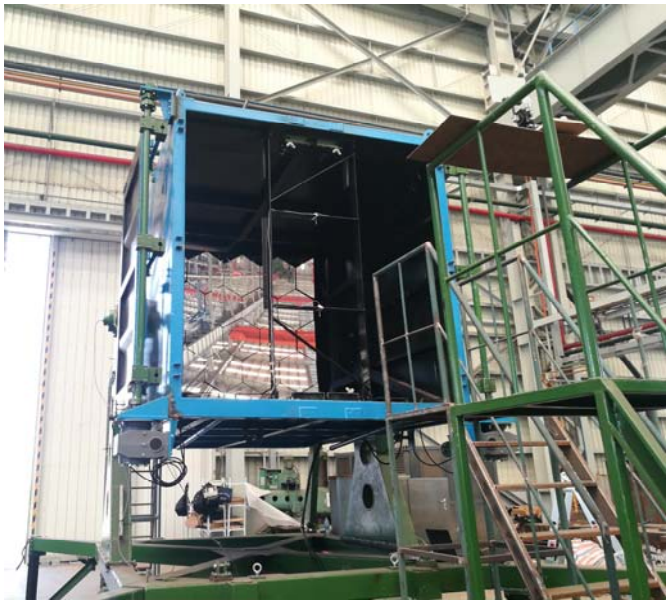
January 2018

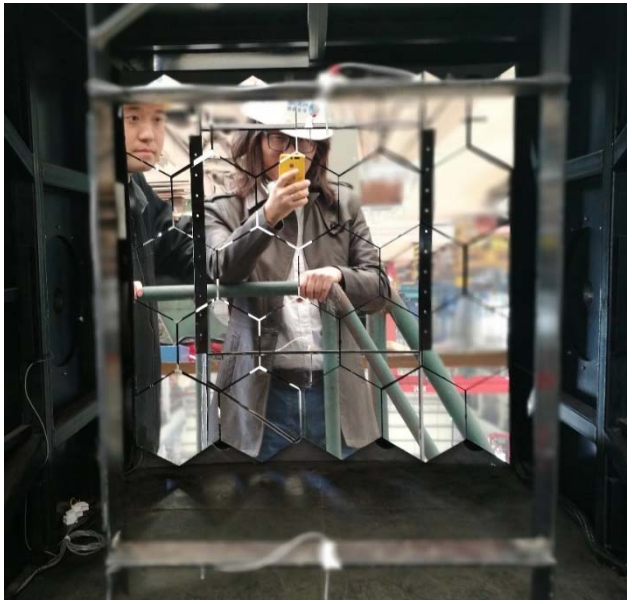
April 2018

May 2018

May 2018

WFCTA Telescope

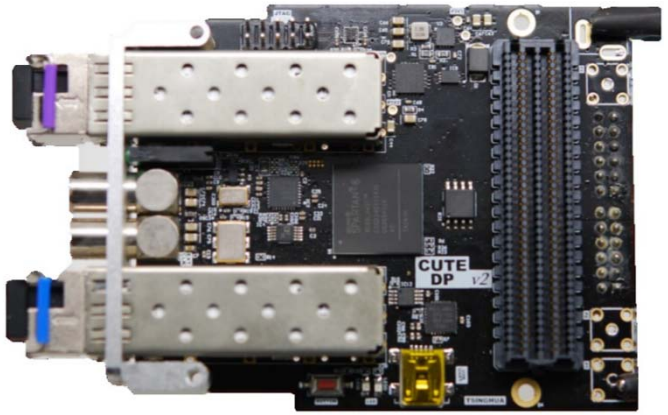




WR Switches & CUTDP

Qsinghua U.

~600 WR switches;
“Fanless” design;
Manufactured in China.



~6500 CUTDP

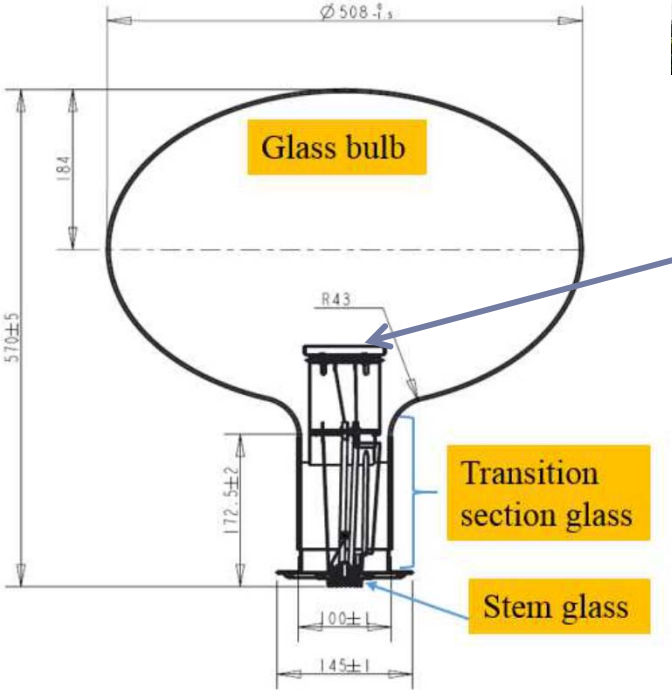
Home Base in Daocheng

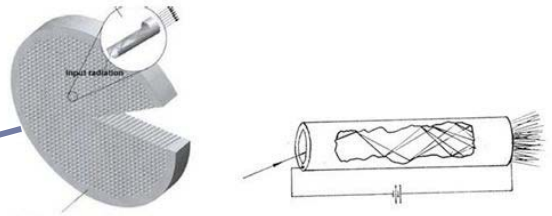
Schedule

- EDA:
  - 1383 (2018), 1800 (2019), 2008 (2020).
- MDA:
  - 300 (2018), 415 (2019), 456 (2020).
- WCDA:
  - 1st pool (2018.11), 2nd pool (2018.9), 3rd pool (2020.7).
- WFCTA:
  - 1st telescope (2018.8), up to 4 telescopes (2018.10), up to 10 telescopes (2020.1), up to 18 telescopes (2020.12).

- By the end of 2018: a quarter of LHAASO detectors are scheduled to operate.

New: NNVT 20” PMT



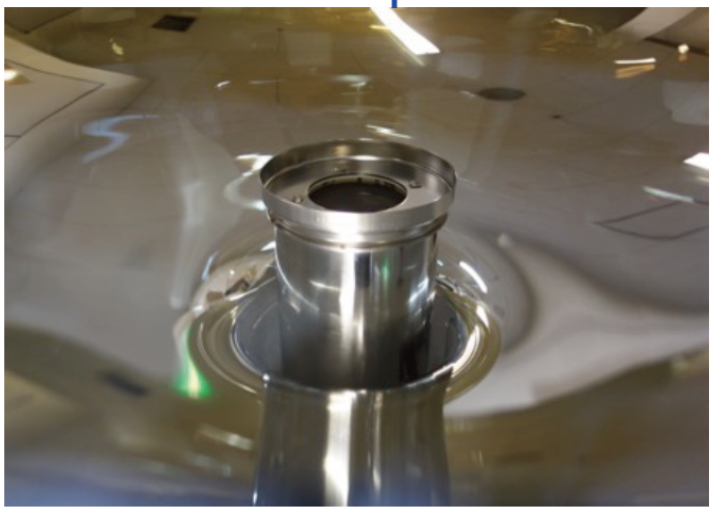


Double-layer millions of channels

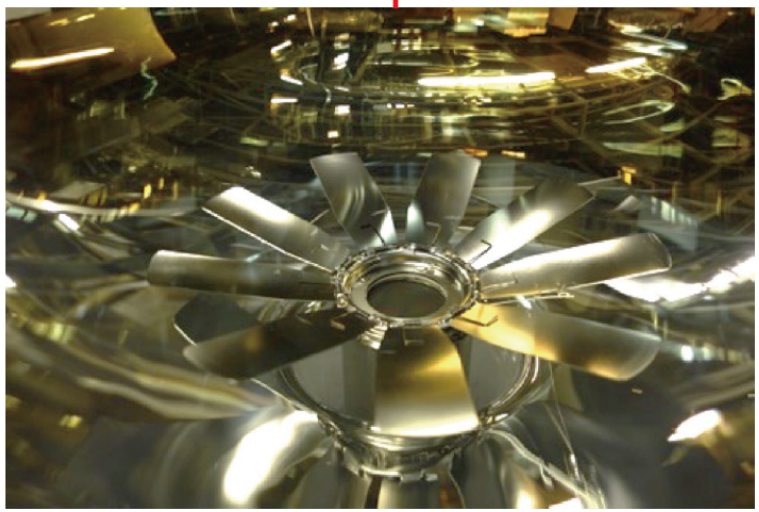
- JUNO:
  - Ordered 15000 pieces, with high collection efficiency (>98%);
  - NNVT built plenty of production lines for the order;
  - Willing to provide new designed 20” PMTs for LHAASO.

TTS

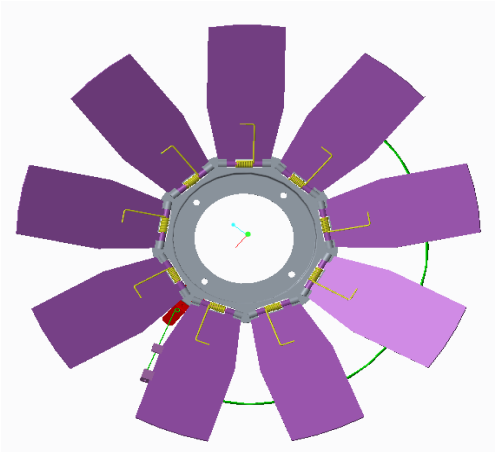
Before improved

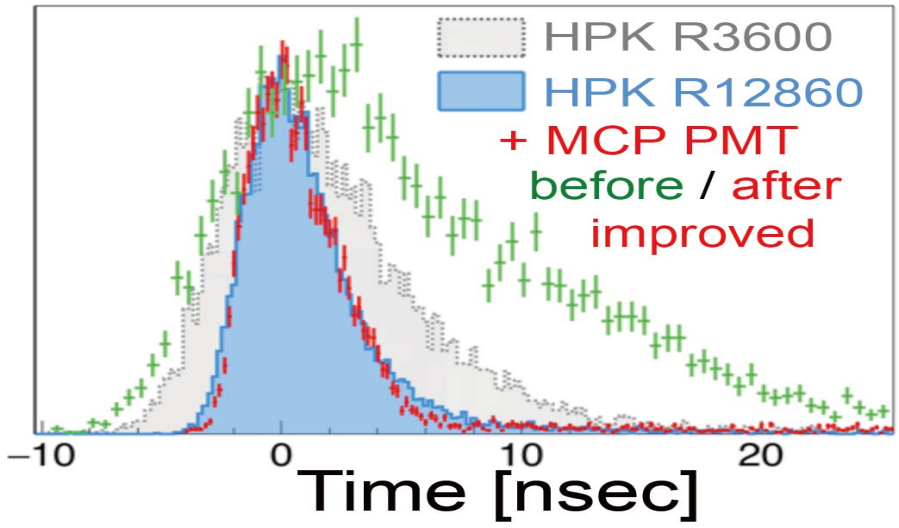


After improved



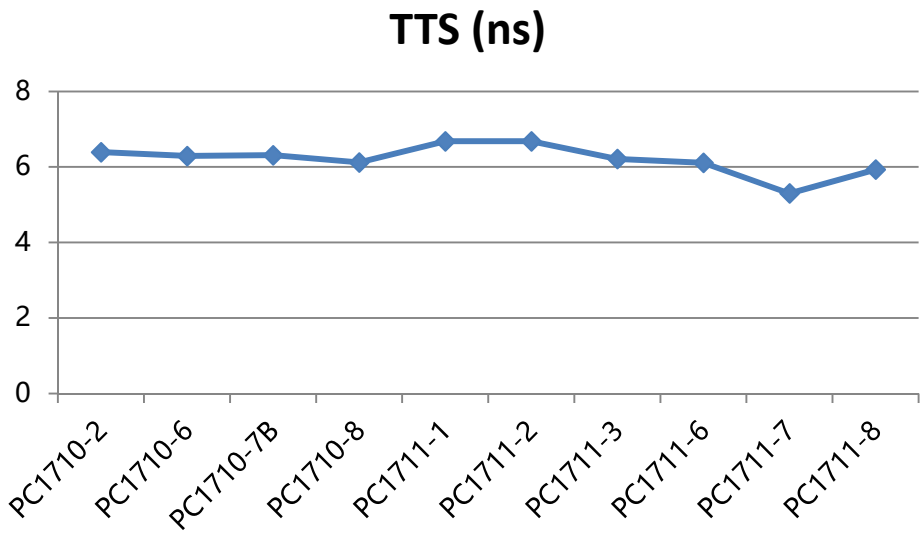
Modification to the focusing electrode to lotus-like

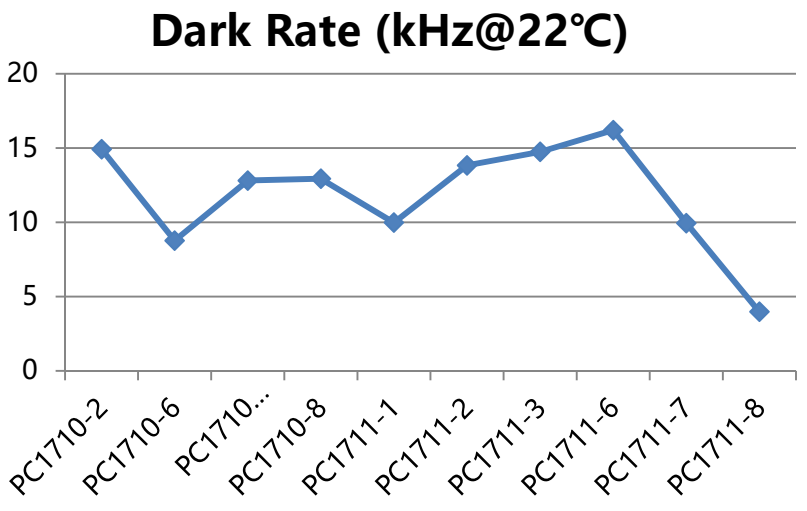


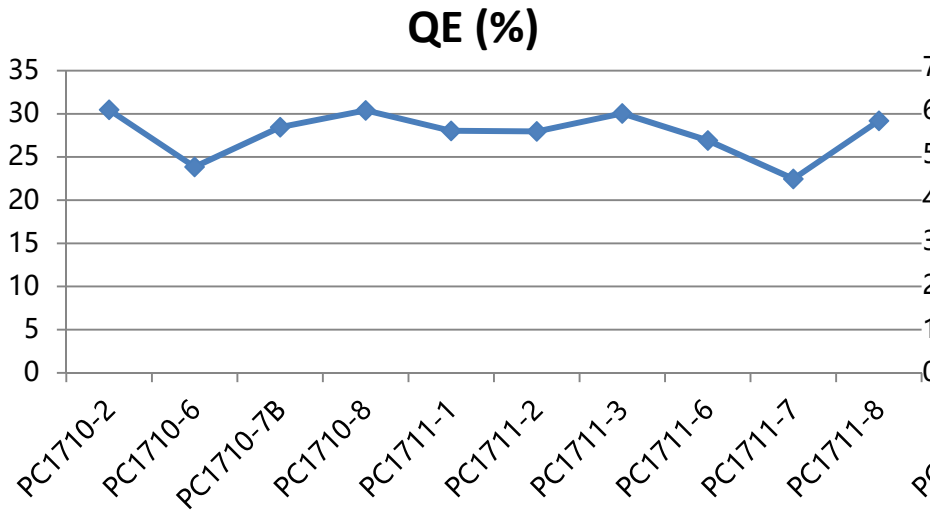


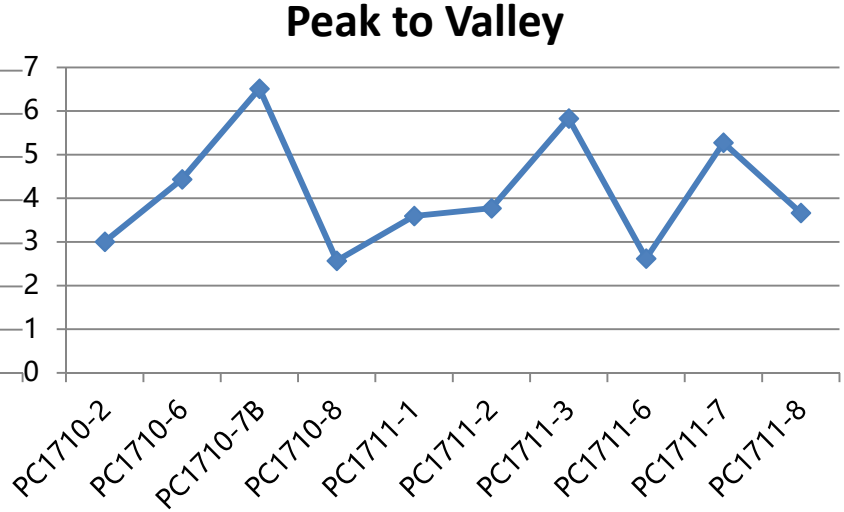
FWHM:
20 ns → 6 ns

Properties & Uniformity

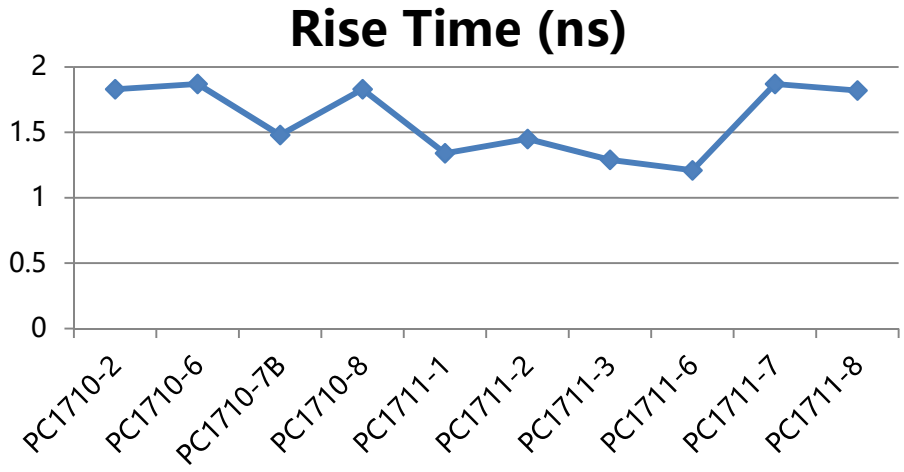


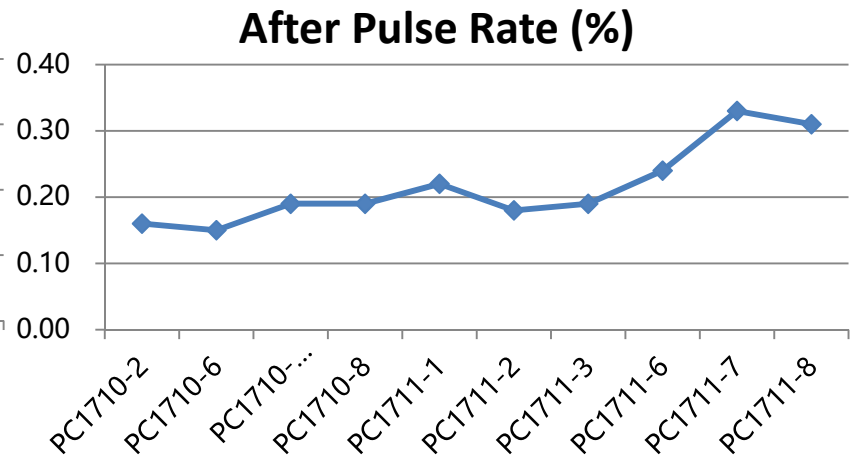


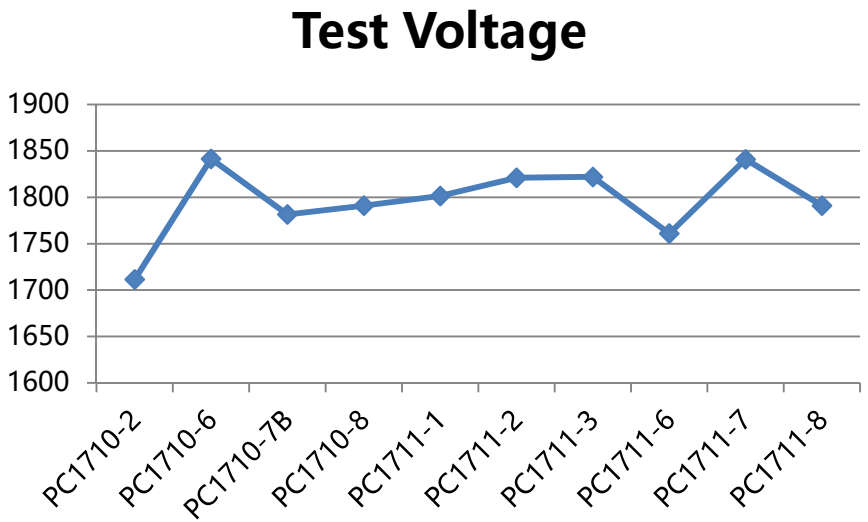


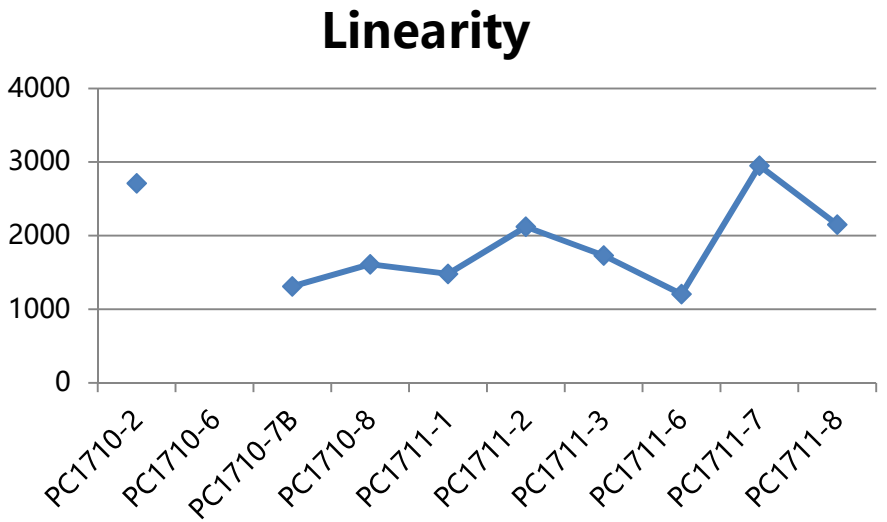


Properties & Uniformity

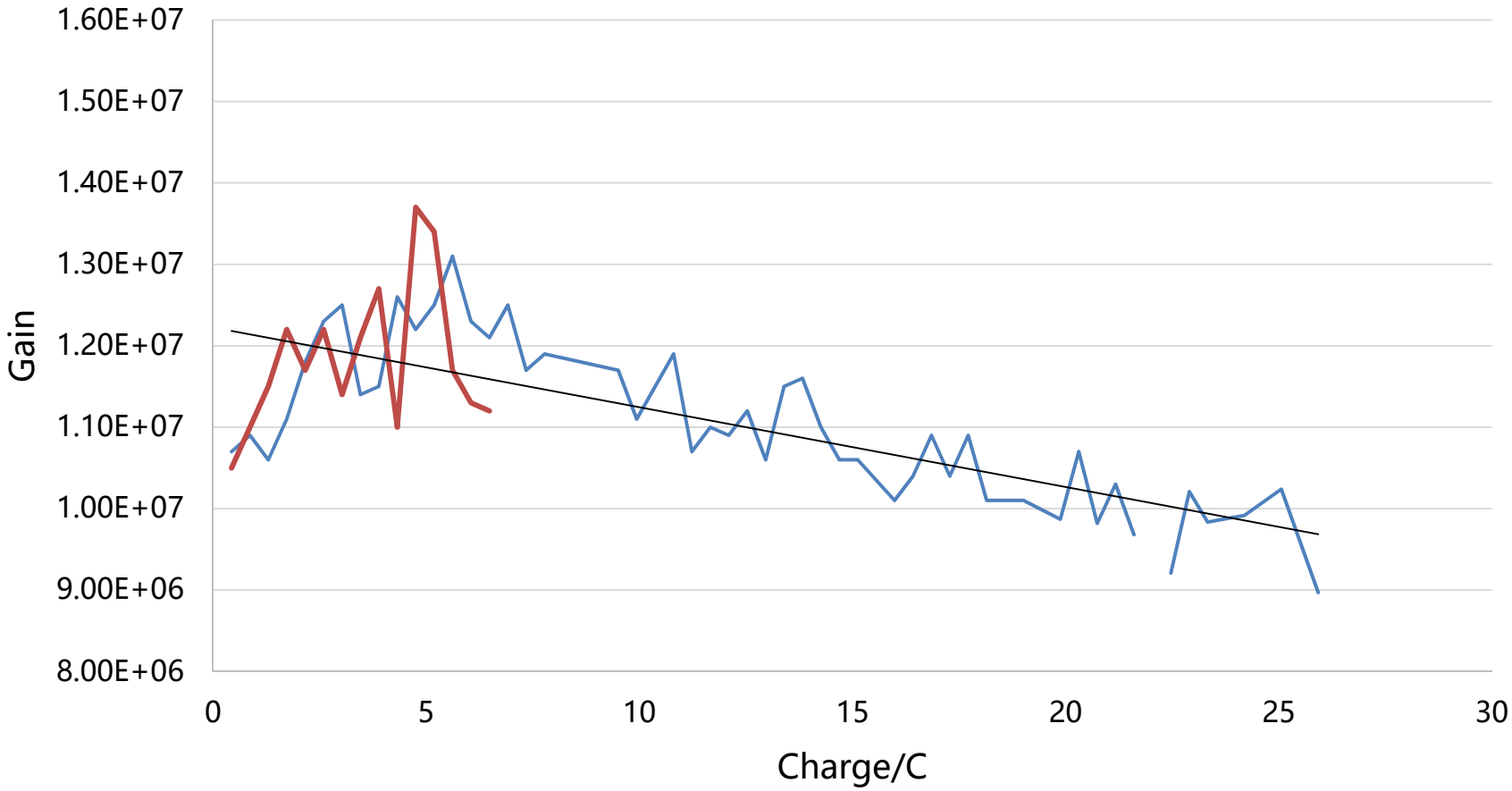








Aging

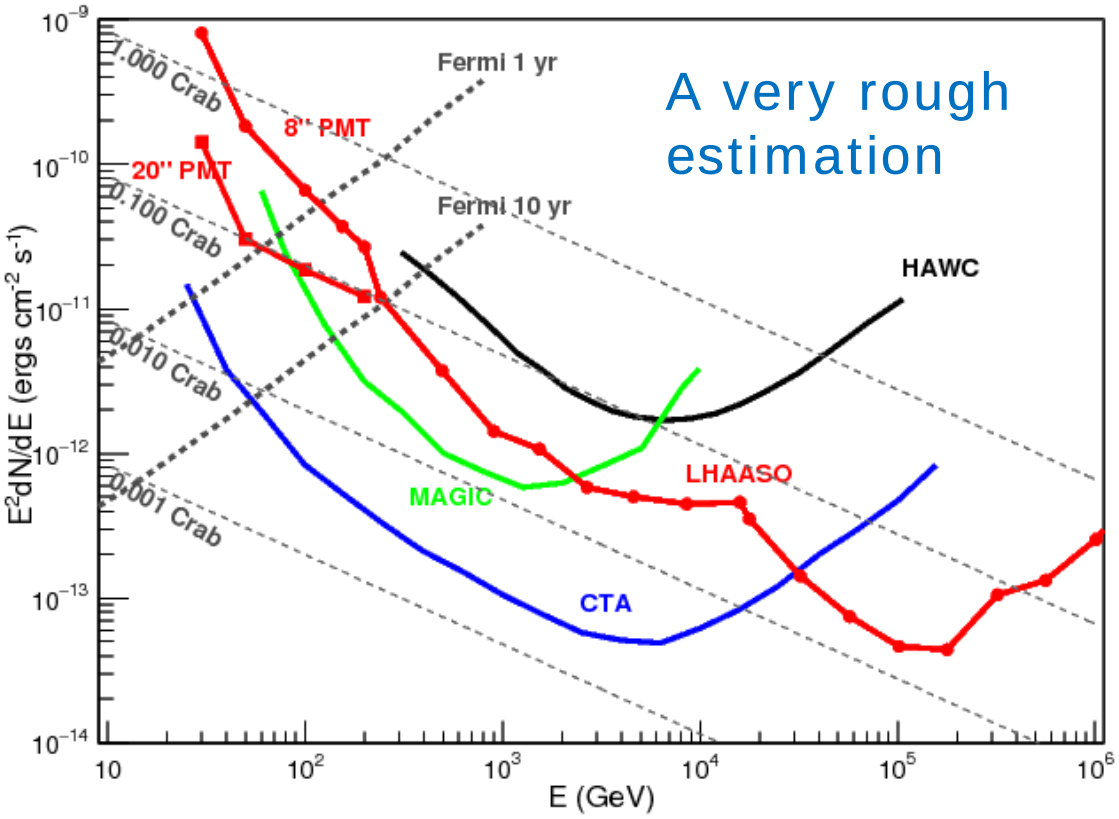

1.60E+07
1.50E+07
1.40E+07
1.30E+07
1.20E+07
1.10E+07
1.00E+07
9.00E+06
8.00E+06
Gain
0
5
10
15
20
25
30
Charge/C

New Configuration for WCDA?

20” PMT

3” PMT

20” PMT + 3” PMT to replace the 8” one for the 2nd and 3rd water pond.



Summary

- LHAASO is a new and big tool for VHE gamma ray astronomy and UHE cosmic ray physics.
- ¼ of the detector array is scheduled to take date by the end of 2018.
- Full array will be operated by the end of 2020.
- A solution on lowering the energy threshold of WCDA is under investigation, and will be decided very soon.
- Any input or contribution from you is important for us!