An introduction to LHAASO-WCDA detector

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IHEP, CAS

Particles and Nuclei International Conference 2017

Outline

- Site & Overview
- Physics goals
- Design & Specifications
- Performance
- R&D work
- Collaborators & Schedule
- Summary

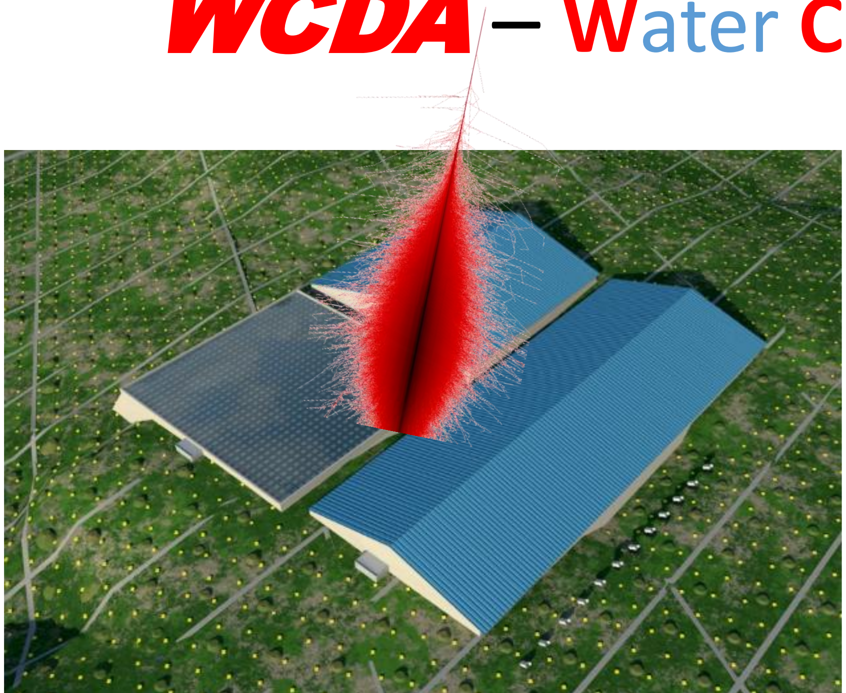
Site

- Location:
  29º21’30.7” N
  100º08’14.7” E
- 4,400 m a.s.l;
- 700 km to Chengdu;
- 8 km to airport;
- 50 km to Daocheng City.

Four types of detectors:

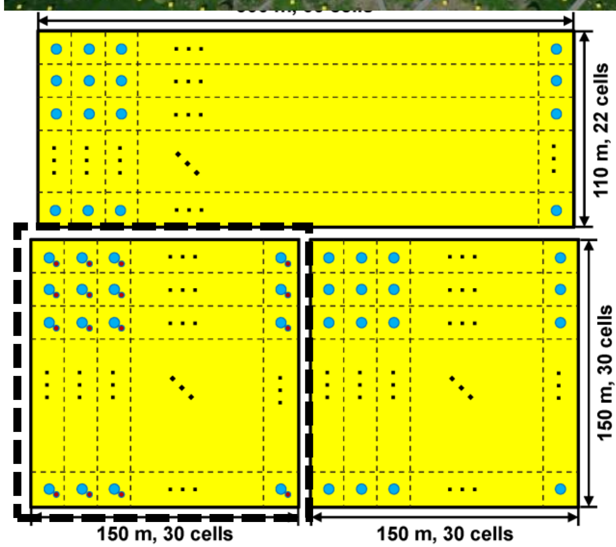
1. The Electromagnetic particle Detector (ED) array --5195 units;
2. Muon Detector Array --1171 units;
3. Wide Field Cherenkov Telescope Array;
4. Water Cherenkov Detector Array

WCDA – Water Cherenkov Detector Array

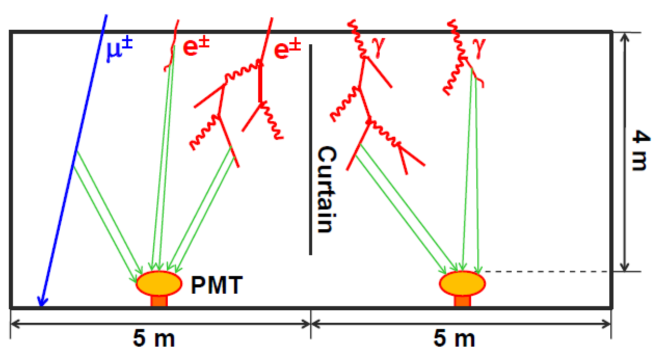


3 water ponds

- 7,800 m^2 in total;
- 4.4 m water depth;
- 3,120 cells, with an 8/9 inch PMT in each;
- Cells are partitioned with black curtains;
- 1 water pond with the dynamic range extension system (900 1’5 inch PMTs).

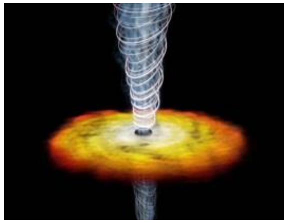


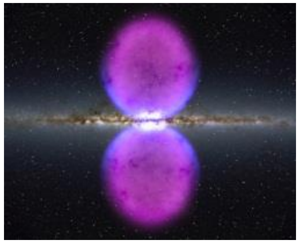
Detect air shower secondary particles



- Electrons / positrons;
- Muons;
- Gammas;

Physics goals



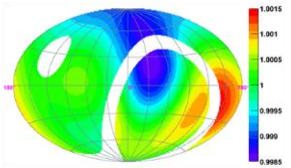


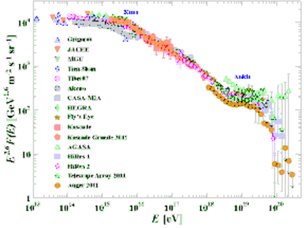
VHE gamma sky survey (100 GeV-30 TeV):

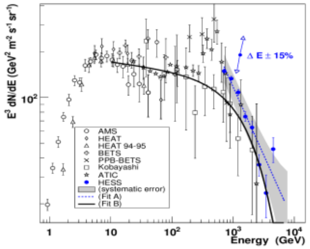
- ➢Extragalactic sources & flares;
- ➢VHE emission from Gamma Ray Bursts;
- ➢Galactic sources;
- ➢Diffused Gamma rays.

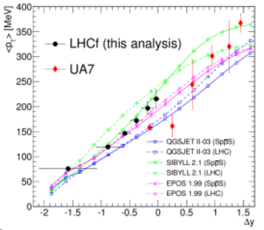
Cosmic Ray physics (1 TeV-10 PeV):

- ➢Anisotropy of VHE cosmic rays;
- ➢Cosmic ray spectrum;
- ➢Cosmic electrons;
- ➢Hadronic interaction models.



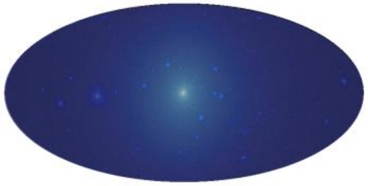


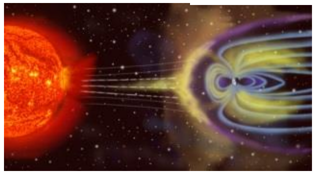




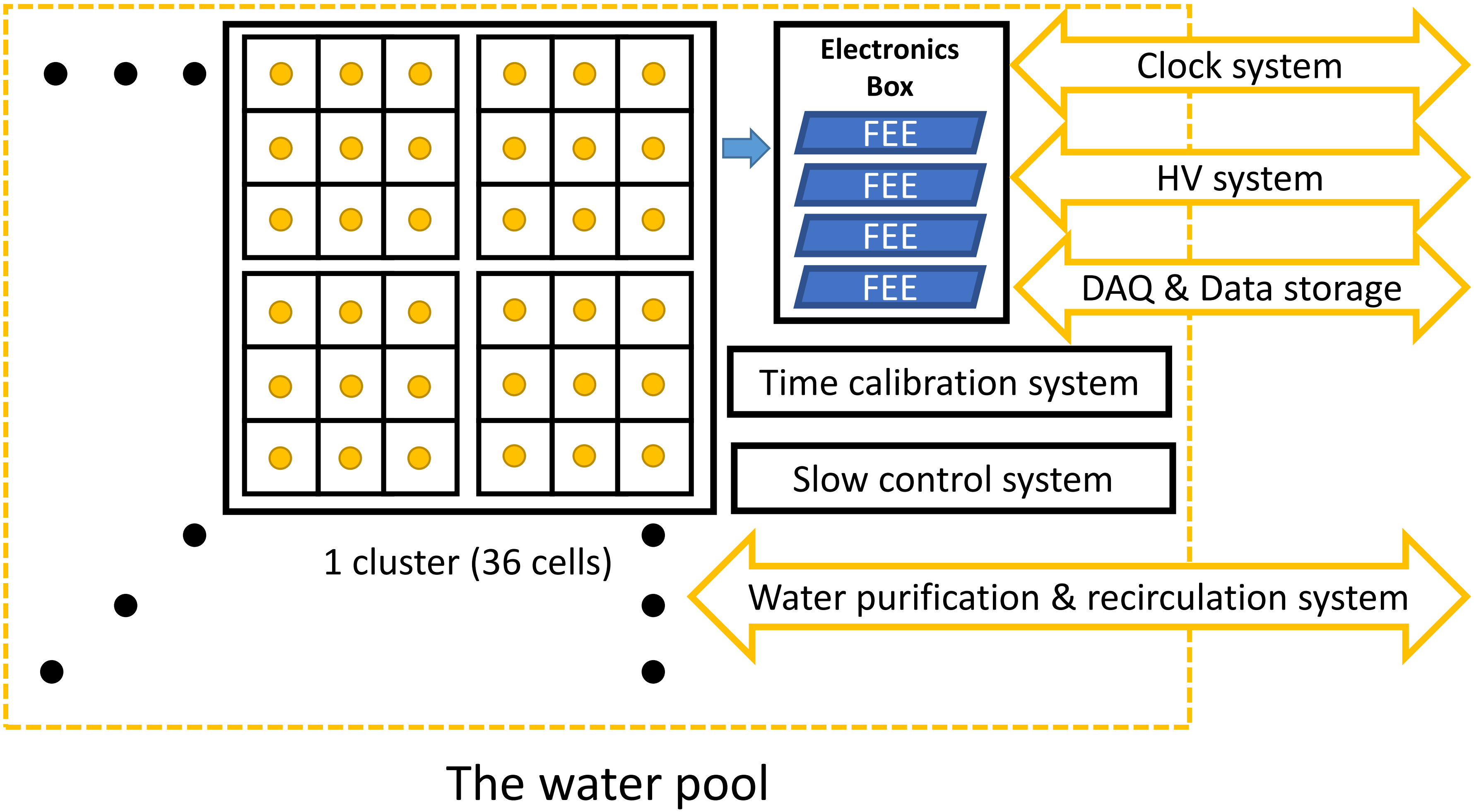
Miscellaneous:

- ➢Gamma rays from dark matter;
- ➢Sun storm & IMF.



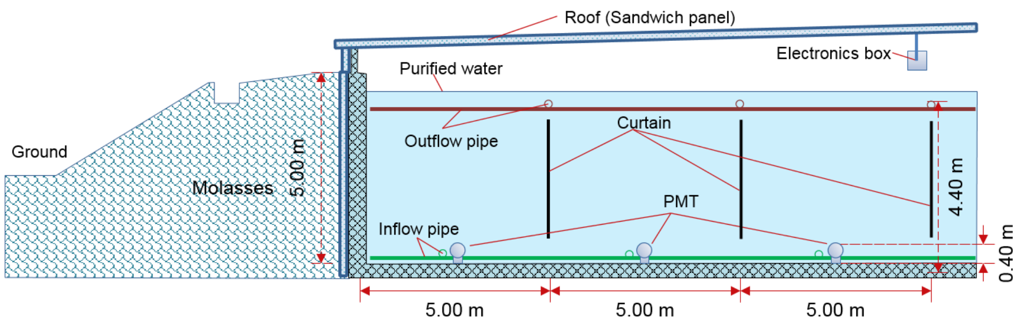


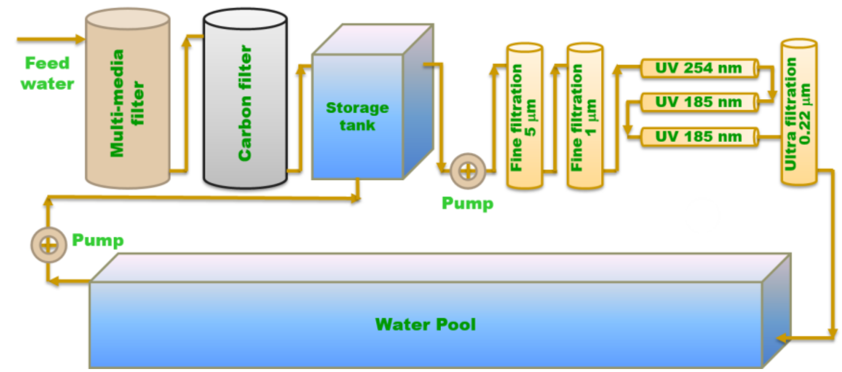
Design



Electronics Box
FEE
FEE
FEE
FEE
Clock system
HV system
DAQ & Data storage
Time calibration system
Slow control system
Water purification & recirculation system
1 cluster (36 cells)
The water pool

Engineering of the water pool





The pool requirements

- ➢Water-proof: water loss <1/1000 volume/day;
- ➢Light-proof: luminous flux (300-650 nm) <100k photons/m2/s;
- ➢Tolerance to snow, rain, wind, dust, earth-quake & anti-freezing;
- ➢Compatible to clean water;
- ➢Light mass of roof and top materials.

The water purification & recirculation

Major pollution is **TOC/DOC:**

- ➢ **UV185 + 0.22 µm.**

Other pollutions:

- ➢ Industrial solutions.

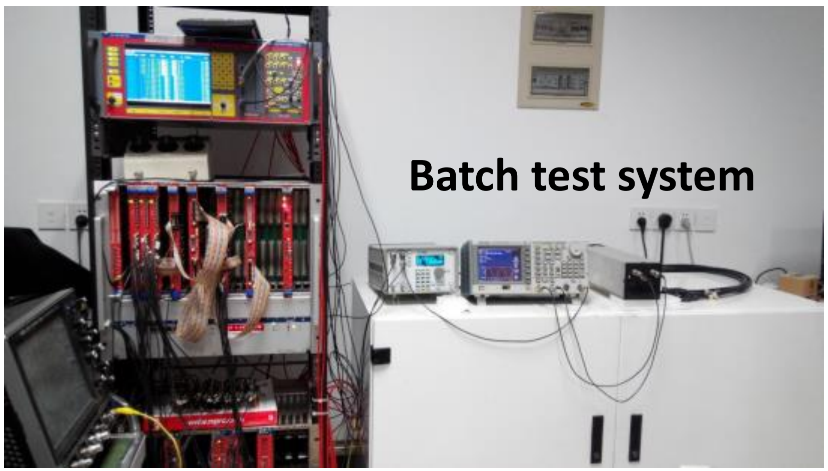
- ➢ Pollution tends to appear in the top of the water;
- ➢ Water is exchanged uniformly;
- ➢ Low water flow: 1 volume/month ➔ low maintenance cost.

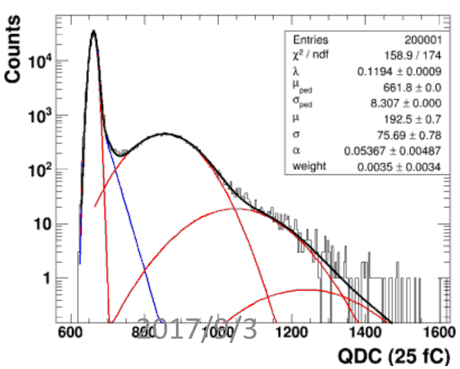
Photo Multiplier Tube

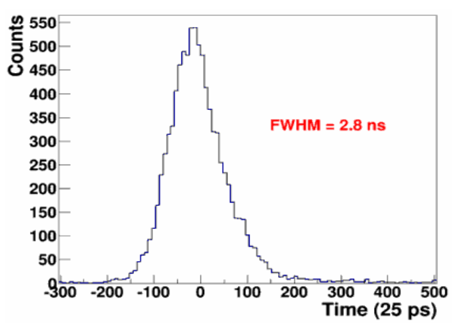
Large area
Single photon-electron
Large dynamic range
High time performance
Low noise rate

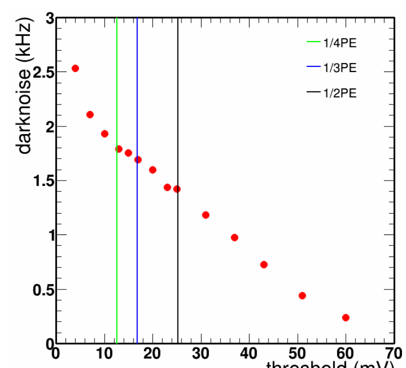
8/9-in
P/V>2.0
Anode & Dynode outputs
TTS<4.0ns
Noise rate<5KHz

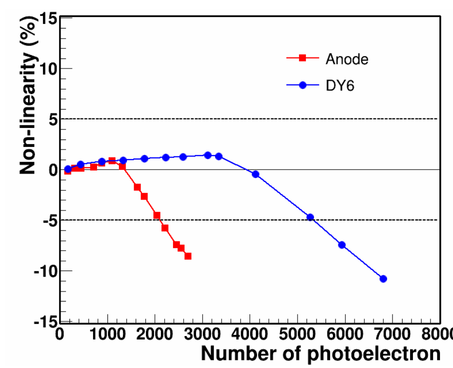
Candidates:
- ☐ R5912
- ☐ CR365
- ☐ XP1805



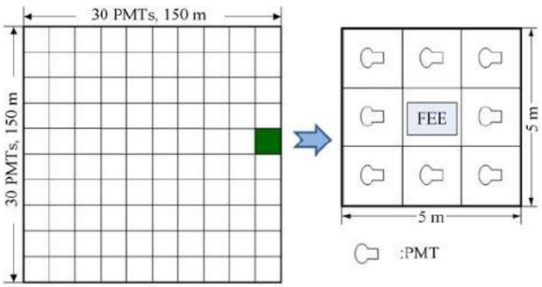


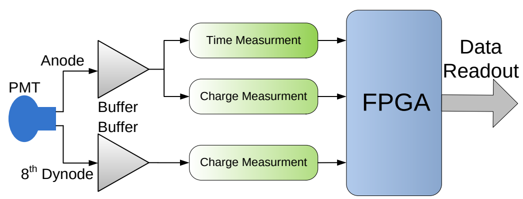


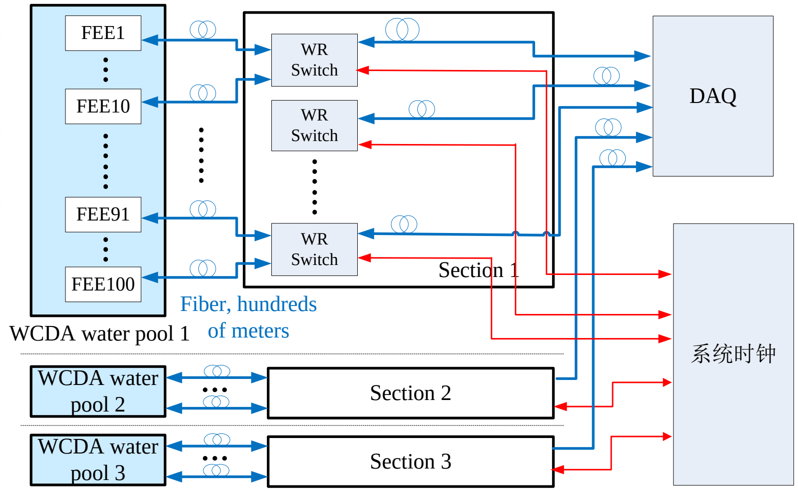




Readout Electronics

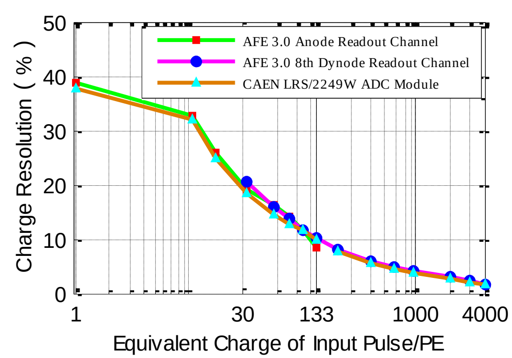


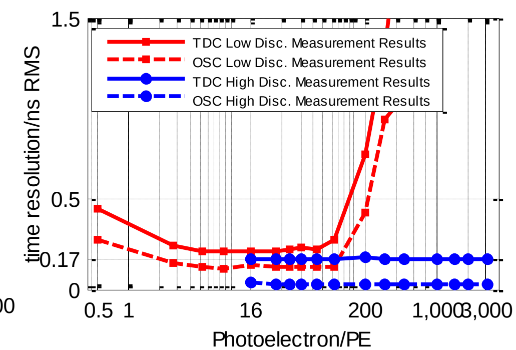




9 PMTs share a FEE board.

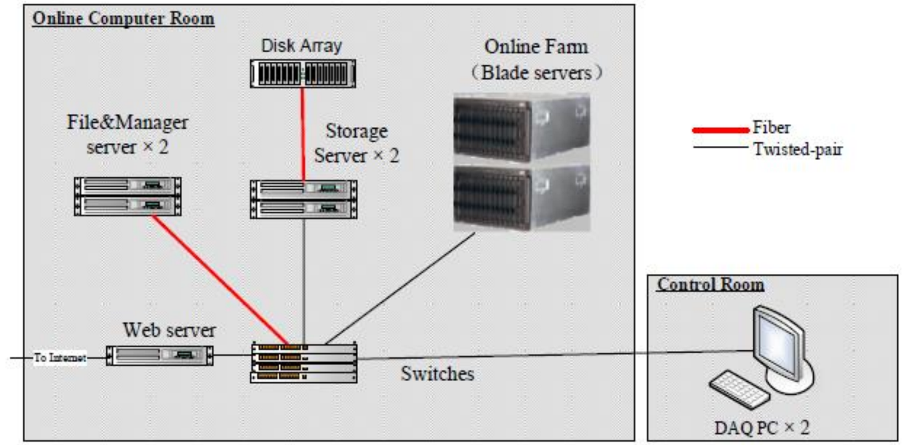
- Charge/ADC: filter & shaping with RC2， peak finding with FPGA;
- Time/TDC: leading edge discriminating, time being measured with FPGA-TDC (bin-size 0.333 ns);

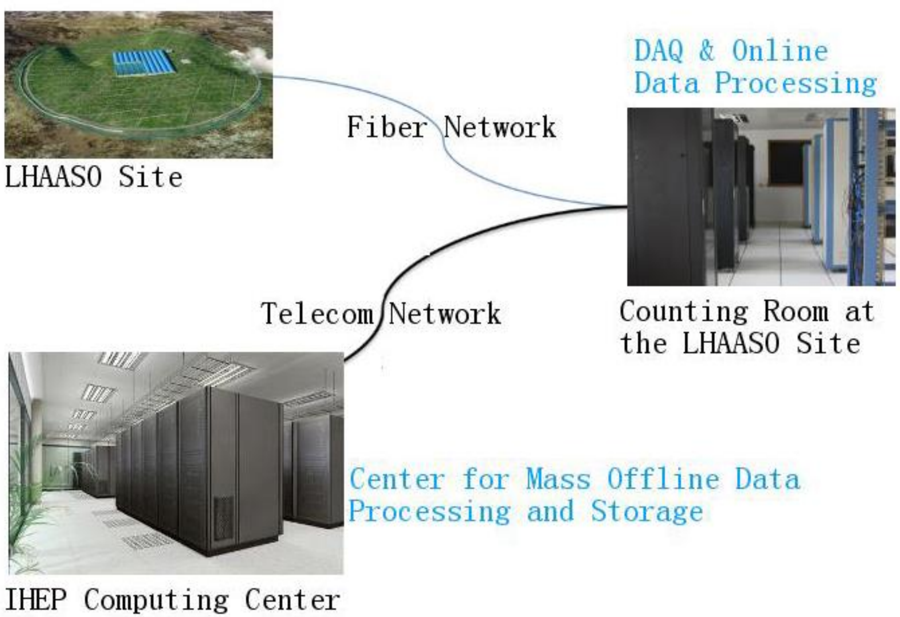




DAQ & Data processing

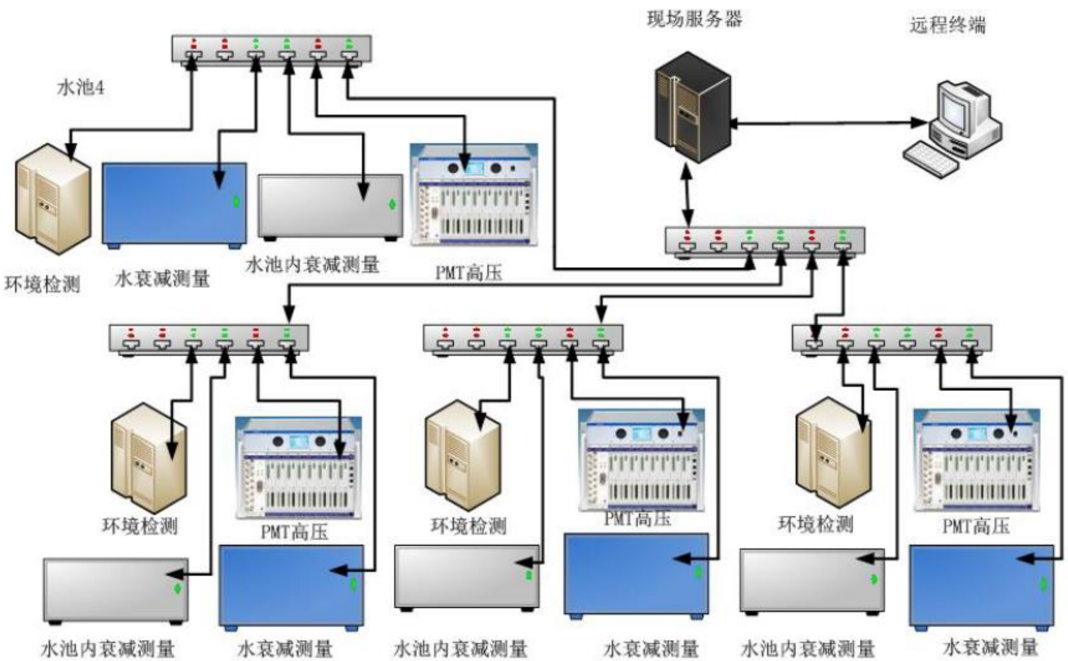
- A computer cluster consists of ~4,000 CPU cores;
- DAQ Software implementation is based on the ATLAS TDAQ framework.

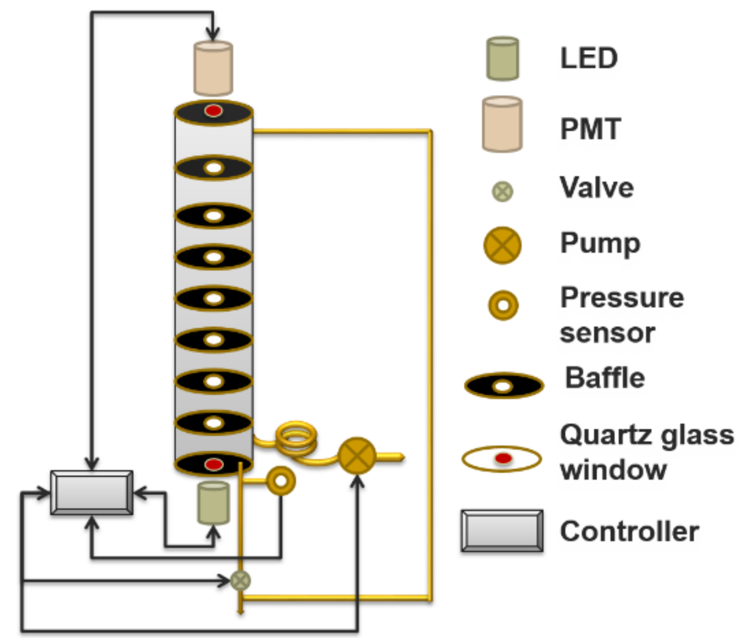




- Data are transferred to a computing center at IHEP (or other site) via commercial network links;
- Data are stored (disk + tape), accessed and processed in the infrastructure of the computer center.

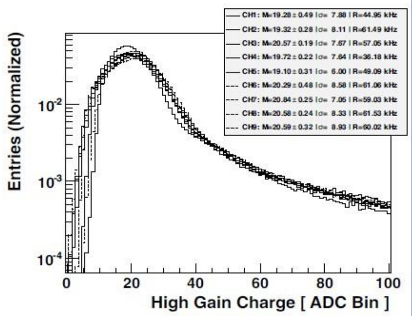
Slow Control System

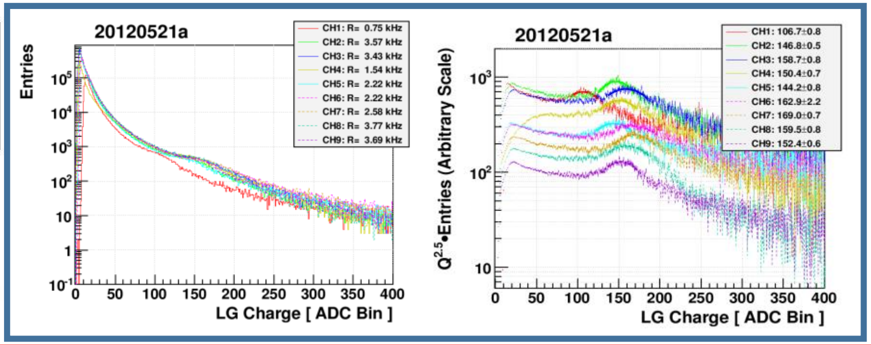


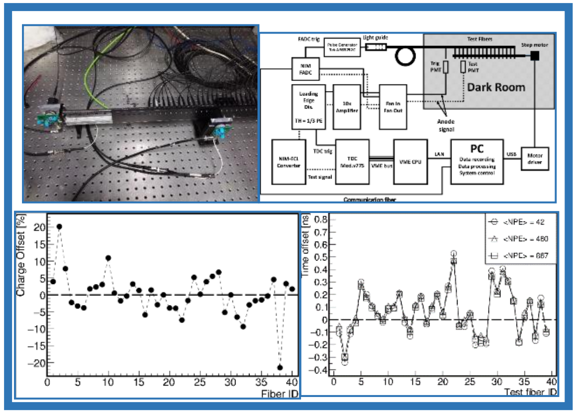


- Monitor environment parameters(temperature, pressure, humidity, water depth, …);
- Monitor & control of HV of PMTs;
- Water attenuation length measurement.

Calibration – *Charge* / *Time*







Charge calibration

Low range: single rate (peak-i)

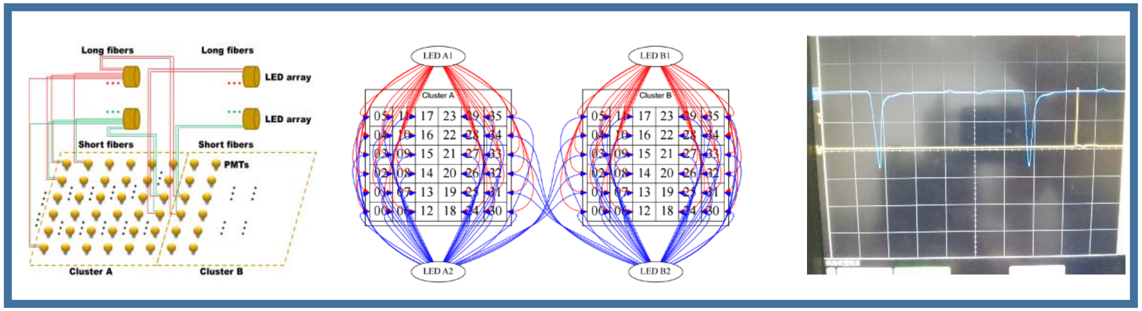
- ~20 kHz;
- SPE signal dominated;
- Including PMTGain + cable + pre-amp + low range electronics.

High range: muon peak (peak-iii)

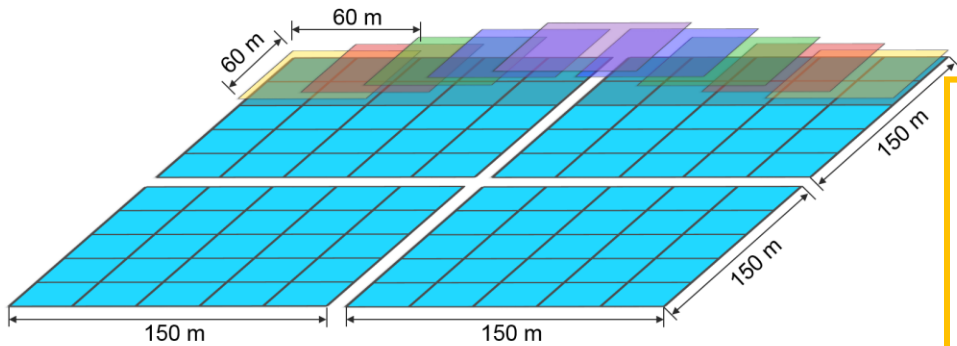
- ~10 Hz;
- Vertical muons hitting the photo-cathode;
- PMT high range gain + QE + CE + cable + pre-amp + high range electronics.

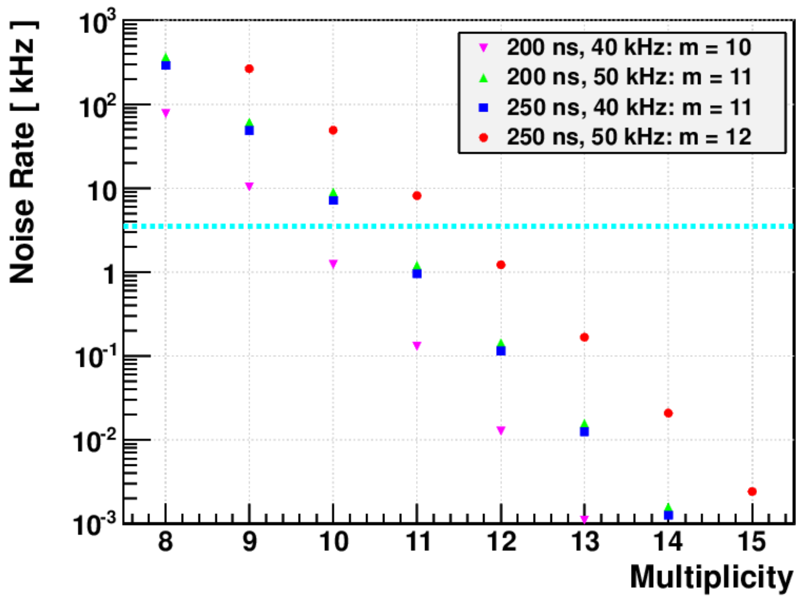
Time calibration

- Cluster-based, cross-calibrated:
- 2 fibers per PMT separately;
- 2 LEDs per cluster, lit in turn;
- 2-4fibers are crossed over neighboring clusters;
- Frequency of LED pulsing: 5-10 Hz.



Trigger cluster & Trigger Pattern



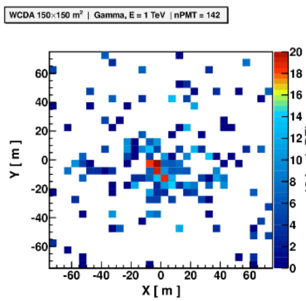


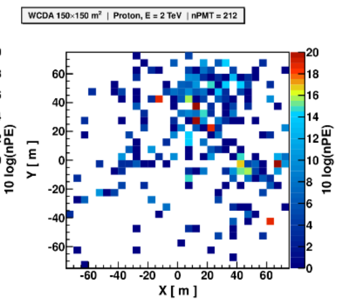
- Subdivided into 81 half-overlapped "trigger clusters";
- Each trigger cluster governs 6×6×4 =144 cells;
- When number of fired PMTs in any trigger cluster ≥12 during any 250 ns, the array is triggered;
- Noise trigger can be depressed to a level of **<3 kHz**.
- This scheme has many advantages such as scalability.

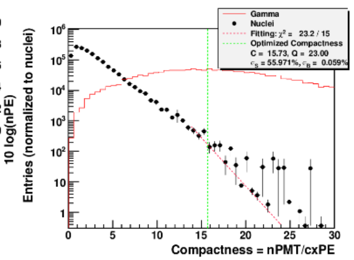
WCDA Specifications

Item	Value
Cell area	25 m ^{2}
Effective water depth	4 m
Water transparency	> 15 m @ 400 nm
Precision of time measurement	1~4000 Pes
Dynamic range	< 2 ns
Time resolution	50% @ 1 PE
Charge resolution	5% @ 4000 Pes
Accuracy of charge calibration	< 2 %
Accuracy of time calibration	< 0.2 ns
Total area	78,000 m ^{2}
Total cells	3,120

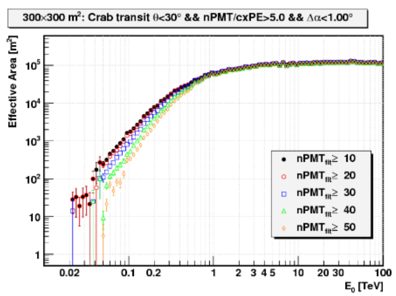
Performance

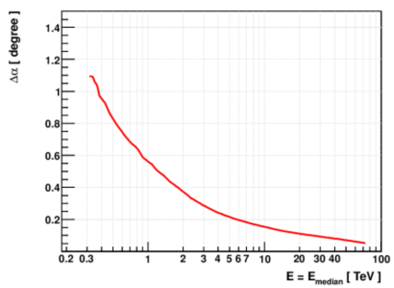




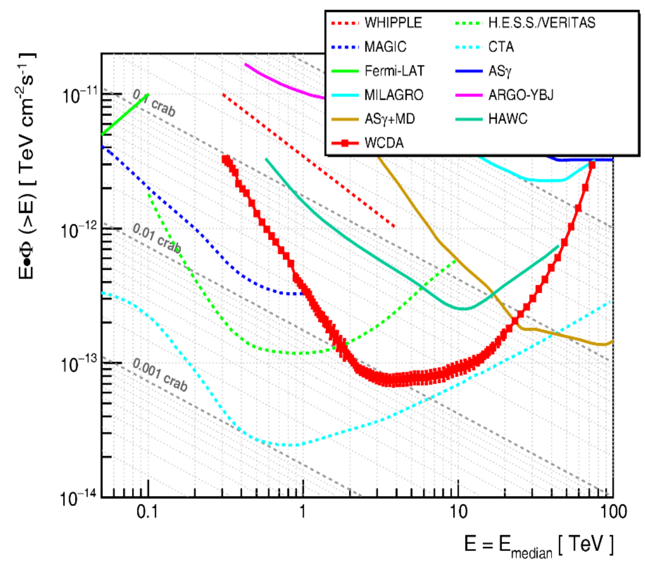


- Brightest “sub-core”:
  - Signal of the brightest PMT outside the shower core region (e.g., 45 m);
- “Compactness” can be employed to reject cosmic ray background efficiently.



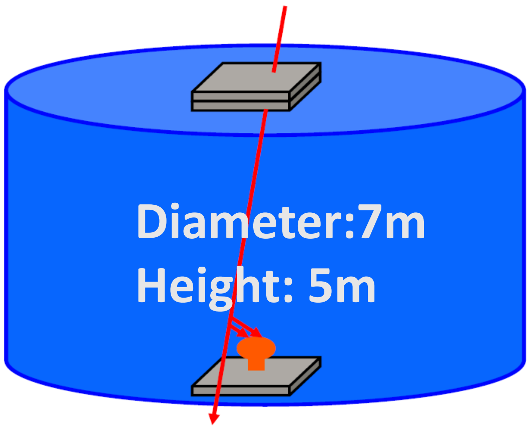


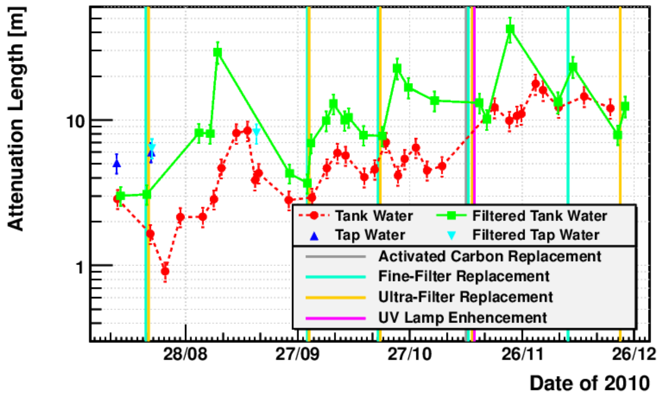
- Effective area:
  - ~1000 m^2 @ 100 GeV; >80,000 m^2 @ 5 TeV.
- Angular resolution:
  - Optimized bin size: 0.55° @ 1 TeV; 0.23° @ 5 TeV.

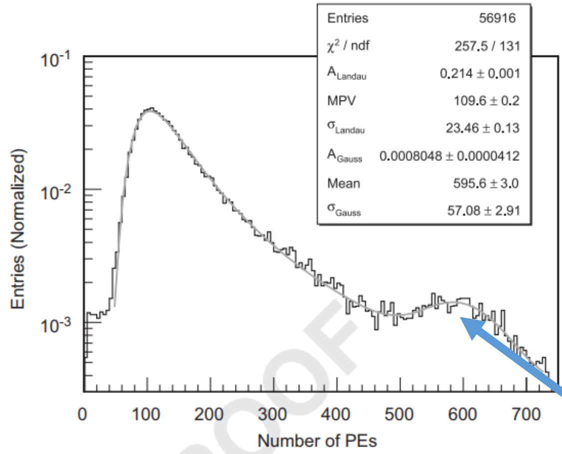


- Sensitivity : 0.013 Crab@2TeV

R&D work *– prototype @ IHEP, Beijing*



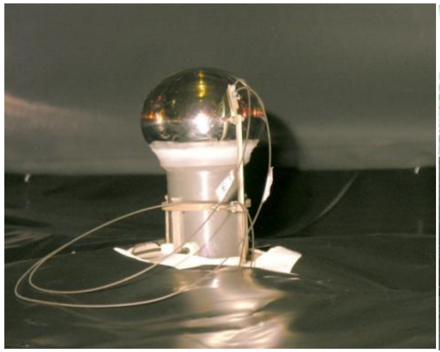




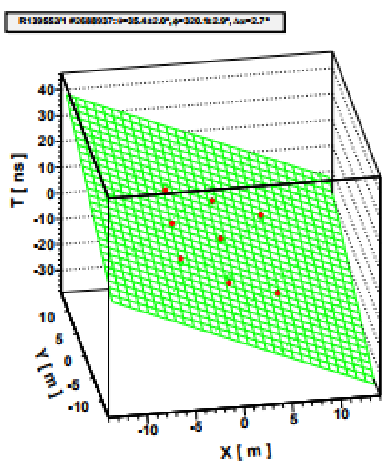
Muon peak-iii

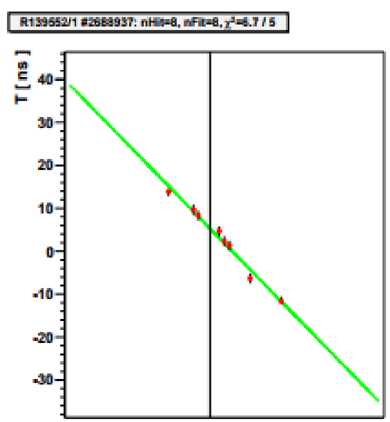
NIMA, Volume 644, Issue 1, Pages 11-17

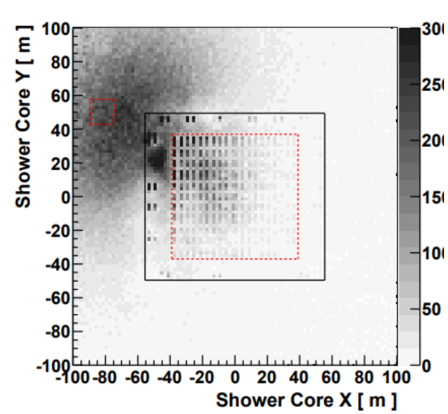
R&D work *– engineer array @ YBJ, Tibet*

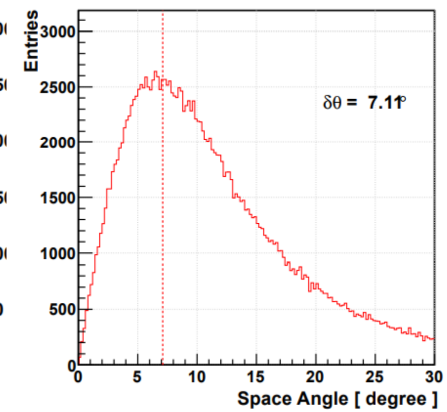


A reconstructed shower-core distribution from ARGO-YBJ for the GPS time-matched events of the prototype array and ARGO-YBJ.









The space angles of the reconstructed shower directions between the two experiments for the matched shower events.

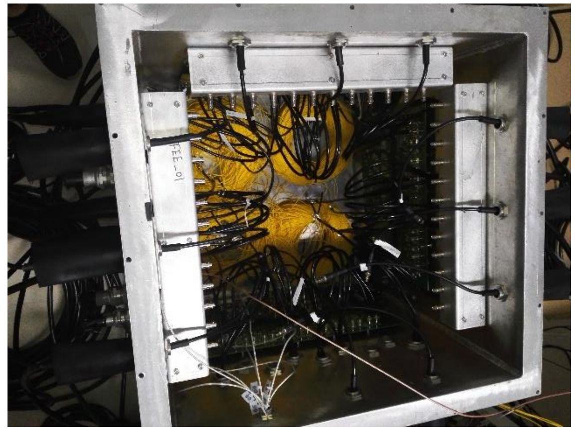
NIMA, Volume 724, Pages 12-19

Collaborators & Schedule

University of Science and Technology of China	**Electronics, PMTs**
National Space Science Center, CAS	**Slow Control System**
Tsinghua University	**WR Clock system**
Institute of High Energy Physics, CAS	**Detector installation, DAQ, data, etc.**

2018.6	Start detector installation of the 1st pond.
End of 2018	Installation finished of the1stpond.
Beginning of 2021	The whole WCDA installation completed.

And now …



Summary

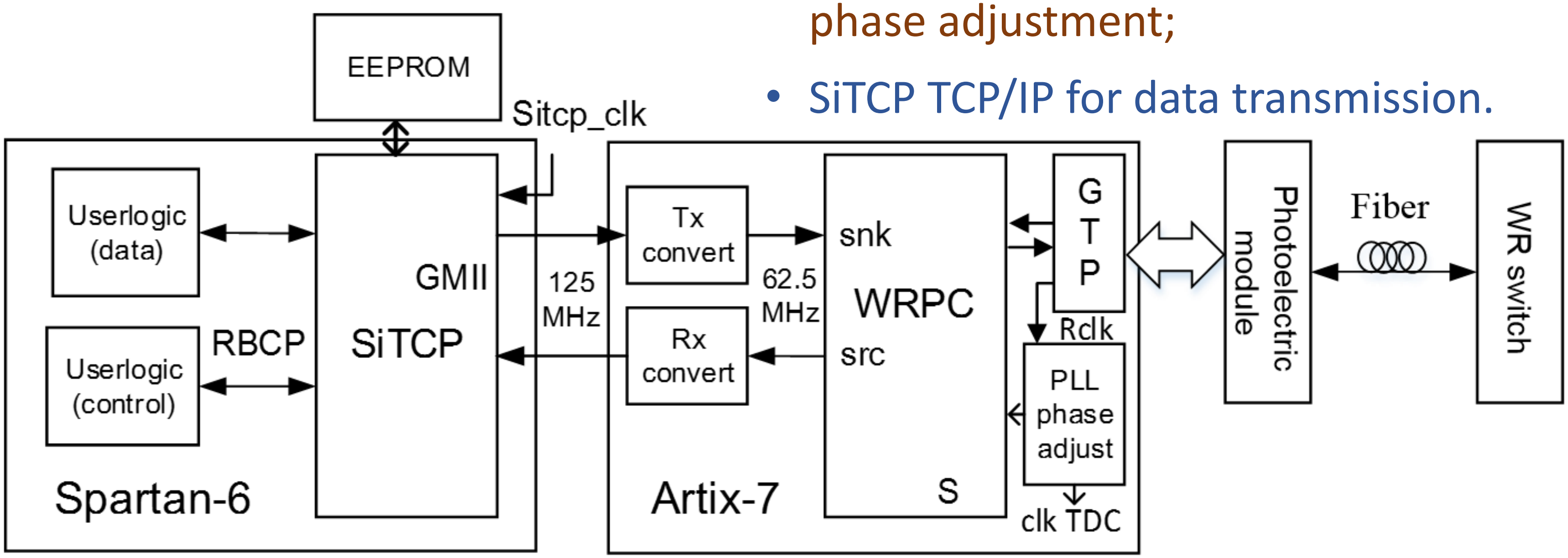
- LHAASO-WCDA, as a component of LHAASO project, aims at playing an important role in the Gamma astronomy.

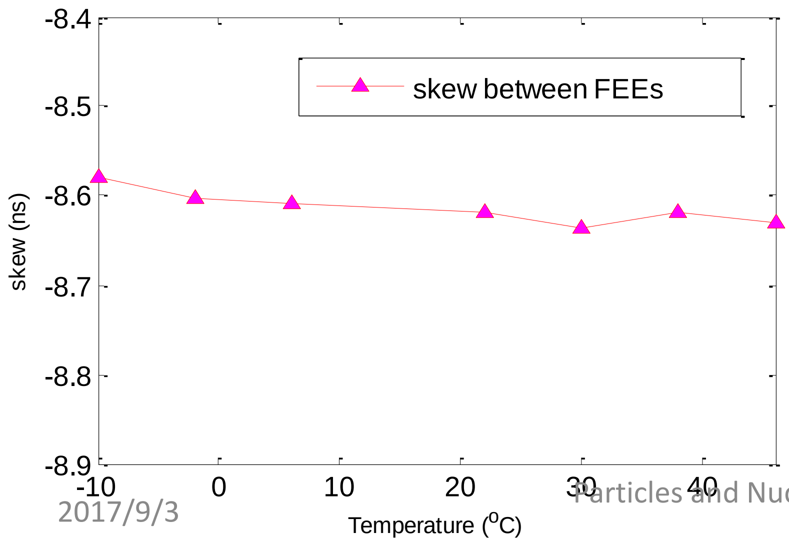
- LHAASO-WCDA already started construction. And one quarter of array will start operation in the end of 2018.

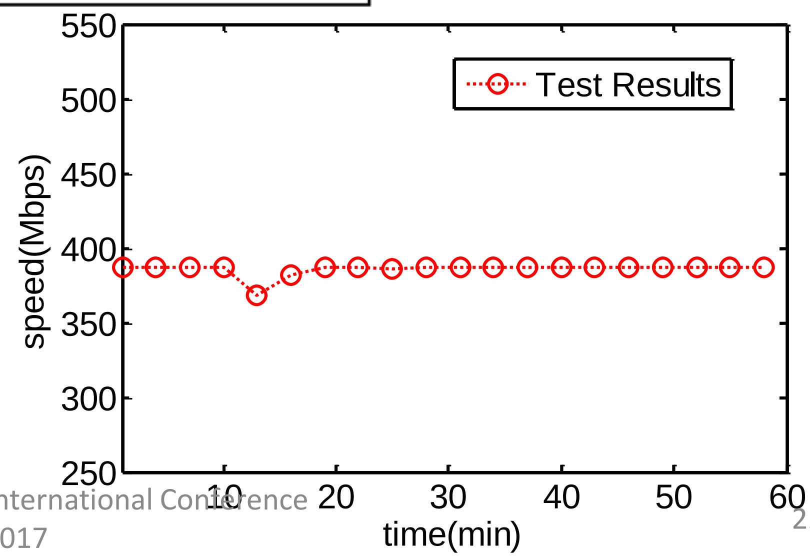

Thank you!
2017年5月-LHAASO

Clock & Data Transmission

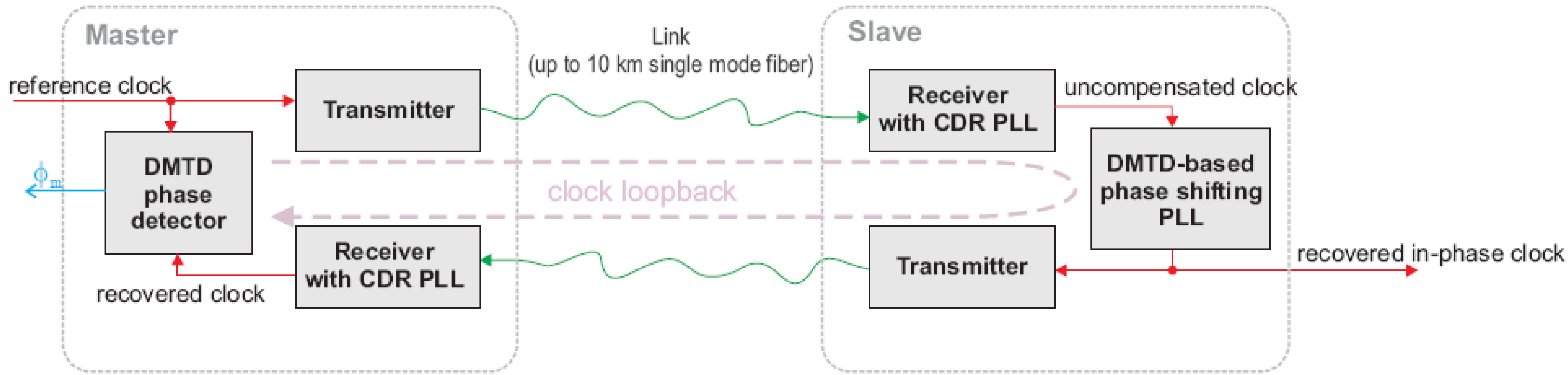
- Artix-7 based WR PTP core & FPGA PLL phase adjustment;
- SiTCP TCP/IP for data transmission.



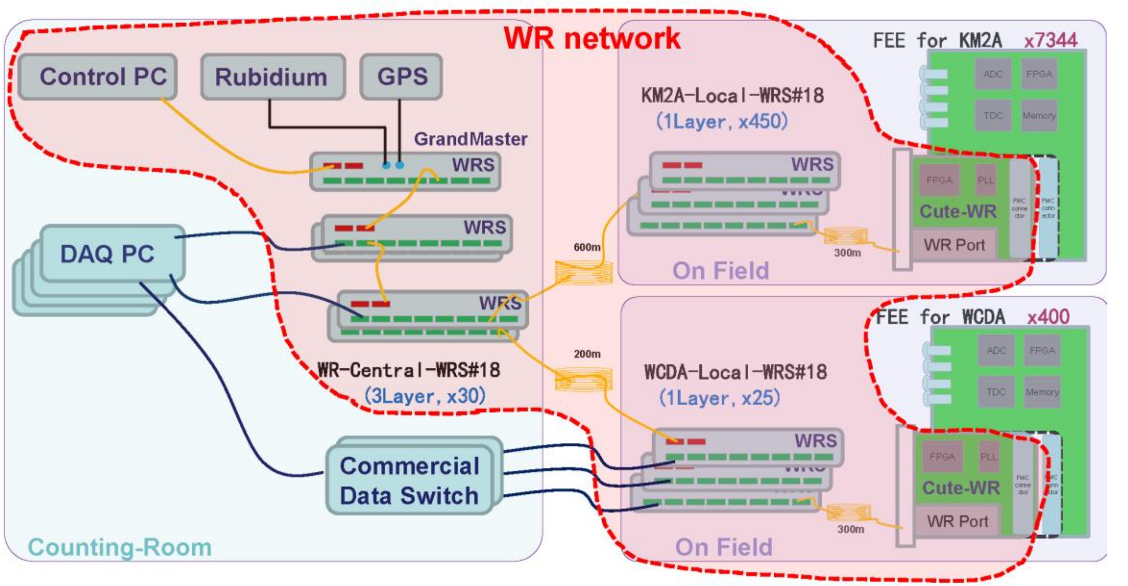




Clock Distribution: White Rabbit

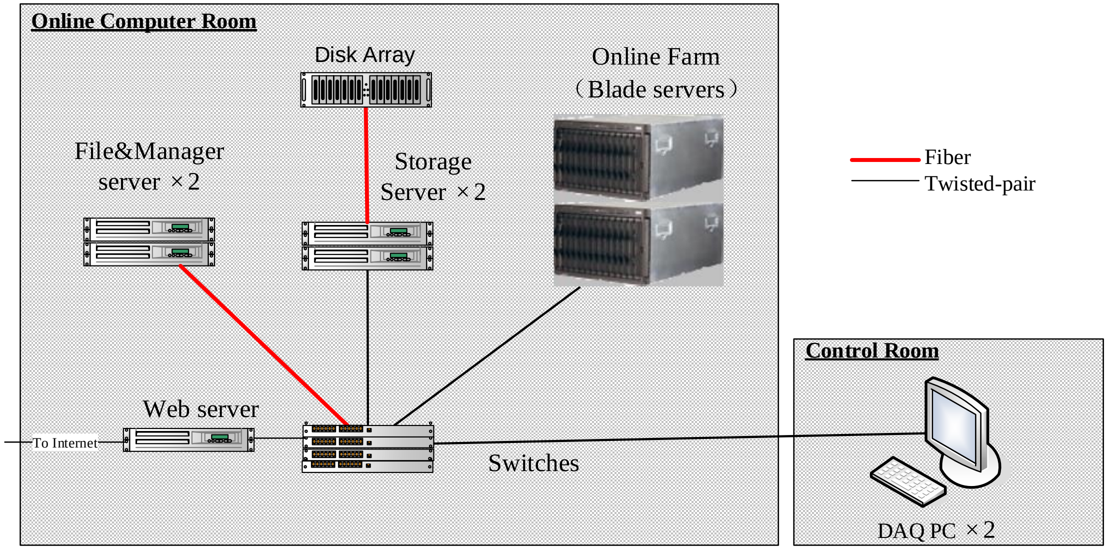


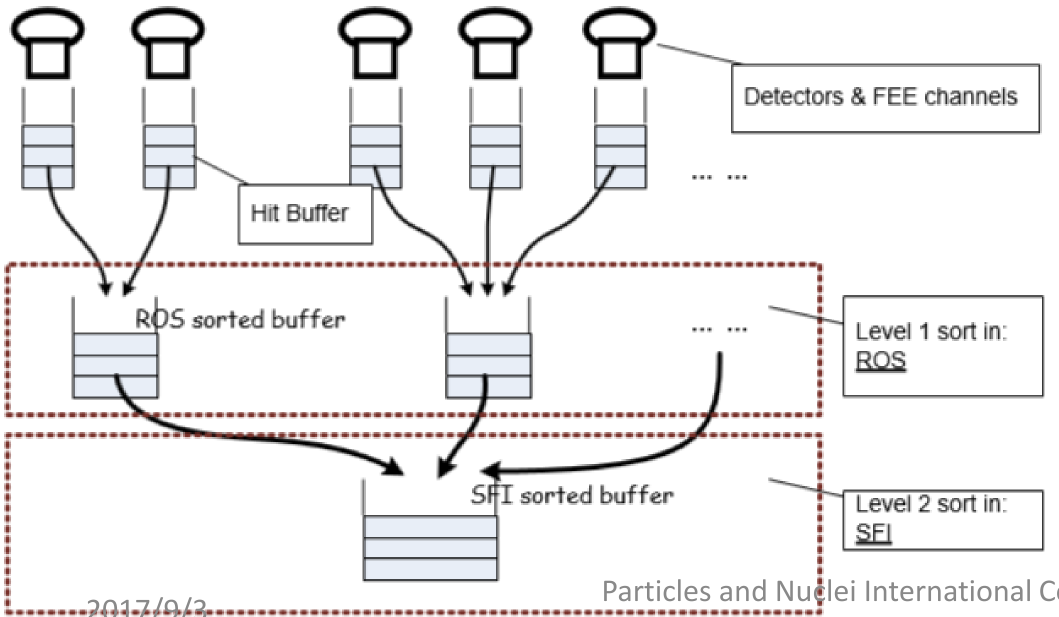
- Dedicated switch and fiber connections are to be employed for clock distribution and data transferring.
- Precise synchronization (<0.3 ns) for all FEEs in the range of at least >1 km;
- Assistance to FEE, every hit can be tagged with the absolute time.



DAQ (Original Implementation)

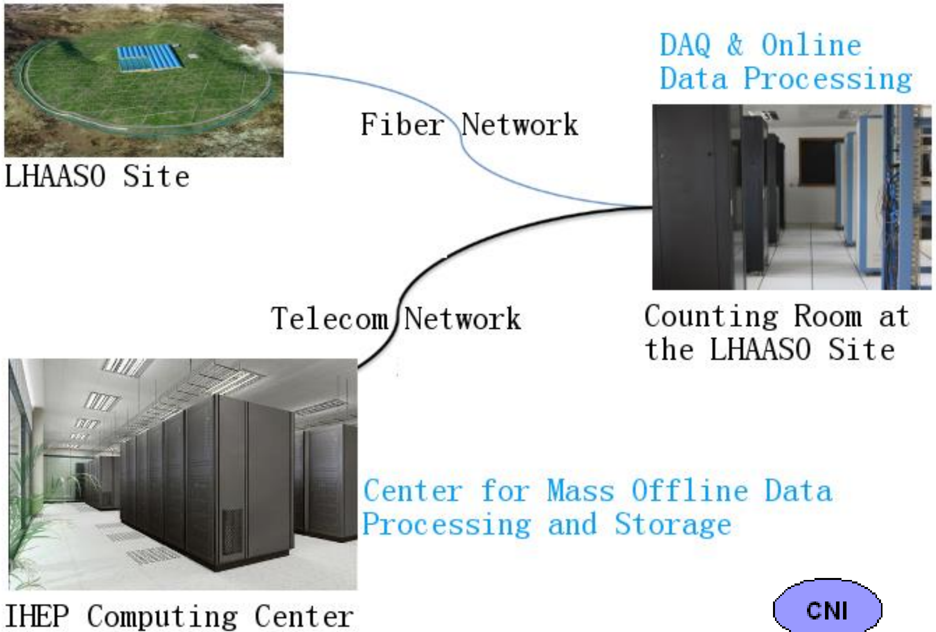
- A computer cluster consists of ~4000 CPU cores;
- Many Giga-byte switches & > 100 TB disk storage buffers are set up in addition.





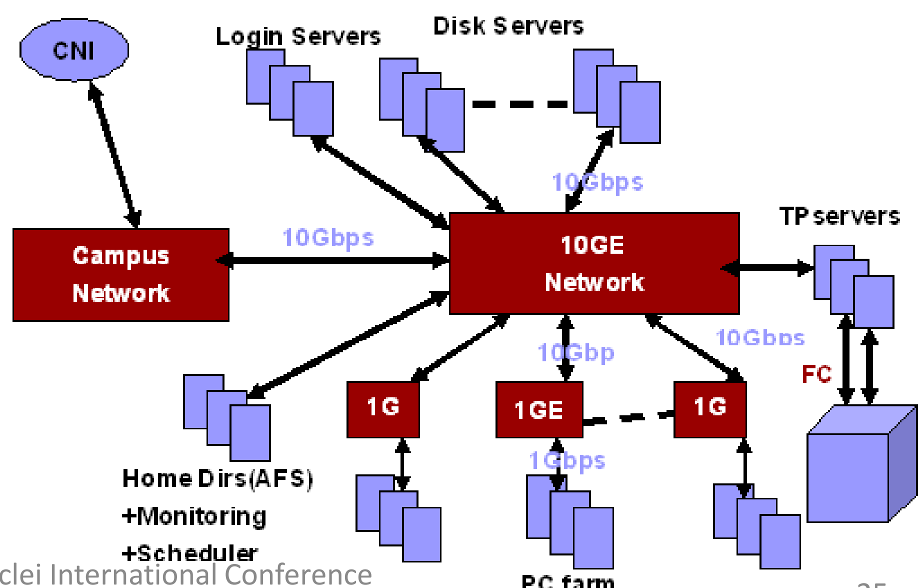
- Software implementation is based on the ATLAS TDAQ framework

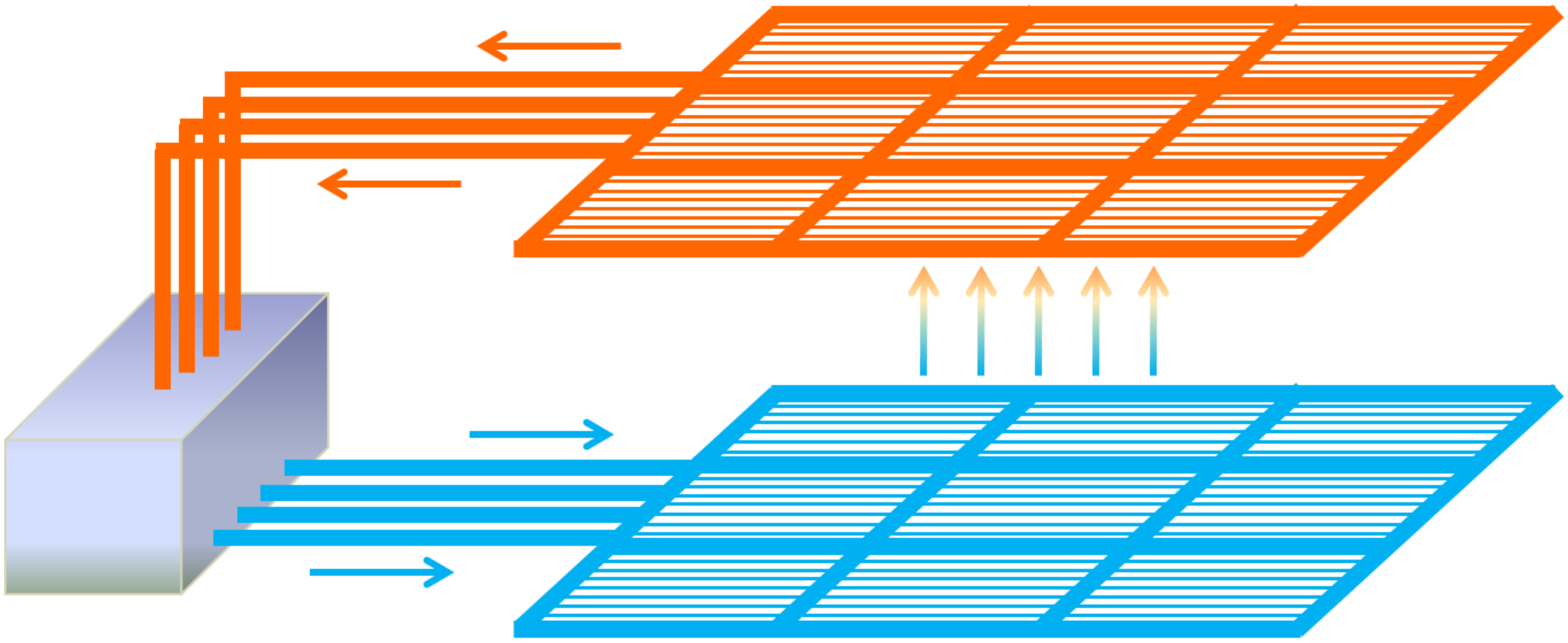
Data Storage & Processing

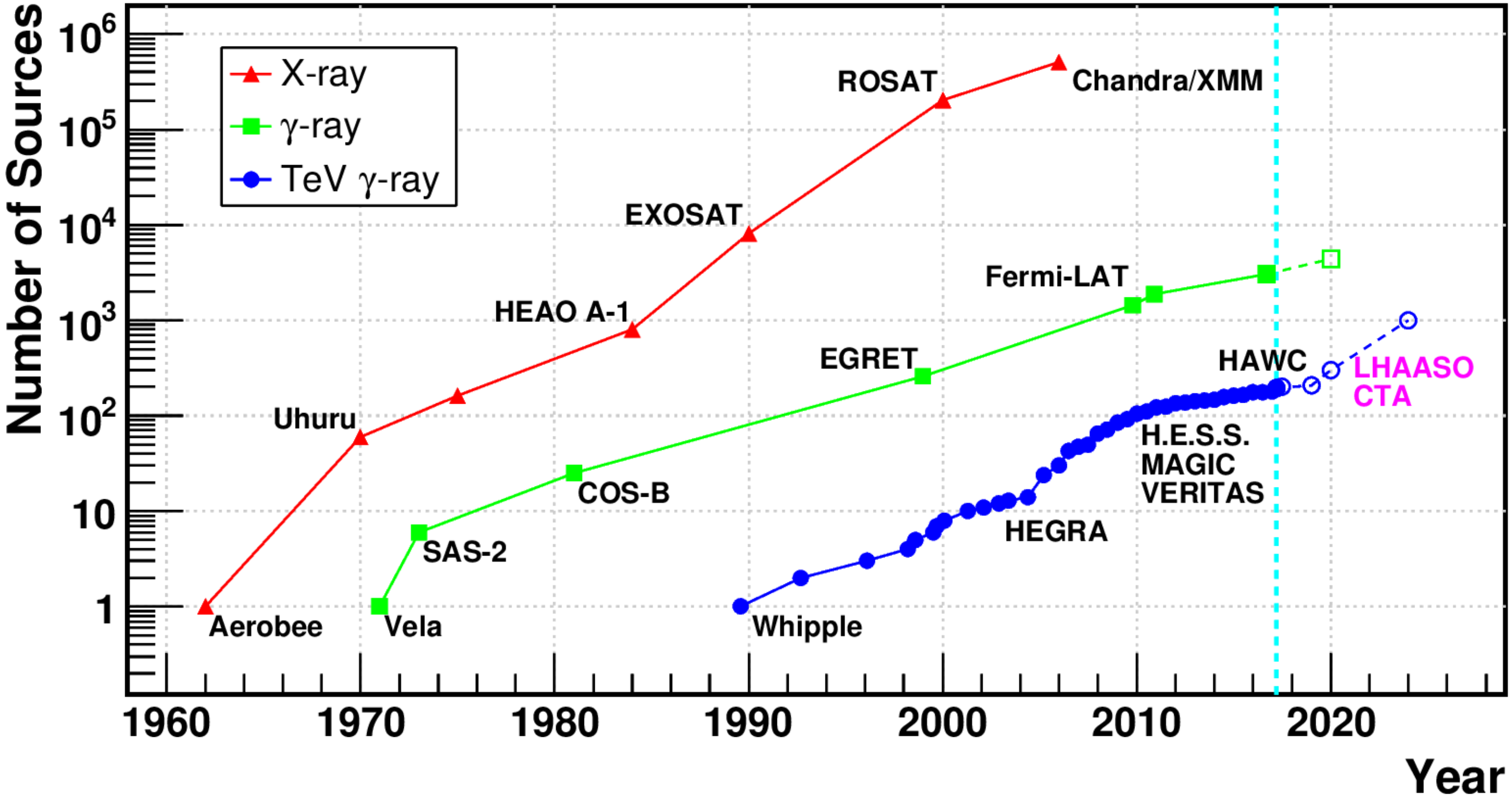


- Data are transferred to a computing center at IHEP (or other site) via commercial network links;
- The detectors are monitored and controlled at Daocheng.

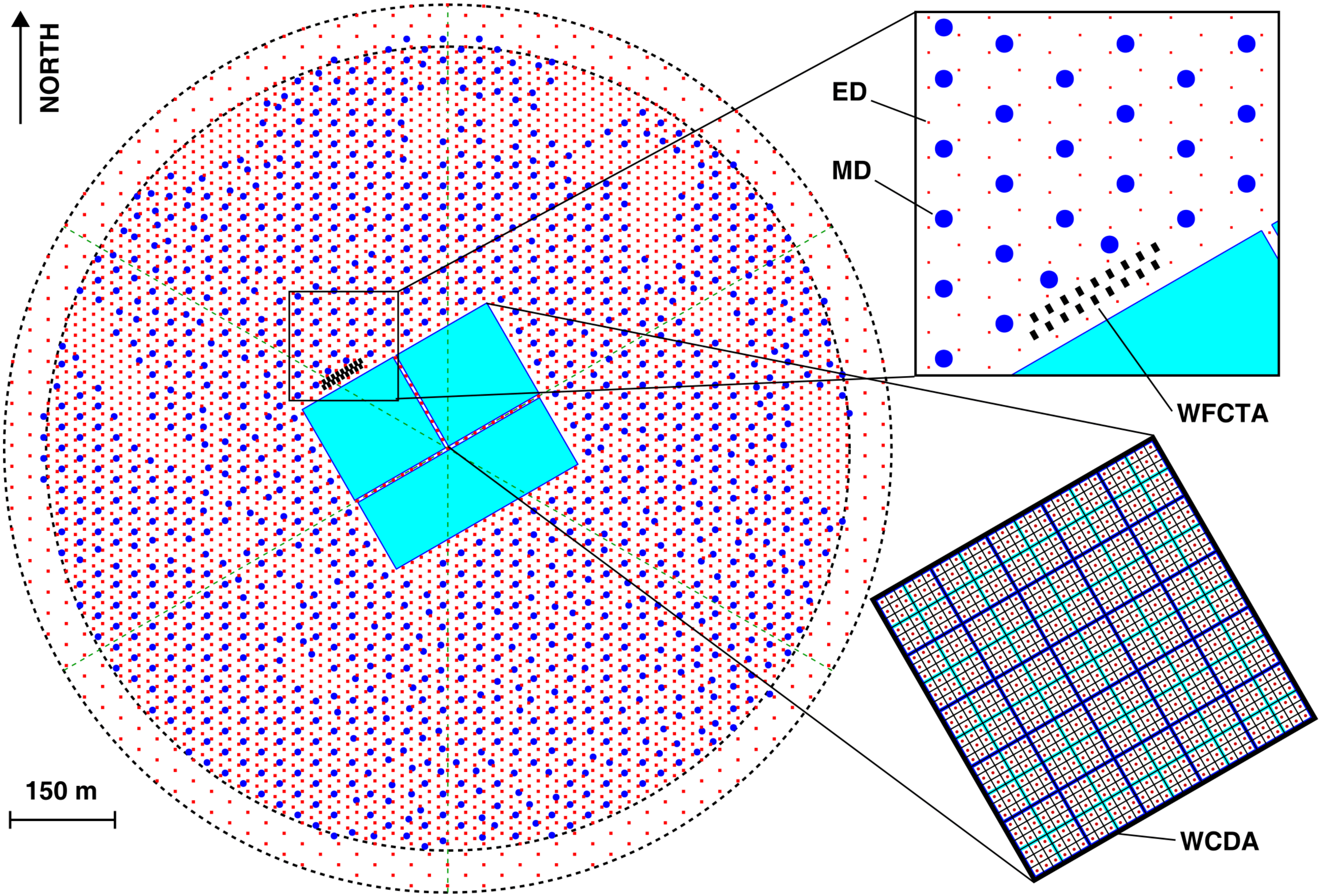
◆ Data are stored (disk + tape), accessed and processed in the infrastructure of the computer center.

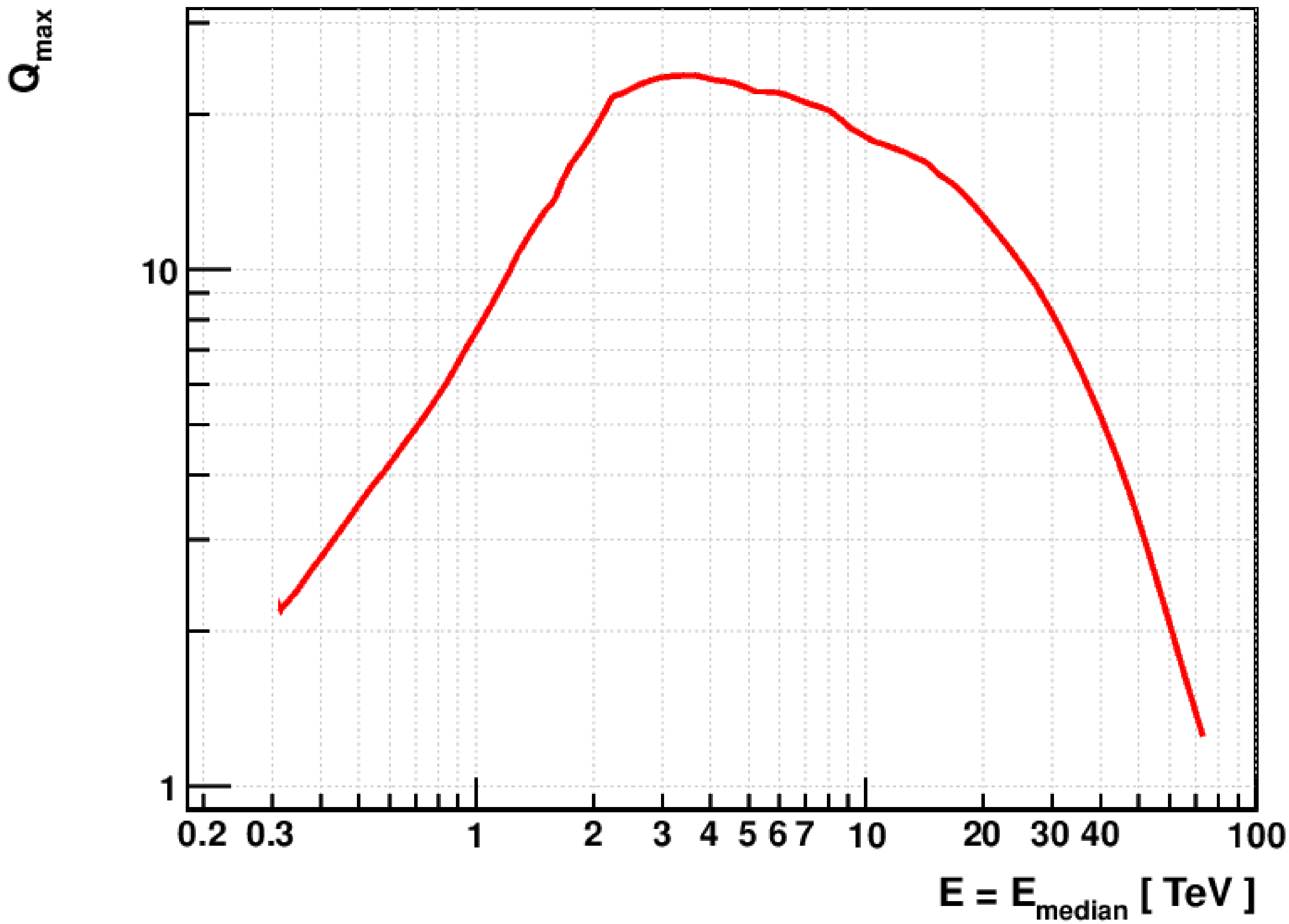






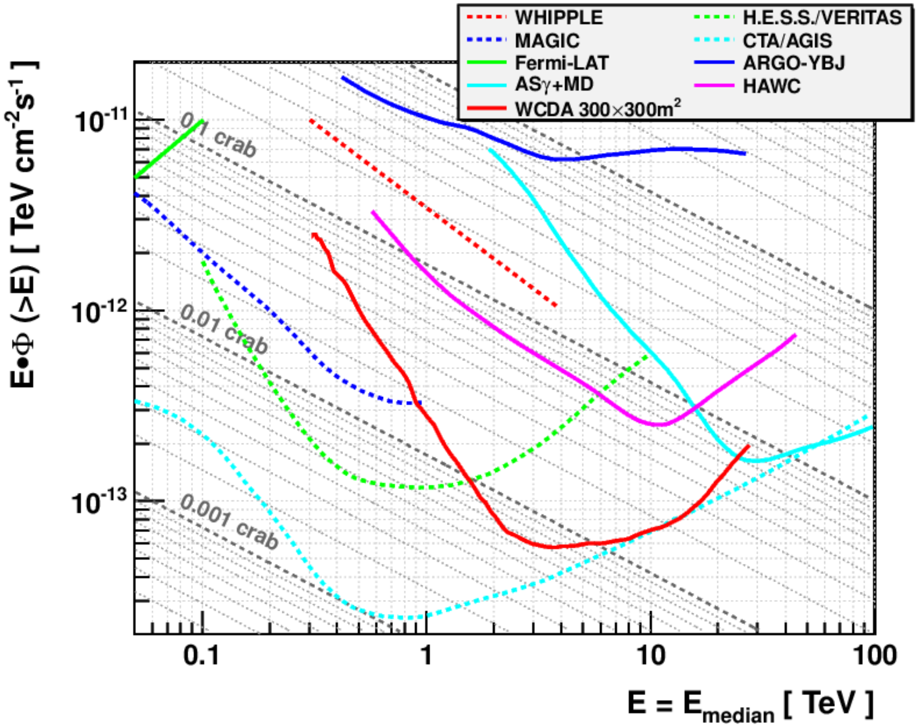
- Kifune's plot: new detectors on TeV Gamma rays are awaited to keep the discovery pace. CTA & LHAASO-WCDA will do help.
- Can the number of sources climb to ~1000 by **2020** ?


NORTH
ED
MD
WFCTA
WCDA
150 m

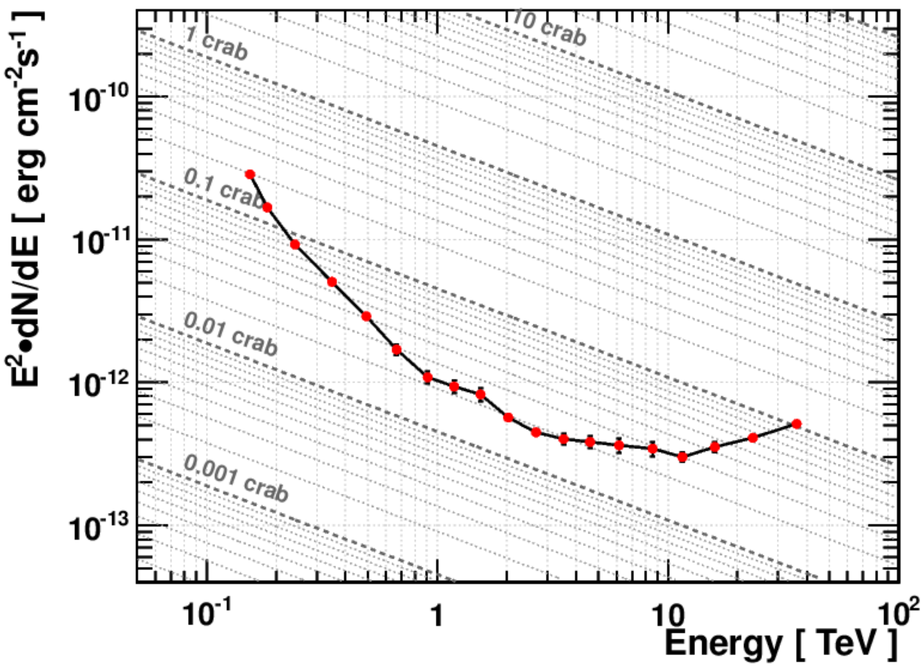


Q-factor: 7 @ 1 TeV; 22 @ 5 TeV.

Sensitivity



Integral

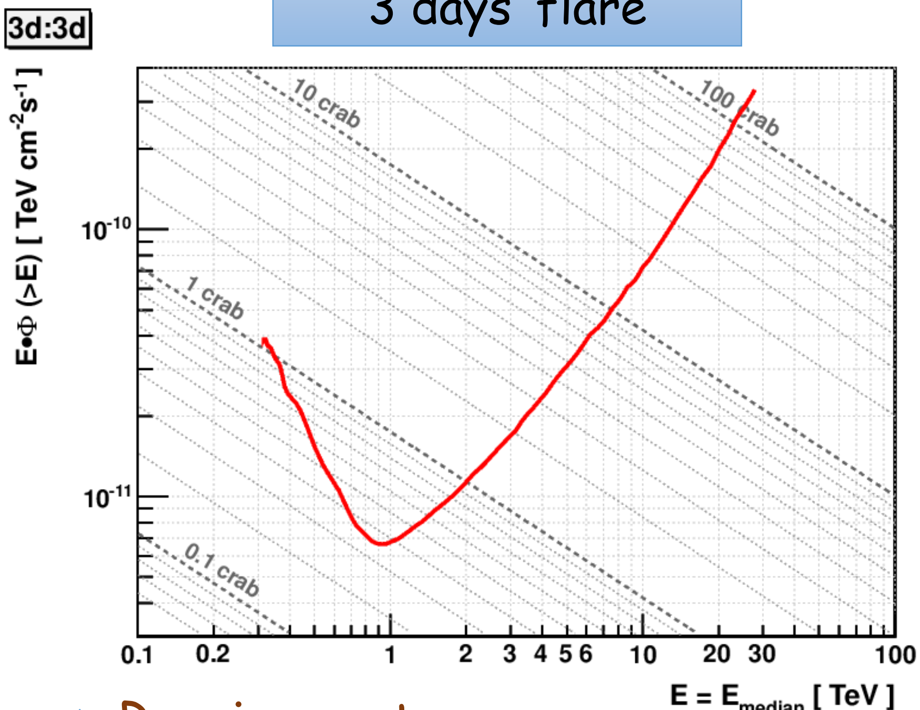


Differential

- Note:
  - Still for 90,000 m^2 water pool;
  - A factor of 30% deterioration for 78,000 m^2.

Sensitivity to Flares / GRBs

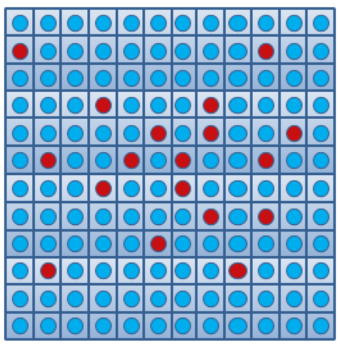
3 days' flare



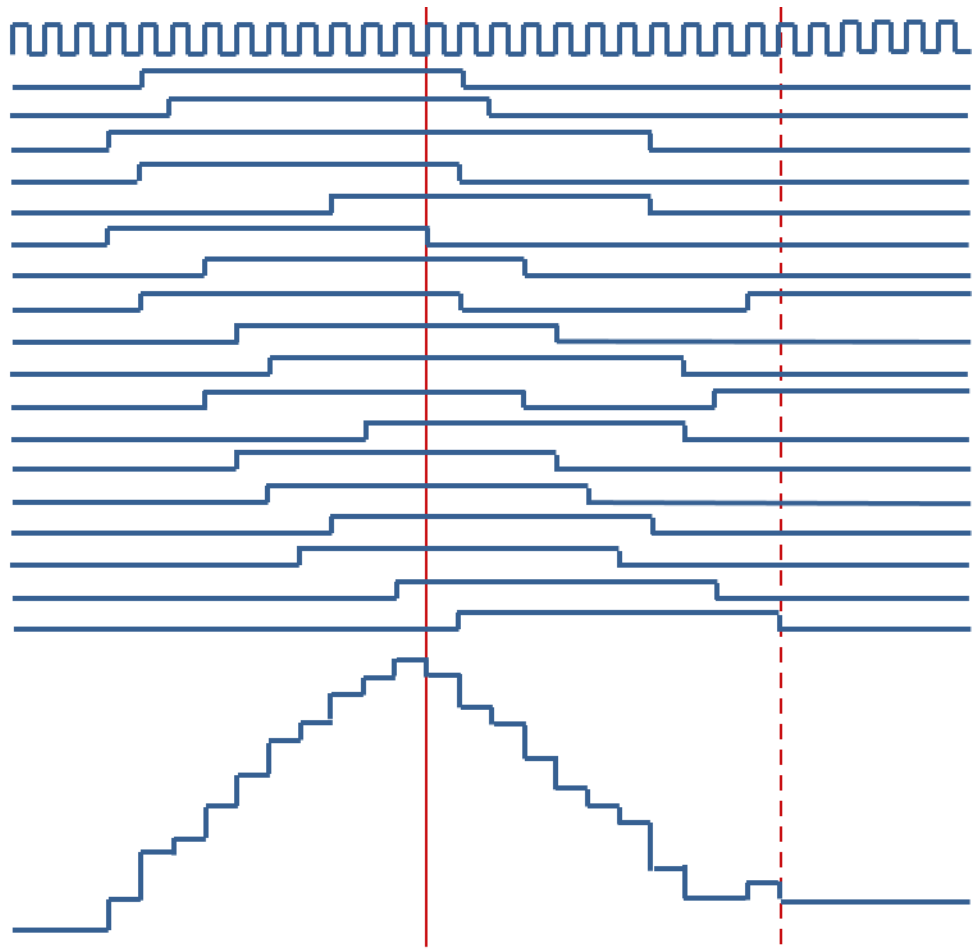
- Requirements:
  - 30 events;
  - 5 s.d.
- Calculation bases on a power law spectrum (λ=-2.62).
- Partly limited by statistics;
- 5σ/day: the detector can be very well calibrated by the Crab.

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

How to Count the Multiplicity

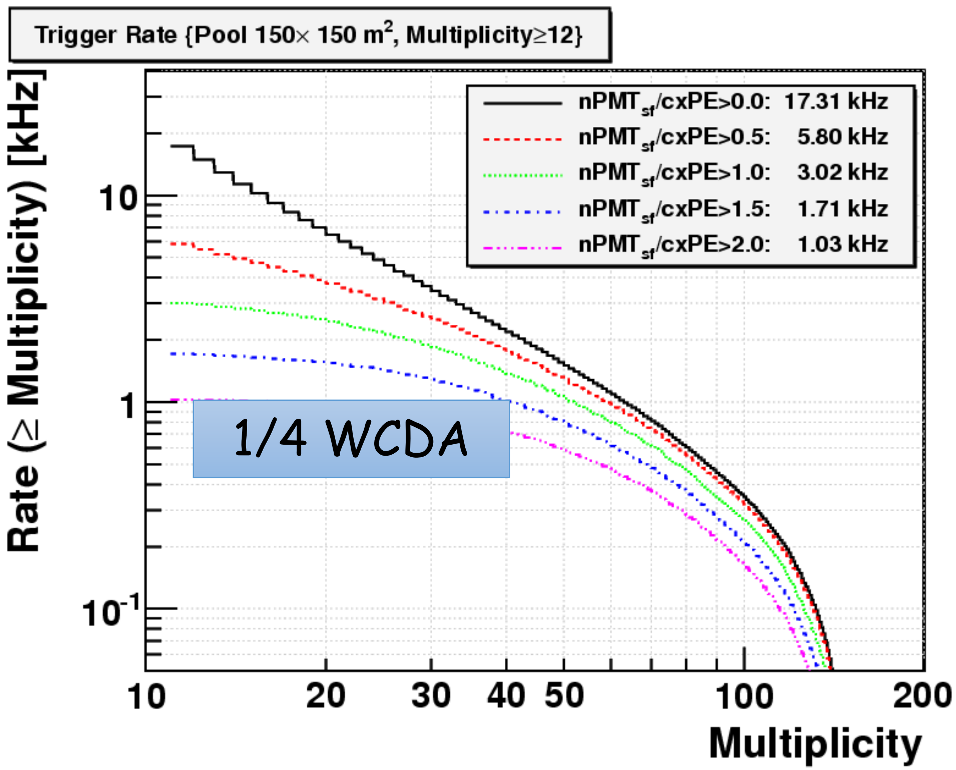


A *trigger cluster* consists of 144 detector cells



Evaluate at the falling edge next to a rising one

Trigger Rate & Data Volume



- Trigger rate:
  - 17 kHz × 4 ~ 70 kHz.
- DAQ raw input:
  - 100 bit/hit × 3600 hit × 50 kHz = 18 Gbps ~ 72 PB/yr.
- Data volume after trigger:
  - 100 bit/hit × (70 + 50 kHz × 2000 ns × 3600) hit × 70 kHz = 3 Gbps ~ 12 PB/yr.

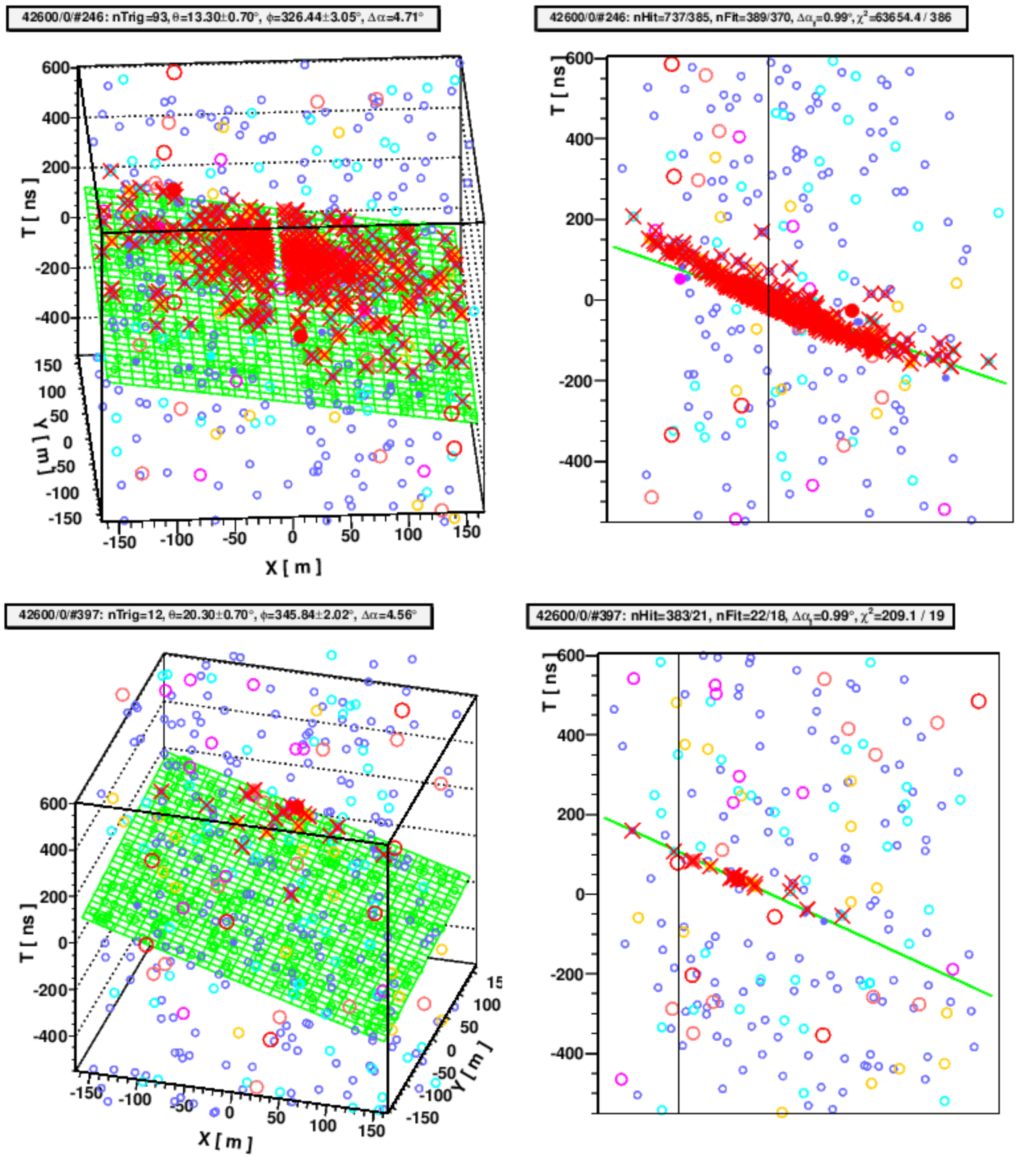
Big data require an online pre-reconstruction solution.

Trigger Cluster ID VS. Cluster ID

➔ scc / stt (tt: trigger cluster number)

104/NA	109/NA	114/NA	119/NA	124/NA	304/NA	309/NA	314/NA	319/NA	324/NA
103/103	108/107	113/111	118/115	123/**412**	303/303	308/307	313/311	318/315	323/NA
102/102	107/106	112/110	117/114	122/**411**	302/302	307/306	312/310	317/314	322/NA
101/101	106/105	111/109	116/113	121/**410**	301/301	306/305	311/309	316/313	321/NA
100/100	105/104	110/108	115/112	120/**409**	300/300	305/304	310/308	315/312	320/NA
004/**400**	009/**401**	014/**402**	019/**403**	024/**408**	204/**413**	209/**414**	214/**415**	219/**416**	224/NA
003/003	008/007	013/011	018/015	023/**407**	203/203	208/207	213/211	218/215	223/NA
002/002	007/006	012/010	017/014	022/**406**	202/202	207/206	212/210	217/214	222/NA
001/001	006/005	011/009	016/013	021/**405**	201/201	206/205	211/209	216/213	221/NA
000/000	005/004	010/008	015/012	020/**404**	200/200	205/204	210/208	215/212	220/NA

Online Pre-reconstruction



- Fast iteration on all sky cells;
- Rotate all the hits into the plane perpendicular to the cell and sort the time;
- Find the maximum number of consecutive hits that could be in the plane;
- Compare the maximum number from different sky cells, find the best sky cell;
- Plane fit;
- Reject the noises +/- 100 ns outside the shower plane;
- This can be called “L2” trigger (as some events may fail to pass through).