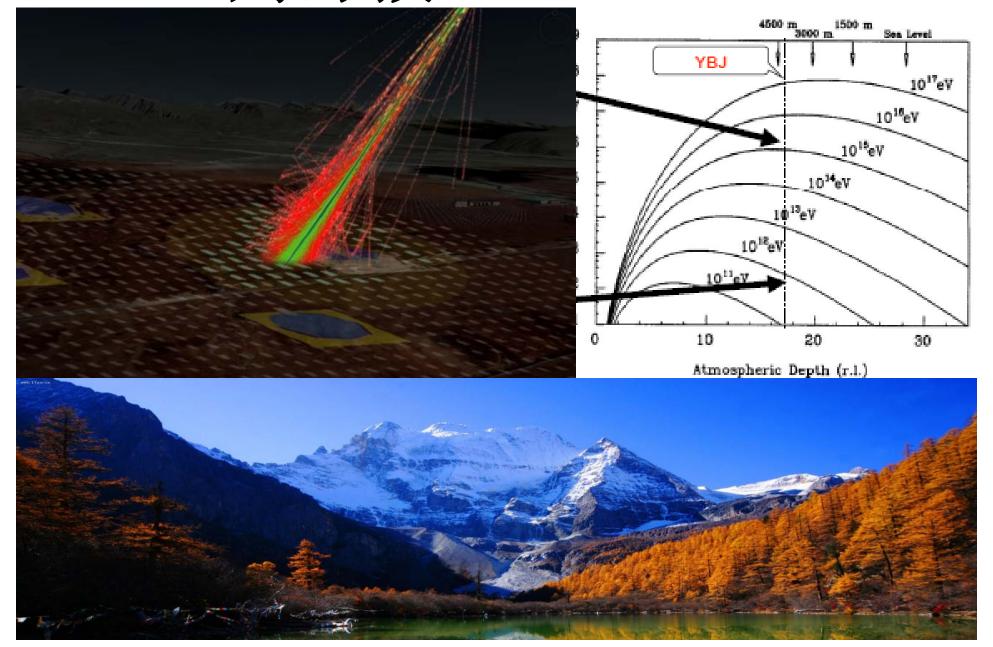
# 高海拔宇宙线观测站 LHAASO: Design Highlights

曹臻,高能物理研究所

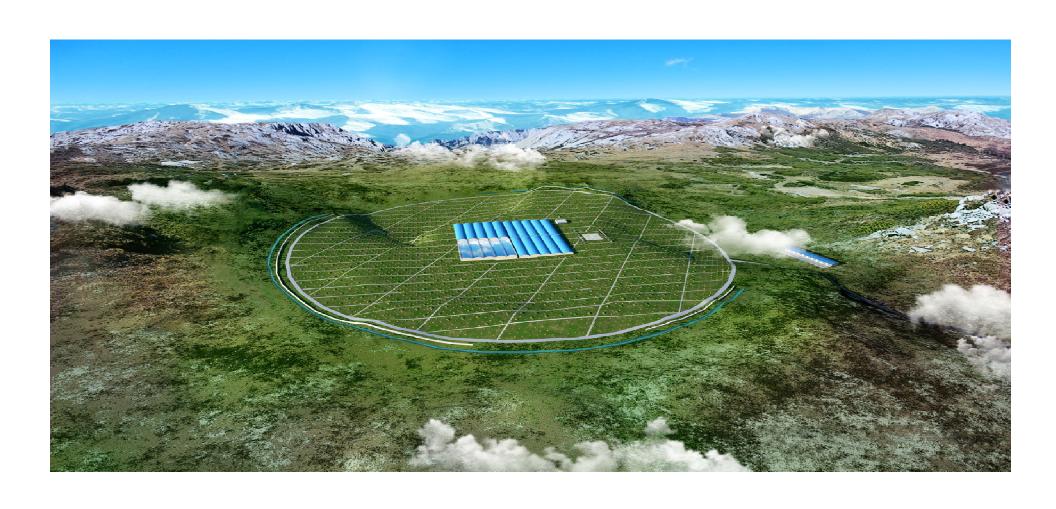
NED'2014, 兰州, 2014-08

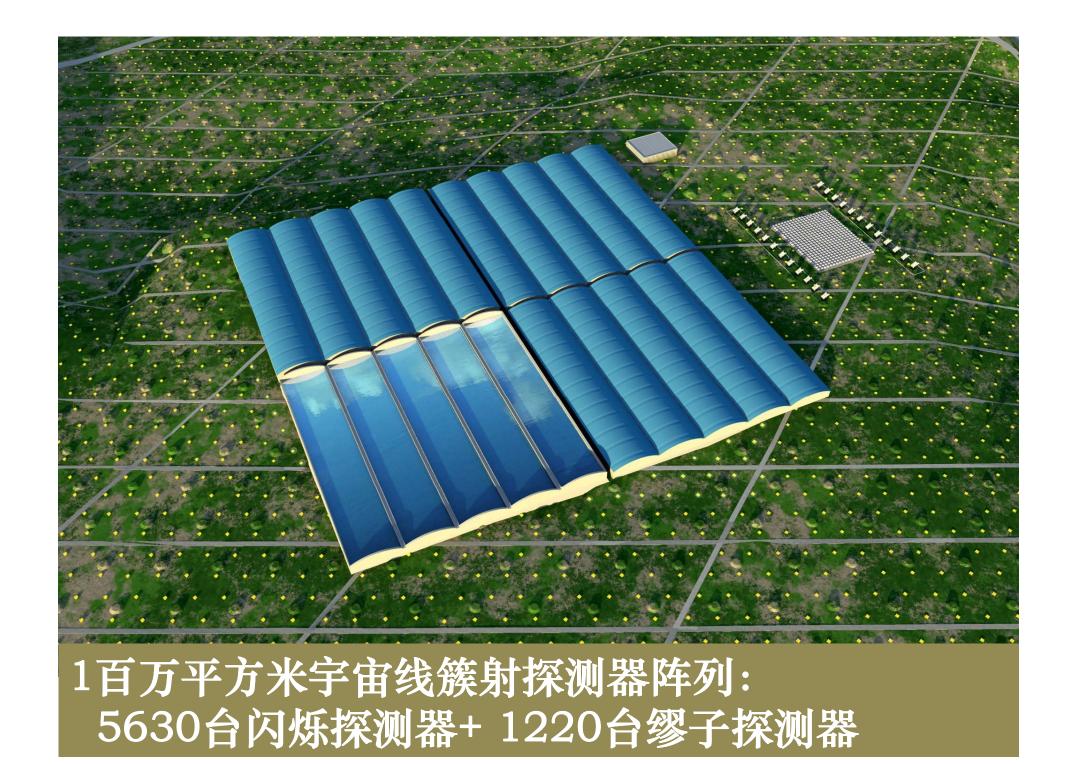
## 高海拔

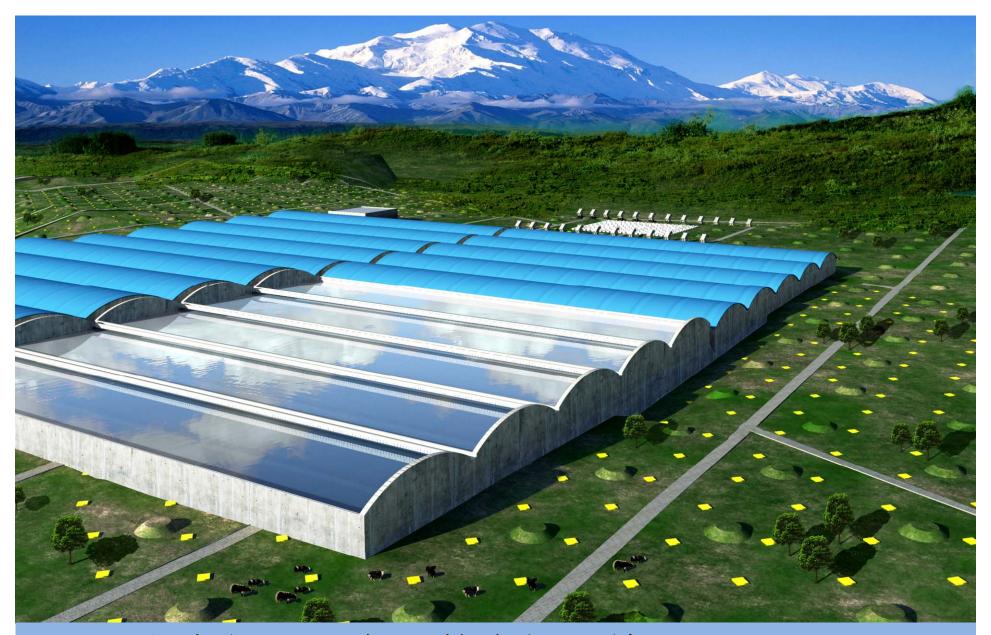
#### 高能宇宙线探测



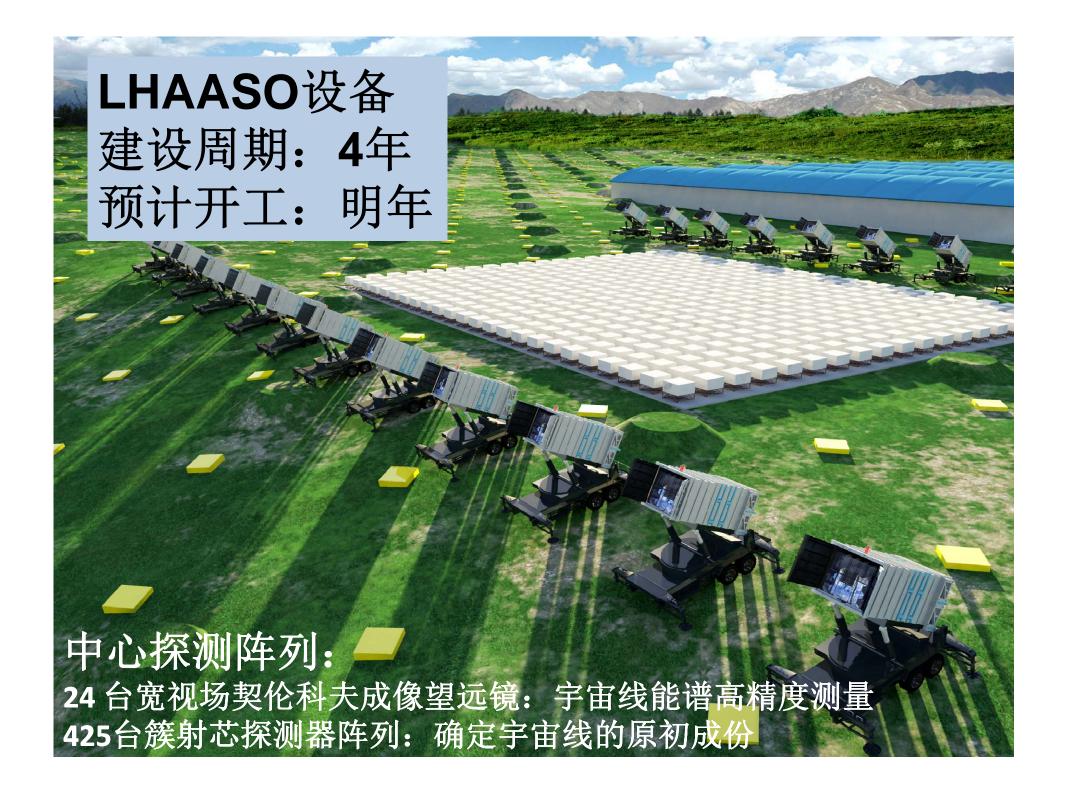
## 高海拔宇宙线观测站 (LHAASO) 总体布局







9万平方米伽马源全天普查望远镜 面积相当于12个标准游泳池



## 提纲

一. LHAASO探测器 "大"而"散": KM2A "大"而"密": WCDA 参数多: WFCTA + SCDA

二. LHAASO电子学

分布范围大: WR

密度高: ASIC

多参数: Trigger-less

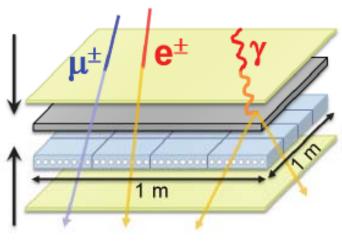
数据量大

三. 总结、展望

## **ED Specifications**

Item	Value
Effective area	1 m <sup>2</sup>
Thickness of tiles	2 cm
Number of WLS fibers	32/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%)	>10 years
Spacing	15 m
Total number of detectors	5635
15 m 15 m	15 m

## Electromagnetic Particle Detector (ED)



Steel Case Lead (0.5 cm)

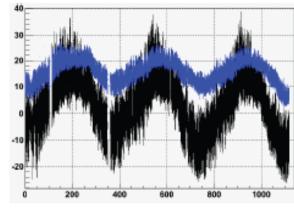
SC Tiles (2 cm)

Steel Case



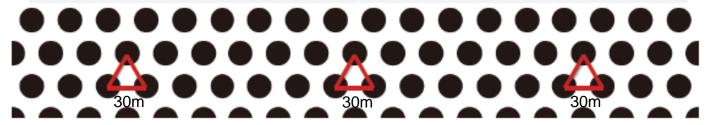


- Uniformity for 5635 units: < 10%</li>
- Stability with ±30°C: <5%</li>
- Aging in 10 years: <20%

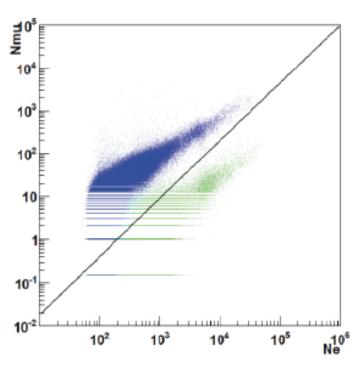


### MD Specifications

Item	Value
Area	36 m <sup>2</sup>
Water Depth	1.2 m
Molasses overburden	2.5 m
Water transparency (att. len.)	> 30 m (400 nm)
Reflection coefficient	>95%
Dynamic range	1-10,000 particles
Time resolution	<10 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging (<20%)	>10 years



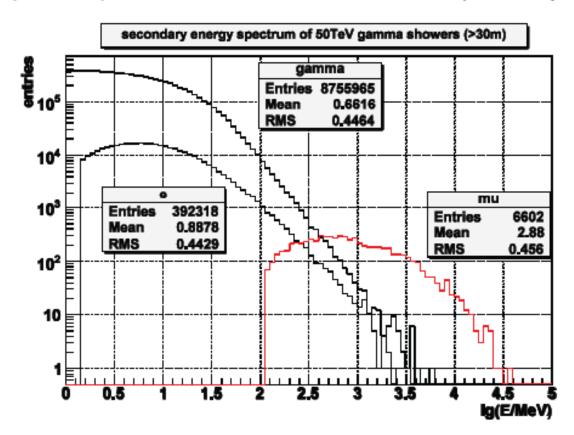
## Gamma/proton Discrimination - KM2A



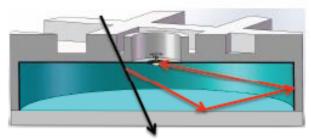
nHit	log <sub>10</sub> (E) GeV	Q-factor
20-30	3.60	2.67
30-45	3.87	5.62
45-65	4. 12	11.9
65-90	4. 35	20.7
90-120	4. 55	46.4
120-180	4. 76	86.6
180-260	5. 03	backgroud free
260-360	5. 28	backgroud free
360-500	5. 53	backgroud free
500-700	5.82	backgroud free
700-1000	6. 11	backgroud free

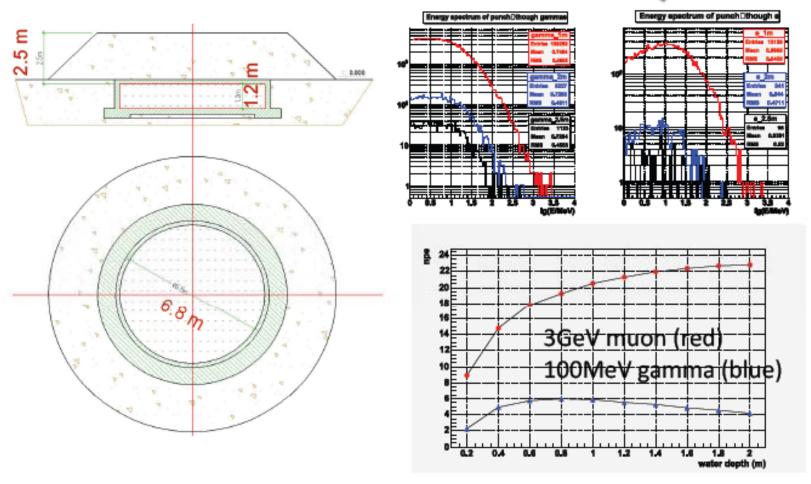
## A large area (pure) muon detector

- Muon detection efficiency
- $N_{\gamma}:N_{e}:N_{\mu}^{2}:5\%:0.1\%$ , (>1GeV,  $N_{\mu}>>N_{\gamma}$ )



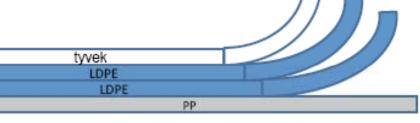
## Muon Detector (MD)





高能所: 李秀荣(周四下午,第一会场)













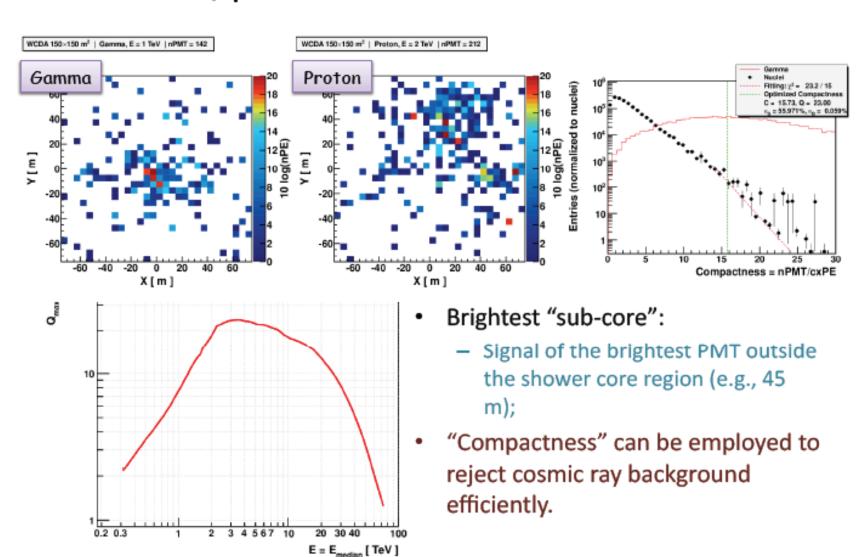
## 水Cherenkov望远镜"大"而"密"



WCDA: Survey of the VHE gamma ray sky

• <1% I<sub>Crab</sub>→300m\*300m 4 m 8"/9" PMT 5 m 5 m 127.3 Mean **RMS** 8.426 wirhCurtain 17710 **Entries** Mean 120.6 **RMS** 3.027 200 time[ns]

#### Gamma/proton Discrimination - WCDA

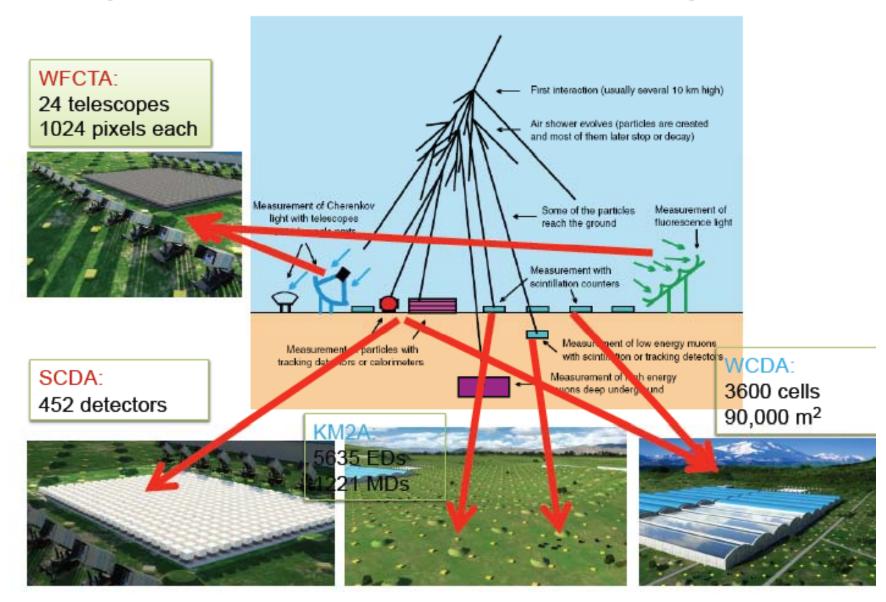


## **WCDA Specifications**

Item	Value
Cell area	25 m <sup>2</sup>
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	90,000 m <sup>2</sup>
Total cells	3600

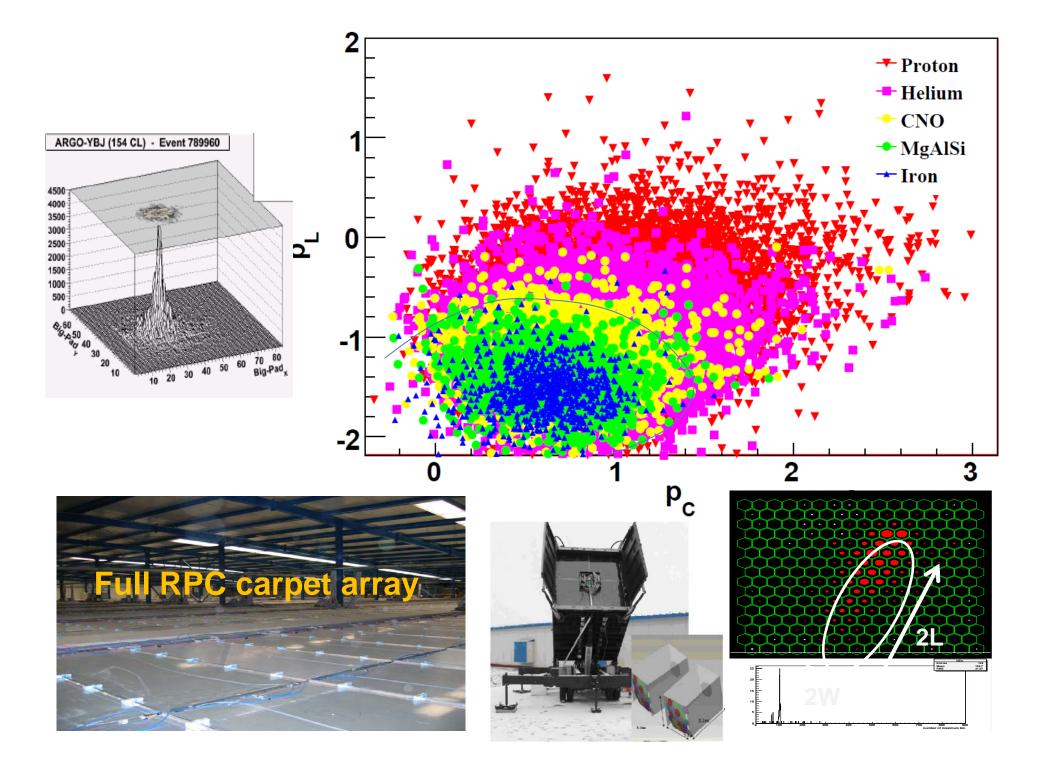
## 多参数:

#### **Hybrid Detection of Extensive Air Showers by LHAASO**



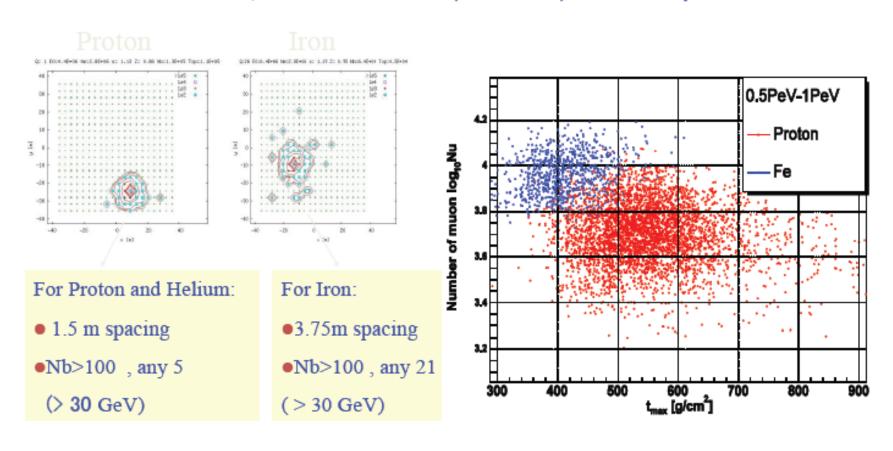
## **LHAASO** observables of showers

	Ground-based EAS arrays	Air Cherenkov/Fluorescence Telescopes	
Direction	Space-time	Image (stereo)	Image (stereo)
Core	Lateral distribution	Stereo imaging	Stereo imaging
Energy	Lateral distribution	Cerenkov light, geometry	Longitudinal development
Composition	Lateral distribution, muons (π±),	Image, Xmax	Xmax
	particles near the core $(\pi^0)$		



#### Resolution for light and heavy compositions

μ -content, Xmax and HE (>30TeV) shower particles



## **LHAASO** detector signals

- LHAASO measures the density, energy and direction of shower secondary particles which emit UV photons through
  - Air (Cherenkov and Fluorescence for WFCTA)
  - Water (Cherenkov for WCDA and KM2A-MD)
  - Scintillating (for KM2A-ED and SCDA)
- PMTs are used to convert the lights to photoelectrons
- All LHAASO detector signals come from PMTs
  - Timing: direction
  - Charge: energy, composition

## 提纲

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二. LHAASO电子学

分布范围大: WR

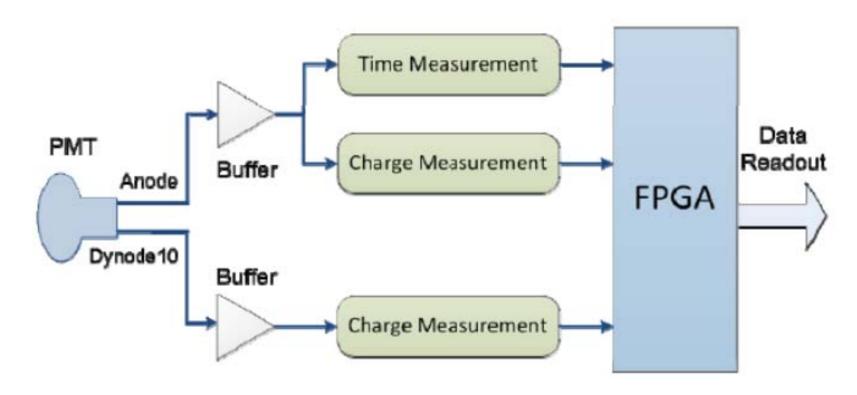
密度高: ASIC

多参数: Trigger-less

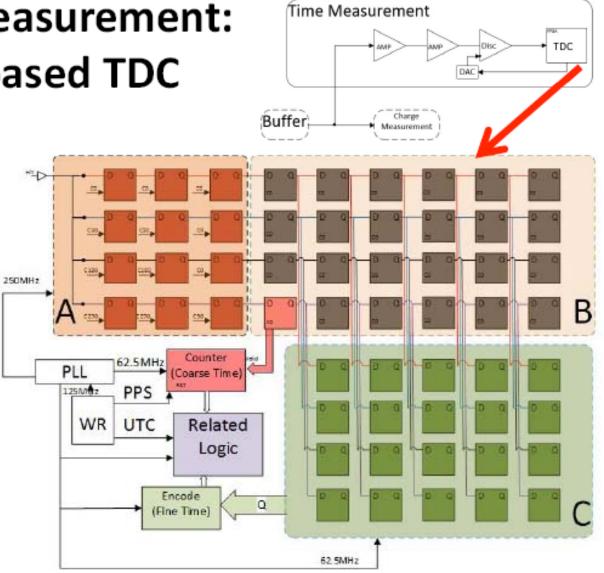
数据量大

三. 总结、展望

## Basic FEE Design



## **Timing Measurement: FPGA-based TDC**



## **LHAASO Timing Measurement**

- Gamma Ray Astronomy
  - Pointing accuracy: <0.1 deg</li>
    - Timing accuracy: <0.2ns(WCDA)/0.5ns (KM2A)</li>
  - Sensitivity ~ angular resolution
    - time jitter: <0.5ns(WCDA)/1ns(KM2A)</li>

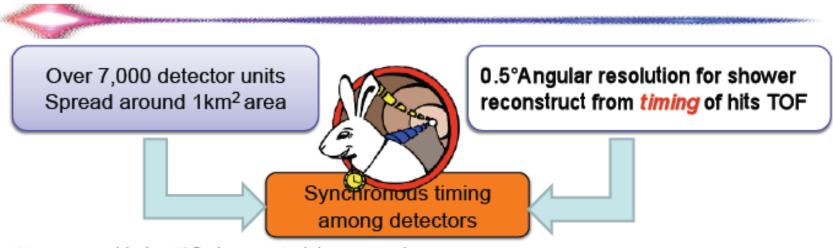




- Maximum daily temperature variation: 30 deg
- Annual temperature variation: ±30 deg

定时的特殊要求: 1km内同步精度0.1ns

## LHAASO detector timing



1000m coax cable in 30°C change,  $\Delta$  delay = 15ns!

#### Time-stamp Synchronization

Time stamps of >7,000 nodes to be aligned <500ps (rms).

#### Frequency distribution & phase locking

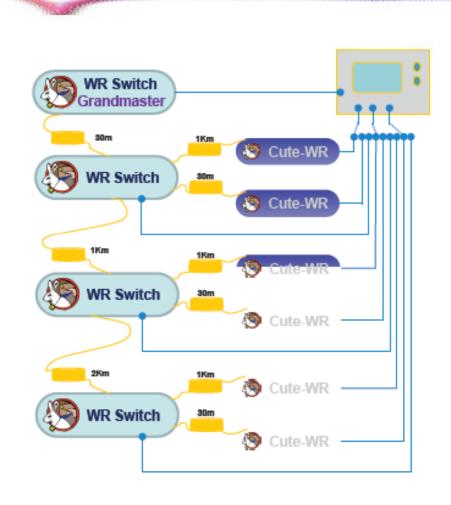
Distribute synchronous ADC clock with <100ps skew.

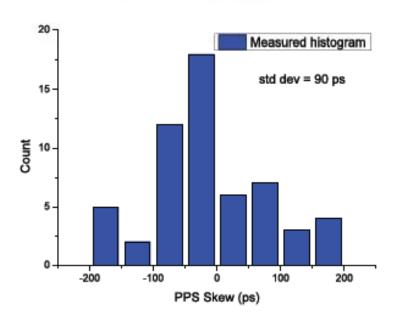
#### Traceability & Real-time calibration

Timing delay compensation due to environmental perturbation in hardware in real time.

清华:李鸿明(周四上午,第二会场)

## WR performance



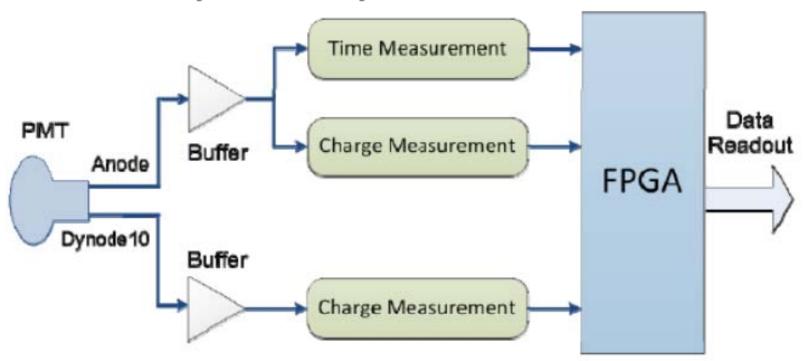


Cascade topology

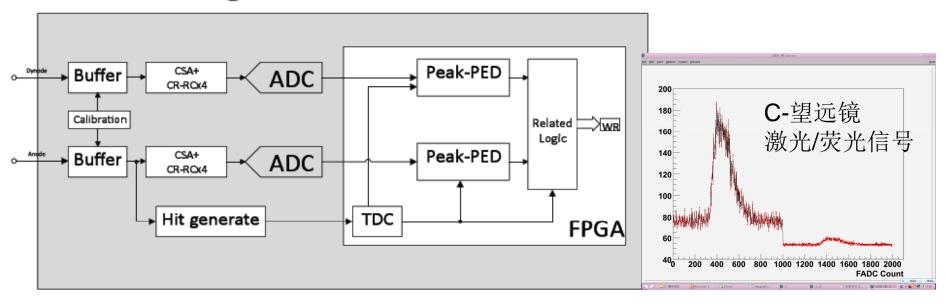
WR CERN: 1ns

## **Charge Measurement**

 Each array covers a wide energy band, requiring a large dynamic range which is achieve by anode+dynode readout of PMTs.

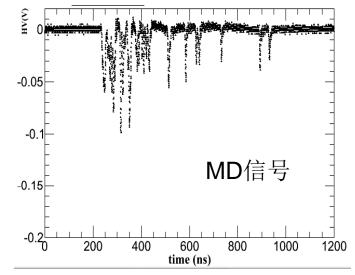


#### **Charge Measurement**



 (KM2A-ED and WFCTA: 500/50MHz FADCbased waveform digitization)

电荷测量的特殊要求: 信号持续时间长,随机性大, 信号弱 动态范围大 川大张京隆



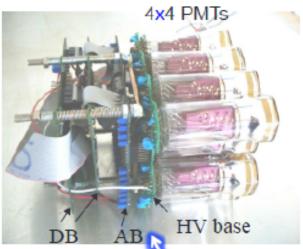
川大张京隆(周五上午,第二会场

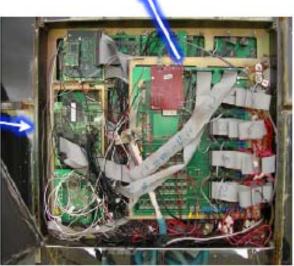
## Challenges for electronics

- ♦ High altitude and low air pressure → decreased heat dissipation
- Large number of channels > increased density, complexity and power consumption
- ♦ Harsh environment and remote location → require stability, reliability and maintainability
- Design based on IC > simplified design, decreased power consumption, increased reliability
- Compact design
- High stability
- High reliability
- Easy to maintain
- · Large number of channels
  - WFCTA: 1024 channels each
- Heat dissipation at 4300m
  - Air density: 60%
  - · Active heat dissipation system



The ASICs can be used to simplify the electronics of LHAASO





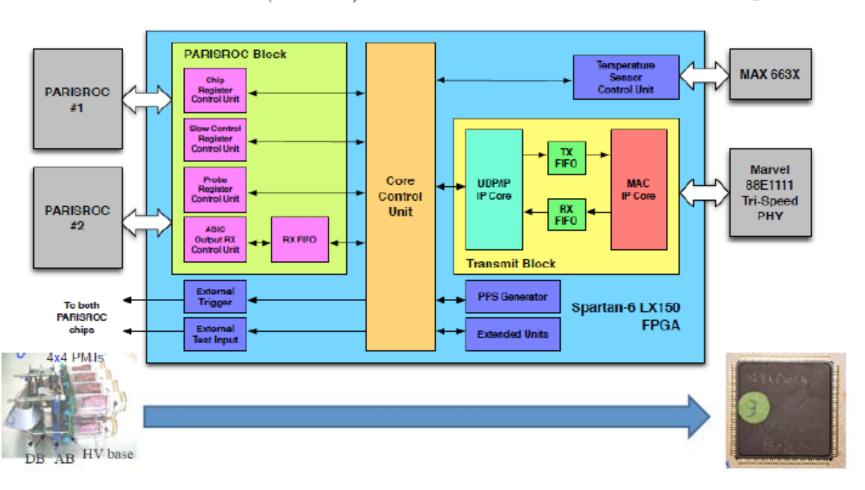
Prototypes in YBJ, Tibet

#### ASIC: IPNO+OMEGA: LHAASOROC, 科大: 梁宇(周四上午,第二会场)

## Software block & power consumption

Unit	Power Consumption
PARISROC 2 X 2	~ 1.0W
Ethernet Interface	- 1.1W
FPGA & Peripherals	~ 0.9W
_	~ 3 OW (2.98W meas)

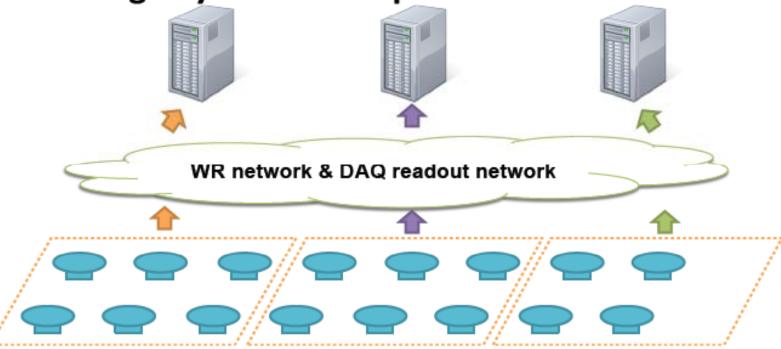
- ♦ Fully described in VHDL and FSM structure
- ♦ Resource occupation: < 10% (XS6LX150)</p>
- Power consumption: ~ 128 W for 64 clusters without Ethernet Interface (260W budget)



### "Triggerless" DAQ

#### ---hybrid measurement of shower

 Triggering, building, (re-construction) and storage by online computers



## **Data Rate**

		WCDA	KM2A
	Single rate(Hz)	50k	ED: 1k MD: 12k
	No. of Channels	3600	ED: 5635 MD: 1221
	Hits in trigger(MHz)	180	5.6
DAQ-in	Pre-Trigger(MB/s)	2160	450
DAQ-out	After-Trigger(MB/s)	300~400	~10

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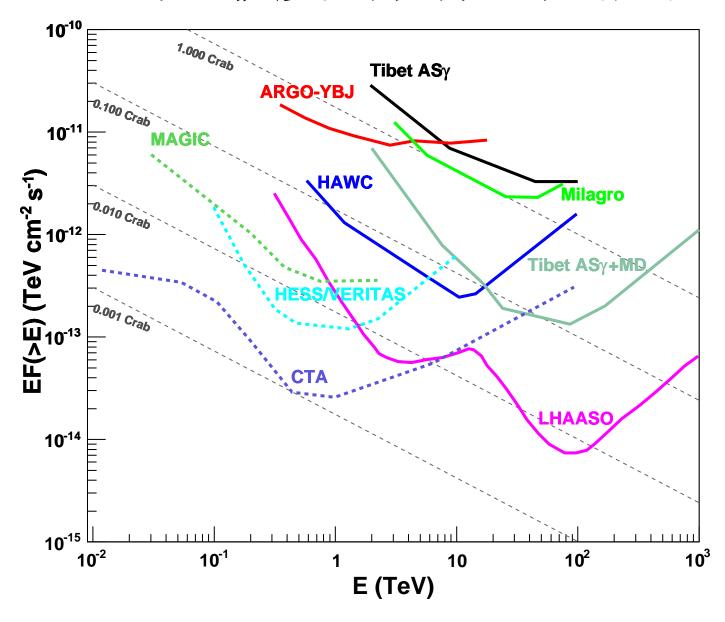
数据量大

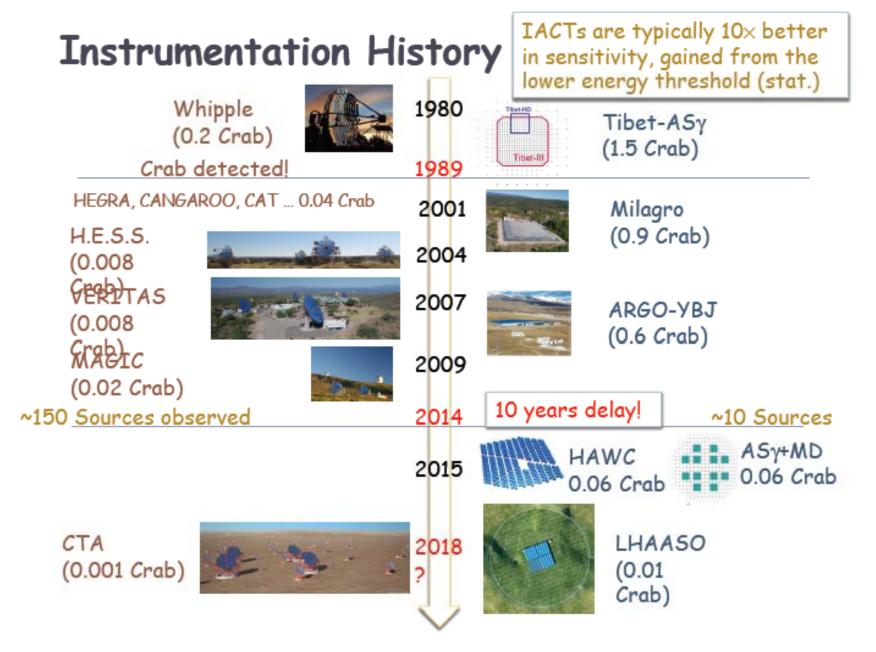
三. 总结、展望

## 总结

- LHAASO初步设计方案基本完成
- 针对其"大""散""密""多参数"等特点 采用了多项先进技术
  - WR、ASIC、高速FADC、绝对时间戳、triggerless、事例在站重建、Clock/Data共光纤网等等
- 综合这些设计要点实现了所有科学目标的测量要求,使LHAASO成为新一代伽马射线全天普查探测器和"膝区"性能最优的探测器,长期占据领先地位。

## LHAASO灵敏度与其他计划的对比





更加精密,分辨率更高,测量参数更多,原初成份鉴别能力更强 ...