Status of SiPM Camera for Cherenkov Telescope in LHAASO Experiment

Shoushan Zhang

Institute of High Energy Physics, Beijing, China

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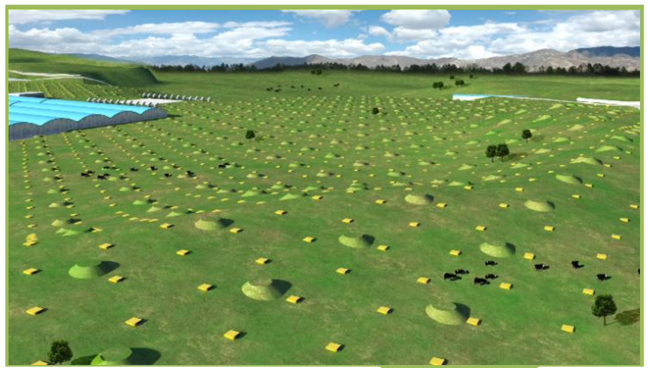
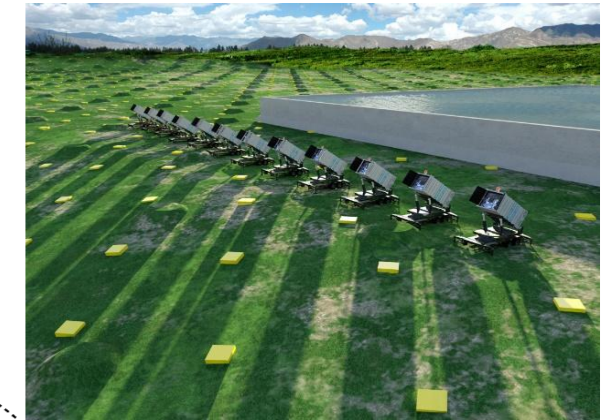
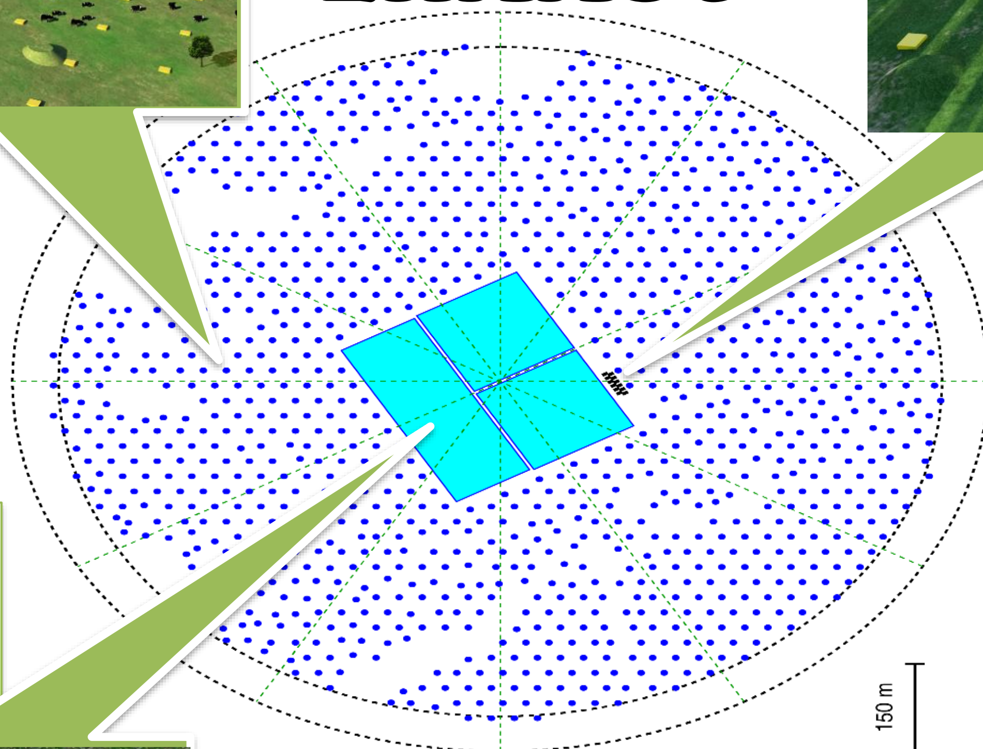
LHAASO



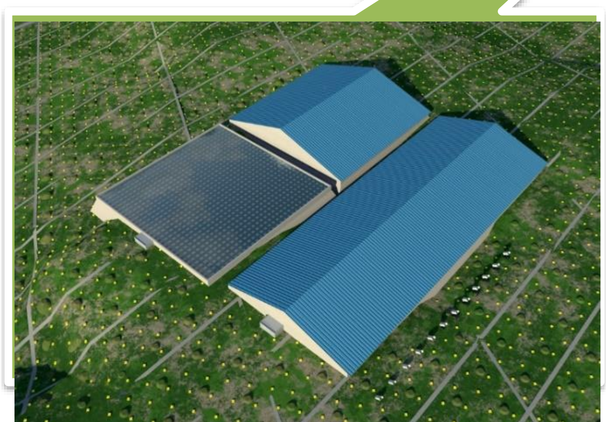
KM2A:
5195 EDs
1171 MDs

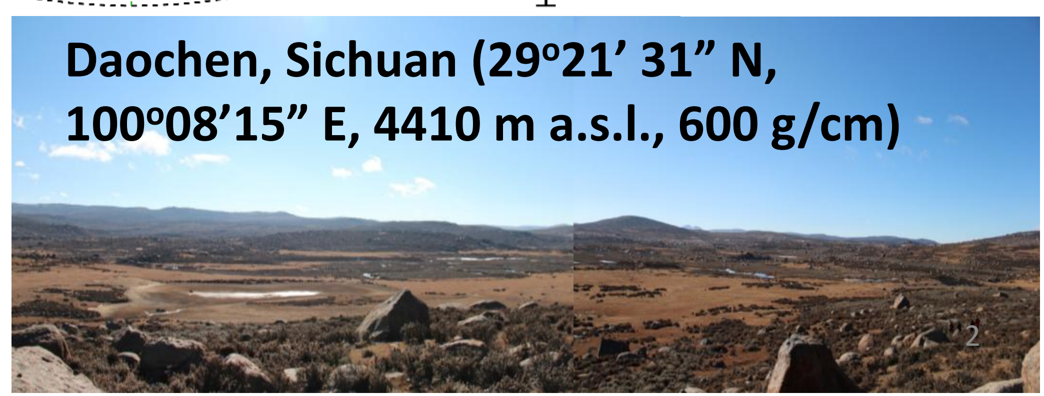


WFCTA:
18 Cherenkov telescopes (1024 pixels/telescope)



WCDA: 78,000 m^2
3000 cells
(25m^2/cell)



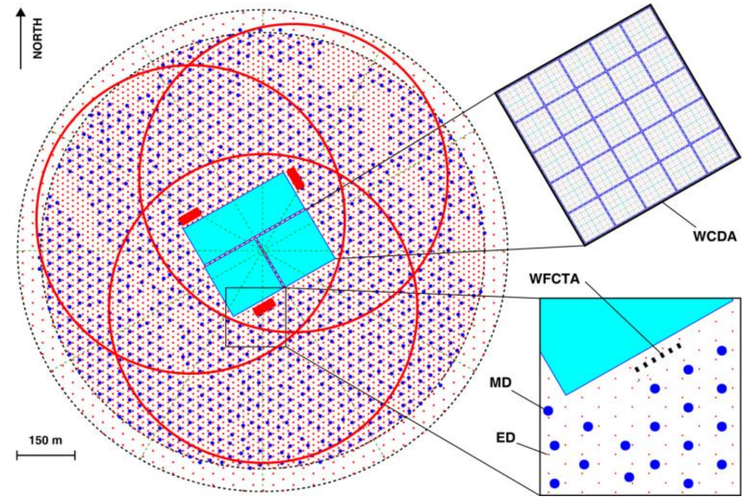


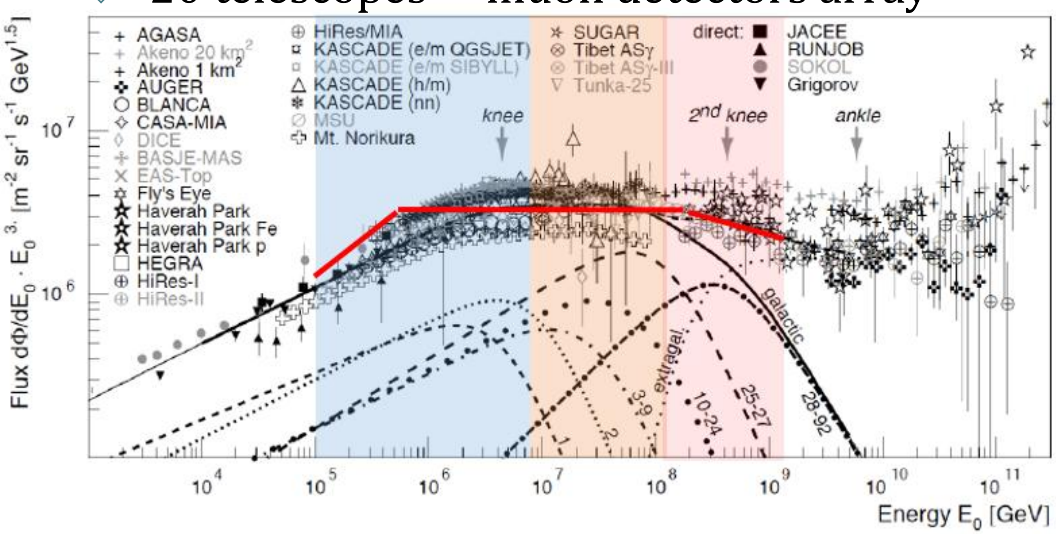
LHAASO science in cosmic ray measurement

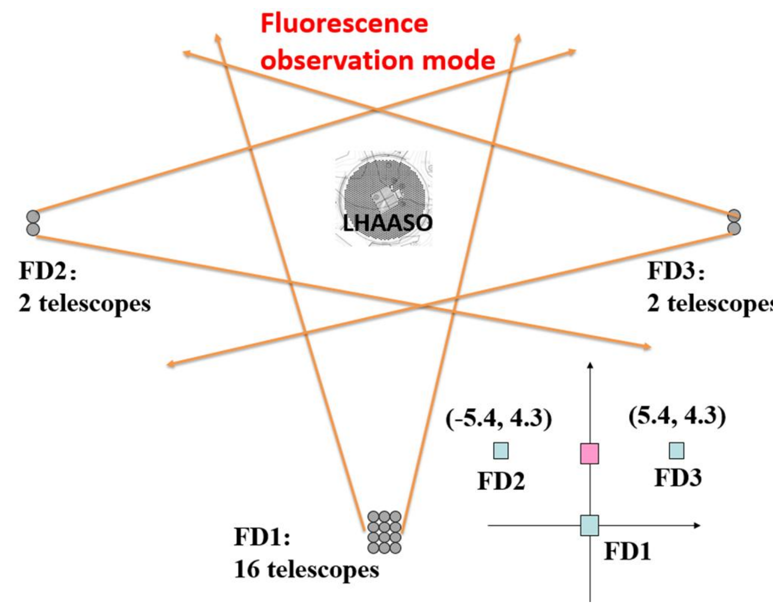
– **Measure individual cosmic ray spectra from 10TeV to EeV**

– **Multi-parameters, Multi-stages**

- 0.1-10 PeV (Cherenkov mode)
  - pure proton and light nuclei (P+He) spectra
  - 6 telescopes (30° in zenith) + ¼ WCDA
- 1- 100 PeV (Cherenkov mode)
  - Pure iron or heavy nuclei spectra
  - 18 telescopes (45 ° in zenith) + scintillator detectors + muon detectors array
- >100 PeV (fluorescence mode)
  - 2^{nd} knee
  - 20 telescopes + muon detectors array

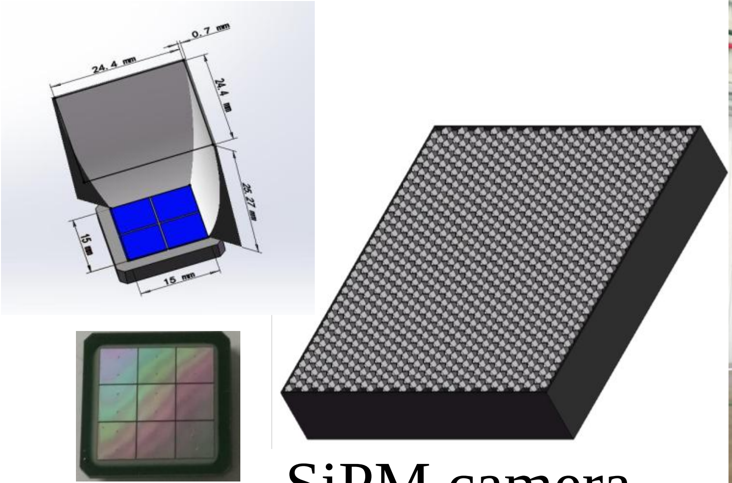




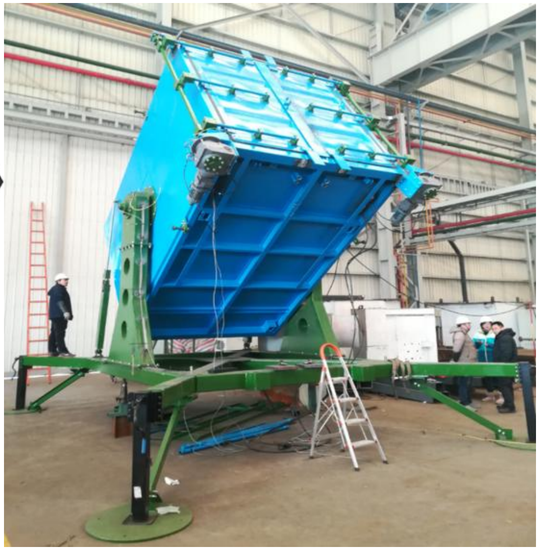


Wide Field of View Cherenkov Telescope (WFCTA)

- **$5m^2$ spherical mirror**
- **32×32 SiPMs array**
- **Pixel size 0.5°**
- **FOV: 16° × 16°**
- **Portable design: easy to switch the array configurations**



SiPM camera



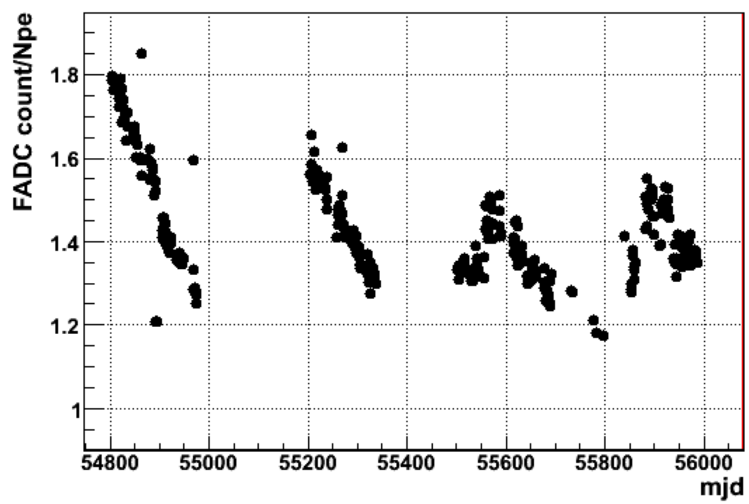
A prototype of WFCTA

SiPM-based Cherenkov telescope
To get a higher duty cycle

- SiPM can not be aging due to strong light exposure:
- SiPM-based camera can be operated in moon conditions, thus achieve a higher duty cycle than PMT-based camera.
- The duty cycle of SiPM-based camera is more than 30%, while the PMT is about 10%.

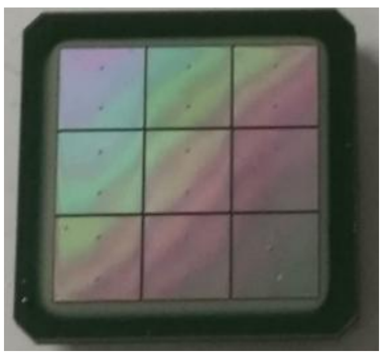
LHAASO-WFCTA prototype (PMT-based)

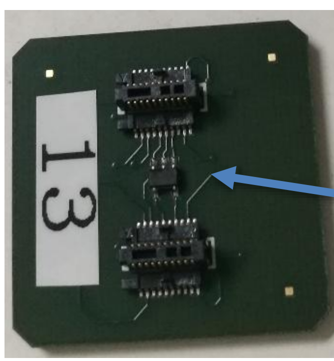
PMT aging with exposure time



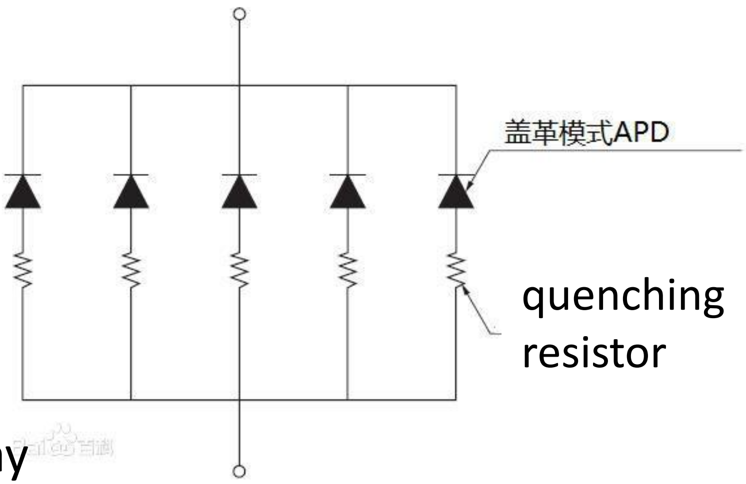
LHAASO-WFCTA SiPM (HAMAMASTU) parameters

Parameter	Performances
MPPC type	TSV-MPPC, 3×3 channels array, 5 mm × 5mm/channel
Effective photosensitive area	15 mm × 15 mm
Pixel pitch (APD size)	25 µm × 25 µm
Gain @ $V_{op}=V_{br}+7.7V$	8×10^5 , (V_{br}=53V)
PDE	>29%@400nm, >23%@350nm, >18%@310nm
Dark count rate	~60 kHz/mm² @ 20℃
Cross talk	＜5%
After pulse	＜5.5%
Temperature coefficient	~54mV/℃, gain variation: 1%/℃

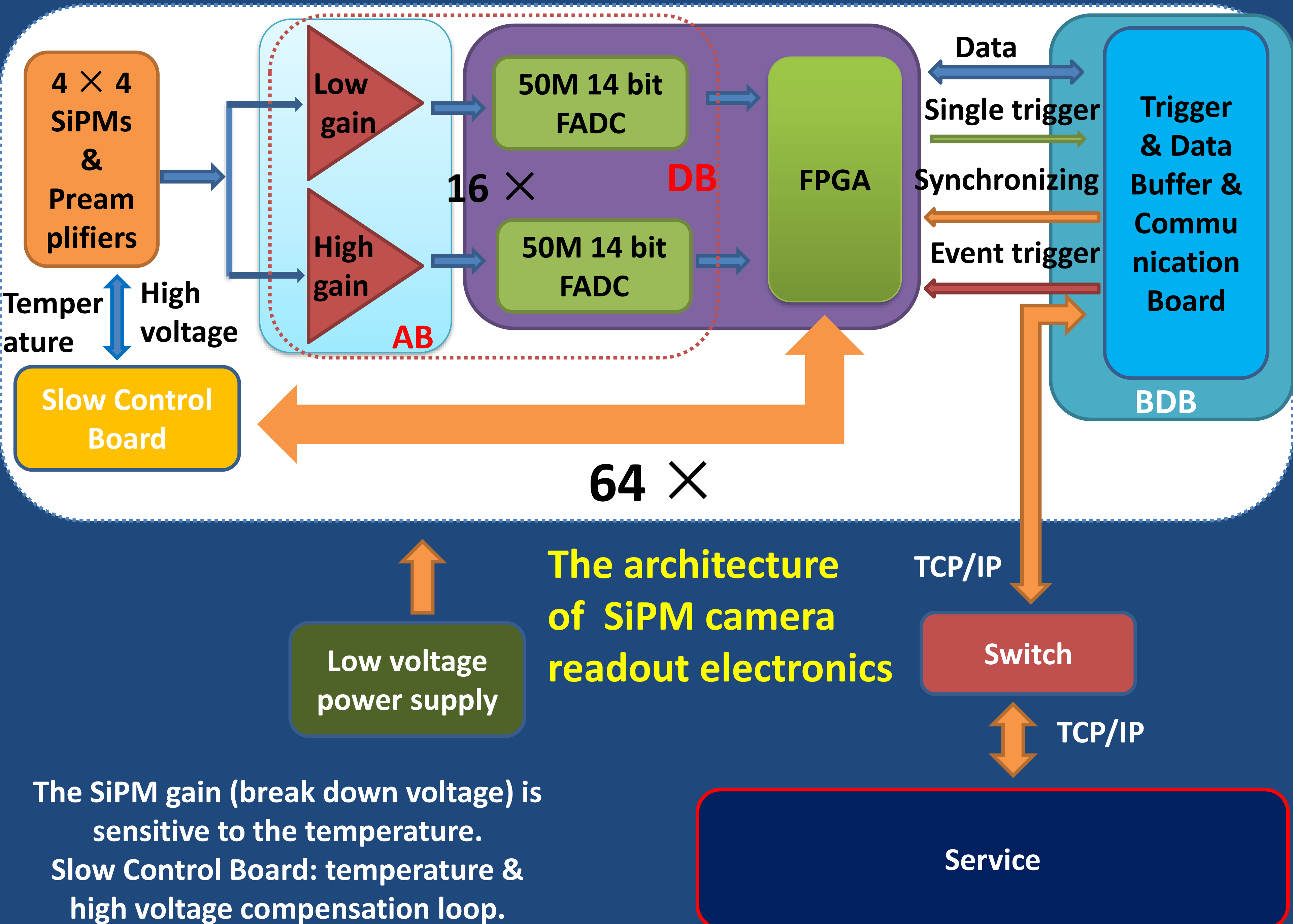




Temperature sensor



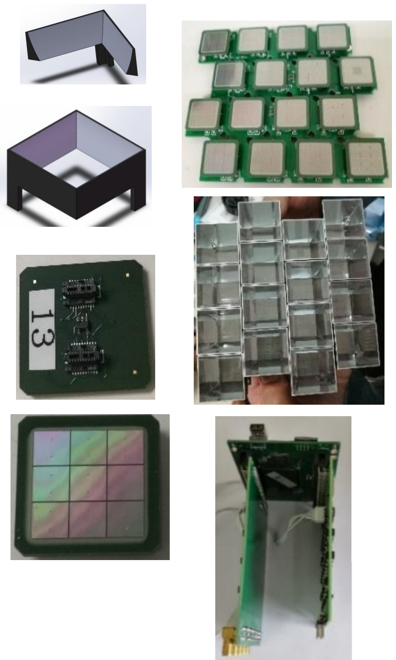
- Is made of an (APD + quenching resistor) array
- APD: operates in Geiger mode, the output signal is 0 and 1 analog signal
- 1600 APDs/mm² （25µm）， 360,000 APDs in total, can handle the dynamic range from 10 pe to 32,000 pe



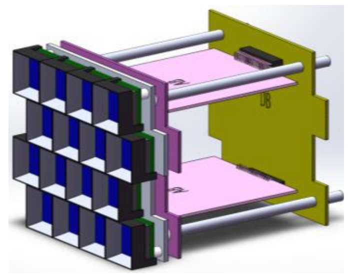
The architecture of SiPM camera readout electronics

The SiPM gain (break down voltage) is sensitive to the temperature.
Slow Control Board: temperature & high voltage compensation loop.

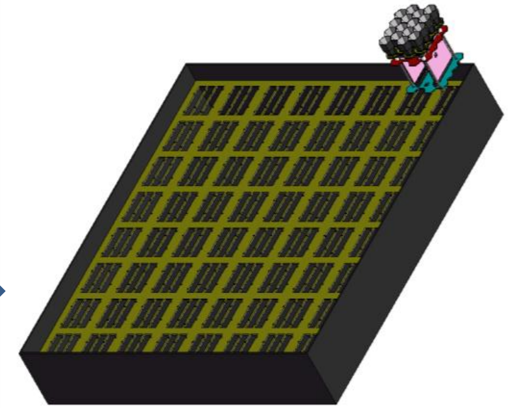
Schematic diagram of SiPM camera assembly



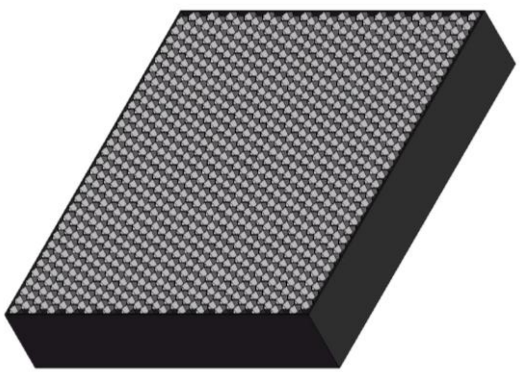
64 ×



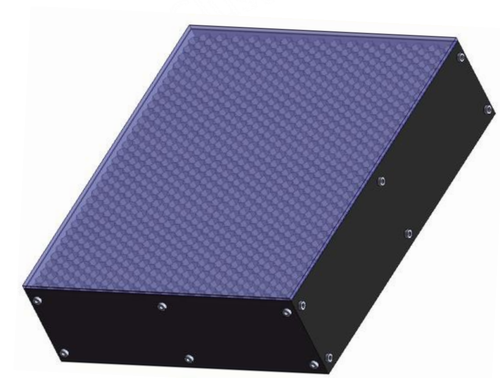
A module has 4×4 SiPMs.



SiPM camera box



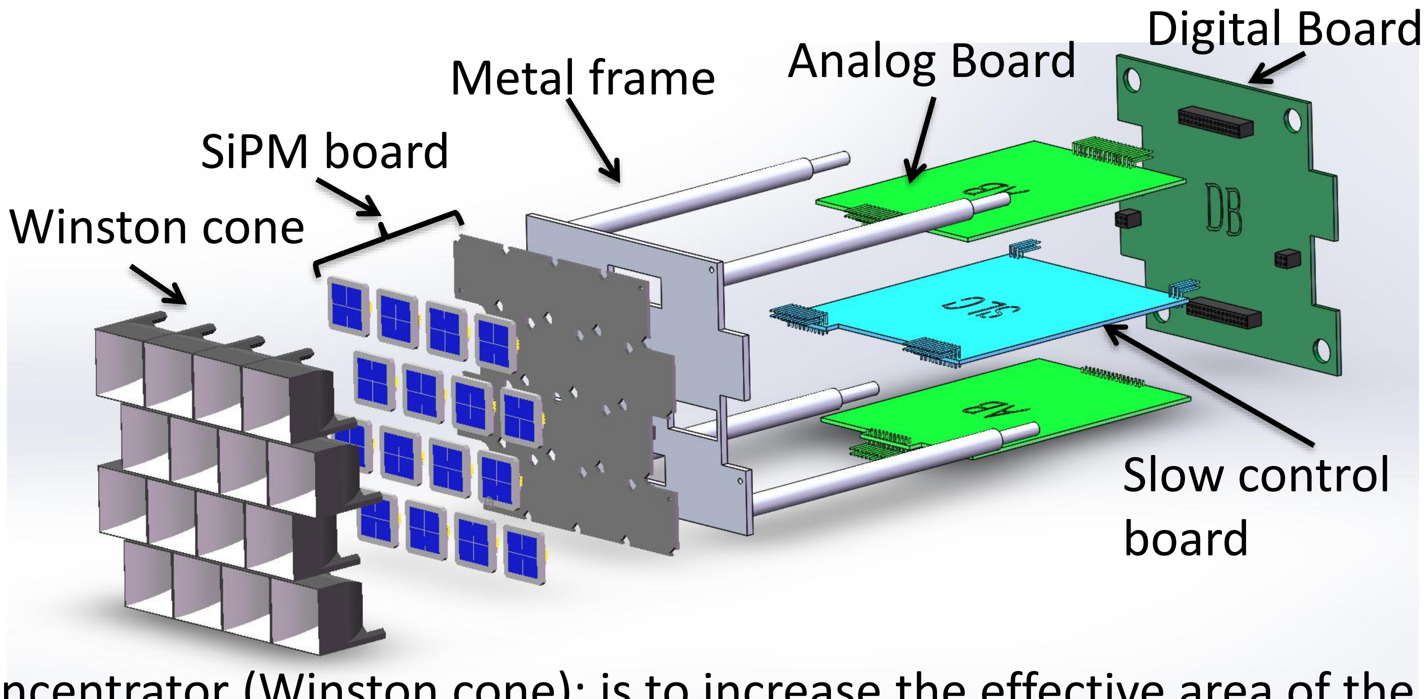
SiPM camera： 32×32 SiPMs



Optical filter

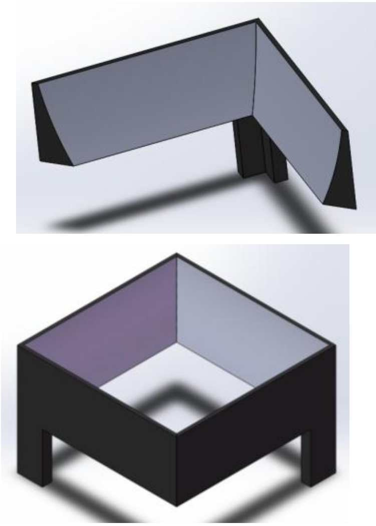
In the clean room

Square SiPM： 15 mm × 15 mm



- Light concentrator (Winston cone): is to increase the effective area of the SiPM
- SiPM board: 16 SiPMs, 16 temperature sensors (embedded in the SiPM chip), and 16 pre-amplifiers
- Slow control board:
  - 16 temperature and high voltage compensation loops;
  - 16 channels of high voltage power supply.
- Analogue board: 16 channels of amplifier and shaping circuit
- Digital board: 50 MHz FADC and FPGA

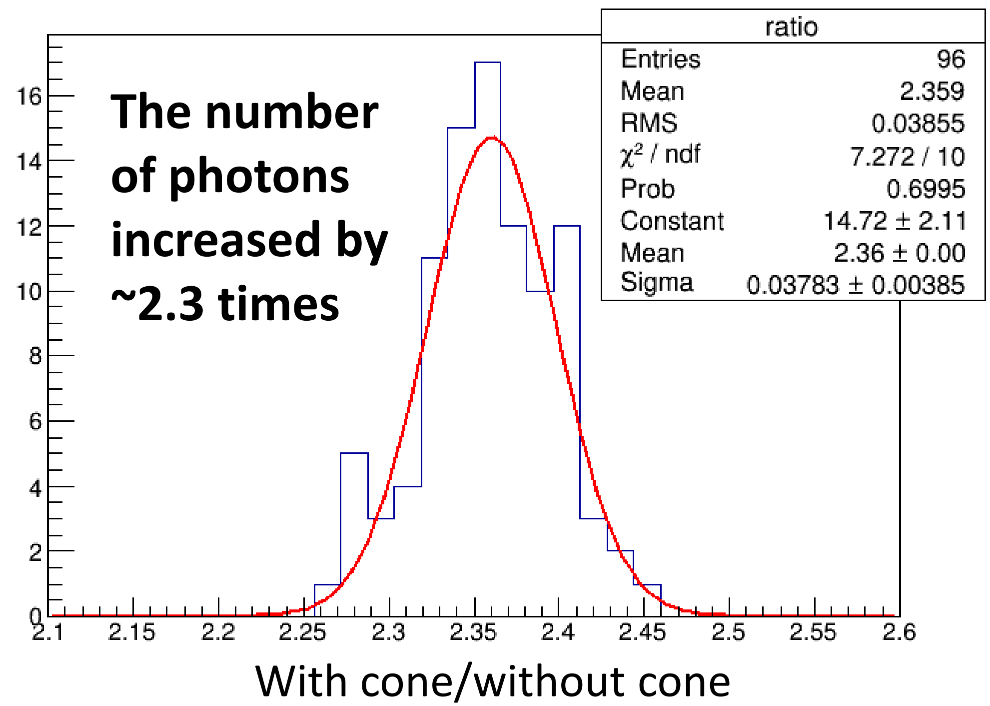
Square SiPM： 15 mm × 15mm

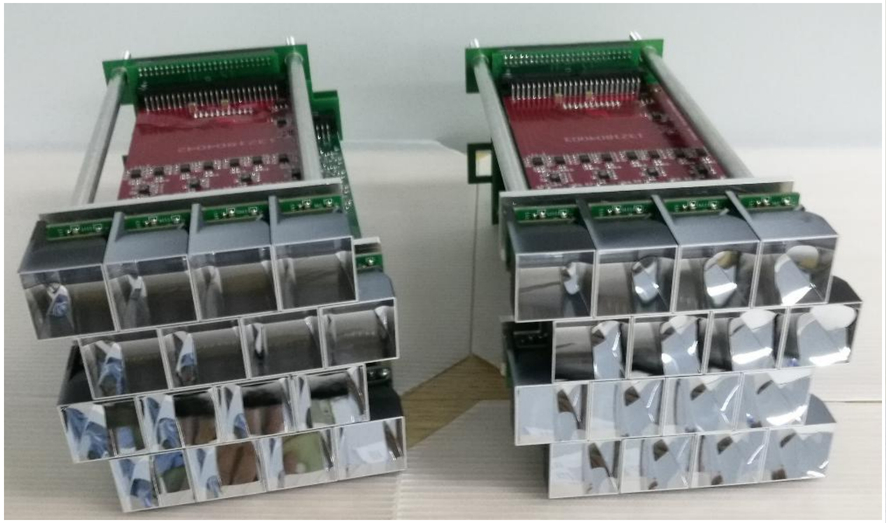


Pixel size: 25.4 mm × 25.4 mm
SiPM size: 15 mm × 15 mm

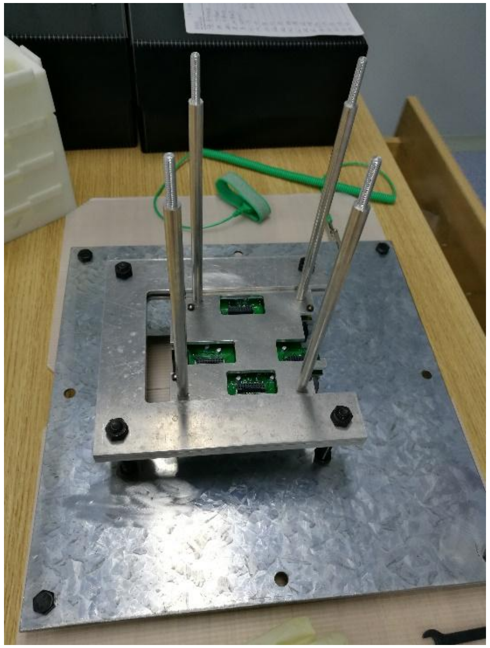
Light concentrator (cone)：
- **Outlet: 15 mm × 15 mm**
- **Inlet: 25.4mm × 25.4mm**
- **Height: 25.3mm**

light concentrators (cone)

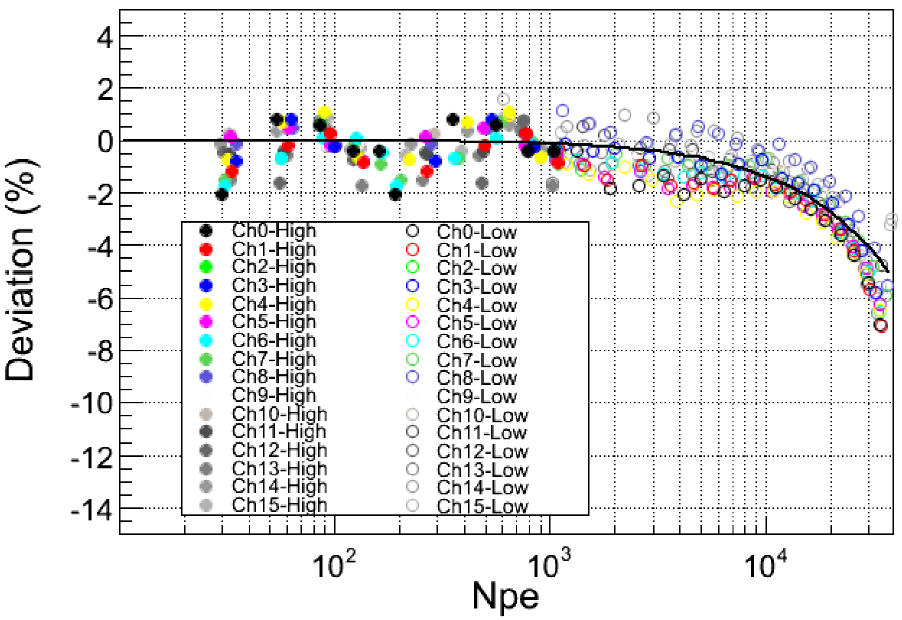




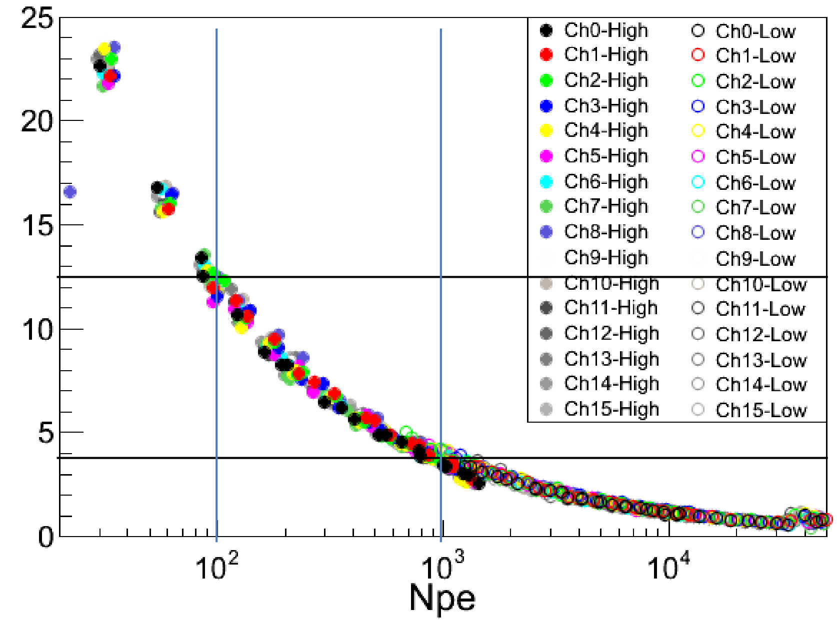

64 sub-clusters have been assembled in the clean room



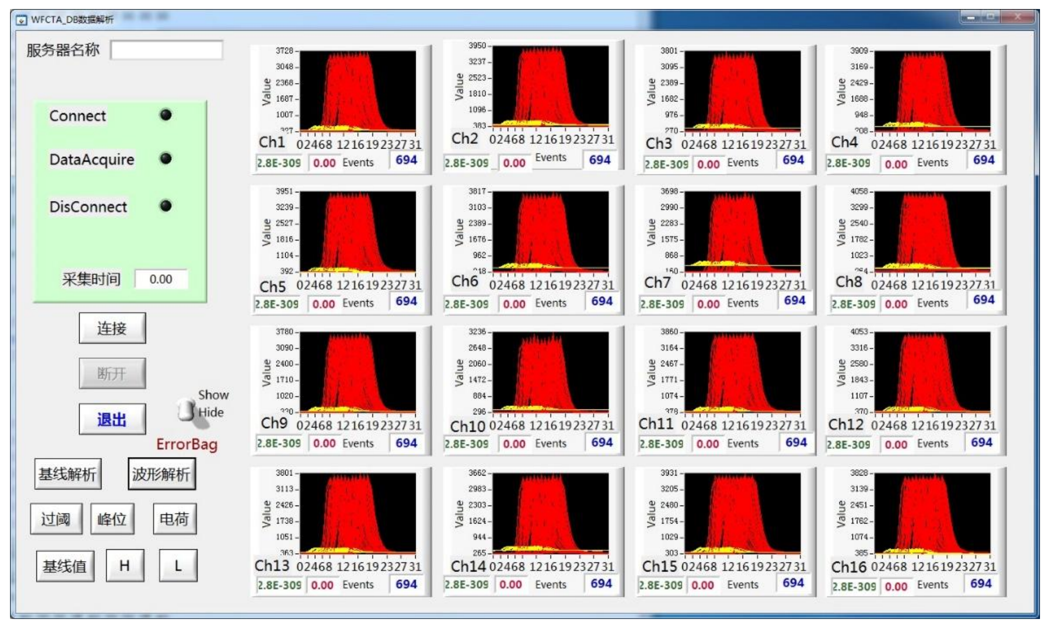
Dynamic range

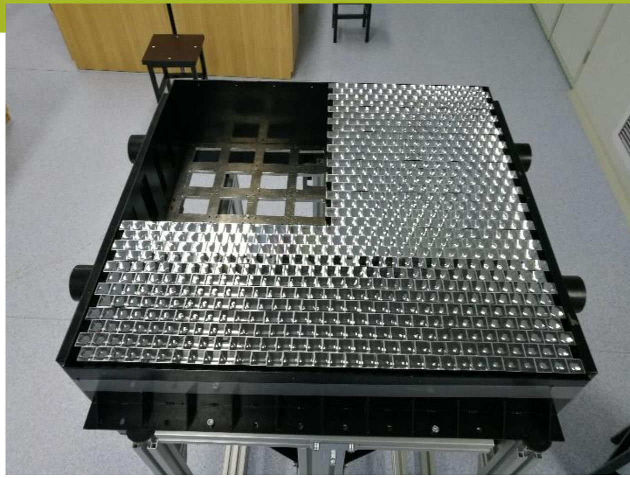


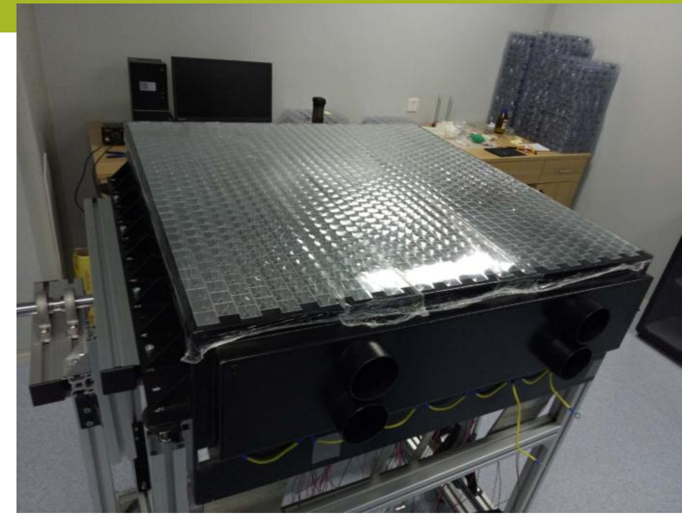
resolution

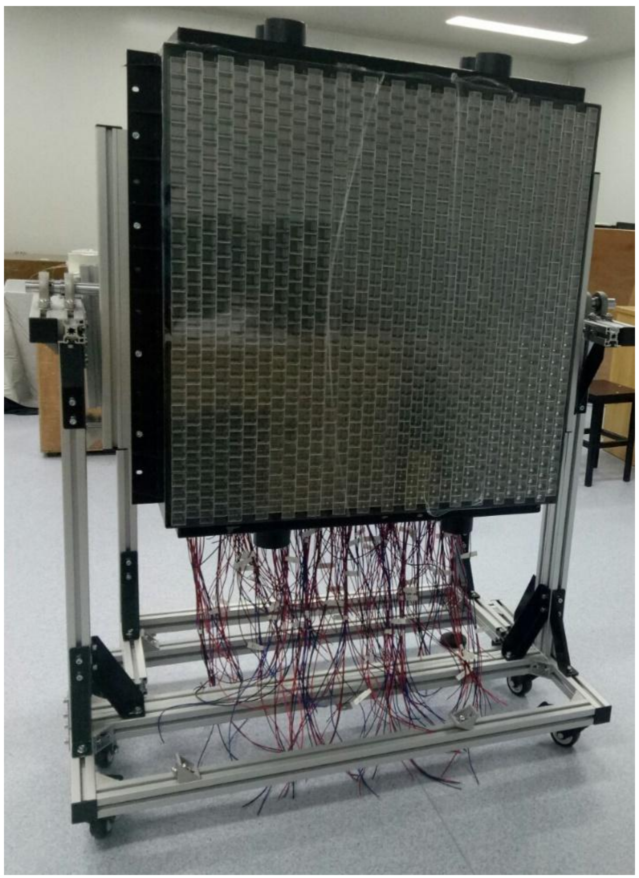


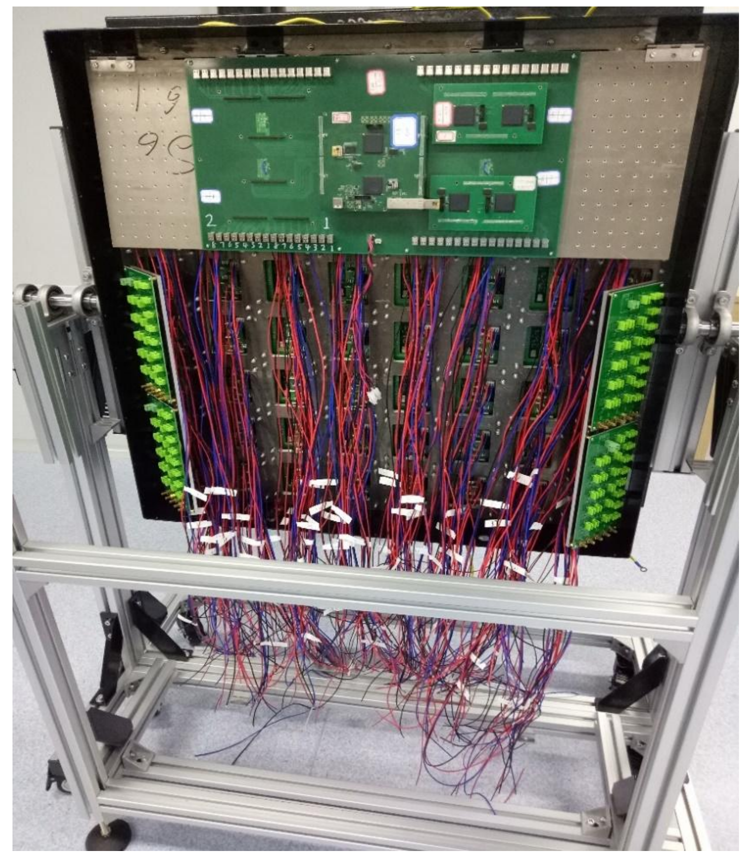
64 sub-clusters have passed the test.





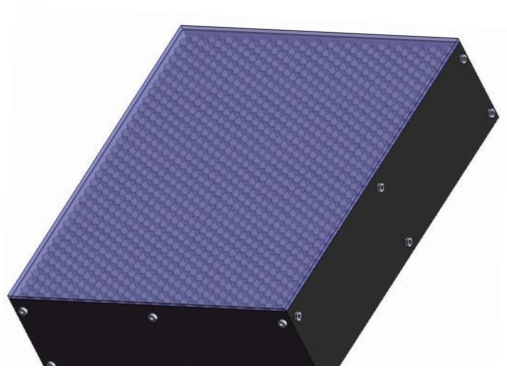


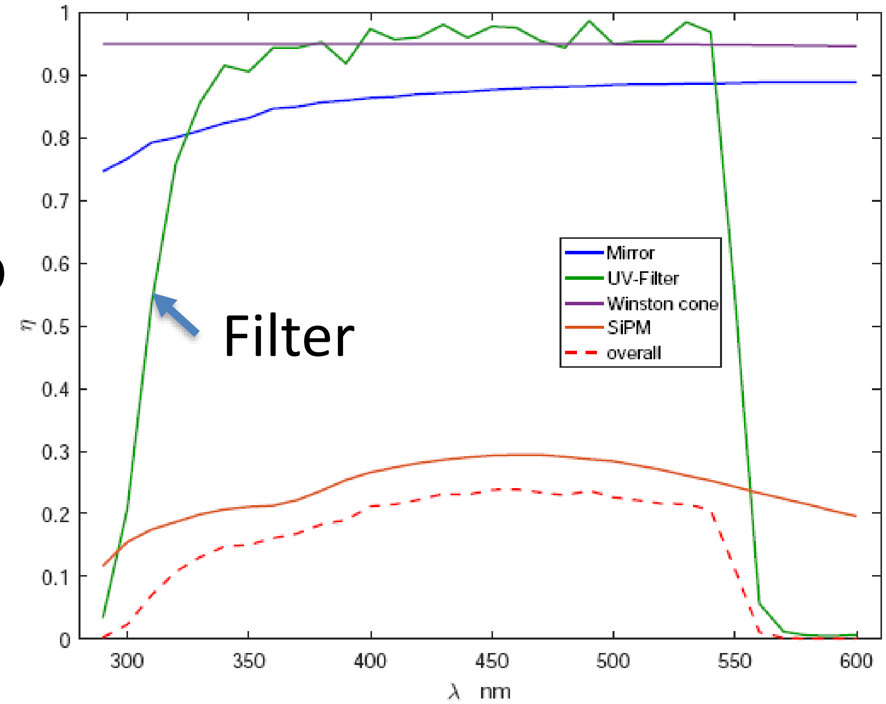


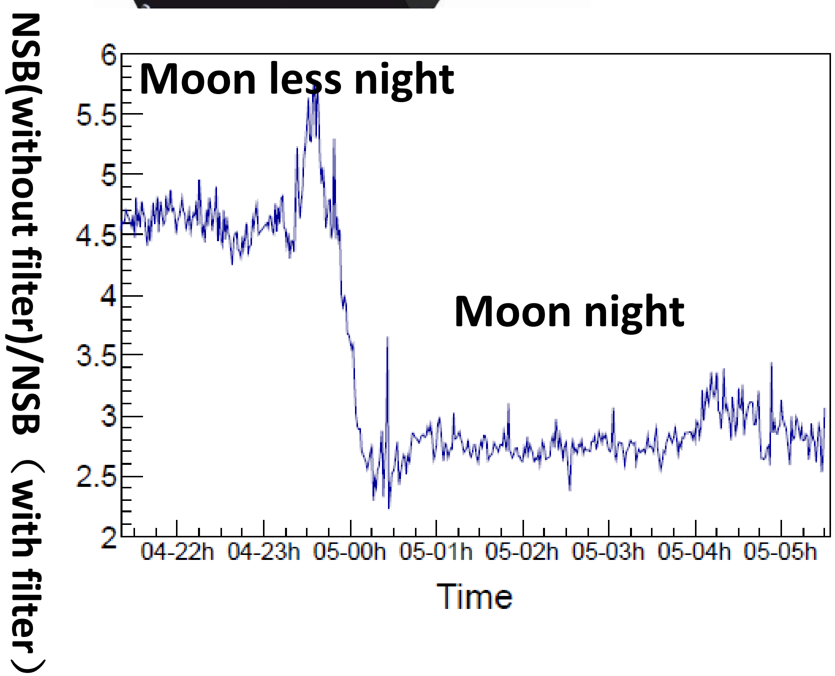


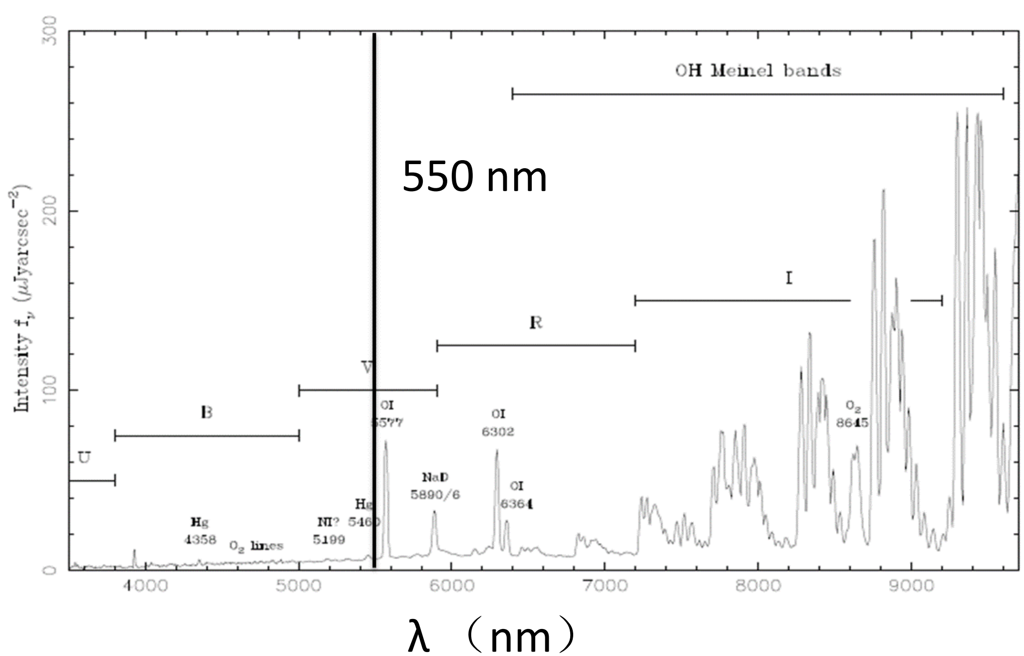
Filter window： AR + cutoff

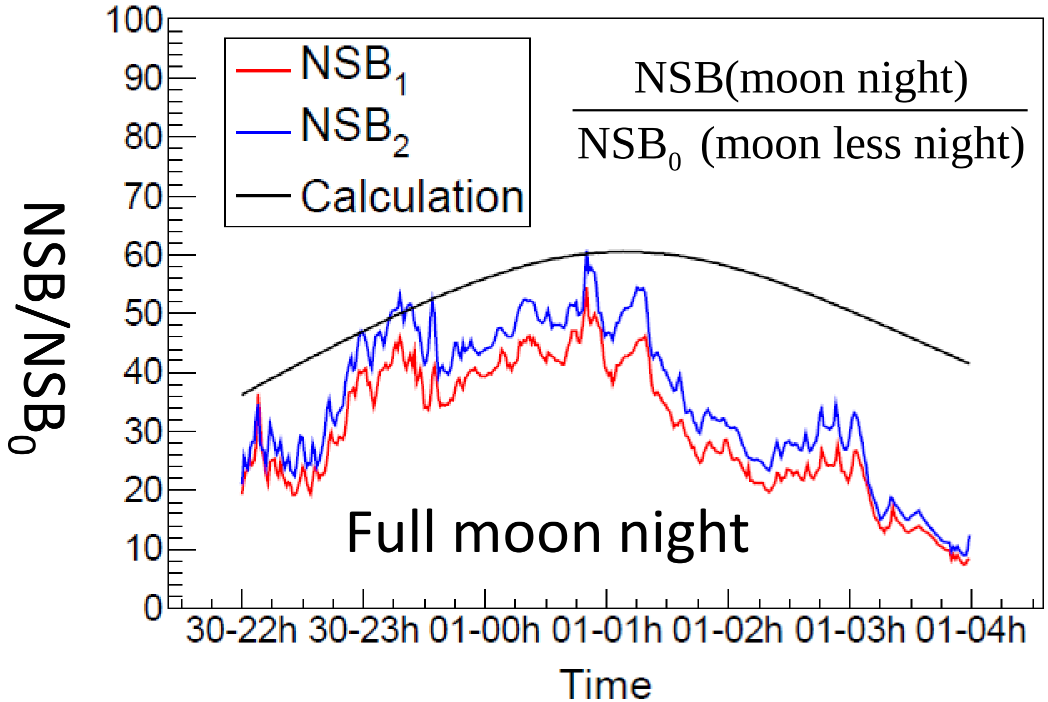
To improve signal to noise ratio











Threshold of the telescope：

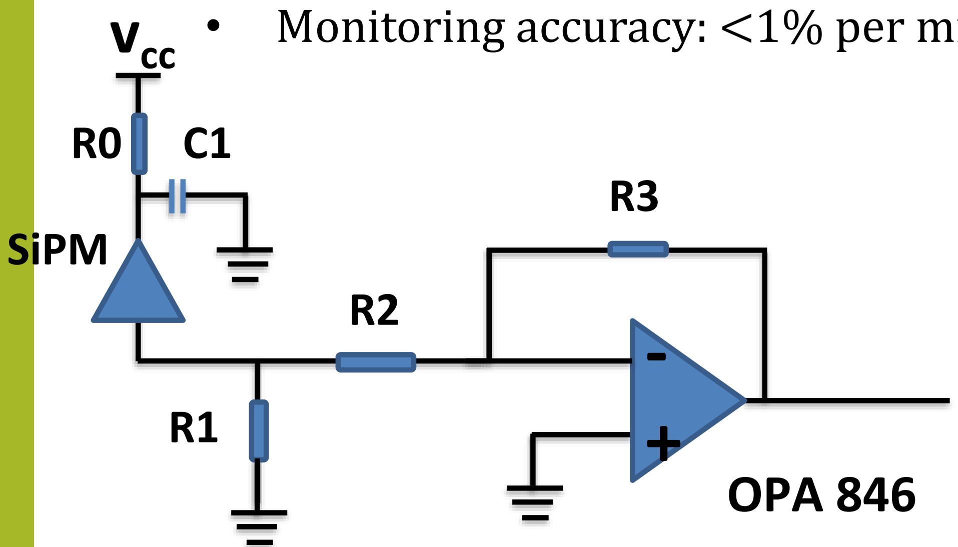
~15 TeV @ moonless night，

~100 TeV @ full moon night

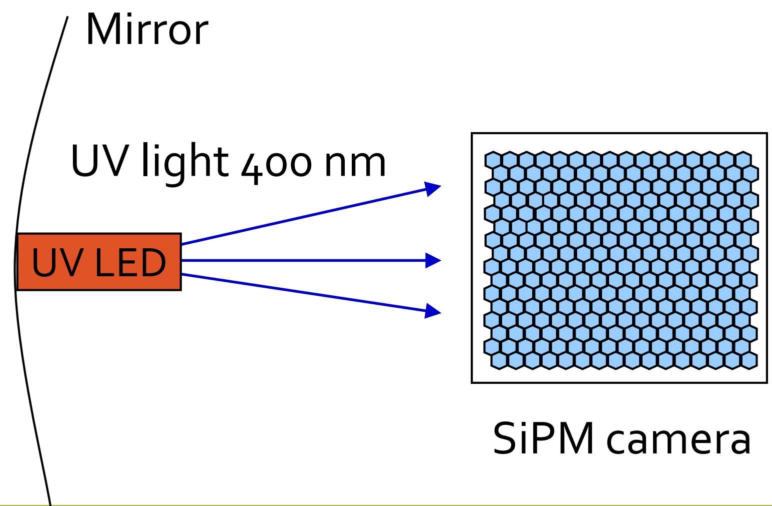
NSB/NSB_0	1	2	5	10	20	50	100
Proton	14.3TeV	17.4TeV	25.6TeV	35.0TeV	53.0TeV	80.6TeV	107TeV
Helium	15.5TeV	19.0TeV	27.3TeV	37.2TeV	54.2TeV	82.6TeV	110TeV
CNO	20.7TeV	24.1TeV	33.5TeV	43.6TeV	60.3TeV	87.1TeV	115TeV
MgSiAl	25.8TeV	29.4TeV	39.2TeV	51.3TeV	68.3TeV	98.3TeV	127TeV
Iron	33.8TeV	39.0TeV	51.4TeV	62.3TeV	80.5TeV	112TeV	139TeV

Gain monitor

- UV-LEDs are mounted at the center of the mirror to monitor and calibrate the gain of the SiPM-based camera.
  - The SiPM gain is sensitive to the temperature.
  - The SiPM gain varies with the intensity of the sky background light, because the voltage drop on the R0 varies with the intensity of the sky background light.
  - To monitor the high gain and the low gain of the electronics.
- UV-LEDs configuration
  - LEDs is working in a thermostat system to keep LED stable.
  - The photons intensity: ~3000 photons/pixel.
  - Frequency of LED pulse: 1 Hz
  - Monitoring accuracy: <1% per minute.

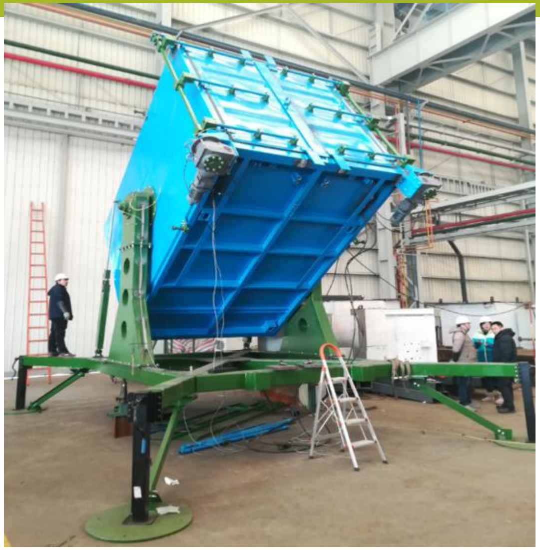


The supply voltage of the SiPM is equal to Vcc-V_{R0} .



Summary

- The first SiPM camera has been built in the lab and its performance is under test.
  - The duty cycle of SiPM-based camera is more than 30%
  - The threshold of telescope is about 15 TeV @ moon less night and 100 TeV @ full moon night
- Time schedule
  - The first SiPM camera will be send to LHAASO site in October
  - The first telescope will be run in November
  - 6 telescopes will be built before May 2019.



- 6 Movable/adjustable containers have been built and is under test.
- Mirrors for 6 telescopes have been produced and will be assembled in the container in next two month.

Thank you for your attention!

Signal to noise ratio

SiPM: 15mm╳15mm， 25μm

	FBK	SensL	Hamamatsu	PMT （R7899）
Relative PDE/QE	**38%@400 nm**	**31%@400 nm**	**29%@400 nm**	**16%@400 nm**
Dark count rate @ threshold=0.5pe	**18 MHz**	**11.3MHz**	**11.3MHz**	**<1kHz**
Sky background noise	**~49 MHz**	**~40 MHz**	**~37 MHz**	**~21MHz**

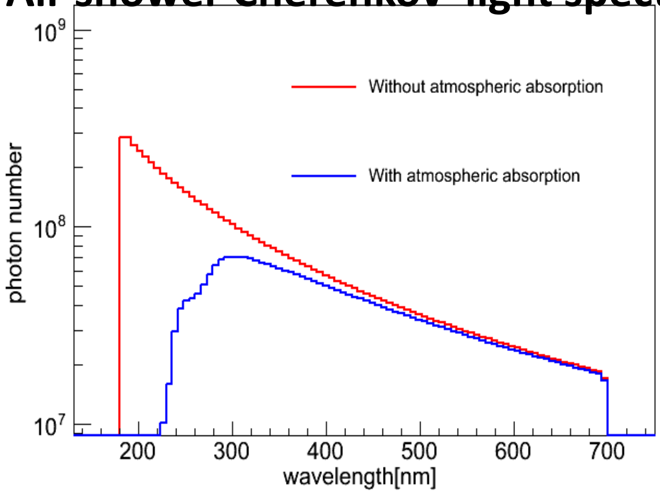
$$\frac{Signal}{Noise} = \frac{N_s^{ph} \bullet PDE}{\sqrt{N_{BG}^{ph} \bullet PDE + N_{DCR}^{pe}}}$$

$$\frac{S/N(\mathrm{SiPM})}{S/N(\mathrm{PMT})} \geq 1$$

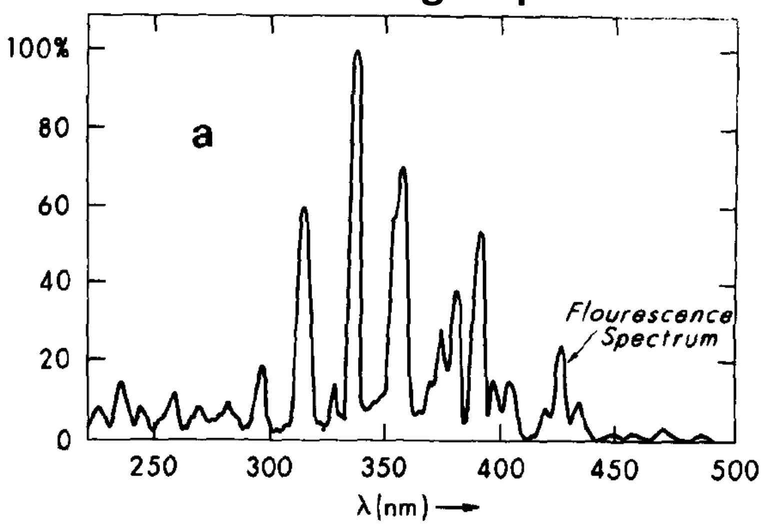
LHAASO-WFCTA vs. CTA

	CTA-SSTs	LHAASO-WFCTA
Energy range	3 TeV – 300 TeV	30 TeV – 1 EeV (Cherenkov mode: 30TeV – 10 PeV, 10PeV-100PeV; Fluorescence mode: > 100PeV)
Diameter of mirror	~ 4 m	~ 2.3 m
Pixel size	~ 0.25	~ 0.5
Number of pixels	1296	1024
Dynamic range	1 pe - 2000 pe	10 pe – 32000 pe
Light pulse duration	6 ns - 50 ns	6 ns - 3 µs
Observation mode	Cherenkov light	Cherenkov and Fluorescence light

Air shower Cherenkov light spectrum

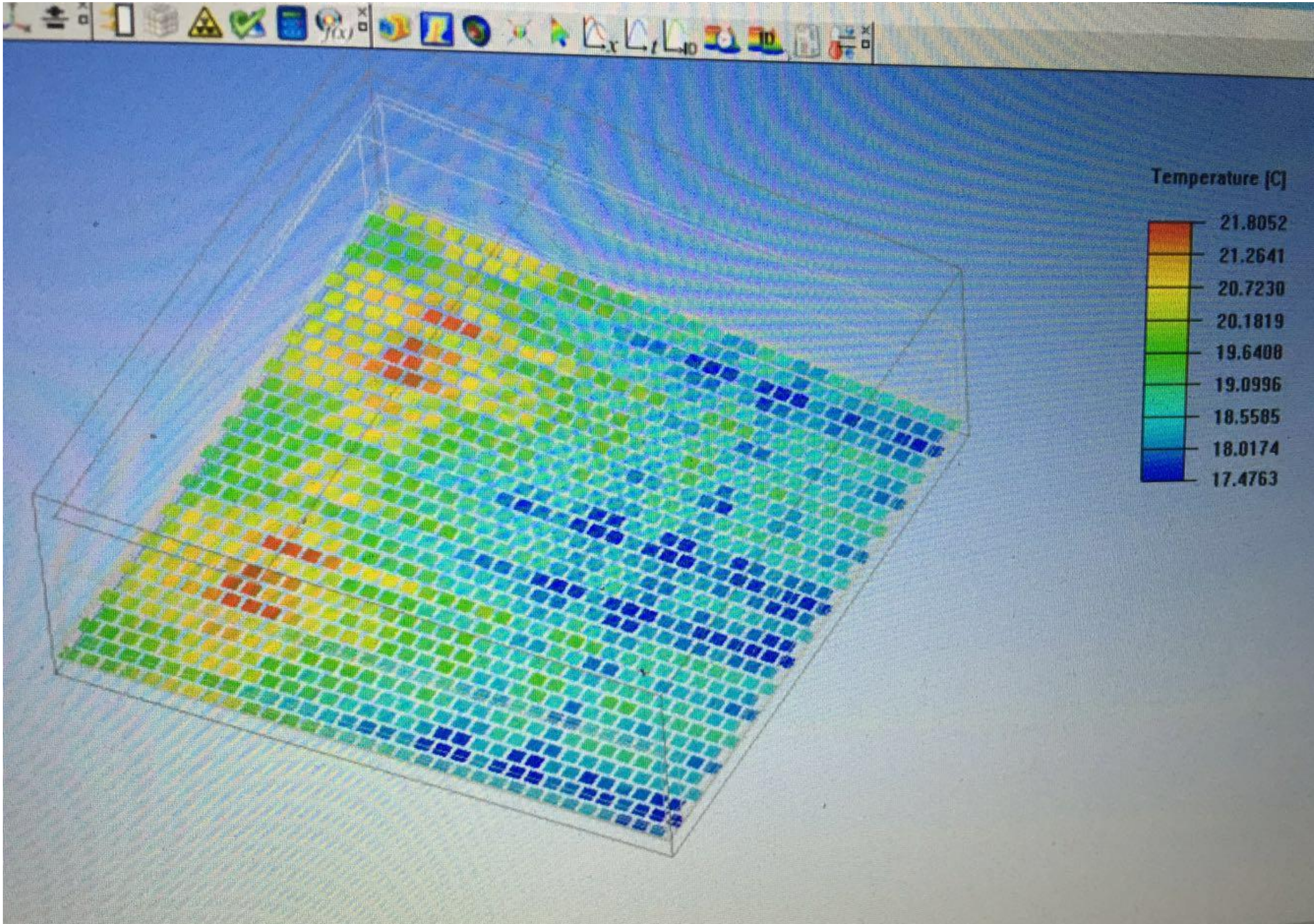


Fluorescence light spectrum



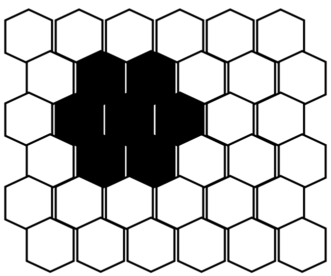
SiPM 40mW

初始温度：15℃（入风口）
空气密度：0.58大气压（4400米海拔）

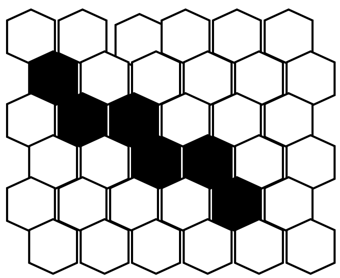


Trigger algorithm

- **First level trigger： single channel trigger**
  - Signal to noise ratio: S/N>n
  - Threshold varies with the intensity of the sky background light.
- **Second level trigger： pattern recognition**

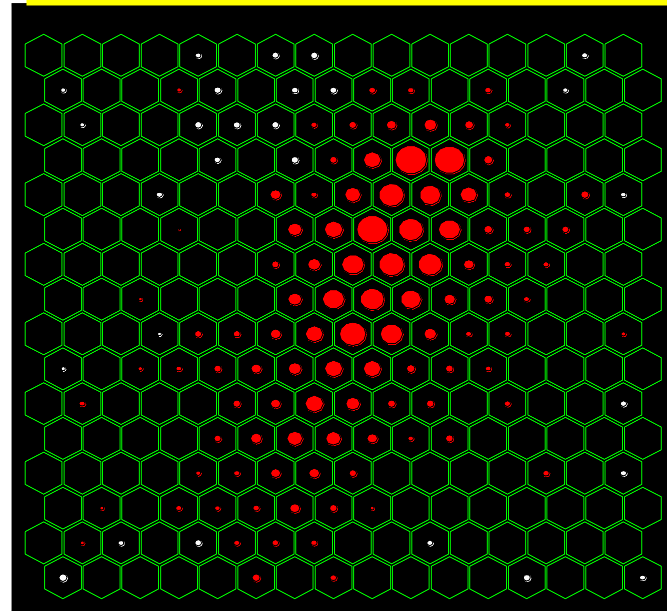


Round-shaped pattern



Line-shaped pattern

One of Cherenkov event



Fluorescence event