WSF read-out and calibration light source of the 3-D crystal array of HERD calorimeter

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CALOR 2022, May 16-20, 2022

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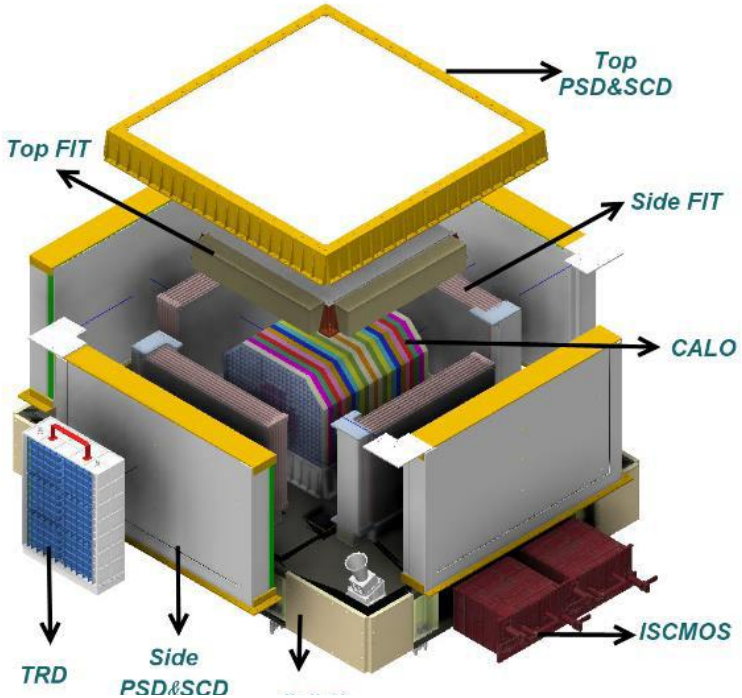
The High Energy cosmic-Radiation Detection

The High Energy cosmic-Radiation Detection (HERD) has been proposed as a space experiment which will be installed on the China's Space Station around 2027

- The key science objectives
  - searching for dark matter particles, extend high precision and high statistics spectral measurements of individual cosmic ray species up to few PeV
  - study of cosmic ray chemical composition, reach the knee of the all-particle spectrum
  - high energy gamma-ray observations, observe the gamma-ray sky from a few hundred of MeV up to 1 TeV

HERD sub-detectors

- HERD consists of a calorimeter (CALO), a fiber tracker (FIT), a plastic scintillator detector (PSD), a silicon charge detector (SCD) and a transition radiation detector (TRD).



CALO:Energy measurement
SCD:Z measurement
PSD:Gamma ID and Z measurement
FIT:Tracking and Gamma conversion
TRD:TeV nuclei calibration

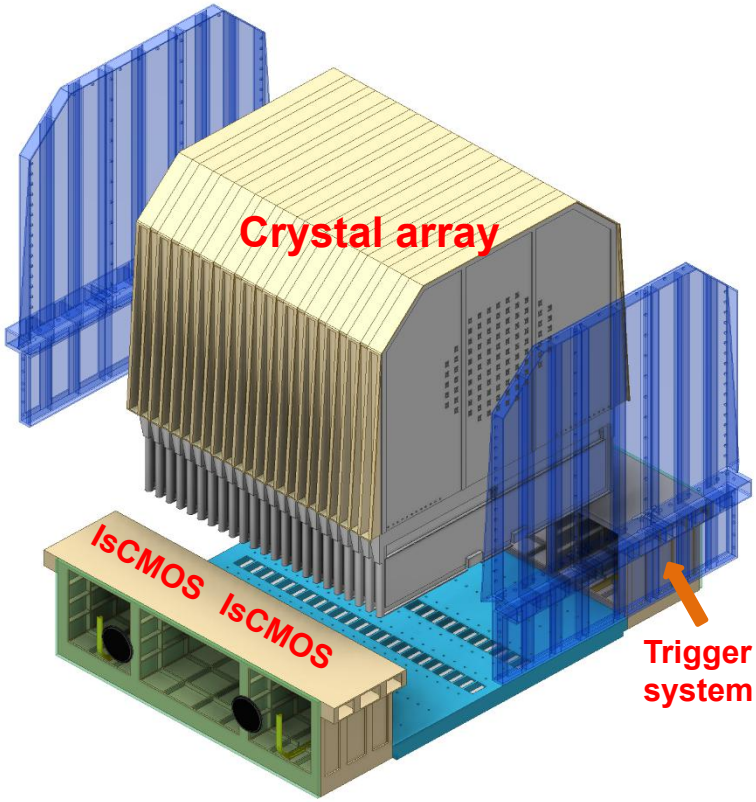
HERD calorimeter

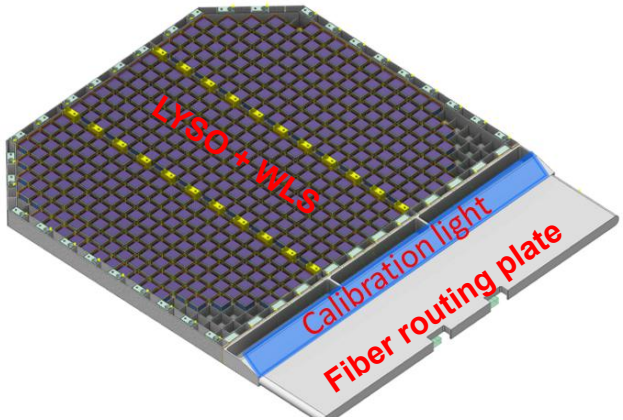
- The CALO is a 3D segmented calorimeter which can accepts particles coming from each surface
- The effective geometric factor of CALO is more than one order of magnitude larger than that of previous missions

Mission (Launch time)	Energy range (e/γ)	Energy range (p)	Energy resolution (e)	Energy resolution(p)	e/p separation	G.F.(e) (m^2sr)	G.F.(p) (m^2sr)
FERMI (2008)	1GeV-300GeV	30GeV-10TeV	10%	40%	10^3	0.9	<0.28
ISS-AMS02 (2011)	1GeV-1TeV	1GeV-1.8TeV	2%	-	10^6	0.12	0.12
ISS-CALET (2015)	1GeV-10TeV	50GeV-10TeV	2%	35%	10^5	0.12	--
DAMPE(2015)	5GeV-10TeV	40GeV-100TeV	≤1.5%	25-35%	$3*10^4$	0.3	0.04
HERD (~2027)	10GeV-100TeV 0.5GeV-100TeV (γ)	30GeV-1 PeV	<1.5%	<22%	$3*10^5$	**>3**	**>2**

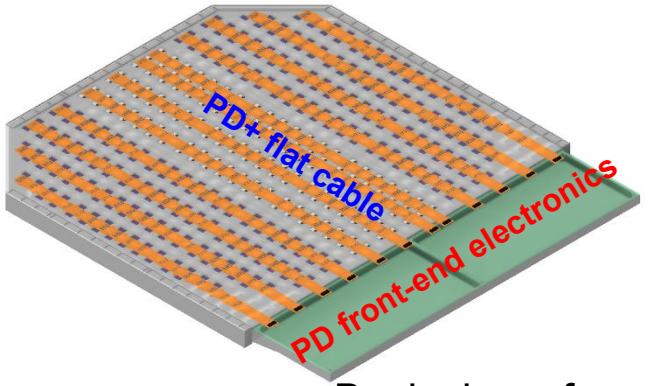
CALO components

- CALO consists of a crystal array, a WSF+IsCMOS read-out system, a PD read-out system, a calibration light source and a trigger system





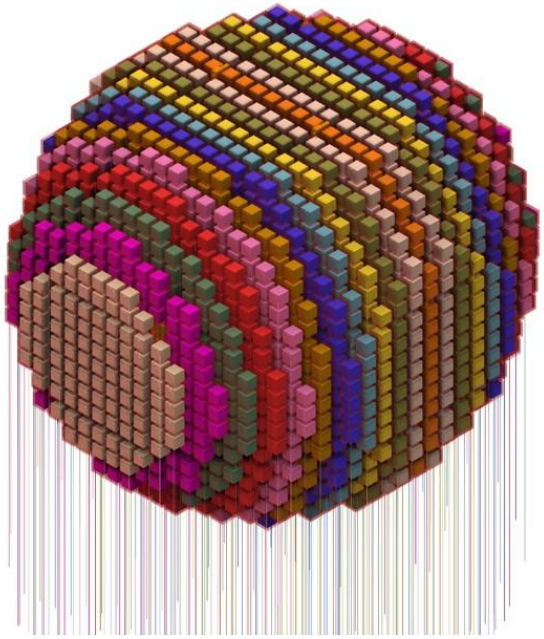
Front view of one tray



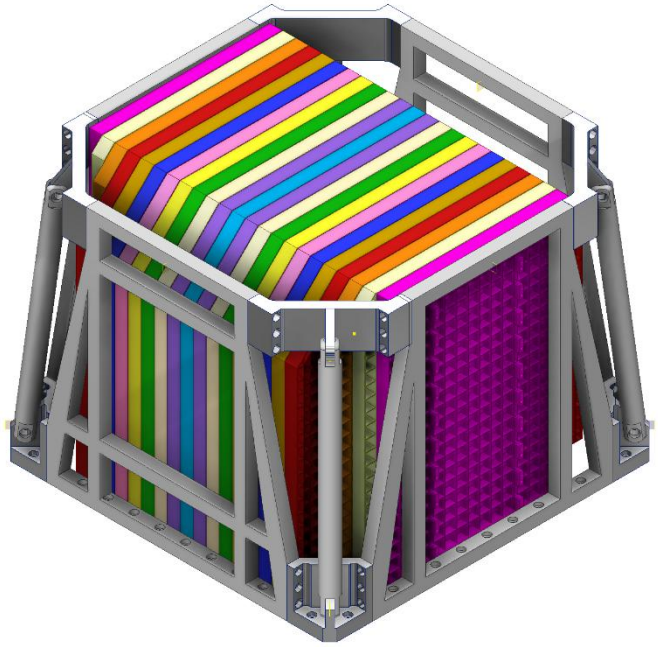
Back view of one tray

Crystal array

- About 7500 LYSO cubes, the active envelope is similar to a sphere, corresponding to about 55 radiation lengths and 3 nuclear interaction lengths for central incidence
- The LYSO cubes are arranged on vertical CFRP trays with different dimension

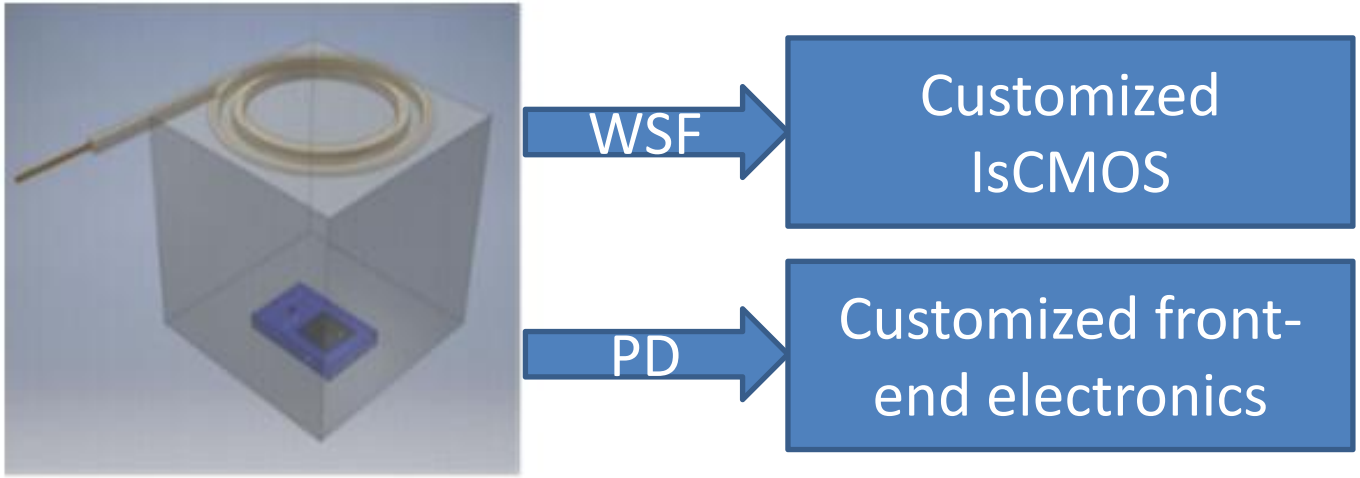


CALO Crystal array



CALO double read-out

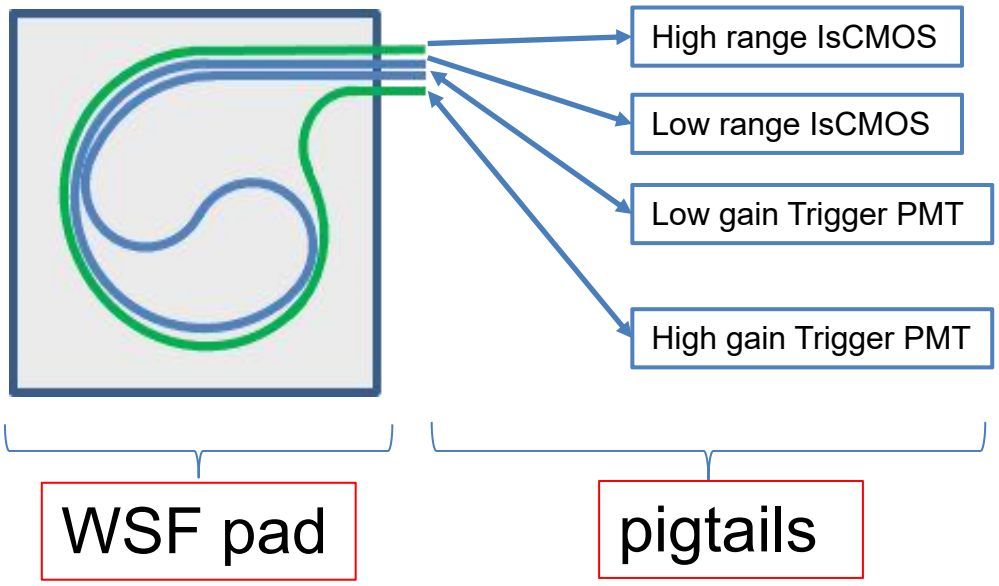
- Edge length of each LYSO is 3 cm, corresponding to about 2.6 radiation lengths and 1.4 Molière radius
- The scintillation light of each LYSO is read-out by Wavelength shifting fiber(WSF) + IsCMOS system and PD read-out system independently
- The reliability of the data will be improved significantly by cross calibration between the double read-out systems.



The PD read-out system will be introduced in P. Betti's poster of this conference.

Wavelength shifting fibers

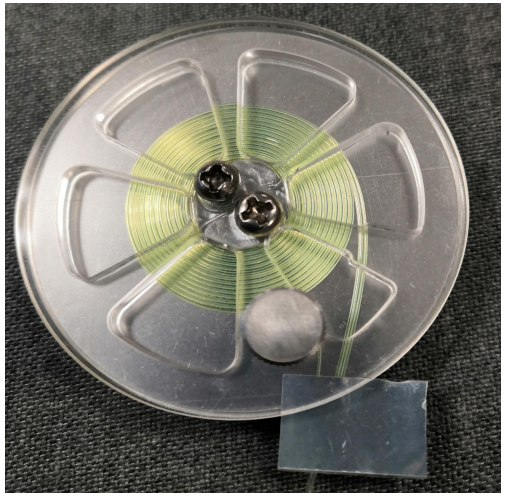
- Two pieces of WSFs are winded by different loops to match specific contacting area on LYSO face
- Two fiber ends are routed to IsCMOS cameras, the other two opposite ends are connected to the trigger system



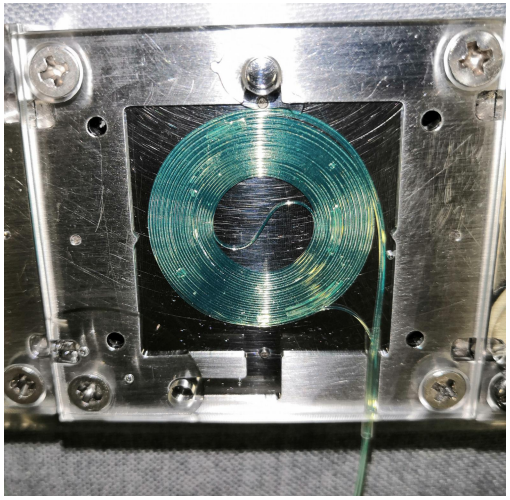
Conception of WSF winding

WSF pad fabrication

- WSF pad is fabricated to hold WSF loops and serves as a coupling medium

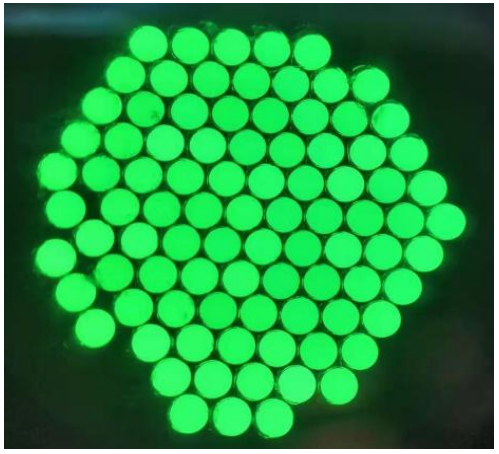


Winding and thermoforming



Silicone perfusion molding

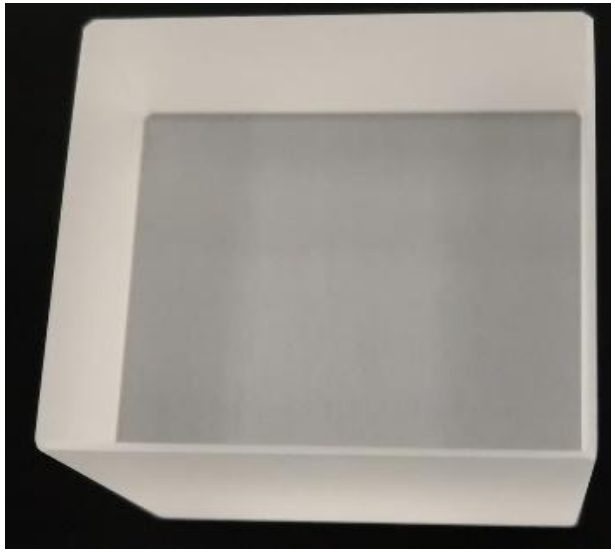
WSF pad

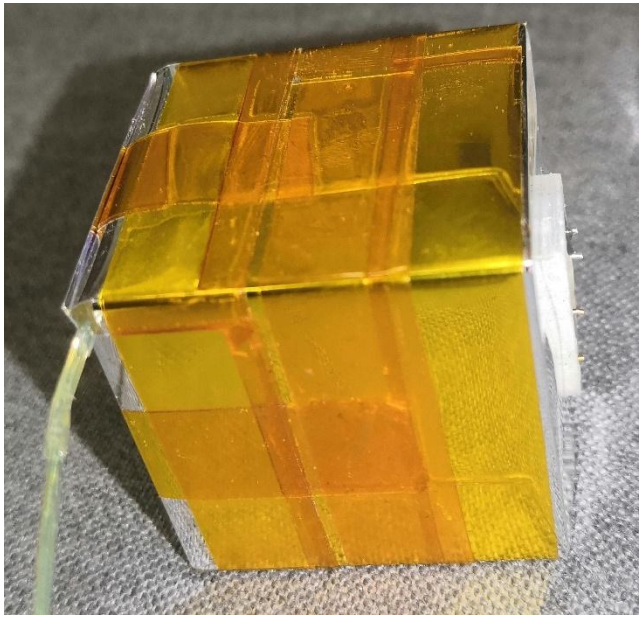


Bundle for polishing ends

LYSO encapsulation

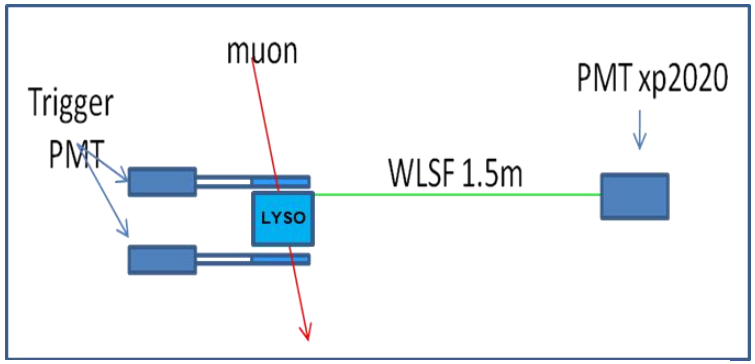
- Five faces of LYSO are roughed and WSF coupling face is polished.
- WSF pad is attached to LYSO polished face and the integral unit is encapsulated by ESR film
- PDs are glued on opposite face W.R.T the WSF coupling face

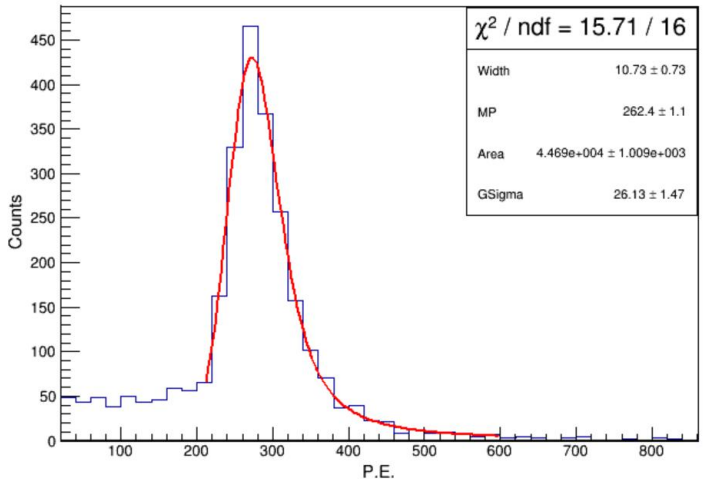




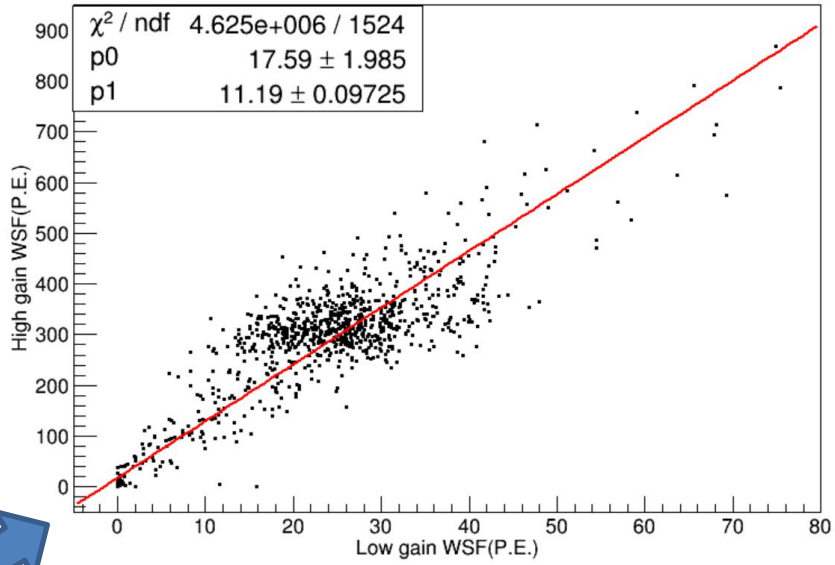
WSF test result

- Low and high range WSF signals are collected by two PMTs(xp2020) independently
- Two PS detectors are in coincidence as a trigger





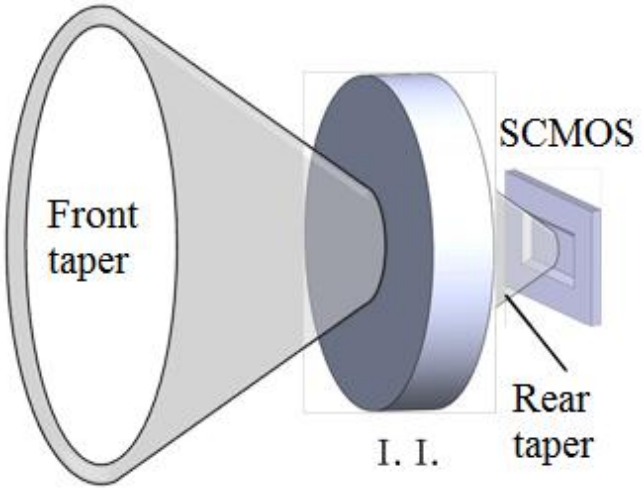
The P.E. number distribution triggered by muon of low range WSF



Relationship between low gain(outer) WSF and the high gain(inner) one

IsCMOS

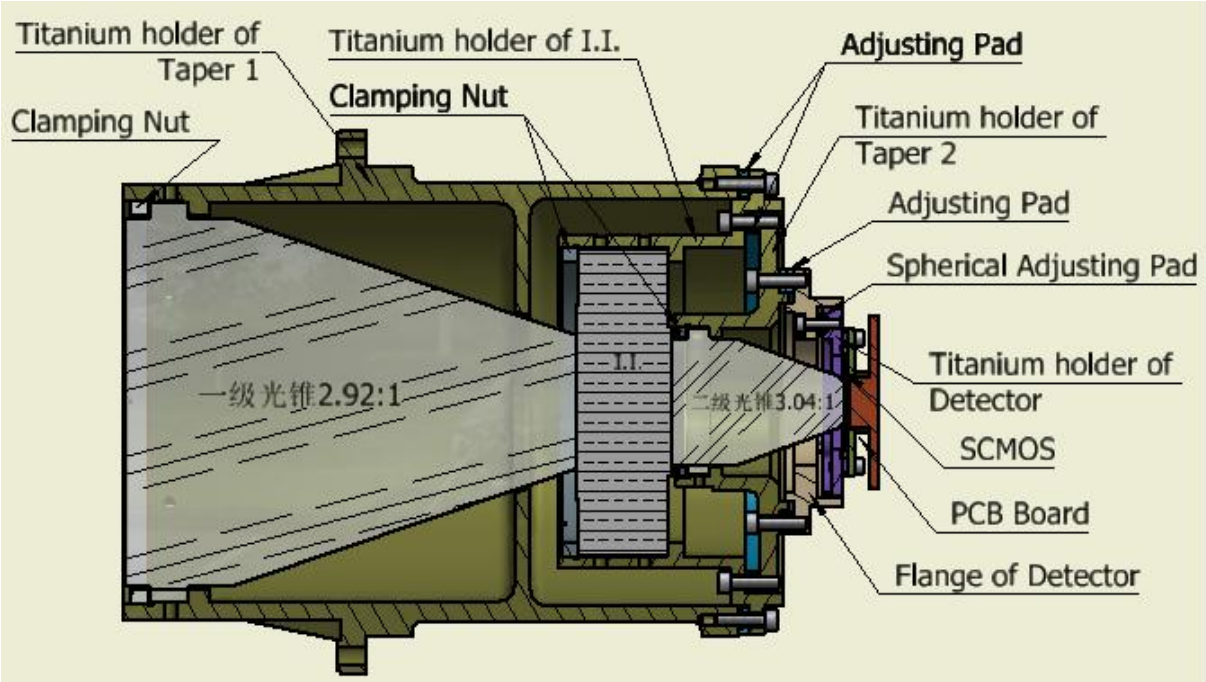
- The IsCMOS system includes a low range camera and a high range camera.
- Each camera is composed of an integrated image intensifier and a customized sCMOS sensor.
- The dynamic range of each camera is more than 5000, the DR of combined two cameras is up to 10^7



Integrated image intensifier

- Image intensifier integrates the front taper and the rear tapper, removes front and rear fiber optic panel

  --Optical transmission loss is reduced



SCMOS

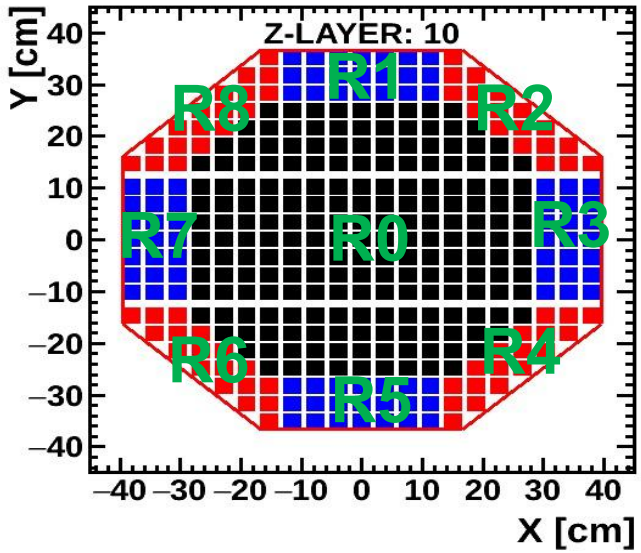
- SCMOS has a big pixel with sides length 5.5 μm
  --for higher sensitivity and lower date rate
- Global Reset exposure mode

  --lower readout noise, higher speed, no image distortions

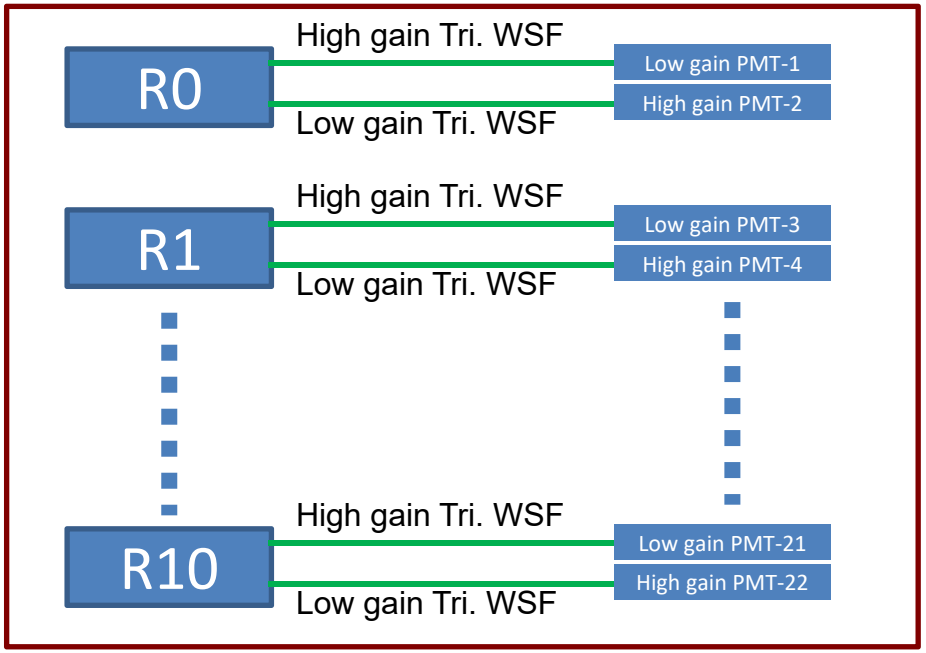
Parameters on single IsCMOS	Commercial sensor	Customized sensor
Frame rate	400fps	≥800fps
Readout noise	5e-	1.5e-
Power consumption	280Watts	About 40Watts
Mem Storage	64Gbits	8Gbits
sensor data rate	≥60Gbps	about 3Gbps

Trigger system

- To provide common trigger signals to all the other instruments after veto and coincidence logic.
- Crystal array is divided into several shell regions and one core region to efficiently trigger high and low energy events
- Trigger fibers from each region are collected by an individual PMT, the two trigger fibers are redundancy for each other



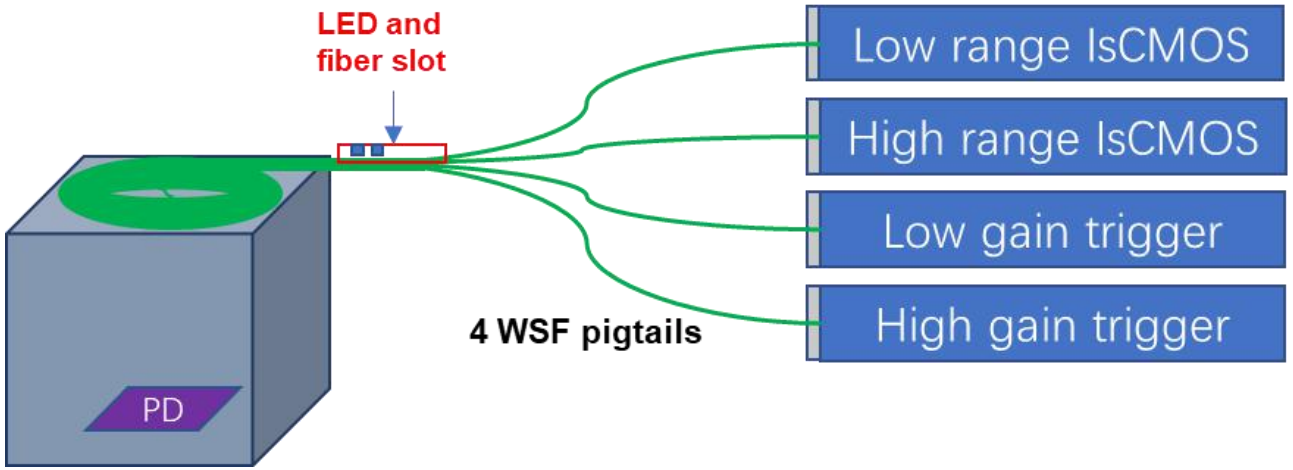
Triggering partitions of one tray



Two shell regions(R9,R10) in Z direction are not shown

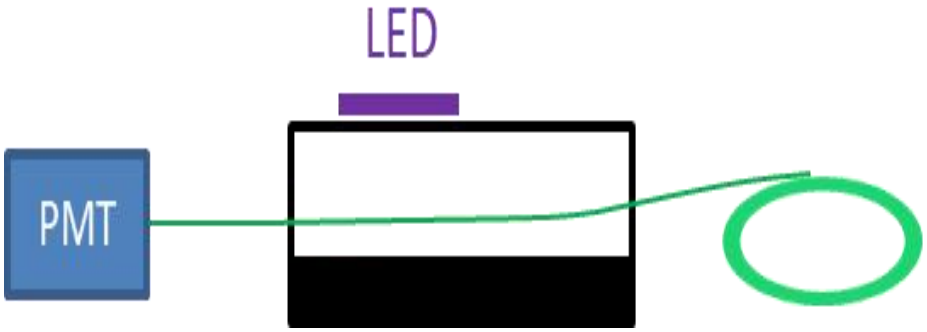
Calibration light source

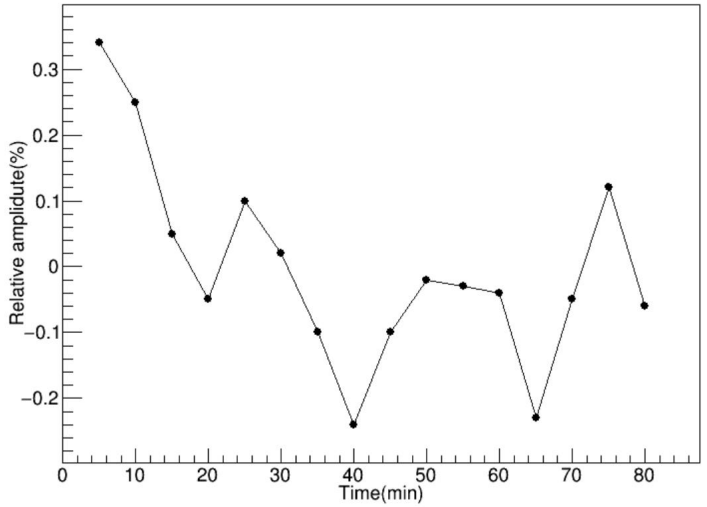
- Calibration light source calibrate IsCMOS in a short time scale at WSF spot level
- A set of LEDs, as the light source, are mounted on the side of WSFs which coupled to IsCMOS on every LYSO tray
- Expected upper limit of calibration energy is ~3*10^6 MeV.

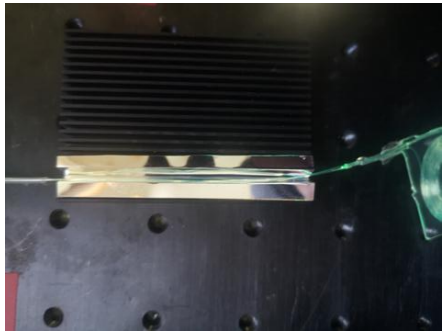


Preliminary test result of LED

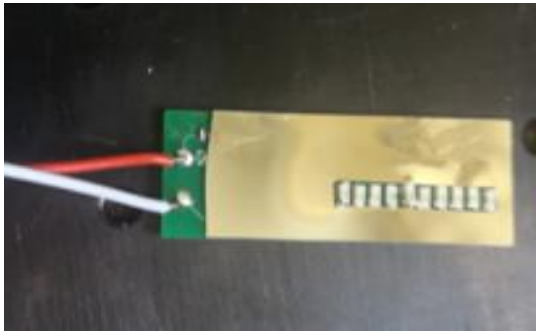
- The variation of LED is less than 0.4% working in 1 hour at 100Hz frequency







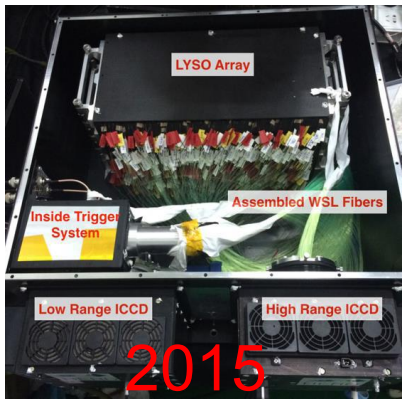
WSF slot

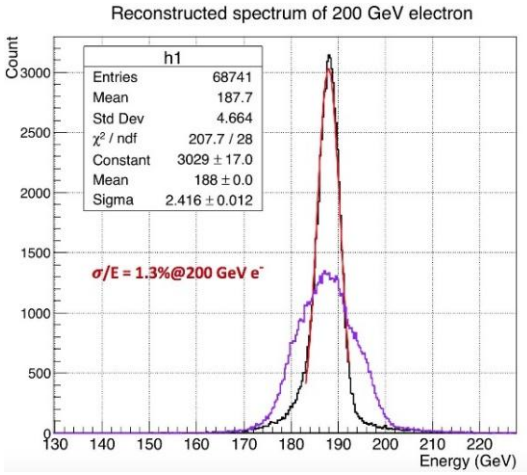


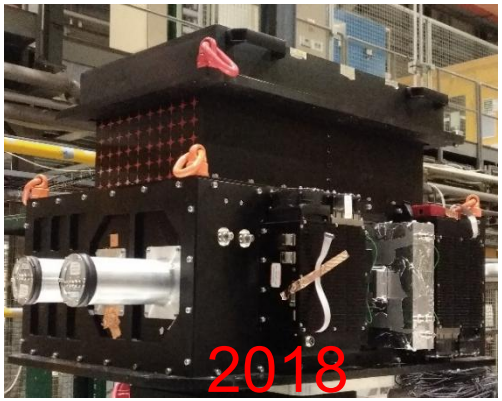
A group of LEDs

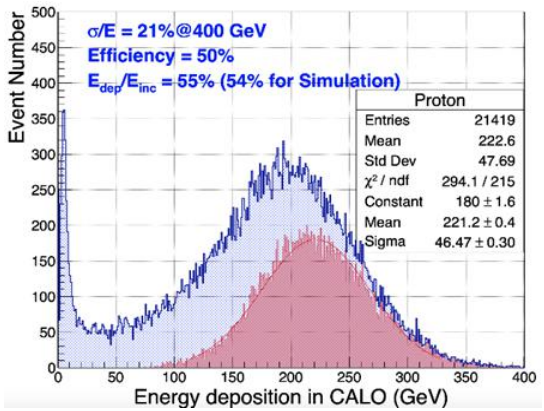
Prototypes

- Four CALO prototypes are build and tested at CERN Super Proton Synchrotron(SPS) beam line for performance validation









Conclusion

- HERD has been proposed as a space experiment which will be installed on the China's Space Station around 2027
- The design of CALO is introduced and the effective geometric factor is more than one order of magnitude larger than that of previous missions
- Each LYSO read-out by two pieces of WSF with four pigtails and expected dynamic range is more than 10^7
- A set of LEDs laid out in WSF path to calibrate IsCMOS at WSF spot level
- Prototypes are build and the performance are verified at CERN SPS beam line

Thanks for your attention!