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

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On behalf of HERD CALO collaboration
CALOR 2022, May 16-20, 2022
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
- The CALO is a 3D segmented calorimeter which can accept particles coming from each surface.
- The effective geometric factor of CALO is more than one order of magnitude larger than that of previous missions.

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

pigtails
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.

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

The P.E. number distribution triggered by muon of low range WSF.
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 taper, removes front and rear fiber optic panel

--Optical transmission loss is reduced
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

<table>
<thead>
<tr>
<th>Parameters on single IsCMOS</th>
<th>Commercial sensor</th>
<th>Customized sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame rate</td>
<td>400fps</td>
<td>≥800fps</td>
</tr>
<tr>
<td>Readout noise</td>
<td>5e-</td>
<td>1.5e-</td>
</tr>
<tr>
<td>Power consumption</td>
<td>280Watts</td>
<td>About 40Watts</td>
</tr>
<tr>
<td>Mem Storage</td>
<td>64Gbits</td>
<td>8Gbits</td>
</tr>
<tr>
<td>sensor data rate</td>
<td>≥60Gbps</td>
<td>about 3Gbps</td>
</tr>
</tbody>
</table>
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.

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 $\sim 3 \times 10^6$ MeV.

![Diagram of calibration setup](attachment:diagram.png)
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
Four CALO prototypes are build and tested at CERN Super Proton Synchrotron (SPS) beam line for performance validation.
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!