The **H**igh **E**nergy cosmic **R**adiation **D**etection (**HERD**) facility onboard China's Space Station

Zhigang Wang
On behalf of the HERD group

Institute of High Energy Physics
Chinese Academy of Sciences

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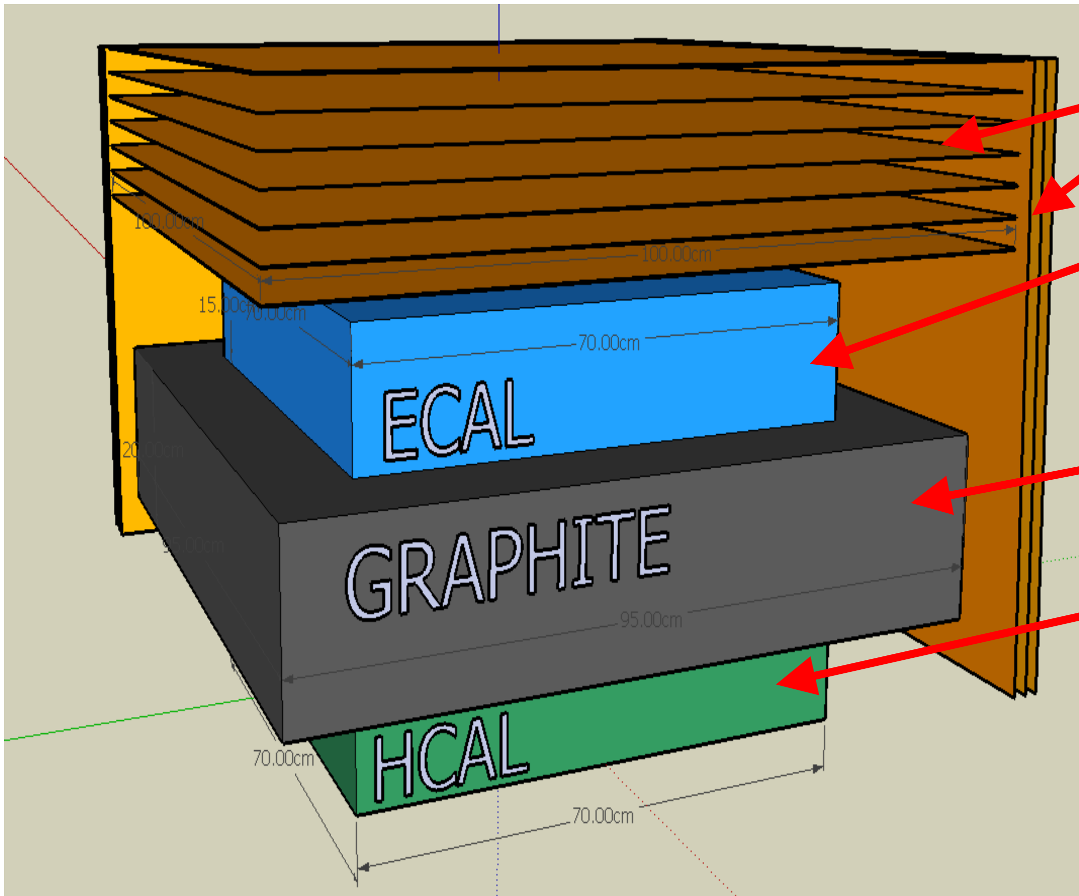
Science goals and requirements for HERD

Science goals	Mission requirements
Dark matter search	R1: Better direction and energy measurements of e/γ between 100 MeV to 10 TeV
Origin of Galactic Cosmic rays	R2: Better spectral and composition measurements of CRs between 300 GeV to PeV with a large geometrical factor

Secondary science: monitoring of GRBs, micro quasars, Blazars and other transients.

Baseline design of HERD

The detector consist of 4 parts:



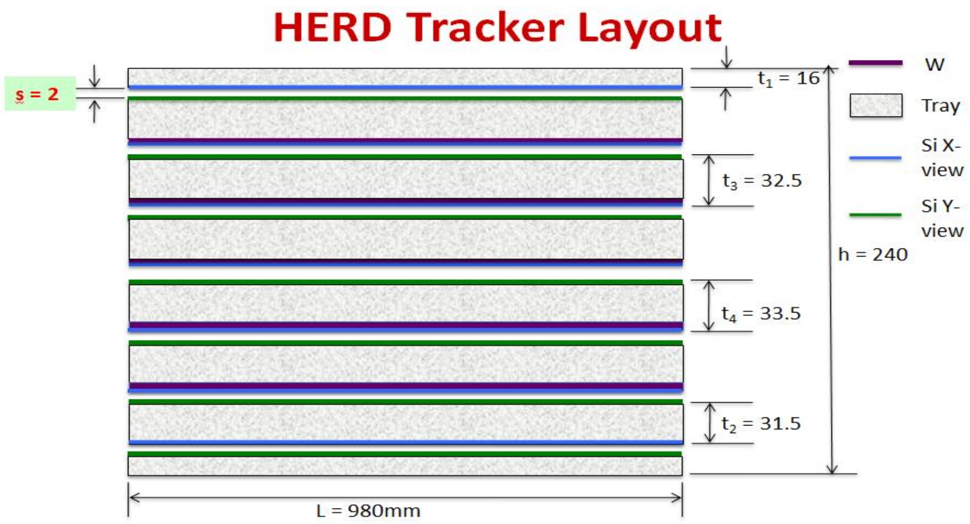
The micro silicon strip tracker (orange)

ECAL: The electromagnetic calorimeter(blue)

The graphite target(gray)

HCAL: The hadronic calorimeter (green)

The micro silicon strip tracker

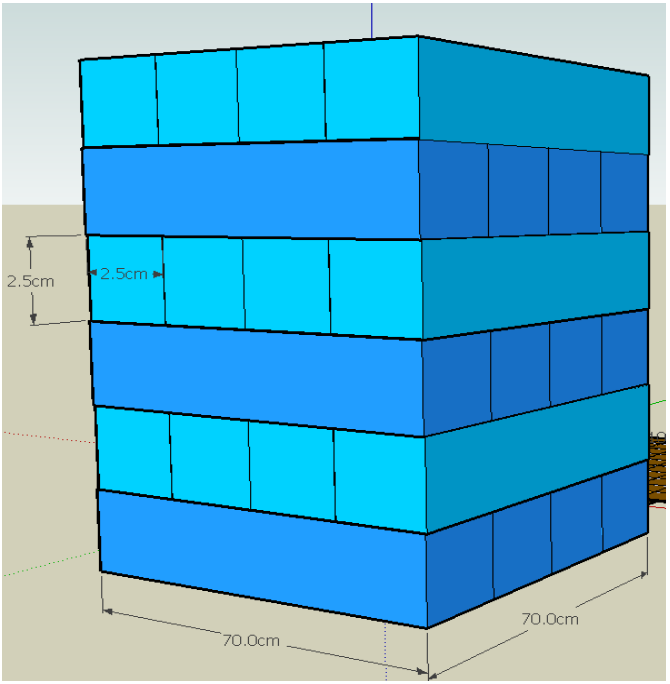


It cover the top and four sides of the instrument , for incident particle trajectory and nucleon charge measurement.

The top tracker is constituted of micro silicon strips and thin tungsten foils, the latter act as converter for gamma-rays. There are seven tracking planes of x-y layers of silicon strips, each with the dimension of 100 cm × 100 cm, and five converter layers of tungsten sandwiched between layer 2-6, with thickness 3×1 mm + 2×2 mm = 2 X0.

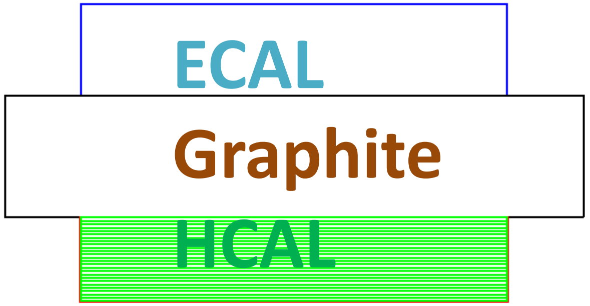
The other 4 sides are covered with three layers silicon strip detector the same as the top one, only with a dimension of 100 cm × 70 cm without tungsten foils.

ECAL: The total absorbing calorimeter



ECAL is a stack of 2.5 cm×2.5 cm×70 cm bars of BGO crystal arranged in x-y layers. Each bar is read out with a photomultiplier. ECAL has a total thickness of 15 cm (13 X0). The full active ECAL measures the total energy deposited by gamma or electron.

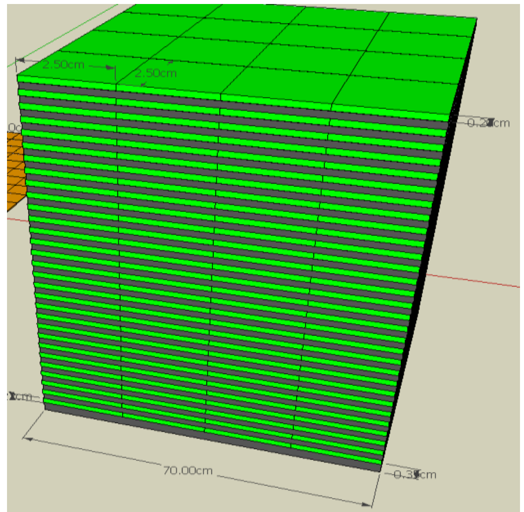
Graphite target



The graphite target is a 95 cm × 95 cm × 20 cm (0.5 λ) block, between ECAL and HCAL.

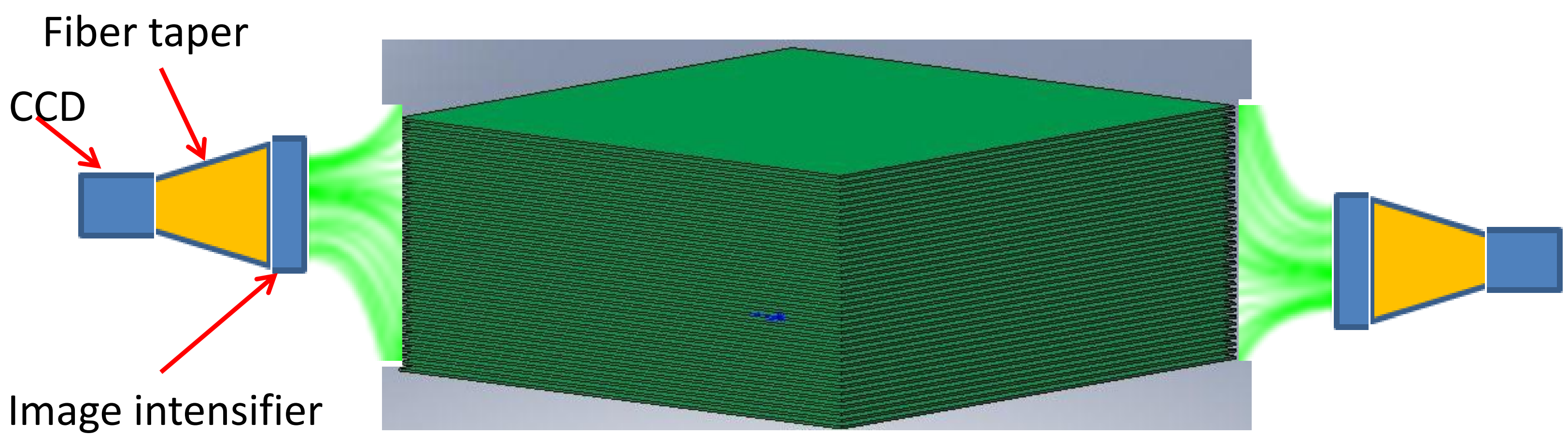
It is designed to induce nuclear interactions of incident cosmic rays before entering HCAL, in order to maximize the nuclear interaction length while minimizing the total weight.

HCAL: The Sampling calorimeter



HCAL is a stack of sandwich structure of 25 layers. Each layer consist of a tungsten plate of 0.35 cm thick placed between CsI(Na) scintillator cells of 2.5 cm $\times$ 2.5 cm $\times$ 0.2 cm read out by fibers coupled with ICCD. HCAL has a dimension of 70 cm $\times$ 70 cm $\times$ 14 cm(0.9 λ), providing cosmic ray energy measurement and correction of the shower energy leakage of ECAL, and enhancement of the electron/proton separation power.

Readout system of the HCAL

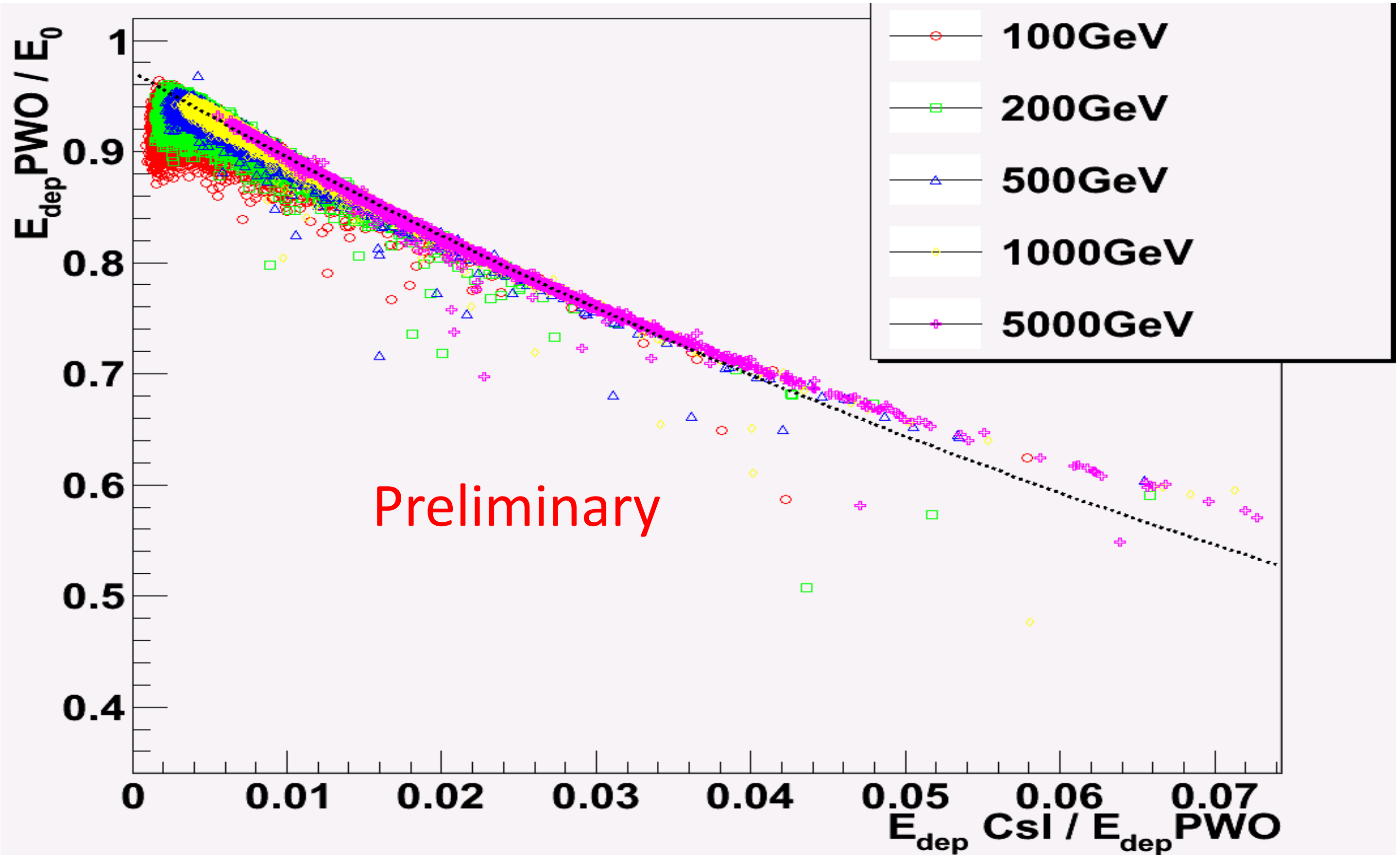


The scintillation light of crystals is absorbed by a 300 um diameter wavelength shifting(WLS) fiber which is attached to the surface of the scintillator with a spiral structure.

There are total 20 thousand readout channels, the fiber ends are bundled in one compact bunch, which has a size of only a couple of centimeters. The fibers at the end of the bundle can be glued together and polished making a ”fiber optic plate”-like structure.

The shower development profile of an event in HCAL is then translated into the surface of the fiber optic plate (FOP). This image on the FOP can be photographed by using an externally triggered ICCD.

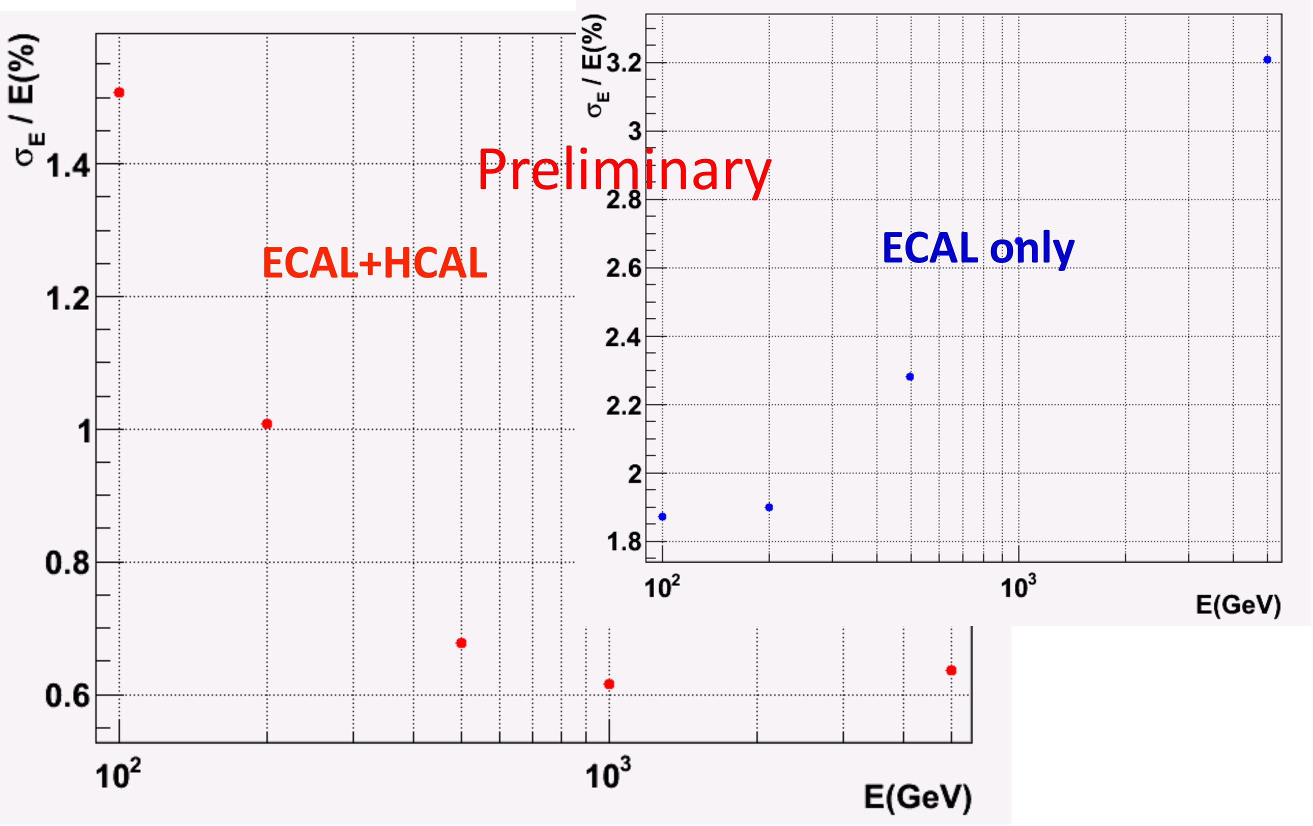
Energy correction for gamma & electron



Fitting function: Y = p0*expo(p1*x)

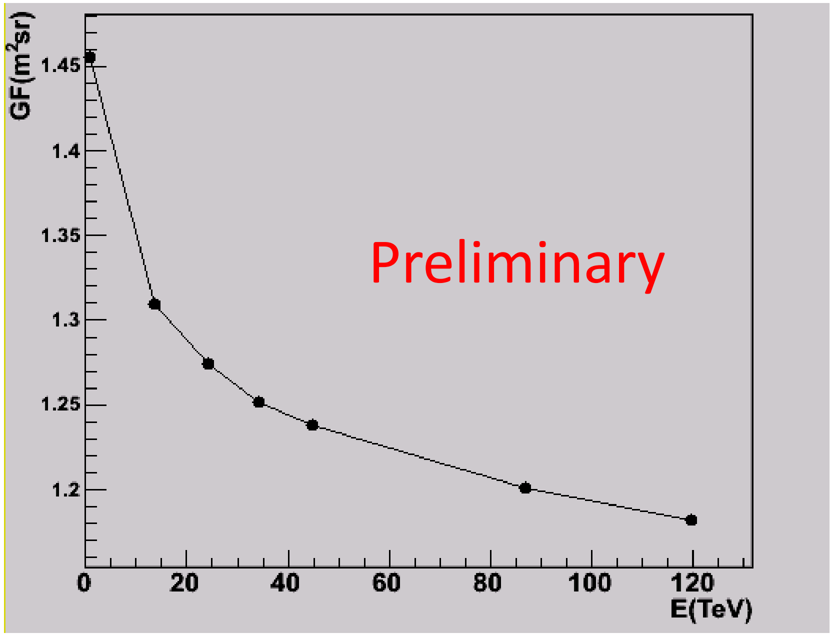
E_reco = E_depPWO / p0*expo(p1*x)

Energy resolution of ECAL(gamma/e)



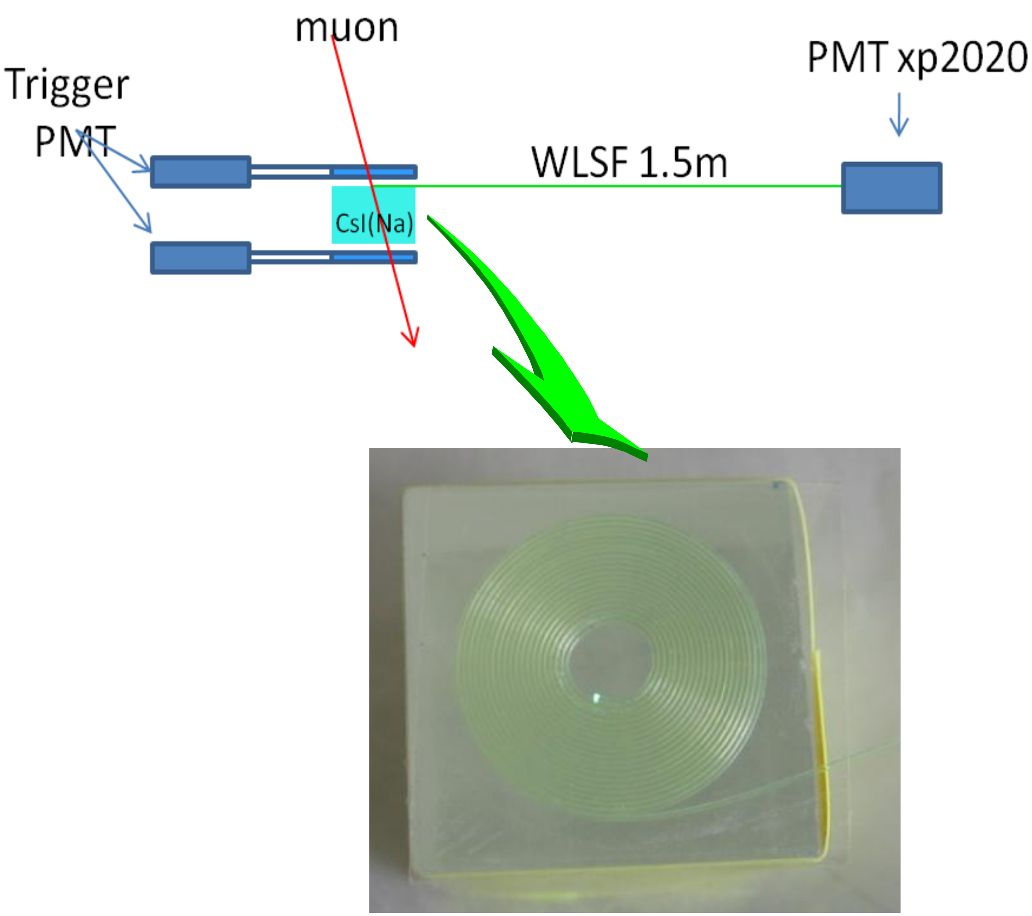
There are no obvious difference when energy below 100GeV.
The energy resolution will be better than 1% with the correction of HCAL, if energy above 200GeV, while with no correction, the value is large than 2%.

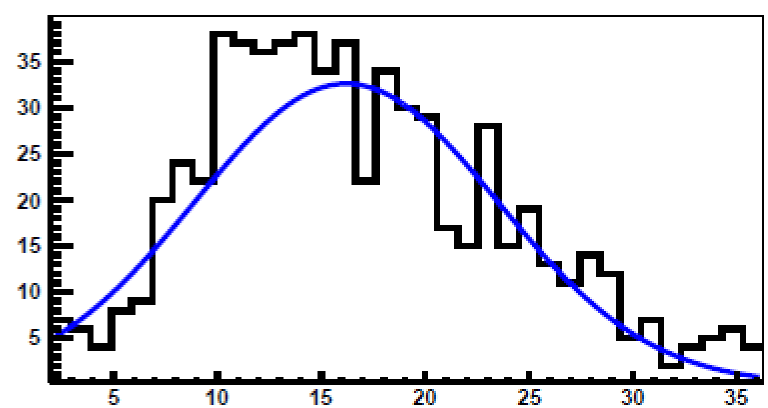
Geometry factor of HCAL for proton



The geometry factor of HCAL is larger than 1.2 m^2sr until energy up to 100 TeV.
This is one of the advantages of HERD compare with other missions .

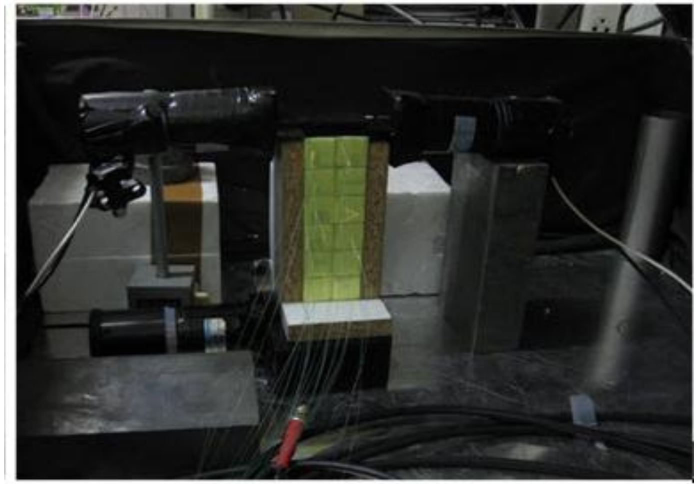
Cosmic Ray test result



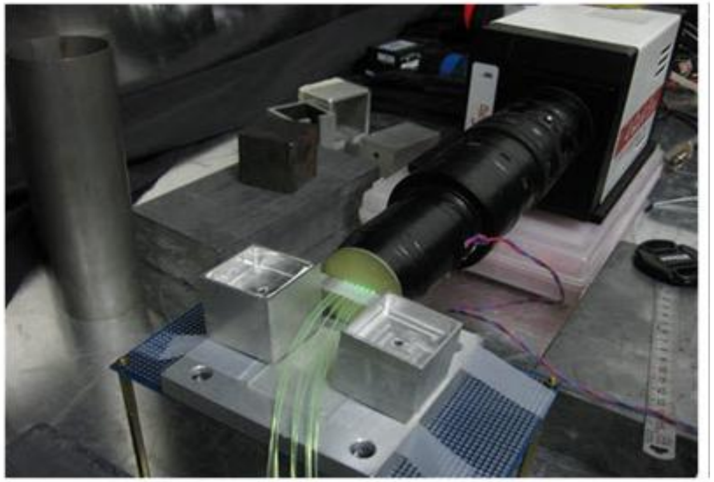


2.5 cm × 2.5 cm × 0.2 cm CsI(Na):
~ 15 p.e. for a passing muon

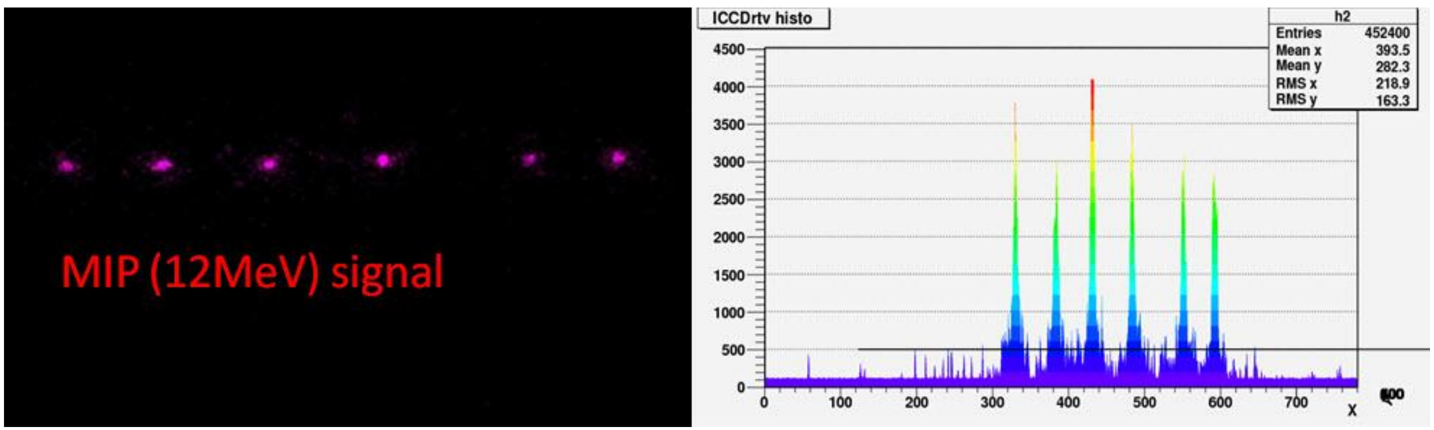
ICCD test set-up and results



2×2×6 cubic CsI(Na) with fibers sandwiched between two scintillator



Taper +Imaging Intensifier + ICCD



ICCD image of typical muon events

Characteristics of all components of HERD

	structure	size	thickness	unite/cell size	readout	main function
tracker (top)	silicon strip	100 cm × 100 cm	2X0	7 x-y layers (tungsten foils interspersed)	--	charge identification. Trajectory detection
tracker (side×4)	silicon strip	100 cm × 70 cm	--	3 x-y layers	--	charge identification. Trajectory detection
ECAL	BGO bar stack	70 cm × 70 cm × 15 cm	13 X0 0.7 λ	2.5 cm × 2.5 cm × 70 cm	PMT	e (gamma) energy detection e/p separation.
graphite	--	95 cm × 95 cm × 20 cm	1 X0 0.5 λ	--	--	induce nuclear interactions.
HCAL	sandwich (tungsten interspersed between CsI(Na))	70 cm × 70 cm × 13.75cm	25 X0 0.9 λ	2.5 cm × 2.5 cm × 0.2 cm	WLS fiber + ICCD	Nucleon energy detection leakage of ECAL detection Enhancement of e/p separation

Resource requirements of each component

	Readout channel	Power consumption (W)	Weight(kg)
silicon tracker	$7m^2$(top)+$8.4m^2$(4 sides) 10 million	720+865=1585	230
ECAL(BGO)	168	100	524
graphite	--	--	397
HCAL	19600	100	938
total	--	~1800	~2090

The total mass and power consumption of HERD meet the requirements of space station.

Expected performance of HERD

Gamma-ray(electron) energy range	Tens of GeV – 10 TeV
nucleon energy range	Up to hundreds of TeV
Gamma-ray (electron) energy resolution	1%@200GeV
Gamma-ray angular resolution（silicon）	0.1 degree
nucleon charge resolution（silicon）	0.1-0.15c.u
e/p separation power（90% electron efficieency）	10^{-5}
Gamma-ray (electron) geometric factor	0.4 m^2sr@200 GeV
Proton geometric factor	1.2 m^2sr@100 TeV

HERD is advantageous in terms of energy resolution (e/γ), geometrical factor (CR) and energy range (e/γ & CR).

Summary

1, HERD is a space station instrument with science goals of dark matter and cosmic ray research.

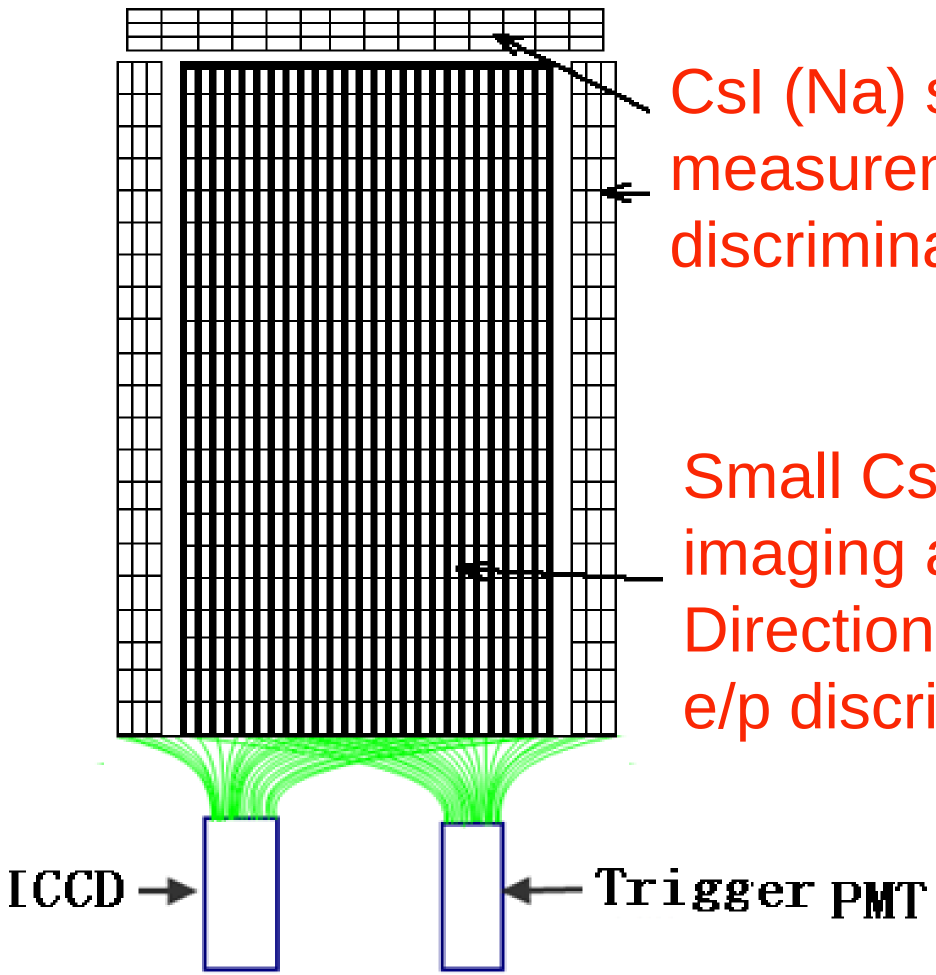
2, The baseline design of HERD have been proposed.

3, The expected performance of HERD is advantageous.

Thanks!

Back up

Design A for China's Space Station

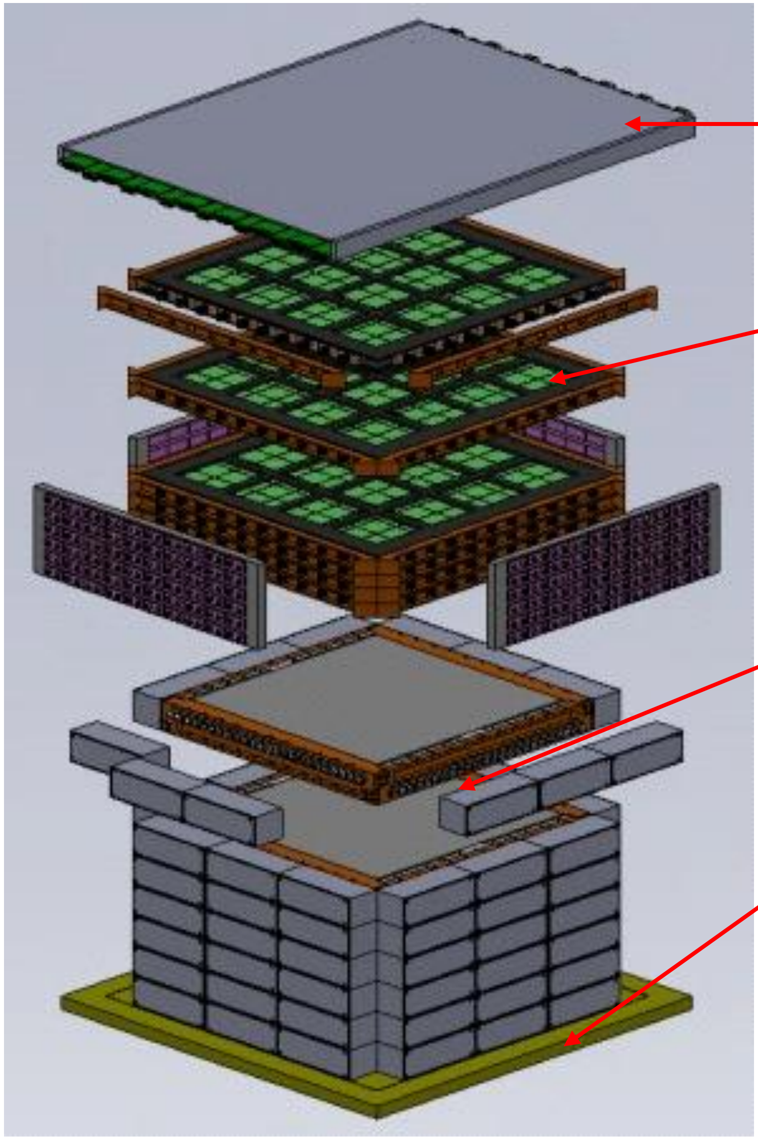


CsI (Na) slices with fibers: charge measurement and e/gamma discrimination.

Small CsI (Na) slices with fibers+W: imaging and sampling calorimeter. Direction and energy measurement, e/p discrimination

One PMT for trigger and one I-CCD for readout

Design B for China's Space Station



Charge sensitive detector: Double-layered Si-PIN

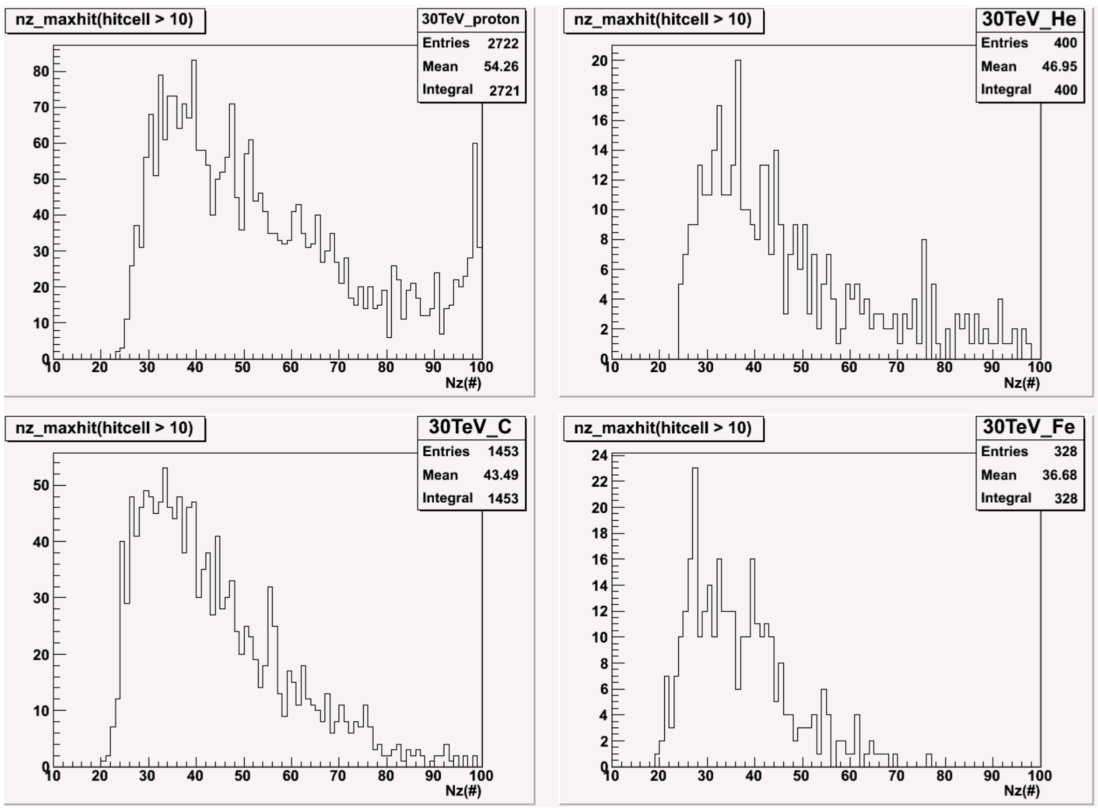
Imaging calorimeter: 8 layers scintillation fibers + W. e/γ discrimination and direction reconstruction.

ECAL: PWO or BGO. Energy measurement and e/p discrimination

Neutron detector: B-doped plastic scintillator. Enhanced lepton/hadron discrimination.

CR detection VS detector thickness

Minimum detector thickness: shower maximum + 3 more layers

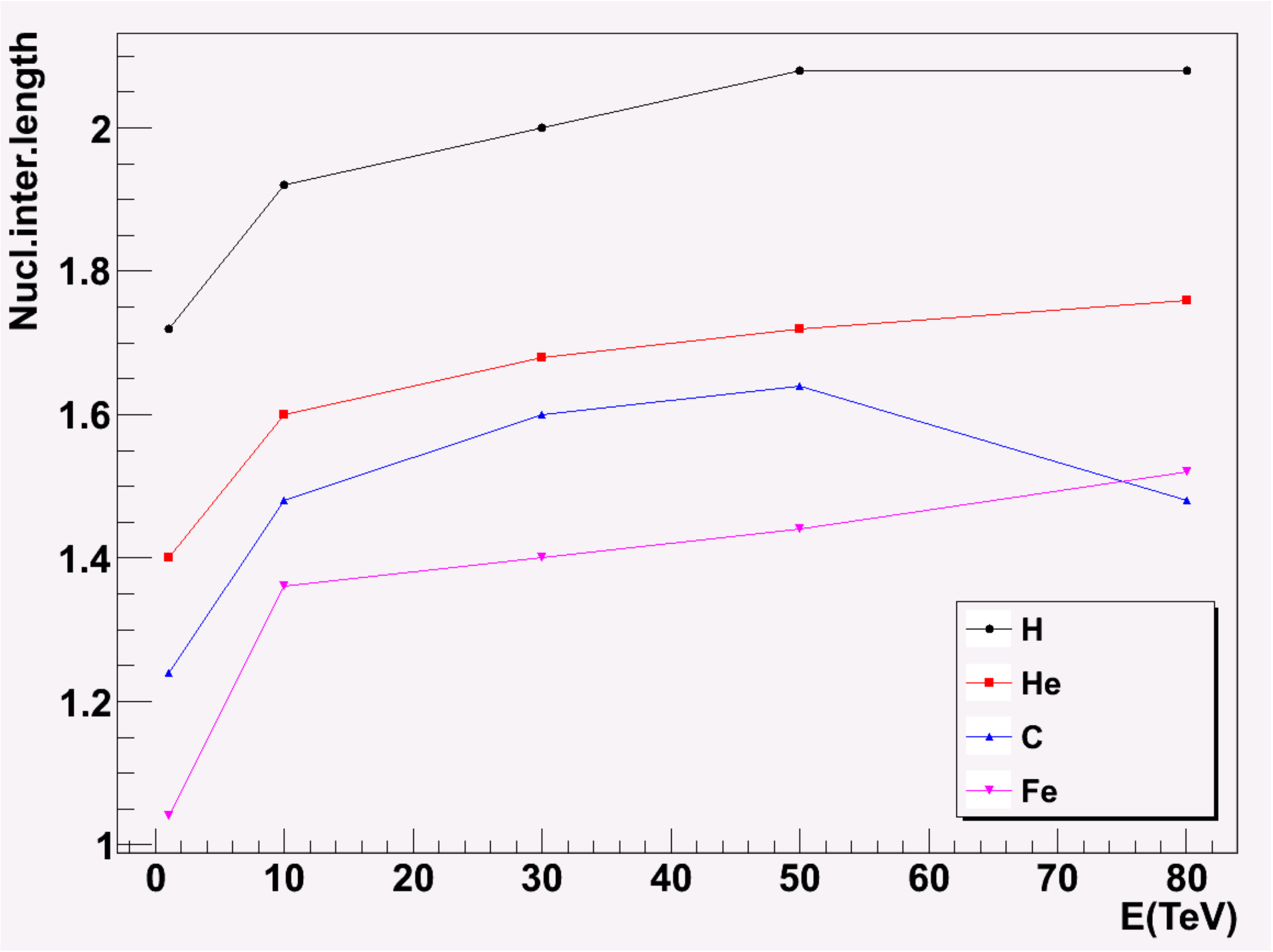


1Nz =
0.04 nucl.inter.length

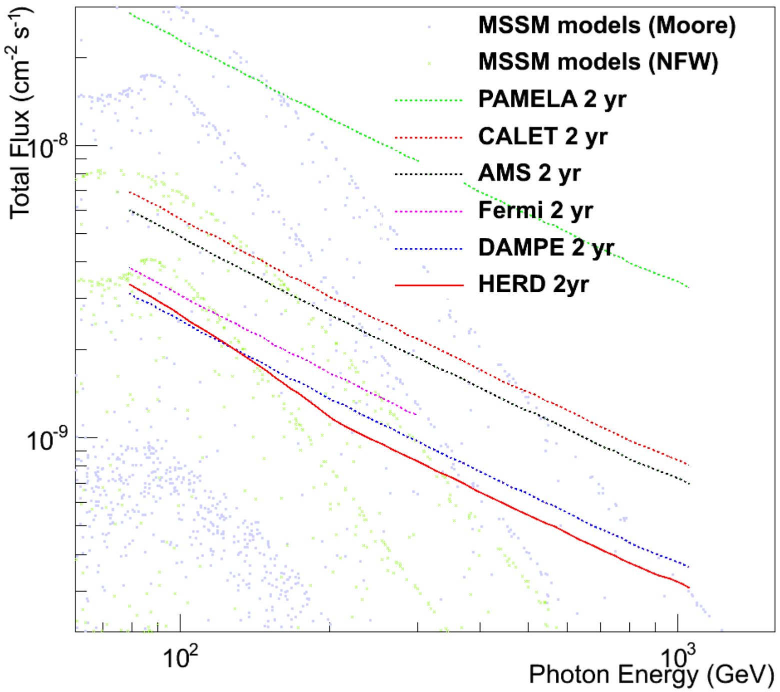
Shower maximum distribution of different nuclei(proton, helium, carbon and ion) @30TeV

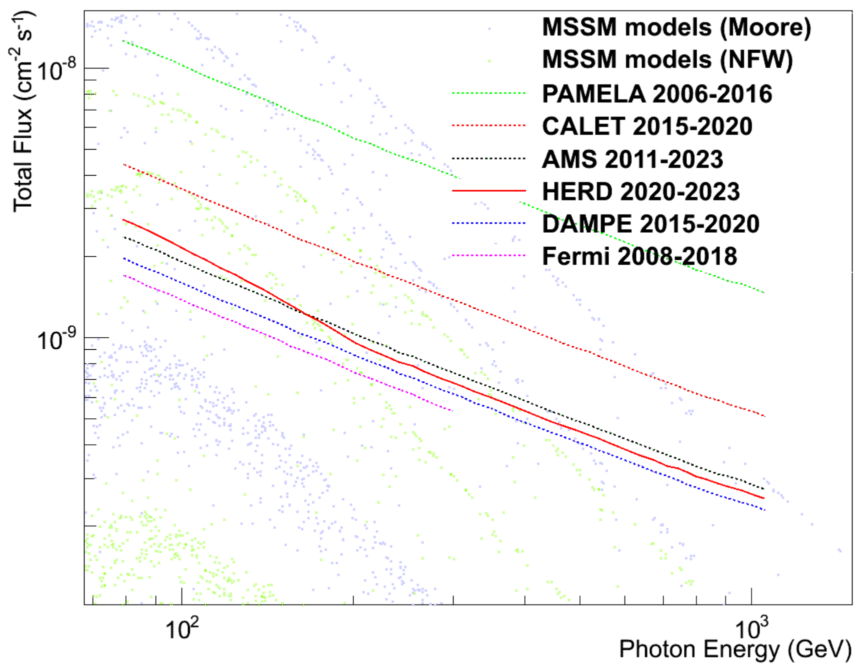
50% events of the distribution as the thickness we need in a certain energy range.

CR detection vs detector thickness



Annihilation line detection sensitivity

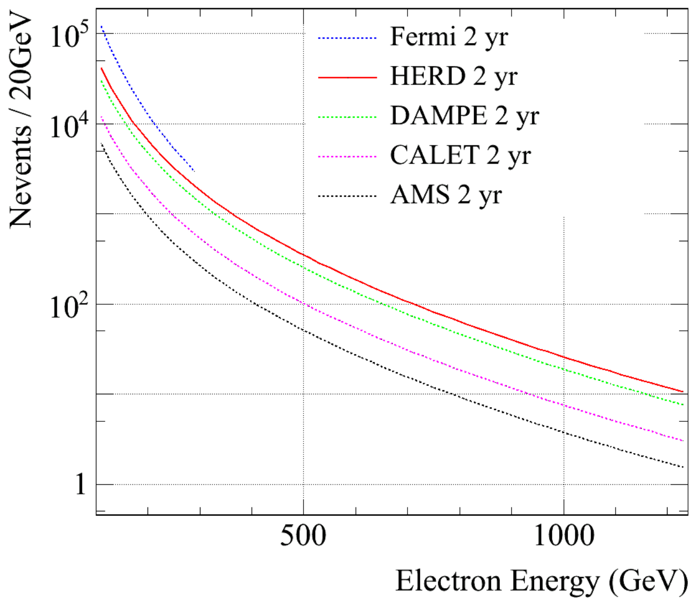


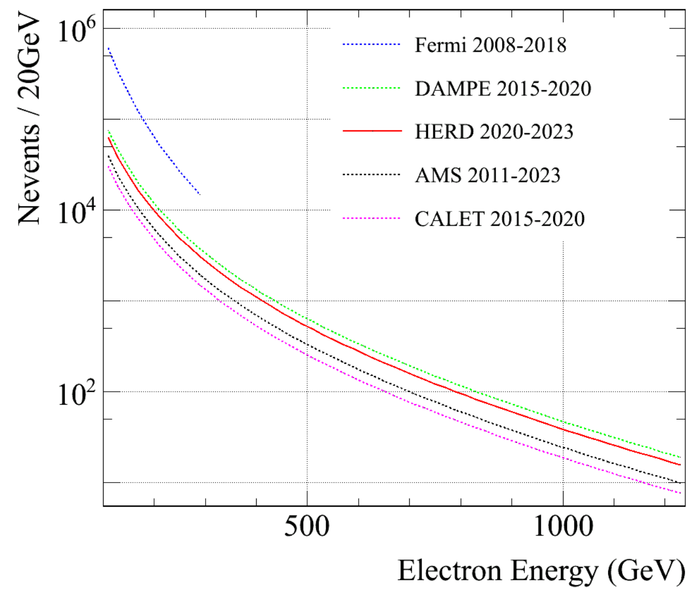


High energy photon annihilation line detection sensitivity curve. Y axis is photon flux of 5 sigma discovery, the lower of curve means the higher sensitivity.
The left plot is the detection capability in 2 yr of HERD and other experiment. In unit observation time, HERD and DAMPE have the strongest capability of dark matter detection capability.

The right plot consider the mission time of different experiment. For photon energy below 300GeV, Fermi is the best detector for photon detection, but it can't measure energy greater than 300GeV because of leakage. After 3 years of mission time, HERD have the same sensitivity with AMS form 2011-2023.

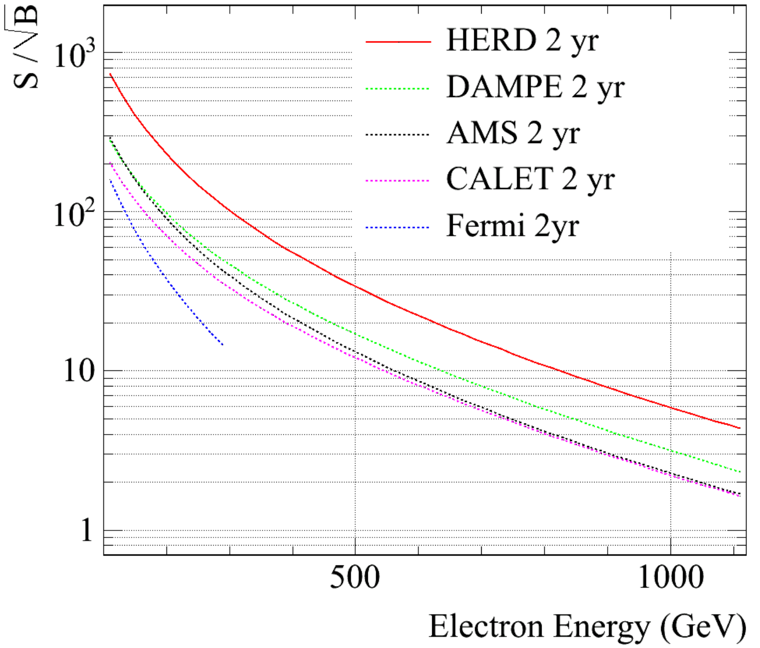
Electron detection sensitivity(event number)

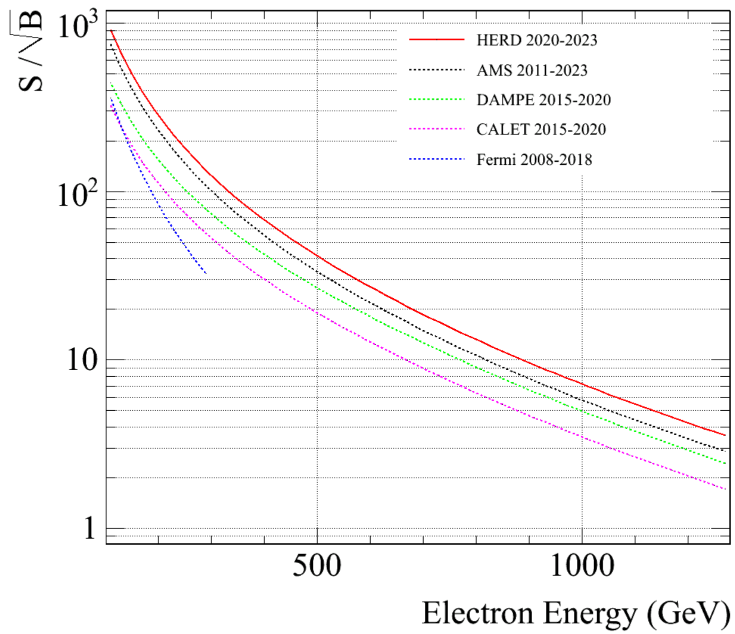




The left plot is the detection capability in 2 yr, HERD and DAMPE can observe the most events in unit time.
After consider the mission time, DAMPE is a little higher than HERD, but these two detection still higher than AMS(right plot).

The significance of electron



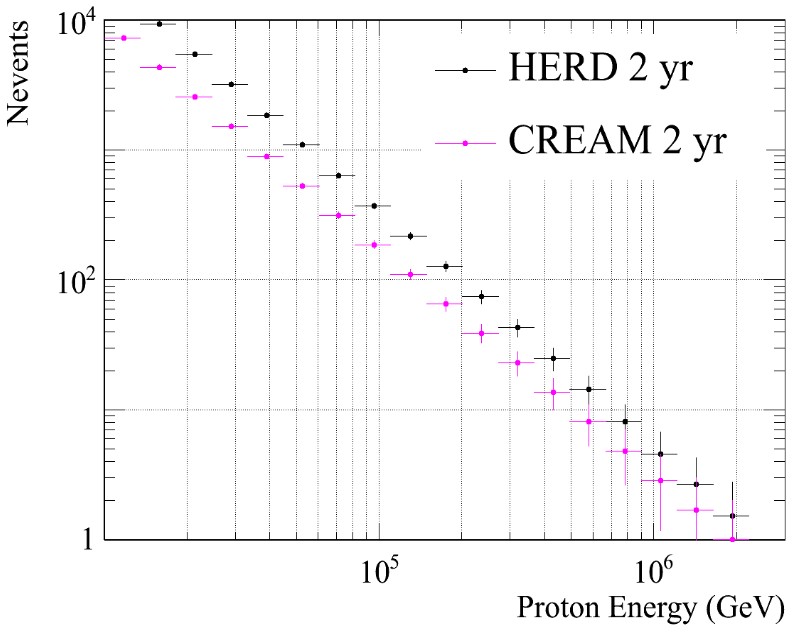


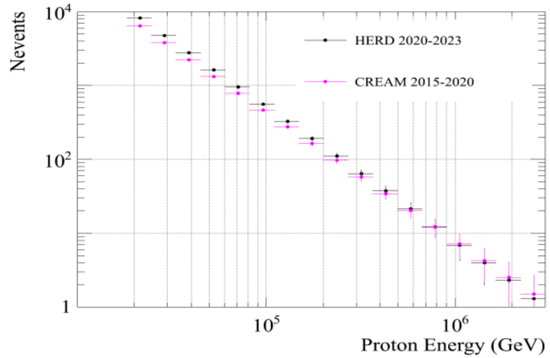
The significance of electron(background include cosmic nucleon and electron migration)

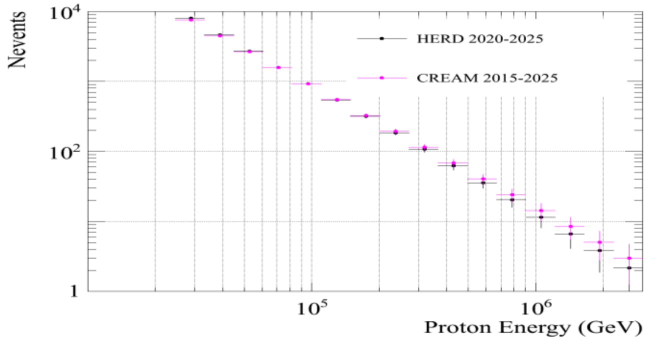
The left plot is the electron significance in 2 yr. HERD have a better e/p separation power, and it’s significance is higher than DAMPE.

After consider the mission time, until year 2023, HERD will surpass AMS(right plot).

Proton detection sensitivity







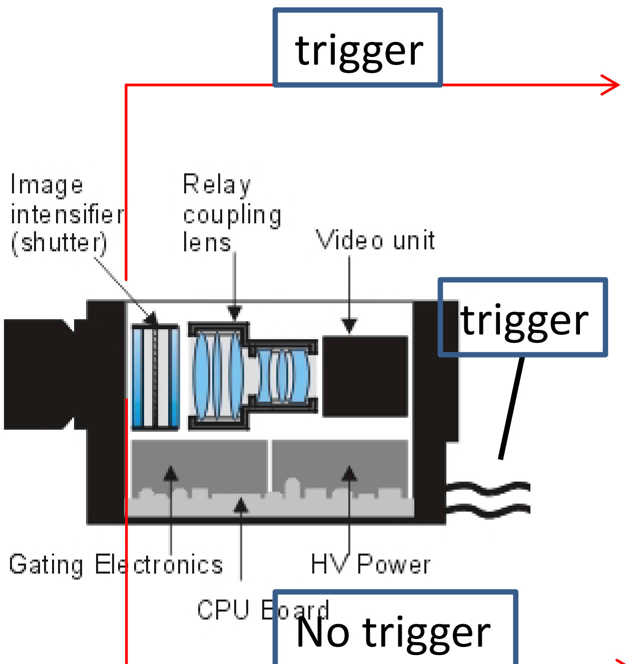
Only consider CREAM, because other experiment didn't have a strong detection capability of proton beyond 100TeV.

Proton events in two 2yr, HERD higher than CREAM(left plot).

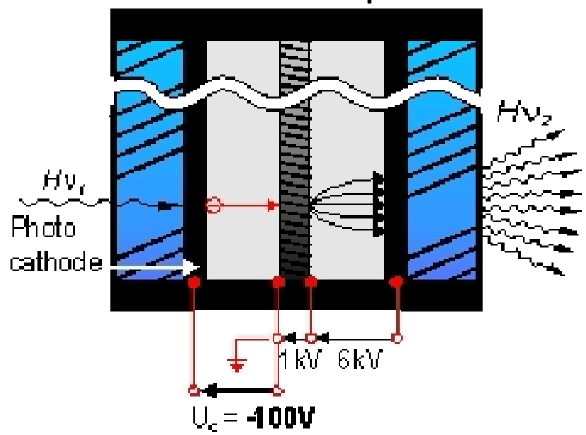
Consider the mission time, if CREAM's life is 5yr, HERD will surpass CREAM in 2023; consider CREAM have a unlimited life, until year 2028, after 8yr of mission time, HERD will surpass CREAM .

ICCD system

Gating:
a crucial feature of high speed ICCD cameras

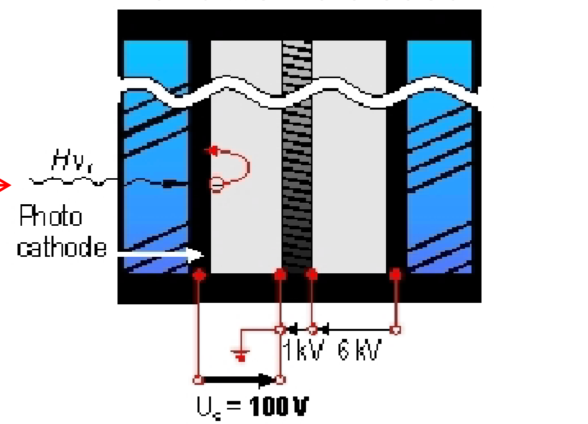


shutter is open



If the voltage U_C between photocathode and multichannel plate is negative, the photoelectrons are accelarated towards the multi channel plate. This means that the shutter is open.

shutter is closed



If the voltage U_C is positive, the photoelectrons are kept at the photoathode, thus the shutter is closed