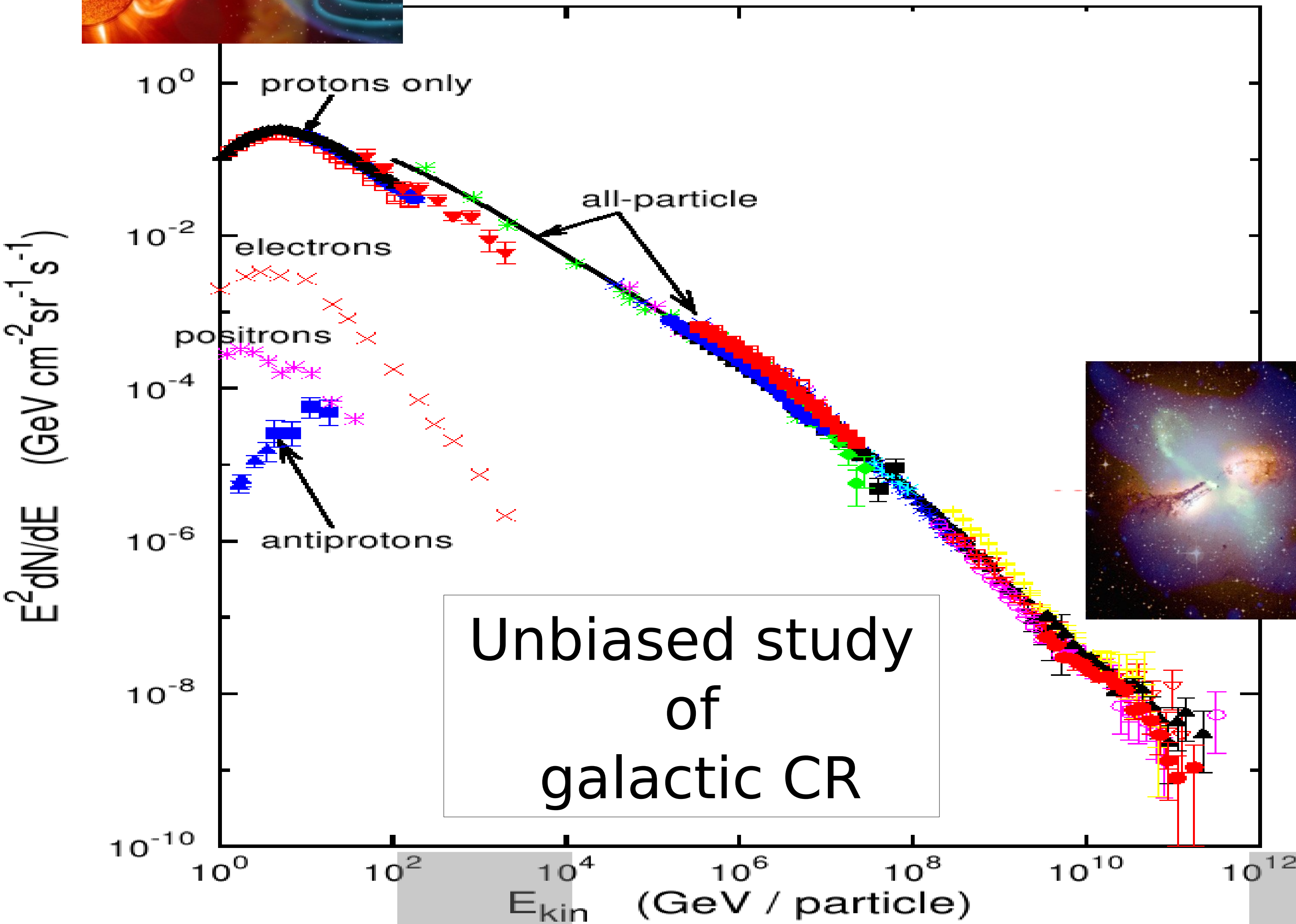
The HERD space mission

Paolo W. Cattaneo

INFN Pavia

On behalf of the HERD Pavia group

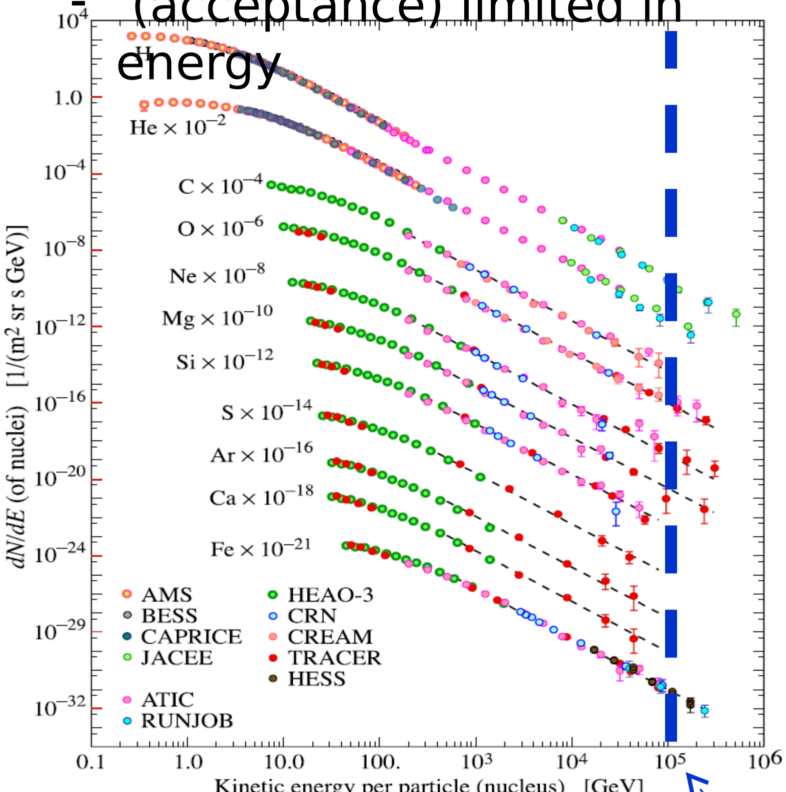


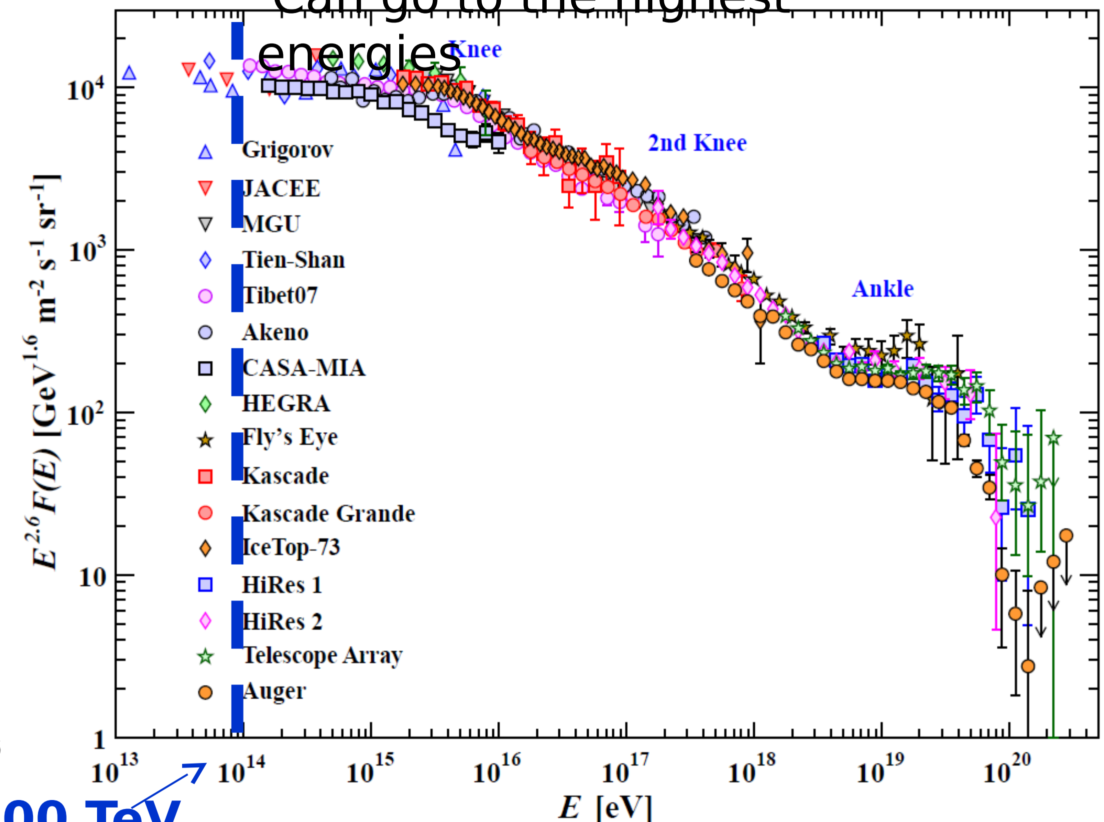
Unbiased study of galactic CR

What we have…

Direct measurements
- High precision
- fluxes of single components
- (acceptance) limited in energy

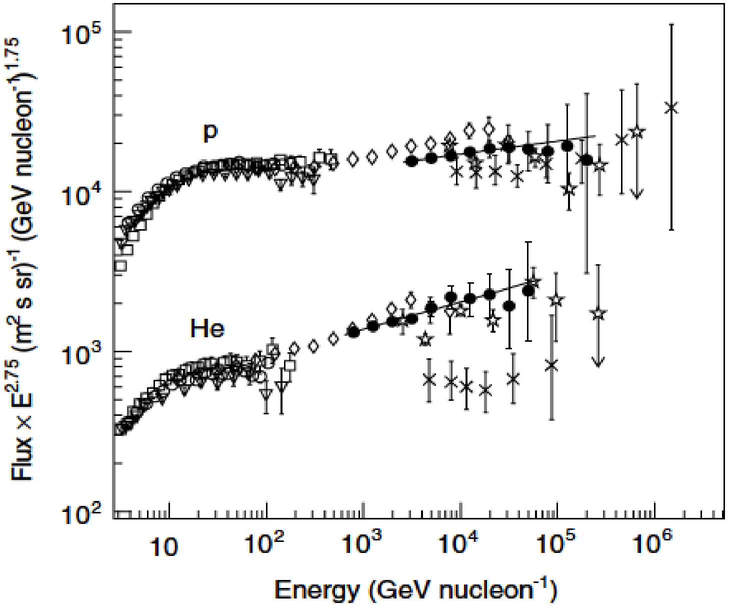
Indirect measurements
- Larger systematics
- Difficult composition measurements
- Can go to the highest energies





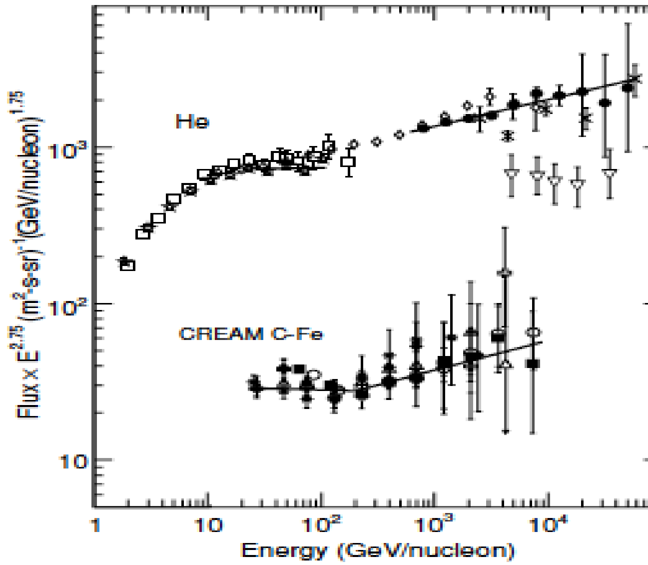
100 TeV

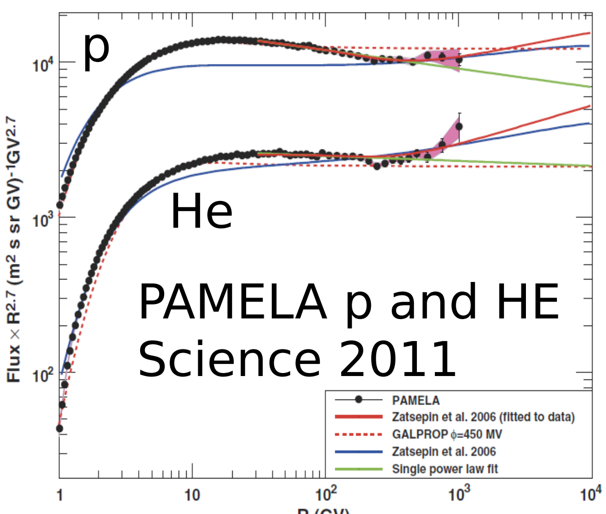
p and He spectral hardenings



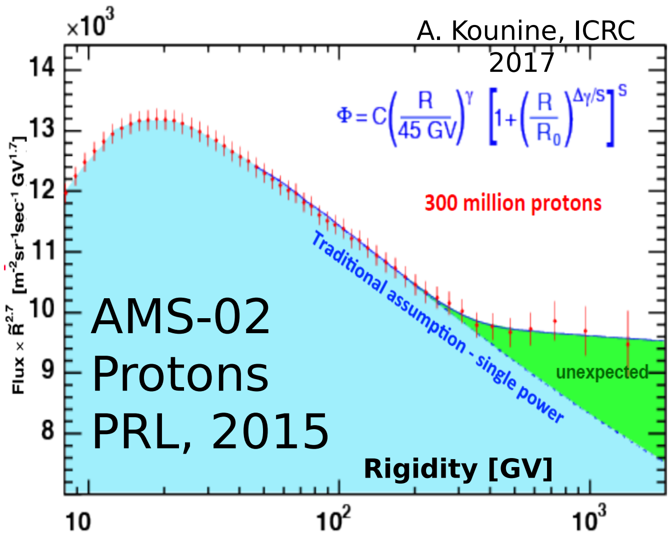
CREAM
First hints for Hardenings.

PAMELA and AMS
Direct detection fo the break at about 250GeV/n

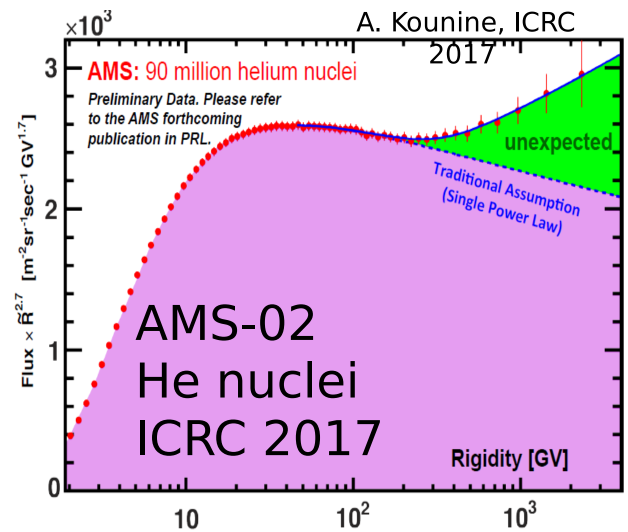




PAMELA p and HE
Science 2011

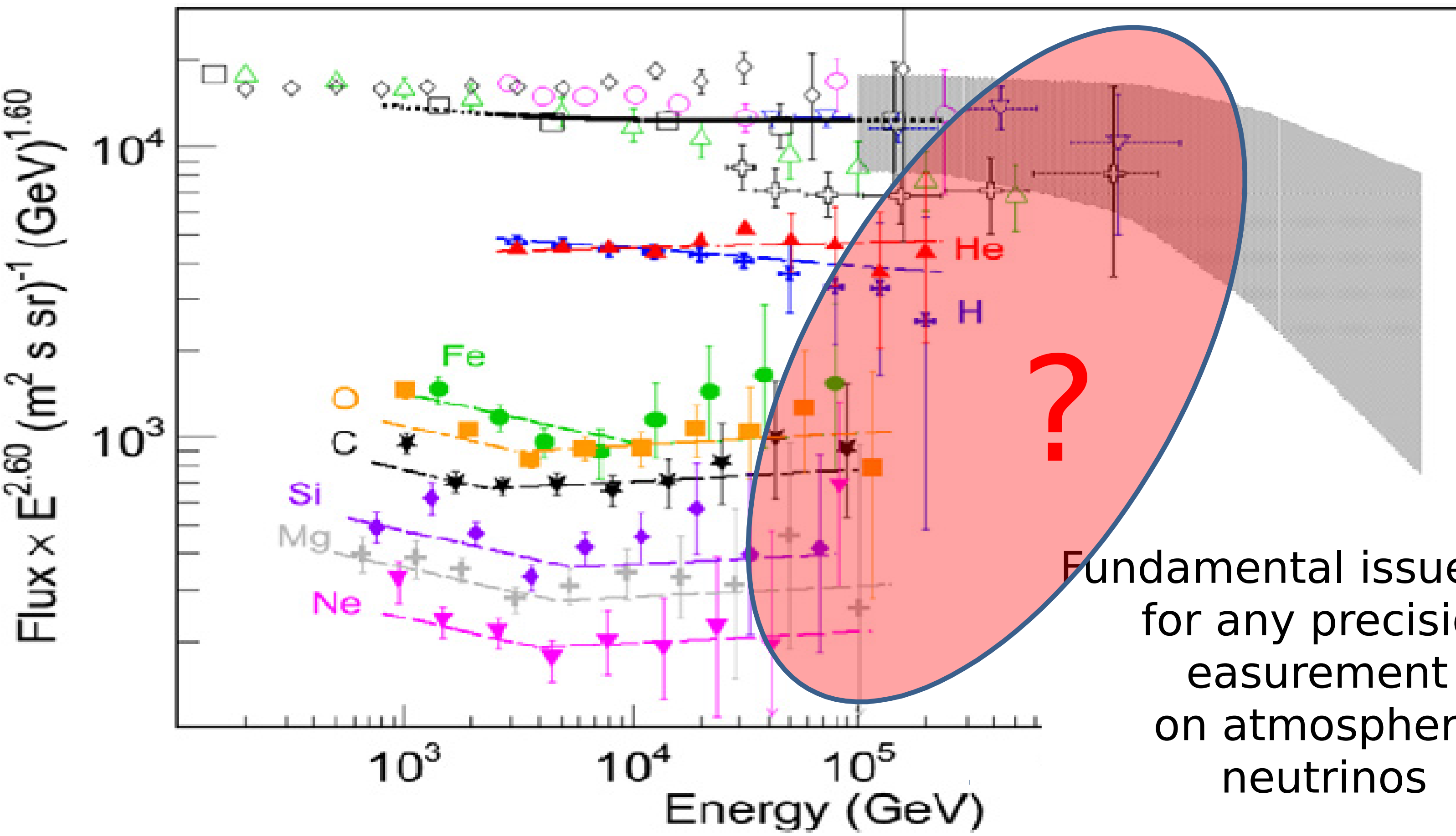


AMS-02
Protons
PRL, 2015



AMS-02
He nuclei
ICRC 2017

E.S. Seo/Astroparticle Physics 39–40 (2012) 76–87



Fundamental issue also for any precision easurement on atmospheric neutrinos

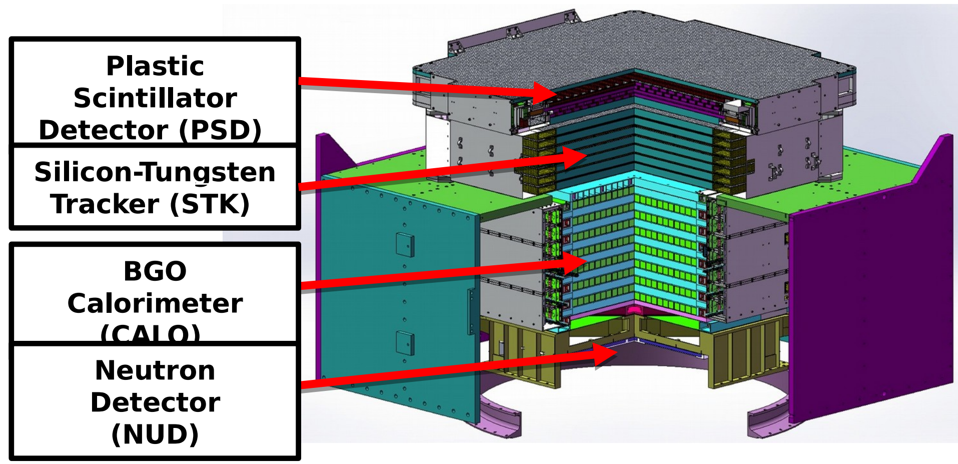
Fig. 11. The all-particle spectrum (black solid curve) obtained by summing up CREAM elemental spectra from p to Fe (filled symbols) is compared with previous measurements (open symbols): ATIC-1 [35], black squares; JACEE, blue downward triangles; RUNJOB, black crosses; Ichimura et al. [71], green upward triangles; SOKOL [72], pink circles. The gray shaded area indicates ground based indirect measurements. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

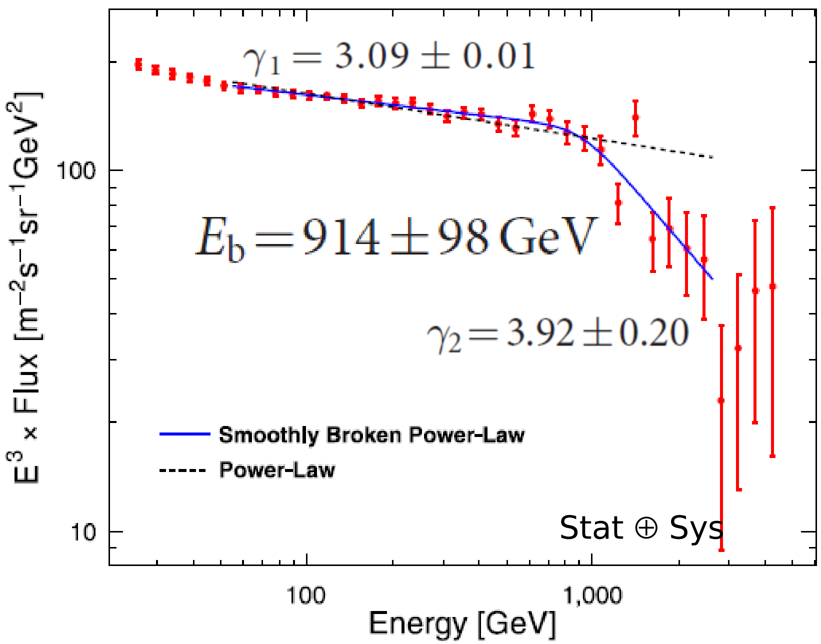
The DAMPE ($e^+ + e^-$) spectrum

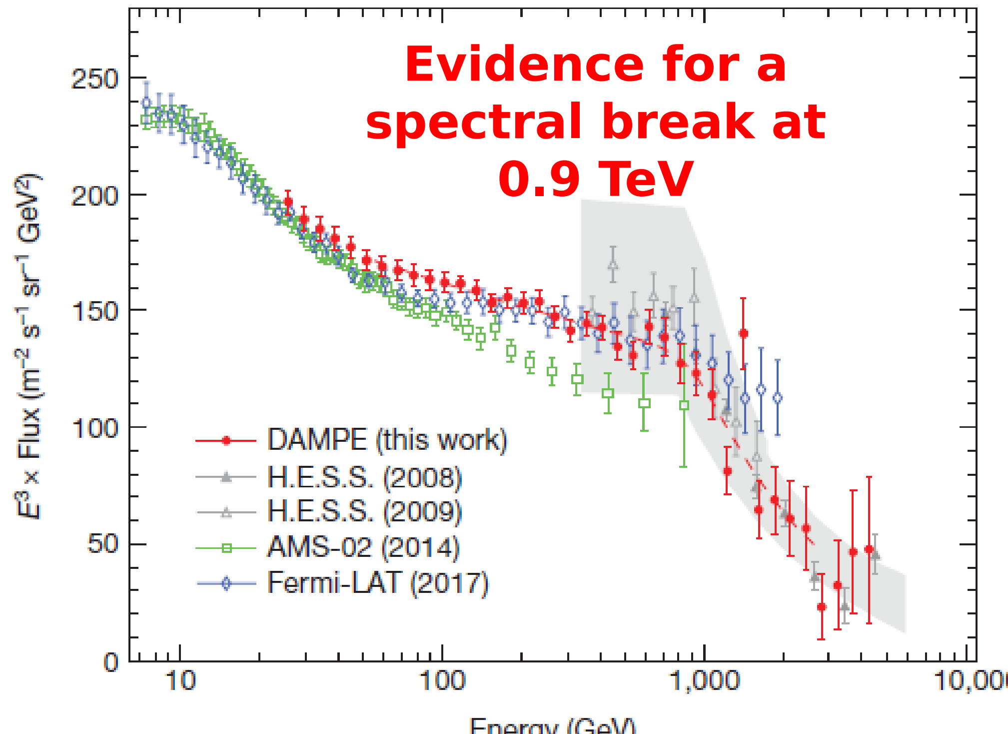
LETTER nature International weekly journal of science
doi:10.1038/nature24475

Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons

DAMPE Collaboration*

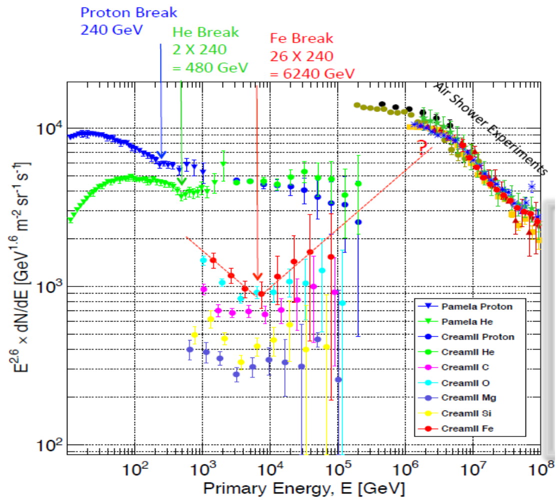


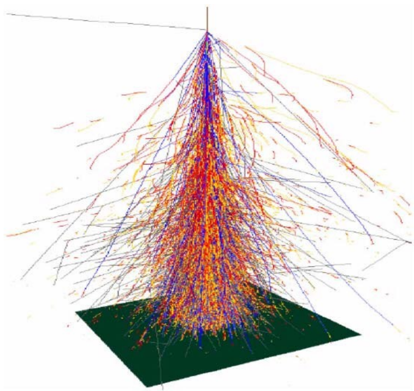




- 530 days
- 2.8 billions CR events
- 1.5 million CREs above 25 GeV

Space/balloon vs Ground based





Direct measurements

Requirements:
Calorimetry vs Spectrometry
Large acceptances
<20% resolutions

Output:
Fully explore the sub-PeV region

Limitations:
Surface/weight limited
Hard to reach the all-particle knee
Need high technology

Indirect measurements

Requirements:
Multi-Hybrid approach
Operate at (not too) high altitude
Large surfaces / samplings

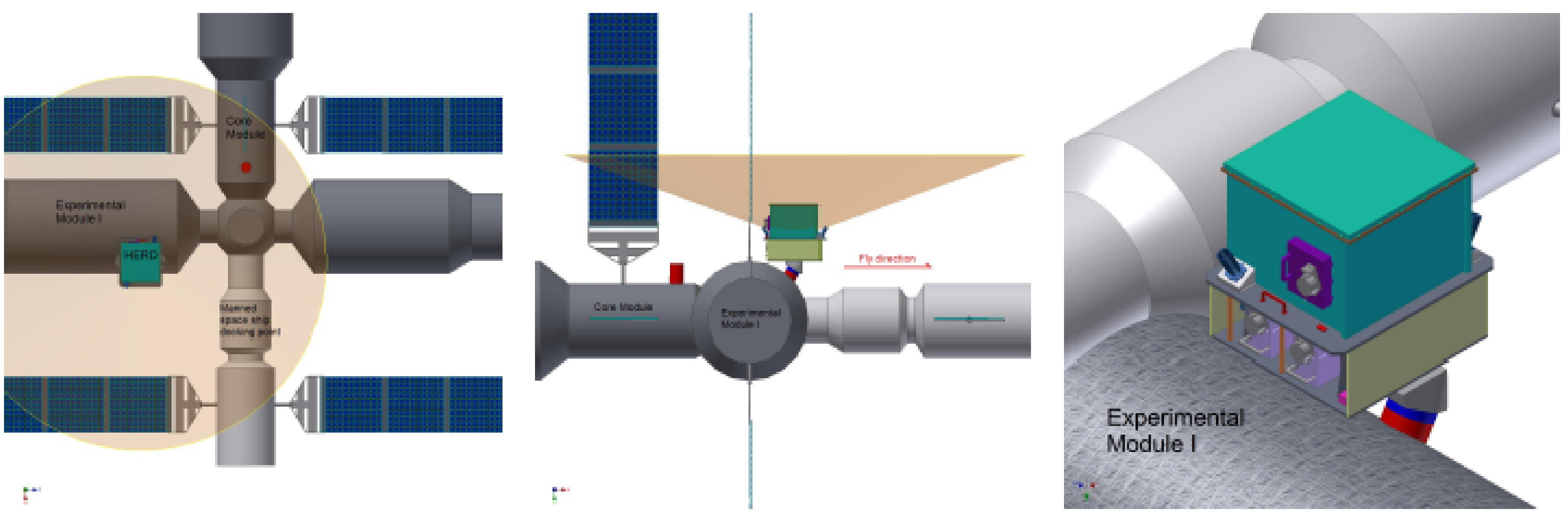
Output:
Reach the highest energies

Limitations:
Poor mass resolution
Intrinsically limited by systematics
Large model dependence

HERD

High Energy cosmic-Radiation Detection

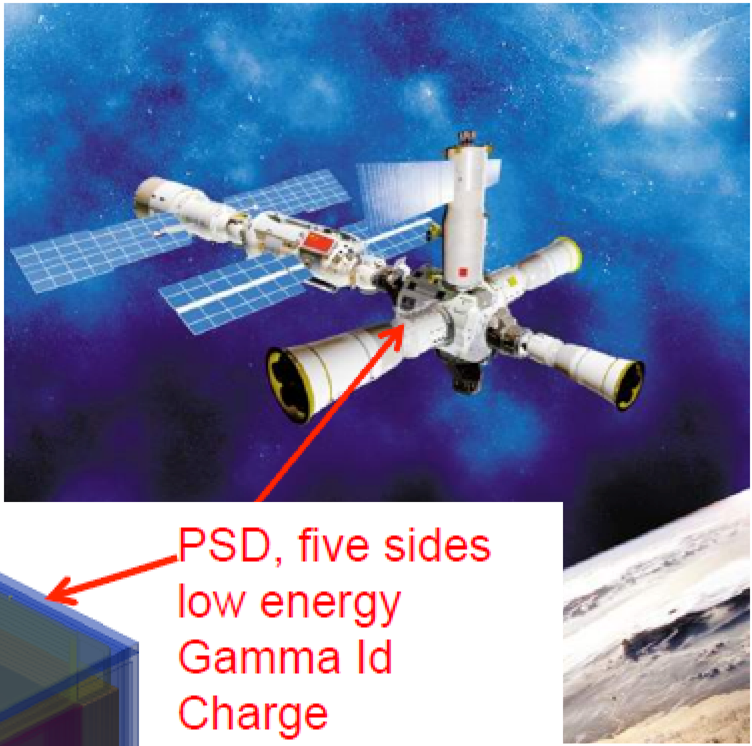
- HERD: a cosmic ray experiment onboard the China's Space Station (CSS)
- Science:
  - Precise cosmic ray spectra and composition up to the “knee”
  - Gamma-ray astronomy and transient studies e.m. follow
  - Electrons spectra (and anisotropy) up to tens of TeV
  - Indirect dark matter searches with high sensitivity



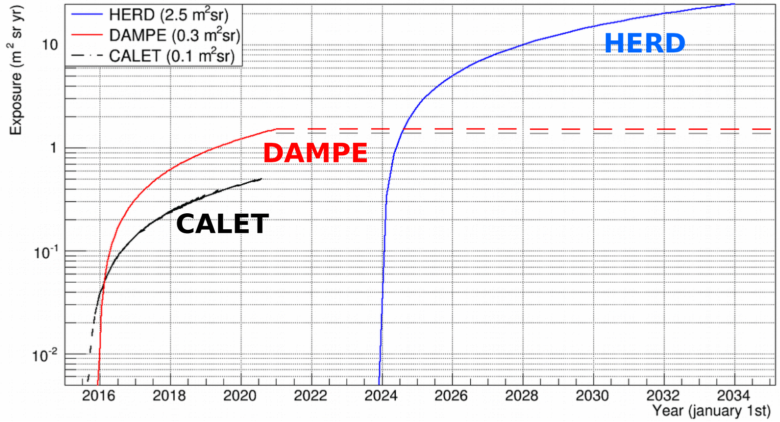
(a) Top view (b) Side view (c) Oblique view

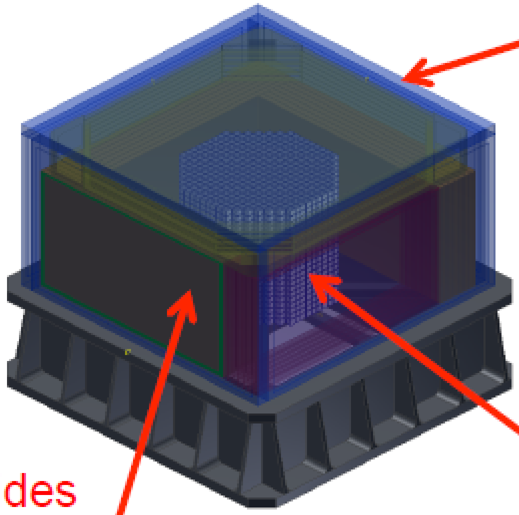
The HERD payload

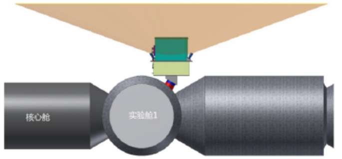
Large acceptance, deep, 3D calorimeter, equipped with silicon tracker (STK) and plastic scintillators (PSD) for primary identification, onboard CSS for a long duration mission.



One order of magnitude jump in exposure wrt current generation CR experiment: 15 m² sr yr



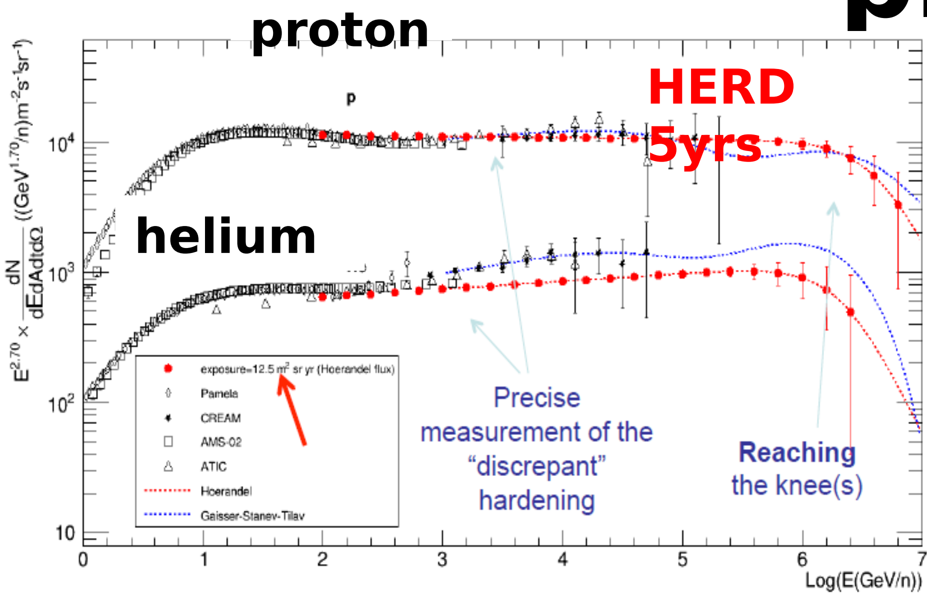


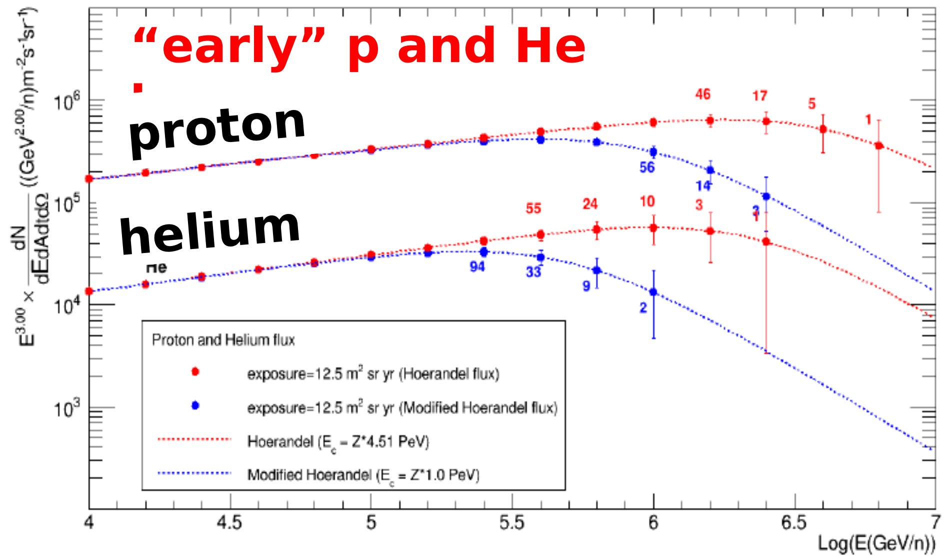


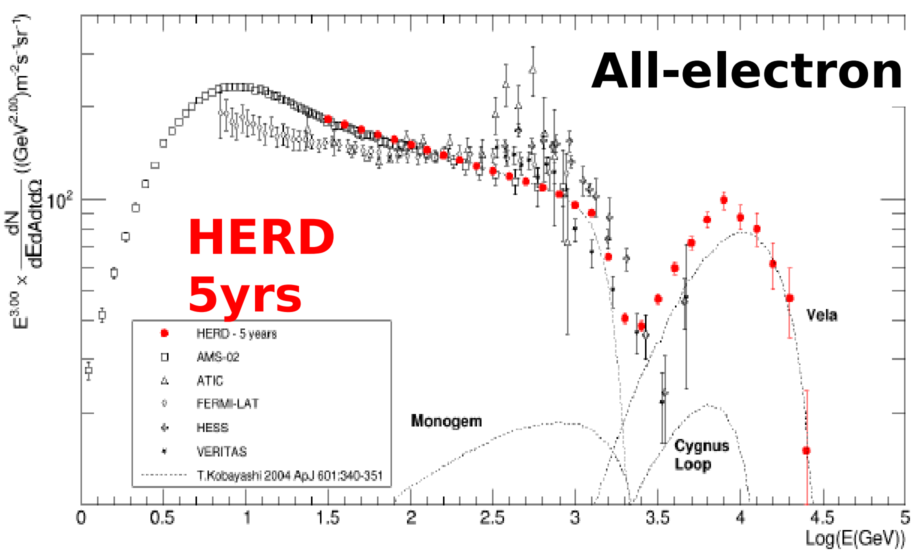
HERD specifications

Item	Value
Energy range (e/γ)	10 GeV-100 TeV(e); 0.5 GeV-100 TeV (γ)
Energy range (CR)	30 GeV — 3 PeV
Angle resolution	0.1 deg.@10 GeV
Charge measurement resolution	0.15-0.2 c.u
Energy resolution (e)	1-2%@200 GeV
Energy resolution (p)	20-30%@100 GeV – PeV
e/p separation	~10^{-6}
G.F. (e)	>3 m^2sr@200 GeV
G.F. (p)	>2 m^2sr@100 TeV
Pointing	Zenith
Field of View	+/-70 deg (targeting +/-90 deg)
Measur. accuracy of attitude	<0.1 deg
Measur. accuracy of angular speed	<0.005 deg/s
Lifetime	>10 years

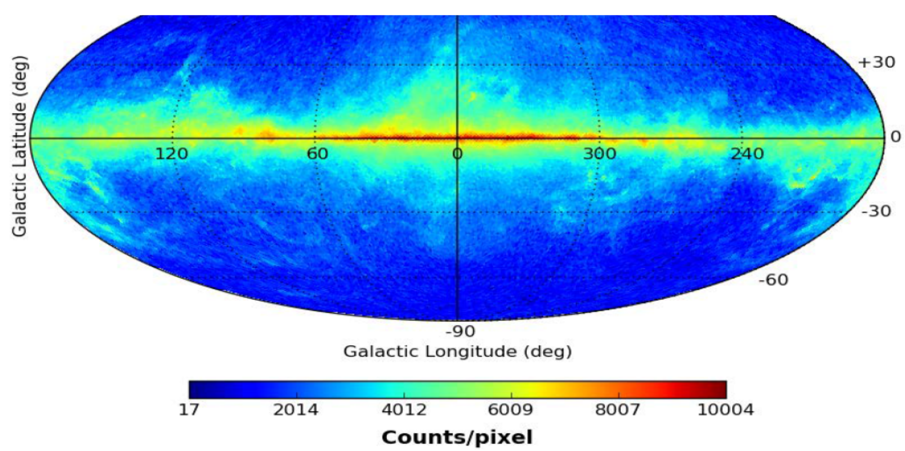
HERD: some performance plots



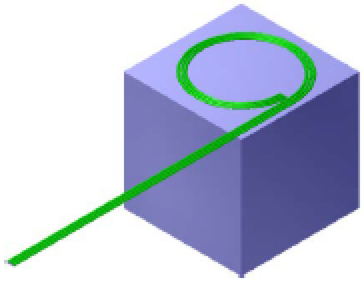
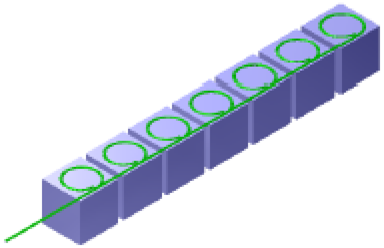
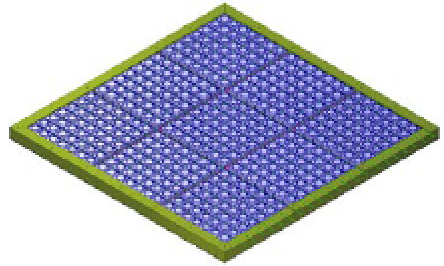
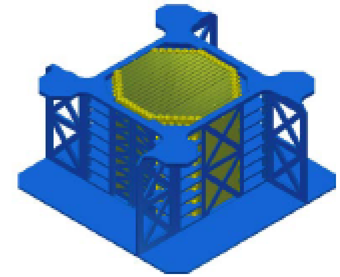
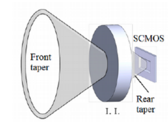


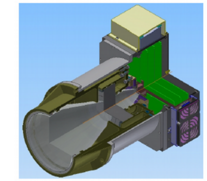


HERD 5yrs, photon map, E_γ > 1GeV

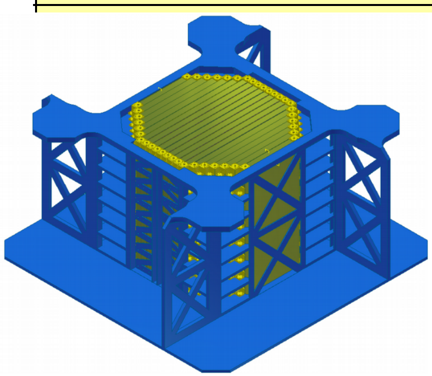
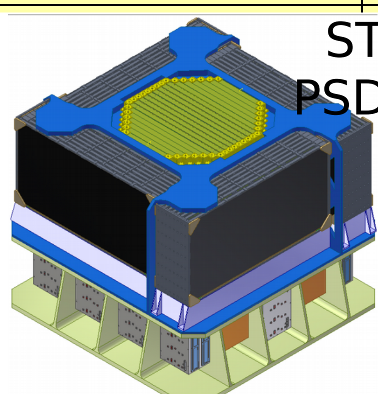


The HERD Calorimeter

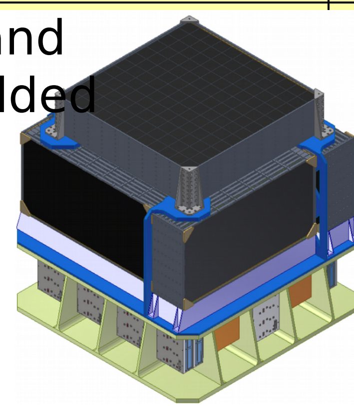








item	Value	Note
Type of crystal	LYSO	
Nuclear Interaction Length	3 (55 X_0)	~ 21 LYSO crystals
Number of crystals	~7500	
Crystal dimension	3cm*3cm*3cm	
Fiber readout	3 WLSF/crystal	Low range, high range & trigger

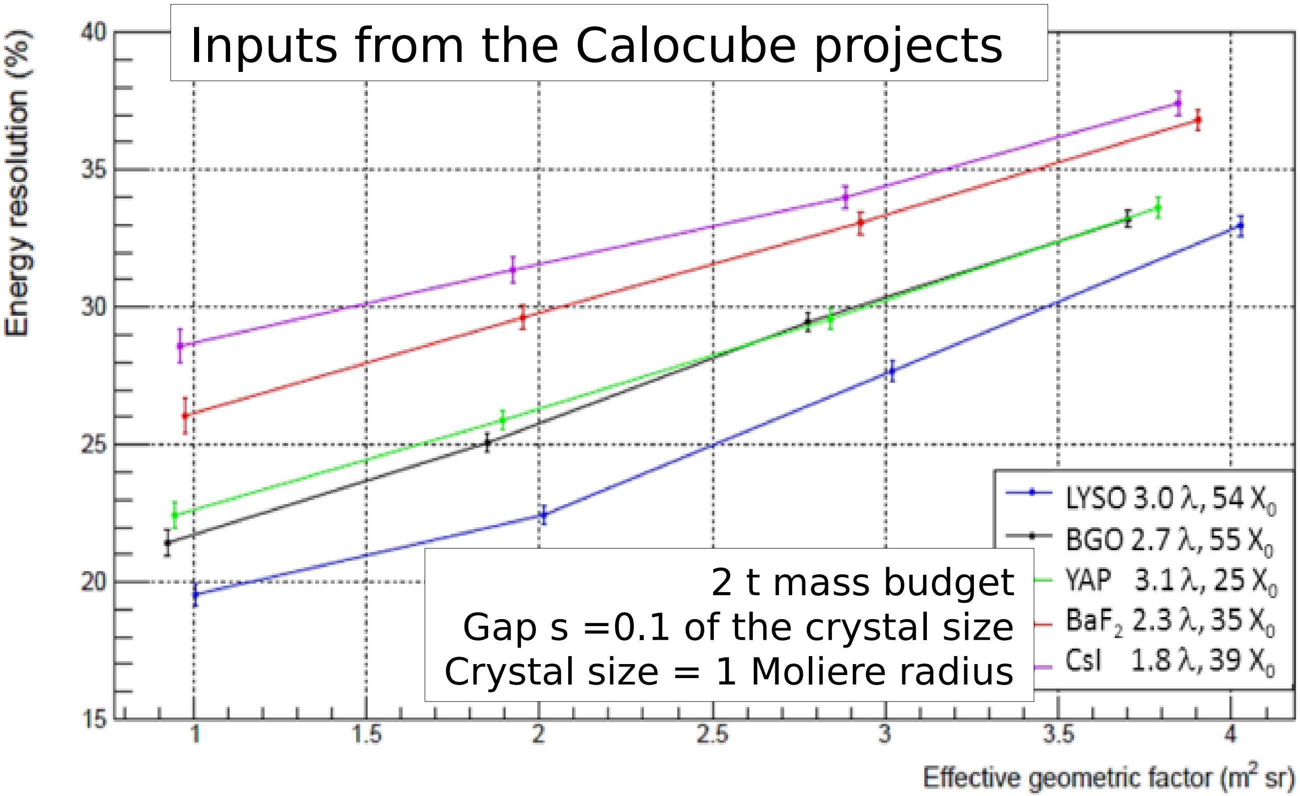



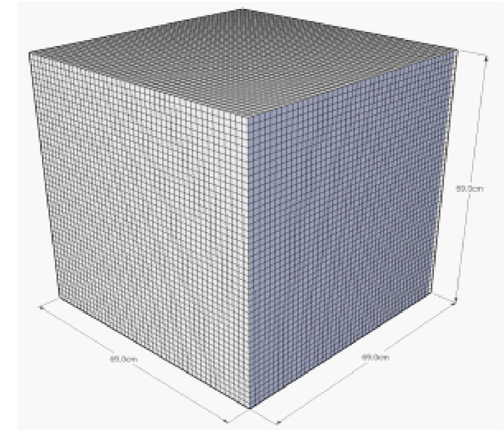
STK and PSD added



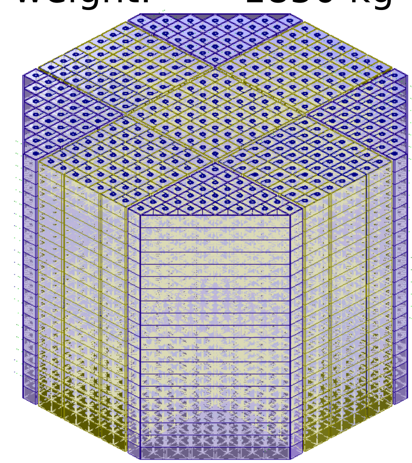
Possible readout of part of crystals with PhotoDiodes (Calocube) for calibration and extended dynamic range

Optimizing scint. / shape /readout





LYSO size: 3cm*3cm*3cm
Detector dimension: 21
LYSO number: ~9300
Calo weight: ~ 1850 kg



LYSO size: 3cm*3cm*3cm
Detector dimension: 21
LYSO number: ~7500
Calo weight: ~ 1500 kg

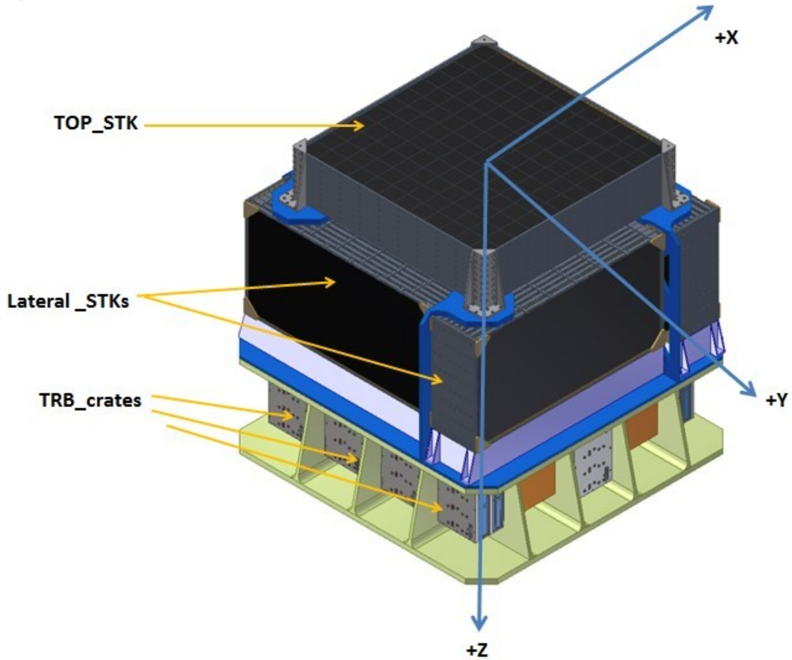
Photodiodes

	VTH2090	VTP9412H
Active area (mm^2)	84.6	1.6
Sp.response range/peak (nm)	400÷1100 / 960	400÷1150 / 925
C_J(pF)	70 @30V	6 @15V

The HERD Si-Tracker

- CR/e trajectory
- Gamma ray conversion & tracking
- Complementary charge measurement

Item	Value
Coverage ratio	>80%
Z measurement	Z = 1 - 20 (26); 0.1-0.15 c.u
Angle resolution	0.1 deg.@10 GeV
Layers of SSD	6 X/Y (top);3/6 X/Y (Lateral)
Active converter	1 R.L.
Dead time	<2 ms
Working mode	External trigger
Eff. Area (top)	~133 cm*133 cm
Eff. Area (lateral)	~114 cm*66.5 cm
Channels	~240,000/368,000

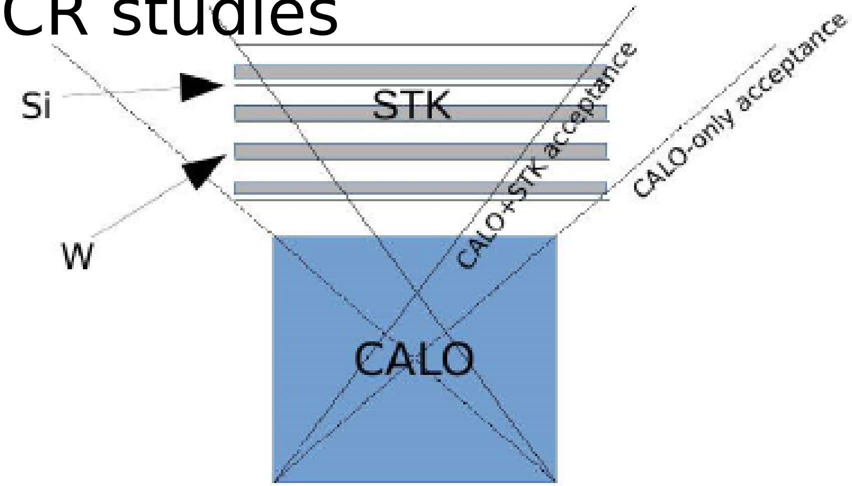


Based on the experience with AGILE, AMS-02,FERMI, DAMPE missions

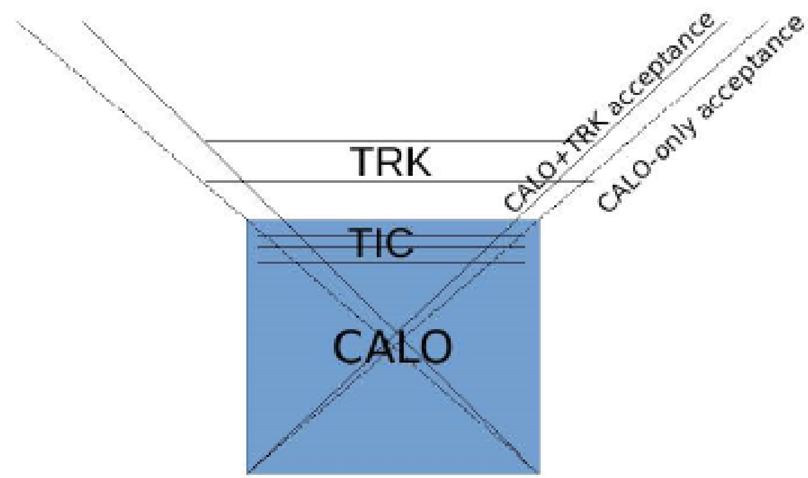
TIC: Tracker In Calorimeter

A possible TIC design is under study to:

- Optimize photon tagging and direction reconstruction
- Give multiple charge measurements (CR identification)
- Maximize calorimeter mass, i.e acceptance for the CR studies



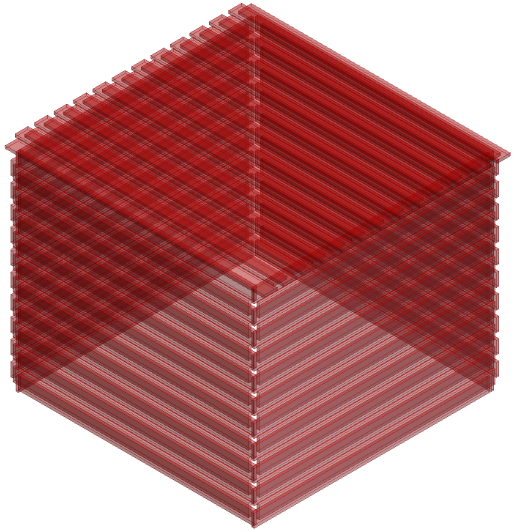
Standard Design



TIC Design

The HERD PSD
plastic scintillator detector

- Low energy gamma identification
- CR identification by Charge Measurement

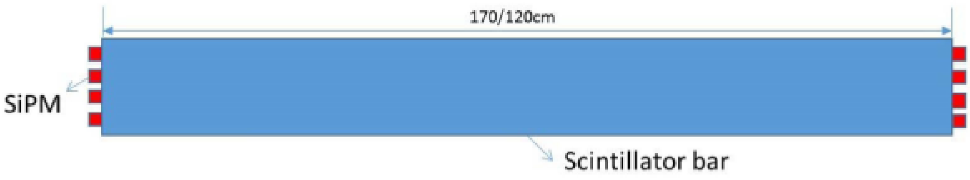


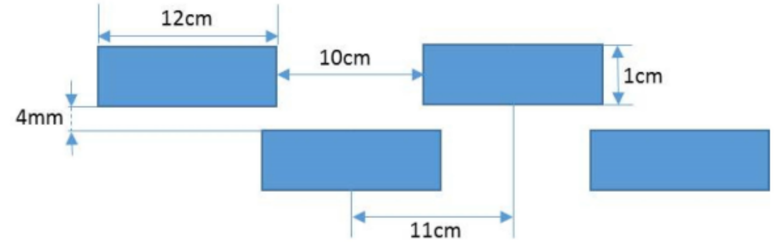
- Design
  - 1 X/Y layer on top and 4 lateral sides
    - X layer for LE photon trigger
    - X & Y layers for Z measurement and e/gamma discrimination
  - 1 X layer on bottom side
  - SiPM + IDE3380 ASIC
    - Low & high range to cover Z=1-26
    - Redundancy SiPMs

Bars vs Tiles layout resulting from the optimization of efficiency / mechanics / no. channels and backsplash effects

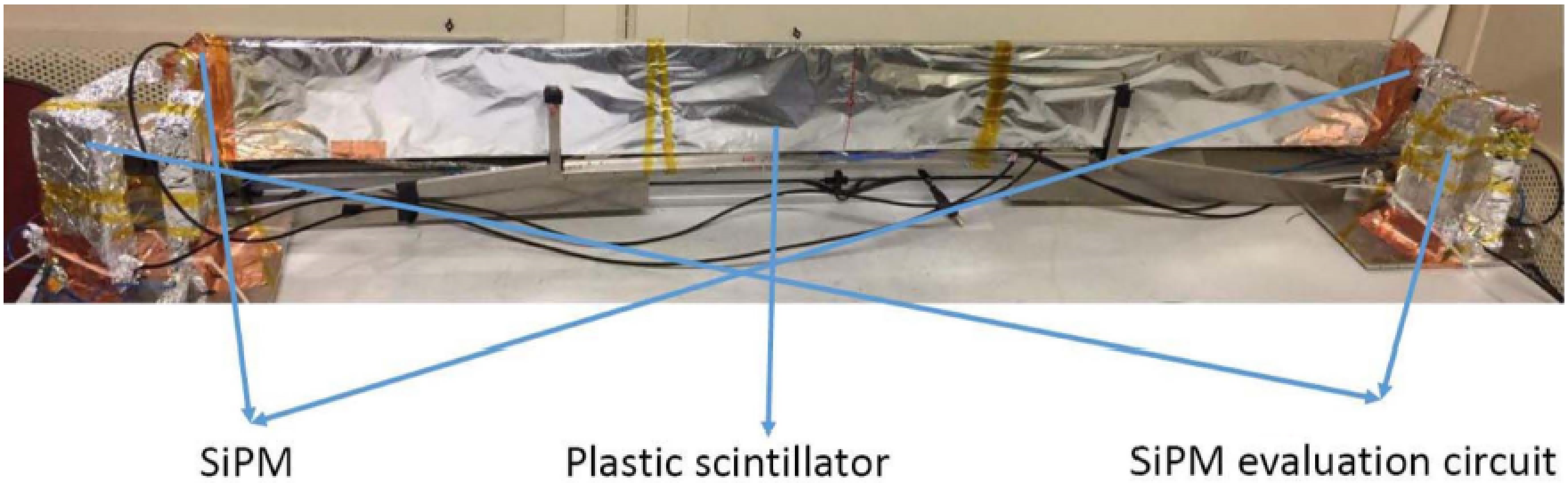
Alternative approach: tile geometry

The HERD PSD
plastic scintillator detector

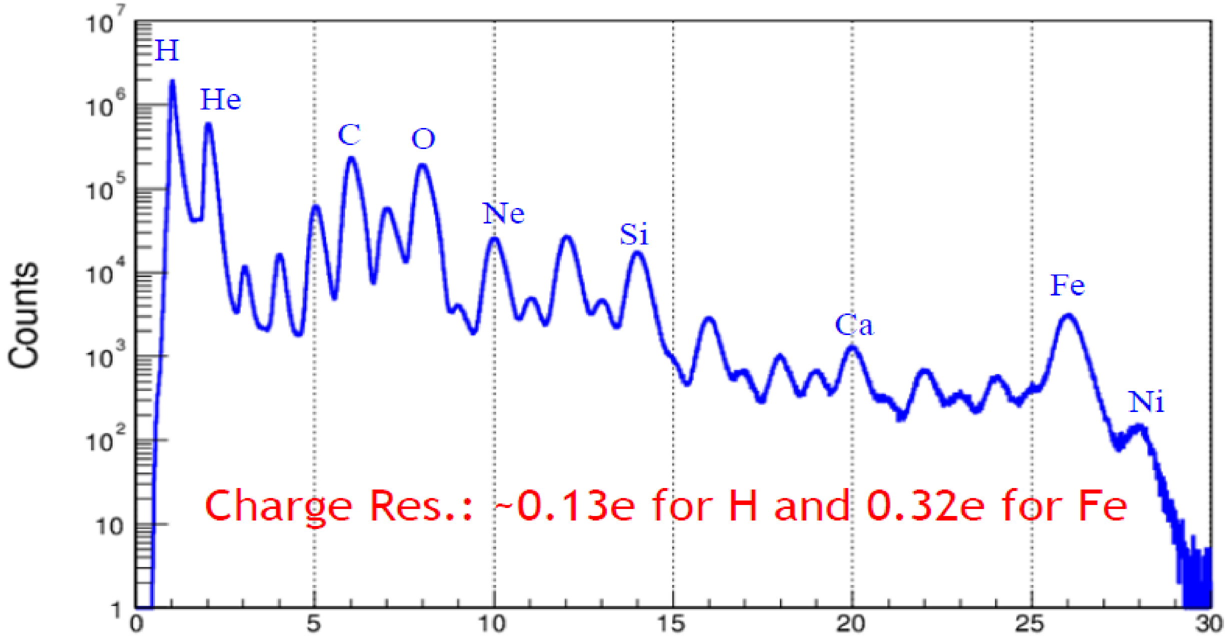




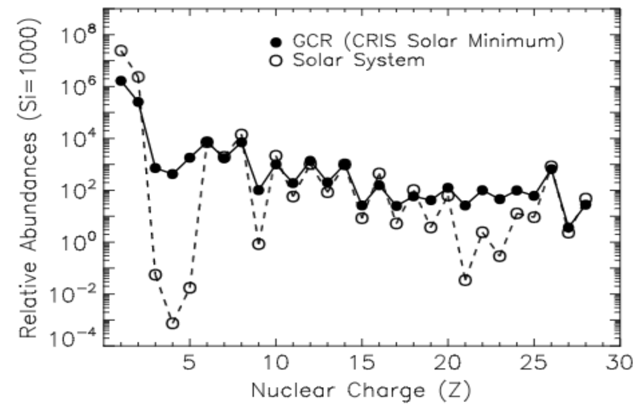
At each end of PS, 4 redundant SiPMs attached to readout as 2 low range signals and 2 high range signals



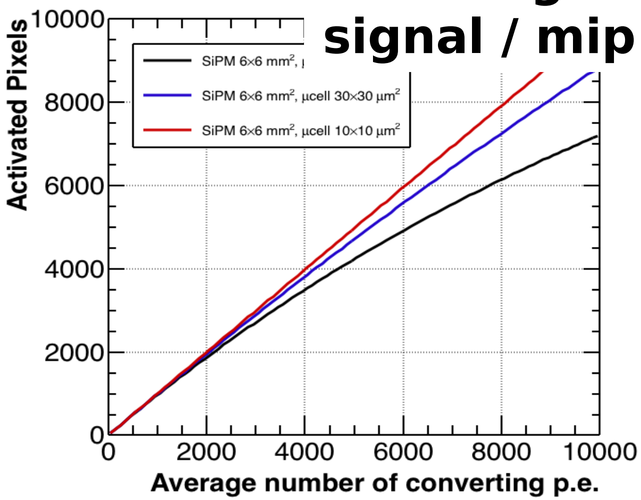
The HERD PSD
plastic scintillator detector



CR charge ~ Sqrt(PSD signal / mip)

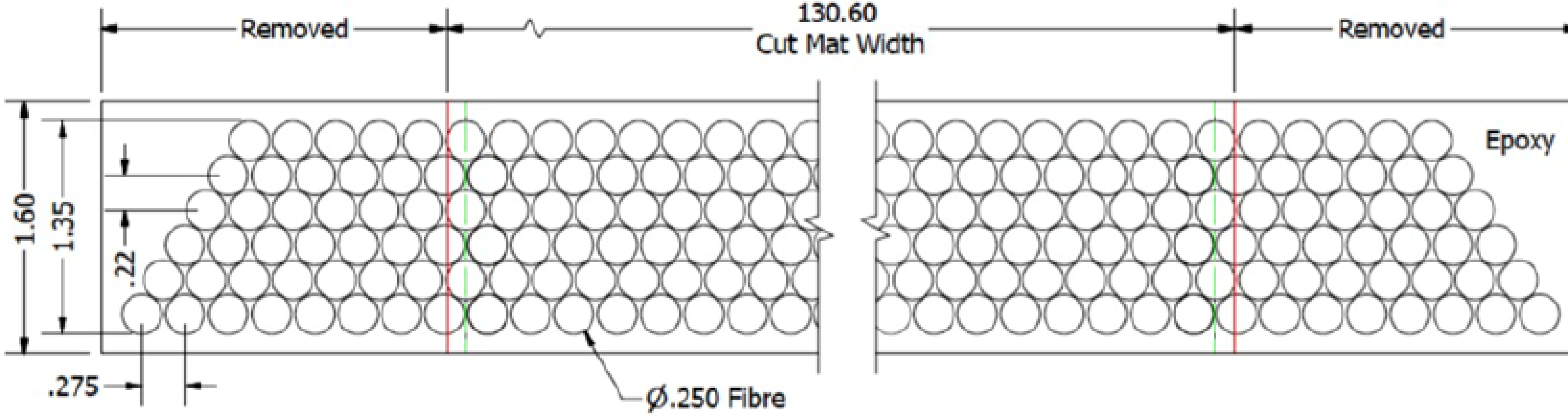


DAMPE preliminary results

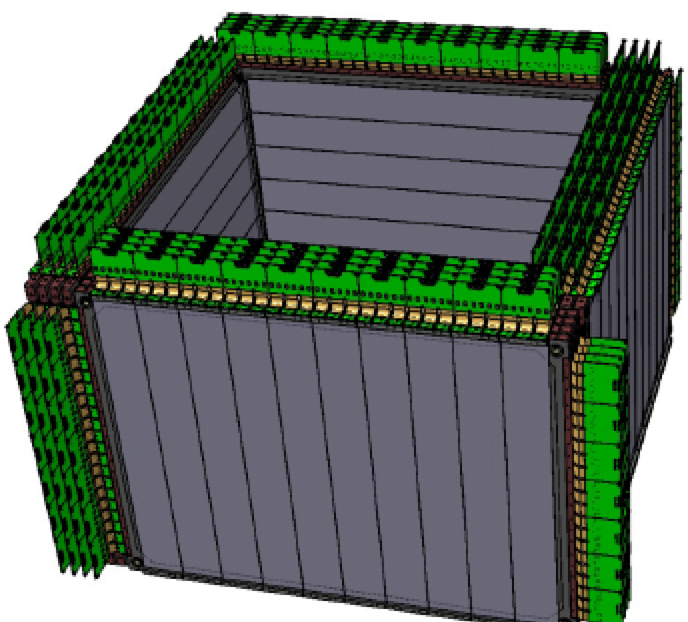


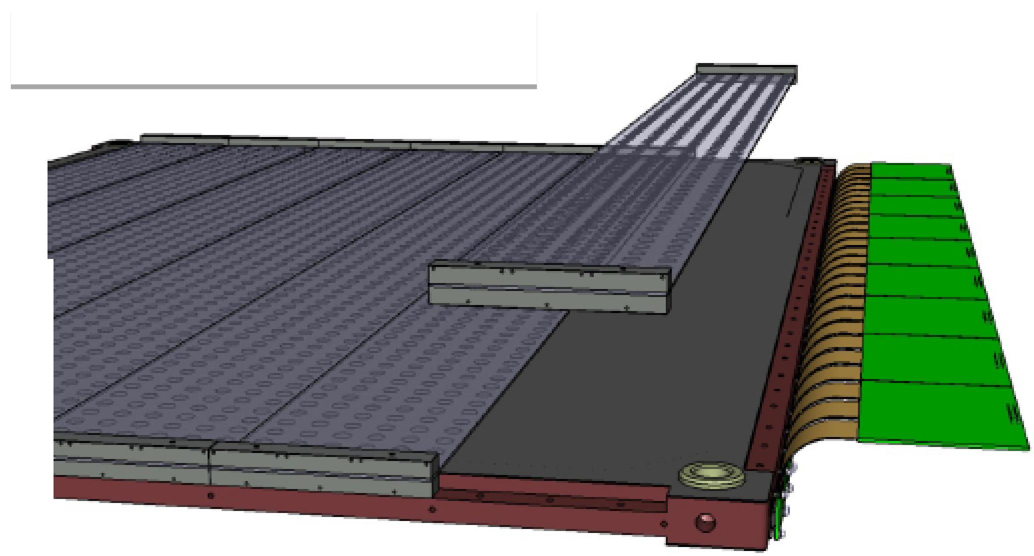
Need a dynamic range ~10^3

SciFi Tracker with SiPM readout

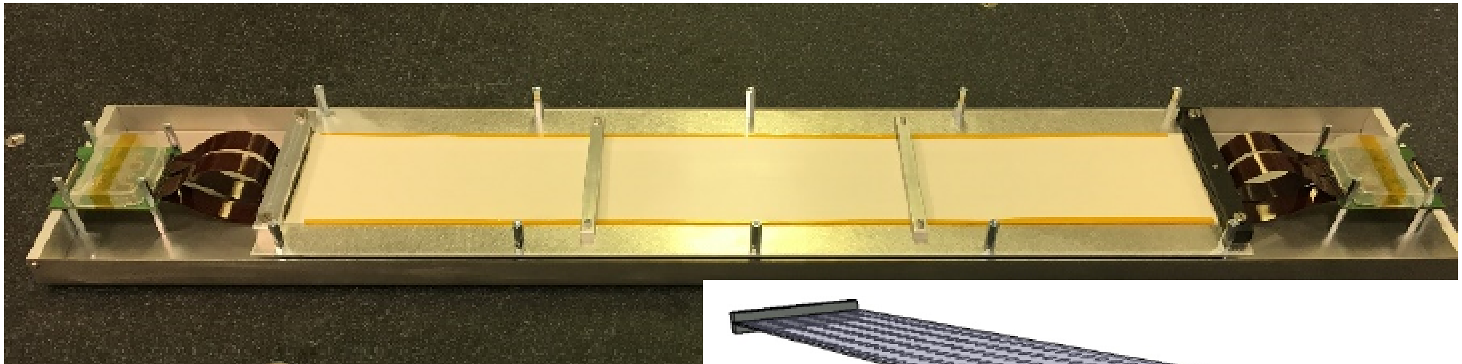


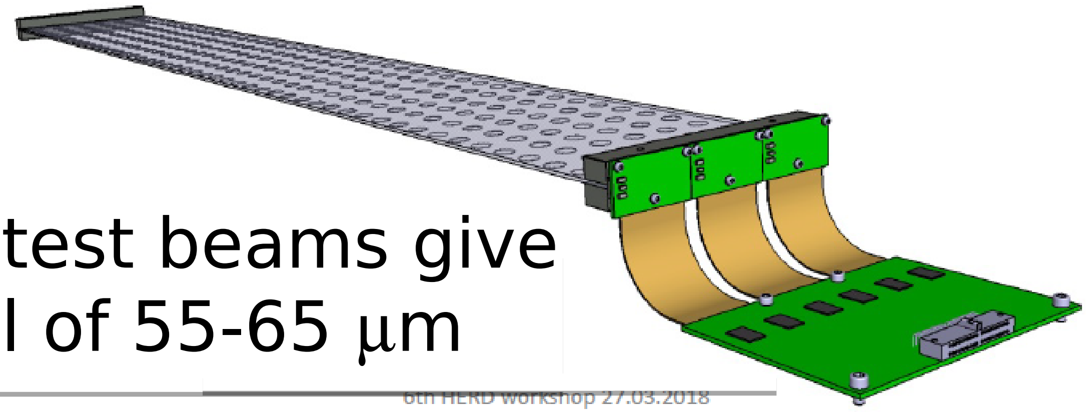
HERD mat: 97.80 mm width + 200 µm inter-mat gap to match for 3 SiPM





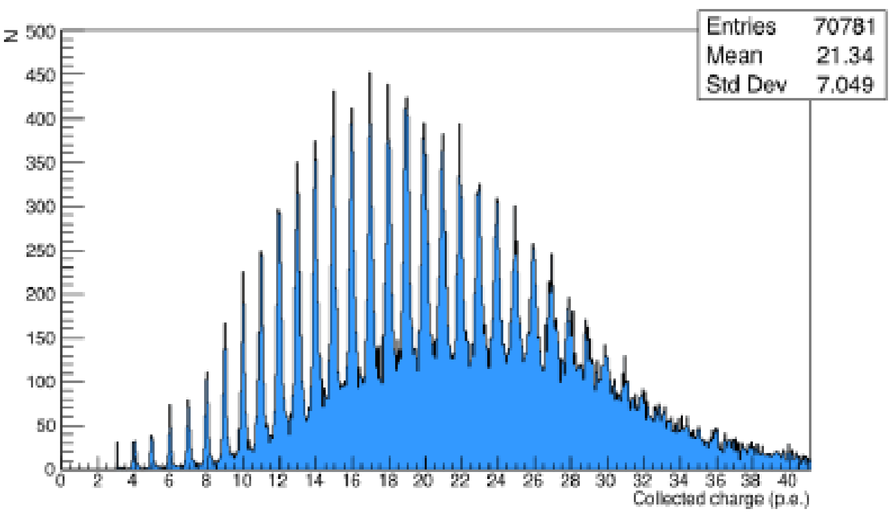
SciFi Tracker with SiPM readout

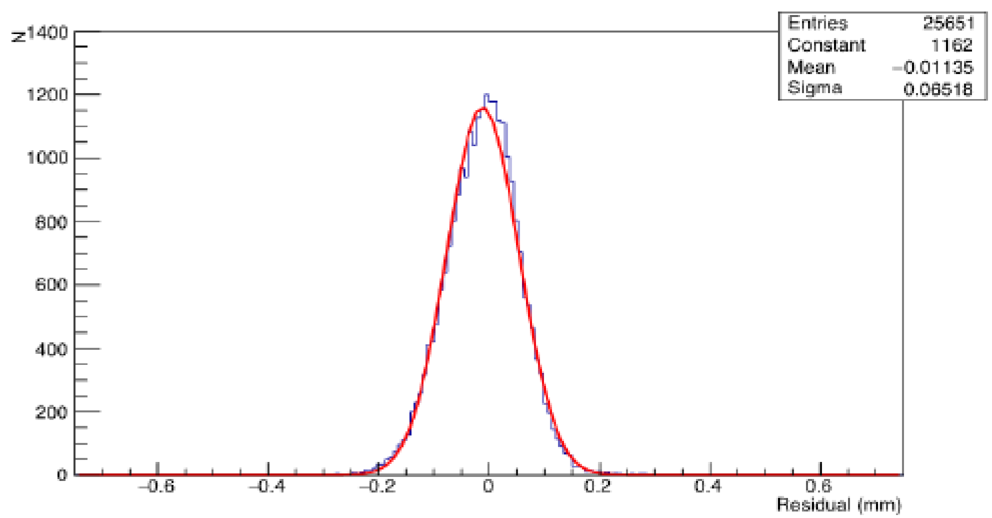




Preliminary results on test beams give resolutions at the level of 55-65 μm

6th HERD workshop 27.03.2018



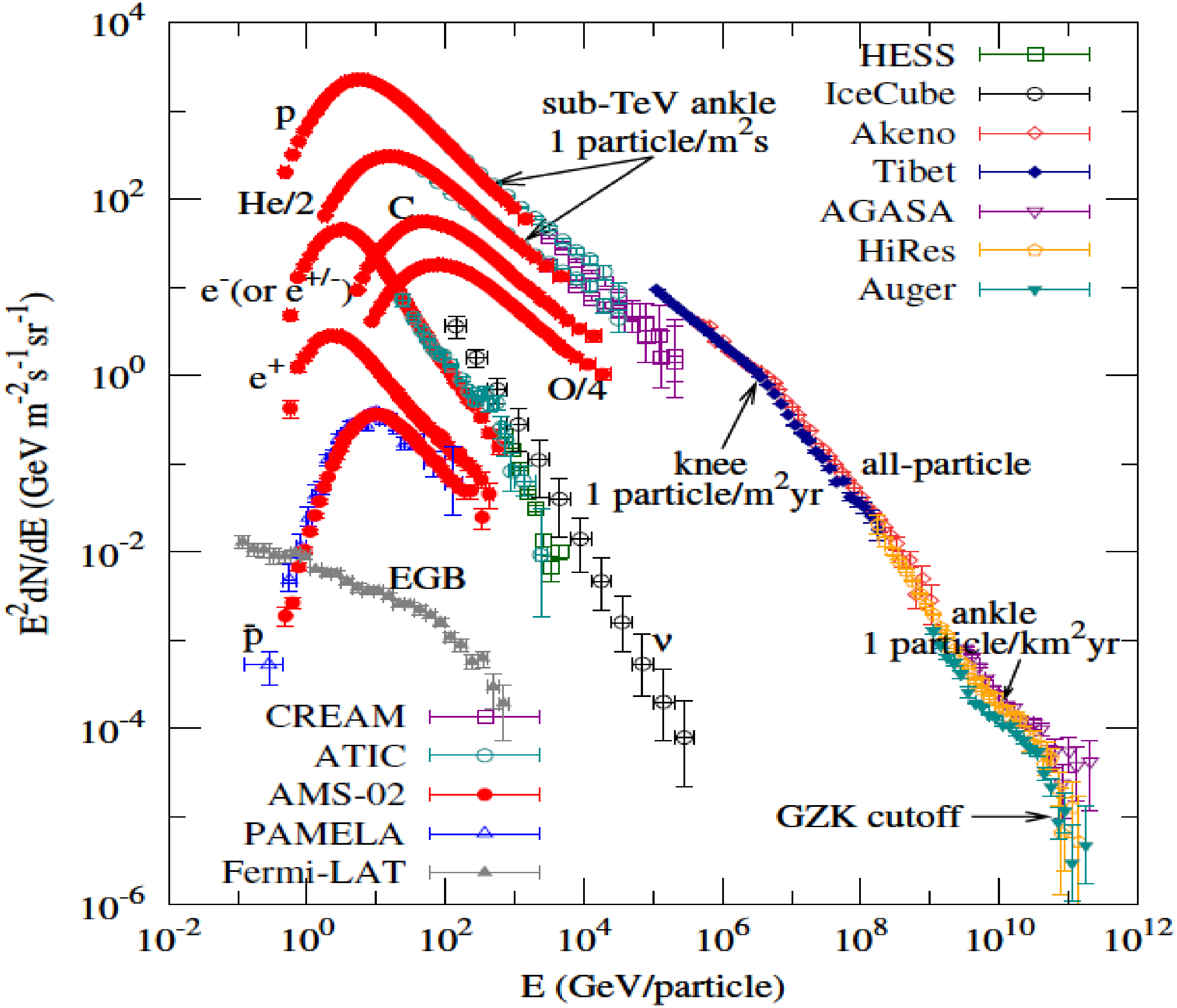


The HERD Collaboration

- **China**
  CSU, IHEP, XIOPM, PMO, USTC, IGG, XAO, NAOC, TSU, GXU, PKU, NJU, YNU, NBU, SYSU, University of Hong Kong (HKU), National Central University (NCU)
- **Italy**
  INFN Perugia, University & INFN Firenze, University & INFN Bari, University & INFN Pisa, University of Salento and INFN Lecce, University & INFN Napoli, University & INFN Pavia, Gran Sasso Science Institute
- **Switzerland**: University of Geneva
- **Spain**: CIEMA

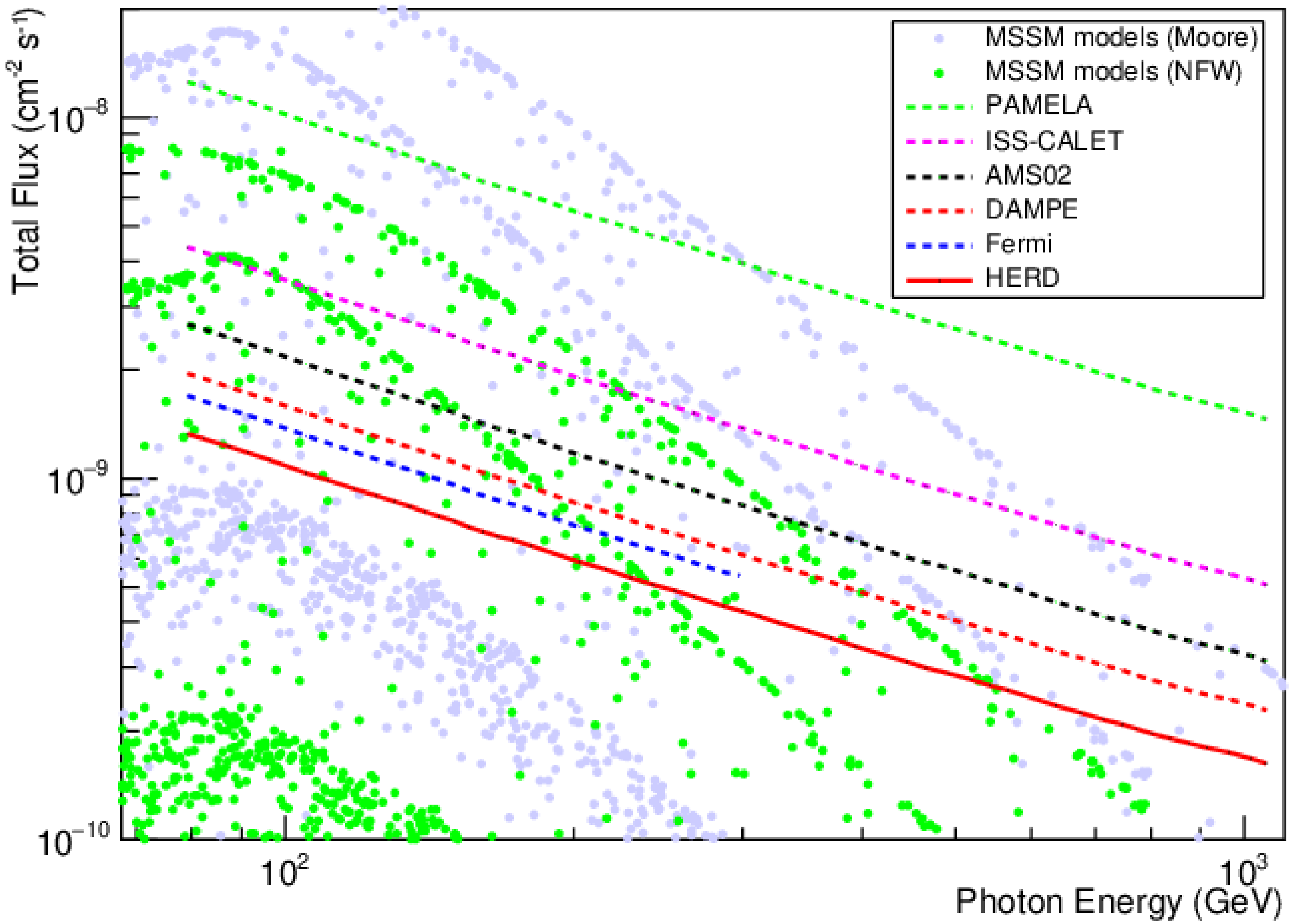
International collaboration (120+ colleagues)

More Stuff



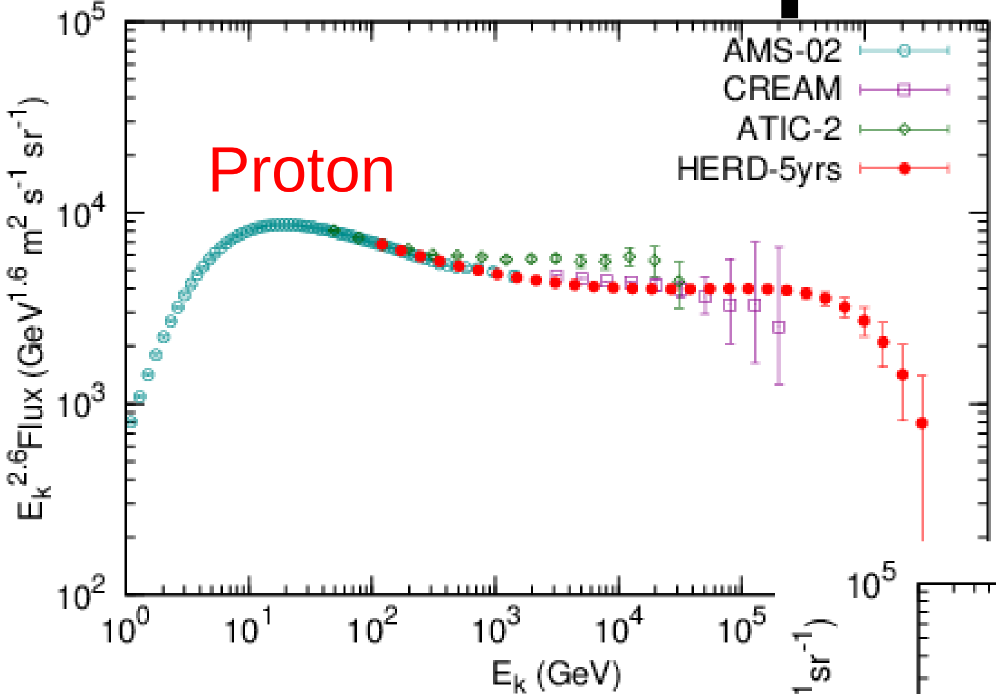
E^{2}dN/dE (GeV m^{-2}s^{-1}sr^{-1})
E (GeV/particle)
p
He/2
C
e$^-$(or e$^{+/-}$)
e$^+$
O/4
EGB
$\bar{p}$
ν
sub-TeV ankle
1 particle/m^{2}s
knee
1 particle/m^{2}yr
all-particle
ankle
1 particle/km^{2}yr
GZK cutoff
HESS
IceCube
Akeno
Tibet
AGASA
HiRes
Auger
CREAM
ATIC
AMS-02
PAMELA
Fermi-LAT

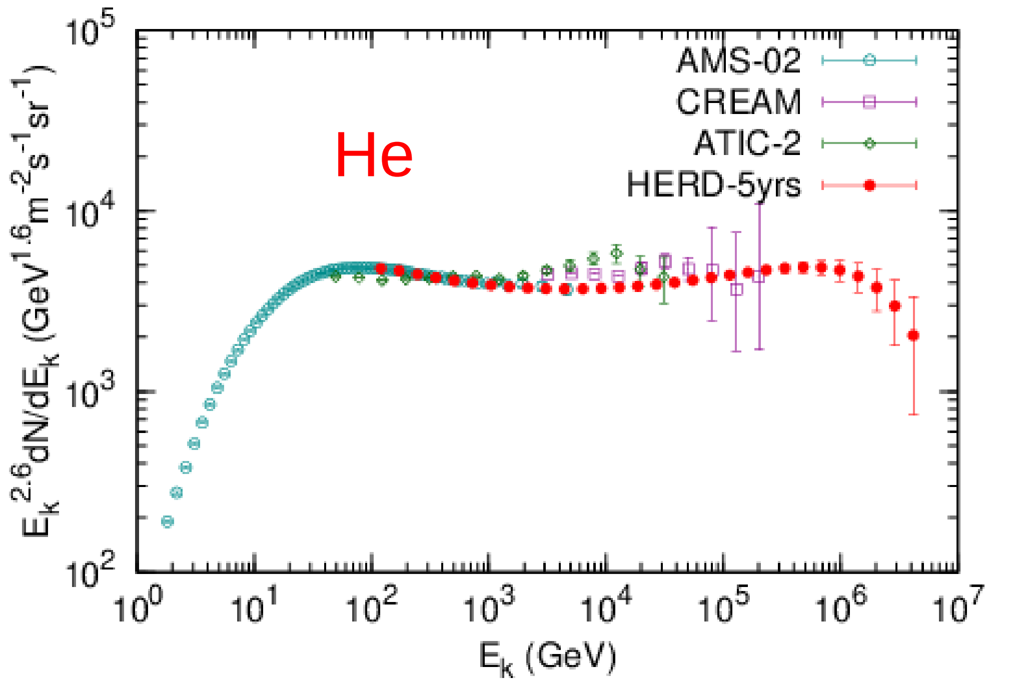
Sensitivity for gamma ray line by different experiments



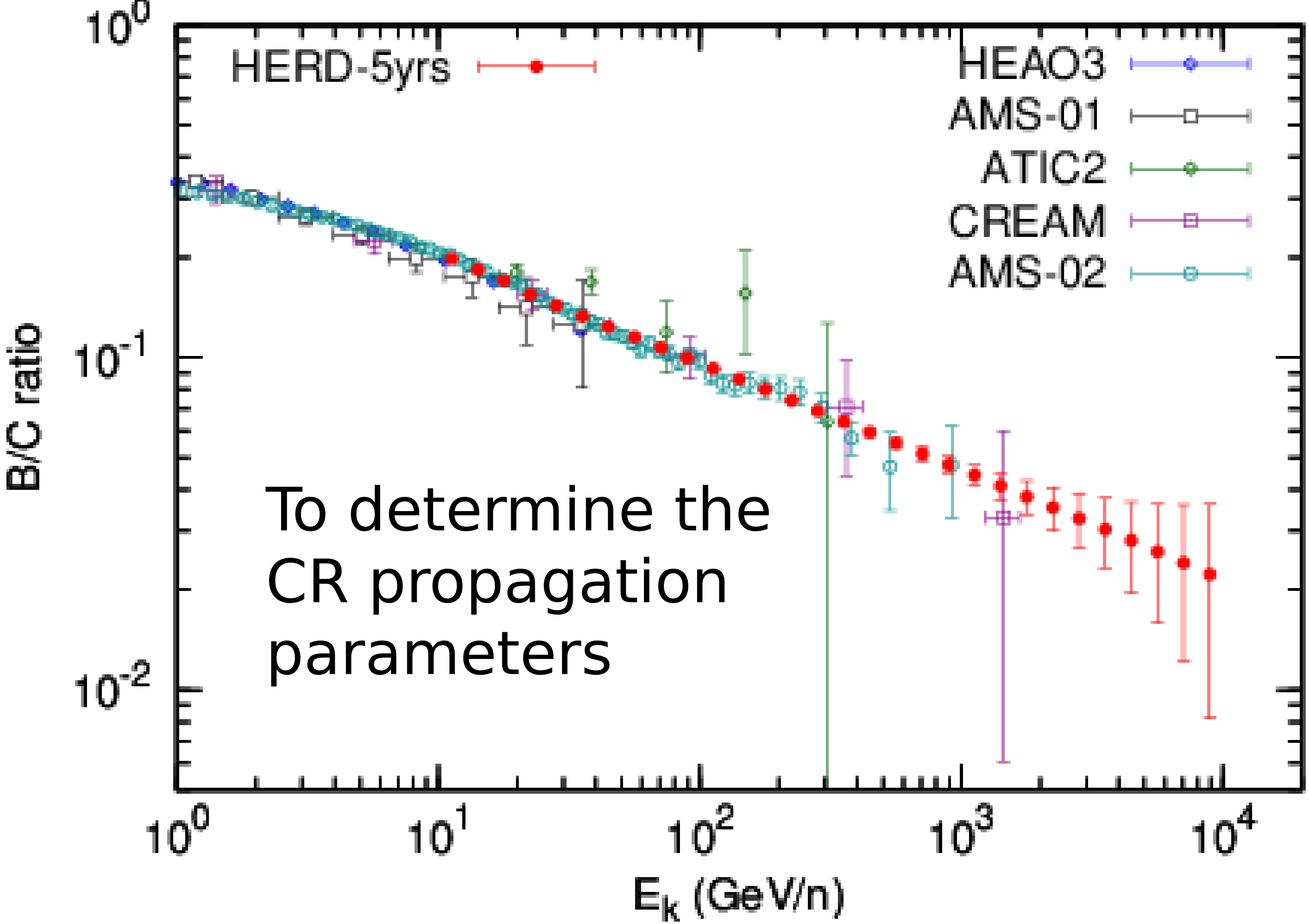
PAMELA: 2006-2016 CALET: 2015-2020; AMS: 2011-2024; DAMPE: 2015-2020; Fermi: 2008-2018; HERD: 1 year

Expected HERD Proton and He Spectra



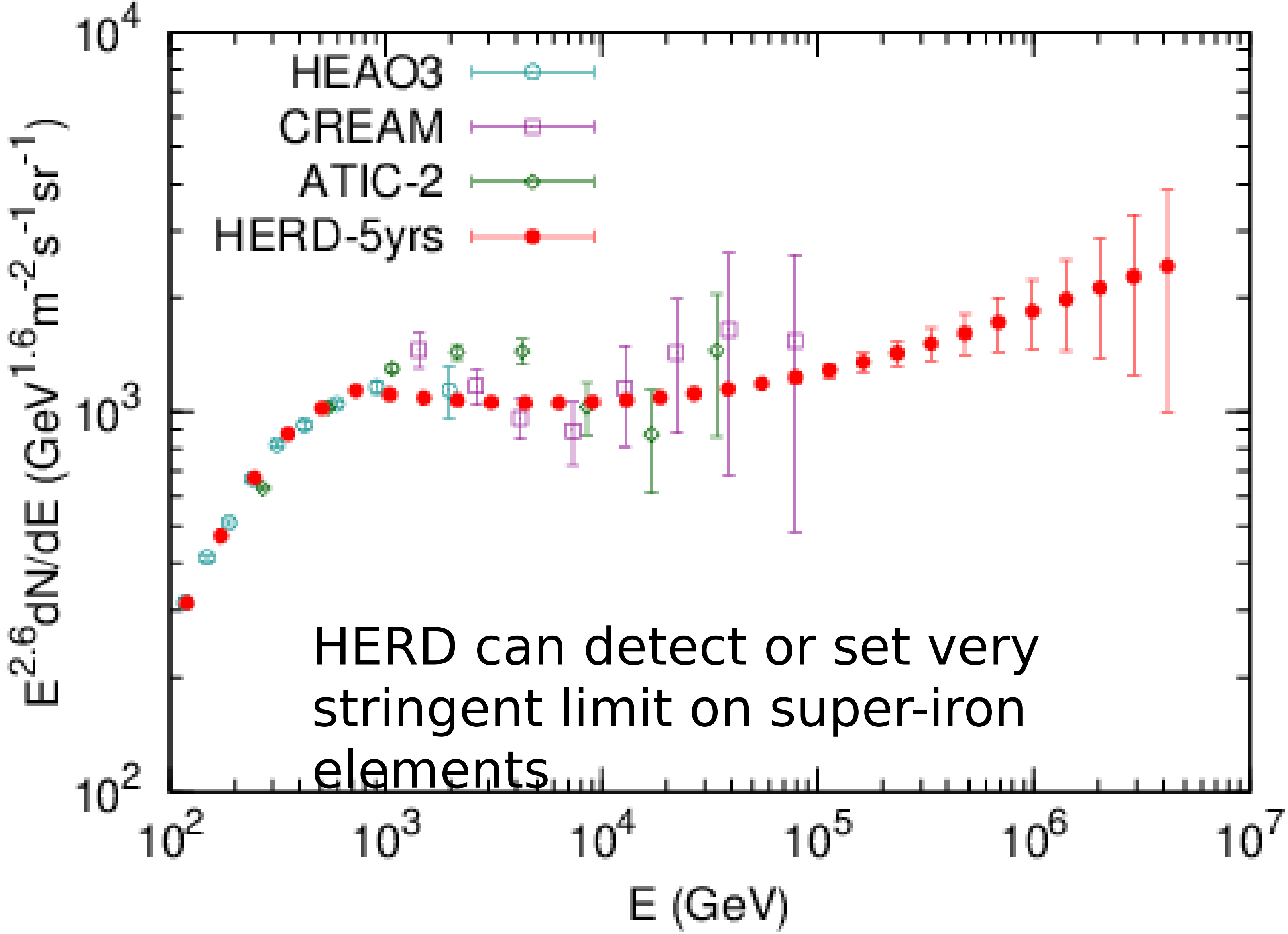


B/C measurement at HERD



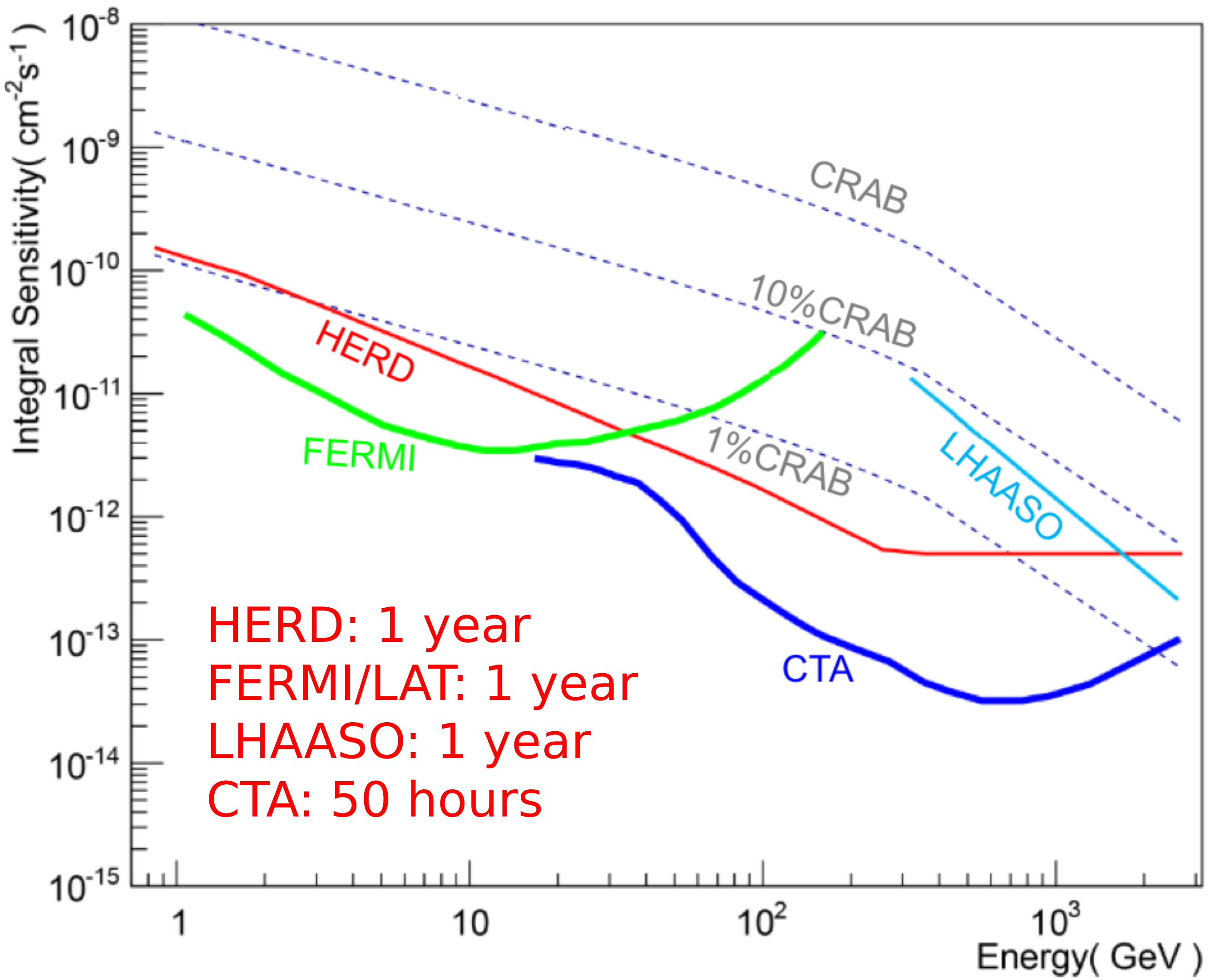
To determine the CR propagation parameters

Iron nucleon and super-iron elements



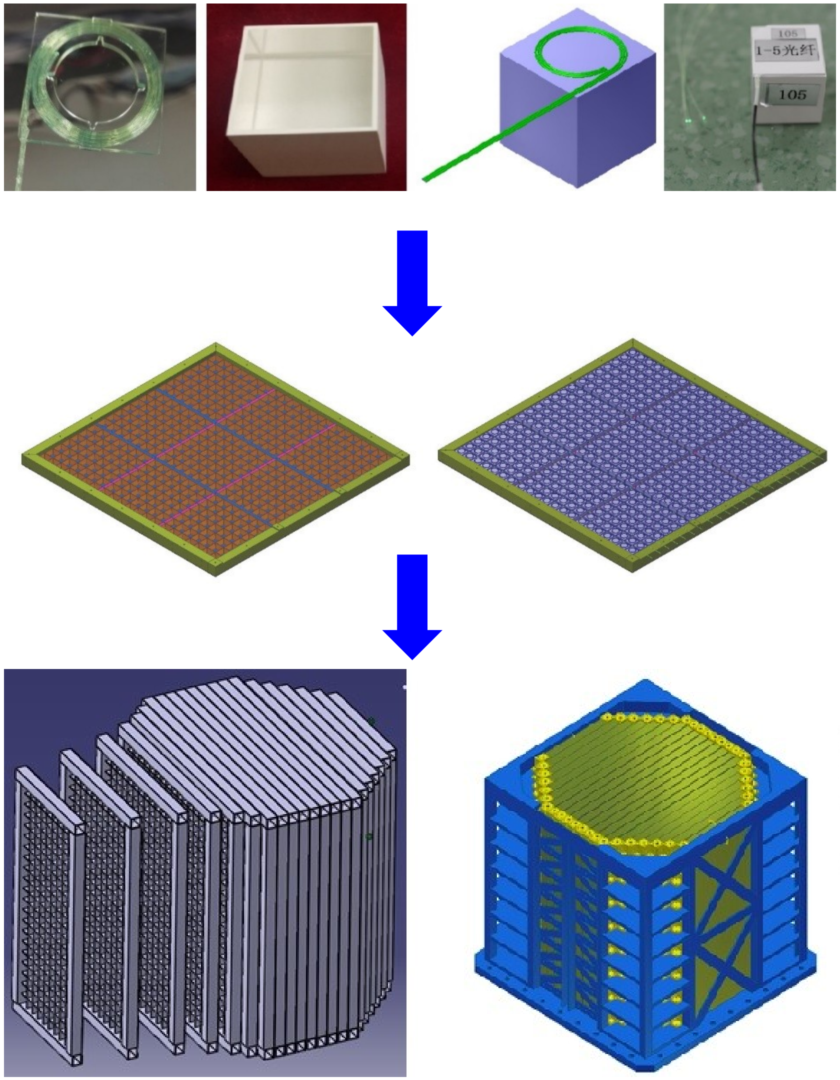
HERD can detect or set very stringent limit on super-iron elements

Gamma-ray sky survey

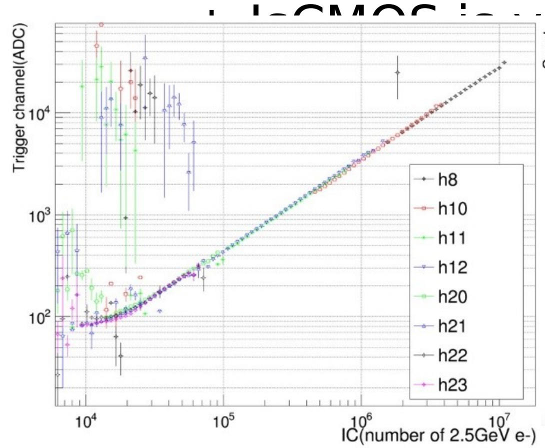


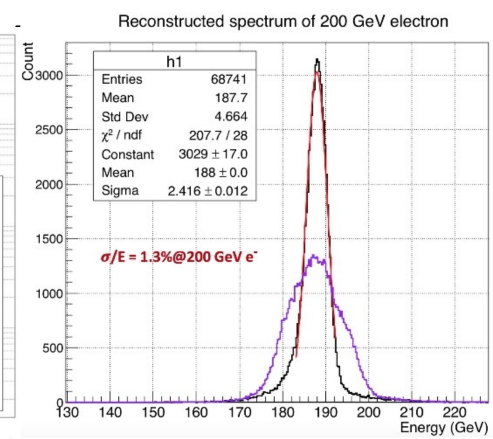
Expected HERD gamma-ray sky survey sensitivity (5σ)

Payload design - CALO



- CALOrimeter (3 N.I.L. and 55 R.L.)
  - A 3-d crystal array (~7500 LYSO)
  - IsCMOS camera
  - Trigger sub-system
- Novel readout method
  - WLSF + IsCMOS
  - Linearity of LYSO+WLSF is verified.
  - Energy measurement of WLSF

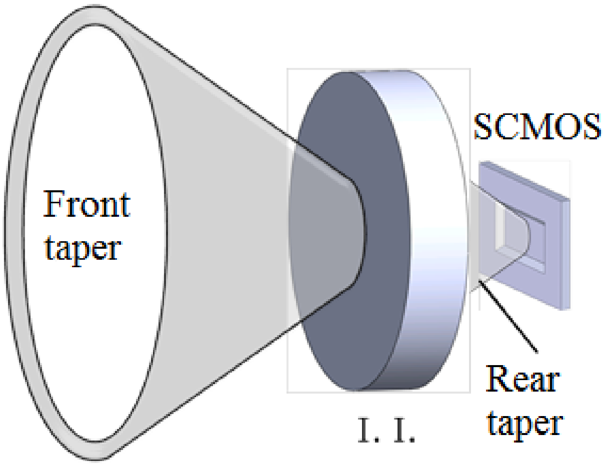




Alternative approach: Photo diode readout

CALO – ISCMOS sub-system

- IsCMOS to collect WLSF photons
  - Faster: Global shutter; ROI readout
  - Lower noise
- Accurate energy measurement
  - 1 fiber ~ 20*20 pixels
  - Saturation effect to increase DR



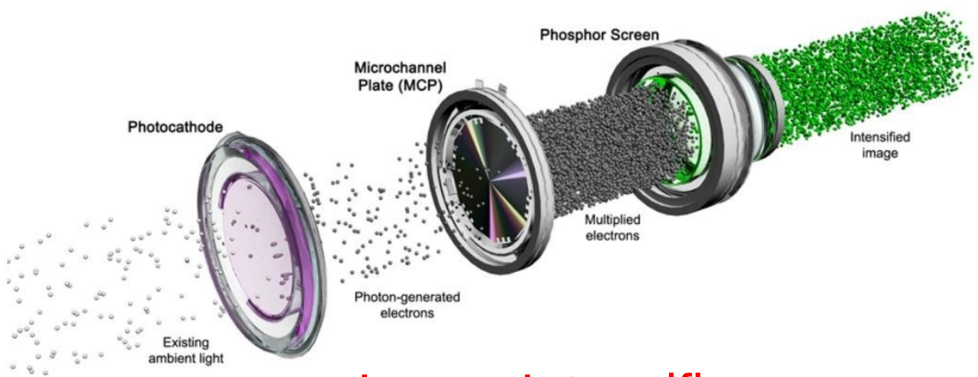
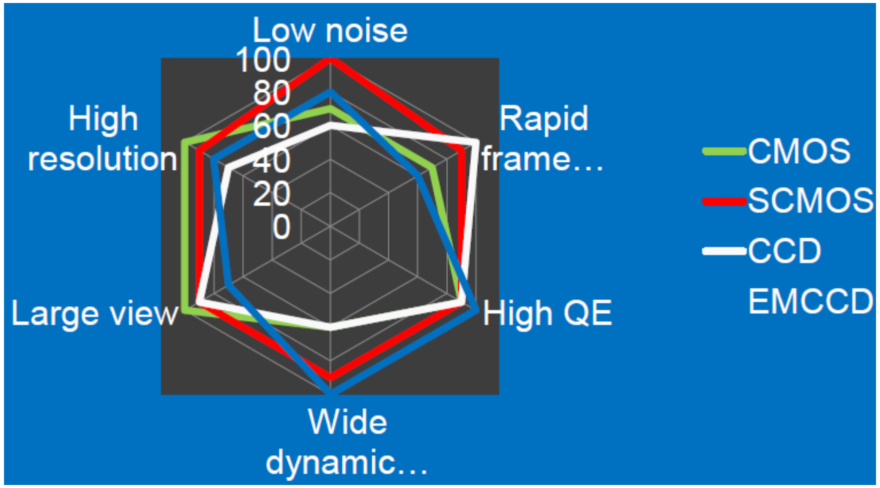
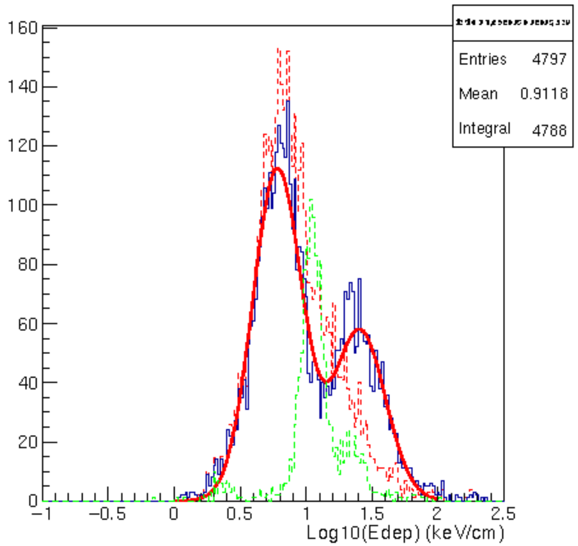


Image Intensifier

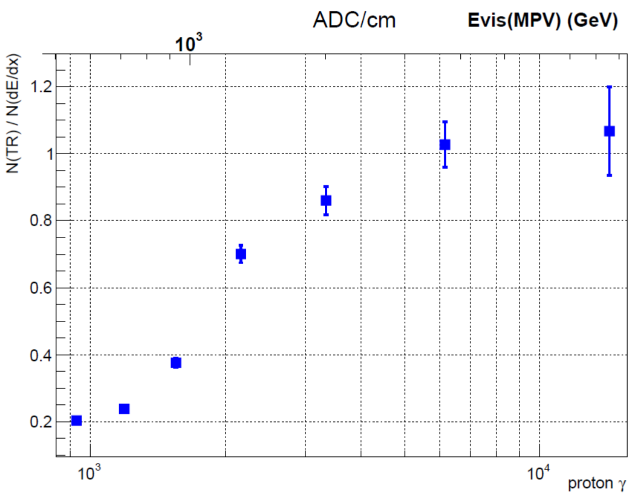


TRD payload

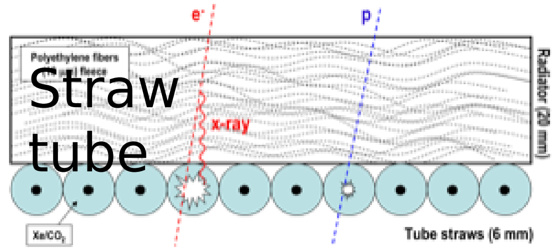
- Energy calibration of TeV protons and other nuclei
- A complete calibration in 2-3 months in-orbit operation

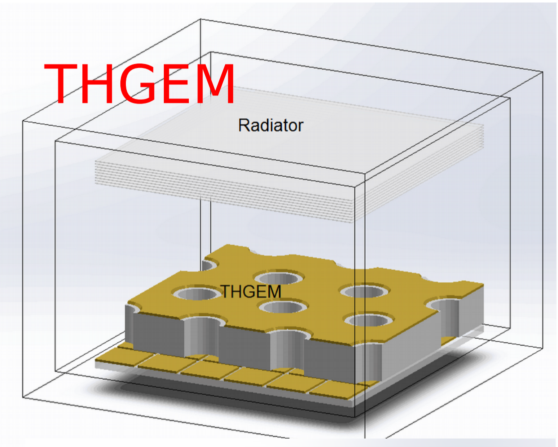


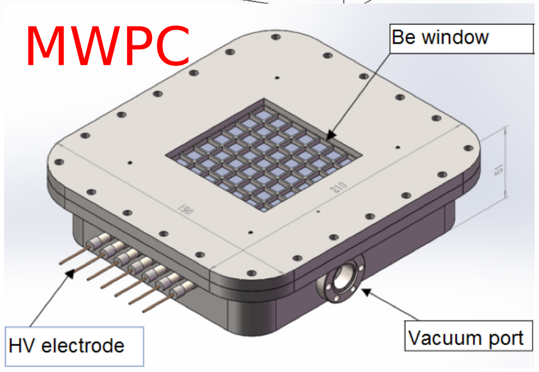
MWPC energy response to [2.25, 2.5] TeV protons



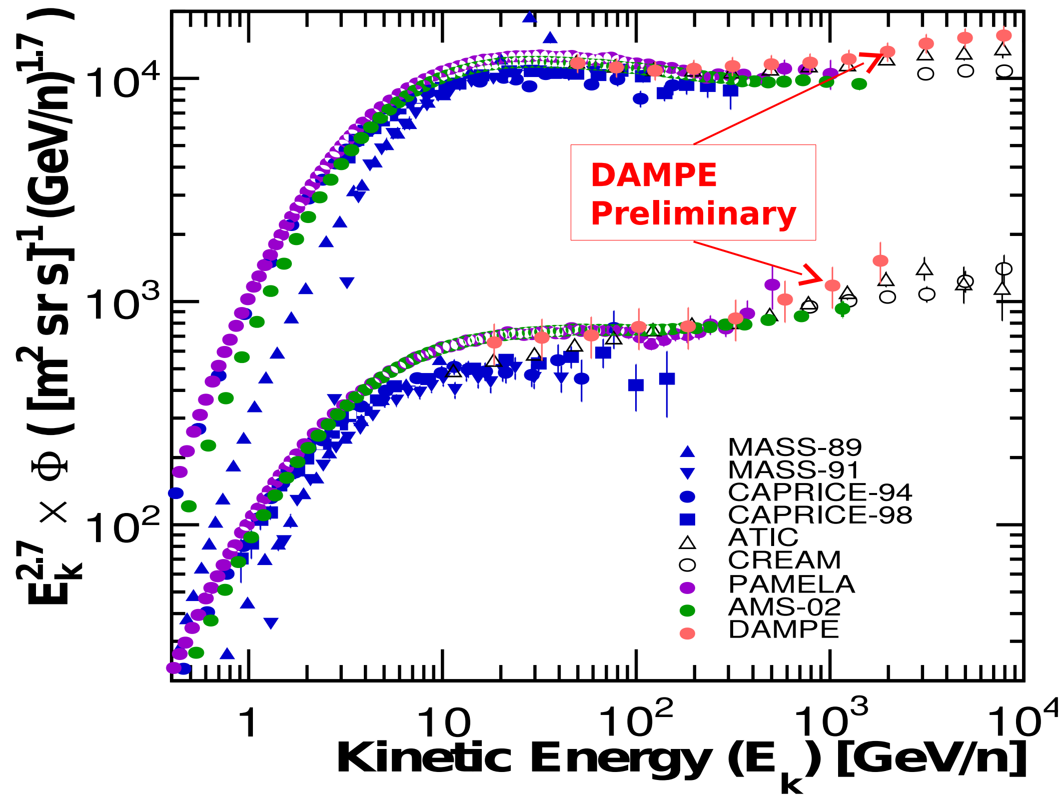
2 months simulated observation, ~6300cm² TRD.

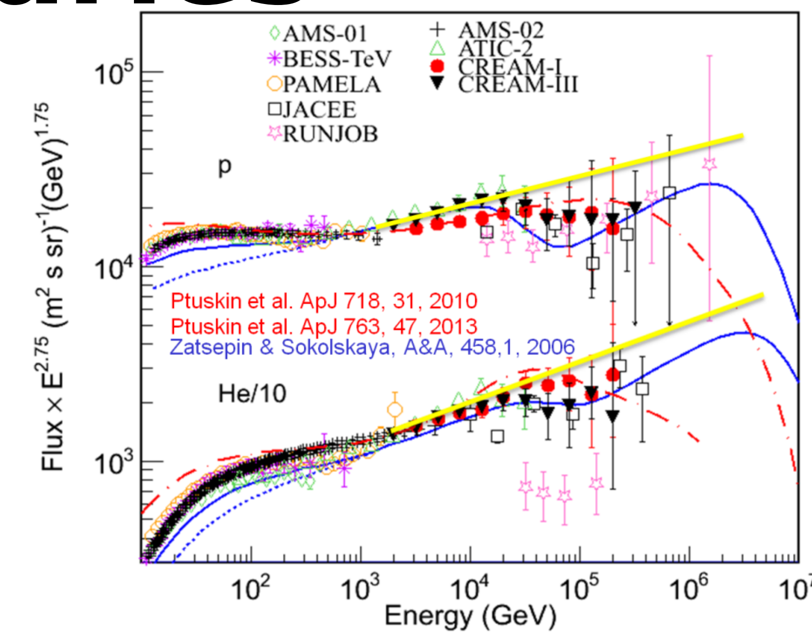


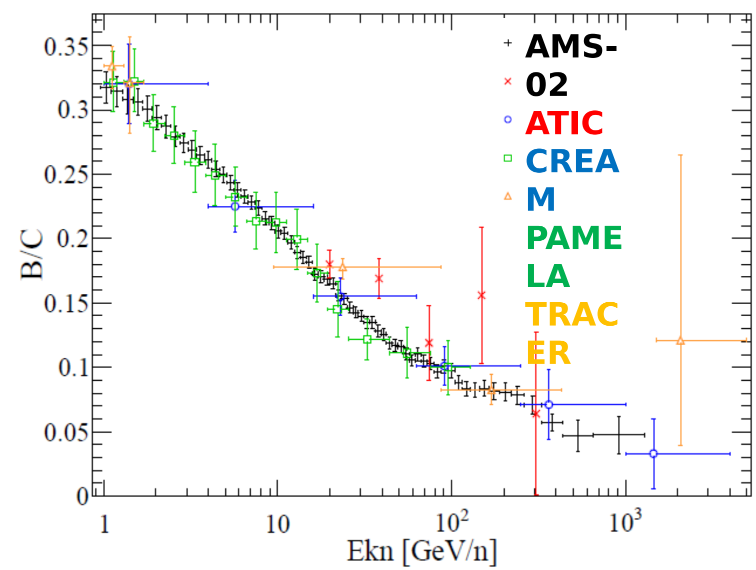




Higher energies and secondaries







1-100 TeV
Explored by CREAM & NUCLEON
Preliminary results from DAMPE, CALET

Go to higher energies: ISS-CREAM and HERD