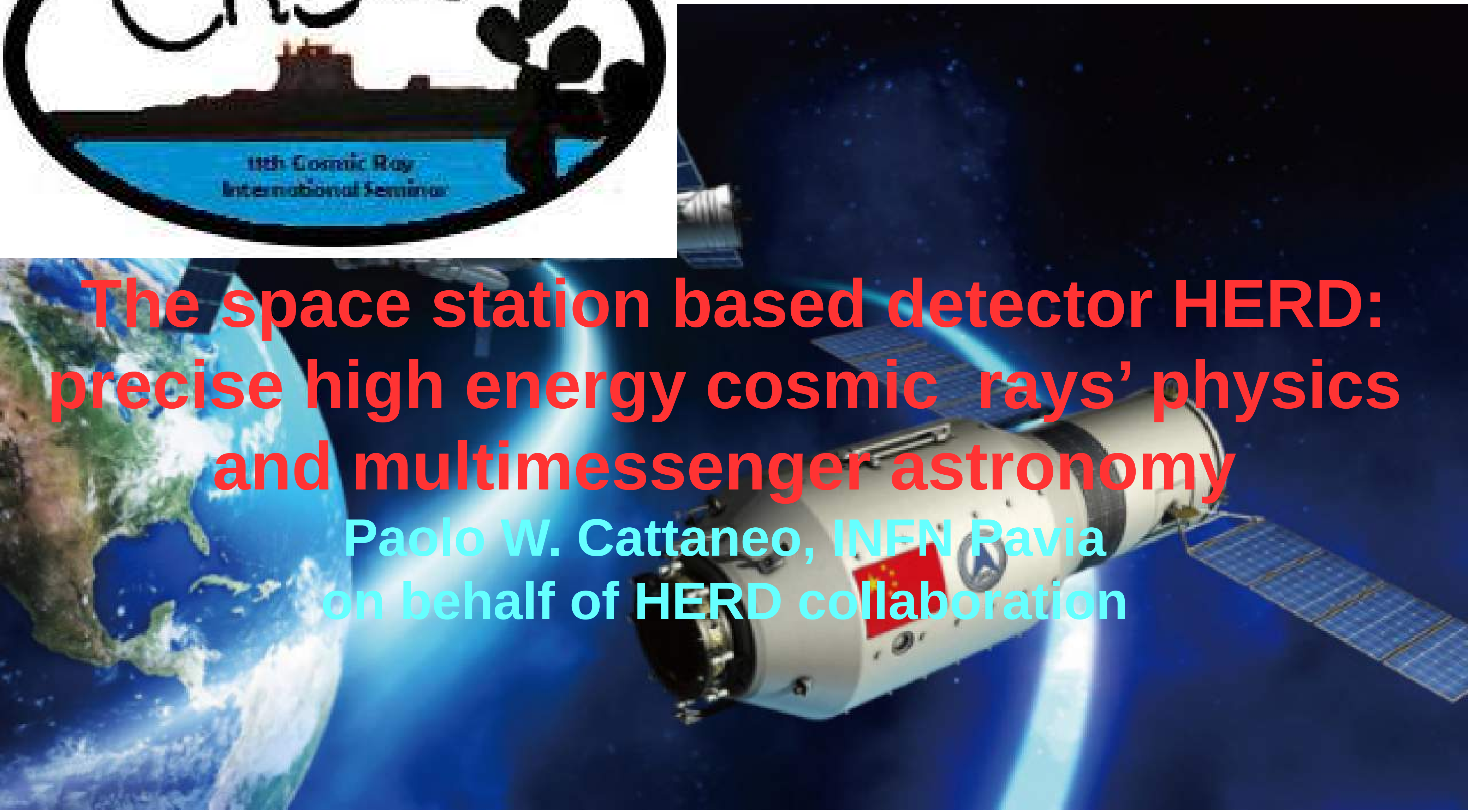
CRiS 2018

11th Cosmic Ray International Seminar

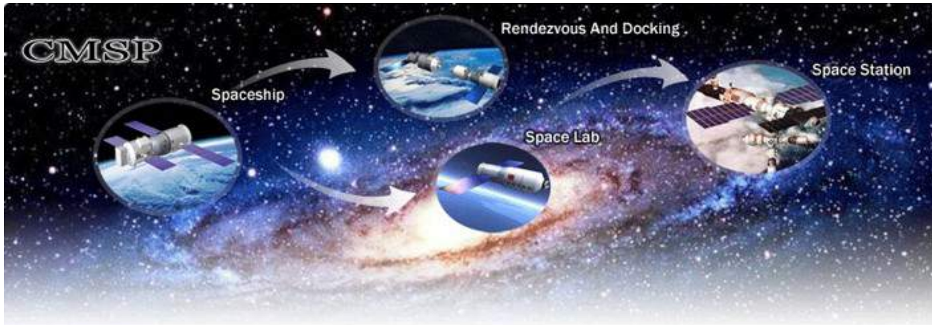


The space station based detector HERD: precise high energy cosmic rays' physics and multimessenger astronomy

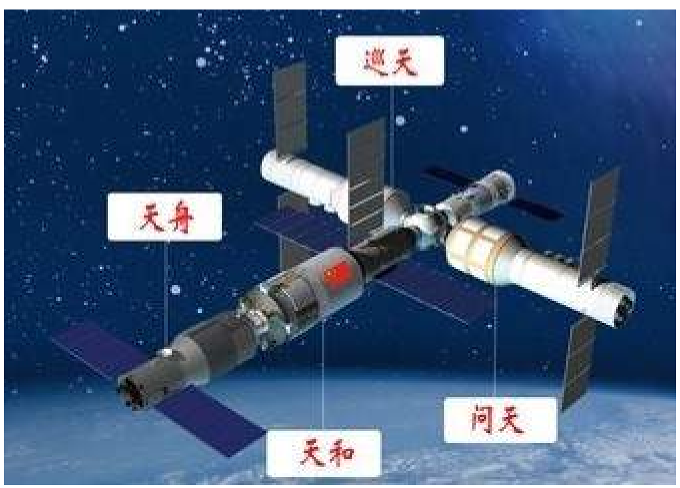
Paolo W. Cattaneo, INFN Pavia

on behalf of HERD collaboration

The Chinese Space Station



The Chinese Manned Space Program



Mission lifetime	2025 + >= 10 years
Outside environment	Vacuum -100 C-- +100 C
Orbit	350-450 km 41~43 deg
Measurement accuracy	<= 0.02^0 (3σ)
Control accuracy	<= 0.1^0 (3σ)
Maintenance	Manned or cargo ship Astronauts required
TC/TM	1000 Mbps(download) 6 Mbps (upload)

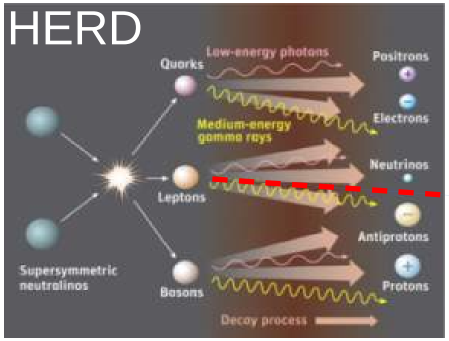
China’s Space Station Program

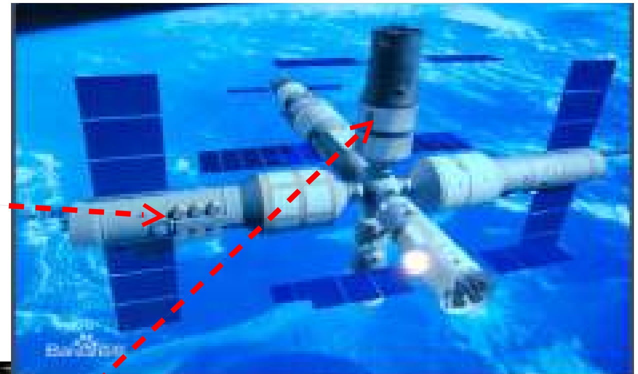
2025

Phase -II
2016

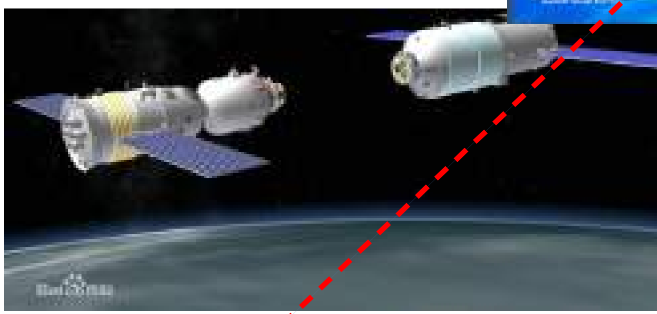
Phase -II
2011

Phase -I
2003





Space Station
3 large modules
+ 2 m telescope
~10-year lifetime



Space lab: no living cabin

10 astronauts in 5 flights space walk

The HERD Collaboration Team

- Chinese institutions
  - Institute of High Energy Physics, Purple Mountain Observatory, Xi'an Institute of Optical and Precision Mechanics, University of Science and Technology of China, Nanjing University, Peking University, Yunnan University, China University of Geosciences, Ningbo University, Guangxi University
- International institutions
  - Italy: Università di Pisa/INFN, University of Florence/INFN, University of Perugia/INFN, University of Bari/INFN, University of Salento/INFN-Lecce, University of Pavia/INFN, GSSI/INFN
  - Spain/CIEMAT
  - Switzerland: University of Geneva

HERD: High Energy cosmic-Radiation Detector

Science goals	Mission requirements
Dark matter search	R1: Better statistical measurements of e/γ between 100 GeV 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

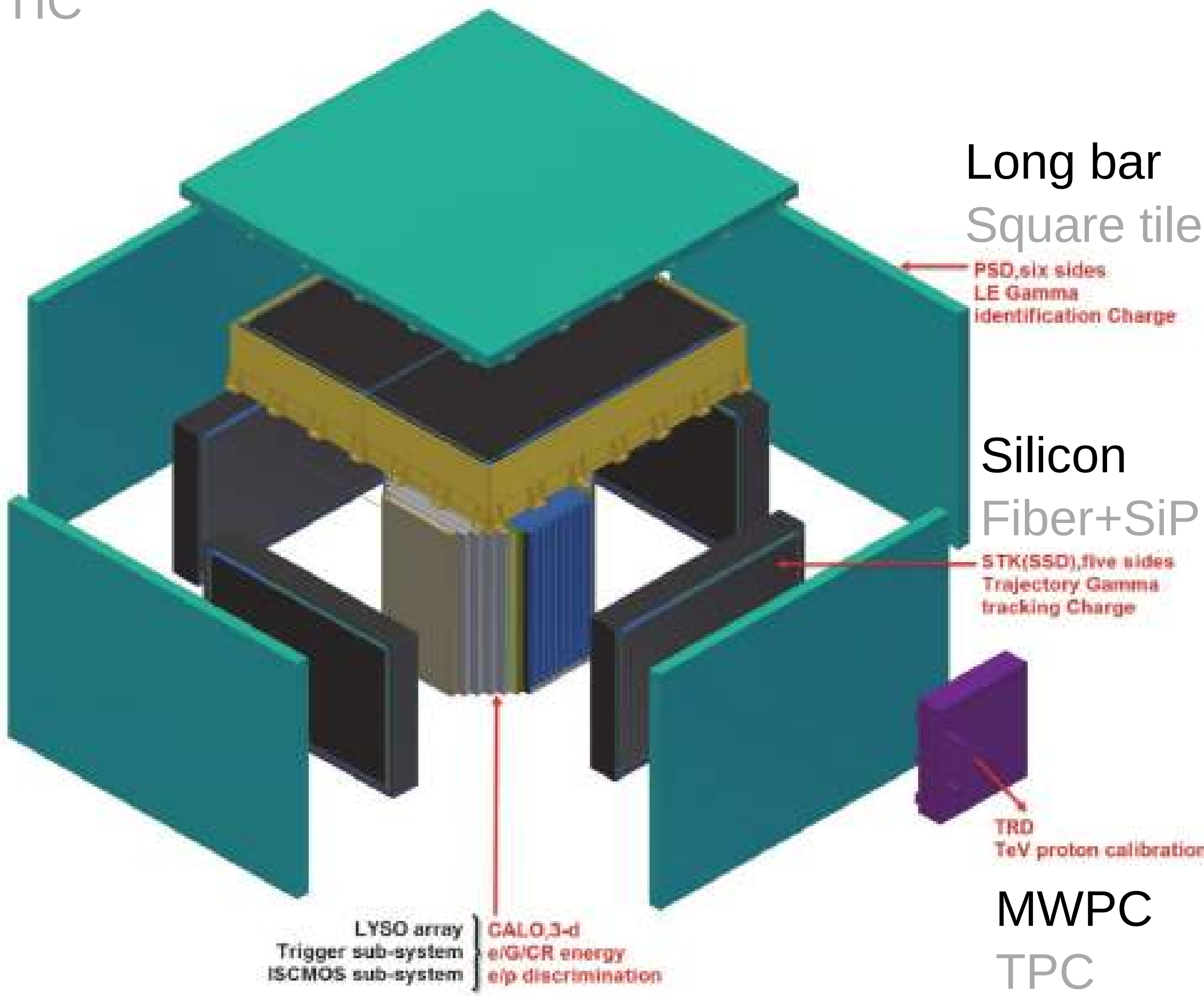
Additional science: γ-ray astronomy, monitoring of GRBs, microquasars, Blazars and other transients, down to ~1 GeV for γ-rays.

*complementary to high altitude cosmic-ray observations

Baseline design

CALO + TRACKER

TIC



Long bar

Square tile

Silicon

Fiber+SiPM

MWPC

TPC

WLSF+IsCMOS

Characteristics of all components

	type	size	X_0,λ	unit	main functions
tracker (top)	Si strips	70 cm × 70 cm	2 X_0	7 x-y (W foils)	Charge Early shower Tracks
tracker 4 sides	Si strips	65 cm × 50 cm	2 X_0	7 x-y (W foils)	Charge Early shower Tracks
CALO	~10K LYSO cubes	63 cm × 63 cm × 63 cm	55 X_0 3λ	3 cm × 3 cm × 3 cm	e/γ energy nucleon energy e/p separation
PSD	Plastic scintill.	120/170cm x 12 cm x 1xcm	0.1 X_0	~70 bar	Anticoincidence Trigger Charge

Expected performance of HERD

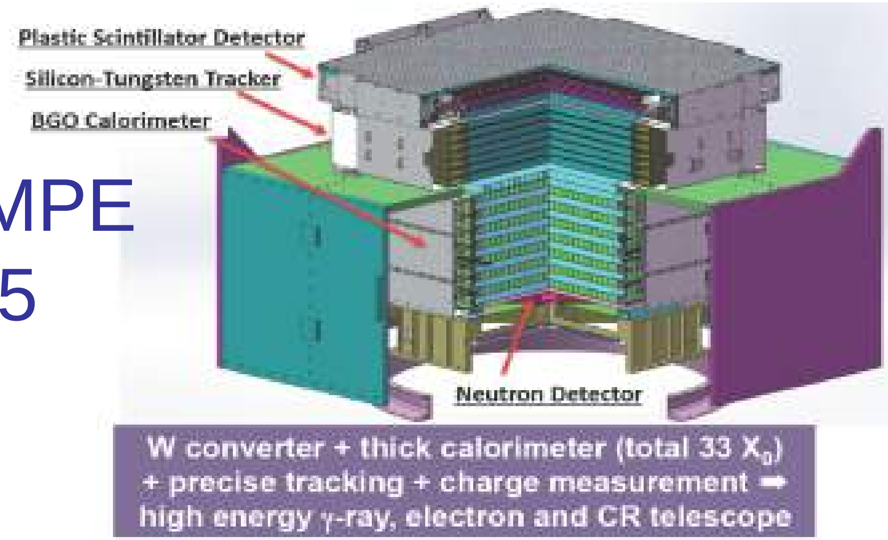
γ/e energy range (CALO)	10 GeV-10TeV
nucleon energy range (CALO)	30 GeV-PeV
γ/e angular resol.	0.1^{o}@10GeV
nucleon charge resol.	0.1-0.15 c.u
γ/e energy resolution (CALO)	<1%@200GeV
proton energy resolution (CALO)	20%@100GeV-1PeV
e/p separation power (CALO)	$<10^{-5}$
electron eff. geometrical factor (CALO)	3.7 m^2sr@600 GeV
proton eff. geometrical factor (CALO)	2.6 m^2sr@400 TeV

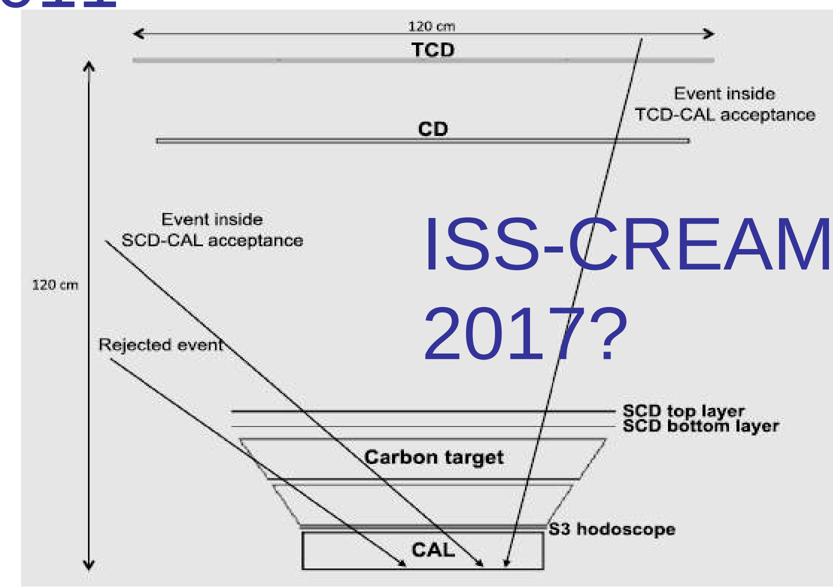
Acceptance & H-energy > 10 X other experiments

Other detectors: Top down “small” FoV

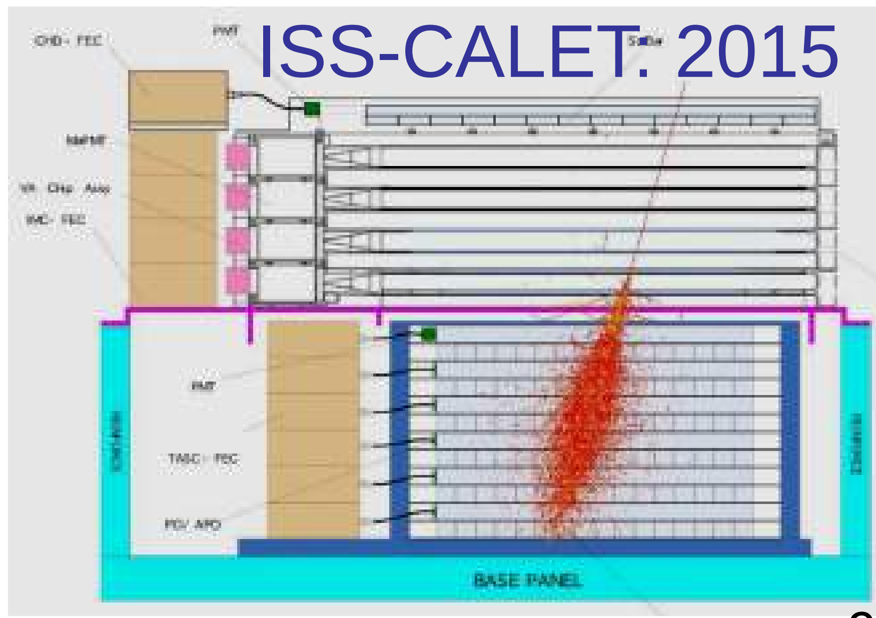
ISS-AMS: 2011

DAMPE 2015





ISS-CREAM: 2017?

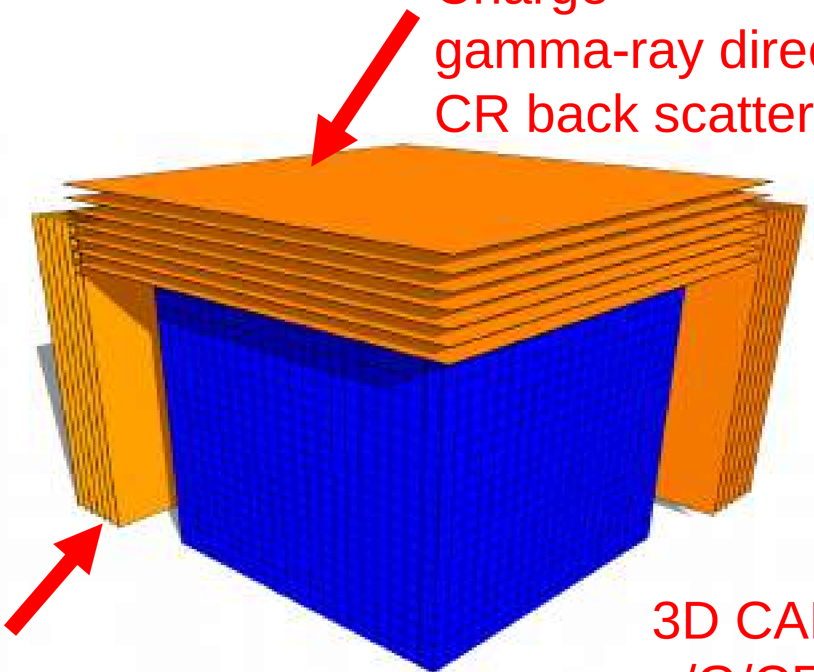


ISS-CALET: 2015

HERD Design： 3D Calo & 5-Side Sensitive

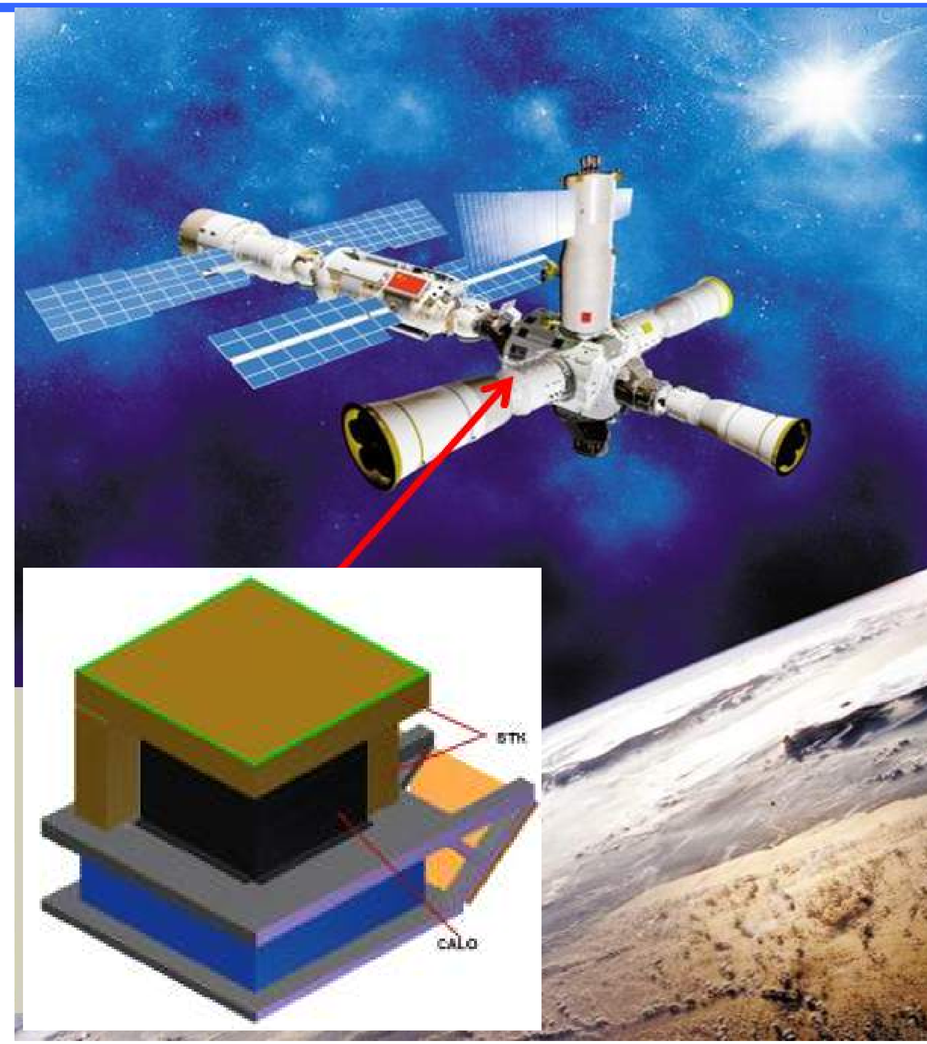
10X acceptance than others, but weight 2.3 T ~1/3 AMS

STK(W+SSD)
Charge
gamma-ray direction
CR back scatter



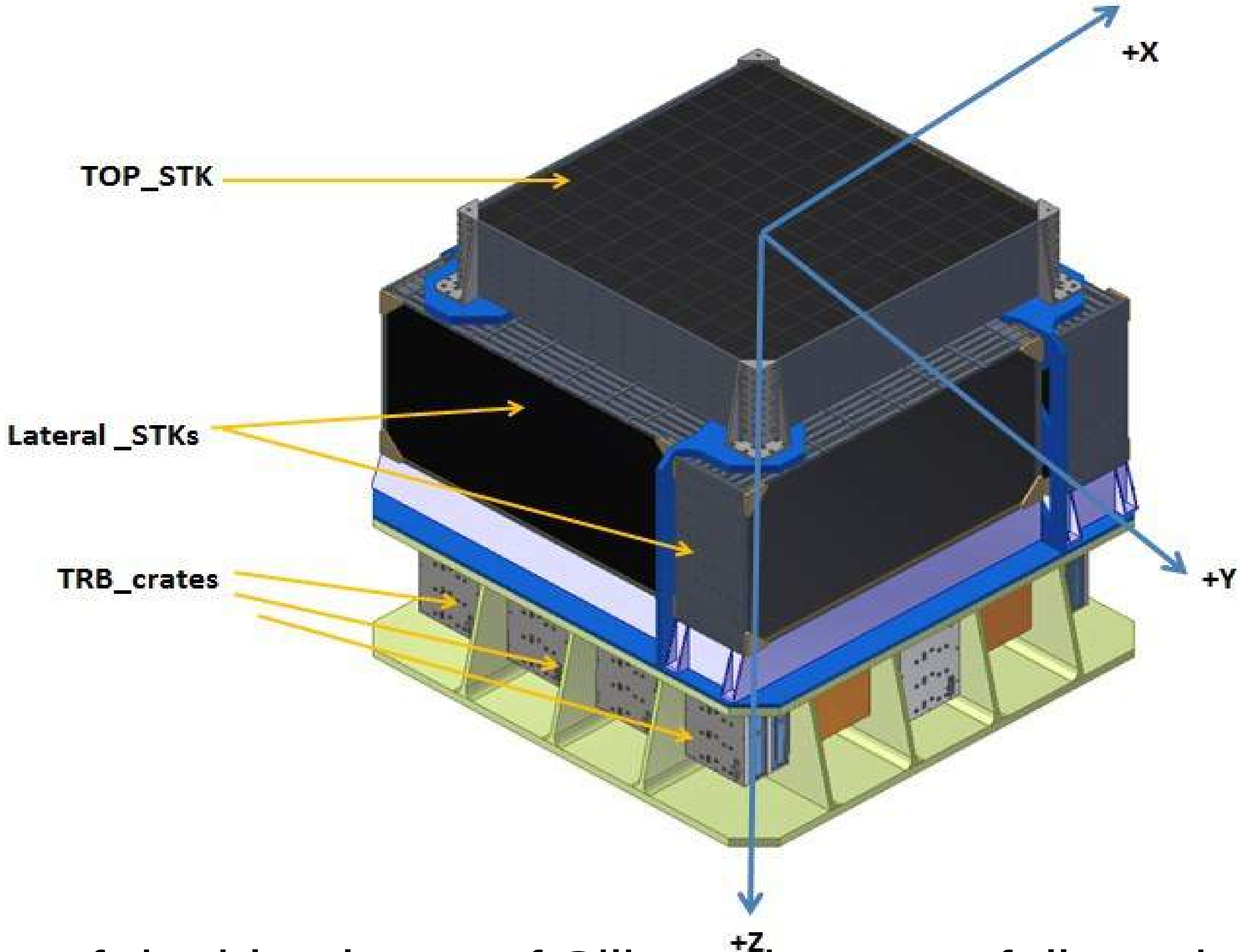
STK(W+SSD)

3D CALO
e/G/CR energy
e/p discrimination



HERD STK Tracker

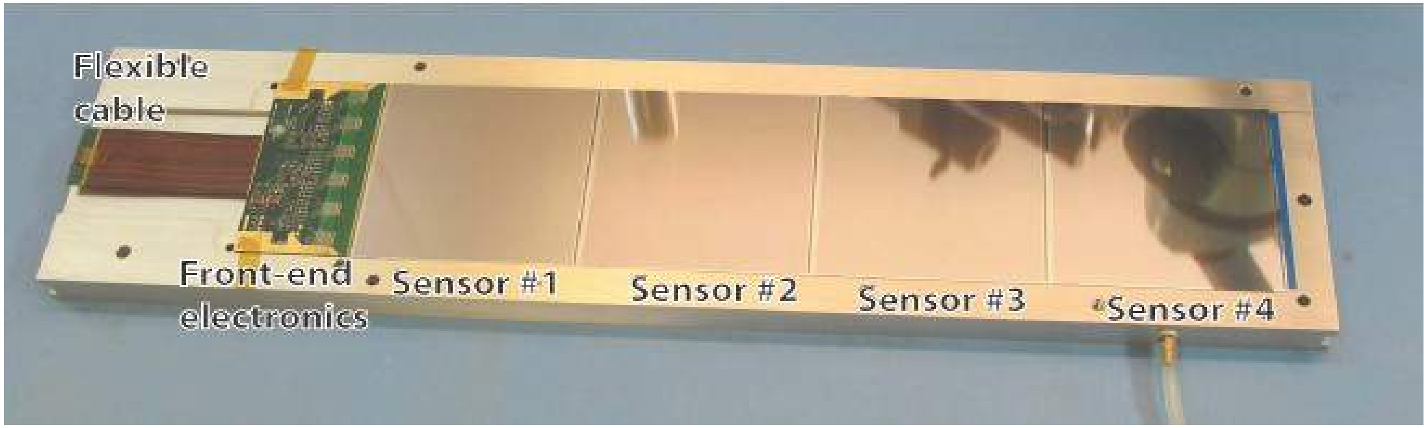
- measure CR tracks
- measure charge dE/dx
- preshower
- convert γ-rays



Baseline: multiple layers of double planes of Silicon detectors followed by W converter planes on 5 sides (FERMI/Agile like).

HERD STK Tracker

DAMPE module to be used but longer.

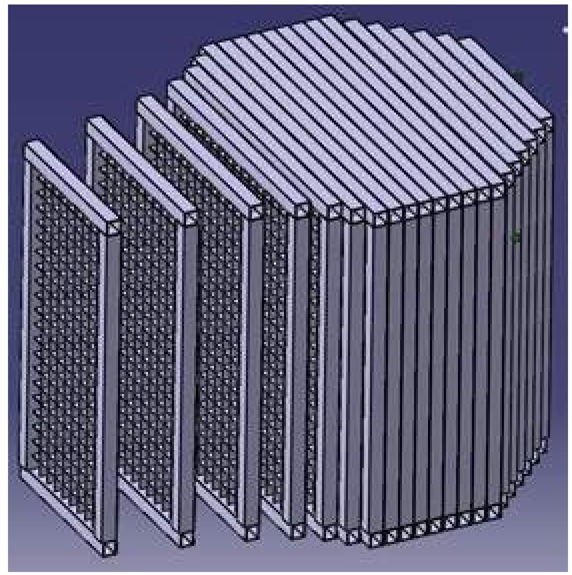


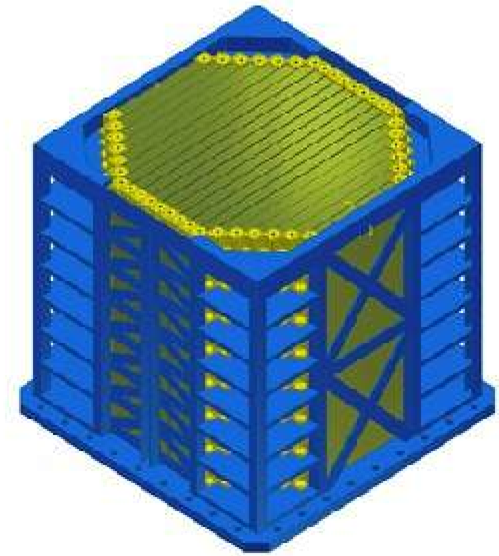
Many parameters still to be optimised:
- number of planes
- Si+W or Si only
- thickness of STK

Calorimetric measurements for CR physics favors shallow STK
Multiple dE/dx favors many active planes
γ-ray effective area requires thick STK
Weight and space constraints to be optimised with calorimeter
Compromise to be found depends on phisics goals

HERD Design: 3D Imaging Calorimeter

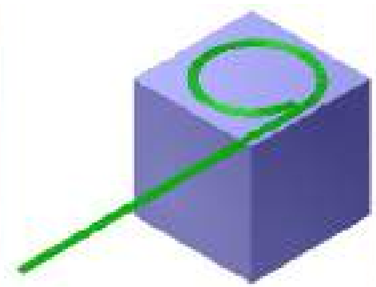
At HERD's core there is a calorimeter segmented in 3D (CaloCube concept)





The calorimeter consists of many (~7500) small crystal cubes.
Full 3D reconstruction of showers.
Particles can impinge on 5 sides.

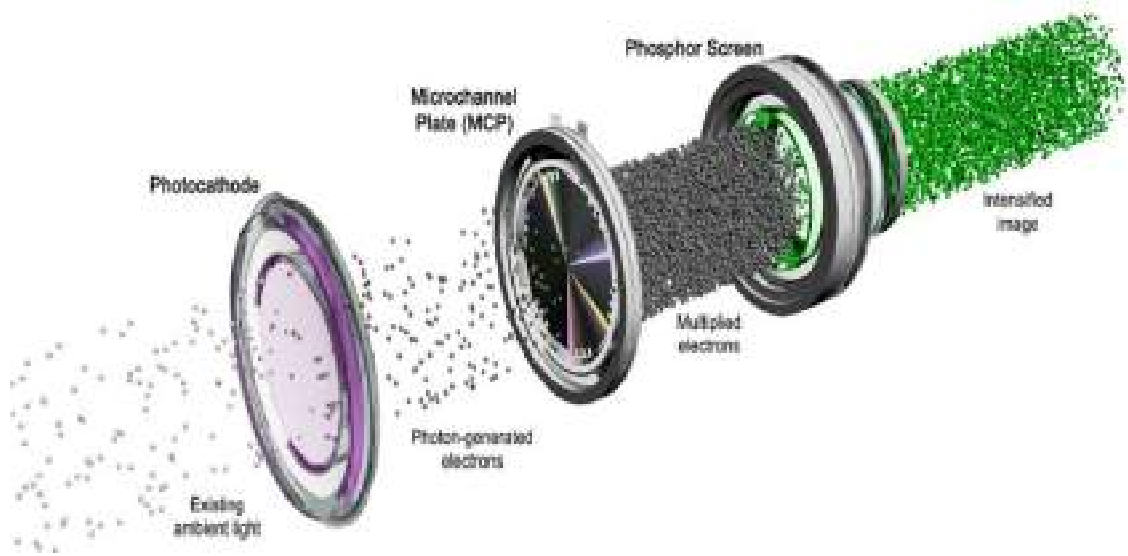
Each cube read out by WLS fiber.



HERD Design： 3D Imaging Calorimeter

The light from fiber read out through an image intensifier.

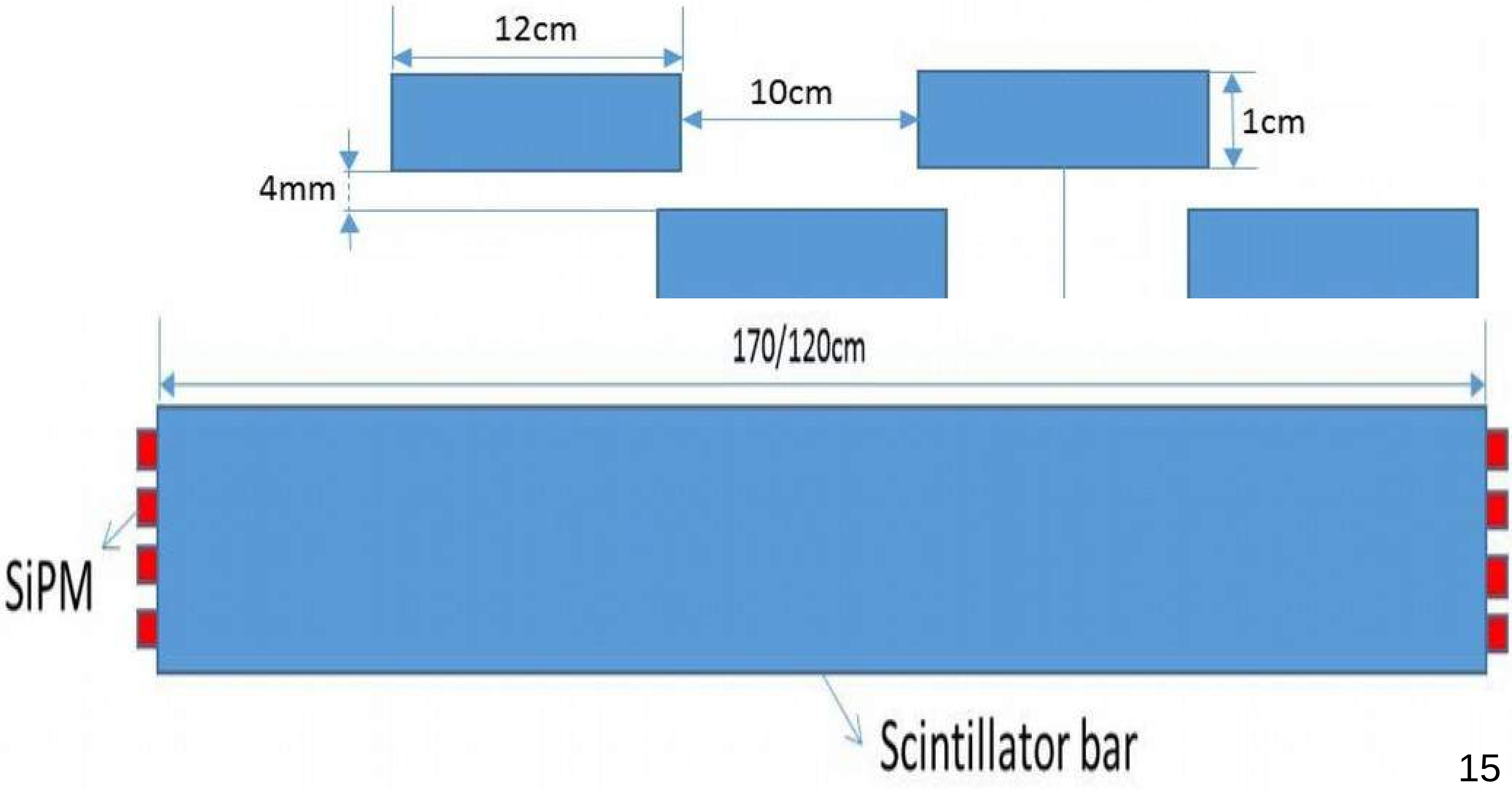
Subset of channels can be read also by photodiode for calibration purpose.



The camera is expected to be replaced by astronauts after few years!!

HERD Design： Plastic Scintillator Detector

HERD is surrounded by layers of scintillator bars (or tiles) readout by SiPMS.



HERD Design： Plastic Scintillator Detector

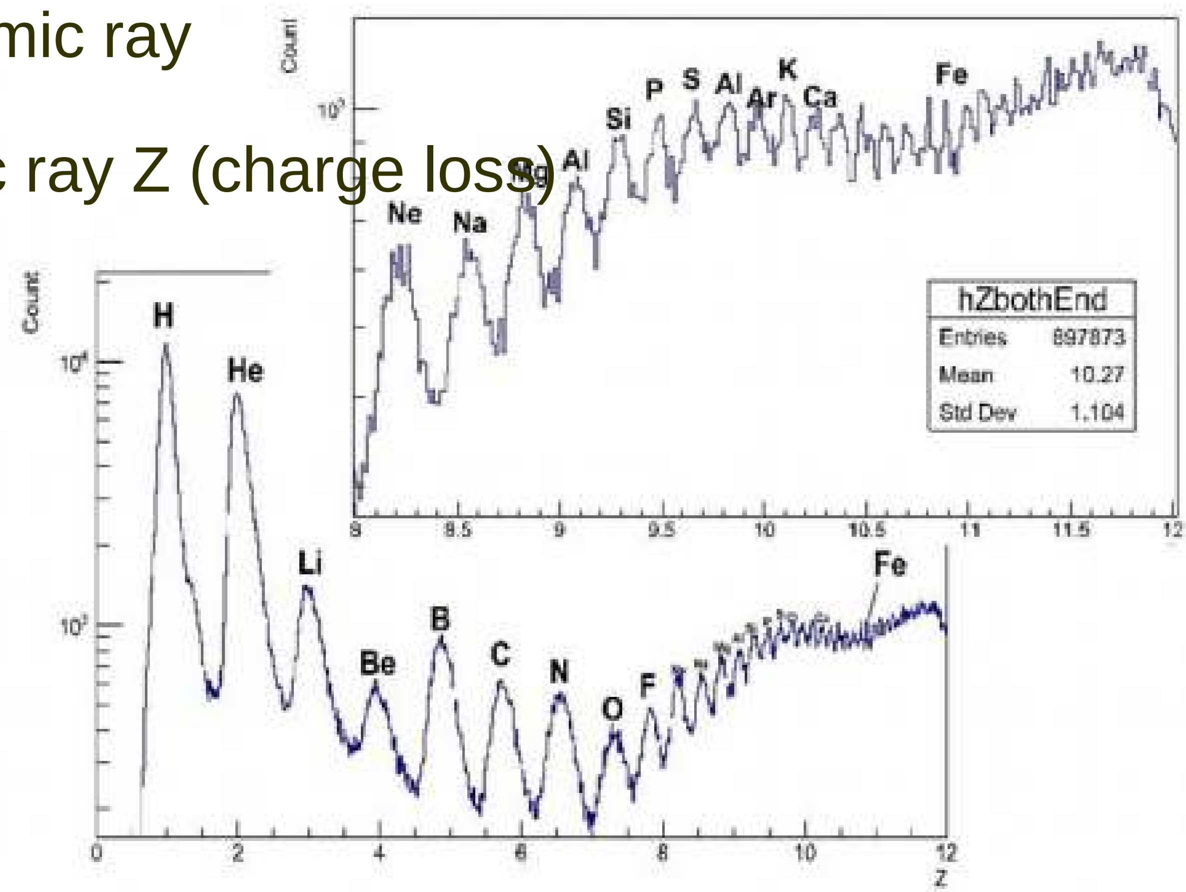
PSD has several tasks:

- Anti Coincidence for γ-ray physics (veto for charge particle)

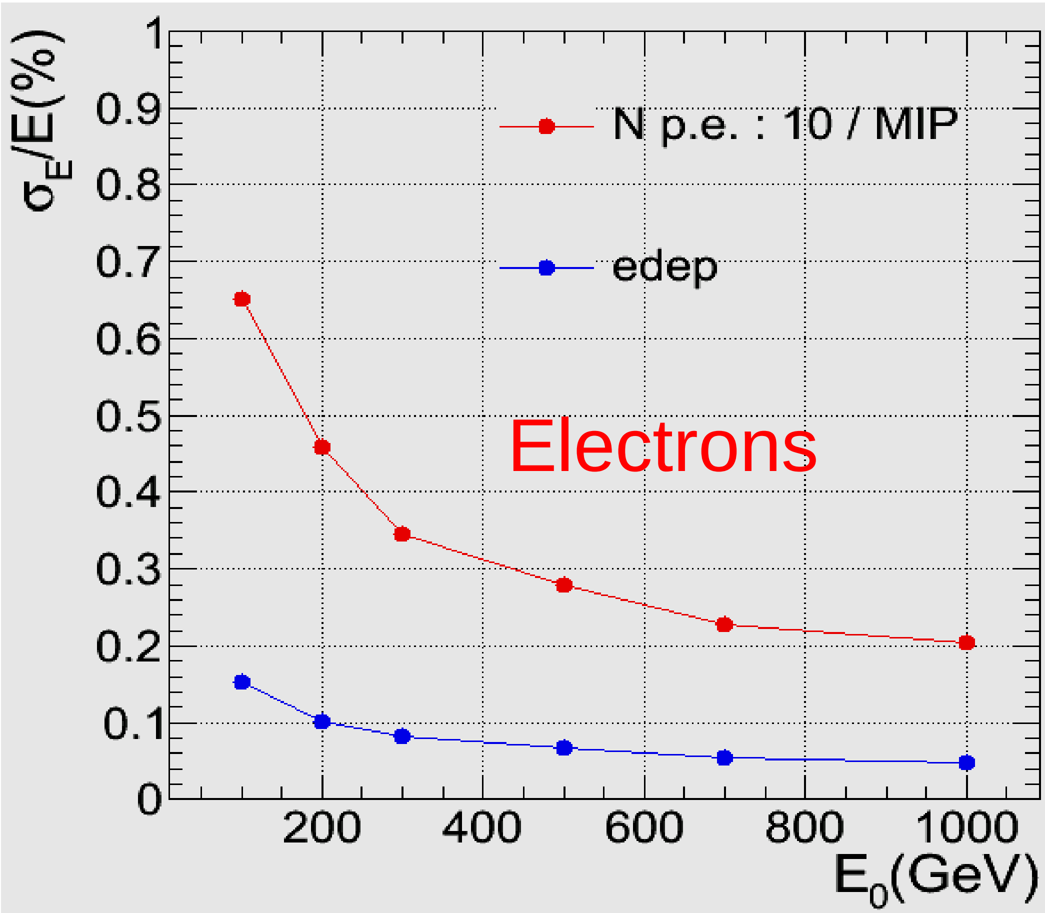
- Trigger for charged cosmic ray

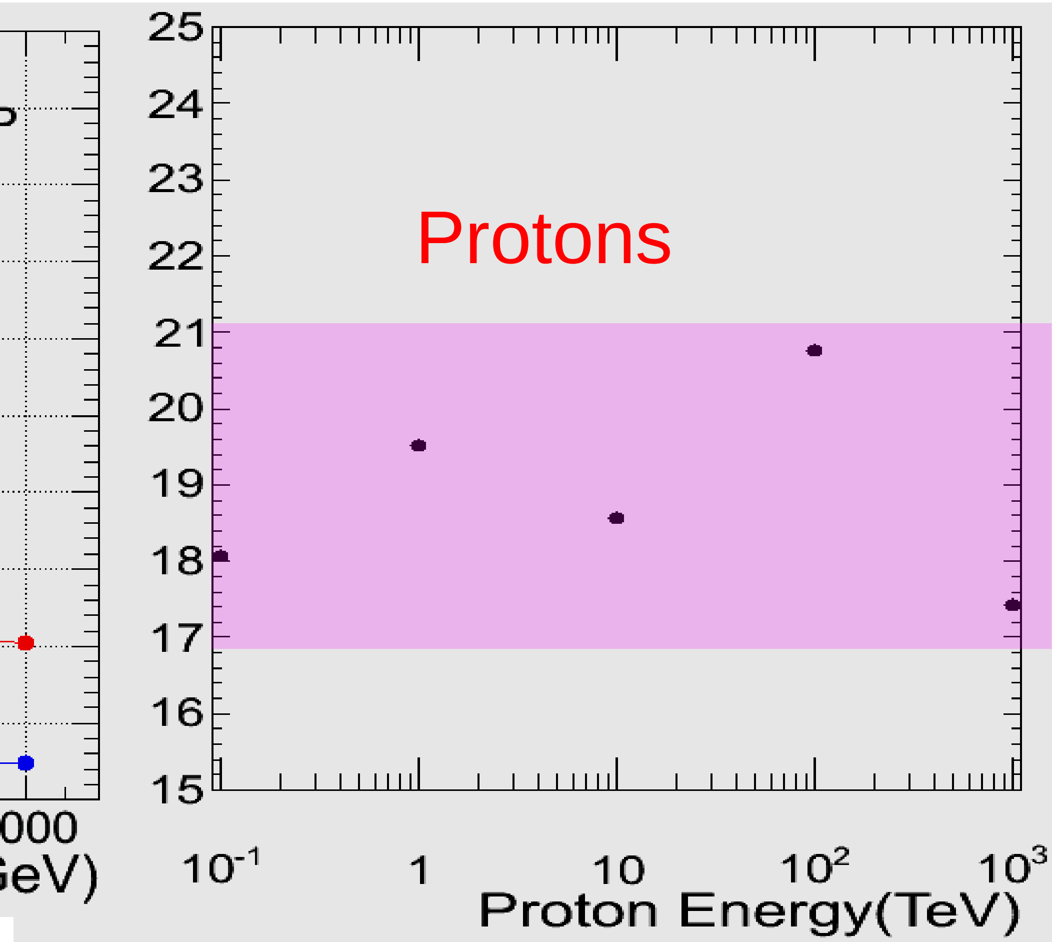
- Measurement of cosmic ray Z (charge loss)

Geometry optimization still ongoing:
- bar/tiles
- thickness
- number of layers



Simulation results: energy resolutions

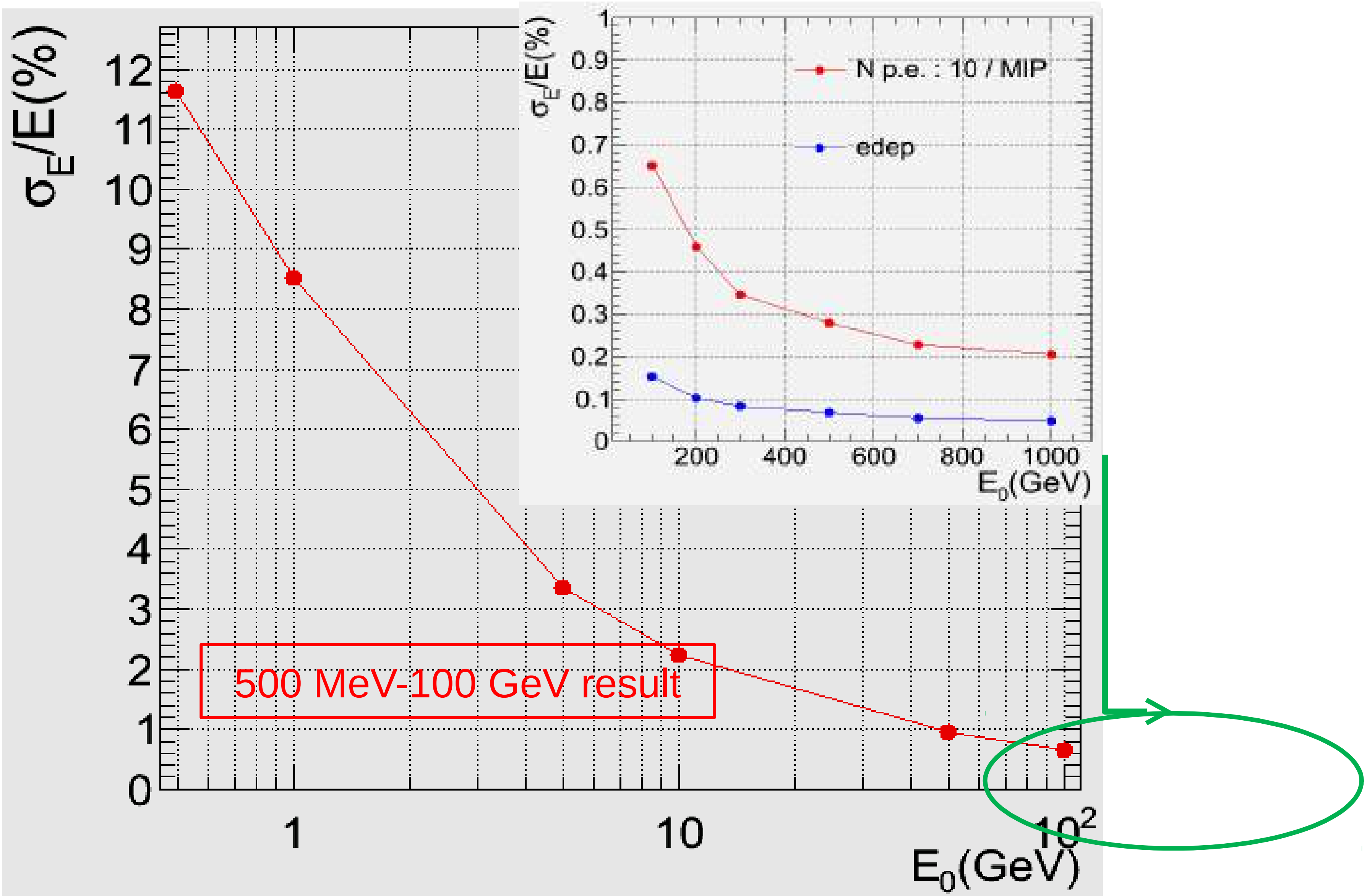




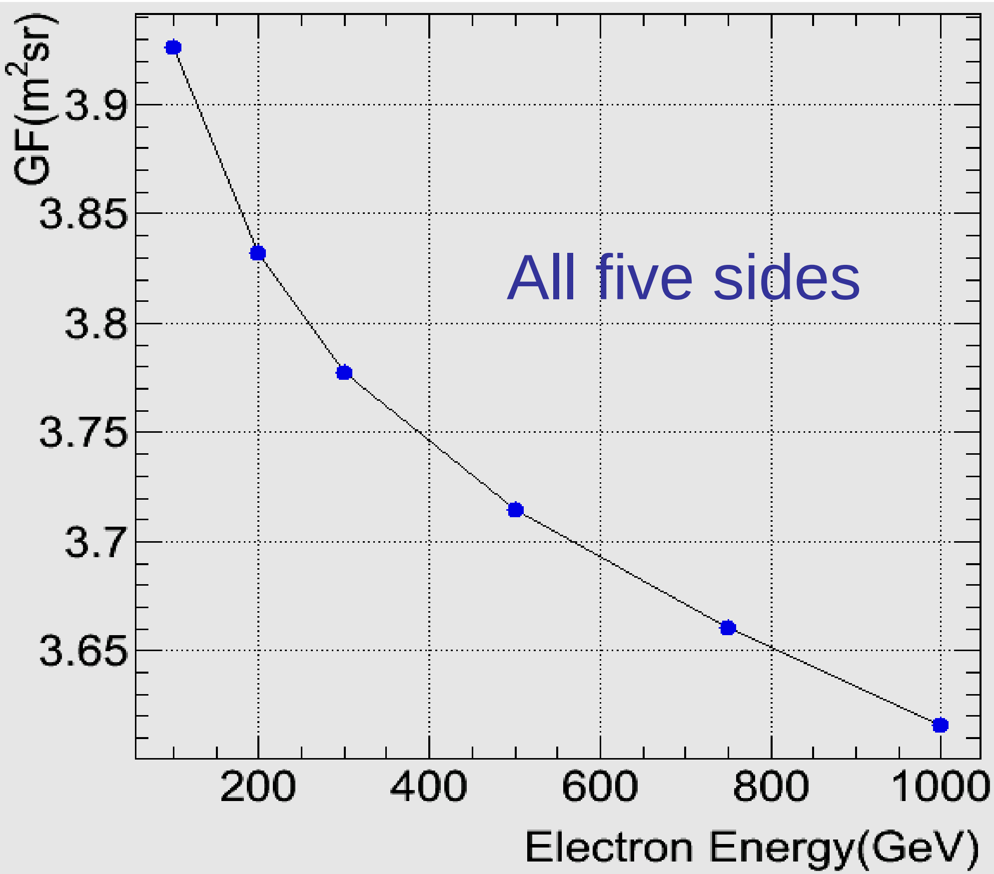
Electron < 1%; Proton: ~20%

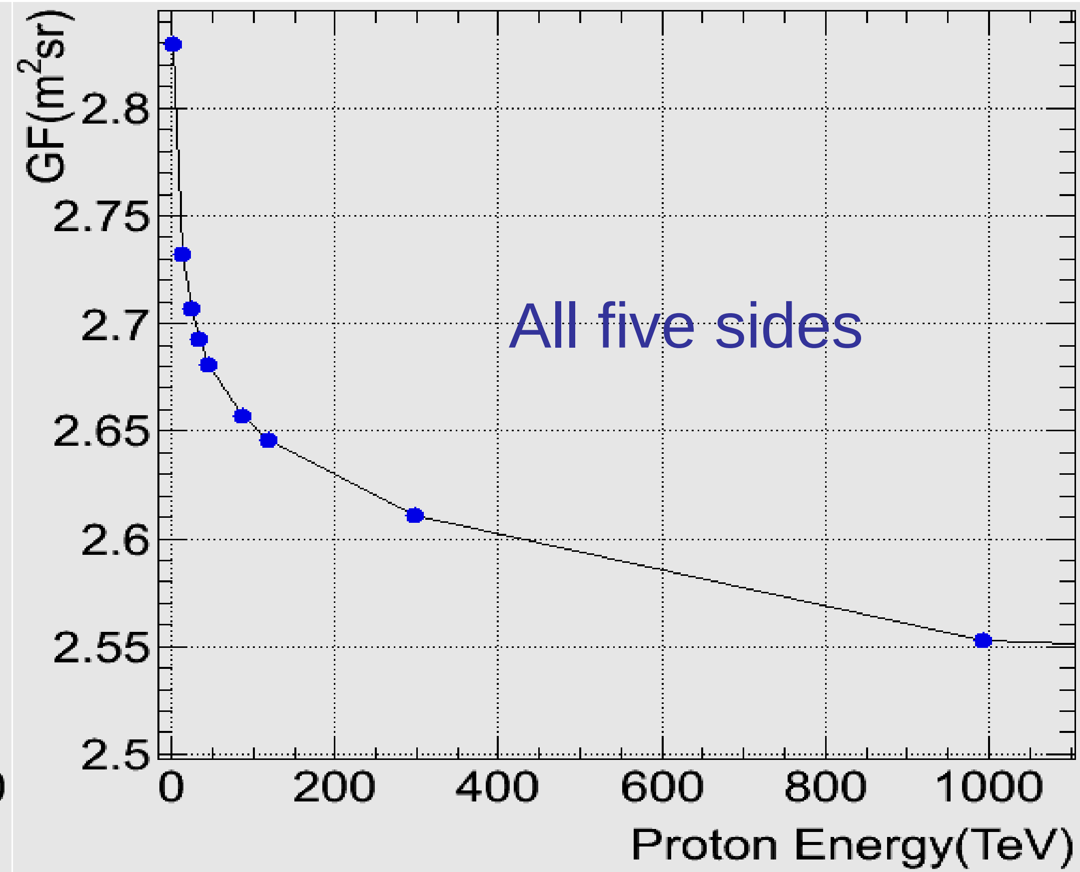
Essential for spectral features!

Energy Resolution for gamma-rays

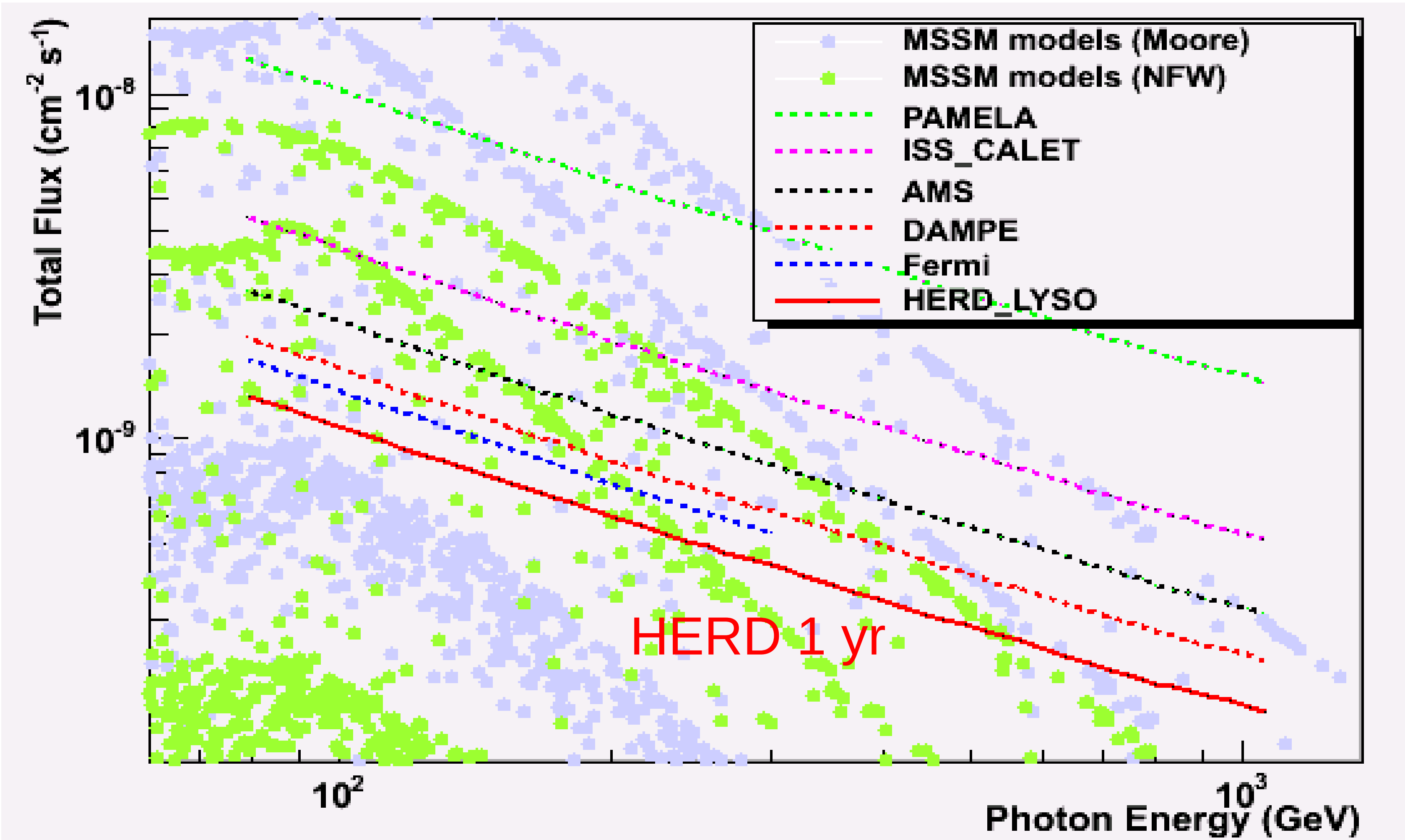


HERD Eff. Geometrical Factor: CALO



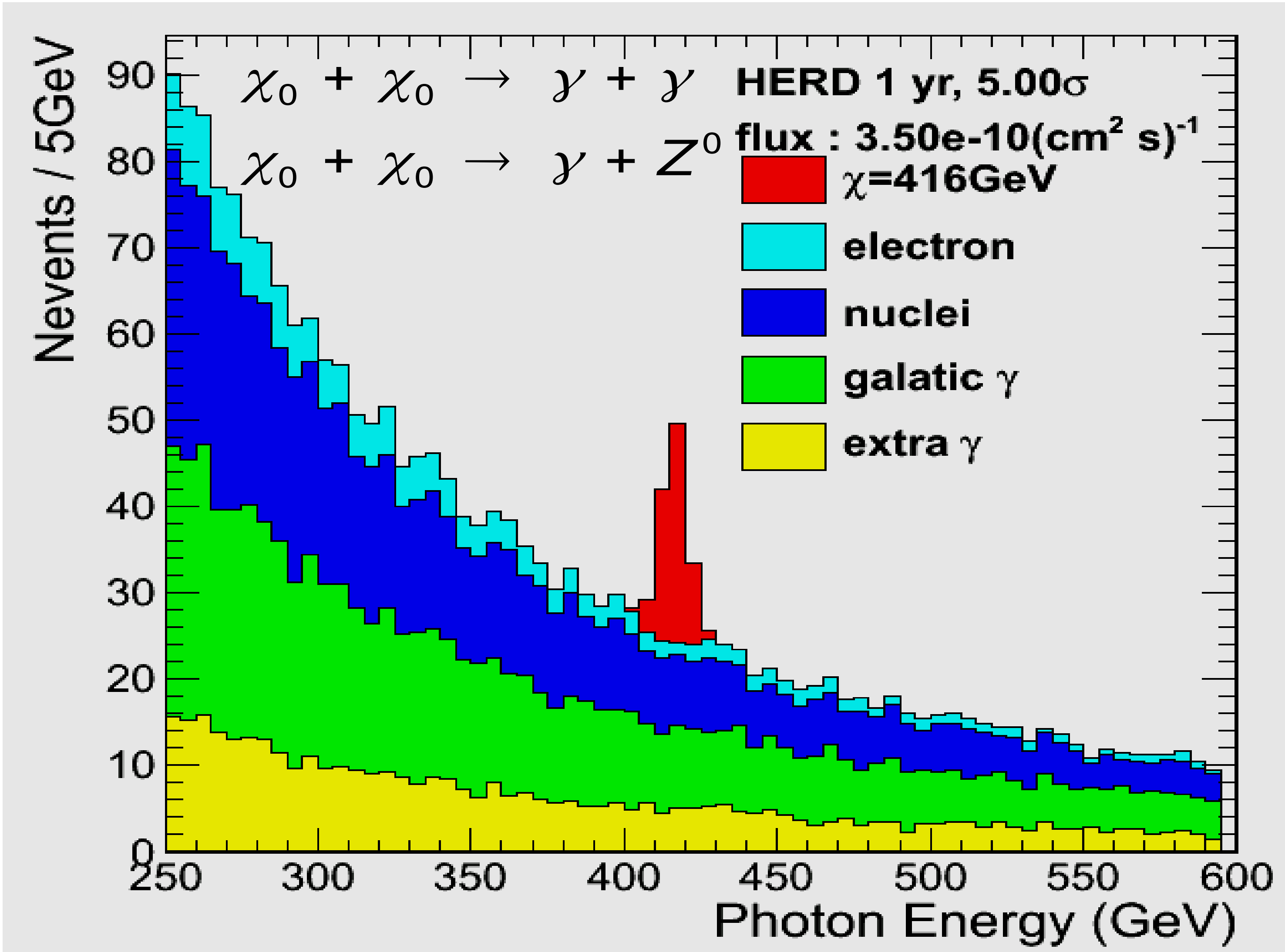


HERD sensitivity to gamma-ray line

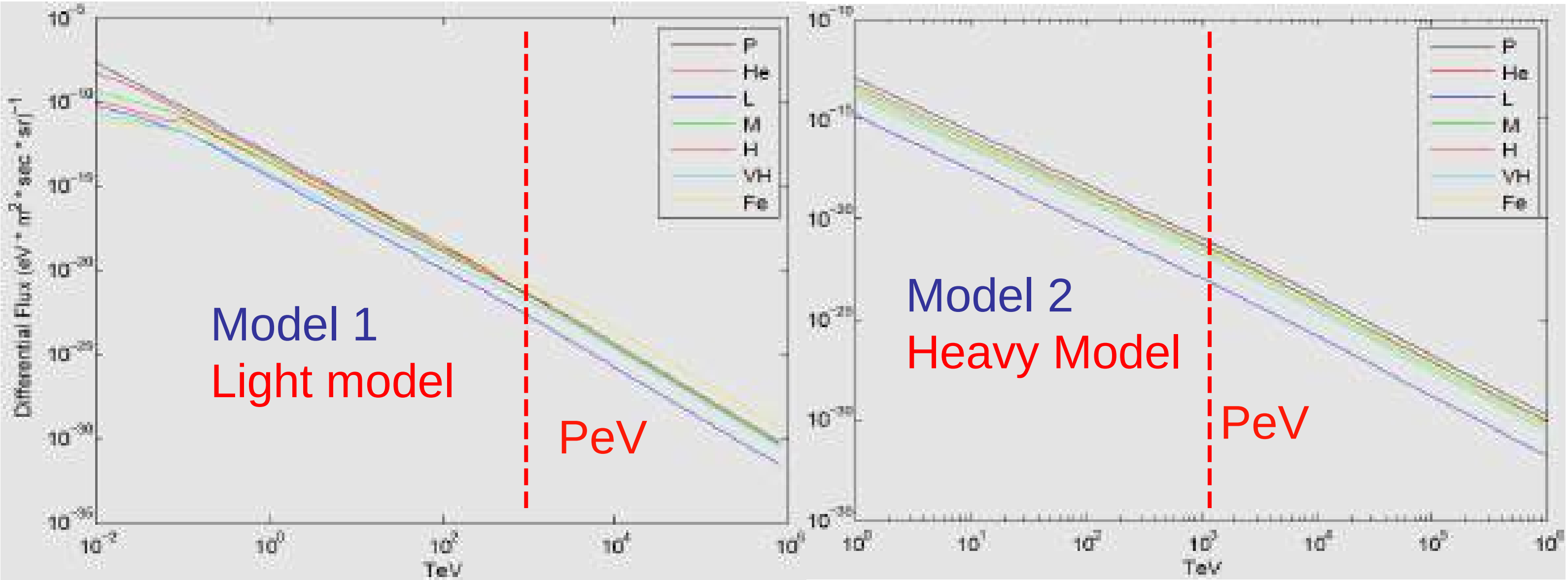


PAMELA: 2006-2016 CALET: 2015-2020; AMS: 2011-2021;
DAMPE: 2015-2020; Fermi: 2008-2018; HERD

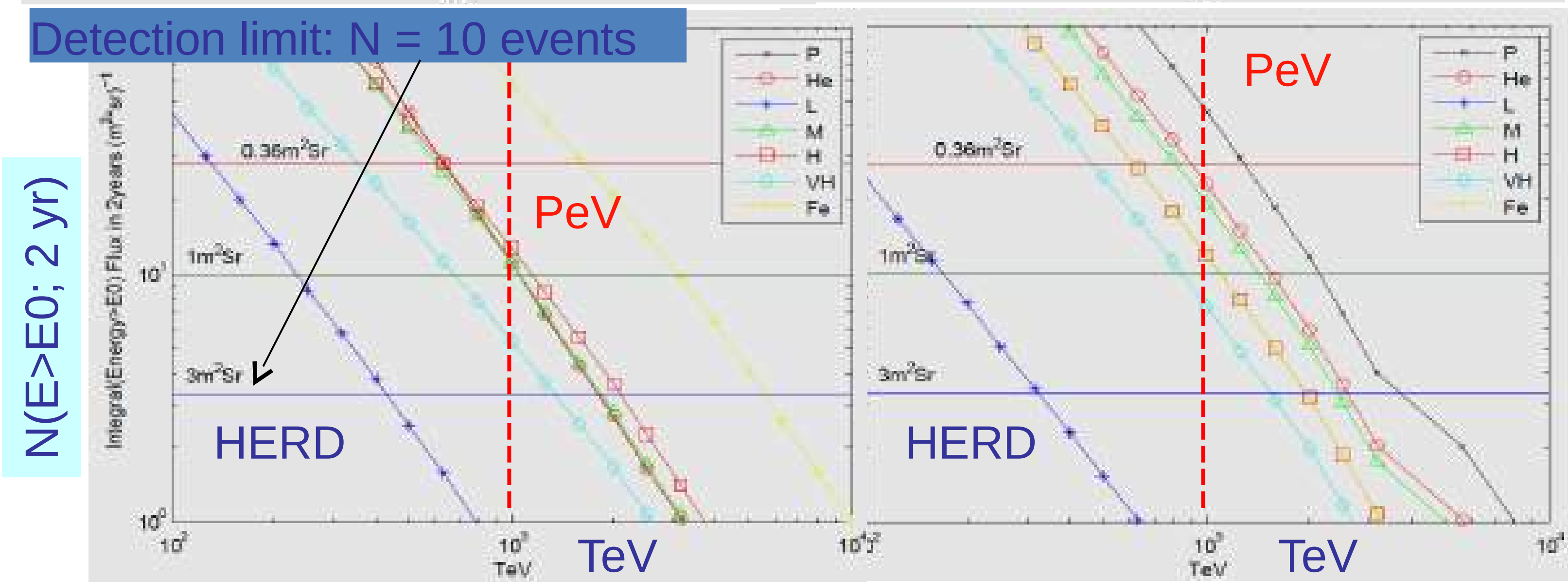
DM annihilation line of HERD



HERD Cosmic Ray Capability Requirement

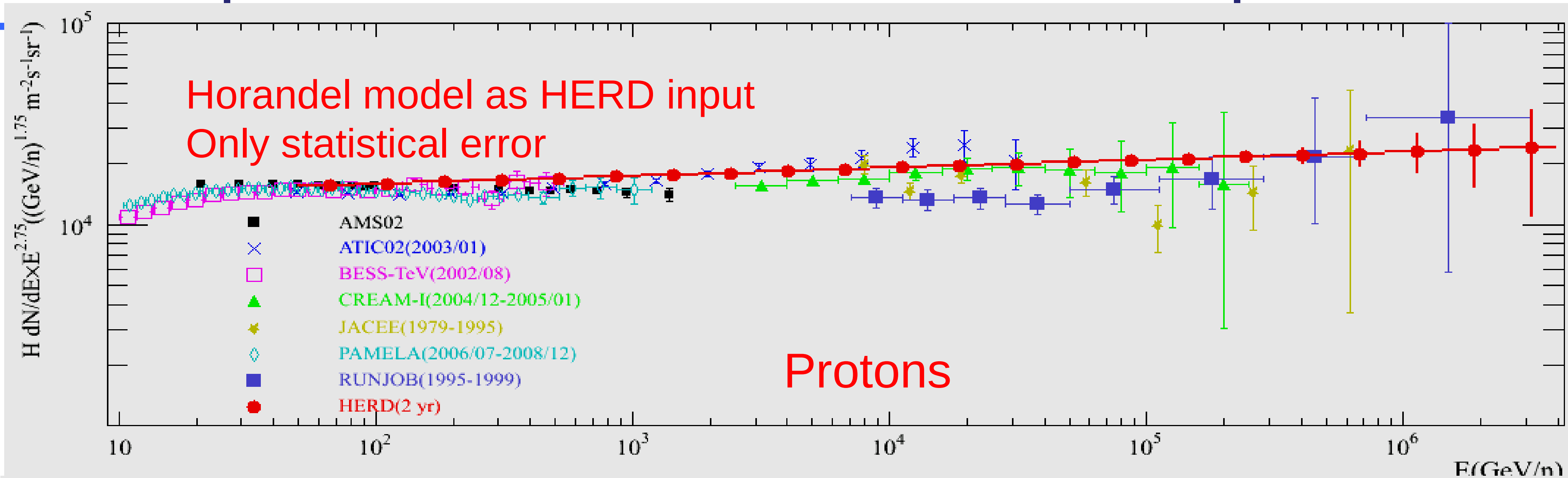


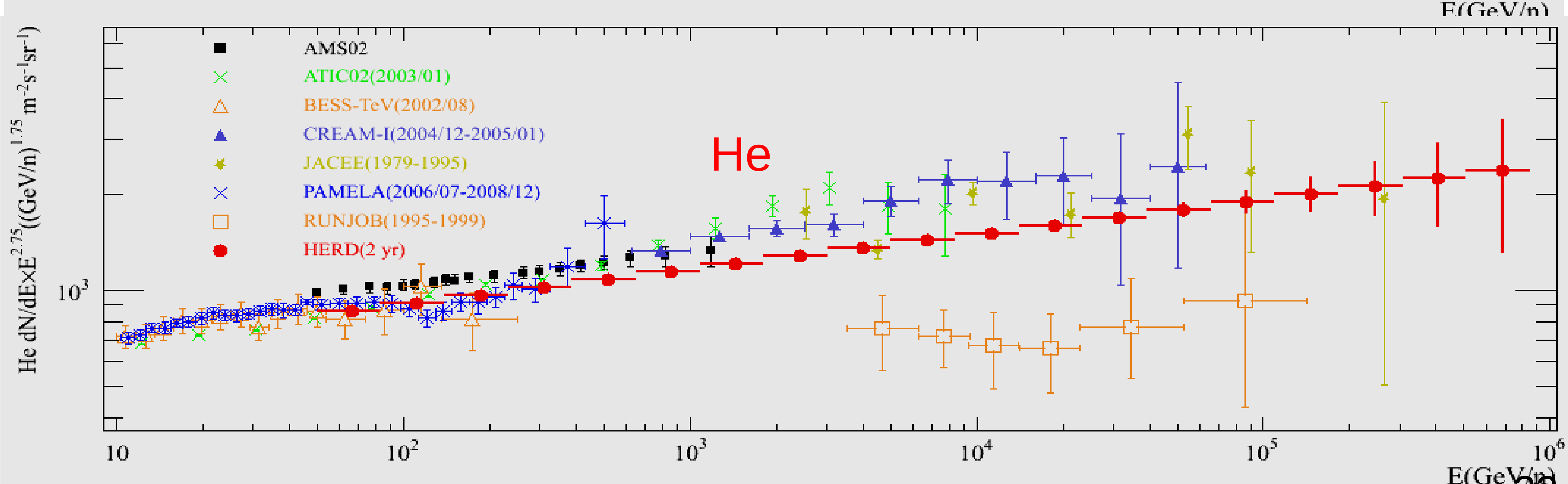
P (<A> ~ 1)
He (<A> ~ 4)
L (<A> ~ 8)
M (<A> ~ 14)
H (<A> ~ 25)
VH (<A> ~ 35)
Fe (<A> ~ 56)



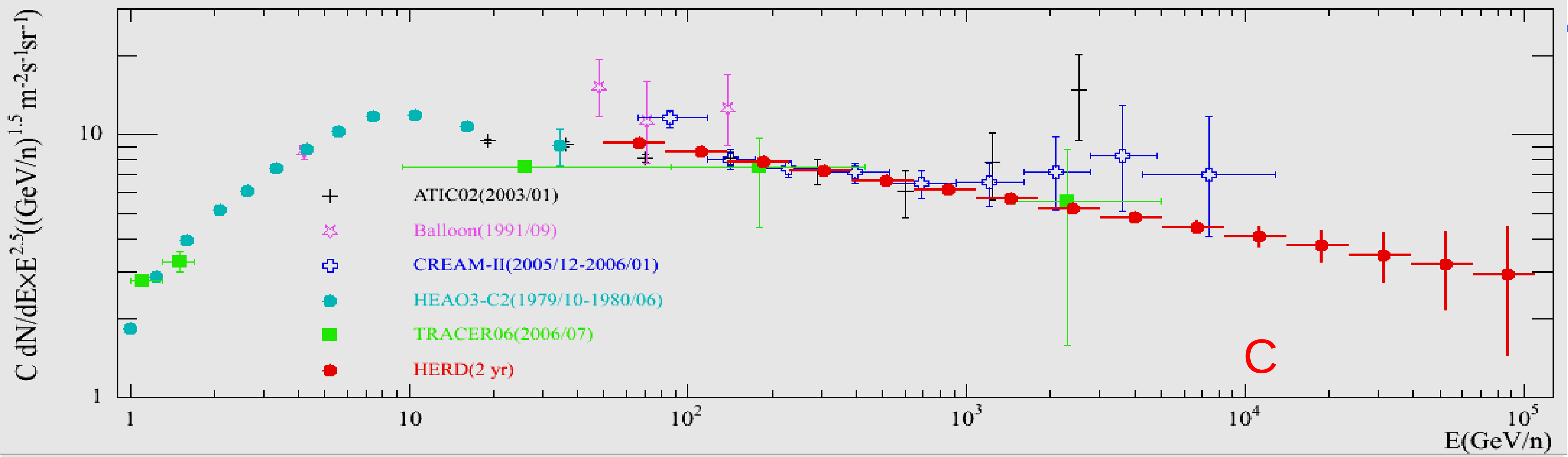
Except for L, up to PeV spectra feasible with GF~2-3 in ~years: discriminate between models.

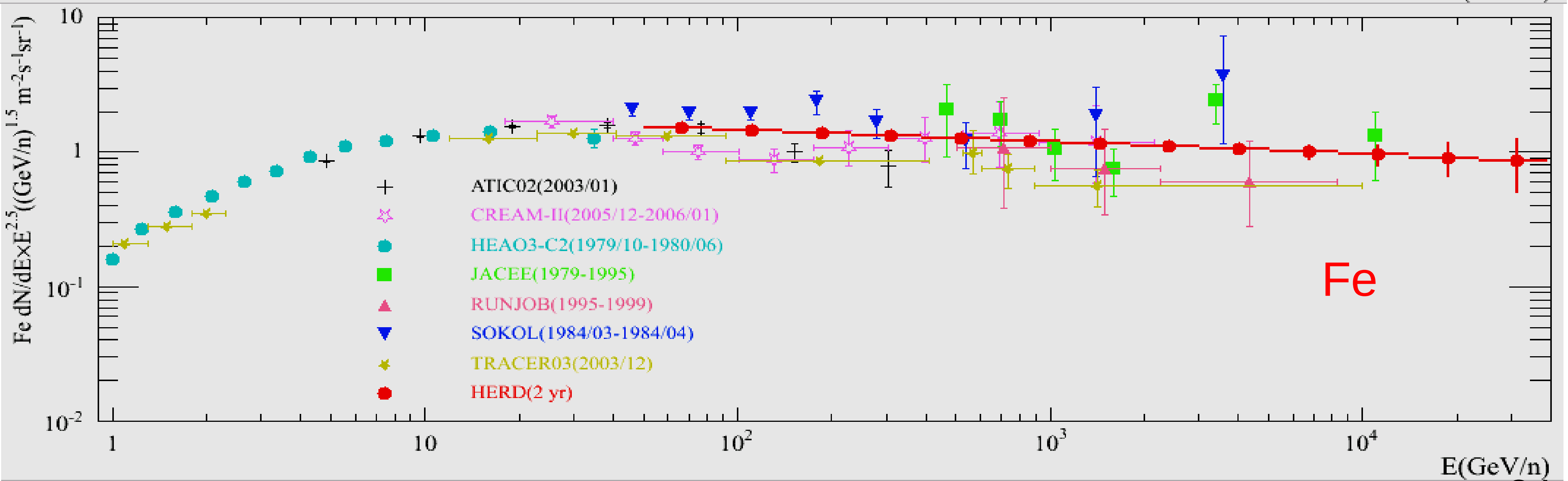
Expected HERD Proton and He Spectra





Expected HERD Spectra of C and Fe





Conclusions

HERD will operate on the CSS starting since middle 2020

It will be a calorimetric detector with unprecedent GF

Its main scientific goals will be CR physics at the knee above the PeV

It can become the only space-borne high energy γ-ray detector

Detailed design compromise between conflicting requirements

Possibilities of covering lower (sub GeV) γ-ray physics are under study