HERD

High Energy cosmic-Radiation Detection facility onboard China's Space Station

G. Ambrosi
INFN Perugia

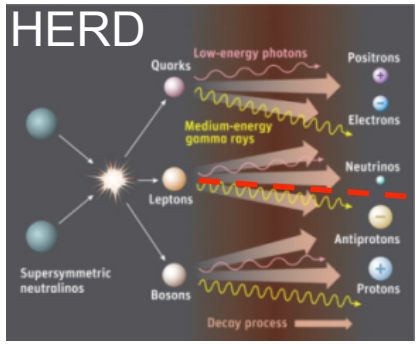
China's Space Station Program

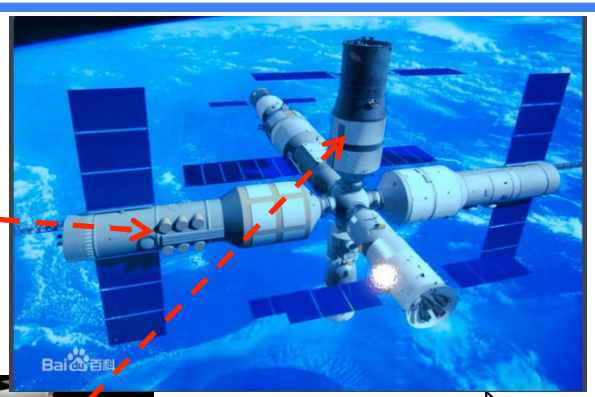
2022 — Phase -II

2018 — Phase -II

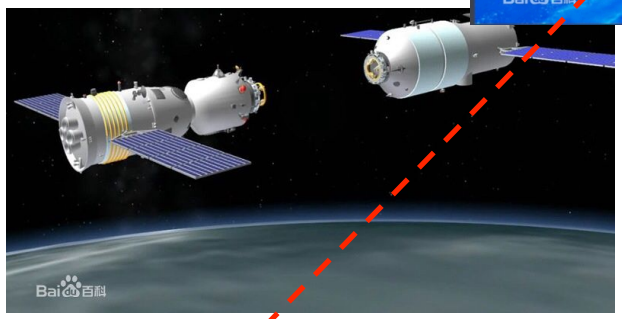
2011 — Phase -I

2003

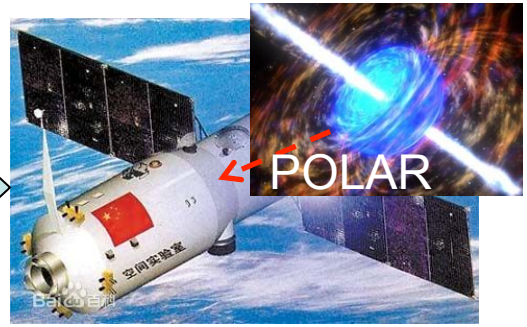


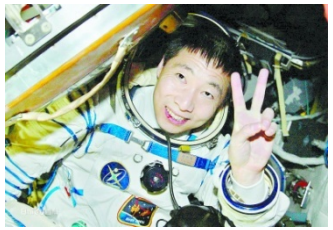


Space Station
3 large modules
+ 2 m telescope
~10-year lifetime



Space lab:
no living cabin





10 astronauts in 5 flights → space walk

China's Space Station Astronomy Program

e/CR

HERD

γ-ray

POLAR

NEATER

(a mini XTP but with low-E pol.)

X-ray

ASM

(EP in scanning mode without XFT)

IR/O

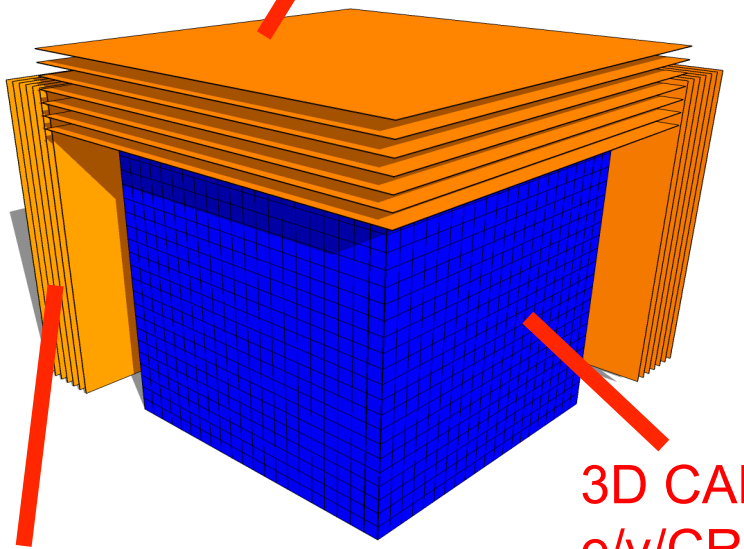
Chinese Space Station Optical Survey

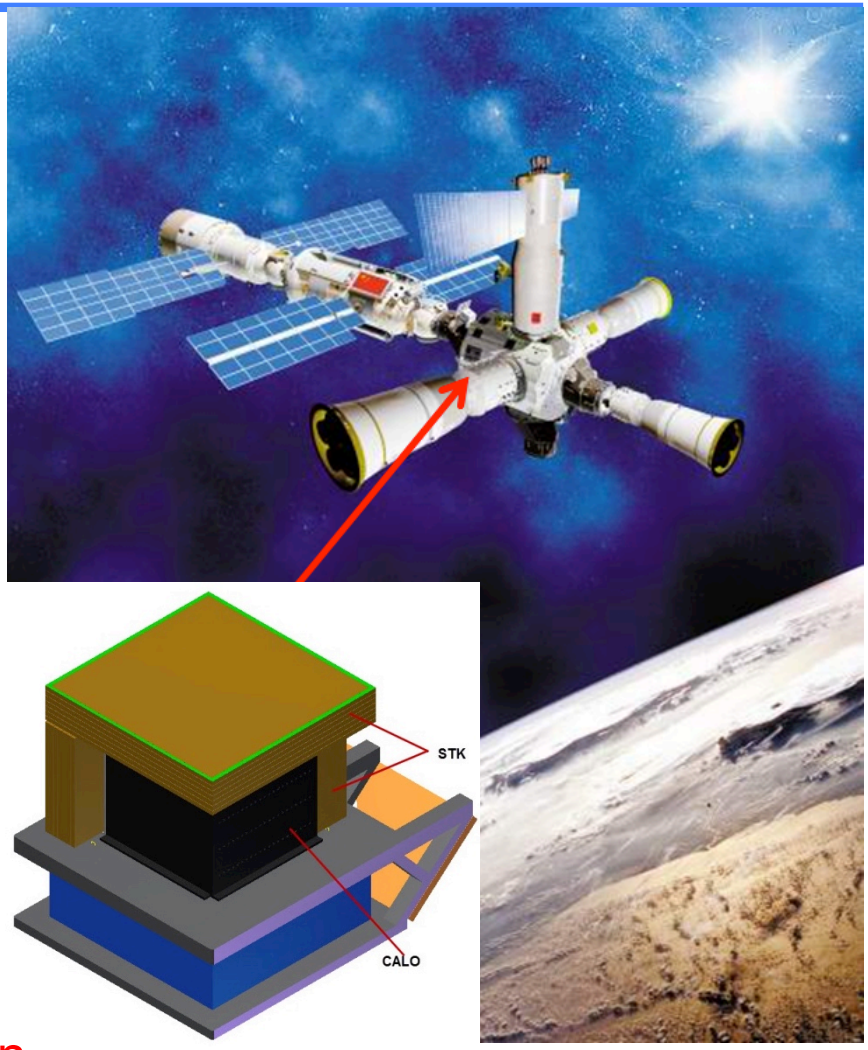
Dark Energy

2015 2020 2025 2030

High Energy cosmic-Ray Detector (HERD)

n10X acceptance than others, but weight 2.3 T ~1/3 AMS

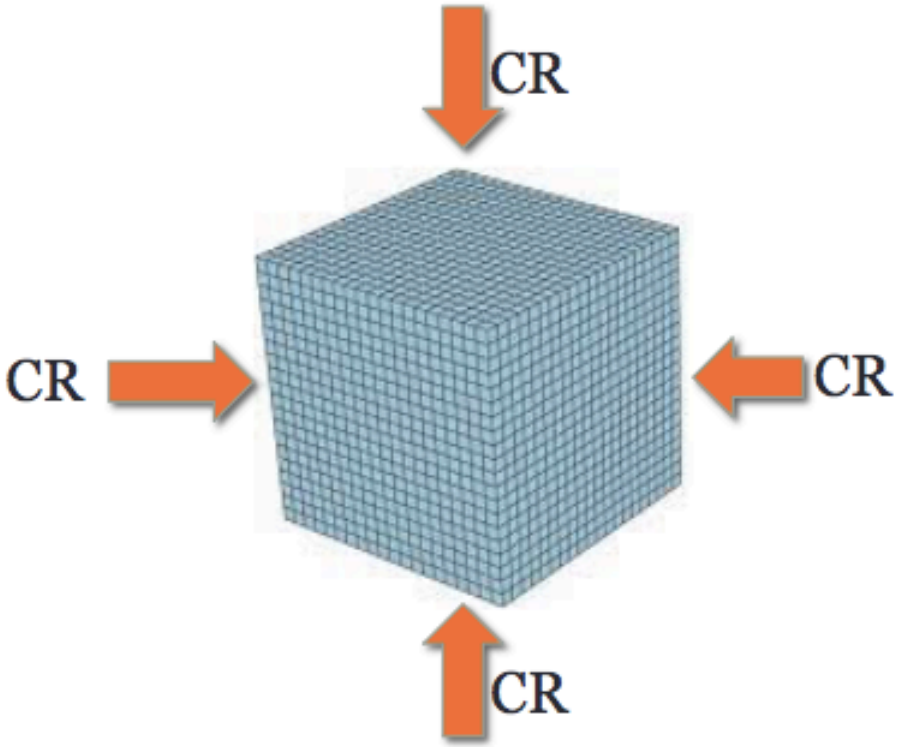




CaloCube (INFN CSN5)

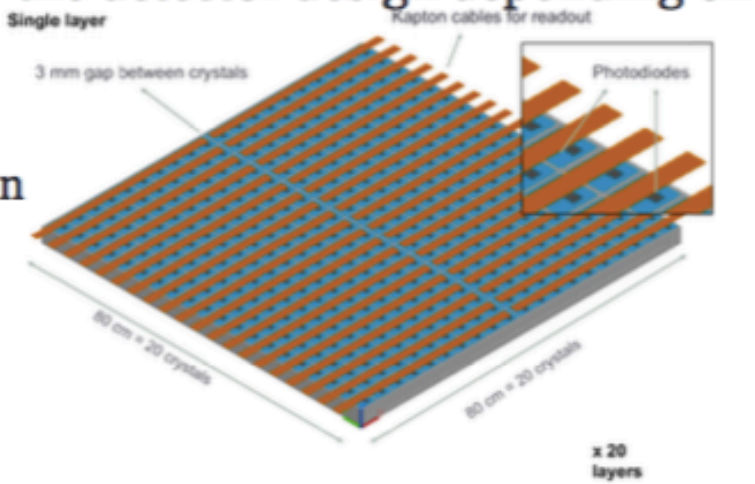
- Exploit the CR isotropy to maximize the effective geometrical factor, by using all the surface of the detector (aiming to reach $\Omega = 4\pi$)

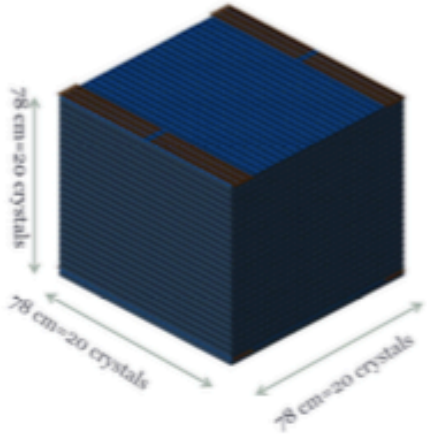
- The calorimeter should be highly isotropic and homogeneous



The basic ideas of the CaloCube project

- **An homogeneus, deep, isotropic calorimeter**
  - can accept events from all sides → ~GF * 6
  - segmentation in every direction gives e/p rejection power by means of topological shower analysis
  - small size (~Molière radius) scintillating crystals for homogeneity
  - gaps between crystals increase GF and can be used for signal readout
    - small degradation of energy resolution
  - modularity allows for easy resizing of the detector design depending on the available mass&power
  - dual/multiple readout
    - Improve the hadronic energy resolution
    - Improve the p/e rejection



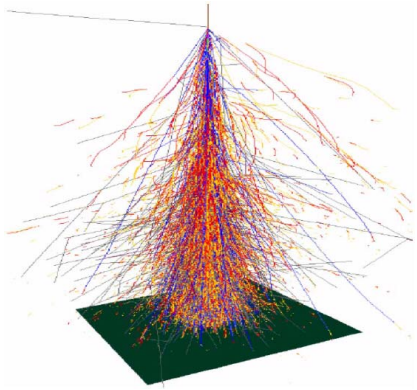


Direct measurements

Requirements:
Calorimetry vs Spectrometry
Large acceptances
<30% 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:
Very poor mass resolution
Intrinsically limited by systematics
Give many hints but few answers

What we have

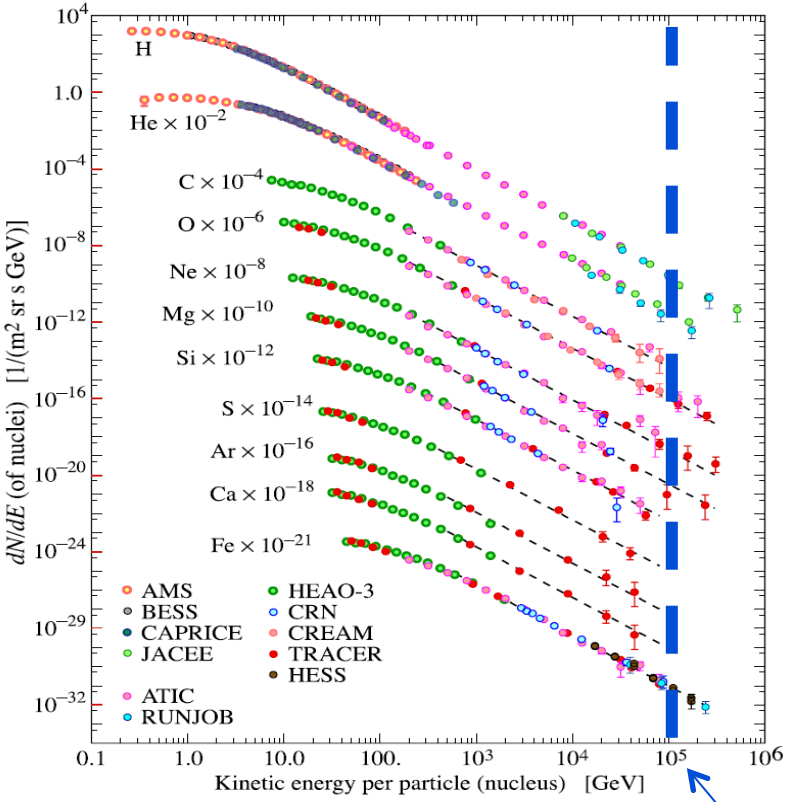
(from PDG)

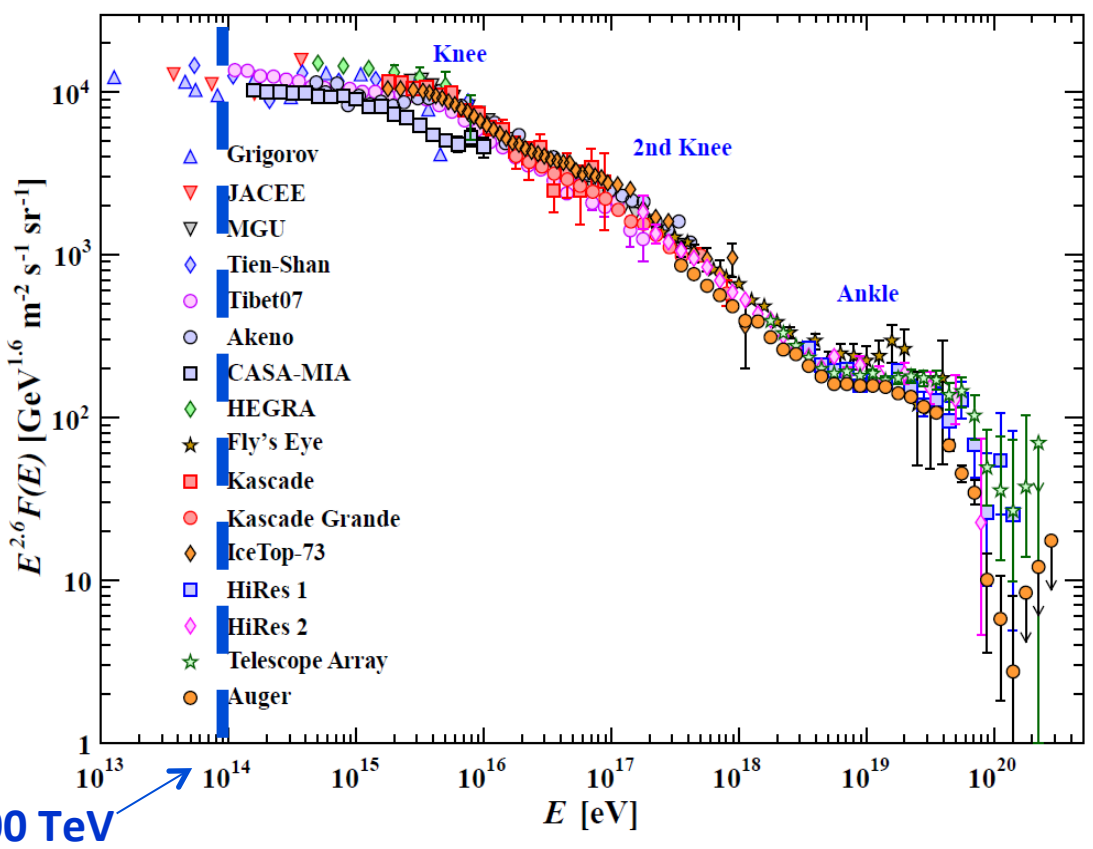
Direct measurements

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

Indirect measurements

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



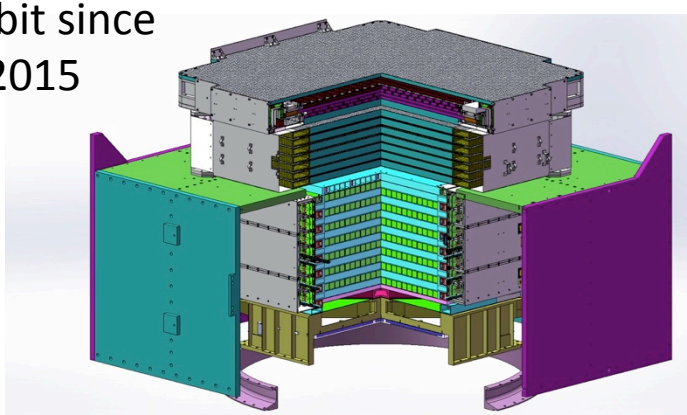


100 TeV

‘usual’ detectors

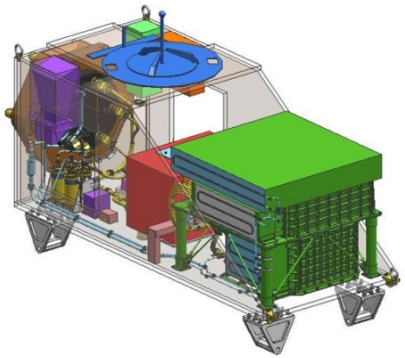
DAMPE

In orbit since dec 2015



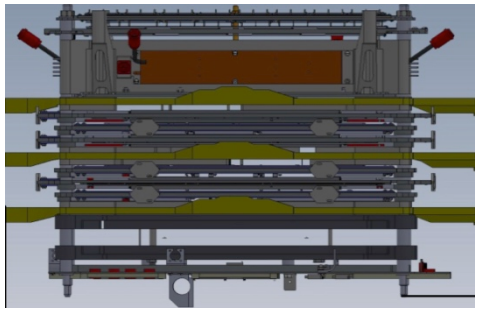
CALET

on the ISS since August 2015



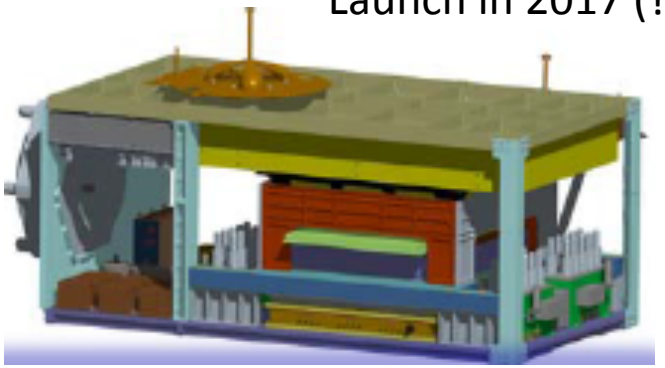
NUCLEON

In orbit since dec 2014



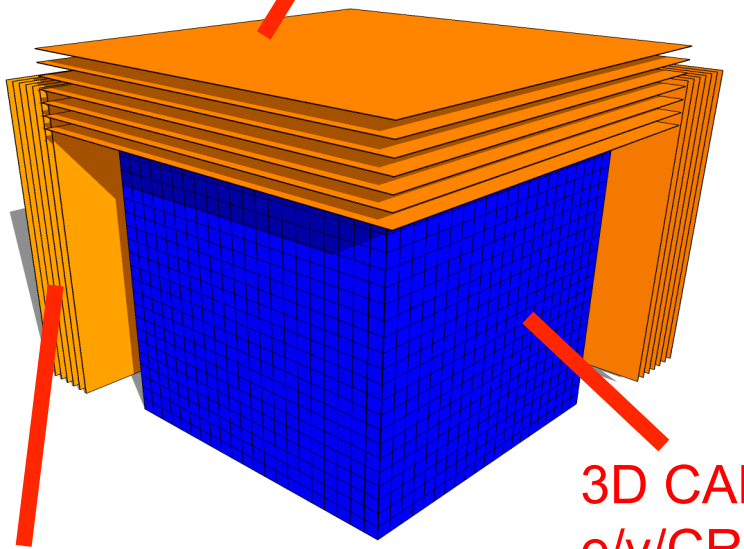
ISS_CREAM

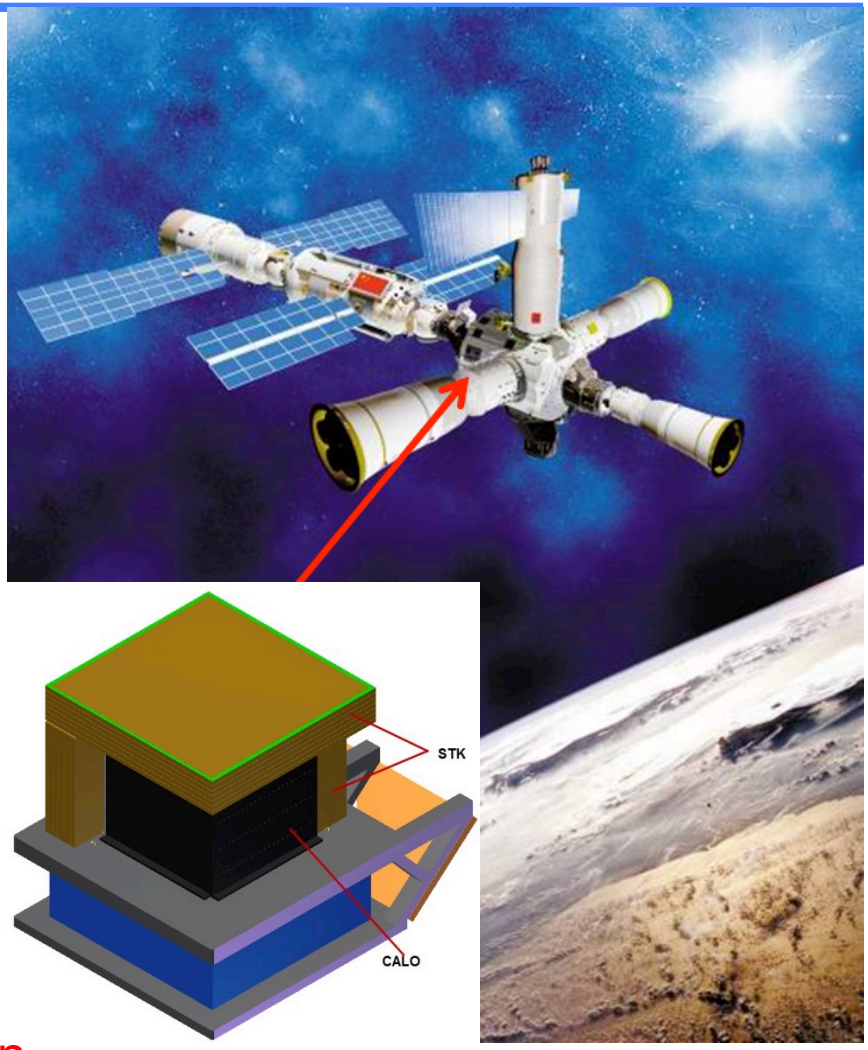
Launch in 2017 (?)



High Energy cosmic-Ray Detector (HERD)

n10X acceptance than others, but
weight 2.3 T ~1/3 AMS





Planned launch 2022-2025

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

Secondary science: γ-ray astronomy → monitoring of GRBs, microquasars, Blazars and other transients → down to 100 MeV for γ -rays → plastic scintillator shields for γ -ray selection

*complementary to high altitude cosmic-ray observations

Characteristics of all components

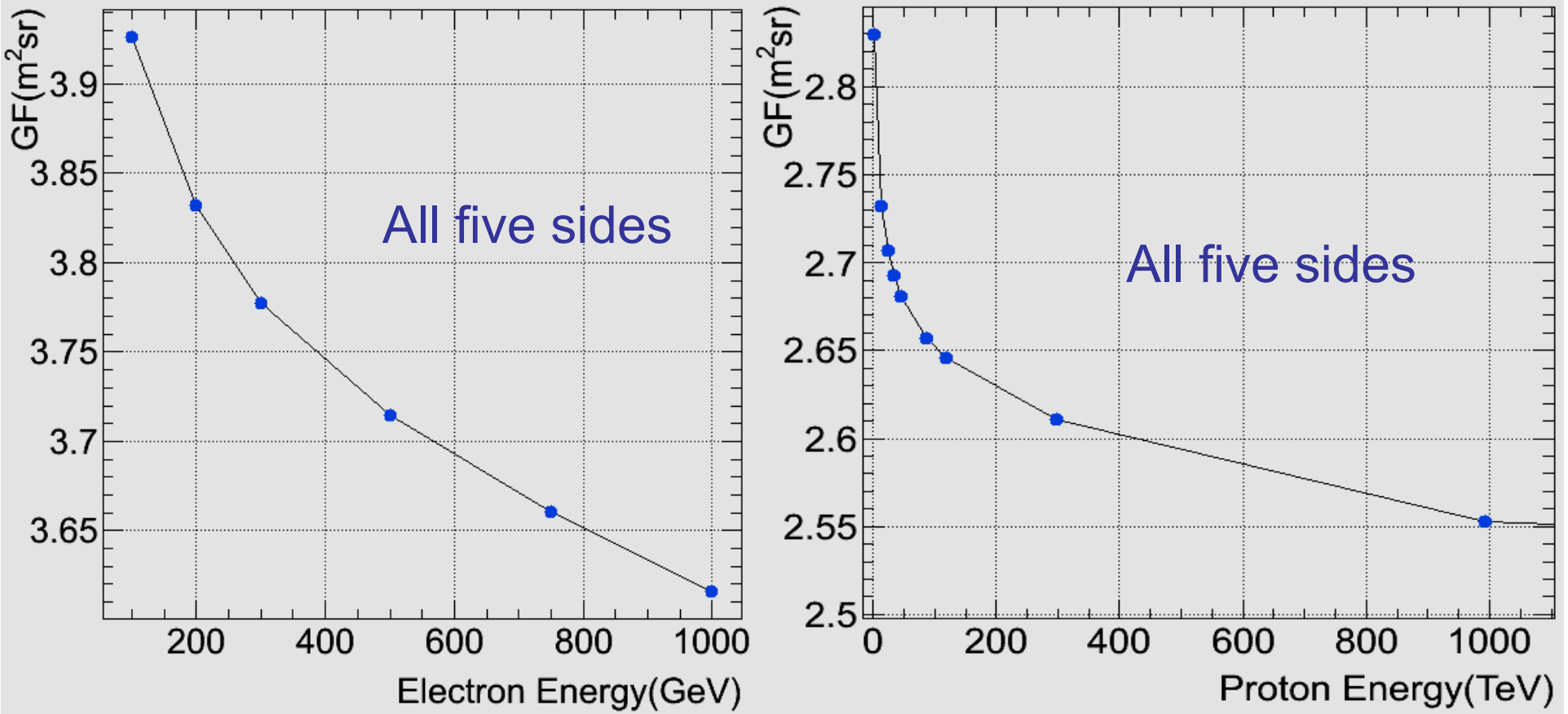
	type	size	X0,λ	unit	main functions
tracker (top)	Si strips	70 cm × 70 cm	2 X0	7 x-y (W foils)	Charge Early shower Tracks
tracker 4 sides	Si strips	65 cm × 50 cm	2 X0	7 x-y (W foils)	Charge Early shower Tracks
CALO	~10K LYSO cubes	63 cm × 63 cm × 63 cm	55 X0 3 λ	3 cm × 3 cm × 3 cm	e/γ energy nucleon energy e/p separation

Total detector weight: ~2000 kg

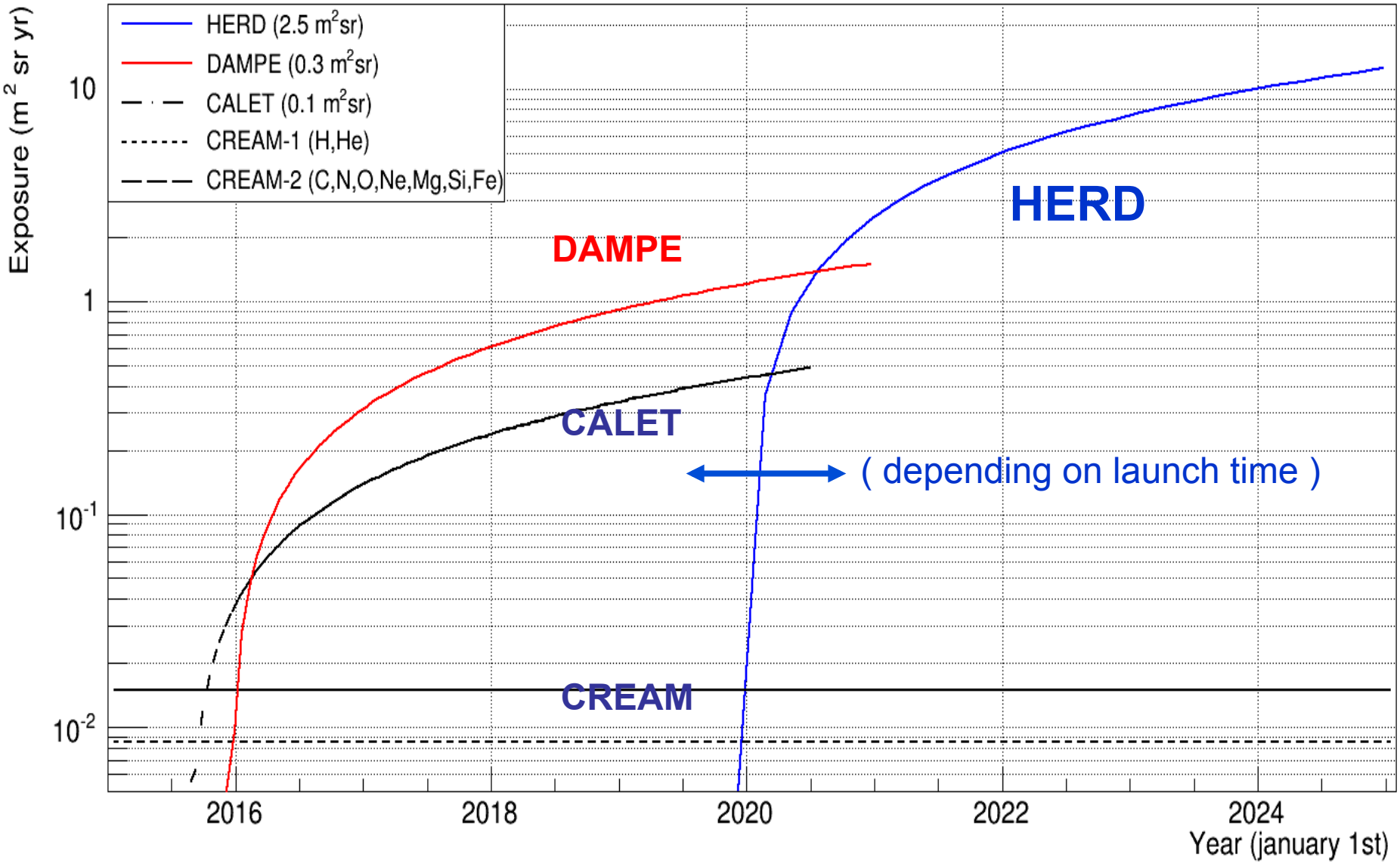
Expected performance of HERD

γ/e energy range (CALO)	tens of GeV-10TeV
nucleon energy range (CALO)	up to PeV
γ/e angular resol.	0.1°
nucleon charge resol.	0.1-0.15 c.u
γ/e energy resolution (CALO)	<1%@200GeV
proton energy resolution (CALO)	20%
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

HERD Eff. Geometrical Factor: CALO

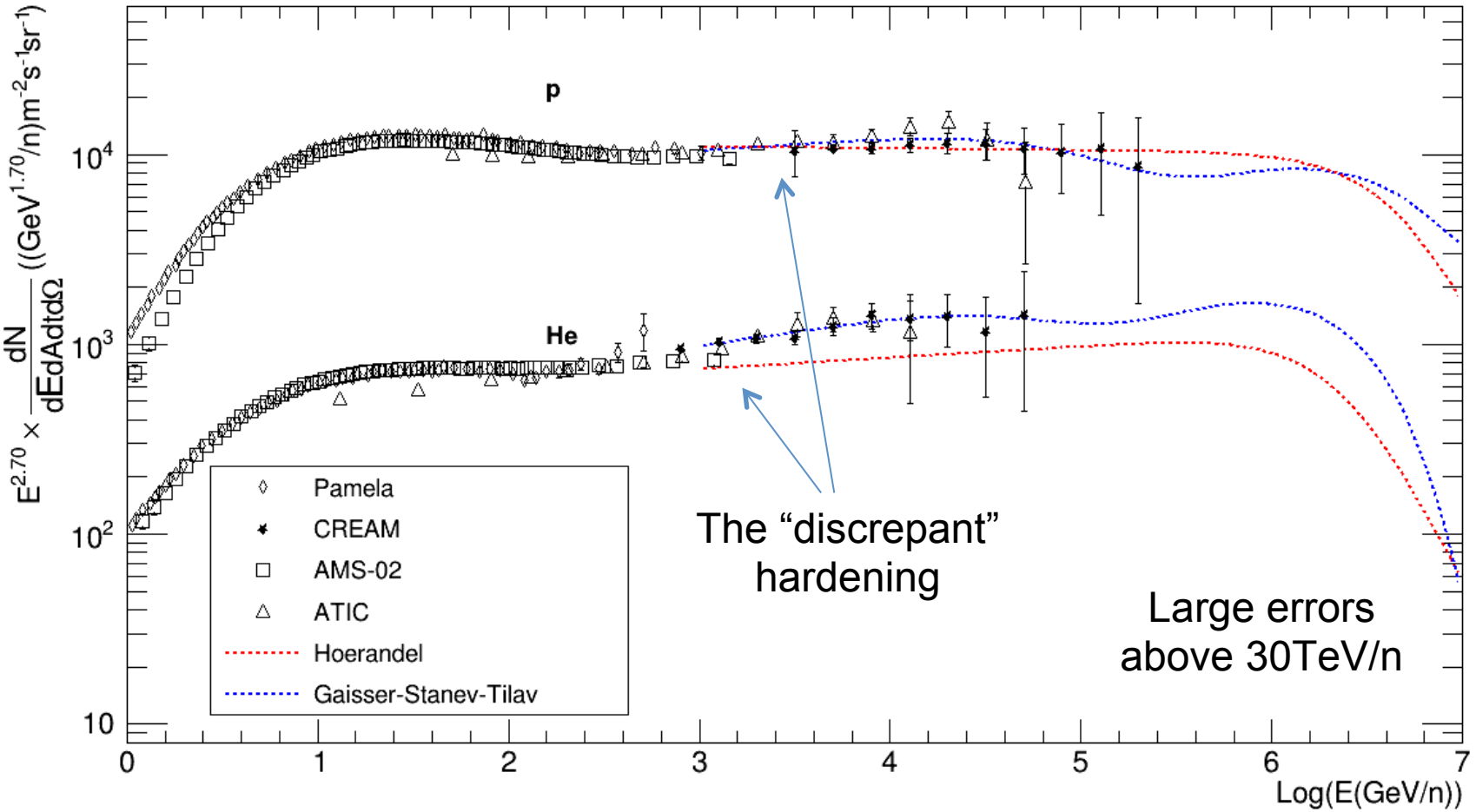


Exposure (assuming GF=2.5m^{2}sr)



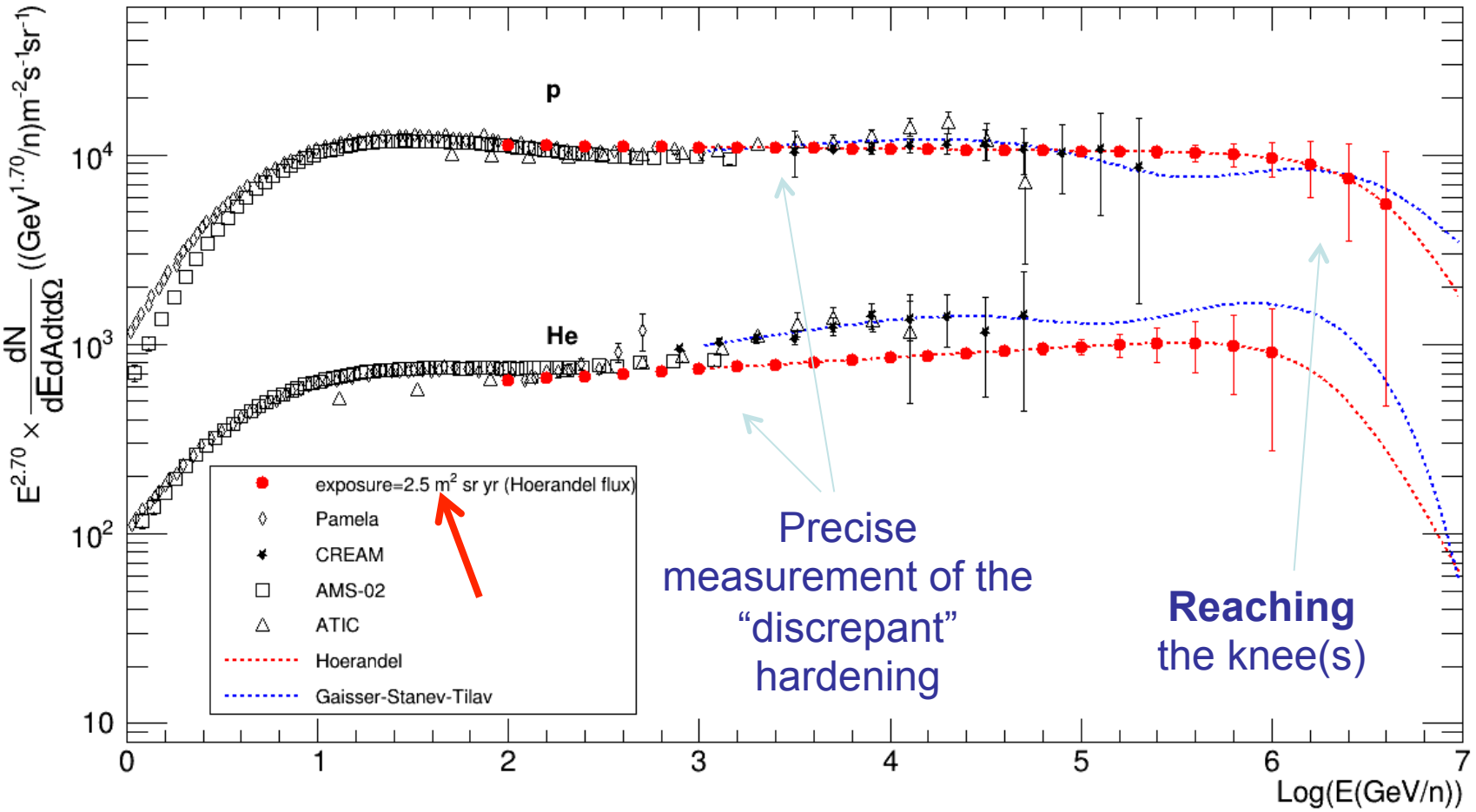
Proton and He Spectra

Existing measurements



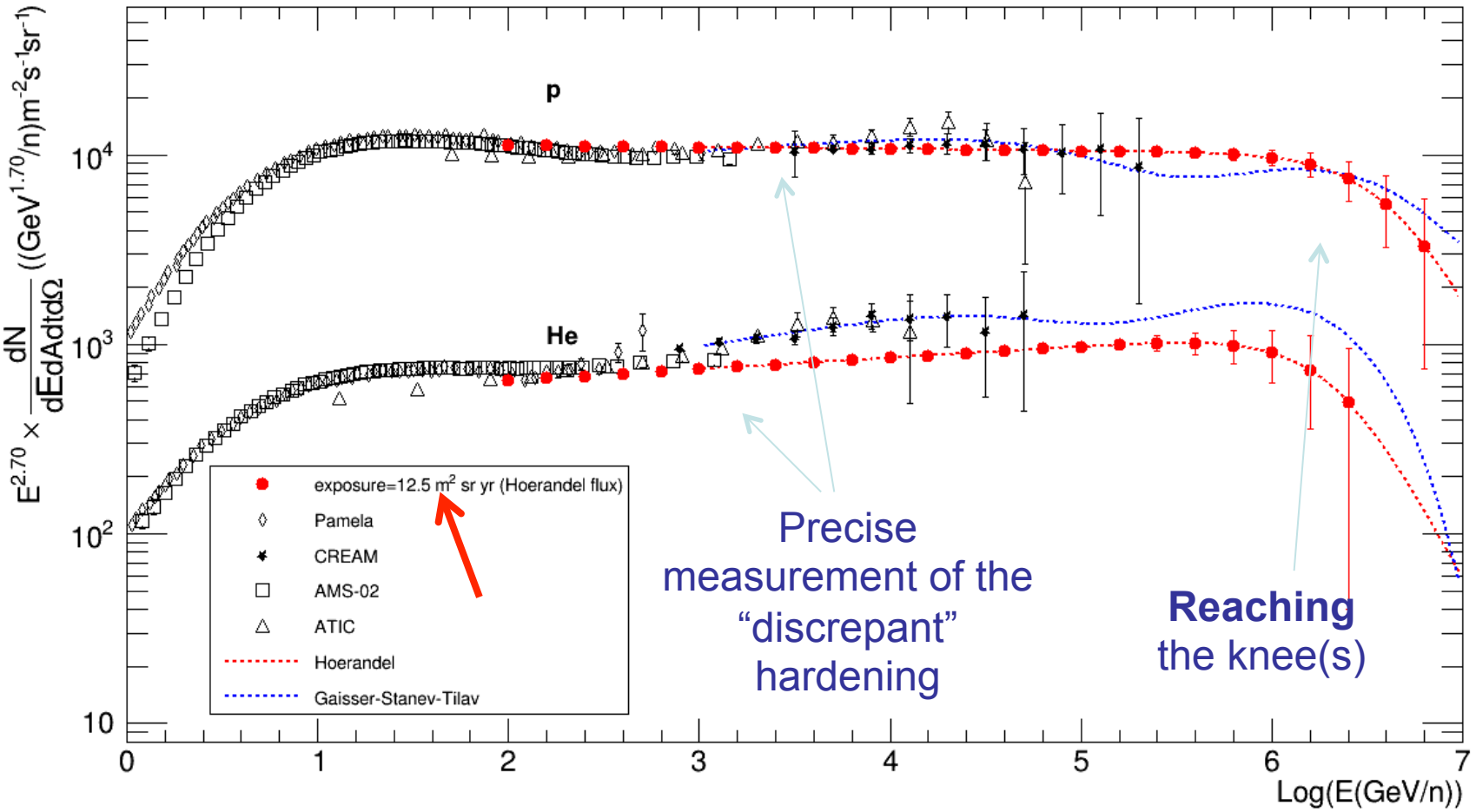
Expected HERD Proton and He Spectra

one year operation



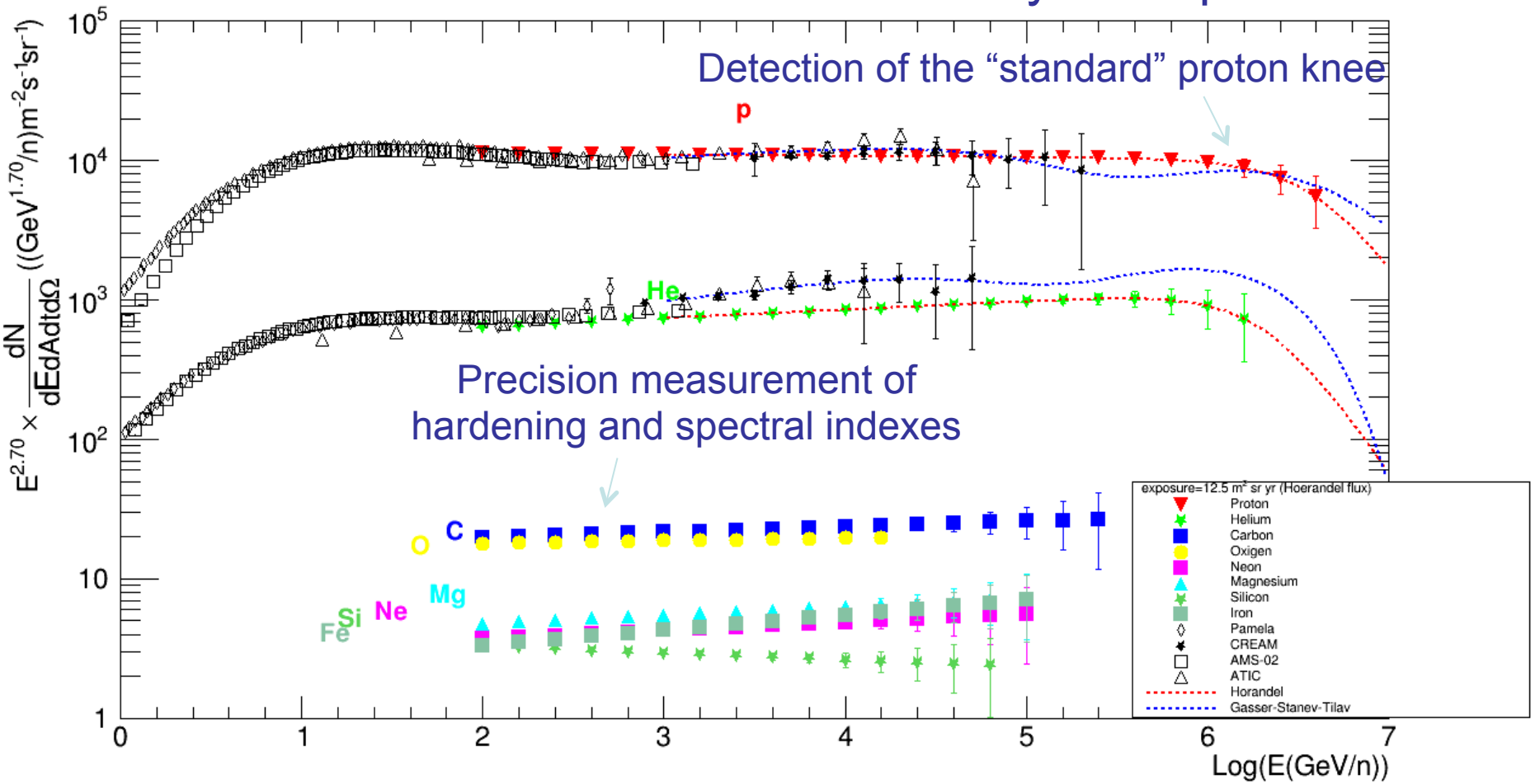
Expected HERD Proton and He Spectra

five years operation



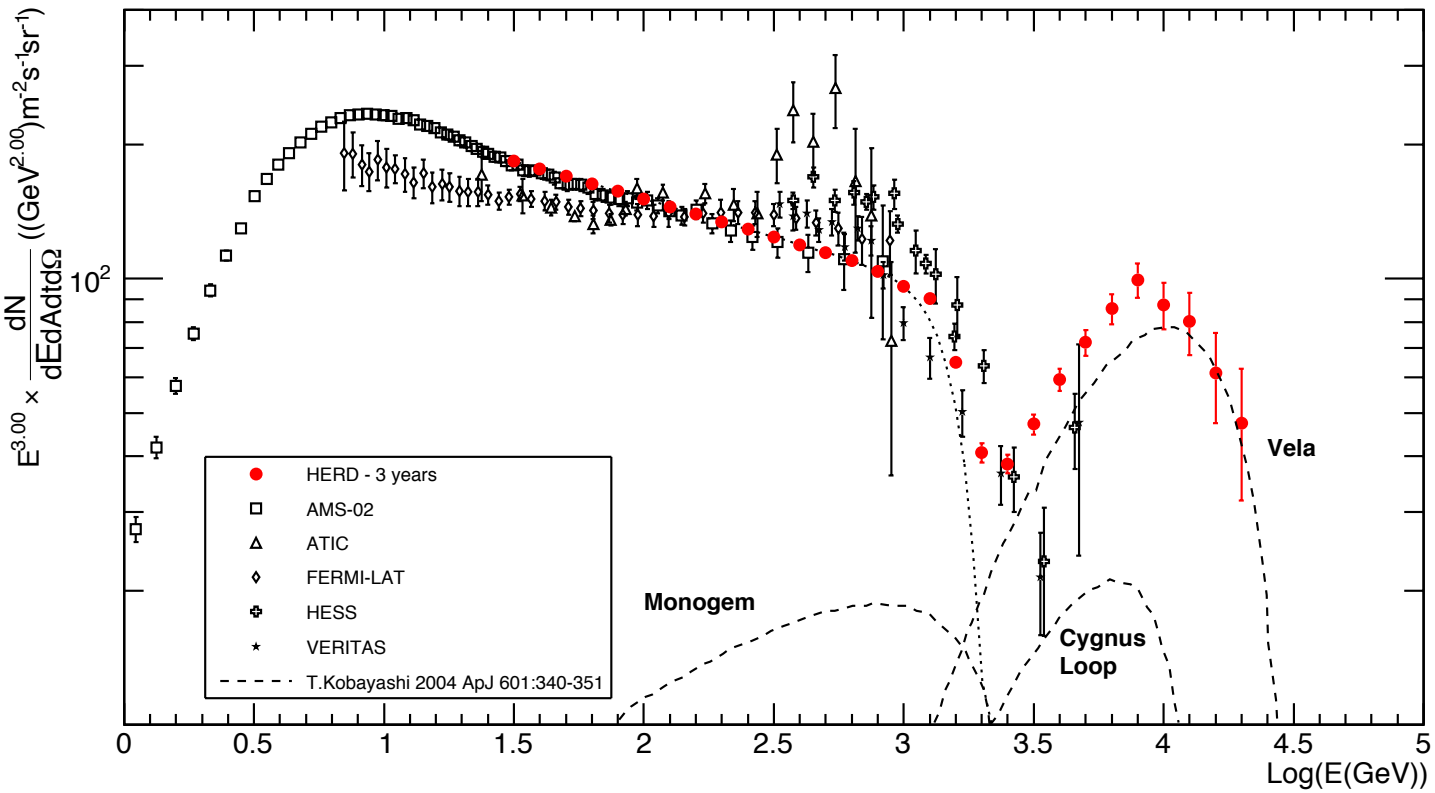
Expected HERD Spectra for ions

five years operation

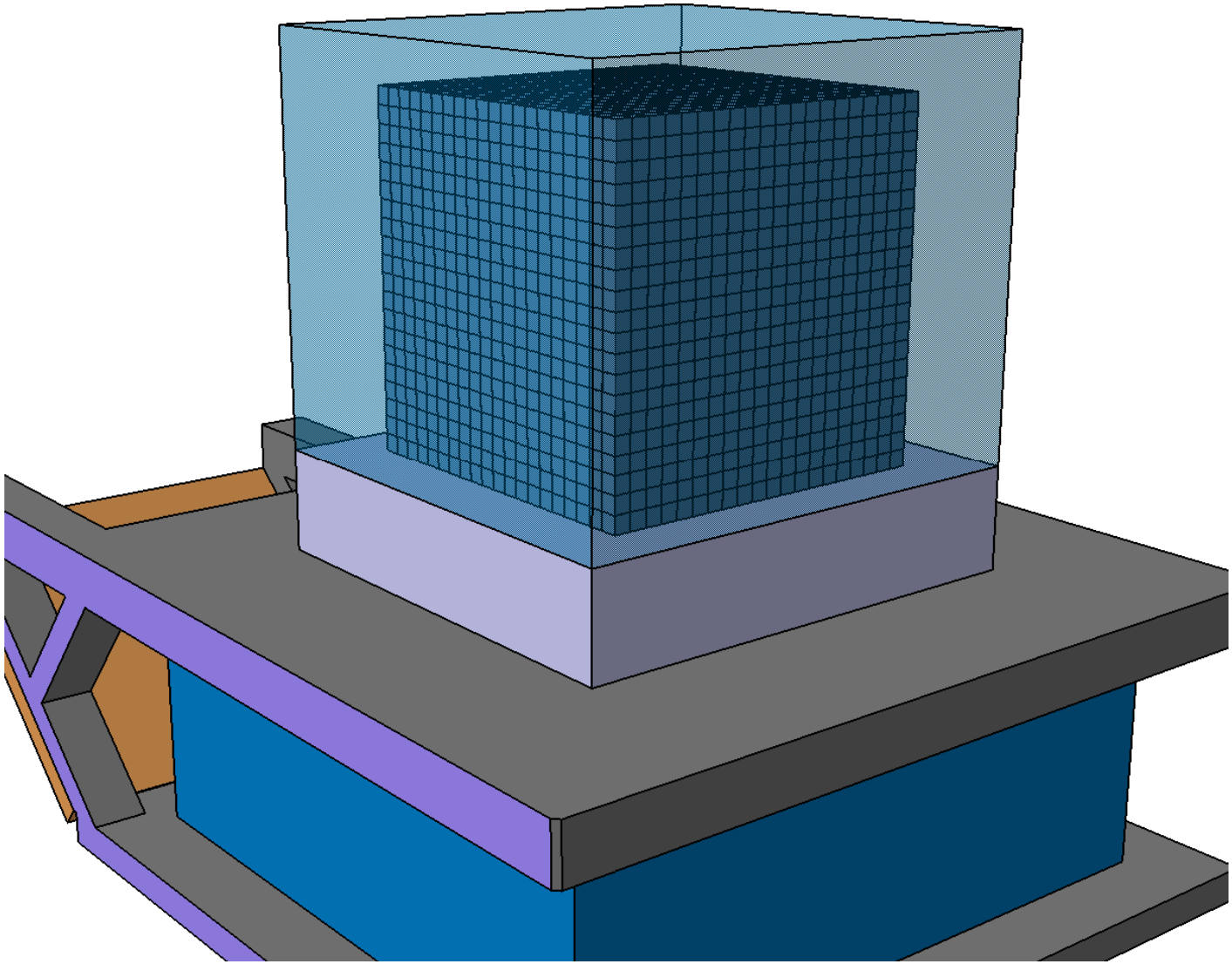


Expected HERD Spectra for electrons

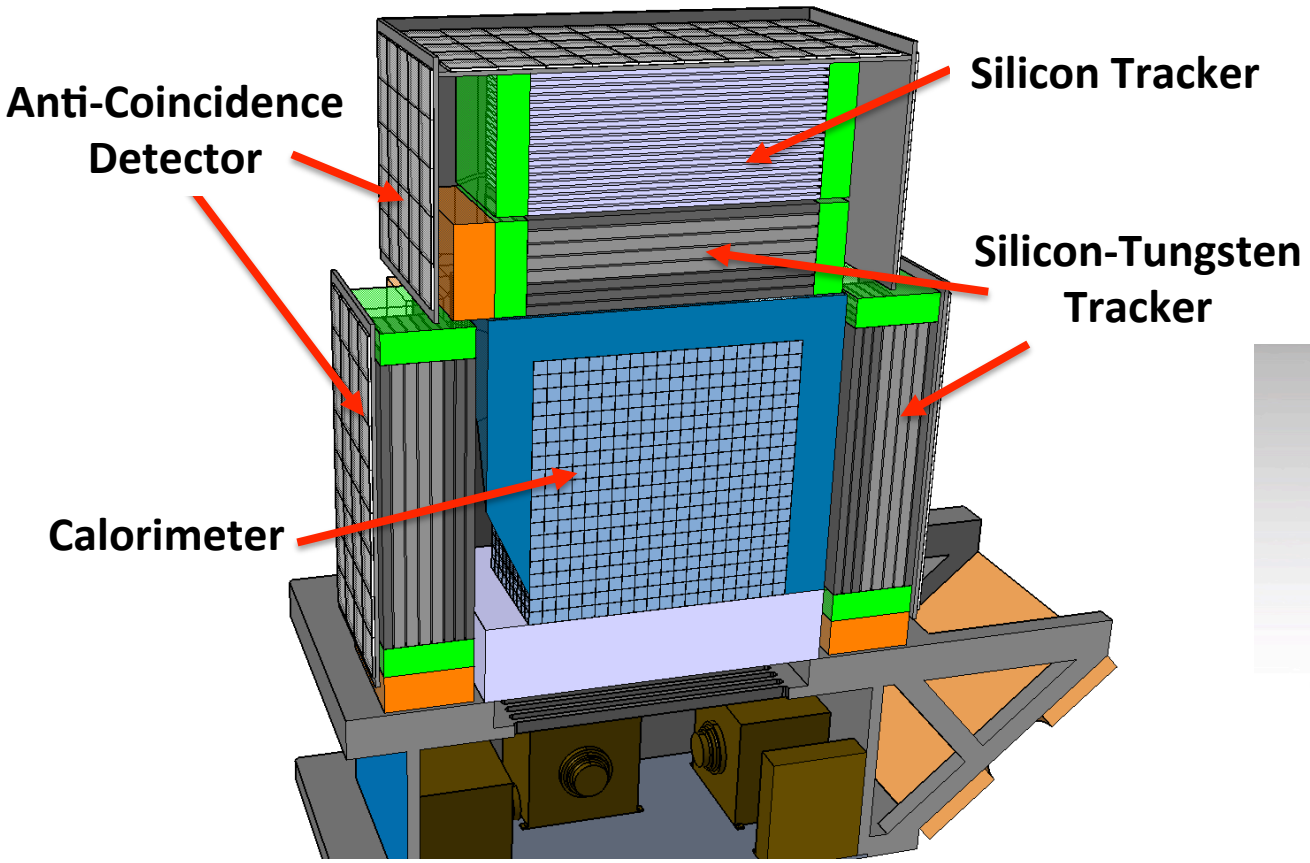
three years operation

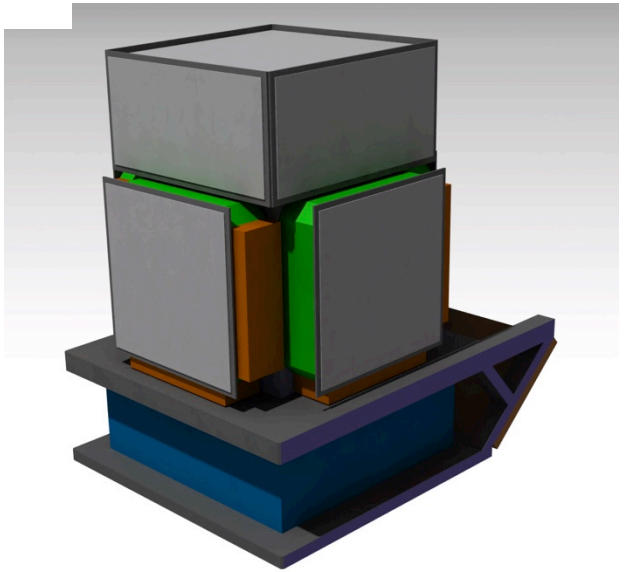


Now to wrap a beautiful gift …



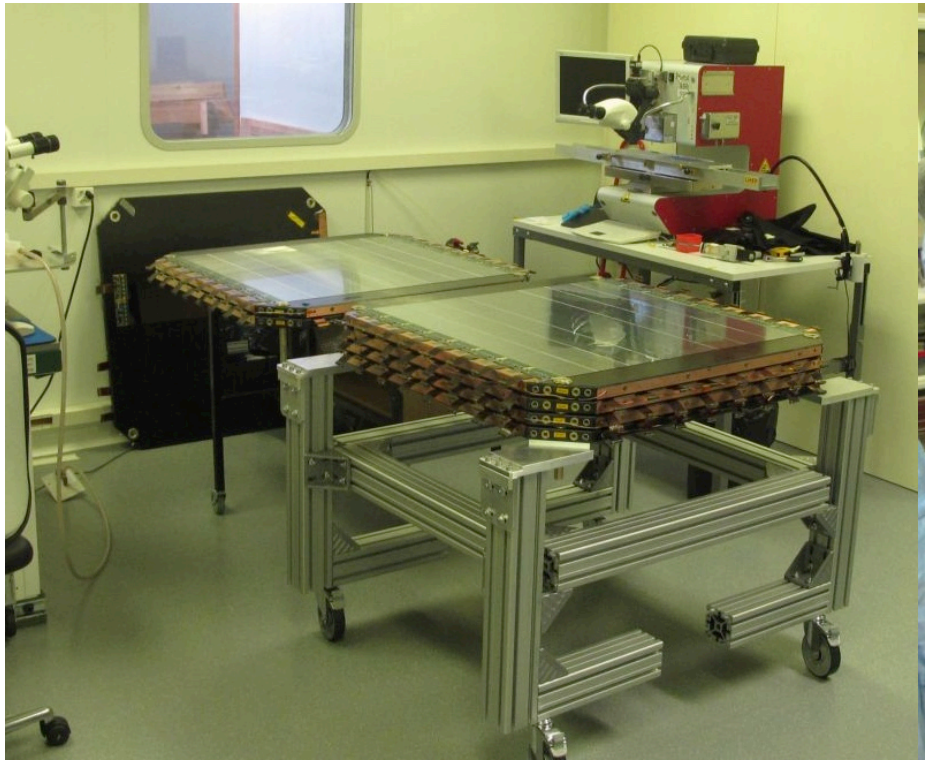
… add the Tracker

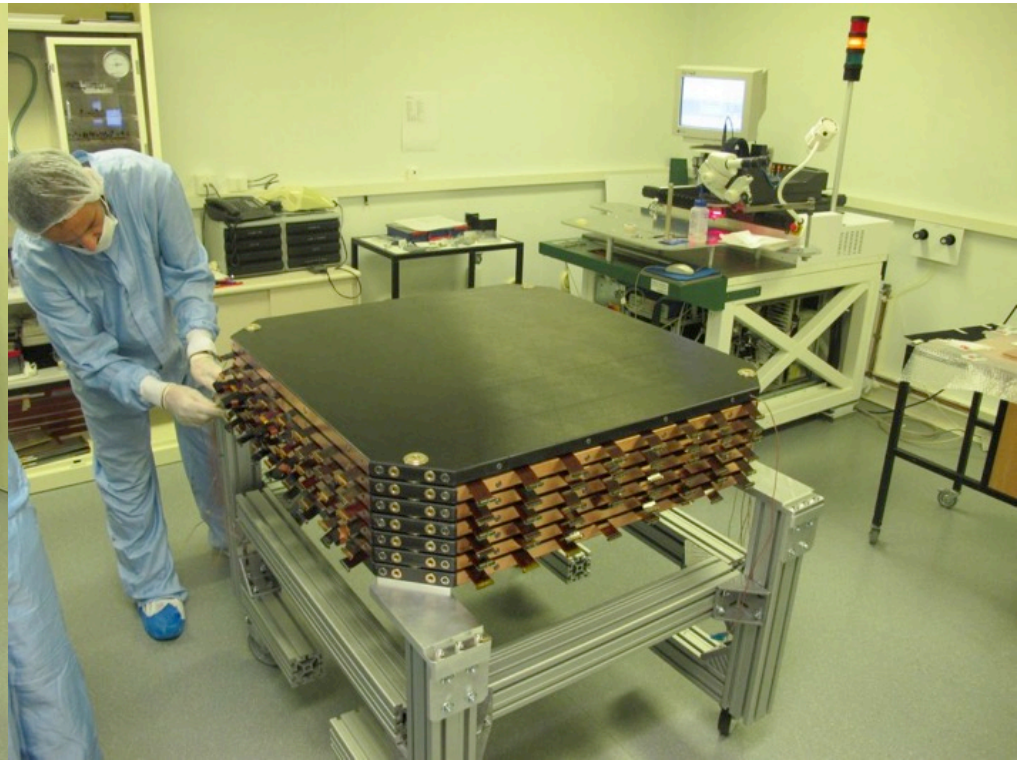




- First try to fit the envelop: 1510×1480×1580 (overall) and 880×834×729 (calorimeter)
  - Very challenging to fit services for a 5-sides outward sensitive detector
  - Simple approach first: 5 identical sides (“DAMPE”) + a light top

an example: the DAMPE STK





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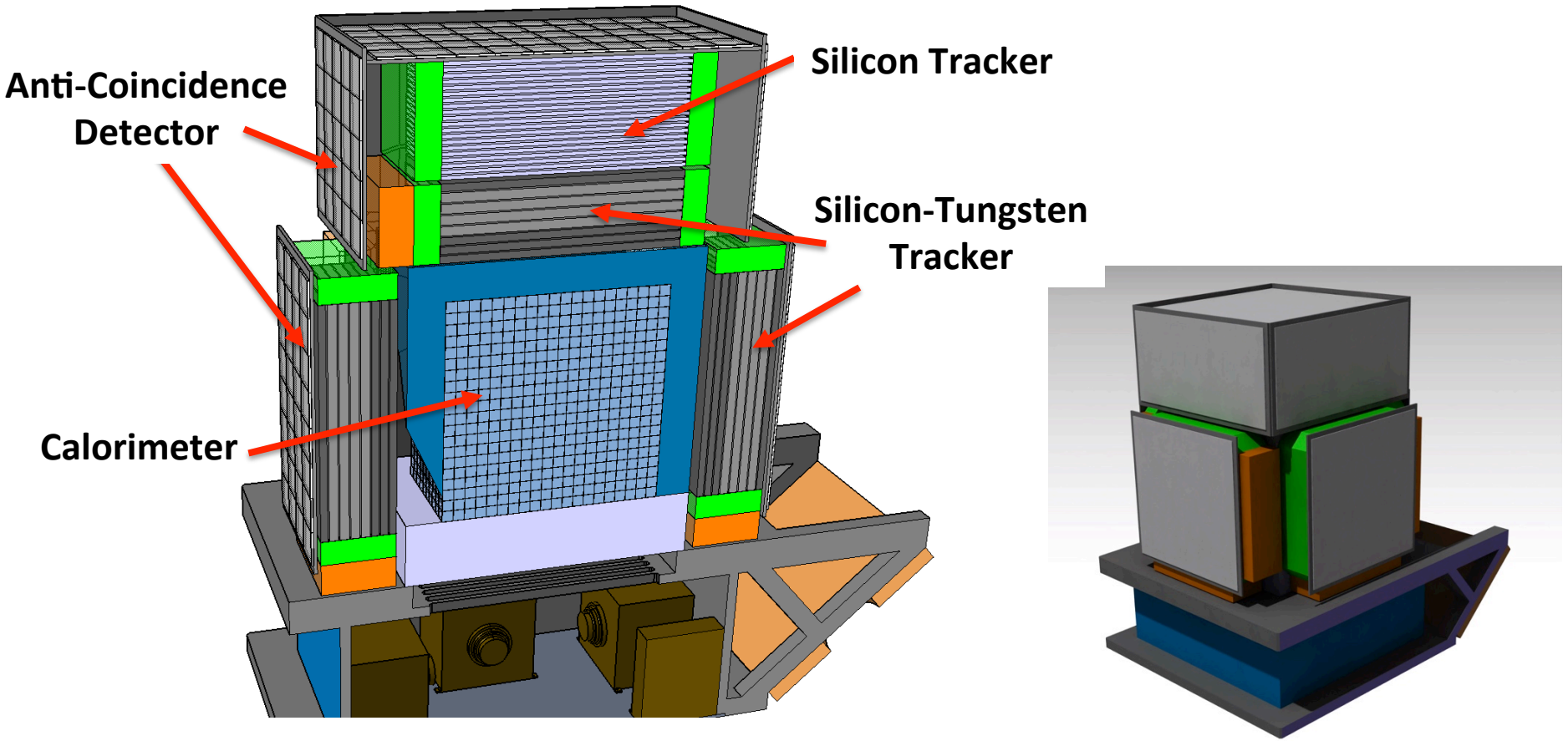

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calo@CERN: beam test Nov. 2015

Final test @ IHEP

HERD beam test @ SPS H4 2015/11

China (hardware+data analysis)

- 1 LYSO array
  - 5*5*10 crystals
- Fibers: 2 ICCD + 2 PMT

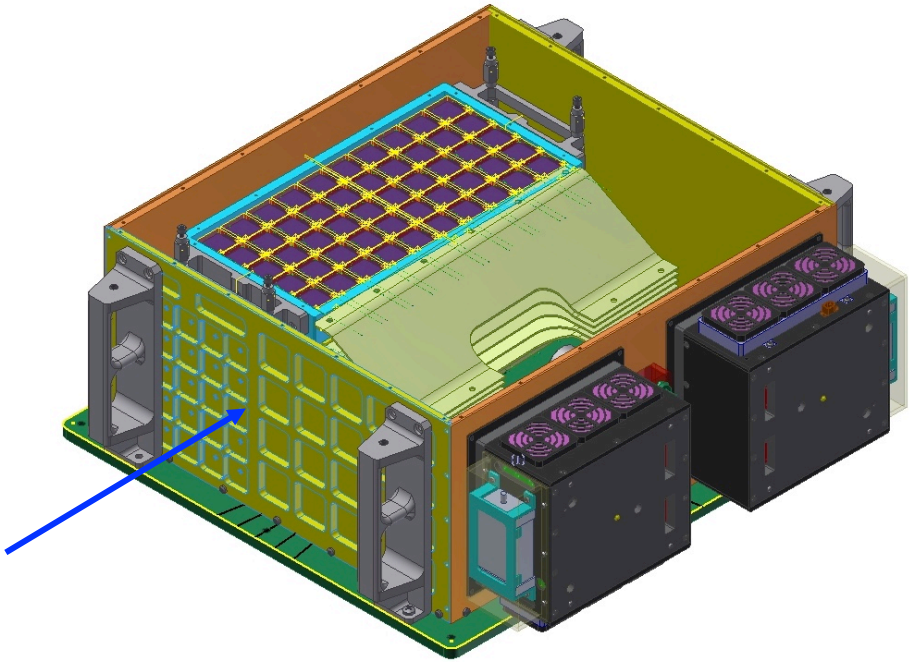
Geneva: beam ccordination

Italy (hardware+data analysis)

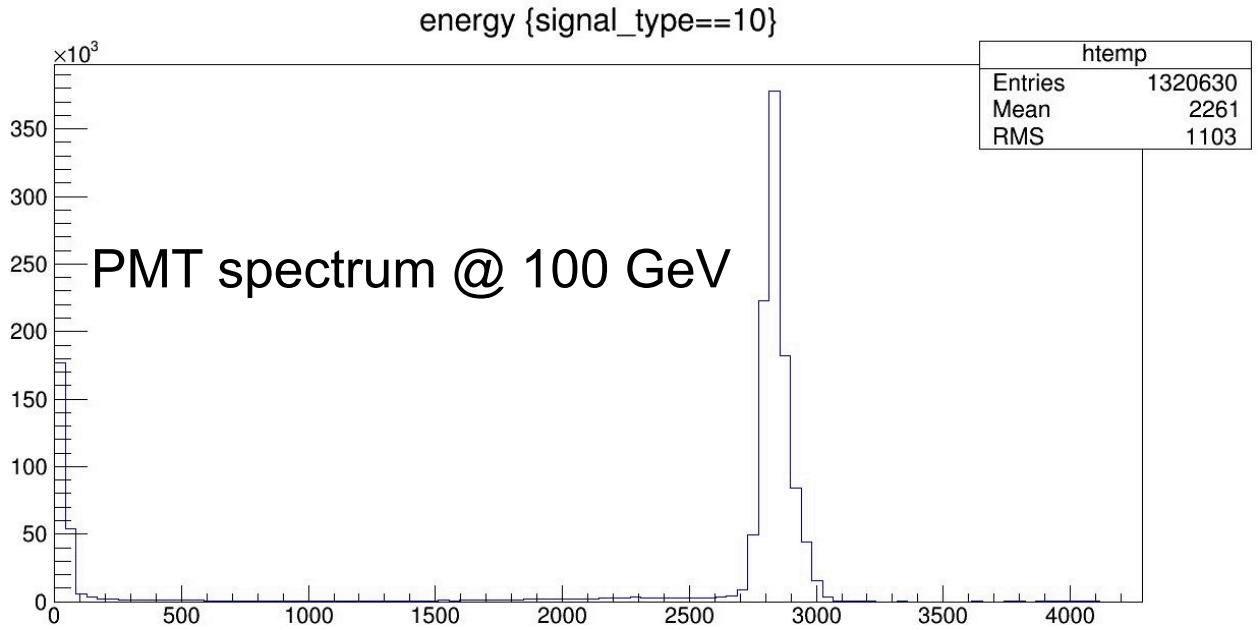
- Silicon microstrip tracker
- Plastic scintillator trigger

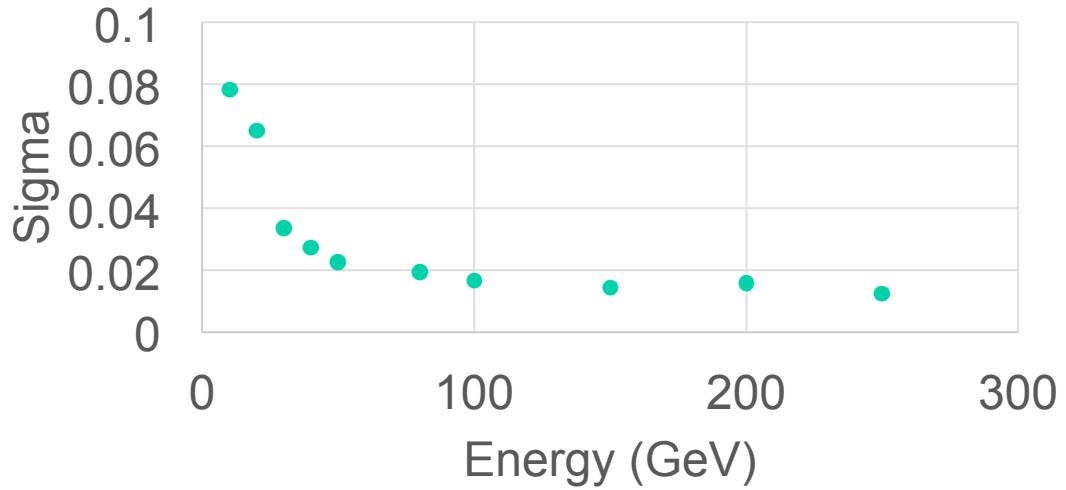
Conclusion: success

- ICCD performance: OK
- Energy resolution: OK
- Dynamic range: ~OK
- Improved design started

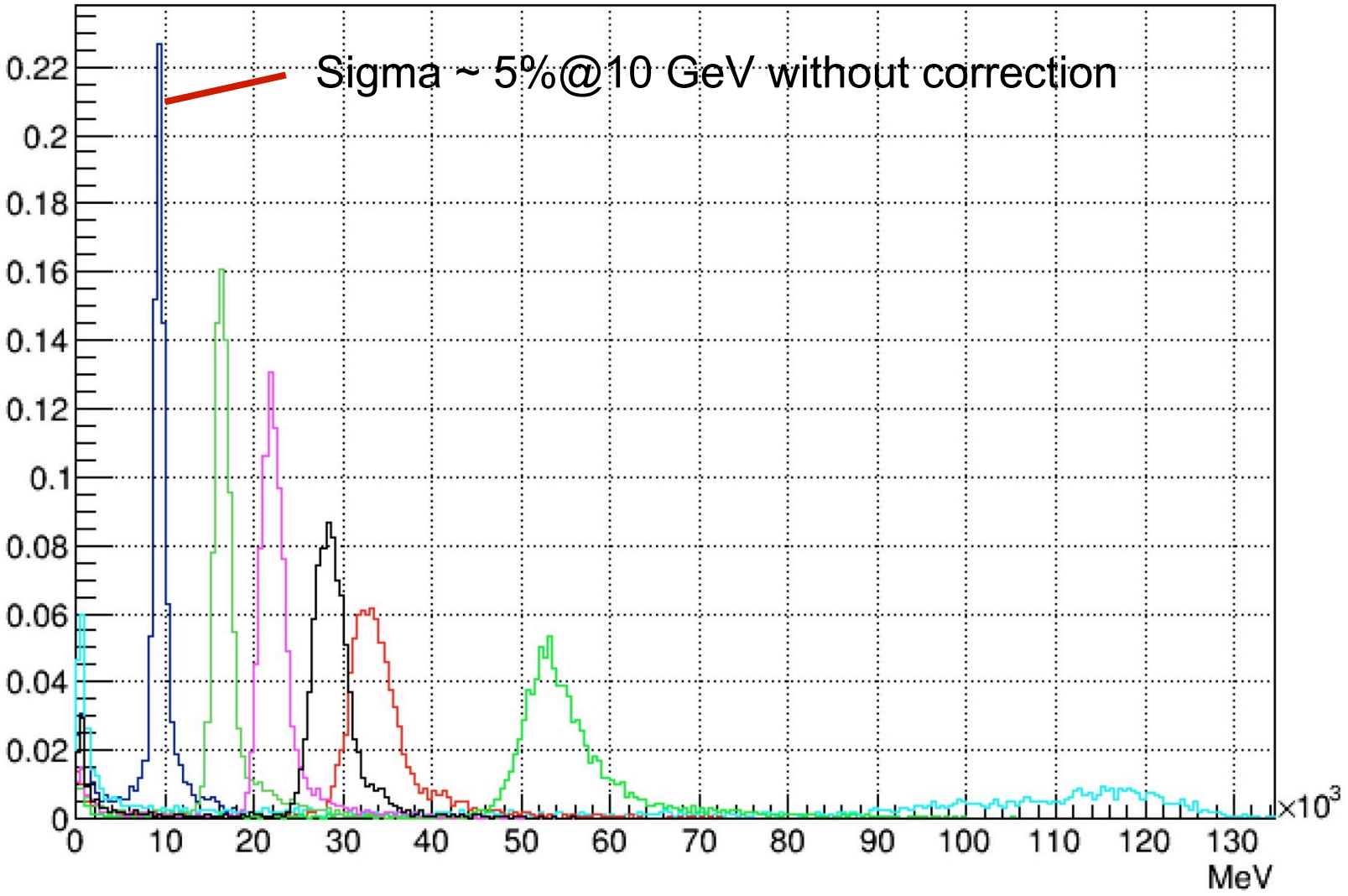


Preliminary result – PMT readout

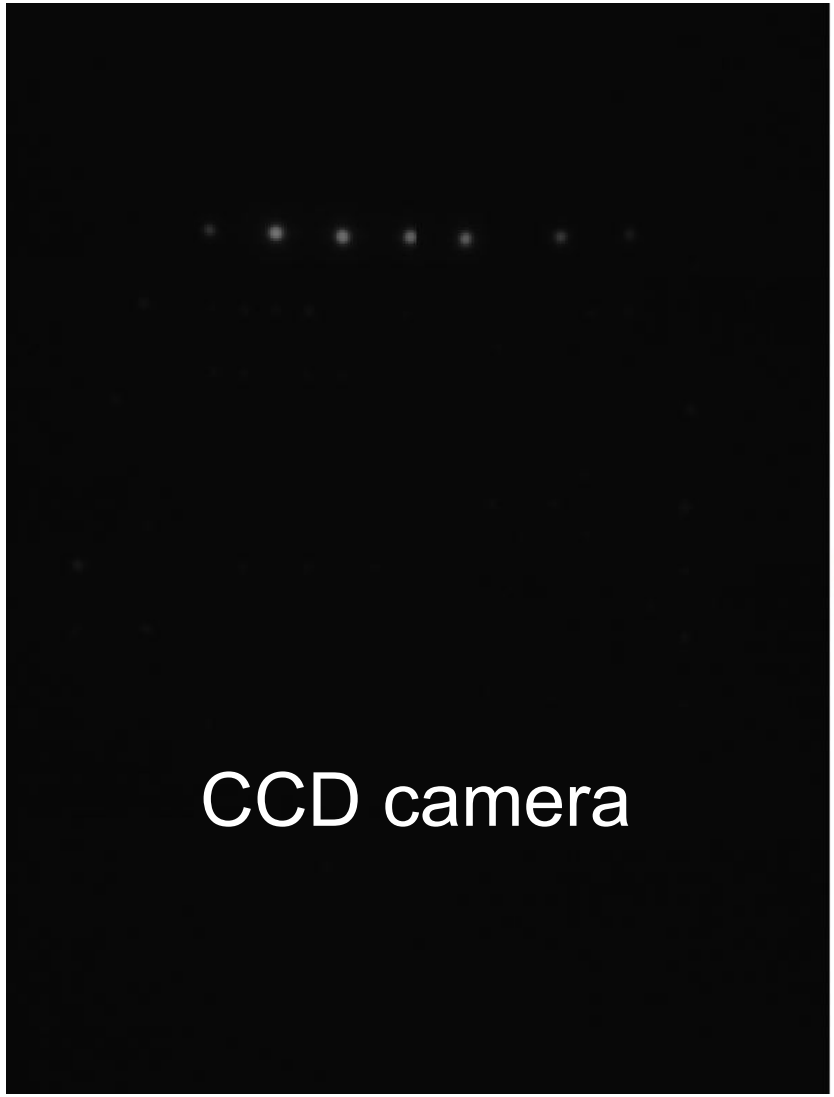


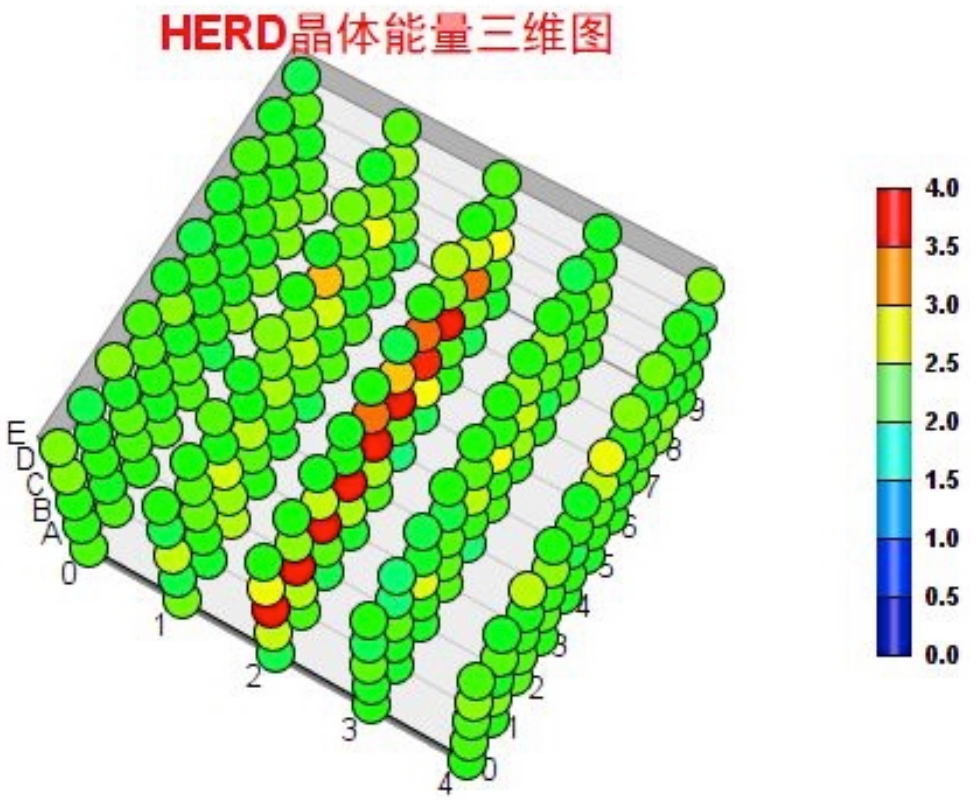


Preliminary result – ICCD low range readout



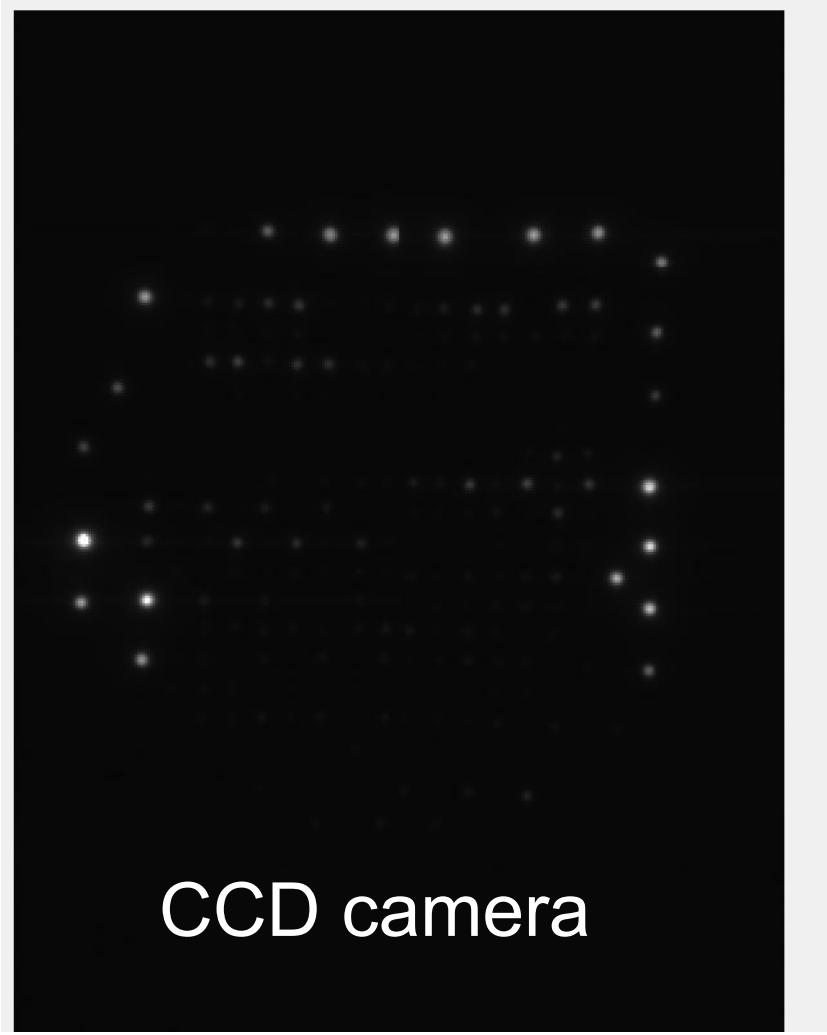
20 GeV electron shower

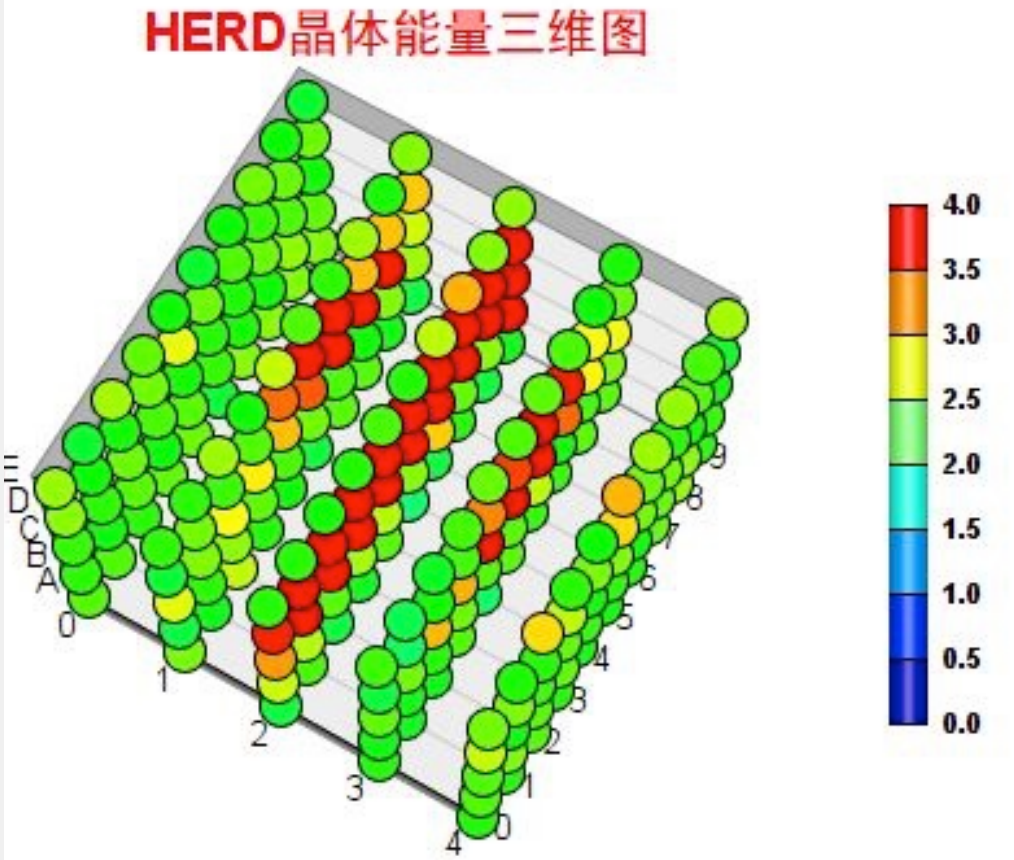




3D shower

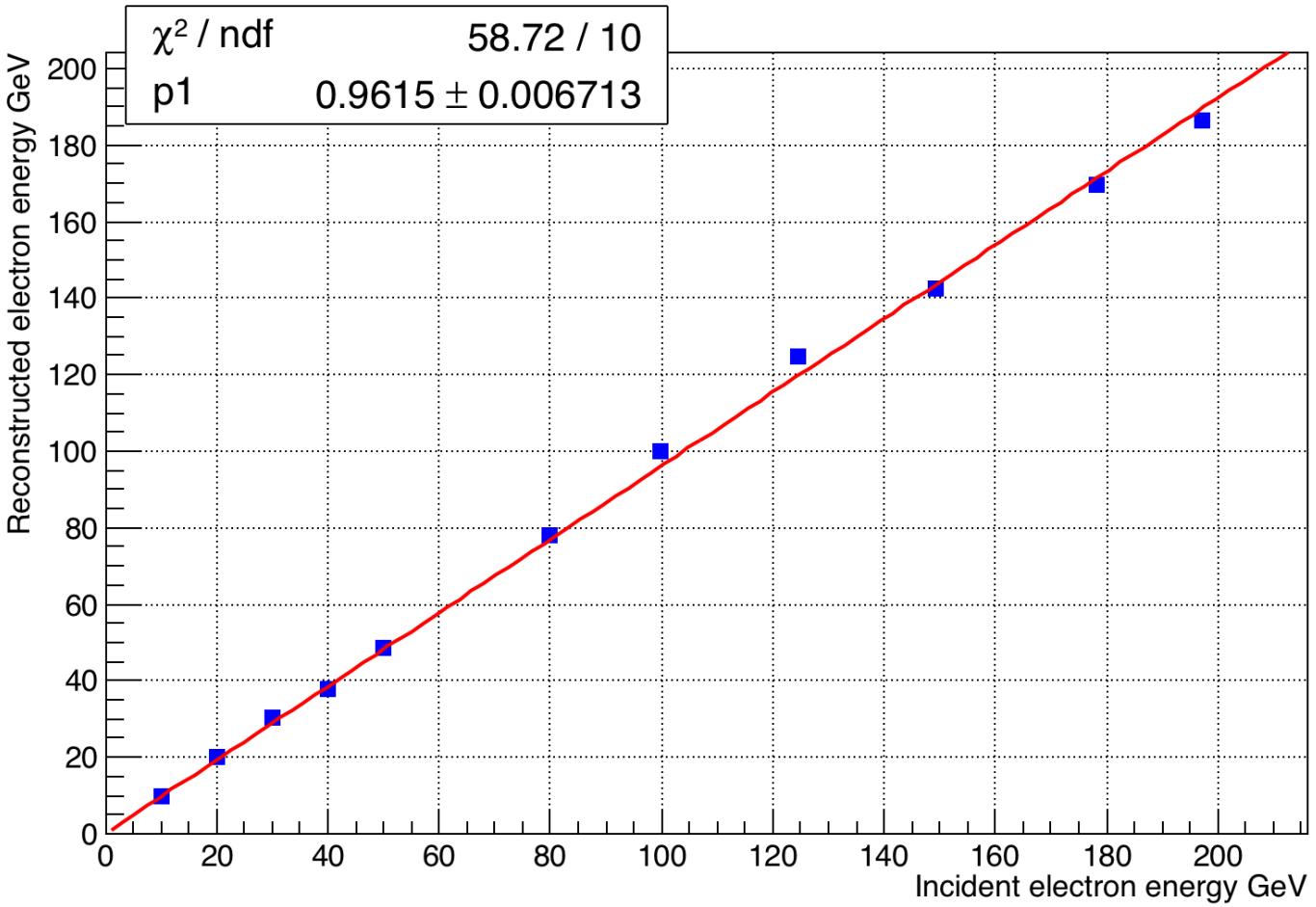
250 GeV electron shower





3D shower

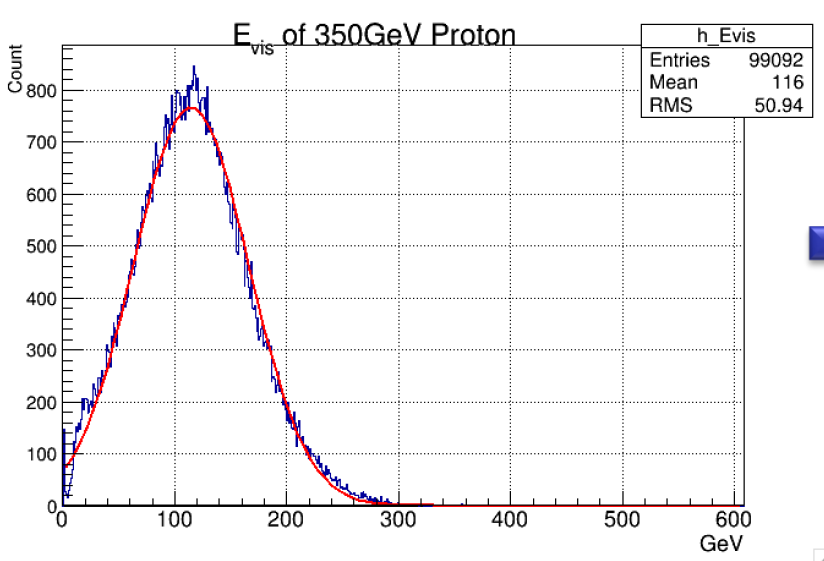
Electron energy

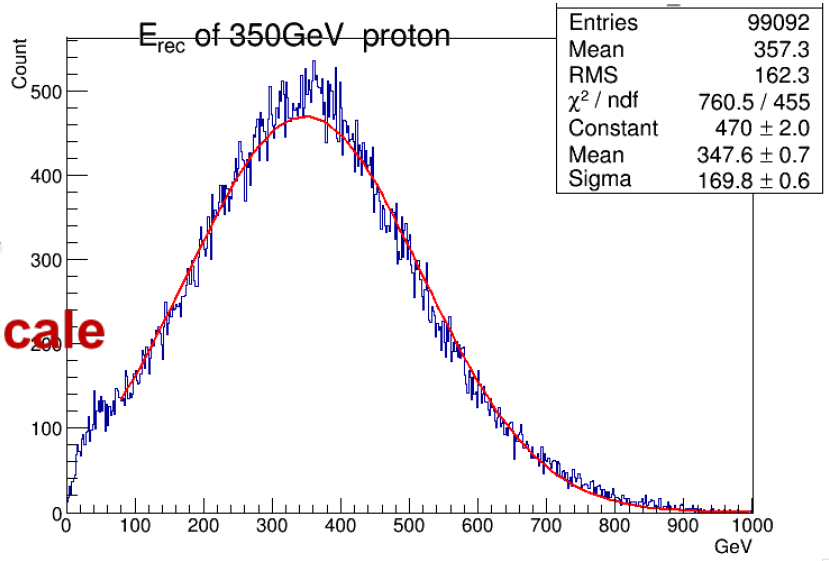


Proton

Event Selection:

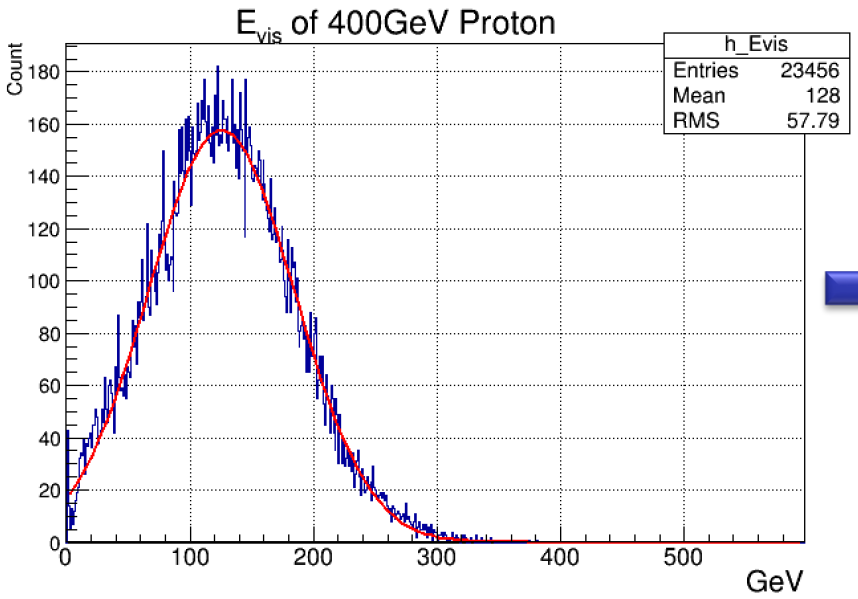
- Enough valid hits to exclude MIP events;
- Shower maximum is contained;
- Shower starts at first few layers;

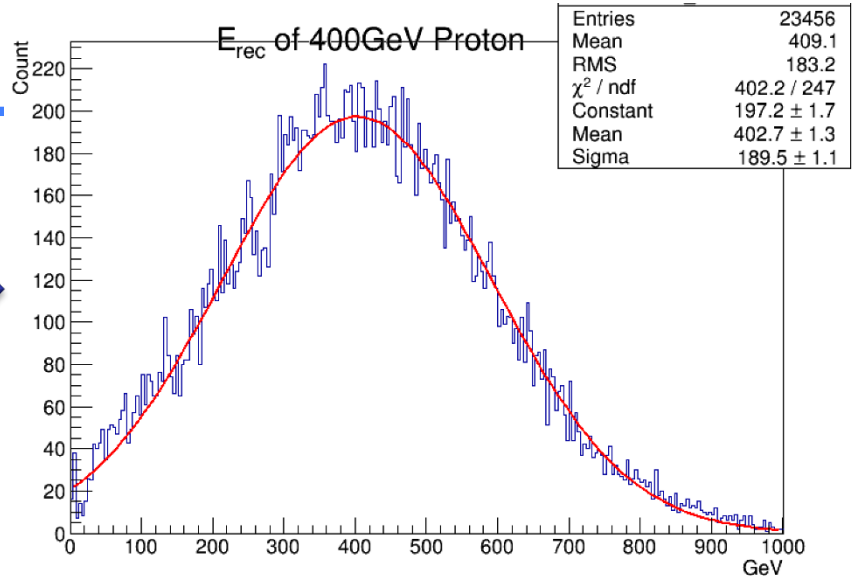




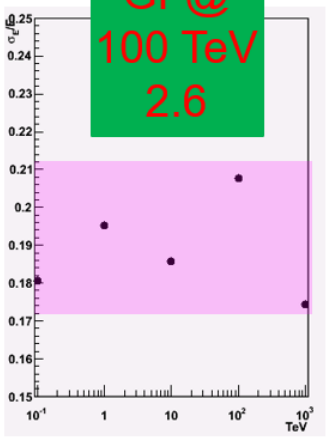
Scale

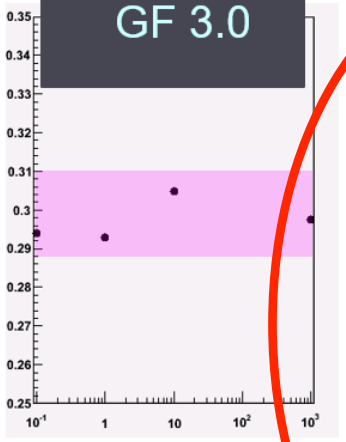
$\frac{E_{vis}}{}$ ~0.3

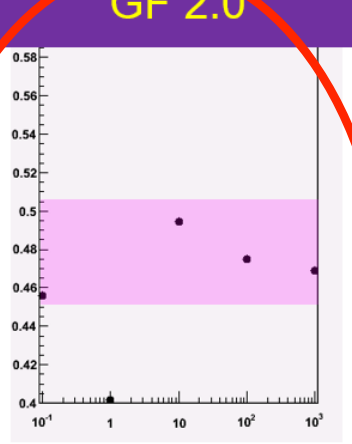




$\sigma/E \sim 50\%$







➔63*63*63cm
3 nucl.inter.length,
20% resolution

➔77*77*42cm
2 nucl.inter.length,
30% resolution

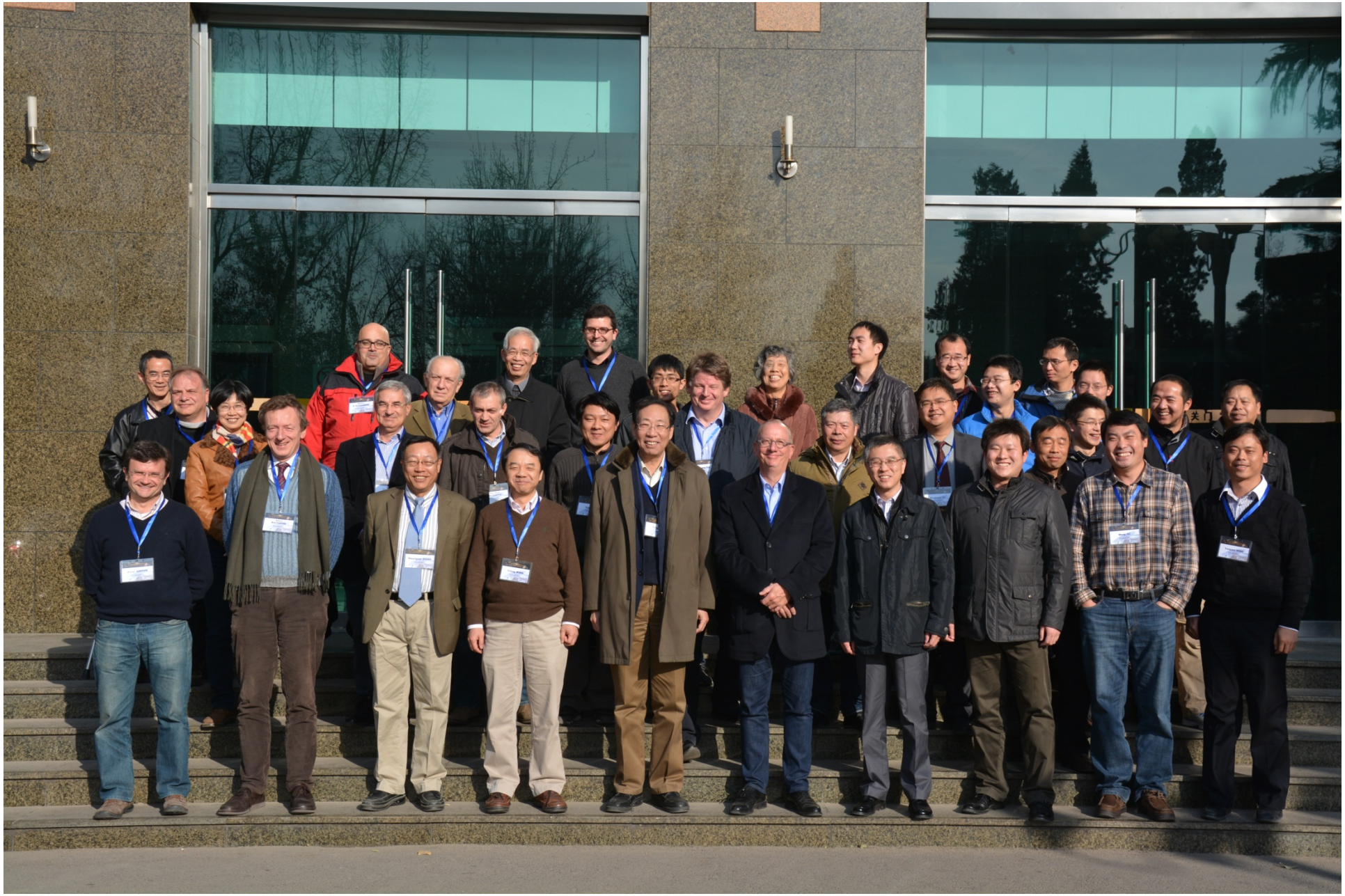
➔90*90*31cm
1.5 nucl.inter.length,
50% resolution

Simulation results
Thickness~1.5λ

⇒Energy resolutio

1st HERD workshop, Oct.17-18, 2012, IHEP, Beijing

2nd HERD Workshop @IHEP 2013/12/2-3



3rd HERD Workshop Xi'An 2016/1/18-21

~20 international participants from Europe

The HERD Proto-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 (more are welcome!)
  - Switzerland: University of Geneva
  - Italy: U. Florence/INFN, U. Perugia/INFN, U. Trento/ INFN, U. Bari/INFN, U. Salento/INFN-Lecce, U. Napoli/ INFN, IAPS/INAF
  - Sweden: KTH
  - USA: MIT/Harvard

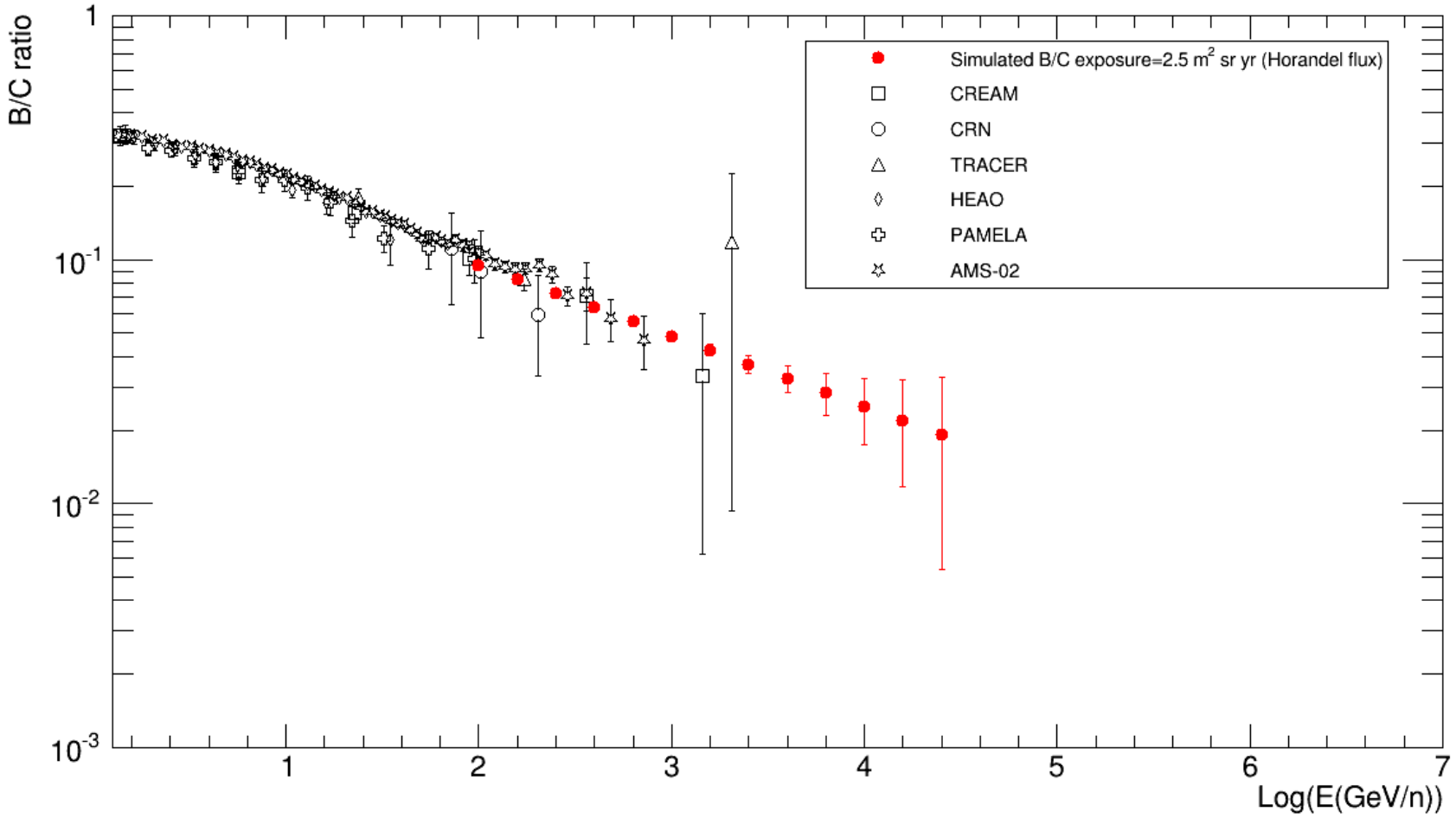
Collaboration status

- Joint key technology demonstration at CERN completed
- Joint working groups are being setup
- Regular telecons are used to discuss results
- Ready to move forward to the next stage

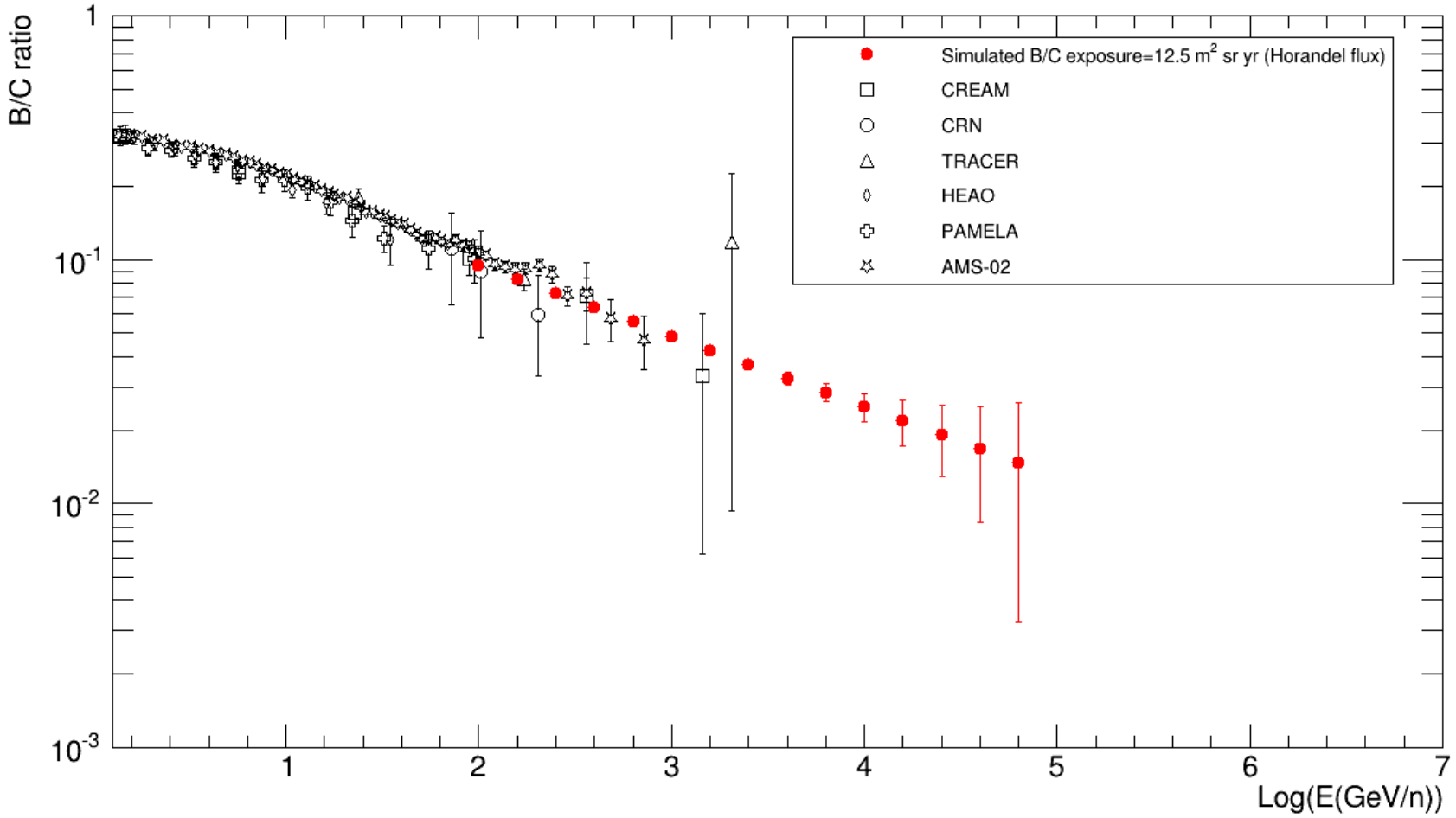
Conclusions

- China has an aggressive space program
- HERD detector on board the CSS is a real opportunity to perform direct HE cosmic rays measurements up to the PeV scale
- Work is in progress for a proposal: there is plenty of room for contributions!

B/C ratio (1 yr)

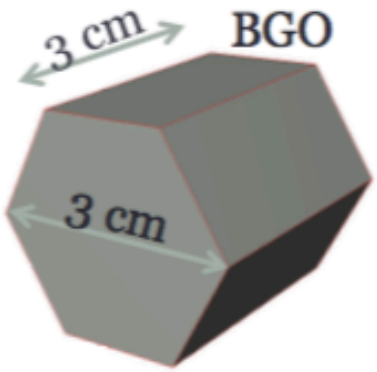

B/C ratio
1
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
Log(E(GeV/n))
Simulated B/C exposure=2.5 m^2 sr yr (Horandel flux)
CREAM
CRN
TRACER
HEAO
PAMELA
AMS-02

B/C ratio (5yr)


B/C ratio
1
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
Log(E(GeV/n))
Simulated B/C exposure=12.5 m^2 sr yr (Horandel flux)
CREAM
CRN
TRACER
HEAO
PAMELA
AMS-02

A Cylindrical shape calorimeter with 3D hexagonal tesselation

Weight~2000 kg
N. crystals: 15925



Basic crystal: hexagonal base prisma