INFN PERUGIA

Istituto Nazionale Fisica Nucleare – Sezione di Perugia

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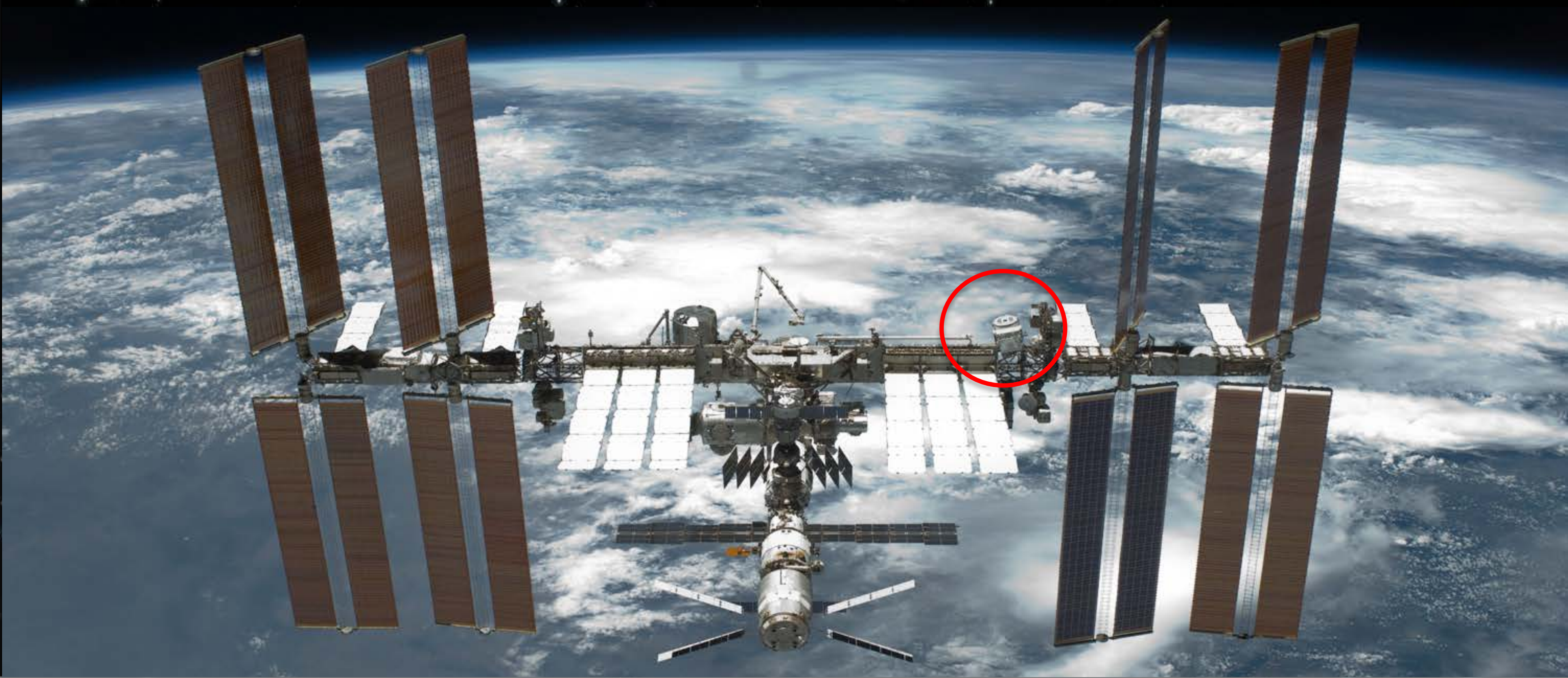
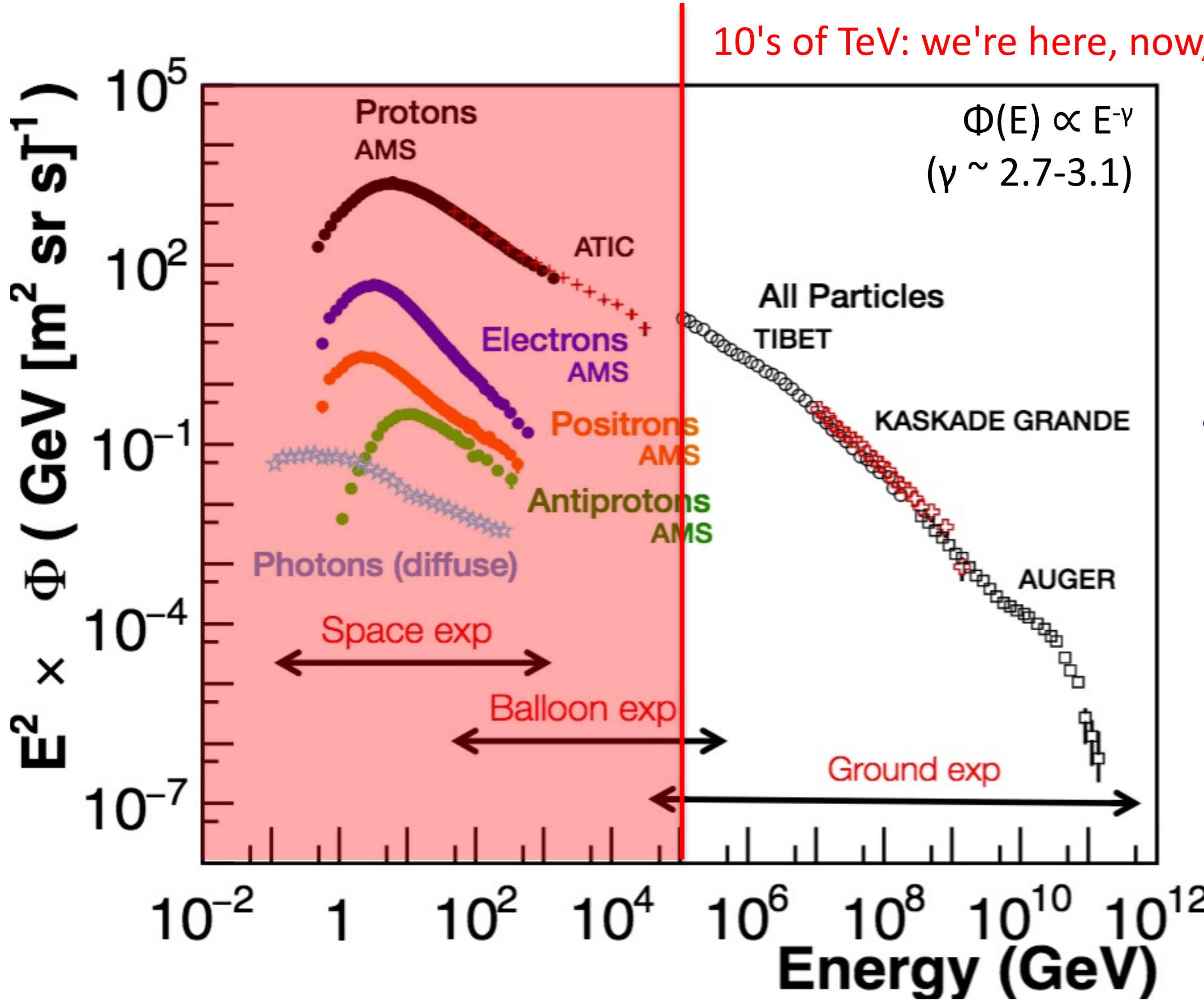
Futuro prossimo e remoto nella rivelazione diretta dei Raggi Cosmici nello Spazio



Cosmic Rays



measuring in Space (or balloon) permits to measure at single particle level
→ precise composition and spectra measurement

BUT

cosmic ray spectra are tipically power laws:
1 order of magnitude in energy → 3 orders of magnitude in flux (i.e. in statistics)

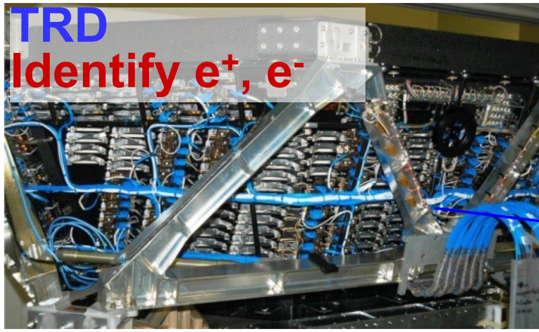
Outline

- Current experiments: key concepts/detectors

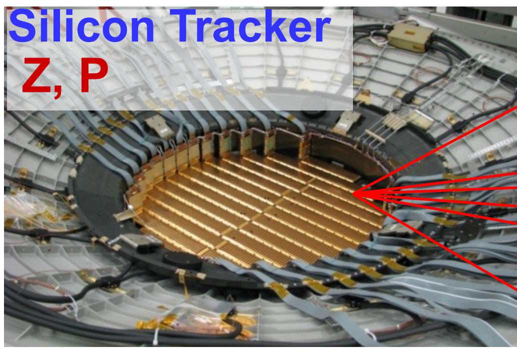
- Future/proposed 4π experiments
  - HERD
  - ALADInO
  - AMS-100

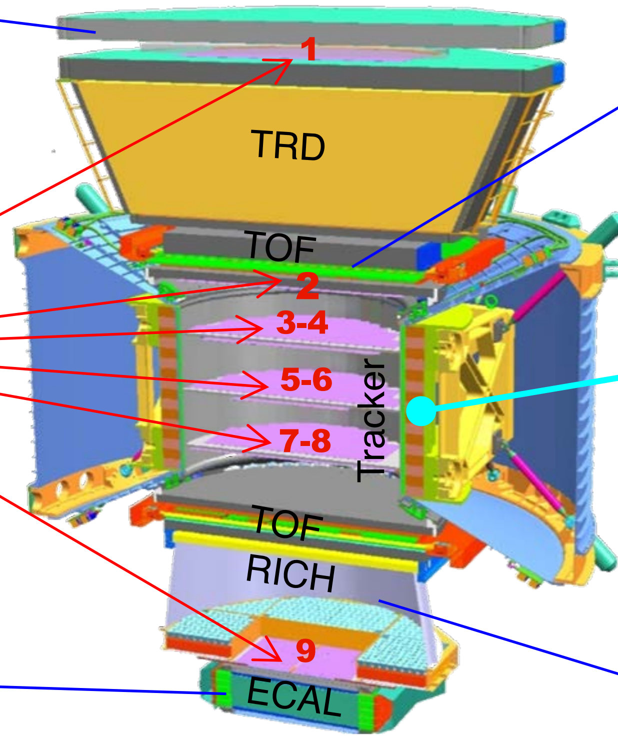
Current experiments: key concepts/detectors

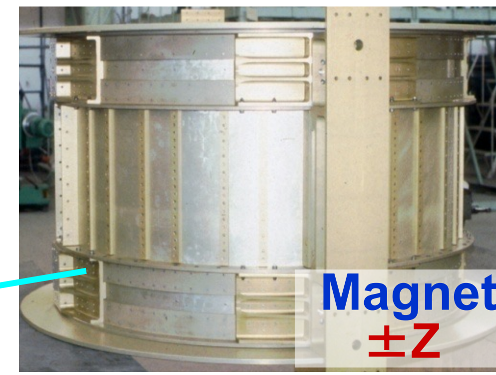
Current operating experiments – AMS-02

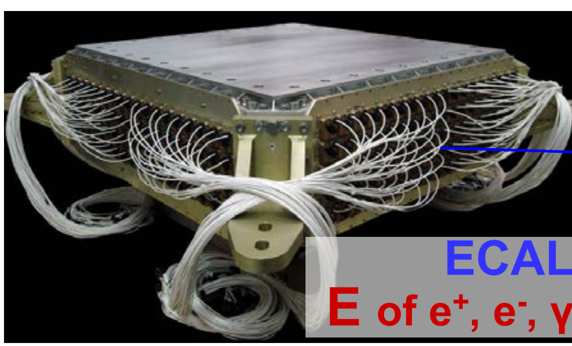


Z, P independently measured by Tracker, RICH, TOF and ECAL

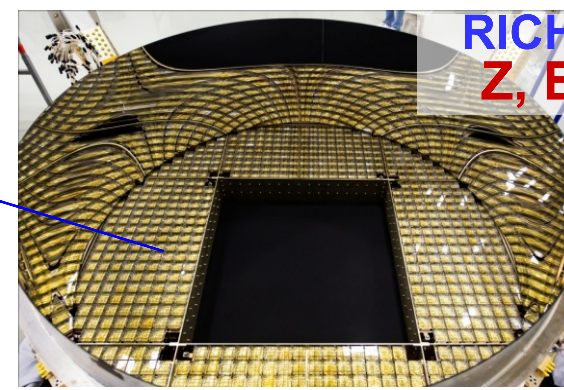








On ISS since 16 May 2011

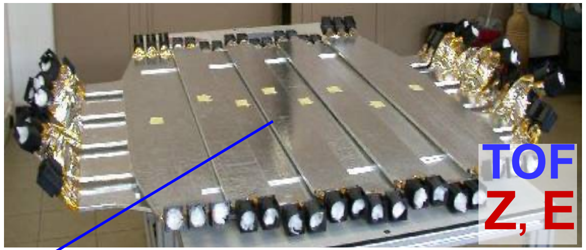


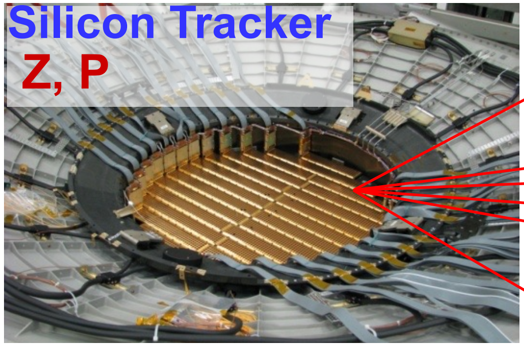
Key concepts/detectors

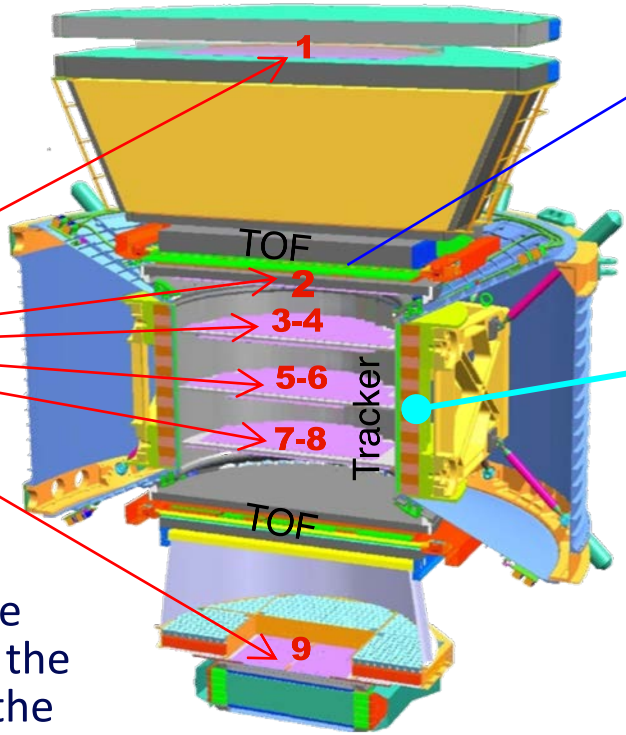
<u>Charge sign measurement:</u>
- matter/anti-matter

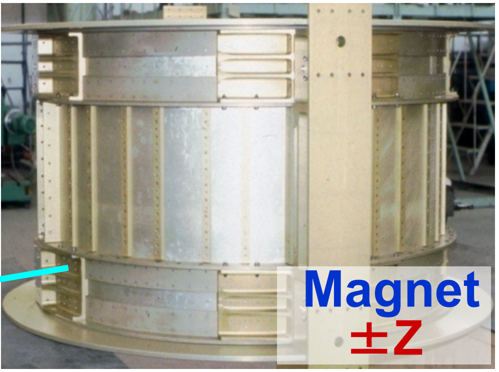
The measured quantity is <u>Rigidity</u>, R:

$R = p/q$









The intensity of the magnetic field (B), the lever arm (L) and the spatial resolution (σ_x) determine the momentum resolution (δp) and the detector Maximum Detectable Rigidity, MDR ($\delta p/p=1$):

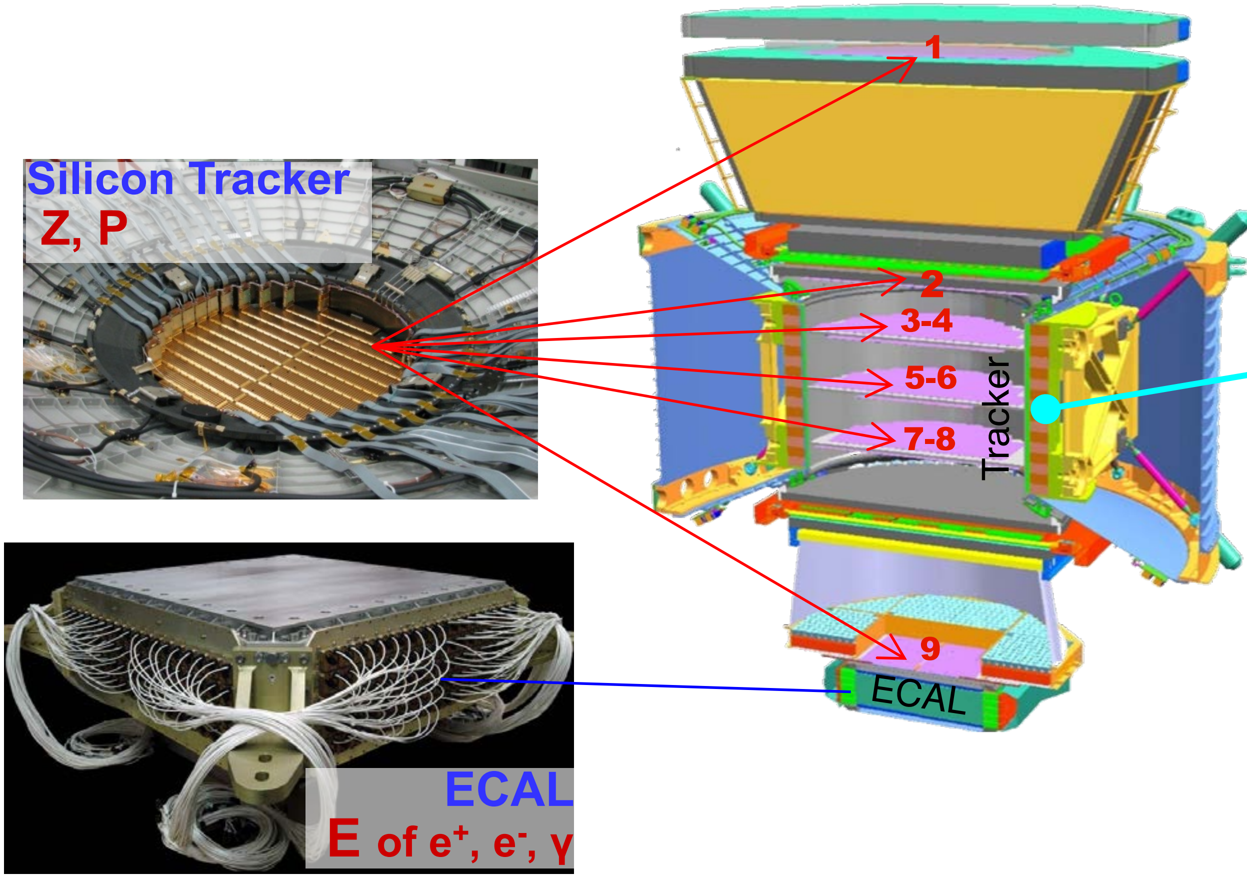
$$MDR \propto B L^2 / \sigma_x$$

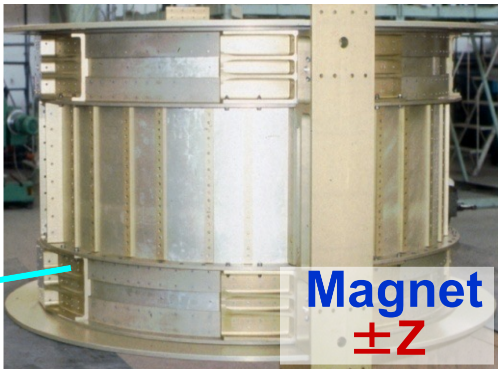
<u>Techniques:</u>
- Spectrometry + ToF

Key concepts/detectors

Energy/momentum measurement:

- search for spectral features

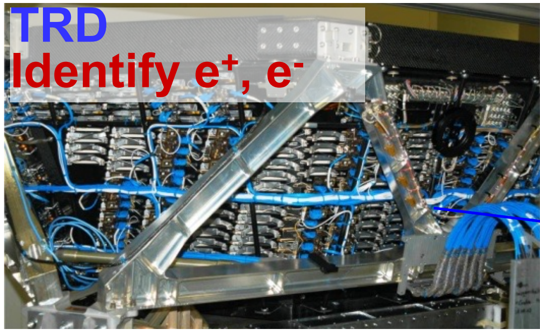


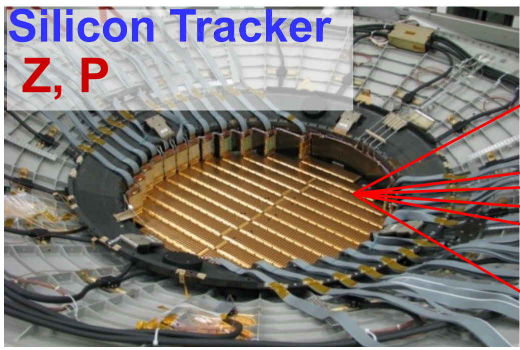


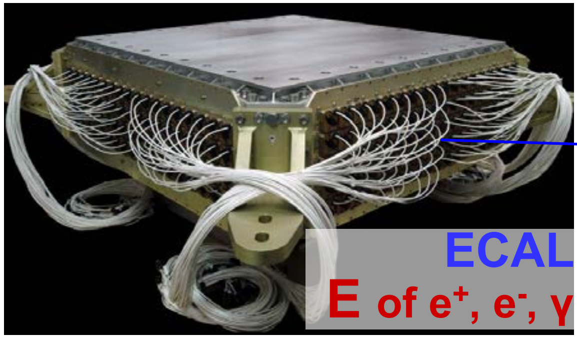
Techniques:

- Spectrometry
- Calorimetry
- Transition Radiation (measuring γ)

Key concepts/detectors

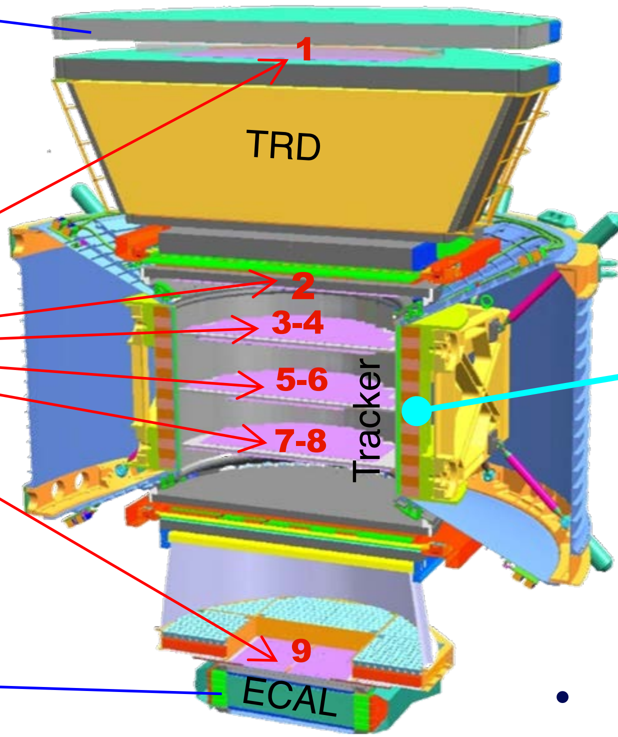


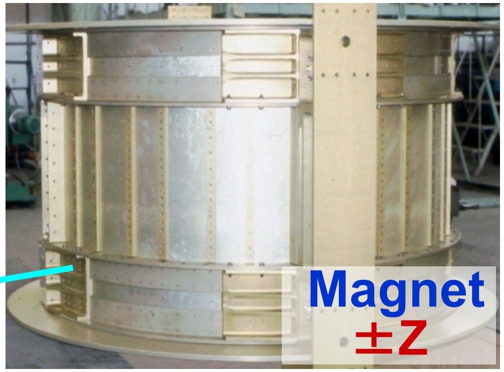




Techniques:

- Transition Radiation
- Shower development topology
- Energy/Momentum (E/p) match
- neutrons produced in the hadronic shower



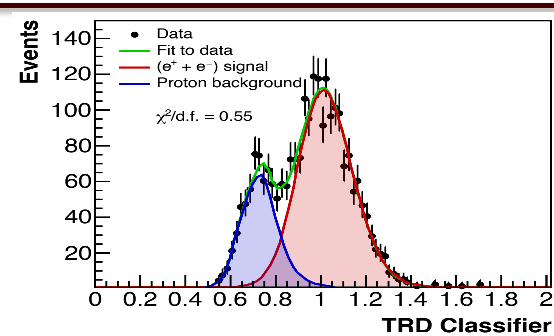


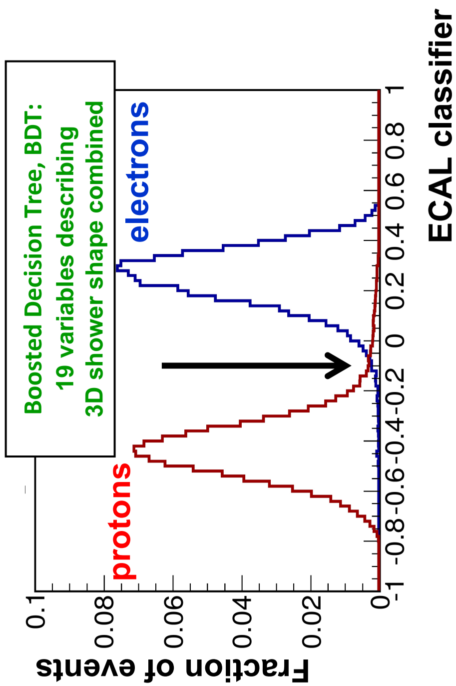
Electron/proton separation:

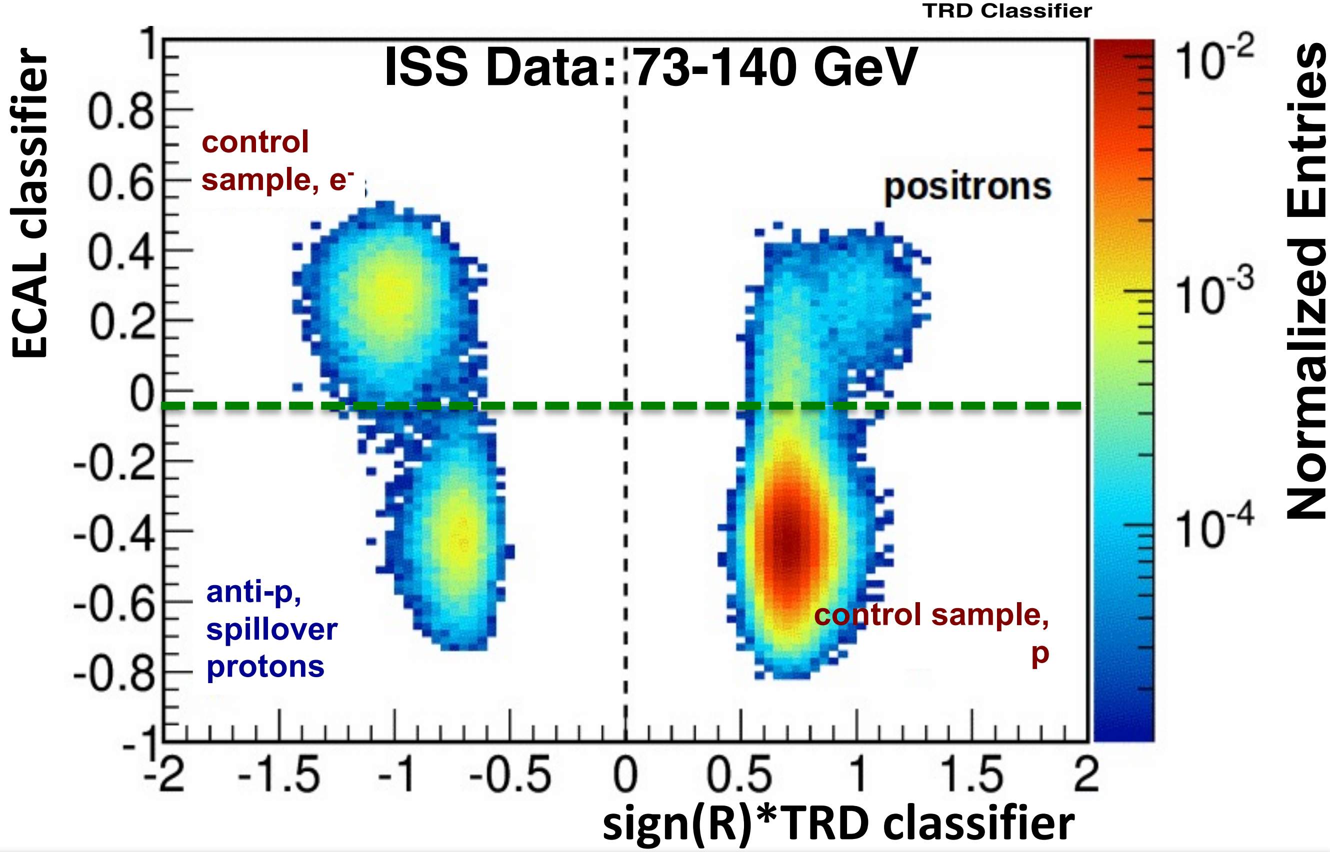
- e^- wrt the p background
- e^+ wrt to the p background
- anti-p wrt to the e^- background
- γ's wrt the p background

Key concepts/detectors

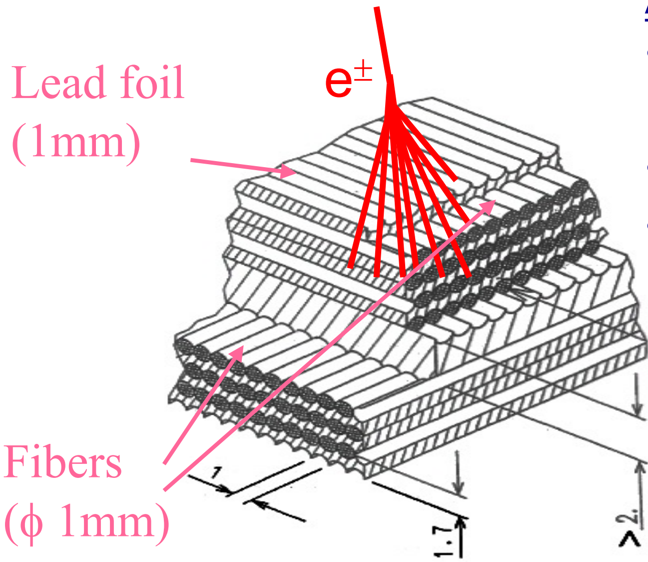
One important lesson from the AMS experiment is the importance of the redundancy: use one detector to create control sample for another one.

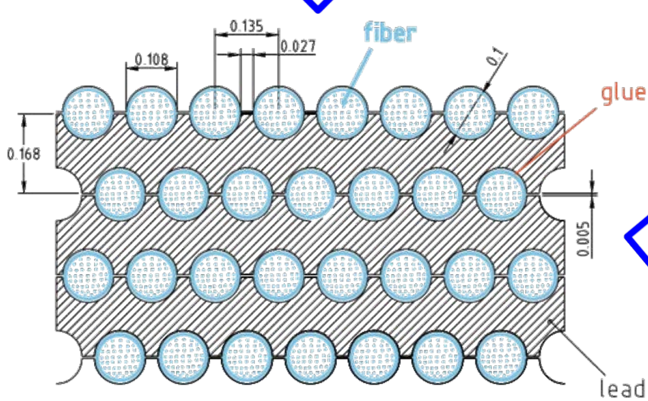




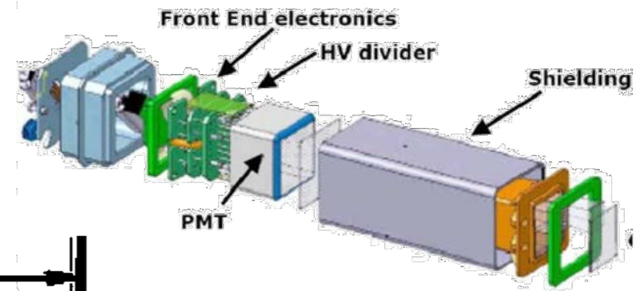


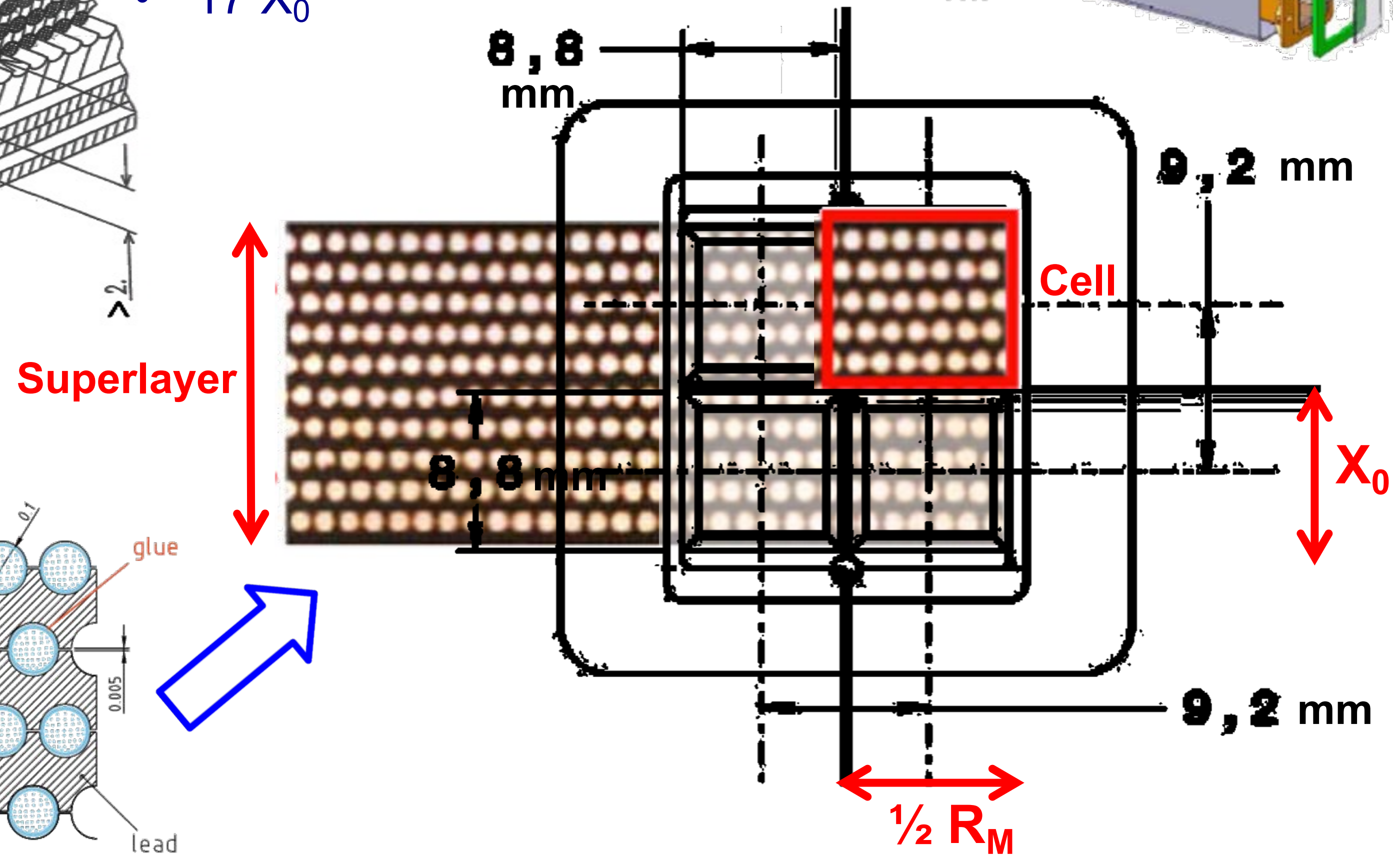
Shower development topology: segmentation





AMS ECAL:
- Lead-SciFi sampling calorimeter
- 18 layers (9 super-layers)
- 17 X_0



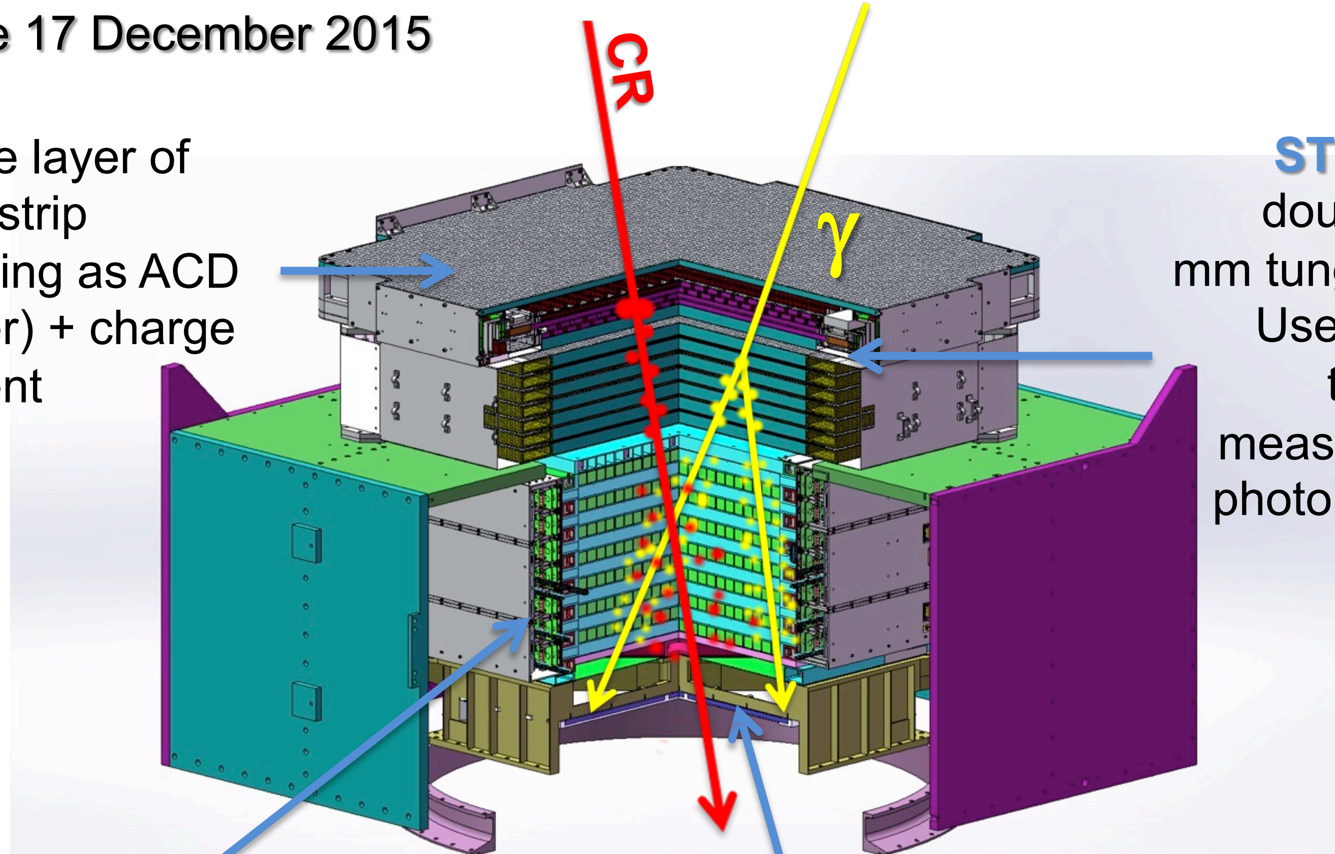


Current operating experiments - DAMPE

In orbit since 17 December 2015

PSD: double layer of scintillating strip detector acting as ACD (anti-counter) + charge measurement

STK: 6 tracking double layer + 3 mm tungsten plates. Used for particle track, charge measurement and photon conversion (~ 2 X_0)



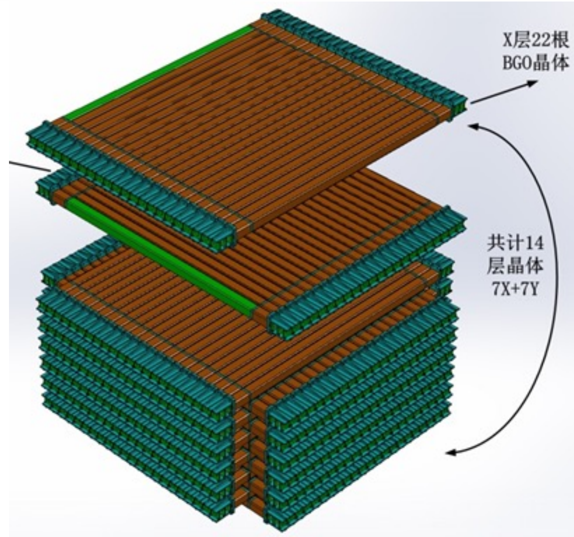
BGO: the calorimeter is made of 308 BGO bars in hodoscopic arrangement (~31 X_0). Performs energy measurements, hadron/lepton identification (*e/p rejection*), and trigger

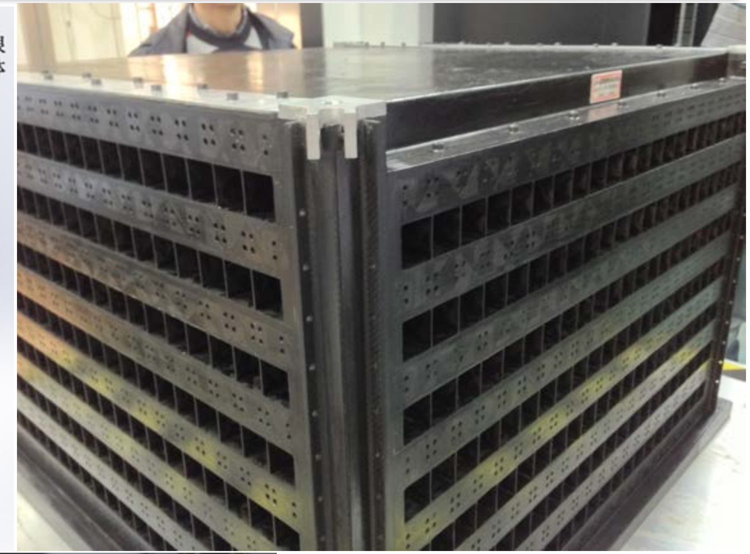
NUD: it's complementary to the BGO e/p rejection, by measuring the thermal neutron shower activity. Made up of boron-doped plastic scintillator

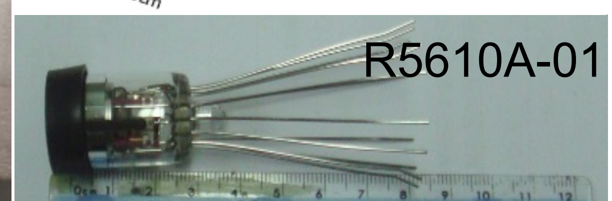
Shower development topology: segmentation

DAMPE BGO:

- homogeneous calorimeter
- ~ 31 X_0
- 14 layers (~ $2X_0$ per layer)







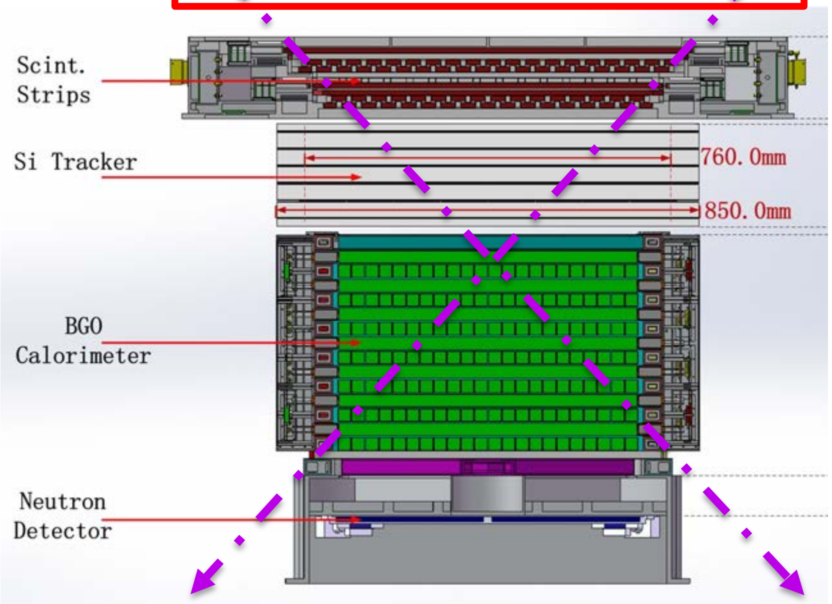
308 bars
616 PMTs

Future/proposed 4π experiments

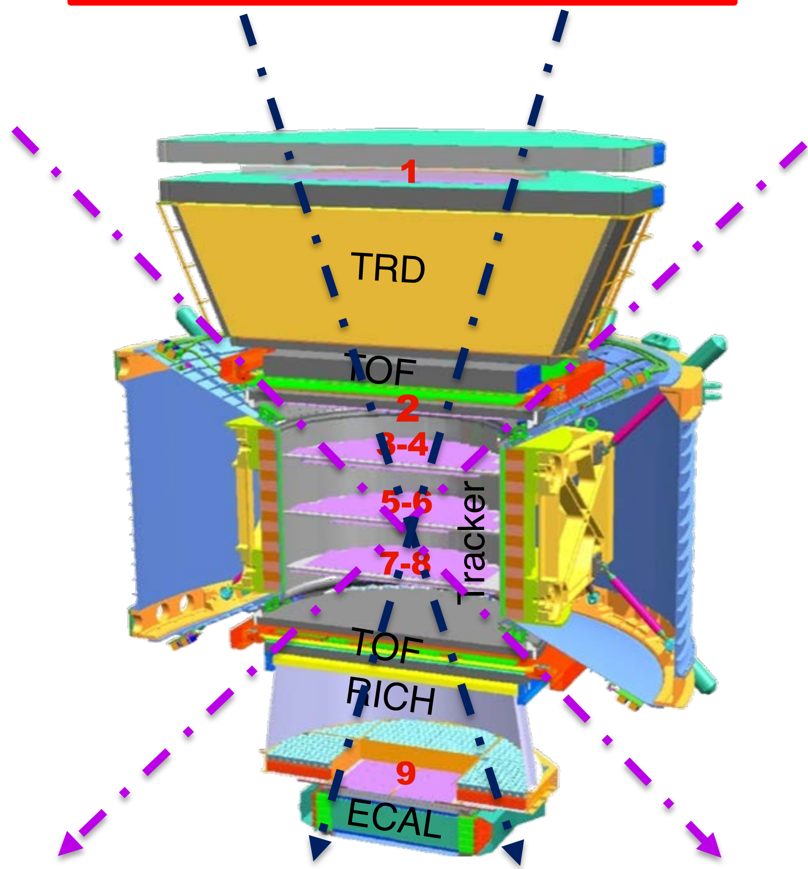
– HERD
– ALADInO
– AMS-100

Current operating "telescopes"

DAMPE Field of View ~ 1 sr
→ Acc ~ 0.3 m² sr



AMS Inner ~ 0.5 m² sr
AMS Full Span ~ 0.05 m² sr



All the current and past detectors are designed as 'telescopes': they're sensitive only to particles impinging from "the top"

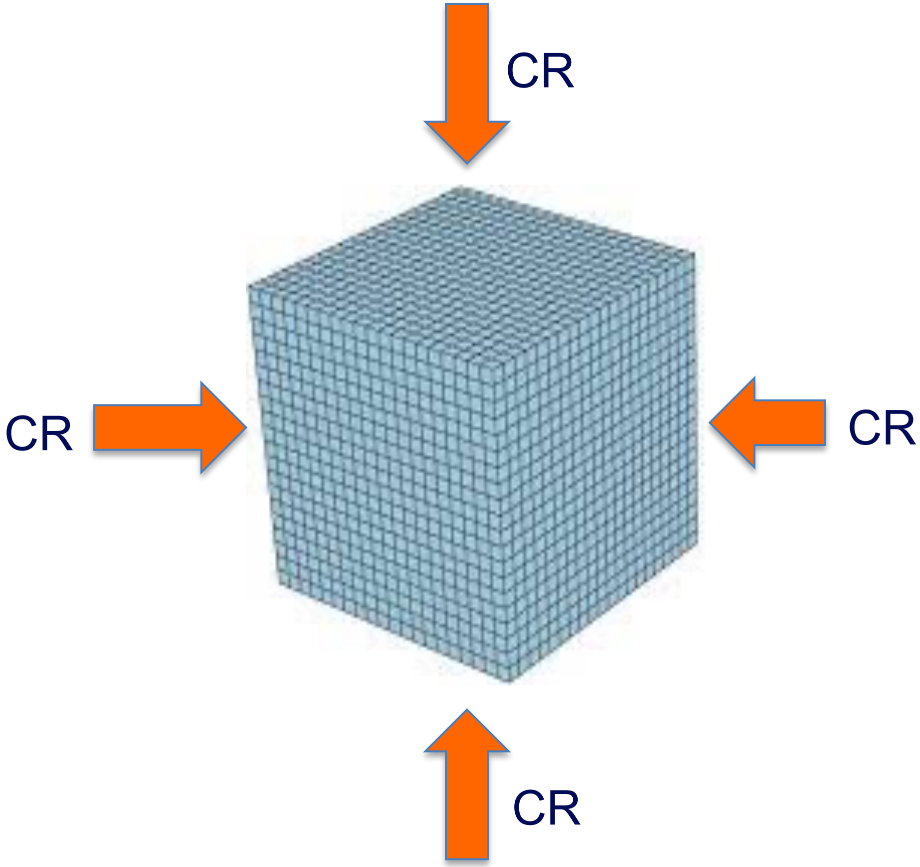
limited FoV → small acceptance

New paradigma - CaloCube

- 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 needed depth of the calorimeter must be guaranteed for all the sides (i.e. cube, sphere, …)
  - the segmentation of the calorimeter should be isotropic

  → this is in general doable just with an homogeneous calorimeter

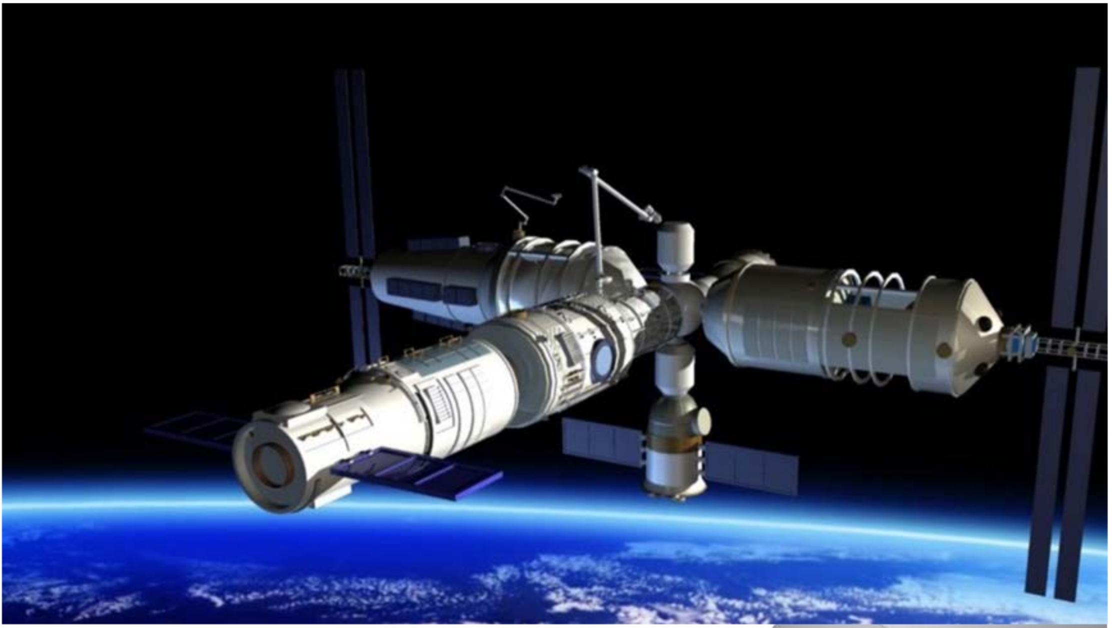


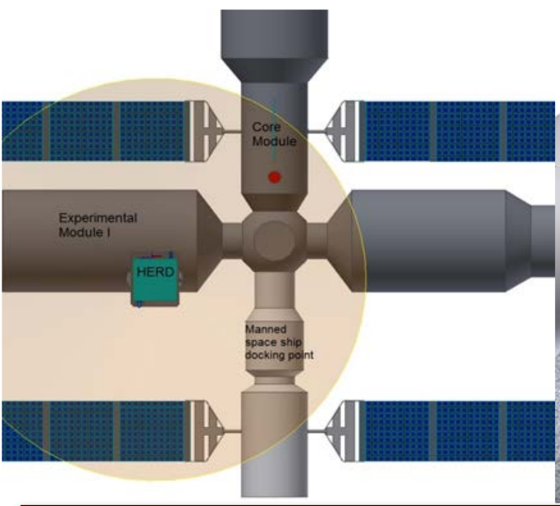
CaloCube is an INFN R&D initiated in Florence (Adriani et al.), almost always inspiring the next generation of large space cosmic rays detectors

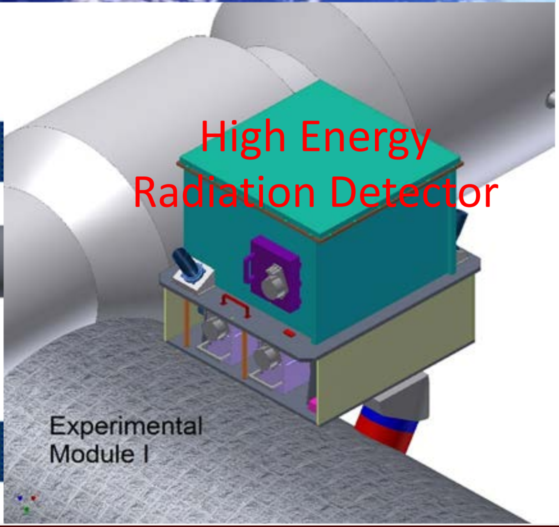
4π experiments

- HERD on the Chinese Space Station (CSS)
- ALADInO (in L2)
- AMS-100 (in L2)

HERD on the CSS







CSS expected to be completed in 2025

Life time	> 10y
Orbit	Circular LEO
Altitude	340-450 km
Inclination	42°

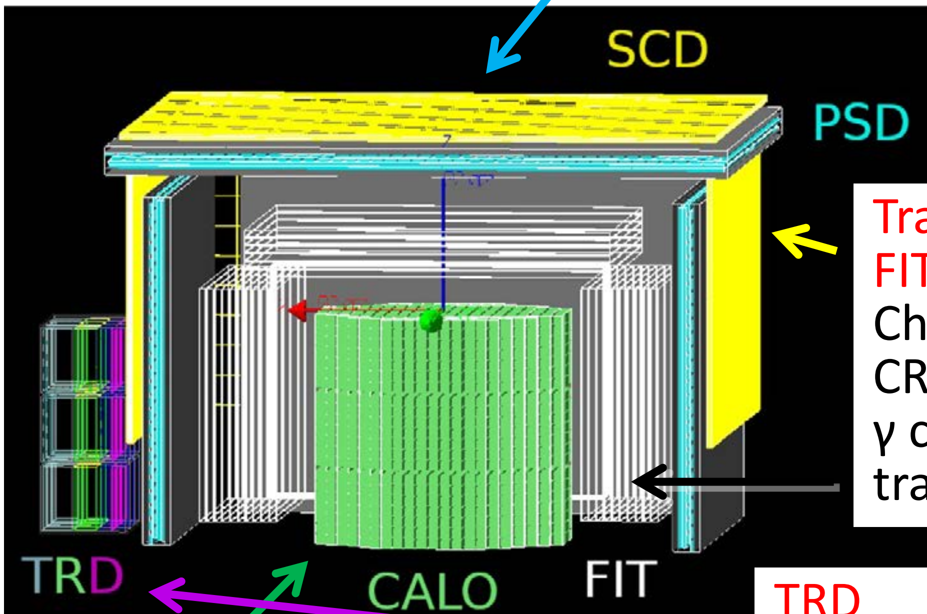
HERD expected to be installed around 2026

Life time	> 10y
FOV	+/- 70°
Power	< 1.5 kW
Mass	< 4 t

HERD detector

~ 300k readout channels

PSD, 5 sides
γ identification
Charge



Tracker (SCD + FIT), 5 sides
Charge
CR trajectory
γ conversion & tracking

TRD
TeV CR calibration

CALO: 3-D
Energy
e/p separation

~7500 LYSO crystals (55 X_0, 3 λ_I)
Trigger sub-system
Dual readout with IsCMOS & PD/SiPM

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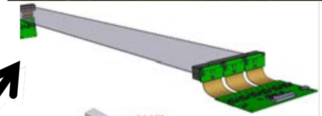

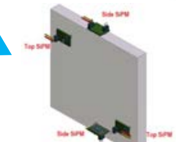

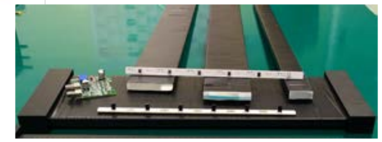

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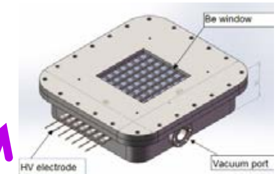
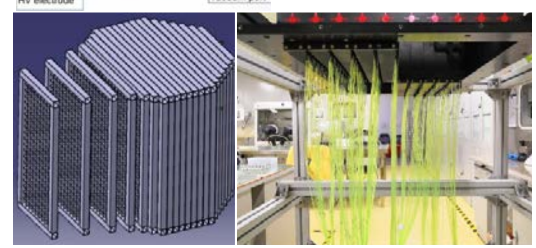
@CIEMAT Madrid

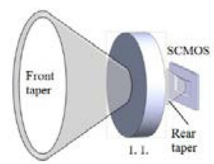
@INFN BA-GSSI-LE-PV-NA & IHEP



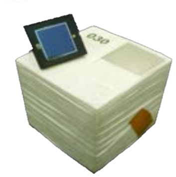
@Guangxi Univ.



@IHEP



@XIOPM



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HERD performances

Item	Value
Energy range (e/γ)	10 GeV - 100 TeV (e); 0.5 GeV-100 TeV (γ)
Energy range (nuclei)	30 GeV - 3 PeV
Angle resolution	0.1 deg.@10 GeV
Charge resolution	0.1-0.15 c.u
Energy resolution (e)	1-1.5%@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
Field of View	~ 6 sr
Envelope (L*W*H)	~ 2300*2300*2000 mm^3
Weight	~ 4000 kg
Power Consumption	~ 1400 W

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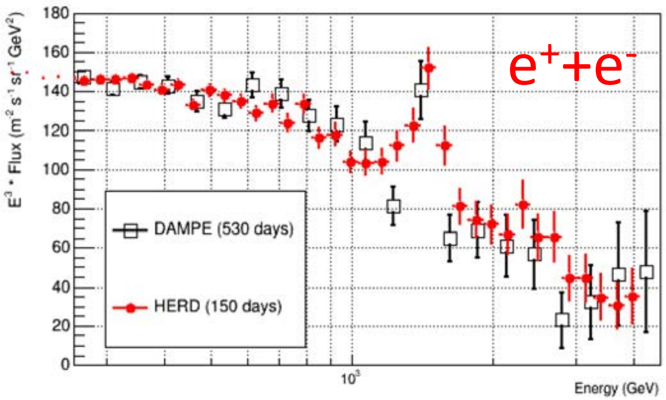
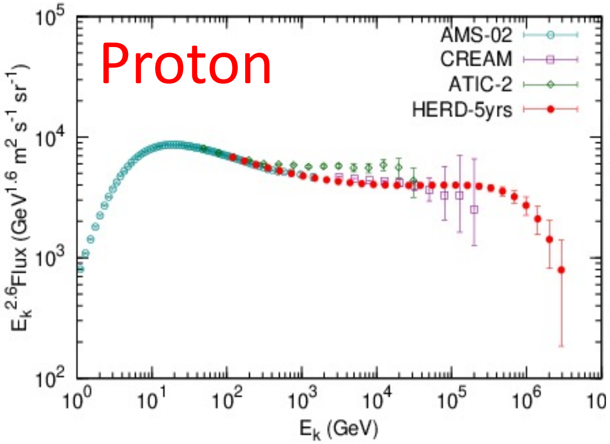
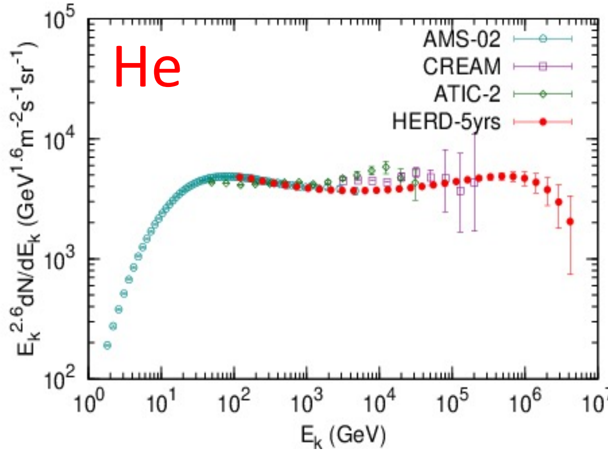
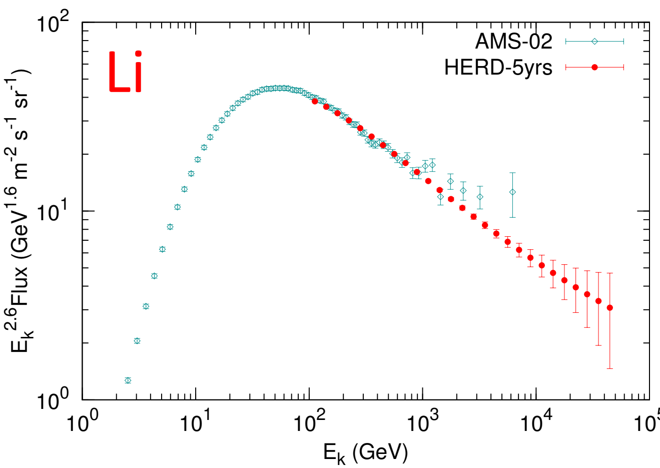
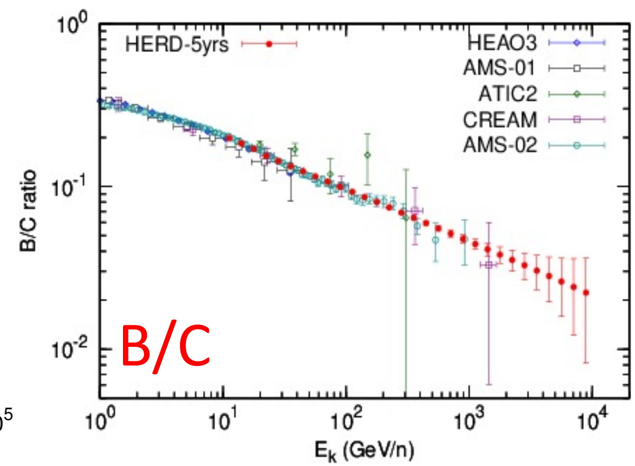
HERD capabilities

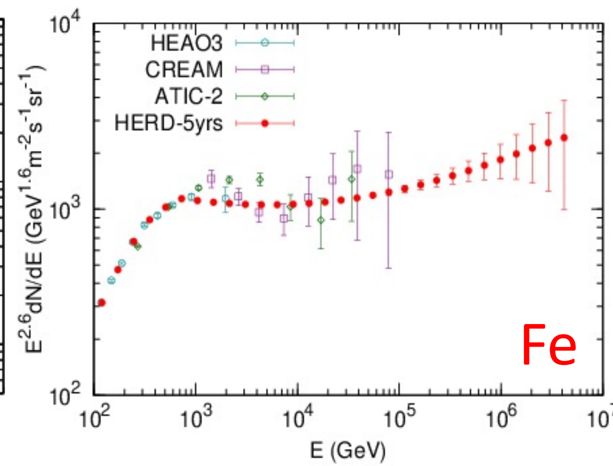












HERD consortium

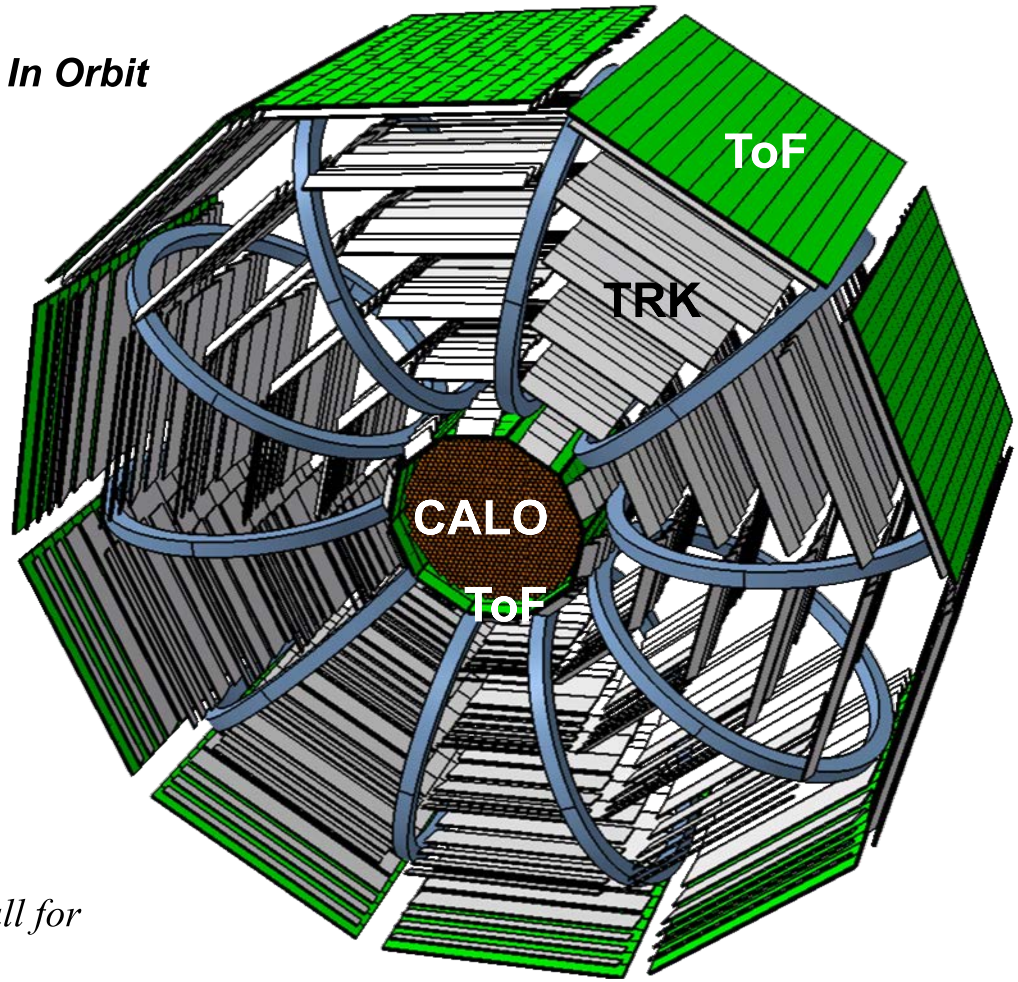
- The HERD consortium includes 130+ scientists from China, Italy, Switzerland, Spain: most of the members have been collaborating on previous high energy experiments, both on hardware development and data analysis
- 9 HERD international workshops have been organized in China and Europe since 2012. Last one"f2f" in China in December 2019. Last, "remote", on 22-23th February 2021…
- 3 CERN beam tests on HERD prototypes have been successfully implemented by Chinese and European colleagues. Next will be in Oct-Nov. 2021…

ALADInO (in L2)

High Precision Particle Astrophysics as a New Window on the Universe

with an Antimatter Large Acceptance Detector In Orbit

(ALADInO)



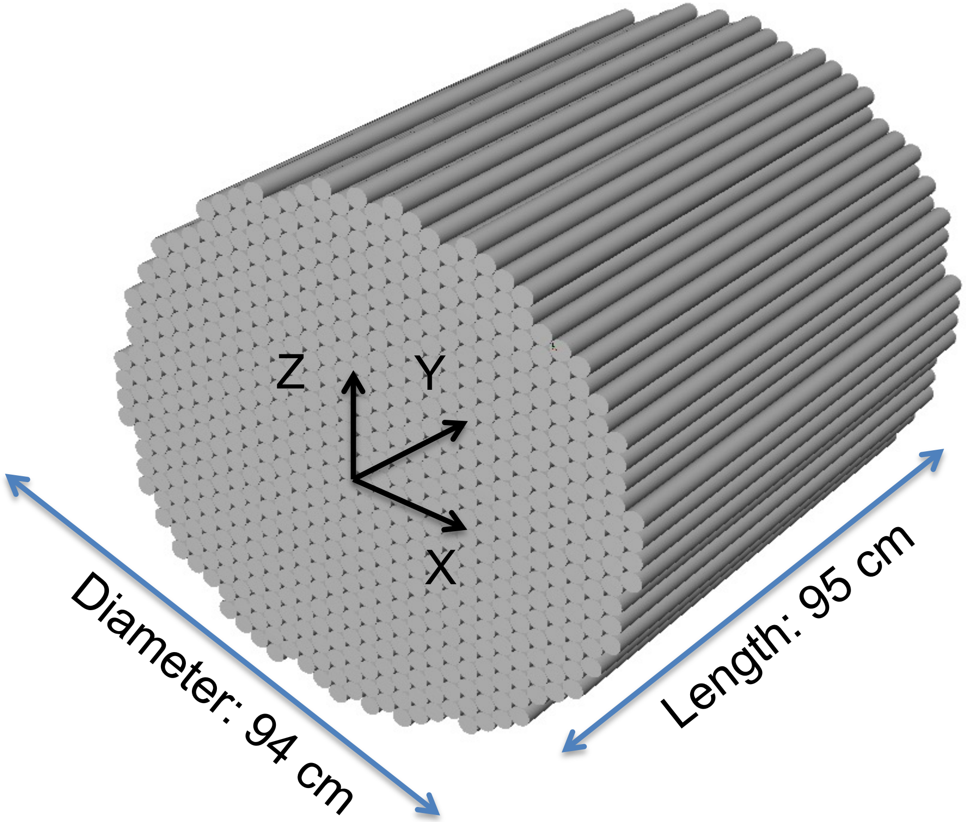
A White Paper submitted in response to ESA's Call for the VOYAGE 2050 long-term plan

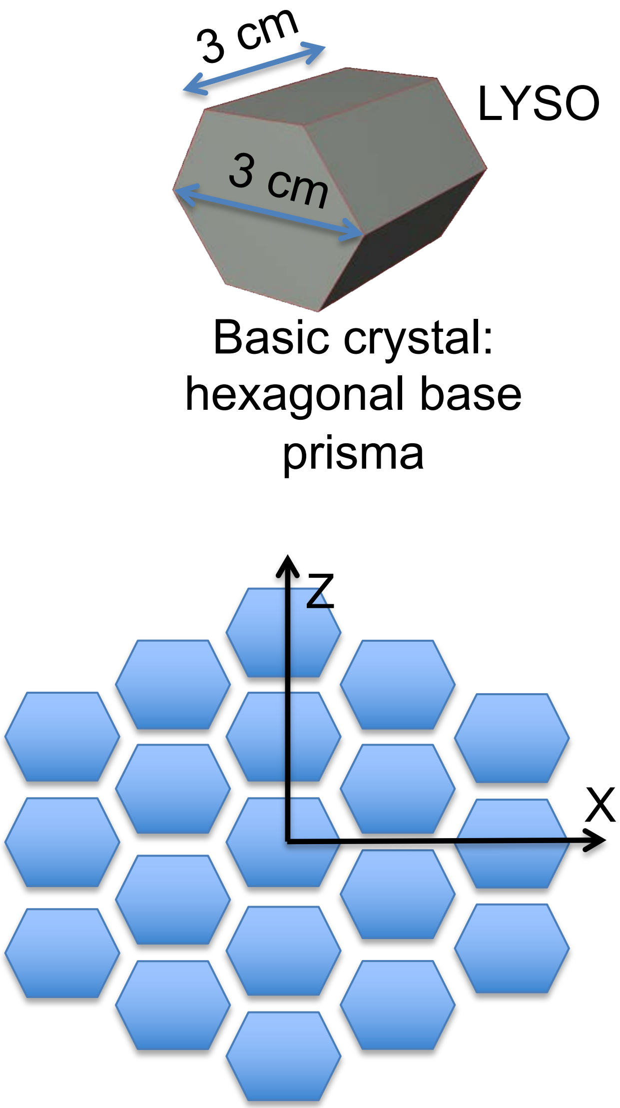
https://www.cosmos.esa.int/web/voyage-2050/white-papers

https://www.cosmos.esa.int/documents/1866264/3219248/BattistonR_ALADINO_PROPOSAL_20190805_v1.pdf

ALADInO calorimeter

Weight~(2300+300) kg
N. crystals: ~20.000

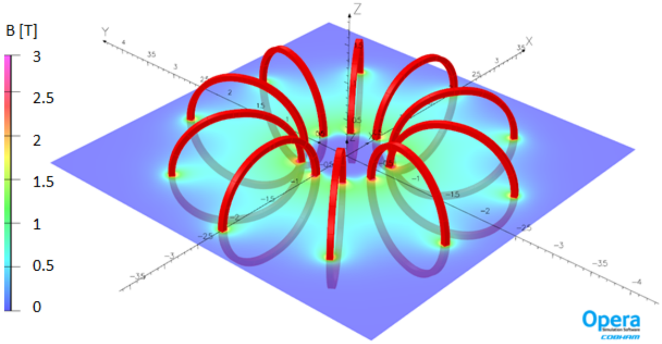


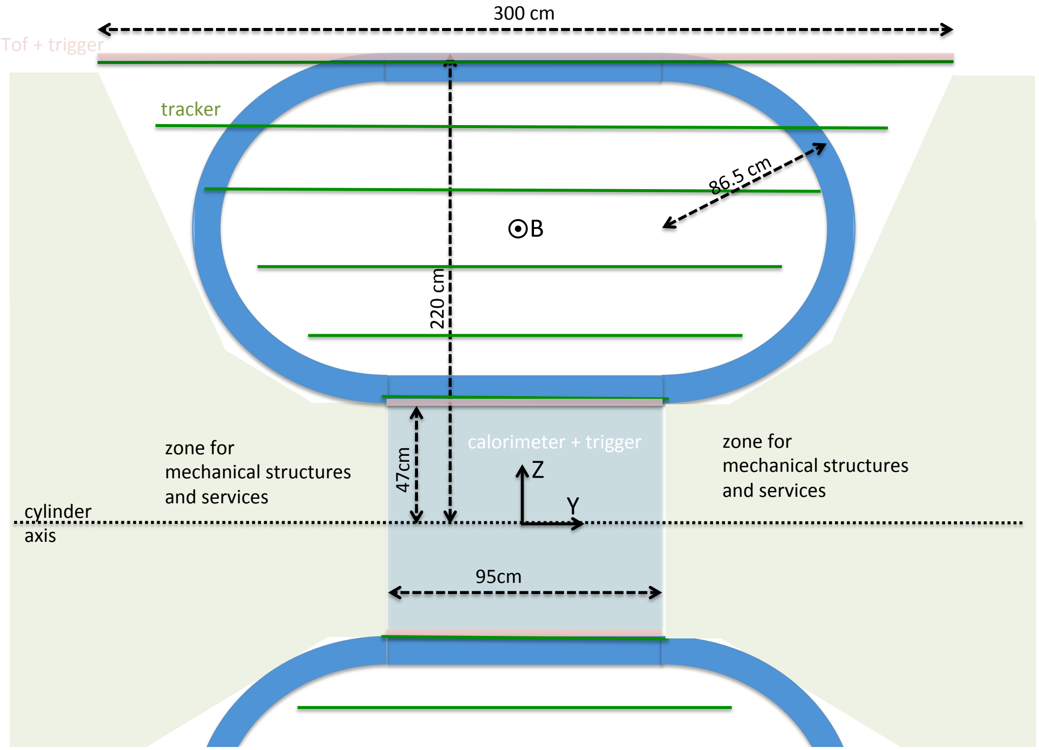


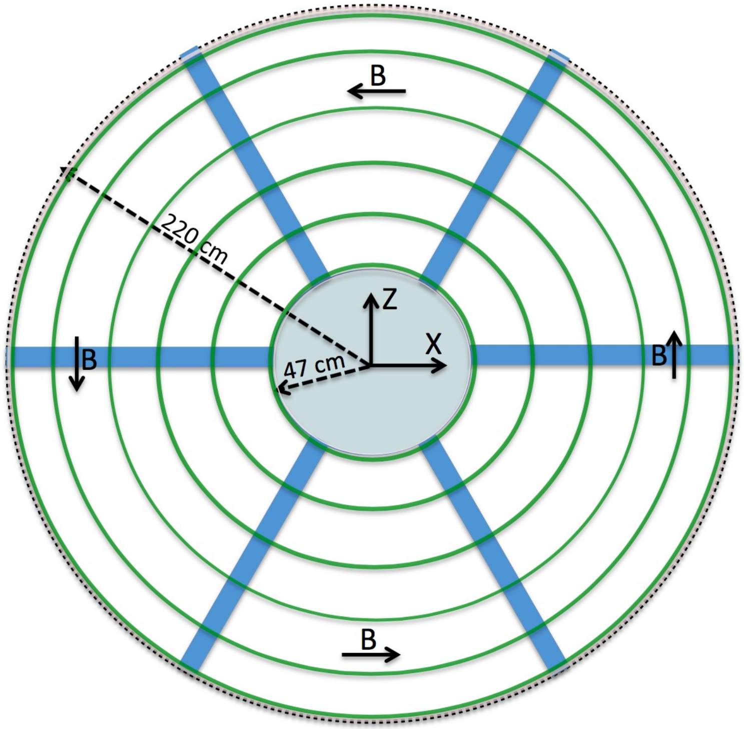
ALADInO magnet

Benefit from the R&D of high temperature superconducting magnets (MgB_2, YBCO and in particular REBCO) for space applications (T ≈ 15÷40° K)

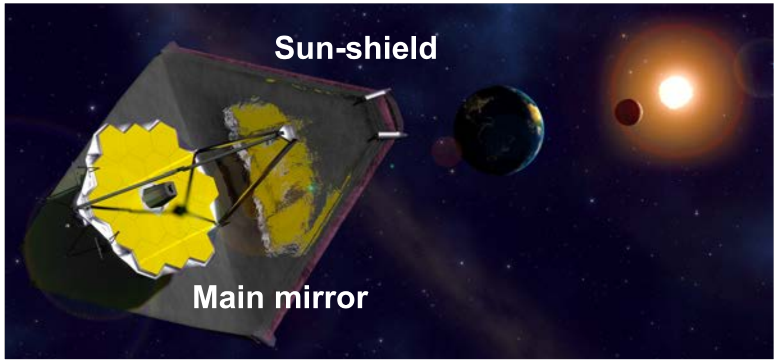
Field 0.8 T
Bending power > 1.1 T m
Weight ~ 1000 Kg



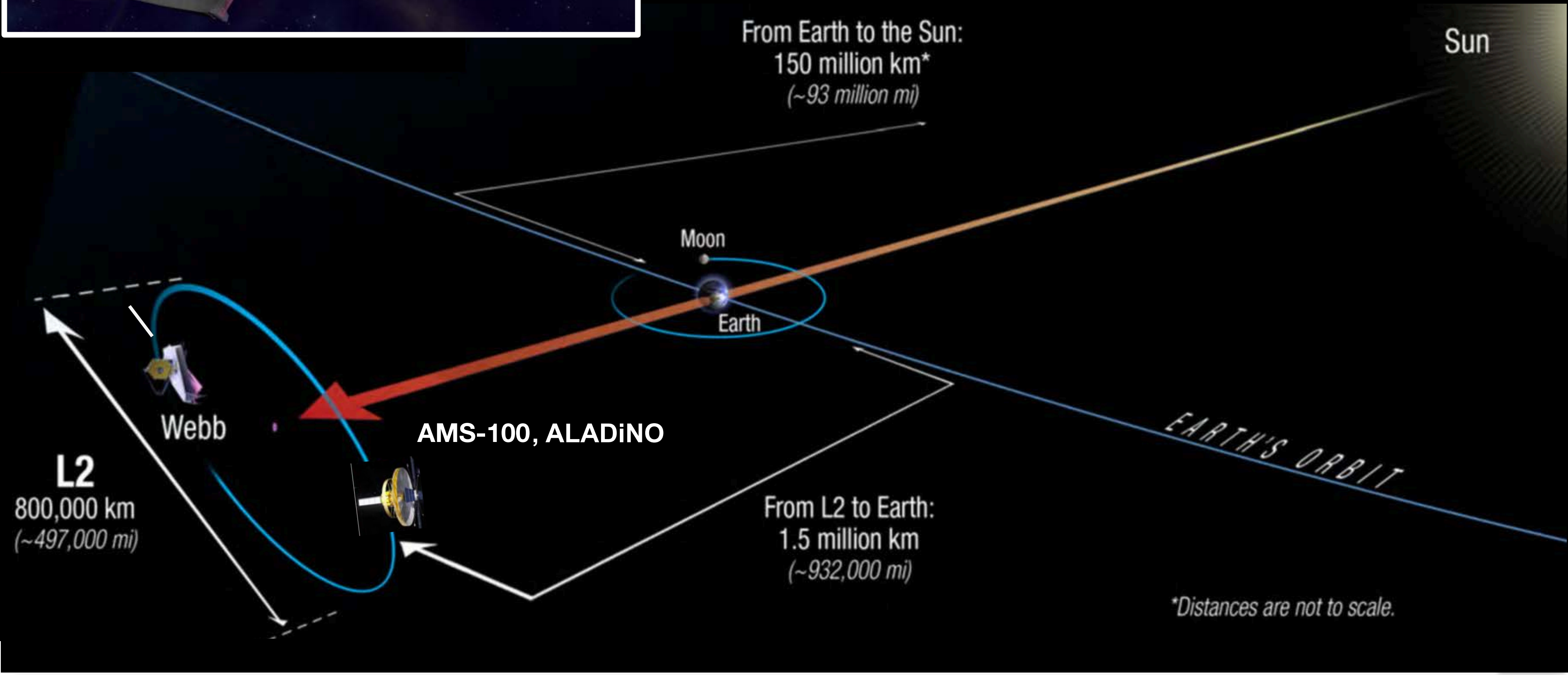




James Webb Telescope - L2



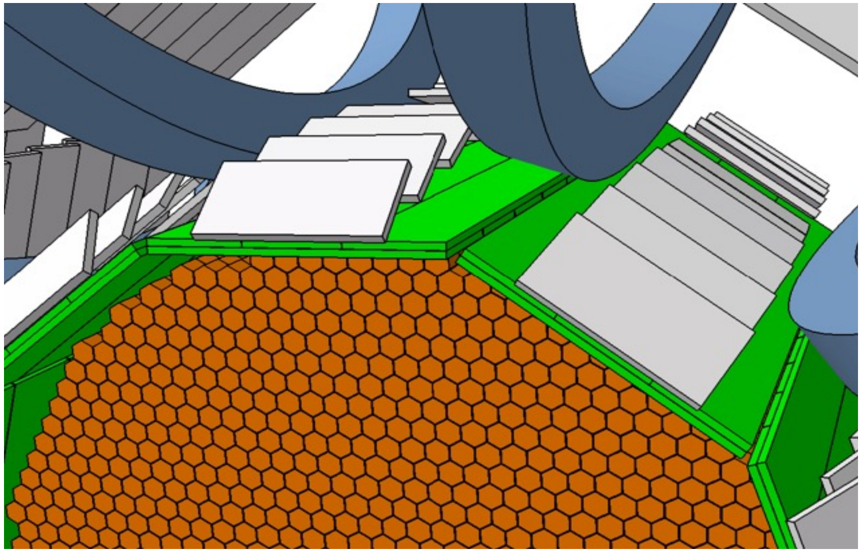
The best place where to operate a cryogenic superconducting magnet is the Lagrange Point 2, like the Webb space telescope

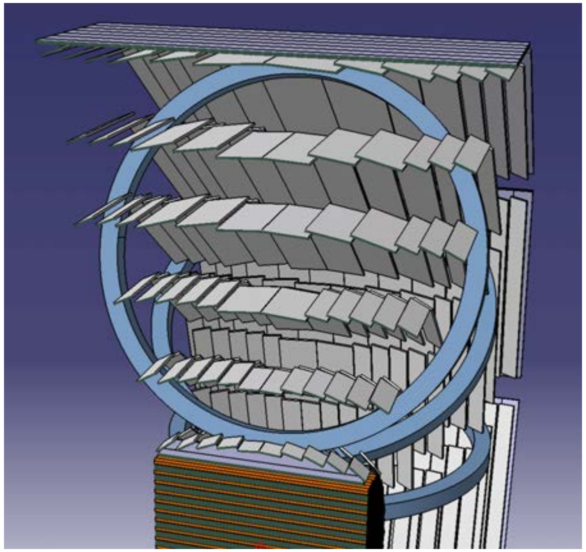


ALADInO performances

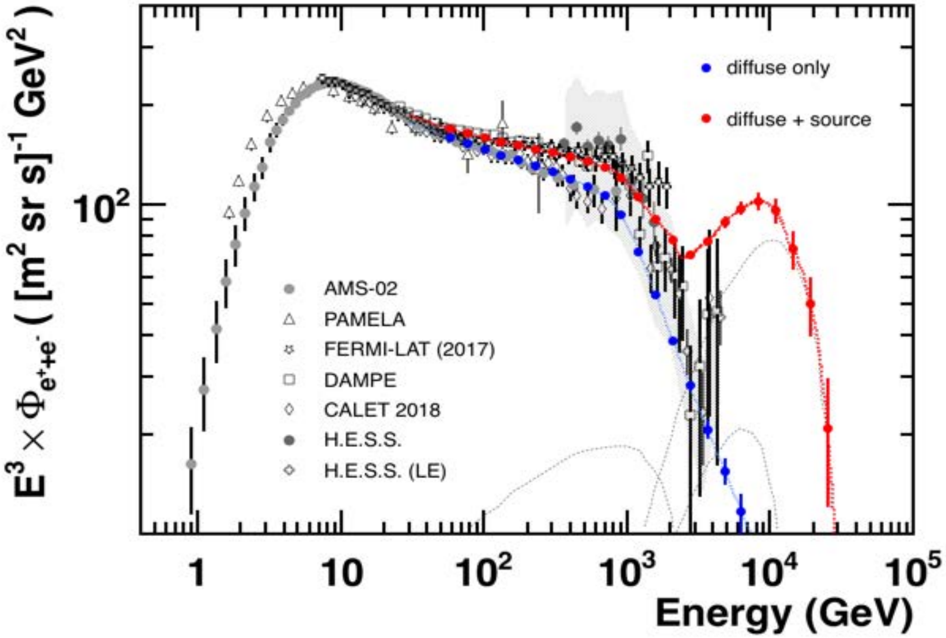
Calorimeter acceptance	~ 9 m^2 sr
Spectrometer acceptance	>10 m^2 sr (~ 3 m^2 sr w/i CALO)
Spectrometer Maximum Detectable Rigidity (MDR)	> 20 TV
Calorimeter depth	61 X_0, 3.5 λ_I
Calorimeter energy resolution	25% ÷ 35% (for nuclei) 2% (for electrons and positrons)
Calorimeter e/p rejection power	> 10^5
Time of Flight measurement resolution	~100 ps
High energy γ-ray acceptance (Calorimeter)	~ 9 m^2 sr
Low energy γ-ray acceptance (Tracker)	~ 0.5 m^2 sr
γ-ray Point Spread Function	< 0.5 deg

Weight: ~ 6 Tons
Power: ~ 4 kW
channels: 2.5 M





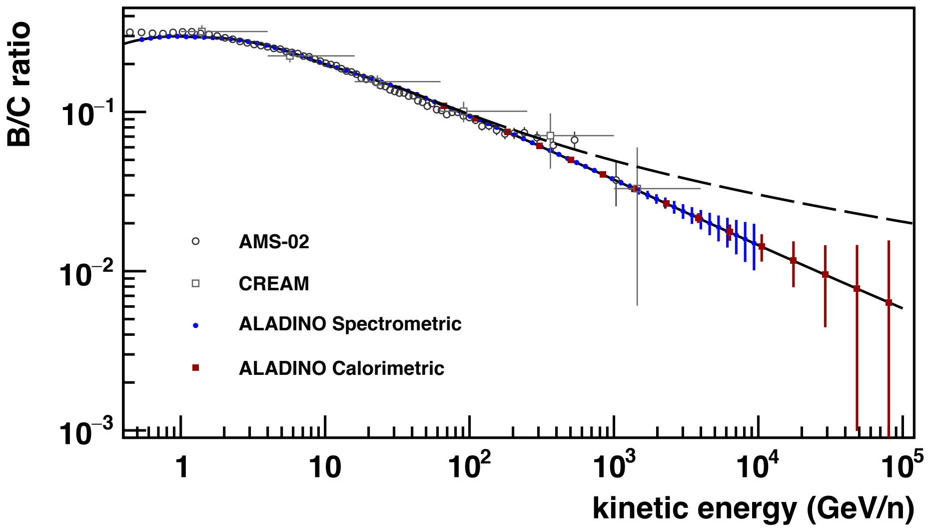
ALADInO capabilities



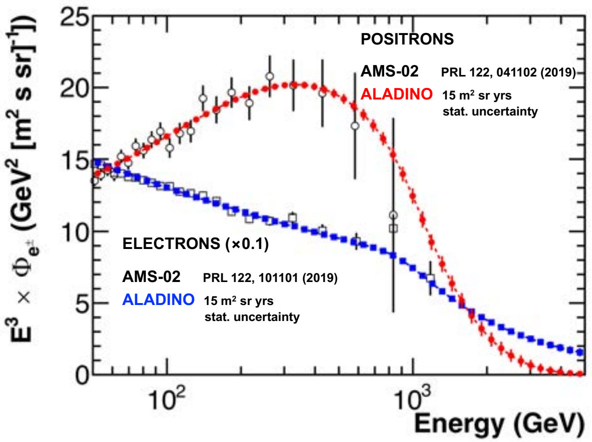
The calorimeter is slightly bigger than the HERD one but is very similar:

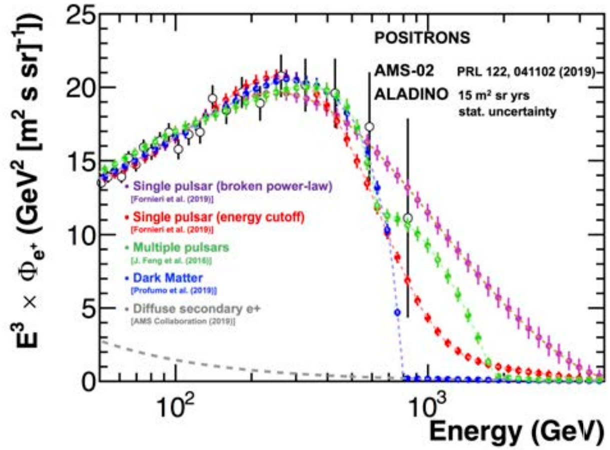
- similar statistical errors similar energy reach
- similar energy resolution, both for electromagnetic particles and nuclei

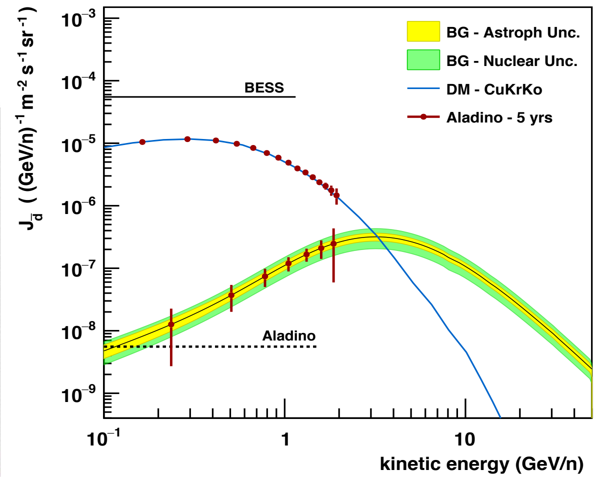
The possibility to crosscheck the Energy in the Calorimeter with the Rigidity (i.e. Momentum) in the Spectrometer will permit lower systematics

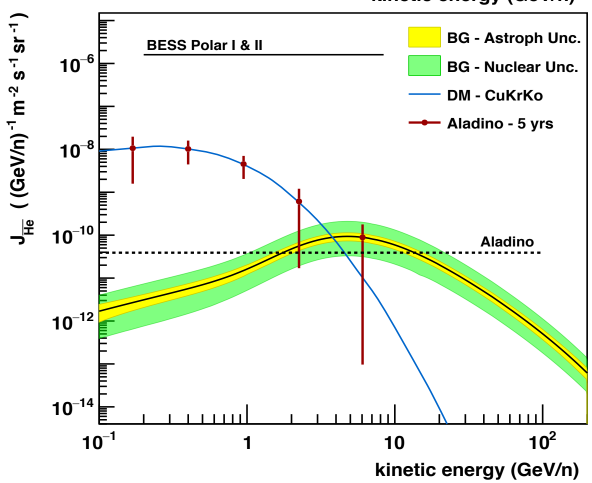


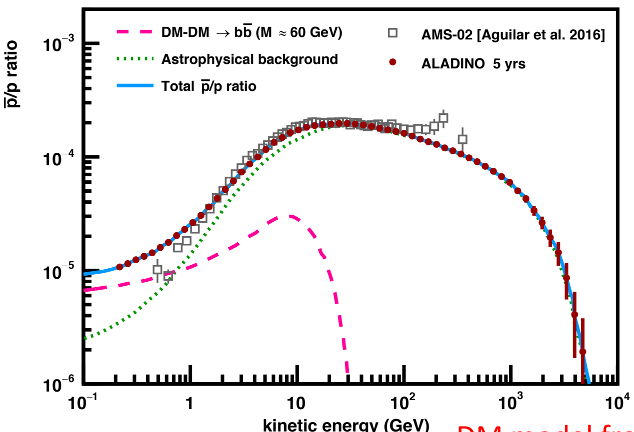
ALADInO capabilities

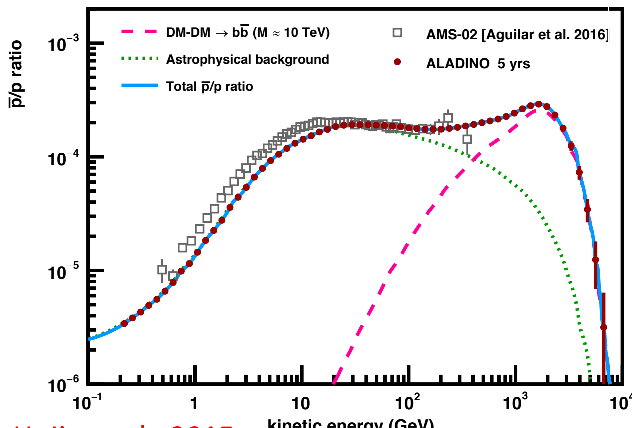










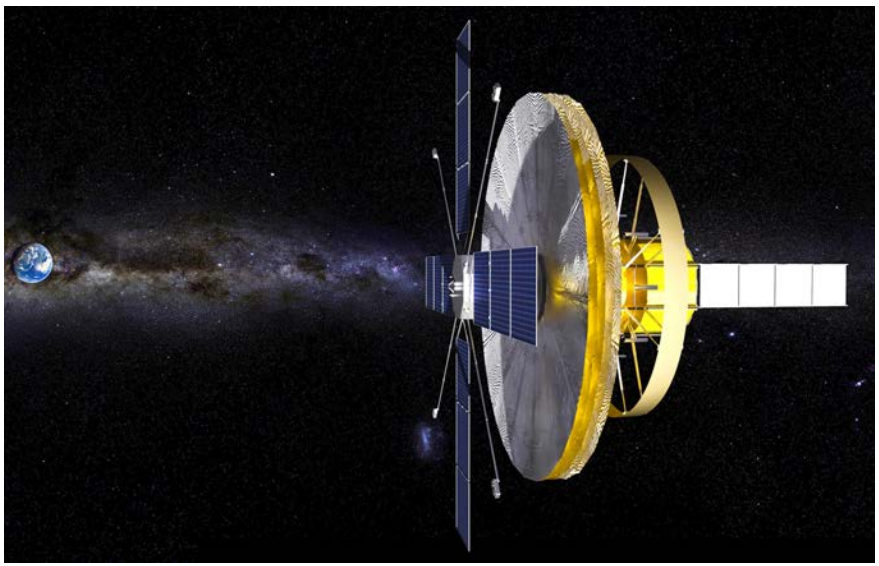


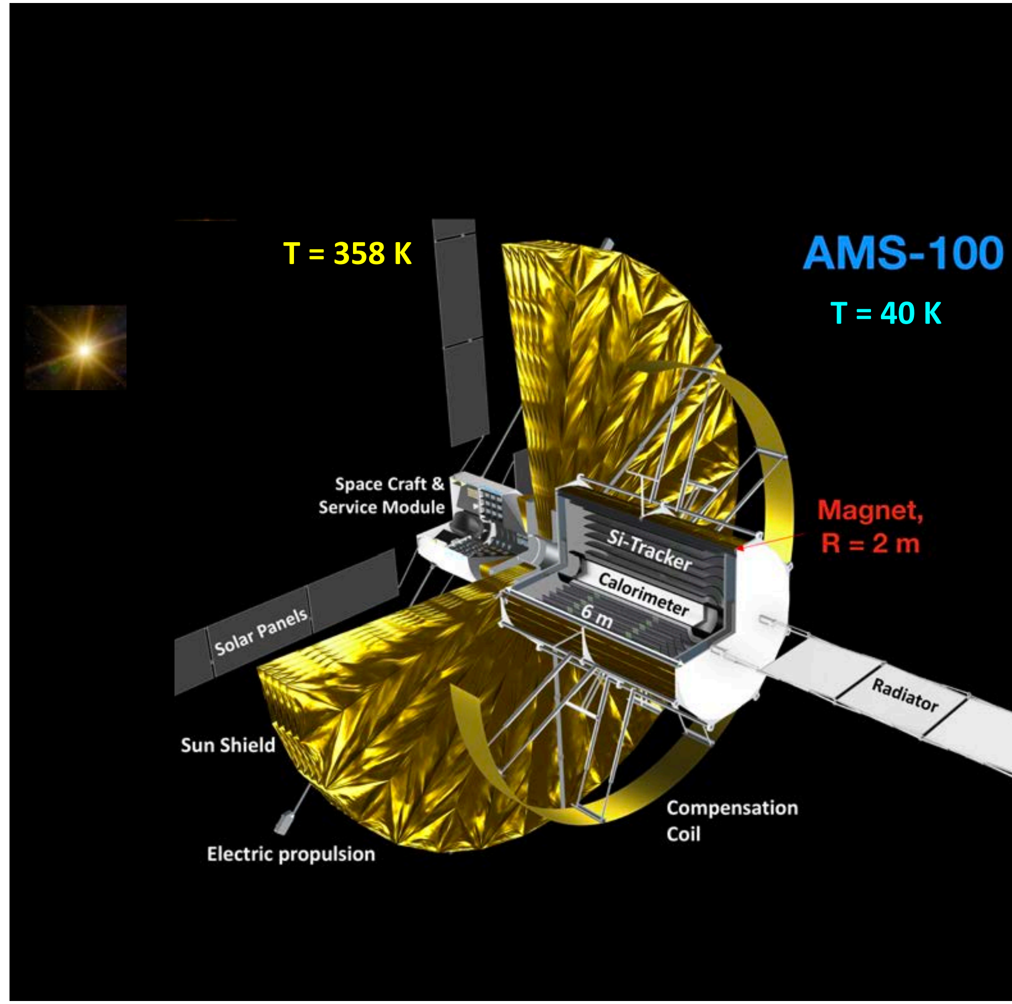
DM model from H. Jin et al., 2015, Phys. Rev. D 92, no. 5, 055027

DM model from A. Cuoco et al. 2017, Phys. Rev. Lett. 118, 191102, M. Korsmeier et al., 2018, Phys. Rev. D 97 n.10, 103011
BKG model from N. Tomassetti and A. Oliva, 2017, ApJ Lett. 844

AMS-100 (in L2)

AMS-100
The Next Generation Magnetic Spectrometer in Space –
An International Science Platform for Physics and Astrophysics at
Lagrange Point 2

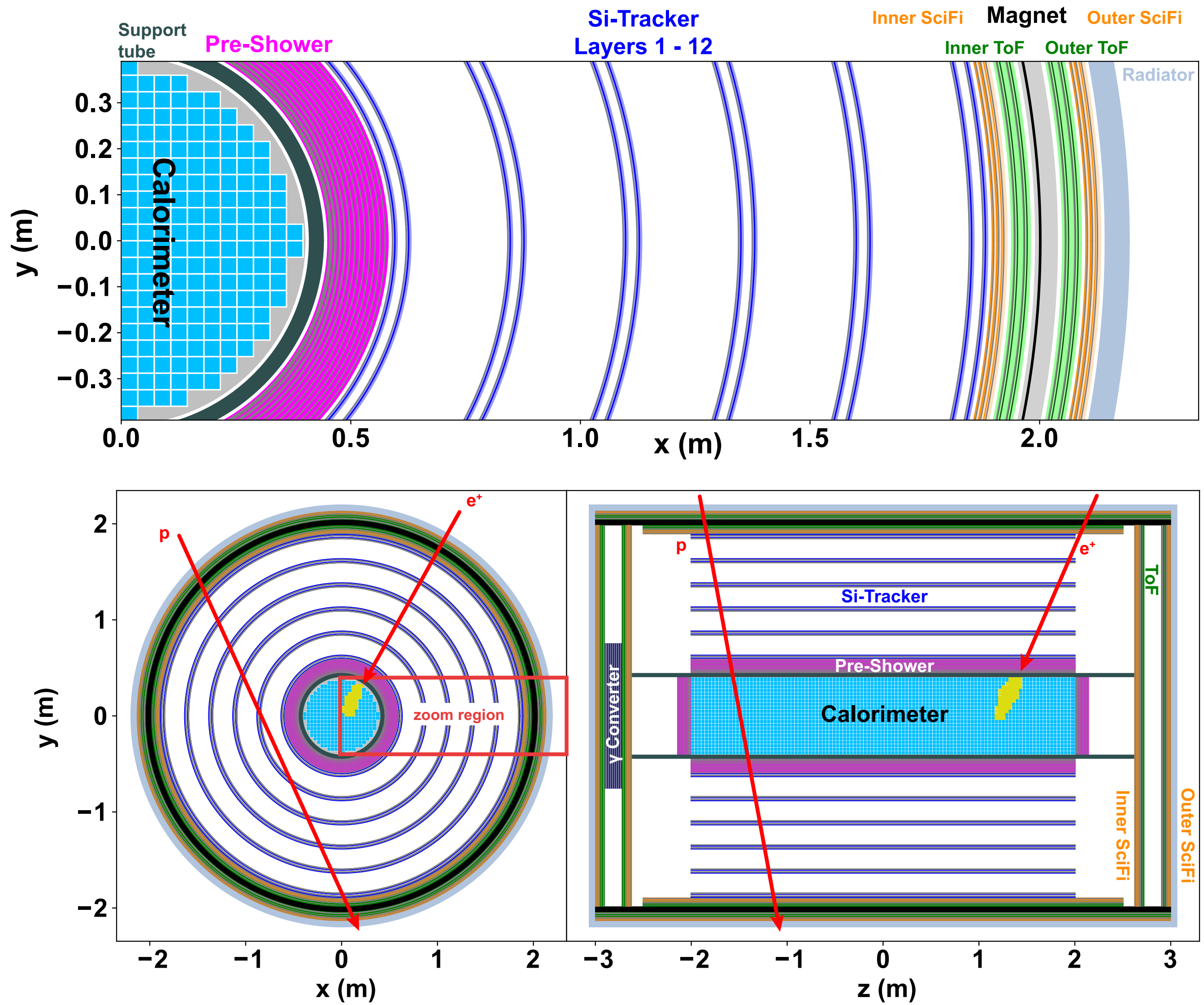




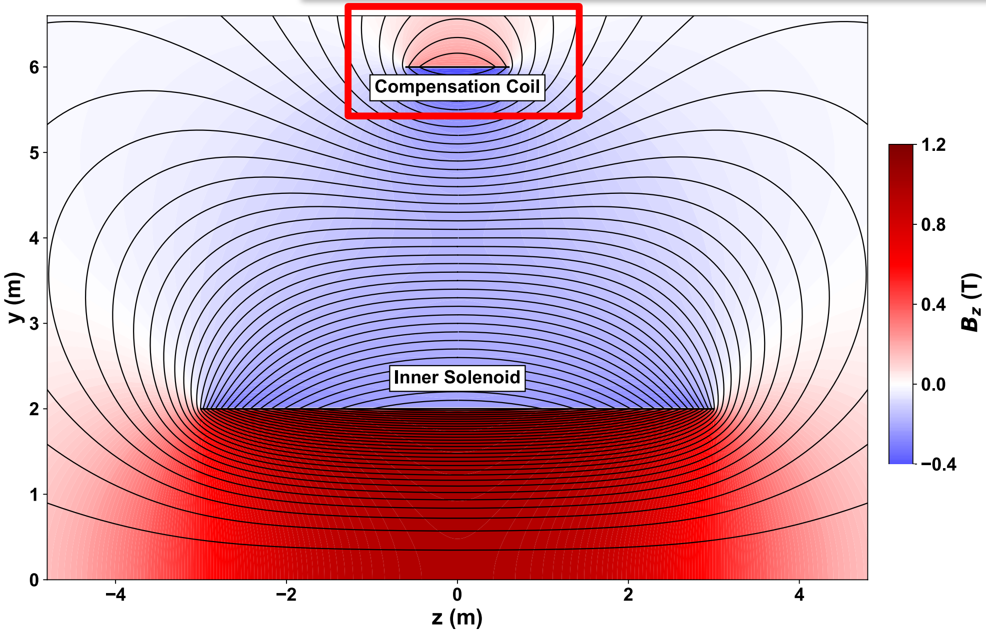
https://www.cosmos.esa.int/web/voyage-2050/white-papers
https://www.cosmos.esa.int/documents/1866264/3219248/SchaelS_AMS100_Voyage2050.pdf
arXiv:1907.04168v1 [astro-ph.IM] 9 Jul 2019

AMS-100 detector

- The Calorimeter is essentially based on the HERD design
- A Pre-Shower (silicon detectors + tungsten) is foreseen to provide an angular resolution for γ-rays similar to the Fermi-LAT one
- An additional external γ-ray converter on the end-cap is foreseen to increase the γ-ray acceptance



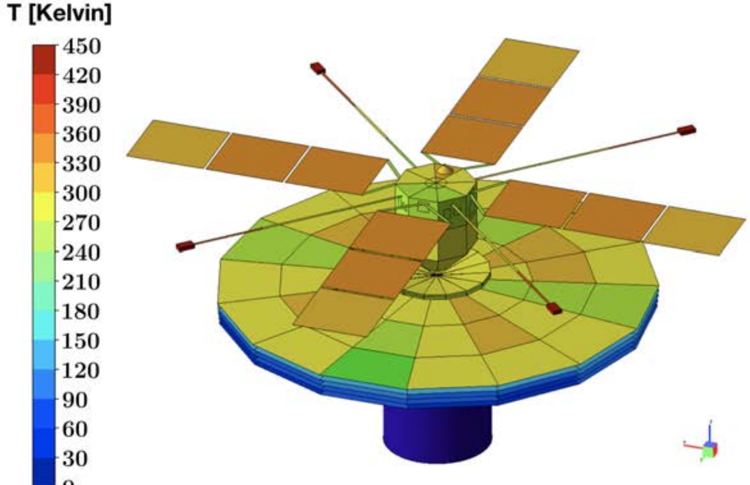
AMS-100 magnet and thermal system

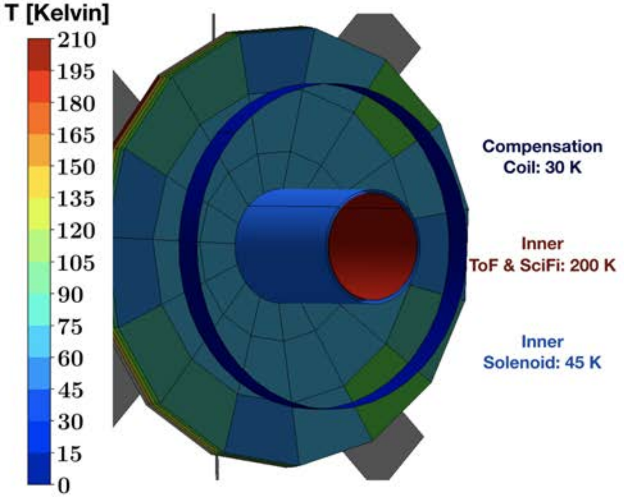


An (expandable) compensation coil balances the magnetic moment of the solenoid and allows the attitude control of the instrument within the heliospheric magnetic field

The High Temperature Superconducting magnetic system is based on REBCO tapes operated at 50-60° K

The sunshield is a key component of AMS-100, allowing the HTS magnet to operate without cryogens. It has a radius of 9 m and is designed similar to the concept developed for the James Webb Space Telescope

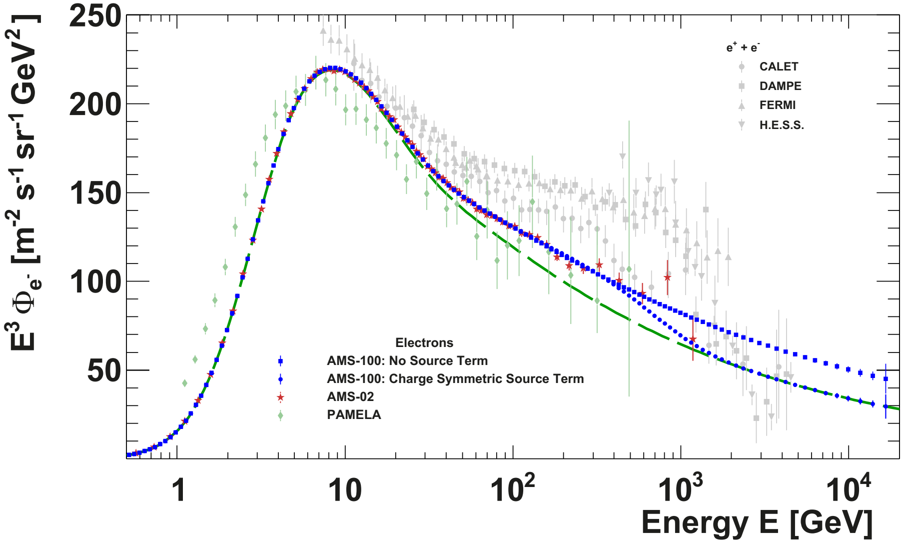


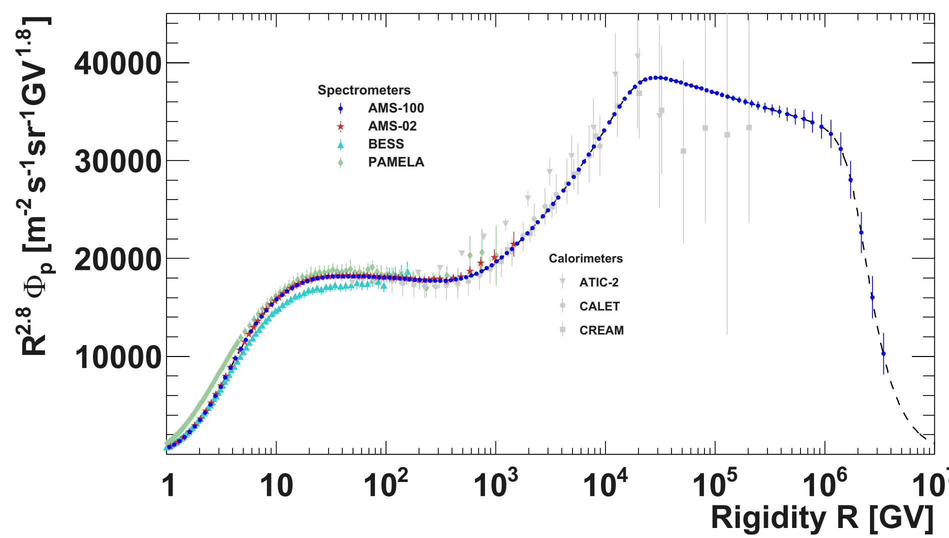


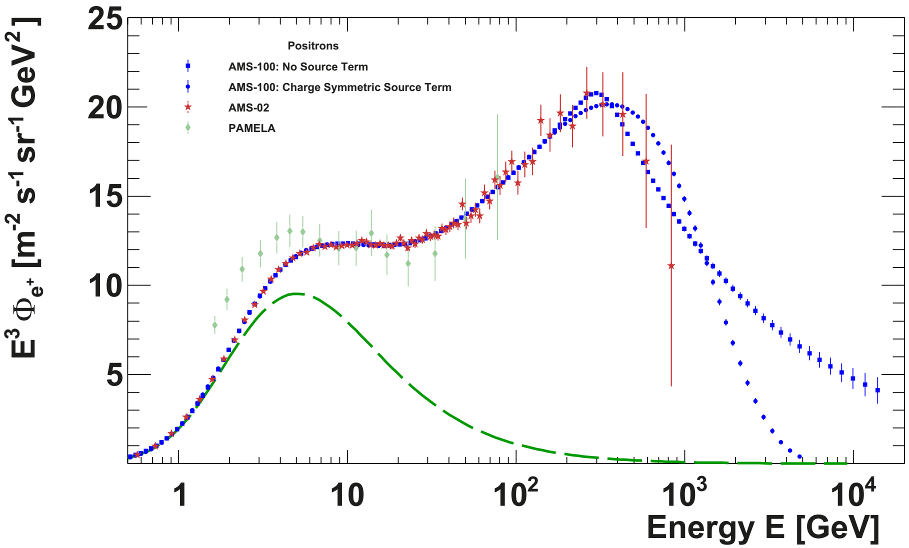
AMS-100 performances

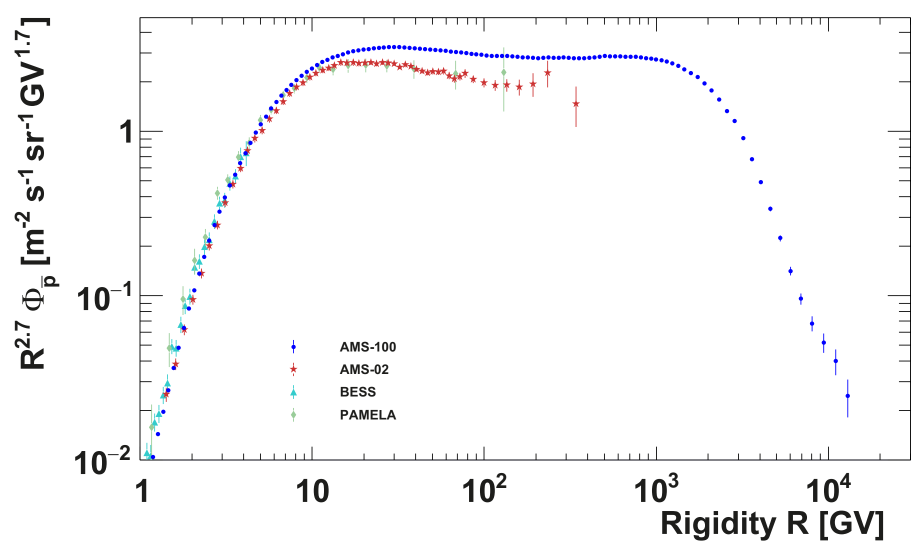
Quantity	Value	
Acceptance	$100\,\mathrm{m}^2\,\mathrm{sr}$	
MDR	100 TV	for $\lvert Z \rvert = 1$
Material budget	$0.12\,X_0$	
of main solenoid	$0.012\,\lambda_I$	
Calorimeter depth	$70\,X_0,\ 4\,\lambda_I$	
Energy reach	10^{16} eV	for nucleons
	10 TeV	for e^+, $\bar{p}$
	8 GeV/n	for $\bar{D}$
Angular resolution	4″	for photons at 1 TeV
	0″.4	for photons at 10 TeV
Spatial resolution (SciFi)	40 µm	
Spatial resoultion (Si-Tracker)	5 µm	
Time resolution of single ToF bar	20 ps	
Incoming particle rate	2 MHz	
High-level trigger rate	few kHz	
Downlink data rate	~28 Mbps	
Instrument weight	43 t	
Number of readout channels	8 million	
Power consumption	15 kW	
Mission flight time	10 years	

AMS-100 capabilities

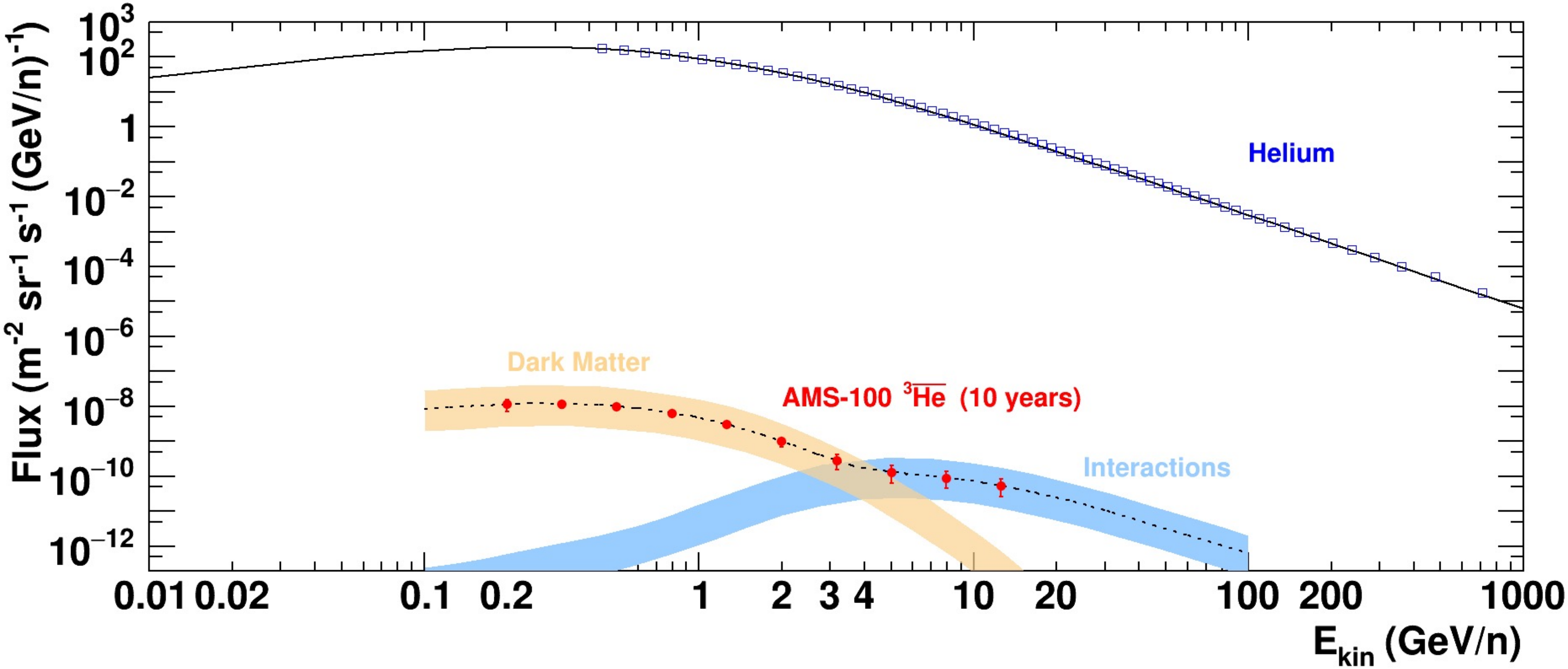








AMS-100 capabilities



- E. Carlson et al., 2014, Phys. Rev. D 89, 076005
- M. Cirelli et al., 2014, JHEP 1408, 009
- A. Coogan and S. Profumo, 2017, Phys. Rev. D 96, 083020

Instrument performances

Item	HERD	ALADINO	AMS-100
Electromagnetic calorimeter depth	55 X_0	61 X_0	70 X_0
Hadronic calorimeter depth	3 λ_I	3.5 λ_I	4 λ_I
MDR	-	20 TV	100 TV
Acceptance (spectrometer)	-	~ 10 m^2 sr	~ 100 m^2 sr
Acceptance (spectrometer + calorimeter	-	~ 3 m^2 sr	~ 30 m^2 sr
Acceptance (calorimeter)	~ 3 m^2 sr	~ 9 m^2 sr	~ 30 m^2 sr
# of channels	300 k	2.5 M	8 M
Weight	~ 4000 kg	~ 6000 kg	~ 40000 kg
Power Consumption	~ 1400 W	~ 4000 W	~ 15000 W

Stay tuned…