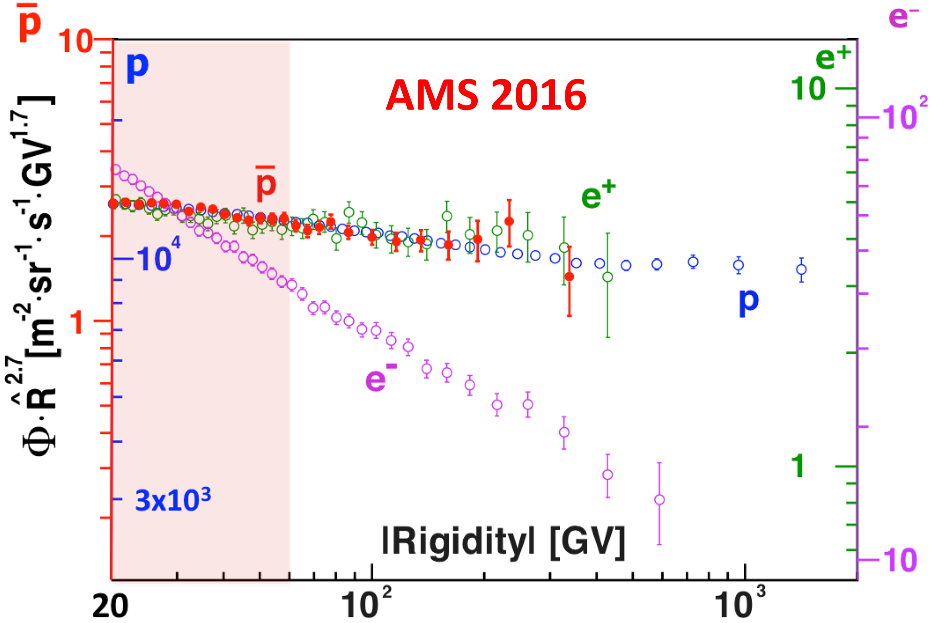
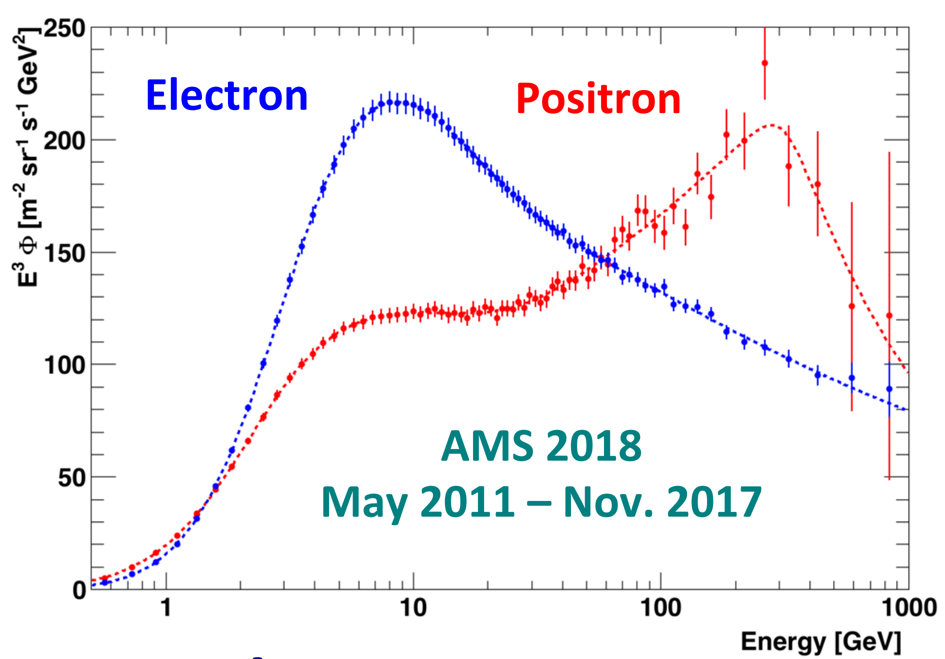
AMS-100 -
A Magnetic Spectrometer at Lagrange Point 2

- AMS-02 is an excellent experiment on the Space Station. It is now operational since 7 years. We plan to operate it till the end of the lifetime of the ISS in 2024. Is is now time to think about the next step!

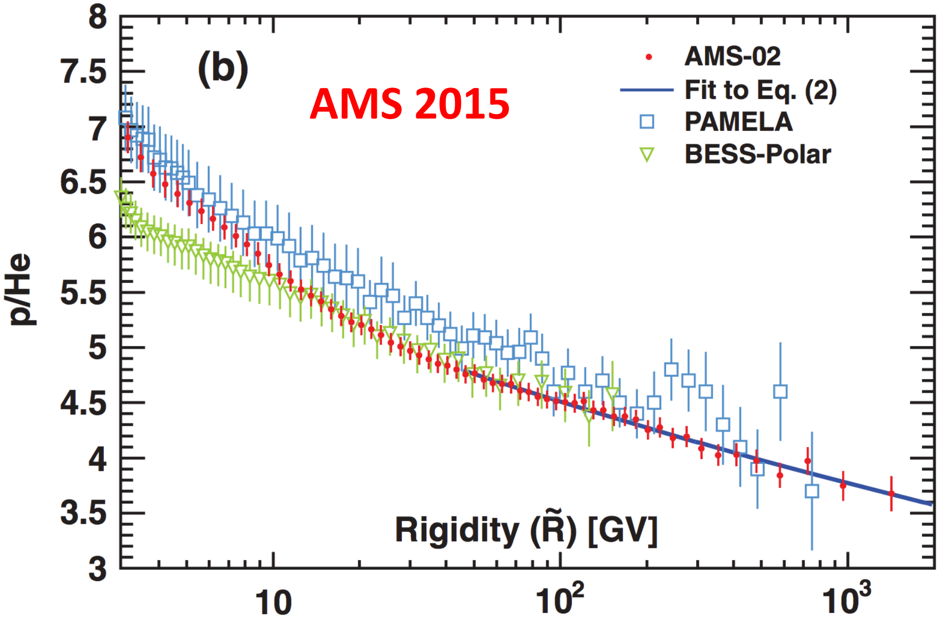
Stefan Schael, RWTH Aachen University

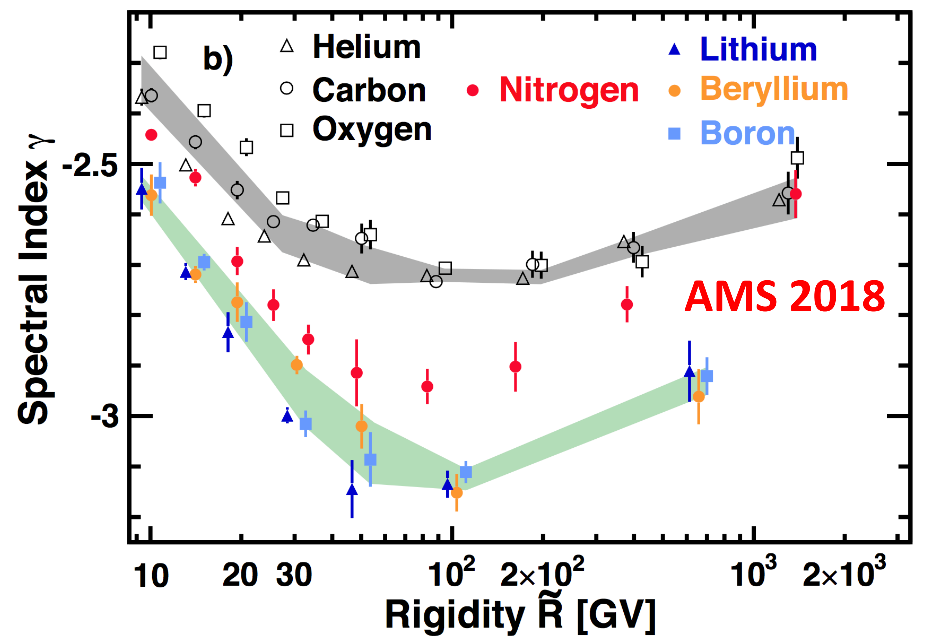
La Palma, April 2018





Recent AMS Results





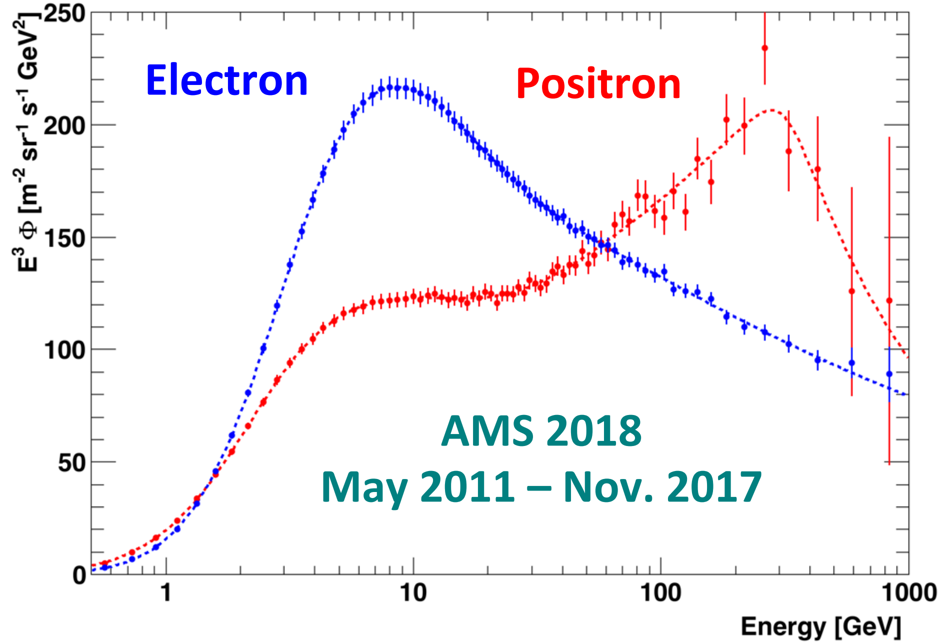
Discussion at this conference:

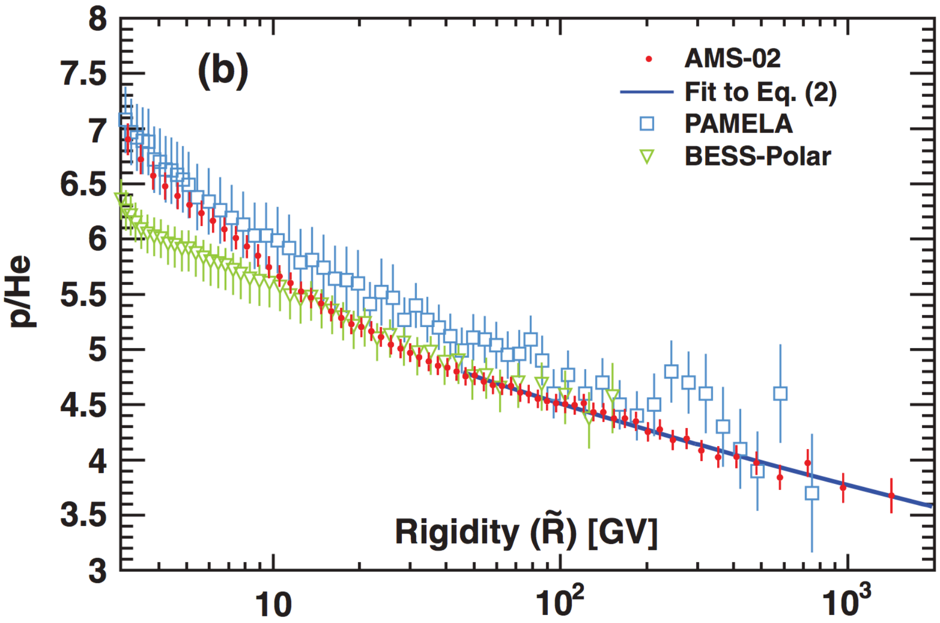
„We need to measure He/Proton to higher energies.“, Pasquale Blasi

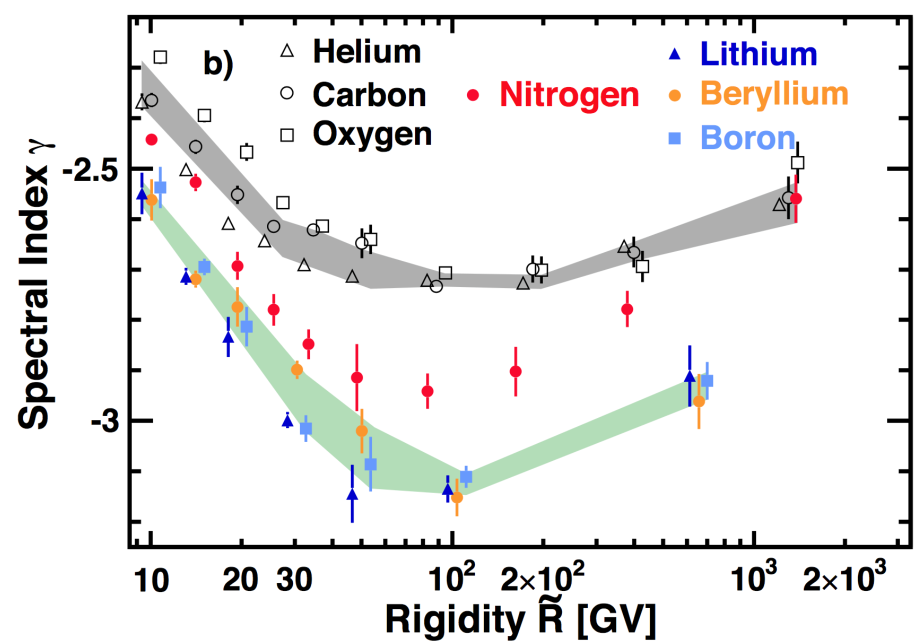
„We need to measure photons in the energy range 300 GeV-3000 GeV with high precision.“, Ilias Cholis.

„To have the rigidity distribution for anti He would be great. “, Igor Moskalenko

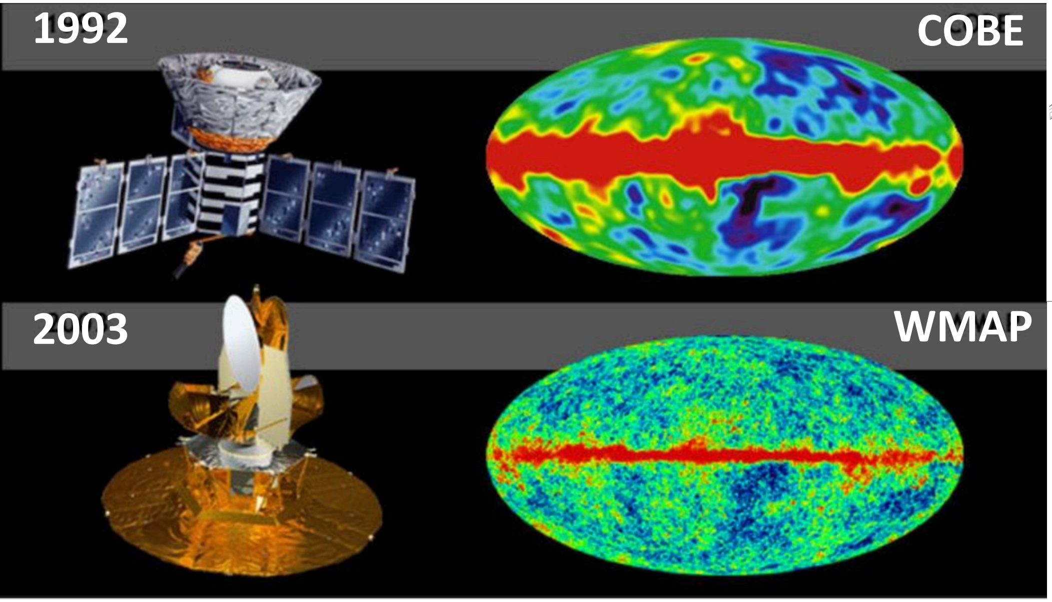
As hosts we try to fulfill the wishes of our guests ...

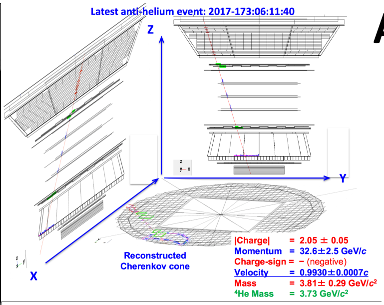




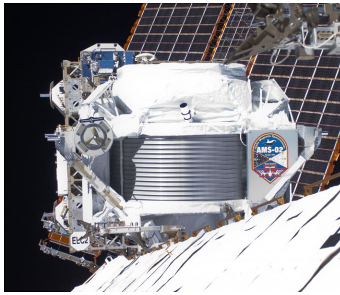


AMS-100: A Magnetic Spectrometer at Lagrange Point 2





AMS-02
2011



AMS-100
2022

- Similar to COBE and WMAP or the Hubble- and the James Webb Space Telescope the only option for significant improvements compared to AMS-02 is a large magnetic spectrometer operated at Lagrange Point 2.

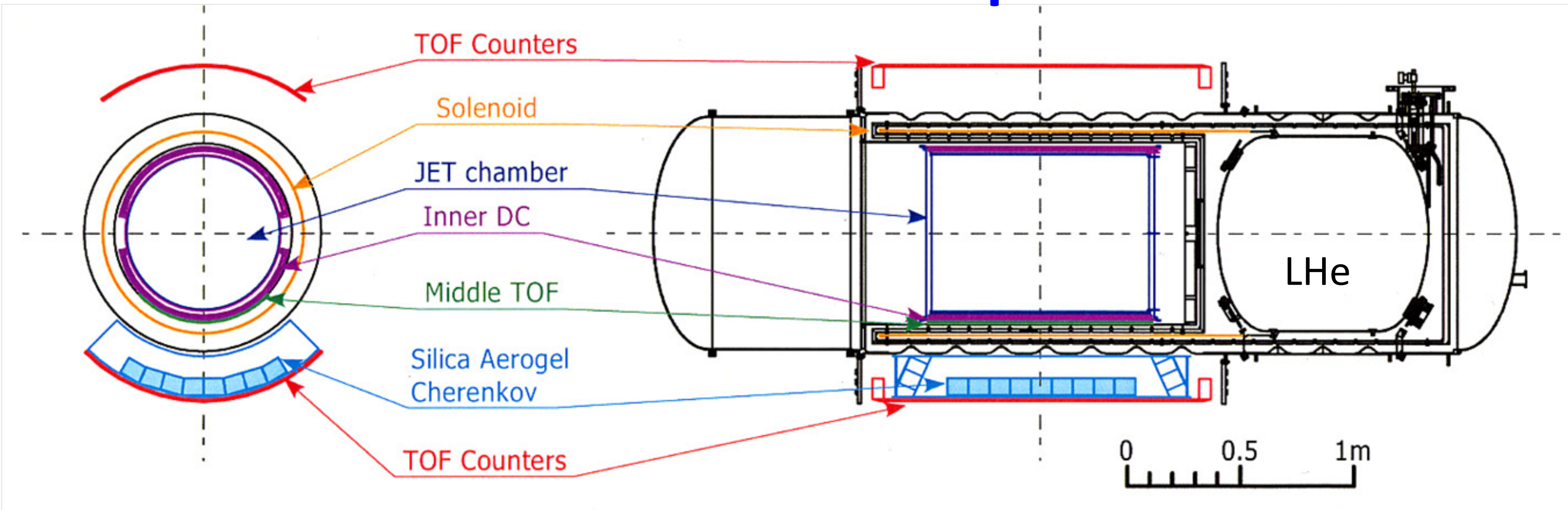
- A factor 10 in energy reach requires a factor 1000 in acceptance.
  AMS-02 has an acceptance of 0.1 m^2 sr at high energies and weights 7 tons.

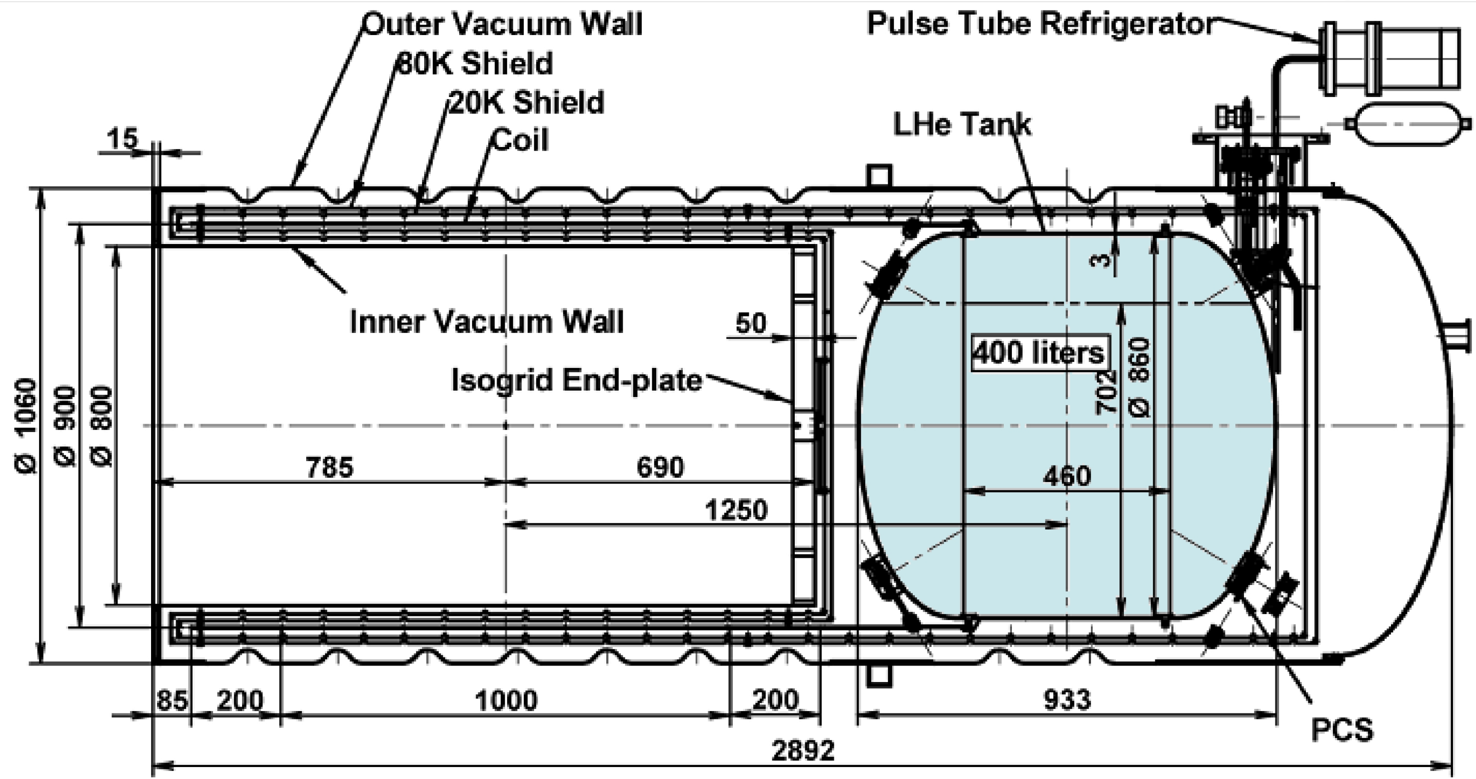
BESS Polar – Balloon Experiment

December 13, 2004

The concept of AMS-100 is inspired by the design of the successfull BESS Polar Experiment.

BESS Polar – Balloon Experiment

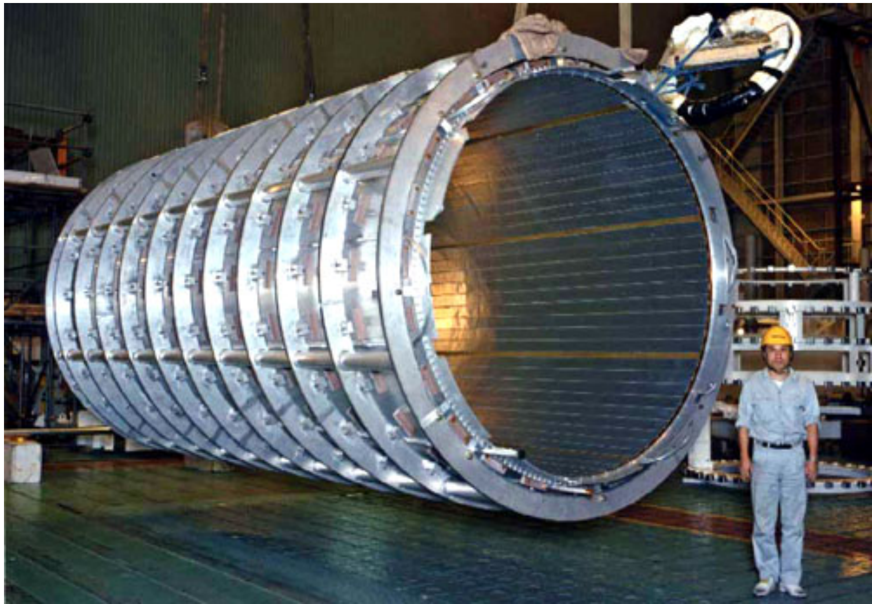




ATLAS Central Solenoid Magnet

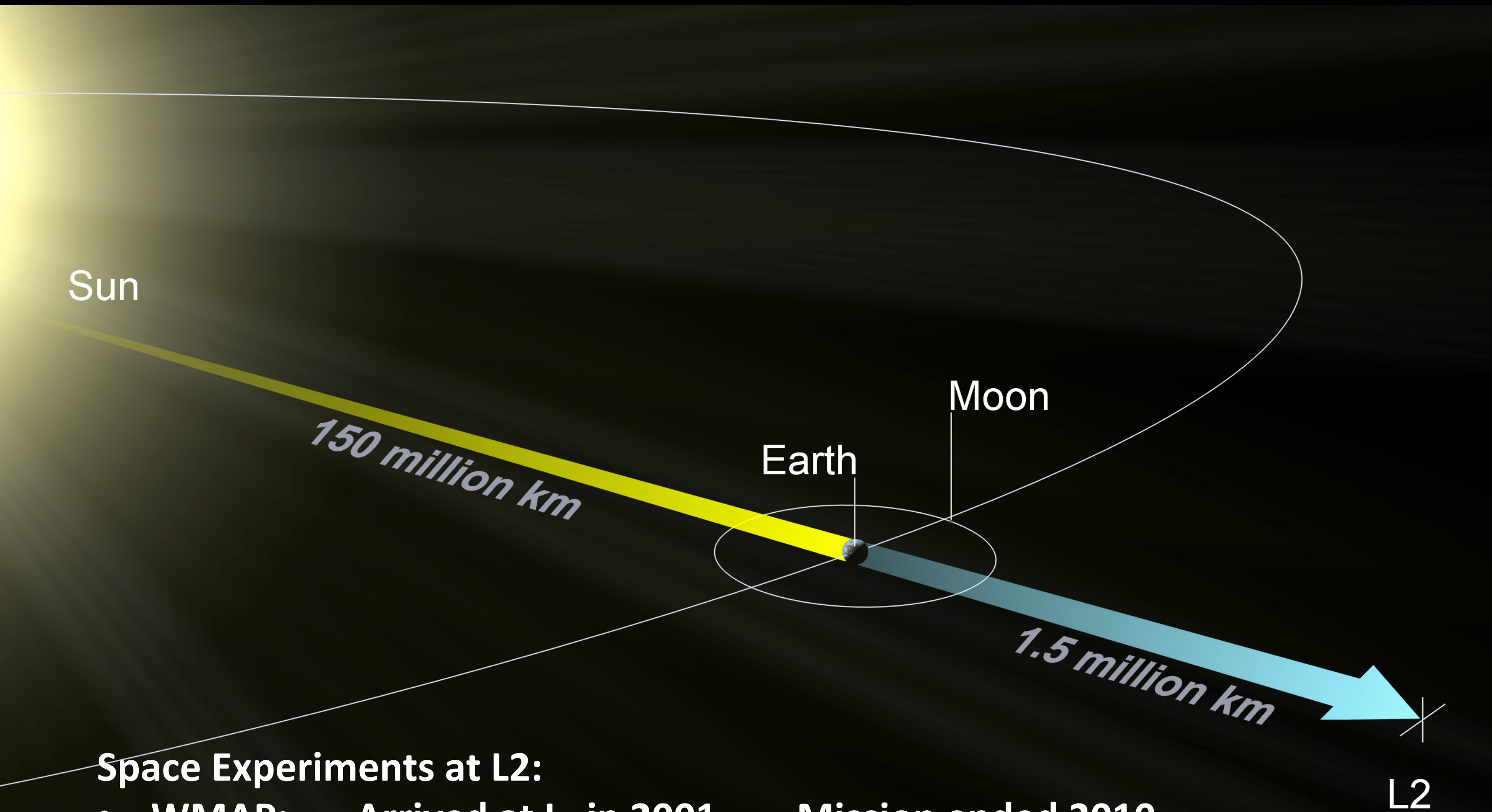
- **only 0.66 radiation lengths X0 thick**
- **made from aluminium enforced Nb/Ti conductor**
- **operation temperature 4.5 K**

- 5.3 long, 2.4 m diameter, 4.5 cm thick
- 5 tonne weight
- 2 tesla (T) magnetic field with a stored energy of 38 megajoules (MJ)
- 9 km of superconducting wire
- Nominal current: 7.73 kiloampere (kA)



AMS-100: Operation at Lagrange Point 2

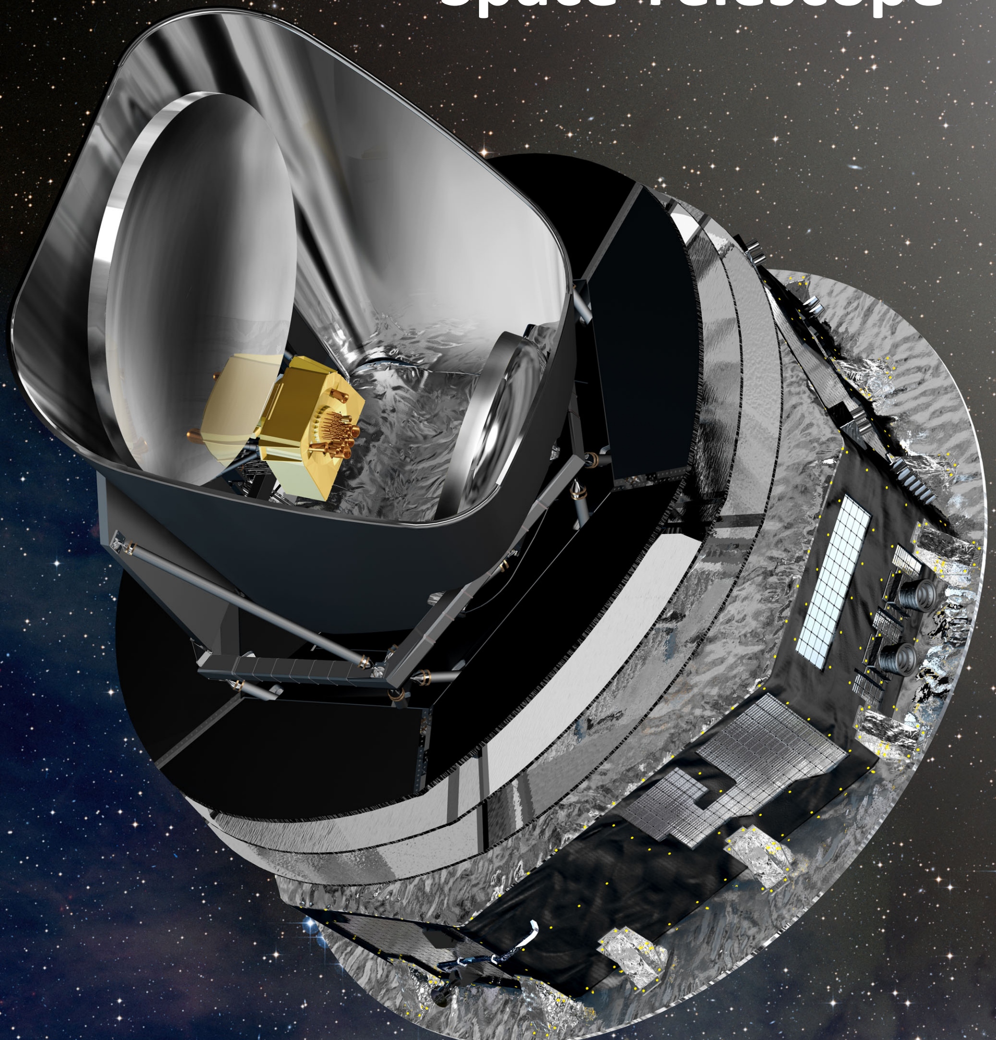
Due to earth magnetic field a cryogenic solenoid magnet can only be operated at L2.



Space Experiments at L2:

- **WMAP:** **Arrived at L_2 in 2001. Mission ended 2010**
- **Herschel:** **Arrived at L_2 July 2009. Ceased operation on 29 April 2013**
- **Planck:** **Arrived at L_2 July 2009. Mission ended on 23 October 2013**
- **Chang'e 2:** **Arrived in August 2011 after completing a lunar mission before departing en route to asteroid 4179 Toutatis in April 2012.**

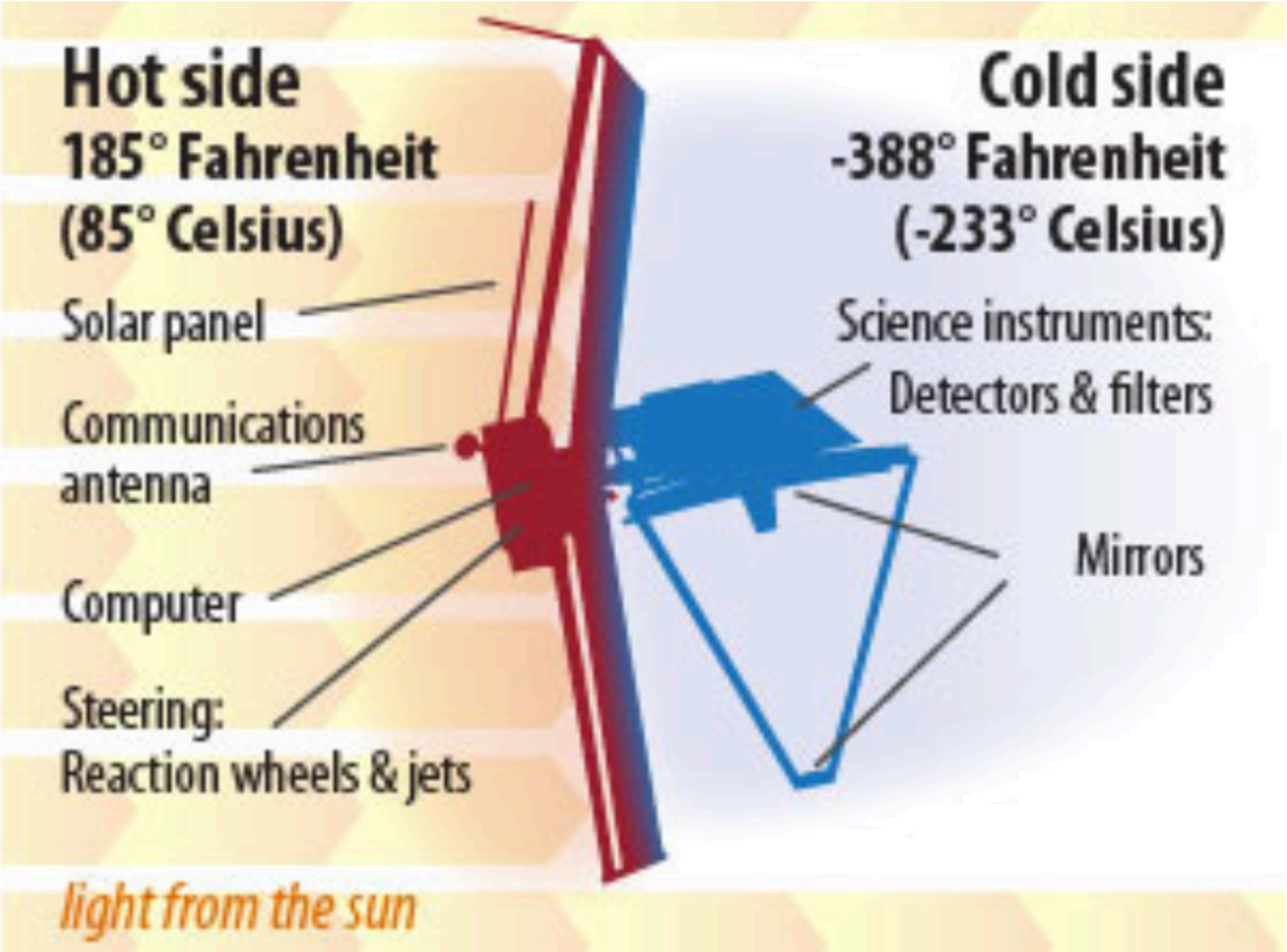
PLANCK
Space Telescope



Planck's cooling systems allow it to maintain a temperature of −273.05 °C. From August 2009, Planck was the coldest known object in space.

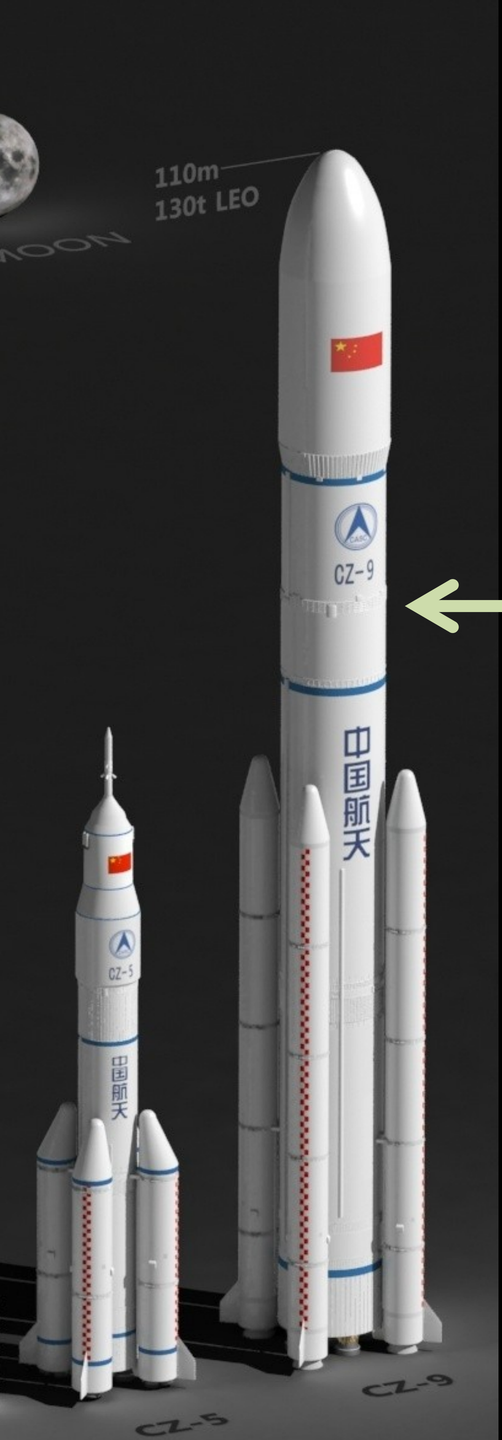
Mission duration	Planned: >15 months Final: 4 years, 5 months, 8 days
Spacecraft properties	
Manufacturer	Thales Alenia Space
Launch mass	1,950 kg (4,300 lb)[1]
Payload mass	205 kg (452 lb)
Dimensions	Body: 4.20 m × 4.22 m (13.8 ft × 13.8 ft)
Start of mission	
Launch date	14 May 2009, 13:12:02 UTC
Rocket	Ariane 5 ECA
Launch site	Guiana Space Centre, French Guiana
Contractor	Arianespace
Entered service	3 July 2009
End of mission	
Disposal	Decommissioned
Deactivated	23 October 2013, 12:10:27 UTC
Orbital parameters	
Reference system	L_2 point (1,500,000 km / 930,000 mi)
Regime	Lissajous

James Webb Telescope -
a space telescope at Lagrange Point 2



The science phase of the mission is expected to start in 2018 and to last for 10.5 years.

This sunshield support structure is very strong, yet quite light, weighing only 63 kilograms (139 pounds), while supporting the sunshield itself, which weighs 700 kilograms (1,543 pounds).



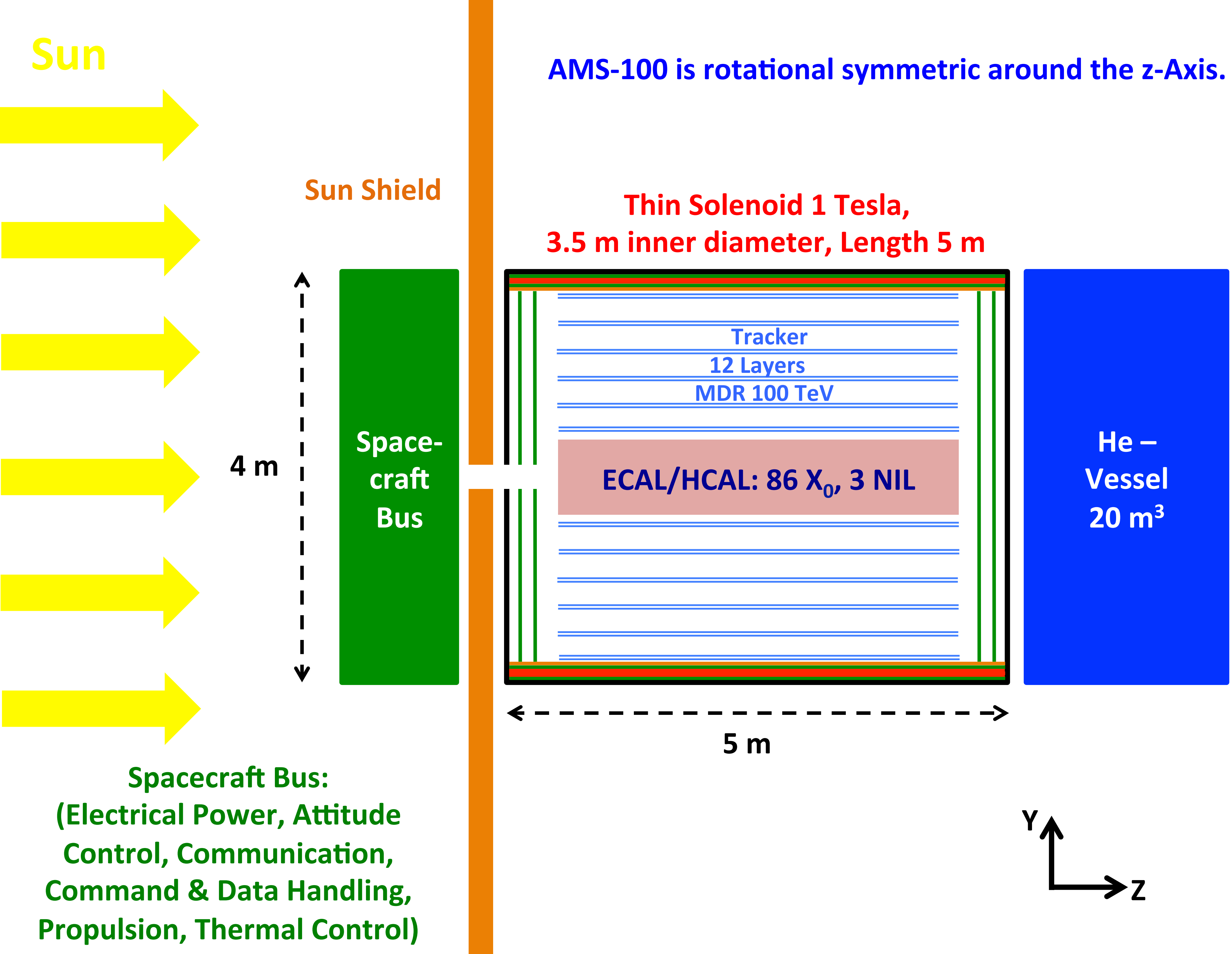
Current and upcoming rockets

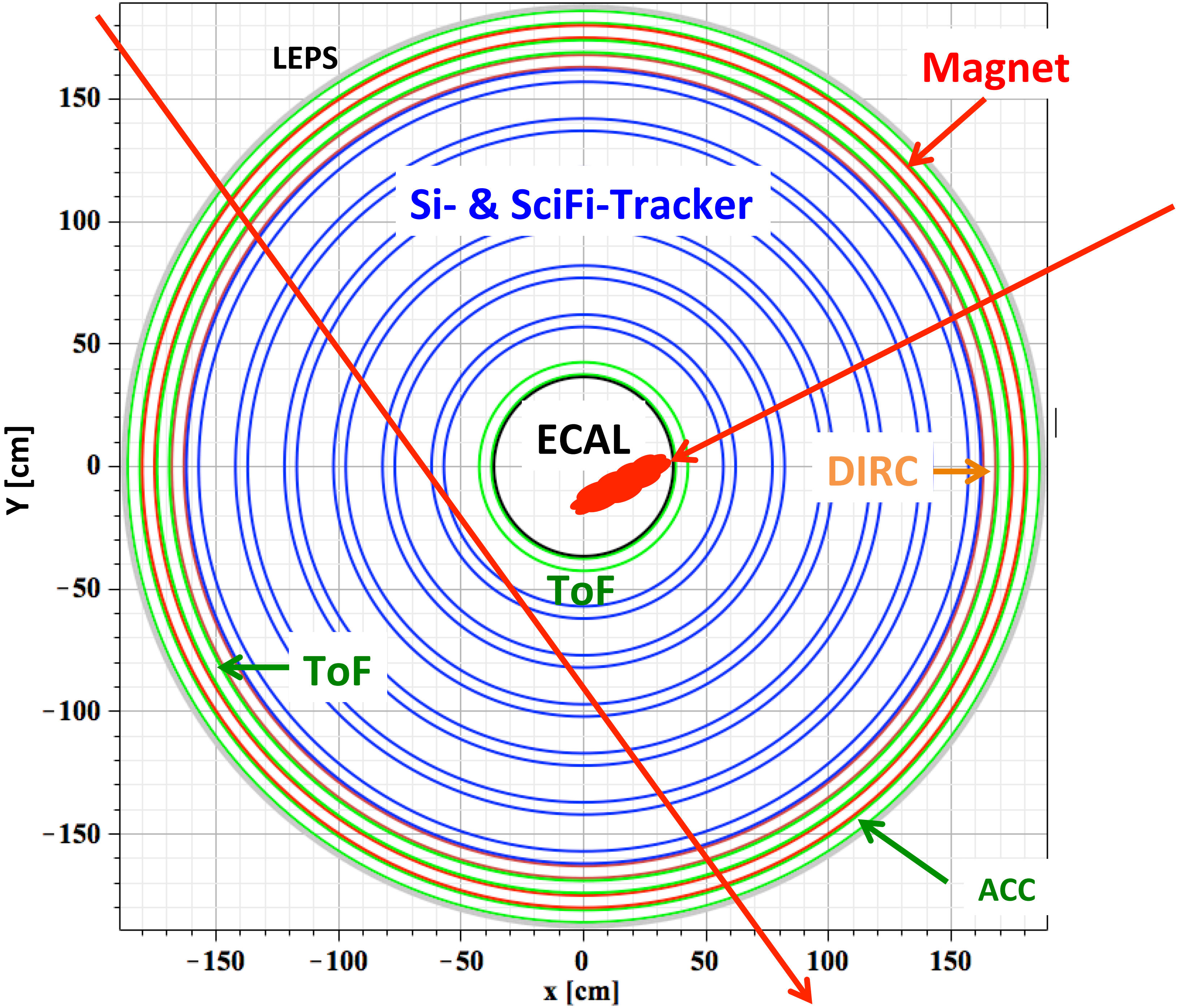
Name	LEO [kg]	other [kg]	First flight	
Ariane 5	21,000	10,730 GTO	2002	ESA
Falcon Heavy	63,800	26,700 GTO	2018	SpaceX
Long March 5	25,000	8,000 TLI	2016	CALT
Long March 9	130,000	50,000 TLI	2025	CALT
SLS Block 1B	105,000	39,100 TLI	2022	NASA
SLS Block 2	130,000	45,000 TLI	2025	NASA

Operational

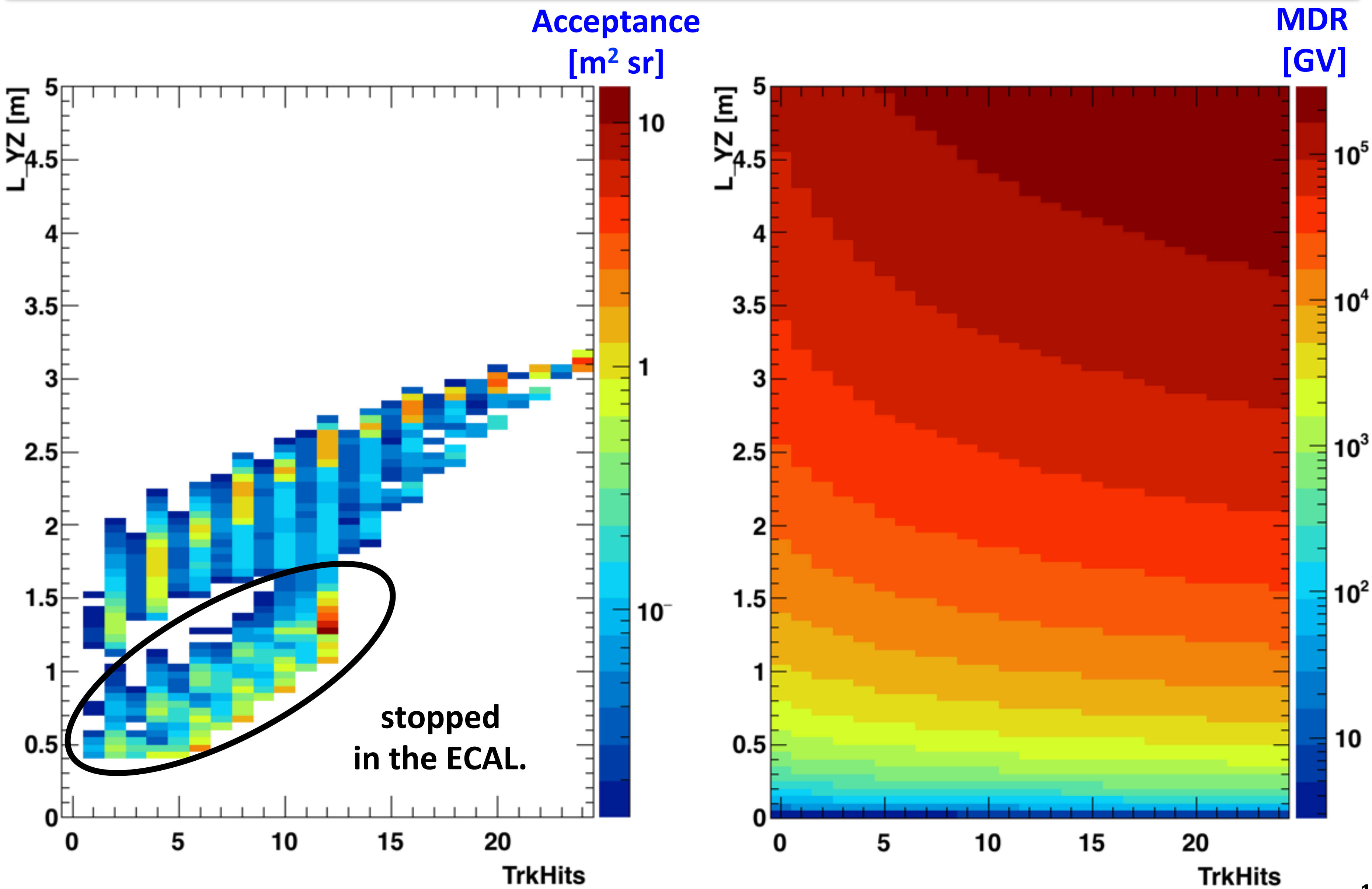
Under development

LEO: Low Earth orbit
GTO: Geostationary transfer orbit
TLI: Trans-lunar injection


Sun
AMS-100 is rotational symmetric around the z-Axis.
Sun Shield
Thin Solenoid 1 Tesla,
3.5 m inner diameter, Length 5 m
4 m
Space-
craft
Bus
Tracker
12 Layers
MDR 100 TeV
ECAL/HCAL: 86 X_0, 3 NIL
He –
Vessel
20 m^3
5 m
Spacecraft Bus:
(Electrical Power, Attitude
Control, Communication,
Command & Data Handling,
Propulsion, Thermal Control)
Y
Z


LEPS
Magnet
Si- & SciFi-Tracker
ECAL
DIRC
ToF
ToF
ACC
150
100
50
0
−50
−100
−150
Y [cm]
−150
−100
−50
0
50
100
150
x [cm]

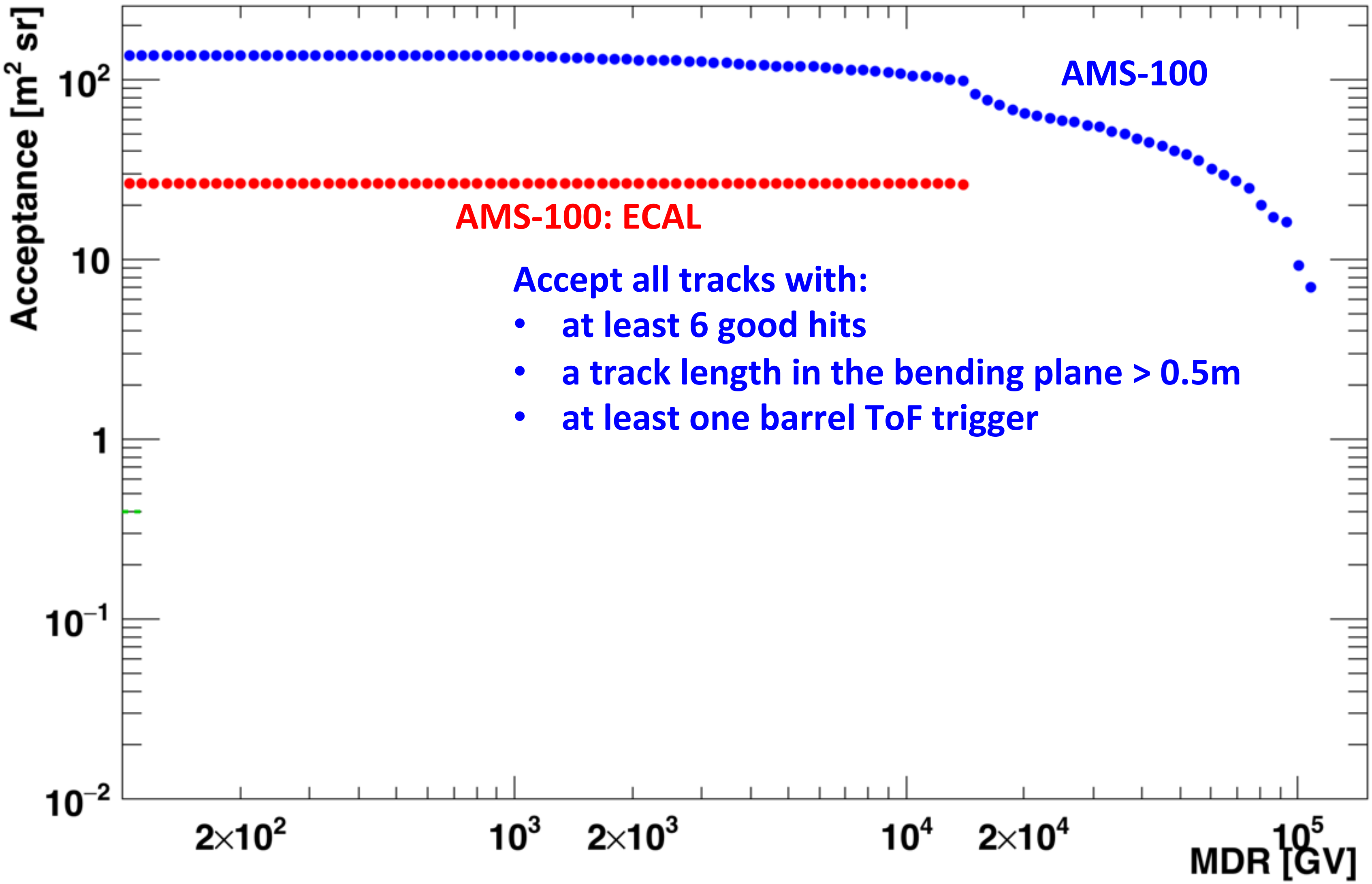
Acceptance & MDR



Acceptance

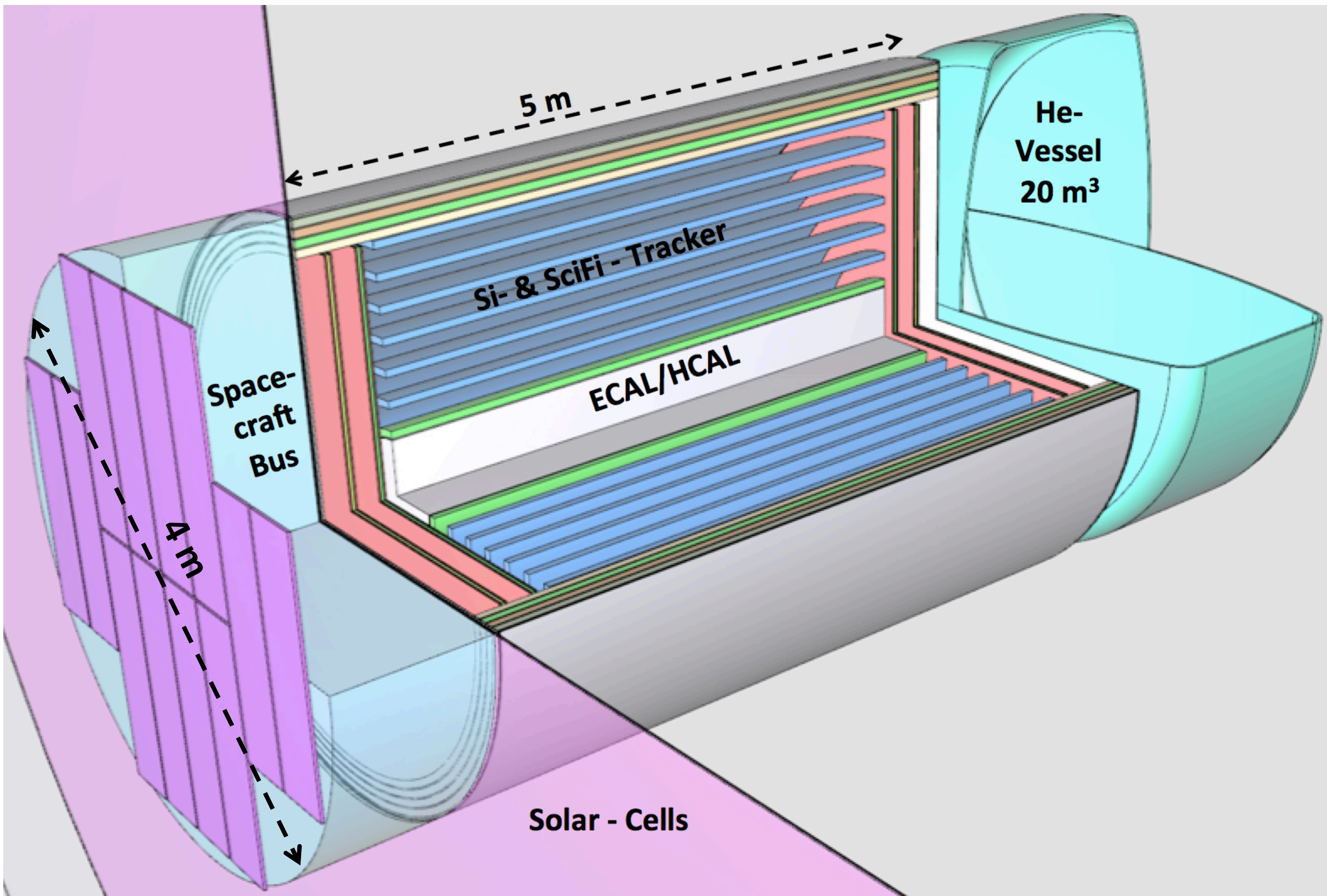
At 10 TeV: Tracker: 81 [m^2 sr] ECAL: 26 [m^2 sr] Total: 107 [m^2 sr]

At 100 TeV: Tracker: 10 [m^2 sr] ECAL: 0 [m^2 sr] Total: 10 [m^2 sr]



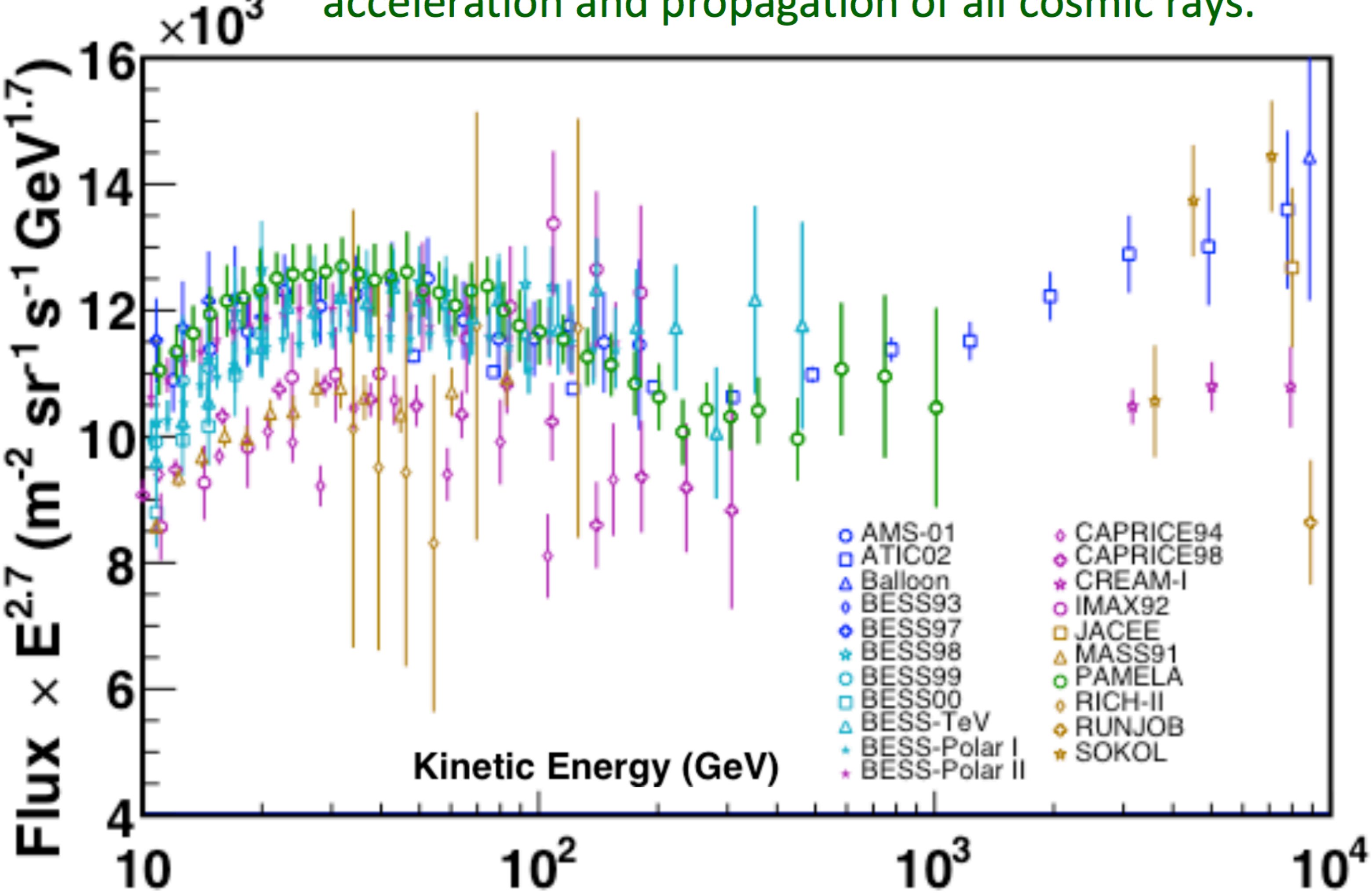
AMS-100: A Magnetic Spectrometer at LP-2

Weight: 43 t | Readout-Channels: 4 10^6 | Power: 40 kW | Trigger Rate: 1 MHz
MDR: 100 TeV | Acceptance: 100 m^2 sr | B-Field: 1 Tesla

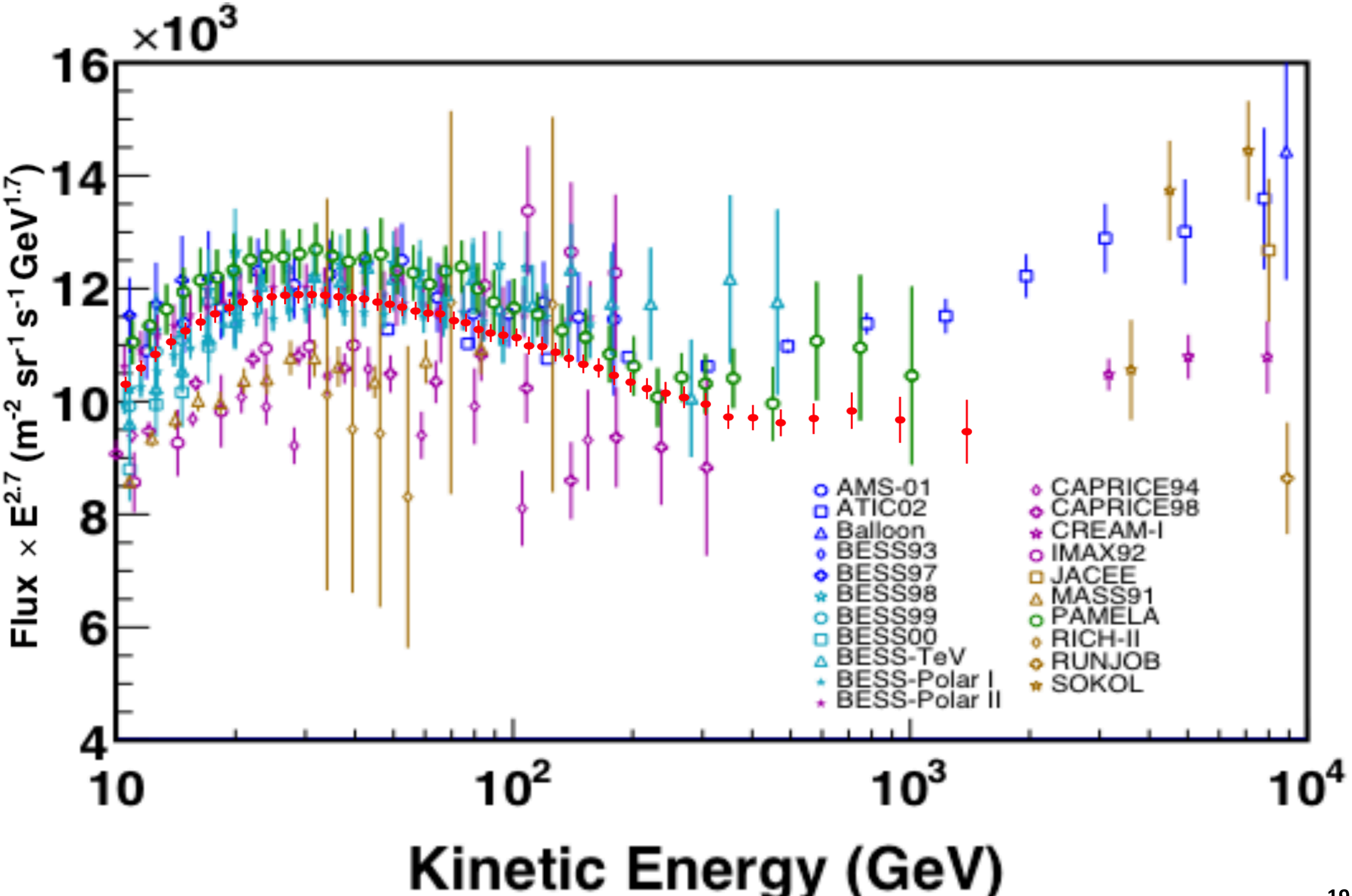


Measurements of proton spectrum before AMS

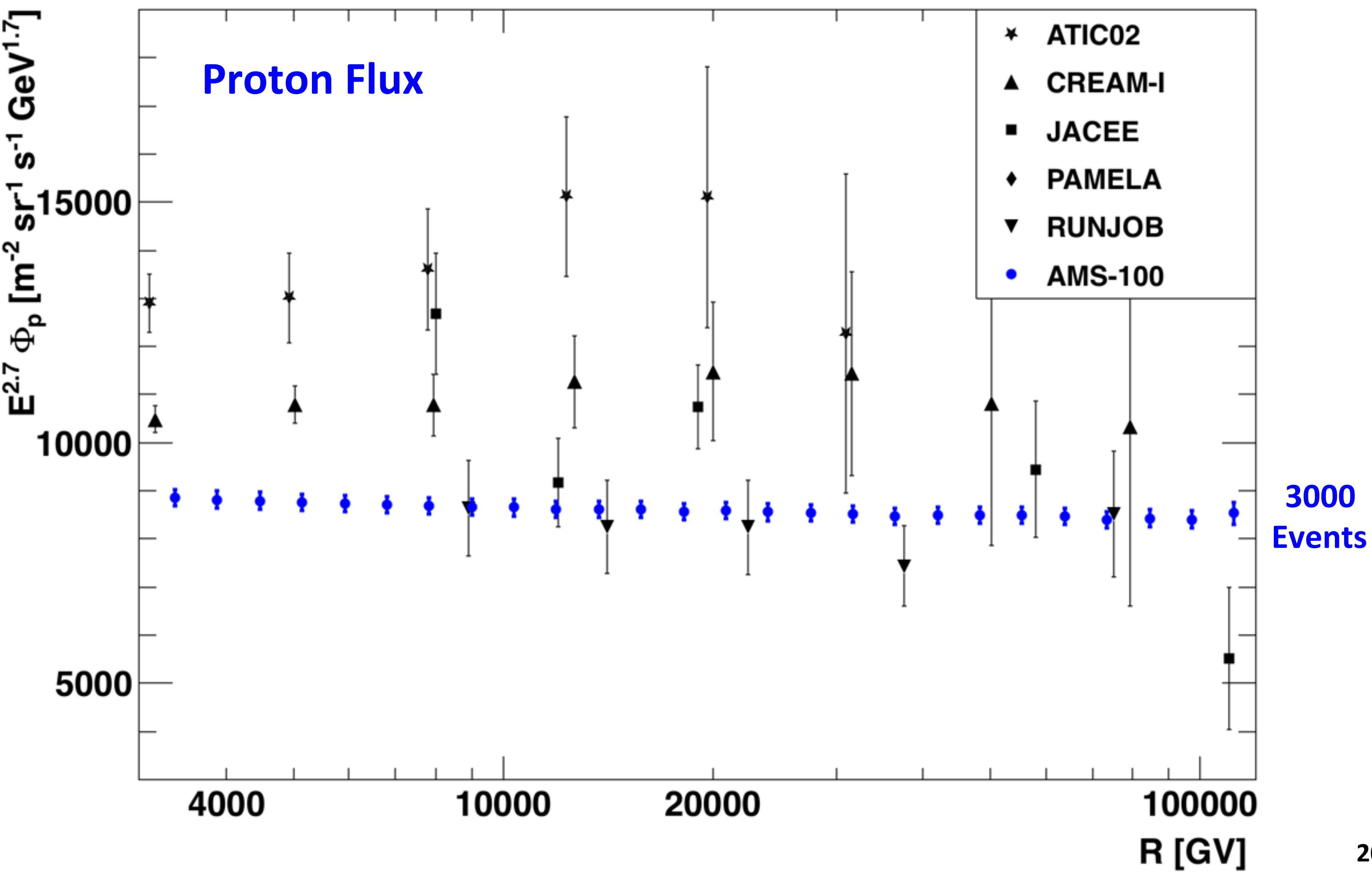
1. Protons are the most abundant charged cosmic rays.
2. These were the best data over the last hundred years.
3. Nonetheless, the data have large errors and are inconsistent.
4. These data limit the understanding of the production, acceleration and propagation of all cosmic rays.



AMS Measurement of the proton spectrum



We don‘t know what we would find in this energy region with an instrument with 1% accurancy and an MDR of 100 TV.



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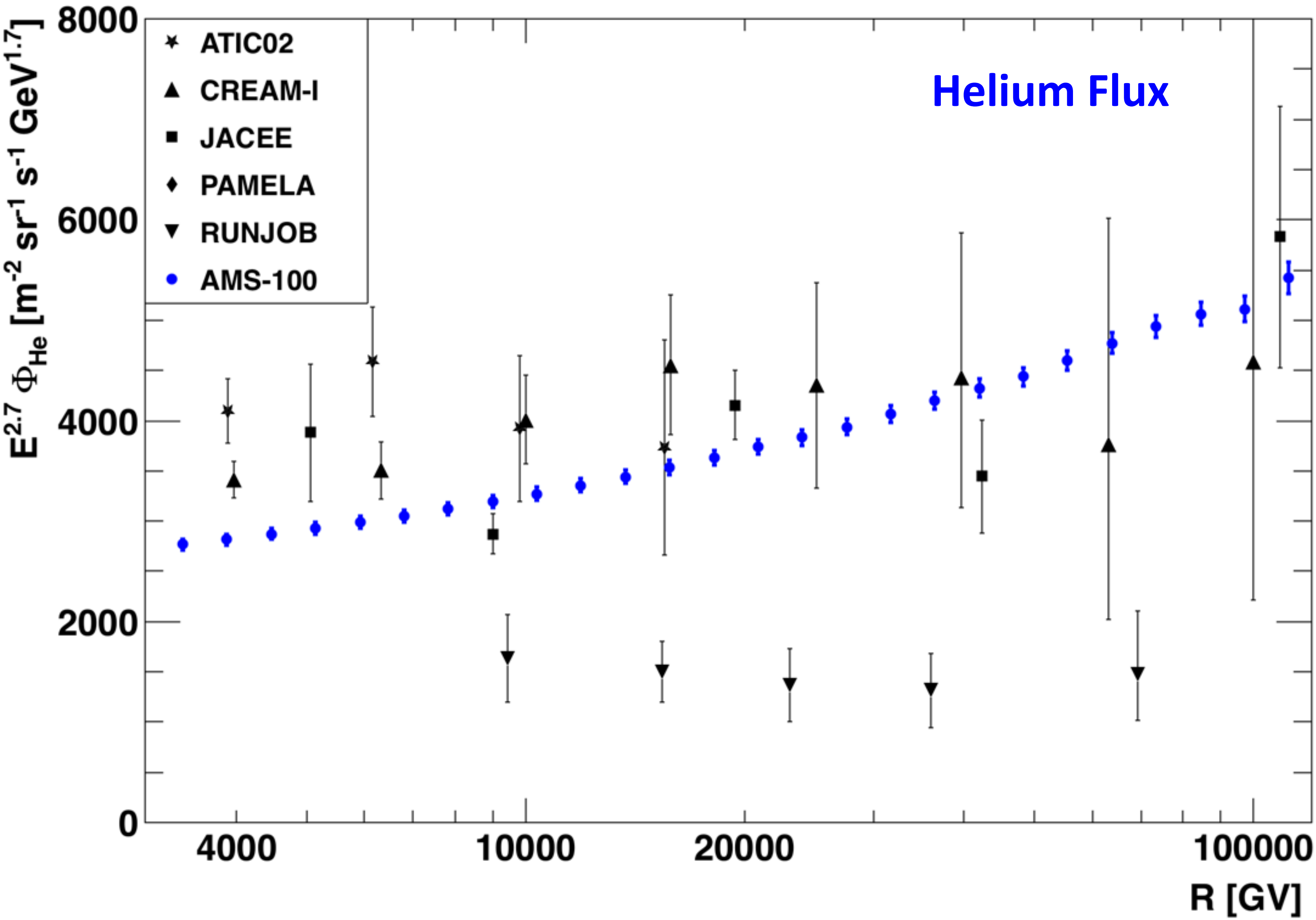
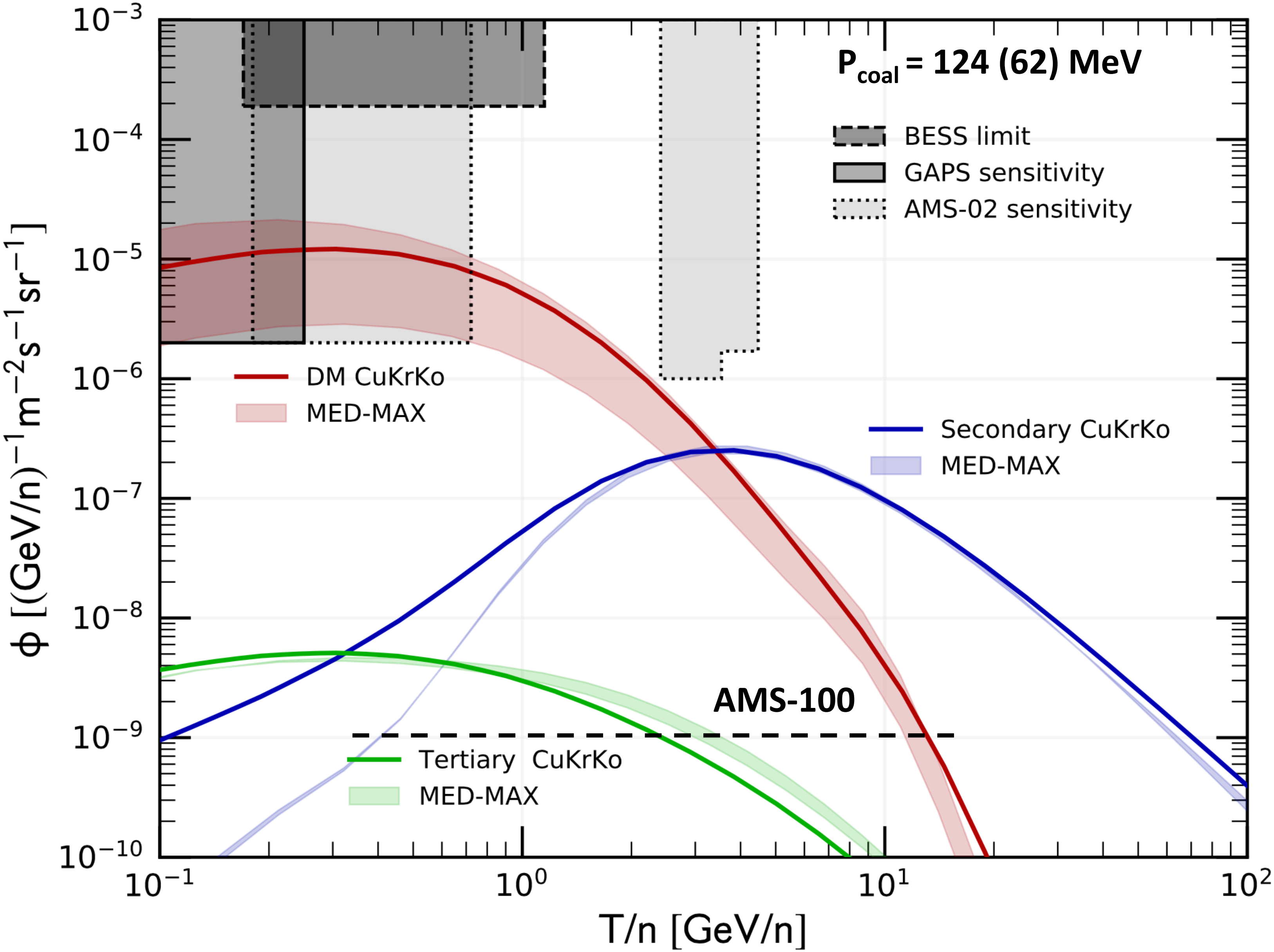


Anti-Deuteron

F. Donato, Fornengo, Korsmeier, 1711.08465 subm. PRD



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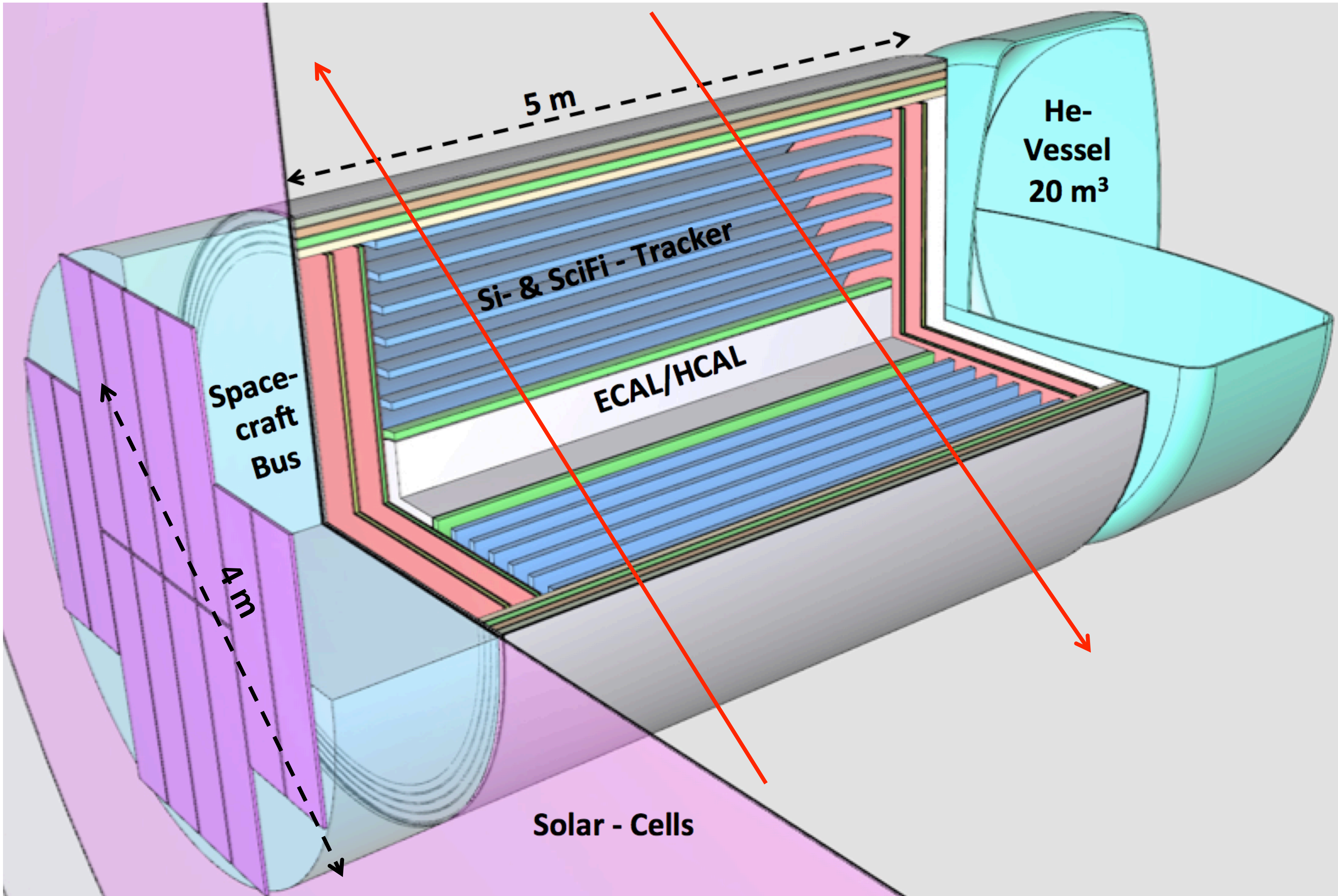
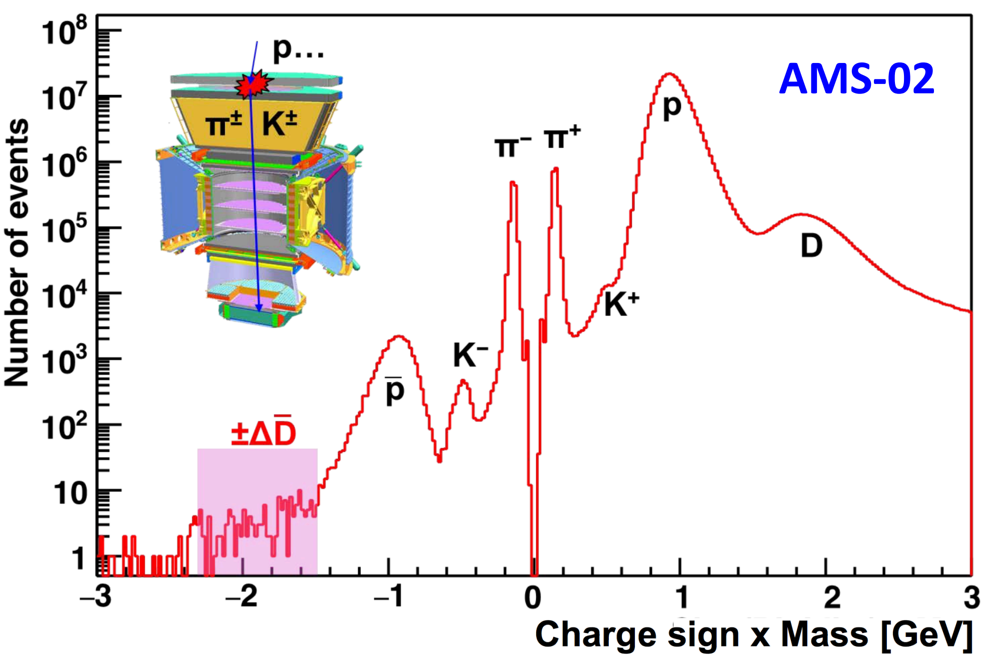
Due to the rotational symmetry of the instrument one would expect the same number of anti-He particles going upwards or going downwards.
This is equivalent to a change of the polarity of the magnetic field.

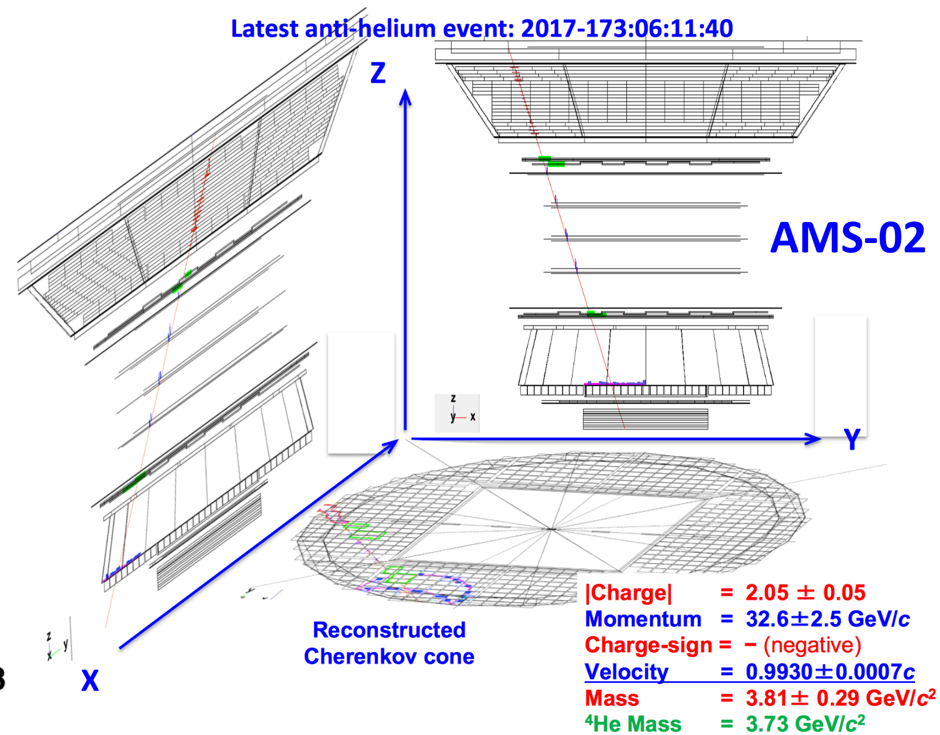


AMS-100: Charged Cosmic Rays

- Proton and Helium Spectra in the rigidity range R=500 GV - 100 TV
- Carbon and Oxygen Spectra in the rigidity range R=100 GV - 50 TV.
- Lithium, Berylium and Boron Spectra in the rigidity range R=100 GV-30 TV.
- Electron and Positron Spectra in the energy range E=100 GeV - 10 TeV.
- Anti-Proton Spectrum in the rigidity range R=100 GV - 10 TV.

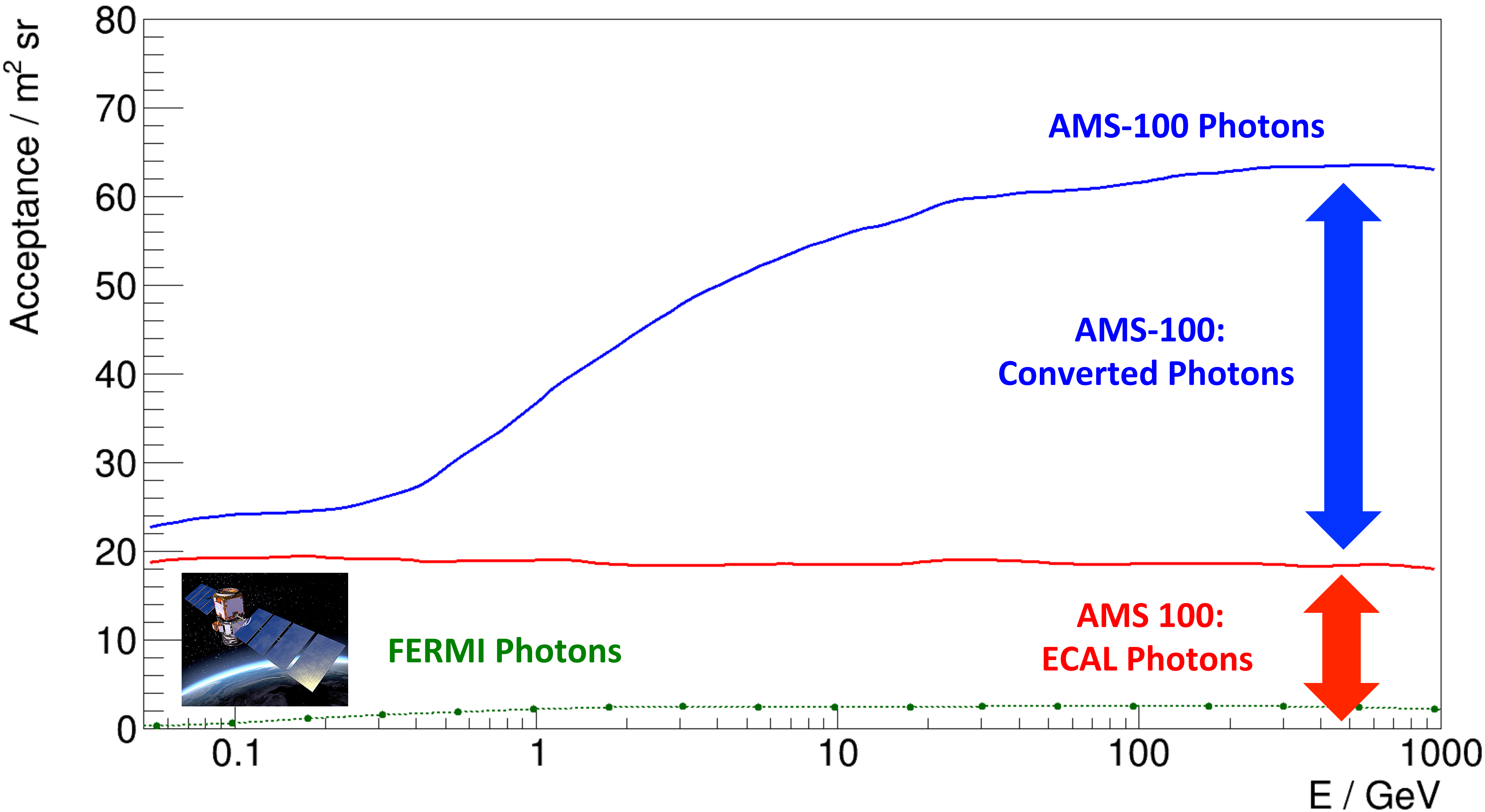
If AMS-02 indentifies Anti-Deuterium, Anti-Helium 3 and Anti-Helium 4 in primary cosmic rays, AMS-100 would be able to measure the spectra with >1000 Events for each species.





AMS-100 will monitor the whole sky continously.

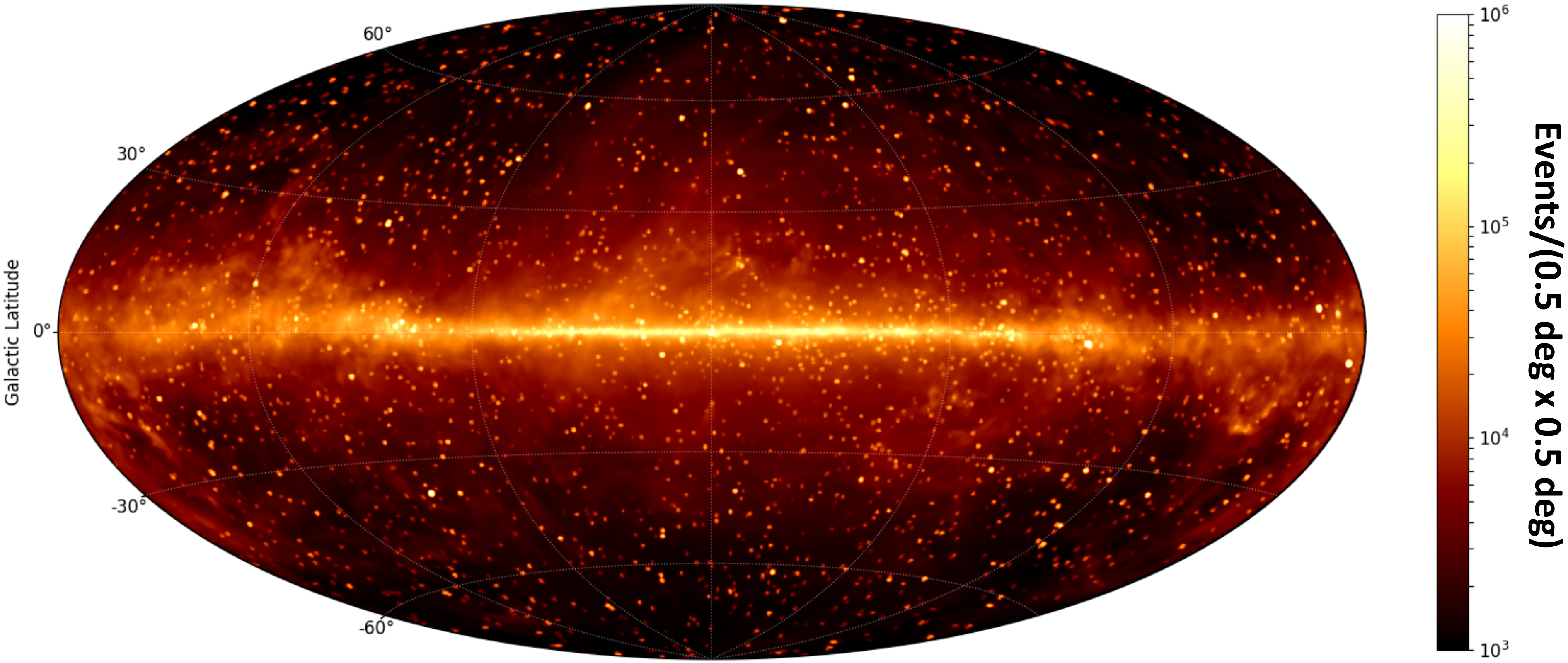
The acceptance for photons is up to 65 m^2 sr compared to FERMI 2.5 m^2 sr.



The angular Resolution for converted photons is 0.005 mm/3.5m = 1 10^{-4} deg and will be ~1,000 better than the FERMI resolution.

The 3. FERMI catalog includes 3033 sources above 4 sigma significance.

AMS-100: Expected counts for 5 years for E=50 MeV – 1 TeV



- For every source in the 3. FERMI catalog we expect at least 1000 events in AMS-100.
- We expect to see 10000 new sources in AMS-100.

AMS-100: A Magnetic Spectrometer at LP-2

- The scale of this project is the scale of a LEP Experiment ⇔ inner part of (ATLAS,CMS) ⇔ 250 Million (€,$,CHF) but for space application i.e. 500 Million - 1000 Million (€,$,CHF).
- It requires a collaboration of 500 physicists, it is time to start the R&D now.

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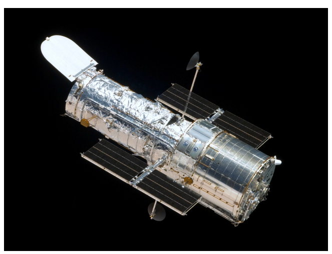
1990 Hubble

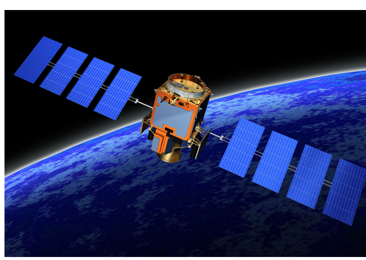
2008 FERMI

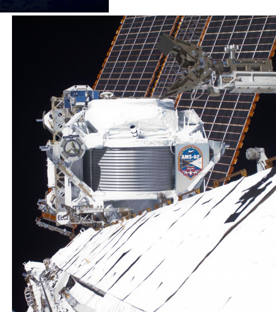
2011 AMS-02

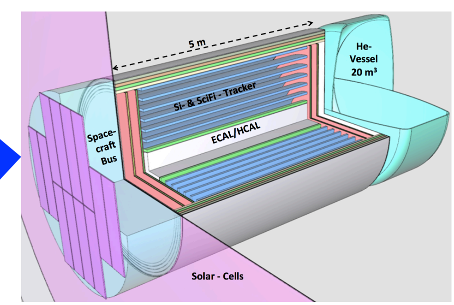
2020 James Webb

2030 AMS-100









AMS-100: A Magnetic Spectrometer at LP-2

- **A large scale superconducting magnet in space has large implications for human space exploration.**
- **To get a large scale superconducting magnet into space was even for S. Ting a challenge.**
- **We need a precursor flight with AMS-10, i.e. Acceptance 10 m^2 sr, MDR 10 TeV, to LP-2 in 2025 to prove the technical concept.**

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- A large scale superconducting magnet in space has large implications for human space exploration.
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"All the News That's Fit to Print"

The New York Times

Late Edition

Today, clouds and some sun, cooler, high 67. **Tonight,** partly cloudy, low 55. **Tomorrow,** clouds and sun, shower or thunderstorm, high 72. Weather map appears on Page A32.

VOL. CLXIII . . . No. 56,516 + © 2014 The New York Times NEW YORK, THURSDAY, September 10., 2027 $2.50

Second Nobel Prize for Samuel C. C. Ting from MIT for the discovery of anti-matter in space.

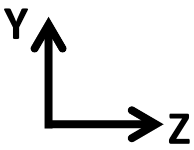
AMS-10 first data confirmed the AMS-2 discoveries of anti-helium in space.

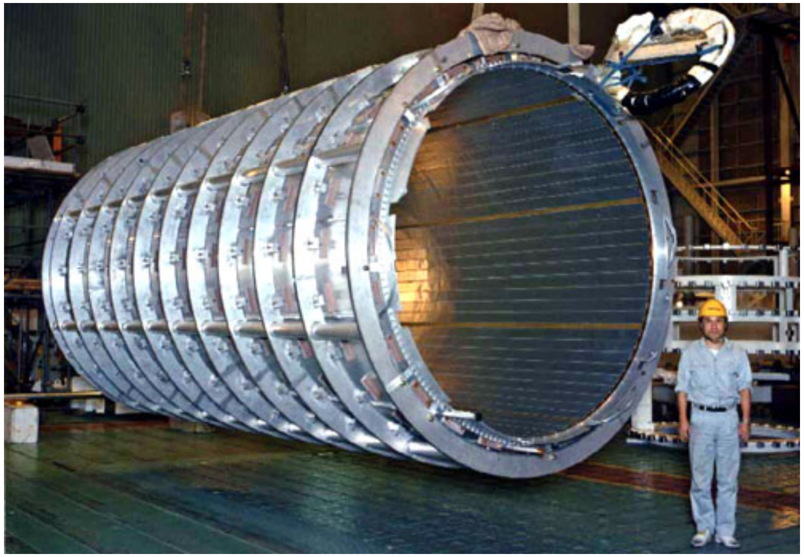
AMS-10 is the first space experiment with a large superconducting magnet and was launched in 2025.

Backup Slides

Magnet

- Thinn superconducting solenoid, B=1 Tesla, T=4.5 Kelvin made from aluminium enforced Nb/Ti conductor
- Inner diameter 3.5 m, Length 5 m, Material 0.48 X0
- Weight 7,400 kg (11,500 kg extrapolated from BESS, 3,500 kg extrapolated from ATLAS)
- 20 m^3 liquid He (2400 kg) should cool the magnet for >6 years. Vessel weight estimated to be 1700 kg.





Ams100_DetectorKonzept_v03.mw

```
> n                    := 140/Unit(m):          # turns/m
  Ix                   := 7.73*Unit(kA):        # from ATLAS solenoid
  Magnet_Wire_Length := simplify(n*Magnet_LenY*2.*Pi*rMagnet_in);
```

$$Magnet\_Wire\_Length := 7696.902002 \, [\![m]\!] \quad (3.1)$$

```
> x1    := -0.5*Magnet_LenY: x2    :=  0.5*Magnet_LenY:
  R     := rMagnet_in:
  mu_0 := evalf(Constant(mu[0], units)):
  fB  := x->simplify(mu_0*n*Ix/2*((x-x1)/sqrt((x-x1)^2+R^2)-(x-x2)/sqrt((x-x2)^2+R^2)));
```

$$fB := x \rightarrow simplify\left(\frac{1}{2}\, mu\_0\; n\; Ix \left(\frac{x - x1}{\sqrt{(x-x1)^2 + R^2}} - \frac{x - x2}{\sqrt{(x-x2)^2 + R^2}}\right)\right) \quad (3.2)$$

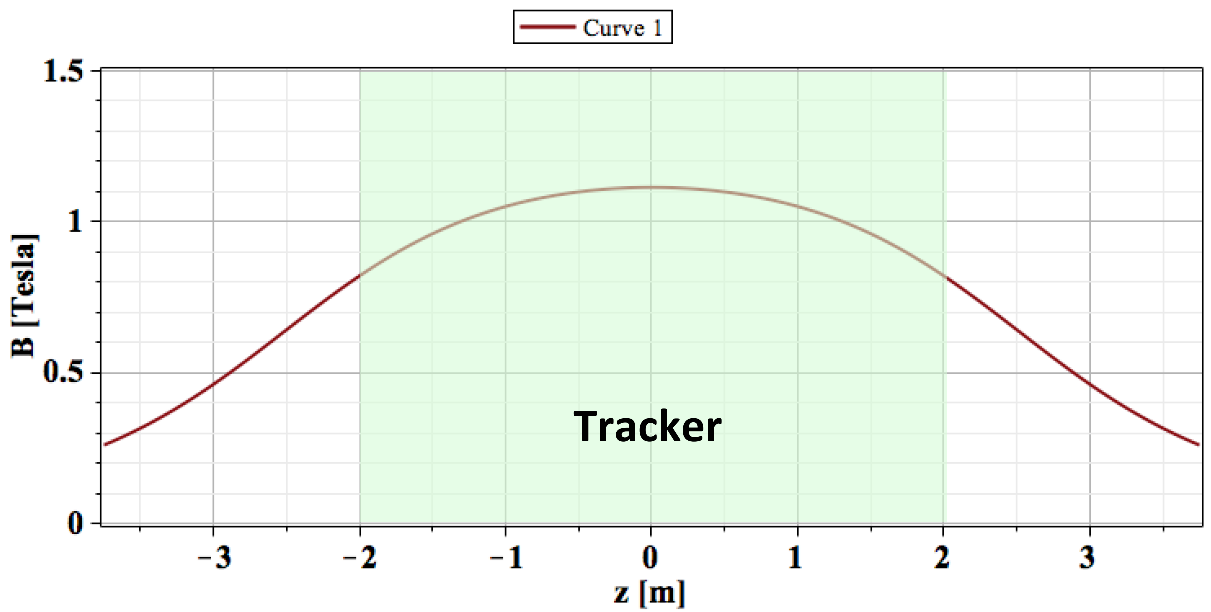
```
> B_TrackerCenter  := fB(0*Unit(m));
  B_TrackerEdge    := fB(0.5*SiTrk_LenY);
  B_Mean           := int(fB(x*OneM),x=-0.5*SiTrk_LenY/OneM..0.5*SiTrk_LenY/OneM)*OneM/SiTrk_LenY;
```

$$B\_TrackerCenter := 1.114100220 \, [\![T]\!]$$

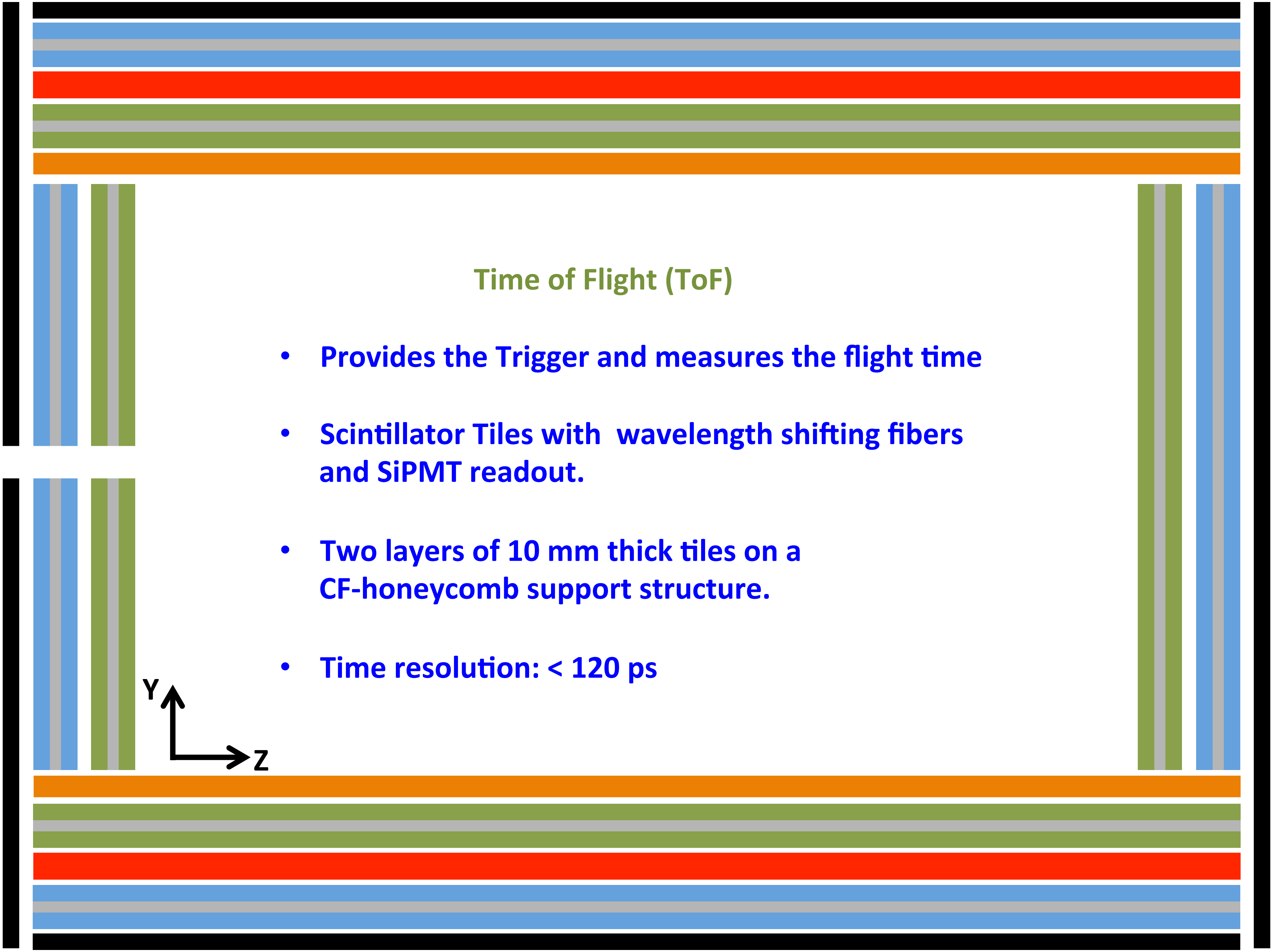
$$B\_TrackerEdge := 0.8205328942 \, [\![T]\!]$$

$$B\_Mean := 1.022762664 \, [\![T]\!] \quad (3.3)$$

```
> plot(fB(x*OneM)/OneT,x=simplify(1.5*x1/OneM)..simplify(1.5*x2/OneM),gridlines=true,y=0..1.5,
  labels=["z [m]","B [Tesla]"]);
```



/Users/stefan/Documents/hep/experimente/ams/software/SscAnalysis/maple Server: 4 Memory: 23.19M Time: 3.88s Text Mode

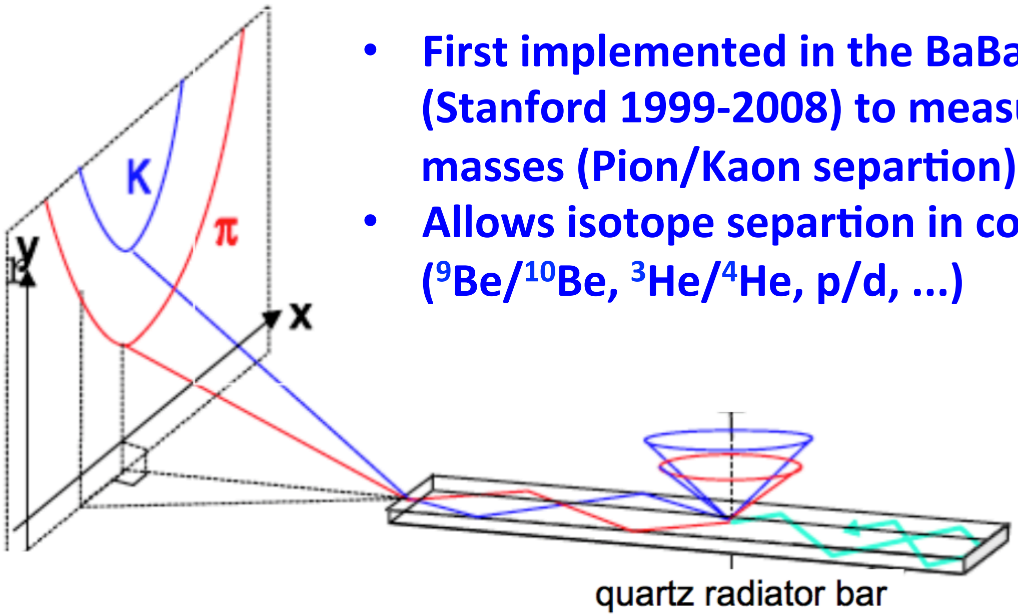


Time of Flight (ToF)

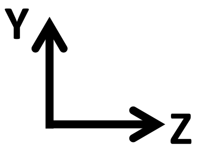
- **Provides the Trigger and measures the flight time**
- **Scintillator Tiles with wavelength shifting fibers and SiPMT readout.**
- **Two layers of 10 mm thick tiles on a CF-honeycomb support structure.**
- **Time resolution: < 120 ps**

DIRC: Detection of Internally Reflected Cherenkov light

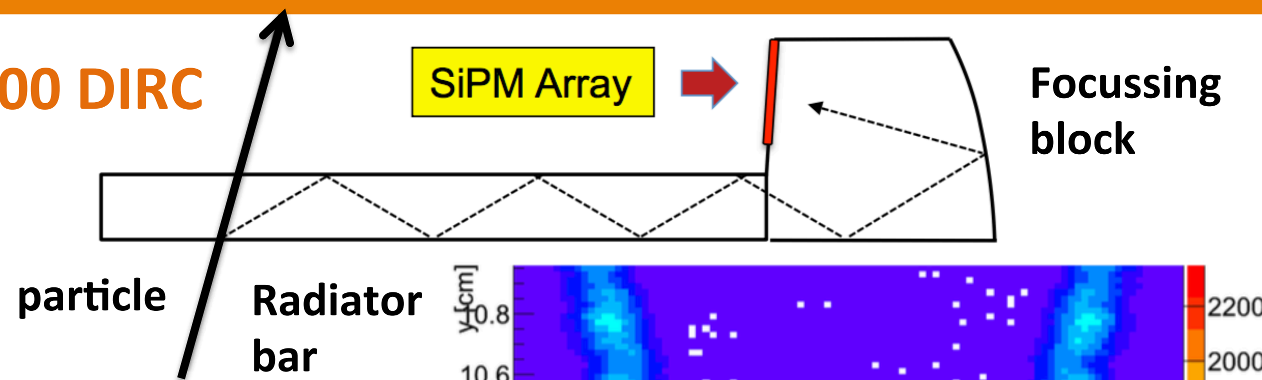
- First implemented in the BaBar Experiment (Stanford 1999-2008) to measure particle masses (Pion/Kaon separtion).
- Allows isotope separtion in cosmic rays ($^{9}Be/^{10}Be$, $^{3}He/^{4}He$, p/d, ...)



BaBar used fused silica radiator bars,
4.9 m (length) x 17.25 mm (thickness) x 35 mm (width).

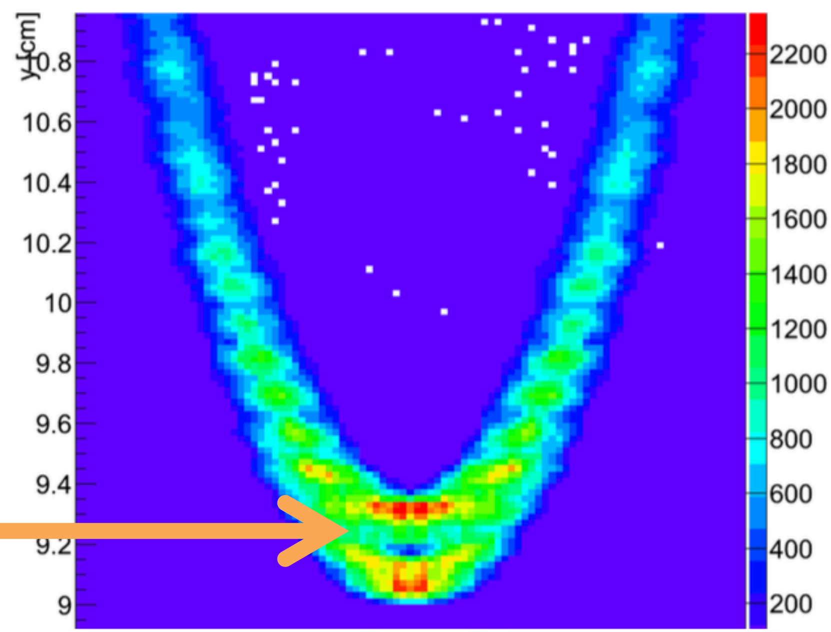


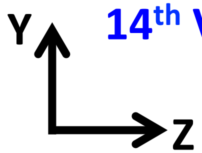
AMS-100 DIRC

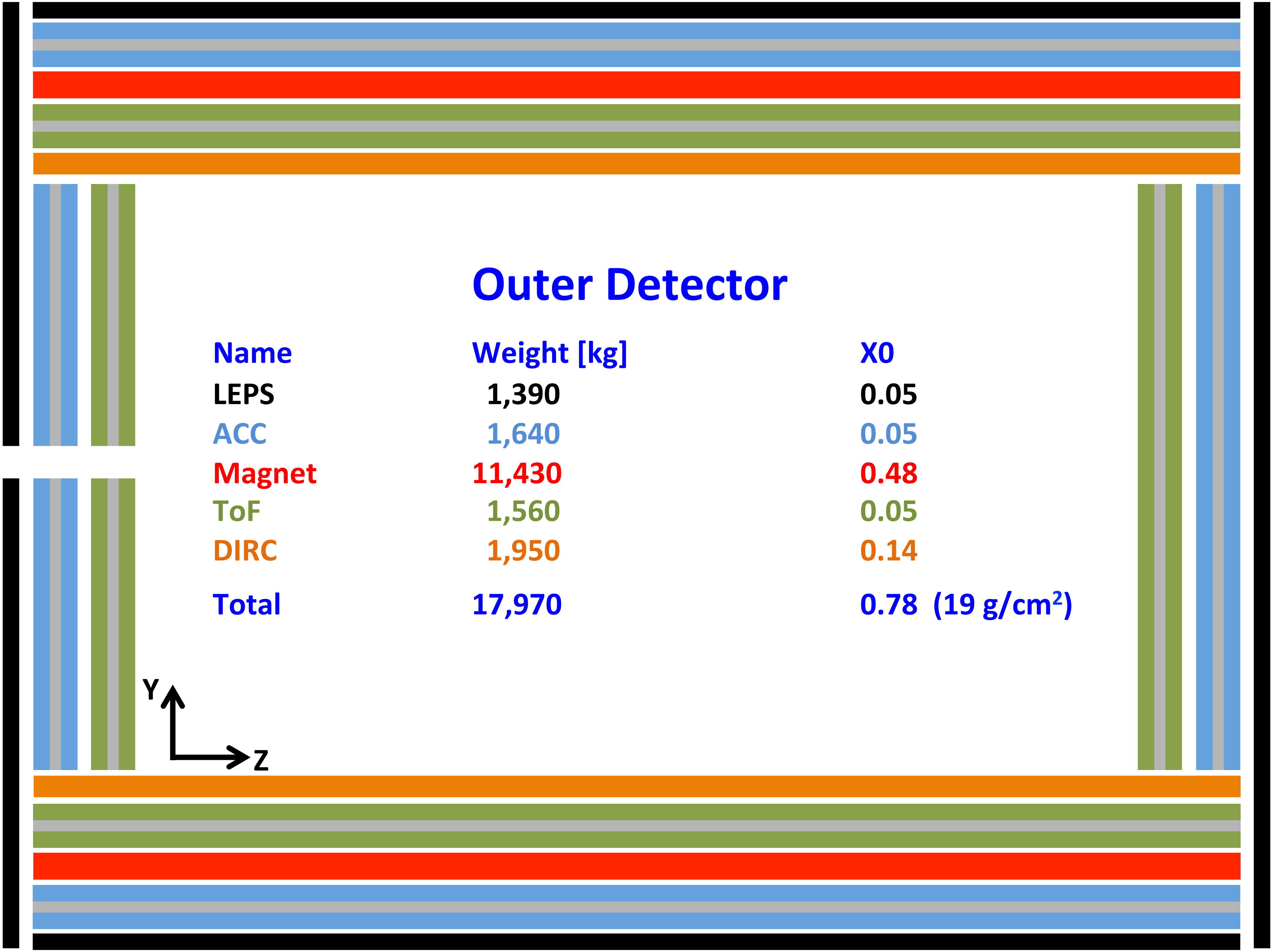


- Focal Plane instrumented with SiPM arrays.

- $^{9}Be/^{10}Be$ at 25 GeV/c momentum from P.S. Marrocchesi, 14th VCI, Feb. 2016





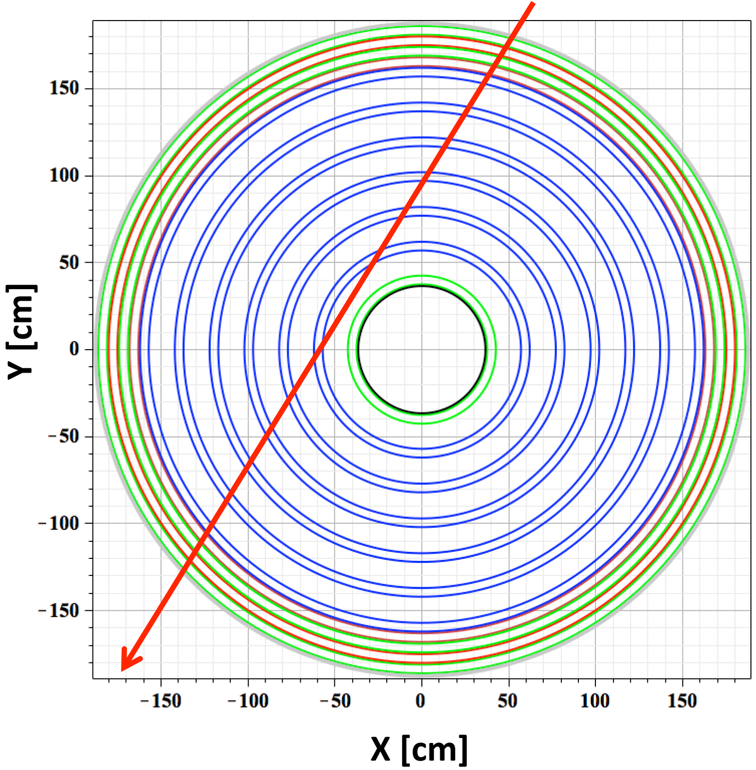


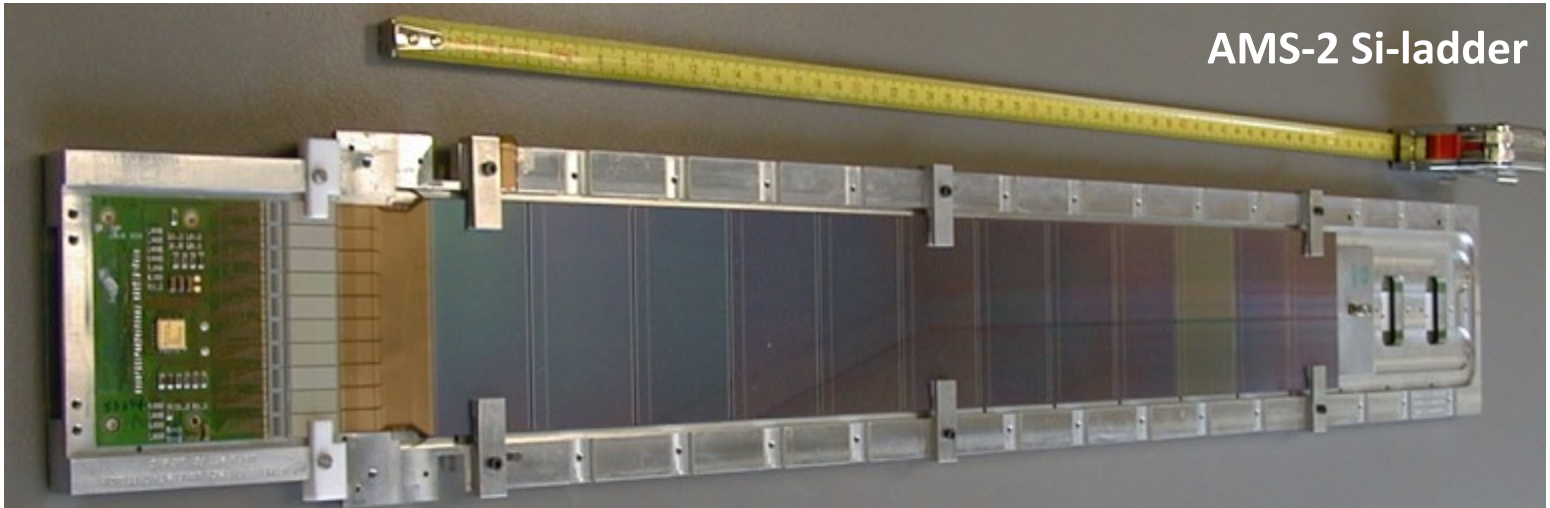
Outer Detector

Name	Weight [kg]	X0
LEPS	1,390	0.05
ACC	1,640	0.05
Magnet	11,430	0.48
ToF	1,560	0.05
DIRC	1,950	0.14
Total	17,970	0.78 (19 g/cm^2)

Silicon Tracker

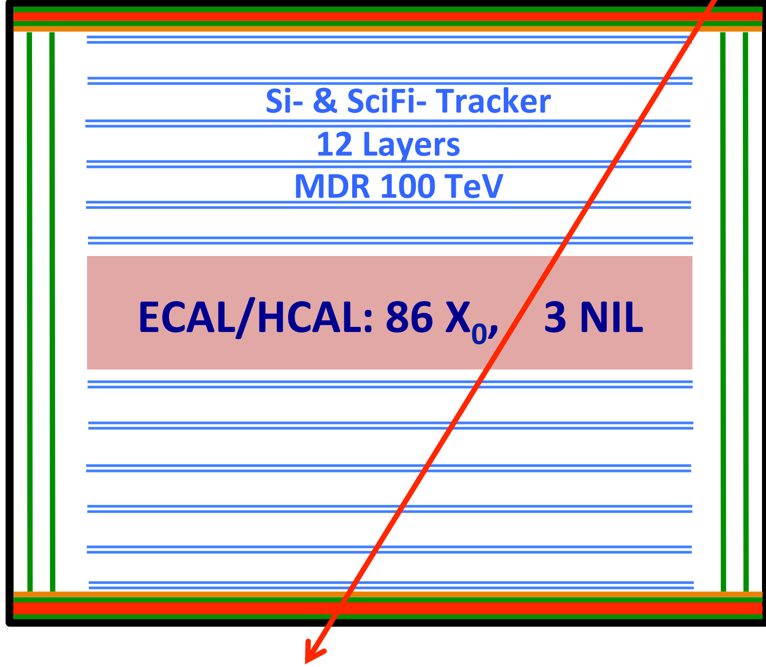
- Measures the particle track in the bending plane with up to 24 points.
- Readout pitch 0.1 mm, single point resolution 5 μm.
- Single sided Si-detectors (10cm x 10cm) form a ladder of 1m length. In total 3300 ladders are needed.
- Total area 330 m^2, 3.3 10^6 readout channels, Power consumption Front-End 1 mW/Channel ⇔ 3300 W total.

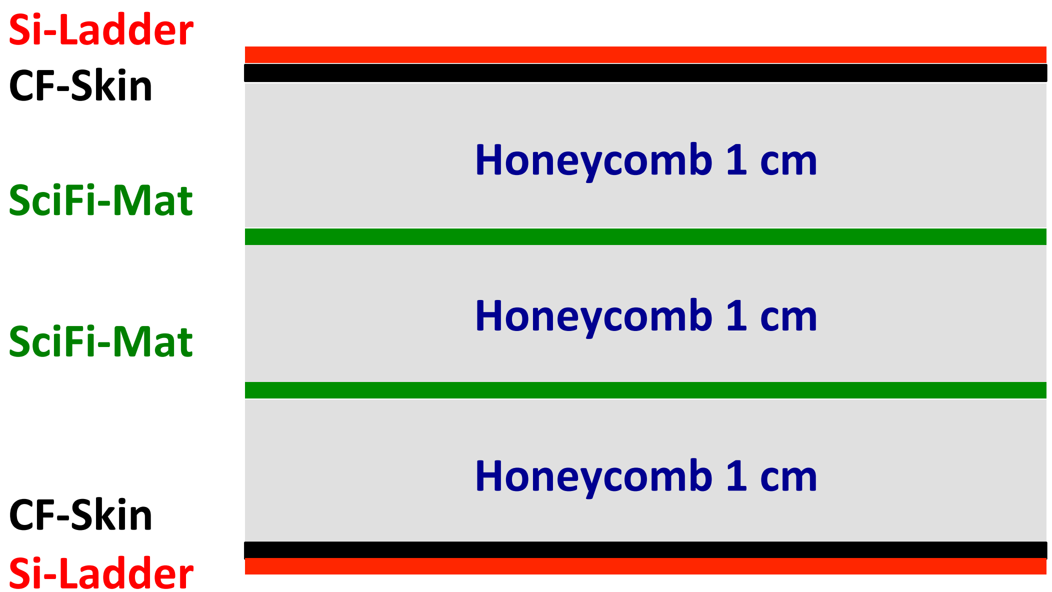


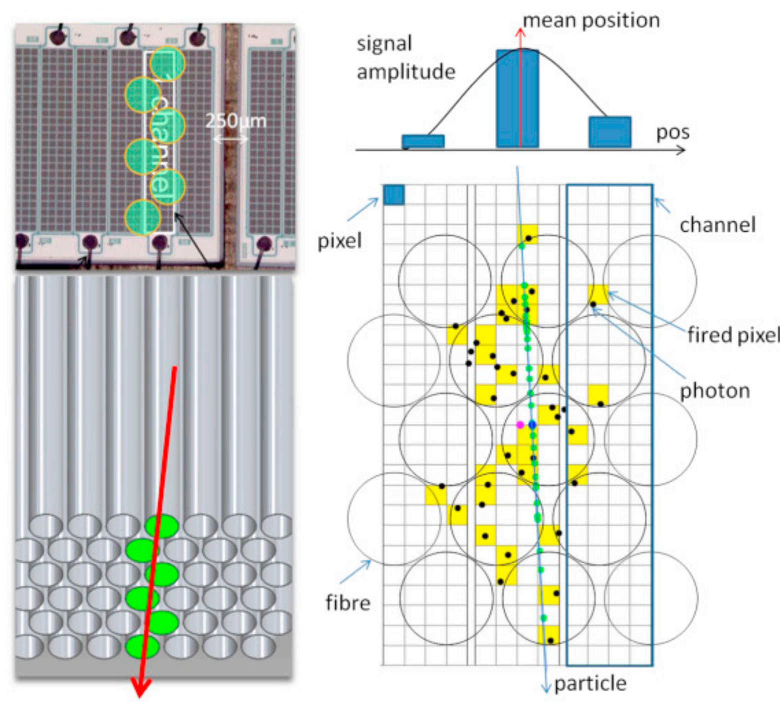


SciFi Tracker

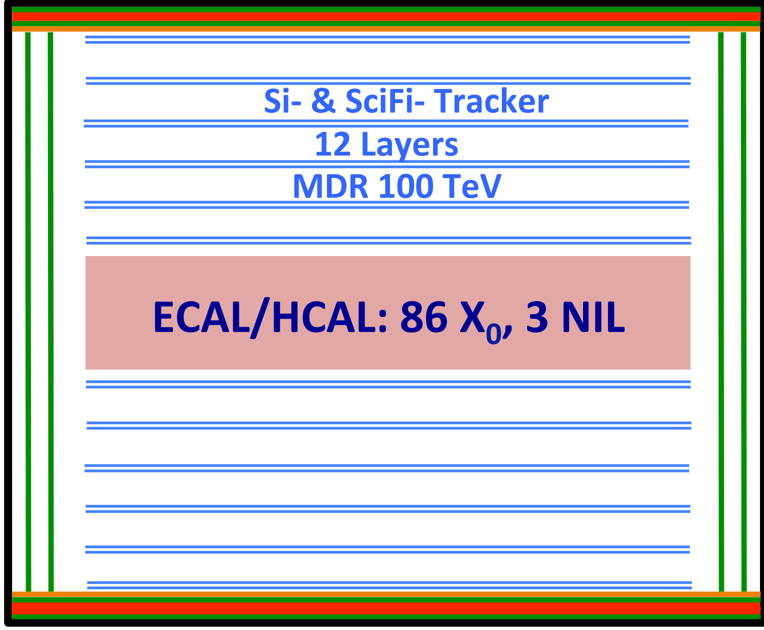
- Measures the particle track in the non bending plane with up to 24 points.
- Readout pitch 0.25 mm, single point resolution 50 µm.
- Constructed from 0.25 mm diameter scintillating fibers, aranged in 6 layers to form a up to 2.5m long fiber mat.
- 0.576 Million SIPM readout channels, 8000 km fibers.





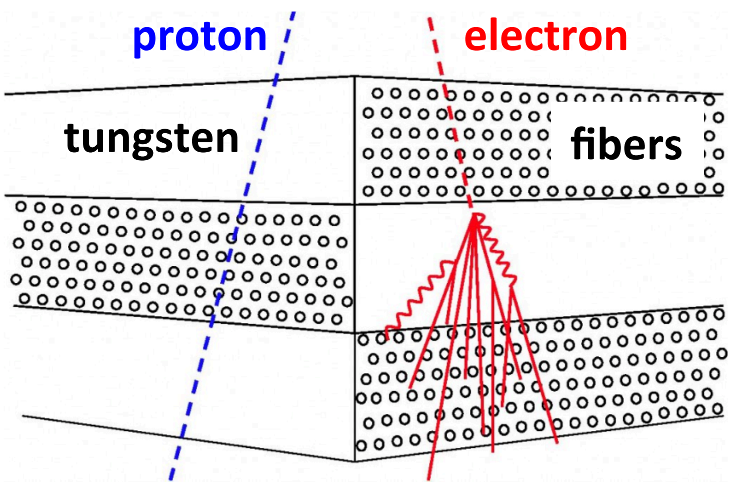


Calorimeter System ECAL/HCAL



It is a fine grained tungsten-scintillating fiber sampling calorimeter with SiPM readout that allows precise, 3-dimensional imaging of the longitudinal and lateral shower development, providing high electron/hadron discrimination and good energy resolution.

- **Diameter 73 cm, Length 4 m, Weight 14,550 kg, depth 86 X0/3 NIL, 100,000 readout channels**
- **The maxium of hadron showers will be contained up to 100 TeV.**



A non interacting proton passing through ECAL. The electron produces an electromagnetic shower.