INFN
Istituto Nazionale
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Università
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di Perugia

53° International Winter Meeting on Nuclear Physics

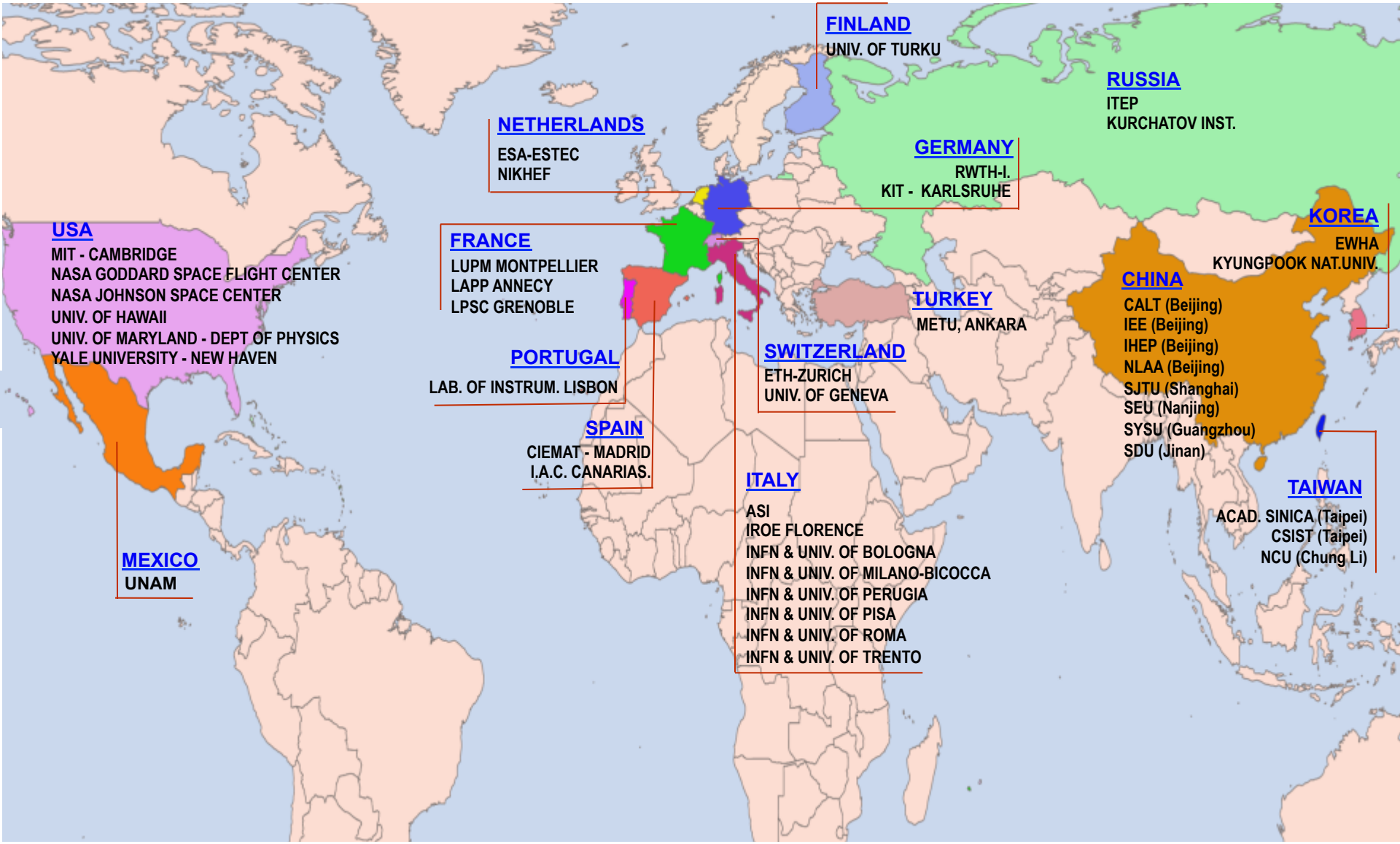
26-30 January 2015 Bormio (Italy)

The AMS-02 experiment on the International Space Station: Latest results

Maura Graziani
Università & INFN Sez. Perugia

On behalf of the AMS-02 Collaboration

15 Countries, 44 Institutes and 600 Physicists



AMS-02: (part) of the Collaboration @ NASA-JSC

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Outline:

1. Physics of AMS

2. AMS-02: Detector & Operations

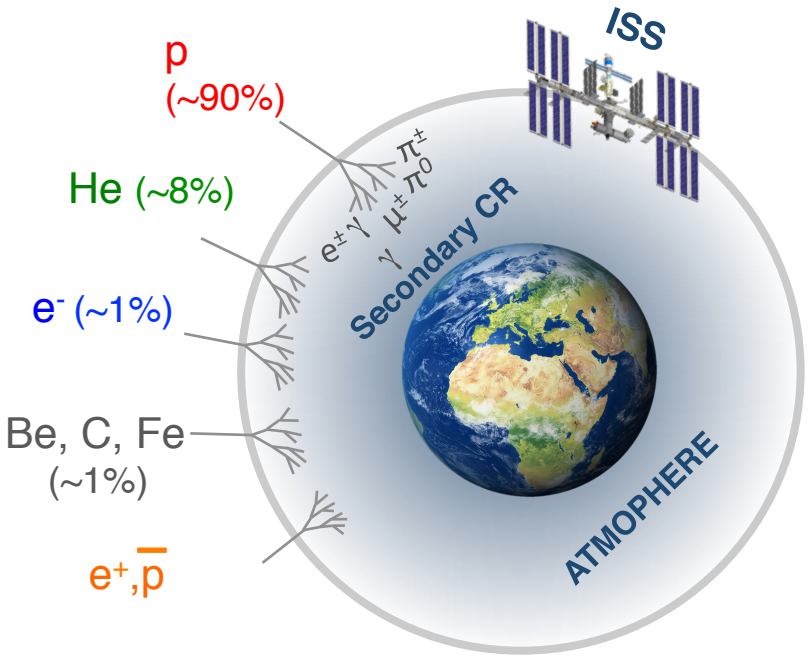
3. AMS-02: Results
   - Positrons fraction
   - e^+, e^- fluxes
   - $(e^+ + e^-)$ flux

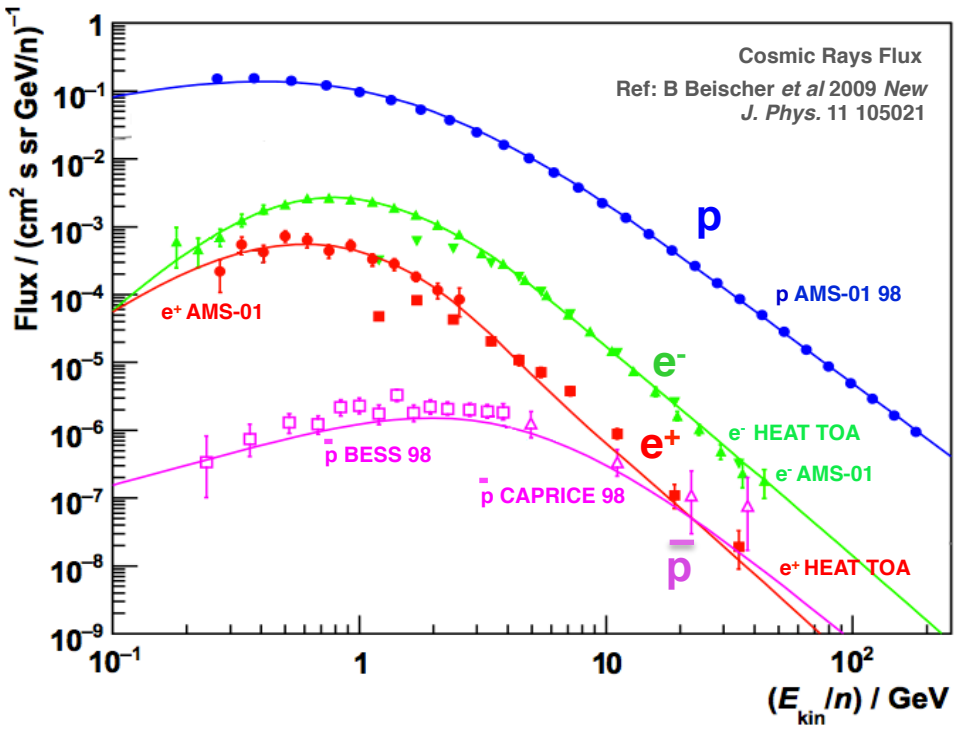
1. Physics of AMS

2. AMS-02: Detector & Operations

3. AMS-02: Results

→ measurements of *charged cosmic rays* (O(GV) - O(TV) and γ rays (E>1GeV)





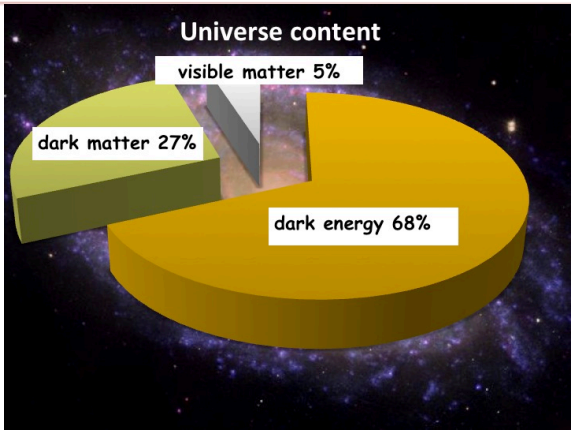
Cosmic rays → carry information about the universe

- Fundamental physics & Antimatter :
  - Primordial origin (Signal: anti-nuclei)

Dirac's Nobel speech

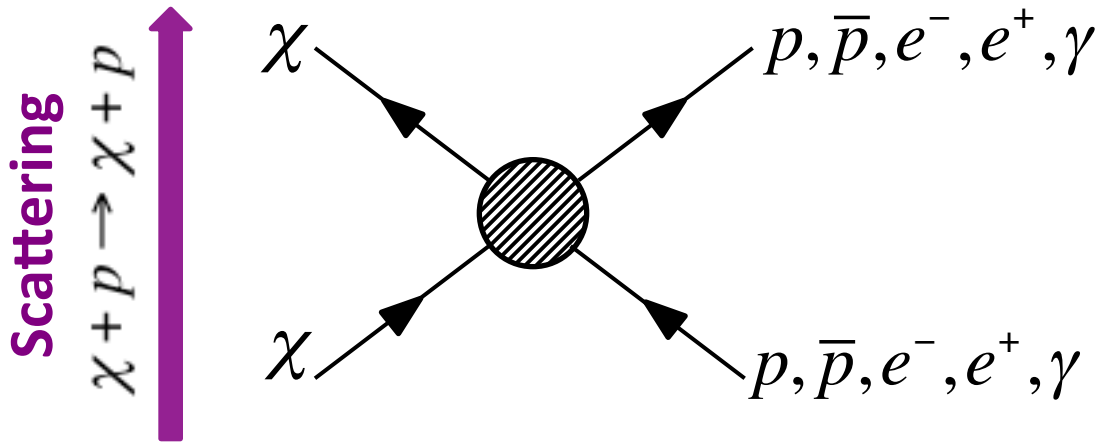
"We must regard it rather as an accident that the Earth [...] contains a preponderance of negative electrons and positive protons. It is quite possible that for some stars it is the other way about."

The Physics: The quest for Dark Matter



Annihilation

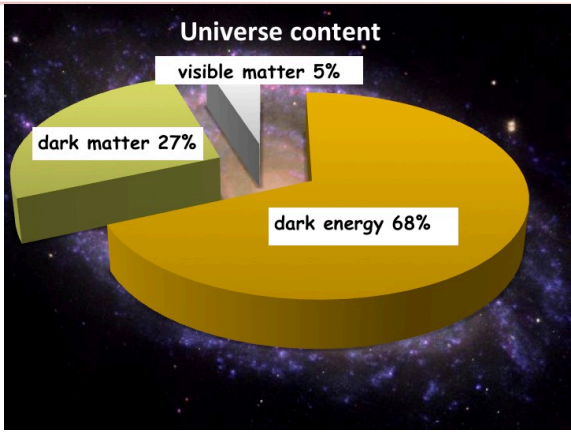
$$\chi + \chi \rightarrow p, \bar{p}, e^-, e^+, \gamma$$



$$\chi + \chi \leftarrow p + p$$

Production

The Physics: The quest for Dark Matter

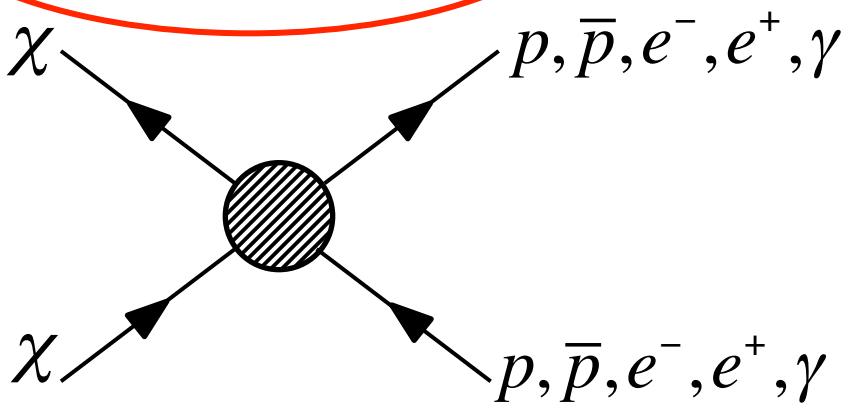


Annihilation

$$\chi + \chi \rightarrow p, \bar{p}, e^-, e^+, \gamma$$

Scattering

$$\chi + p \rightarrow \chi + p$$



$$\chi + \chi \leftarrow p + p$$

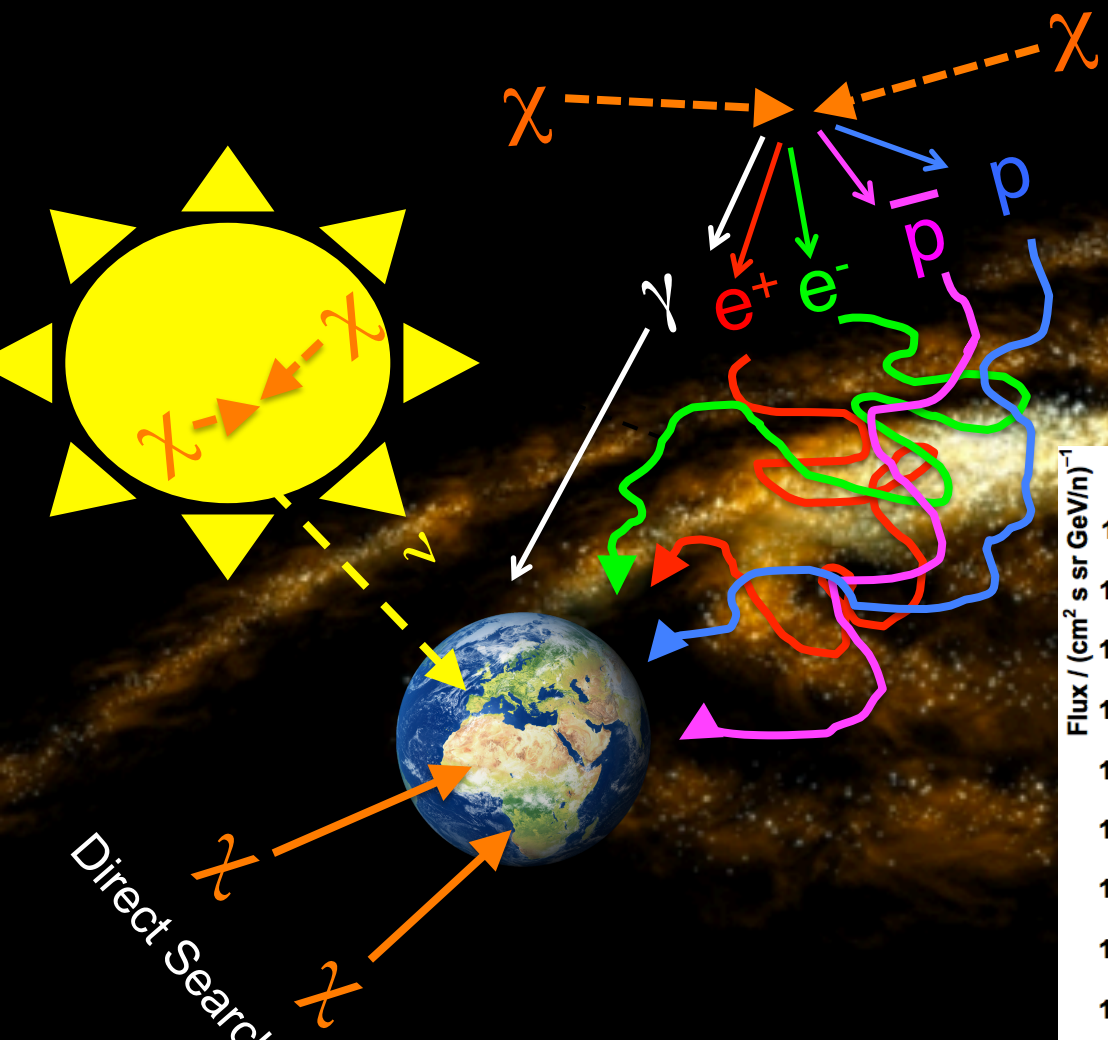
Production

The Physics: Anti-Matter & Dark Matter

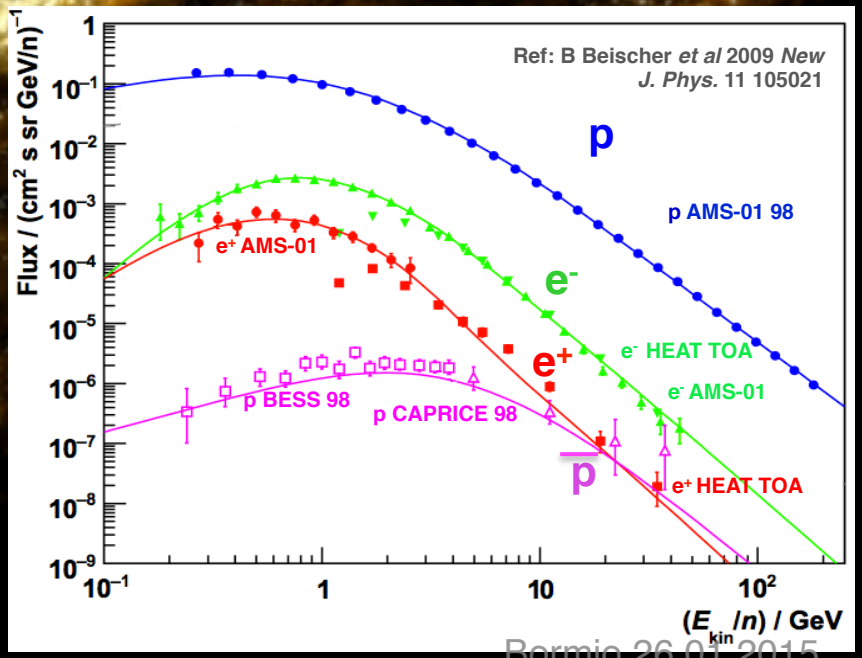
WIMP as the responsible of Dark Matter (?)

Direct Searches

Indirect DM search → search for (RARE IN CR) products from their annhilation….

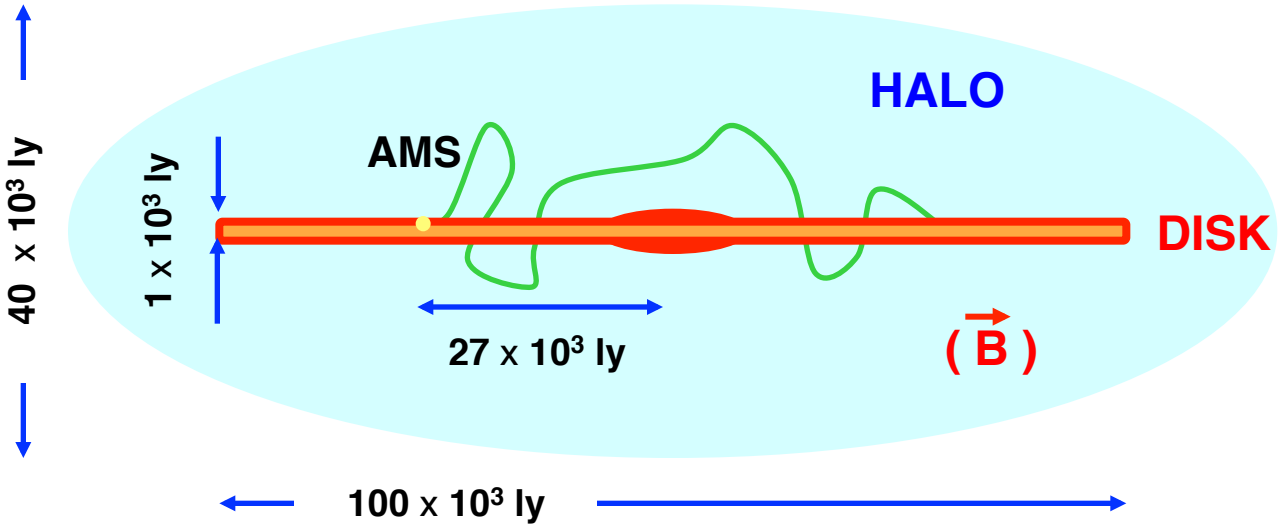


But you should know what you expect in the ISM !!



Precise measurement of the energy spectra of B, C …
provides information on Cosmic Ray Interactions and Propagation

Interactions with the Interstellar Medium:
C + (p,He) → B + ...

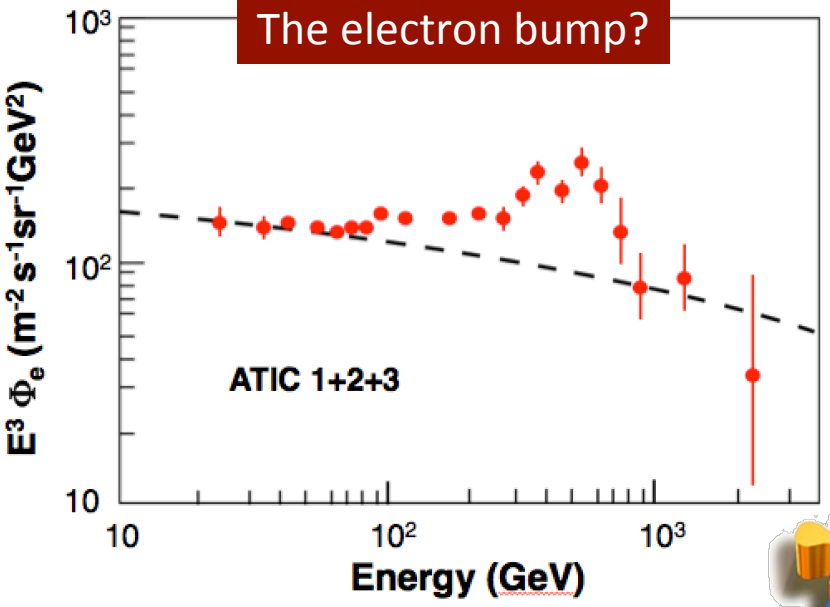


Diffusion
Convection
Reacceleration

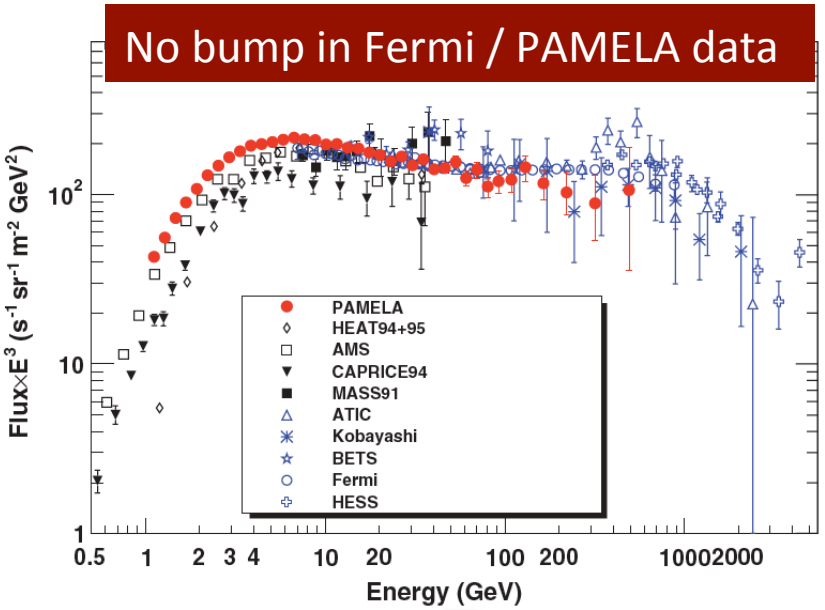
Interactions with the Interstellar Medium (ISM):
- Fragmentation
- Secondaries
- Energy loss

The Physics: DM/exotic sources

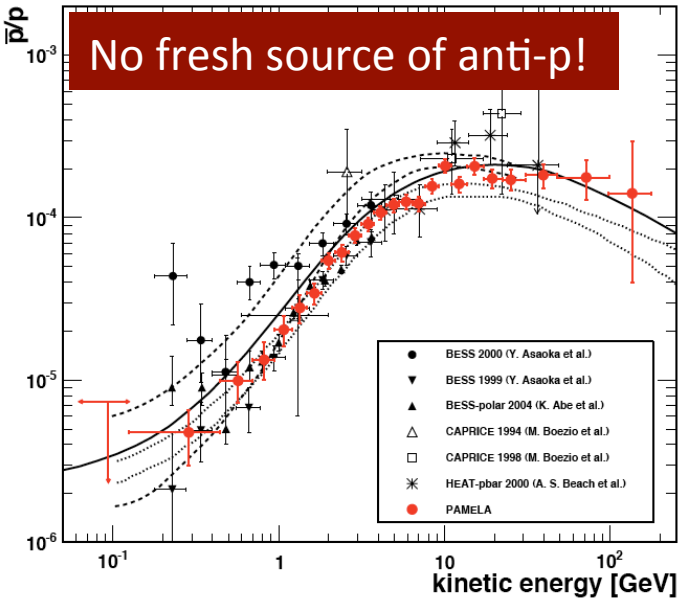
The electron bump?



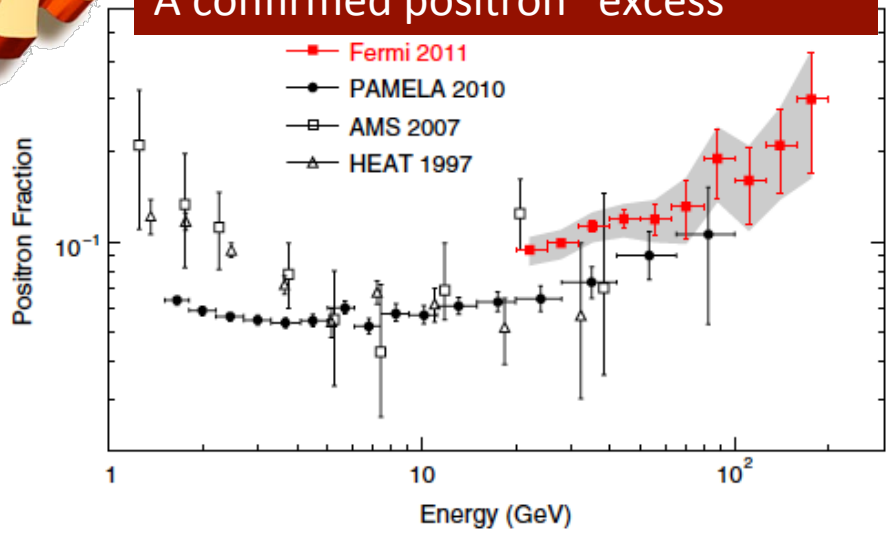
No bump in Fermi / PAMELA data



No fresh source of anti-p!



A confirmed positron "excess"



1. Physics of AMS

2. AMS-02: Detector & Operations

3. AMS-02: Results

AMS-02: Objectives

Fundamental physics & Antimatter :

- Primordial Antimatter search with 10^{-9} sensitivity
- Indirect Dark Matter search (e^+, p, …)

The Cosmic Ray composition and energy spectrum:

(how to understand the beam…)

- Sources & Acceleration : Proton and He
- Propagation in the ISM : Relative abundances of nuclei and isotopes in primary cosmic rays

What is needed?

→ **Particle identification and E measurement up to TeV:**

- e/p separation at the 10^4 level by means of independent detectors
- Z : redundant measurements to evaluate fragmentation along the detector
- Charge sign: matter to anti-matter separation (magnetic field!)

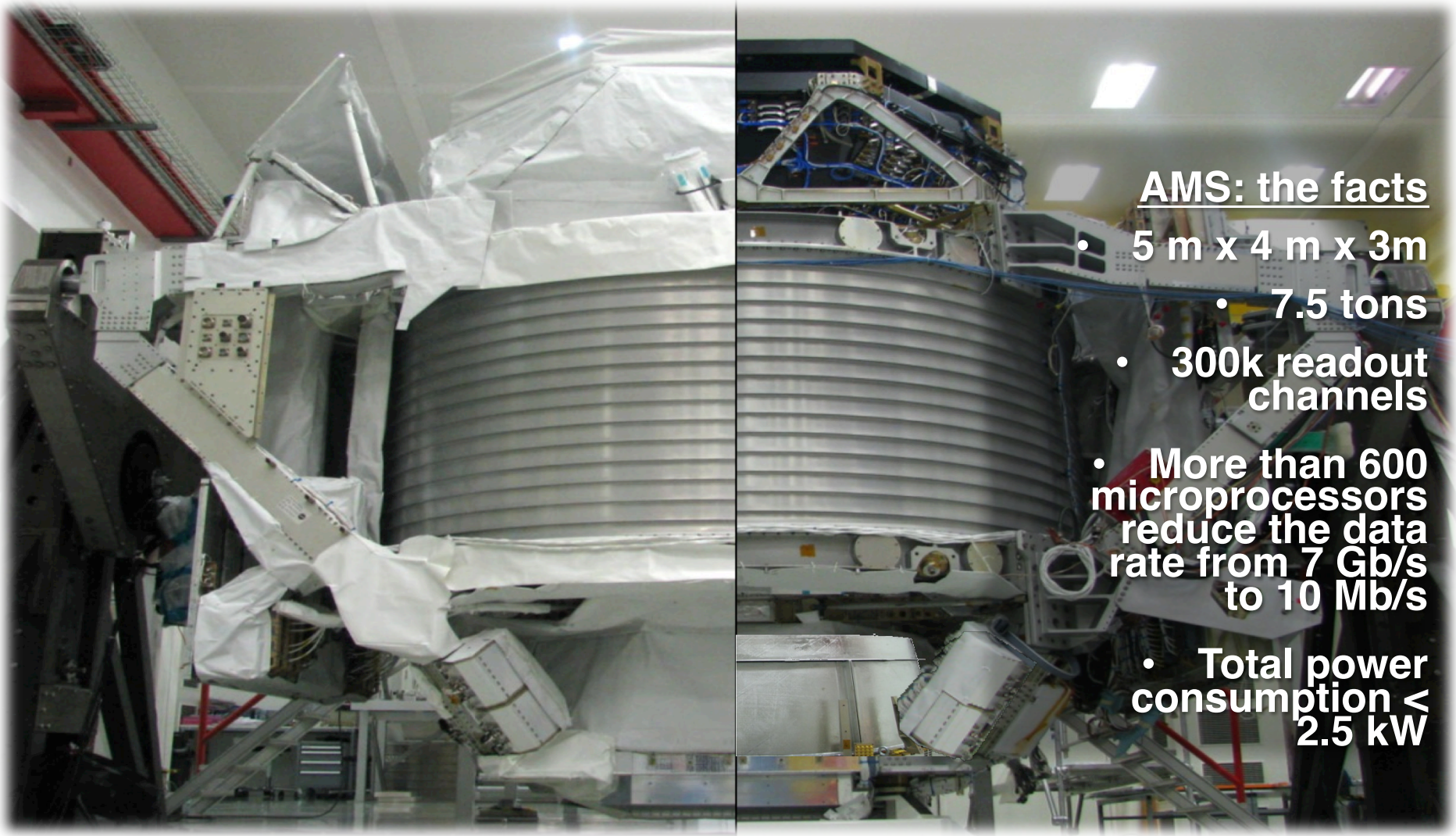
→ **Statistics**

- Acceptance & efficiency: **size**
- Exposure time: **space**

AMS-02: The detector

AMS with MLI

AMS without MLI



AMS: the facts

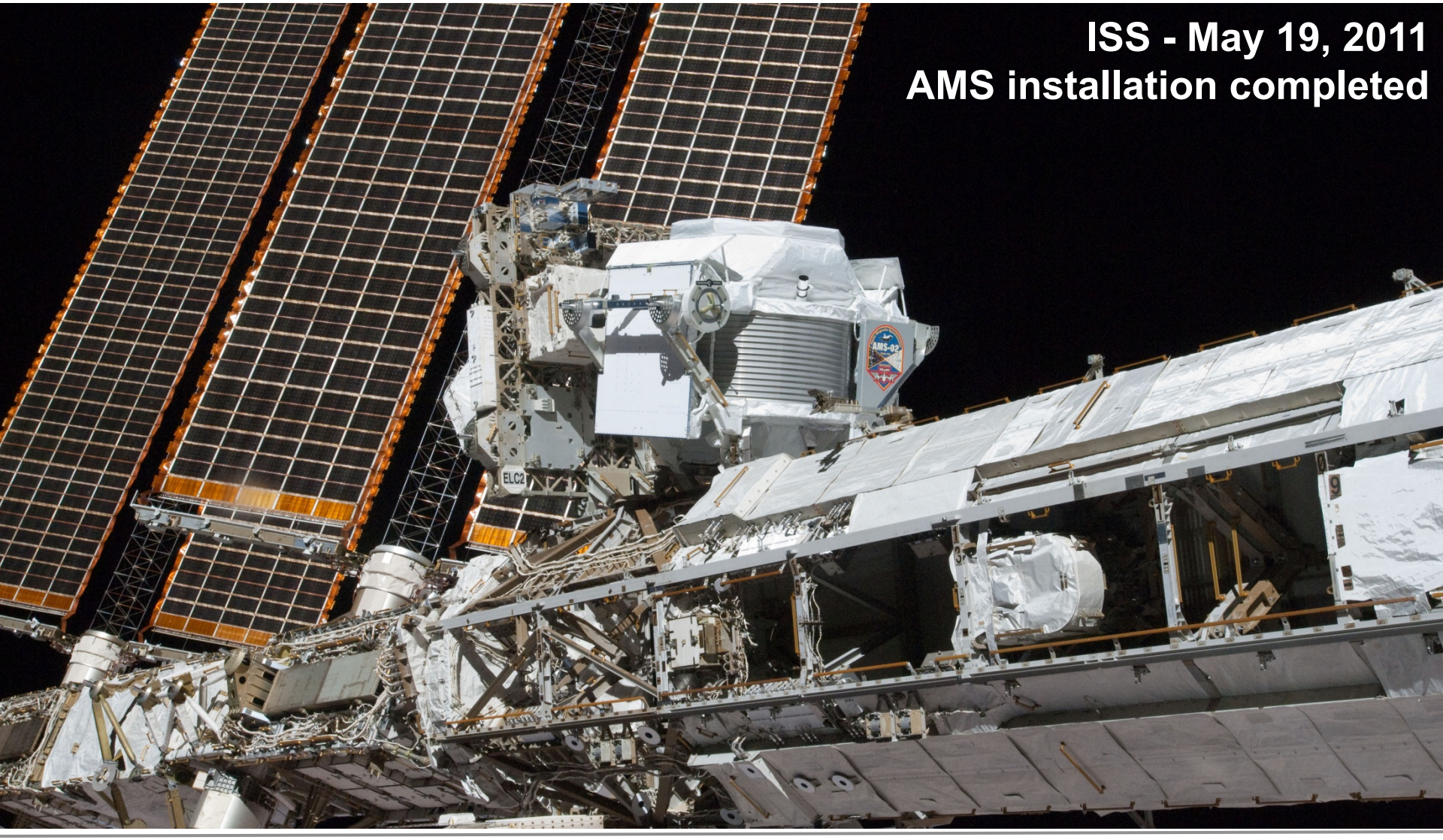
- 5 m x 4 m x 3m
- 7.5 tons
- 300k readout channels
- More than 600 microprocessors reduce the data rate from 7 Gb/s to 10 Mb/s
- Total power consumption < 2.5 kW

AMS-02: the launch

May 16th 2011

AMS-02: the installation

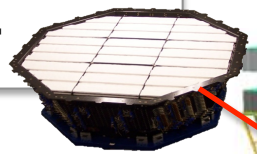
May 19th 2011



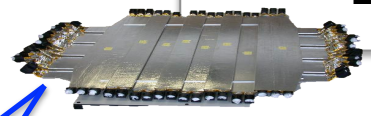
AMS: A TeV precision, multipurpose spectrometer

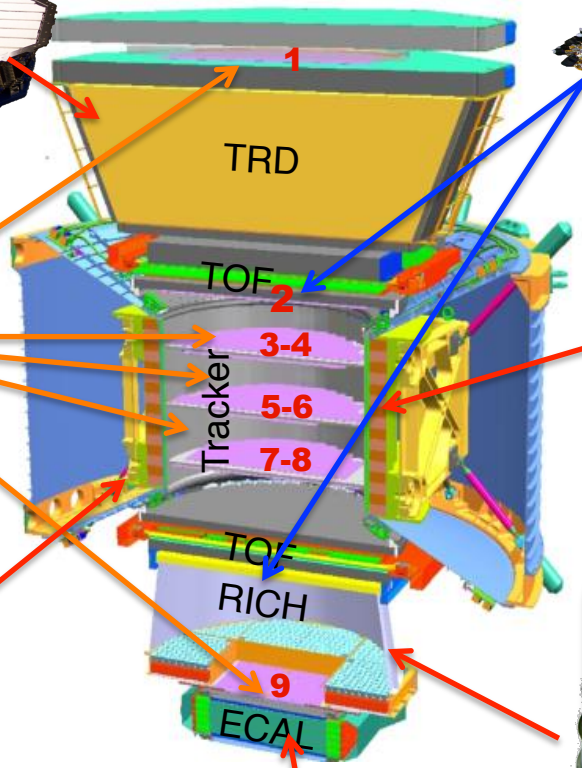
Z, P are measured independently by the Tracker, RICH, TOF and ECAL

TRD, *Transition Radiation Detector*
Identify e+, **e-**

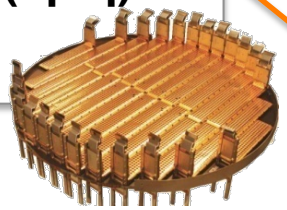


TOF
"Time of Flight"
Z, E

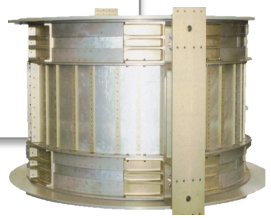




Silicon Tracker
Z, R(=p/q)

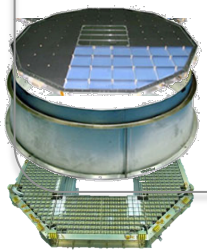


Permanent Magnet
±Z

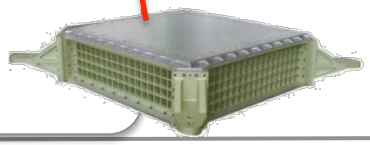


Anti-Coincidence Counters (ACC)

RICH, *Ring Imaging Cherenkov*
Z, E
($\sigma_\beta/\beta \sim 0.1\%$)



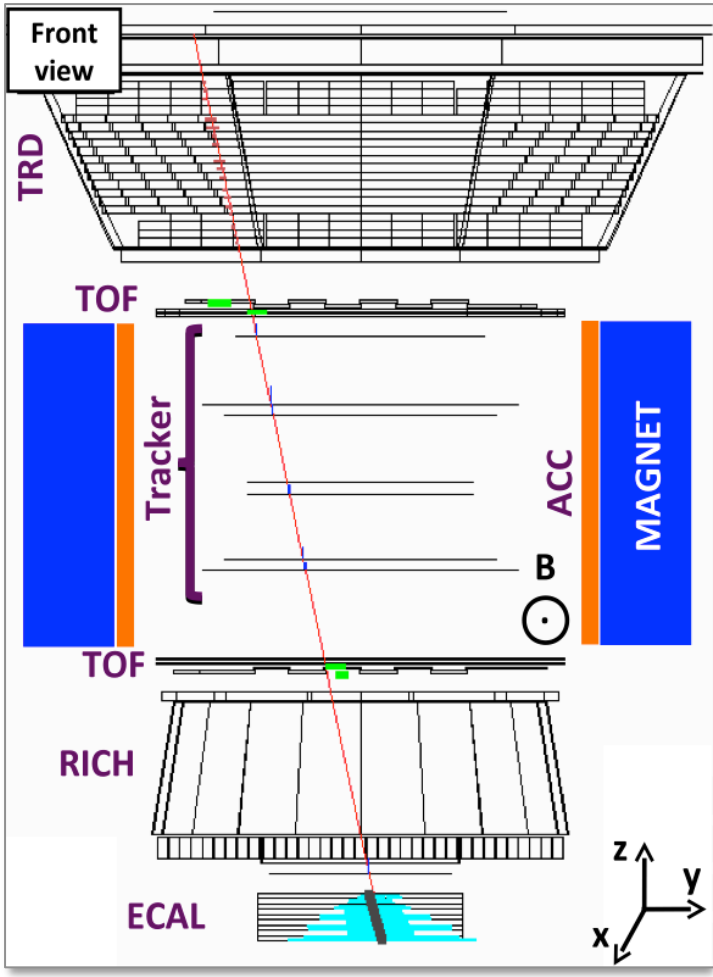
ECAL, *Electromagnetic Calorimeter*
E of e^+, e^-, γ



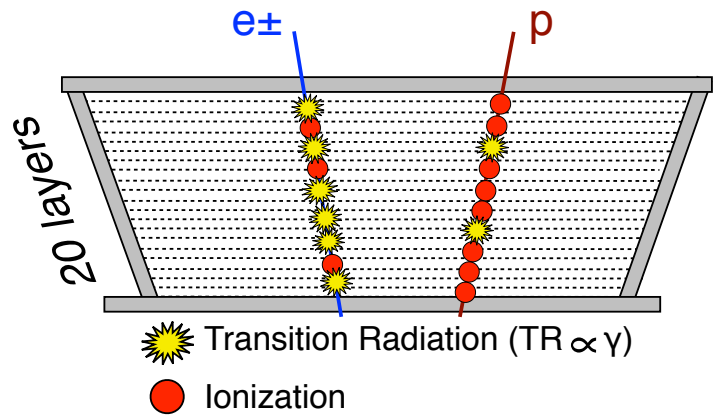
Full coverage of anti-matter and CR physics

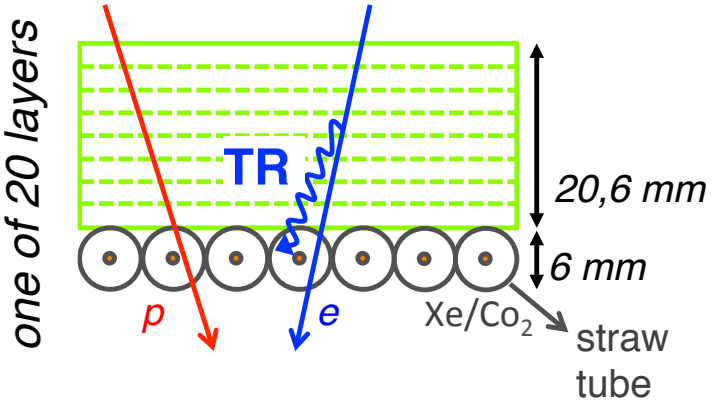
	e^-	P	He,Li, Be,..Fe	γ	e^+	$\bar{P}$	$\bar{He}$, $\bar{C}$
TRD							
TOF							
Tracker +Magnet							
RICH							
ECAL							
Physics example	**Cosmic Ray Physics**				**Dark matter**		**Anti matter**

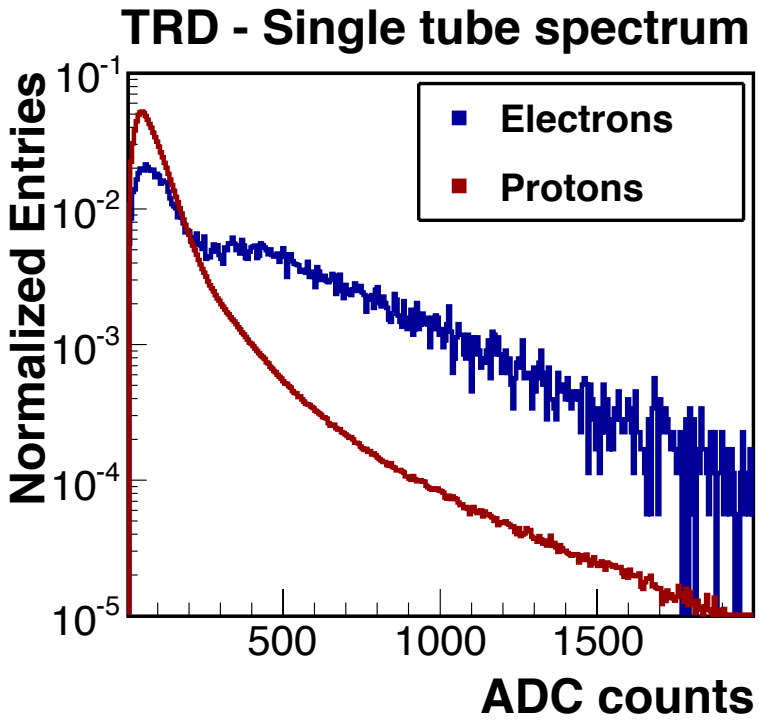
600 GeV electron



20 layers of fiber fleece radiators interleaved with 80:20 Xe/Co_2 straw tubes.





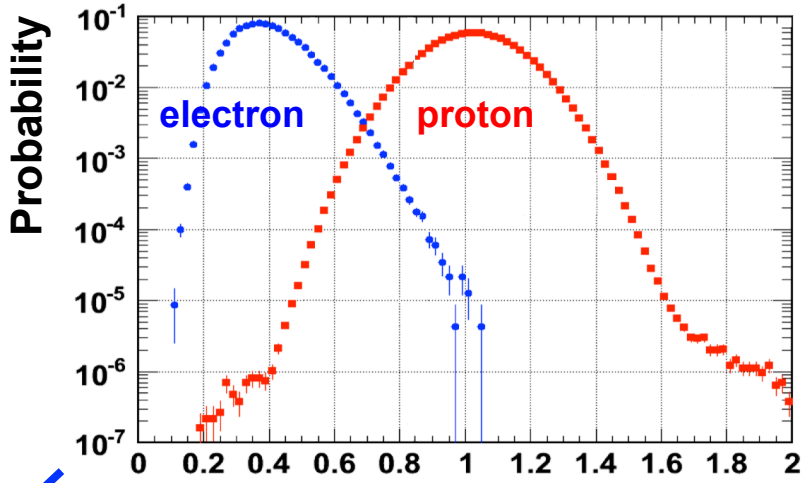


over all 20 layers

$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

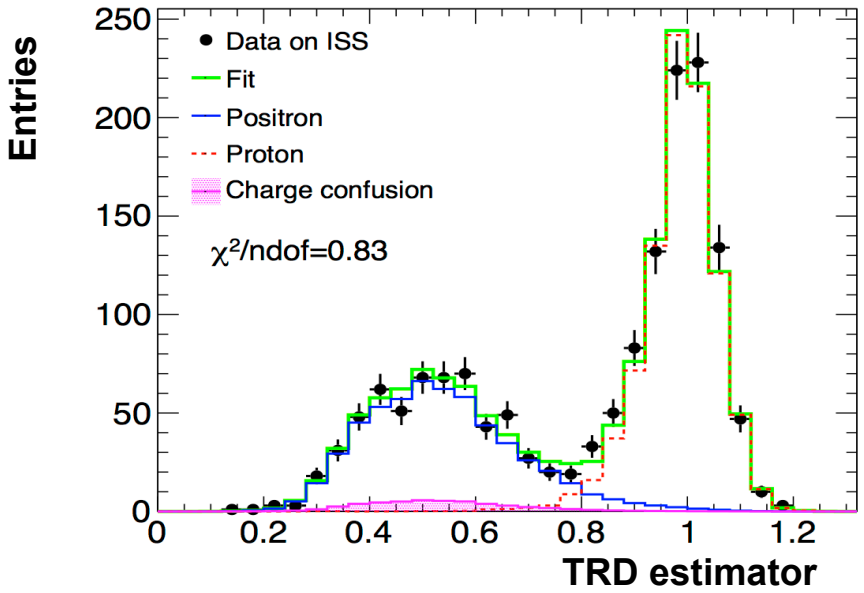
$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

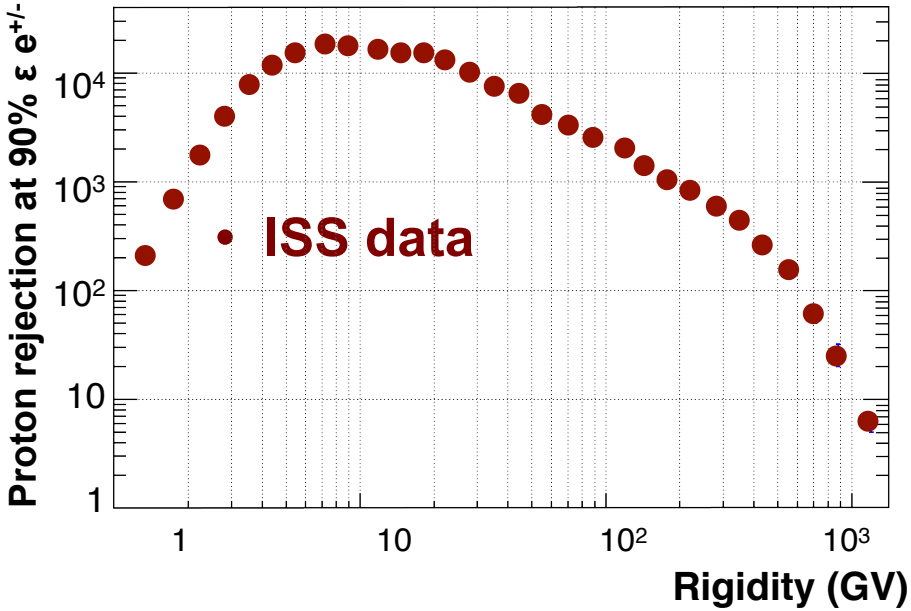
TRD e/p separation



FIT

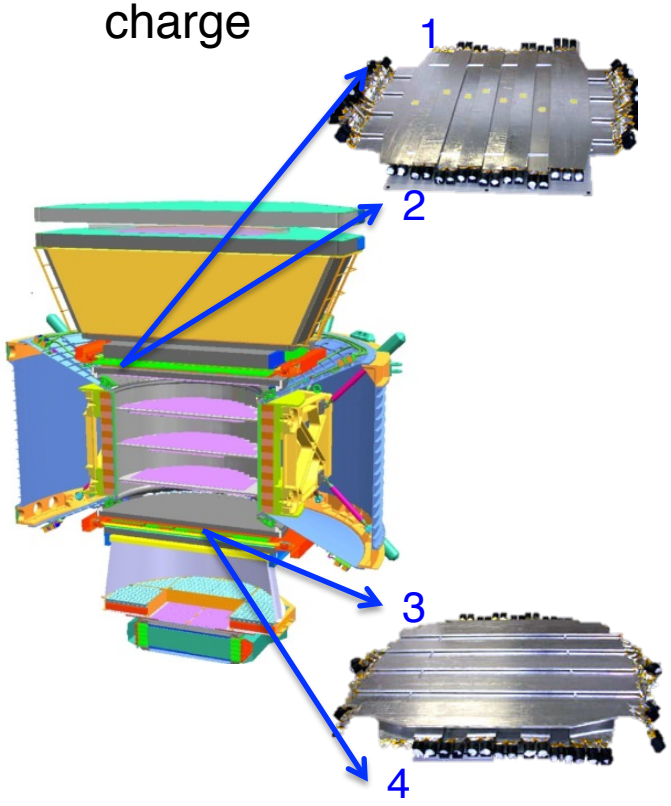
CUT

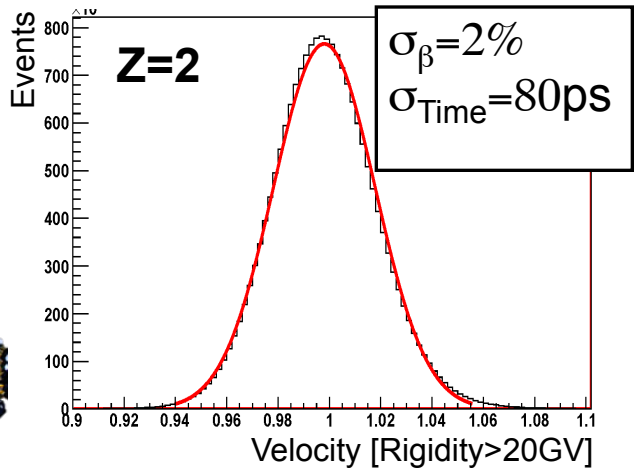


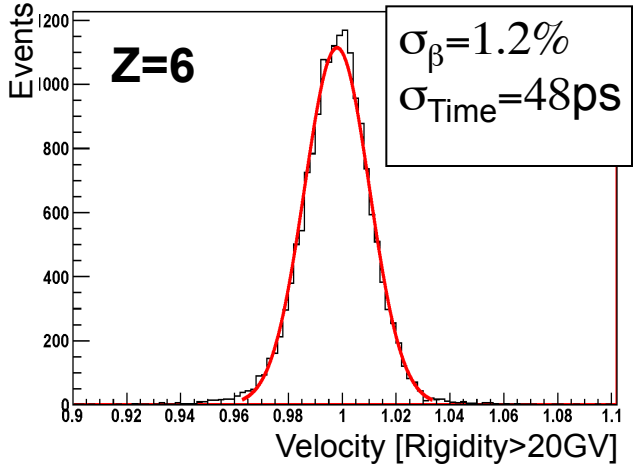


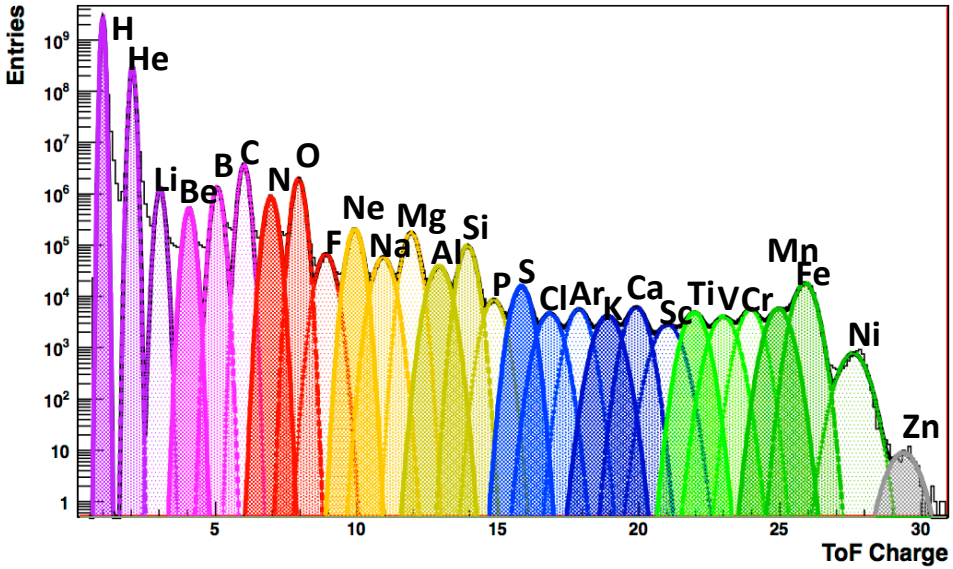
Time of Flight System

- 4 Layers of scintillation counter
- *Main trigger*
- *Measurement of* β=v/c (Δt~180 ps)
- Measurement of charge



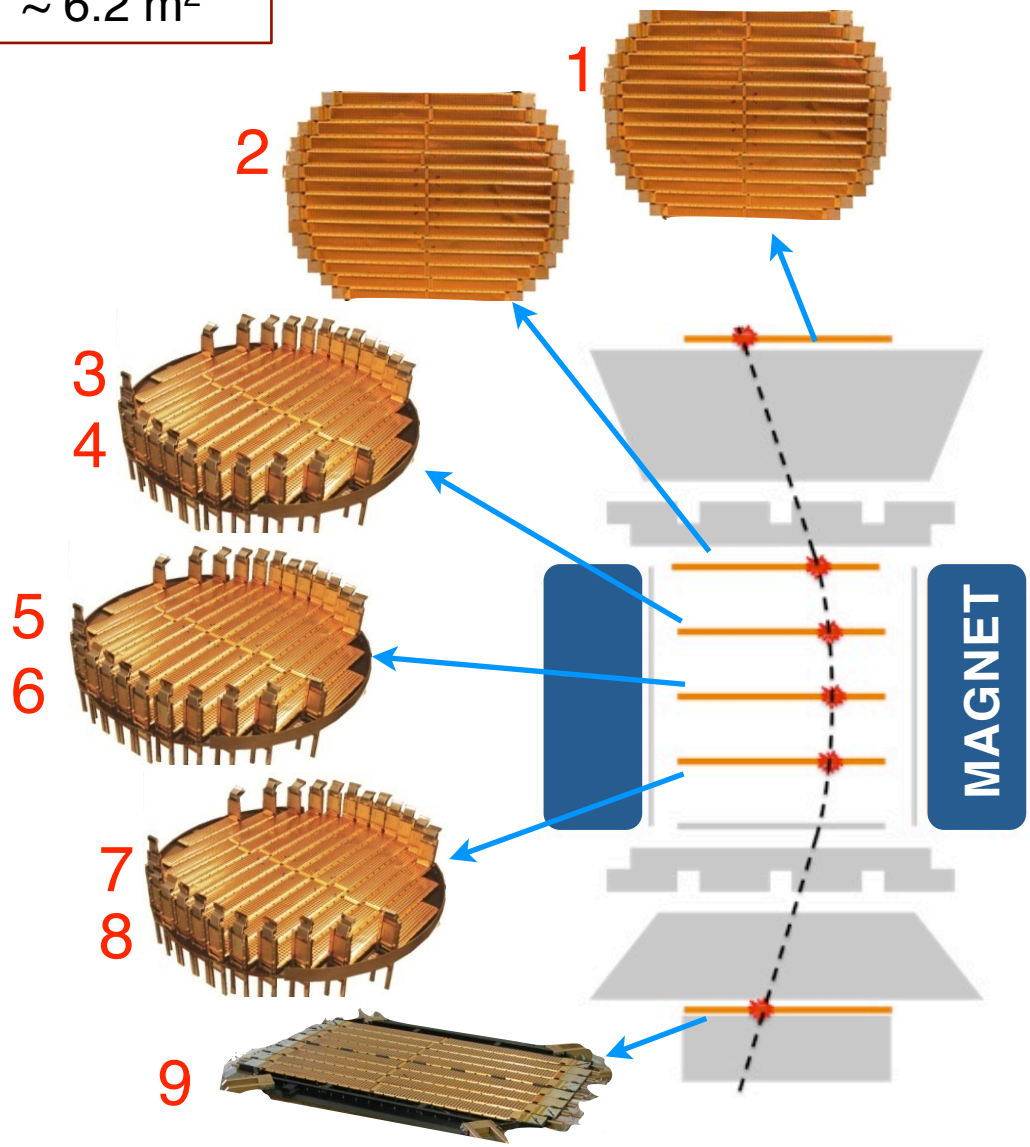






Silicon Tracker

active area
~ 6.2 m^2



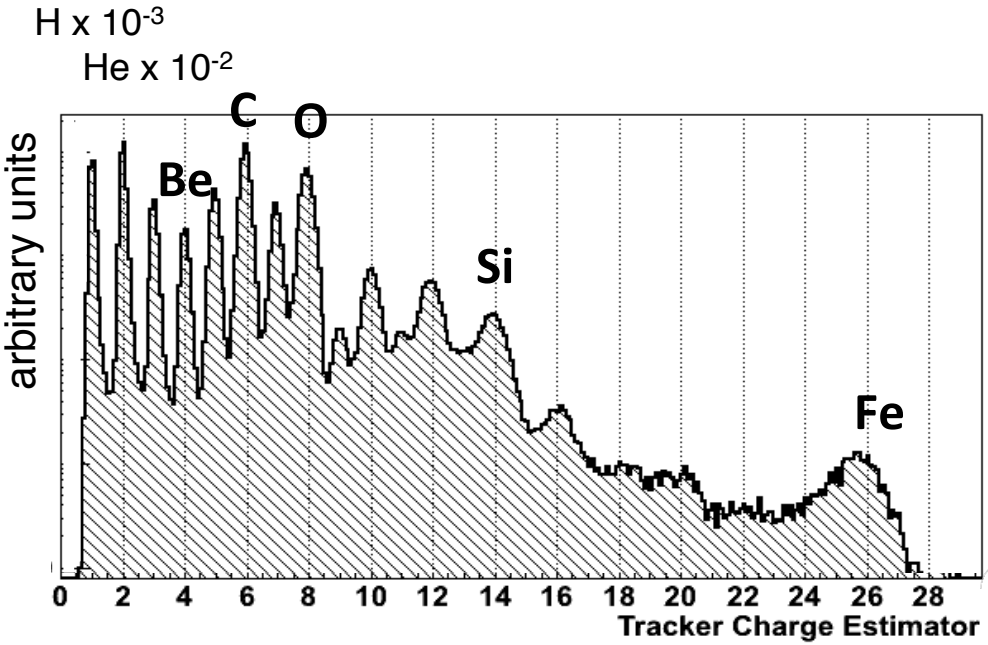
Silicon Tracker

- 9 layers of double-sided micro-strip silicon sensors
- Spatial accuracy in bending direction: *~10 μm*

Purpose:

- *Measurement of rigidity* (**R=p/q**) (MDR~2 TV)
- *Measurement of the sign of charge:* ***detection of anti-matter***

Charge measurement :

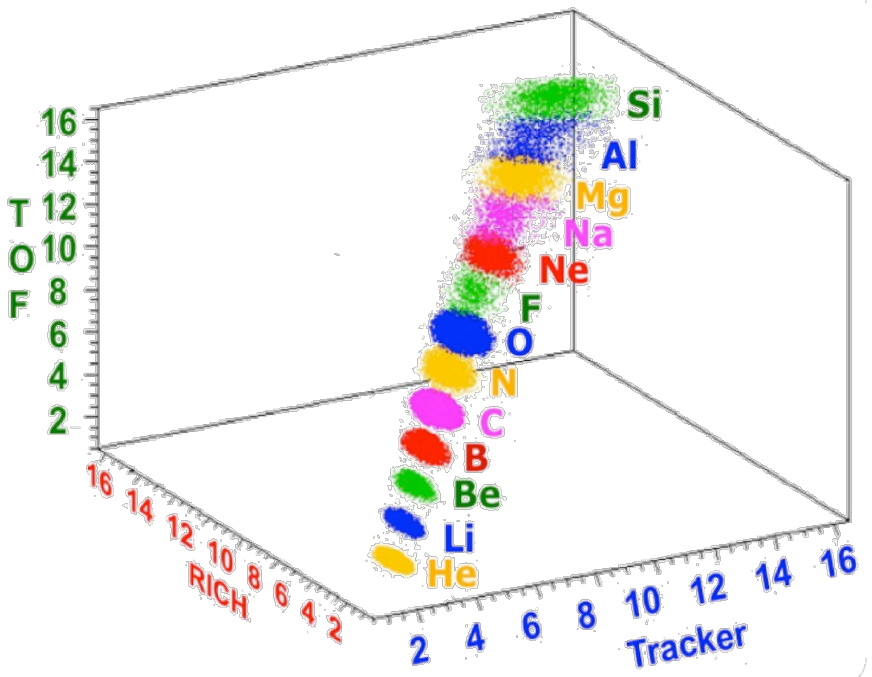


dE/dx in each layer →

Silicon Tracker has a very accurate charge resolution (~ 0.1 c.u.)

Redundant measurement of Z

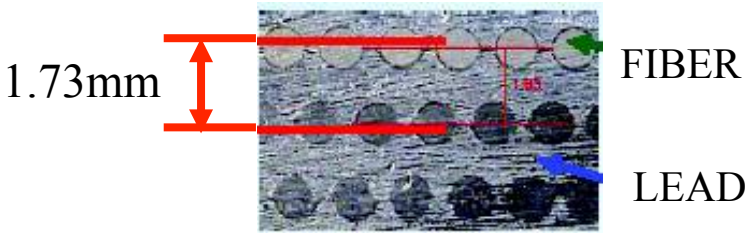
→

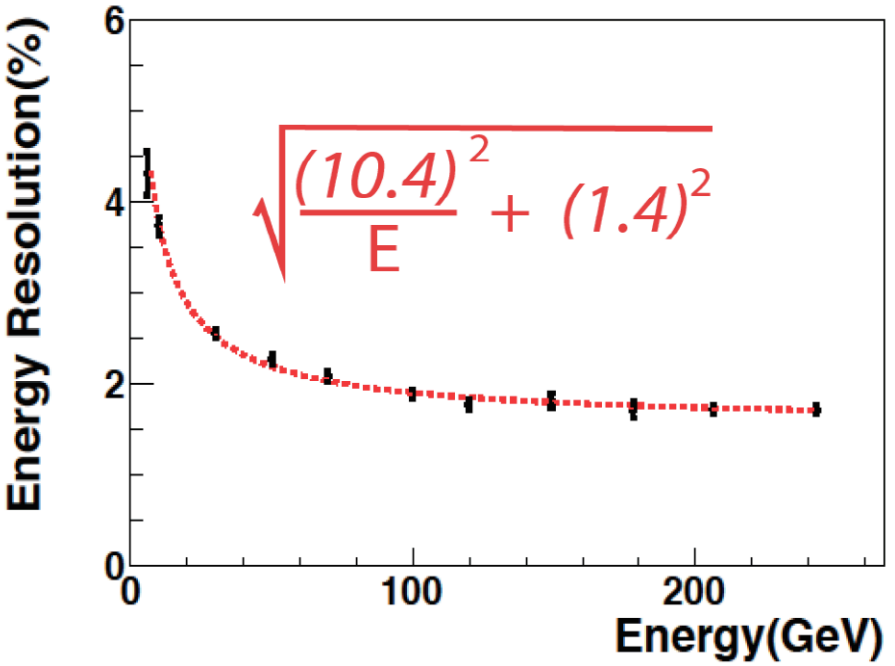


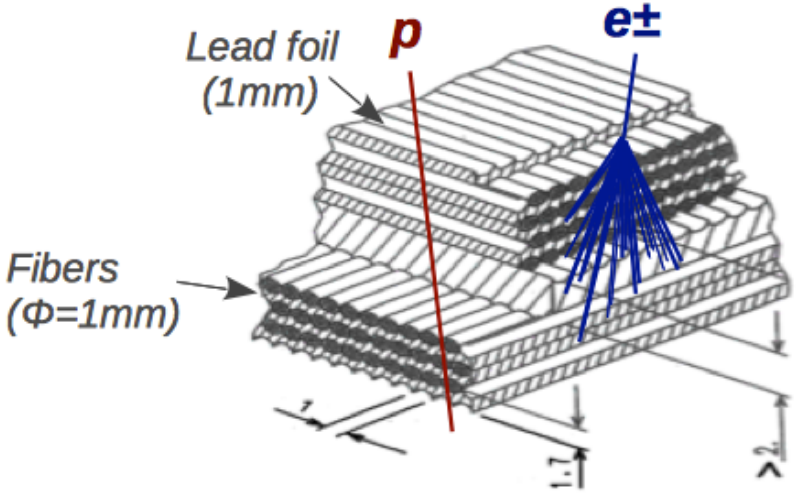
3D Electromagnetic Calorimeter (ECAL)

- Measurement of $e^{\pm}$ and γ energy ($\Delta E/E \sim 2\%$@100 GeV).
- *p/e rejection* $>10^4$
- 18 layers of lead and scintillating fiber

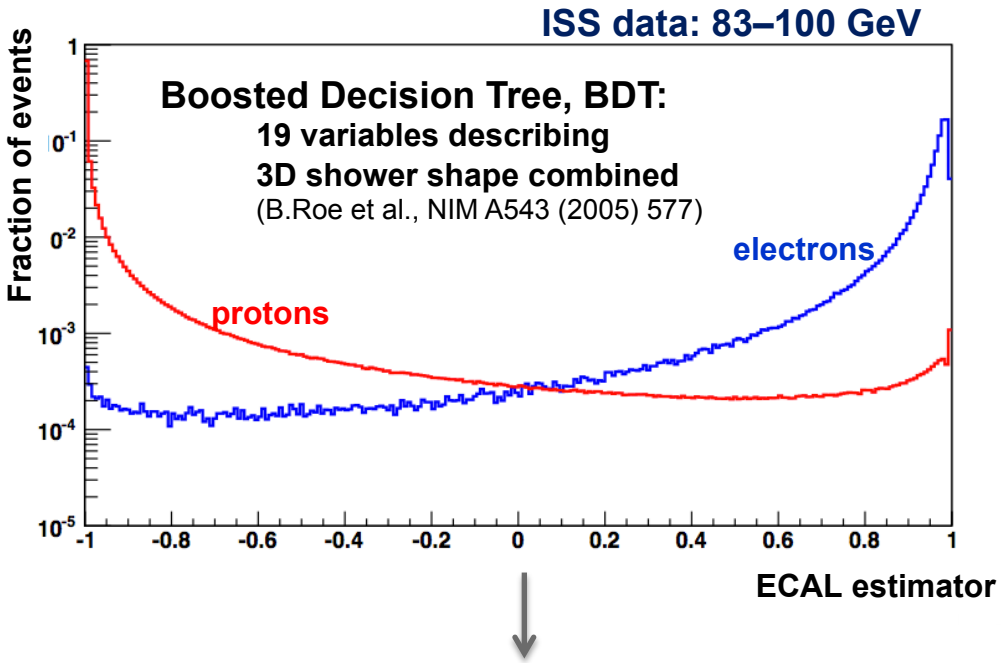
50,000 fibers, $\phi = 1$ mm distributed uniformly inside 600 kg of lead: Total ***~17 X_0***

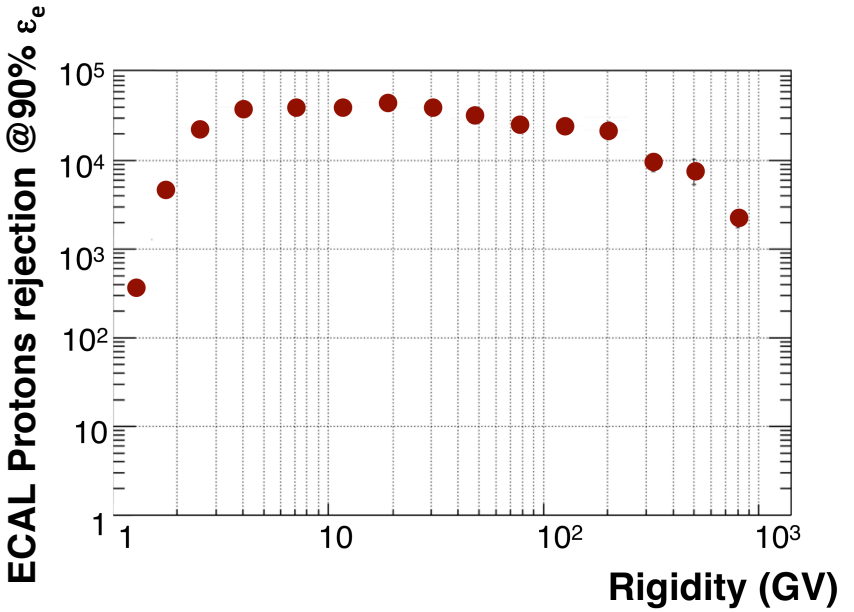






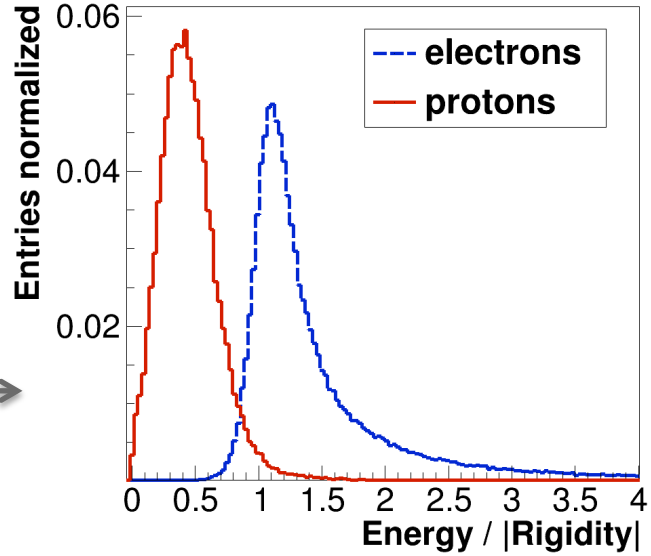
ECAL: e/p separation





Thanks to its shower shape imaging capabilities can **discriminate** very sensibly **eletromagnetic from hadronic showers**

Combining the ECAL energy information with the Tracker Rigidity (E/R) the **e/p rejection** can be further **increased**



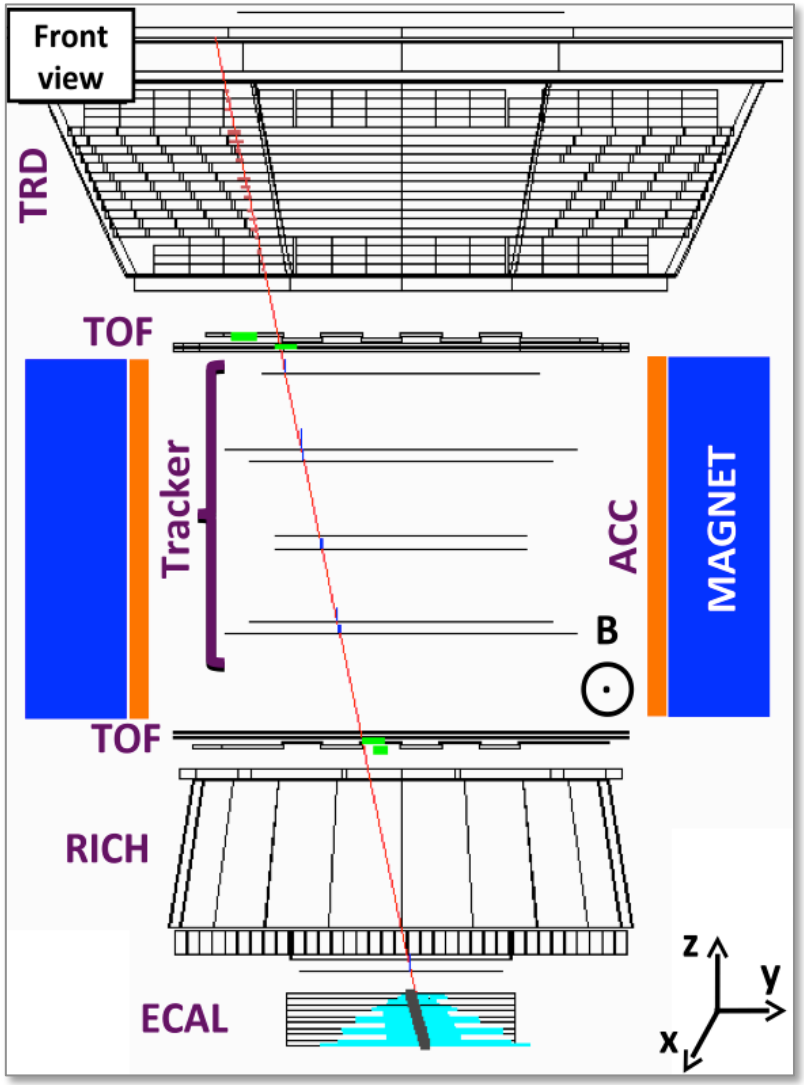
A 600 GeV electron in AMS

-TRD:
- identify the particle as e^+/e^- rejecting the hadronic hypotesys

-TOF:
- main trigger
- down going relativistic particle
- Z=1

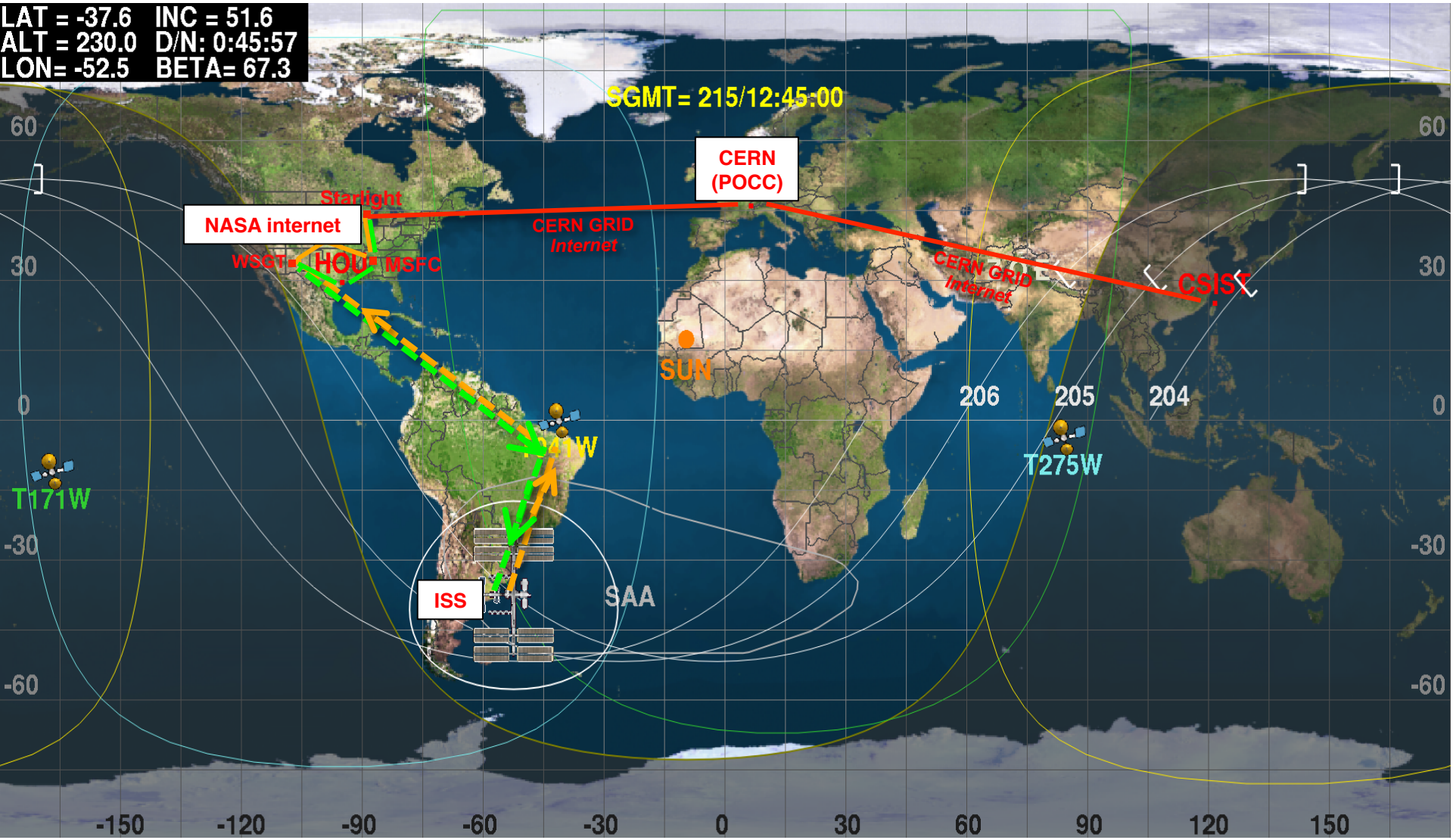
-TRACKER:
- identify negative charge (e^-)
- Z=1

-ECAL:
- identify the particle as $e^+/e^-/\gamma$ rejecting the hadronic hypotesys
- measurement of energy



AMS on orbit @ 400 Km

1 orbit ~93 min



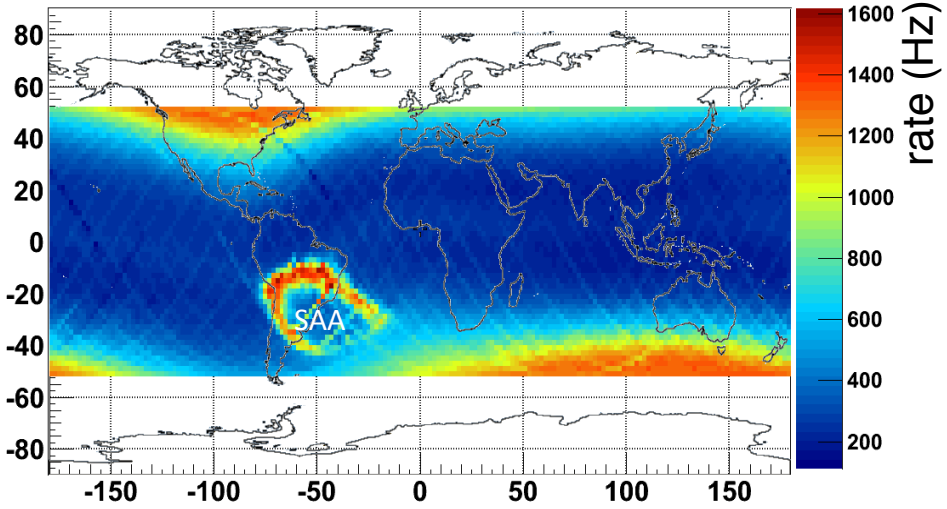
Payload Operation Control Center (POCC) @ CERN

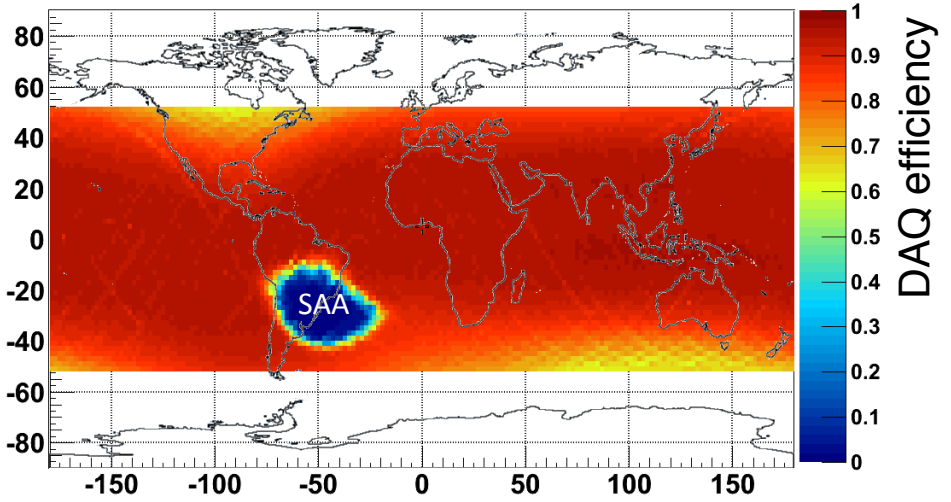
24/24 hours

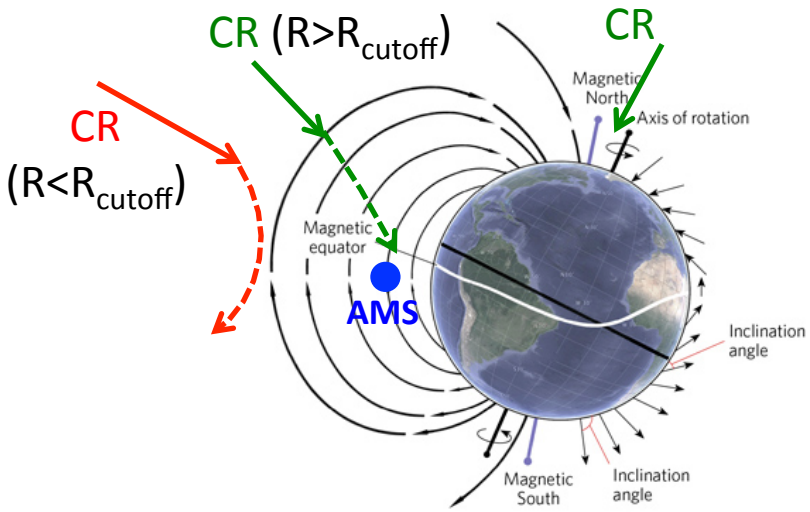
all days of the year

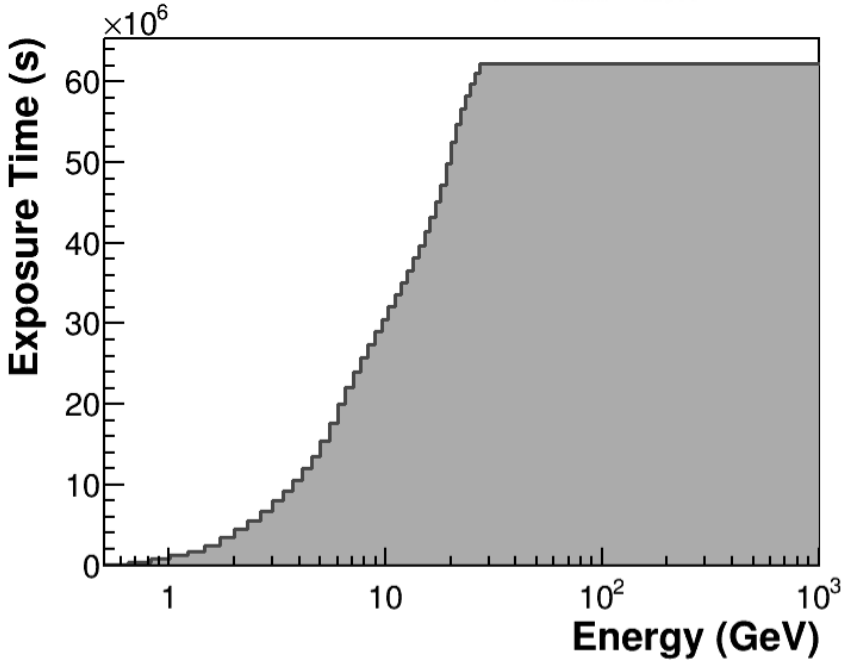
Orbital DAQ parameters

<Acquisition rate> ≈ 500 Hz









Cutoff & Orbit → Average life time fraction T_{exp}/44 months ~ 80 %

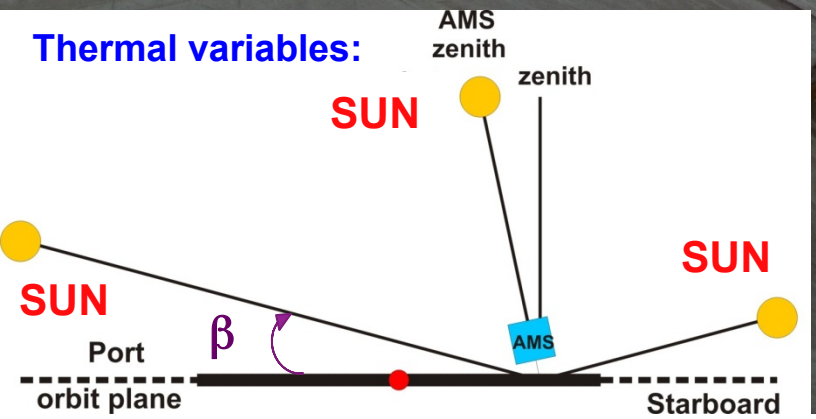
The Thermal environment

AMS-02 is not a free-flyer attitude and sun exposition **cannot be controlled**!

- 70° C

+ 70° C

Thermal variables:

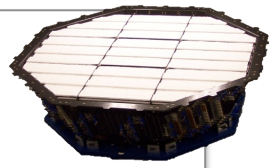


Thermal environment

TOF & ACC

64 Temperature Sensors

TRD

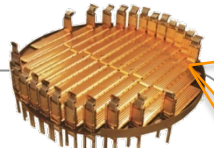


24 Heaters

8 Pressure Sensors

482 Temperature Sensors

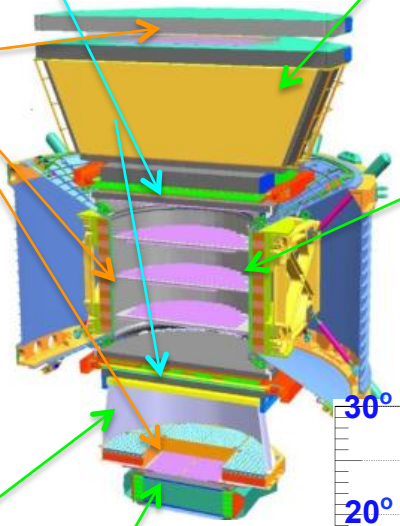
Silicon Tracker



4 Pressure Sensors

32 Heaters

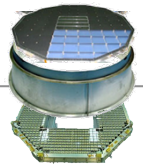
142 Temperature Sensors



Magnet

68 Temperature Sensors

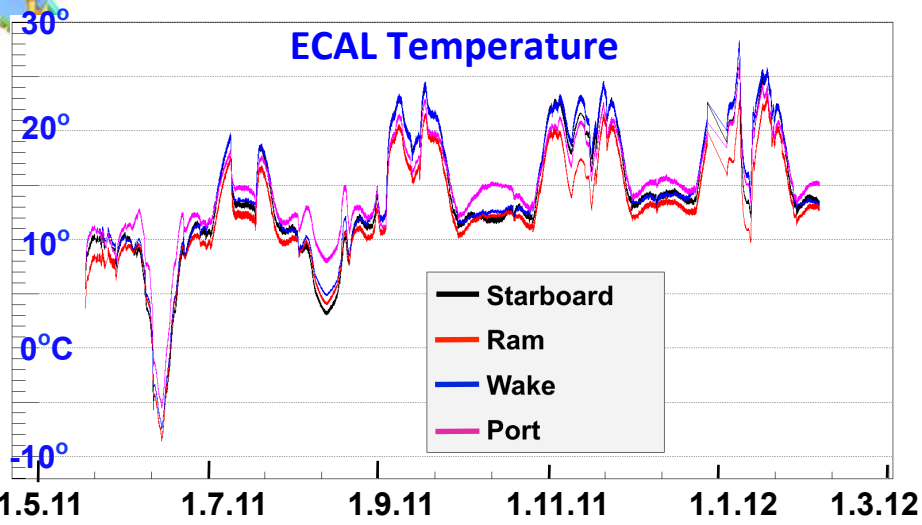
RICH



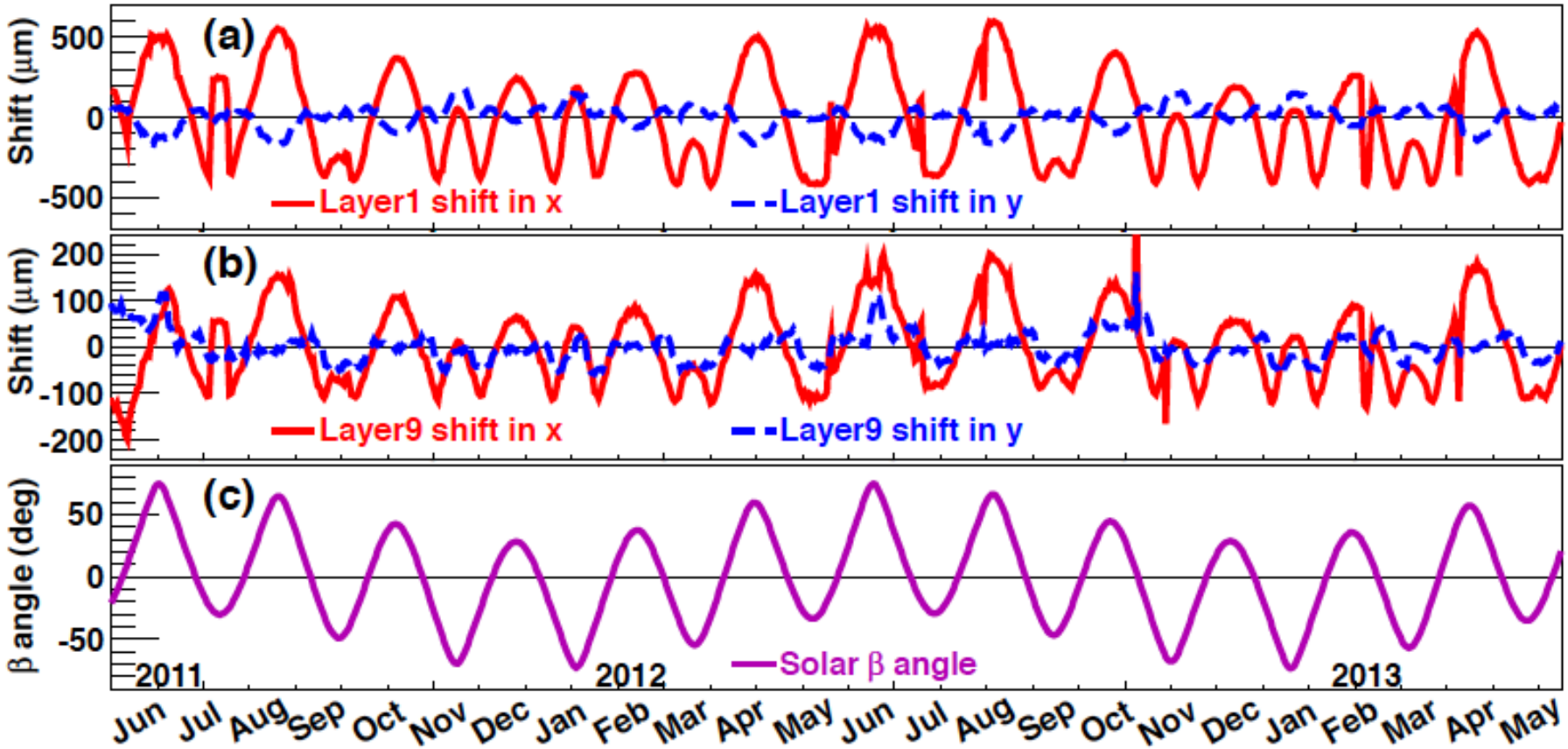
96 Temperature Sensors

ECAL

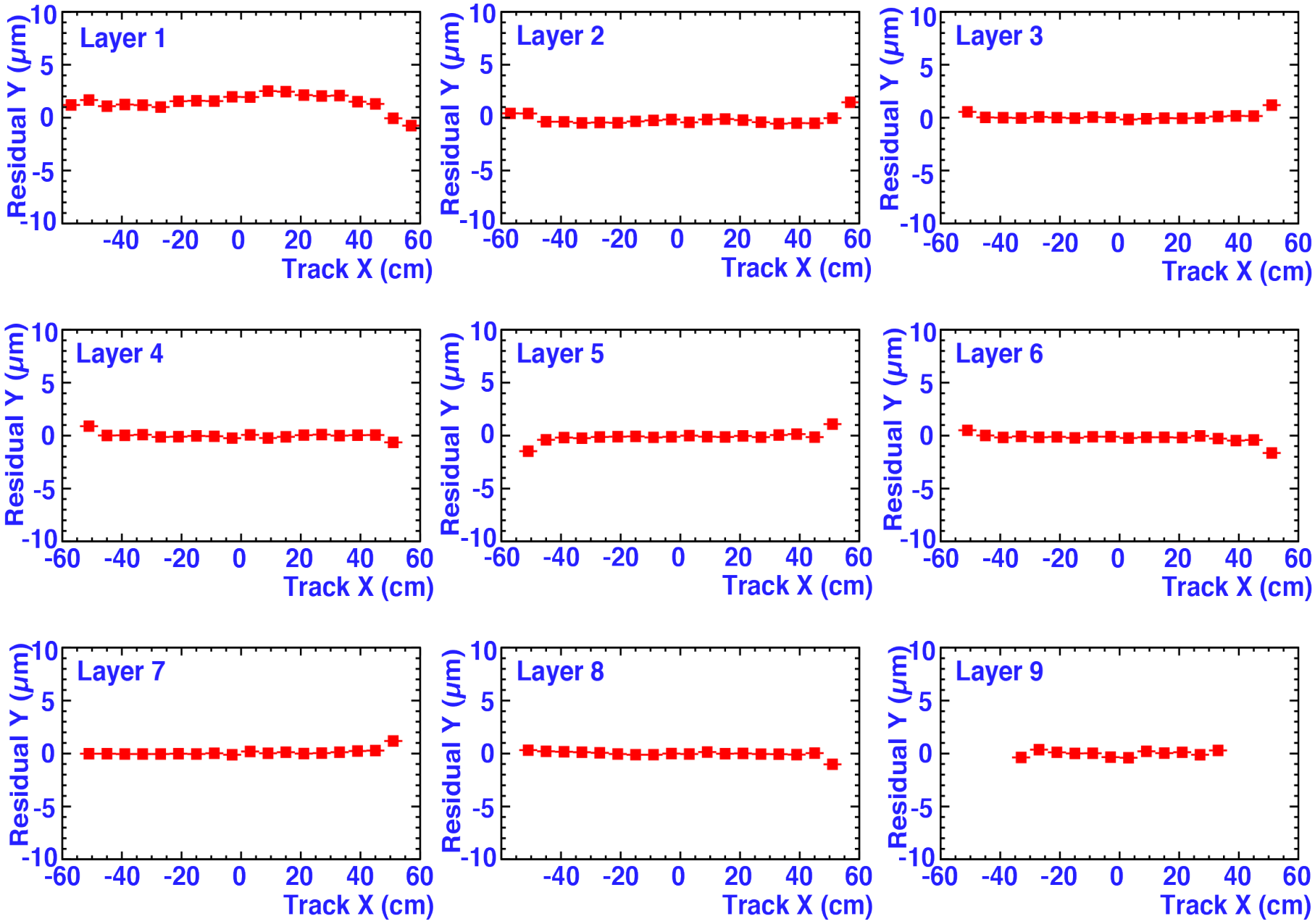
80 Temperature Sensors



Seasonal effects on Tracker



Alignment accuracy of the 9 Tracker layers over the full period



1. Physics of AMS

2. AMS-02: Detector & Operations

3. AMS-02: Results

In 44 months, AMS has collected 60 billion cosmic rays.

This is much more than all the cosmic rays collected in the last 100 years.

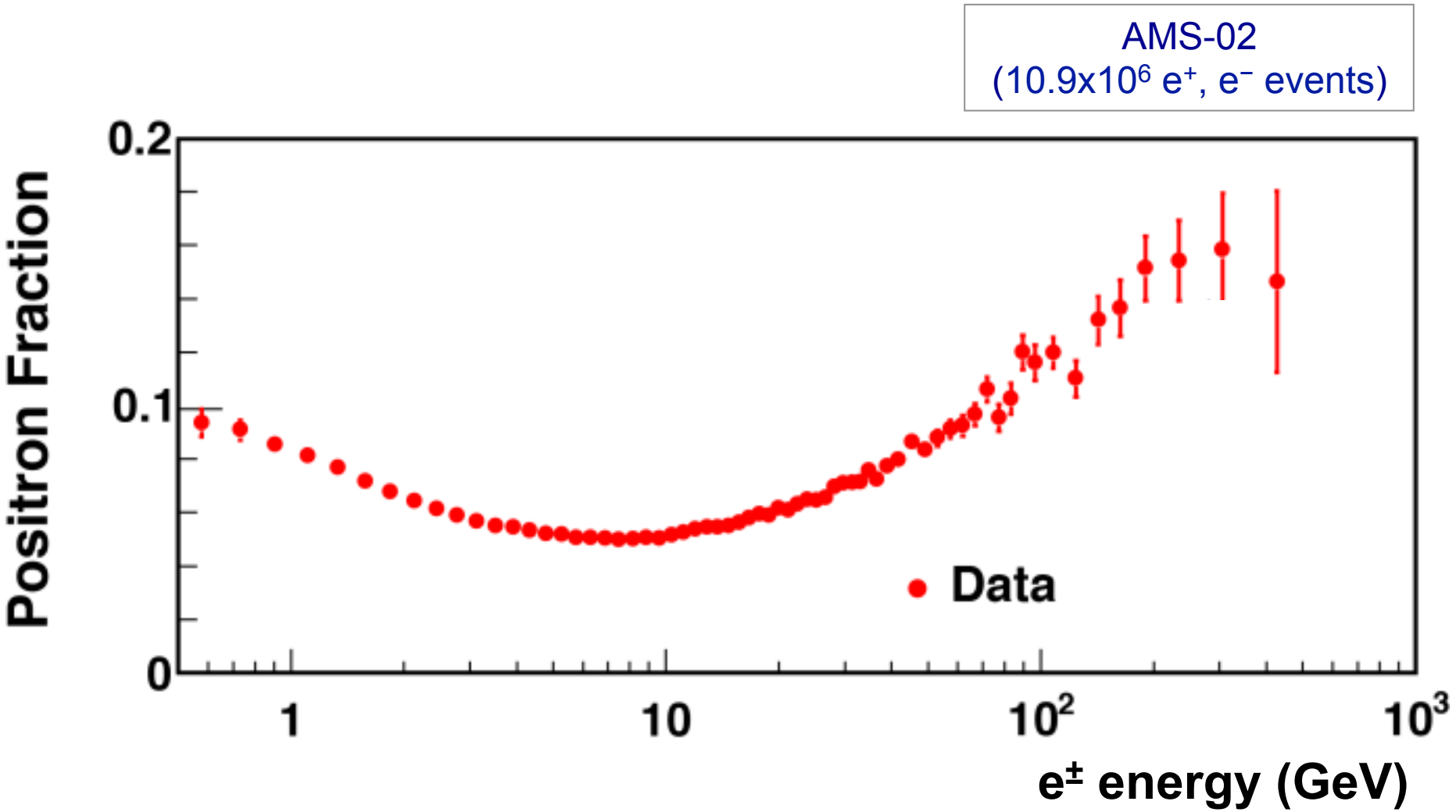
AMS latest results

1. **Positron Fraction** (0.5–500 GeV)

2. **Electron** (0.5–700 GeV) and **Positron Fluxes** (0.5–500 GeV)

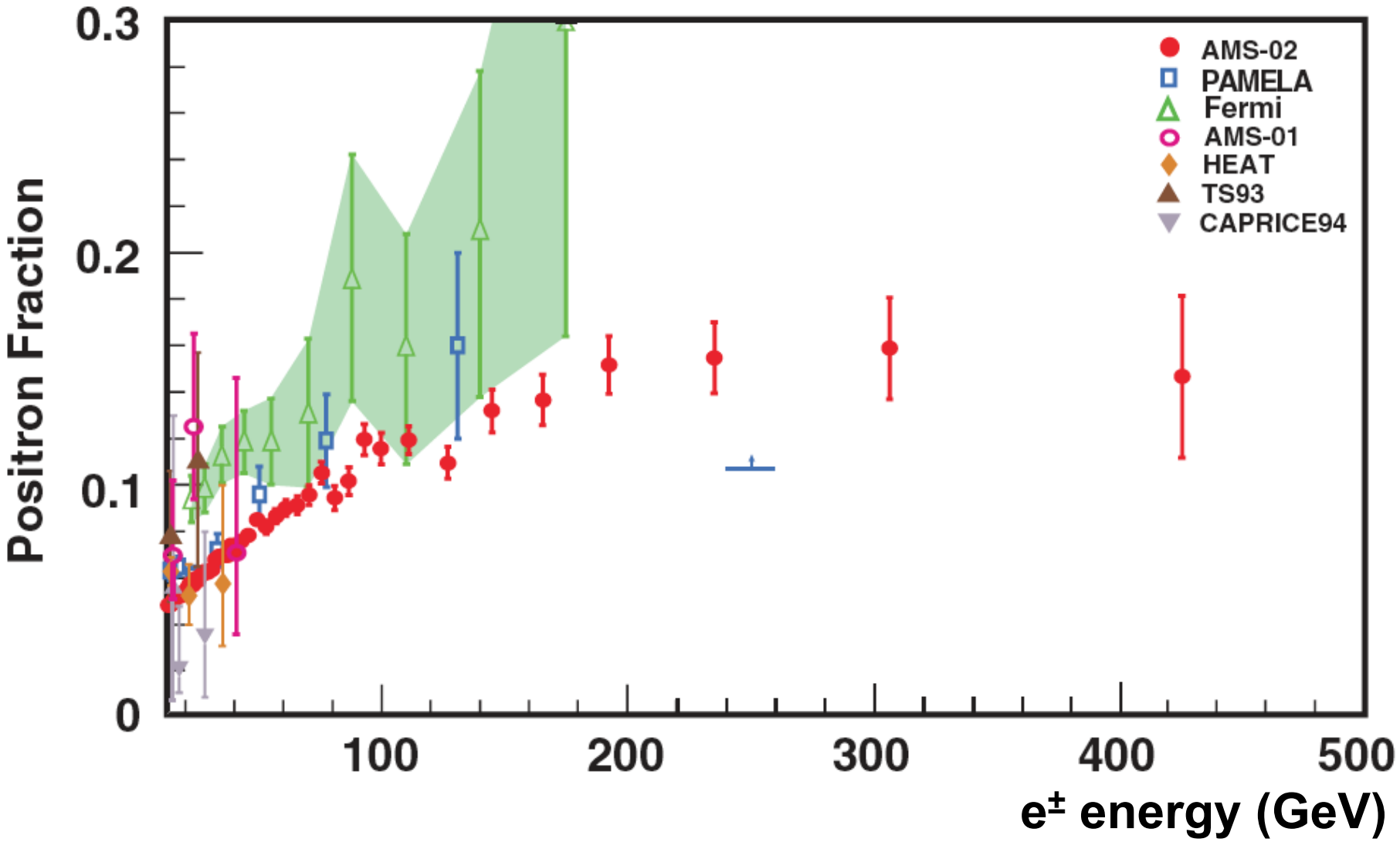
3. **All electrons Flux** (0.5 GeV – 1 TeV)

Positron fraction (0.5 – 500 GeV)



No fine structures are observed

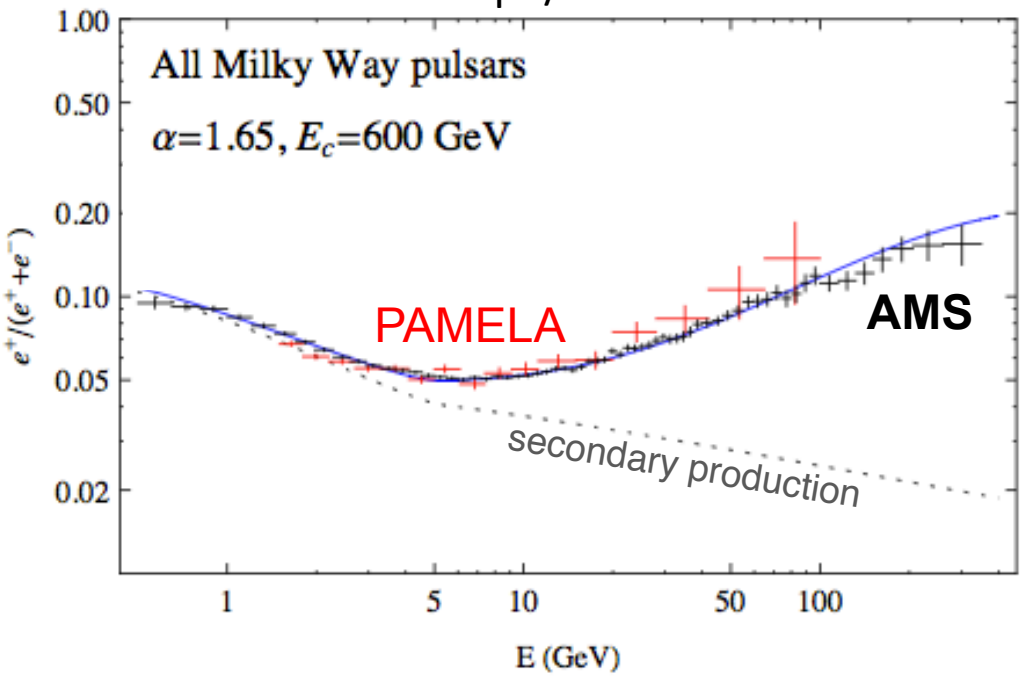
Positron fraction @ high energies



Origin of the excess

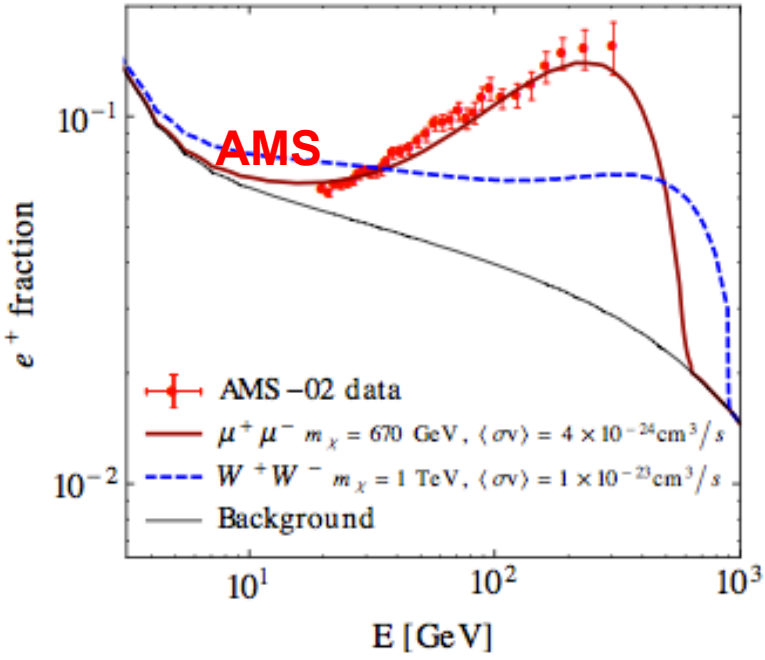
Astrophysical objects

Cholis arXiv: astro-ph/1304.1840



Dark Matter

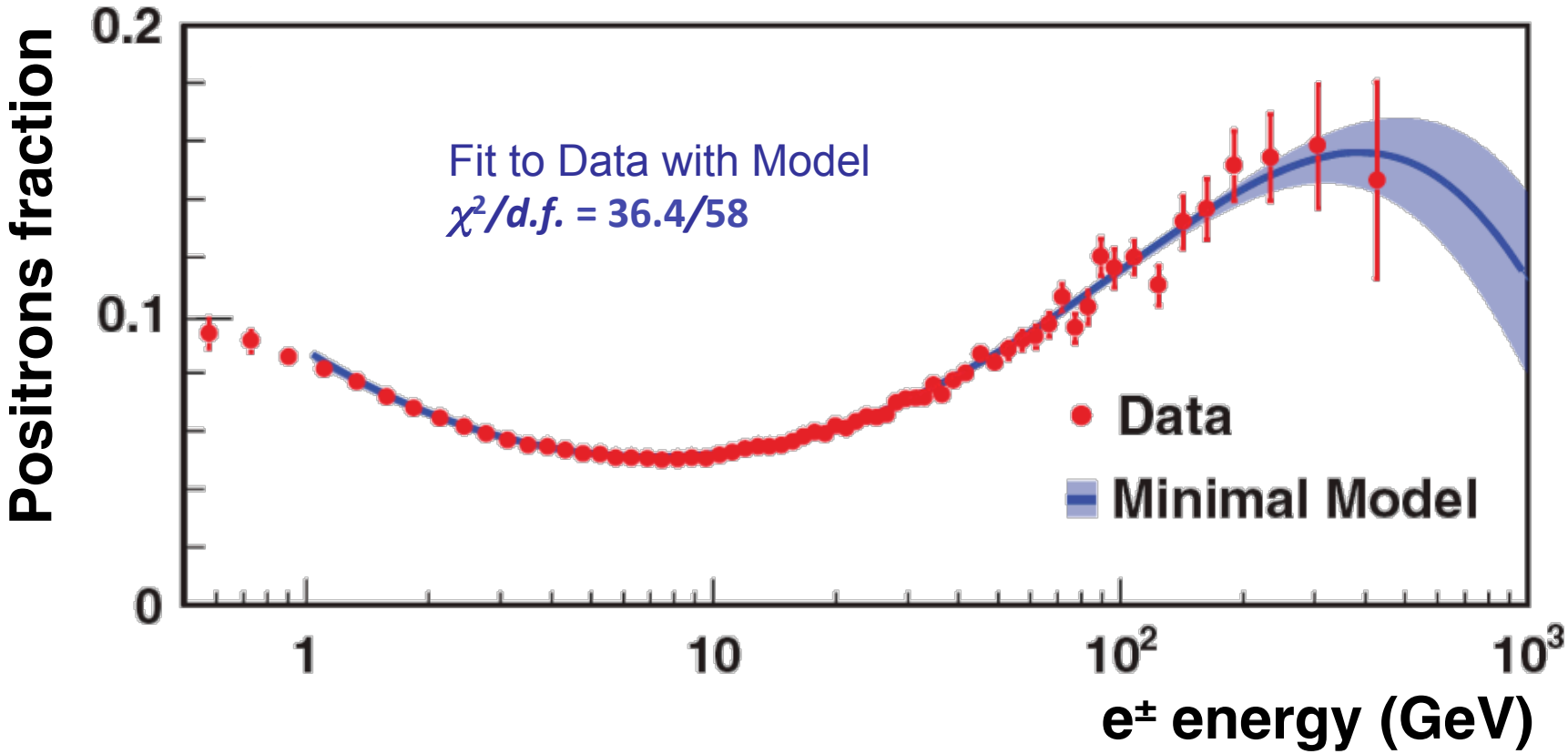
Kopp hep-ph/1304.1184



Different energy behavior of the positron fraction:

- **Pulsars predictions:**
  - **slow fall at high energies**
  - **anisotropic positron flux**
- **Dark Matter prediction:**
  - **steeper fall at high energies**
  - **isotropic positron flux**

Minimal empirical model

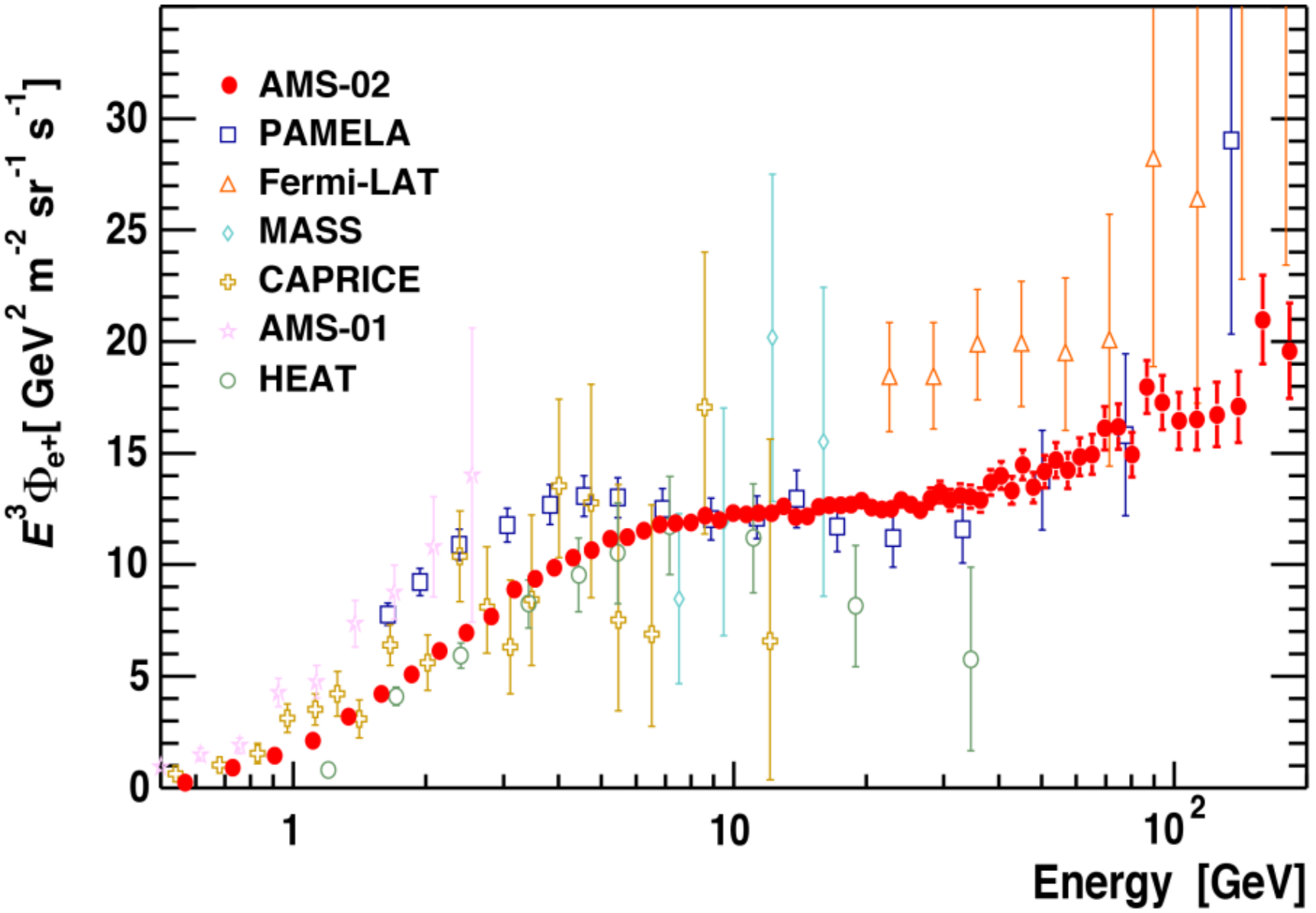


Describe electron and positron fluxes as a sum of a **diffuse component** and a **common source** with a cutoff energy :

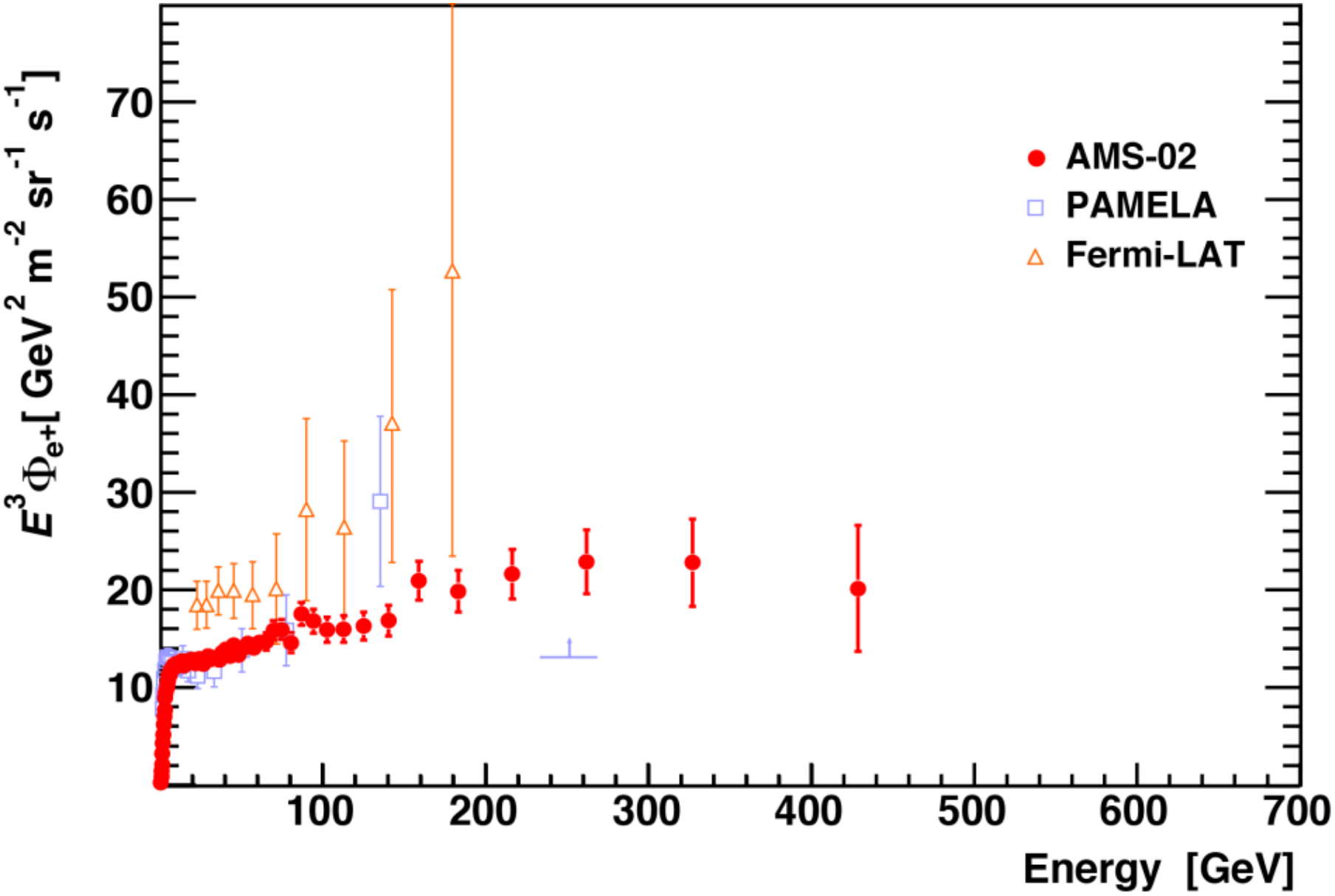
$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$\gamma_{e^-} - \gamma_{e^+} = -0.56 \pm 0.03$
$\gamma_{e^-} - \gamma_S = 0.72 \pm 0.04$
$C_{e^+}/C_{e^-} = 0.091 \pm 0.001$
$C_S/C_{e^-} = 0.0061 \pm 0.0009$
$1/E_s = 1.84 \pm 0.58\ \text{TeV}^{-1}$

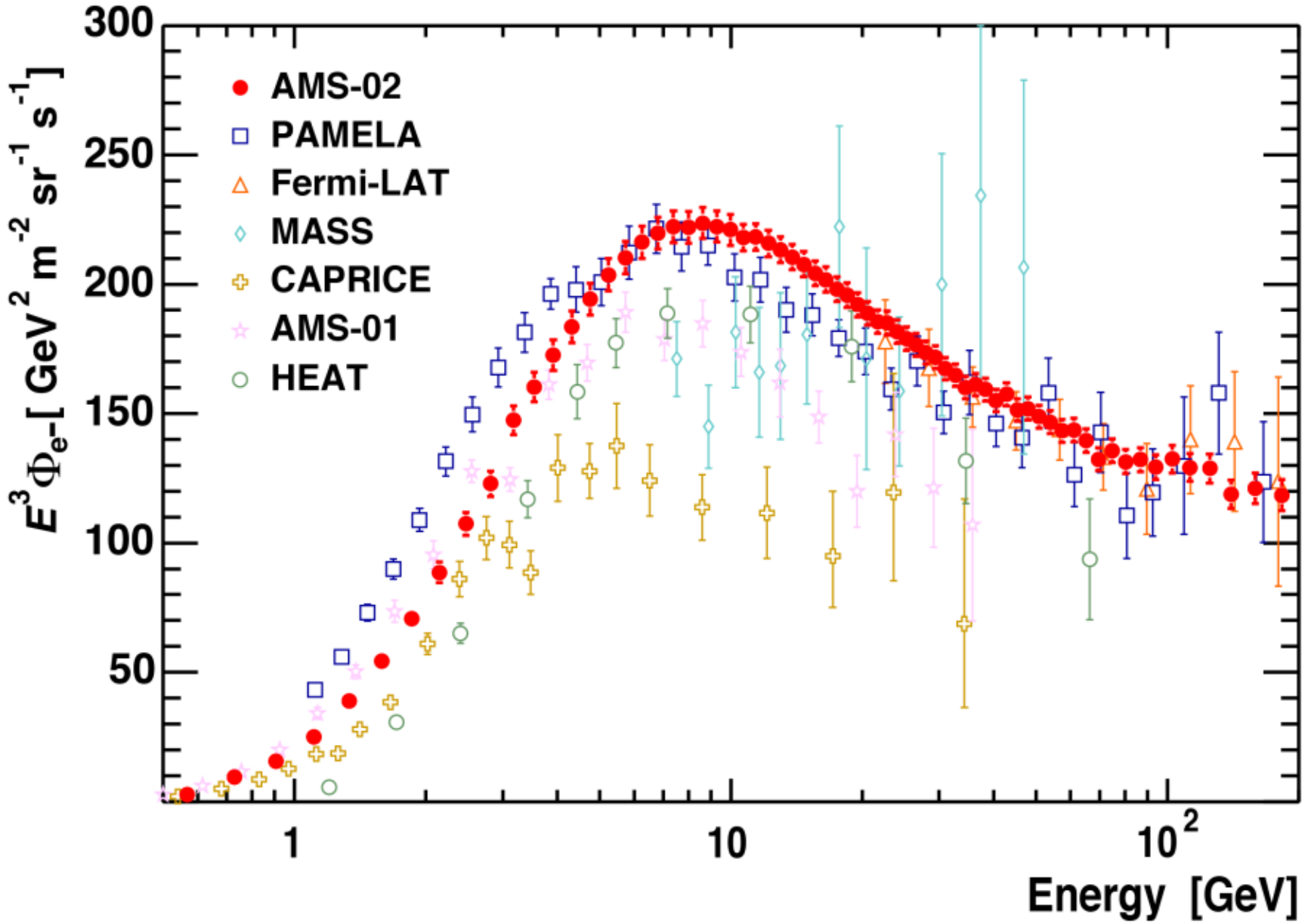
Positron (e+) flux



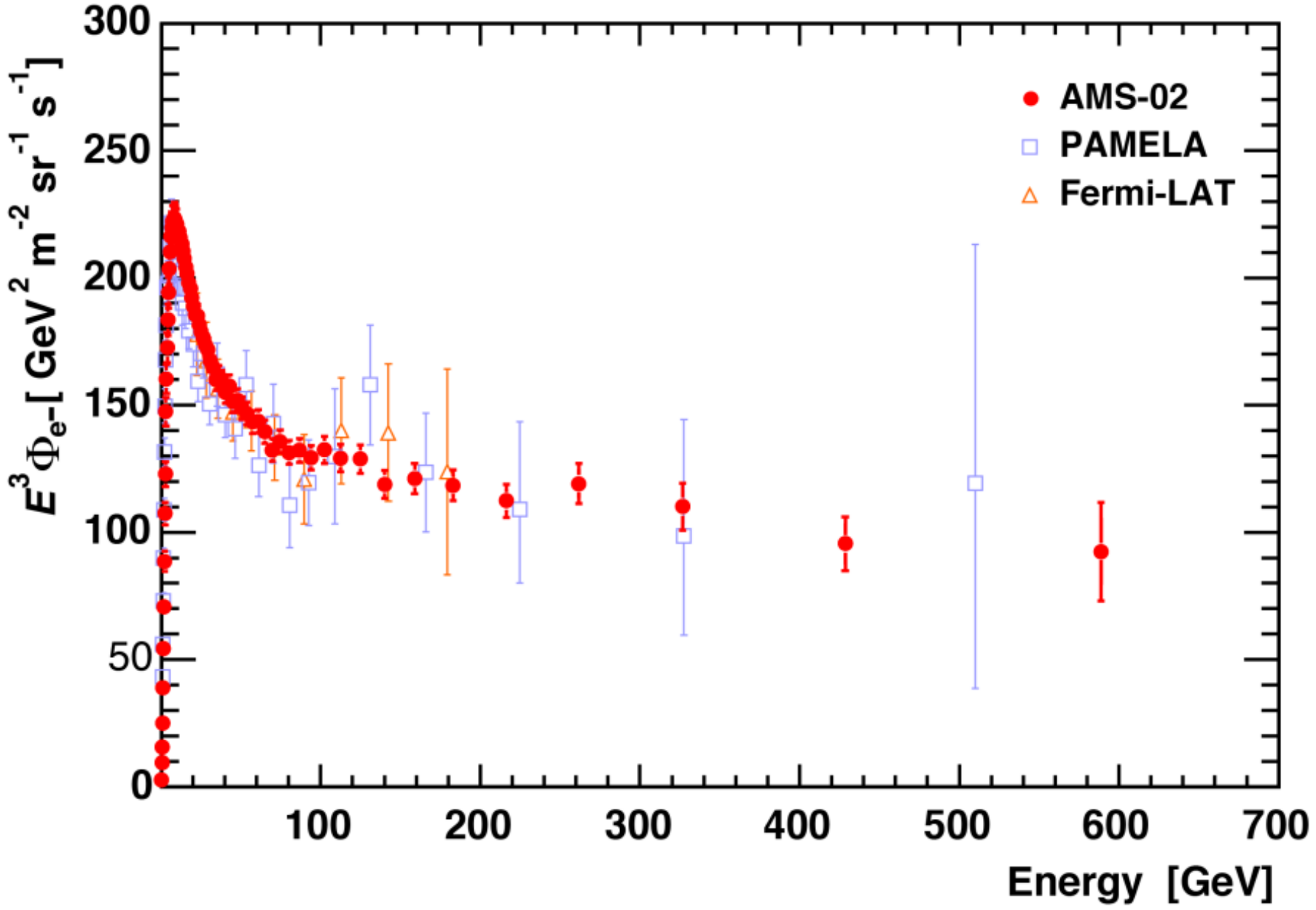
Positron (e+) flux



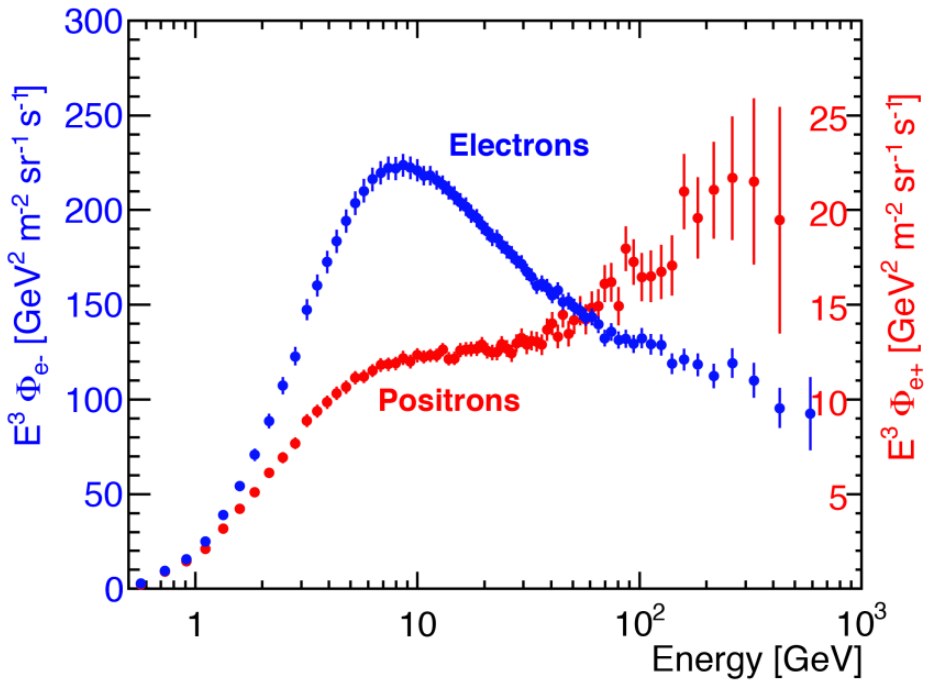
Electron (e^-) flux

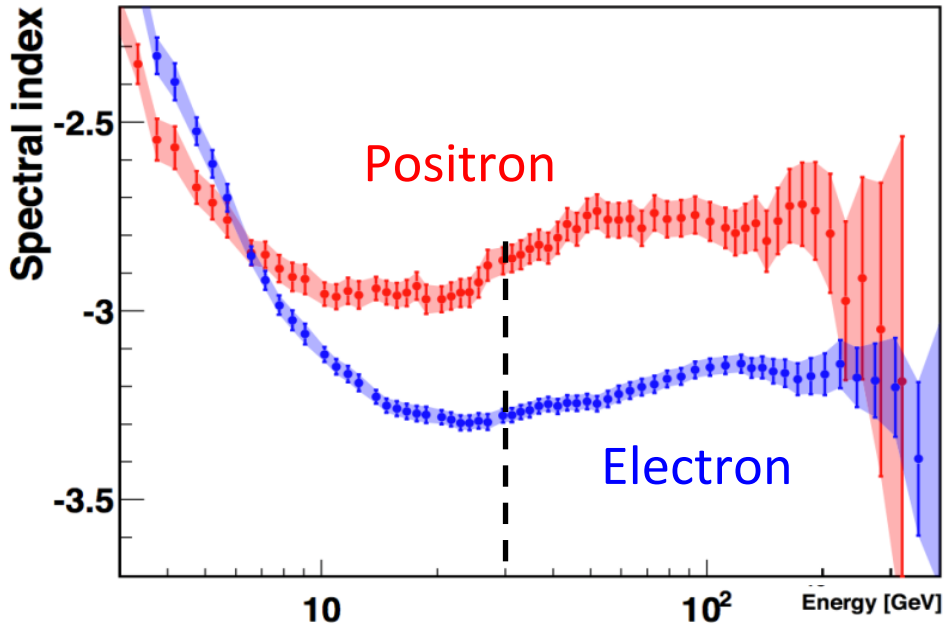


Electron (e^-) flux



Observation on electrons and positrons fluxes

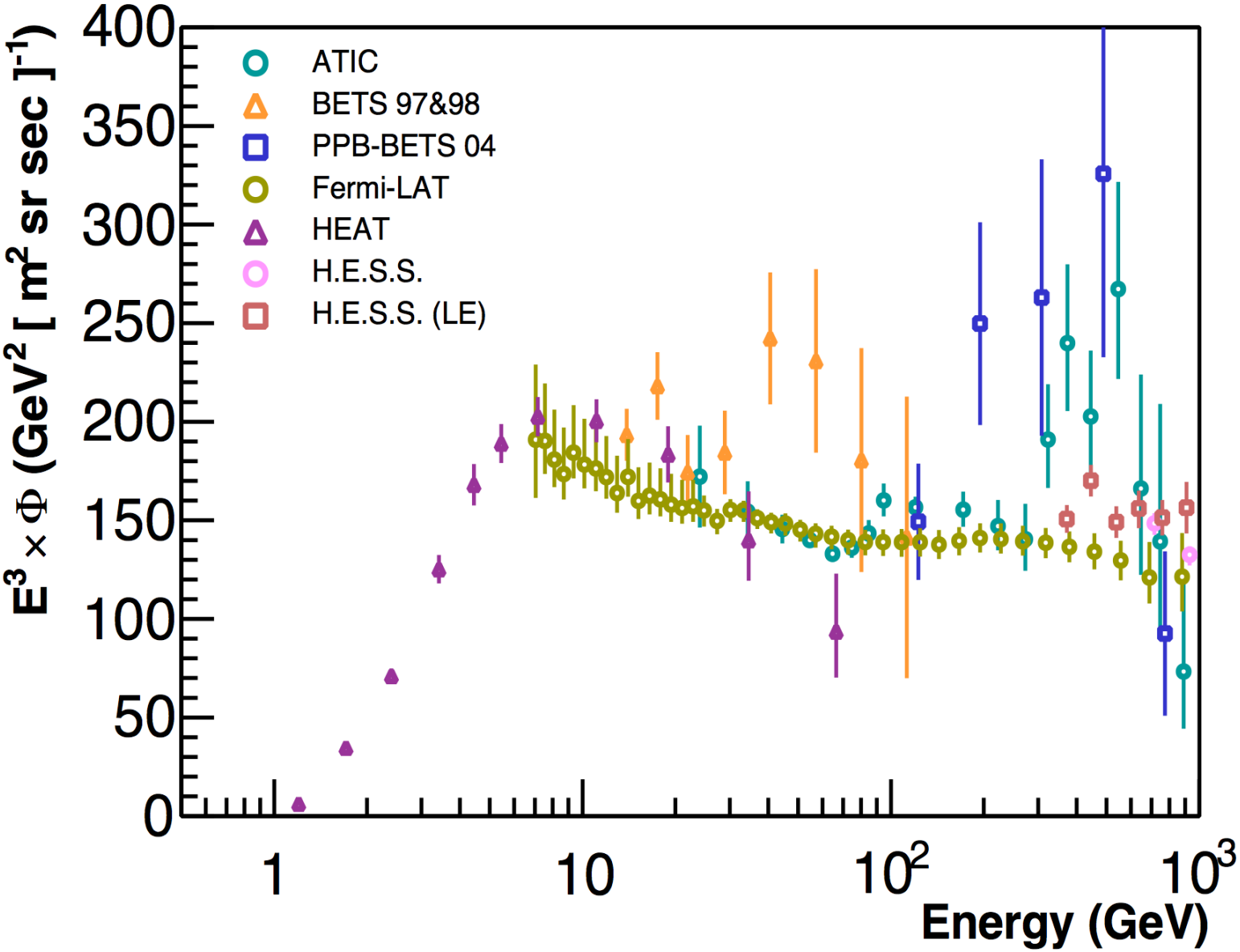




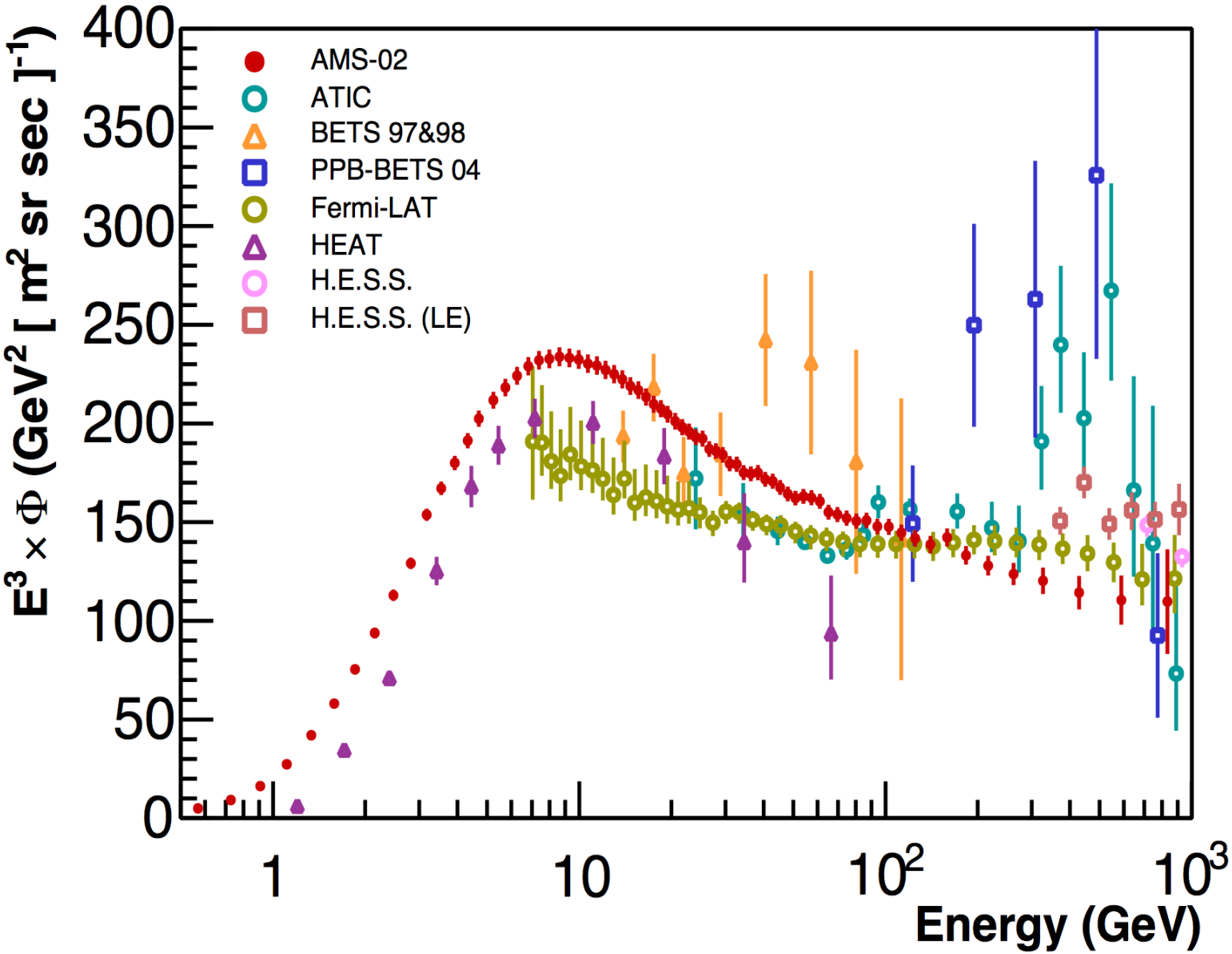
Observations:

1. Both the electron flux and the positron flux **are significantly different in their magnitude and energy dependence**.
2. Both spectra **cannot be described by single power laws**.
3. The **spectral indices** of electrons and positrons **are different**.
4. Both change their behavior at **~30GeV**.
5. The **rise in the positron fraction** from 20 GeV **is due to an excess of positrons**, not the loss of electrons (the positron flux is harder).

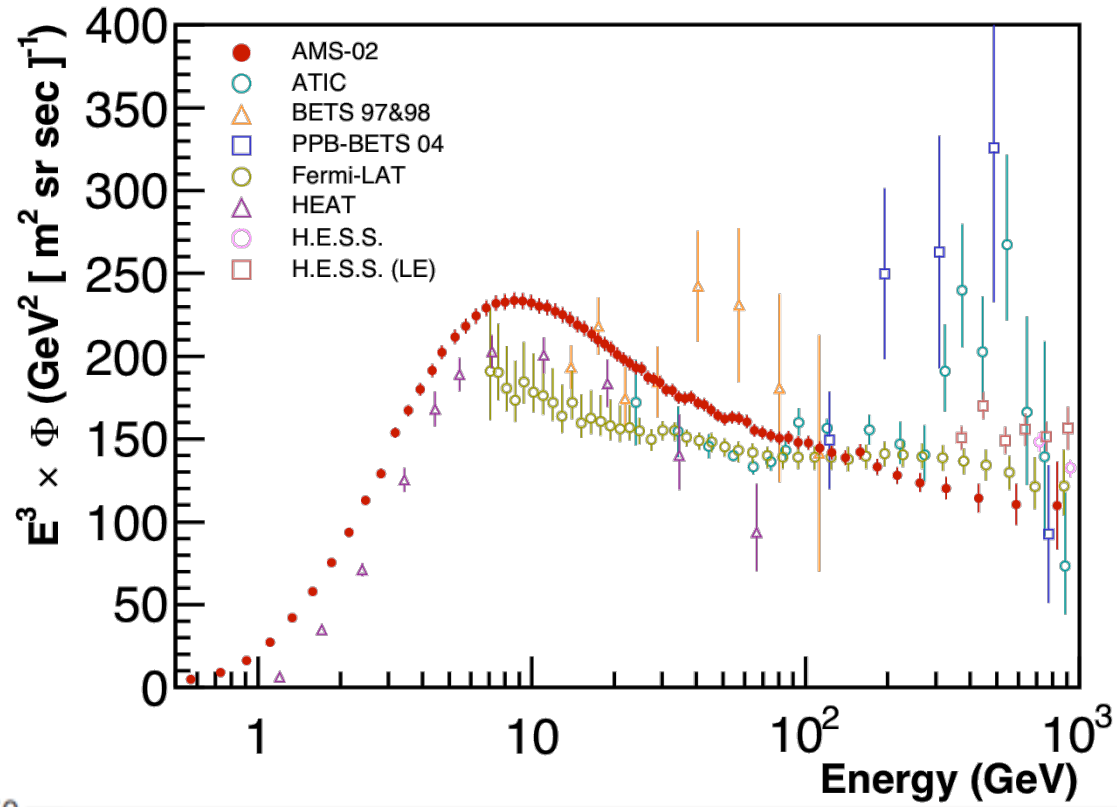
All-electrons (e^++e^-) flux – before AMS

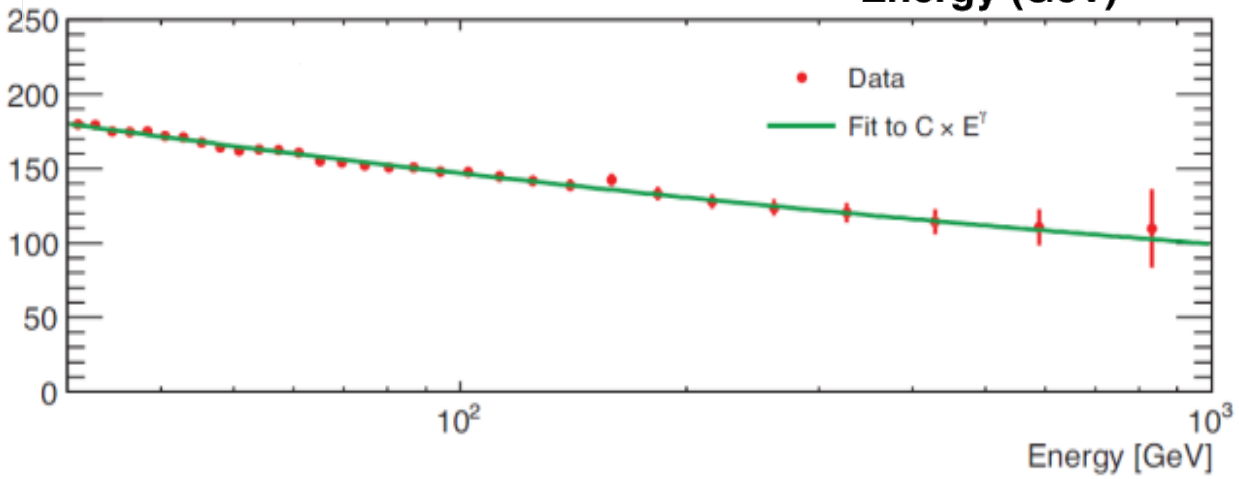


All-electrons (e^++e^-) flux – after AMS



All-electrons (e^++e^-) flux





The flux is smooth and reveals new and distinct information.

No structures were observed.

It is consistent with a single power law above 30 GeV.

Conclusions

- AMS will continue its mission until ISS will be operated : a Cosmic Rays observatory of the next decade
- The observed positron excess may imply a heavy Dark Matter WIMP particle or a new mechanism of acceleration in the pulsars
  - Observation of anomalies in the anti-proton spectrum would be an evidence of the DM hypothesis
  - Accurate measurements of the “standard” CR components are being performed and will allow to tune the “background”
- AMS data have the potential to shed a light on the nature of the Dark Matter : More statistics…higher energies, more channels, more information !

Work in progress !!

THANKS FOR YOUR ATTENTION