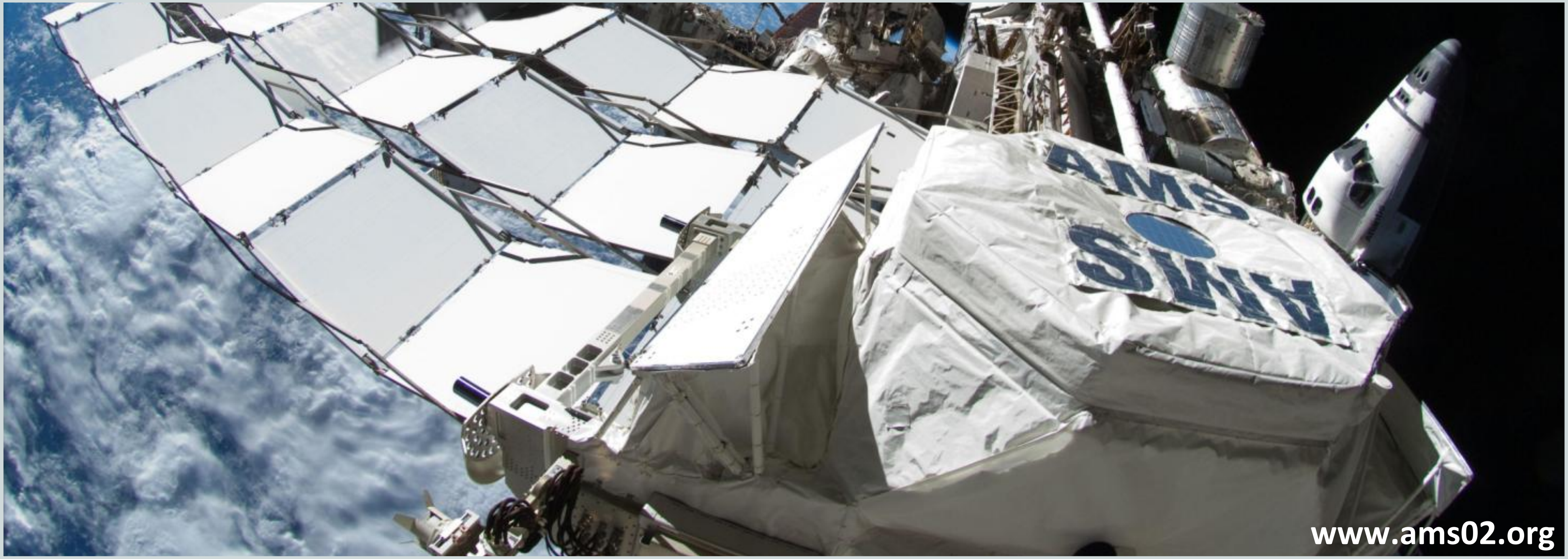
Recent results from the AMS-02 experiment on the International Space Station after 4 years in Space

Valerio Vagelli I.N.F.N. Perugia

LFC15: physics prospects for Linear and other Future Colliders after the discovery of the Higgs
Trento, September 2015



i) Introduction of Cosmic Rays
ii) AMS in a nutshell
iii) Data analysis and recent results

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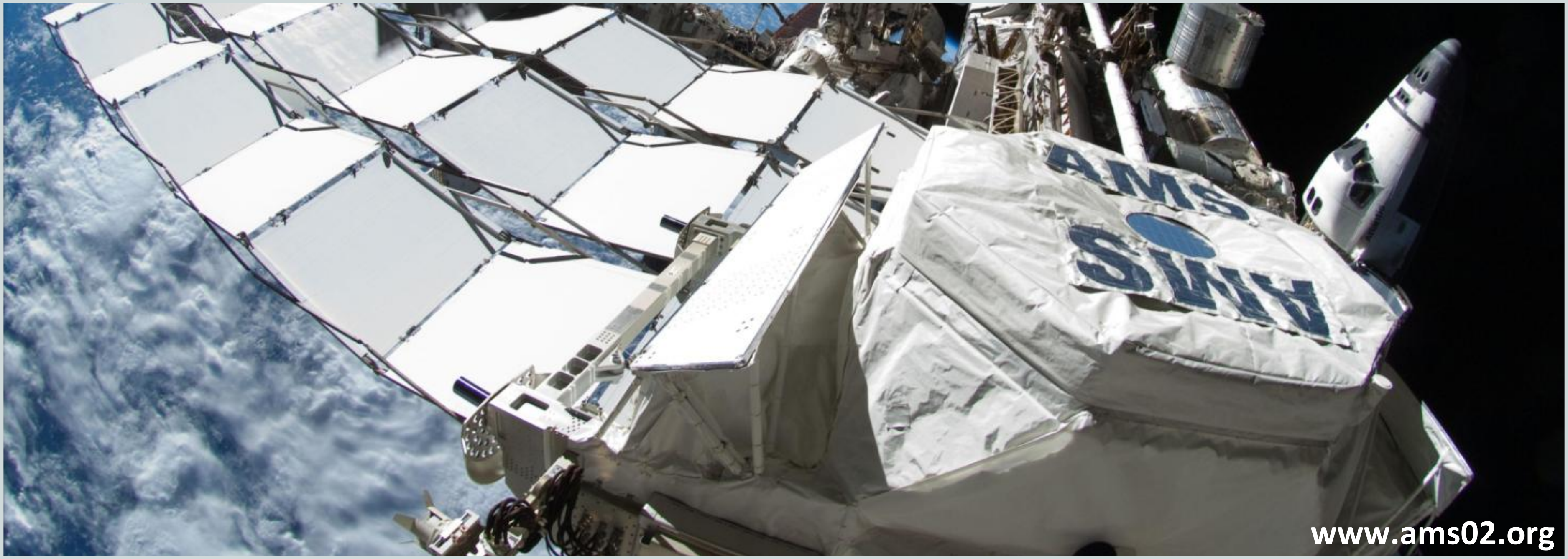
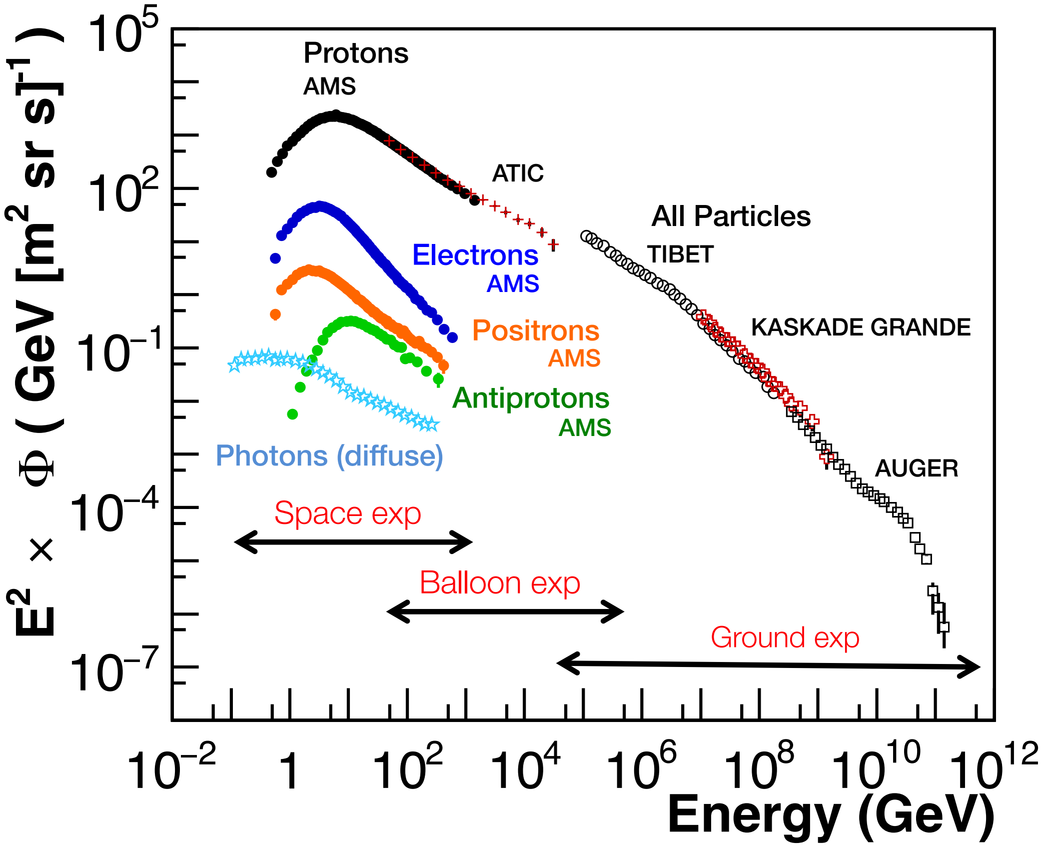
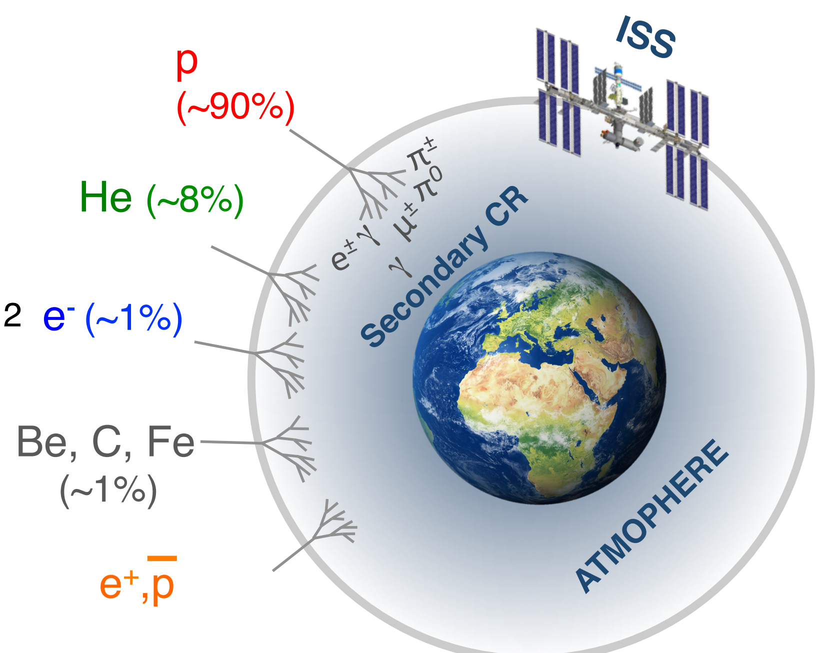


Cosmic Rays

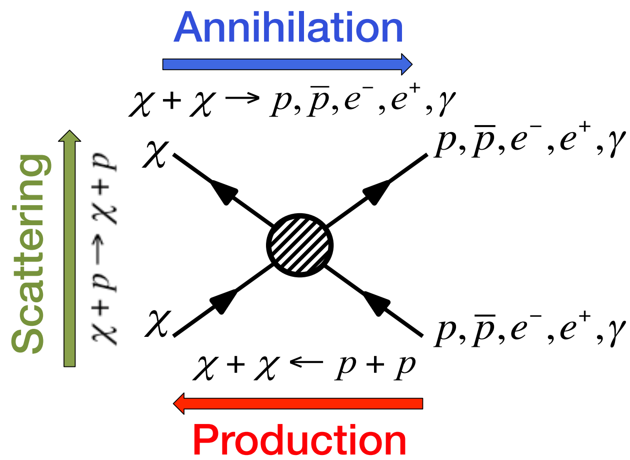


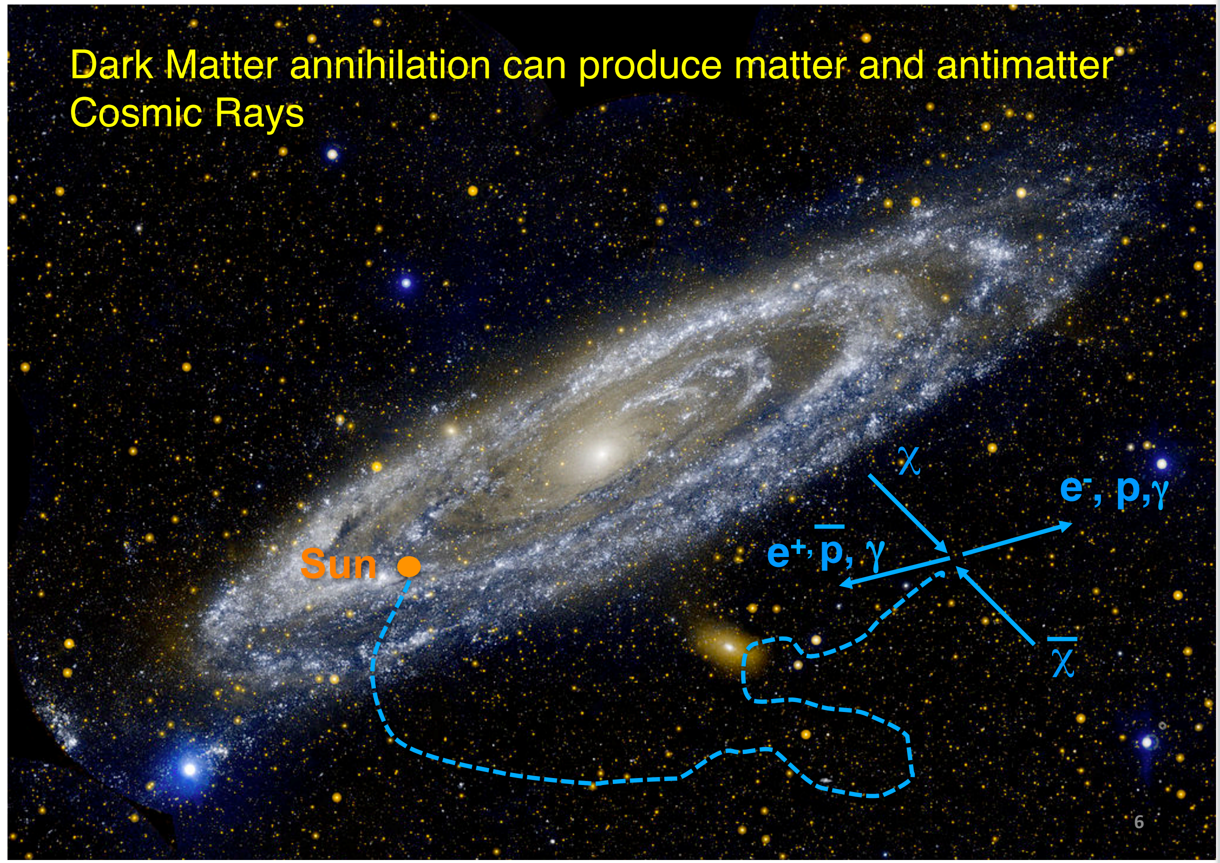
- Cosmic rays cover an energy range up to 10^{20} eV
- Most of cosmic rays are protons and nuclei produced by standard astrophysical mechanisms
- New physics can be hidden in rare components spectra ($e^{+/-}$, $\overline{p}$, $\overline{D}$, γ, ….)



The nature of the incoming cosmic rays can be precisely identified only outside the atmosphere

The quest for Dark Matter





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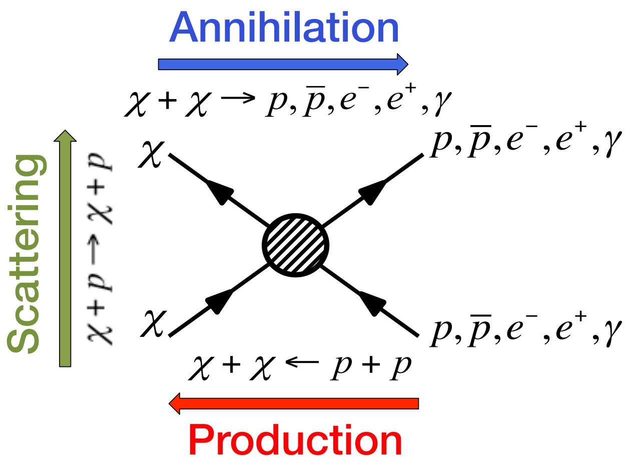
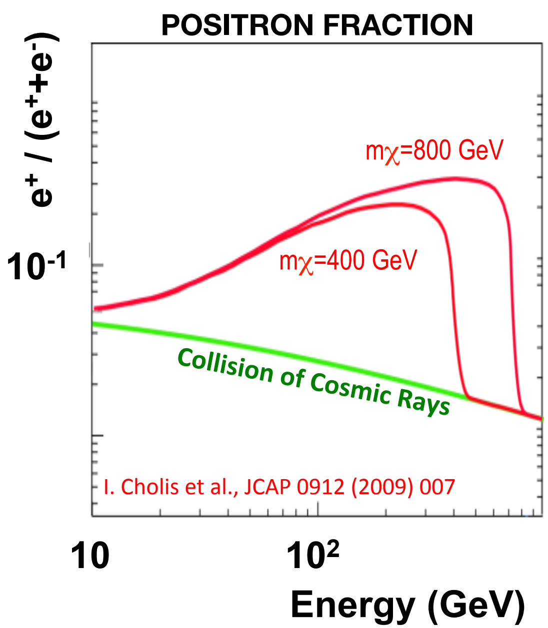
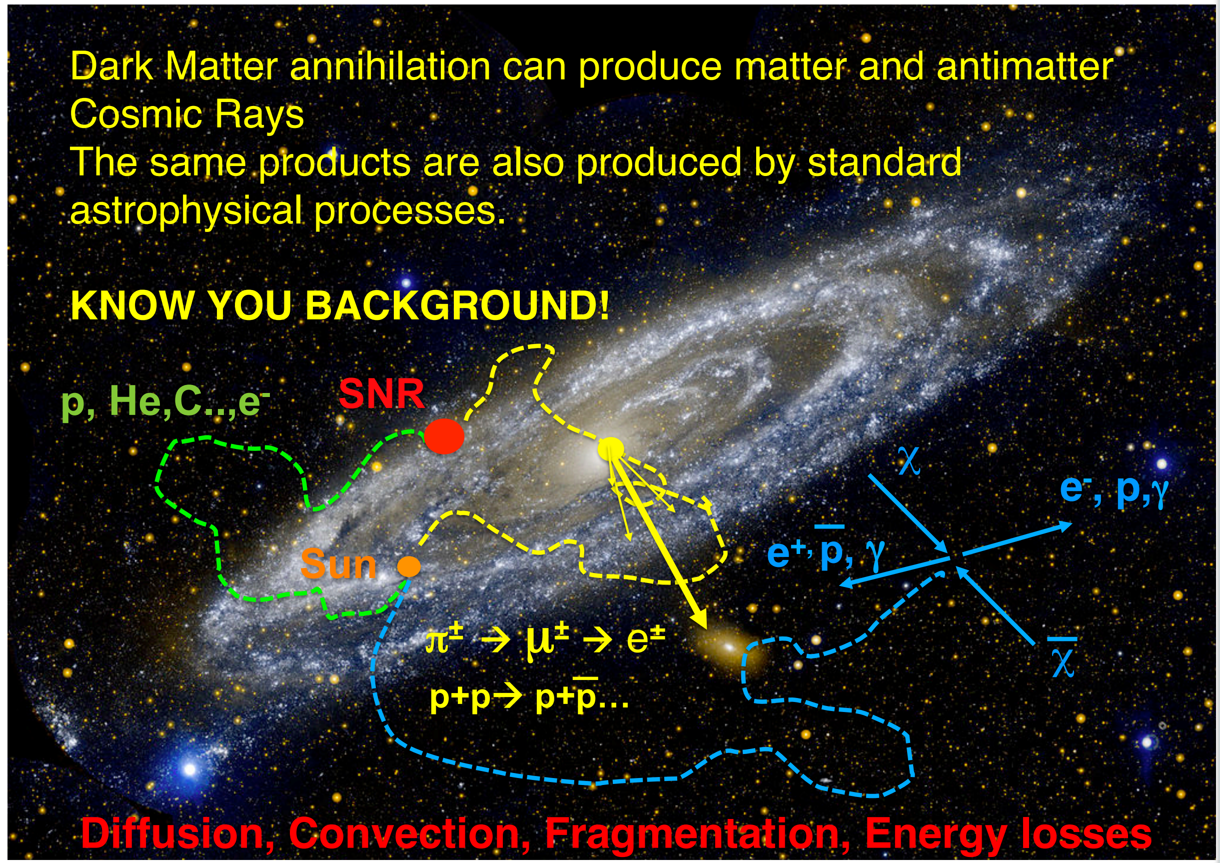






A comprehensive *standard model* of CR **origin**, **acceleration** and **propagation** is mandatory to search for antimatter excesses in CRs.

AMS-02 Physics

FUNDAMENTAL PHYSICS

- Indirect search for Dark Matter (e^+, anti-p,….)
- Search for primordial antimatter (anti-He)

COSMIC RAY COMPOSITION AND ENERGETICS

- Precise measurement of the energy spectra of H, He, Li, B, C

to provide information on CR interactions and propagation in the galactic environment

TO ACHIEVE THIS…..

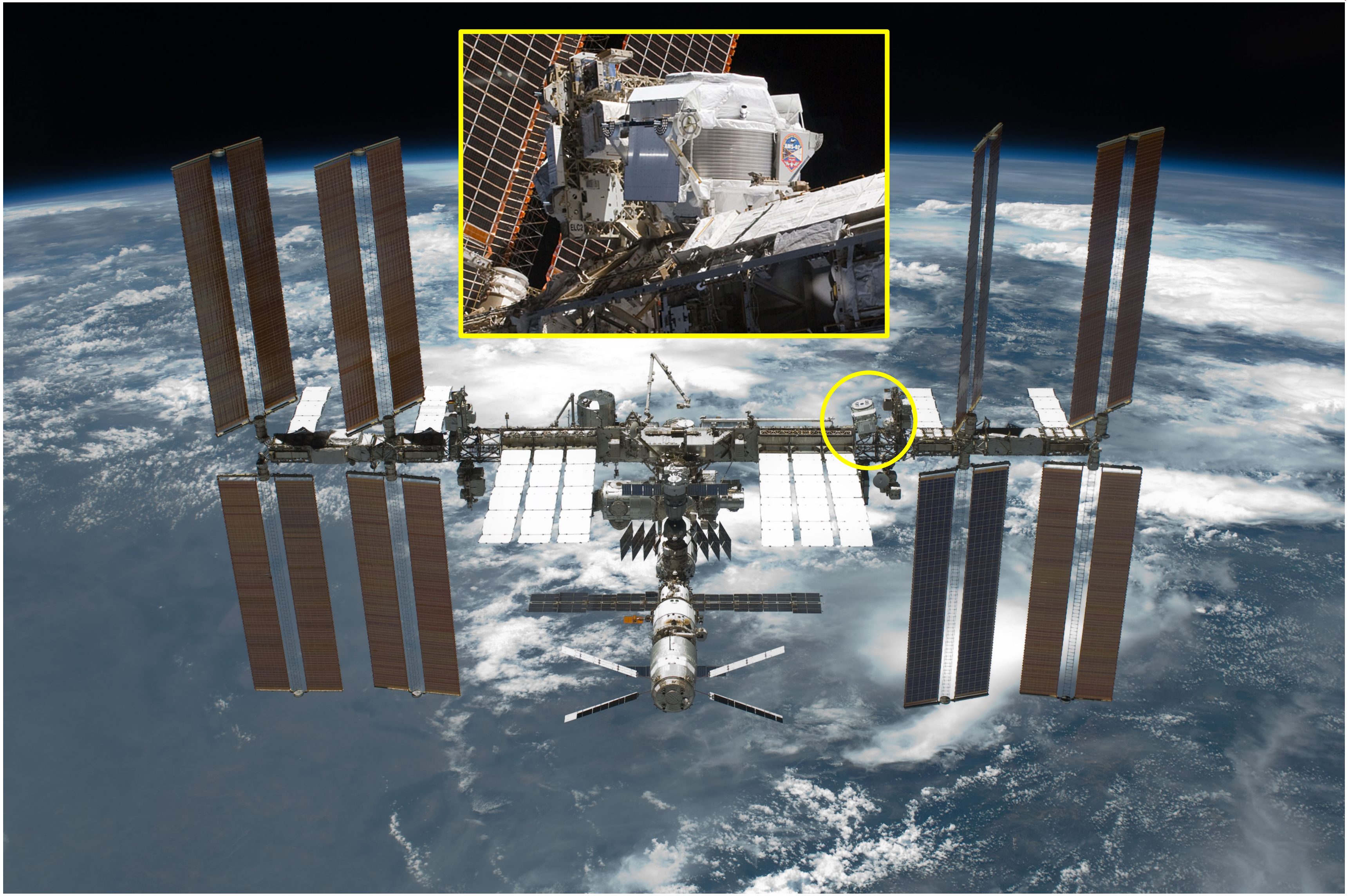
Particle identification and Energy measurement up to TeVs

- Matter/antimatter separation using magnetic field
- e/p separation using independent subdetectors

Maximize the data sample

- Detector size (acceptance)
- Exposure time: ISS in space

AMS-02 on the ISS



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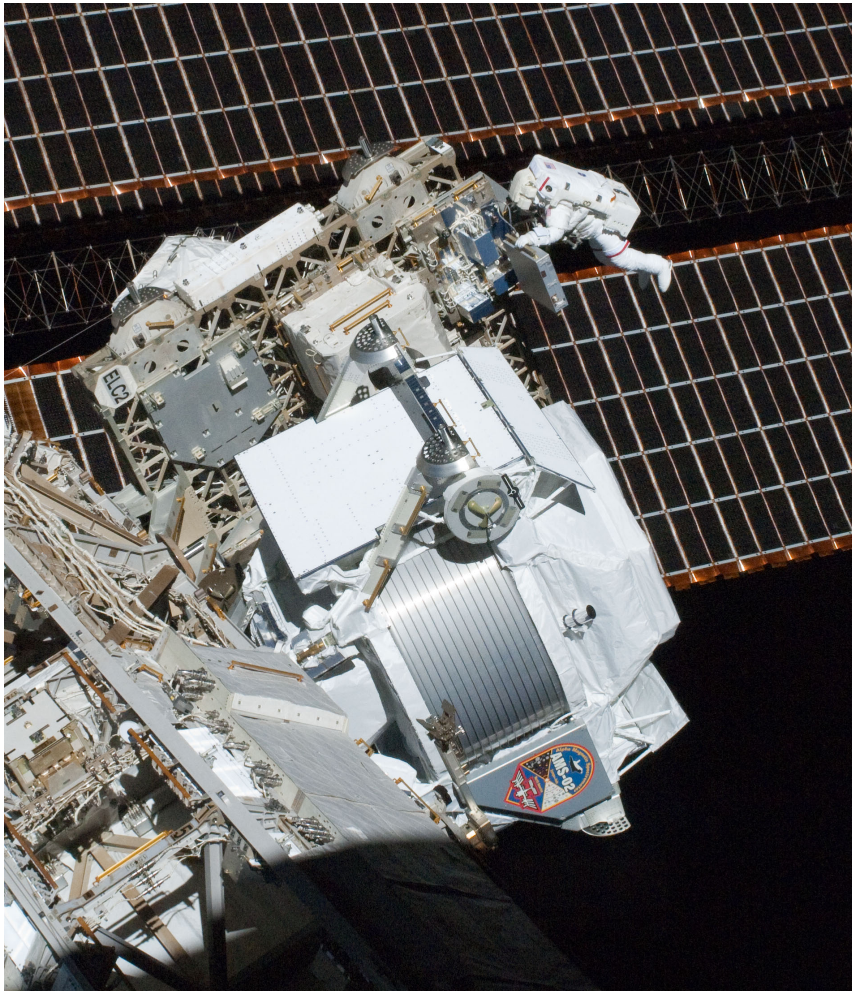
The AMS-02 detector

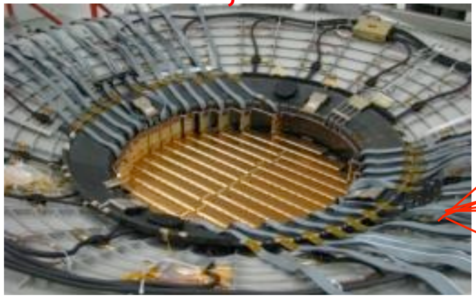


- **Size** 5 x 4 x 4 m, 7500 kg
- **Power** 2500 W
- **Data Readout** 300,000 channels
- **<Data Downlink>** ~ 12 Mbps
- **Magnetic Field** 0.14 T
- **Mission duration** until the end of the ISS operations (currently 2024)

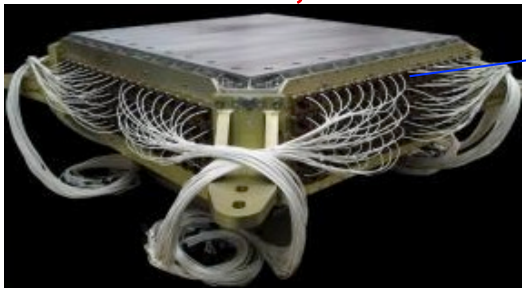
AMS: TeV precision spectrometer

TRD
Identifies e^+, e^-

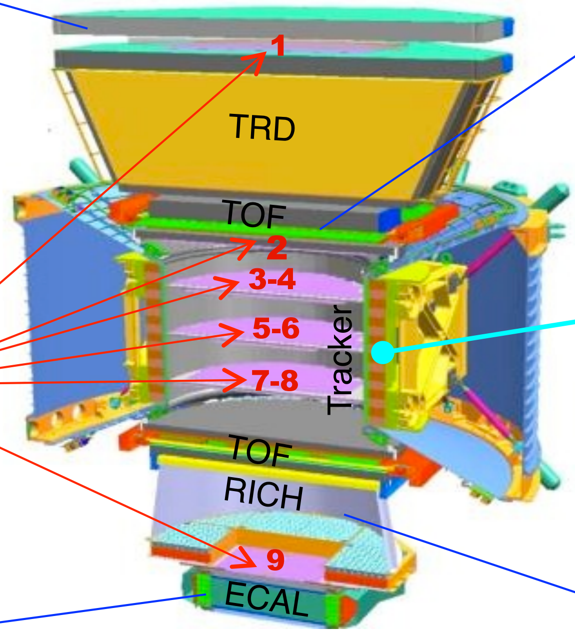
Silicon Tracker
Z, P



ECAL
E of e^+, e^-



Particles and nuclei are defined by their charge (Z) and energy (E ~ P)



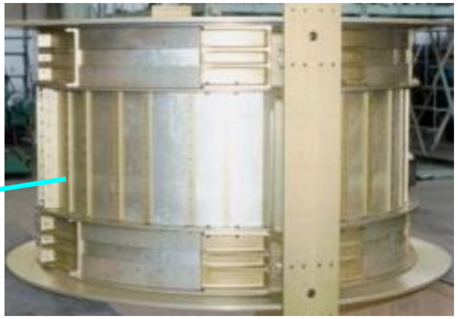
Z and P ~ E

are measured independently by the

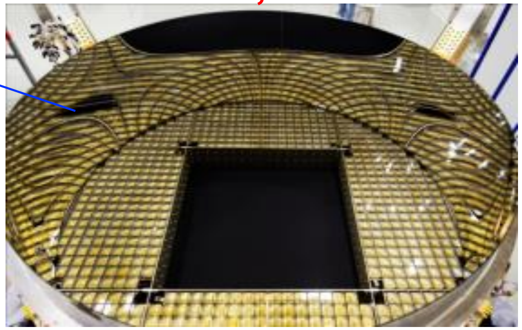
Tracker, RICH, TOF and ECAL

TOF
Z, E

Magnet
±Z



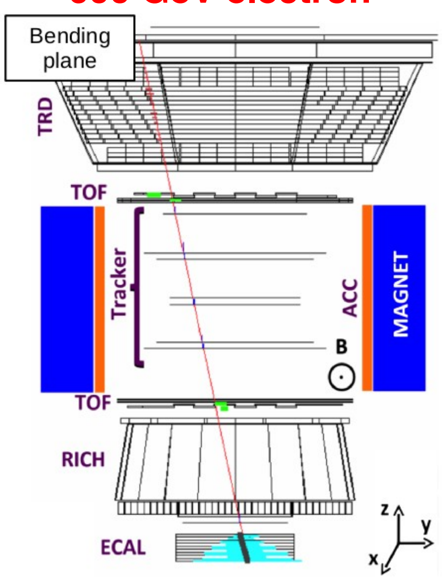
RICH
Z, E



AMS: TeV precision spectrometer

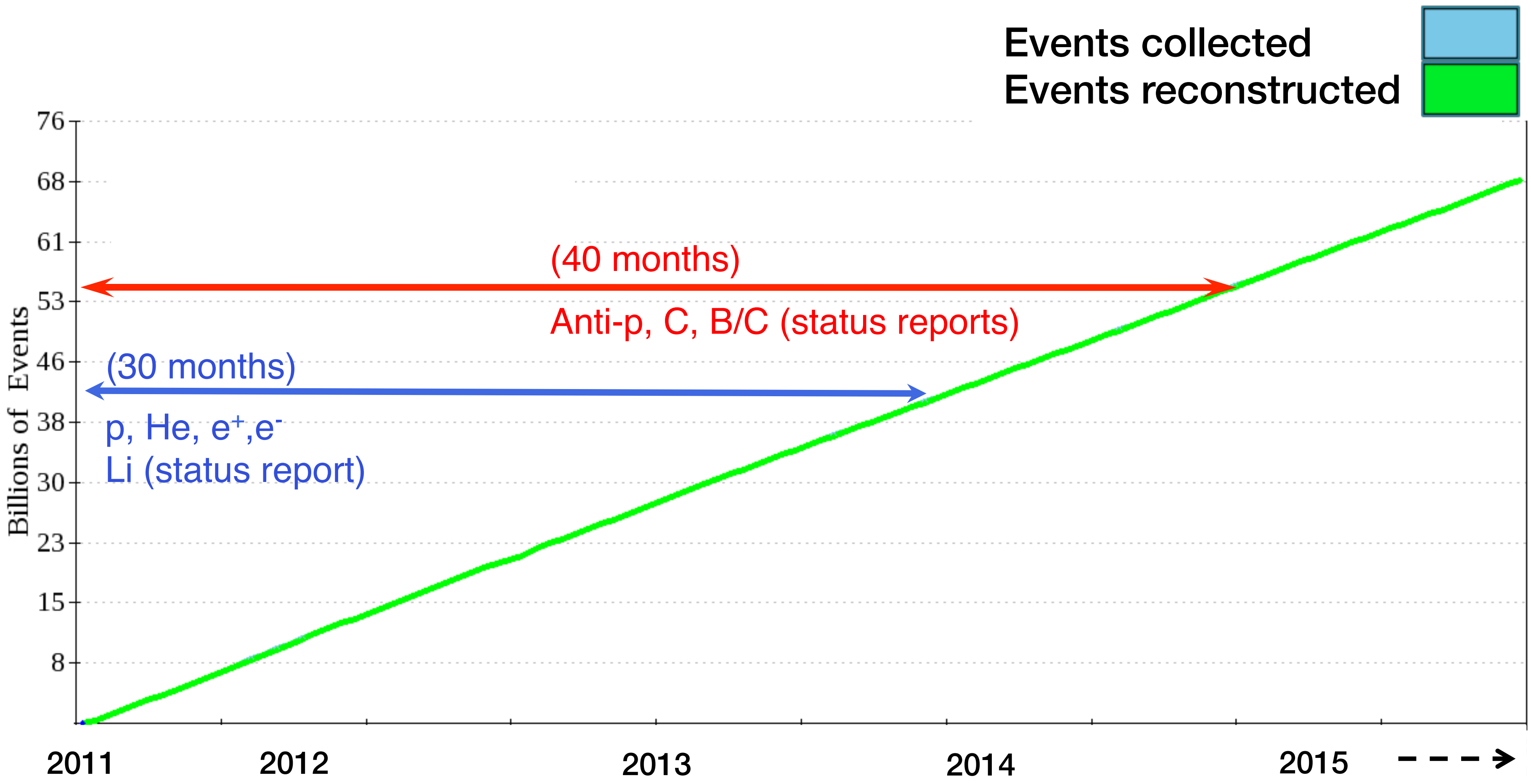
Full coverage of anti-matter and CR physics

600 GeV electron



	e^+	e^-	p	$\bar{p}$	He	$\overline{\text{He}}$	
TRD 20 layers							e/p separation charge (|Z|)
TOF 4 layers							trigger velocity (β) charge (|Z|)
TRK 9 layers							momentum (p) sign (±Q) charge (|Z|)
RICH							velocity (β) charge (|Z|)
ECAL 18 layers							$e^{\pm}$ energy e/h separation γ trigger

Cosmic rays collected in space



~ 70,000 million events collected after 50 months of AMS operations

AMS physics results

LEPTONS / ANTIMATTER

- Positrons fraction $e^+/(e^++e^-)$
- Electron and Positron fluxes (e^+, e^-)
- Electron plus Positron flux (e^++e^-)
- Antiprotons/protons

Sensitive to Dark Matter signal

HADRONS

- Proton and Helium (p, He)
- Lithium, Boron, Carbon (Li, B, C)

Probes to improve the astrophysical background knowledge

AMS-02 is providing precise data to search for new physics in the Cosmic Ray channels while improving the understanding of the astrophysical background with a coherent set of data

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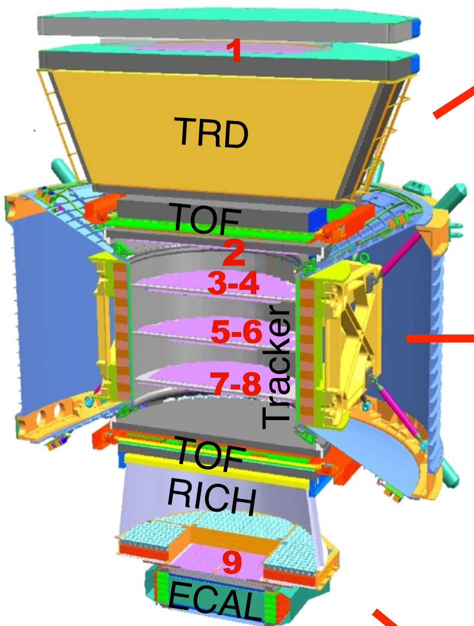
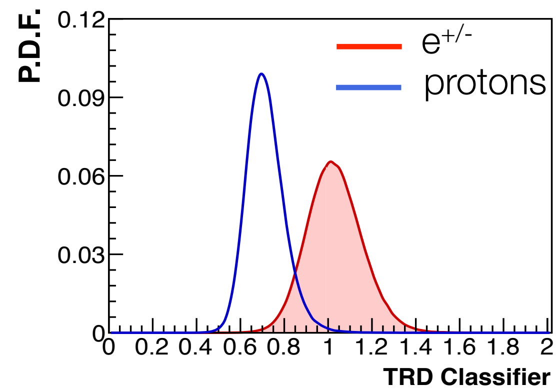
Identification of $e^{+/-}$



TRD

Transition Radiation

to identify $e^{+/-}$

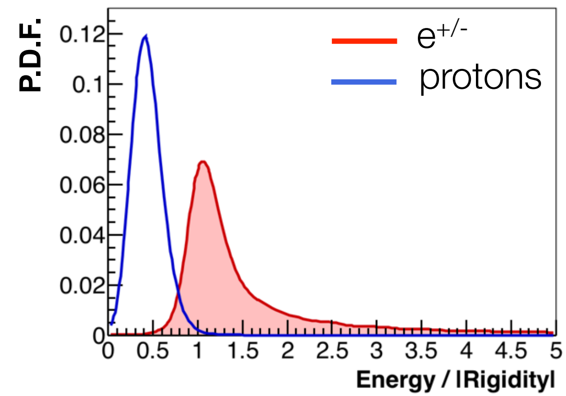


TRACKER

Momentum P

$e^{+/-}$: $P_{TRK} = E_{ECAL}$

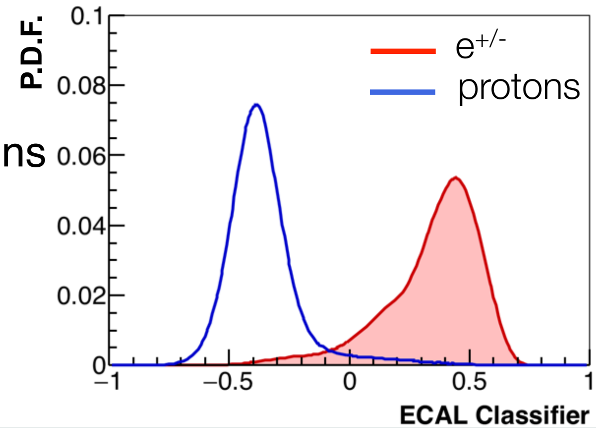
Protons: $P_{TRK} >> E_{ECAL}$



ECAL

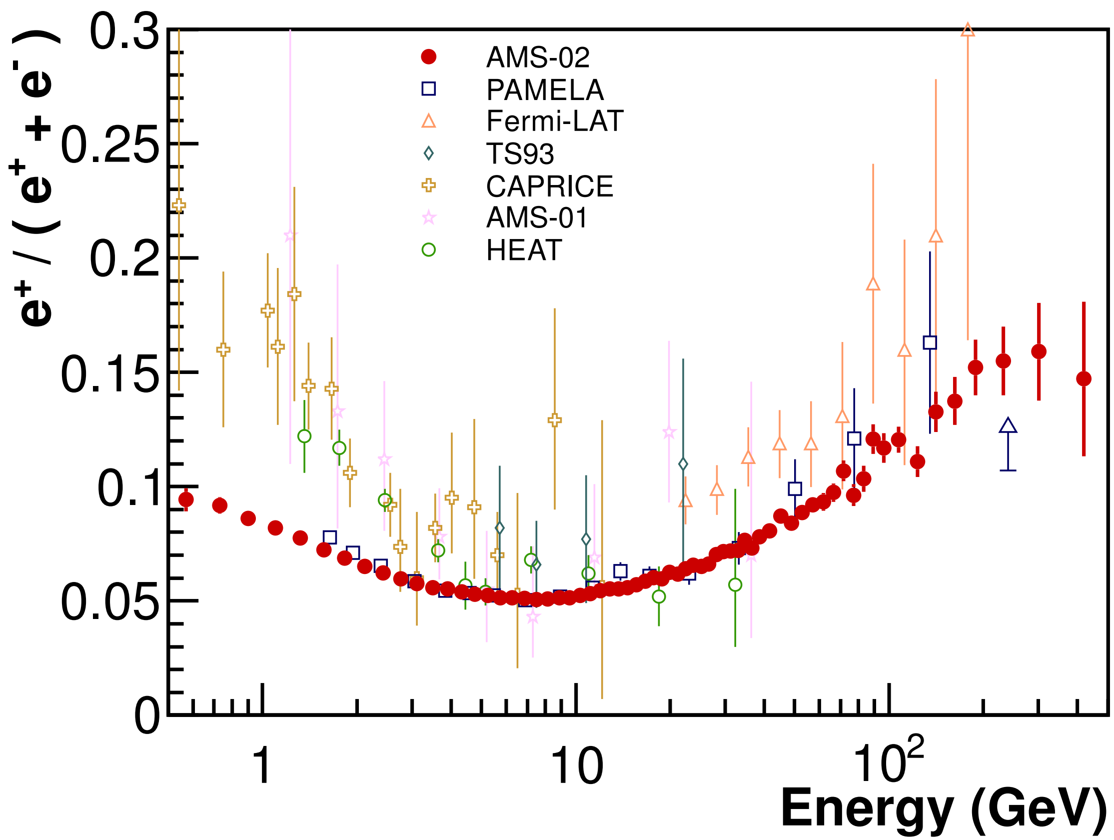
Shower Topology

to separate $e^{+/-}$ from protons



Positron Fraction

Rise in the fraction of positrons (antimatter) over electrons (matter) not expected by the current Standard Model of CR origin and propagation



Unprecedented accuracy and energy range allowed a detailed study of the positron fraction behavior with energy

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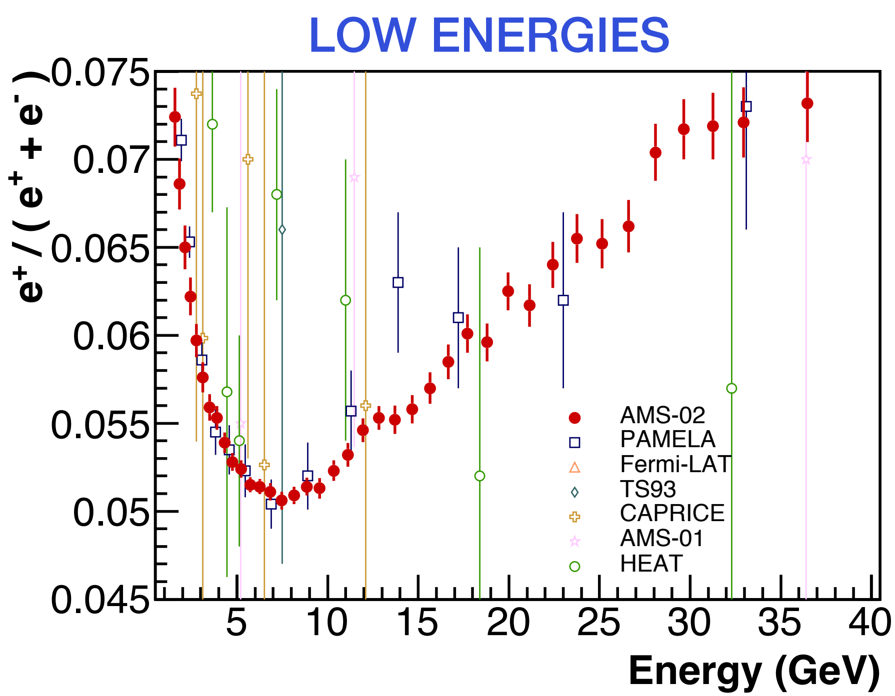

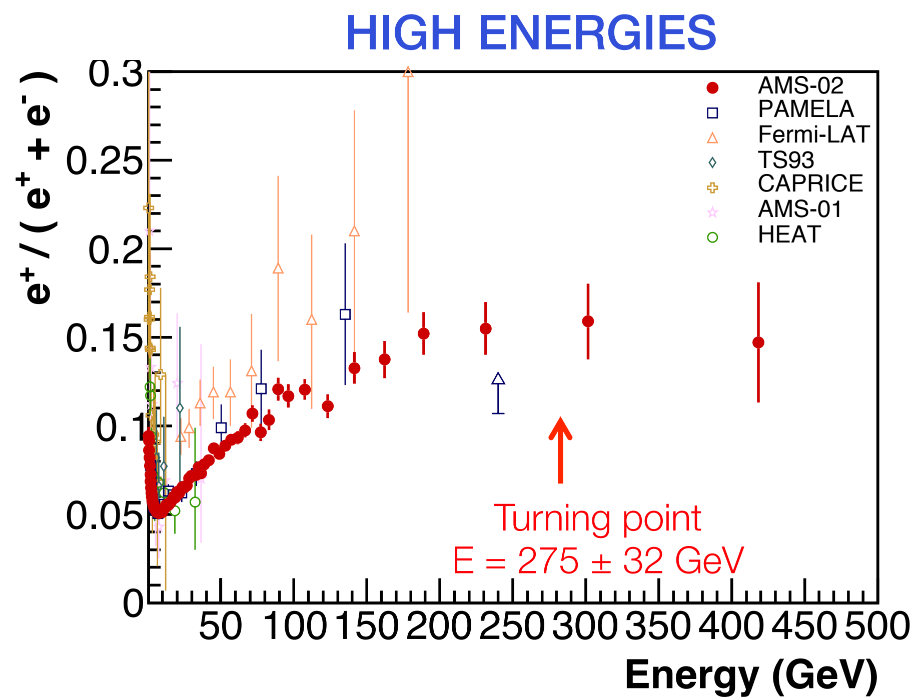

- Precision measurement of the fraction minimum
- No sharp structures observed in the spectrum
- The slope decreases with increasing energy

Positron Fraction

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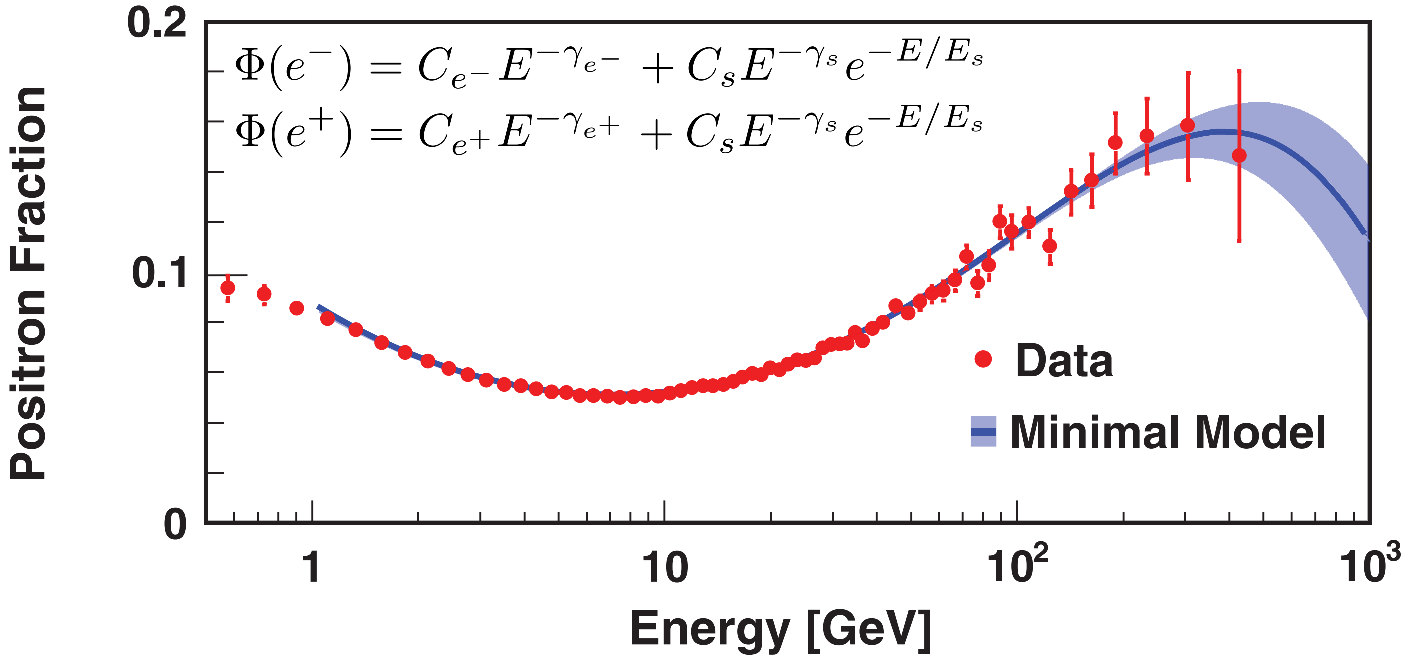
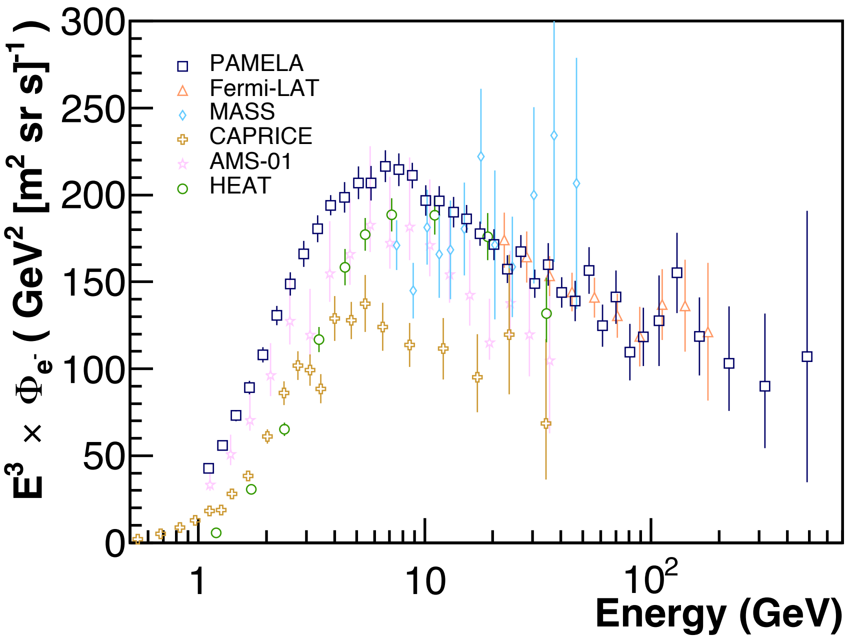
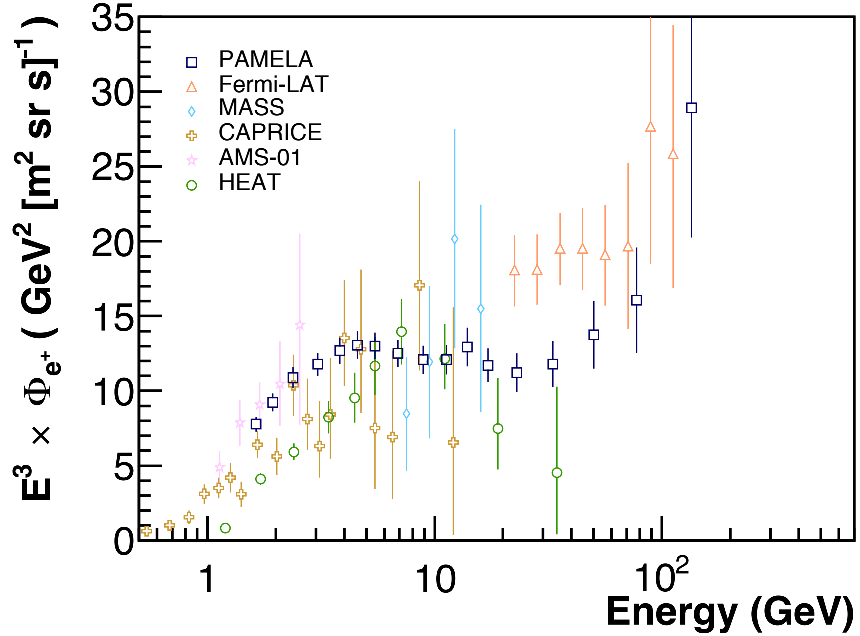


Rise well described by an empirical model with a common $e^{+/-}$ source

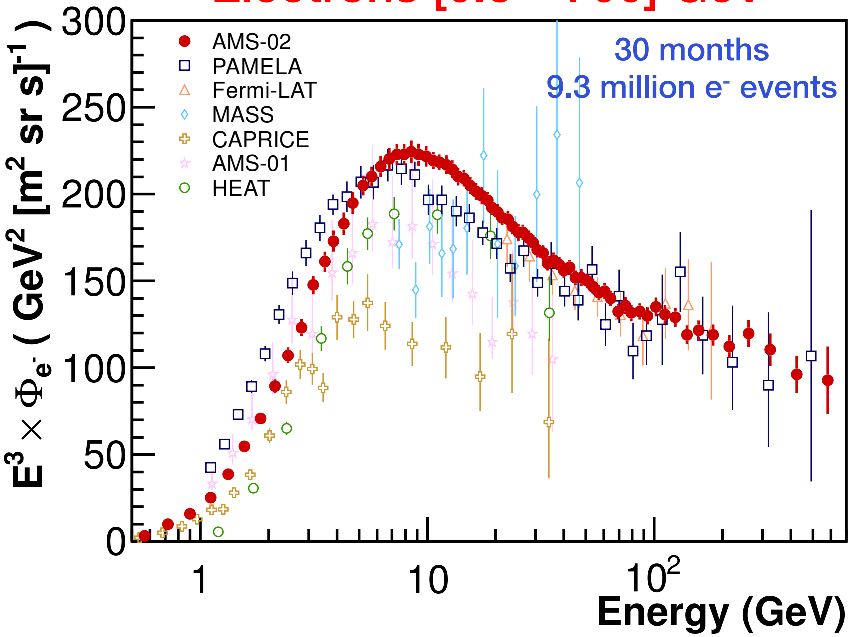
e^+ and e^- Fluxes



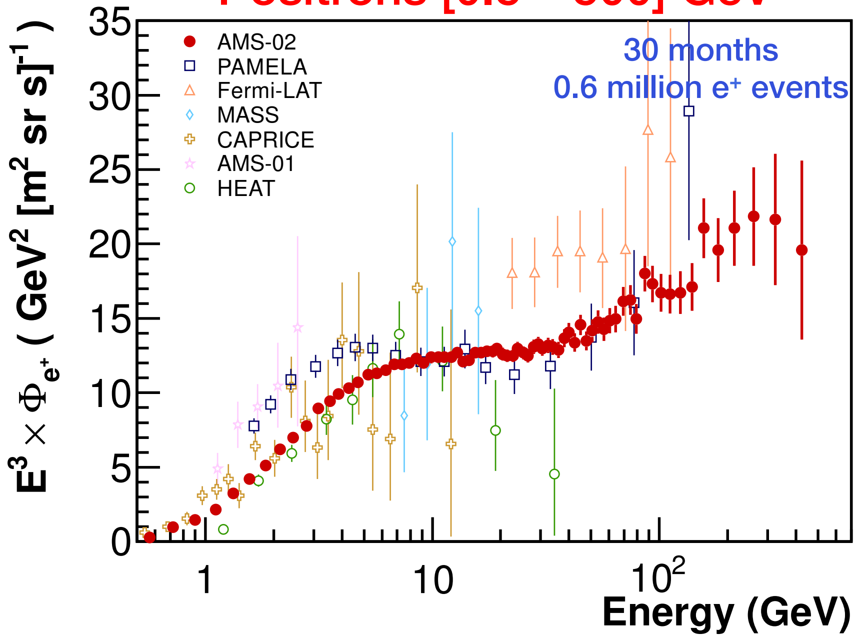


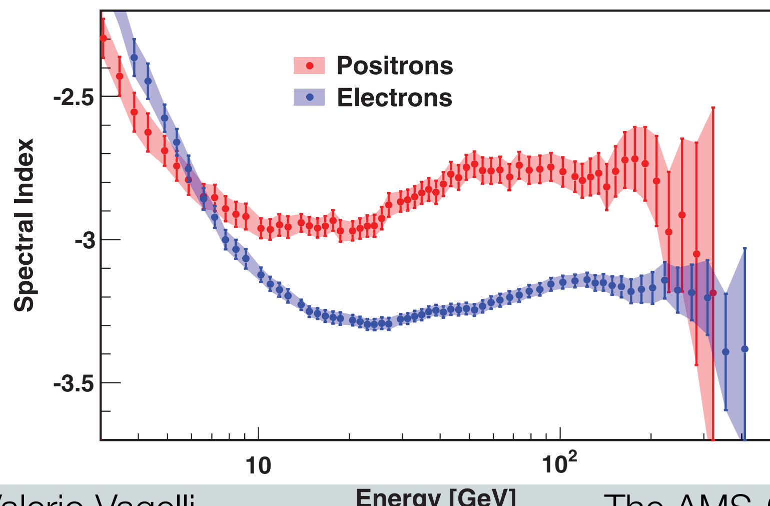
e^+ and e^- Fluxes

Electrons [0.5 – 700] GeV



Positrons [0.5 – 500] GeV



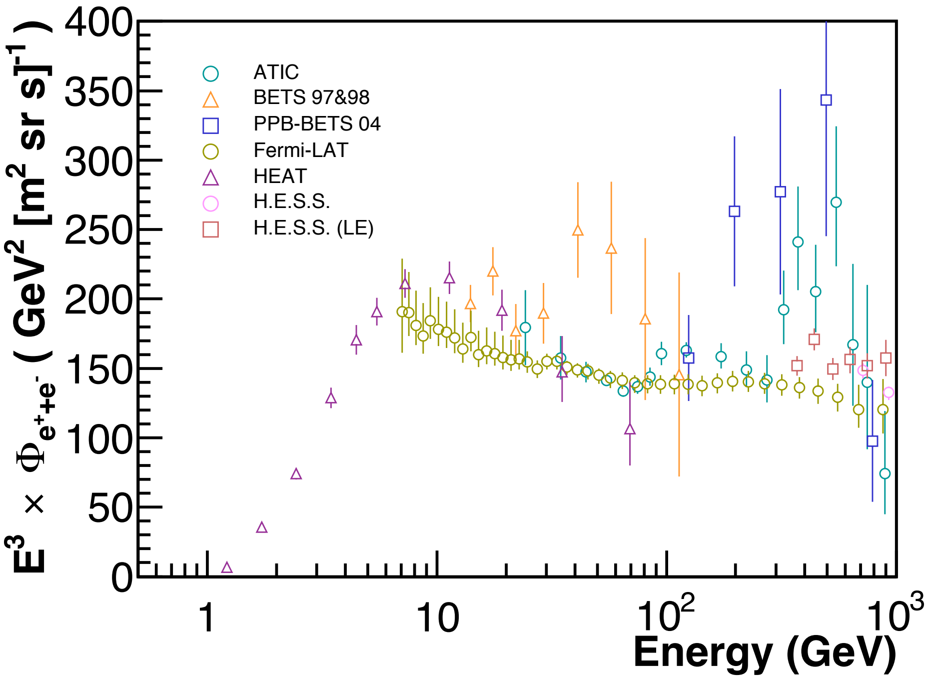


e^+ and e^- flux are significantly different in their magnitude and energy dependence

The positron fraction rise is due to an **excess of positrons**, not due to a unpredicted decrease of electrons.

(e$^+$+e$^-$) Flux

Independent measurement of the total e$^{+/-}$ flux without identification of the charge sign.
Higher energy reach and improved accuracy due to looser selection.



$(e^{+}+e^{-})$ Flux

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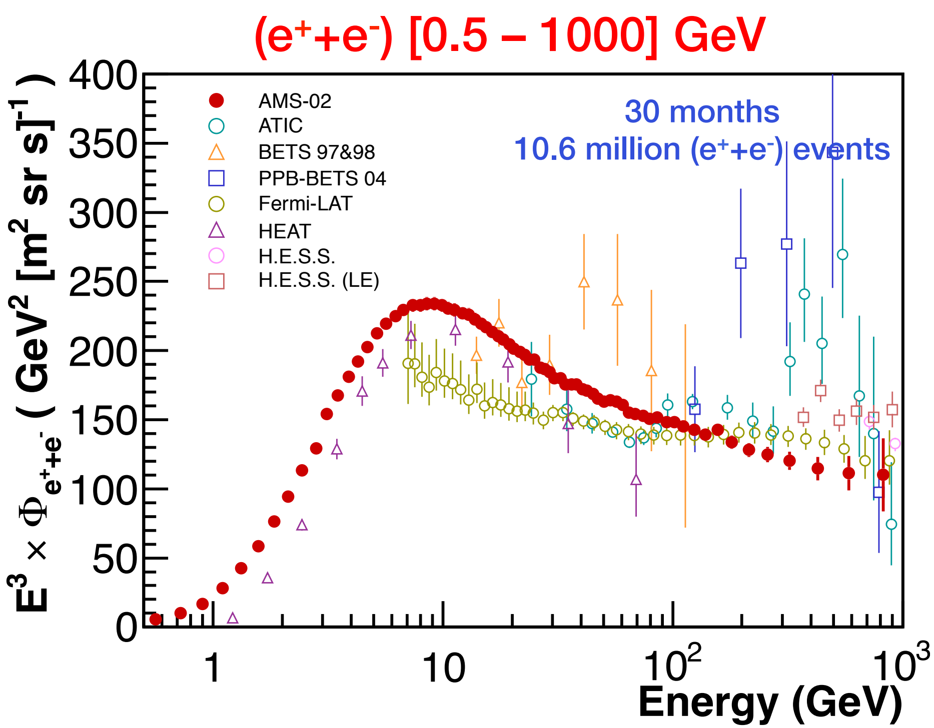
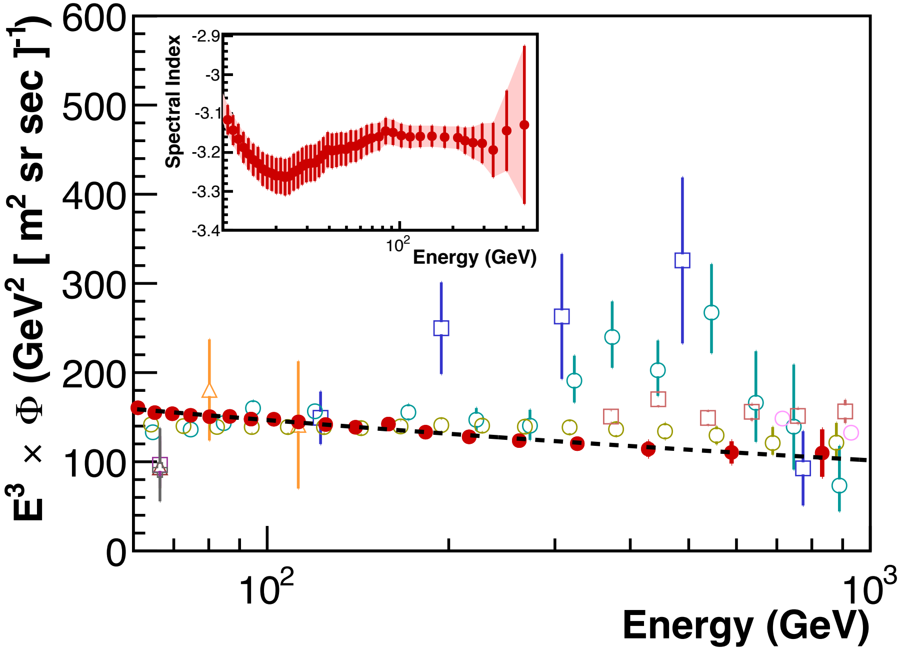
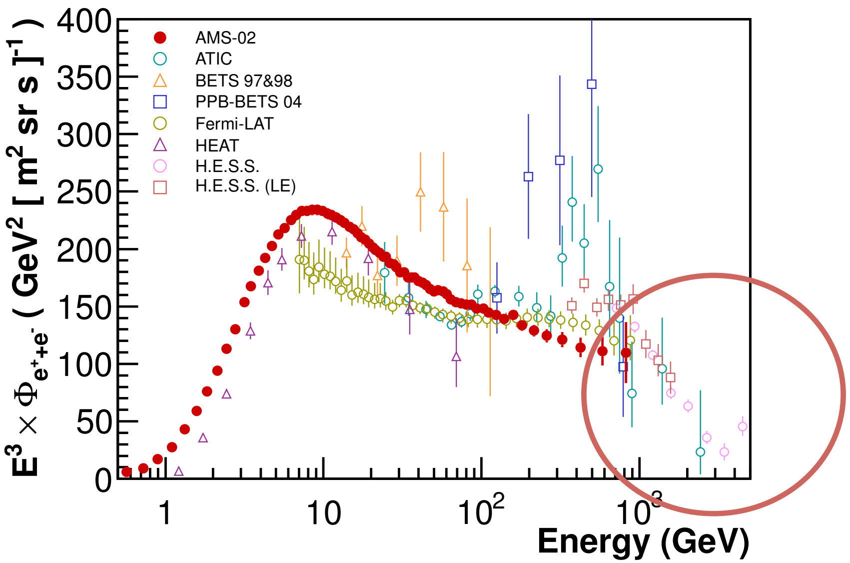




The $(e^{+}+e^{-})$ flux is smooth, and can be described by a single power law starting from 30 GeV up to 1 TeV.

No evidence of fine structures has been observed in the $(e^{+}+e^{-})$ spectrum.

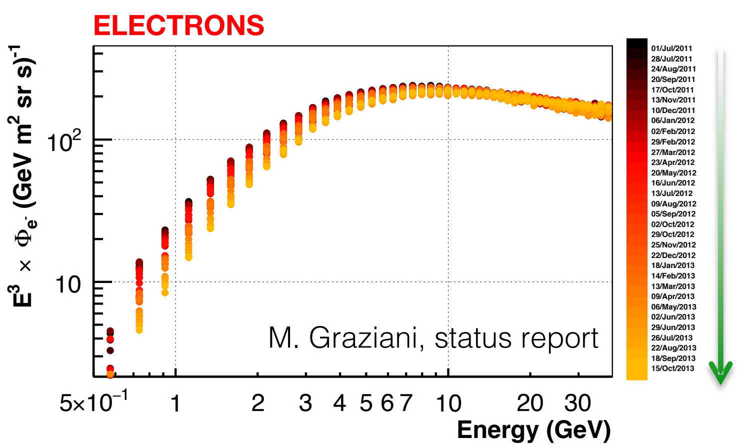
What’s next…..

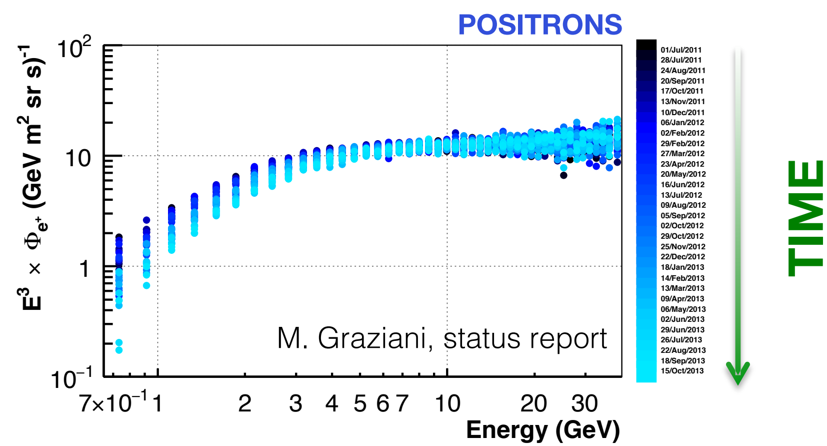


Explore the TeV energy range

- Overlap with ground experiments
- Search for spectral features

Explore the GeV range to study for Solar time dependent modulation and transient effects





What is AMS observing?

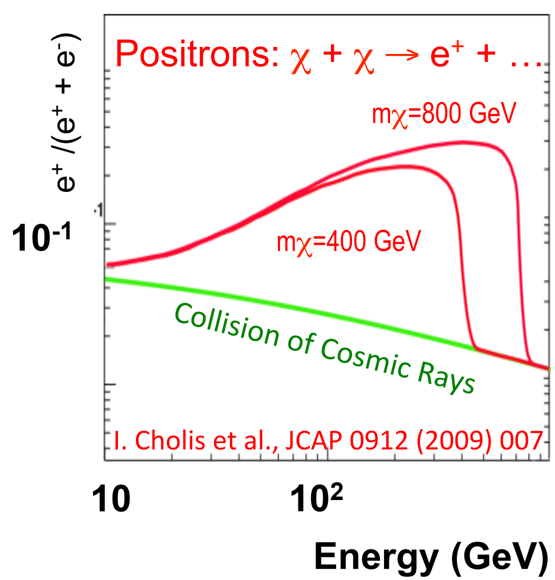
Something "different" with respect to conventional models of e^+ production by collisions of CR hadrons with the interstellar medium (ISM)

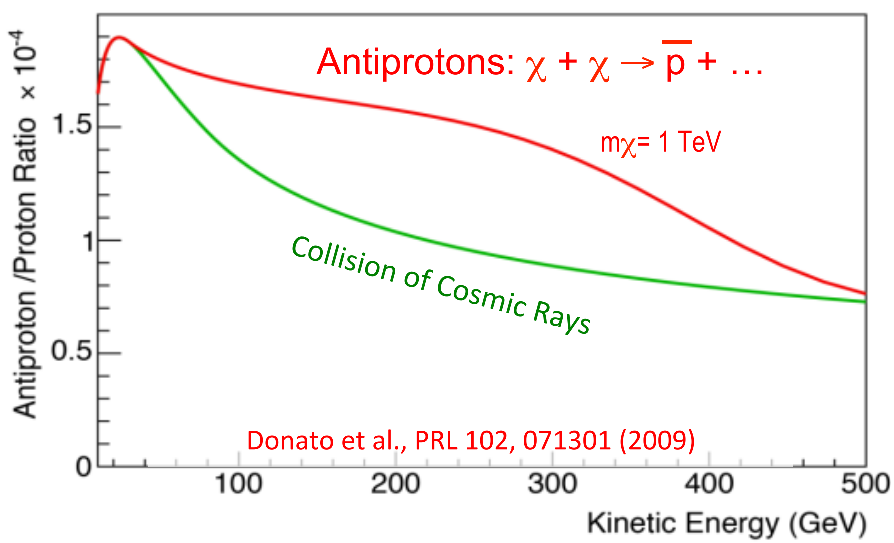
Astrophysical Sources?

- Local sources as pulsars ($e^{+/-}$ only source, anisotropy..)
- Additional acceleration mechanisms (reacceleration of CR hadrons in old SNRs)

Dark matter?

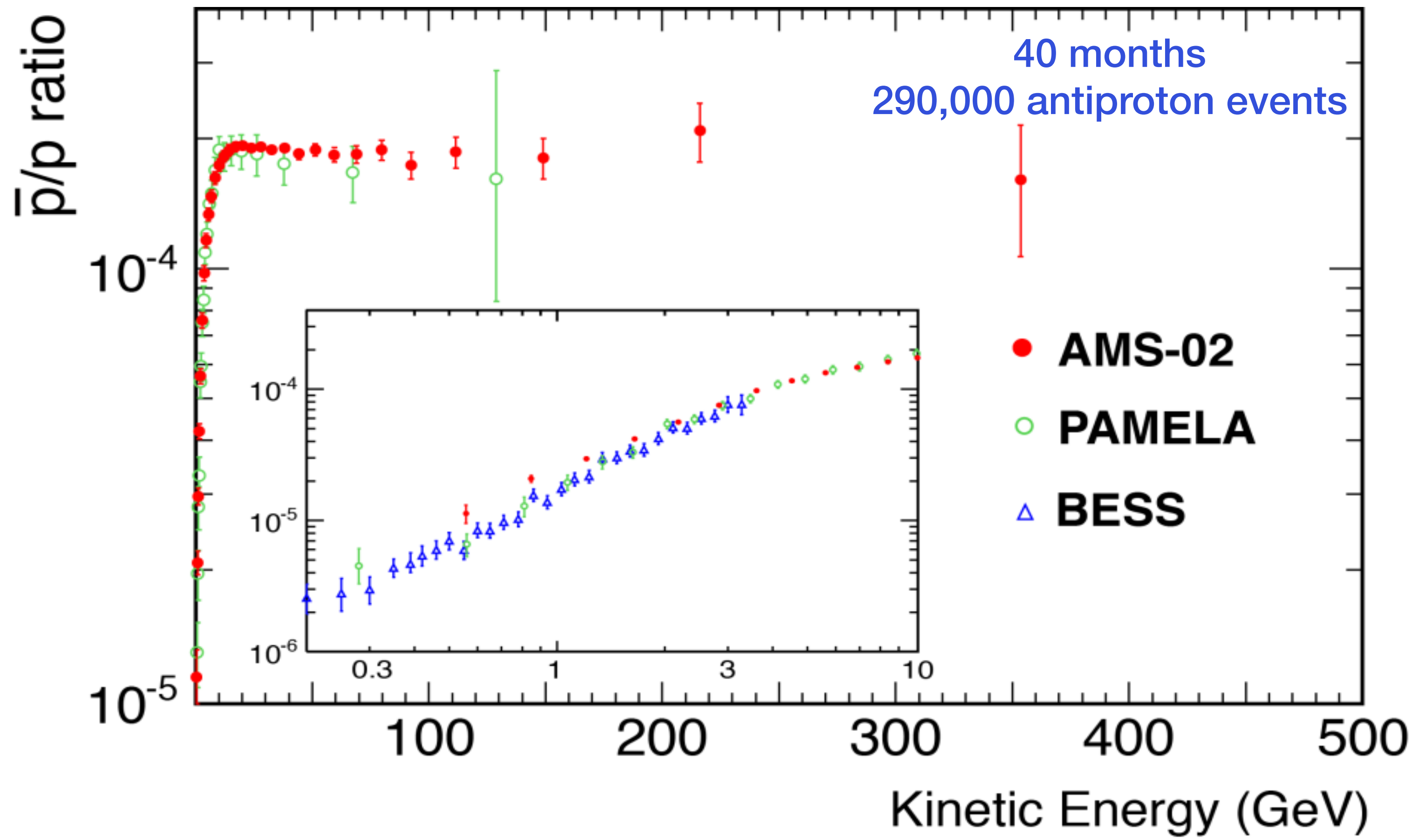
- Isotropic distribution arrival for $e^{+/-}$
- Signatures in other channels (like antiprotons)





Antiprotons

$\bar{p}/p$ ratio [1 – 450] GeV

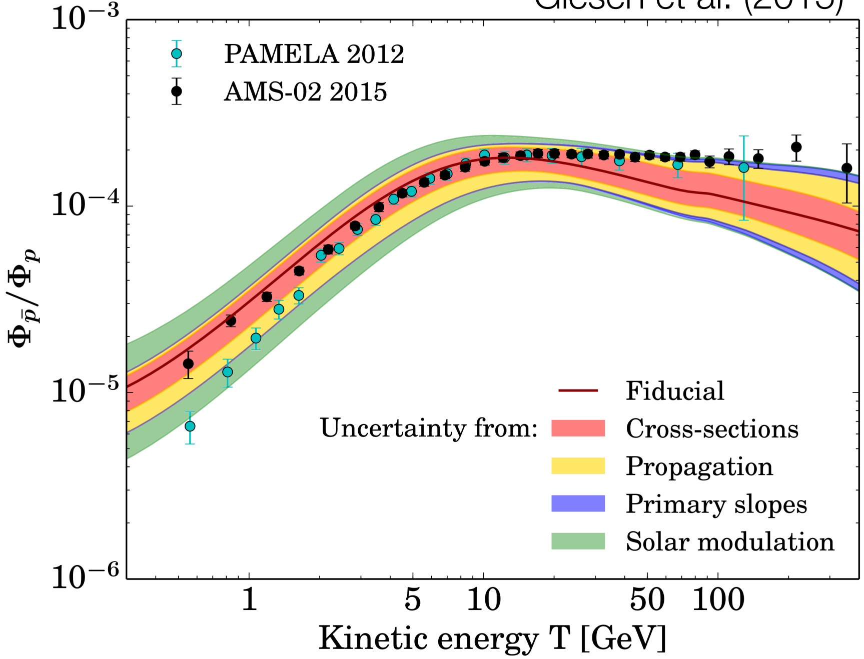


The AMS measurement extends with high precision into a new energy frontier.

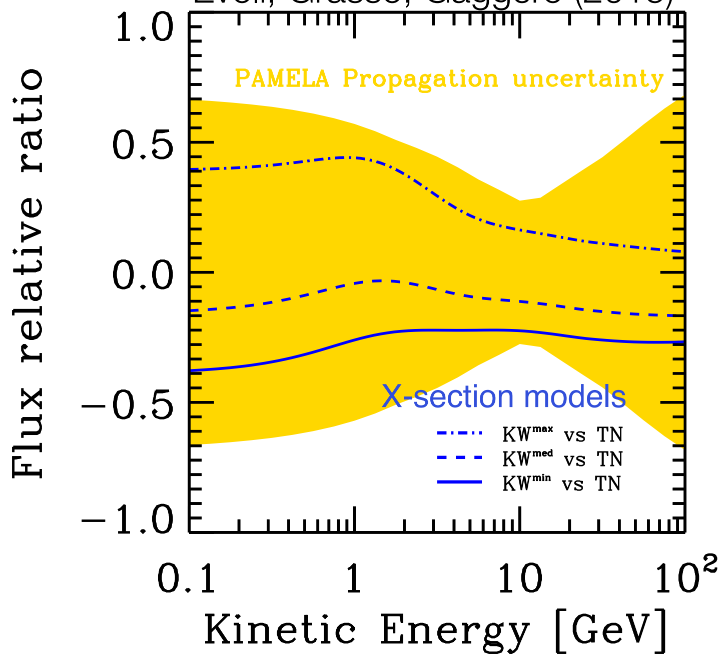
Antiprotons

The accuracy of the AMS measurement challenges the current knowledge of cosmic background

Giesen et al. (2015)



Evoli, Grasso, Gaggero (2015)



Evoli, Grasso, Gaggero (2015)

Upcoming measurements (in particular, from AMS-02 [1], CALET [54], and ISS-CREAM [49]) are expected to significantly improve our knowledge of propagation parameters and then to reduce the associated uncertainties. In that situation, antiproton production cross sections will prevent us to provide predictions for the astrophysical backgrounds as accurate as the forecasted sensitivities.

AMS physics results

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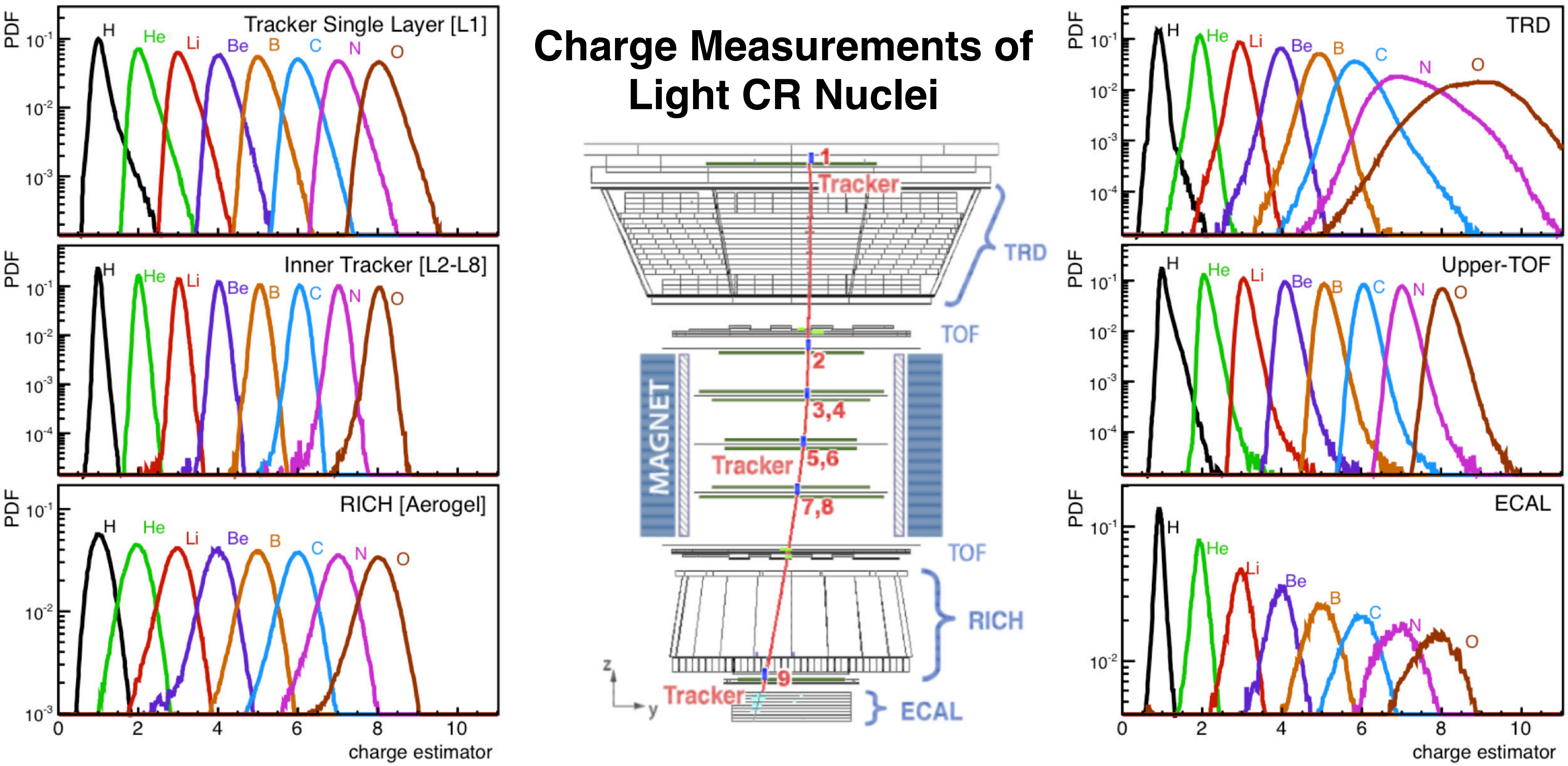
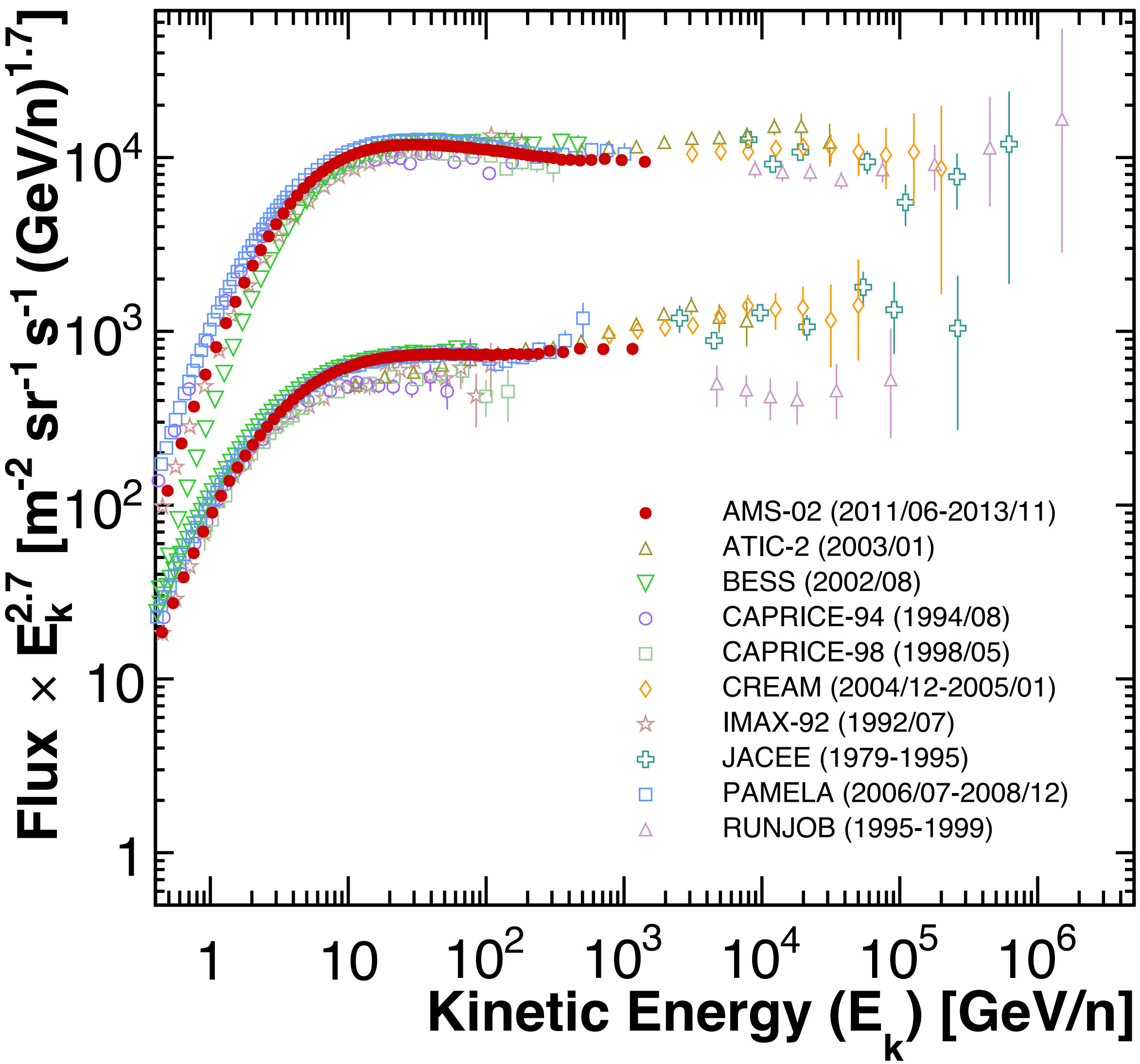
AMS-02 Charge Measurement



Redundant measurements of the nuclear charge at different depths of the detector.

Precise understanding of nuclear fragmentation in the materials.

Proton and Helium Fluxes



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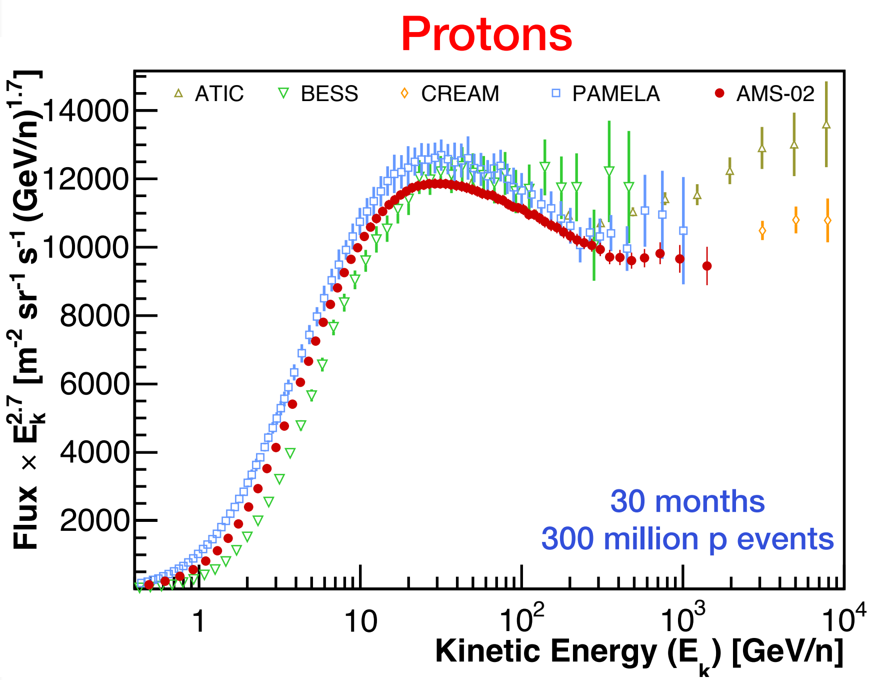

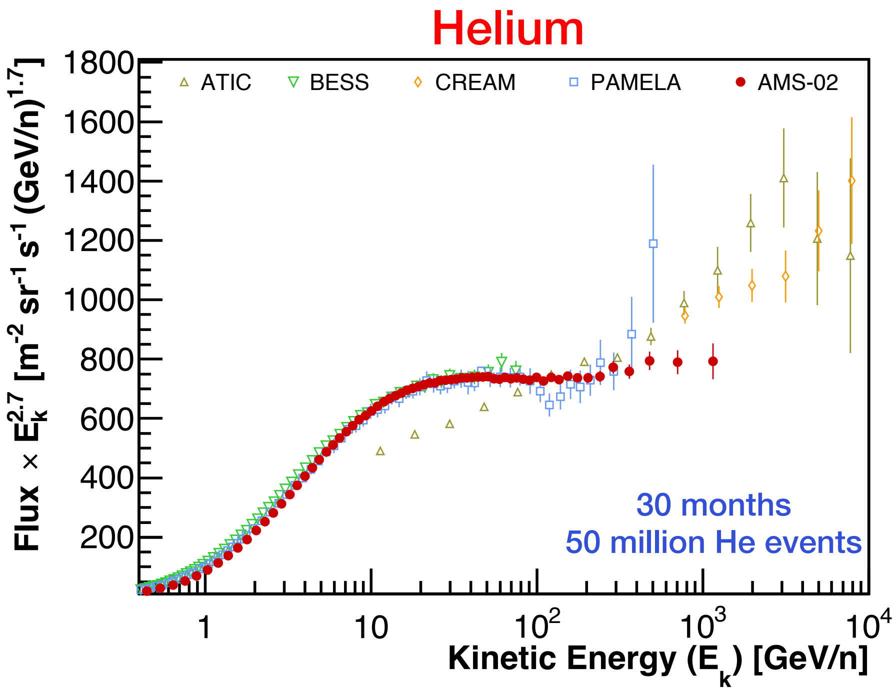

Proton and Helium Fluxes

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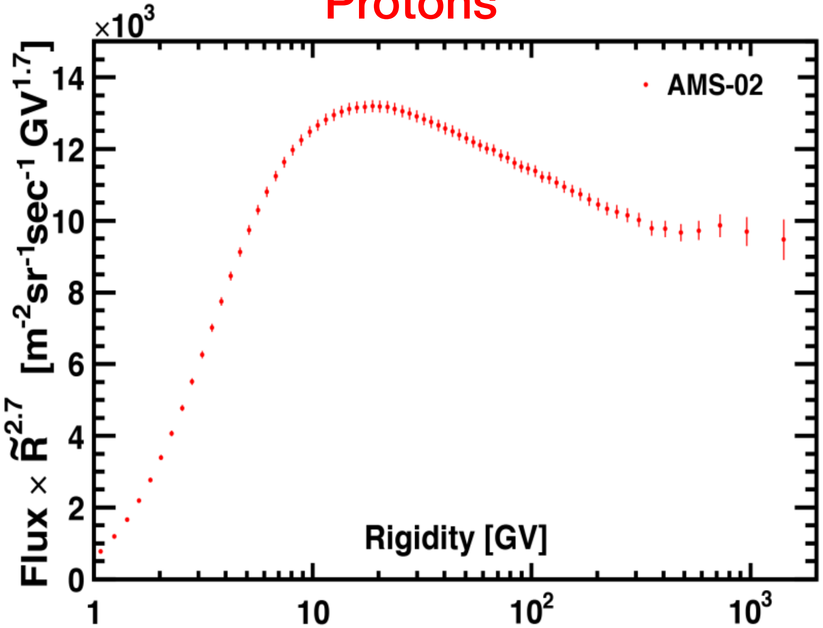
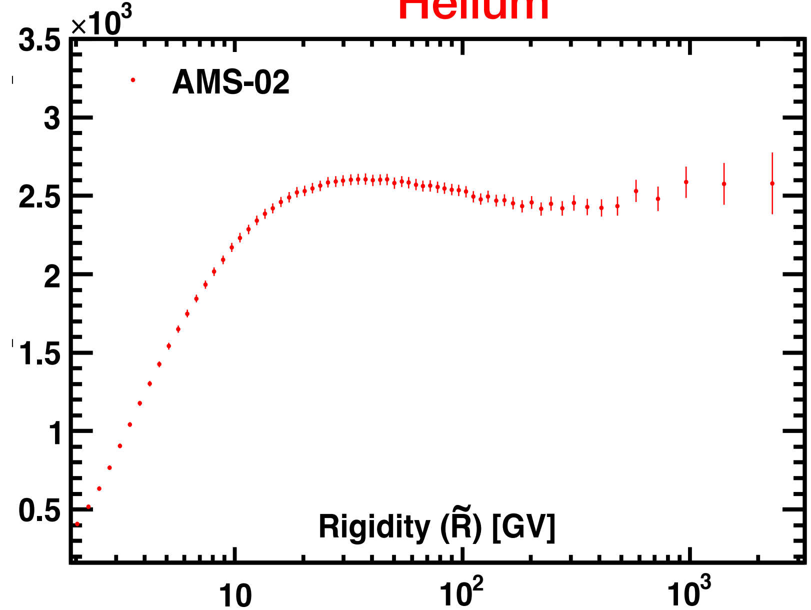


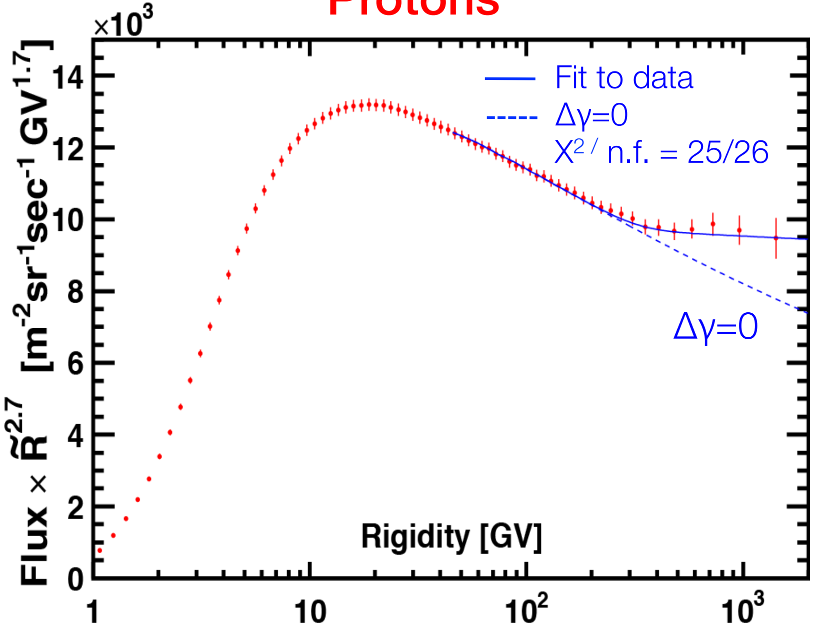


The H and He spectra harden with increasing rigidity

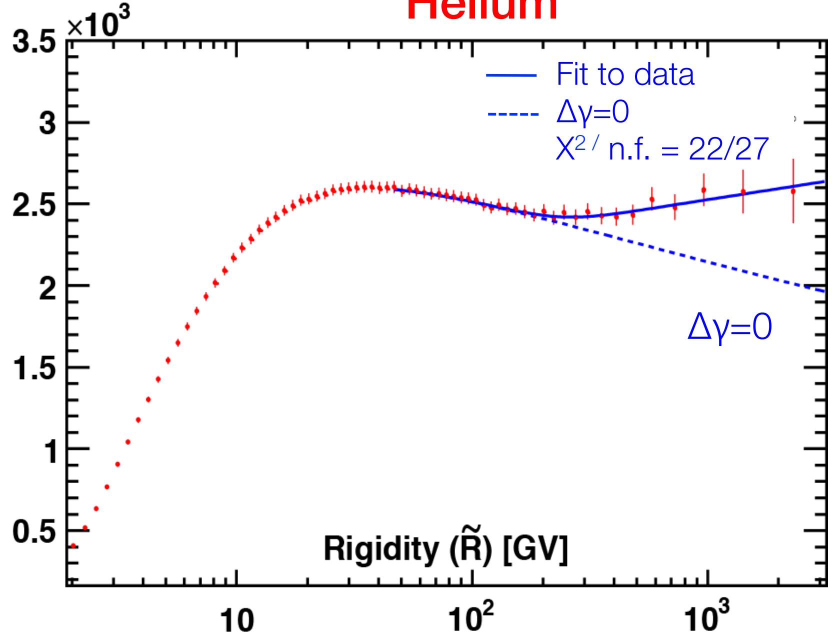
Proton and Helium Fluxes

$$\Phi = C\left(\frac{R}{45\,\mathrm{GV}}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$$

Protons



Helium

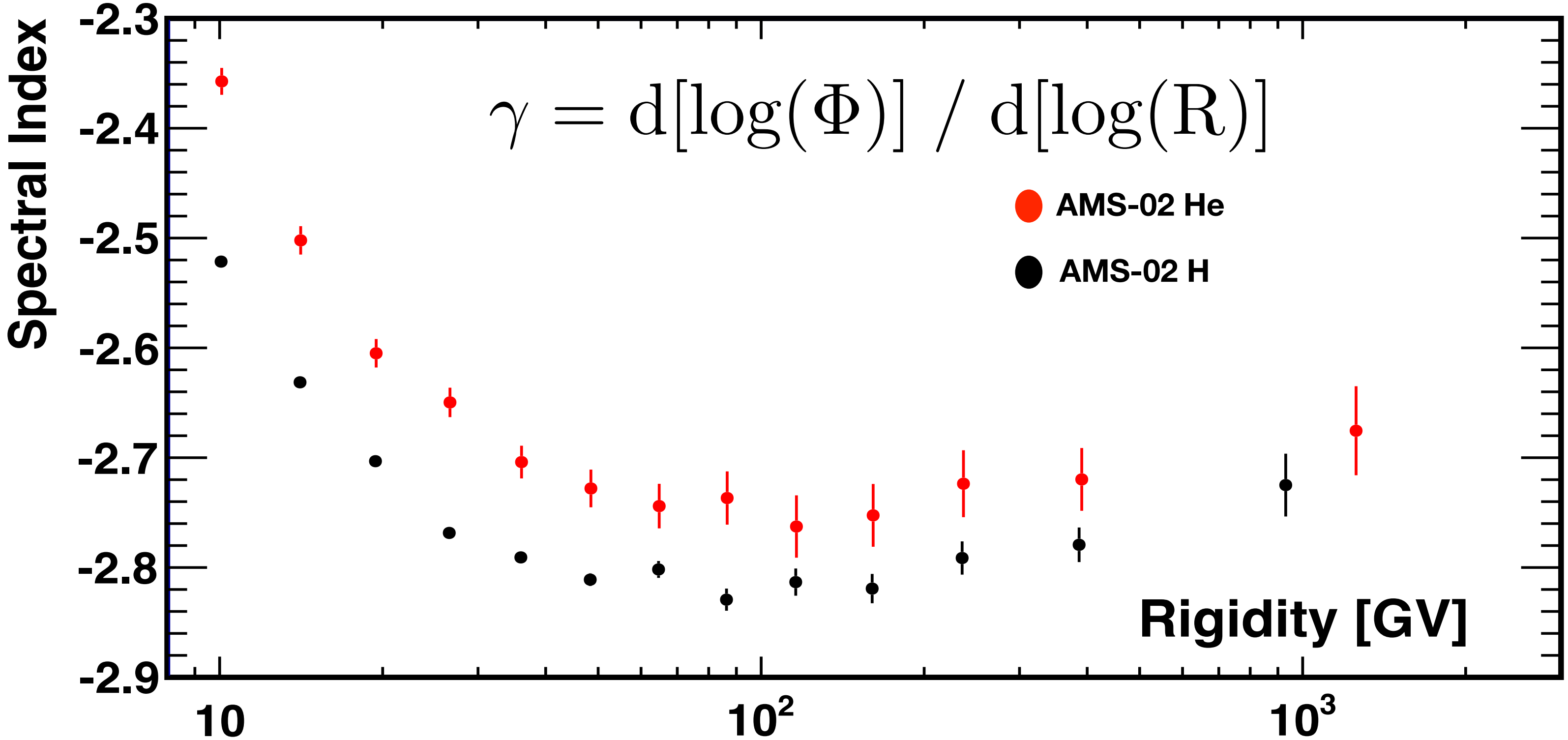


The H and He spectra harden with increasing rigidity

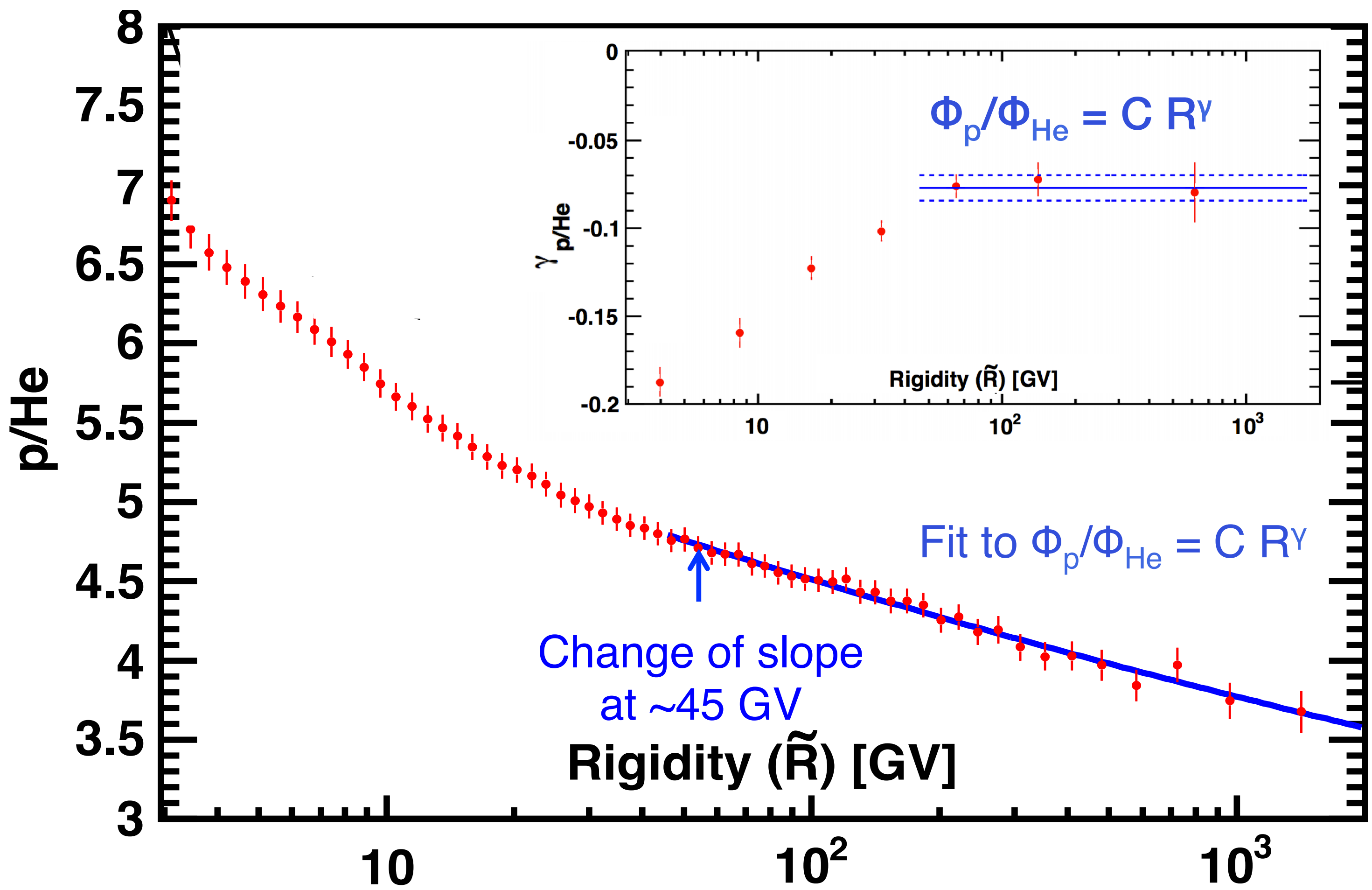
Both fluxes cannot be described by single power laws. A break in the power law at R~300 GV is required to describe the data.

Proton and Helium Fluxes

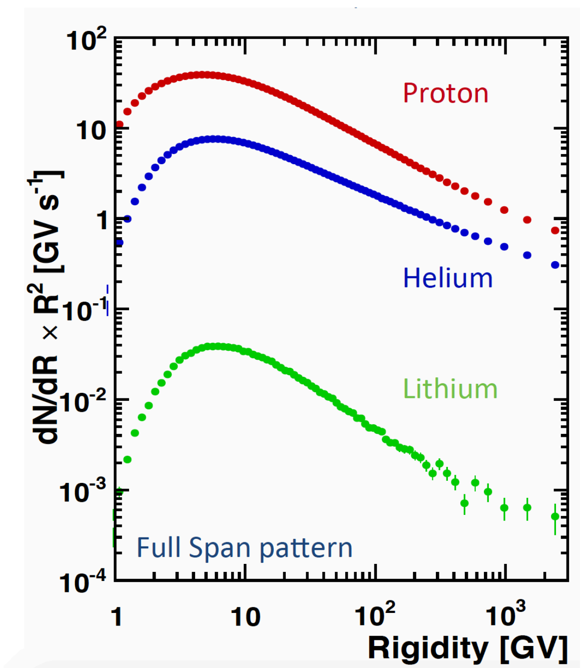
Model independent spectral index analysis



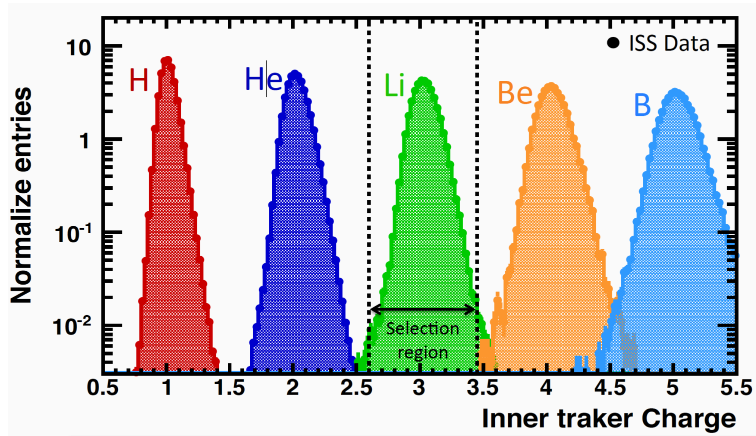
Proton and Helium Fluxes

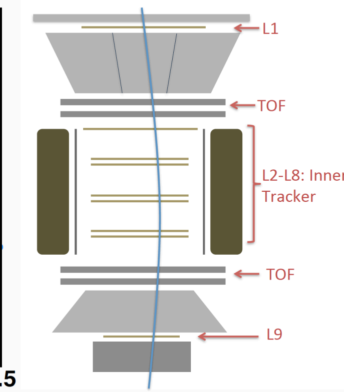


Lithium

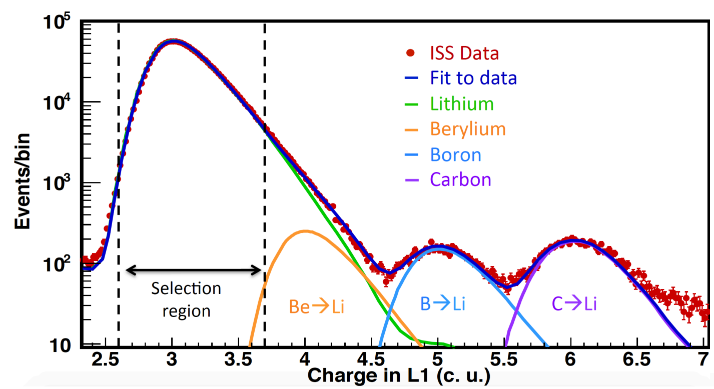


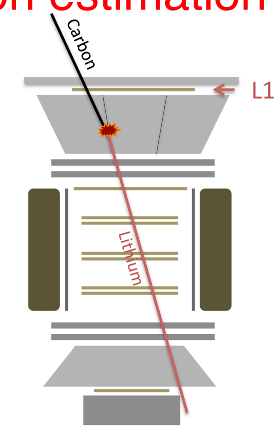
Inner Tracker IZI selection



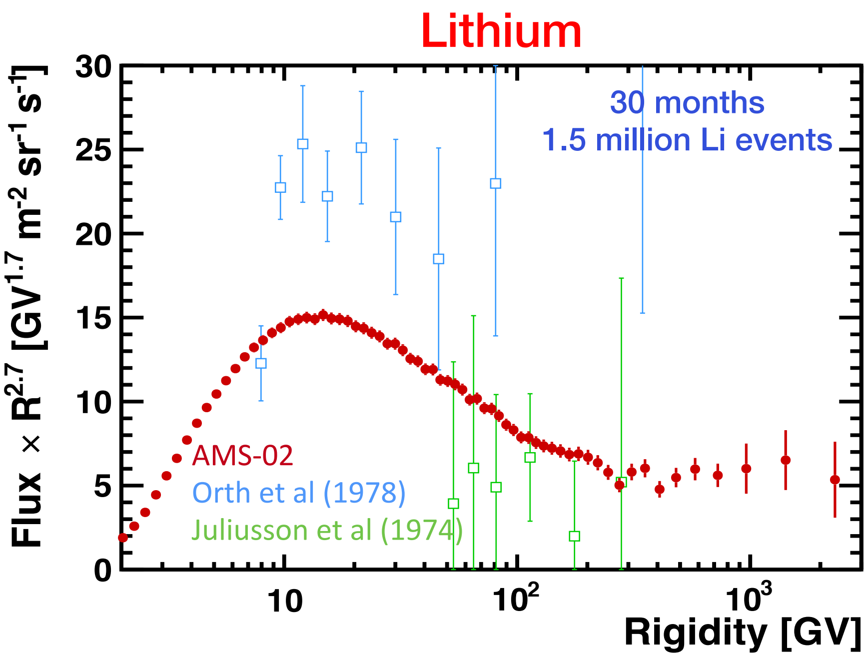


Tracker L1 fragmentation estimation



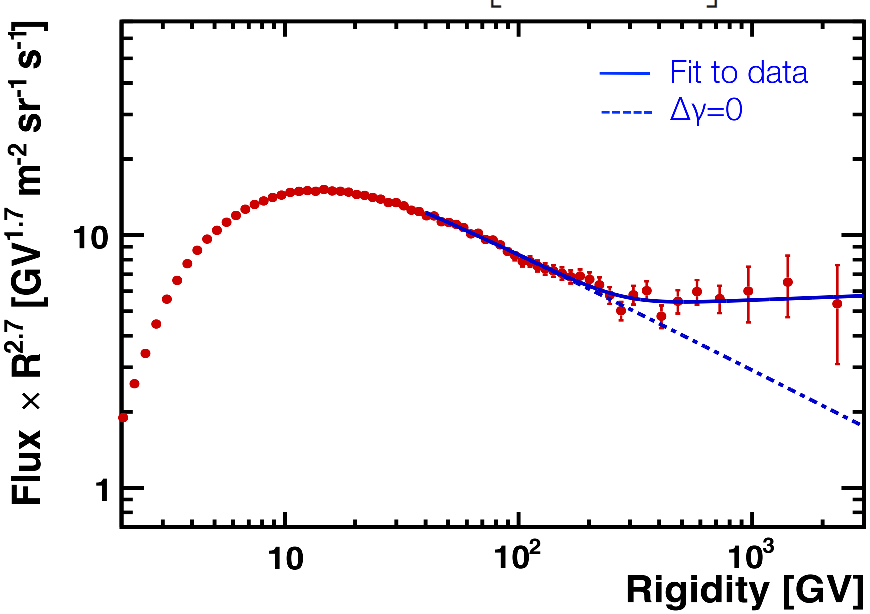


Lithium Flux



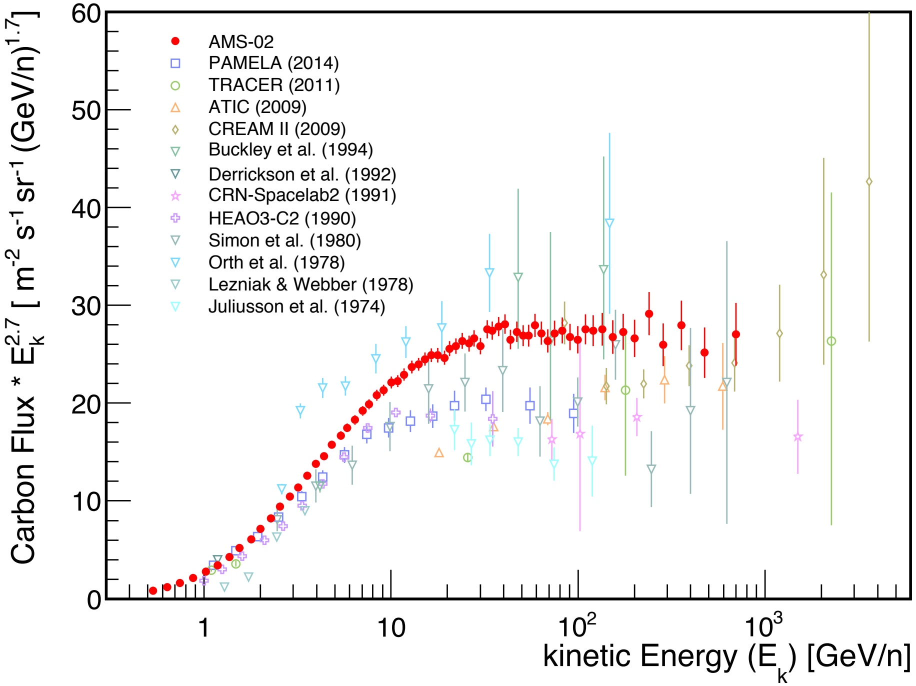
The large size of the collected statistics and the charge identification capabilities of AMS allow to measure the Li flux with unprecedented precision.

$$\Phi = C\left(\frac{R}{45\,\mathrm{GV}}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$$

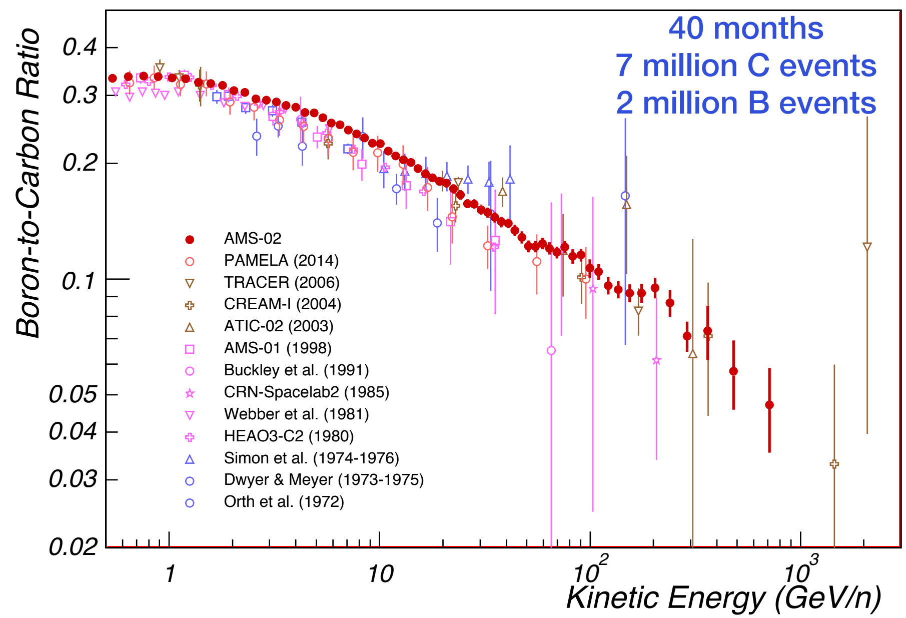


Carbon and Boron

Carbon



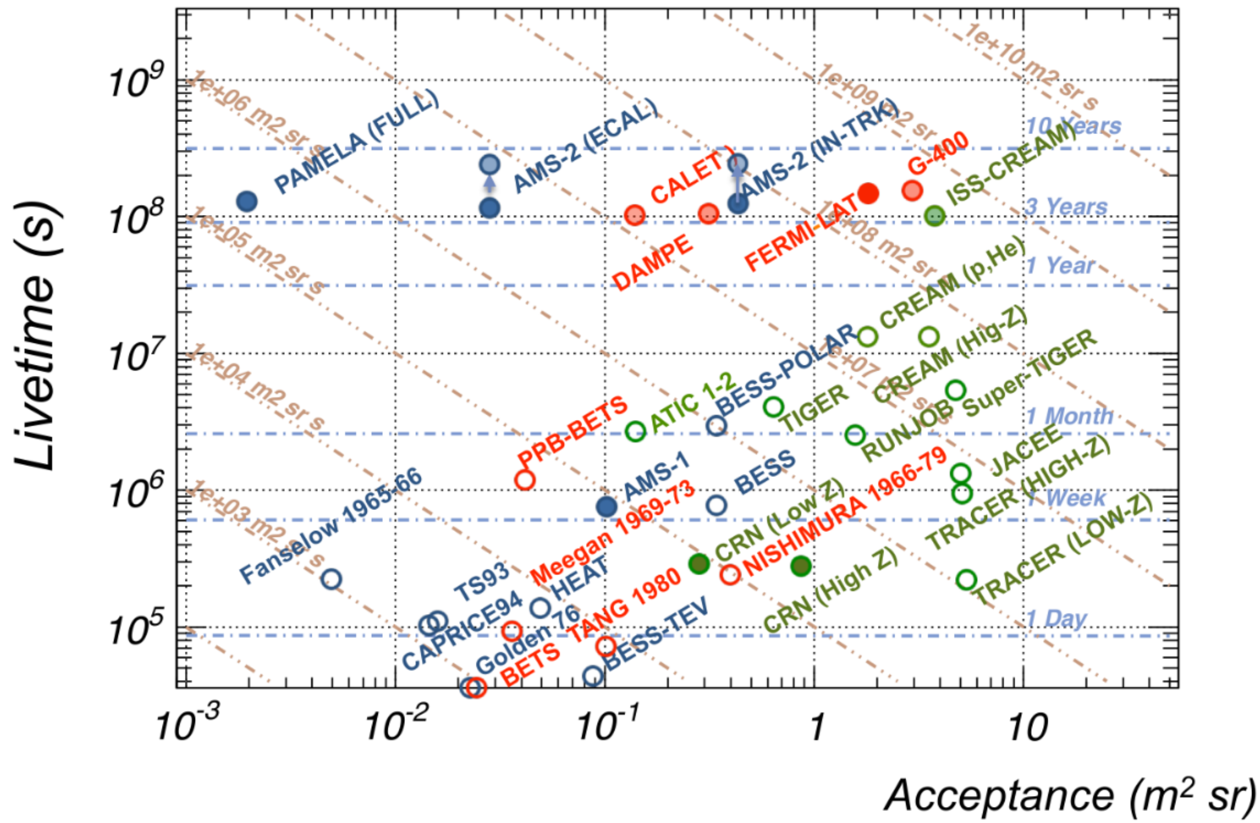
Boron/Carbon



No structures or features are observed in the C flux nor in the B/C ratio.

Additional statistics will provide more quantitative information on the behavior at high energies

Future experiments

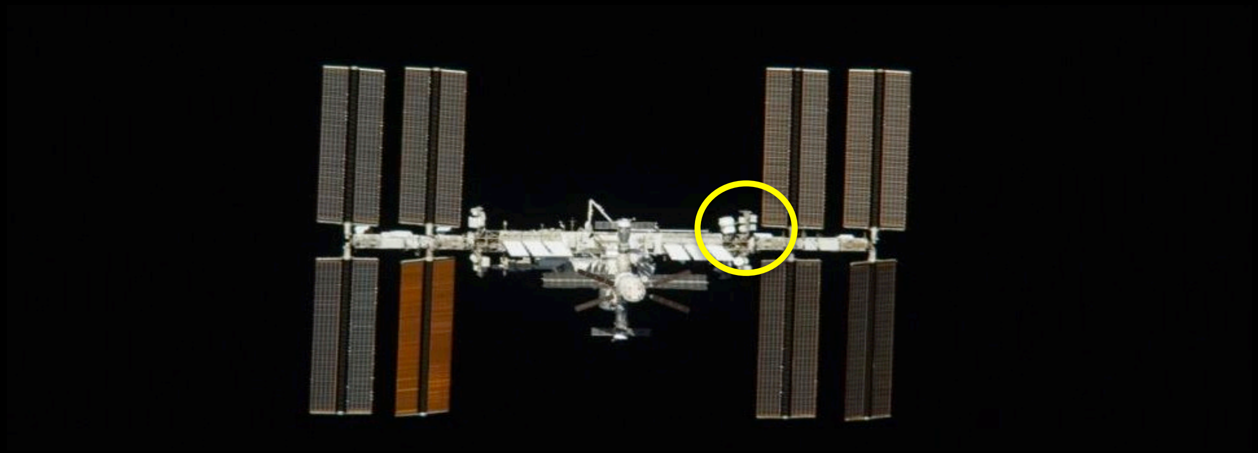


- No B field, different techniques with main focus on Z
- No B field, different techniques with main focus on e,γ
- Magnetic spectrometers

- Balloon
- Space
- Space (planned)

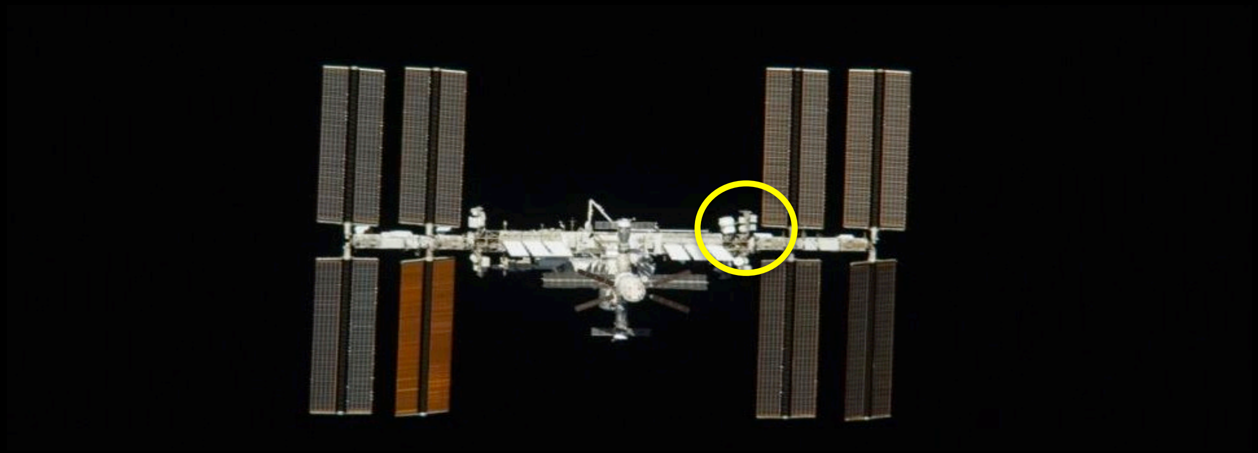
AMS-02 will be the unique magnetic spectrometer in space able to distinguish matter from antimatter for the next 10 years.

Conclusions



- AMS is providing simultaneous measurements of different cosmic ray species with O(%) accuracy in an extended energy range.
- New phenomena are being highlighted by these measurements, whose nature will be further clarified as more data will be collected by the experiment.

Conclusions



AMS will match the lifetime of the Space Station

- Continue the search for Dark Matter
- Improve the CR origin and propagation models
- Quest for the existence of primordial Antimatter
- Search for new phenomena, …
- Time dependent effects of low energy CR


Thank you for your attention
AMS
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