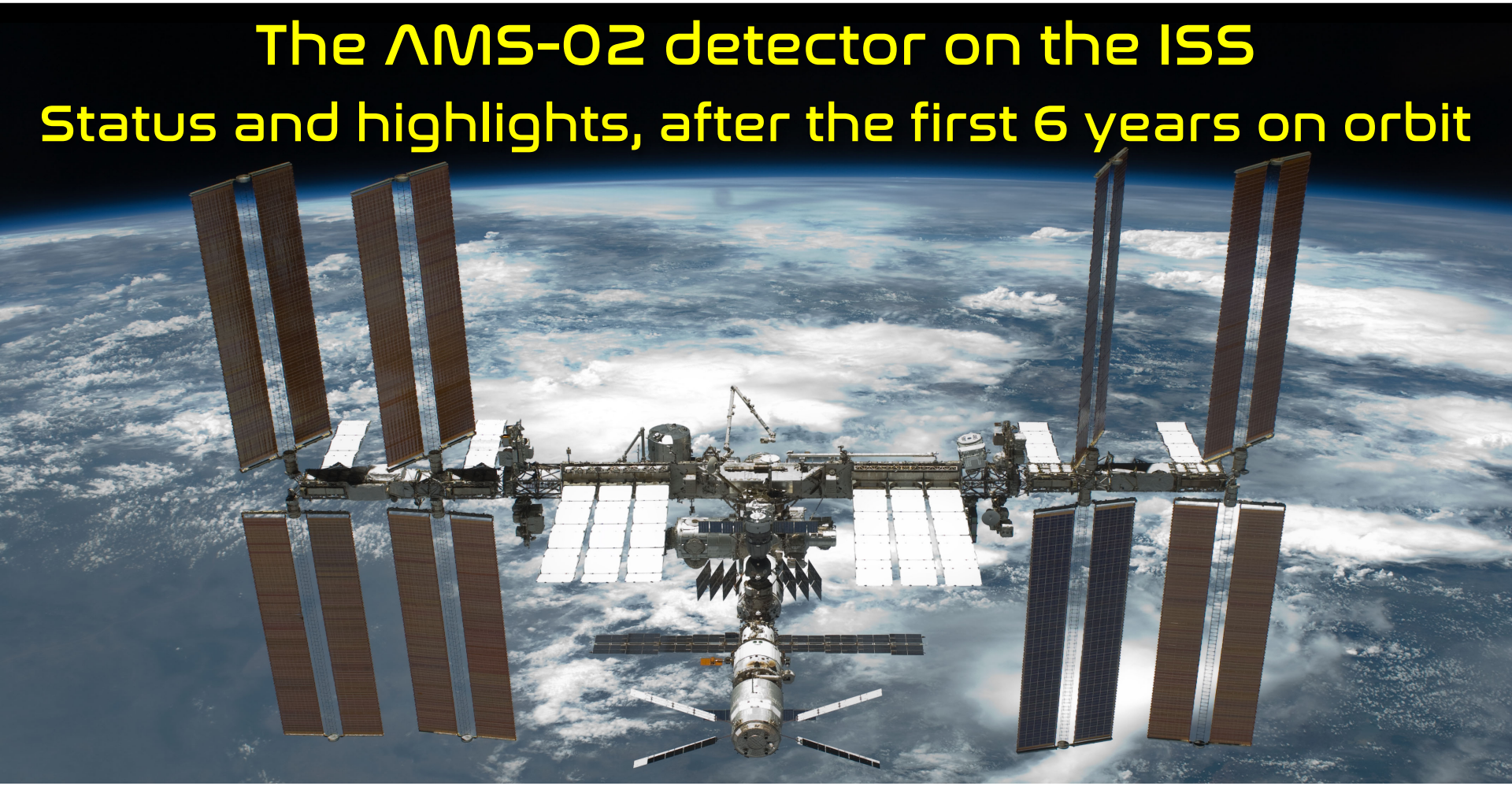
JPS The Physical Society of Japan

# The AMS-02 detector on the ISS

## Status and highlights, after the first 6 years on orbit



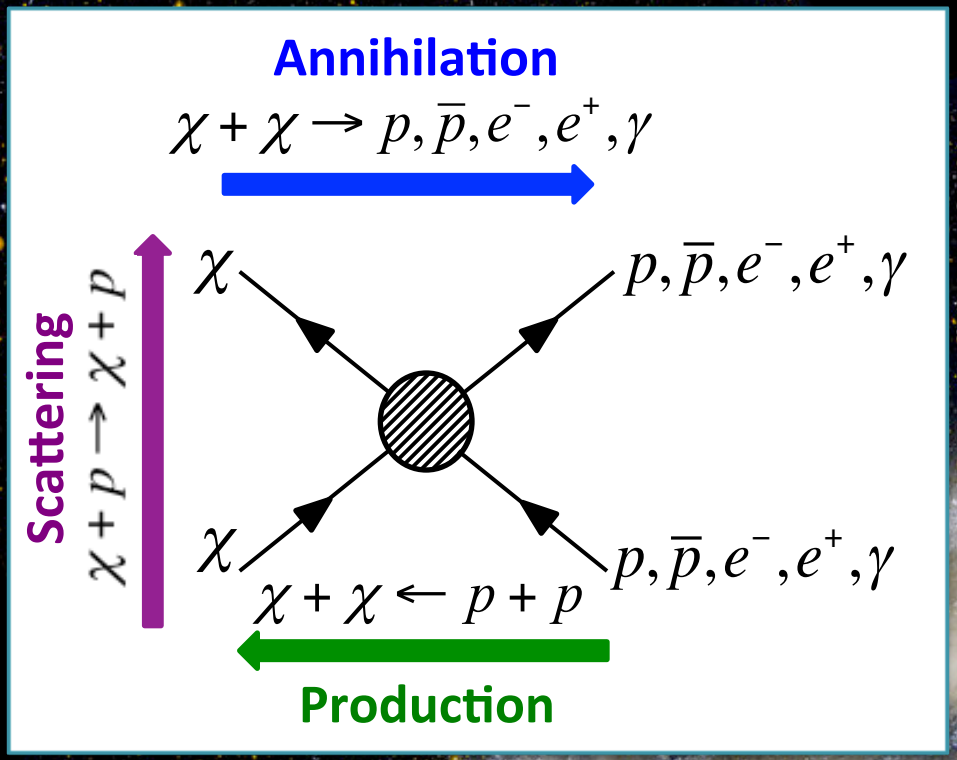

**Matteo Duranti on behalf of the AMS collaboration**

Istituto Nazionale Fisica Nucleare, INFN Perugia

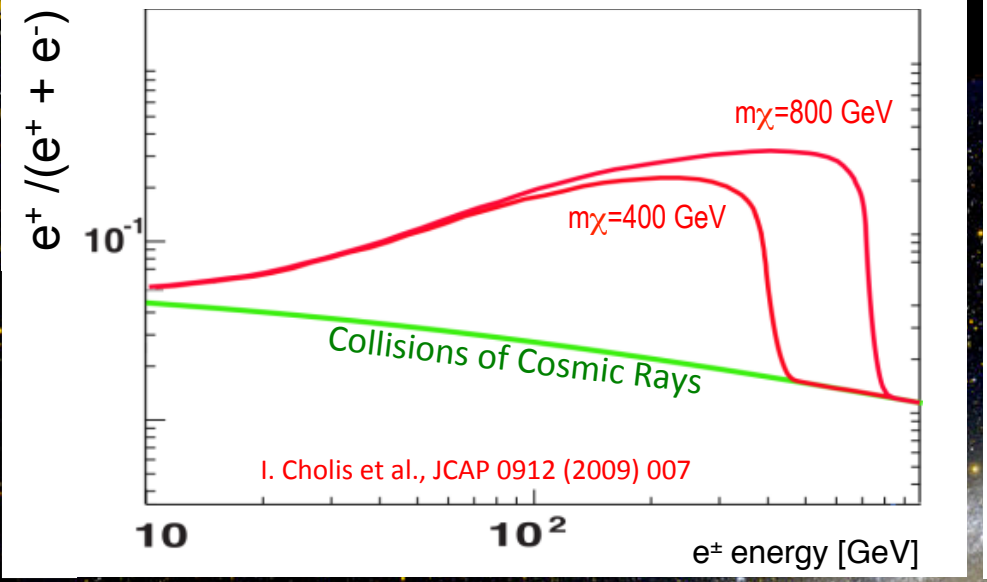
# Objectives

- Fundamental physics and antimatter:
  - primordial origin (signal: anti-nuclei)
  - "exotic" sources (signal: positrons, anti-p, anti-D, $\gamma$)

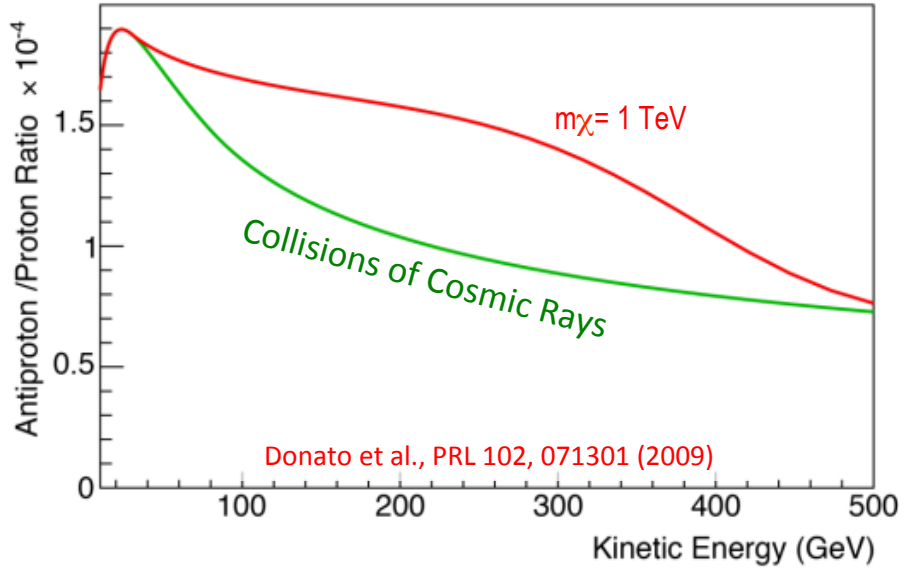
Dark Matter search

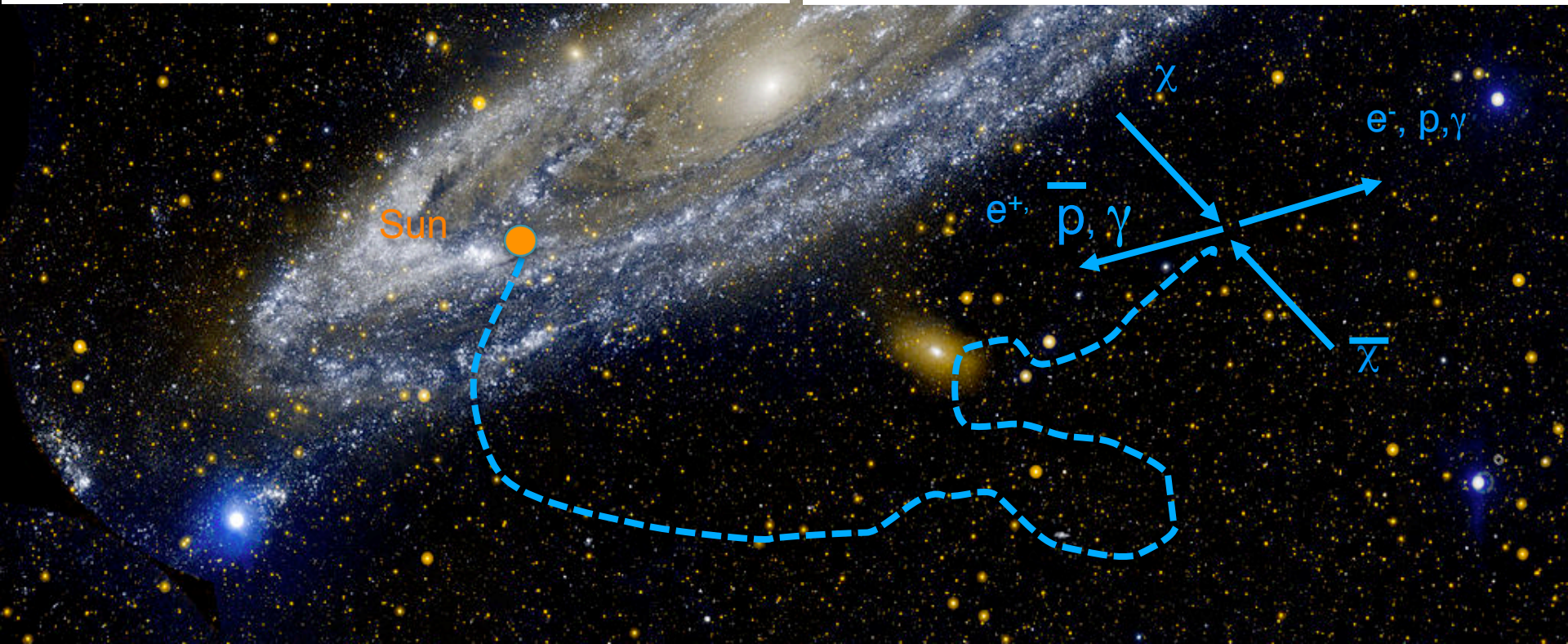


## Positrons: $\chi + \chi \rightarrow e^+ + \ldots$




## Antiprotons: $\chi + \chi \rightarrow \bar{p} + \ldots$



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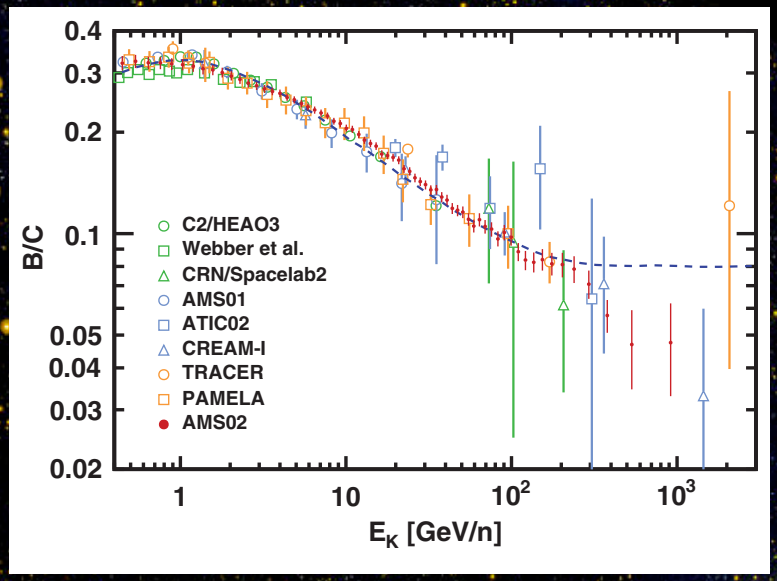
  - primordial origin (signal: anti-nuclei)
  - "exotic" sources (signal: positrons, anti-p, anti-D, $\gamma$)
- Origin and composition of CRs
  - sources and acceleration: primaries (p, He, C, ...)
  - propagation in the ISM: secondaries (B/C, ...)

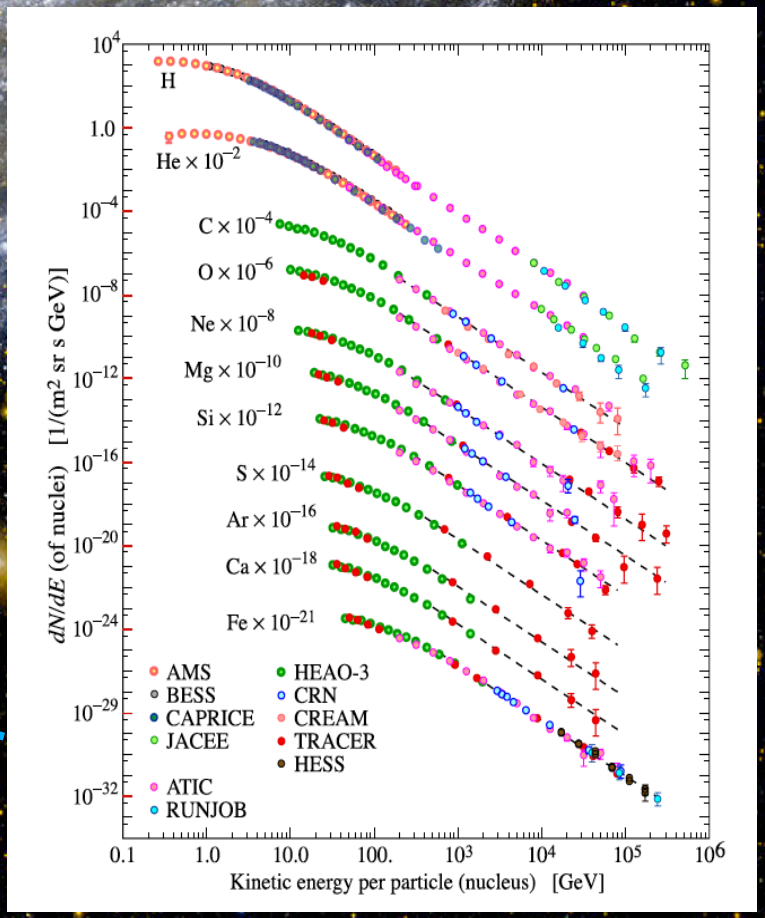



p, He,C..,e⁻

Sun

$\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$

$p+p \rightarrow p\bar{+}p\ldots$



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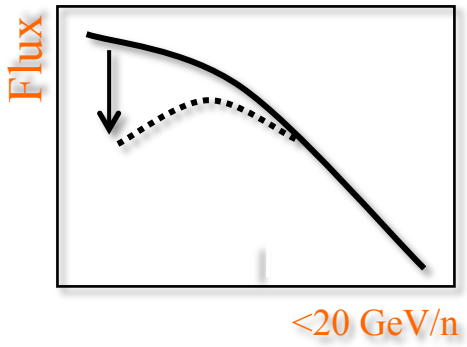
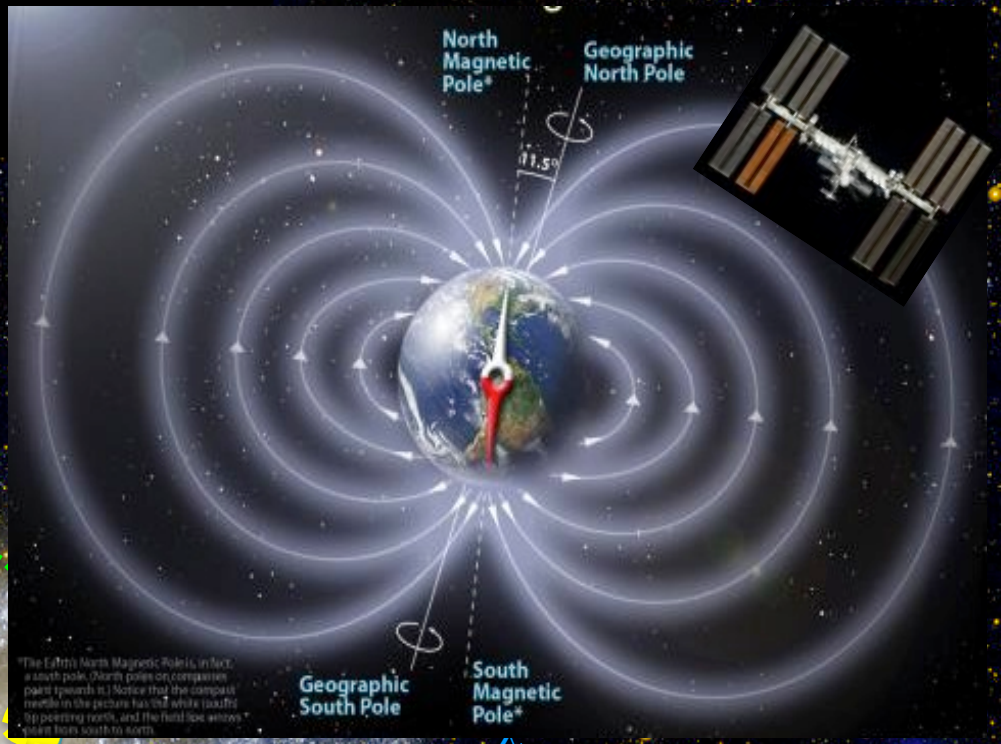
- Origin and composition of CRs
  - sources and acceleration: primaries (p, He, C, ...)
  - propagation in the ISM: secondaries (B/C, ...)
- Study of the solar and geomagnetical physics
  - effect of the solar modulation
  - geomagnetic cutoff

## Solar modulation




p, He,C..,$e^-$

Sun

$e^{+,}$ $\bar{p}$, $\gamma$

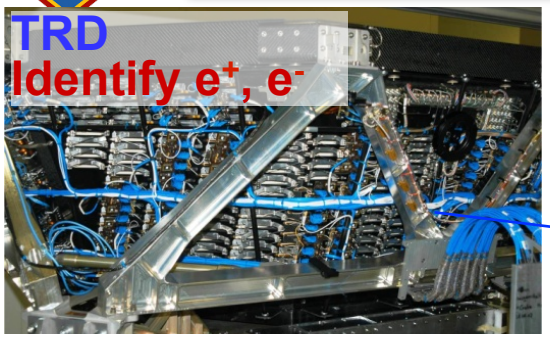
$e^-$, p,$\gamma$

$\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$

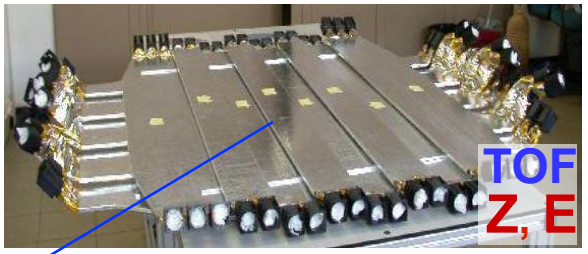
$p+p \rightarrow p+\bar{p}$...

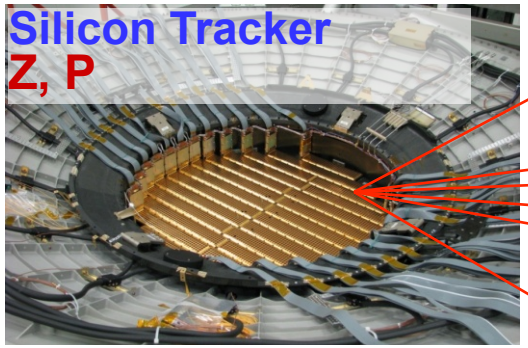
$\bar{\chi}$

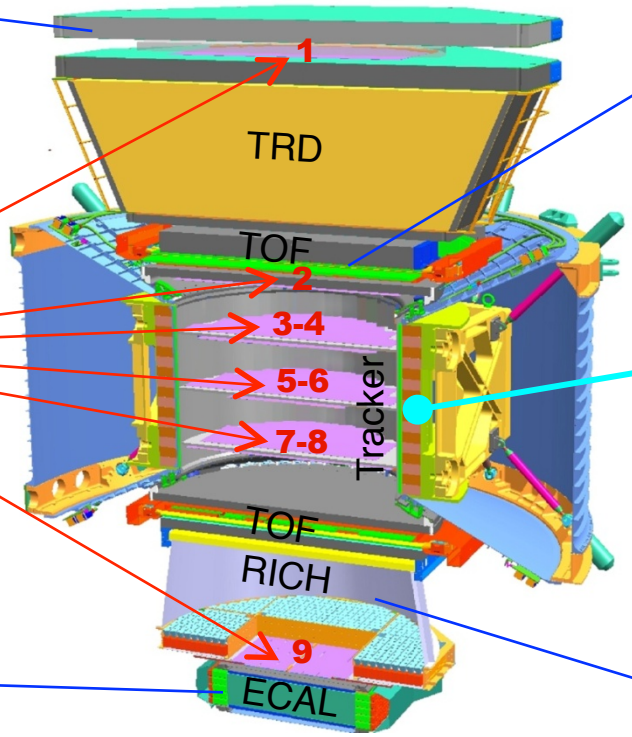
# Alpha Magnetic Spectrometer – AMS-02

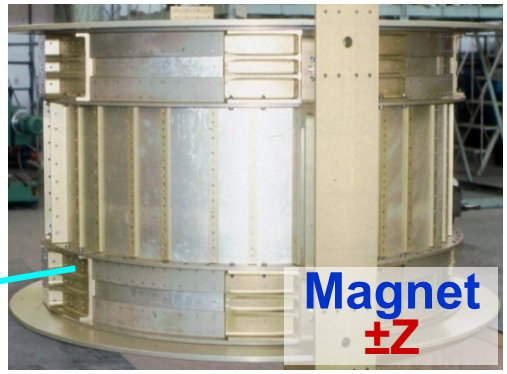


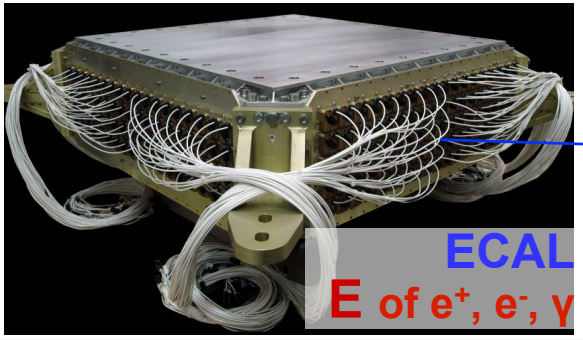

*Z, P are measured independently by Tracker, RICH, TOF and ECAL*

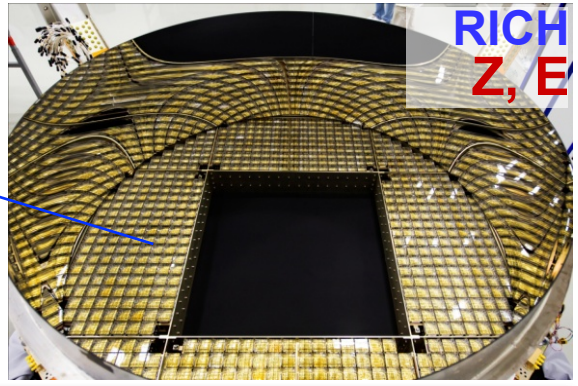


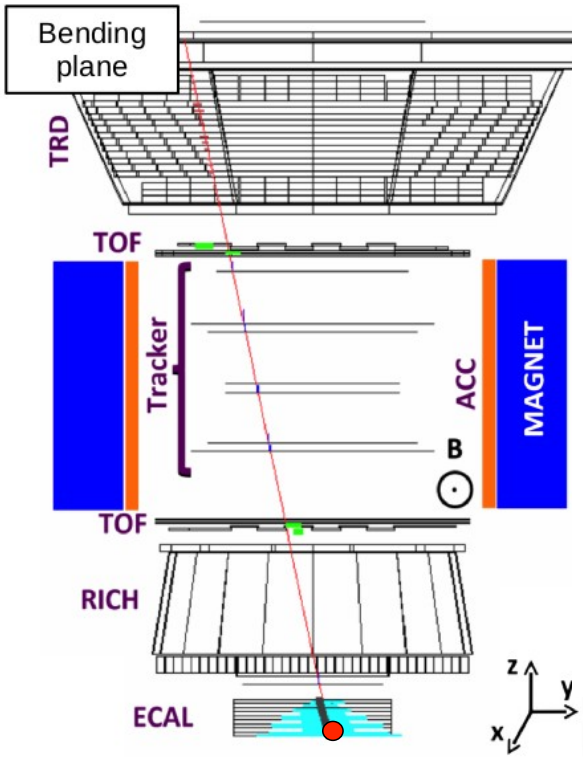



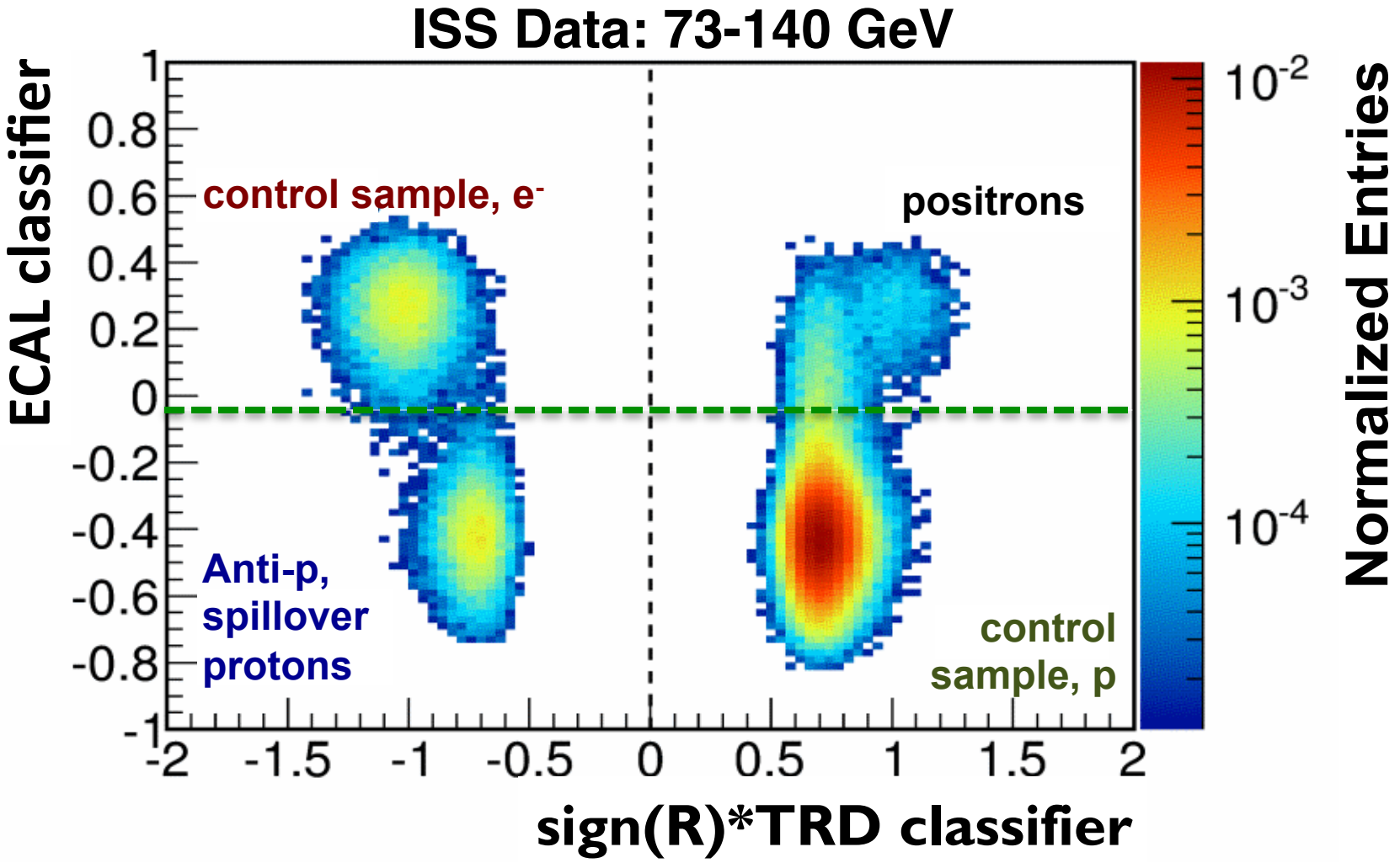
# Single particle identification

**Full coverage of anti-matter and CR physics**

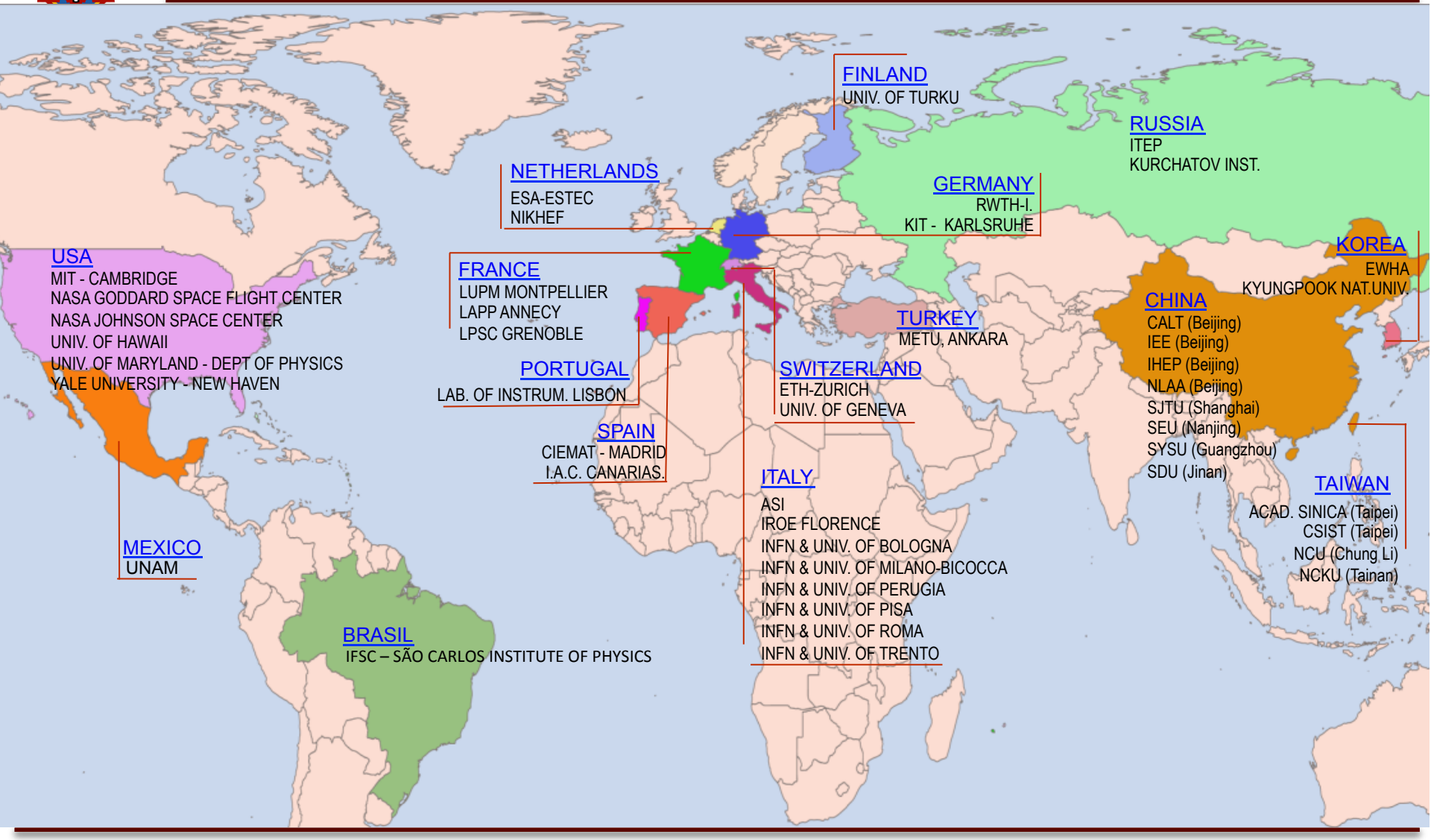



| | $e^-$ | p | He | |
|---|---|---|---|---|
| **TRD** 20 layers | | | | e/p separation<br>charge (\|Z\|) |
| **TOF** 4 layers | | | | trigger<br>velocity (β)<br>charge (\|Z\|) |
| **TRK** 9 layers | | | | momentum (p)<br>sign (±Q)<br>charge (\|Z\|) |
| **RICH** | | | | velocity (β)<br>charge (\|Z\|)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

# Redundancy and complementarity

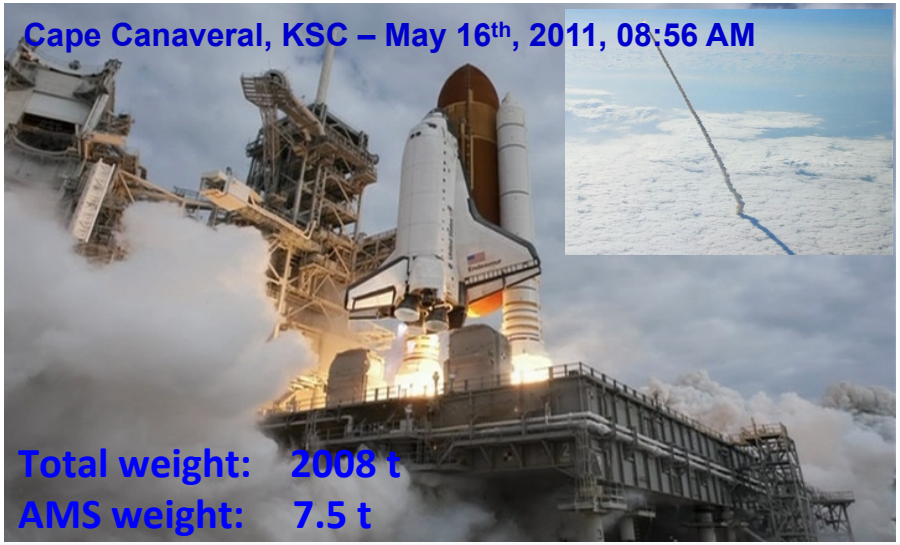


# The International Collaboration: since 1995



# AMS launch and data taking start: May 2011





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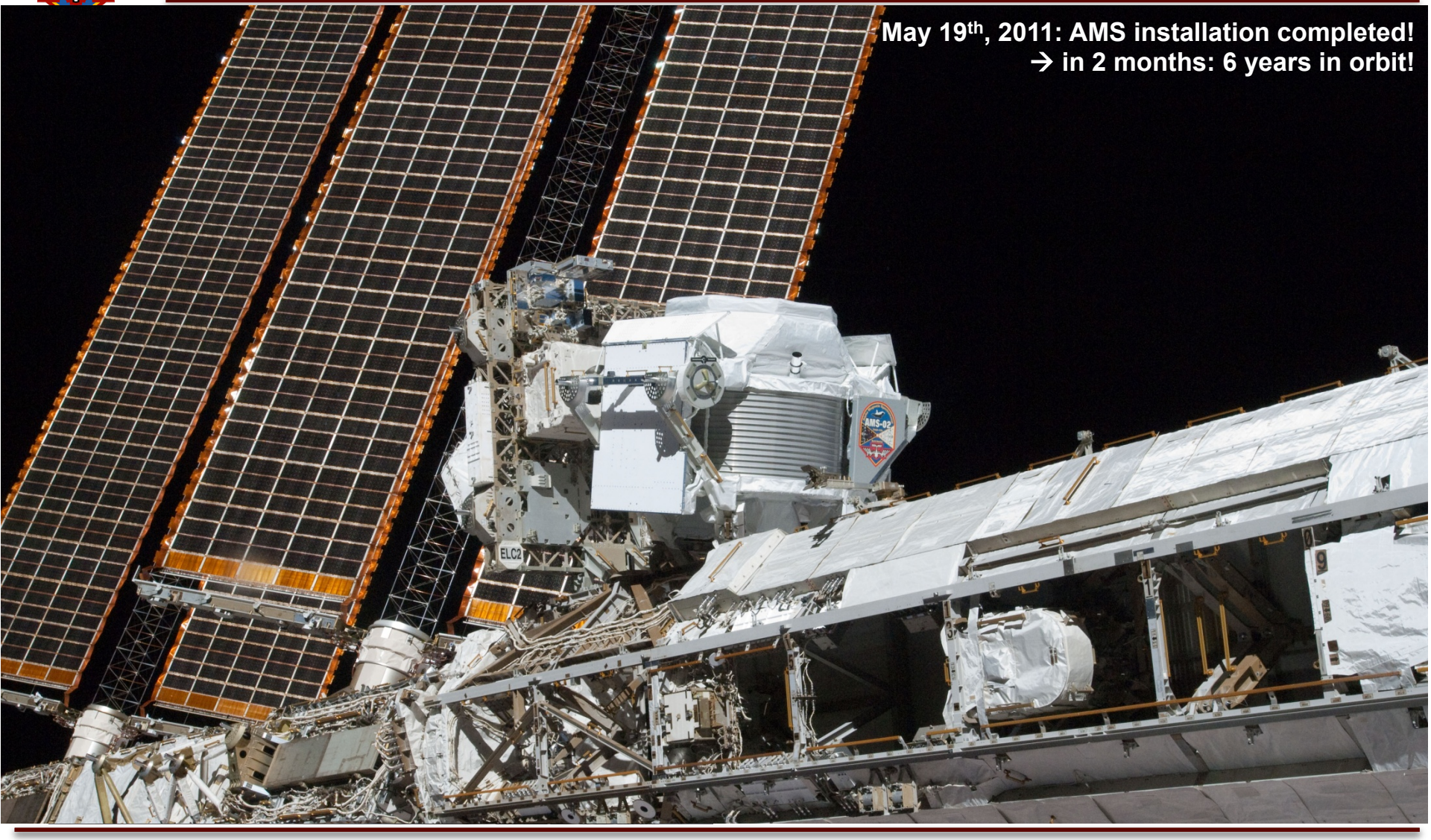
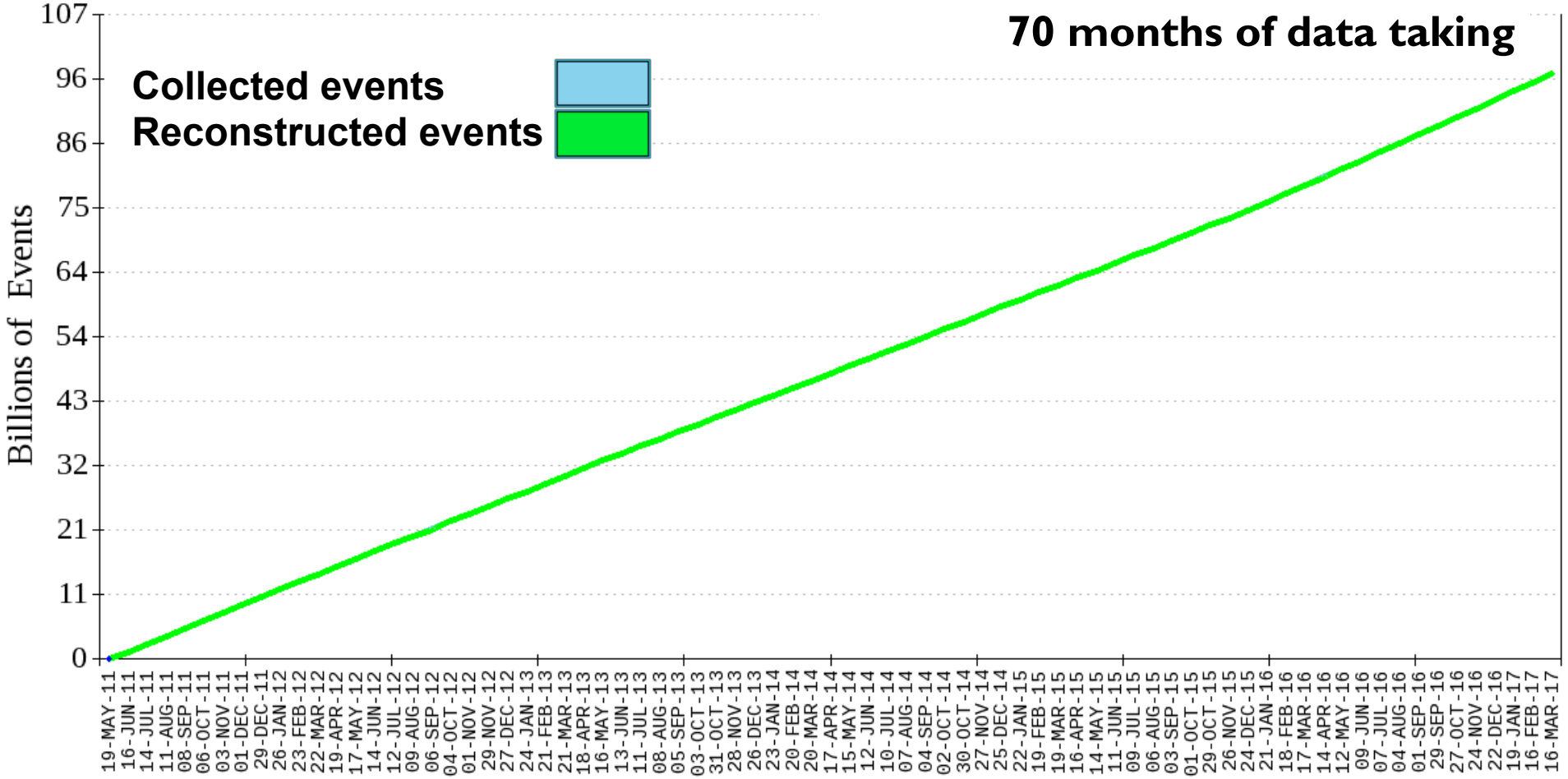


# The collected statistics

## Today AMS collected ~ 95 billion of events



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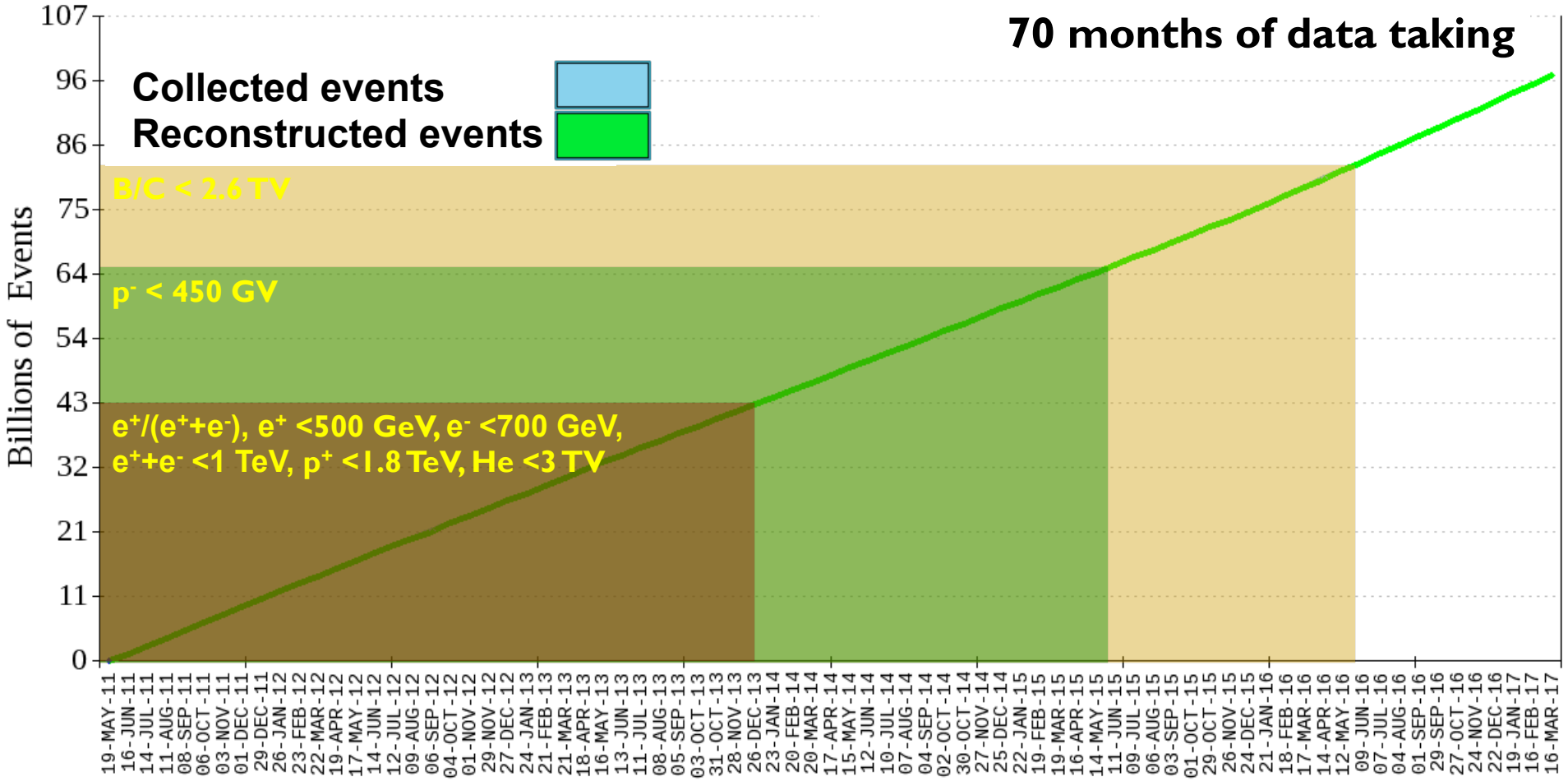
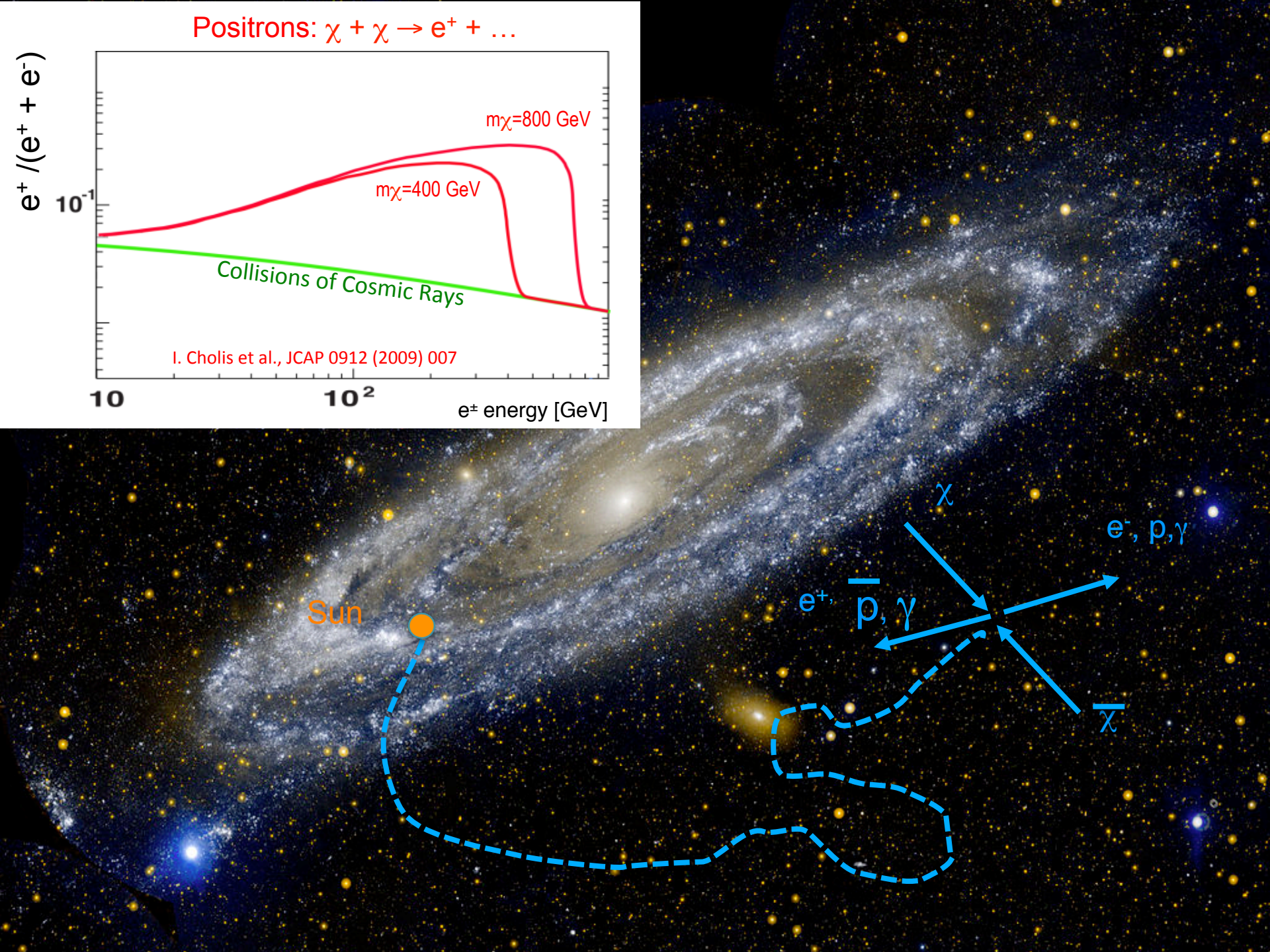
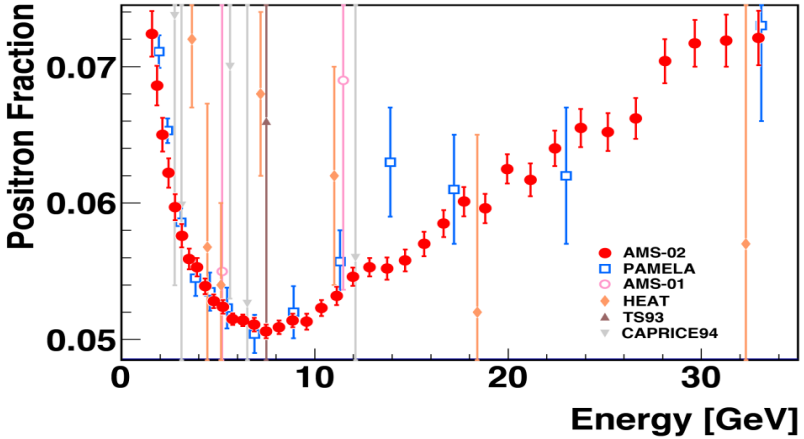
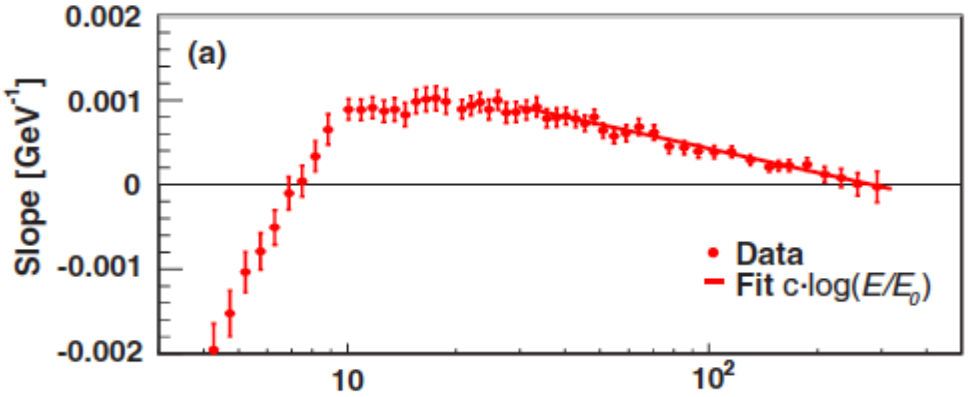


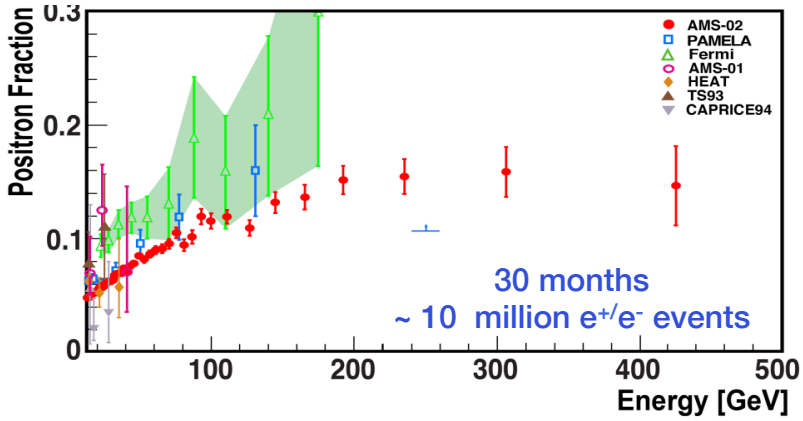

Positrons: χ + χ → e+ + …
e+ /(e+ + e-)
10-1
mχ=800 GeV
mχ=400 GeV
Collisions of Cosmic Rays
I. Cholis et al., JCAP 0912 (2009) 007
10
10 2
e± energy [GeV]
Sun
χ
e-, p,γ
e+, p̄, γ
χ̄

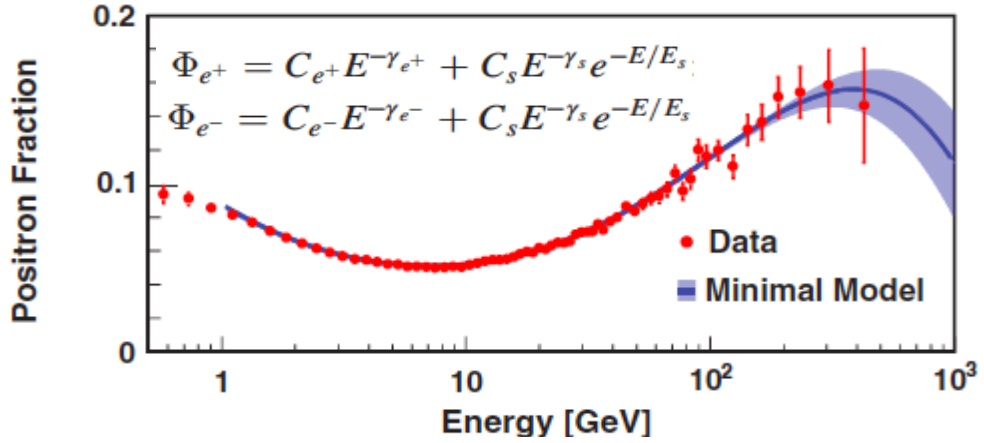
# Positron fraction (PRL 110, 141102 - 2013 & 113, 121101 - 2014)

- ✓ No evidence of structures
- ✓ Steady increase up to ~ 275 GeV
- ✓ Well described by a power law + cut-off term, common for $e^+/e^-$

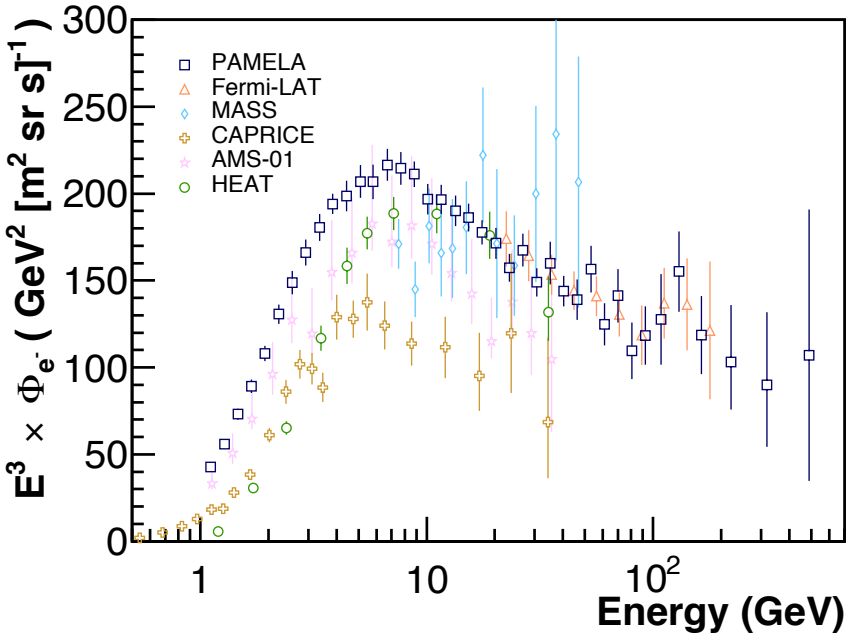


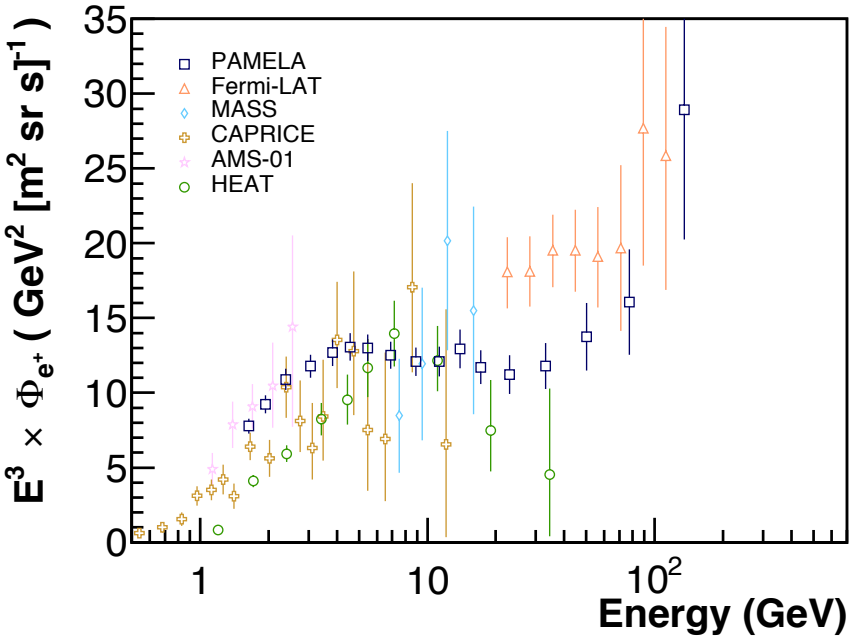



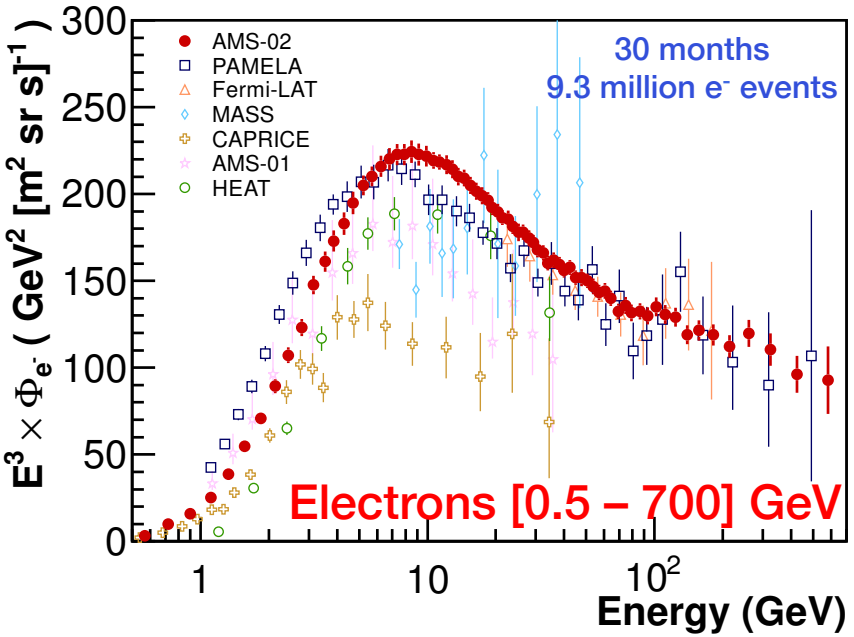



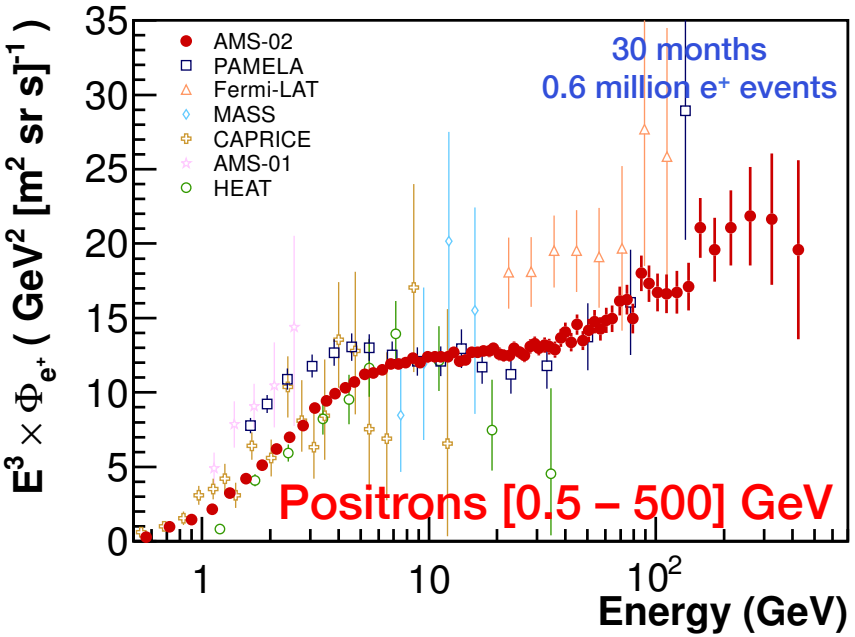
# Positron and electron fluxes

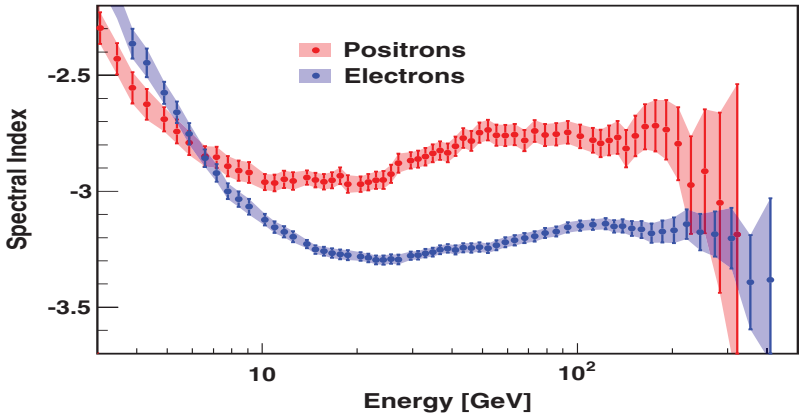


# Positron and electron fluxes (PRL 113, 121102 - 2014)



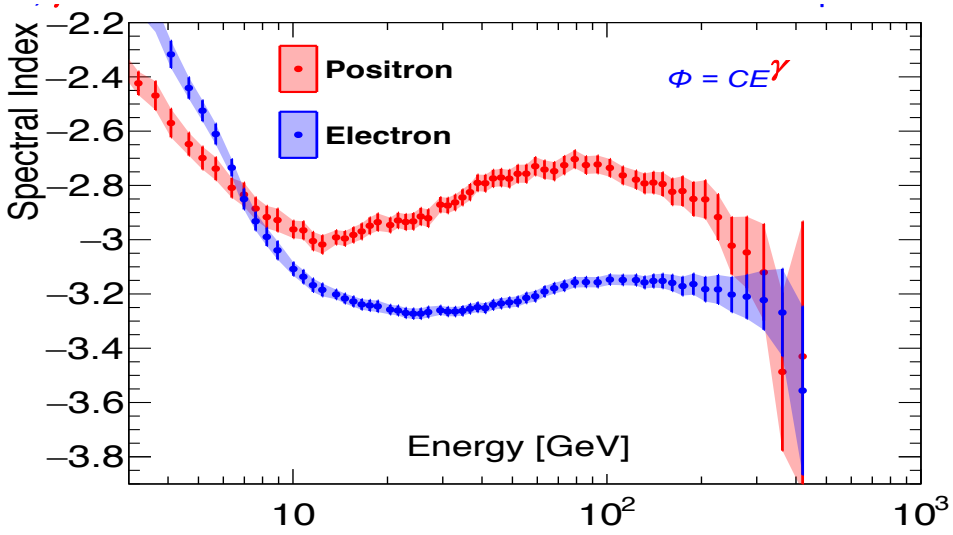

The two fluxes of $e^+$ and $e^-$ are significantly different in absolute value and energy dependence

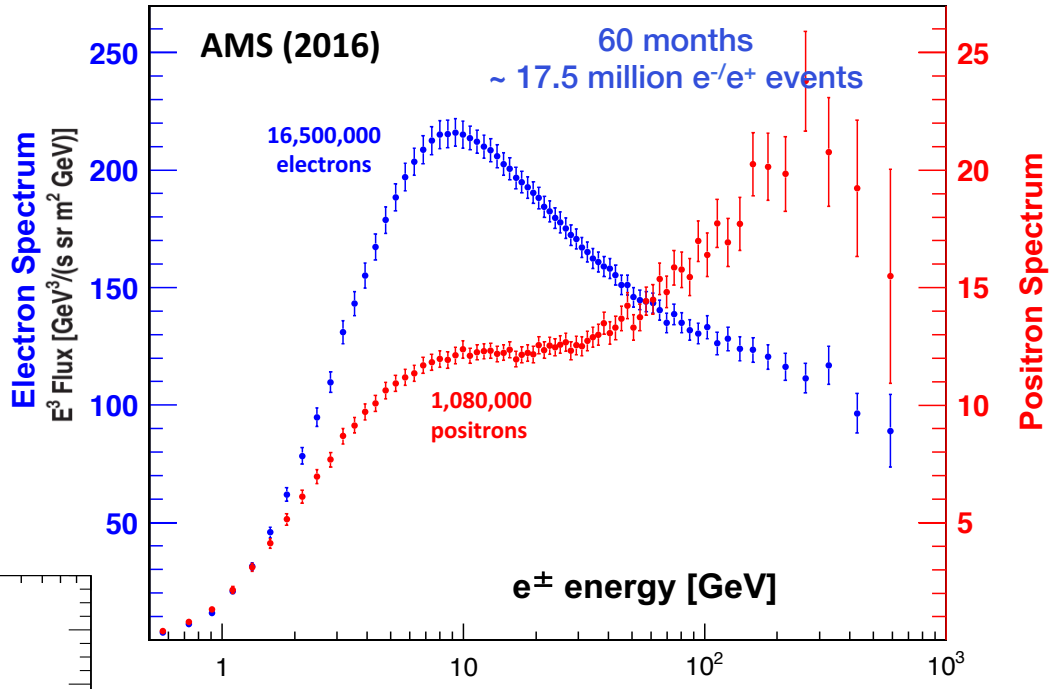
The positron "raise" is due to an **excess of positrons**, not to a lack of electrons

# Positron and electron fluxes (status report)

We're updating the results, including the last data collected (more than the double w.r.t. the publication) and trying to reach higher energies

**Electrons and Positrons [0.5 – 700] GeV**

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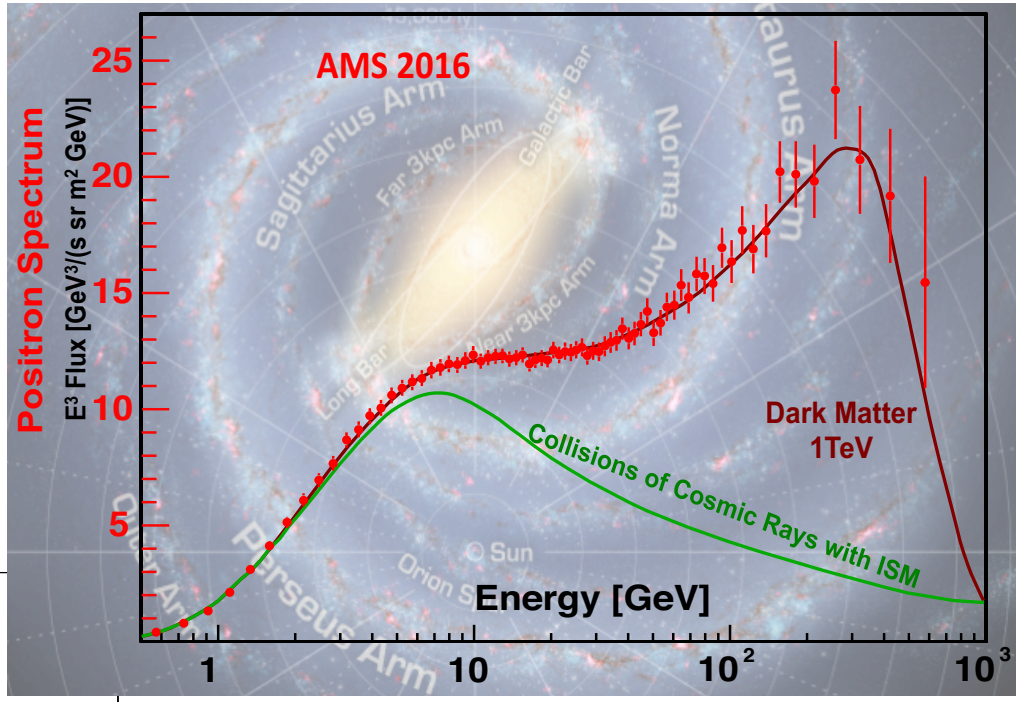


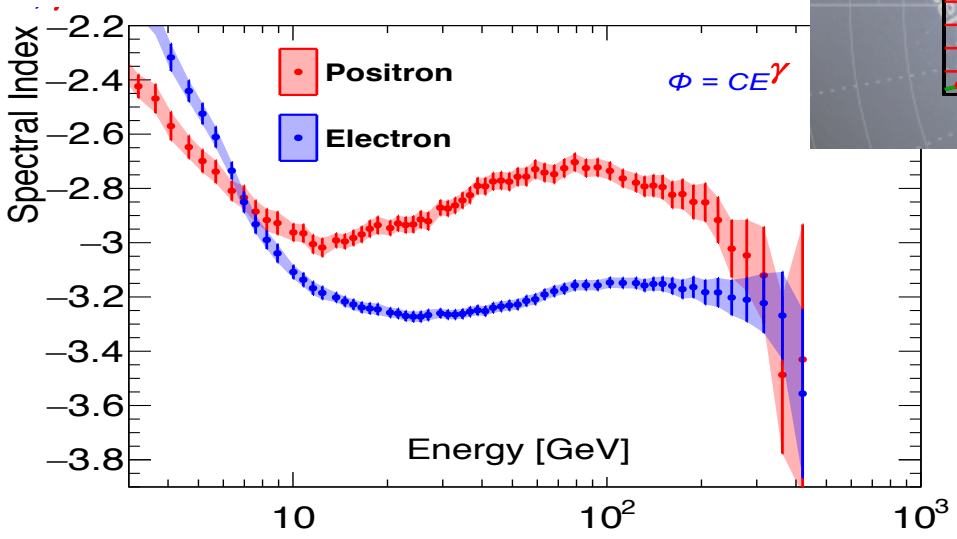


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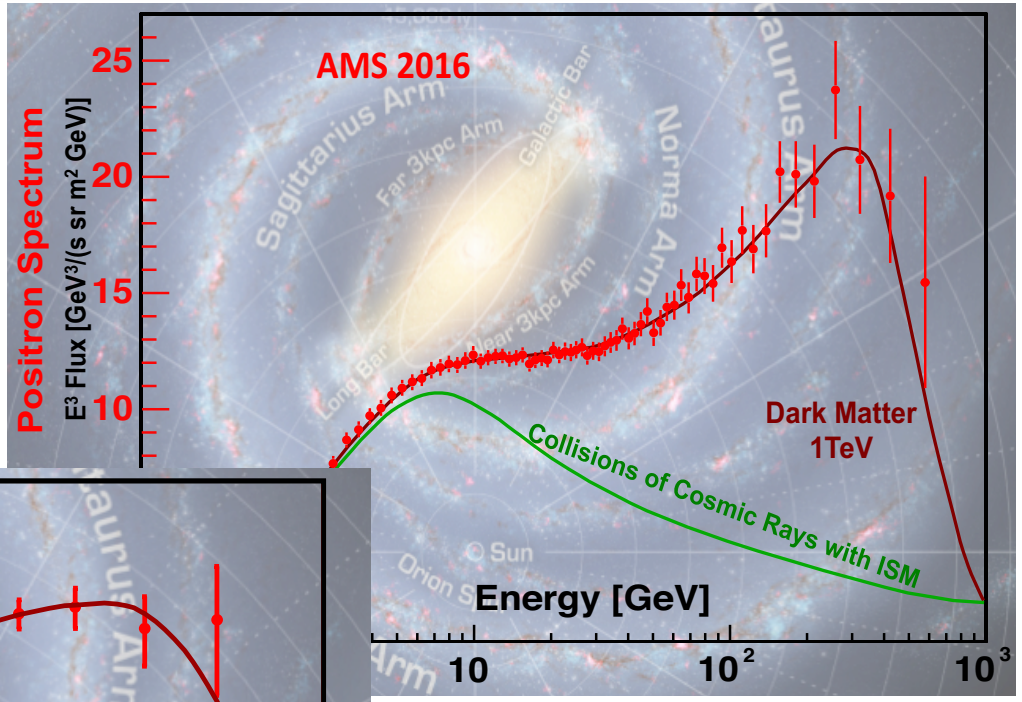
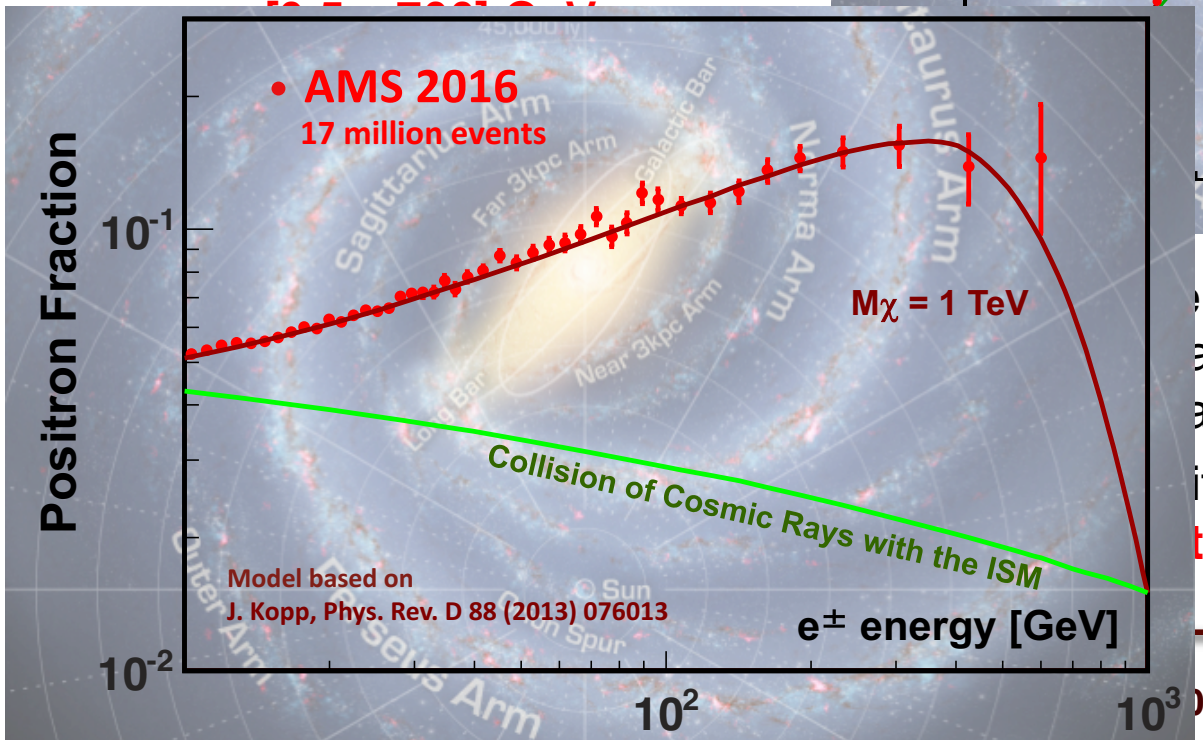
Electrons and Positrons

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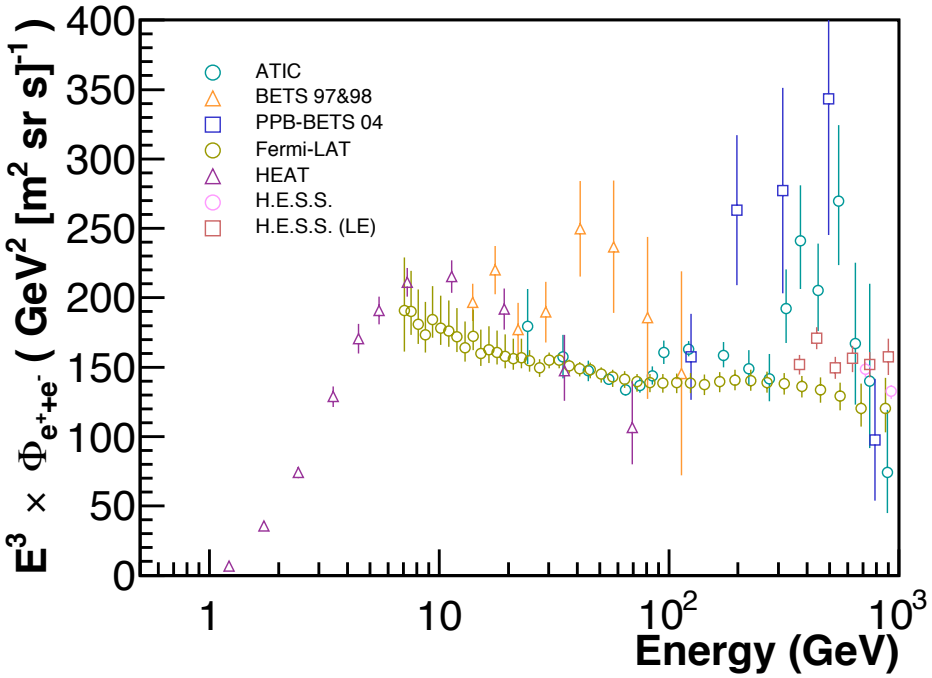
# “All electrons” (electron+positron) flux

Independent measure of the total $e^+ + e^-$ without identification of the charge sign.
Less systematic uncertainties, higher energy reach, directly comparable with purely calorimetric measurements.



# "All electrons" flux (PRL 113, 221102 - 2014)

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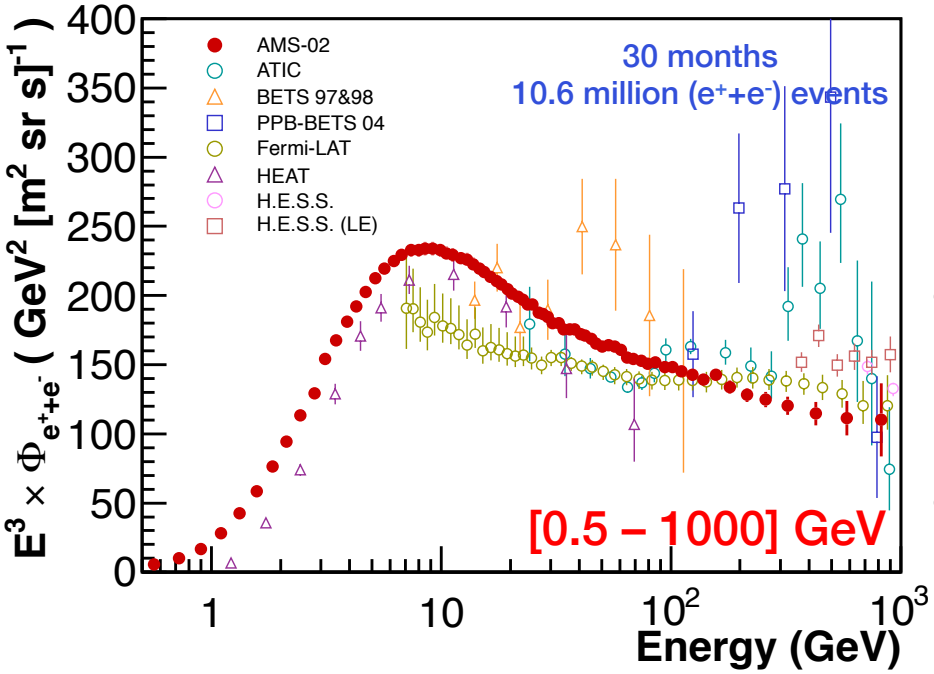
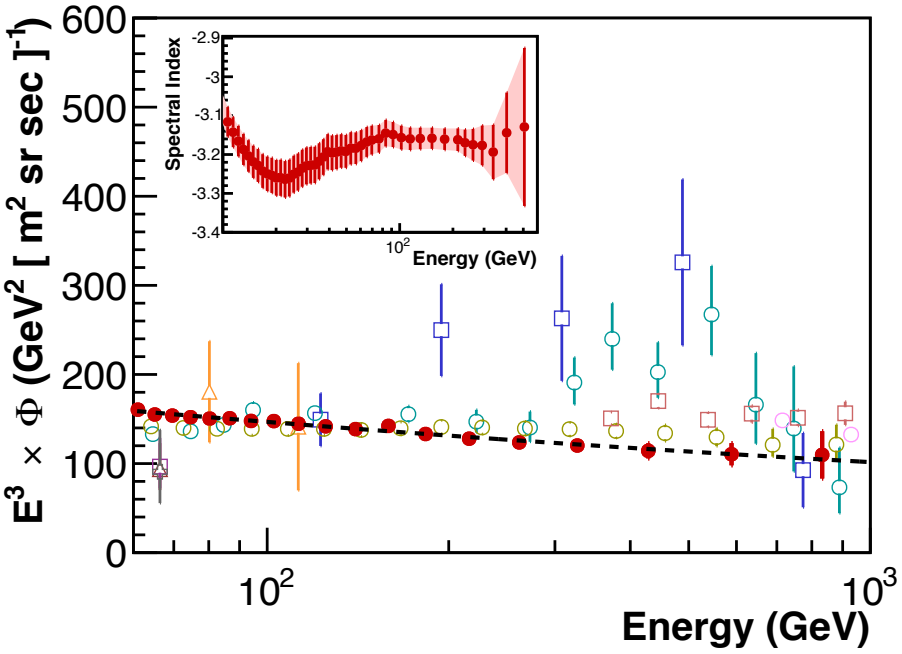
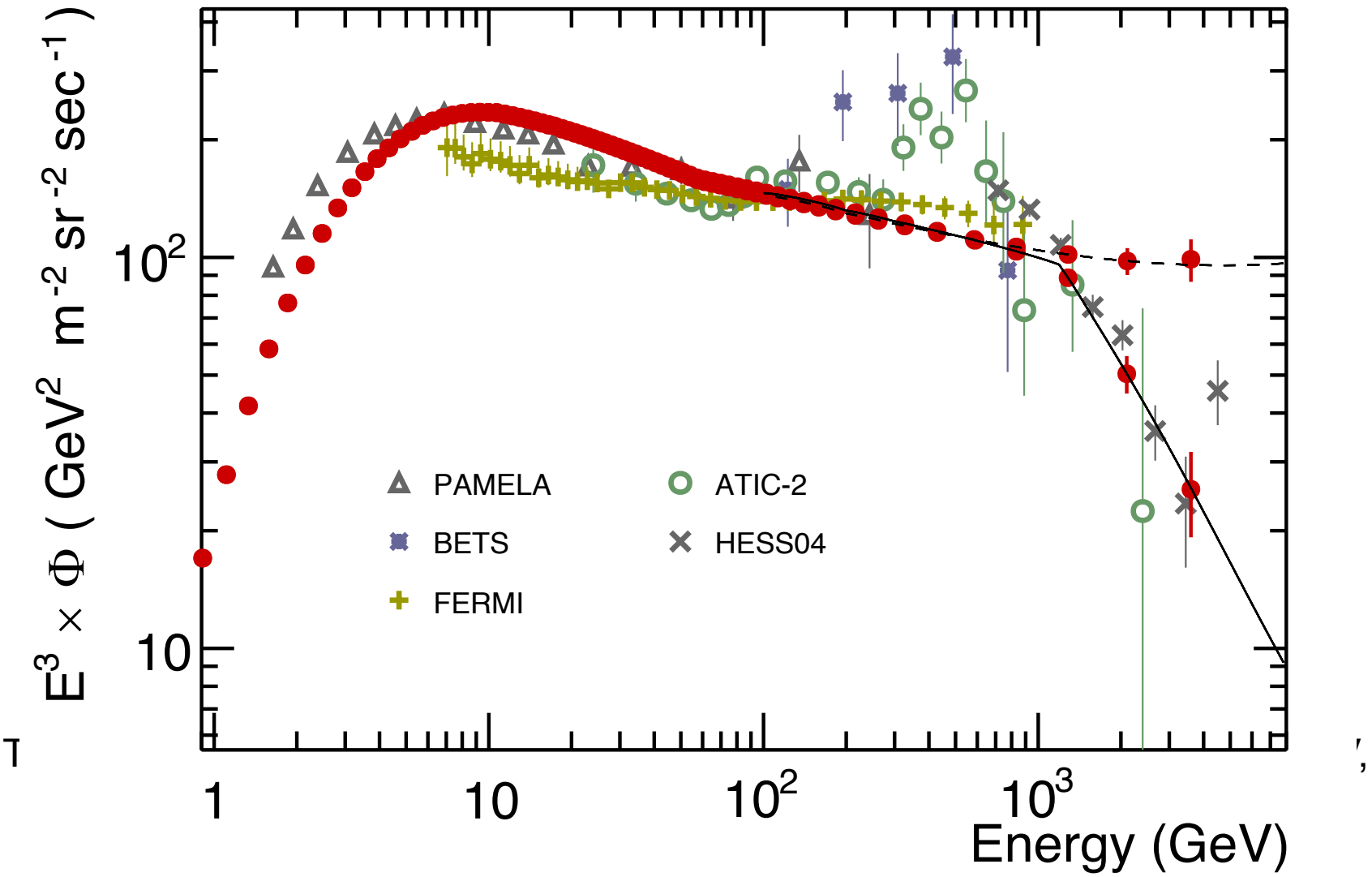


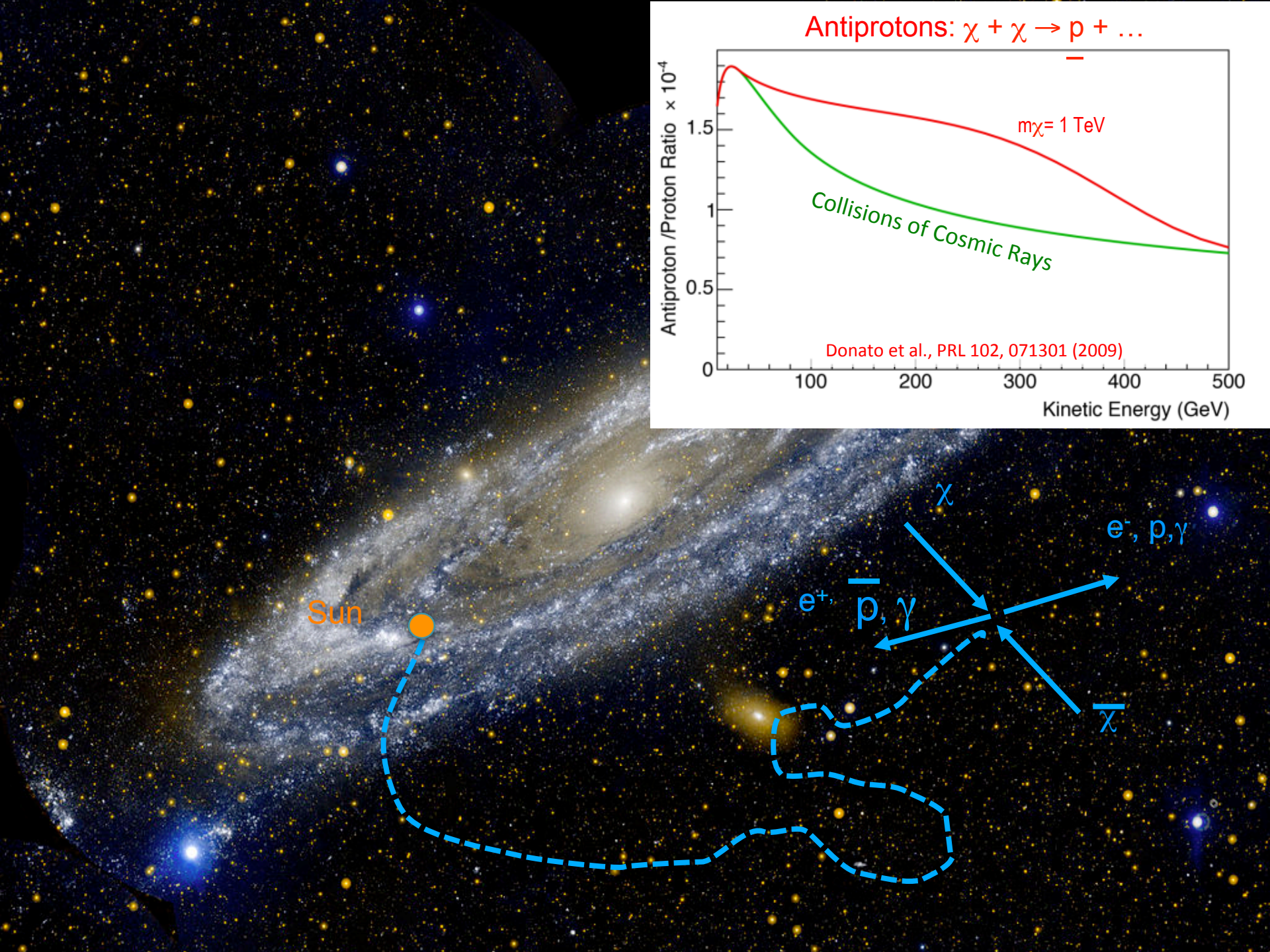




The $(e^+ + e^-)$ flux can be described by a single power-law, starting from ~30 GeV, and up to 1 TeV.

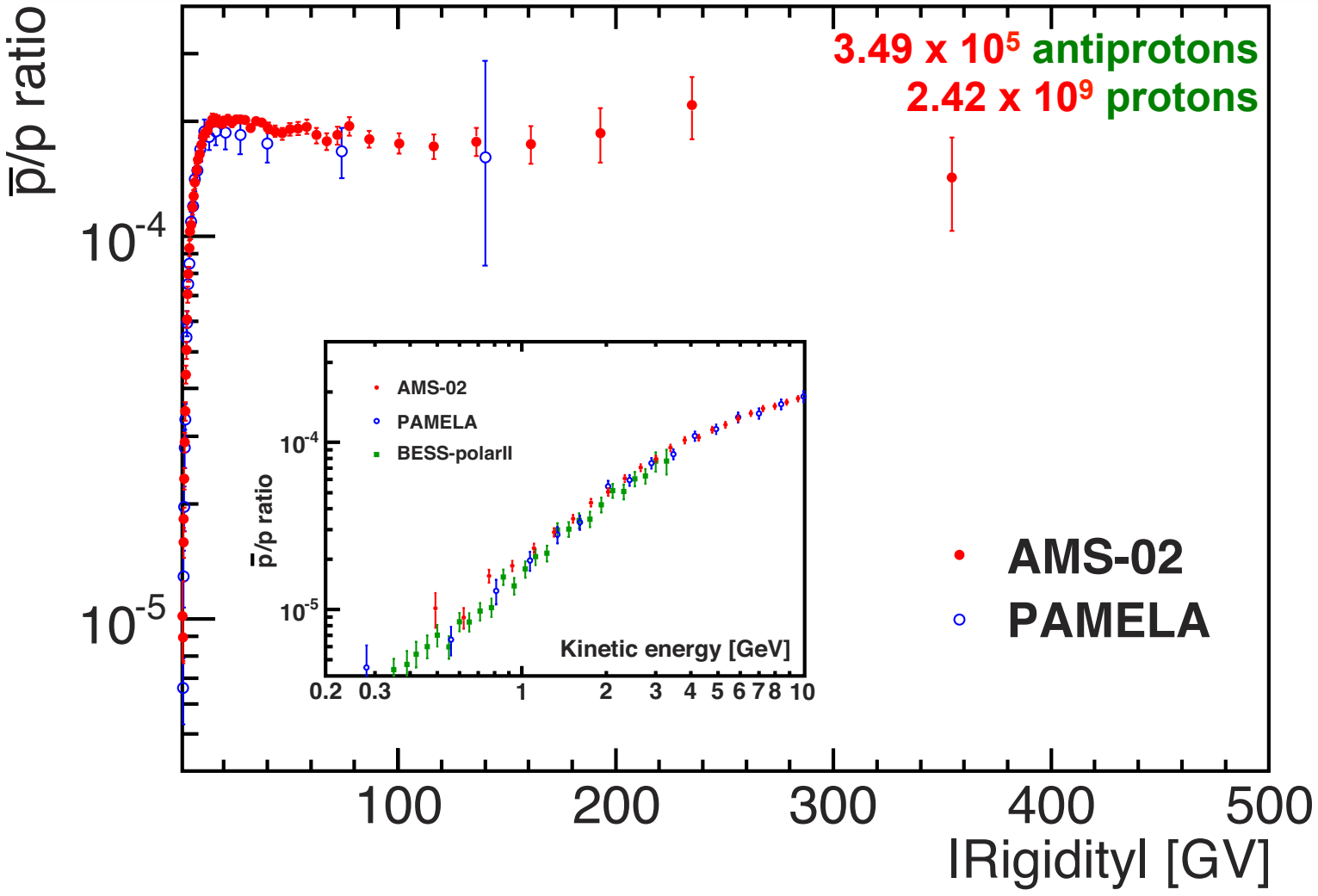
**No evidence of fine structures**

# “All electrons” flux capability (2024)




Antiprotons: $\chi + \chi \rightarrow \bar{p} + \ldots$
Antiproton /Proton Ratio $\times 10^{-4}$
1.5
1
0.5
0
100
200
300
400
500
Kinetic Energy (GeV)
$m_\chi$= 1 TeV
Collisions of Cosmic Rays
Donato et al., PRL 102, 071301 (2009)
Sun
$\chi$
$e^-$, p,$\gamma$
$e^+$, $\bar{p}$, $\gamma$
$\bar{\chi}$

# Anti-proton/proton ratio (PRL 117, 091103 - 2016)



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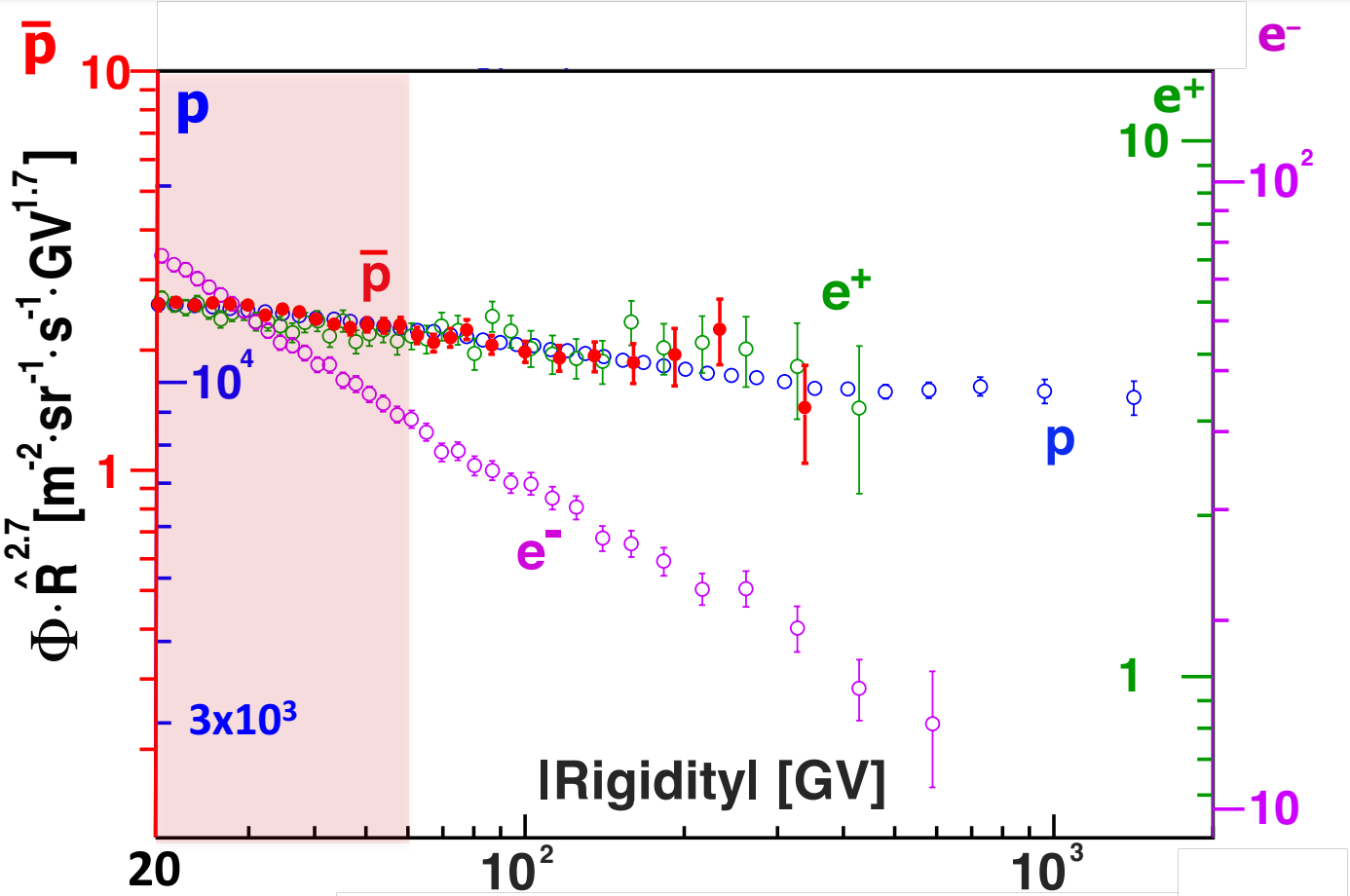
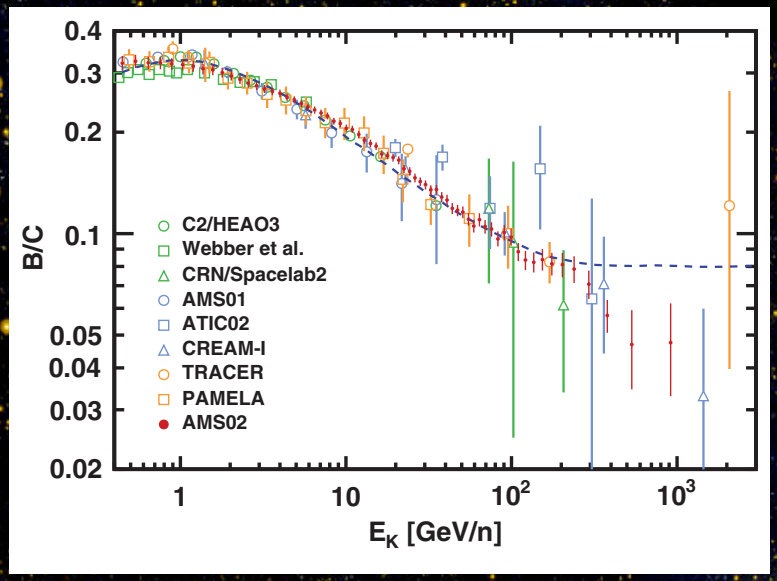



**The study of the flux variation with energy seems to indicate that protons, antiprotons and positrons, but not electrons, have the same spectral index. By chance or something more profound?**

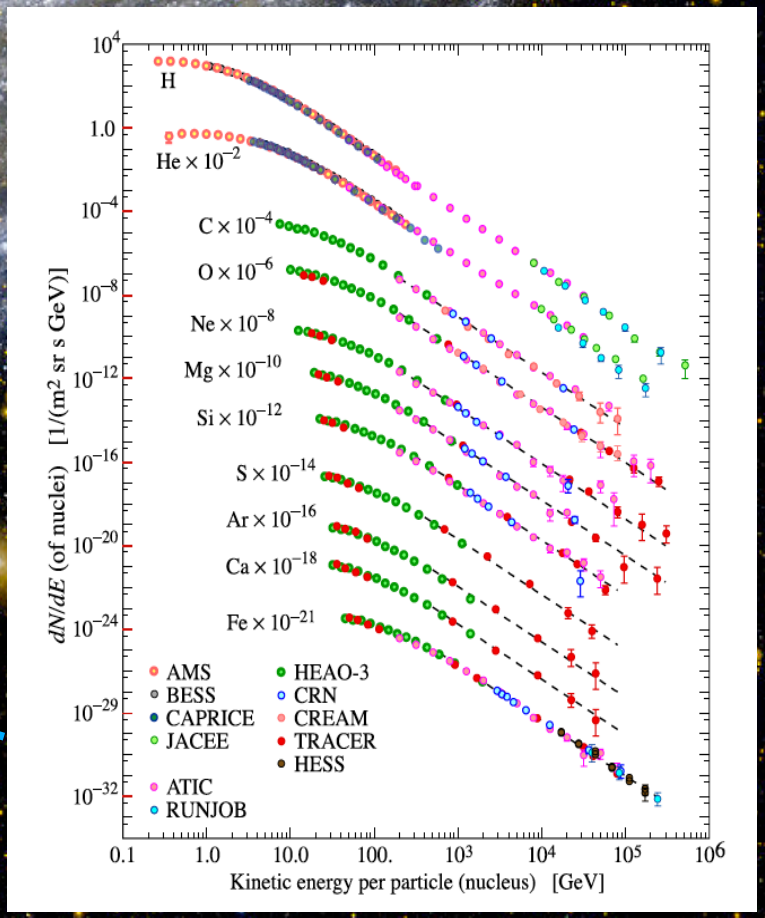



p, He,C..,e⁻

Sun

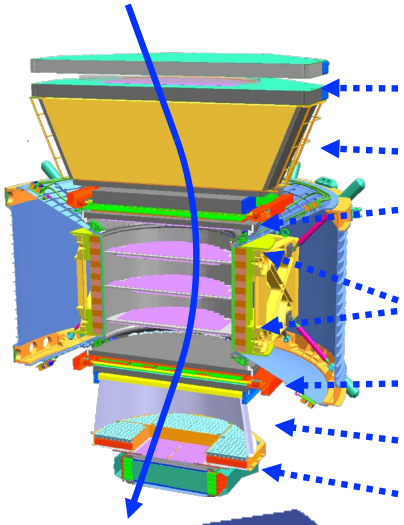
$\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$

$p+p \rightarrow p\bar{+}p\ldots$



# Nuclear identification

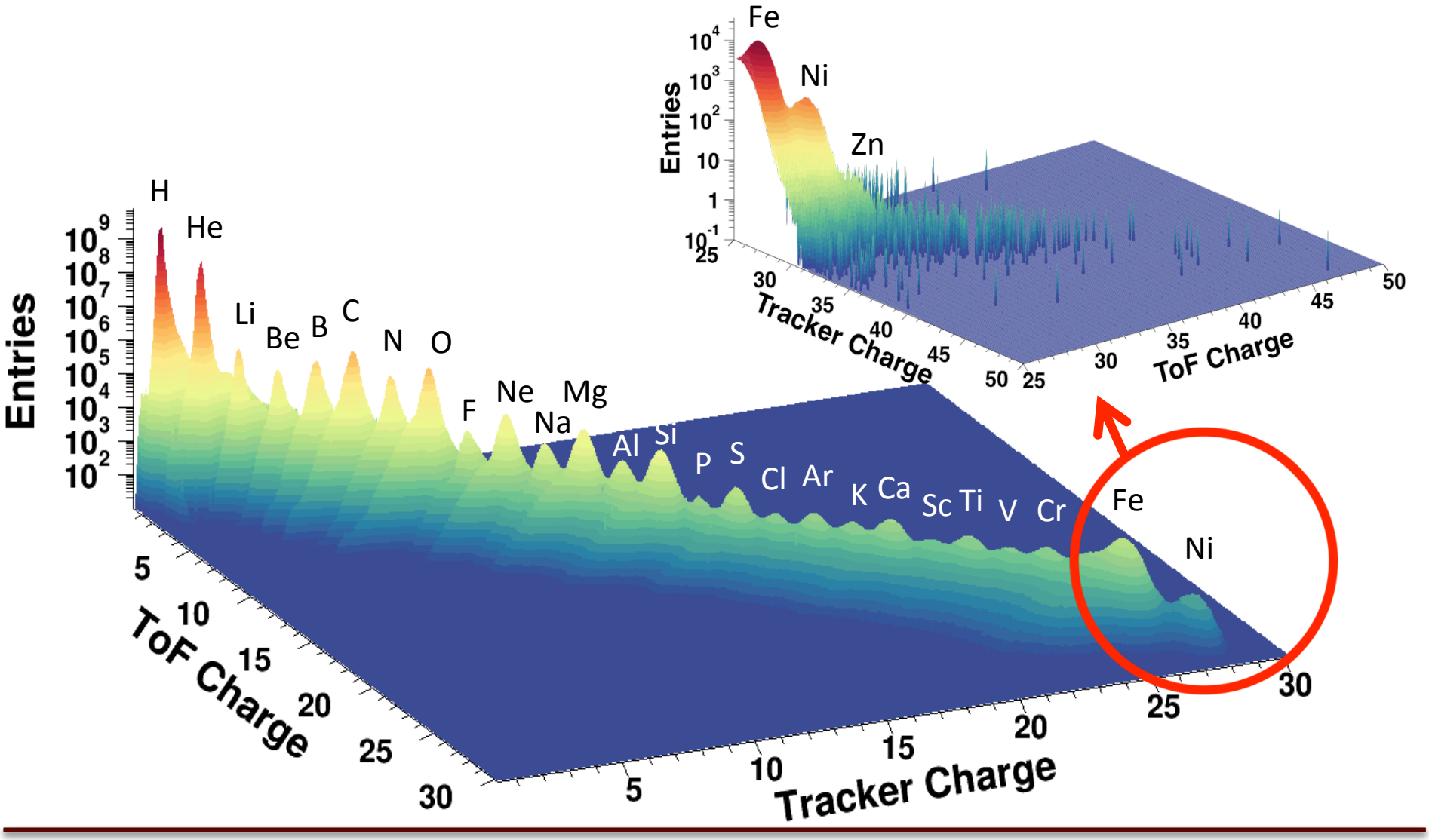
Seven instruments which independently identify different elements



**Charge Resolution Z=6**

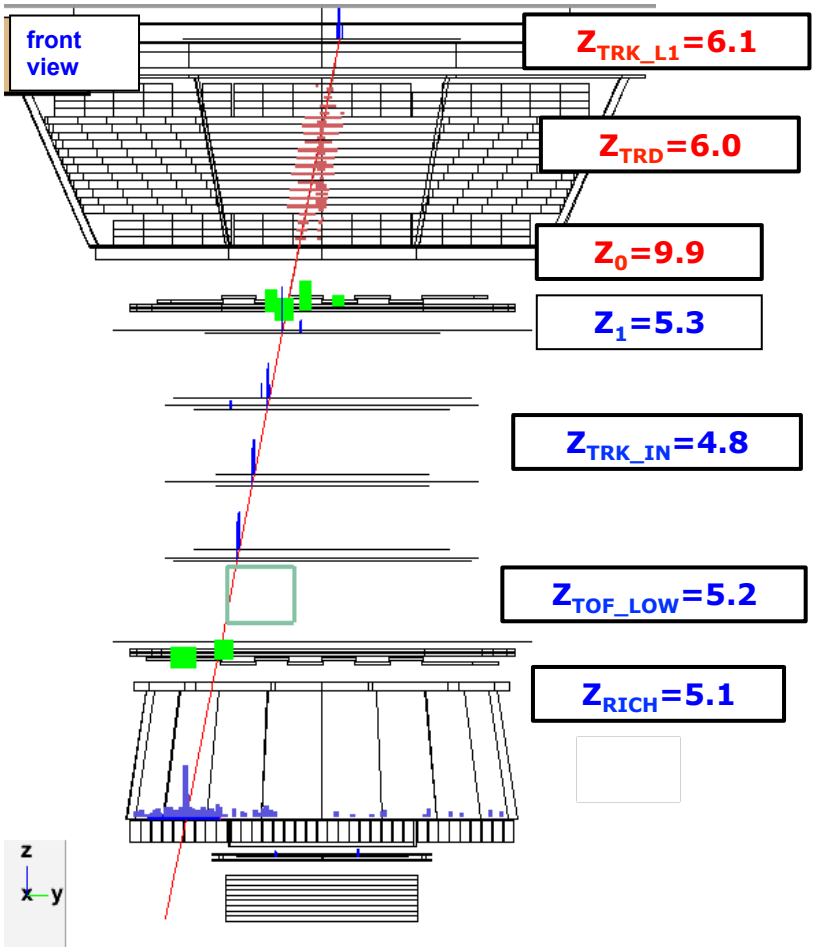
| | |
|---|---|
| Tracker Plane 1 | 0.30 |
| TRD | 0.33 |
| Upper TOF | 0.16 |
| Tracker Plane 2-8 | 0.12 |
| Lower TOF | 0.16 |
| RICH | 0.32 |
| Tracker Plane 9 | 0.30 |

# … even beyond Iron!

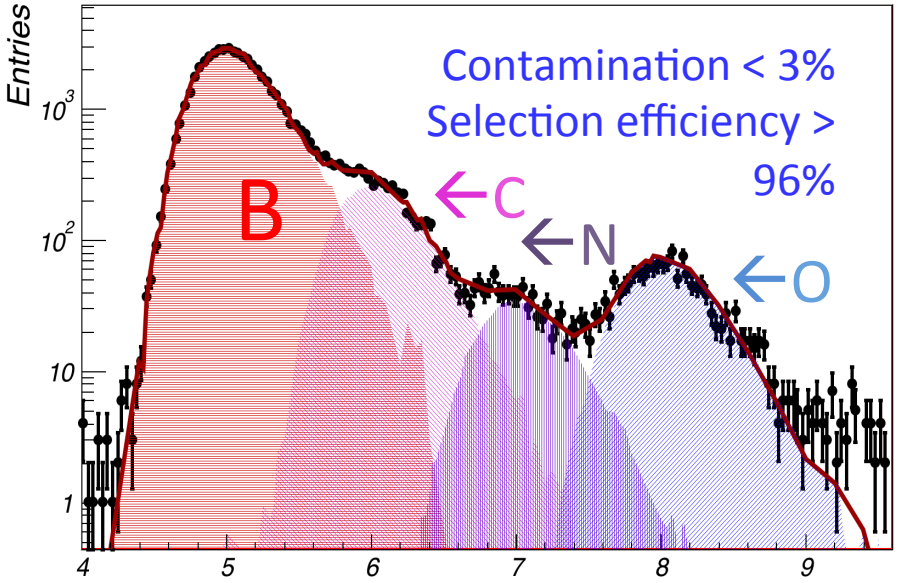


# Control of fragmentation inside the detector

**Carbon Fragmentation to Boron R = 10.6 GV**

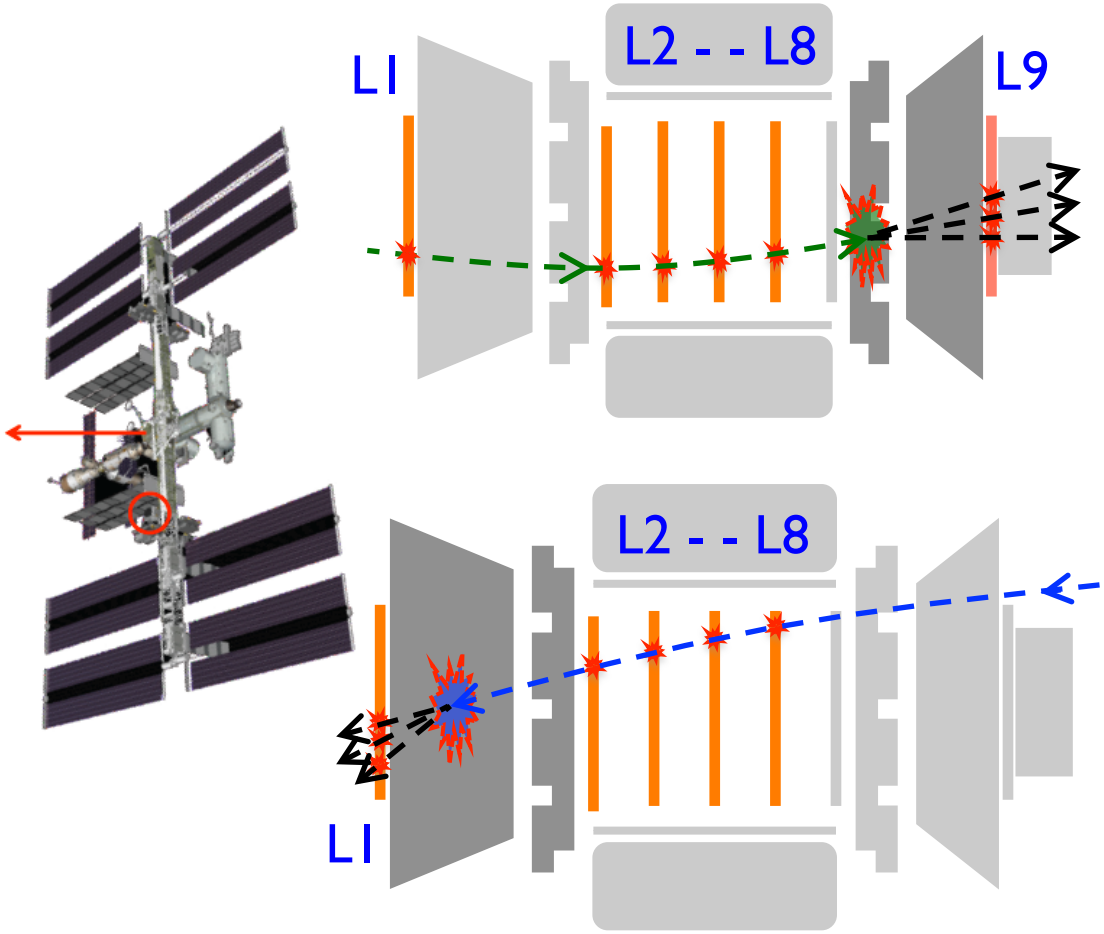



**For all the nuclear species, AMS-02 can measure, directly from data, the fraction of the 'flux' coming from the fragmentation of heavier species**



# Full control of the effects from detector material

Measurement of nuclear cross sections / accurate check of the materials when AMS is flying in horizontal attitude




First, we use the seven inner tracker layers, L2-L8, to define beams of nuclei: He, Li, Be, B, …

Second, we use left-to-right particles to measure the nuclear interactions in the lower part of the detector.

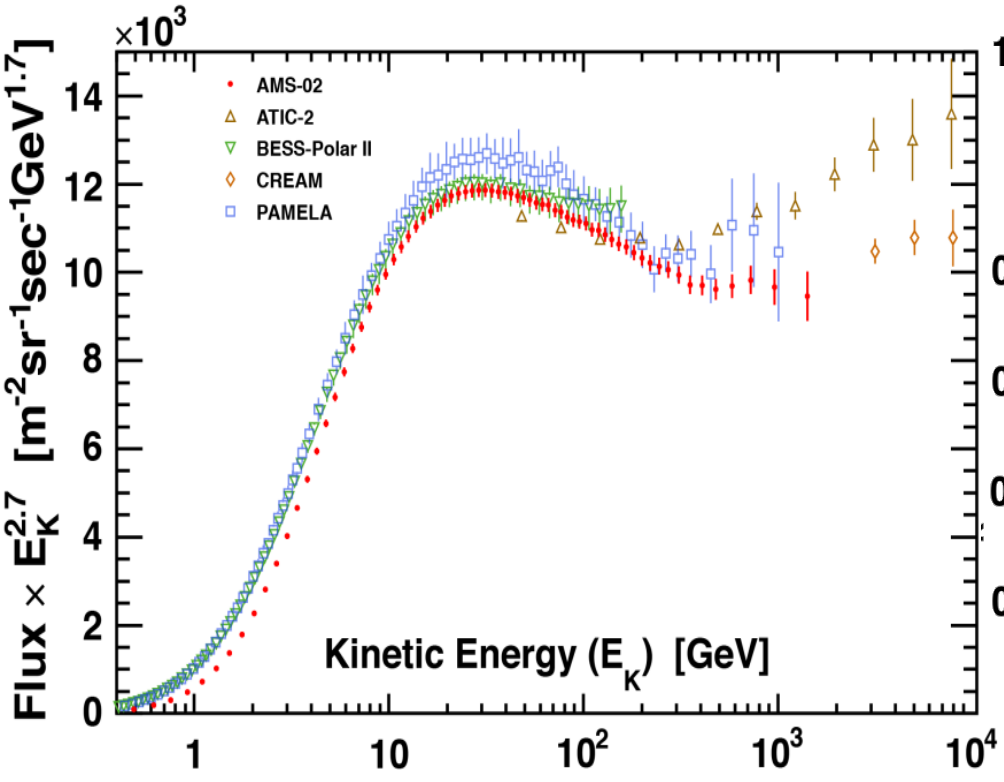
Third, we use right-to-left particles to measure the nuclear interactions in the upper part of detector.

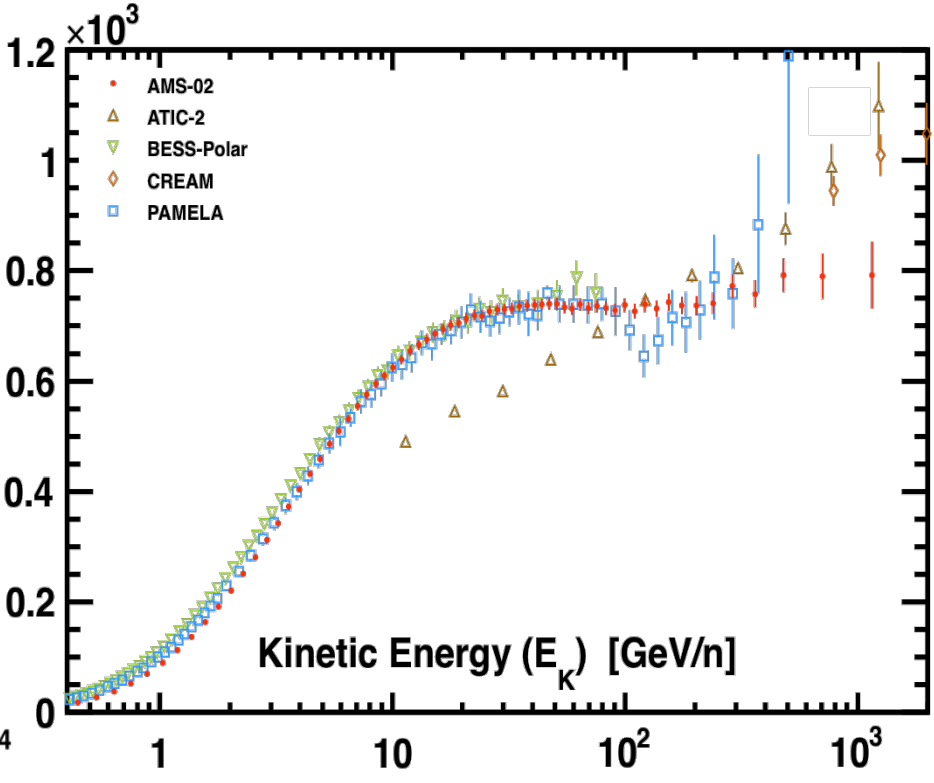
# Proton and Helium fluxes (PRL 114, 171103 & 115, 211101 – 2015)

Both proton and helium fluxes show an hardening

H flux measurement:
300 million events

He flux measurement:
50 million events

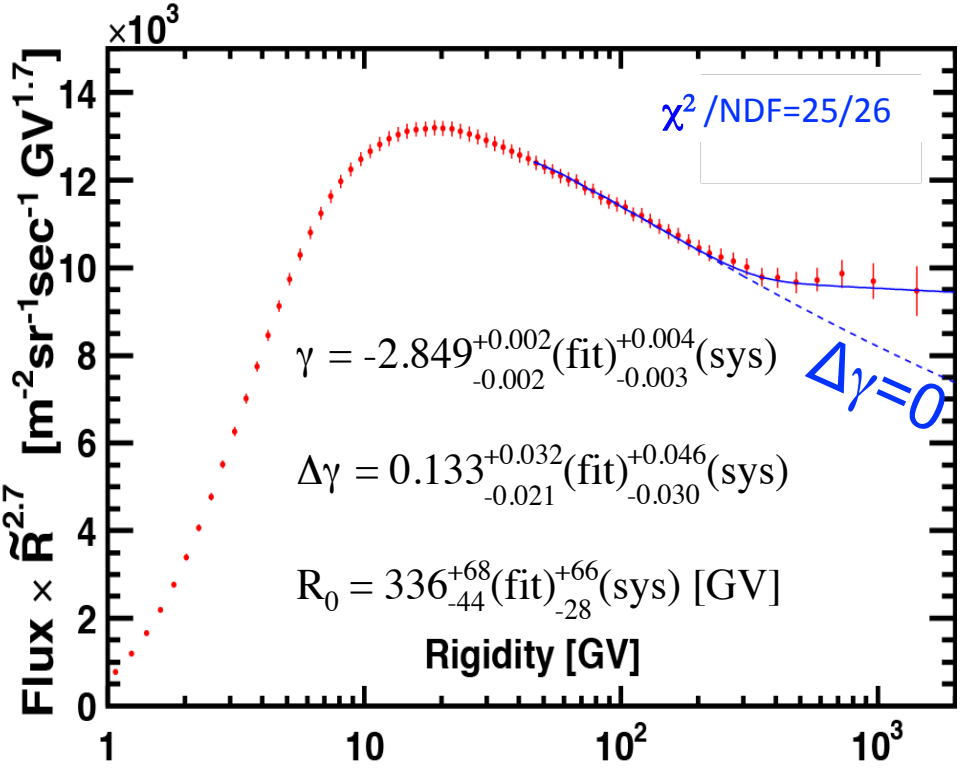


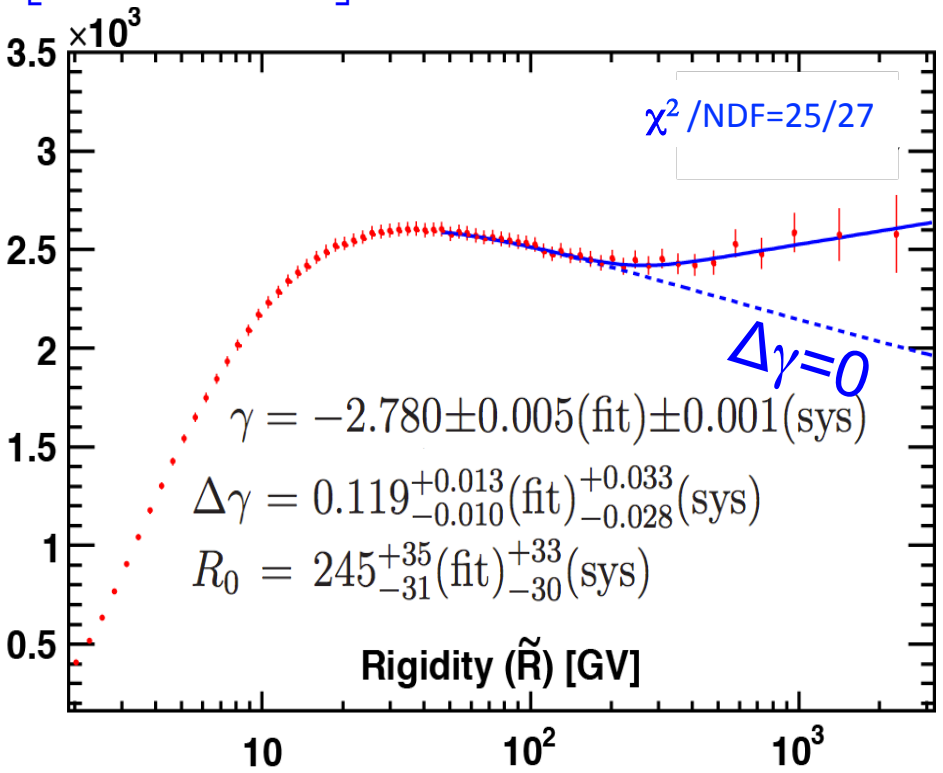



# Proton and Helium fluxes (PRL 114, 171103 & 115, 211101 – 2015)

Two power-laws $R^{\gamma}$,$R^{\gamma+1}$ with a transition rigidity $R_0$ and a *smoothness* parameters: this well describe the experimental data:

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



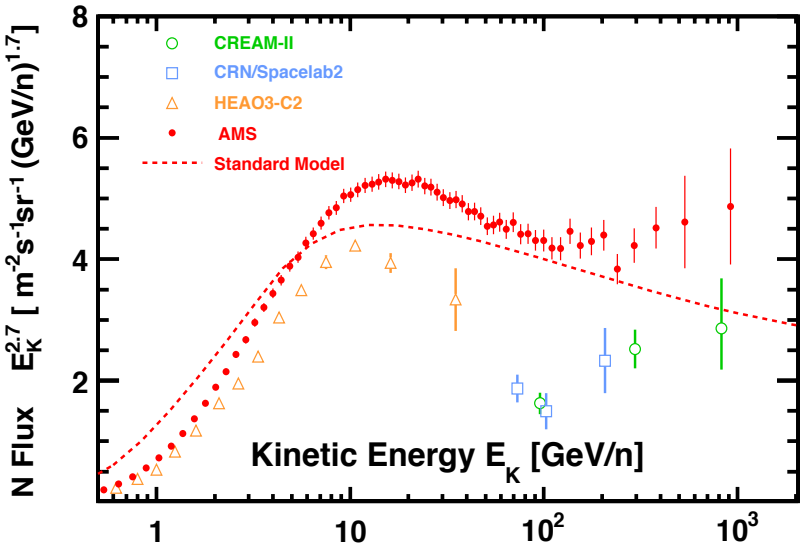



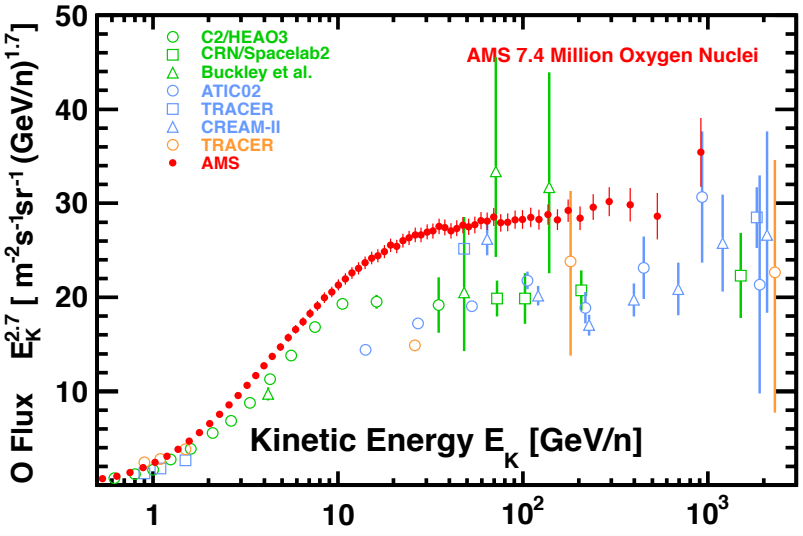
# Primaries with higher charge…

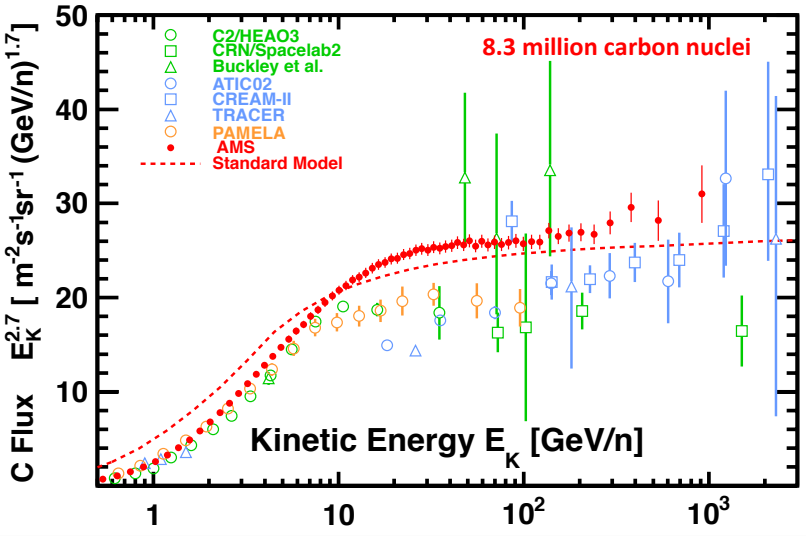
AMS-02 measures Carbon, Nitrogen, Oxygen fluxes in an extended energy range and unprecedented prevision.

Ongoing analyses based on ~ 6 years data (2011-2017):

- Standard model: GALPROP with best fit parameters *Trotta et al, 2011*

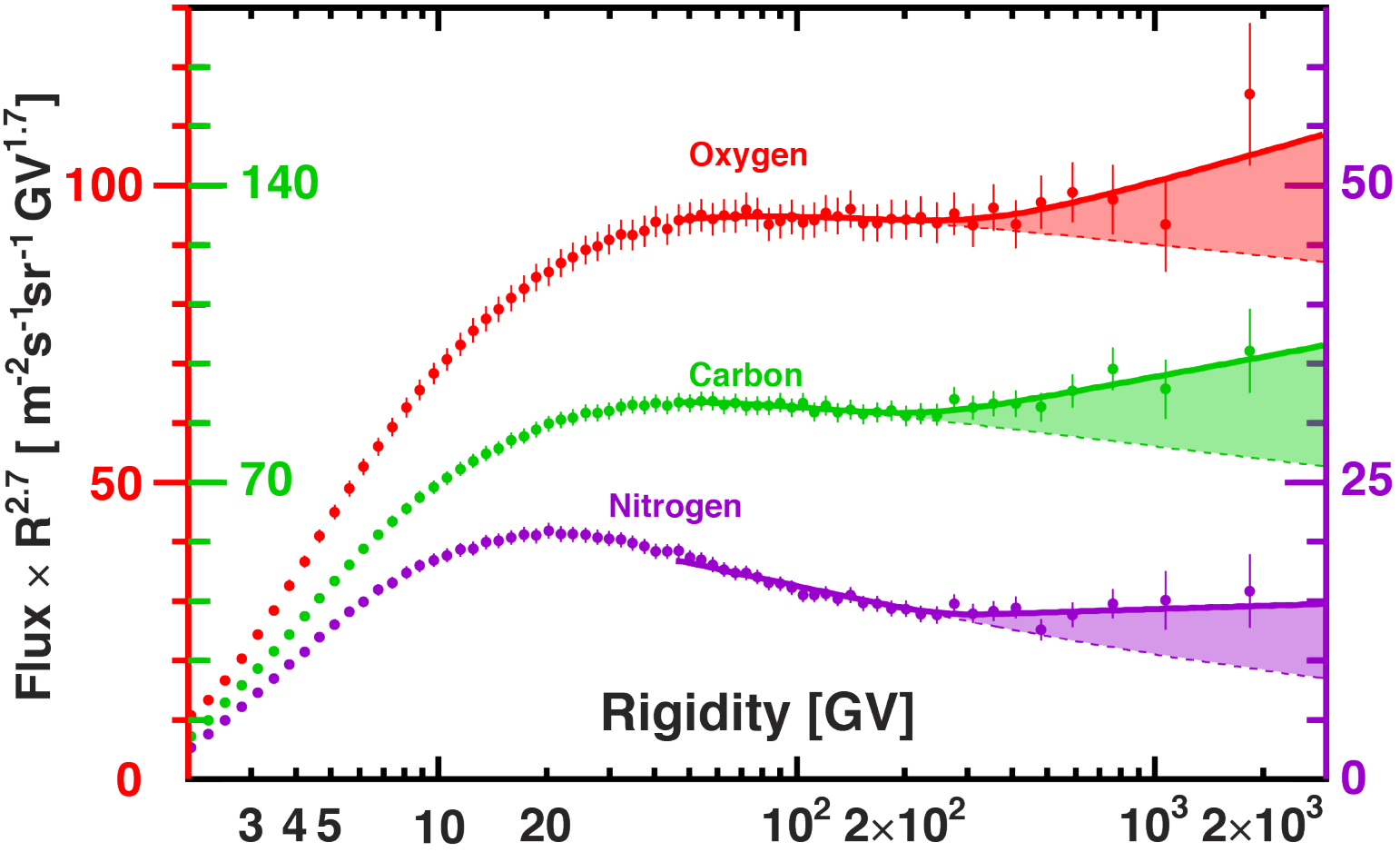


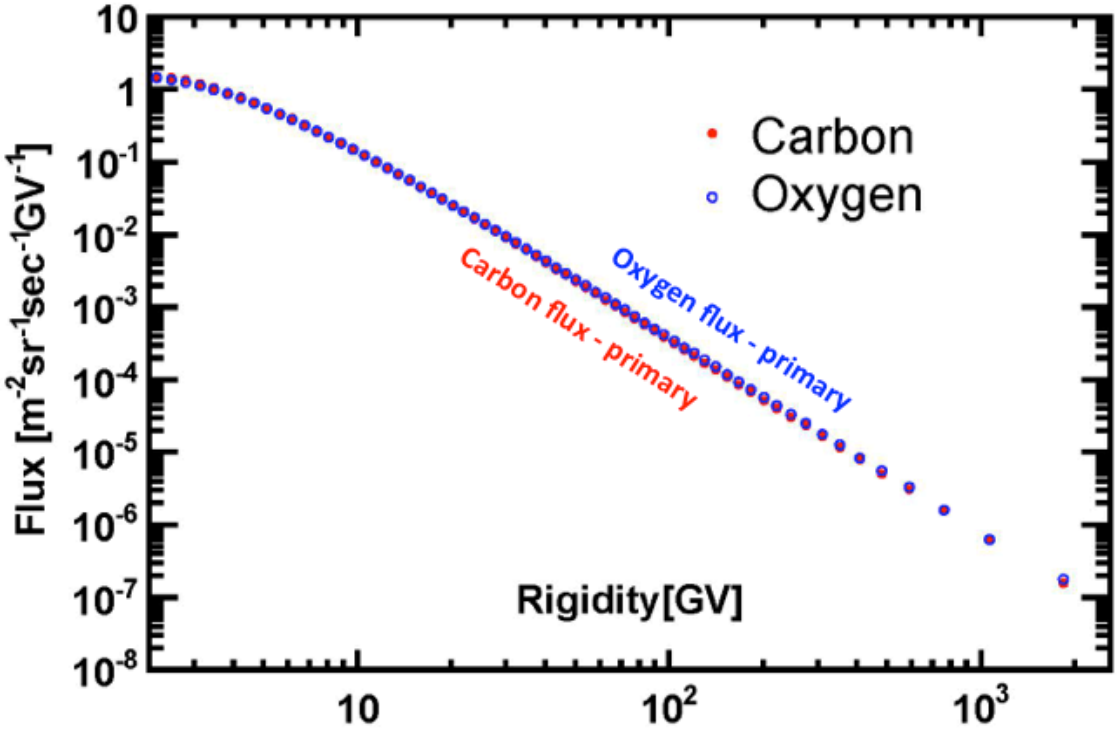
# Primaries with higher charge…

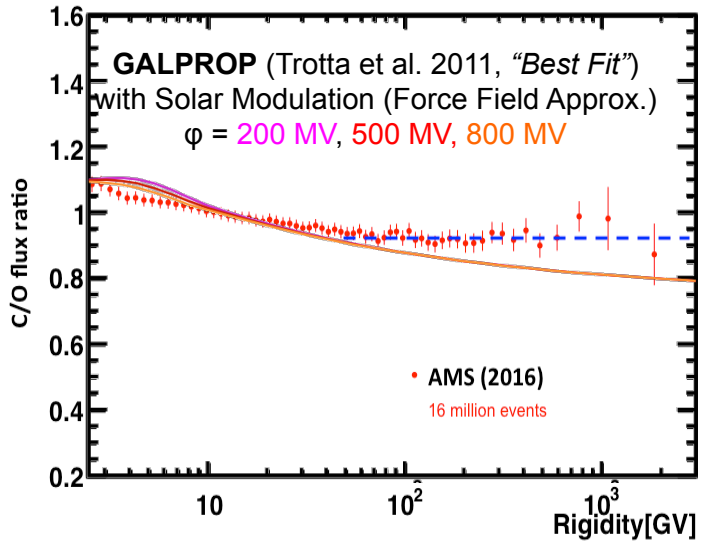
Also for Carbon, Nitrogen and Oxygen the single-power law behaviour is excluded by AMS-02 data: a change of spectral index is observed at ≈ the same rigidity.

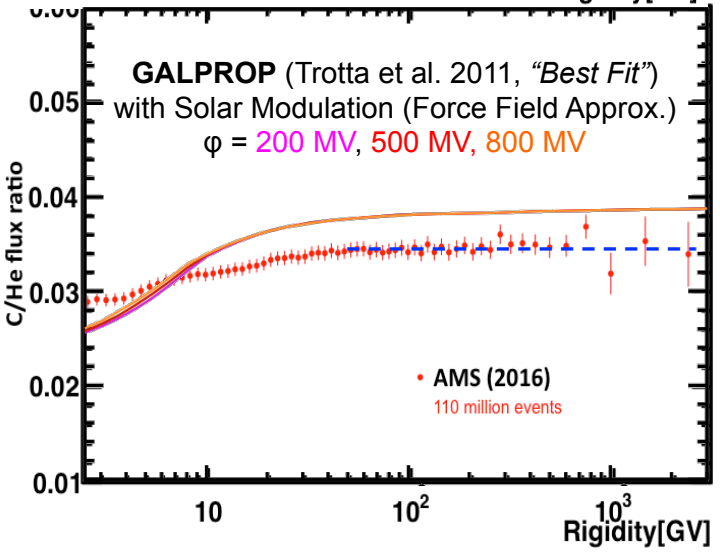


# Primaries with higher charge…

flux ratios C/O and C/He are flat at high energies

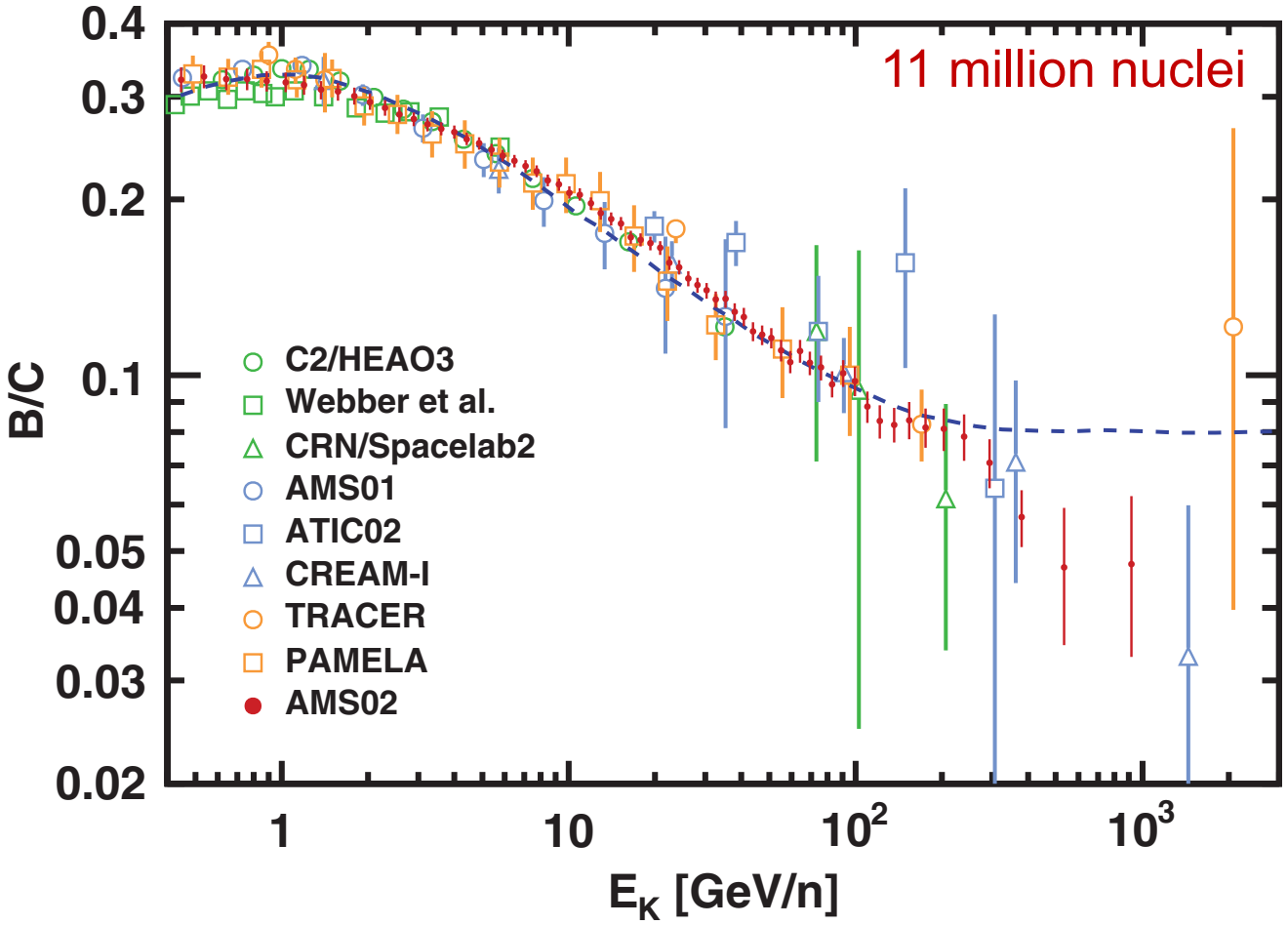


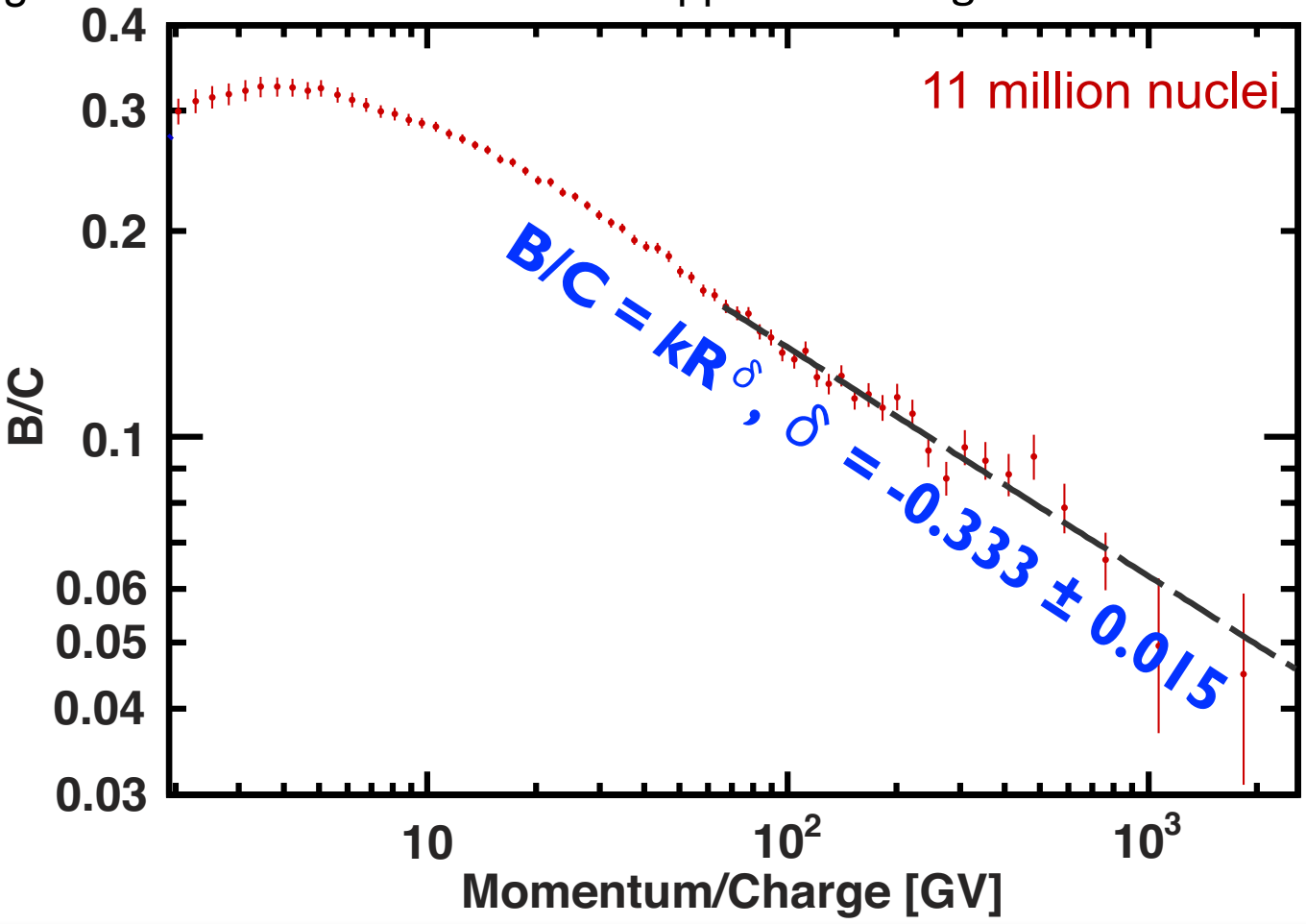
# Secondary CRs: Boron to Carbon flux ratio (PRL 117, 231101 – 2016)

The flux ratio between primaries (C) and secondaries (B) provides information on propagation and the ISM



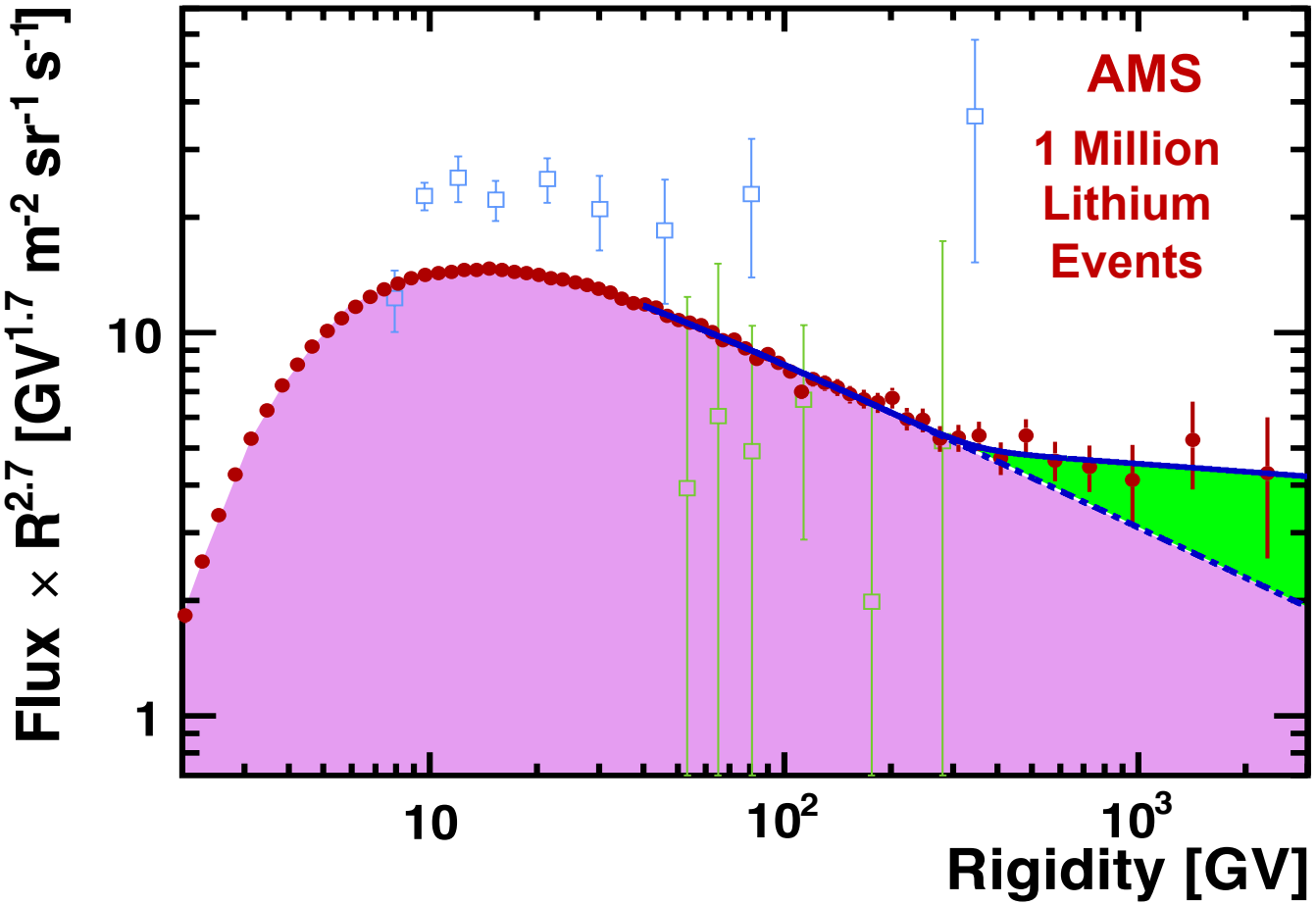
# Secondary CRs: Boron to Carbon flux ratio (PRL 117, 231101 – 2016)

The flux ratio between primaries (C) and secondaries (B) provides information on propagation and the ISM: AMS data supports Kolmogorov turbulence model



# Other secondaries: Lithium

Lithium (secondary) exhibits a double power law behaviour as for the primaries

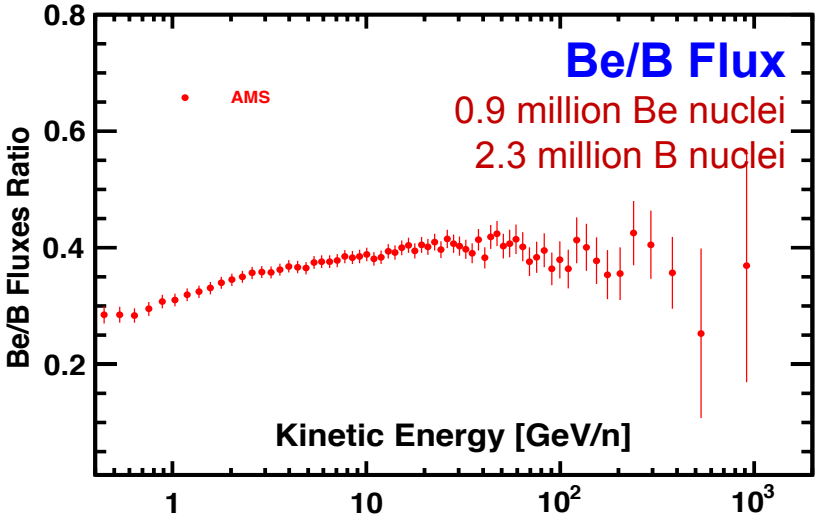


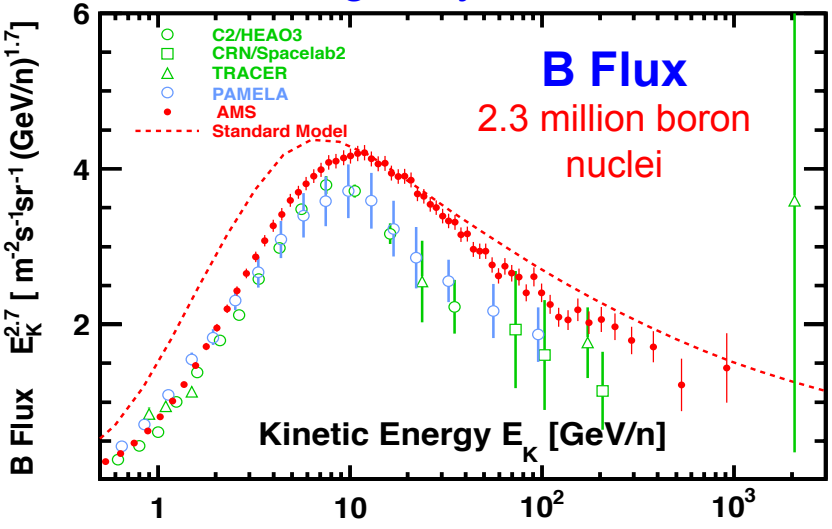
# Still on secondaries…

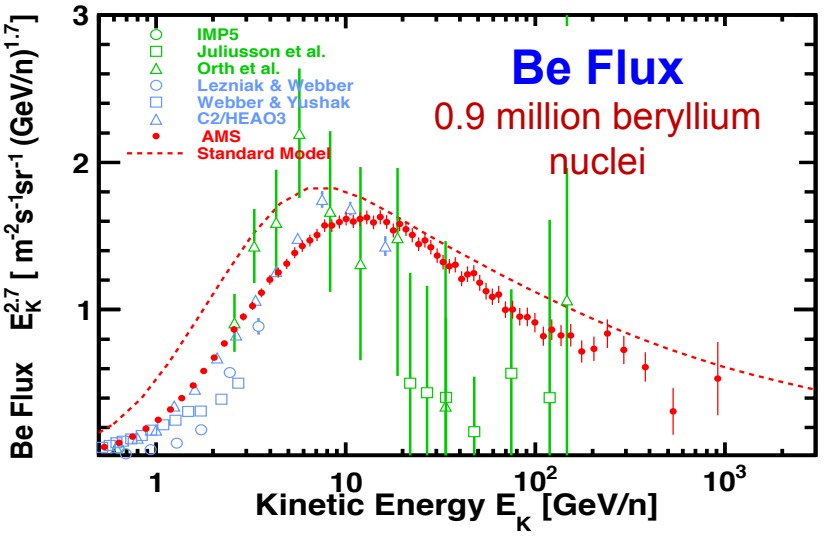
$^{10}$Be is a natural *clock* to measure the residence time of CR in the galaxy: $^{10}$Be → $^{10}$B + $e^-$ + $\nu_e$ with half-life of 1.5 x $10^6$ years

Relativistic time dilation at high energies delays the $^{10}$Be decay and makes the the Be/B ratio to increase.

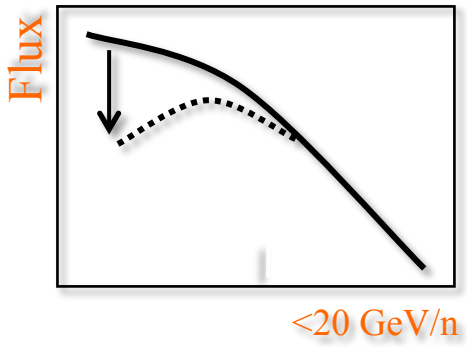
A fit to the Be/B ratio can be used to extract residence time in the galaxy

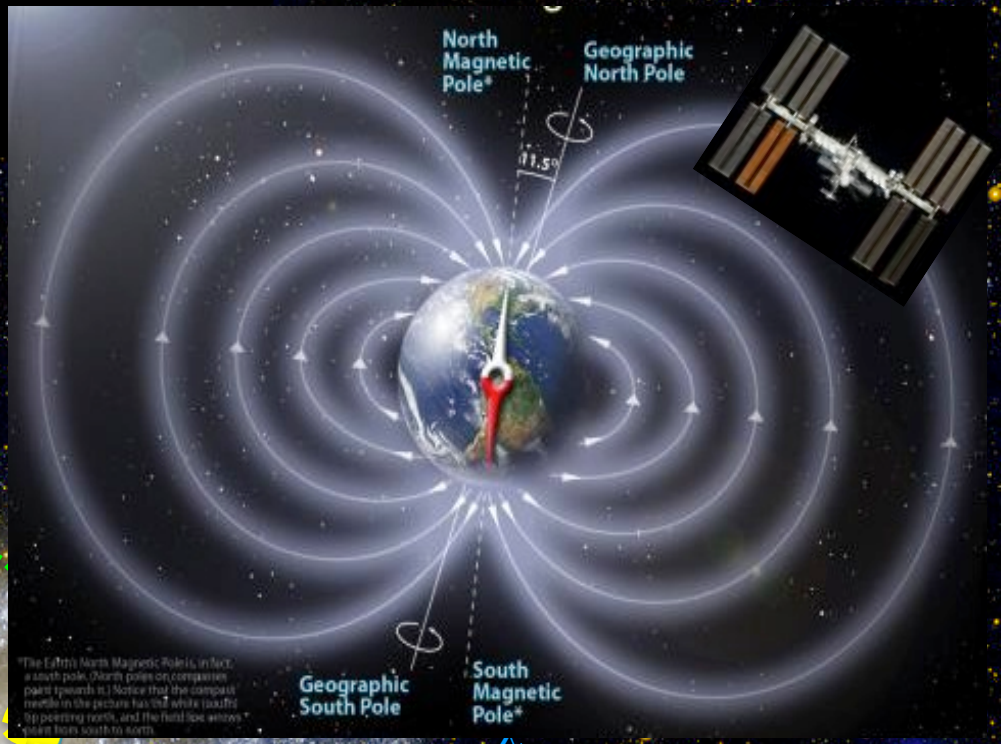


## Solar modulation




p, He,C..,$e^-$

Sun

$e^{+,}$ $\bar{p}$, $\gamma$

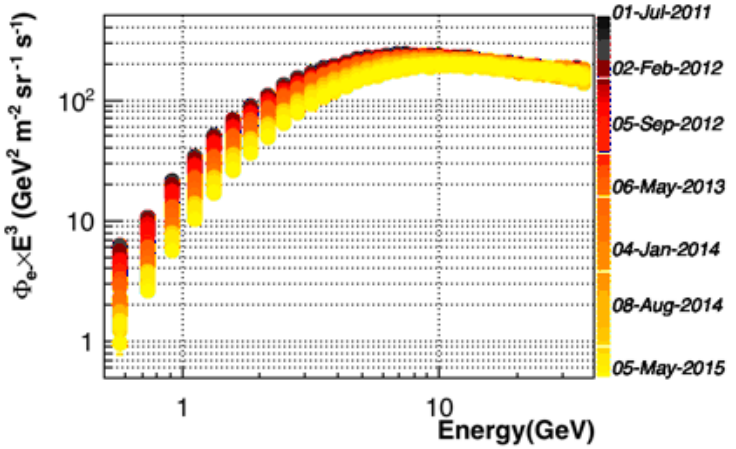
$e^-$, p,$\gamma$

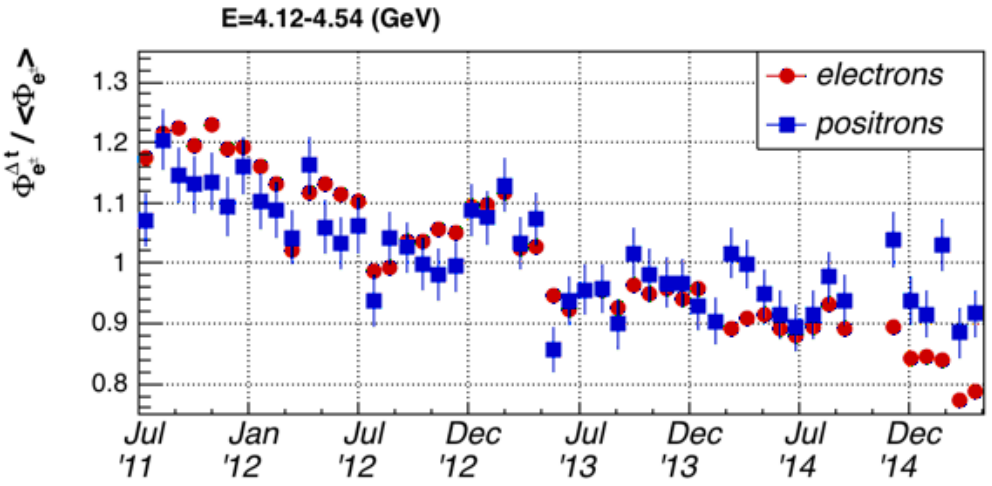
$\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$

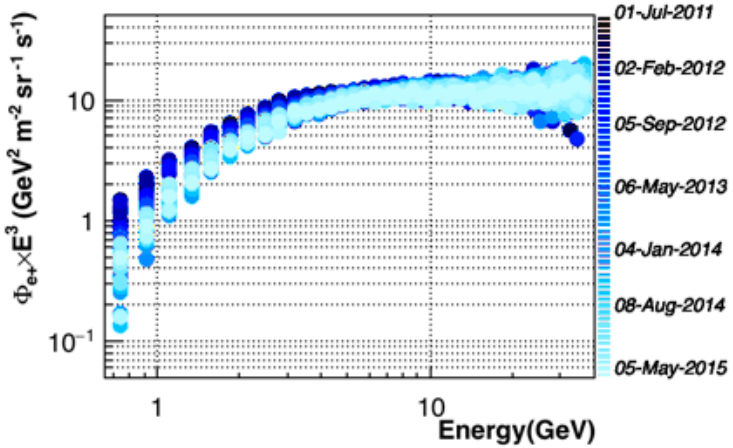
$p+p \rightarrow p+\bar{p}$...

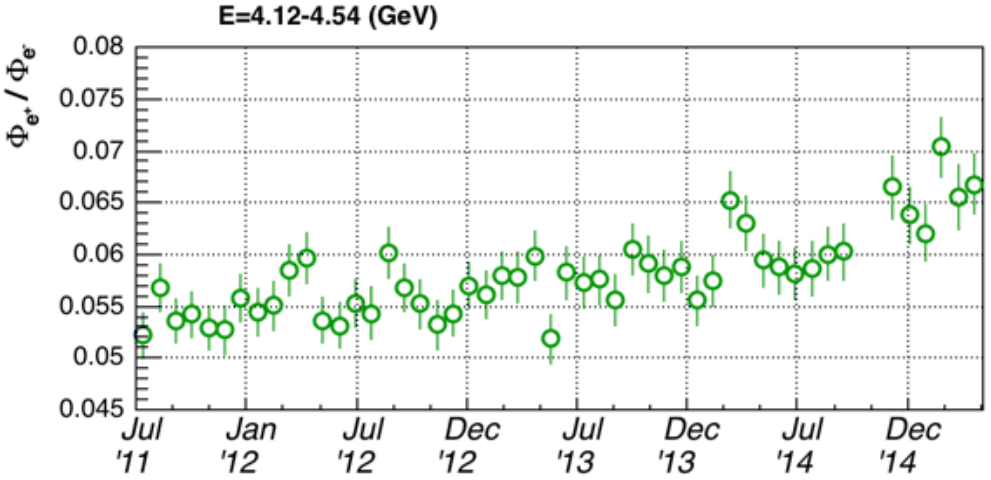
$\bar{\chi}$

# Fluxes as function of time, $e^+/e^-$



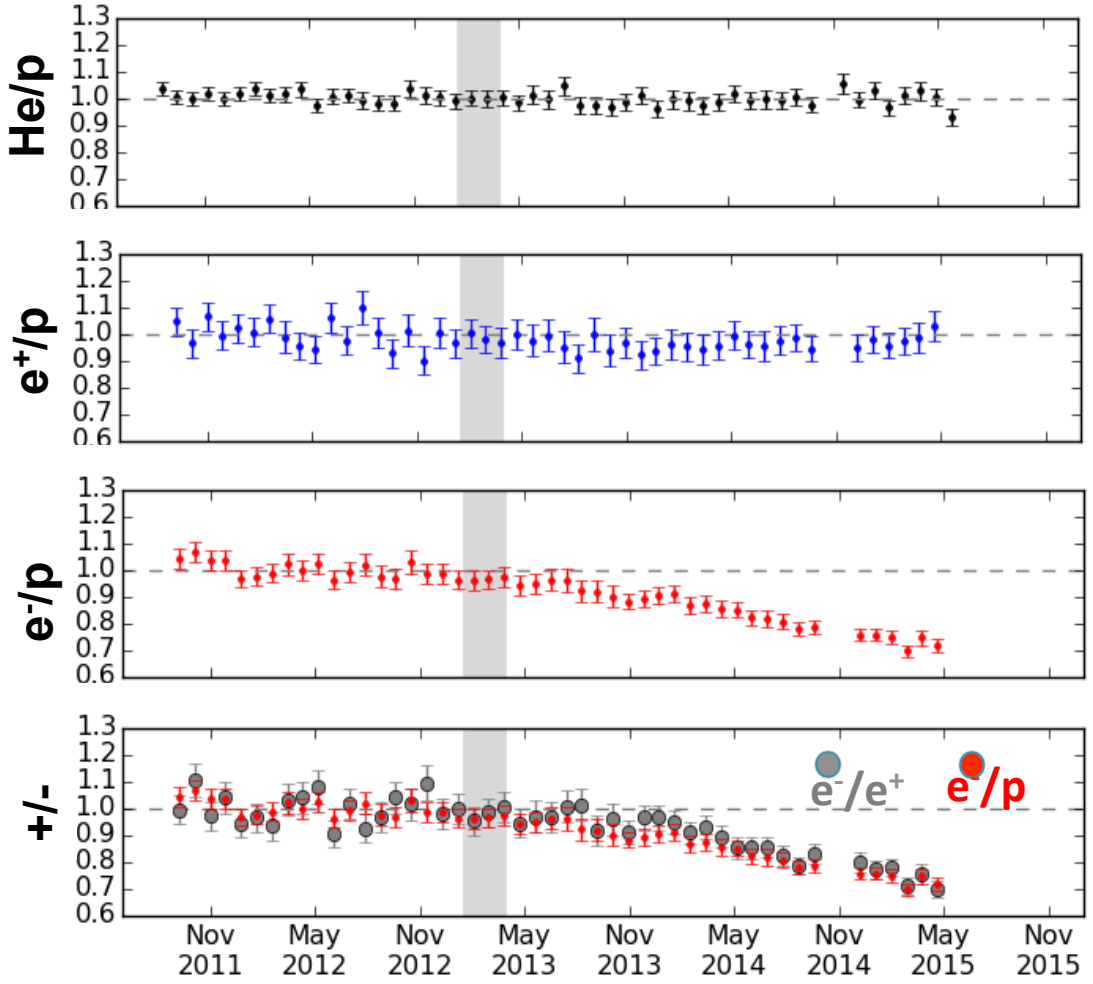



# Fluxes as function of time, charge sign effects

## 2 GeV

**Different species, same sign of charge**

**Different species, different sign of the charge**



# Conclusions

- AMS is the Cosmic Rays observatory and it will stay also in next decade
- The collaboration is providing the absolute and relative abundances of the various species
- The accuracy of the experimental measurements is currently better than the uncertainty in the phenomenological models and is allowing very detailed studies

If nothing happens, AMS will take data up to 2024…