@ Neutel 2017

AMS-02 latest results & Indirect DM searches

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@ Neutel 2017

Outline

① AMS in a nutshell

② Data analysis

③ Results

④ Conclusions

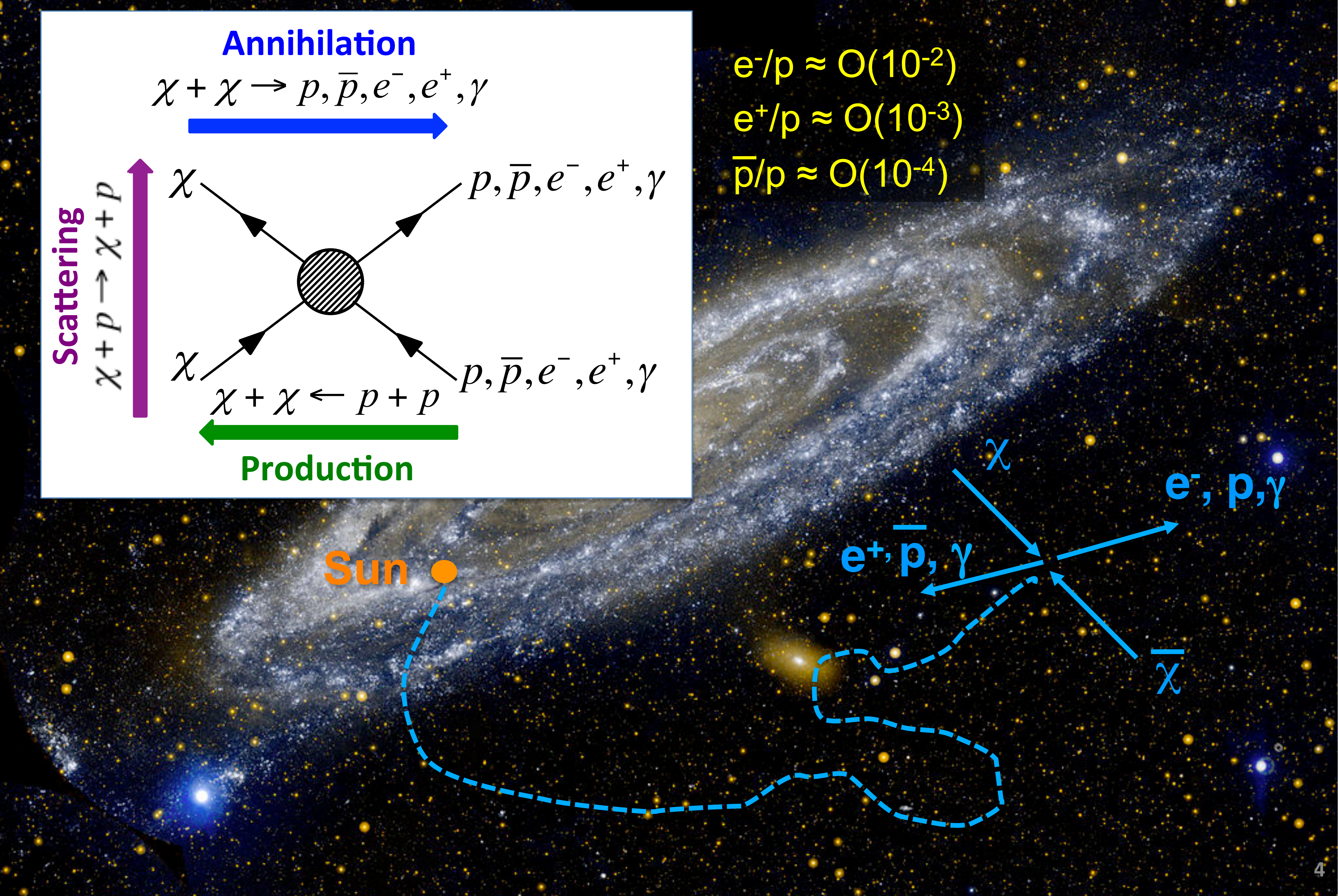
What is AMS ?

AMS is a precision, multipurpose magnetic spectrometer operating on the ISS since 2011 to perform accurate measurements of charged cosmic rays in the GeV-TeV energy range:

Its main objectives:

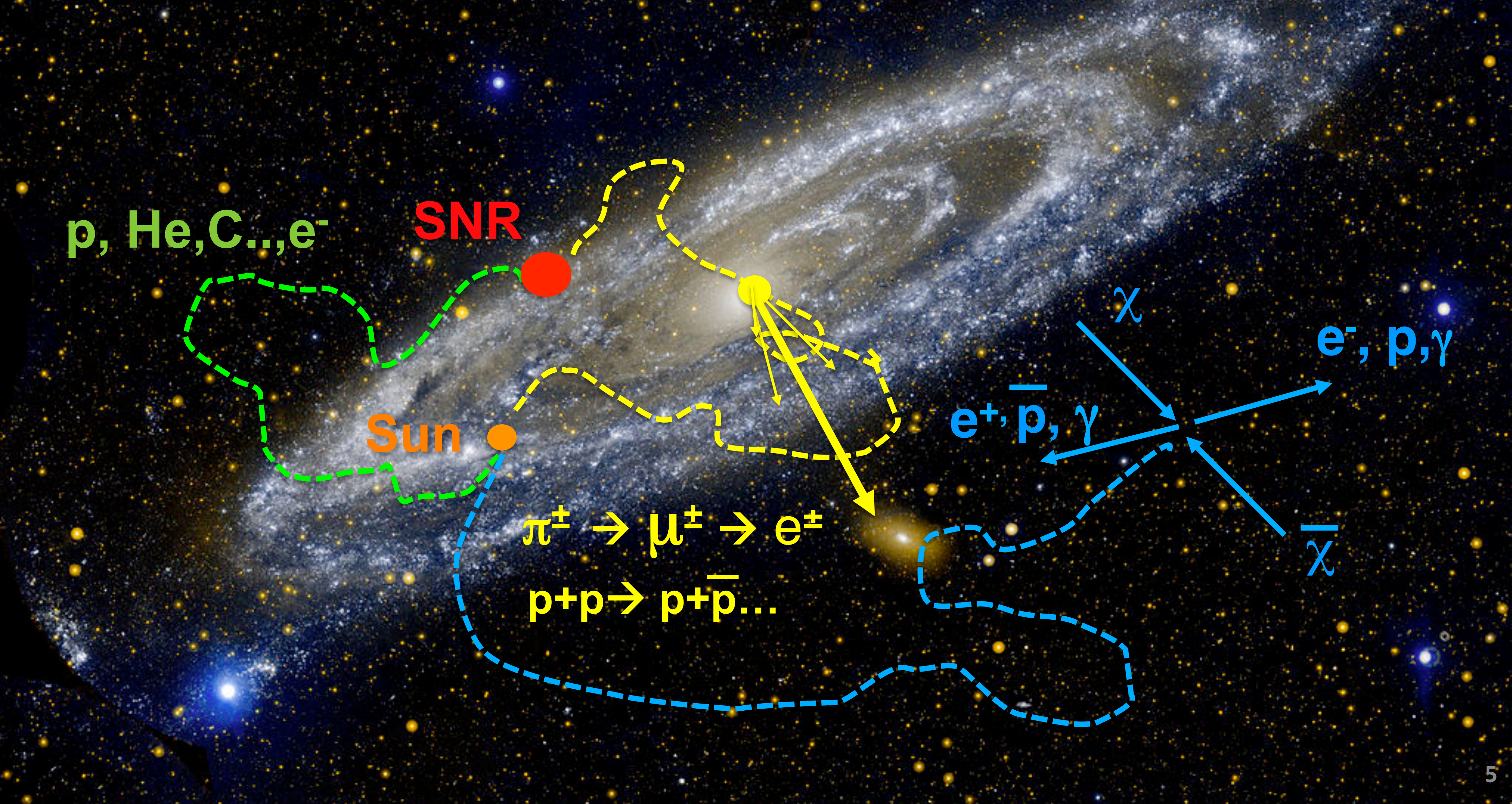
- Search for new physics: anti-matter, dark matter, strange matter
- Shed light on the origin of cosmic rays and their propagation into the galaxy

The quest for Dark Matter



The Astrophysical Background:

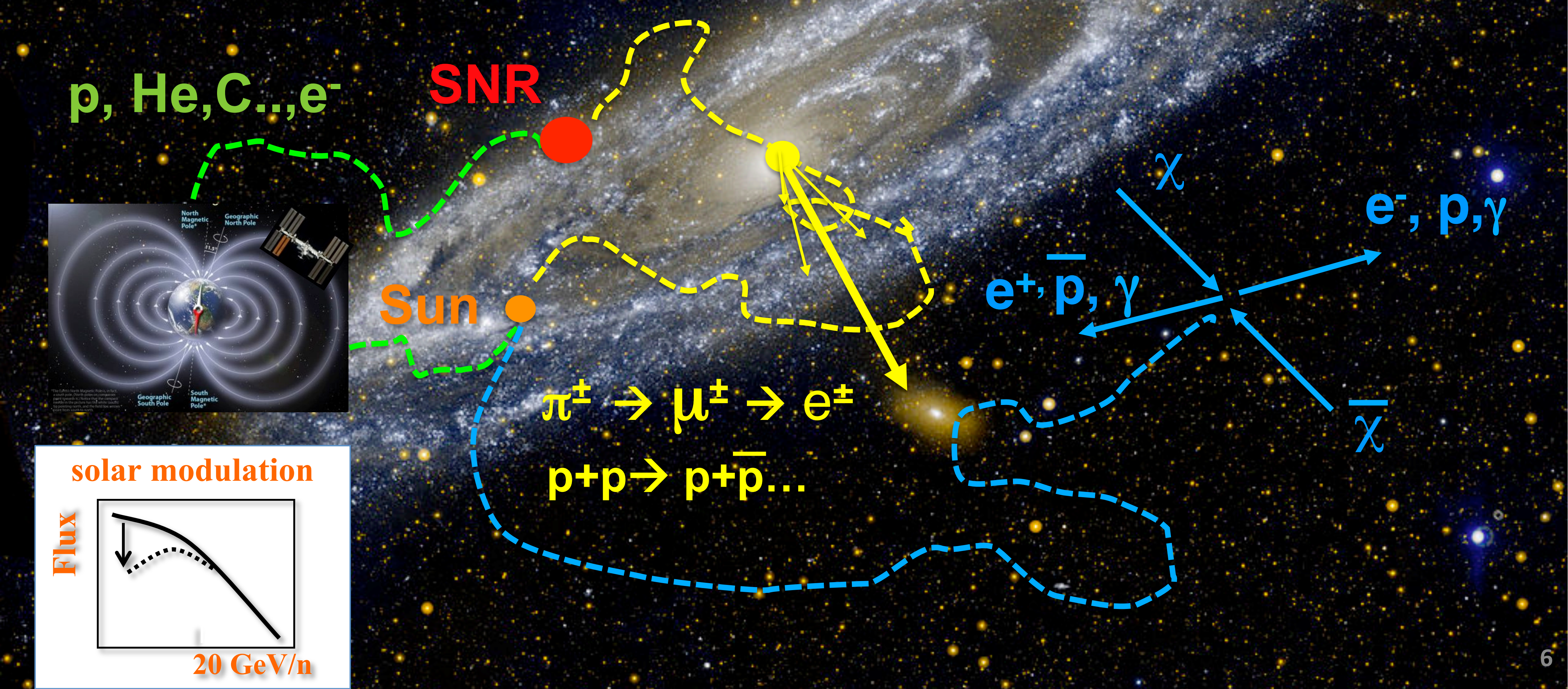
Origin, propagation and production of CRs and their secondaries in the galaxy



The Astrophysical Background:

Origin, propagation and production of CRs and their secondaries in the galaxy

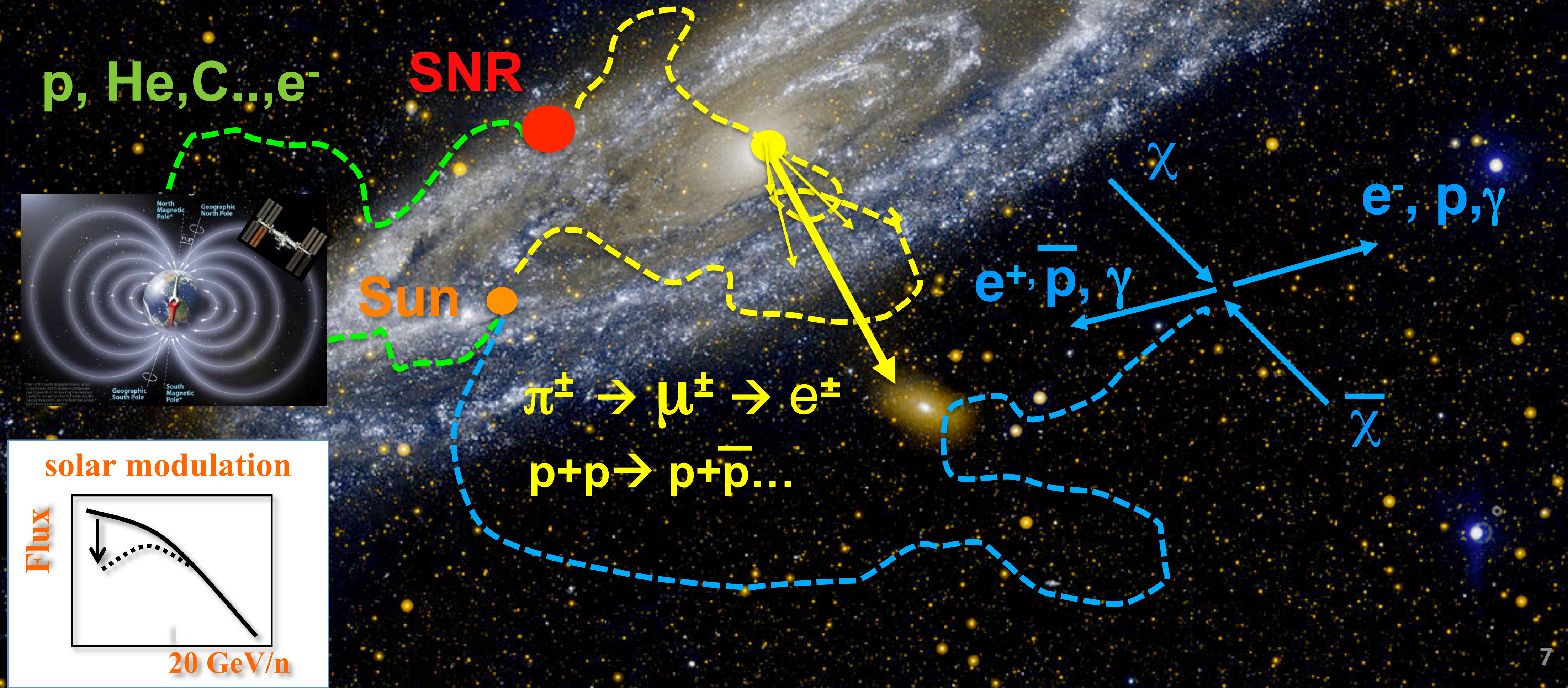
+ heliospheric / magnetospheric effects…



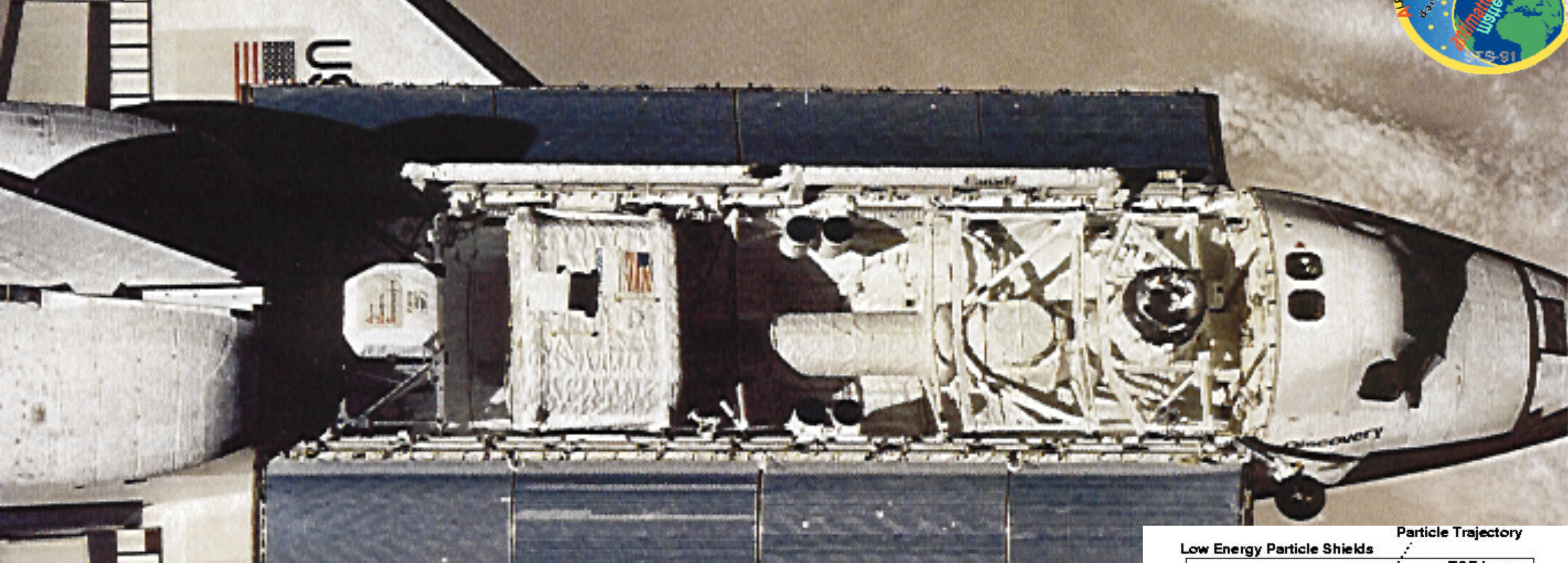
The experimental challenge

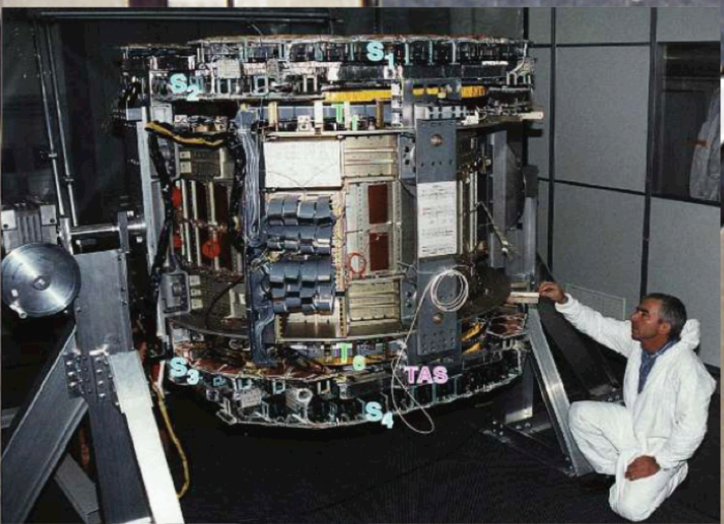
Hunt rare signals (anti-matter) and provide accurate flux measurements of the CR components to constraint astrophysical models

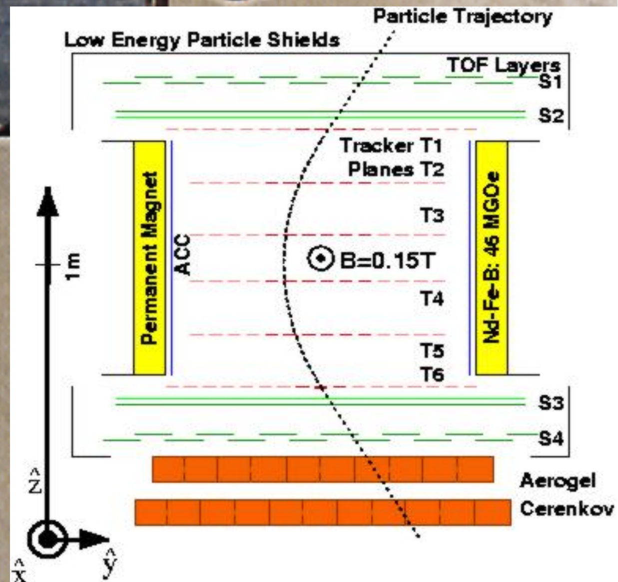
1) DESIGN : state of the art detectors providing redundant particle measurements
2) TEST: test and calibration on ground
3) OPERATION on ISS : continuous monitoring and calibration
4) DATA ANALYSIS: different independent analyses for internal cross check & reduced systematics.



Alpha Magnetic Spectrometer on STS-91
AMS-01 (1998)
First silicon tracker in space

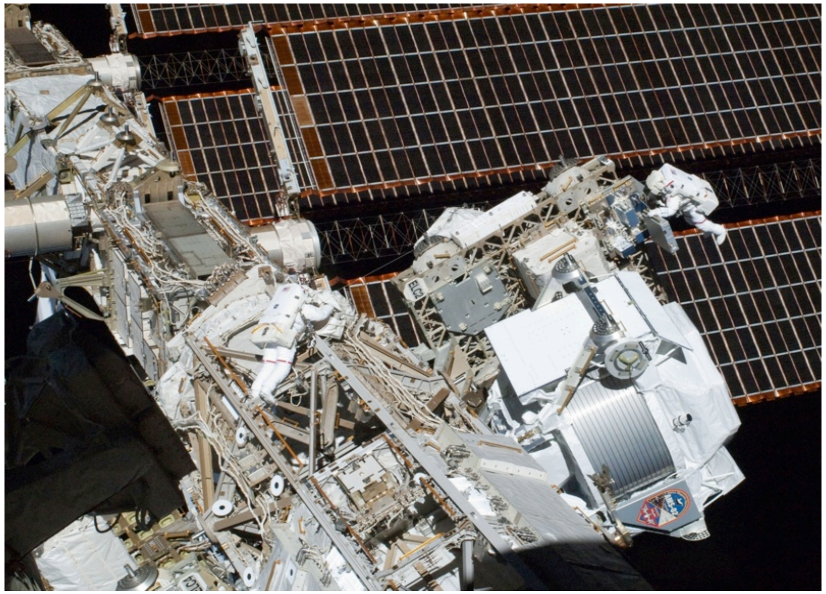






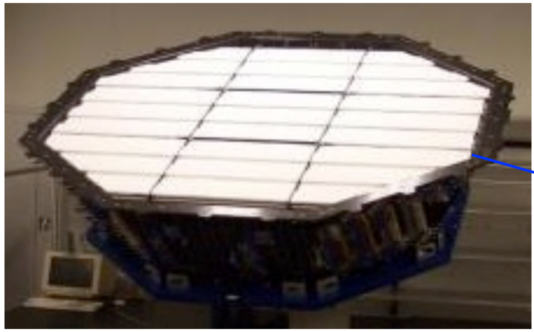
Alpha Magnetic Spectrometer on the ISS: AMS-02

→ Launched on May 16, 2011
→ Installed on ISS May 19, 2011
→ AMS-02 foreseen to operate for the entire ISS lifetime (2024)

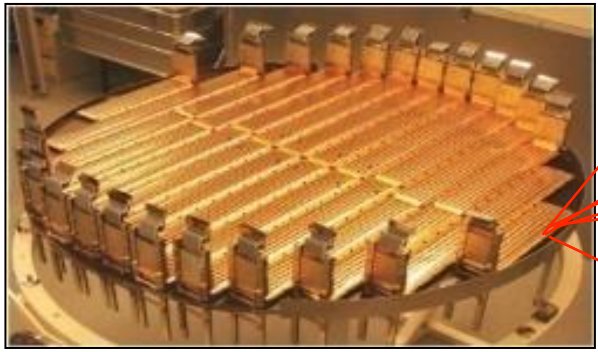


AMS-02: A TeV precision, multipurpose spectrometer

Transition Radiation Detector (TRD)
Identify e^+, e^-

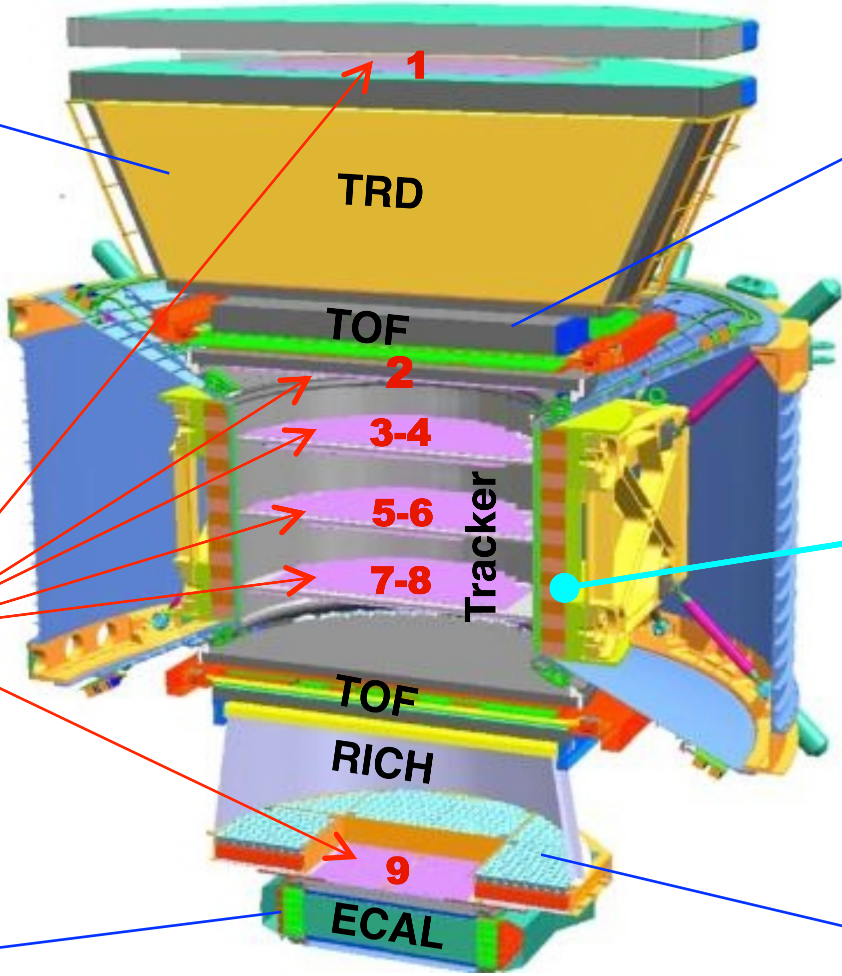


Silicon Tracker
Z, P



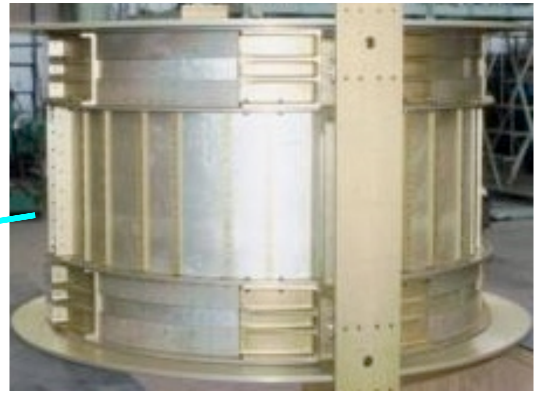
Electromagnetic Calorimeter (ECAL)
E of e^+, e^-, γ

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



Time of Flight (TOF)
Z, E

Magnet (0.15 T)
±Z

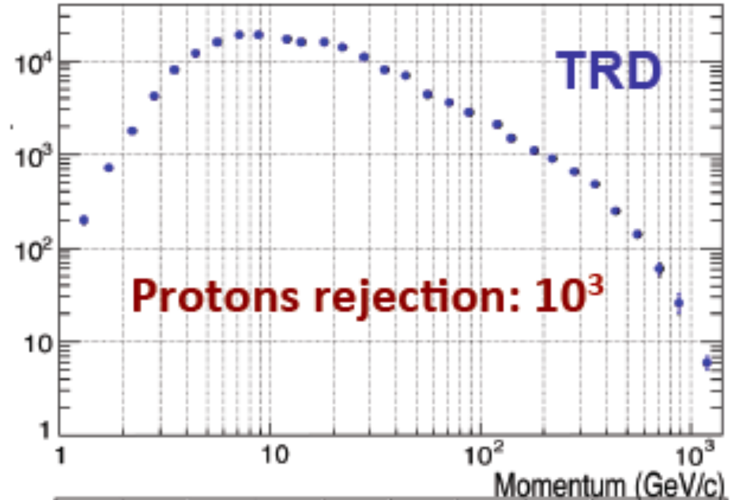


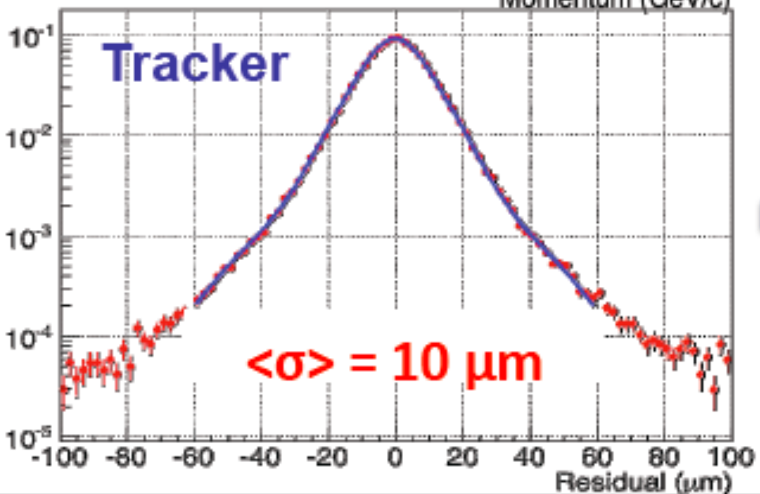
Ring Imaging Cherenkov (RICH)
Z, E

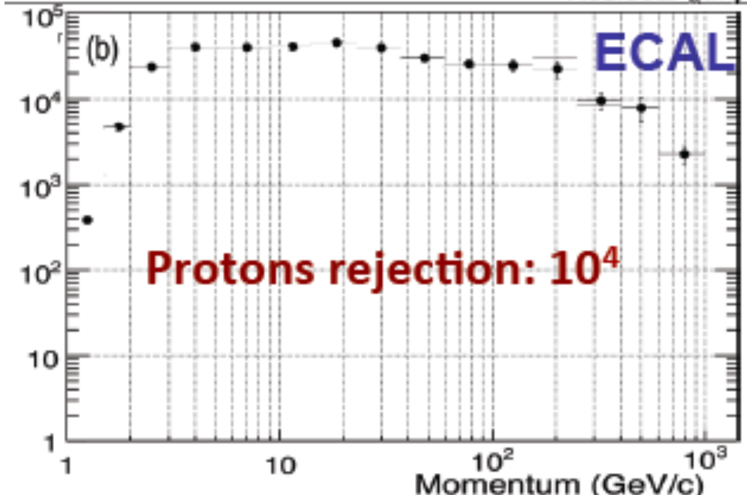
Z, E, R, β

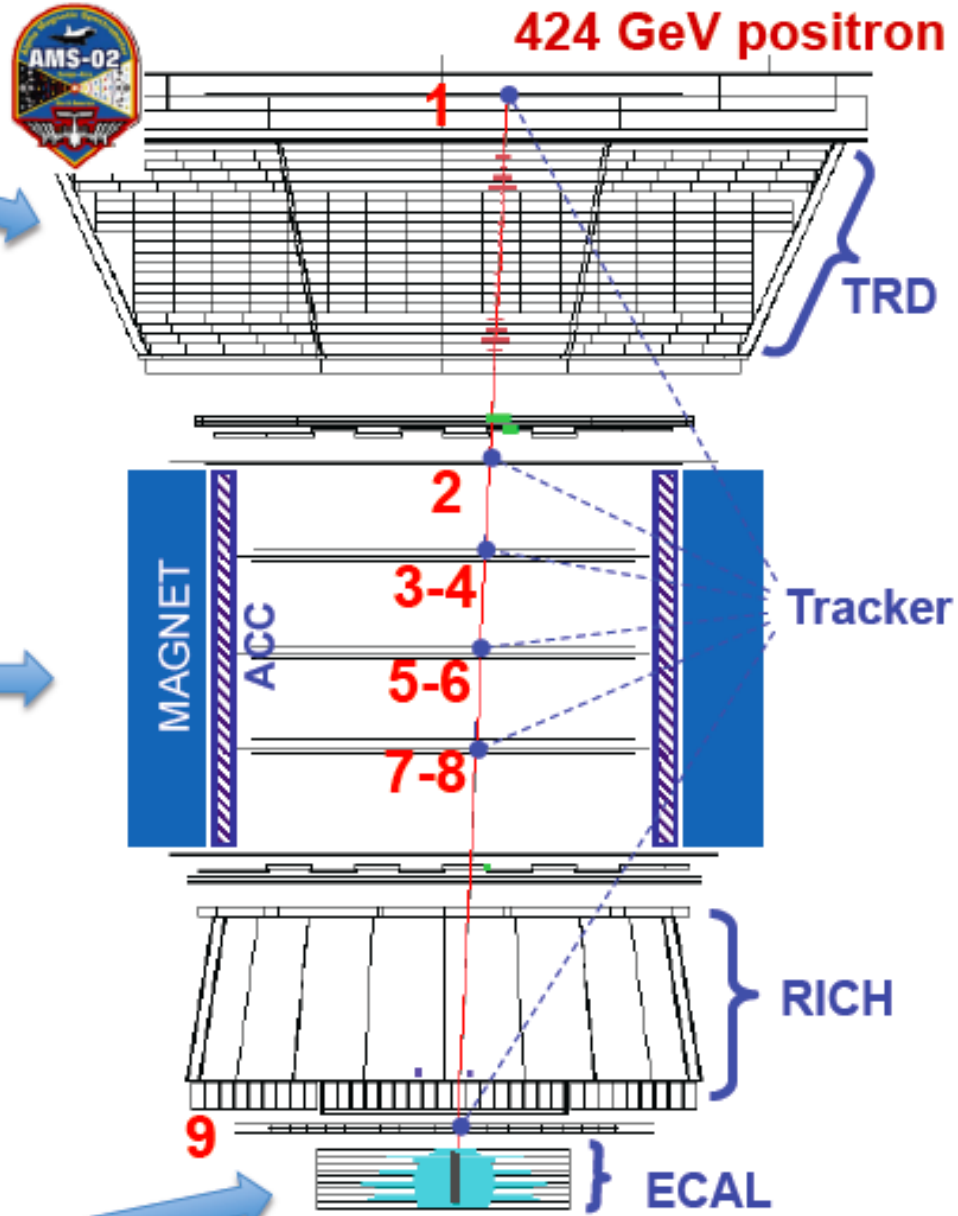
for the same particle are measured independently by the Tracker, RICH, TOF and ECAL

Positron fraction analysis



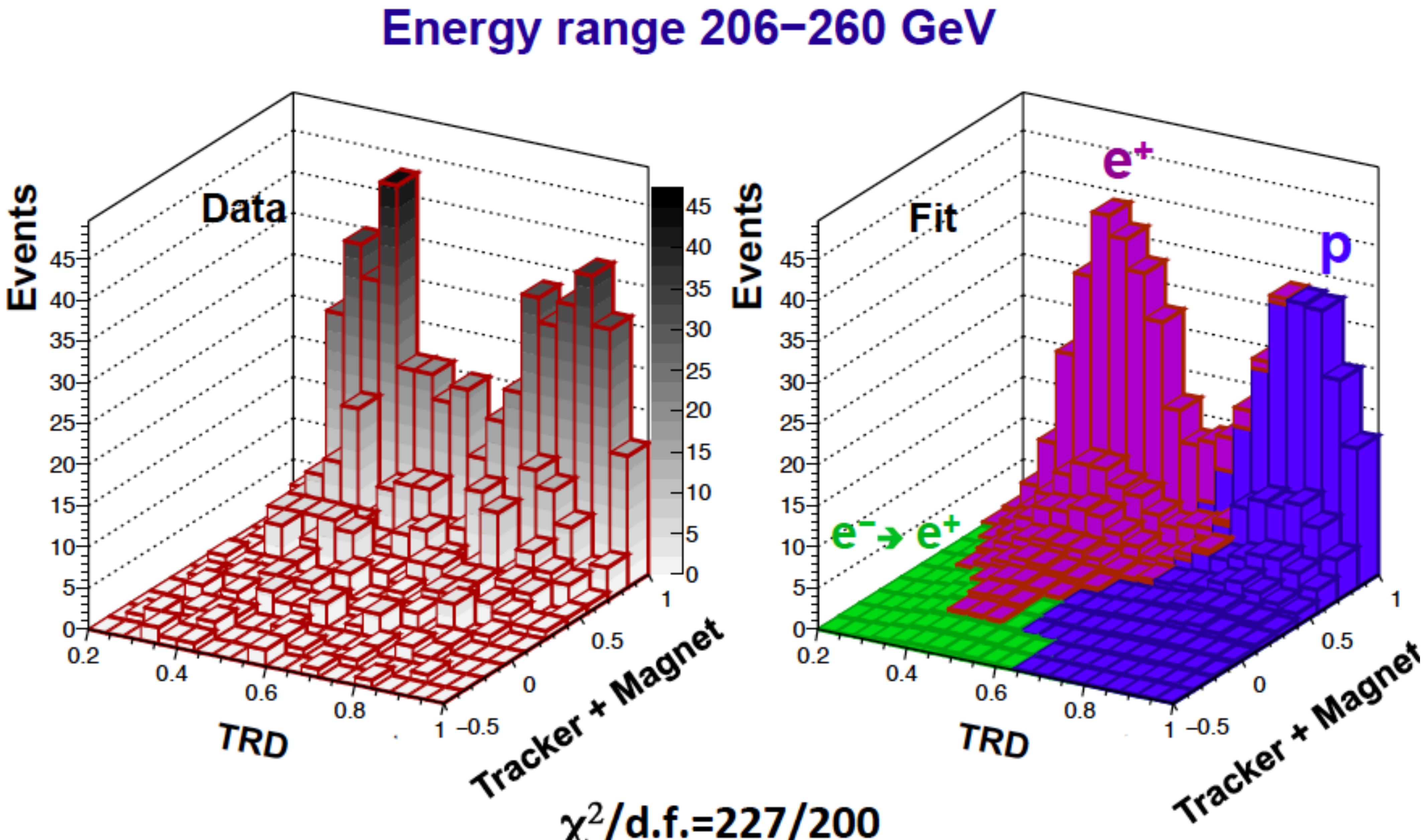






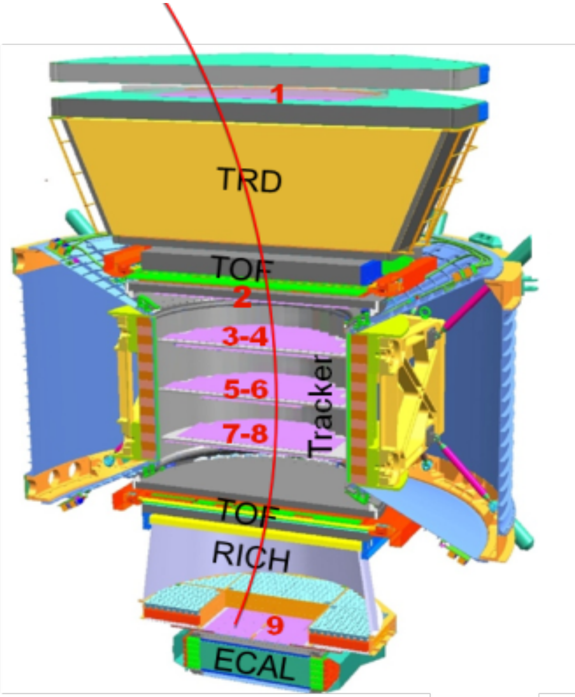
20 million of $e^{\pm}$ events are selected in the energy range 0.5–700 GeV

TRD Estimator shows clear separation between positrons and protons with a small charge confusion background

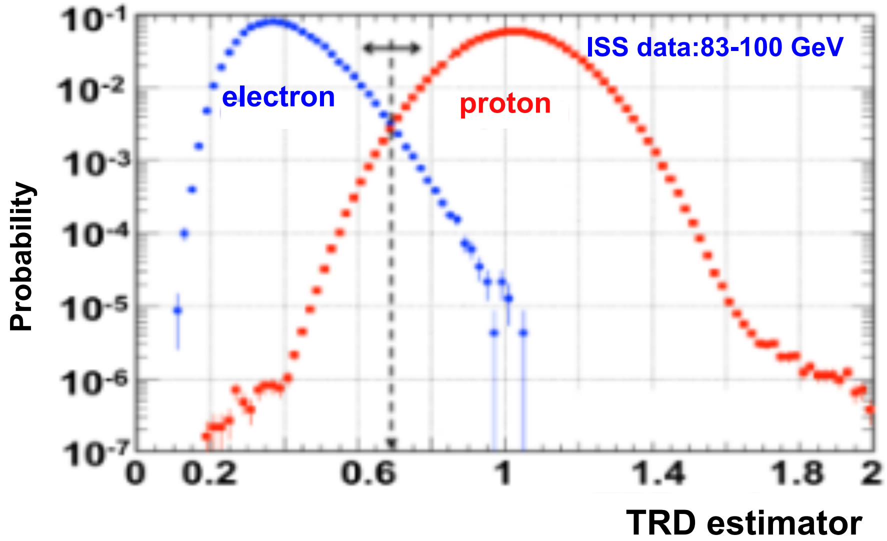


Antiproton analysis

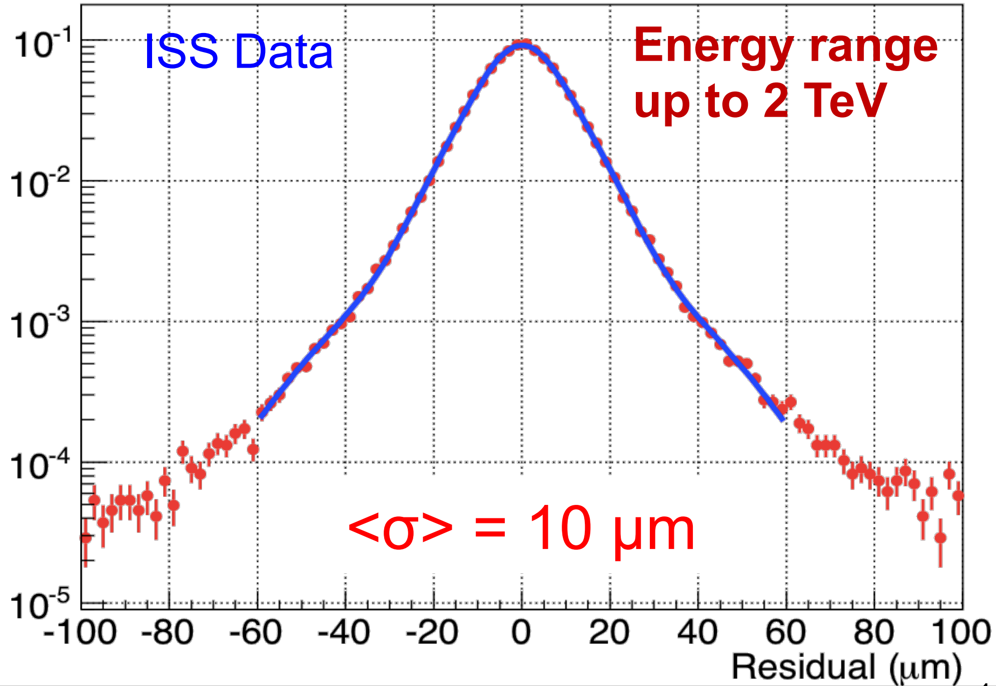
6.5 · 10^{10} cosmic rays
3.49 · 10^{5} antiprotons
2.42 · 10^{9} protons



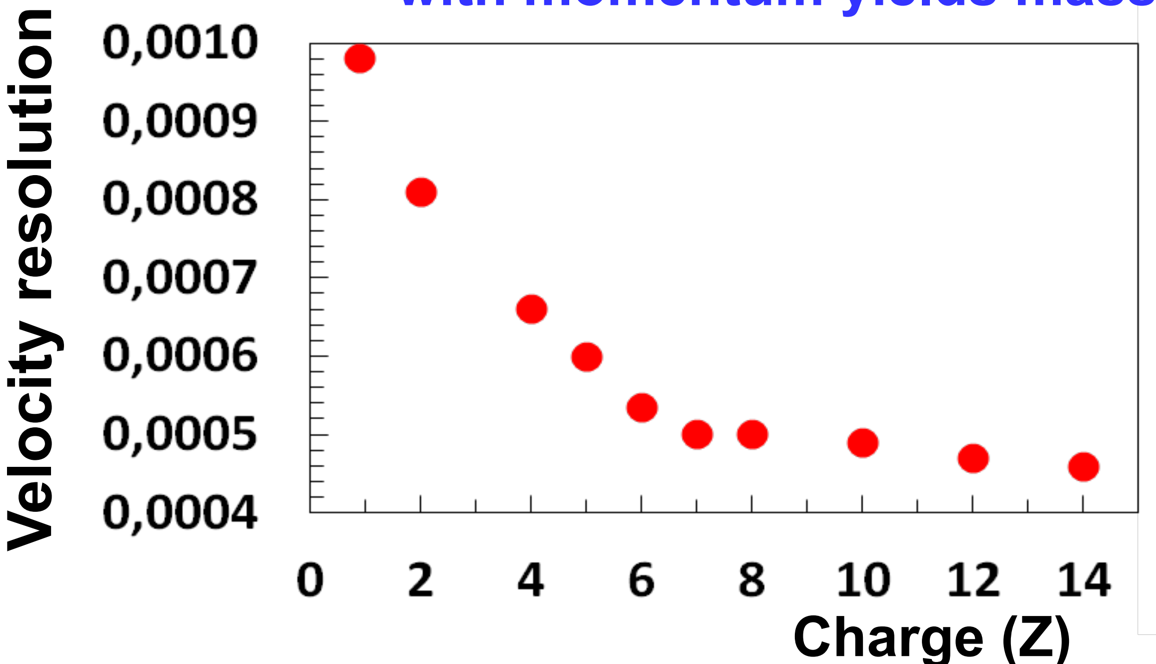
1. TRD (transition radiation) to separate $e^{\pm}$ from $p^{\pm}$



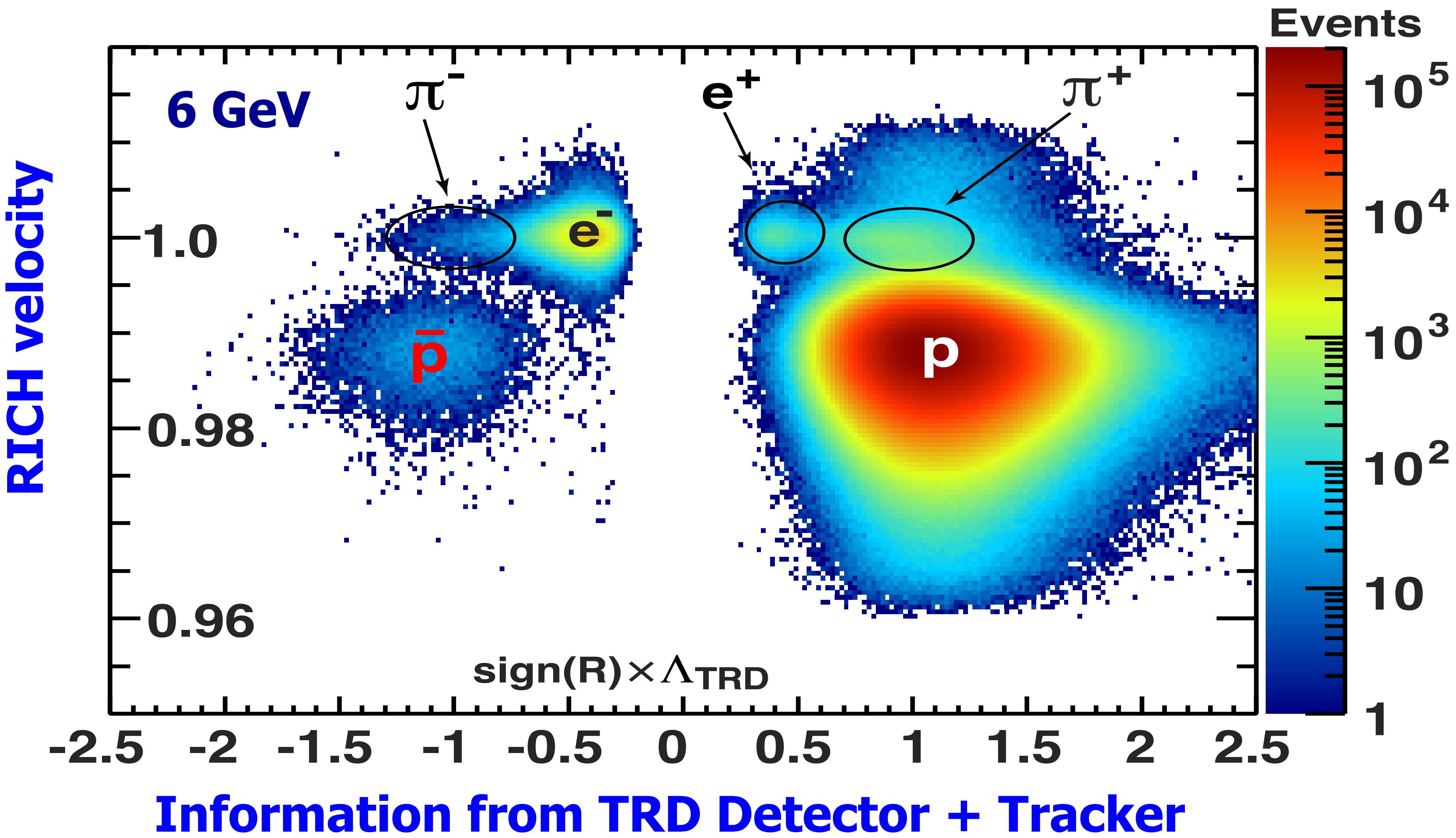
2. Tracker measures momentum and separates + from −



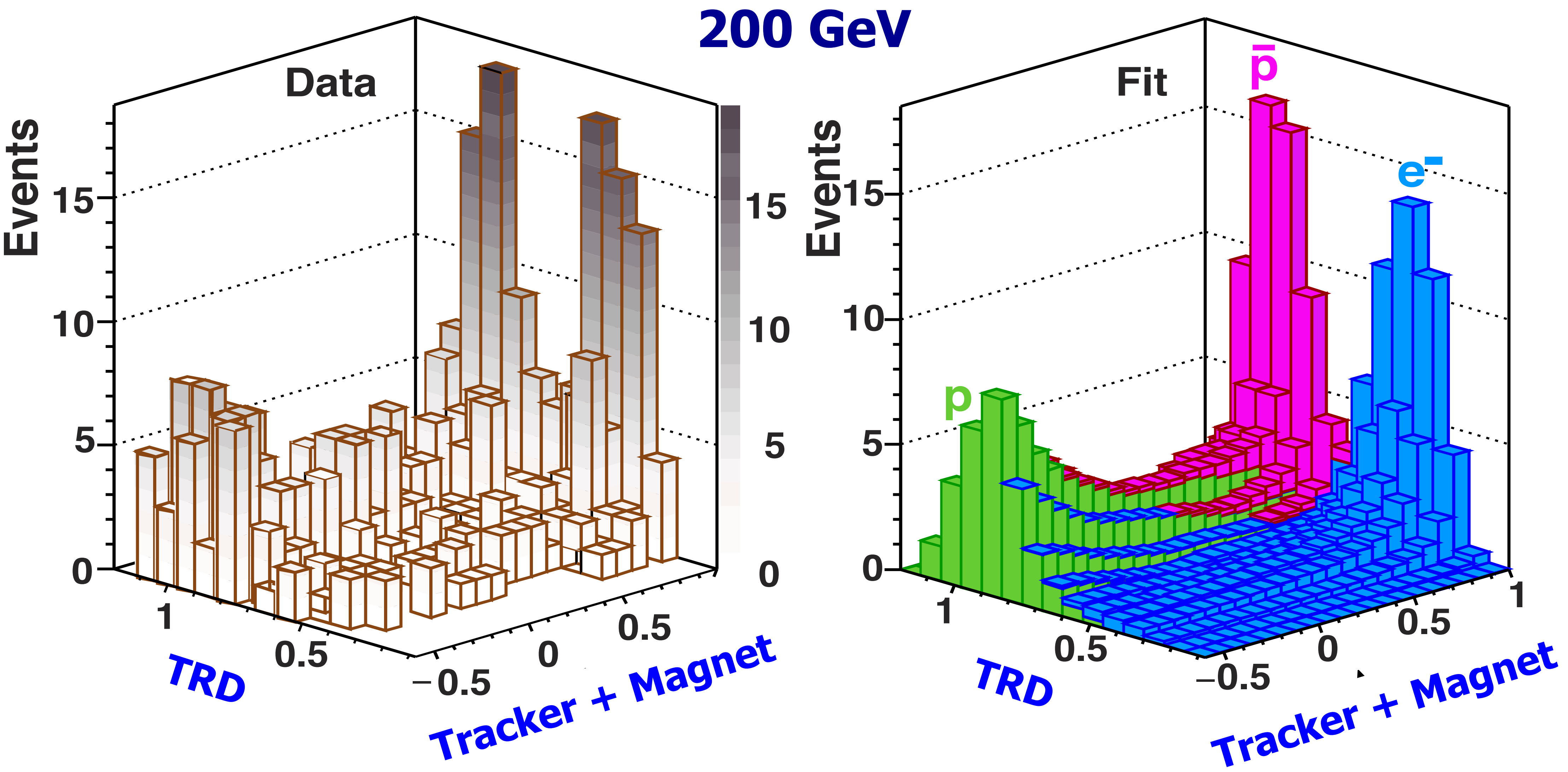
3. RICH measures velocity, with momentum yields mass



Selection of the signal at low energies.
The $\bar{p}$ signal is well separated from the backgrounds.



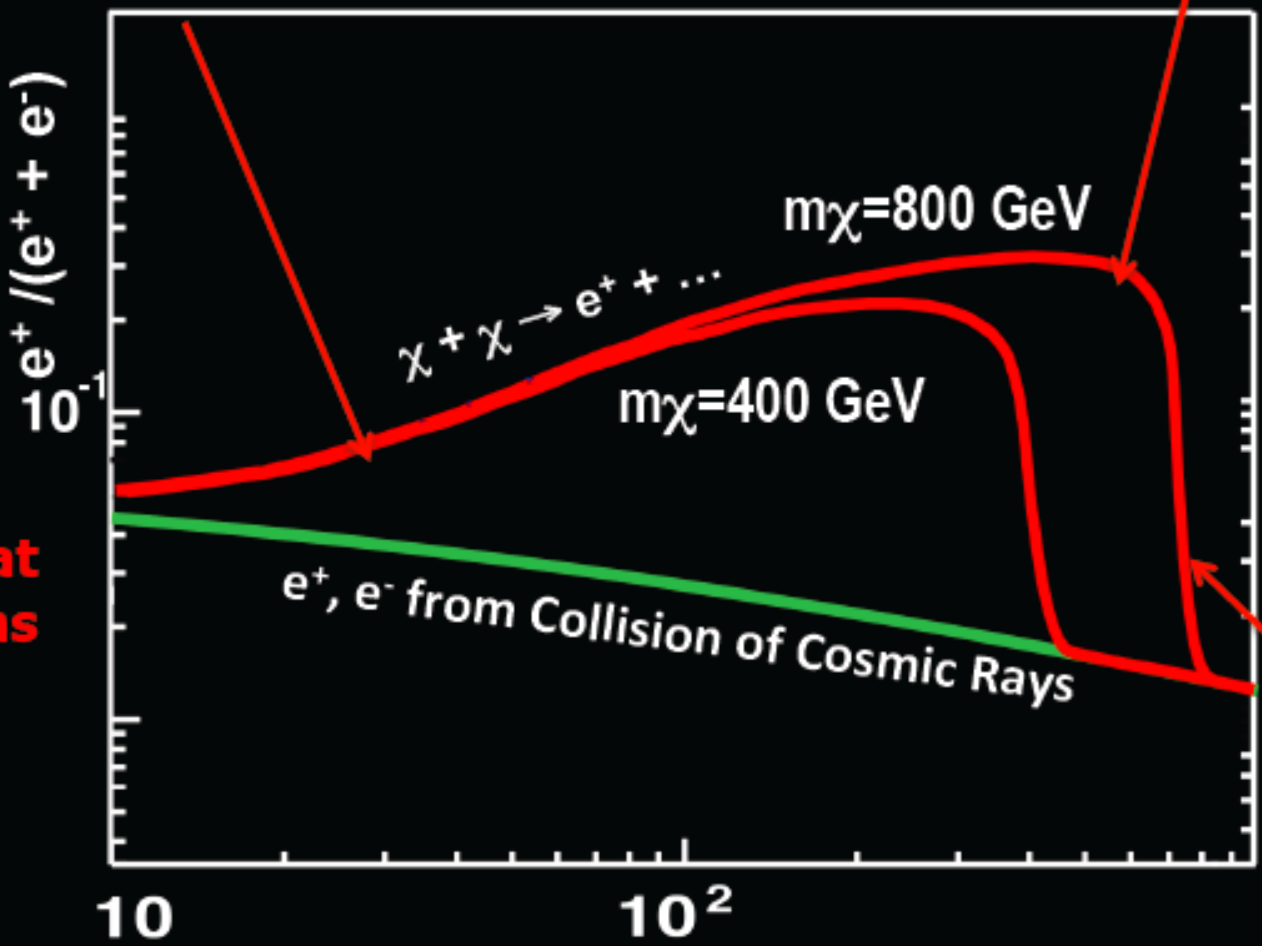
Selection of the signal at high energies.
Background rejection close to 1 particle in a million.



Positrons & Electrons

2. The rate of increase with energy compared with models

3. The energy beyond which it ceases to increase.

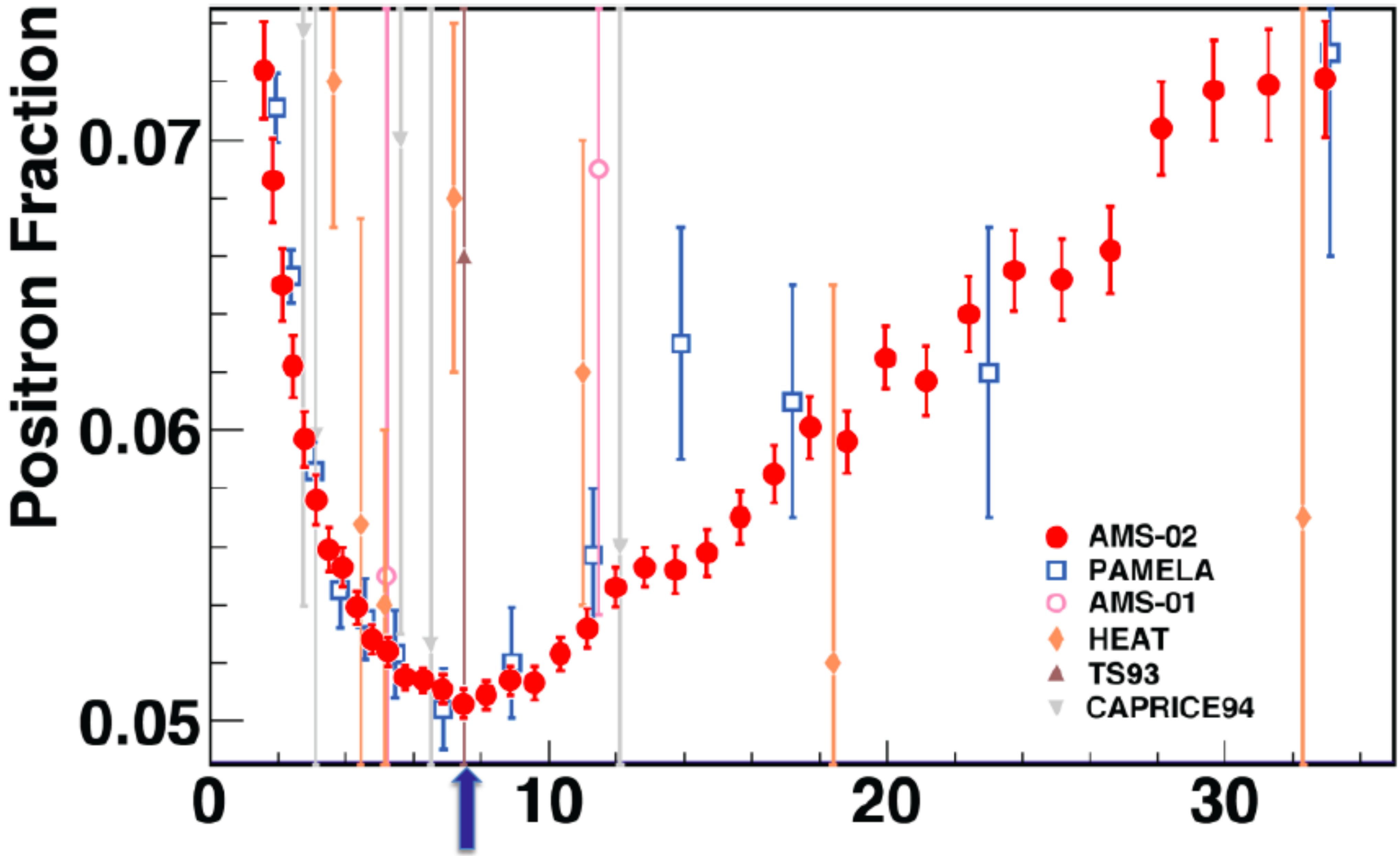


4. Anisotropy

1. The energy at which it begins to increase.

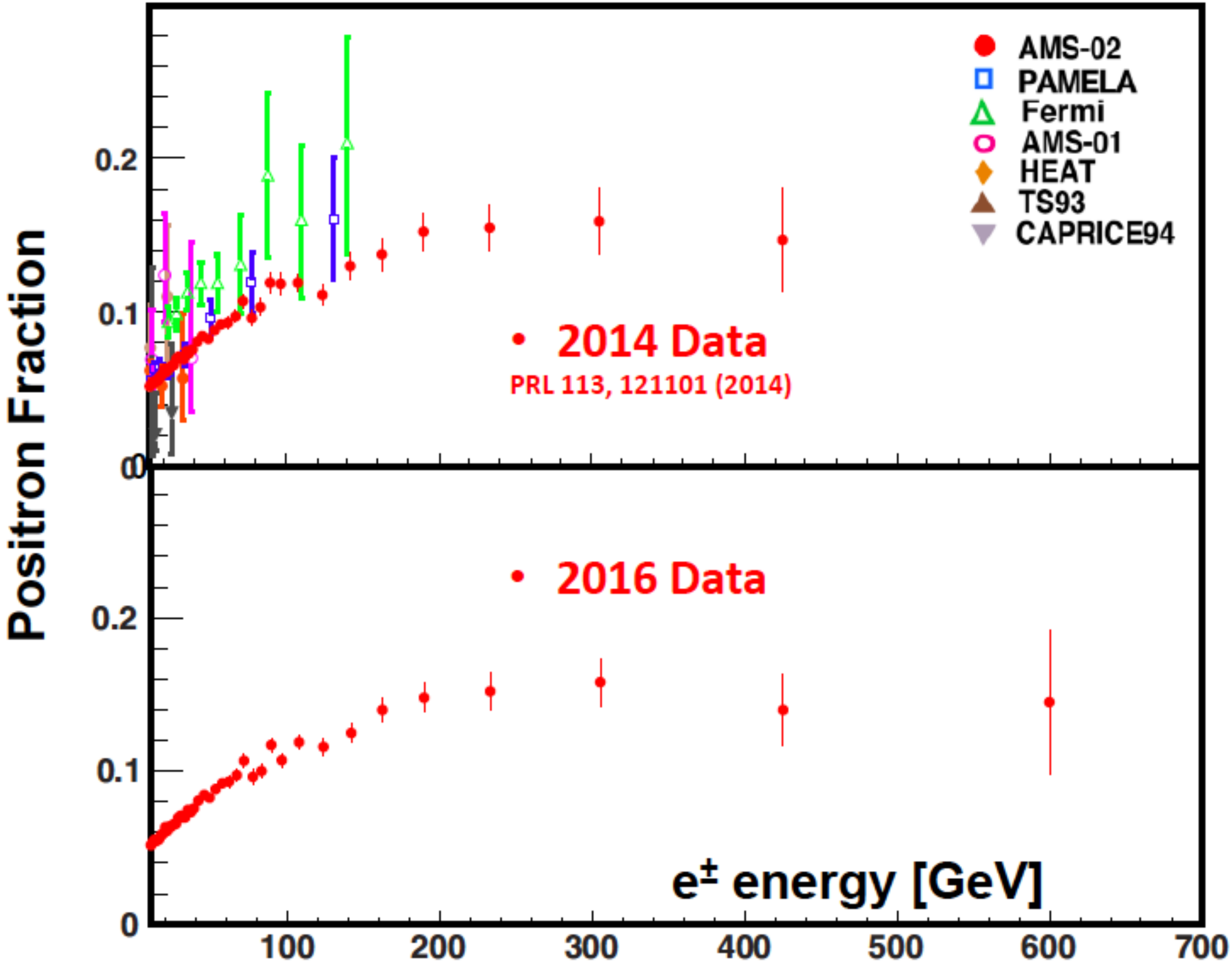
5. The rate at which it falls beyond the turning point.

1. The energy at which positron fraction begins to increase

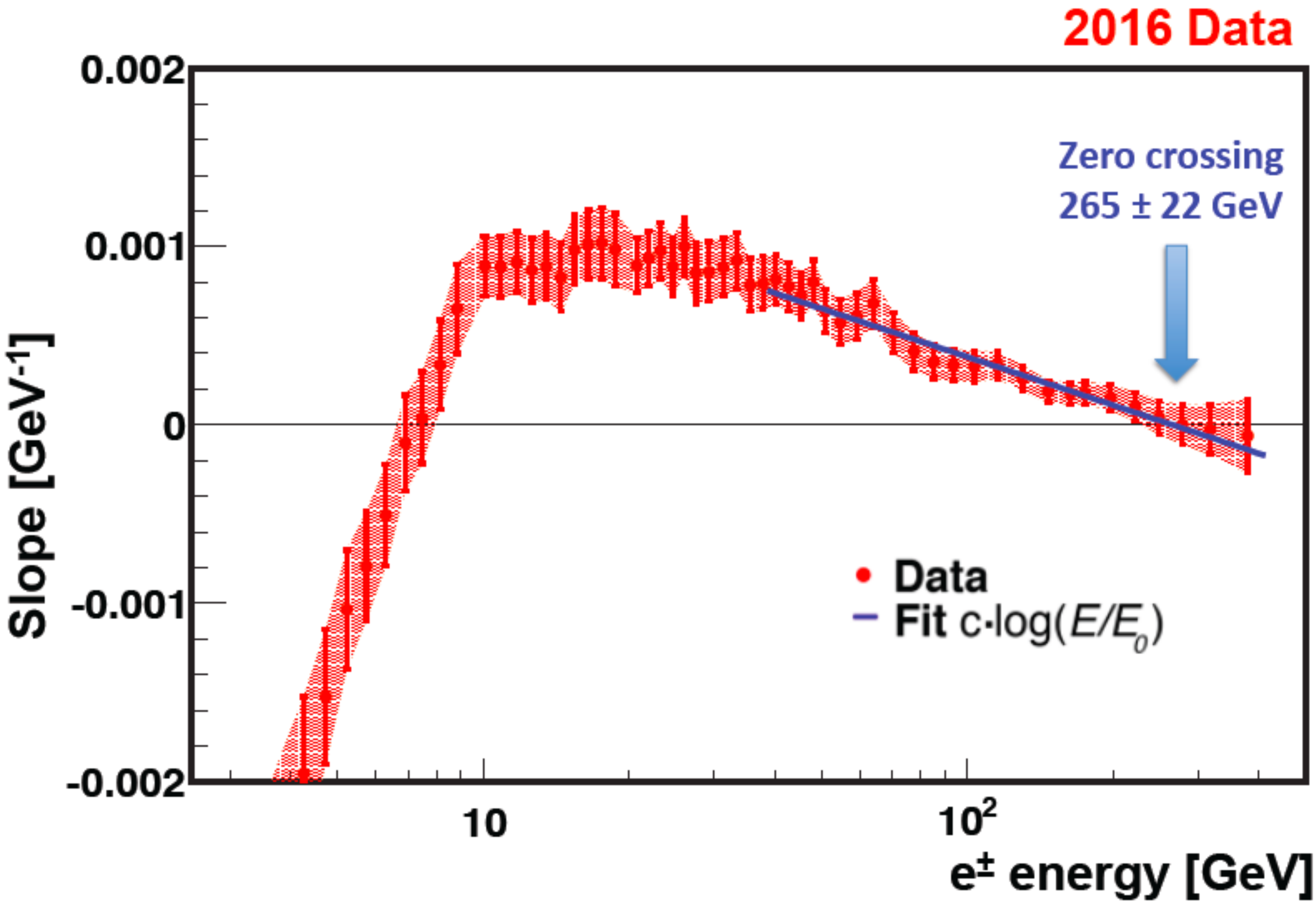


Positron fraction reaches minimum at 7.8 GeV

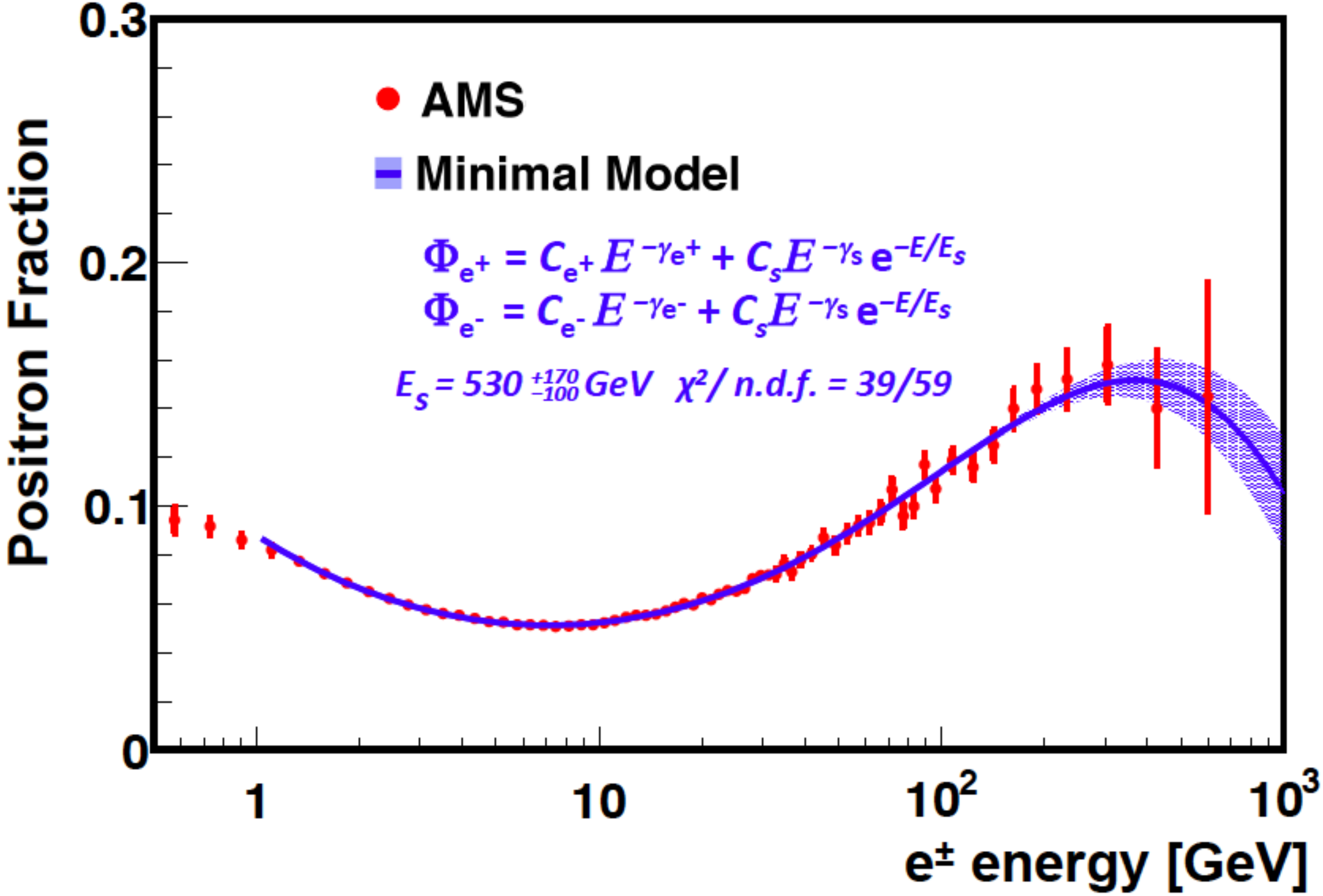
2. The rate of increase with energy.
The non-existence of sharp structures.



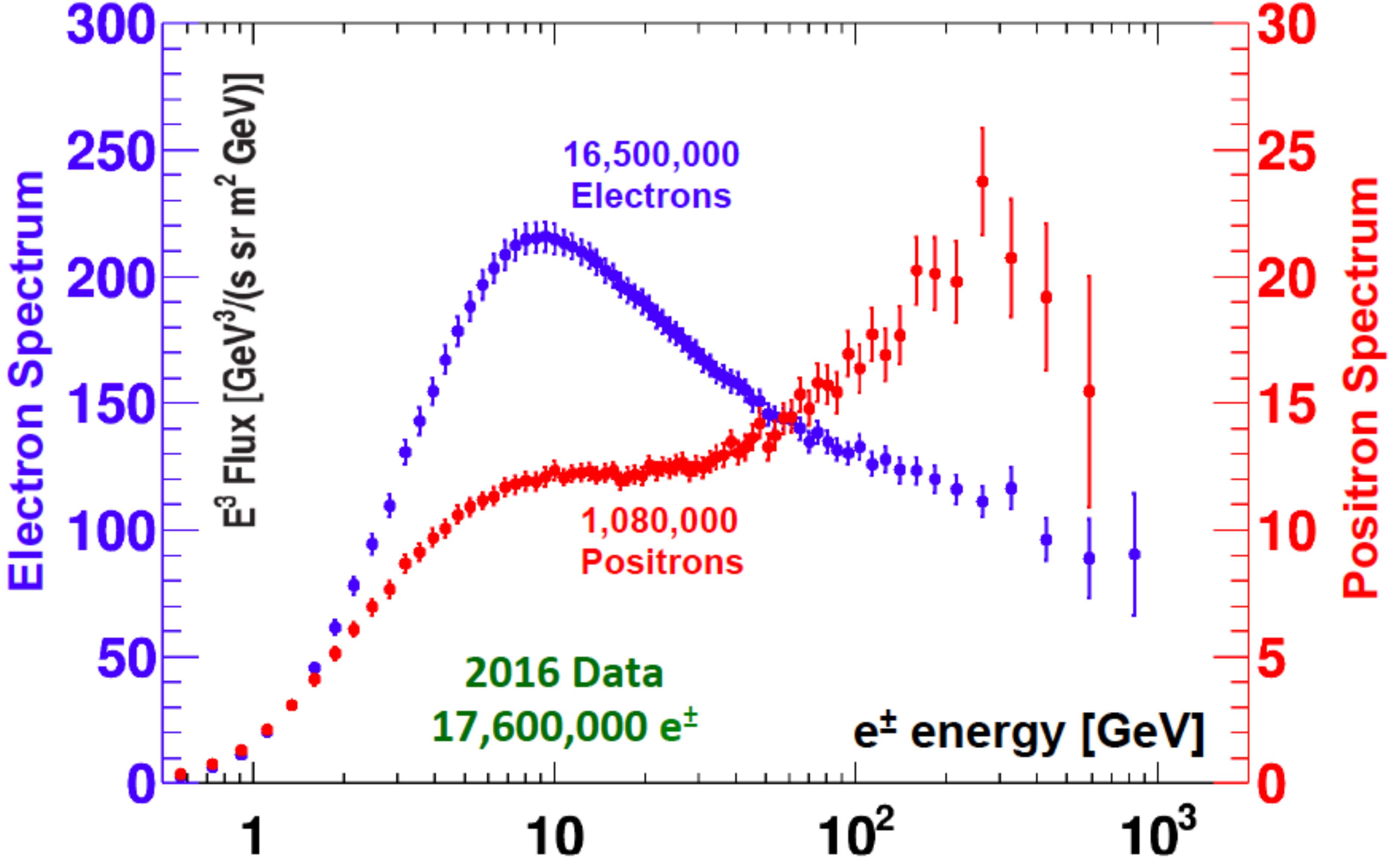
3. The energy beyond which it ceases to increase.



Additional source of positrons



Electron & Positron spectra



What is AMS observing?

From Dark Matter

1) J. Kopp, Phys. Rev. D 88, 076013 (2013);
2) L. Feng, R.Z. Yang, H.N. He, T.K. Dong, Y.Z. Fan and J. Chang Phys.Lett. B728 (2014) 250
3) M. Cirelli, M. Kadastik, M. Raidal and A. Strumia ,Nucl.Phys. B873 (2013) 530
4) M. Ibe, S. Iwamoto, T. Moroi and N. Yokozaki, JHEP 1308 (2013) 029
5) Y. Kajiyama and H. Okada, Eur.Phys.J. C74 (2014) 2722
6) K.R. Dienes and J. Kumar, Phys.Rev. D88 (2013) 10, 103509
7) L. Bergstrom, T. Bringmann, I. Cholis, D. Hooper and C. Weniger, PRL 111 (2013) 171101
8) K. Kohri and N. Sahu, Phys.Rev. D88 (2013) 10, 103001
9) P. S. Bhupal Dev, D. Kumar Ghosh, N. Okada and I. Saha, Phys.Rev. D89 (2014) 095001
10) A. Ibarra, A.S. Lamperstorfer and J. Silk, Phys.Rev. D89 (2014) 063539
11) Y. Zhao and K.M. Zurek, JHEP 1407 (2014) 017
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13) H. B. Jin, Y. L. Wu, and Y.-F. Zhou, Phys.Rev. D92, 055027 (2015)
14) M-Y. Cui, Q. Yuan, Y-L.S. Tsai and Y-Z. Fan, arXiv:1610.03840 (2016)
15) A. Cuoco, M. Krämer and M. Korsmeier, arXiv:1610.03071 (2016)

From Astrophysical Sources

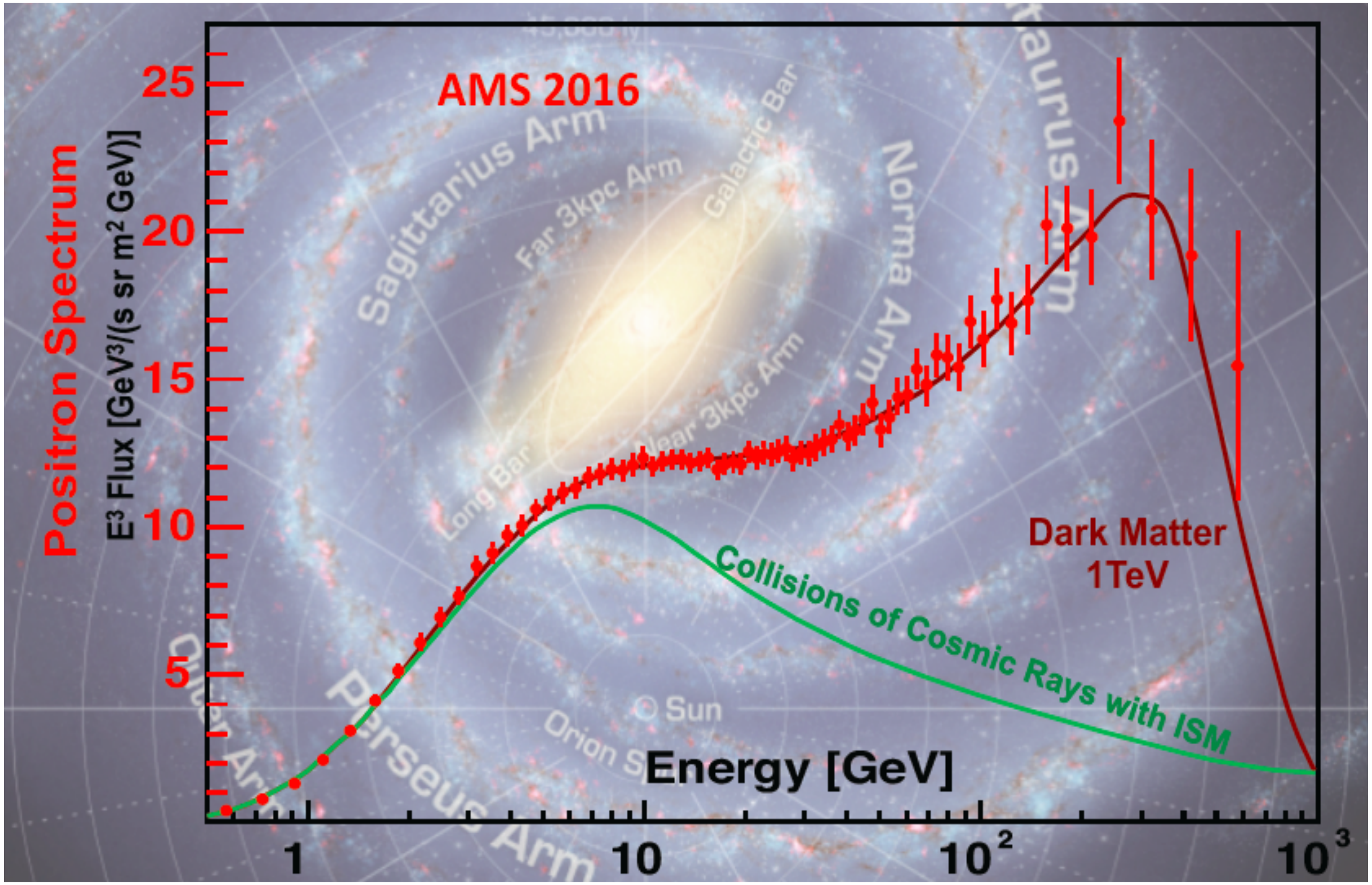
1) T. Linden and S. Profumo, Astrophys.J. 772 (2013) 18
2) P. Mertsch and S. Sarkar, Phys.Rev. D 90 (2014) 061301
3) I. Cholis and D. Hooper, Phys.Rev. D88 (2013) 023013
4) A. Erlykin and A.W. Wolfendale, Astropart.Phys. 49 (2013) 23
5) P.F. Yin, Z.H. Yu, Q. Yuan and X.J. Bi, Phys.Rev. D88 (2013) 2, 023001
6) A.D. Erlykin and A.W. Wolfendale, Astropart.Phys. 50-52 (2013) 47
7) E. Amato, Int.J.Mod.Phys.Conf.Ser. 28 (2014) 1460160
8) P. Blasi, Braz.J.Phys. 44 (2014) 426
9) D. Gaggero, D. Grasso, L. Maccione, G. DiBernardo and C Evoli, Phys.Rev. D89 (2014) 083007
10) M. DiMauro, F. Donato, N. Fornengo, R. Lineros and A. Vittino, JCAP 1404 (2014) 006
11) K. Kohri, K. Ioka, Y. Fujita, and R. Yamazaki, Prog. Theor. Exp. Phys. 2016, 021E01 (2016)

From Secondary Production

1) R.Cowsik, B.Burch, and T.Madziwa-Nussinov, Ap.J. 786 (2014) 124
2) K. Blum, B. Katz and E. Waxman, Phys.Rev.Lett. 111 (2013) 211101
3) R. Kappl and M. W. Winkler, J. Cosmol. Astropart. Phys. 09 (2014) 051
4) G.Giesen, M.Boudaud, Y.Gènolini, V.Poulin, M.Cirelli, P.Salati and P.D.Serpico, JCAP09 (2015) 023;
5) C.Evoli, D.Gaggero and D.Grasso, JCAP 12 (2015) 039.
6) R.Kappl, A.Reinertand, and M.W.Winkler, arXiv:1506.04145 (2015)

What is AMS observing?

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



Model based on
J. Kopp, Phys. Rev. D 88 (2013) 076013

What is AMS observing?

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

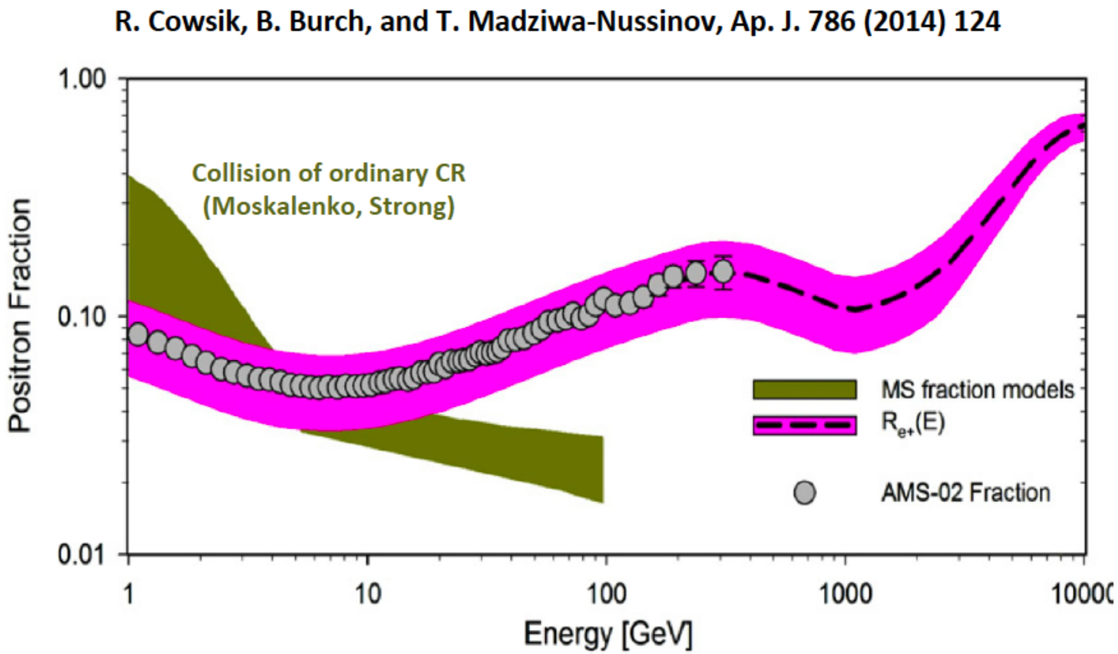
Astrophysical Sources:

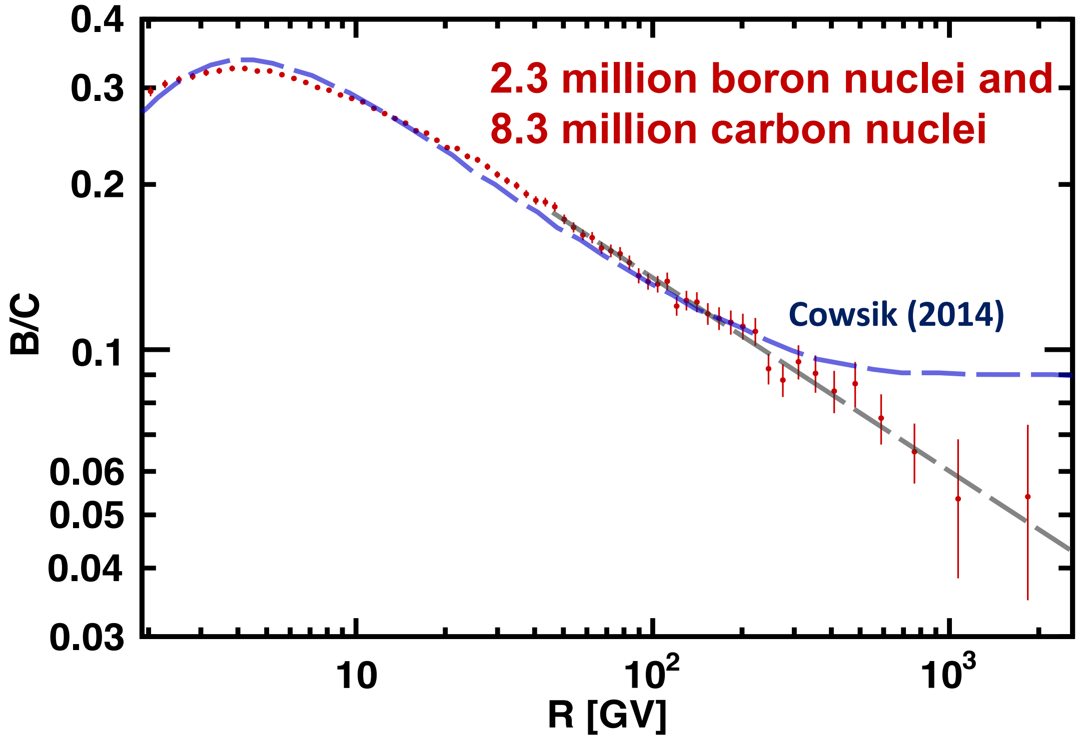
- Local sources as pulsars (slow fall at high energies, anisotropy..)
- Interactions of CR hadrons in old SNR (but this should affect also other secondary species as anti-protons, B/C)
- purely secondary production in non-conventional models

Dark matter:

- The mass of the DM particle could give a sharp cutoff with energy
- Isotropic distribution
- Effects also on anti-p

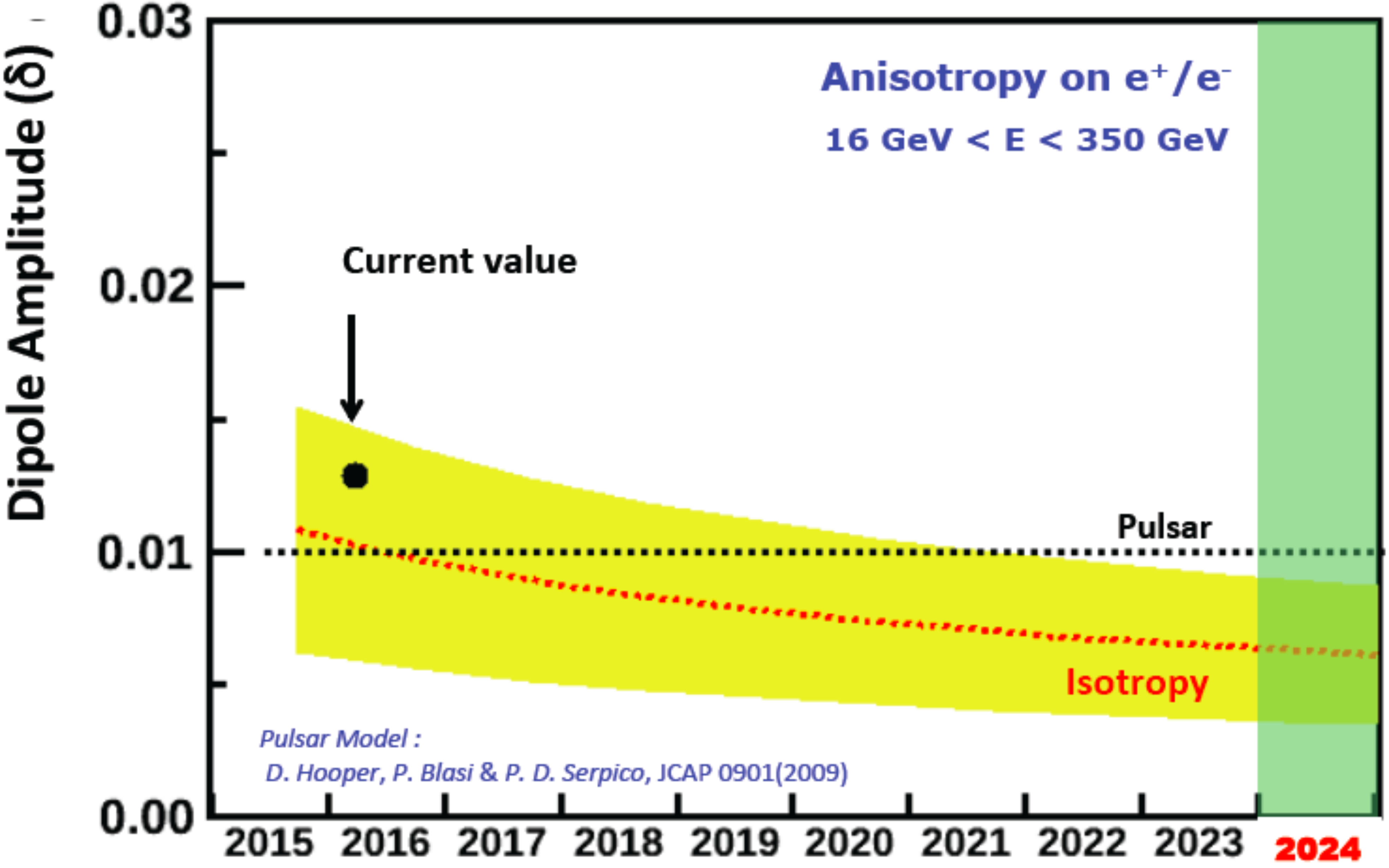
Secondary production



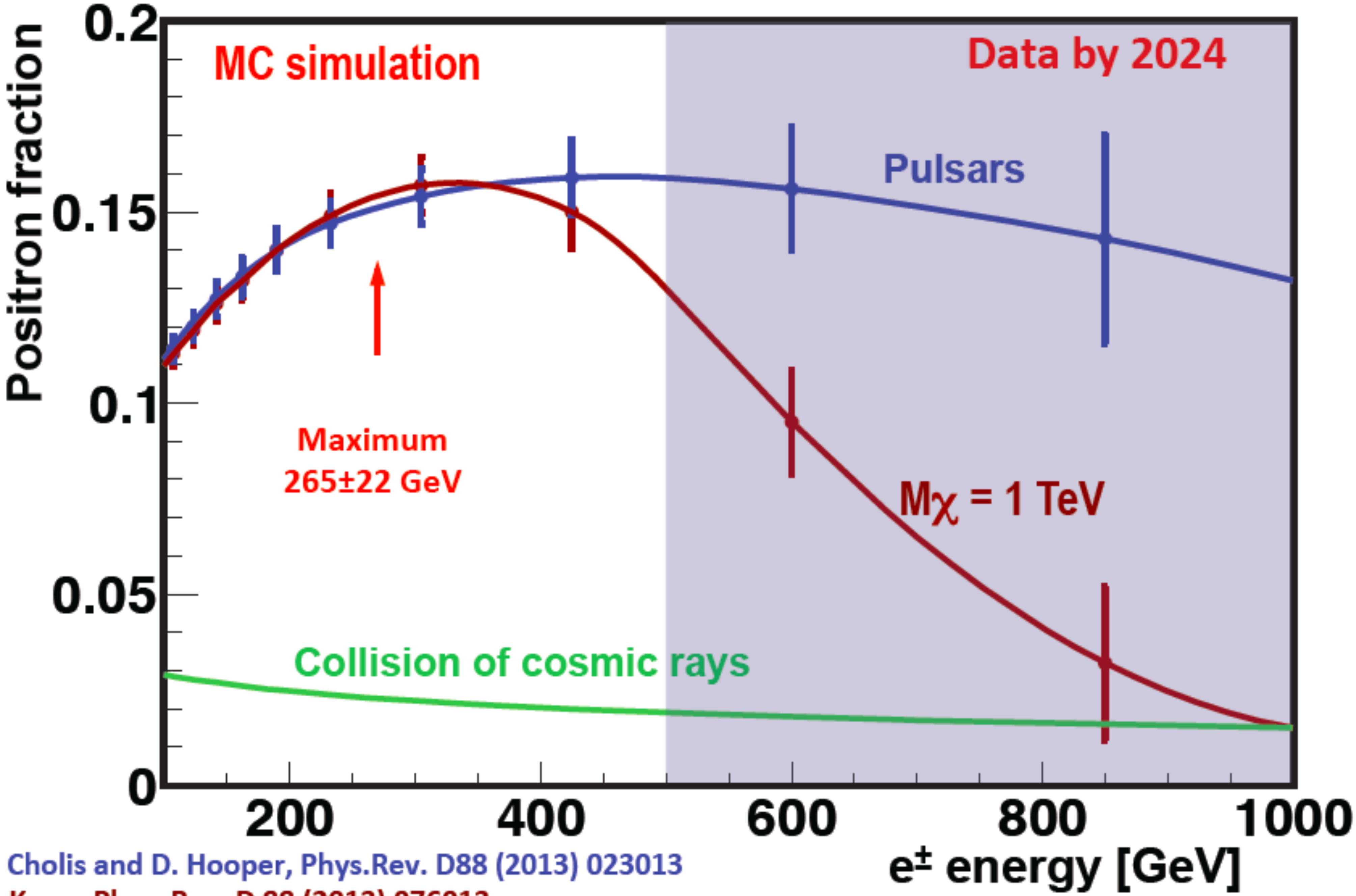


4. Anisotropy on e^+/e^- : dipole amplitude

In 2024, AMS will collect above 200,000 positron events in the energy range 16 GeV < E < 350 GeV



5. The expected rate at which it falls beyond the turning point.

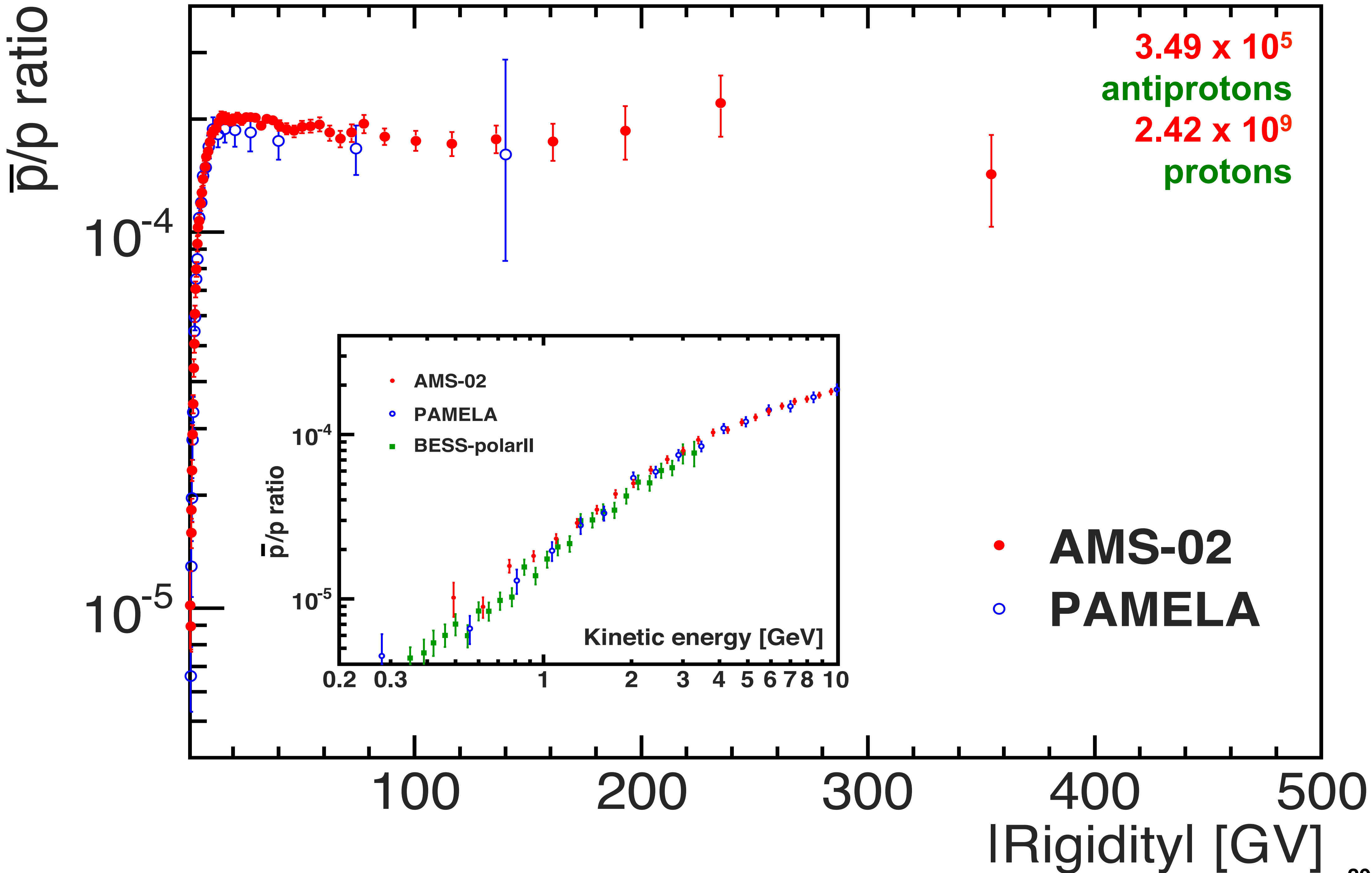


I. Cholis and D. Hooper, Phys.Rev. D88 (2013) 023013

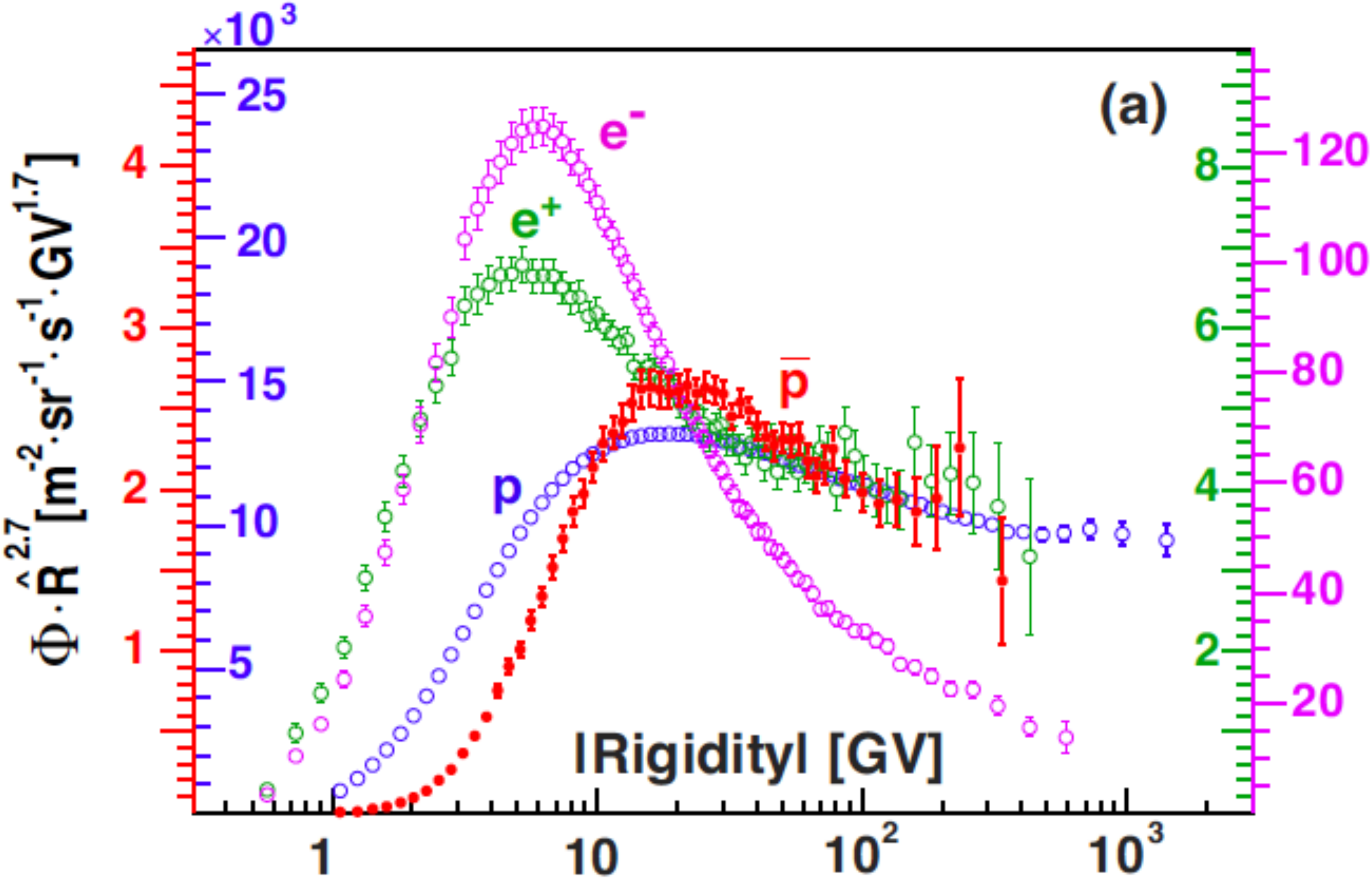
J. Kopp, Phys. Rev. D 88 (2013) 076013

Other channels…?
e.g. anti-p

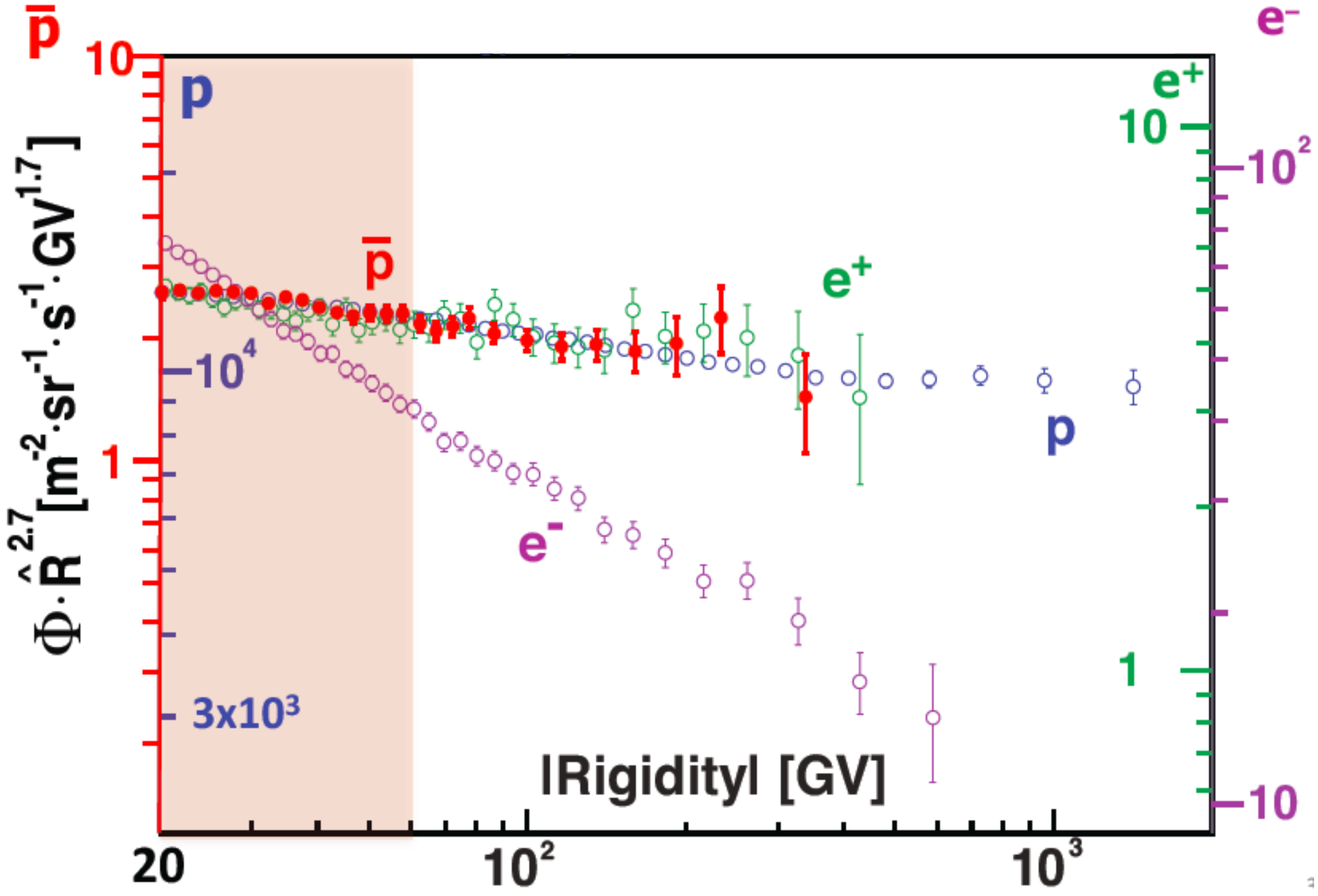
AMS results on the p̄/p flux ratio



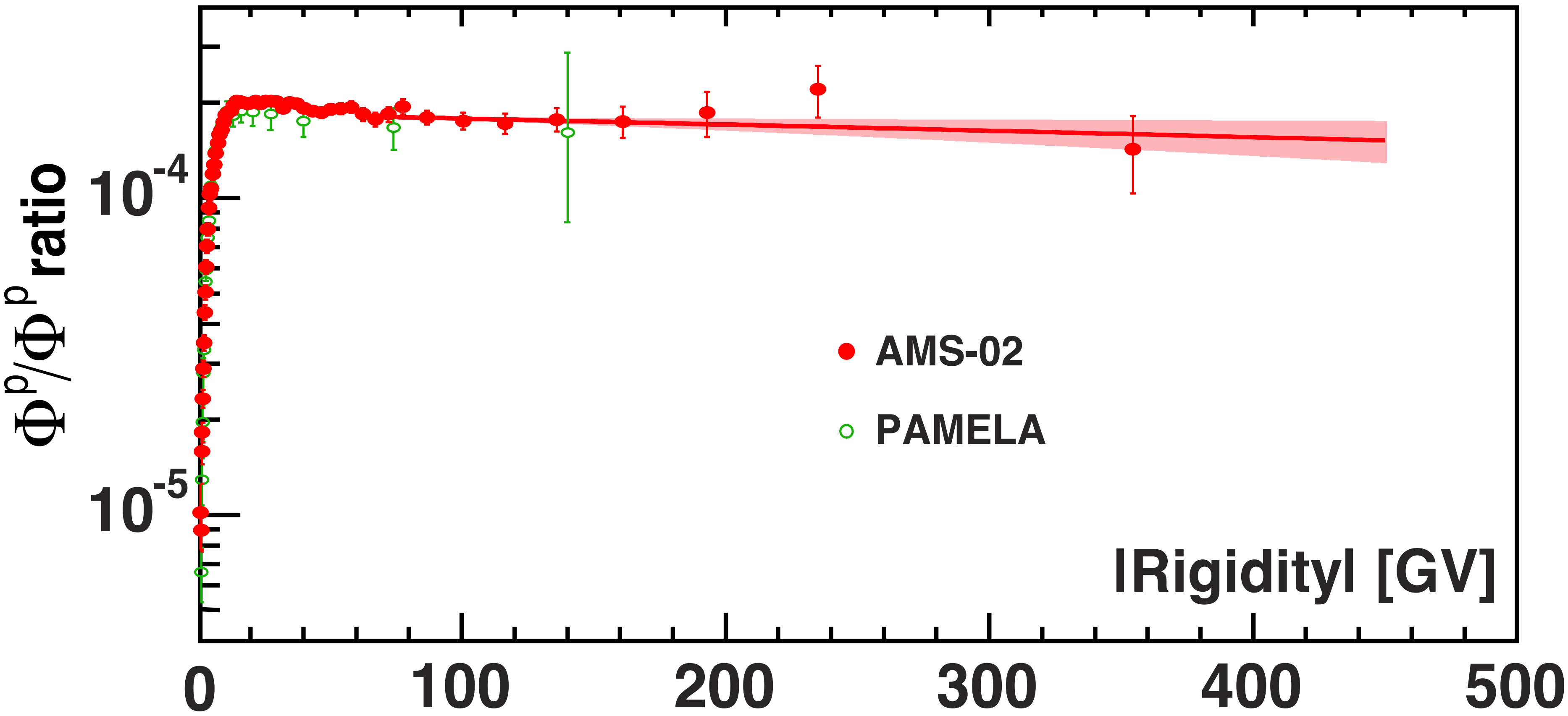
Elementary particle fluxes measured by AMS



Spectrum of Elementary Particles e^+, $\bar{p}$, p have identical energy dependence above 60 GeV
e^- does not

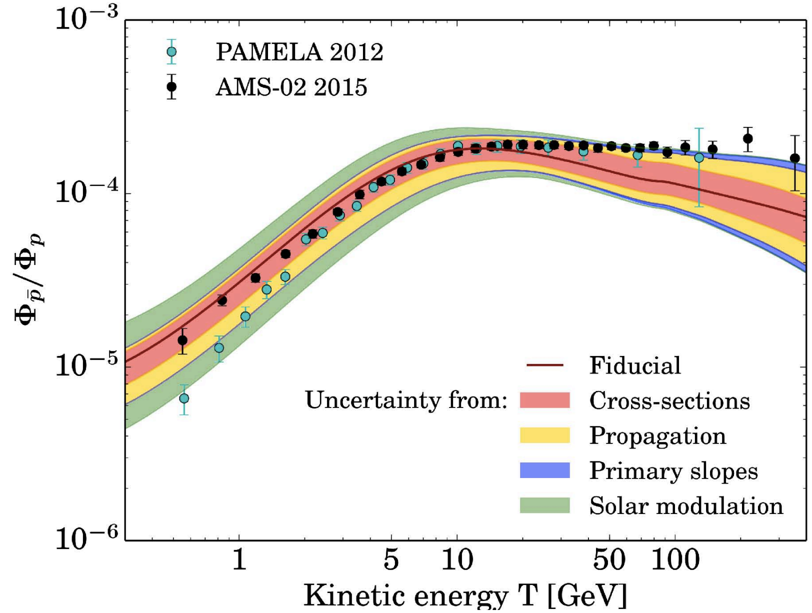


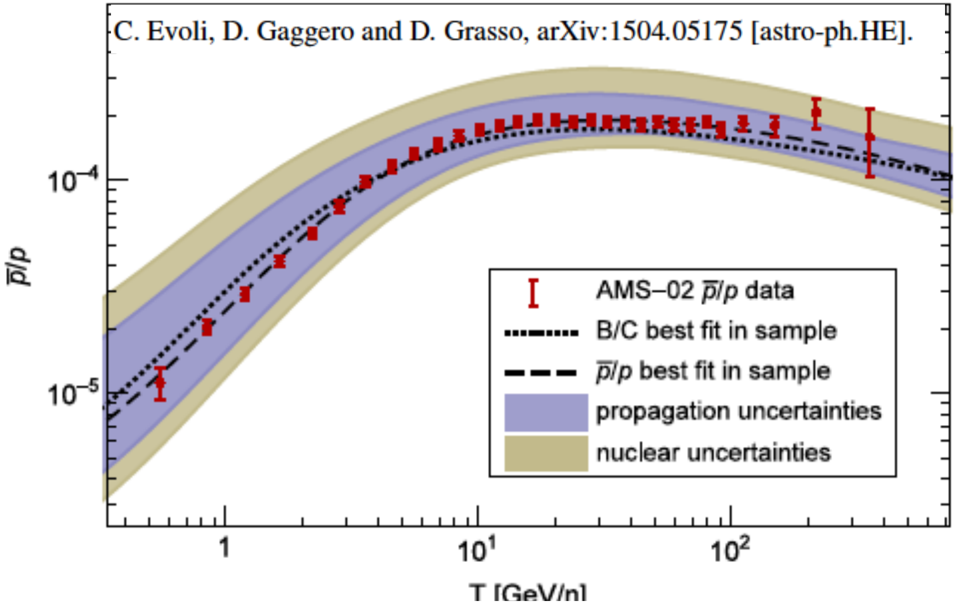
The pbar/p ratio flattens above 60 GeV..

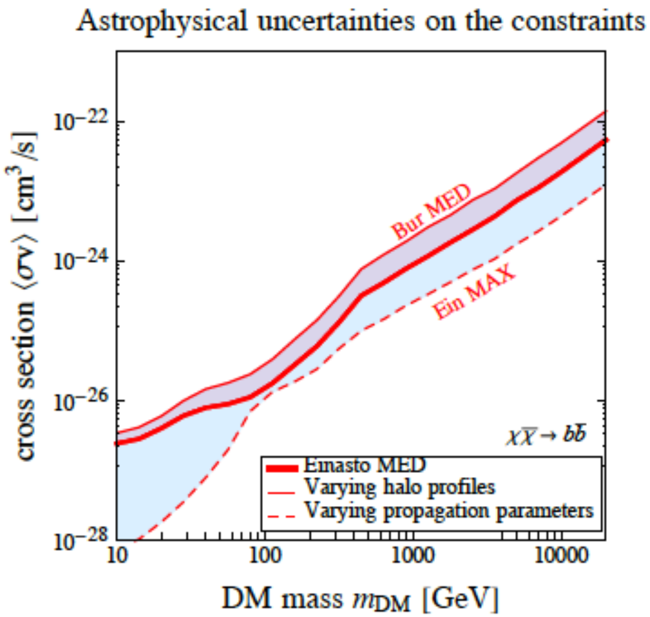


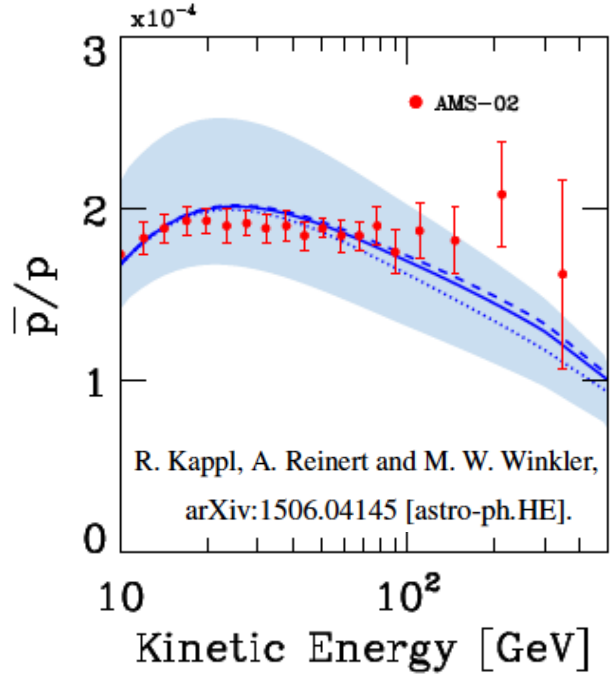
What is AMS observing?

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









XSCRC2017: Cross sections for Cosmic Rays @ CERN

29 Mar 2017, 14:00 → 31 Mar 2017, 19:00 Europe/Zurich

503-1-001 - Council Chamber (CERN)

Description New space borne experiments are ushering us into the era of precision direct measurements in cosmic ray physics. However, a poor knowledge of several particle physics and nuclear physics inputs - such as antiproton production or spallation cross sections - can seriously limit the relevant astroparticle physics information that can actually be extracted from these data, for instance for Galactic propagation parameters or indirect dark matter searches. The goal of the workshop, bringing together different communities, is to review theoretical motivations for the measurements of key processes, current galactic models and recent advances in cosmic ray observations that crucially depend on some of these inputs. The workshop also strongly aims at presenting current efforts and discussing forthcoming perspectives for particle/nuclear measurement campaigns.

Duration: The workshop will start Wednesday, March 29 in the late morning, and will end Friday, March 31 at about 4pm.

Organizing Committee: Bruna Bertucci (Perugia University), F. Donato (Torino University, chair), G. Giudice (CERN), Giovanni Passaleva (INFN, Florence), P. D. Serpico (LAPTH, Annecy, co-chair)

Scientific Advisory Committee: Oscar Adriani (Univ. and INFN, Firenze), Luca Latronico (INFN, Torino), Julie McEnery (Goddard NASA), Nadia Pastrone (INFN, Torino), Pierre Salati (LAPTH, Annecy), Andy Strong (MPE, Munich), Samuel C.C. Ting (MIT, Cern), Guy Wilkinson (Oxford Univ)

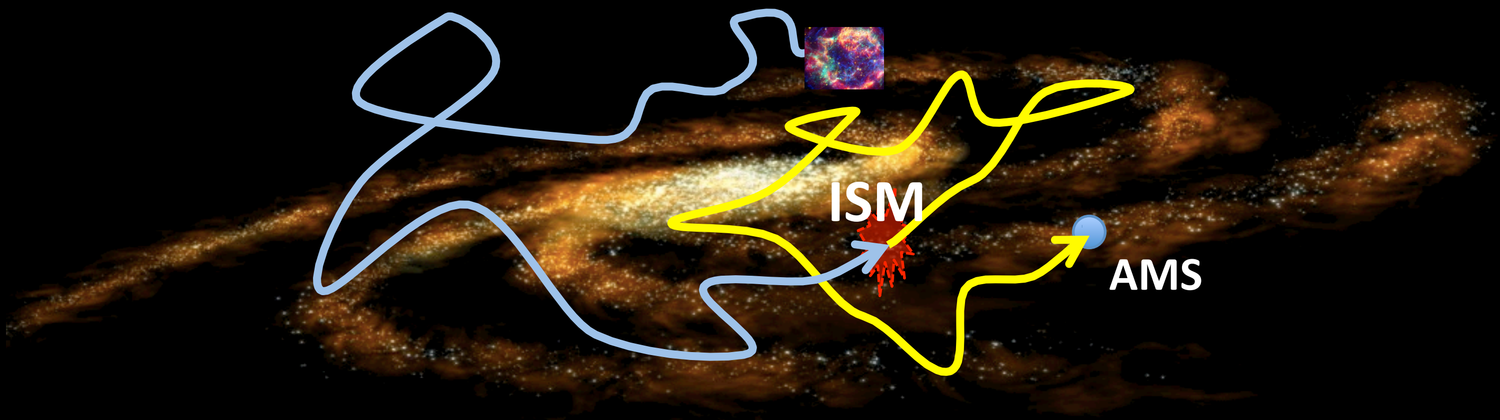
Invited Speakers: AMS Collaboration, Compass Collaboration, LHCb Collaboration, Alfredo Ferrari, Nicolao Fornengo, Guðlaugur Jóhannesson, Vladimir Ivanchenko, Tune Kamae, David Maurin, Nicola Mazziotta, Igor Moskalenko

Registration *This event is open to new participants.* Register

AMS provides a comprehensive set of measurements to constrain astrophysical background:

Primary Cosmic Rays (p, He, C, O, …)

C, O, …, Fe + ISM → Li, Be, B + X

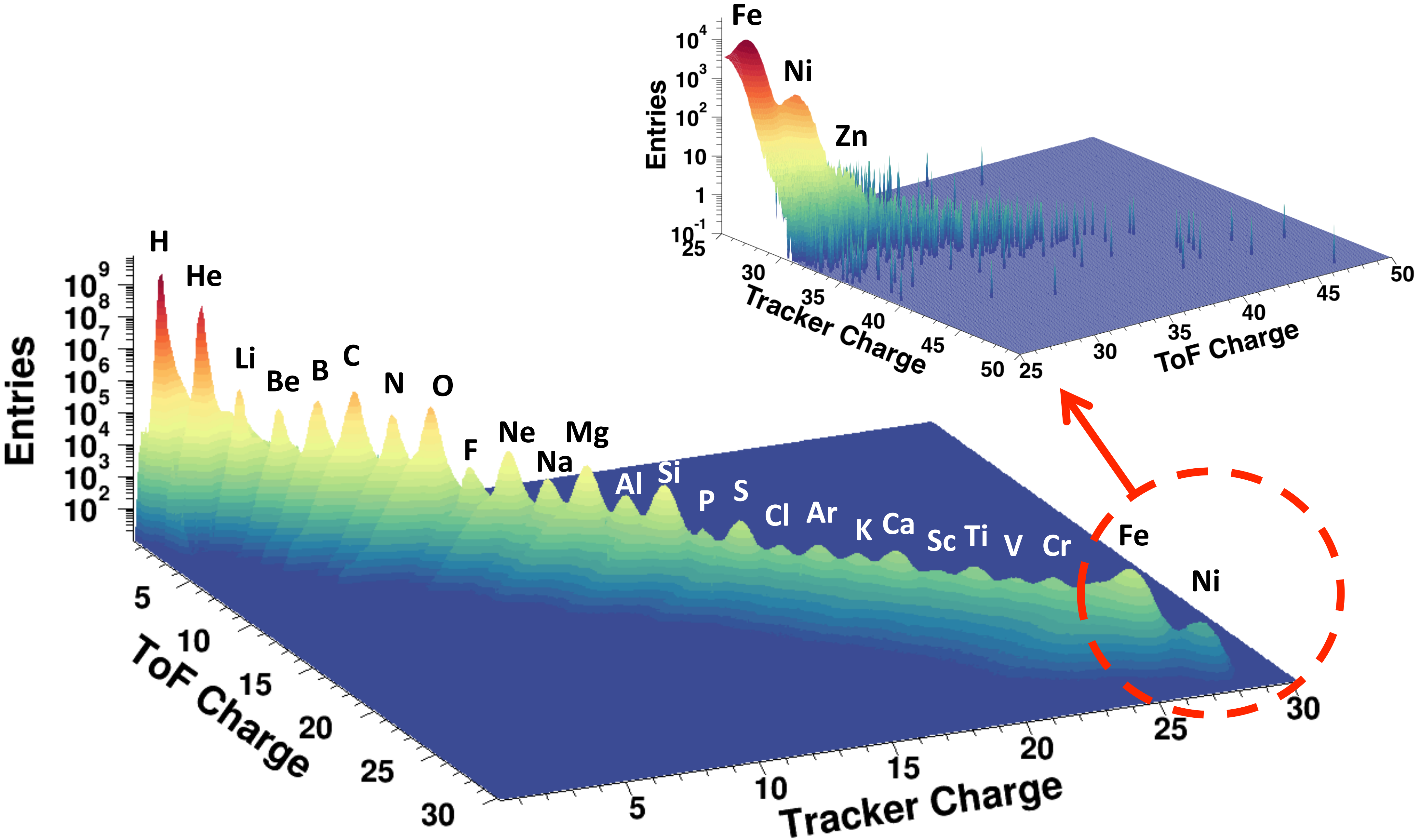


Secondary Cosmic Rays (Li, Be, B, …)

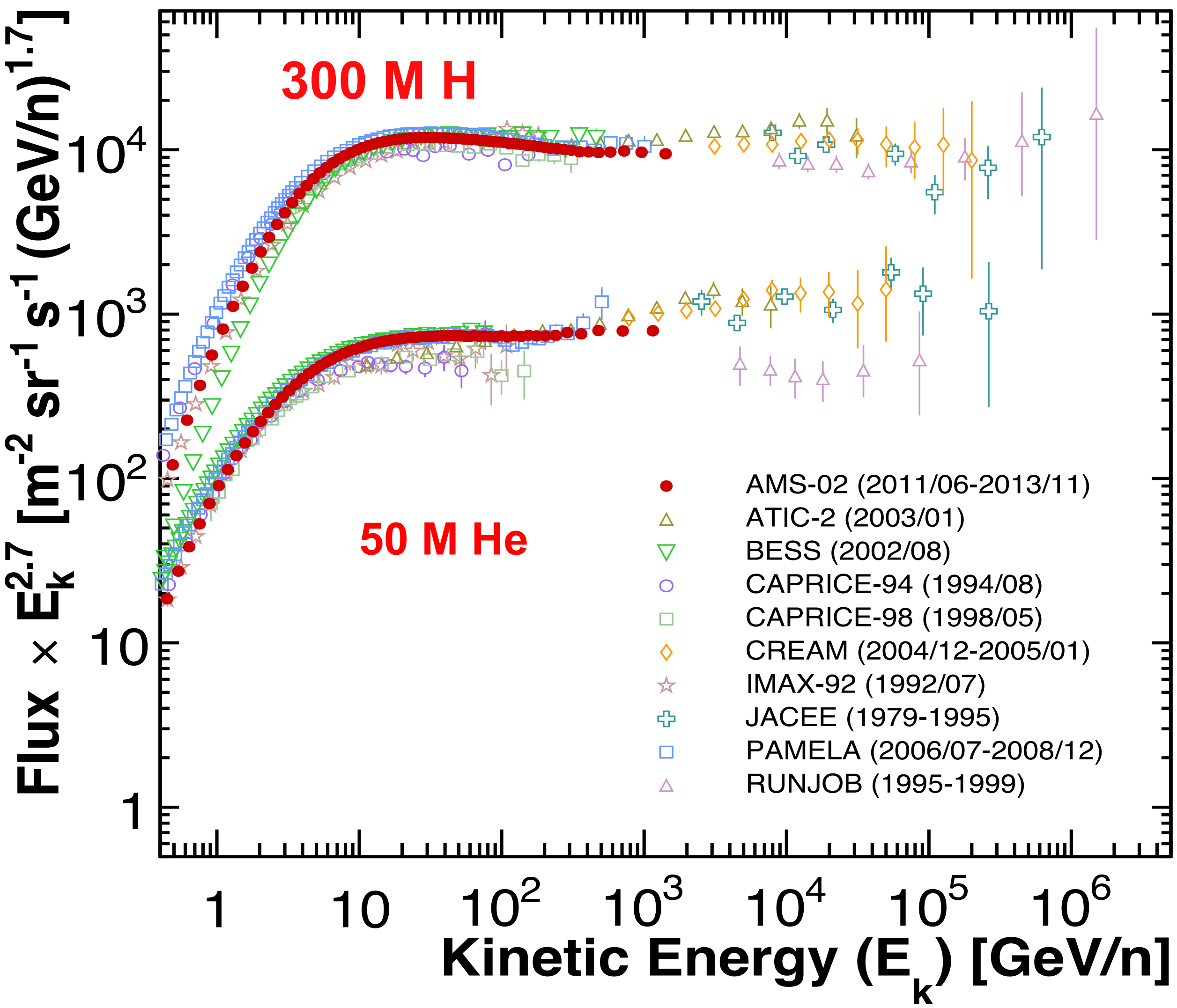
Cosmic ray composition:

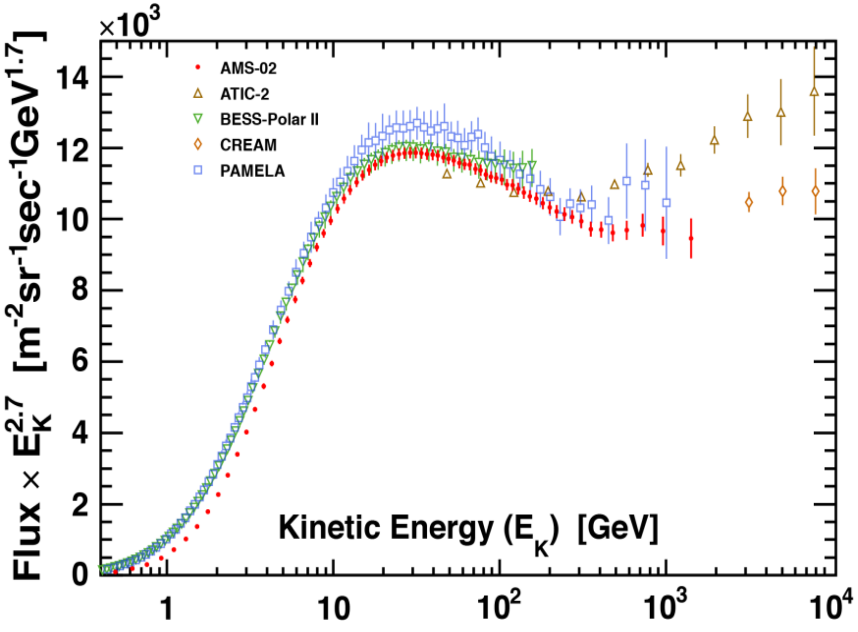
- for Z > 2 statistical error is our limit !

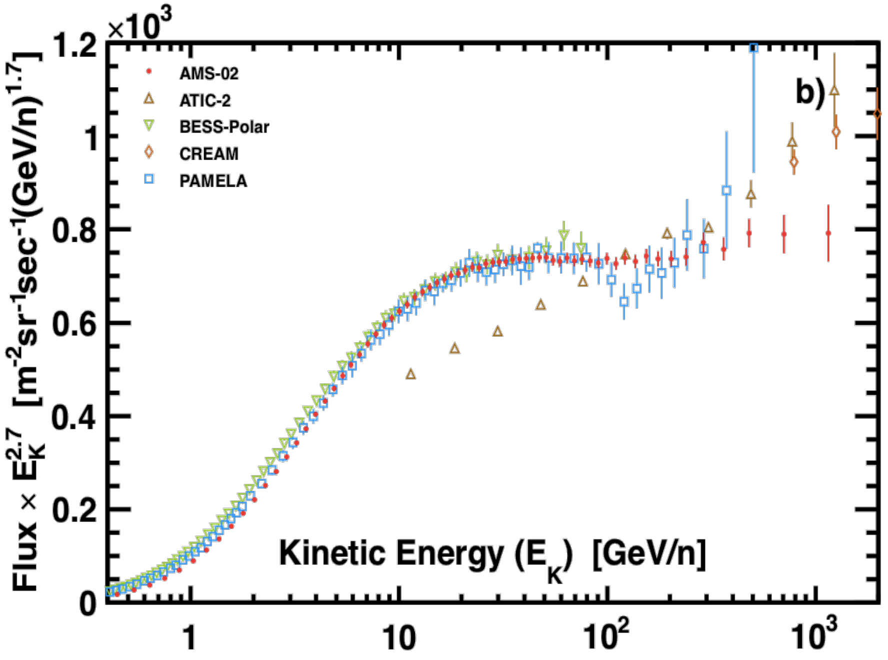
Energy reach for less abundant species is just matter of statistics (i.e. time)



H and He fluxes



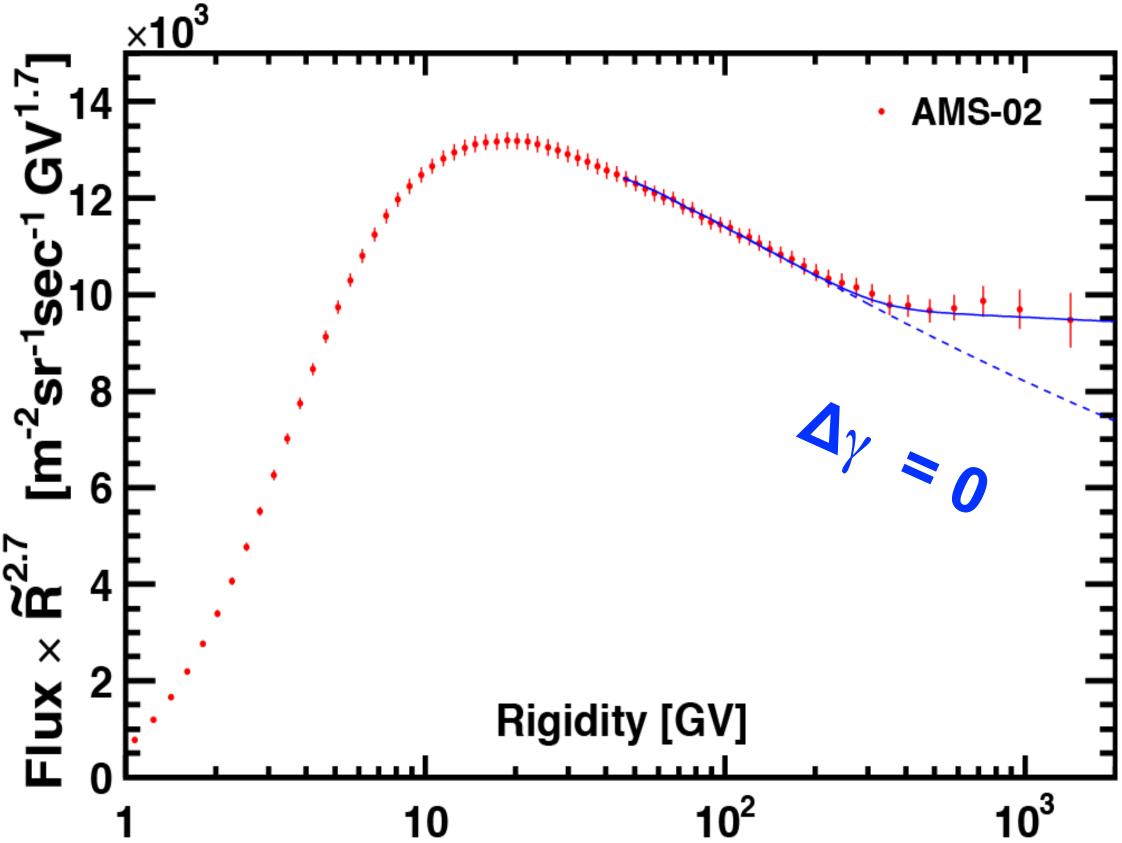




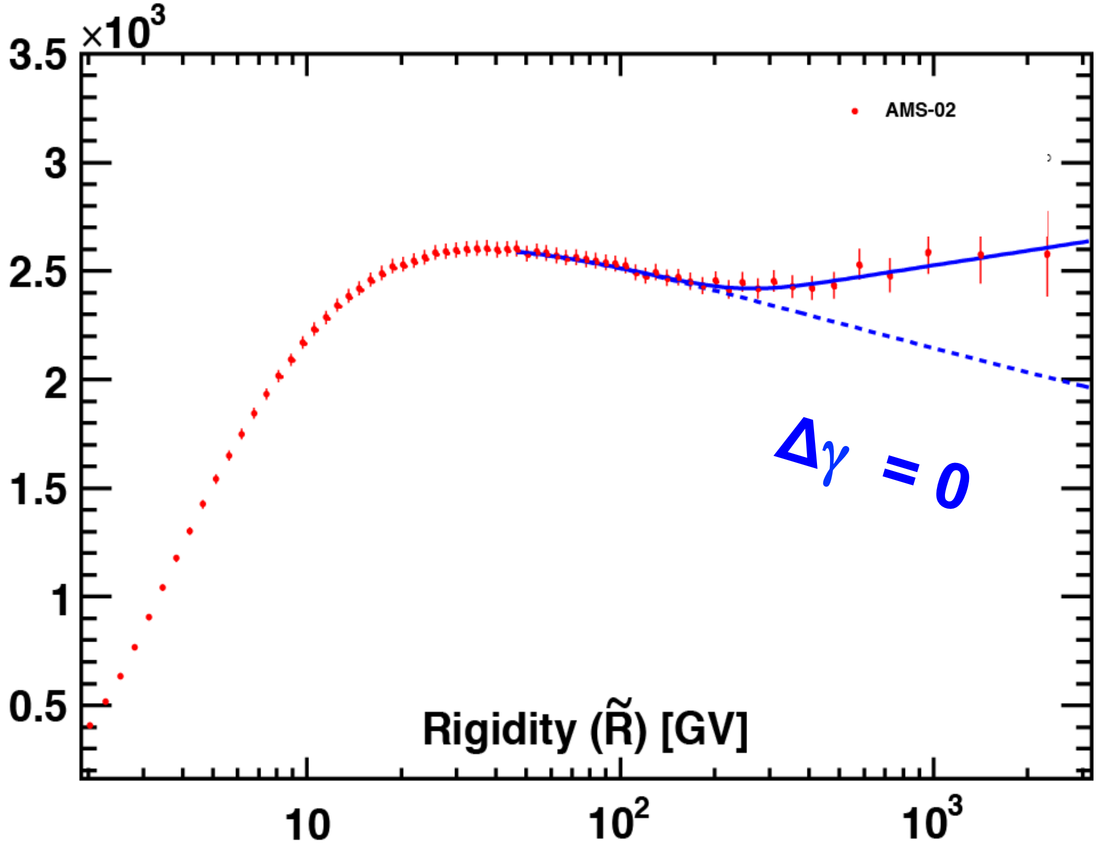
AMS H and He fluxes

Two power laws R^{γ},$R^{\gamma+1}$ with a characteristic transition rigidity R_0 and a smoothness parameter s well describe H, He measured spectra:

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

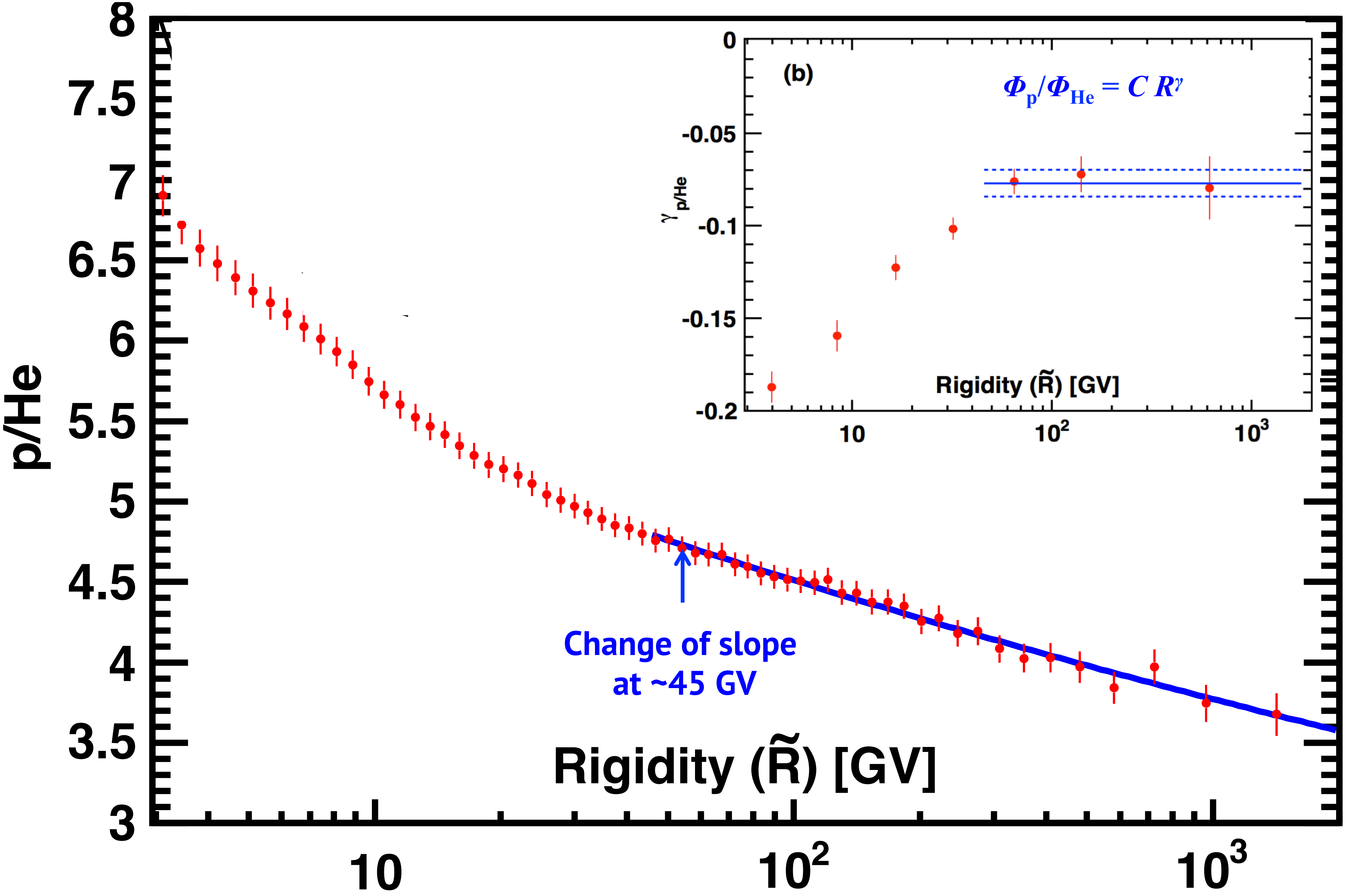


γ = -2.849 ± 0.002 + 0.004/-0.003
s = 0.024 +0.020/-0.013+0.027/-0.016
$\Delta\gamma$ = 0.133 + 0.032/-0.021 +0.046/-0.030
R_0 = 336 +68/-44 + 66/-28 GV



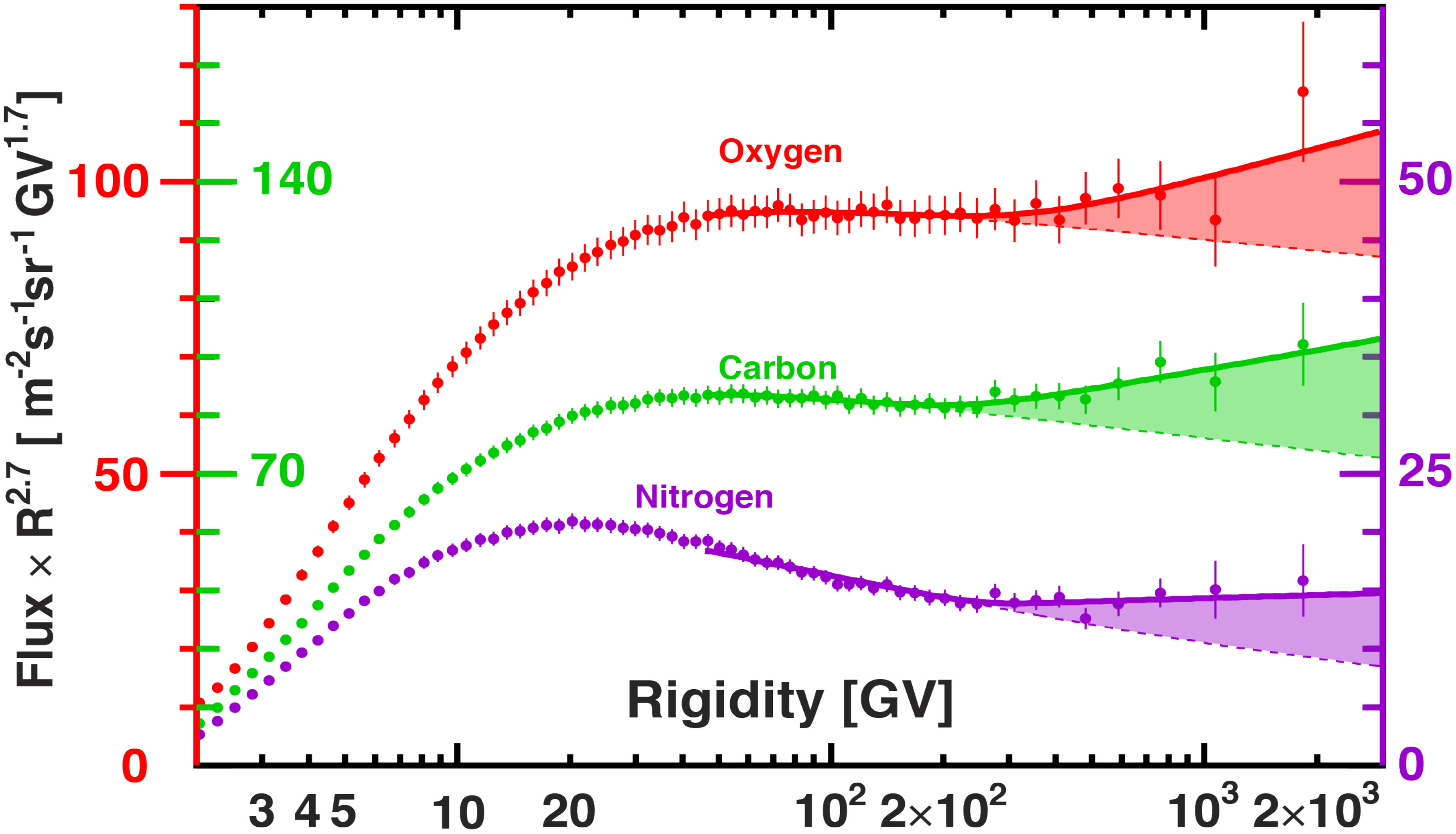
γ = -2.781 ± 0.005 + 0.005/-0.004
$\Delta\gamma$ = 0.127 + 0.025/-0.017 +0.035/-0.031
s = 0.040 +0.032/-0.020+0.021/-0.016
R_0 = 264 +50/-32 + 33/-32 GV

AMS p/He flux ratio



What about other primary CRs?

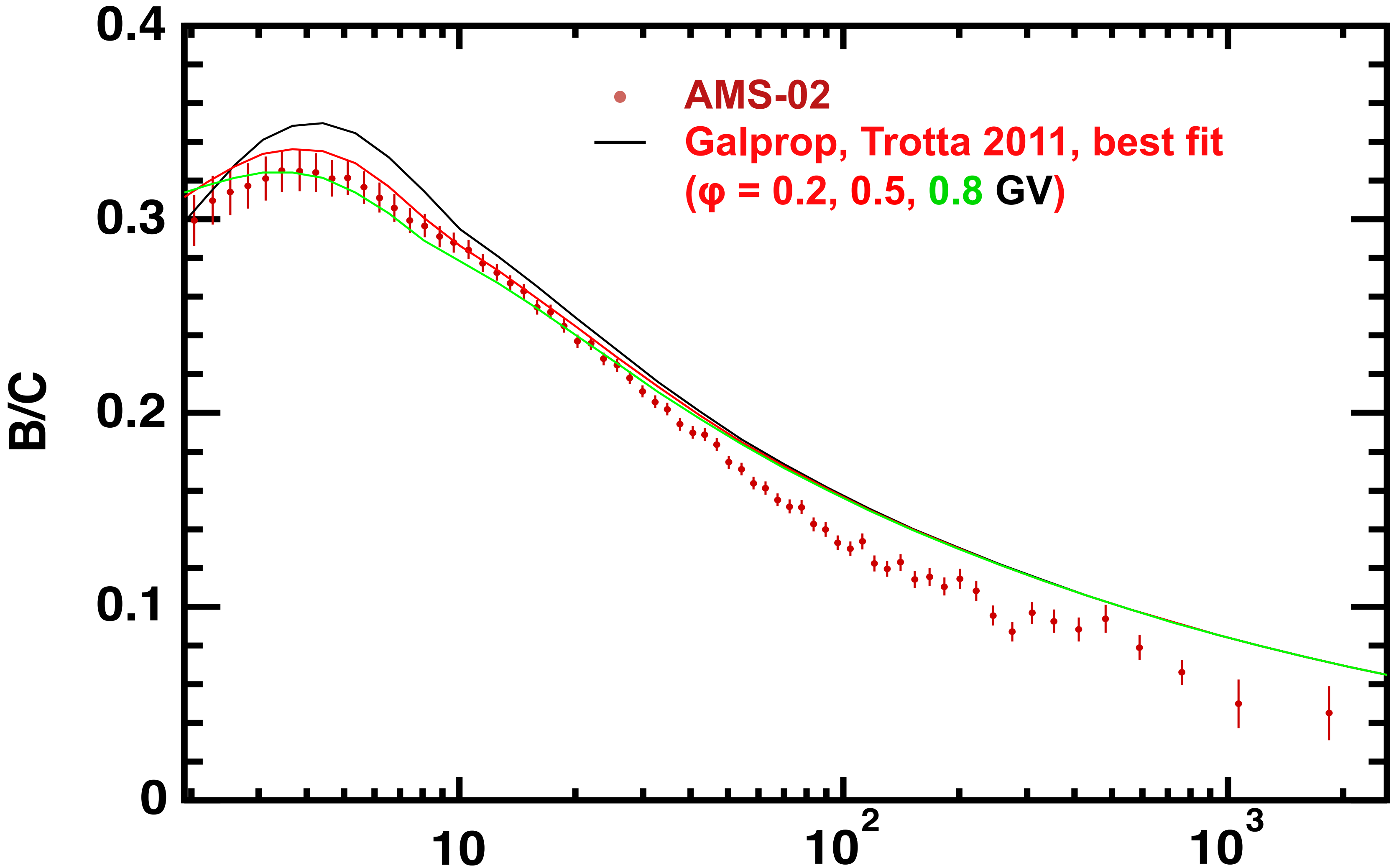
Also for Carbon, Nitrogen and Oxygen the single-power law behaviour is excluded by AMS-02 data: a change of spectral index is observed at ≈ the same rigidity.



Analysis ongoing

Secondary CRs: Boron to Carbon flux ratio

AMS-02 precision challenges current theoretical models

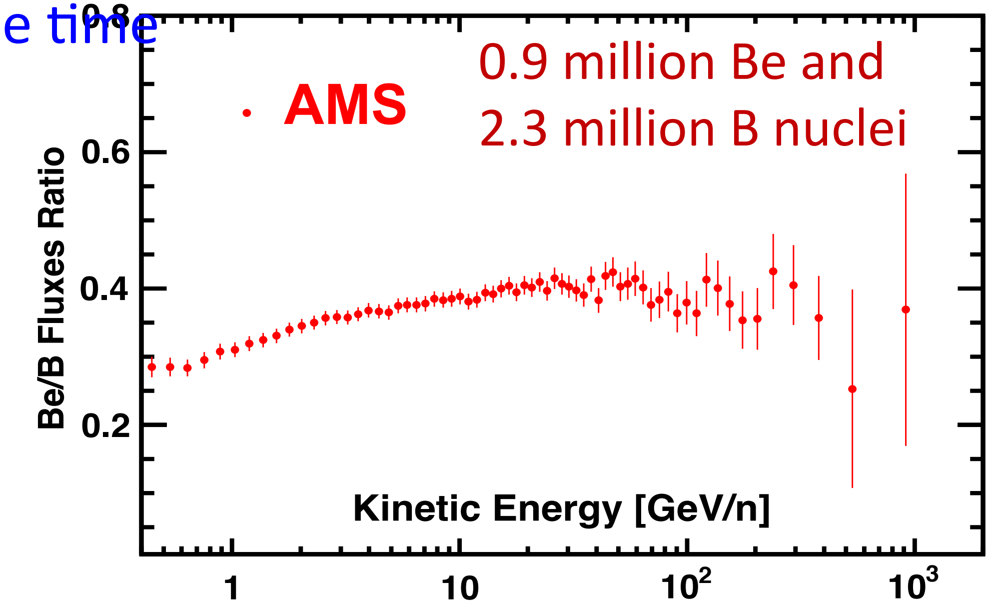


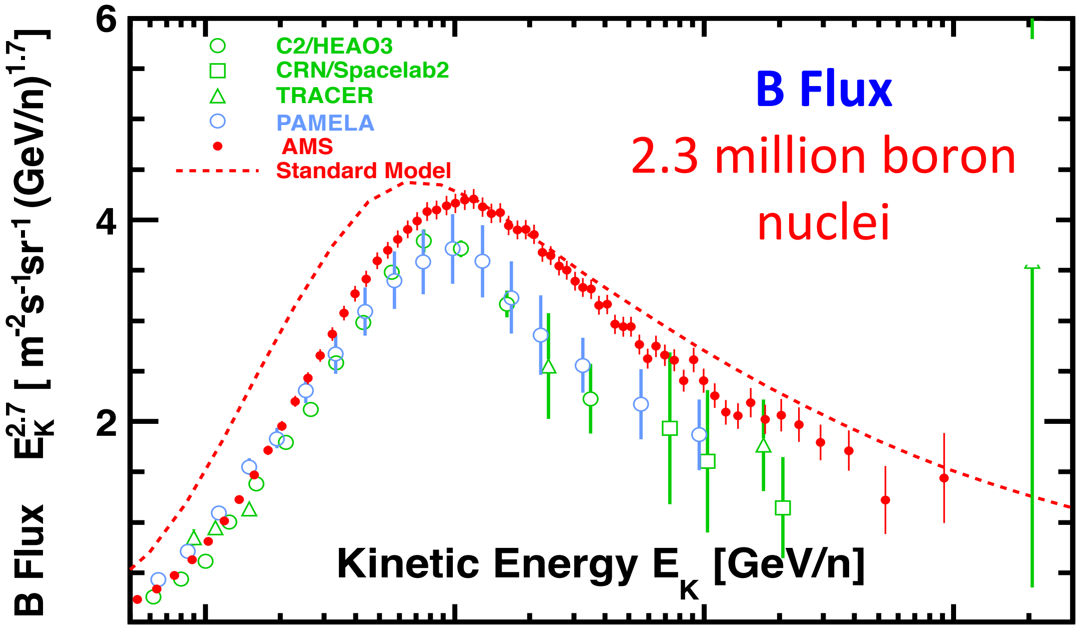
More on Secondary CRs:

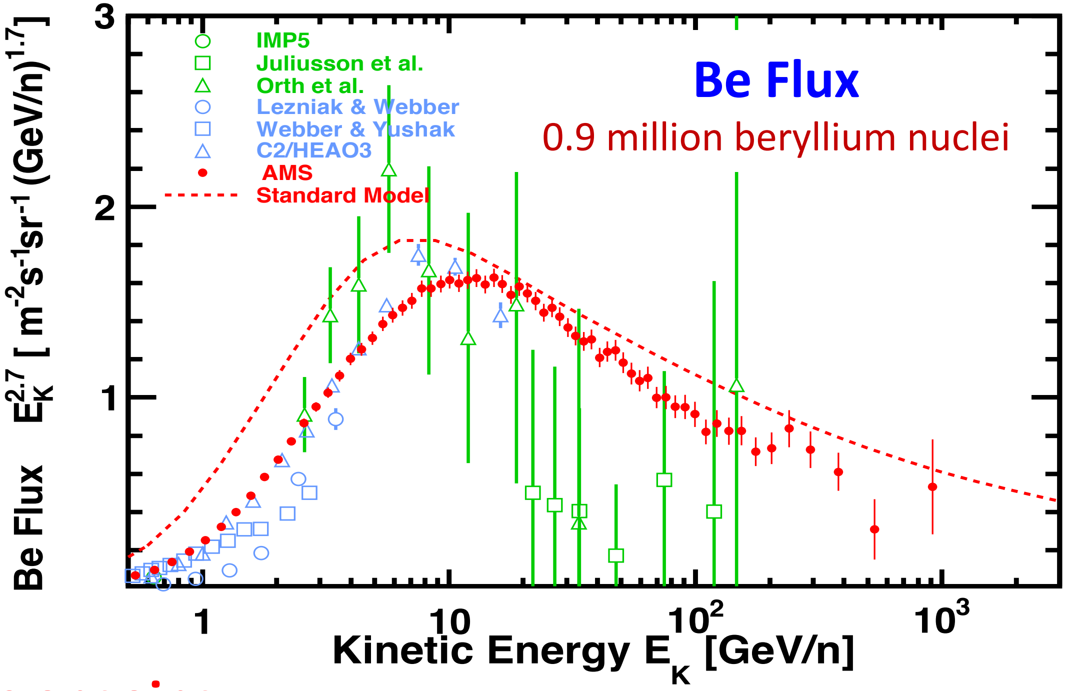
^{10}Be is a natural *clock* to measure the residence time of CR in the galaxy: $^{10}\text{Be} \rightarrow {}^{10}\text{B} + e^{-} + \nu_e$ with half-life of 1.5×10^6 years

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

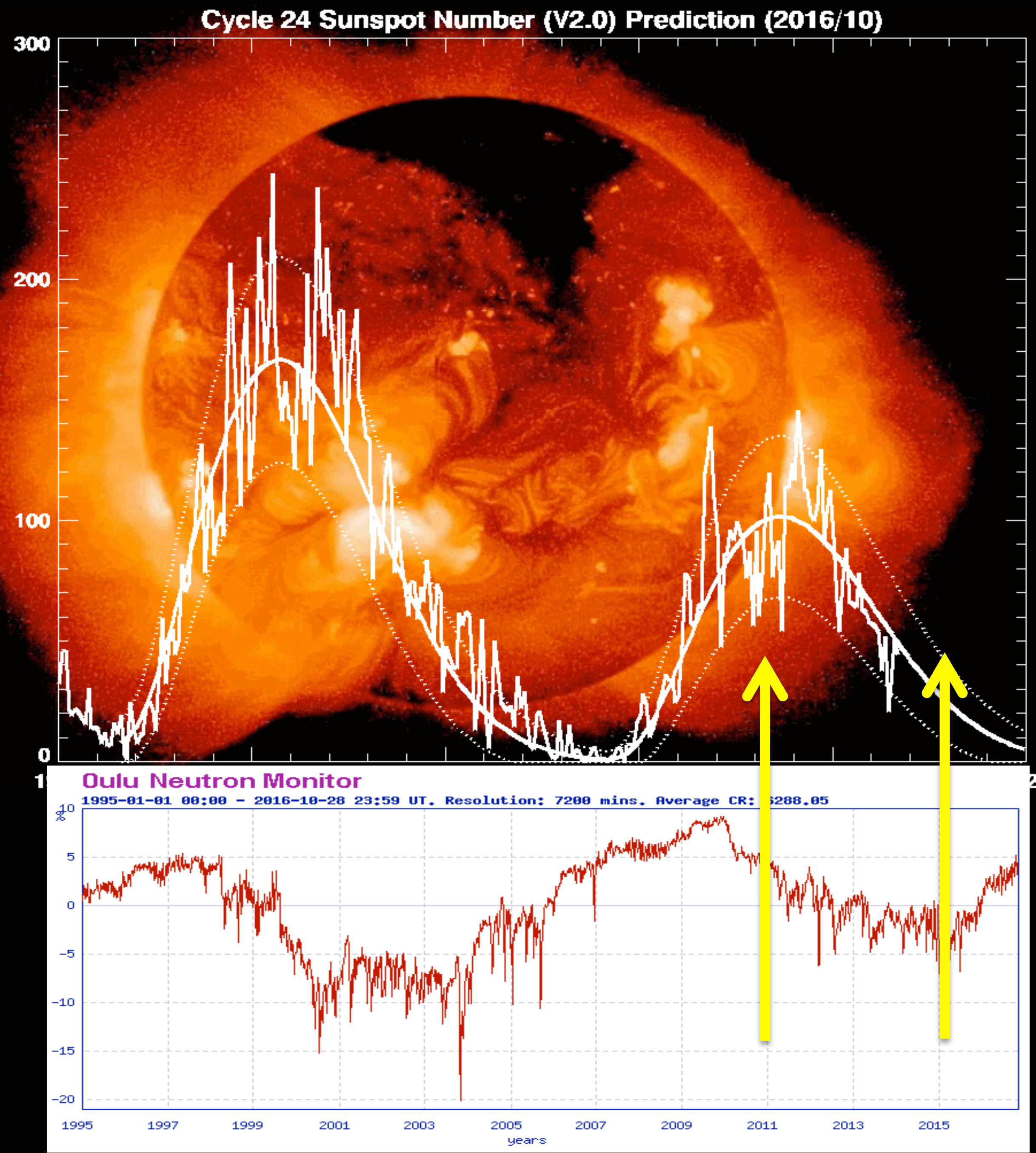


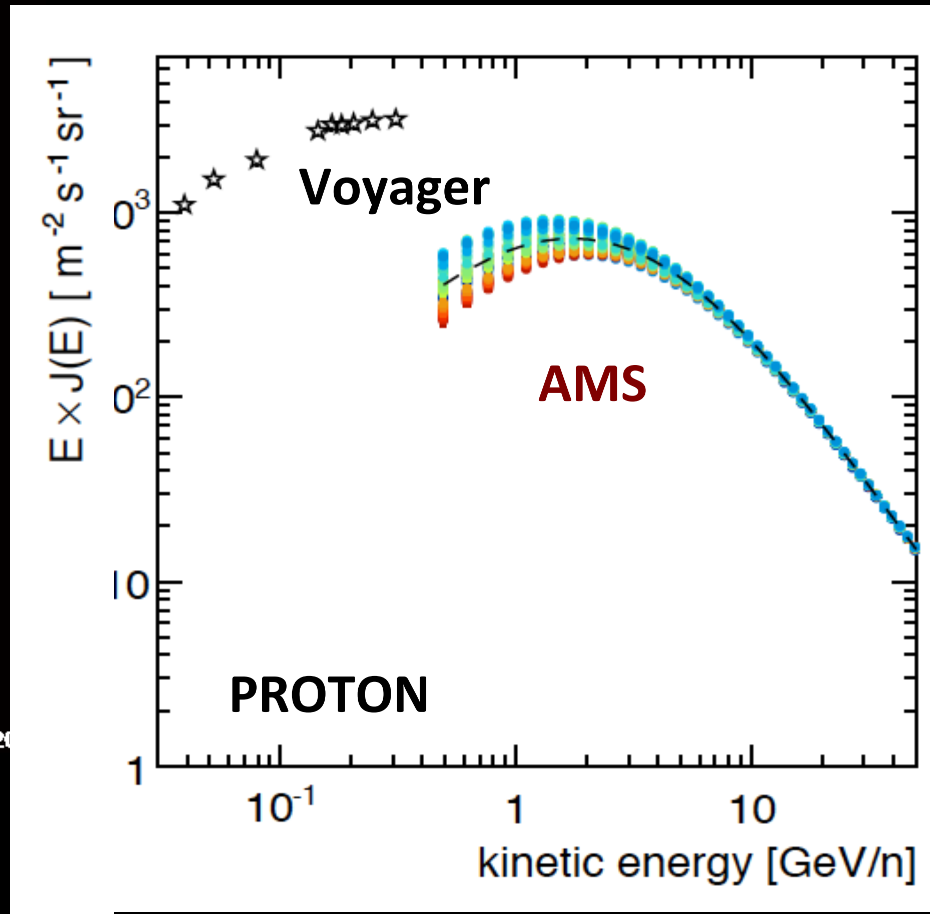




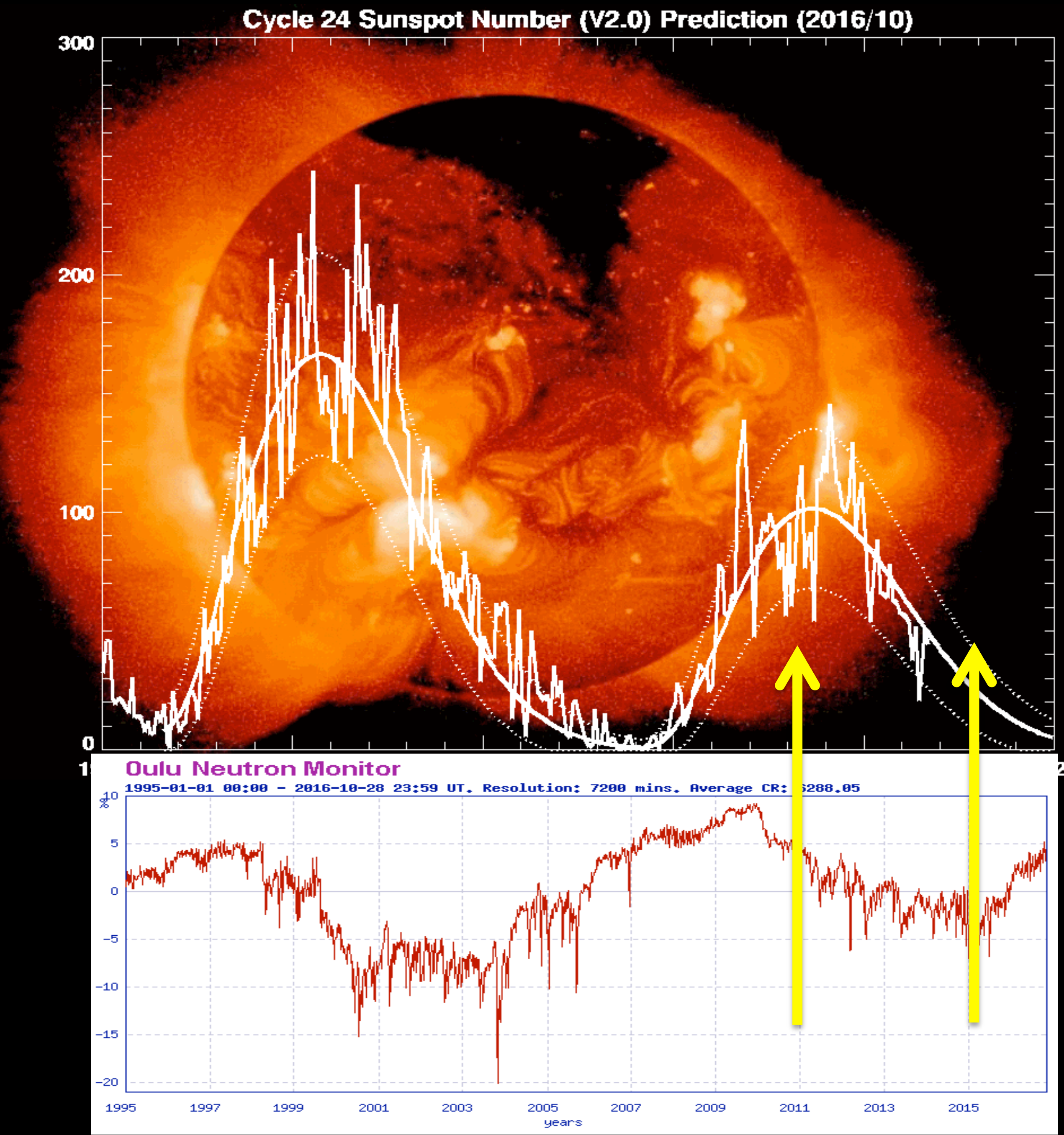
Analysis ongoing

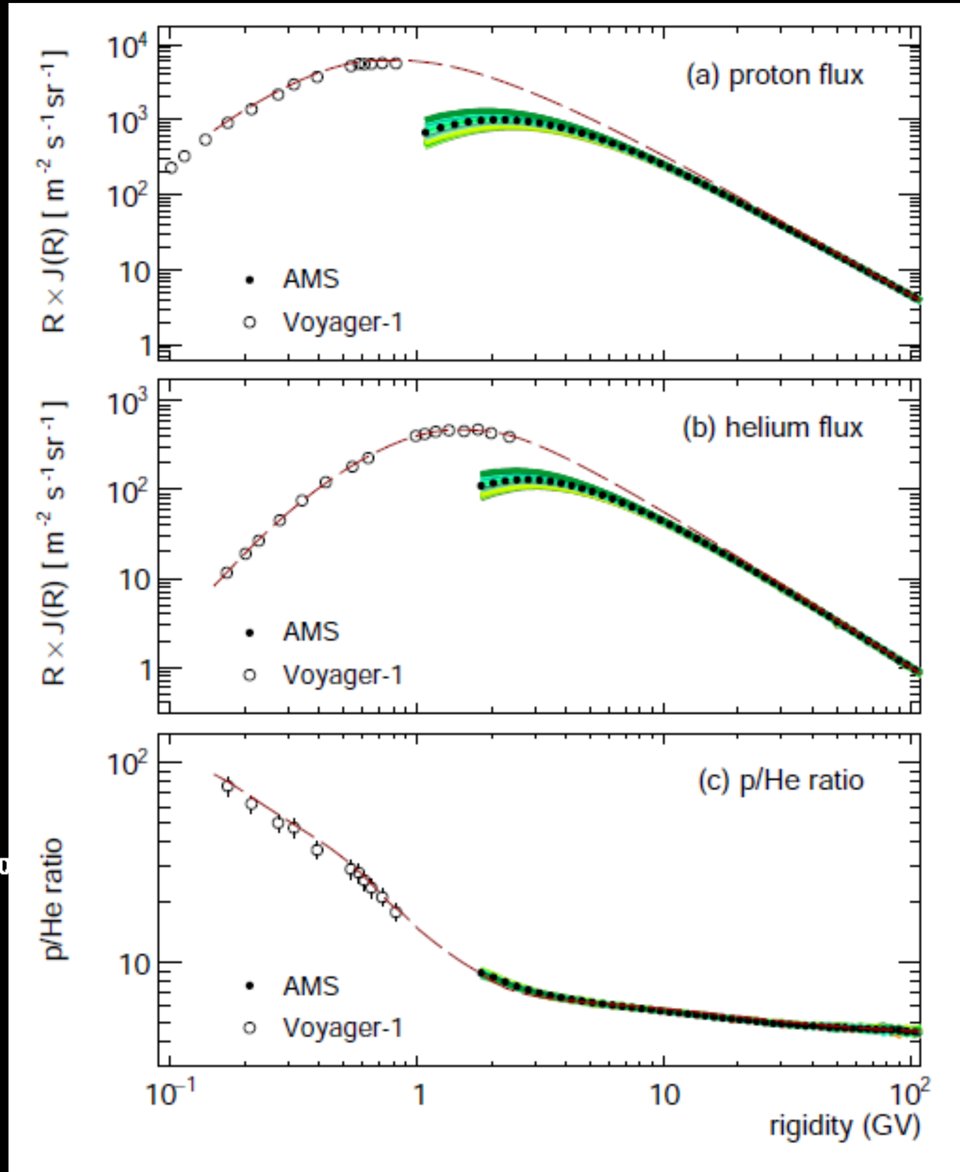
Heliospheric effects: time dependent measurement of ALL particle fluxes to retrieve properties of the LIS



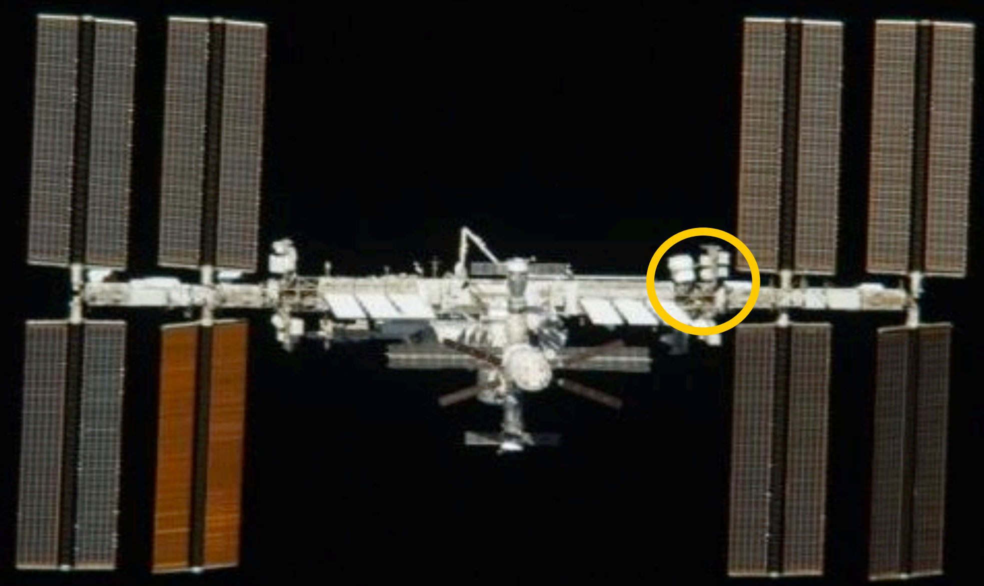


Heliospheric effects: time dependent measurement of ALL particle fluxes to retrieve properties of the LIS





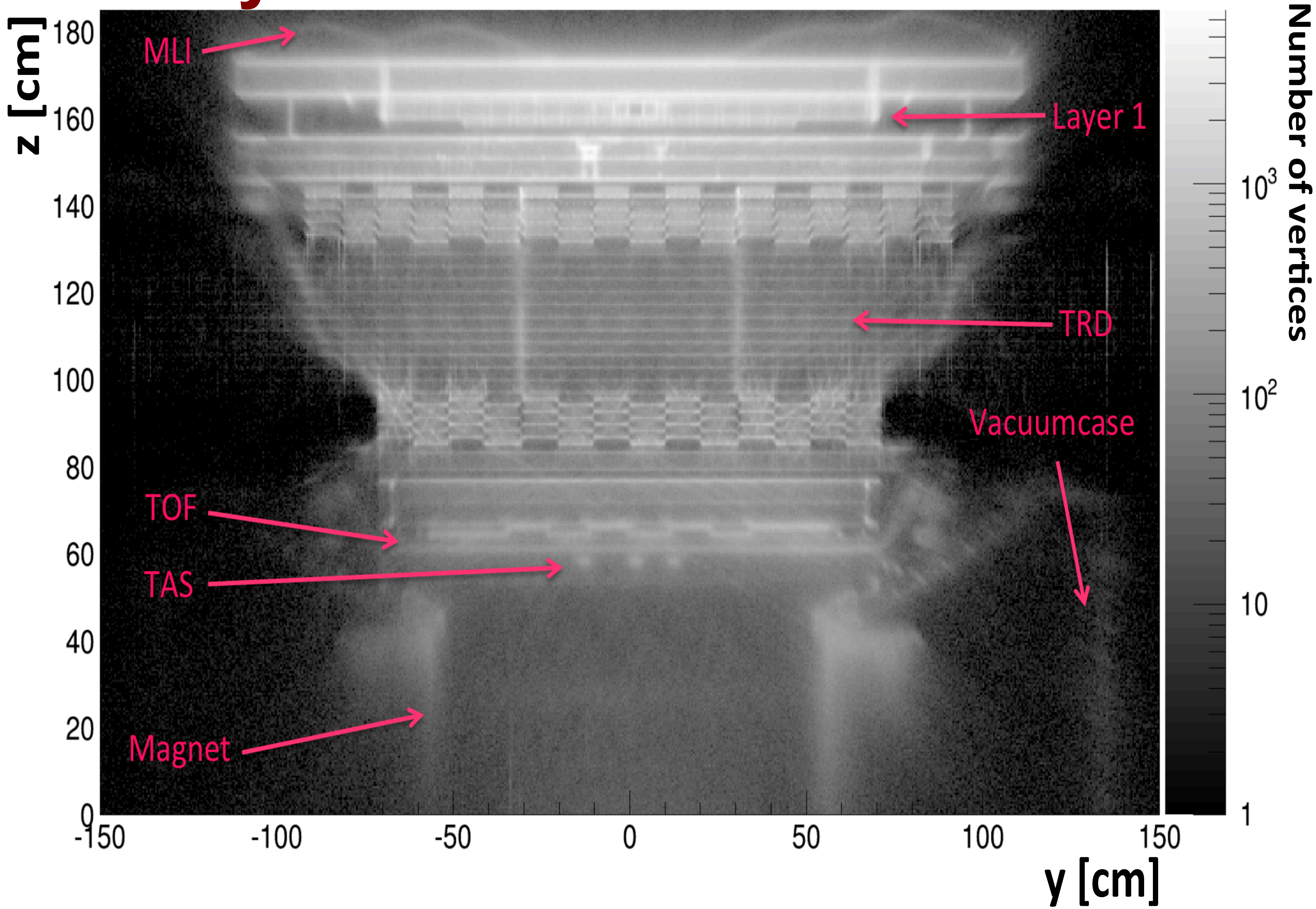
Conclusions



- AMS is providing simultaneous measurements of different cosmic ray species with O(%) accuracy in an extended energy range
- new phenomena are being highligted by these measurements whose nature will be further clarified as more data will be collected by the experiment.
- AMS will match the lifetime of the Space Station: stay tuned !

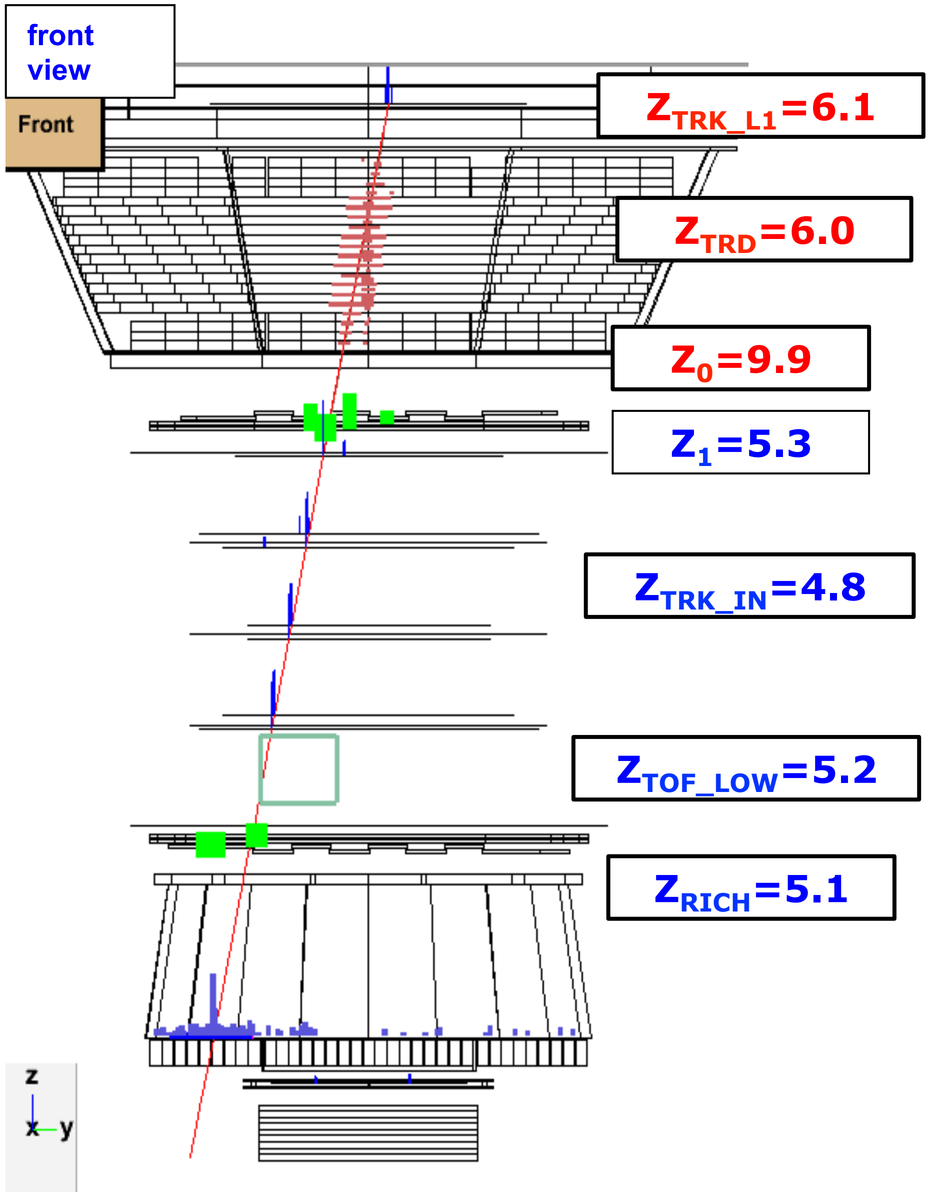
BACKUP

Tomography of detector materials by means of CR interactions

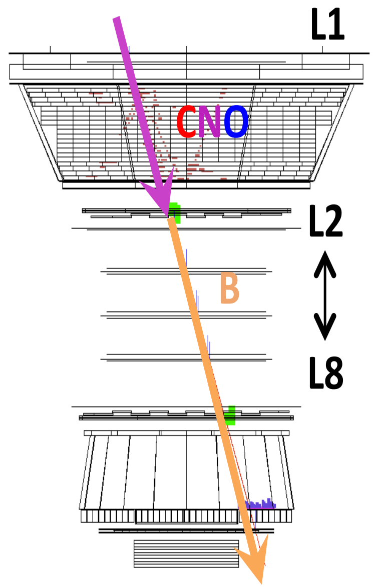


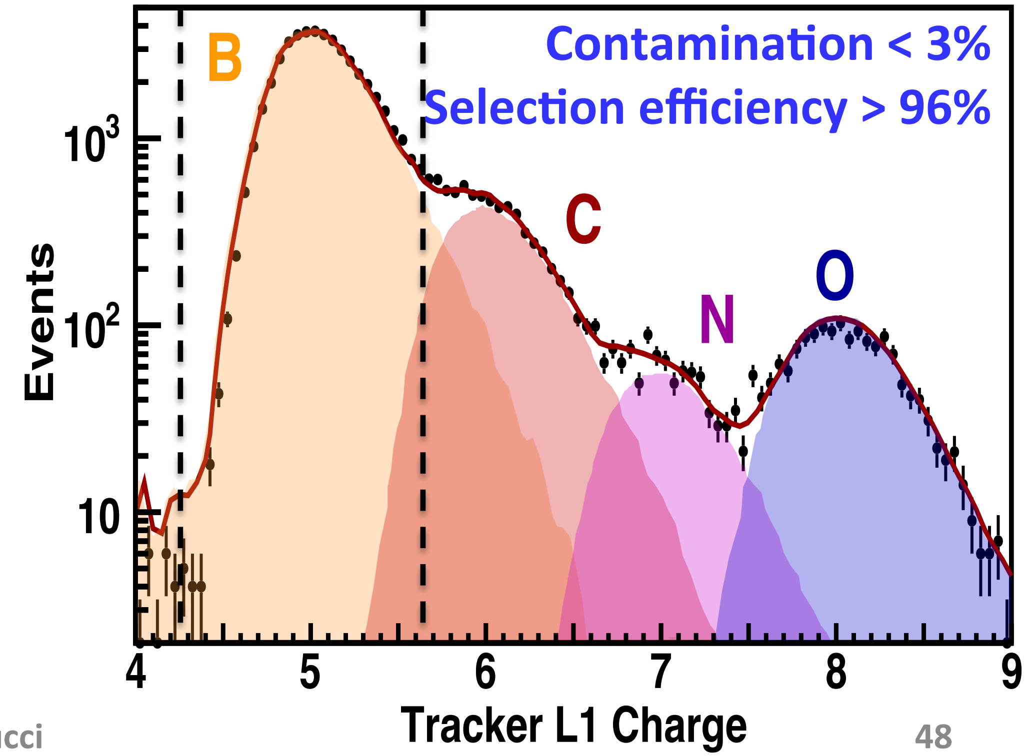
Full Control of fragmentation in the detector: e.g. background from interactions below L1

Carbon Fragmentation to Boron R = 10.6 GV



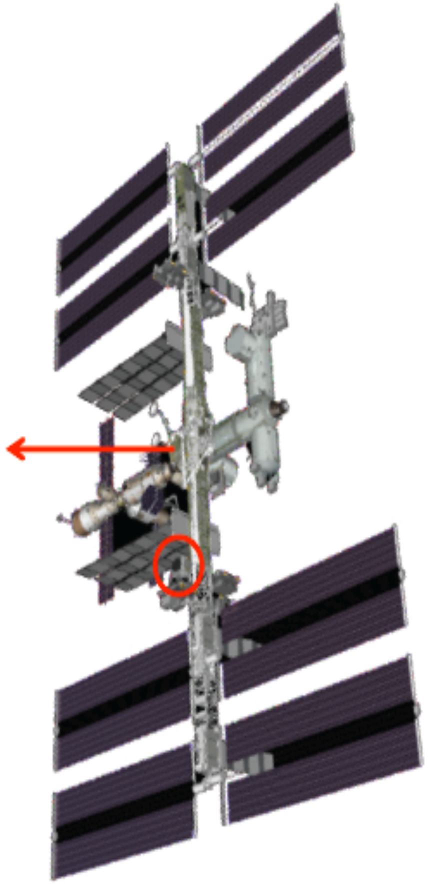
Measured from Data by fitting the Charge Distribution in L1 with Charge Distribution in L2 obtained by pure nuclear samples selected by charge in the Inner Tracker. Typical systematic error < 0.5%.

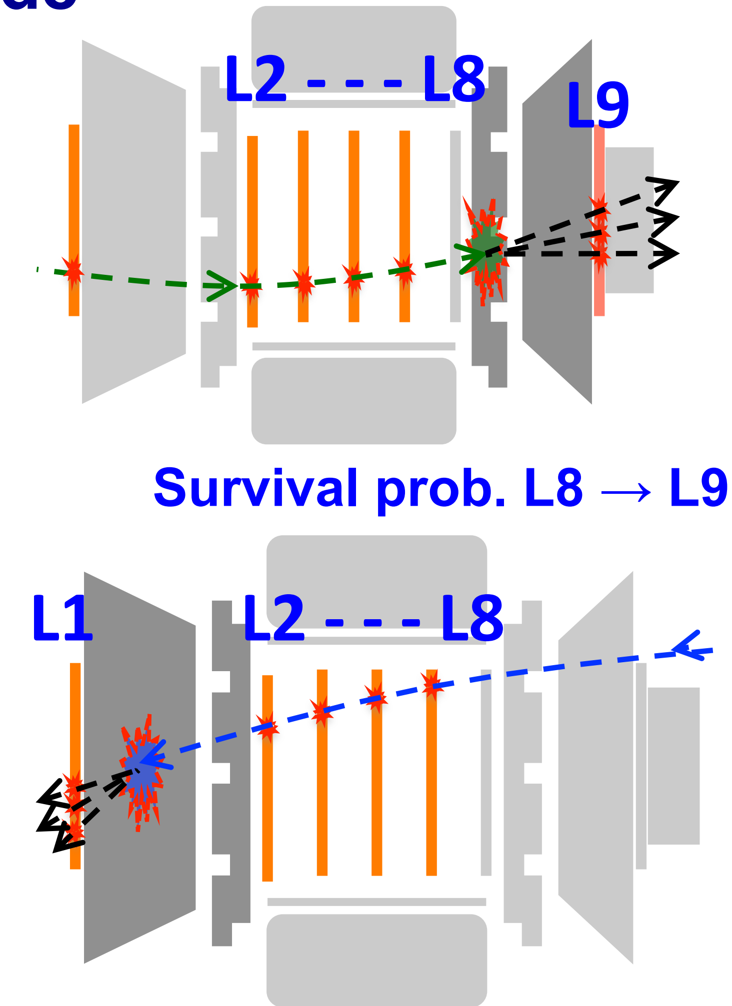




Direct measurement of survival probabilities:

Measurement of nuclear cross sections when AMS flies in horizontal attitude





Survival prob. L8 → L9

Survival prob. L2 → L1

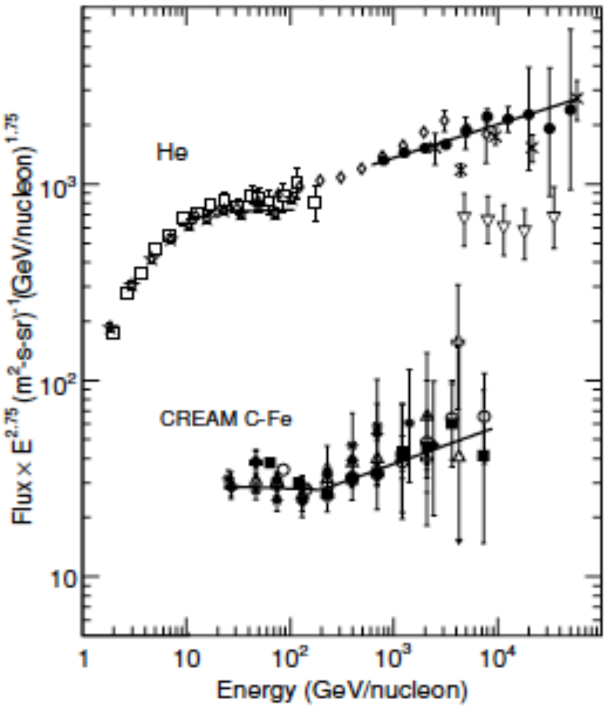
First, we use the seven inner tracker layers, L2-L8, to define beams of nuclei: He (Li, Be, B, …)

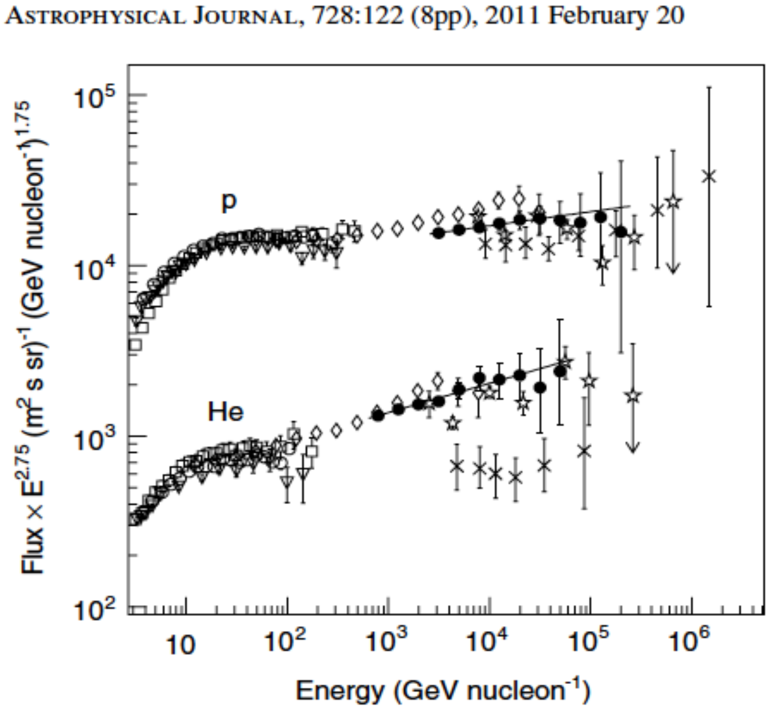
Second, we use left-to-right particles to measure the nuclear interactions in the lower part of the detector.

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

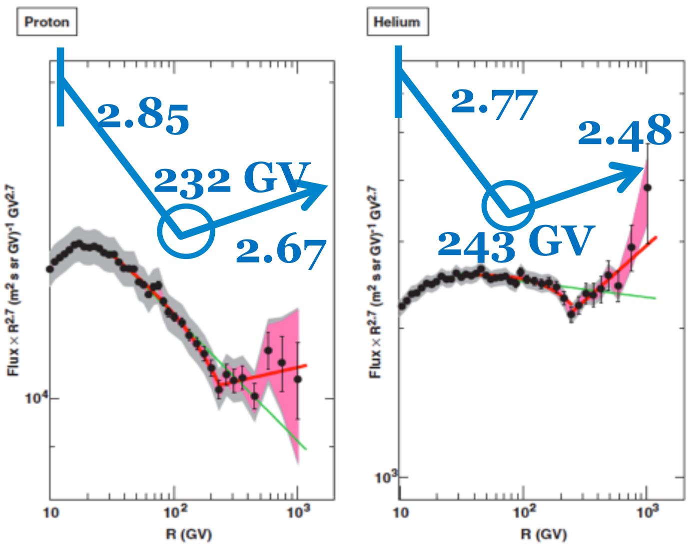
Survival probabilities L8-L9 can be evaluated with high statistics in "normal" data taking conditions

Spectral features & composition



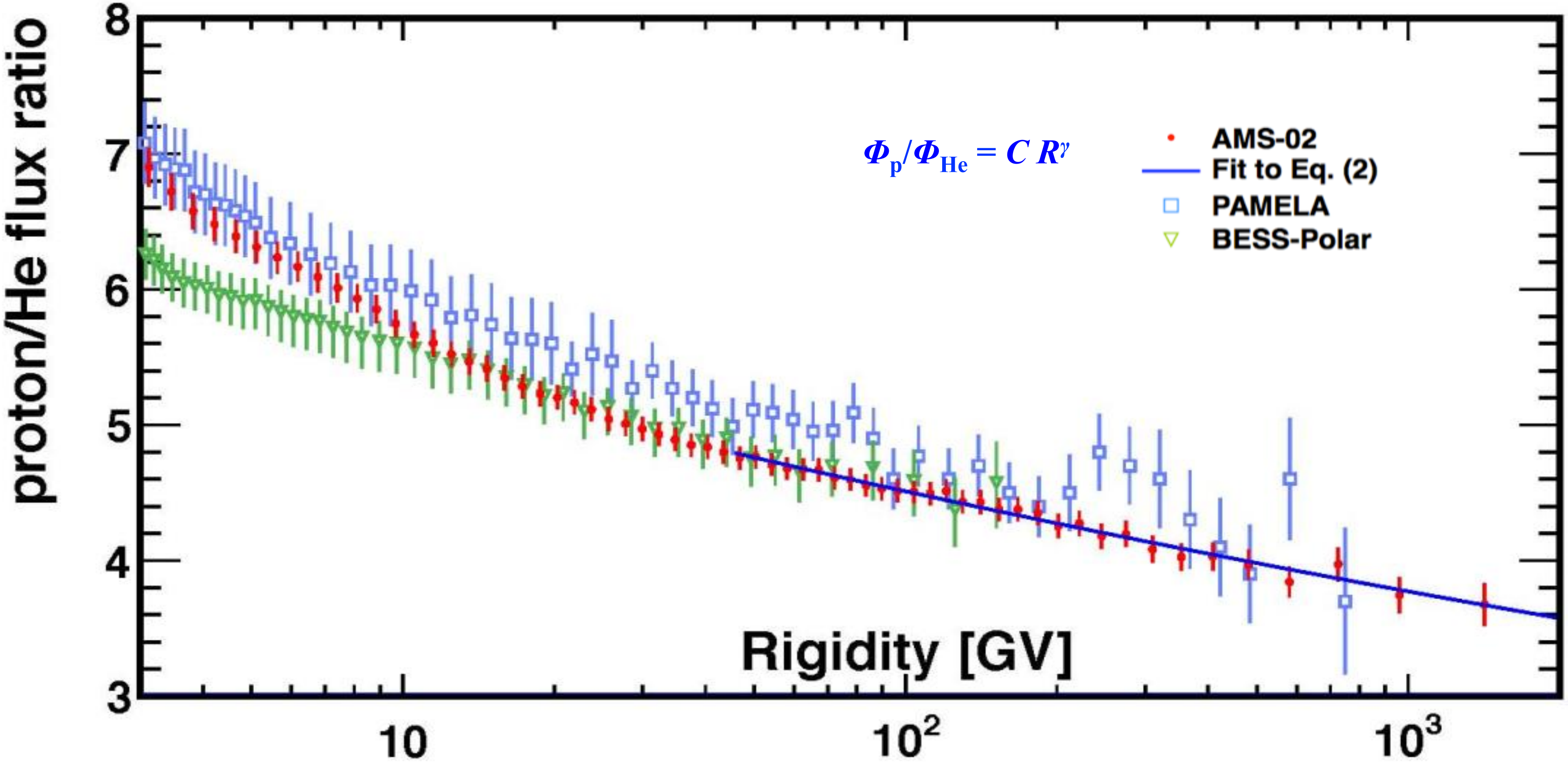


CREAM, APJ 2010, 2011



PAMELA, Science 2011

Breaks occur also at "low" energies…



proton/He flux ratio
8
7
6
5
4
3
10
10^2
10^3
Rigidity [GV]
$\Phi_p/\Phi_{He} = C\,R^\gamma$
AMS-02
Fit to Eq. (2)
PAMELA
BESS-Polar

Anti-proton/proton

the early times (1984)

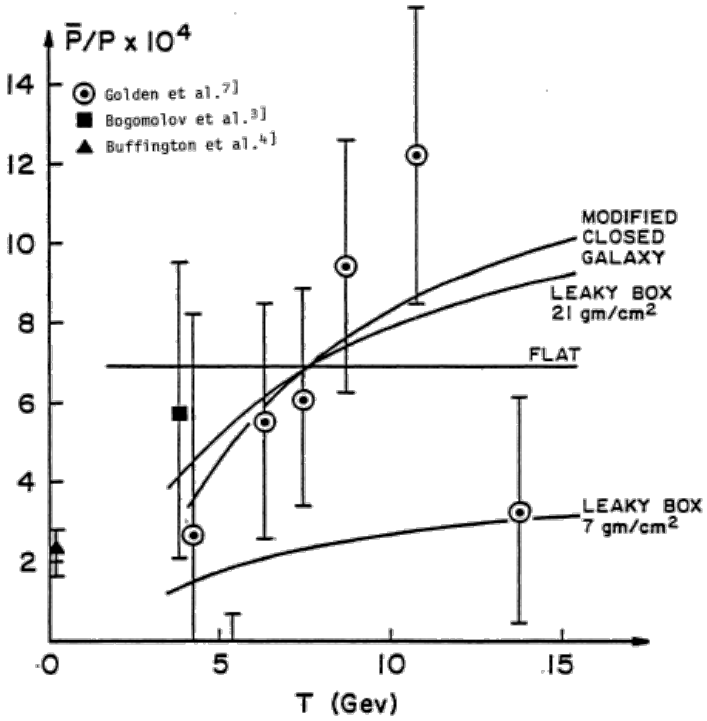
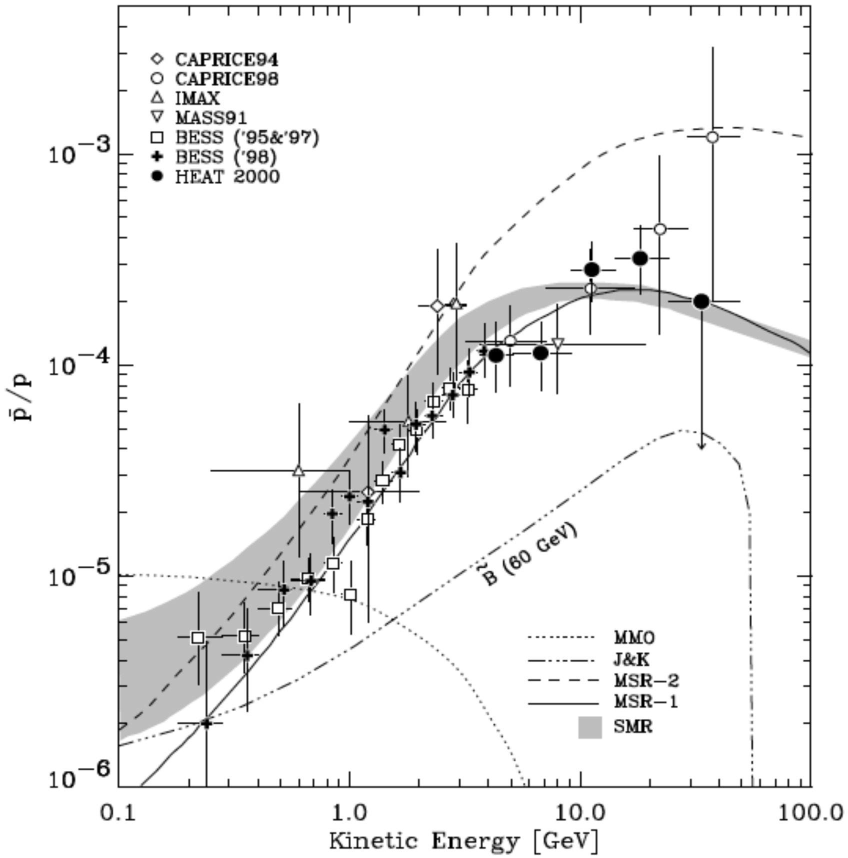


Figure 1. Antiproton Observations and Predictions

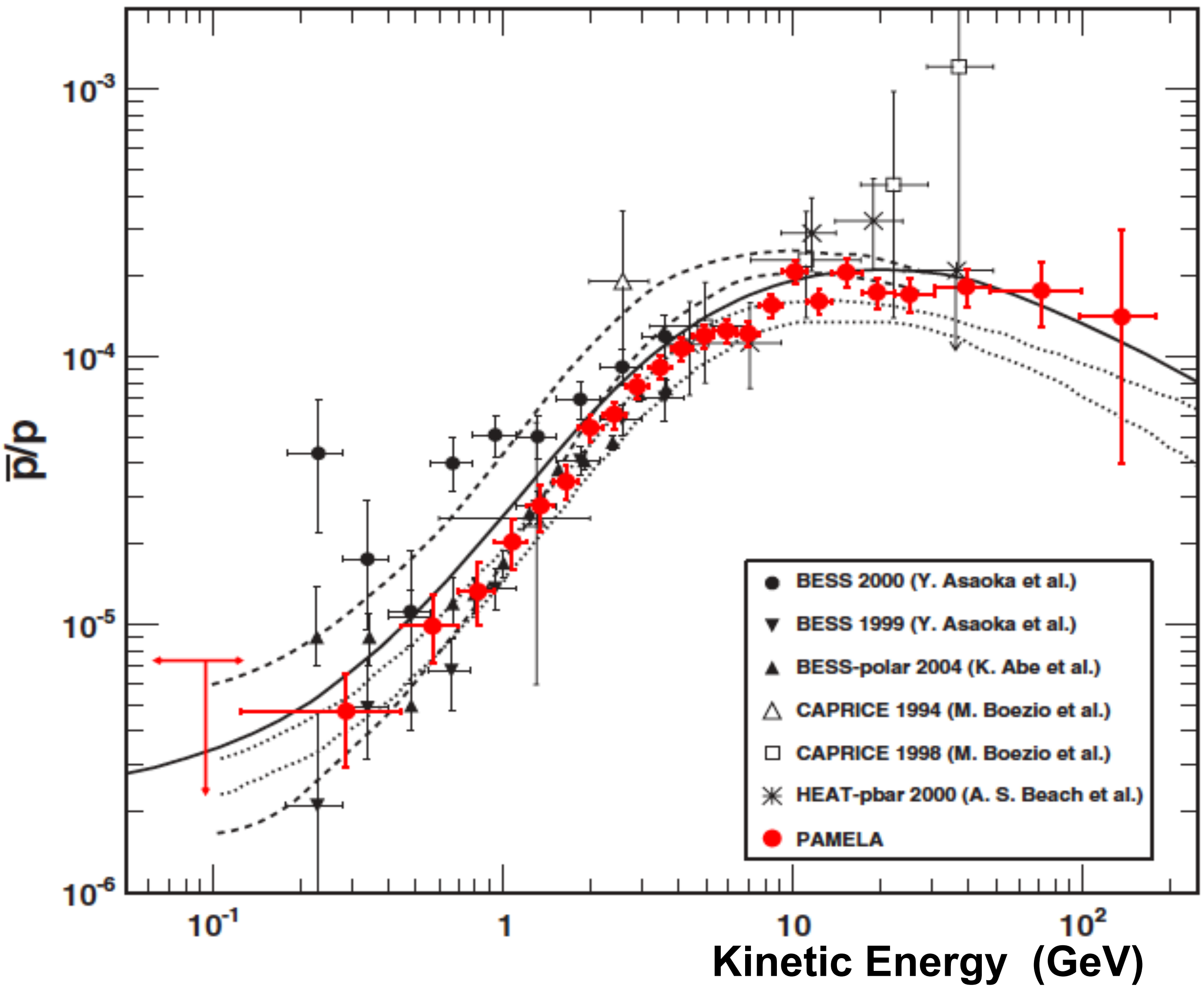
...around 2000



HEAT ≈ 70 events
CAPRICE ≈ 31 events

Anti-proton/proton : 2010

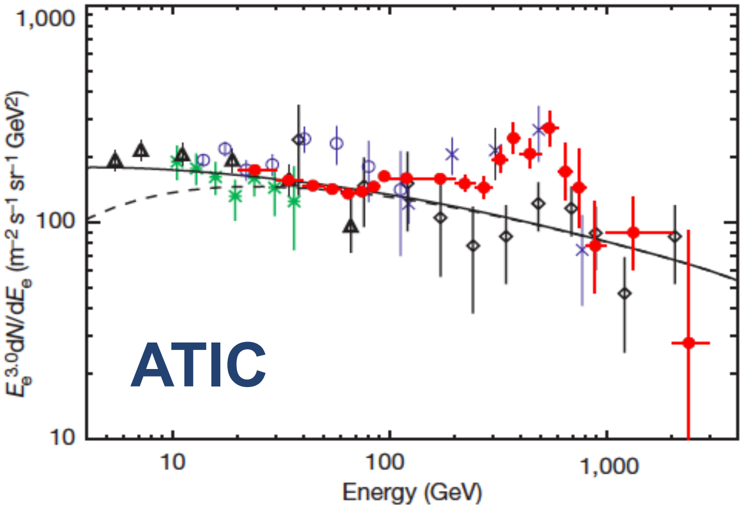
BESS-POLAR (2004) ≈ 1520 event < 4.2 GeV
PAMELA (2006-2009) ≈ 1500 events



2008-2009: the e^+/e^- puzzle

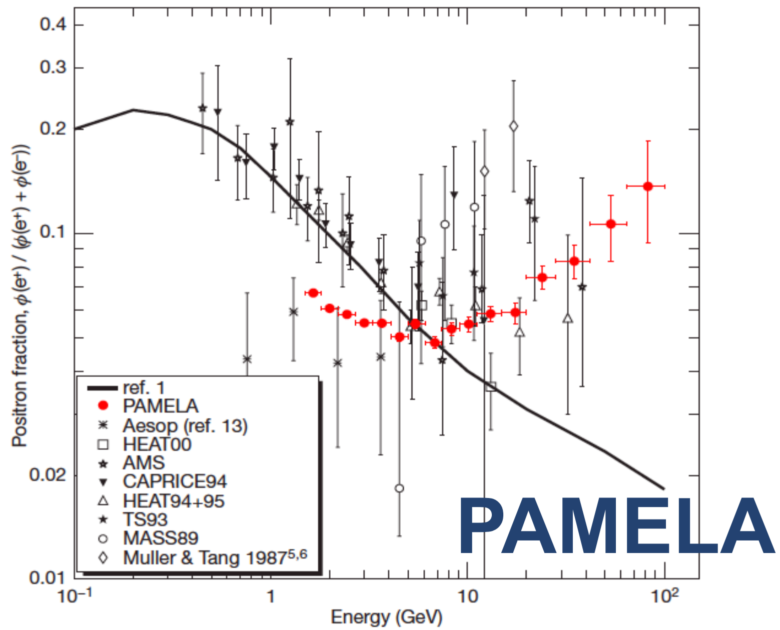
An excess of cosmic ray electrons at energies of 300–800 GeV

Vol 456 | 20 November 2008 | **doi:10.1038/nature07477**



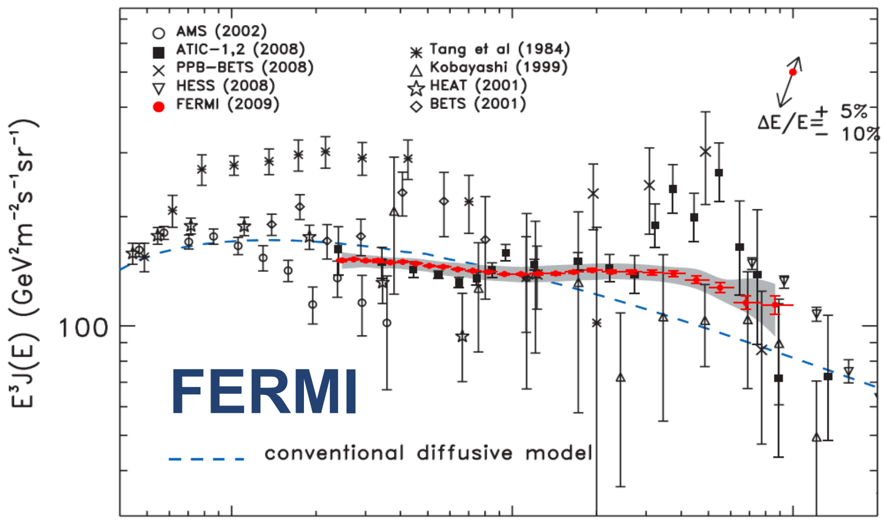
An anomalous positron abundance in cosmic rays with energies 1.5–100 GeV

Vol 458 | 2 April 2009 | **doi:10.1038/nature07942**

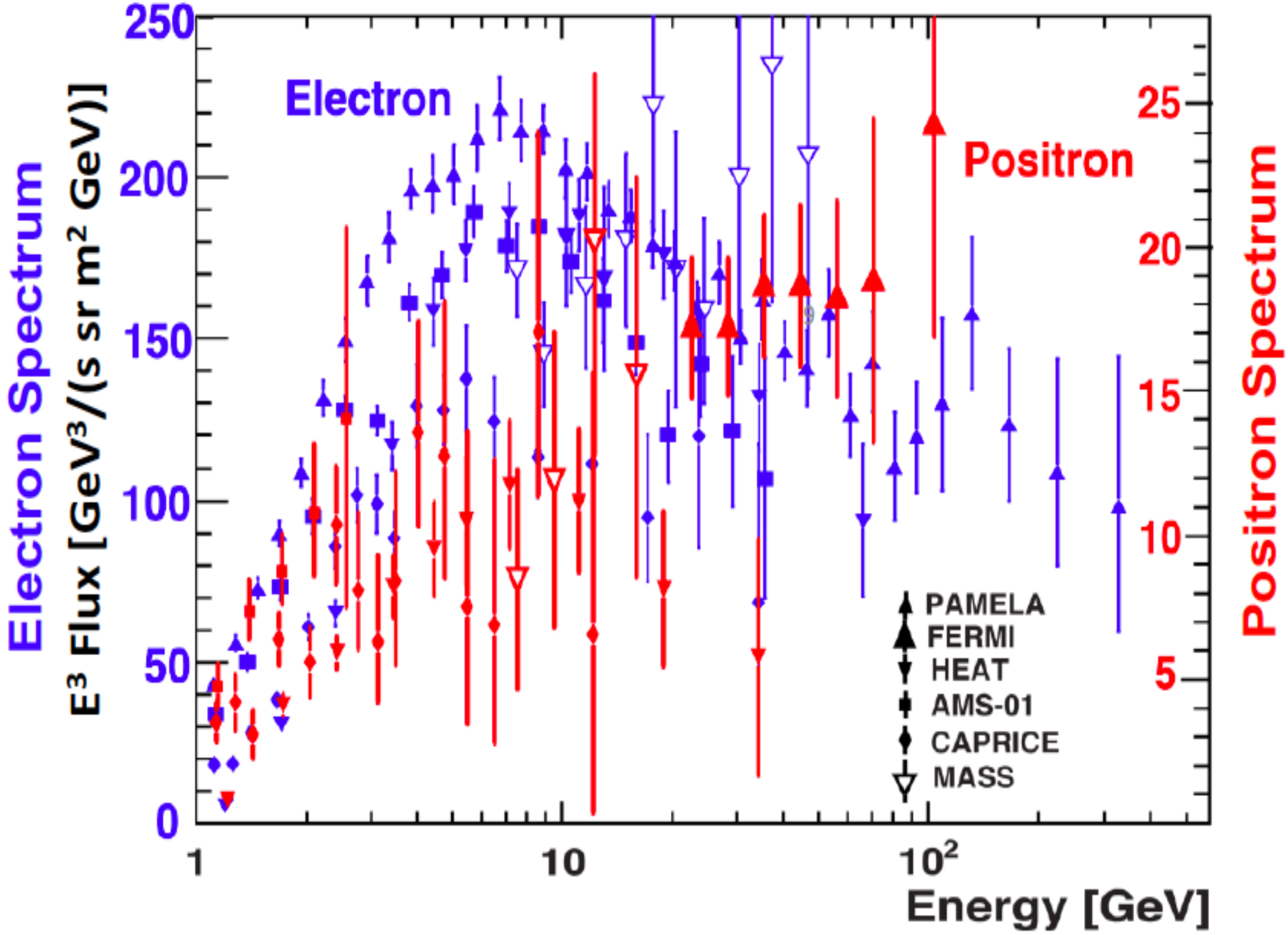


Measurement of the Cosmic Ray $e^+ + e^-$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope

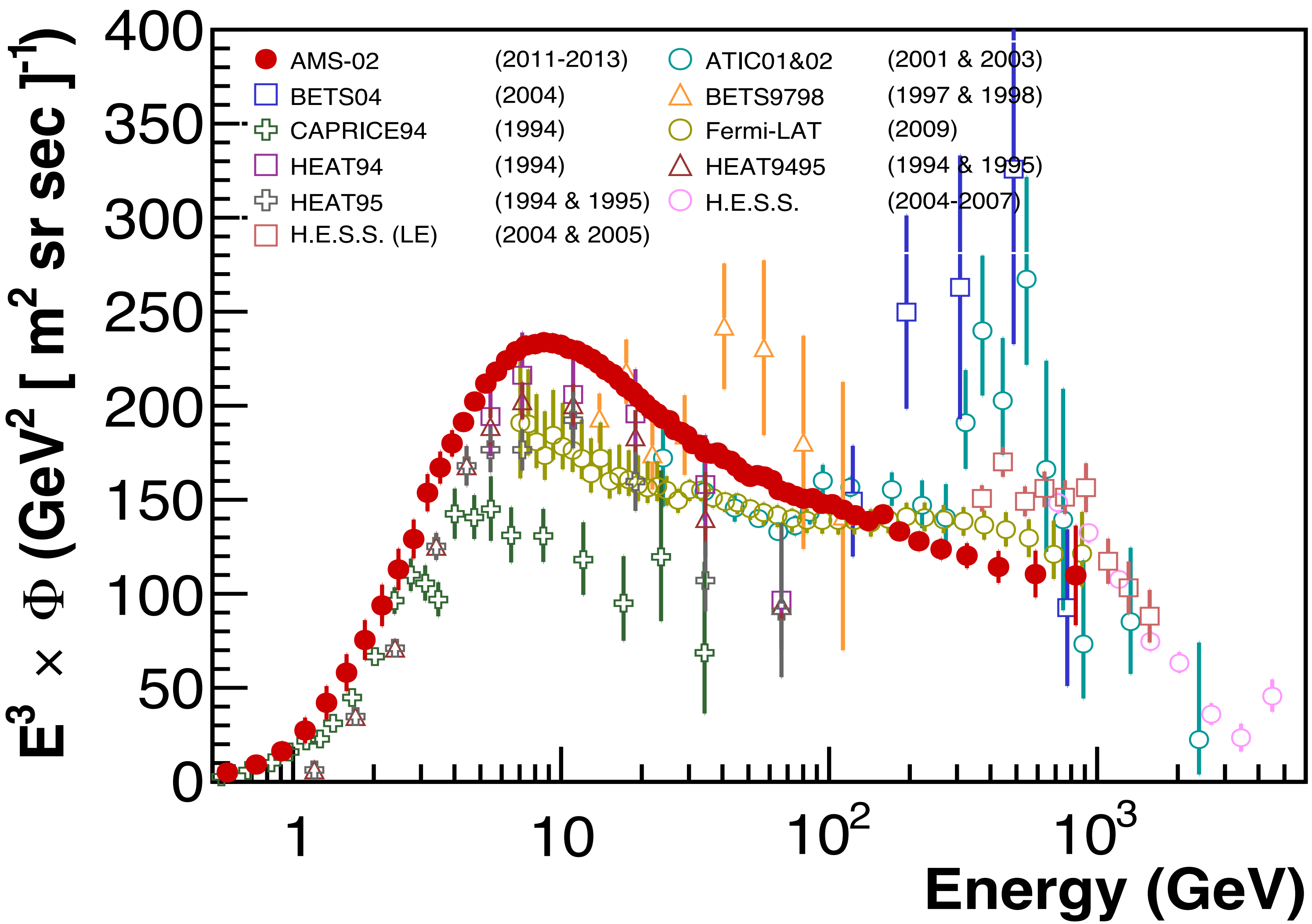
PRL **102,** 181101 (2009)



Electron & Positron measurements before AMS

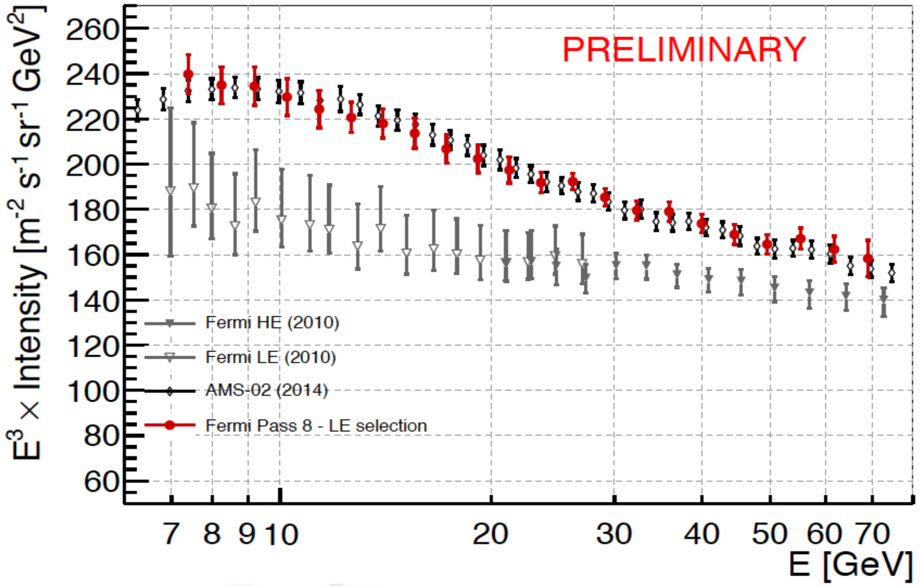


e⁺+e⁻ fluxes



AMS-02 (2011-2013)
BETS04 (2004)
CAPRICE94 (1994)
HEAT94 (1994)
HEAT95 (1994 & 1995)
H.E.S.S. (LE) (2004 & 2005)
ATIC01&02 (2001 & 2003)
BETS9798 (1997 & 1998)
Fermi-LAT (2009)
HEAT9495 (1994 & 1995)
H.E.S.S. (2004-2007)
E³ × Φ (GeV² [m² sr sec]⁻¹)
Energy (GeV)
0
50
100
150
200
250
300
350
400
1
10
10²
10³

$e^+ + e^-$ fluxes @ SciNeGhe 2016



Waiting for new results from:

- **+ AMS**
- **+ CALET**
- **+ DAMPE**