



Dark Matter signal from $e^+ / e^- / \bar{p}$ with the AMS Detector on the International Space Station

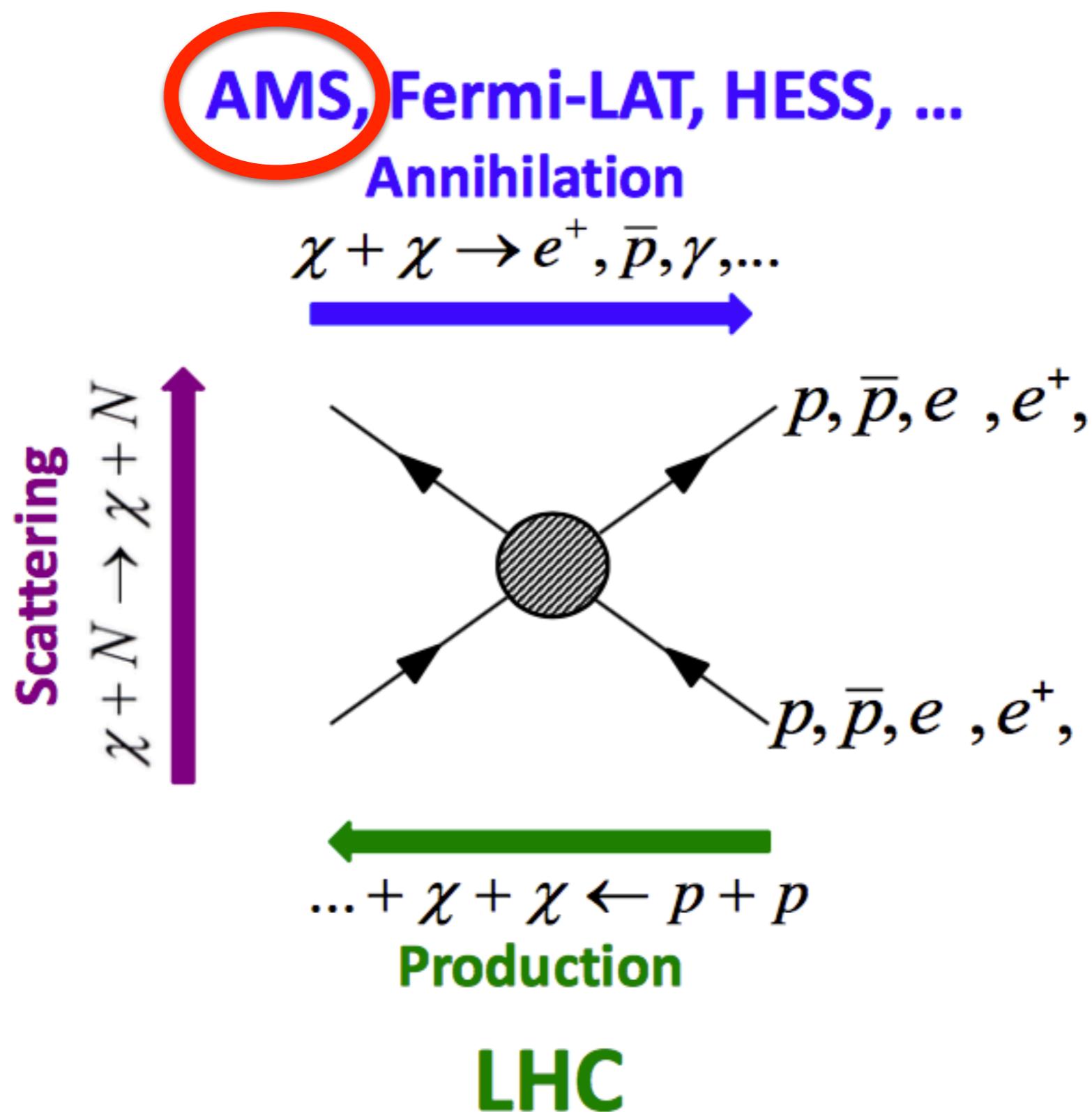
Nikolas Zimmermann on behalf of the AMS collaboration
07.07.2017 | EPS HEP 2017, Venice



RWTH AACHEN
UNIVERSITY

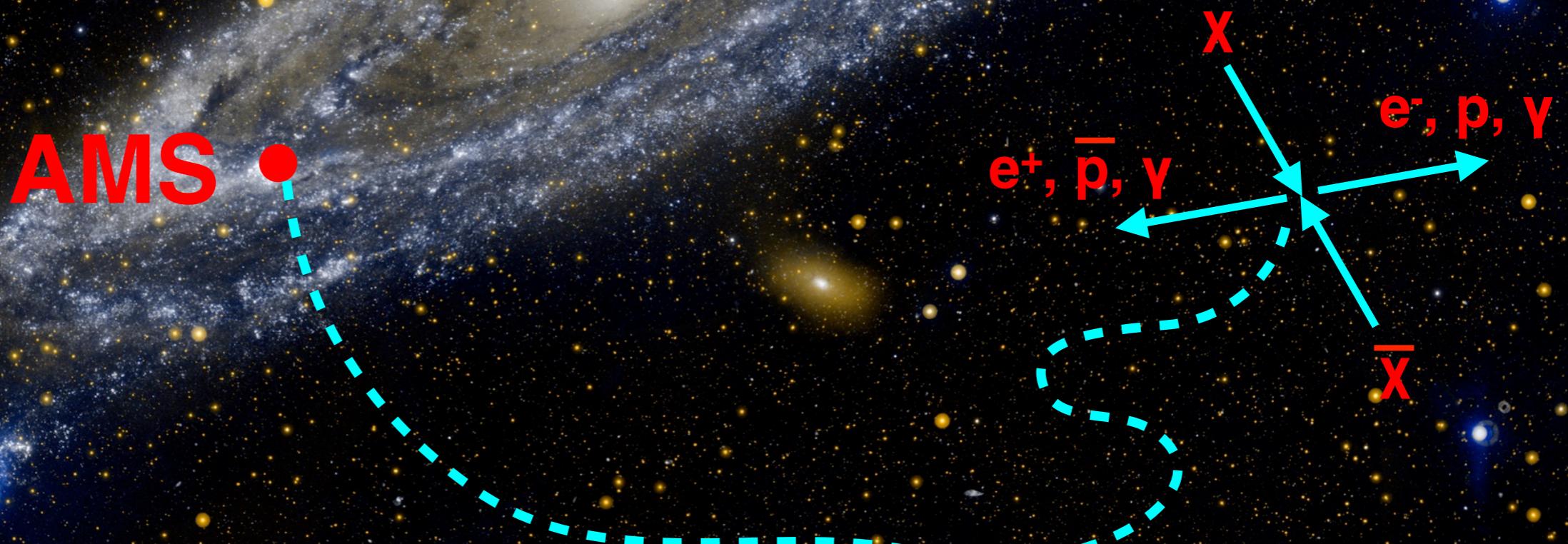
Multiple methods to search for dark matter...

LUX
DARKSIDE
XENON 100
CDMS II
...



The search for dark matter in cosmic rays

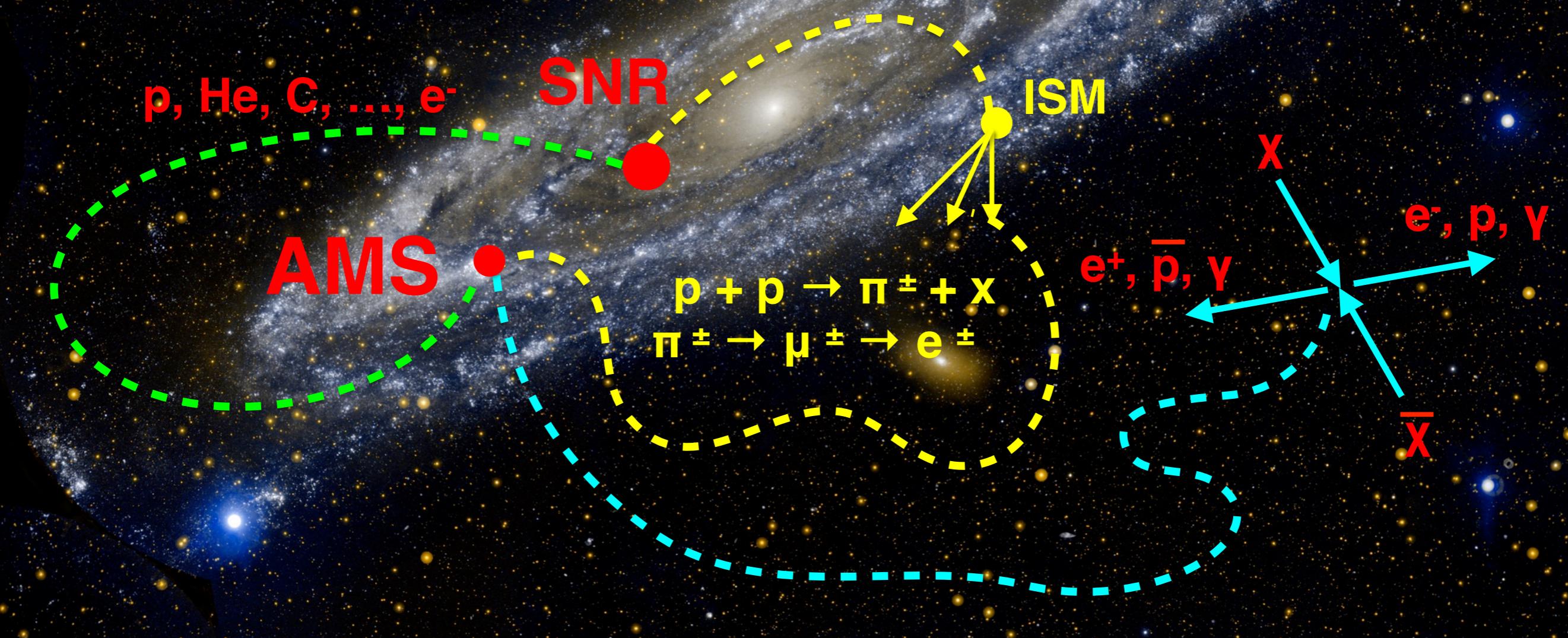
Dark matter annihilation can produce SM matter and antimatter cosmic rays.



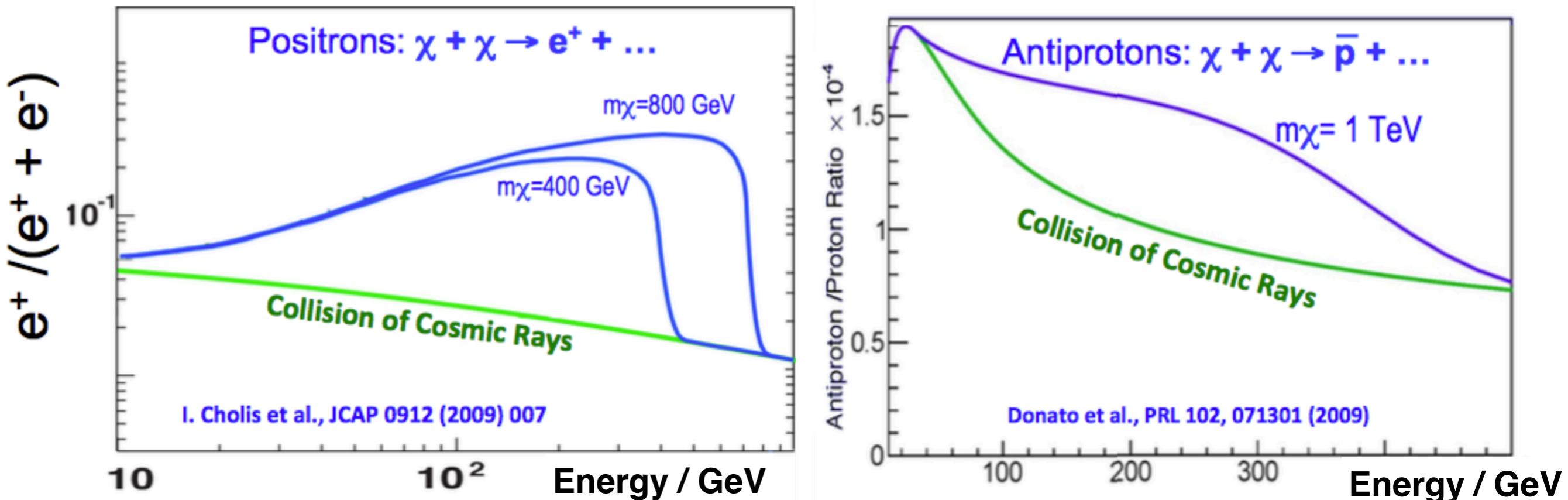
The search for dark matter in cosmic rays

Dark matter annihilation can produce SM matter and antimatter cosmic rays.

The same processes are also originated by standard astrophysical processes.

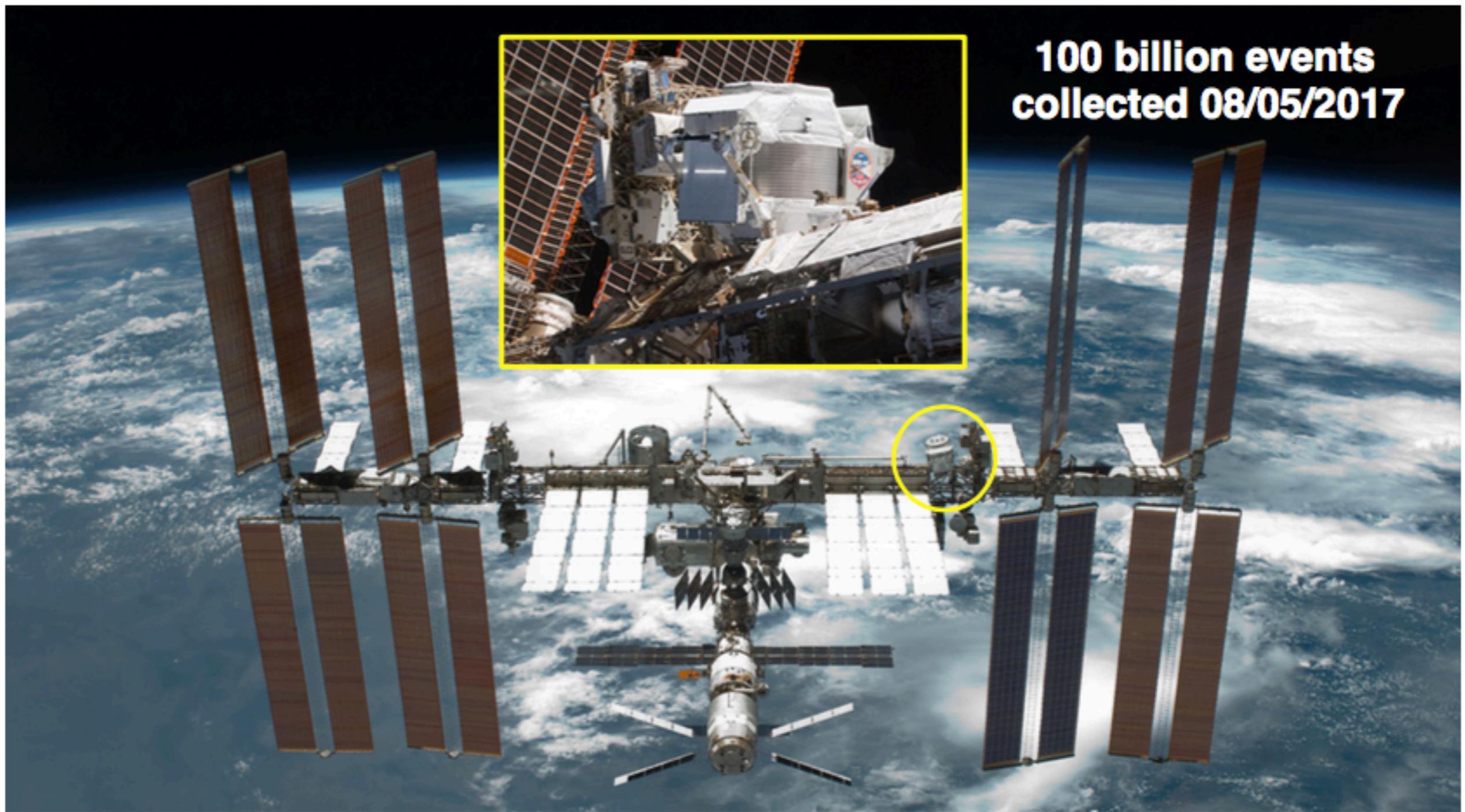


The search for dark matter in cosmic rays



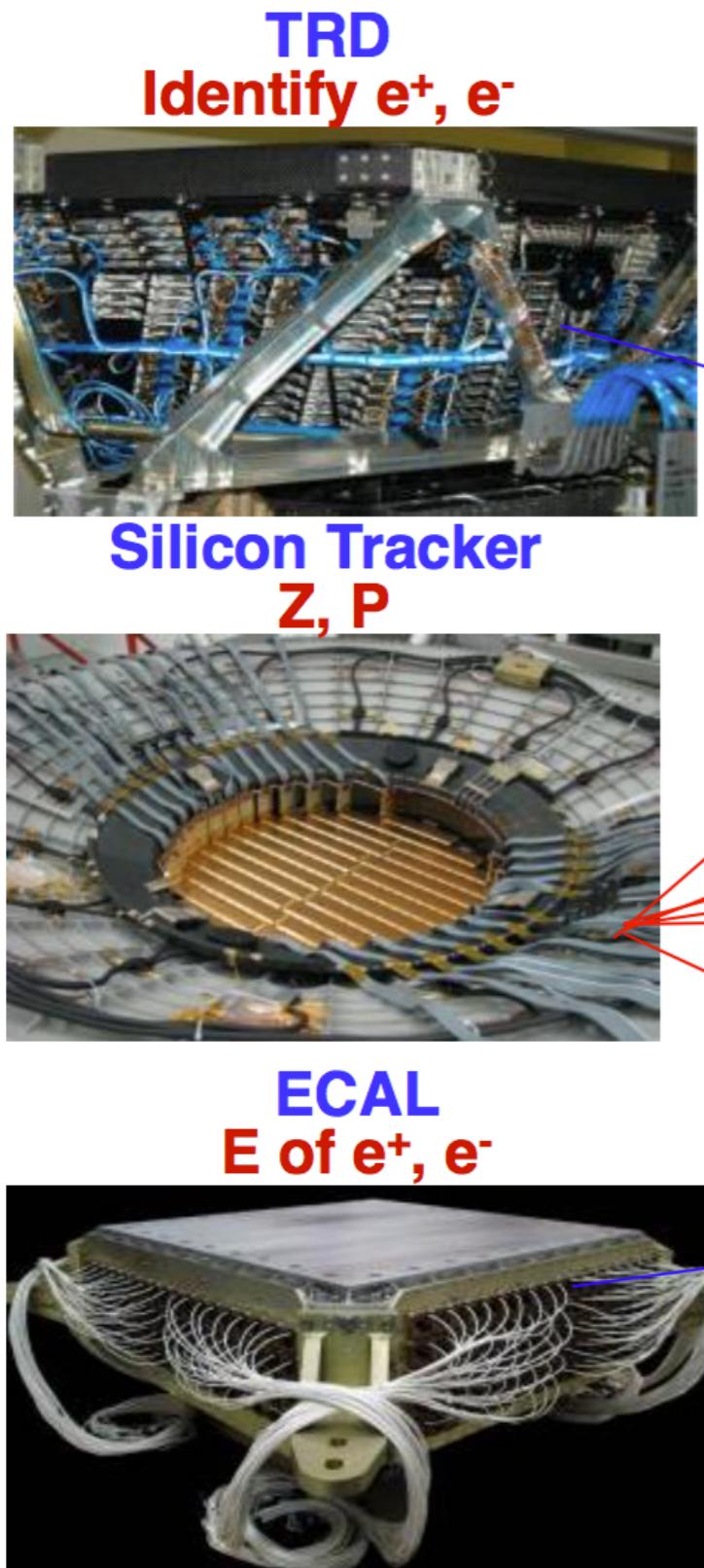
**e^+ / \bar{p} are sensitive
probes for dark matter**

The AMS-02 detector on the ISS

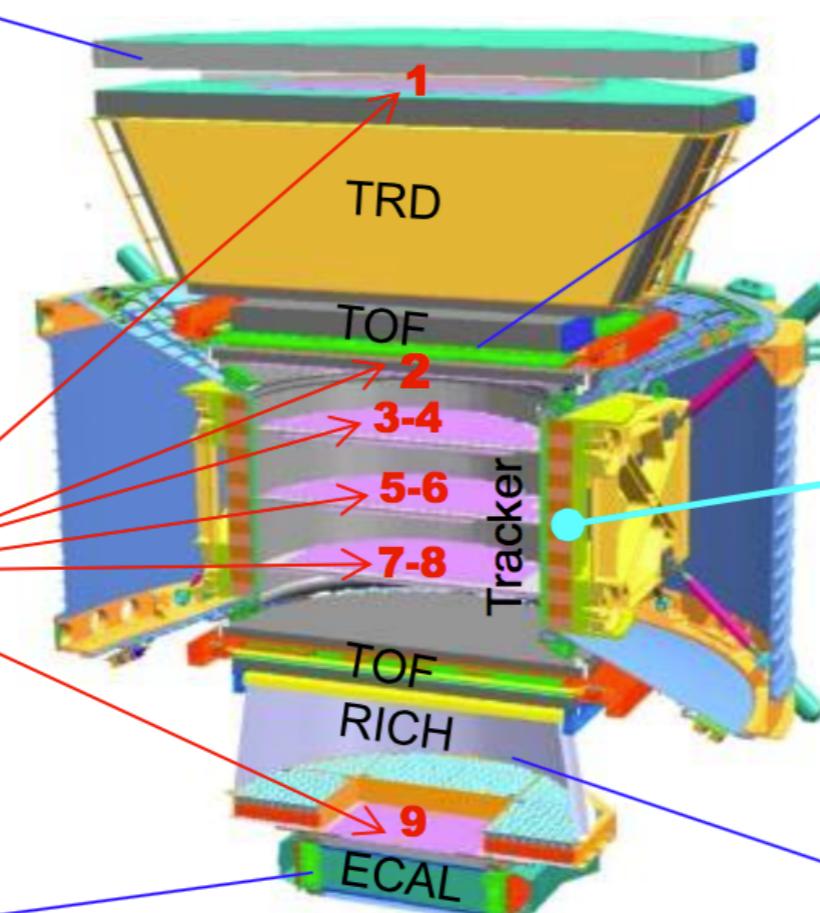


- Indirect search for Dark Matter ($e^{+/-}$, anti-p,...)
 - Search for primordial antimatter (anti-He)
- CR composition and energetics (of H, He, Li, B, C, ...)

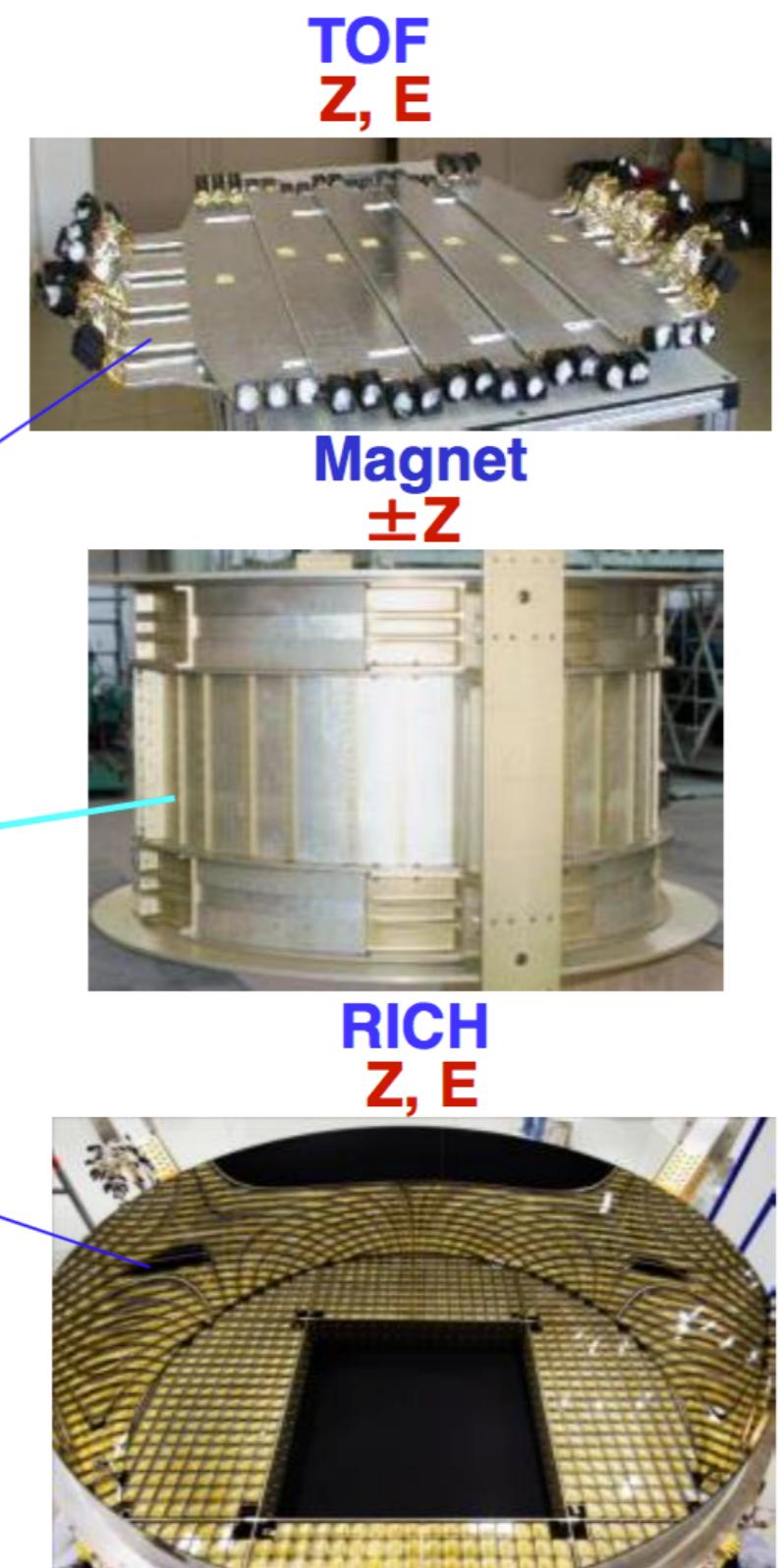
AMS-02: A TeV precision magnetic spectrometer



**Particles and nuclei
are defined
by their charge (Z)
and energy ($E \sim P$)**



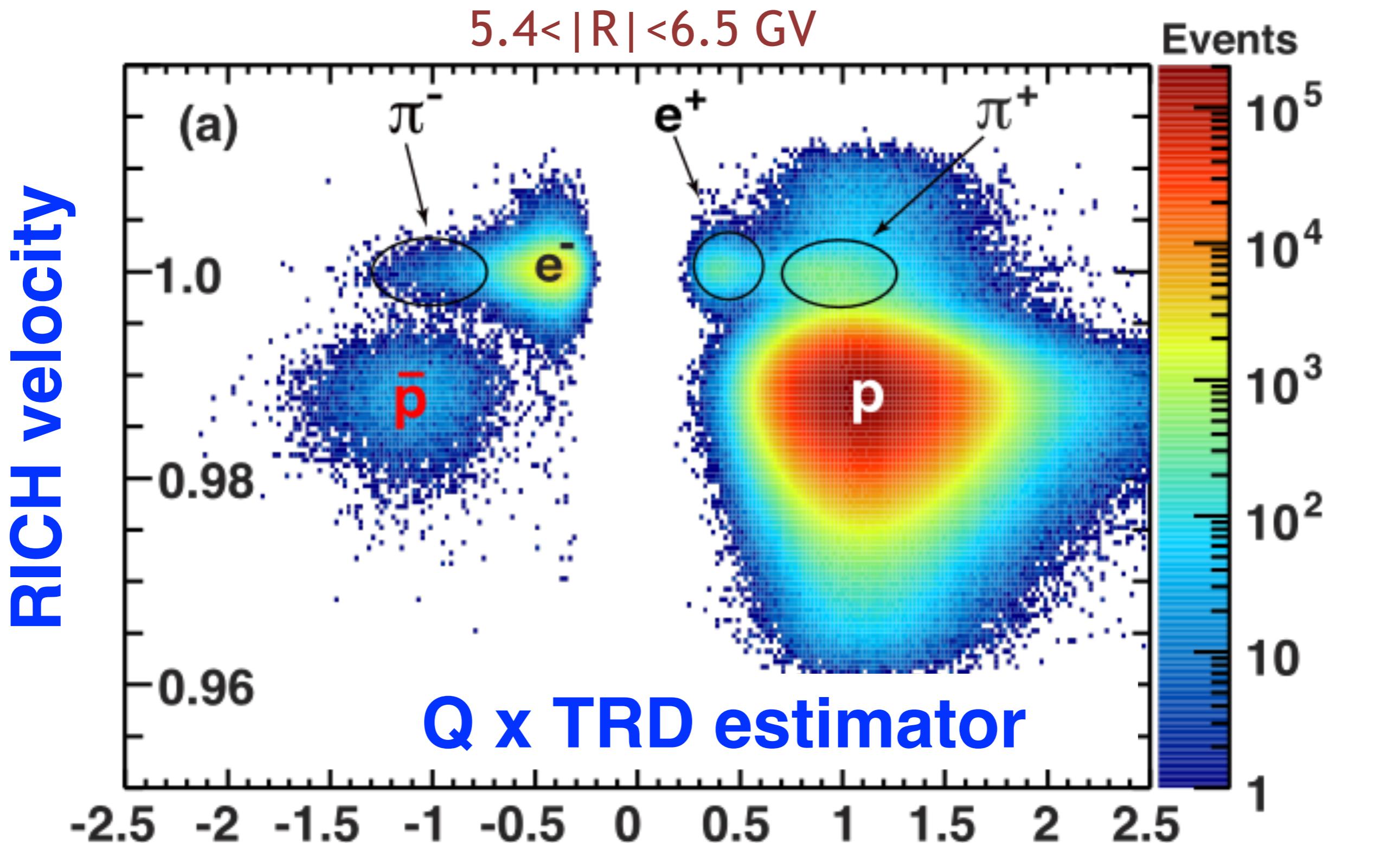
Z and P
*are measured independently by the
Tracker, RICH, TOF and ECAL*



Part 1: Antiproton / proton ratio

Antiproton /
proton ratio

Antiproton identification at intermediate rigidity

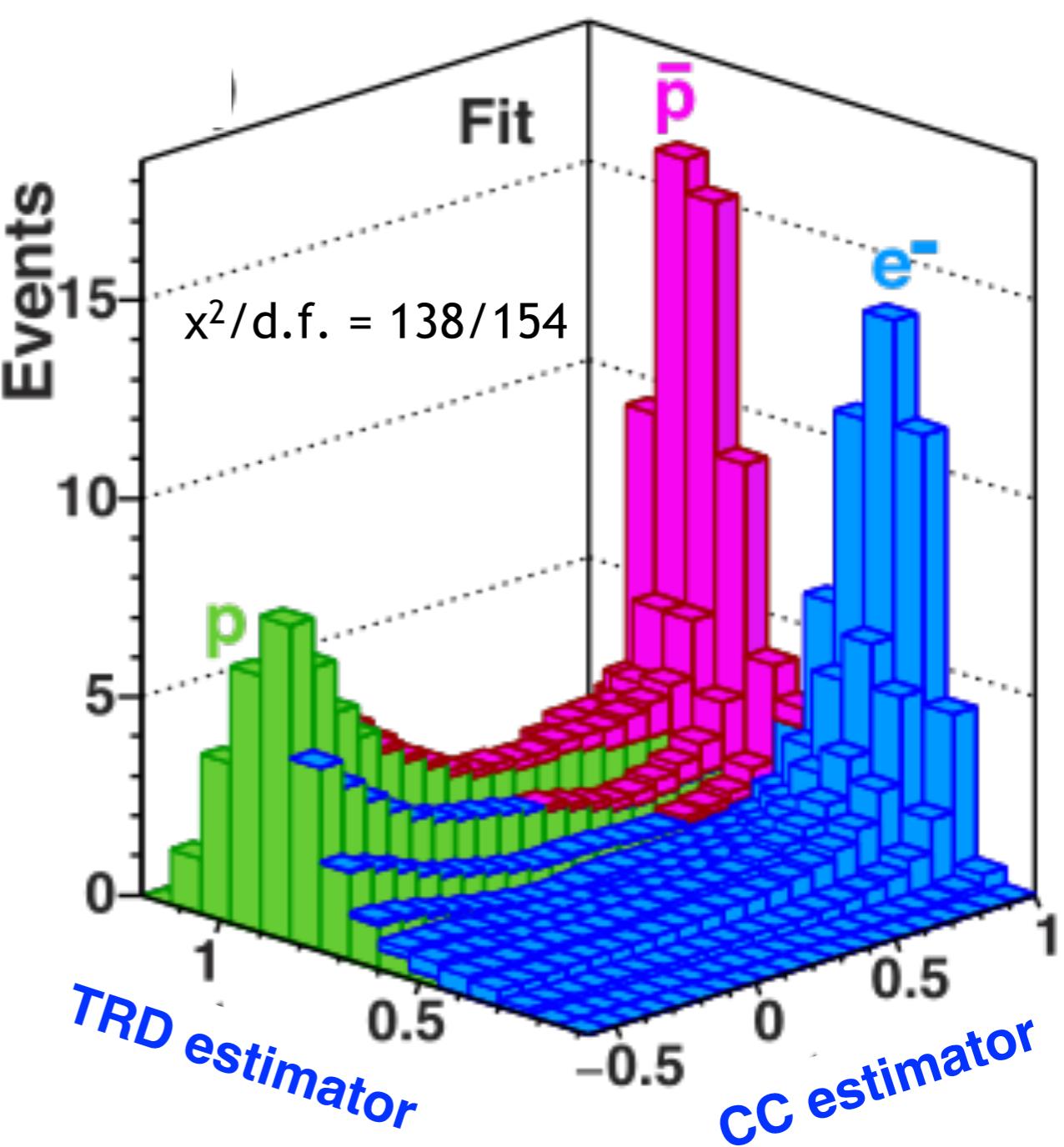
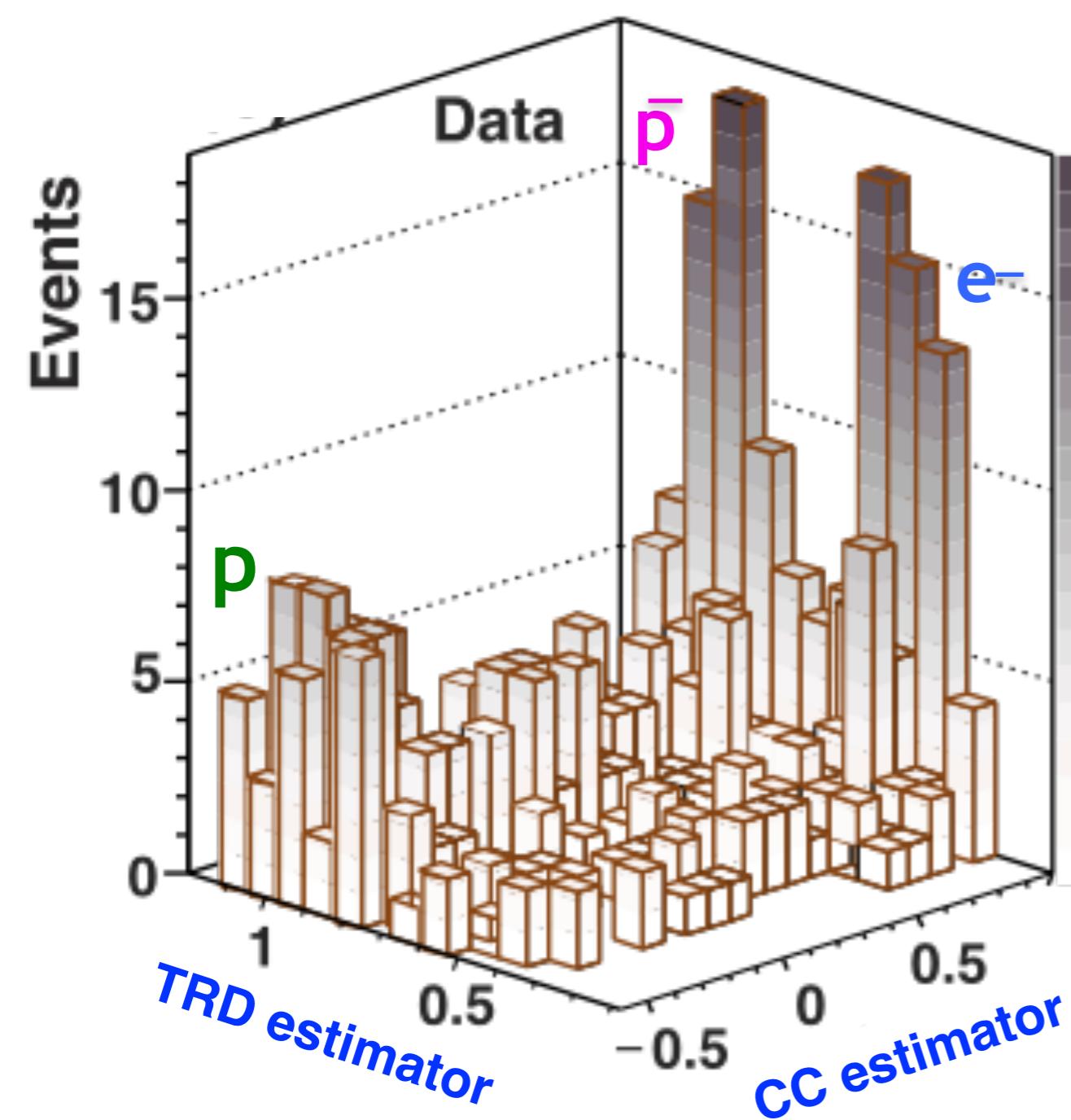


→ \bar{p} signal is well separated from the backgrounds.

Antiproton identification at high rigidity

$R < 0$

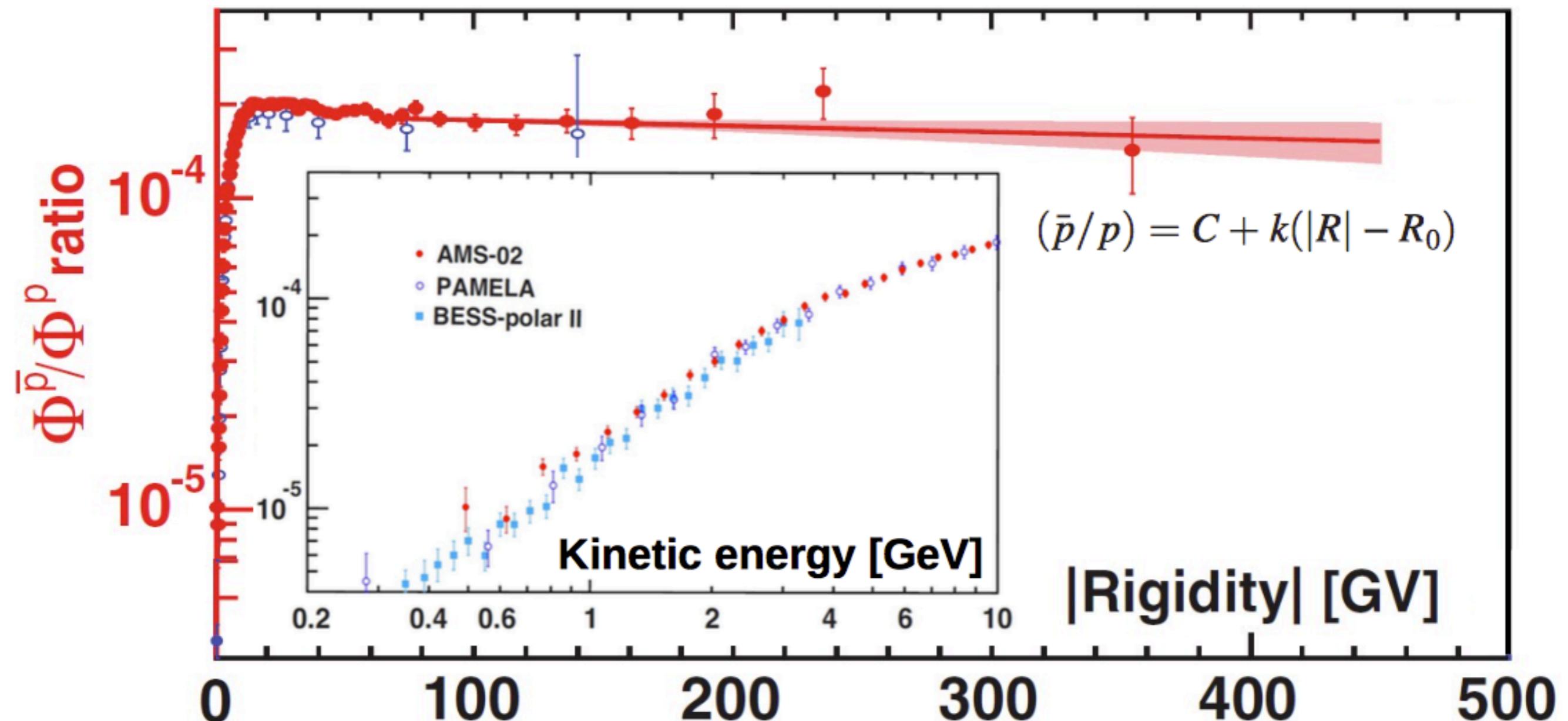
$175 < |R| < 211 \text{ GV}$



→ Advanced techniques allow to explore high energies.

Antiproton/proton ratio - results

M. Aguilar et al., Phys. Rev. Lett. 117 (2016) 091103.



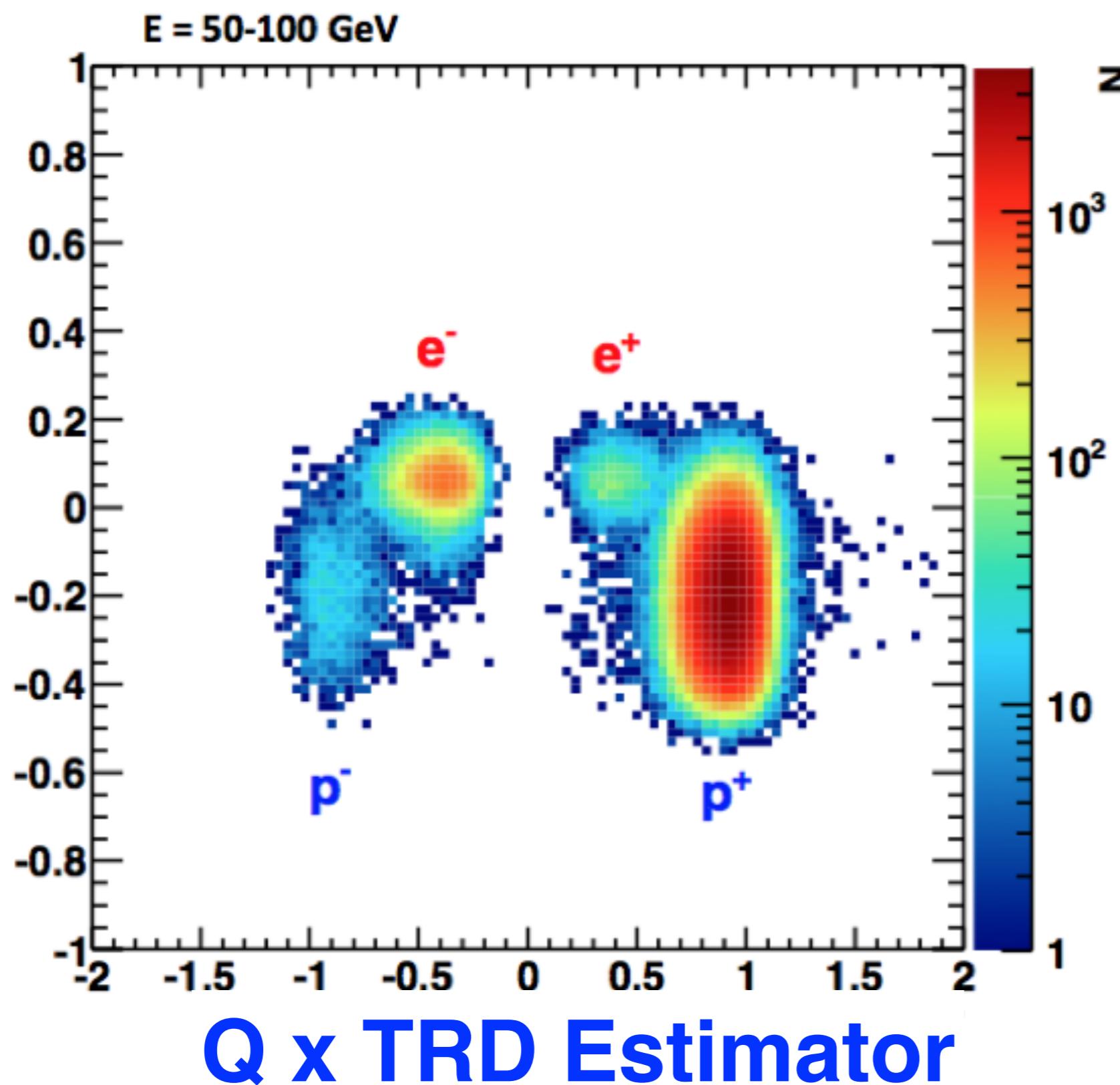
**The fitted value of the slope
Above 60.3 GV:** $k = (-0.7 \pm 0.9) \times 10^{-7} \text{ GV}^{-1}$
is consistent with zero.

Part 2: Electron / positron fluxes

Electron /
positron fluxes

Electron / positron identification

ECAL Estimator

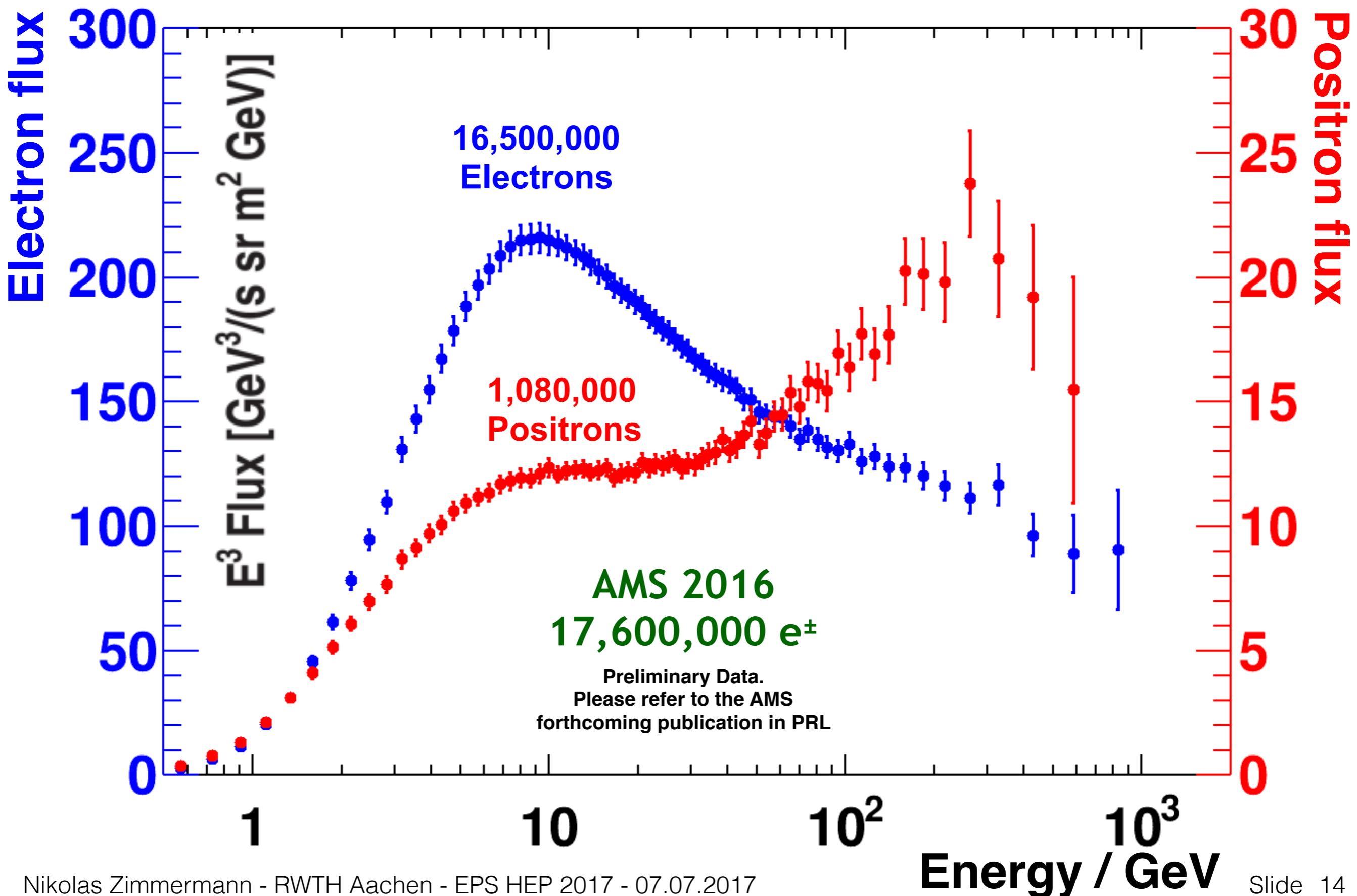


A sample of e^+ / e^- candidates is prepared utilizing the redundancy of the AMS-02 detector.

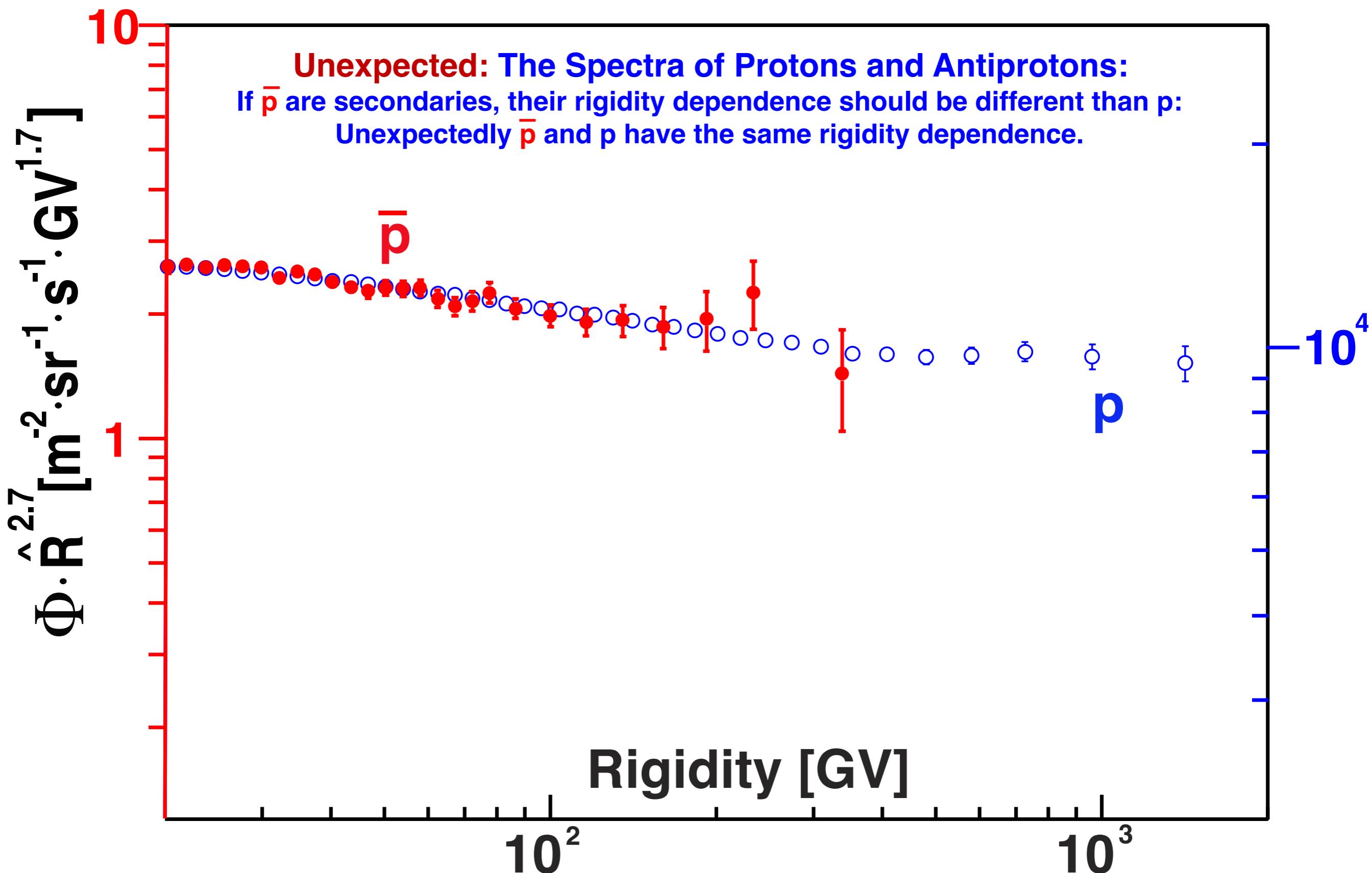
Finally 2D reference spectra for the signal and the background are fitted to data after an efficient ECAL selection to remove the majority of protons.

→ Extract counts.

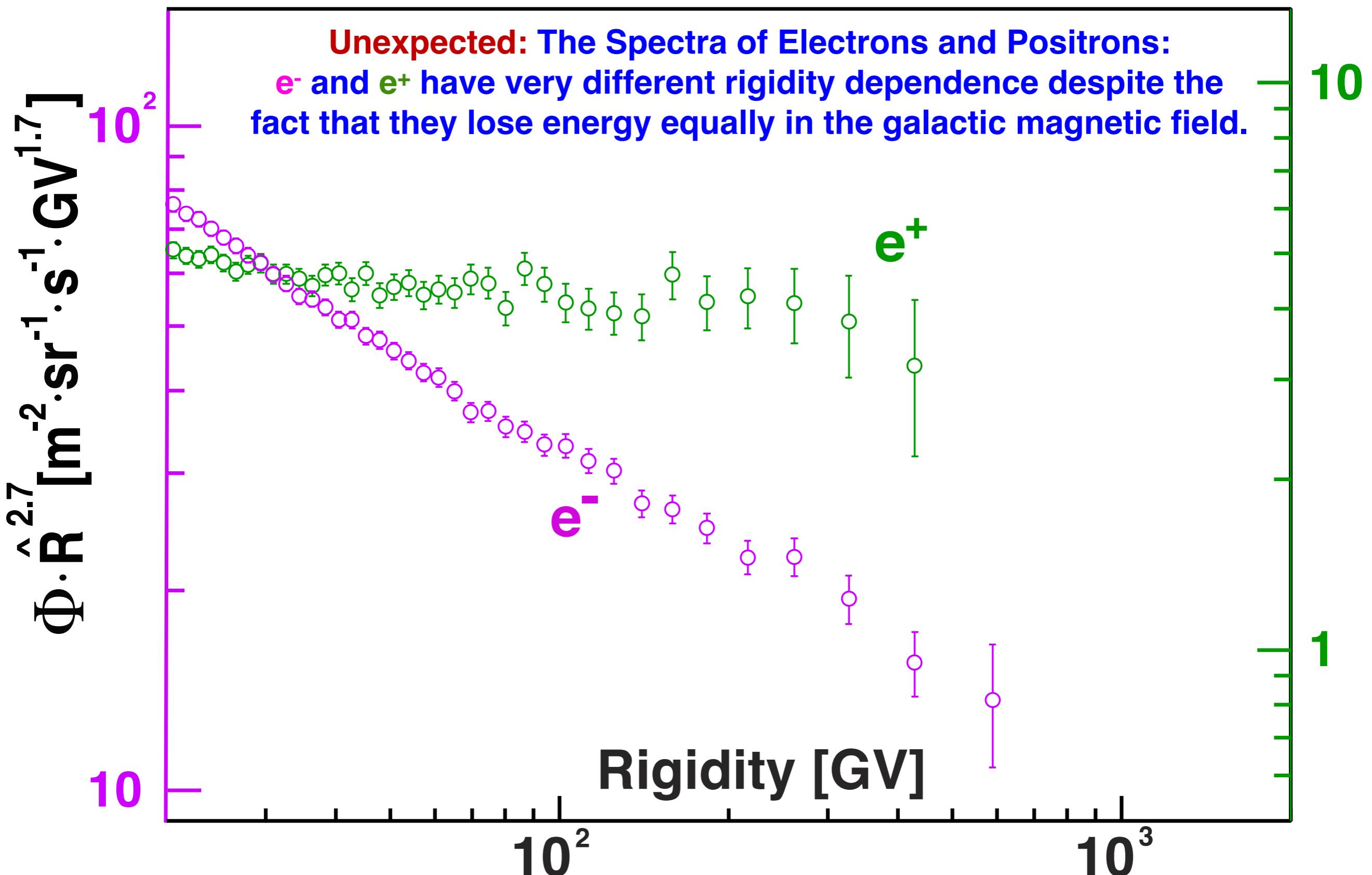
Electron / positron flux with 5 years data



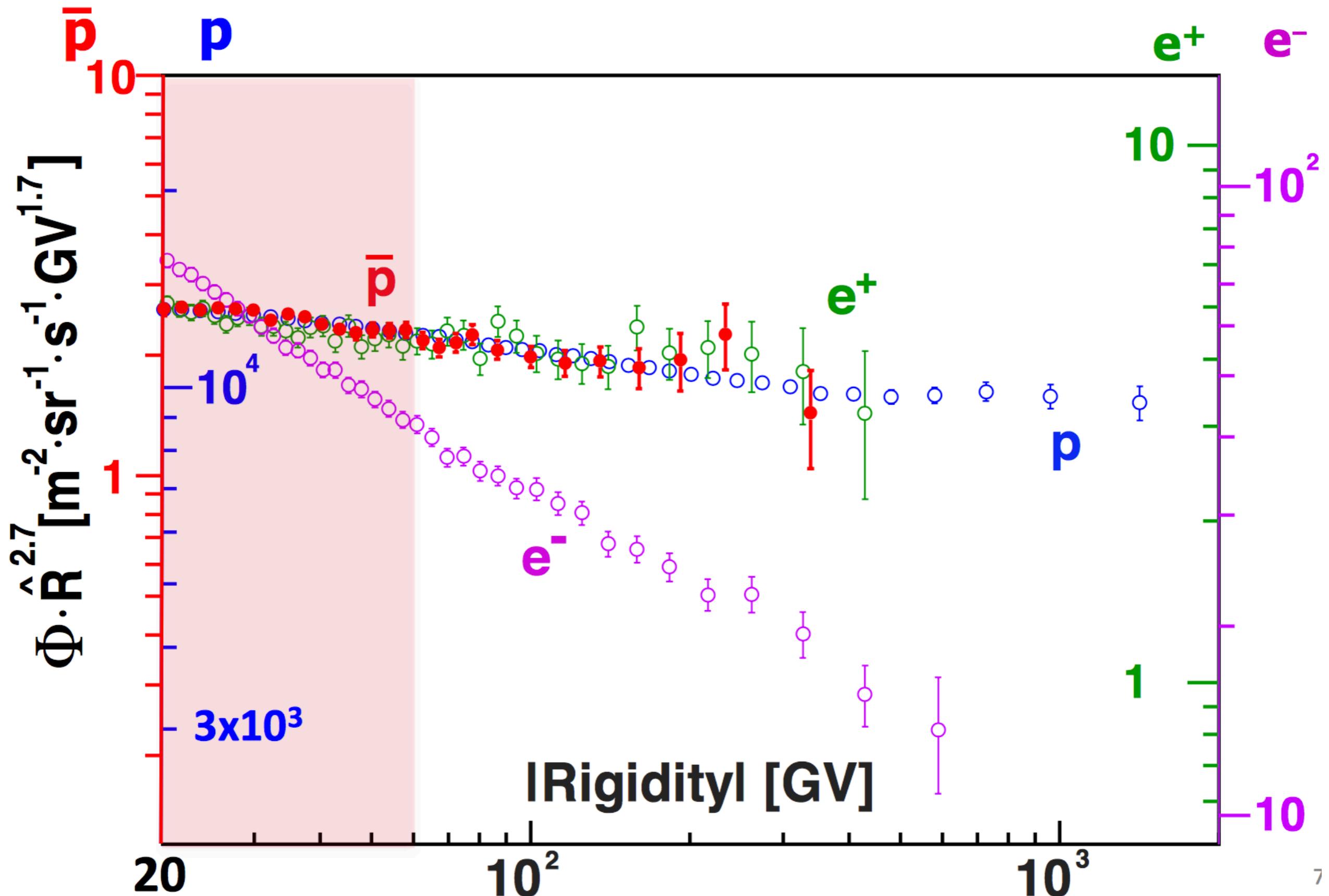
AMS-02 e⁺ / p⁺ / e⁻ / p⁻ results combined



AMS-02 e⁺ / p⁺ / e⁻ / p⁻ results combined



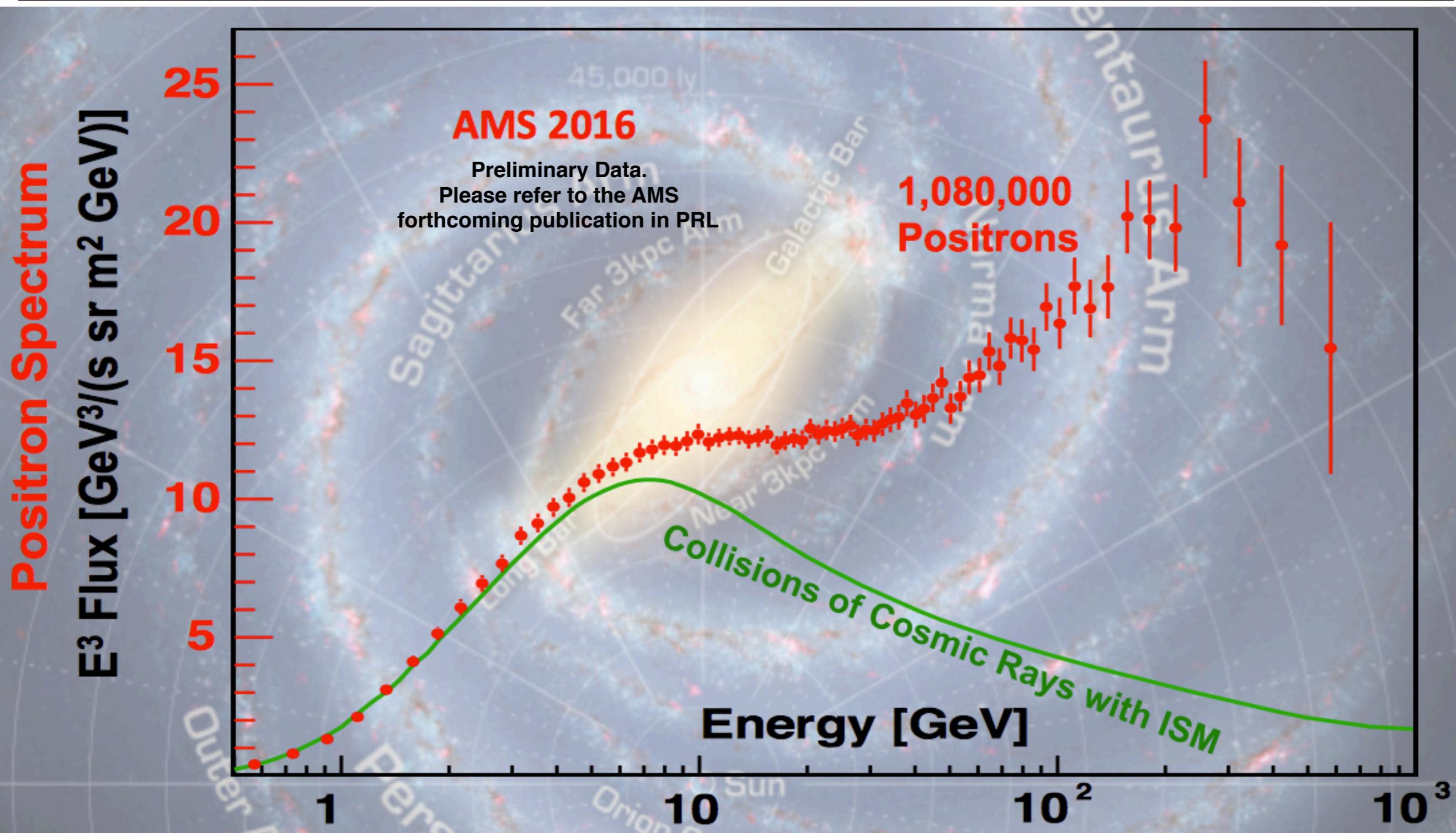
AMS-02 e⁺ / p⁺ / e⁻ / p⁻ results combined



Part 3: Interpretation

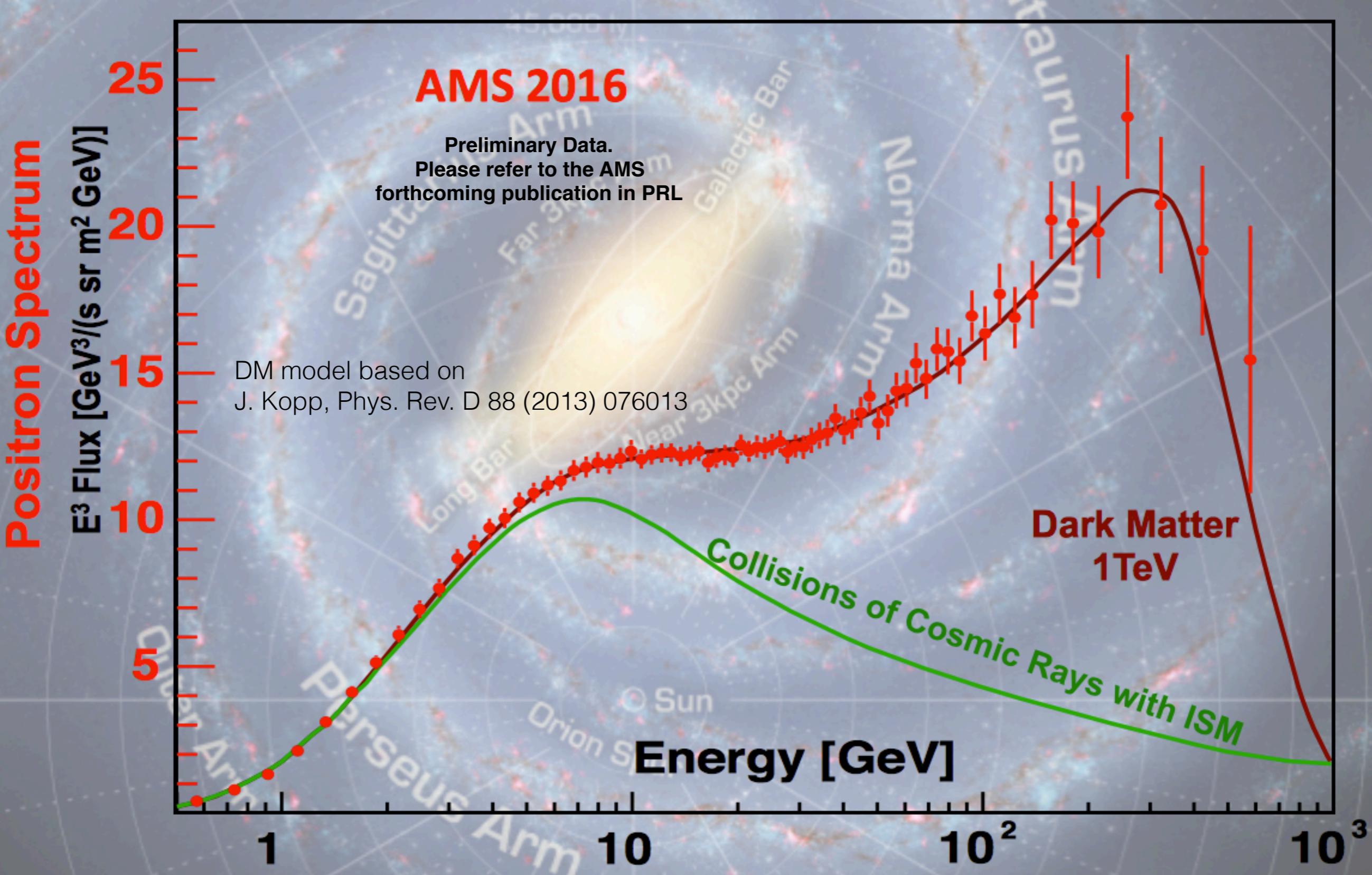
Interpretation

Positron flux - results

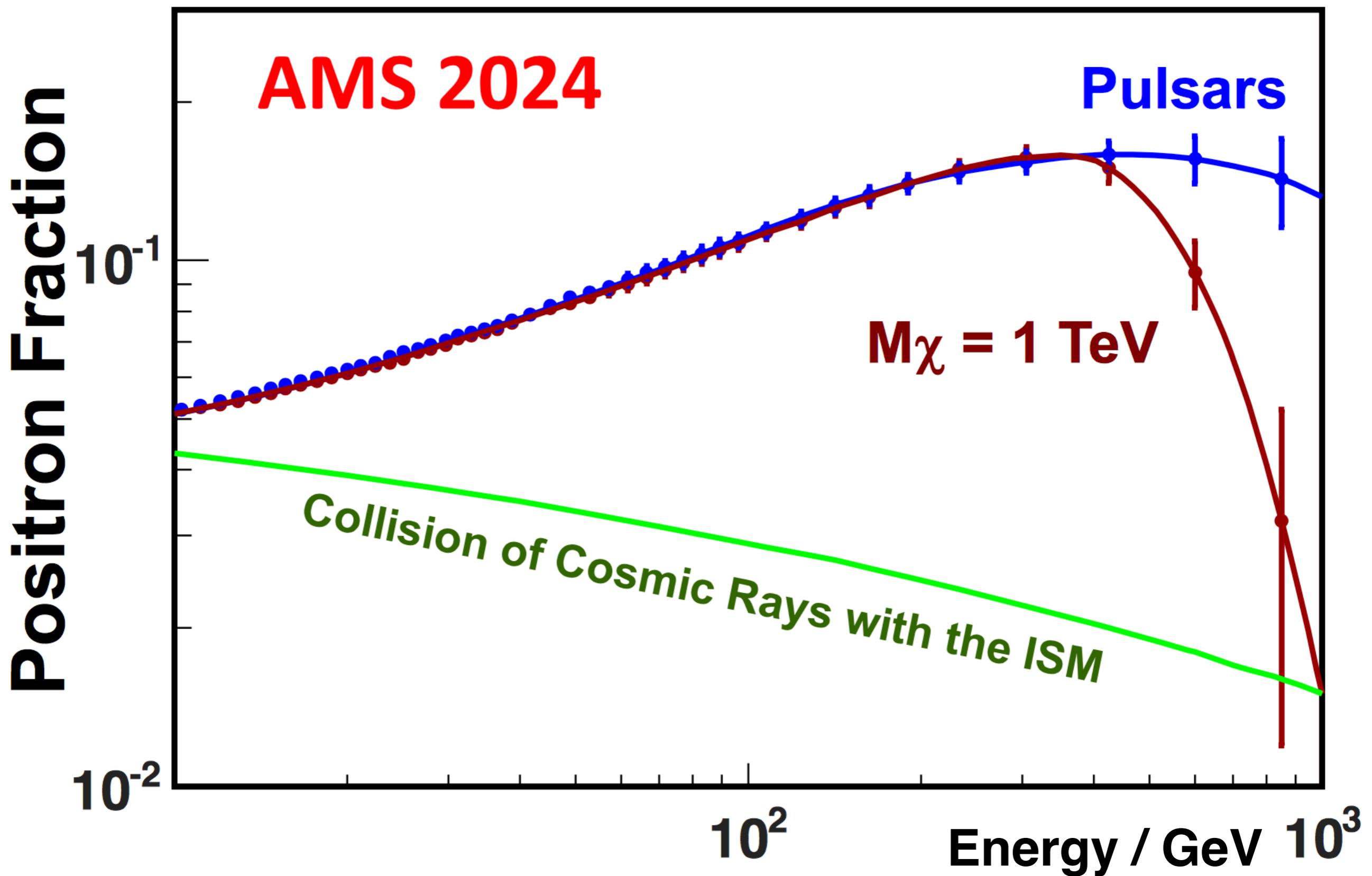


Collision of Cosmic Rays with the Interstellar Media produce e⁺ ... and this is indeed true at low energies.

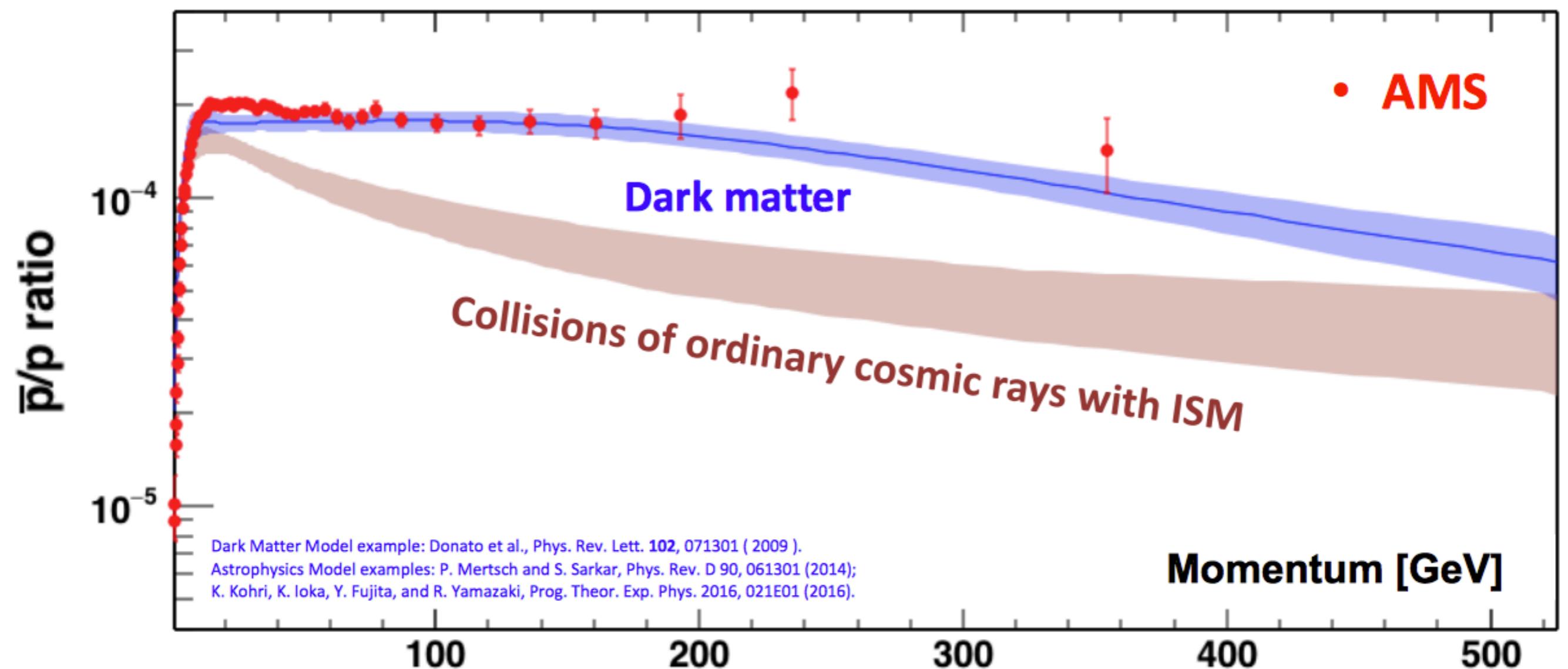
Positron flux - dark matter model



Positron fraction - extrapolation to 2024



Antiproton/proton ratio - dark matter model



**The excess of antiprotons observed by AMS
cannot come from pulsars.**

**It can be explained by Dark Matter
or by new astrophysics phenomena.**

Example of theoretical models for e⁺ / p-

- 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
- 12) C. H. Chen, C. W. Chiang, and T. Nomura, Phys. Lett. B 747, 495 (2015)
- 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)
and many other excellent papers ...

From Dark Matter

- 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)
and many other excellent papers ...

From
Astrophysical
Sources

- 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)
and many other excellent papers ...

From Secondary
Production

Example of theoretical models for e⁺ / p-

- 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. Koh
- 9) P. S. B
- 10) A. Ibari
- 11) Y. Zhao
- 12) C. H. O
- 13) H. B. J
- 14) M-Y. C
- 15) A. Cu

- and many other papers ...
- 1) T. Lindenbaum
 - 2) P. Mertens
 - 3) I. Cholis
 - 4) A. Erlykin
 - 5) P.F. Yin
 - 6) A.D. Erlykin
 - 7) E. Amato
 - 8) P. Blas
 - 9) D. Gaggero
 - 10) M. DiMauro
 - 11) K. Kohl

AMS-02 will continue to measure until the end of the ISS lifetime, to help resolving the mysteries!

- 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.Boudaoud, 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)
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