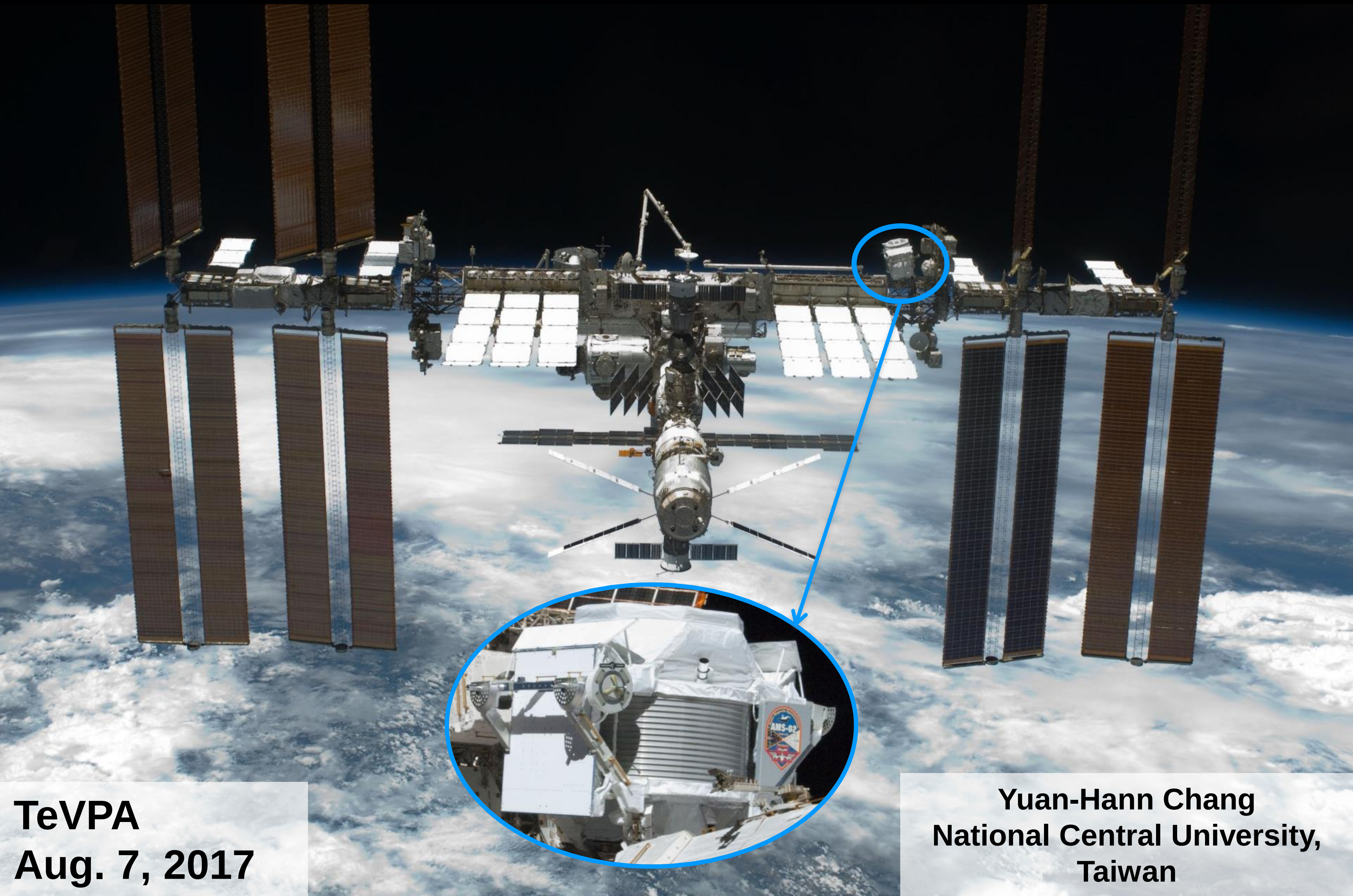
Properties of Elementary Particle Fluxes in Cosmic Rays



TeVPA
Aug. 7, 2017

Yuan-Hann Chang
National Central University, Taiwan

Elementary Particles in Space

There are hundreds of different kinds of charged elementary particles.

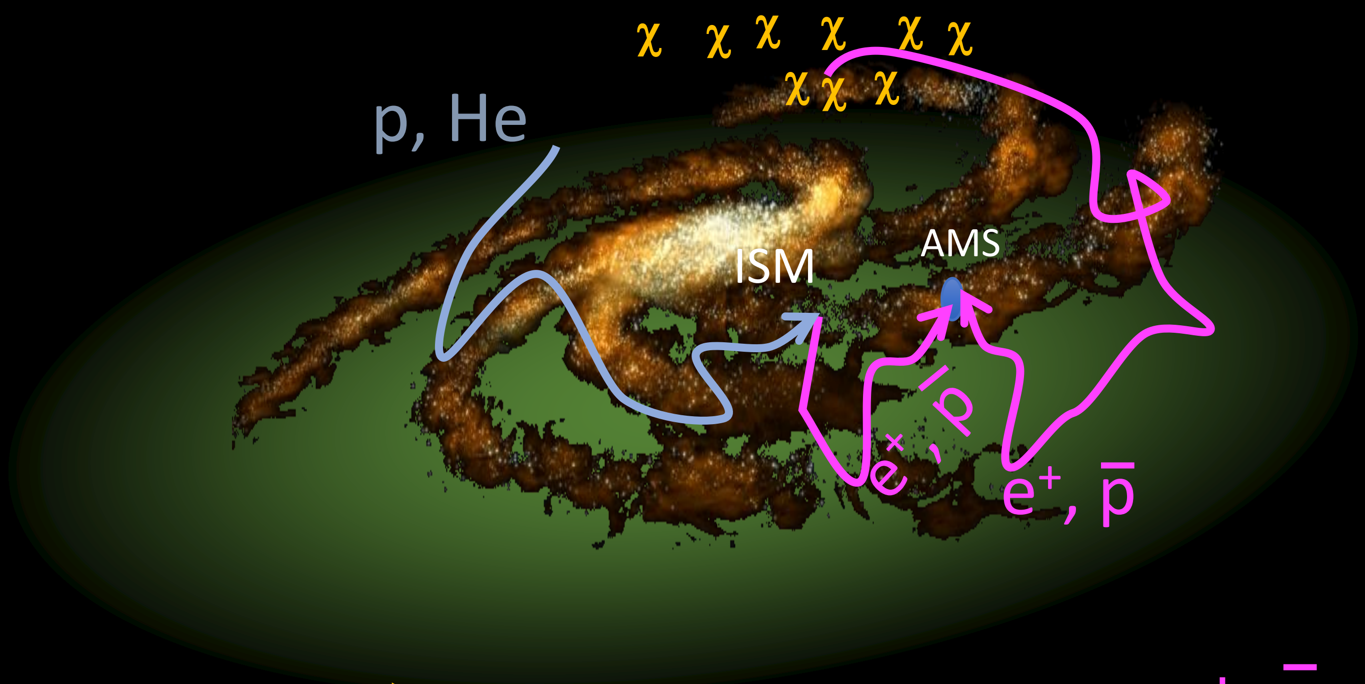
Only four of them, e^-, e^+, p, $\bar{p}$ are stable particles, and can travel in the cosmos forever

Elementary particles in the cosmic rays are uniquely important because, in addition to probing the production and propagation of cosmic rays, they are also sensitive to the fundamental physics processes.

Example: Dark Matter χ

Collision of Cosmic Rays with the Interstellar Media will produce e^+, $\bar{p}$…

p, He + ISM → e^+, $\bar{p}$ + …



Dark Matter (χ) annihilations $\chi + \chi \rightarrow e^+, \bar{p} + \ldots$
create extra e^+ and $\bar{p}$

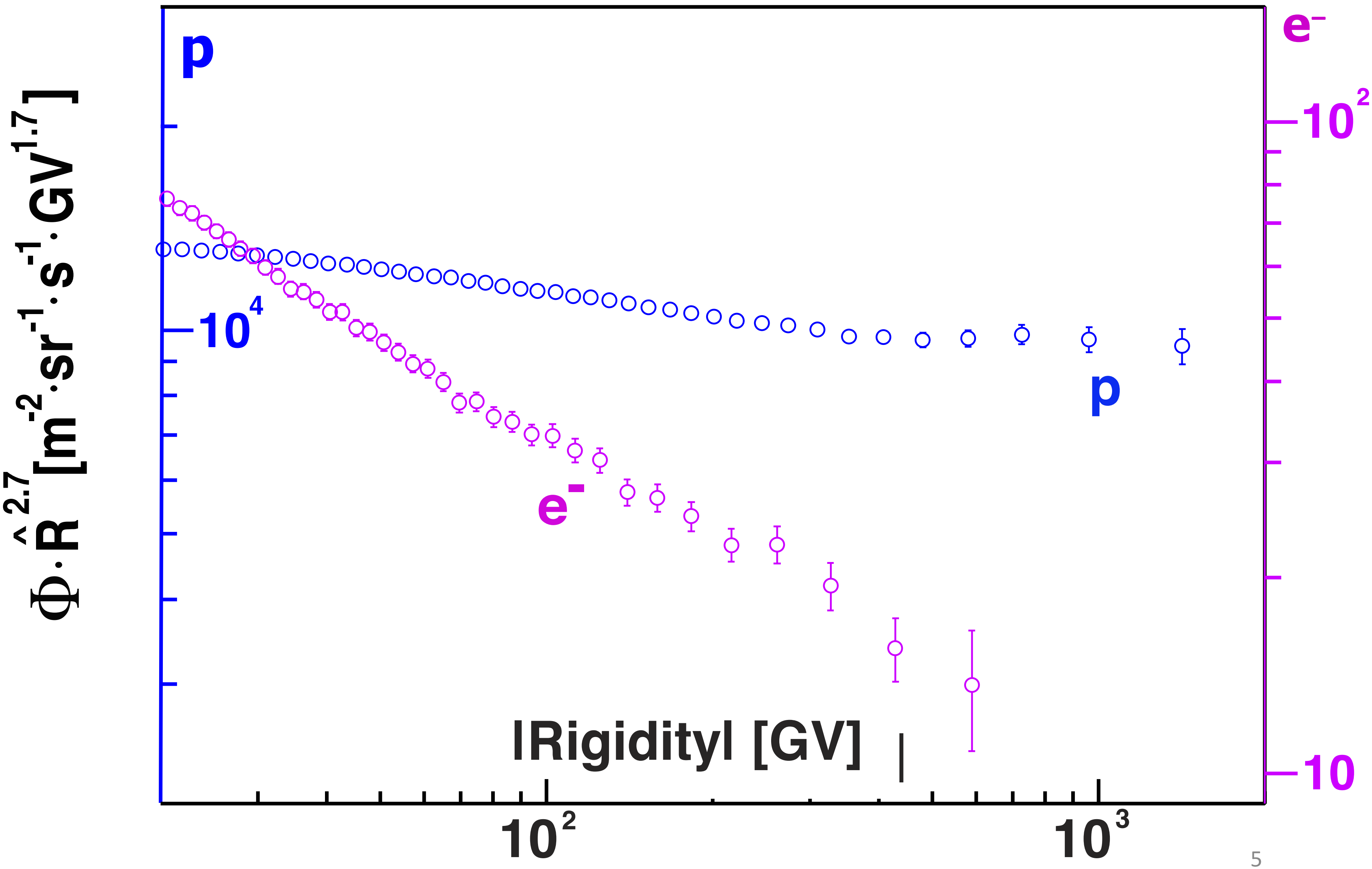
Spectra of elementary particles provide Complementary measurements:

- Electrons and positrons are ~2000 times lighter than Protons and Antiprotons. They loss energy at a much higher rate during propagation.
- Protons and electrons are primary cosmic rays. Antiprotons and positrons are considered secondary in ordinary cosmic ray models.
- In case of exotic sources (e.g., Dark Matter or Pulsars), the production of e^+/e^- and $\bar{p}/p$ can be very different. For example, antiprotons are not produced in pulsars.

Simultaneous high precision measurement of $\bar{p}$, p, e^+, e^-, with the same detector, for the same period of time, provide unbiased comparisons which are critical for the understanding of the cosmic rays and fundamental physics.

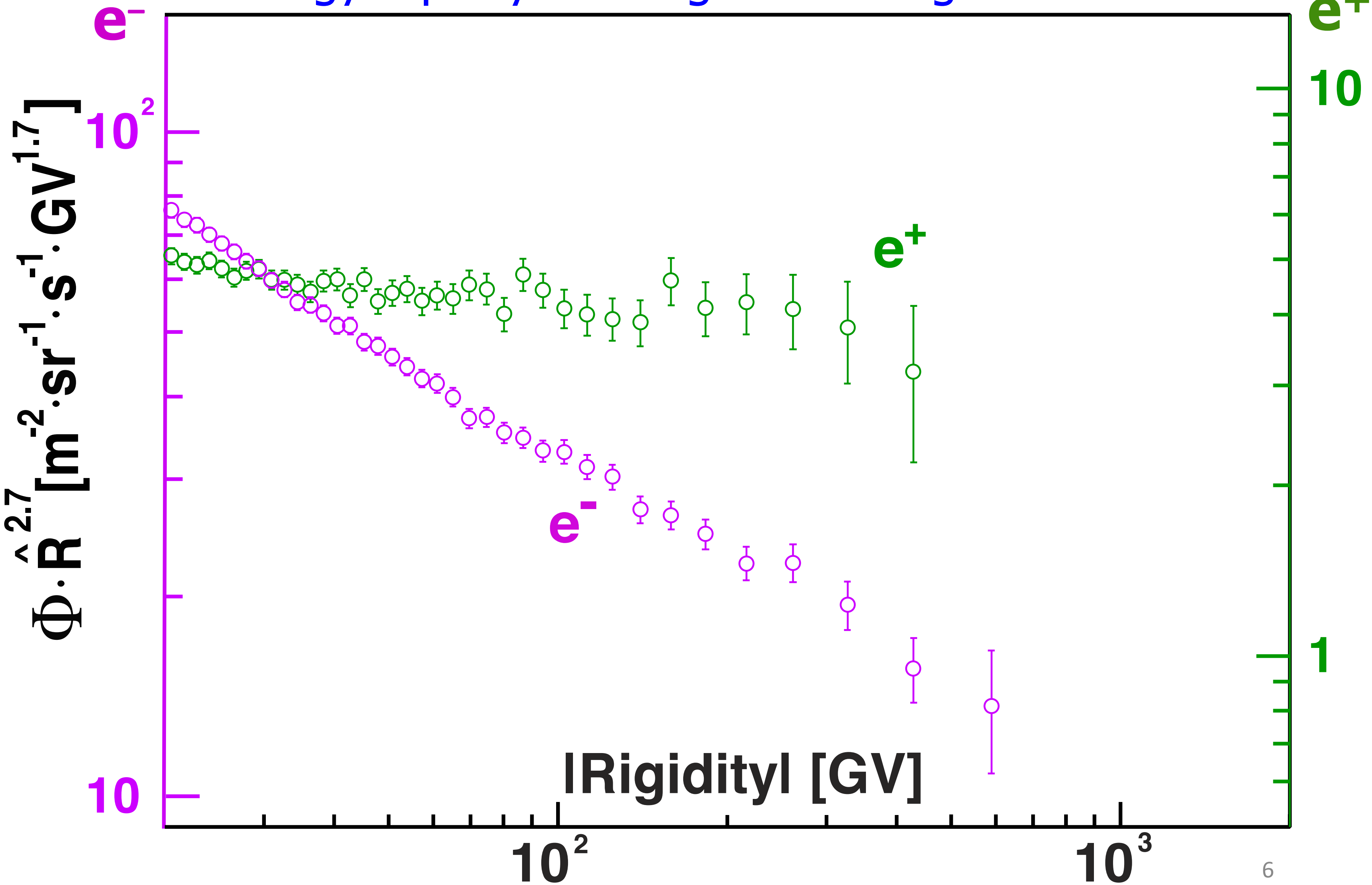
The Spectra of Protons and Electrons:

e^- and p are different, as expected



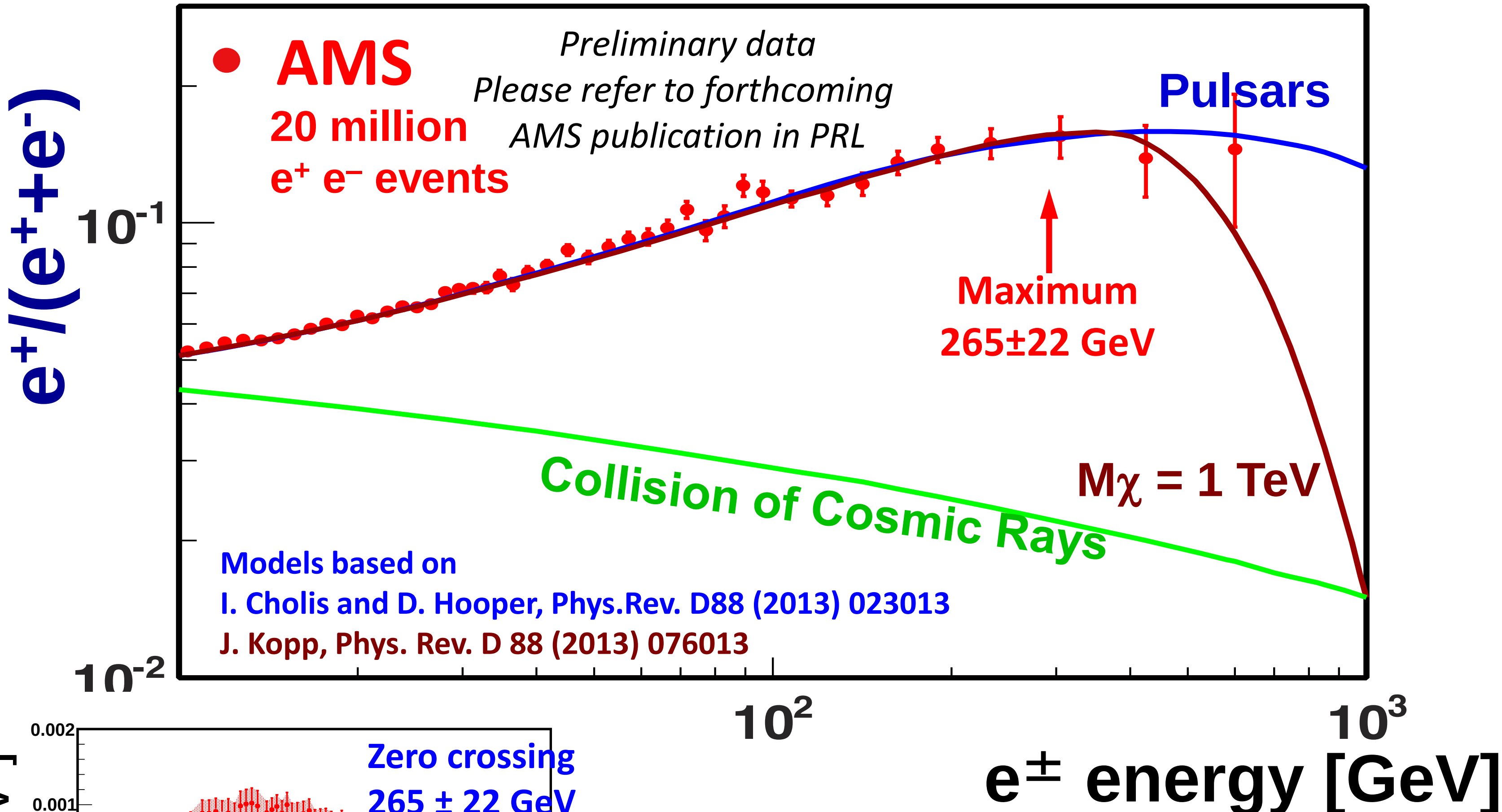
M. Aguilar *et al.*, Phys. Rev. Lett. **117,** 091103 (2016)

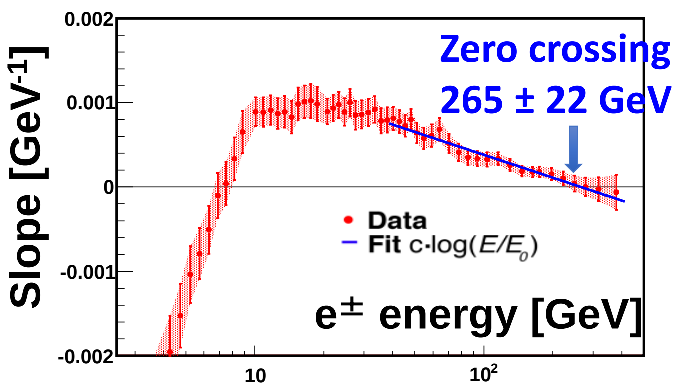
The Spectra of Electrons and Positrons: e^- and e^+ have very different spectra, despite the fact that they lose energy equally in the galactic magnetic field.



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

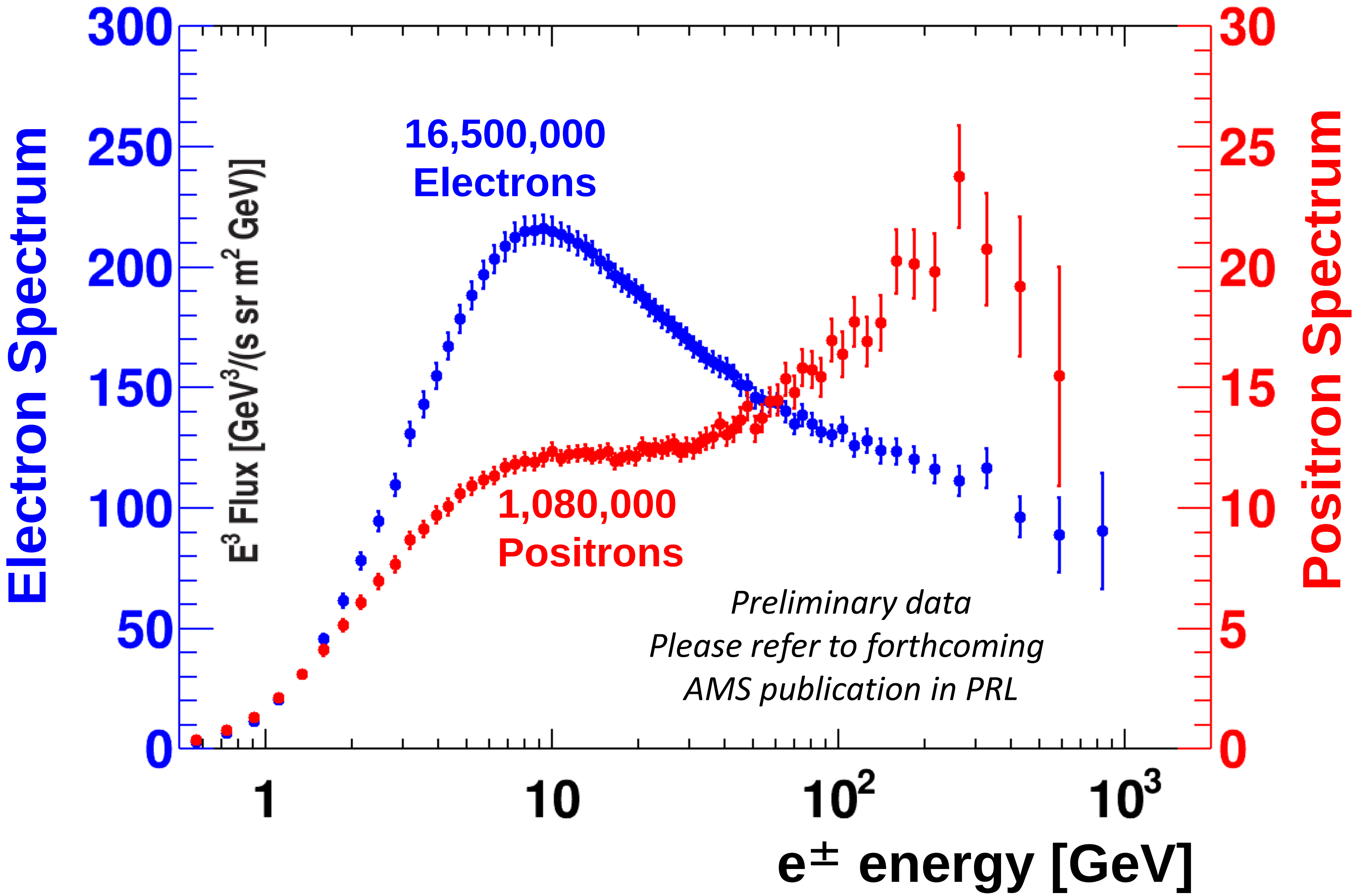
Positron fraction: the smoking gun of an unknown source of positrons





Sliding window analysis shows that the positron fraction reaches a maximum at around 265 GeV, and start to decrease.

AMS data is precise enough to look into details of Electron and Positron spectra separately



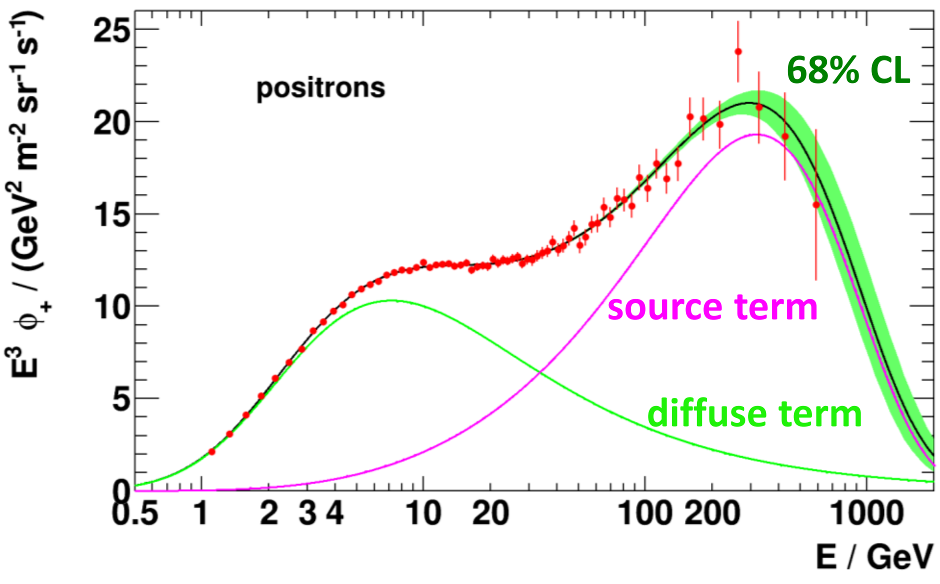
Additional source of high energy e^+ and e^-

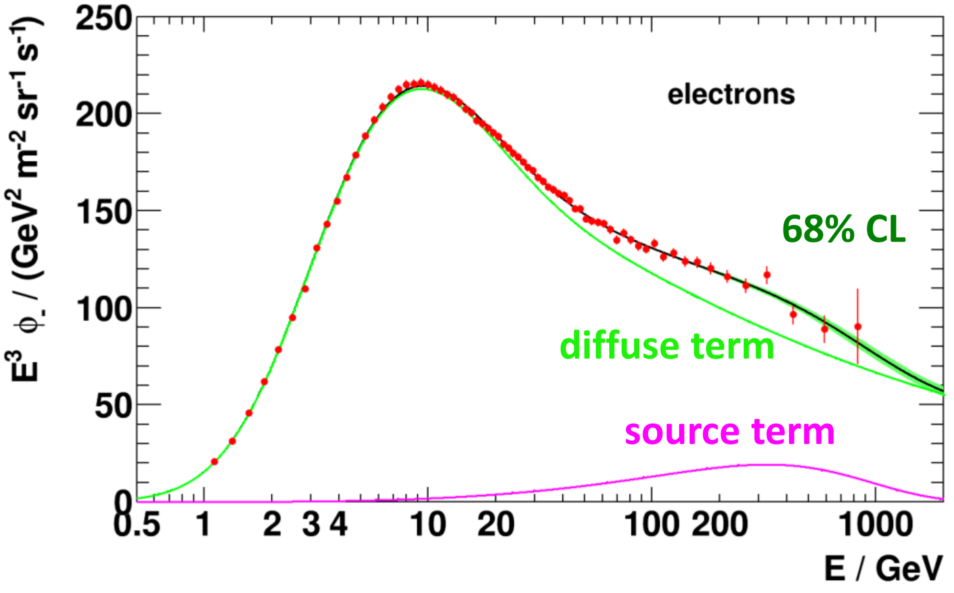
Minimal Model:

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

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

$E_s = 530^{+170}_{-100}$ GeV $\chi^2/n.d.f. = 39/59$



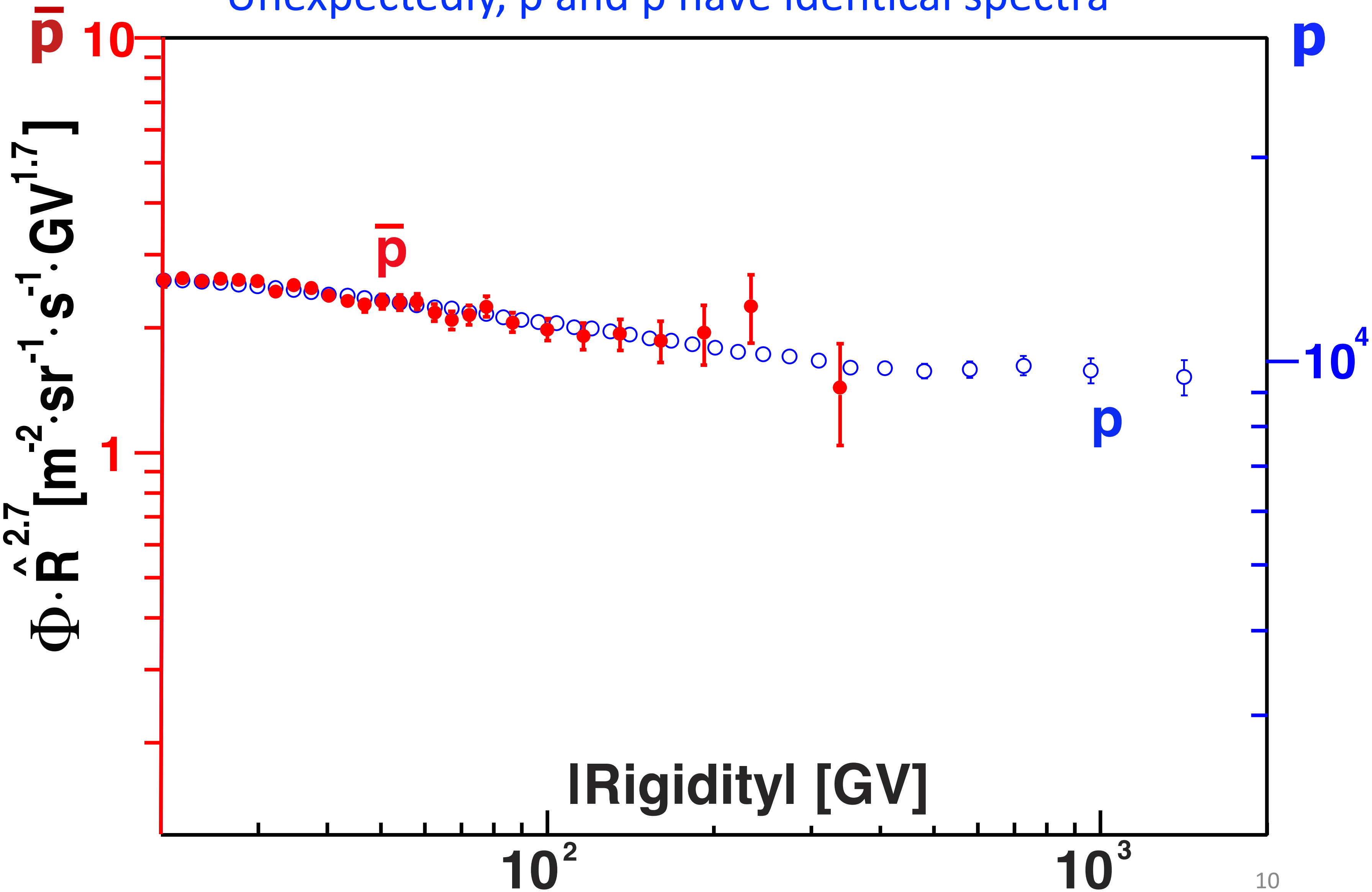


- The same source term describes the anomalous behavior of both e^+ and e^- spectra very well.
- The significance of the energy cutoff of the source term is ~3σ.

The Spectra of Protons and Antiprotons:

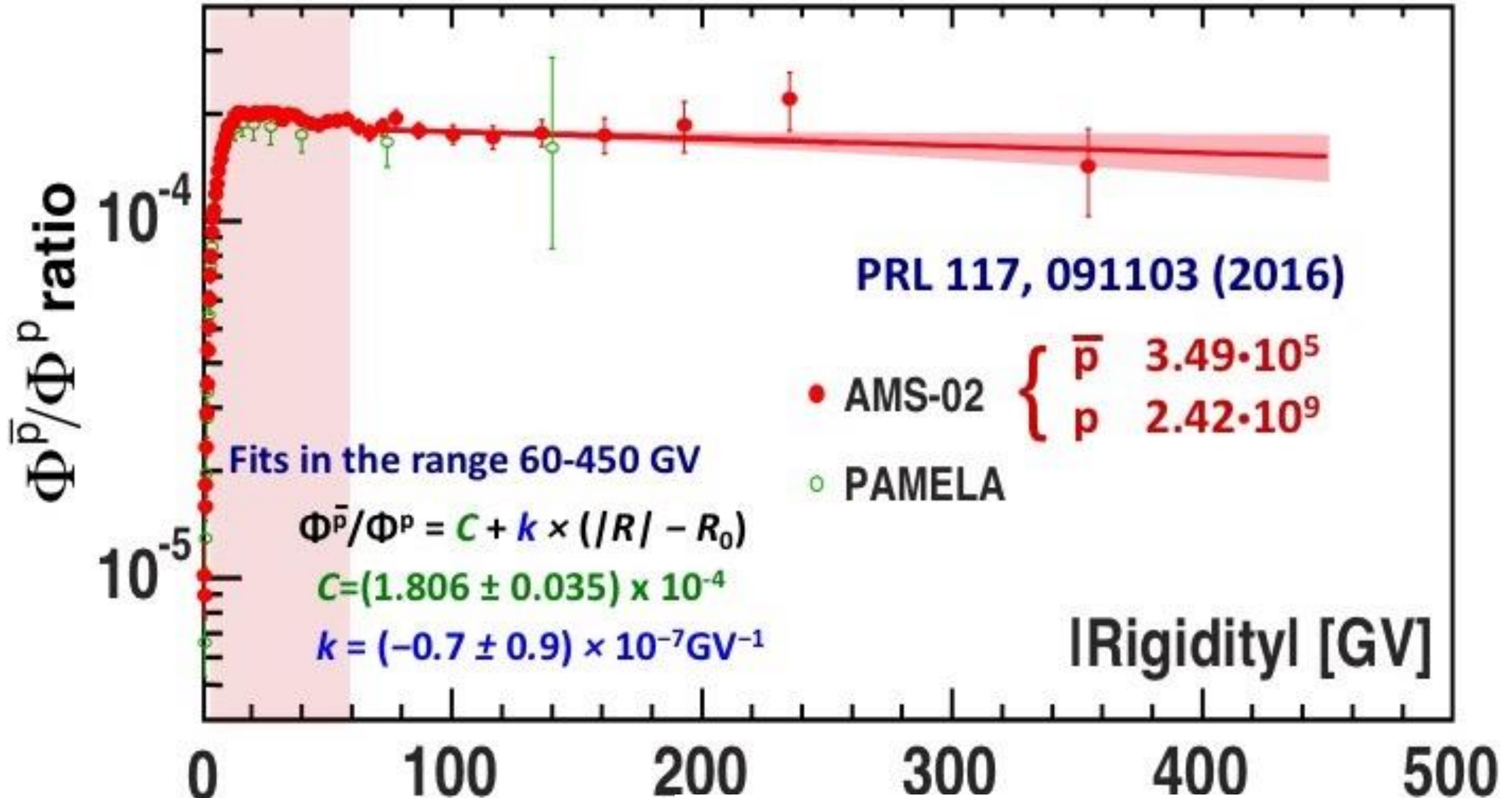
If $\bar{p}$ are secondaries, their spectrum should be different than p.

Unexpectedly, $\bar{p}$ and p have identical spectra

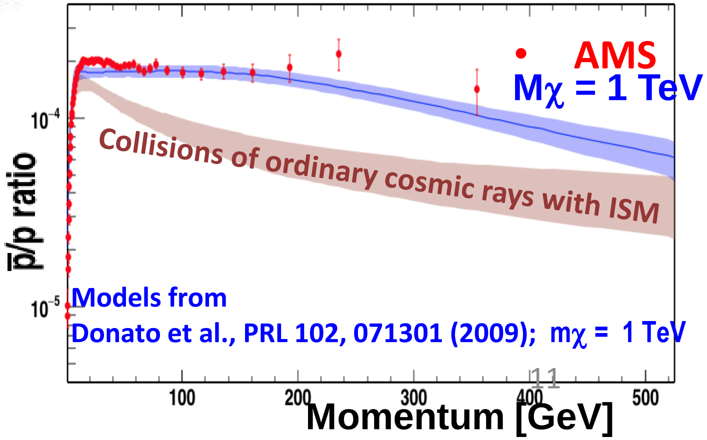


M. Aguilar *et al*., Phys. Rev. Lett. **117,** 091103 (2016)

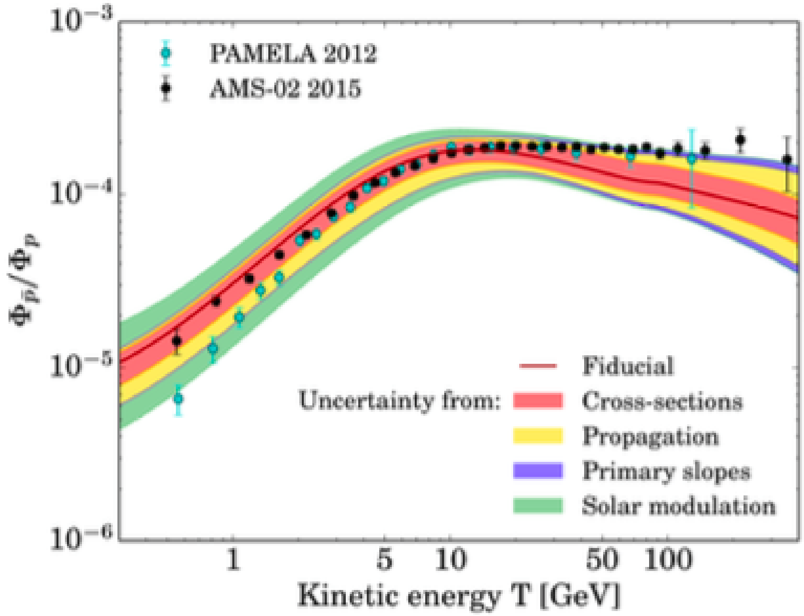
Flux Ratio of Elementary Particles $\bar{p}/p$ is energy independent above 60 GeV

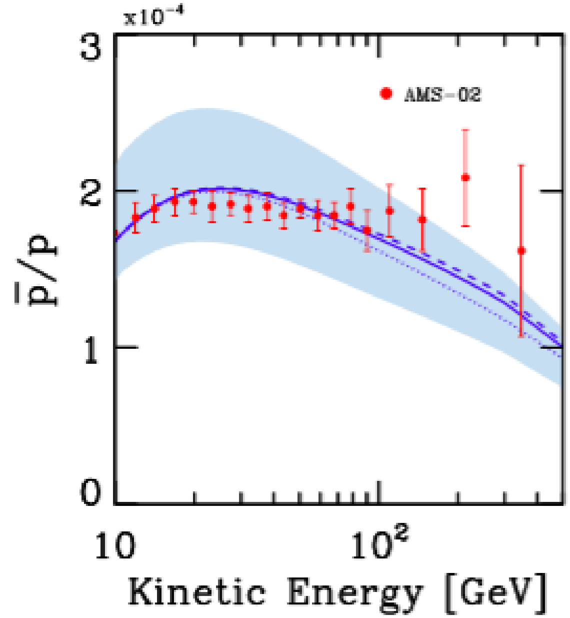


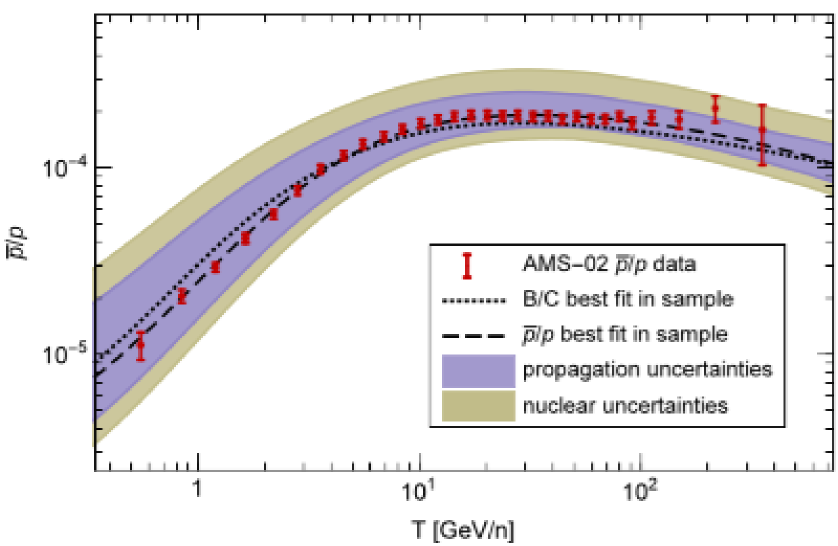
Before AMS data, it was generally believed that the secondary should have softer spectrum.



Phenomenological Models for the p̄/p ratio







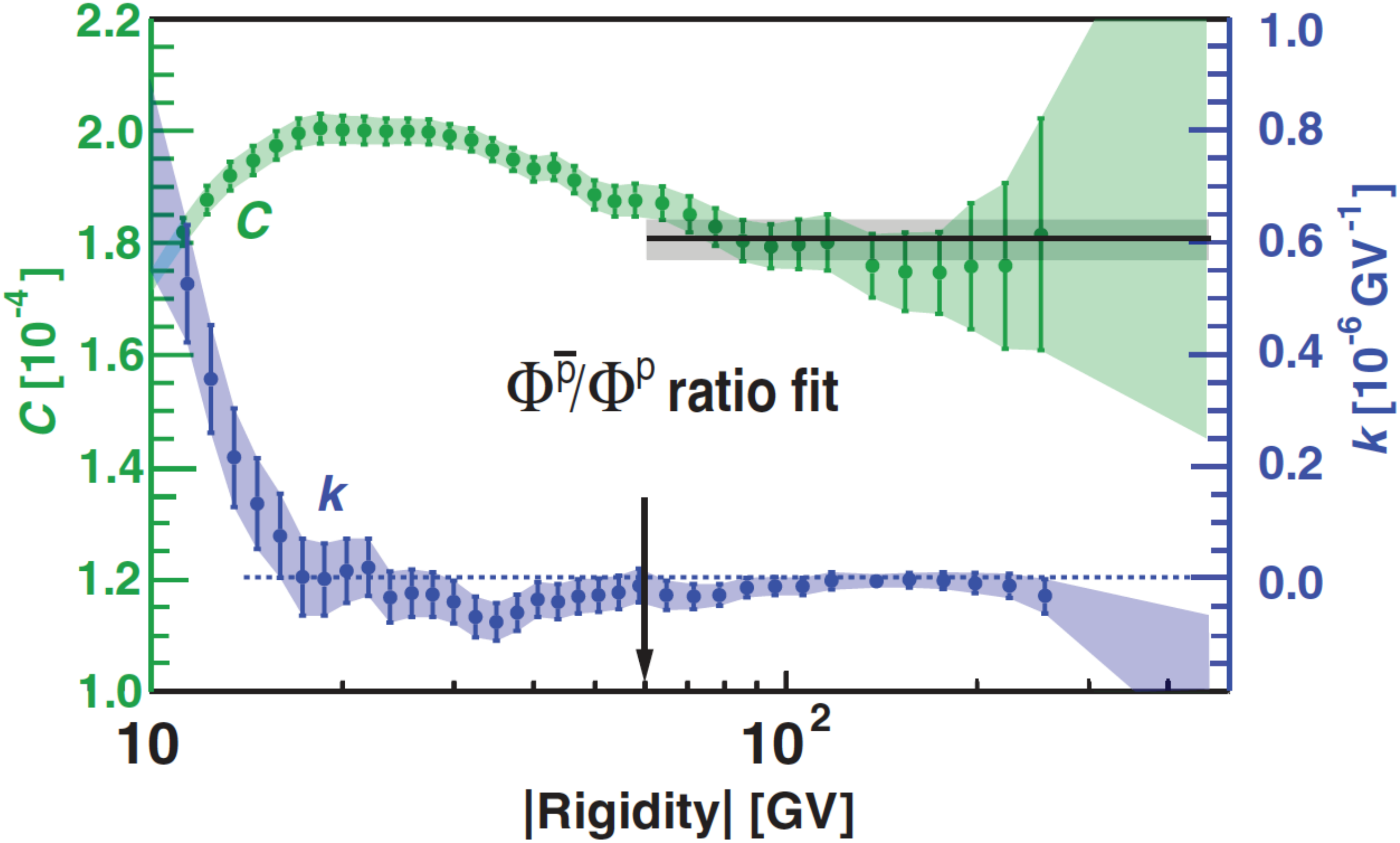
(a) G.Giesen, M.Boudaud, Y.Gènolini, V.Poulin, M.Cirelli, P.Salati and P.D.Serpico, JCAP09 (2015) 023; [arXiv:1504.04276].

(b) C.Evoli, D.Gaggero and D.Grasso, arXiv:1504.05175; JCAP 12 (2015) 039.

(c) R.Kappl, A.Reinertand, and M.W.Winkler, arXiv:1506.04145 [astro-ph.HE].

Slide window fit of $\bar{p}/p$ ratio:

$\Phi^{\bar{p}}/\Phi^{p} = C + k \times (|R| - R_0)$, fit for every 4-5 Rigidity bins



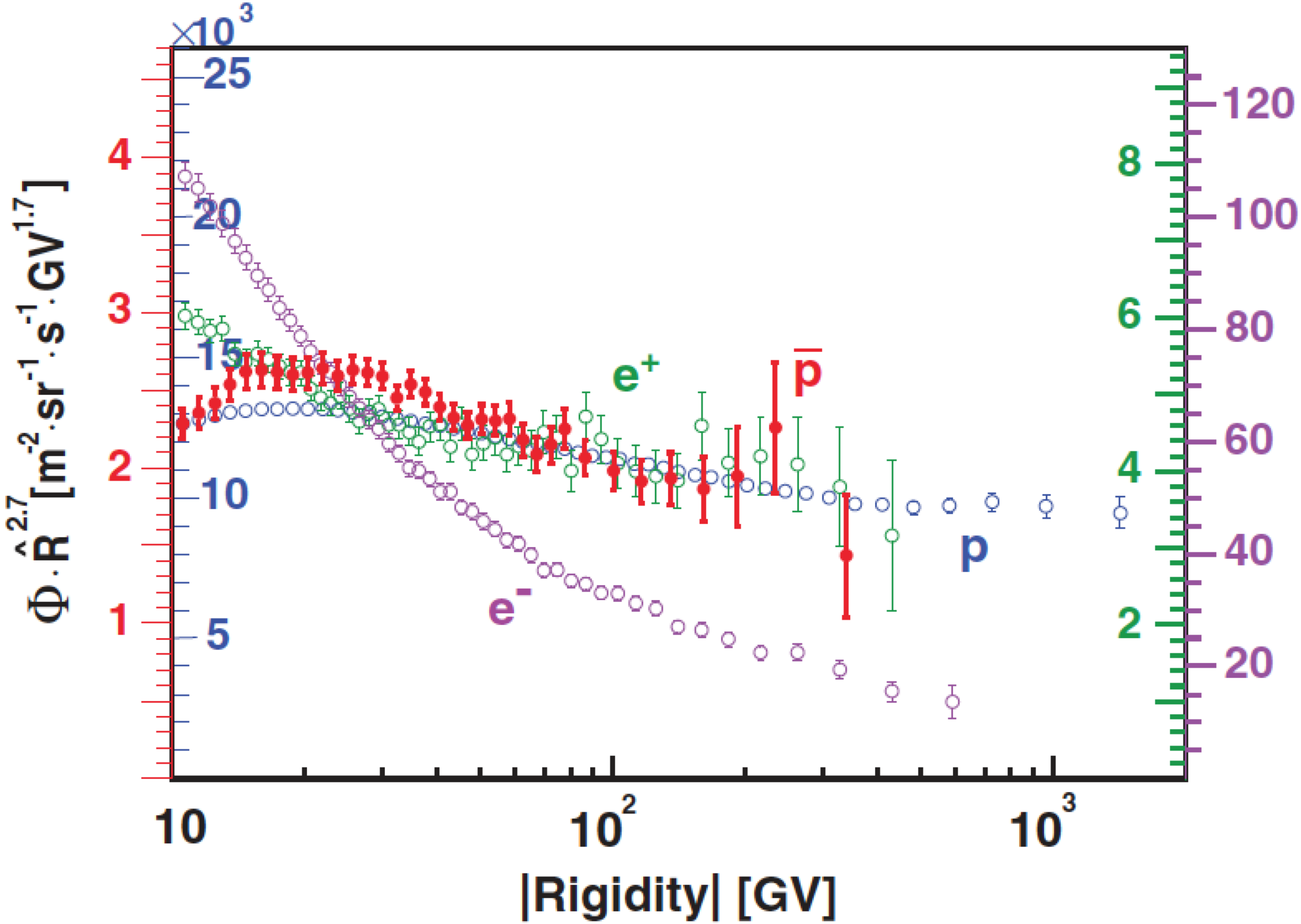
Features:

- Slope term (*k*) is everywhere consistent with zero in 60-250 GeV
- Constant term (*C*) overshoot at ~20 GeV before settling down to a constant value. (e.g. PRL 118.191101, PRL 118.191102 (Dark Matter), APJ 586, 1050 (local bubble))

The Rigidity Dependence of Elementary Particles

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

are identical from 60-500 GV.



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

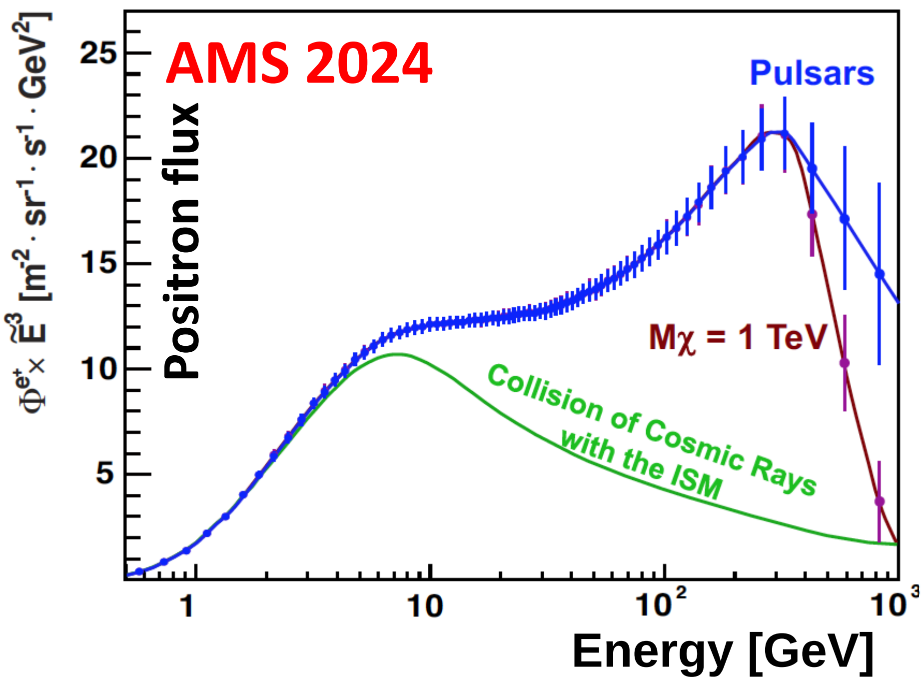
The same rigidity dependence of e^+, $\bar{p}$, p is intriguing:

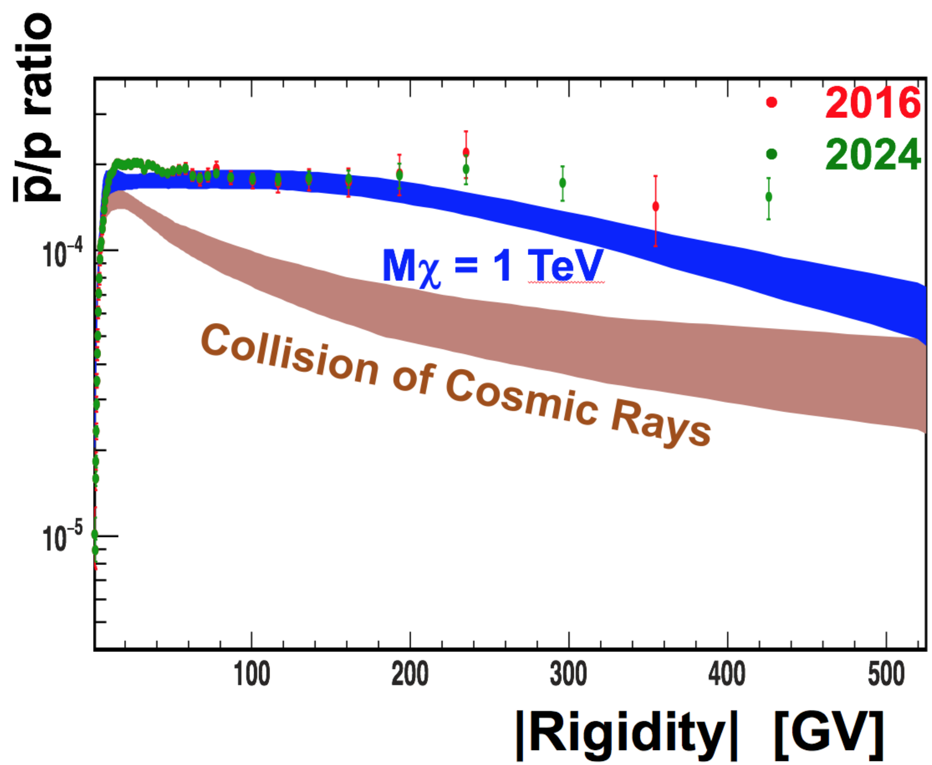
- Three particle types with very different production and propagation mechanism, show the same Rigidity dependence. Accidental?
- The hard positron spectrum indicates that excess of positrons are from local sources, or cosmic ray residence time is very short.
- The magnitude of high energy e^+ and $\bar{p}$ are similar within a factor of 2. Same production mechanism?

It is very challenging for any model to describe simultaneously all four spectra.

To answer these questions, more data with larger energy extent is needed.

By 2024, AMS will have enough data to understand the origin of the positron excess.





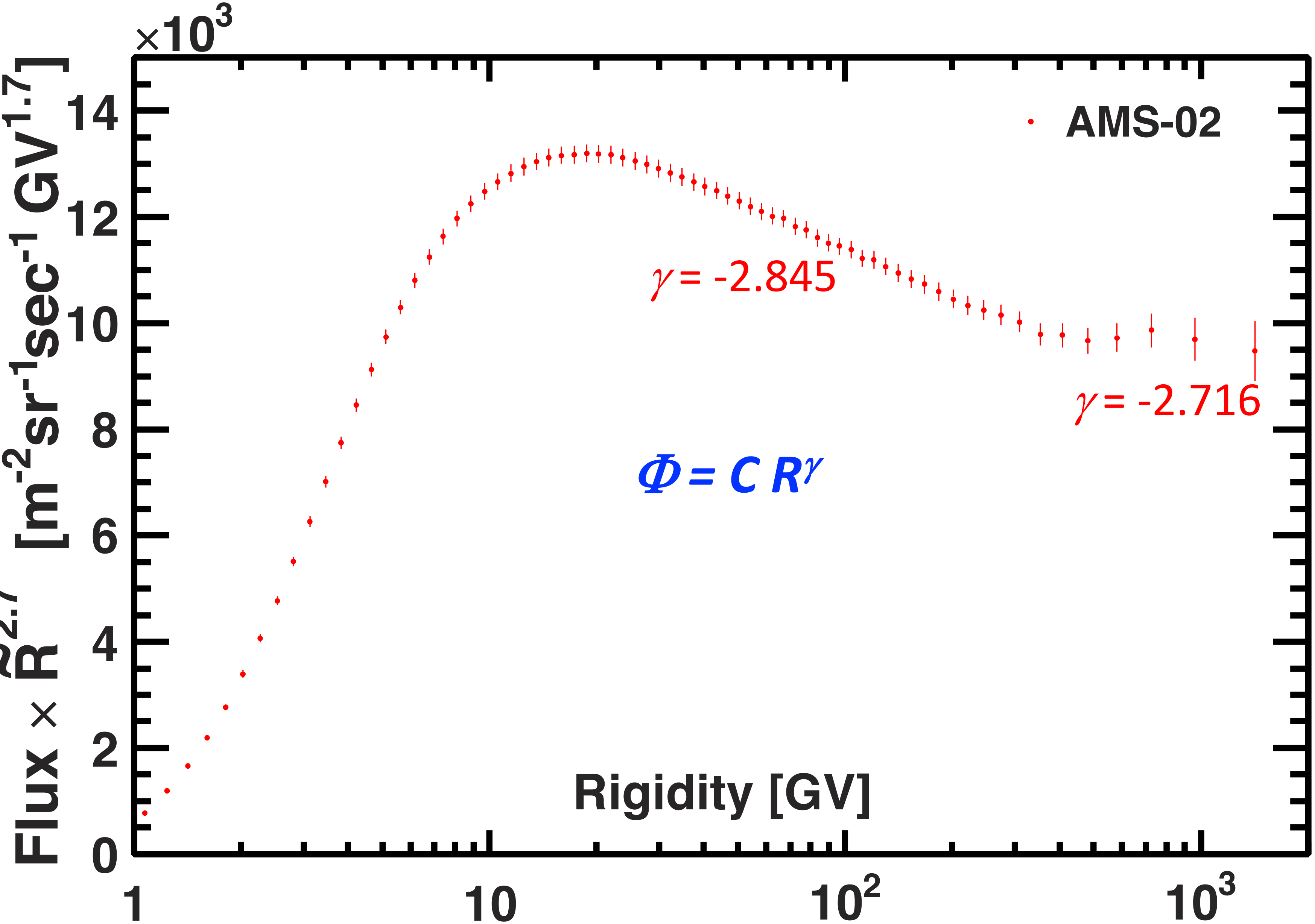
Models based on
I. Cholis and D. Hooper, Phys.Rev. D88 (2013) 023013
J. Kopp, Phys. Rev. D 88 (2013) 076013

Conclusions

1. Positron fraction (1.1×10^6 e^+ events) requires an additional source of high energy e^+ and e^- :
   - can't be explained by the ordinary CR collisions
   - at 265±22 GeV the fraction reaches its maximum;
   - Anomalous behavior of e^+ and e^- described by a single source term.
2. Antiproton-to-proton flux ratio (3.5×10^5 $\bar{p}$ events) in cosmic rays show unexpected behavior:
   - can't be explained by the ordinary CR collisions
   - $\bar{p}/p$ ratio is rigidity independent above 60 GV
3. Identical flux behavior for p, $\bar{p}$ and e^+ from 60–450 GV
4. Requires a new understanding of elementary particles in cosmic rays.
5. Operating AMS to the lifetime of ISS will provide further information to resolve some of these mysteries.

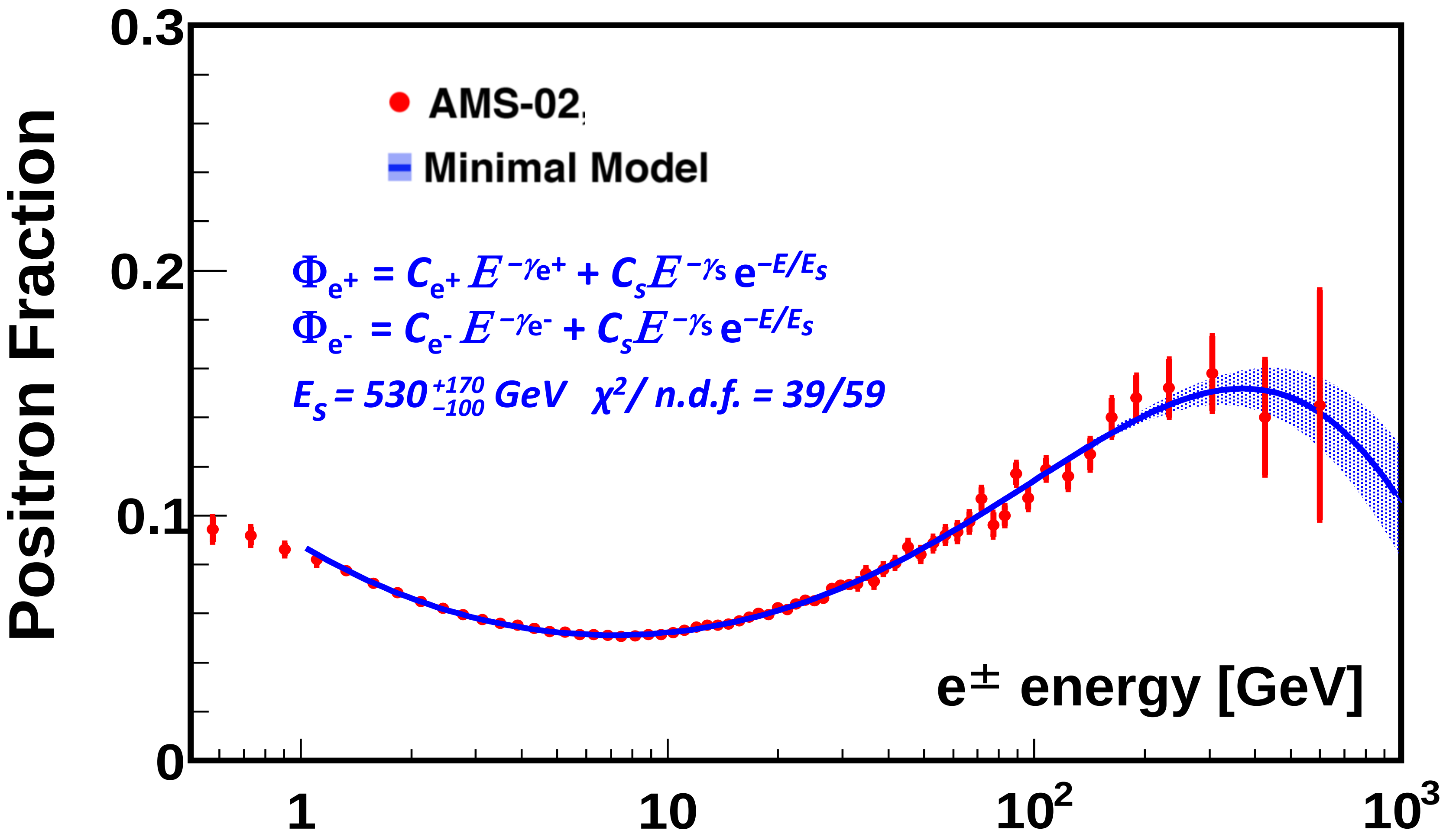
Backups

Precision Measurement of proton flux up to 2 TeV



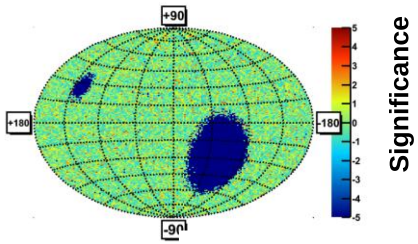
M. Aguilar *et al*., Phys. Rev. Lett. **114,** 171103 (2015)

Additional source of high energy e^+ and e^-

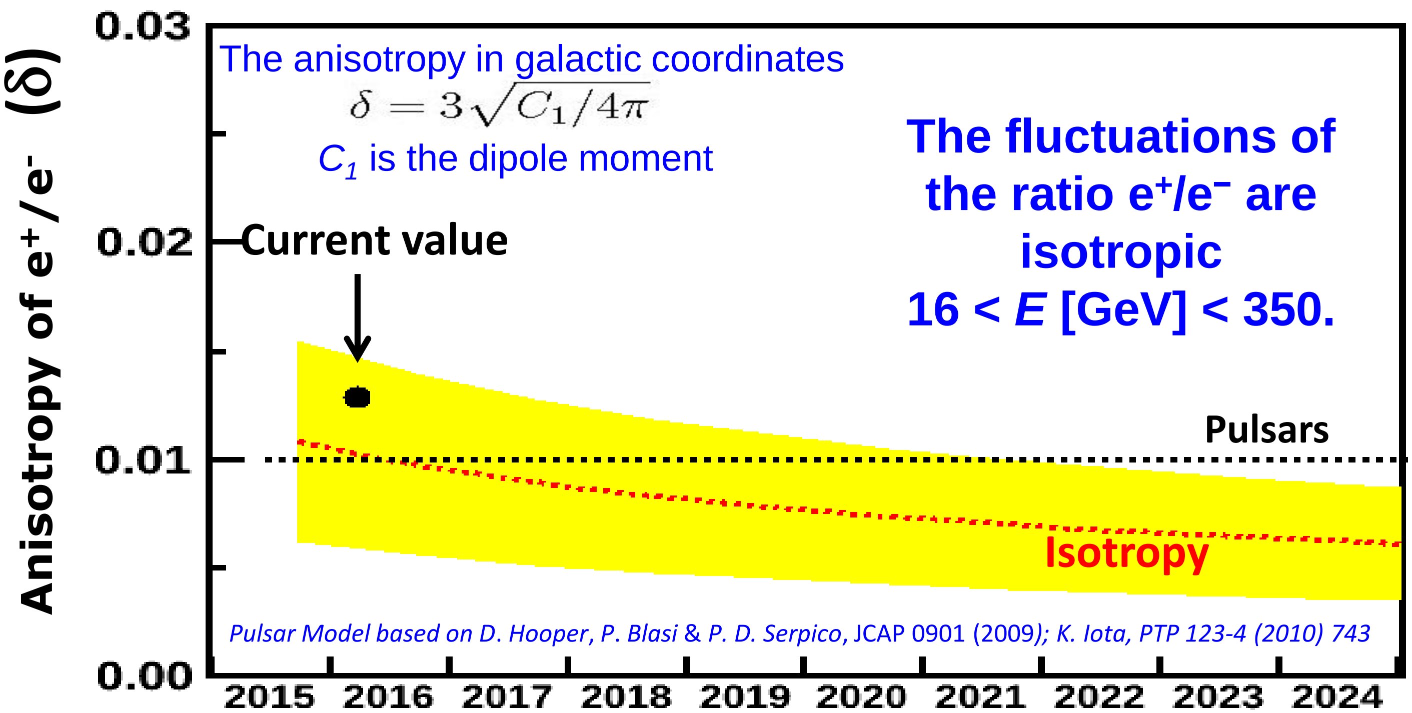


The anisotropy of the e^+/e^- ratio

Astrophysical point sources like pulsars will imprint a higher level of anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.



Galactic coordinates (b,l)



Data taking to 2024 will allow to explore anisotropies of 1%