Searching for WIMPs with Charged Cosmic Rays

Martin W. Winkler

JCAP 10 (2015)	R. Kappl, A. Reinert, M.W.
JCAP 02 (2017)	M.W.
(work in progress)	A. Reinert, M.W.

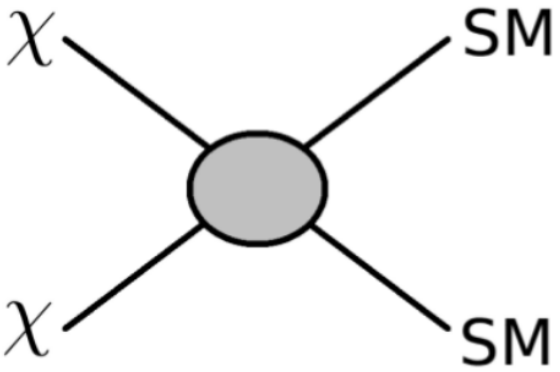
DESY THEORY WORKSHOP
September 27, 2017

Stockholm University

Antiprotons in Cosmic Rays

primary antiprotons

- dark matter annihilation

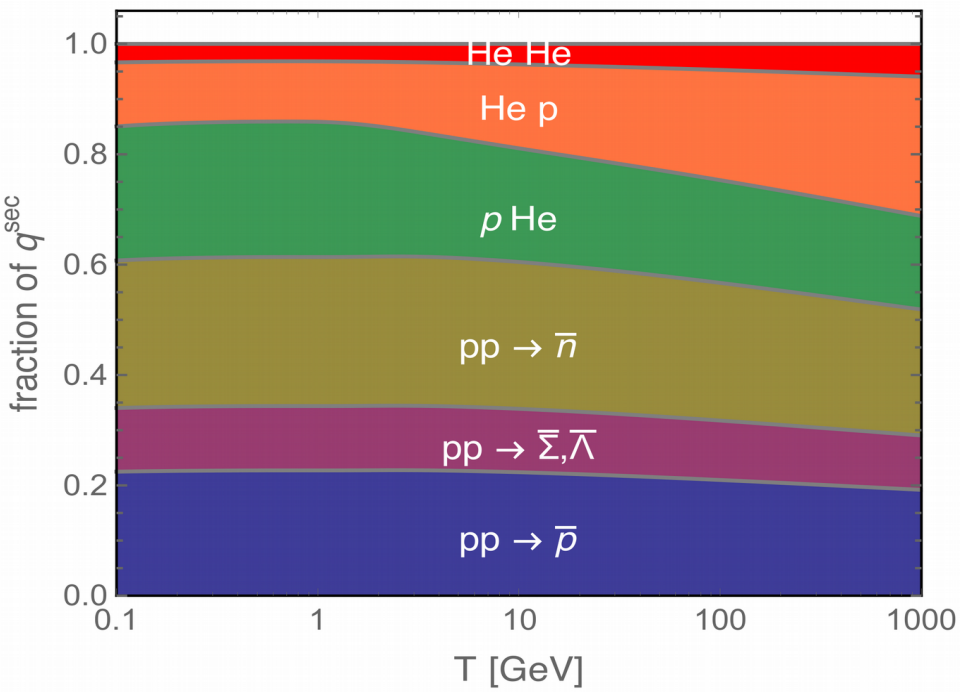


- smooth spectrum
- propagation washes out directional information

secondary antiprotons

- primary cosmic rays (p,He) scatter on interstellar matter

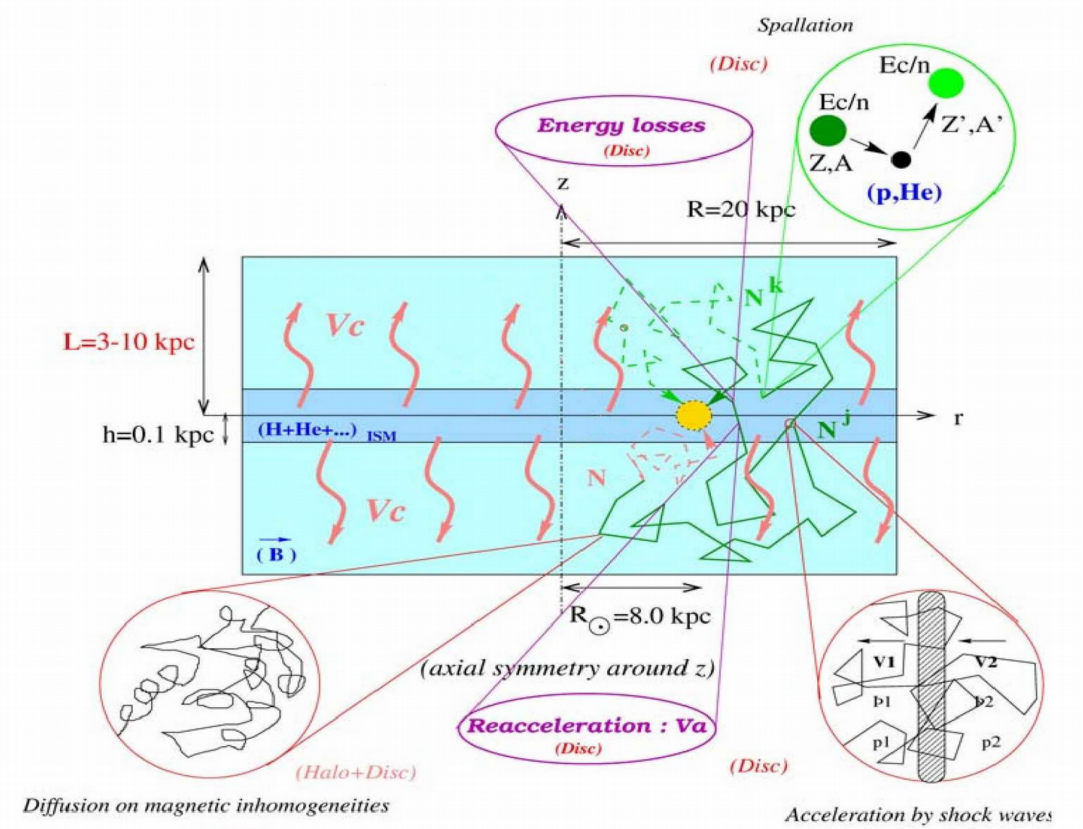
$$q^{\mathrm{sec}}(T) \sim \int dT' \left(\frac{d\sigma_{\bar{p}}}{dT}\right) \rho_{p,He}\, \Phi_{p,He}$$



Propagation

- propagation described by diffusion equation

$$\nabla(-K\,\nabla N_{\bar{p}} + \mathbf{V}_c\, N_{\bar{p}}) + \partial_E(b_{loss}\, N_{\bar{p}} - K_{EE}\,\partial_E N_{\bar{p}}) + \Gamma_{ann}\, N_{\bar{p}} = q_{\bar{p}}$$



- semi-analytic solution in two-zone diffusion model

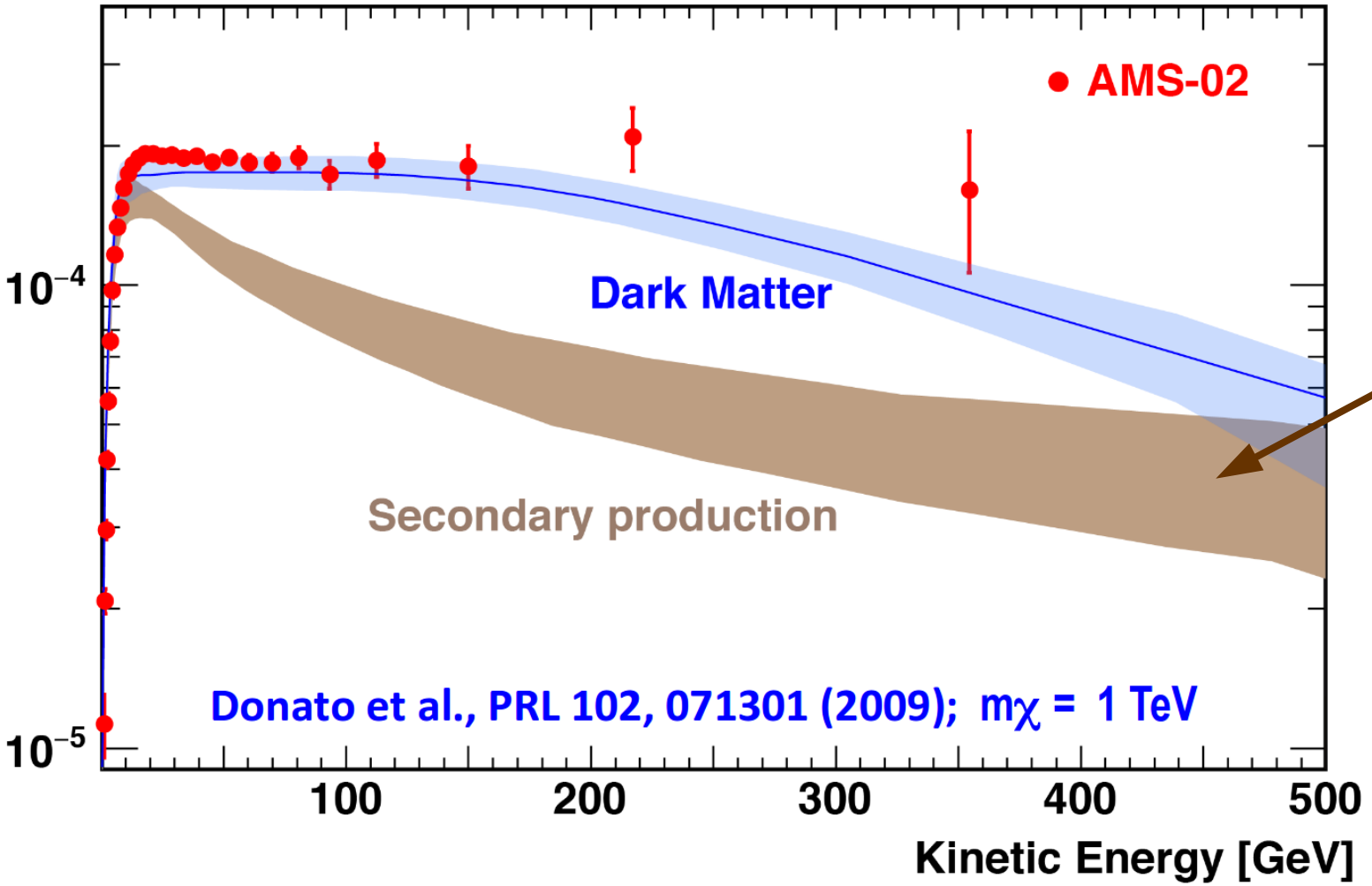
  Maurin et al., Astrophys. J. 555 (2001), Donato et al., Astrophys. J. 563 (2001)

- 5 propagation parameters: K_0, δ, L, V_a, V_c

AMS-02 Antiprotons

- AMS-02 in 2015: surprisingly hard $\bar{p}$ spectrum

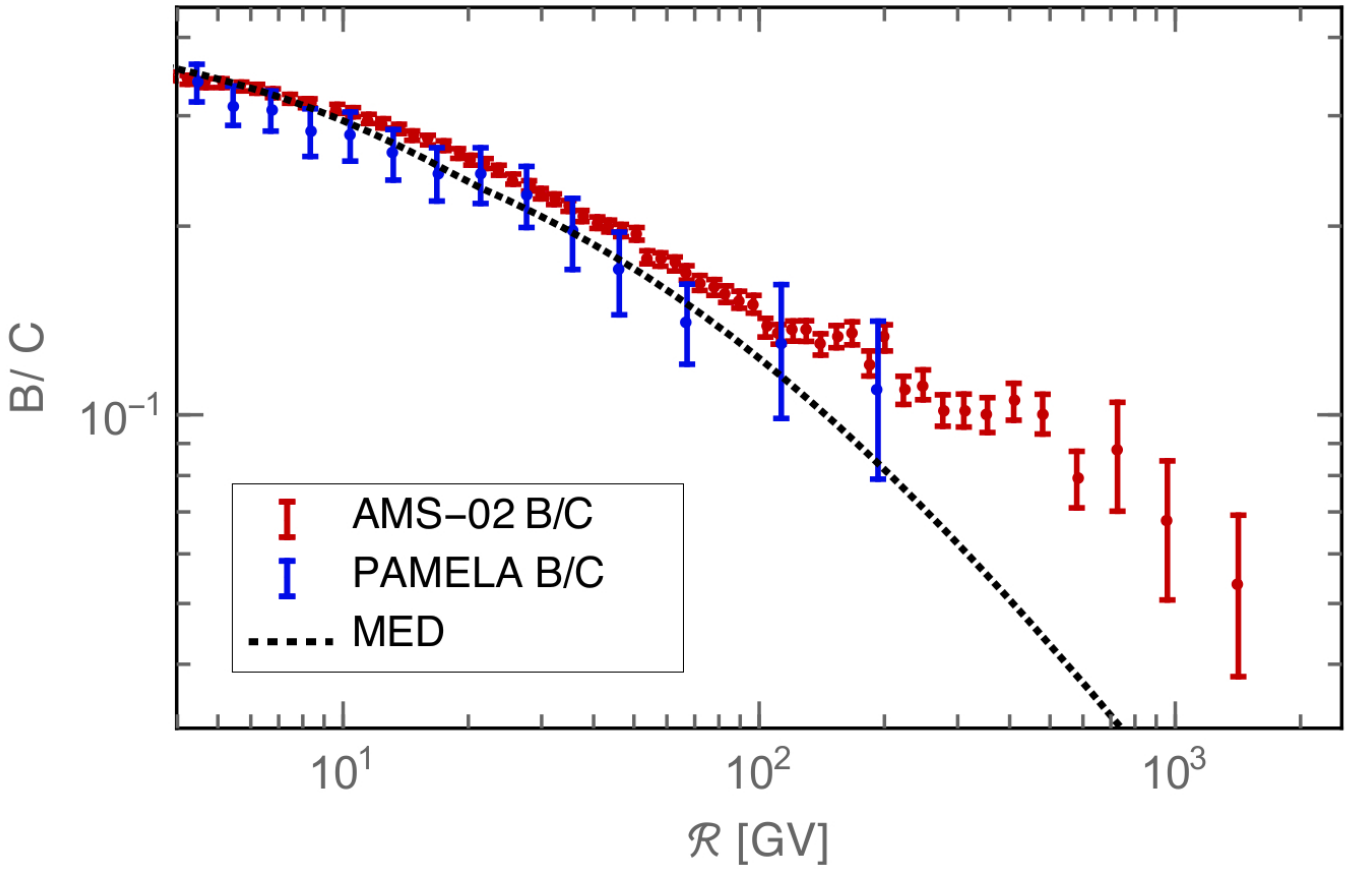
S.Ting, A. Kounine, AMS Days at CERN (2015)



Uncertainties:
cross section,
propagation

A Look at B/C

- propagation parameters were extracted from pre-AMS data

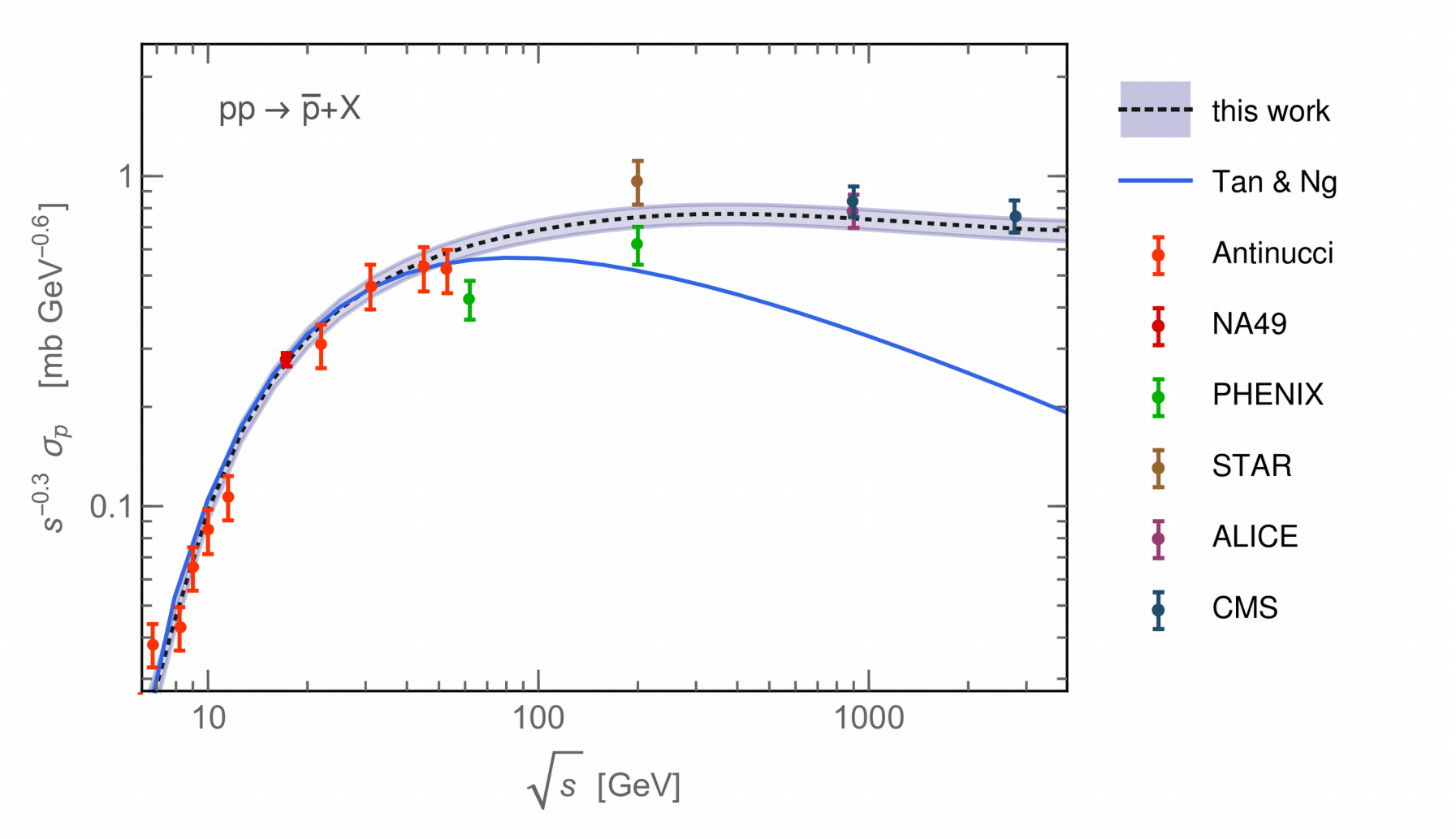


- harder spectrum also seen in B/C

see also: Giesen, JCAP 09 (2015), Evoli et al. JCAP 12 (2015)

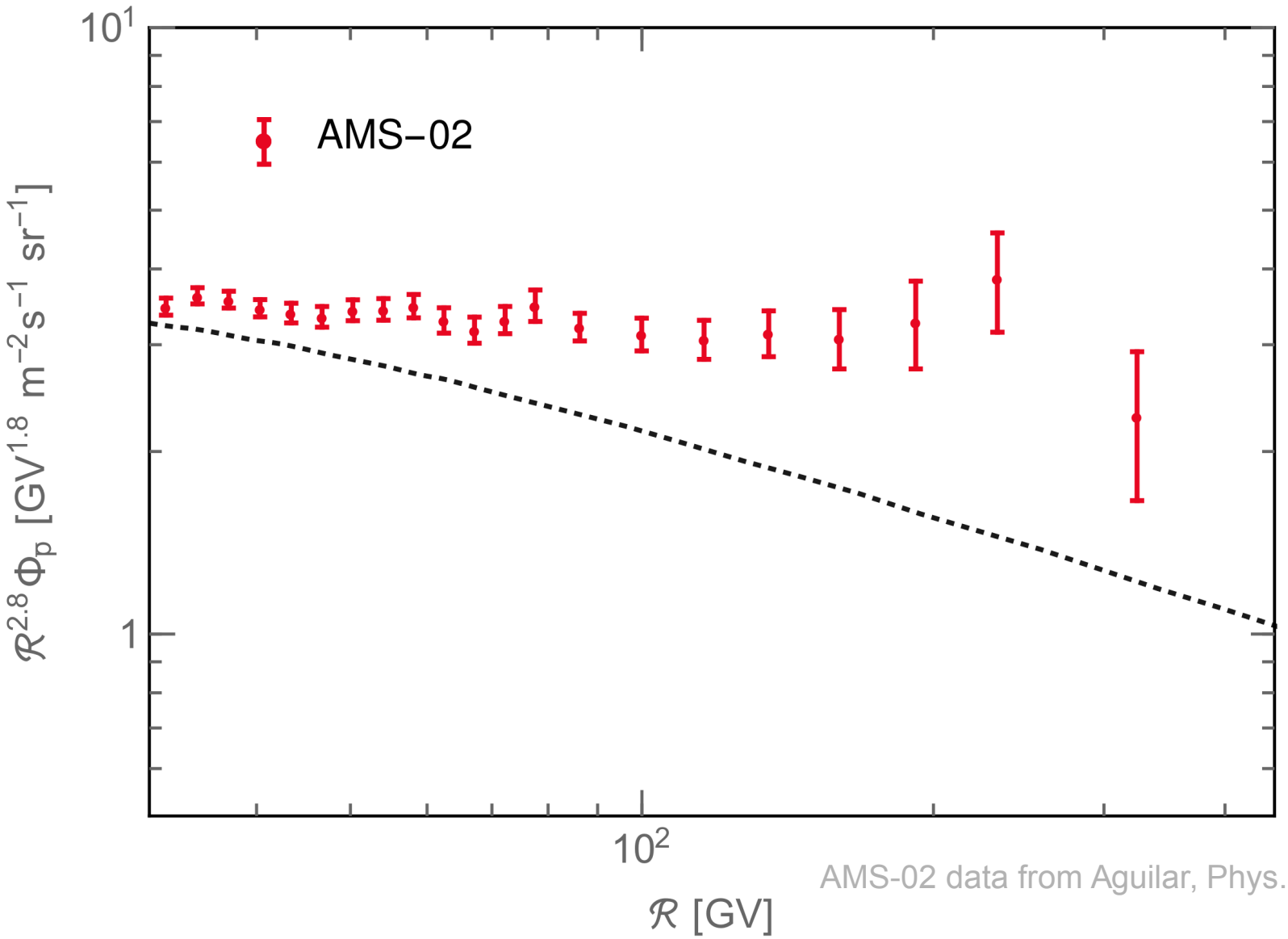
Increasing Antiproton Cross Section

- scaling violation in antiproton production



Tan, Ng Phys.Rev. D26 (1982), PHENIX, Phys. Rev. C83 (2011), STAR, Phys. Rev. C79 (2009), ALICE, Eur. Phys. J. C71 (2011), CMS, Eur. Phys. J. C72 (2012), NA49, Eur. Phys. J. C65 (2010)

High Energy Antiproton Flux

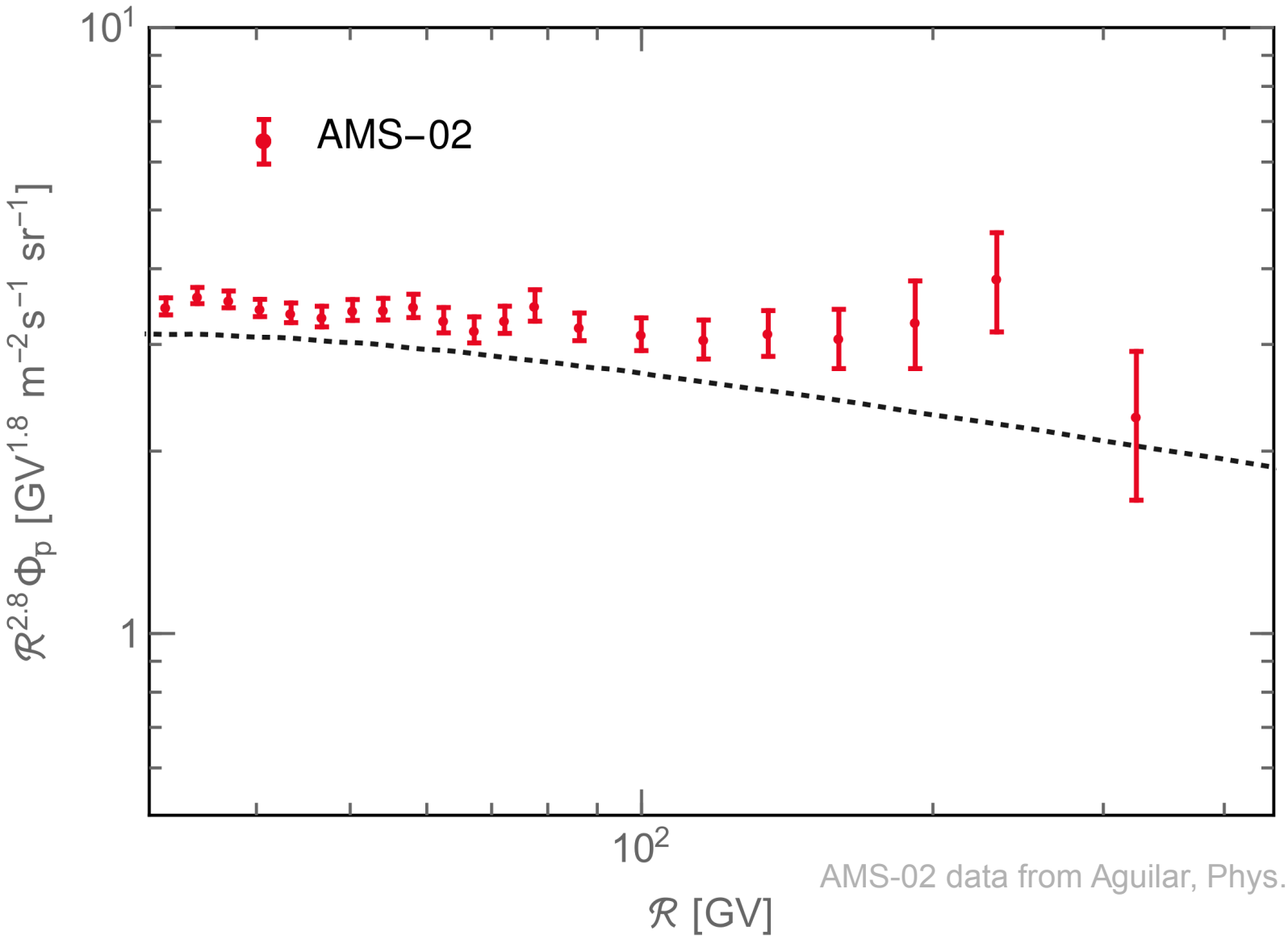


background

2015

AMS-02 data from Aguilar, Phys. Rev. Lett. 117 (2016)

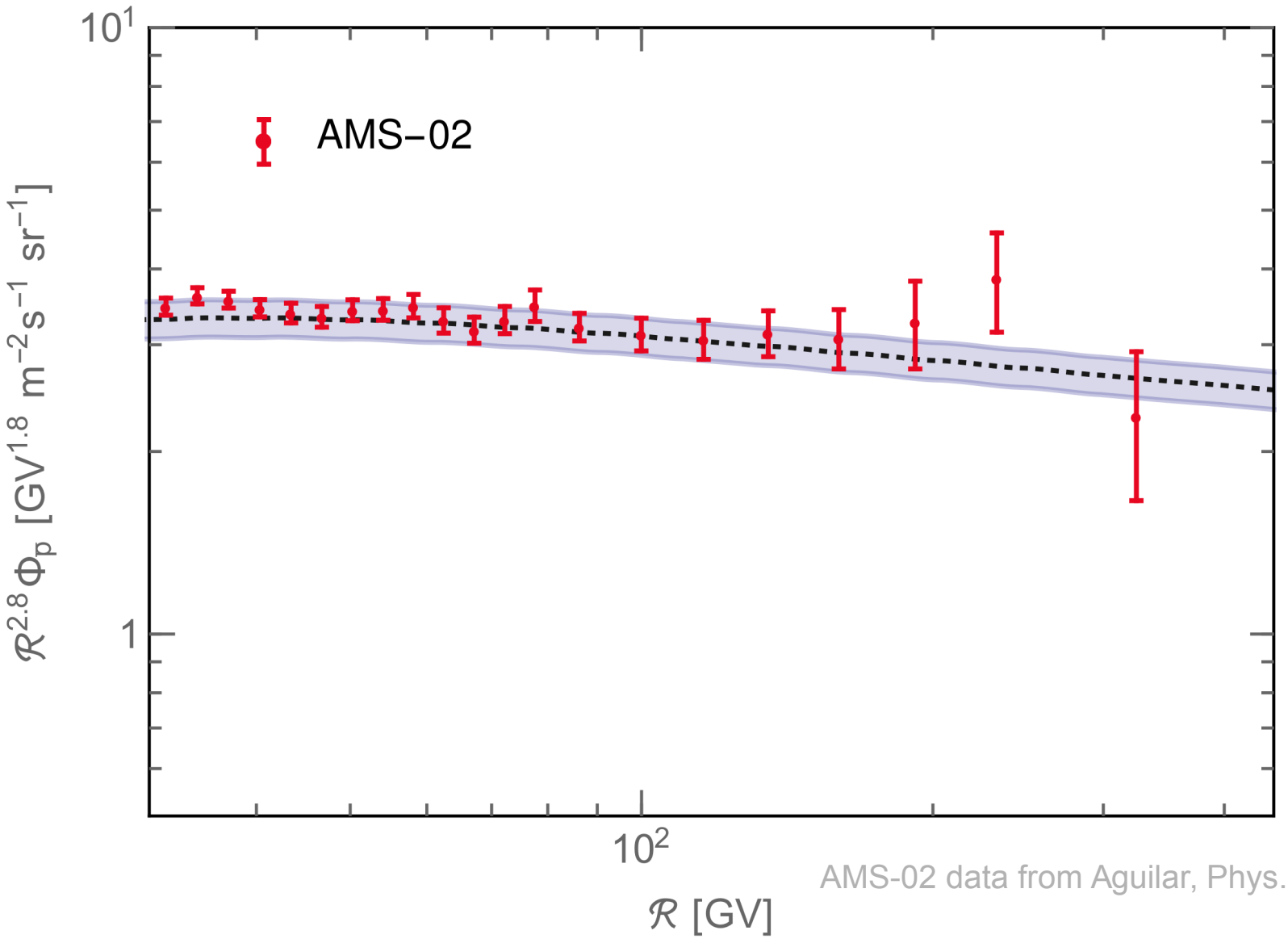
High Energy Antiproton Flux



updated propagation

AMS-02 data from Aguilar, Phys. Rev. Lett. 117 (2016)

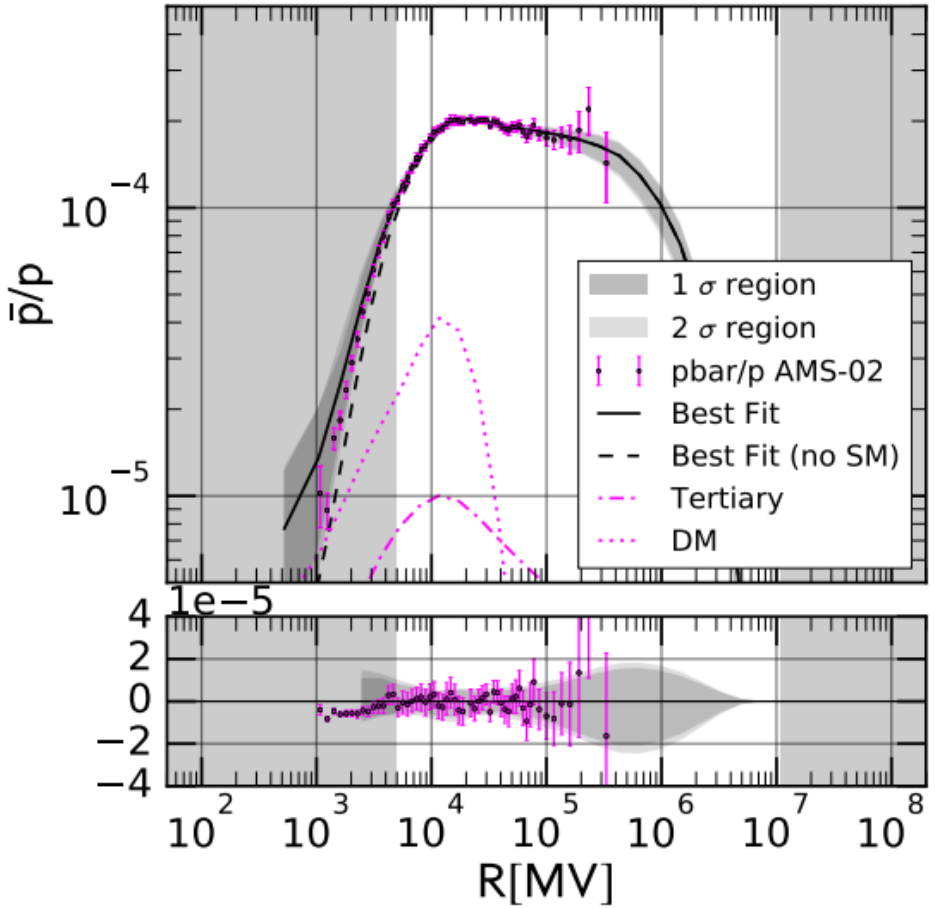
High Energy Antiproton Flux



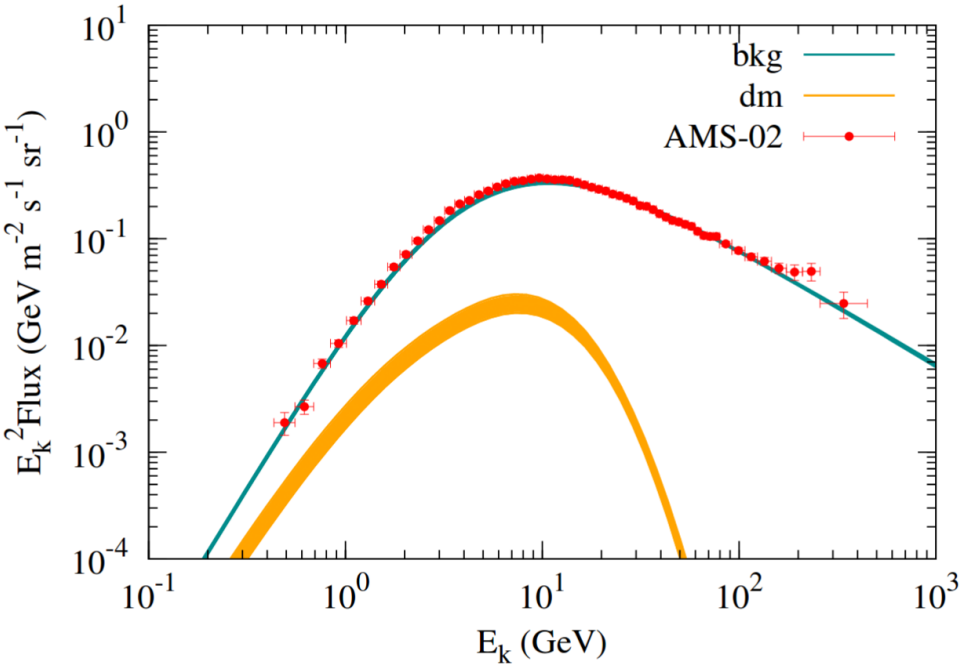
new cross section

AMS-02 data from Aguilar, Phys. Rev. Lett. 117 (2016)

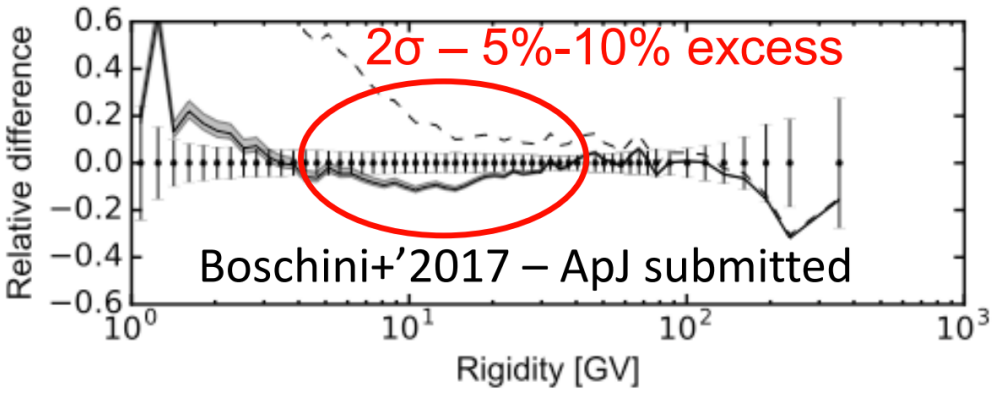
A new Antiproton Excess



Cuoco, Krämer, Korsmeier, PRL 118 (2017)

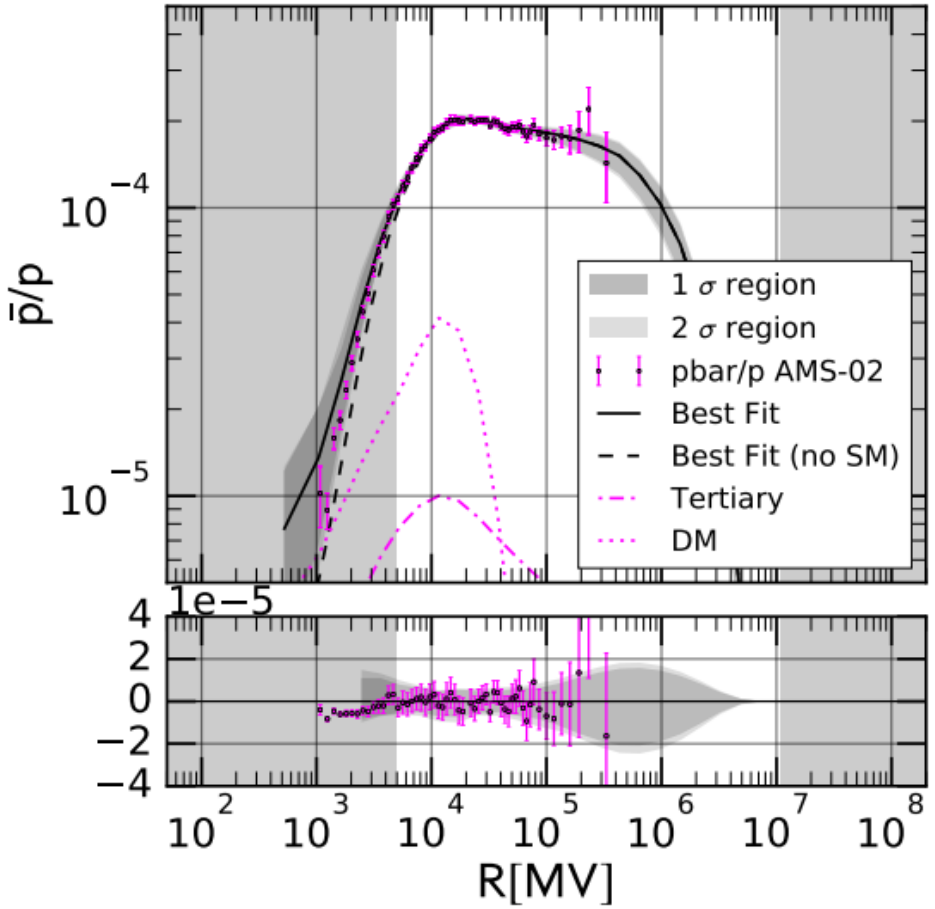


Cui, Yuan, Tsai, Fan, PRL 118 (2017)

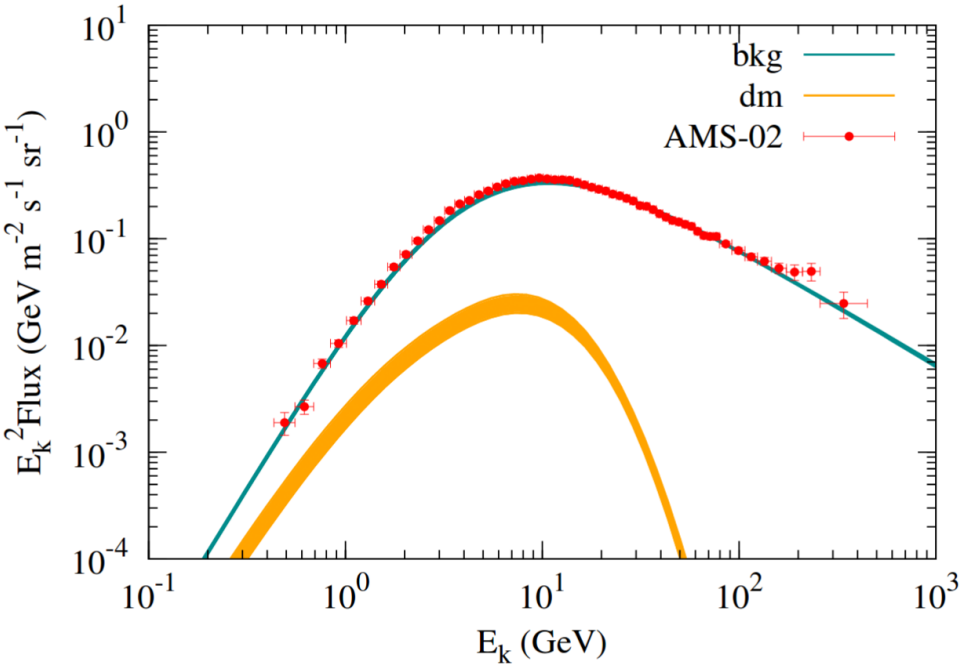


Moskalenko, XSCRC 2017, CERN

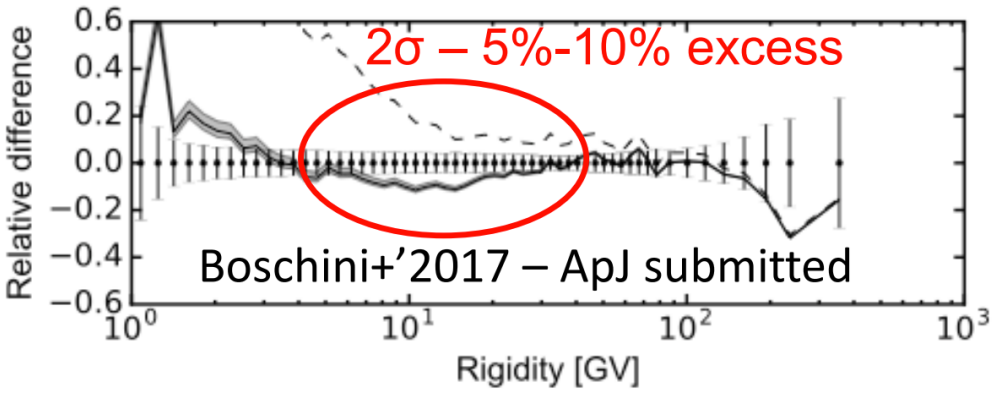
A new Antiproton Excess



Cuoco, Krämer, Korsmeier, PRL 118 (2017)



Cui, Yuan, Tsai, Fan, PRL 118 (2017)

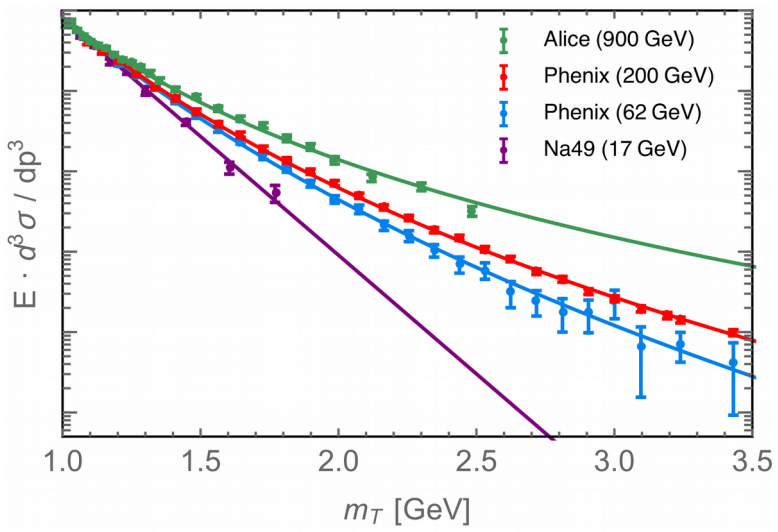


Moskalenko, XSCRC 2017, CERN

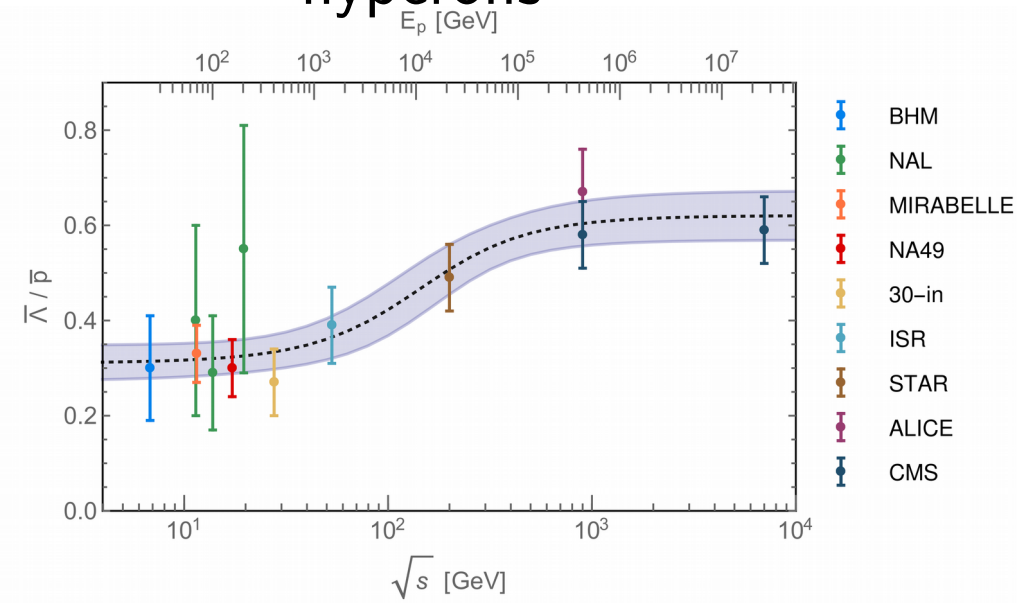
- include low energy spectrum, B/C and cross section uncertainties

Antiproton Cross Section

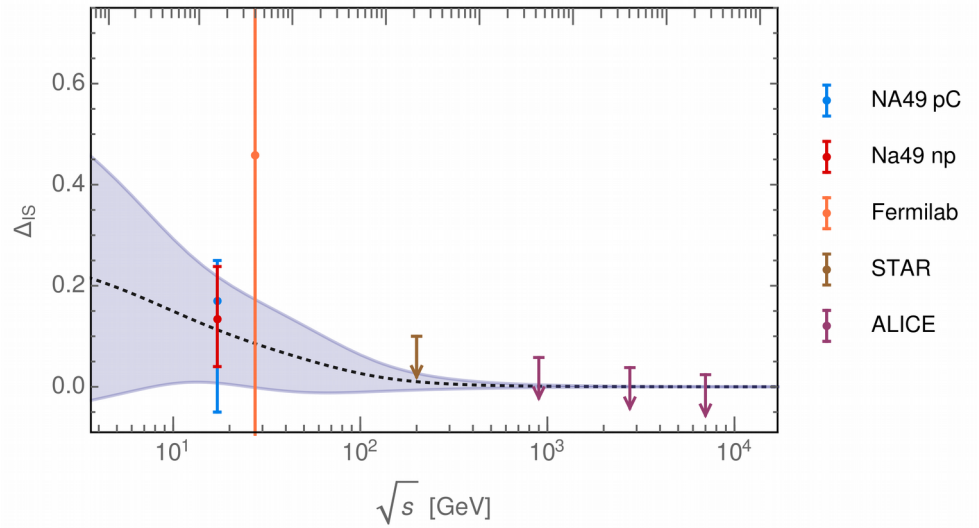
scaling violation



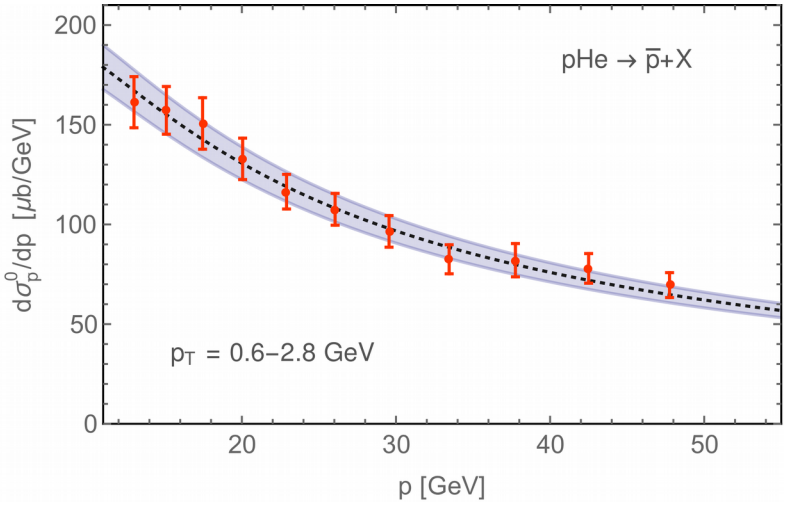
hyperons



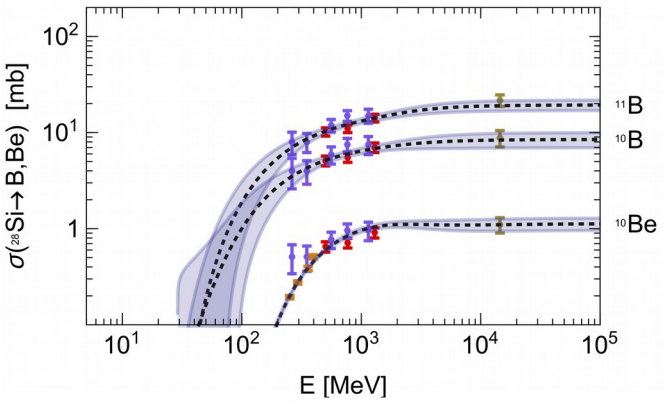
antineutrons

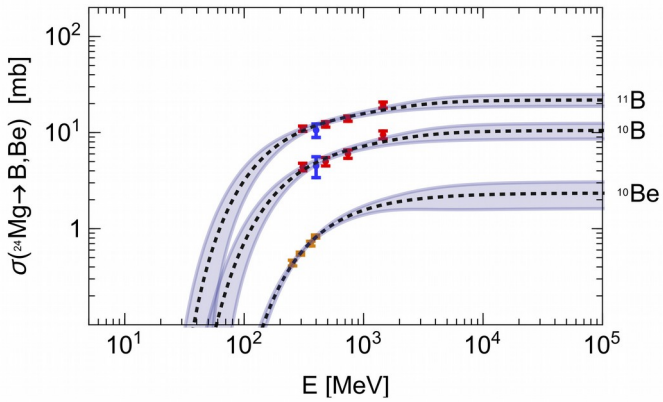


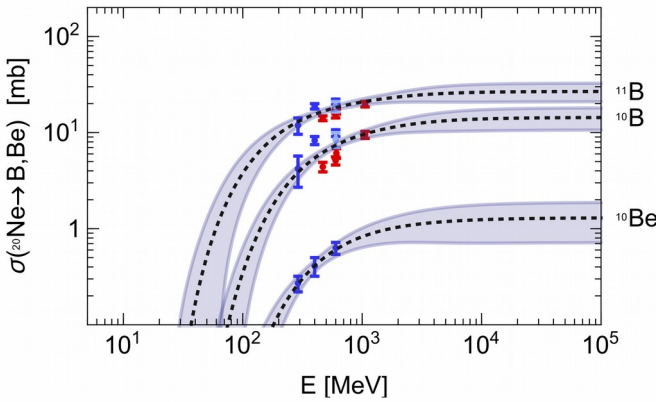
proton helium scattering

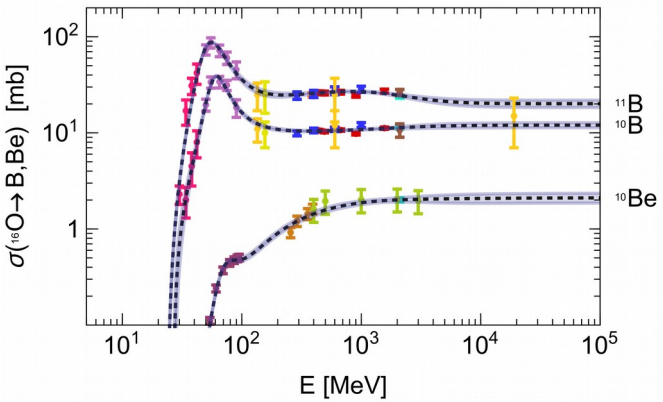


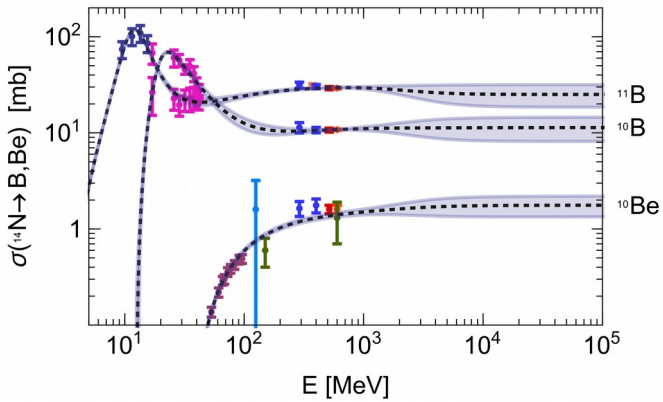
Boron Production

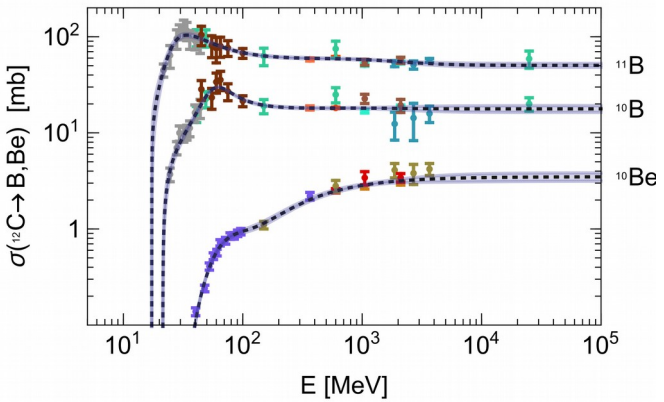


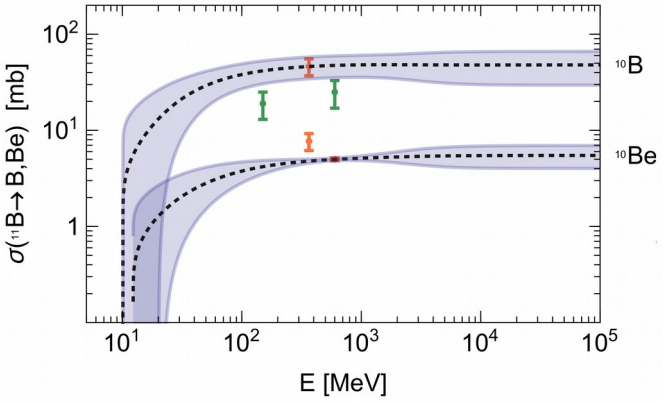








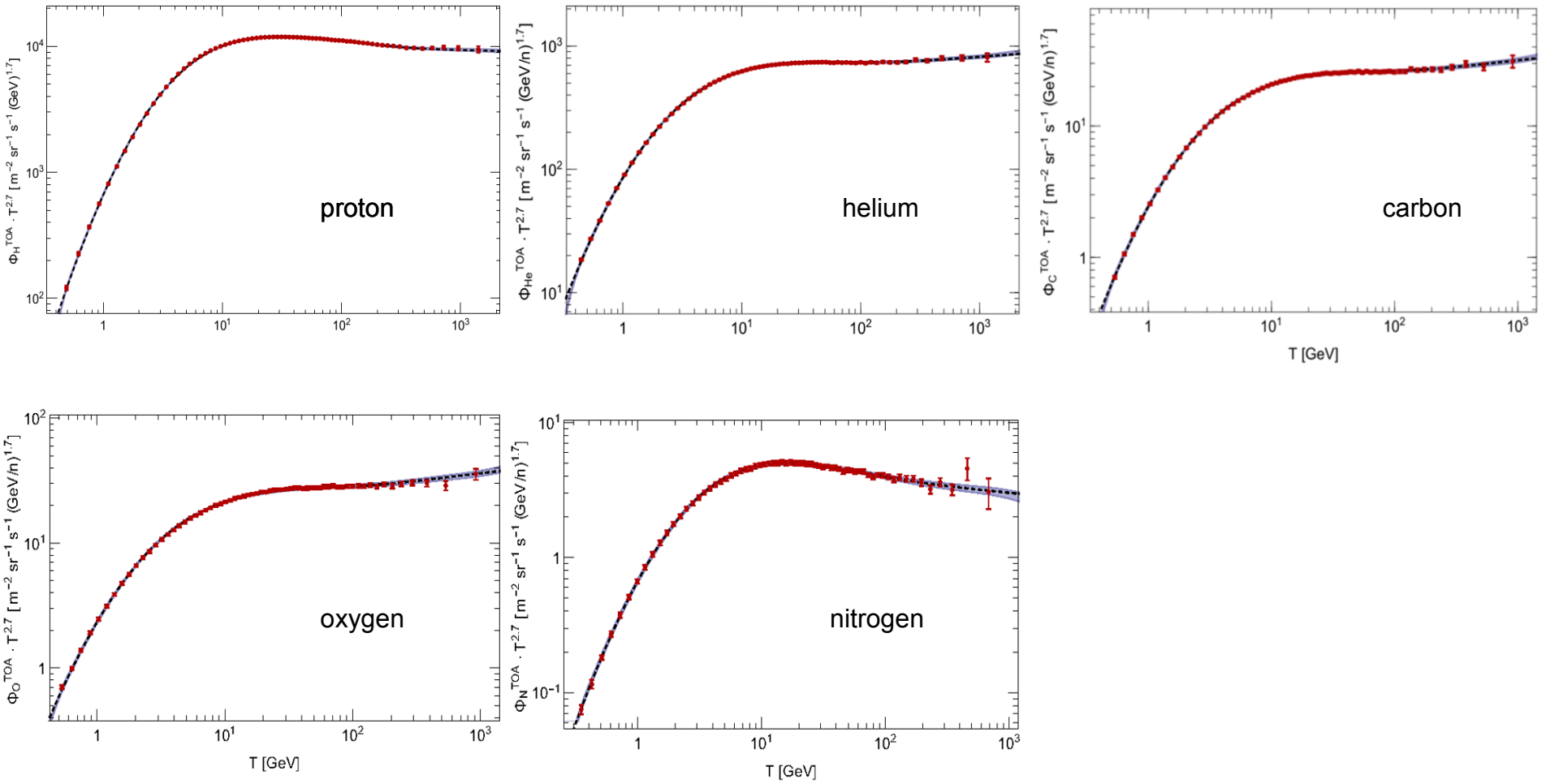




Fit to:

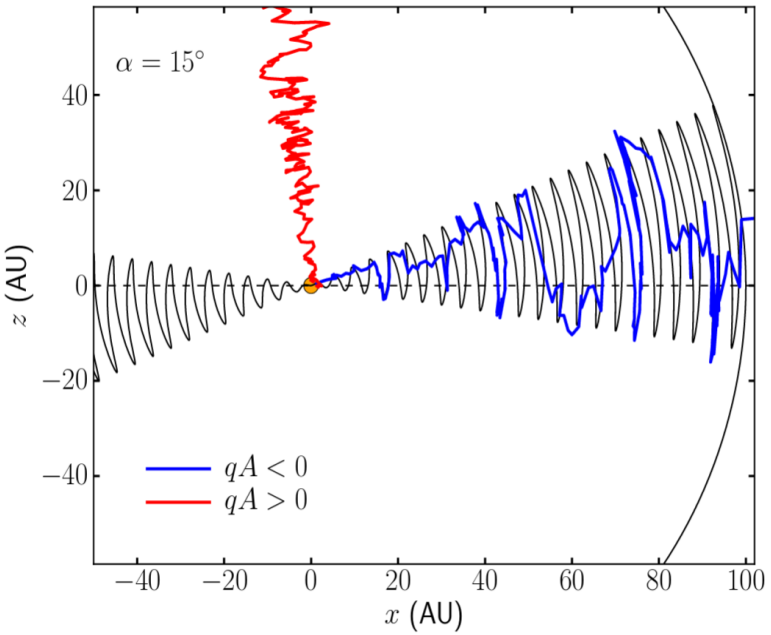
Bodansky et al., Astrophys. J. 202 (1975), Bodemann et al., Nucl. Instr. 82 (1993), Brechtmann et al. Phys.Rev. C39 (1989), Davids et al., Phys. Rev. C1 (1970), Epherre et al., Nucl. Phys. A139 (1969), Fontes et al.,Nucl. Phys. A165 (1971), Phys. Rev. C15 (1977), Goel et al., Nature 223 (1969), Jung et al., Phys. Rev. C1 (1970), Korejwo et al., J. Phys. G28 (2002), Laumer et al., Phys. Rev. C8 (1973), Phys. Rev. C10 (1974), Lindstrom et al., LBL-3650 (1975), Moyle et al., Phys. Rev. C19 (1979), Olson et al., Phys. Rev. C28 (1983), Raisbeck et al., Phys. Rev. C9 (1974), Raisbeck et al., PRL 27 (1971), Roche et al., Phys. Rev. C14 (1976), Schiekel et al., Nucl. Instr. 114 (1996), Webber et al. Phys. Rev. C41 (1990), Astrophys. J. 508 (1998), Yiou et al. J. of Geophy. Res. 74 (1969), Zeitlin et al. Nucl.Phys. A784 (2007), Phys.Rev. C83 (2011), Phys.Rev.C64 (2001)

Primary Cosmic Ray Fluxes



AMS-02 data from Yoon et al., Astrophys. J. 728 (2011), Aguilar et al., Phy. Rev. Lett. 114 & 115 (2015), Yan, XSCRC 2017, CERN

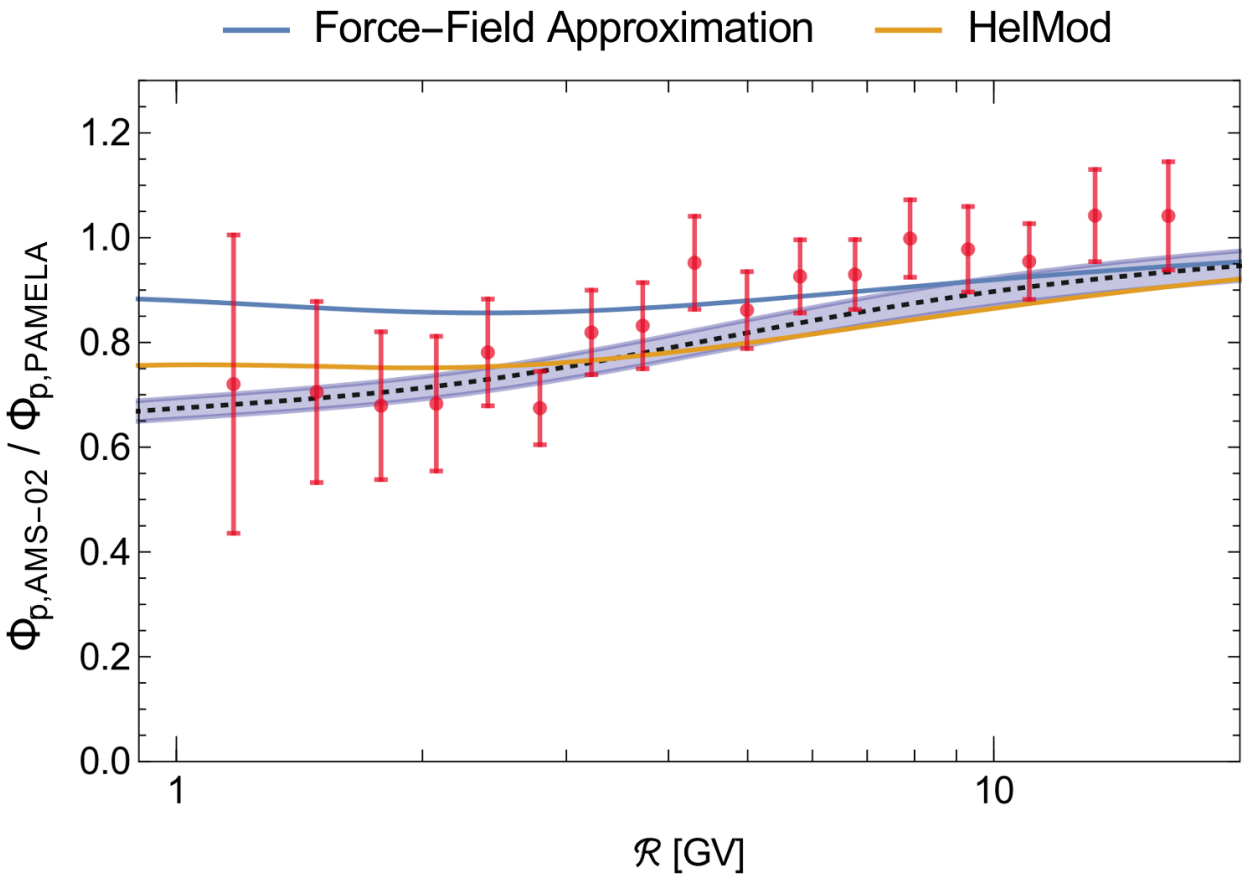
Solar Modulation



- charge-sign effects extracted from $\Phi_{\bar{p},\mathrm{AMS}}/\Phi_{\bar{p},\mathrm{PAMELA}}$

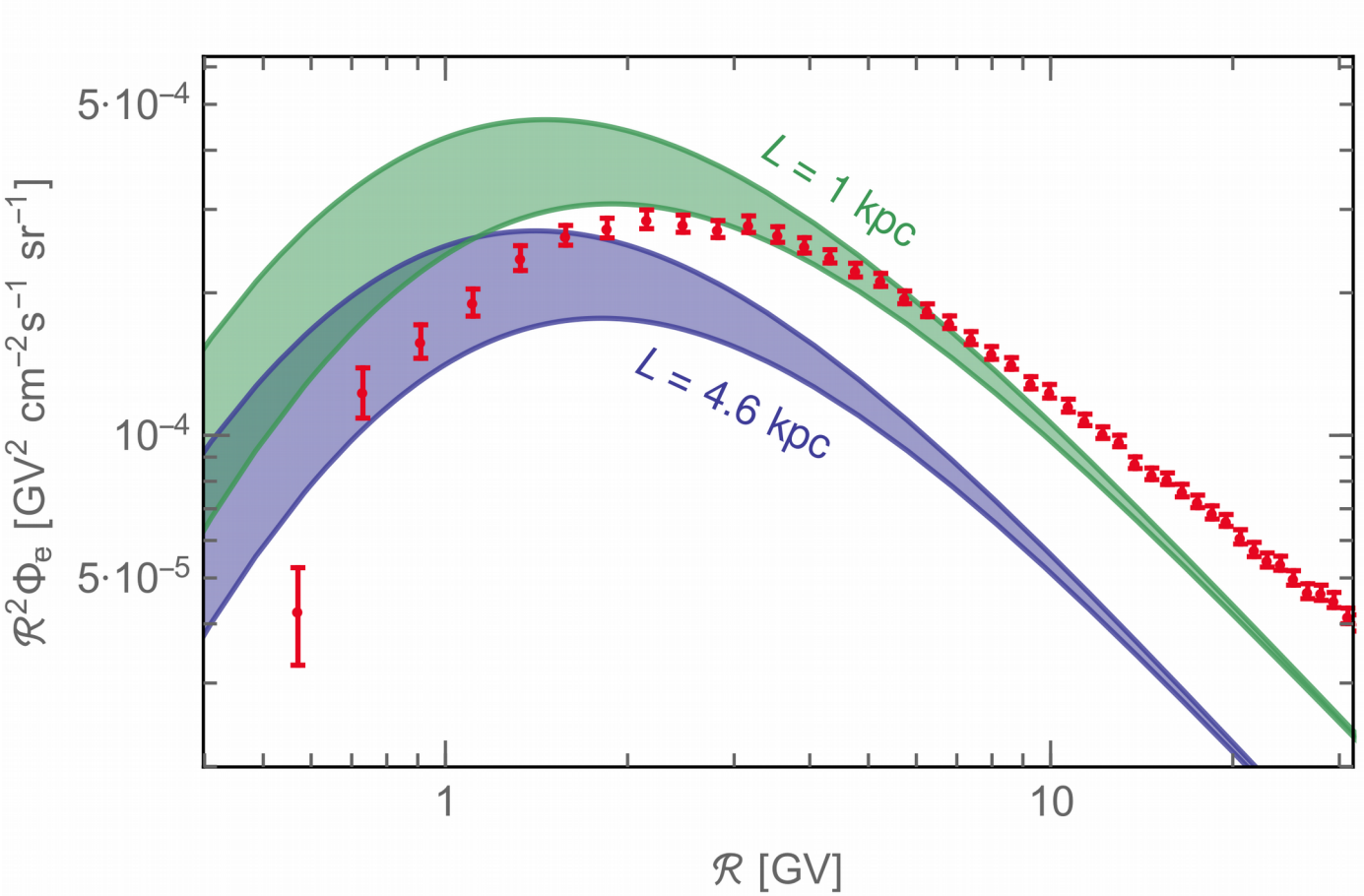
- modify force-field approximation to account for charge-sign effects

Jokipii, Thomas, Astrophys. J. 243 (1981), Cholis, Hooper, Linden, Phys. Rev. D 93 (2016)



Positrons

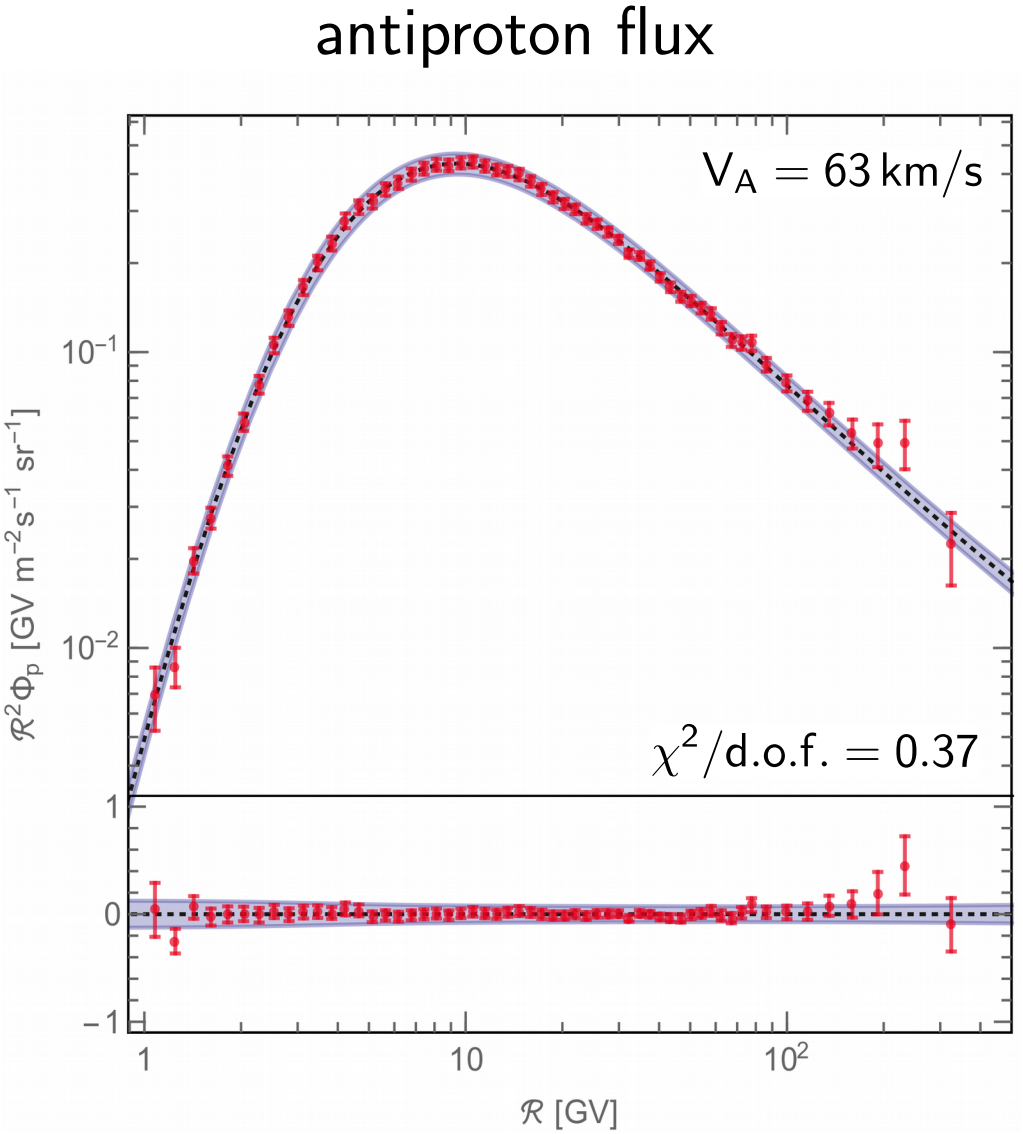
- secondary $\bar{p}$ and B/C insensitive to L (for fixed K_0/L)



- degeneracy is lifted by positrons

Lavalle, Maurin, Putze, Phys.Rev. D90 (2014), Boudaud et al. arxiv:1612.03924 (2016)

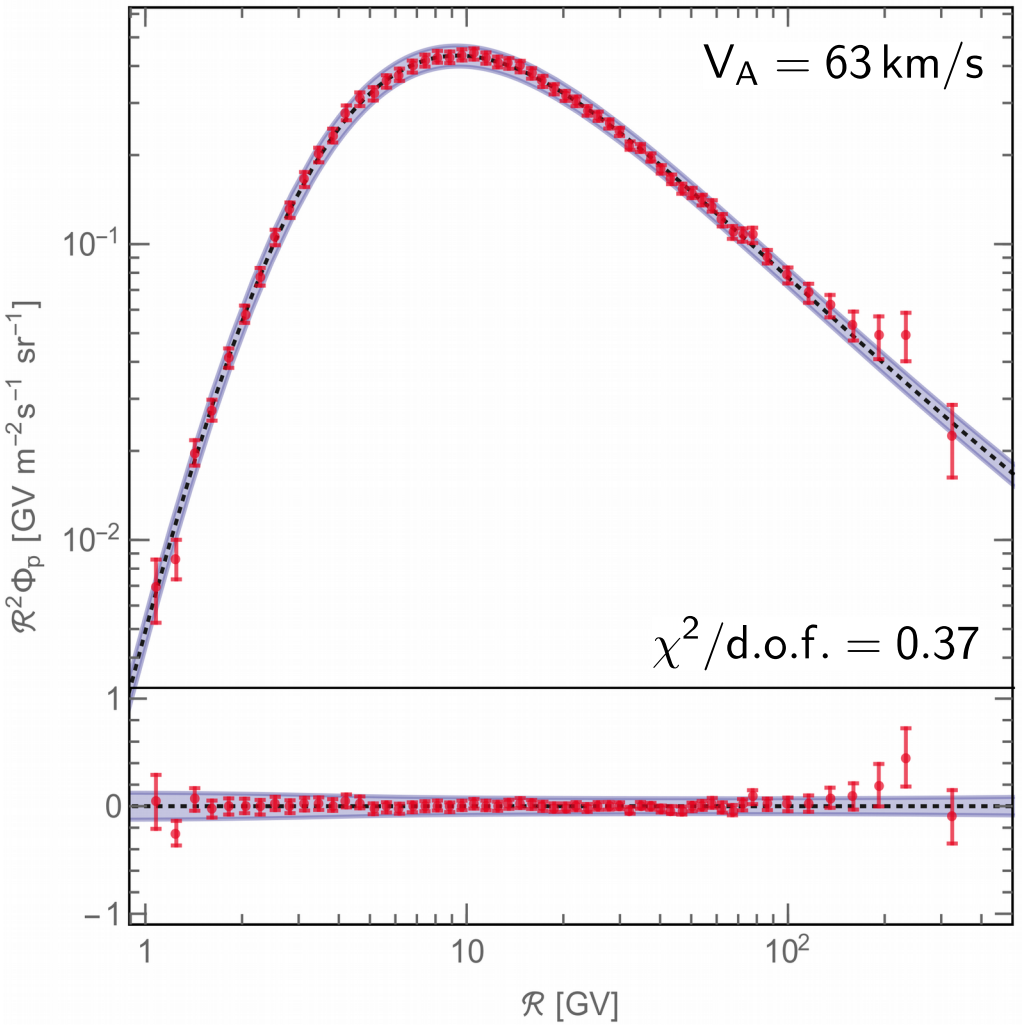
Antiproton Fit



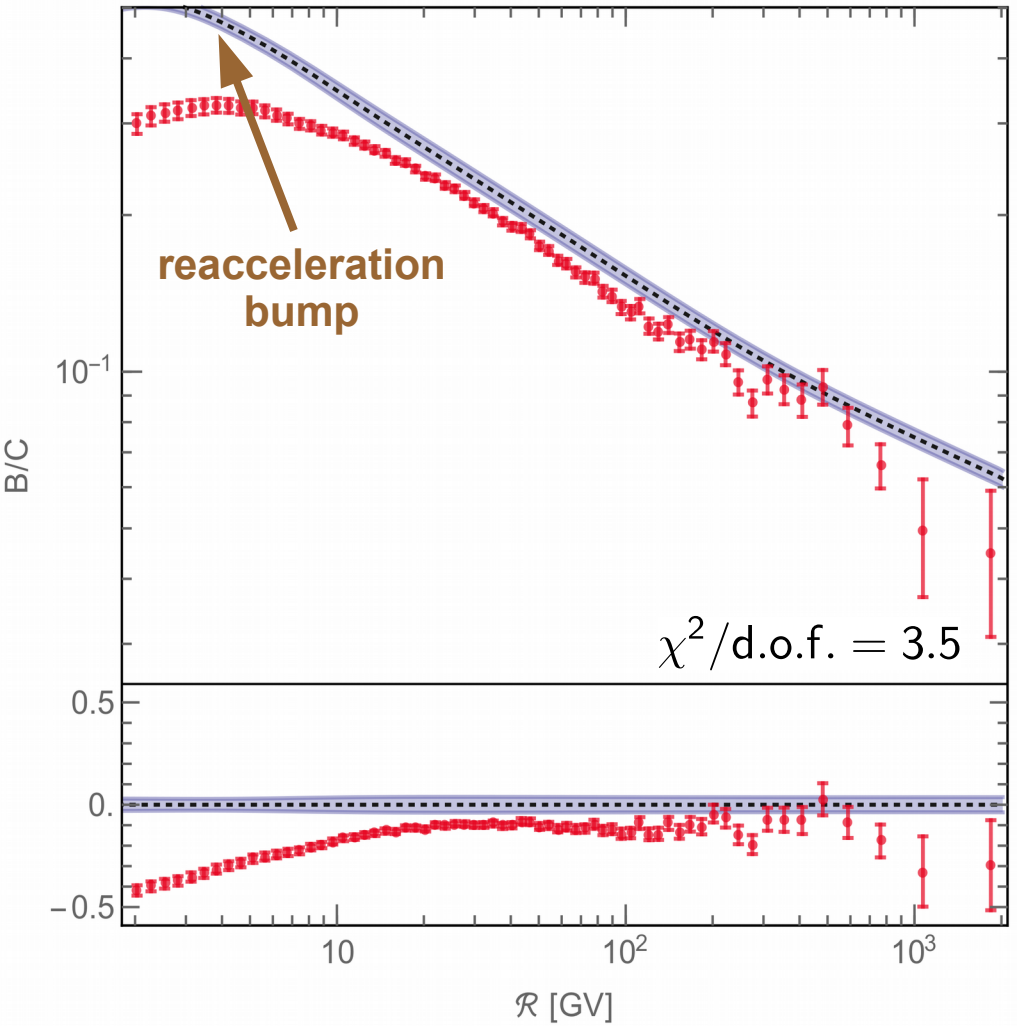
AMS-02 data: Aguilar et al., Phys. Rev. Lett. 117 (2016)

Antiproton Fit

antiproton flux

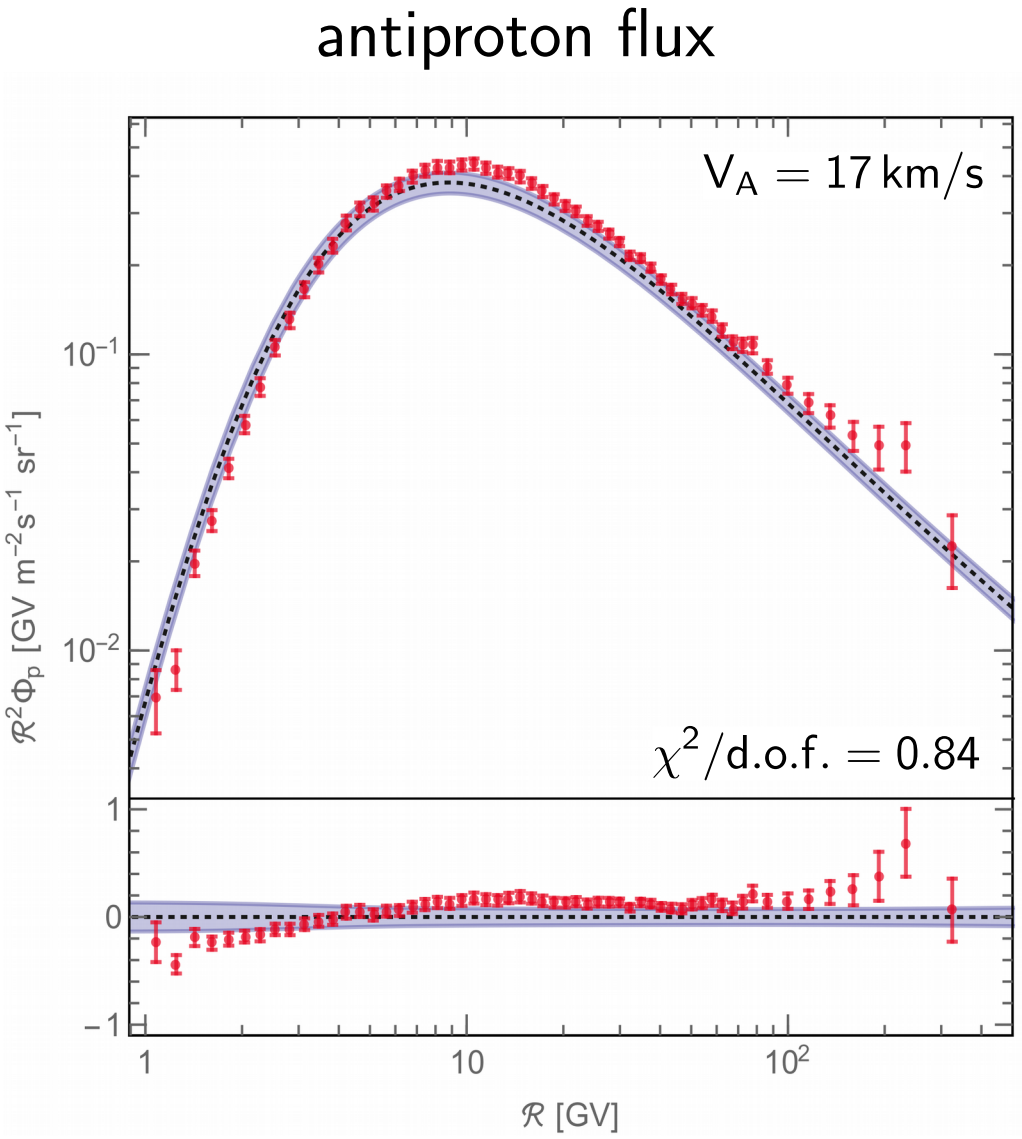


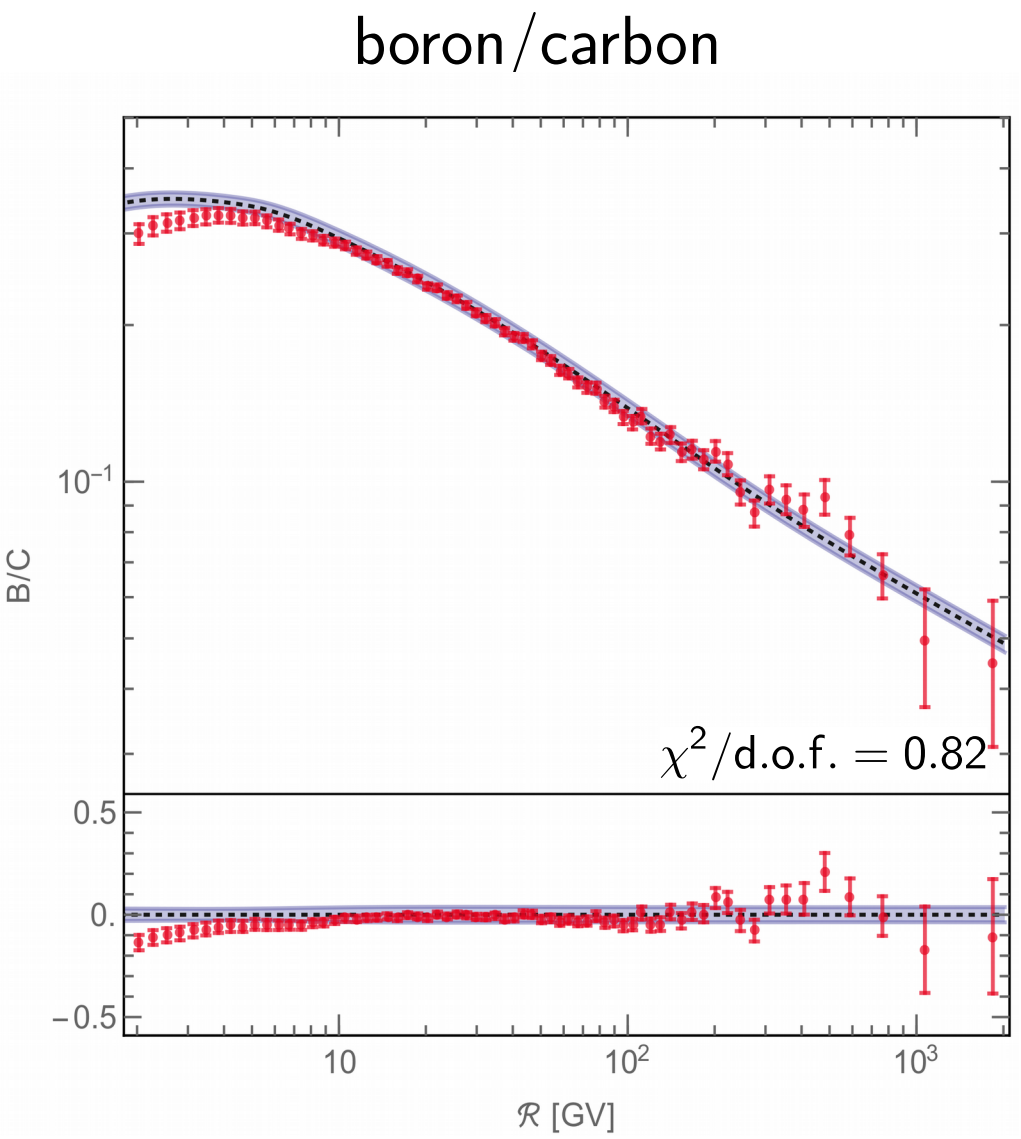
boron/carbon



AMS-02 data: Aguilar et al., Phys. Rev. Lett. 117 (2016)

Antiproton + B/C Fit

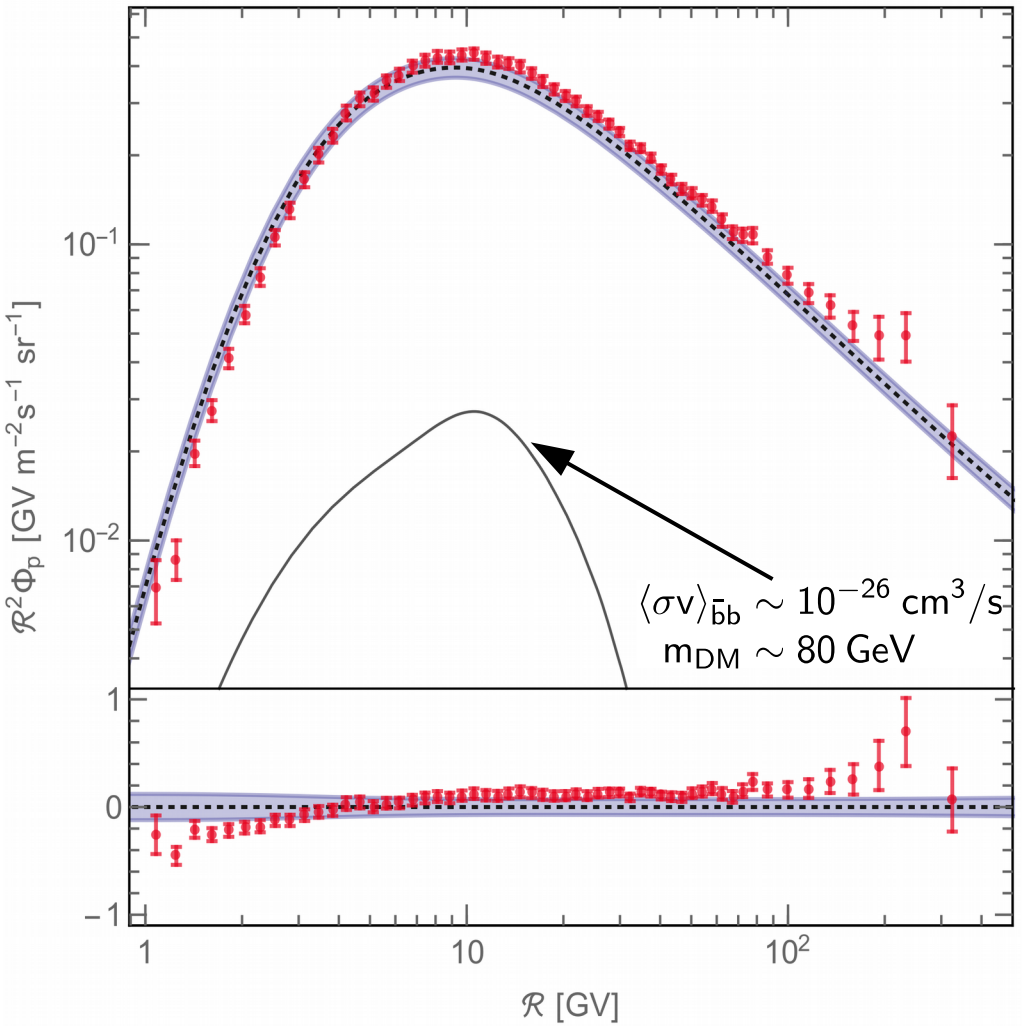




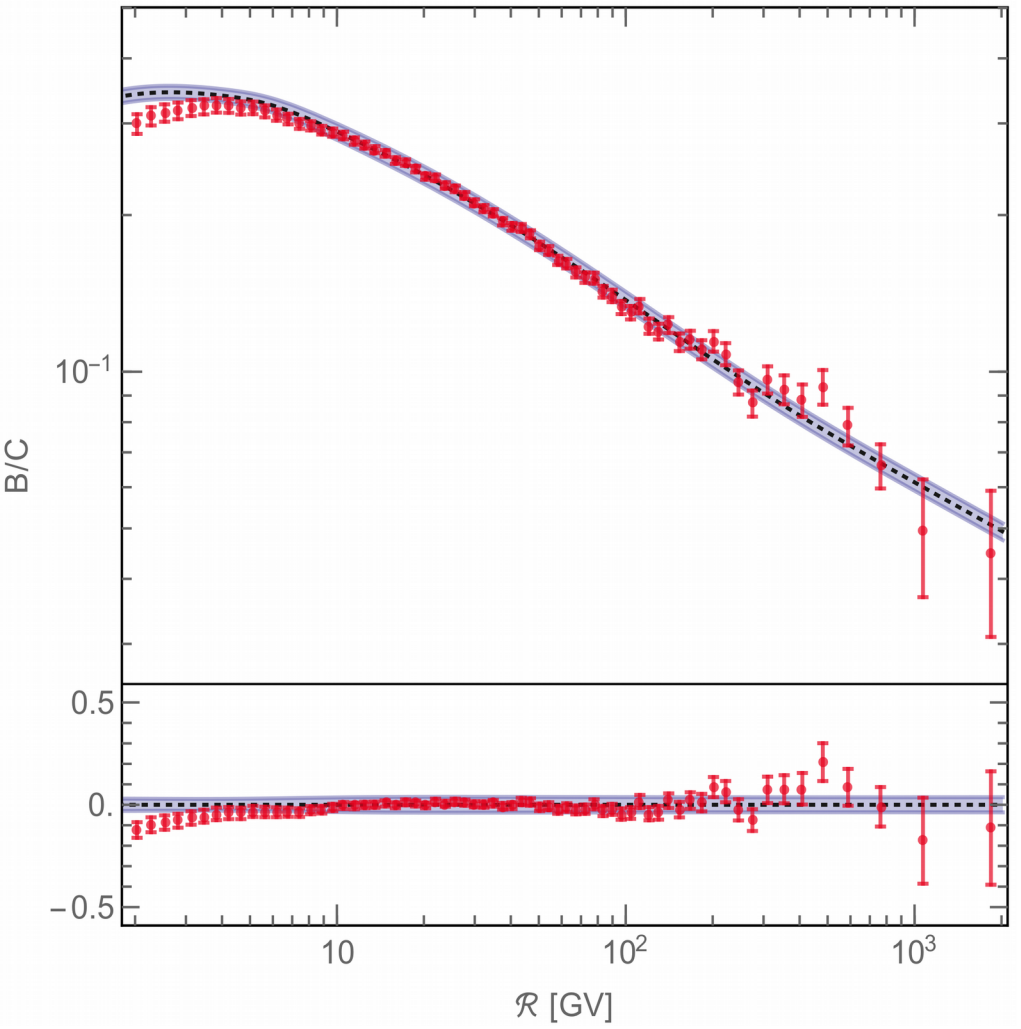
AMS-02 data: Aguilar et al., Phys. Rev. Lett. 117 (2016)

Fit with Dark Matter

antiproton flux

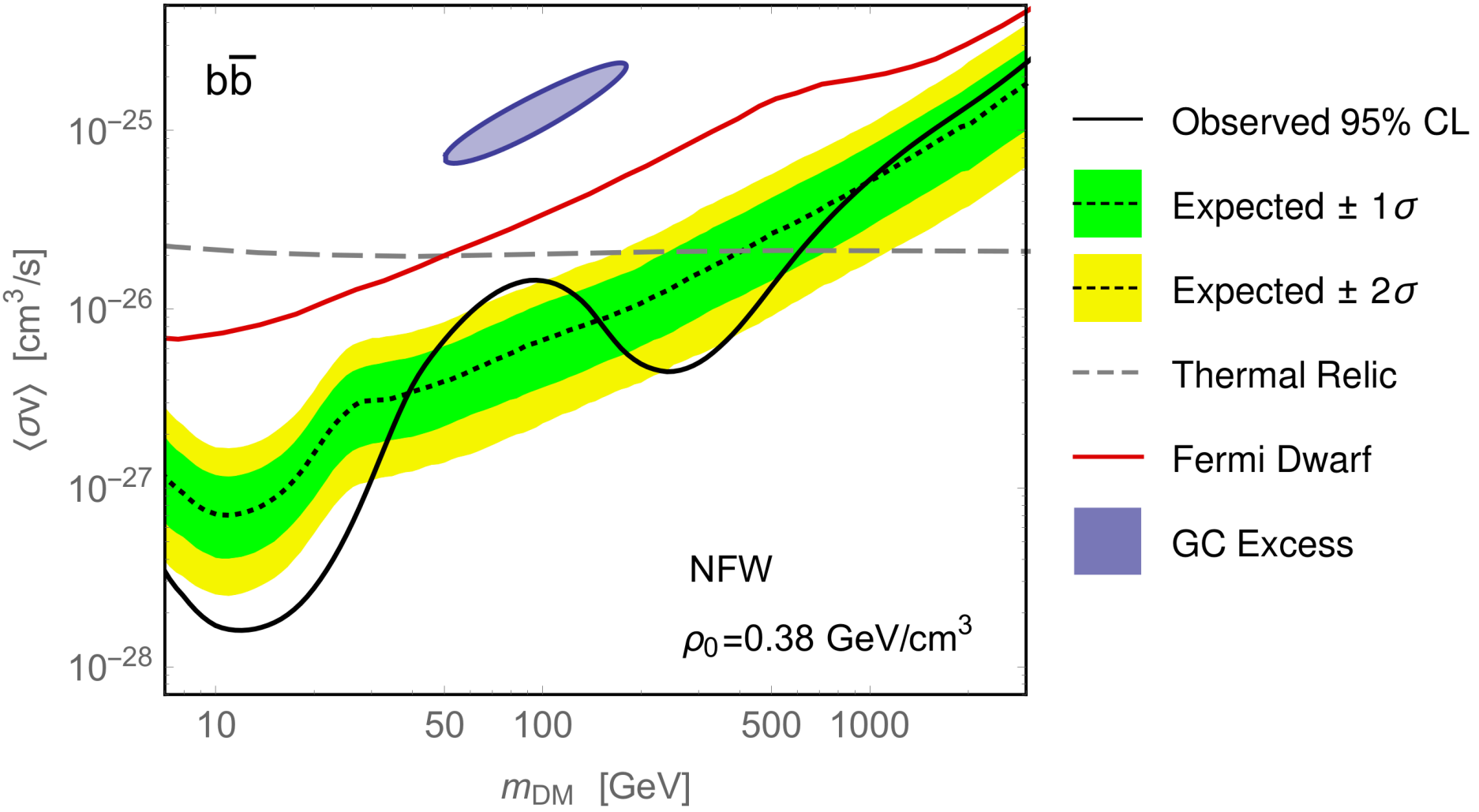


boron/carbon



significance 2.2σ (look-elsewhere ▶ 1.1σ)

Constraints on Dark Matter



Steigman, Phys.Rev. D86 (2012), McMillan, Mon. Not. R. Astron. Soc. 465 (2017), Fermi-LAT, Astrophys.J. 834 (2017)

Conclusion

- uncertainties in the antiproton flux have been addressed systematically
- antiprotons currently set the strongest constraints on hadronic WIMP annihilation
- a reported excess at R $\sim$ 10 GV is not significant in our analysis