Dark Matter Searches with Charged Cosmic Rays

Martin W. Winkler

JCAP 10 (2015) R. Kappl, A. Reinert, M.W.
JCAP 02 (2017) M.W.
JCAP 01 (2018) A. Reinert, M.W.

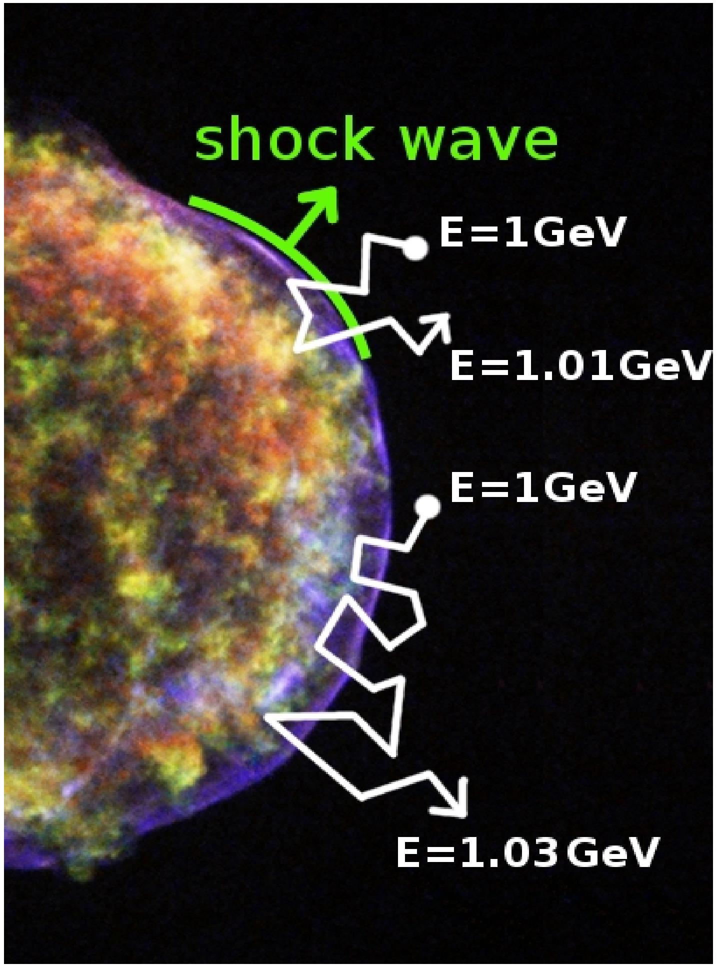
NORDITA

Planck 2018,
Bonn, May 25

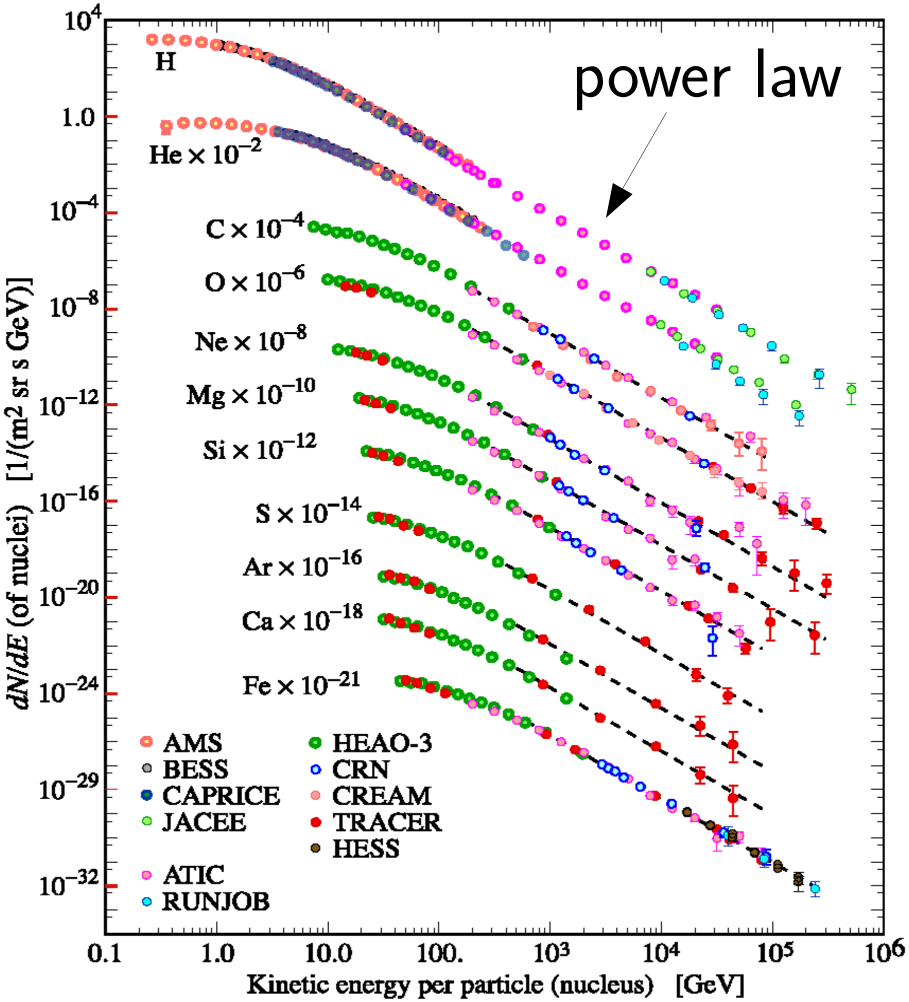
Stockholm University

Primary Cosmic Rays

- primary cosmic rays are energized by supernova shock acceleration
  Fermi, Phys. Rev. 75 (1949), Krymsky Sov. Phys. Dokl. 22 (1977), Axford, Leer, Skadron, ICRC (1977)



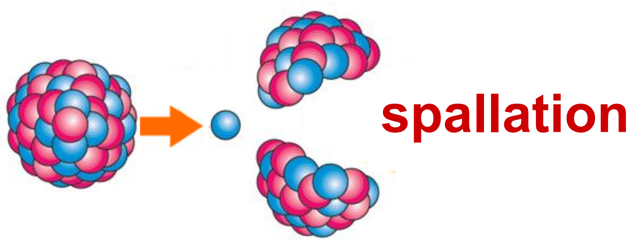
Chandra X-ray Observatory

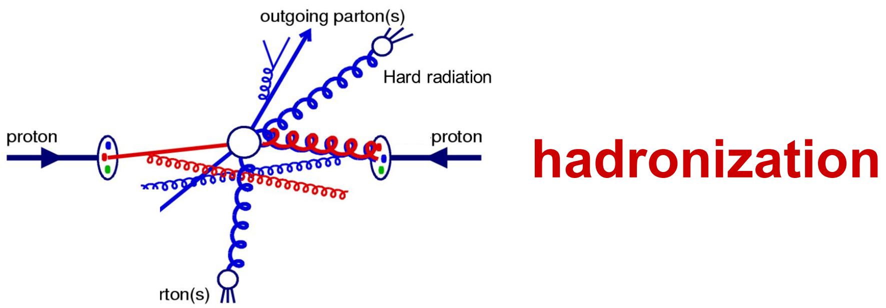


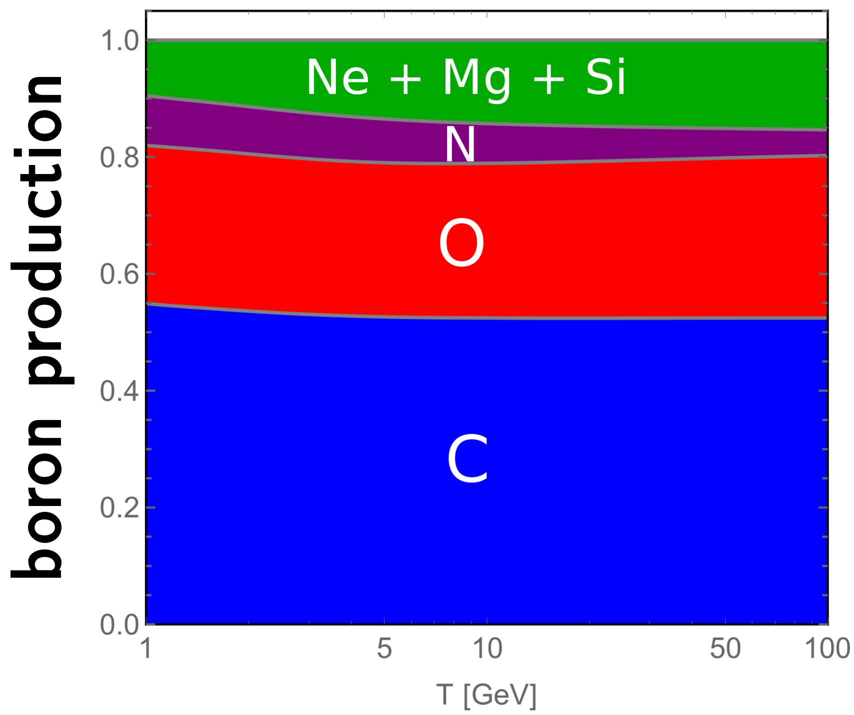
by P. Boyle and D. Muller for PDG review

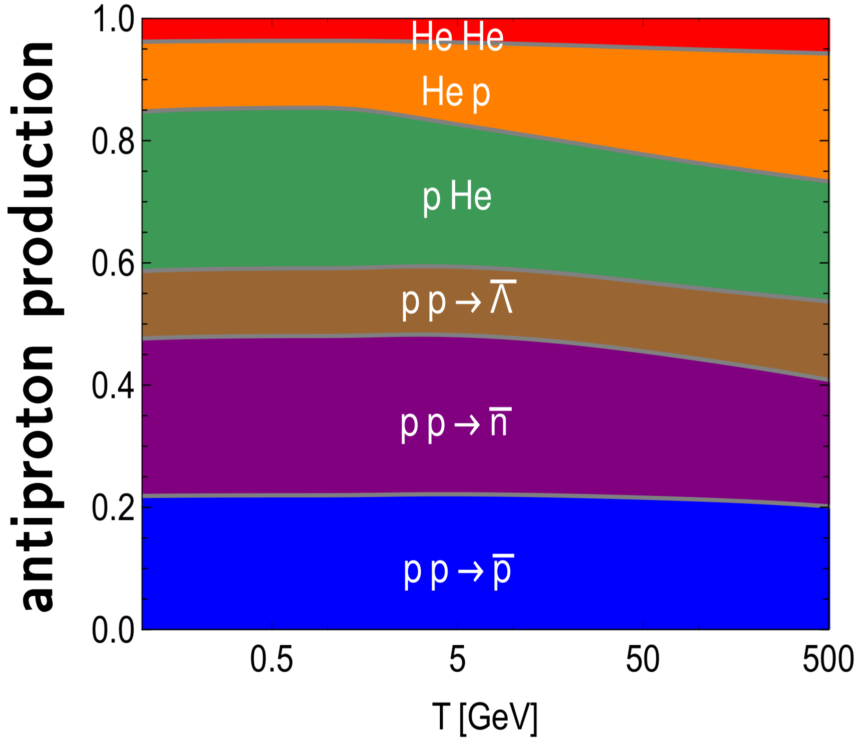
Secondary Production

- primary cosmic rays scatter on interstellar matter and produce secondaries: some nuclei (Li, Be, B), antimatter

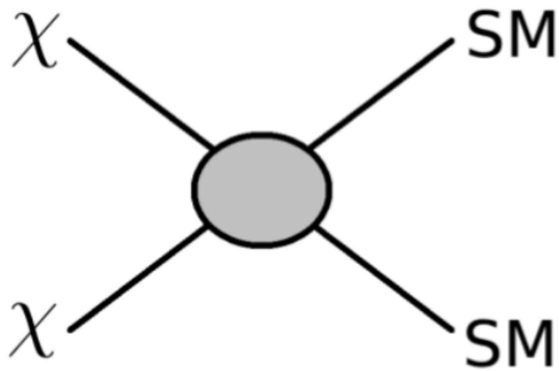








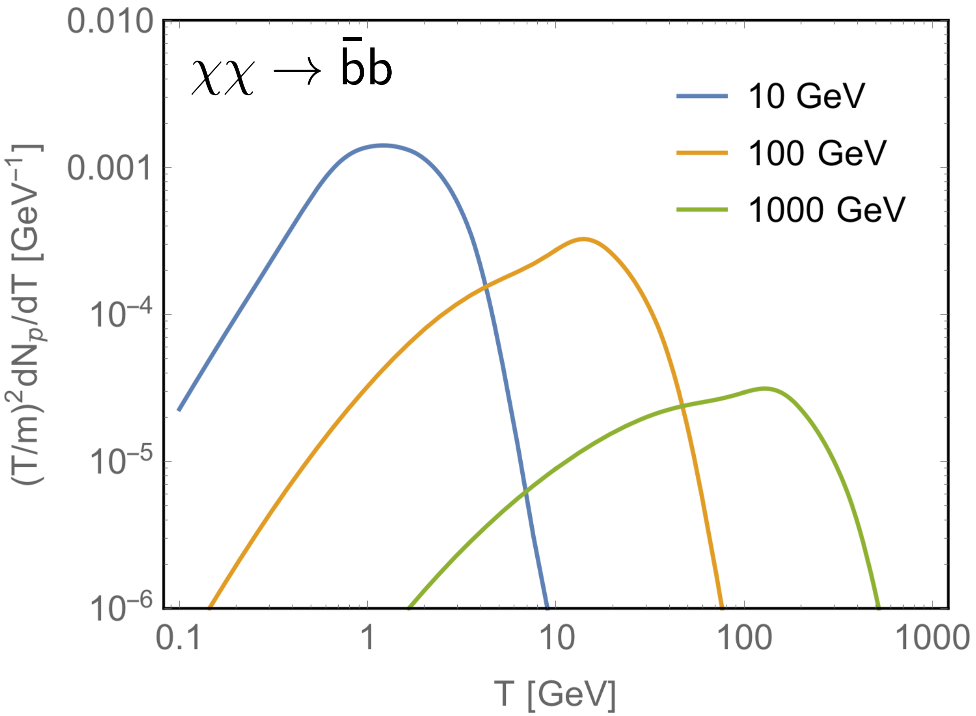
Dark Matter Annihilation



- would mainly be seen in antimatter fluxes

- smooth spectra, difficult to distinguish from astrophysics

- dark matter annihilation in the galactic halo

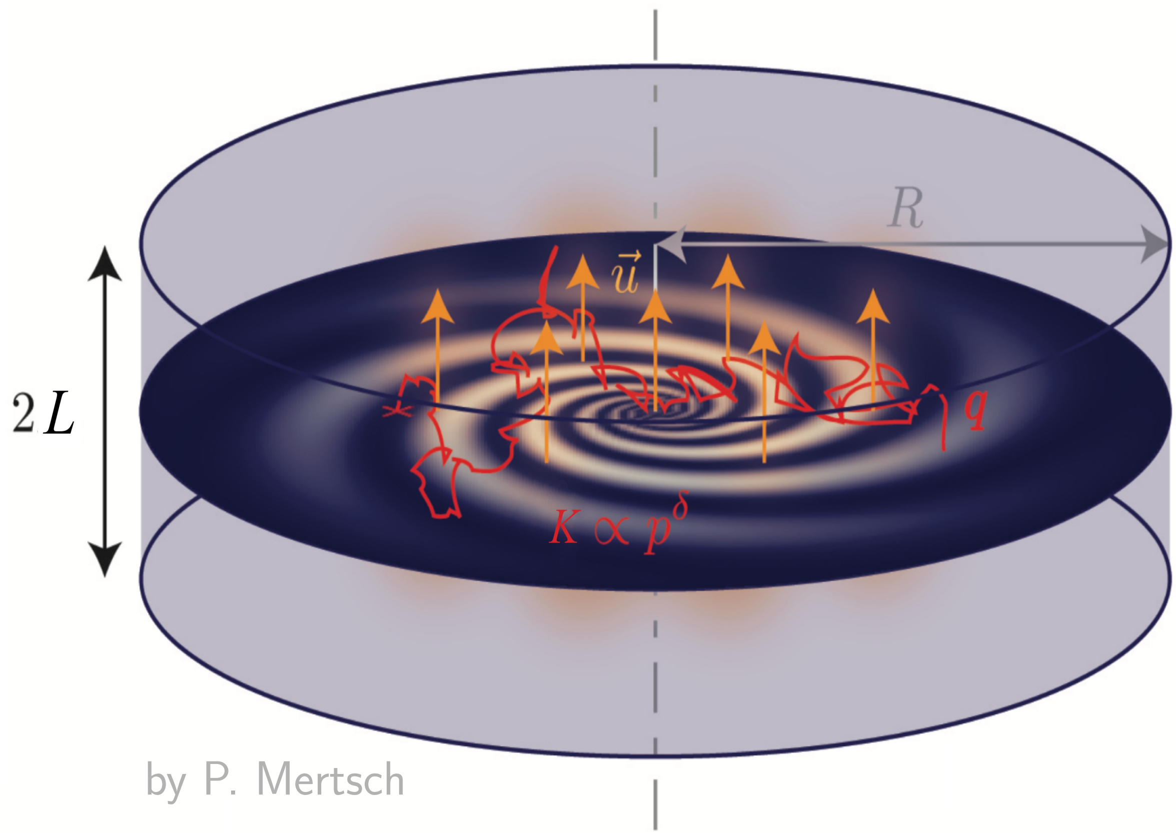


spectra from PPPC 4 DM ID

Propagation

- propagation of cosmic rays

e.g. Strong, Moskalenko, Astrophys. J. 509 (1998),Maurin et al., Astrophys. J. 555 (2001), Donato et al., Astrophys. J. 563 (2001)



- diffusion
- convection
- reacceleration
- energy losses
- annihilation

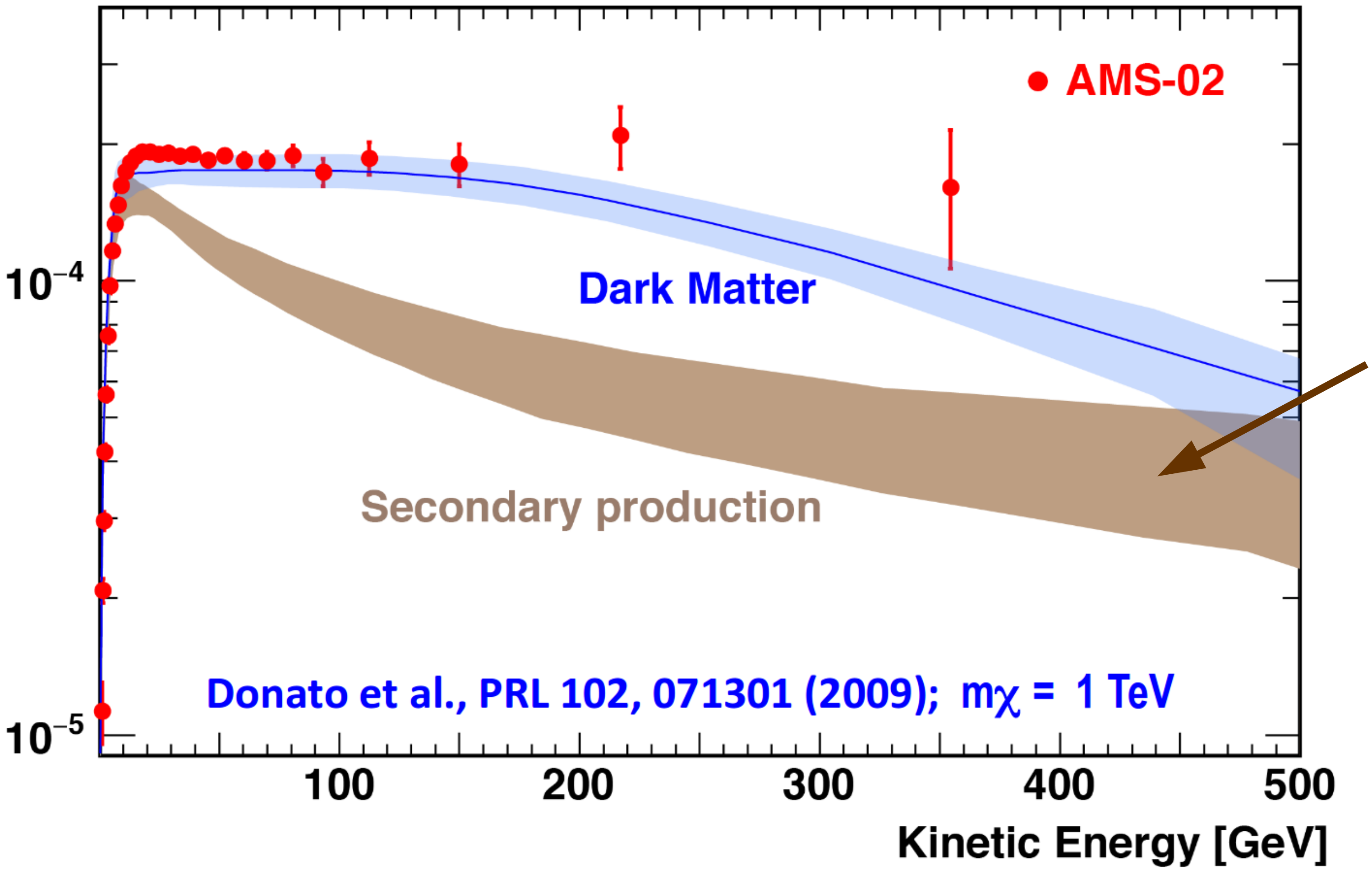
5 free parameters
$K_0,\ \delta,\ L,\ V_c,\ V_a$

high energy limit (hadrons) : $\Phi \propto$ injection spectrum $\times\ p^{-\delta}$

AMS-02 Antiprotons

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

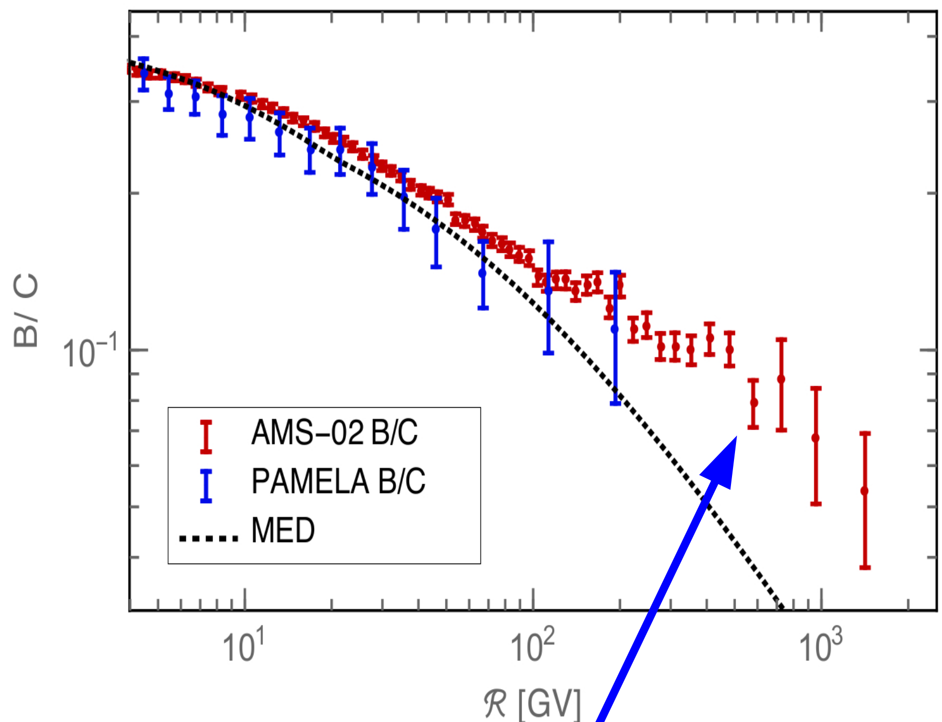
S.Ting, A. Kounine, AMS Days at CERN (2015)

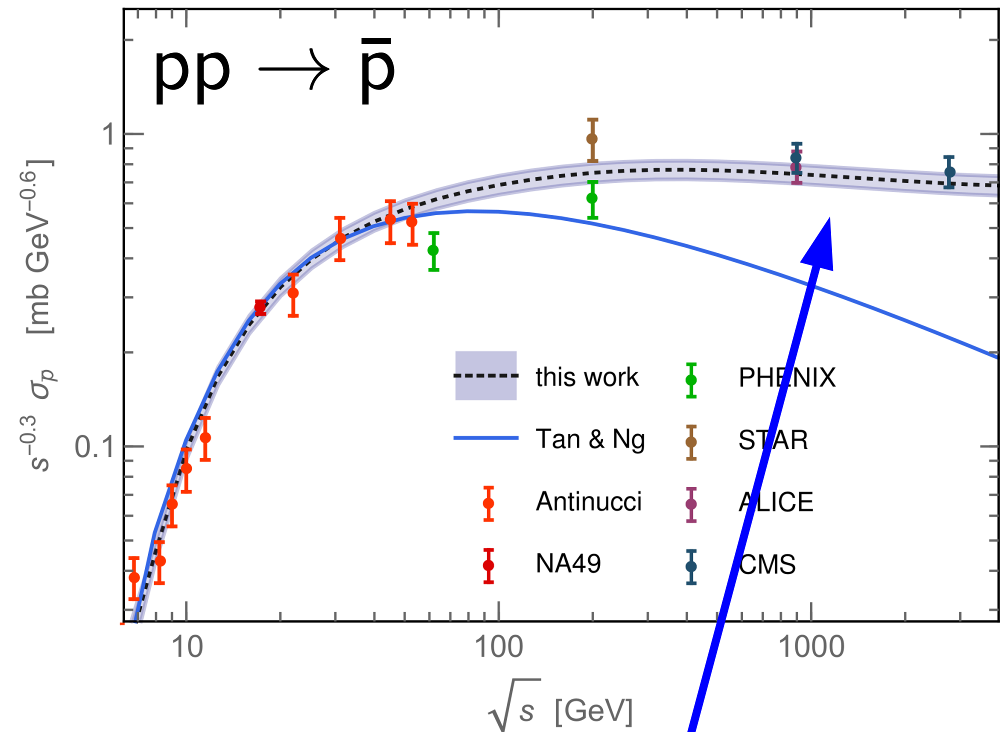


Uncertainties:
cross section,
propagation

High Energy Antiprotons

- background improvements





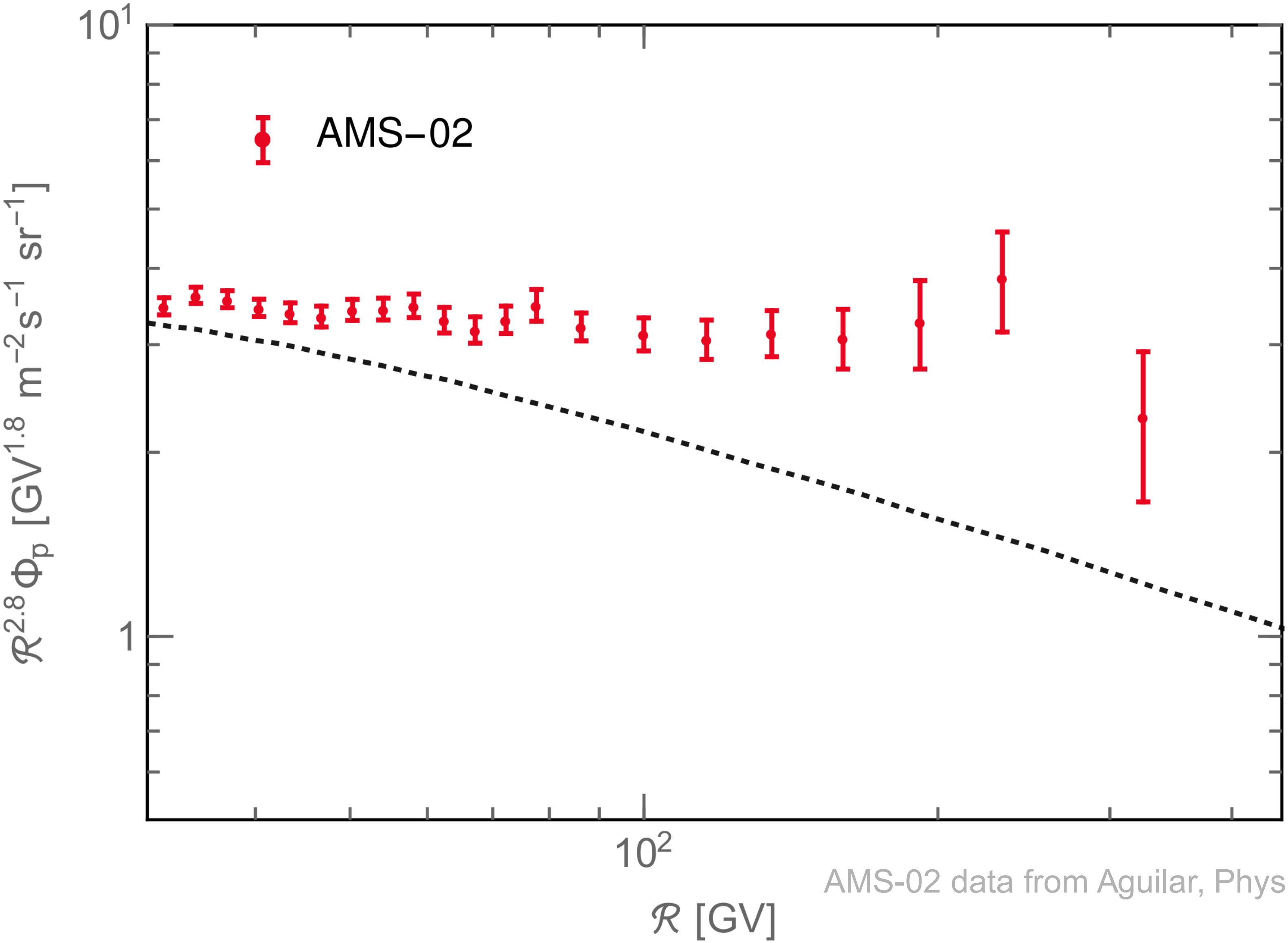
propagation update to fit B/C

Giesen et al., Evoli et al.,
Kappl, Reinert, M.W., JCAP (2015)

cross section increase

M.W., JCAP 02 (2017)

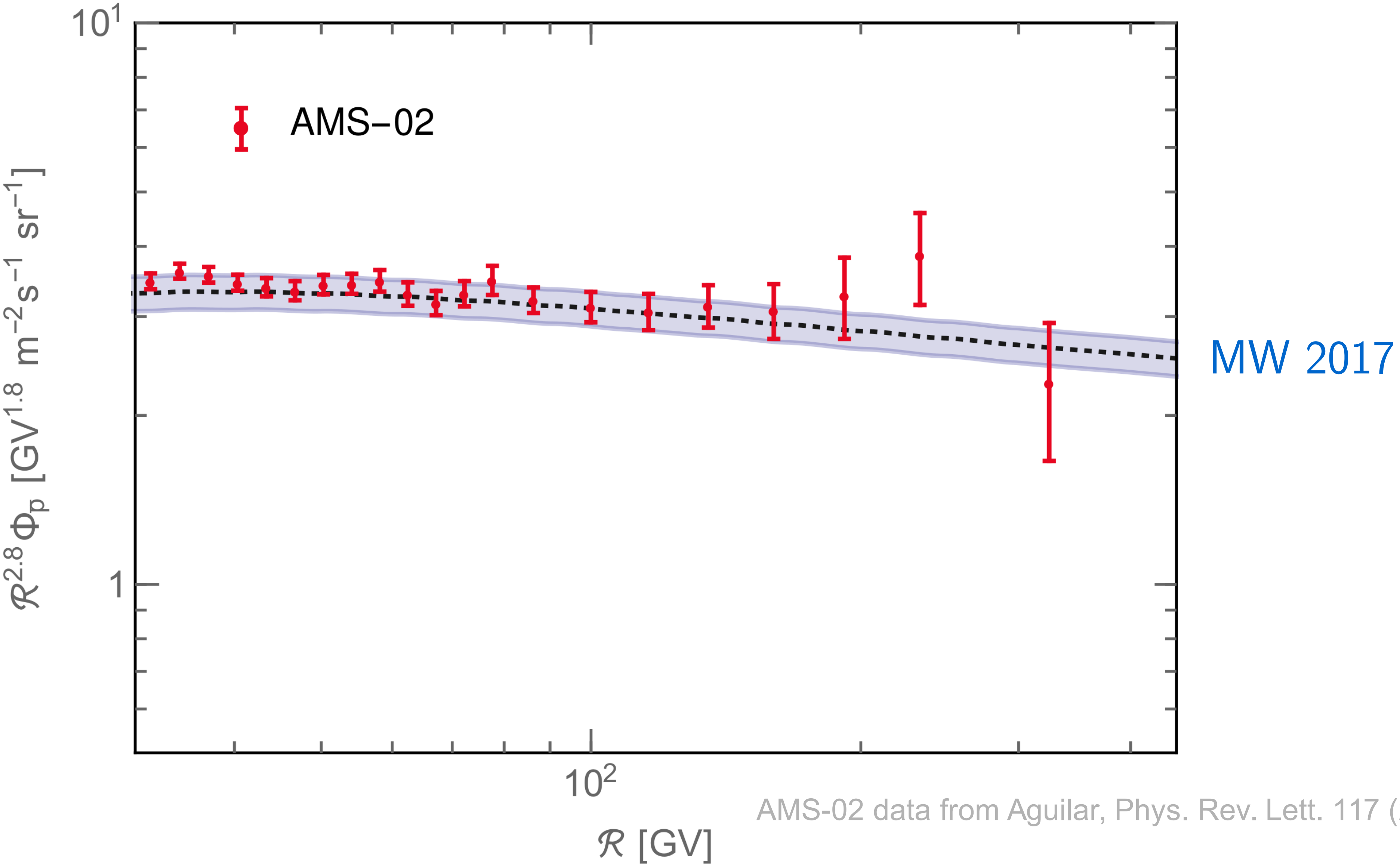
High Energy Antiproton Flux



background
2015

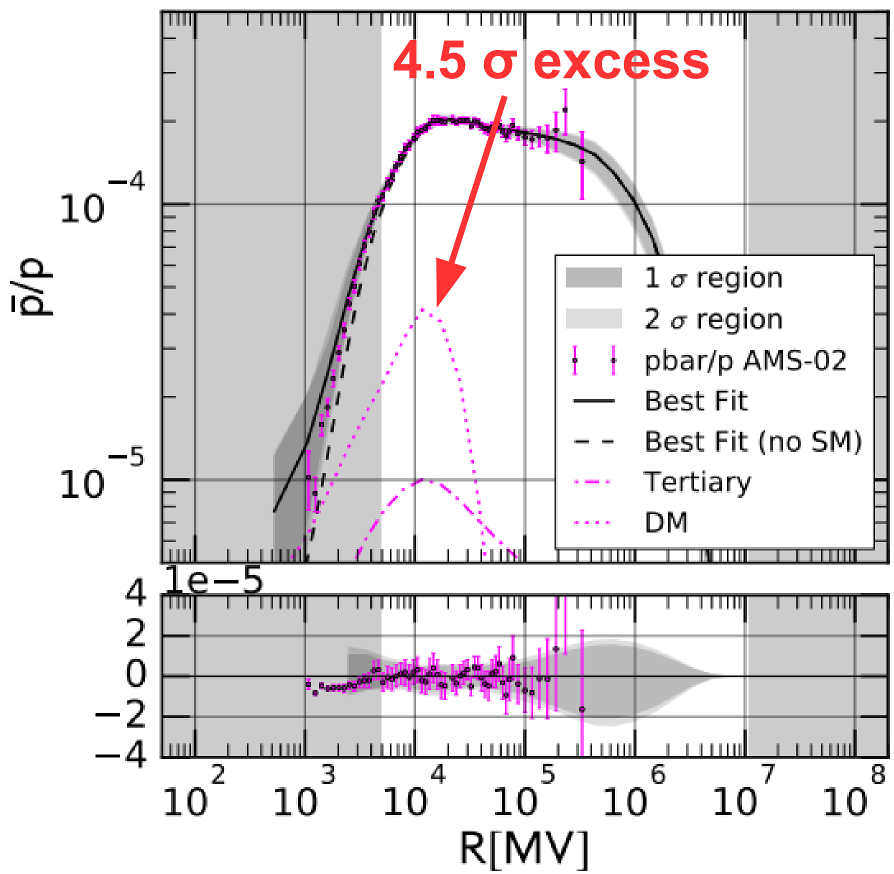
AMS-02 data from Aguilar, Phys. Rev. Lett. 117 (2016)

High Energy Antiproton Flux

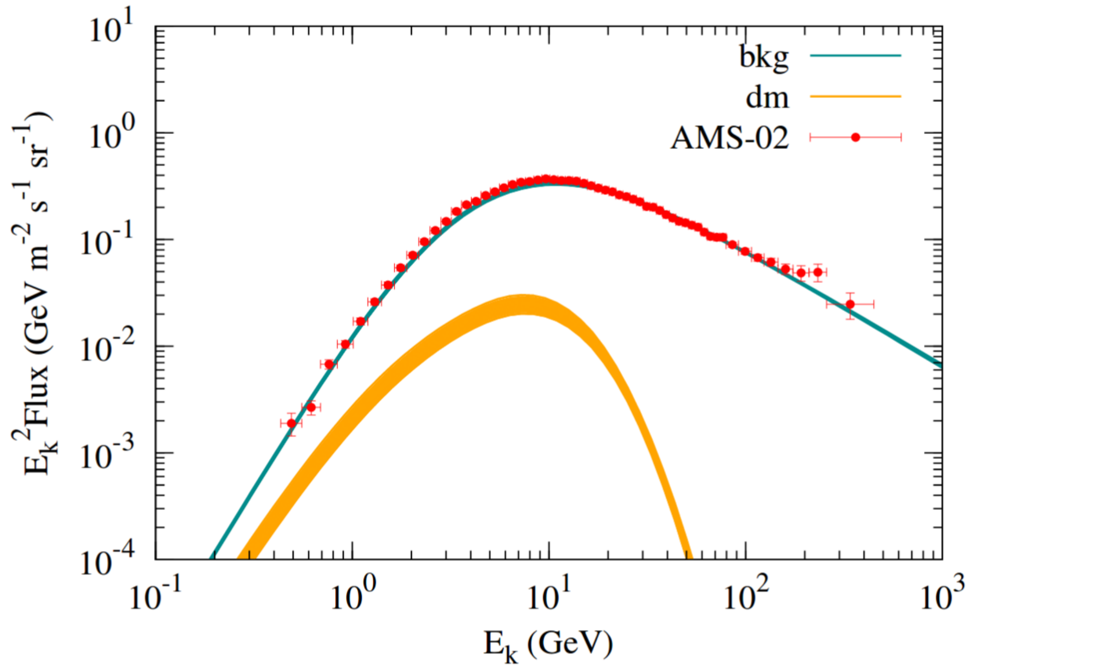


AMS-02 data from Aguilar, Phys. Rev. Lett. 117 (2016)

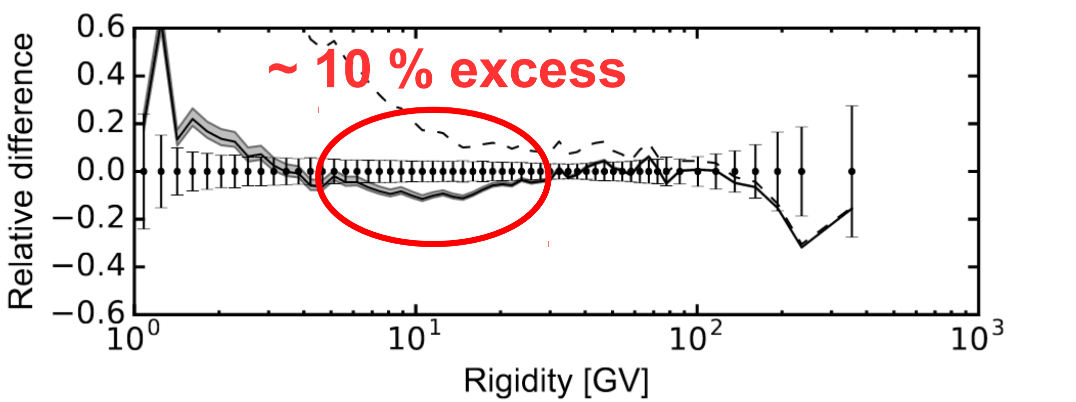
New Antiproton Excess



Cuoco, Krämer, Korsmeier, PRL 118 (2017)



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



Boschini et al., Astrophys. J. 840 (2017)

best fit similar as for GC gamma ray excess

$m_{DM} \sim 70\ \text{GeV}$

$\langle \sigma v \rangle_{\bar{b}b} \sim 2 \cdot 10^{-26}\ \text{cm}^3 \text{s}^{-1}$

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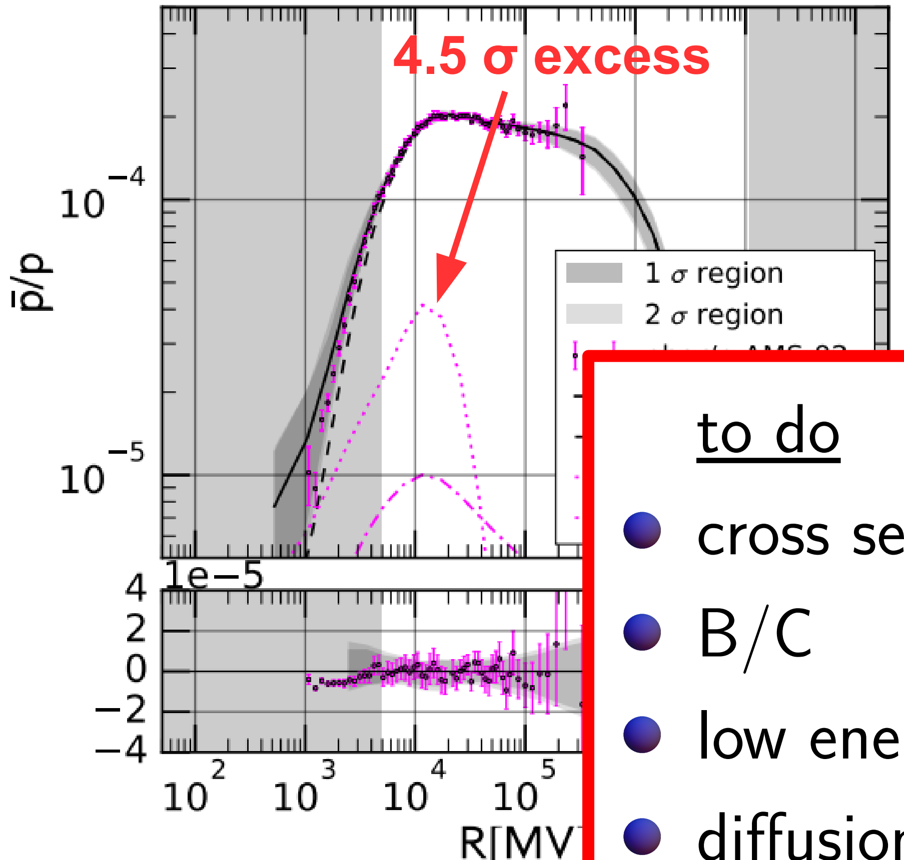
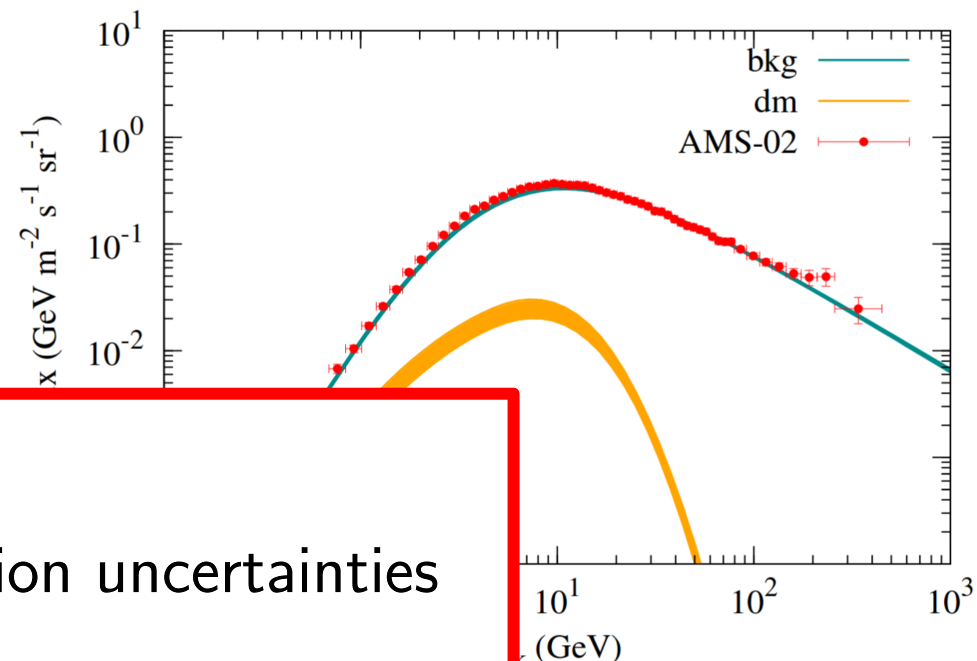


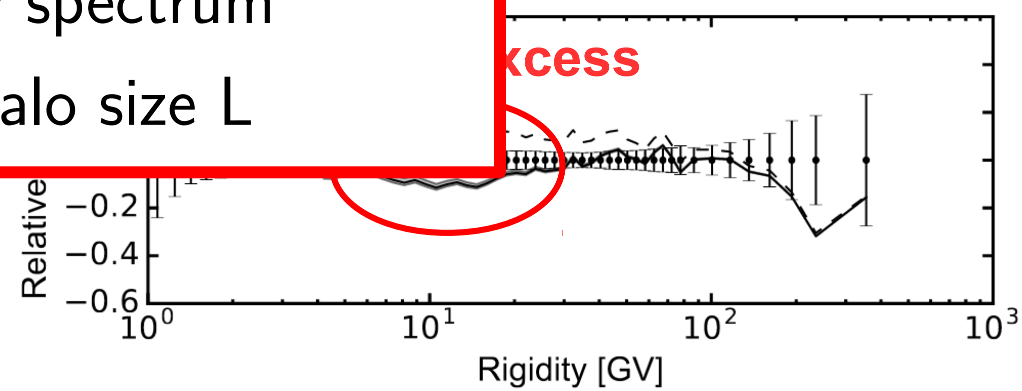
Cuoco, Krämer, Korsmei...



...an, PRL 118 (2017)

to do

- cross section uncertainties
- B/C
- low energy spectrum
- diffusion halo size L



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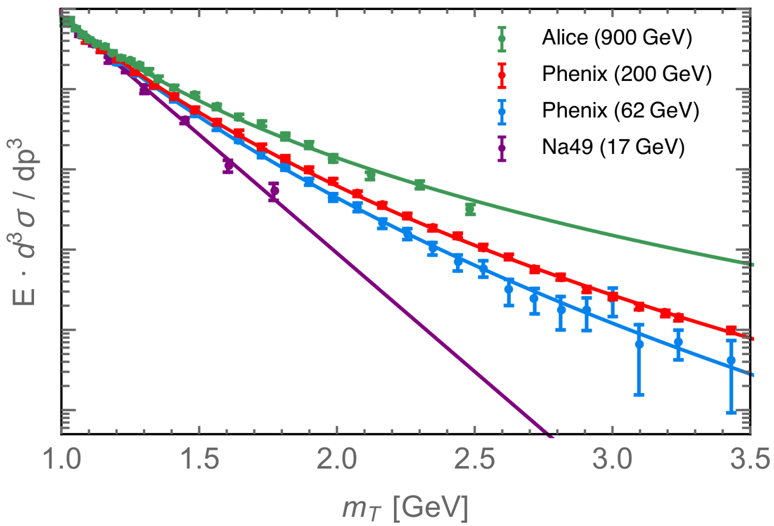
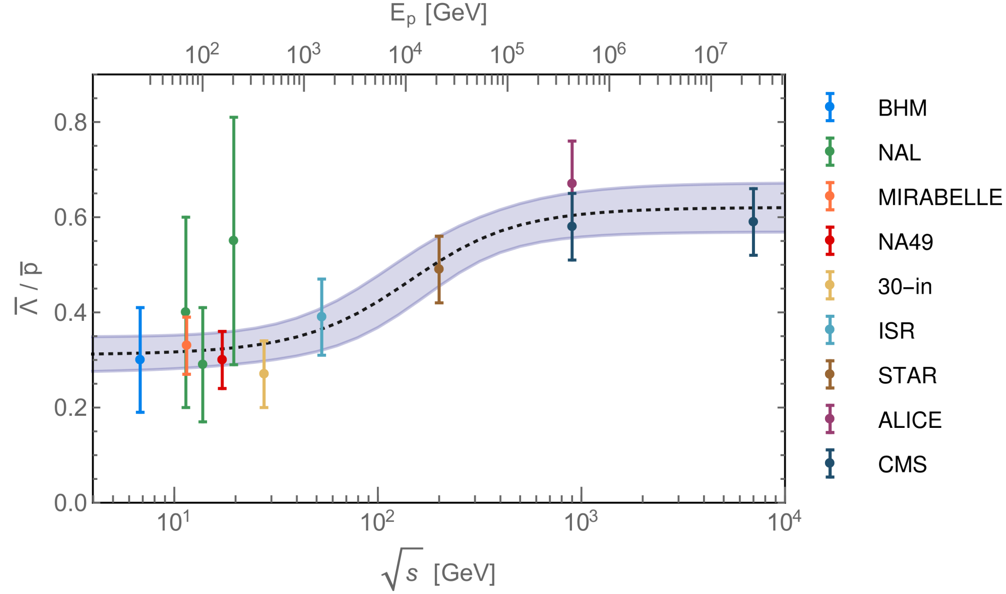
Antiproton Cross Section

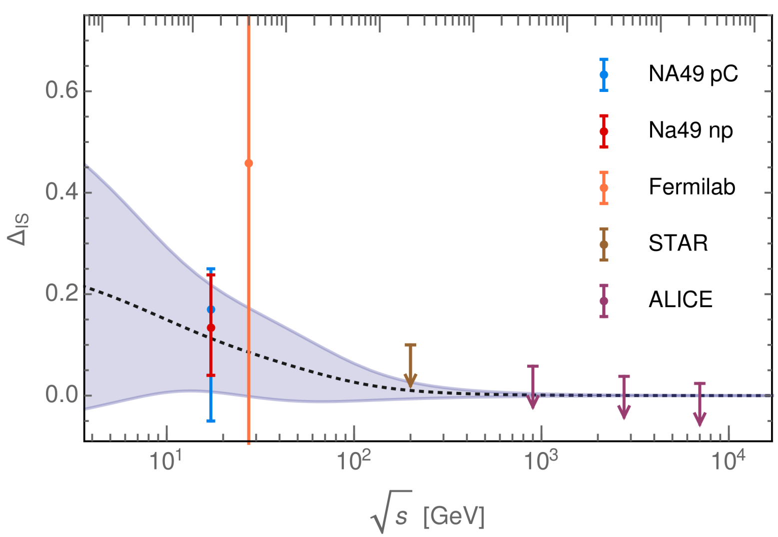
scaling violation



hyperons



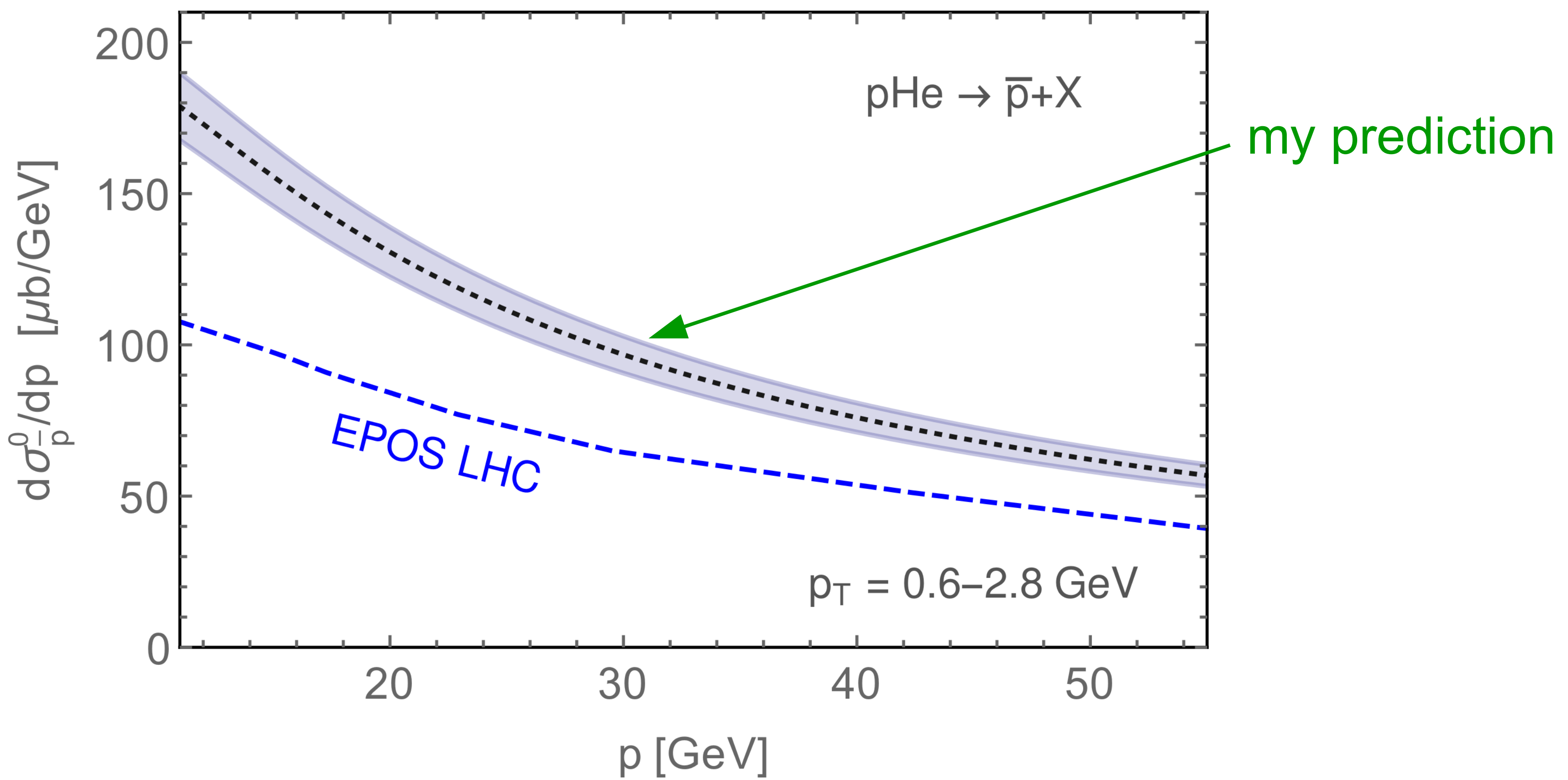
antineutrons



Data: PHENIX, Phys. Rev. C83 (2011), ALICE, Eur. Phys. J. C71 (2011), CMS, Eur. Phys. J. C72 (2012), Blobel, Nucl. Phys. B69 (1974), Amaldi, Nucl. Phys. B86 (1975), Whitmore, Phys. Rept. 10 (1974), Kichimi, Phys. Rev. D20 (1979), Ammosov, Nucl. Phys. B115 (1976), Abelev, Phys. Rev. C75 (2007), Aamodt, Eur. Phys. J. C71 (2011), Khachatryan, JHEP 05 (2011), Antreasyan, Phys. Rev. D19 (1979), Fischer, Heavy Ion Phys. 17 (2003), Baatar, Eur. Phys. J. C73 (2013), Aamodt et al., Phys. Rev. Lett. 105 (2010), Abbas et al., Eur. Phys. J. C73 (2013)

Proton Helium Scattering

- p-He scattering predicted from pp and p-C data
- confirmed by first LHCB measurement
  LHCb-CONF-2017-002



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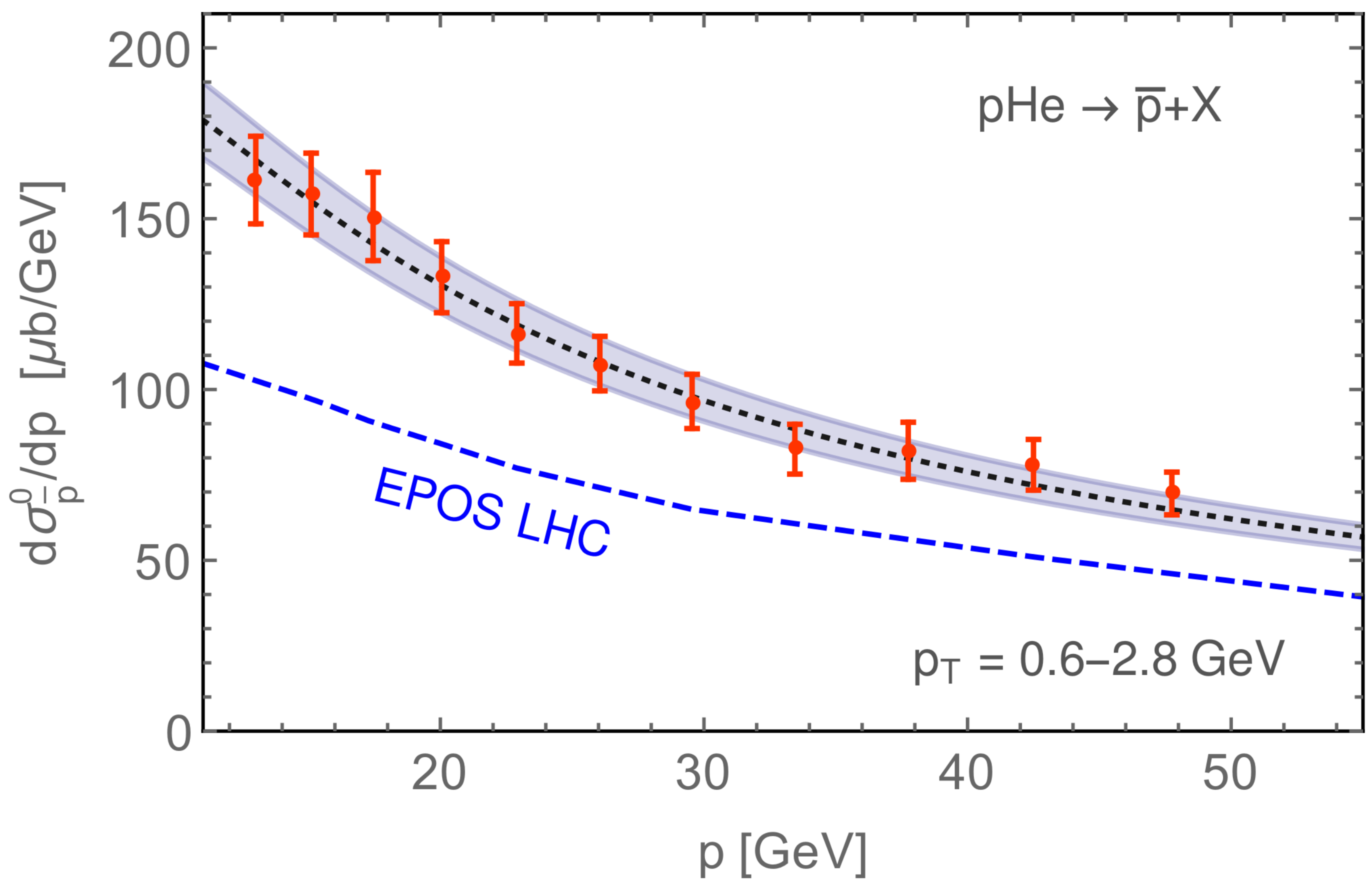
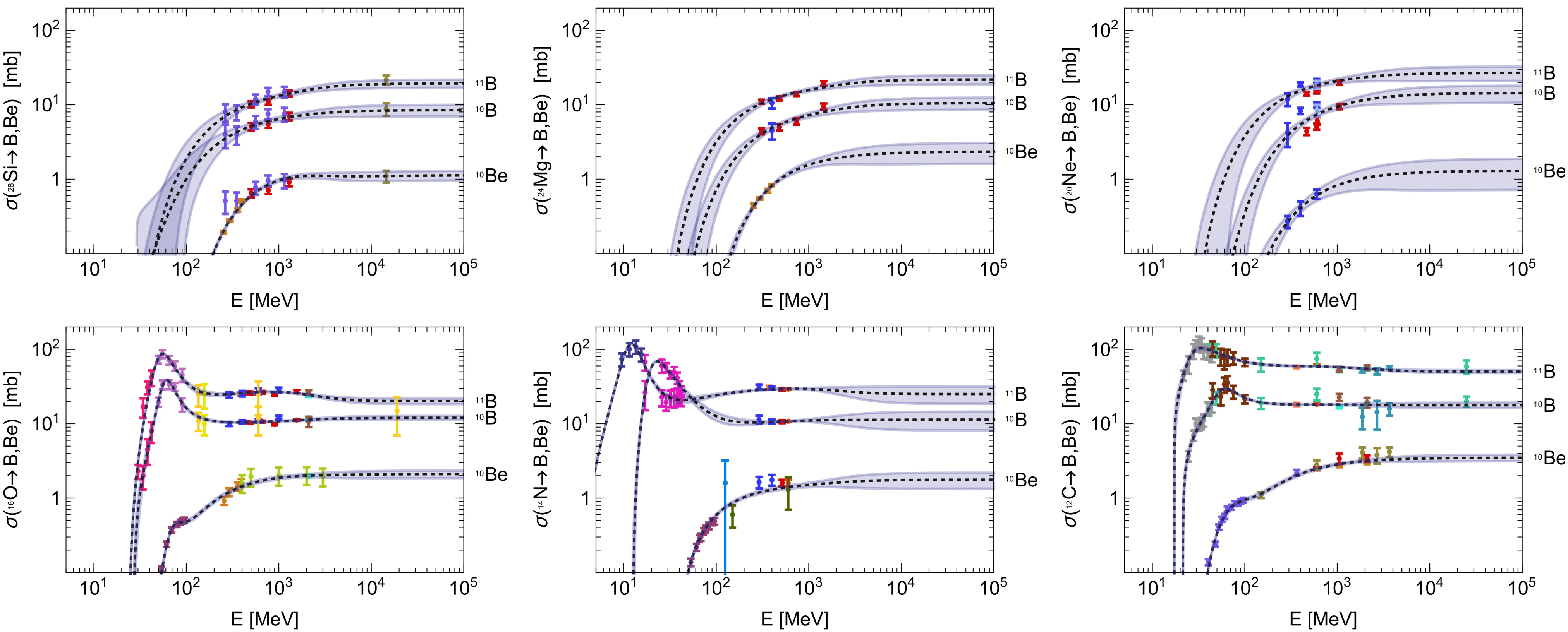
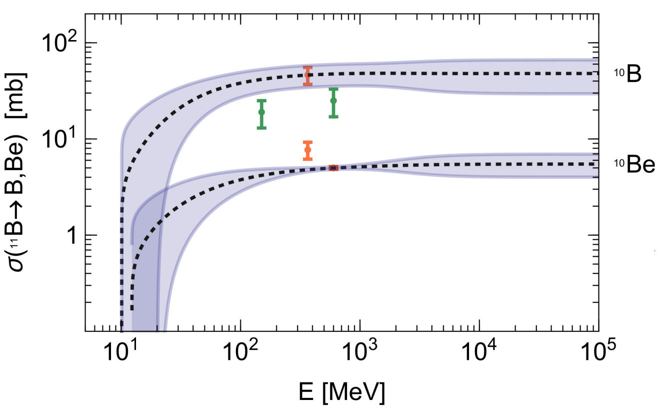


Boron Production





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)

Solar Modulation

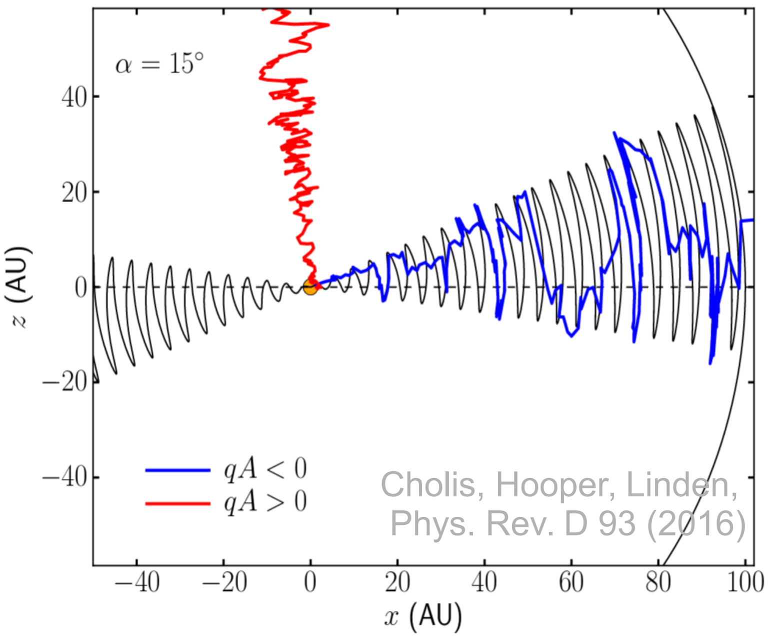
- force field approximation works reasonably for $\mathbf{qA > 0}$

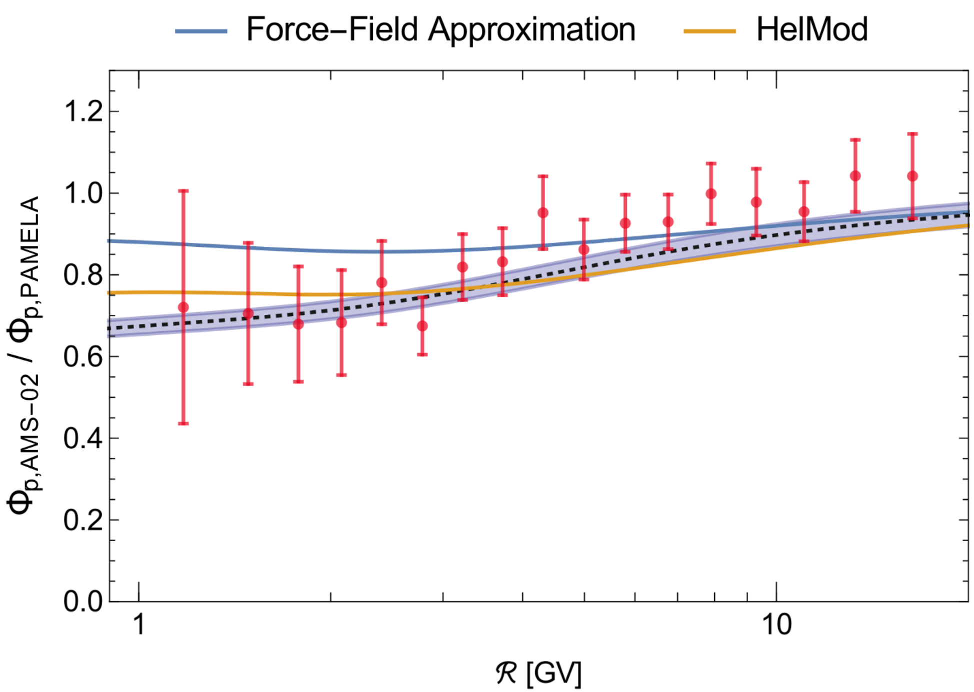
$$\Phi^{\mathrm{TOA}}(\mathrm{T}) = \Phi^{\mathrm{IS}}(\mathrm{T}+\phi)\left(\frac{\mathrm{p}^{\mathrm{TOA}}}{\mathrm{p}^{\mathrm{IS}}}\right)^2$$

Gleeson, Axford, Astrophy. J. 154 (1968)

- heliospheric current sheet significantly affects fluxes for $\mathbf{qA < 0}$

Jokipii, Thomas, Astrophys. J. 243 (1981)

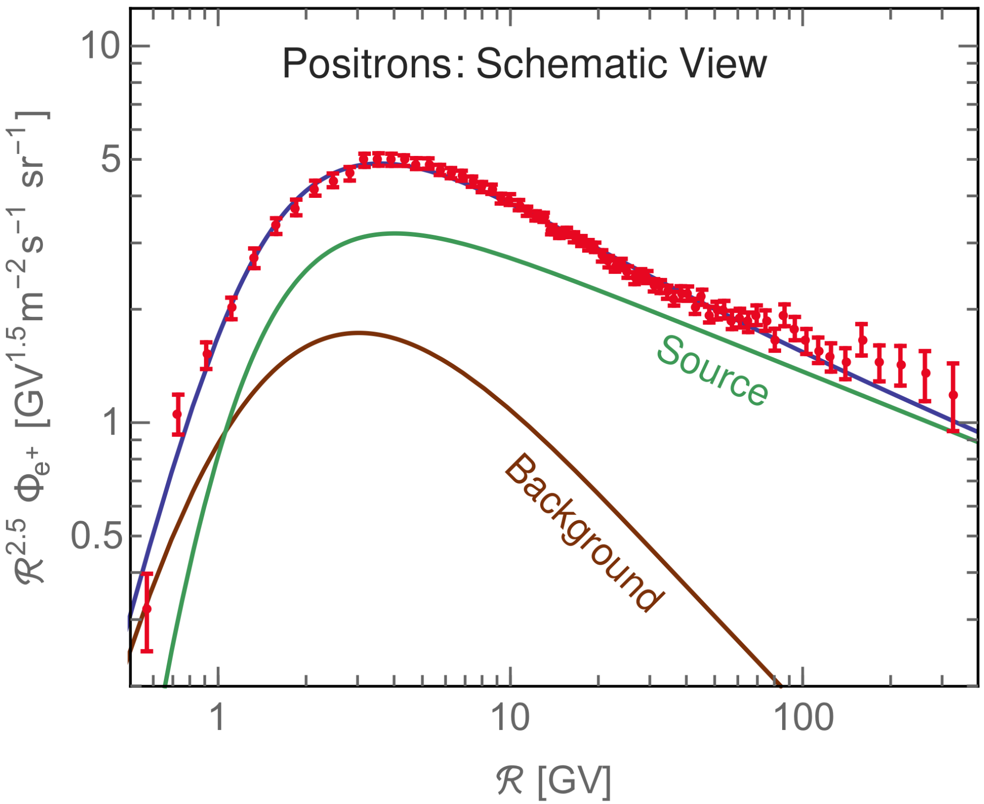


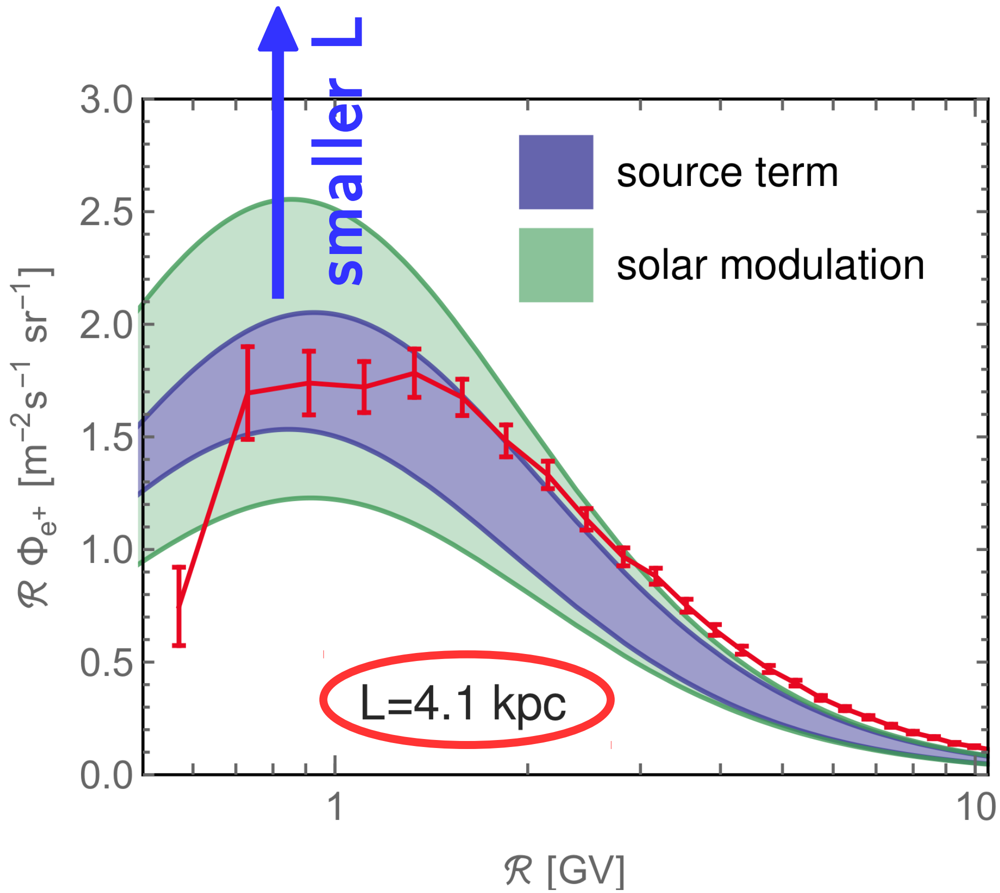


- charge-breaking extracted from PAMELA/AMS-02

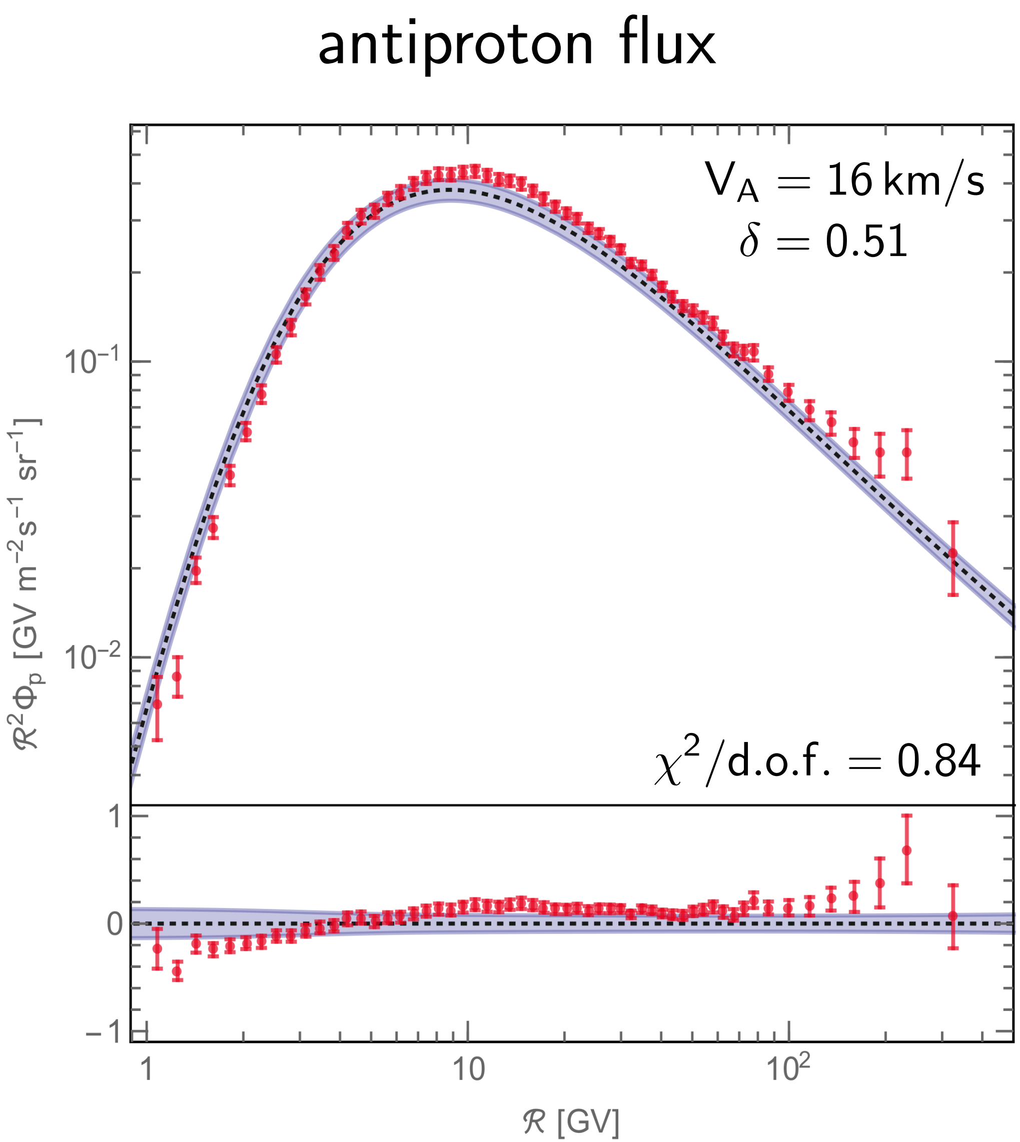
Positrons

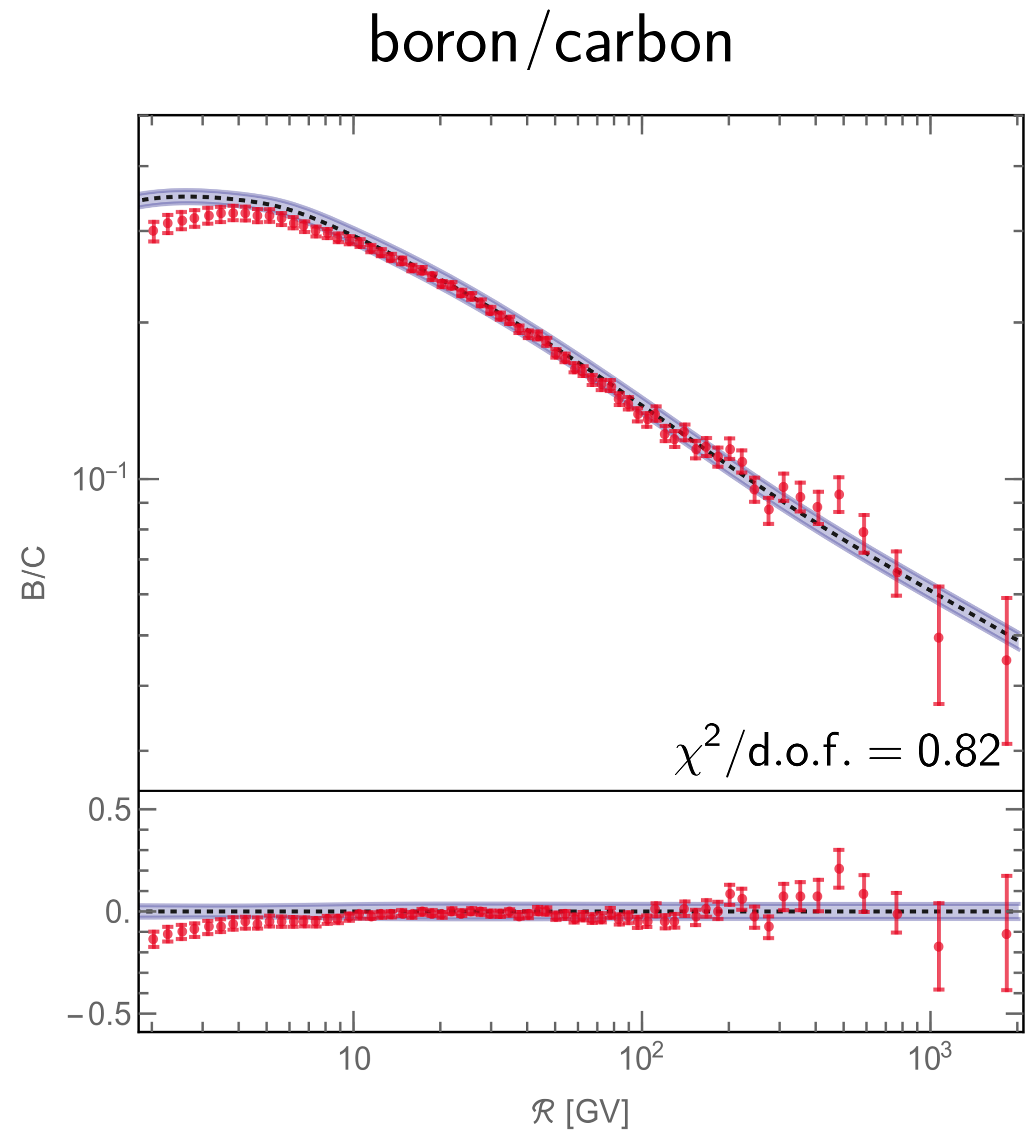
- positron spectrum requires extra source (e.g. pulsars)
  PAMELA, Nature 458 (2009)
- low energy e^+ can still be used to constrain diffusion zone L
  Lavalle, Maurin, Putze, Phys.Rev. D90 (2014), Boudaud et al, Astron.Astrophys. 605 (2017)





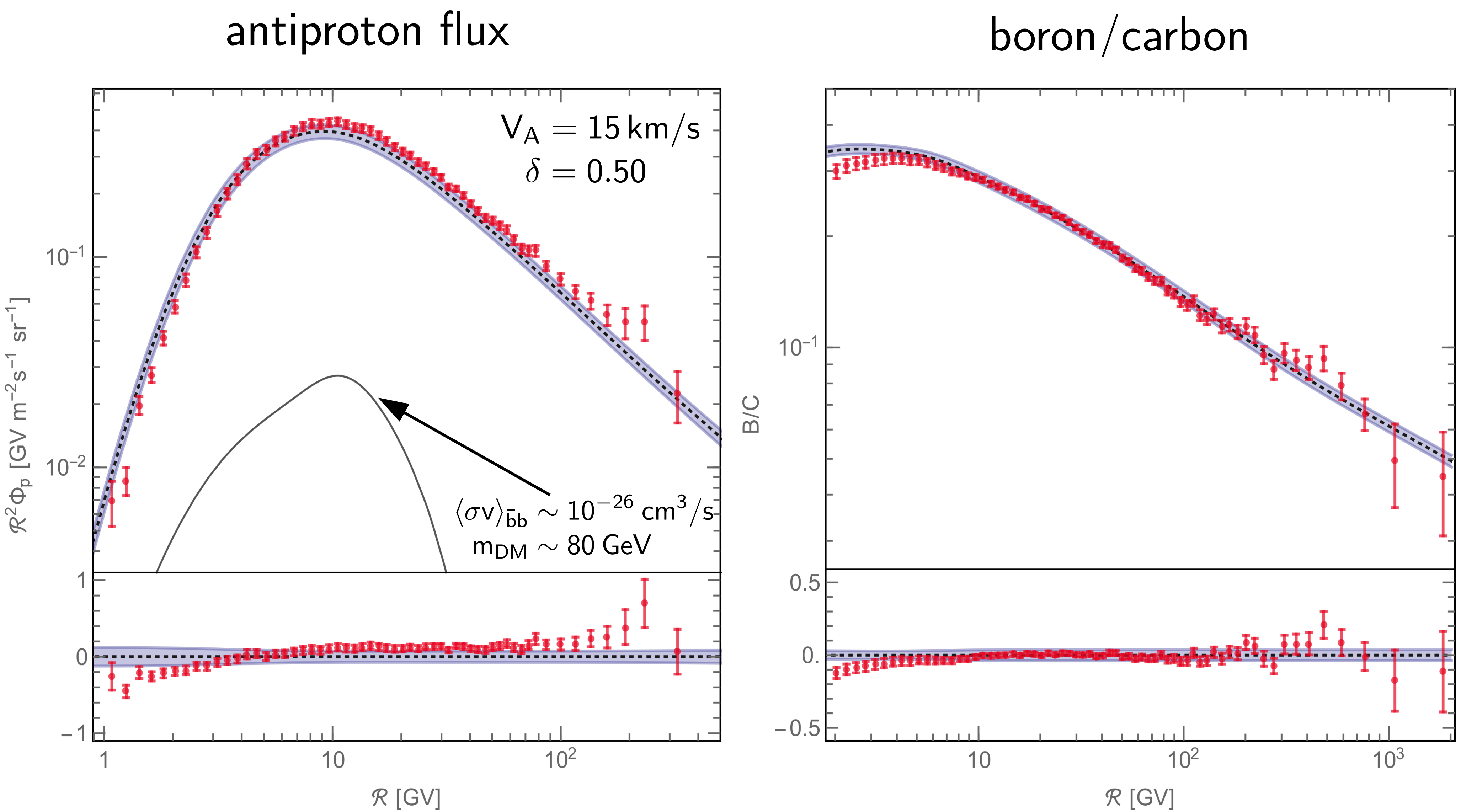
Antiproton + B/C Fit





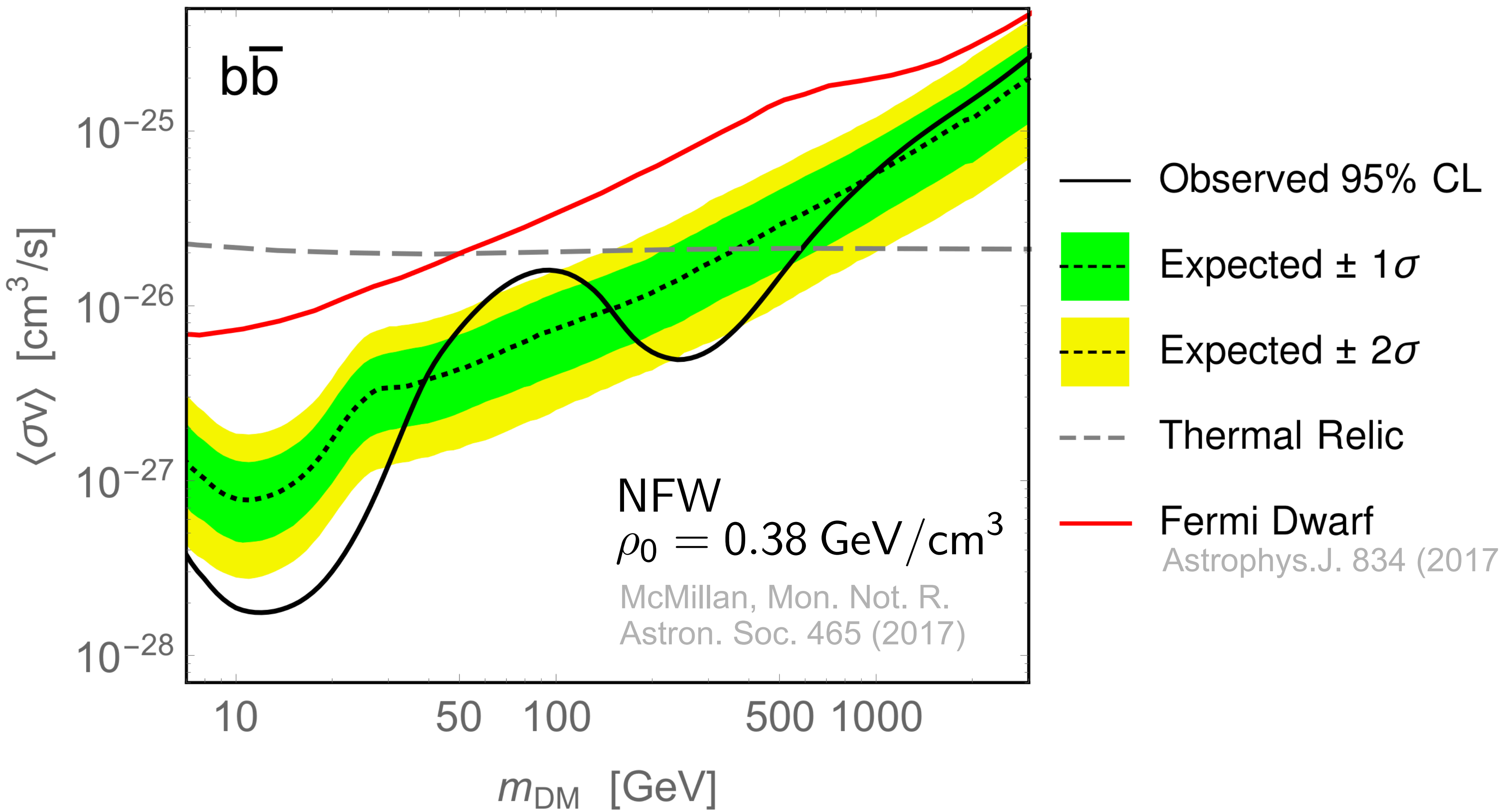
AMS-02 data: Aguilar et al., Phys. Rev. Lett. 117 (2016)

Fit with Dark Matter



local significance 2.2σ (look-elsewhere ▶ 1.1σ)

Constraints on Dark Matter



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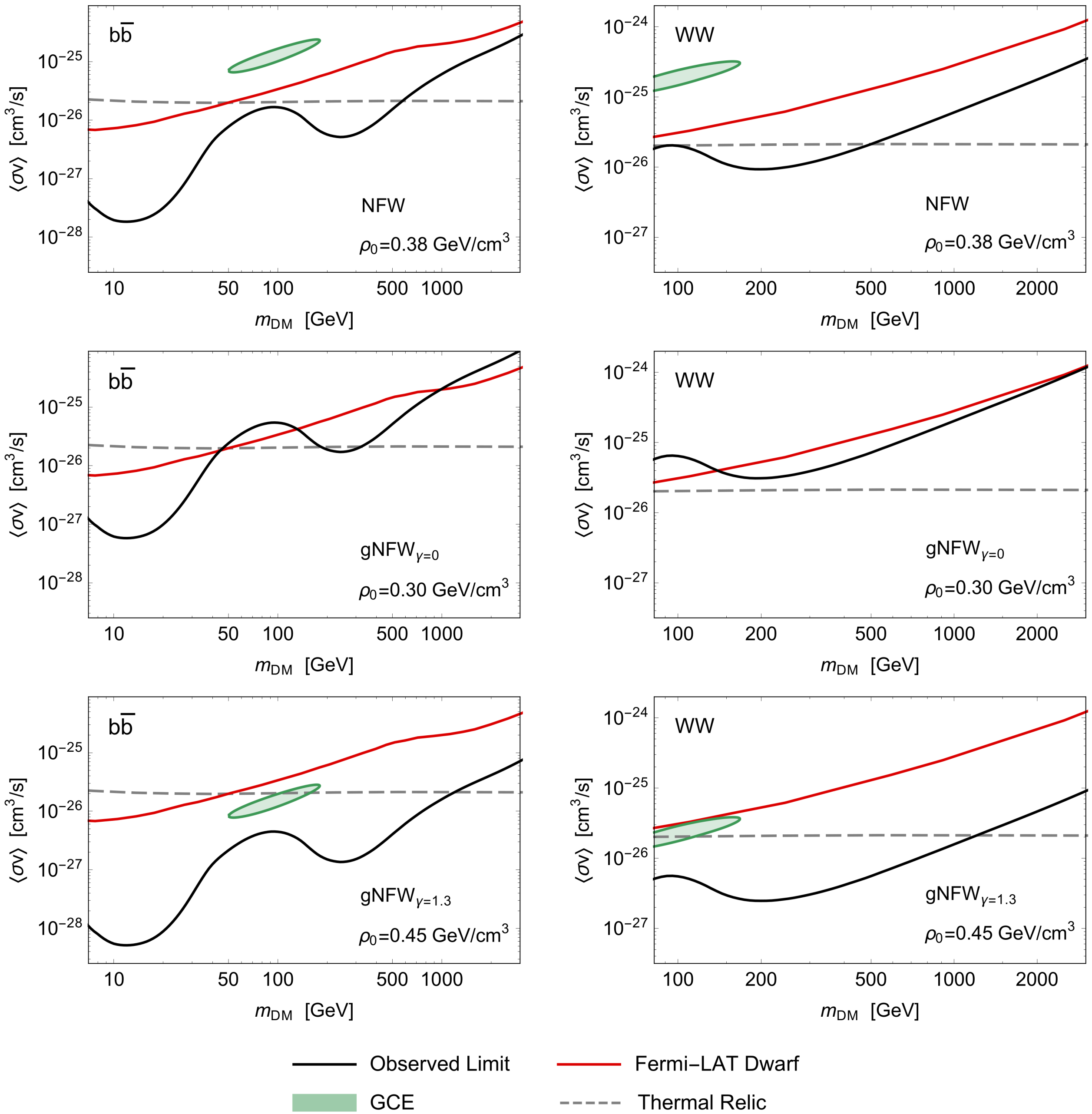
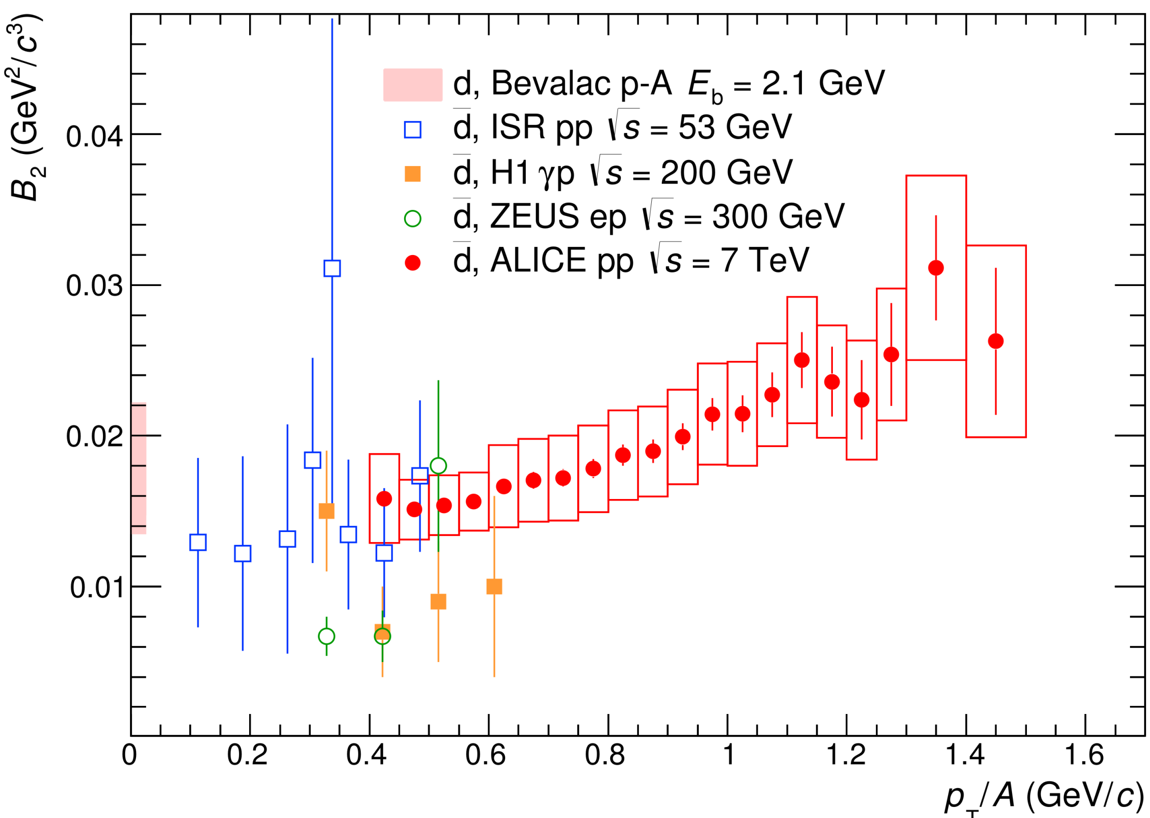


- simplistic coalescence model

Schwarzschild, Zupancic, Phys. Rev. 129 (1963)

$$\frac{d^3 n_d}{dp_d^3} = \frac{1}{8} \int d^3q \; \frac{d^6 n_{pn}}{dp_p^3 \, dp_n^3}\bigg|_{\mathbf{p}_{p,n} = \frac{\mathbf{p}_d \pm \mathbf{q}}{2}} \Theta\left(p_c{}^2 - |q^2|\right)$$



ALICE, arXiv:1709.08522 (2017)

Antideuteron Coalescence

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Schwarzschild, Zupancic, Phys. Rev. 129 (1963)

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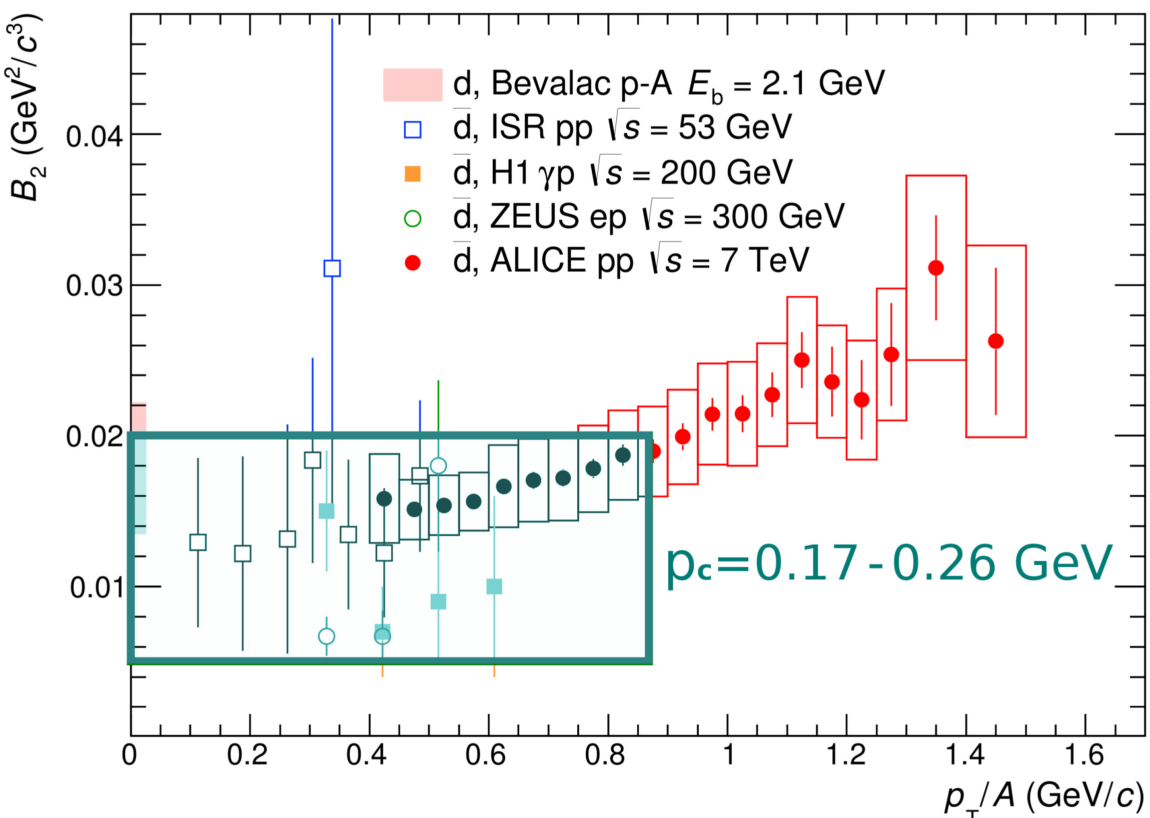
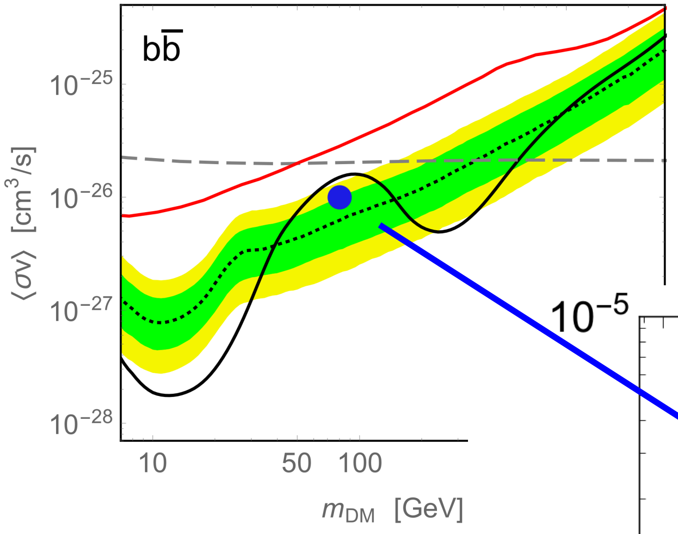


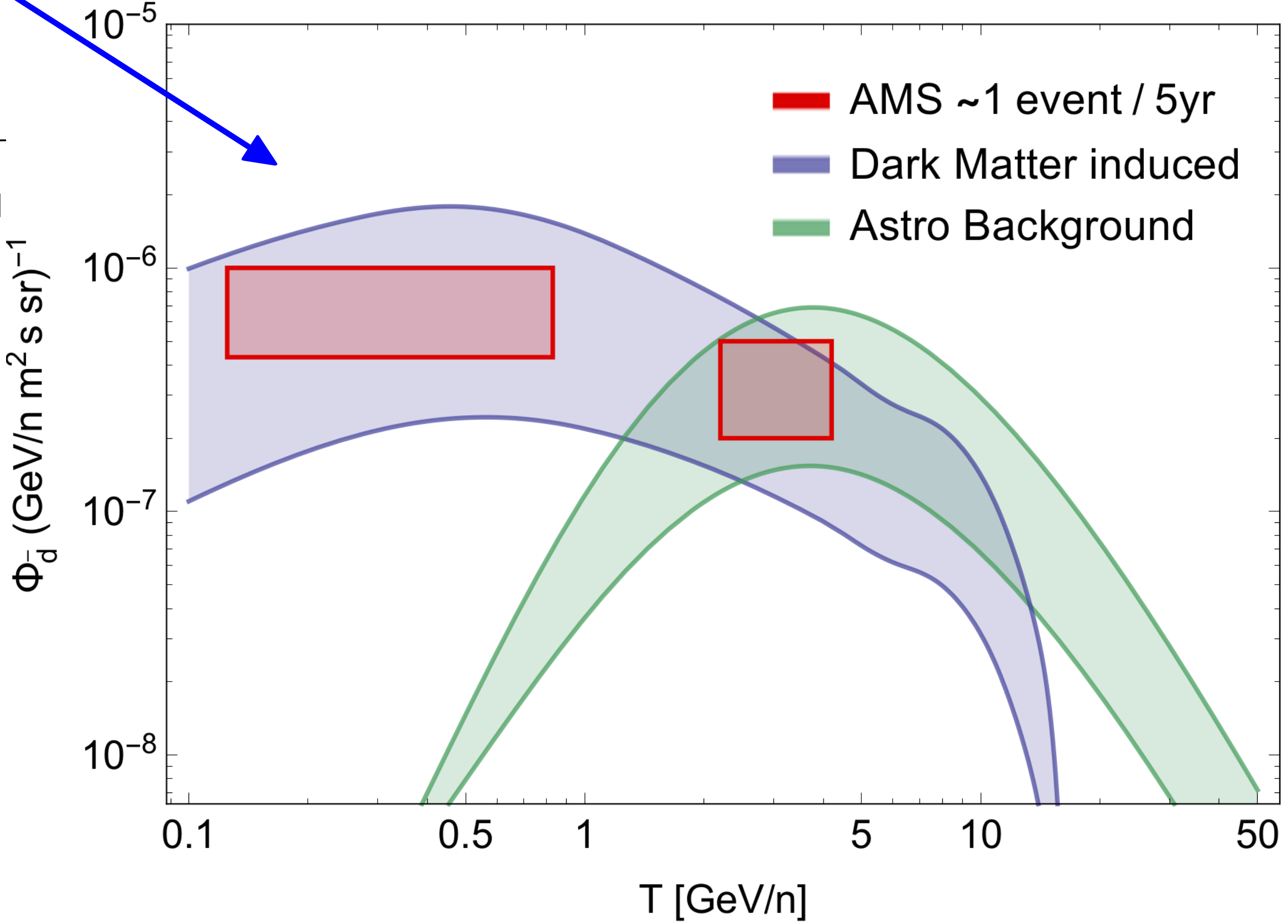
ALICE, arXiv:1709.08522 (2017)

Antideuteron Sensitivity



- antideuterons might provide a test for dark matter interpretation

see also: Korsmeier, Donato, Fornengo, arXiv:1711.08465 (2017)



Conclusion

- cross section, propagation, solar modulation uncertainties on $\bar{p}$ and B/C systematically addressed
- strongest constraints on hadronic WIMP annihilation from $\bar{p}$ and B/C
- a reported $\bar{p}$ excess at $R \sim 10$ GV is not significant
- antideuterons may test a dark matter signal in the near future