AMS-02 Antiprotons Reloaded

Martin W. Winkler

in collaboration with R. Kappl and A. Reinert

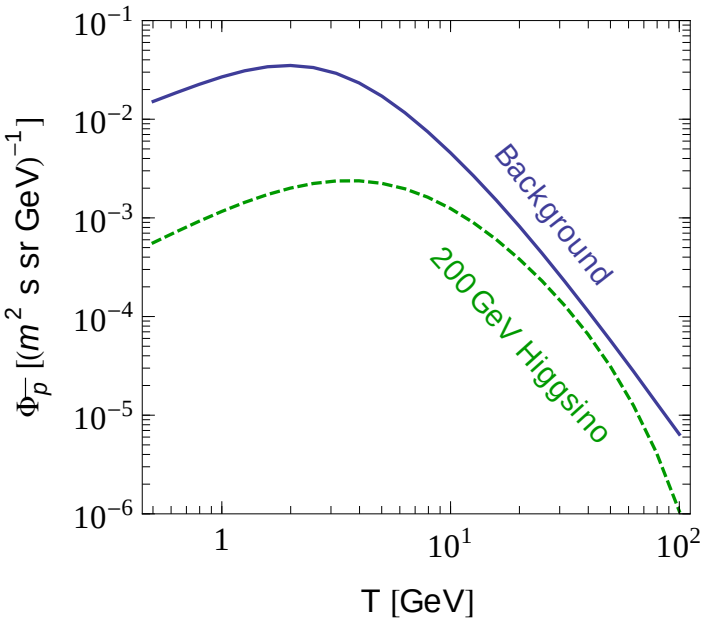
based on JCAP 09/2014 and arXiv:1506.04145

TAUP 2015
Torino

September 9 2015

Why Antiprotons?

- low fraction of antimatter in cosmic rays $\bar{p}/p \sim 10^{-4}$
- very sensitive probe for new physics
- complemantary to gamma ray searches



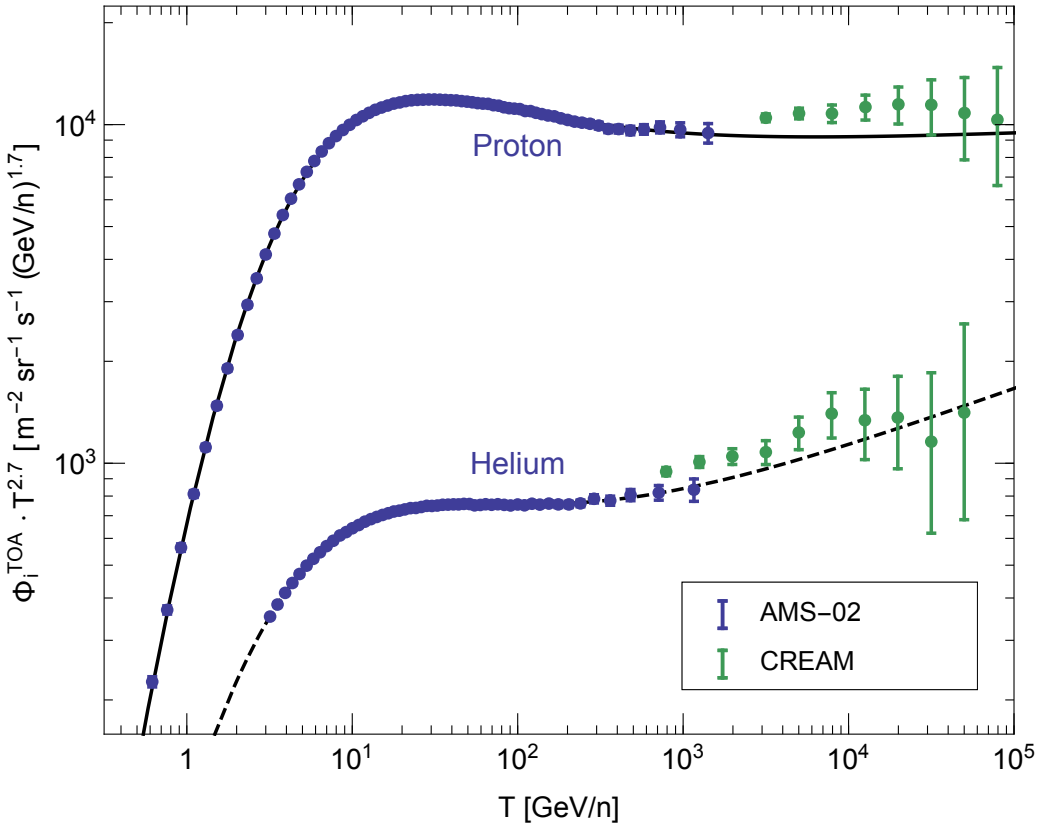
- example: dark matter pair-annihilation
- no clear spectral features expected

precise prediction for the $\bar{p}$-background is indispensable

Secondary Antiprotons

- scattering of primary cosmic rays (p,He) on the interstellar matter

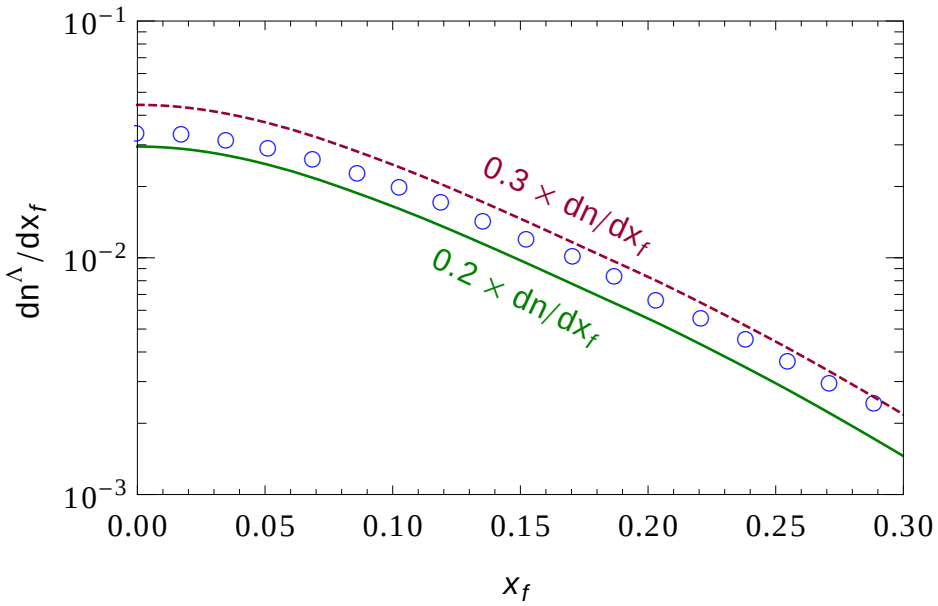
$$q^{\mathrm{sec}}(T) \sim \int dT' \left(\frac{d\sigma}{dT}\right)_{\bar{p}\,prod} n_{\mathrm{A_{ISM}}} \Phi_A \qquad A = H, He, \ldots$$



- primary proton and helium fluxes
  Yoon et al., Astrophys. J. **728** (2011)
  Aguilar et al., Phy. Rev. Lett. **114** (2015)
- clear indication of spectral breaks

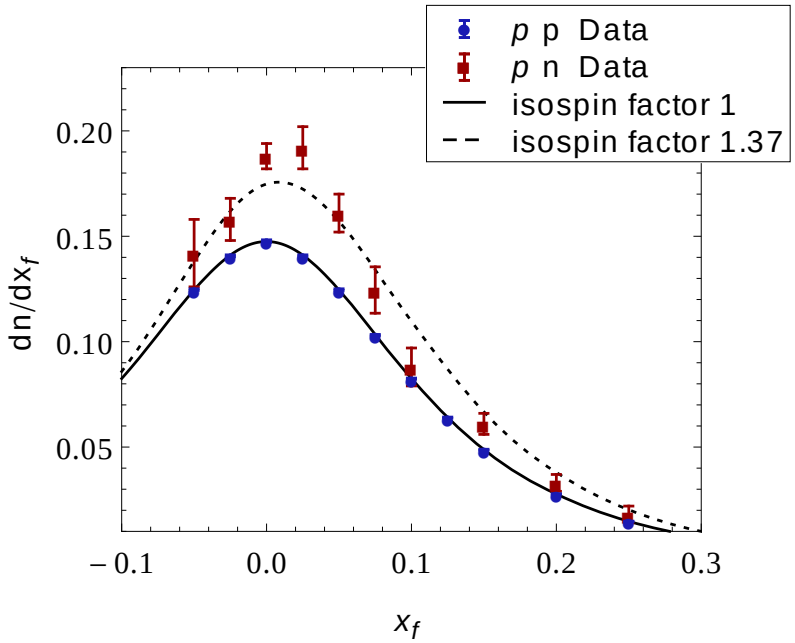
Antiproton Cross Sections

- new calculation of $\bar{p}$ production
  di Mauro et al., Phys. Rev. **D90** (2014)
  Kappl et al., JCAP **09** (2014)
- experimental data from NA49
  NA49 collaboration, Eur. Phys. J. **C65** (2010)
- hyperon decay



data from Alt et al., Eur. Phys. J. **C45** (2006)

- isospin enhanced $\bar{n}$ production

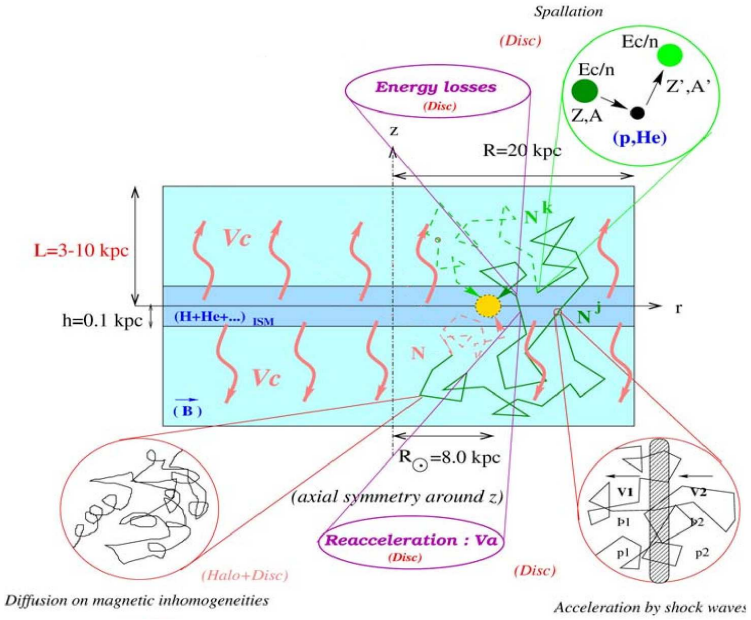


data from Fischer et al., Heavy Ion Phys. **17** (2003)

- improved modeling of proton-nucleus scattering

Propagation

- propagation: random walk through the galaxy



from D. Maurin

- diffusion equation

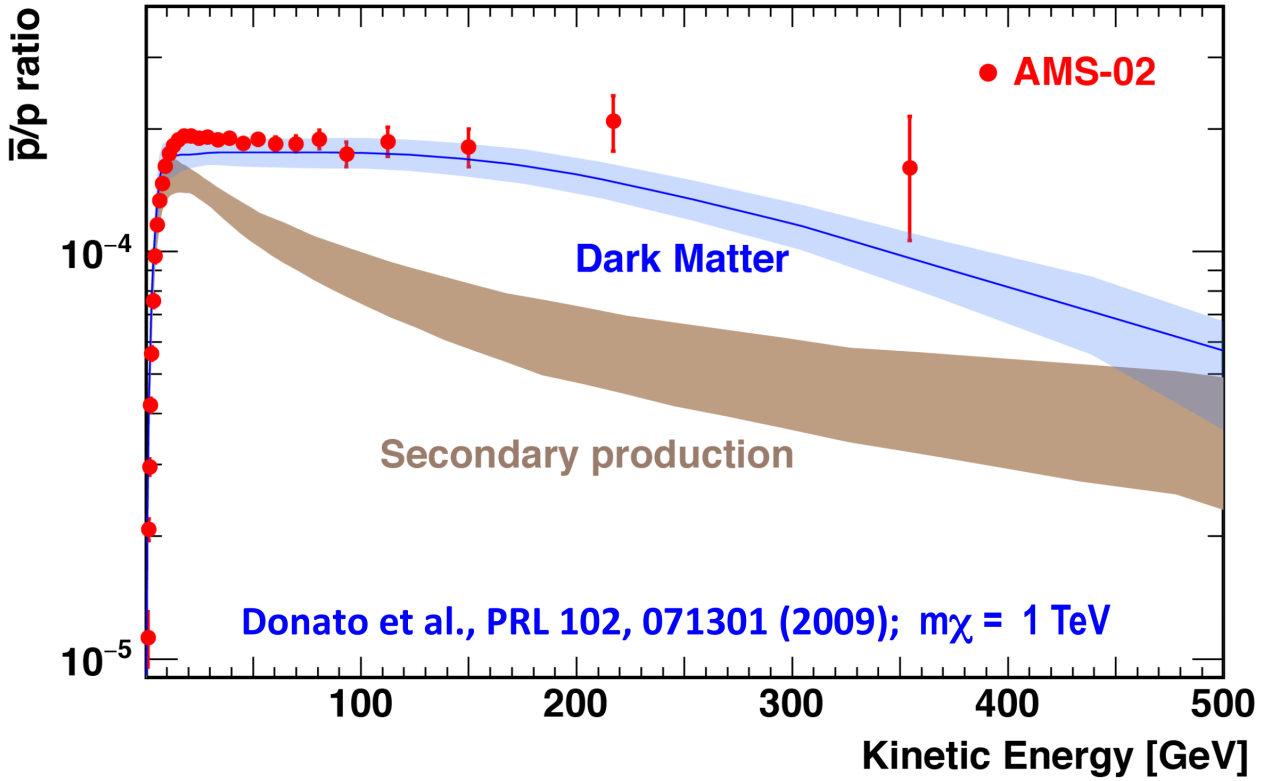
$$\nabla(-K\,\nabla N_{\bar{p}} + \mathbf{V}_c\,N_{\bar{p}}) + \partial_E(b_{\text{loss}}\,N_{\bar{p}} - K_{EE}\,\partial_E N_{\bar{p}}) + \Gamma_{\text{ann}}\,N_{\bar{p}} = q_{\bar{p}}$$

- semi-analytic solution in two-zone diffusion model
  Maurin et al., Astrophys. J. **555** (2001), Donato et al., Astrophys. J. **563** (2001)

- five transport parameters: K_0, δ, L, V_c, V_a $\Longleftarrow$ **B/C analysis**

Antiproton Excess in AMS-02?

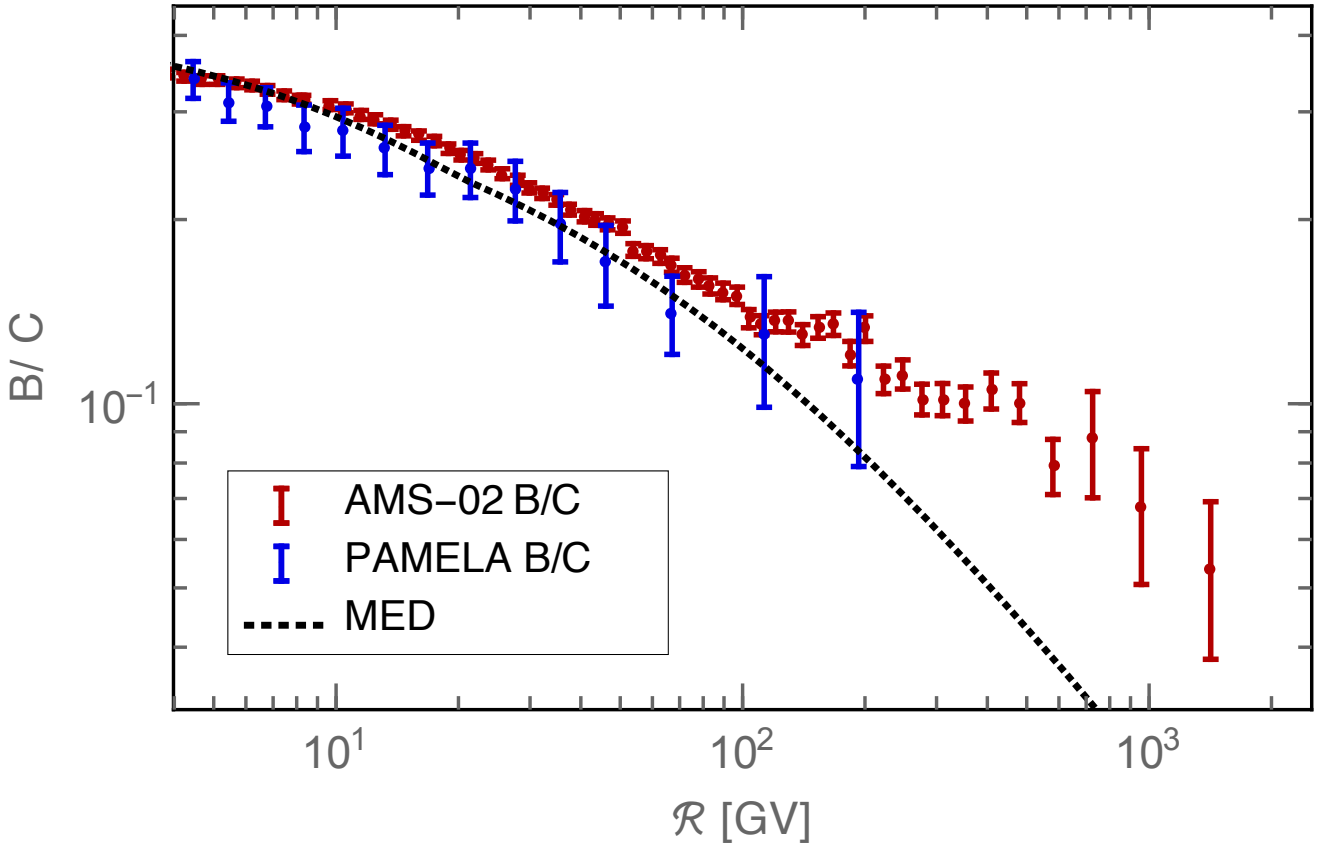
- preliminary data on the antiproton fraction in cosmic rays
  A. Kounine, Talk at the AMS Days at CERN (2015)



- dark matter interpretation
  Ibe et al., Phys. Rev. **D91** (2015), Hamaguchi et al., Phys. Lett. **B747** (2015)
- background underestimated? Giesen et al., arXiv:**1504.04276** (2015)

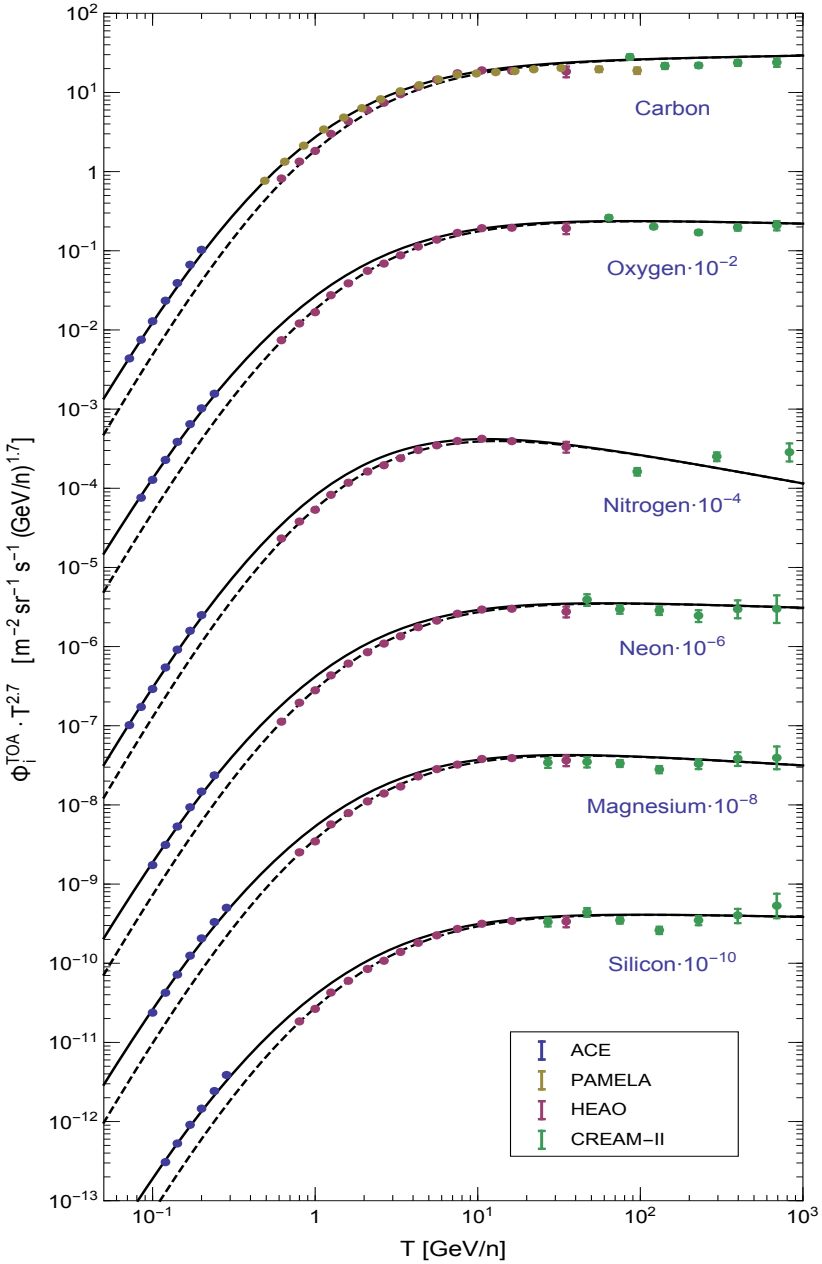
A Glance at B/C

- preliminary B/C data
  A. Oliva, Talk at the AMS Days at CERN (2015)



- indicate that propagation parameters are outdated $\Longleftarrow$ **reanalysis**

Primary Fluxes

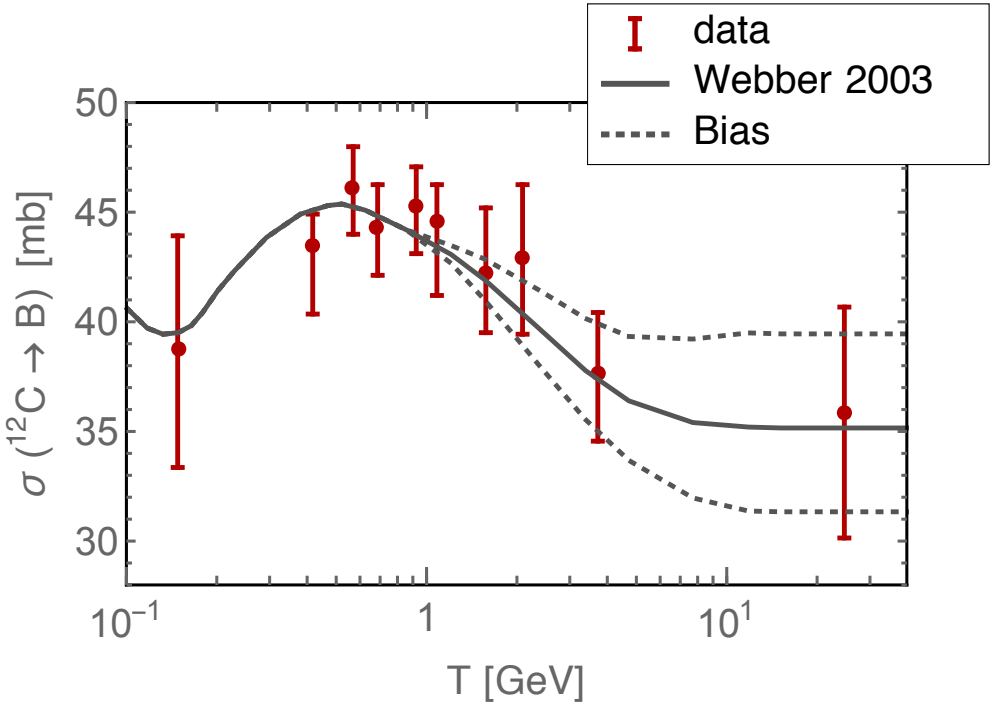


- B/C ratio used to determine propagation parameters
- B is pure secondary
- C, N, O, Ne, Mg, Si spallation contributes $\gtrsim$ 98% to B flux
- data from ACE, HEAO, CREAM-II, PAMELA

  Lave et al., Astrophys. J. **770** (2013), Engelmann et al., Astronom. Astrophys. **233** (1990), Ahn et al., Astrophys. J. **707** (2009), Adriani et al., Astrophys. J. **791** (2014)

Spallation Cross Sections

- σ_{spall}: straight-ahead approximation
- constant at $T \gtrsim 10$ GeV

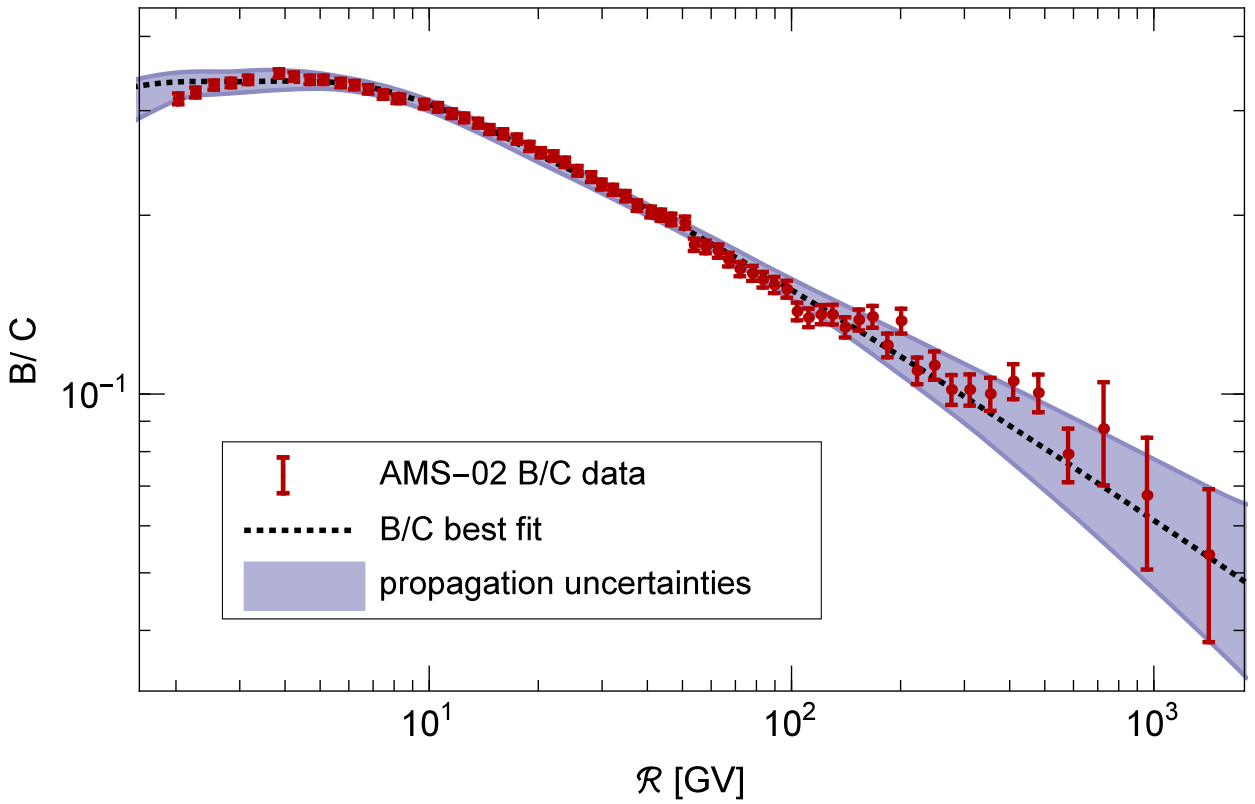


- Webber parameterization
  Astrophys. J. Suppl. **144** (2003)
- large uncertainties, no high-energy data
- introduce energy bias
  Maurin et al., Astron. Astrophys. **516** (2010)

needed: experimental data on spallation cross sections

B/C Analysis

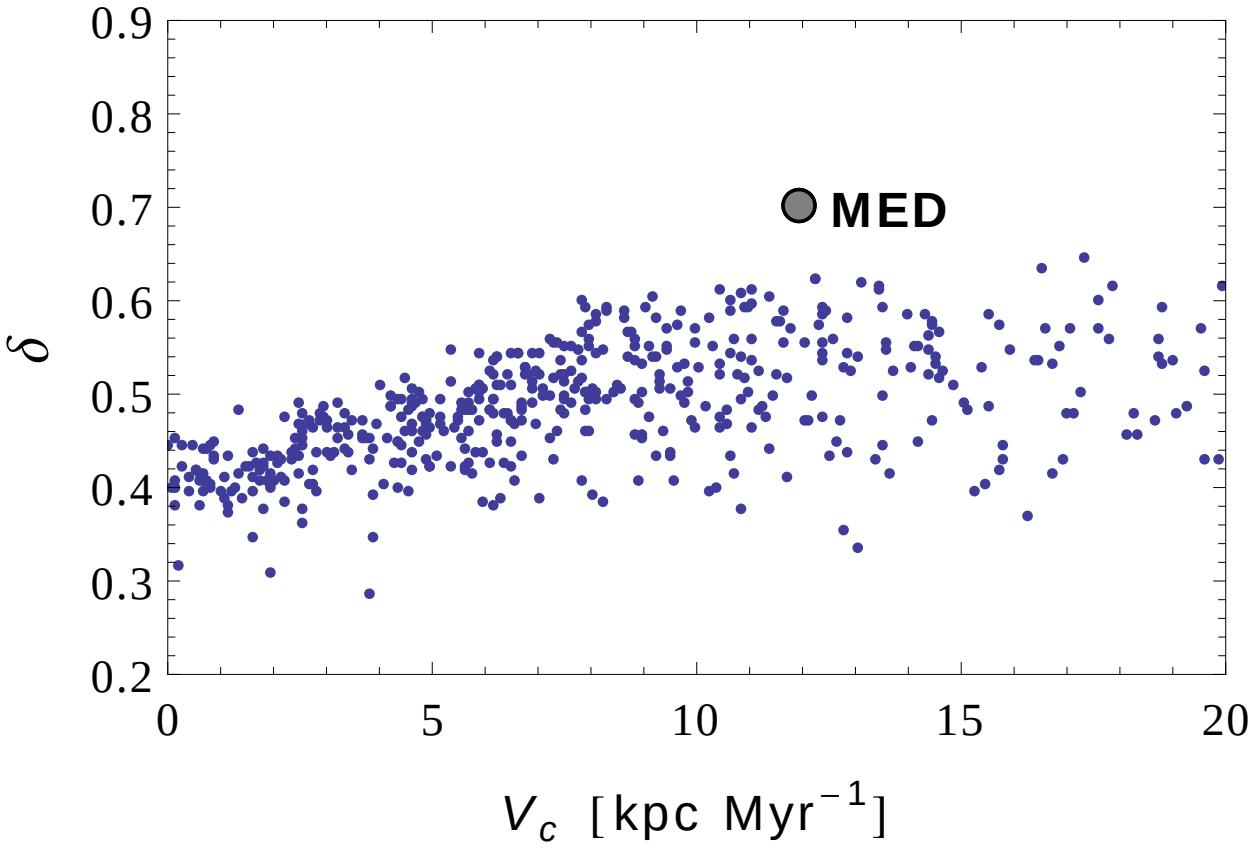
- new AMS-02 data on B/C ratio
  A. Oliva, Talk at the AMS Days at CERN (2015)



- selected 500 configurations, trend towards smaller $\delta = 0.3 - 0.6$

B/C Analysis

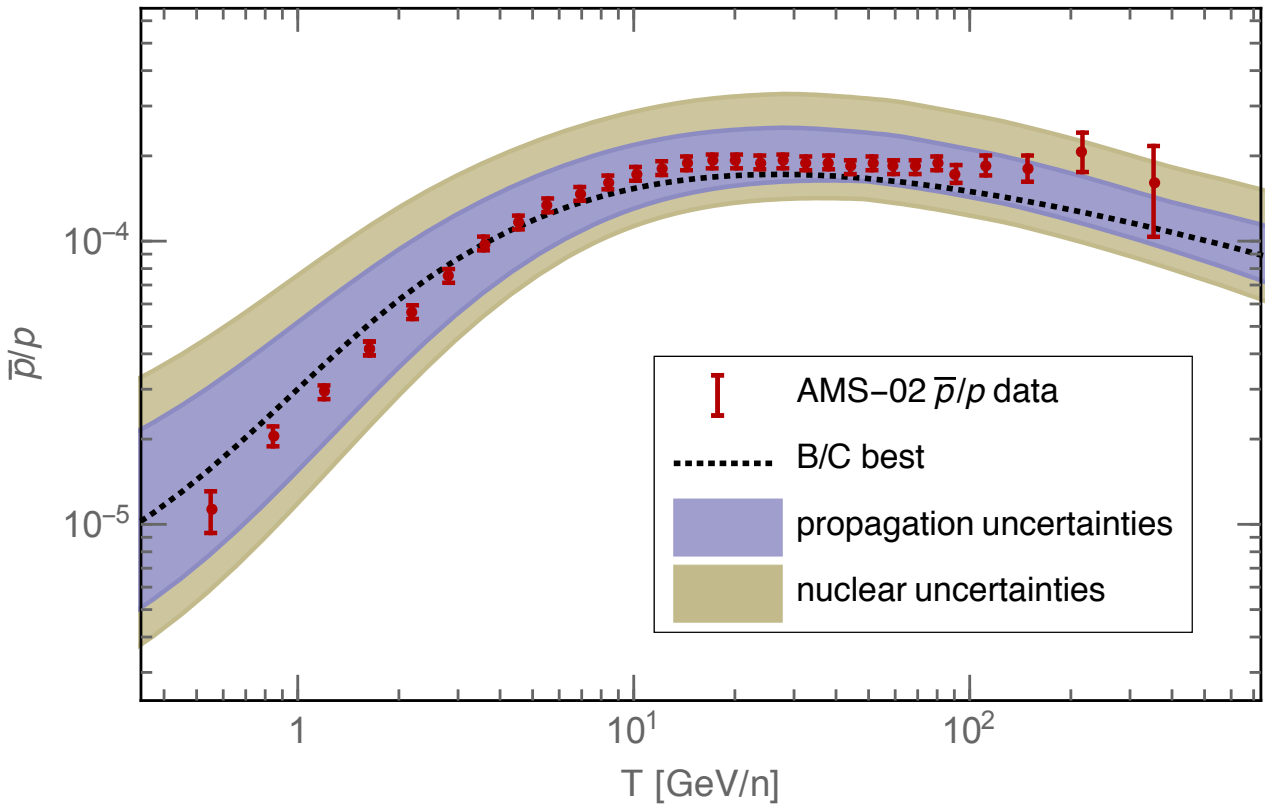
- new AMS-02 data on B/C ratio
  A. Oliva, Talk at the AMS Days at CERN (2015)



- selected 500 configurations, trend towards smaller $\delta = 0.3 - 0.6$

Antiproton Fraction

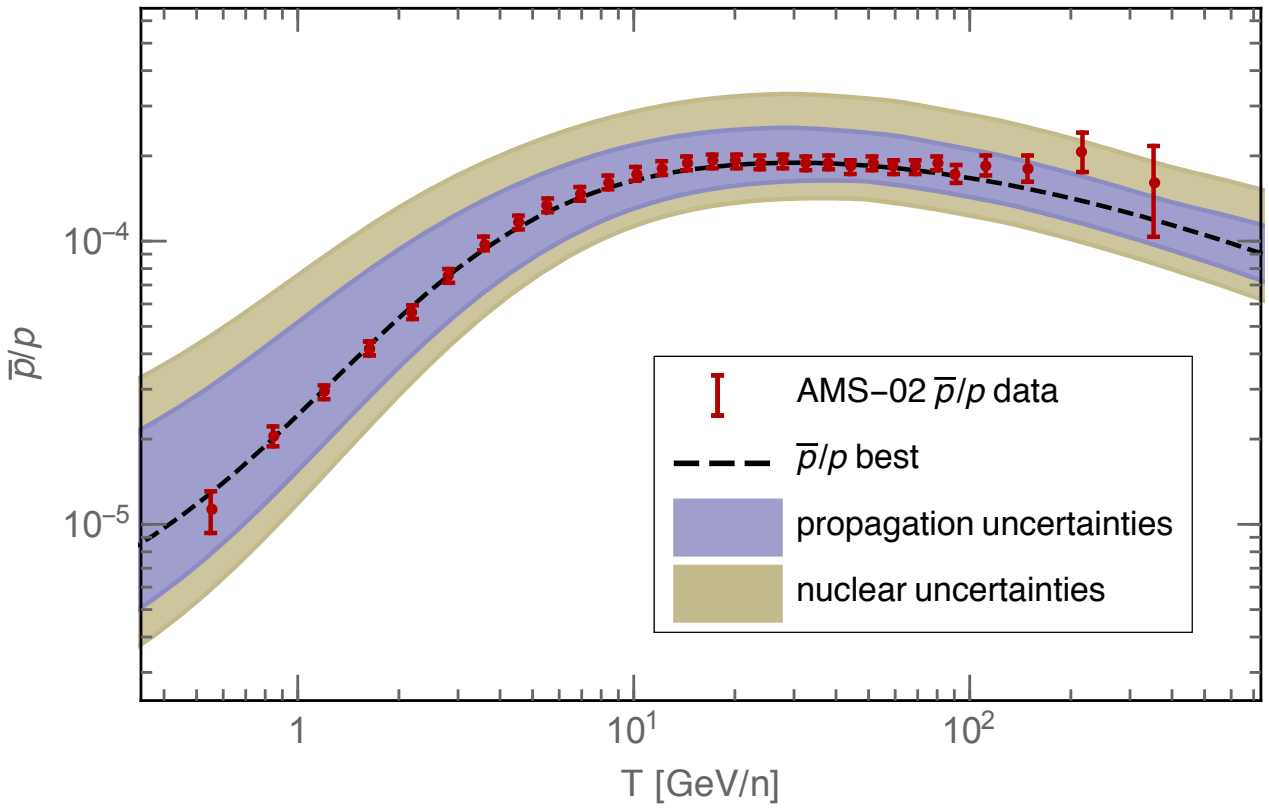
- comparison of $\bar{p}$ background with new AMS-02 data
  A. Kounine, Talk at the AMS Days at CERN (2015)



- updated background consistent with data

Antiproton Fraction

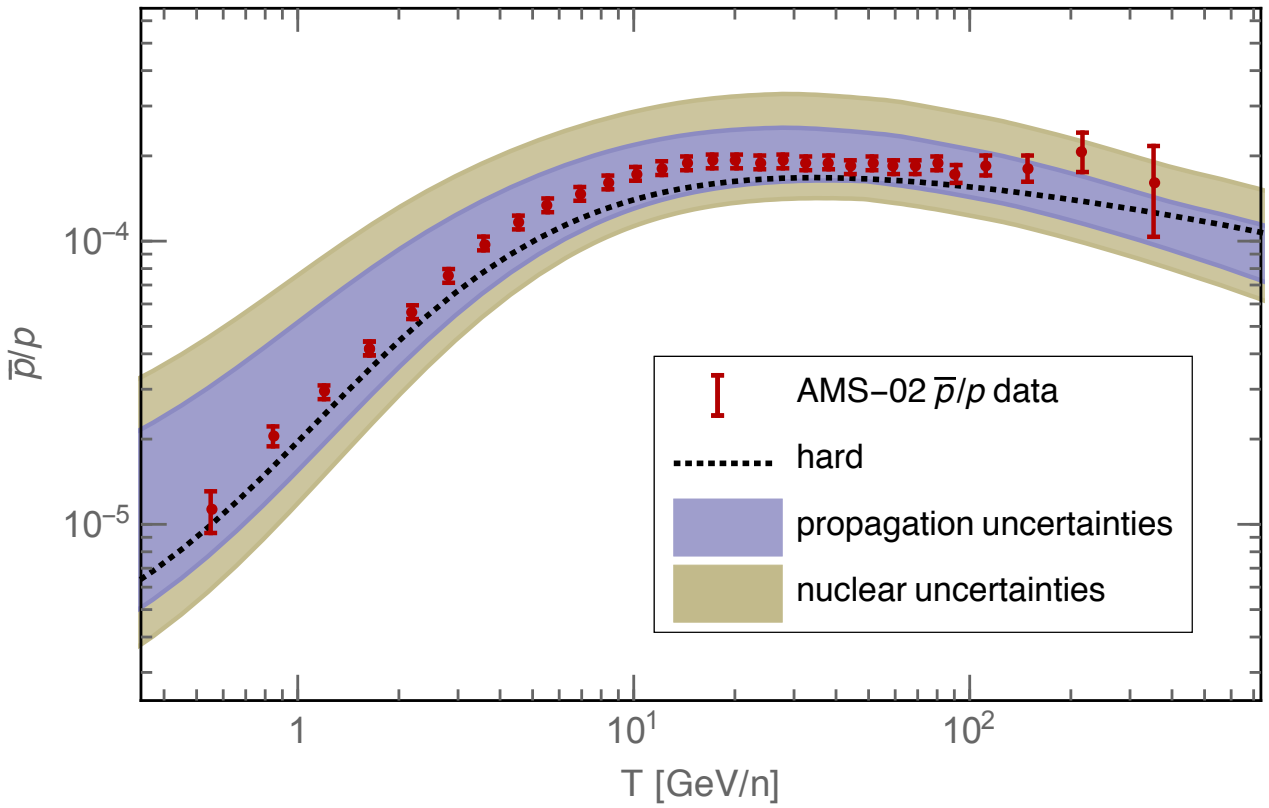
- comparison of $\bar{p}$ background with new AMS-02 data
  A. Kounine, Talk at the AMS Days at CERN (2015)



- updated background consistent with data

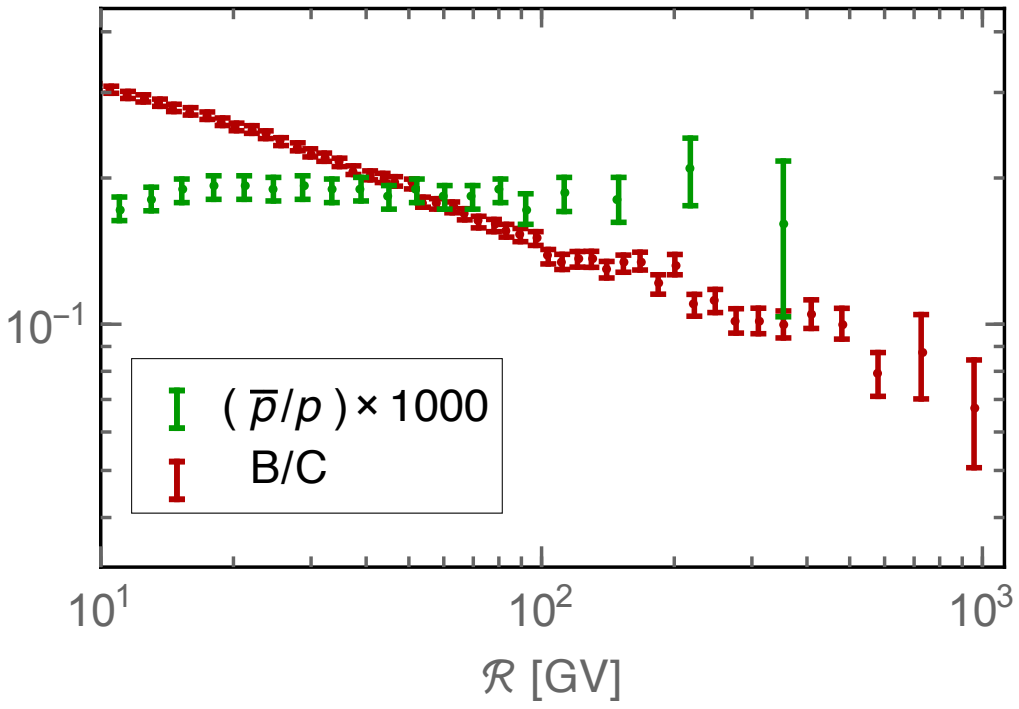
Antiproton Fraction

- comparison of $\bar{p}$ background with new AMS-02 data
  A. Kounine, Talk at the AMS Days at CERN (2015)

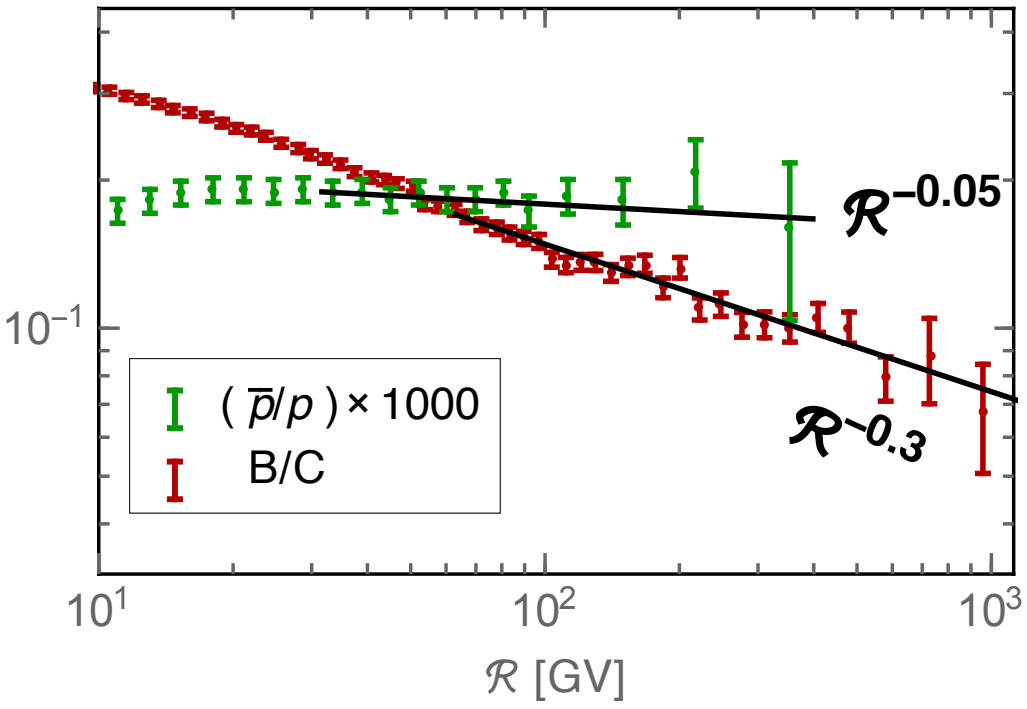


- updated background consistent with data

Comparison of $\bar{p}/p$ and B/C

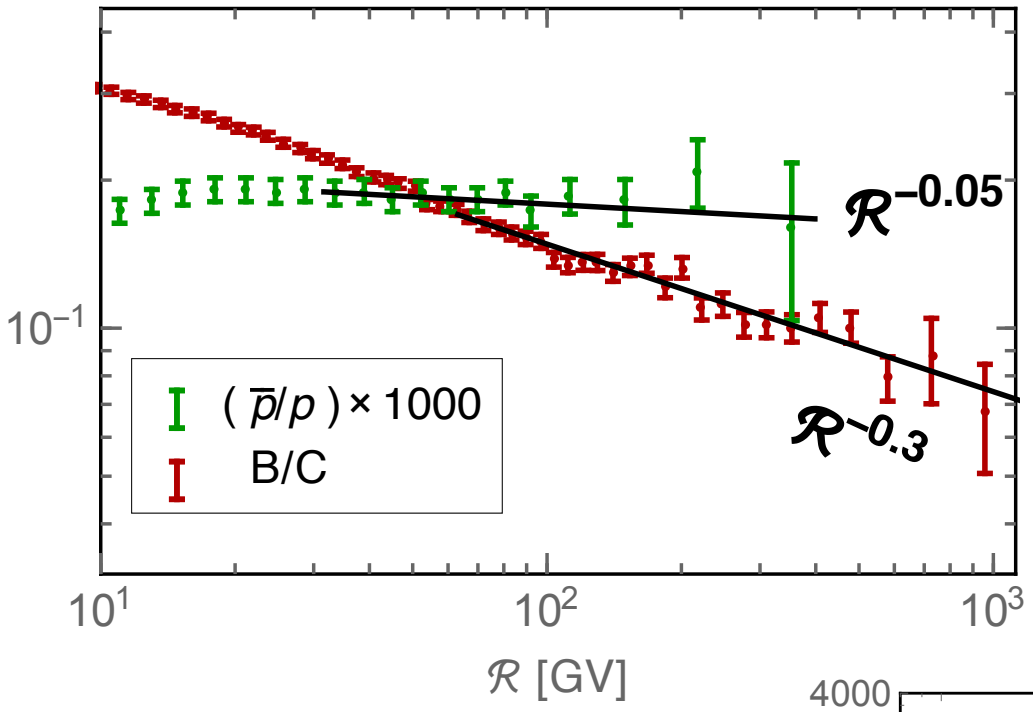


Comparison of $\bar{p}/p$ and B/C



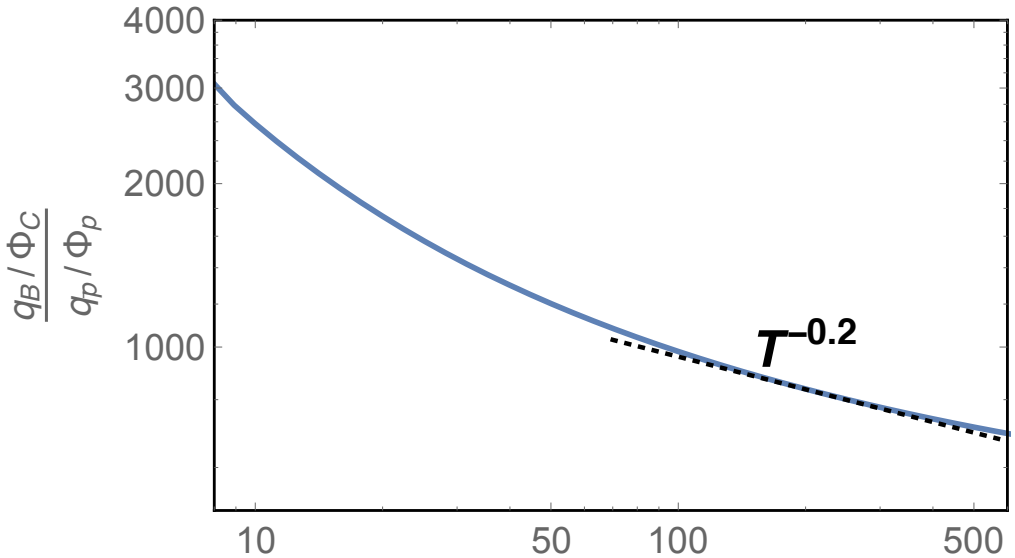
$\bar{p}/p$ flatter by $\sim \mathcal{R}^{0.25}$

Comparison of $\bar{p}/p$ and B/C

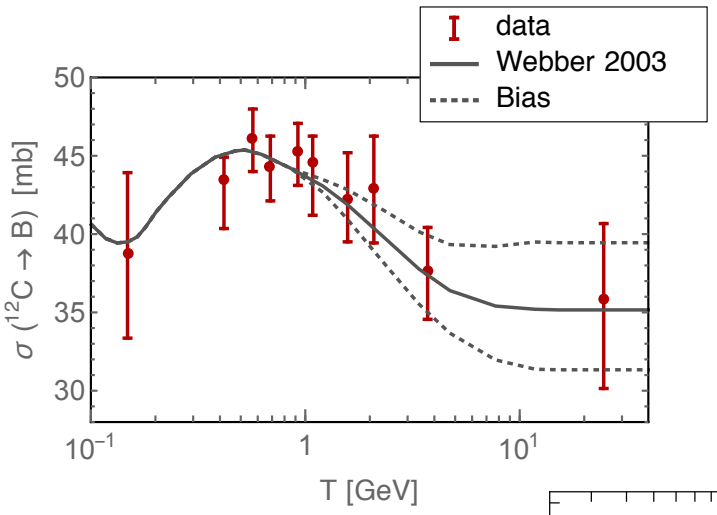


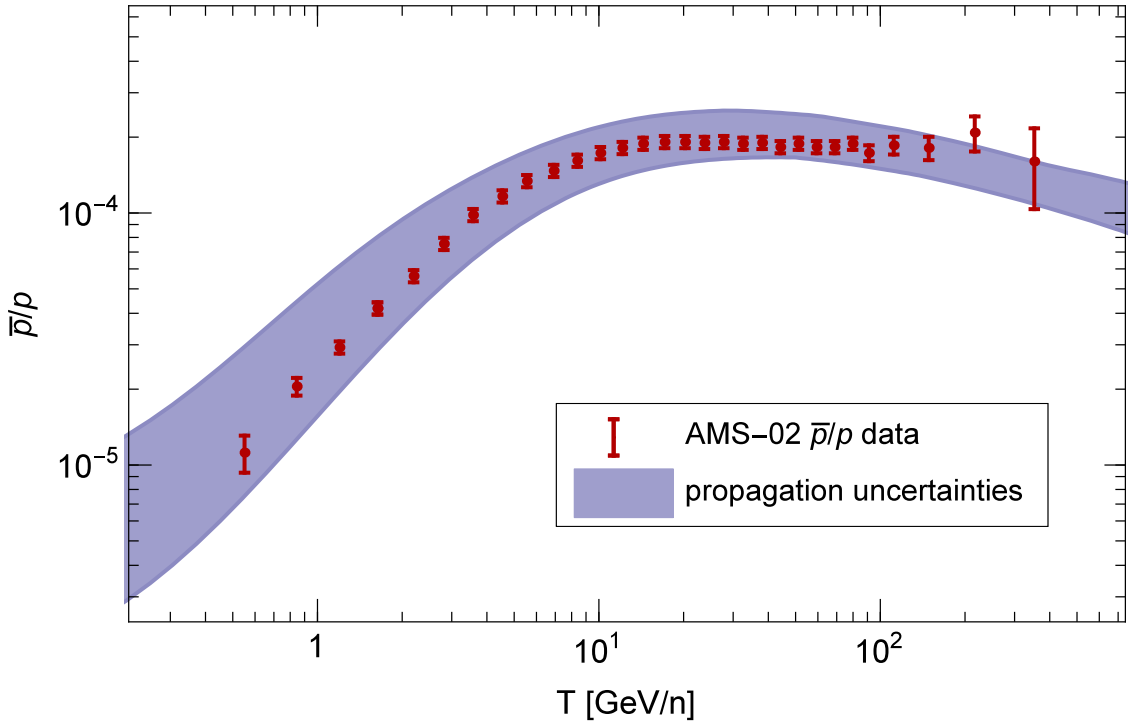
$\bar{p}/p$ flatter by $\sim \mathcal{R}^{0.25}$

explained by injection

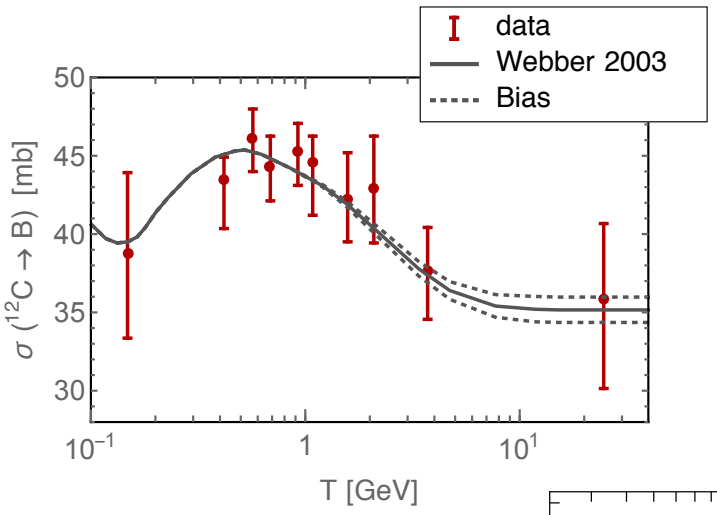


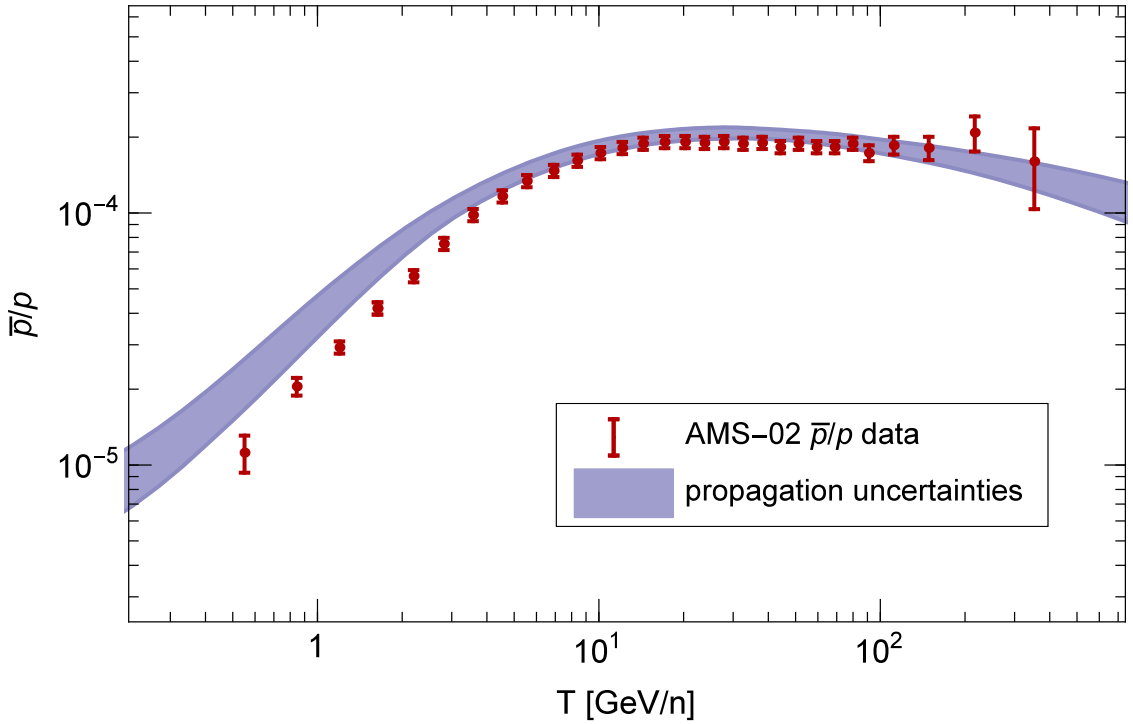
Remark on Propagation Unceratinties





Remark on Propagation Unceratinties





Conclusion

- substantial progress in modeling antiproton production
- AMS-02 B/C data have strong impact on propagation parameters: higher slope of diffusion coefficient
- AMS-02 antiproton data are consistent with background