The Cosmic Ray Antiproton Background for AMS

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based on work in progress with R. Kappl

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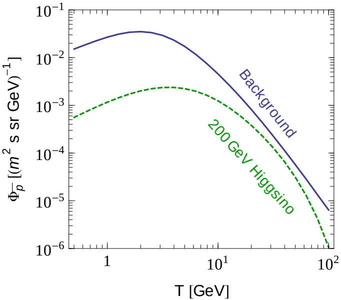
Why Antiprotons?

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

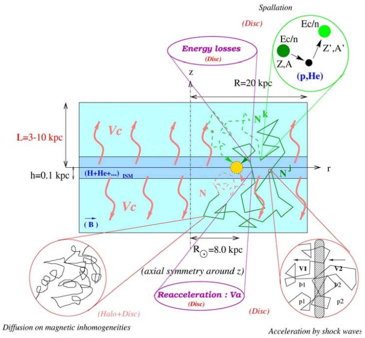


- example: dark matter pair-annihilation
- no clear spectral features expected

precise prediction of the $\bar{p}$-background is essential

Secondary Antiprotons

- spallation of primary cosmic rays (p,He) on the interstellar matter
- propagation: random walk through the galaxy



from D. Maurin

- diffusion equation

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

Secondary Source Term

- antiproton production rate in the disc

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

existing determinations

- Tan Phys. Rev. **D26** (1982)
  parameterization fitted to data, only *pp* scattering
- Duperray Phys. Rev. **D68** (2003)
  includes nuclear scattering, based on parameterization by Kalinovski et al.
- DTUNUC by Roesler et al.
  Monte Carlo approach
  Simon, Astrophys. J. **499** (1998), Donato, Astrophys. J. **563** (2001), Moskalenko, Astrophys. J. **565** (2002)

our approach

- new precision data by Na49
  Eur. Phys. J. **C65** (2010)
- first attempt to assess particle physics uncertainties
- hyperons, isospin effects
- improve description of $p\,N$ scattering
- include AMS-02 primary proton and helium fluxes

Invariant Cross Section

- Lorentz invariant differential cross section

$$f(pp \to \bar{p} + X) = E_{\bar{p}} \frac{d^3\sigma}{dp_{\bar{p}}^3} ,$$

- define scaling variable $x_R = \frac{E^*}{E^*_{\text{max}}}$ or $x_f = \frac{p_L^*}{\sqrt{s}/2}$
- constituent exchange models predict power law behavior
  Low, Phys. Rev. **D12** (1975), Nussinov, Phys. Rev. Lett. **34** (1975), Brodsky et al., Phys. Rev. Lett. **37** (1976)

$$f \propto (1 - x_R)^n$$

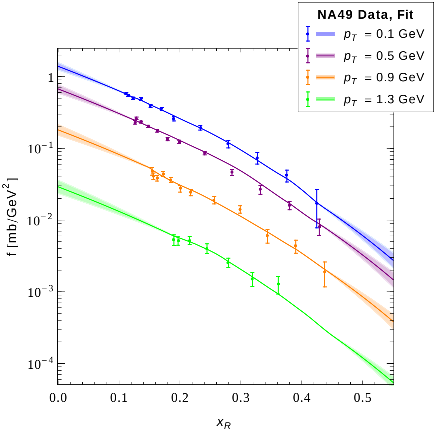
- radial scaling regime
  Taylor et al., Phys. Rev. **D14** (1976)

$$f(\sqrt{s}, x_R, p_T) \xrightarrow{\sqrt{s}\ >\ 10\ \text{GeV}} f(x_R, p_T)$$

Cross section at one $\sqrt{s}$ determines cross section at all $\sqrt{s} > 10$ GeV

The Invariant Cross Section from Na49

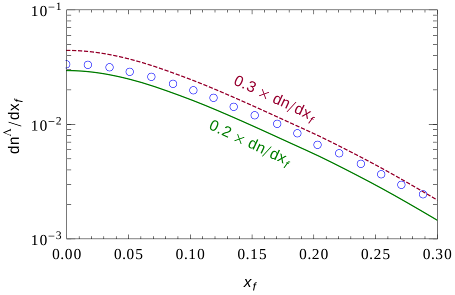
- Na49 at CERN SPS: fixed target pp collisions with $E_p = 158$ GeV
- large acceptance hadron detector, $> 70\%$ of charged particles identified



- $f(x_R, p_T)$ from fit function provided by collaboration
  NA49, Eur. Phys. J. **C65** (2010)
- extrapolation with $(1 - x_R)^n$
- include uncertainties in fragmentation power, normalization

Strange Hyperons

- in proton collisions 1/4 of $\bar{p}$ are produced via $\bar{\Lambda}, \bar{\Sigma}$-decay
- decay length comparable to detector scales $c\tau_{\bar{\Lambda},\bar{\Sigma}} \sim 0.1$ m
- "feed-down problem" due to escaping hyperons
- introduce systematic error in $\sigma_{\bar{p}}$



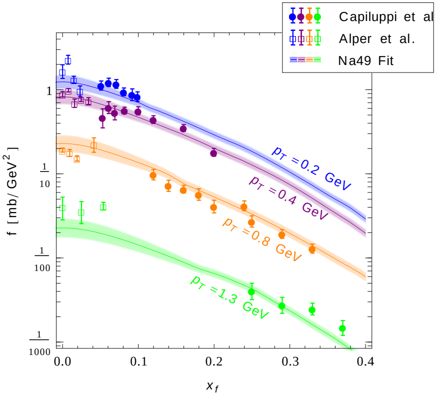
data from Alt et al., Eur. Phys. J. **C45** (2006)

our approach

- precision tracking allows to separate prompt and late $\bar{p}$
  NA49, Eur. Phys. J. **C65** (2010)
- deduce $\sigma_{\bar{\Lambda},\bar{\Sigma}\to\bar{p}}$ from phase space distribution of parent hyperons

Energy Scaling

- verify radial scaling with high energy data



CERN ISR data at $\sqrt{s} = 53$ GeV ($E_p = 1.5$ TeV) Nucl. Phys. **B100** (1975)

Energy Scaling

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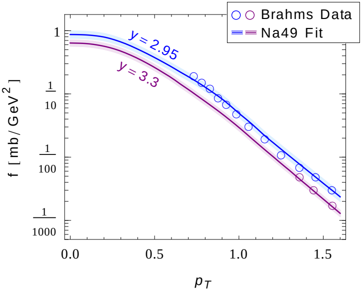

data from RHIC Brookhaven at $\sqrt{s} = 200$ GeV ($E_p = 20$ TeV)

BRAHMS, arXiv:**0801.1696** (2008)

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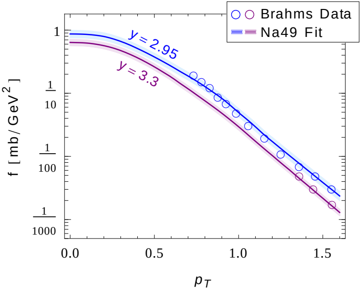

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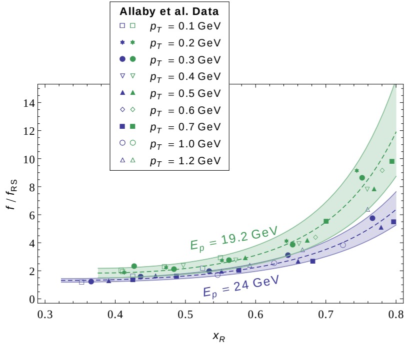
BRAHMS, arXiv:0801.1696 (2008)

- scaling violation at $\sqrt{s} < 10\,\text{GeV}$
- scaling approached faster at low x_R, weak p_T dependence
- data rare $\hookrightarrow$ uncertainties

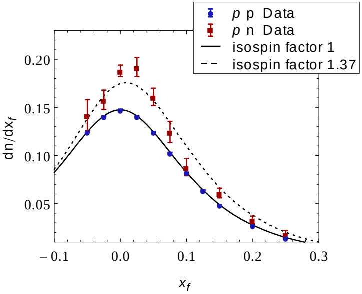
Allaby et al., CERN-70-12 (1970), Proceedings of Internat. Conference on High-Energy Collisions (1972)



Comment on Antineutrons

- standard assumption in cosmic ray physics $\sigma_{pp\to\bar{p}} = \sigma_{pp\to\bar{n}}$
- suggests equal $\bar{p}$-production in $p\,p$ and $p\,n$ scattering

<u>But:</u>



$\sigma_{np\to\bar{p}} \simeq 1.4\,\sigma_{pp\to\bar{p}}$
in projectile hemisphere

- isospin effect

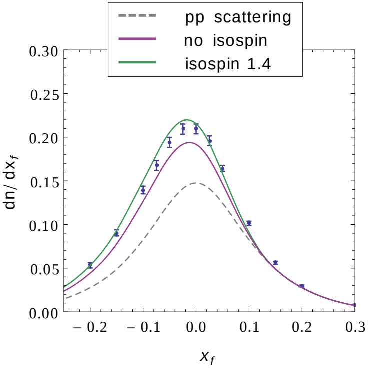
Fischer et al., Heavy Ion Phys. **17** (2003)

projectile	n			p	
final state	$\bar{p}n$		$\bar{p}p, \bar{n}n$		$p\bar{n}$
I_3	-1	-1/2	0	1/2	1

- suggests enhanced $\bar{n}$-production in $p\,p$ collisions
- consistent with nuclear scattering data ? $\bar{p}$ flux ?

Proton Nucleus Scattering

- Duperray et al. fit Kalinovski formula to large number of proton-nuleus scattering data
- for light nuclei, it seems better to construct $p\,A$ cross section from $p\,p$ cross section

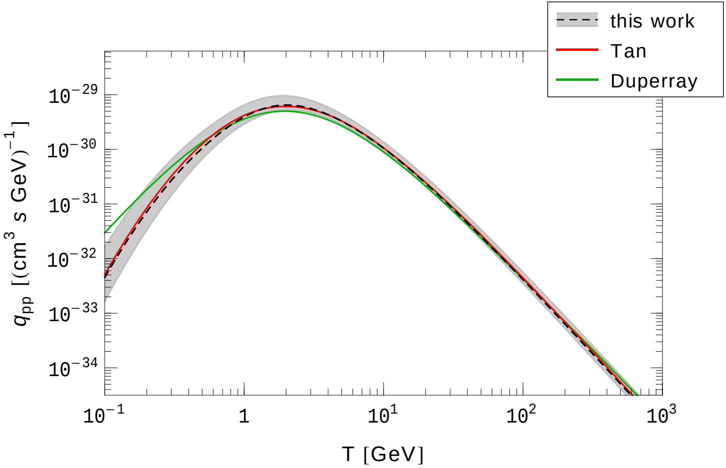


data from Na49, Eur. Phys. J. **C73** (2013)

- no $p\,He$ data available, but $p\,C$
- separate target and projectile hemisphere
- enhancement of multiplicity in target region due to multiple scatter and isospin effects
- tiny Cronin effect for $p\,C$ scattering, negligible for $p\,He$

Source Term

- comparison with Tan & Ng, Duperray et al.



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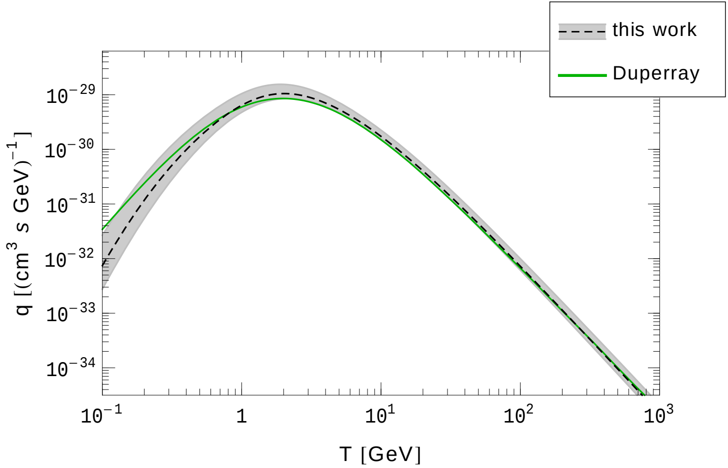
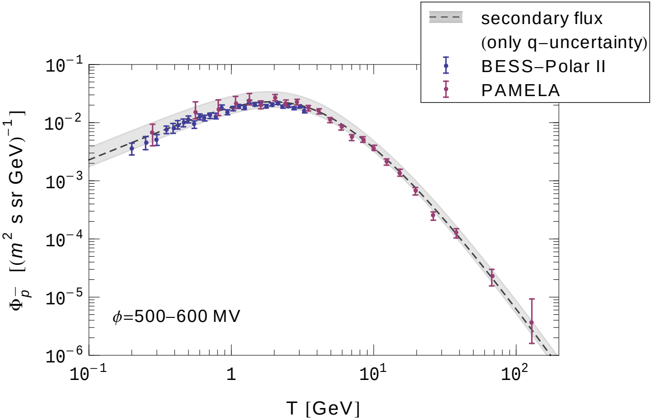


The Cosmic Ray Antiproton Flux

- comparison with BESS-Polar II, PAMELA

BESS-Polar II, Phys. Rev. Lett. **108** (2012), PAMELA, Phys. Rev. Lett. **105** (2010)



- AMS-02 data expected early 2015

Conclusion

- cosmic ray antiprotons play a key role in the search for new physics
- upcomming AMS-02 antiproton data will exceed precision of background calculation
- we will provide a revised and in several ways improved prediction for the $\bar{p}$-background
- first attempt to realistically quantify particle physics uncertainties