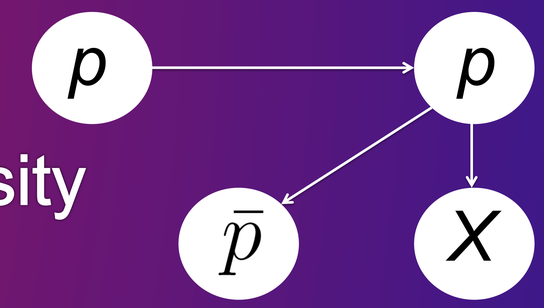
Cosmic Rays and Production of Antimatter



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Abstract

High-energy protons, the dominant component of cosmic-ray primaries, collide with the interstellar medium (ISM) and produce secondary particles as well as antiparticles. For cosmic-ray astrophysics as well as cosmology, we would like to be able to answer the question as to whether the published parameterizations of the production cross sections of antiparticles in these collisions can be applied reliably and are up to date. Many researchers in the field have applied "standard" parameterizations to both old and new data, without necessarily checking their general validity and robustness. After extensive literature search of relevant cosmic-rays and high-energy particle physics published data and parameterizations, the "standard" parameterizations to be examined have been isolated. We fit the published data by manipulating these parameterizations. These studies are important for astrophysical studies in general. For example, antimatter in cosmic rays can be a probe to look for primordial black holes. Antiprotons provide information about the propagation of the proton component of the cosmic ray primaries, and are also related to the annihilation of neutralinos (postulated mass of the galactic dark matter).

Introduction

- Cosmic-rays consist mostly of high-speed protons [1]
- The cross section is the effective target size expressed in terms of area [1]
- Proton-proton collisions are studied at high energies [2]
- Parameterizations for such interactions are in terms of differential cross sections and the radial variable, transverse momentum, or energy [2]

Changes made to turn X_R into p_t and to normalize parameterization

$$E^* = X_R E^*_{max}$$

$$p_t = \sqrt{E^2 - m_p^2}$$

$$\left(\frac{Ed^3\sigma}{d^3p}\right)_{RS} = 28 f(X_R) exp[-(Ap_t + Bp_t^2)]$$

Methodology

- **Background Research:** Become acquainted with cosmic-rays, extensive air showers, antimatter, particle collisions, and dark matter
- **Literature Search:** Collect articles about above topics that include either experimental data or parameterizations of production cross sections (or both)
- **Programming:** Write programs for relevant and useful parameterizations in desired language (such as MATLAB)
- **Digitize:** Use "Plot Digitizer" to extract data from plots in articles
- **Reproduction:** Plot given experimental data with given parameterizations to confirm understanding of parameterization
- **Mixing and Matching:** Find newer data from the same kind of reaction and with the same units as an older parameterization
- **Plotting:** Put new combinations of data and parameterizations on a plot
- **Normalization:** Make the y-intercept of the parameterization curve appear at the same point on the y-axis as the first point of the data by implementing a normalization constant (if it does not already)
- **Manipulation:** Change parameters in the parameterization equation so that the curve appears to fit the experimental data (if it does not already)

On Left: Artist's depiction of antiprotons detected by scientists using PAMELA, a satellite launched in 2006 meant to study cosmic rays [4]

Data & Equations

Tan & Ng 1982 Parameterization [2]

Radial Variable X_R in calculating the invariant cross section for $p + p \rightarrow \bar{p} + X$

$$X_R = \frac{E^*}{E^*_{max}}$$

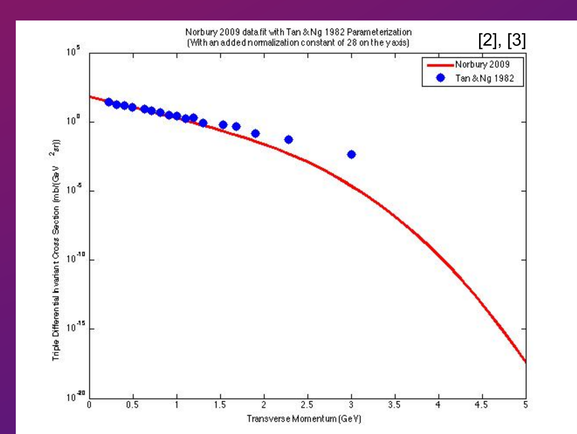
$$X_R = \frac{E^* 2\sqrt{s}}{s - \bar{M}_X^2 + m_p^2}$$

$$\left(\frac{Ed^3\sigma}{d^3p}\right)_{RS} = f(X_R) exp[-(Ap_t + Bp_t^2)]$$

$$f(X_R) = 3.34 exp(-17.6X_R)\theta(0.5 - X_R) + 2.10(1 - X_R)^{7.80}$$

$$A = 3.95 exp(-2.76X_R)$$

$$B = 40.5 exp(-3.21X_R)X_R^{2.13}$$



Why is this Important?

- Cosmic-ray antiproton measurements provide information on CR origin [5] and parameters such as gas density and the diffusion coefficient that are needed to understand CR propagation [6]
- The CR-antiproton component provides information about the acceleration process caused by hydromagnetic turbulence during CR propagation (this is important when distinguishing between models that either favor no reacceleration or some reacceleration) [6]
- While most antiprotons originate from high-energy collisions of CR-protons with hydrogen gas in the ISM, some may come from the evaporation of primordial black holes or the annihilation of supersymmetric dark matter particles [6]

Conclusion

- To figure out the sources of CR-antiprotons, parameters that govern CR propagation in the Galaxy must be clarified in addition to the improvement of data quality [6]
- Accurate production models for simulating extensive air showers involve Monte Carlo transport models that use cross section parameterizations as input [3]
- Accurate simulations of the air shower help to find sources of high-energy CR [3]
- There are many options for furthering this work: comparing different parameterizations to each other, continuing to compare data to parameterizations, and manipulating parameterizations meant for certain collisions (such as proton-proton) and applying them to other collisions (such as proton-heavy nuclei)

References

[1] Friedlander, Michael W., *Cosmic Rays*, President and Fellows of Harvard College, USA, 1989.
[2] Tan, L.C., and Ng, L.K., "Parameterization of p-bar invariant cross-section in p-p collisions using a new scaling variable," *Physical Review D*, Vol. 26, No. 5, 1982, pp. 1179-1182.
[3] Norbury, John W., "Parameterizations of Inclusive Cross Sections for Kaon, Proton, and Antiproton Production in Proton-Proton Collisions," *The Astrophysical Journal Supplemental Series*, No. 182, 2009, pp. 120-126.
[4] Ouellette, Jennifer, "Smidgen of Antimatter Surrounds Earth," *Discovery News*, Discovery Channel, August 2011, [http://news.discovery.com/space/pamela-spots-a-smidgen-of-antimatter-110811.html. Accessed 7/16/12]
[5] Wu, J., "Measurements of cosmic-ray antiprotons with PAMELA," *ASTRA*, 7, 2011, pp. 225-228.
[6] Shibata, T., Futo, Y., and Sekiguchi, S., "Antiprotons and Cosmic-Ray Propagation in the Galaxy," *The Astrophysical Journal*, No. 678, 2008, pp. 907-921.