Large-scale simulations of antihelium production in cosmic-ray interactions

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Abstract

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The possibility of antihelium production in interaction of cosmic rays with the interstellar gas is studied using large-scale Monte Carlo simulations. For this purpose, an energy-dependent coalescence mechanism developed previously is extended to estimate the production of light antinuclei (antideuteron and antihelium). The uncertainty in the coalescence parameter and its effect on the expected antiparticle flux is also investigated.

The simulated background antihelium fluxes are found to be lower than the fluxes predicted by simplified models using numerical scaling techniques.

Background

- Antinuclei are a potential breakthrough approach for dark matter searches.
- Dark matter induced antinuclei fluxes are expected to exceed the astrophysical background by three orders of magnitude in the low kinetic energy region (1-10 GeV).
- The space-based AMS-02 experiment recently reported several antihelium candidates.
- Naively, large number of antideuterons should be observable as well.
- However, thus far, no strong antideuteron candidates have been reported.

Simple Coalescence Model

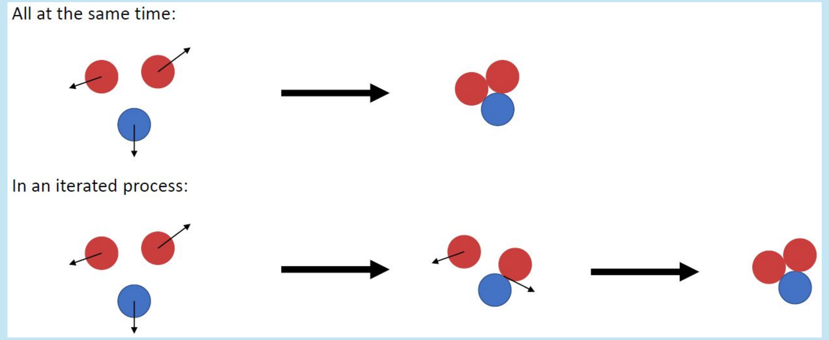
- Light antinuclei production in hadronic interactions is poorly understood.
- The simple coalescence model is overly simplistic.

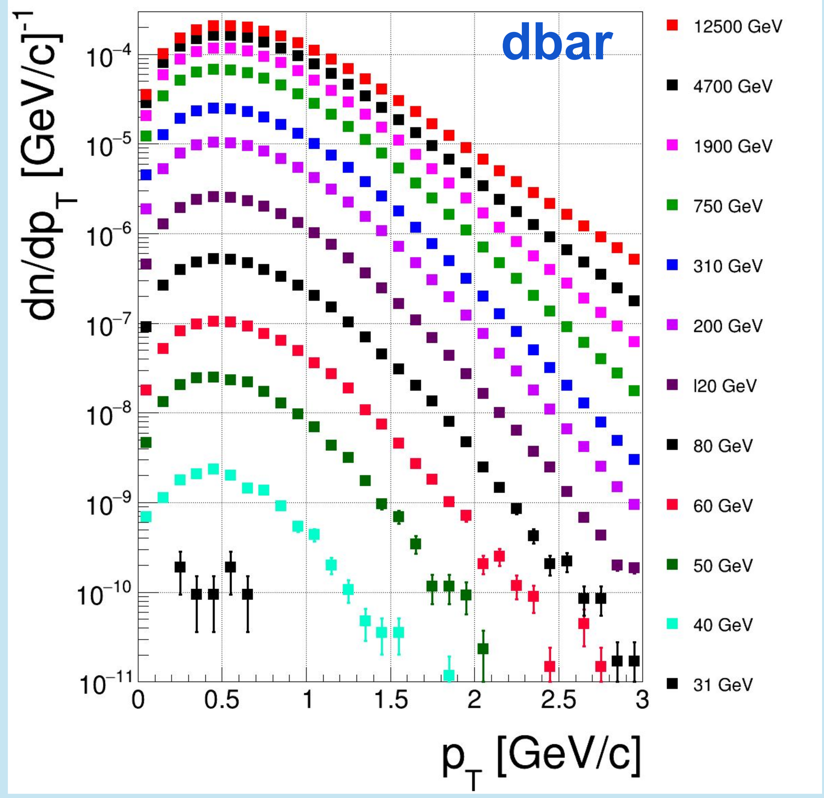
$$\gamma_d \frac{\mathrm{d}^3 N_{\bar{d}}}{\mathrm{d}p_{\bar{d}}^3} = \frac{4\pi}{3} p_0^3 \left(\gamma_p \frac{\mathrm{d}^3 N_{\bar{p}}}{\mathrm{d}p_{\bar{p}}^3}\right)\left(\gamma_n \frac{\mathrm{d}^3 N_{\bar{n}}}{\mathrm{d}p_{\bar{n}}^3}\right)$$

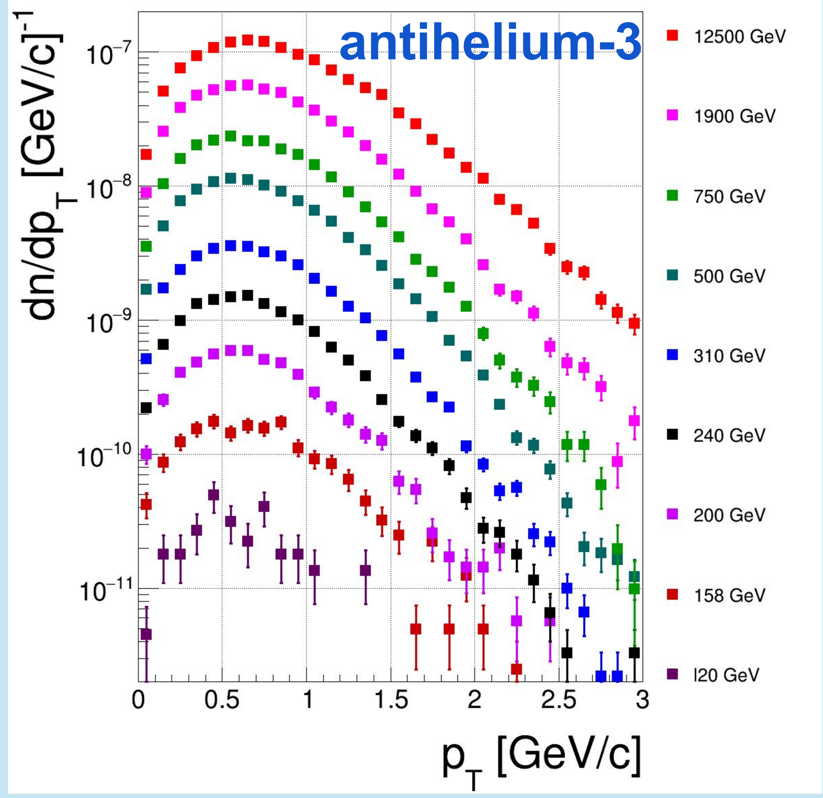
- MC hadronic event generators are used to take into account the hadronic physics (energy and momentum conservation, angular correlations, event topography, antiproton-antineutron production asymmetry, etc.).
- EPOS-LHC was used for this study as it showed best consistency with antiproton production data.
- Typical hadronic generators do not produce (anti)deuterons.
- An **event-by-event coalescence model afterburner** is used to apply the coalescence condition to all (anti)nucleon pairs on a per-event basis.

Multi-particle coalescence

- Extend the coalescence mechanism of two-particle (anti)nuclei to estimate the production of larger (anti)nuclei.
- Two mechanisms were implemented:
  - Simultaneous coalescence
  - Iterated coalescence
- 30 trillion p-p collisions simulated.
- 6000 years of single-CPU time.

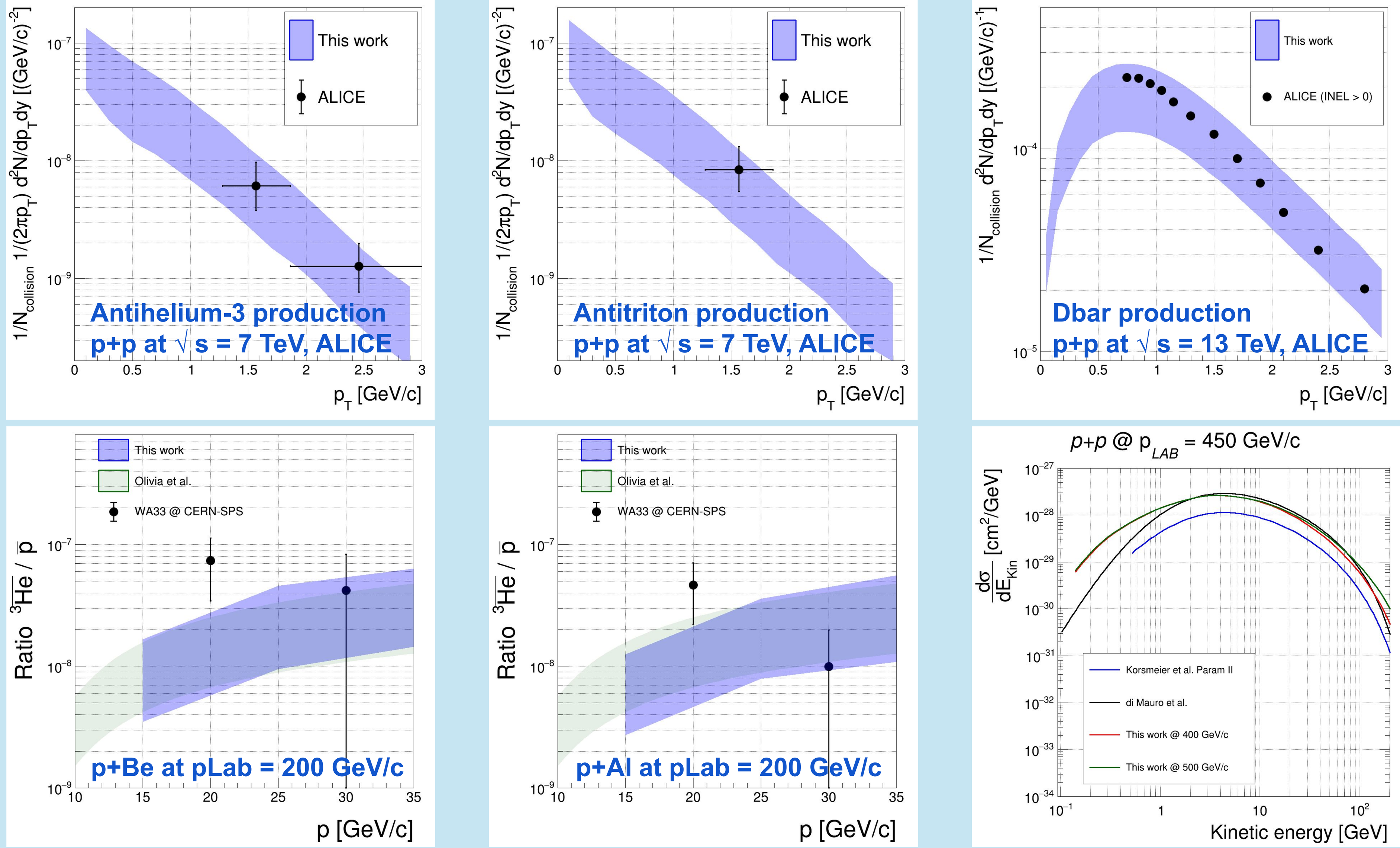






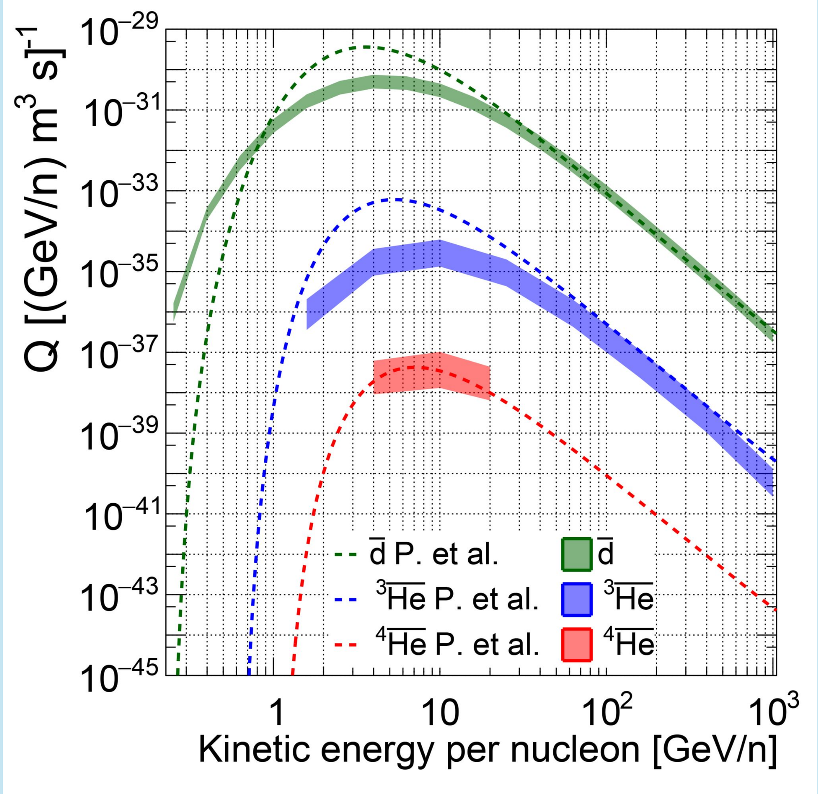
Validation of the model

The model agrees with available experimental data within the uncertainties.

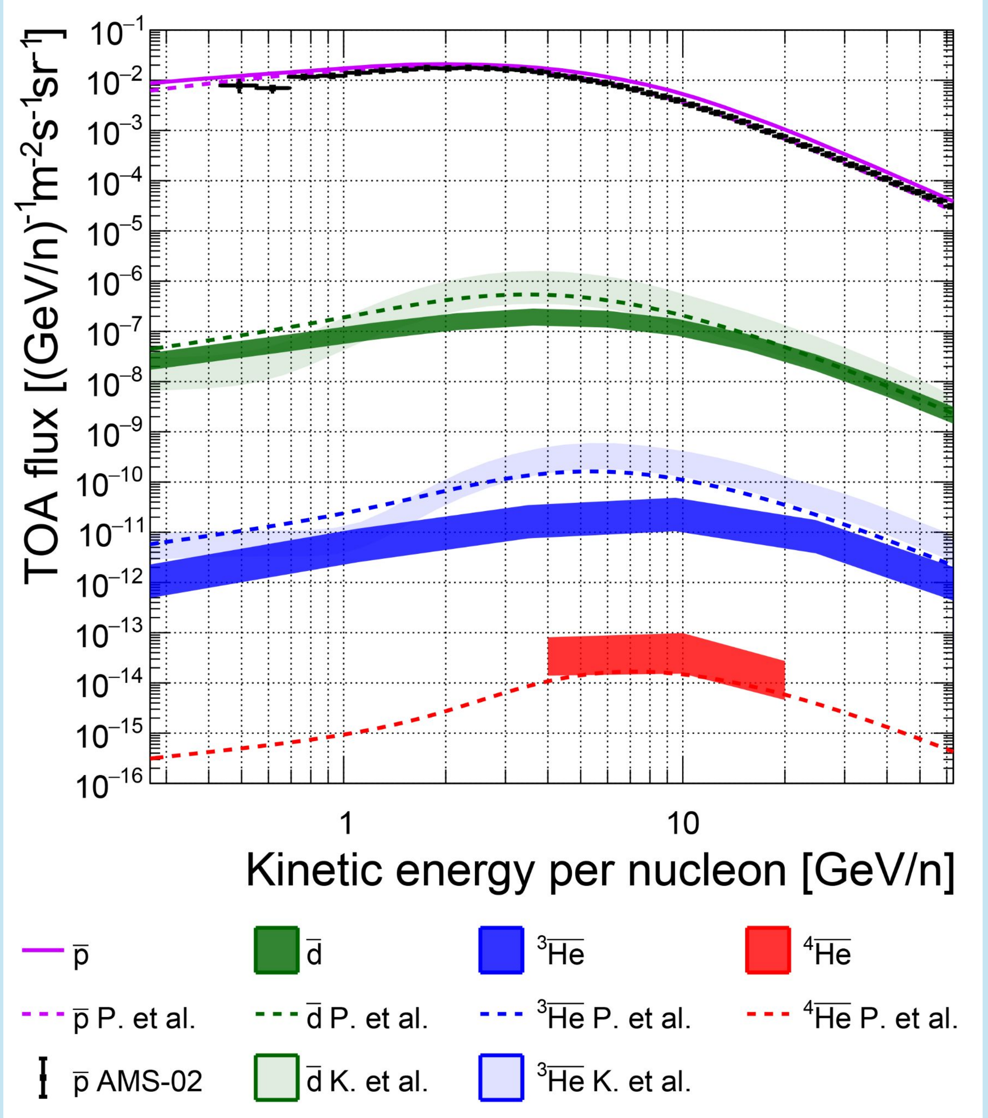


Propagation in the Galaxy

- Galactic propagation software by Poulin et al. (Phys. Rev. D 99, 023016) was used with the MED propagation model.
- Secondary antinuclei source terms and final top-of-atmosphere (TOA) fluxes are shown. The uncertainty bands represent the uncertainty in the coalescence parameter.
- Comparisons are shown with Poulin et al. (Phys. Rev. D 99, 023016) and Korsmeier et al. (Phys. Rev. D 97, 103011).



First-time antihelium-4 differential cross sections calculated using event-by-event coalescence!



Conclusions

- A multiparticle coalescence model was developed to simulate the interaction of cosmic rays with the ISM.
- The antinuclei were propagated to predict the TOA secondary fluxes, and compared to previous studies which use numerical scaling techniques to estimate the light antinuclei production cross sections.
- The coalescence model predicts about an order-of-magnitude lower antideuteron and antihelium fluxes than the numerical scaling models.

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