Coalescence afterburner for antinuclei production in hadronic collisions with input from PYTHIA8

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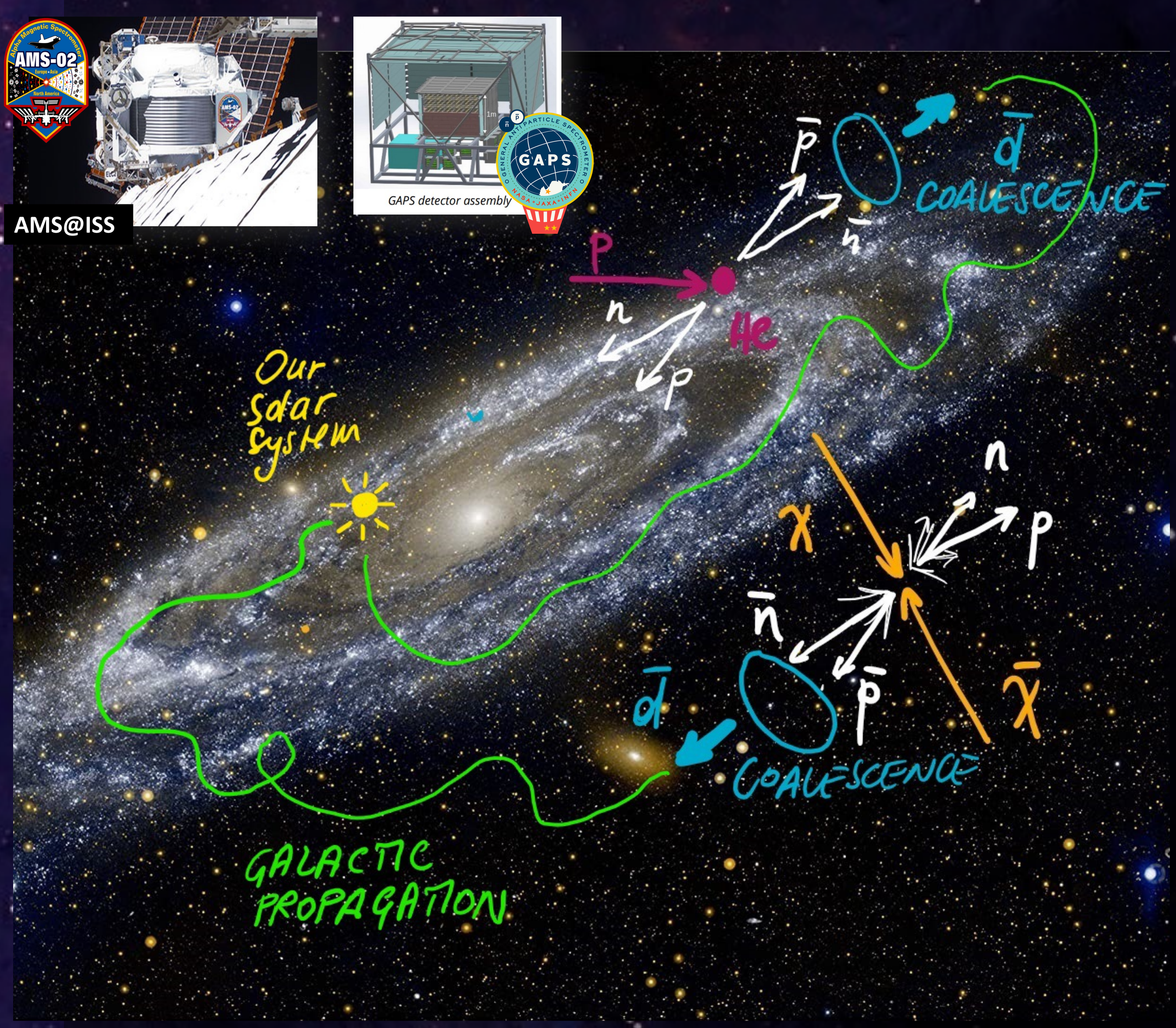
1. Cosmic antinuclei as smoking guns for dark matter



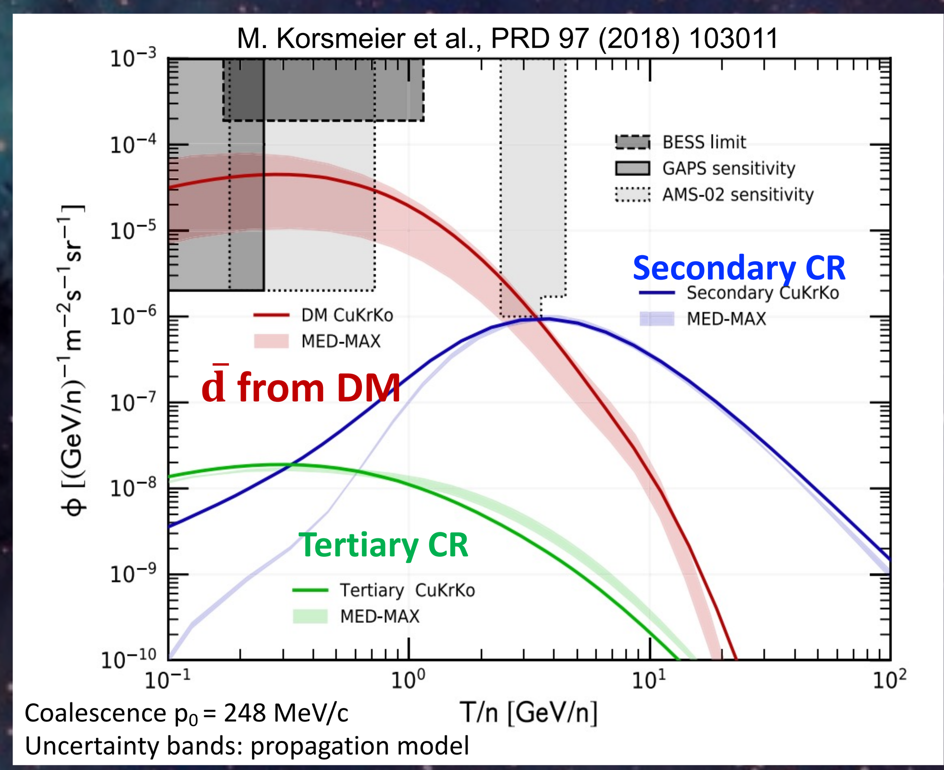
Indirect searches for dark matter with space-based experiments[1] look for Standard Model particles (e.g. e^+, $\bar{p}$) coming from the annihilation of dark matter WIMPs in the Galactic halo.

The detection of cosmic antideuterons ($\bar{d}$) and antihelium nuclei ($^3\overline{He}$, $^4\overline{He}$) is a promising smoking gun signature[2] because of the low background coming from secondary cosmic rays (CR), i.e. from hadronic interactions of primary CR with the interstellar matter (pp, p-He...) in the Galaxy.

One key ingredient for the prediction of signal and background rates is the modelling of the formation mechanism[3] of antimatter clusters.

→ Antinuclei formation via coalescence of antinucleons, constrained by measurements at the LHC.

→ Implementation of an afterburner to to produce antideuterons using PYTHIA8.3 event generator input



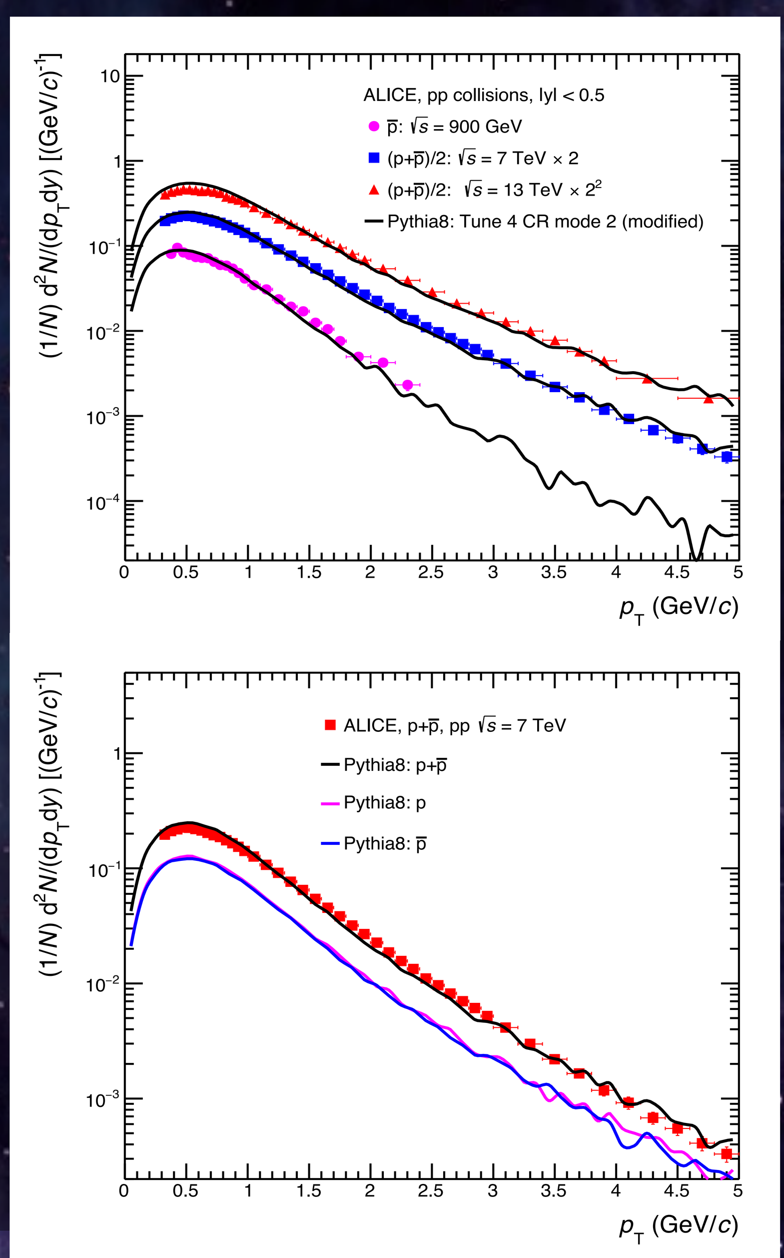
2. From antinucleons to antinuclei

2.1 Antinucleons from PYTHIA8.3 tuned to LHC data

PYTHIA8.3[4] is tuned to reproduce the p_T distributions of p and $\bar{p}$ measured by ALICE in inelastic pp collisions at LHC energies[5,6].

This choice is driven by the availability of precise and copious antideuteron data from ALICE, not available at the energies mostly relevant for cosmic rays, $\sqrt{s}$ ~ 10-25 GeV.

In PYTHIA, p ($\bar{p}$) and n ($\bar{n}$) are produced in the same amount and with the same p_T-distributions.



2.2 Coalescence based on state-of-the-art Wigner function approach

The formation of a $\bar{d}$ by coalescence is the result of final state interactions[7,8] between a $\bar{p}$ and a $\bar{n}$.

The coalescence probability is given by the overlap of the nucleon and the nucleon wave functions and depends on

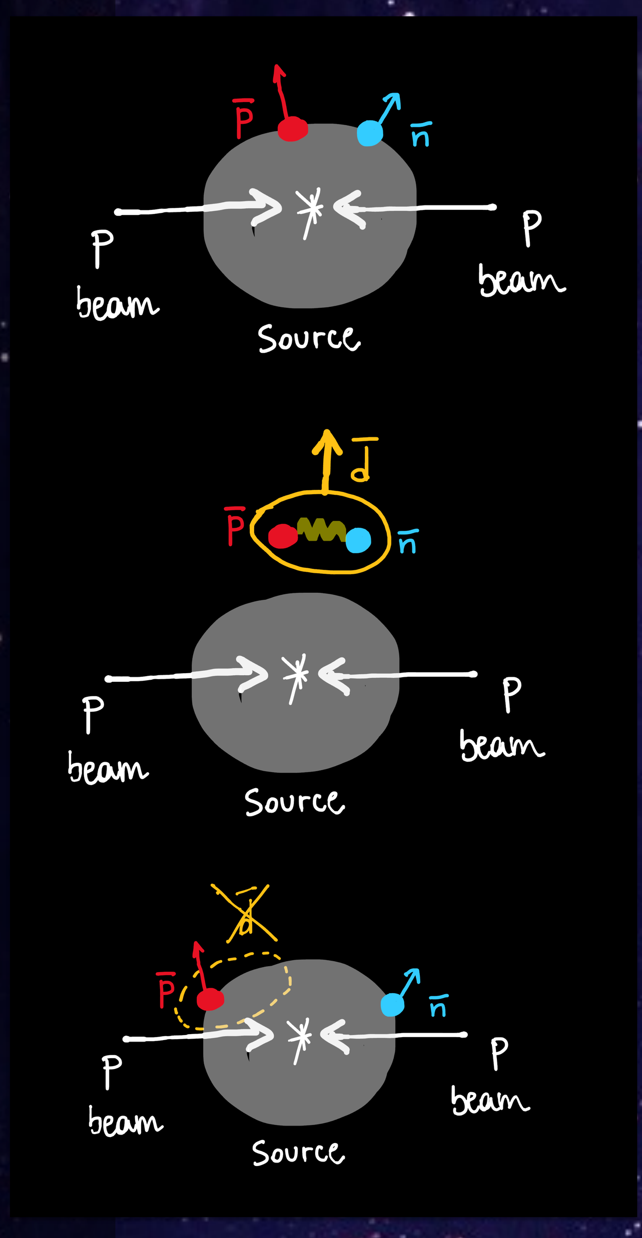
- the momentum
- the size of the nucleon source
- the nucleus wavefunction

We compute this probability, w, event by event and for each possible ($\bar{p}$, $\bar{n}$) pair following the approach in [9]

E.g. For a $\bar{d}$ single-Gaussian wf.

$$w = 3\left(\frac{d^2}{d^2+4\sigma^2}\right)^{3/2} e^{-q^2d^2}$$

$q = |\vec{p_n} - \vec{p_p}|/2$,
d = RMS charge radius of $\bar{d}$ = 3.2 fm
σ = source size (fixed) = 0.84 fm (Realistic? Unmeasured!)

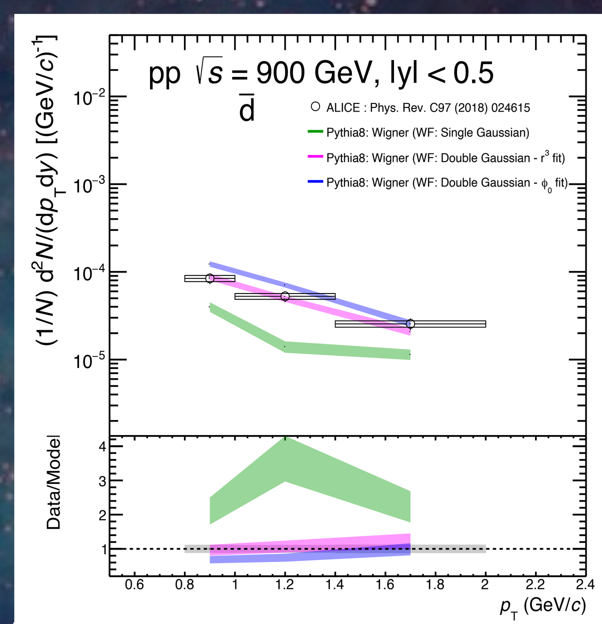


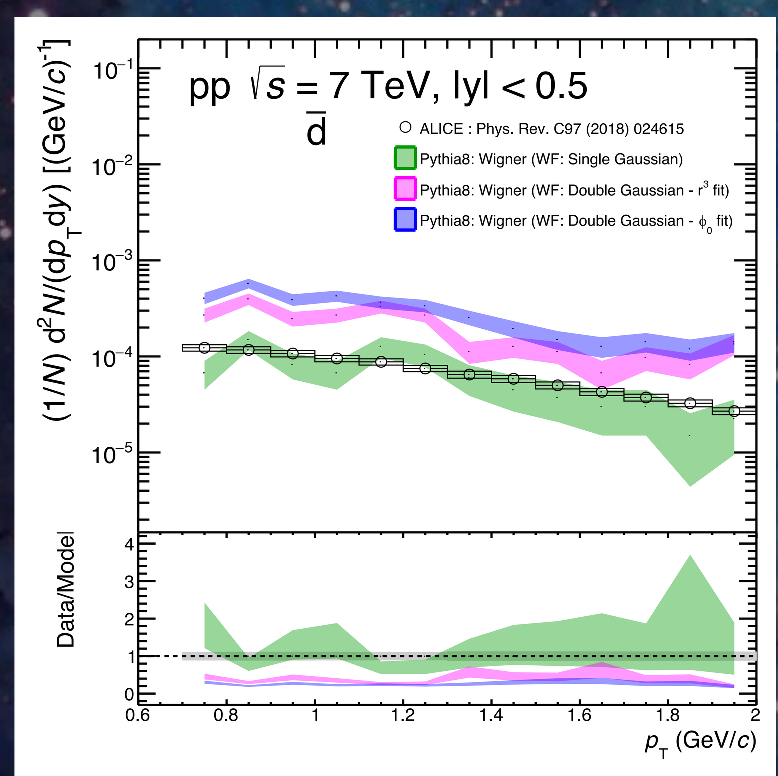
3. Results from the afterburner

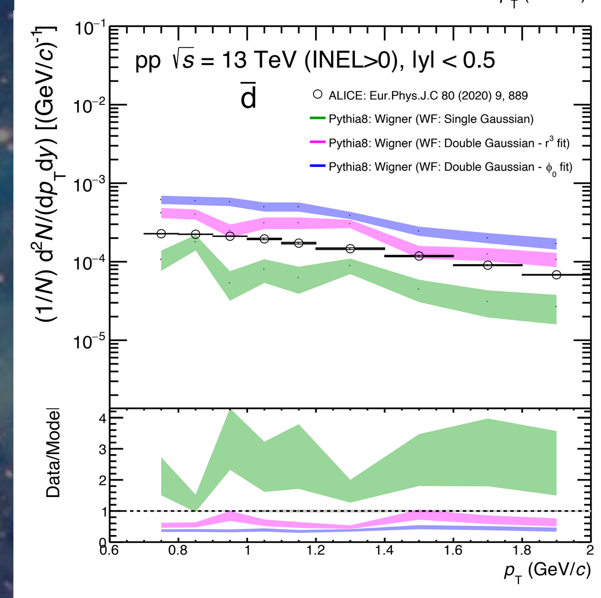
3.1 Antideuterons from prompt nucleons

The antideuteron spectra are obtained for various $\sqrt{s}$ and compared to data:

- p_T shape described
- sensitivity to different $\bar{d}$ wave functions (bands: single-Gaussian, double-Gaussian fitted to realistic Hulthén wave-function[9])





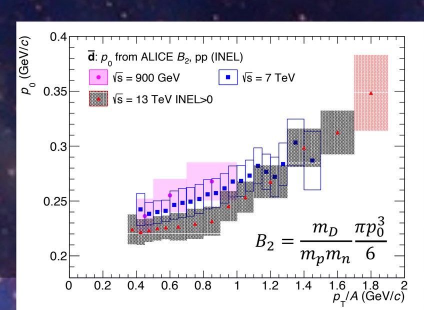


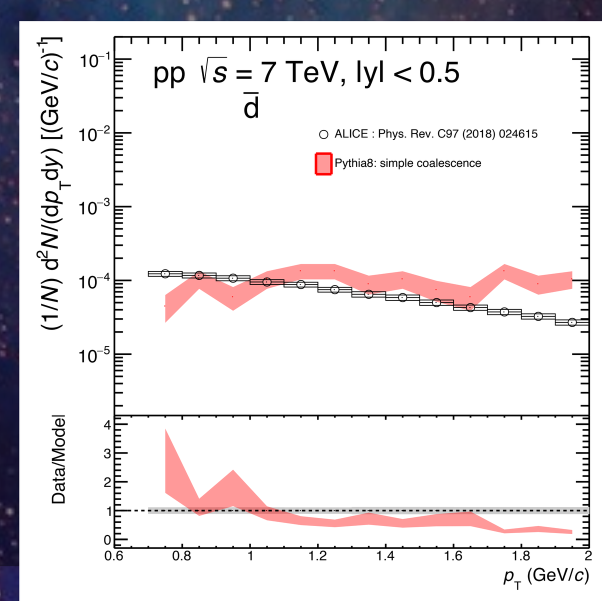
3.2 Comparison to "simple coalescence"

The Wigner approach results in a more accurate description of the p_T spectrum shape than obtained with the simplest coalescence condition

$$|\vec{p_n} - \vec{p_p}| < p_0$$

with p_0 extracted from ALICE data[5].





4. Conclusions and next steps

The current implementation, for prompt antinucleons, is promising and the development will continue to address

- Coalescence from non-prompt (resonances) antinucleons
- Source size from generator and/or constrained on data
- Predictions of $\bar{d}$ yield at low collision energy

References

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CosmicAntiNuclei

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