Enhanced anti-deuteron Dark Matter signal and the implications of PAMELA

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The DM abundance is naturally produced in thermal freeze-out if it has weak interaction and the mass is of O(TeV). This can be tested by looking at the cosmic rays for DM annihilation (decay).

A particularly sensitive channel is that of anti-particles: positrons (e^+), anti-protons ($\bar{\mathrm{p}}$) and anti-deuterium ($\bar{\mathrm{d}}$)

The first two have been probed by various experiments like PAMELA, Fermi and ATIC and the search for $\bar{\mathrm{d}}$ has been mostly geared towards sub-GeV searches

Looking at various possible DM final states the PAMELA, FERMI, ATIC etc data constrains DM to be either decaying leptonically at low masses or it should be quite massive to allow for W,Z,h and quark final states as otherwise we would be seeing contributions to the $\bar{\mathrm{p}}$ spectrum.

Coalescence

$\bar{\mathrm{d}}$ is formed in cosmic rays via $\bar{\mathrm{p}}\ \bar{\mathrm{n}} \rightarrow \bar{\mathrm{d}}\ \gamma$ if $\bar{\mathrm{p}}$ and $\bar{\mathrm{n}}$ are produced with a momentum difference less than $p_0 < 160$ MeV

Spherical approximation

In the usual assumption of spherical symmetry and no correlation in $\bar{\mathrm{p}}\ \bar{\mathrm{n}}$ distribution and writing it in terms of adimensional $x = T/M$ the yield is:

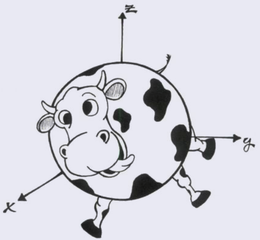
$$\frac{dN_d}{dx_d} = \frac{p_0^3}{3M^2 m_p} \frac{1}{\sqrt{x_d^2 + 4m_p x_d/M}} \frac{dN_p}{dx_p} \frac{dN_n}{dx_n},$$

which is explicitly suppressed by $1/M^2$ for large DM mass M. This however is qualitatively wrong.

Spherical approximation

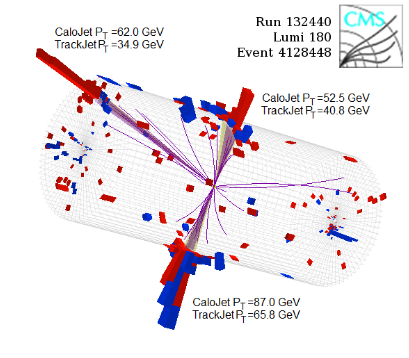
It is assumed that $\bar{\mathrm{p}}$ and $\bar{\mathrm{n}}$ distributions are uncorrelated and hence:

$$\frac{dN_p dN_n}{d^3k_p\, d^3k_n} = \frac{dN_p}{d^3k_p} \cdot \frac{dN_n}{d^3k_n}$$

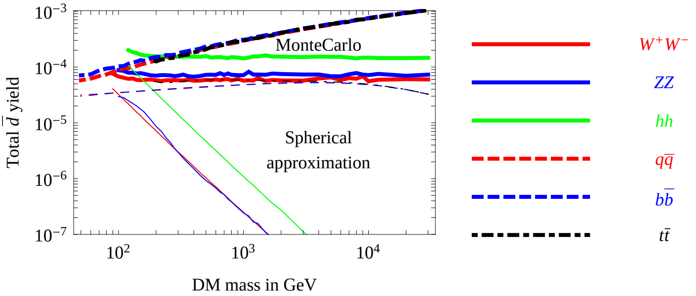


Jet structure

In real-life particle collisions or decay produce jet-like particle structures:

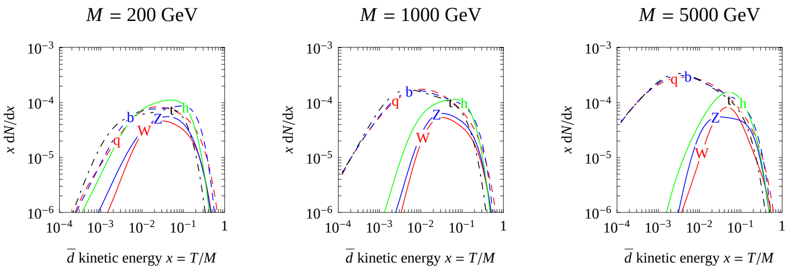


As the Jet structure actually enhances the probability of a $\bar{\mathrm{p}}$ and $\bar{\mathrm{n}}$ to have comparable momenta the more boosted it is, then there is no supression with increasing mass as can be seen in the following plot:



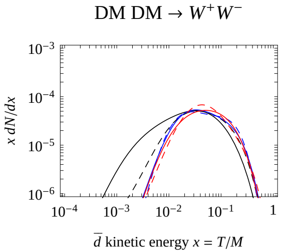
Thin lines represent spherical approximation, thick lines the Monte Carlo simulated results. In all cases the enhancement is orders of magnitude.

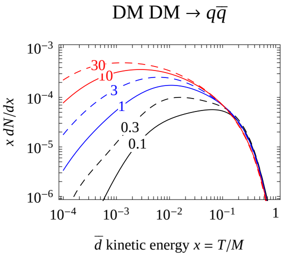
The MC results for $\bar{\mathrm{d}}$ spectra $x \cdot dN/dx$ produced per DM annihilation channel for three masses.



As can be seen the yield doesn't depend really on the mass of DM.

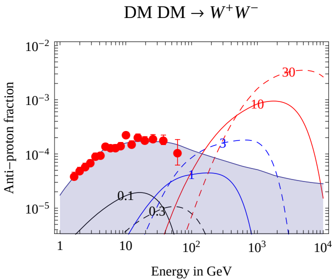
There are qualitatively three different cases for the final state: (i) W, Z, h (ii) quarks or (iii) leptons. The last doesn't give $\bar{\mathrm{d}}$ so the yield is zero. For the other two the dependence on mass is different:

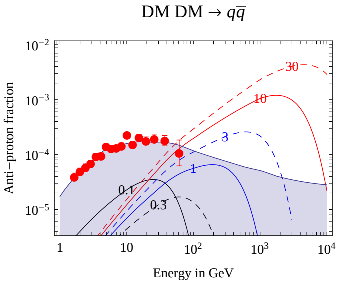




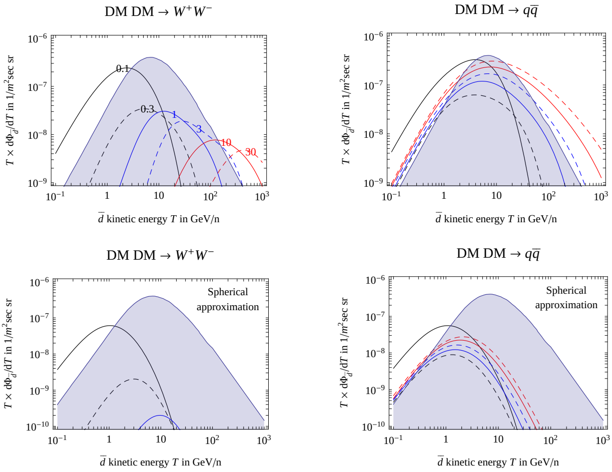
As can be seen there is no big dependence on DM mass for the first case and the spectrum actually increases in case of quarks in final state with the mass of DM allowing for better possibilities for detection.

The masspoints we have considered are in fact in agreement with PAMELA results of $\bar{p}$ spectra being in agreement with expected astrophysical background:





After confirming that our MC simulation represents the cosmic p p and $p\,\bar{p}$ collisions as background closely we have propagated the spectra using various profiles.
The following are the results comparing our results to that of the previous results:



Conclusions

- Spherical approximation overestimates low mass DM yields and underestimates by orders of magnitude higher mass $\bar{\mathrm{d}}$ yields
- Jet structure enhances the $\bar{\mathrm{d}}$ yield by many orders of magnitude in the case of higher masses thanks to Lorentz boost
- Our results are in agreement with PAMELA and other experiments and show a significant boost for possible DM detection
- In addition we also show that looking at above GeV $\bar{\mathrm{d}}$ spectra may open new avenues for DM detection, especially at high mass
- For further details, please refer to:
  Kadastik, M., Raidal, M., Strumia, A., "Enhanced anti-deuteron Dark Matter signal and the implications of PAMELA", Phys.Lett.B683:248-254,2010, arXiv:0908.1578