Reconciling relic density with indirect signals with Sommerfeld enhancement

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- Thermal relic density

$$\Omega h^2 = 0.1 \frac{(3 \times 10^{-26} cm^3 sec^{-1})}{\langle \sigma v \rangle}$$

- From WMAP observations $\Omega h^2 = 0.1123 \pm 0.0105(3\sigma)$.

- To get the Pamela positron flux we need an annihilation cross section $\chi^0 \chi^0 \to e^+ e^-$ of the order of $(\sigma v) \sim 10^{-22} cm^3 sec^{-1}$.

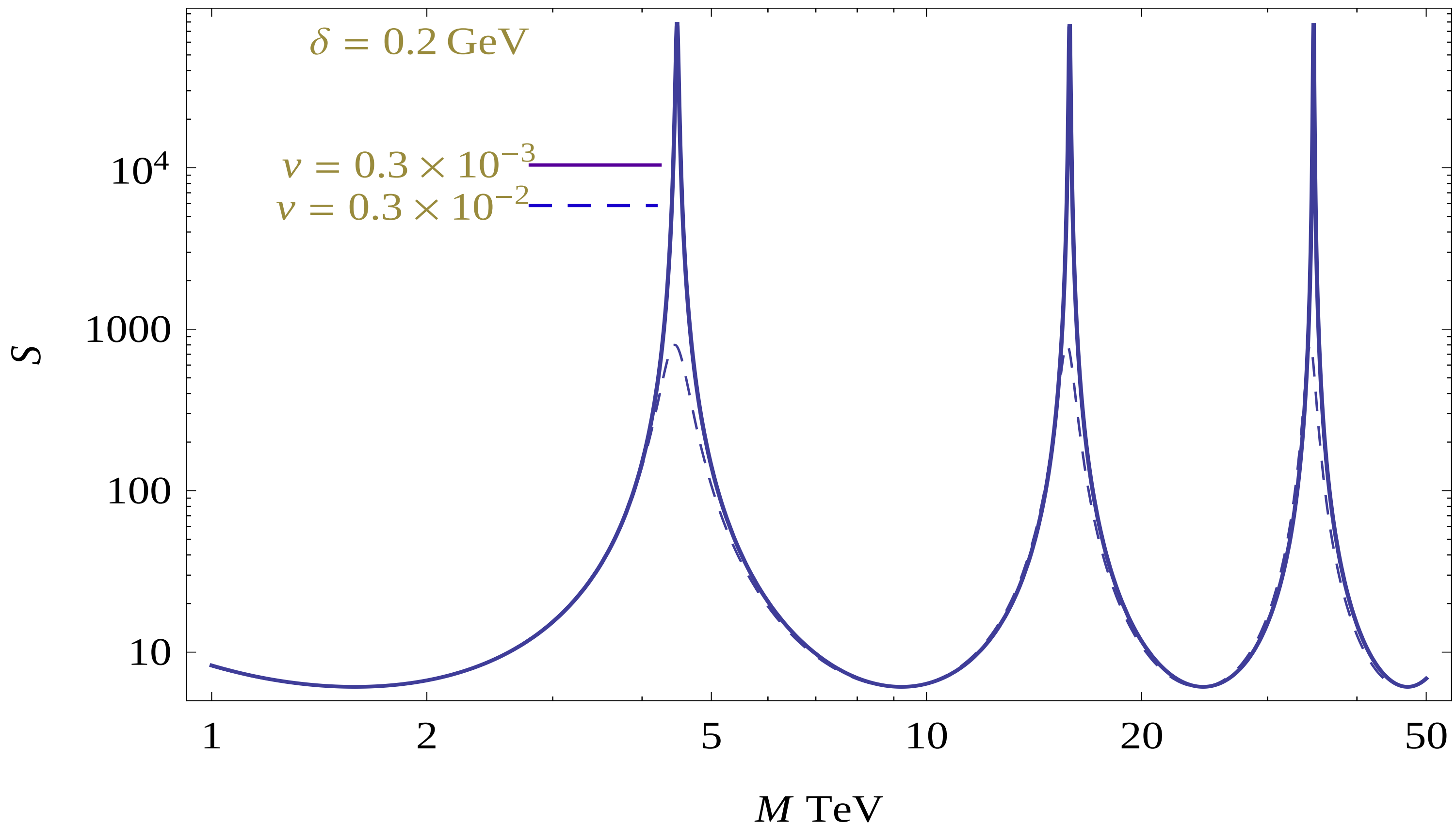
Sommerfeld enhancement of annihilation cross section

The Sommerfeld enhancement factor is

$$S = \frac{(\sigma v)}{(\sigma v)_0} = \frac{|\psi(0)|^2}{|\psi^0|^2}$$

Where the radial wave function obeys the Schrodinger equation

$$-\frac{1}{M}\frac{d^2\psi}{dr^2} + \left(\frac{l(l+1)}{Mr^2} - \frac{\alpha}{r}e^{-m_\phi r}\right)\psi = Mv^2\psi$$



Sommerfeld enhancement factor of heavy wino annihilation cross section due to W exchange as a function of DM mass at different velocities.

Thermal relic density

The thermal averaged annihilation cross section $\langle \sigma v \rangle (x)$ determines the relic density n_χ through the Boltzman equation

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle \sigma v \rangle \, (n_\chi^2 - n_{\chi_{eq}}^2) \tag{1}$$

Thermal averaged cross section at,

$$\langle \sigma v \rangle = \frac{x^{3/2}}{2\sqrt{\pi}} \int_0^\infty dv \, (\sigma v) \, S(v, M) \, v^2 \, e^{-xv^2/4} \tag{2}$$

At freeze-out $v \sim T/M \sim 10^{-1}$ and $S \sim 1$. So Sommerfeld enhancement has very little effect on relic density.

Kinetic decoupling:

Scattering with radiation bath keeps Winos in thermal equilibrium

$$f\chi \leftrightarrow f'\chi^+$$

Chargino-neutralino mass difference is $\Delta M = 200MeV$.

This interaction is not energetically possible below $T \sim 200MeV$, this is the KD temperature.

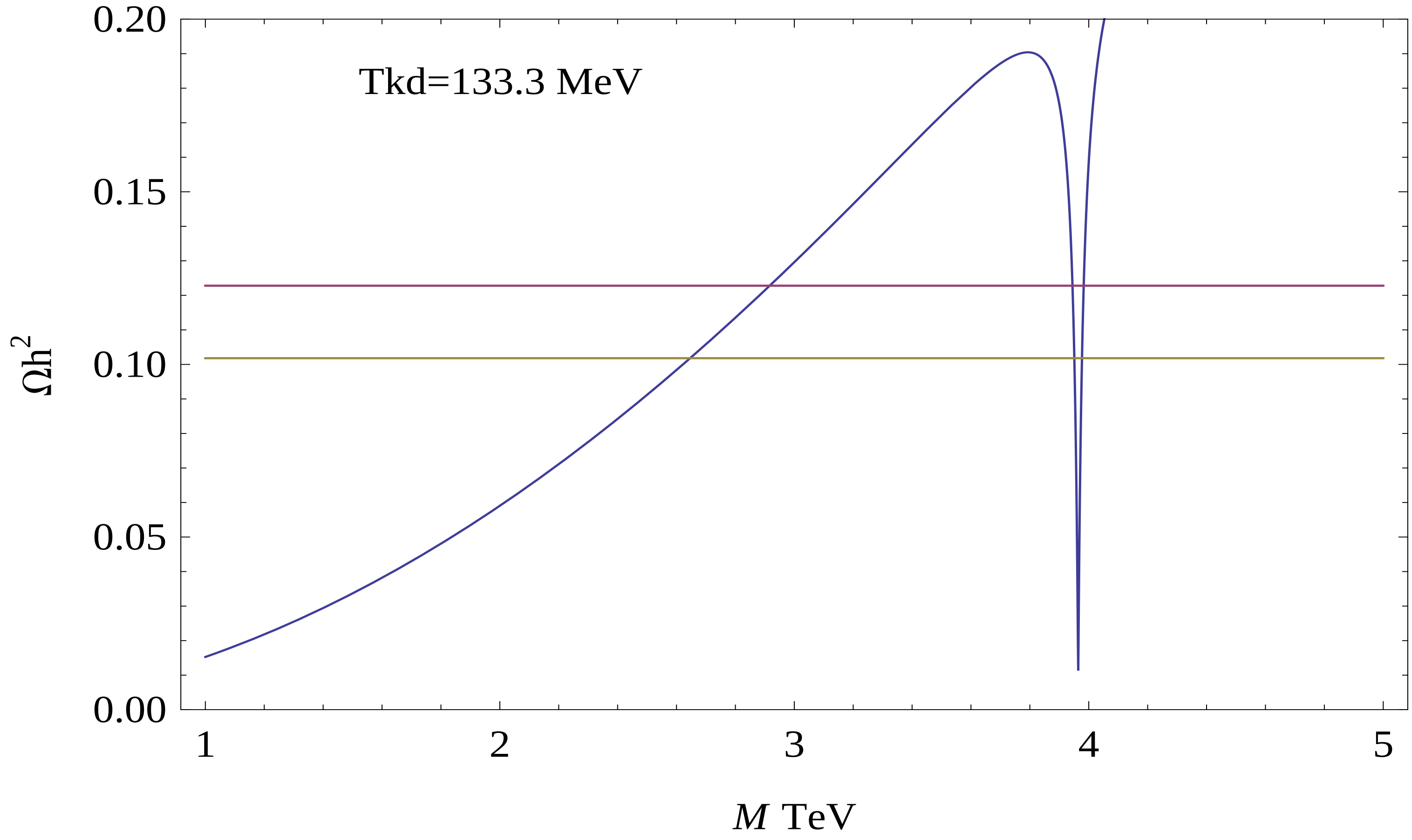
Since Wimps are Non-reletivistic their velocity goes down as

$$v \propto 1/a$$

The temperature of the Wimp distribution goes as

$$T = (1/2)Mv^2 \propto 1/a^2$$

Radiation temperature falls as $1/a$. Below KD temperature Wimps cool rapidly. This leads to large annhilation after KD due to the Sommerfeld factor which grows at low velocities.

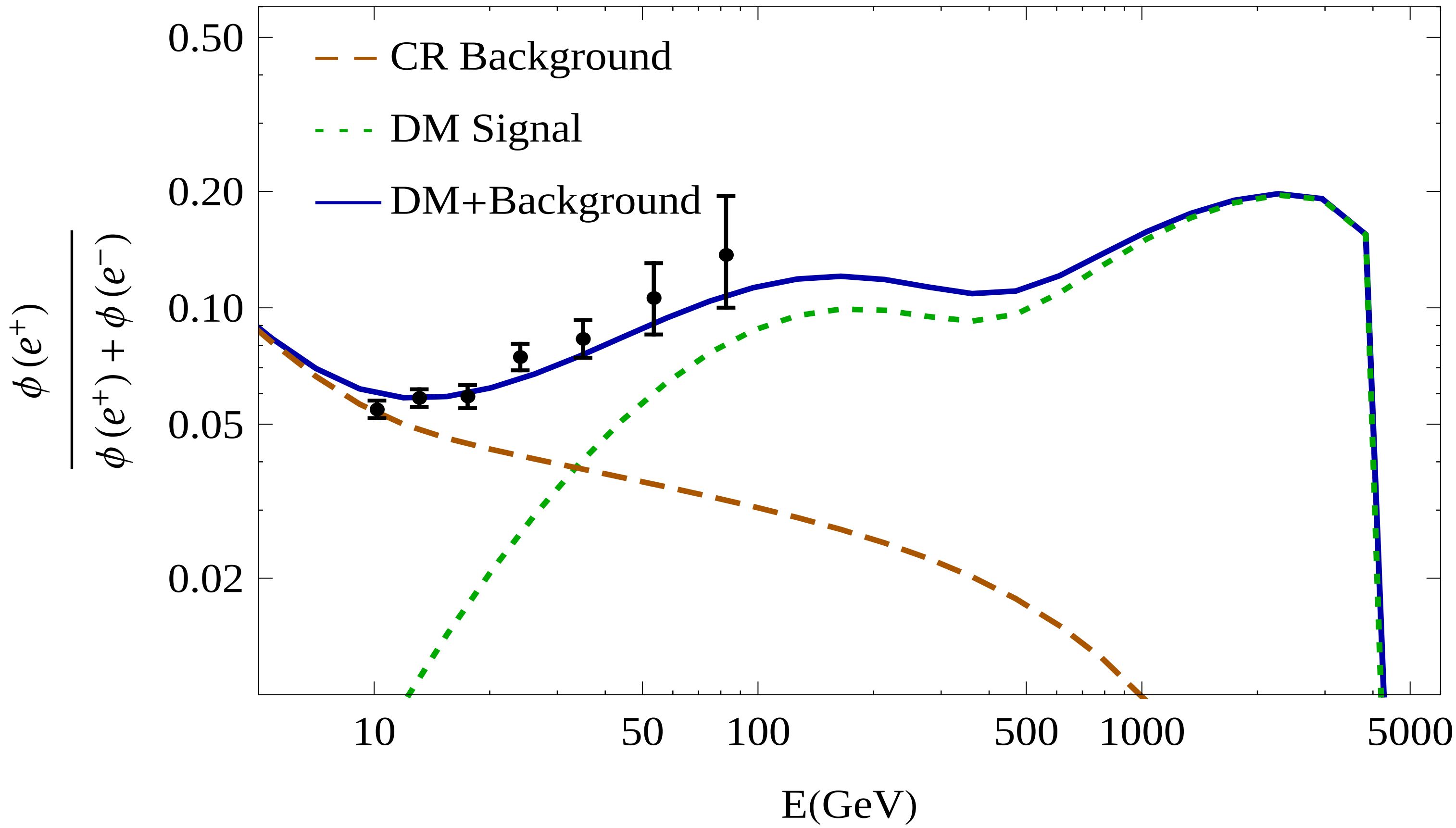


Thermal relic density as function of DM mass. The dip at Sommerfeld peak value is due to enhanced annihilation after kinetic decoupling.

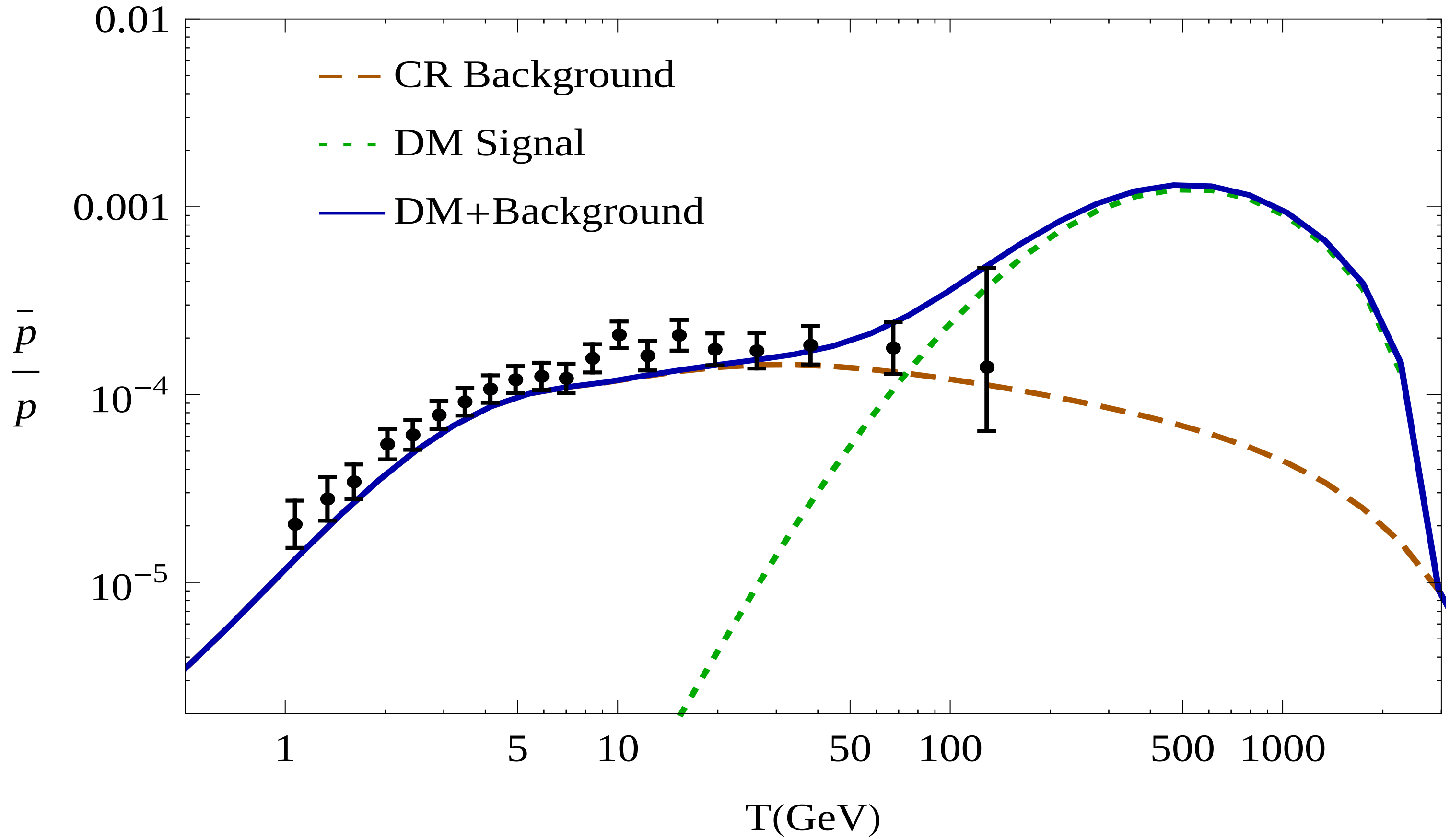
To fit the data from Pamela and FermiLat we choose wino DM with mass at the Sommerfeld peak $M = 4.5$TeV.

The primary annihilation channel is $\chi\chi \rightarrow W^+ W^-$.

We get large positron flux from decays of W. The anti-proton peak is at higher energies. The gamma rays are consistent with observations from FermiLat and HESS.



Fit to Pamela [2] positron fraction wino mass M=4.5 TeV and Sommerfeld enhanced cross section $S\sigma v = 10^{-22} cm^3/sec$.



Fit to Pamela [3] antiproton data with wino mass M=4.5 TeV and Sommerfeld enhanced cross section $S\sigma v = 10^{-22} cm^3/sec$.

Conclusions: A 4.5 TeV wino model can simultaneously satisfy the relic density observation from WMAP and give large positron signal observed by Pamela. The antiproton signal is consistent with Pamela observations and gamma rays are consistent with observations from FermiLat and HESS.

References:

[1] S. Mohanty, S. Rao and D. P. Roy, "Reconciling heavy wino dark matter model with the relic density and PAMELA data using Sommerfeld effect," arXiv:1009.5058 [hep-ph].

[2] O. Adriani *et al.* [PAMELA Collaboration], "An anomalous positron abundance in cosmic rays with energies 1.5-100 GeV," Nature **458**, 607 (2009) [arXiv:0810.4995 [astro-ph]].

[3] O. Adriani *et al.* [PAMELA Collaboration], "PAMELA results on the cosmic-ray antiproton flux from 60 MeV to 180 GeV in kinetic energy," Phys. Rev. Lett. **105**, 121101 (2010) [arXiv:1007.0821 [astro-ph.HE]].

Thank You