Implications of the PAMELA & ATIC excesses on Dark Matter properties

1) The data
2) DM annihilations?
3) photon and $\nu$ constraints
4) DM decays?

Alessandro Strumia

Indirect signals of Dark Matter

DM DM annihilations in our galaxy might give detectable $\gamma$, $e^+$, $\bar{p}$, $\bar{d}$. 
The galactic DM density profile

DM velocity: $\beta \approx 10^{-3}$. DM is spherically distributed with uncertain profile:

$$\rho(r) = \rho_\odot \left[ \frac{r_\odot}{r} \right]^\gamma \left[ \frac{1 + (r_\odot/r_s)\alpha}{1 + (r/r_s)\alpha} \right]^{(\beta-\gamma)/\alpha}$$

$r_\odot = 8.5$ kpc is our distance from the Galactic Center, $\rho_\odot \equiv \rho(r_\odot) \approx 0.3$ GeV/cm$^3$,

<table>
<thead>
<tr>
<th>DM halo model</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>$r_s$ in kpc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isothermal ‘isoT’</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Navarro, Frenk, White ‘NFW’</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Moore ‘Moore’</td>
<td>1</td>
<td>3</td>
<td>1.16</td>
<td>30</td>
</tr>
</tbody>
</table>

DM is like capitalism according to Marx: a gravitational system has no ground state so everything is (slowly) collapsing to a point and maybe $\rho(r \to 0) = \infty$. 

![Graph showing DM density profile](image)
DM DM signal boosted by sub-halos?

$N$-body simulations suggest that DM might clump in subhalos:

Annihilation rate $\propto \int dV \rho^2$ increased by a boost factor $B = 1 \leftrightarrow 100 \sim a few$

Simulations neglect normal matter, that locally is comparable to DM.
Propagation of $e^\pm$ in the galaxy

$\Phi_{e^+} = v_{e^+} f / 4\pi$ where $f = dN/dV dE$ obeys:

$$-K(E) \cdot \nabla^2 f - \frac{\partial}{\partial E} (b(E) f) = Q.$$

- DM DM injection term: $Q = \frac{1}{2} \left( \frac{\rho}{M} \right)^2 \langle \sigma v \rangle \frac{dN_{e^+}}{dE}$.
- Diffusion coefficient: $K(E) = K_0 (E / \text{GeV})^\delta$. ($K \sim R_{\text{Larmor}} = E / eB$).
- Energy loss: $b(E) = E^2 / \text{GeV} / \tau_E$ with $\tau_E = 10^{16} \text{s}$.
- Boundary: $f$ vanishes on a cylinder with radius $R = 20 \text{kpc}$ and height $2L$.

<table>
<thead>
<tr>
<th>Propagation model</th>
<th>$\delta$</th>
<th>$K_0$ in $\text{kpc}^2 / \text{Myr}$</th>
<th>$L$ in kpc</th>
<th>$V_{\text{conv}}$ in km/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>min</td>
<td>0.85</td>
<td>0.0016</td>
<td>1</td>
<td>13.5</td>
</tr>
<tr>
<td>med</td>
<td>0.70</td>
<td>0.0112</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>max</td>
<td>0.46</td>
<td>0.0765</td>
<td>15</td>
<td>5</td>
</tr>
</tbody>
</table>
Do $e^\pm$ reach us from the Galactic Center?

Maybe, if $r_\odot \lesssim L, \lambda_D$ where $\lambda_D$ is the diffusion length from energy $E'$ to $E$:

$$\lambda_D(E', E) = \sqrt{4K_0\tau E \left[ \frac{(E/\text{GeV})^{\delta-1} - (E'/\text{GeV})^{\delta-1}}{\delta - 1} \right]}$$

Semi-analytic solution: $\Phi_{e^+}(E) = B\frac{v_{e^+}}{4\pi} \frac{\tau E}{E^2} \int_E^{M_{DM}} dE' Q(E') \cdot I(\lambda_D(E', E))$ with
1

The data
ABC of charged cosmic rays

$e^\pm$, $p^\pm$, He, B, C... Their directions are randomized by galactic magnetic fields $B \sim \mu G$. The info is in their energy spectra.

We hope to see DM annihilation products as excesses in the rarer $e^+$ and $\bar{p}$.

Experimentalists need to bring above the atmosphere (with balloons or satellites) a spectrometer and/or calorimeter, able of rejecting $e^-$ and $p$.

This is difficult above 100 GeV, also because CR fluxes decrease as $\sim E^{-3}$.

Energy spectra below a few GeV are $\sim$useless, because affected by solar activity.
$\bar{p}/p$: PAMELA

Consistent with background

Future: PAMELA, AMS
PAMELA is a spectrometer + calorimeter sent to space. It can discriminate $e^+, e^-, p, \bar{p}, \ldots$ and measure their energies up to (now) 100 GeV. Astrophysical backgrounds should give a positron fraction that decreases with energy. This happens below 10 GeV, where the flux is reduced by the present solar polarity.

**Growing excess above 10 GeV**

The PAMELA excess suggest that it might manifest in other experiments: if $e^+/e^-$ continues to grow, it reaches $e^+ \sim e^-$ around 1 TeV...
These experiments cannot discriminate $e^+/e^-$, but probe higher energy.

Near future: ATIC-4, GLAST/Fermi, PAMELA

ATIC-4 preliminary results: 

FERMI preliminary results: 

PAMELA: $\Phi_{e^-} \propto E^{-3.3}$ today. Precise points of ATIC tell $\Phi_{e^+e^-} \propto E^{-3}$.
Could the excesses be due to systematics?

- **ATIC.** The problem could be **discriminating** $1\ e^{\pm}$ from $1000\ p \rightarrow \pi^0$: MC tested below 200 GeV. The peak is a few points. ATIC-4 enlarged the calorimeter, so that a electromagnetic shower is contained.
- **PPB-BETS.** Very small. **Not cleanly compatible** with ATIC-2 and EC.
- **PAMELA.** Needs to find $1e^+$ among $5000\ p$. Calibrated below 200 GeV. Due to small size, $\sim 50\%$ of the shower is lost laterally.

If the excess is due to DM:

- DM is a WIMP. (A gravitino-like particle is allowed if unstable).
- DM annihilates, so it is not there due to an asymmetry like protons
- DM is a strange WIMP...
... Just a pulsar?

A pulsar is a neutron star with a rotating intense magnetic field. The resulting electric field ionizes and accelerates $e^-$ (and maybe iron) $\rightarrow \gamma \rightarrow e^+e^-$, that are presumably further accelerated by the pulsar wind nebula (Fermi mechanism).

- \( E_{\text{pulsar}} = I\omega^2/2 \), \( \dot{E}_{\text{pulsar}} = -B_{\text{surface}}^2 R^2 \omega^4/6c^3 \) = magnetic dipole radiation.

- The guess is \( \Phi_{e^-} \approx \Phi_{e^+} \propto \epsilon \cdot e^{-E/M}/E_p \) where \( p \approx 2 \) and \( M \) are constants.

Far galactic pulsars can fit PAMELA, but \( M \) is (?) too low \( M \) for ATIC?

Known nearby pulsars (B0656+14, Geminga, ?) can reach a higher \( M \), but would need an unreasonably large fraction \( \epsilon \) of energy that goes into \( e^\pm \): \( \epsilon \sim 0.3 \).

Tests: ● \( \gamma \) (but beamed? pulsar still alive?); ● angular anisotropies (but local \( B \)?) ; ● is the ATIC peak smooth? (but a \( \delta(t) \) pulsar can be sharper than DM)
2

Model-independent theory of DM indirect detection
Model-independent DM annihilations

Indirect signals depend on the DM mass $M$, non-relativistic $\sigma v$, primary BR:

$$\text{DM DM} \rightarrow \begin{cases} W^+W^-, ZZ, Zh, hh & \text{Gauge/higgs sector} \\ e^+e^-, \mu^+\mu^-, \tau^+\tau^- & \text{Leptons} \\ b\bar{b}, t\bar{t}, q\bar{q} & \text{quarks, } q = \{u, d, s, c\} \end{cases}$$

No $\gamma$ because DM is neutral. Direct detection bounds suggest no $Z$.

The energy spectra of the stable final-state particles

$$e^\pm, p^\pm, \text{ the undetectable } (\bar{\nu}_{e,\mu,\tau}, \gamma$$

depend on the polarization of primaries.

The higher-order $\gamma$ spectrum is model-dependent:

$$\gamma = (\text{Brehmstalung/fragmentation}) + (\text{one-loop}) + (3\text{-body})$$
The DM spin

Non-relativistic $s$-wave DM annihilations can be computed in a model-independent way because they are like decays of the two-body $\mathcal{D} = \text{DM DM}$ state.

If DM is a fundamental weakly-interacting particle, its spin can be 0, 1/2 or 1, so the spin of $\mathcal{D}$ can only be 0, 1 or 2

$$1 \otimes 1 = 1, \quad 2 \otimes 2 = 1_{\text{asymm}} \oplus 3_{\text{symm}}, \quad 3 \otimes 3 = 1_{\text{symm}} \oplus 3_{\text{asymm}} \oplus 5_{\text{symm}}$$

So:

- $\mathcal{D}$ can have spin 0 for any DM spin;
- $\mathcal{D}$ can have spin 1 only if DM is a Dirac fermion or a vector.

We will see that this is needed for having large DM DM $\rightarrow f \bar{f}$
DM annihilations into $W, Z$

- The effective interactions

$$\mathcal{D} F_{\mu\nu} \epsilon_{\mu\nu\rho\sigma} F_{\rho\sigma}$$

and

$$\mathcal{D} F_{\mu\nu}^2$$

give vectors with Transverse polarization (with different unobservable helicity correlations), that decay in $f \bar{f}$ with $E = x M$ as:

$$\frac{dN}{d \cos \theta} = \frac{3(1 + \cos^2 \theta)}{8}$$

$$\frac{dN}{dx} = \frac{3(1 - 2x + 3x^2)}{2},$$

- $\mathcal{D} A_\mu^2$ gives Longitudinal vectors (accounting for DM annihilations into Higgs Goldstones), that decay as

$$\frac{dN}{d \cos \theta} = \frac{3(1 - \cos^2 \theta)}{4}$$

$$\frac{dN}{dx} = 6x(1 - x).$$
DM annihilations into the higgs $h$

We can again focus on $\mathcal{D}$, so that the effective interaction $\mathcal{D}h^2$ gives DM annihilations into $hH$. Since they have no spin, there are no polarization issues.

We assume $m_h = 115$ GeV, so $h$ decays mostly into $b\bar{b}$.

DM annihilations into $Zh$ will not be considered, as they are essentially given by the average of the $Z_LZ_L$ and $hh$ channels.
DM annihilations into fermions $f$

- $\mathcal{D}$ can only couple as
  
  \[ \mathcal{D} f_L f_R + \text{h.c.} = \mathcal{D} \bar{\Psi}_f \Psi_f \]

  with $\Psi_f = (f_L, \bar{f}_R)$ in Dirac notation. It means zero helicity on average, and is typically suppressed by $m_f/M$.

- $\mathcal{D}_\mu$ can couple as
  
  \[ \mathcal{D}_\mu [\bar{f}_L \gamma_\mu f_L] = \mathcal{D}_\mu [\bar{\Psi}_f \gamma_\mu P_L \Psi] \]

  or

  \[ \mathcal{D}_\mu [\bar{f}_R \gamma_\mu f_R] = \mathcal{D}_\mu [\bar{\Psi}_f \gamma_\mu P_R \Psi] \]

  i.e. fermions with Left or Right helicity.

  Decays like $\mu^+ \rightarrow \bar{\nu}_\mu e^+ \nu_e$ give $e^+$ with

  \[ dN/dx|_L = 2(1 - x)^2(1 + 2x) \]

  \[ dN/dx|_R = 4(1 - x^3)/3 \]
Final state spectra for $M = 1$ TeV

We consider the allowed $s$-wave primary annihilation channels:

$$\{e, \mu_L, \mu_R, \tau_L, \tau_R, W_L, W_T, Z_L, Z_T, h, q, b, t\},$$

computed with our Mathematica MonteCarlo + Phytia8 + (Tauola+Phytia6)

Annihilations into leptons give qualitatively different energy spectra.
3

Implications of the data
Fitting procedure

- **PAMELA systematic uncertainties?**

- multiply each expected $e^+$, $e^-$, $p^+/p^-$ backgrounds times $A_i E^{p_i}$ with free $A_i$ and $p_i = 0 \pm 0.05$, and marginalize over $A_i, p_i$.

- **solar modulation** as uncorrelated uncertainty below 20 GeV: ±6% at 10 GeV, ±30% at 1 GeV.

- **DM halo**: marginalize over isoT/NFW/Moore with flat prior.

- **Propagation**: marginalize over MIN/MED/MAX with flat prior. (MED is favored?).

If $M > \text{TeV}$ everything fits. At smaller $M$ only annihilations into leptons or $W$. 
The $\sigma v$ needed for PAMELA

$\sigma v$ larger than what suggested by cosmology by a factor $B_e$
The cosmological $\sigma v$

Thermal DM reproduces the cosmological DM abundance $\Omega_{DM} h^2 \approx 0.11$ for

$$\sigma v \approx 3 \times 10^{-26} \text{cm}^3/\text{sec}$$

around freeze-out, i.e. $v \sim 0.2$.

up to co-annihilations and resonances. Possible extrapolations to $v \sim 10^{-3}$:

The Sommerfeld effect is the quantum analogous of this classical effect: the sun attracts slower bodies, enhancing its cross section:

$$\sigma = \pi R_\odot^2 (1 + \frac{v_{\text{escape}}}{v^2})$$

If DM is thermal PAMELA needs $s$-wave + Sommerfeld and/or a boost factor (DM in sub-halos has small velocity dispersion: Sommerfeld boosts the boost)
Non thermal DM

E.g. a wino that with $M \approx 100 \text{ GeV}$ annihilates into $W^+_T W^-_T$ with the correct

$$\sigma v = \frac{g^4_2(1 - M^2_W/M^2)^{3/2}}{2\pi M^2(2 - M^2_W/M^2)^2}$$

But it contradicts PAMELA $\bar{p}$ data (unless $B_p \ll B_e$ or low $L$ or etc...):

DM with $M = 150 \text{ GeV}$ that annihilates into $W^+ W^-$
Fitting PAMELA $e^+ \text{ anti } \bar{p}$ data

Assuming equal boost & propagation for $e^+$ and $\bar{p}$ (otherwise everything goes):

DM must annihilate into leptons or into $W, Z$ with $M \gtrsim 10$ TeV

Indeed a $W$ at rest gives $\bar{p}$ with $E_p > m_p$. So a $W$ with energy $E = M$ gives $E_p > Mm_p/M_W$, above the PAMELA threshold for $M > 10$ TeV.
The Minimal Dark Matter 5-plet

MDM predicted: • annihilations into $W_T^+ W_T^-$; • $M = 9.6 \pm 0.2$ TeV, imposing $\Omega_{\text{DM}} h^2 \approx 0.11$; • a $10^3$ Sommerfeld enhancement; • no ATIC peak.

DM with $M = 10$ TeV that annihilates into $W^+ W^-$
The possible excess in $e^+ + e^-$ around 700 GeV is compatible with the PAMELA excess in $e^+$ above 10 GeV, if DM annihilates into leptons with TeV mass.

In any case, balloons disfavor/exclude the following PAMELA interpretations:
- DM with mass $M \lesssim$ TeV
- DM that annihilates in leptons with $M \gtrsim$ TeV.
DM with $M = 1$ TeV that annihilates into $\mu^+\mu^-$
Dark Matter mis-identified?

DM with $M = 2$ TeV that annihilates into $\tau^+\tau^-$
Connection with direct detection

Qualitative connection between \( \sigma_{\text{ann}}v \sim 3 \cdot 10^{-23} \text{ cm}^3/\text{sec} \cdot (M/\text{TeV})^2 \) and \( \sigma_{\text{dir}} \):

i) if DM annihilates into quarks:

\[
\sigma_{\text{dir}} \sim \frac{m_N^2 \sigma_{\text{ann}}v}{M^2 B e S} \sim \frac{10^{-39} \text{ cm}^2}{B e S}
\]

(possibly times \( m_N^2/M^2 \)). The experimental bound is \( \sigma_{\text{dir}} \gtrsim 10^{-41} \text{ cm}^2 \).

ii) if DM annihilates into \( W, Z, h, \mu, \tau \), the connection is model-dependent: as in i) times one or two loop factors \( \sim (4\pi)^{-2} \), possibly times \( M^2/M_W^2 \). The MDM 5plet predicts \( \sigma_{\text{dir}} \sim 10^{-44} \text{ cm}^2 \).

iii) if DM annihilates into and interacts with \( e \) (that in atoms reach \( p \sim m_e \)), the recoil energy is \( \Delta E \sim vp \), above threshold in DAMA, but

\[
\sigma_{\text{dir}} \sim \frac{m_e^2 \sigma_{\text{ann}}v}{M^2 B e S} \sim \frac{10^{-45} \text{ cm}^2}{B e S}.
\]

is negligibly small.
PAMELA vs SUSY & co

- Fit PAMELA with a neutralino at $M \sim 100$ GeV that annihilates into $e^+e^-\gamma$ thanks to a fine-tuned slepton mass, invoking a huge boost $B_e \sim 10^6$;

- Unnatural SUSY at 10 TeV with $\sigma v$ enhanced by Sommerfeld;

- Unnatural SUSY at 1 TeV and we are inside/close to a DM clump. ($\gamma$?)

- SUSY + ad hoc stable new particles. 2-component DM: one more abundant (small $\sigma v$) that decays in the other (bigger $\sigma v$ for PAMELA).

- A $\tilde{\nu}_R$ lighter than $M_W$ and with a large Yukawa $\nu_RLH$ annihilates into $L$;

- DM vectors or fermions suggested by wUED (would be Universal Extra Dimensions) or by LHT (Little Higgs with non-anomalous $T$-parity) annihilate $\sim 30\%$ into leptons, but $\sim 70\%$ into $q, W$. 
DM models for PAMELA and ATIC

DM is charged under a dark gauge group, to get the Sommerfeld enhancement.

For PAMELA and ATIC. [Cirelli, Kadastik, Raidal, Strumia] proposed that DM as a Dirac fermion with \( M \approx 1.5 \) TeV and charge \( q \approx 2 \) under \( L_\mu - L_\tau \) (suggested by \( \theta_{23} \approx \pi/4 \)), gauged with \( \alpha_V \approx 1/50 \) (giving the correct thermal abundance) and mass \( M_V \approx M_Z \), giving the \( g_\mu - 2 \) anomaly + Sommerfeld.

At 1 loop \( L_\mu - L_\tau \) mixes with the photon: \( \theta \sim e g_V \ln(m_\tau/m_\mu)/6\pi^2 \sim 0.005 \). Direct cross section: \( \sigma_{SI} = 4\pi q^2 \alpha_V \alpha m_N^2 \theta^2 / M_V^4 \approx 10^{-42} \) cm\(^2\).

For PAMELA and ATIC and DAMA (?) and INTEGRAL (?). [Arkani-Hamed, Weiner et al.] proposed that the new vector is light \( M_V \lesssim m_N \) and couples to SM particles only via a mixing with the photon,

\[
\theta \sim e g_V \ln(M_{Pl}/m_?) / 6\pi^2 \sim 10^{-2\div 3}
\]

so that: • \( V \) automatically decays into light leptons \( e, \mu, \pi^\pm \); • \( V \) gives a small \( \delta a_\mu \sim \alpha \theta^2 (m_\mu/M_V)^2 / \pi \sim 10^{-9} \); • \( V \) gives a \( 10^{-6} \) too large elastic \( \sigma_{SI} \). If the DM gauge group is non abelian, DM has multiple components with 100 keV (\( \sim \alpha_V M_V \)) mass splittings, one can instead get an inelastic \( \sigma_{dir} \) that can explain DAMA (but \( M = 1 \) TeV is too heavy?)
3

Bounds from photon indirect detection
Photons from DM

DM DM $\rightarrow \ell^+ \ell^-$ is unavoidably accompanied by:

- $\gamma$ from brehmstralung.
- $e^\pm$ synchrotron in the galactic magnetic fit.
- $\gamma$ from $e^\pm$ scatterings on star-light
\[
\frac{d\Phi_\gamma}{d\Omega \, dE} = \frac{1}{24\pi} \frac{r_\odot^2 \rho_\odot^2}{M_{DM}^2} J \langle \sigma v \rangle \frac{dN_\gamma}{dE}, \quad J = \int_{\text{line-of-sight}} \frac{ds}{r_\odot} \left( \frac{\rho(r)}{\rho_\odot} \right)^2
\]

\[
\langle J \rangle_{\Delta \Omega} = \begin{cases} 
\text{NFW} & 14700 & 7600 & 14 & \text{Galactic Center} & 1 \cdot 10^{-5} \\
\text{Einasto} & 2400 & 3000 & 14 & \text{Galactic Ridge} & 3 \cdot 10^{-4} \\
\text{isoT/cored} & 1000 & - & 140 & \text{Sagittarius dSph} & 2 \cdot 10^{-5}
\end{cases}
\]
DM signals computed for NFW and $\sigma v = 10^{-23}$ cm$^3$/sec. We conservatively impose that no point is exceeded at $3\sigma$: so the 1st example above is allowed.

Another bound from the DM-dominated Sagittarius dwarf spheroidal galaxy at 24 kpc from us, that was observed by HESS for 11h finding no $\gamma$ excess.
Radio observations

Around the GC magnetic fields $B$ contain more energy than light, diffusion and advection seem negligible, so the $e^\pm$ energy $E$ goes into synchrotron radiation. The unknown $B$ only determines the maximal $\nu_{\text{syn}}$:

$$\frac{dW_{\text{syn}}}{d\nu} \approx \frac{2e^3 B}{3m_e} \delta\left(\frac{\nu}{\nu_{\text{syn}}} - 1\right) \quad \text{where} \quad \nu_{\text{syn}} = \frac{eBE^2}{4\pi m_e^3} = 1.4 \text{ MHz} \frac{B}{G} \left(\frac{p}{m_e}\right)^2.$$

Davies 1976 observations at the lower $\nu = 0.408$ GHz give the robust and dominant bound as the observed GC radio-spectrum is harder than synchrotron:

$$\nu \frac{dW_{\text{syn}}}{d\nu} = \frac{\sigma v}{2M^2} \int_{4'' \text{ cone}} dV \ \rho^2 \ E(\nu) \ N_e(E(\nu)) < 4\pi r_\odot^2 \times 2 \cdot 10^{-16} \ \text{erg cm}^{-2} \text{s}^{-1}.$$

The uncertainty is in the DM density $\rho$ at 1pc from the GC: NFW or ...?
ν observations

$\langle \bar{\nu}_\mu \rangle$ scattering in the rock below the detector produce trough-going $\mu^\pm$

$$\Phi_\mu = \frac{r}\rho M^2 \frac{3G_\mu^2}{2\pi \alpha_\mu} \times J \cdot \Delta\Omega \cdot \int_{0}^{1} dx \frac{x^2 dN_\nu}{dx}$$

where $p \sim 0.125$ is the momentum fraction carried by each quark in the nucleon and $\alpha_\mu = 0.24 \text{ TeV/kmwe} = -\frac{dE}{d\ell}$ is the $\mu^\pm$ energy loss.

The total $\mu^\pm$ rate negligibly depends on the DM mass $M$.

SuperKamiokande got the dominant bounds in cones up to $30^\circ$ around the GC

$$\Phi_\mu < 0.02/cm^2s$$
The photon bounds

Assuming NFW, **conservative** bounds from HESS $\gamma$ observations of the **Galactic Center, Galactic Ridge, Sagittarius Dwarf** and from radio observations of the GC exclude the green (region allowed by PAMELA) and red bands (ATIC):

$$10^{-26} \leq \text{DM mass in GeV} \leq 10^{-20}$$

$$10^{-24} \leq \nu \leq 10^{-22}$$

Way out: Sommerfeld $\times$ boosts can enhance GC $\gamma$ less than $e^{\pm}$?
An isotheramal profile is ok

![Graphs showing DM DM → e^+ e^−, Einasto profile](image1)

DM DM → e^+ e^−, Einasto profile

![Graphs showing DM DM → μ^+ μ^−, Einasto profile](image2)

DM DM → μ^+ μ^−, Einasto profile

![Graphs showing DM DM → τ^+ τ^−, Einasto profile](image3)

DM DM → τ^+ τ^−, Einasto profile

![Graphs showing DM DM → e^+ e^−, isothermal profile](image4)

DM DM → e^+ e^−, isothermal profile

![Graphs showing DM DM → μ^+ μ^−, isothermal profile](image5)

DM DM → μ^+ μ^−, isothermal profile

![Graphs showing DM DM → τ^+ τ^−, isothermal profile](image6)

DM DM → τ^+ τ^−, isothermal profile
4

DM decays
DM decays are compatible with NFW

If instead DM decays with life-time $\tau$, replace $\rho^2 \sigma v / 2M^2 \rightarrow \rho^1 / M \tau$:

$\rho^1$ and $\rho^2$ are observable via PAMELA and ATIC, and testable by GR observations.

**PAMELA/ATIC** are allowed with all profiles and testable by GR observations.
Fermion DM $\rightarrow W^{\pm}\ell^{\mp}$

DM with $M = 2$ TeV that decays into $W^{\pm}\ell^{\mp}$
$B - L$-mediated DM $\rightarrow f\bar{f}$

BR in $\ell^+\ell^-$ 3 times higher than BR into $q\bar{q}$:

$B-L$-mediated DM decay with $M = 2$ TeV, min

Too much $\bar{p}$ even for min?
ATIC suggests SU(2) technicolor!?  

ATIC as DM decays needs $M \sim 2\text{ TeV}$, which naturally implies the observed 

$$\frac{\rho_{\text{DM}}}{\rho_b} \sim \frac{M}{m_p} \left( \frac{M}{T_{\text{dec}}} \right)^{3/2} e^{-M/T_{\text{dec}}}$$

if the DM density is due to a baryon-like asymmetry kept in thermal equilibrium by weak sphalerons down to $T_{\text{dec}} \sim 200\text{ GeV}$: $\rho_{\text{DM}}/\rho_b \sim 5$ if $M \approx 9T_{\text{dec}} \sim 2\text{ TeV}$

Possible if DM is a chiral fermion or is made of chiral fermions.  
The DM mass is $M \sim \lambda v \sim 2\text{ TeV}$ for $\lambda \sim 4\pi$: strong dynamics a-la technicolor.  
GUT-suppressed dimension 6 4-fermion operators give $\tau \sim M^4_{\text{GUT}}/M^5 \sim 10^{26}\text{ s}$.  
If the technicolor group is SU(2) with techni-q $Q = (2, 0)$ under SU(2)$_L \otimes U(1)_Y$

- DM is a $QQ$ bound state, scalar and SU(2)-singlet as suggested by data.

- A 4-fermion $QQ\bar{L}L$ operator allows a slow $\text{DM} \rightarrow \ell^+\ell^-$: no $\Pi \simeq W_L$ involved.

- Usual problems of technicolor: minimal correction to the $S$ parameter...
Conclusions

The PAMELA/ATIC excesses might be due to pulsars or to DM:

- if the ATIC peak is true: DM as 1 TeV WIMP that annihilates into $e, \mu, \tau$;
- if not: a 10 TeV WIMP that annihilates into $W, Z, h$ as predicted by MDM;
- $M \sim 100$ GeV seems disfavored/excluded by $\bar{p}$ and/or $e^+ + e^-$ data.
- Photon bounds might disfavor DM annihilations and hint to DM decays.

This can soon be tested by new experimental results:

- **The $e^+$ fraction at higher energies continues to grow?**
  PAMELA09 up to 270GeV? Later AMS.

- **Is an excess present in $\bar{p}$ at higher energies?**
  One more data-point from PAMELA09? Later AMS up to 1 TeV?

- **Is the $e^+ + e^-$ ATIC peak really there?**
  ATIC-4 and Fermi with its LAT calorimeter in space already have data.