Electroweak Corrections to Dark Matter Indirect Detection

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Outline

What Dark matter (DM): indirect signals

Why Indirect detection experiments:
interesting (= unexpected) results in 2008-2011

How Electroweak corrections inclusion in the computation of primary fluxes dN/dE

Based on
P. Ciafaloni, D. Comelli, A. Riotto, F. Sala, A. Strumia and A. Urbano, JCAP 1103, 019 (2011), arXiv:1009.0224

Dark Matter

DM seen only through its gravity

What we know

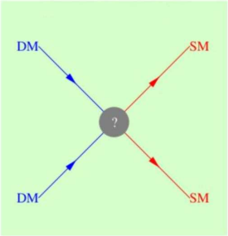
non-baryonic non-luminous matter is 23% of Universe

What we believe

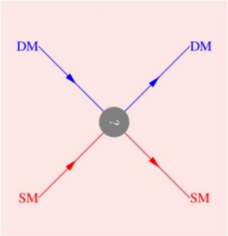
- DM is a WIMP: $\langle \sigma_A v \rangle \simeq 10^{-26} cm^3/s$
- DM is <u>cold</u>, i.e. $M \gg T_{eq}$ (non relativistic)

Experiments

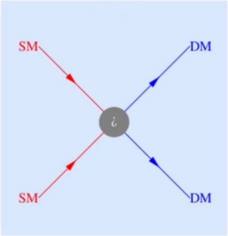
Indirect Detection



Direct Detection

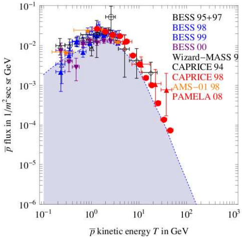


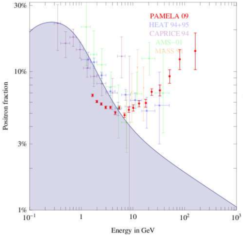
Colliders

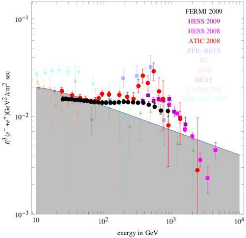


- Colliders: nothing yet. Hope: LHC
- Direct Detection: Xenon100, CoGeNt, CDMS-II, DAMA...
- Indirect Detection: PAMELA, Hess, Fermi, AMS/02, IceCube...

Indirect Detection: Results







- $\bar{p}/(\bar{p}+p)$: consistent with background
- $e^+/(e^+ + e^-)$: excess (PAMELA 2009 & FERMI 2011)
- $e^+ + e^-$: deviation from background (FERMI & HESS 2010)

Consistent interpretations: pulsar, **dark matter**

Learning from ID Results

$$\text{DM} \xrightarrow{\textit{particle physics}} \text{primary fluxes} \xrightarrow{\textit{astrophysics}} \text{observed fluxes}$$

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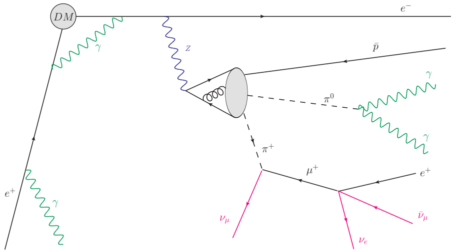

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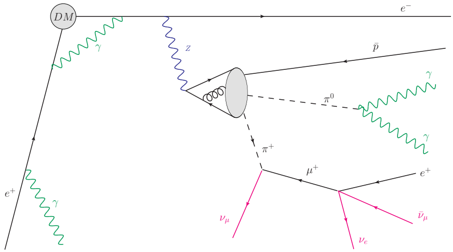

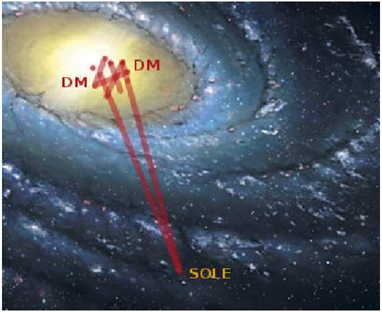

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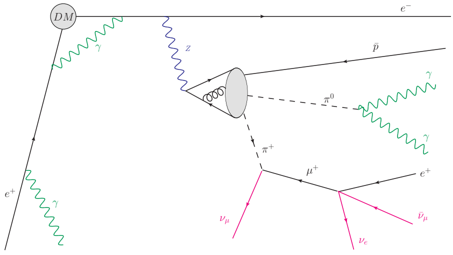

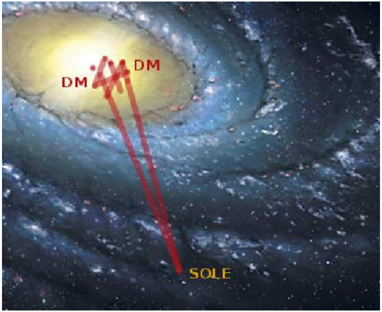

What we learn

- Mass: $M \sim \mathcal{O}(1)\,\mathrm{TeV}$
- Leptophilic DM
- Decay: $\tau \approx 10^{26} s$ Annihilation: $\langle \sigma_A v \rangle \approx 10^{-23} cm^3/s$

Primary Fluxes

DM $\xrightarrow{\textit{specific model}}$ primary SM channels $\xrightarrow{\textit{radiation}}$ primary fluxes

Model-independent radiation description

starting from experimental data one can give general constraints on DM properties.

Radiation is computed by simulations with usual **Monte Carlo programs**:

QCD ✓ QED ✓ (only $\ell \to \ell\gamma$, $\gamma \to f\bar{f}$) Weak ×

What about Electroweak radiation?

ELECTROWEAK CORRECTIONS
TO PRIMARY FLUXES

- Importance
- Inclusion

ELECTROWEAK CORRECTIONS

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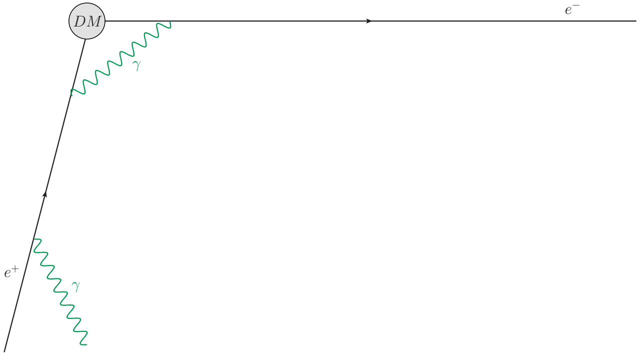
- **Importance**
- Inclusion

Are they important?

Example: $DM \to e^+e^-$



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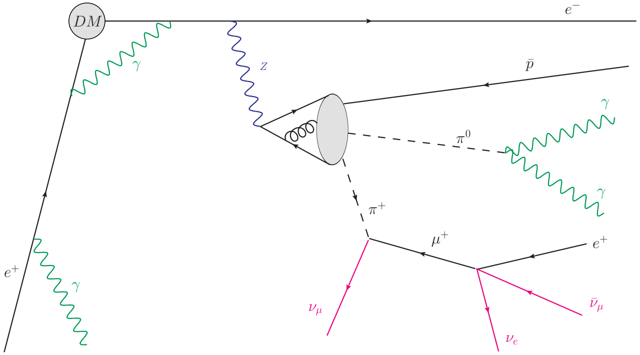
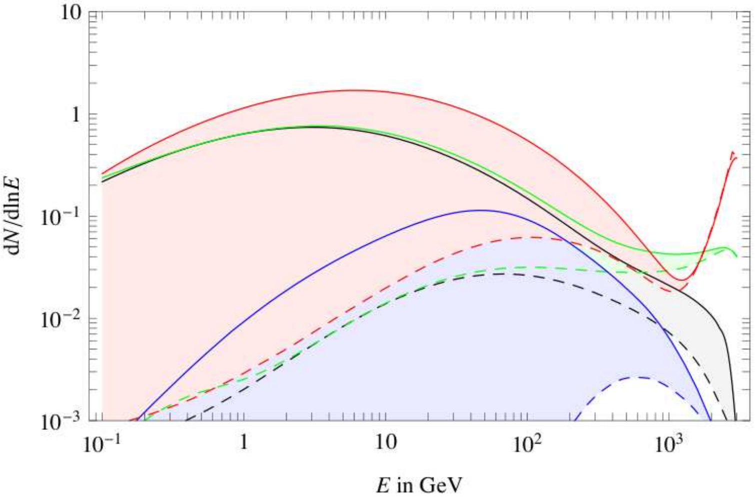


Example: DM DM $\to \mu^+\mu^-$

γ, e^+, $\bar{p}$, $\nu = \nu_e + \nu_\mu + \nu_\tau$, $M = 3\,\text{TeV}$



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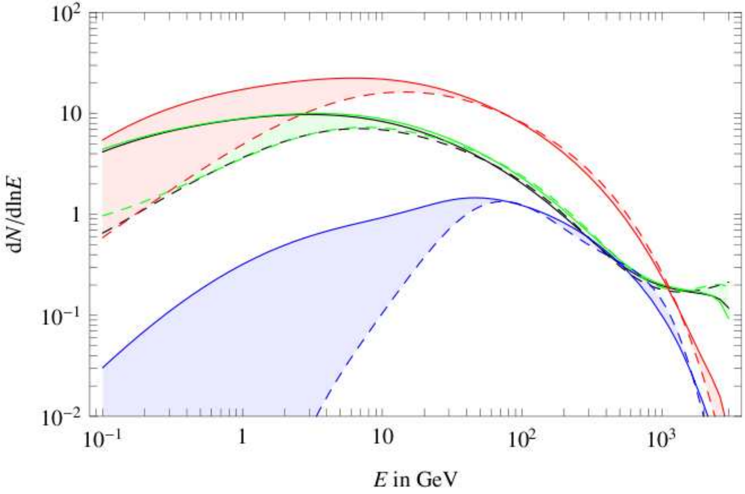

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EW Corrections Inclusion

$$\frac{dN_{I\to f}}{dx}(M,x) = \sum_J \int_x^1 dz\, D^{\rm EW}_{I\to J}(z) \frac{dN^{\rm MC}_{J\to f}}{dx}(zM, \frac{x}{z}) \qquad x = E_f/M$$

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EW fragmentation functions:

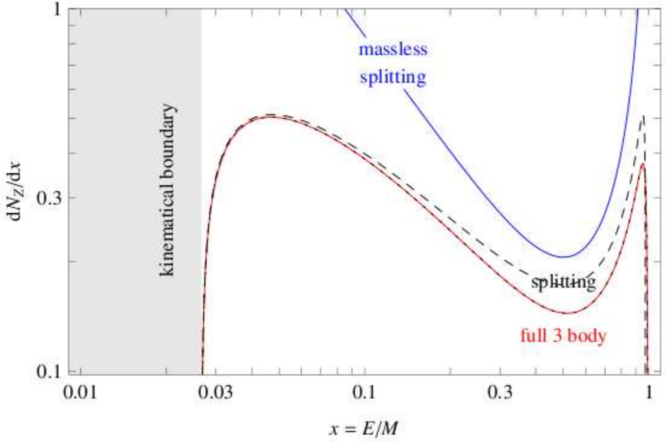
- inclusion at $\mathcal{O}(\alpha_w)$ (no interplay EW-QCD)
- factorization $D^{\rm EW} = d_2\alpha_w log^2\frac{M^2}{M_W^2} + d_1\alpha_w log\frac{M^2}{M_W^2} + d_0$
- this inclusion is model-independent (d_2 and d_1, not d_0)

Generalization to massive partons

- correct kinematical domain $\frac{M_W}{M} < x < 1 - \frac{M_W}{M}$
- extra $\log x$ factors, particularly relevant at kinematical extremes

Comparison with Full Computation in MDM

Z radiation from DM DM $\to W^+W^-$, $M = 3\,\mathrm{TeV}$



Summary

DM indirect detection: interesting experimental results

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For $M \sim \mathrm{TeV}$ relevant changes in spectra!

- new channels otherwise absent
- more products at low energy (regions experiments observe)

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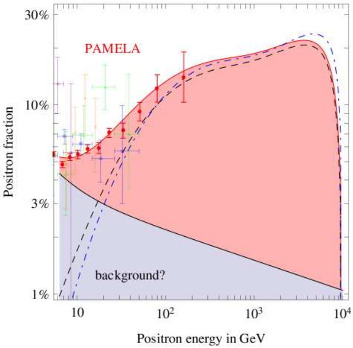
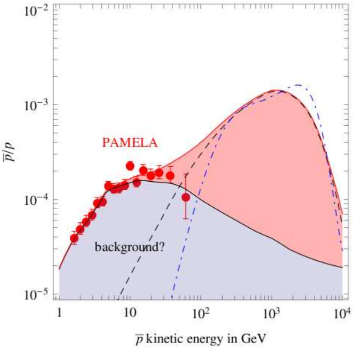
Thank you for your attention!

Effects on observed fluxes: DM DM $\to W^+W^-$

$M = 10\,\mathrm{TeV}$, MIN, NFW





Effects on observed fluxes: DM DM $\to \mu^+\mu^-$

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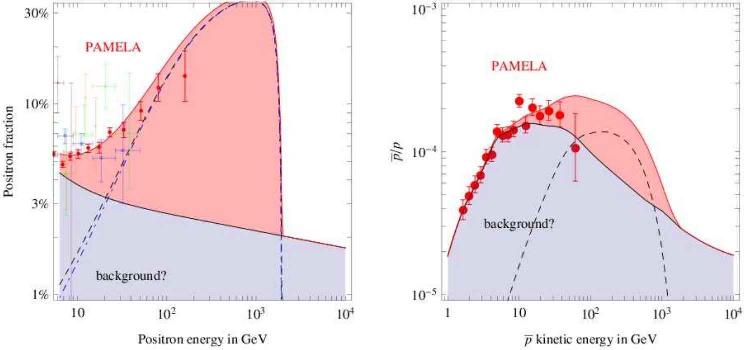

Technicalities 1: Evolution equations for the D^{EW}

$$\mu^2 \frac{\partial}{\partial \mu^2} D(x,\mu^2) = \frac{\alpha_s}{2\pi}\ D \otimes P^{\rm QCD}\ \theta(\Lambda < \mu < M) + \frac{\alpha_w}{2\pi}\ D \otimes P^{\rm EW}\ \theta(M_W < \mu < M)$$

$$(f \otimes g)(x) \equiv \int_x^1 dz/z f(z) g\left(x/z\right) = \int_0^1 dz \int_0^1 dy f(y) g(z) \delta(x - zy)$$

Approximated solution ($\mathcal{O}(\alpha_s, \alpha_w)$):

$$D^{\rm EW}(x,\mu^2) = \delta(1-x)\ \mathbb{I}\ + \frac{\alpha_2}{2\pi} \int_{\mu^2}^{s} P^{\rm EW}(x,\mu'^2) \frac{d\mu'^2}{\mu'^2}$$

Technicalities 2: Splitting Functions - Preliminars

From p_1 p_2 to p_1 p_2 k

$$\begin{aligned} k &= \left(zE, k_t, 0, \sqrt{z^2E^2 - k_t^2}\right), \\ p_1 &= \left(xE, -k_t, 0, \sqrt{x^2E^2 - k_t^2}\right), \\ p_2 &= (yE, 0, 0 - yE); \end{aligned}$$

4-momentum conservation and kinematical conditions:

$$\begin{cases} x + y + z = 2, \\ \sqrt{z^2E^2 - k_t^2} + \sqrt{x^2E^2 - k_t^2} - yE = 0, \end{cases}$$

$$x^2E^2 \geq k_t^2, \qquad z^2E^2 \geq k_t^2, \qquad 0 \leq x, y, z \leq 1$$

Phase space of the emitted soft particle

$$\frac{d^3\vec{p}_1}{(2\pi)^3 2p_1^0} = \frac{dx dk_t^2}{16\pi^2} \frac{E}{\sqrt{x^2E^2 - k_t^2}}.$$

Technicalities 3: Splitting Functions

Collinear Approximation

Example:
Heavy neutral Z', $\mathcal{L}_{\rm int} = f_L Z'_\mu \overline{L} \gamma^\mu L$, with: $L = (\nu_L, e_L)^T$

Factorization of the amplitude and of phase space yields to:

$$|\mathcal{M}_3|^2 \approx \frac{g^2}{2c_W^2} \frac{x(1+x^2)}{k_t^2} |\mathcal{M}_{\rm Born}|^2$$

$$d\Gamma_3 \left(Z' \to \nu_L \overline{\nu_L} Z\right) \approx d\Gamma_2 \left(Z' \to \nu_L \overline{\nu_L}\right) \frac{\alpha_2}{2\pi} \frac{1}{4(1-s_W^2)} \frac{1+x^2}{1-x} \frac{dx dk_t^2}{\sqrt{x^2 E^2 - k_t^2}}$$

Integrating over the final phase space:

$$d\Gamma_3(x) = \Gamma_2 \frac{\alpha_2}{2\pi} \frac{1}{4(1-s_W^2)} \frac{1+x^2}{1-x} L(1-x)\, dx$$

Technicalities 4: $DM \to F\bar{F}V, \quad \sqrt{s} \gg m_F, M_V$

F charged under a vector V, gauge coupling α

$$D_{F\to F}(x) = \delta(1-x)[1+\frac{\alpha}{2\pi}P^{\rm vir}_{F\to F}] + \frac{\alpha}{2\pi}P_{F\to F}(x),$$
$$D_{F\to V}(x) = \frac{\alpha}{2\pi}P_{F\to V}(x)$$

$$P_{F\to F} = \frac{1+x^2}{1-x}L(1-x), \qquad P^{\rm vir}_{F\to F} = \frac{3}{2}\ell - \frac{1}{2}\ell^2$$

$$\ell = \ln\frac{s}{M_V^2},$$
$$L(x) = \ln\frac{sx^2}{4M_V^2} + 2\ln\left(1+\sqrt{1-\frac{4M_V^2}{sx^2}}\right).$$

3-body processes in the Minimal Dark Matter model

Minimal Dark Matter (MDM): Construction

1. add to SM a multiplet χ charged under $SU(2)_L \otimes \mathrm{U}(1)_Y$
2. conditions: stability, χ neutral under $SU(3)_c$, Z, γ...
3. 2 candidates survive: scalar 7-plet and fermionic 5-plet, with only gauge interactions

Sole tree-level annihilation: $\chi\chi \to W^+W^-$

3-body processes:

- $\chi\chi \to W^+W^-\gamma$
- $\chi\chi \to W^+W^-Z$

MDM: Computing the Spectra for DM DM $\to W^+W^-f$

Splitting $\delta = \Delta M/M_W$ neglected ($\delta/\epsilon \approx \Delta M/M \ll 1$). Then:

Check 1 In Feynman gauge, for $M_W = 0$ the amplitude is transverse - Collinear Approximation

Check 2 If 2 vectors are transvers and one is longitudinal,
in unitary gauge the amplitude is $\propto M_W$

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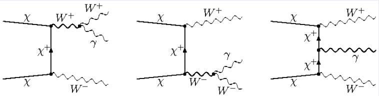
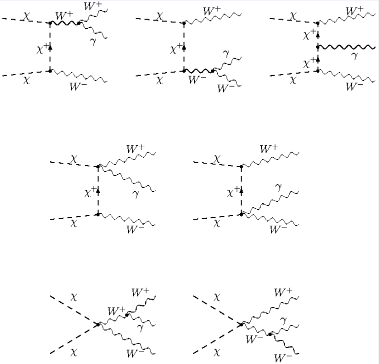
$$\frac{dN_f}{dx} \equiv \frac{1}{\sigma_{WW}} \frac{d\sigma_{WWf}}{dx}$$

Fermionic DM



Scalar DM



Some DM Properties

Cold

- when DM decoupled
- from cosmic structures formation (*bottom-up mechanism*)

WIMP

- again cosmic structures formation
  (if highly energetic, DM will slow down this formation)
- freeze-out $\langle \sigma v \rangle$