On the Electroweak Corrections for Dark Matter Hunters

Alfredo Urbano

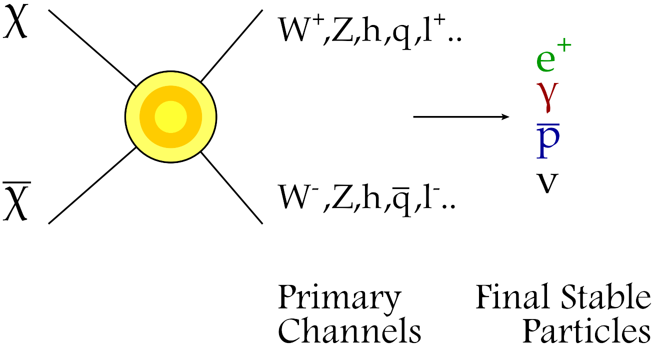
SISSA - International School for Advanced Studies, Trieste

LC13 Workshop, 16 - 20 September 2013
ETC*, Villa Tambosi, Villazzano, Trento

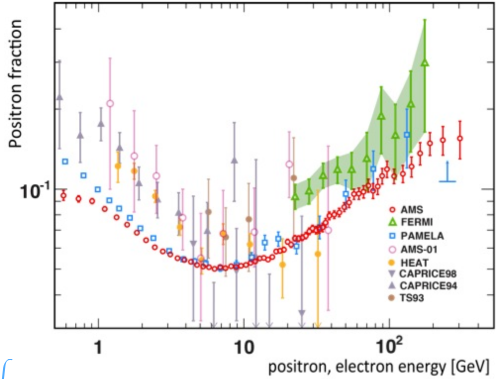
"Everything we see hides another thing,
we always want to see what is hidden by what we see."

René Magritte

$$1 \approx \frac{\Omega_{DM} h^2}{0.119} \approx \frac{3 \cdot 10^{-26}\ \mathrm{cm^3/s}}{\langle v\sigma \rangle}$$

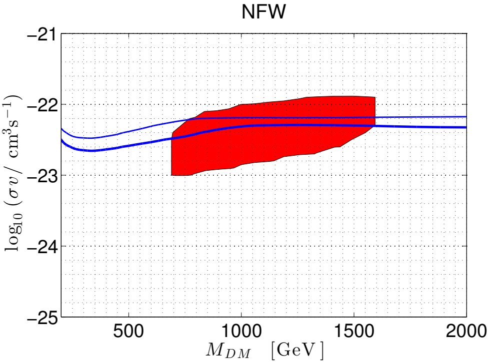

χ
χ̄
W+,Z,h,q,l+..
W-,Z,h,q̄,l-..
e+
γ
p̄
ν
Primary Channels
Final Stable Particles

AMS collaboration, Phys. Rev. Lett. 110, 141102

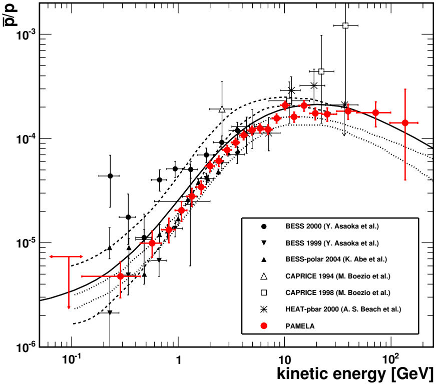


The astrophysical background decreases with the energy!

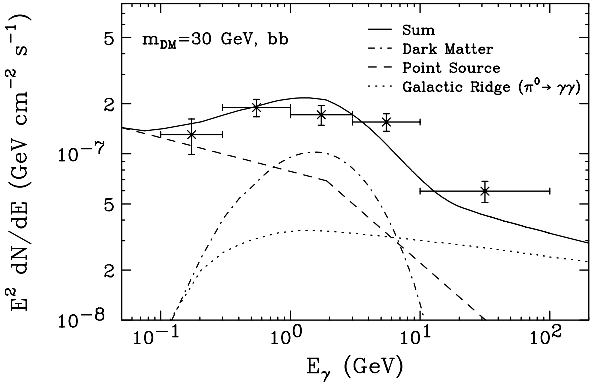
De Simone, Riotto, Xue, JCAP 1305 (2013) 003



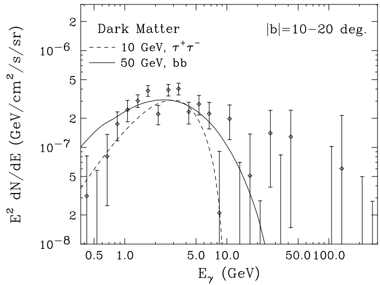
PAMELA collaboration, Phys.Rev.Lett. 105 (2010) 121101

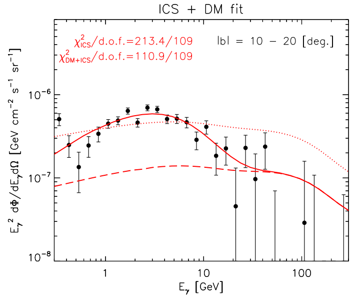


Hooper and Linden, Phys.Rev. D84 (2011) 123005



Hooper and Slatyer, arXiv:1302.6589





Huang, AU, Xue, arXiv:1307.6862

Huang, AU, Xue, arXiv:1307.6862

Table 1: *DM contribution to the fit of the Fermi bubbles energy spectrum. In correspondence of each channel we show the best-fit values for mass and cross section together with the corresponding 1-σ errors and the ratio* $\chi^2_{\rm min}$/d.o.f..

DM annihilation	$M_{\rm DM}$ [GeV]	$\langle\sigma v\rangle$ [$cm^3 s^{-1}$]	$\chi^2_{\rm min}$/d.o.f.
$b\bar{b}$	$61.8^{+6.9}_{-4.9}$	$3.30^{+0.69}_{-0.49} \times 10^{-26}$	110.9/109
$c\bar{c}$	$29.3^{+2.4}_{-3.4}$	$1.54^{+0.26}_{-0.30} \times 10^{-26}$	112.7/109
$q\bar{q}$	$32.0^{+2.6}_{-3.8}$	$1.73^{+0.30}_{-0.30} \times 10^{-26}$	111.9/109
$\tau^+\tau^-$	$10.6^{+0.5}_{-0.6}$	$5.63^{+0.58}_{-0.64} \times 10^{-27}$	120.6/109

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma \rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma \rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

"n", dark matter number density, related to the distribution of dark matter in the Galaxy

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma \rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

Dark matter annihilation rate

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma\rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

Energy spectrum: number of photons per dark matter annihilation

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma \rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma \rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

Q: May the electroweak corrections be important
in the computation of the dark matter cross-section?

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma \rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

NA: Of course not!
There are large astrophysical uncertainties
very far from the precision reachable by ground-based experiment at colliders!

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma\rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

NA: Of course not!
Even a relative correction as large as 30%
has a minor impact!

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma \rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

CA: Yes, they are very important!

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma \rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

They affect the energy spectra of final stable particles rather then the annihilation cross section!

Phys.Rev. D82 (2010) 043512

TeV scale Dark Matter and electroweak radiative corrections

Paolo Ciafaloni* and **Alfredo Urbano**†
INFN - Sezione di Lecce and Università del Salento
Via per Arnesano, I-73100 Lecce, Italy

Abstract

Recent anomalies in cosmic rays data, namely, from the PAMELA Collaboration, can be interpreted in terms of TeV scale decaying/annihilating dark matter. We analyze the impact of radiative corrections coming from the electroweak sector of the standard model on the spectrum of the final products at the interaction point. As an example, we consider virtual one loop corrections and real gauge bosons emission in the case of a very heavy vector boson annihilating into fermions. We find electroweak corrections that are relevant, but not as big as sometimes found in the literature; we relate this mismatch to the issue of gauge invariance. At scales much higher than the symmetry breaking scale, one loop electroweak effects are so big that eventually higher orders/resummations have to be considered: we advocate for the inclusion of these effects in parton shower Monte Carlo models aiming at the description of TeV scale physics.

see also: Kachelriess, Serpico, Solberg, Phys.Rev. D80 (2009) 123533

JCAP 1103 (2011) 019

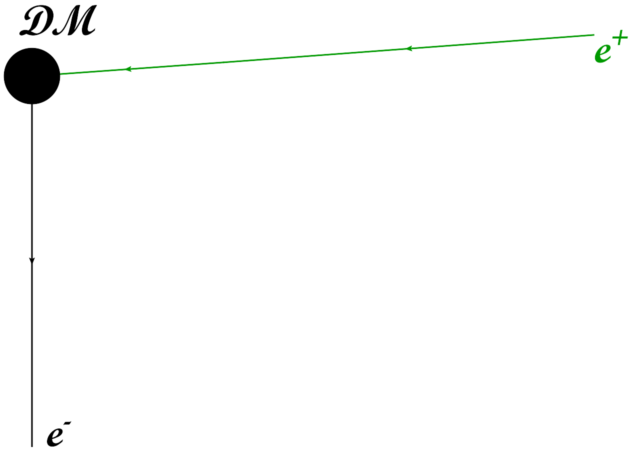
Weak Corrections are Relevant for Dark Matter Indirect Detection

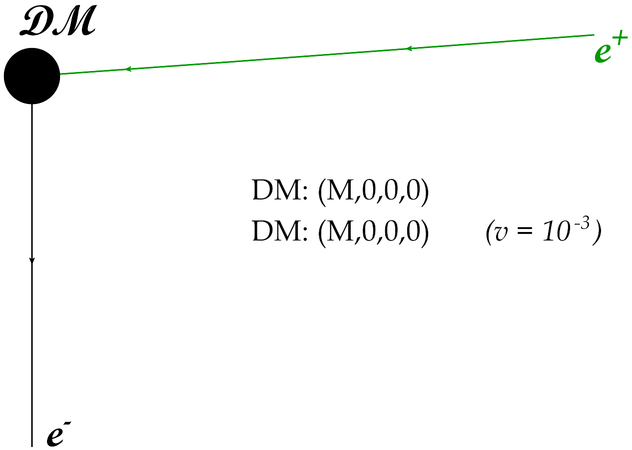
Paolo Ciafaloni[(a)], **Denis Comelli**[(b)], **Antonio Riotto**[(c,d)], **Filippo Sala**[(e,f)], **Alessandro Strumia**[(c,e,g)], **Alfredo Urbano**[(h)]

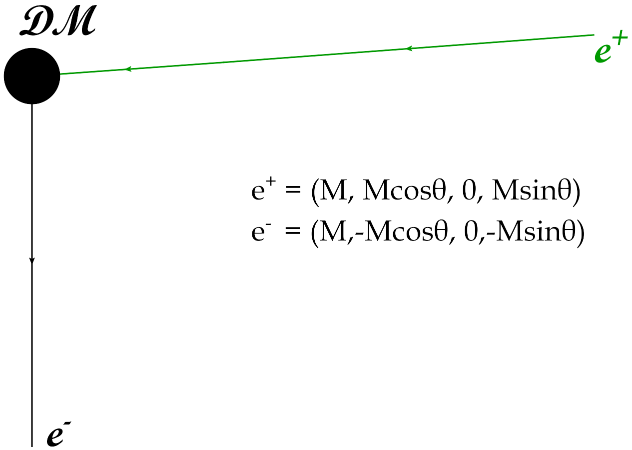
[a] *INFN - Sezione di Lecce, Via per Arnesano, I-73100 Lecce, Italy*
[b] *INFN - Sezione di Ferrara, Via Saragat 3, I-44100 Ferrara, Italy*
[c] *CERN, PH-TH, CH-1211, Geneva 23, Switzerland*
[d] *INFN, Sezione di Padova, Via Marzolo 8, I-35131, Padova, Italy*
[e] *Dipartimento di Fisica dell'Università di Pisa and INFN, Italy*
[f] *Scuola Normale Superiore, Piazza dei Cavalieri 7, I-56126 Pisa, Italy*
[g] *National Institute of Chemical Physics and Biophysics, Ravala 10, Tallin, Estonia*
[h] *Dipartimento di Fisica, Università di Lecce and INFN - Sezione di Lecce, Via per Arnesano, I-73100 Lecce, Italy*

Abstract

The computation of the energy spectra of Standard Model particles originated from the annihilation/decay of dark matter particles is of primary importance in indirect searches of dark matter. We compute how the inclusion of electroweak corrections significantly alter such spectra when the mass M of dark matter particles is larger than the electroweak scale: soft electroweak gauge bosons are copiously radiated opening new channels in the final states which otherwise would be forbidden if such corrections are neglected. All stable particles are therefore present in the final spectrum, independently of the primary channel of dark matter annihilation/decay. Such corrections are model-independent.

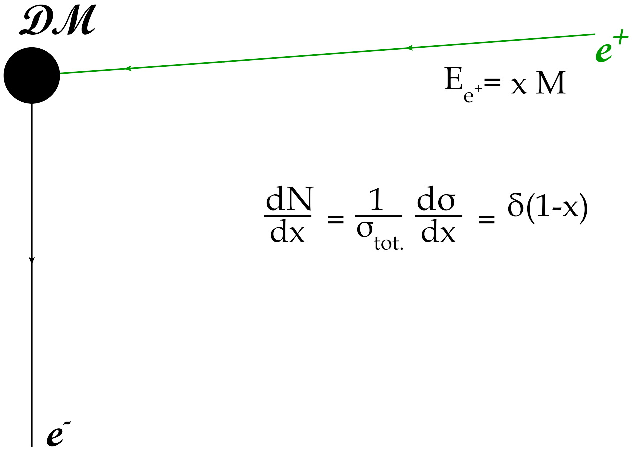

$\mathcal{DM}$
e^+
e^-


DM
e+
e-
DM: (M,0,0,0)
DM: (M,0,0,0) (v = 10-3)



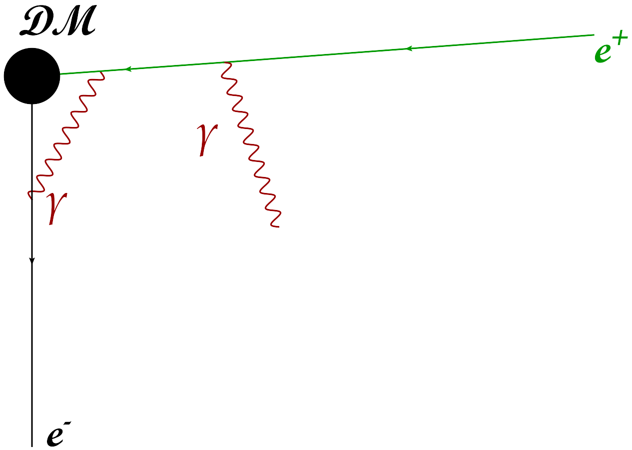
$e^+ = (M, M\cos\theta, 0, M\sin\theta)$

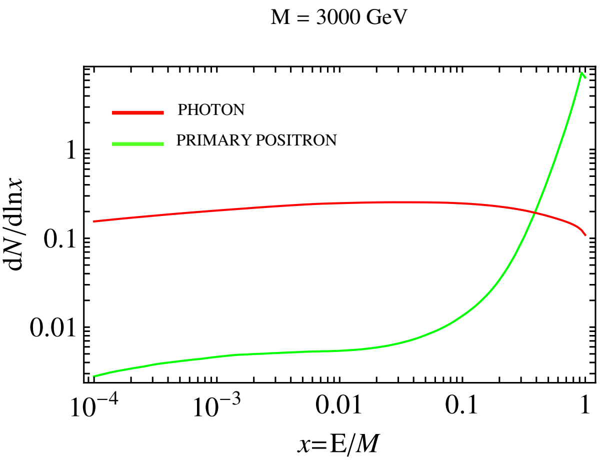
$e^- = (M, -M\cos\theta, 0, -M\sin\theta)$

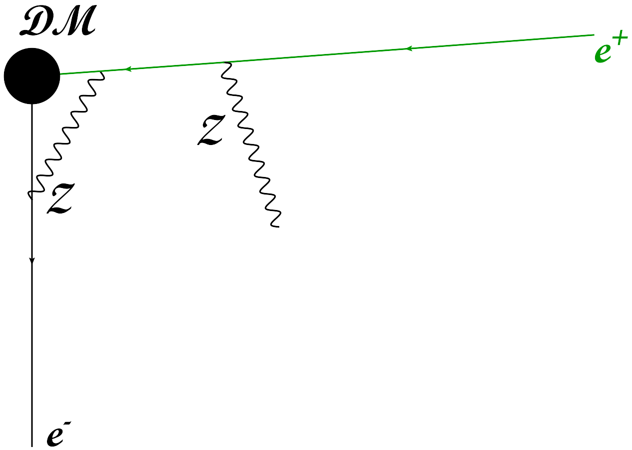


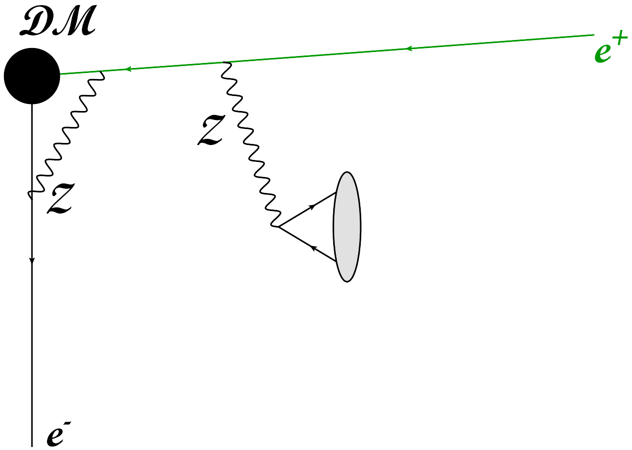
$$E_{e^+} = x\,M$$

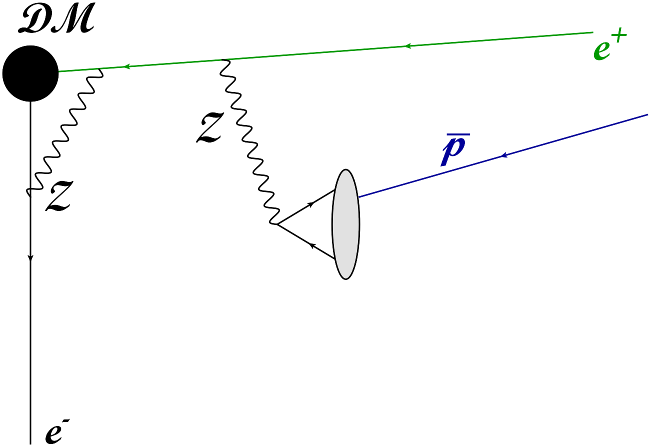
$$\frac{dN}{dx} = \frac{1}{\sigma_{tot.}}\frac{d\sigma}{dx} = \delta(1-x)$$

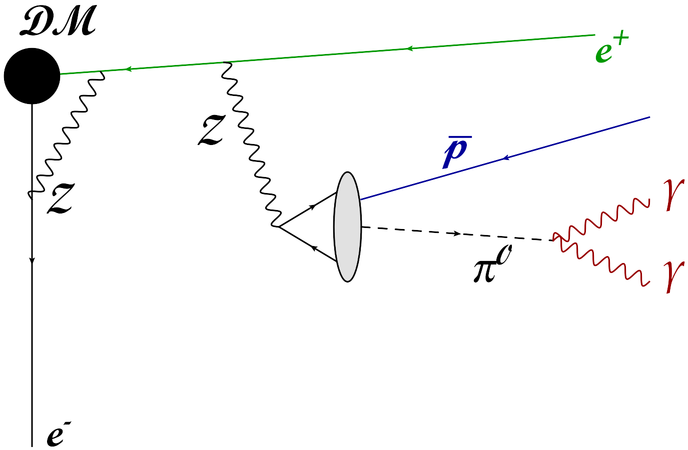

DM
e+
γ
γ
e-

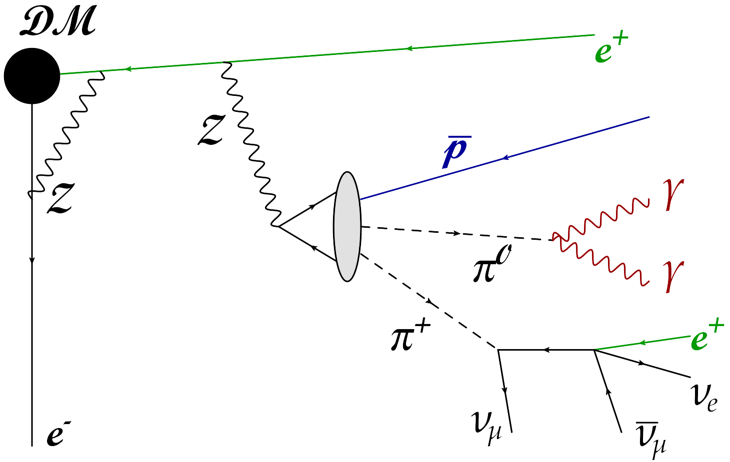

M = 3000 GeV
PHOTON
PRIMARY POSITRON
dN/dlnx
1
0.1
0.01
10^−4
10^−3
0.01
0.1
1
x=E/M

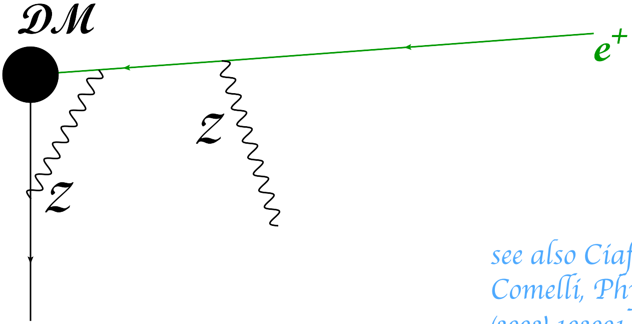

DM
e^+
Z
Z
e^-


DM
e+
Z
Z
e-


$\mathcal{DM}$
e^+
Z
$\bar{p}$
Z
e^-

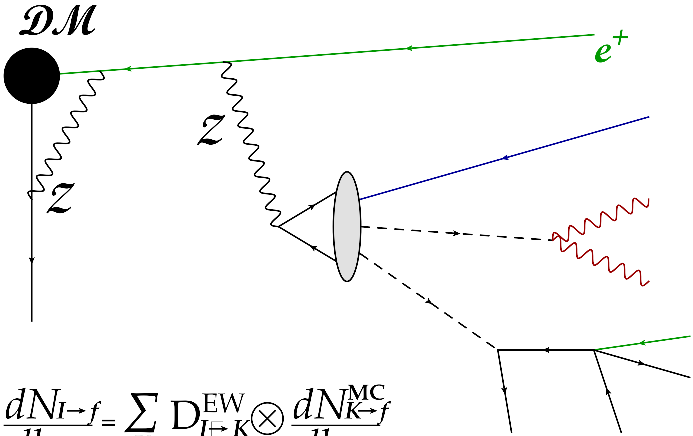

$\mathcal{DM}$
e^+
$\mathcal{Z}$
$\bar{p}$
$\mathcal{Z}$
γ
π^0
γ
e^-


DM
e+
Z
p̄
Z
γ
π0
γ
π+
e+
νe
e-
νμ
ν̄μ



see also Ciafaloni, Ciafaloni, Comelli, Phys.Rev.Lett. 88 (2002) 102001

$$\frac{dN_{I\to f}}{d\ln x} = \quad D^{EW}_{I \to K}$$



$$\frac{dN_{I\to f}}{d\ln x} = \sum_K D^{EW}_{I\to K} \otimes \frac{dN^{MC}_{K\to f}}{d\ln x}$$

$$D^{EW} = f_0 + f_1\, \alpha_w \ln \frac{M^2}{M_W^2} + f_2\, \alpha_w \ln^2 \frac{M^2}{M_W^2}$$

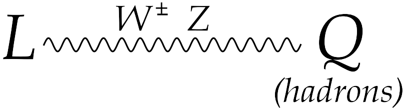
$$D^{EW} = f_0 + f_1 \alpha_W \ln\frac{M^2}{M_W^2} + f_2\, \alpha_W \ln^2\frac{M^2}{M_W^2}$$

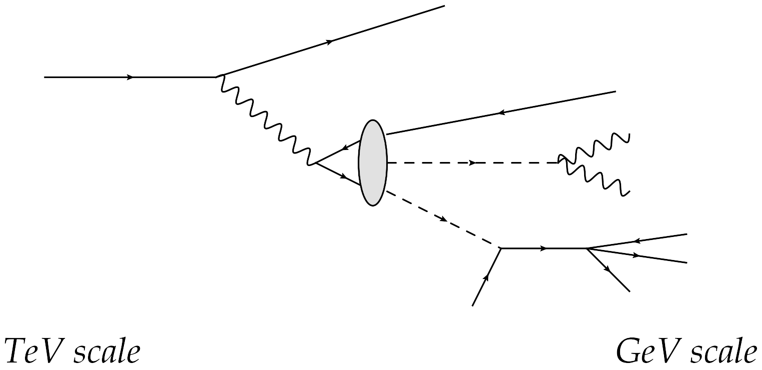
$\alpha_W \rightarrow 0.03$

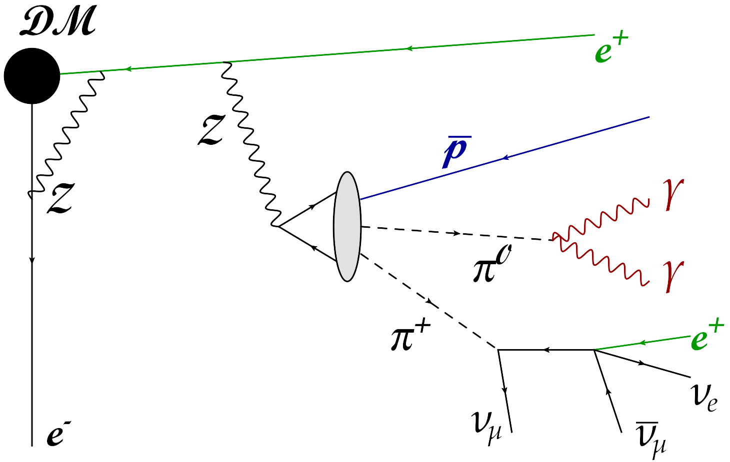
$$D^{EW} = f_0 + f_1 \alpha_w \ln\frac{M^2}{M_W^2} + f_2 \alpha_w \ln^2\frac{M^2}{M_W^2}$$

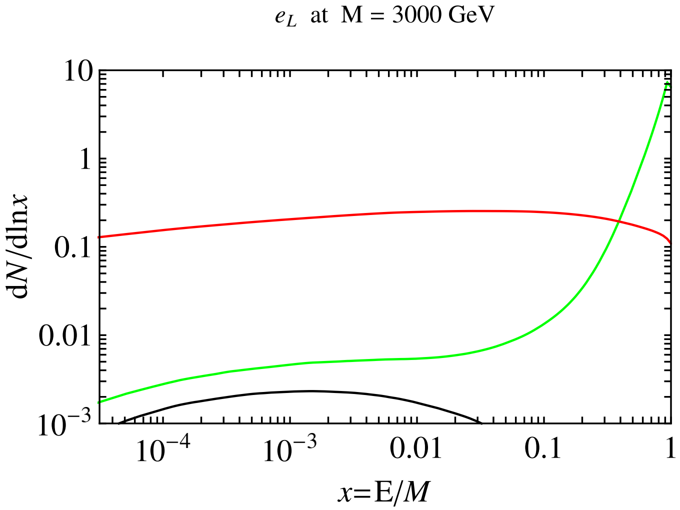
0.3

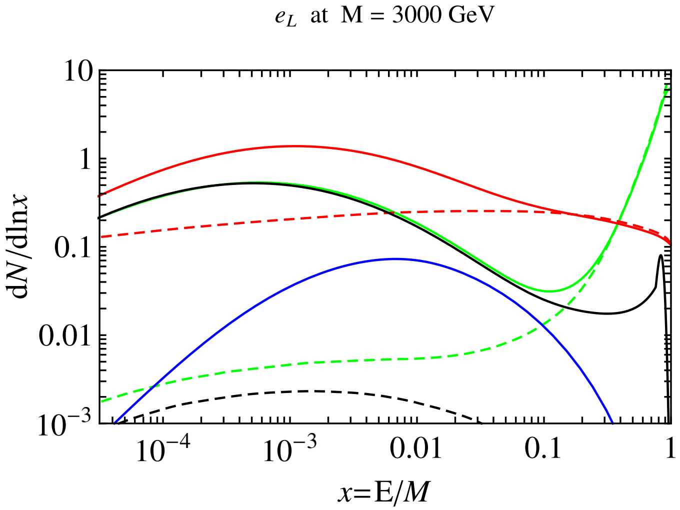
M~TeV

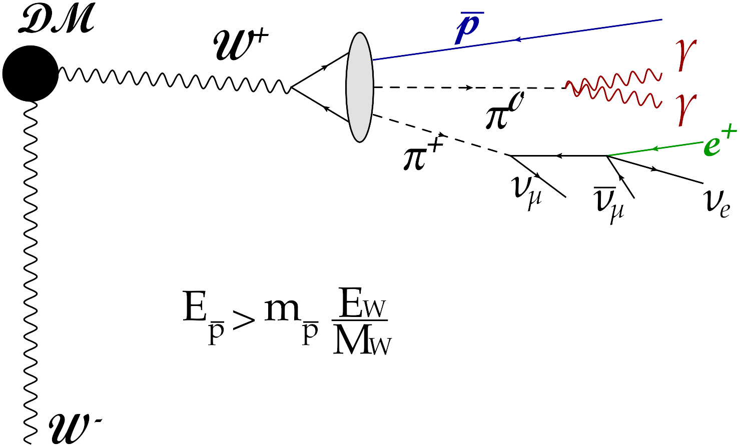

L
W± Z
Q
(hadrons)


TeV scale
GeV scale

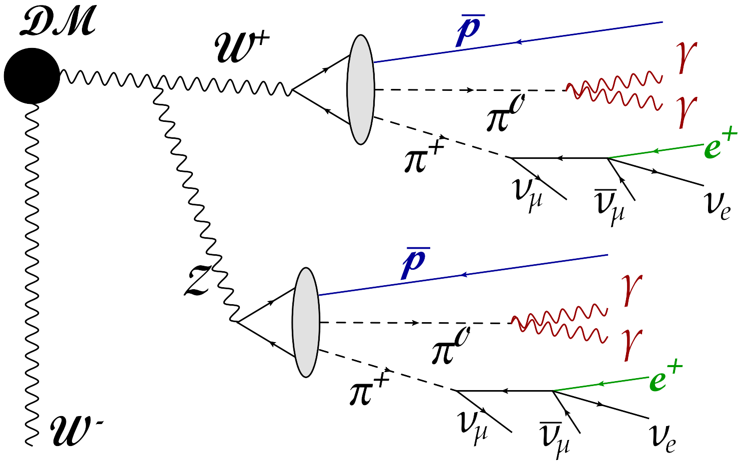

$\mathcal{DM}$
e^+
Z
Z
$\bar{p}$
γ
γ
π^0
π^+
e^+
ν_e
ν_μ
$\bar{\nu}_\mu$
e^-

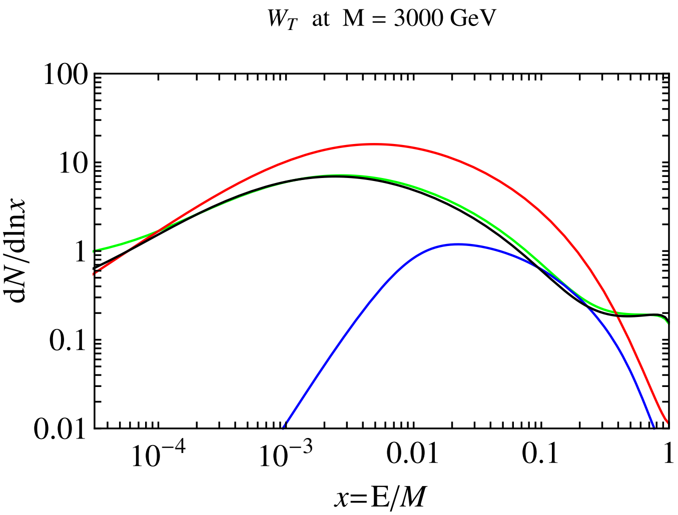

e_L at M = 3000 GeV
10
1
0.1
0.01
10^{-3}
dN/dlnx
10^{-4}
10^{-3}
0.01
0.1
1
x=E/M

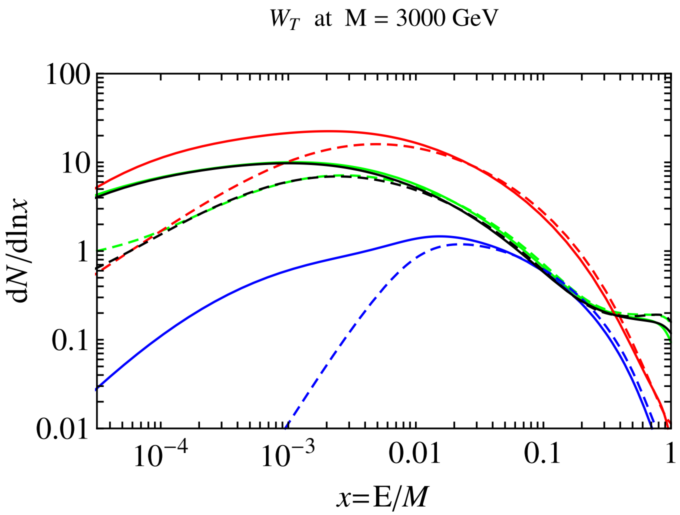

e_L at M = 3000 GeV
dN/dln$x$
10
1
0.1
0.01
10^{-3}
10^{-4}
10^{-3}
0.01
0.1
1
x=E/M



$$E_{\bar{p}} > m_{\bar{p}} \frac{E_W}{M_W}$$


DM
W+
$\bar{p}$
γ
γ
π^0
π^+
e^+
ν_μ
$\bar{\nu}_\mu$
ν_e
Z
$\bar{p}$
γ
γ
π^0
π^+
e^+
ν_μ
$\bar{\nu}_\mu$
ν_e
W-


W_T at M = 3000 GeV
100
10
1
0.1
0.01
dN/dlnx
10^{-4}
10^{-3}
0.01
0.1
1
x=E/M


W_T at M = 3000 GeV
100
10
1
0.1
0.01
dN/dln$x$
10^{-4}
10^{-3}
0.01
0.1
1
x=E/M

- Relevant for energy spectra when DM mass is much larger than EW scale
- All final stable particles are present
- The low energy part can be greatly enhanced

$$\frac{d\Phi}{dE_\gamma} = n^2 \langle v\sigma\rangle_{e^+e^-} \frac{dN}{dE_\gamma}$$

There is one relevant case in which
the cross section can be greatly altered...

JCAP 1106 (2011) 018

On the Importance of Electroweak Corrections for Majorana Dark Matter Indirect Detection

Paolo Ciafaloni [a], Marco Cirelli [b,c], Denis Comelli [d]
Andrea De Simone [e], Antonio Riotto [b,f], Alfredo Urbano [a,g]

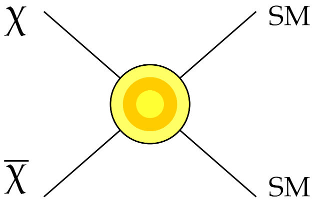
[a] *Dipartimento di Fisica, Università di Lecce and INFN - Sezione di Lecce, Via per Arnesano, I-73100 Lecce, Italy*
[b] *CERN, PH-TH Division, CH-1211, Genève 23, Switzerland*
[c] *Institut de Physique Théorique, CNRS URA 2306 and CEA/Saclay, F-91191 Gif-sur-Yvette, France*
[d] *INFN - Sezione di Ferrara, Via Saragat 3, I-44100 Ferrara, Italy*
[e] *Institut de Théorie des Phénomènes Physiques, École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland*
[f] *INFN, Sezione di Padova, Via Marzolo 8, I-35131, Padova, Italy*
[g] *IFAE, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Spain*

Abstract

Recent analyses have shown that the inclusion of electroweak corrections can alter significantly the energy spectra of Standard Model particles originated from dark matter annihilations. We investigate the important situation where the radiation of electroweak gauge bosons has a substantial influence: a Majorana dark matter particle annihilating into two light fermions. This process is in p-wave and hence suppressed by the small value of the relative velocity of the annihilating particles. The inclusion of electroweak radiation eludes this suppression and opens up a potentially sizeable s-wave contribution to the annihilation cross section. We study this effect in detail and explore its impact on the fluxes of stable particles resulting from the dark matter annihilations, which are relevant for dark matter indirect searches. We also discuss the effective field theory approach, pointing out that the opening of the s-wave is missed at the level of dimension-six operators and only encoded by higher orders.

$$v\sigma(2 \rightarrow 2) = a + bv^2$$

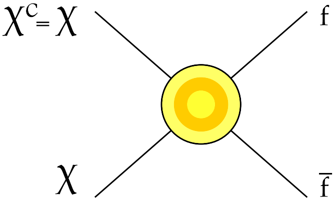
"s-wave" "p-wave"

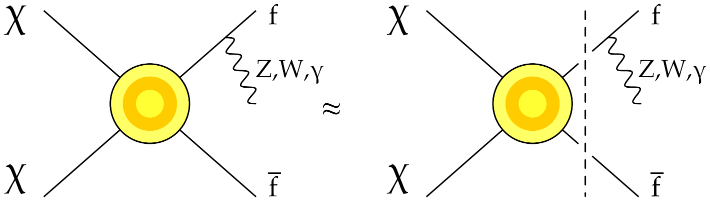


$$v\sigma(2\rightarrow 2) = \cancel{a} + b v^2$$

p-wave suppression

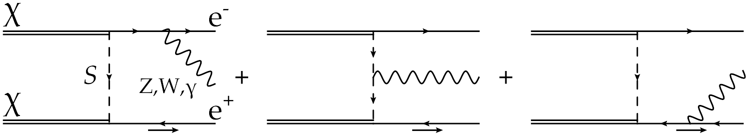
(remember $v = 10^{-3}$)





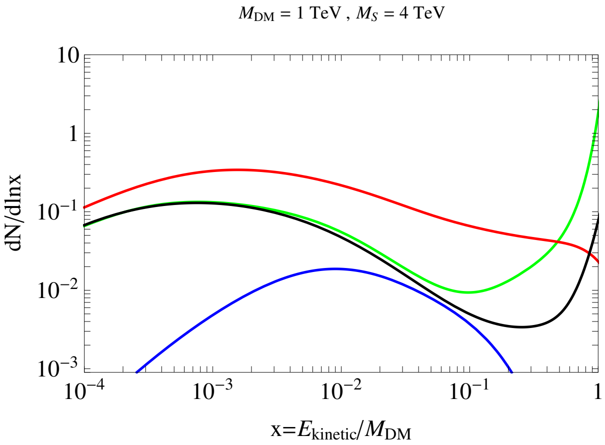
$$v\sigma(2 \rightarrow 3) \approx v\sigma(2 \rightarrow 2) \cdot D^{EW}$$

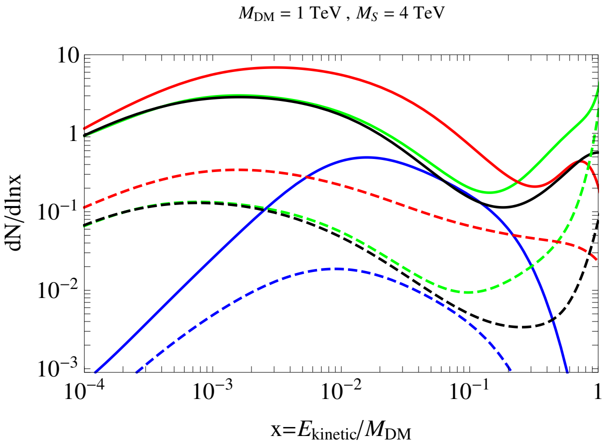
still $a = 0$ *!*



$$v\sigma(2\rightarrow 3) = a + bv^2$$

see L.Bergstrom, Phys. Lett. B225, 372 (1989) for γ


M_{DM} = 1 TeV , M_S = 4 TeV
dN/dlnx
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x=$E_{kinetic}/M_{DM}$


M_{DM} = 1 TeV , M_S = 4 TeV
10
1
10^{-1}
10^{-2}
10^{-3}
dN/dlnx
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x=$E_{kinetic}/M_{DM}$

- Relevant for energy spectra when DM mass is much larger than EW scale
- Relevant when there is a suppression mechanism for the 2-body cross section
- All final stable particles are present
- The low energy part can be greatly enhanced