The role of ElectroWeak corrections in indirect Dark Matter searches

Paolo Ciafaloni

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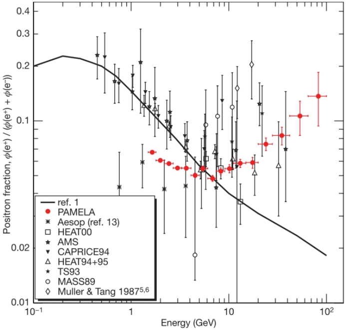
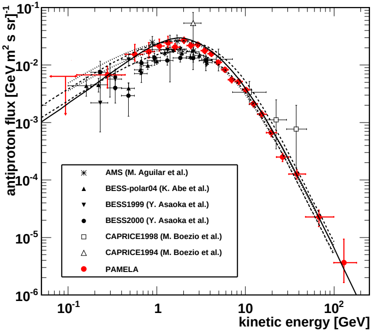
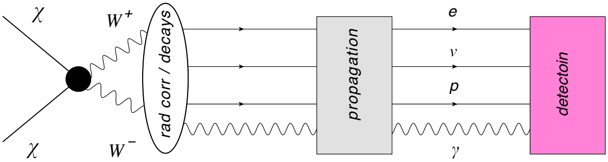
Firenze, 18/12/2013

Results from PAMELA (2008-2009)





Indirect DM search and radiative corrections



- If Physics ($\mathcal{L}$) is known, what is the spectrum of stable particles ($e^{\pm}, \nu, p, \gamma$) at the interaction point?
- Radiative EW corrections significantly alter the final answer?

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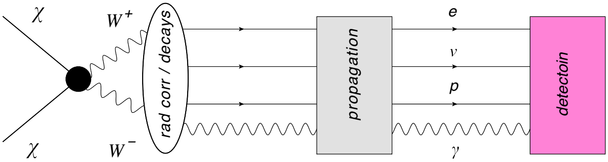

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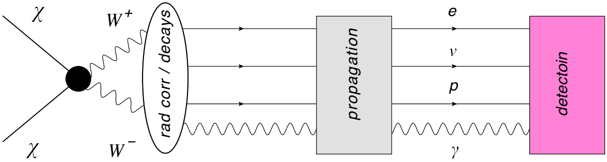

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Effects of radiative weak corrections

P.C., D. Comelli, A. Riotto, F. Sala, A. Strumia, A. Urbano (arXiv:1009.0224)

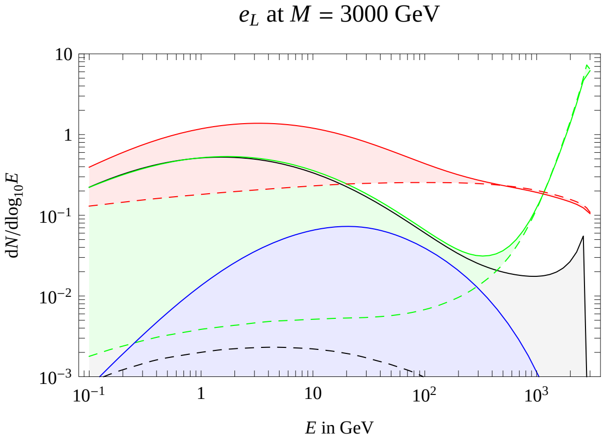

Figure: e^+ (green), $\bar{p}$ (blue), γ (red), $\nu = (\nu_e + \nu_\mu + \nu_\tau)/3$ (black)

Assumptions: SM up to $M > M_W$, extended preserving gauge invariance.

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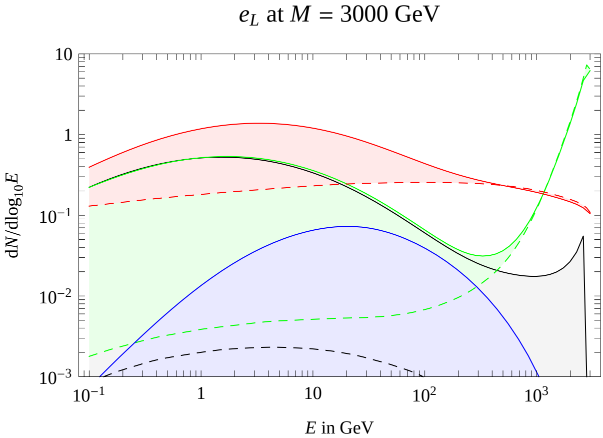

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Effects of radiative weak corrections

Why do weak corrections have such a big effect on the spectrum?

I) Weak corrections "not so weak" at the TeV scale

II) Soft gauge bosons emission → high multiplicity, soft spectrum greatly enhanced

III) Weak interactions connect all SM particles

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EW corrections - I

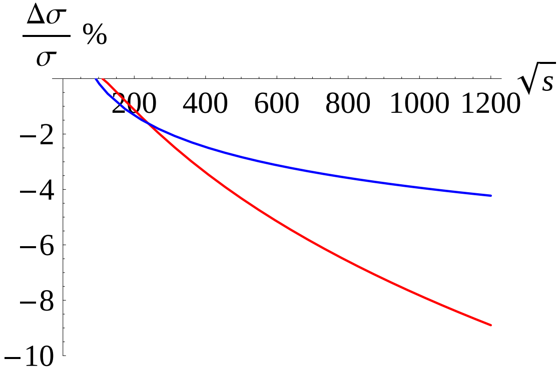
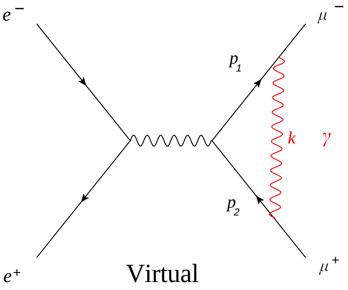
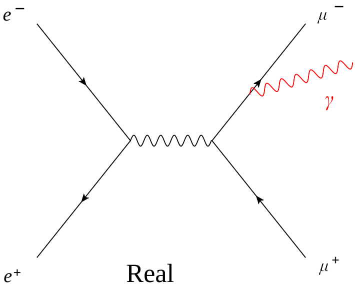


Figure: 1 loop EW and RGE relative corrections to $\sigma(e^+e^- \to \mu^+\mu^-)$ as a function of the c.m. energy in GeV.

EW corrections - I



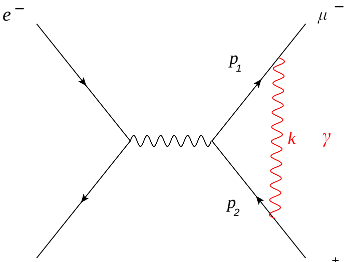
Virtual



Real

- $\int \frac{d^3k}{\omega} \frac{(p_1 p_2)}{(p_1 k)(p_2 k)} \approx \int \int \frac{d\omega}{\omega} \frac{d\theta}{\theta} \sim -\alpha \log^2 \frac{E}{\lambda}$
- $\sigma^V + \sigma^R \approx \sigma_B (1 - \alpha \log^2 \frac{s}{\Delta^2})$
- $(\sigma^V + \sigma^R)_{Resum} \approx \sigma_B \exp[-\alpha \log^2 \frac{s}{\Delta^2}]$

EW corrections - I



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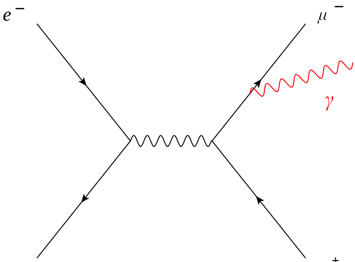

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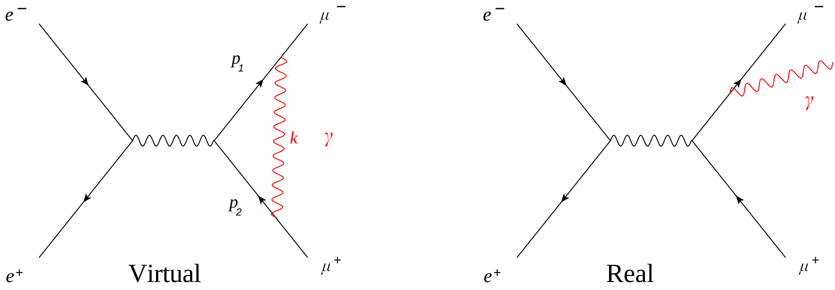

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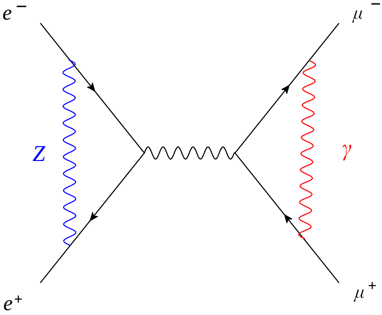

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- no *need* to add real emission
- $\alpha_w \log^2 \frac{s}{M^2} \sim 10$ % at 1 TeV: Dominant contribution. Higher orders?

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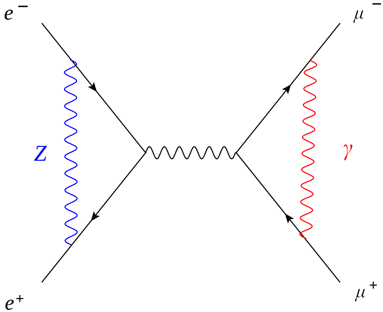

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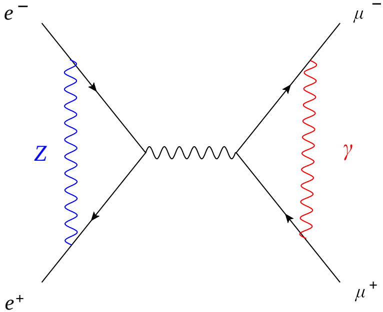

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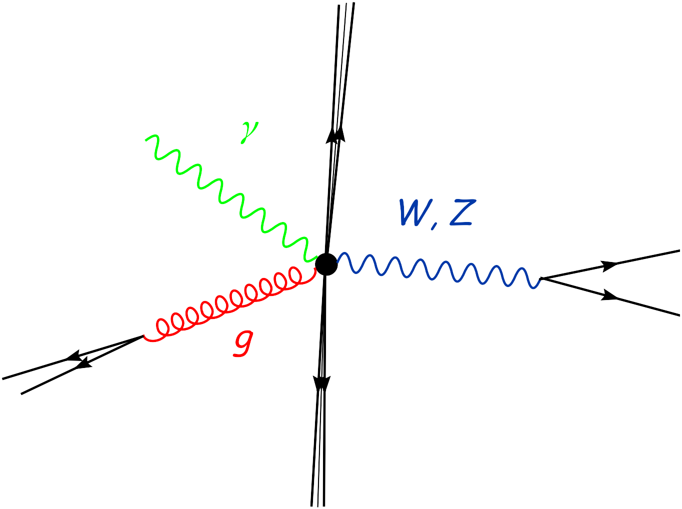
EW corrections - I

Inclusive observables



Include real emission ⇒ "infrared safe, no large logs?

EW corrections - I

Early Unification

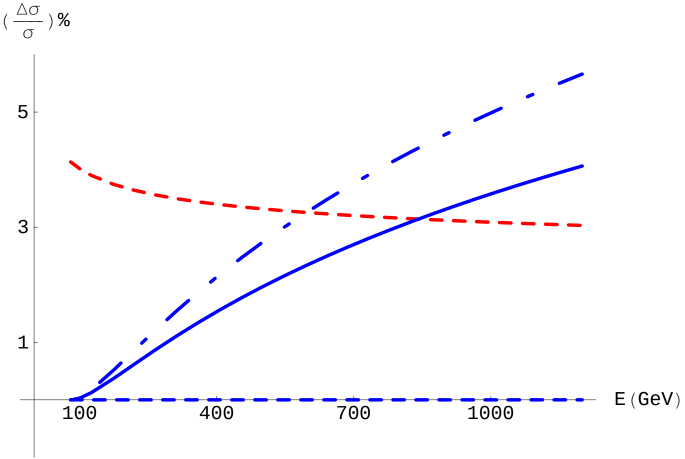
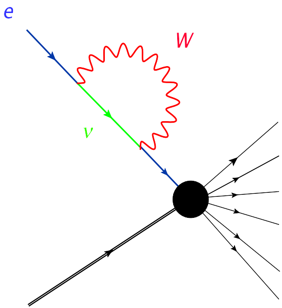
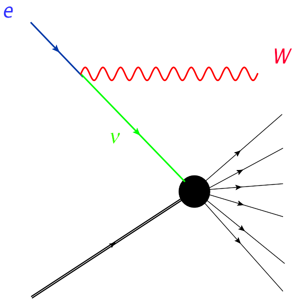


Figure: QCD ($\propto \frac{\alpha_s}{\pi}$) and EW ($\propto \frac{\alpha_s}{\pi} \log^2 \frac{s}{M_W^2}$) corrections to $e^+e^- \to 2j + X$

EW corrections - I

BN Violation





- $-\sigma_e \log^2 \frac{s}{M_W^2} + \sigma_\nu \log^2 \frac{s}{M_W^2} \neq 0$
- What about IR theorems?
- A neat example of the effects of spontaneous symmetry breaking!

EW corrections - I

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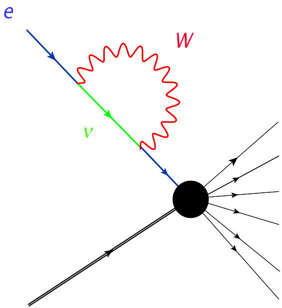

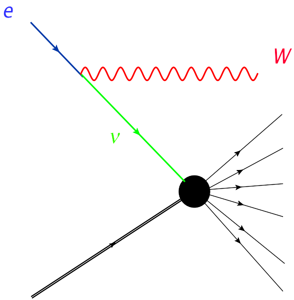

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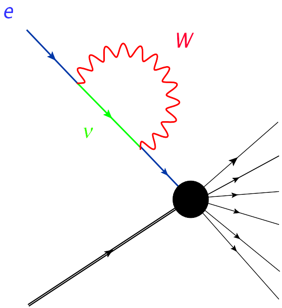

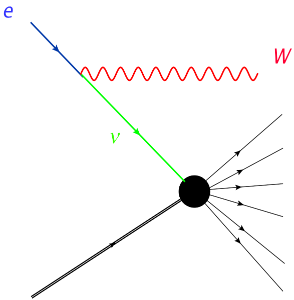

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EW corrections - I

Where we stand

- Fixed order calculations (up to 2 loops) and resummations (Comelli, M.Ciafaloni, P.C, Pozzorini, Denner, Kühn, Melles, Fadin,....)
- Asymptotic behaviour ($s >>> M_W^2$) for fully inclusive and fully exclusive observables can be written in terms of external legs quantum numbers.
- Surprise! Charge violating amplitudes can grow indefinitely with energy!

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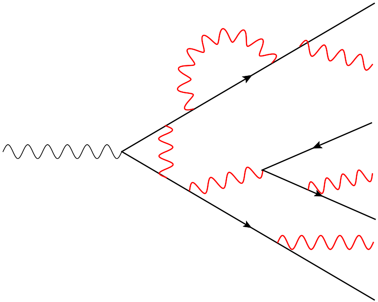

- Factorization: $\sigma_i = \sigma_B P_i$
- Unitarity: $\sigma_{TOT} = \sigma_B(P_0 + P_1 + P_2 + \dots) = \sigma_B$
- As energy grows, $P_0 \to 0$ and probability shifted towards higher i's
- One hard (TeV) positron becomes 1000 soft (GeV) particles

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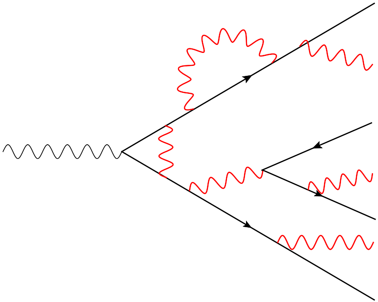

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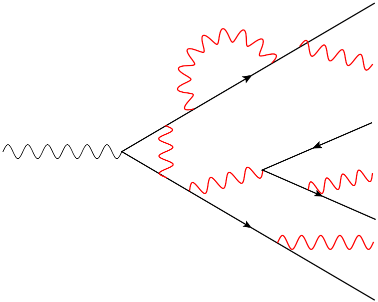

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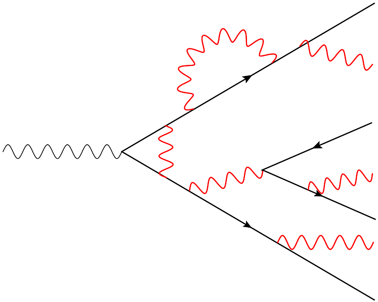

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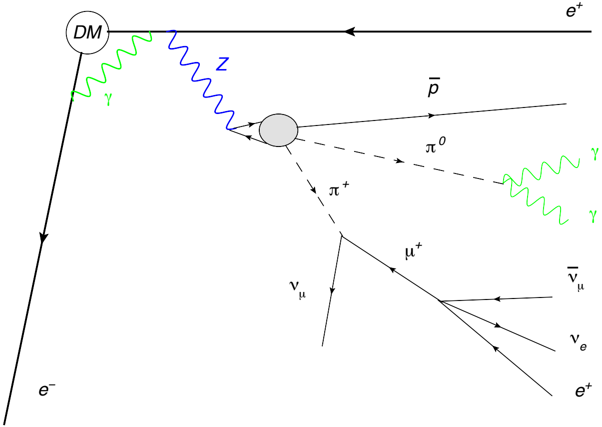
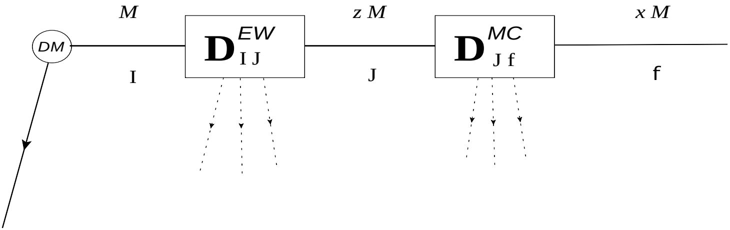
EW Corrections - III

Electroweak cascade



Calculating spectra of stable particles



$$\frac{dN_{I\to f}}{d\ln x}(M,x) = \sum_J \int_x^1 dz\, D^{\rm EW}_{I\to J}(z)\; D^{\rm MC}_{J\to f}\left(\frac{x}{z}\right)$$

$$I,J = W^{\pm}_{T,L}, e^{\pm}_{L,R}, .. \qquad f = e^{\pm}, \gamma, \bar{p}, \nu$$

Calculating spectra of stable particles

EW Evolution Equations

$$\frac{\partial D^{\rm EW}_{I\to J}(z,\mu^2)}{\partial \ln \mu^2} = -\frac{\alpha_2}{2\pi} \sum_k \int_x^1 \frac{dy}{y} P^{\rm EW}_{I\to K}(y,\mu^2)\, D^{\rm EW}_{K\to J}(z/y,\mu^2).$$

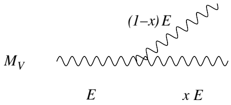
$$D^{\rm EW}_{I\to J}(z,\mu^2=s) = \delta_{IJ}\,\delta(1-z);$$

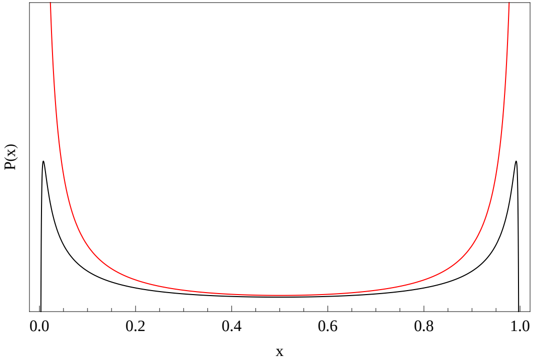
EW kernels P^{EW} feature log μ^2 terms, therefore:

$$D^{\rm EW}_{I\to J}(z) = D_2(z)\,\ln^2\frac{M}{M_W} + D_1(z)\,\ln\frac{M}{M_W} + D_0(z)$$

Generically neglect D_0, however for $x\to 0$ and $x\to 1$ ....

A side remark





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- Improve through *eikonal* approximation: $P_{V\to V}(x = \frac{M_V}{E}, 1 - \frac{M_V}{E}) = 0$
- Possibly relevant also for "Effective W approximation"

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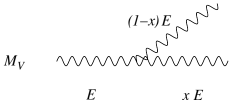

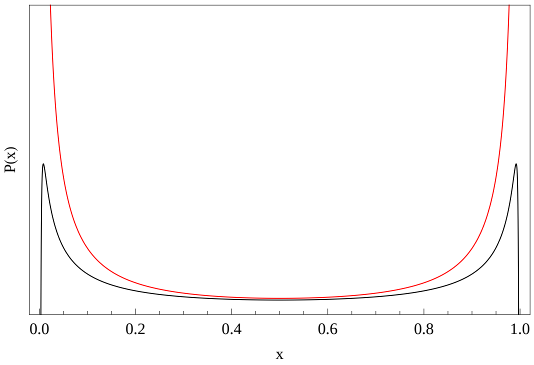

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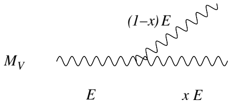

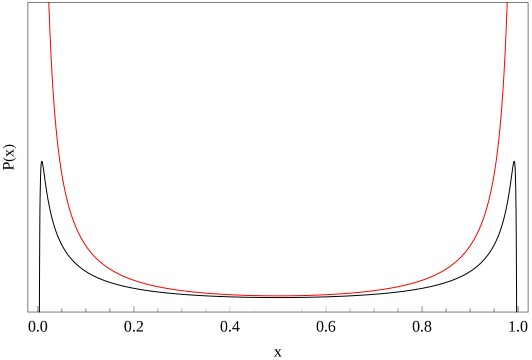

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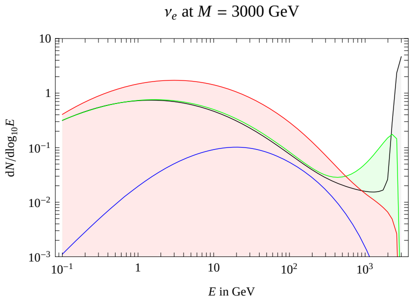
Primary Spectra



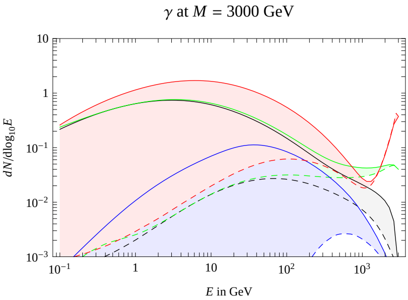
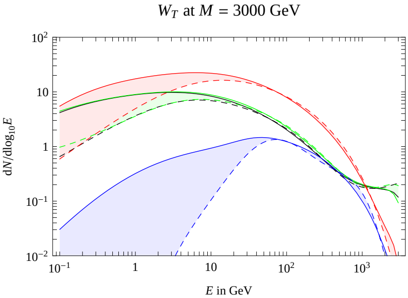
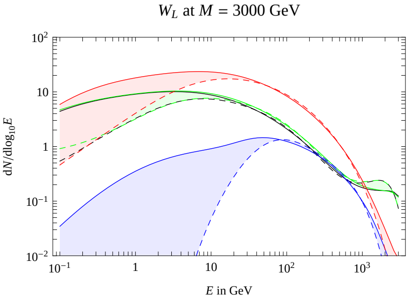
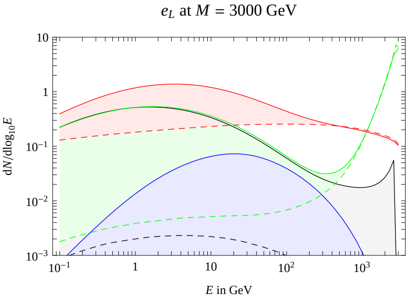


Figure: *Comparison between spectra with (continuous lines) and without EW corrections (dashed). The final states are: e^+ (green), $\bar{p}$ (blue), γ (red), $\nu = (\nu_e + \nu_\mu + \nu_\tau)/3$ (black).*


W_T at M = 3000 GeV
dN/dlog$_{10}E$
10^2
10
1
10^{-1}
10^{-2}
10^{-1}
1
10
10^2
10^3
E in GeV


W_L at M = 3000 GeV
dN/dlog$_{10}E$
10^2
10
1
10^{-1}
10^{-2}
10^{-1}
1
10
10^2
10^3
E in GeV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dN/dlog$_{10}E$
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
10
10^2
10^3
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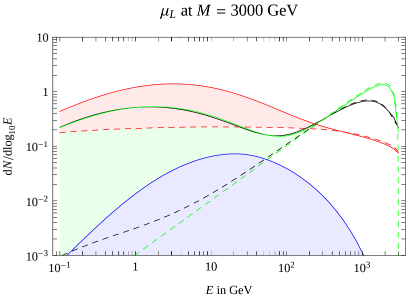

μ_L at M = 3000 GeV
dN/dlog$_{10}E$
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
10
10^2
10^3
E in GeV

Effects of propagation - an example

DM DM → $W_T^+ W_T^-$ with M = 10 TeV, MIN, NFW

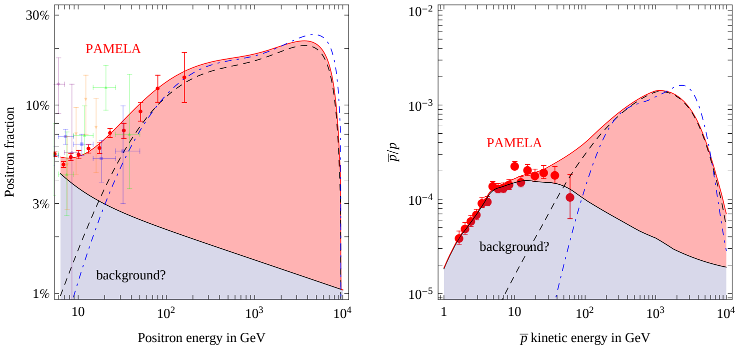
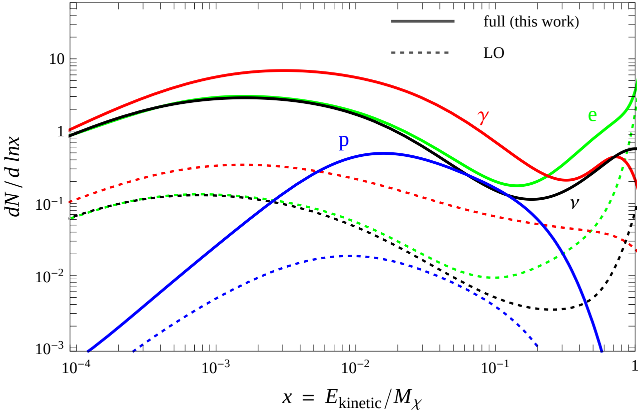


Figure: *DM signals in the e^+ (left) and $\bar{p}$ (right) fraction, with (dashed) and without (dot-dashed) electroweak corrections for a $W_T^+ W_T^-$ channel.*

Opening forbidden channels

$$\langle v\sigma \rangle = a + bv^2; \quad v \approx 10^{-3} \quad \chi\chi \to f\bar{f} \Rightarrow a = 0$$

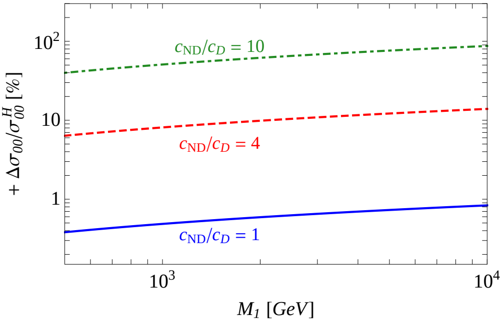
$$\chi\chi \to f\bar{f}V \Rightarrow a \neq 0 \text{ (ang. mom. cons., C arguments fail)}$$



Thermal abundance

$$\frac{d(na^3)}{a^3 dt} = -\langle v\sigma_{eff}\rangle(n^2 - n_{eq}^2); \quad \langle v\sigma_{eff}\rangle = \sum_{abf} r^a r^b (\sigma_{\chi^a\chi^b\to ff} + \sigma_{\chi^a\chi^b\to ffW})$$

$$r_a = \frac{n_a^{eq}}{n_a} \propto \delta_{a0} + \cdots \text{ for } \Delta_a = \frac{M_\chi^a - M_\chi^0}{M_\chi^0} \geq \frac{1}{25}$$



Conclusions (Summary)

- "One-loop Bloch-Nordsieck Theorem":

$$\sum_{a,b,f}\left[\left|\mathcal{M}^{(0)}+\mathcal{M}^{(1)}\right|^2_{ab\to f}+\int d\Pi_W \left|\mathcal{M}\right|^2_{ab\to f+W}\right] \overset{IR}{=} 0$$

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- Large BN violating corrections:

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  - LHC, ILC: isolated initial charges
  - Indirect DM: not fully inclusive energy spectra
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Extra slide

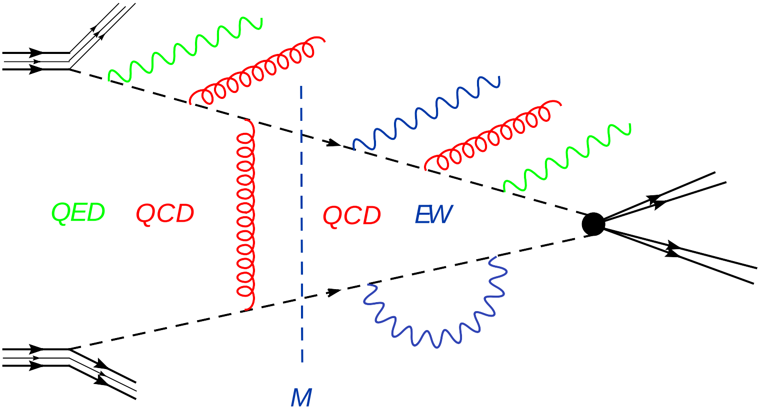

Figure: Equazioni di evoluzione IR. Sotto M: QED, QCD Sopra M: QCD, "symmetric" EW con 4 gauge bosons degeneri. $\sigma = f(\mu^2) \otimes \sigma_H(E)$; $\frac{\partial f}{\partial \log \mu^2} = P(\mu^2) \otimes f$