Weak corrections are relevant for indirect Dark Matter searches

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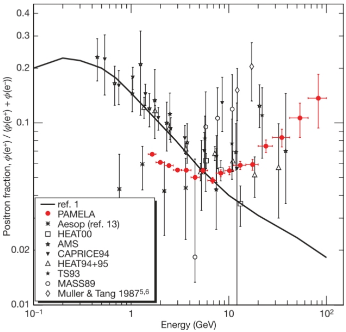
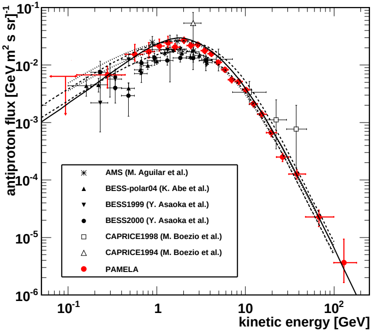
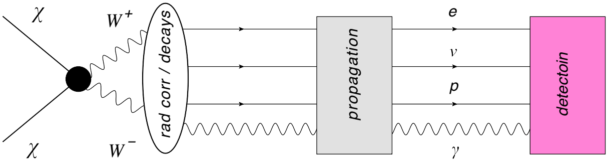
Results from PAMELA (2008-2009)





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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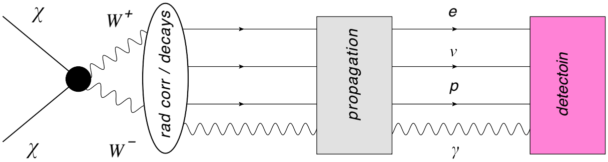

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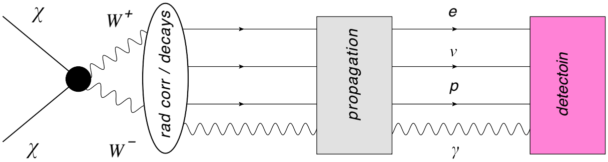

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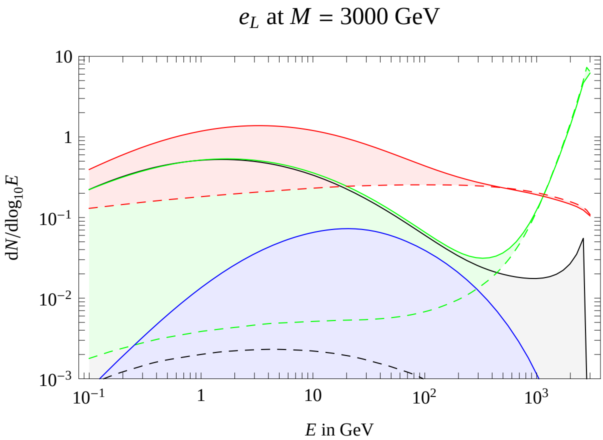

Figure: e^+ (green), $\bar{p}$ (blue), γ (red), $\nu = (\nu_e + \nu_\mu + \nu_\tau)/3$ (black)

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

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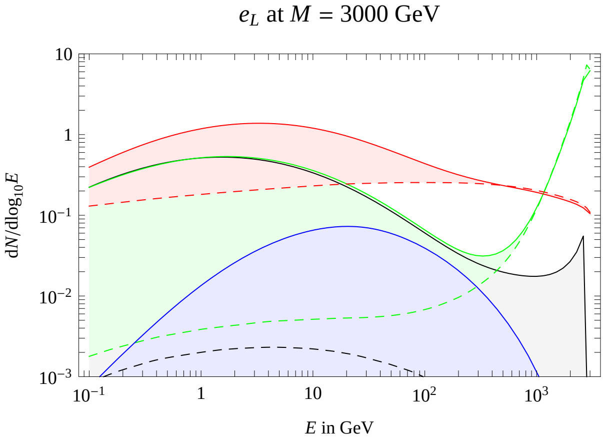

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Effects of radiative weak corrections

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

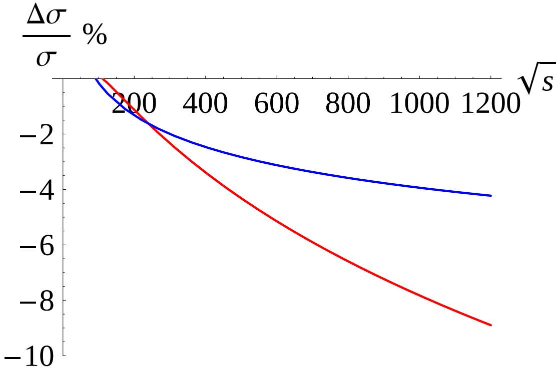
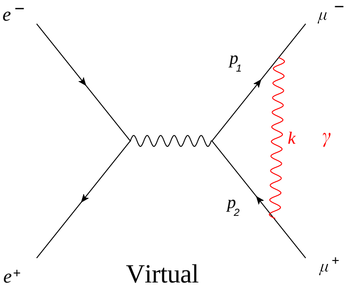
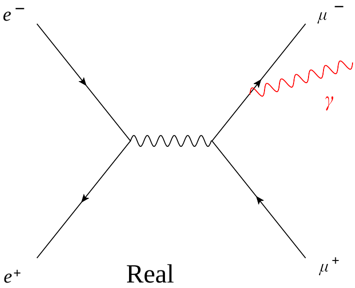


Figure: 1 loop EW and RGE relative corrections to $\sigma(e^+e^- \to \mu^+\mu^-)$ as a function of the c.m. energy in GeV.

EW corrections - I





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

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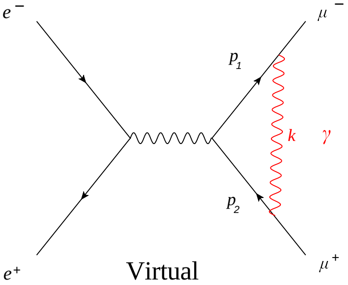

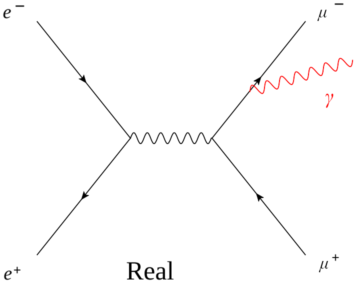

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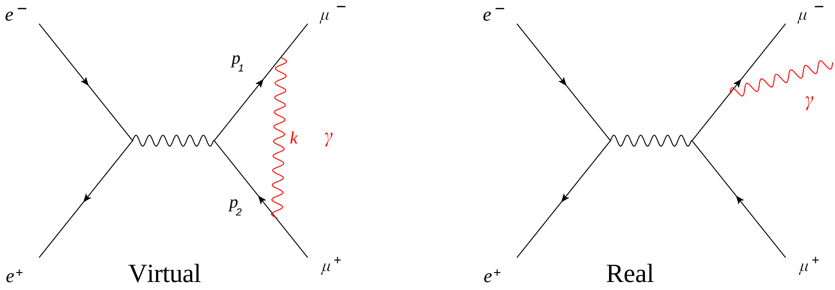

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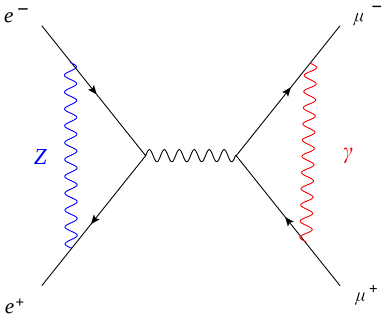

- $\sigma \sim \sigma_B \exp[-\alpha_w \log^2 \frac{s}{M^2}]$ $\qquad M = M_Z \sim M_W$
- no *need* to add real emission
- $\alpha_w \log^2 \frac{s}{M^2} \sim 10\ \%$ at 1 TeV: Dominant contribution. Higher orders?

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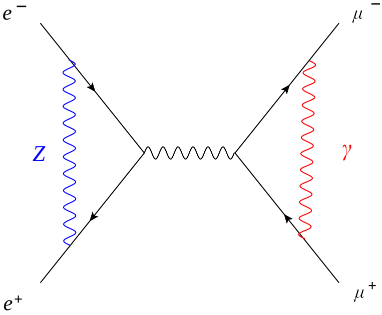

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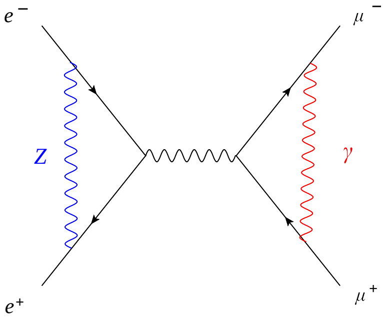

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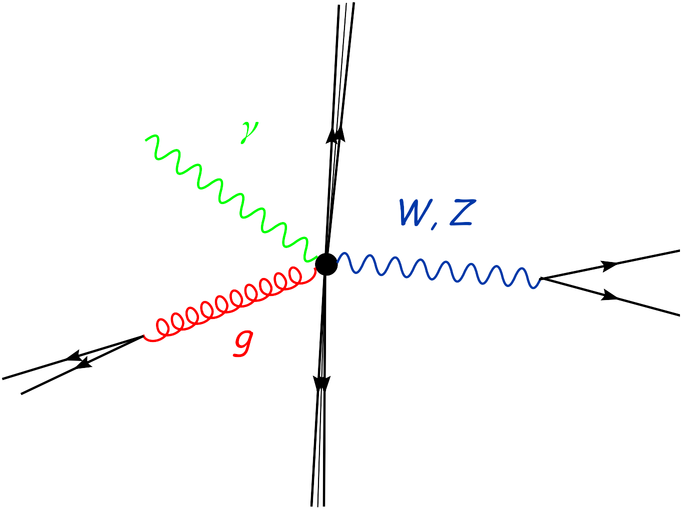
EW corrections - I

Inclusive observables



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

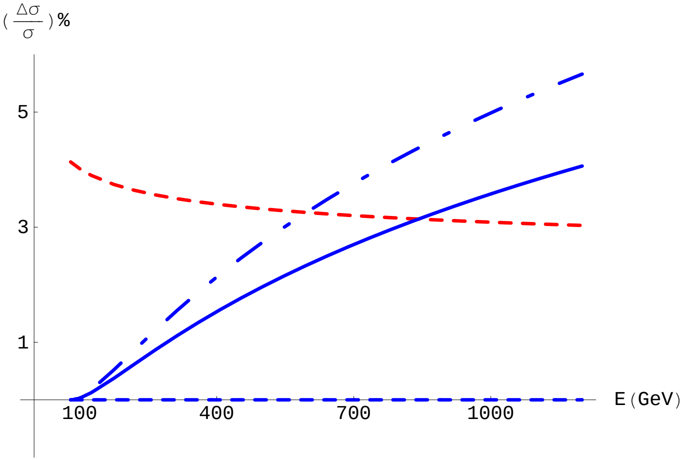
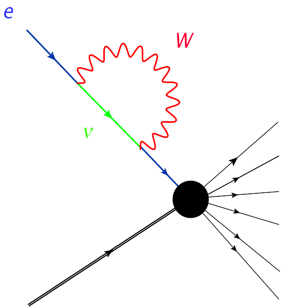
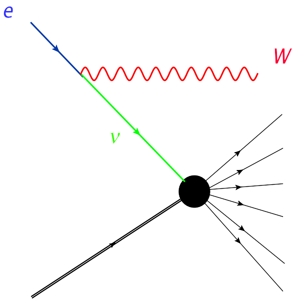


Figure: QCD ($\propto \frac{\alpha_s}{\pi}$) and EW ($\propto \frac{\alpha_s}{\pi} \log^2 \frac{s}{M_W^2}$) corrections to $e^+e^- \to 2j + X$

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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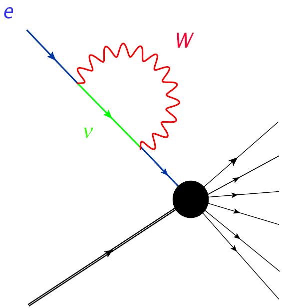

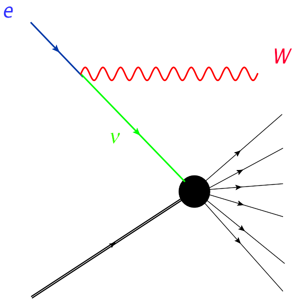

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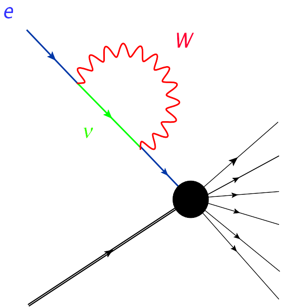

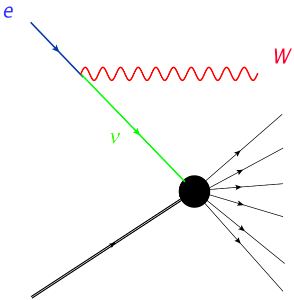

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EW corrections - I

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.
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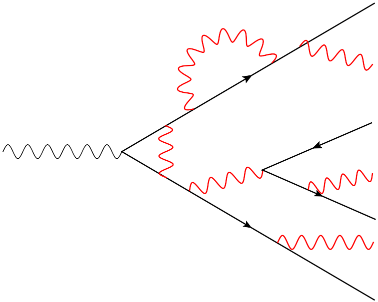
EW Corrections - II

High Multiplicity



- Factorization: $\sigma_i = \sigma_B P_i$
- Unitarity: $\sigma_{TOT} = \sigma_B(P_0 + P_1 + P_2 + \ldots) = \sigma_B$
- 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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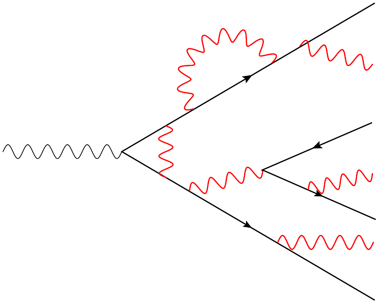

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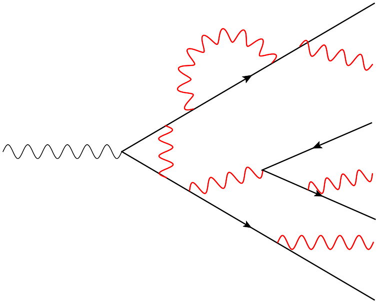

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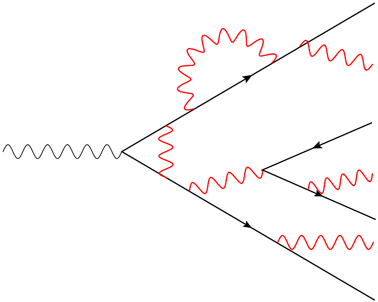

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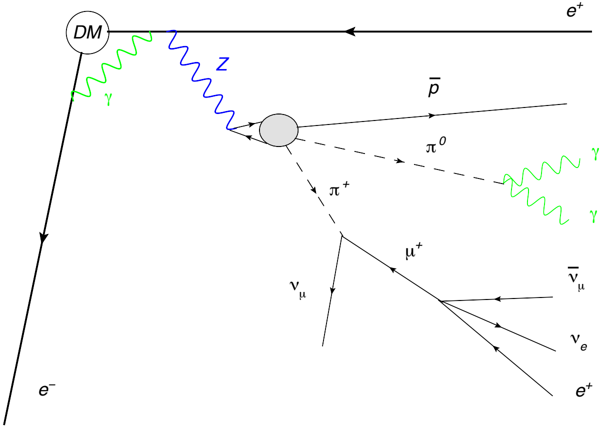
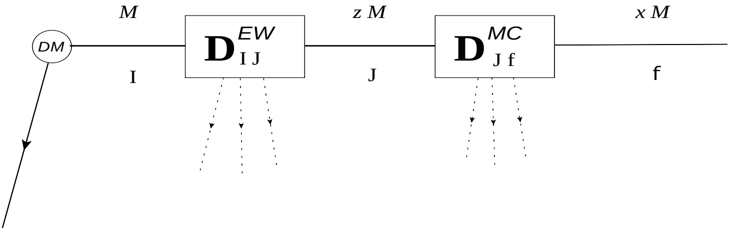
EW Corrections - III

Electroweak cascade



Calculating spectra of stable particles



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

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

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

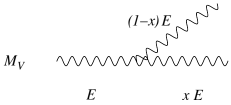
$$D^{\rm EW}_{I\to J}(z,\mu^2=s) = \delta_{IJ}\,\delta(1-z);$$

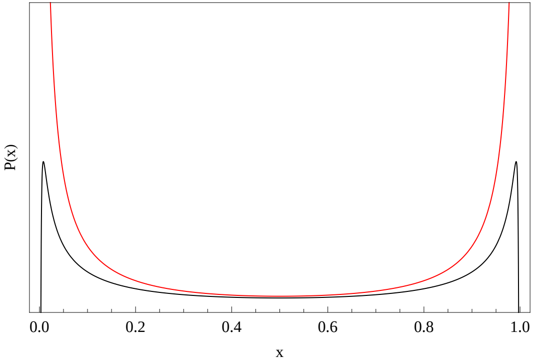
EW kernels P^{EW} feature log μ^2 terms, therefore:

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

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

A side remark





- $P^{coll}_{V\to V}(x) = \left[\frac{x}{1-x} + \frac{1-x}{x} + x(1-x)\right] \ln \frac{E^2}{M_V^2}$
- 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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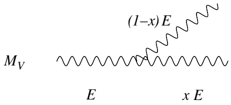

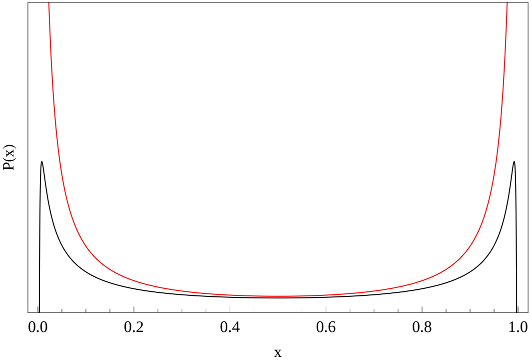

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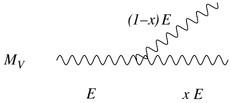

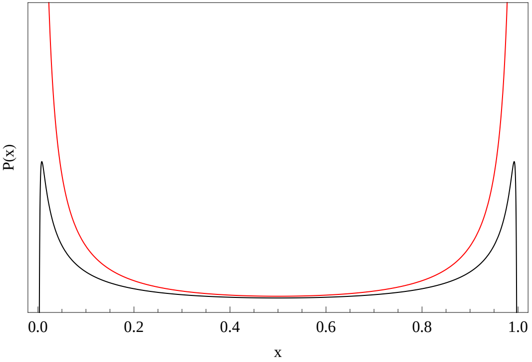

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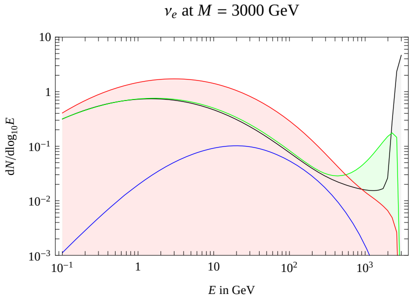
Primary Spectra



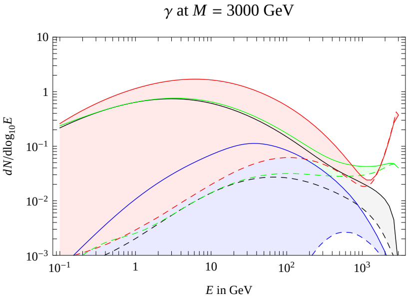
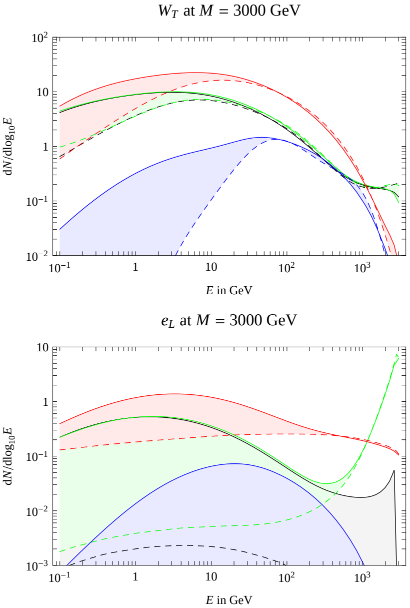


Figure: *Comparison between spectra with (continuous lines) and without EW corrections (dashed). The final states are:* e^+ *(green),* $\bar{p}$ *(blue),* γ *(red),* $\nu = (\nu_e + \nu_\mu + \nu_\tau)/3$ *(black).*


W_T at $M = 3000$ GeV
W_L at $M = 3000$ GeV
e_L at $M = 3000$ GeV
μ_L at $M = 3000$ GeV
$dN/d\log_{10}E$
E in GeV
10^{-1}
1
10
10^2
10^3
10^{-2}
10^{-3}

Effects of propagation - an example

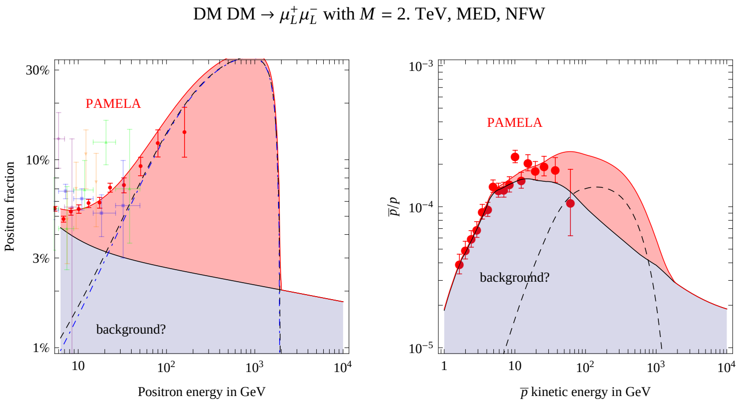


Figure: *DM signals in the e^+ (left) and $\bar{p}$ (right) fraction, with (dashed) and without (dot-dashed) EW corrections for a muonic channel.*

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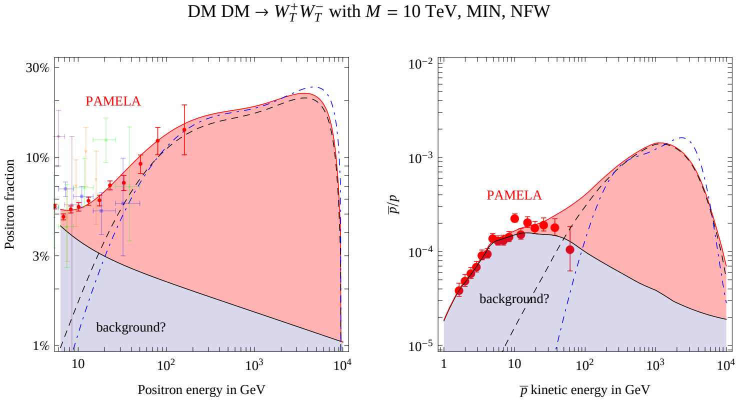
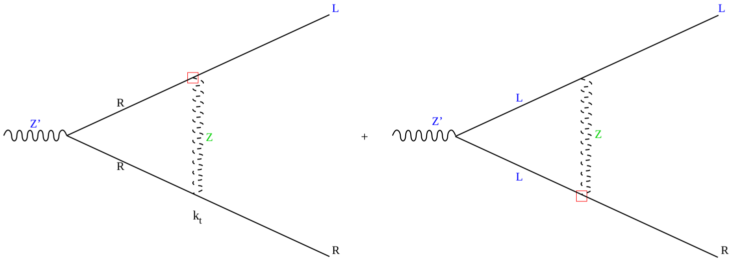


Figure: *DM signals in the e^+ (left) and $\bar{p}$ (right) fraction, with (dashed) and without (dot-dashed) electroweak corrections for a $W_T^+ W_T^-$ channel.*

Exotica

Exotica - I

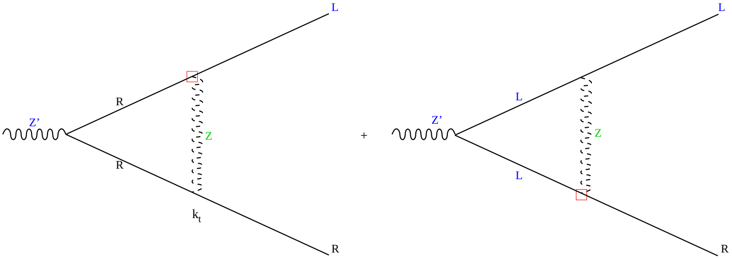
Anomalous Sudakov F.F. - P.C, M. Ciafaloni, D. Comelli



- Resummed IR DL: $\Gamma \sim e^{-L^2} + \rho e^{+L^2}$; $\rho = \frac{m^2}{s}$, $L^2 = \frac{\alpha}{4\pi} \log^2 \frac{s}{M_Z^2}$.
- Phenomenology: $\Gamma_{+-} \sim \Gamma_{++}$ for $\sqrt{s} \sim e^{\frac{\pi}{\alpha}}$
- Theory: Unitarity? Optical Theorem? KLN?
- To do: extension to nonabelian case (SM), cross sections, real emissions

Exotica - I

Anomalous Sudakov F.F. - P.C, M. Ciafaloni, D. Comelli



- Resummed IR DL: $\Gamma \sim e^{-L^2} + \rho e^{+L^2}$; $\rho = \frac{m^2}{s}$, $L^2 = \frac{\alpha}{4\pi} \log^2 \frac{s}{M_Z^2}$.
- Phenomenology: $\Gamma_{+-} \sim \Gamma_{++}$ for $\sqrt{s} \sim e^{\frac{\pi}{\alpha}}$
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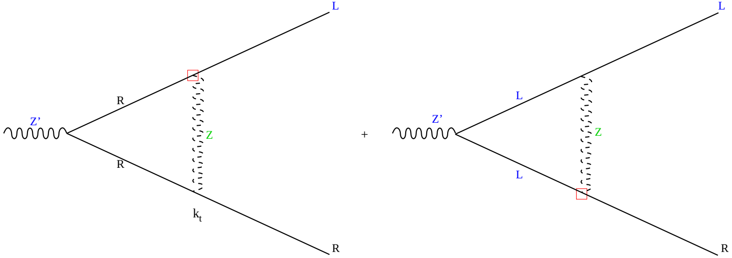

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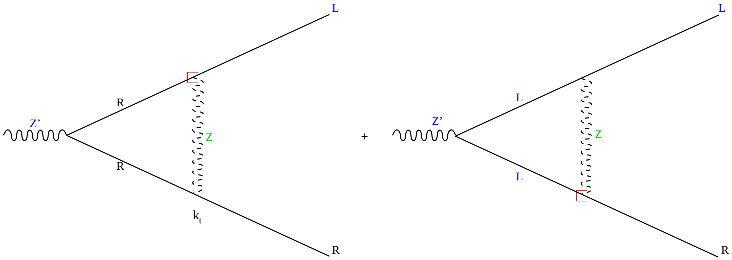

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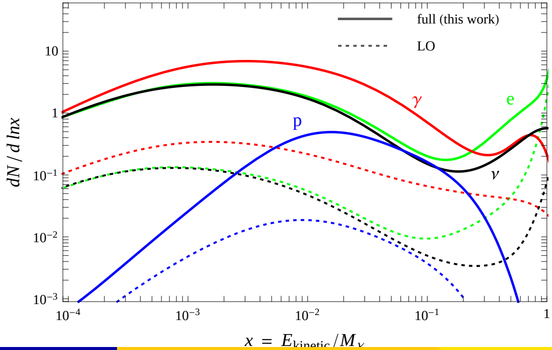
Exotica - II

P.C, M. Cirelli, D. Comelli, A. De Simone, A. Riotto, A. Urbano

- $v\sigma = a + bv^2 + \mathcal{O}(v^4)$; $\chi_M \chi_M \to f\bar{f}$: $a = 0$ for $m = 0$.
- $\chi\chi \to f'\bar{f}W$: one α_W more, but no $v^2 \sim 10^{-6}$ suppression $\Rightarrow$ it is dominant.
- Non factorized corrections can be dominant even for $\sqrt{s} \gg M_Z, M_W$.



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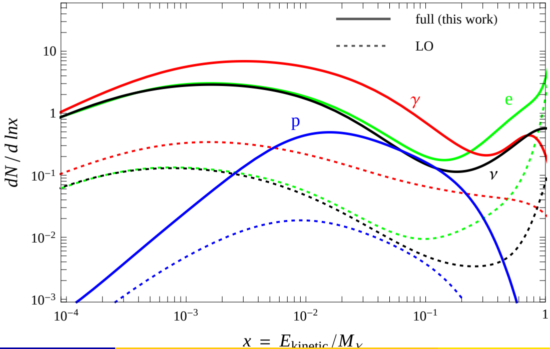

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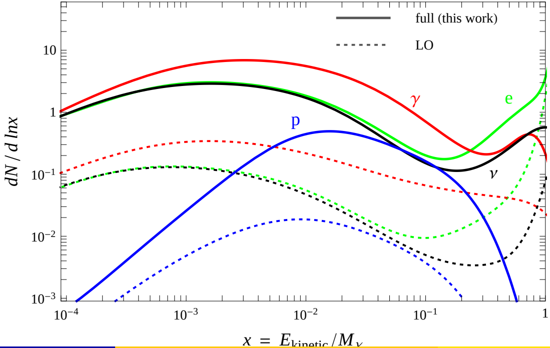
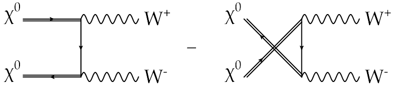
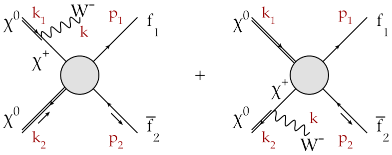
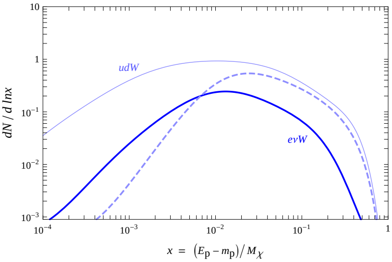


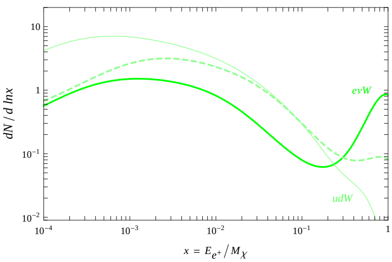
Exotica - II

Initial State Radiation









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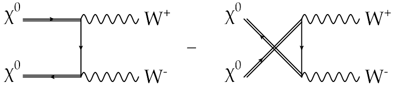

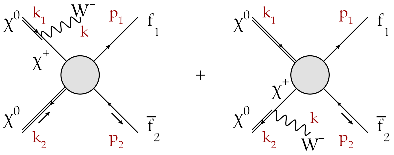

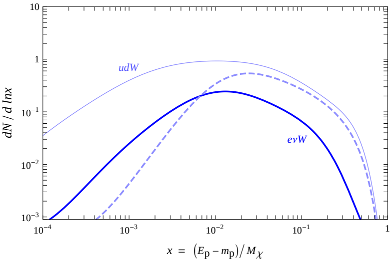

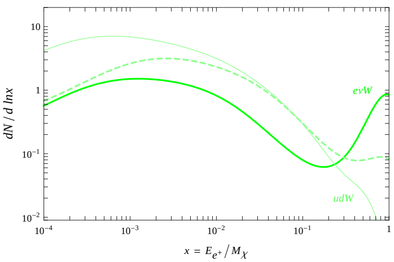

Conclusions

- EW corrections of IR origin potentially relevant if scale > few hundred GeV
- Indirect searches: EW corrections make DM more visible: spectra are more "democratic"
- Harder to reconcile with "one channel anomaly" situation: correlations are interesting in future perspective
- Other situations in Cosmology/Astroparticle where "big" EW corrections are interesting?

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Extra slide

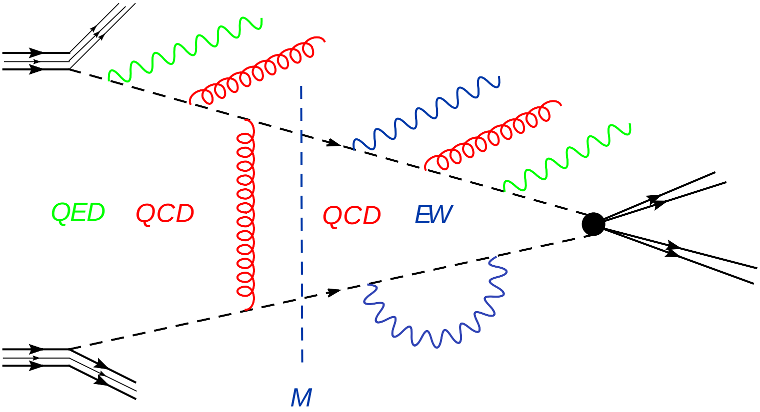

Figure: Equazioni di evoluzione IR. Sotto M: QED, QCD Sopra M: QCD, "symmetric" EW con 4 gauge bosons degeneri. $\sigma = f(\mu^2) \otimes \sigma_H(E)$; $\frac{\partial f}{\partial \log \mu^2} = P(\mu^2) \otimes f$