EW LIGHTS FROM DM ANNIHILATIONS

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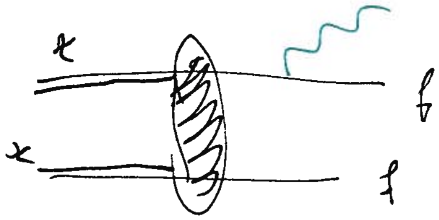
- Indirect Searches for DM look for fluxes of particles originating from annihilations of DM in the halo
- Very important to have under control all effects having an impact on the predicted fluxes.
- Radiation of EW bosons from the final state is one such example.

~~Big impact~~



Big Impact in 3 situations:

1. low-energy tails: mostly populated by the decay products of the extra gauge boson
2. Secondary species: when some stables particles are absent without EW radiation (e.g. $\chi\chi \to e^+e^-$ gives $\bar{p}$)
3. $2 \to 2$ suppression: $\sigma_{ann}(2\to2)$ suppressed so $\sigma(2\to3)$ can even dominate.

DM (χ): Majorana fermion and SM singlet (e.g. BINO in SUSY)

$$\sigma(\chi\chi \to f\bar{f}) = \cancel{a} + b v^2 \qquad (v \sim 10^{-3})$$

$a \propto \left(\frac{m_f}{m_{DM}}\right)^2$; $b v^2 \to$ p-wave.

- The inclusion of EW radiation can elude the suppression and open up the s-wave.
  (known already for the photon radiation)

- Even if suppressed by $\frac{\alpha_W}{4\pi}$, the $\sigma(\chi\chi \to f\bar{f}Z)$ can be comparable with $\sigma(\chi\chi \to f\bar{f})$ because $v \sim 10^{-3}$.

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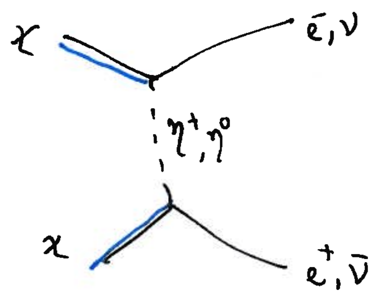
Toy MODEL:

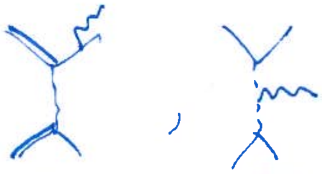
$$S = \begin{pmatrix} \eta^+ \\ \eta^0 \end{pmatrix}$$

$$\mathcal{L} = -M_S^2 S^\dagger S + y_L\left[\bar{\chi}(L \cdot S) + h.c.\right]$$



MASS PARAMETERS $M_\chi, M_S \rightsquigarrow M_\chi,\ r = \left(\frac{M_S}{M_\chi}\right)^2 \geq 1$

Now add EW emission



FSR , VIB

Schematically:

$$\mathcal{M} \sim \frac{1}{M_\chi}\left\{ v \left[\frac{1}{r} + \frac{1}{r^2} \right]_{FSR} + \left[\frac{1}{r^2}\Big|_{VIB} + \frac{1}{r^2}\Big|_{FSR} \right] \right\}$$

$\mathcal{O}(\frac{1}{r})$ **LO**

Important lesson 1: limiting the expansion to $\mathcal{O}(\frac{1}{r})$ in the amplitude would keep the p-wave

Important lesson 2: at $\mathcal{O}(\frac{1}{r^2})$, with VIB diagrams, an s-wave is opened.

Estimate

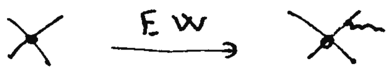
$$v\sigma_{2\to2} \sim \frac{1}{M_\chi^2}\frac{v^2}{r^2}$$

$$v\sigma_{2\to3} \sim \frac{1}{M_\chi^2}\frac{\alpha_w}{4\pi}\frac{1}{r^4}$$

3-body dominates when $\frac{v^2}{r^2} \lesssim \frac{\alpha_w}{4\pi}\frac{1}{r^4} \Rightarrow$ $r \lesssim \sqrt{\frac{\alpha_w}{4\pi}}\frac{1}{v} \sim \mathcal{O}(10)$

WARNING ON EFT

Integrate out the scalar: $\mathcal{L}_{eff} = \mathcal{L}_{SM} + \mathcal{L}_\chi + \frac{1}{r}\frac{\mathcal{O}_6}{M_\chi^2} + \frac{1}{r^2}\frac{\mathcal{O}_8}{M_\chi^4} + \ldots$

$\mathcal{O}_6 \sim$  LO $\Rightarrow$ p-wave

MISLEADING! NDA fails to assess the relative importance of operators.

$\mathcal{O}_8 \to$ s-wave, can be larger than $\mathcal{O}_6$ despite larger dimensionality.

MORE QUANTITATIVE ANALYSIS OF ENERGY SPECTRA

$$\chi\chi \rightarrow e^+e^-, \nu\bar{\nu} + \gamma/Z/W$$

→ MC generates primary annihilation events ($2\rightarrow 3$) according to squared-amplitude distributions.

→ PYTHIA for showering + hadronization + decay to final stable SM particles

→ Compared $\frac{dN/dE}{dN/dE|_{LO}} \sim \mathcal{O}(10-100)$ ($M_S = 4, 6, 8$ TeV) ($M_\chi = 1$ TeV)

Propagation in galactic halo does not spoil the effect.

CONCLUSION: RELIABLE CALCULATIONS OF FLUXES FOR INDIRECT DM DETECTION SHOULD TAKE EW CORR. INTO ACCOUNT

- Majorana DM can annihilate through s-wave
- Care when dealing with EFT.