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.

- Realization of EW bosons from the final state in one such an example.

[Diagram of EW boson decay]

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 stable particles are absent, different EW radiation (e.g., \(Z \rightarrow \text{stable} \rightarrow \text{products}\)).

3. 2-2 suppression: \(\sigma_{\text{cm}}(2 \rightarrow 2)\) suppressed so \(\sigma_{\text{cm}}(2 \rightarrow 3)\) can win dominate.
DM (2) Majorana fermion and SM singlet (e.g. Bino in SUSY)

\[ \sigma(x\rightarrow f \bar{f}) = \frac{\alpha}{m_f^2} + 6\nu^2 \left( \nu \approx 10^{-3} \right) \]

\[ \alpha \left( \frac{m_f}{m_{\text{min}}} \right)^2 \text{ p-wave.} \]

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

- Even if suppressed by \( \frac{\alpha}{m_f^2} \), the \( \sigma(x\rightarrow f \bar{f}) \) can be compatible with \( \sigma(x\rightarrow f \bar{f}) \) becomes \( \nu \approx 10^{-3} \).

Toy Model:

\[ S = \left( \begin{array}{c} \eta^+ \\ \eta^0 \end{array} \right) \]

\[ \mathcal{L} = -M_S^2 \eta^+ \bar{\eta} + y_L [E(L \cdot S) + h.c.] \]

MASS PARAMETERS \( M_\chi, M_S \rightarrow M_\chi, R = \frac{(M_S)^2}{(M_\chi)^2} \gg 1 \)
Now add EW emission

Schematically:

\[ H \sim \frac{1}{M^2} \left\{ \sum \left[ \frac{1}{r^2} + \frac{1}{r^2} \right]_{\text{FSR}} + \left[ \frac{1}{r^2} + \frac{1}{r^2} \right]_{\text{VIB}} \right\} \]

\[ O(\frac{1}{f}) \]

**Important lesson:** Limiting the expansion to \( O(\frac{1}{f}) \) in the amplitude would keep the p-wave.

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

**Estimate**

\[ \sqrt{G_{2\to 2}} \sim \frac{1}{M^2} \frac{\sqrt{s}}{r^2} \]

\[ \sqrt{G_{2\to 3}} \sim \frac{1}{M^2} \frac{\Delta \omega}{4\pi} \frac{1}{r^4} \]

3-body decay, where

\[ \frac{\sqrt{s}}{r^2} \ll \frac{\Delta \omega}{4\pi} \frac{1}{r^4} \Rightarrow r_s \leq \sqrt{\frac{\Delta \omega}{4\pi}} \frac{1}{\sqrt{s}} \sim O(10) \]

**WARNING on EFT**

Integrate out \( \phi \) to obtain:

\[ \text{Left} = \mathcal{L}_{\text{SM}} + \frac{1}{f} \mathcal{L}_x + \frac{1}{r} \frac{\mathcal{O}_6}{M^6} + \frac{1}{r^2} \frac{\mathcal{O}_8}{M^8} + \ldots \]

\[ O_6 \sim \mathcal{E} \rightarrow \mathcal{E} + \mathcal{L}_0 \rightarrow \mathcal{O}_p \rightarrow \text{p-wave} \]

**MISLEADING!** No \( \phi \) fails to assess the relative importance of operators.

\( O_6 \to s\text{-wave}, \) can be stronger than \( O_6 \) despite being dominantly.

\[ \text{LO} \]
More quantitative analysis of energy spectra

\[ \tau \rightarrow \ell^+\ell^-, \nu\bar{\nu} + \gamma/\text{W} \]

\[ \rightarrow \text{MC generates primary annihilation events (2 \rightarrow 3)} \]
\[ \text{according to squared-amplitude distributions.} \]

\[ \rightarrow \text{PYTHIA for showering + hadronization + decay to} \]
\[ \text{final stable SM particles} \]

\[ \text{Expected } \frac{dN/dE}{dN/dE|_{W}} \sim 0(10-100) \]
\[ (M_5 = 4, 6, 8 \text{ TeV}) \]
\[ (M_3 = 1 \text{ TeV}) \]

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