A TeV scale messenger (e.g. 750 GeV) of Dark Matter

Andi Hektor
(NICPB, Tallinn, Estonia)
[in collaboration with L. Marzola, M. Raidal, S. Di Chiara, K. Kannike]

CERN, TeVPA
Sept 16, 2016
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• From the effective WIMP to the simplified WIMP
• Two ways to escape from Direct Detection
  (i) ‘Coy DM’
  (ii) ‘Resonance Portal’
• ‘Coy DM’
  • Gamma-ray line signal from Coy DM
  • A pseudoscalar case of TeV-scale mediator
• ‘Resonance portal’
  • Life in the resonance zone is interesting — velocity dependent annihilation signal!

Based on:
1403.3401, 1507.05096, 1602.00004, 1603.07263
& two appearing in some next weeks
Effective WIMP

thermal freeze-out (early Univ.)
indirect detection (now)

direct detection

production at colliders

\[ \mathcal{L}_{\text{EFT}} = \frac{1}{M_*^2} (\bar{q} q)(\bar{\chi} \chi) \]
From the effective to the simplified DM

\[ \mathcal{L}_{\text{EFT}} = \frac{1}{M_{\chi}^2} (\bar{q} q) (\bar{\chi} \chi) \]

\[ \mathcal{L}_{0_{SS\frac{1}{2}}} = \frac{1}{2} (\partial_{\mu} S)^2 - \frac{1}{2} m_S^2 S^2 + \bar{\chi} (i \partial_{\mu} - m_\chi) \chi - g_S S \bar{\chi} \chi - g_{SMA} S \sum_f \frac{y_f}{\sqrt{2}} \bar{f} f \]

\[ \mathcal{L}_{0_{AS\frac{1}{2}}} = \frac{1}{2} (\partial_{\mu} A)^2 - \frac{1}{2} m_A^2 A^2 + \bar{\chi} (i \partial_{\mu} - m_\chi) \chi - ig_A \bar{\chi} \gamma^5 \chi - ig_{SMA} \sum_f \frac{y_f}{\sqrt{2}} \bar{f} \gamma^5 f \]
The model killer, Direct Detection

Surface rejection demonstrated <0.6 evt/0.3 ton yr

Cylindrical Surface rejection still needs to be satisfactorily demonstrated
Escaping from the killer Direct Detection:

A. ‘Coy DM’
B. ‘Resonance Portal’
\[ \mathcal{L}_{0A^s_{1/2}} = \frac{1}{2} (\partial_\mu A)^2 - \frac{1}{2} m_A^2 A^2 + \bar{\chi}(i\gamma^\mu D^\mu - m_\chi)\chi - ig_\chi A \bar{\chi} \gamma^5 \chi - ig_{SM}A \sum_f \frac{y_f}{\sqrt{2}} \bar{f} \gamma^5 f. \]

Bohm et al, 1401.6458; Berlin et al, 1404.0022; Dolan et al, 1412.5174

Coy DM

\[ \sigma_{SI} \propto v^2 \]
Coy DM has surprisingly many features…

- Self-interacting DM, DAMA/LIBRA etc
- Muon g-2
- $\gamma$-ray line
Coy DM & muon g-2

Chang et al, hep-ph/0009292

‘Leptophilic’ Coy DM,
Hektor & Marzola, 1403.3401
Coy DM & $\gamma$-ray line
Coy DM & $\gamma$-ray line

$m_\chi < m_t$

\[
\mathcal{L}_{0A^{1/2}} = \frac{1}{2} (\partial \mu A)^2 - \frac{1}{2} m^2 A^2 + \bar{\chi}(i\not\! \! \! \partial - m_\chi) \chi - ig_\chi A \bar{\chi} \gamma^5 \chi - i g_{\text{SM}} A \sum_f \frac{y_f}{\sqrt{2}} \bar{f} \gamma^5 f.
\]
Coy DM & $\gamma$-ray line

- Loop suppression, $\sim 10^{-2} \ldots 10^{-3}$
- Sensitivity of line/broader distribution search, $\sim 10^2$
$\gamma$-ray line signal alone

\[
\sigma_{\chi\chi \to \gamma\gamma} = \frac{1}{512\pi^3} \frac{(g_\chi g_f \alpha Q_f N_c^f)^2}{(m_a^2 - 4m_\chi^2)^2 + m_a^2 \Gamma_a^2} \left| \frac{A_1(\tau_f)}{m_f} \right|^2
\]
\[ \sigma_{\chi\chi \rightarrow \gamma\gamma} = \frac{1}{512\pi^3} \frac{(g_X g_f \alpha Q_f N_C^f)^2 (2m_\chi)^4}{(m_a^2 - 4m_\chi^2)^2 + m_a^2 \Gamma_a^2} \left| \frac{A_1(\tau_f)}{m_f} \right|^2 \]

\[ \sigma_{\chi\chi \rightarrow b\bar{b}} = \frac{N_c(g_X g_b)^2}{8\pi} \frac{m_\chi^2 \sqrt{1 - \frac{m_b^2}{m_\chi^2}}}{(m_a^2 - 4m_\chi^2)^2 + m_a^2 \Gamma_a^2} \]
Ratio of the $\gamma$-ray line and $bb$ signal

\[ R = \frac{(N^t_c \alpha Q_t y_t)^2}{2\pi^2 N^b_c y^2_b} \frac{m_t^2}{m^2 \sqrt{1 - \frac{m^2}{m^2}}} \left| \arcsin\left(\frac{m_x}{m_t}\right) \right|^2 \]
The $\gamma$-ray line and the Galactic Centre Excess

Calore et al, 1411.4647

$$R = \frac{(N^t_c \alpha Q_t y_t)^2}{2 \pi^2 N^b_c y_b^2} \frac{m_t^2}{m_X^2 \sqrt{1 - \frac{m_t^2}{m_X^2}}} \left| \arcsin^2 \left( \frac{m_X}{m_t} \right) \right|^2$$
The $\gamma$-ray line and the Galactic Centre Excess

\[ R = \left( \frac{N^t_c \alpha Q_t y_t}{2\pi^2 N^b_c y_b^2} \right)^2 \frac{m_t^2}{m_x^2} \sqrt{1 - \frac{m_t^2}{m_x^2}} \left| \arcsin^2 \left( \frac{m_x}{m_t} \right) \right|^2 \]
The $\gamma$-ray line and the Galactic Centre Excess

\[ R = \frac{(N_c^t \alpha Q_t y_t)^2}{2\pi^2 N_c^b y_b^2} \frac{m_t}{m_X} \frac{m_t^2}{m_X^2 \sqrt{1 - \frac{m_t^2}{m_X^2}}} \left| \arcsin^2 \left( \frac{m_X}{m_t} \right) \right|^2 \]
Galactic Centre Excess &
TeV-scale pseudoscalar
mediator

or

What did we learn from the 750
GeV pseudo-particle?
- Pseudoscalar mediator, $m_A = 750$ GeV
- Scalar DM particle
Life in ‘Resonance portal’
Escaping from the killer Direct Detection:

A. ‘Coy DM’
B. ‘Resonance Portal’

Is the Resonance Portal fine tuning?

1. Yes
RP offers interesting phenomenology for indirect section

\[ \sigma_{\chi \chi \rightarrow S \rightarrow f f} = \frac{N_c (g_{\chi} A y_f)^2}{16 \pi} \frac{m^2 \left(1 - \frac{m_f^2}{m^2}\right)^{3/2}}{(M^2 - s[m^2, v_{rel}])^2 + M^2 \Gamma^2} v_{rel} \]

\[ \sigma_{\chi \chi \rightarrow A \rightarrow f f} = \frac{N_c (g_{\chi} A y_f)^2}{16 \pi} \frac{m^2 \left(1 - \frac{m_f^2}{m^2}\right)^{1/2}}{(M^2 - s[m^2, v_{rel}])^2 + M^2 \Gamma^2} v_{rel}^{-1} \]

\[ m^2 = \frac{M^2}{4(1 + \delta)}, \quad s[m^2, v_{rel}] = \frac{4m^2}{1 - v_{rel}^2} \]

\[ M = m_{\text{higgs}}, \quad g_{\chi} = 1 \]

\[ A = 1, \quad y_f = 1 \]

\[ \Gamma = \Gamma_{\text{higgs}} \]
RP offers interesting phenomenology for indirect section
RP offers interesting phenomenology for indirect section

Scalar

Pseudo-scalar

Difference of two orders magnitude!

However, the real life is more complicated!
Takeaway messages from my talk

• Coy DM offers rich phenomenology — be careful with the $\gamma$-ray line!

• ‘Resonance Portal’ — the annihilation cross-section constraints from galaxy clusters, galaxies, dwarfs etc are different!
Thank you!