TRIUMF

Dark Matter with Composite Mediators

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work done with J. Serra and P. Tanedo

Why composite mediators?

Mediators as accessible degrees of freedom can lead to a number of interesting phenomena, such as resonance or on-shell production.

Pseudoscalars are good mediator candidates in that they allow for s-wave annihilation, but require a UV completion.

The composite higgs framework can naturally generate new particles that can also be mediators.

Model Details

Composite higgs models generate light scalars as pseudo-goldstone bosons.

One can extend the symmetry to generate additional bosons, such as SO(6)/SO(5)

$$\Sigma_0 = (0\ 0\ 0\ 0\ 0\ 1)^T$$

$$U = \begin{pmatrix} 1_{3\times 3} & & \\ & 1 - \frac{h^2}{1+\sqrt{1-h^2-\eta^2}} & -\frac{h\eta}{1+\sqrt{1-h^2-\eta^2}} \\ & -\frac{h\eta}{1+\sqrt{1-h^2-\eta^2}} & 1 - \frac{\eta^2}{1+\sqrt{1-h^2-\eta^2}} \\ & -h & -\eta \end{pmatrix} \begin{matrix} h \\ \eta \\ \sqrt{1-h^2-\eta^2} \end{matrix}$$

$$\Sigma = U\Sigma_0 = (0\ 0\ 0\ h\ \eta\ \sqrt{1-h^2-\eta^2})^T$$

Fermion Embedding

$$Q_L = b_L\, v_{b_L} + t_L\, v_{t_L}\,, \quad v_{b_L} = \frac{1}{\sqrt{2}} \begin{pmatrix} i \\ +1 \\ 0 \\ 0 \\ 0 \end{pmatrix}, v_{t_L} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ 0 \\ i \\ -1 \\ 0 \\ 0 \end{pmatrix}$$

$$Q'_L = b_L\, v'_{b_L} + t_L\, v'_{t_L}\,, \quad v'_{b_L} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ 0 \\ -i \\ -1 \\ 0 \\ 0 \end{pmatrix}, v'_{t_L} = \frac{1}{\sqrt{2}} \begin{pmatrix} -i \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

Fermion Embedding

$$T_R = t_R \qquad B_R = b_R v_{b_R}\,, \quad v_{b_R} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ i\,\delta_b \\ 1 \end{pmatrix}$$

$$\bar{\chi}_L \chi_R v_\chi\,, \quad v_\chi = -\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ i \\ \delta_\chi \end{pmatrix}$$

The resulting interactions are:

$$y_t f(\bar{Q}_L \Sigma) T_R + h.c. = -y_t \bar{t}_L h t_R + h.c.$$

$$y_b f(\bar{Q}'_L \Sigma)(\Sigma^T B_R) + h.c. = -y_b \bar{b}_L h b_R \left(\sqrt{1 - \frac{h^2}{f^2} - \frac{\eta^2}{f^2}} + i\delta_b \frac{\eta}{f} \right) + h.c.$$

$$y_\chi f \bar{\chi}_L \chi_R (\Sigma^T v_\chi) + h.c. = -y_\chi f \bar{\chi}_L \chi_R \left(\delta_\chi \sqrt{1 - \frac{h^2}{f^2} - \frac{\eta^2}{f^2}} + i\frac{\eta}{f} \right) + h.c.$$

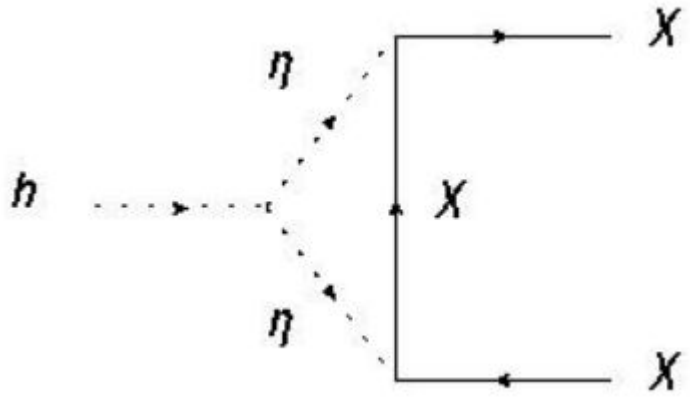
η mass

Since the electroweak gauge group and fermions break the SO(6) symmetry, these interactions contribute to the mass of the would be goldstone bosons.

$$\Delta m_\eta^2 \sim 3 y_b^2 f^2$$

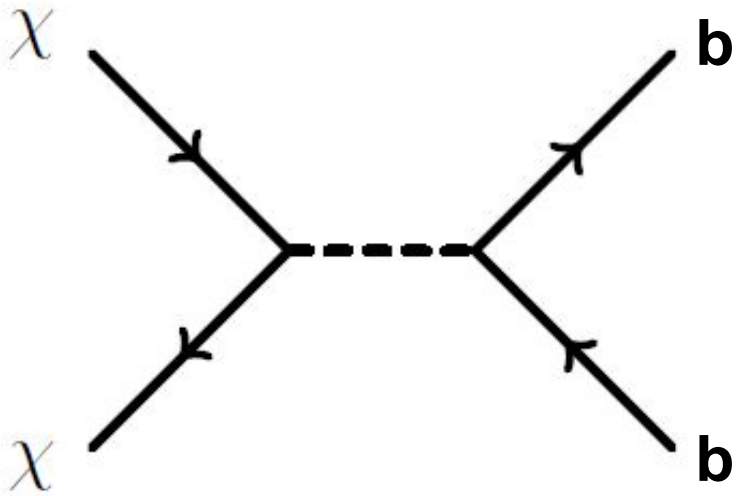
$$\Delta m_\eta^2 \sim y_\chi^2 f^2$$

Induced higgs dark matter coupling



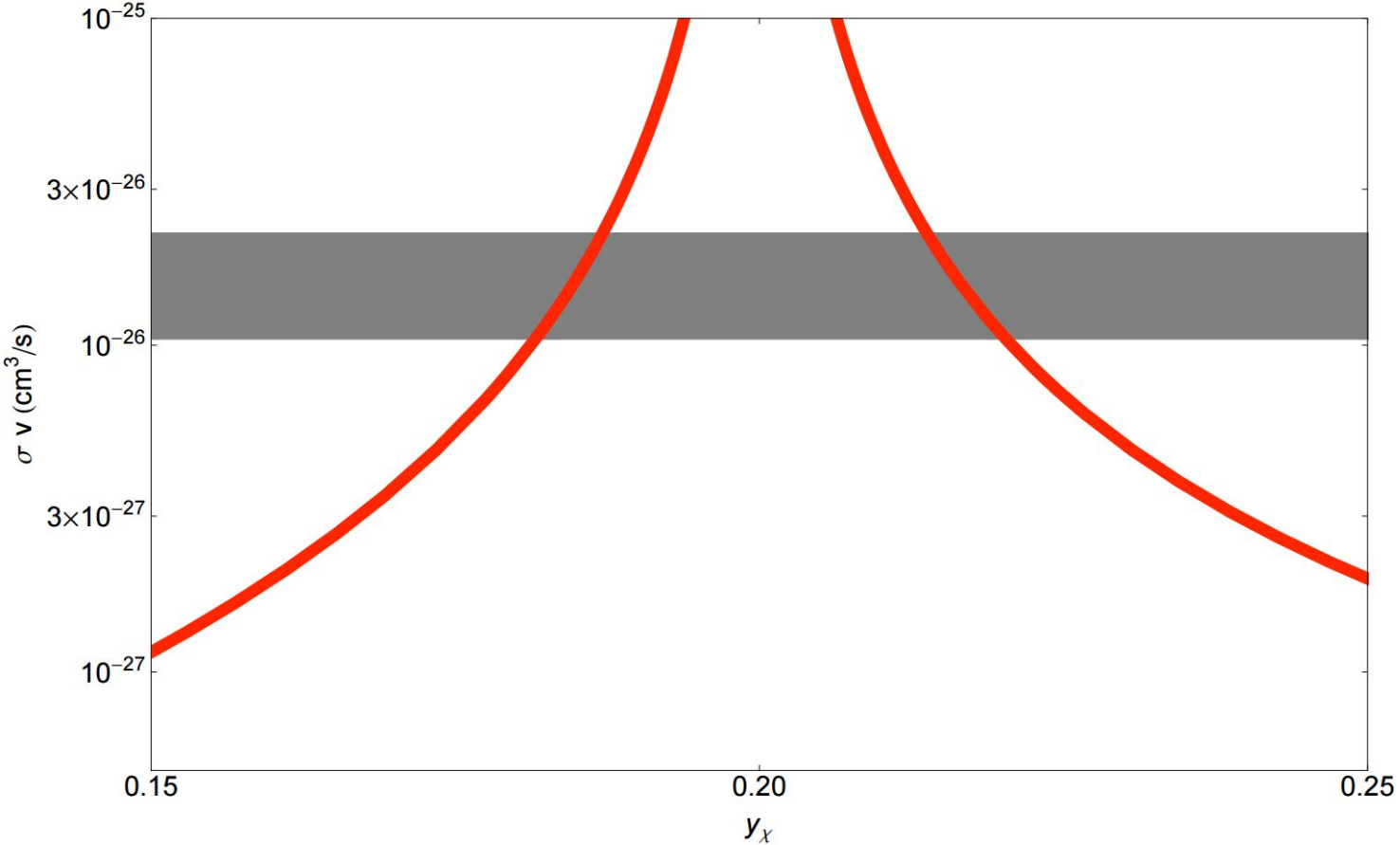
$$g_{h\bar{\chi}\chi}^{(loop)} \sim \frac{y_\chi^2}{16\pi^2}\frac{\widetilde{m}_\chi v}{f^2}$$

Getting the right relic density

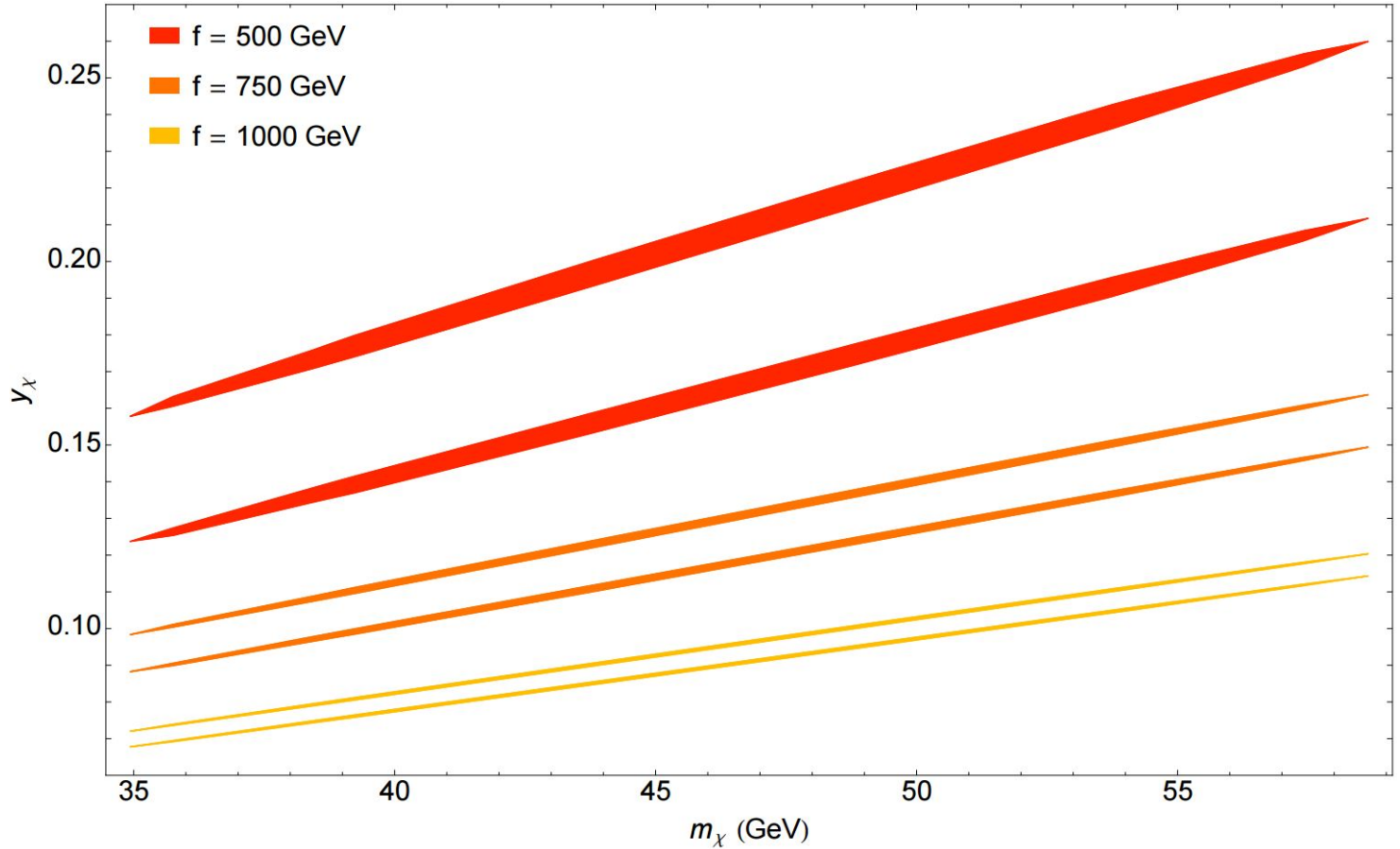


$$<\sigma v> \sim \frac{1}{|4m_\chi^2 - y_\chi^2 f^2 + i y_\chi f \Gamma_\eta|^2}.$$

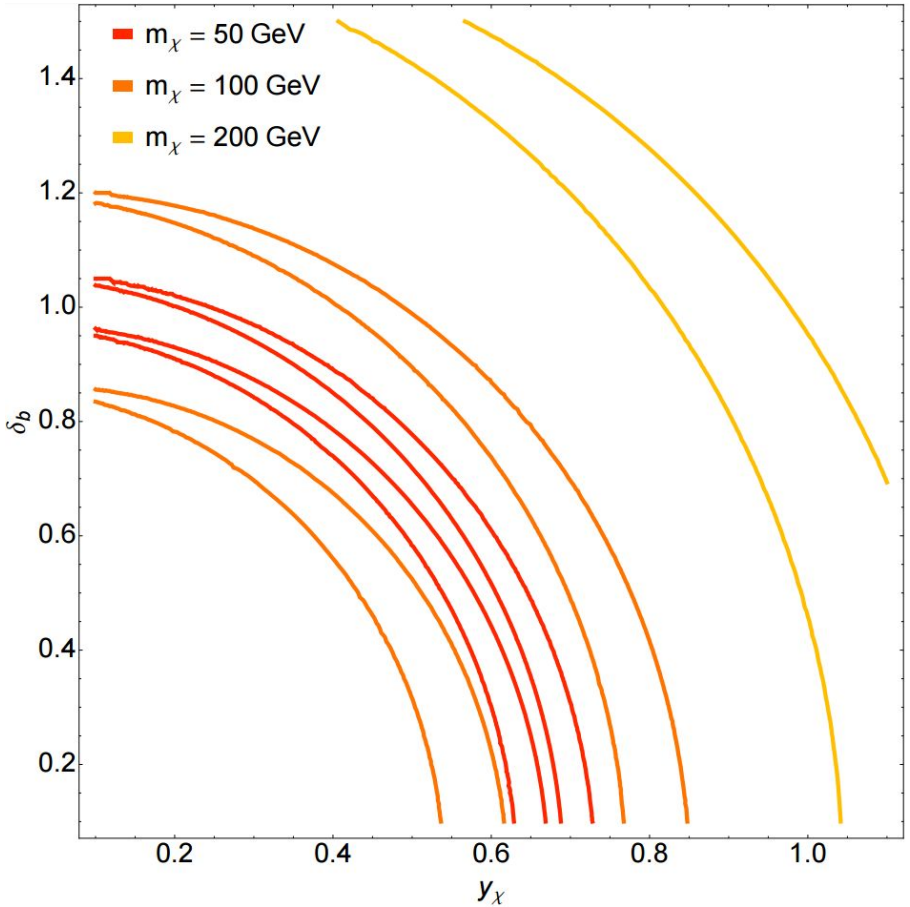
Resonant Annihilation



Resonant Annihilation



Resonant Annihilation

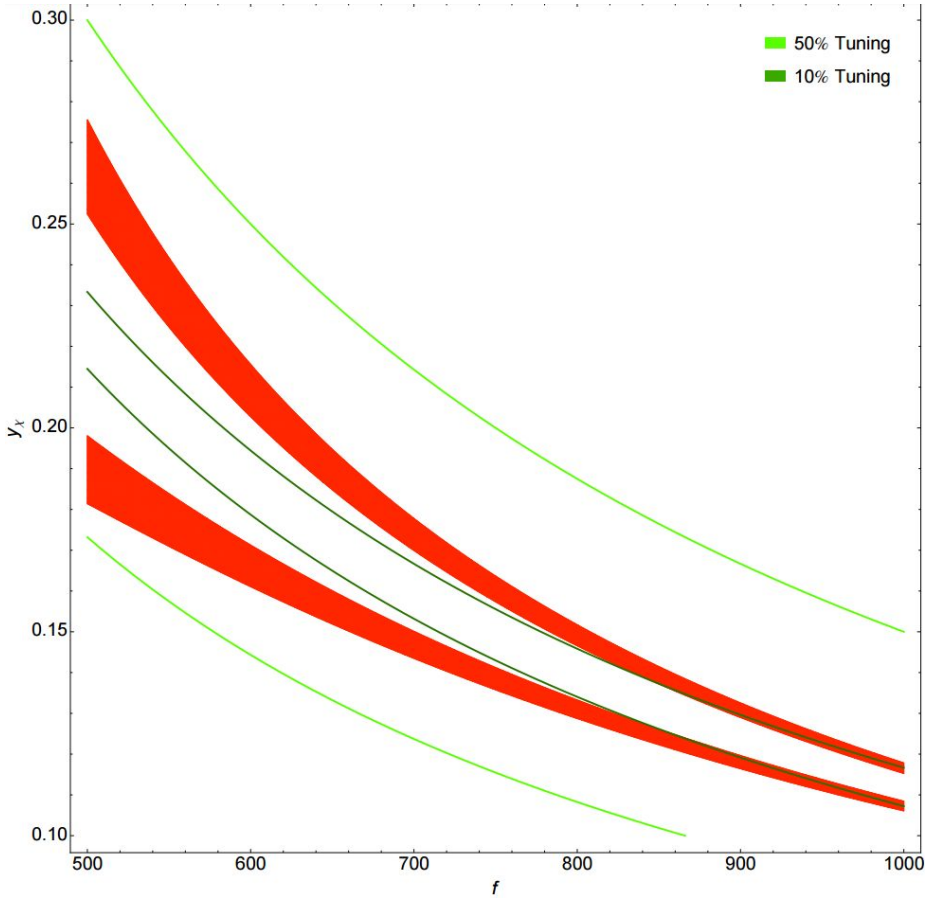


How tuned is it to be on resonance?

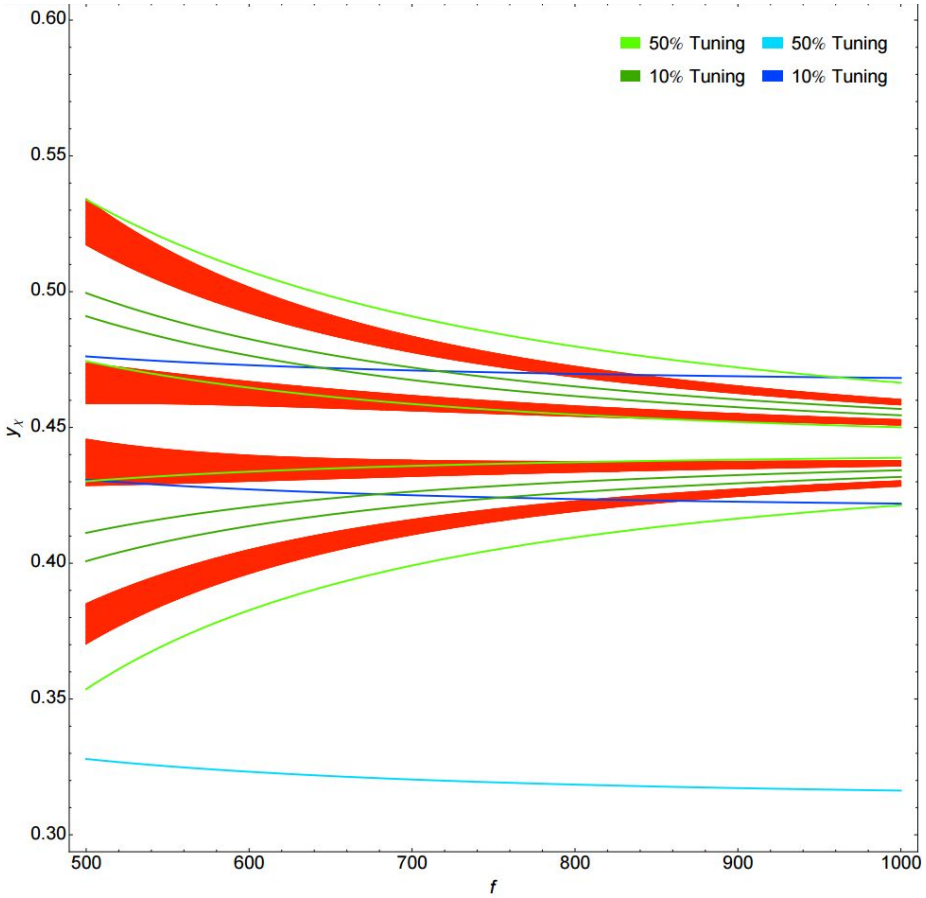
$$\Delta_{\chi\eta} = \frac{4m_\chi^2 - m_\eta^2}{Max(4m_\chi^2, m_\eta^2)}$$

$$\Delta_{b\chi} = \frac{m_\eta^2}{Max((\Delta m_\eta^2)_b, (\Delta m_\eta^2)_\chi)}$$

Resonance Tuning



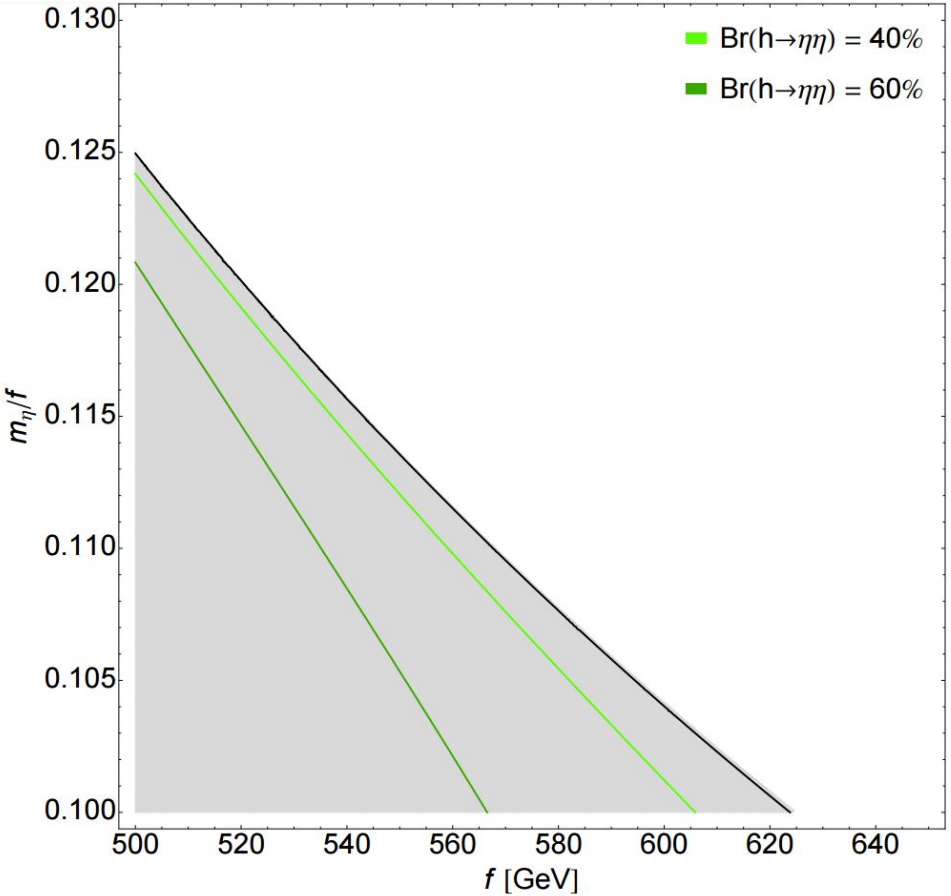
Mass Tuning


50% Tuning
50% Tuning
10% Tuning
10% Tuning
0.60
0.55
0.50
0.45
0.40
0.35
0.30
y_K
500
600
700
800
900
1000
f

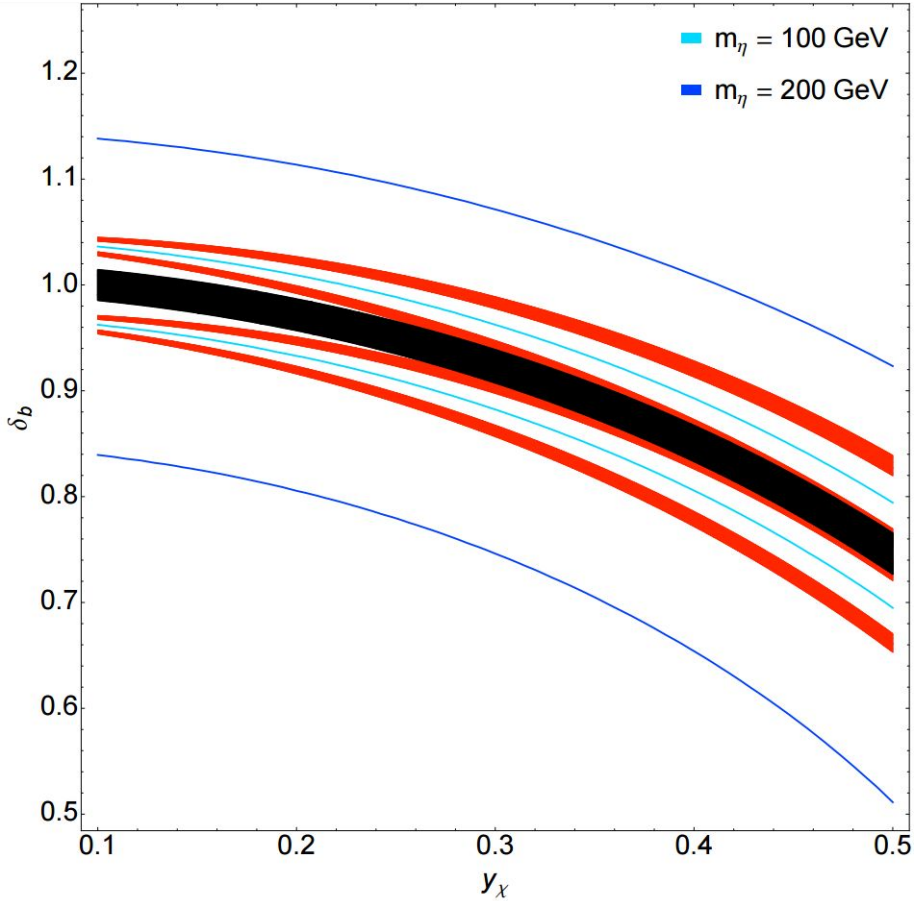
Bounds

- EWPT puts a lower bound on f of about 600 GeV
- Pseudoscalar mediated dark matter has also been studied under the name of Coy Dark Matter and is not particularly constraining.
- The additional features of this model are the h$\eta\eta$ and the loop induced h$\chi\chi$ coupling.

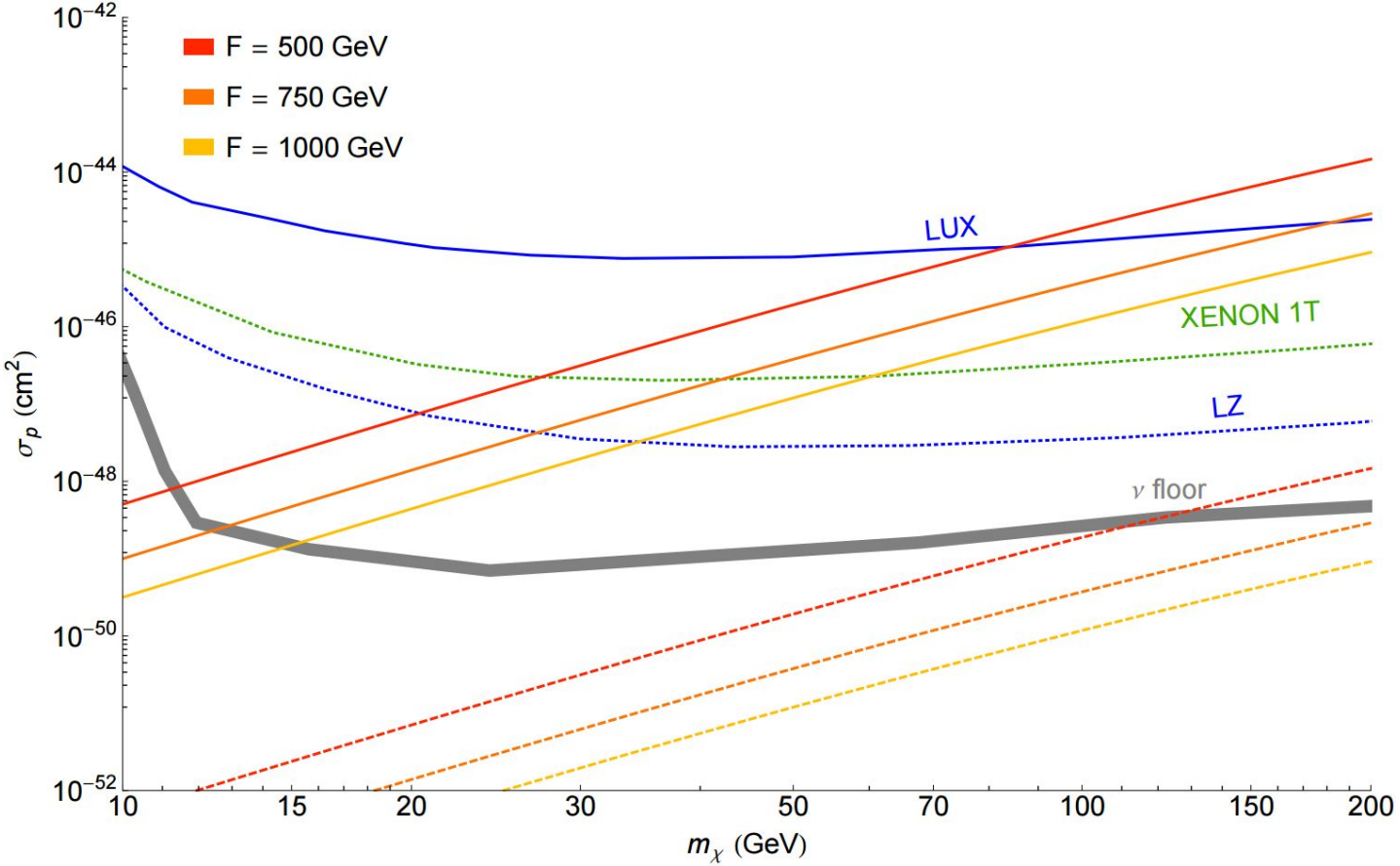
Br(h→ηη)


Br(h→ηη) = 40%
Br(h→ηη) = 60%
0.130
0.125
0.120
0.115
0.110
0.105
0.100
m_η/f
500
520
540
560
580
600
620
640
f [GeV]

LHC bounds on the relic parameter space



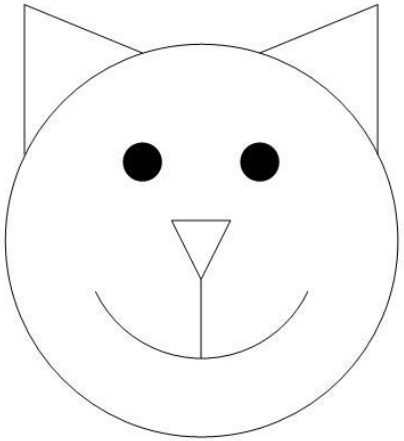
Higgs portal and direct detection



Conclusions

- Composite mediators can be a natural extension of the composite higgs framework, giving one a framework to address both the hierarchy problem and dark matter.
- This framework has the interesting feature of resonant annihilation, where the mediator mass is set by the couplings to dark matter and the standard model.

Thank you!
Merci!



Questions?

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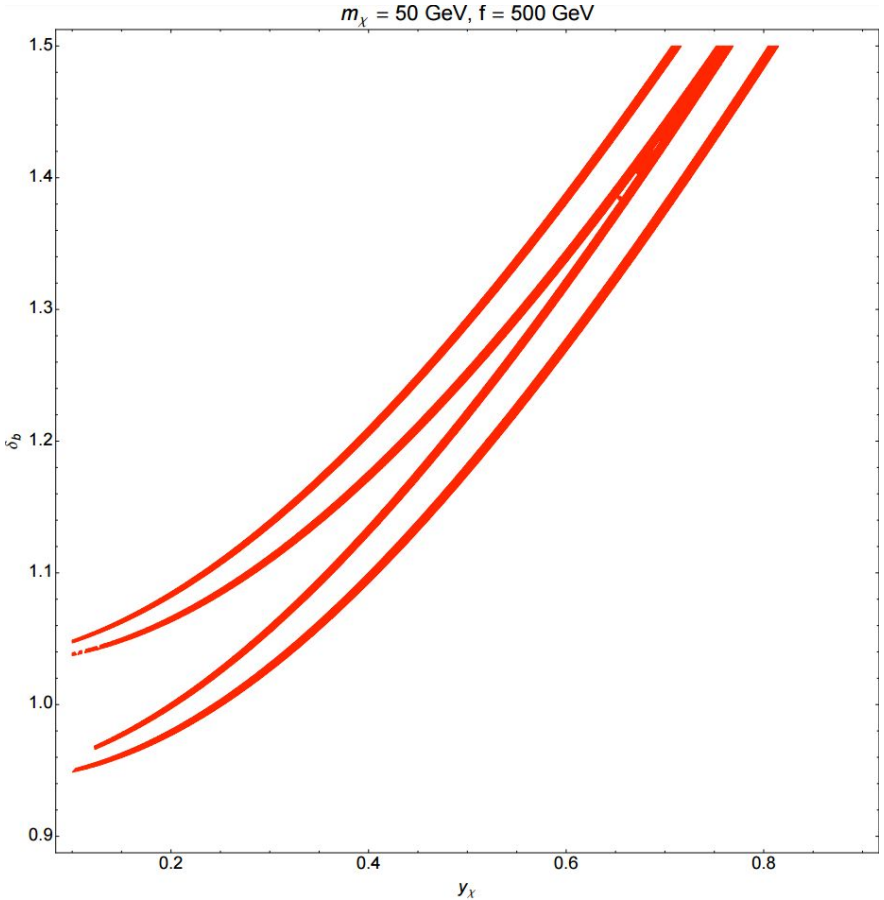
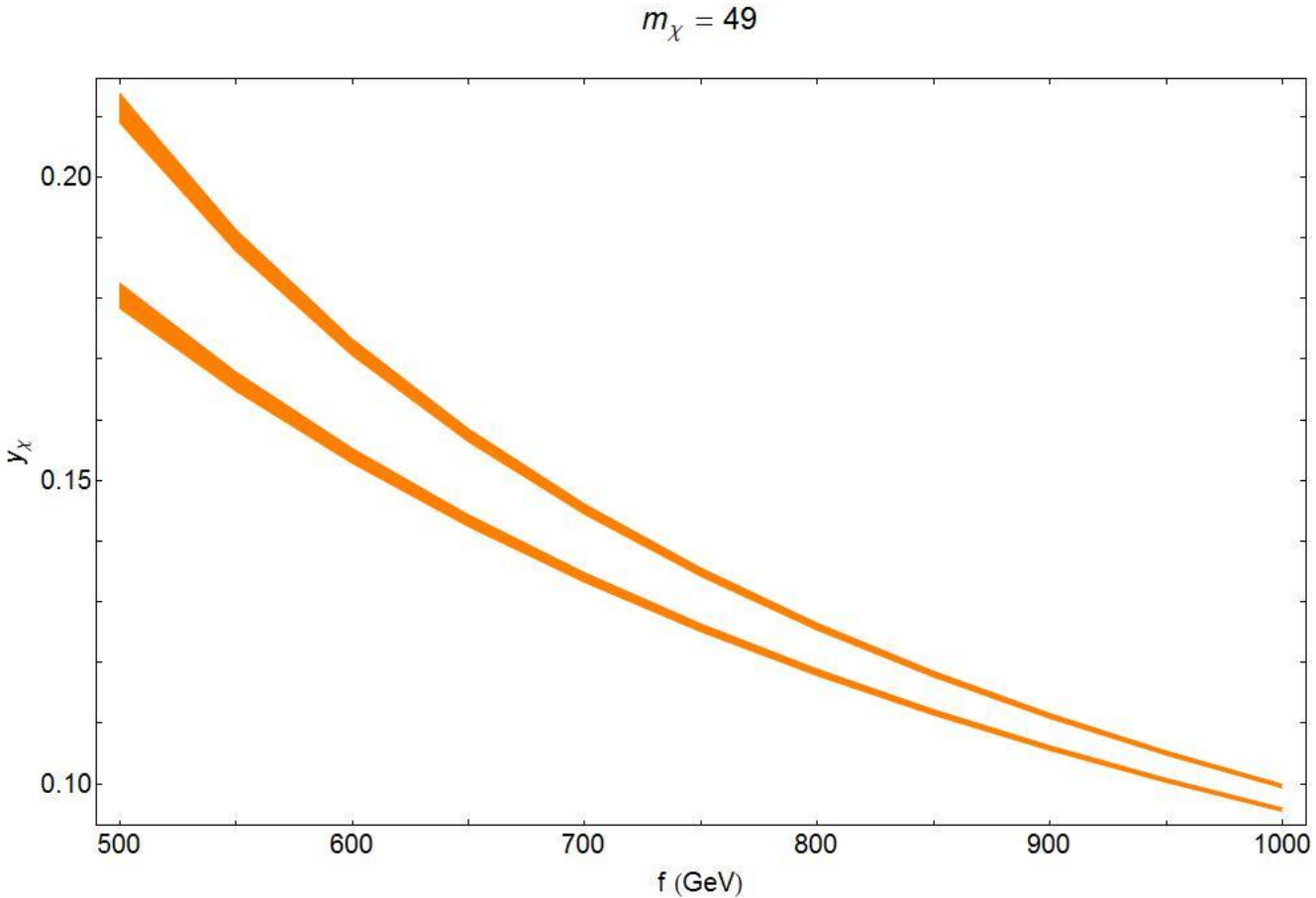
Backup Slides

Other regions of parameter space

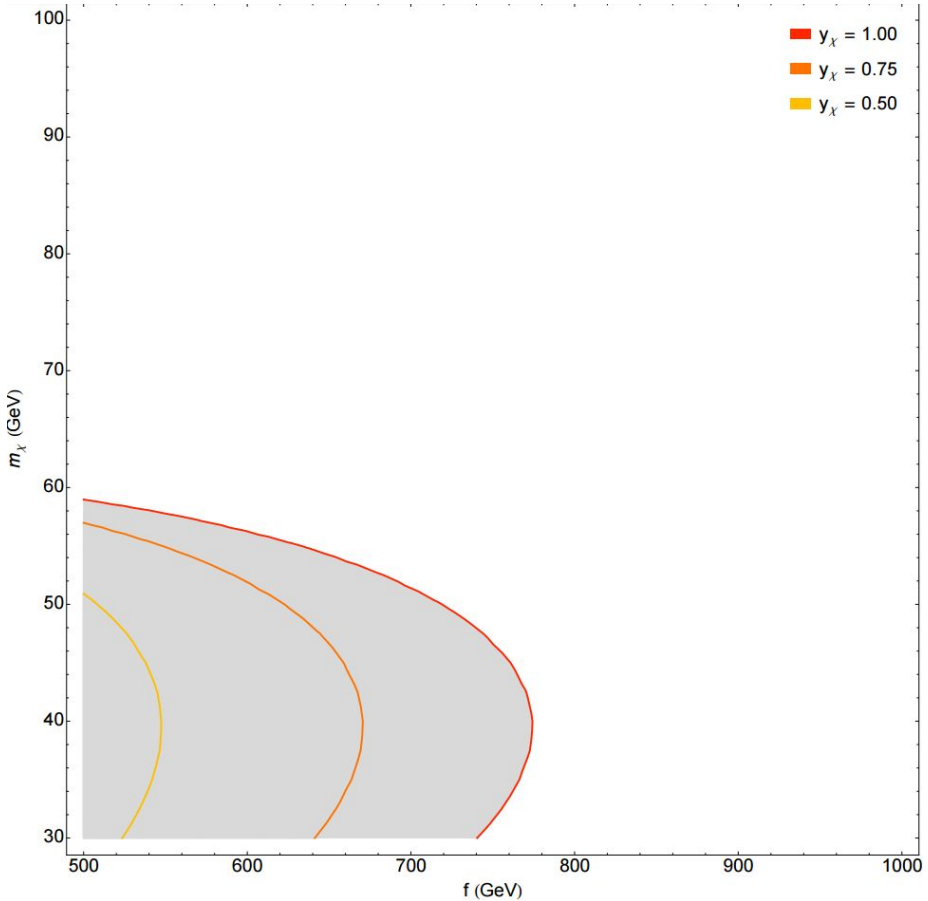


Other regions of parameter space



Other bounds

h→*xx*


y_χ = 1.00
y_χ = 0.75
y_χ = 0.50
m_χ (GeV)
f (GeV)
100
90
80
70
60
50
40
30
500
600
700
800
900
1000

Bounds with opposite sign mass contributions