Next Generation Dark Matter Models

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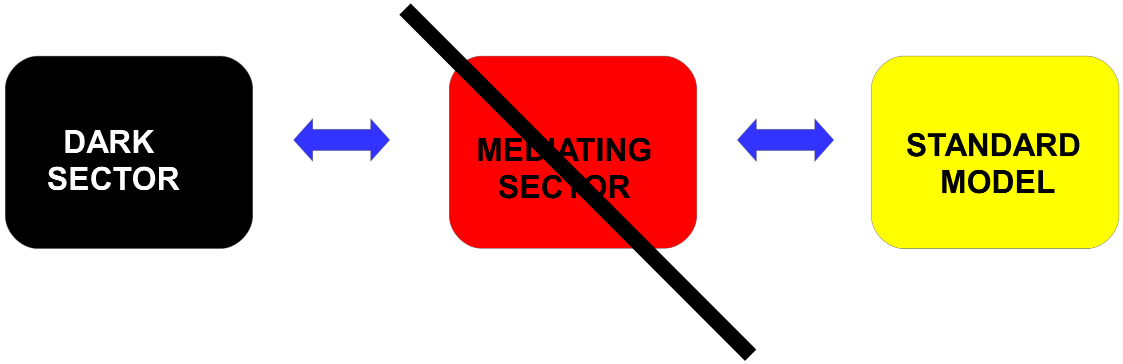
DM Landscape

Effective operators

Name	Operator	Coefficient
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D2	$\bar{\chi}\gamma^5\chi\bar{q}q$	im_q/M_*^3
D3	$\bar{\chi}\chi\bar{q}\gamma^5 q$	im_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D6	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D7	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D8	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu} q$	$1/M_*^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta} q$	i/M_*^2
D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$

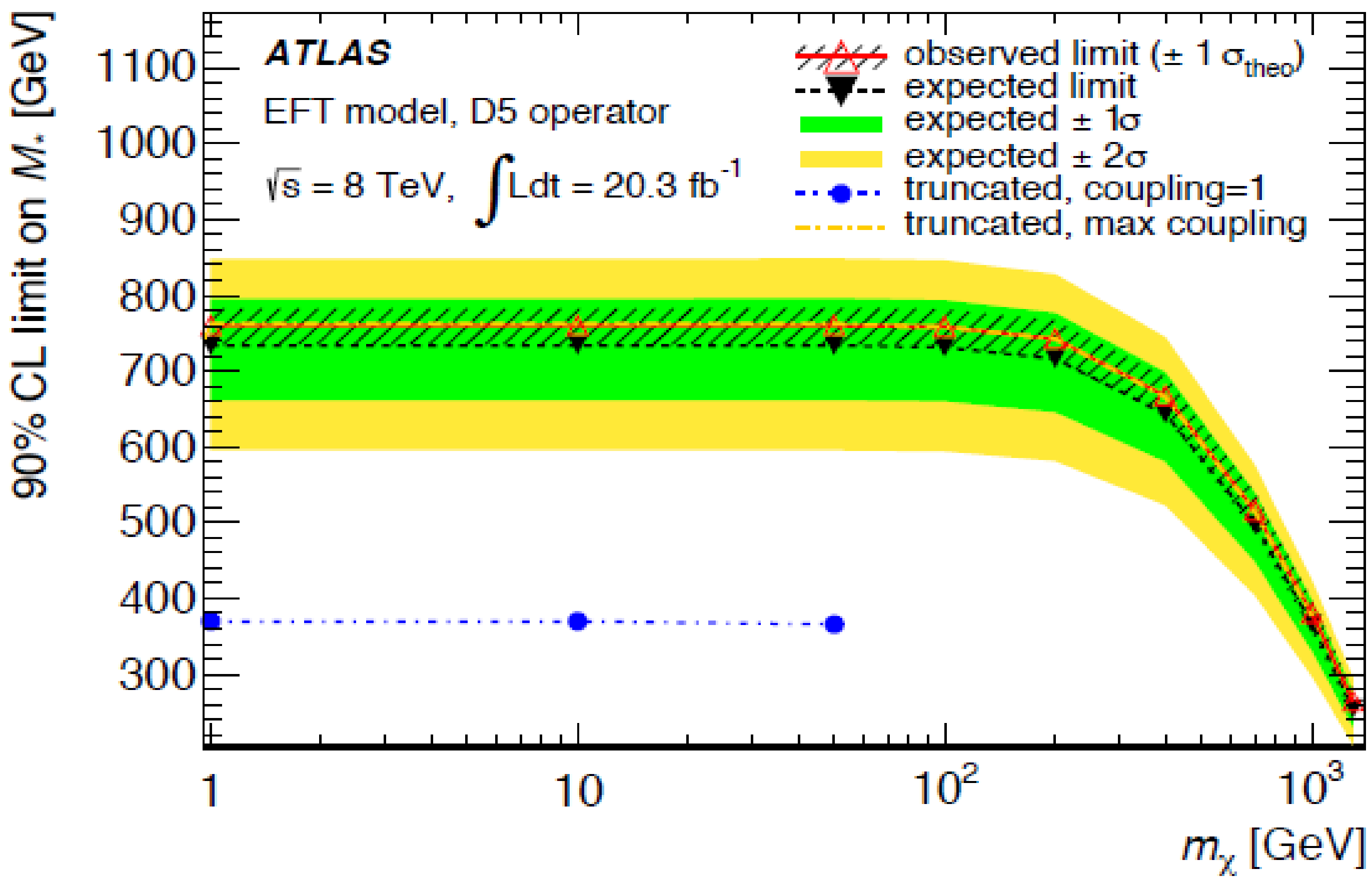


Obfuscates Mediating sector, replaced with general scale

Captures kinematics of coupling to standard model

Limited range of validity

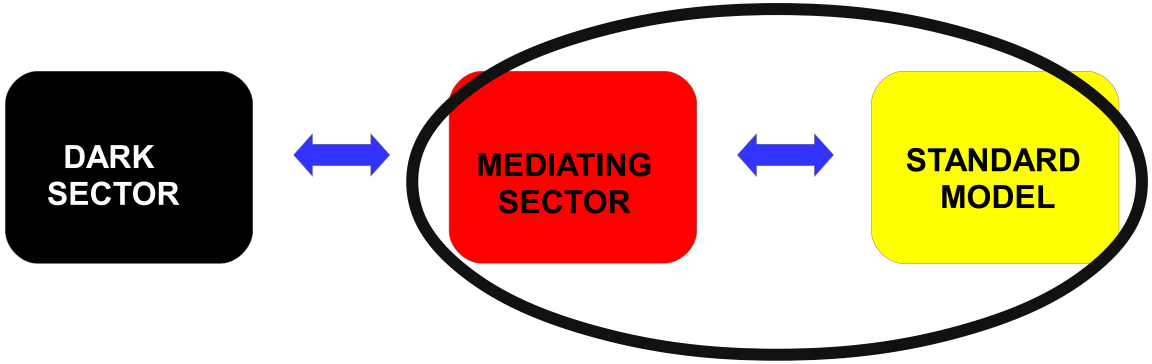
EFT breaks down at high momentum transfer



Truncation proceedure removes events with momentum transfer>M*

ATLAS(arXiv:1411.1559v2)

Simplified Models



- Chooses a mediating mechanism
- Considers limited number of interactions
- Issue with arbitrarity and theoretical consistancy (unitarity, gauge invariance)
- Not every simplified model can be realized in UV completion

Next Generation Models

- **Theoretically consistent** extension of a simplified model
- Generic enough to be used in the context of broader, more complete theoretical frameworks
- Varied phenomenology to encourage comparison of different experimental signals and to search for DM in new, unexplored channels
- Be of interest beyond the DM community, to the point that other direct and indirect constraints can be identified.

ArXiv:1810:09420

Pseudoscalar Mediator

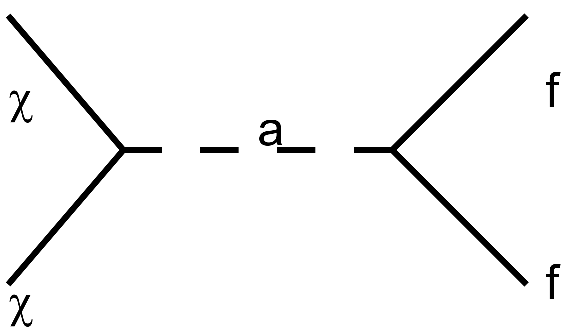
- EFT

$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$ $\bar{\chi}\chi\bar{q}q$ D1 and D3 operators

$$\sum_{f=u,d,s,c,b,t,e,\mu,\tau}\left(\frac{C_1^f}{\Lambda^2}\bar{f}f\bar{\chi}\chi+\frac{C_2^f}{\Lambda^2}\bar{f}\gamma_5 f\bar{\chi}\gamma_5\chi+\dots\right)$$

- Simplified Model

$$\mathcal{L}_{\text{DM-simp}}=-ig_\chi a\bar{\chi}\gamma_5\chi-ia\sum_j\left(g_u y_j^u\bar{u}_j\gamma_5 u_j+g_d y_j^d\bar{d}_j\gamma_5 d_j+g_\ell y_j^\ell\bar{\ell}_j\gamma_5\ell_j\right)$$



Violates gauge invariance!

Remove arbitrarity by selecting BSM scenario that naturally contains the mediating particle. Fix gauge invariance by requiring propser quantum numbers in meditor sector

2HDM containing 2 complex doublet fields H_1 and H_2 plus new pseudoscalar P,yielding 6 fields h, H, H^{+-},A, a

H, h, H^{+-}, A, a

DM coupling to pseudoscalar

$$\mathcal{L}_\chi = -iy_\chi P \bar{\chi}\gamma_5\chi$$

Pseudoscalar mixing with SM

$$V_{HP} = P\left(ib_P H_1^\dagger H_2 + \text{h.c.}\right) + P^2\left(\lambda_{P1} H_1^\dagger H_1 + \lambda_{P2} H_2^\dagger H_2\right)$$

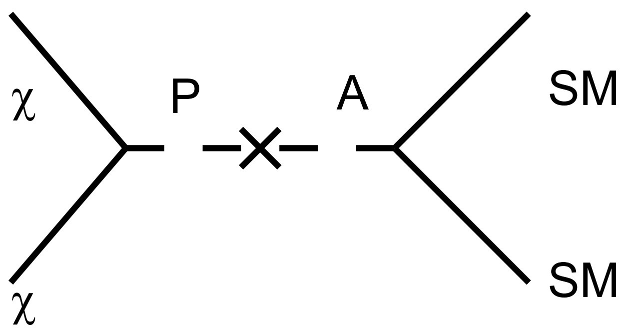
Higgs coupling to SM

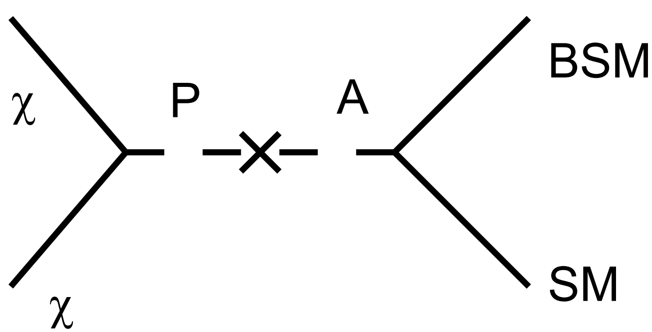
$$\mathcal{L}_Y = -\sum_{i=1,2}\left(\bar{Q}Y_u^i \tilde{H}_i u_R + \bar{Q}Y_d^i H_i d_R + \bar{L}Y_\ell^i H_i \ell_R + \text{h.c.}\right)$$

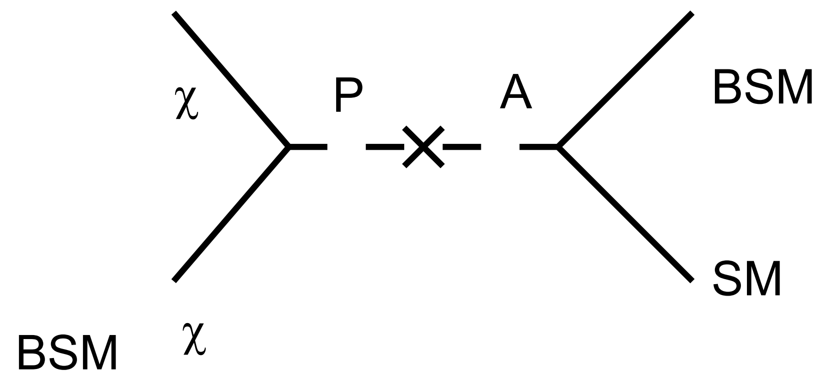
Consequences of Next Generation Models for DM coupling and Indirect detection

- -Multiple coupling between DM and the SM
- -Complex DM annihilation spectrum
- -Multibody kinematics
- -Extremely variable Relic Density

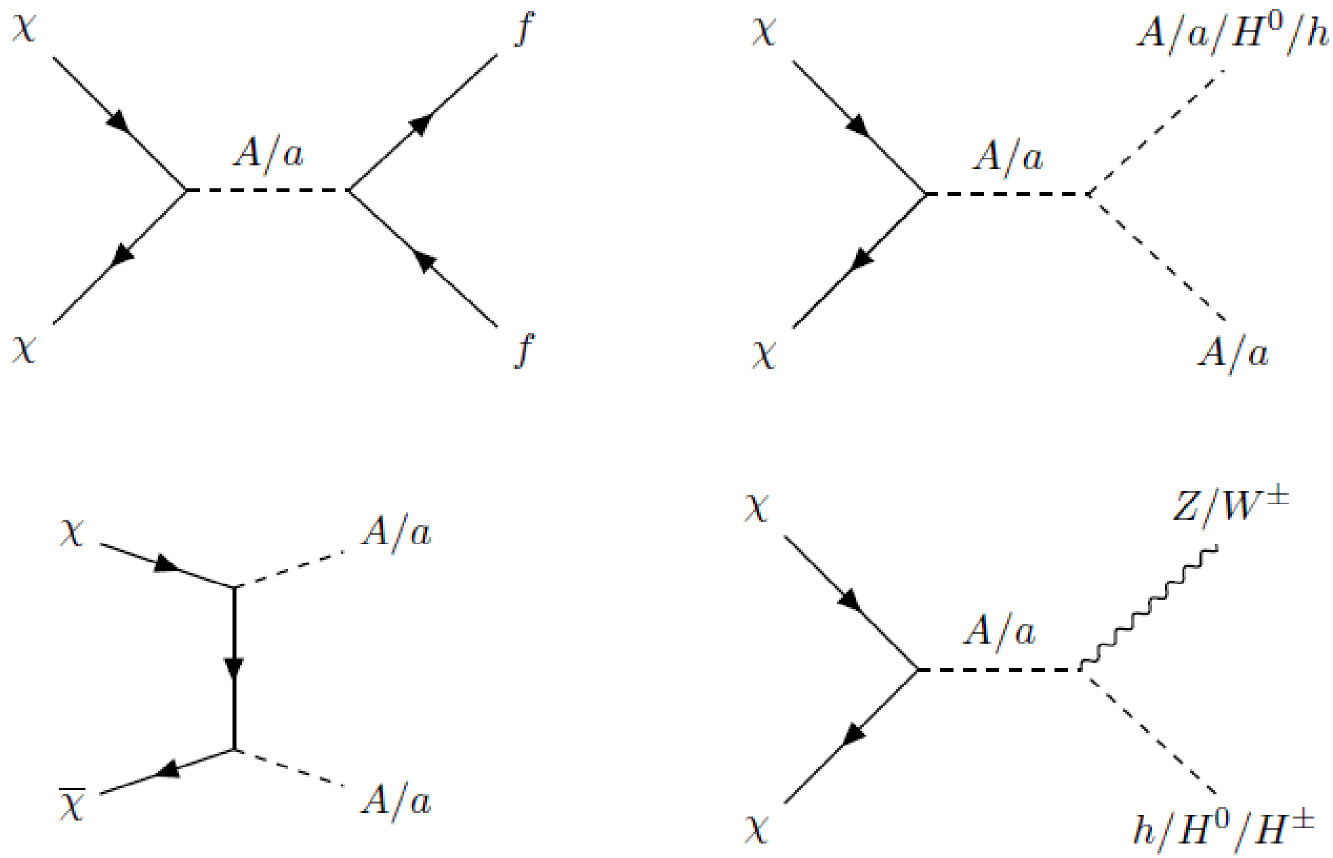
DM couplings to SM and BSM states







BSM states in the extended Higgs sector

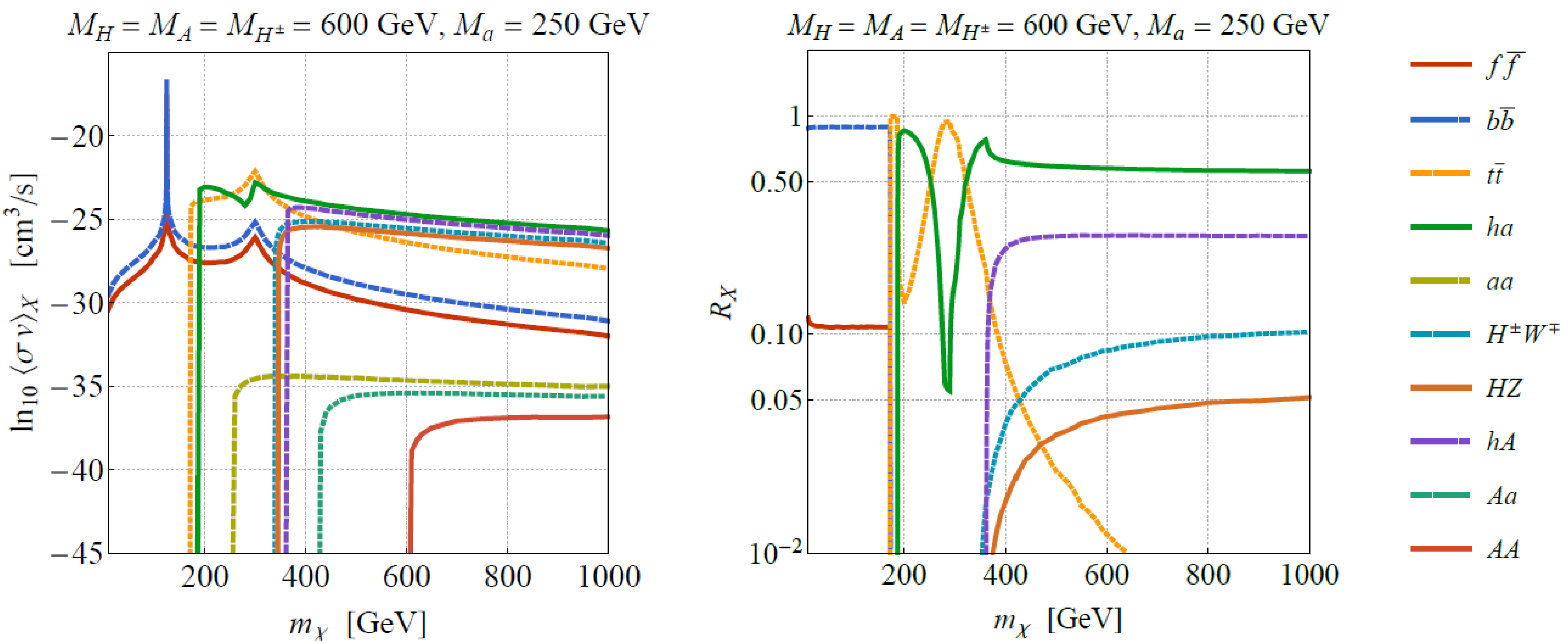


χ
χ
A/a
f
f
χ
χ
A/a
A/a/H⁰/h
A/a
χ
χ̄
A/a
A/a
χ
χ
A/a
Z/W±
h/H⁰/H±

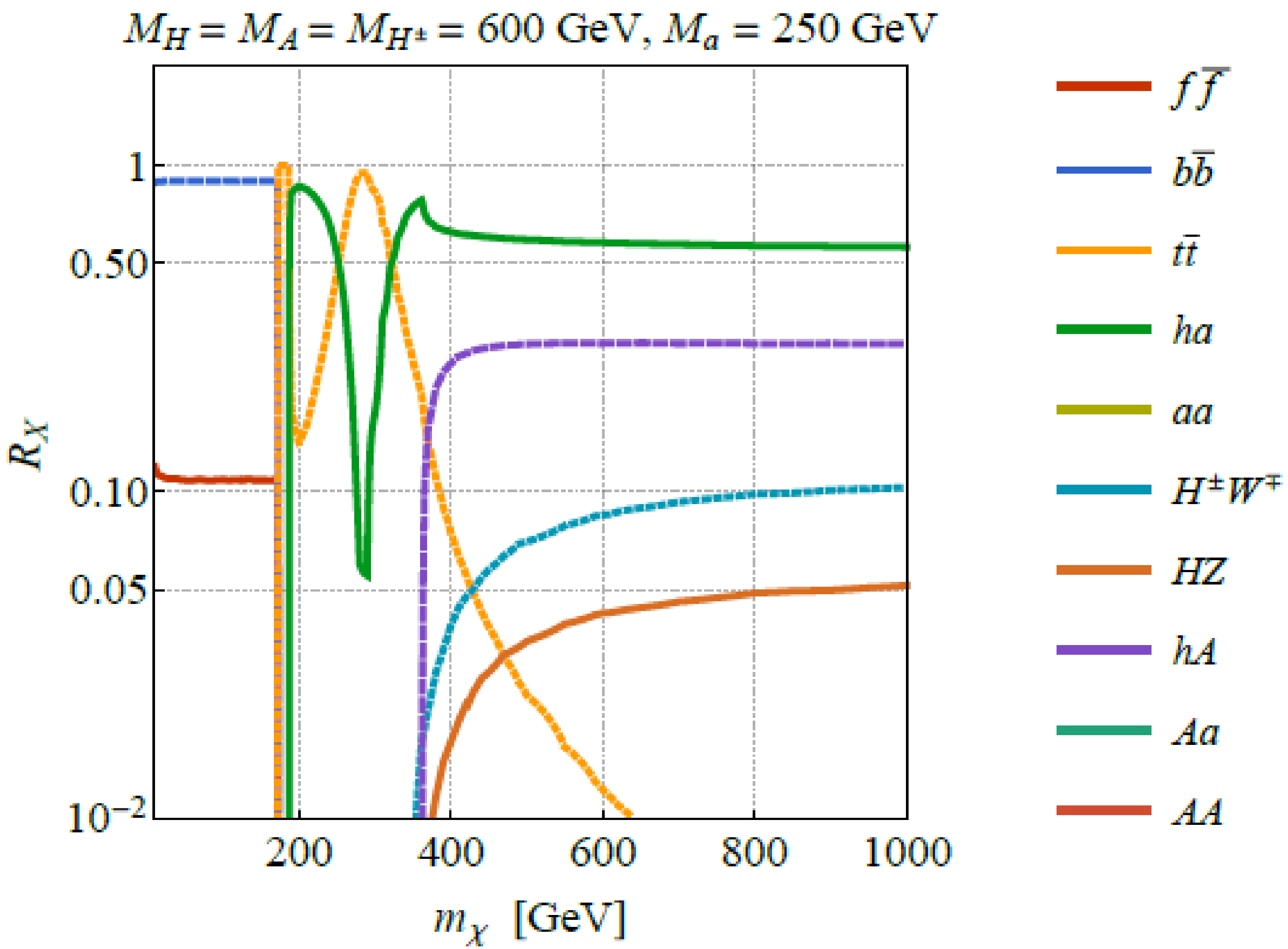
Indirect Detection Constraints

Dark Matter Annihilation channels through pseudoscalar

$f\bar{f}$, hA, HA, HZ, $H^{\pm}W^{\mp}$, ha, Ha, AA, aa and Aa

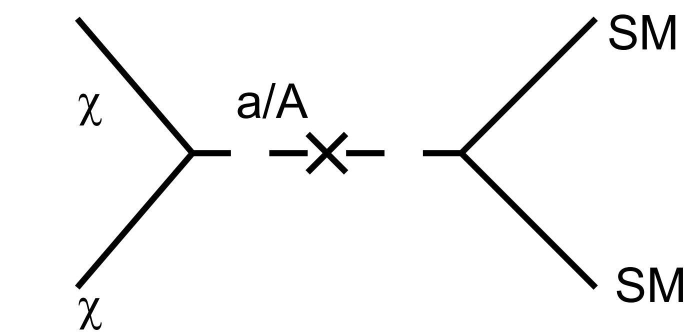


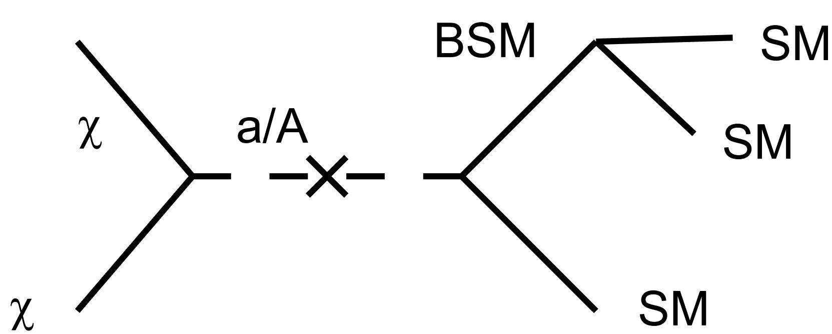
R_X annihilation fraction



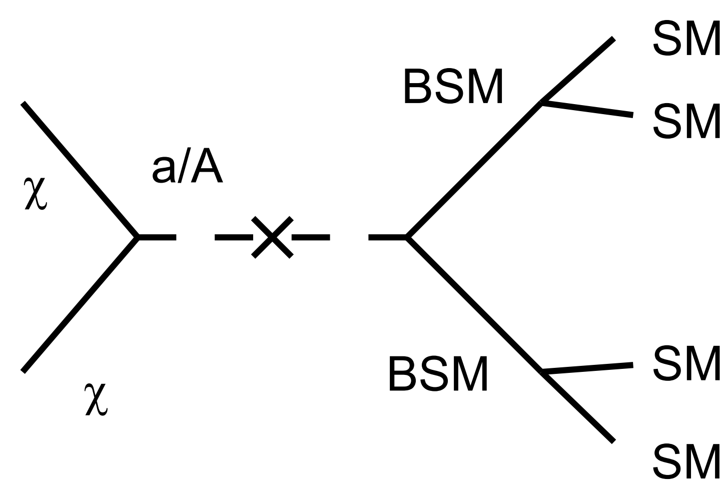
$\Sigma\langle\sigma v\rangle_i = \langle\sigma v\rangle_{Total}$ $R_i = \langle\sigma v\rangle_i / \langle\sigma v\rangle_{Total}$ $\Sigma R_i = 1$

DM couplings to SM and Mediator states



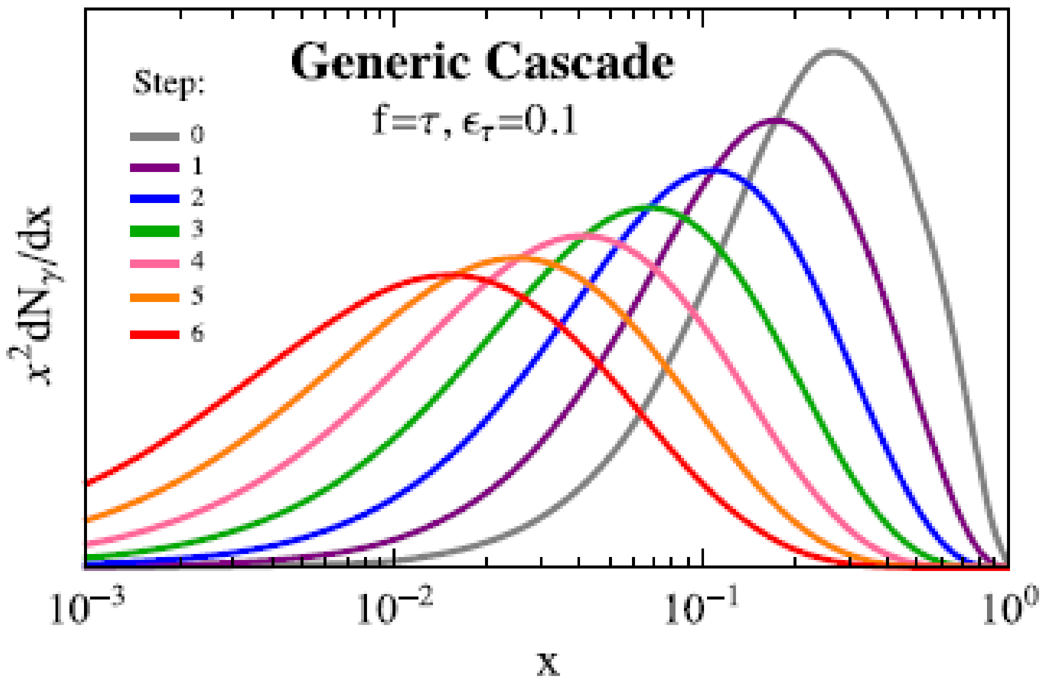


3 final state cascade



4 final state cascade

Cascades shift spectrum

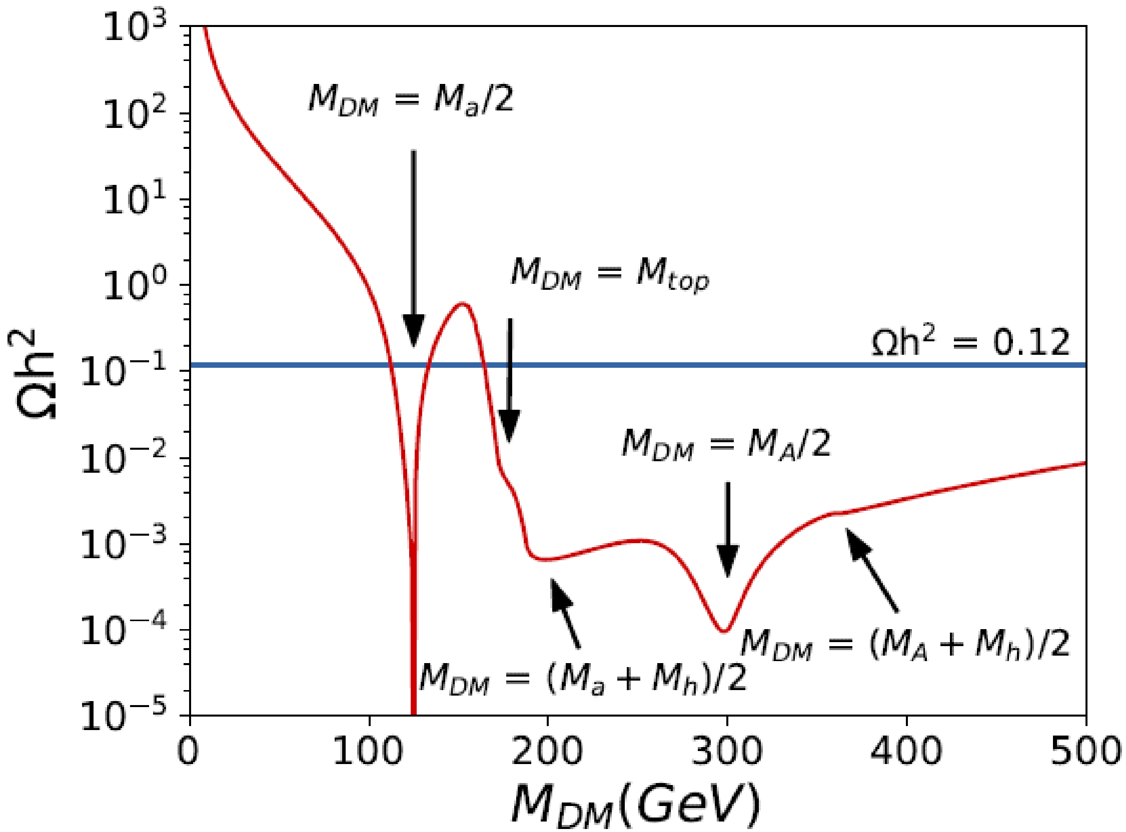


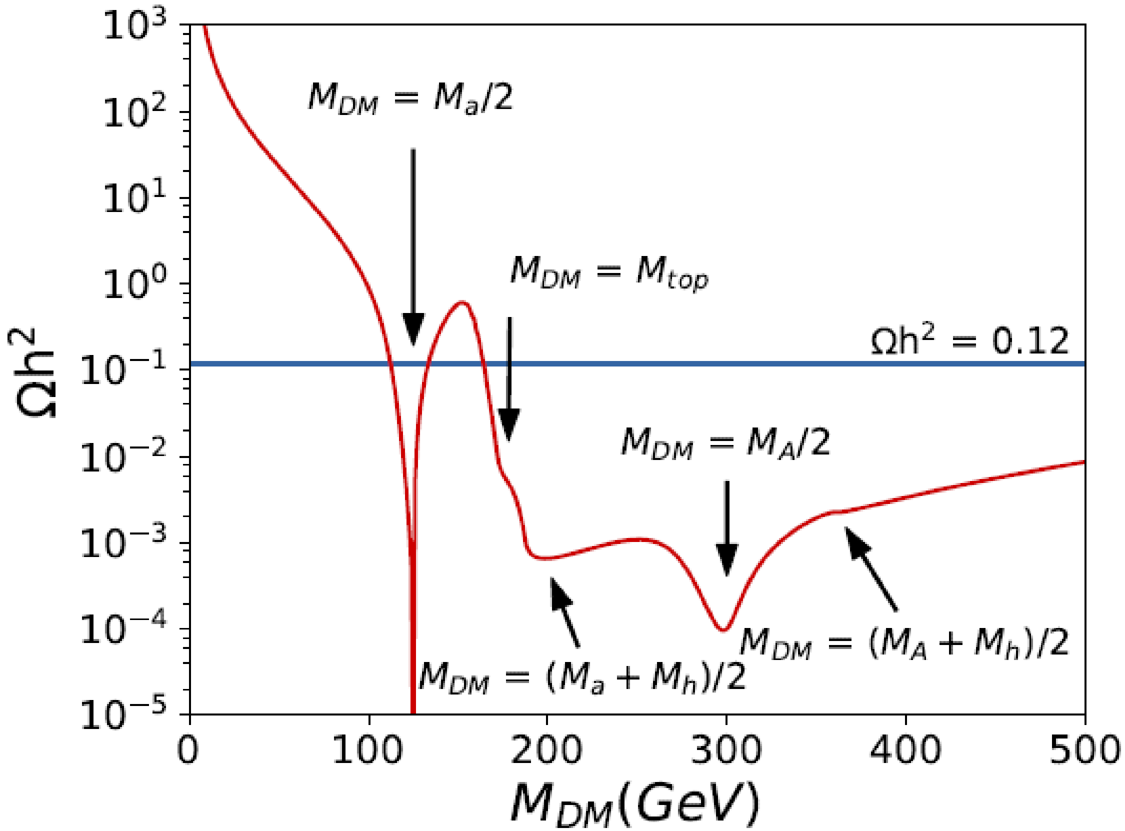
Slatyer group PhysRevD.91.103531

2^N Cascade

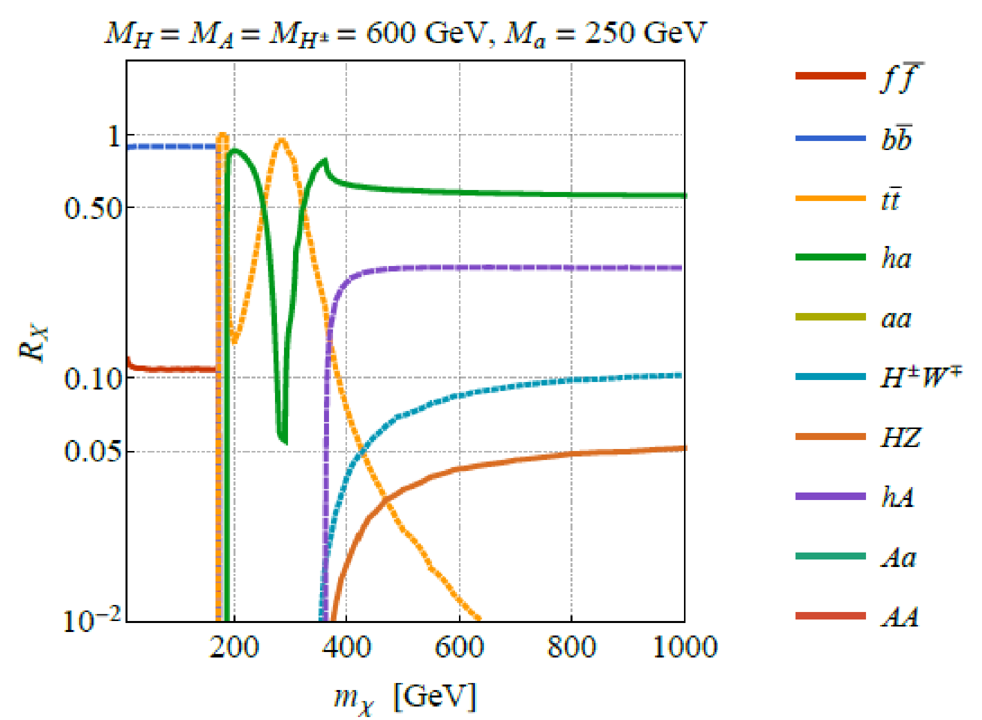
Relic Density Calculation

Orders
Of
magnitude





$M_{DM} = M_a/2$
$M_{DM} = M_{top}$
$\Omega h^2 = 0.12$
$M_{DM} = M_A/2$
$M_{DM} = (M_A + M_h)/2$
$M_{DM} = (M_a + M_h)/2$
Ωh^2
$M_{DM}(GeV)$



$M_H = M_A = M_{H^\pm} = 600$ GeV, $M_a = 250$ GeV
R_X
m_χ [GeV]
$f\bar{f}$
$b\bar{b}$
$t\bar{t}$
ha
aa
$H^\pm W^\mp$
HZ
hA
Aa
AA

Conclusions

Next Generation Models require more complexity in the mediator sector

Consequences for ID and DD detection are manifold

Great multiplicity of DM couplings to SM particles

DM annihilation process becomes complex, multiple final states and cascade decays

Extreme variation in Relic Density calculation