Dark Matter EFT

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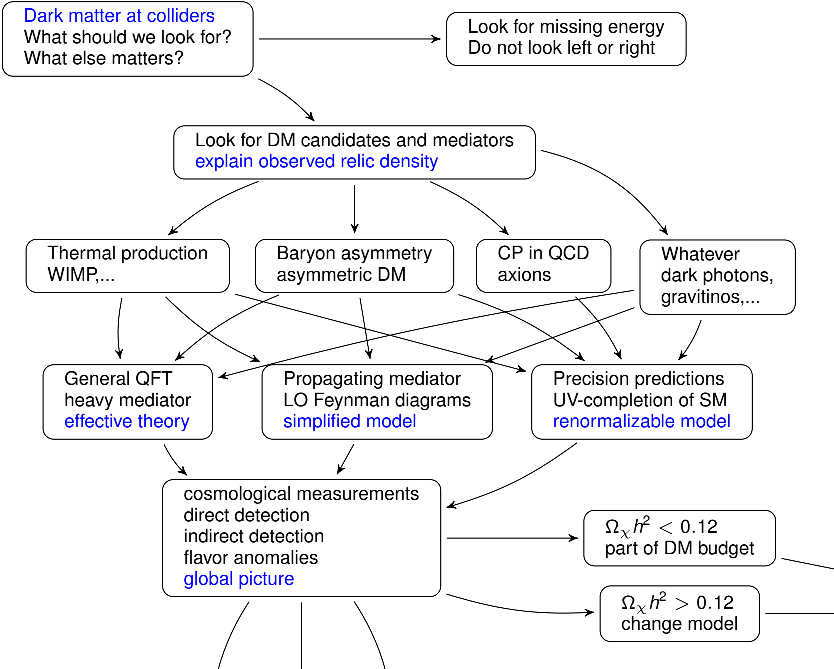
LCWS 3/2021

Dark matter road map



Thermal production

One measurement, many cases [Bauer & TP, lecture notes]

– annihilation rate from Boltzmann equation

$$\Omega_\chi h^2 \approx 0.12 \, \frac{x_\text{dec}}{23} \, \frac{\sqrt{g_\text{eff}}}{10} \, \frac{1.7 \cdot 10^{-9} \, \text{GeV}^{-2}}{\langle \sigma_{\chi\chi} v \rangle}$$

– literal WIMP

$$\langle \sigma_{\chi\chi} v \rangle = \frac{\pi \alpha^2 m_\chi^2}{s_w^4 m_W^4} \qquad \Rightarrow \qquad \Omega_\chi h^2 \approx 0.12 \left(\frac{35 \, \text{GeV}}{m_\chi} \right)^2$$

– Higgs portal

$$\sigma_{\chi\chi} \propto \begin{cases} \dfrac{\lambda_3^2 m_b^2}{m_H^4} & m_S \ll \dfrac{m_H}{2} \qquad \lambda_3 \approx 0.2 \\[2mm] \dfrac{\lambda_3^2 m_b^2}{m_H^2 \Gamma_H^2} & m_S = \dfrac{m_H}{2} \qquad \lambda_3 \approx 10^{-5} \\[2mm] \dfrac{\lambda_3^2}{m_S^2} & m_S > m_Z, m_H \qquad \lambda_3 \approx 0.04 \end{cases}$$

– light mediator

$$\langle \sigma_{\chi\chi} v \rangle \approx \frac{g^4}{16\pi m_\chi^2} \qquad \Rightarrow \qquad \frac{m_\chi}{g^2} \approx 3.4 \, \text{TeV}$$

– heavy mediator

$$\langle \sigma_{\chi\chi} v \rangle \approx \frac{g^4 m_\chi^2}{16\pi \, m_\text{med}^4} \qquad \Rightarrow \qquad \frac{m_\text{med}^2}{g^2 m_\chi} \approx 3.4 \, \text{TeV}$$

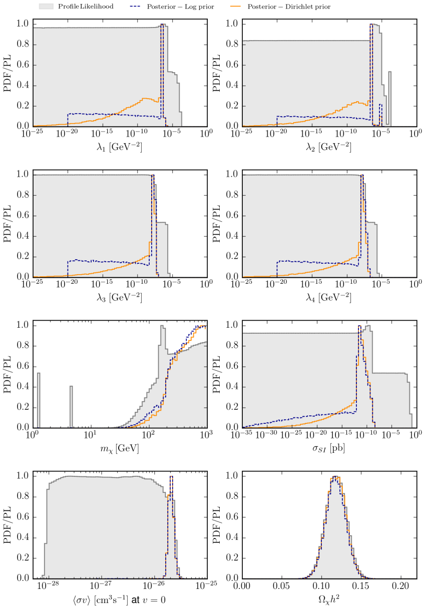
D6 dark matter operators

Classic: relic density plus Hooperon [Liem, Bertone, Calore, Ruiz de Austri, Tait, Trotta, Weniger]

- choose DM candidate
- thermal production
- D6-annihilation $\chi\chi \to$ SM SM
- indirect detection non-relativistic
- direct detection non-relativistic
- example: scalar DM

Coefficient	Operator	σ_{SI}	$\langle\sigma_{ann} v\rangle$
	Real scalar		
R1 $\lambda_1 \sim 1/(2M^2)$	$m_q \chi^2 \bar{q} q$	✓	s-wave
R2 $\lambda_2 \sim 1/(2M^2)$	$i m_q \chi^2 \bar{q} \gamma^5 q$		s-wave
R3 $\lambda_3 \sim \alpha_s/(4M^2)$	$\chi^2 G_{\mu\nu} G^{\mu\nu}$	✓	s-wave
R4 $\lambda_4 \sim \alpha_s/(4M^2)$	$i\chi^2 G_{\mu\nu} \tilde{G}^{\mu\nu}$		s-wave

- profile likelihood
- flat prior on $\log \lambda_i$ [prior $1/\lambda_i$]
- Dirichlet prior prefering similar-sized Wilson coefficients



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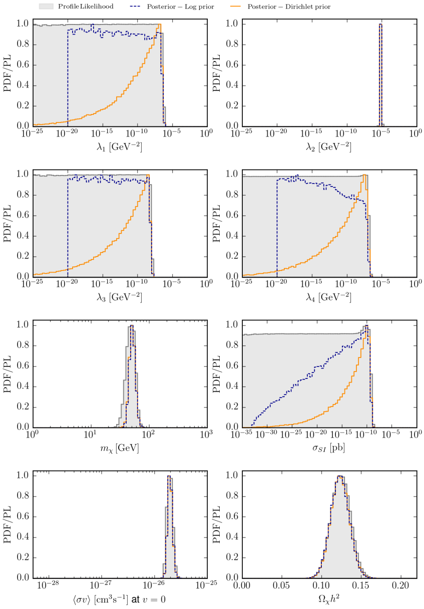
- Fermi: GCE plus dwarf galaxies

$\Rightarrow$ seriously short of measurements...



Effective theory

Decoupled mediator $m_{\text{med}} \gtrsim 2m_\chi$

- direct detection fine [non-relativistic]
- indirect detection, annihilation today fine [very non-relativistic]
- relic density challenging $$\frac{m_{\text{med}}^2}{g^2 m_\chi} \approx 3.4\ \text{TeV} \quad \stackrel{m_{\text{med}} > 2m_\chi}{\Rightarrow} \quad m_{\text{med}} < 1.7\ \text{TeV} \times g^2$$
- collider constraints: $m_{\text{med}} \gtrsim$ TeV

$\Rightarrow$ trouble ahead

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Learning from SMEFT success? [Bauer, Butter, Desai, Gonzalez-Fraile, TP]

– tree-level colored t-channel mediator [squark-neutralino in MSSM]

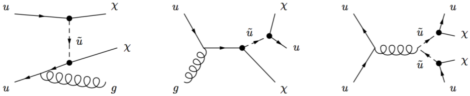
– tree-level vector s-channel mediator [Z' mediator]

– loop-mediated scalar s-channel mediator [heavy Higgs-neutralino in MSSM]

– loop-mediated scalar t-channel mediator [stop-neutralino in MSSM]

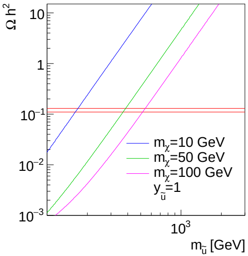
$\Rightarrow$ EFT to represent models?

Models: relic density vs LHC



Tree-level scalar in t-channel [squarks]

– relic density for small $m_{\tilde{u}}$



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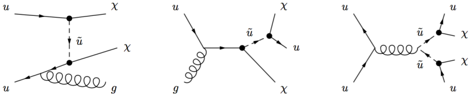
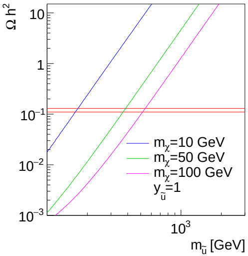


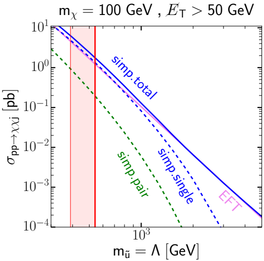
Tree-level scalar in t-channel [squarks]

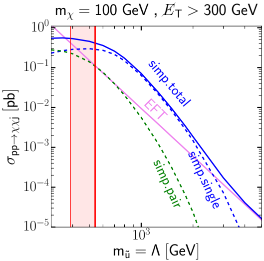
- relic density for small $m_{\tilde{u}}$
- two effective Lagrangians

$$\mathcal{L}_{\text{eff}} \supset \frac{c_{u\chi}}{\Lambda^2} \; (\bar{u}_R \chi) \; (\bar{\chi} u_R) \qquad \mathcal{L}_{\text{eff}} \supset \frac{c}{\Lambda^3} (\bar{\chi}\chi) \, G_{\mu\nu} G^{\mu\nu}$$



- EFT not valid for correct relic density...





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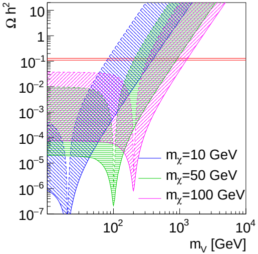
Tree-level vector in s-channel

– relic density for small m_V or around pole



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Tree-level vector in s-channel

- relic density for small m_V or around pole
- only 4-fermion operator
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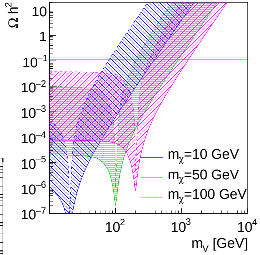

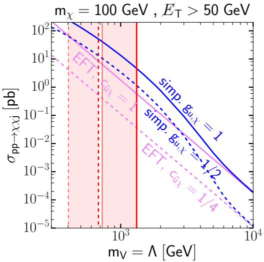

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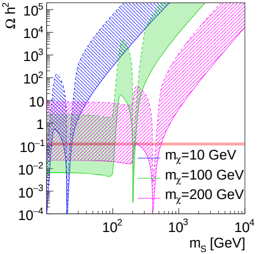

Loop-mediated scalar in s-channel

- relic density around pole

Models: relic density vs LHC

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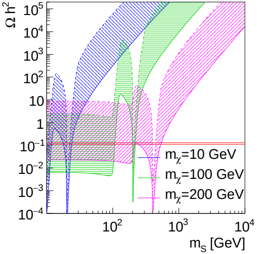

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Loop-mediated scalar in s-channel

– relic density around pole

– two effective Lagrangians

$$\mathcal{L}_{\text{eff}} \supset \frac{c_S^t}{\Lambda^2} (\bar{t}t) \; (\bar{\chi}\chi) \qquad \mathcal{L}_{\text{eff},3} \supset \frac{c_\chi^g}{\Lambda^3} (\bar{\chi}\chi) \; G_{\mu\nu} G^{\mu\nu}$$

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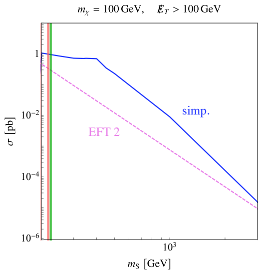
$\Rightarrow$ global DM-EFT framework no success story



Neutrino-inspired DM-EFT

Replace neutralino with RH neutrino [Bischer, TP, Rodejohann]

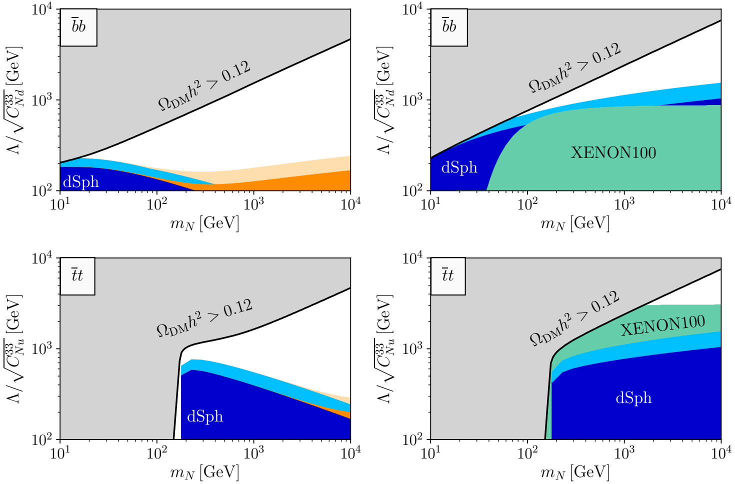
– focus on 4-fermion operators to 3rd generation

$(\bar{L}L)(\bar{L}L)$ and $(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$		$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
$\mathcal{O}_{Ne}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\bar{e}_\gamma \gamma^\mu e_\delta)$	$\mathcal{O}_{Nl}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\bar{l}_\gamma \gamma^\mu l_\delta)$	$\mathcal{O}_{Nlel}$	$(\overline{N}_\alpha l^j_\beta)\epsilon_{jk}(\bar{e}_\gamma l^k_\delta)$
$\mathcal{O}_{Nu}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\bar{u}_\gamma \gamma^\mu u_\delta)$	$\mathcal{O}_{Nq}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\bar{q}_\gamma \gamma^\mu q_\delta)$	$\mathcal{O}_{lNqd}$	$(\bar{l}^j_\alpha N_\beta)\epsilon_{jk}(\bar{q}^k_\gamma d_\delta)$
$\mathcal{O}_{Nd}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\bar{d}_\gamma \gamma^\mu d_\delta)$			$\mathcal{O}'_{lNqd}$	$(\bar{l}^j_\alpha \sigma_{\mu\nu} N_\beta)\epsilon_{jk}(\bar{q}^k_\gamma \sigma^{\mu\nu} d_\delta)$
$\mathcal{O}_{NN}$	$(\overline{N}_\alpha \gamma_\mu N_\beta)(\overline{N}_\gamma \gamma^\mu N_\delta)$			$\mathcal{O}_{lNuq}$	$(\bar{l}^j_\alpha N_\beta)(\bar{u}_\gamma q^j_\delta)$
$\mathcal{O}_{eNud}$	$(\bar{e}_\alpha \gamma_\mu N_\beta)(\bar{u}_\gamma \gamma^\mu d_\delta)$				

Neutrino-inspired DM-EFT

Replace neutralino with RH neutrino [Bischer, TP, Rodejohann]

- focus on 4-fermion operators to 3rd generation
- indirect detection from dwarf spheriodals
- direct detection only for Dirac neutrino [induced vector coupling]

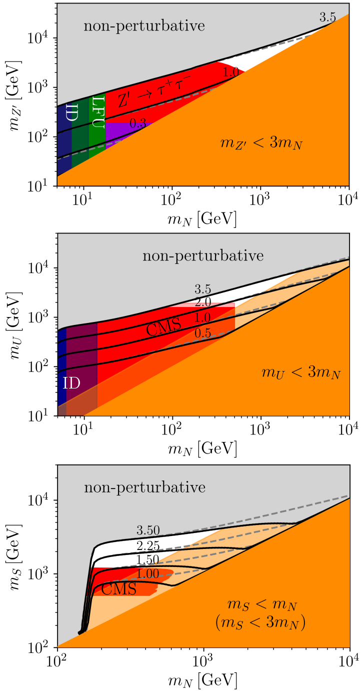


Models, again

Tree-level models, slightly weirder?

- gauged $(B-L)_3$
  vector leptoquarks
  scalar leptoquarks
- relic density required
- EFT constraints for DD, ID, etc
  model constraints from collider
- EFT consistency improved

$\Rightarrow$ still no global analysis framework



DM-EFT(s)

– working for DD and ID
  dodgy for relic density [the one measurement]
  maybe useful for cosmo

– not working for SUSY-like or simple Z' models
  semi-convincing for 3rd-generation models
  no valid collider framework

– DM observables available in public codes [Micromegas, DarkSUSY, ...]
  global fit with one observable?
  EFT with propagating mediator better?

$\Rightarrow$ What's the point, really?