Robust collider limits on heavy-mediator Dark Matter

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arXiv: 1502.04701

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Thursday, 12th March 2015

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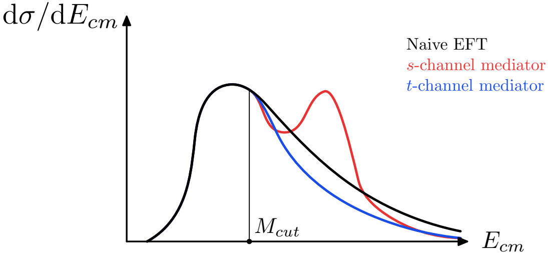
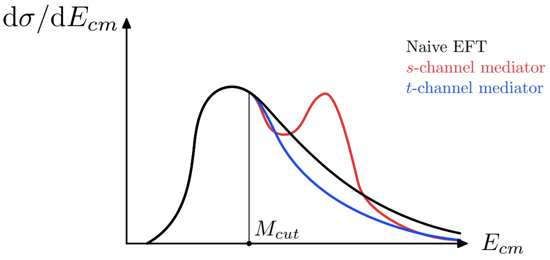
Goal

Use the EFT to get completely general bounds from DM searches at colliders.

- Three free parameters in EFT:
  1. m_{DM};
  2. M_*: effective operator coefficient $\left(1\middle/M_*^{d-4}\right)$;
  3. M_{cut}: *cut-off scale* for the validity of the EFT.



Our strategy



- We restrict the signal to the events for which

$$\boxed{E_{\text{cm}} < M_{\text{cut}}}\,,$$

where E_{cm} is the total invariant mass of the hard final states of the reaction:

$$E_{\text{cm}} = \sqrt{\hat{s}} = \sqrt{\Big(p^\mu(\text{DM}_1) + p^\mu(\text{DM}_2) + p^\mu(\text{jet})\Big)^2}\,.$$

- Indeed, the following *always* holds:

$$\sigma^{\text{signal}}_{\text{true model}} > \sigma^{\text{signal}}_{\text{corresp. EFT}}\Big|_{E_{\text{cm}} < M_{\text{cut}}}\,.$$

Thus we obtain conservative but reliable limits.

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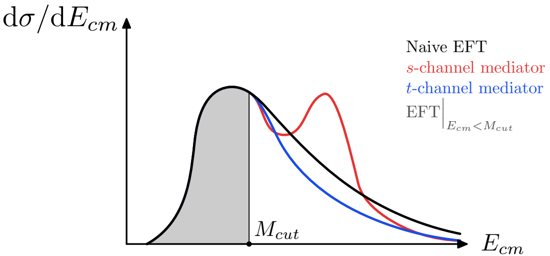

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- We consider the case in which DM is a Majorana fermion X, and the effective operator for the interaction with quarks is D8,

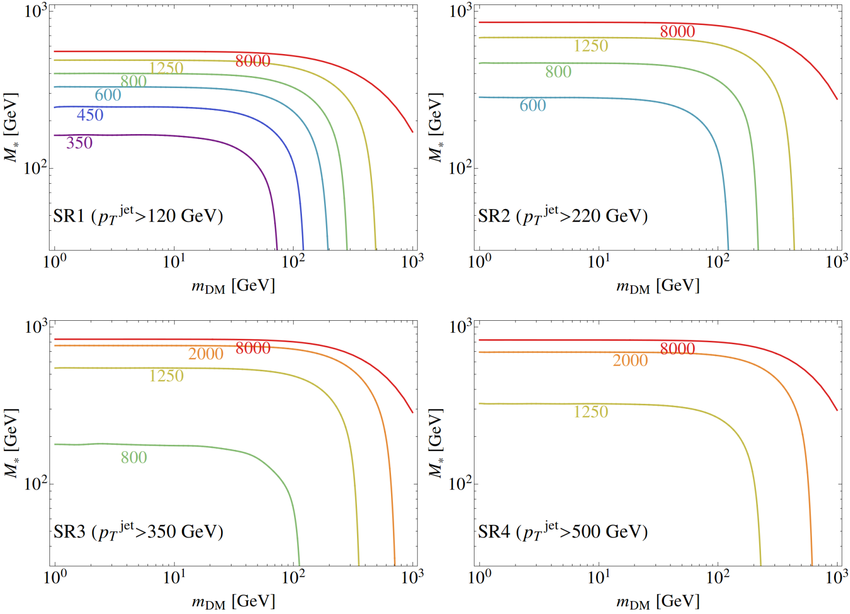
$$\mathcal{L}_{\text{EFT}} = -\frac{1}{M_*^2}\,(\overline{X}\gamma^\mu\gamma^5 X)\left(\sum_{\text{flavours}} \bar{q}\gamma_\mu\gamma^5 q\right) .$$

- We use Atlas monojet search ATLAS-CONF-2012-147 (10.5 fb^{-1} at $\sqrt{s}$ =8 TeV).

signal region	SR1	SR2	SR3	SR4
$p_{\mathsf{T}}^{\text{jet}}$ and $E_{\mathsf{T}}^{\text{miss}}$ [GeV]	>120	>220	>350	>500
σ_{exc}[pb], 95% CL	2.7	0.15	$4.8\,10^{-2}$	$1.5\,10^{-2}$

- We perform a parton-level analysis, and we compute cross-section σ and acceptance A with `MadGraph5`.
- We estimate the efficiency ϵ by matching this output to the experimental limit. The available data allow to extract ϵ for SR3, for three values of m_X.

Results for fixed $M_{\rm cut}$



What are reasonable M_{cut} values?

- EFT Lagrangian:

$$\mathcal{L}_{\text{EFT}} = -\frac{1}{M_*^2} \left(\overline{X}\gamma^\mu\gamma^5 X\right) \left(\sum_{\text{flavours}} \overline{q}\gamma_\mu\gamma^5 q\right) .$$

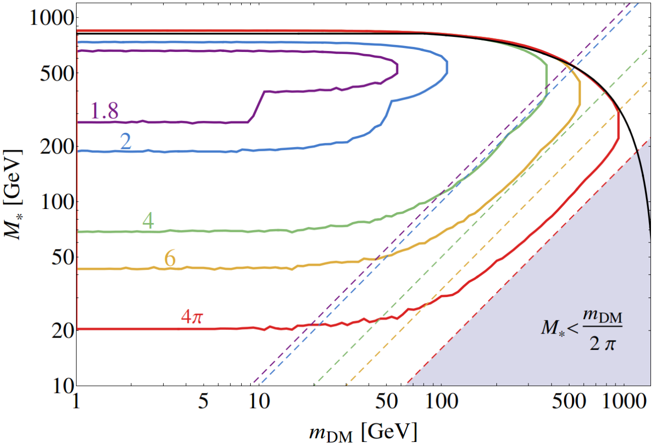
- We can link the two dimensionful parameters M_* and M_{cut} through

$$\boxed{M_{\text{cut}} = g_* M_*} .$$

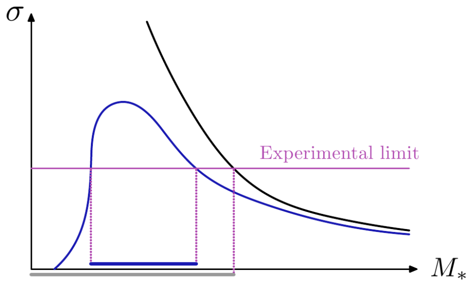
g_*: *effective coupling strength* of the EFT. Justification:

$$\mathcal{M}(2 \to 2) \sim \frac{E^2}{M_*^2} \underset{\text{at cut-off}}{\to} \frac{M_{\text{cut}}^2}{M_*^2} \equiv g_*^2 .$$

Results for fixed g_*



Why is there a lower limit in the excluded region?



$$\sigma_{\text{EFT}}^{\text{signal}}\Big|_{E_{\text{cm}}<g_* M_*} \propto \frac{1}{M_*^4} \cdot \text{Acceptance} \to \begin{cases} \dfrac{1}{M_*^4} & \text{for } M_* \to \infty\,, \\ 0 & \text{for } M_* \to 0\,. \end{cases}$$

- Kinematical threshold:

$$E_{\text{cm}}^{\min} = p_{\text{T}}^{\text{jet}} + \sqrt{\left(p_{\text{T}}^{\text{jet}}\right)^2 + 4\, m_{\text{DM}}^2}\,.$$

The lower is $p_{\text{T}}^{\text{jet}}$, the stronger is the lower limit in the exclusion interval.

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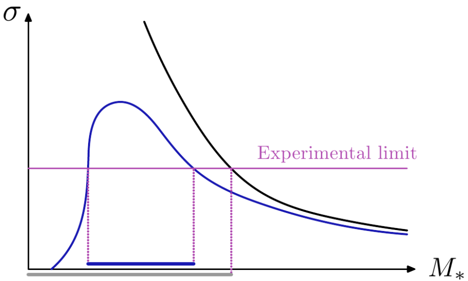

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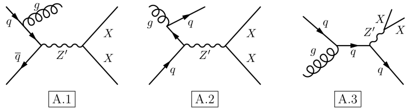
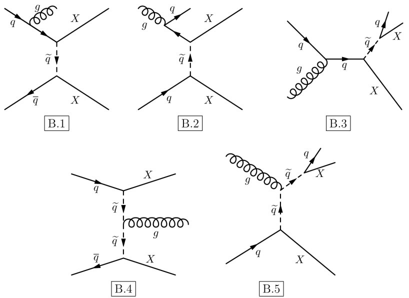
Model A: s-channel vector mediator

$$\mathcal{L}^{\mathsf{A}}_{\mathsf{int}} = Z'_\mu\left(g_q\sum_q \overline{q}\gamma^\mu\gamma^5 q + g_X\overline{X}\gamma^\mu\gamma^5 X\right)$$

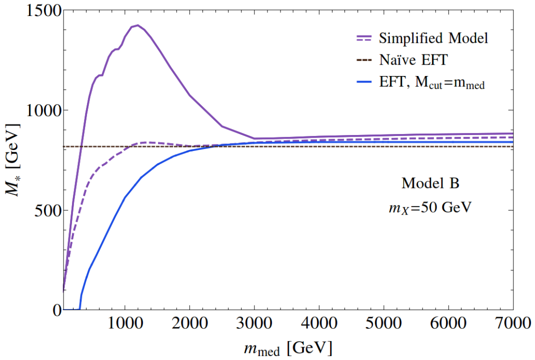


Model B: t-channel scalar mediator

$$\mathcal{L}^{\mathsf{B}}_{\mathsf{int}} = -g_{\mathsf{DM}}\left[\sum_{i=1}^{3}\left(\widetilde{u}_{iL}\,\overline{u_{iL}} + \widetilde{d}_{iL}\,\overline{d_{iL}} + \widetilde{u}_{iR}\,\overline{u_{iR}} + \widetilde{d}_{iR}\,\overline{d_{iR}}\right)X + \text{h.c.}\right]$$



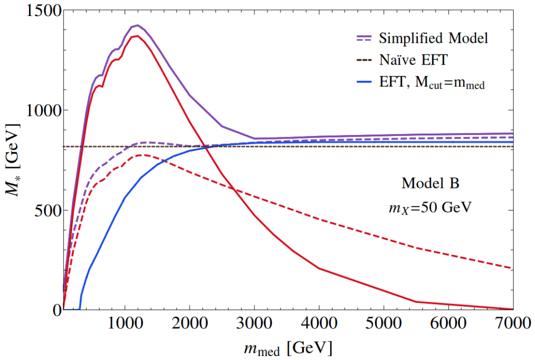
Comparison with the simplified model



- **Blue line**: from model-independent limit, with the identification

$$M_* = \frac{2\widetilde{m}}{g_{\rm DM}}\,, \qquad M_{\rm cut} = \widetilde{m}\,.$$

- **Red lines**: only from the resonant production of the mediator.
  The EFT limit is complemented by the limit from the resonant production.
- **Grey lines**: fixed mediator width.
  The plane $(m_{\rm med}, M_*)$ is not suitable to draw a limit for fixed mediator width.



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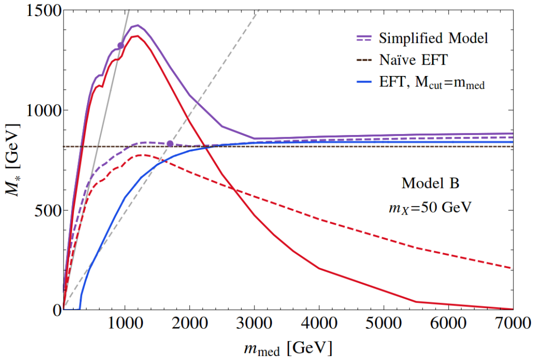

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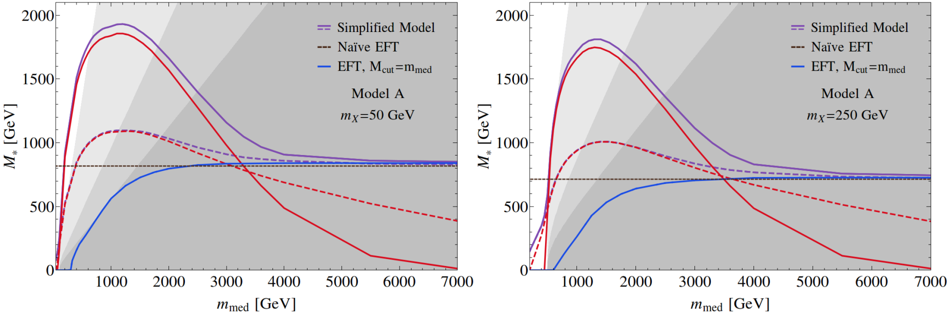
Conclusions

1. The EFT allows to extract **universal bounds** from DM searches. (reinterpretable in any UV model)
2. The prescription $E_{\text{cm}} < M_{\text{cut}}$ can be used for any effective operator.
3. An effective operator as D_8 may have several microscopic origins.
4. Exclusion intervals in M_* have also a *lower* bound. The softer SRs are useful to extend the limits for small M_*.
5. Extended simplified model reach due to resonant production. $\Rightarrow$ complement the monojet EFT search with direct mediator search.
6. Limitation of the plane M_{med}, M_* (inconsistent width).

1. BACKUP SLIDES

Comparison with the simplified model A



Comparison with the choice of $Q_{\rm tr}$