Robust Collider Limits on Heavy-Mediator DM

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Introduction

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Enormous variety of radically different scenarios, extremely challenging to setup a comprehensive exploration strategy

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Model-independence, i.e. broad exploration of the parameter space is mandatory here!

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DM coupling to SM from high scale dynamics

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$$\mathcal{L}_{\mathrm{int}} = \frac{1}{M_*^2} \sum_i c_i \, O_i$$

EFT definitely applies to low-momentum reaction:

$$\left\{ \begin{array}{l} \text{1) thermal relic calculation} \\ \text{2) direct search limits} \\ \text{3) indirect search limits} \end{array} \right.$$

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what instead about … 4) collider limits ??

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Cutoff is part of the EFT definition, one of its free parameters.
In any specific microscopic model, we might read its true value

$$M_{\rm cut} \sim M_{\rm Med}$$

mass of the specific "mediators", or scale of strong UV theory

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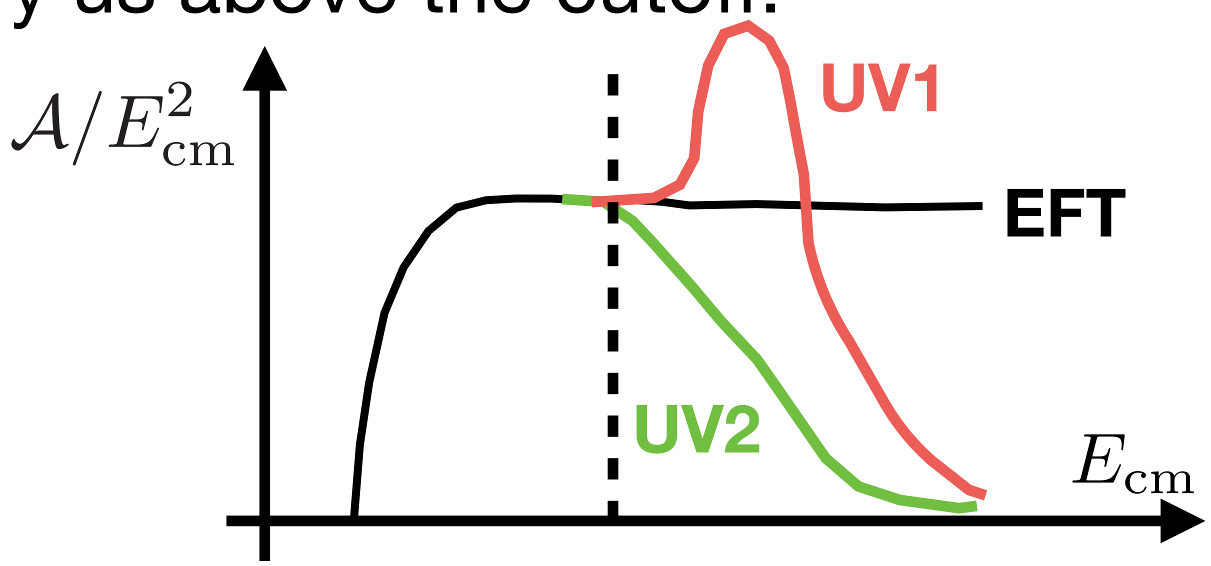
LHC might carry us above the cutoff:



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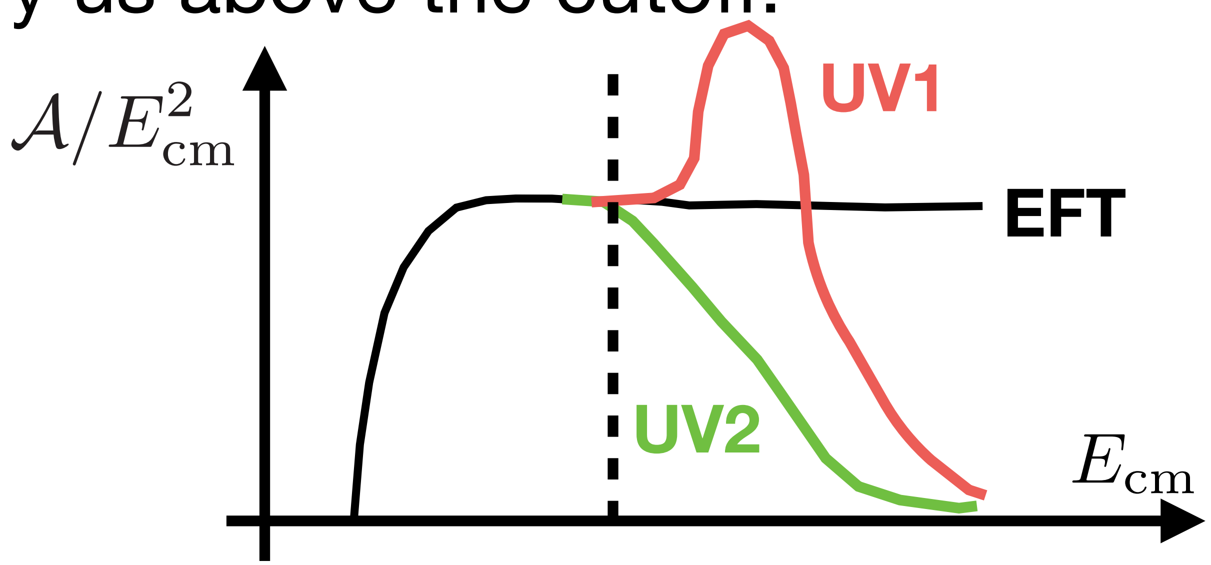

however restricting the signal to the predictable region sets lower bound on the “true” signal, which holds for any mediator model

$$\sigma^S_{EFT}\Big|_{E_{\rm cm}<M_{\rm cut}} \leq \sigma^S_{\rm true} < \sigma_{\rm exc}$$

compared with exclusion upper bound, model indep. limit is set

ATLAS mono-jet recast

chosen operator: $$\mathcal{L}_{\rm int} = -\frac{1}{M_*^2}\,(\overline{X}\gamma^\mu\gamma^5 X)\left(\sum_q \overline{q}\gamma_\mu\gamma^5 q\right)$$

counting in four SR

signal region	SR1	SR2	SR3	SR4
$p_T^{\rm jet}$ and MET	>120	>220	>350	>500
$\sigma_{\rm exc}$[pb]	2.7	0.15	$4.8\,10^{-2}$	$1.5\,10^{-2}$

restricted signal definition:

$$\sigma_{{\rm SR}i}(M_*, m_{DM}, M_{\rm cut}) = \sigma(M_*, m_{DM}, M_{\rm cut}) \times A_i(m_{DM}, M_{\rm cut}) \times \epsilon$$

NOTE: the EFT has **three** parameters

1) $m_{\rm DM}$
2) M_*
3) $M_{\rm cut}$ (as physical as the other two)

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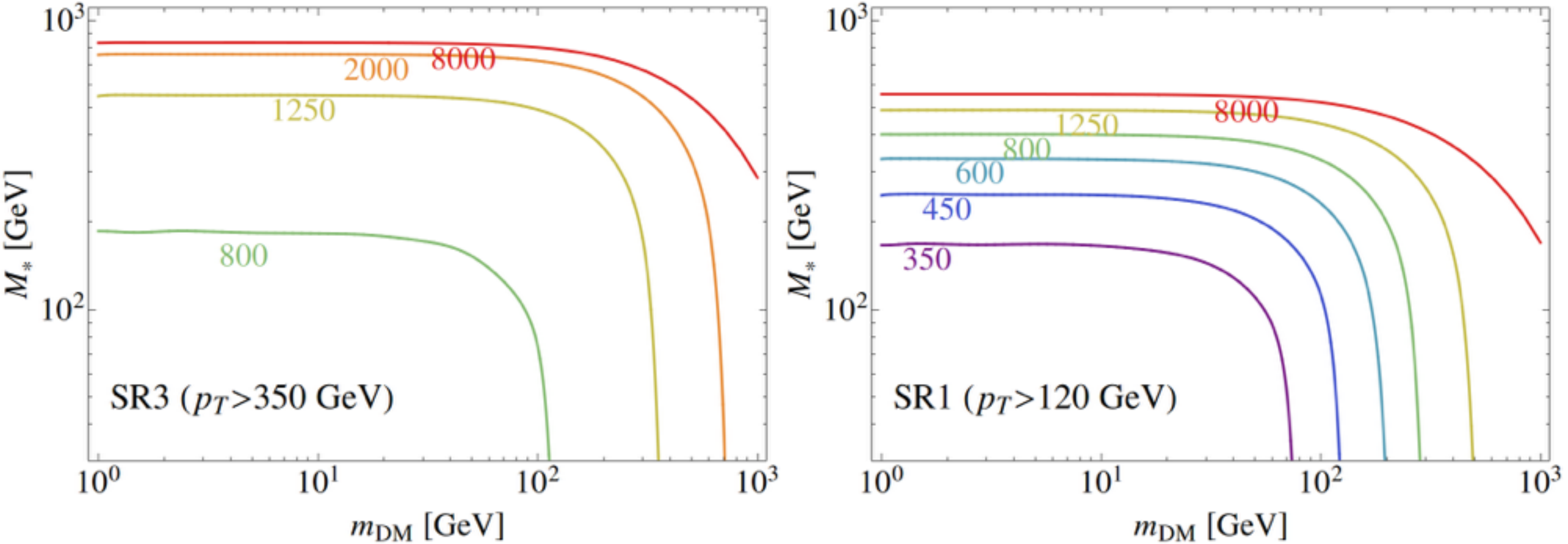
colored lines: fixed $M_{\rm cut}$



Hard signal regions are favored at high cutoff (naive EFT)

But rapidly lose sensitivity: the cut makes distributions softer

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Theoretical connection among M_* and $M_{\rm cut}$:

$$M_{\rm cut} = g_* \, M_*$$

estimated mediator coupling

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Useful redefinition: $\begin{cases} \text{We know for sure that: } & g_* < 4\pi \\ \text{Expected for a WIMP: } & g_* \sim 1 \end{cases}$

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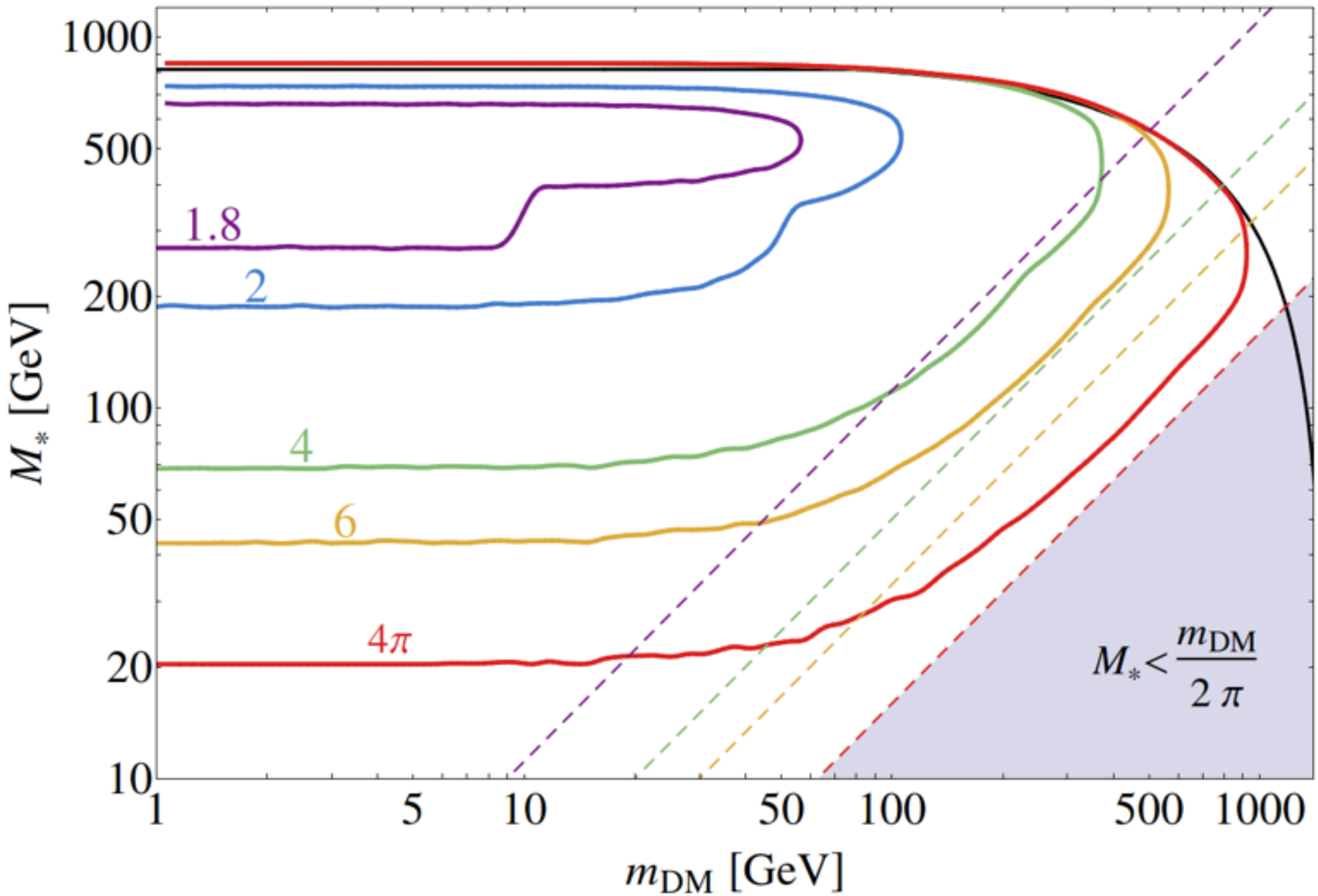
Fixed g_* limits: (from all the SR)



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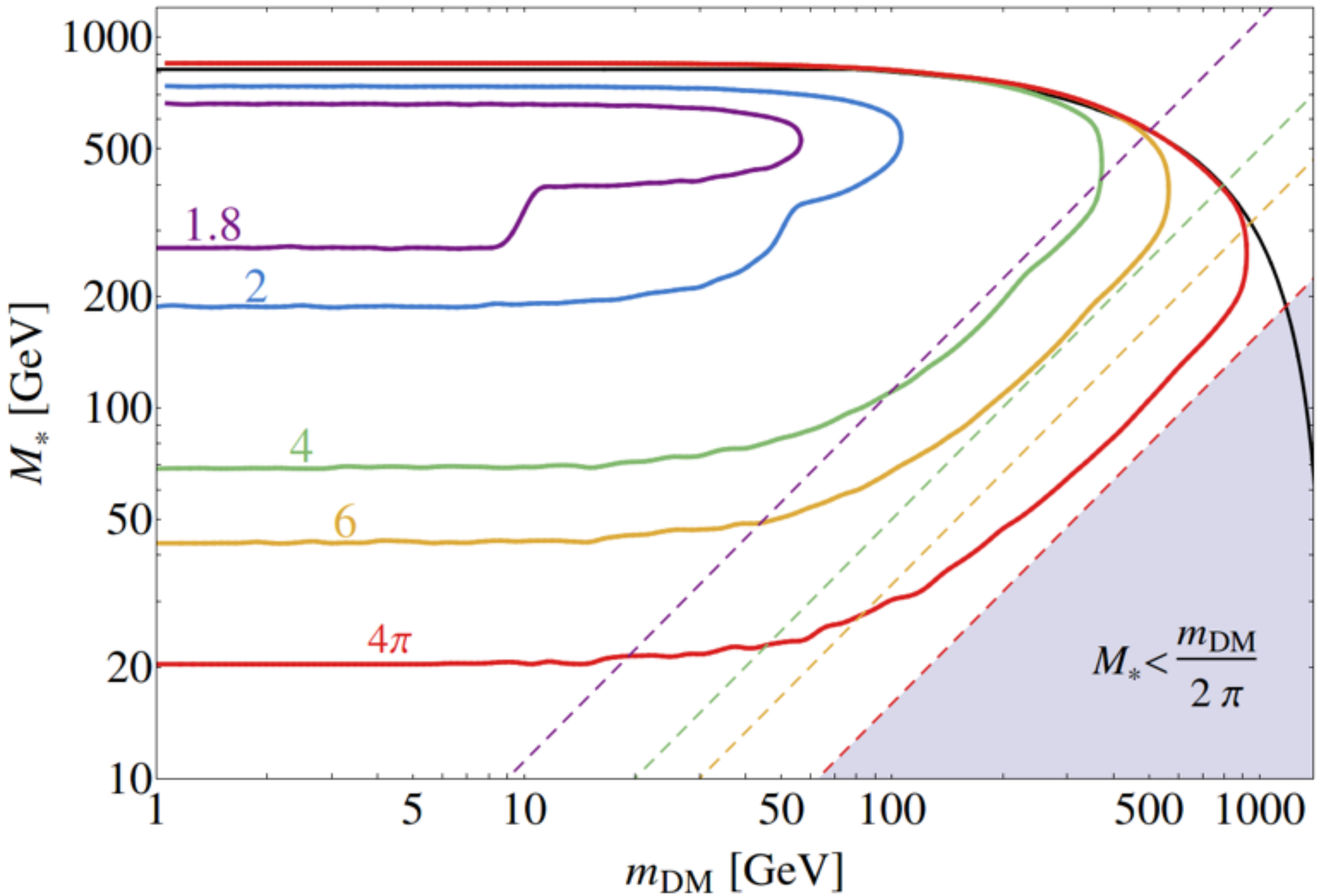

Similar plot in De Simone et. al 1402.1275. Comparison in backup.

Conclusions and Outlook

- Model-independent test of H-M DM is possible
- Parameter space currently far from fully tested

    progress needed in the soft region

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  [with M.Zanetti (CMS) and F.Pobbe]

  1) define ``hard scale” to be cut on. Using MLM matching

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- Beyond EFT’s, the improvement is from mediator prod.:

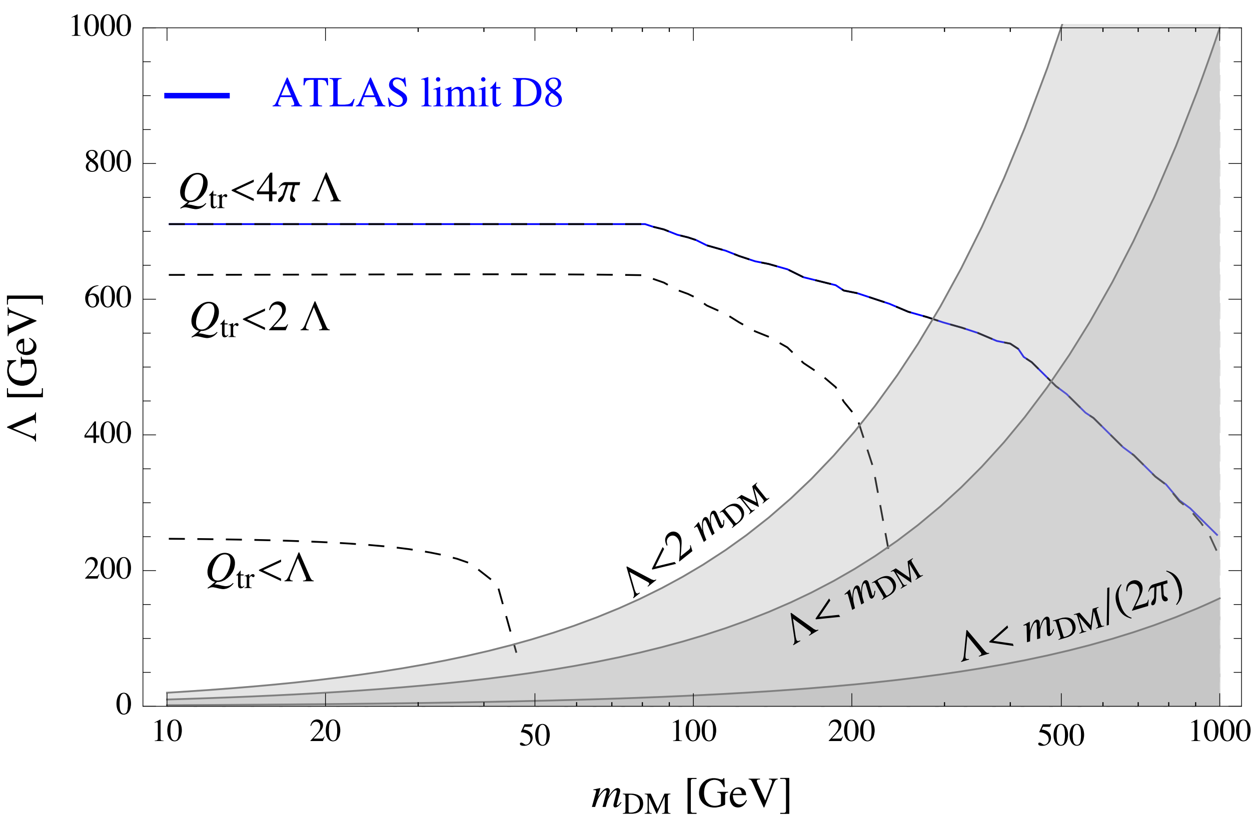
    1) turn to mediator search, appropriate interpretation is $\sigma \times BR$

    2) other search channels for the mediator (e.g., model B is squark)

    3) final goal is cover all models by patches (EFT + mediator search)

Backup

From De Simone et. al 1402.1275:



Conceptual difference: (to me…)

Their aim was show up to when naive EFT limits coincide with UV theory ones.

Our aim is set limits that hold for any UV.

Practical differences:

Model-dependent cut variable $Q_{\rm tr}$.

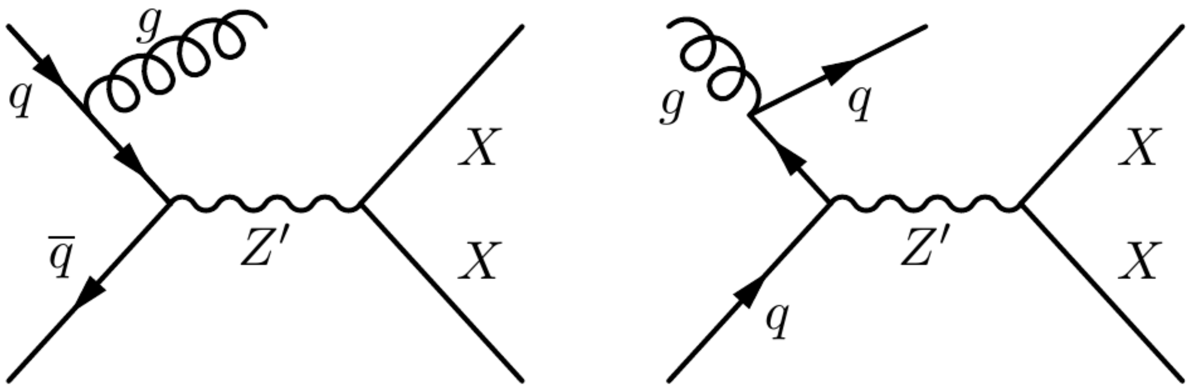
The contours are open! Issue due to Naive EFT limit rescaling.

Other variables

By further specifying mediator dynamics (s- or t-channel)

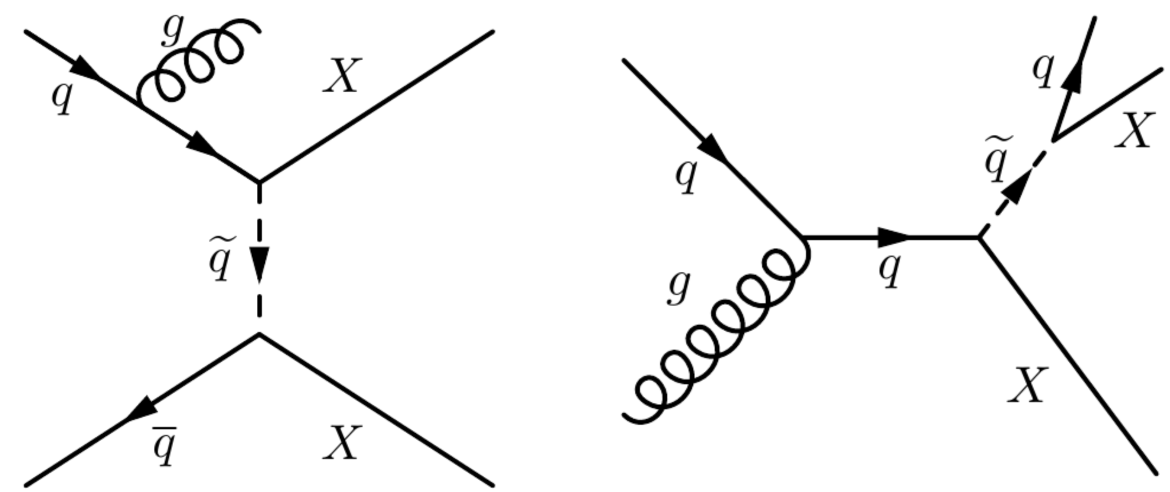
Q_{tr}= max virtuality of mediator propagator

Model A: Z' coup. to q and DM



$$Q_{\mathrm{tr}} = M(DM, DM)$$

Model B: squark-DM-quark coup.

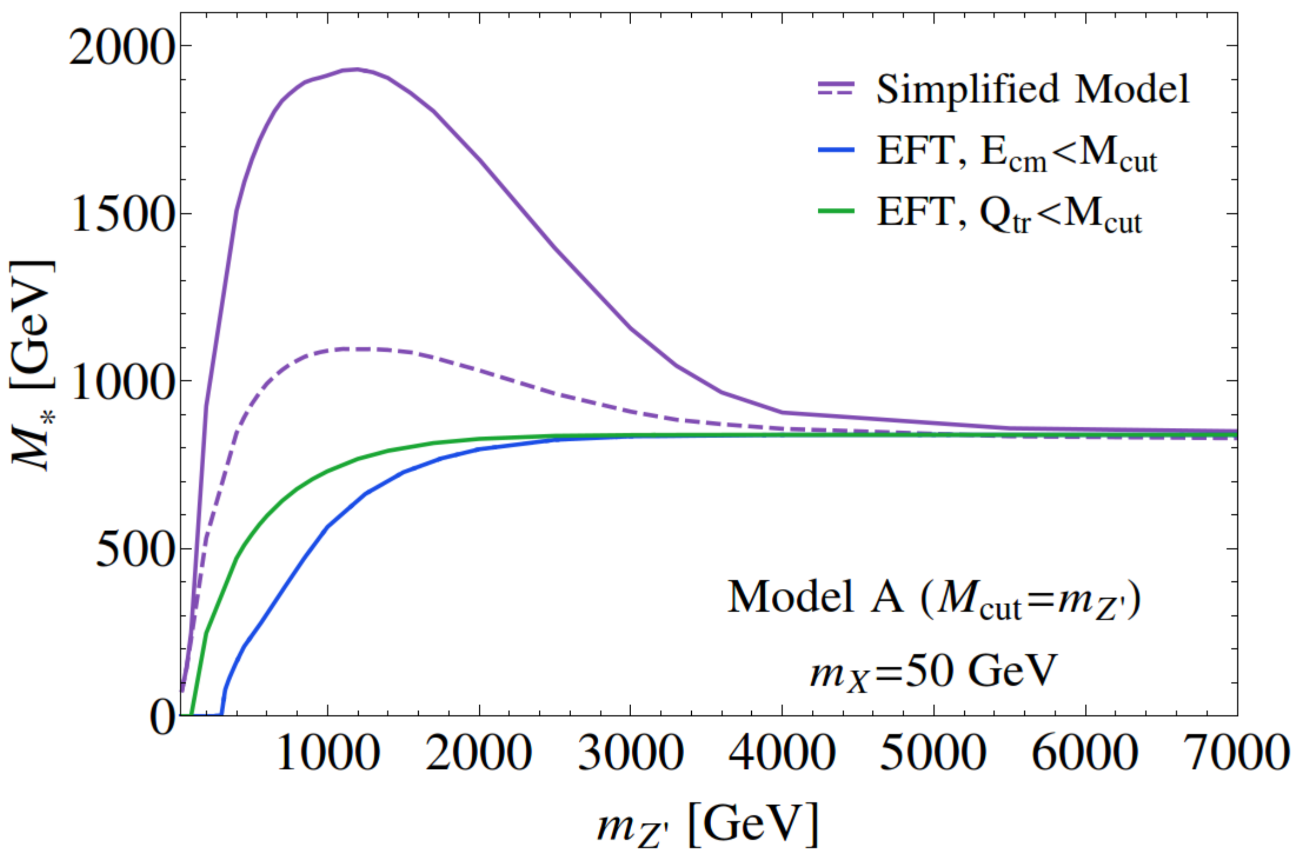


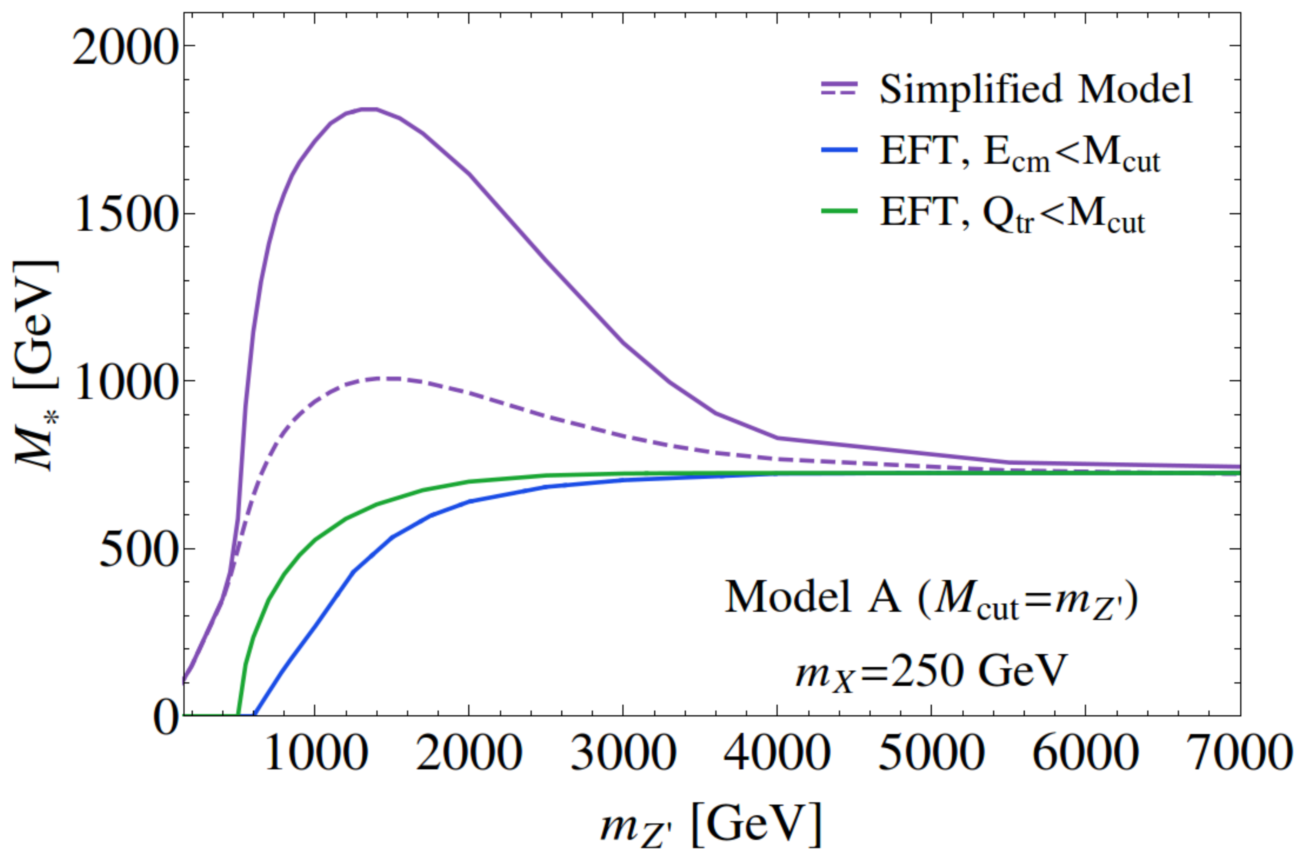
$$Q_{\mathrm{tr}} = \ldots$$

In all cases (kinematical bound): $Q_{\mathrm{tr}} < E_{\mathrm{cm}}$

Other variables

Worth dedicated s- and t-channel analyses for a better bound?





We consider the improvement not sufficient

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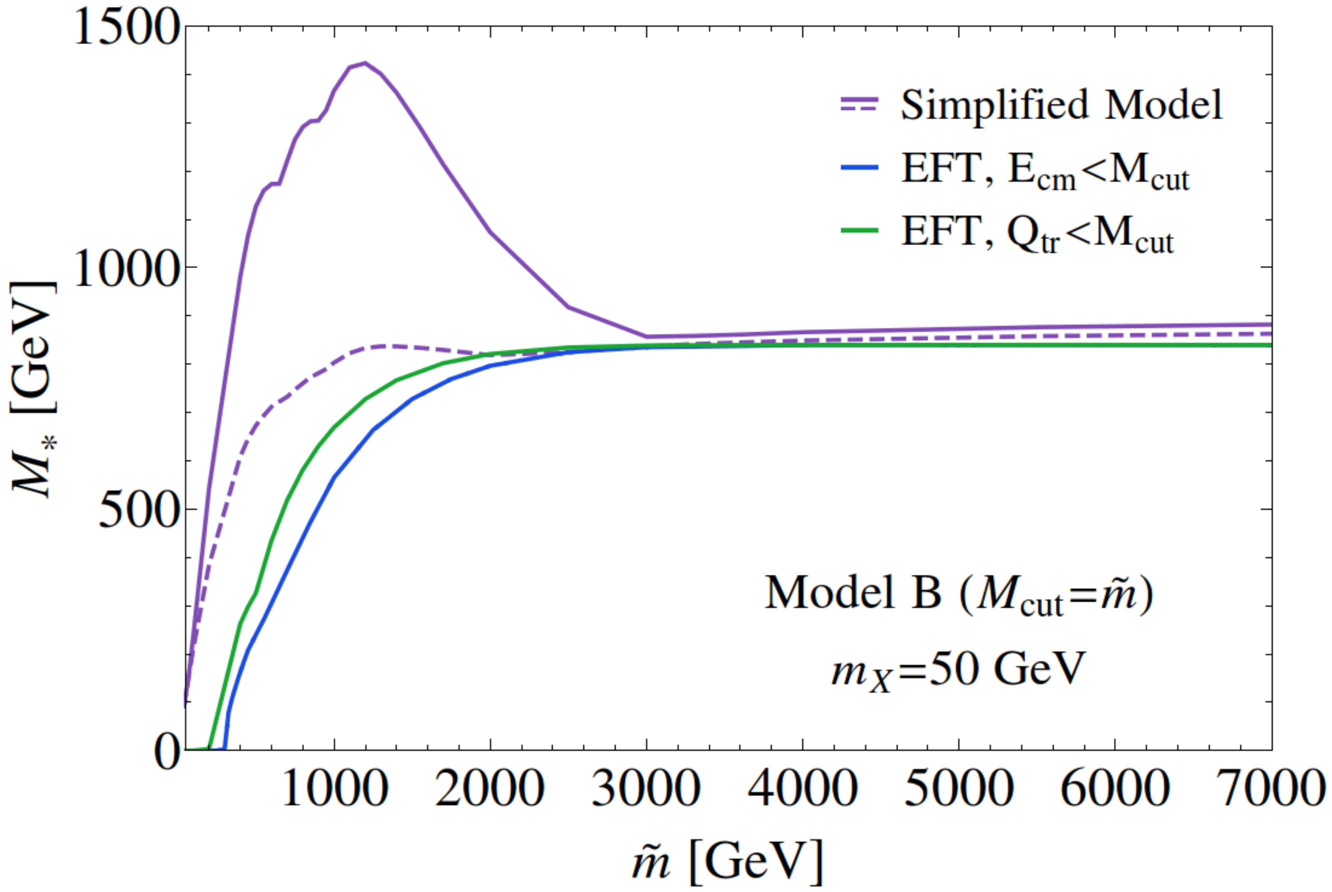

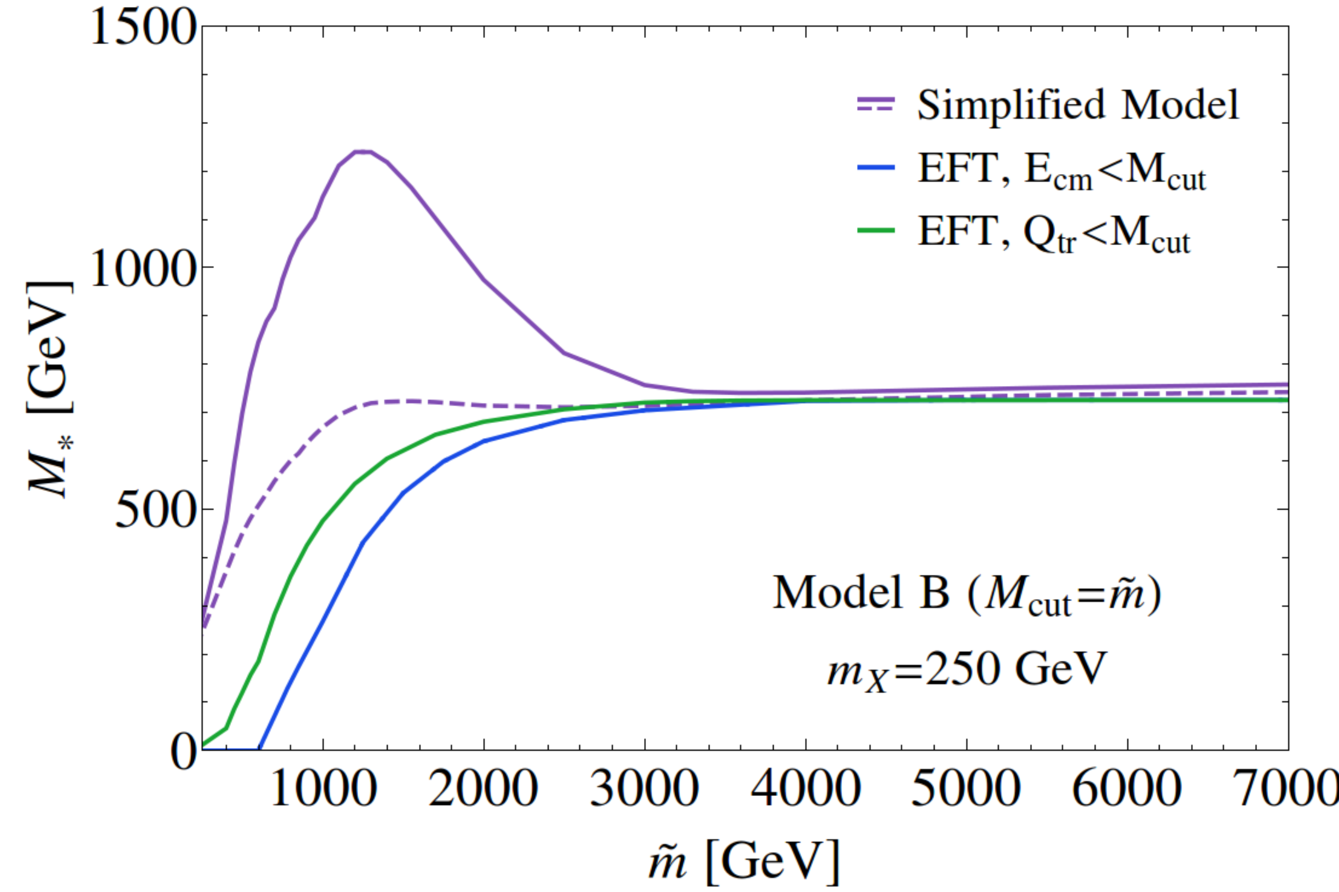

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Simplified models reinterpretation

Properly set EFT limits hold in any microscopic theory.
They are correct, but conservative.

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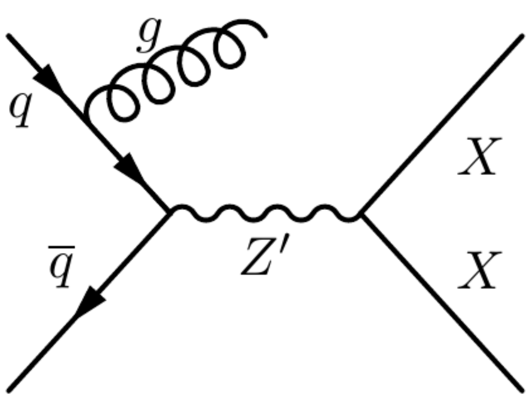
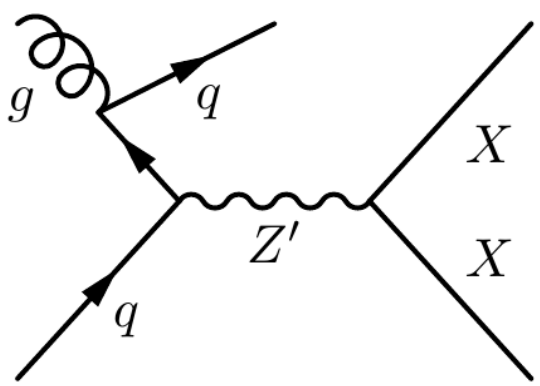
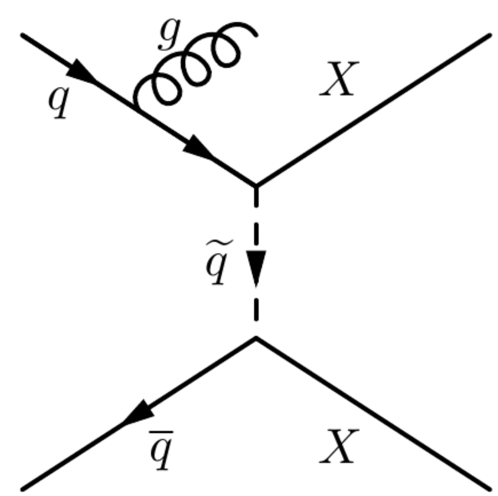
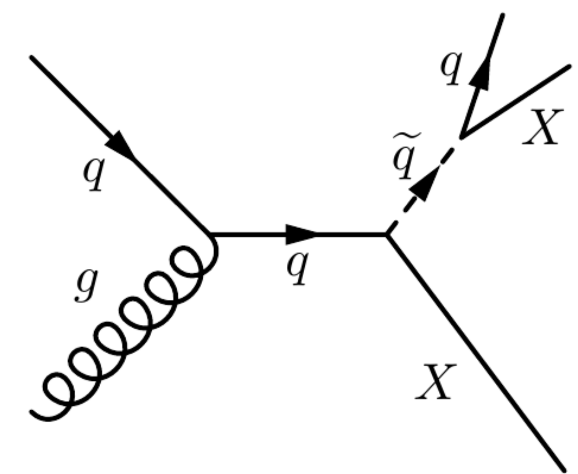




$$M_* = \frac{m_{Z'}}{\sqrt{g_q\, g_X}} \qquad g_* = \sqrt{g_q\, g_X}$$

Model B: squark-DM-quark coup.





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

Compute parameters, use EFT limits, obtain bounds.
Compare with direct recasting of mono-jet.

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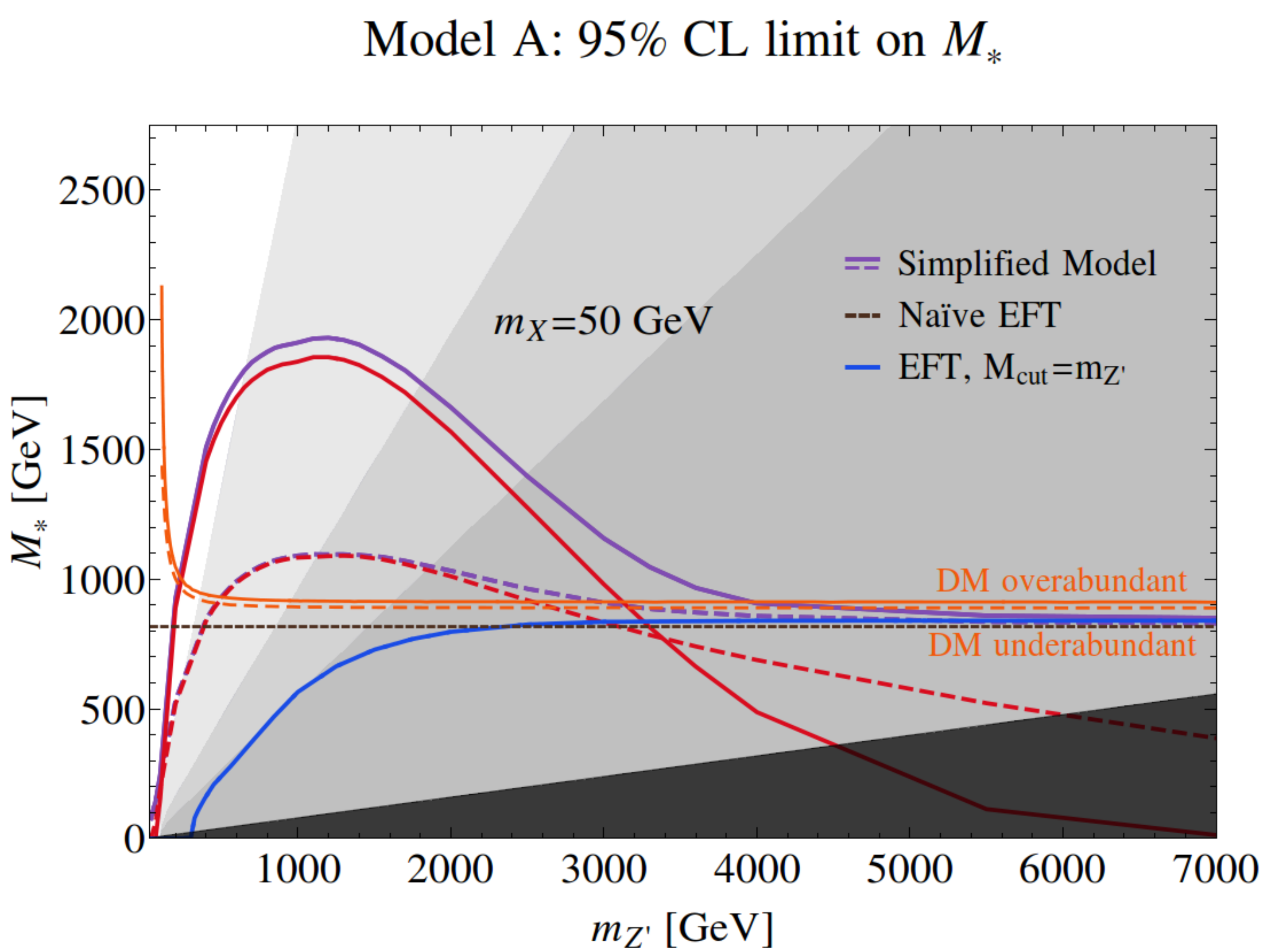

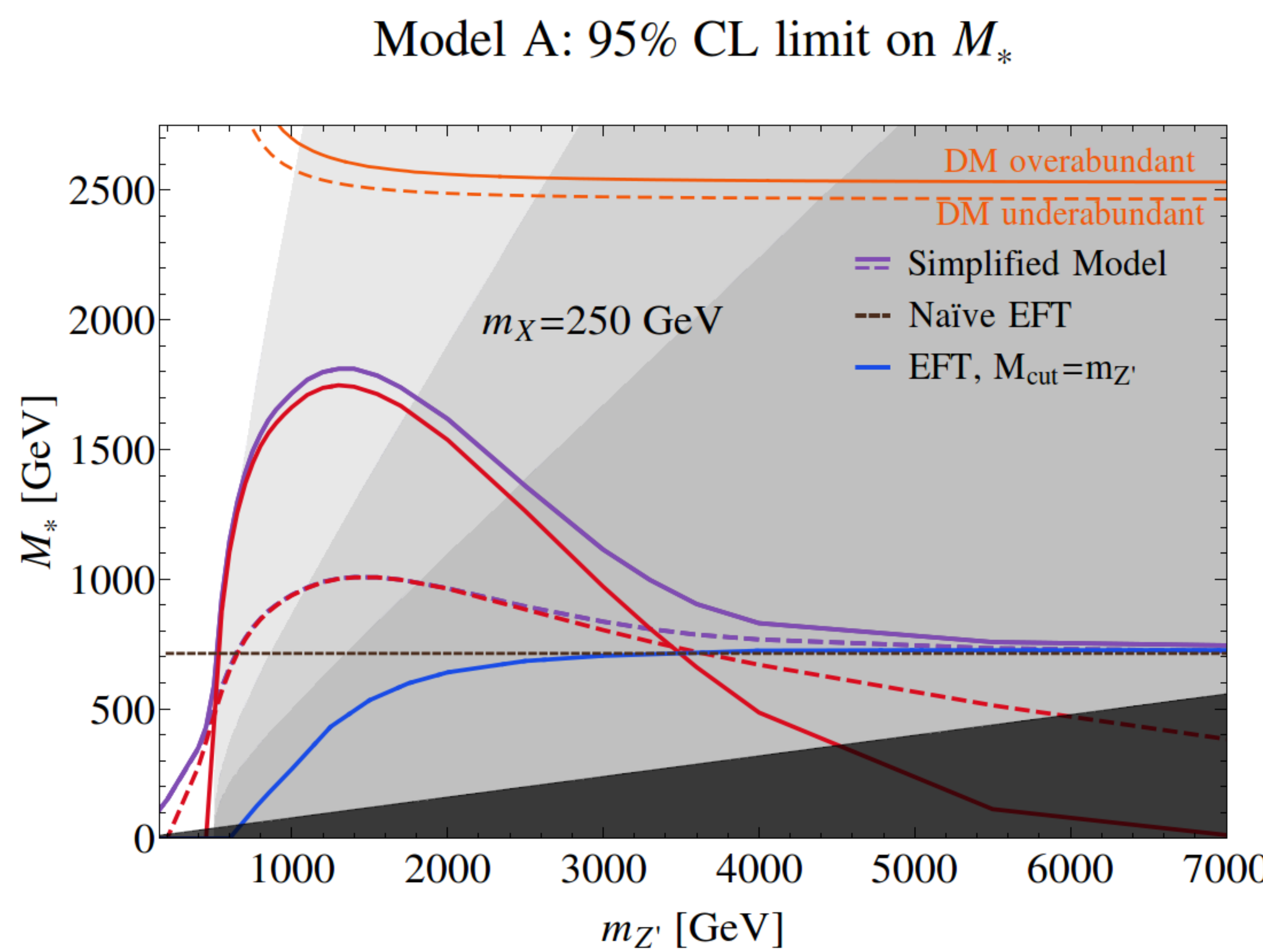

Lines for $\Gamma_{Z'}/m_{Z'} = 1/8\pi$ and $1/3$

Caution remark: most of these lines are **inconsistent**!

$$\frac{\Gamma_{Z'}}{m_{Z'}} = \alpha\, g_q^2 + \beta\, g_X^2 \geq g_q g_X \sqrt{4\alpha\beta} = \frac{m_{Z'}^2}{M_*^2}\sqrt{4\alpha\beta}\,.$$

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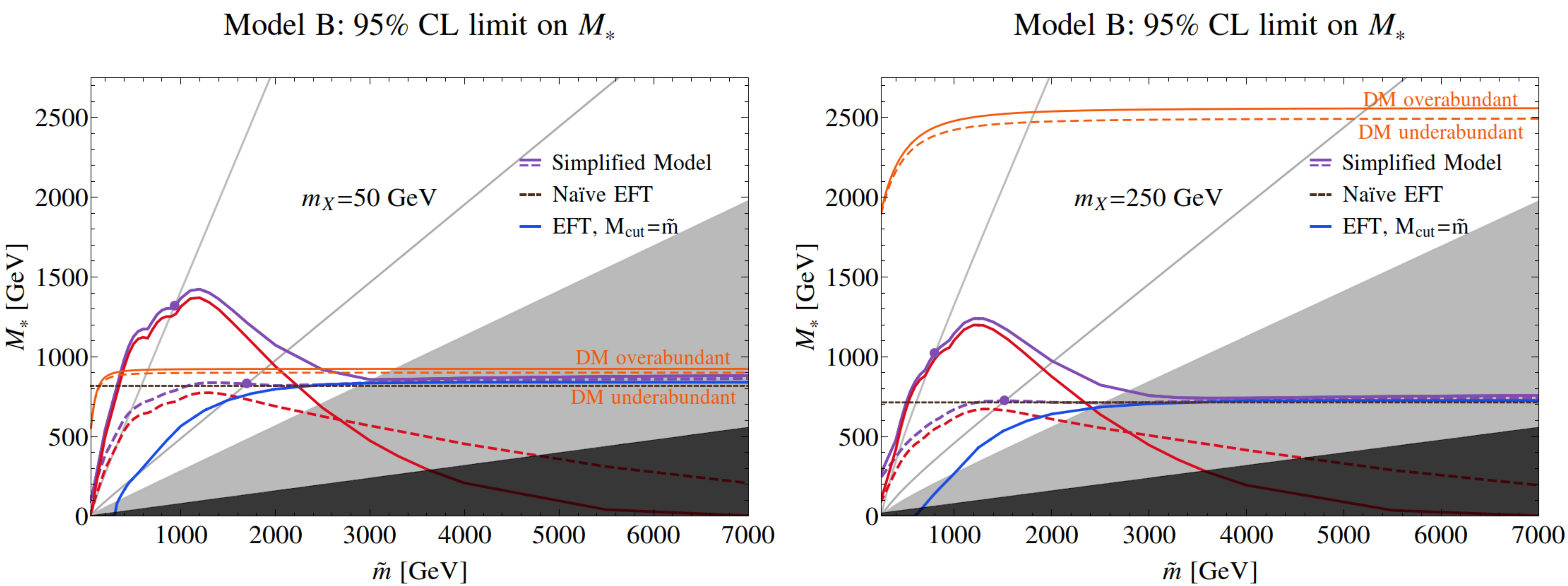

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aside one point …

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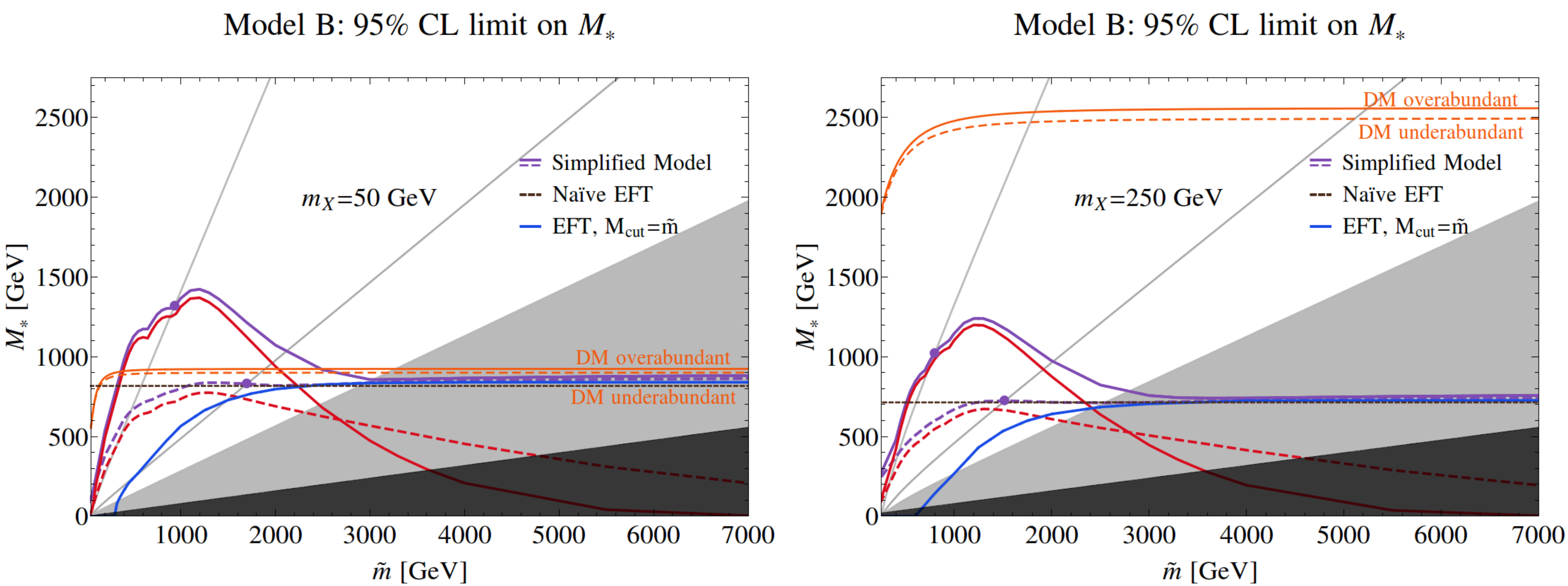

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Notice: improvement due to **resonant mediator production**