HEPHY Institut für Hochenergiephysik

ÖAW Österreichische Akademie der Wissenschaften

Dark matter EFT at present and future colliders

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Based on work in collaboration with
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Outline

- Why a dark matter EFT ?

- What does the EFT mean ?

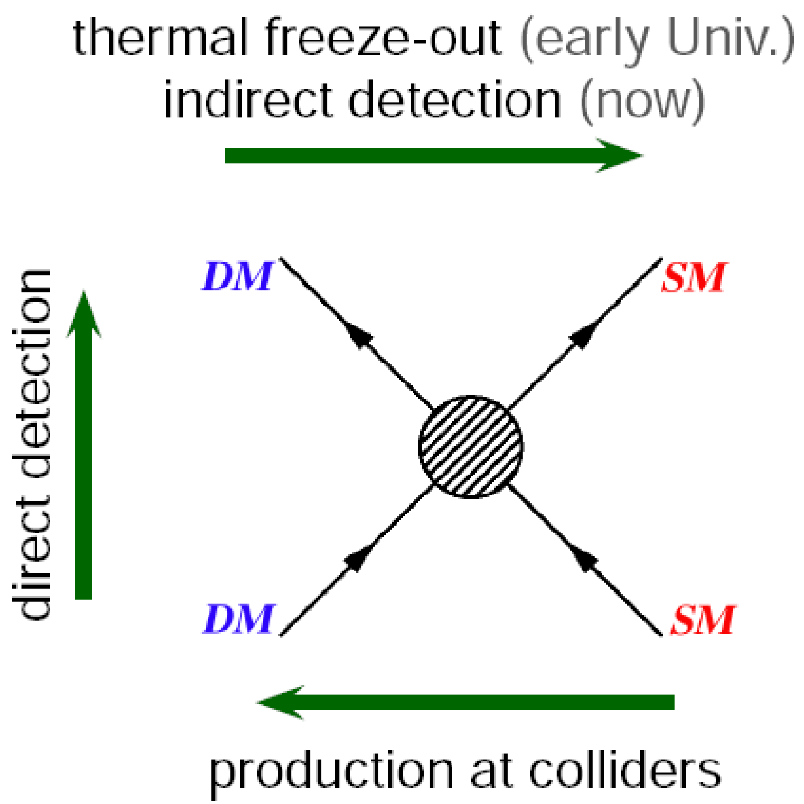
- Dark matter EFT at the LHC and a FCC

- Conclusions

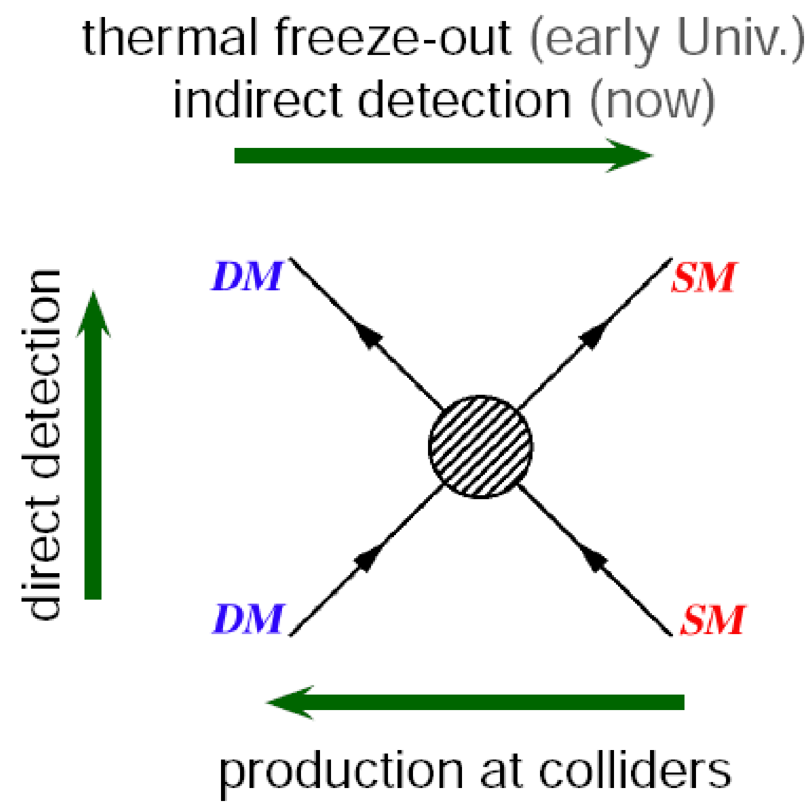
Why a dark matter EFT ?

Based on the the thermal freeze-out picture as well as the Z_2 idea for DM stability, a standard complementarity picture emerged.

→ An exciting dark matter search programme!



Why a dark matter EFT ?



Based on the the thermal freeze-out picture as well as the Z_2 idea for DM stability, a standard complementarity picture emerged.

→ An exciting dark matter search programme!

But :

- We haven't observed any MET or DD signals so far. → Not DM itself
- We haven't observed and BSM behaviour of the known particles. → Not SM mediators
- We haven't observed any BSM particle at the LHC. → Not BSM mediators

→ It seems likely that DM might interact (if at all) very weakly with the SM, e.g. through a very heavy mediator.

What does a DM EFT look like ?

So, assume that indeed DM couples with SM particles through heavy enough mediators that allow one to write down an EFT

$$\mathcal{L}_f = G_\chi \times (\bar{\chi}\Gamma_\chi \chi) \times \left[(\bar{q}\Gamma_q q) \text{ or } (G^{\mu\nu}G_{\mu\nu}) \text{ or } (G^{\mu\nu}\tilde{G}_{\mu\nu})\right]$$

$$\mathcal{L}_s = G_\phi \times (\phi^\dagger \Gamma_\phi \phi) \times \left[(\bar{q}\Gamma_q q) \text{ or } (G^{\mu\nu}G_{\mu\nu}) \text{ or } (G^{\mu\nu}\tilde{G}_{\mu\nu})\right]$$

Name	Type	G_χ	Γ^χ	Γ^q	Name	Type	G_χ	Γ^χ	Γ^q
M1	qq	$m_q/2M_*^3$	1	1	D1	qq	m_q/M_*^3	1	1
M2	qq	$im_q/2M_*^3$	γ^5	1	D2	qq	im_q/M_*^3	γ^5	1
M3	qq	$im_q/2M_*^3$	1	γ^5	D3	qq	im_q/M_*^3	1	γ^5
M4	qq	$m_q/2M_*^3$	γ^5	γ^5	D4	qq	m_q/M_*^3	γ^5	γ^5
M5	qq	$1/2M_*^2$	$\gamma^5\gamma_\mu$	γ_μ	D5	qq	$1/M_*^2$	γ^μ	γ_μ
M6	qq	$1/2M_*^2$	$\gamma^5\gamma_\mu$	$\gamma^5\gamma^\mu$	D6	qq	$1/M_*^2$	$\gamma^\mu\gamma^5$	γ_μ
M7	GG	$\alpha_s/8M_*^3$	1	-	D7	qq	$1/M_*^2$	γ^μ	$\gamma_\mu\gamma^5$
M8	GG	$i\alpha_s/8M_*^3$	γ^5	-	D8	qq	$1/M_*^2$	$\gamma^\mu\gamma^5$	$\gamma_\mu\gamma^5$
M9	$G\tilde{G}$	$\alpha_s/8M_*^3$	1	-	D9	qq	$1/M_*^2$	$\sigma^{\mu\nu}$	$\sigma_{\mu\nu}$
M10	$G\tilde{G}$	$i\alpha_s/8M_*^3$	γ^5	-	D10	qq	i/M_*^2	$\sigma^{\mu\nu}\gamma^5$	$\sigma_{\mu\nu}$
					D11	$G\tilde{G}$	$\alpha_s/4M_*^3$	1	-
					D12	$G\tilde{G}$	$i\alpha_s/4M_*^3$	γ_5	-
					D13	$G\tilde{G}$	$i\alpha_s/4M_*^3$	1	-
					D14	$G\tilde{G}$	$\alpha_s/4M_*^3$	γ_5	-

Name	Type	G_χ	Γ^ϕ	Γ^q	Name	Type	G_χ	Γ^ϕ	Γ^q
R1	qq	$m_q/2M_*^2$	1	1	C1	qq	m_q/M_*^2	1	1
R2	qq	$im_q/2M_*^2$	1	γ^5	C2	qq	im_q/M_*^2	1	γ^5
R3	GG	$\alpha_s/8M_*^2$	1	-	C3	qq	i/M_*^2	∂^μ	γ_μ
R4	$G\tilde{G}$	$i\alpha_s/8M_*^2$	1	-	C4	qq	$1/M_*^2$	∂^μ	$\gamma_\mu\gamma^5$
					C5	GG	$\alpha_s/4M_*^2$	1	-
					C6	$G\tilde{G}$	$\alpha_s/4M_*^2$	1	-

Only two parameters are relevant:

- the DM mass M_{DM}
- the EFT scale M_*

But what does M_* mean ?

- Beltran, Hooper, Kolb, Krusberg (2008)
- Cao, Chen, Li, Zhang (2011)
- Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu (2010, 2011)

Interpreting an EFT and limits of validity

EFT is an incredibly powerful tool but must be used bearing some things in mind:

- Non-renormalisable field theories are perfectly acceptable: input the scale and you get an answer.
- But there *is* a scale, which somehow cries out for a physical explanation!
- The explanation could be very simple, or very complicated. Computing something in the EFT and finding a "UV-completion" are two very different tasks!

One way to think of the EFT scale, is in terms of some "s-channel UV-completion"

$$\frac{g_{\rm DM} g_{\rm SM}}{Q^2_{\rm tr} - M^2_{\rm med}} = -\frac{g_{\rm DM} g_{\rm SM}}{M^2_{\rm med}} \left(1 + \frac{Q^2_{\rm tr}}{M^2_{\rm med}} + \cdots \right) \equiv -\frac{1}{M^2_*} \left(1 + \frac{Q^2_{\rm tr}}{M^2_{\rm med}} + \cdots \right)$$

Perturbativity of the couplings imposes, in any case, $M_* > M_{DM}/(2\pi)$, but a more refined requirement would be to impose that "most" events satisfy

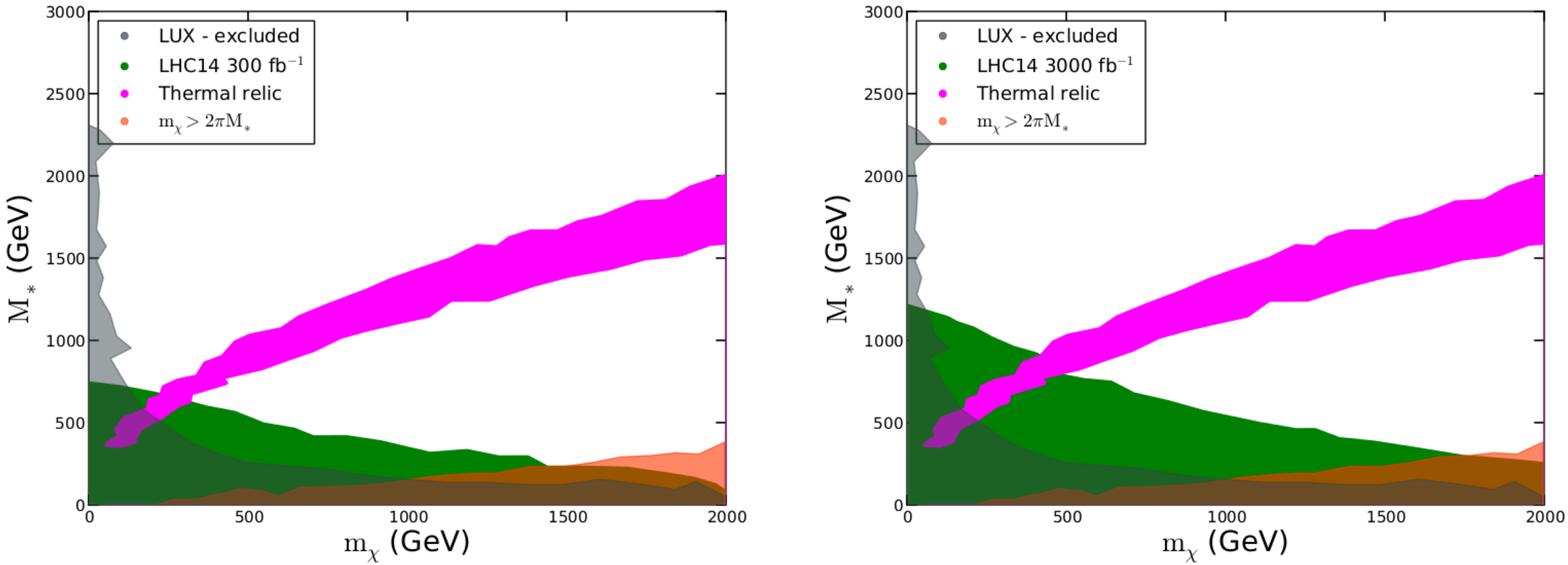
$$Q^2_{\rm tr} \leq 16\pi^2 M^2_*$$

which can be checked at the MC level.

Busoni, De Simone, Gramling, Morgante, Riotto (2013, 2014)
+ Similarly for t-channel

Some (preliminary) results: R3 @ LHC14

Let's put everything together for R3, a gluonic operator.

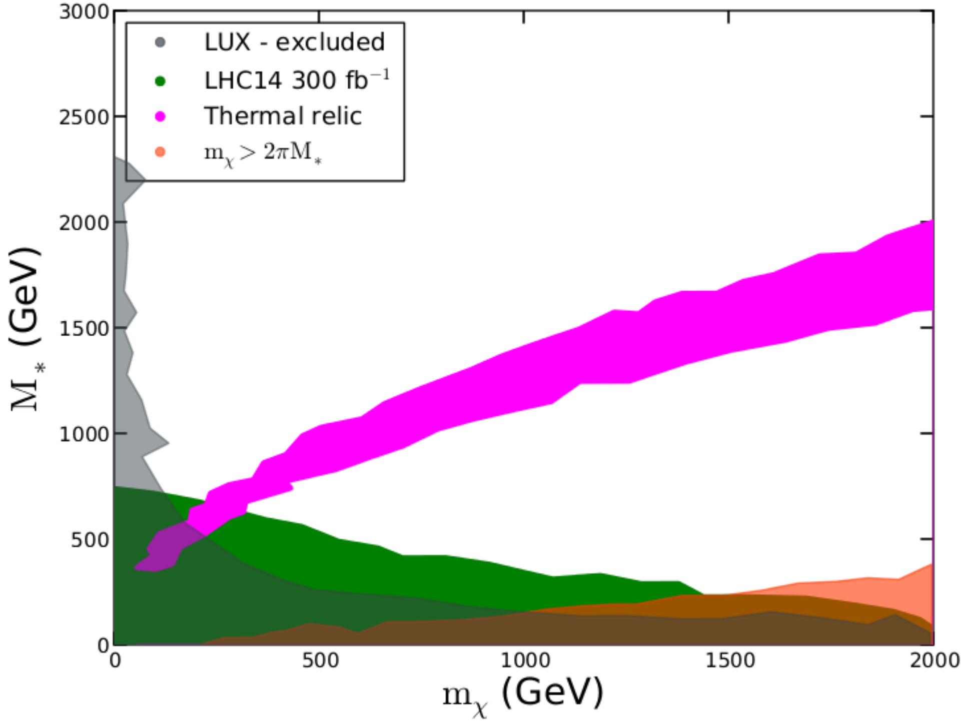


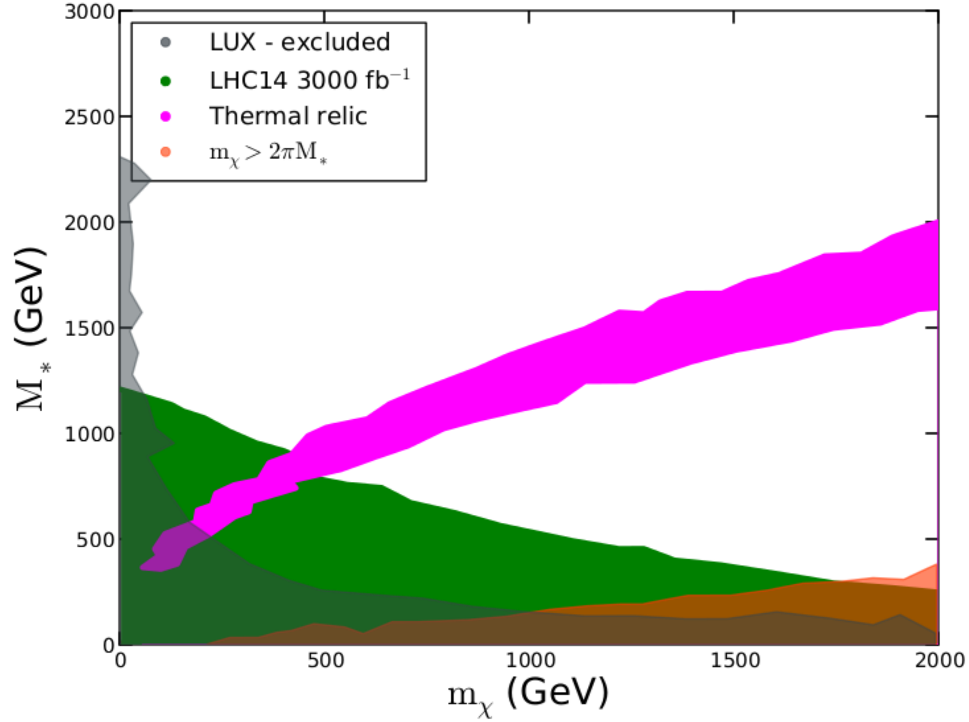
- In principle the LHC14 has something to add especially @ high luminosity.
- Situation pretty similar for *qq* operators that aren't mass-suppressed.
- Frozen-out WIMPs with masses up to ~480 GeV seem accessible.

→ Try to interpret in terms of UV theory ?

Some (preliminary) results: R3 @ LHC14

Assume some s-channel "UV-completion"

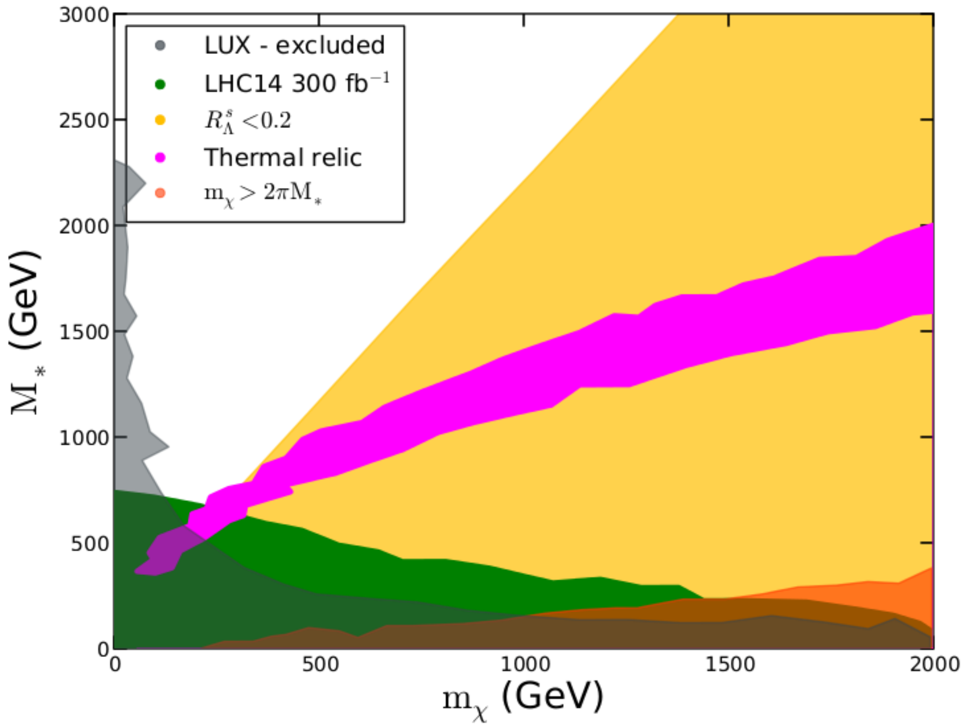


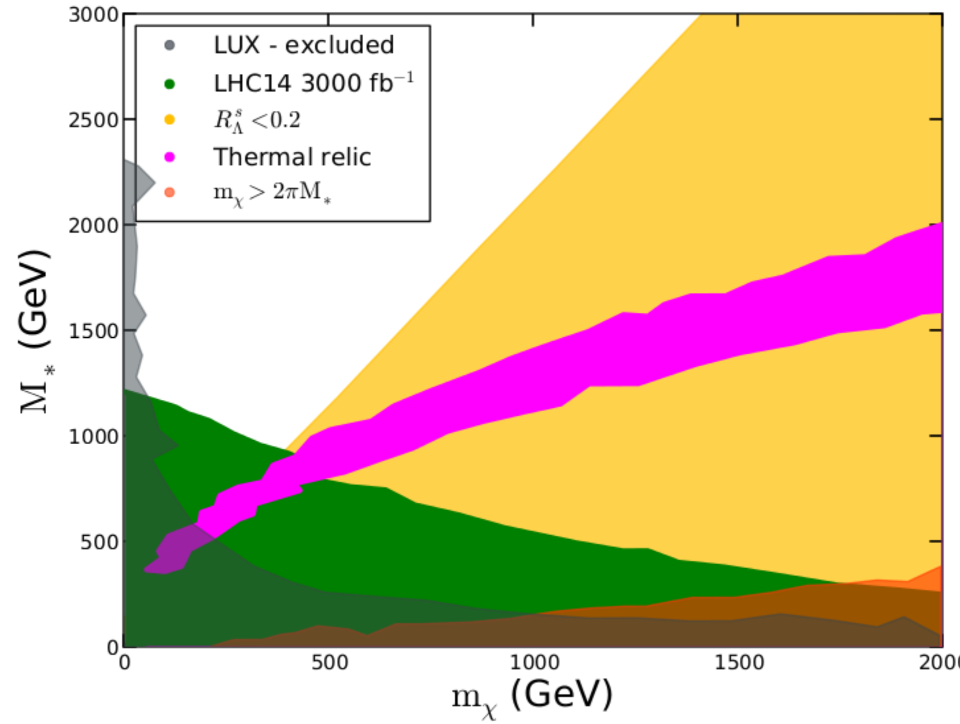


- Impose $Q_{tr}^2 < M_*^2$ event-by-event (corresponds to couplings of $O(1)$).

Some (preliminary) results: R3 @ LHC14

Assume some s-channel "UV-completion"



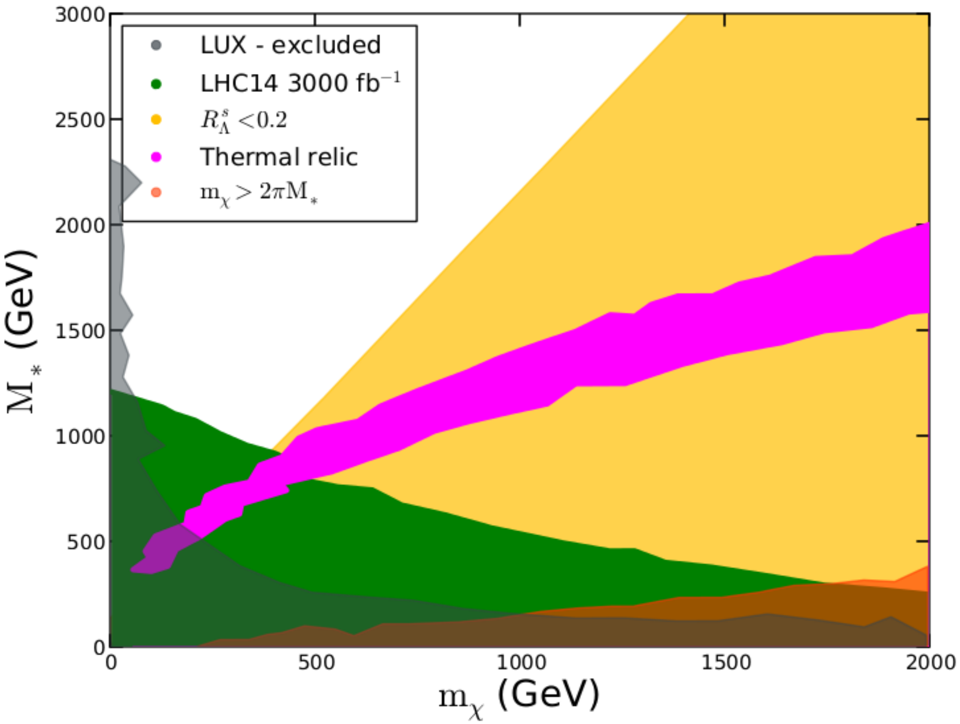


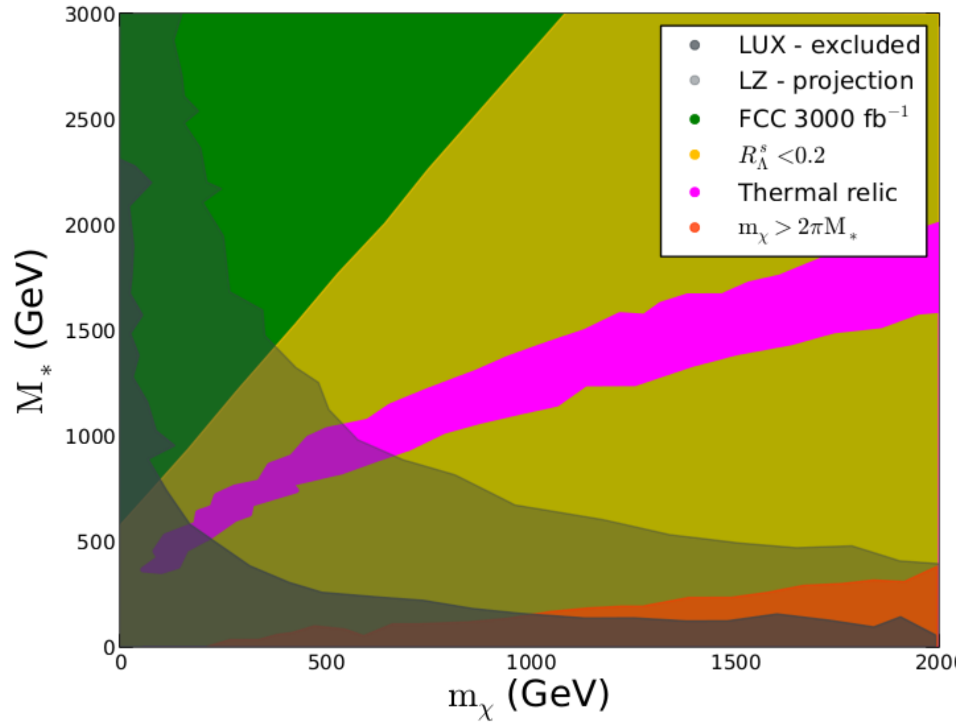
- Impose $Q_{tr}^2 < M_*^2$ event-by-event (corresponds to couplings of $O(1)$).
- Pretty unacceptable level of "good" events to "probe" thermal FO.
- However, by taking $g \sim 4\pi$ essentially the entire Planck region is OK!

→ The EFT is mostly probing a regime of heavy, strongly-ish coupled mediators

Some (preliminary) results: R3 @ FCC

Let's play the same game for a more futuristic FCC





- Situation much better, can probe DM masses up to 2 TeV :)
- But quite hard to find DM-motivated UV completions :(
- A strong coupling assumption doesn't allow going far beyond the LHC...

→ At the FCC, the EFT approach probably will have to be abandoned
→ But in any case, long before, DD will have covered the relevant PS

What to keep from this story

• A dark matter EFT is the most economical way of presenting the results of LHC searches for DM-like particles.

• Once the EFT is taken seriously, one must be extremely careful: the mediators can be (and often are) produced on shell.

•The shift towards simplified models is interesting, but shouldn't replace the EFT results.

...but let's discuss this!

• If at the LHC some DM EFT is useful, at the FCC it's much less so.

• It would be useful if experimentalists showed on their plots a few scenarios for UV-completions : gives an idea of how the EFT is performing.

• Interesting extension of this work: extract limits taking into account the limits in the EFT validity.

...although: under which interpretation?

• Looking forward to the next mono-stuff search results!

...and personally, some ILC-like project!

Thank you!