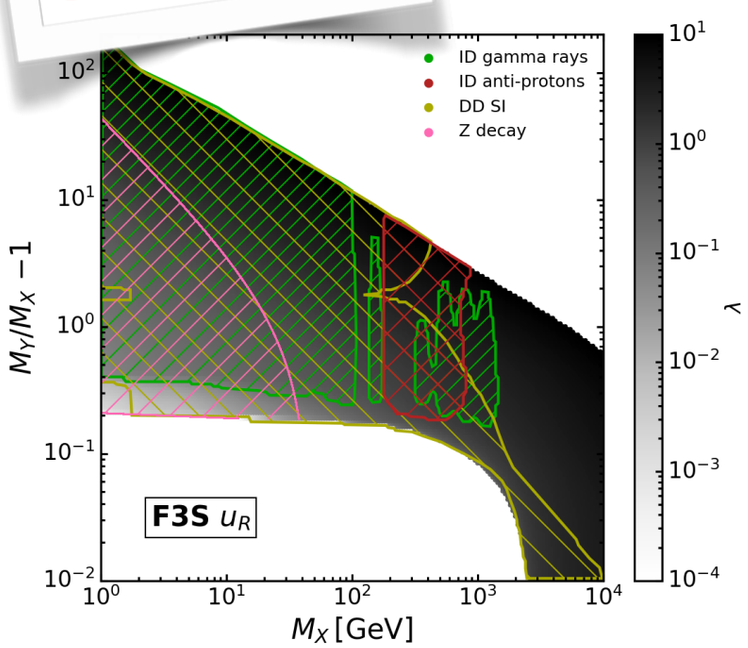
Long-lived particles and *t*-channel models

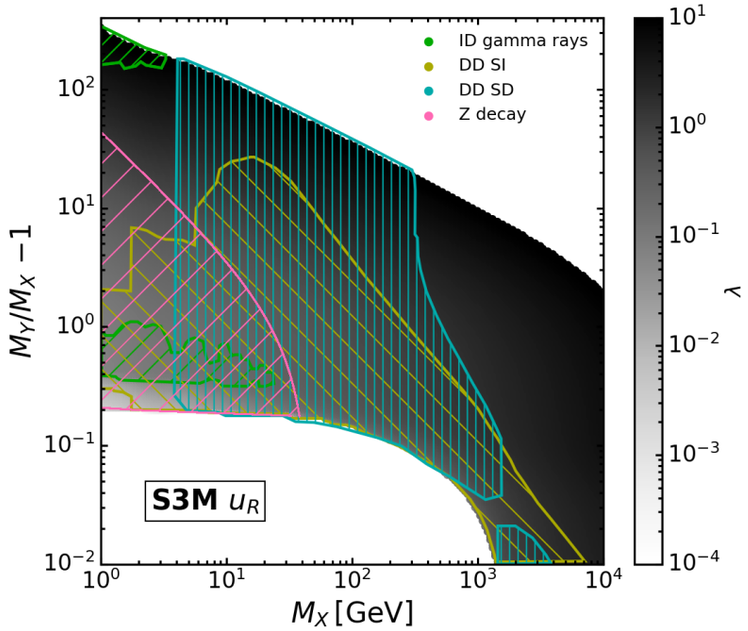
Jan Heisig

Roadmap of Dark Matter models for run 3
CERN, May 13-17, 2024

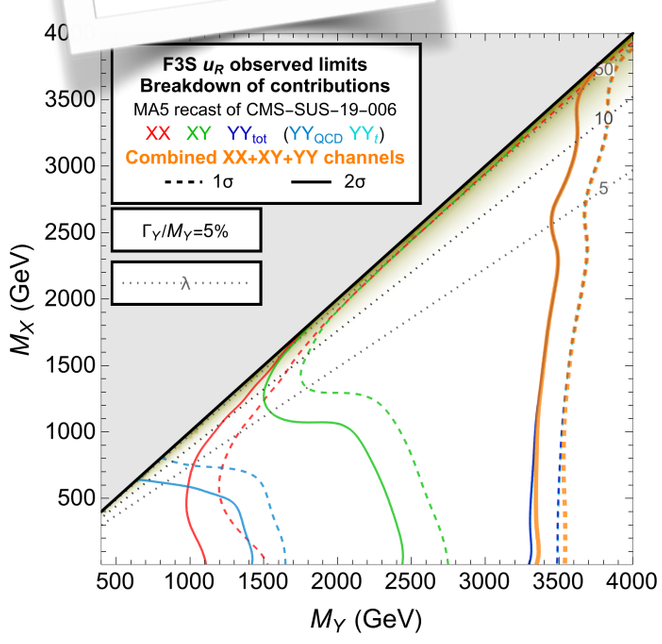
Cosmo constraints and prompt searches

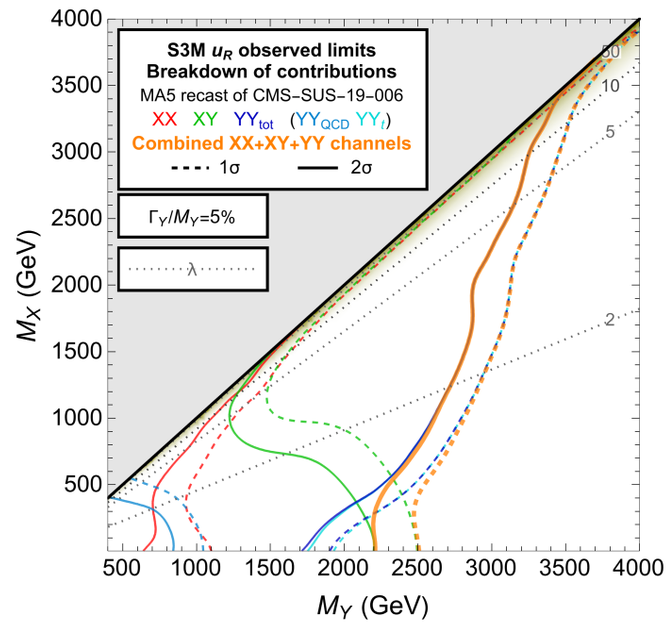
Chiara's talk





Luca's talk





[Arina et al. 2307.10367]

Chiara's talk

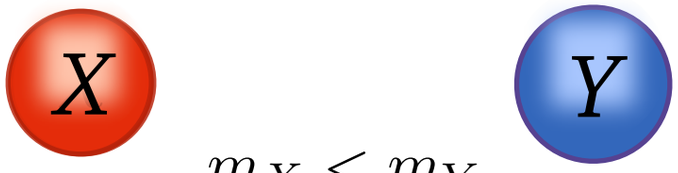
Evading astrophysical bounds

Small couplings

Long-lived particles (LLPs)

Minimal *t*-channel mediator models

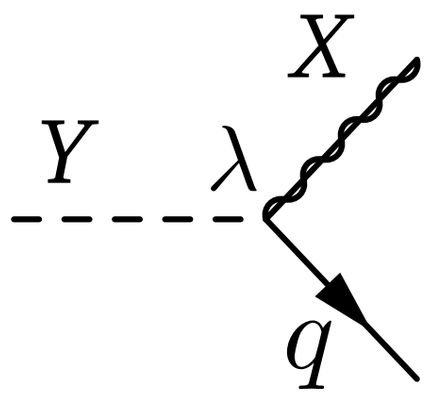
Z_2-odd

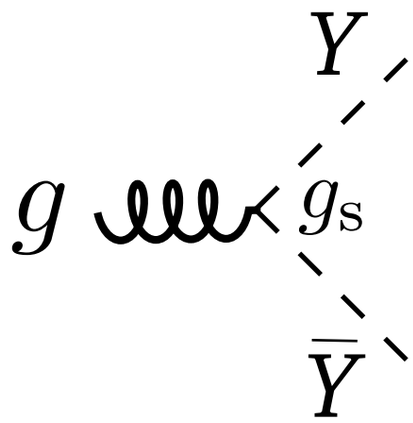


Dark Matter

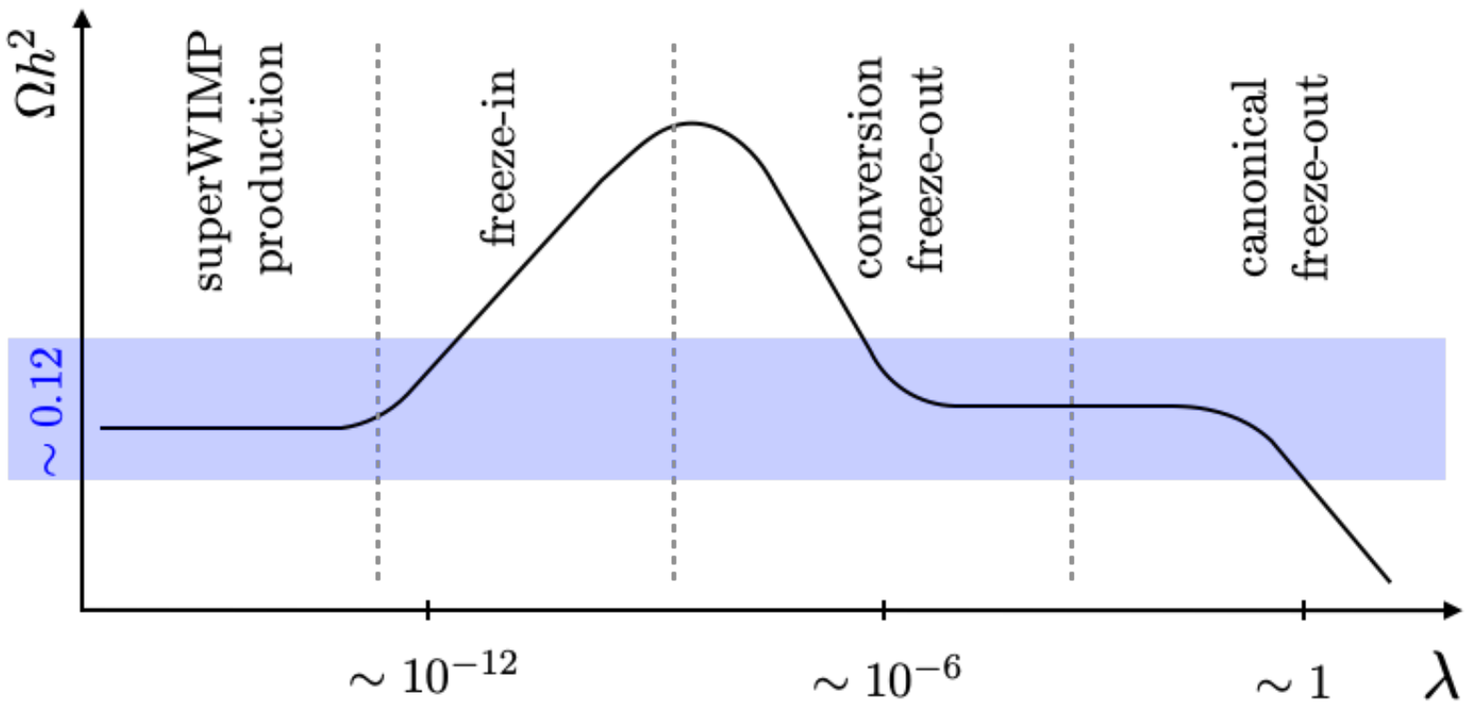
Color mediator

Z_2-even





Two distinct regions for LLPs



Evading astrophysical bounds

⛓

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⛓

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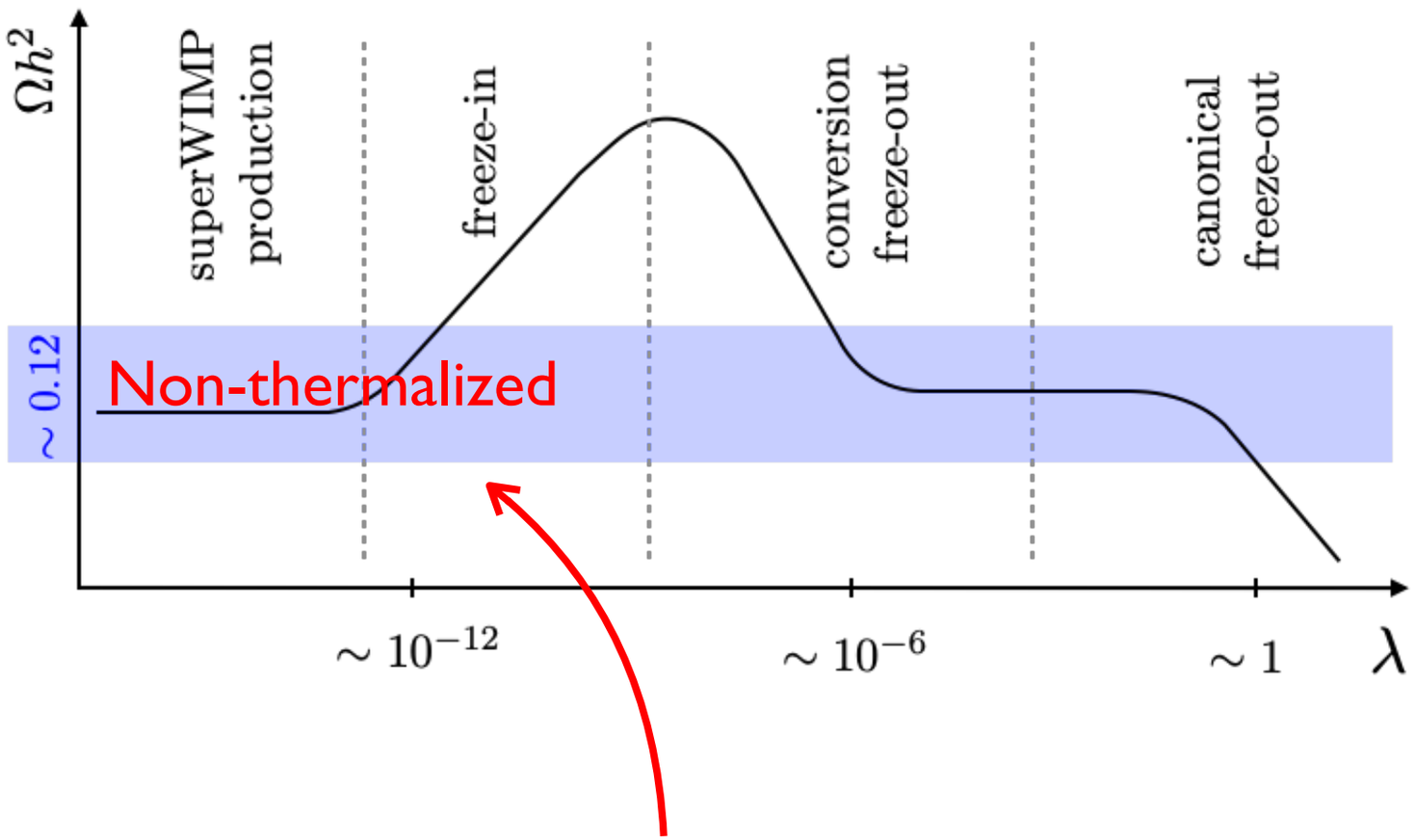

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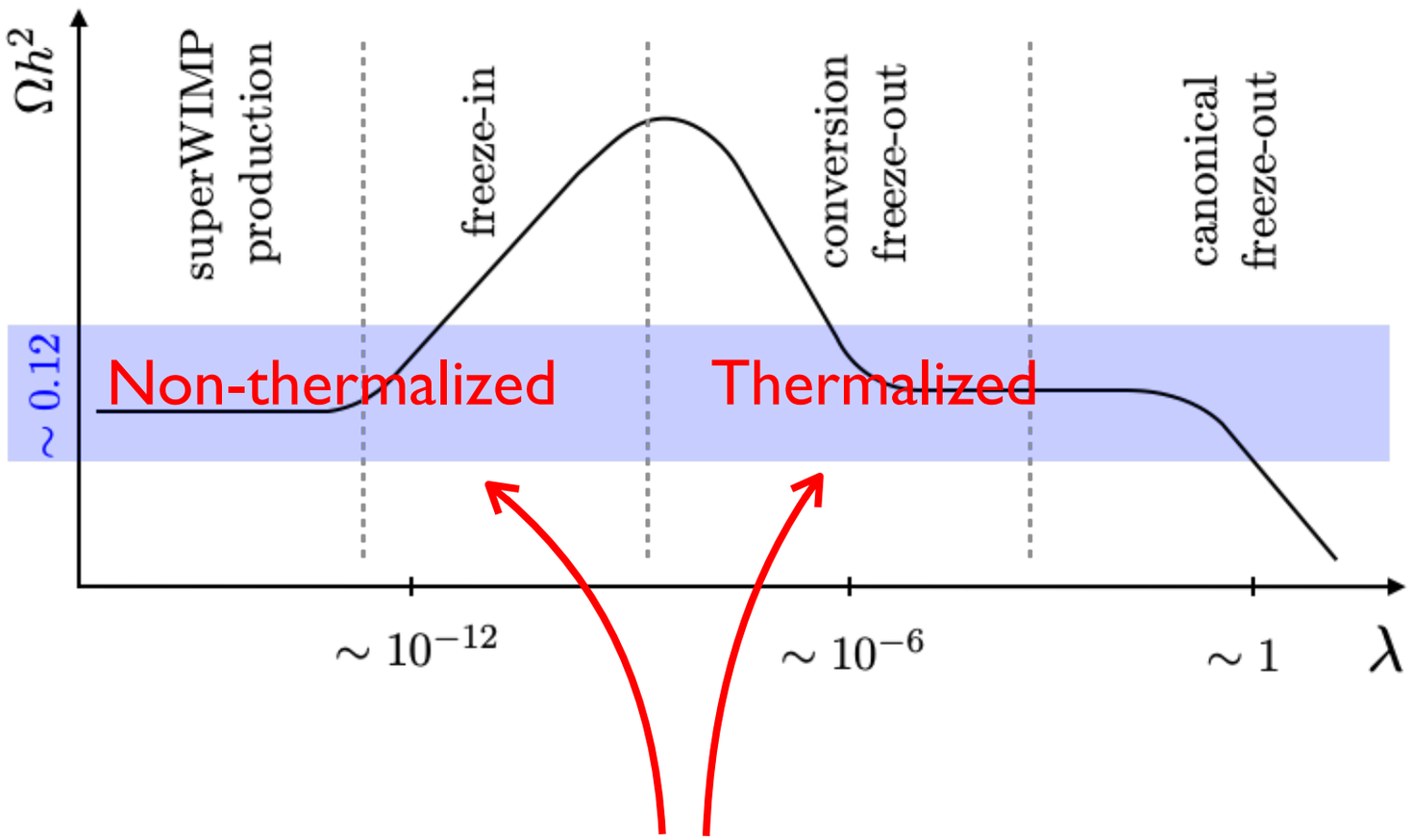

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Long-lived particles

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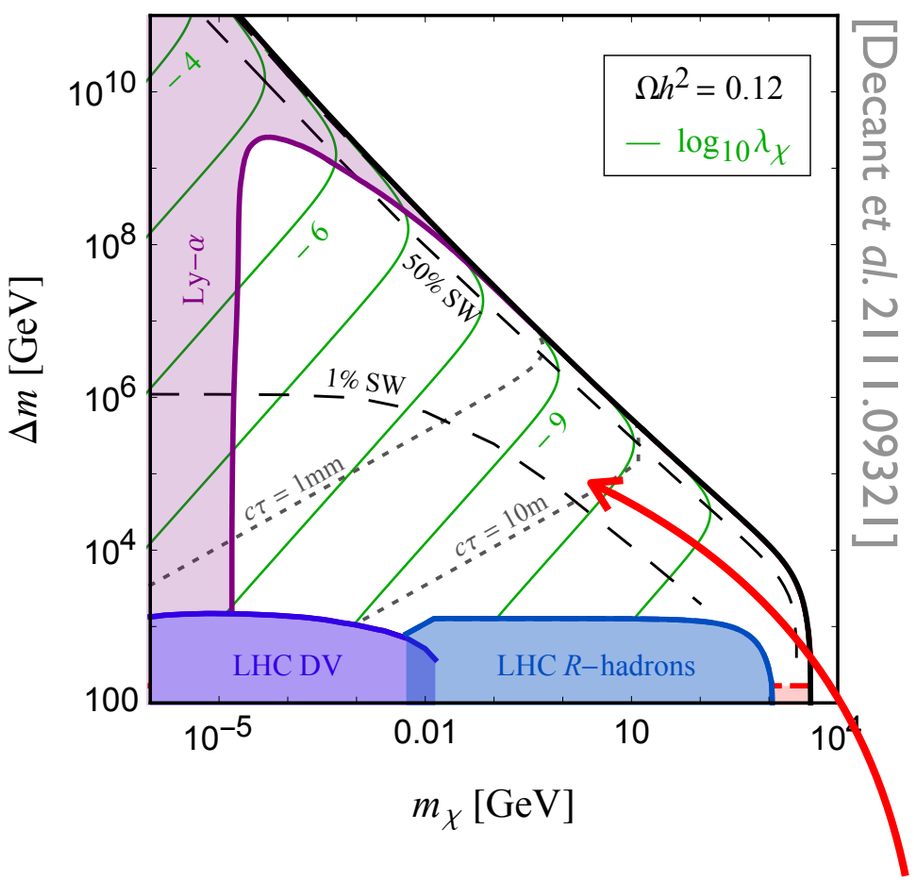
Non-thermalized



[Decant et al. 2111.09321]

Evading astrophysical bounds

⛓

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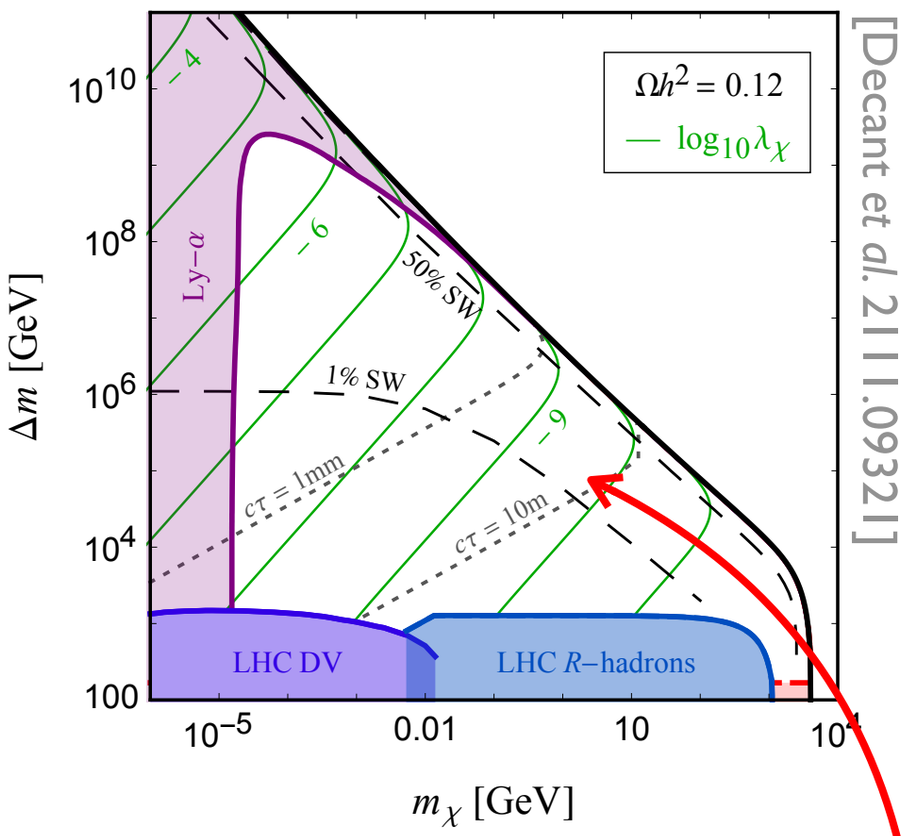
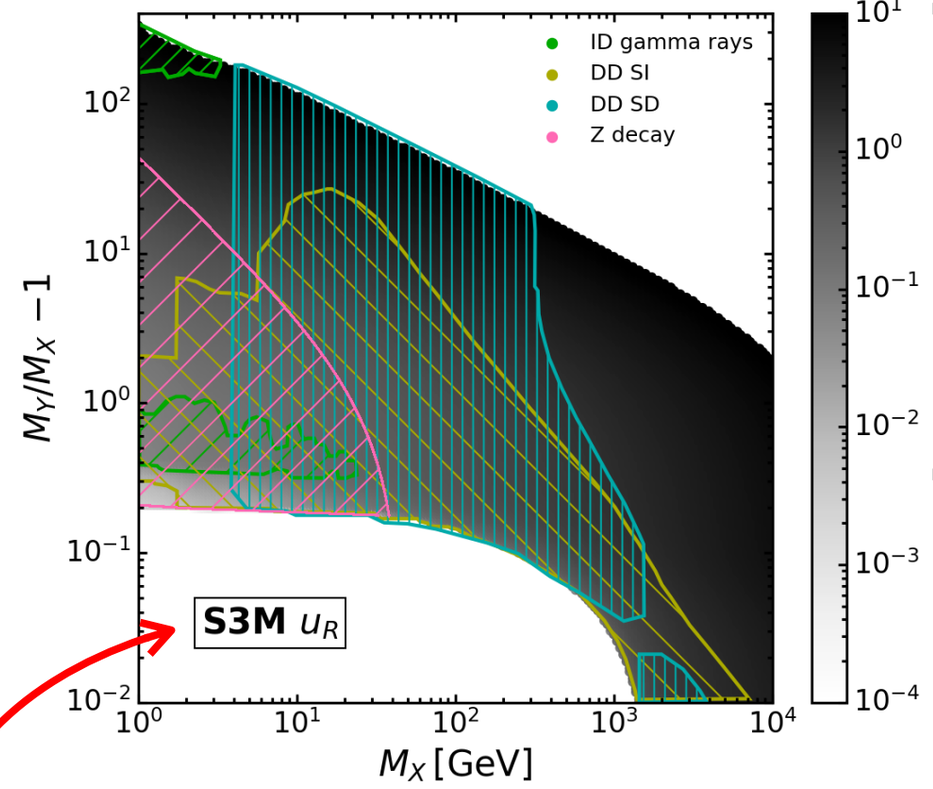


[Decant *et al.* 2111.09321]

Thermalized



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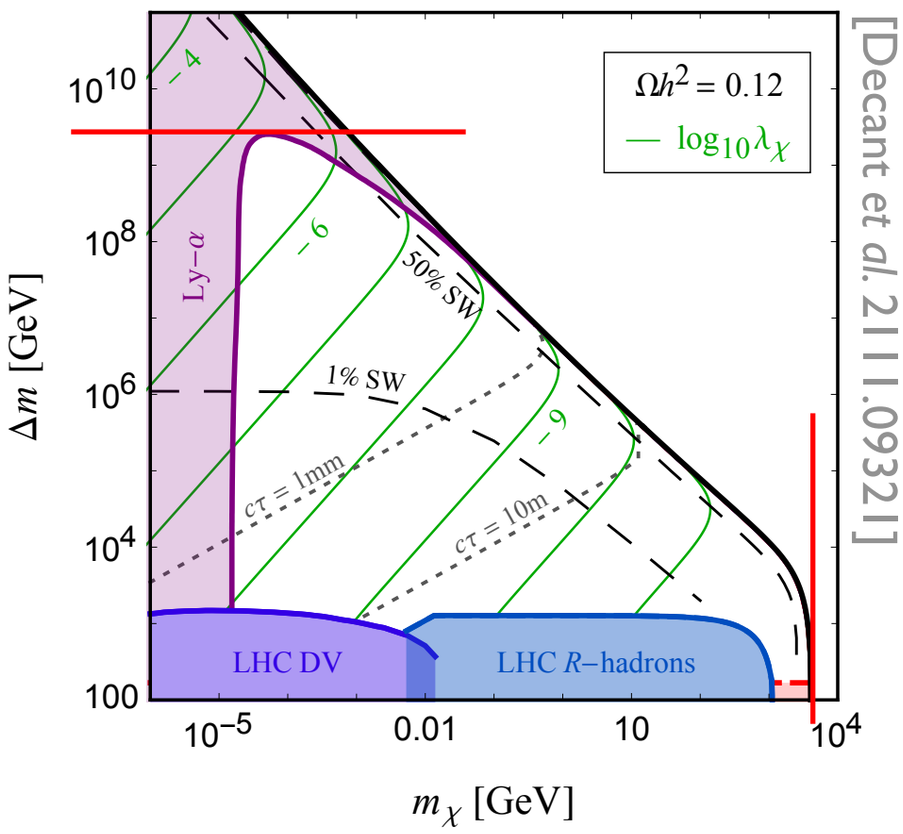
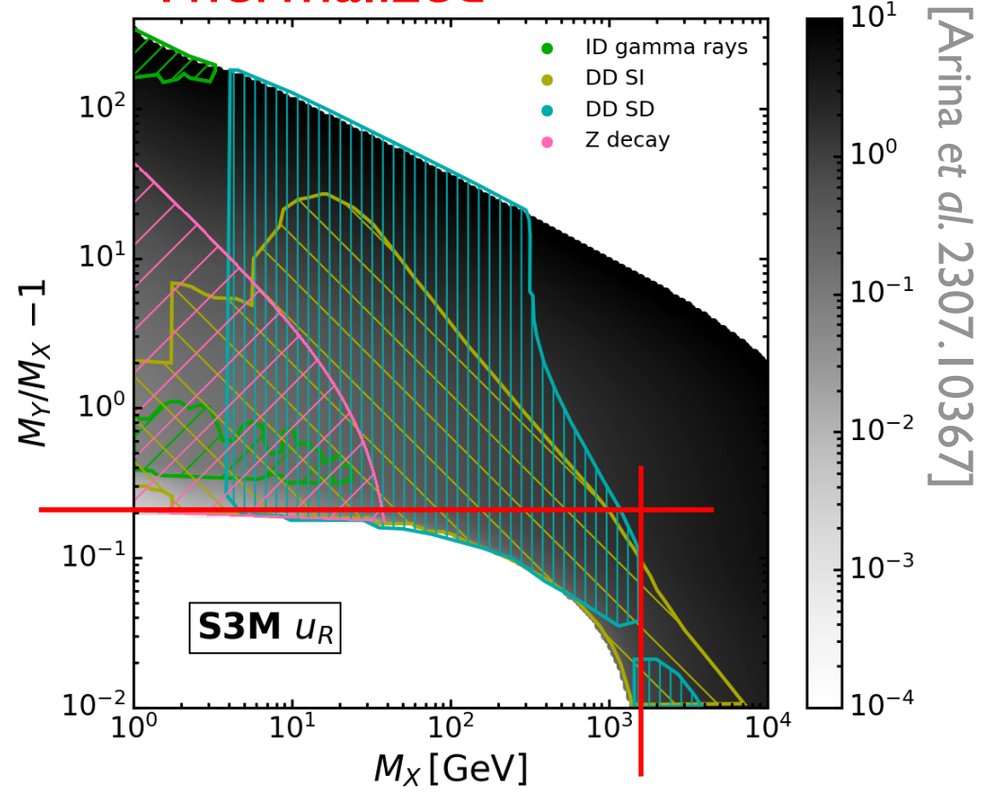


Thermalized



Masses:

- up to 10^9 GeV

⇒ bulk out of reach

- up to few TeV

⇒ testable at colliders!

Two distinct regions for LLPs

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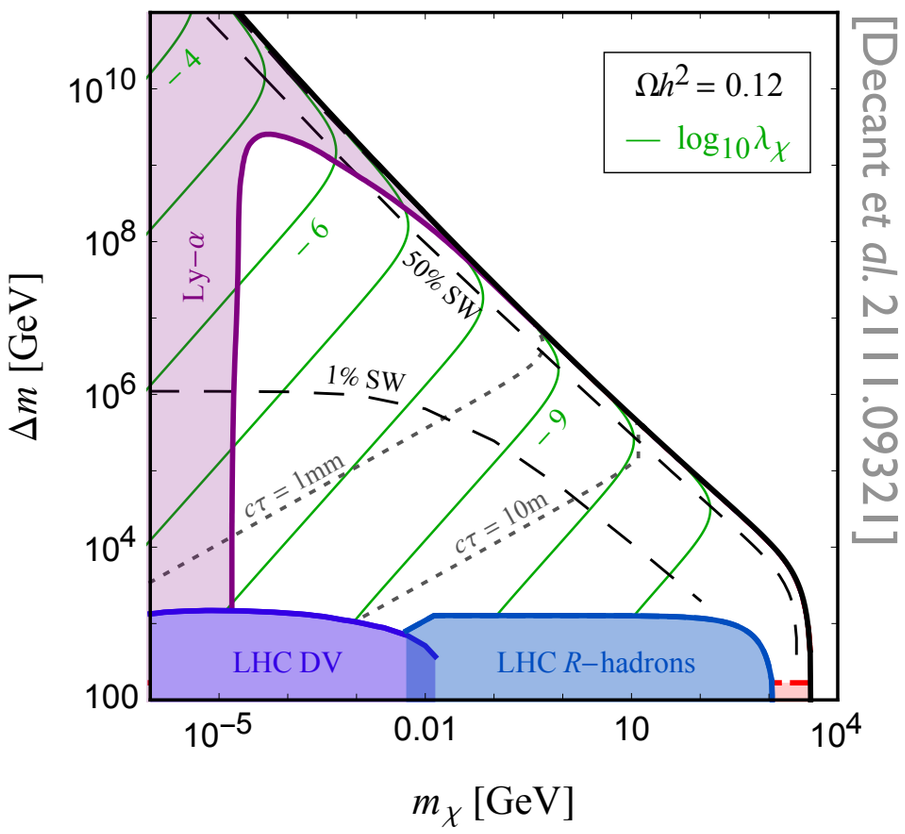
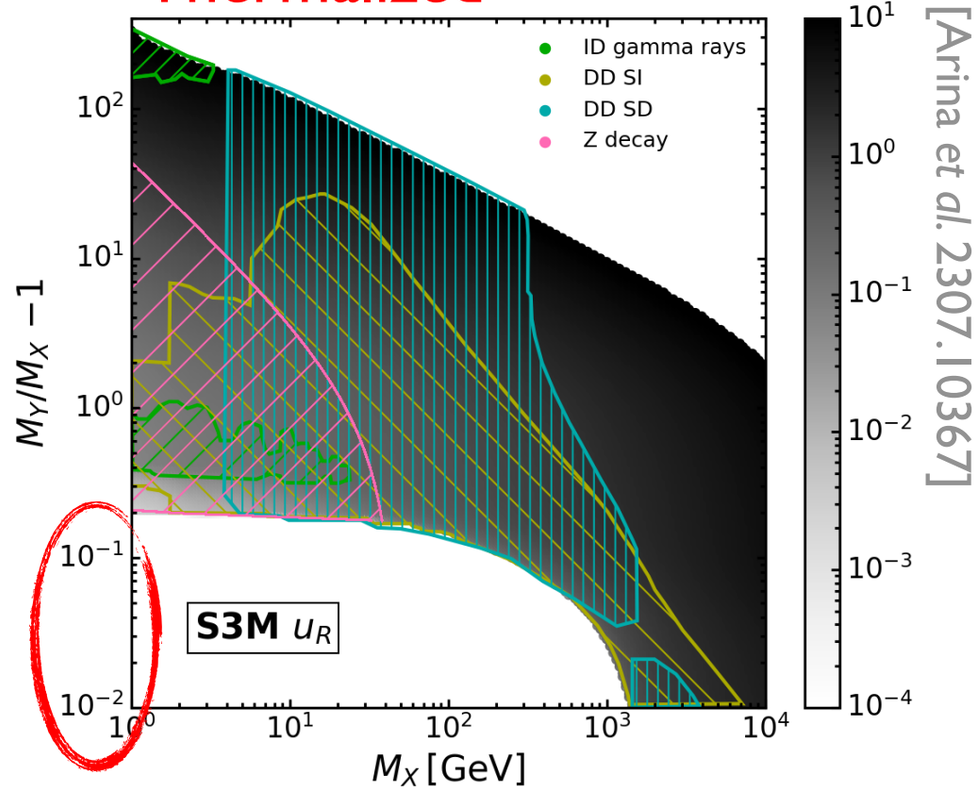


Thermalized



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Visible decay products:

- hard

⇒ covered yet

- soft

⇒ current gaps

Two distinct regions for LLPs

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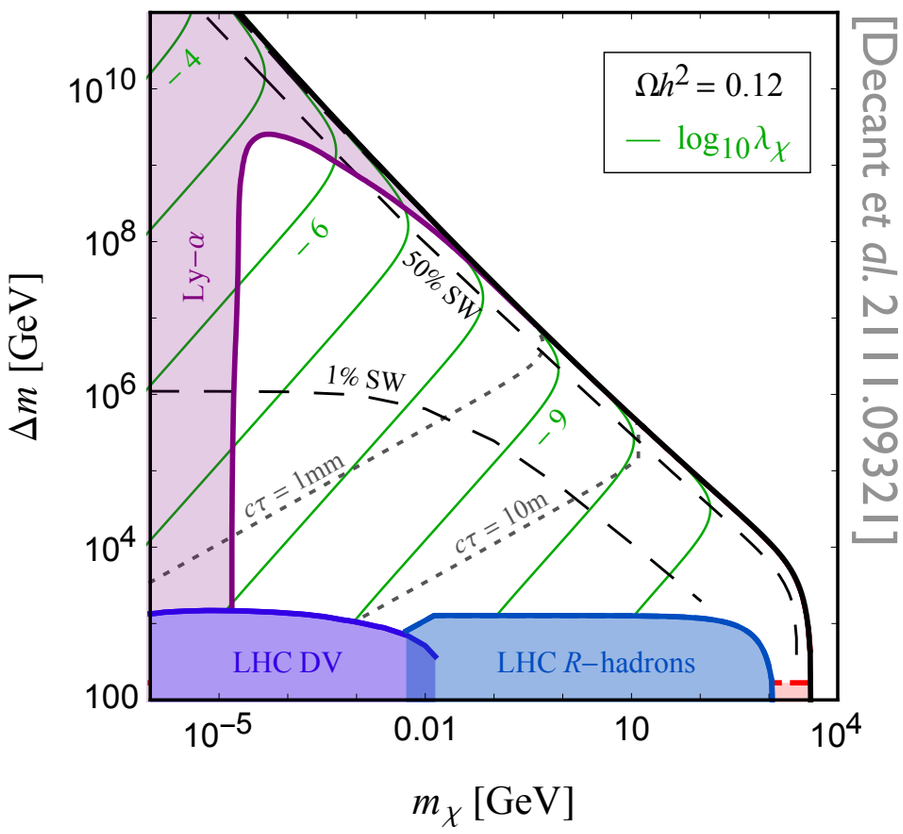

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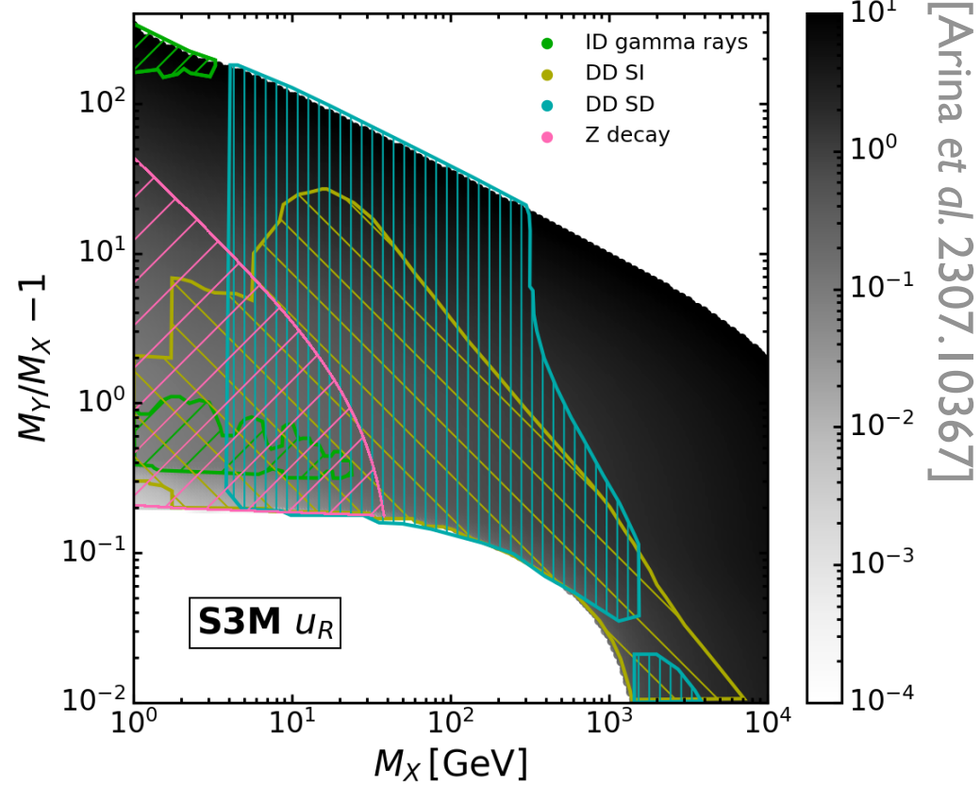

[Arina *et al.* 2307.10367]

- up to few TeV

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⇒ current gaps

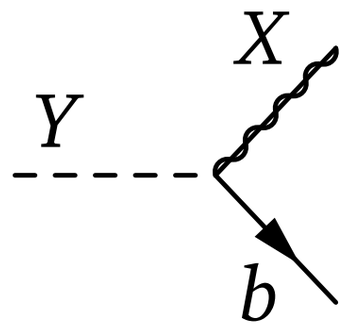
Particularly interesting

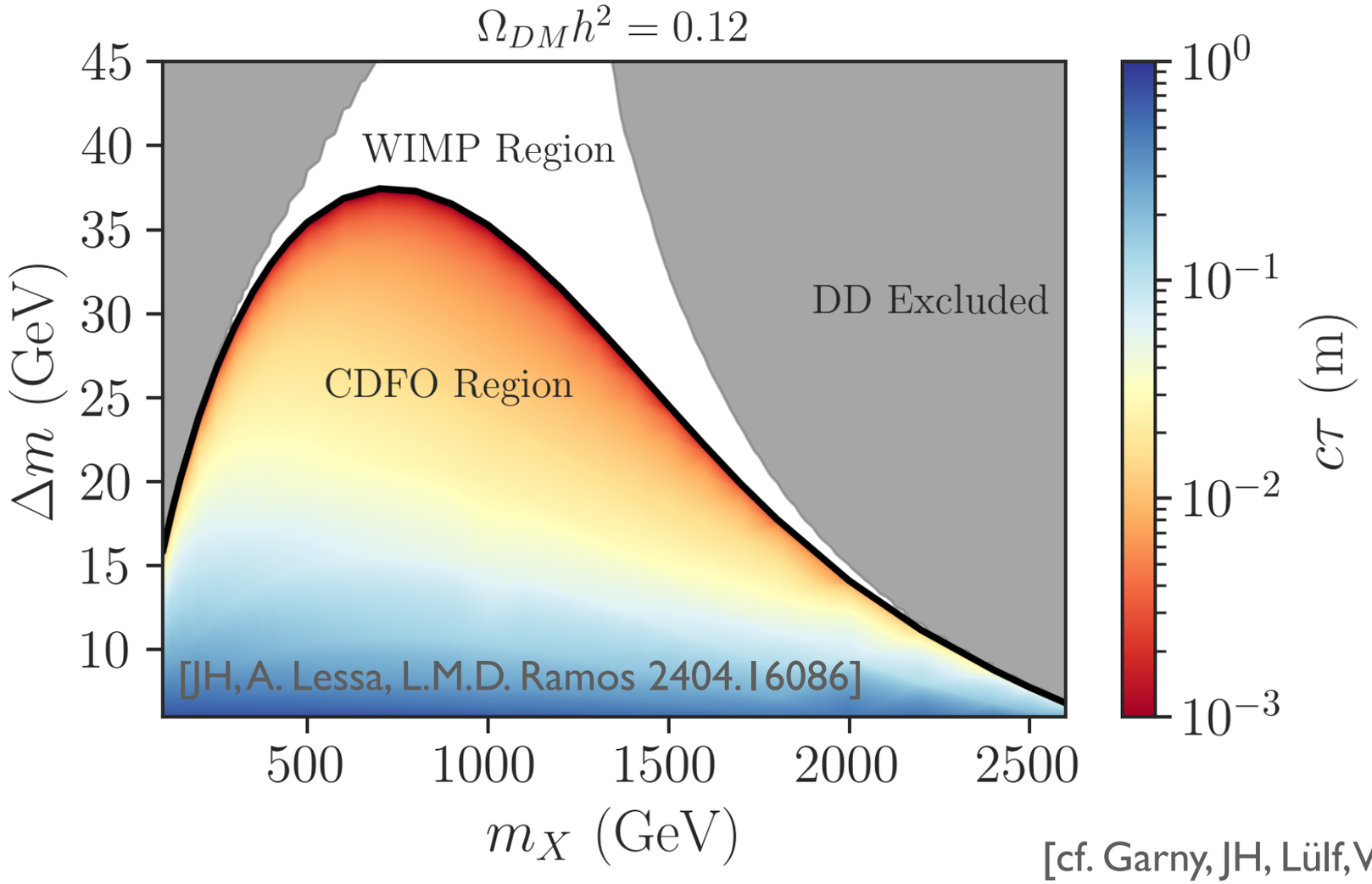
Example I

X: Majorana dark matter

Y: Scalar mediator (bottom-partner)

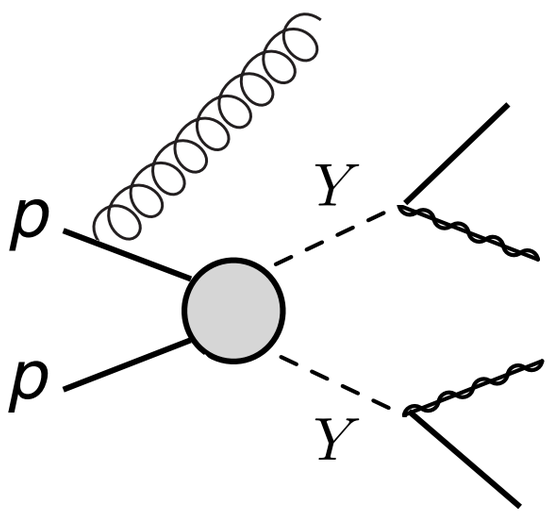
Conversion-driven freeze-out (CDFO):

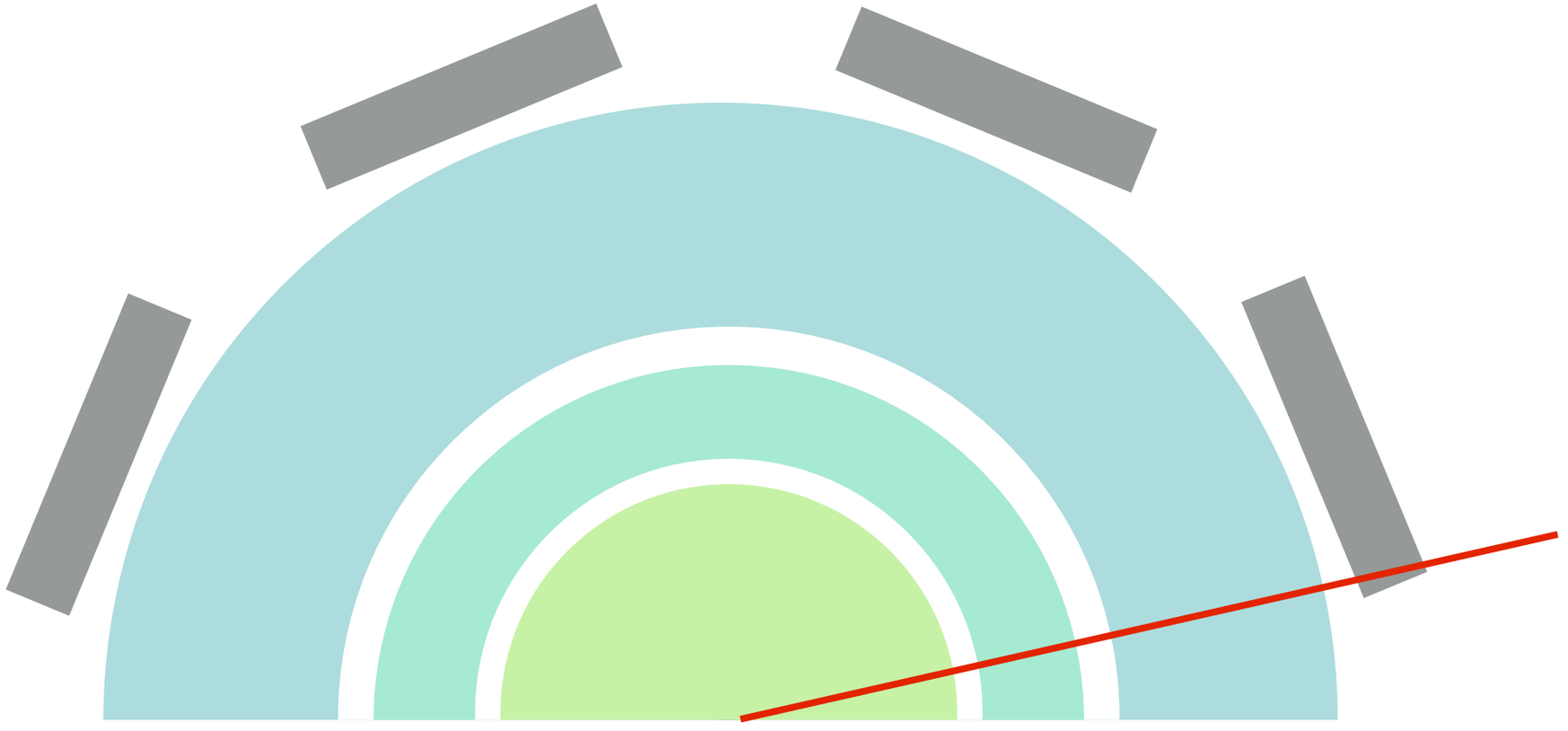




[cf. Garny, JH, Lülf, Vogl 1705.09292; Garny, JH 2112.01499]

LHC Signature

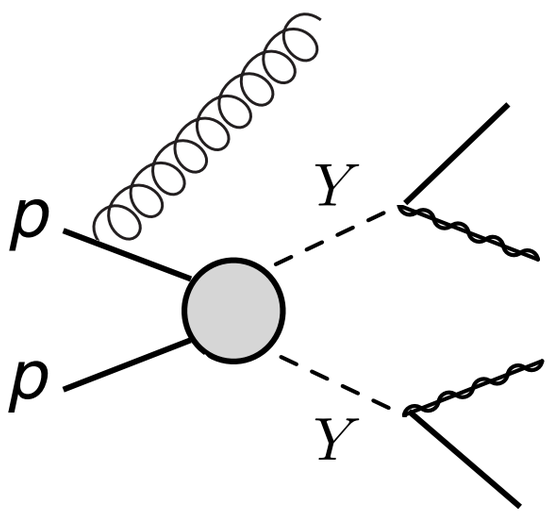


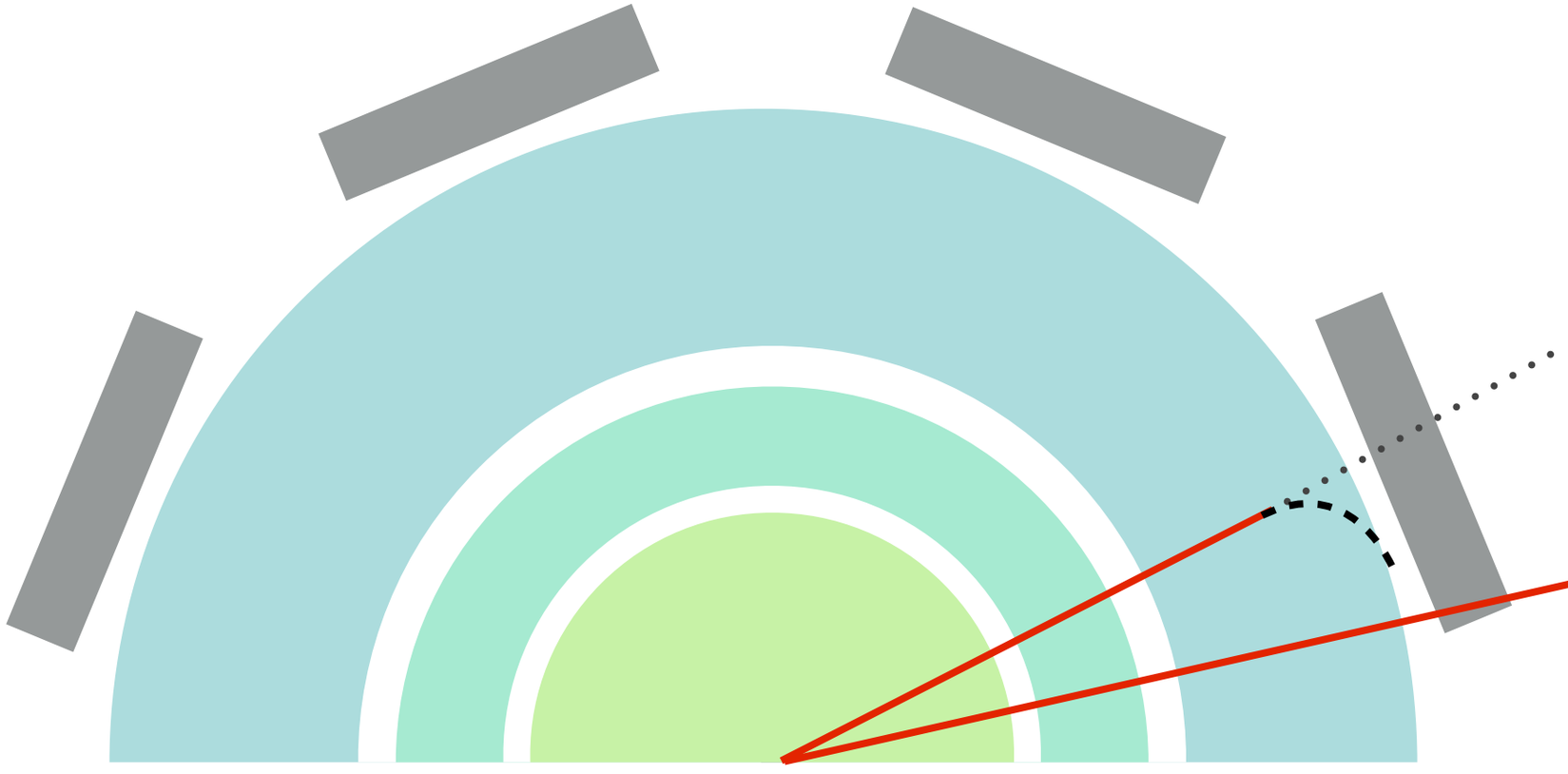


Anomalous tracks
(Heavy stable charged particle searches)

$c\tau_Y > 1\,\mathrm{m}$

LHC Signature





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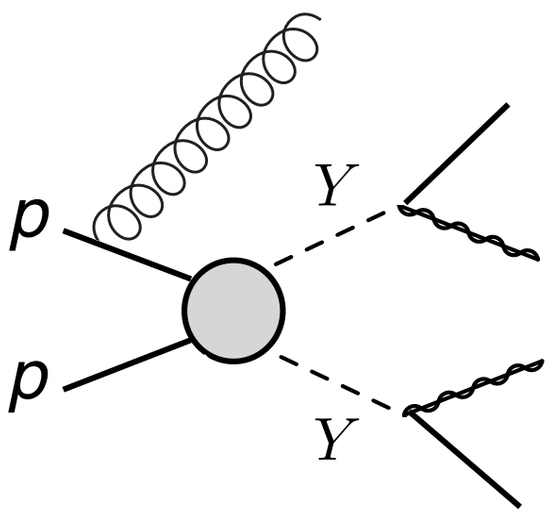

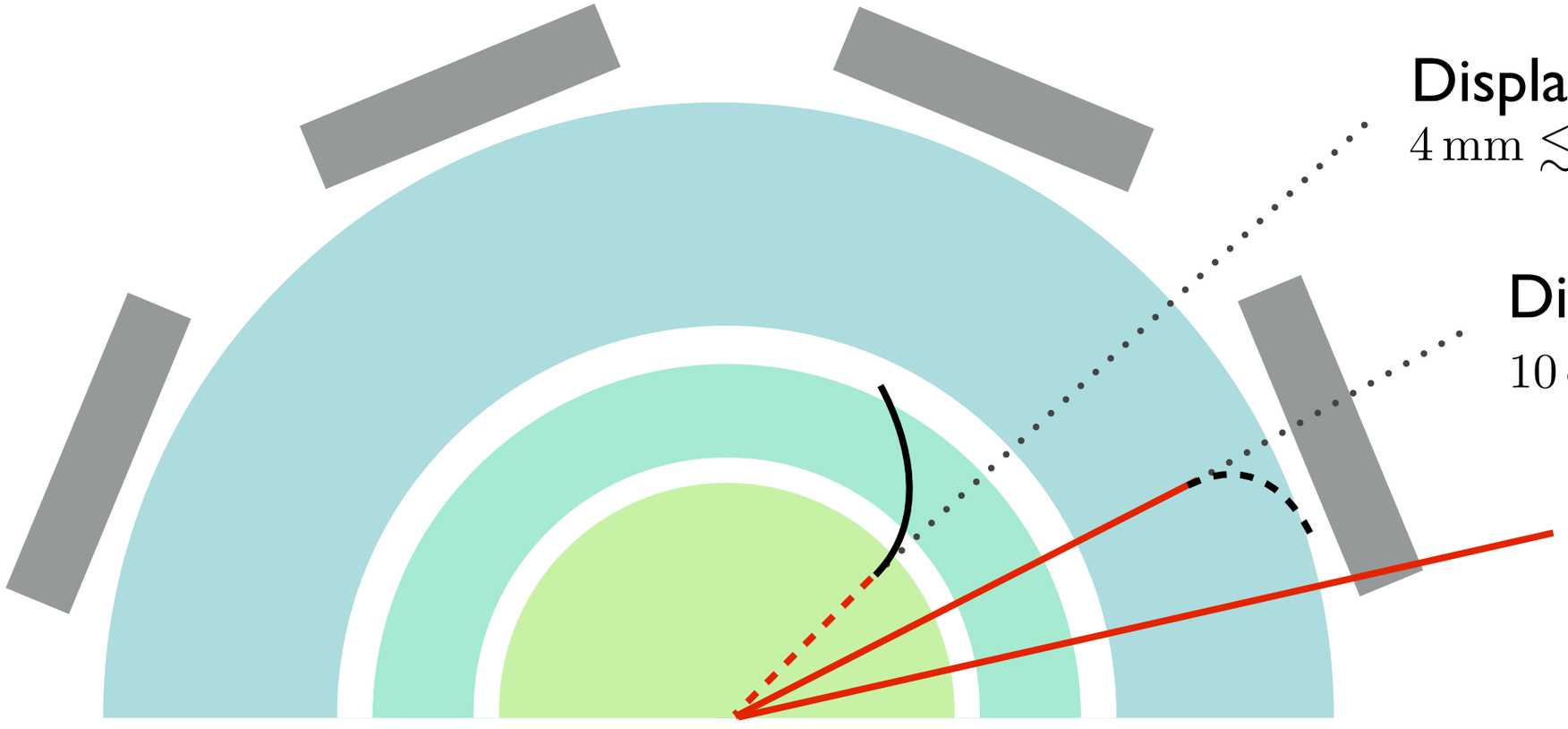

Displaced vertices (+MET)

$4\,\mathrm{mm} \lesssim c\tau_Y \lesssim 30\,\mathrm{cm}$

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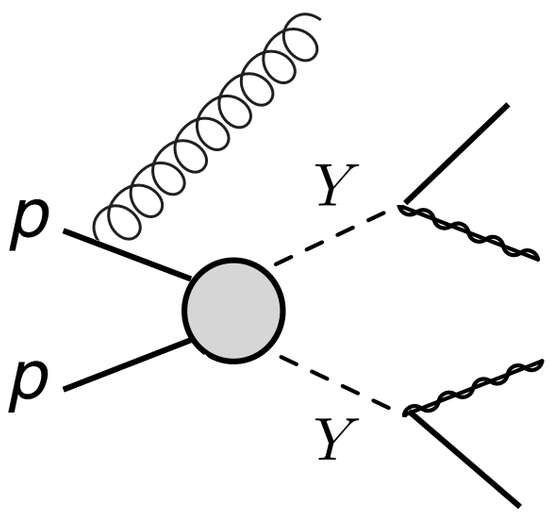

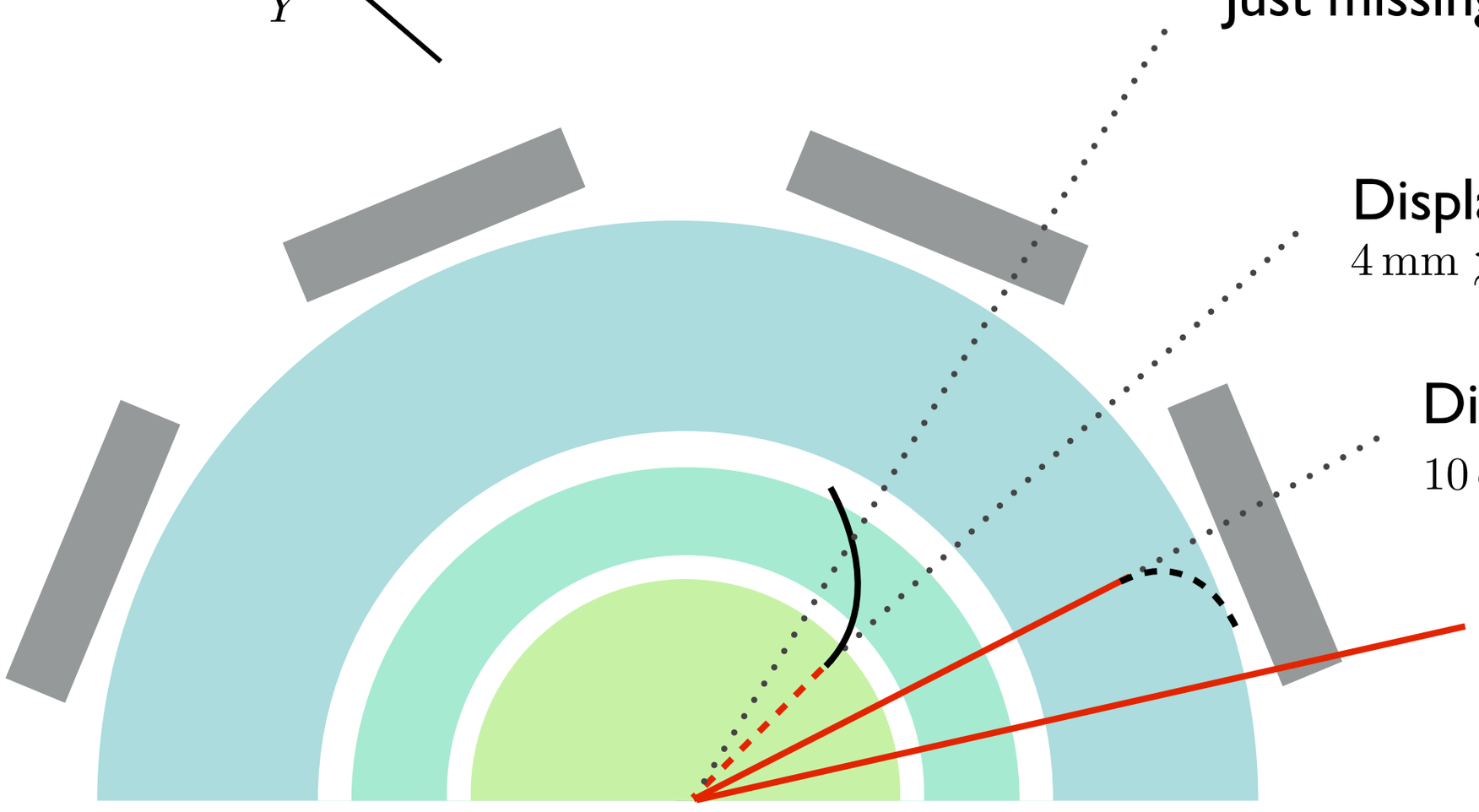

Just missing energy (MET)

Displaced vertices (+MET)

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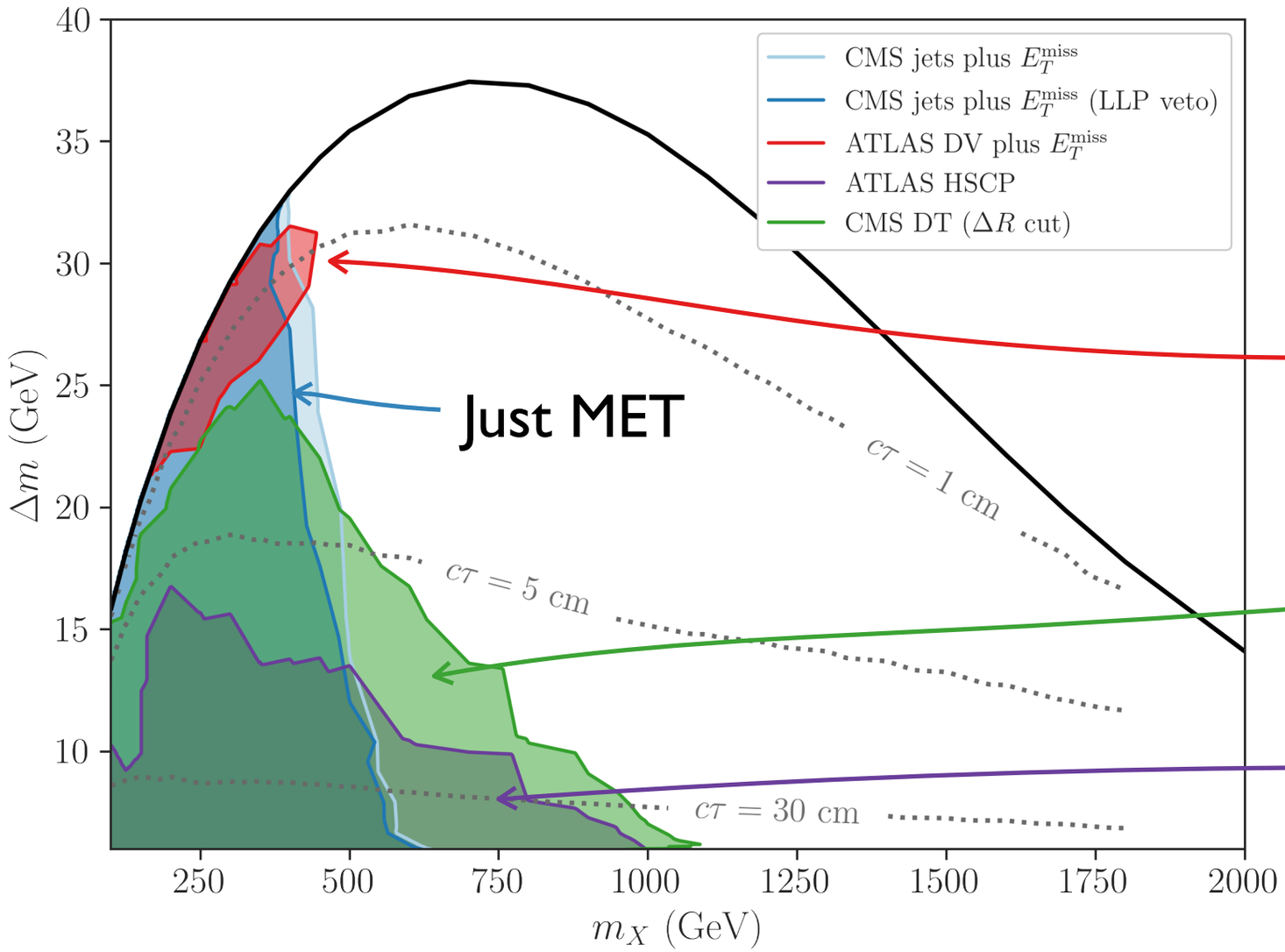
Current LHC constraints

[JH, A. Lessa, L.M.D. Ramos 2404.16086]



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[see also Fuks *et al.*, contr. 7 in 2002.12220]

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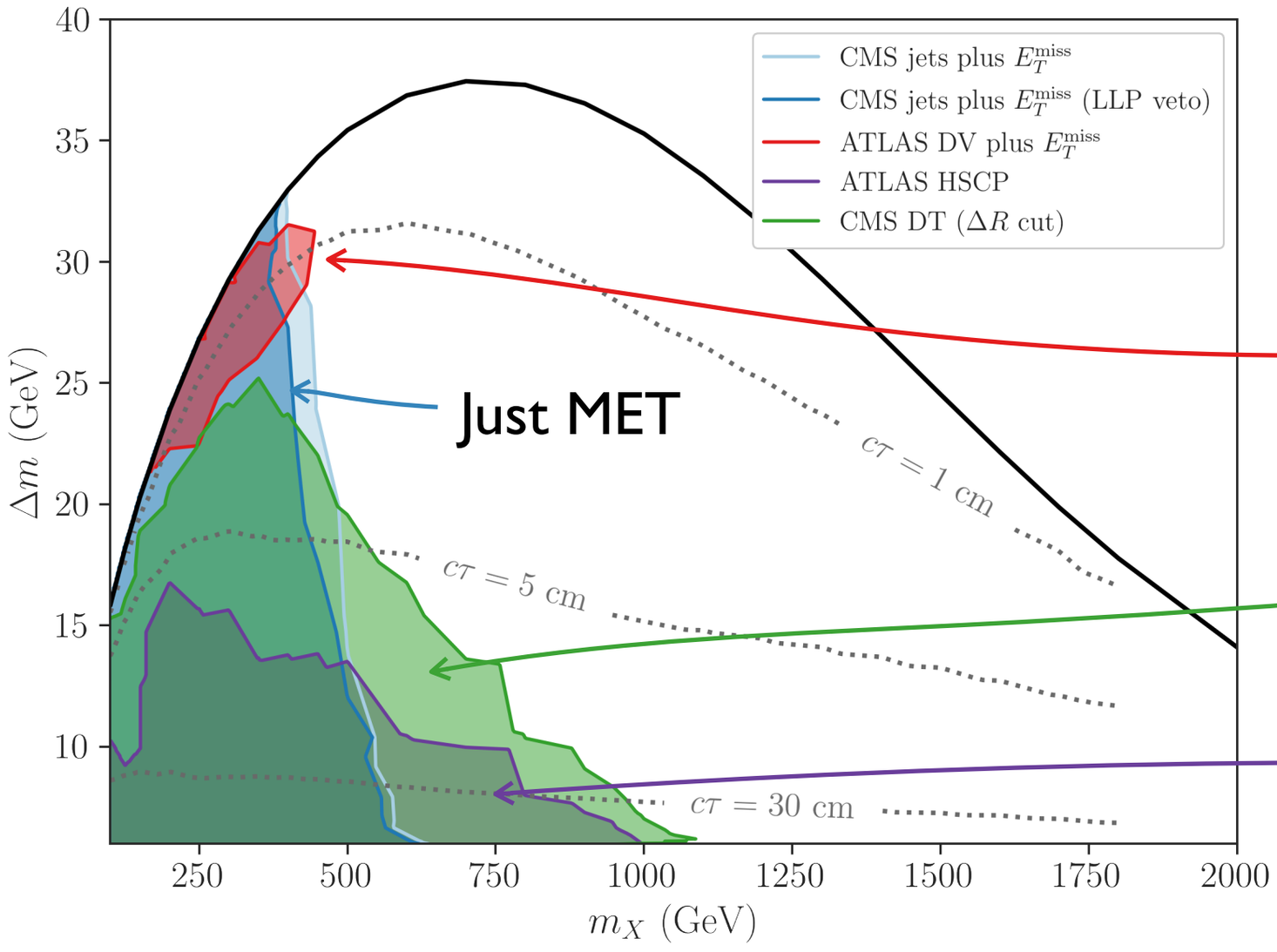

Why poor performance?

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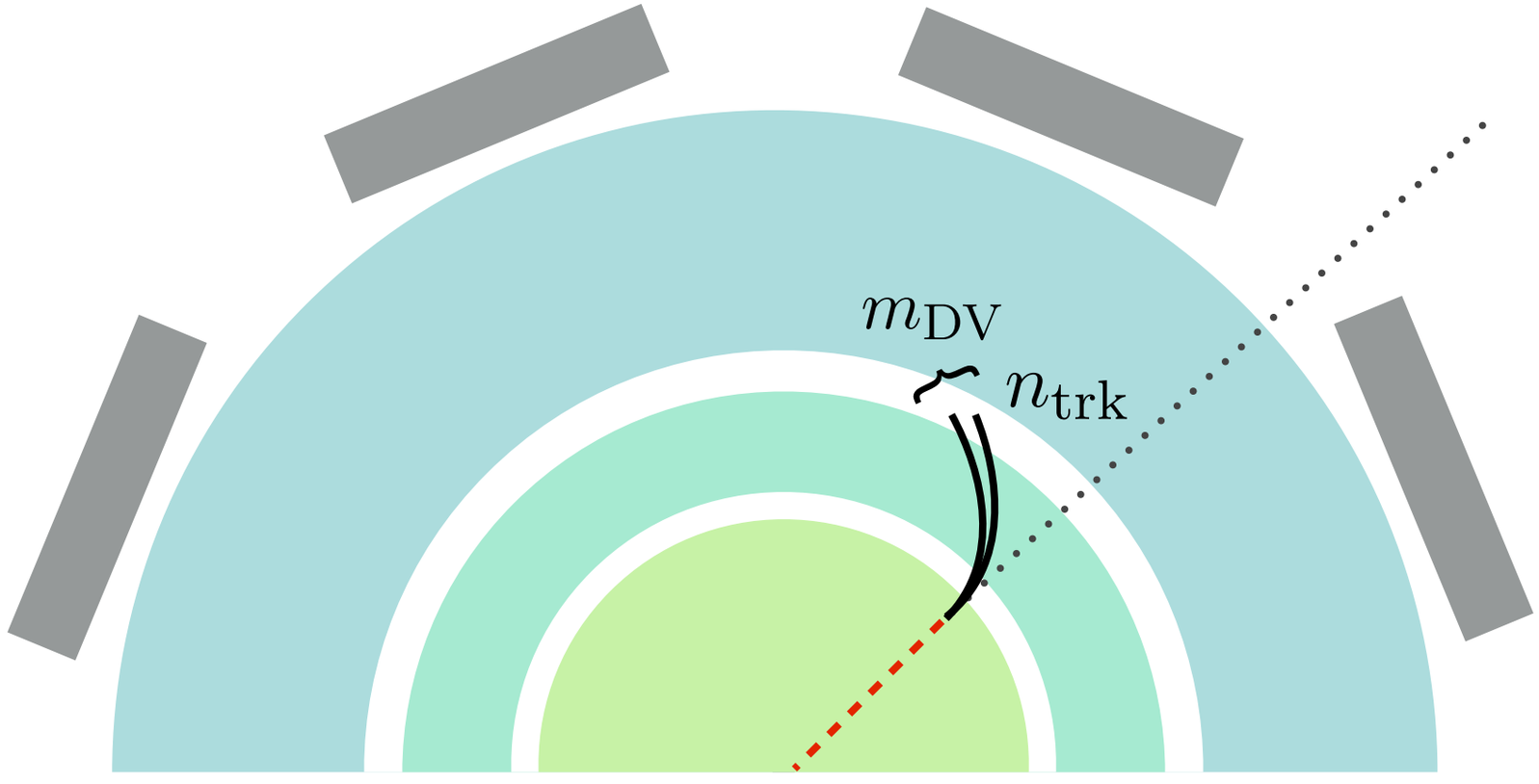
Potential of displaced vertices search

[ATLAS-SUSY-2016-08, 1710.049011]

Search requires:

- Number of displaced tracks: $n_{\mathrm{trk}} \geq 5$
- Invariant mass of displaced vertex: $m_{\mathrm{DV}} > 10\,\mathrm{GeV}$



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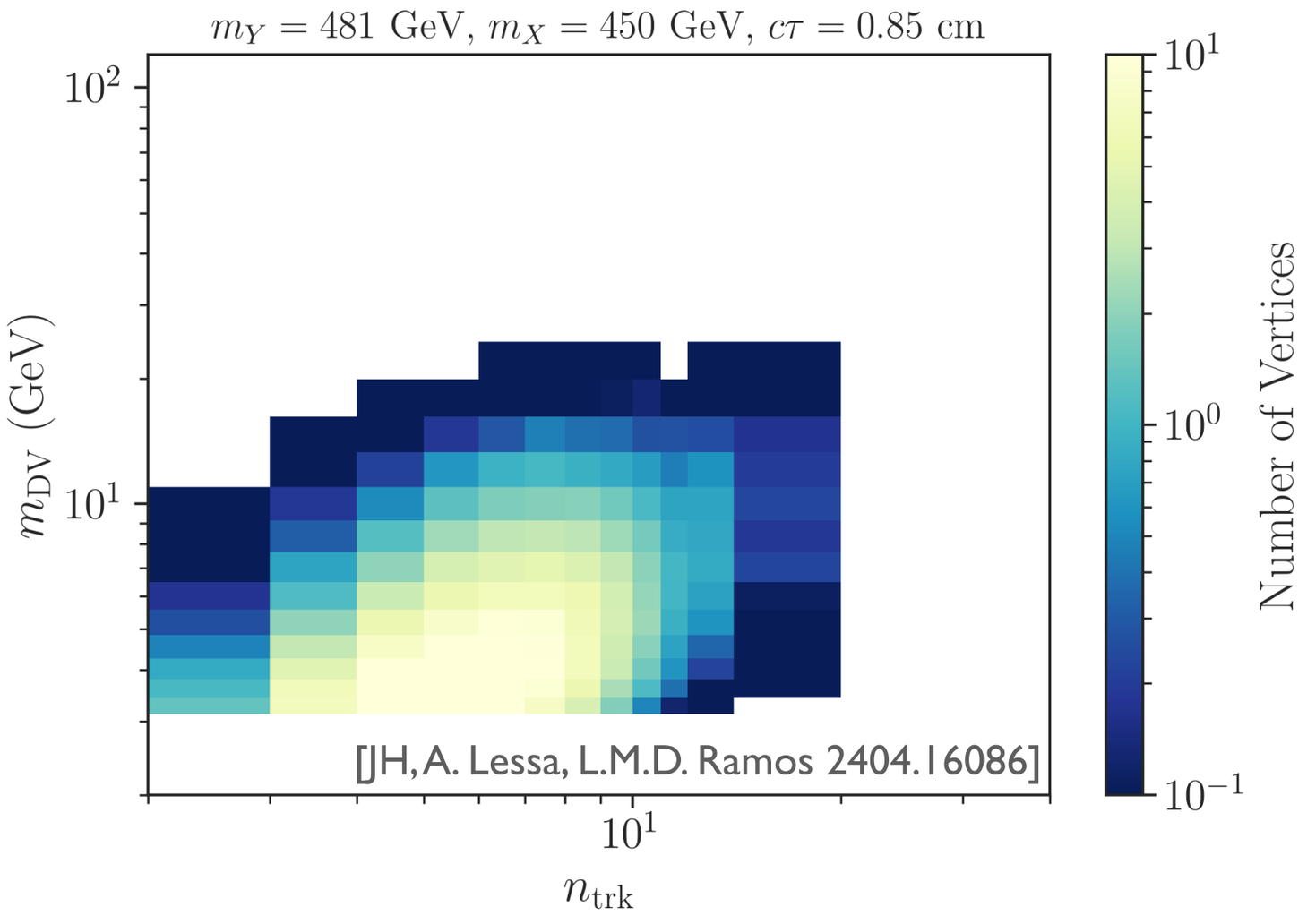

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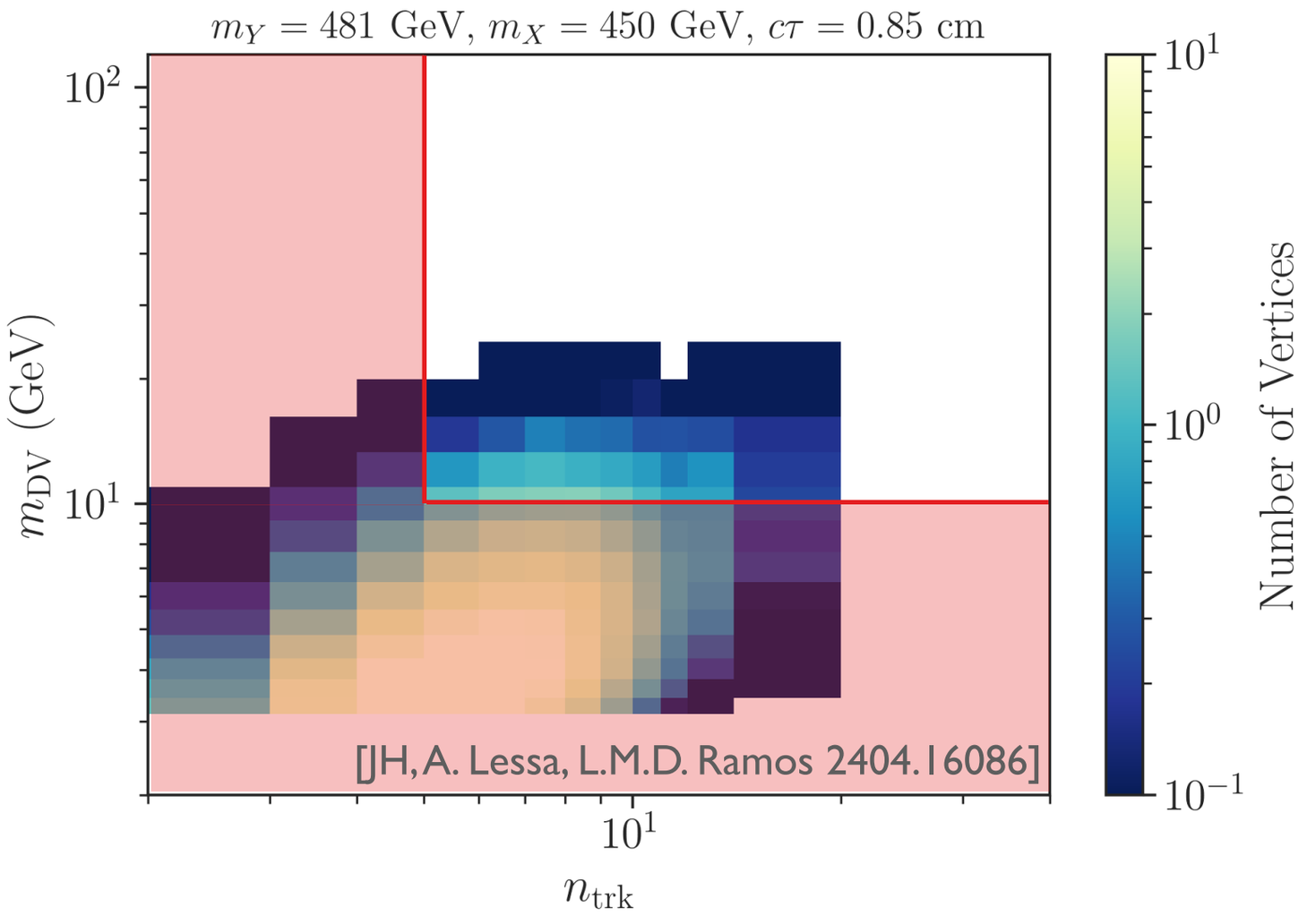

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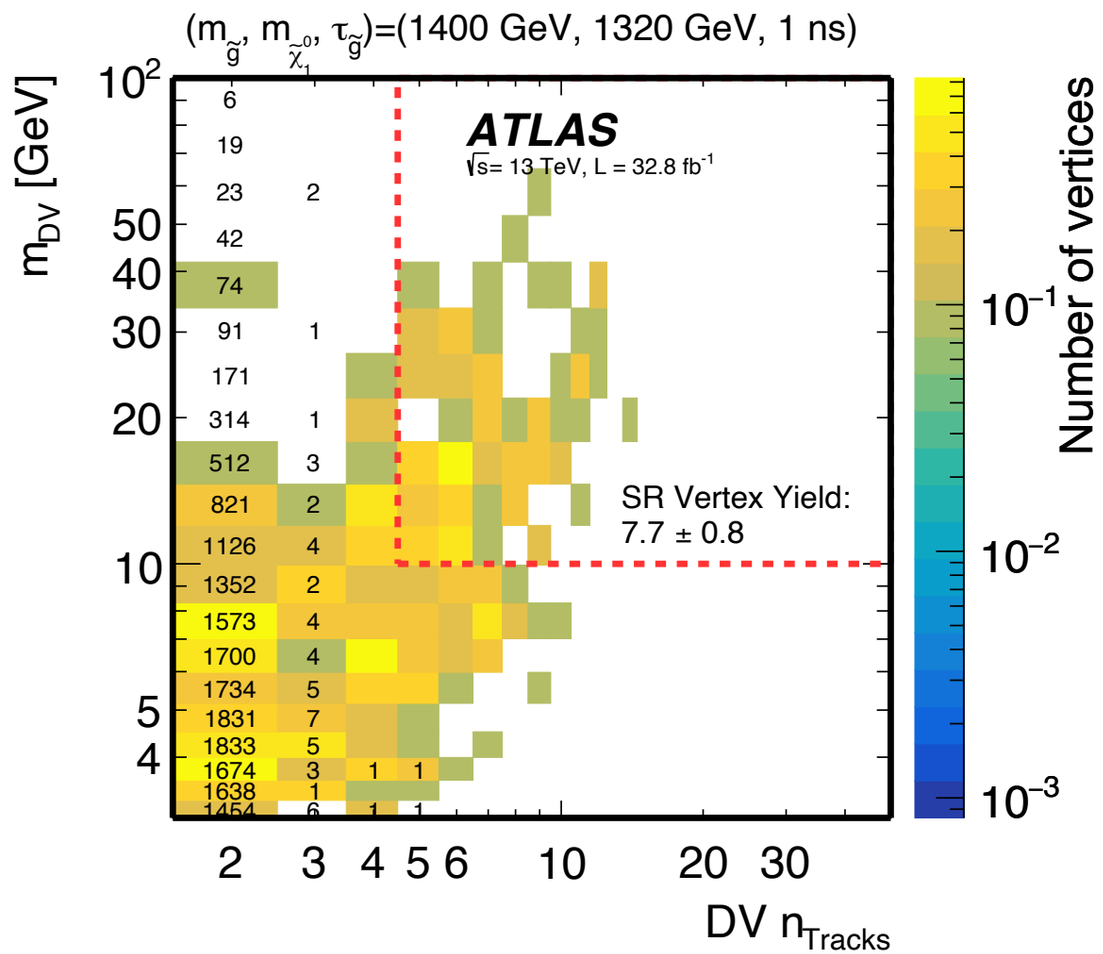

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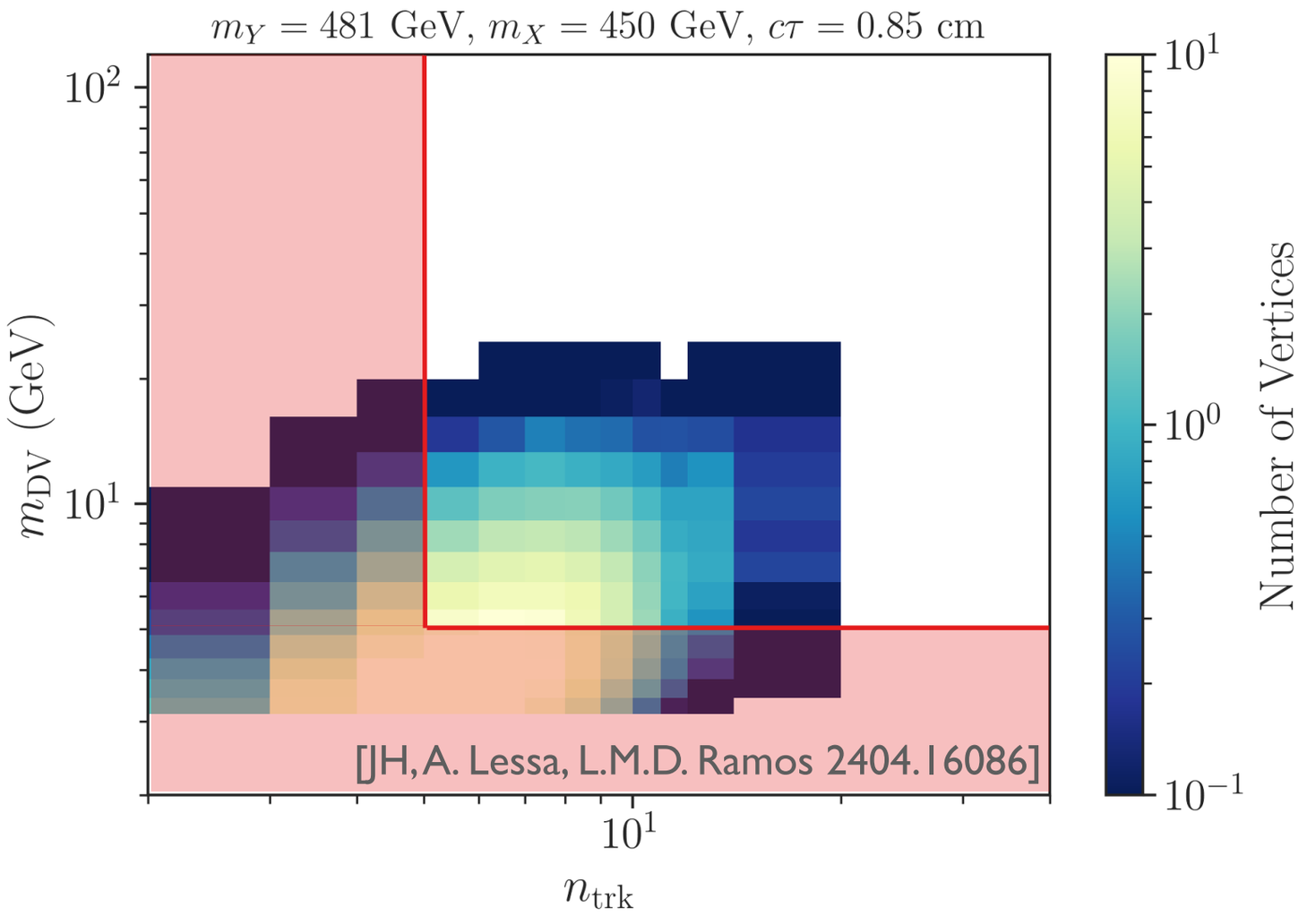

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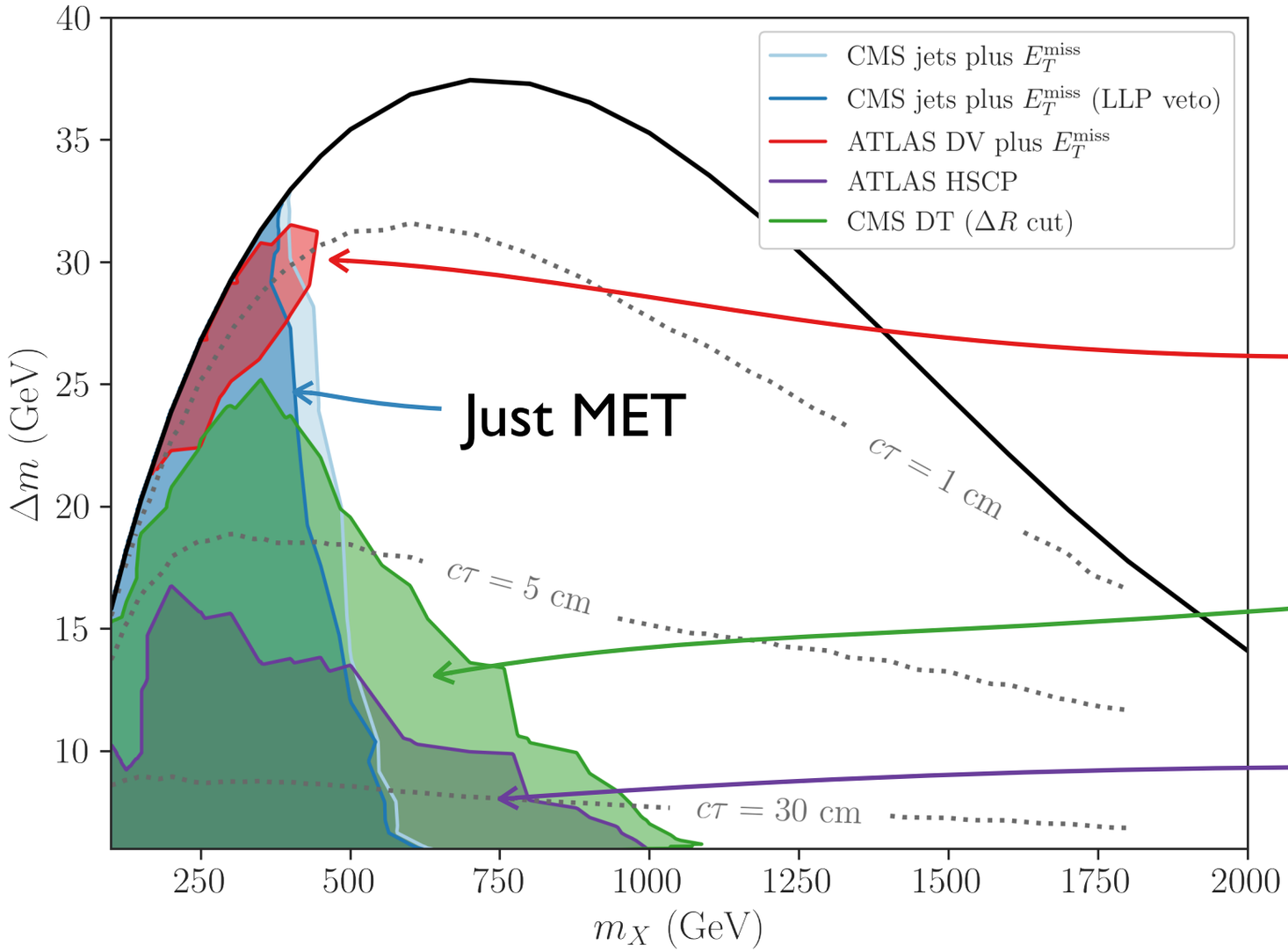

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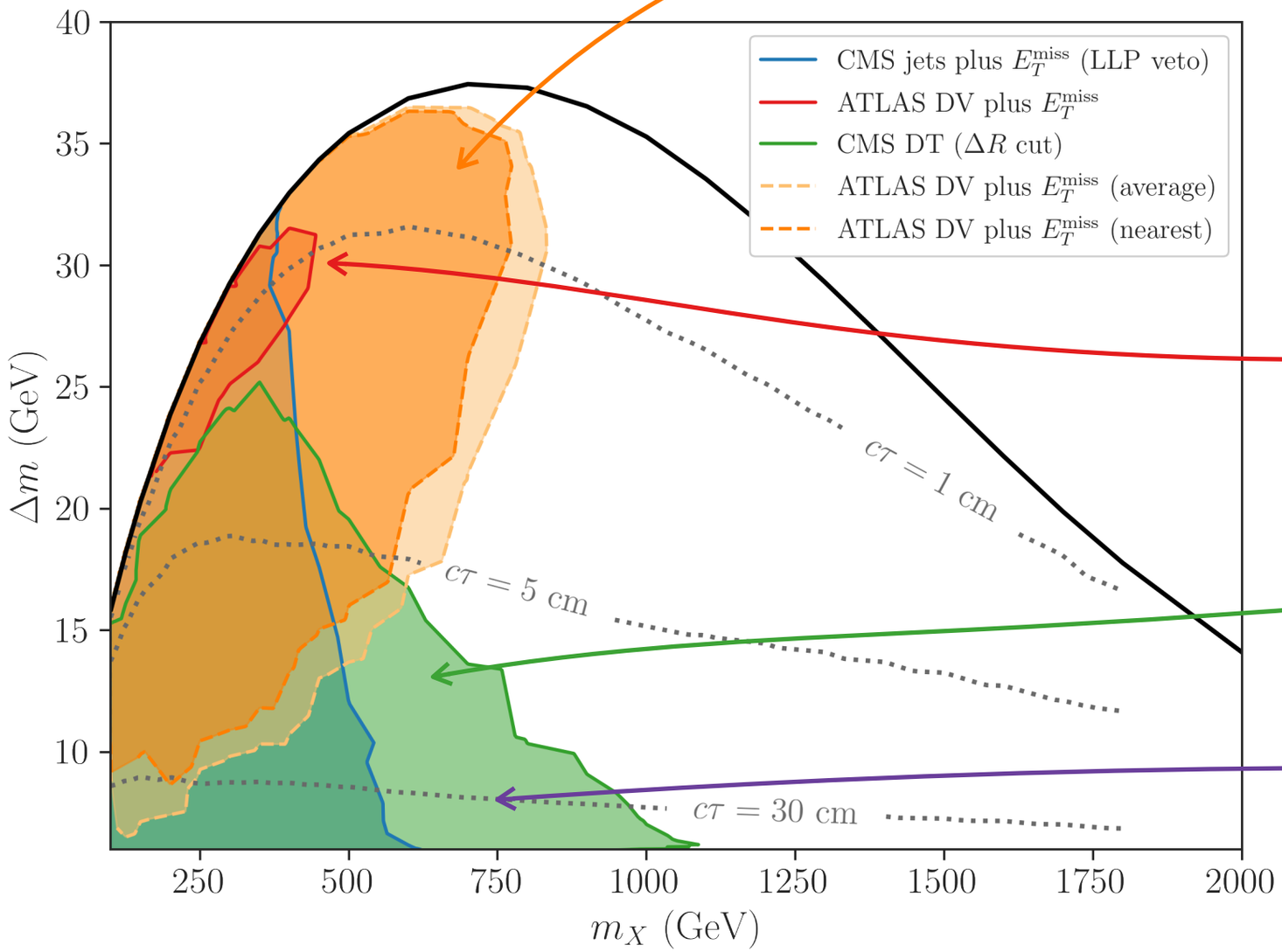
Potential LHC constraints

[JH, A. Lessa, L.M.D. Ramos 2404.16086]

Proposed displaced vertices +MET search

$m_{\rm DV} > 5\,{\rm GeV}$



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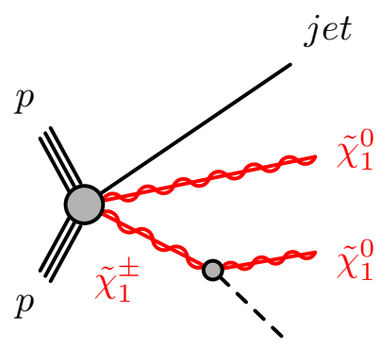
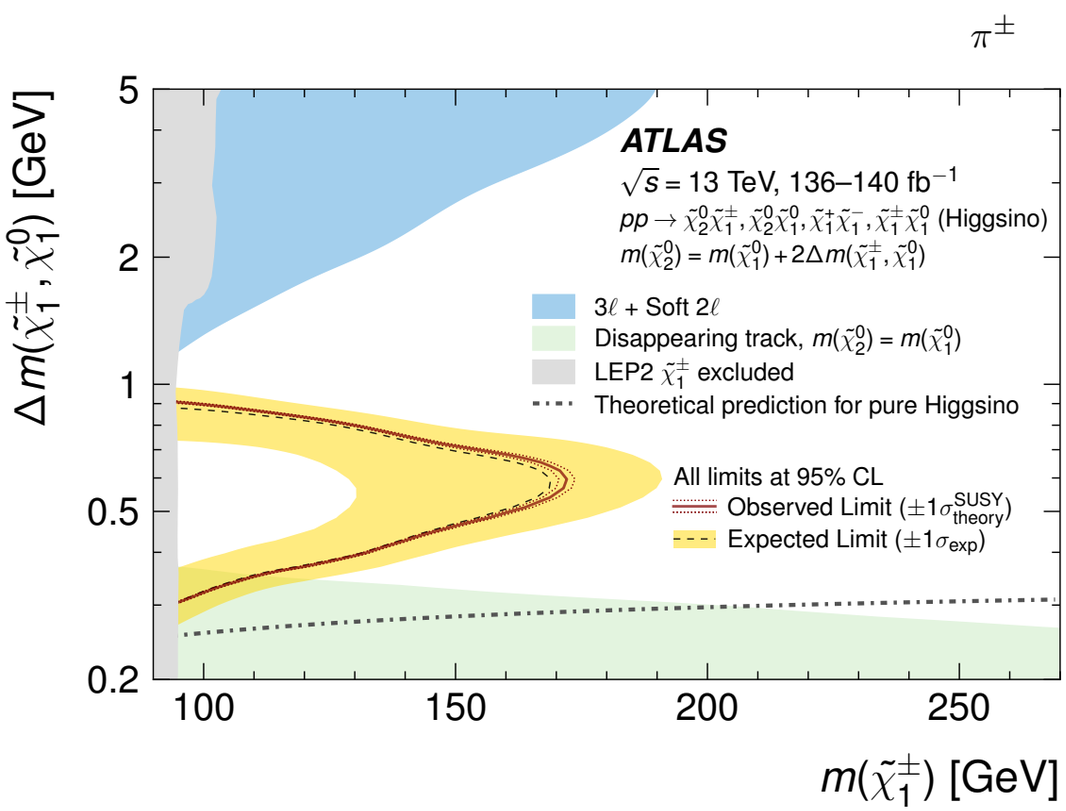
Other searches

Low-momentum mildly-displaced tracks

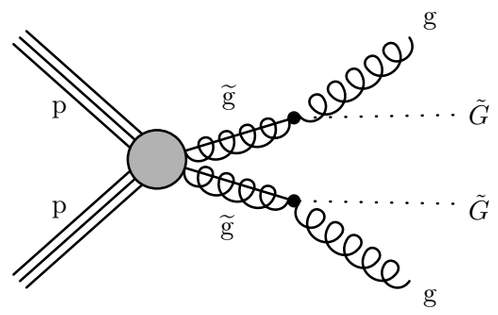
[ATLAS 2401.14046]

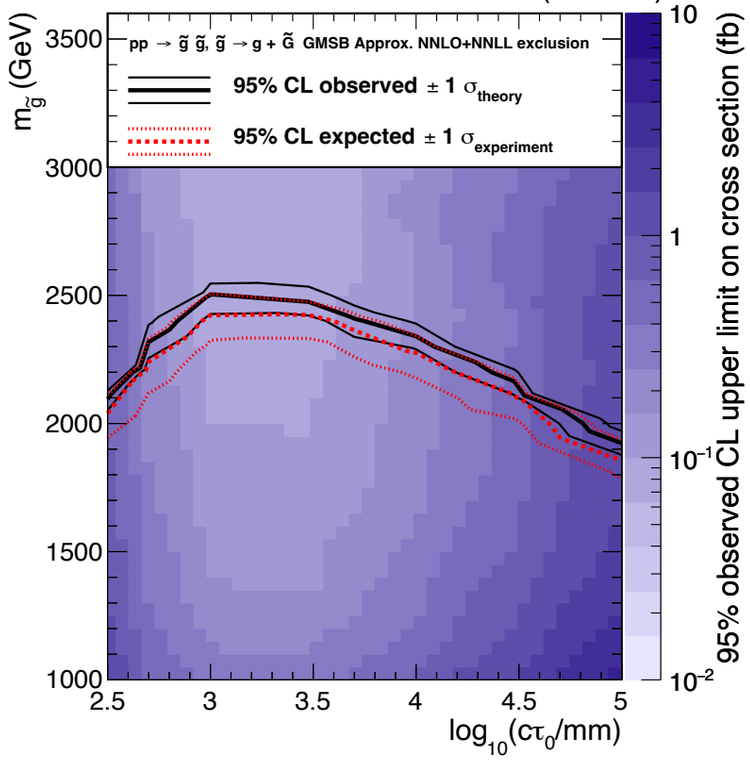




Delayed jets and MET

[CMS 1906.06441]





Example II

Minimal quark-philic models → Non-Minimal models (Flavored DM)

Monika's talk

Example II

Minimal quark-philic models ⟶ Non-Minimal models (Flavored DM)

Monika's talk

Minimal lepto-philic models ⟶ Non-Minimal models (Lepton flavored DM)

Example II

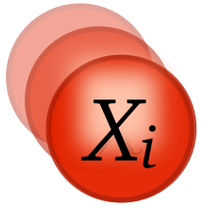
Minimal quark-philic models → Non-Minimal models (Flavored DM)

Monika's talk

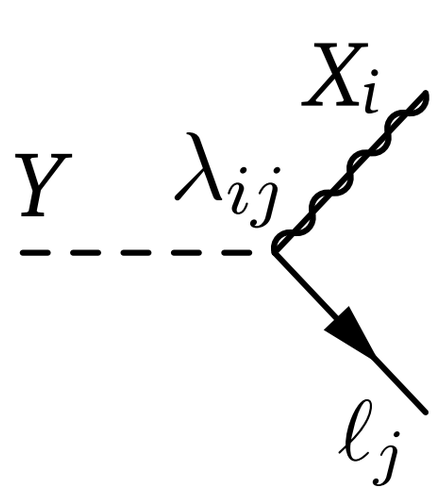
Minimal lepto-philic models → Non-Minimal models (Lepton flavored DM)

Example II

Charged mediator



Dark Matter Multiplet



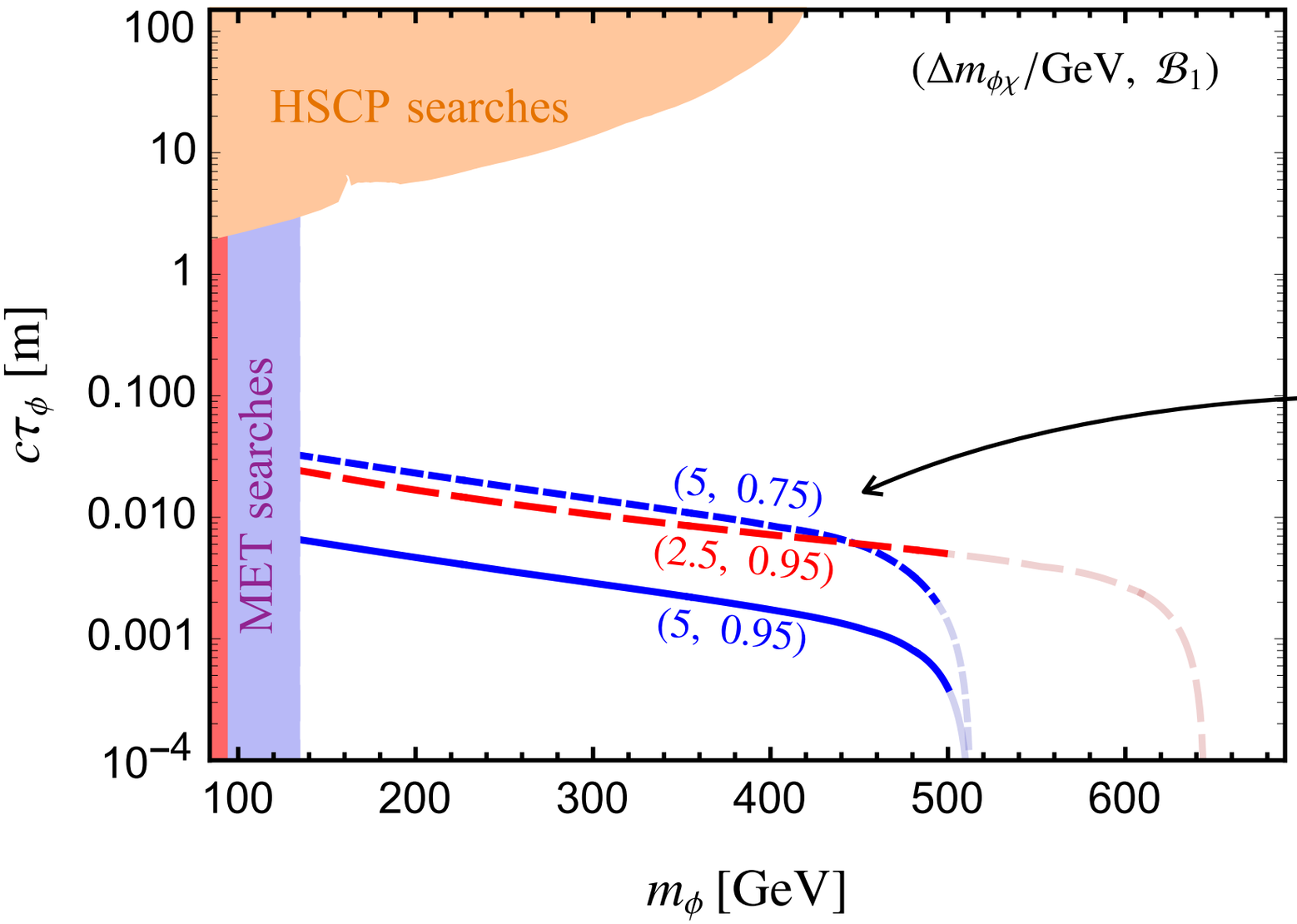
Further motivation:

Simultaneously explain DM and the baryon asymmetry
via *conversion-driven leptogenesis*

[JH 2404.12428]

Example II:
Conversion-driven freezes-out and leptogenesis

[JH 2404.12428]



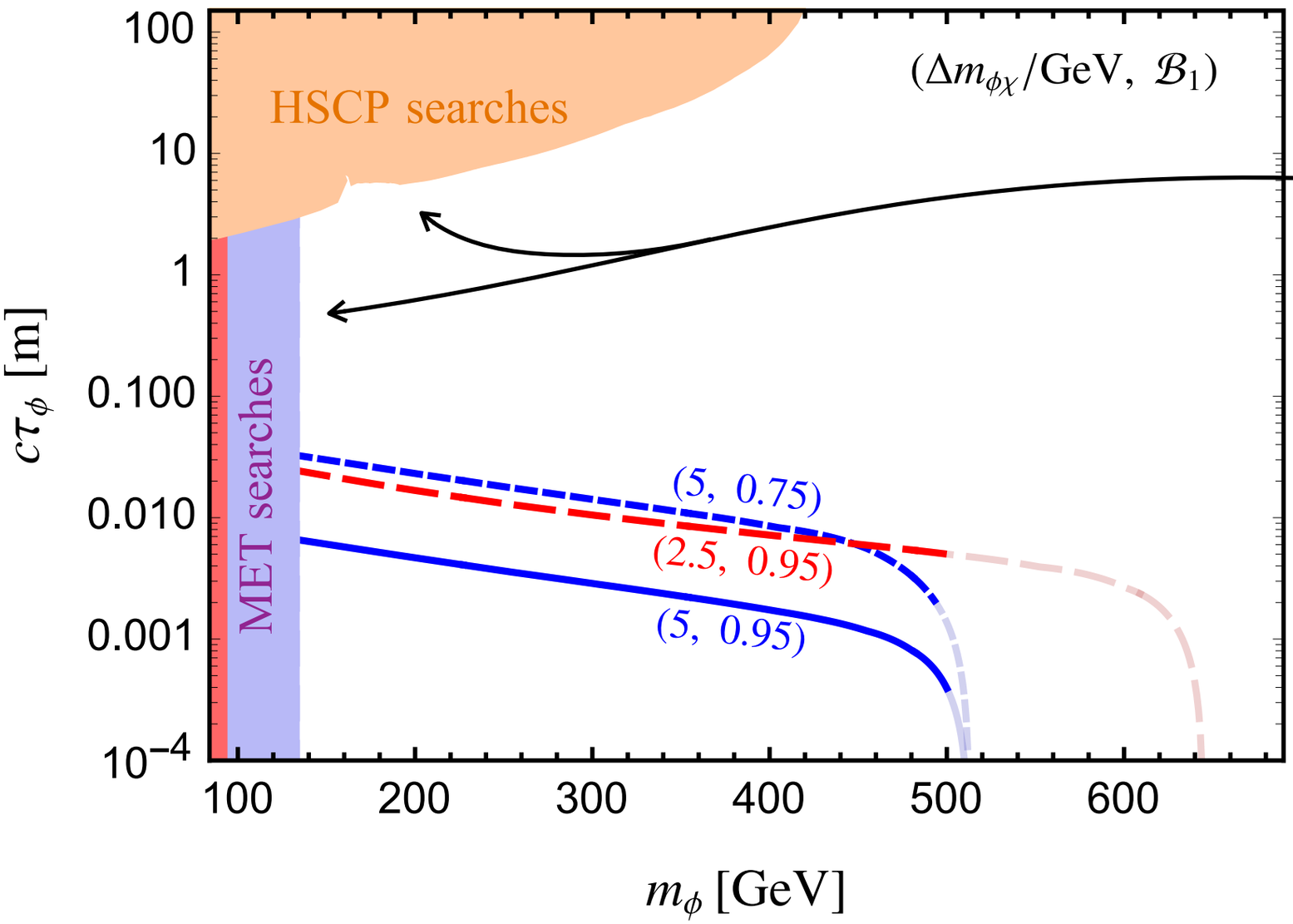
Parameter slices yielding:

$\Omega h^2 = 0.12$

$Y_{\Delta B} = 0.9 \times 10^{-10}$

Example II:
Conversion-driven freezes-out and leptogenesis

[JH 2404.12428]



Current searches at the LHC

Example II:
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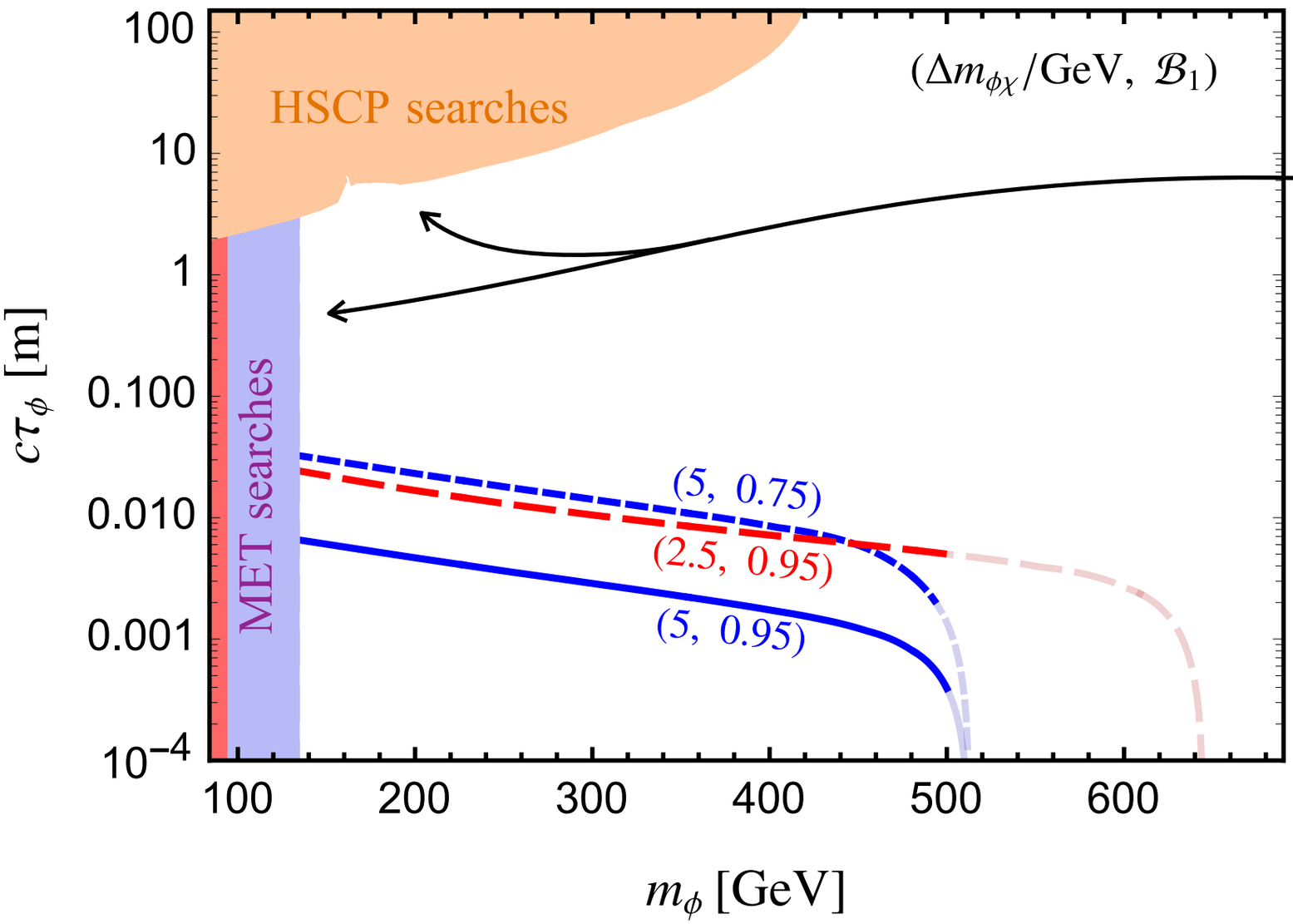

Current searches at the LHC

Displaced leptons?

$p_{\mathrm{T}} > 65\,\mathrm{GeV}$

[ATLAS 2011.07812]

or dileptons with

$p_{\mathrm{T}} > 20\,\mathrm{GeV}$,

$m_{\mathrm{inv}} > 200\,\mathrm{GeV}$

[ATLAS 2305.02005]

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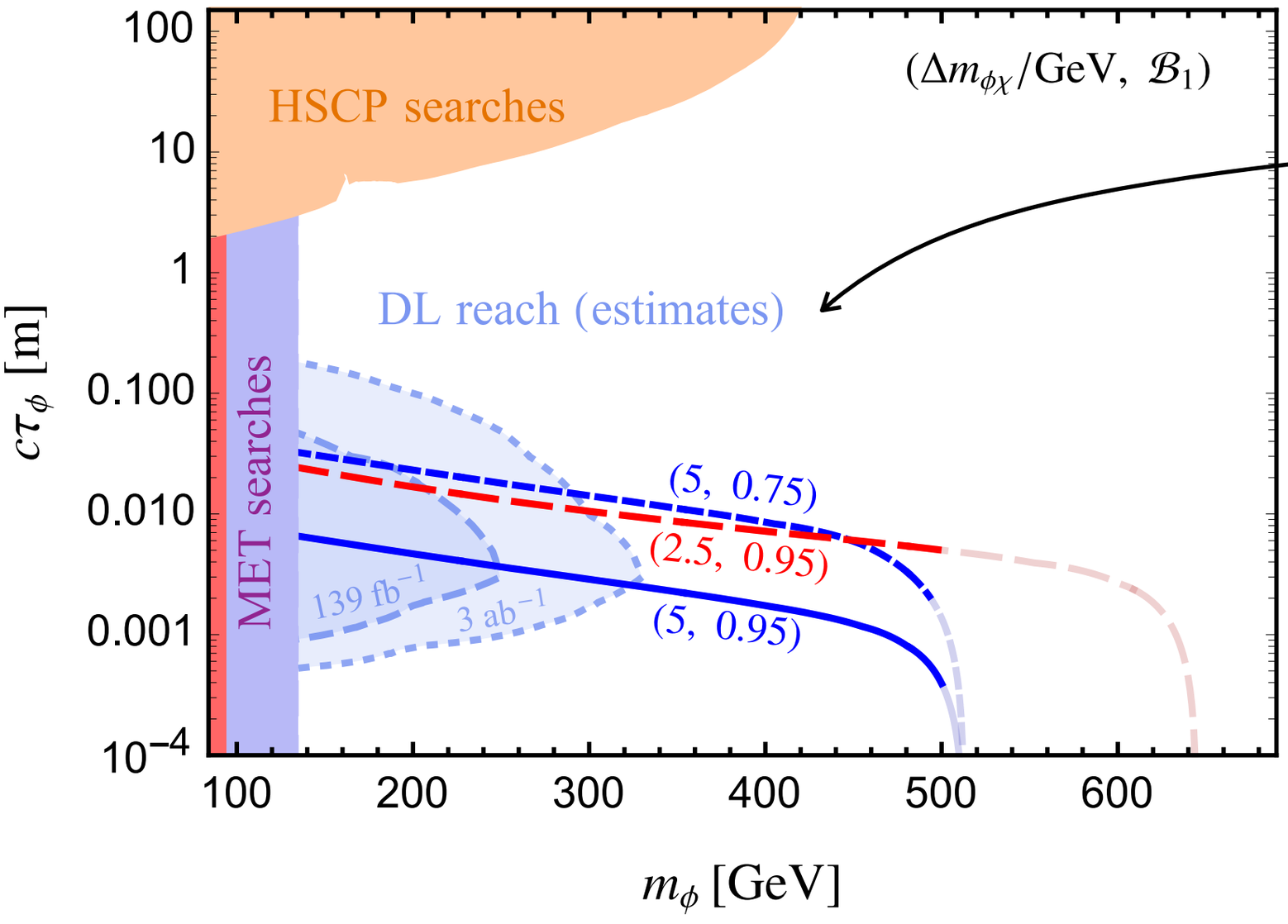

Assuming similar background reduction with $p_{\mathrm{T}} > 10\,\mathrm{GeV}$ but exploiting MET (maybe timing?)

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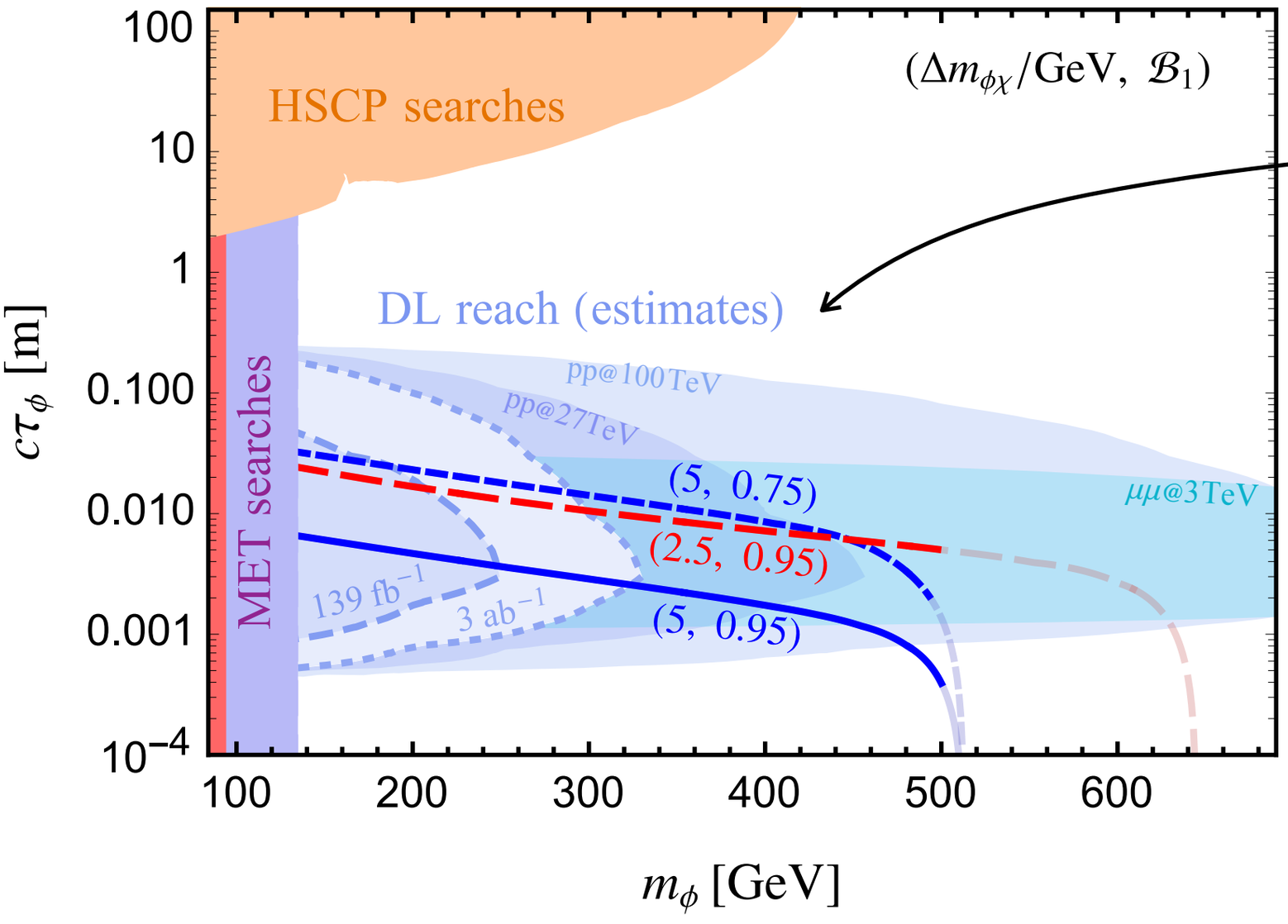

Assuming similar background reduction with $p_{\mathrm{T}} > 10\,\mathrm{GeV}$ but exploiting MET (maybe timing?)

Conclusion

- WIMP parameter space (MET signatures) highly constrain within minimal models
- Parameter region evading bound ↔ small couplings ↔ long-lived particles
- Great potential for (non-)thermalized case
- Non-thermalized case draws particular attention:
  - accessible parameter space
  - soft displaced objects, not yet well covered

  ⇒ prime target for future investigations
- Combine primary and displaced track information ('kinked tracks')