



Universidade Federal do ABC

# Dark Matter, LLP searches and Recasting

2024 LHC DM WG workshop

CERN, May 13th

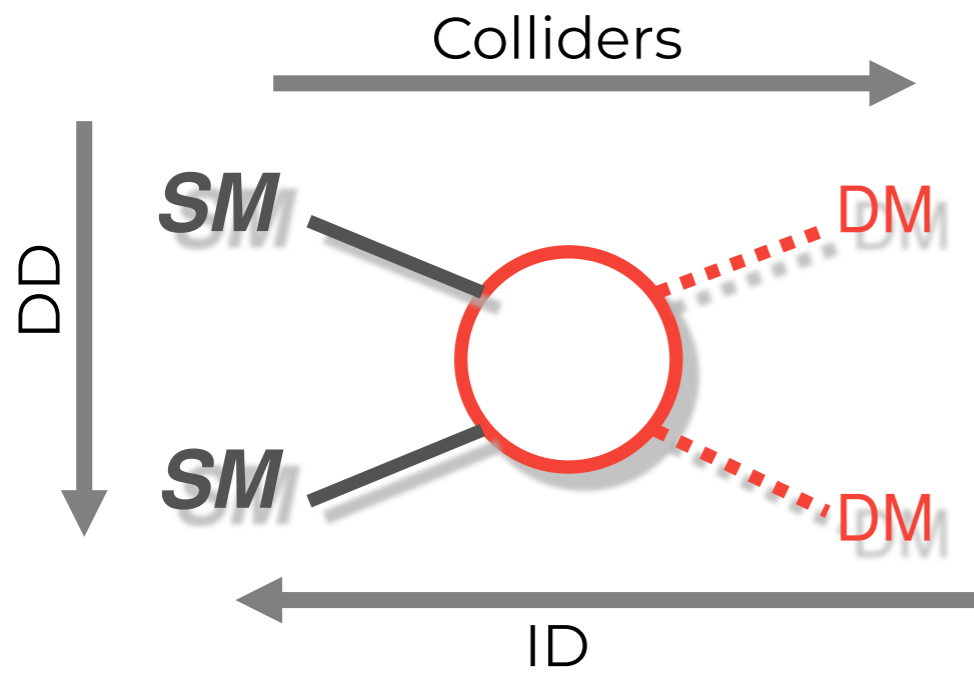
**André Lessa**

UFABC, Sao Paulo, Brazil

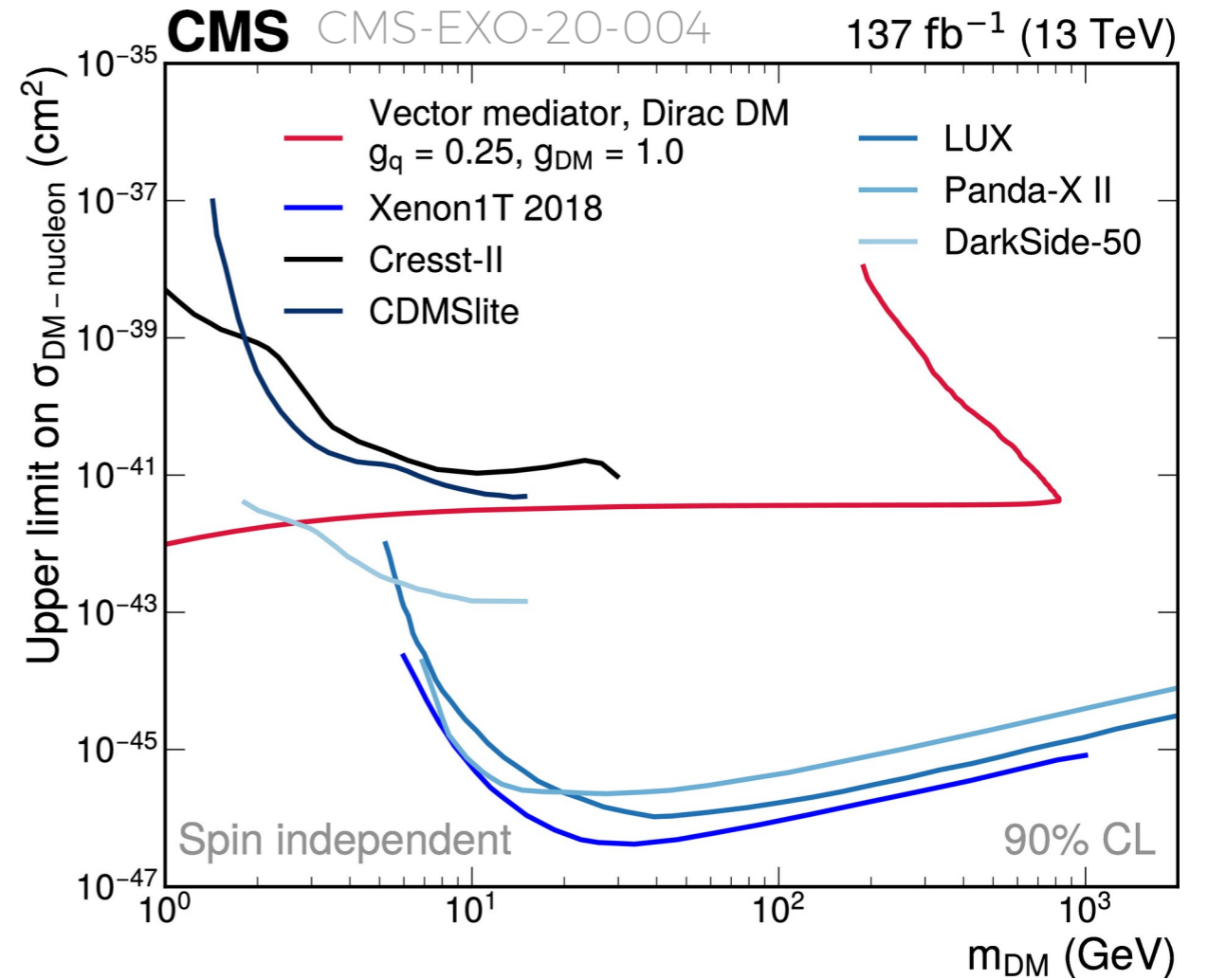
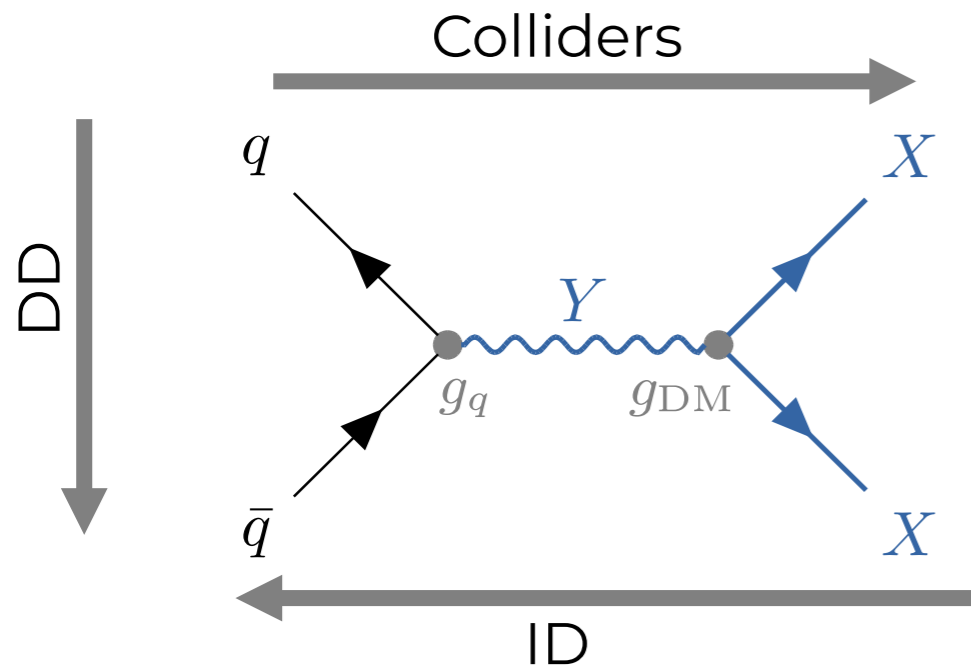


# Dark Matter and LLPs

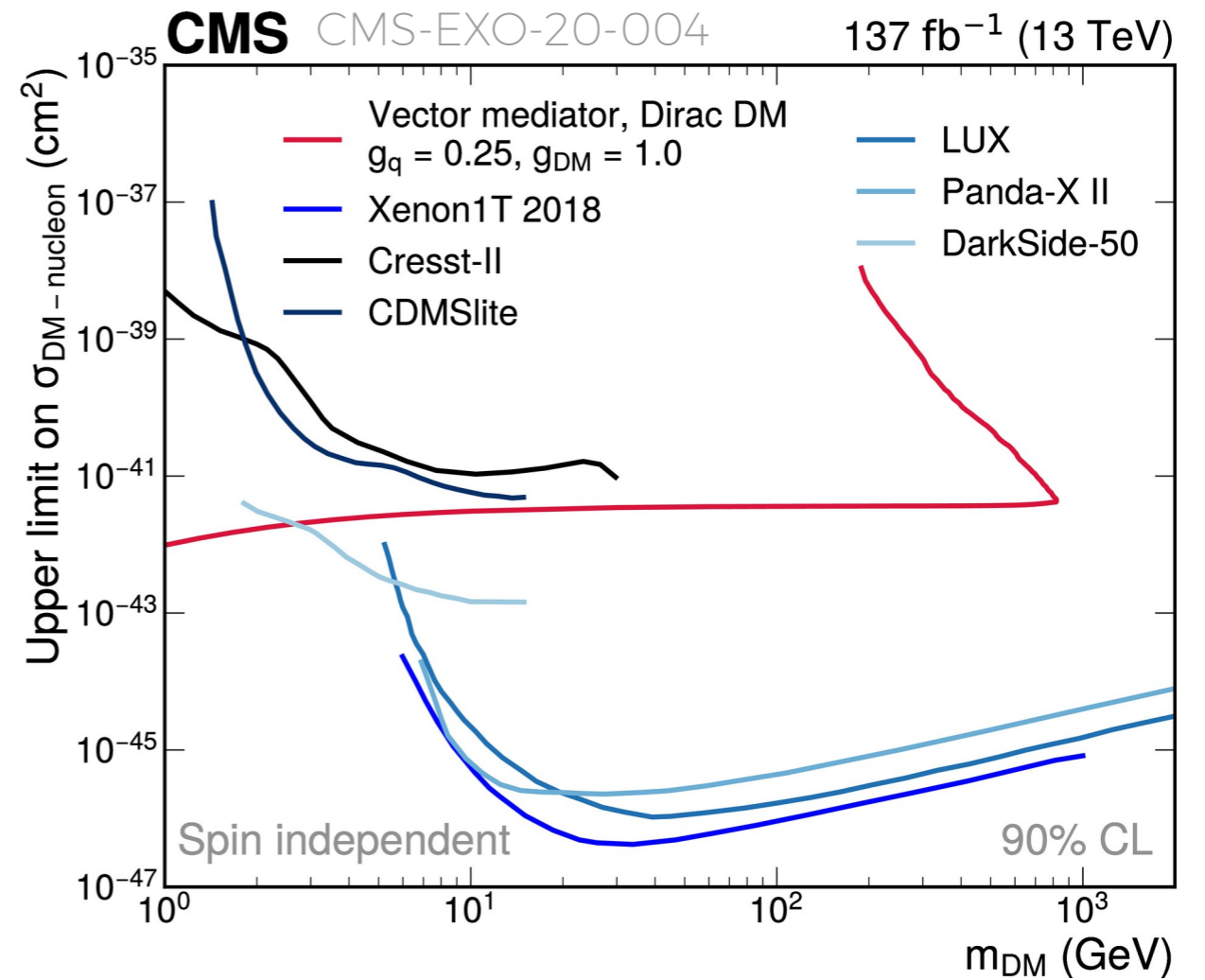
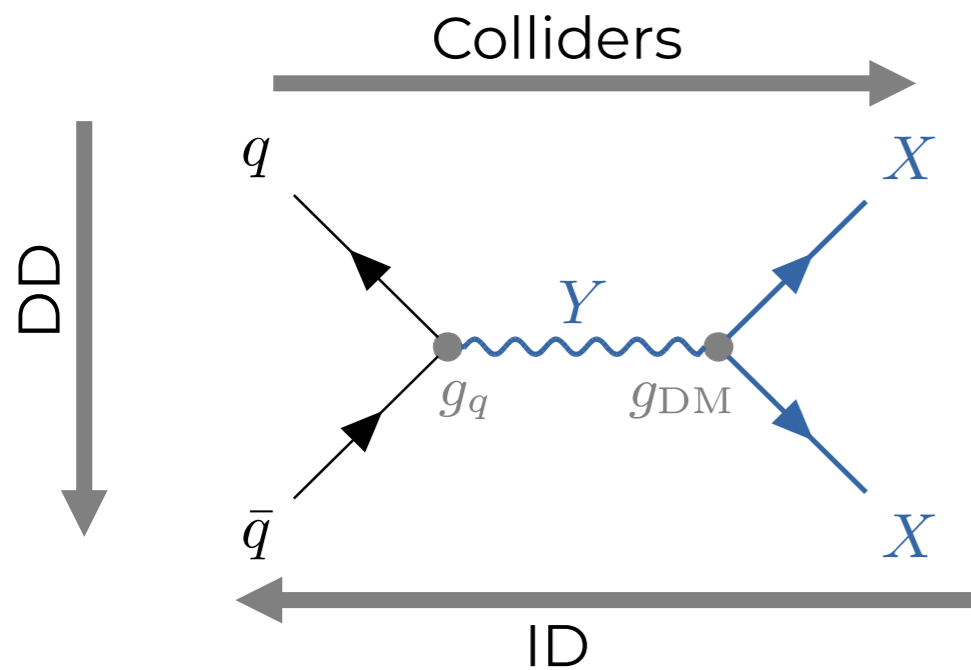
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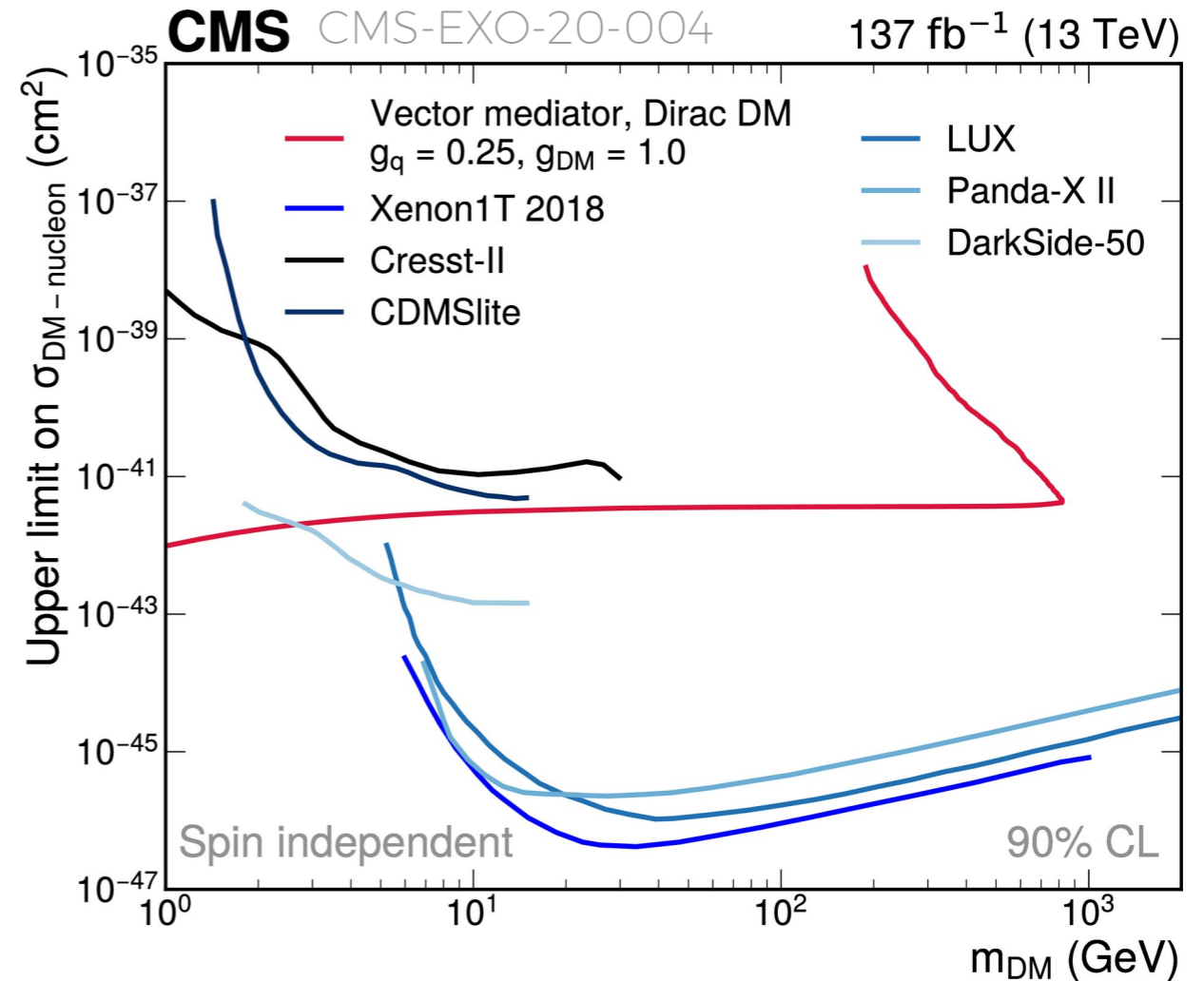
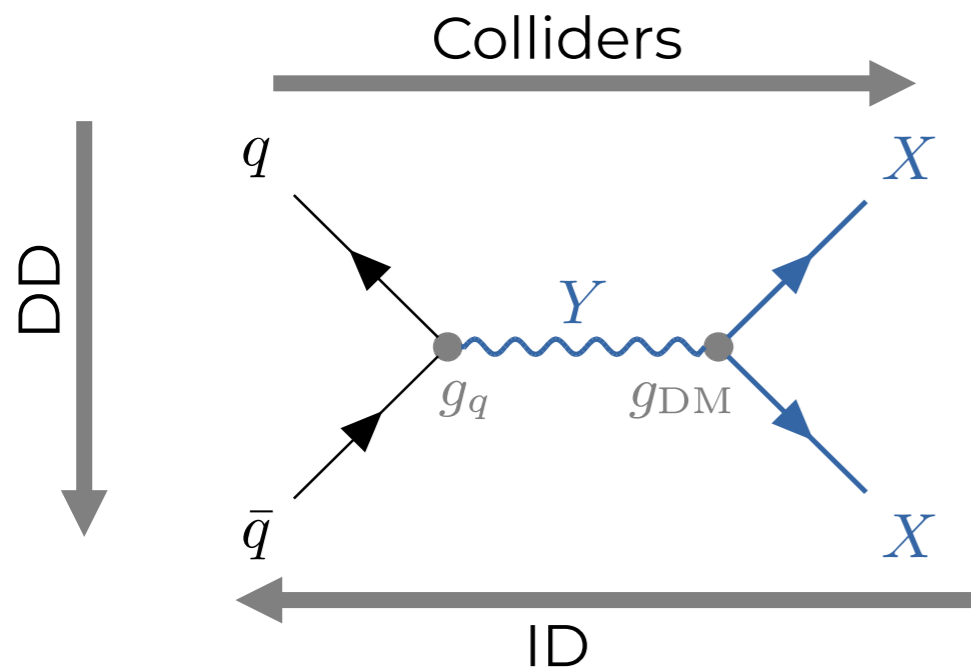


# Dark Matter and LLPs



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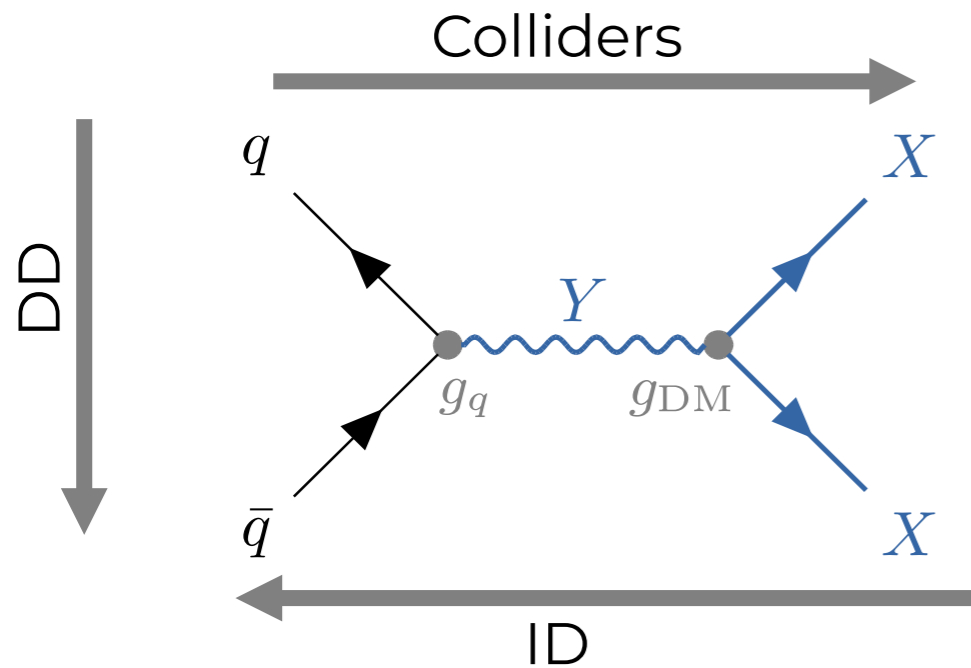
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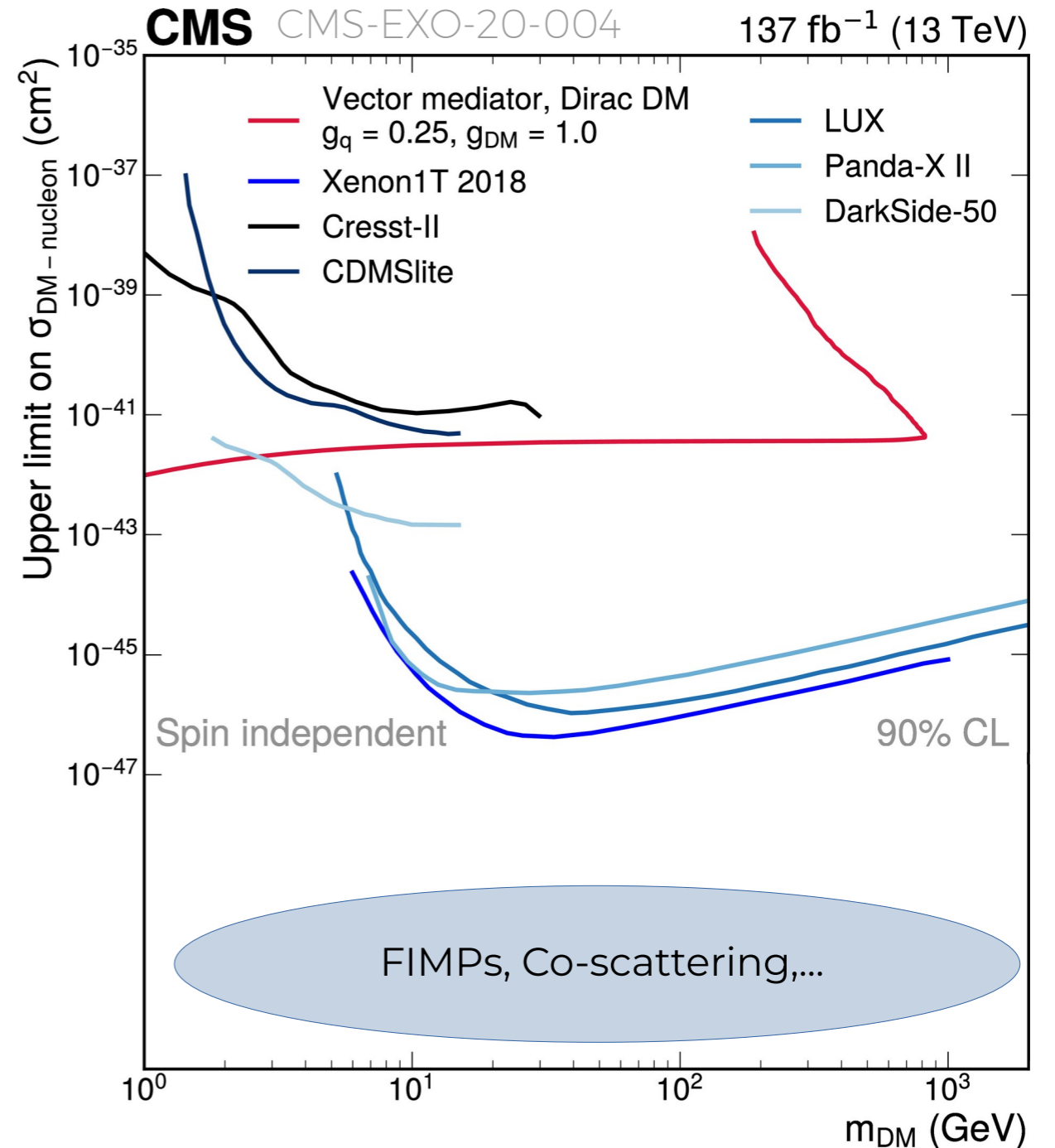
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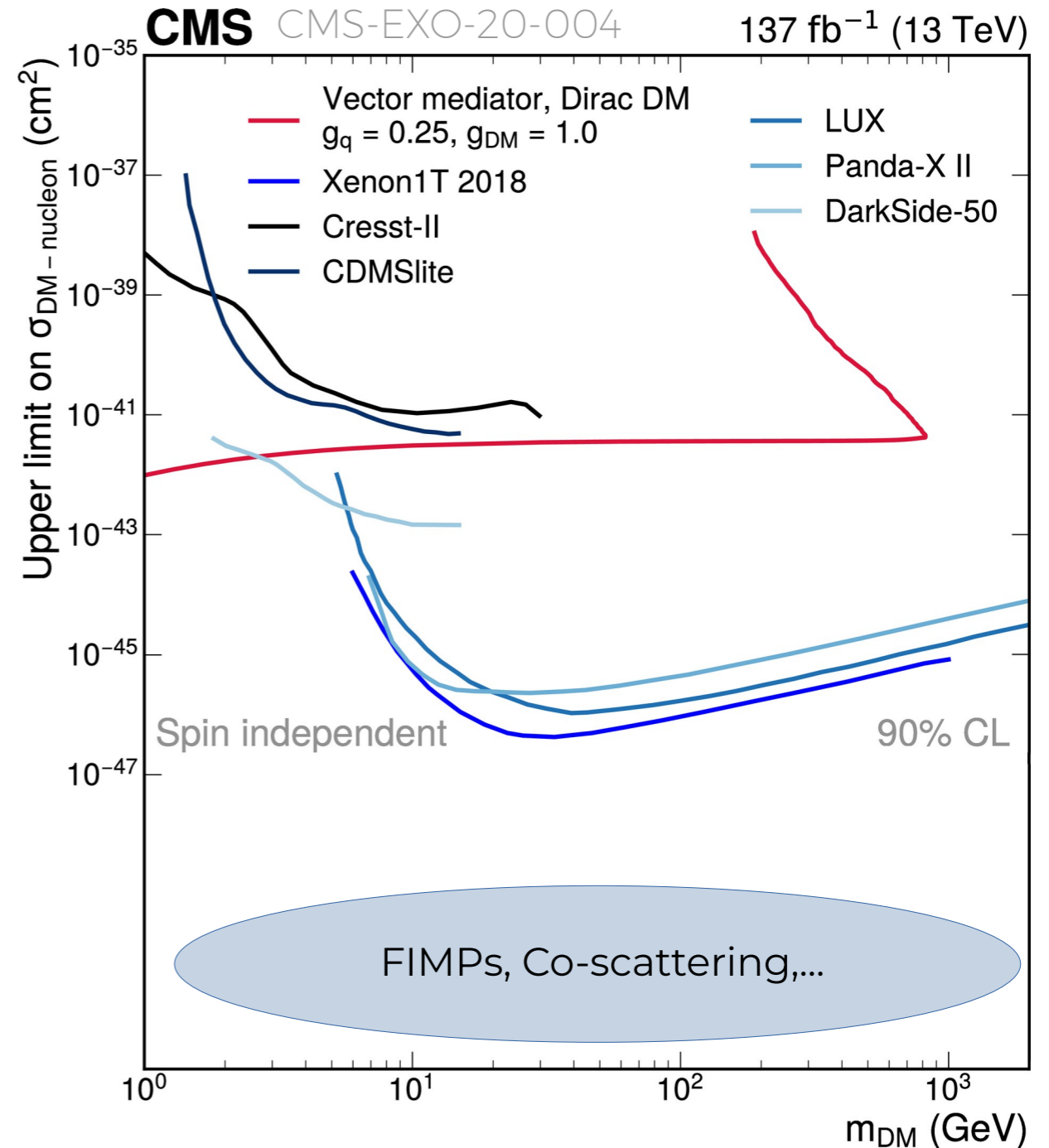
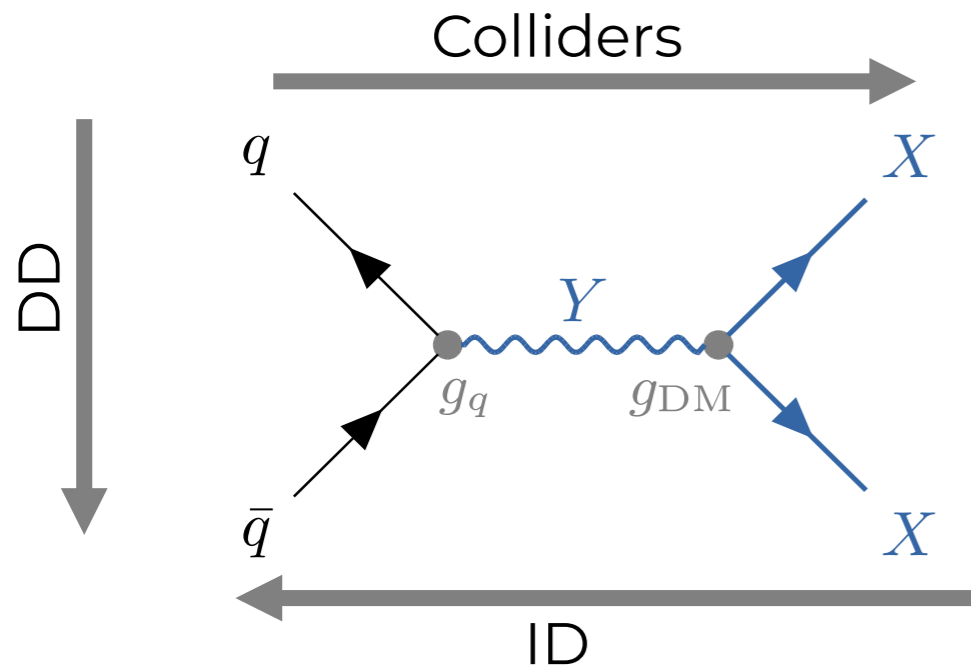


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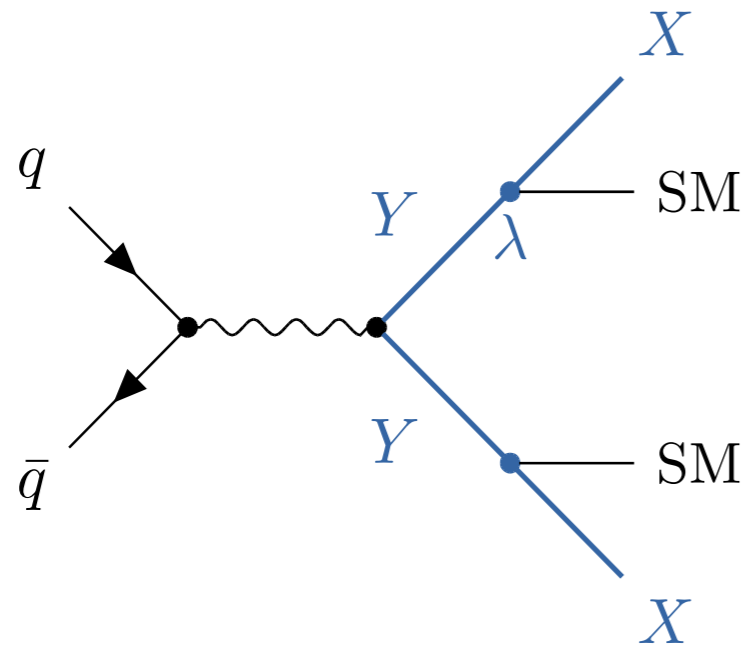
- The complementarity of searches is usually true only for WIMPs.
- Several DM mechanisms (co-scattering, FIMPs,...) can not be tested by DD.
- Many of these lead to long-lived particles (LLPs) at the LHC!

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# Dark Matter and LLPs

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- “Template model” (Mediator+DM):



$$\lambda \ll 1 \text{ and/or } m_X \simeq m_Y$$

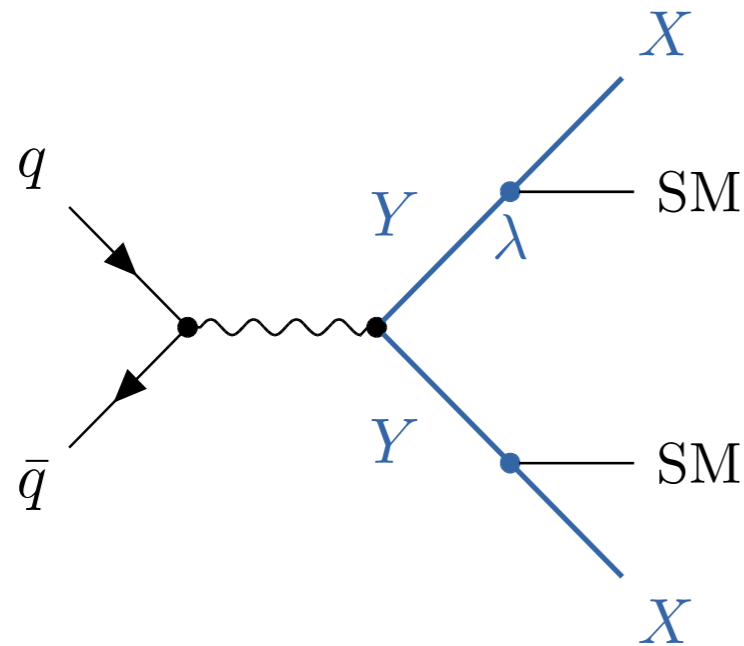
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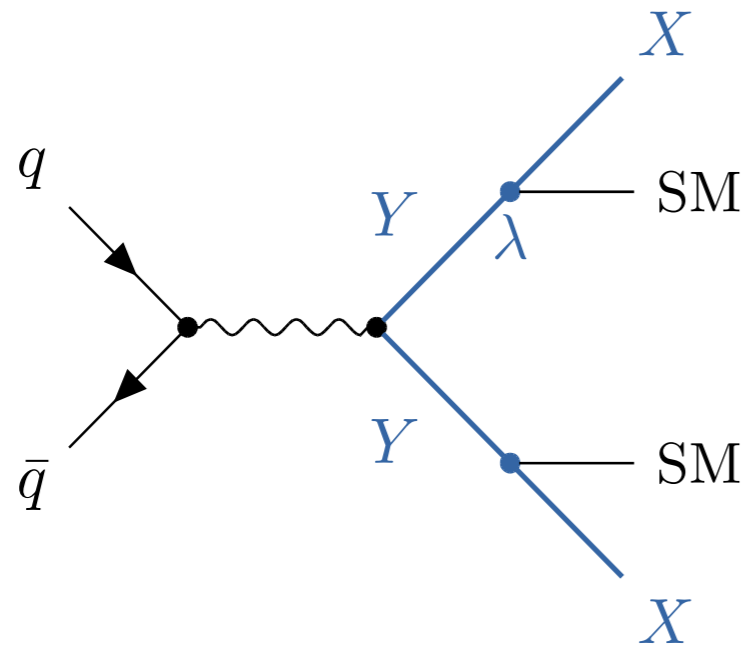
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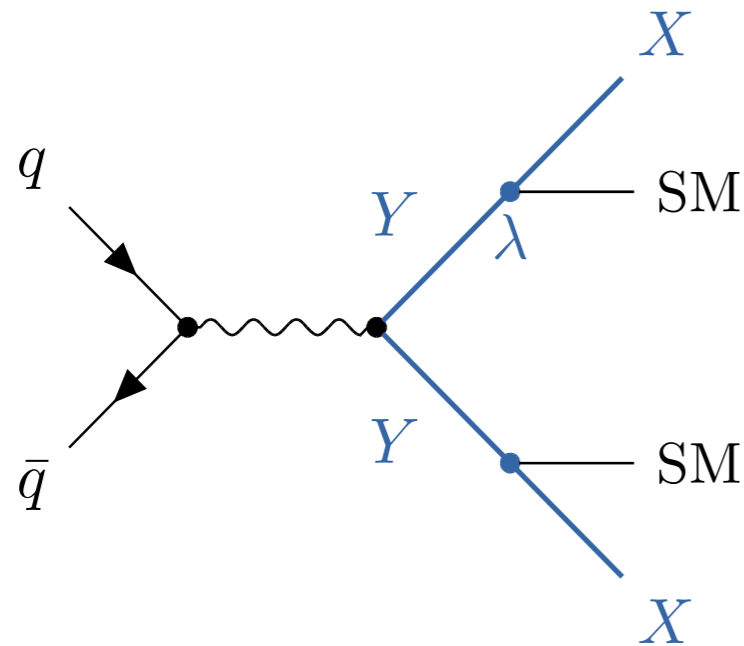
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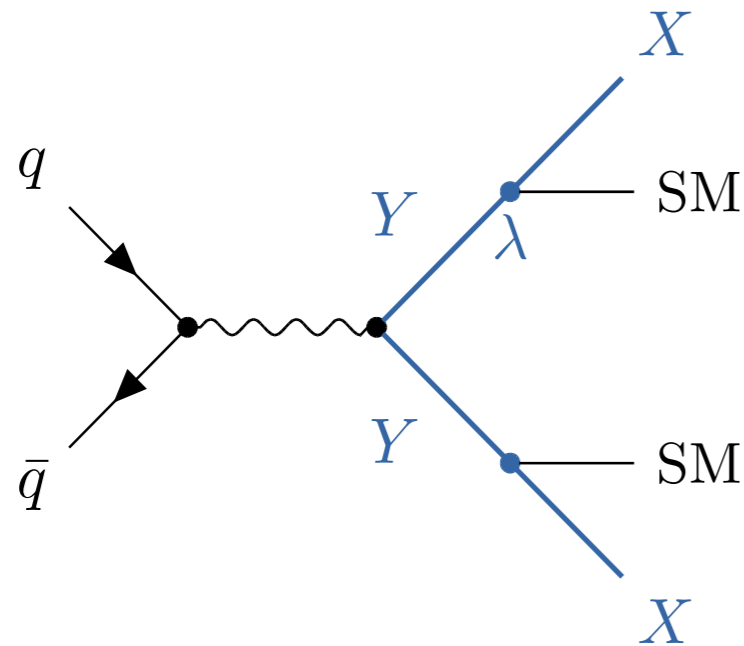
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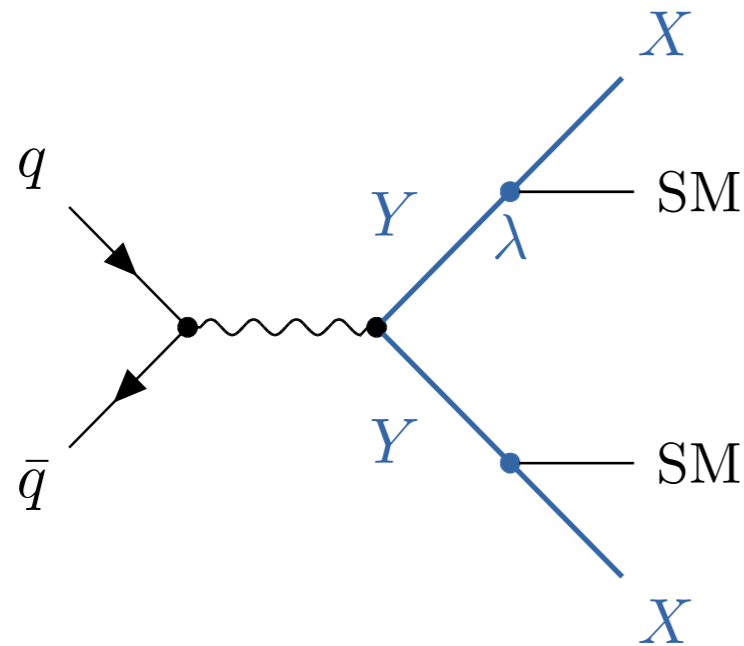
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We need to be able to re-interpret LLP searches for “new” DM models!

# LLP Recasting

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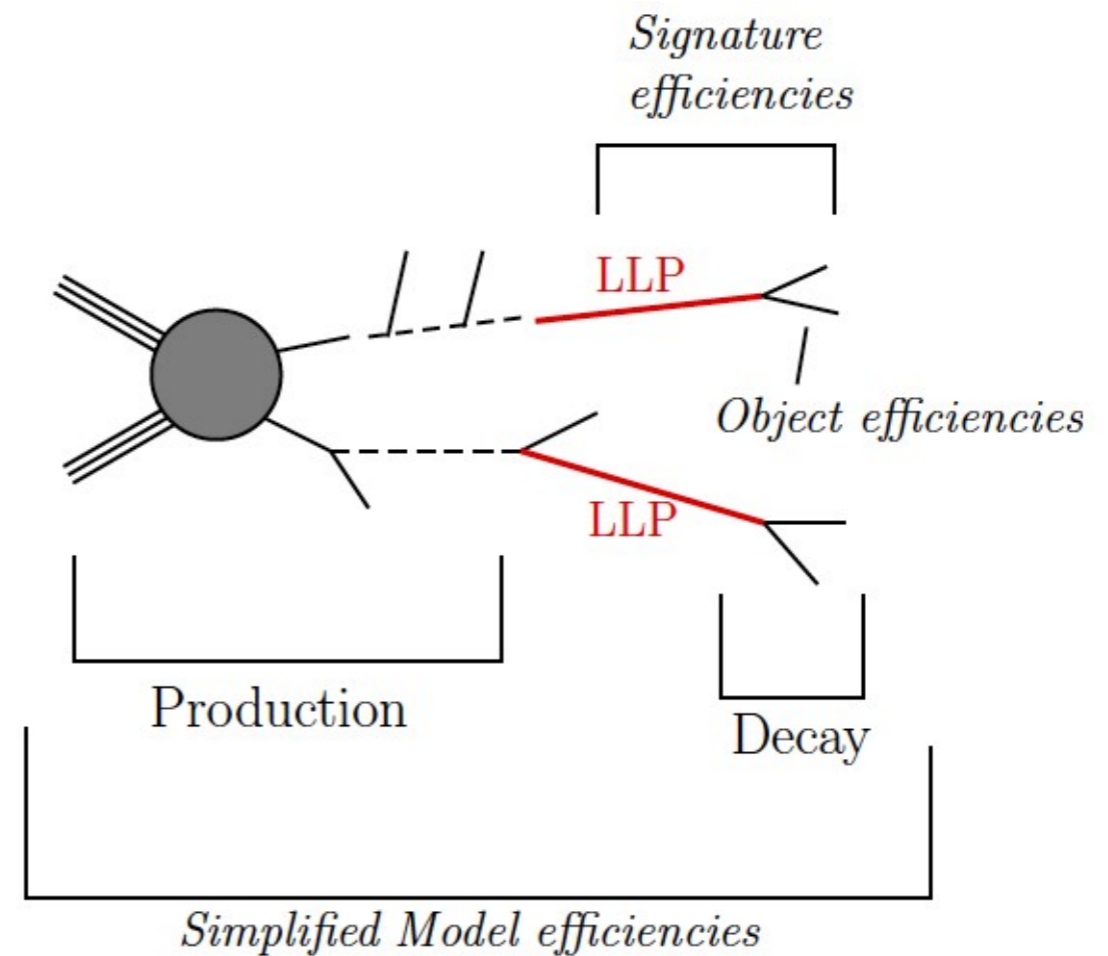
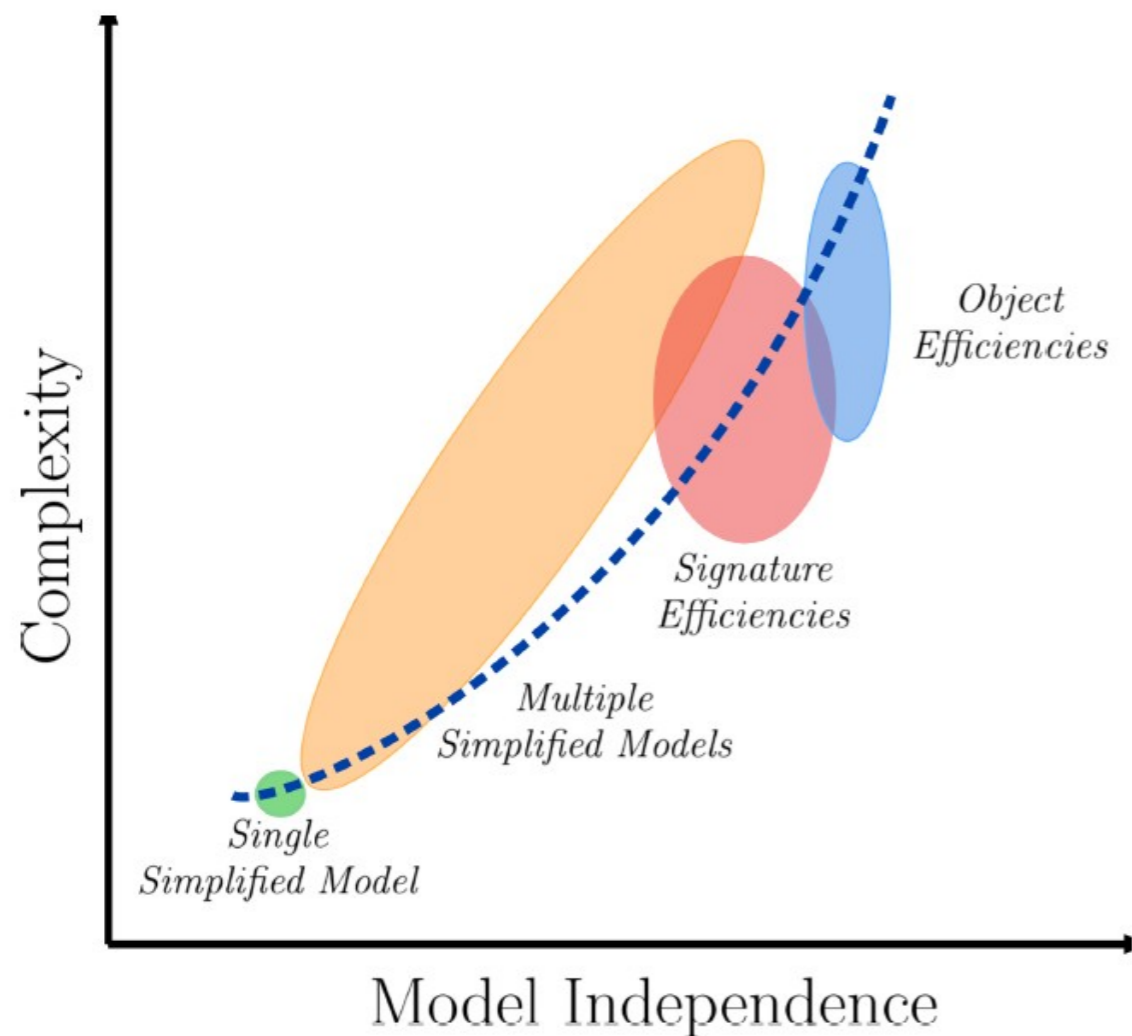
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- Efficiencies for constructing relevant LLP objects can be provided in many ways:

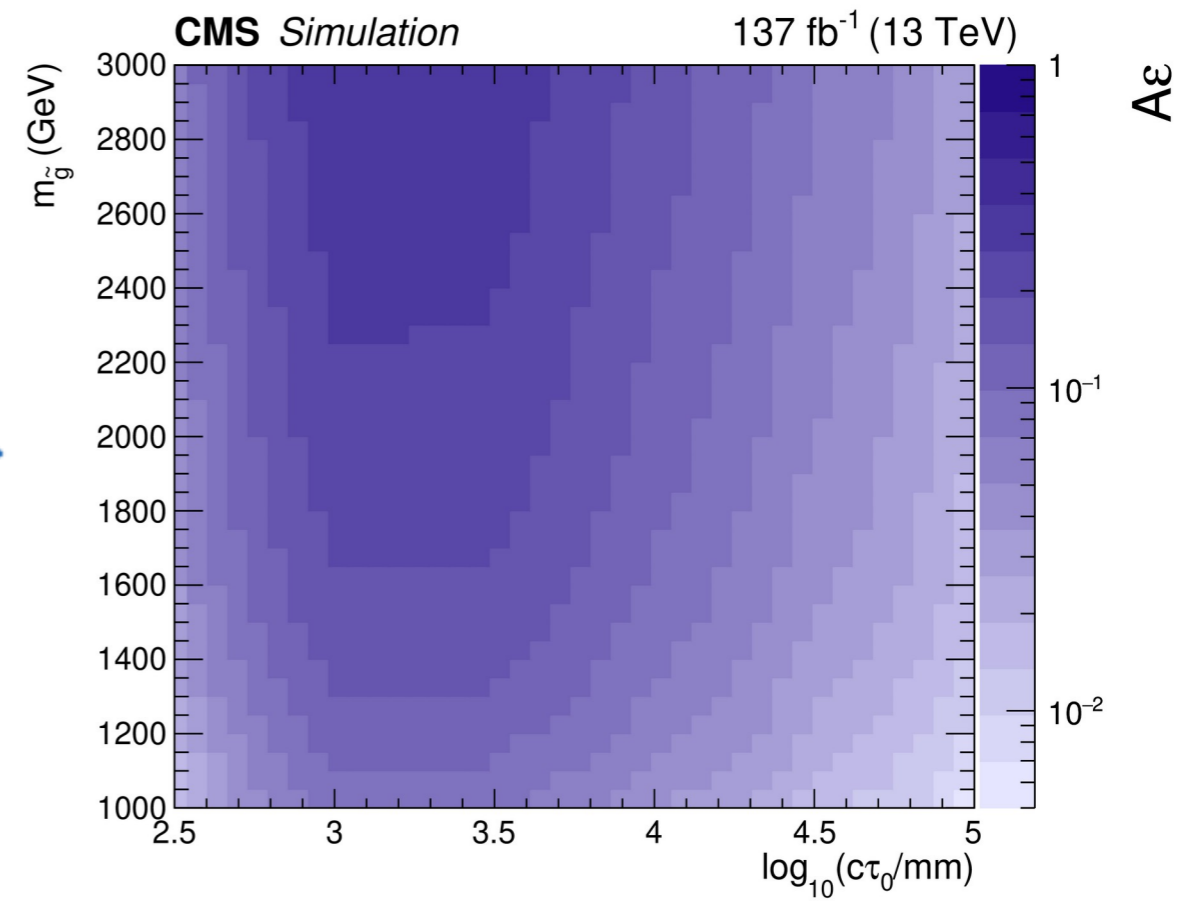
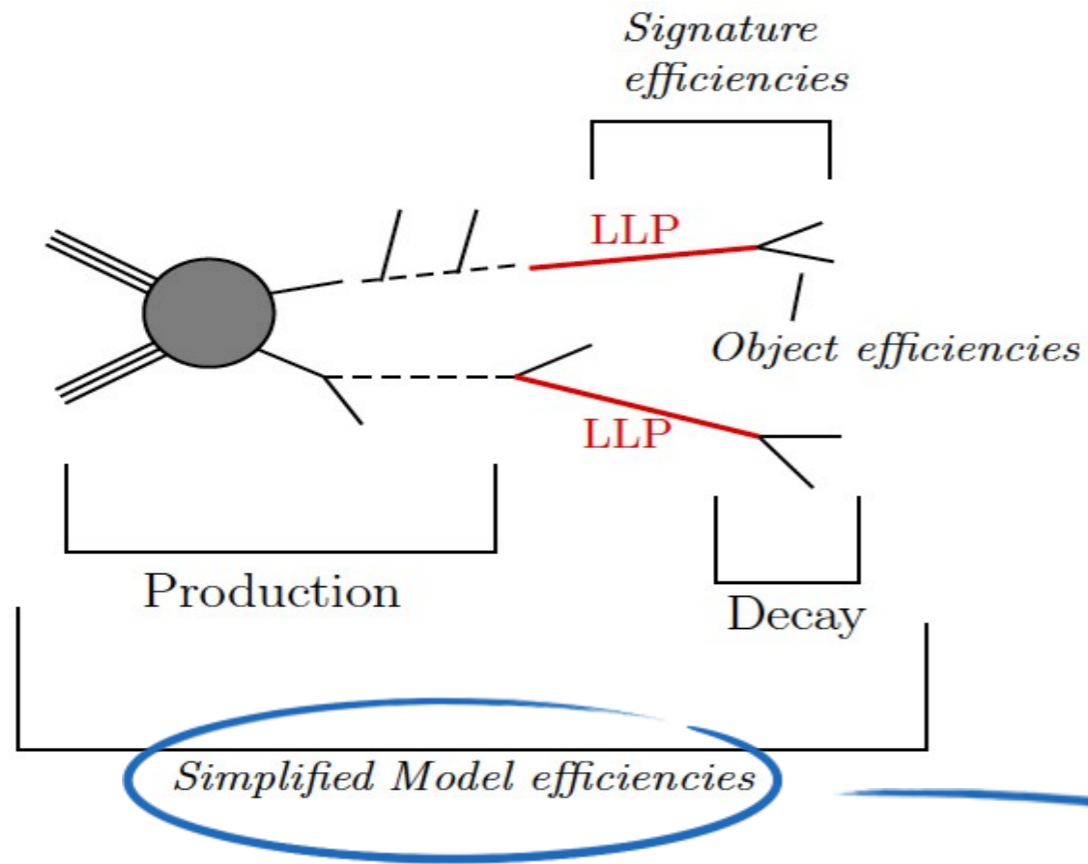
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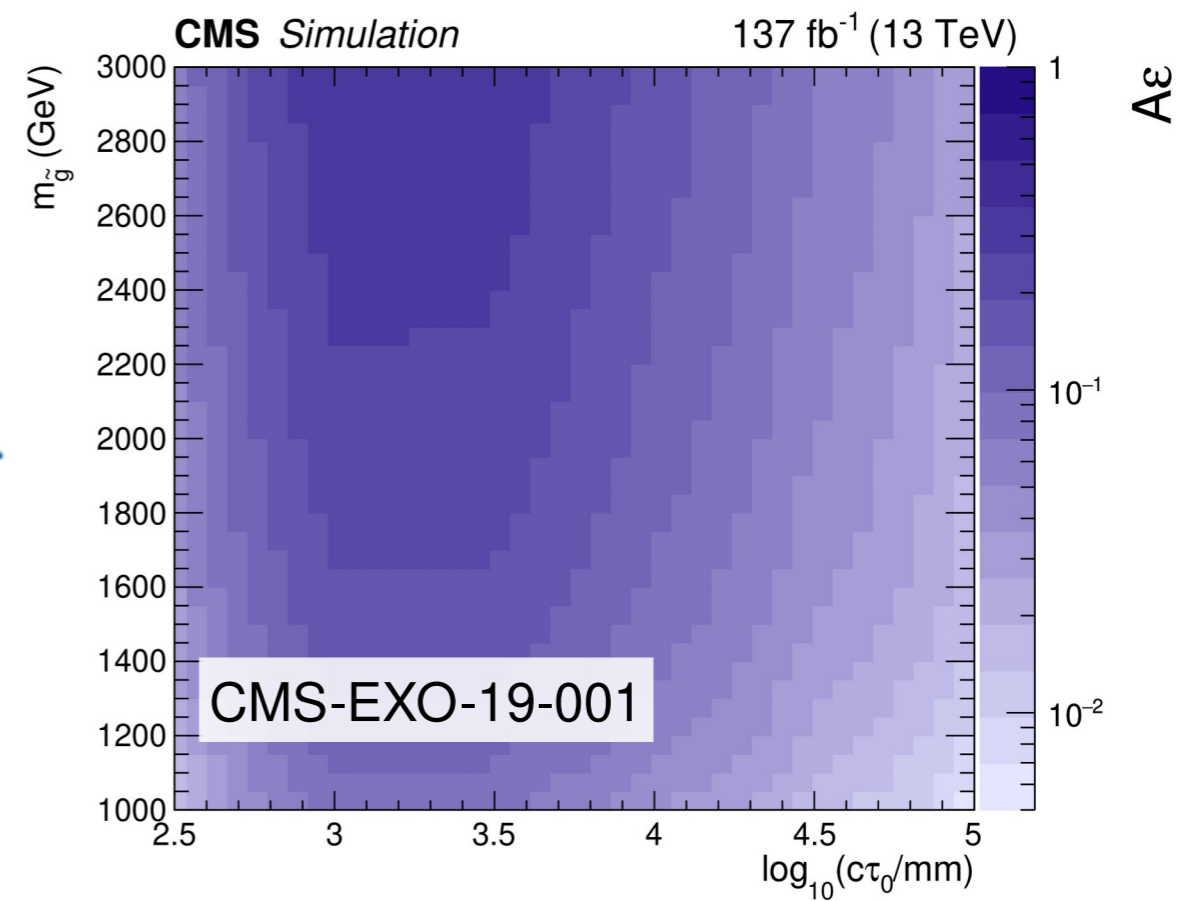
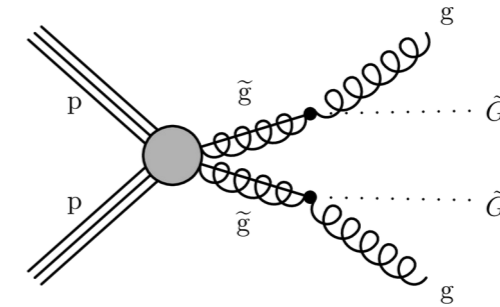
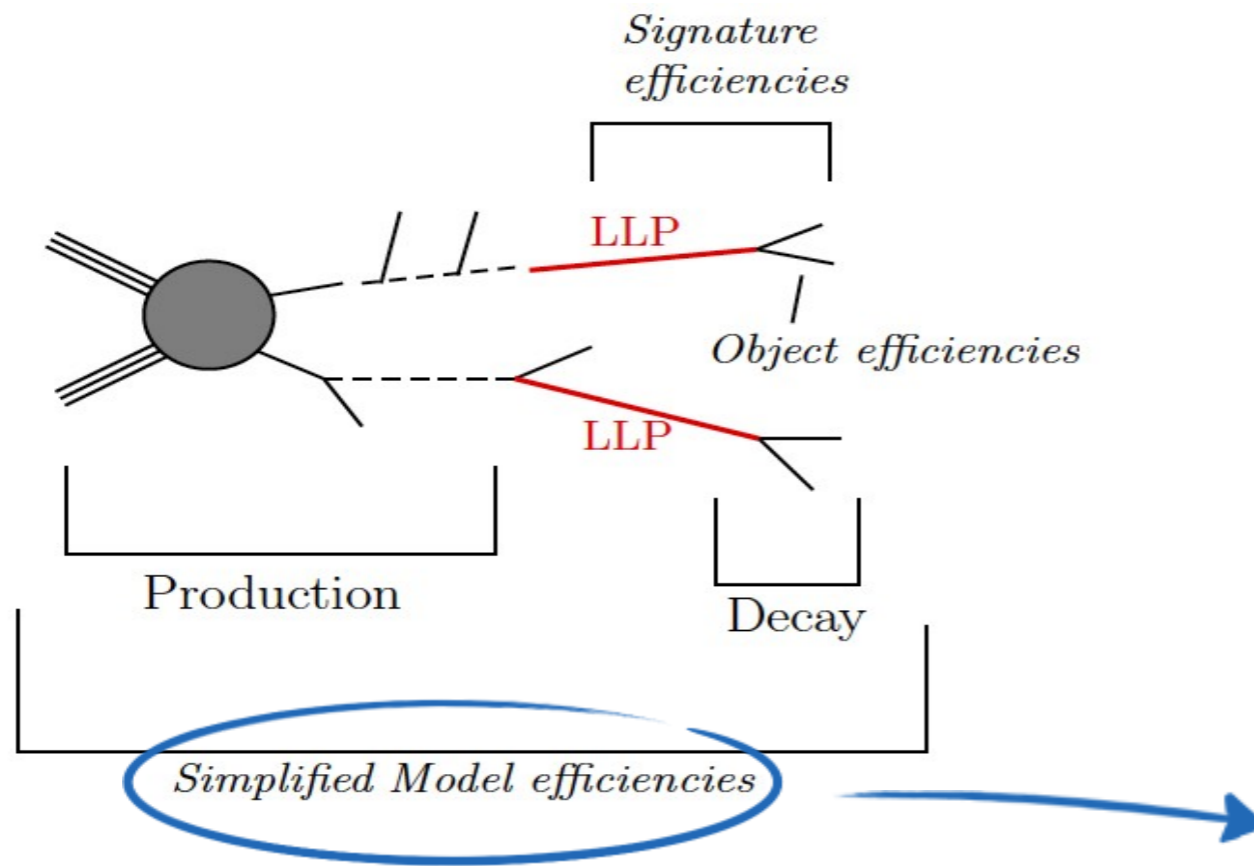
→ for a detailed discussion see the *Reinterpretation and LLP White Papers* (2003.07868 and 1903.04497)

# Simplified Model Results

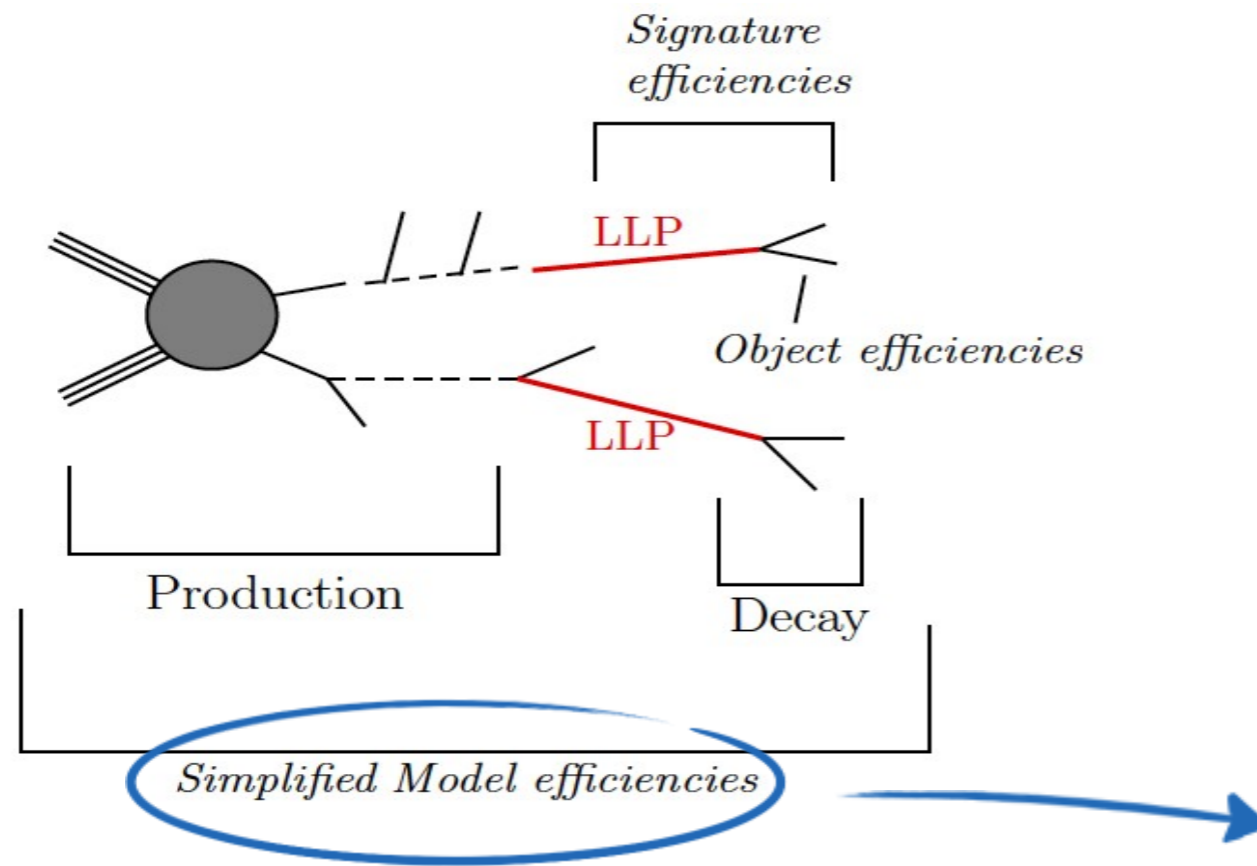




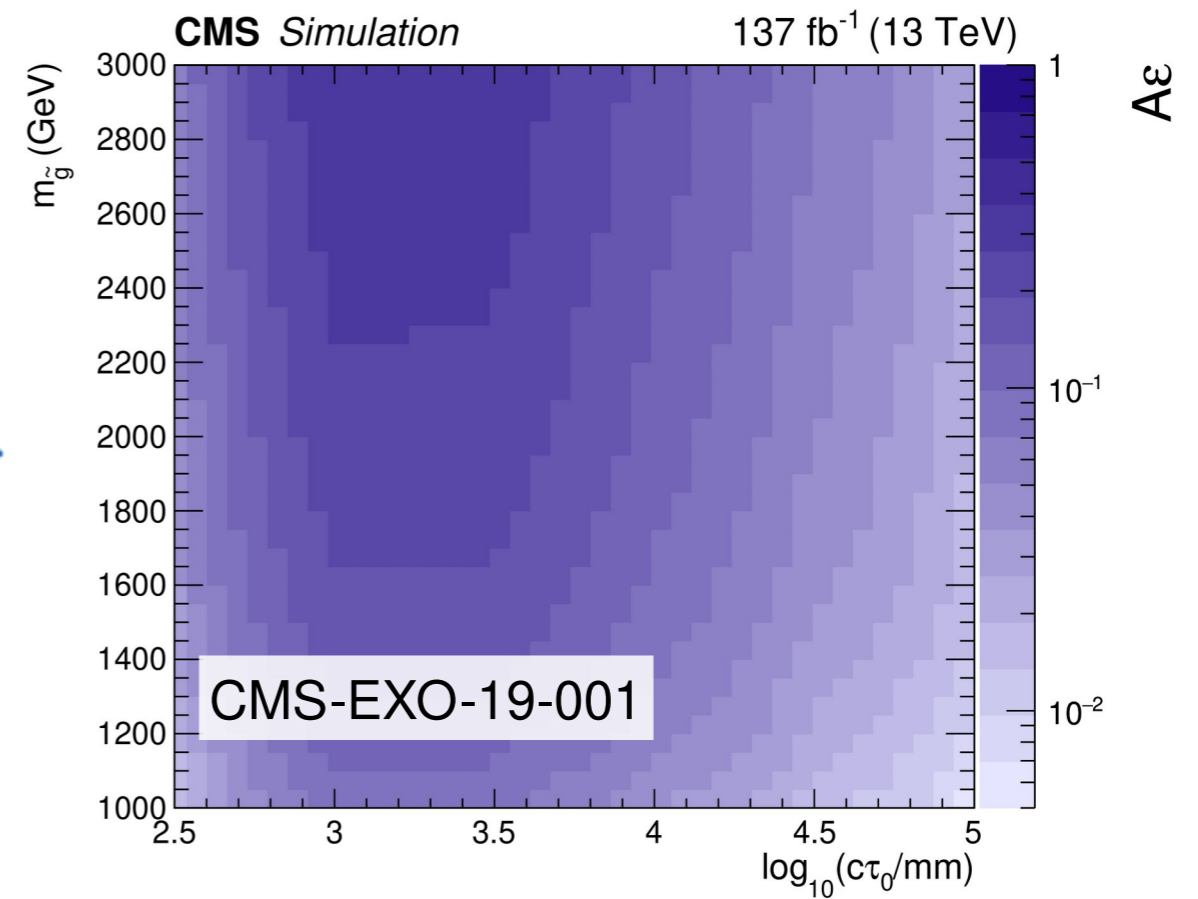
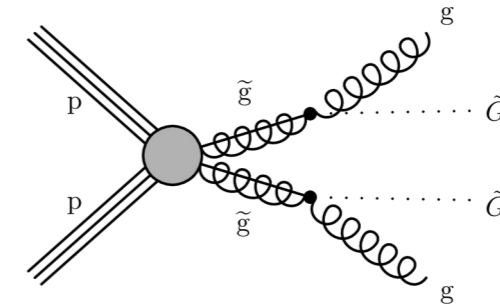
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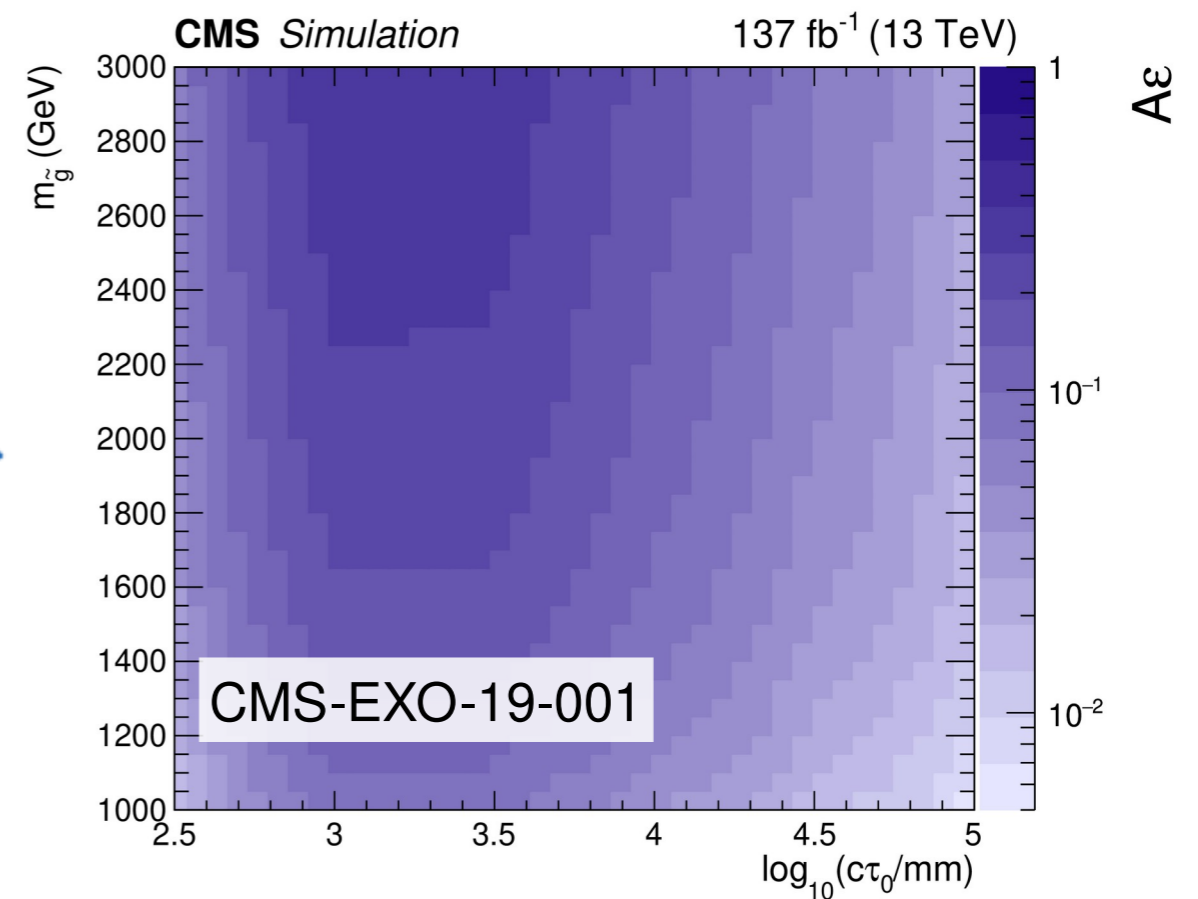
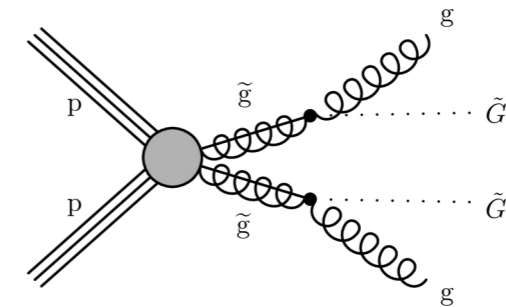
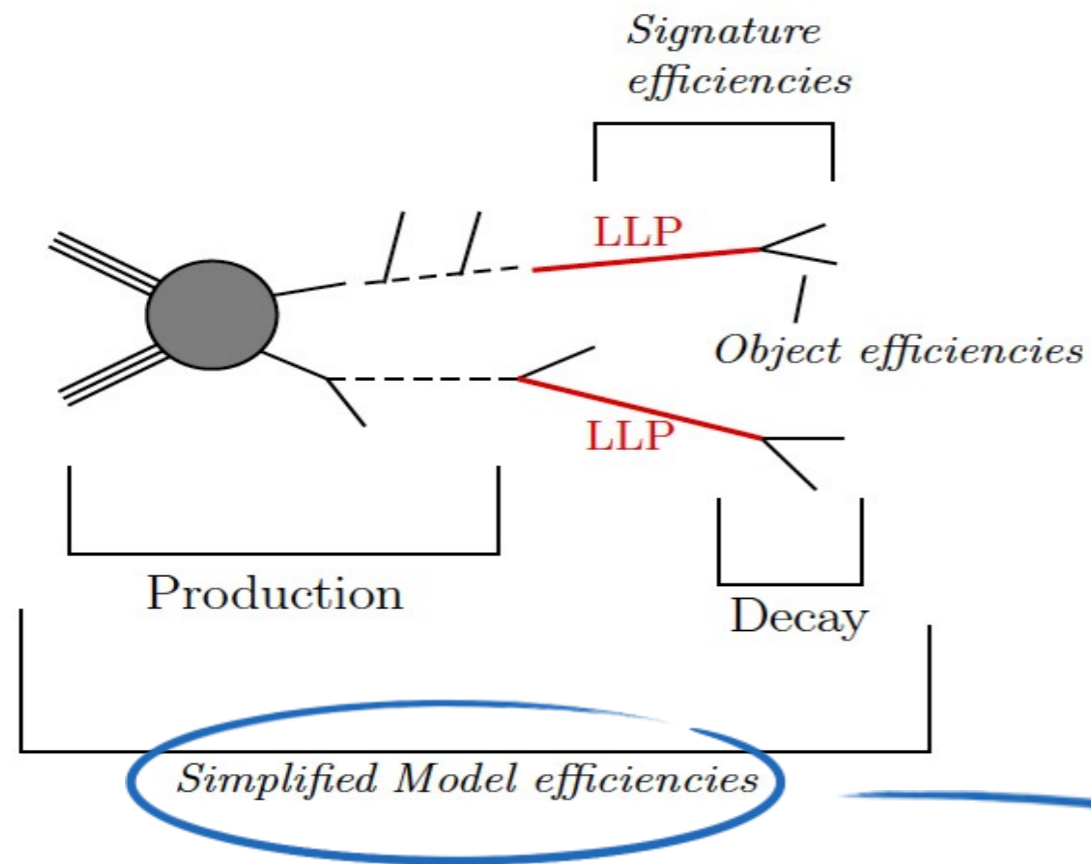
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- Found in almost all analyses
- Avoids simulating the event selection
- Model dependent



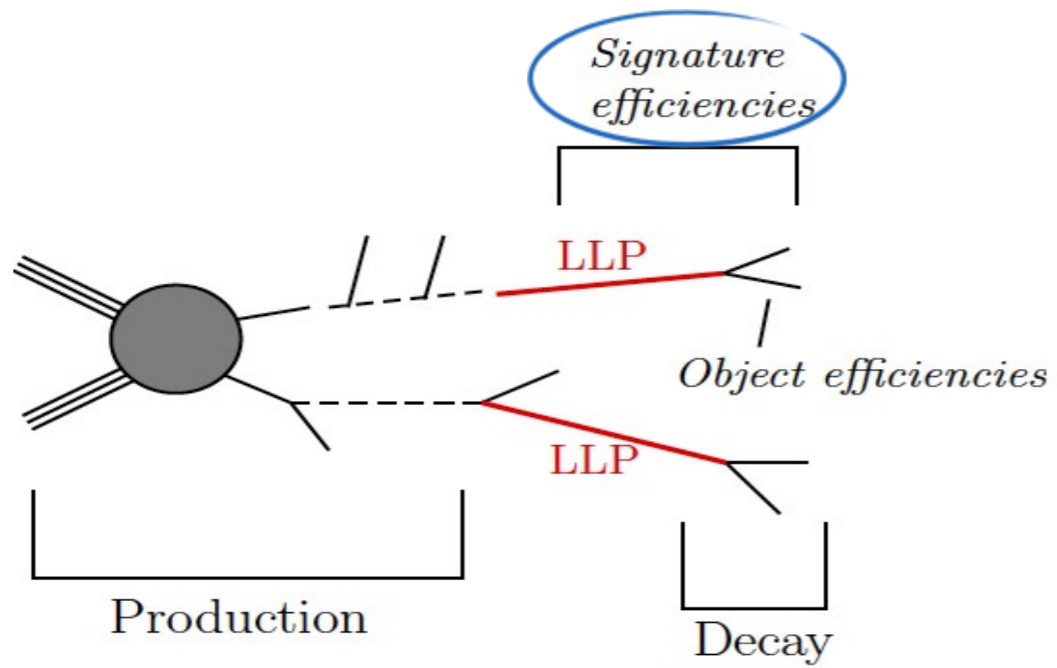
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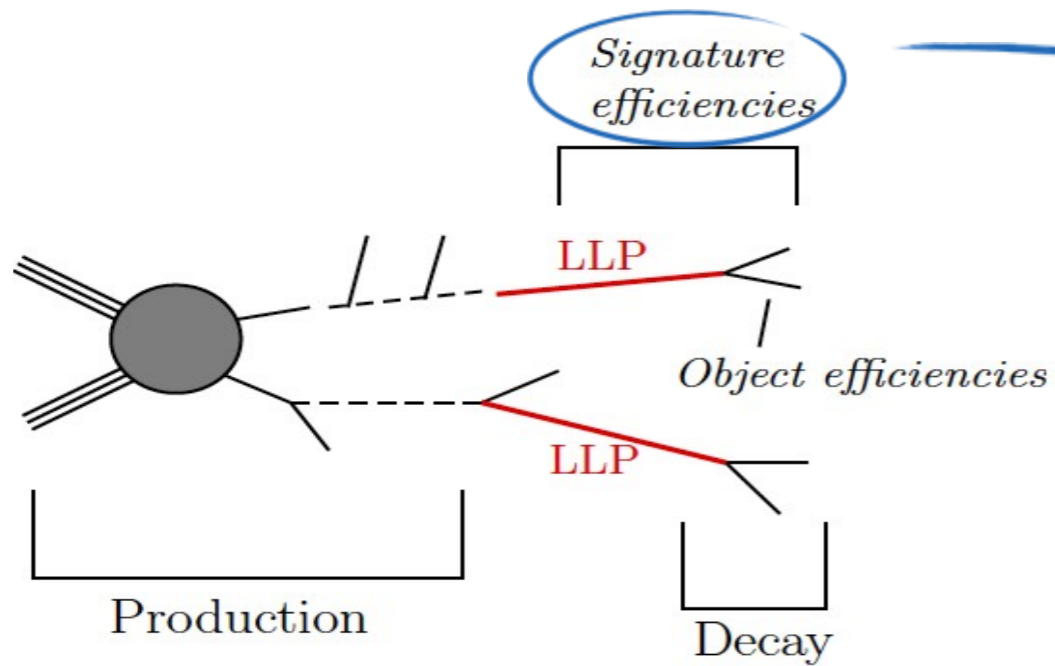
- Found in almost all analyses
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- Model dependent
- It can be useful if the analysis provides:
  - a good coverage of all relevant SMS parameters (e.g. non-zero LSP mass)
  - efficiencies for individual production/decay modes
  - data in digital format!

# Object/Signature Efficiencies

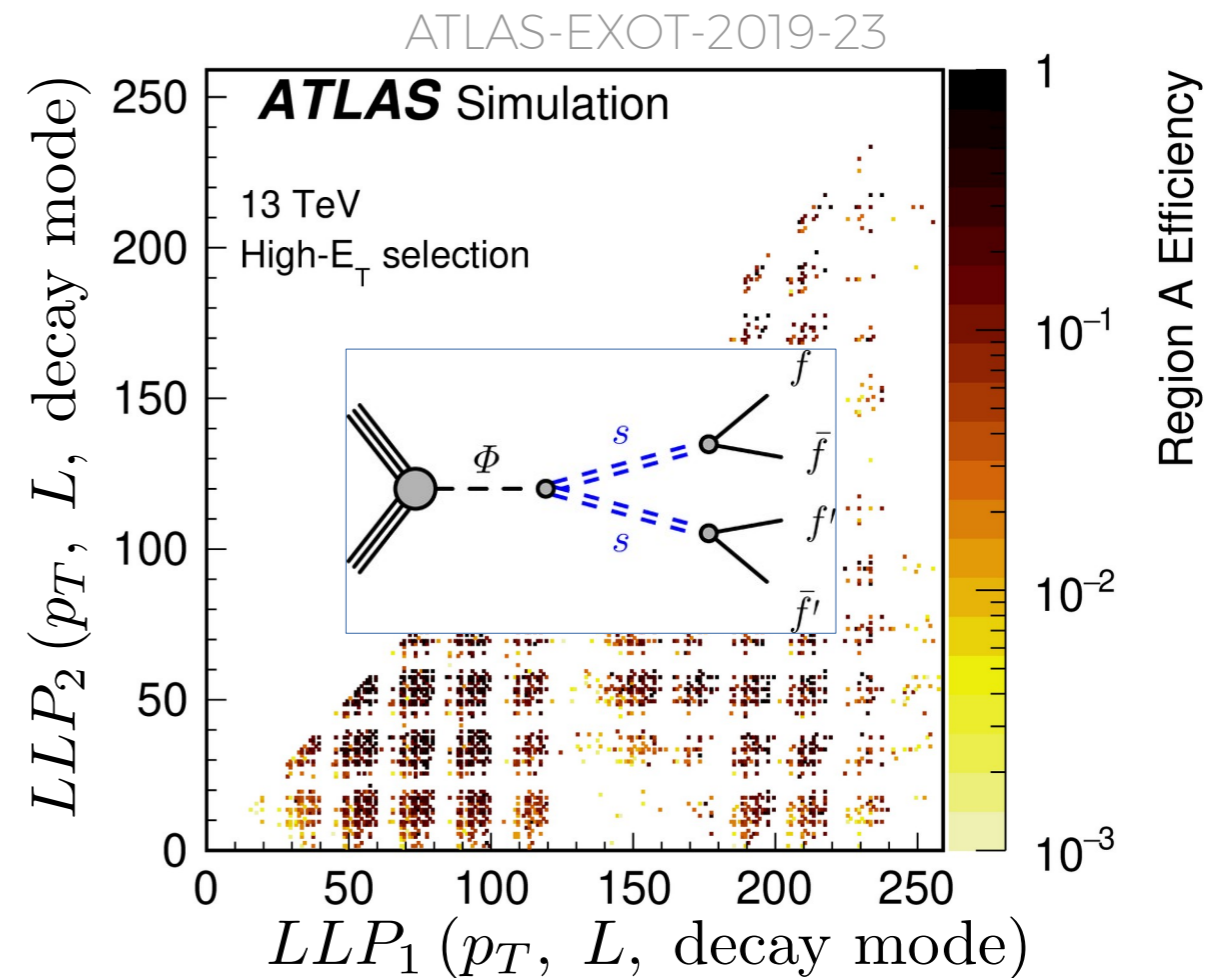
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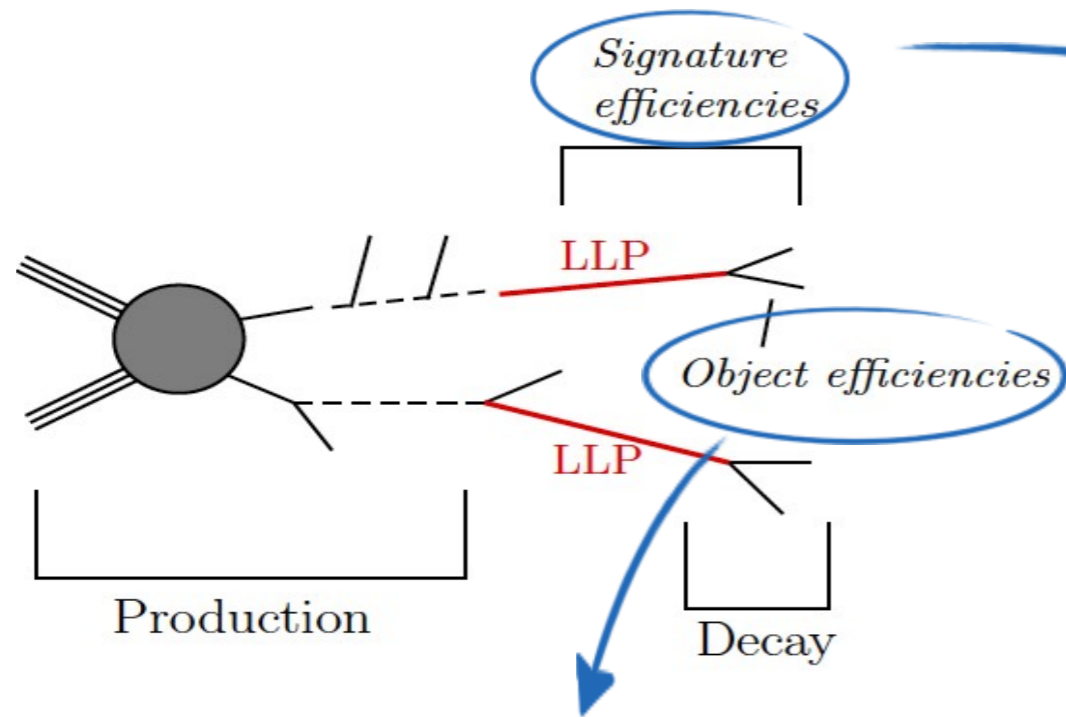


- Assumptions about the decay and/or production mode are folded in (some model bias)



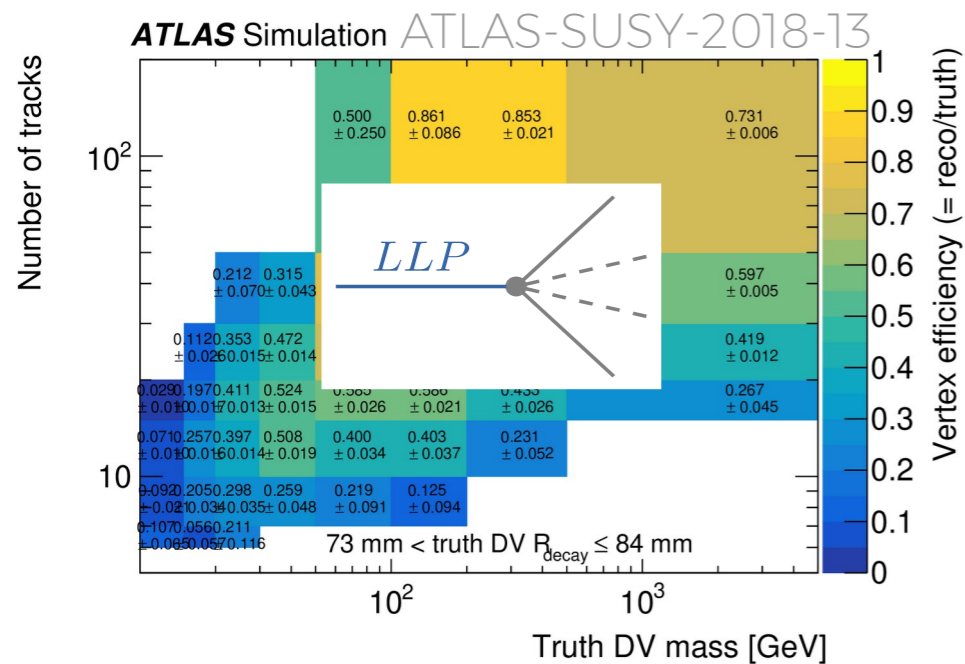


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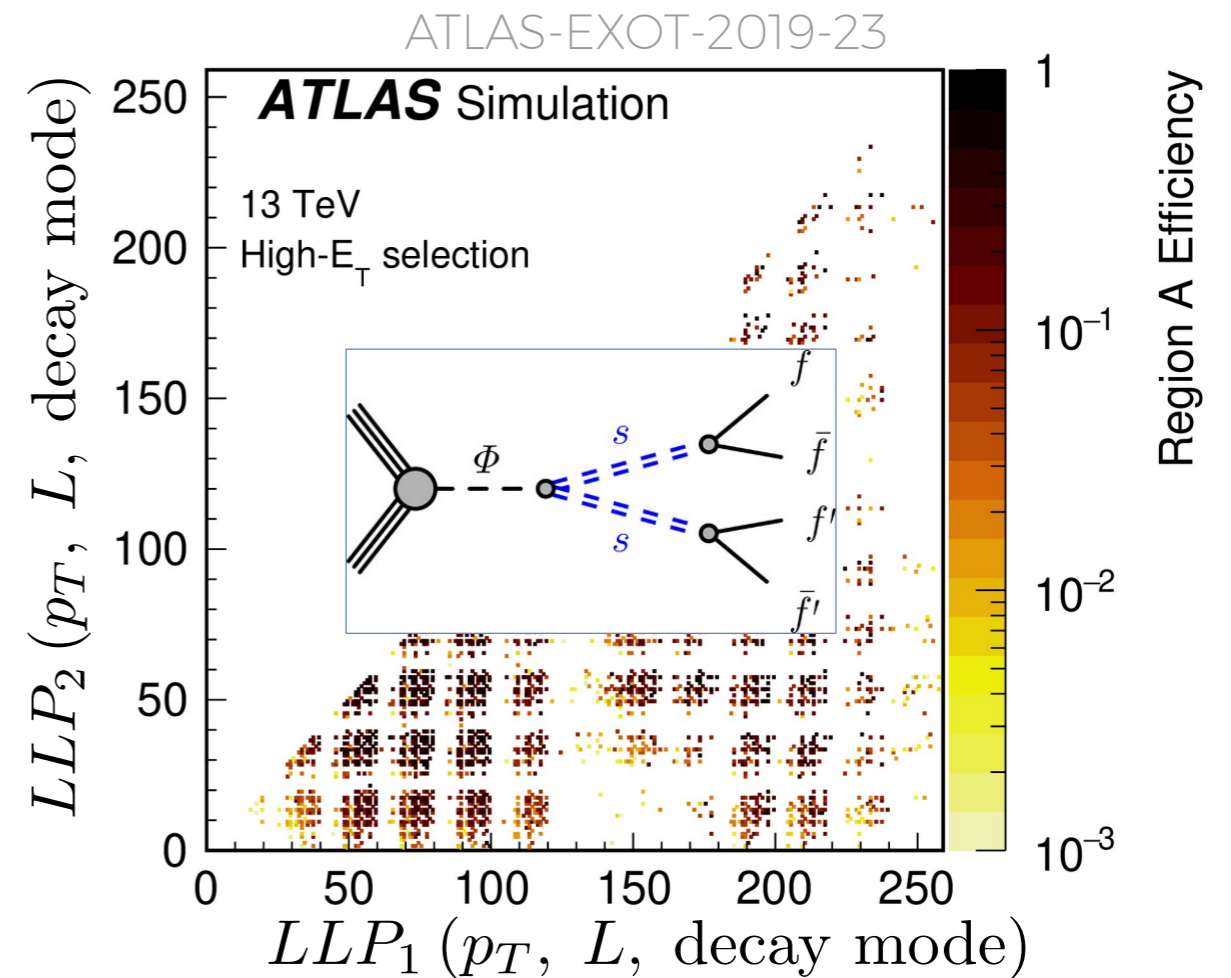


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- Functions of all the relevant (observable) parameters

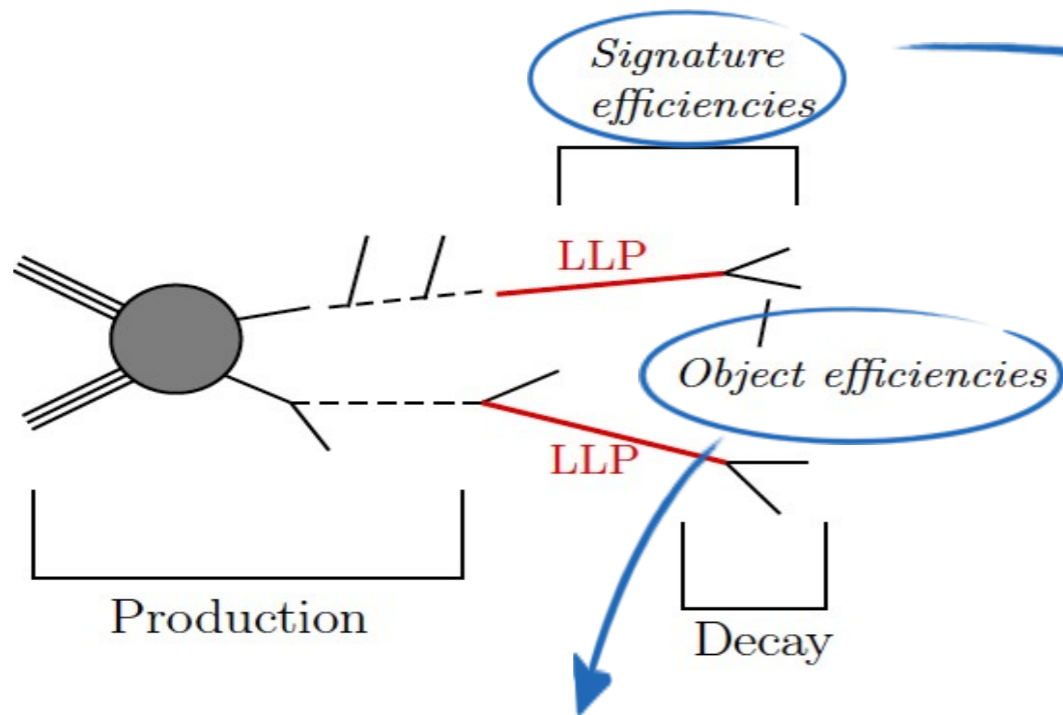


"minimal model bias"



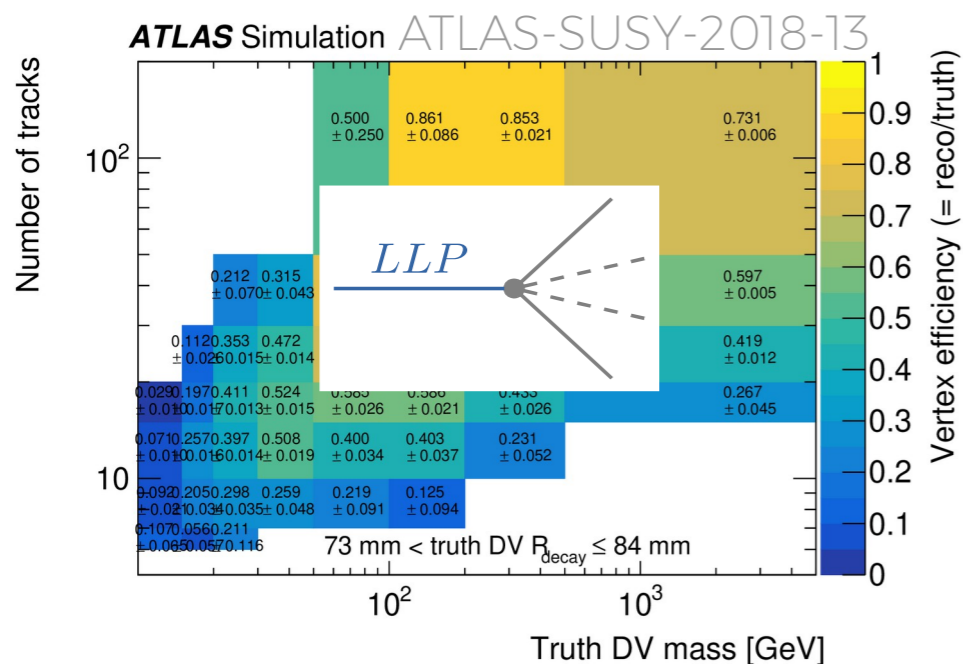


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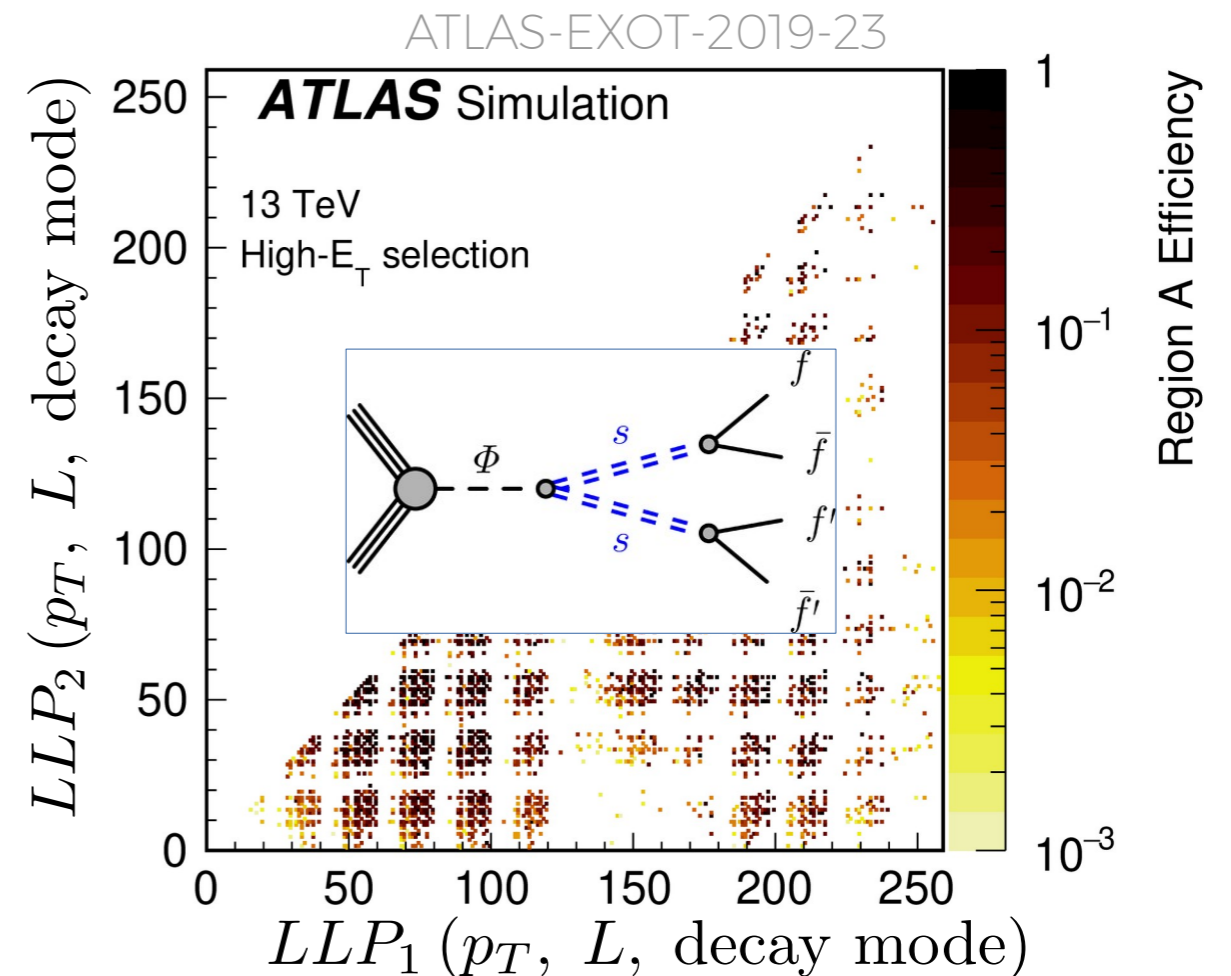


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- In addition to efficiencies, recasting guides/notes and pseudocode are extremely useful!

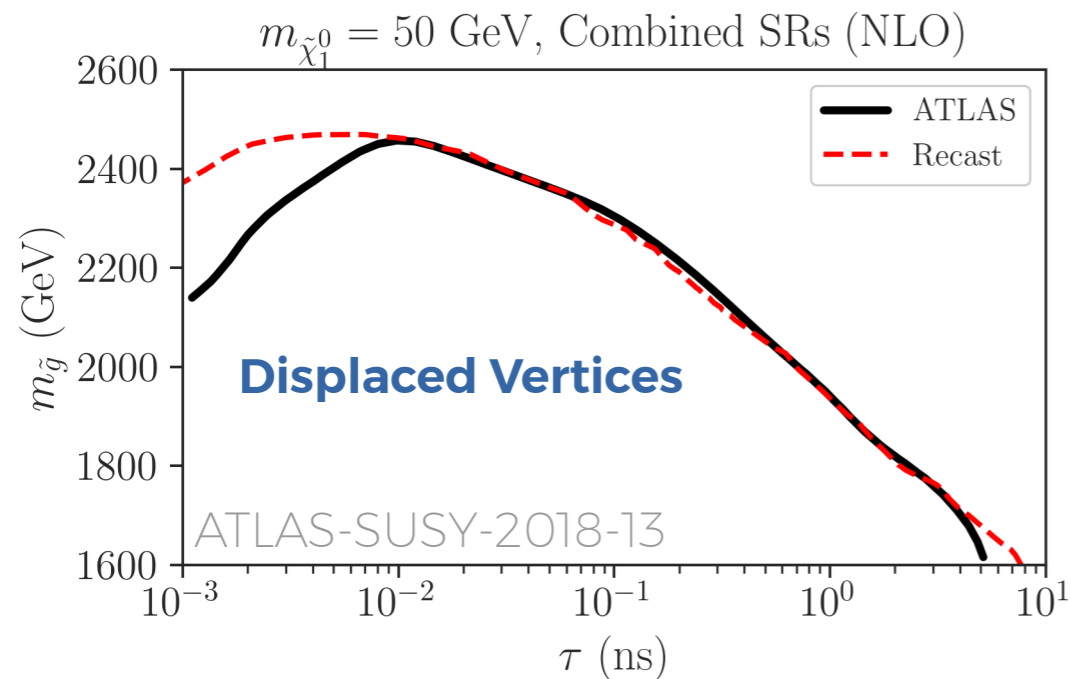
# “Real Life” Recasting

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- The usefulness of the available information can be measured by how well the official results can be reproduced outside the collaboration.
- Some examples:

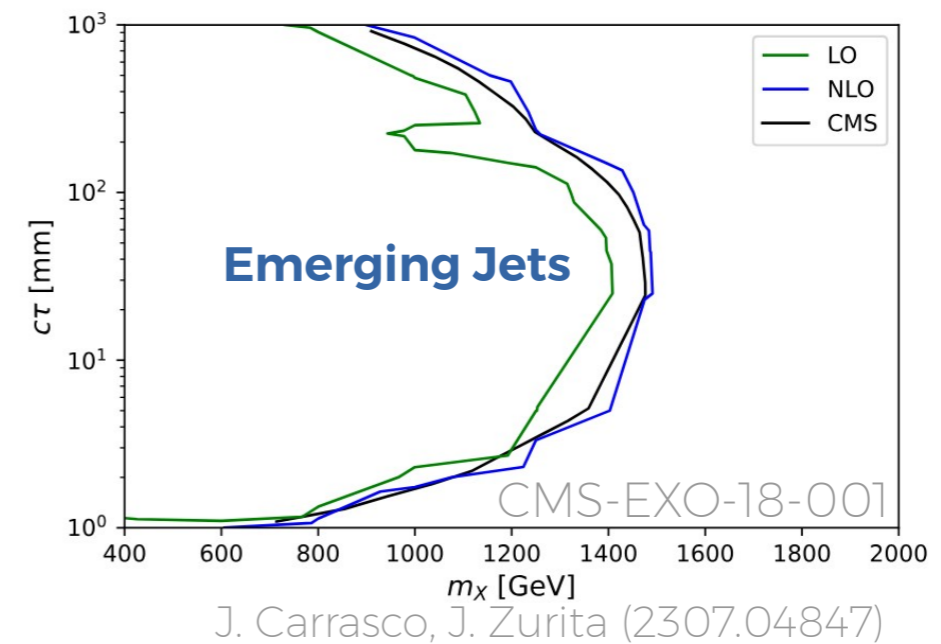
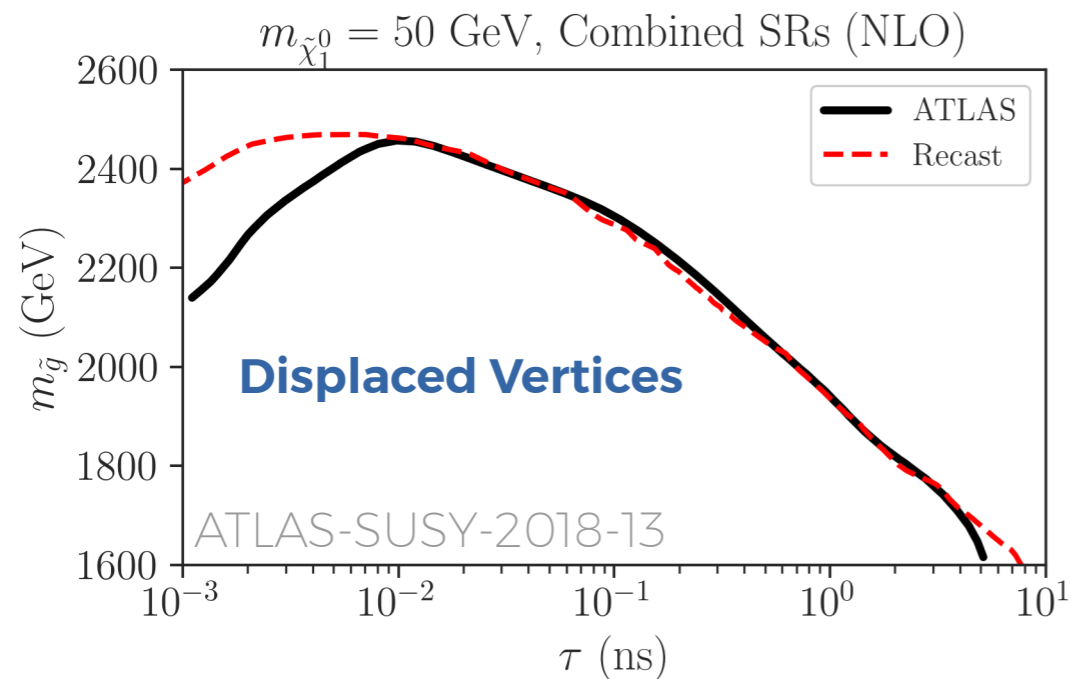
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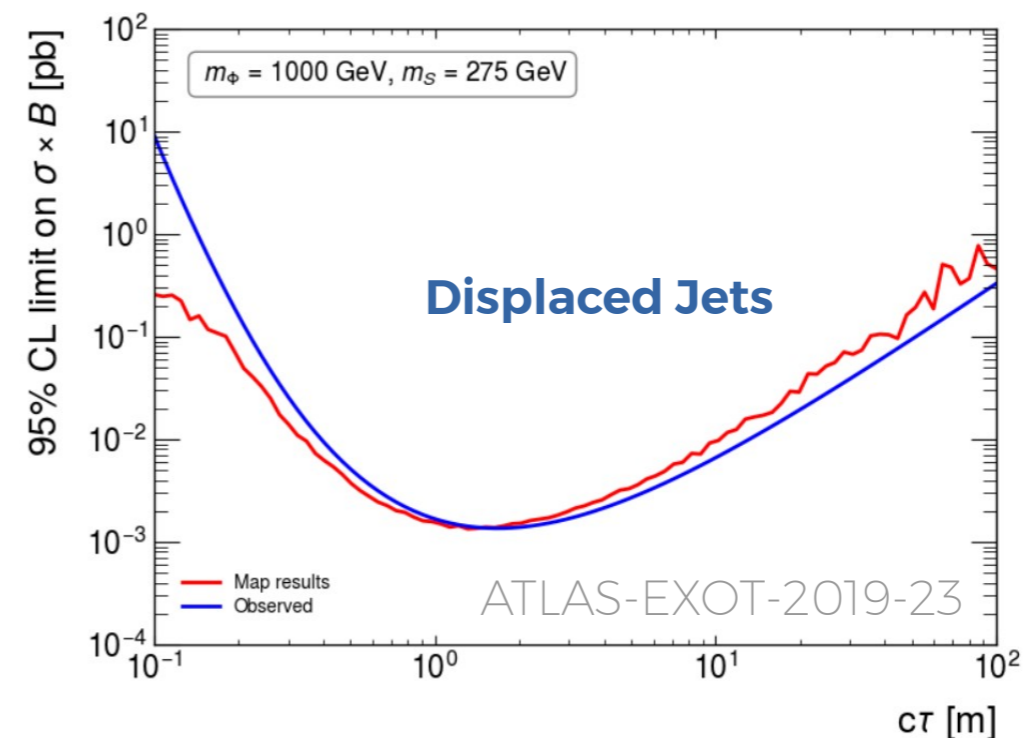
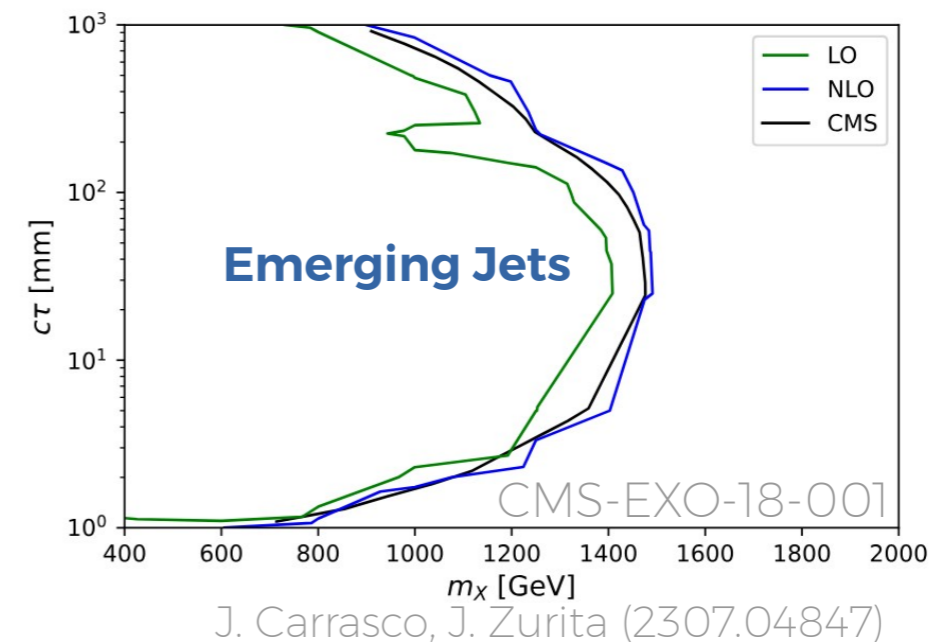
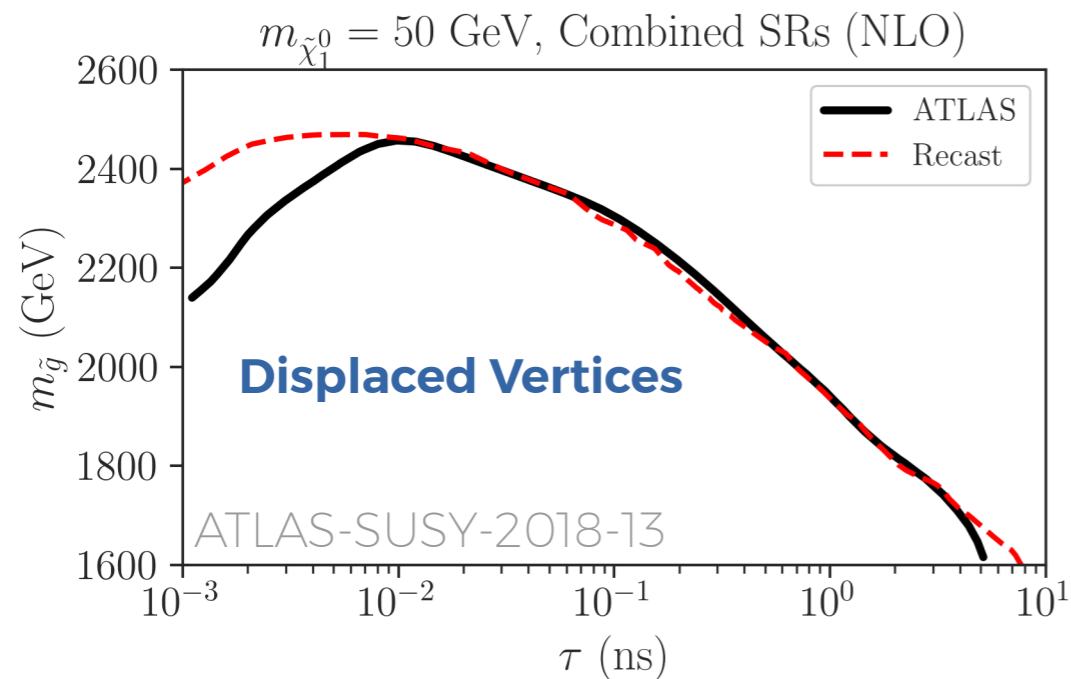
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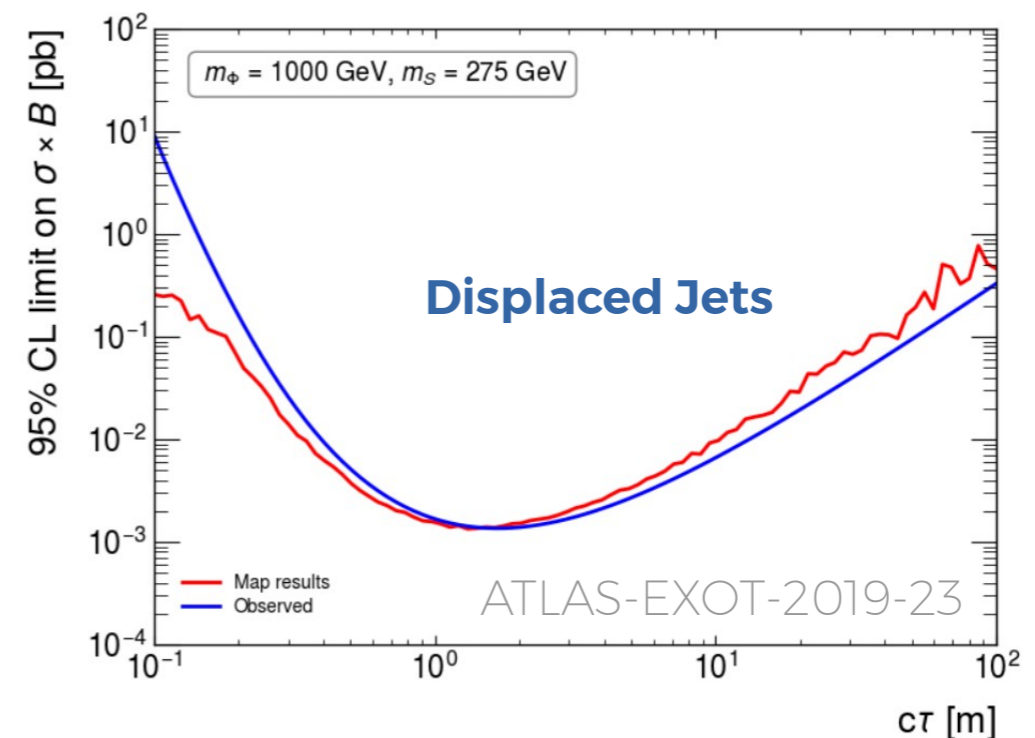
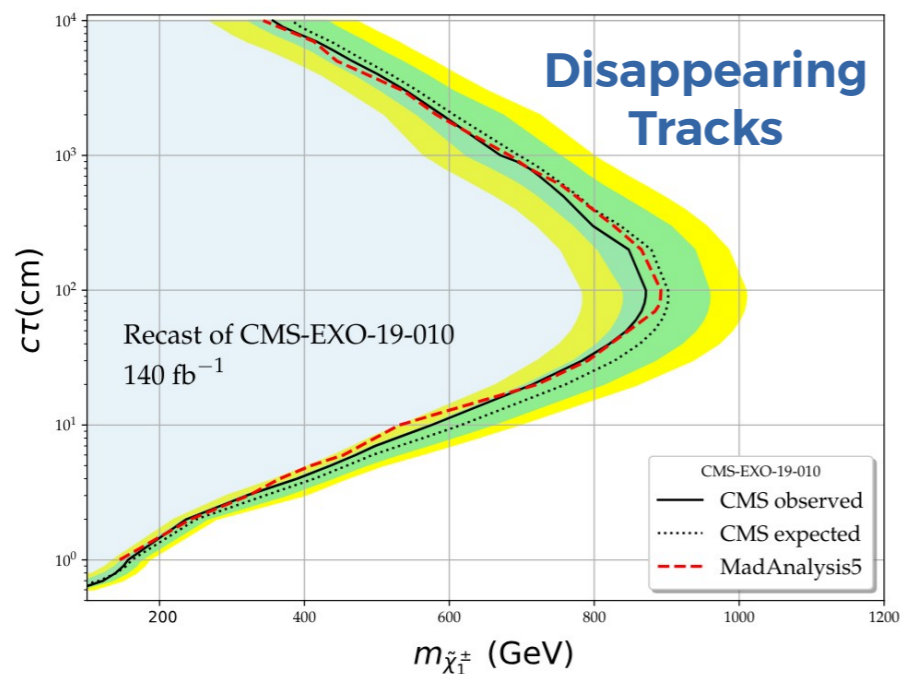
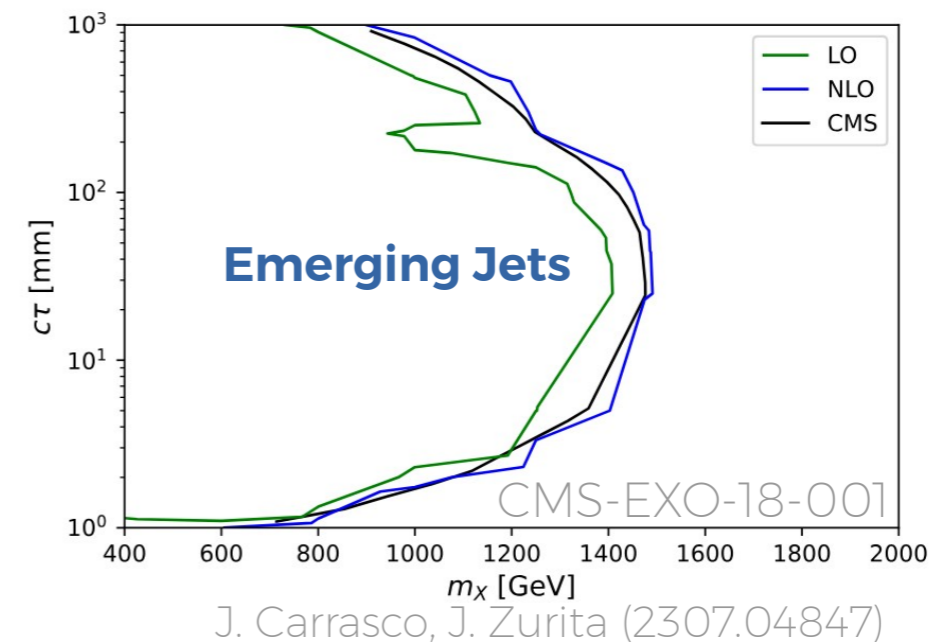
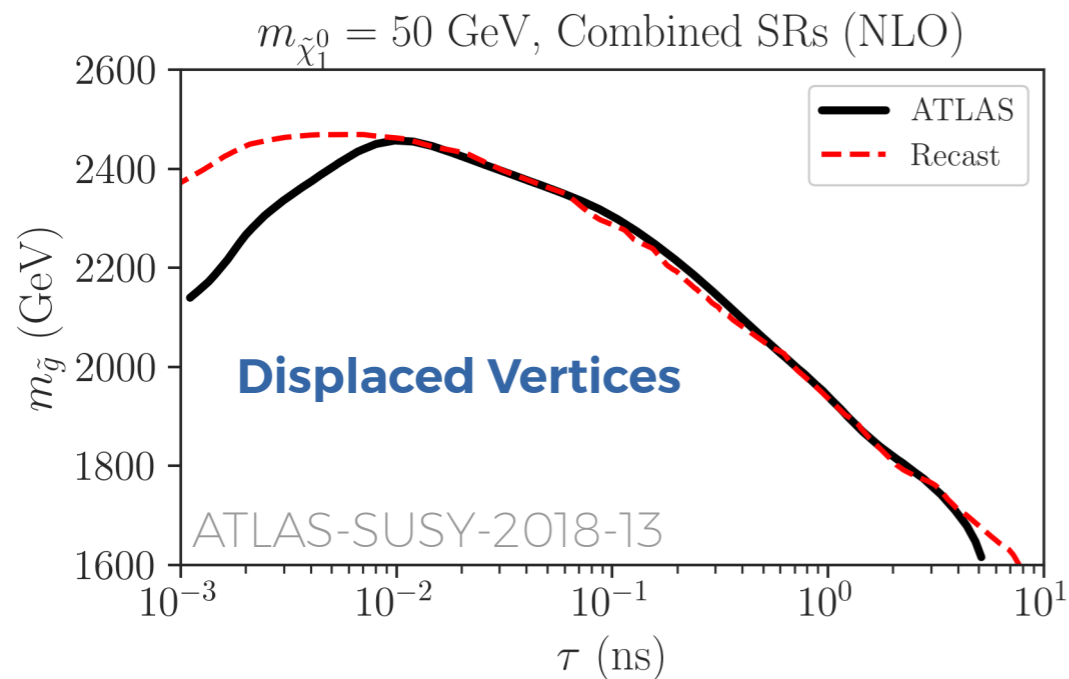
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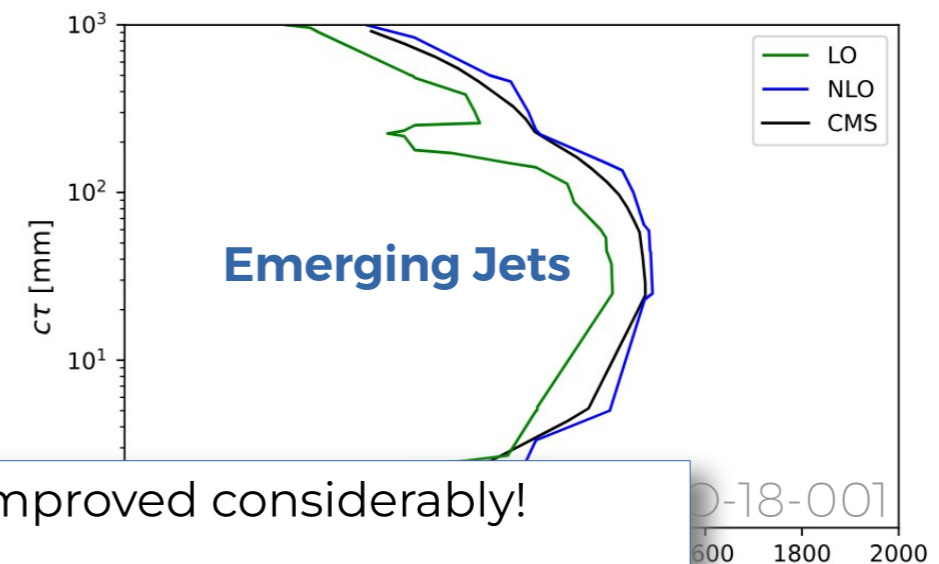
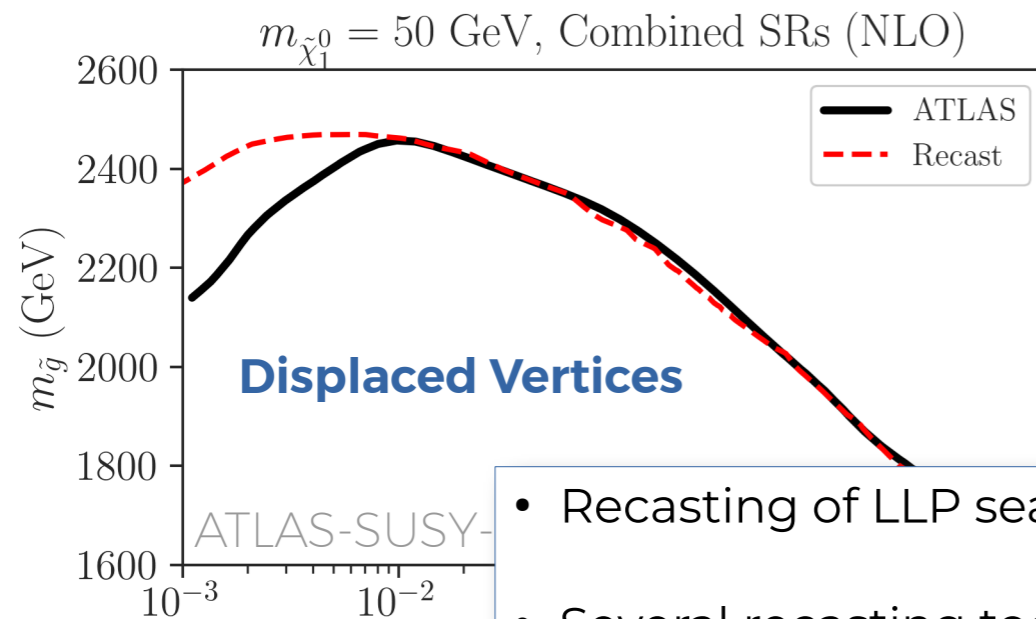
J. Araz, B. Fuks, M. Goodsell and M. Utsch (2112.05163)

L. Corpe, A. Goudelis, T. Chehab – LLP13 Workshop

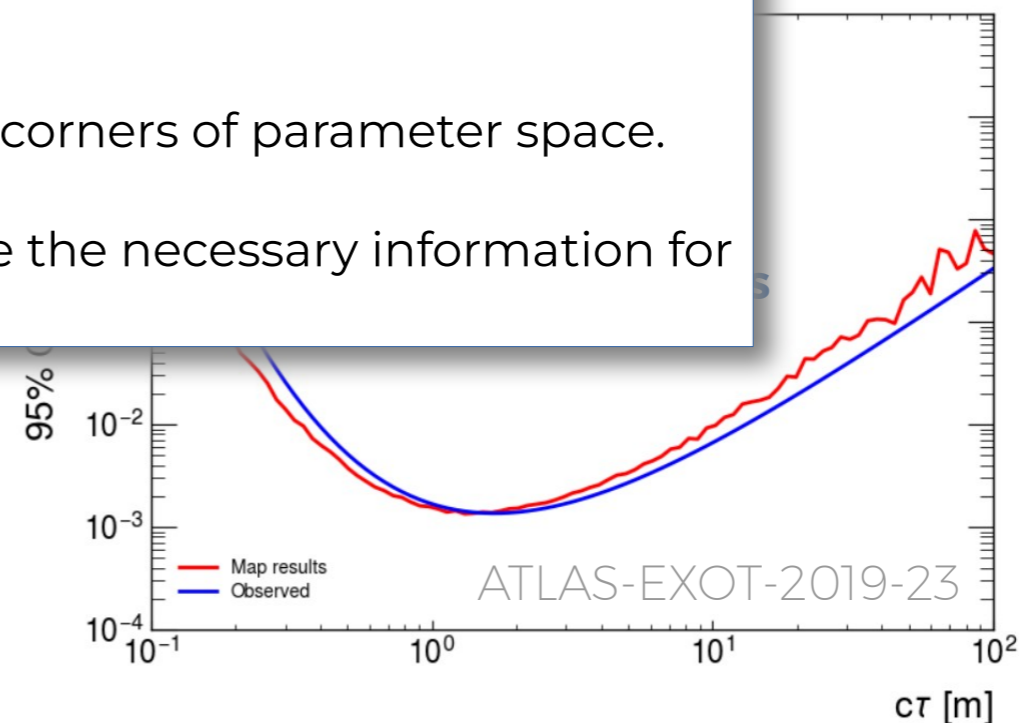
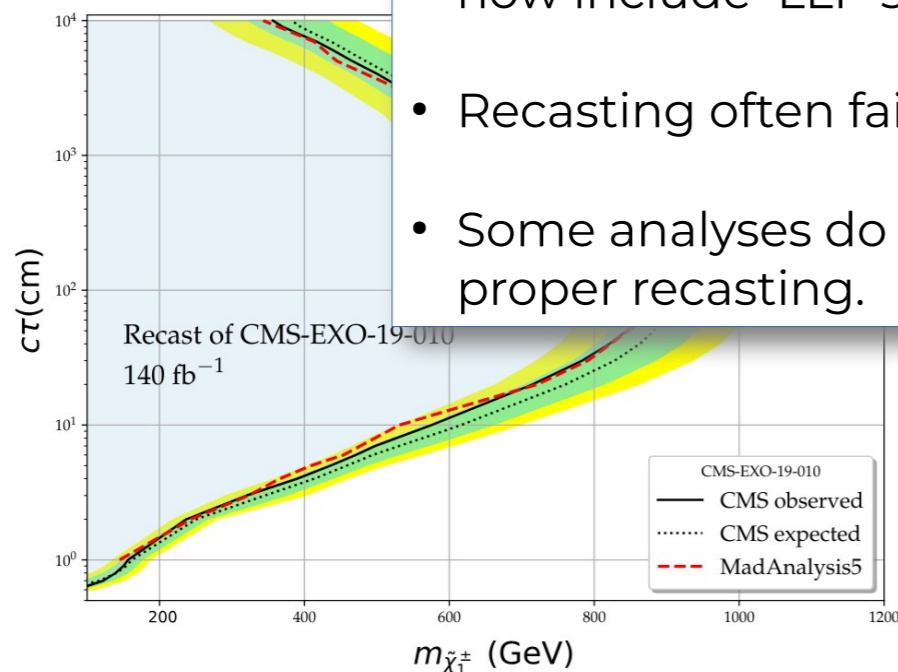


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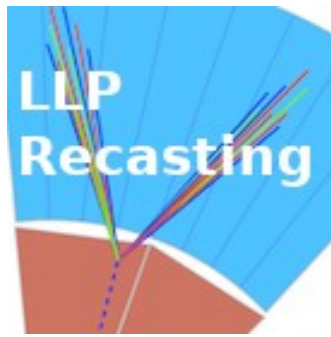
- Recasting of LLP searches has improved considerably!
- Several recasting tools (MadAnalysis, CheckMATE, SModelS) now include LLP searches.
- Recasting often fails at some corners of parameter space.
- Some analyses do not provide the necessary information for proper recasting.



# LLP Recasting Repository

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- Recasting repo @ GitHub: [github.com/llprecasting/recastingCodes](https://github.com/llprecasting/recastingCodes)
  - contains most of the recasting code for the LLP searches mentioned here



## LLP Recasting Repository

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This repository holds example codes for recasting long-lived particle (LLP) searches. The code authors and repository maintainers are not responsible for how the code is used and the user should use discretion when applying it to new models.

### Adding your recasting code

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This is an open repository and if you have developed a code for recasting a LLP analysis, we encourage you to include it here. Please contact [llp-recasting@googlegroups.com](mailto:llp-recasting@googlegroups.com) and we will provide you with the necessary information for including your code.

### Repository Structure

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The repository folder structure is organized according to the type of LLP signature and the corresponding analysis and authors:

- [Displaced Vertices](#)
  - [13 TeV ATLAS Displaced Jets](#)
  - [13 TeV ATLAS Displaced Vertex plus MET by ALESSA](#)
  - [13 TeV ATLAS Displaced Vertex plus MET by GCottin](#)
  - [8 TeV ATLAS Displaced Vertex plus jets by GCottin](#)
- [CalRatio Displaced Jets](#)
  - [13 TeV ATLAS Displaced Jets in the calorimeter](#)
- [Emerging Jets](#)
- [Heavy Stable Charged Particles](#)
  - [13 TeV ATLAS HSCP - 139/fb](#)
  - [13 TeV ATLAS HSCP - 31.6/fb](#)
  - [8 TeV CMS HSCP](#)
- [Disappearing Tracks](#)

### Contributors 7





# Recasting LLP Searches - Physics Impact

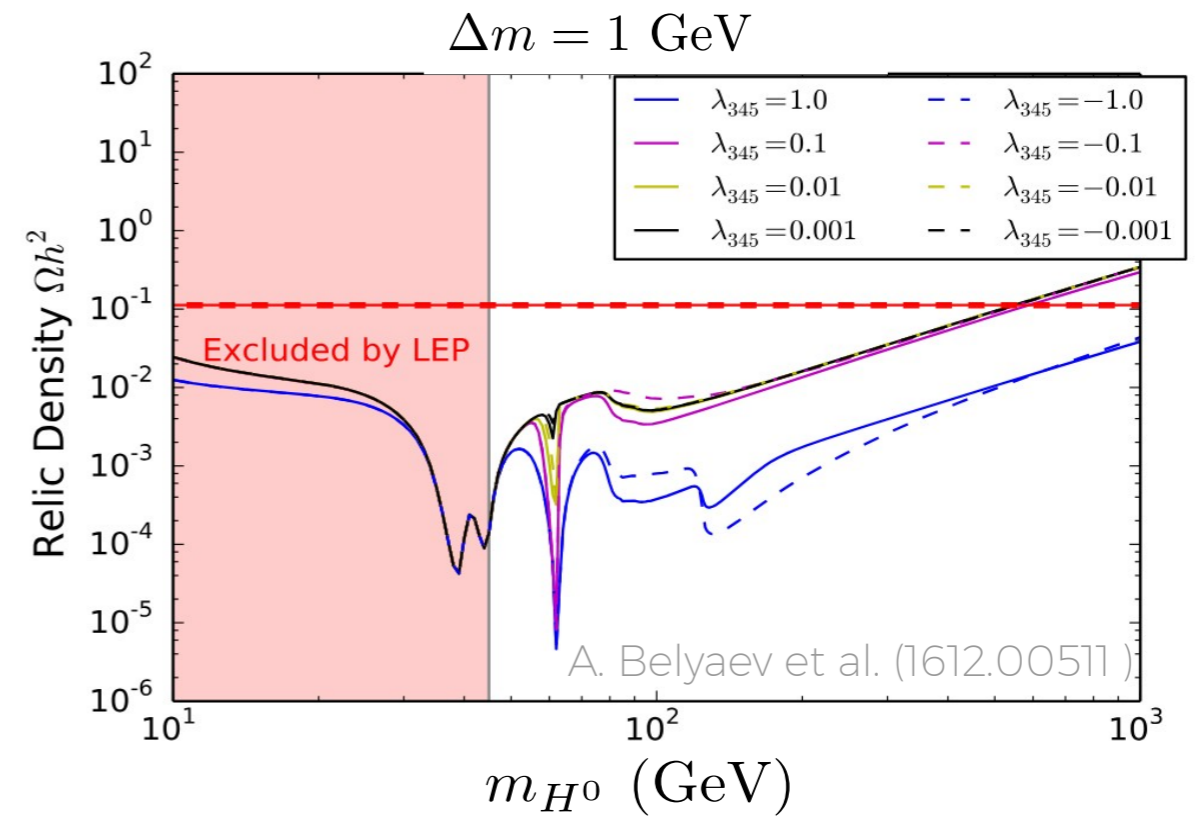
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(highly biased selection)

# Inert 2HDM (IDM)

- 2HDM +  $Z_2$ -Parity

- Sub-TeV masses can generate the correct relic density if there is a high mass compression.



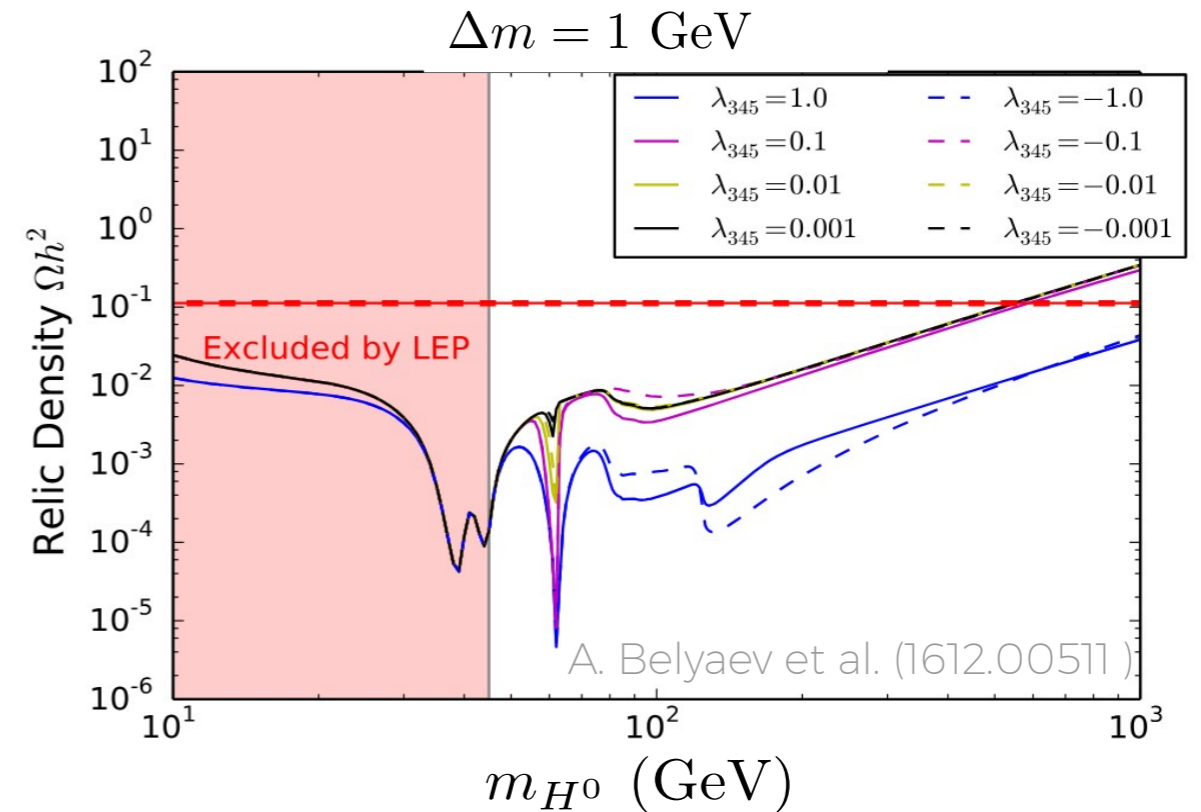
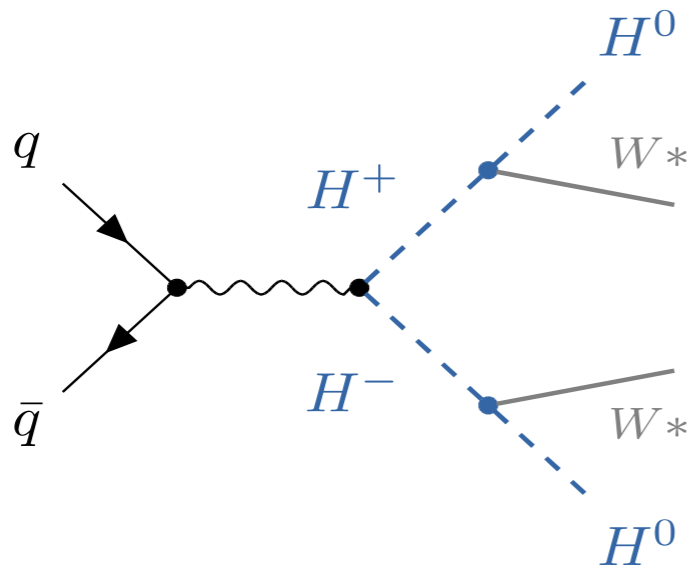
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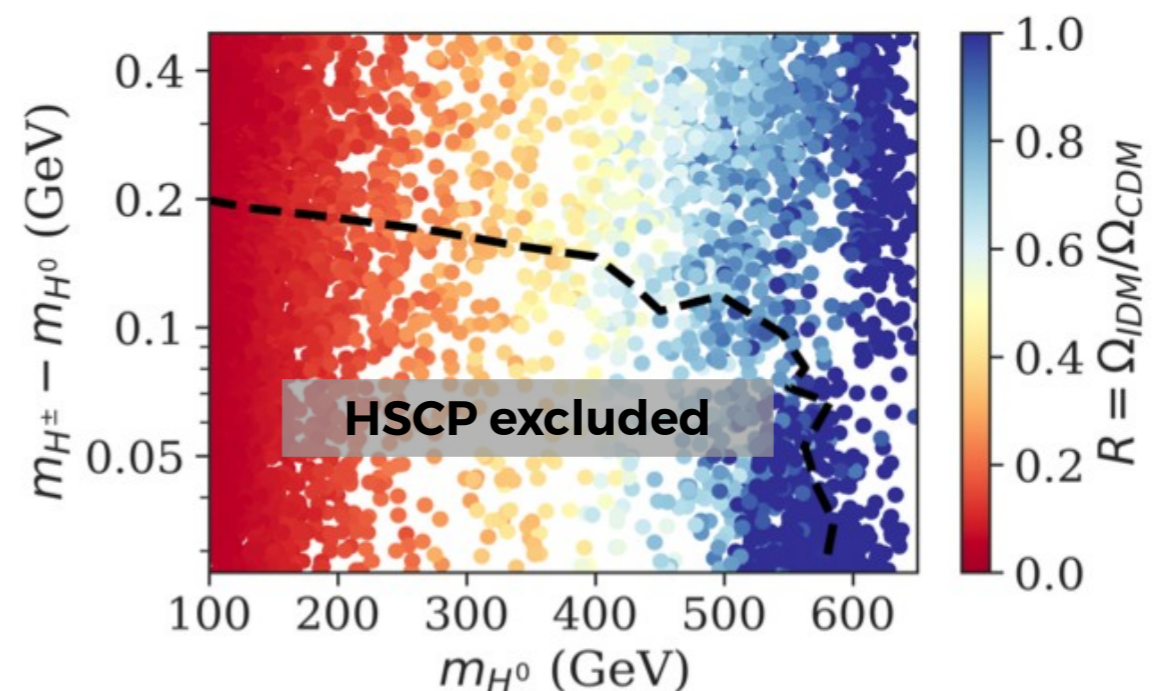
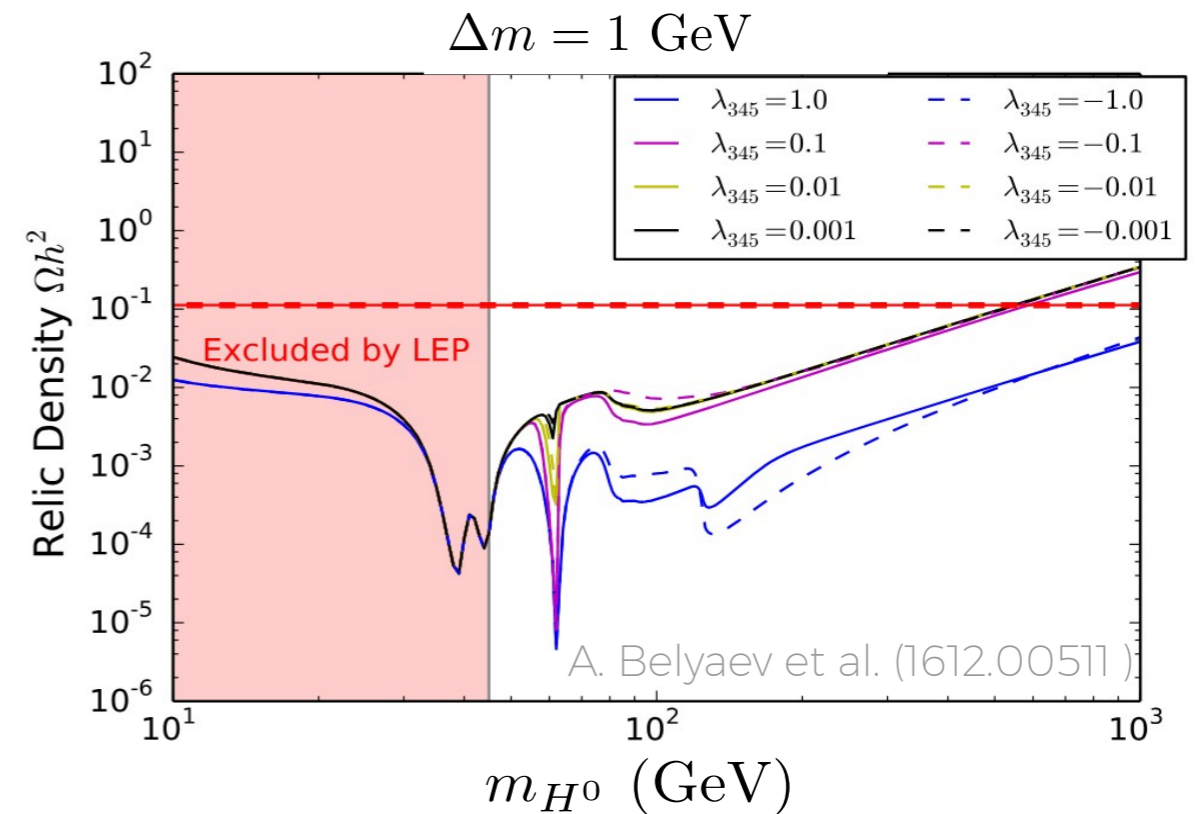
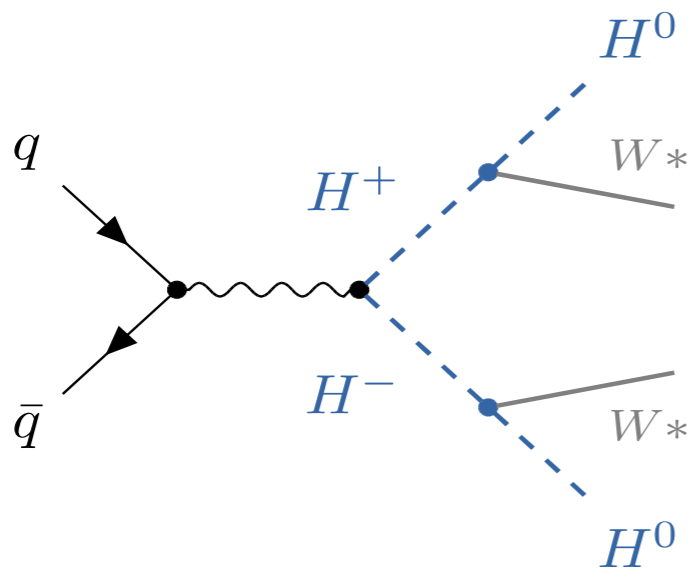
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$\phi_s \rightarrow$  Dark Matter

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$$\Omega_{DM} h^2 \propto \lambda^2 \frac{m_s}{m_F} = 0.12 \rightarrow \lambda \sim 10^{-10}$$
$$c\tau_F \propto \frac{1}{\lambda^2 m_F} \gtrsim 1 \text{ m}$$

# Minimal Freeze-in

---

- Model:

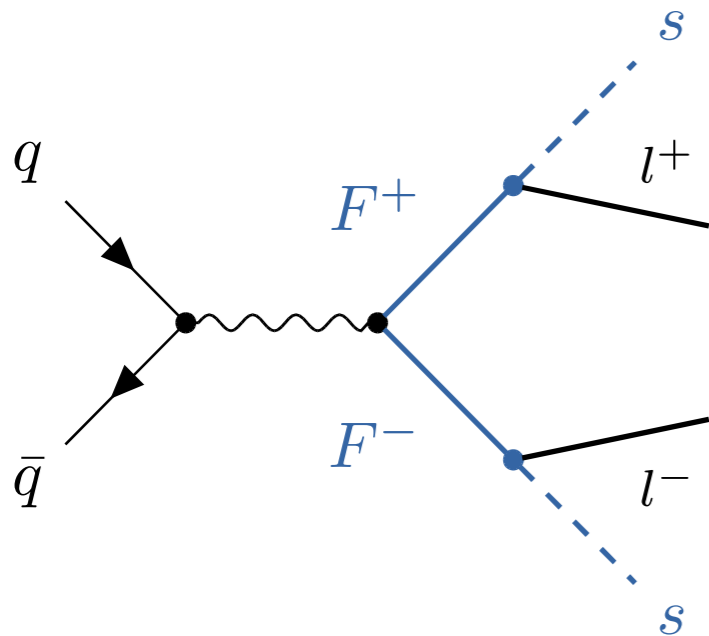
$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \lambda \phi_s \bar{F} e_R + \dots$$

$\phi_s \rightarrow$  Dark Matter

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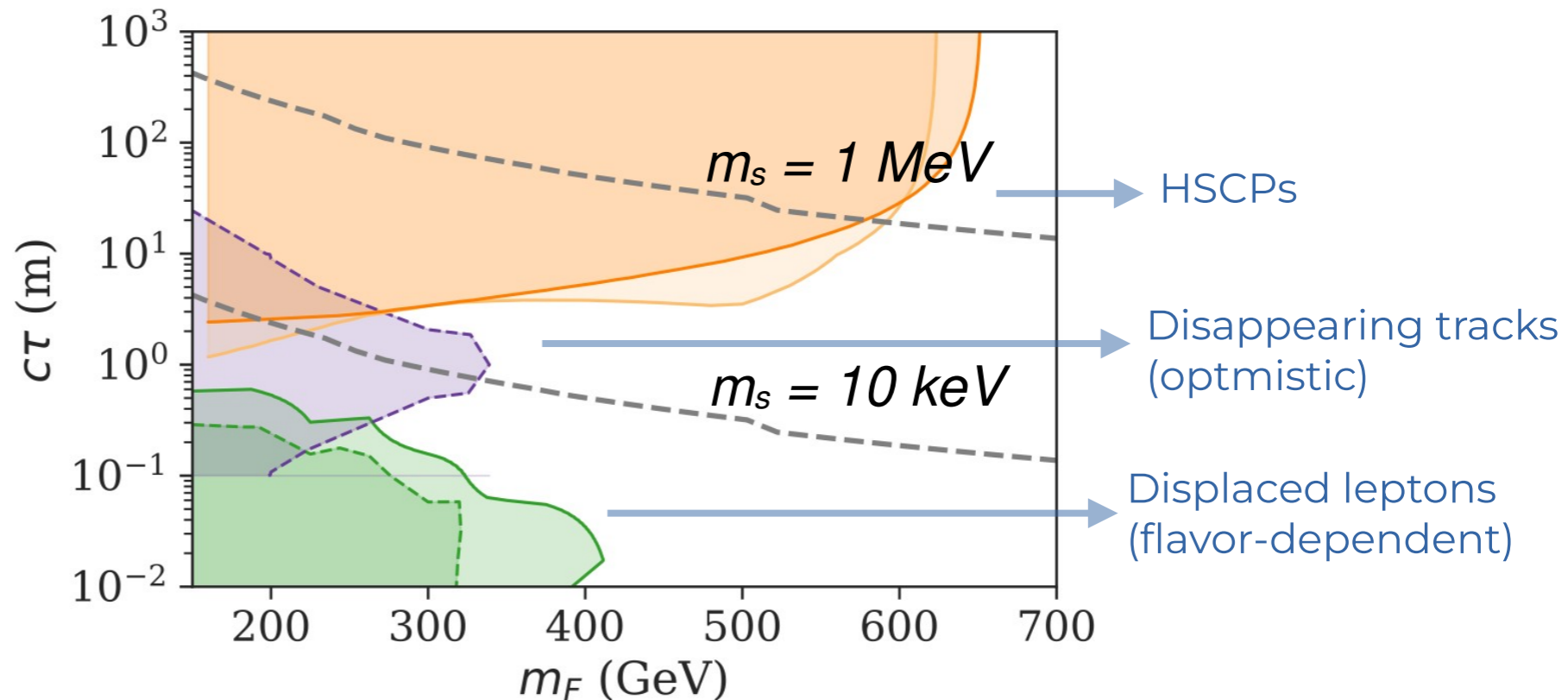
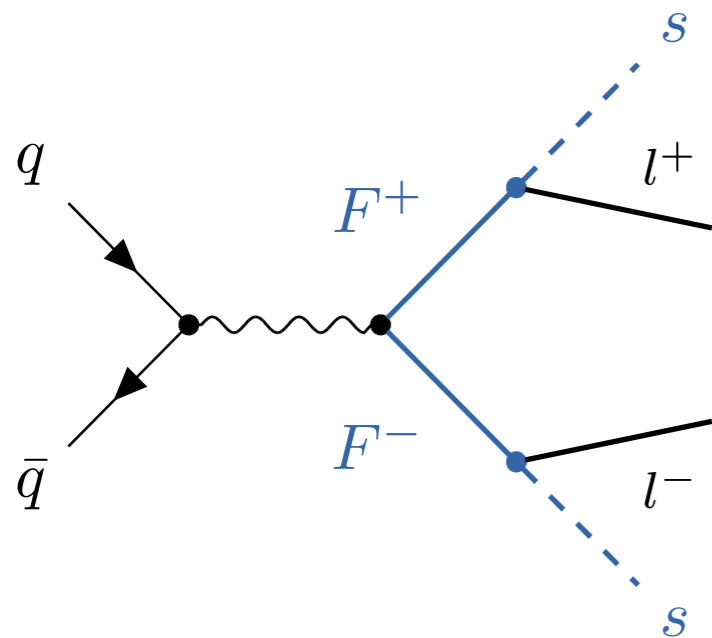
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# Conversion Freeze-out

---

- Model:

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \lambda \tilde{b} \bar{X} b_R + \dots$$

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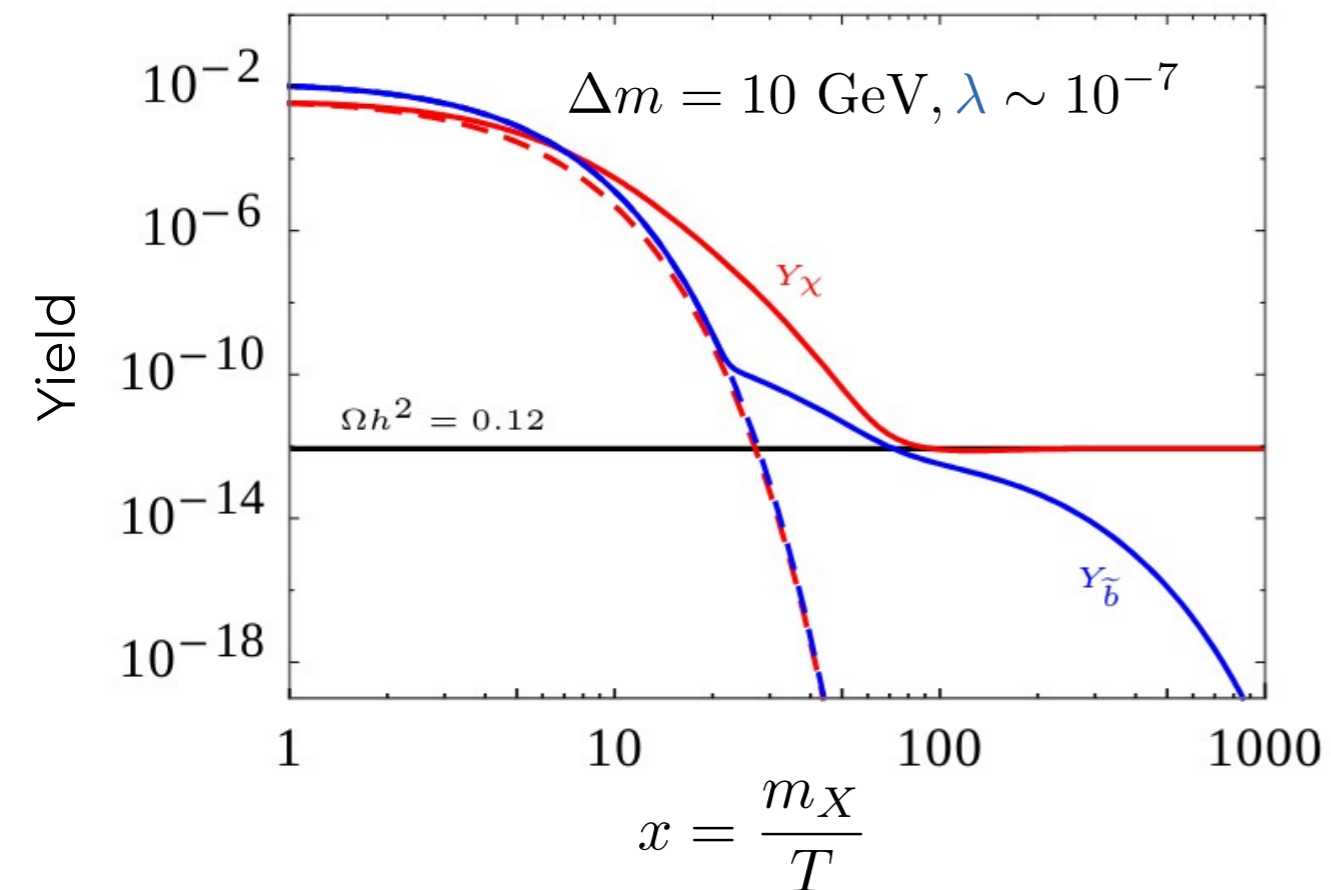
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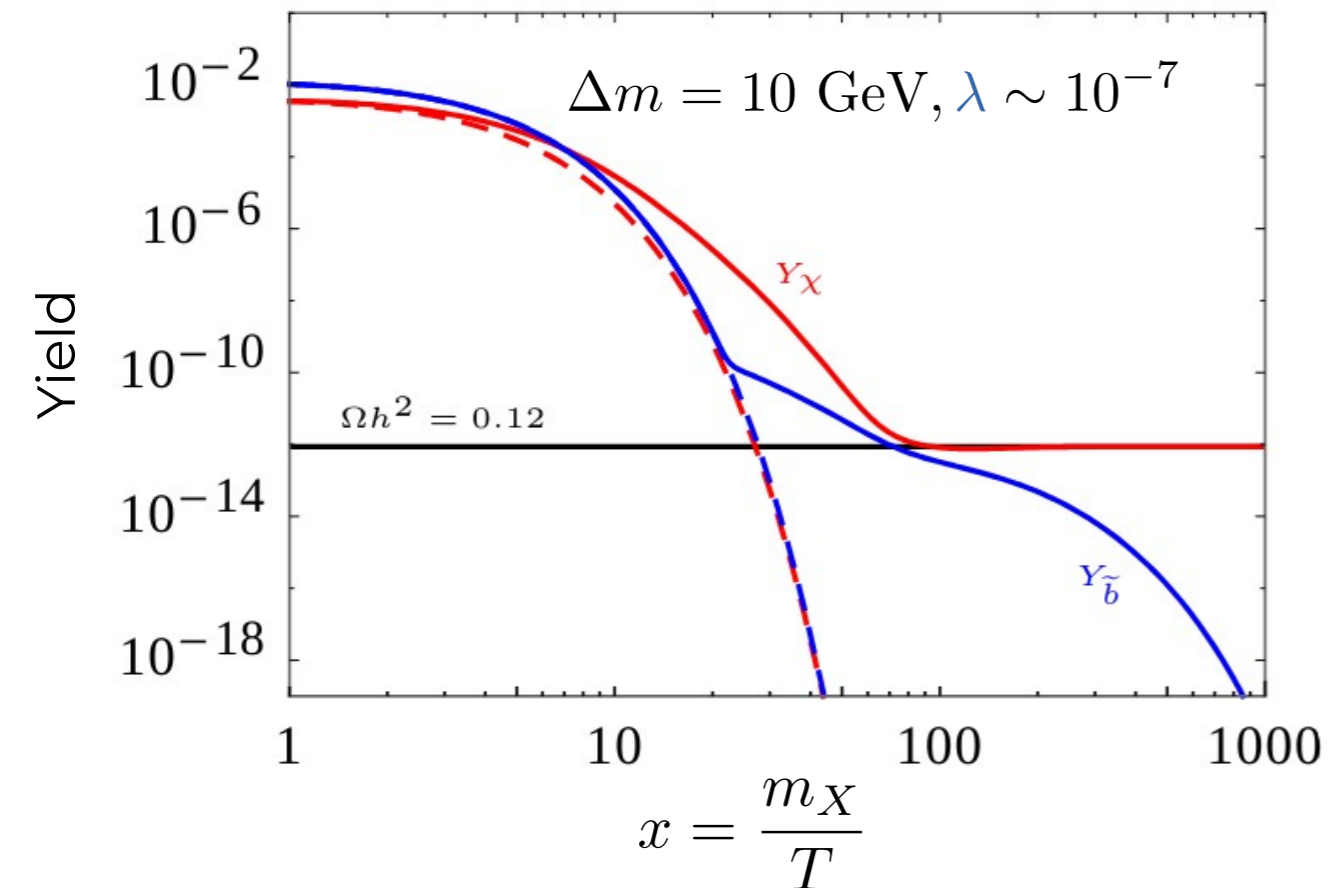
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$$\rightarrow \lambda \sim 10^{-7}, \Delta m \lesssim 35 \text{ GeV}$$



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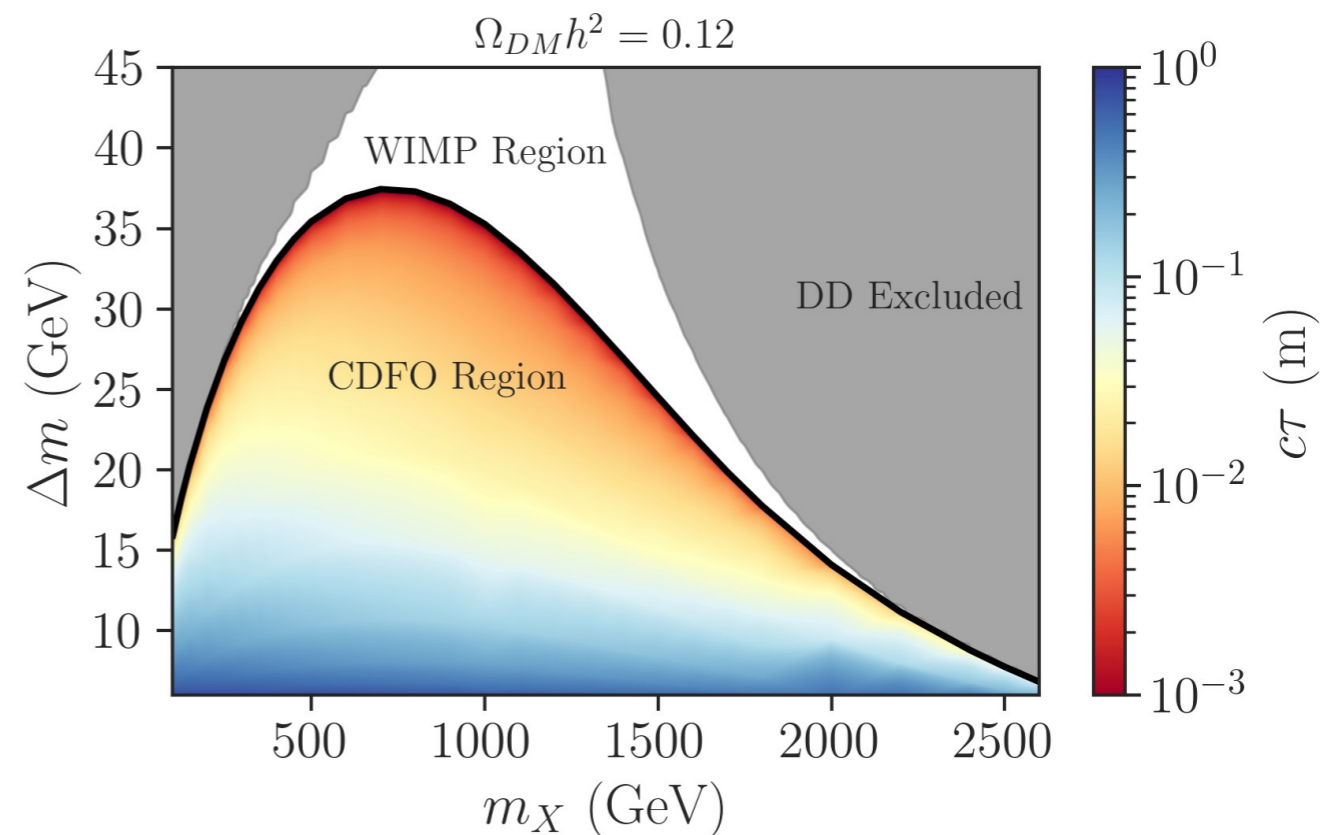
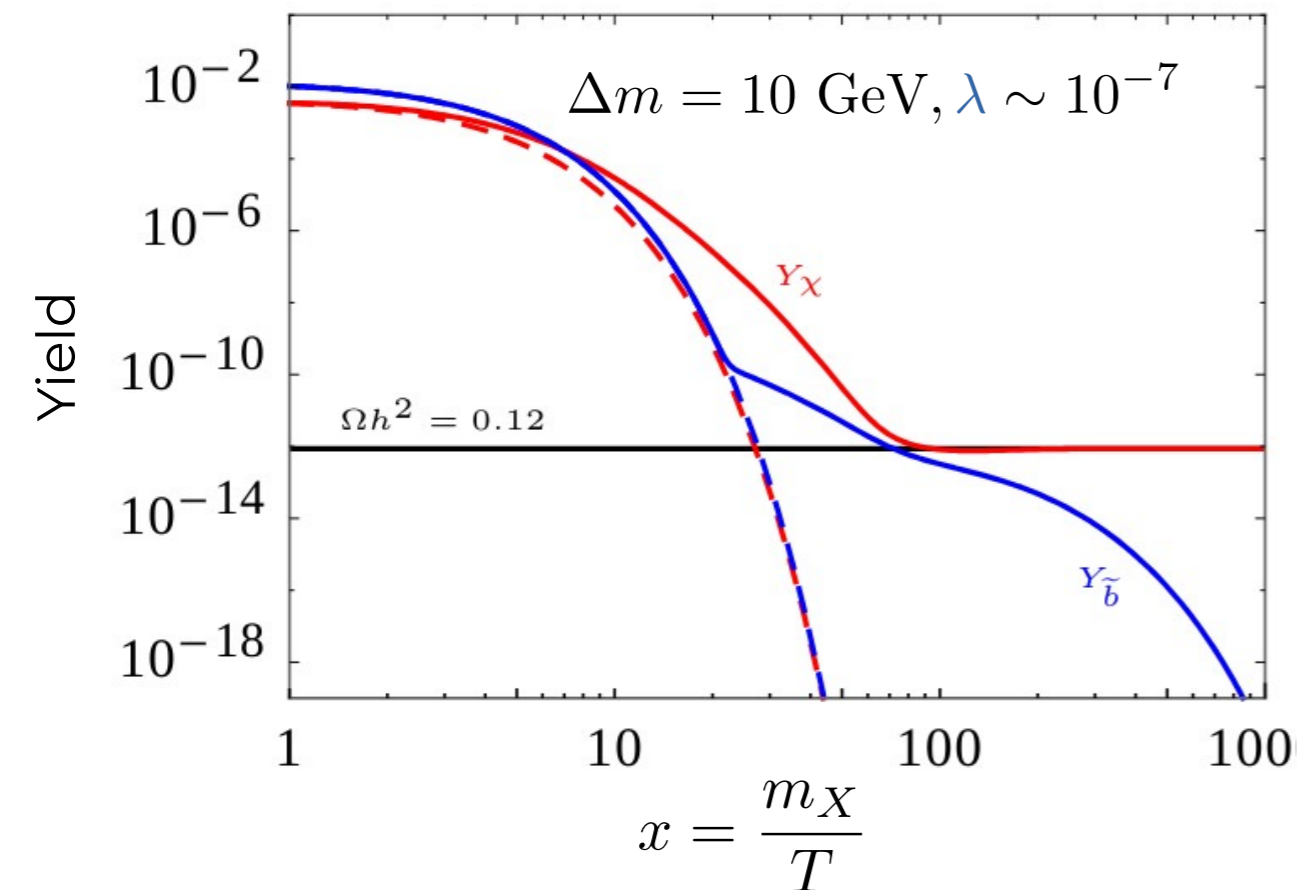
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J. Heisig, AL, L. Ramos (2404.16086)

M. Garny, J. Heisig, B. Lulf, S. Vogl (1705.09292)

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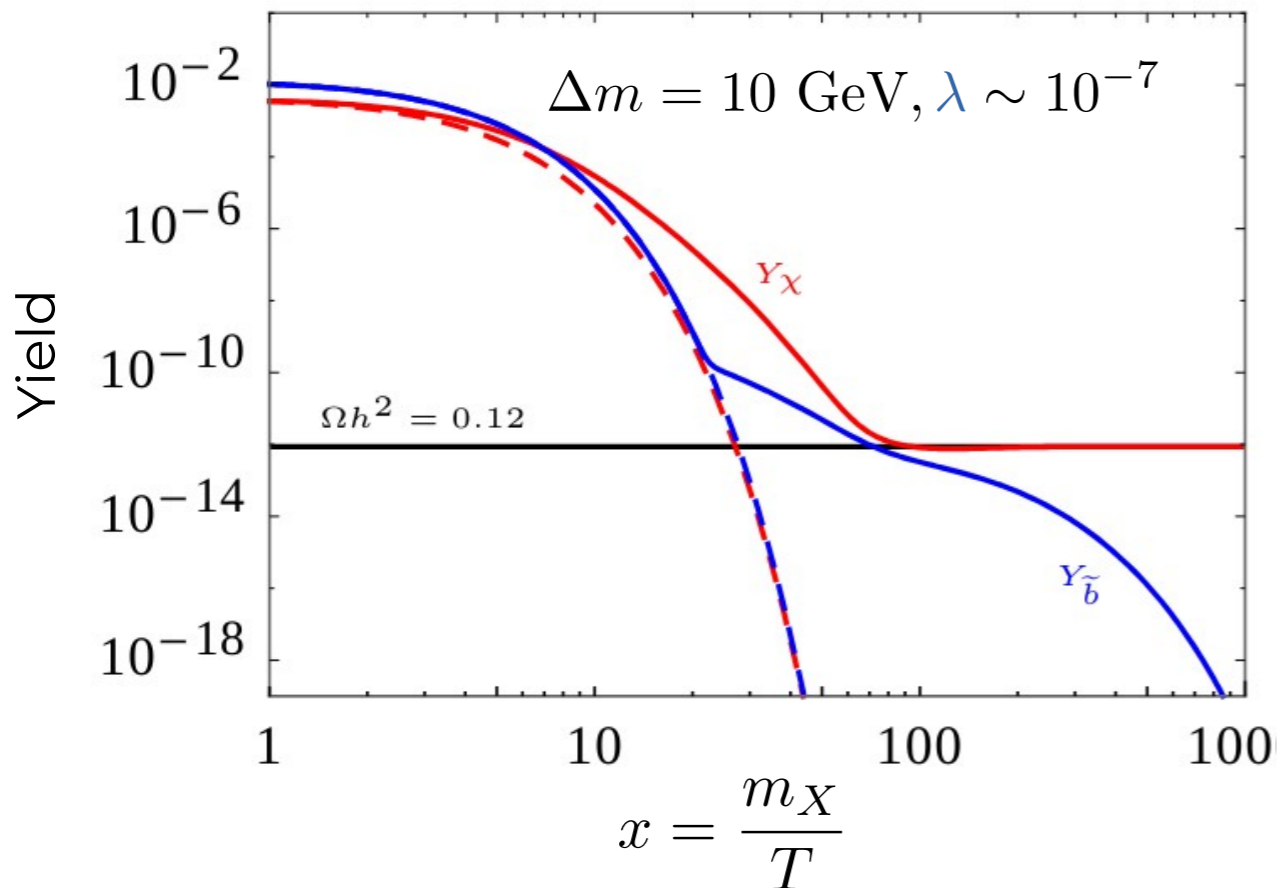
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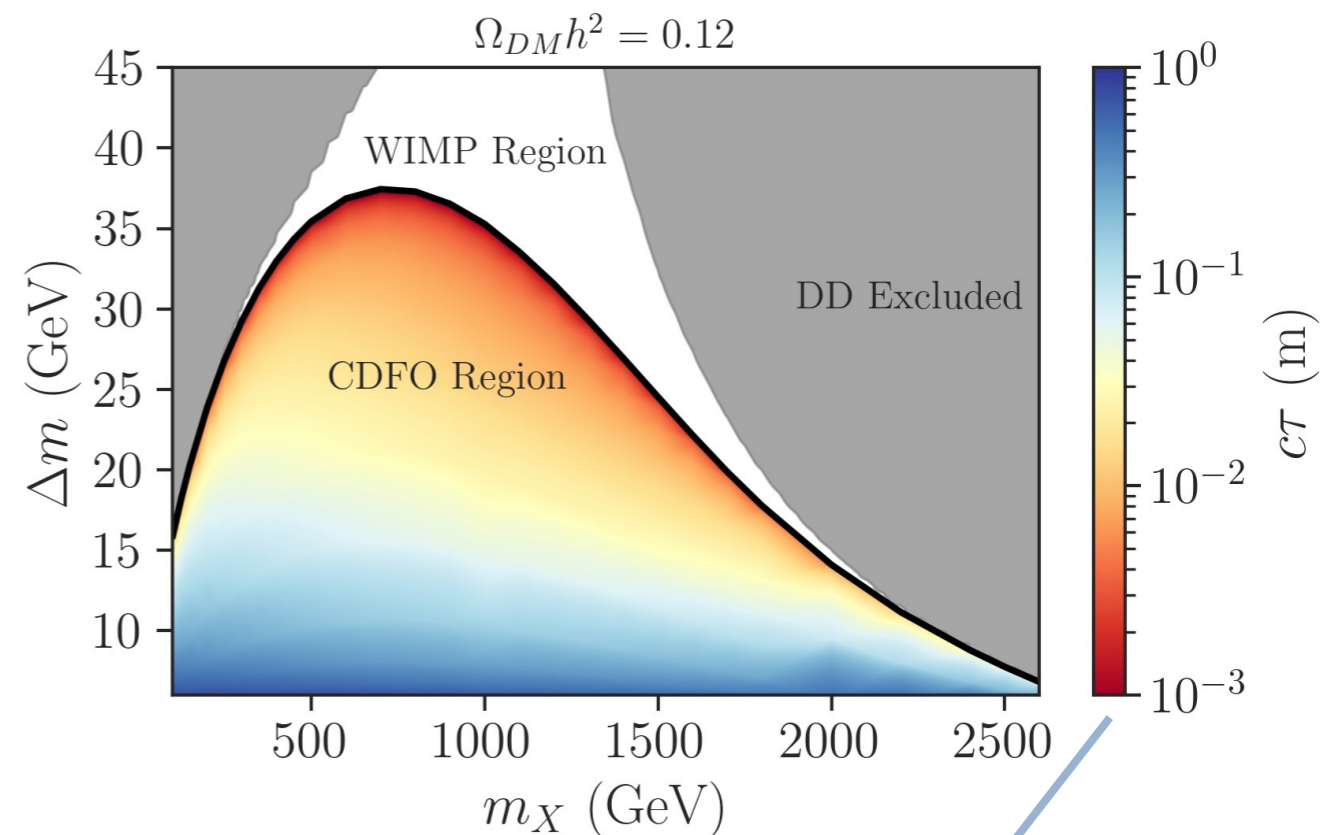
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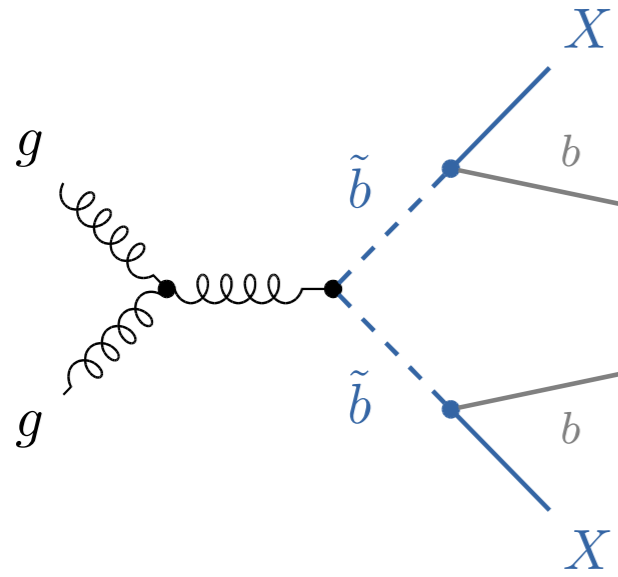
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Within the reach of several LLP searches!

# Impact on DM Models

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- Conversion Driven FO @ LHC

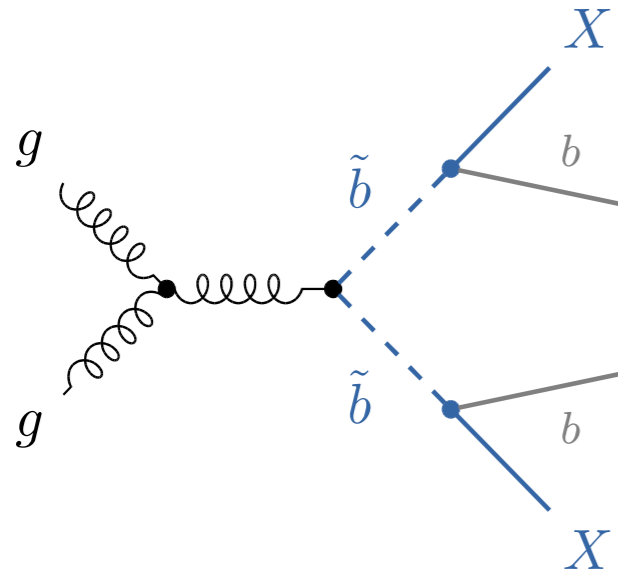




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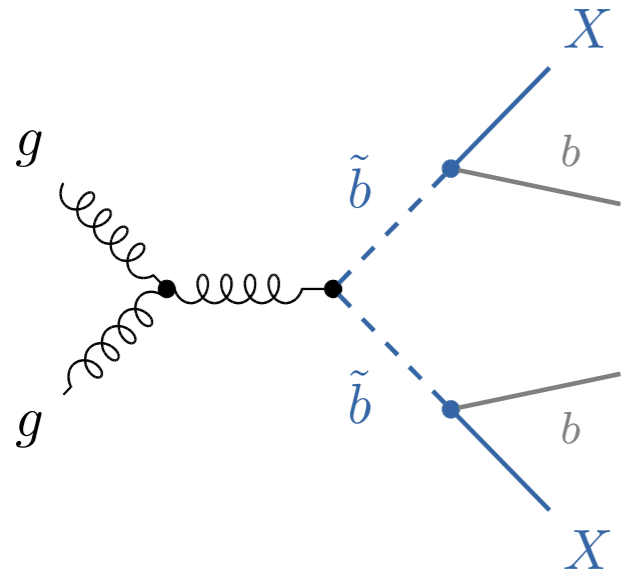


- ~50% charged R-hadrons
  - HSCPs
  - Disappearing Tracks
- Soft and displaced b-jets
  - Displaced Vertices
- Soft MET spectrum
  - Mono-jet

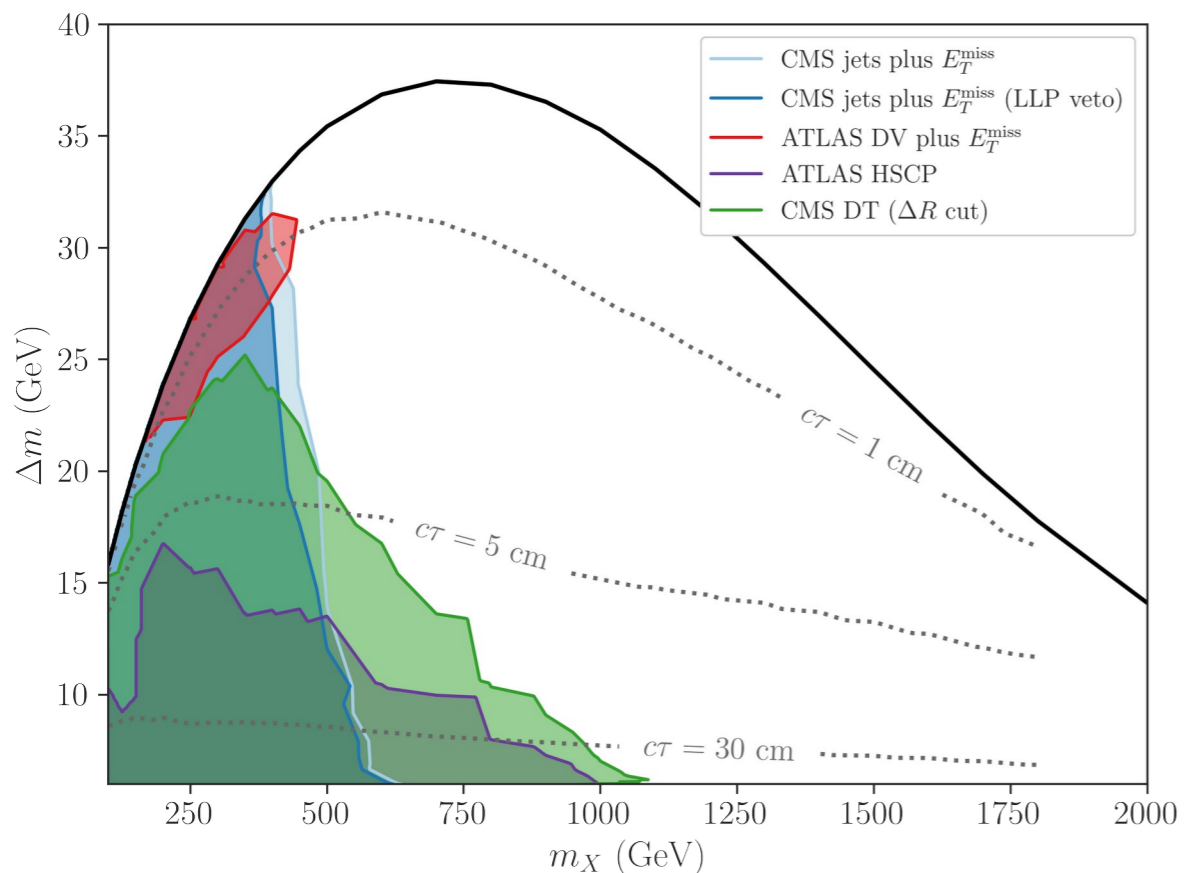


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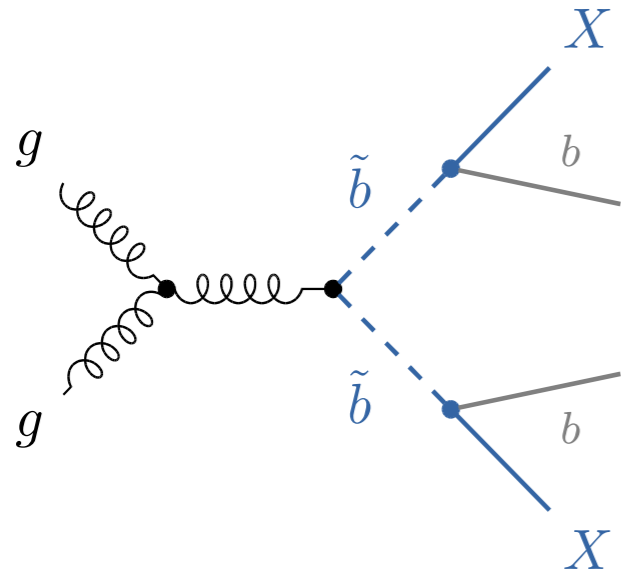


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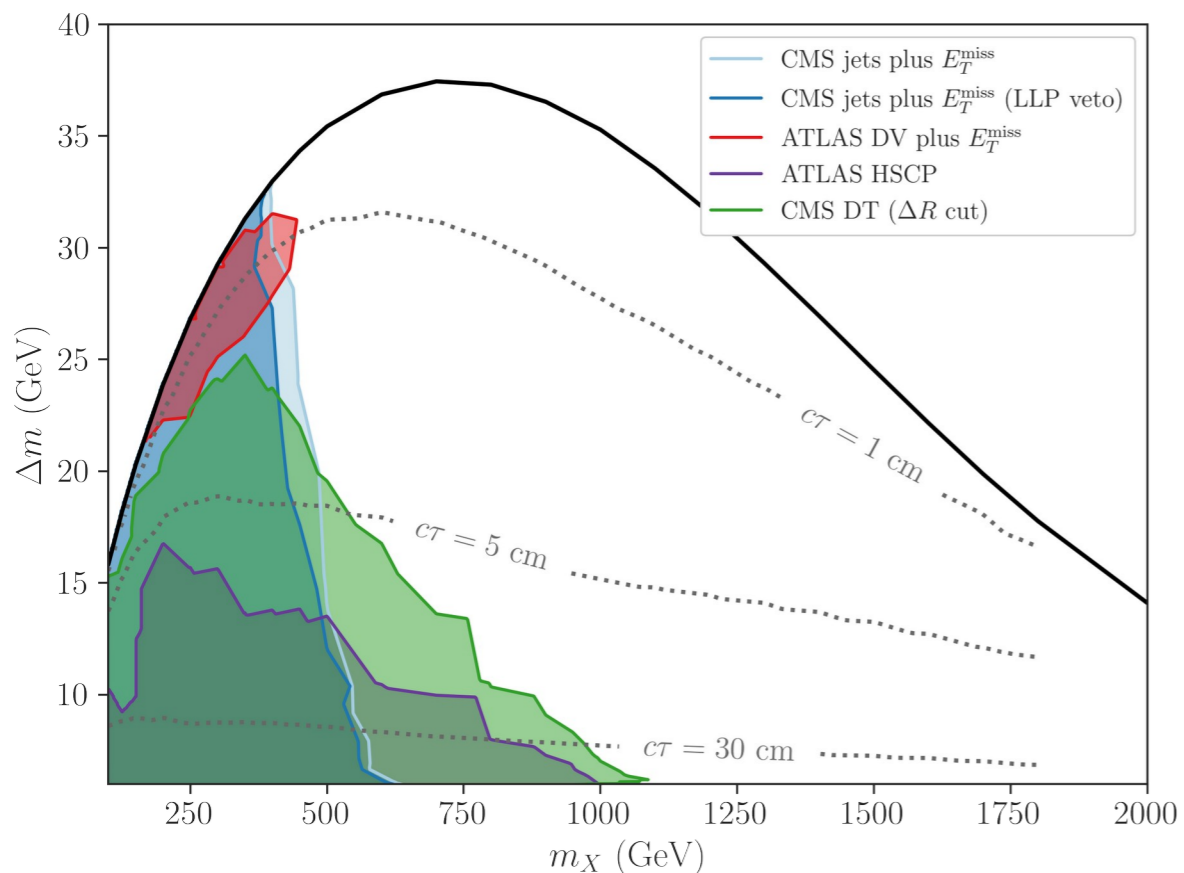
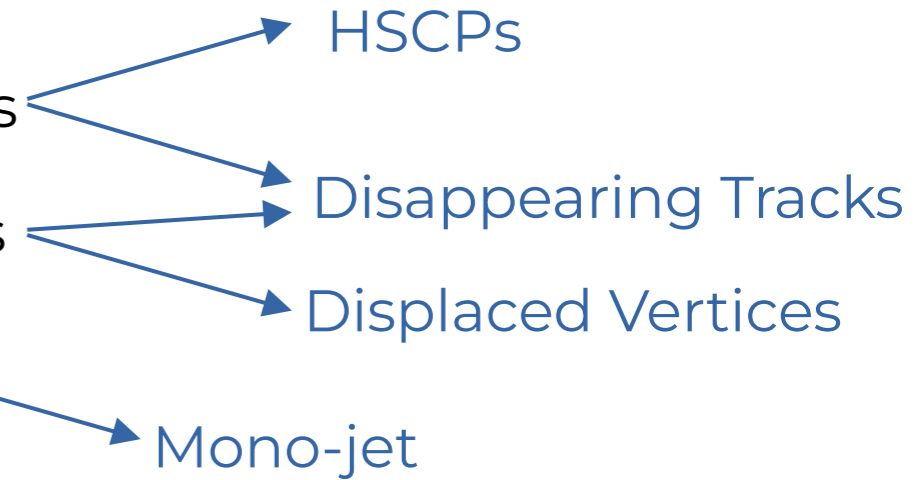


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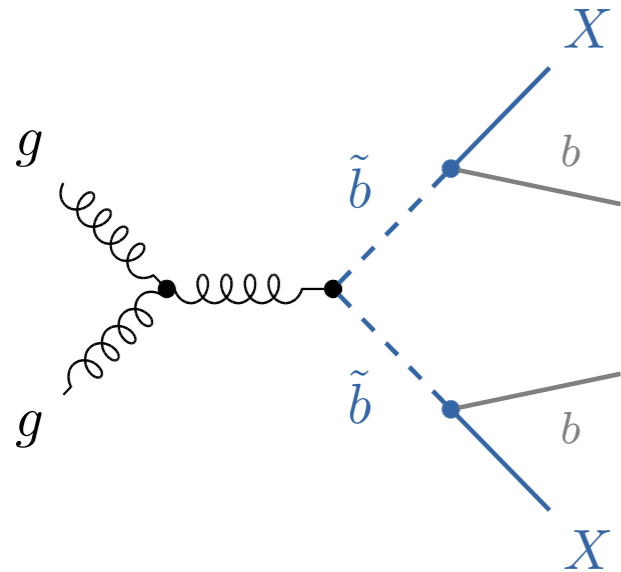
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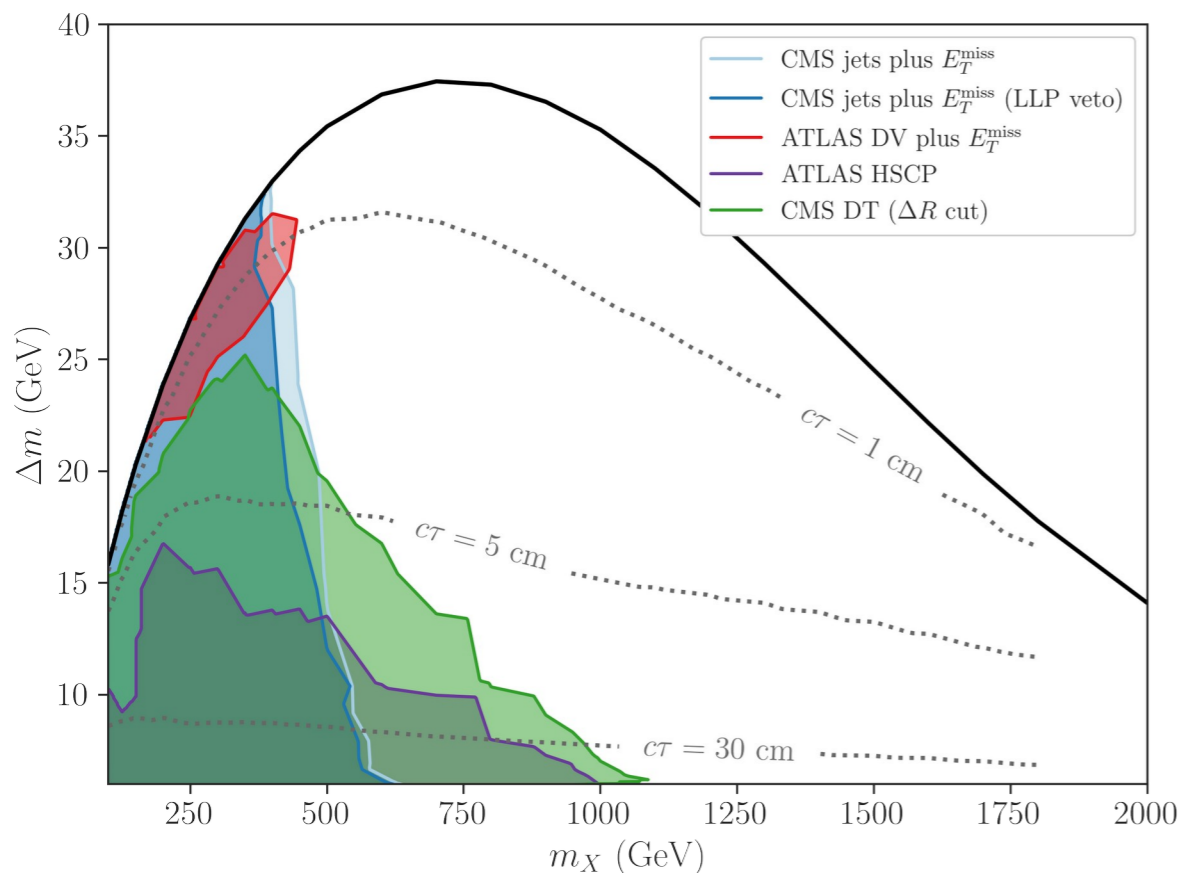
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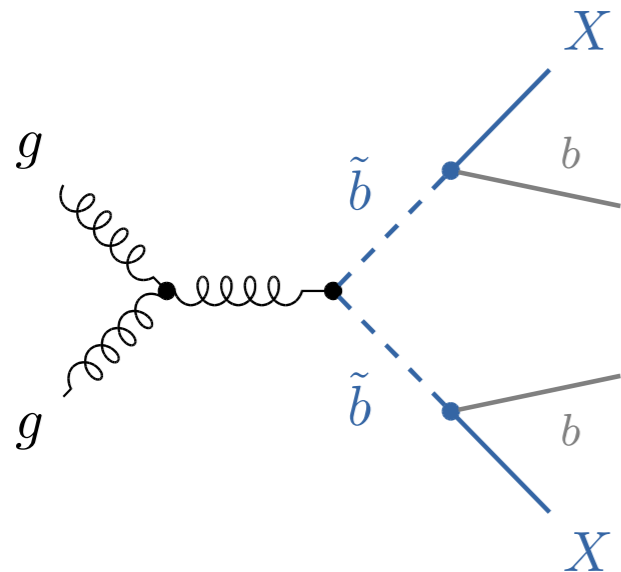
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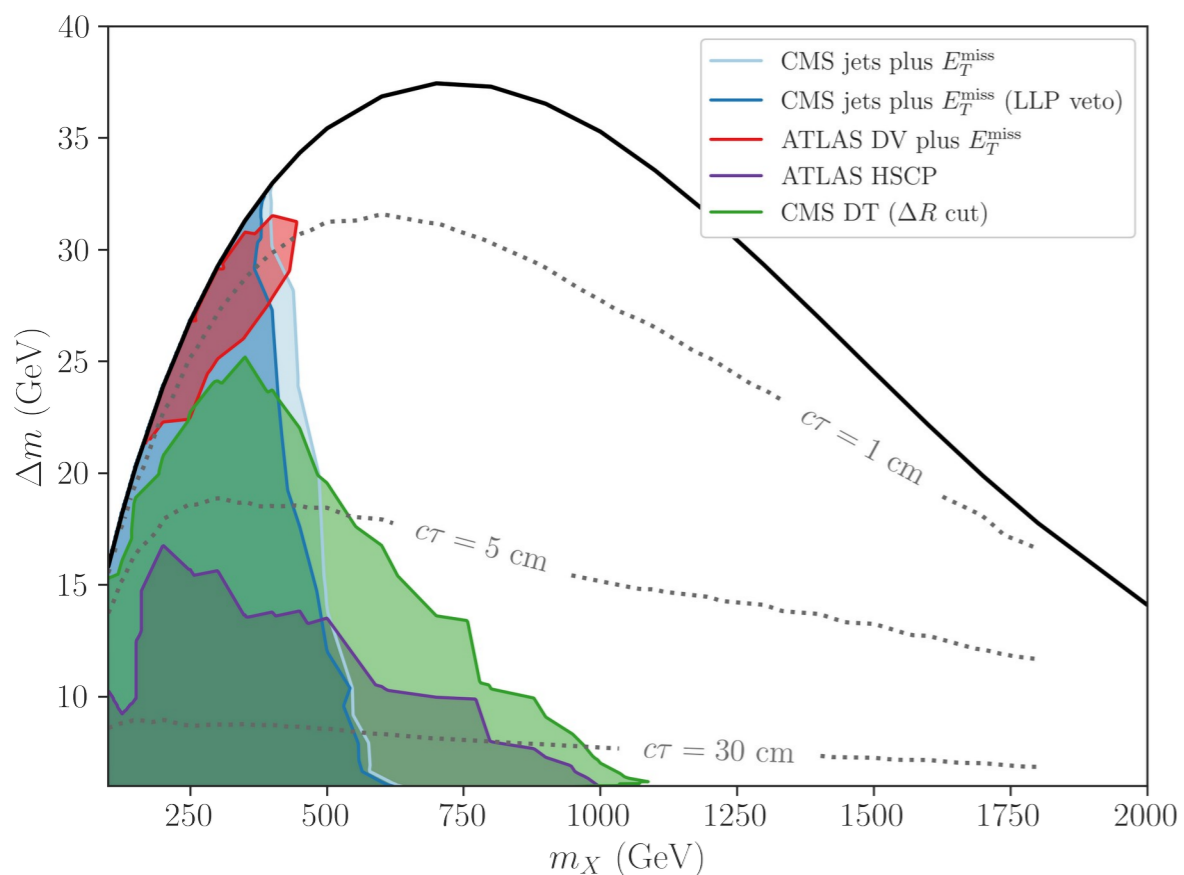
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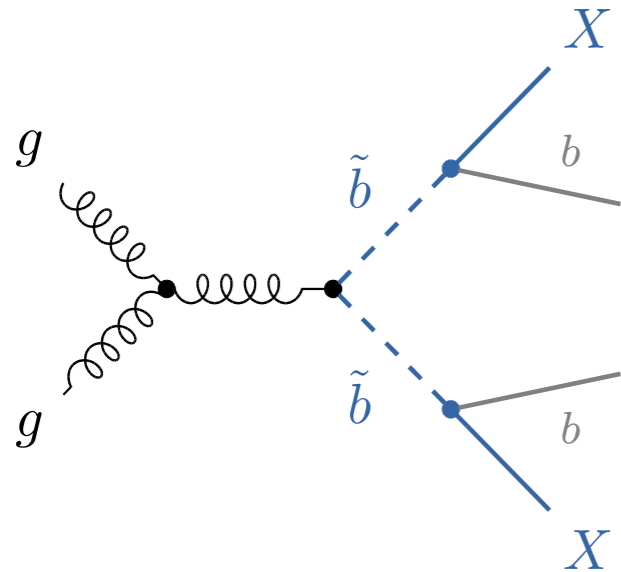


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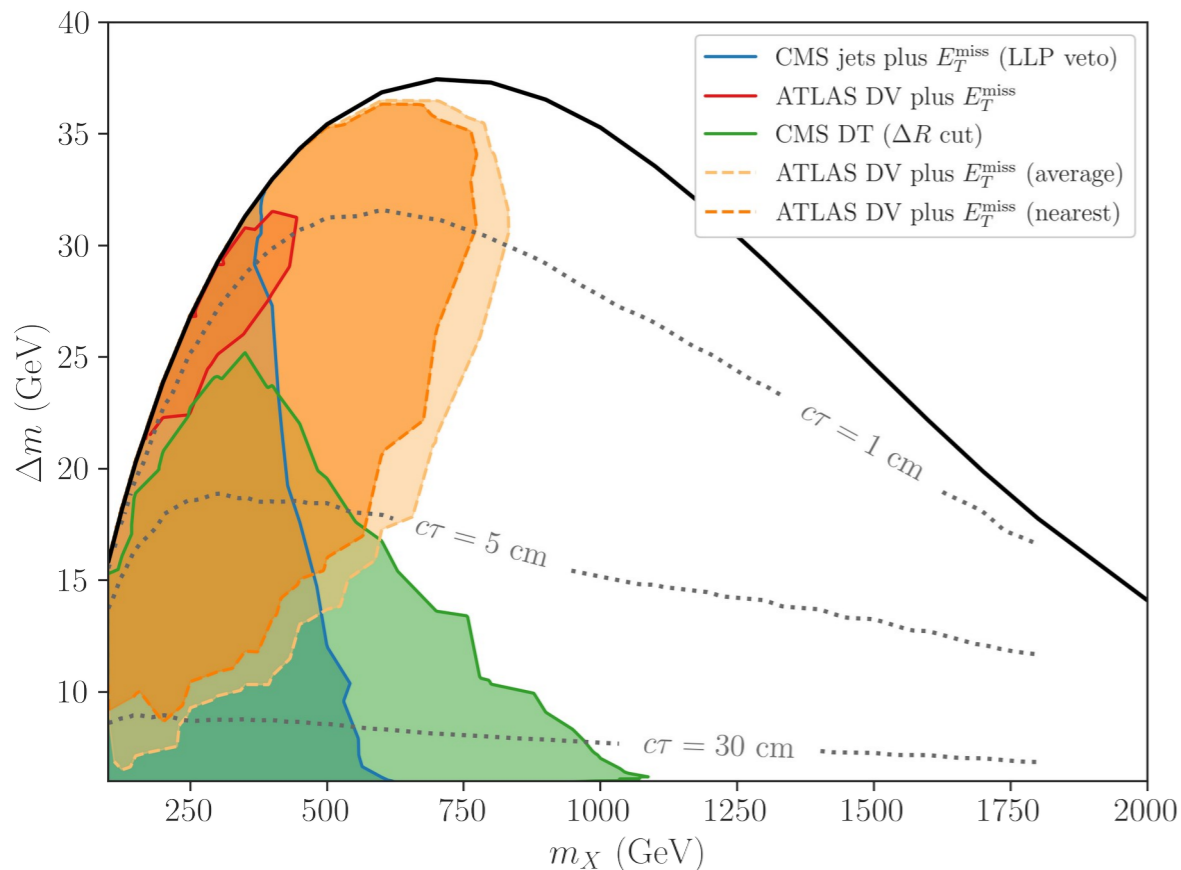
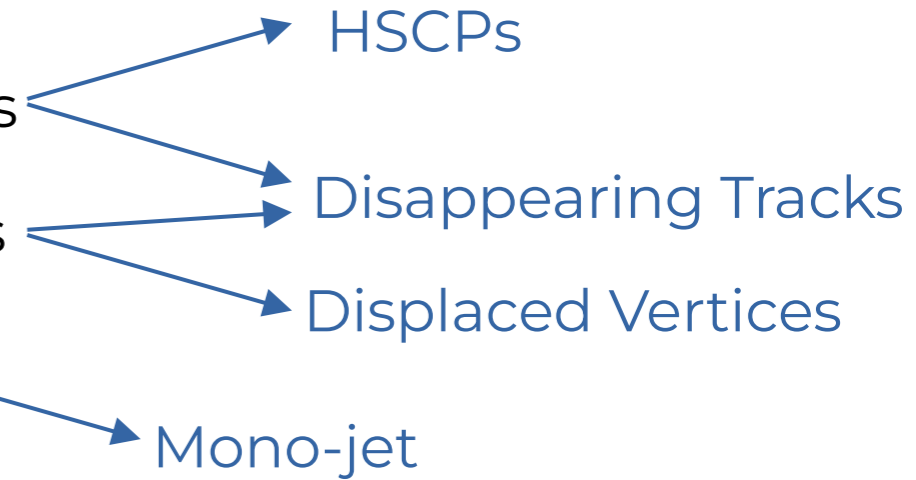
If we relax the SR criteria ( $m_{\text{DV}}$ )...

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  - *recasting guides, pseudocode and cut-flows are [essential](#)!*
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- *Recasting is an essential tool for finding gaps in coverage!*
- *For feebly coupled models the LHC may be the main tool for discovery!*

# Recasting Checklist

- When releasing a new analysis, the following information needed is important for recasting:
  - Parametrized efficiencies (object-level)
  - Cutflows (for benchmarks at the bulk and edge of the exclusion curve)
  - Cards for event generation (benchmark models):
    - Process card
    - Parameters (model) card
    - Pythia card
    - ...
  - Signal Distribution for “recasting observables” (benchmarks)
  - Pseudocode
  - Recasting guide

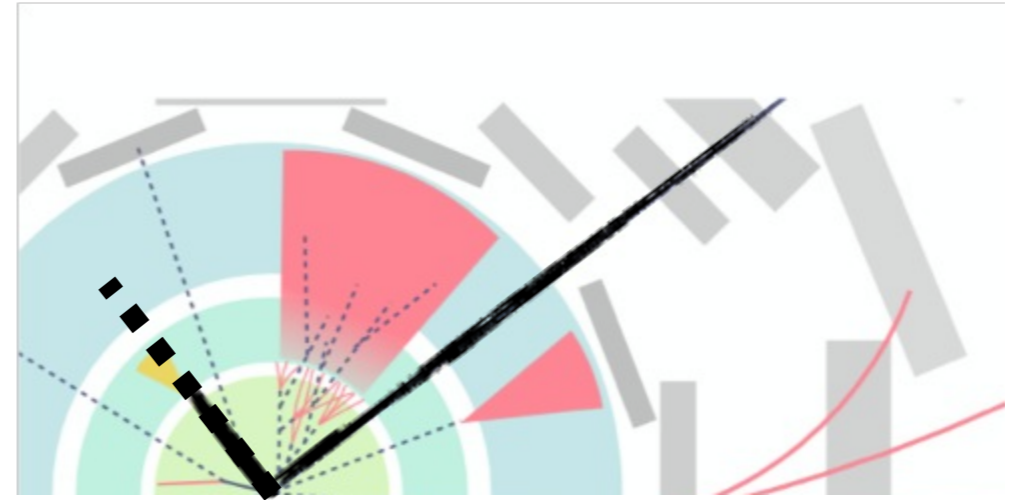
# Backup

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# "Real Life" Examples: HSCPs

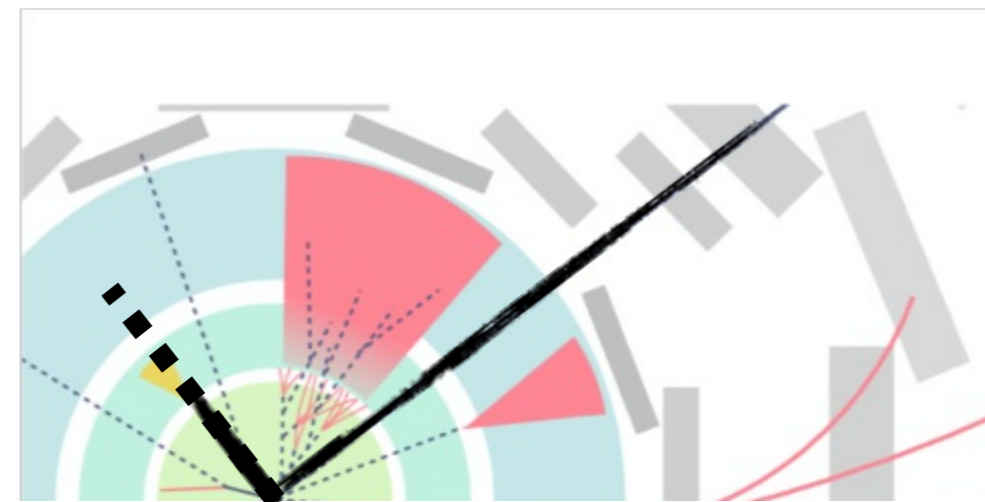
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- HSCPs (plus R-hadrons):
  - *ATLAS-SUSY-2016-32/31* (13 TeV)
  - CMS-EXO-12-026 (8 TeV)



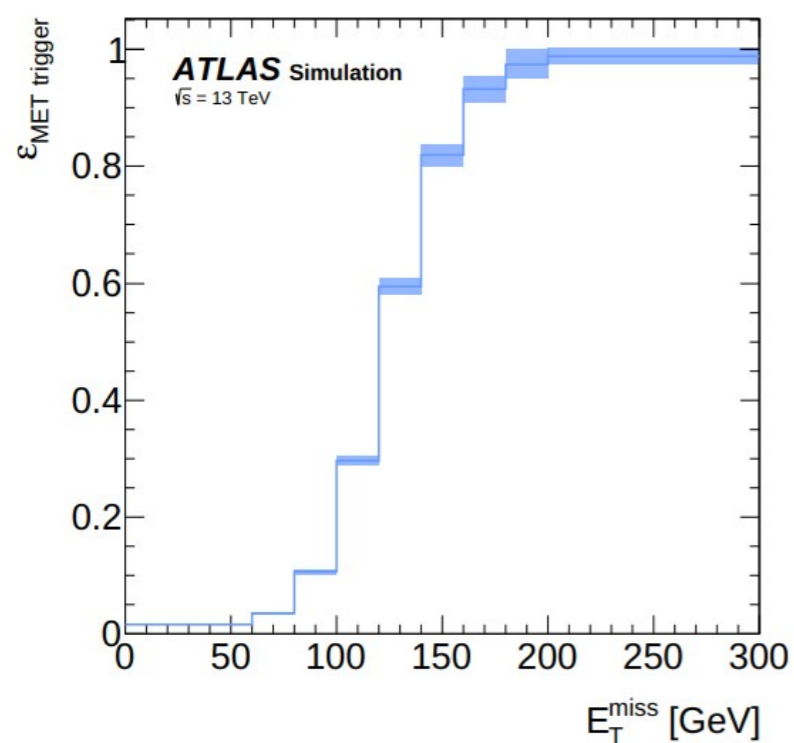
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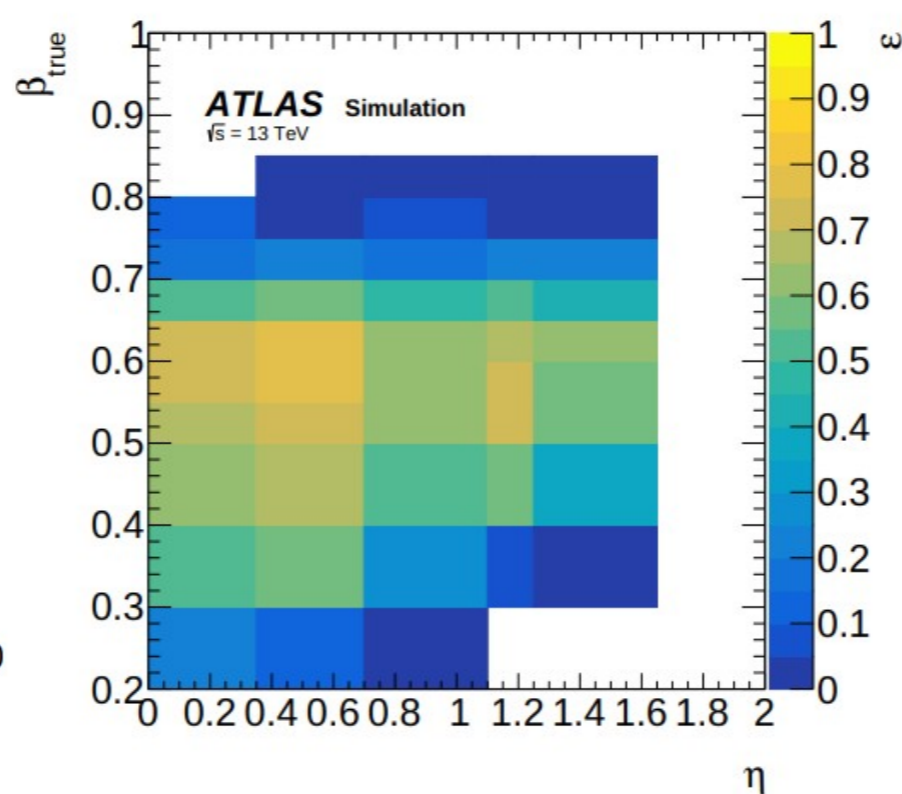


## • Information provided:

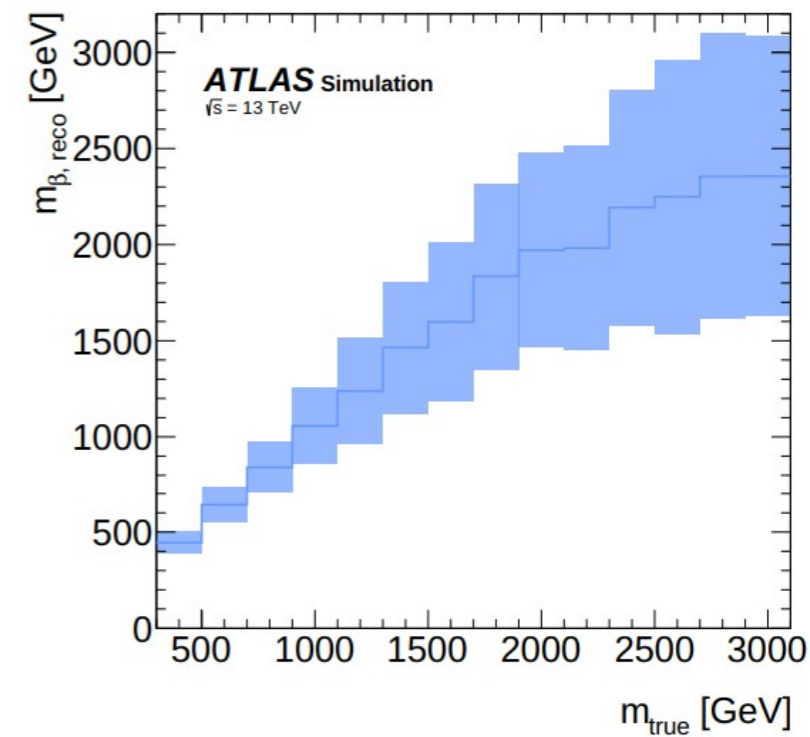
- Trigger efficiency



- Object efficiencies:  $\epsilon(\eta, \beta)$

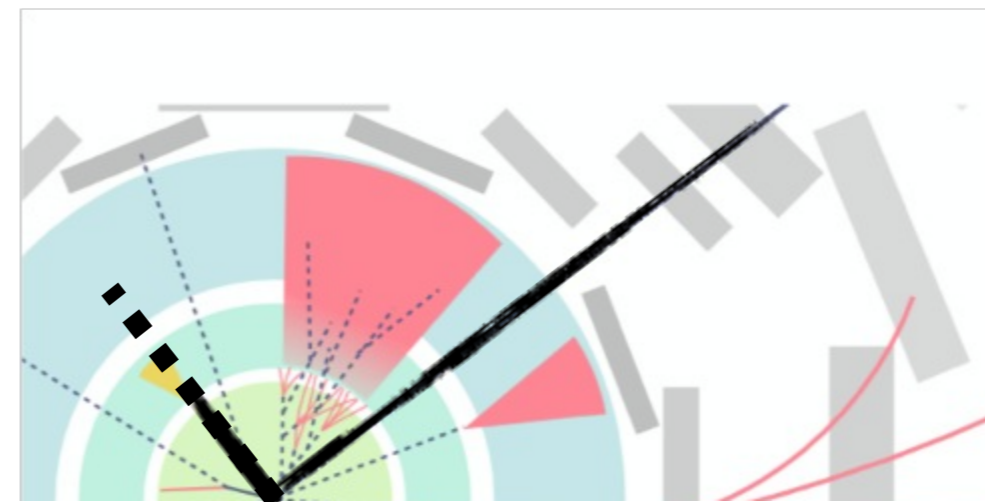


- Mass reconstruction



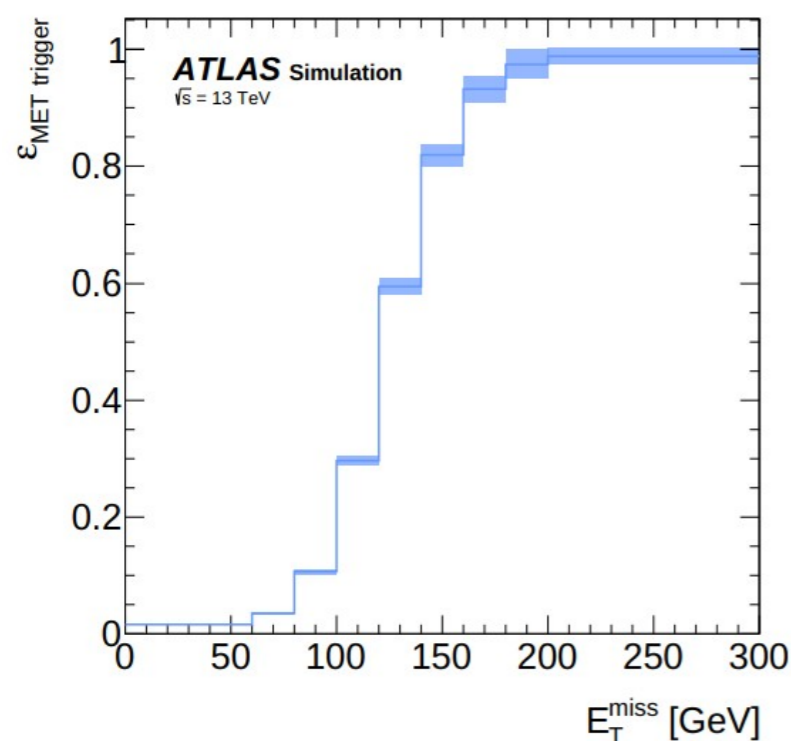
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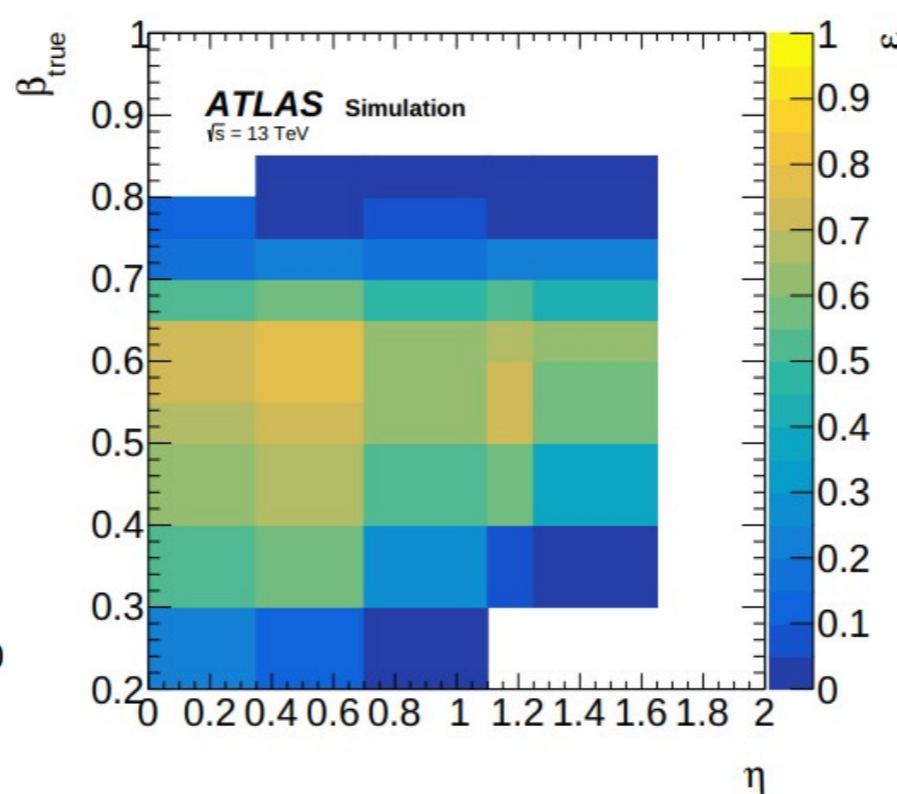


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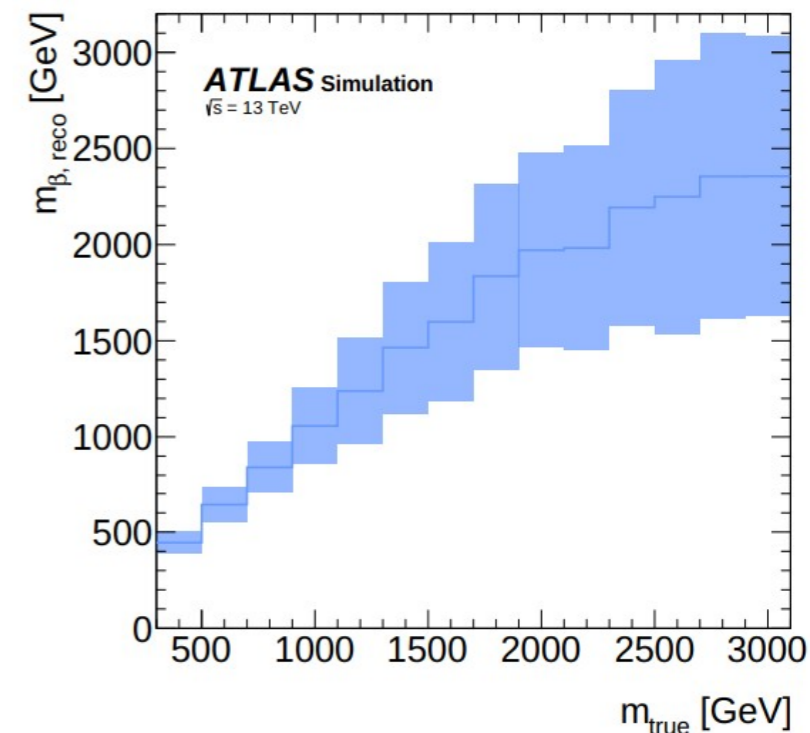
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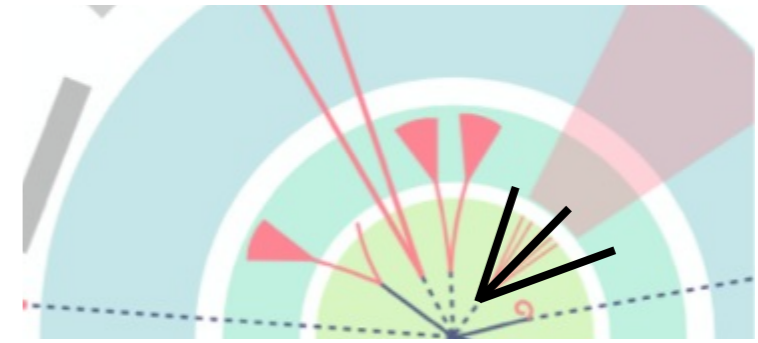
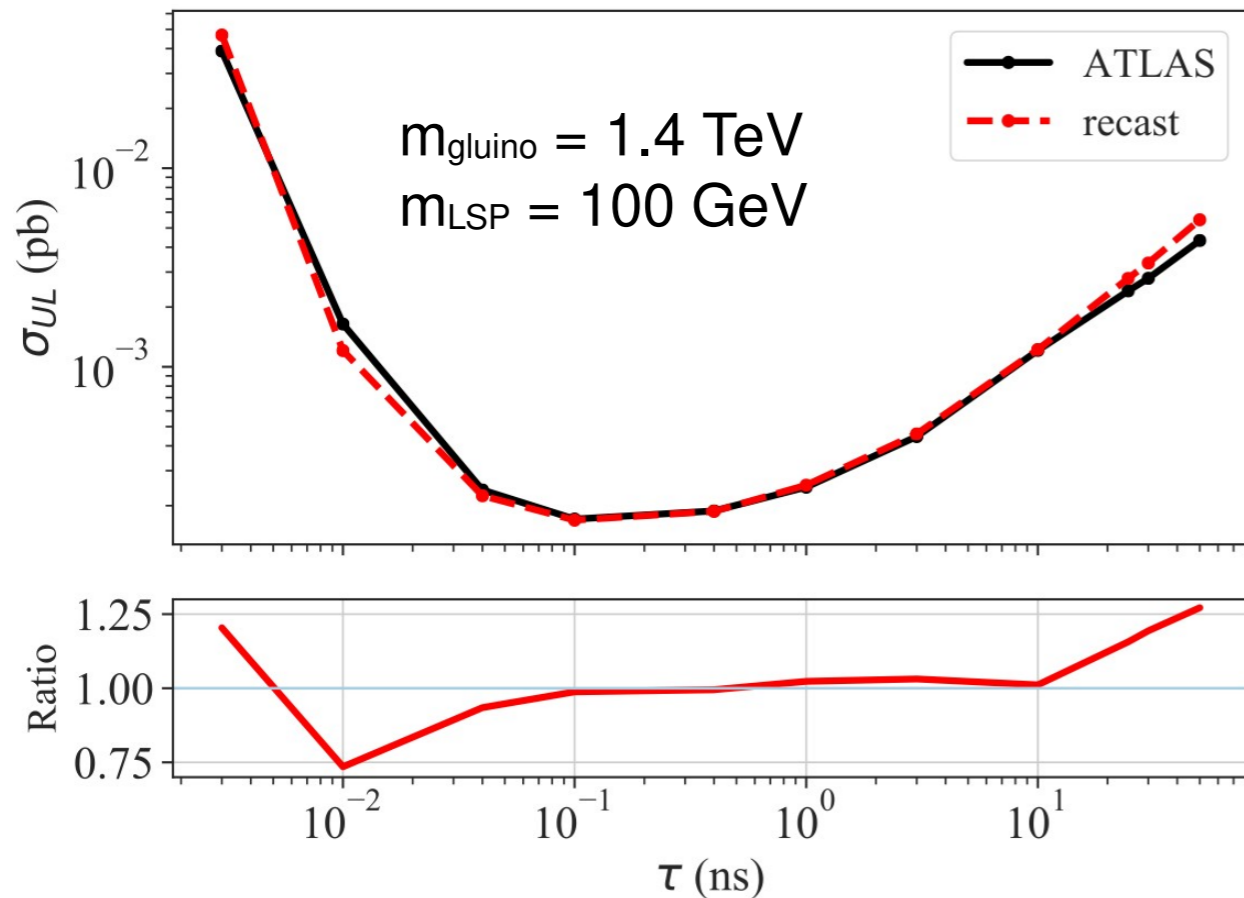


- *All the quantities required for recasting the analysis are provided*



# "Real Life" Examples: Displaced Vertices

- It works well for large mass differences:

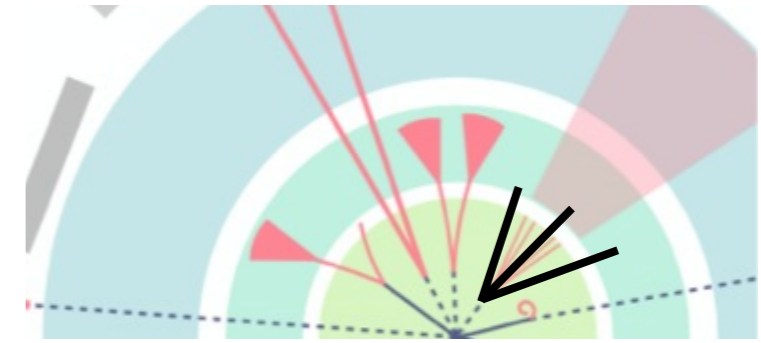
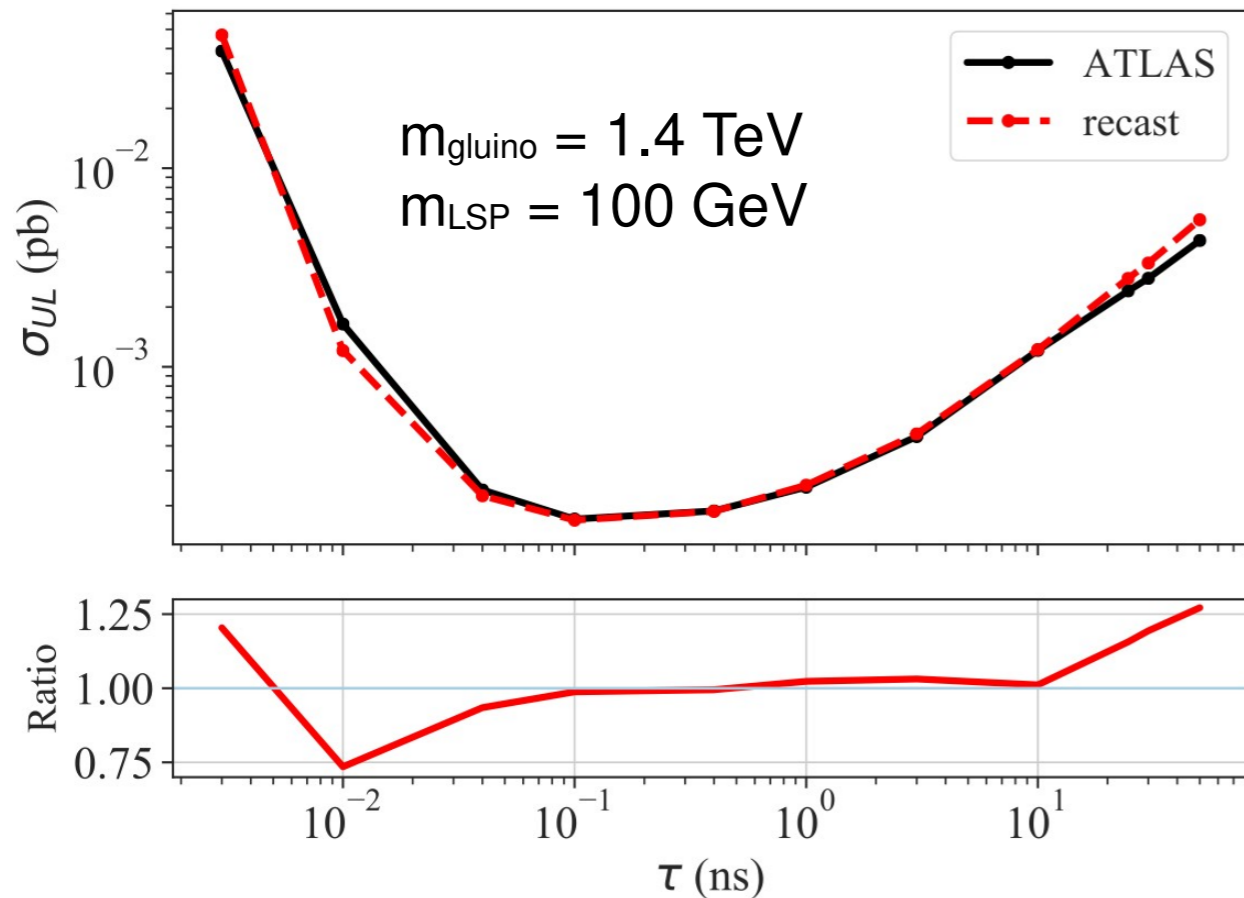


- MET distribution?
- ME/PS matching?
- *Extrapolation to low  $m_{DV}$ ?*

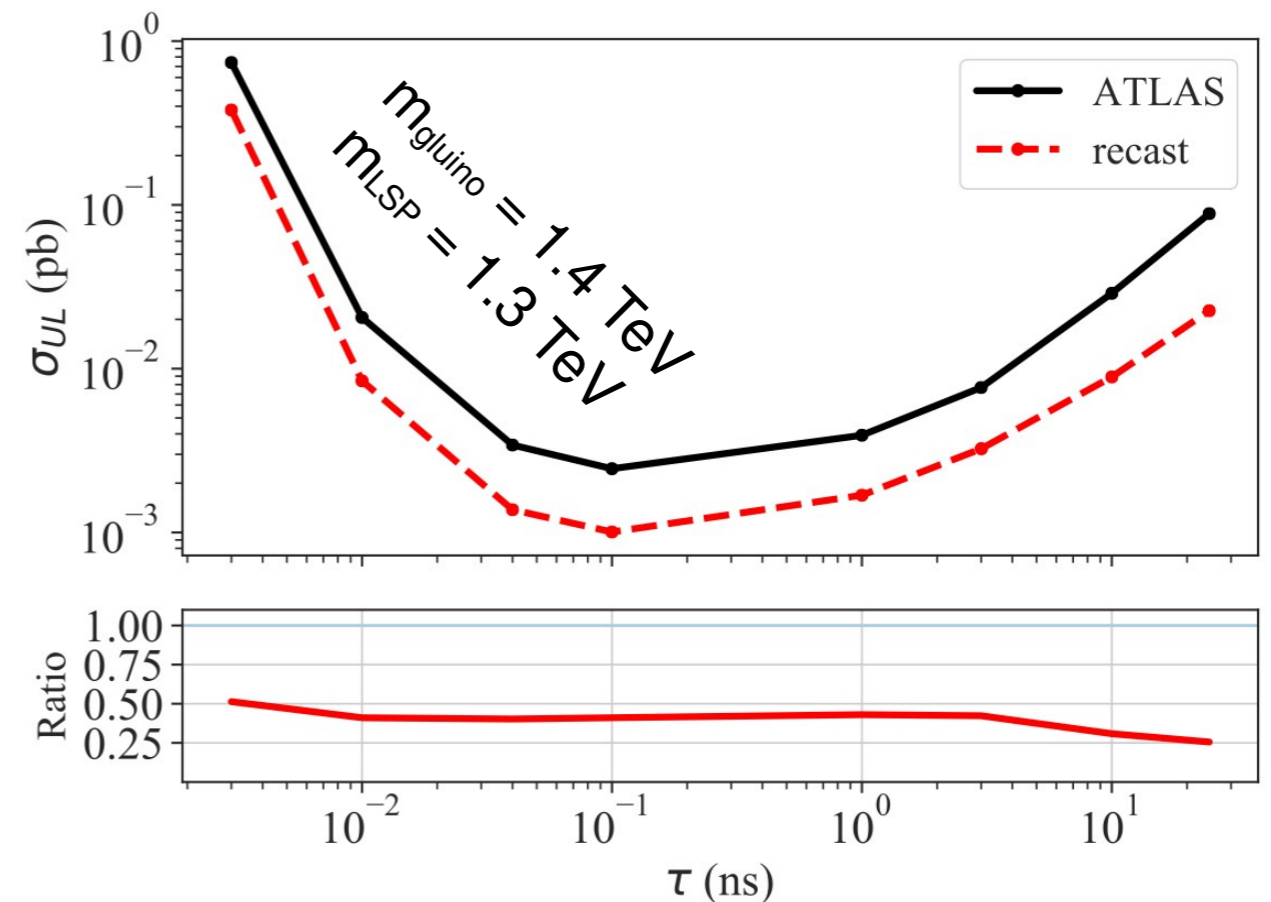


# "Real Life" Examples: Displaced Vertices

- It works well for large mass differences:



- It fails for compressed scenarios:



- MET distribution?
- ME/PS matching?
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