BSM Theory Overview

PhenoEXP Workshop

São Paulo, August 11th 2026

André Lessa

IFUSP

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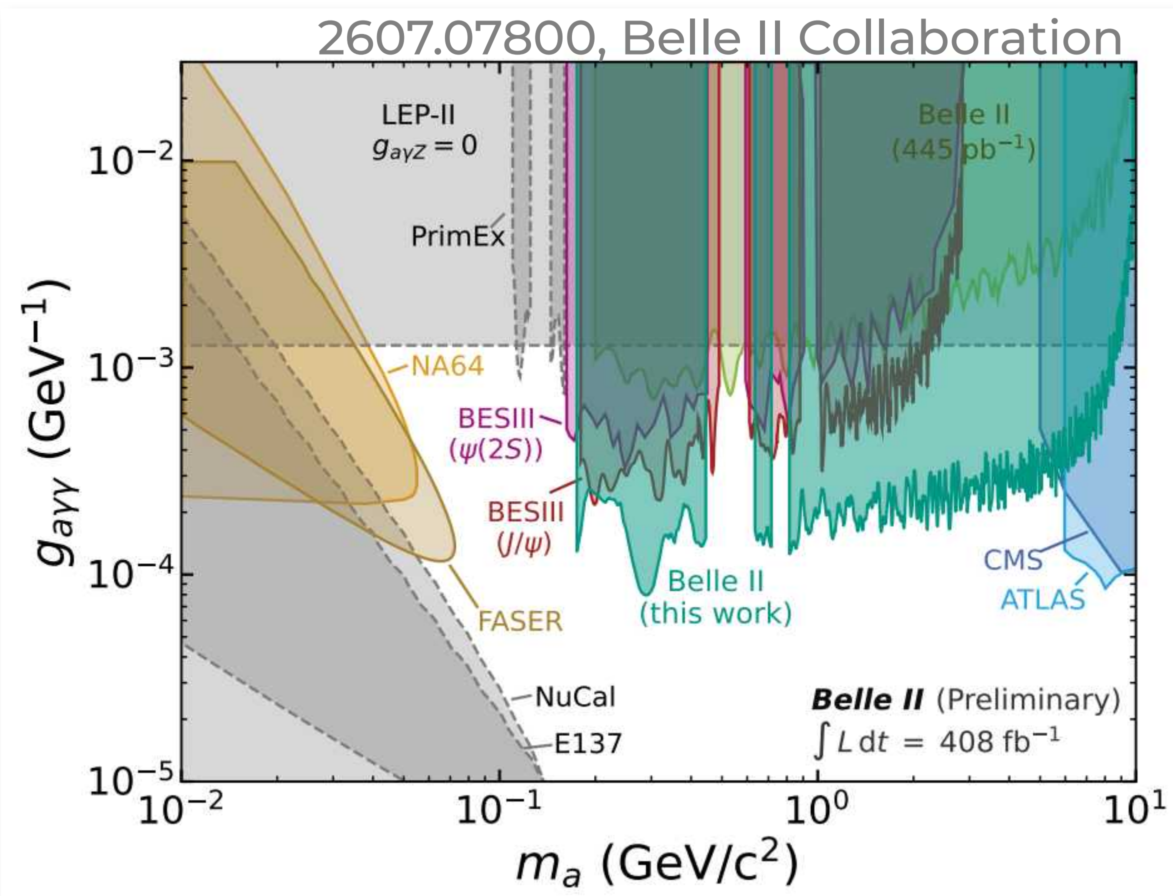
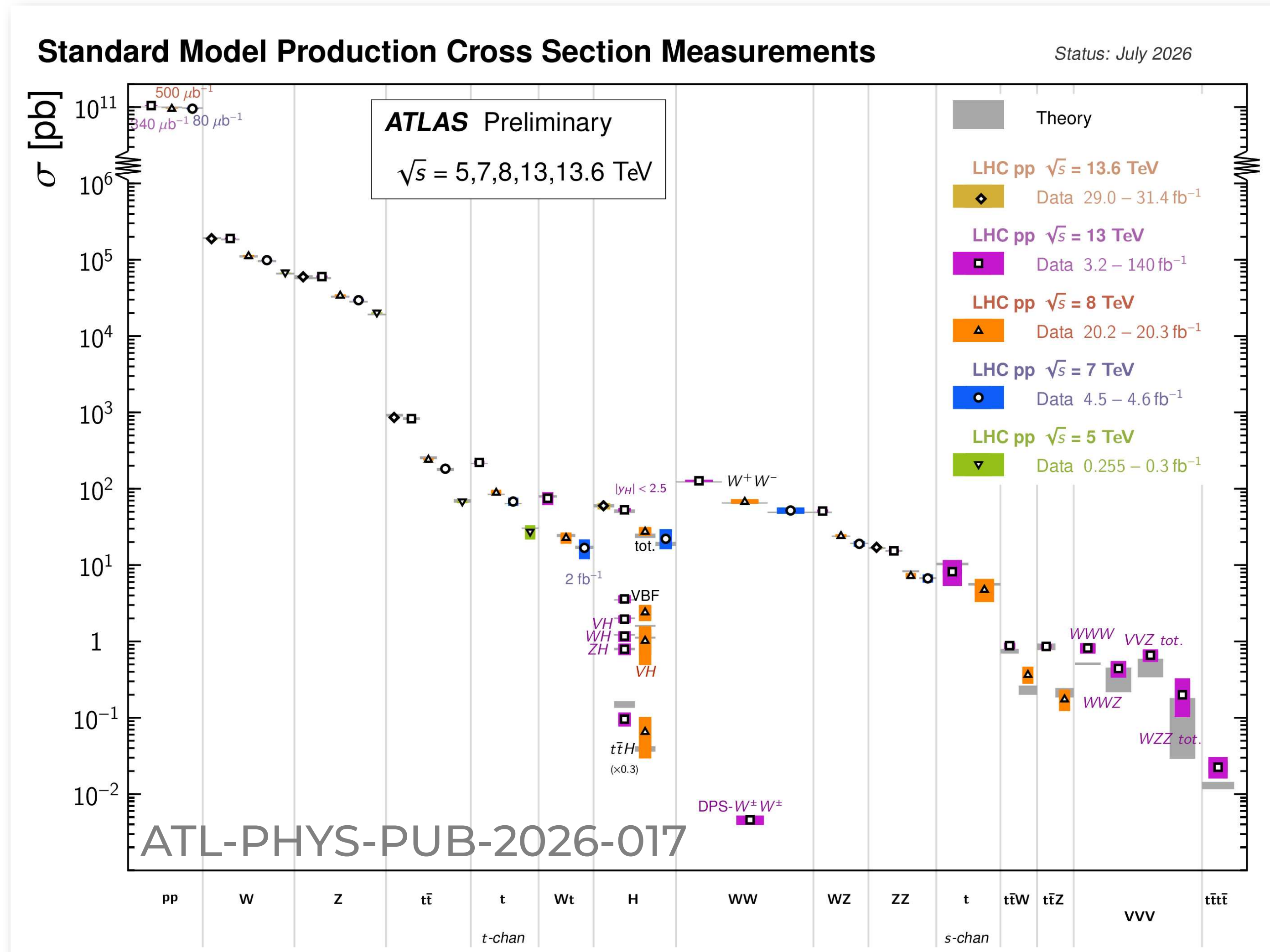
2607.07800, Belle II Collaboration





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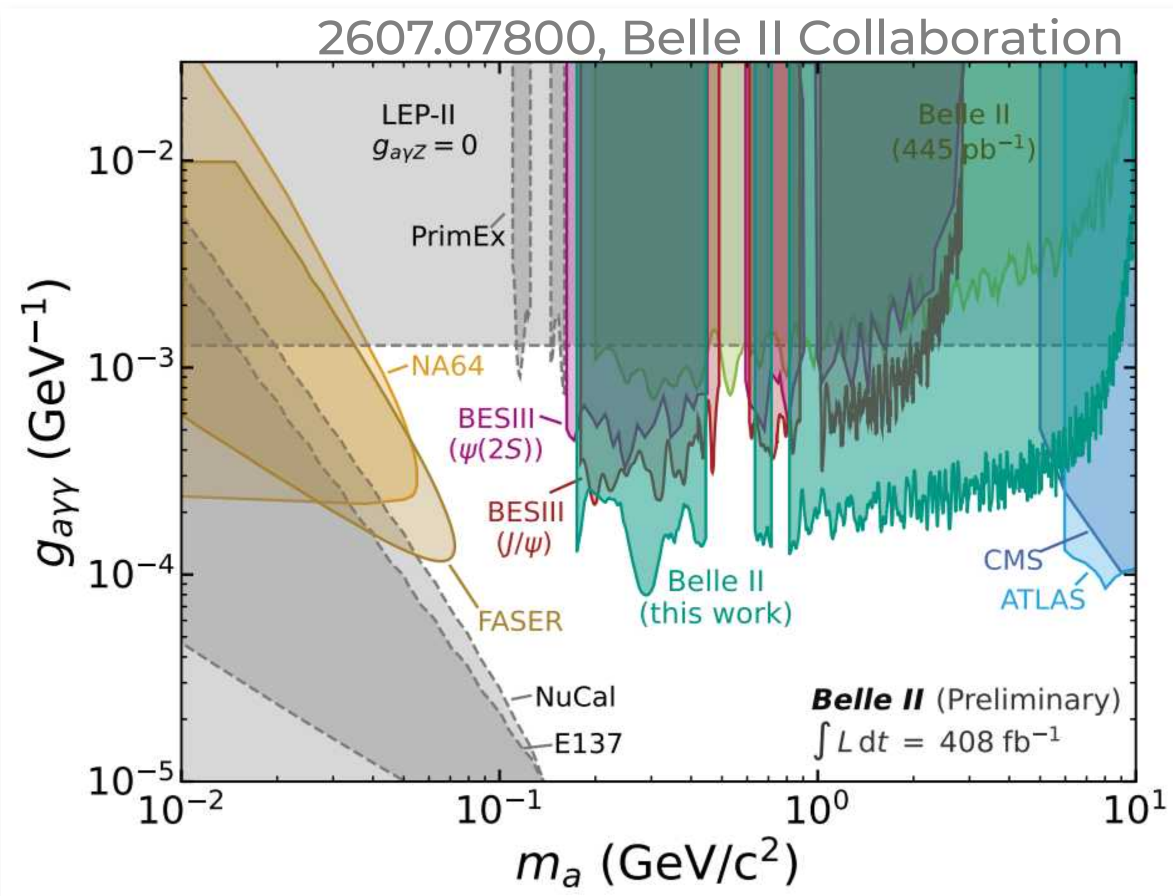

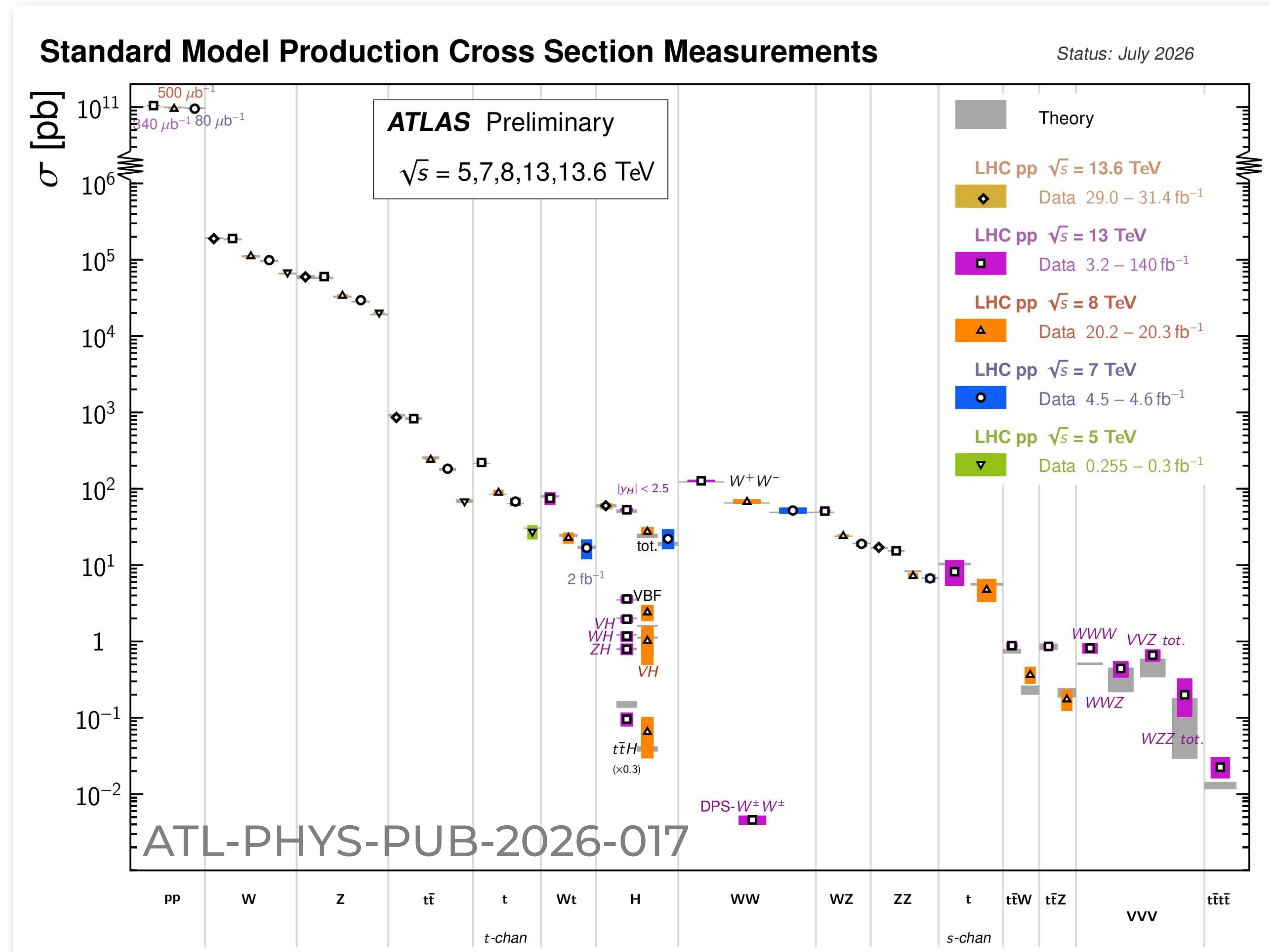

→ No clear evidence for NP

(despite some excesses...)

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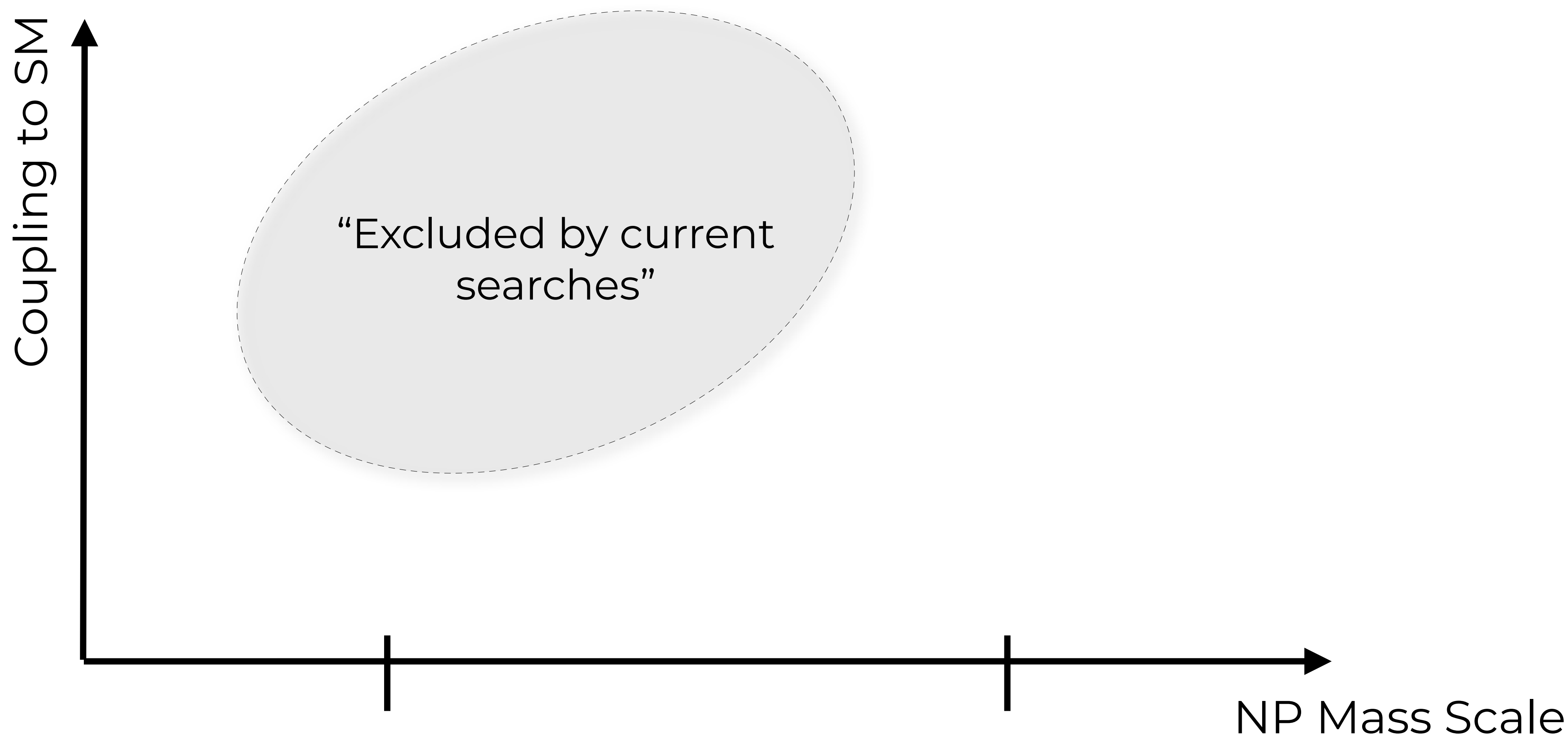

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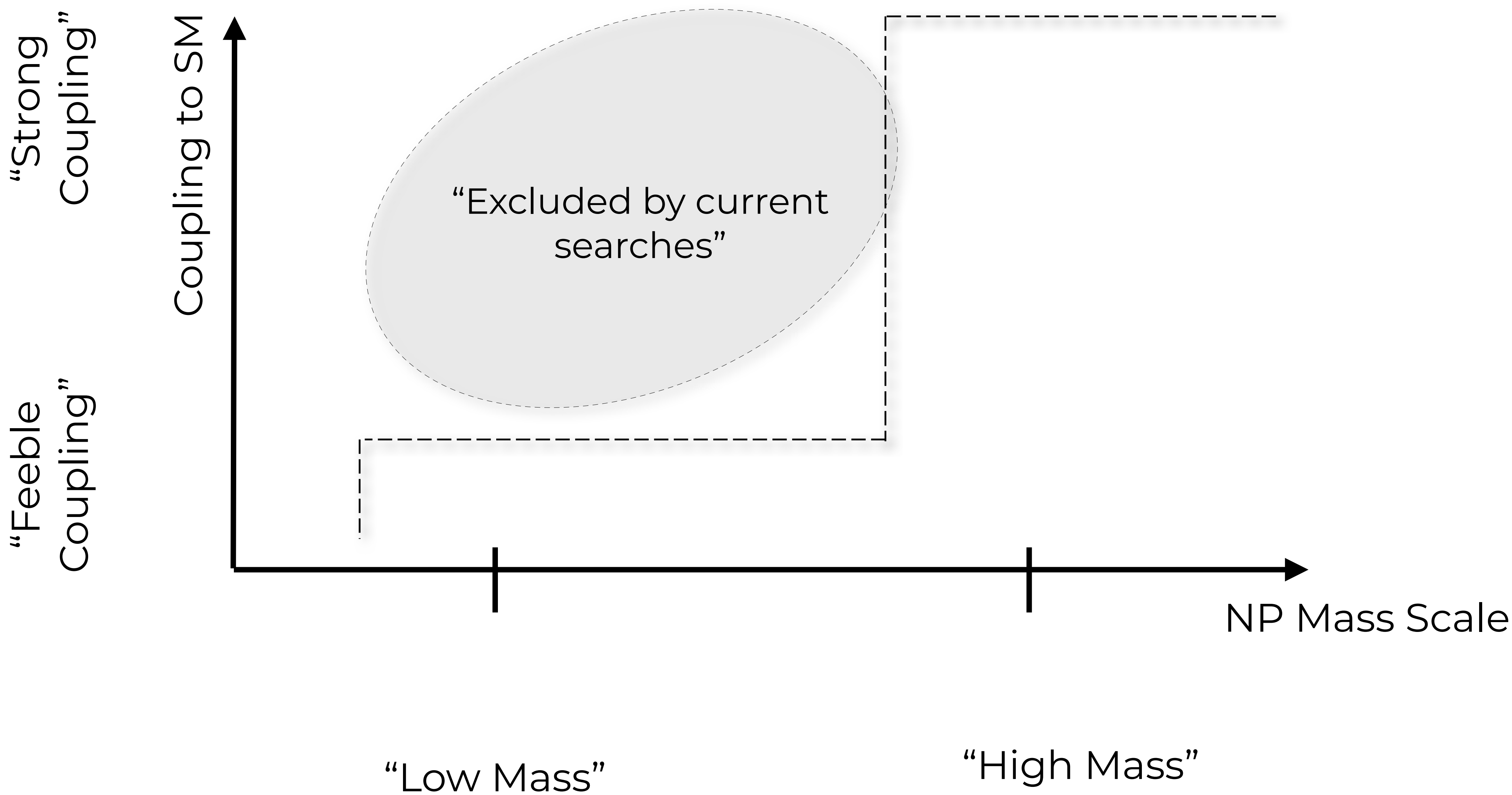

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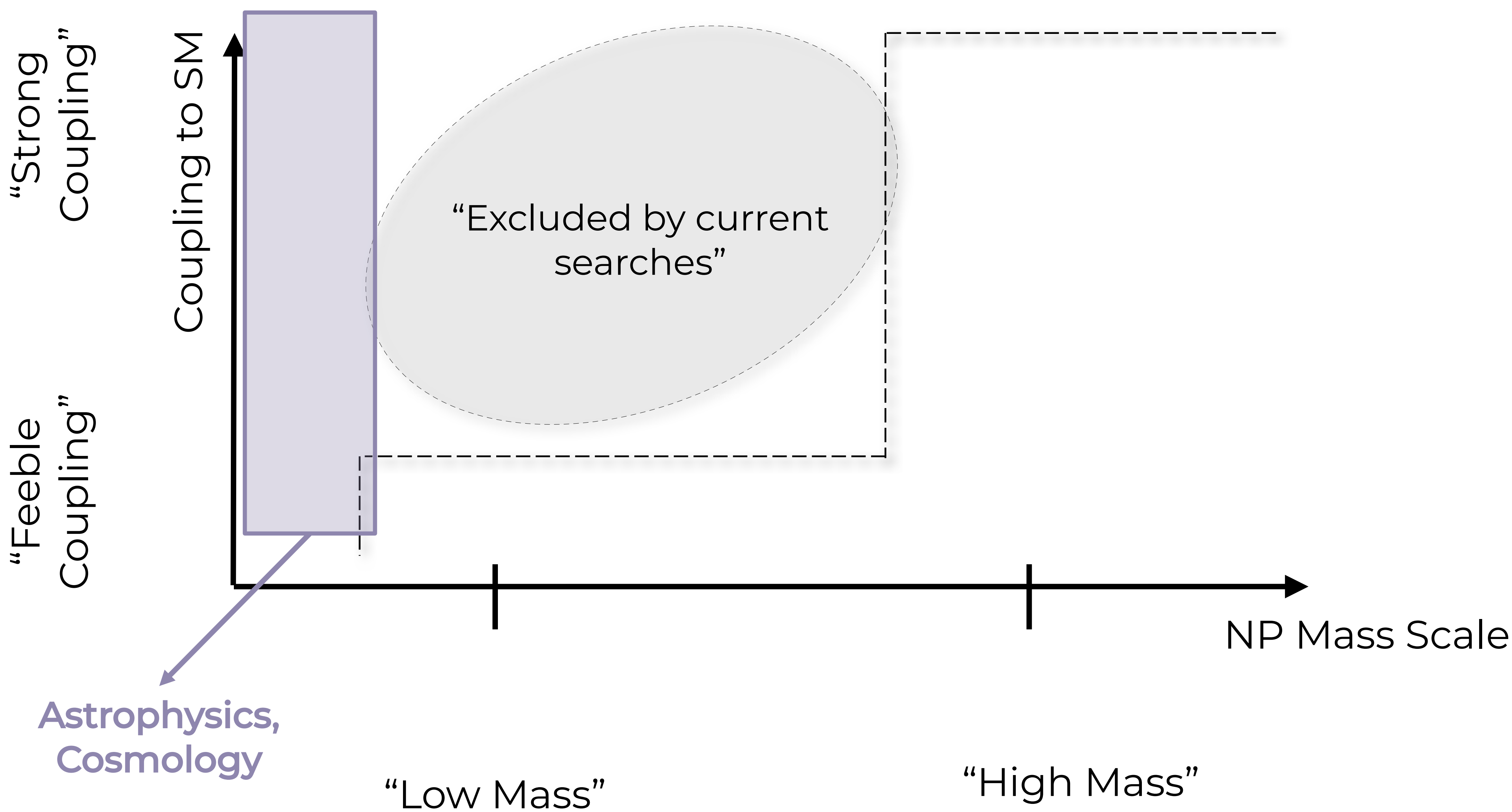

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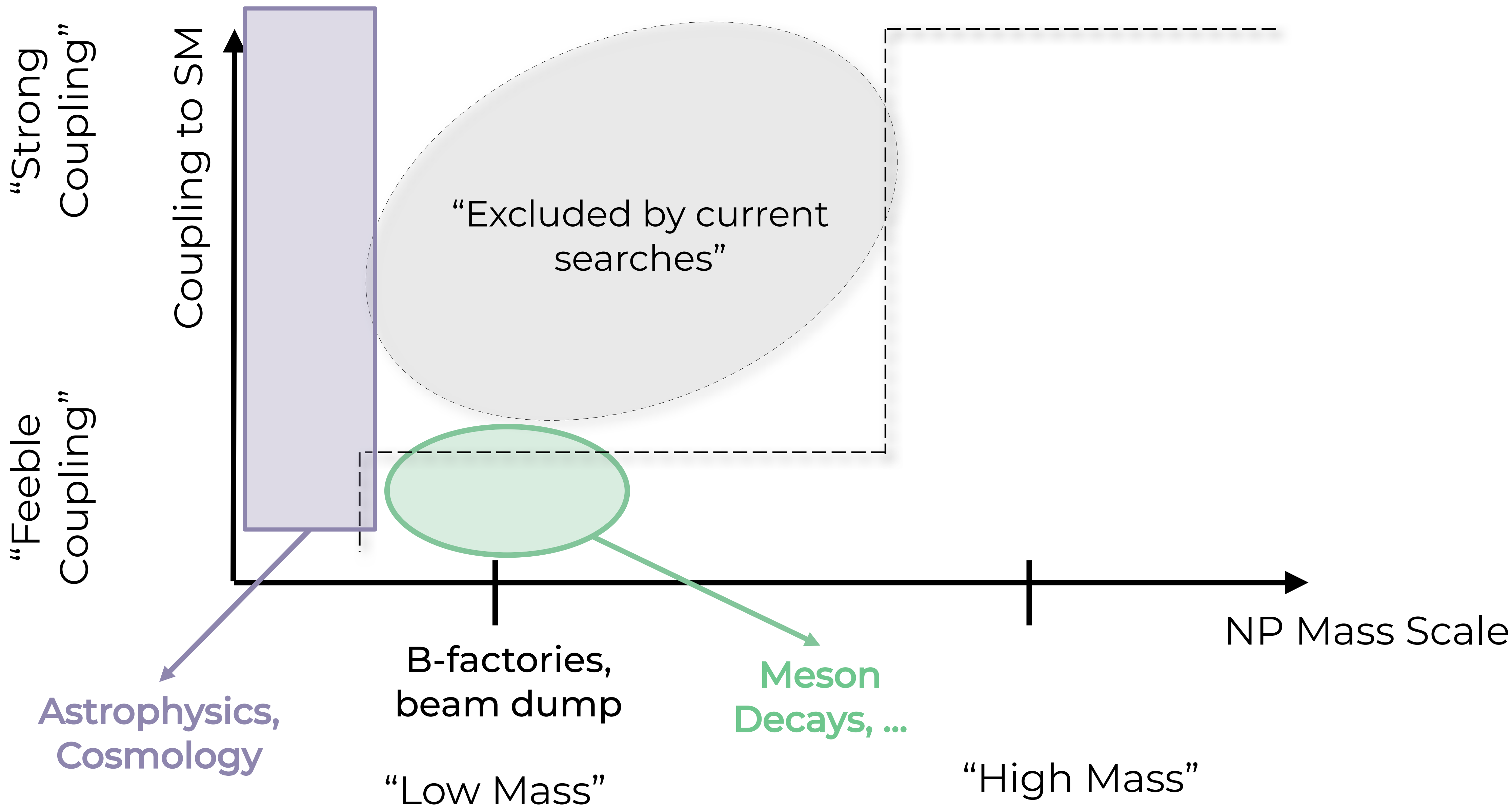

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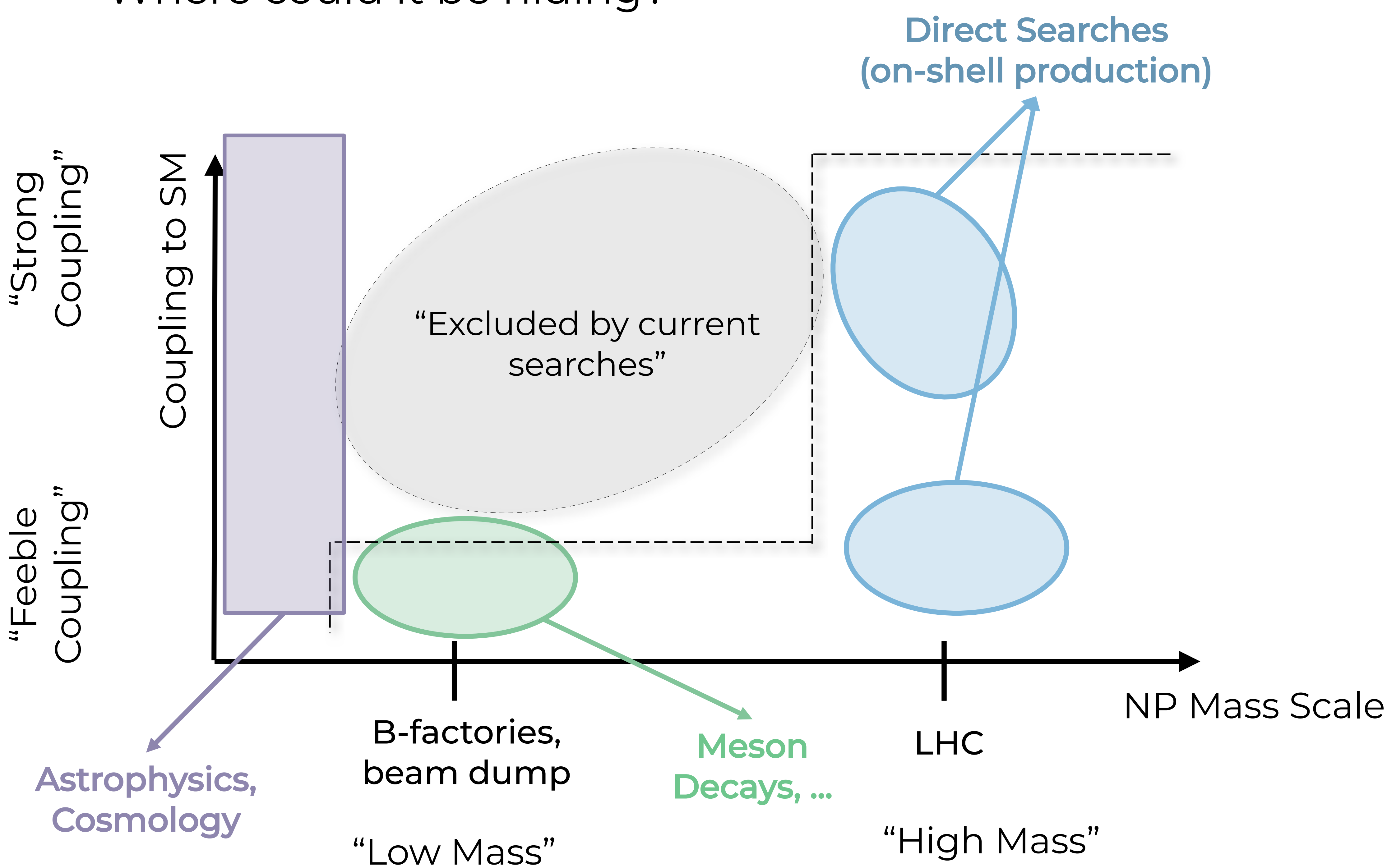

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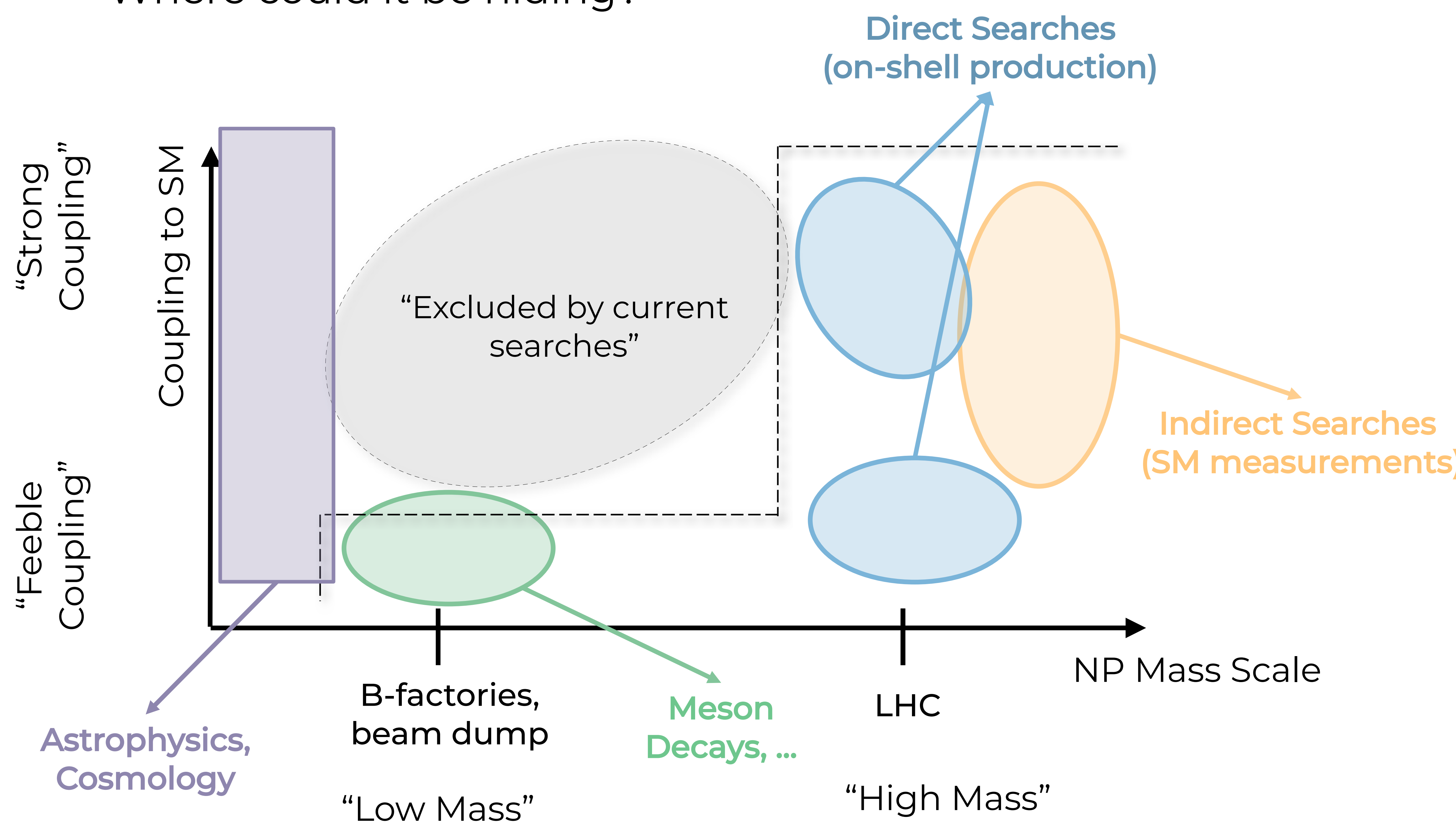

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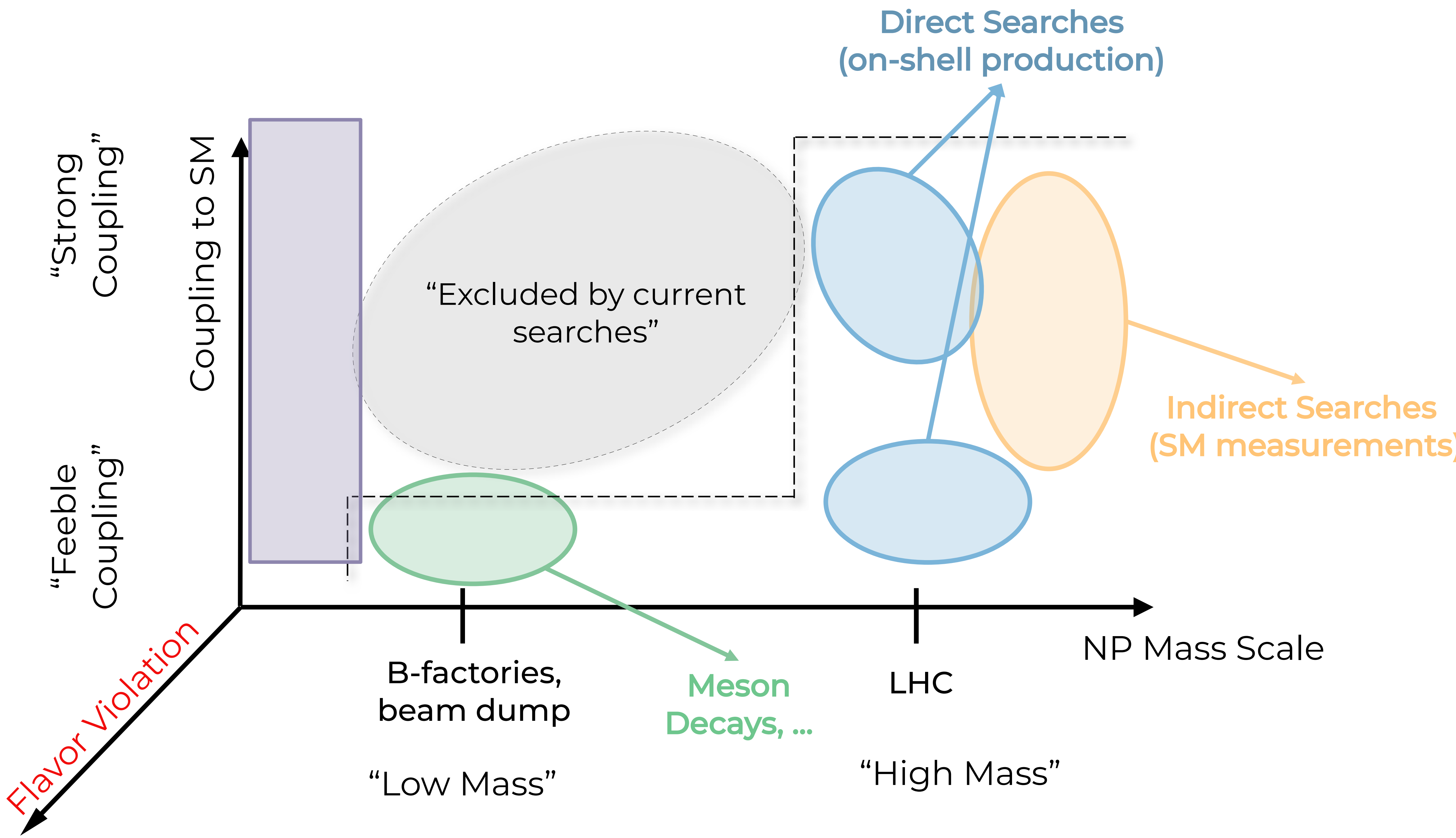
- There is at least a 3rd dimension!



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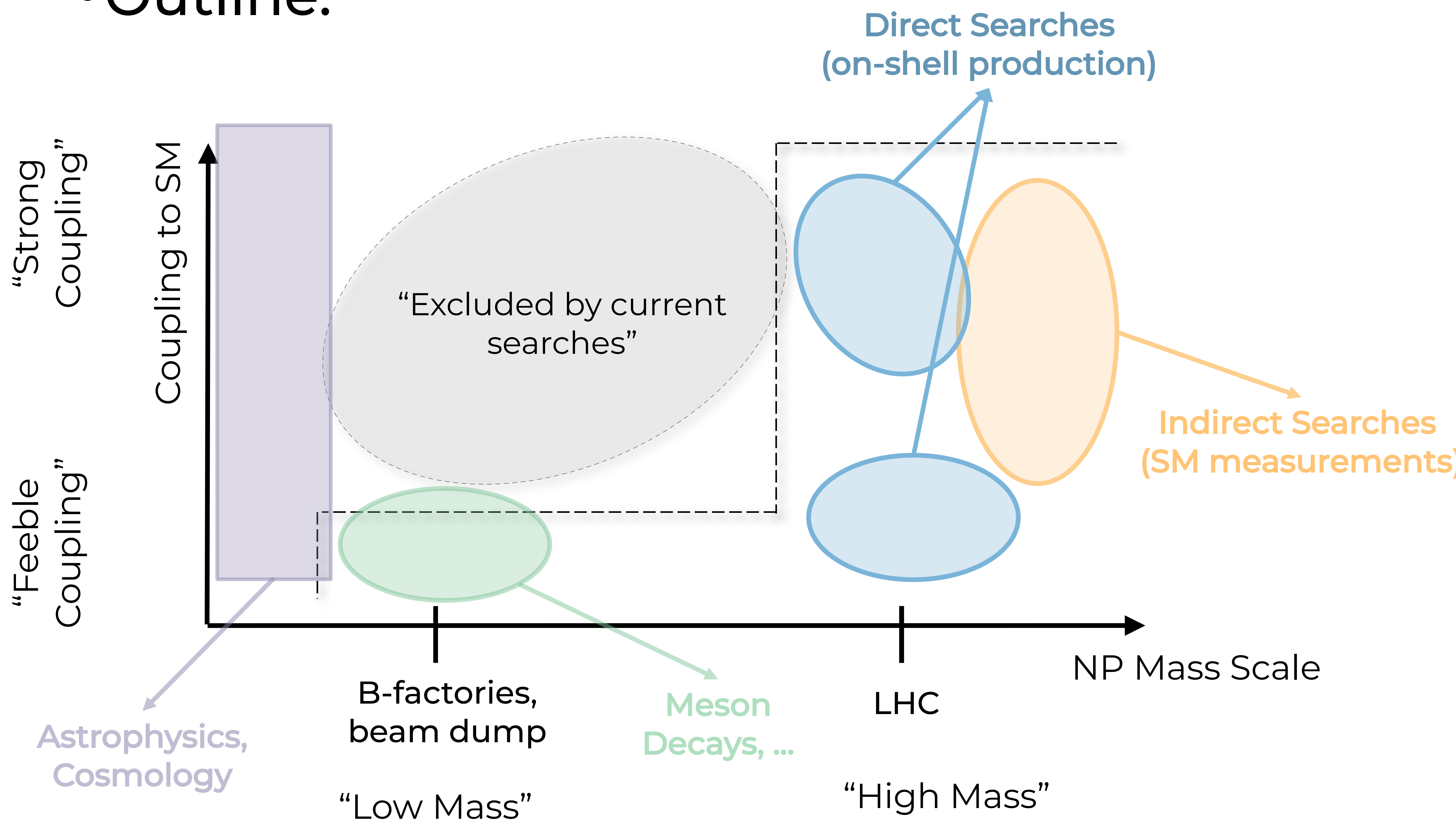

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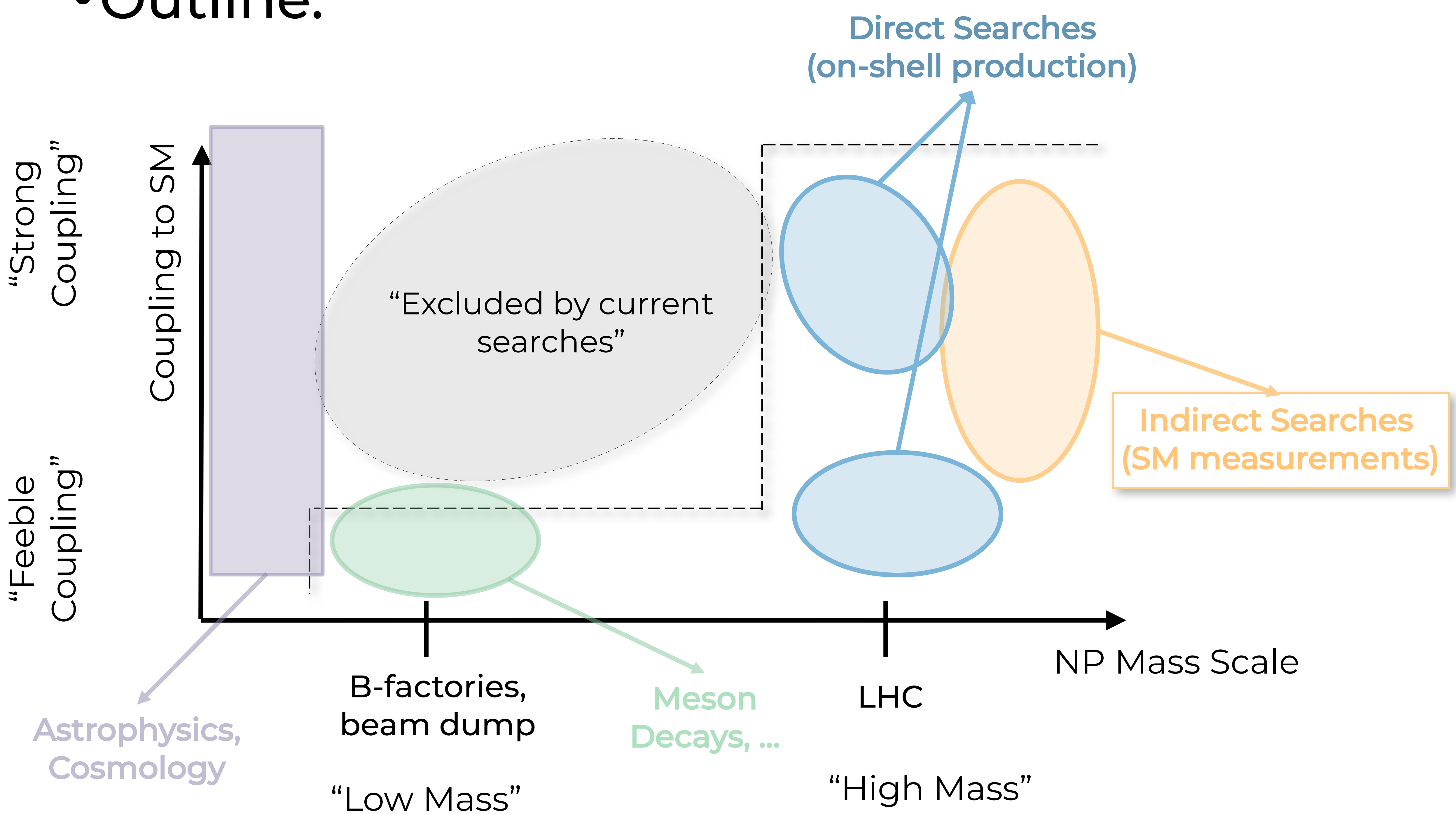

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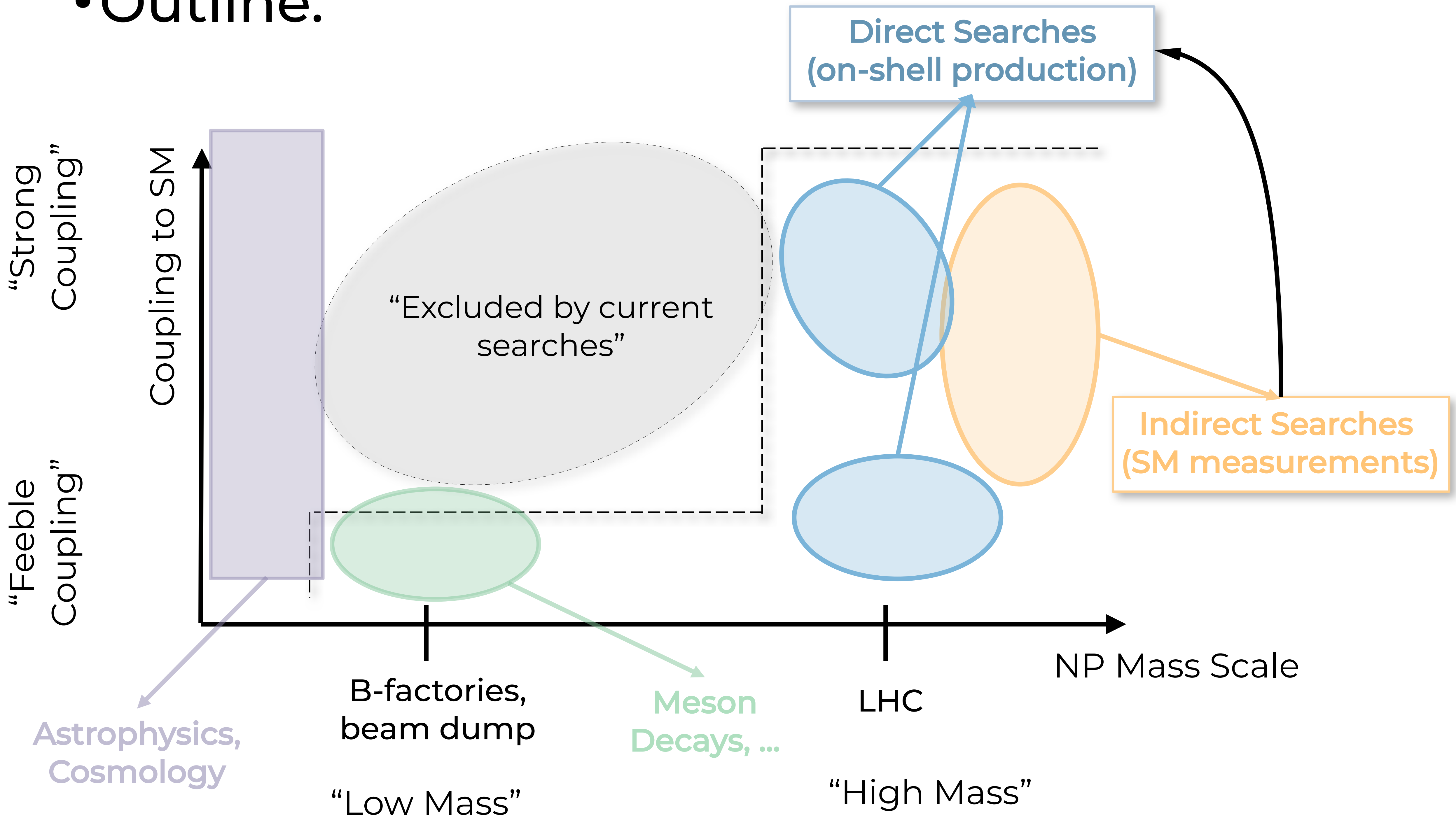

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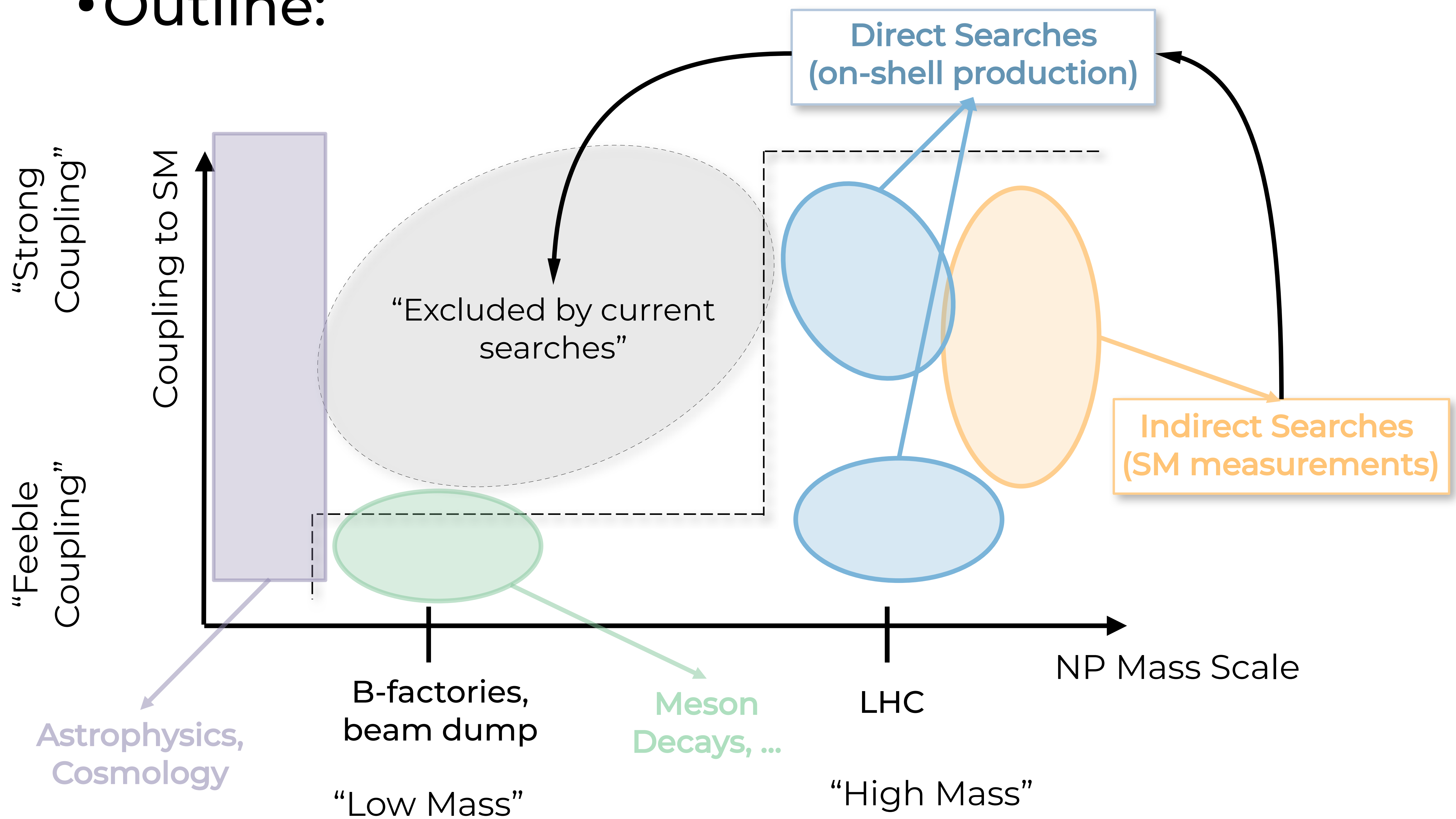

New Physics at High Mass Scales

Heavy New Physics

- If the BSM fields are sufficiently heavy, their impact at low energies can be parametrized by the SM Effective Field Theory (SMEFT):

$$\mathcal{L}_{\mathrm{BSM}}(M_i, g_i, ...) \Rightarrow \mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \frac{C_W}{\Lambda}\mathcal{O}^{(5)}_{\nu\nu} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + ...$$

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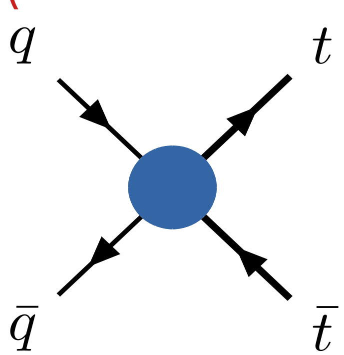
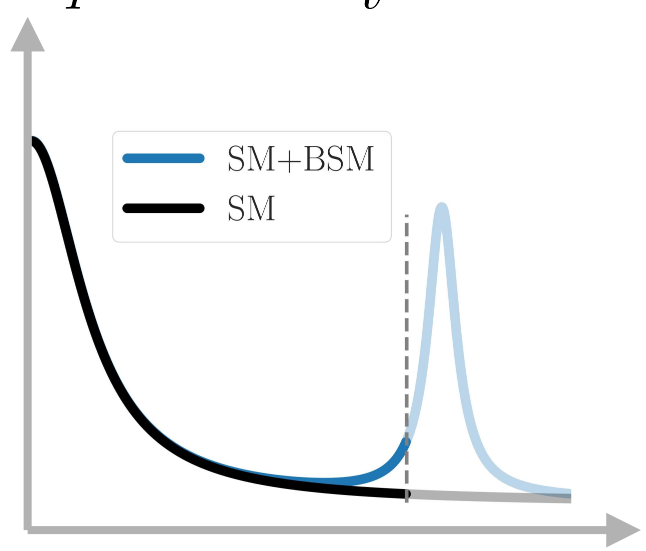
$\Lambda_{\rm BSM} \gg \sqrt{\hat{s}}$

EFT (SM Measurements)





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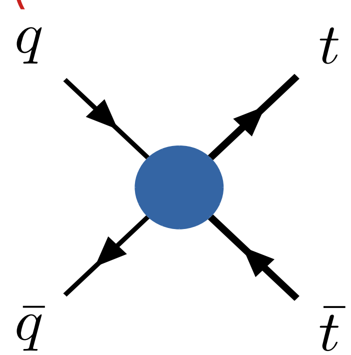
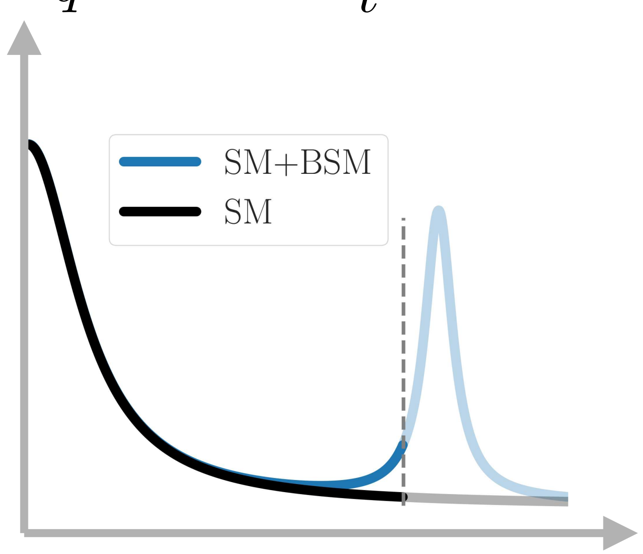




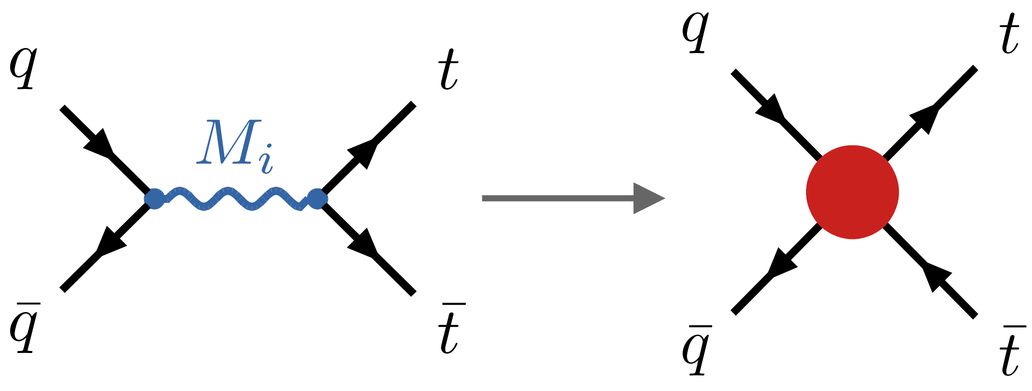
- The SMEFT framework provides a powerful tool for parametrizing BSM contributions to SM observables in a *model independent* way.

- However…
  - It is only valid for NP scales beyond experimental reach
  - It contains a large number of free parameters:

    60 operators (up to dim-6) → 2,500 Wilson coefficients

SMEFT Operators

- Operators can be induced at tree-level:



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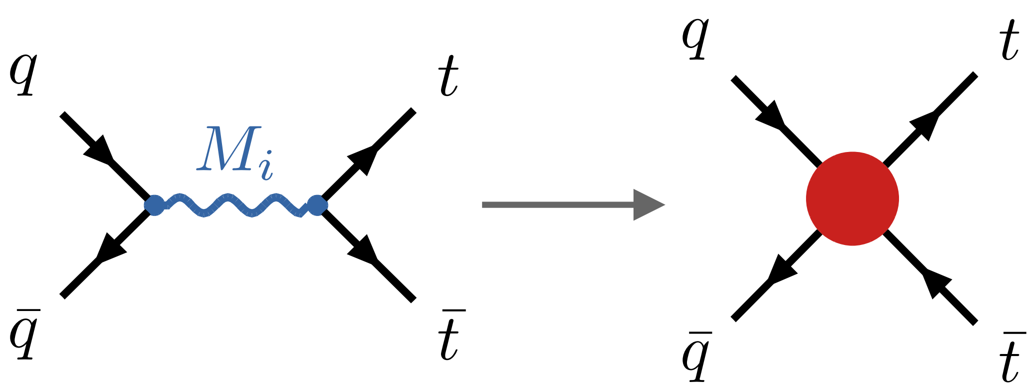

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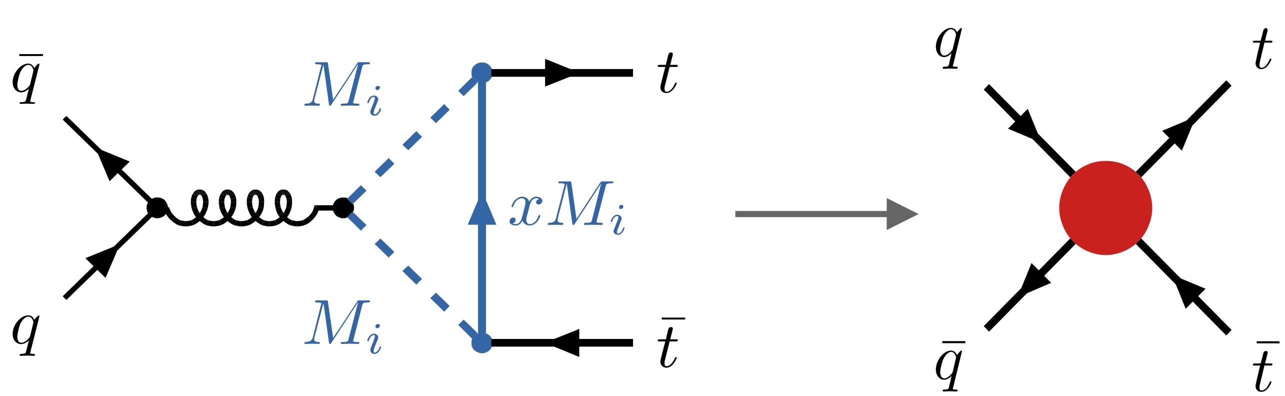
- Or at (n) loop-level:



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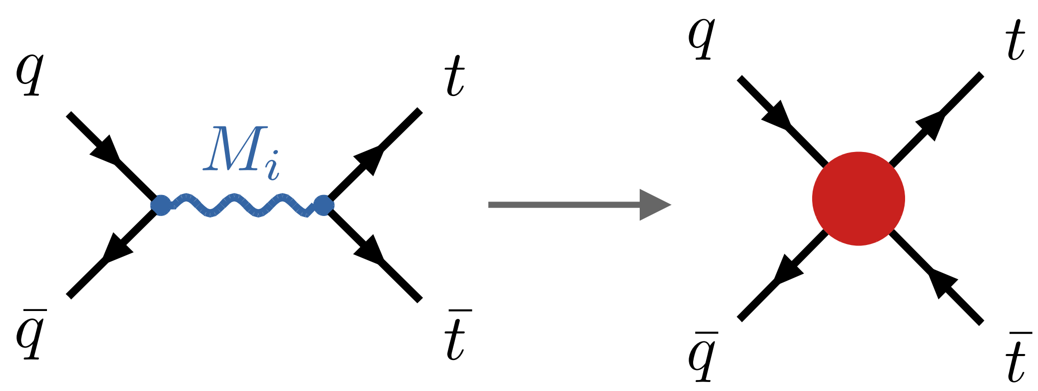

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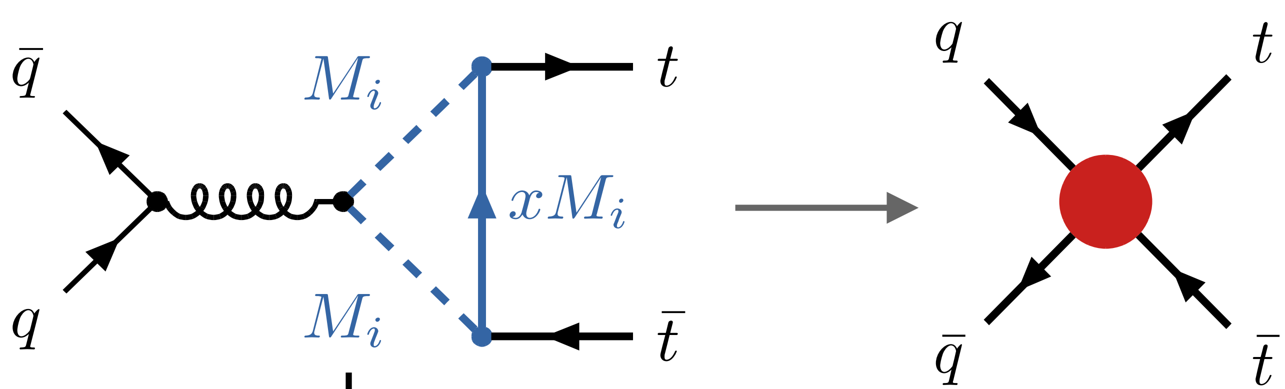

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Often the case if:

- DM is the lightest BSM state
- appears in the loop and
- is protected by a Z_2-type symmetry

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    - single-Higgs data
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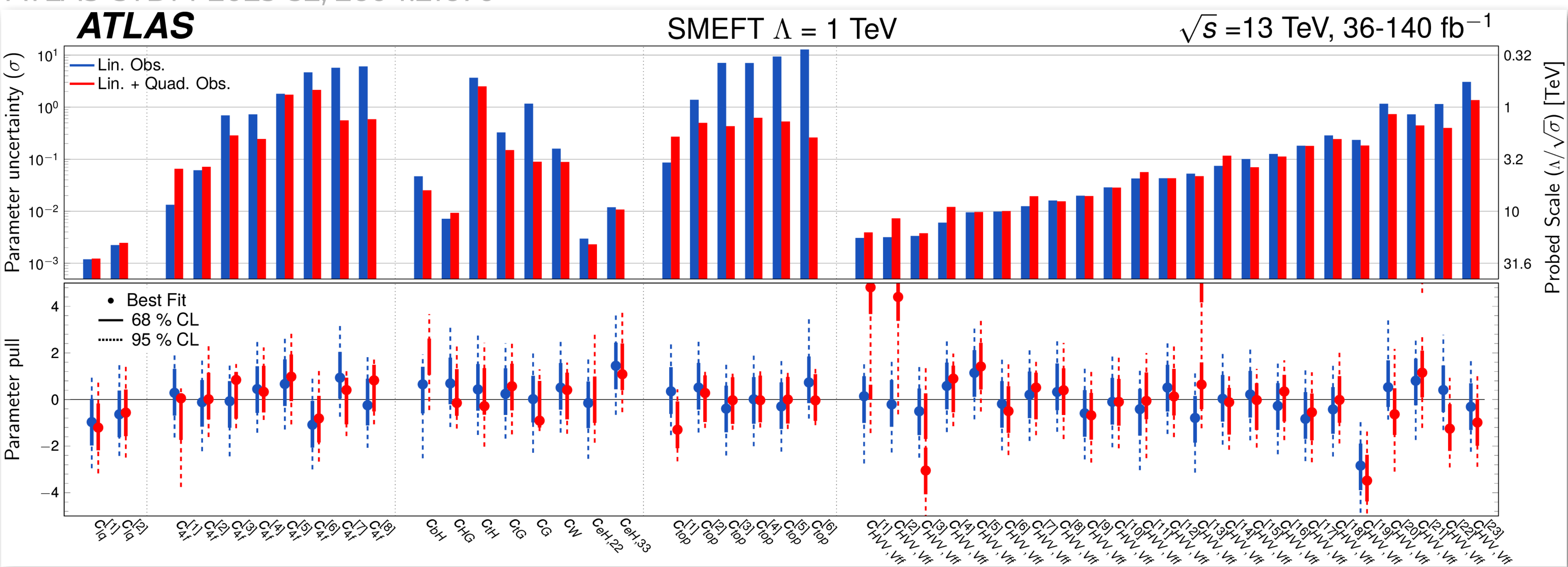
ATLAS-STDM-2023-32, 2604.21670



- Combined fit: all nuisance parameters and other WCs are profiled

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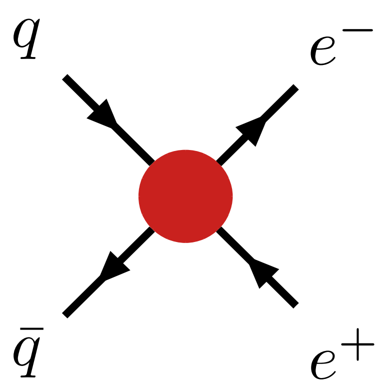
$$\mathcal{O}_{lq}^{(1)} = \bar{L}\gamma^{\mu}L\bar{Q}\gamma_{\mu}Q$$



$$M_i \gtrsim 15\, g_{\rm NP}\ \text{TeV}\ (95\%\ \text{C.L.})$$ (tree-level operators)

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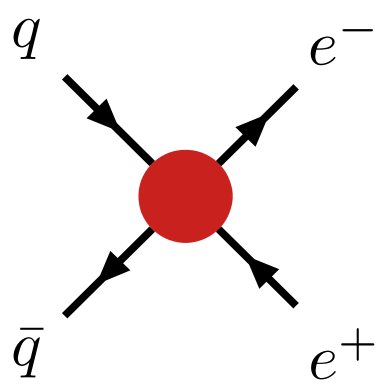

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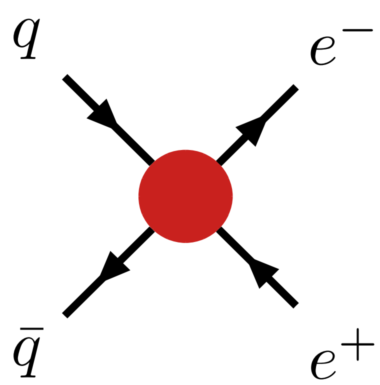

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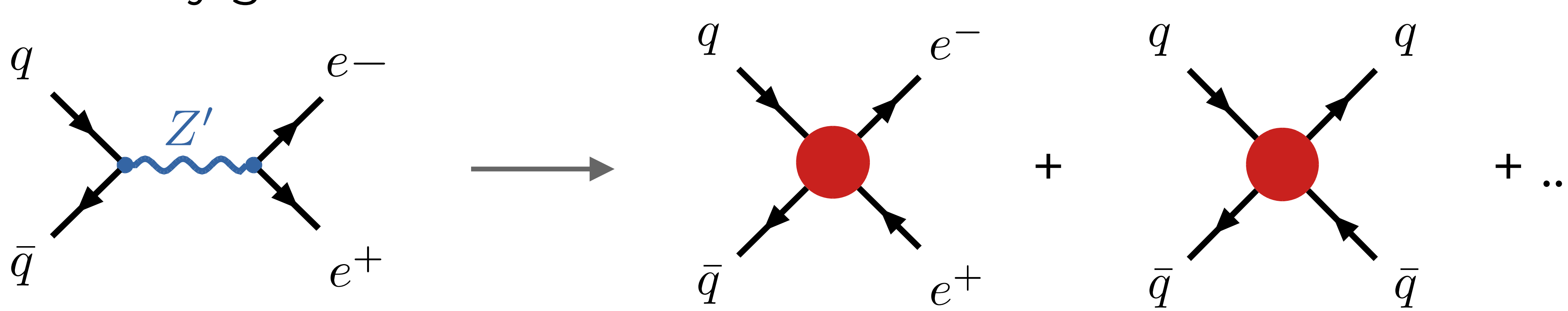
- However, given a BSM model several correlated coefficients will be simultaneously generated:



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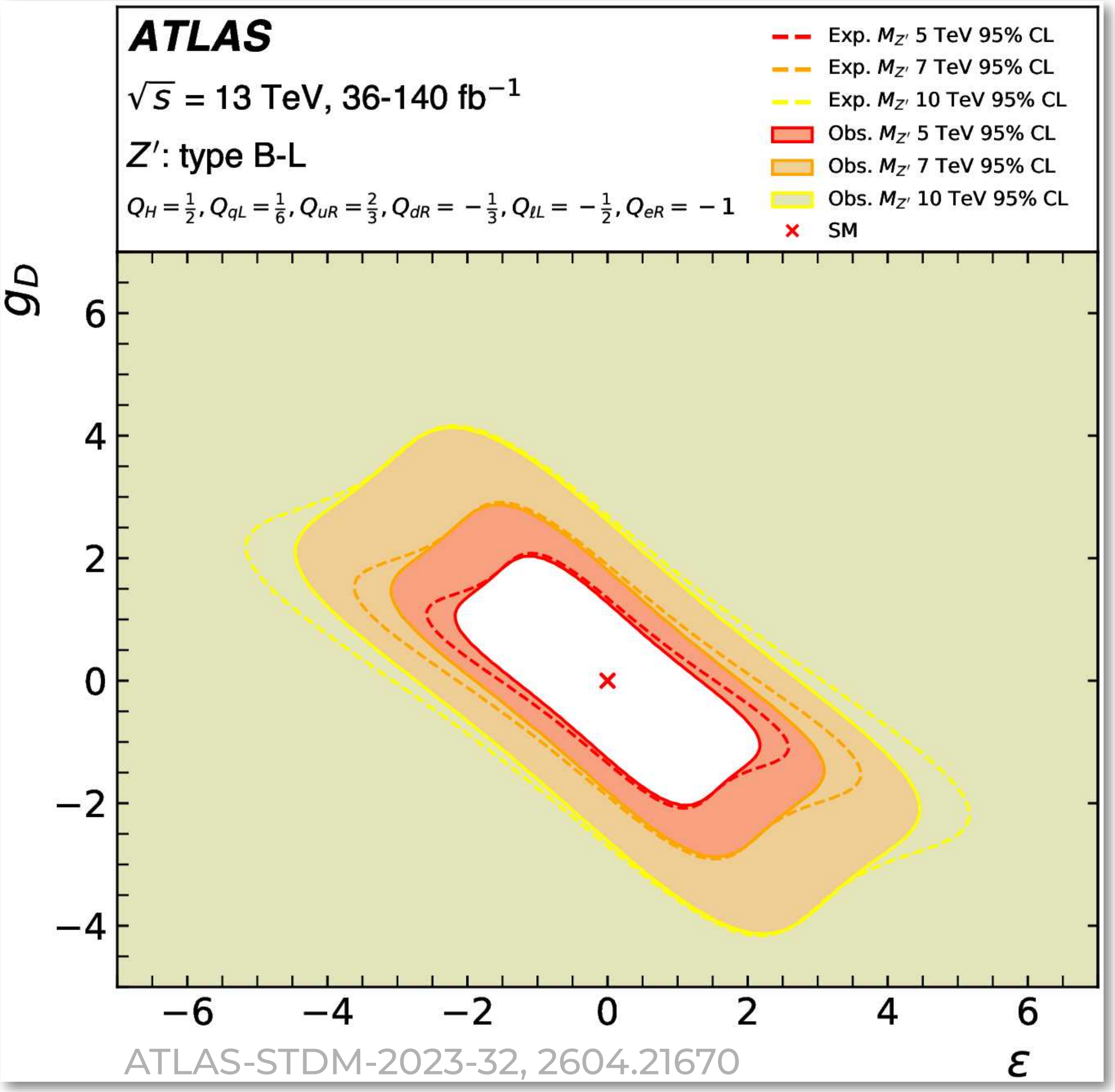

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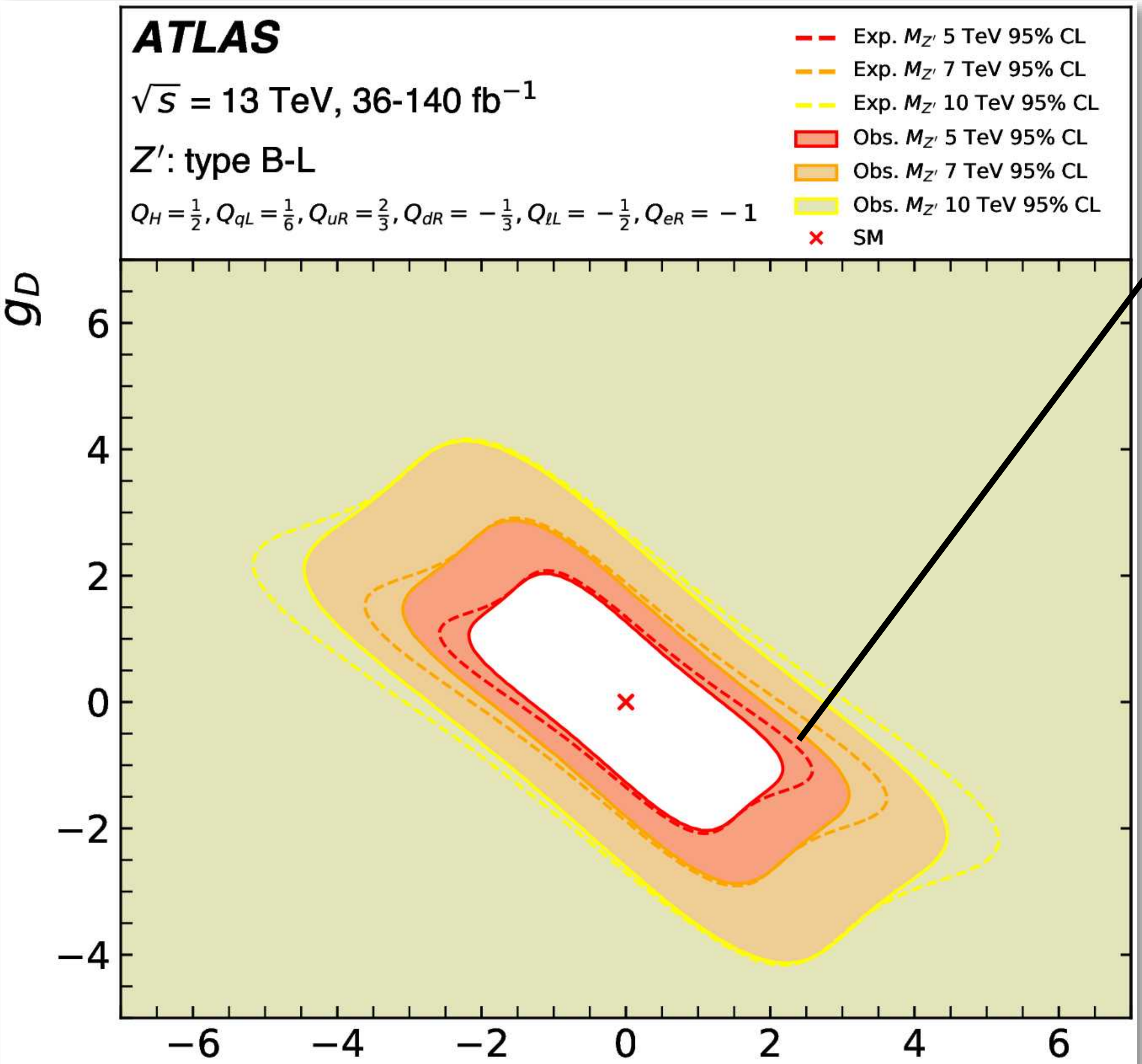

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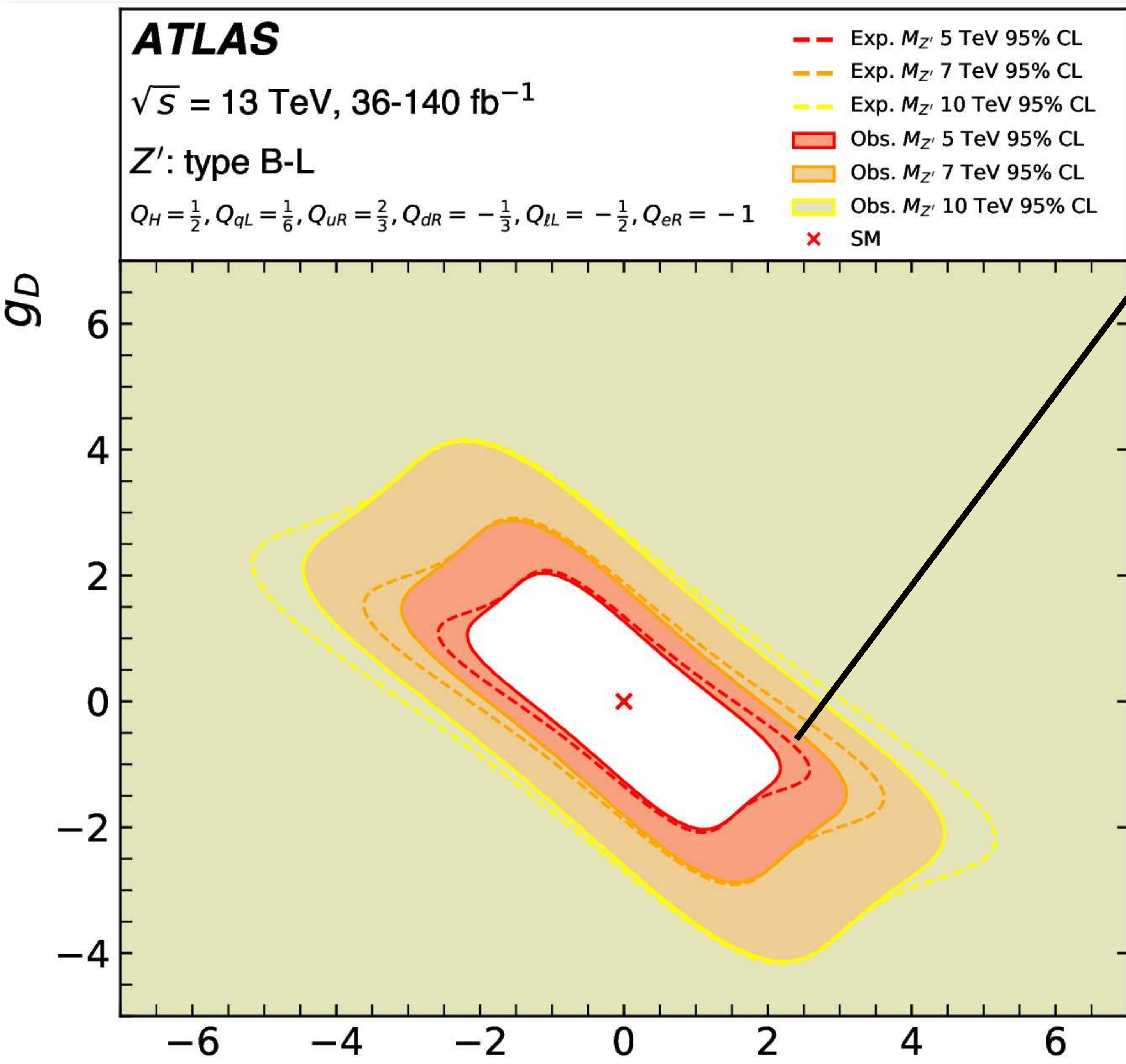

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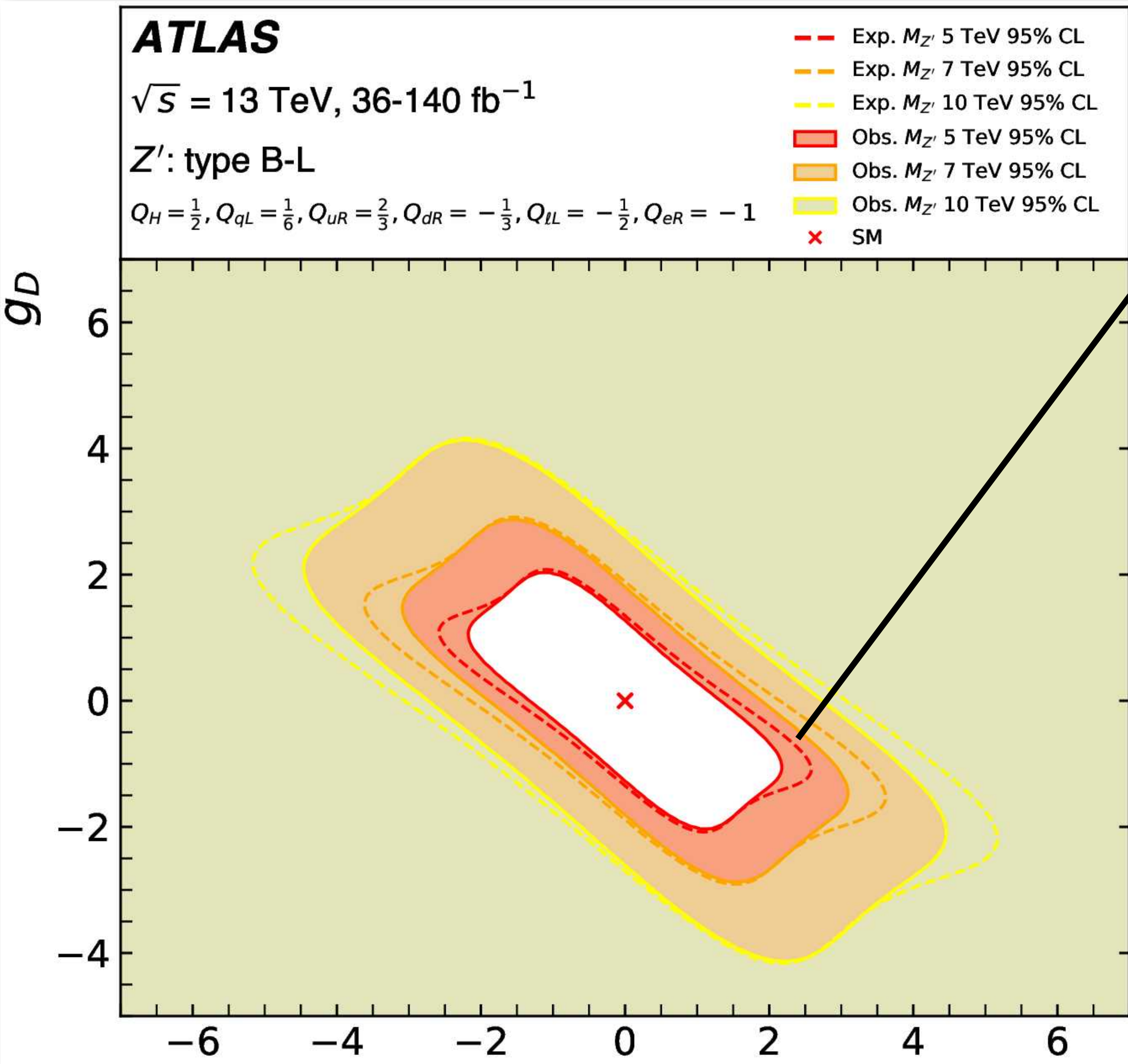

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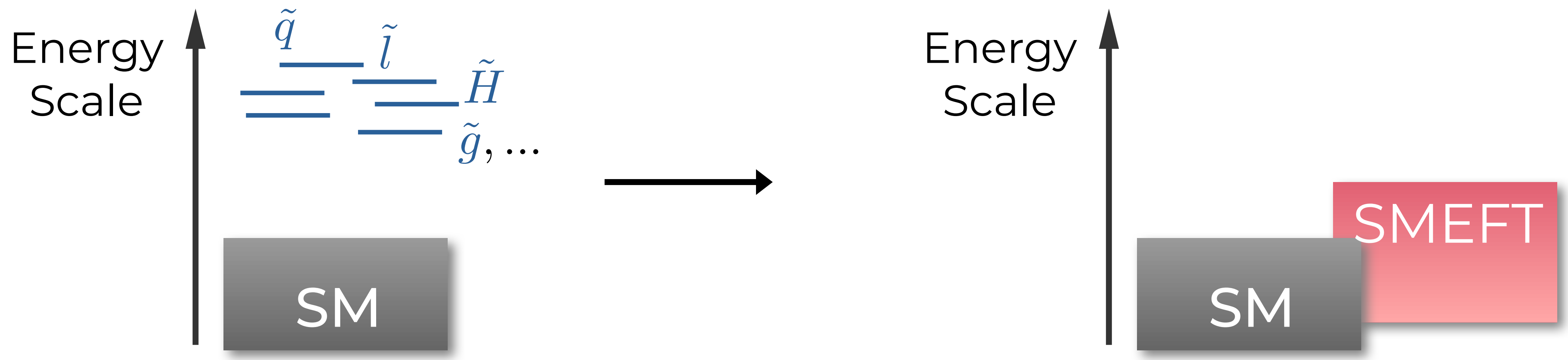
- However…
  - More complex BSM scenarios will generate a large number of WCs
  - Can these constraints be sensitive to complex models, such as the Minimal Supersymmetric SM (MSSM)?

MSSM to SMEFT

- Assuming all superfields and additional Higgs are heavy:



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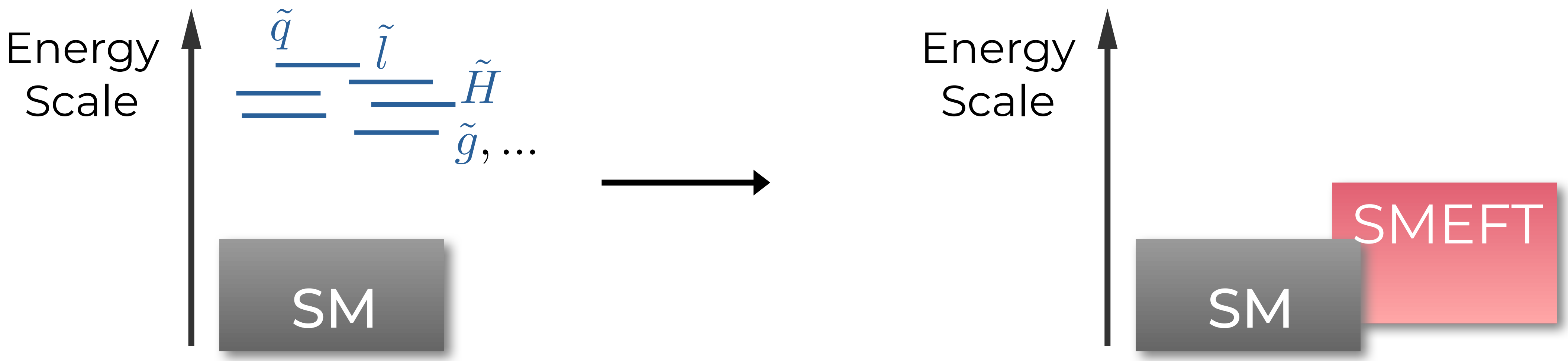

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- We used Matchete to compute the MSSM→ SMEFT matching

MSSM
(31 fields)

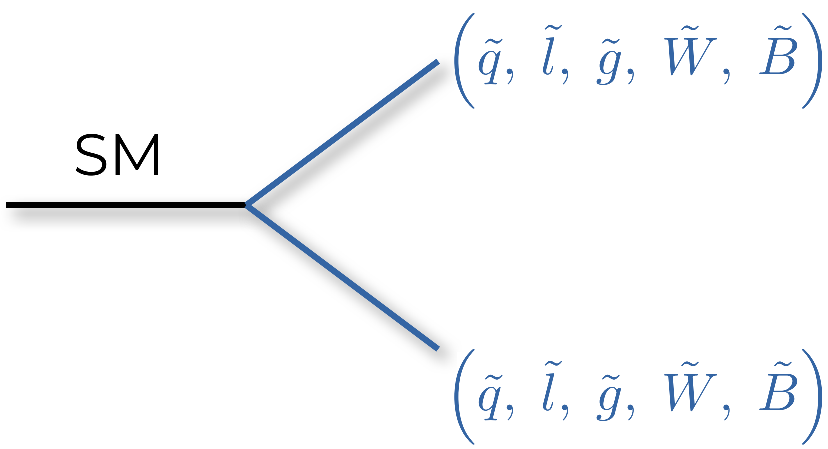
MATCHETE

Functional methods (CDE) →

SMEFT
(Warsaw basis)

Matching Results

- dim-6 Operators:
  - All the R-odd fields (squarks, sleptons, gauginos) appear in pairs when coupling to the SM fields:



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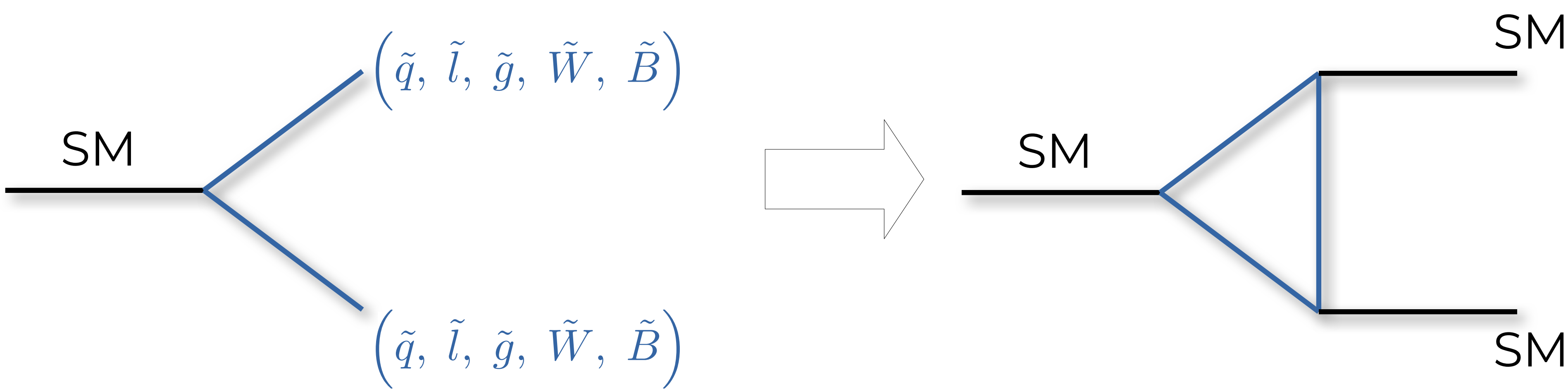

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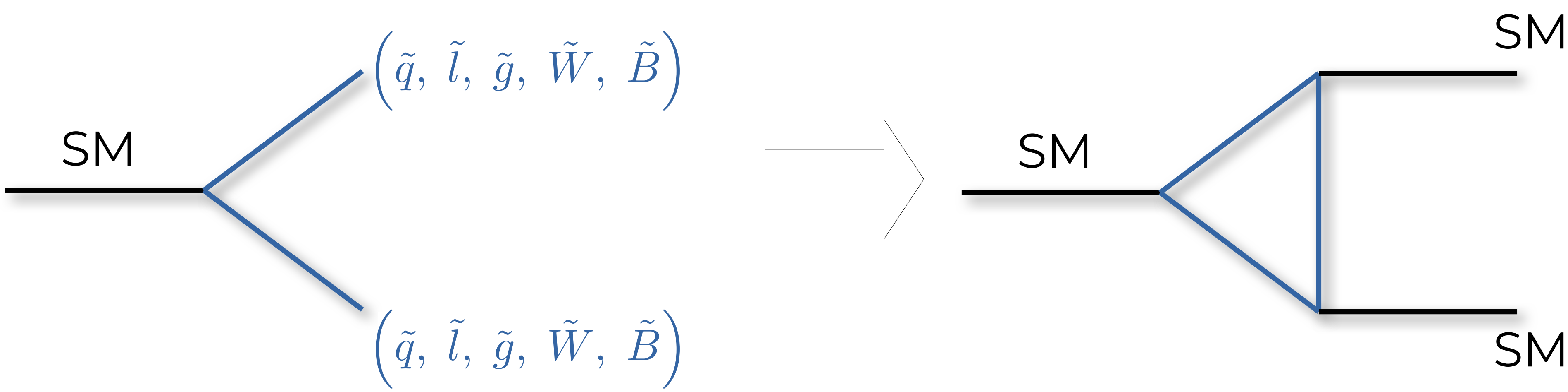

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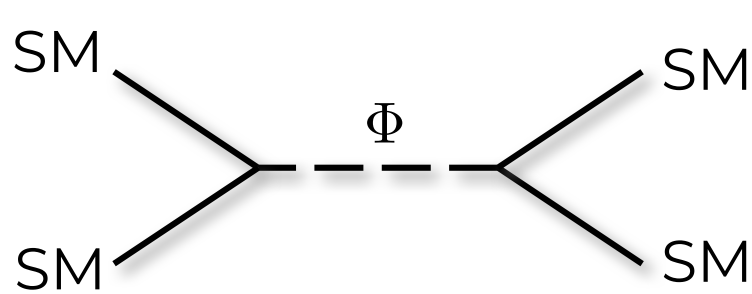

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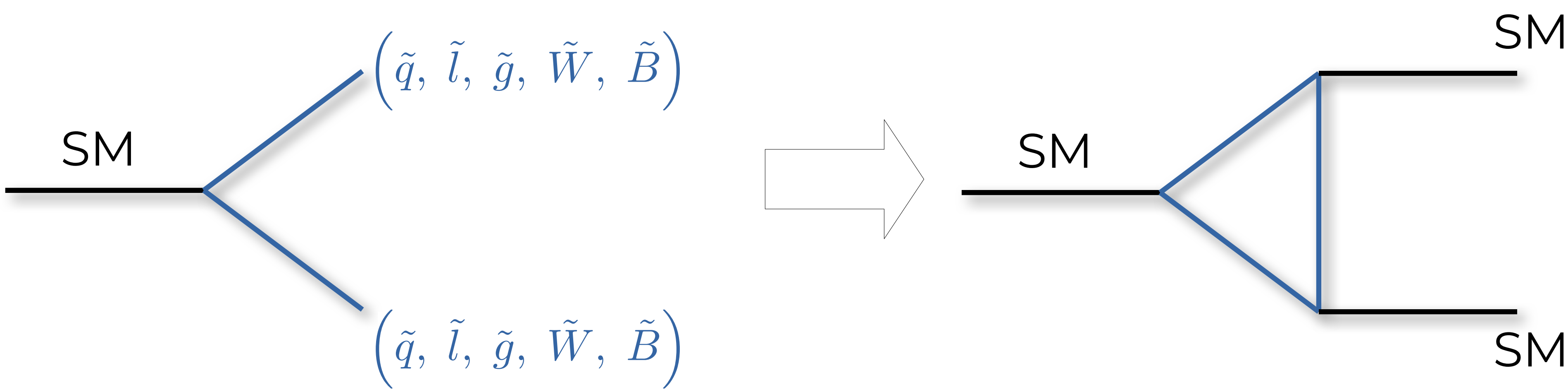

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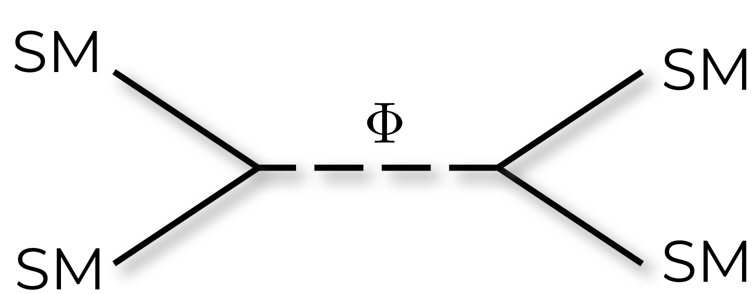

$$C_H = \frac{\sin^2(4\beta)}{m_\Phi^2} \frac{\left(g_1^2 + g_2^2\right)^2}{64}\,,$$

$$C_{qu}^{(1)prst} = \frac{1}{6} C_{qu}^{(8)prst} = -\frac{\cot^2\beta}{6m_\Phi^2} Y_u^{*rs} Y_u^{pt}\,,$$

$$\ldots$$

Fully correlated

Stop-Bino case

- "Light" Stop-Bino case: $v \ll m_{\tilde{t}_R},\ m_1 \ll m_{\text{SUSY}} \longrightarrow$ 22 WCs (8 LI)

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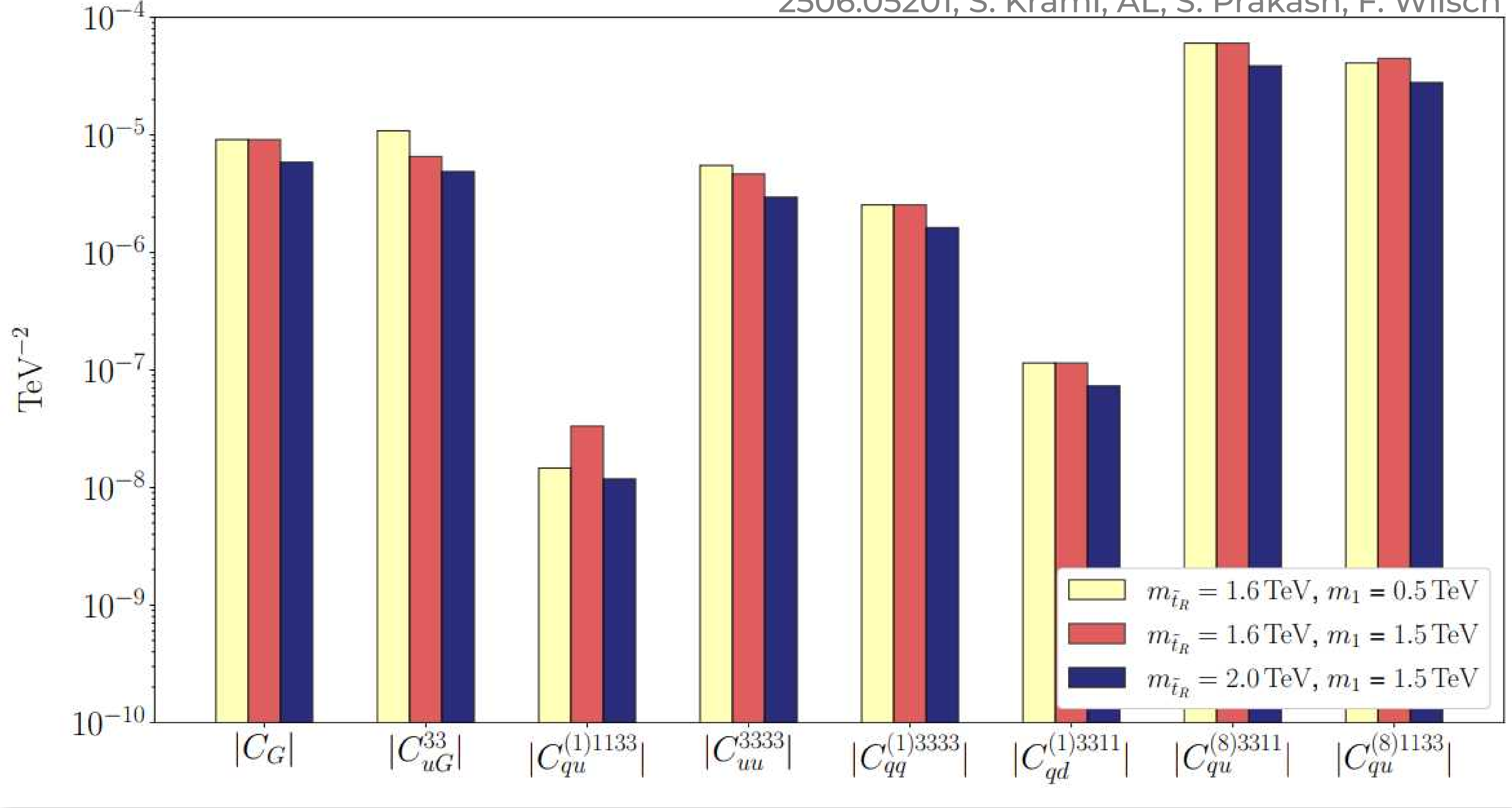
2506.05201, S. Kraml, AL, S. Prakash, F. Wilsch



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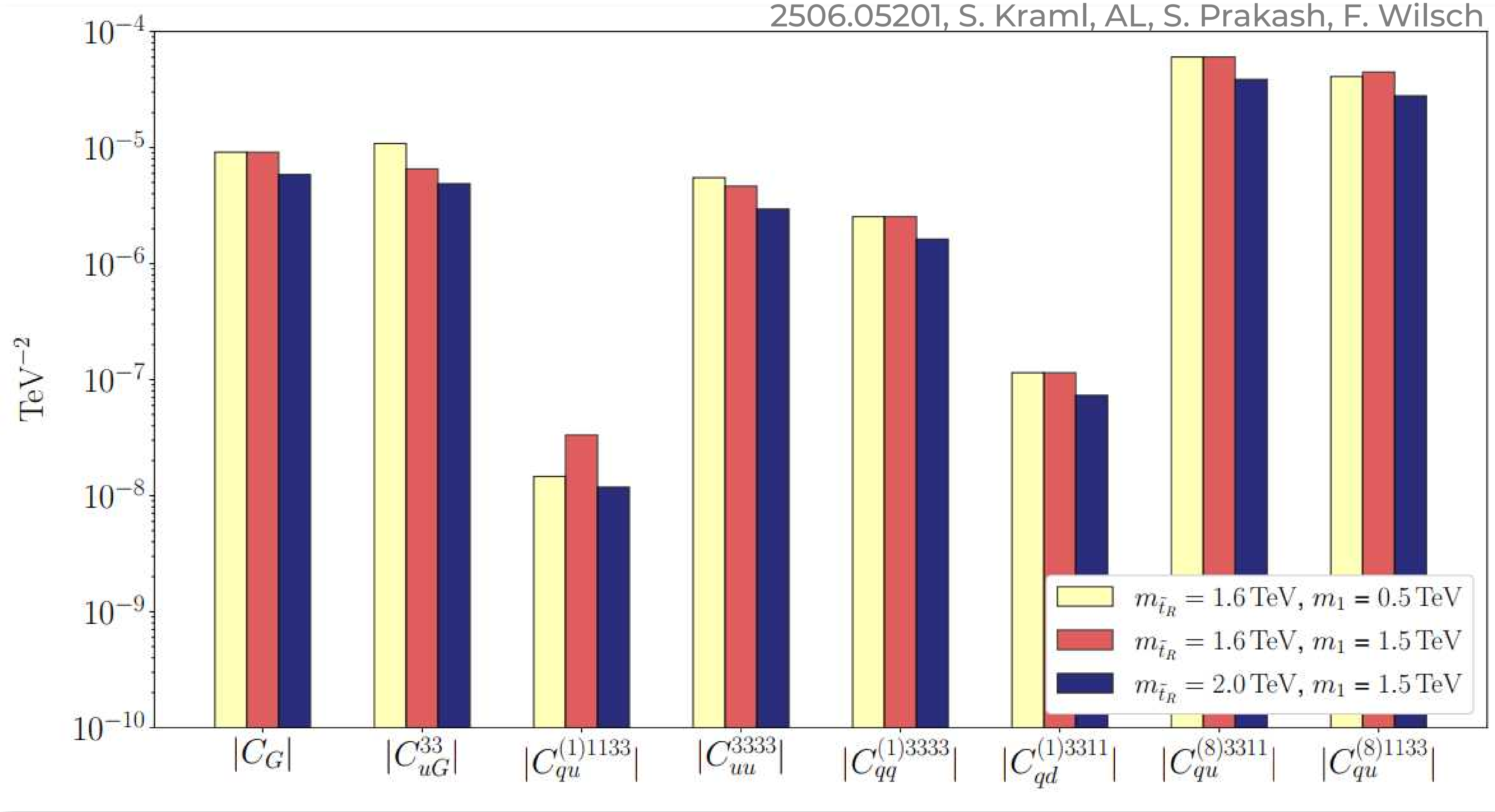

→ Simple fits are still far from probing the MSSM!

Going Beyond EFTs

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$\Lambda < \sqrt{\hat{s}}$

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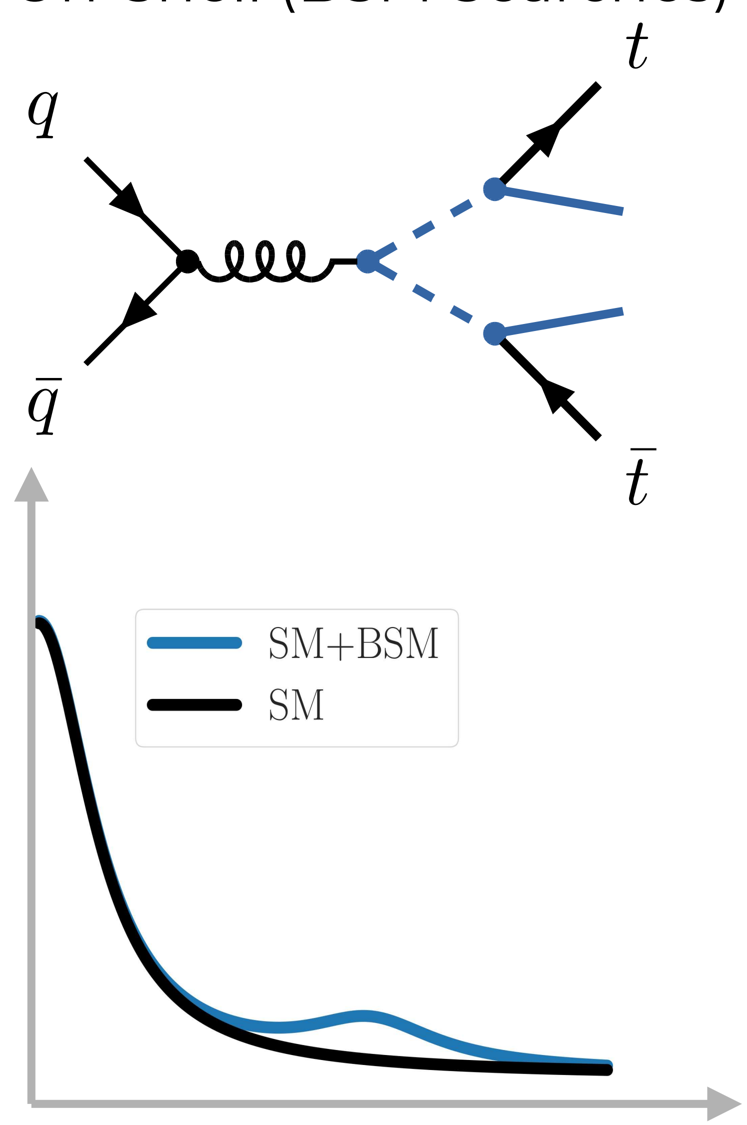

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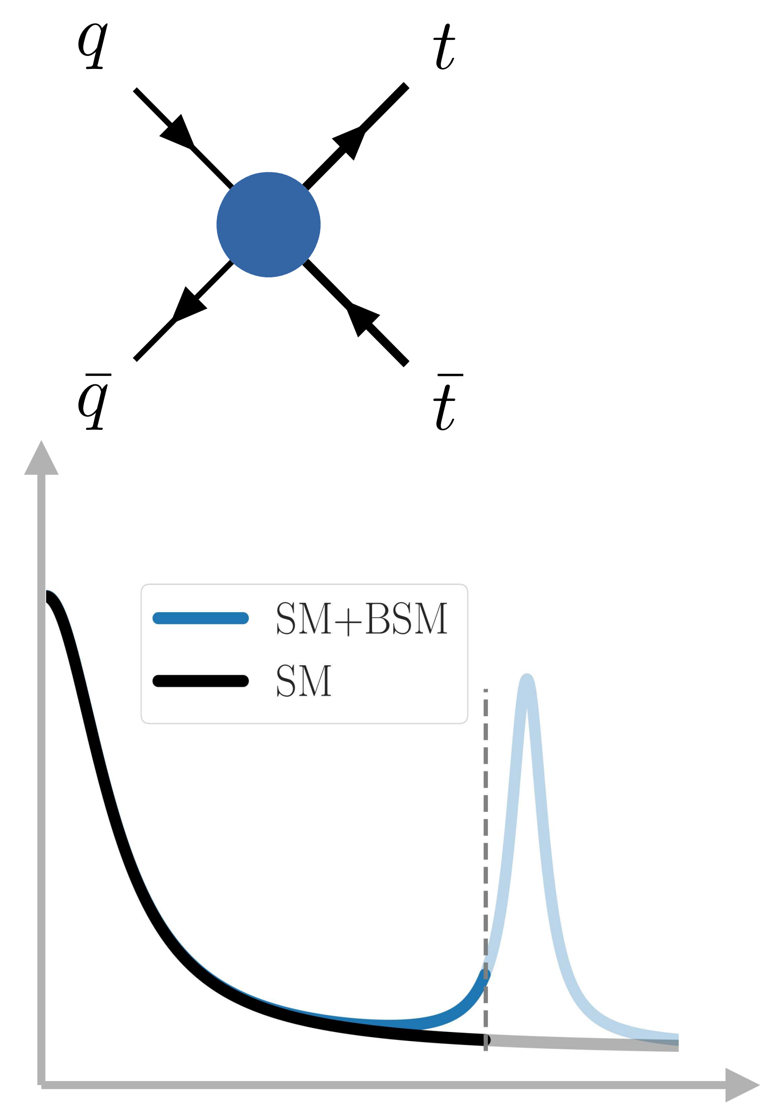

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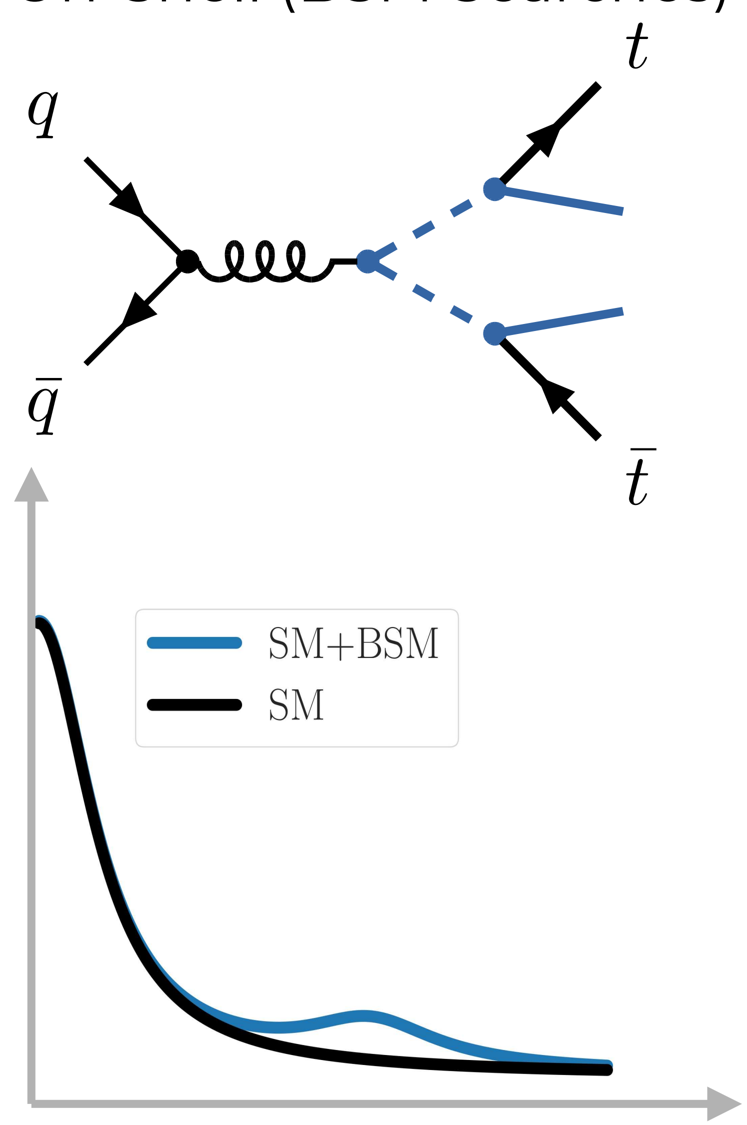
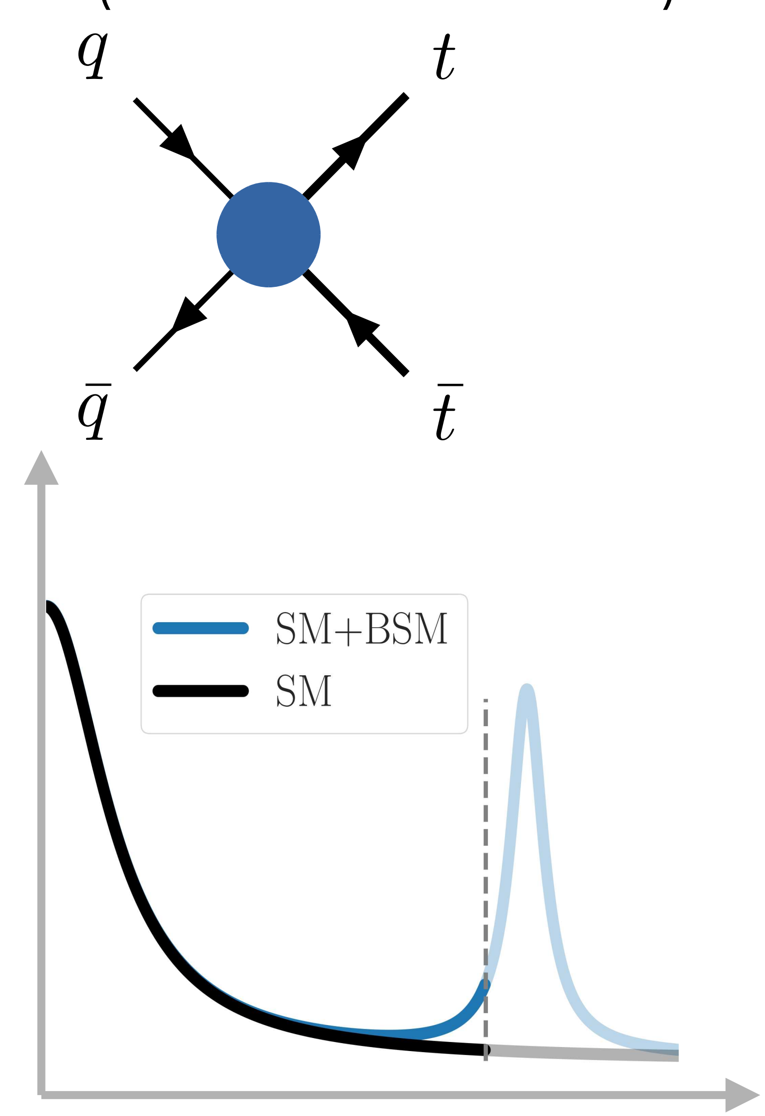


$\Lambda \simeq \sqrt{\hat{s}}$

"Beyond EFT" regime

$\Lambda \gg \sqrt{\hat{s}}$

EFT (SM Measurements)



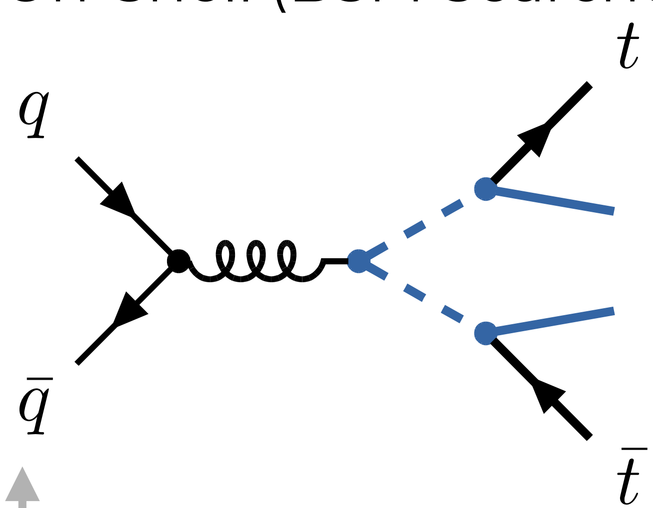
André Lessa | IFUSP

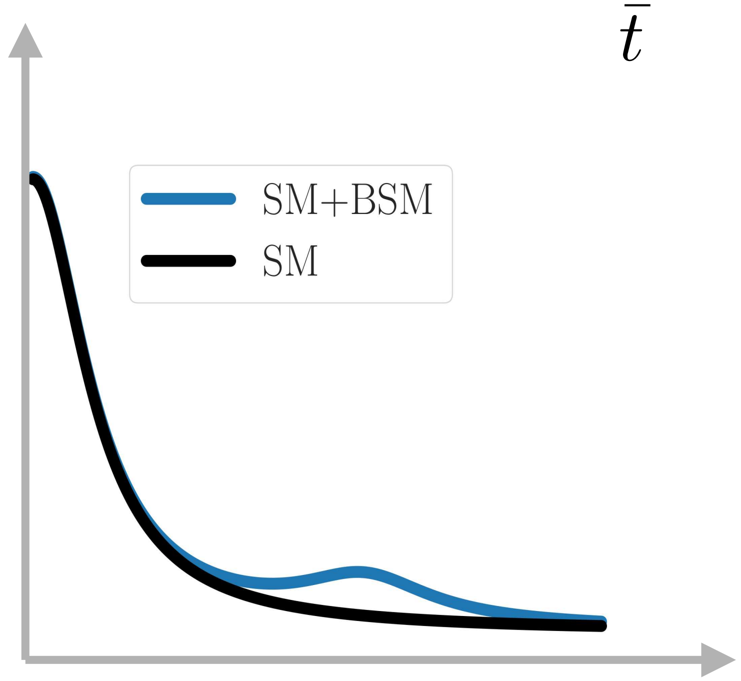
Beyond EFTs

- What if the NP scales are around the experimentally accessible energies, but are challenging to be probed by direct searches?

$\Lambda < \sqrt{\hat{s}}$

On-Shell (BSM Searches)





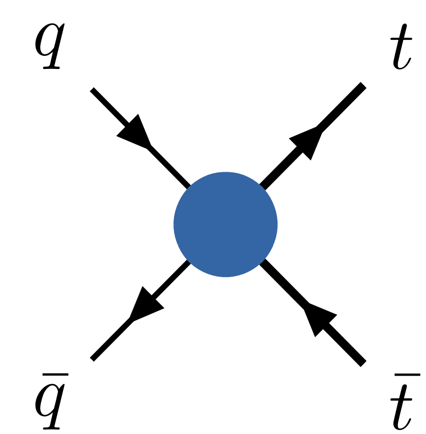
$\Lambda \simeq \sqrt{\hat{s}}$

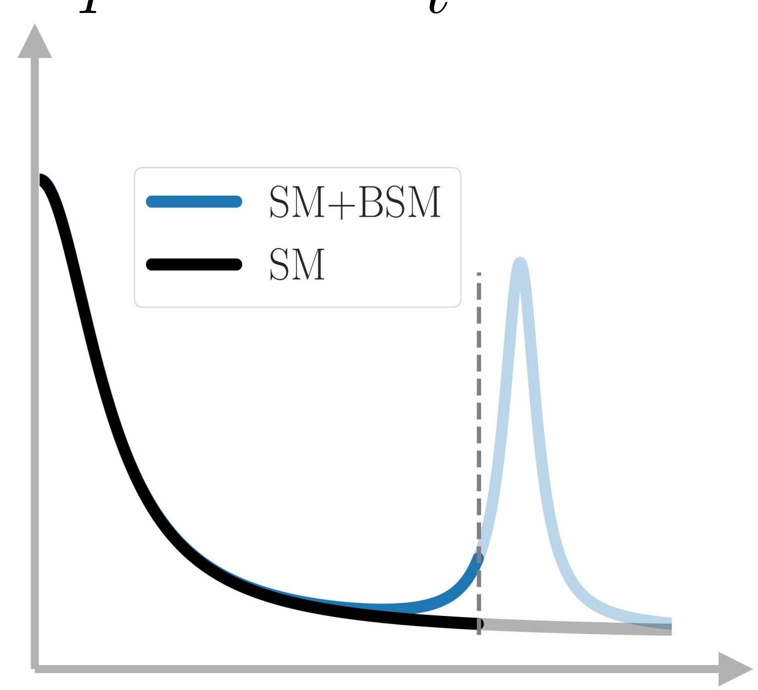
"Beyond EFT" regime

- What happens at the EFT → on-shell transition?
- Are the EFT constraints valid even if the EFT assumption is violated?
- If not, are they too conservative/too aggressive?
- What do we learn going beyond EFT?

$\Lambda \gg \sqrt{\hat{s}}$

EFT (SM Measurements)





Beyond (Top) EFT

- Toy Model (*DM inspired*):

$$\phi_T \rightarrow \text{ scalar top partner} \quad \chi \rightarrow \text{ Majorana singlet}$$

$$\mathcal{L}_{BSM} = \bar{\chi}\left(i\partial - \frac{1}{2}m_\chi\right)\chi + |D_\mu \phi_T|^2 - m_T^2|\phi_T|^2 - \left(y_{\text{DM}}\phi_T^\dagger \bar{\chi} t_R + h.c.\right)$$

$m_T,\ m_\chi,\ y_{\text{DM}}$ → Free parameters

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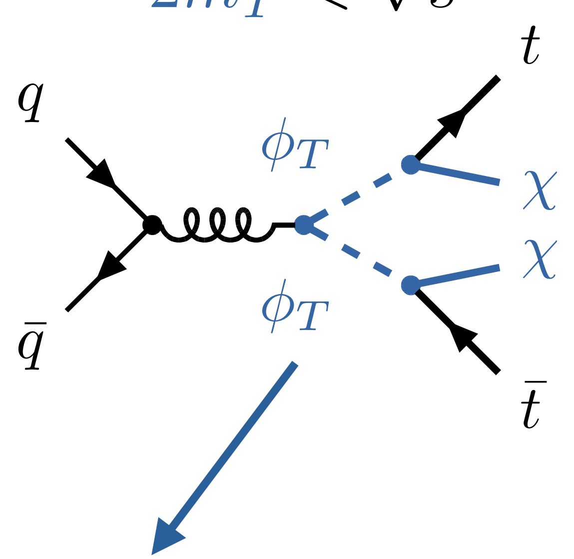

Direct Searches

Challenging signal if:

$m_T \sim m_\chi$

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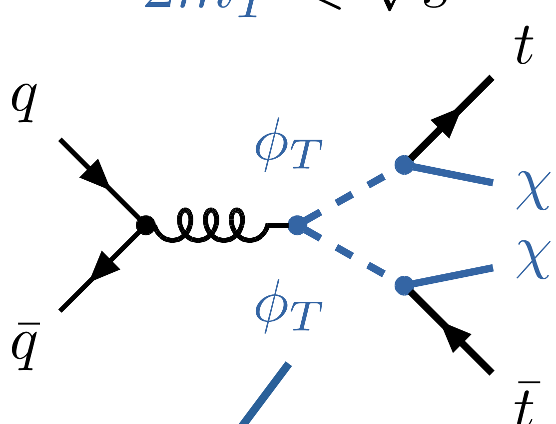

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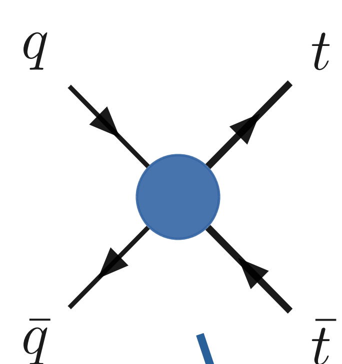

Indirect Searches
(EFT)

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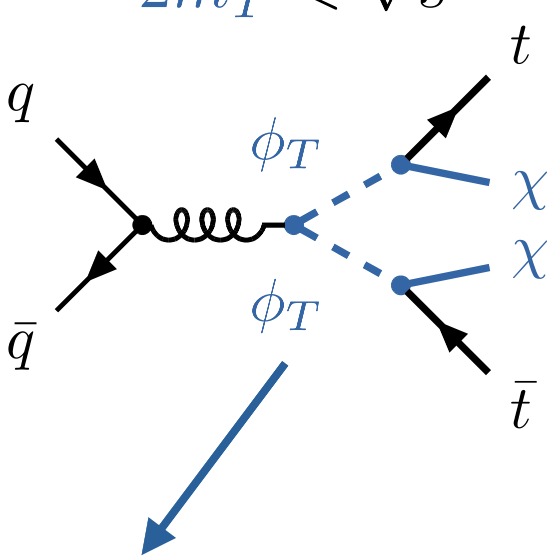

Direct Searches

Challenging signal if:

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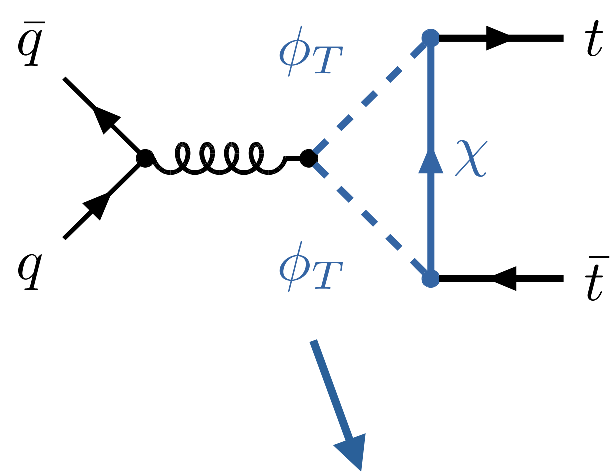
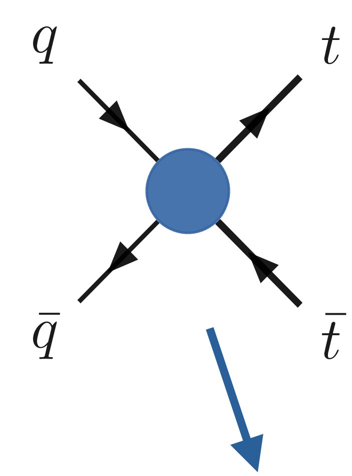


Indirect Searches (1-loop)

$2m_T \gg \sqrt{\hat{s}}$



Indirect Searches (EFT)

Beyond (Top) EFT

- Beyond EFT lagrangian: $C_i \to F_i(q^2)$ (1-loop form factors)

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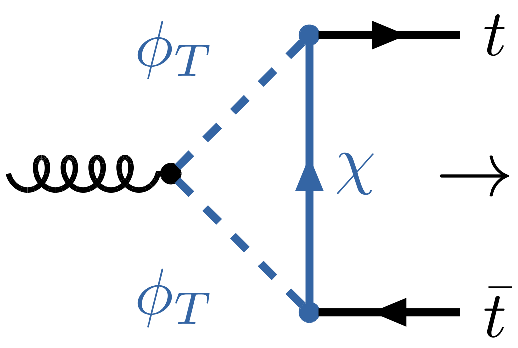

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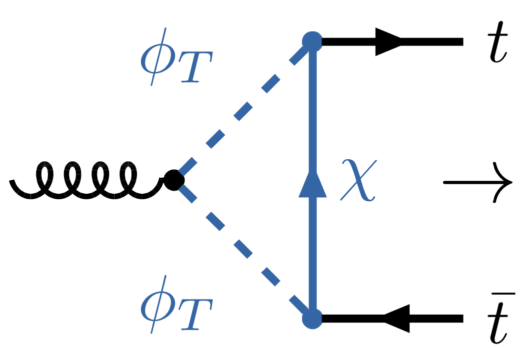

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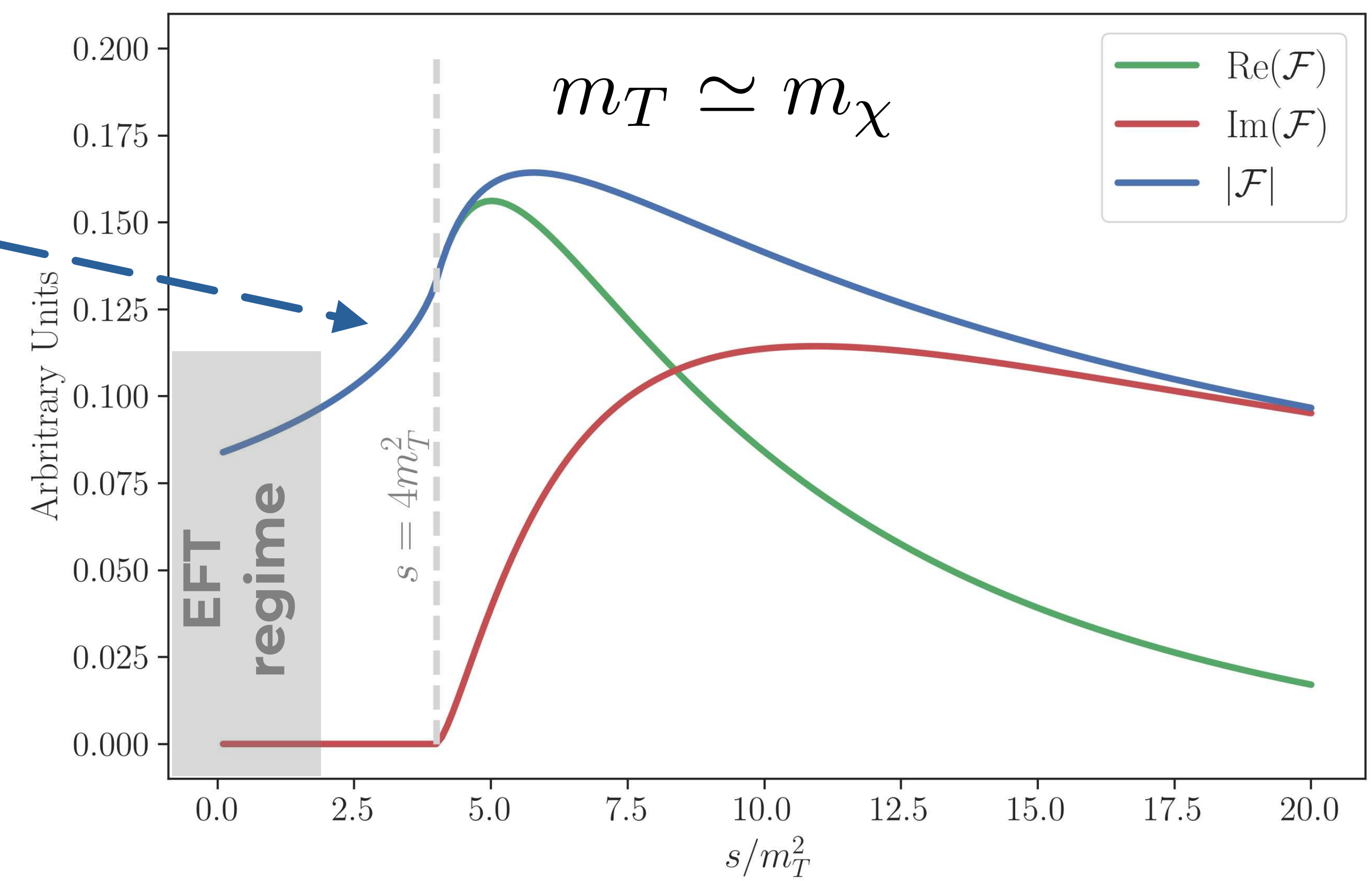

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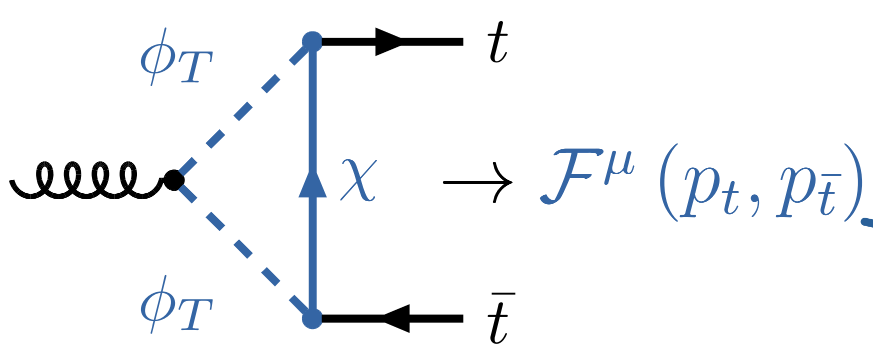
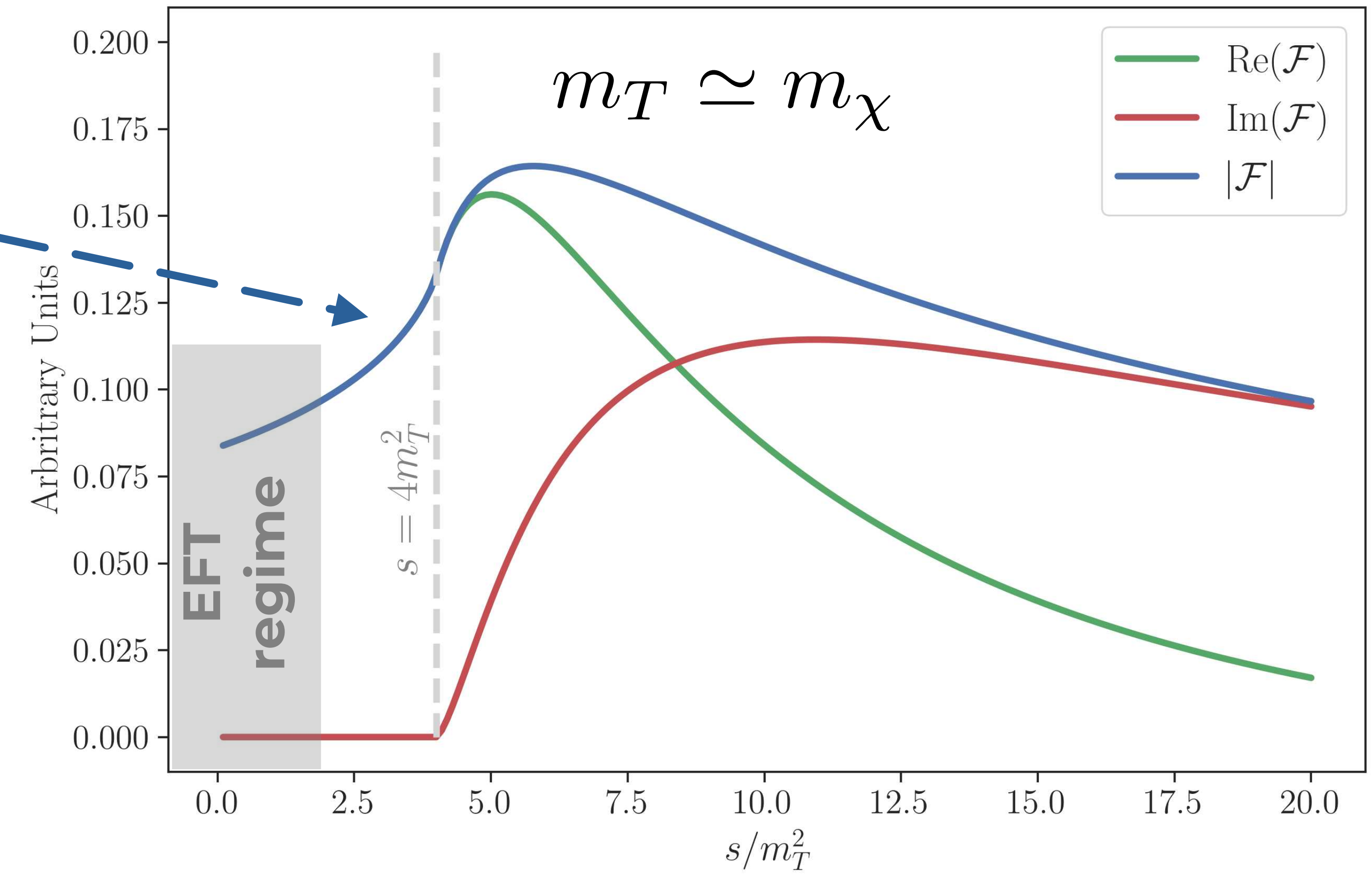
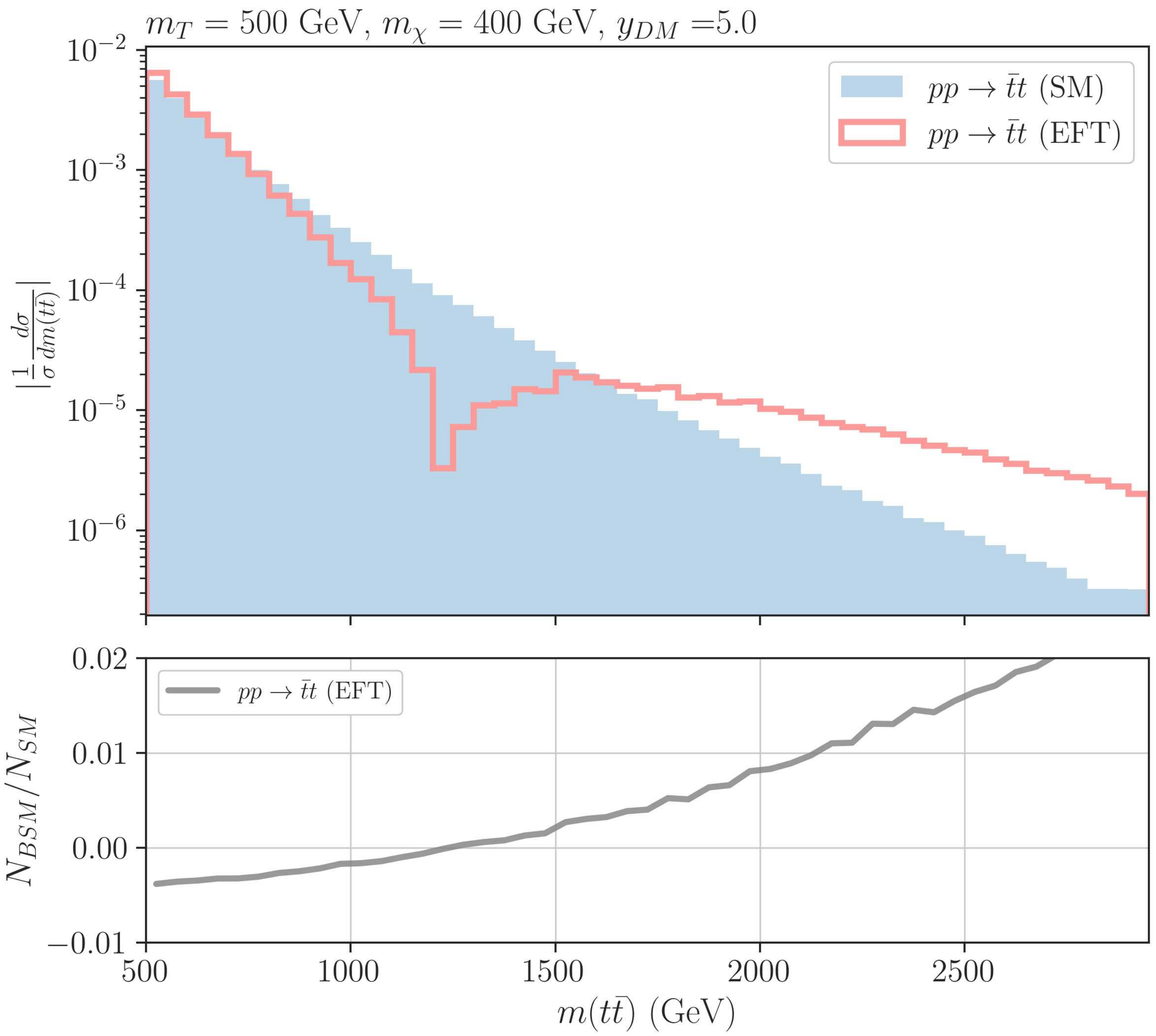




- *Broad bump* behavior
- Form factor is real in the EFT region
- Imaginary part becomes dominant at large energies

Indirect Searches

- Distributions:



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  - grows with energy
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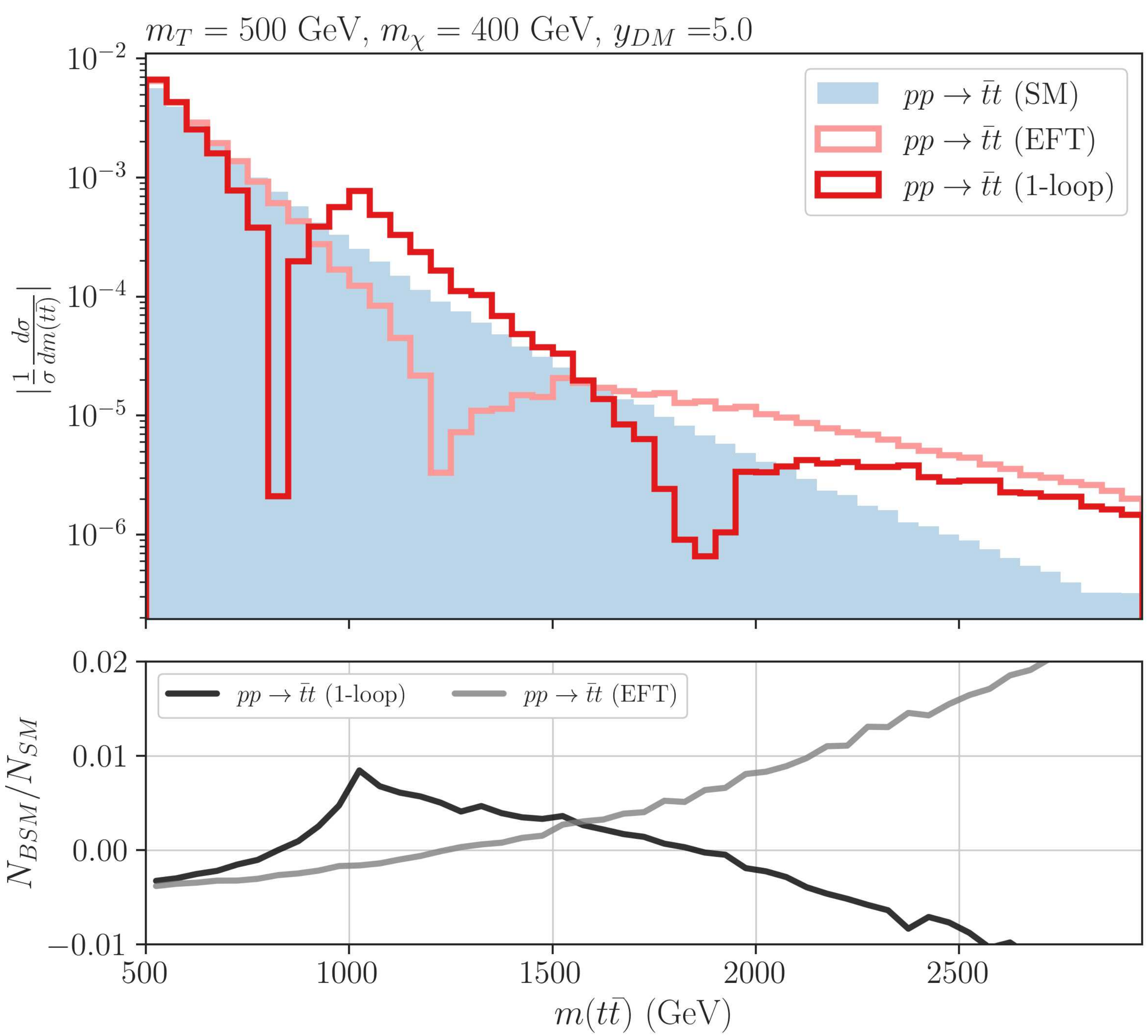

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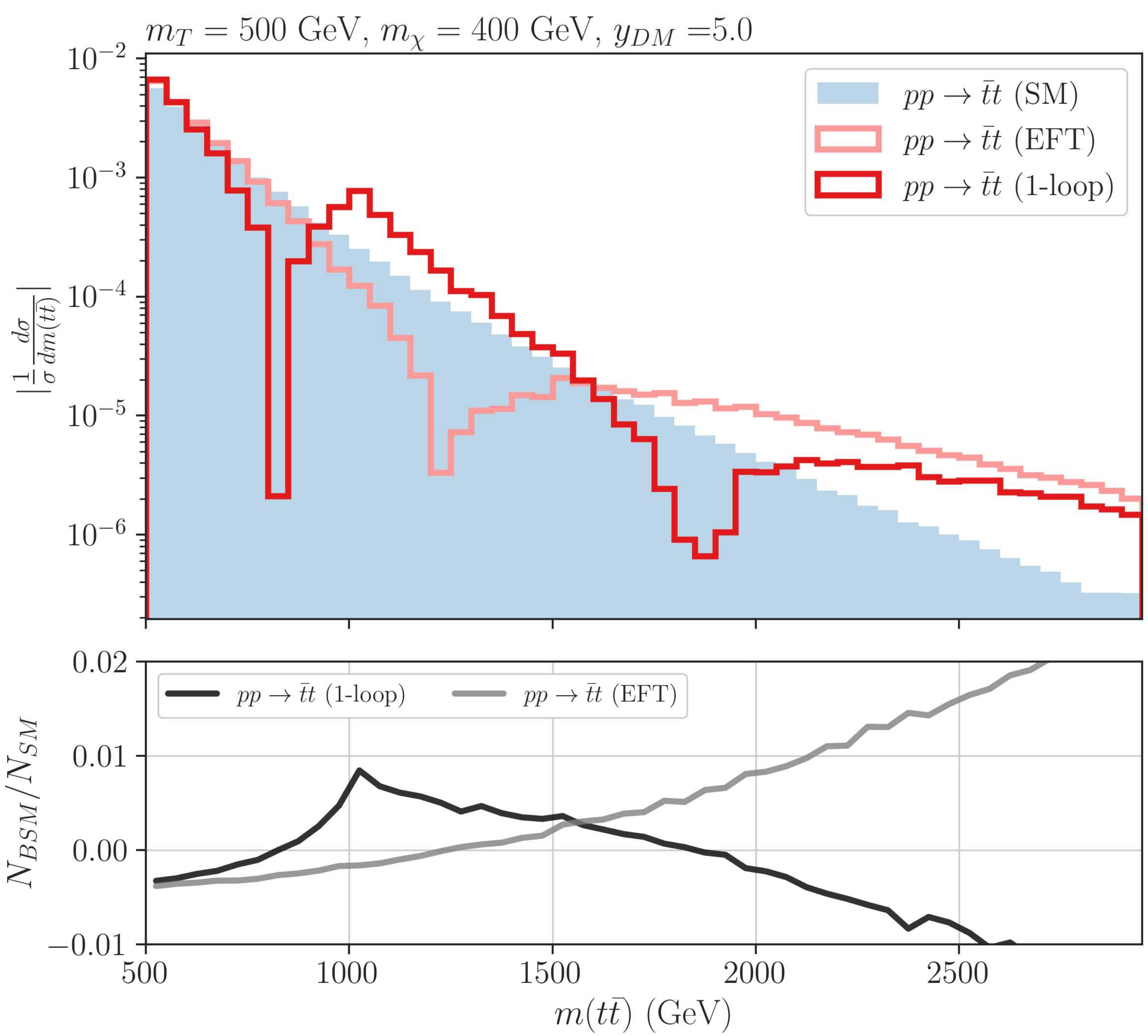

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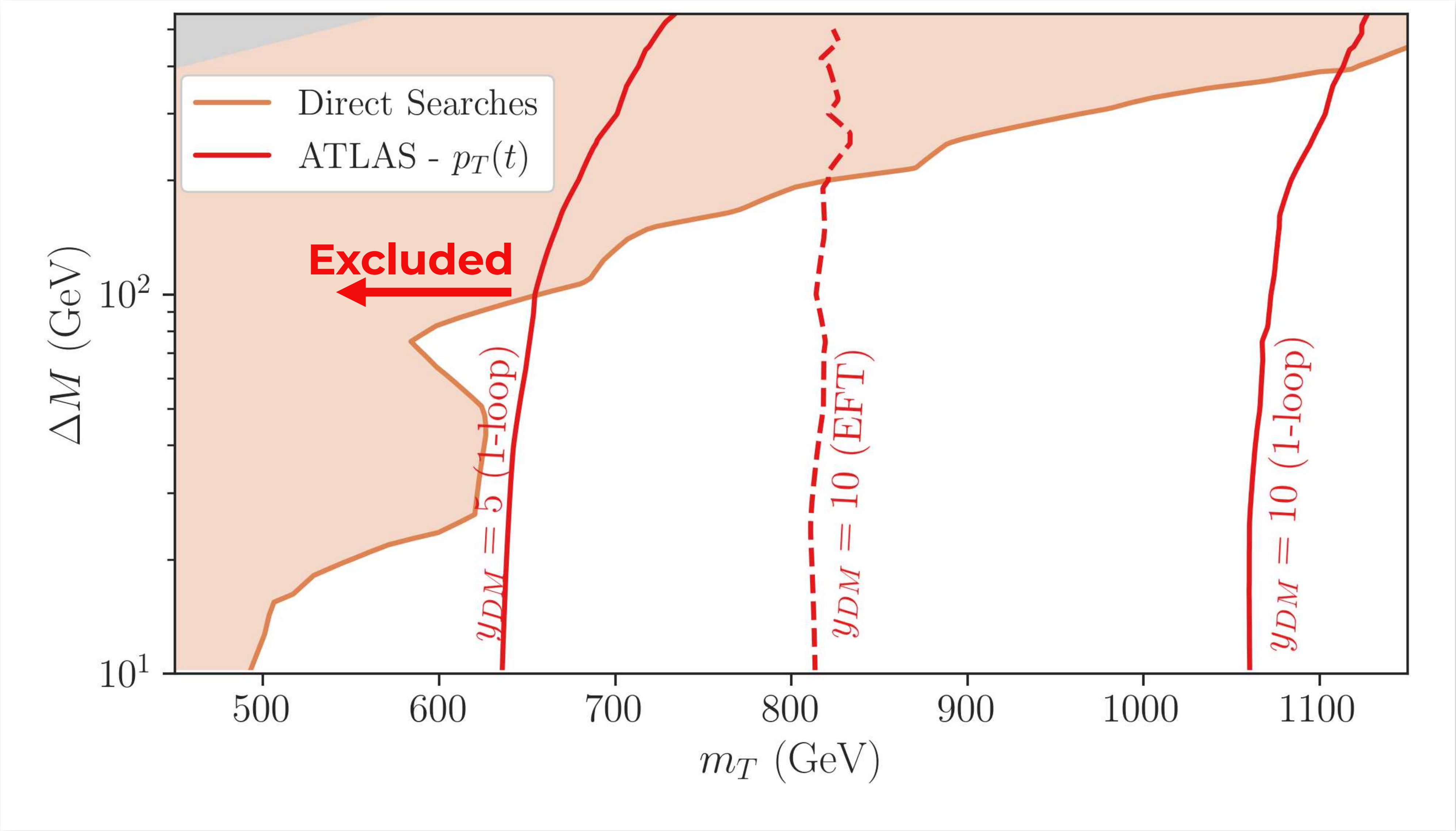
How are these effects constrained by top measurements?

Direct + Indirect

- LHC Constraints:

2312.00670, AL, V. Sanz



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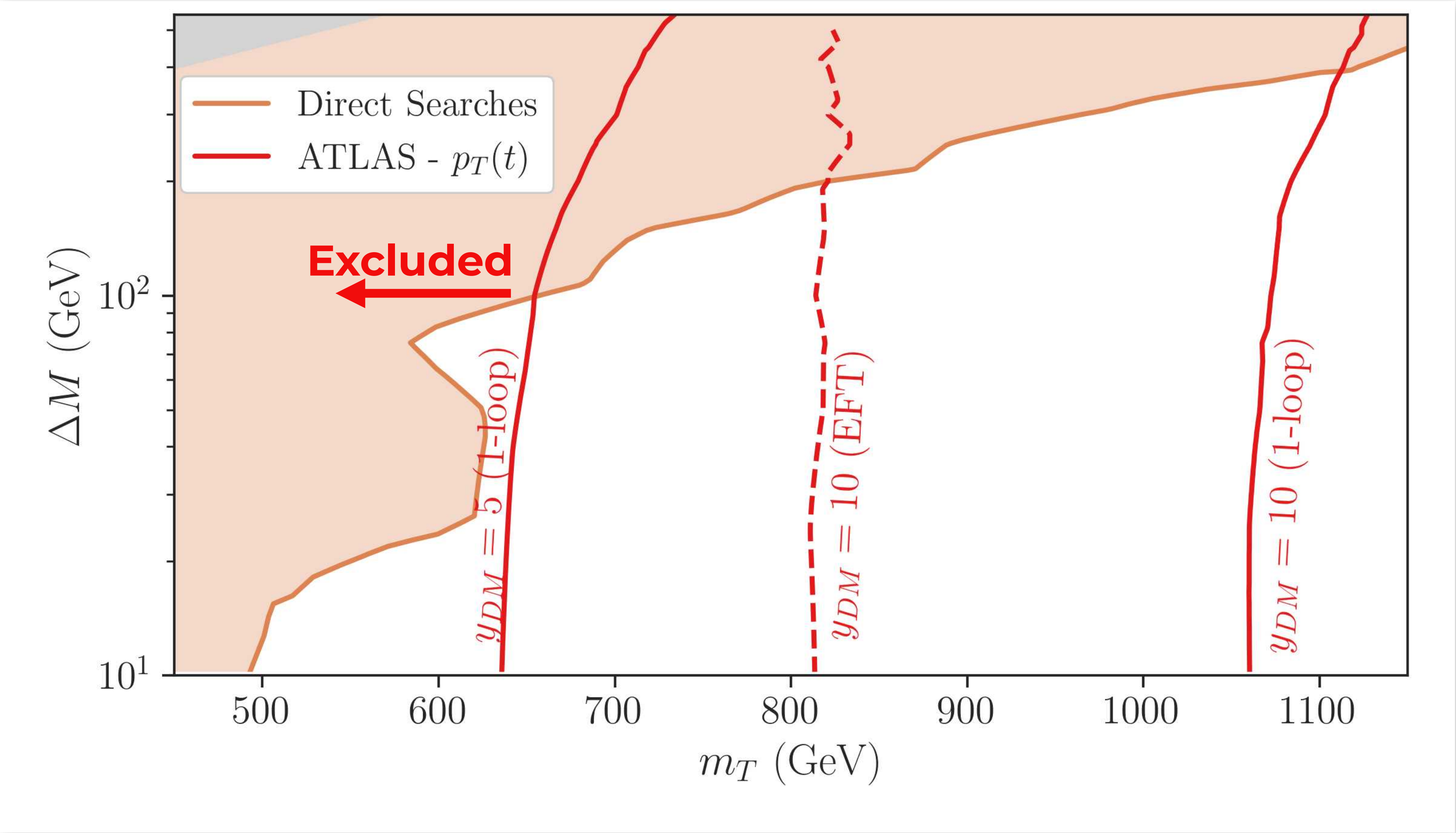


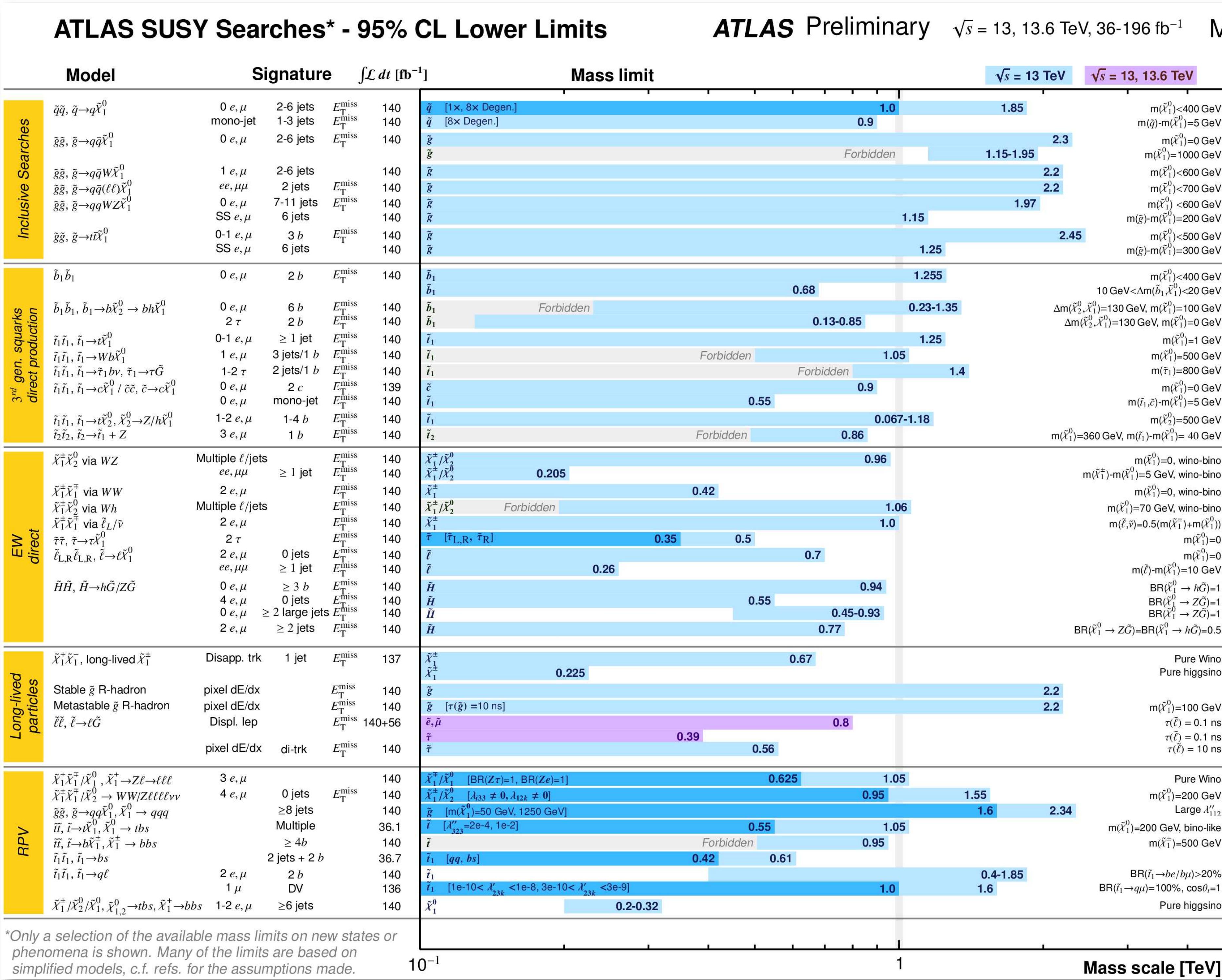
- EFT approximation underestimates the signal!
- Constraints on the compressed region are competitive with direct searches!

Direct (On-Shell) Searches

Direct Searches

- Direct searches “exclude”…

ATL-PHYS-PUB-2026-003



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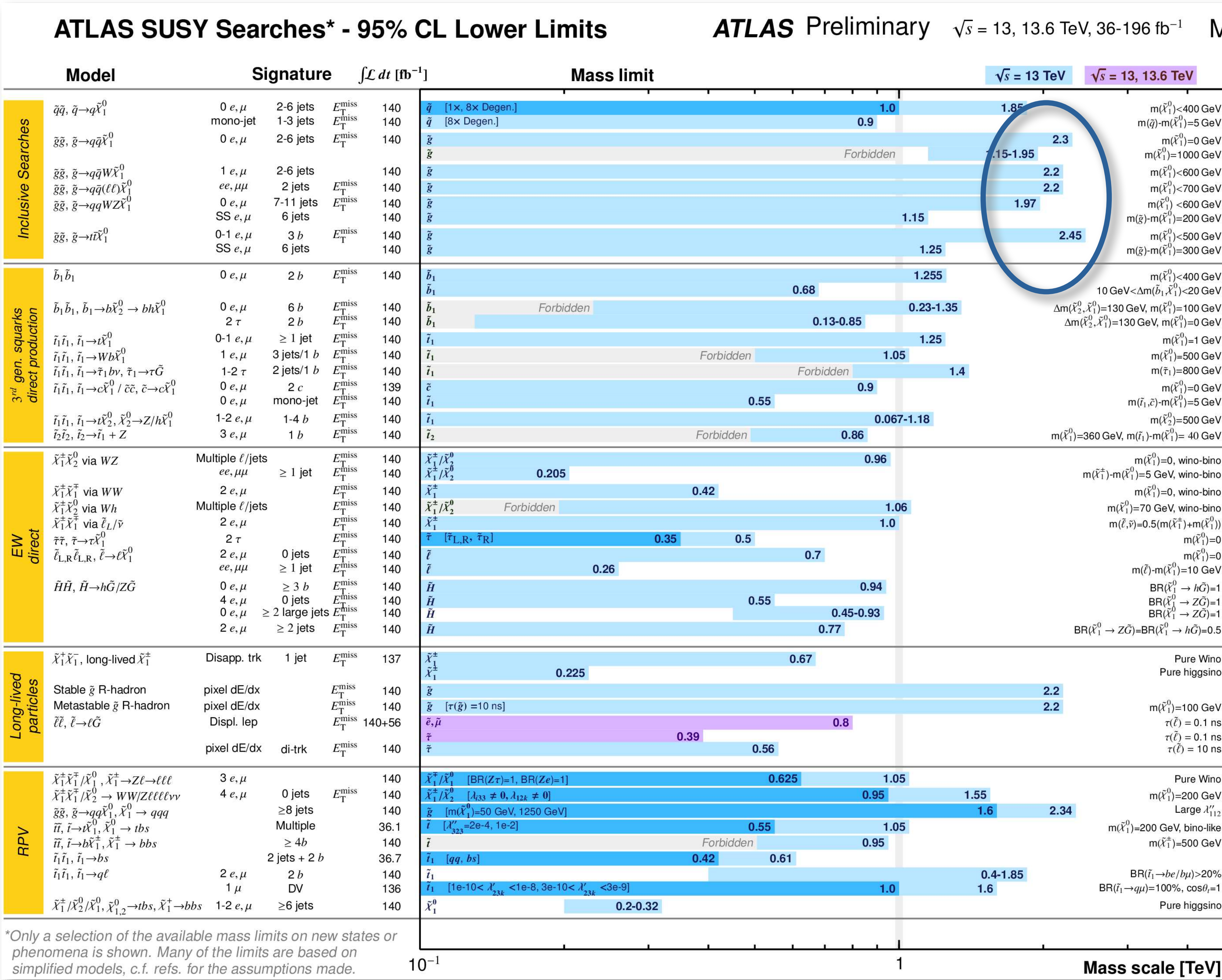
ATL-PHYS-PUB-2026-003



Strongly produced:

$M \gtrsim 1.5 - 2.5$ TeV

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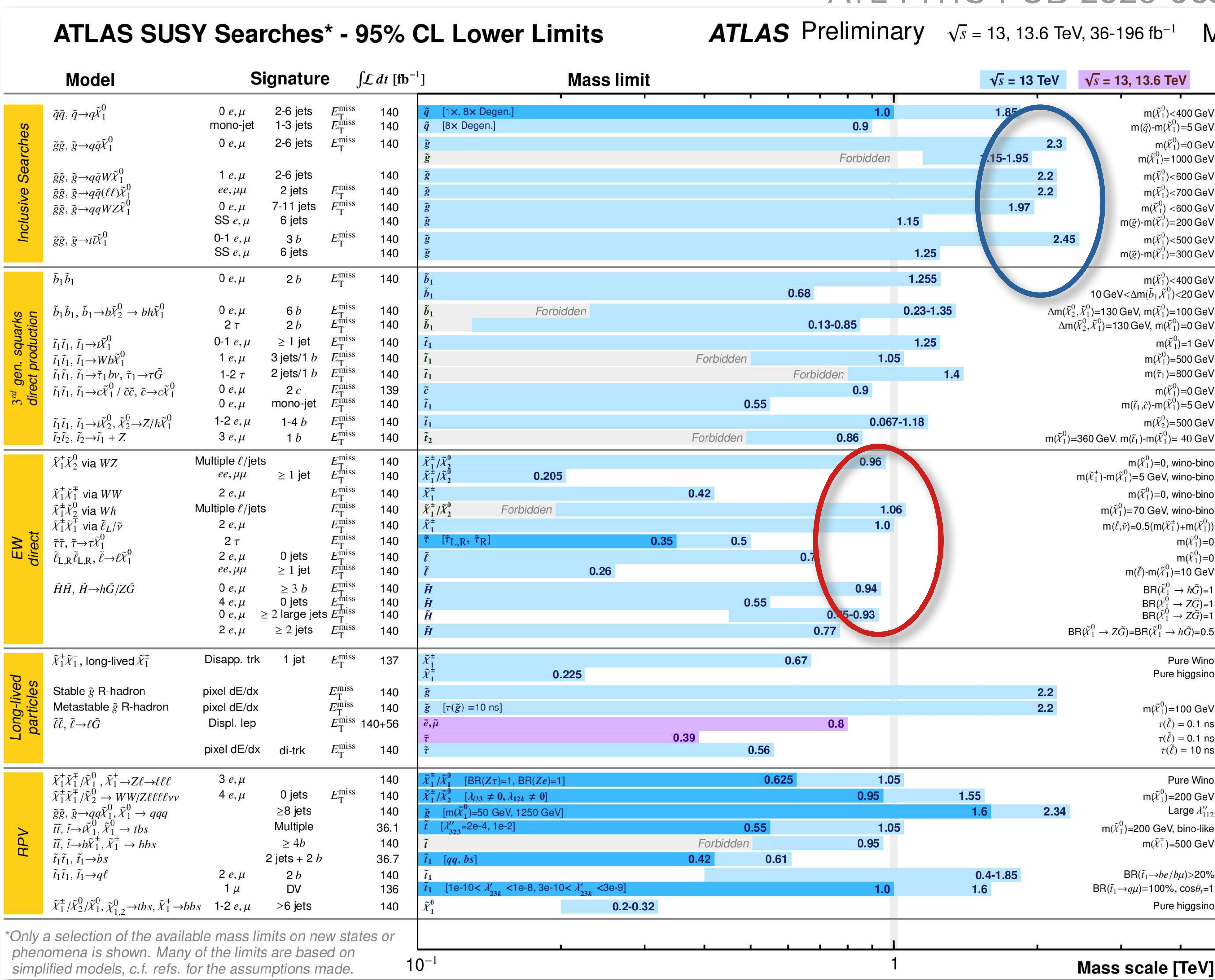
ATL-PHYS-PUB-2026-003



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EW produced:

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Direct Searches

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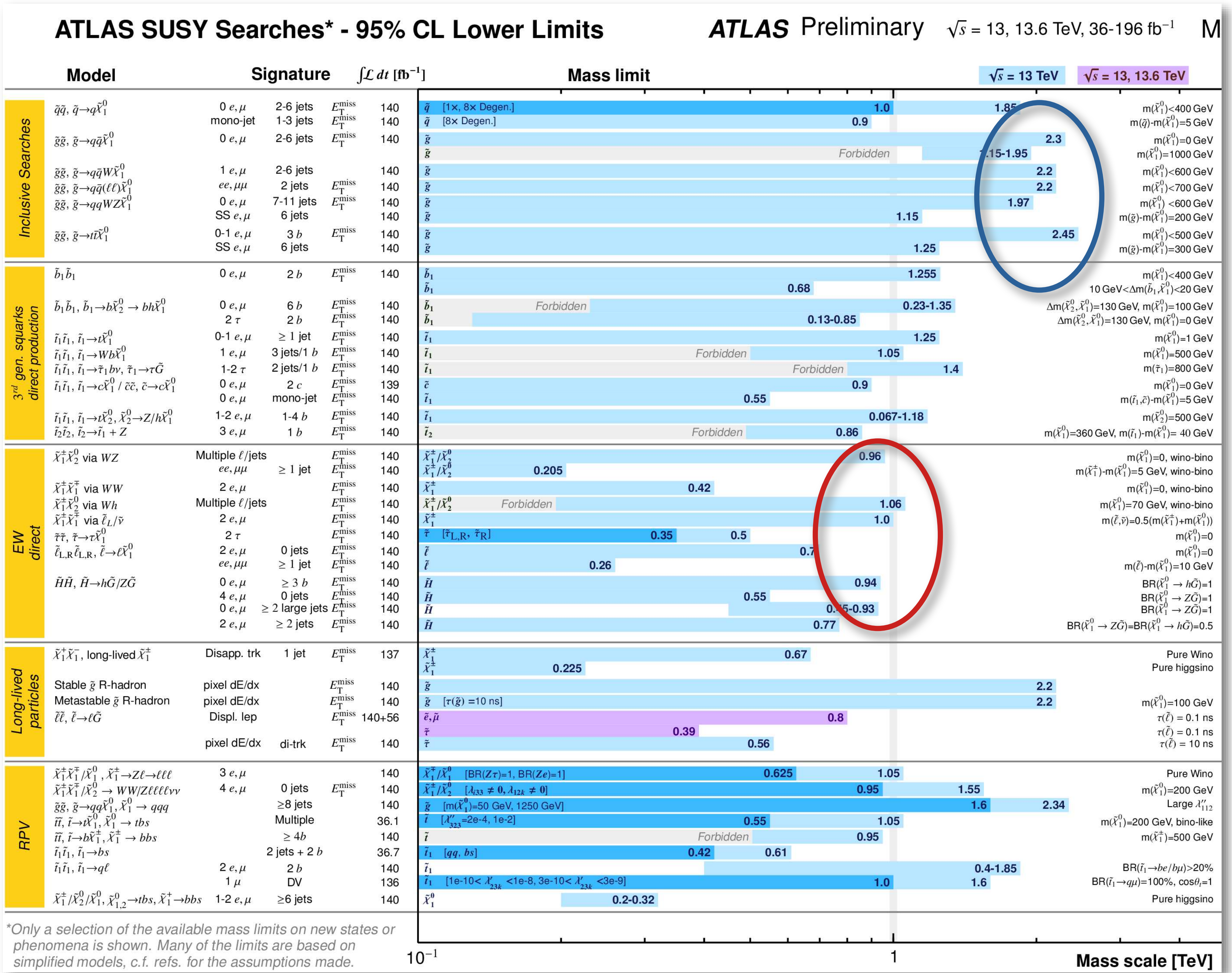
ATL-PHYS-PUB-2026-003



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- However...

these bounds assume simplified models

Direct Searches

- How “reliable” are the current constraints from simplified models?

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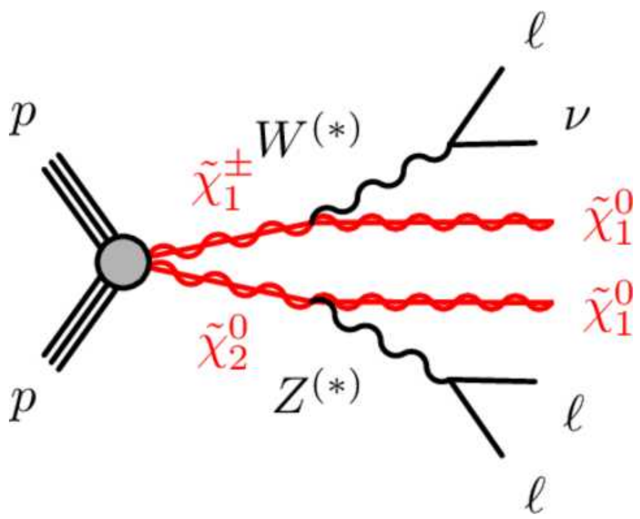
- Example: EW-inos



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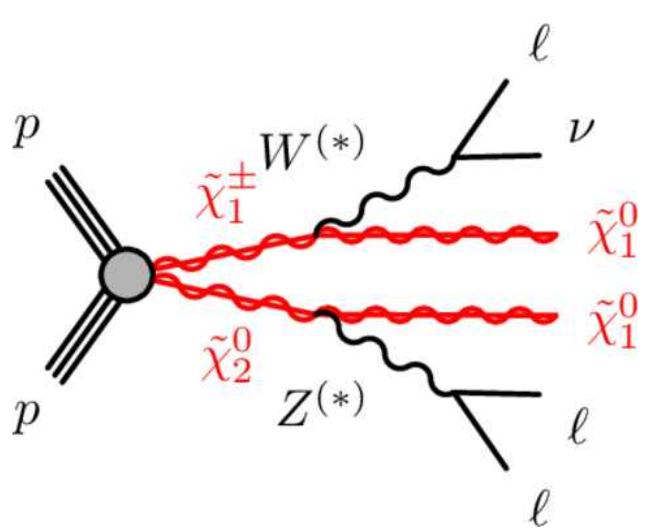

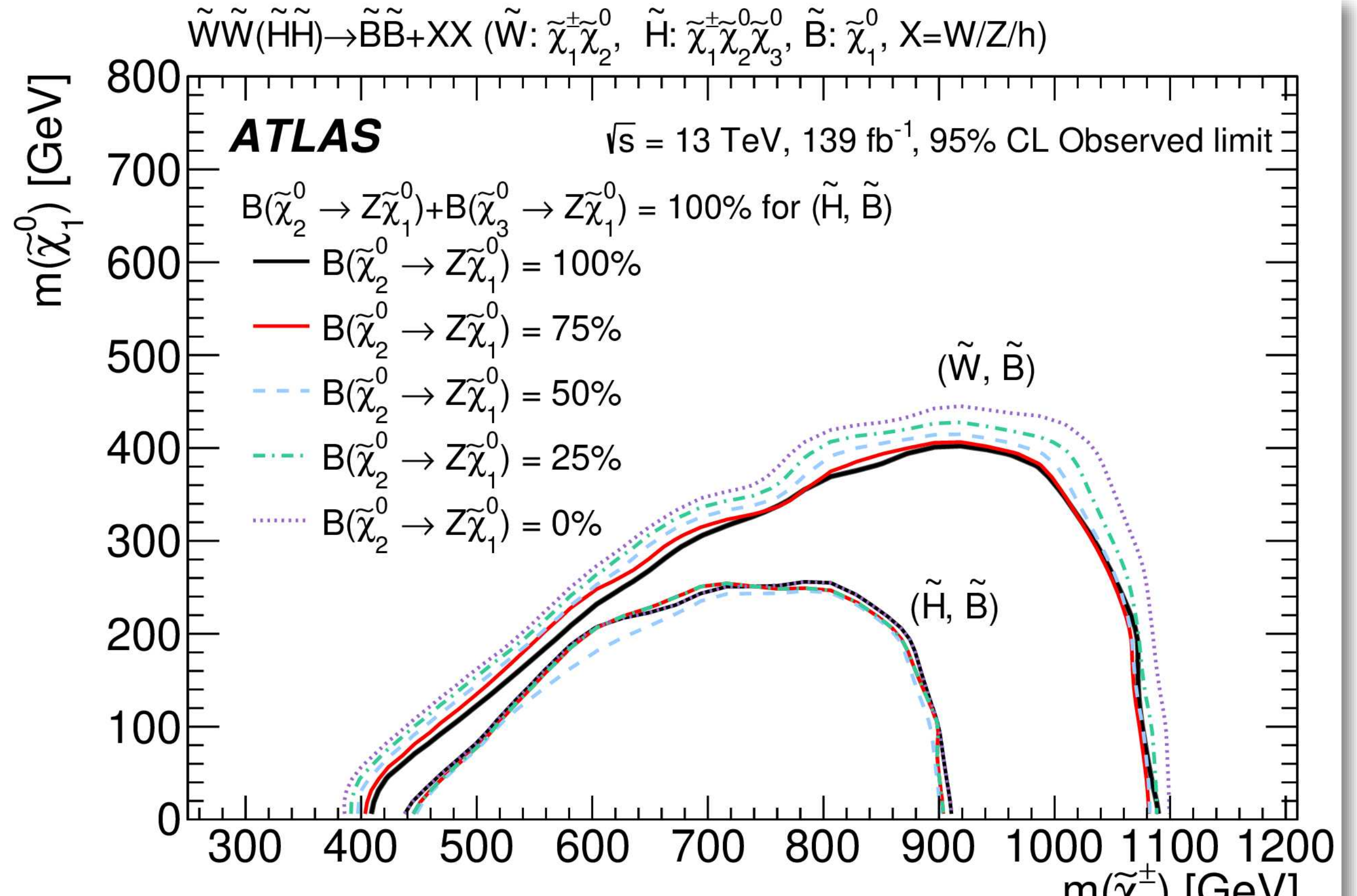

ATLAS-SUSY-2018-41:2108.07586

Direct Searches

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Direct Searches

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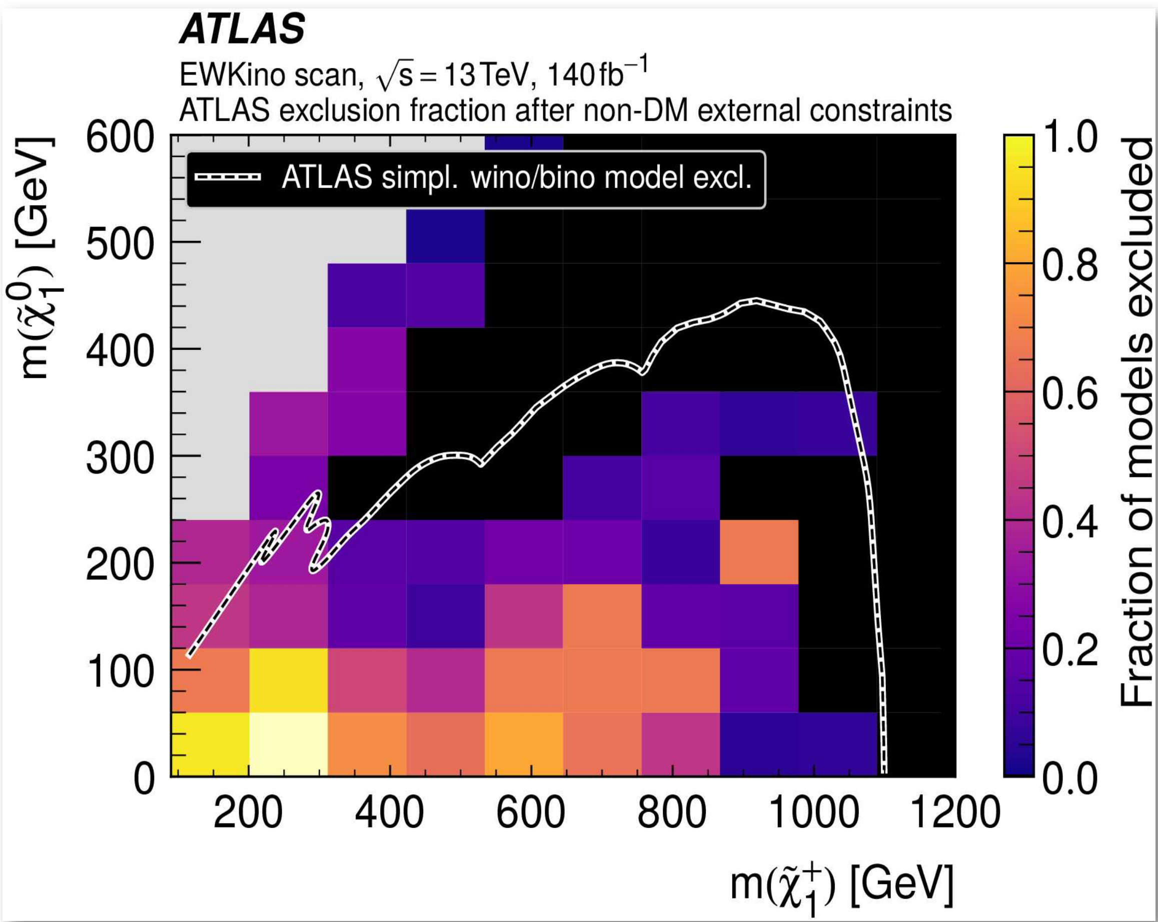

ATLAS-SUSY-2020-15:2402.01392

Direct Searches

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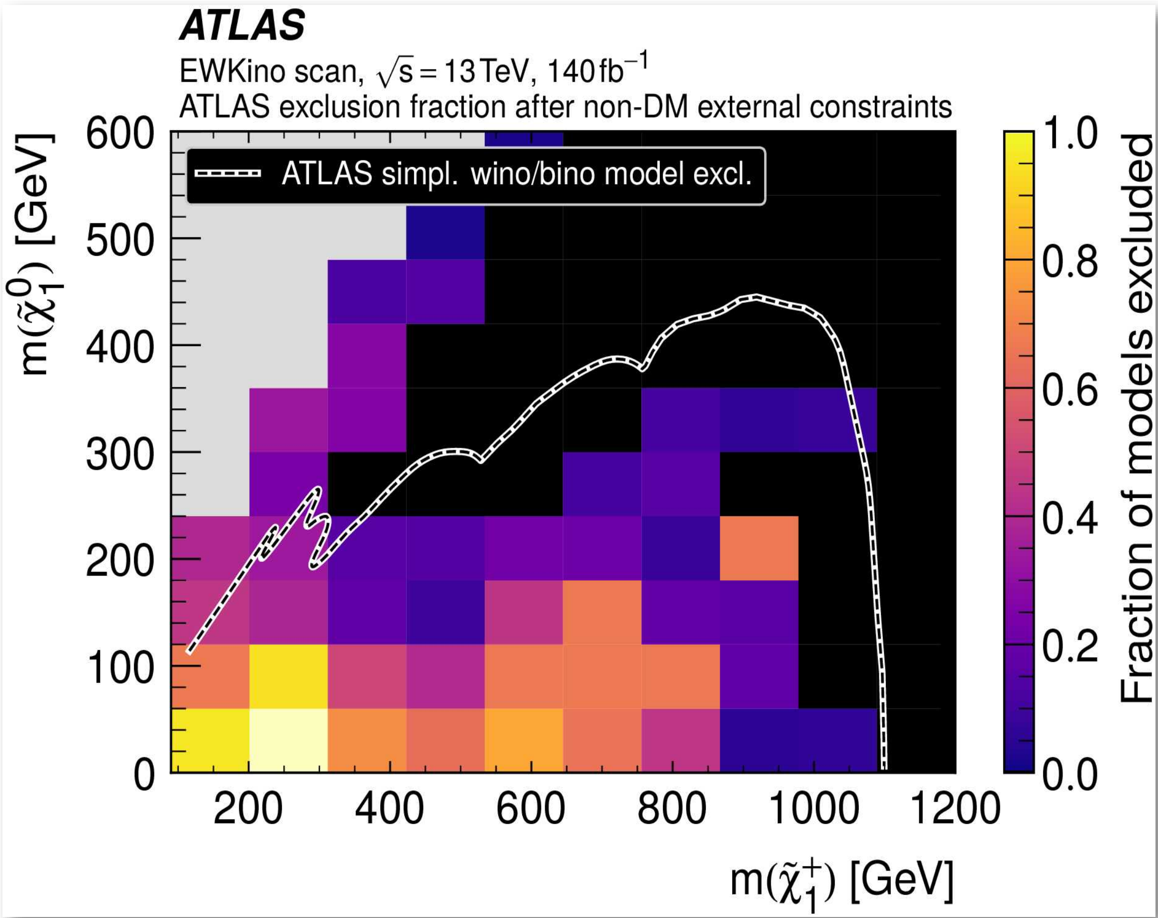
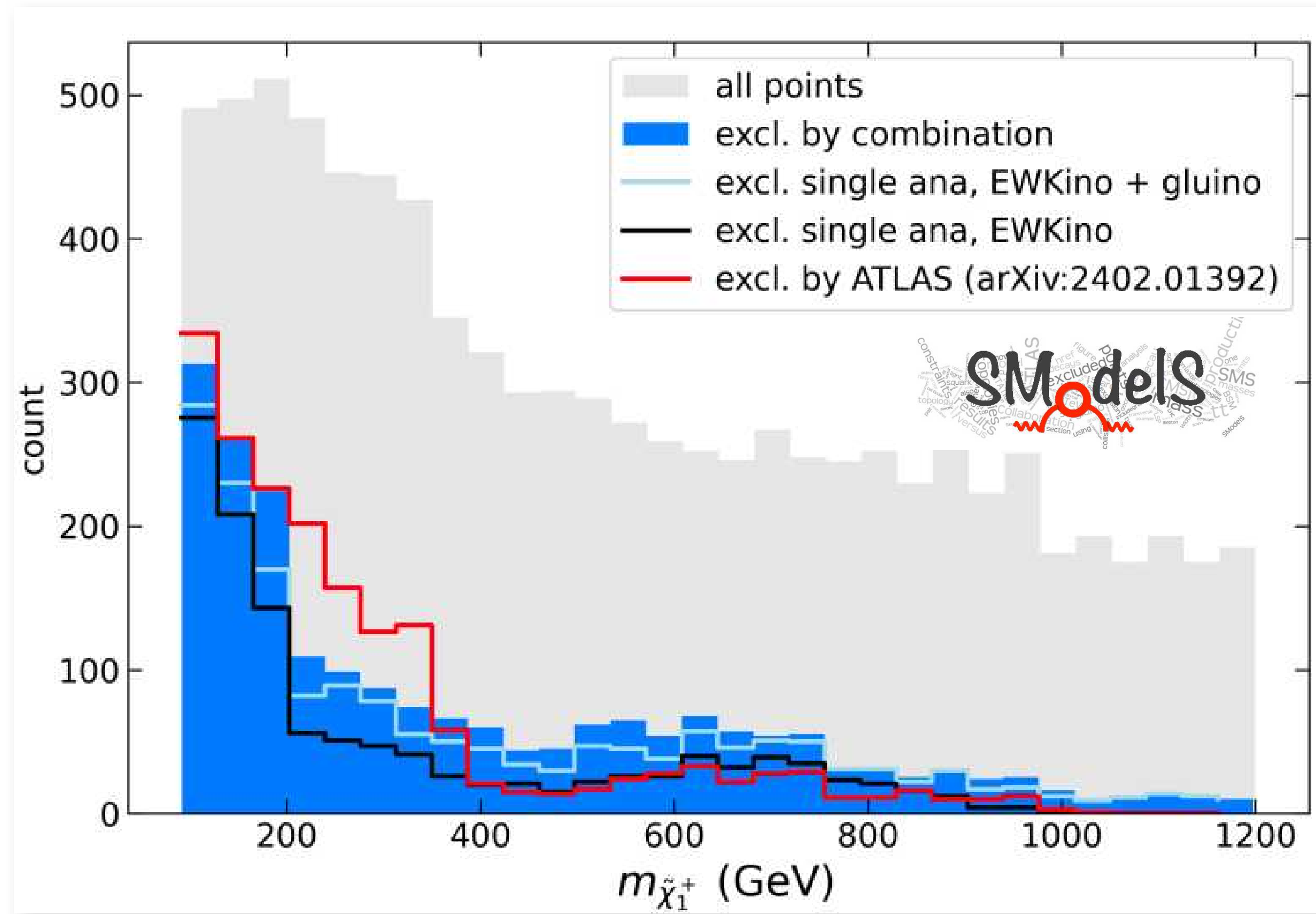


ATLAS-SUSY-2020-15:2402.01392



2512.14502
L. Costantin, S. Kraml, AL, T. Reymermier, W. Waltenberger

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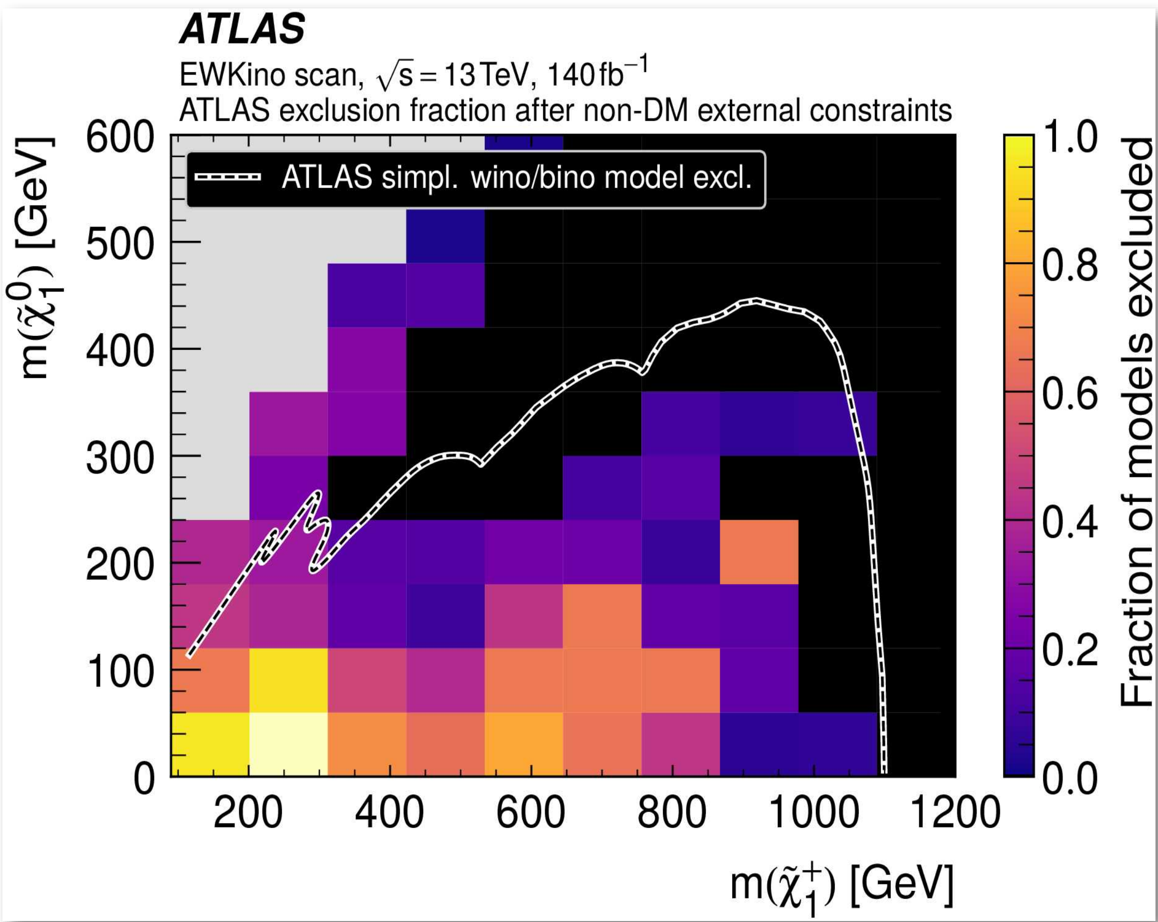

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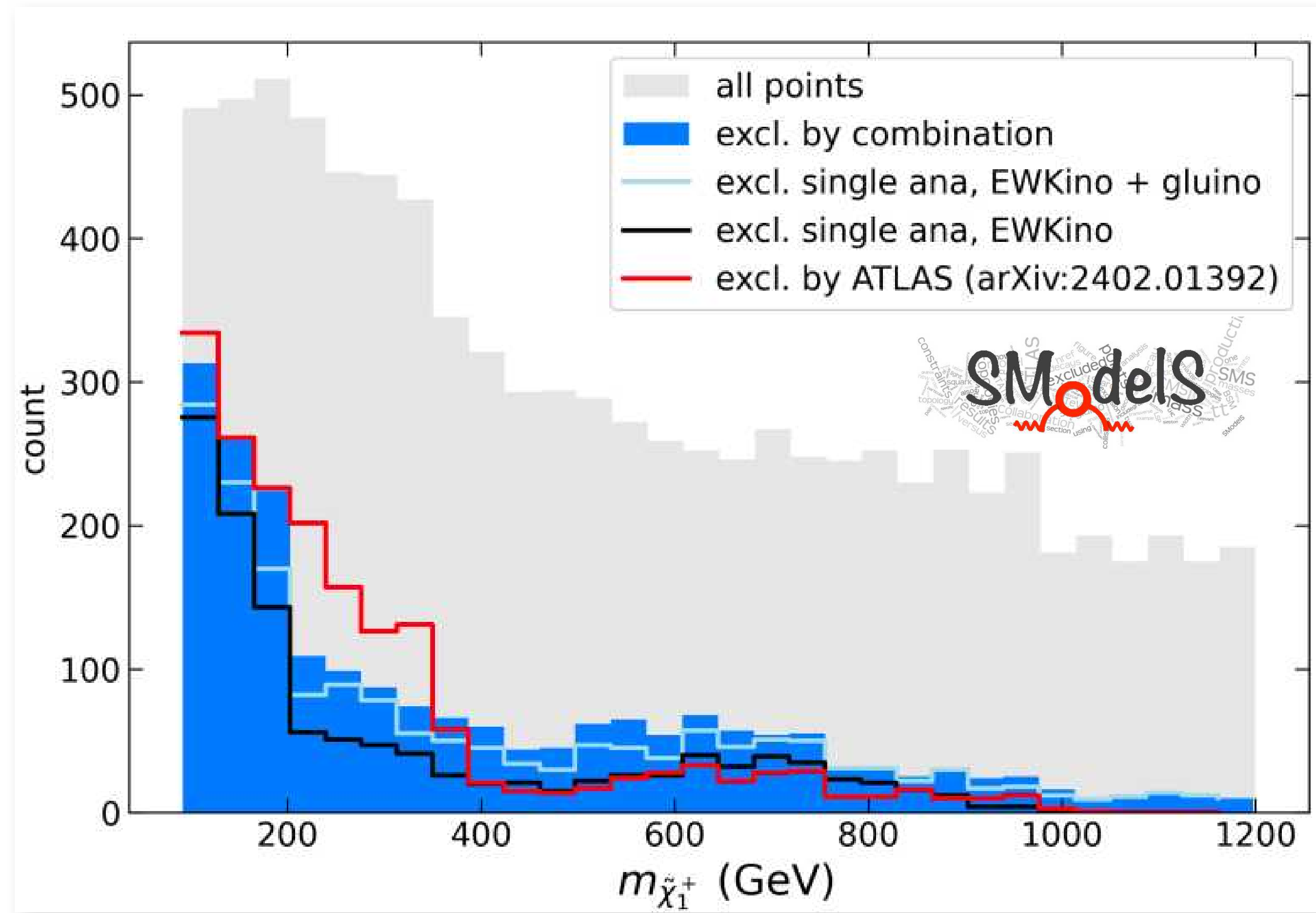
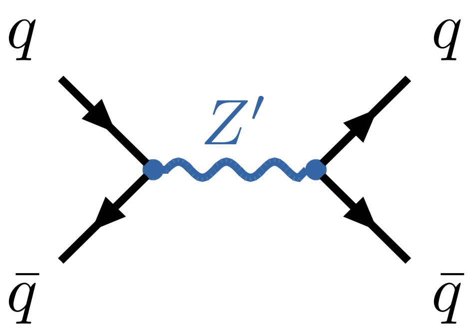


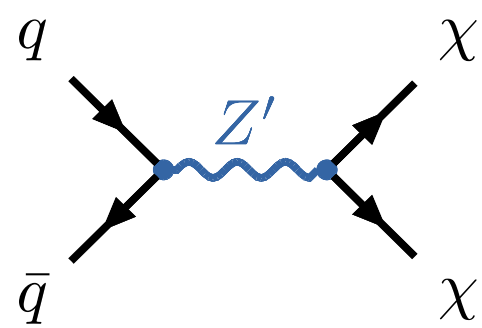
2512.14502
L. Costantin, S. Kraml, AL, T. Reymermier, W. Waltenberger

- Once more "full models" are considered: $m_{\tilde{\chi}_1^\pm} \gtrsim 140$ GeV
- The simplified model results need to be carefully re-interpreted within realistic scenarios → re-interpretation tools

Direct Searches

- Example: Quark-philic Z' model + DM





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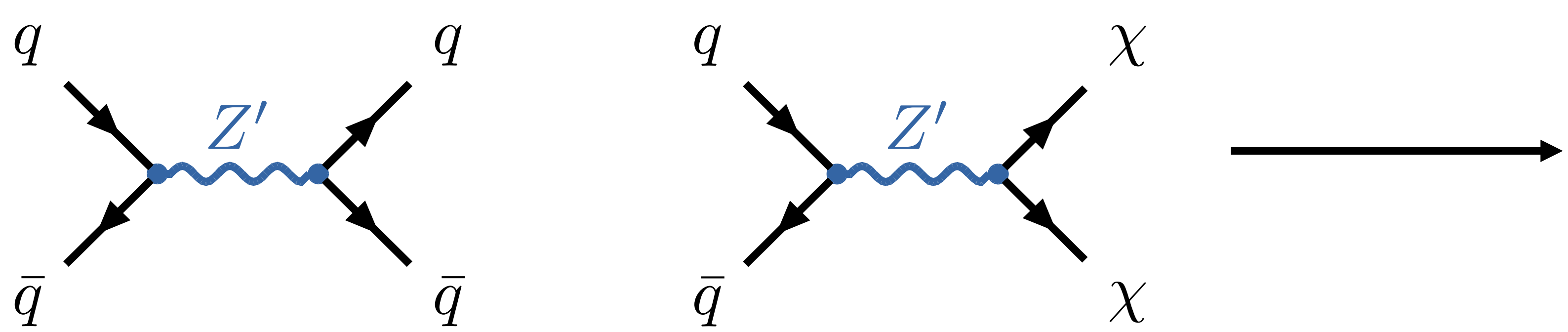

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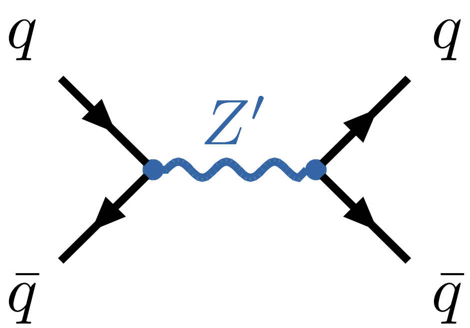

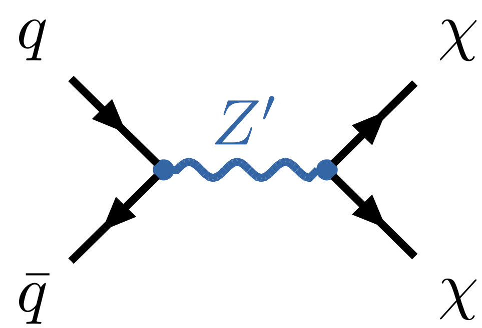

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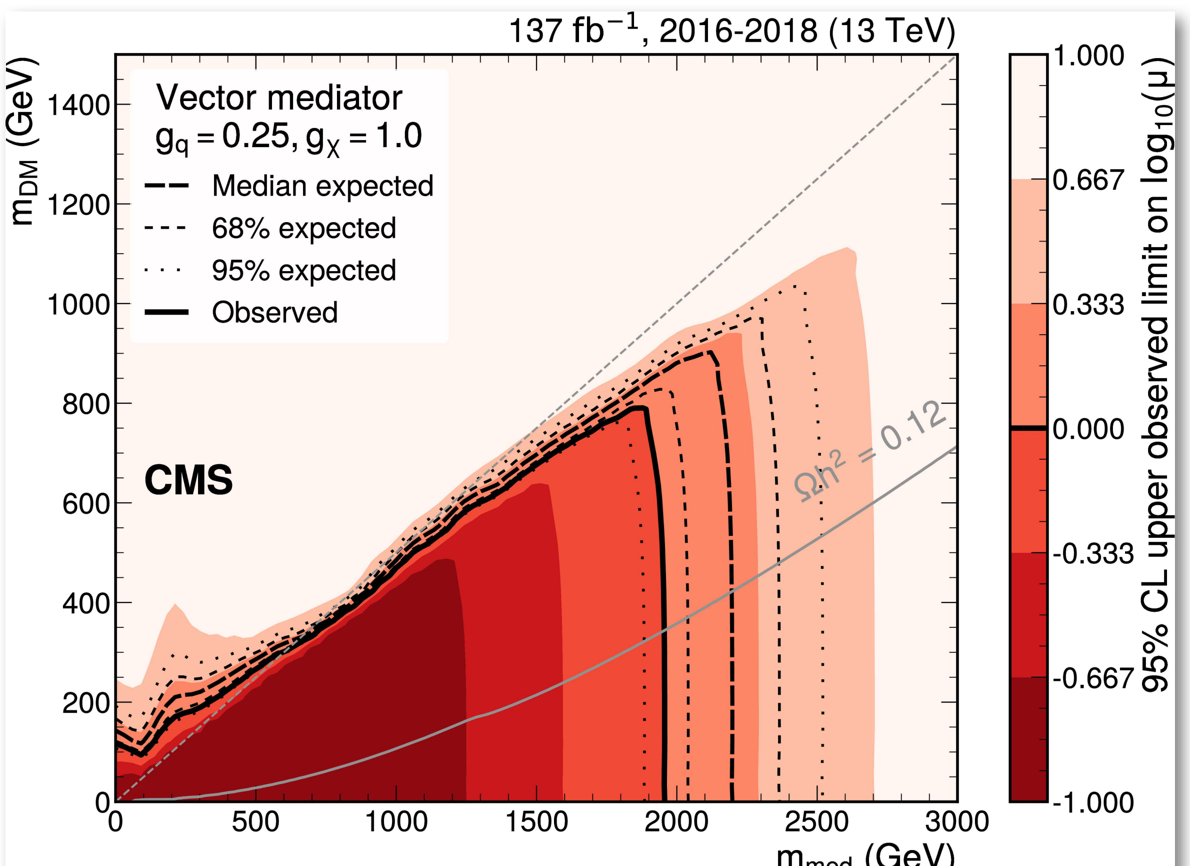

CMS-EXO-20-004, 2107.13021

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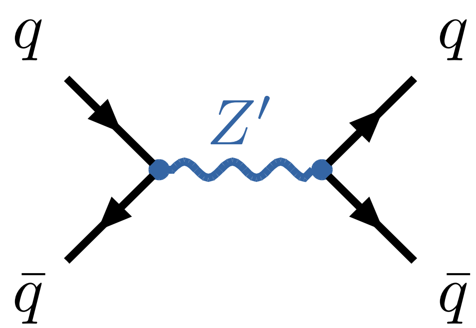

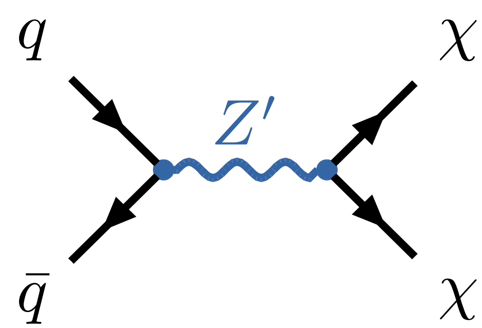

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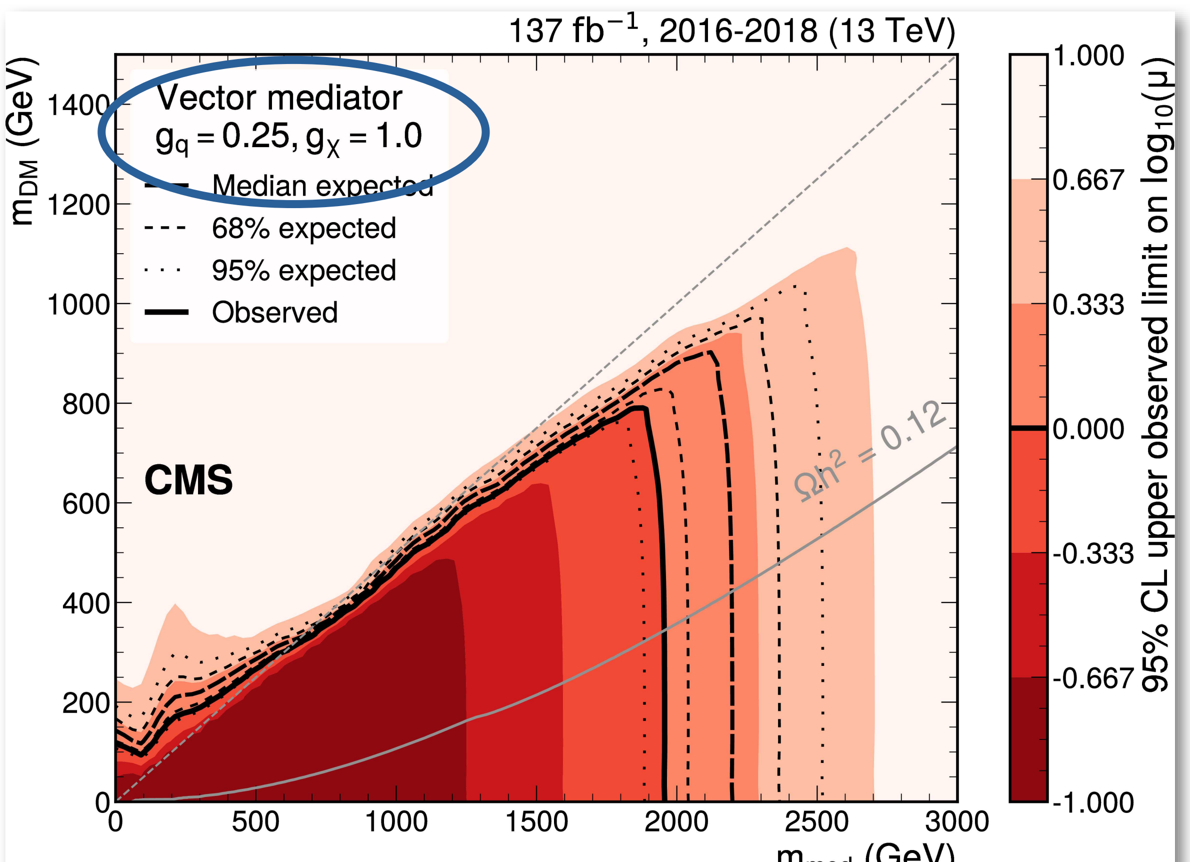

CMS-EXO-20-004, 2107.13021

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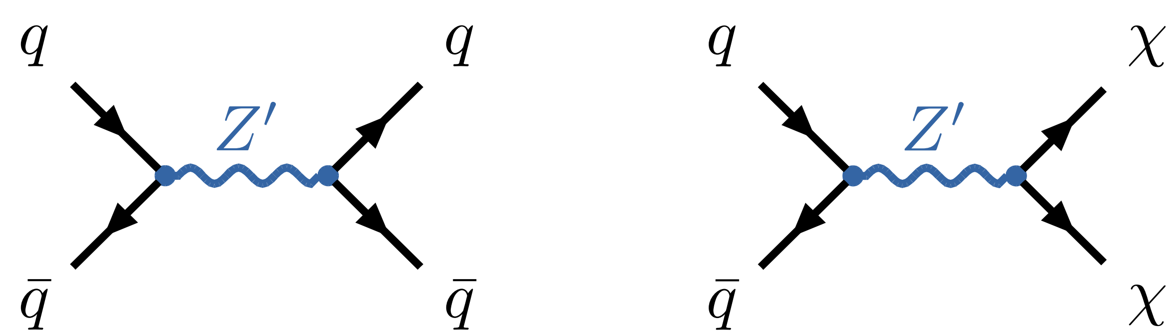

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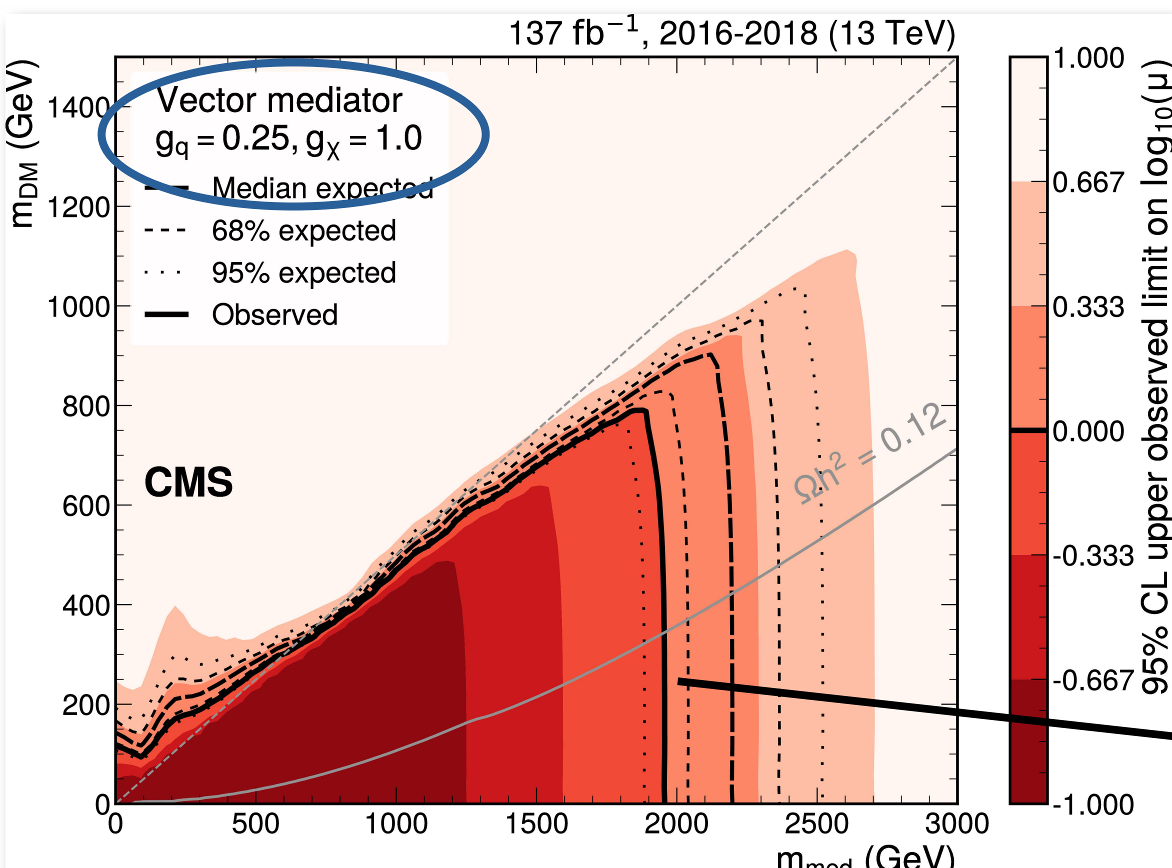
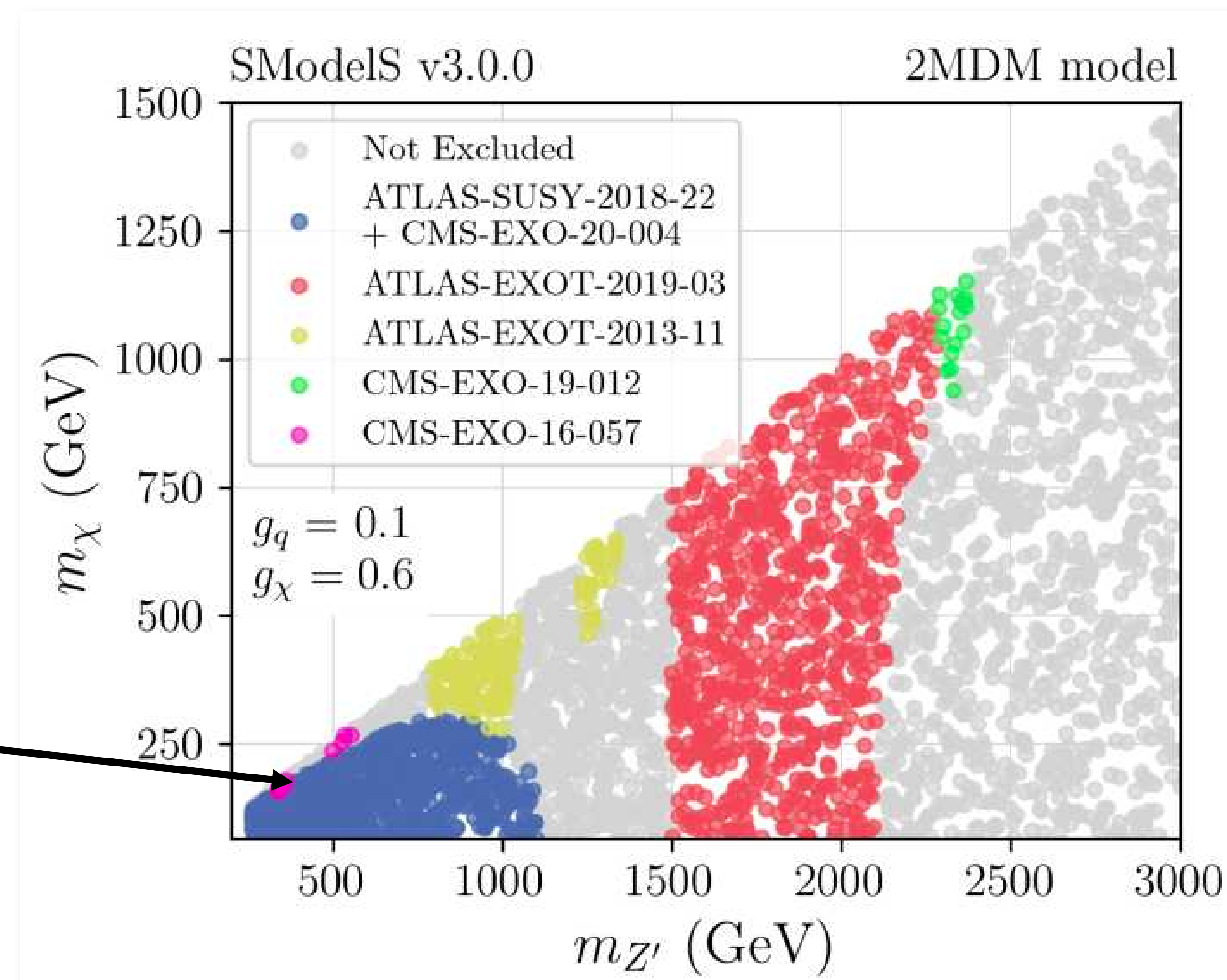


CMS-EXO-20-004, 2107.13021



2409.12942, M. Altakach et al

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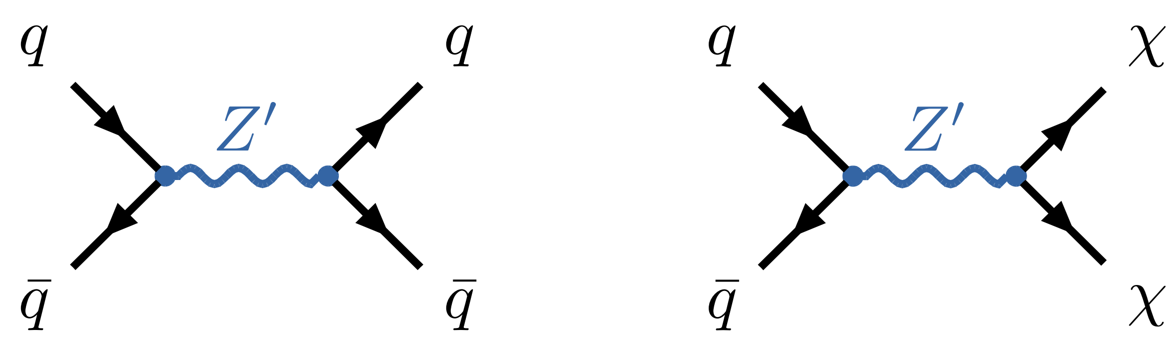

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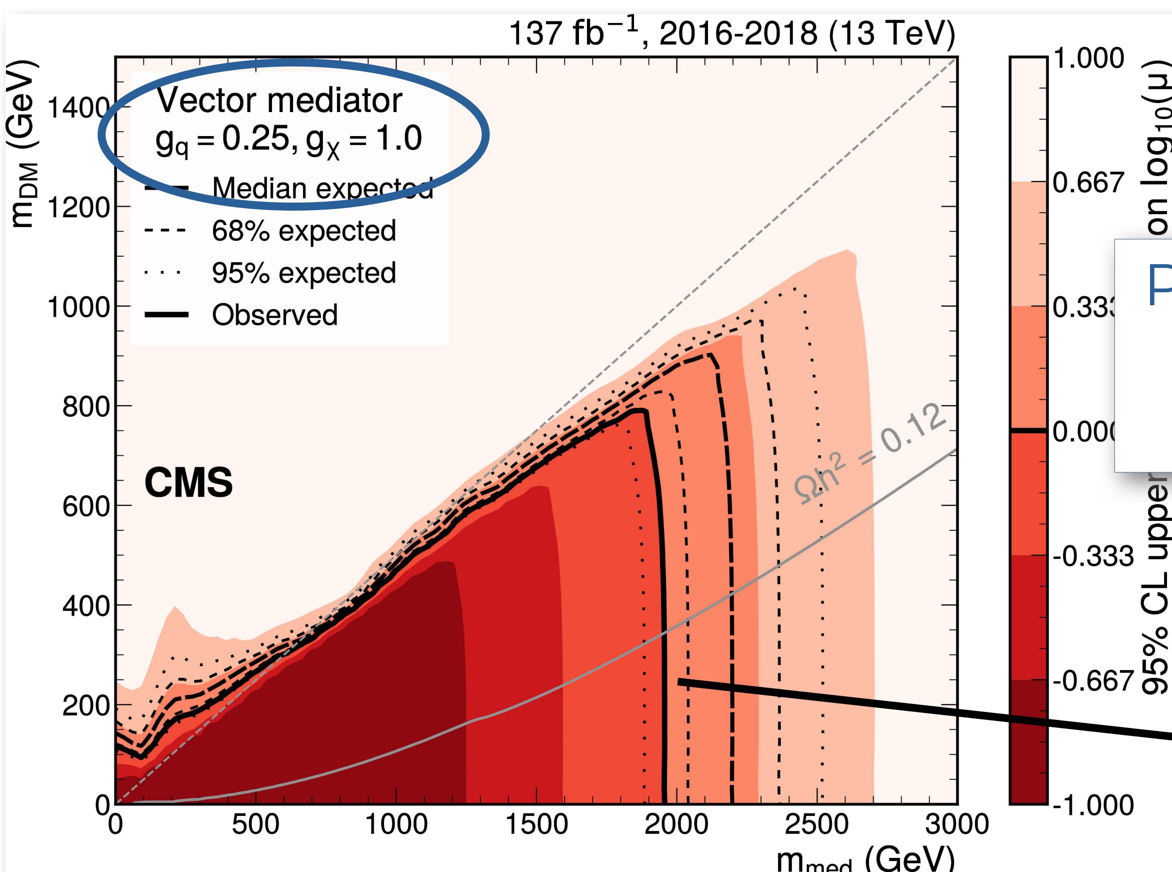
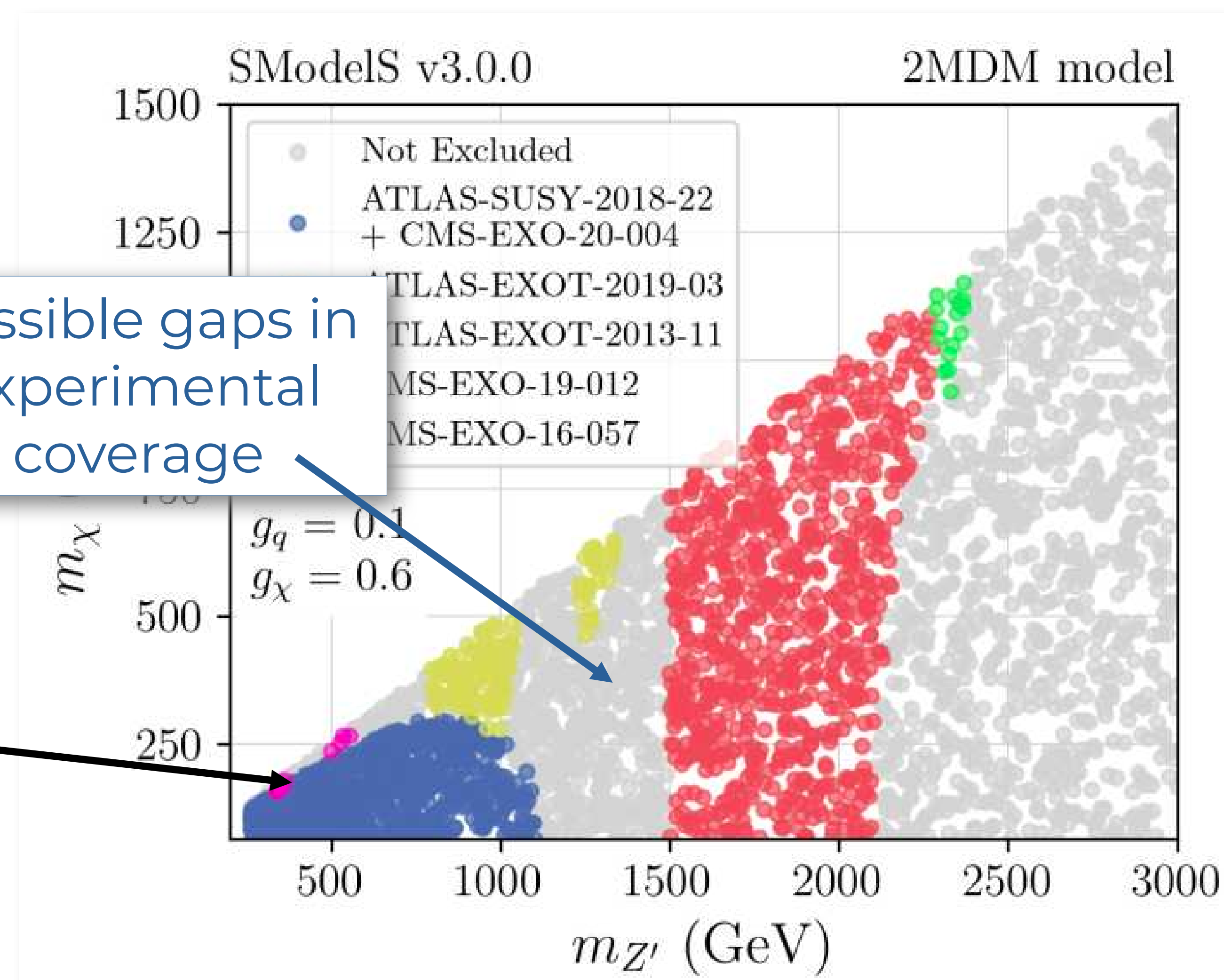
- CMS Exclusion (monojet):



CMS-EXO-20-004, 2107.13021



Possible gaps in experimental coverage

2409.12942, M. Altakach et al

Conclusions

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Obrigado!