Collider probes of real triplet scalar dark matter

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based on arXiv: 2003.07867

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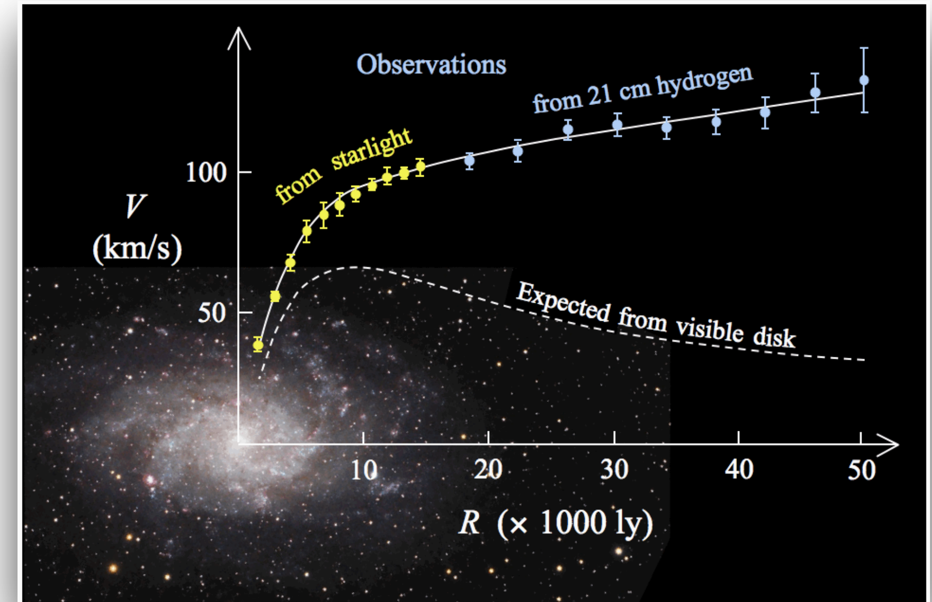
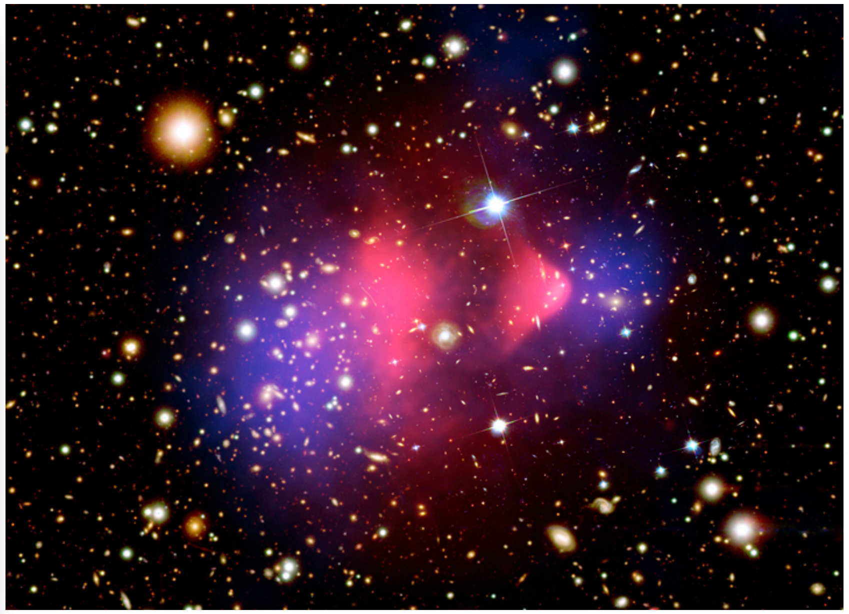
In collaboration with Cheng-Wei Chiang, Giovanna Cottin, Kaori Fuyuto, Michael Ramsey-Musolf

Disclaimer: Apologize for not citing your papers here due to limited time and selected topics.

Amherst Center for Fundamental Interactions
Physics at the interface: Energy, Intensity, and Cosmic frontiers
University of Massachusetts Amherst

Our focus...

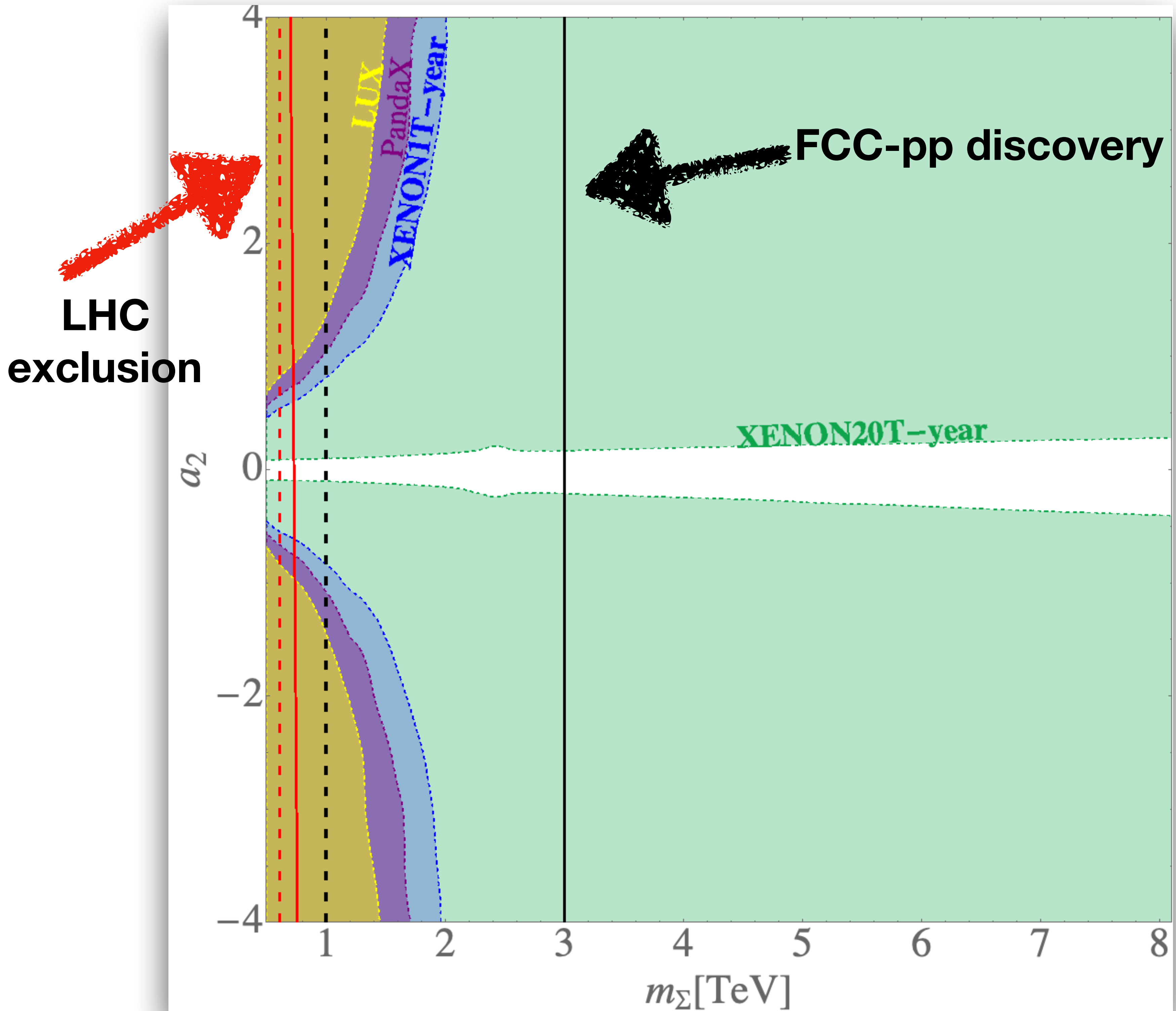




in the real triplet model

WIMP	**ATLAS**
FIMP	**CMS**
SIDM	**MATHUSLA**
Axion/ALPs	**SHiP**
Sterile neutrinos	**CODEX**
LSPs	**FASER**
PBHs	**...**
...	See talks earlier this morning and in the following days

What we find... the spoiler



1. LHC excludes ~300GeV
2. HL-LHC could excludes up to 800GeV
3. FCC-pp could cover O(TeV)
4. DM direct direction could cover almost the entire parameter space

Brief model introduction

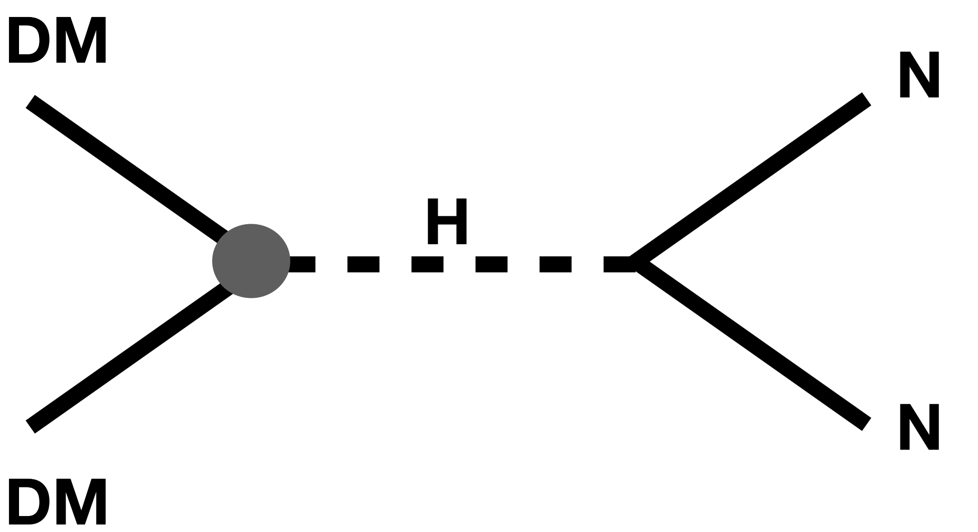
$\Sigma :=$ Real triplet (1, 3, 0)

$$\Sigma = \frac{1}{2}\begin{pmatrix} \Sigma^0 & \sqrt{2}\Sigma^+ \\ \sqrt{2}\Sigma^- & -\Sigma^0 \end{pmatrix}$$

$$V(H,\Sigma) = -\mu^2 H^\dagger H + \lambda_0 (H^\dagger H)^2 - \frac{1}{2} M_\Sigma^2 F + \frac{b_4}{4} F^2 + \frac{a_2}{2} H^\dagger H F$$

$$F = (\Sigma^0)^2 + 2\Sigma^+\Sigma^-$$

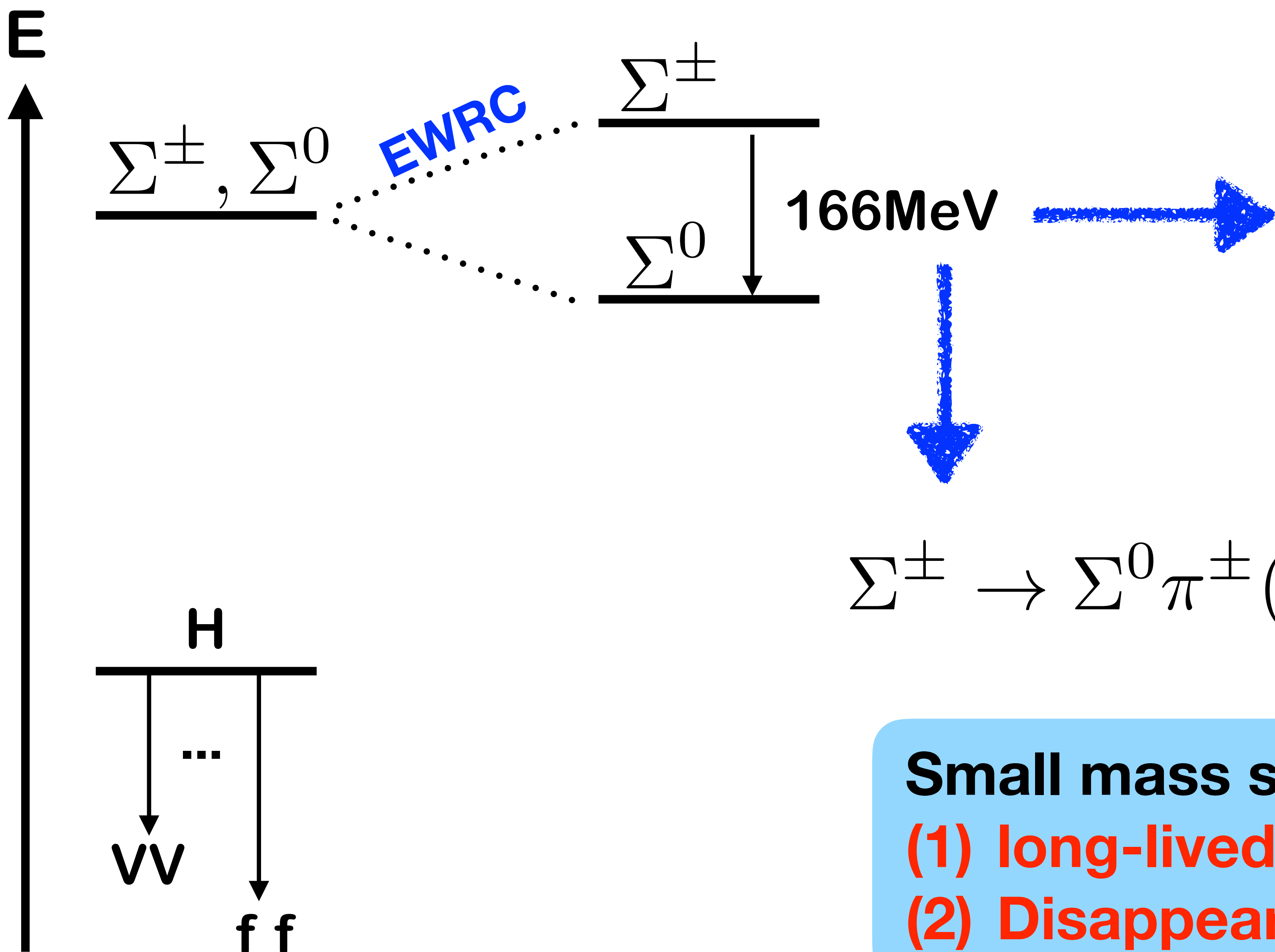
Already ruled out



Collider phenomenologies?

Brief model introduction

$$\mathbf{\Sigma} = \frac{1}{2}\begin{pmatrix} \Sigma^0 & \sqrt{2}\Sigma^+ \\ \sqrt{2}\Sigma^- & -\Sigma^0 \end{pmatrix}$$



$\Sigma^\pm$ is long lived (0.2ns)

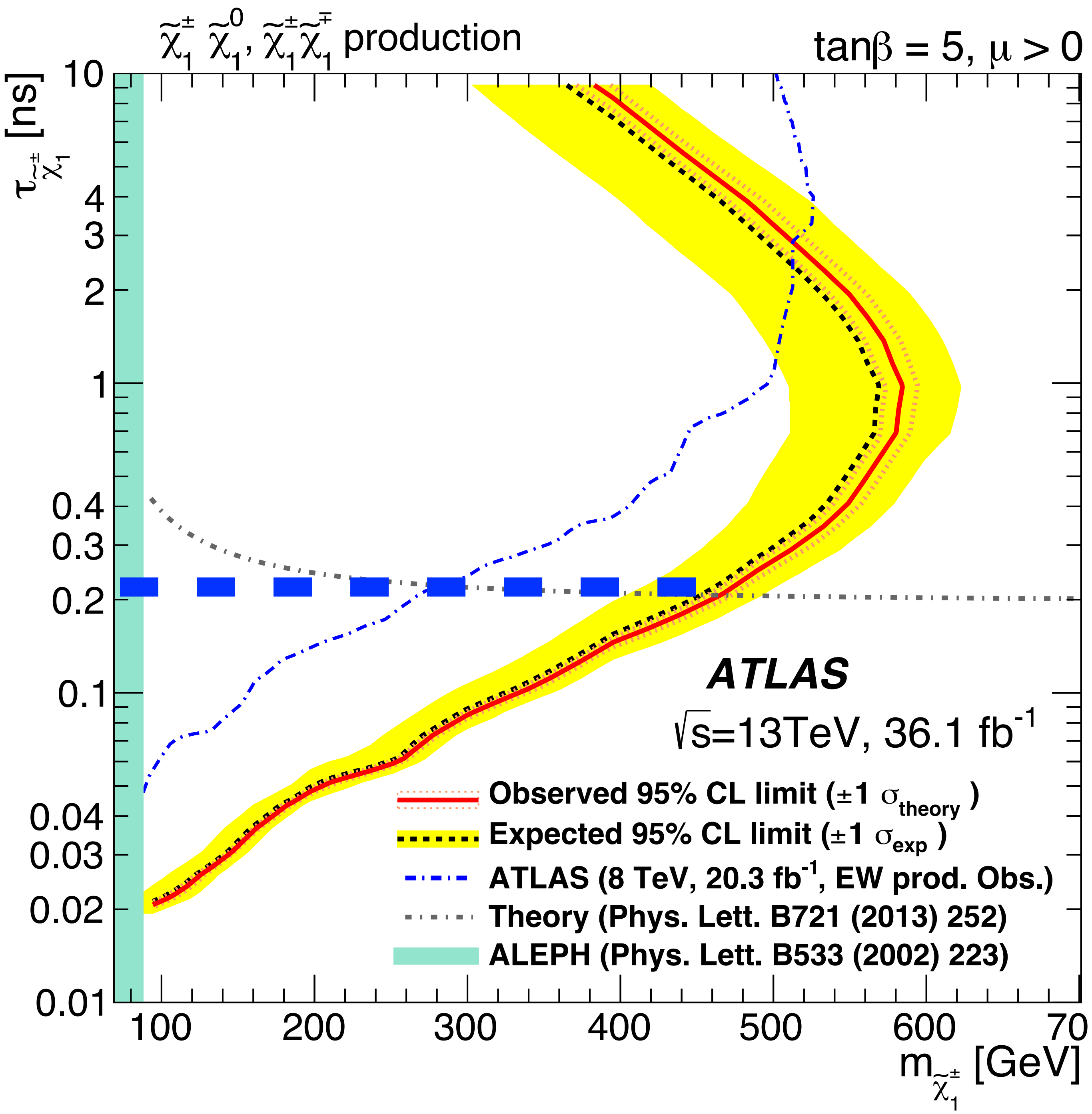
$$\Sigma^\pm \to \Sigma^0 \pi^\pm (97\%)$$

Small mass splitting leads to:
1. **long-lived particles**
2. **Disappearing tracks**

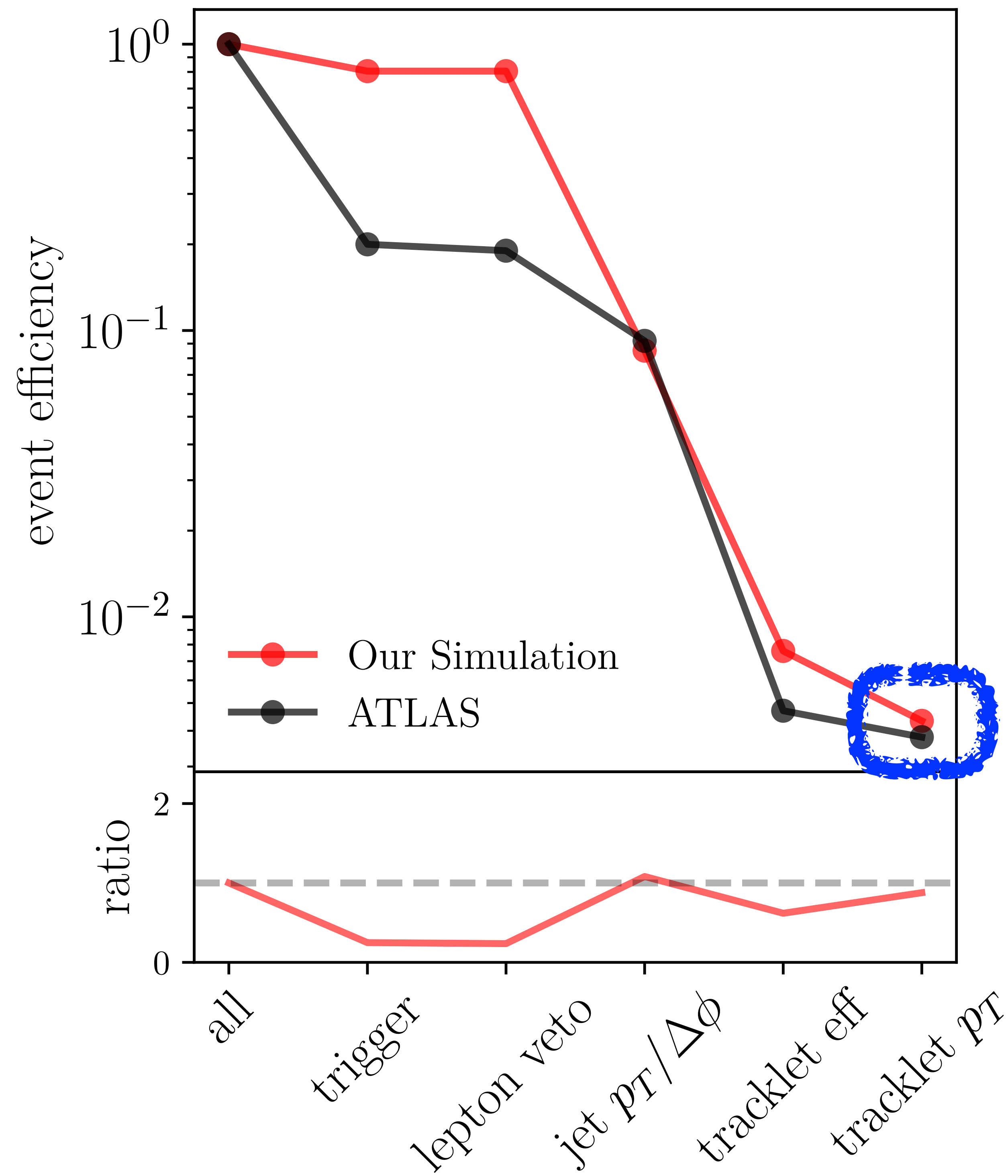
J. Alimena et al., 2019
T. Hambye, F. S. Ling, L. Lopez Honorez and J. Rocher, 2009
R. Mahbubani, P. Schwaller and J. Zurita, 2017

Reproduction of ATLAS result

C.W. Chiang, G. Cottin, Yong Du,
K. Fuyuto, M.J. Ramsey-Musolf
arXiv: 2003.07867



ATLAS collaboration,
arXiv:1712.02118



What we find...Collider part

C.W. Chiang, G. Cottin, Yong Du,
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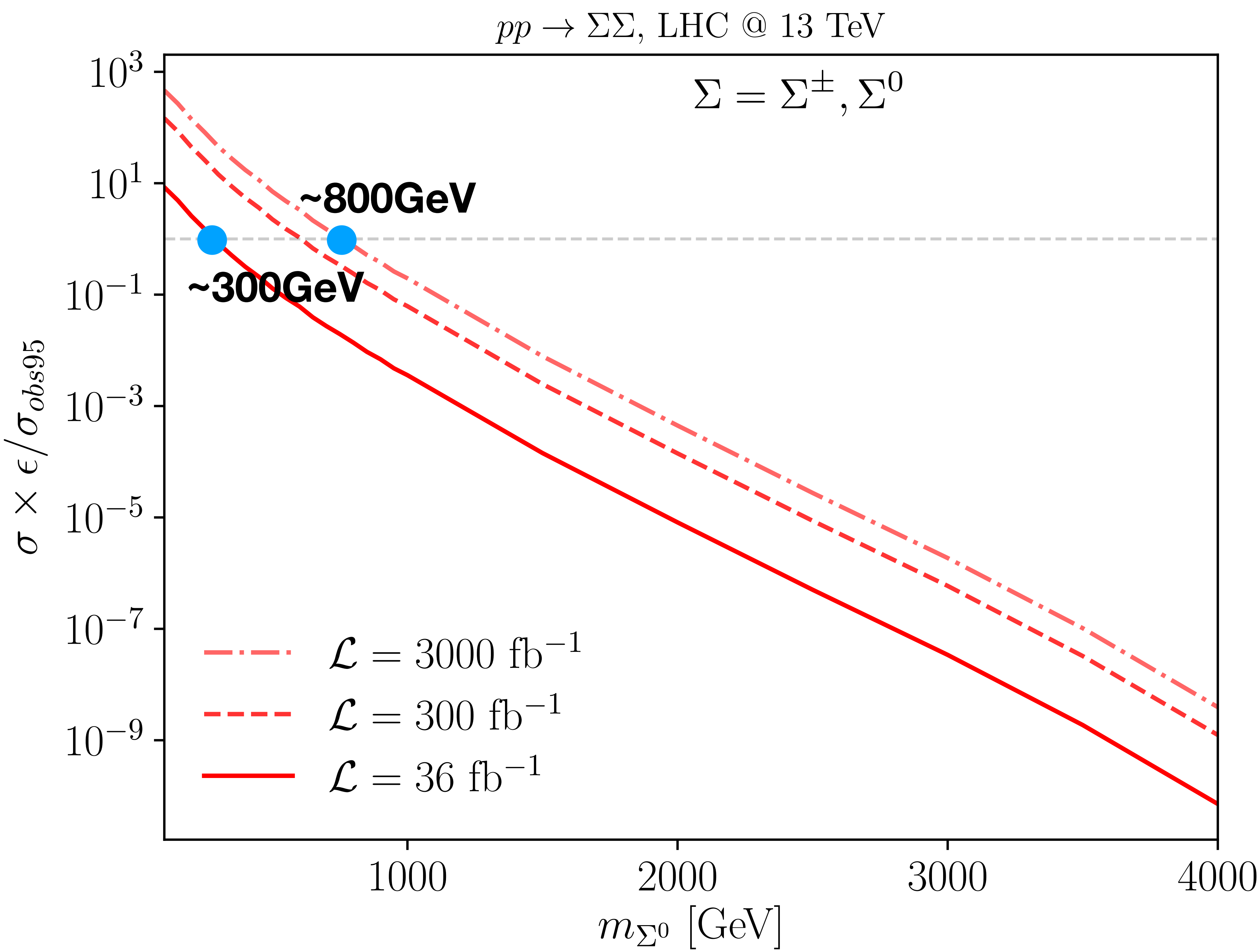
arXiv: 2003.07867

(HL-)LHC exclusion from cross section



What we find...Collider part

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arXiv: 2003.07867

FCC-pp discovery with different pileup control

M. Saito, R. Sawada, K. Terashi and S. Asai, 2019

Benchmark	σ [pb]	ϵ	S	B	$S/\sqrt{B}$
$m_{\Sigma^\pm} = 1.1$ TeV, $\bar{\mu} = 200$	5.8×10^{-2}	3.17×10^{-4}	553	673	21.3
$m_{\Sigma^\pm} = 1.1$ TeV, $\bar{\mu} = 500$	5.8×10^{-2}	3.17×10^{-4}	553	8214	6
$m_{\Sigma^\pm} = 3.1$ TeV, $\bar{\mu} = 200$	9.4×10^{-4}	4.69×10^{-4}	13.3	1.9	9.6
$m_{\Sigma^\pm} = 3.1$ TeV, $\bar{\mu} = 500$	9.4×10^{-4}	4.69×10^{-4}	13.3	27	2.6

3TeV triplet DM could be discoverable at FCC-pp

Collider searches are a2 insensitive!

What we find…Combination

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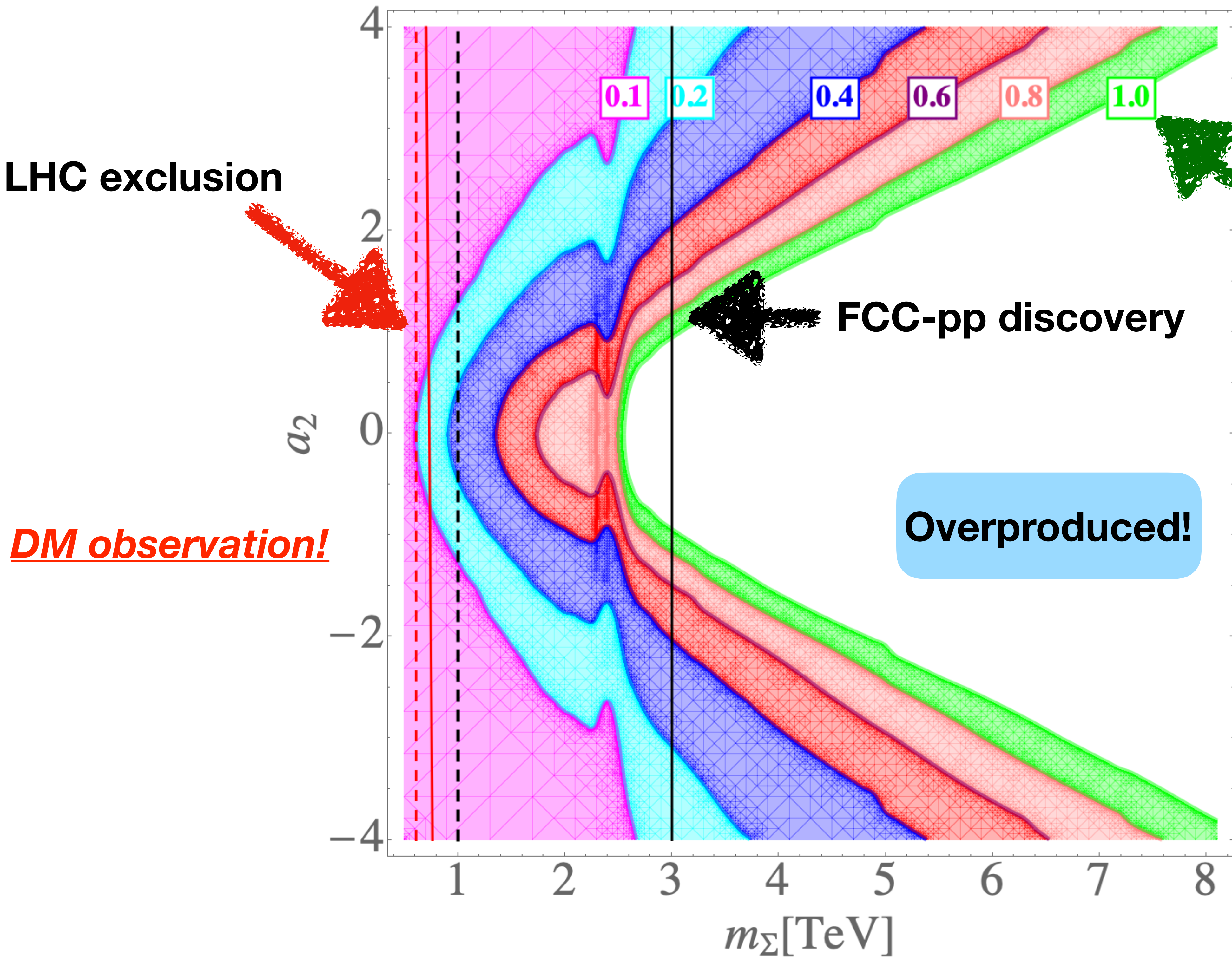
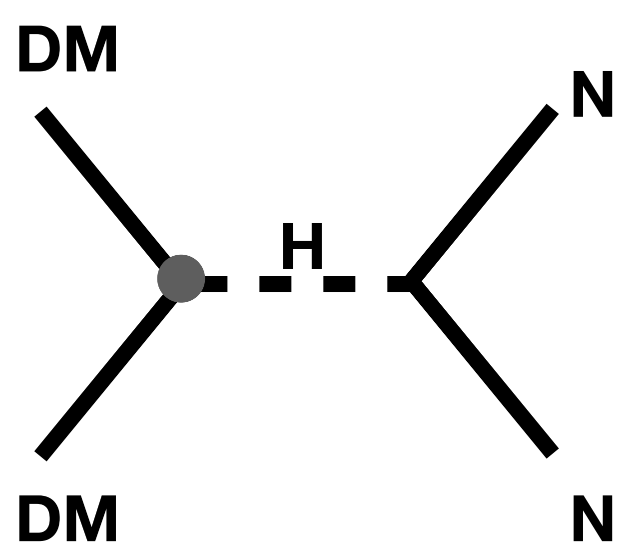
K. Fuyuto, M.J. Ramsey-Musolf
arXiv: 2003.07867

Colliders+relic abundance



$$\mathcal{R} = \frac{\Omega_\Sigma}{\Omega_{\rm DM}}$$



What we find...Combination

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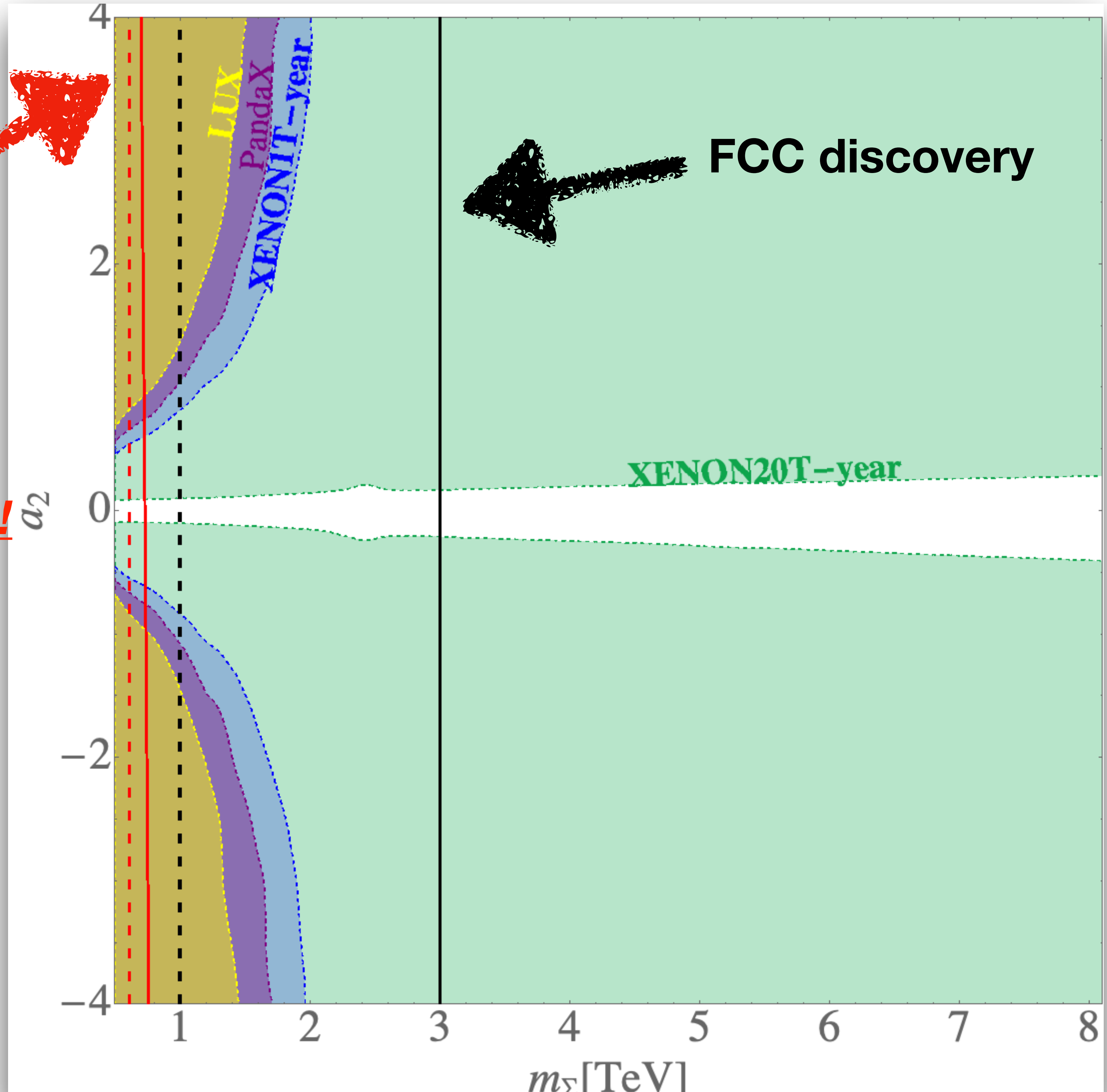
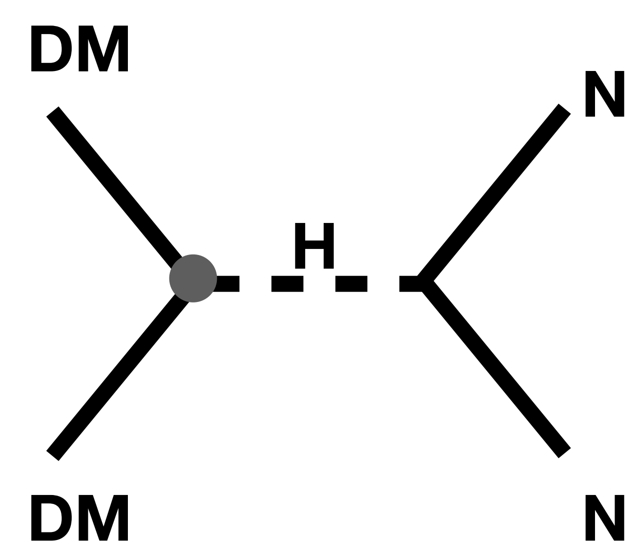
LHC exclusion

Complementary!



$$\sigma_{\rm SI}^{\rm scaled} \equiv \frac{\sigma_{\rm SI}\Omega h^2}{(\Omega h^2)_{\rm Planck}}$$



Summary

1. We study the real triplet (1,3,0) model with the neutral triplet component being our dark matter candidate.

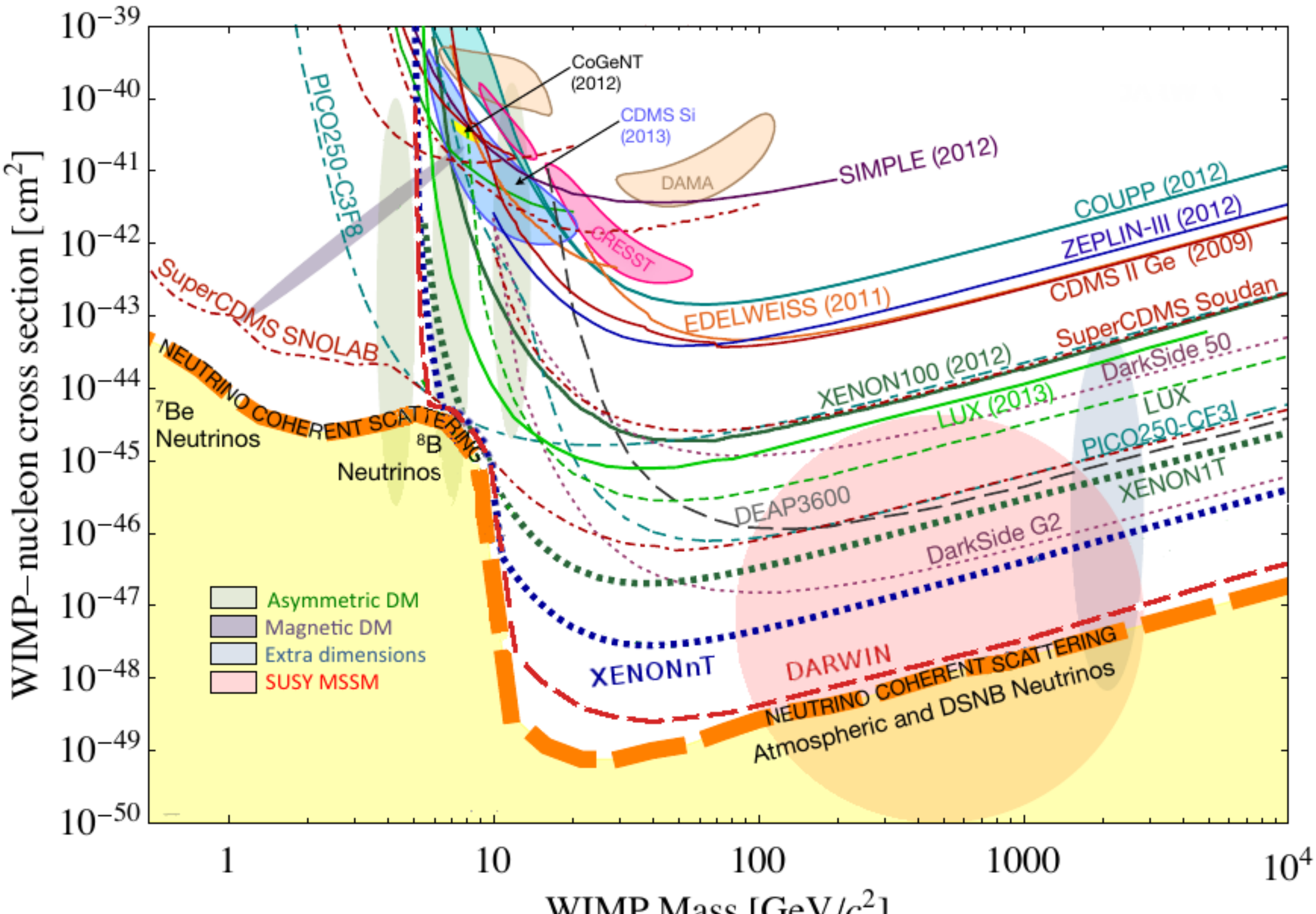
2. Current LHC and HL-LHC (would) exclude the triplet lighter than ~300GeV and ~800GeV. FCC-pp could discover 3 TeV triplet depending on pileup control.

3. XENON1T rules out 1~2TeV triplet (depending on a2), XENON20T would cover almost the entire parameter space.

4. Collider and dark matter direct detection are complementary.

Backup

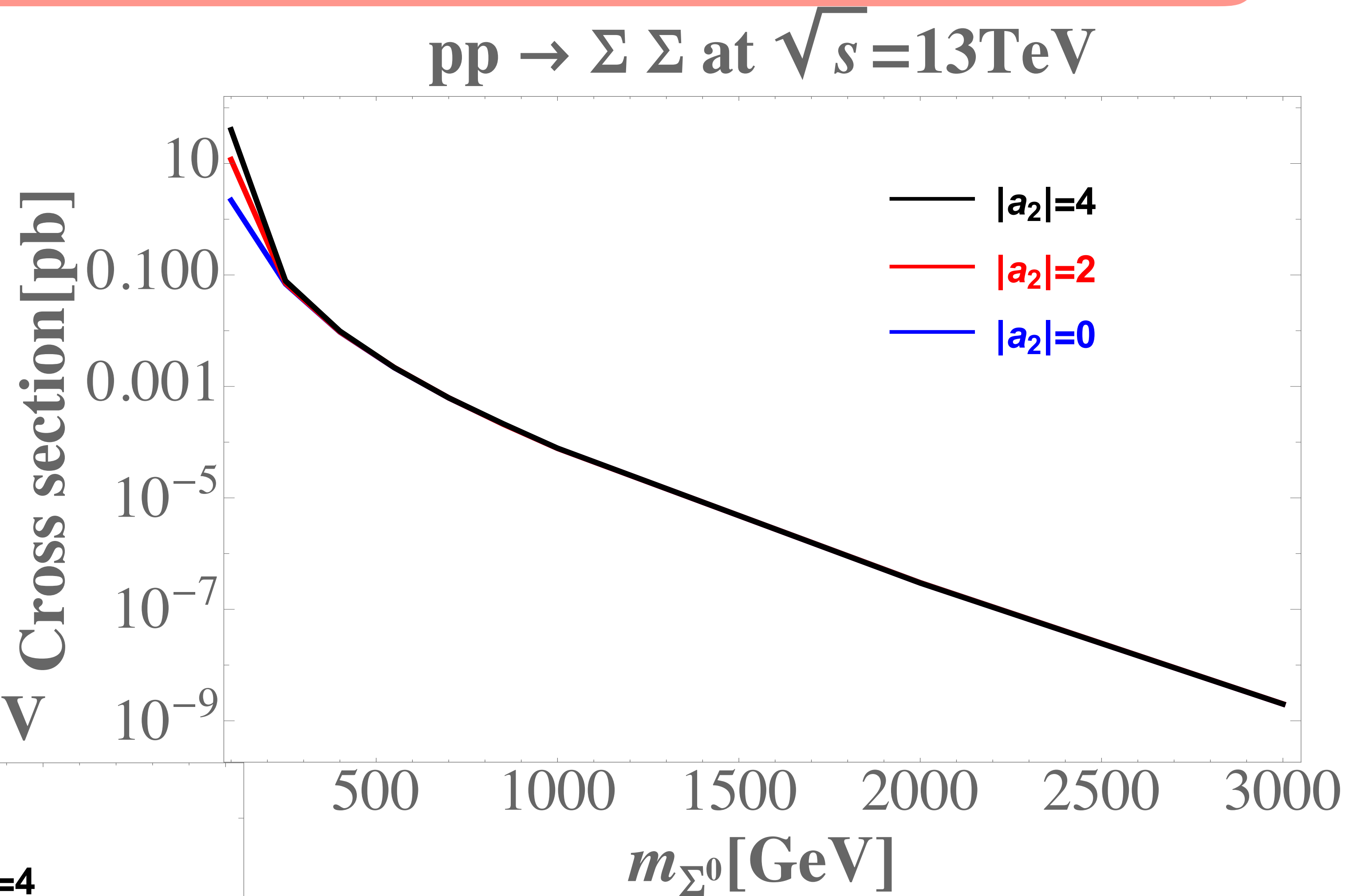
Spin-independent DM-nucleon cross section

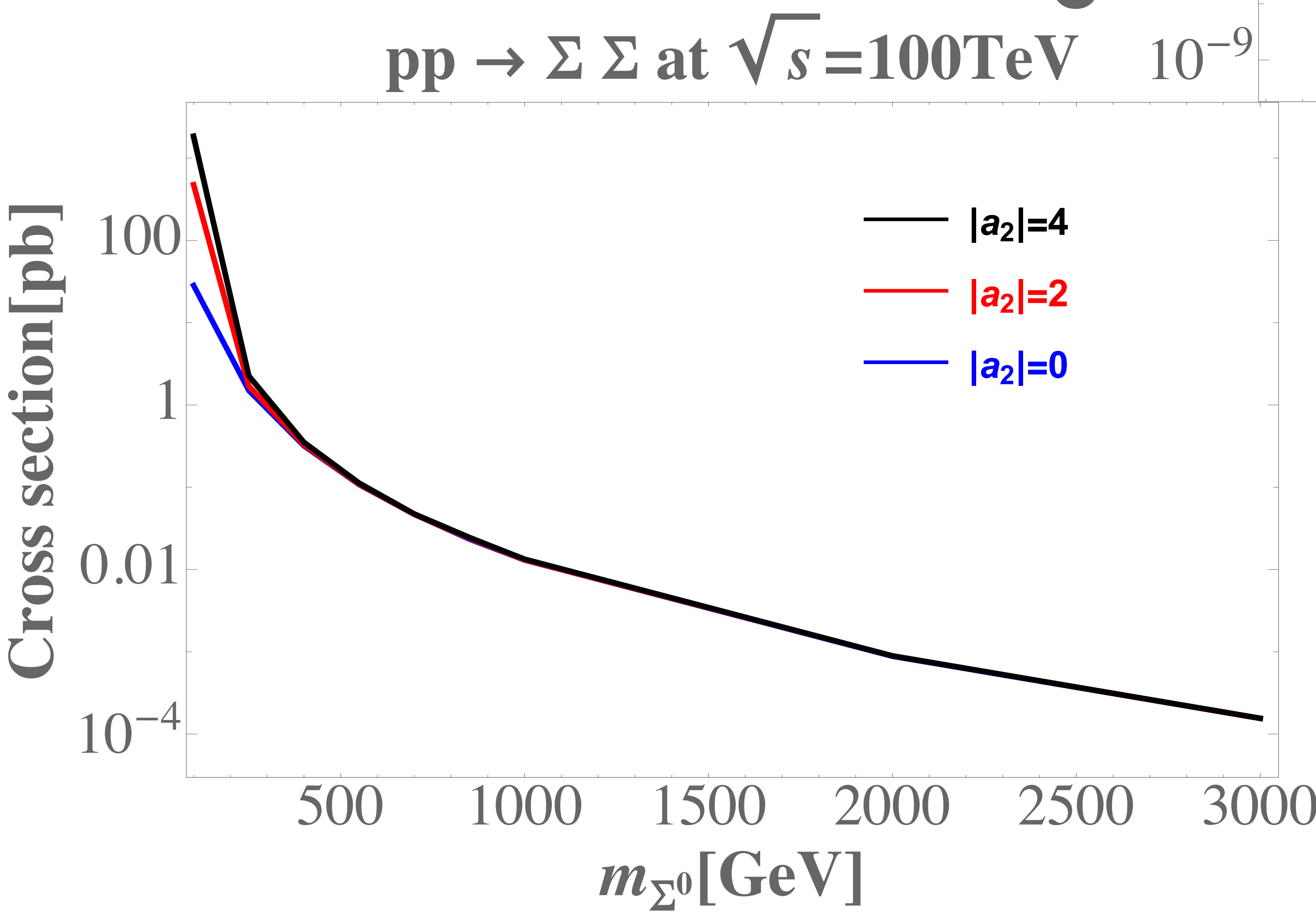


Klasen et al, arXiv: 1507.03800

Production cross section: a2 dependence

13 TeV





100 TeV

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arXiv: 2003.07867

Cuts applied for the (HL-)LHC

- Trigger : $\not{p}_T > 140\,\mathrm{GeV}$
- Lepton veto : no electrons or muons
- Jet $p_T/\Delta\phi$: at least one jet with $p_T > 140\,\mathrm{GeV}$, and $\Delta\phi$ between the $\not{p}_T$ vector and each of the up to four hardest jets with $p_T > 50\,\mathrm{GeV}$ to be bigger than 1.0
- Tracklet selection : at least one tracklet (generator-level chargino) with :
  - $p_T > 20\,\mathrm{GeV}$ and $0.1 < |\eta| < 1.9$
  - 122.5 mm $<$ decay position < 295 mm
  - ΔR distance between the tracklet and each of the up to four highest$-p_T$ jets with $p_T > 50\,\mathrm{GeV}$ to be bigger than 0.4
  - we apply the tracklet acceptance $\times$ efficiency map[6] provided by ATLAS, which is based on the decay position and η. This is applied to selected tracklets passing the above selections.
- Tracklet p_T : Select tracklets with $p_T > 100\,\mathrm{GeV}$.

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Cuts applied for a 100TeV collider

- Trigger : $\not{p}_T > 1\,\text{TeV}$ or $\not{p}_T > 4\,\text{TeV}$ depending on the benchmark as discussed below.
- Lepton veto : no electrons or muons.
- Jet $p_T/\Delta\phi$: at least one jet with $p_T > 1\,\text{TeV}$, and $\Delta\phi$ between the $\not{p}_T$ vector and each of the up to four hardest jets with $p_T > 50\,\text{GeV}$ to be bigger than 1.0.

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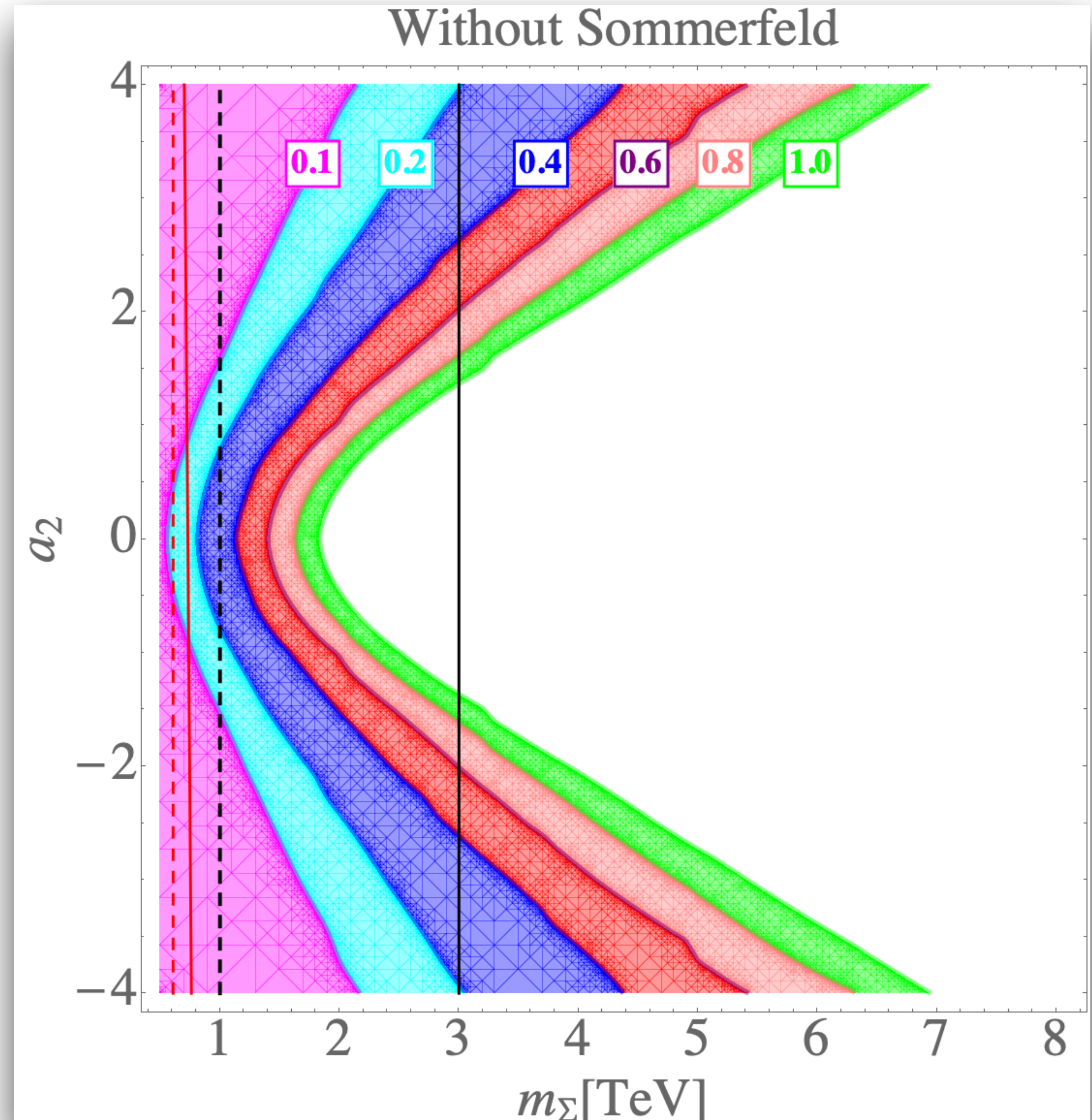
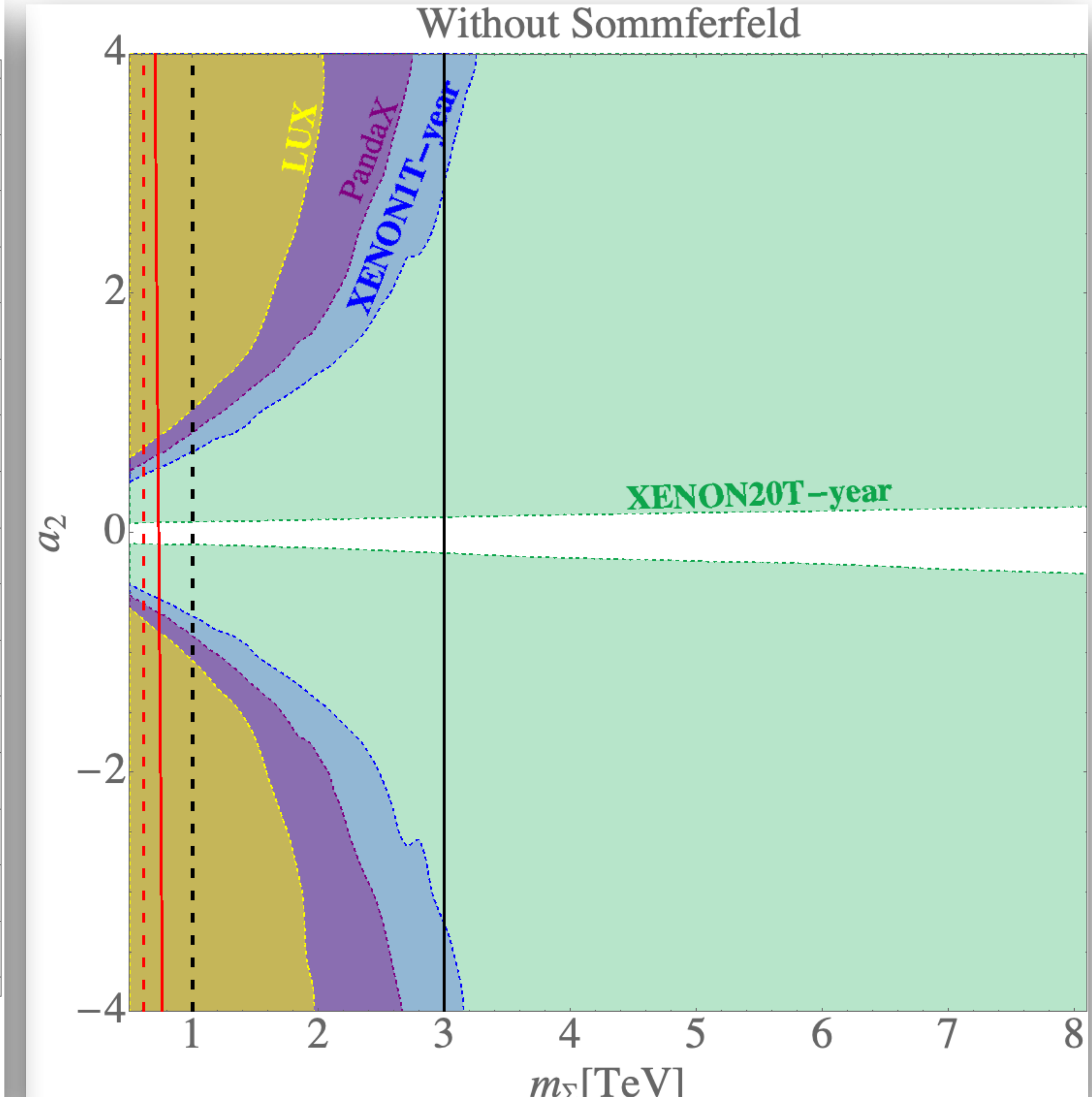
Constraints w/o including the Sommerfeld





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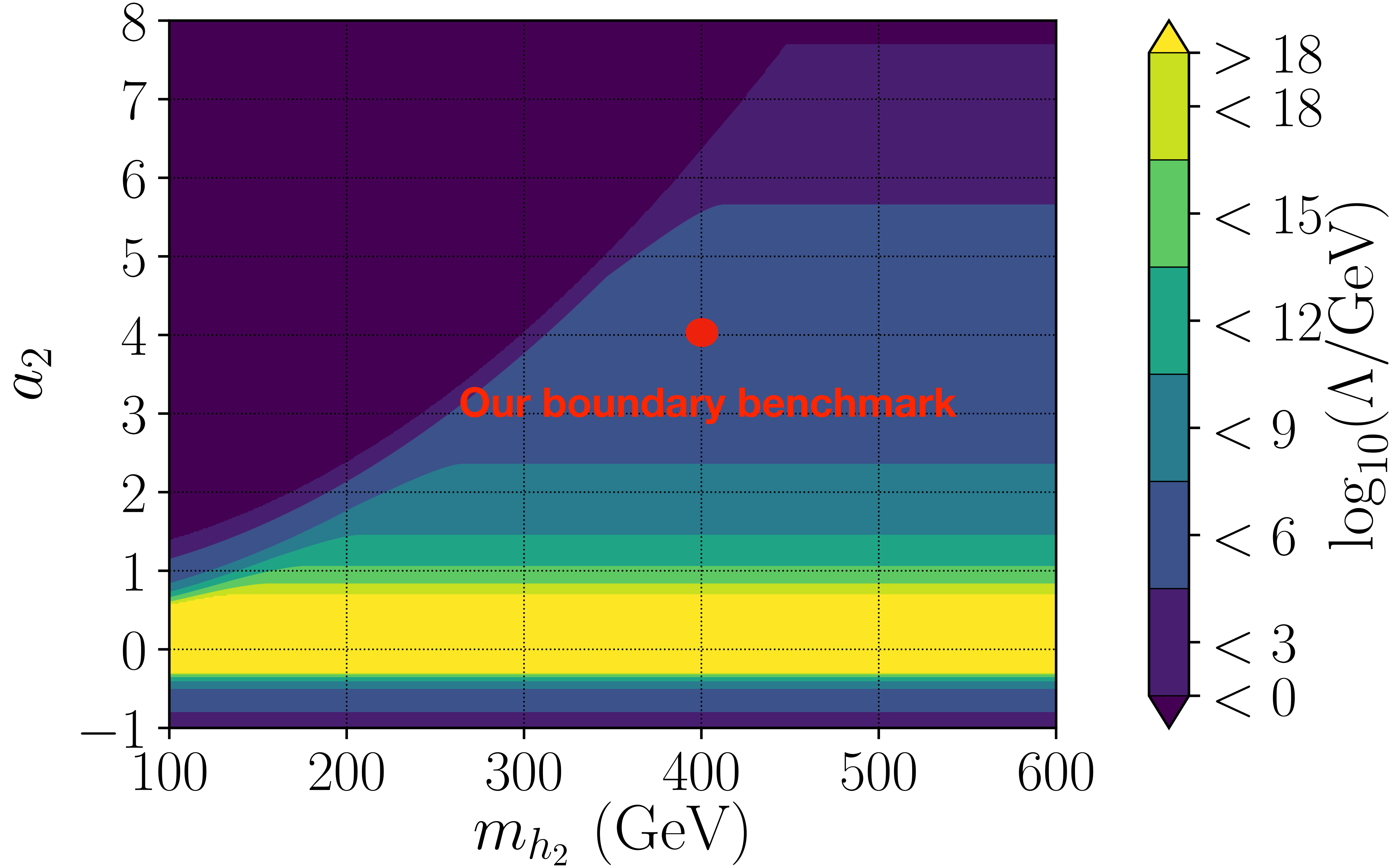
Constraints from perturbativity and perturbative unitarity



Bell et al, arXiv: 2001.05335