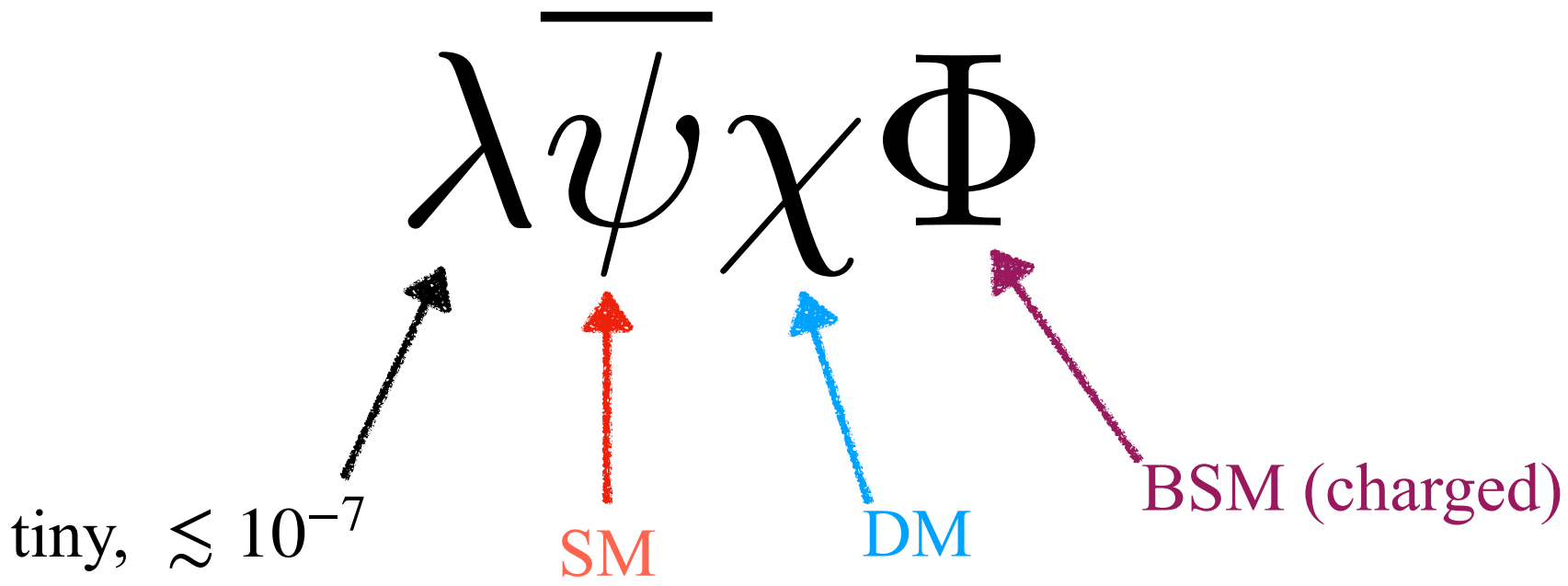
Baryogenesis and dark matter from freeze-in

Dave Tucker-Smith
Williams College

Based on arXiv:2004.00636, with Brian Shuve

An interaction for freeze-in DM and baryogengesis



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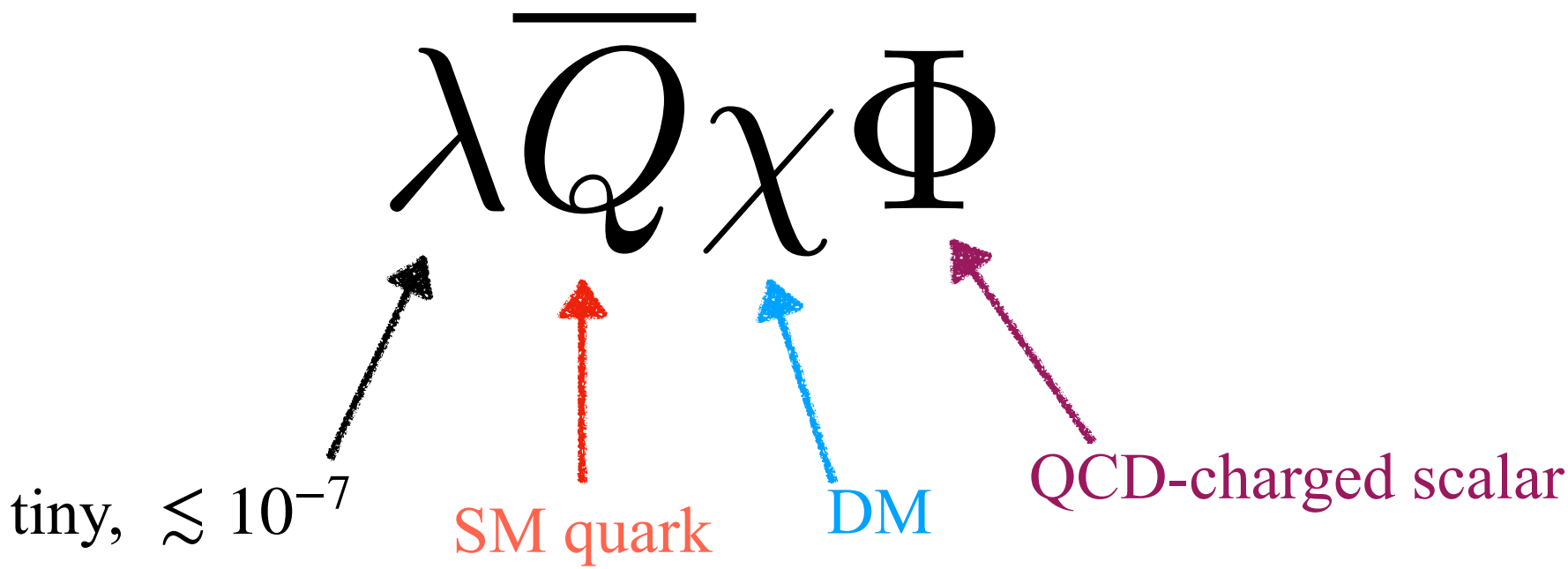
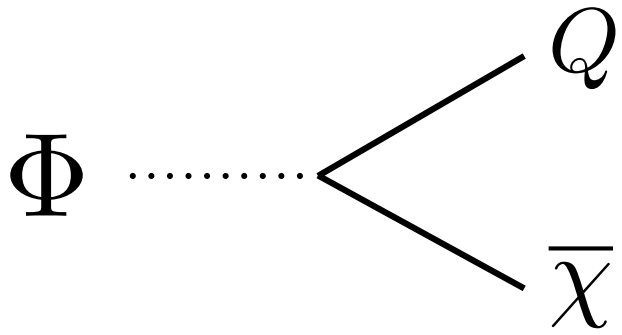


Basic mechanism

DM production



McDonald, hep-ph/0106249
Hall *et* al., arXiv:0911.1920
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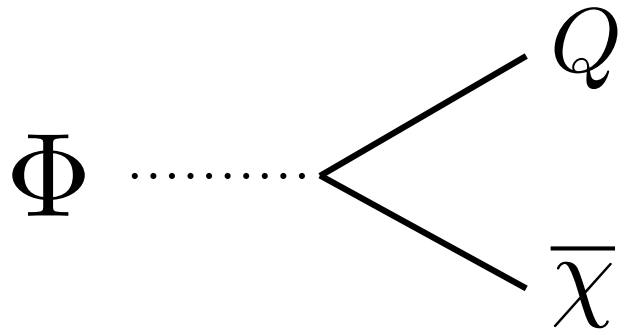

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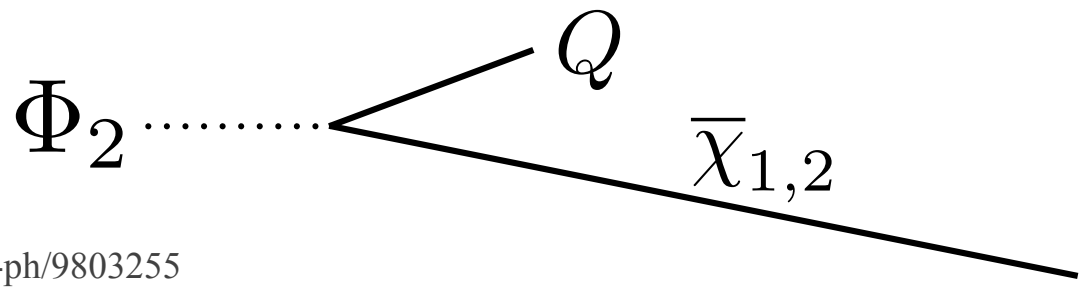
Asymmetry generation



Akhmedov, Rubakov, Smirnov, hep-ph/9803255
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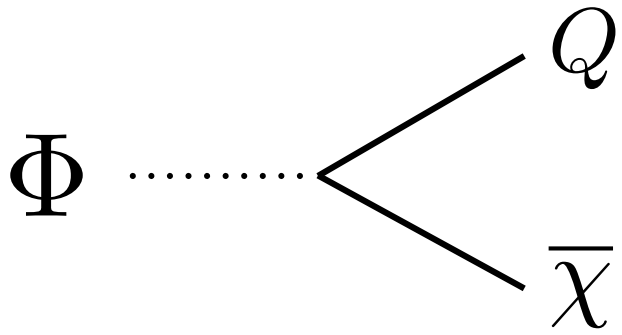

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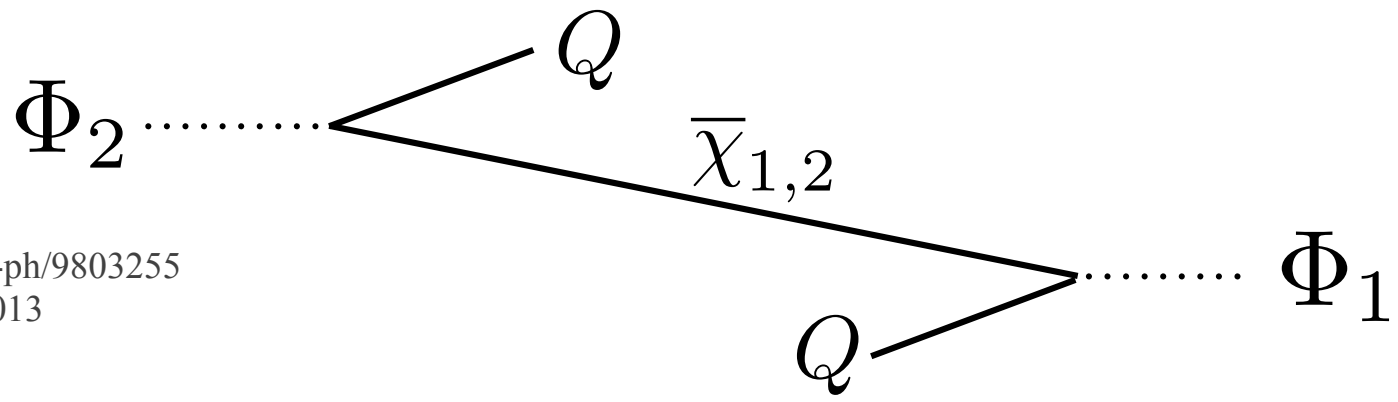

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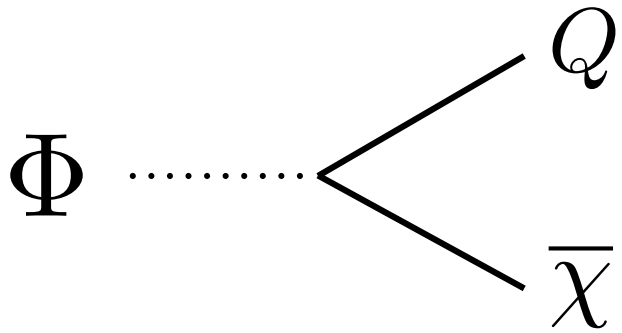

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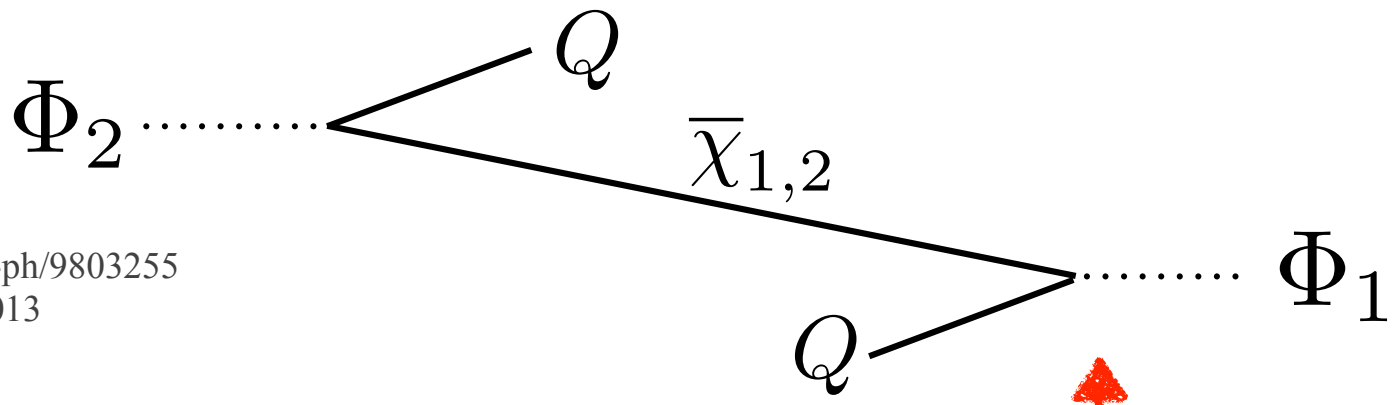

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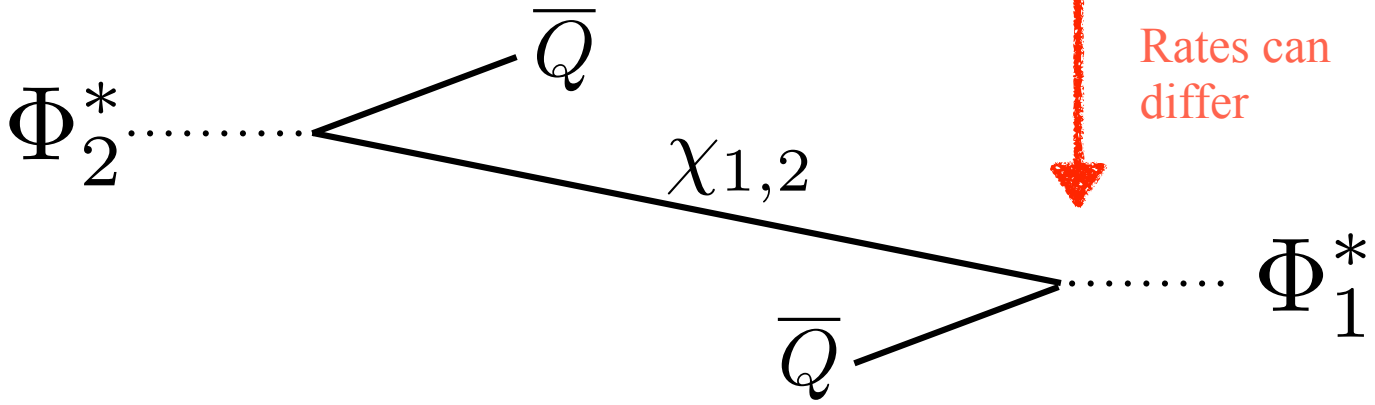
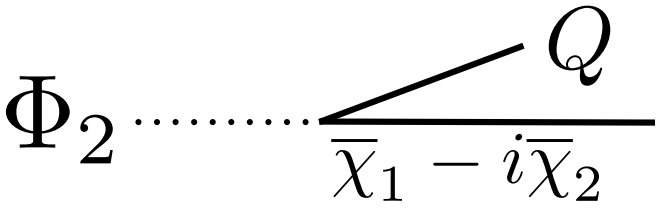
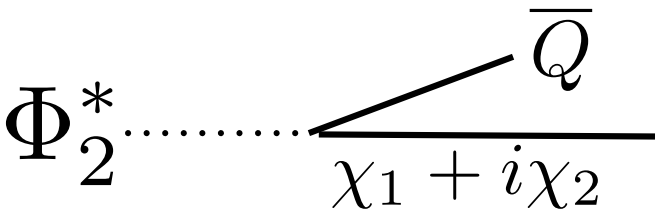


Toy example

$$\mathcal{L} \supset -\lambda_1 \overline{Q}(\chi_1 + \chi_2)\Phi_1 - \lambda_2 \overline{Q}(\chi_1 + i\chi_2)\Phi_2 + h.c.$$





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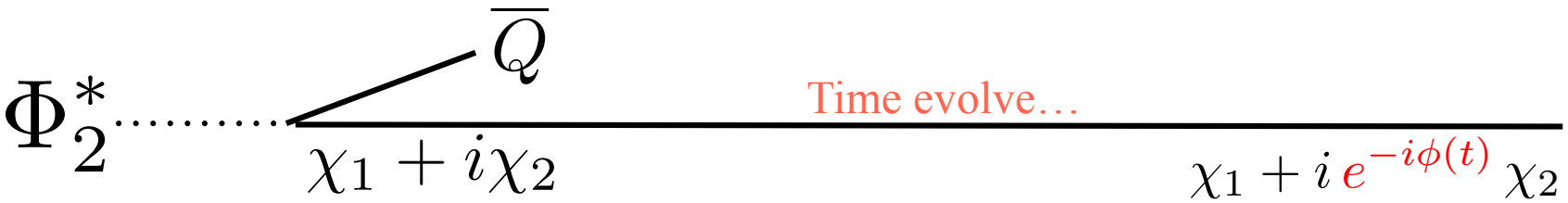

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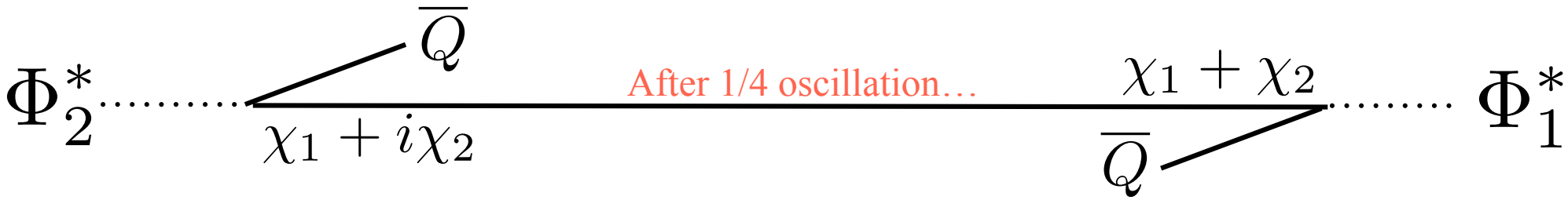
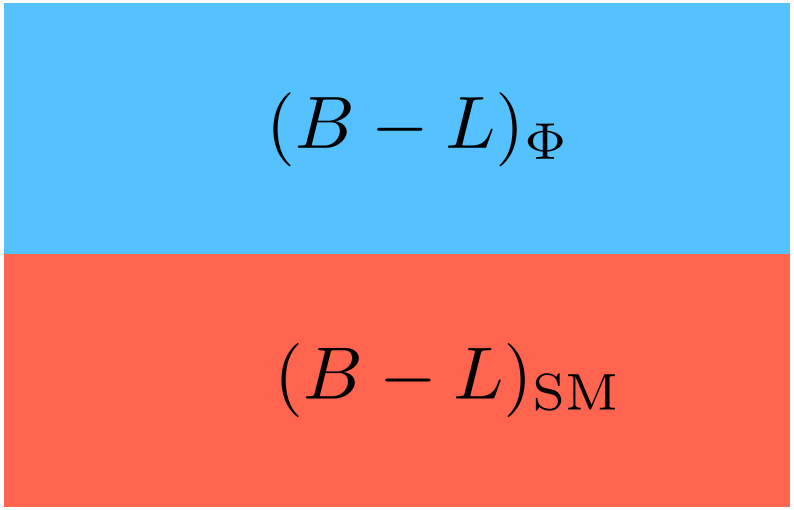
Can't scatter to produce Φ_1



From Φ asymmetry to baryon asymmetry

$$T > T_{\rm ew}$$

- Neither B nor L is separately conserved.
- $B - L$ *is* conserved.



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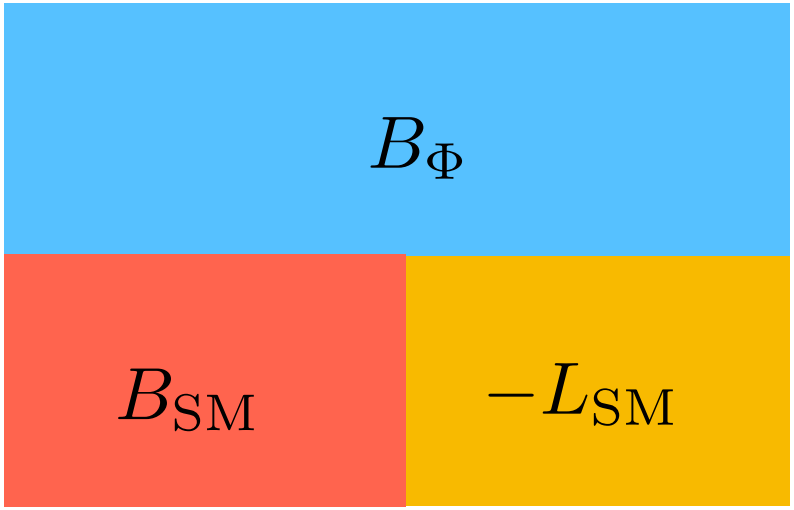

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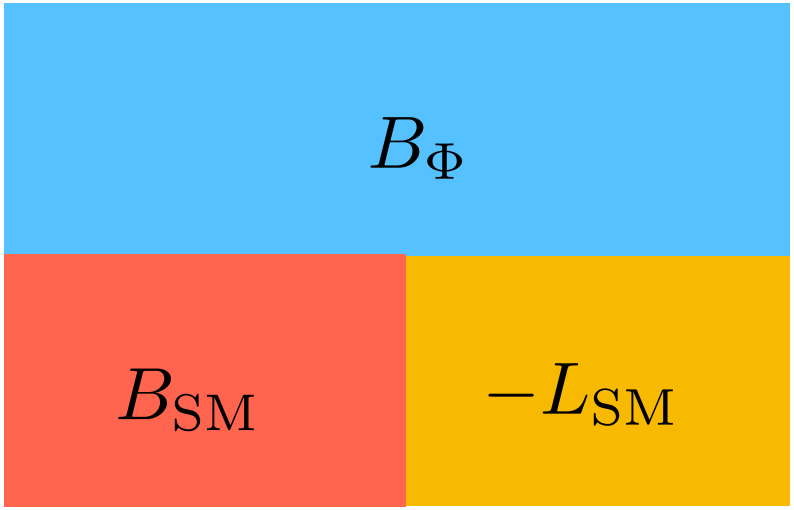

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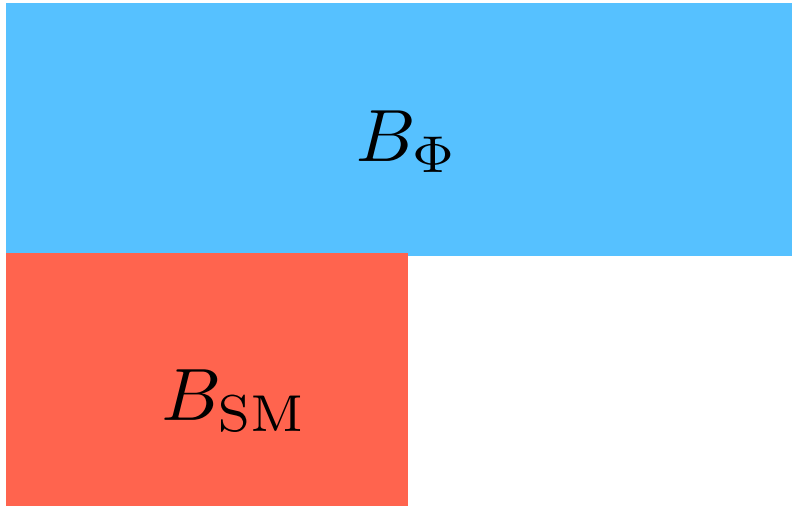


$$B_{\rm total} = L_{\rm total} \neq 0$$

Rough parametrics

- Need Φ particles around at $T_{\rm ew}$: $\quad \Gamma_\Phi \gtrsim H_{\rm ew} \longrightarrow c\tau_\Phi \gtrsim$ cm
- DM constraint also requires long lifetimes.
- Oscillation timescale is set by ΔM_χ^2. Optimal for baryogenesis: an appreciable fraction of an oscillation by $T \sim M_{\Phi_1}$:
  $\longrightarrow \Delta M_\chi^2 \sim (20\ \text{keV})^2$ for $M_\Phi \sim$ TeV.
- Together, DM and baryogengesis requirements prevent scaling the whole mechanism up to arbitrarily high mass scales.

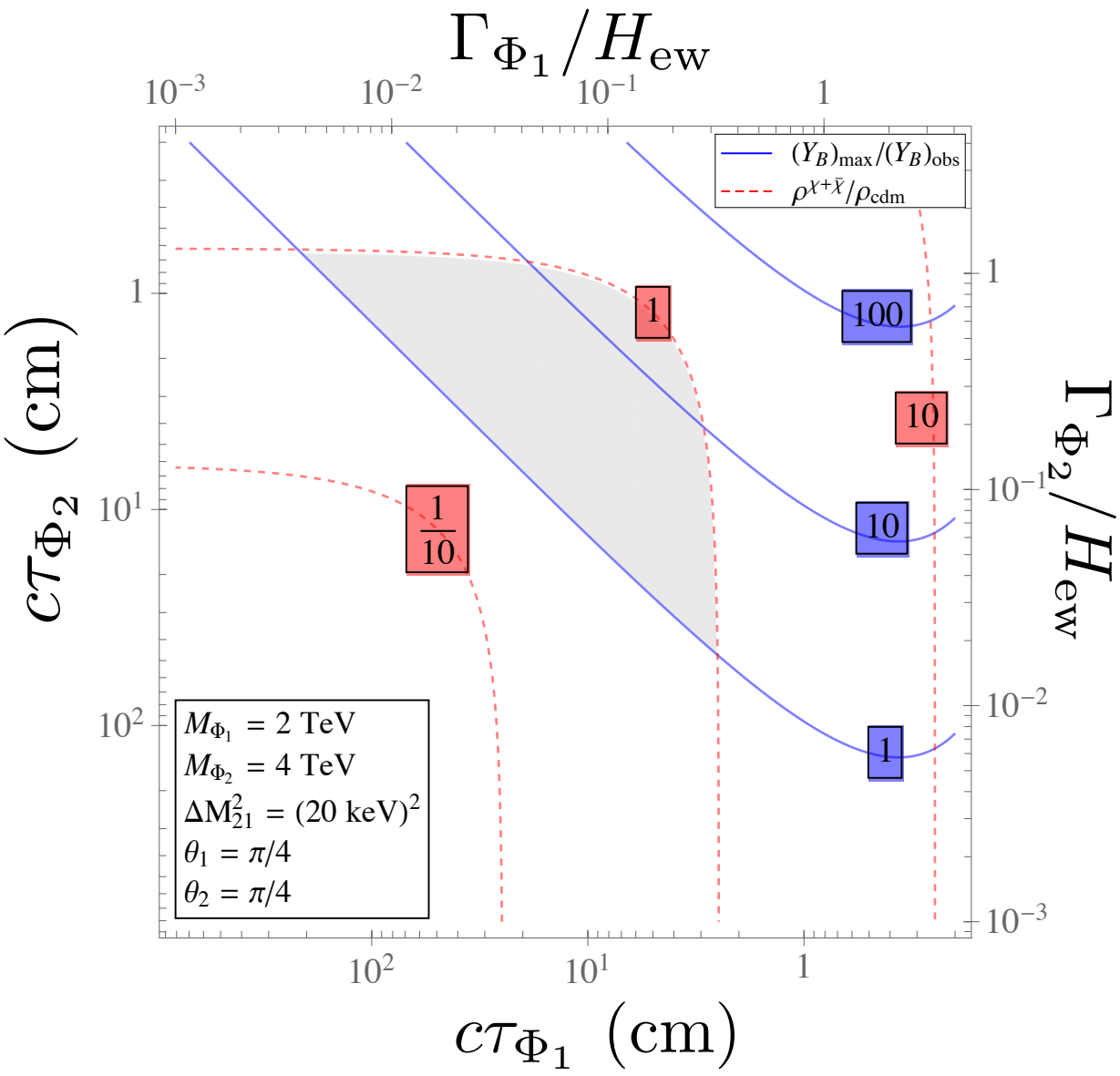
Asymmetry + DM

$$M_{\Phi_1} = \frac{M_{\Phi_2}}{2} = 2 \text{ TeV}$$

$$M_{\chi_1} = 0,\ M_{\chi_2} = 20 \text{ keV}$$

$Y_B^{\max}/Y_B^{\text{obs}}$

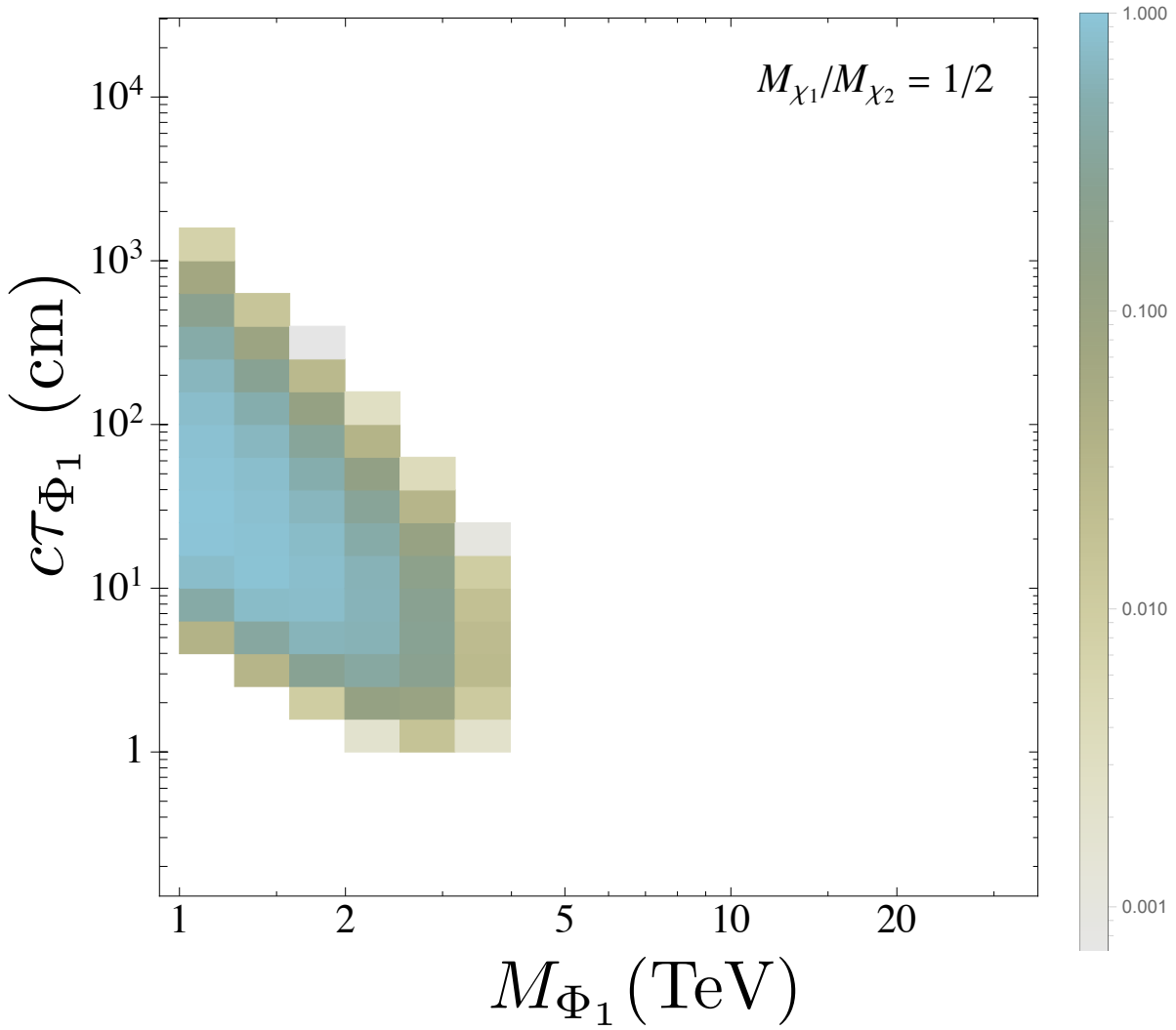
$\rho^{\chi+\bar{\chi}}/\rho_{\text{cdm}}$



Masses + lifetimes

- Require $M_{\chi_2} > 10$ GeV.
- For points with $M_{\chi_1} < 10$ GeV, require $\rho_{\chi_1} < \rho_{DM}/3$.

$$M_{\chi_1}/M_{\chi_2} = 1/2$$



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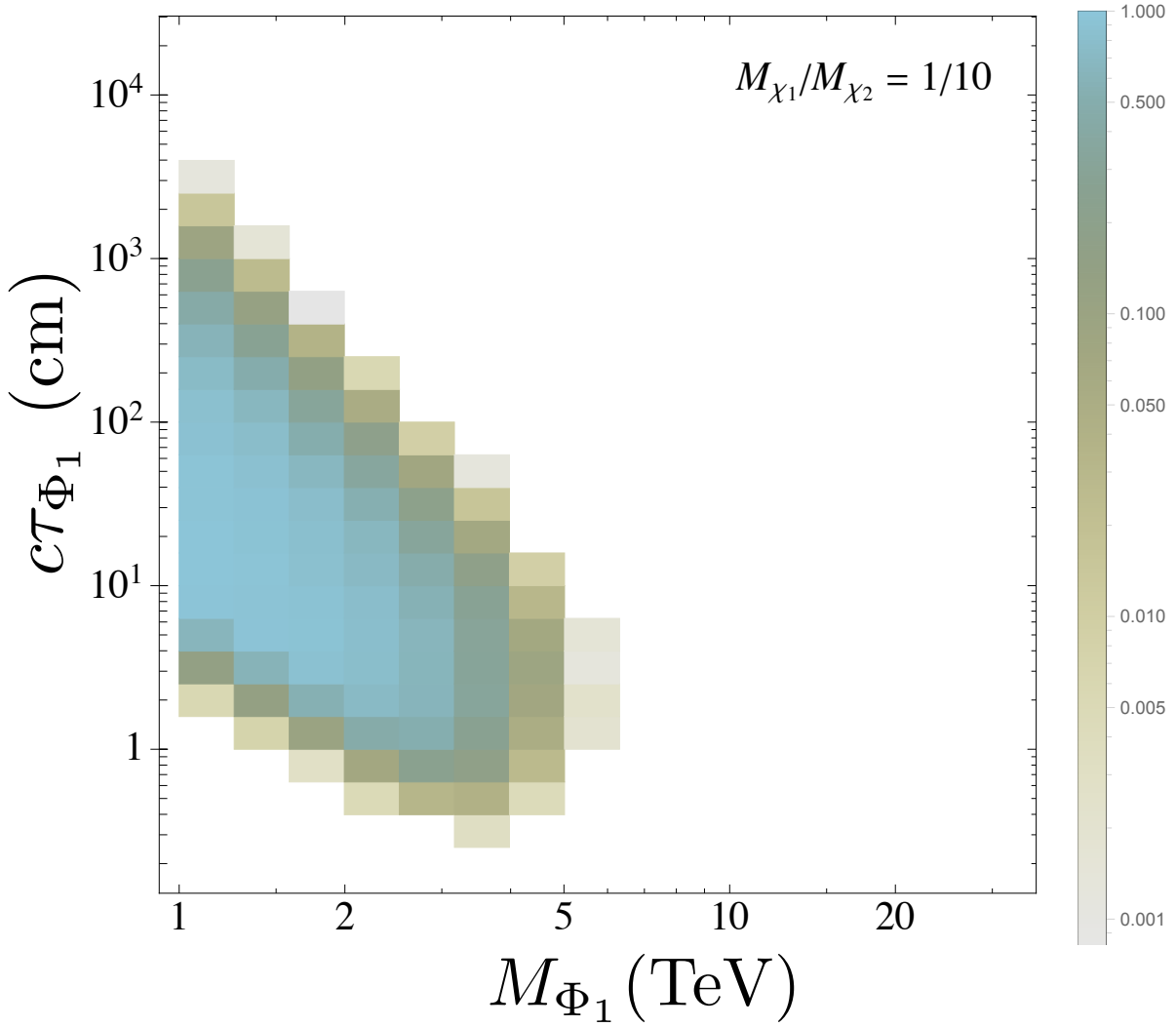
$$M_{\chi_1}/M_{\chi_2} = 1/10$$



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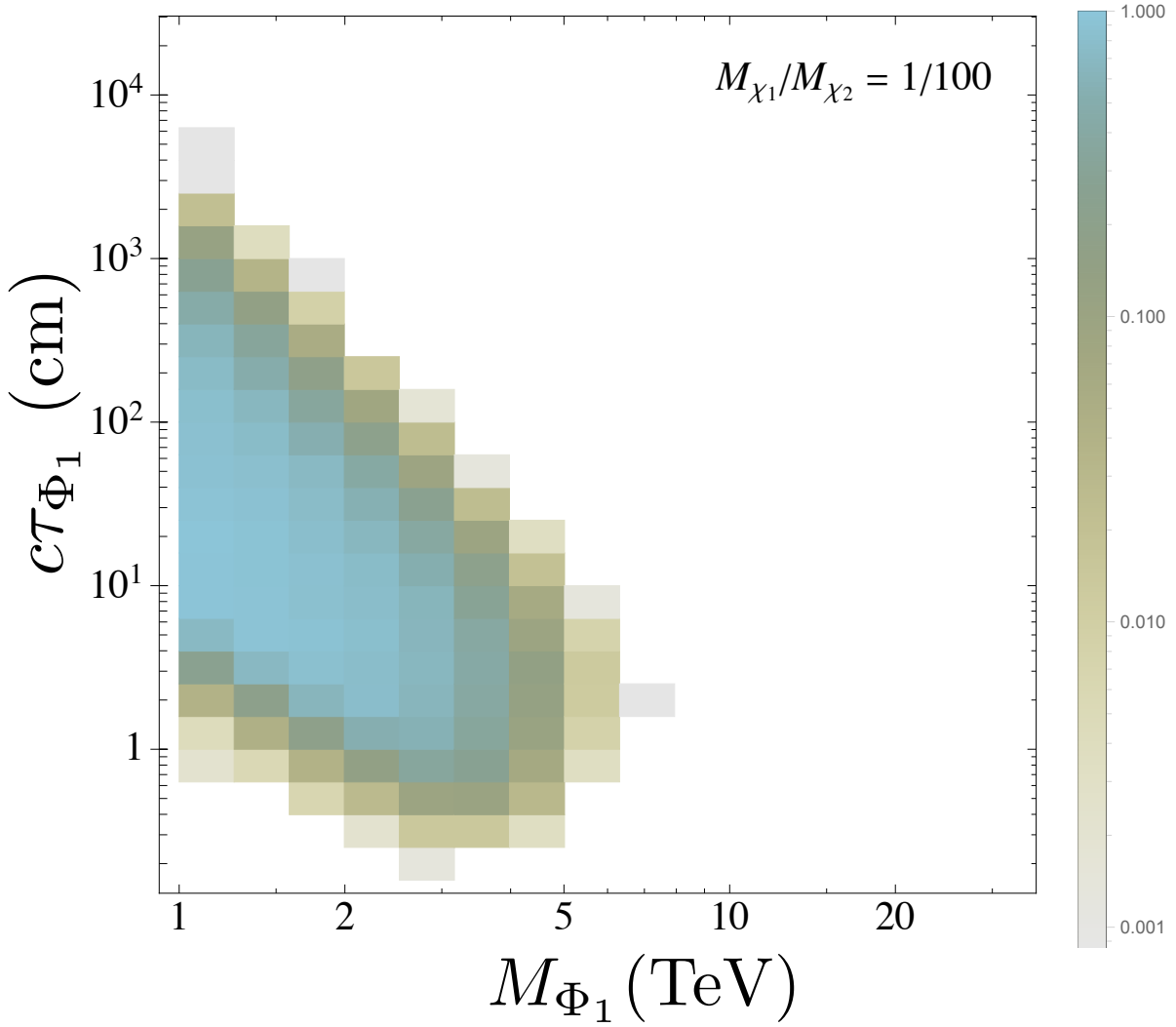
$$M_{\chi_1}/M_{\chi_2} = 1/100$$



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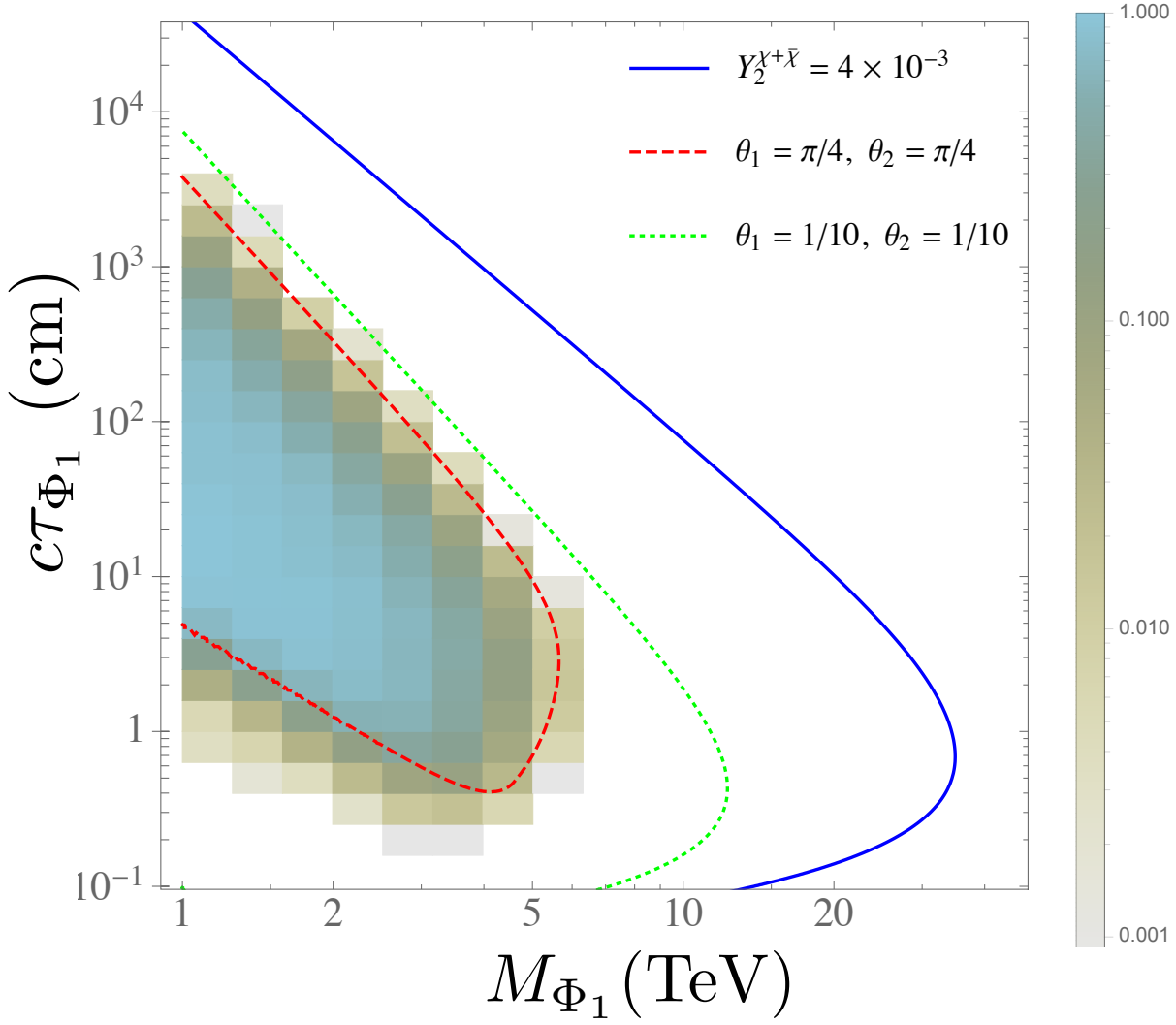
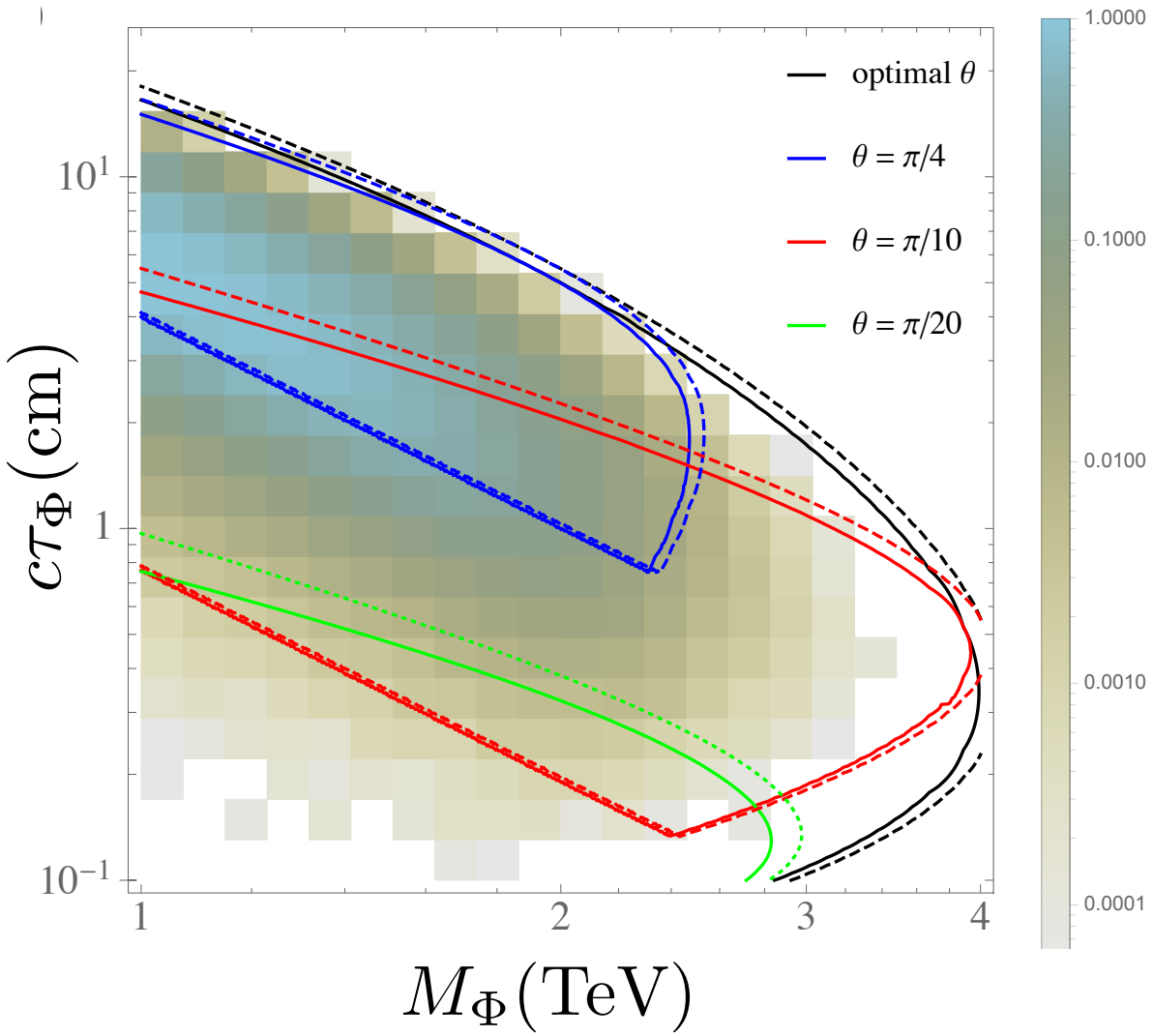
$$M_{\chi_1} = 0$$



Single-scalar results

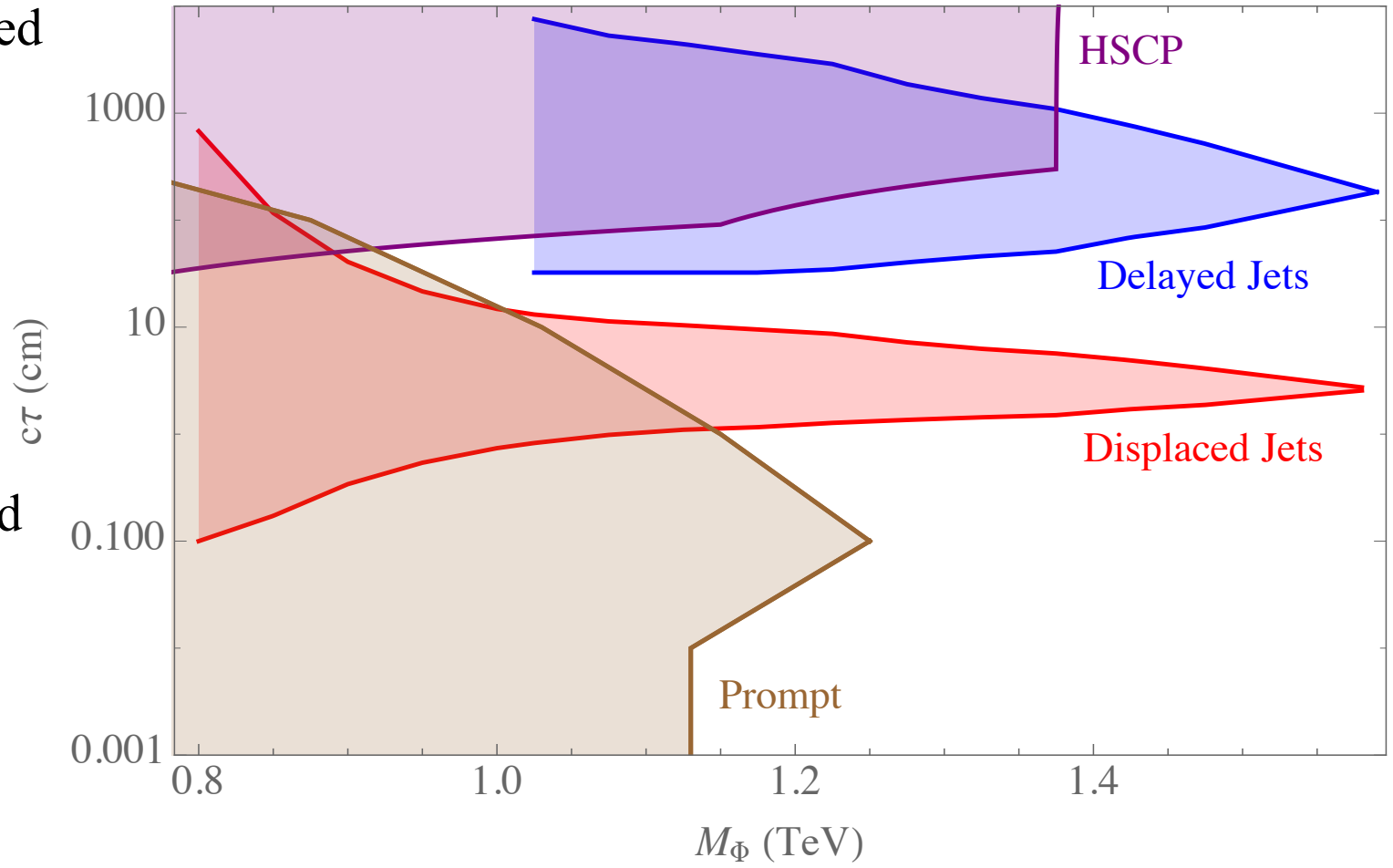
- Need Φ to couple to top and at least one light flavor.
- Without coupling to top: need three χ particles (A. Abada *et* al., arXiv:1810.12463); consistency of asymmetry with DM is borderline.



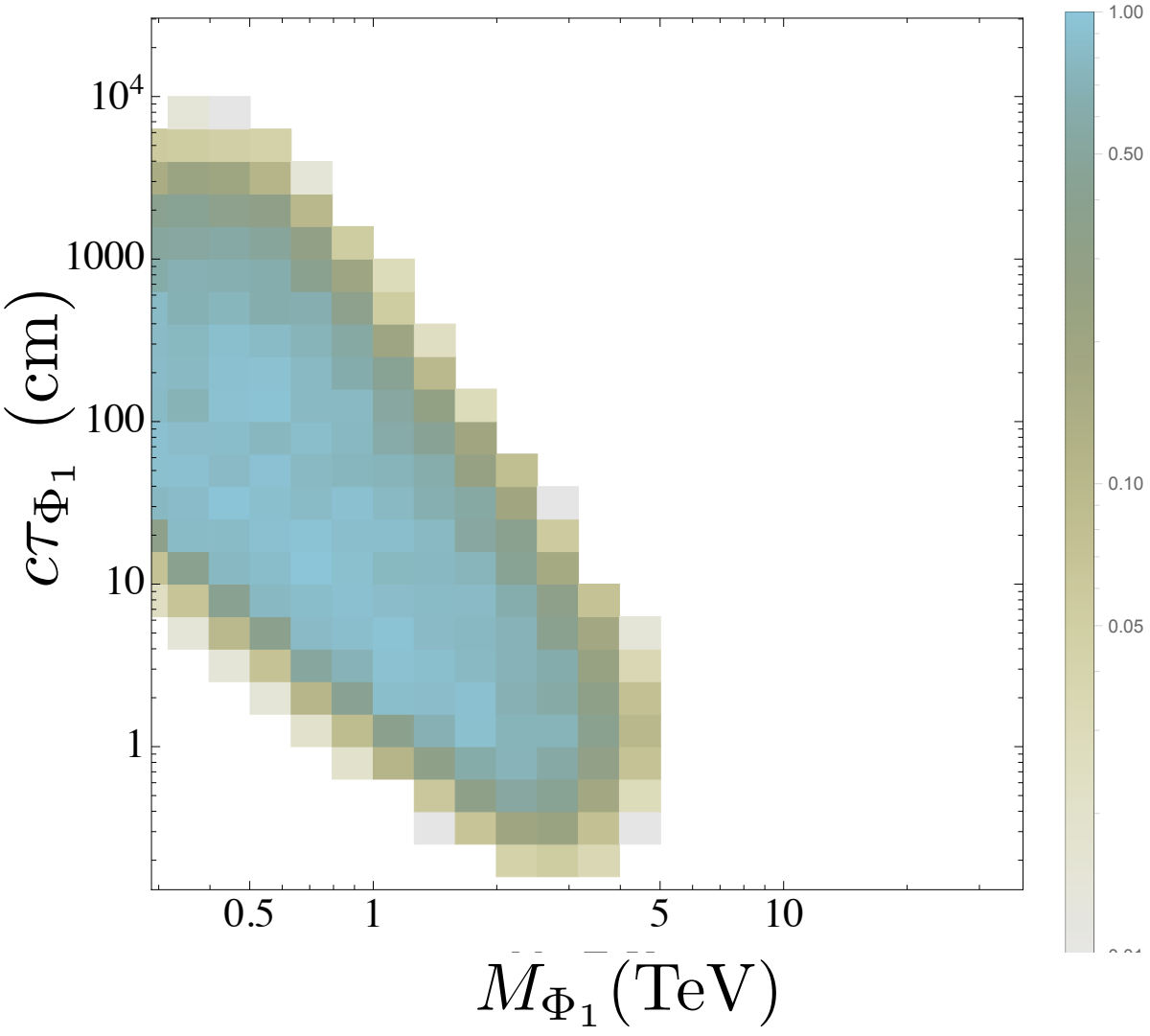
LHC constraints

ATLAS, arXiv:1808.04095; CMS, arXiv:1811.07991; CMS, arXiv:1906.06441; CMS, arXiv:1908.04722

- Φ is pair-produced with a QCD-strength cross section.
- $\Phi \to q + \mathrm{DM}$, leads to events with events with displaced/delayed jets + MET
- Or, HSCP signatures for longer lifetimes



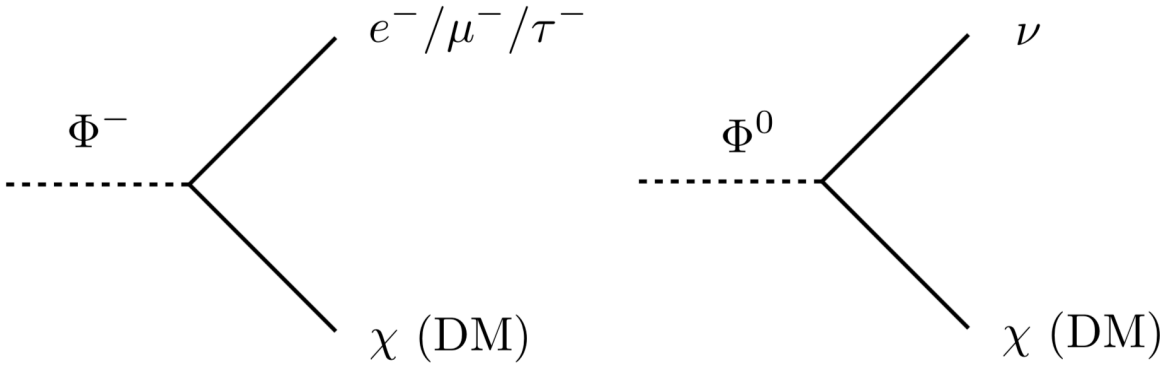
Electroweak scalar (singlet)



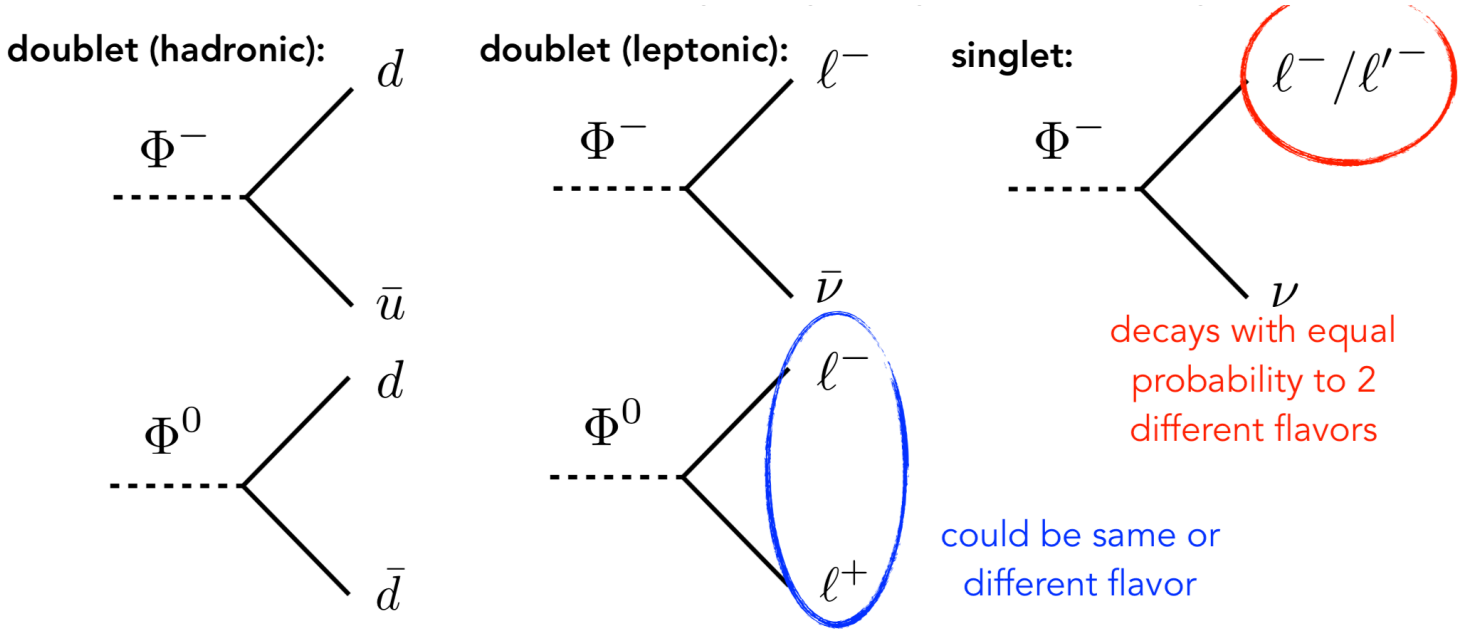
(Work in progress)

Electroweak scalar

Exact Z_2:



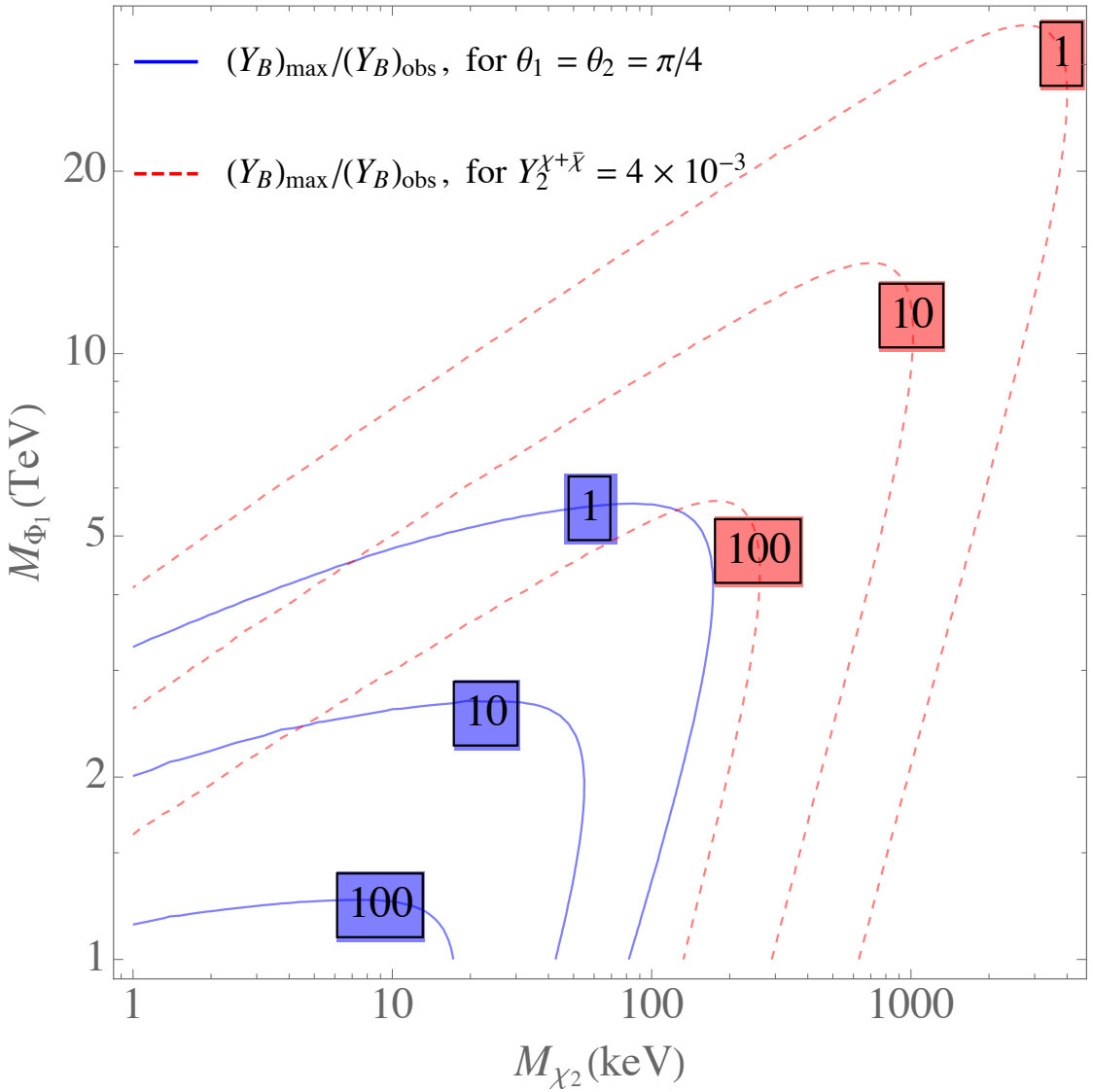
Broken Z_2:



(Work in progress)

Summary

- Models that incorporate both freeze-in DM and baryogengesis can be relatively simple.
- Together, the DM and baryogengesis constraints prefer masses of BSM particles at around the TeV scale, and long lifetimes.
- There are a variety of scenarios and potential LLP signatures to explore!


$(Y_B)_{\rm max}/(Y_B)_{\rm obs}$, for $\theta_1 = \theta_2 = \pi/4$
$(Y_B)_{\rm max}/(Y_B)_{\rm obs}$, for $Y_2^{\chi+\bar{\chi}} = 4 \times 10^{-3}$
1
10
100
1
10
100
20
10
5
2
1
1
10
100
1000
M_{Φ_1} (TeV)
M_{χ_2} (keV)

Asymmetry + DM

- Increasing the Φ_2 mass has little impact on the Φ_1 parameter space.
- Any source of coherent χ background will do!