RPP 2026

Freeze-in with low reheating temperature

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Work in progress with A. Goudelis, A. Lessa

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Matrix elements, contains the particle physics information

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→ Production depends on T_{rh} which is poorly constrained.

Usually, $T_{rh} \to \infty$

What happens if one considers low T_{rh} ?

Case study : a charged parent model

Consider a real scalar singlet s, not charged under the SM gauge groups, and a vector-like fermion F, singlet under $SU(2)$. Both are odd under a $\mathbf{Z}_2$ symmetry to ensure the lightest state is stable.

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We also consider generation-universal couplings

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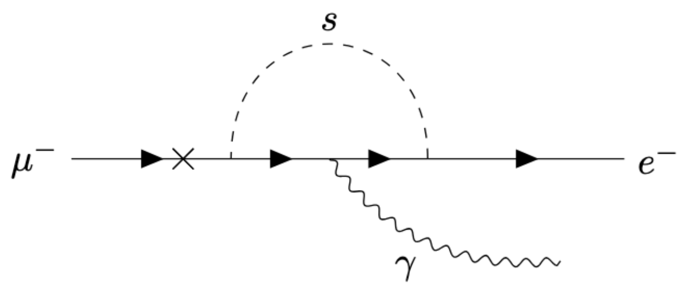
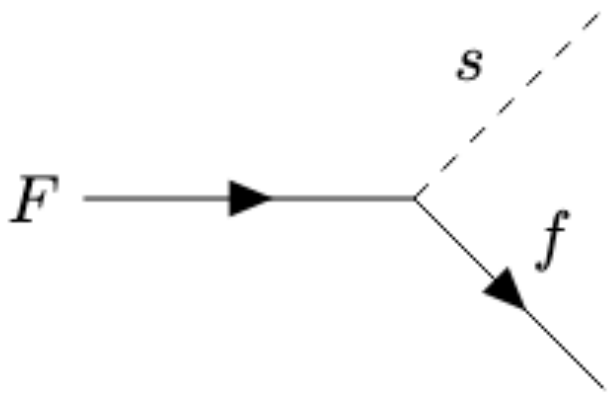


Contributions to the relic density

In the standard infinite reheating temperature scenario, DM production is dominated by decays of F



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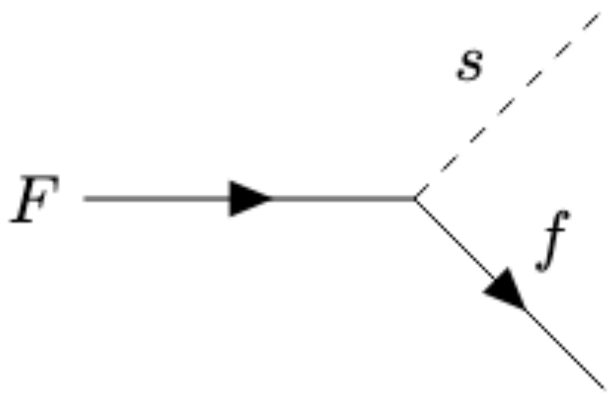

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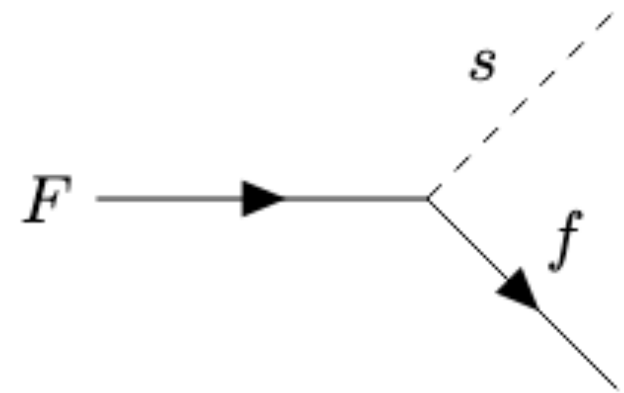

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When T_{rh} sufficiently small

-> F extremely suppressed -> SM particle annihilations can dominate

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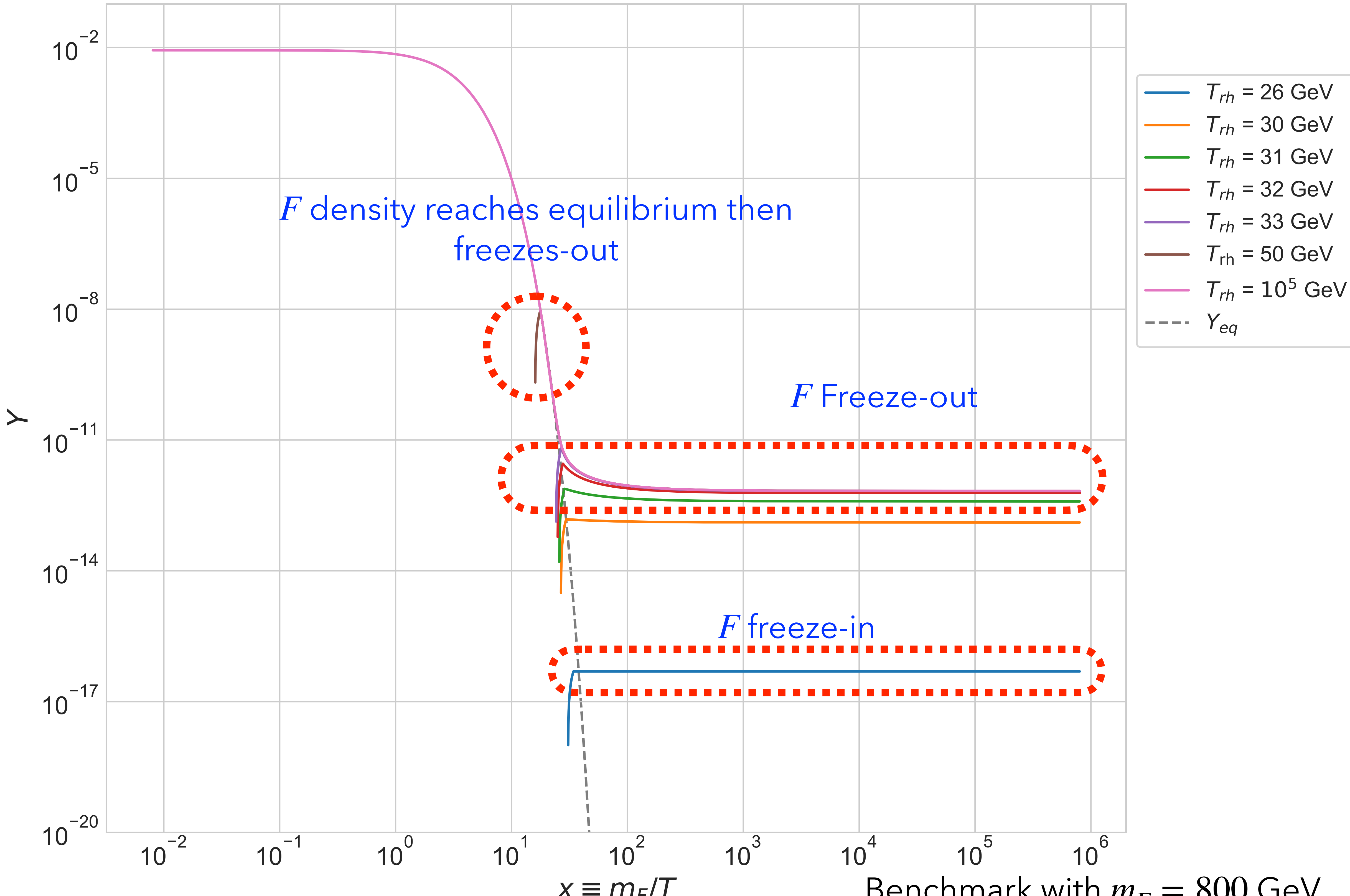
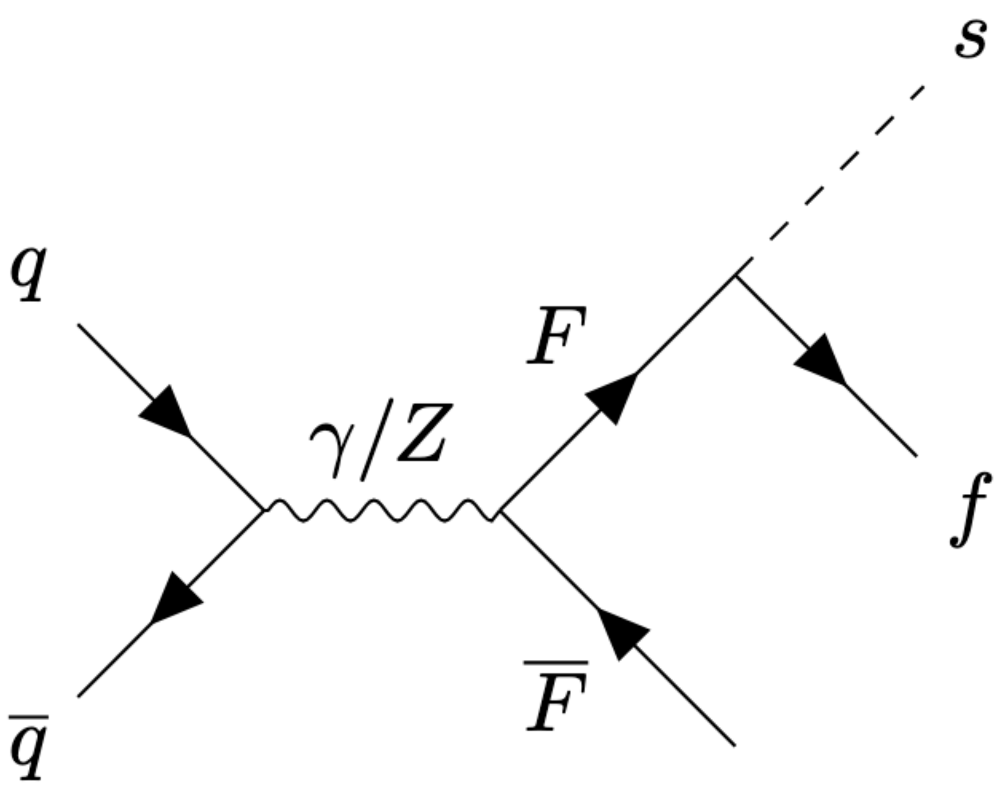


Benchmark with $m_F = 800$ GeV

Constraints form LHC searches

For LHC searches, we focus on the detection of the mediator particle : F

→ F produced through Drell-Yan process



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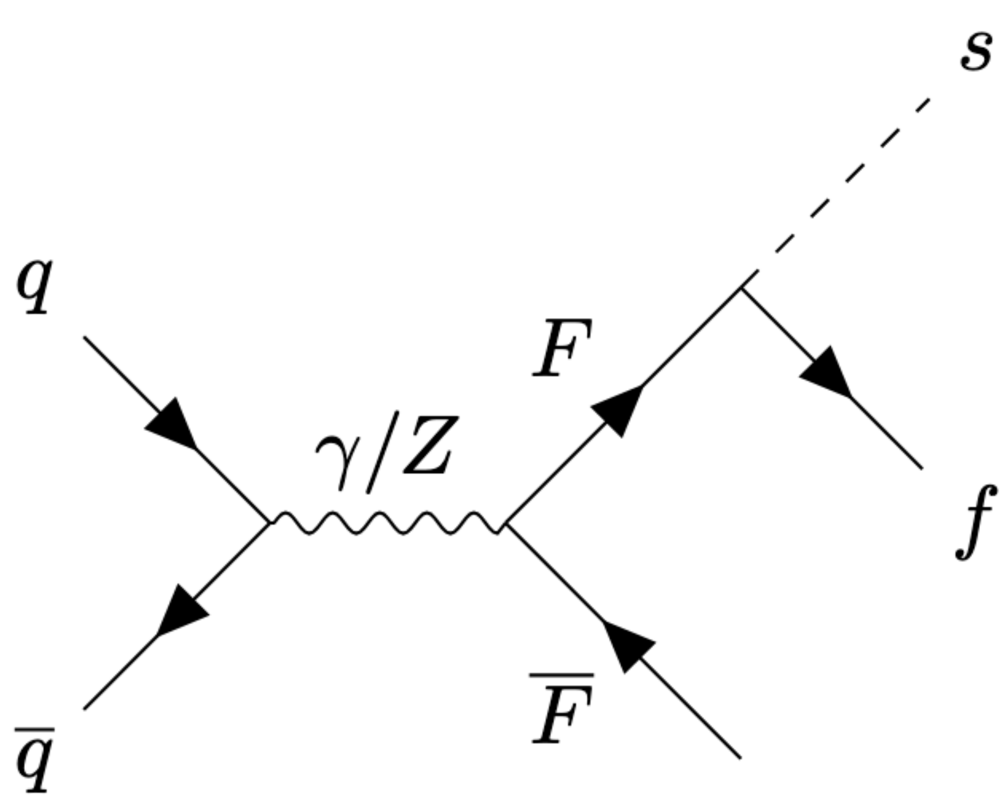

In high T_{rh} freeze-in, this model predicts a very longed-lived F in order to saturate the relic density constraint

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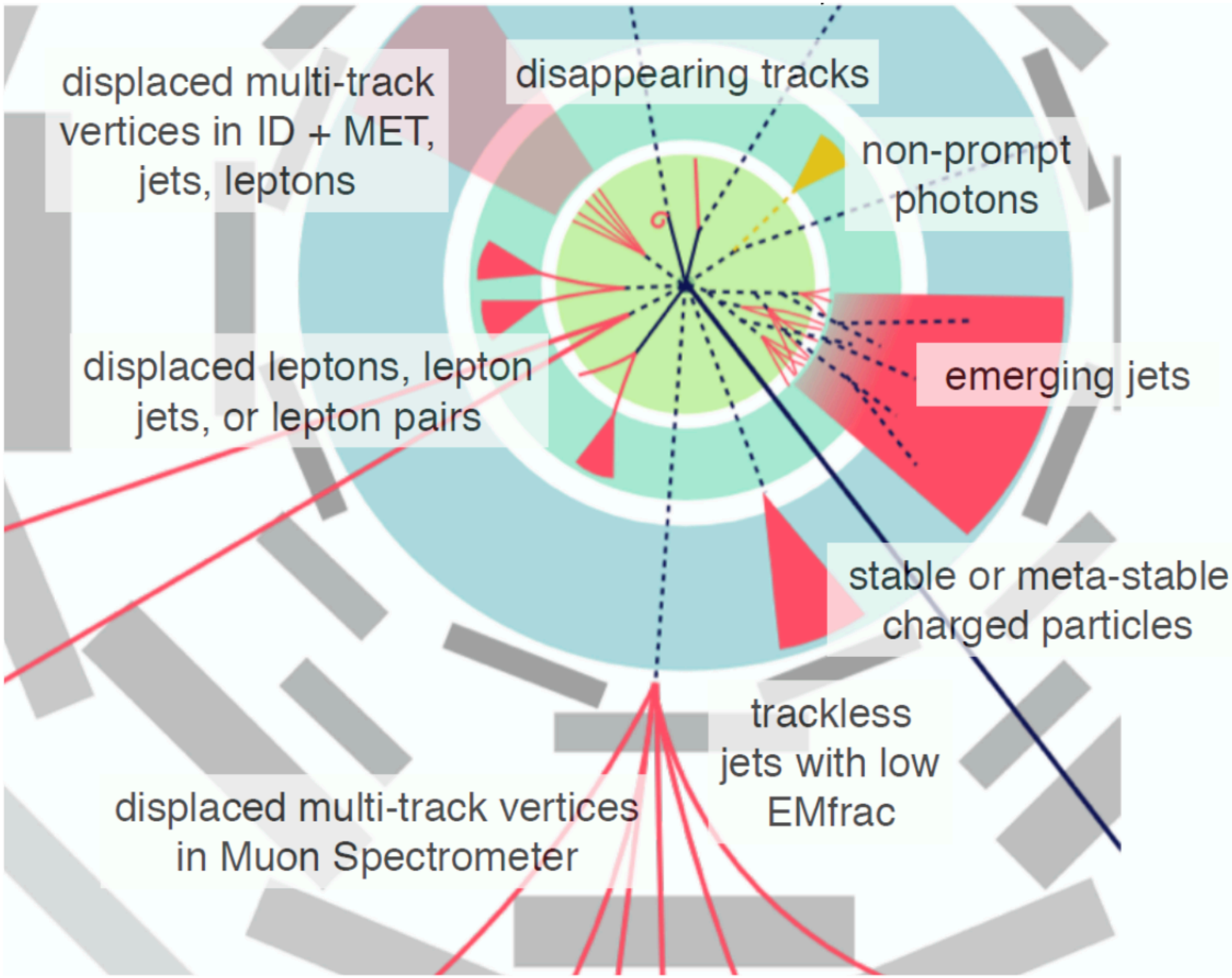
Depending on the lifetime of F, we can have different types of signatures in colliders



Graphic credits : Heather Russel

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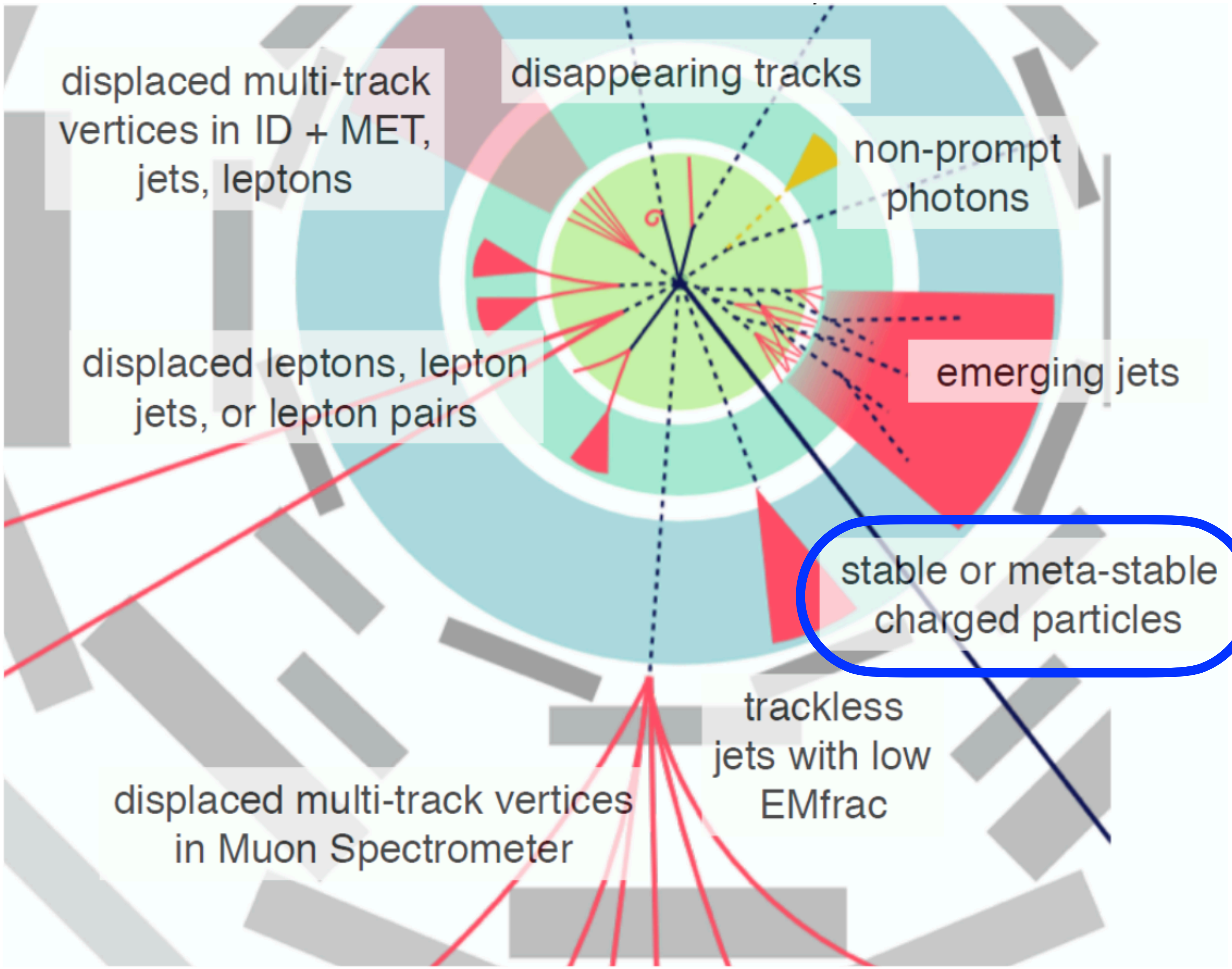

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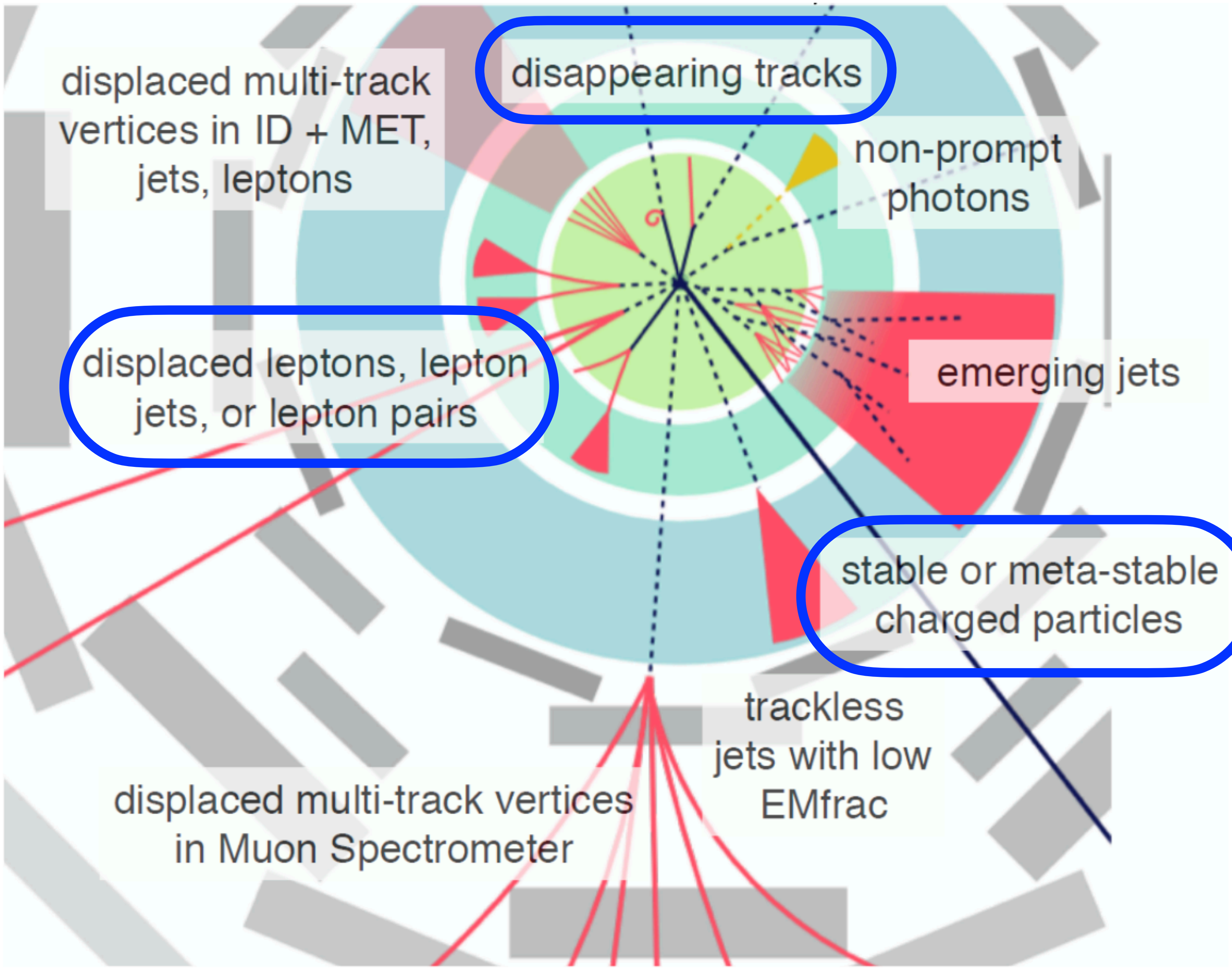

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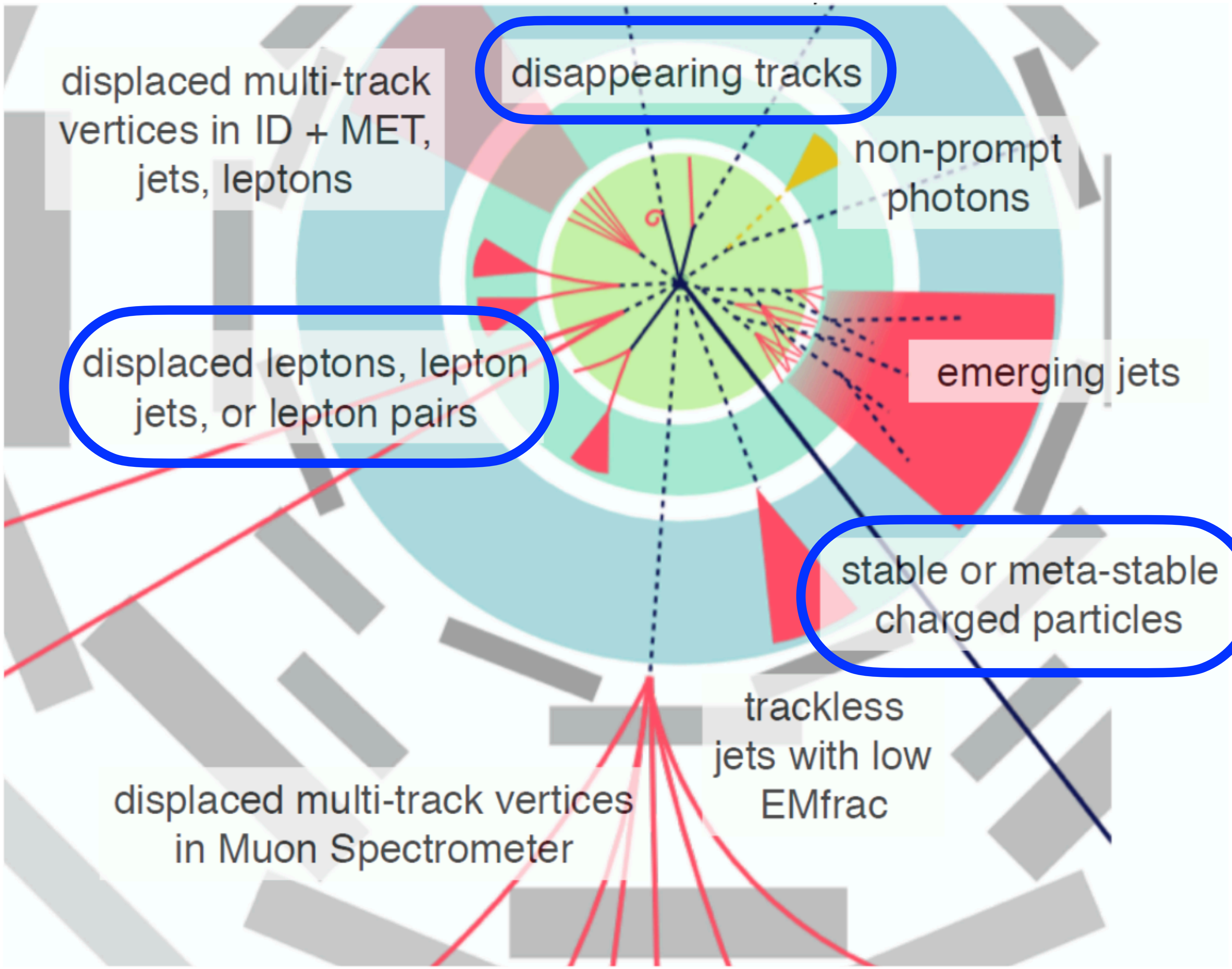

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+ eventually prompt searches for short lifetimes

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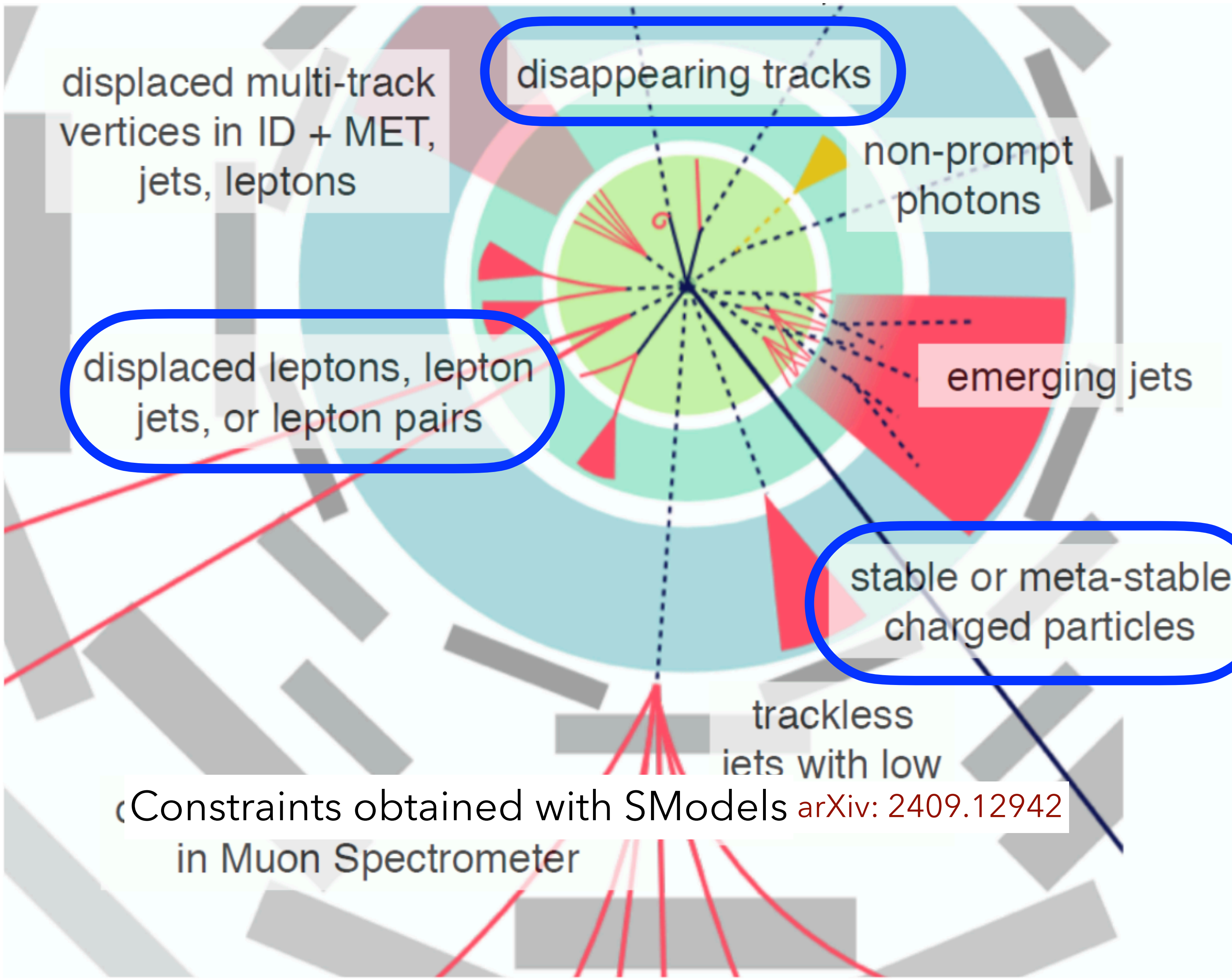

Constraints obtained with SModels arXiv: 2409.12942

Graphic credits : Heather Russel

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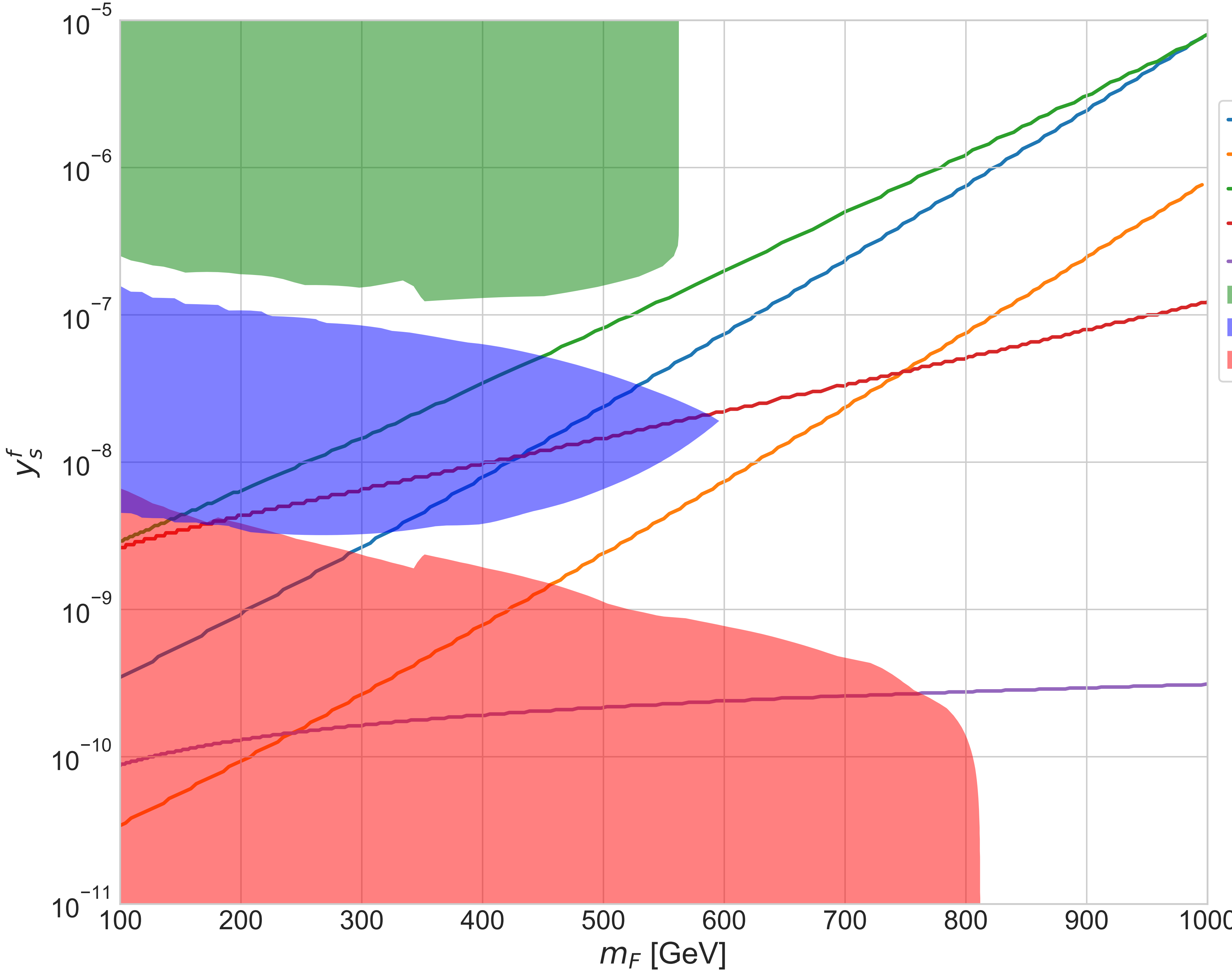
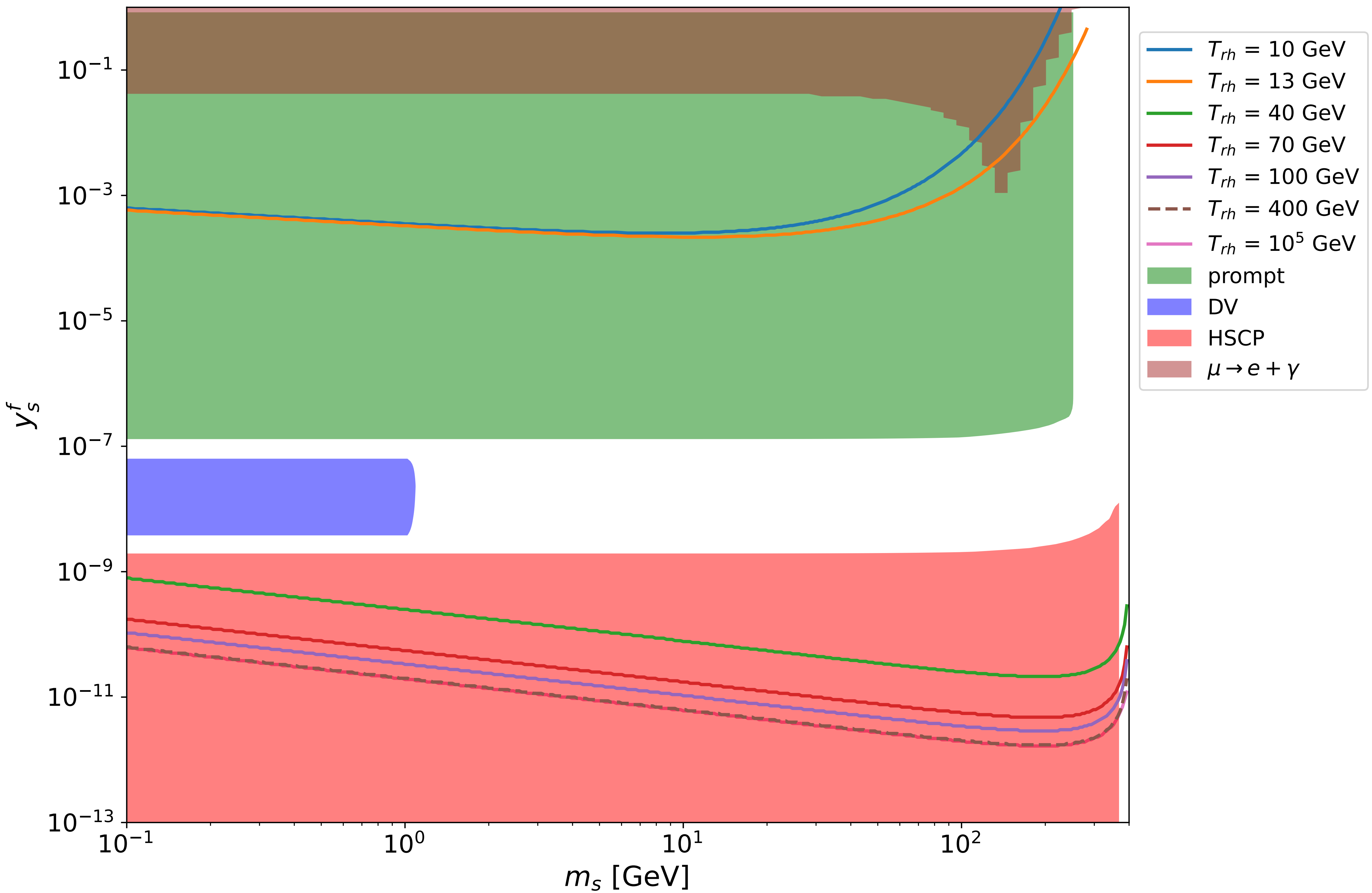
y_s^f vs m_F



Relic contours cross different types of searches

y_s^f vs m_s with $m_F = 400\,\mathrm{GeV}$



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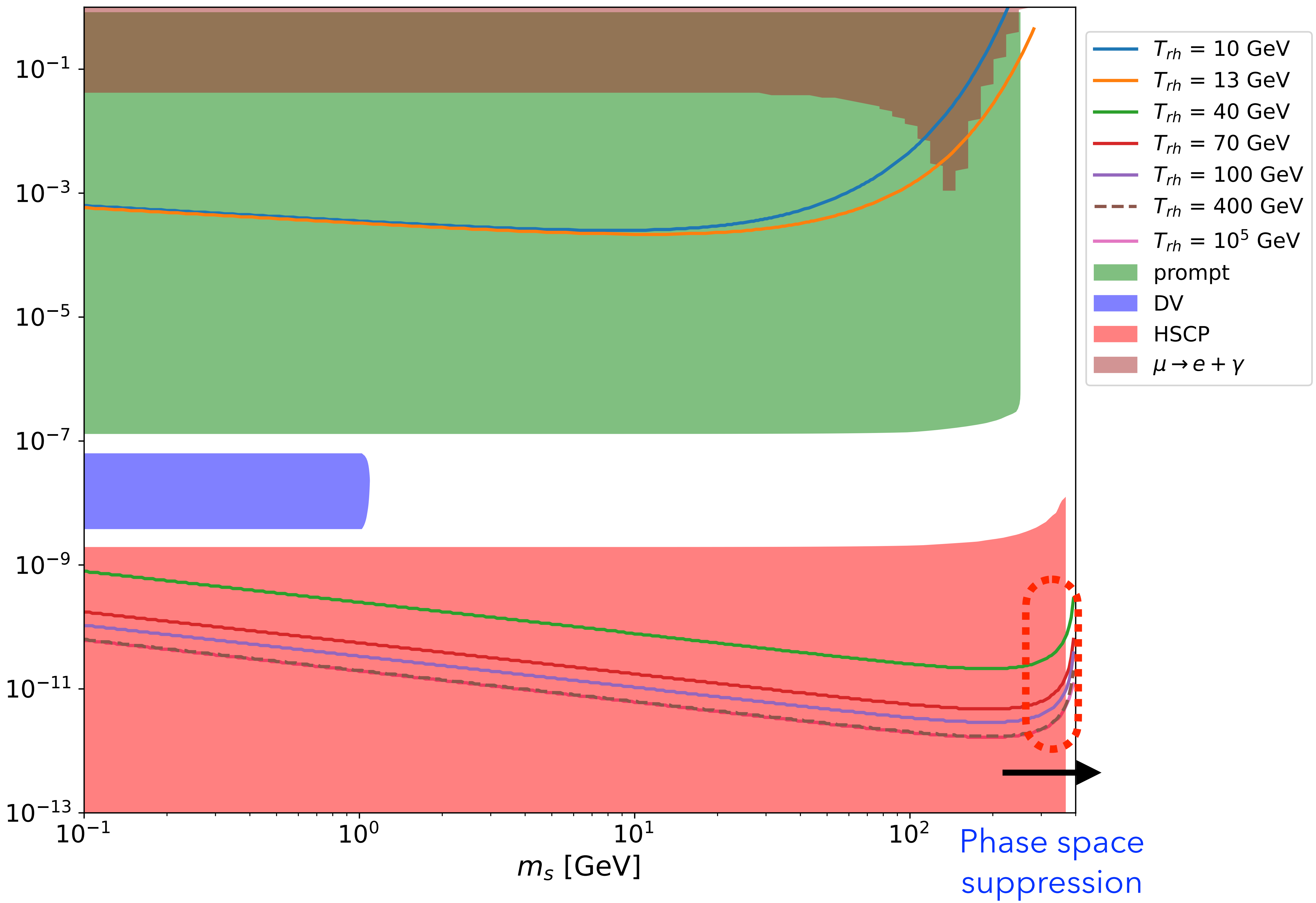

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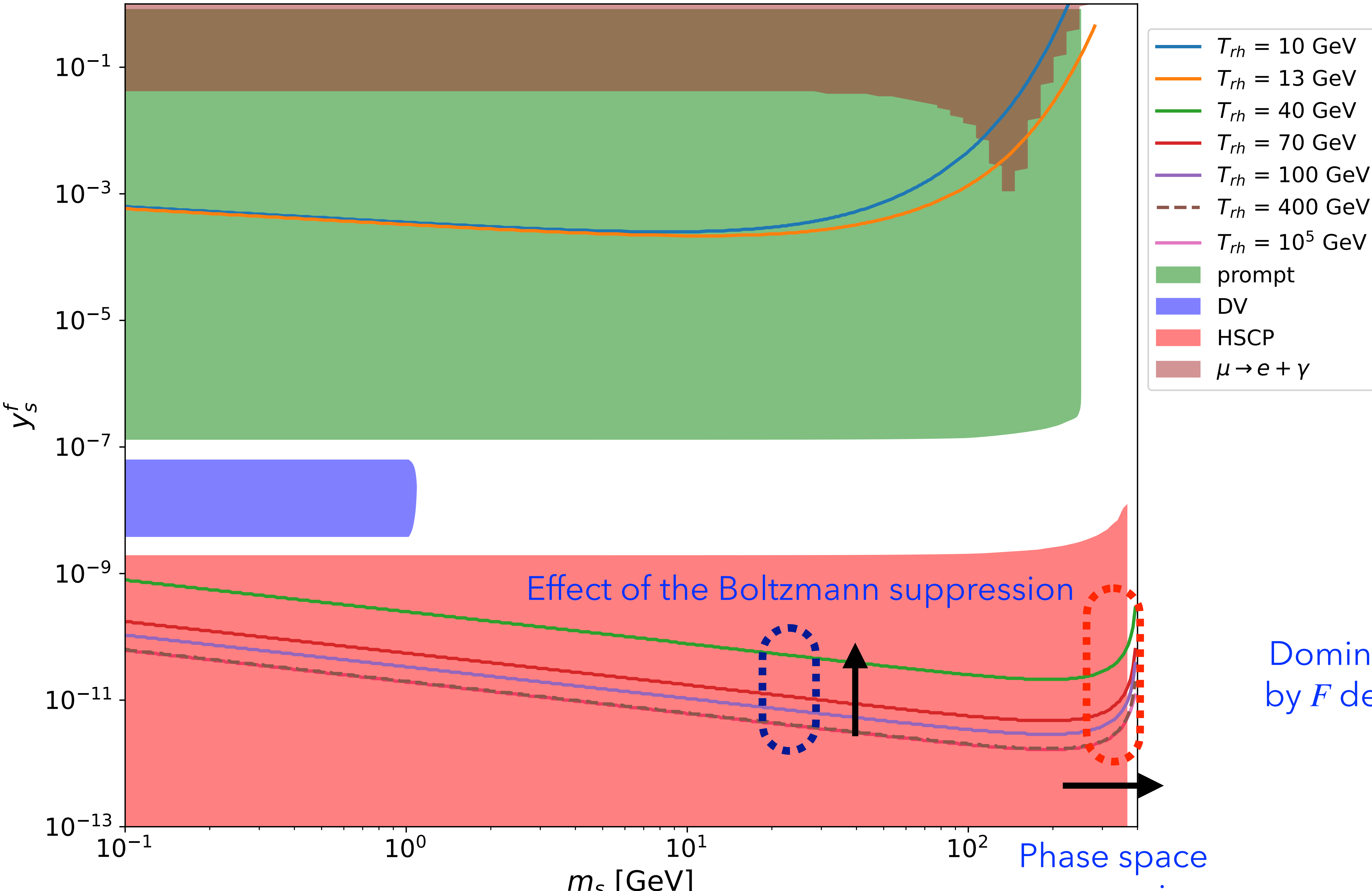

Dominated by F decays

Phase space suppression

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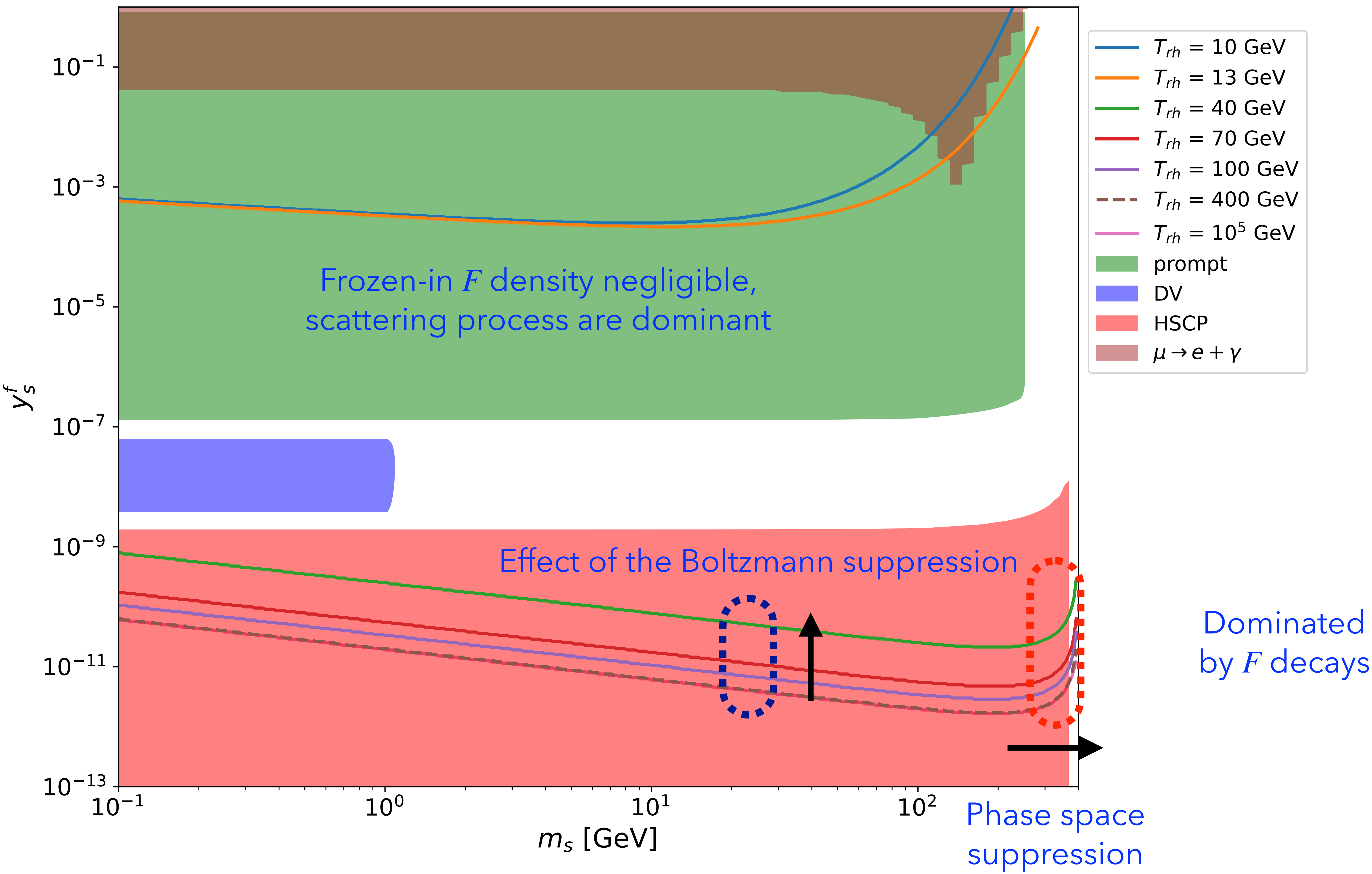
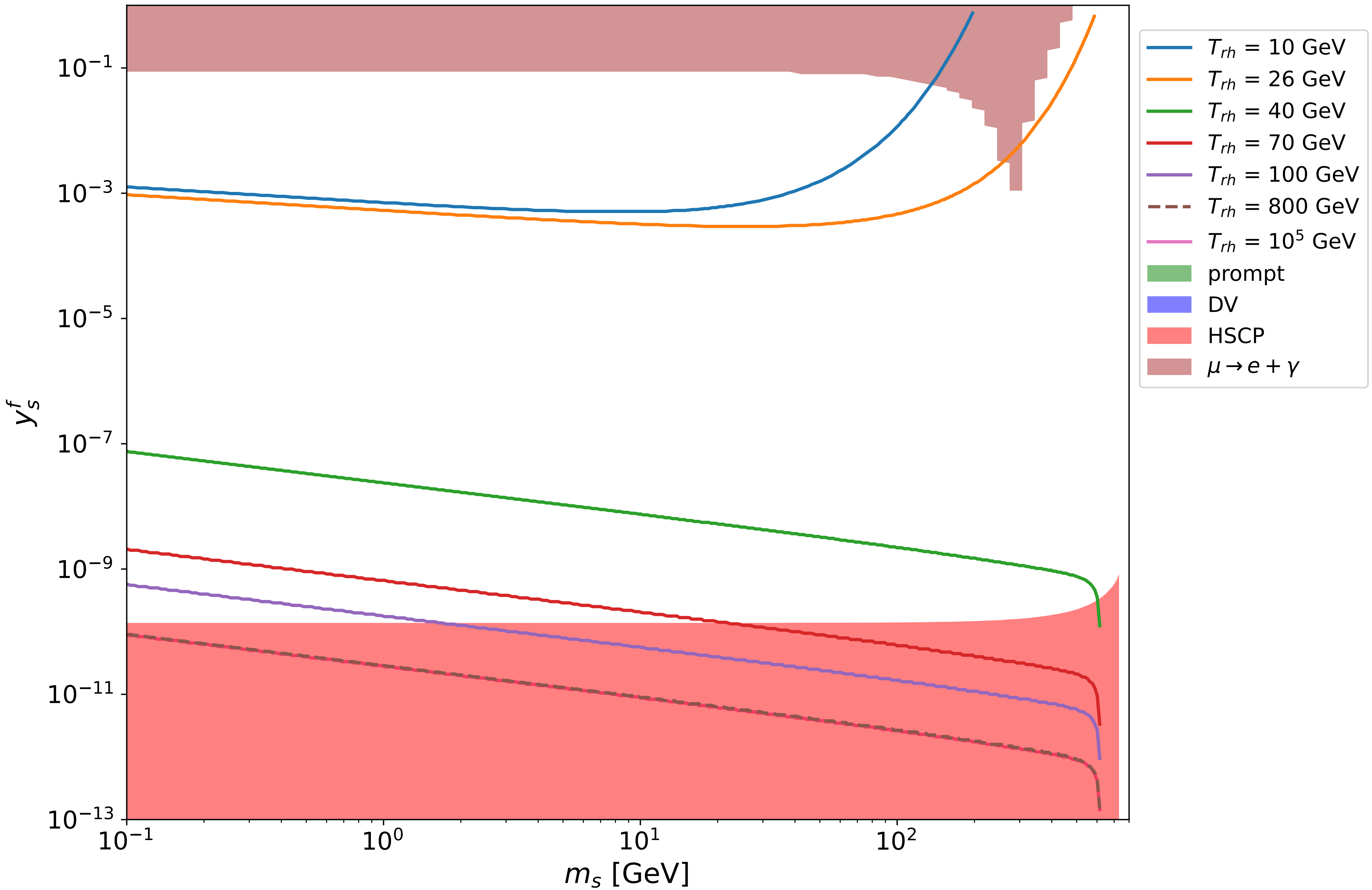


y_s^f vs m_s with $m_F = 800\,\text{GeV}$



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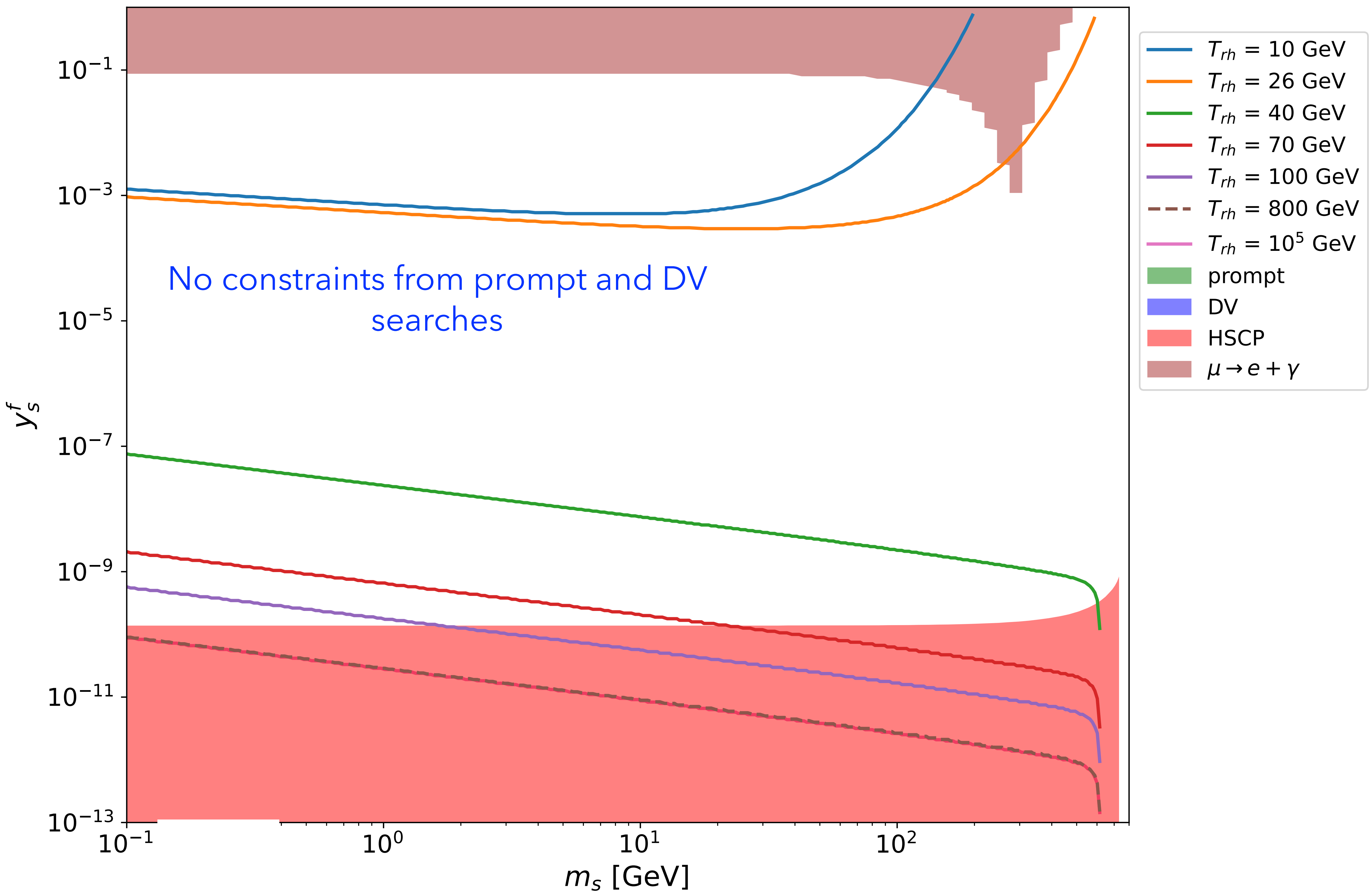

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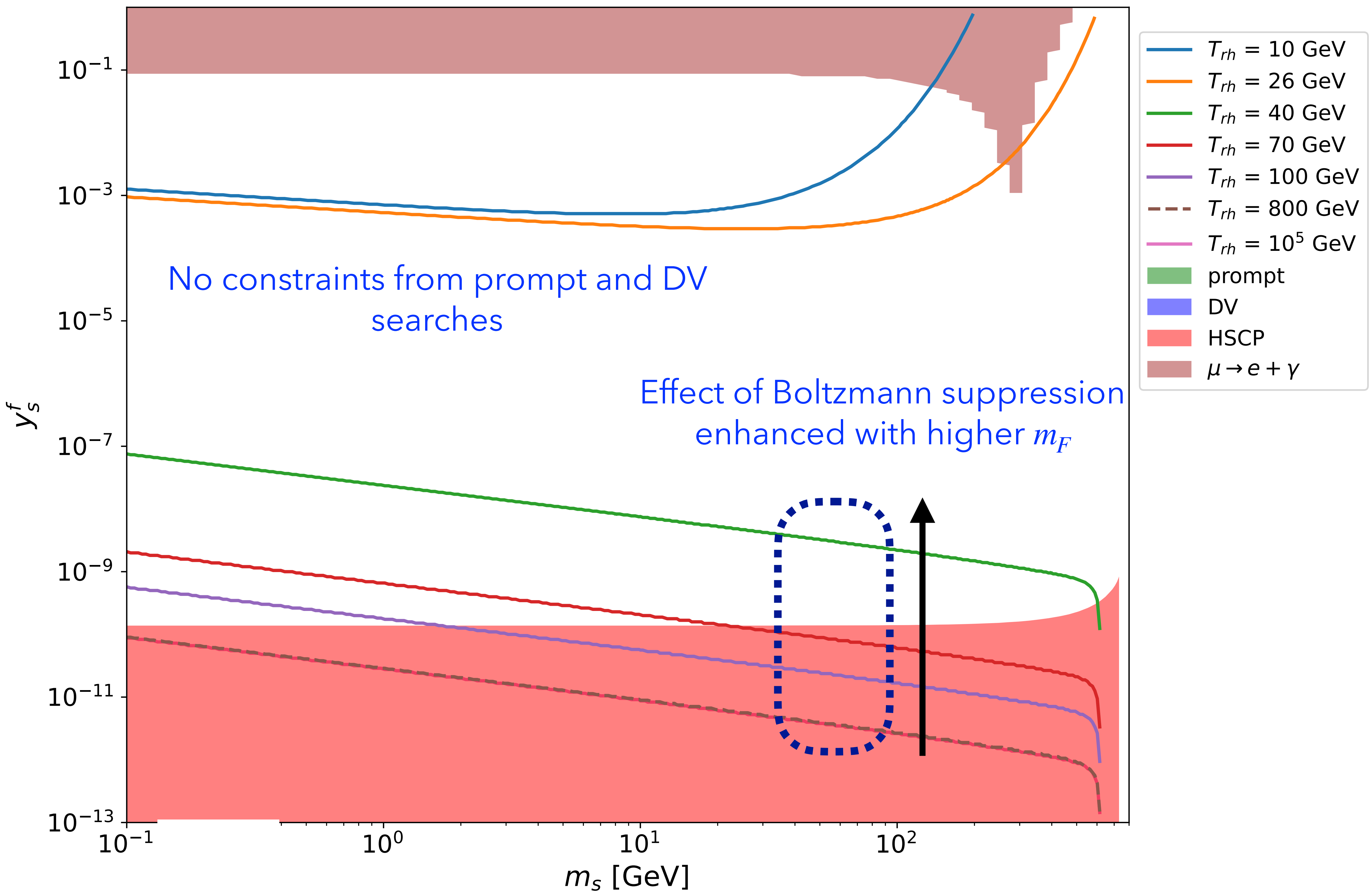

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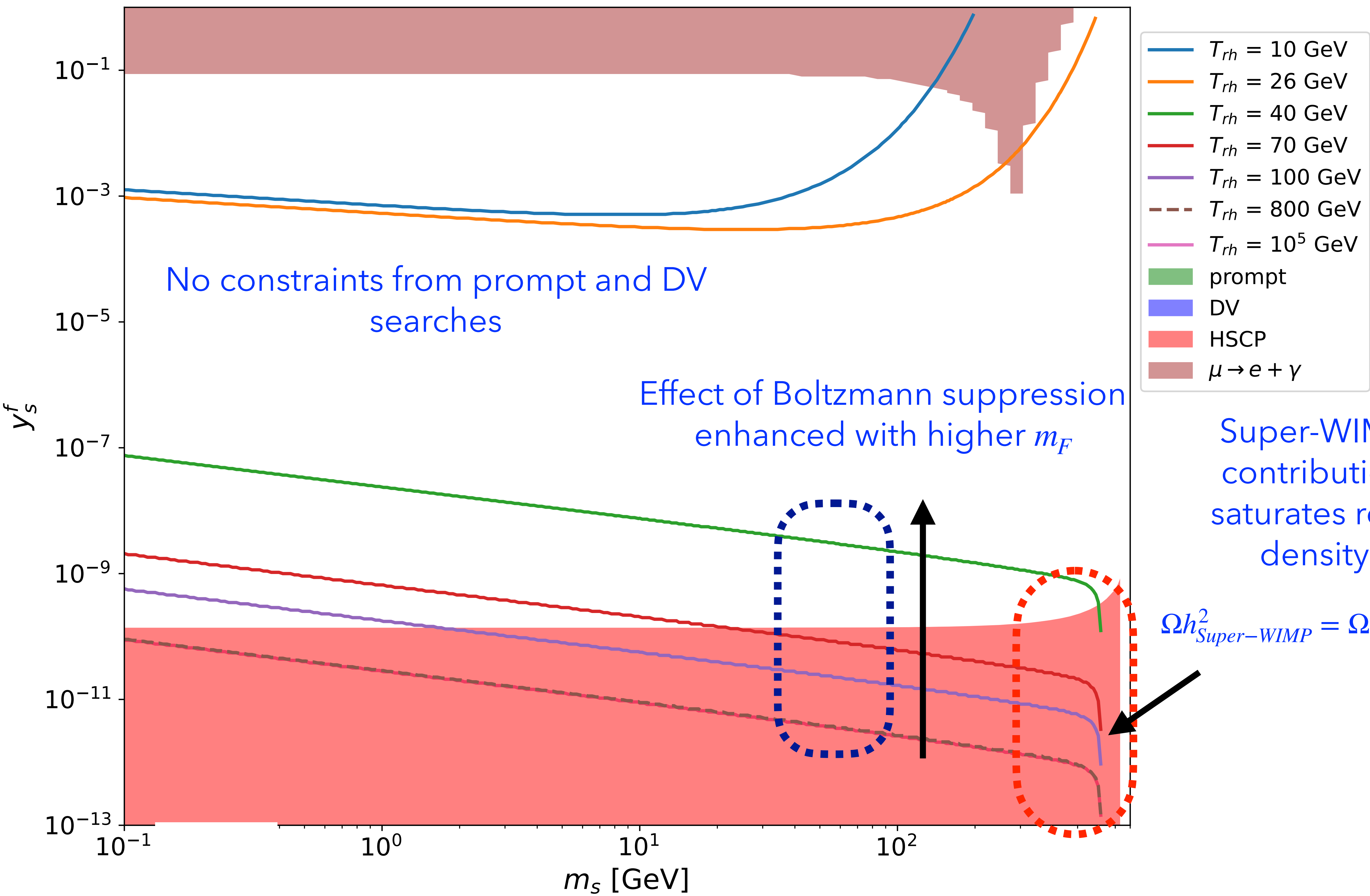


Super-WIMP contribution saturates relic density

$$\Omega h^2_{Super-WIMP} = \Omega h^2_F \times \frac{m_s}{m_F}$$

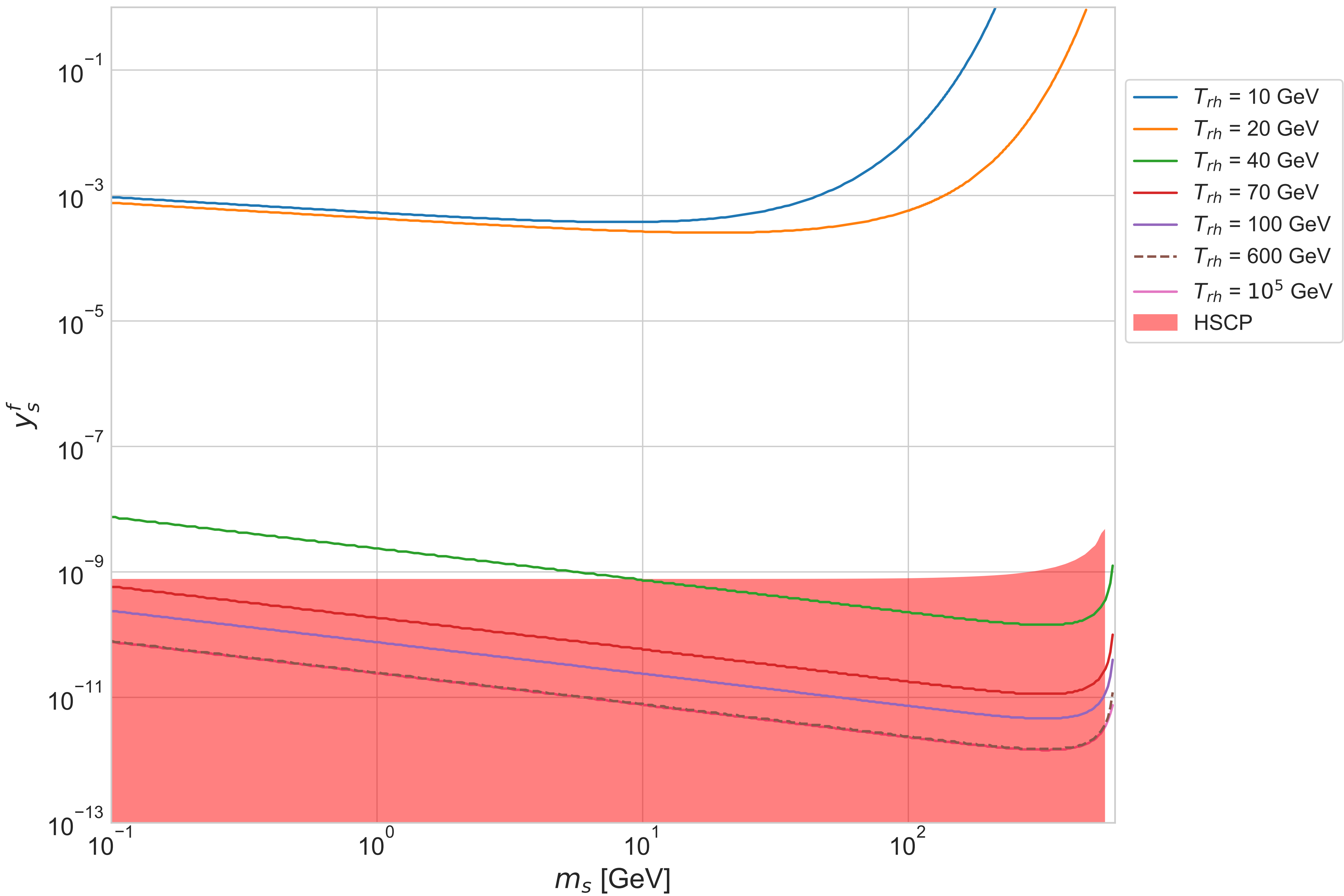
Conclusion and outlook

- In the freeze-in mechanism, dark matter production depends on the reheating temperature which is poorly constrained.
- Usually taken to be effectively infinite, reducing its value leads to stronger coupling in order to reproduce the observed dark matter abundance in the universe.
- Modified cosmological assumptions can open up the parameter space of freeze-in models and lead to alternative phenomenological signatures.
- Different contributions (SM lepton annihilations, Super-WIMP contributions, Frozen-in F decays …) can drive the relic density in different parts of the parameter space.
- To appear : direct detection constraints.

Thank you for your attention !!

Backup slides

y_s^f vs m_s with $m_F = 600\,\text{GeV}$



y_s^f vs m_s with $m_F = 1000\,\text{GeV}$