Probing freeze-in via invisible Higgs decay

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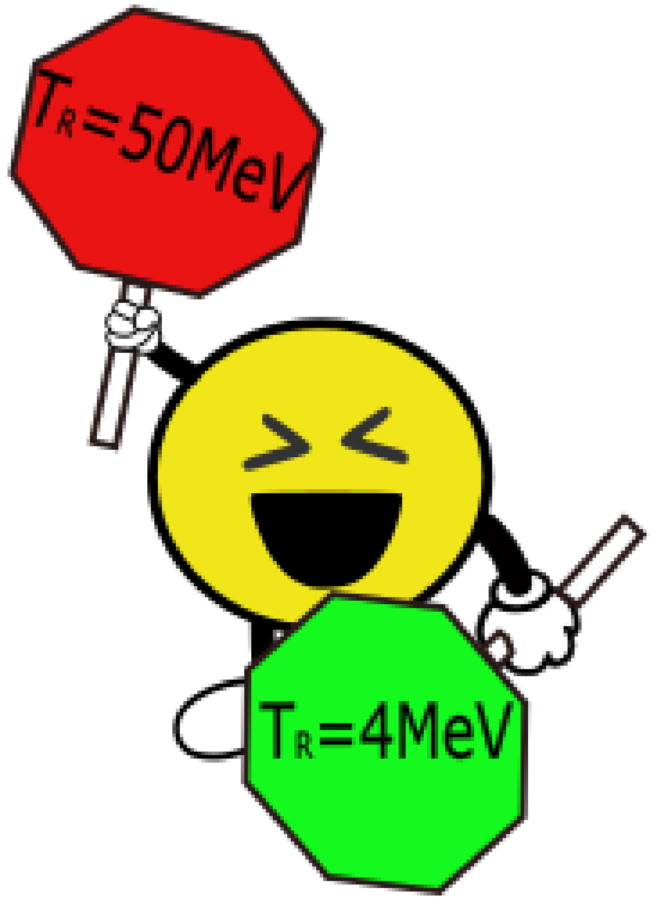
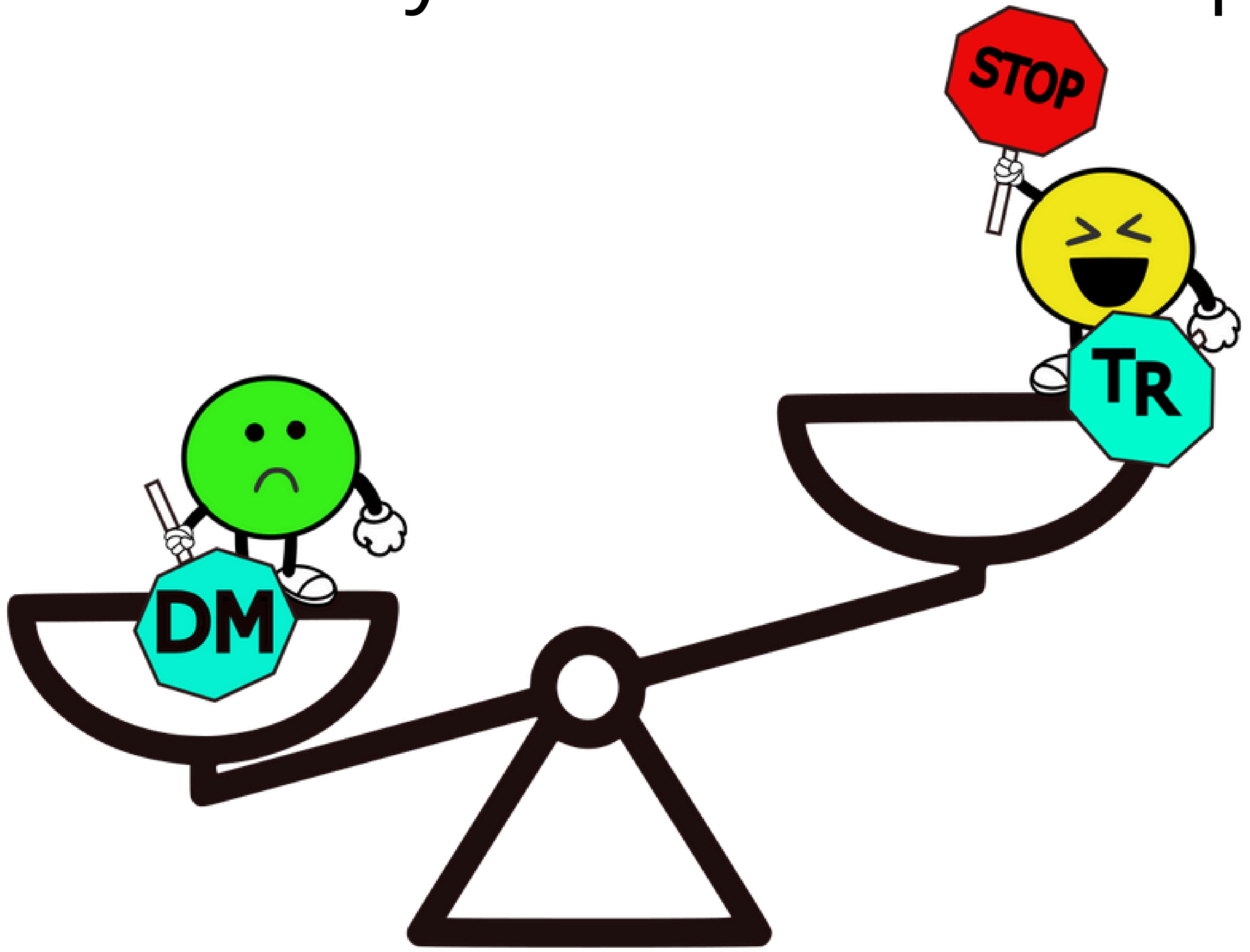
Goal

- Study DM production in a low-reheating temperature $T_R \sim O(4-50) MeV$ scenario;



- We are focus on Higgs portal scenario;
- We are interested in the case where $m_{DM} \gg T_R$;
- The DM is produced non-thermally due Boltzmann suppression.



Lagrangian

- We assume that the scalar S DM candidate couples with SM particles via the Higgs portal, with the Lagrangian

$$L \supset \frac{g m_f}{2 m_W} h \bar{f} f + \frac{\lambda_{hs} v_{SM}}{2} hSS,$$

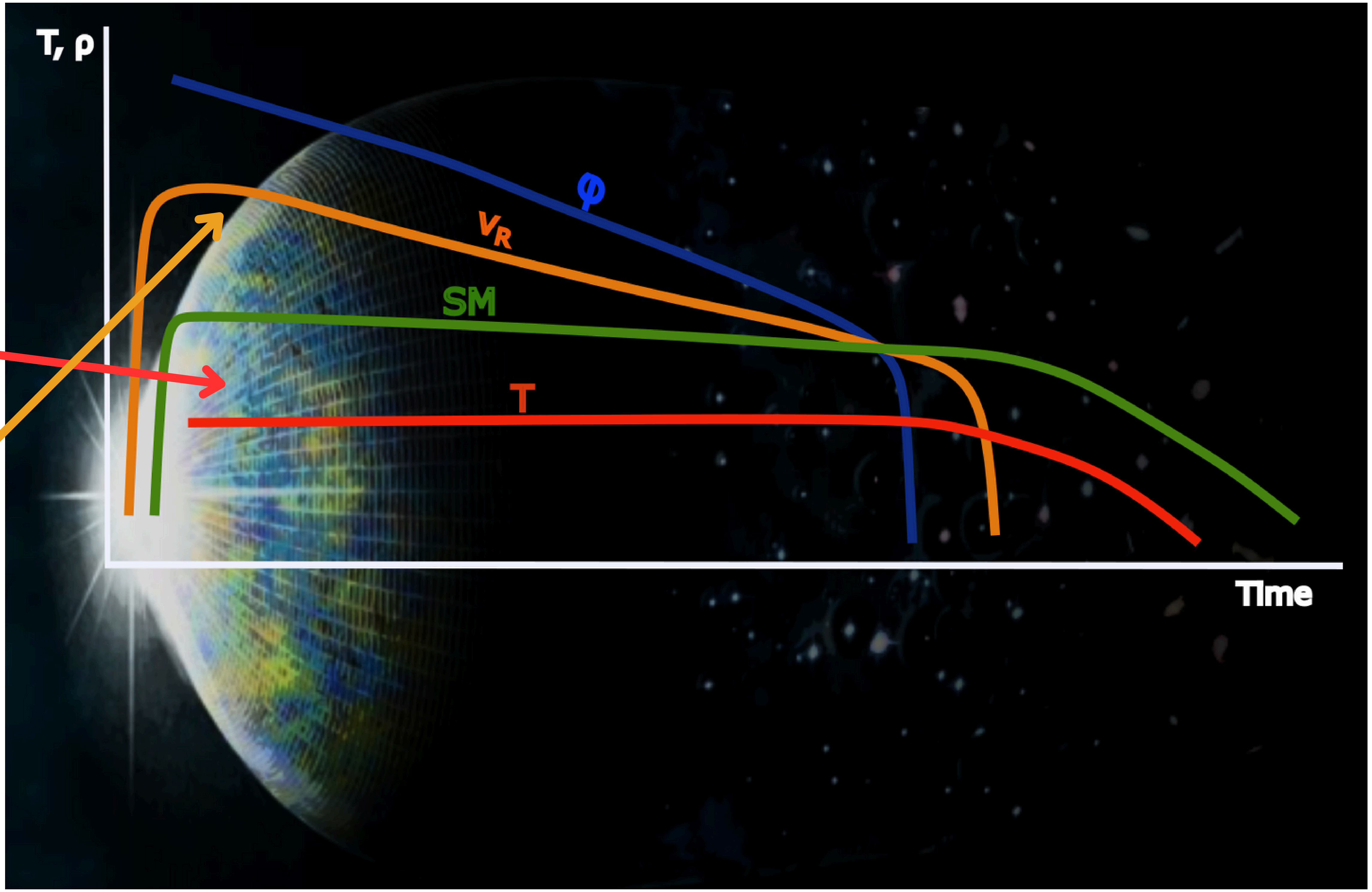
Dark Side

Standard Higgs interaction with fermions

where f represents a fermionic SM particle.

Cosmological History (Based on: arXiv2402.04743)

- We will assume that the maximum temperature of Universe is $T_{MAX} \sim T_R$.
- We can assume it for the scenario where the inflaton decays predominantly in other particle species (e.g. sterile neutrinos).



Boltzmann Equation

- Boltzmann equation for number density

Counts production / annihilation of 2 identical particles

$$\dot{n} + \underbrace{3Hn}_{\text{Dilution effect of Universe expansion}} = 2\underbrace{\Gamma\left(ff \rightarrow SS\right)}_{\text{Production term}} - 2\underbrace{\Gamma\left(SS \rightarrow ff\right)}_{\text{Annihilation term}}$$

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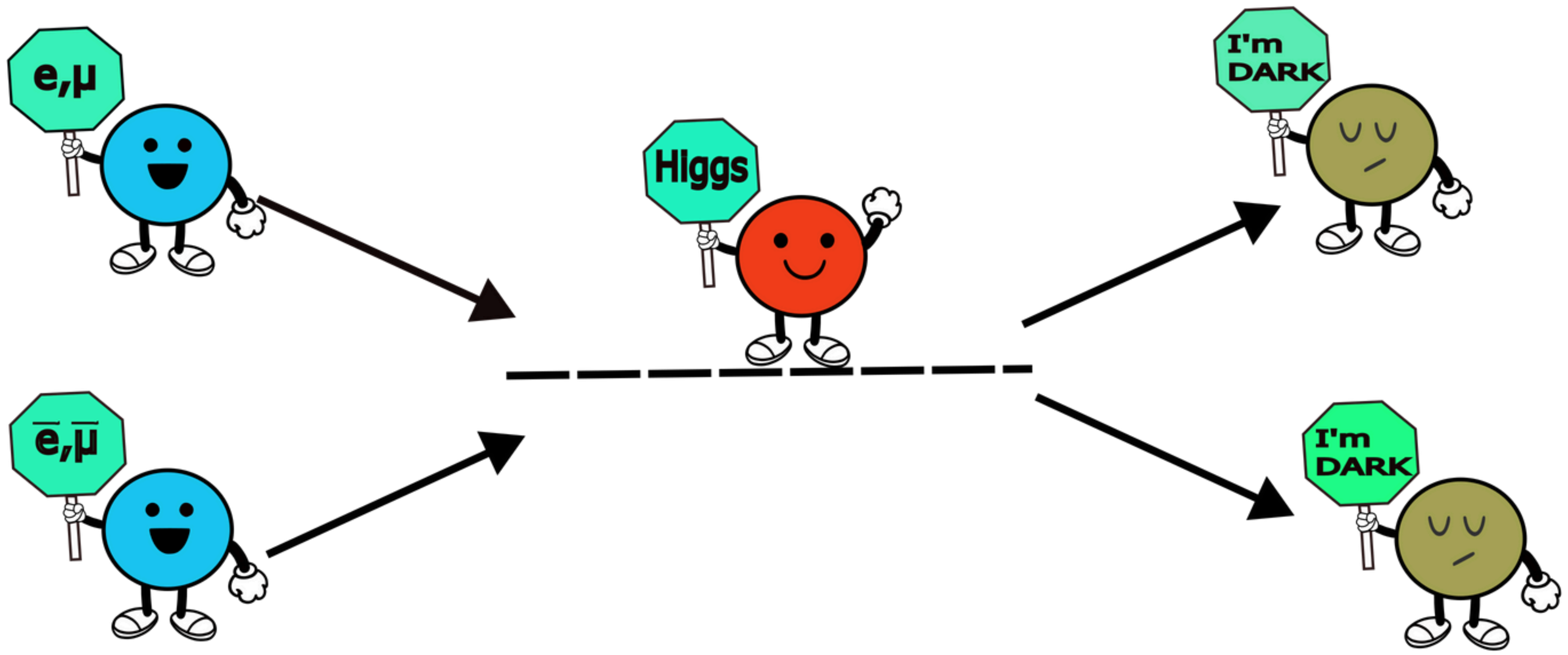
- Most important channels:



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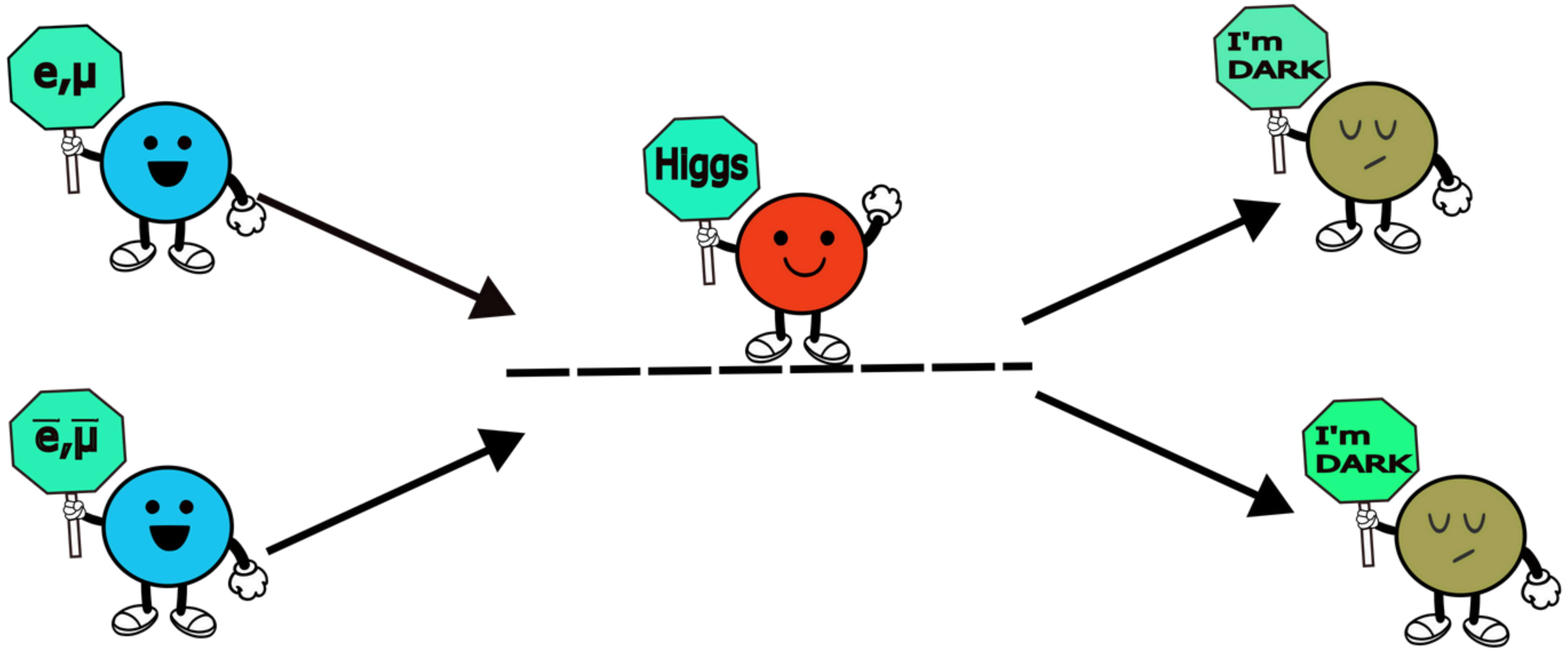
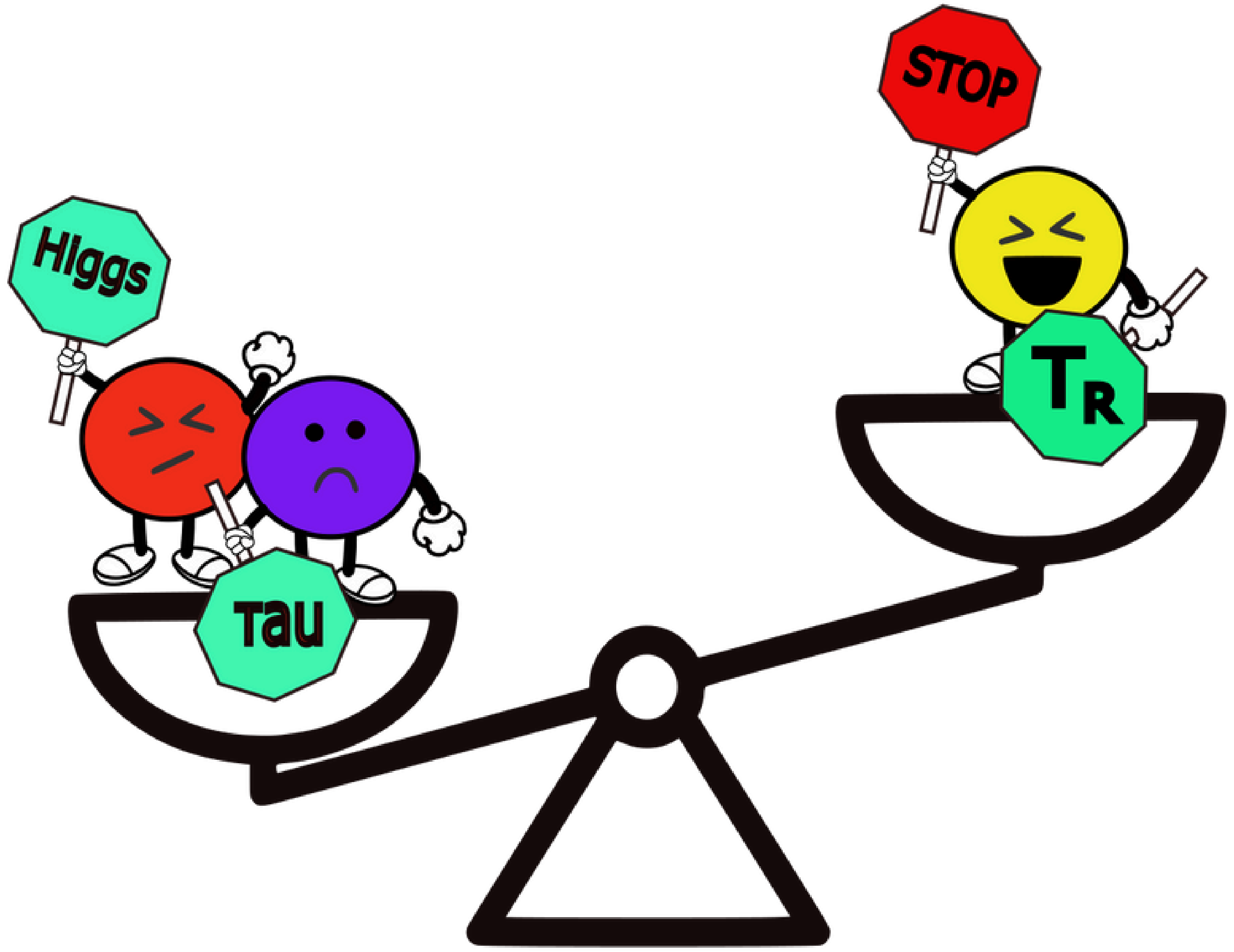


- Processes with τ and Higgs are forbidden, since $m_{\tau,h} \gg T_R$.



Boltzmann Equation

- The production cross section is given by

$$\sigma_{ff\to SS} = \frac{1}{2} \times \frac{1}{4} \times \frac{g^2\lambda^2 m_f^2}{32\pi m_W^2 m_h^4}\sqrt{1-\frac{4m_f^2}{s}}$$

$\frac{1}{4}$ → initial state spin averaging

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- We can estimate the rate

$$\Gamma_e \approx \frac{g^2 \lambda^2 m_s^3 m_e^2 T^3}{256\pi^4 m_h^4 m_W^2} e^{-\frac{2m_s}{T}} \qquad \Gamma_\mu \approx \frac{3g^2 \lambda^2 m_\mu^2 T^4}{512\pi^4 m_h^4 m_W^2} e^{-\frac{2m_\mu}{T}}$$

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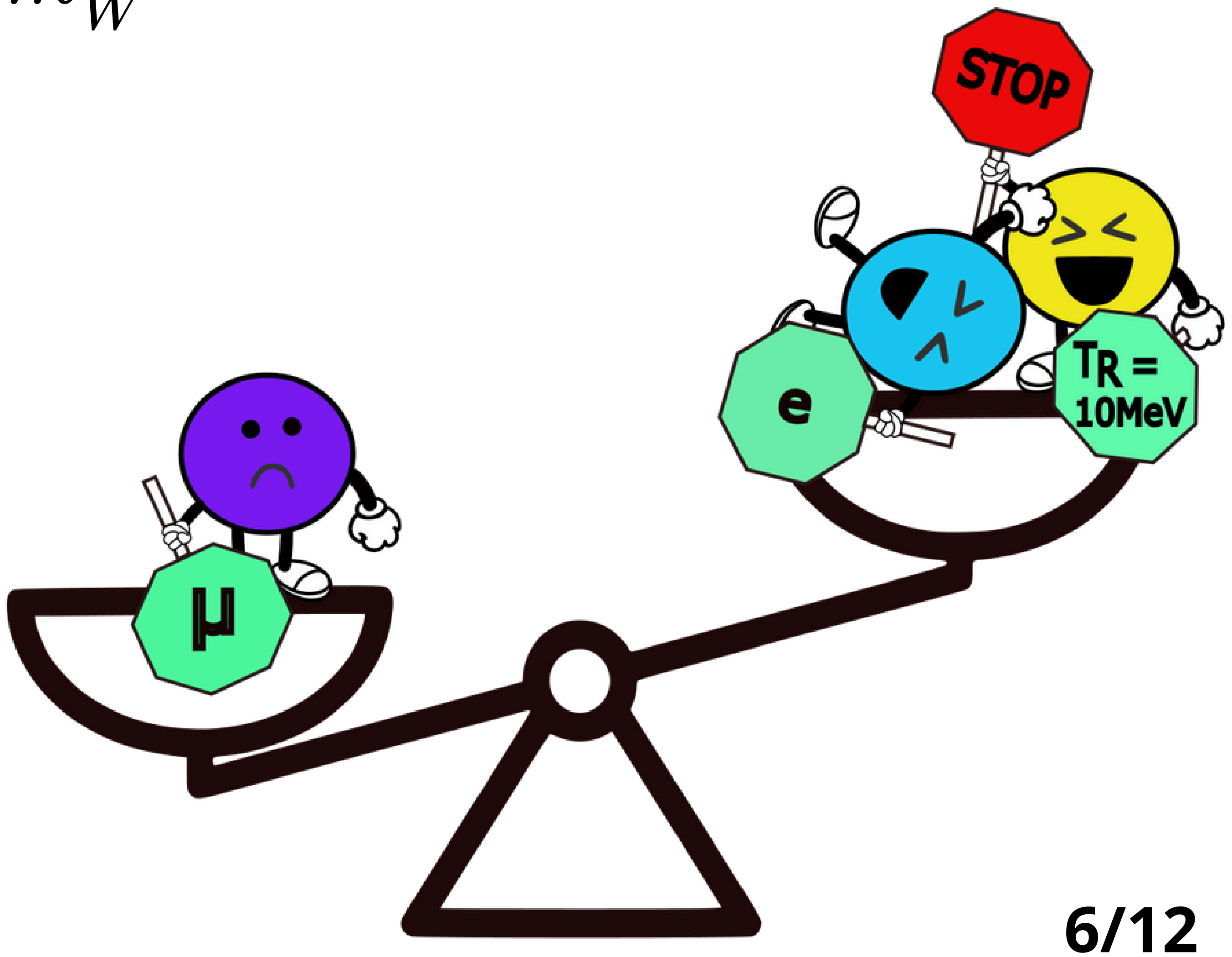
- The ratio of the muon and electron rates for $T = T_R$ is

$$\frac{\Gamma_\mu}{\Gamma_e} \approx \frac{3}{2}\frac{m_\mu^4 T_R}{m_e^2 m_s^3} e^{-2(m_\mu - m_s)/T_R}$$

for $m_S = 50MeV$ we obtain that Γ_μ dominate the contribution for

$$T_R > 10MeV$$



Boltzmann Equation

- For the *pure-freezing* scenario $\Gamma\left(SS \to ff\right) = 0$

$$\frac{dY_S}{dx} = 2\sqrt{\frac{8\pi^2 M_{Pl}^2}{45}}\,\frac{g_*^{1/2} m_s}{x^2} \sum_{f=e,\mu} \langle \sigma_{ff\to SS} v\rangle Y_f^{(eq)2}$$

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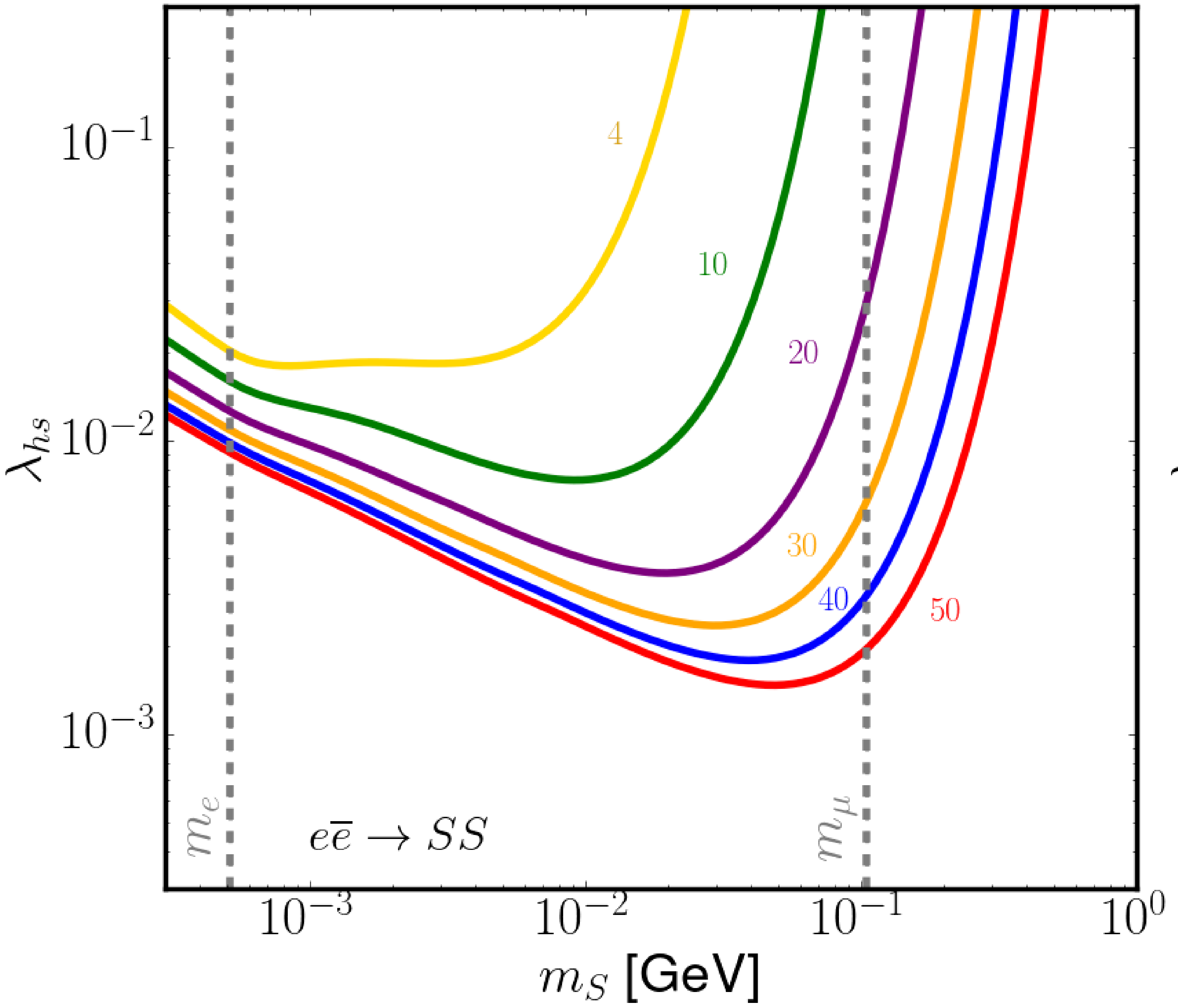
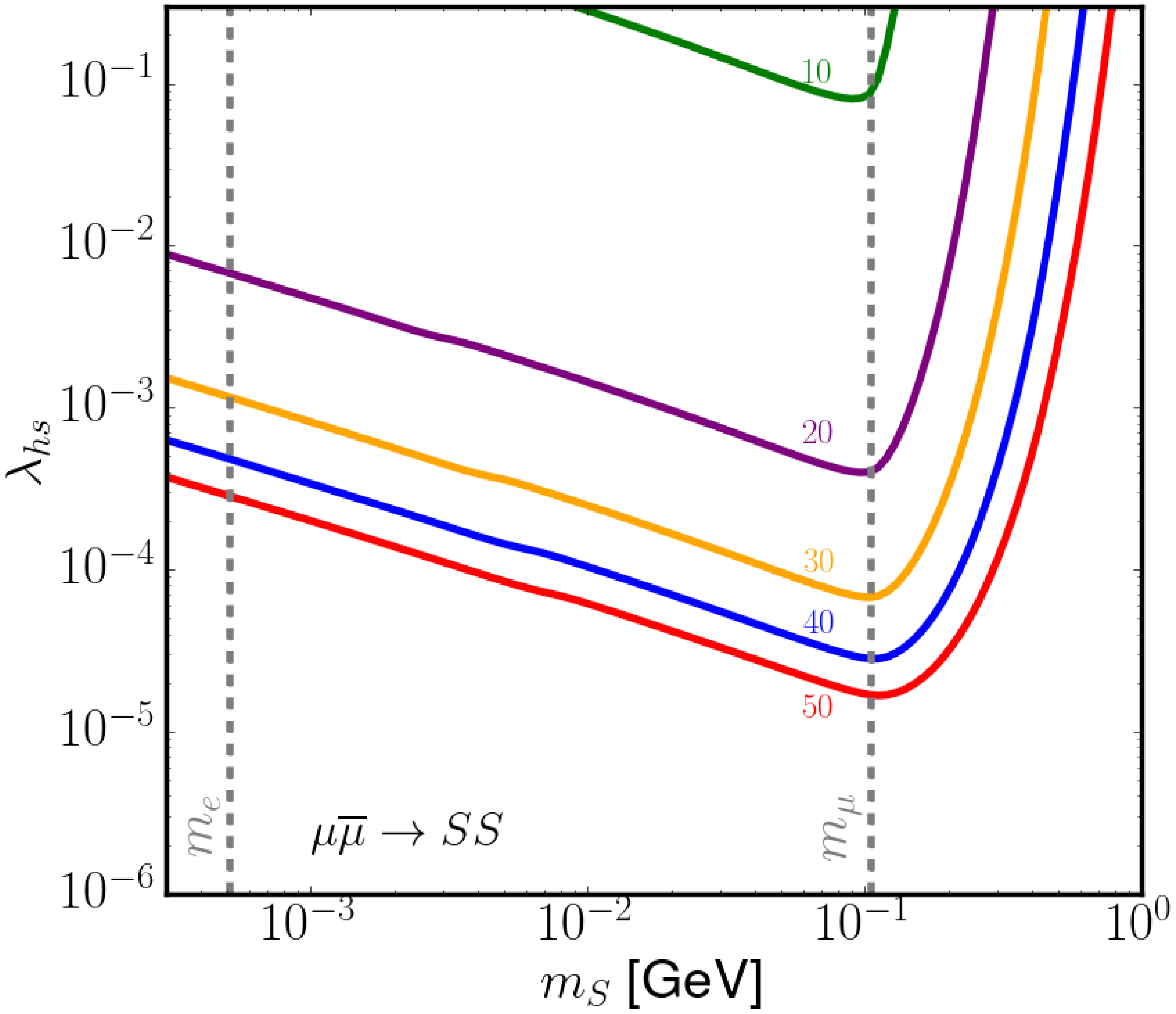




Constraints

- Invisible Higgs decay

$$BR_{inv} = \frac{\Gamma_{h\to ss}}{\Gamma_{SM}^{Tot} + \Gamma_{h\to ss}}$$

where

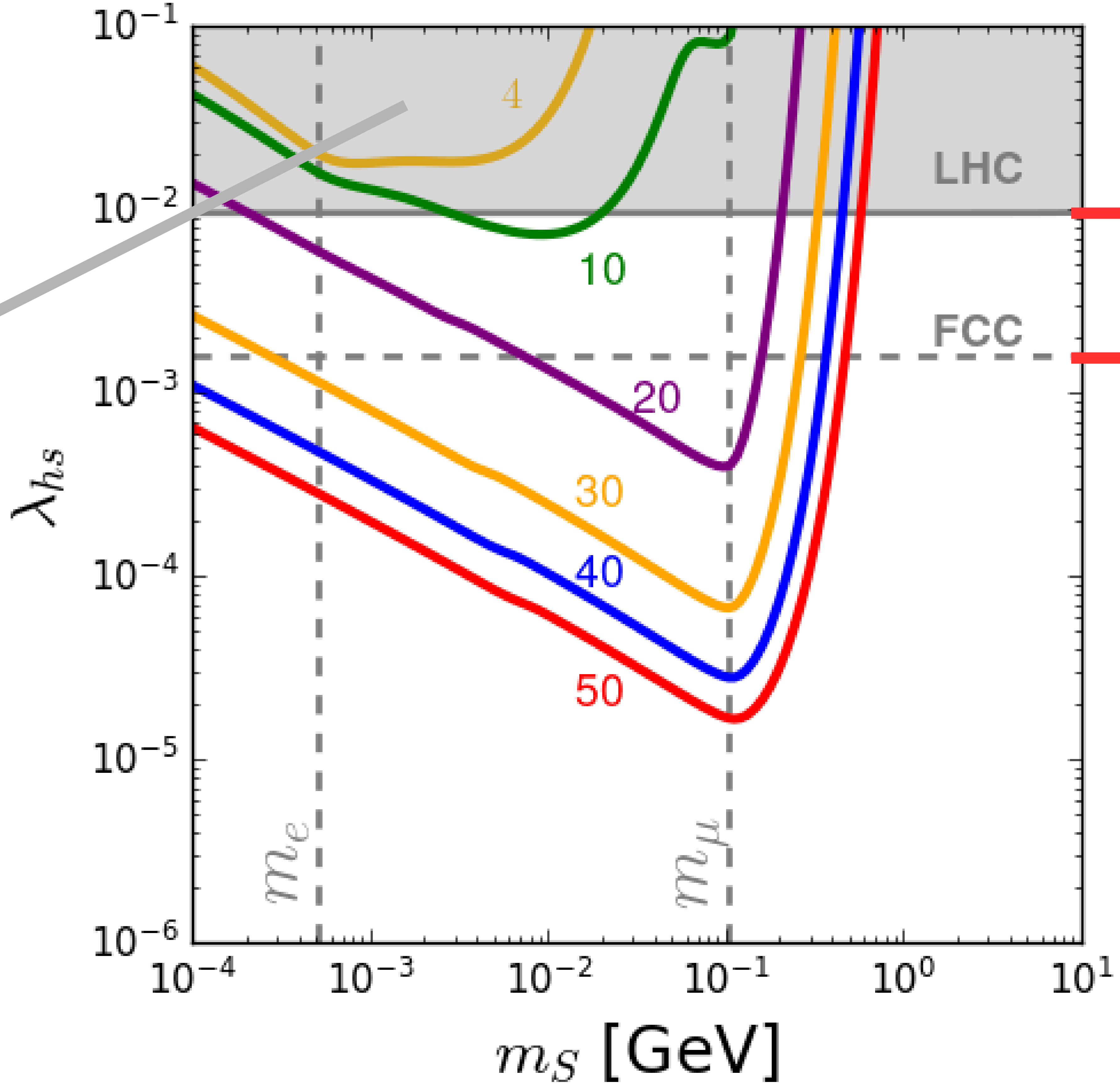
$$\Gamma_{h\to ss} = \frac{\lambda^2}{32\pi m_h}\sqrt{1 - \frac{4m_s^2}{m_h^2}}$$

- We impose $BR_{inv} < 0.1.$

- The future collider FCC tuned as a Higgs factory can reach the limit of

$$BR_{inv} \sim 0.003$$

Results



Excluded Region

$BR_{inv} < 0.1$

$BR_{inv} \sim 0.003$

In progress...

- We will also consider the case of fermionic DM

$$L \supset \frac{g m_f}{2m_W} h\bar{f} f + \frac{\lambda_{hs} v_{SM}}{2} h\chi\bar{\chi}, \qquad L \supset \frac{g m_f}{2m_W} h\bar{f} f + \frac{\lambda_{hs} v_{SM}}{2} i h\chi\gamma^5\bar{\chi}$$

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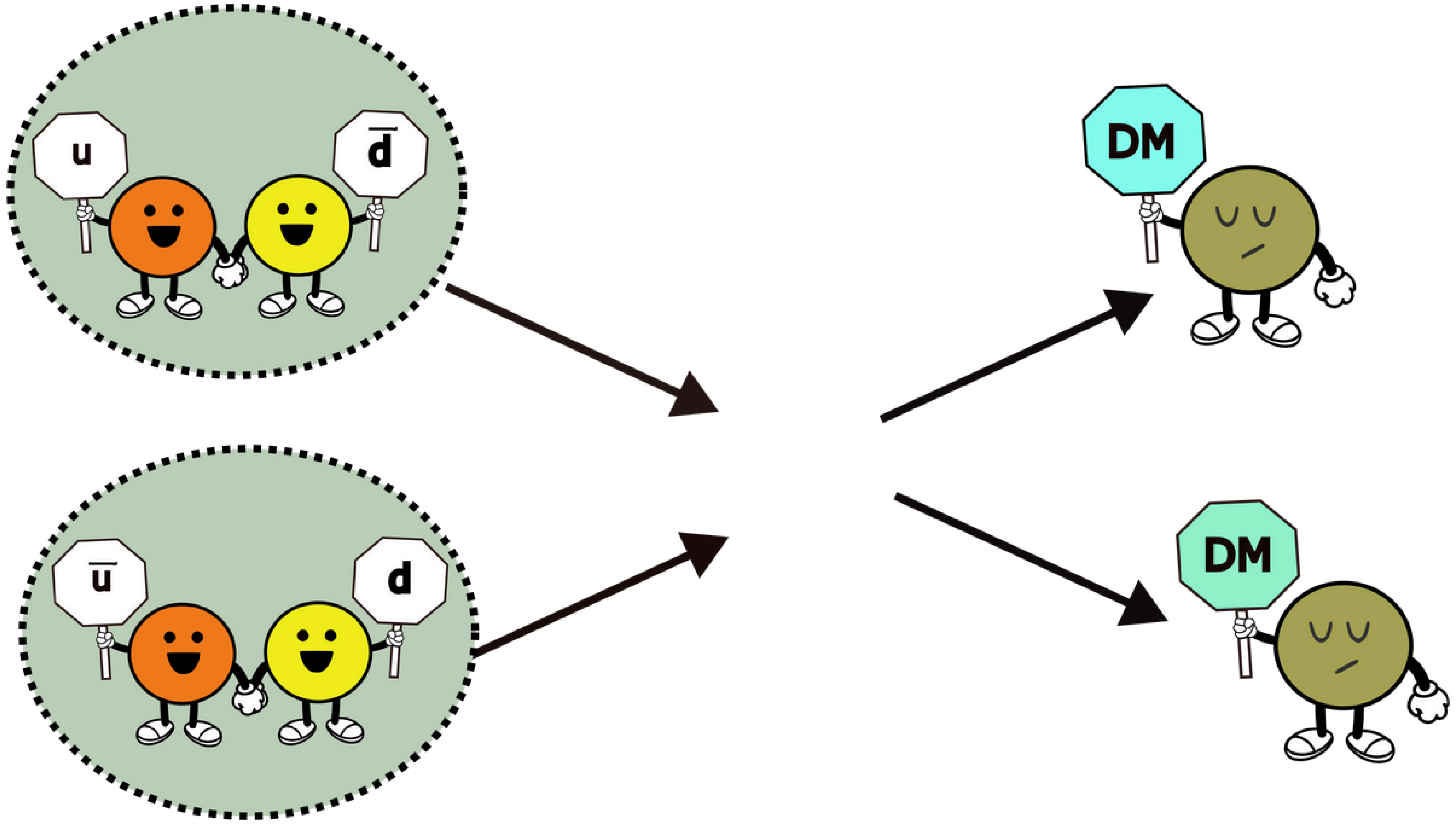
- We will also consider the mesons contributions



Conclusions

- **Freeze-in Mechanism:**
    - Dark Matter is Boltzmann suppressed if its mass exceeds the reheating temperature.
    - Correct DM abundance achieved with lower mass at low reheating temperatures.
- **Viability and Implications:**
    - Scenarios with low reheating temperatures are viable.
- **Future Implications**
    - Significant contribution from mesons after the Quantum Chromodynamics (QCD) phase transition.

THANK YOU!

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