# Spin 3/2 FIMP

## Direct Detection and Collider Bounds

**arXiv: 2304.XXXX**
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HIDDeN
Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

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# Freeze-in Dark Matter

Beyond the WIMP paradigm

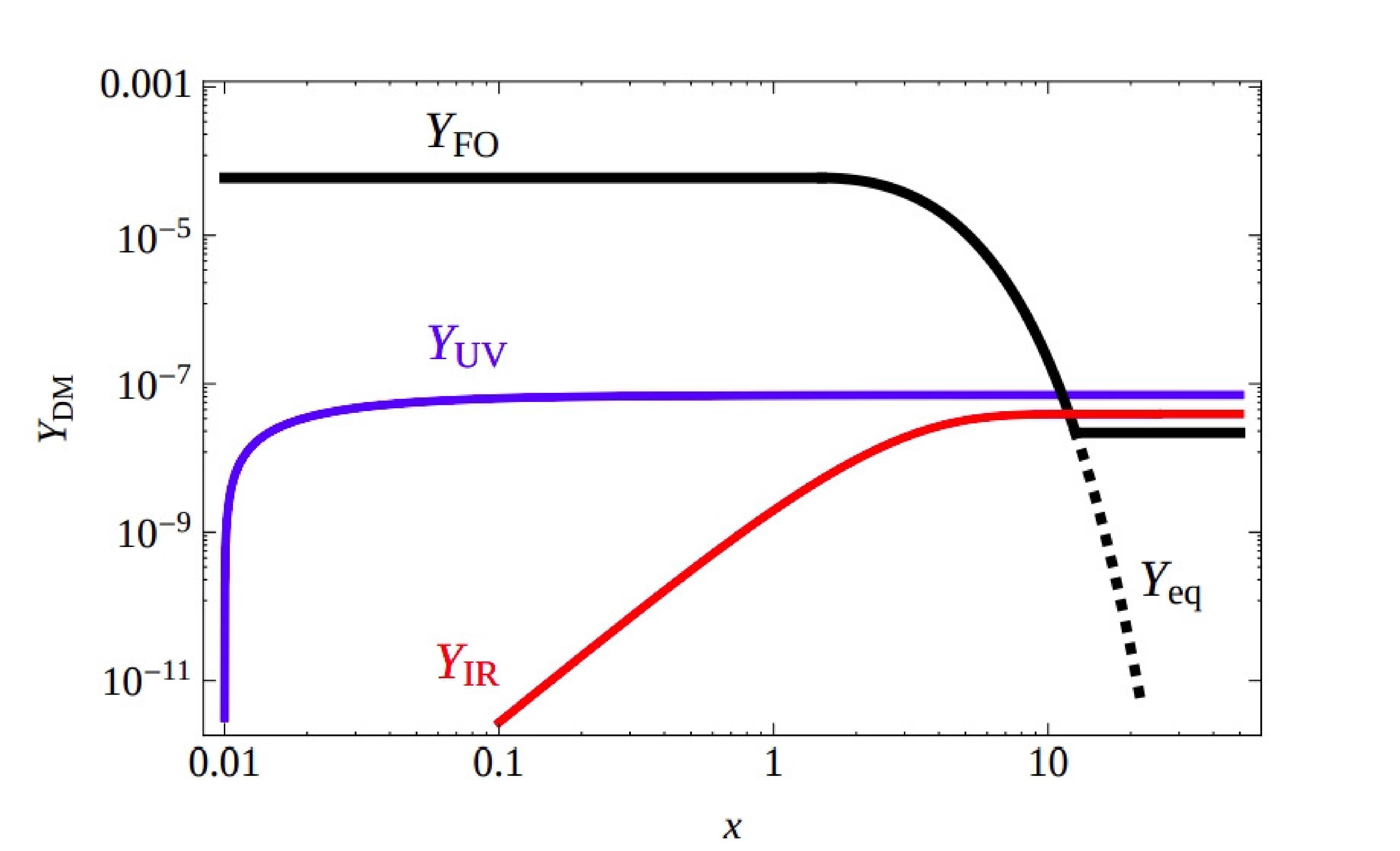



Fig. from Elahi, Kolda and Unwin

# A Natural Candidate

## Spin 3/2 Particle

$$\Psi$$

**1**

$$L \supset \frac{i}{\Lambda_1} \overline{L}\, i\sigma_2 (D_\mu H)^* \psi^\mu$$

**2**

$$L \supset \frac{i}{\Lambda_2} \nu_R \gamma^\mu [\gamma^\rho, \gamma^\sigma] \psi_\mu F_{\rho\sigma} + h.c.$$

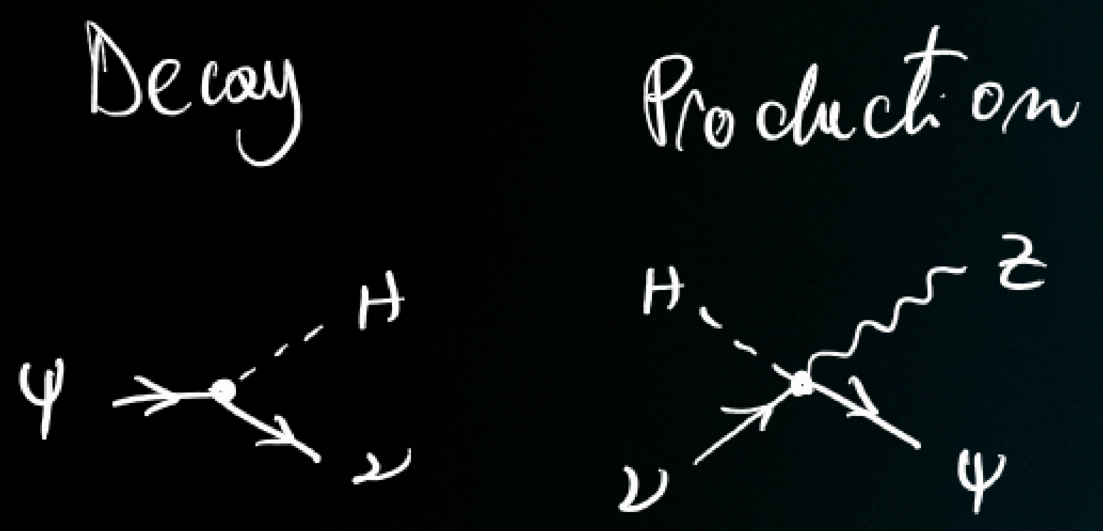
Garcia, Mambrini, Olive and Verner

**3**

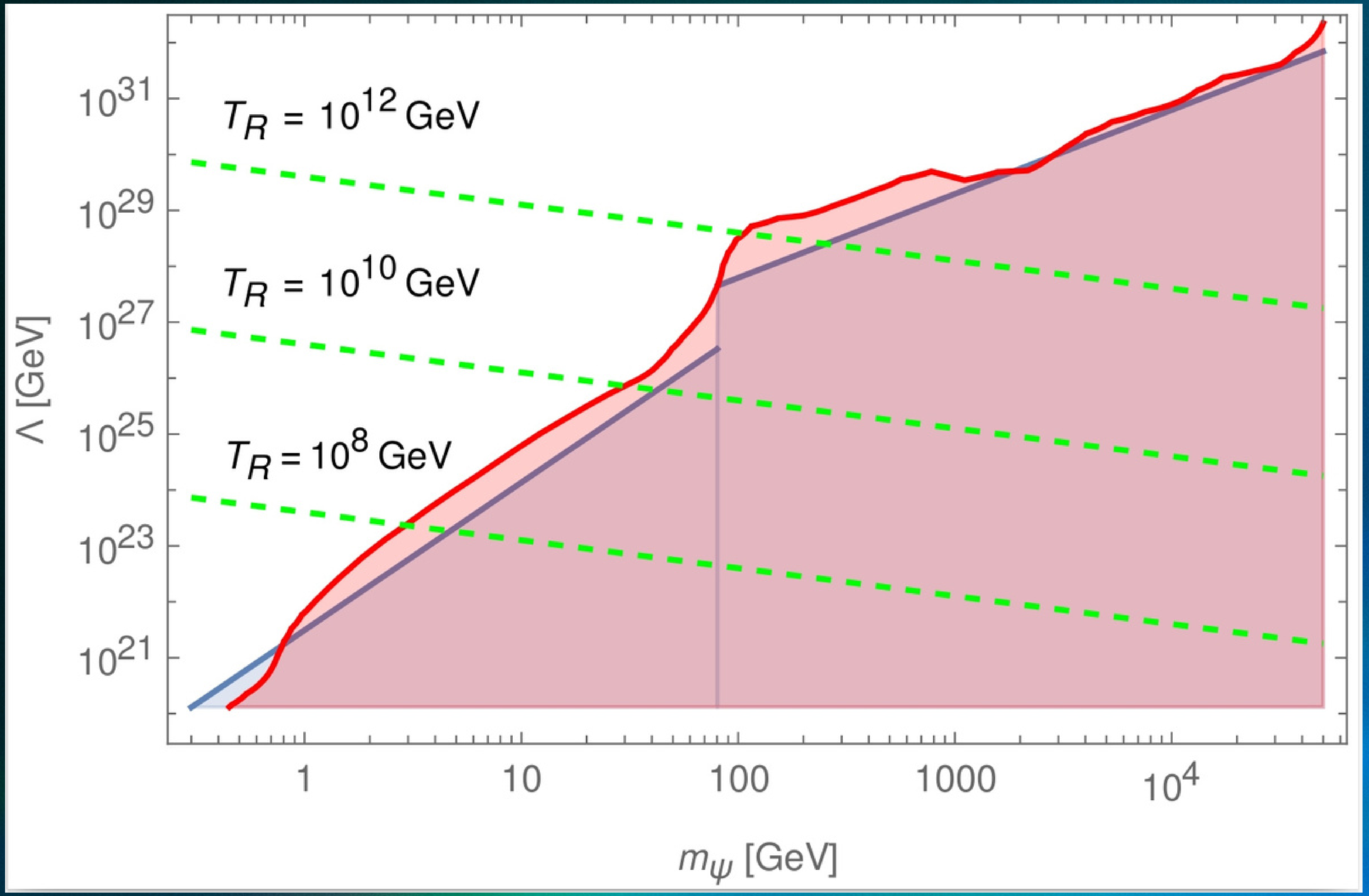
$$L \supset \frac{1}{\Lambda} H H^\dagger \psi^\mu \psi_\mu$$

Ding and Liao

# Decaying FIMP



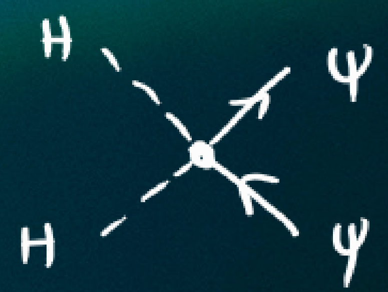

Strong bounds on Λ1 (and Λ2) given by indirect detection experiments

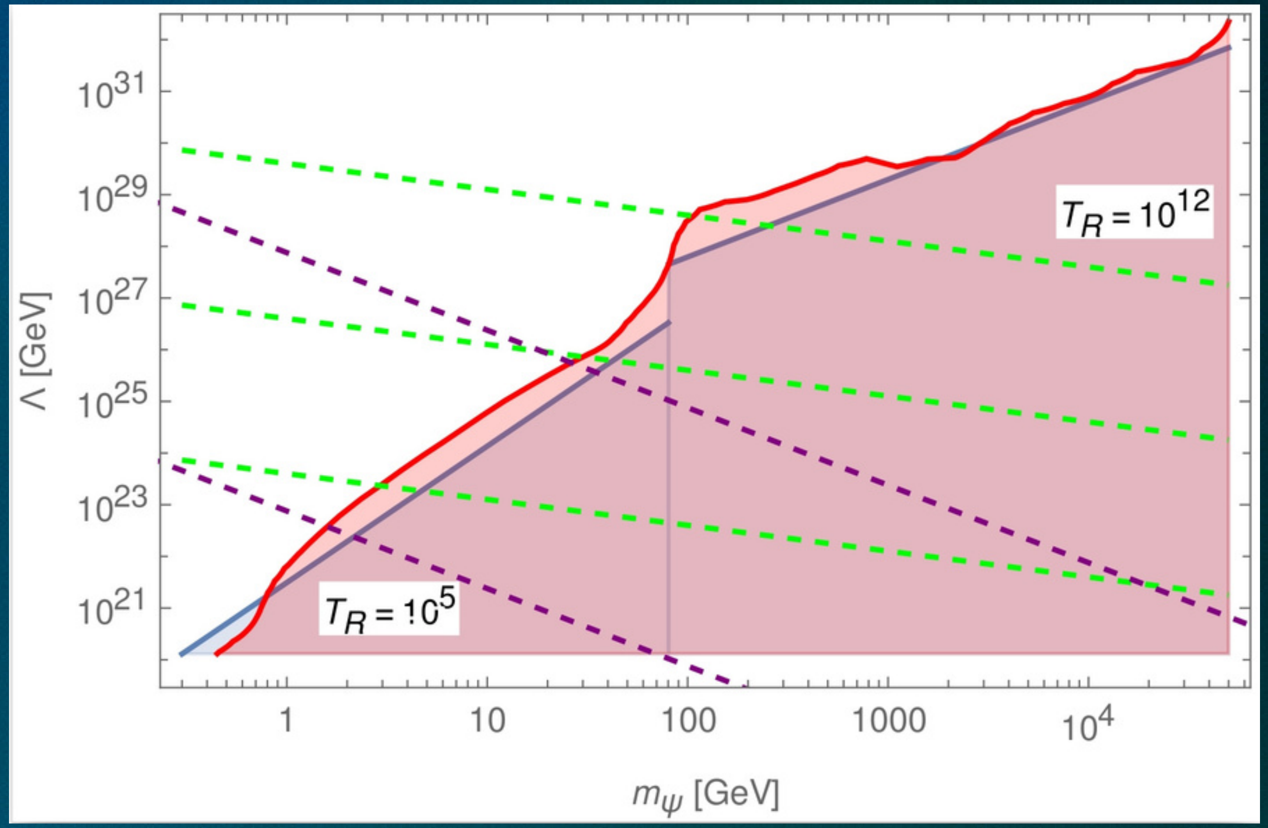


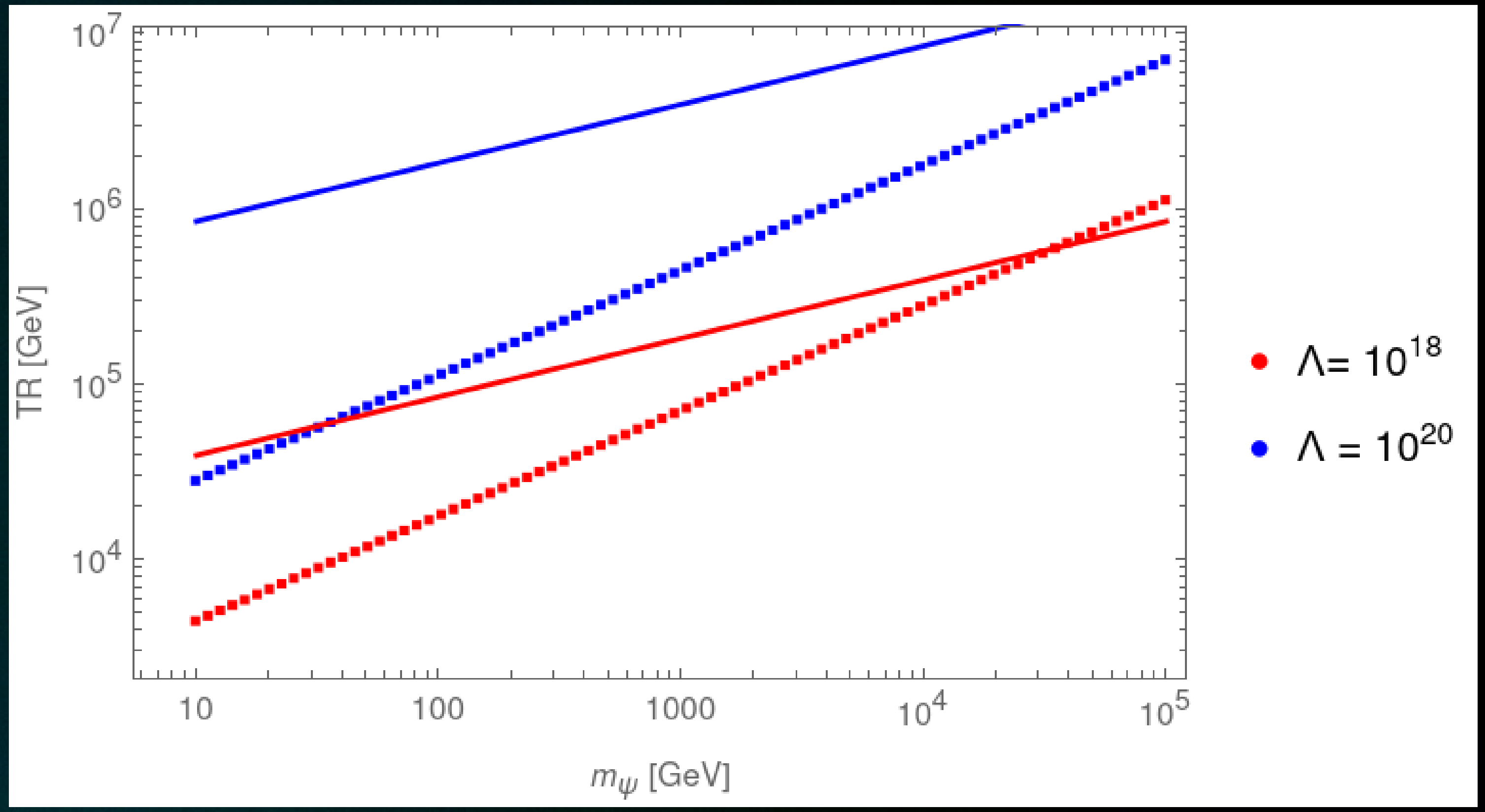

Garcia, Mambrini, Olive and Verner

# Higgs contact term dominates





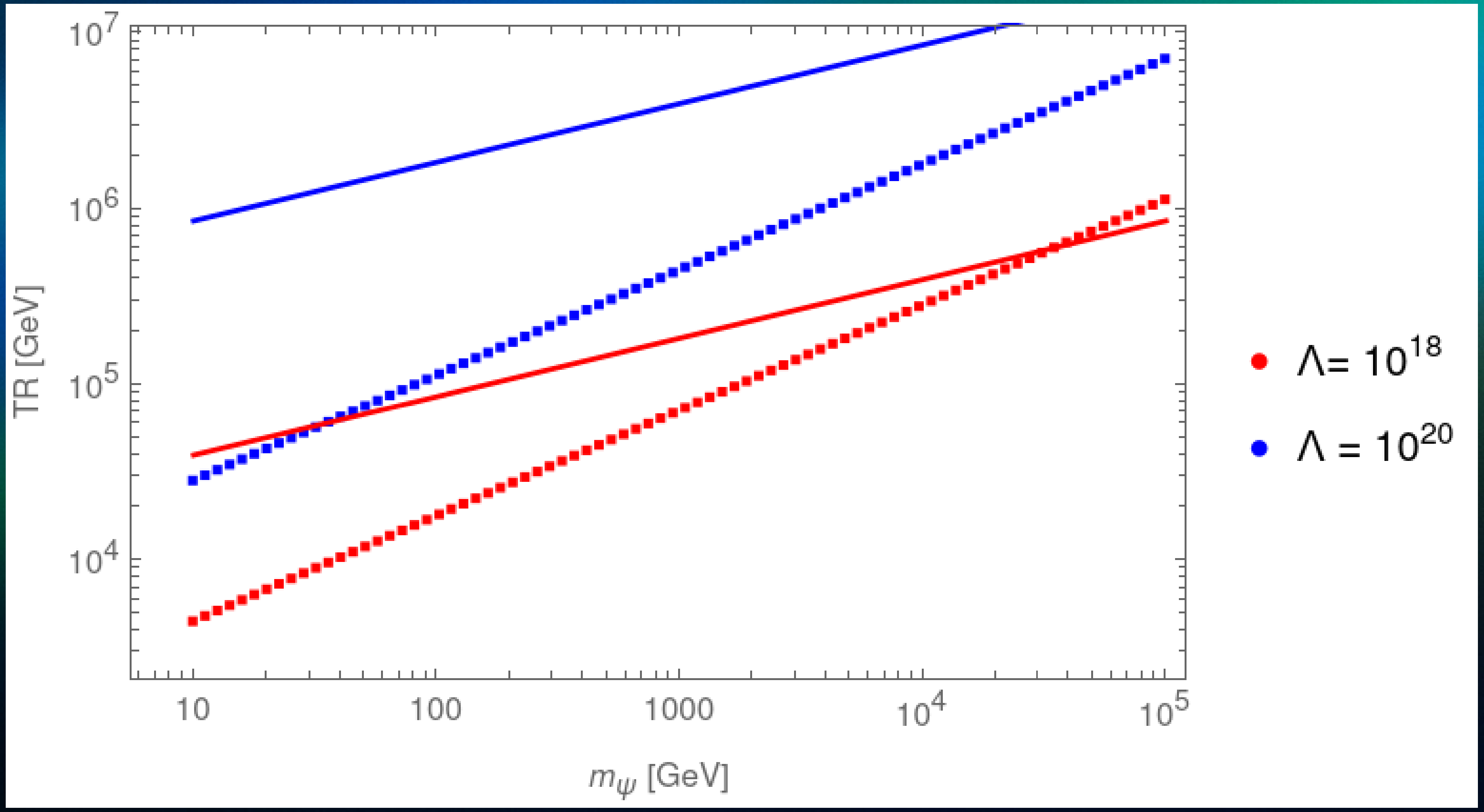




$$\Omega h^2 \sim 0.12 \left(\frac{1.2 \cdot 10^{19}\mathrm{GeV}}{\Lambda}\right)^2 \left(\frac{100\mathrm{GeV}}{m_\psi}\right)^4 \left(\frac{3.8 \cdot 10^4\mathrm{GeV}}{T_R}\right)^5$$

Dotted-lines = production via Λ
Solid-lines = production via Λ1

# Spans a huge range in TR

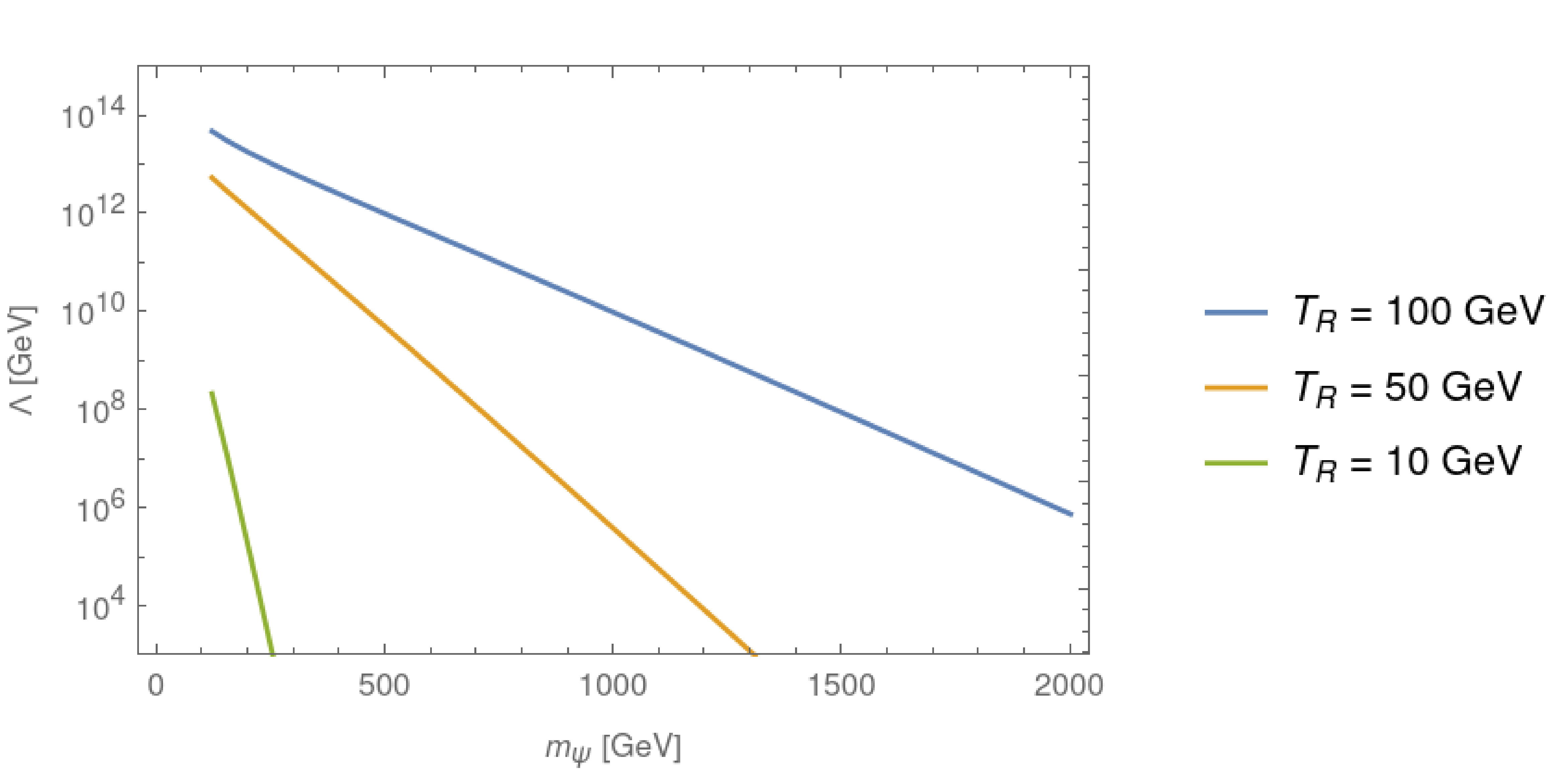





The lower bound on the reheating temperature is ~ MeV from BBN

Only 3 parameters: Λ , mDM and TR

# What happens at "Low" Reheating temperature?

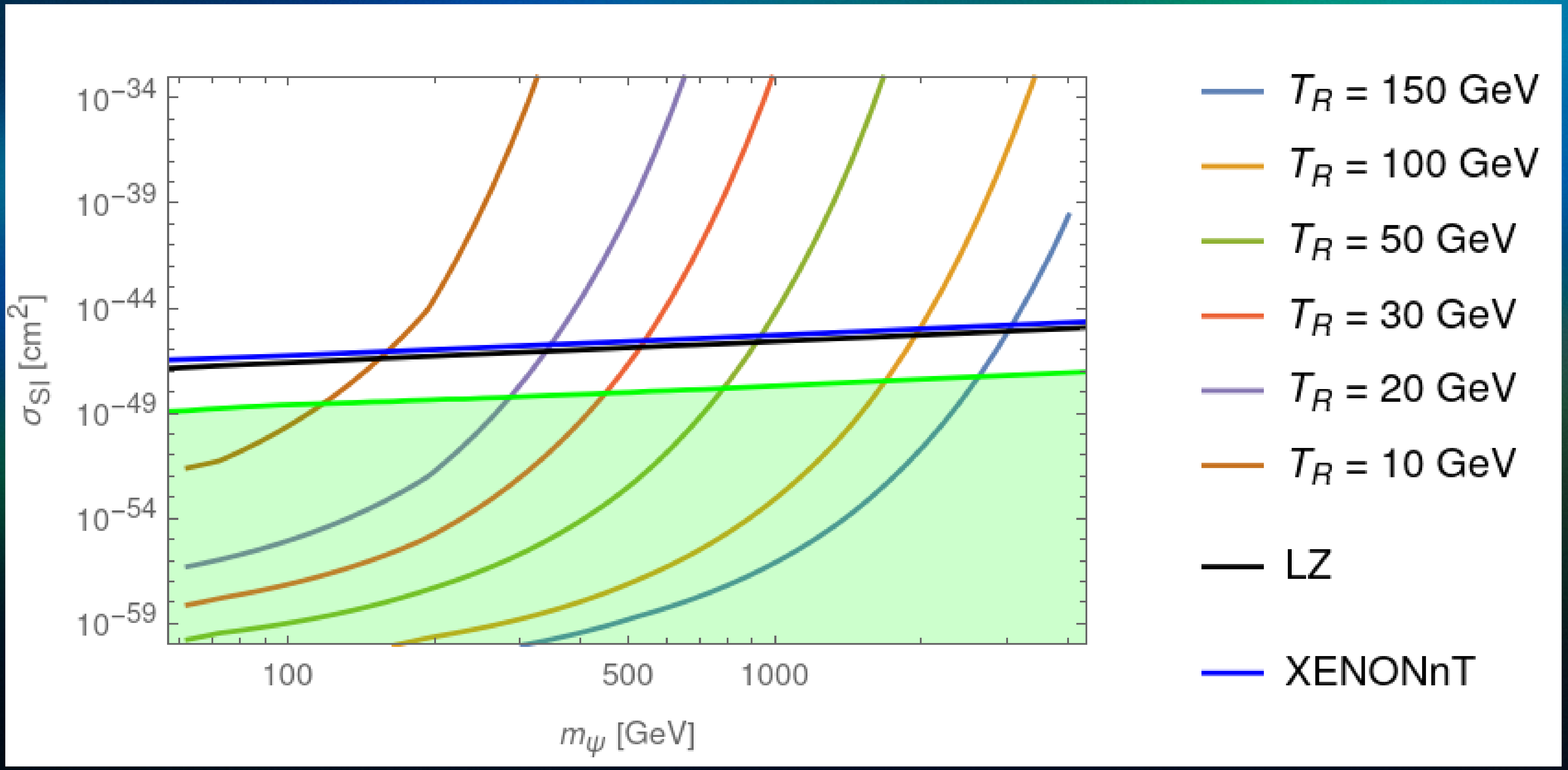



Exponential suppression of the relic density due to the Boltzmann suppression when TR << mDM

$$\Omega h^2 \sim \exp\left(-\frac{m_\psi}{T_R}\right)$$

Steep dependence of Λ on mass and reheating temperature

# FIMP @ DIRECT DETECTION experiments



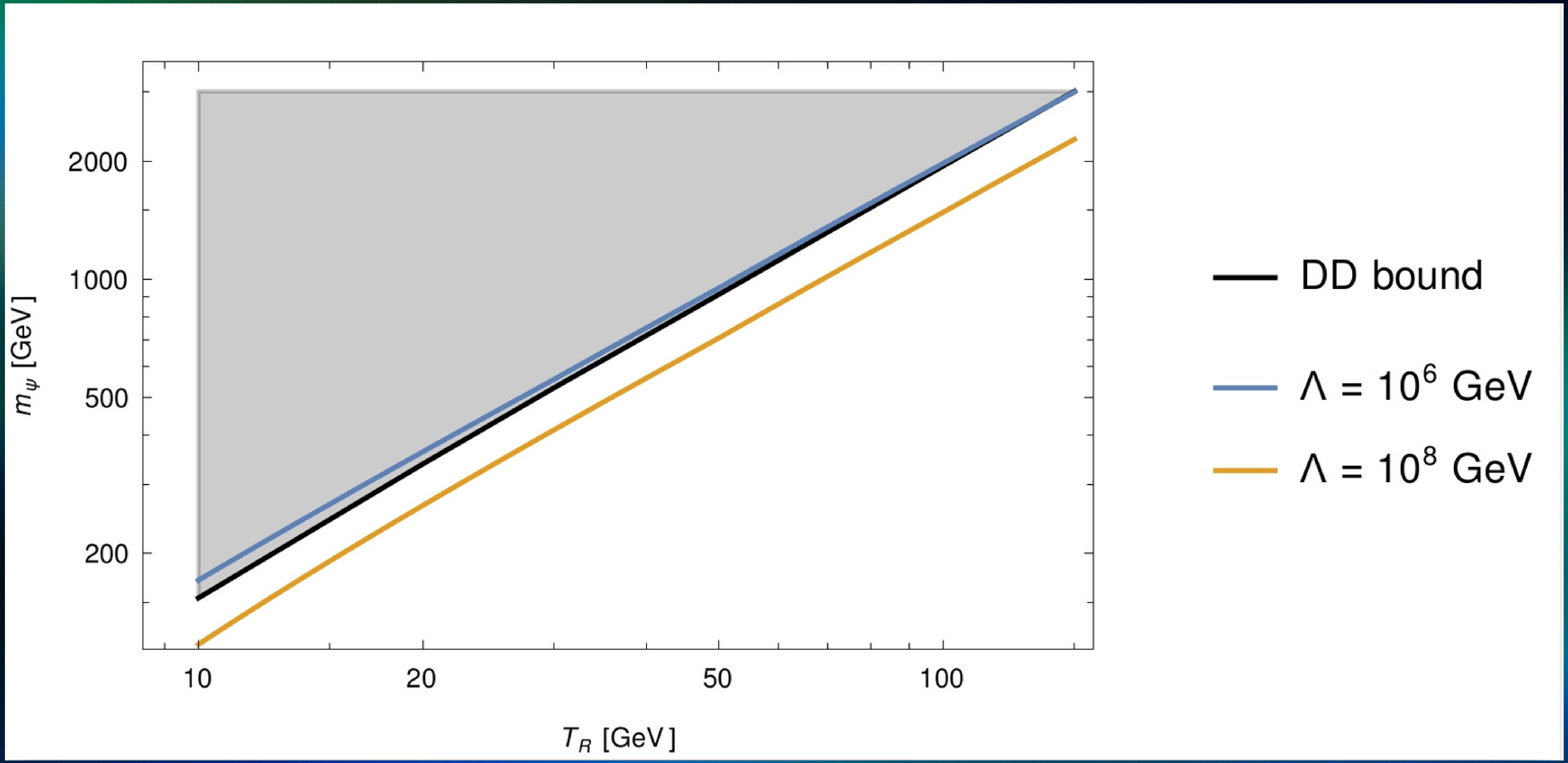

Curves of the correct relic abundance at fixed TR

Exponential Boltzmann suppression when
TR << mDM

$$\Omega h^2 \sim \exp\left(-\frac{m_\psi}{T_R}\right)$$

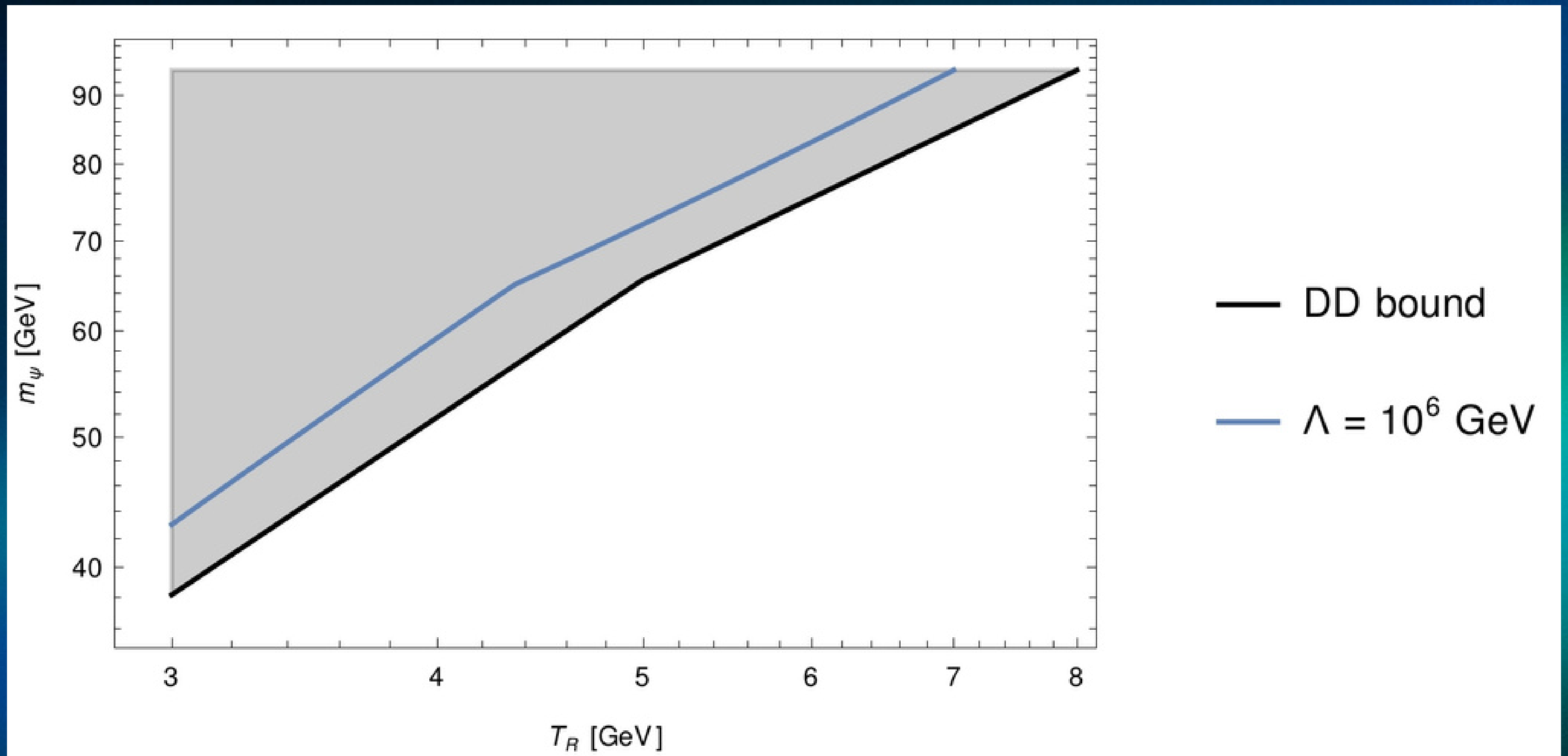
for low TR DM production, see also: Bhattiprolu, Elor, McGehee and Piercea

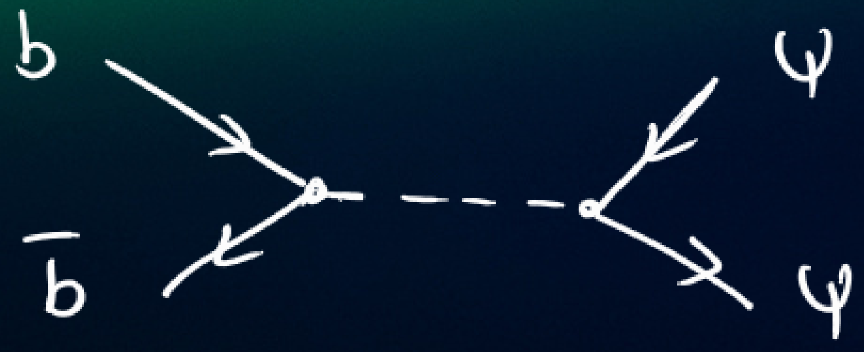
# Bound on the DM mass



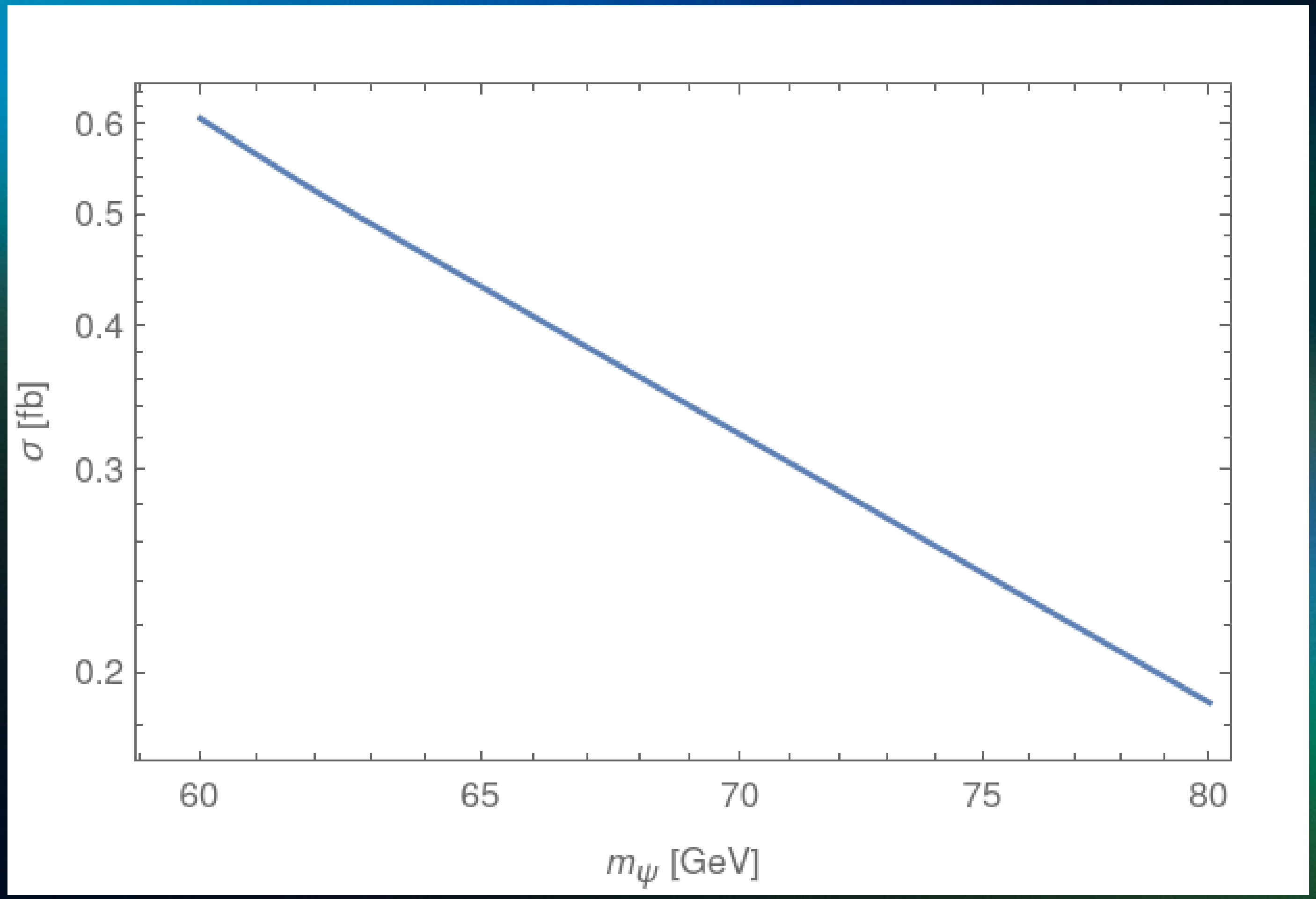

Given TR we have bounds on the DM mass and the NP scale or viceversa we can obtain a lower bound on TR

# Work in progress



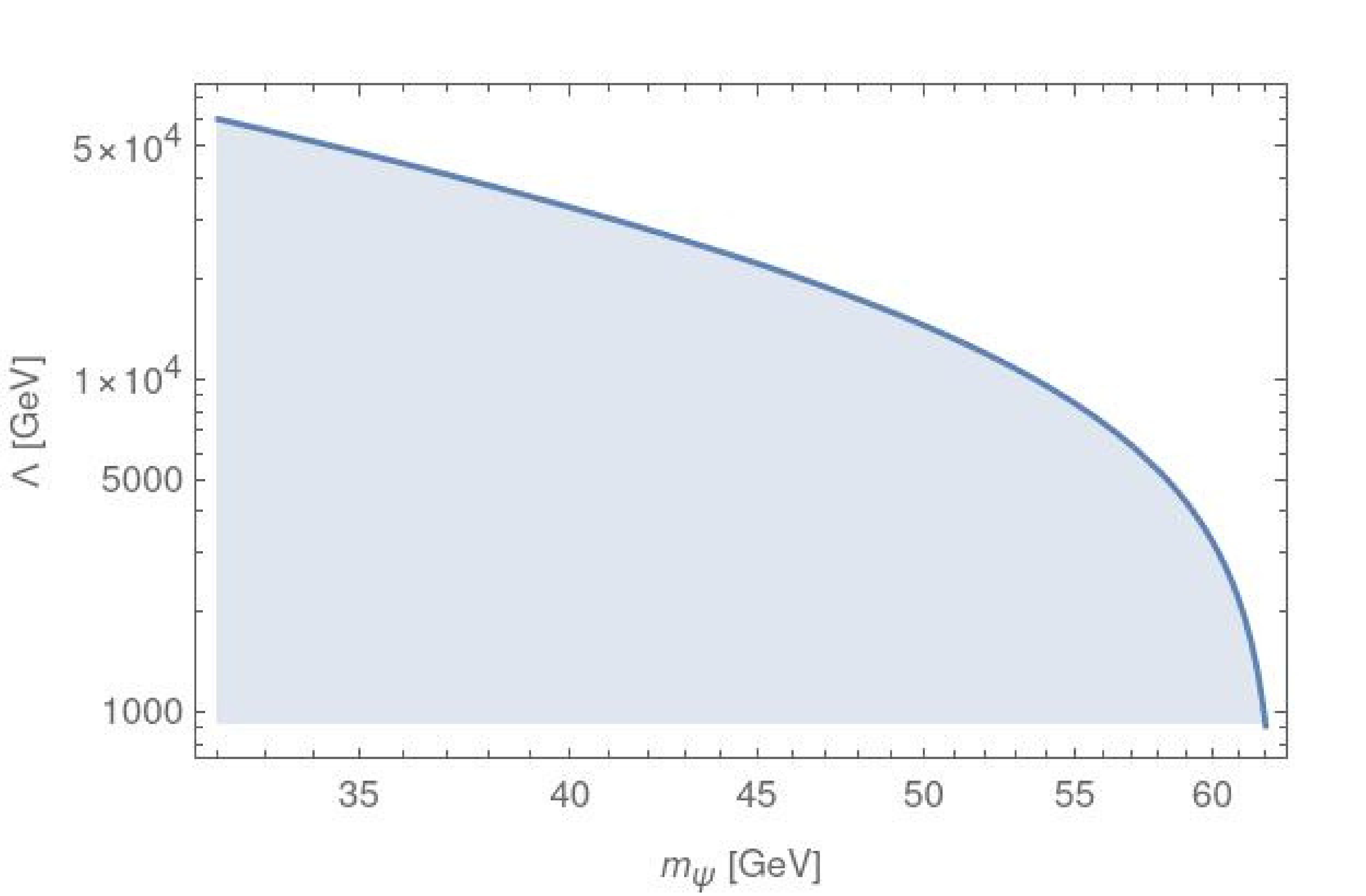

In the range 2 mDM > mH the DD bounds dominate, if this is 100% of the DM → we should still look for it @ collider



# At TR < 9 GeV

Around a temperature of 9 GeV the Higgs goes out of equilibrium and completely decay  and it can't be found in the thermal bath anymore

We can set very strong bounds from the Higgs invisible decay (when
 2 mDM < mH)



# Conclusions

- Spin 3/2 is a natural FIMP DM candidate
- Coupling with the Higgs dominates and spans many order of magnitude in the reheating temperature TR
- At low TR the production is exponentially suppressed
- The scale of new physics can be low and DD and colliders set strong bounds
- At low TR → Direct detection and collider and still Indirect Detection searches

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# Thank you for listening!

Feel free to DM us your questions any time:

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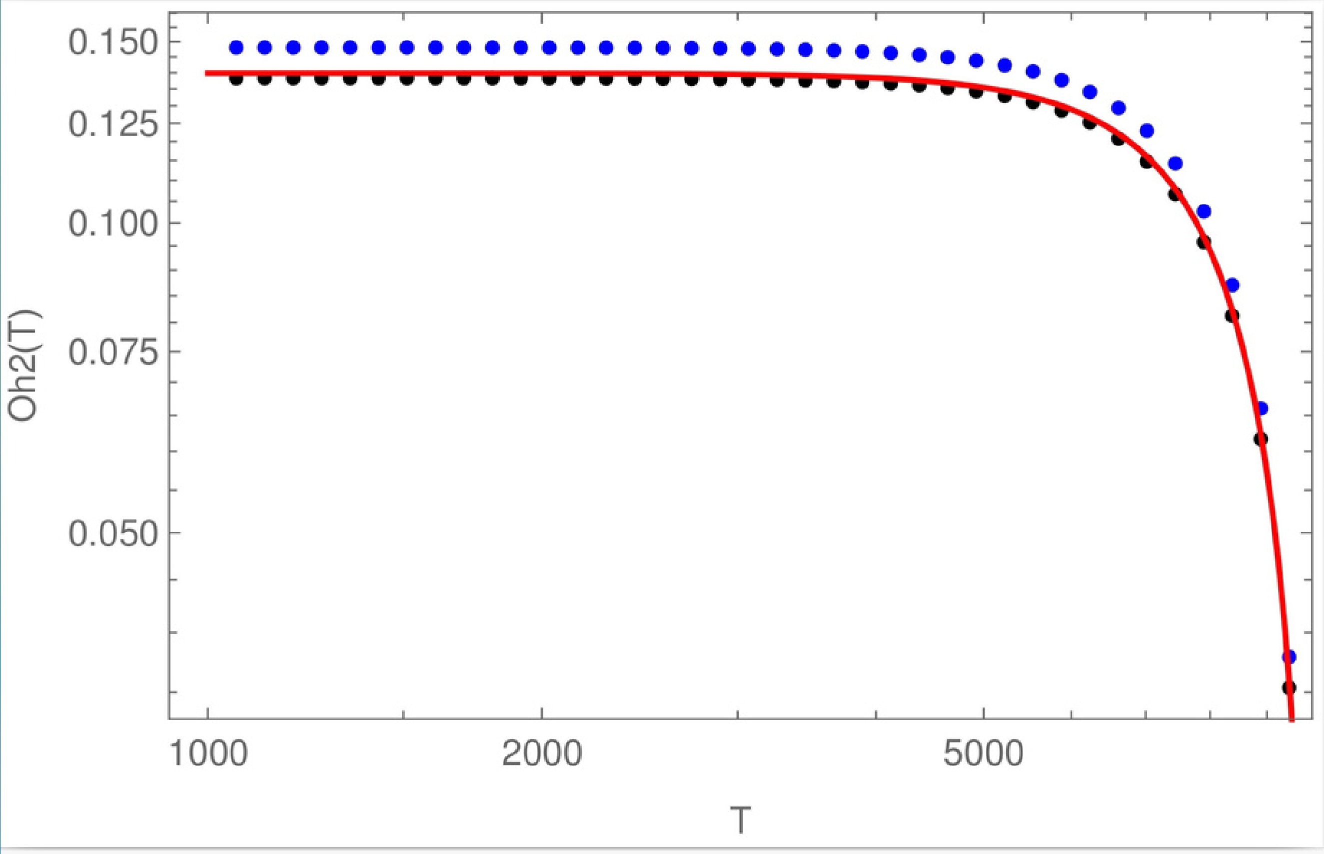
# Back-up slides

# Corrections to the naive computation




with mDM = 10 GeV and TR = 10 000 GeV

- At these temperatures the Higgs is relativistics (BE distribution)

**Lebedev and Toma**

- Instantaneous reheating approximation

**Garcia,Mambrini,Olive and Peloso**