Higgs and Dark Matter hints of an Oasis in the Desert

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w/ C.Cheung & K.Zurek, 1203.5106

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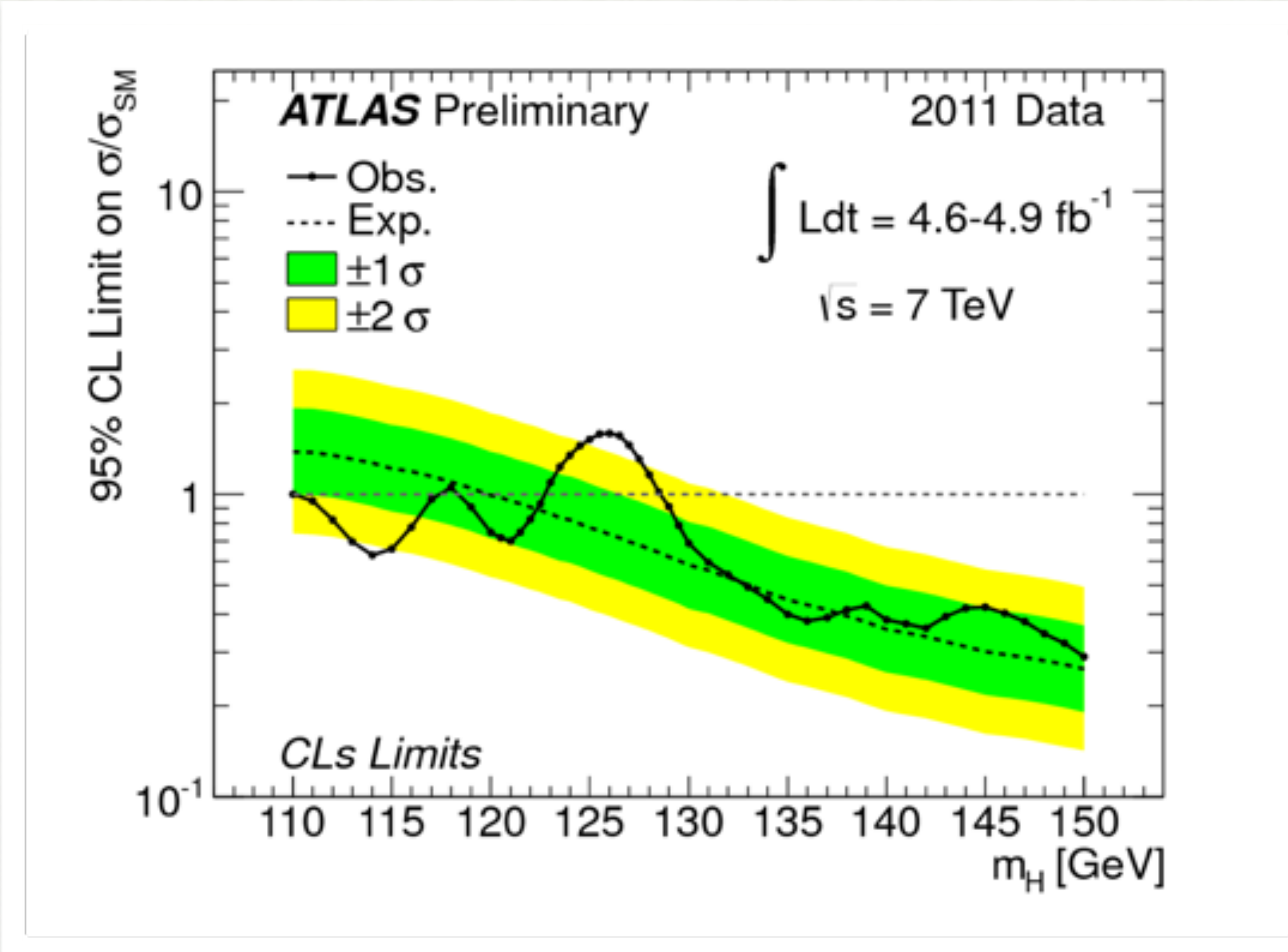
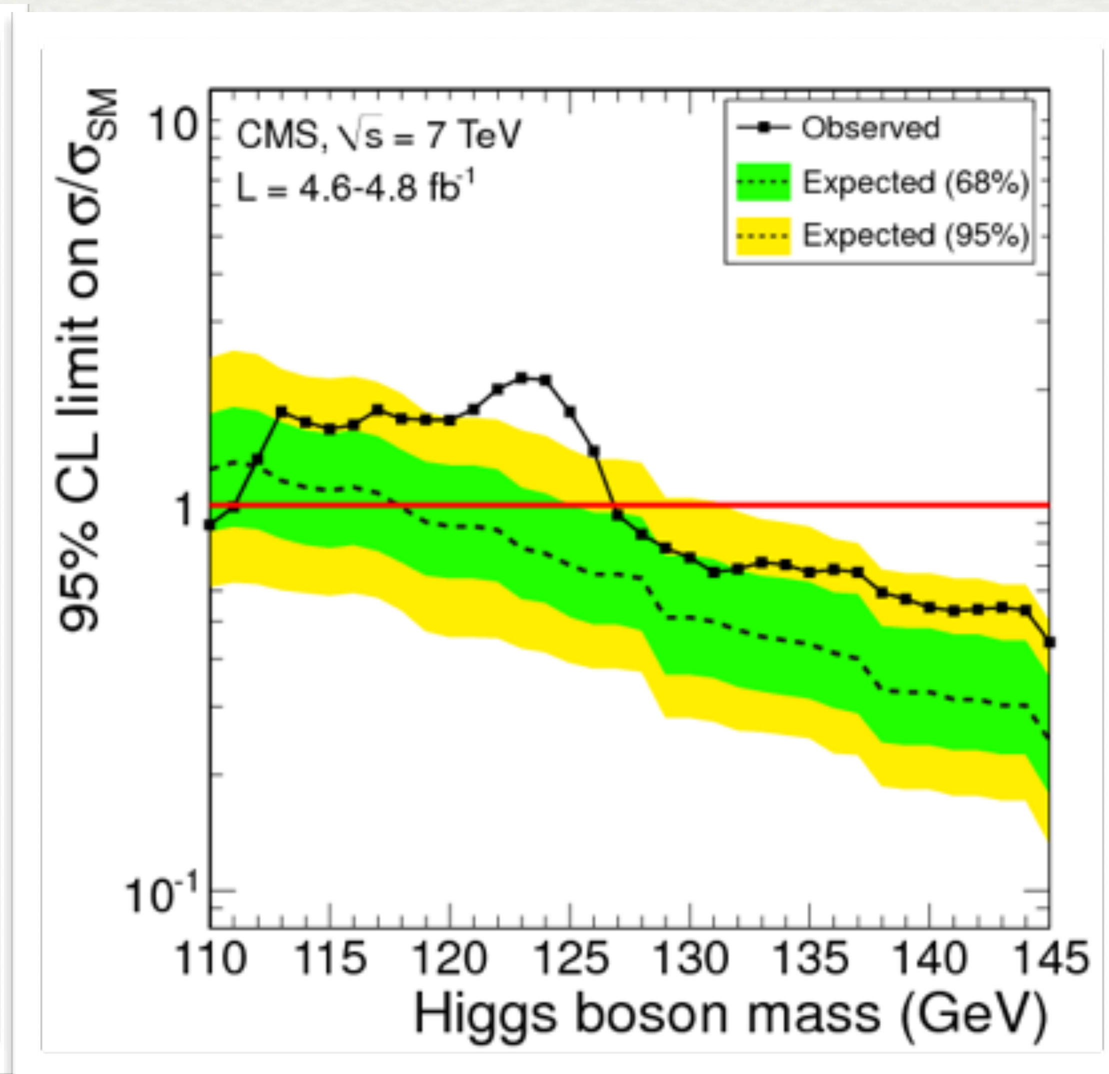
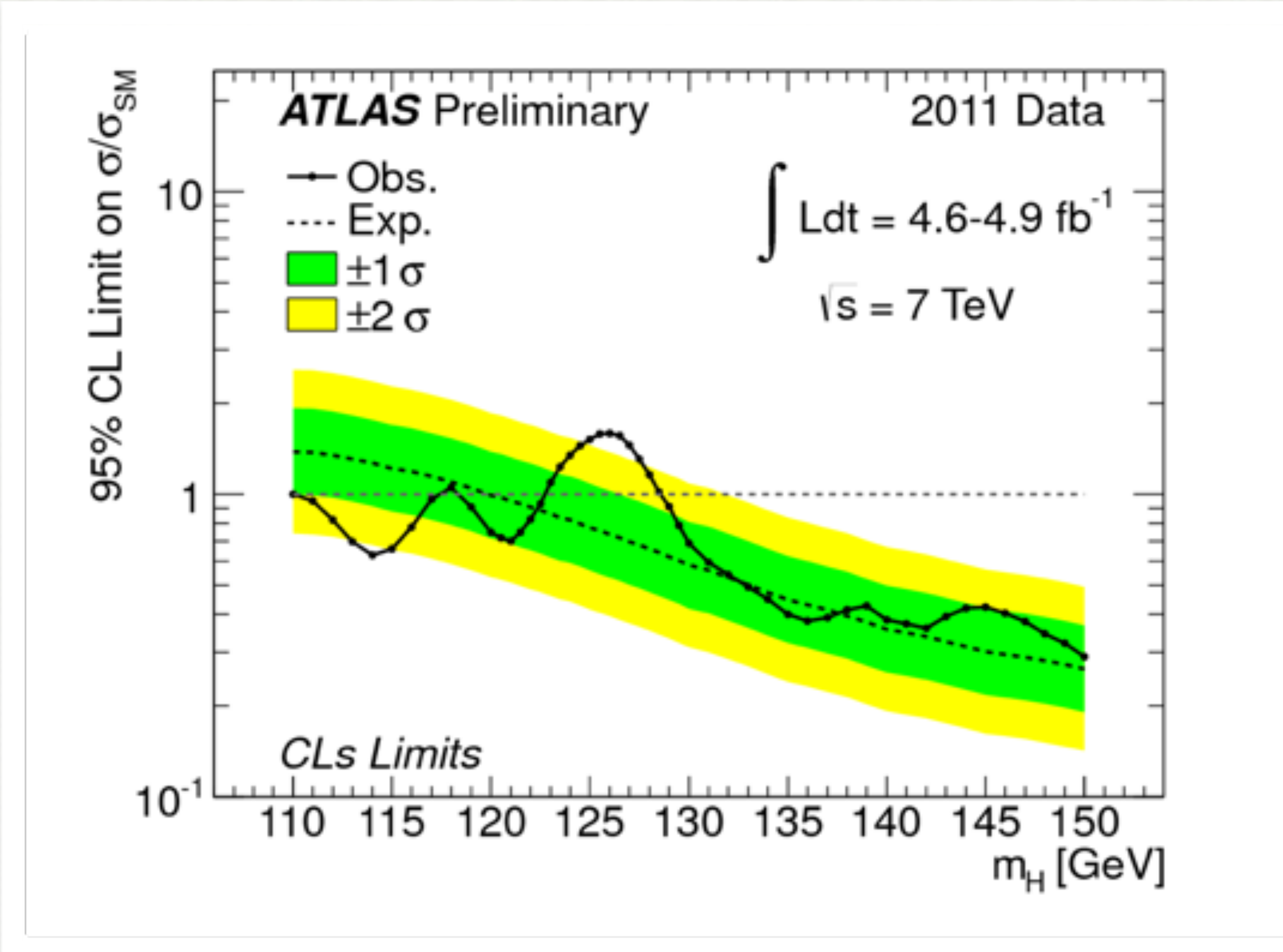
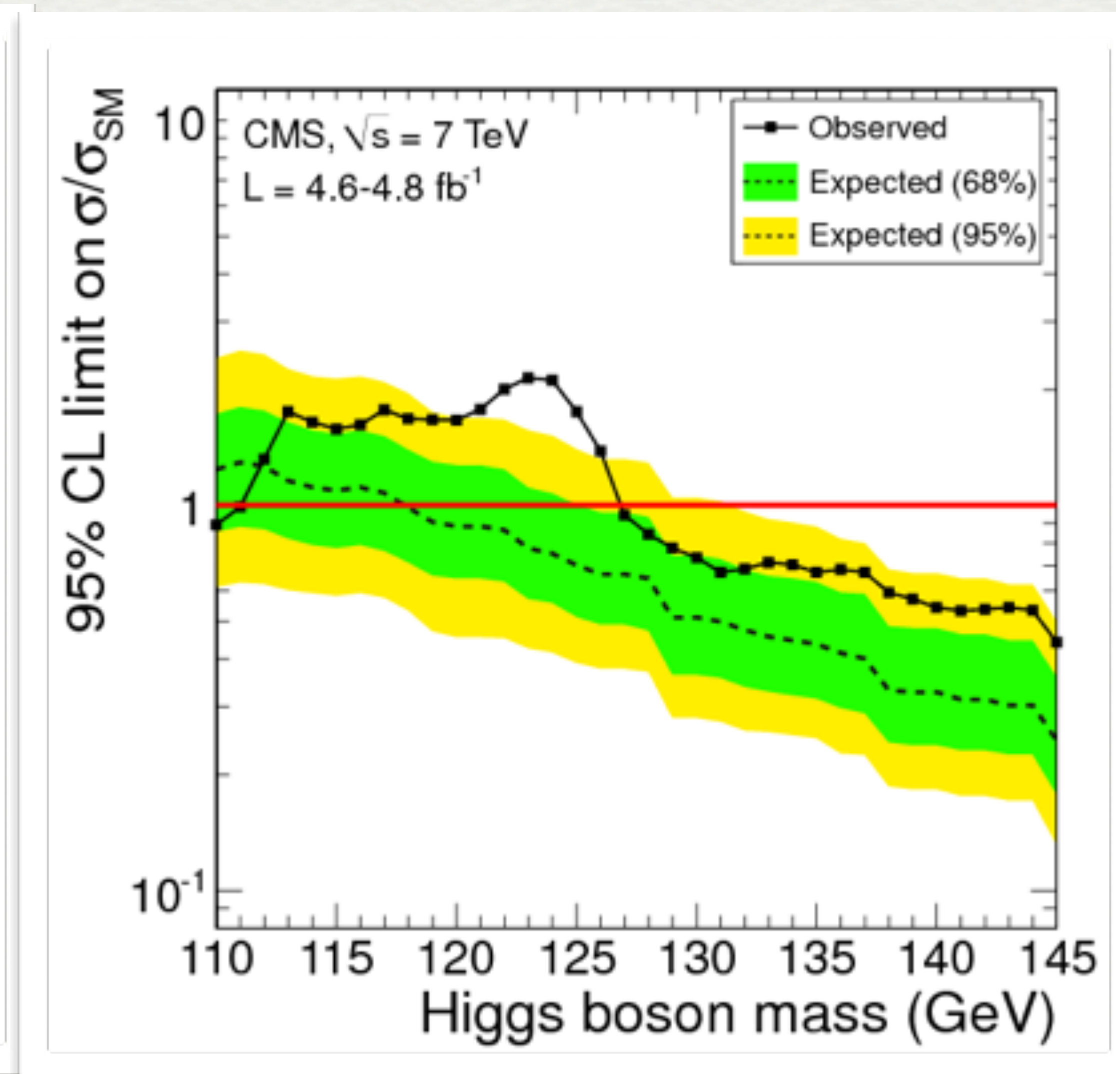




The 125GeV hint may be the Higgs

- Is weak scale natural? (Experimental question)
- If nothing else is found, till which energies the "Standard Model" can be valid?





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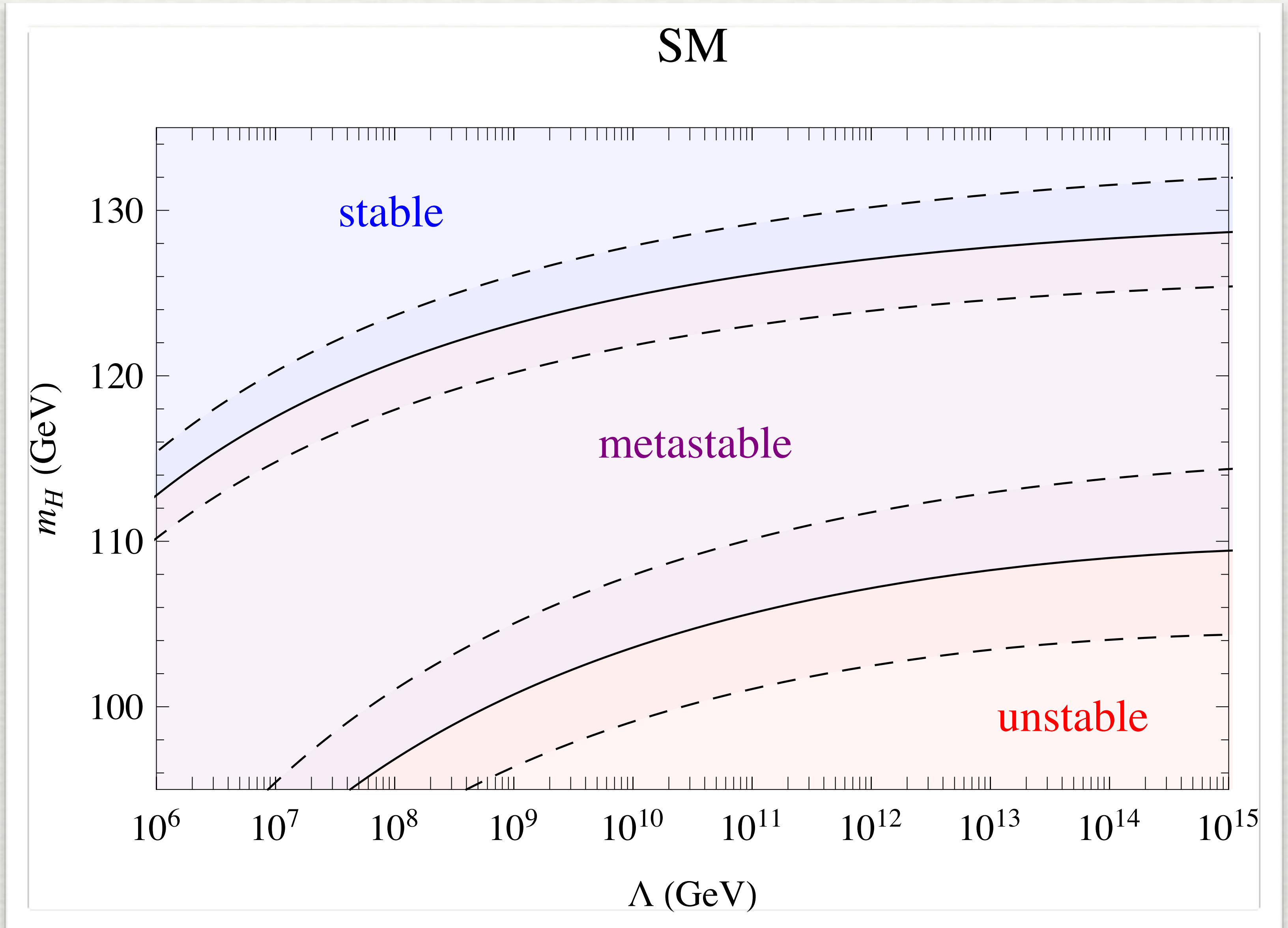
Stability of the Electroweak Vacuum



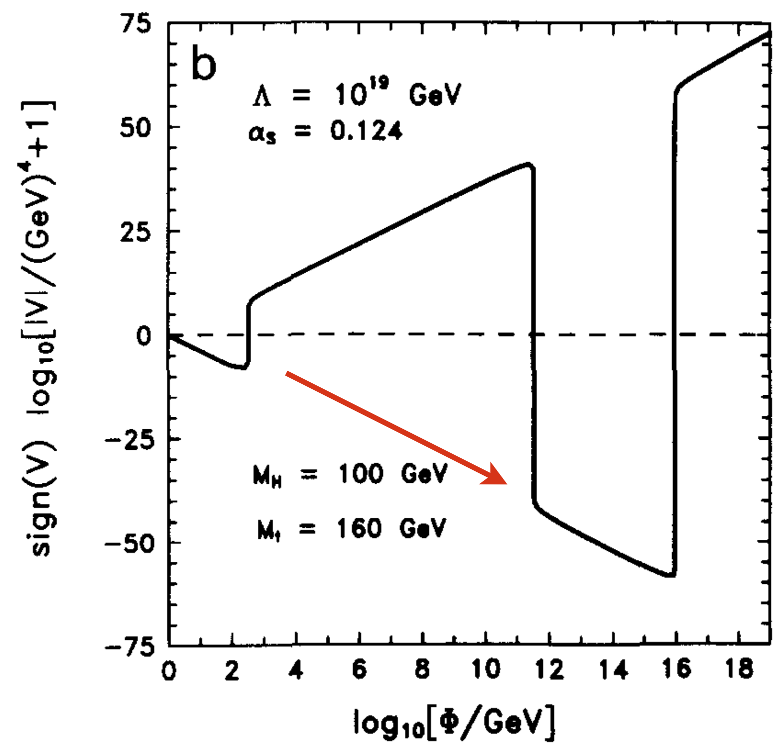
- Question has been addressed long time ago in the Standard Model

Stability of the EW vacuum

- Higgs quartic coupling (a.k.a. m_H) runs at loop level
- Can run non-perturbative or negative
- In the Standard Model depending on the values of the Higgs and top masses there might be another minimum at large field values
- Our vacuum could be absolutely stable, unstable or metastable (but sufficiently long lived)
- For a given Higgs mass, stability constraint up to which scale the SM is a valid theory

$$(4\pi)^2 \frac{d\lambda}{d\log Q} = 12\lambda_H^2 - 12y_t^4 + 12\lambda y_t^2 + \ldots$$

$$V_{\rm eff}(\phi) \overset{\phi\to\infty}{=} \frac{\lambda(\mu=|\phi|)}{2}|\phi|^4$$



PLB342 (1995) 171

SM+??

- We know there is physics beyond the standard model that requires new dynamics
  - neutrino masses
  - dark matter
  - baryonic asymmetry
- Some of the models presented to address these questions require new interactions with the Higgs
- minimally including these new ingredients may change the Higgs stability picture $\rightarrow$ different cutoff

SM+WIMP DM

- WIMP Dark matter is “unique”:
  - weak scale mass → many decades in energy to affect Higgs
  - couplings can be sizable
  - indipendent constraints → correlations with Direct Detection measurements

$\langle\sigma v\rangle \sim 1$ pb

Explore Higgs stability of SM+WIMP DM in the rest

SM+WIMP DM

- Explore lower SU(2)xU(1) representations w/ spin 0 and 1/2 DM

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Scalar Singlet:

$$-\Delta\mathcal{L} \;=\; \frac{1}{2}m_S S^2 + \frac{\lambda_S}{2}S^4 + \frac{\kappa_S}{2}S^2|H|^2$$

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Z_2 sym'

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$$-\Delta\mathcal{L} = m_D|D|^2 + \frac{\lambda_D}{2}|D|^4 + \frac{\kappa_D}{2}|D|^2|H|^2 + \frac{\kappa'_D}{2}|DH^\dagger|^2$$

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PQ sym'

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Singlet/Doublet:

$$-\Delta\mathcal{L} \;=\; \frac{1}{2}m_S S^2 + m_D D D^c + y_S H S D + y_S^c H^c S D^c$$

Triplet/Doublet:

$$-\Delta\mathcal{L} \;=\; \frac{1}{2}m_T T^2 + m_D D D^c + y_T H T D + y_T^c H^c T D^c$$

(vector-like doublets for anomalies)

SM+WIMP DM

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The MSSM is a special case:

$$\begin{array}{ccc} S & \leftrightarrow & \tilde{B} \\ T & \leftrightarrow & \epsilon \tilde{W} \epsilon^T \\ D & \leftrightarrow & \epsilon \tilde{H}_d \\ D^c & \leftrightarrow & \epsilon \tilde{H}_u \end{array} \qquad \begin{array}{ccc} m_S & \leftrightarrow & M_1 \\ m_T & \leftrightarrow & M_2 \\ m_D & \leftrightarrow & \mu \end{array} \qquad \begin{array}{ccc} y_S & \leftrightarrow & \tilde{g}'_d/\sqrt{2} \\ y_S^c & \leftrightarrow & \tilde{g}'_u/\sqrt{2} \\ y_T & \leftrightarrow & -\tilde{g}_d/\sqrt{2} \\ y_T^c & \leftrightarrow & \tilde{g}_u/\sqrt{2} \end{array}$$

$$\tilde{g}_u^{(\prime)} = g^{(\prime)} \sin\beta \qquad \tilde{g}_d^{(\prime)} = g^{(\prime)} \cos\beta$$

Methodology

- Run 2-loop RGE (coded Machacek and Vaughn) + 1-loop threshold corrections (Sirlin & Zucchini, Bagger et al.)
- Compute relic abundance and σ_{SI}
- Check for (meta)-stability and perturbativity

For Scalars:

Stability along all the field directions:

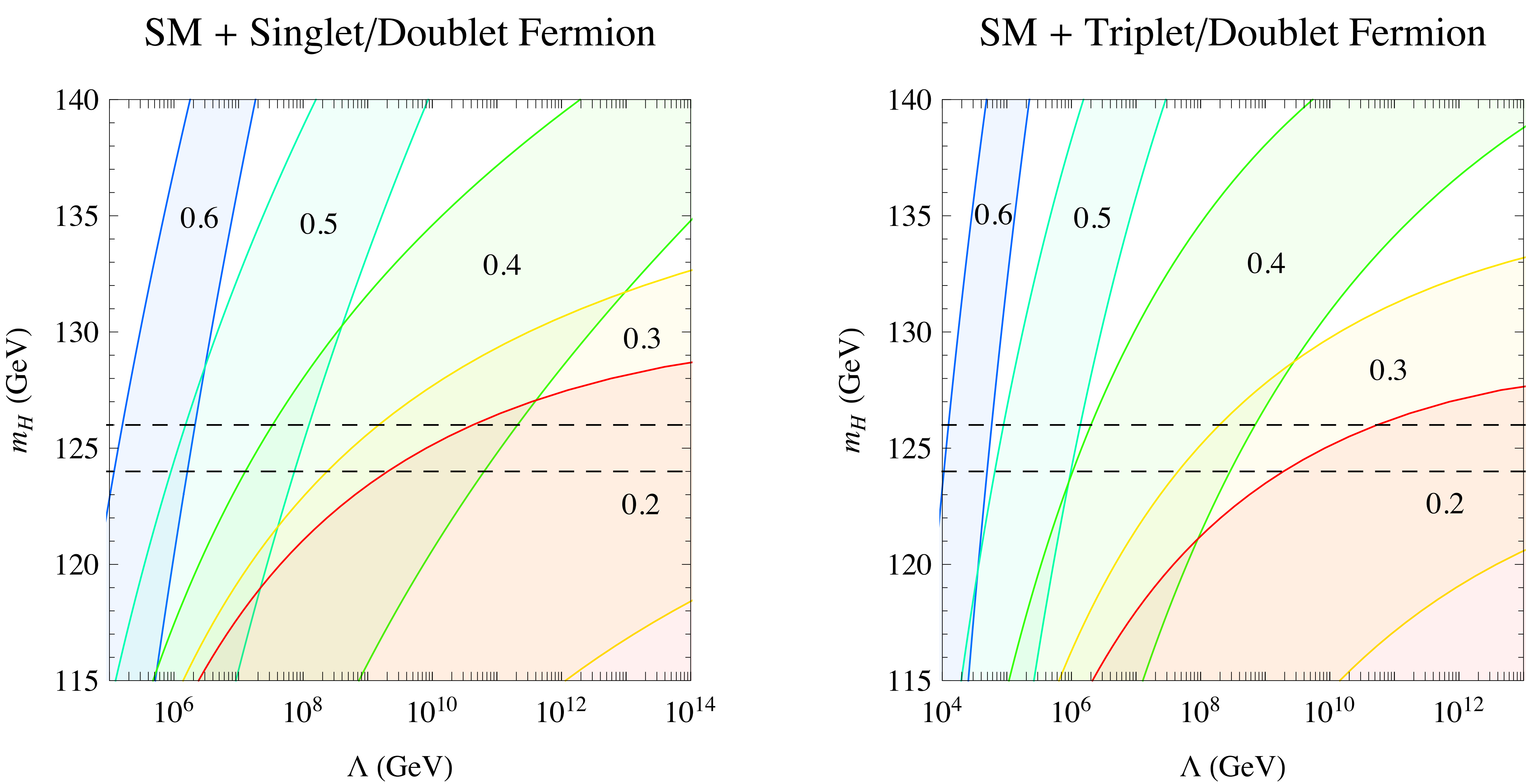
$$\lambda_H \geq 0$$
$$\lambda_S \geq 0$$
$$\kappa_S \geq -2\sqrt{\lambda_H \lambda_S}$$

Perturbativity in all the couplings (:= scale at which RGEs blow up)

$$\begin{aligned} \kappa_S^2 &< 16\pi^2/4, & \lambda_S^2 &< 16\pi^2/36 \\ \kappa_T^2 &< 16\pi^2/4, & \lambda_T^2 &< 16\pi^2/44 \\ \kappa_D^2, \kappa_D'^2 &< 16\pi^2/2, & \lambda_D^2 &< 16\pi^2/12. \end{aligned}$$

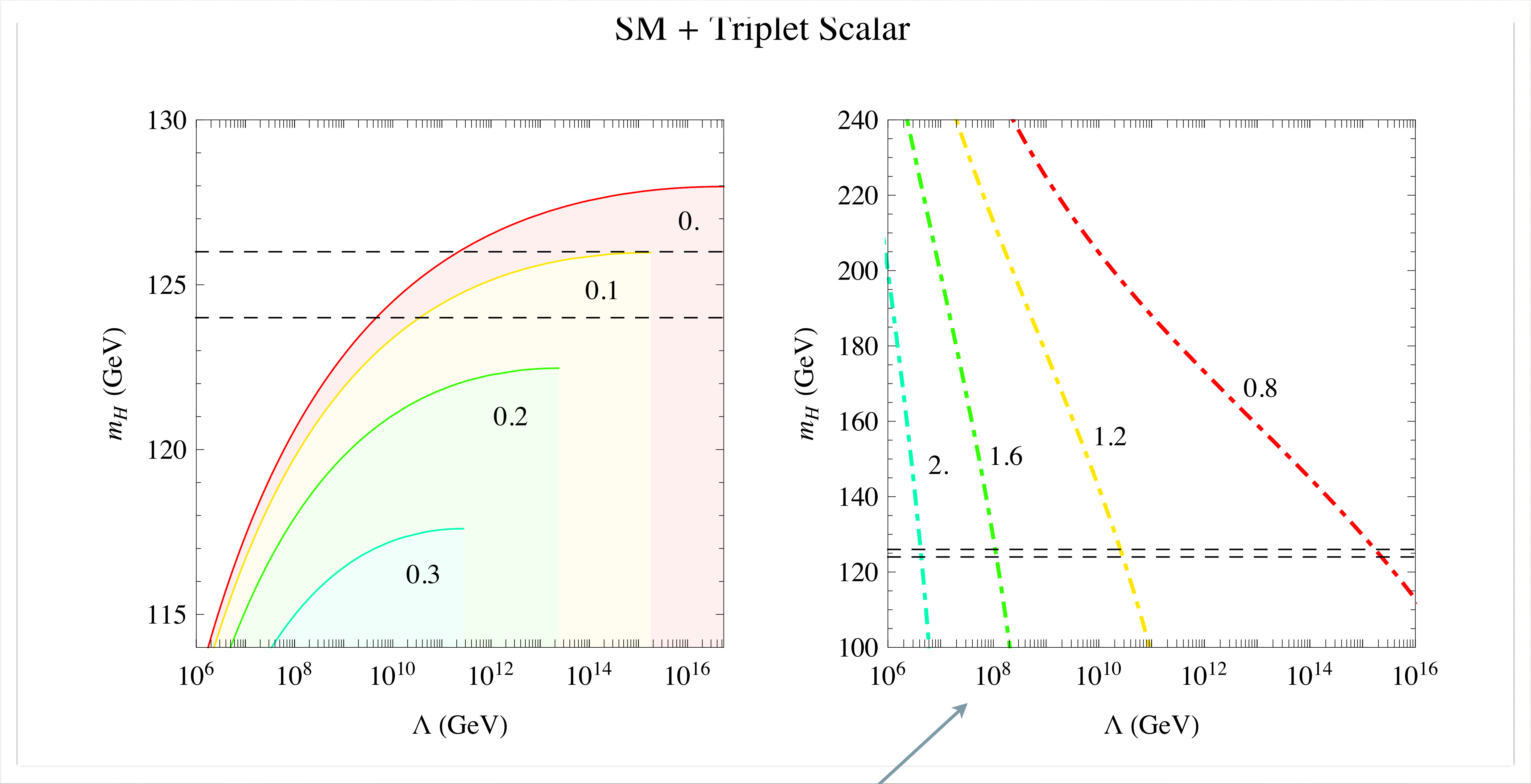
Results

Fermionic DM tend to lower the cutoff scale (acts like the top)



Theoretical uncert' reduced for low cutoffs

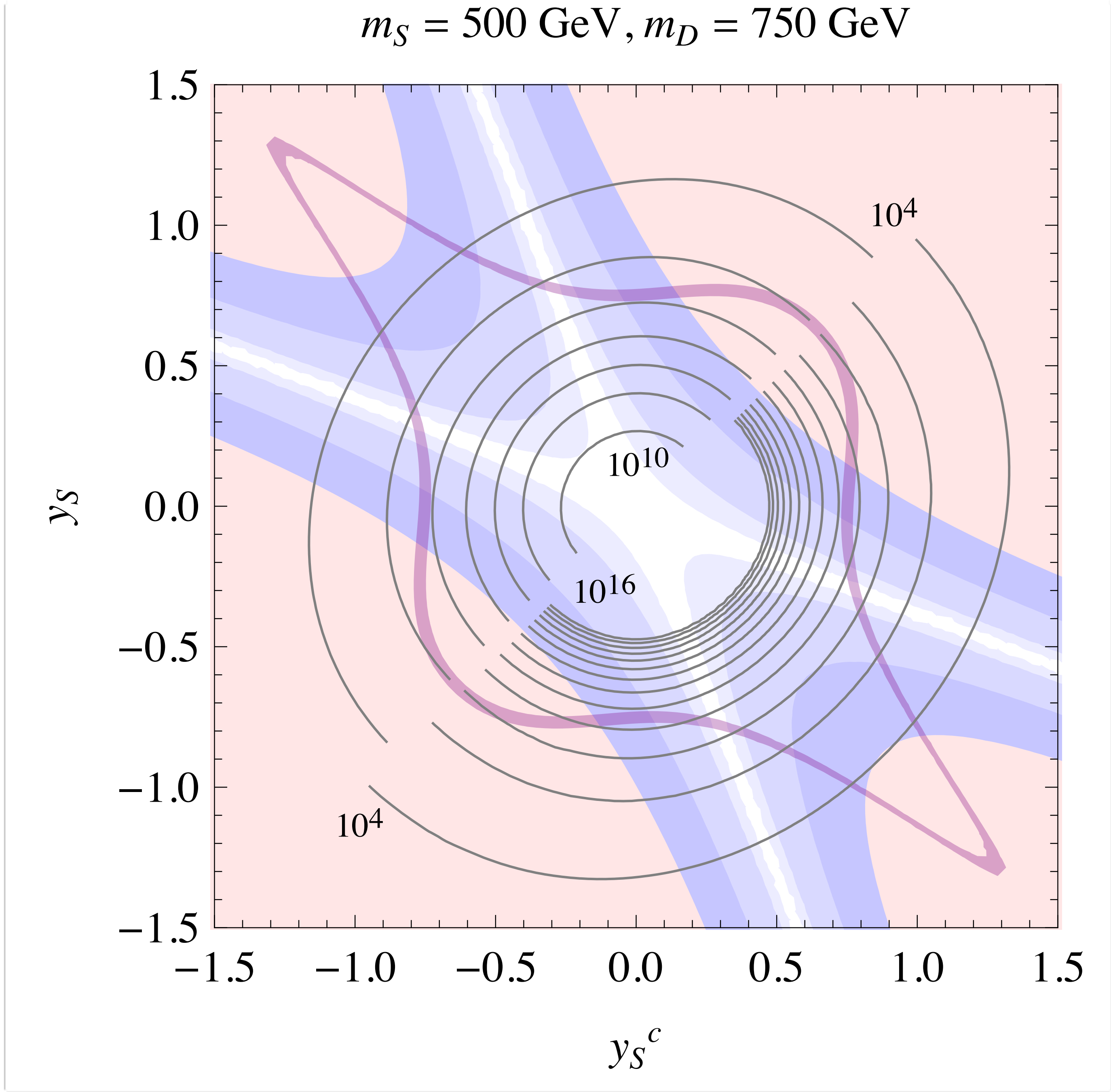
Scalar DM tend to stabilize the Higgs potential

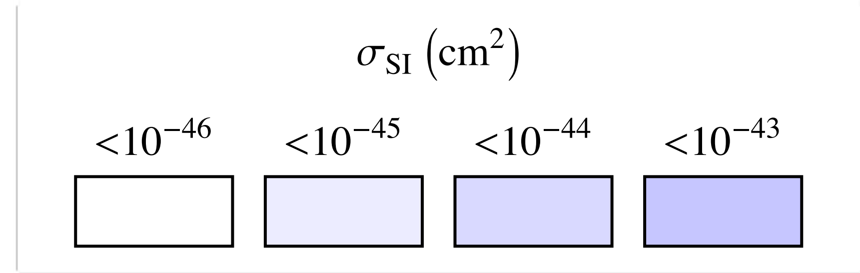


Cutoff may be constrained by perturbativity

Fermionic DM

Full picture:





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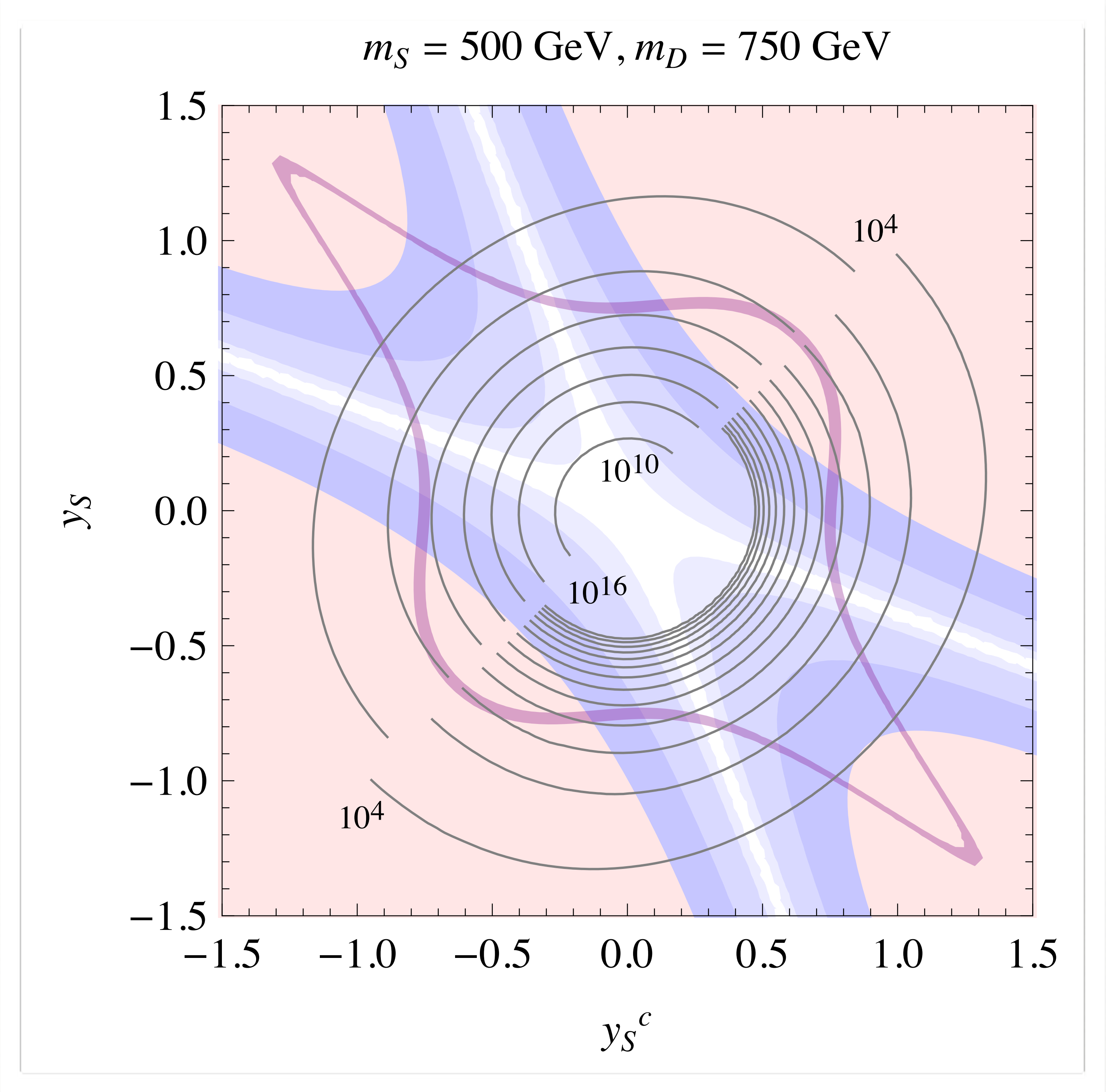
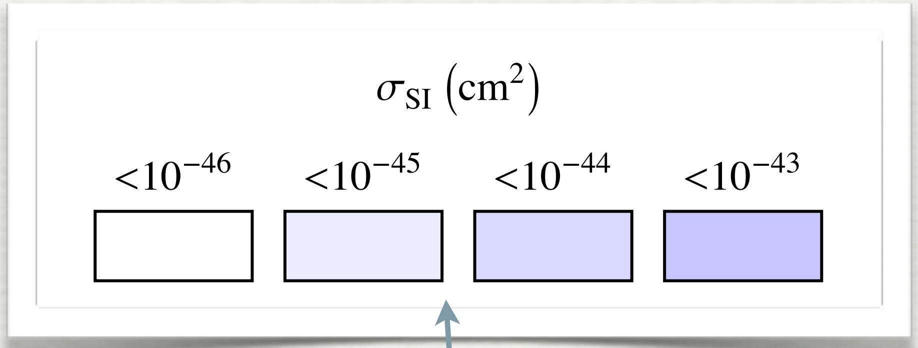
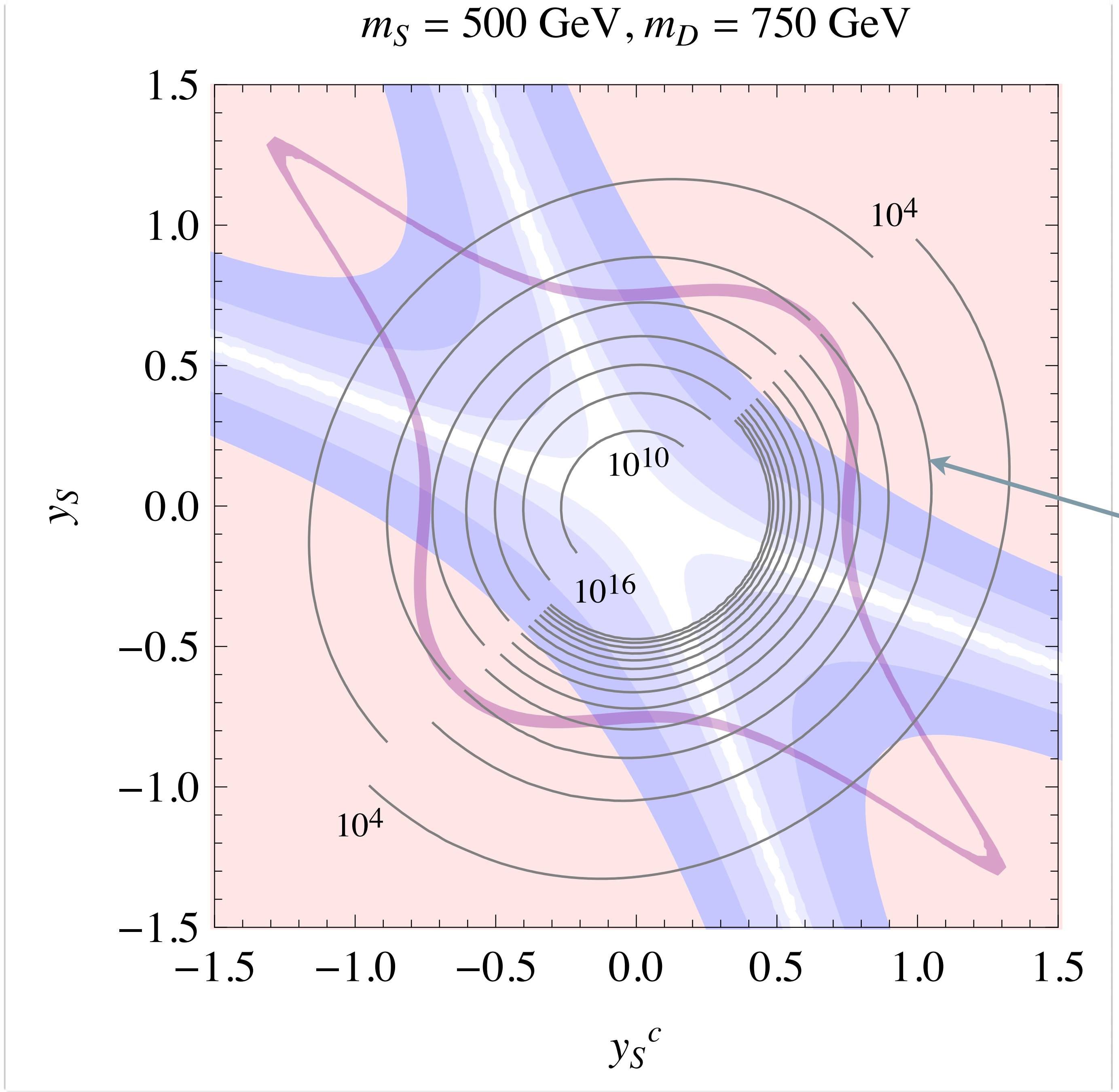
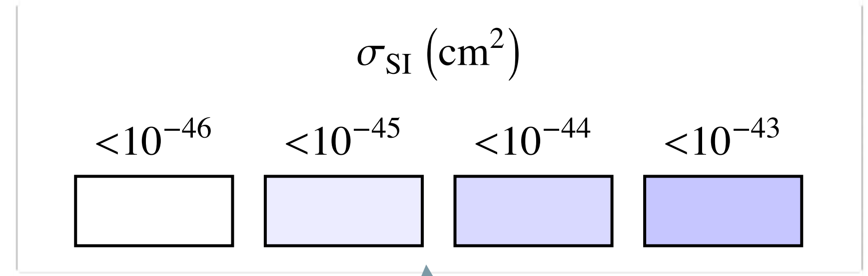




Direct Det’ xsec

Full picture:





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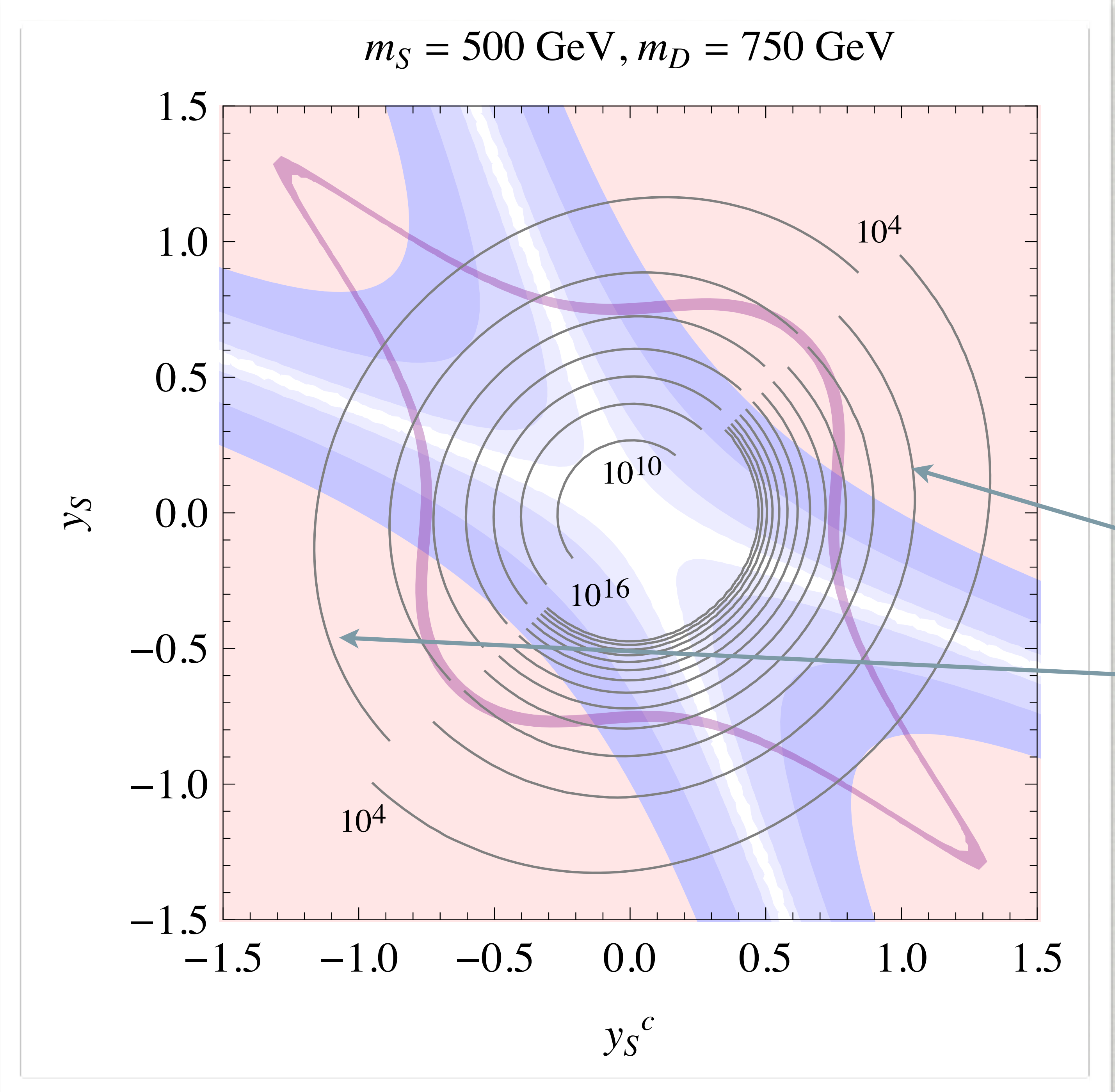
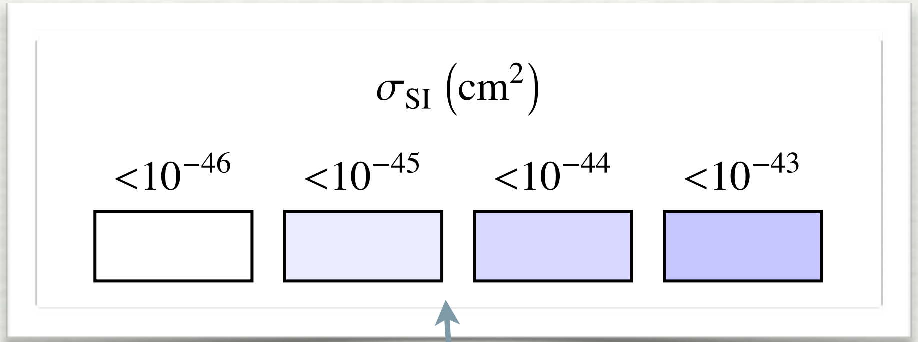
Stability limits

Fermionic DM

Full picture:



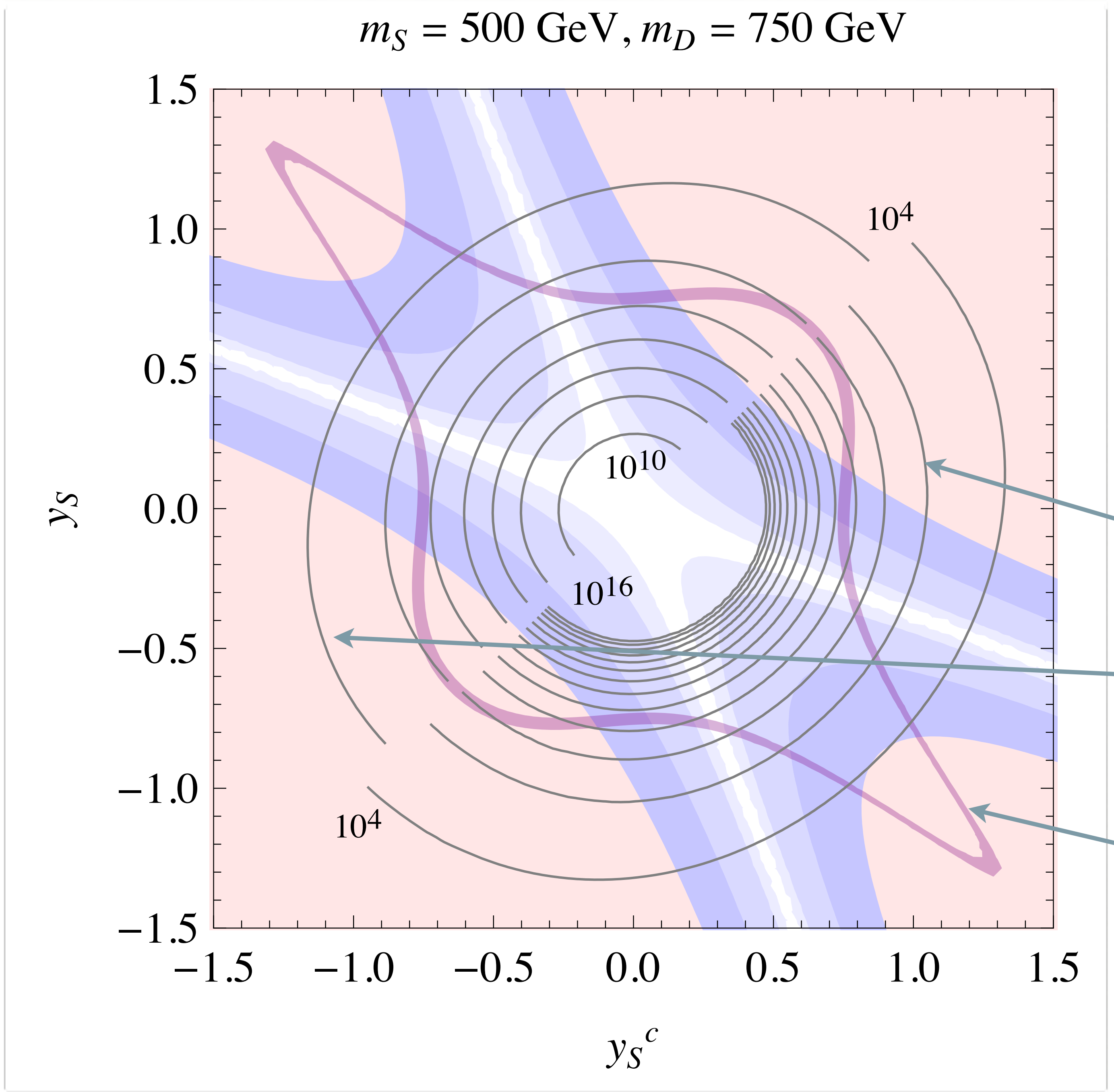


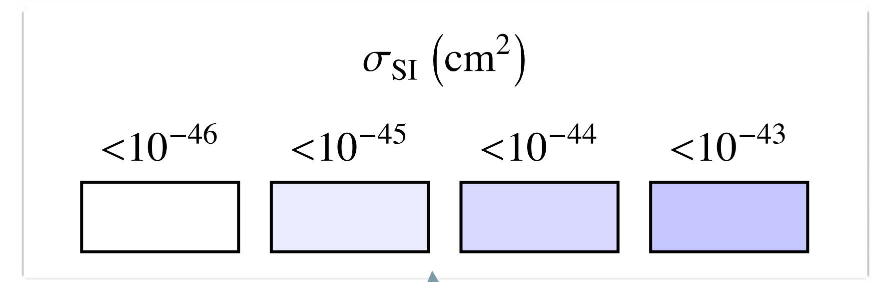
Direct Det' xsec

Stability limits

Metastability limits

Full picture:





Direct Det' xsec

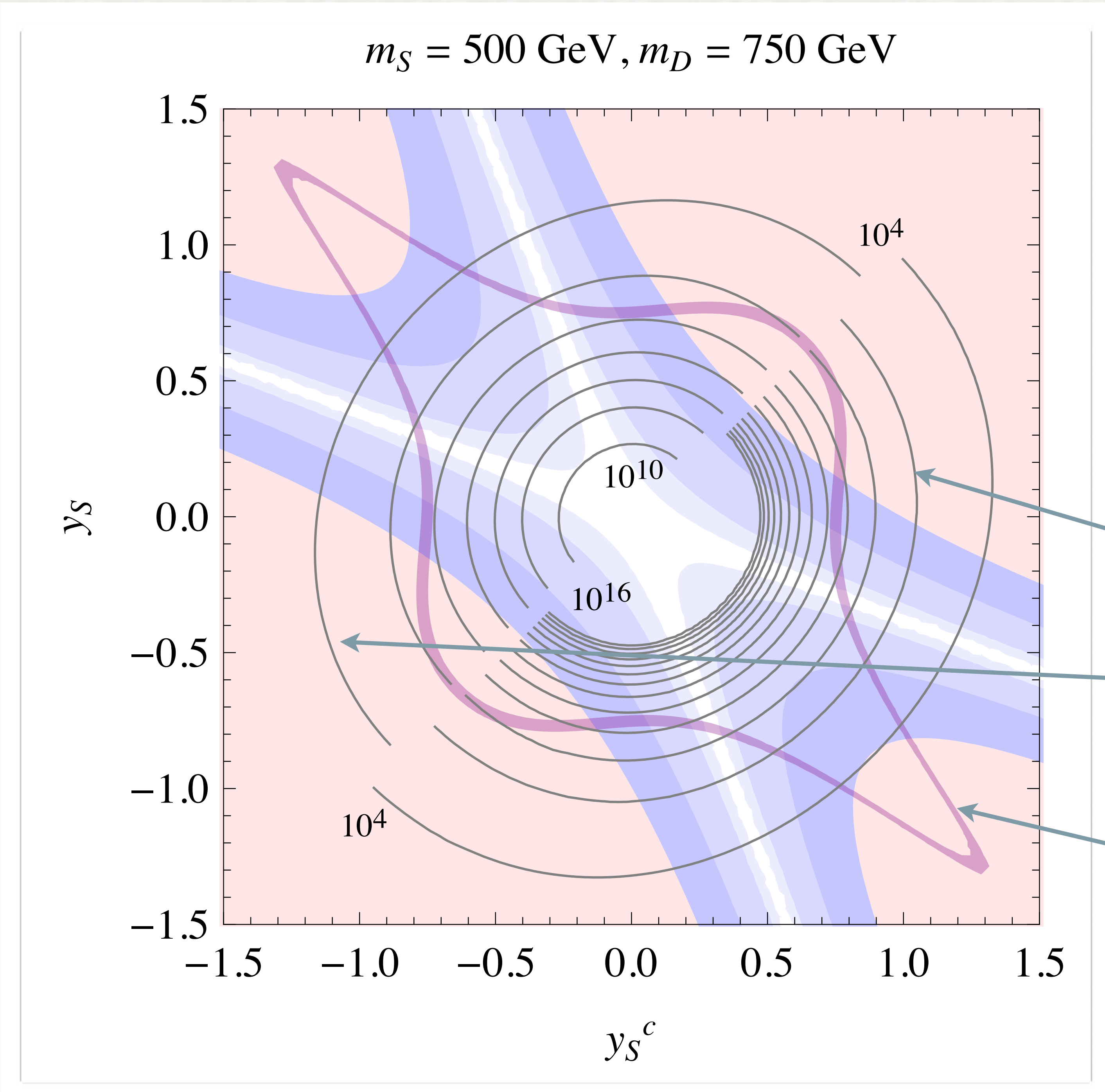
Stability limits

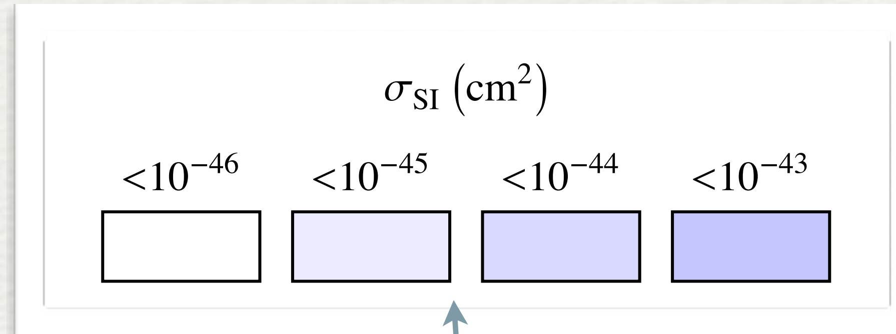
Metastability limits

Relic abundance

Fermionic DM

Full picture:





Direct Det' xsec

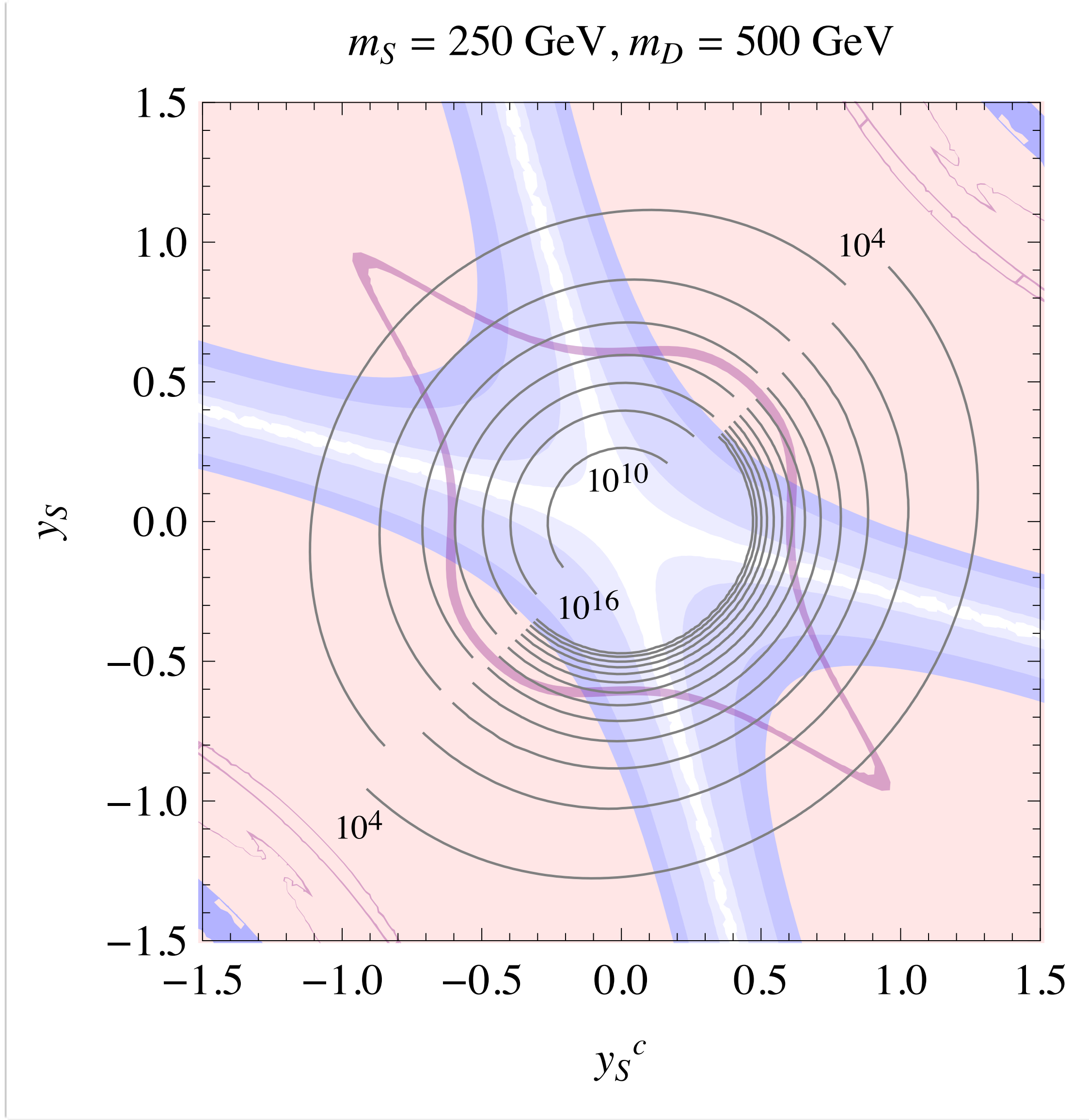
Stability limits

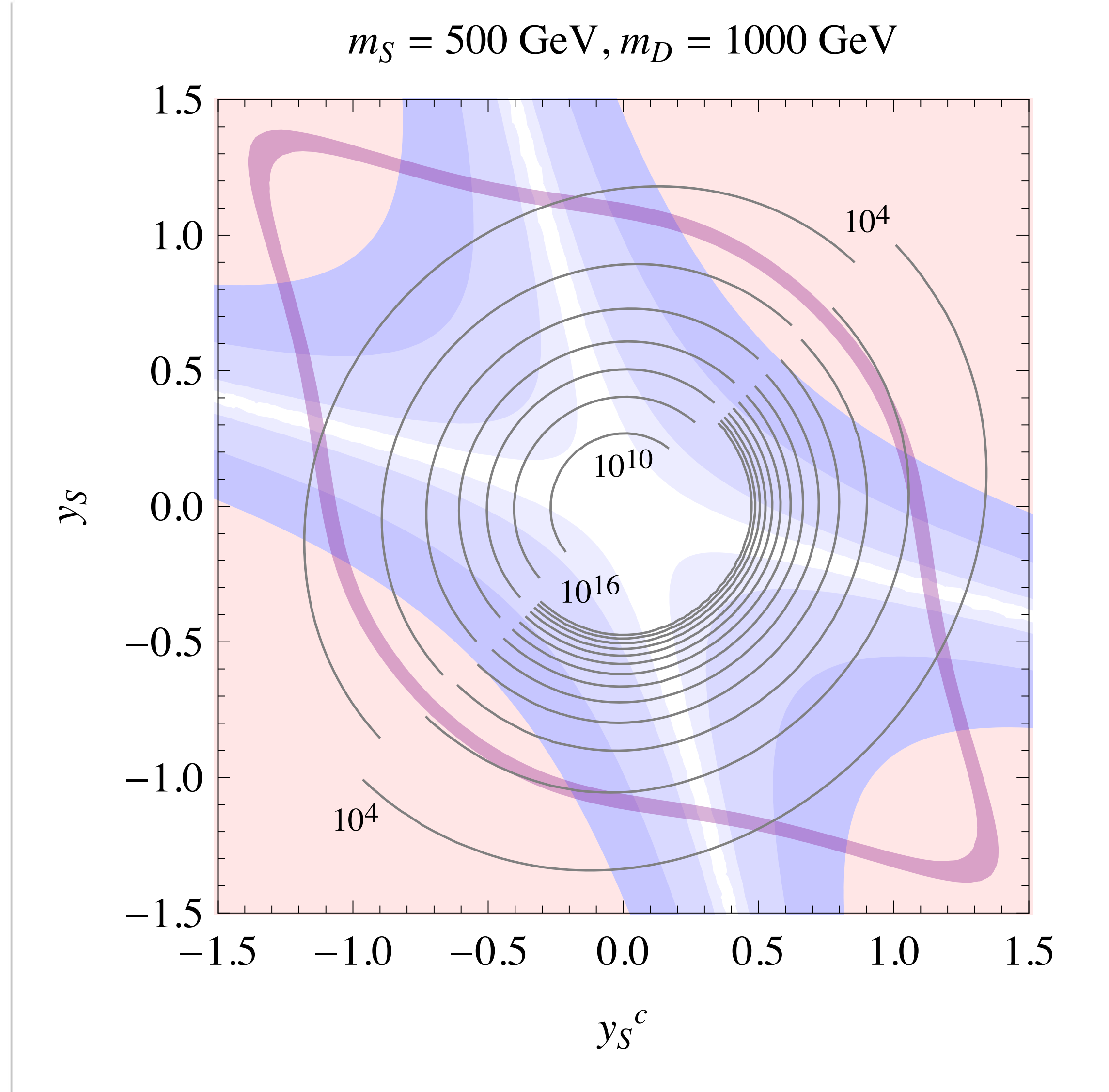
Metastability limits

Relic abundance

- Requirements of relic abundance limit the desert

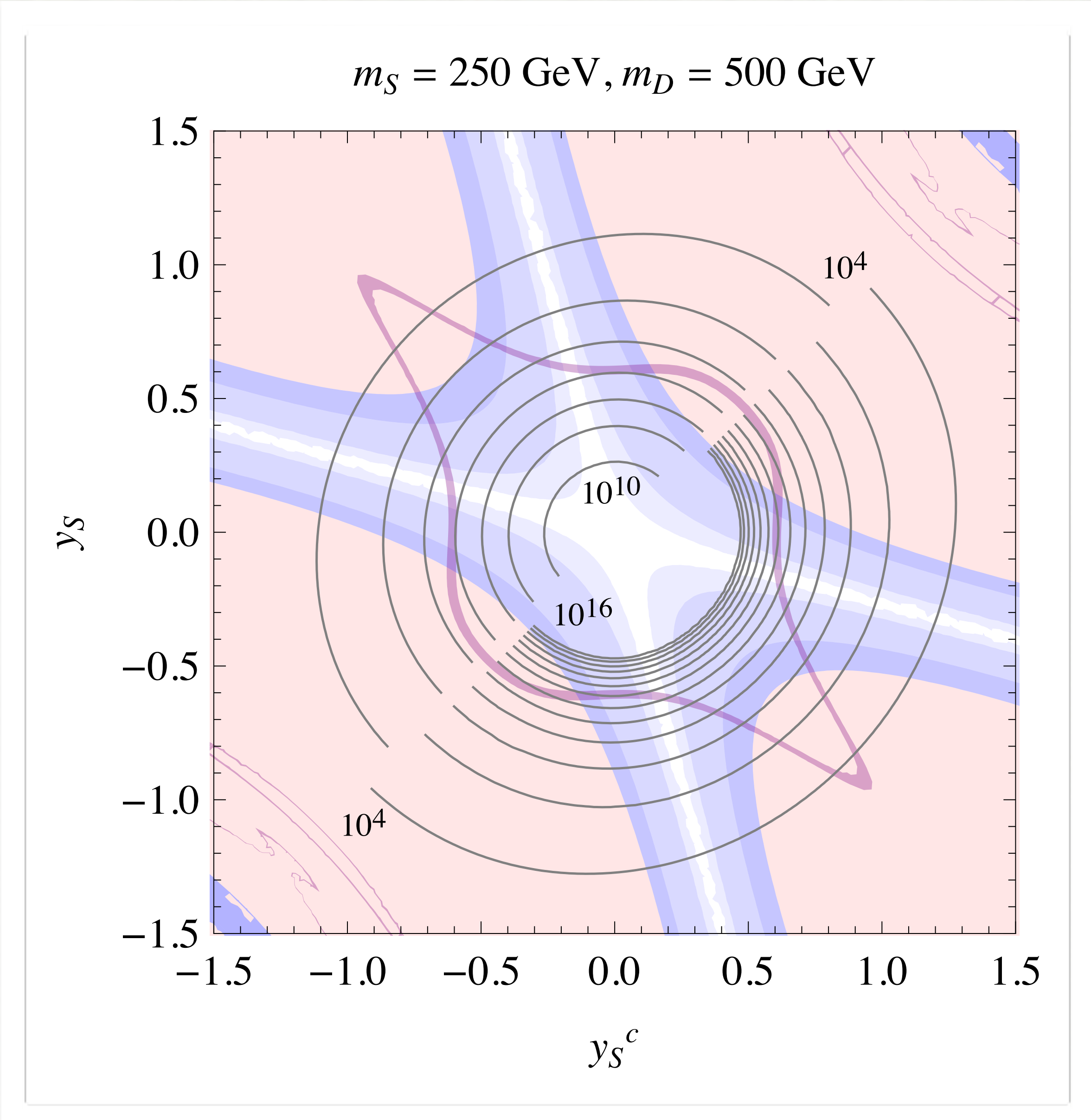
Changing the mass

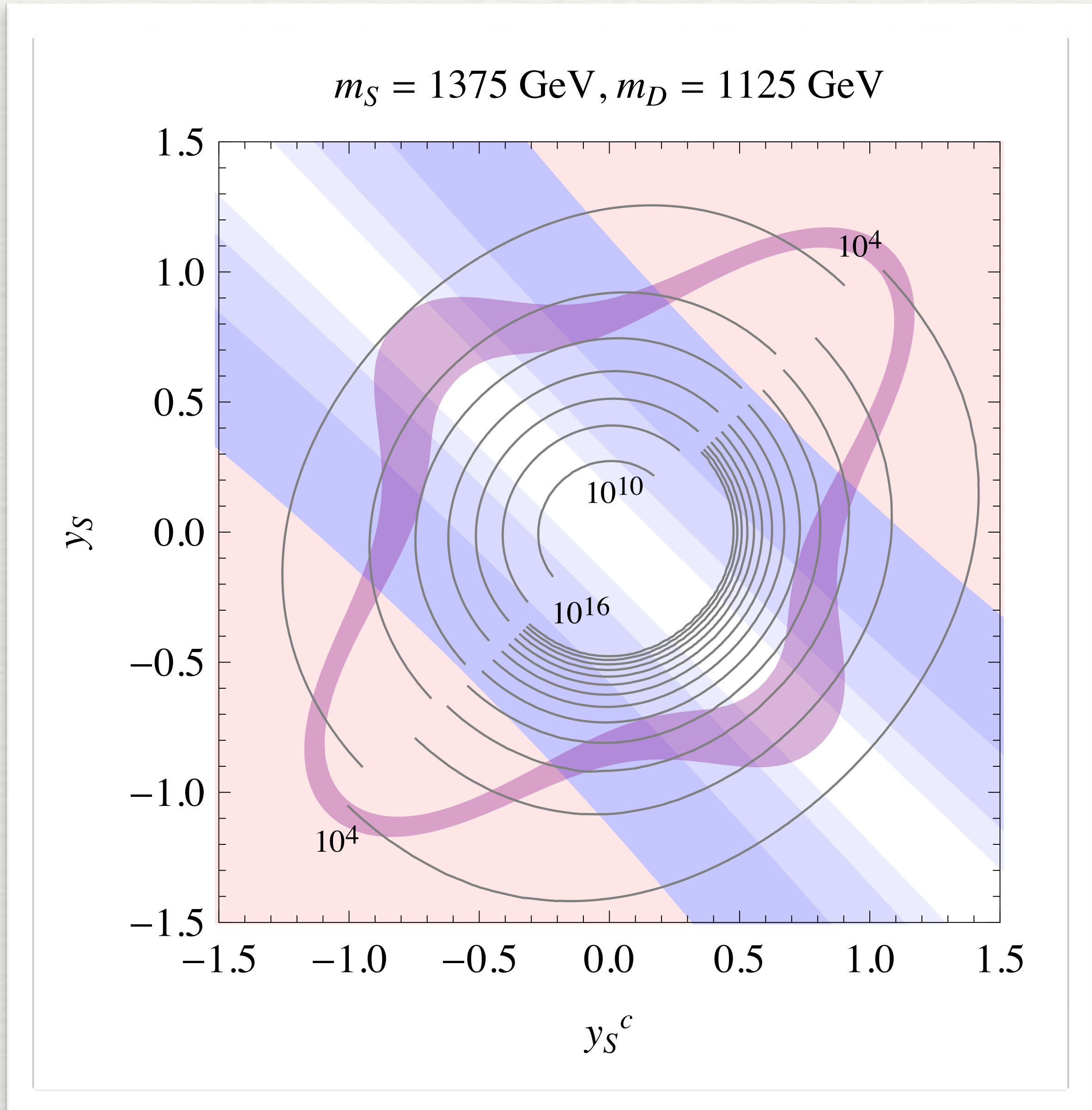




Abundance fixes the couplings → cutoff gets lower for heavier masses

Changing the DM composition





Singlet-like

Doublet-like

Direct detection & the desert

- Dark Matter detection provides an indication of how low additional new physics can be

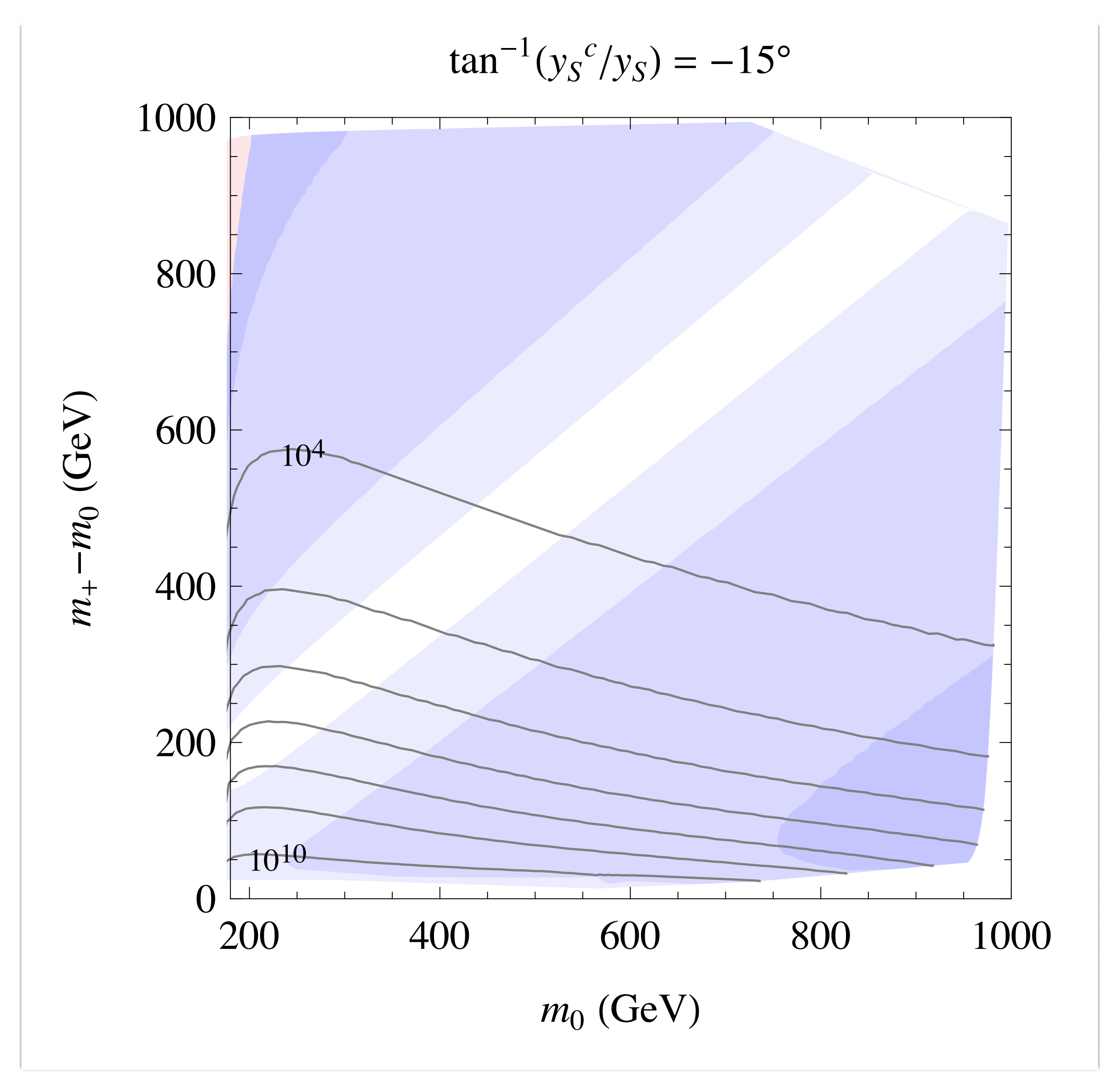
m_S ⟷ Ω_m

m_D ⟷ m_{DM}

y_S ⟷ σ_{SI}

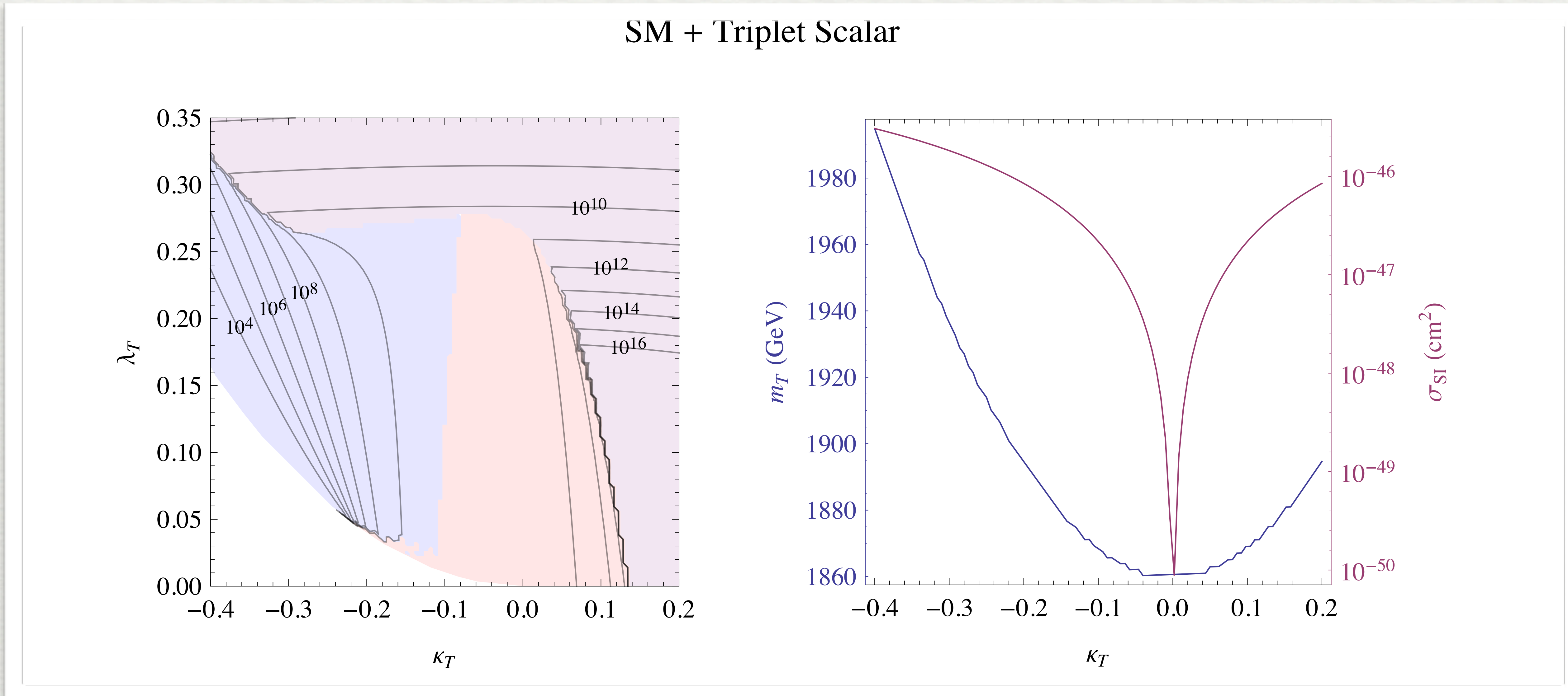
y^c_S ⟷ y^c_S/y_S

...



Scalar DM

- Constraints more complicated:



Λ determined by

Scalar DM

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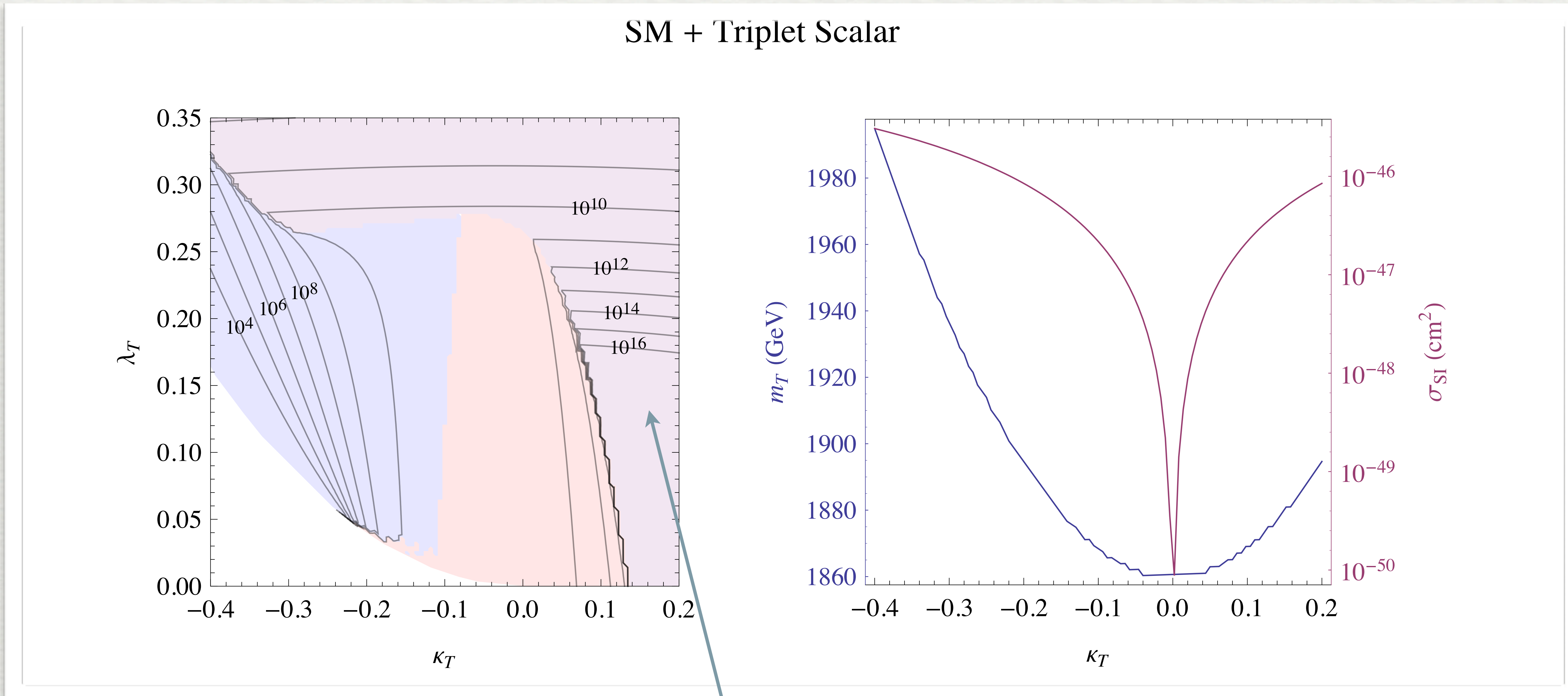

Λ determined by

Non-perturbative

Scalar DM

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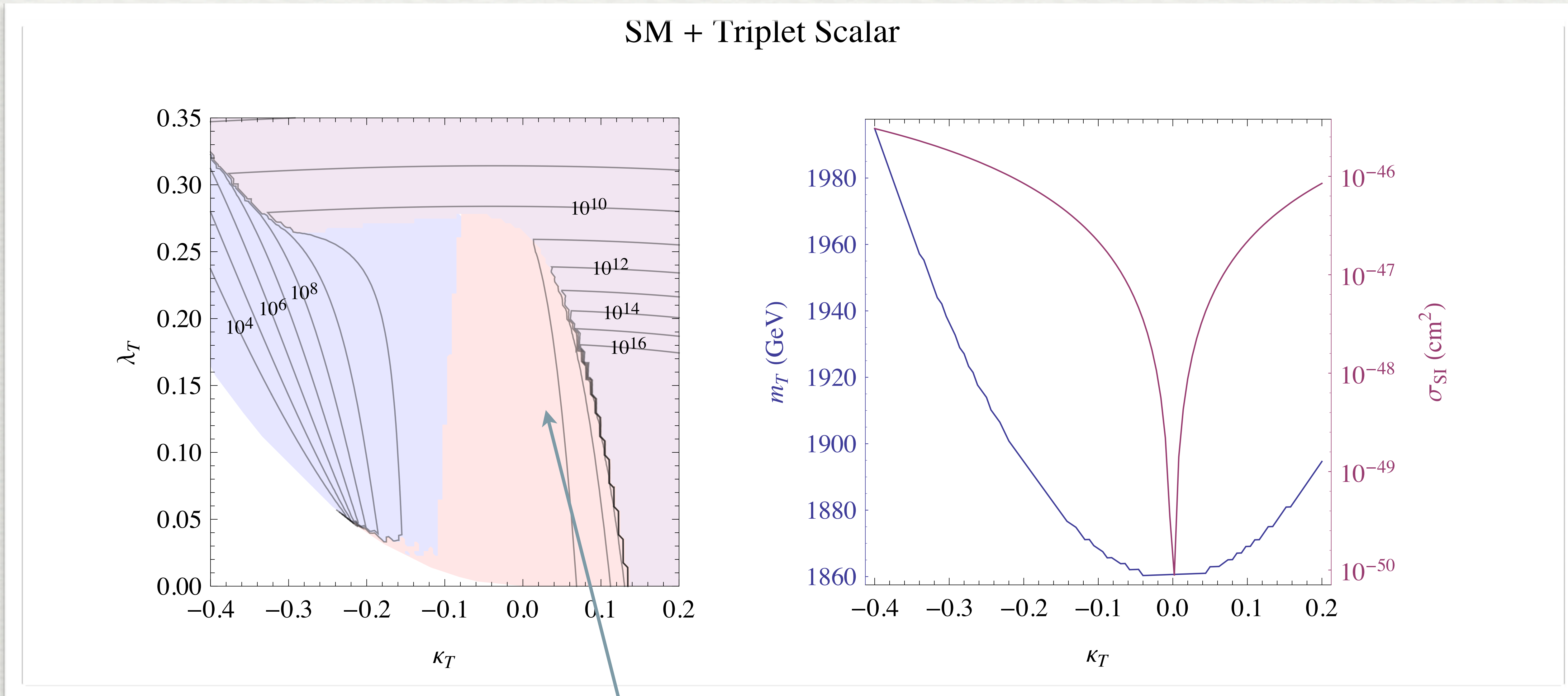

Λ determined by

Metastable along Higgs direction

Scalar DM

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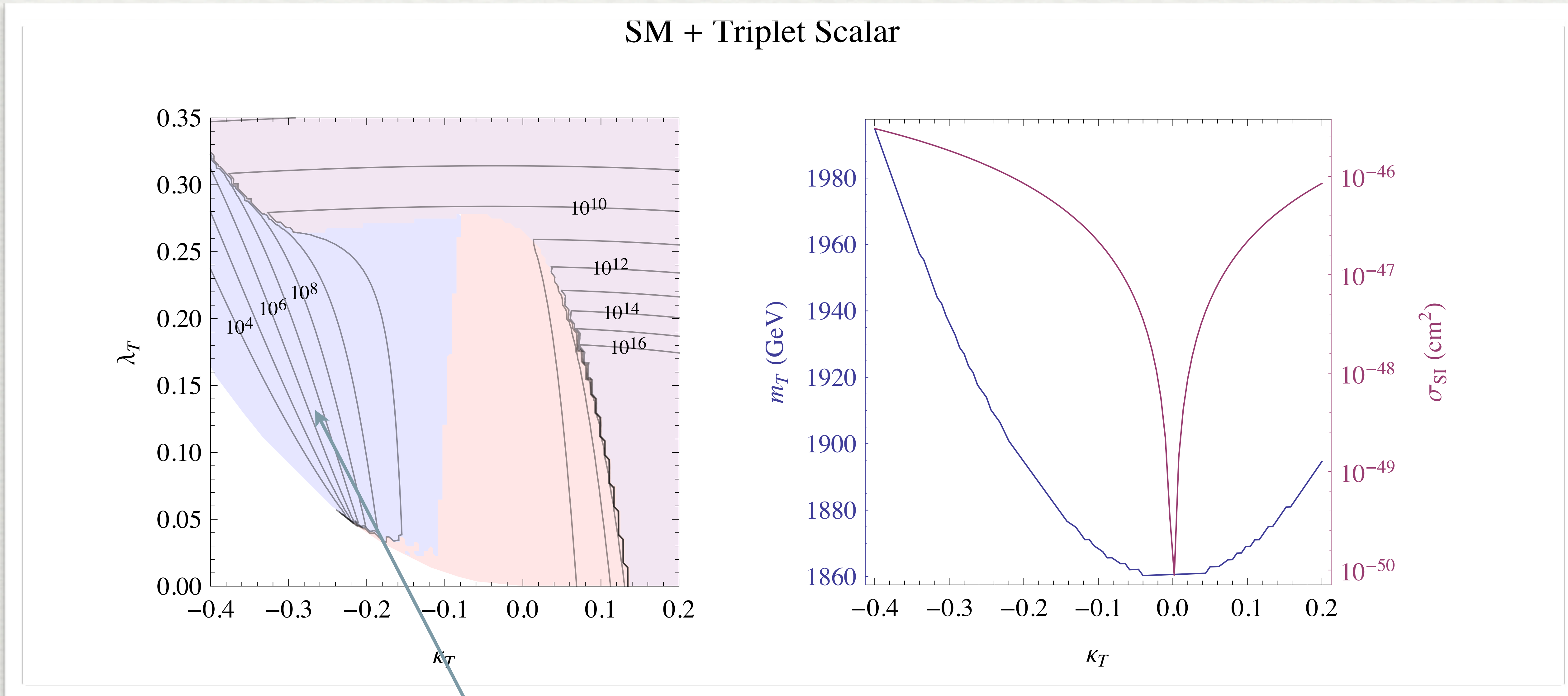

Λ determined by

Metastable along another field direction

Summary

- If a Standard Model-like Higgs and no other sign of new physics is found, the interesting question is how heavy new physics can be
- WIMP DM is a well motivated and appealing extension of the SM
- The presence of WIMP DM coupling to the Higgs modifies the well-known SM answer and in many cases tend to lower the SM cutoff
- Cutoff can be as low as 10-100 TeV
- Low cutoffs easier to be probed
- If SM-like Higgs and WIMP DM only things found, we will have indications of how light other NP must be → presence of “oases” in the energy desert