Prospects and Challenges for Dark Matter Detection

Juri Smirnov
Florence division INFN

Many thanks to: A. Mitridate, M. Redi and A.Strumia

What do we know about DM?

- Gravitative effect
- Clusters in Halos, assuming GR
- If a particle, it must be produced (eg. freeze-out)
- Mediator to the SM needed
- We think: g / γ / W / Z / h/...
- Stability: Z2 or accidental

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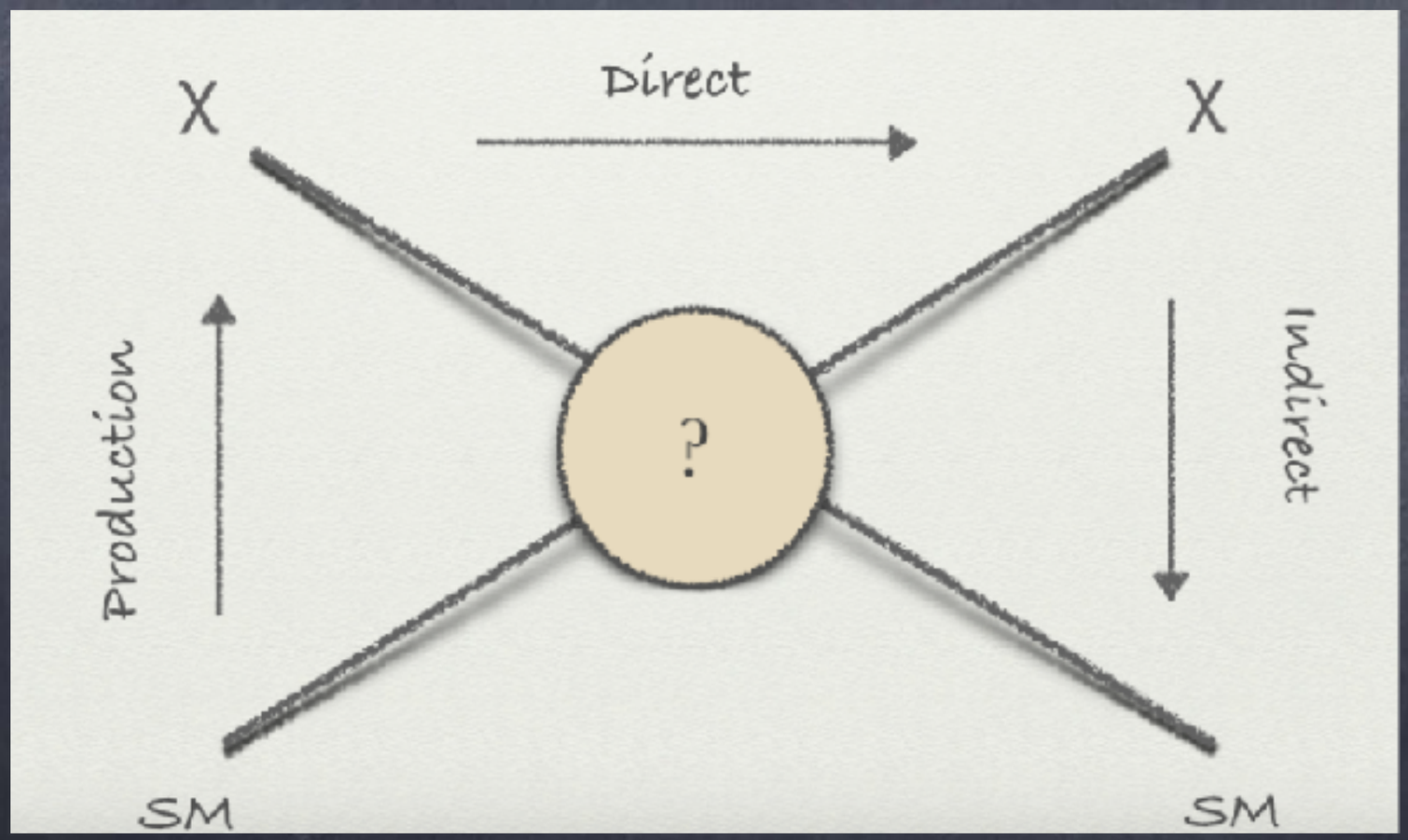
Can we test the thermal hypothesis?

1) $\tau > \tau_{Universe}$
2) What is the mass: M_{DM}?
3) What is the cross section: σ_{SI} ?



Indication of a $\tau > 10^{-8}$ s

1) $\tau > \tau_{Universe}$
2) fit: M_{DM}
3) fit: $\langle\sigma v\rangle$

γ - Rays: Continuos vs. Lines

Can we test the thermal hypothesis?

Degenerate if
$M_{DM} > M_{target}$

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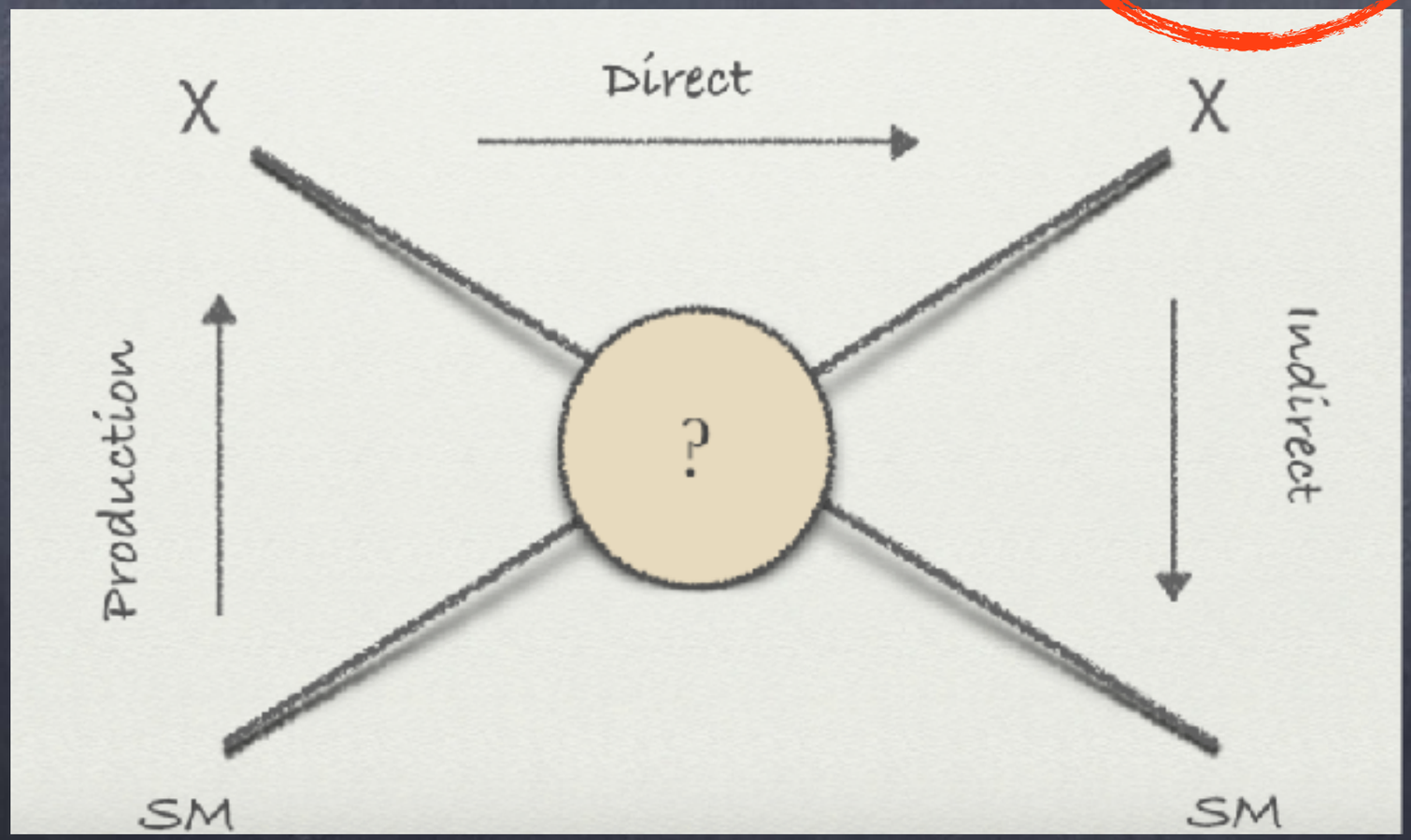

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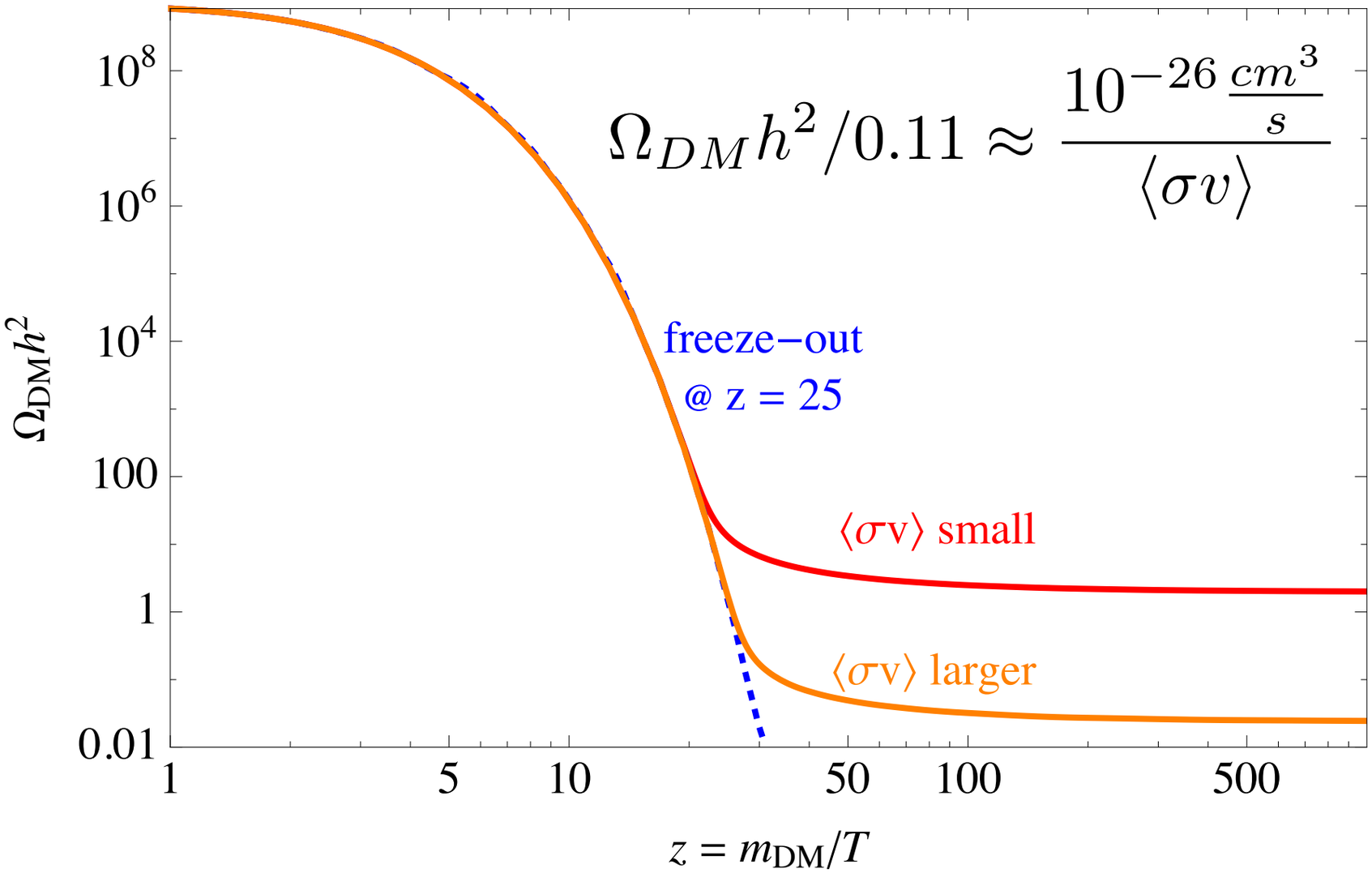
The Thermal Hypothesis



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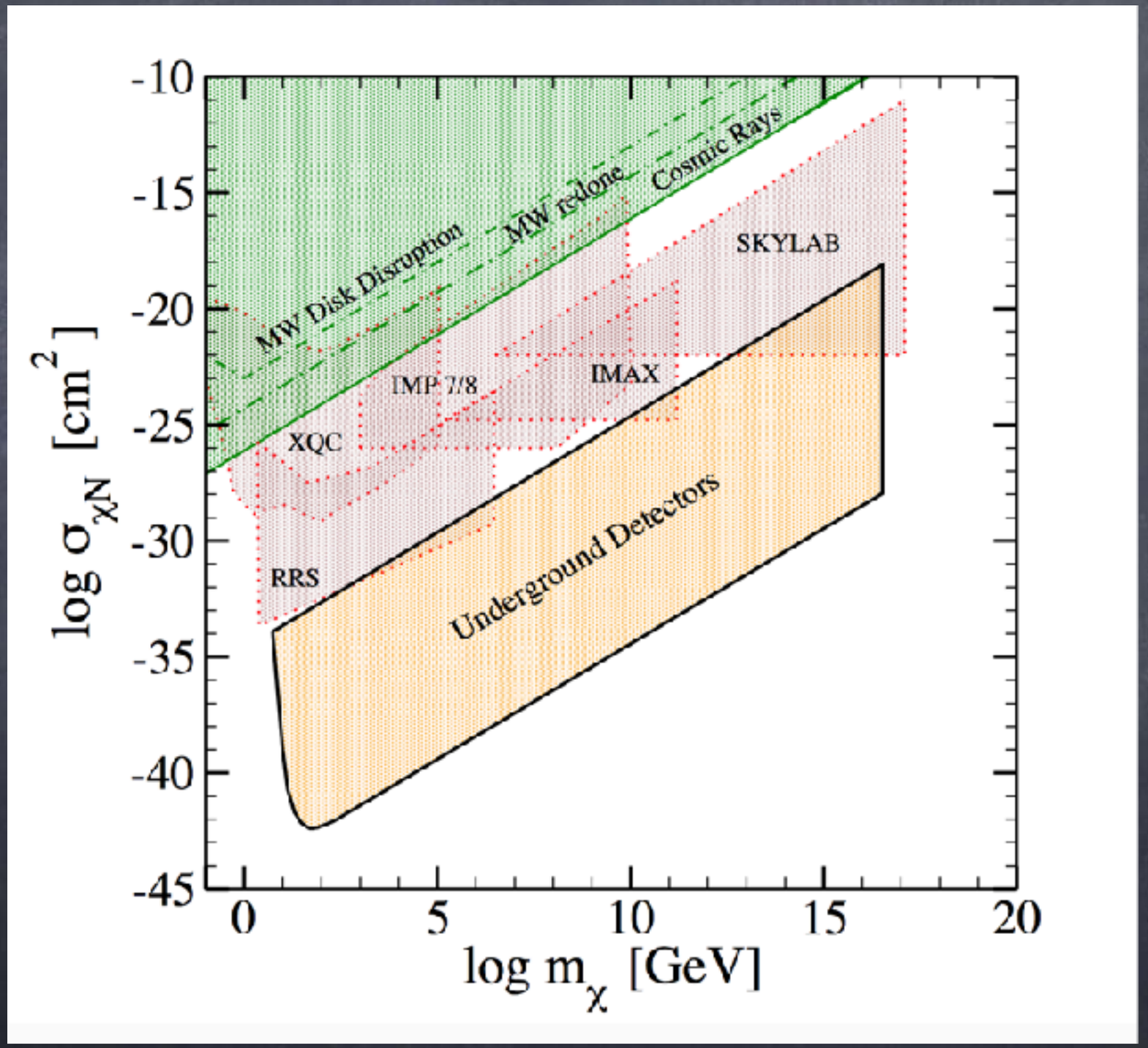

J. Beacom et al. 2007

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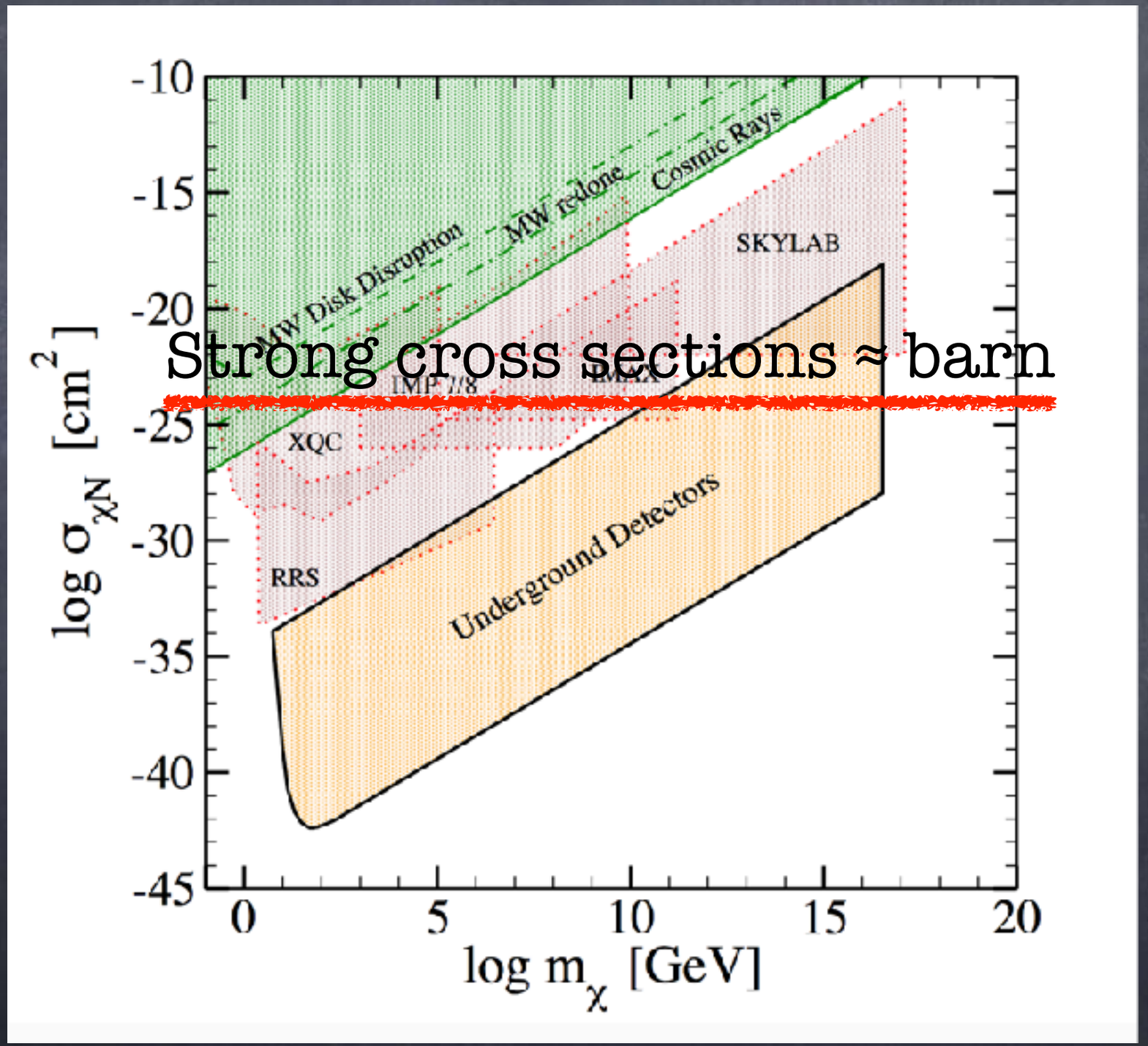

Strong cross sections ≈ barn

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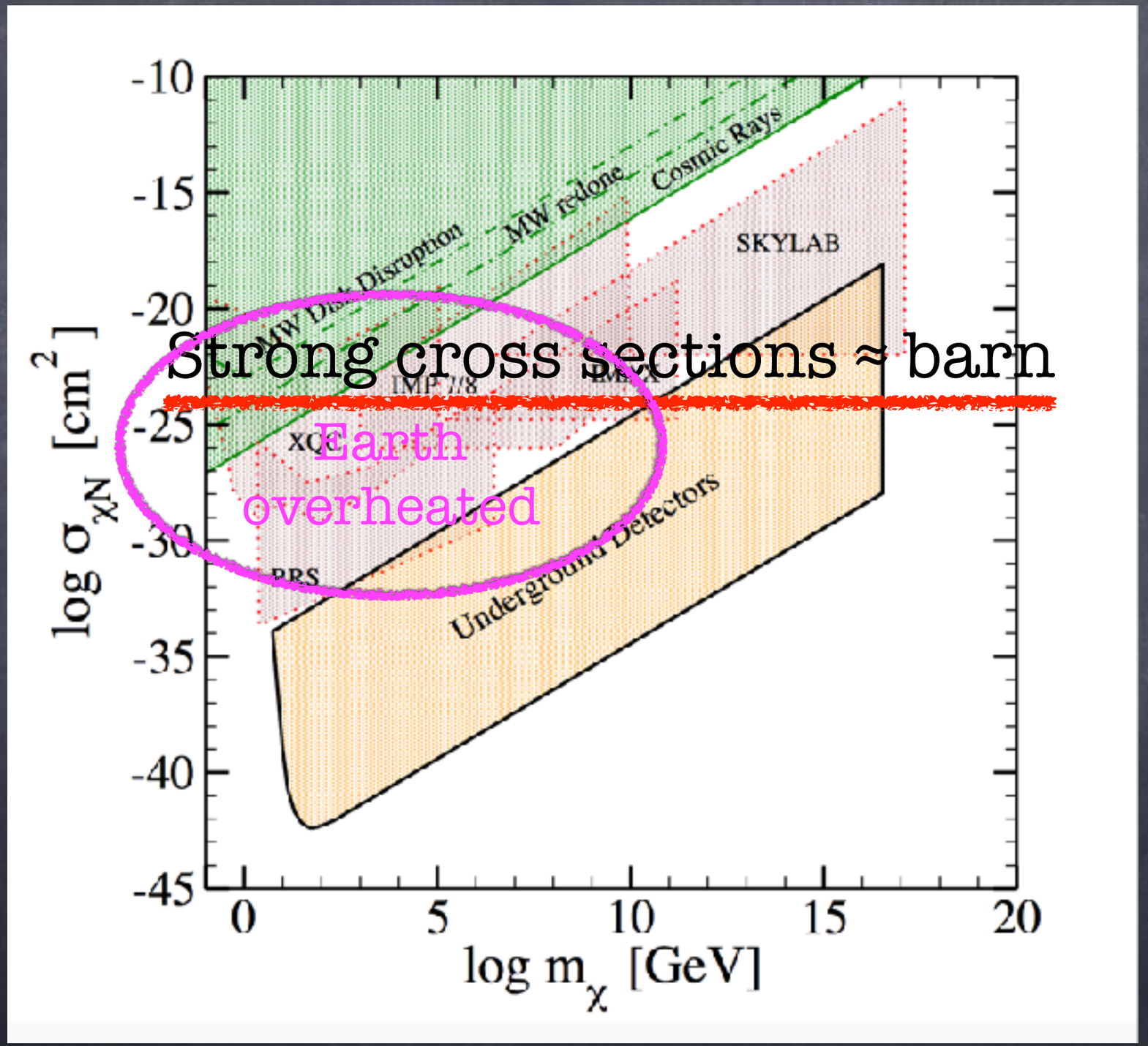

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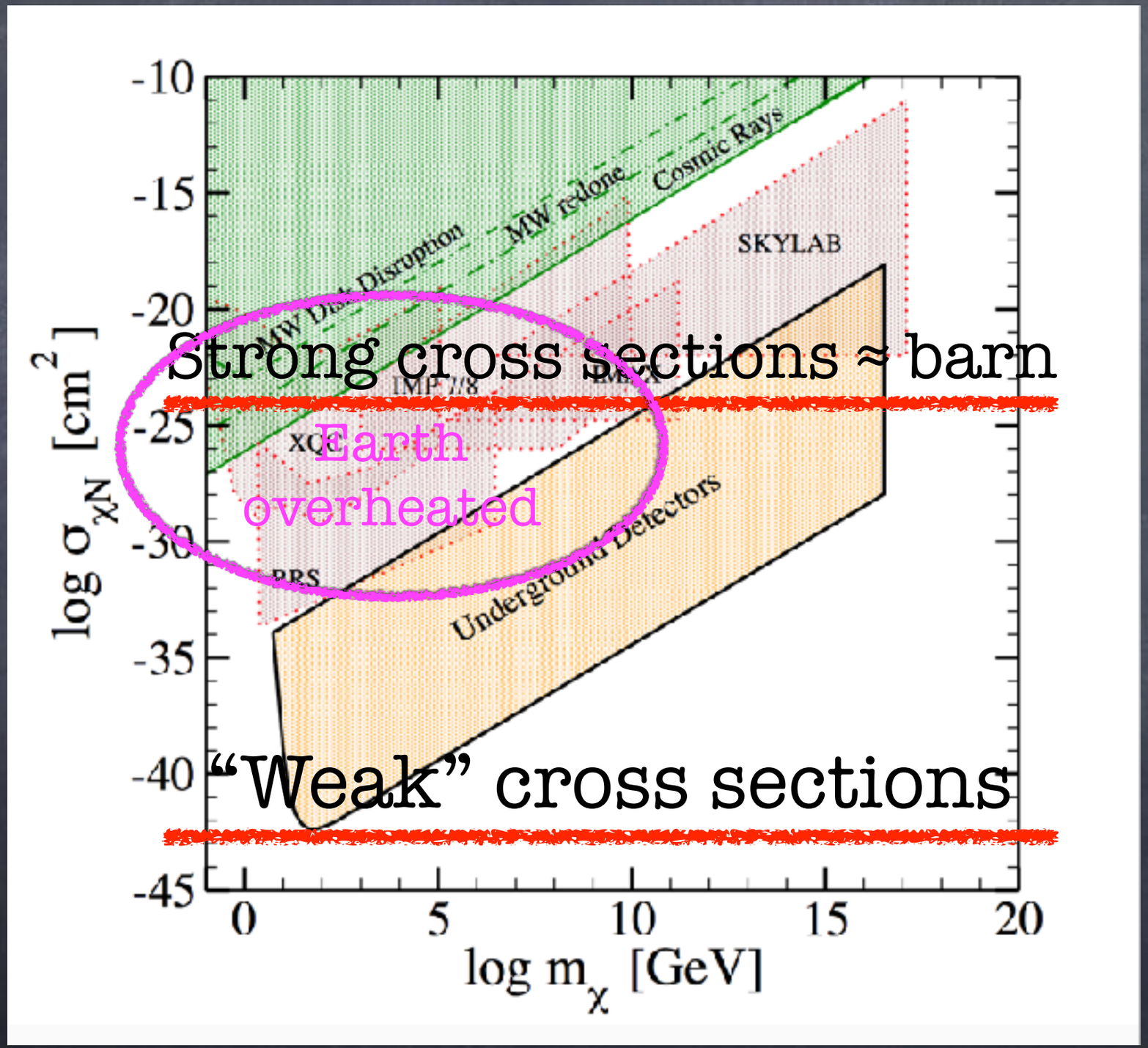

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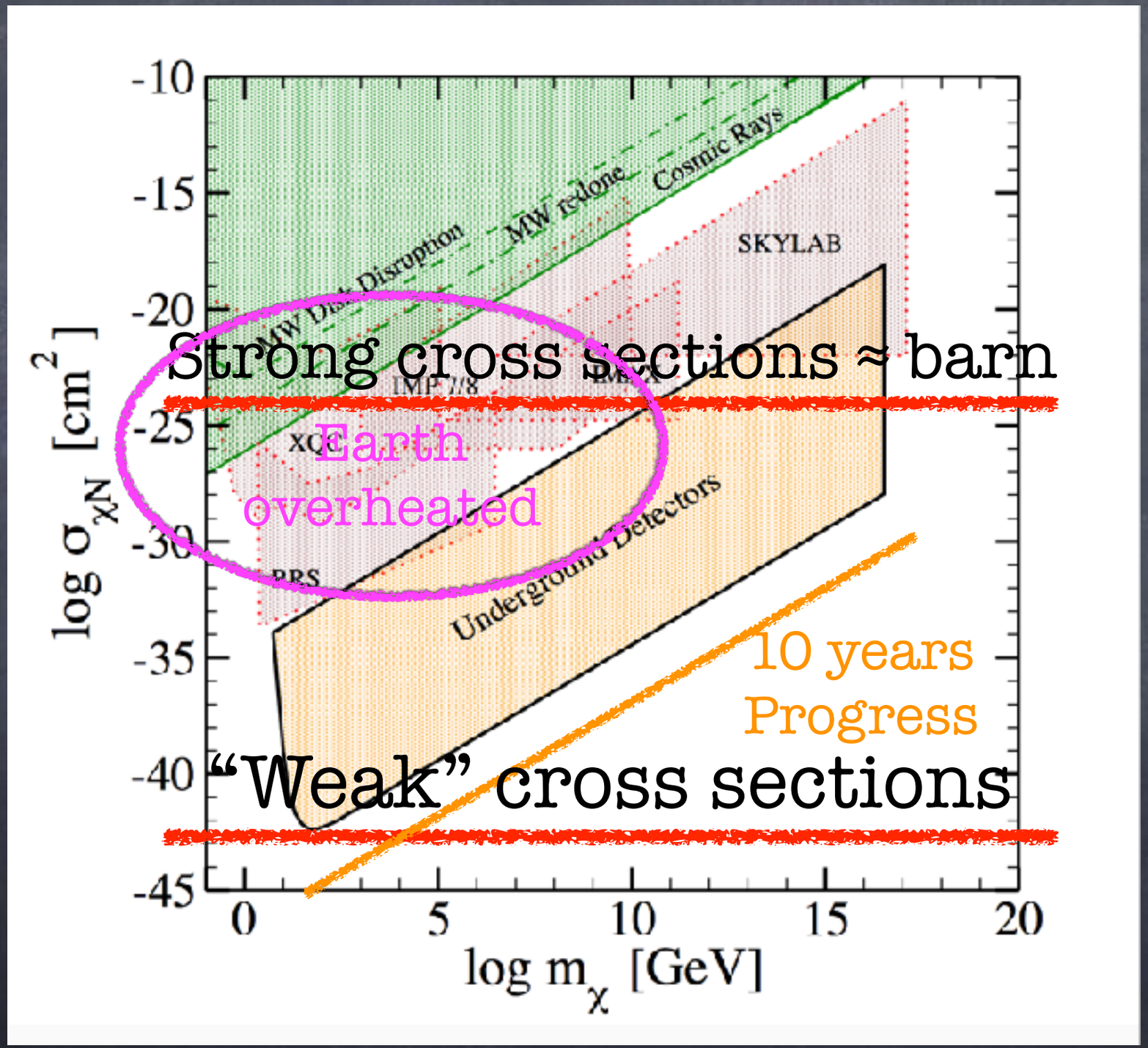

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The Thermal Hypothesis

The annihilation cross section for $\bar{\chi}\chi \rightarrow Z^*_{BL} \rightarrow \bar{f}f$ is given by

$$\sigma(\bar{\chi}\chi \rightarrow Z^*_{BL} \rightarrow f\bar{f}) = \frac{N_c^f (n_{BL}^f)^2 g_{BL}^4 n^2}{12\pi s} \frac{\sqrt{s-4M_f^2}}{\sqrt{s-4M_\chi^2}} \frac{(s+2M_\chi^2)\left(s+2M_f^2\right)}{\left[(s-M_{Z_{BL}}^2)^2 + M_{Z_{BL}}^2 \Gamma_{Z_{BL}}^2\right]}. \quad (14)$$

$$\sigma v = const$$

$$1)\, \sigma v = \frac{\alpha^2}{M_{DM}^2} \text{ if } M_{DM} \gg M_{Z'}$$

$$2)\, \sigma v = \frac{\alpha^2 M_{DM}^2}{M_{Z'}^4} = (G'_F)^2 M_{DM}^2 \text{ if } M_{DM} \ll M_{Z'}$$

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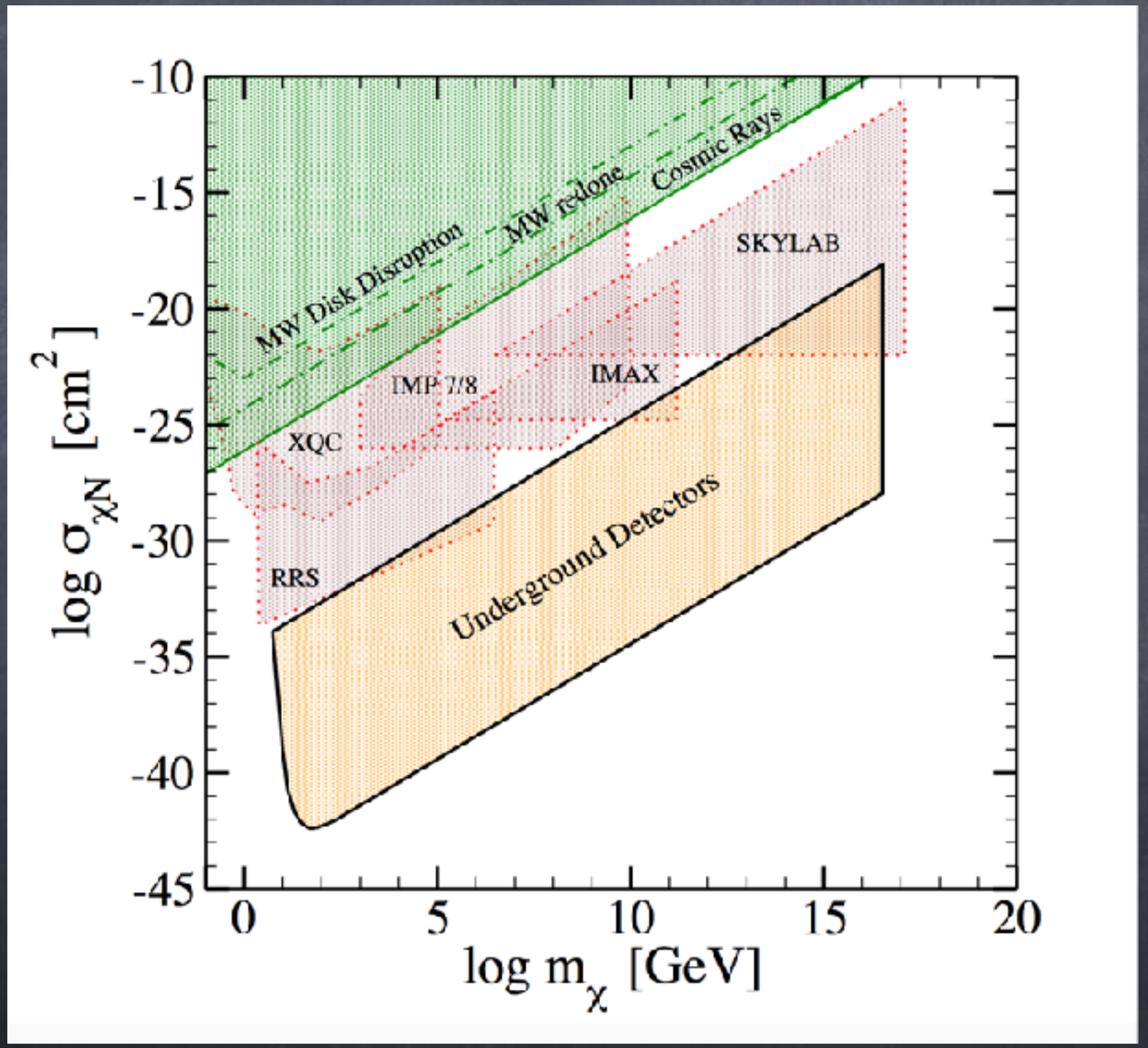
$$G_F^2\,(\text{few } GeV)^2 \approx 10^{-26}\text{cm}^3/s\, 1/c$$

WIMP Miracle?



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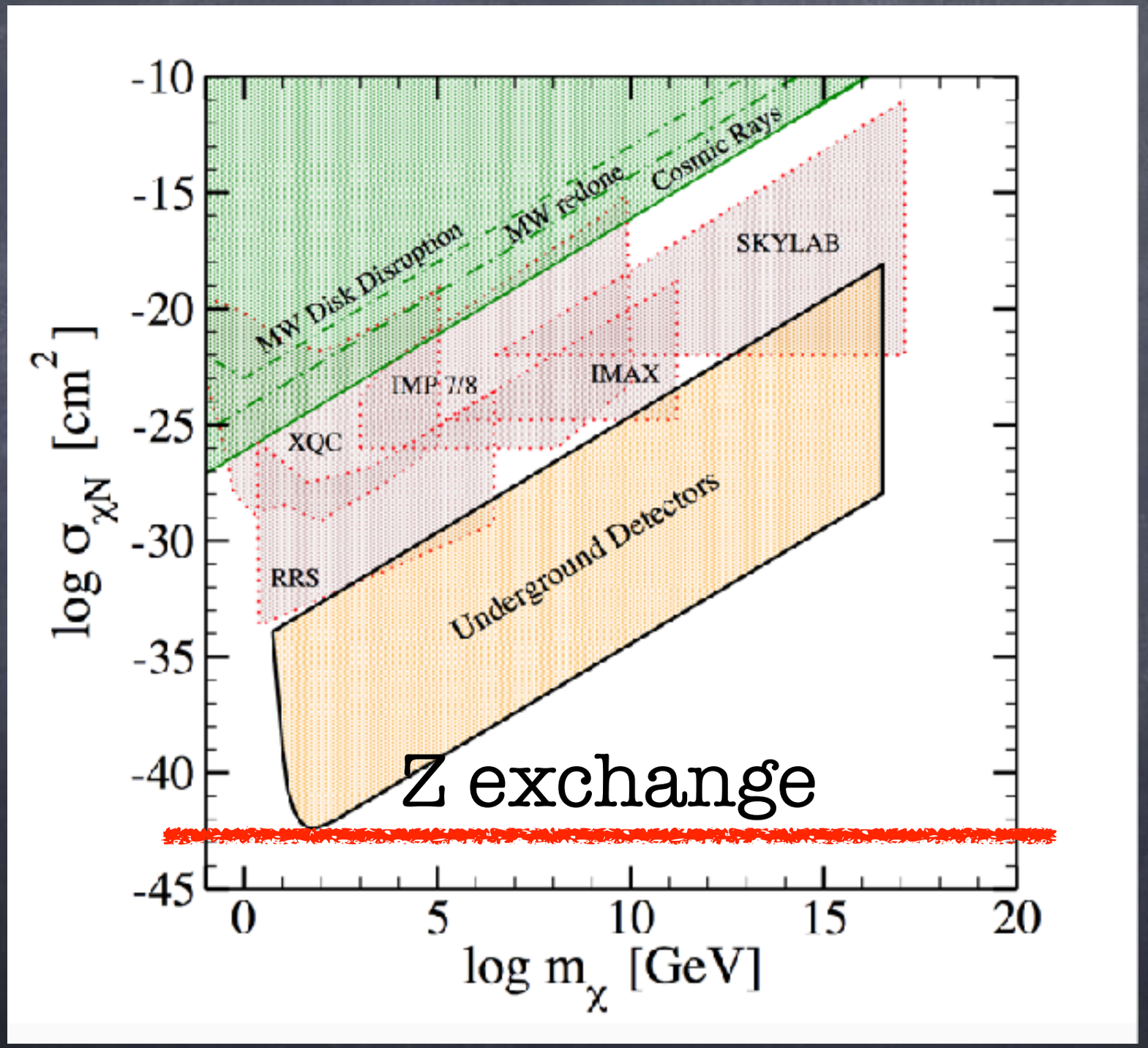

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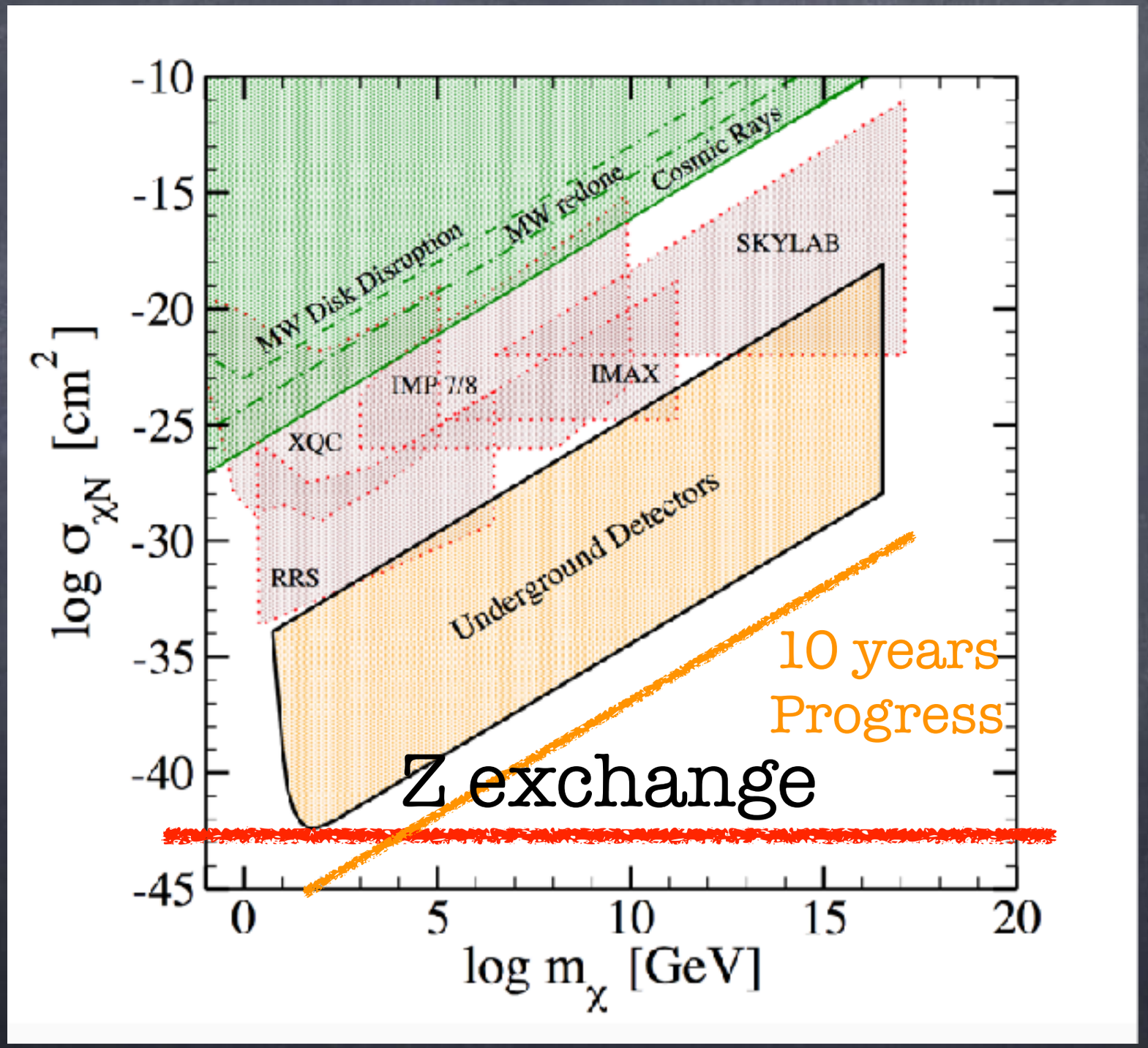

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Weak

Dark Matter: The Gauge Portal

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The Gauge Portal
(single parameter models)

Quantum numbers $SU(2)_L$	$U(1)_Y$	Spin	DM can decay into	DD bound?	Stable?
2	1/2	S	EL	×	×
2	1/2	F	EH	×	×
3	0	S	HH^*	√	×
3	0	F	LH	√	×
3	1	S	HH, LL	×	×
3	1	F	LH	×	×
4	1/2	S	HHH^*	×	×
4	1/2	F	(LHH^*)	×	×
4	3/2	S	HHH	×	×
4	3/2	F	(LHH)	×	×
5	0	S	(HHH^*H^*)	√	×
5	0	F	–	√	√
5	1	S	$(HH^*H^*H^*)$	×	×
5	1	F	–	×	√
5	2	S	$(H^*H^*H^*H^*)$	×	×
5	2	F	–	×	√
6	1/2, 3/2, 5/2	S	–	×	√
7	0	S	–	√	√
8	1/2, 3/2 ...	S	–	×	√

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5	2	S	$(H^*H^*H^*H^*)$	×	×
5	2	F	–	×	√
6	1/2, 3/2, 5/2	S	–	×	√
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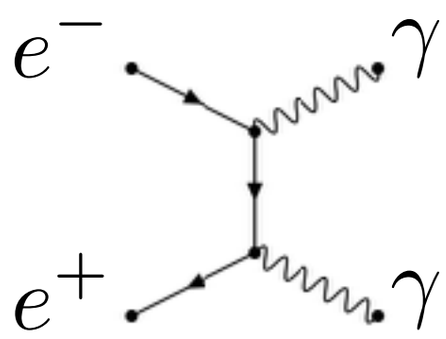
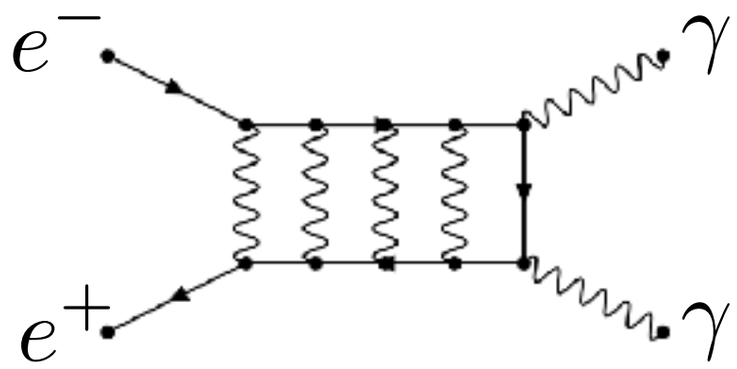
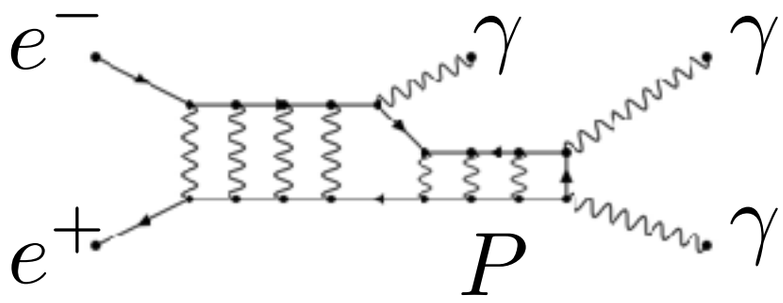
Process	Diagram	Cross-Section area	
I) $e^+ e^- \to \gamma\gamma$			
II) $e^+ e^- \to P^* \to \gamma\gamma$			
III) $e^+ e^- \to P^* \to P\,\gamma$ $P \to \gamma\gamma$			

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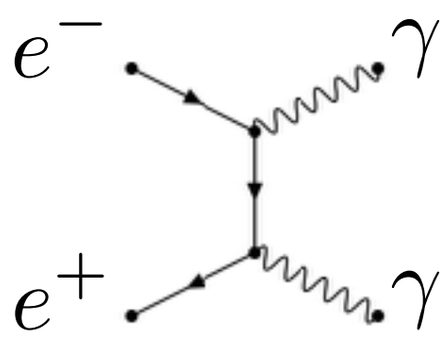
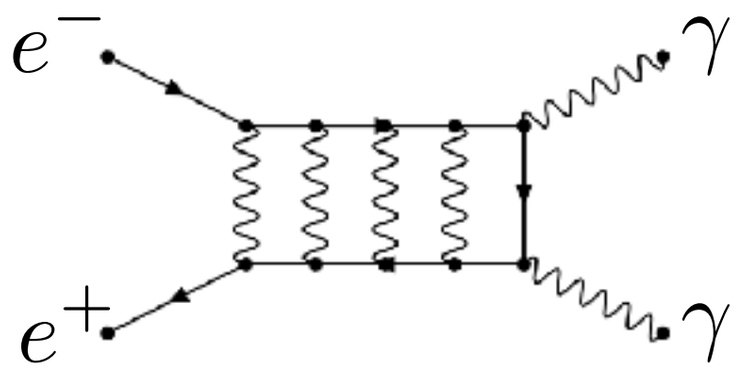
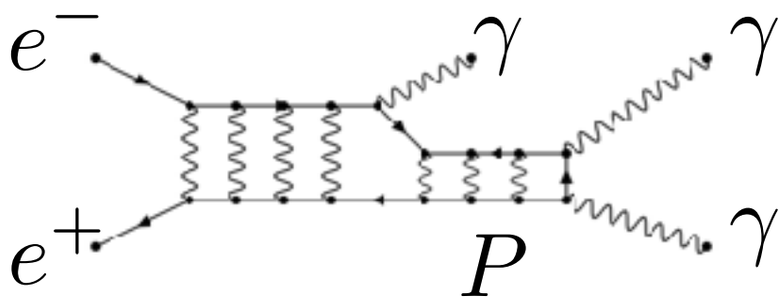
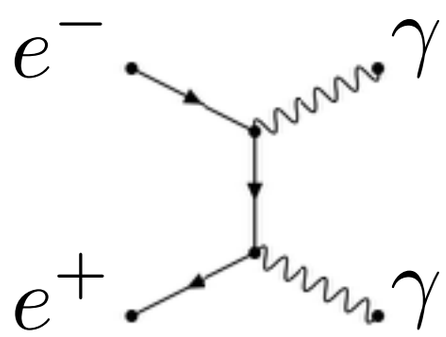
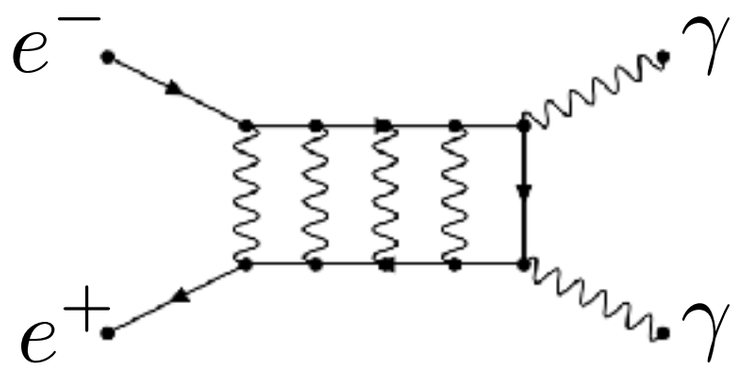
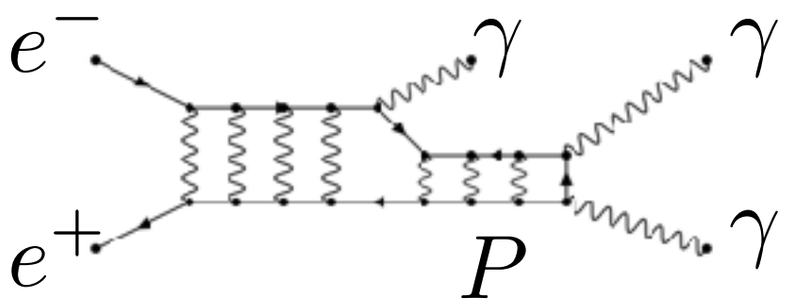
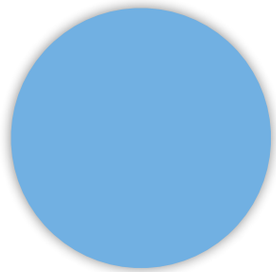
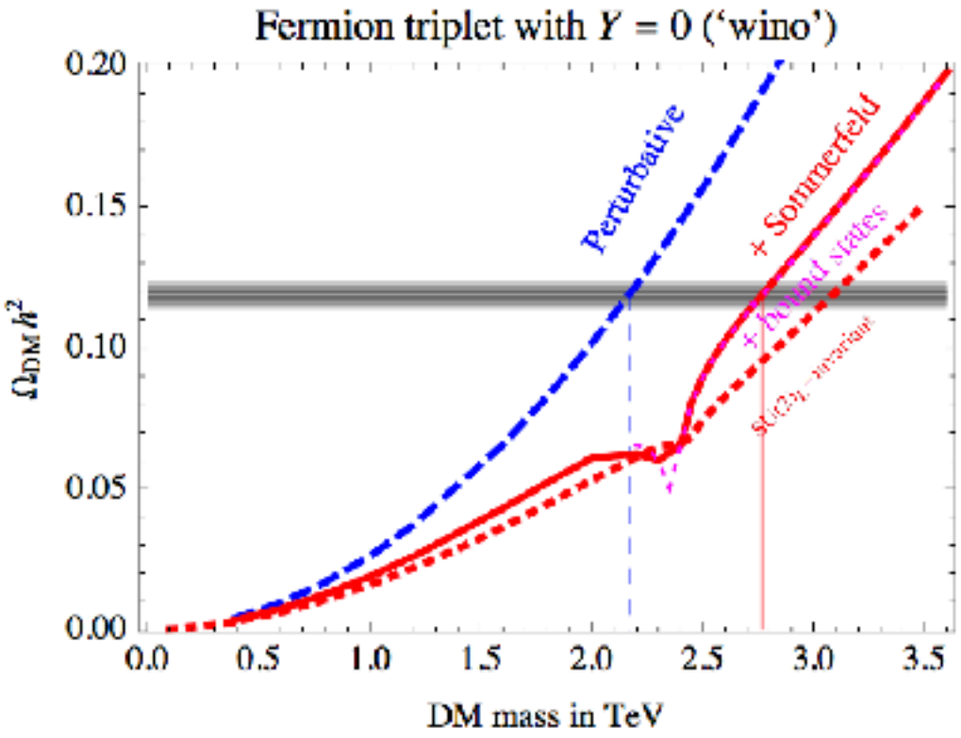
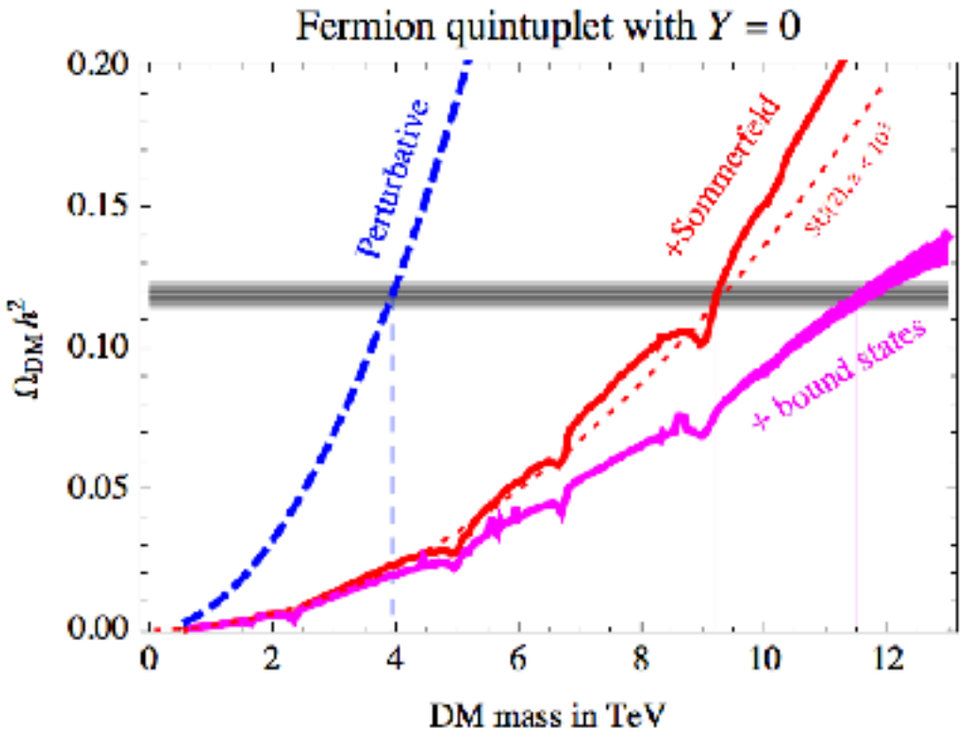
I) $e^+ e^- \to \gamma\gamma$		large velocity
II) $e^+ e^- \to P^* \to \gamma\gamma$		
III) $e^+ e^- \to P^* \to P\,\gamma$ $P \to \gamma\gamma$		

Process	Diagram	Cross-Section area	
		large velocity	small velocity
I) $e^+ e^- \to \gamma\gamma$			
II) $e^+ e^- \to P^* \to \gamma\gamma$			
III) $e^+ e^- \to P^* \to P\,\gamma$ $P \to \gamma\gamma$			

Relic Density: The gauge portal





The Triplet
(Wino)

The Quintuplet
(Minimal Dark Matter)

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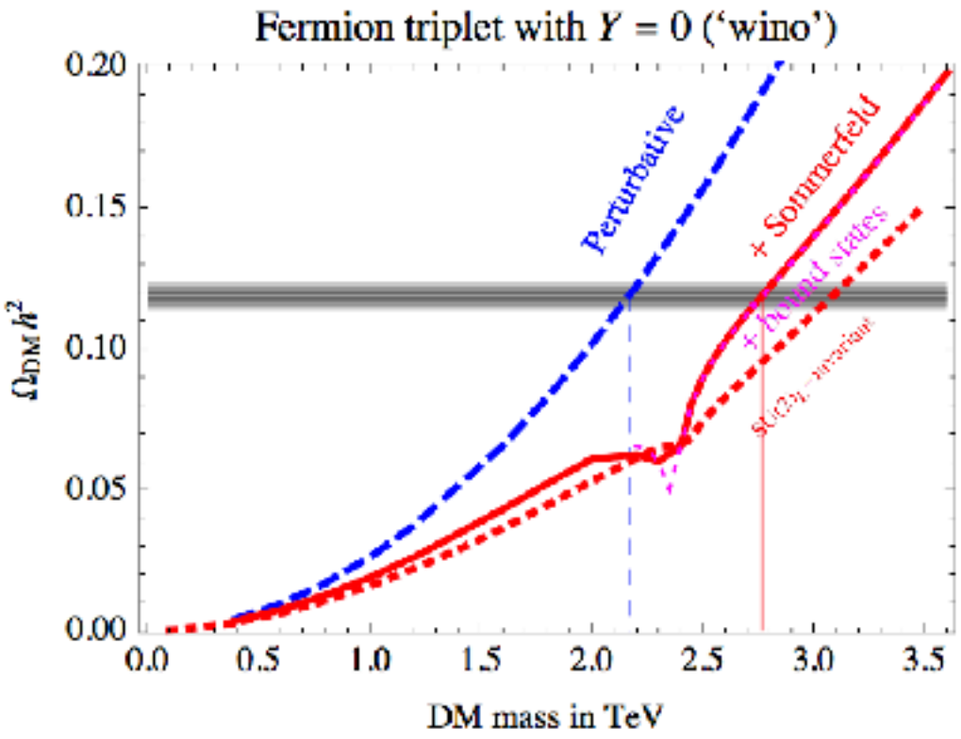
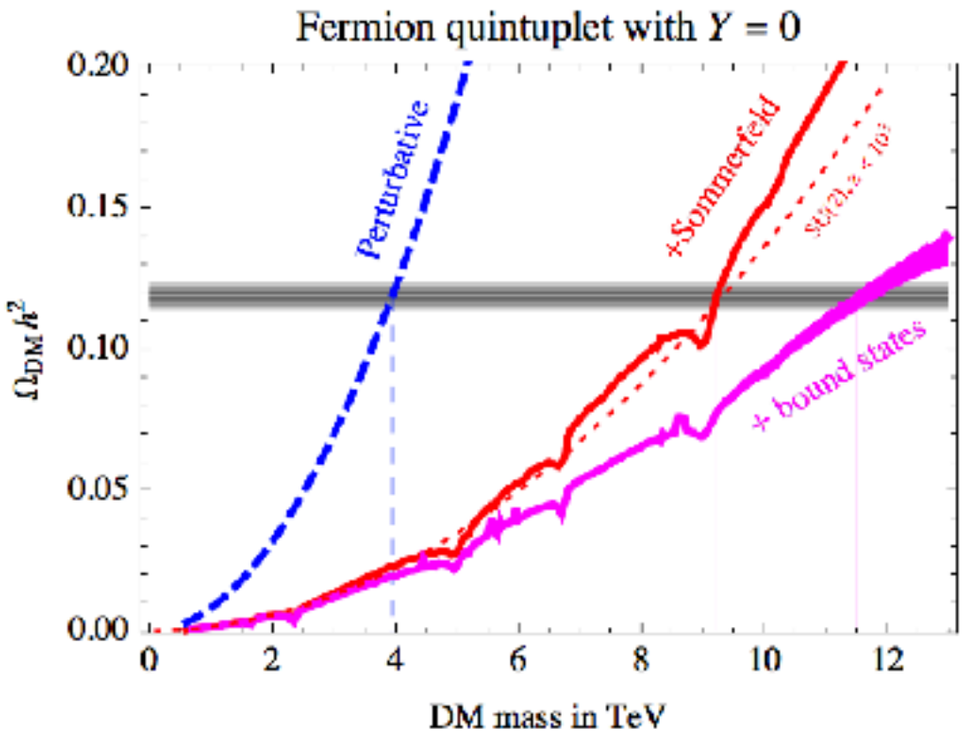


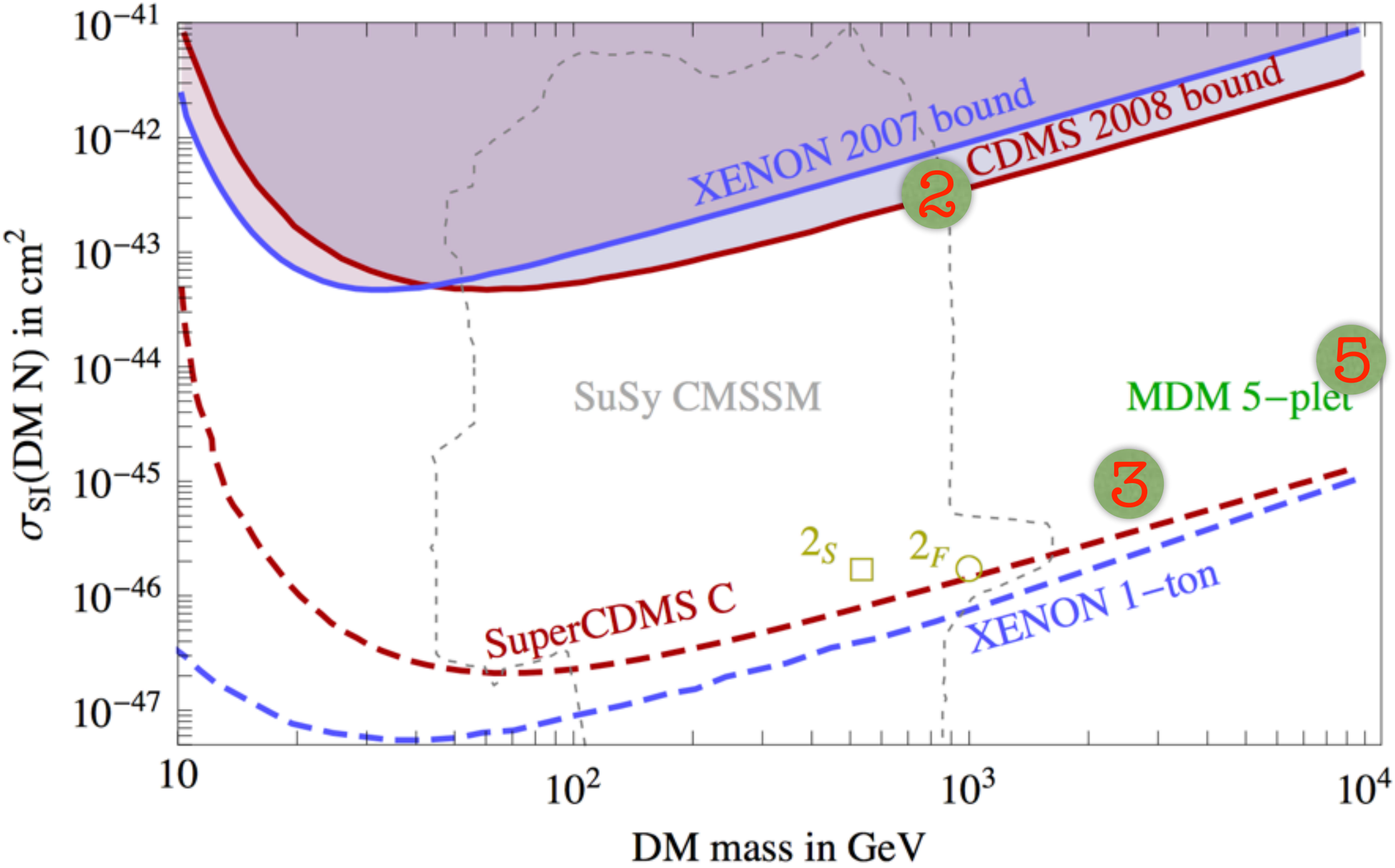


The Triplet (Wino)

The Quintuplet (Minimal Dark Matter)

Timothy Cohen et al.

The gauge portal: Direct Detection



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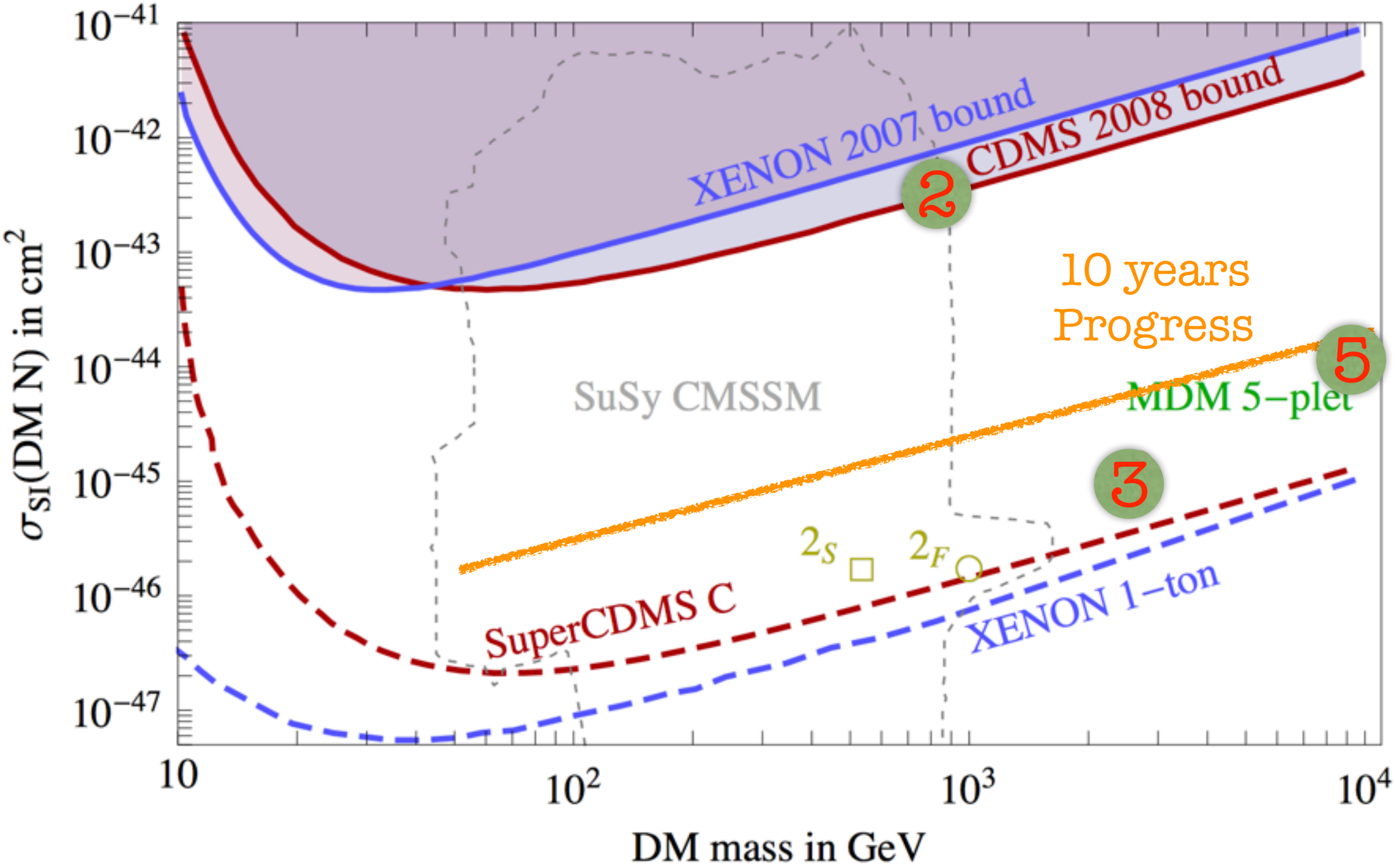

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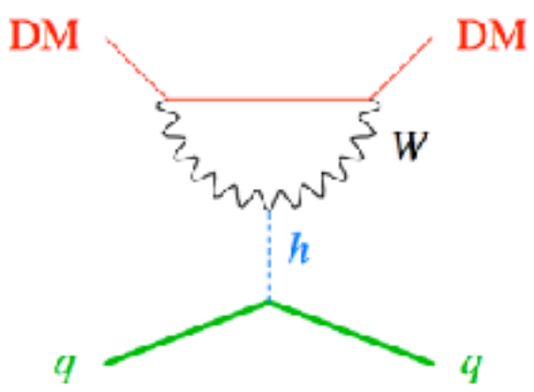
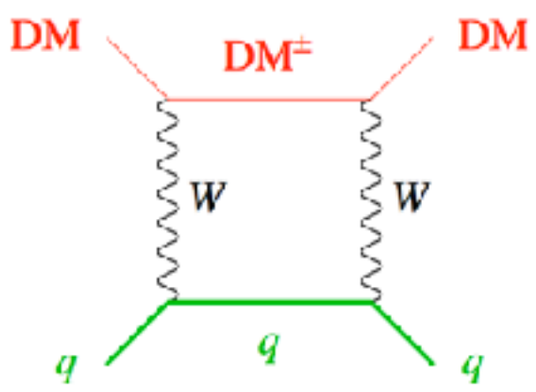
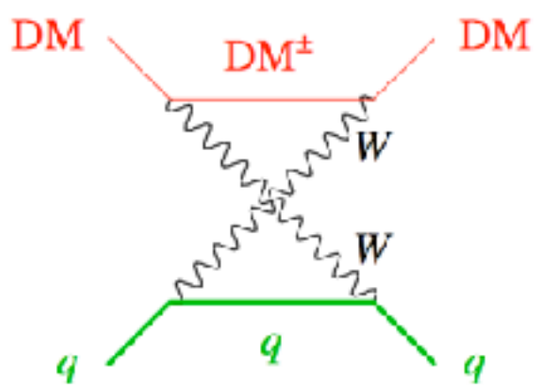
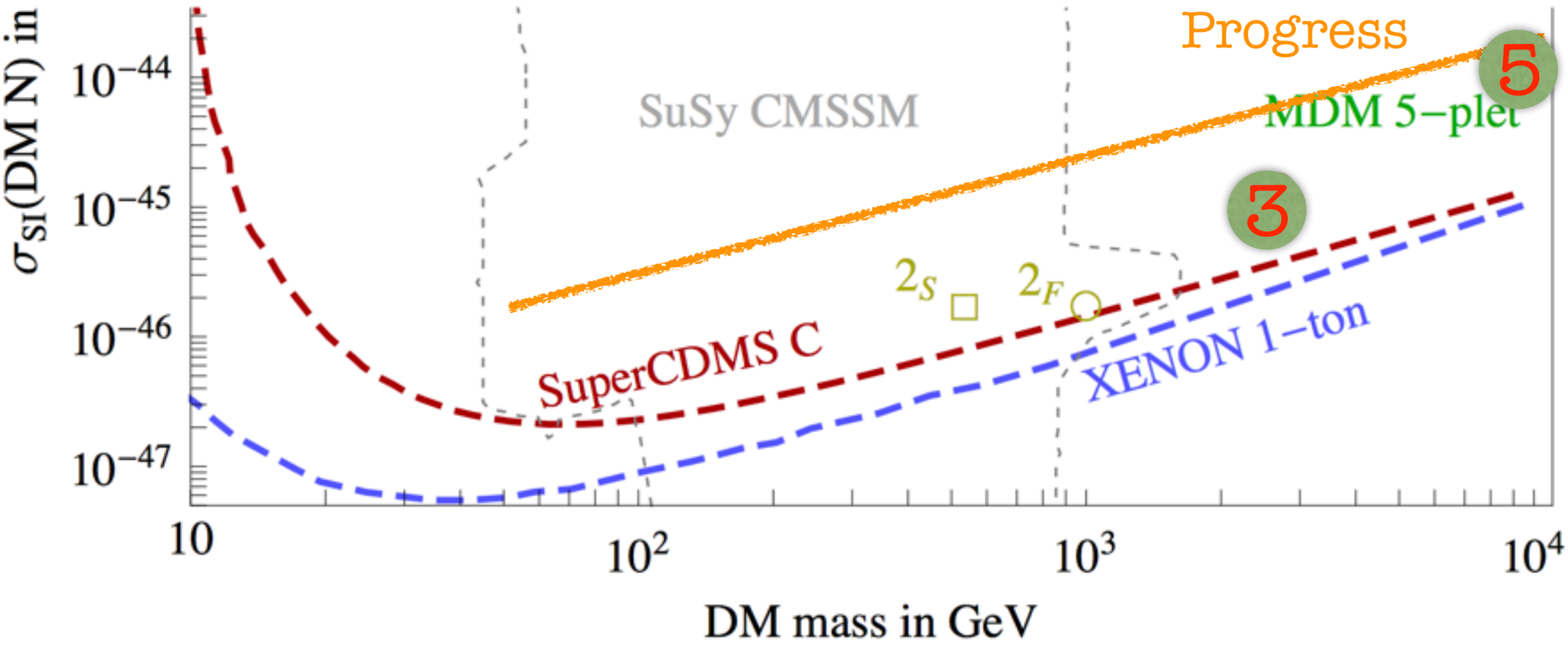
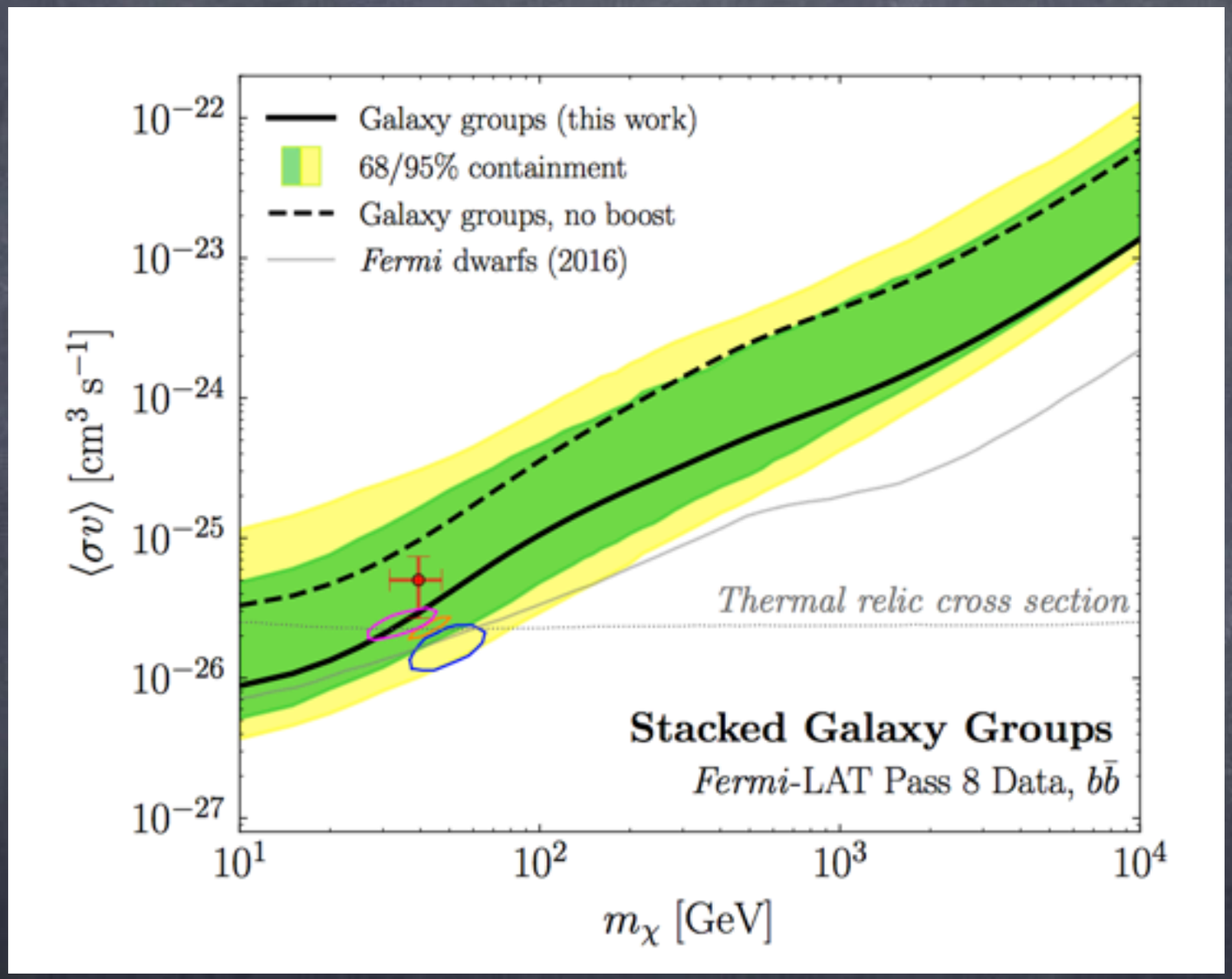






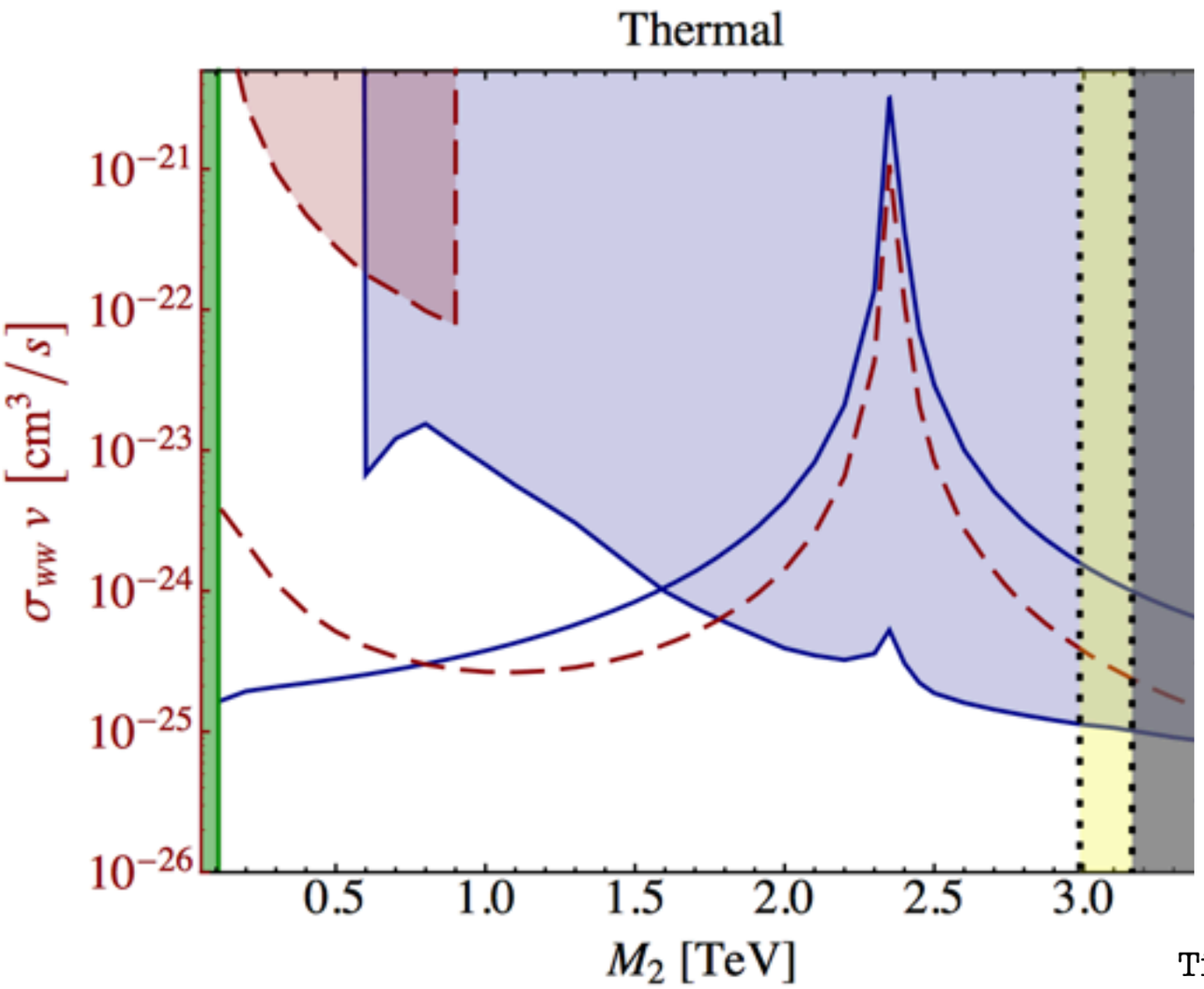


Indirect Search for the gauge portal



M. Lisanti et al. 1708.09385

Indirect Search for the gauge portal



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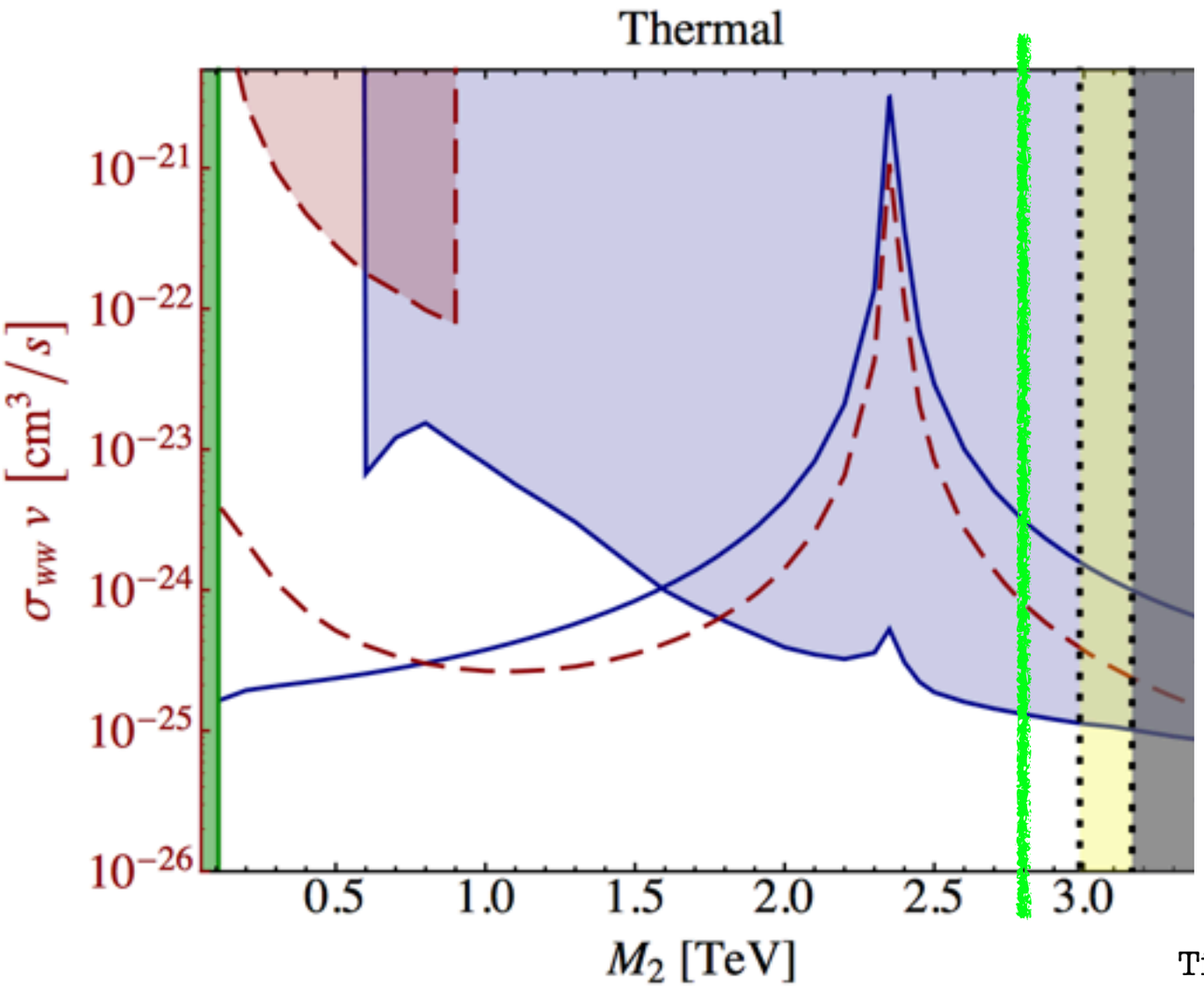

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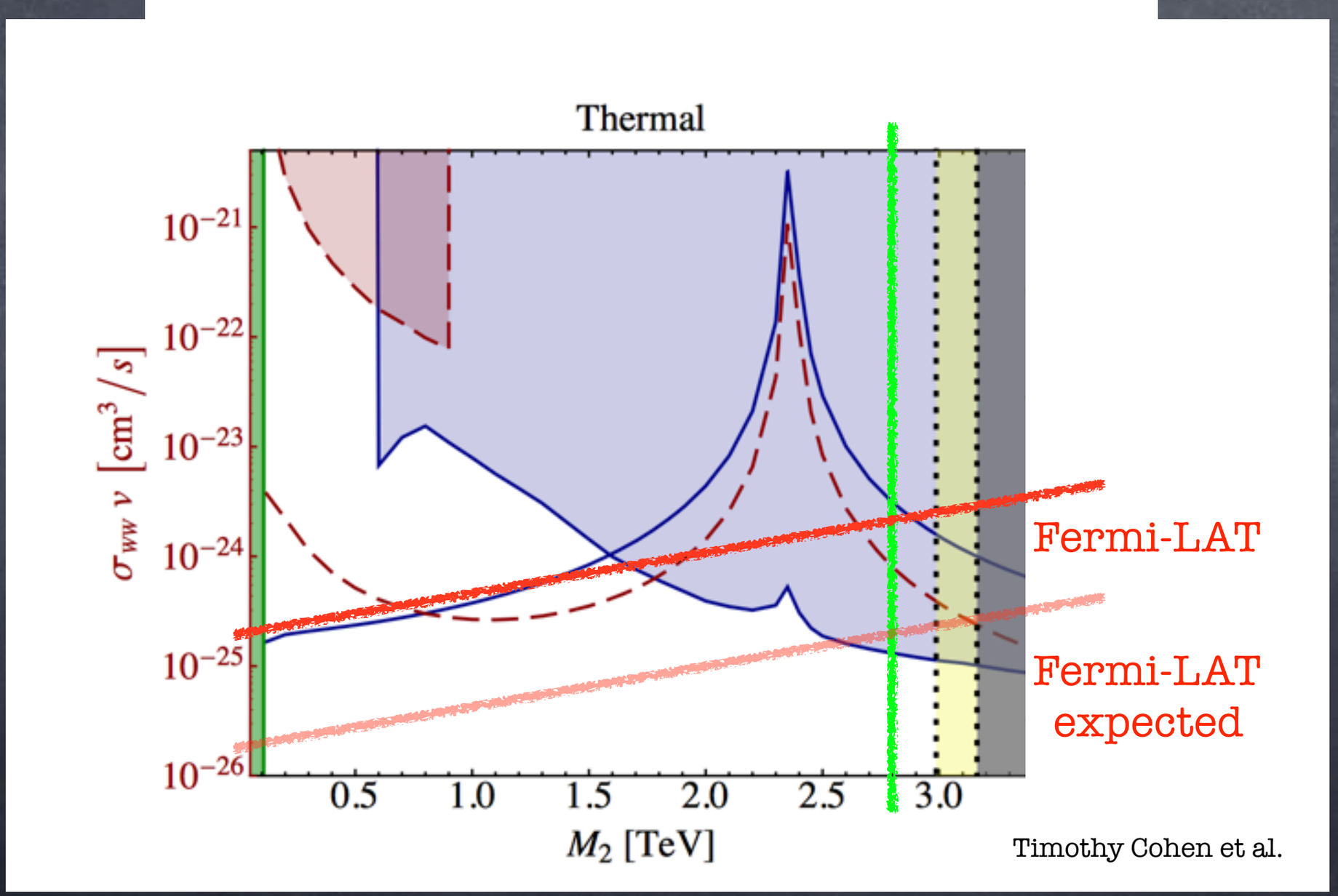

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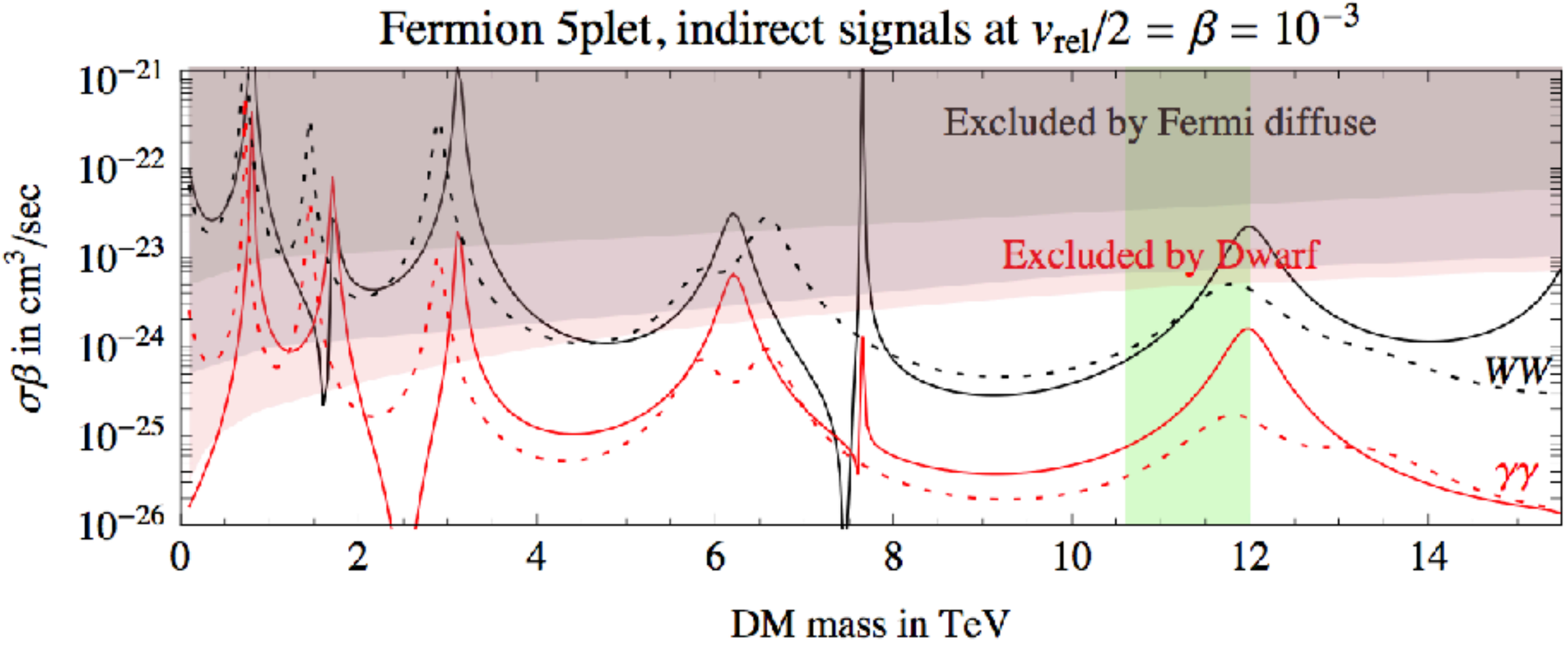
Minimal Dark Matter



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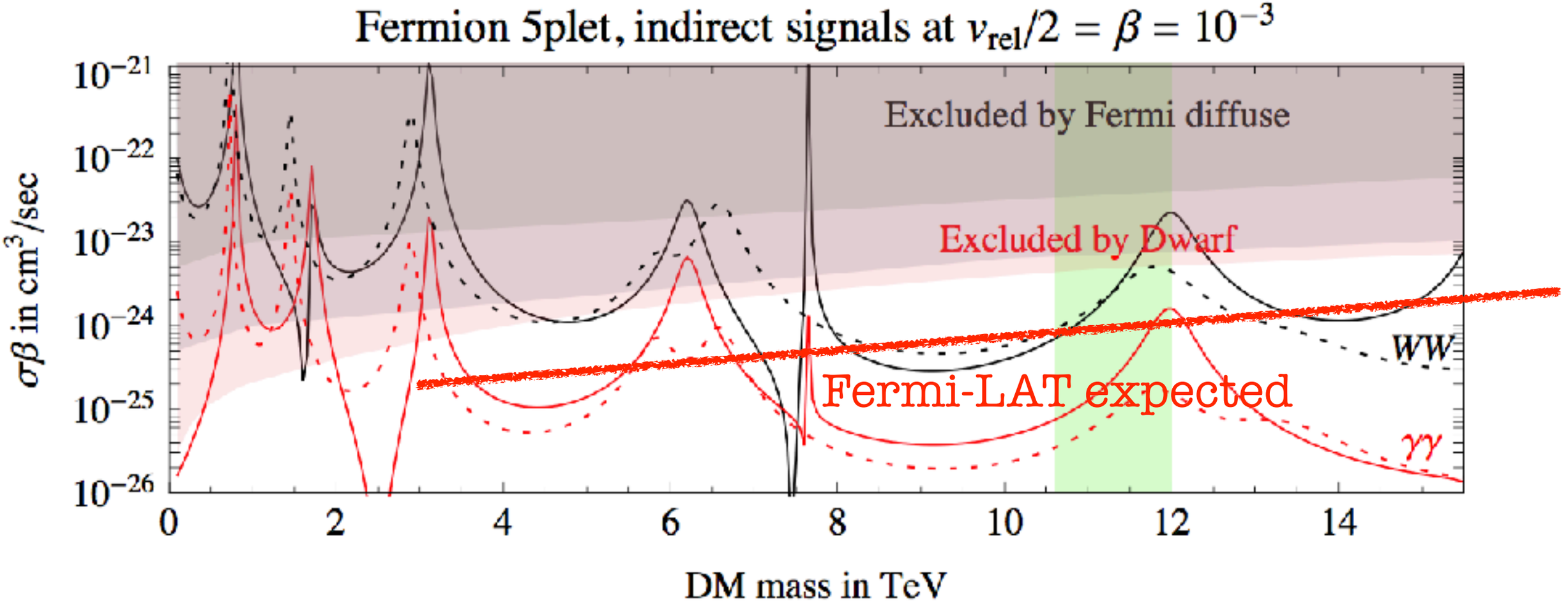
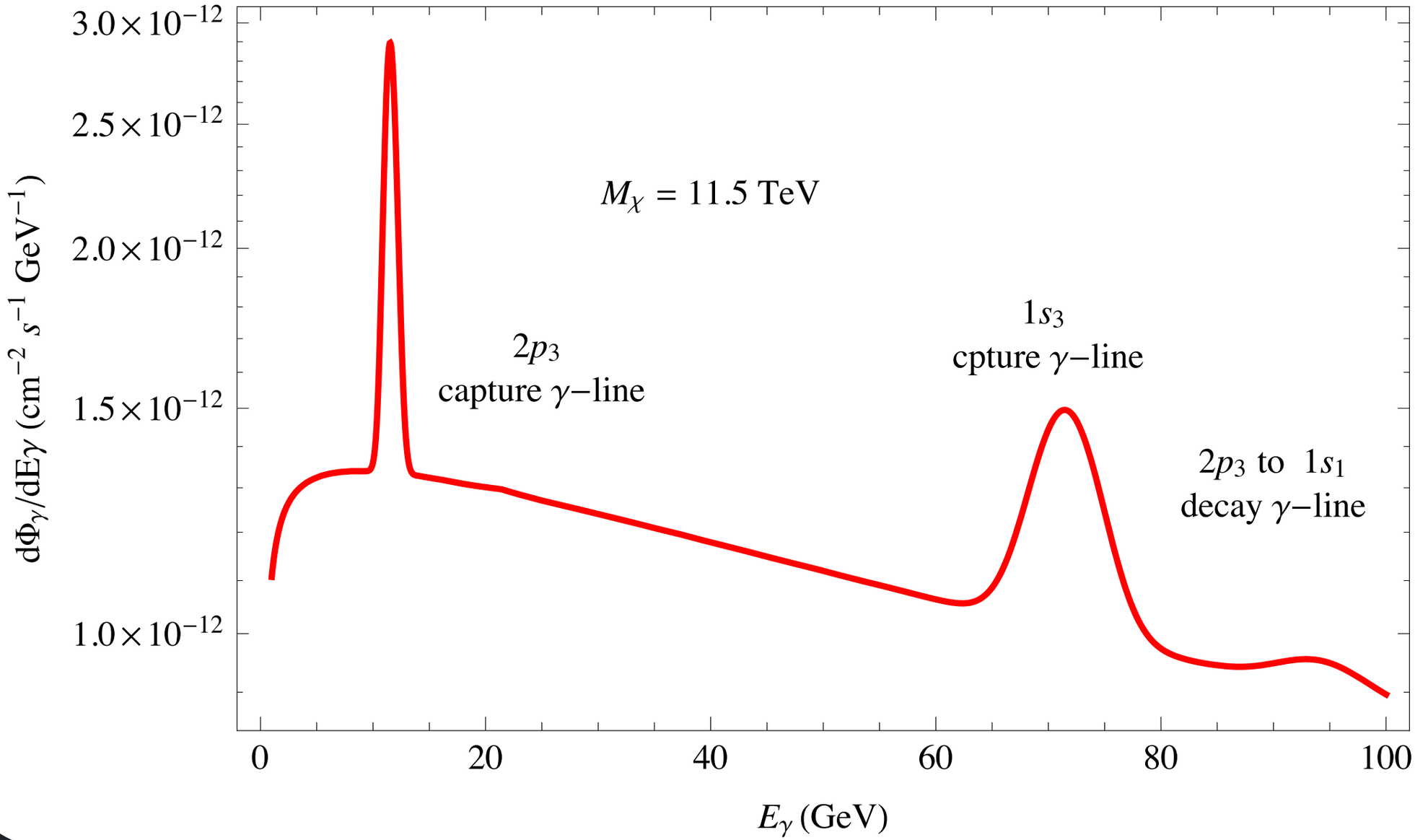


The Quintonium Spectrum



The minimal dark matter spectrum

Juri Smirnov, INFN Florence division

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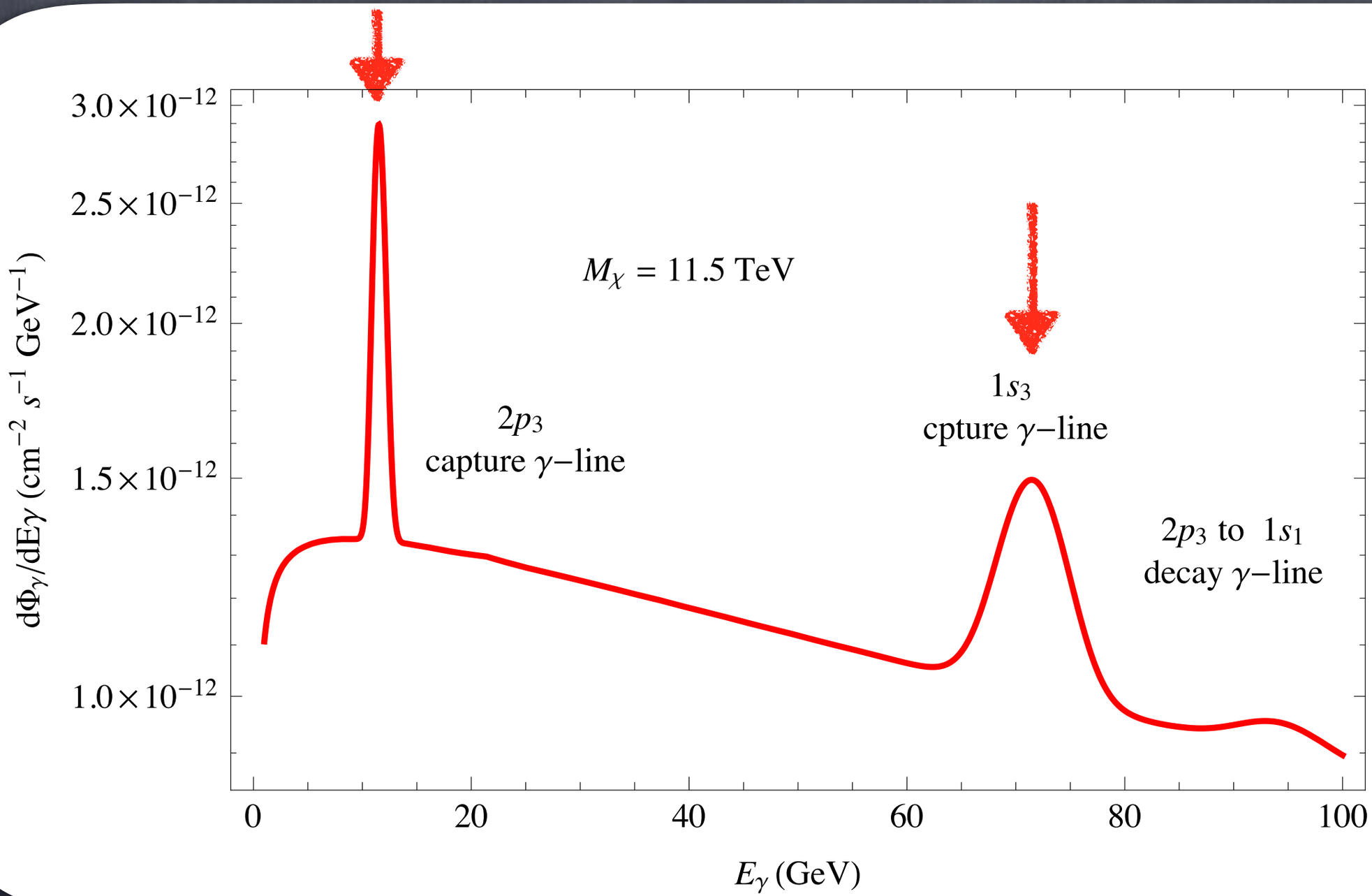

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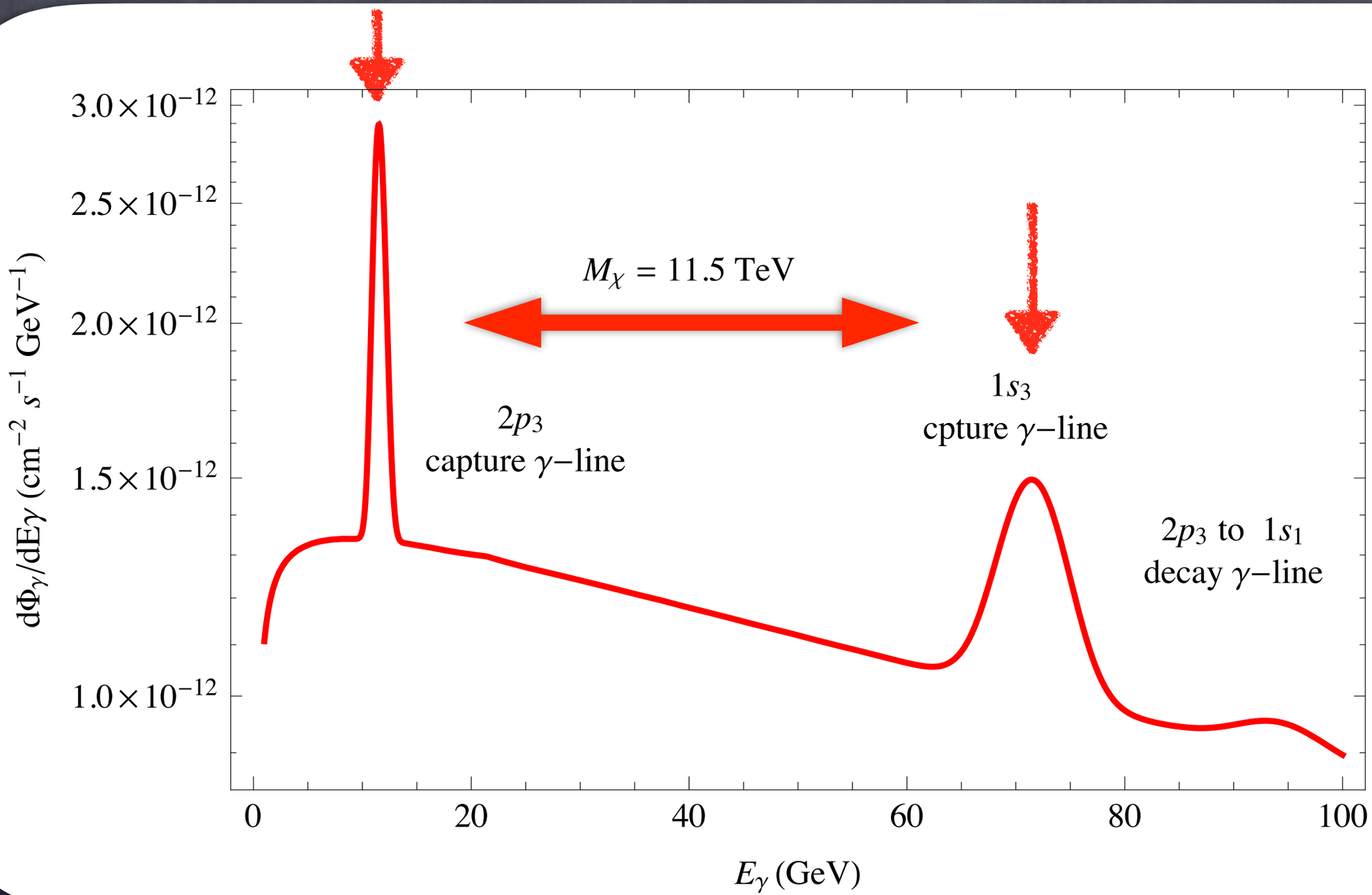

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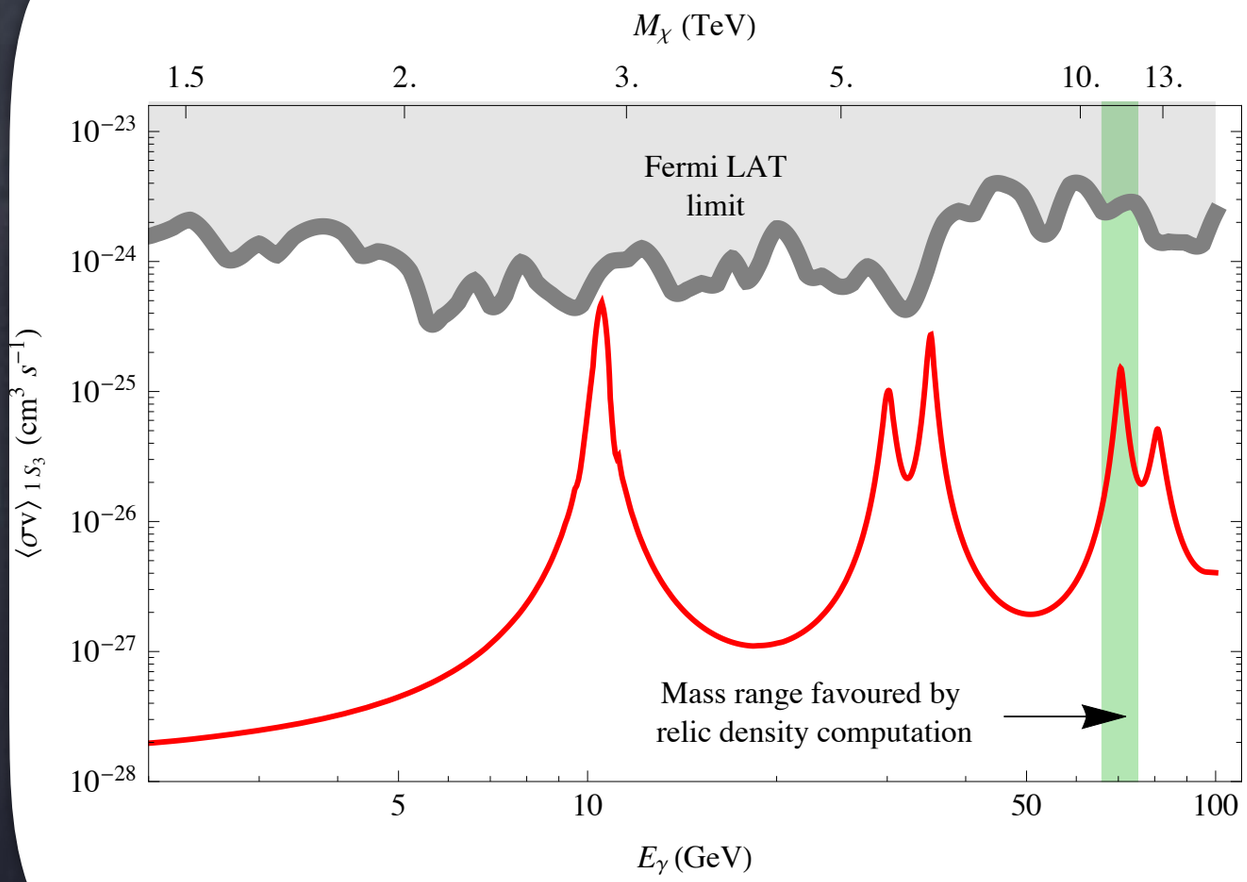
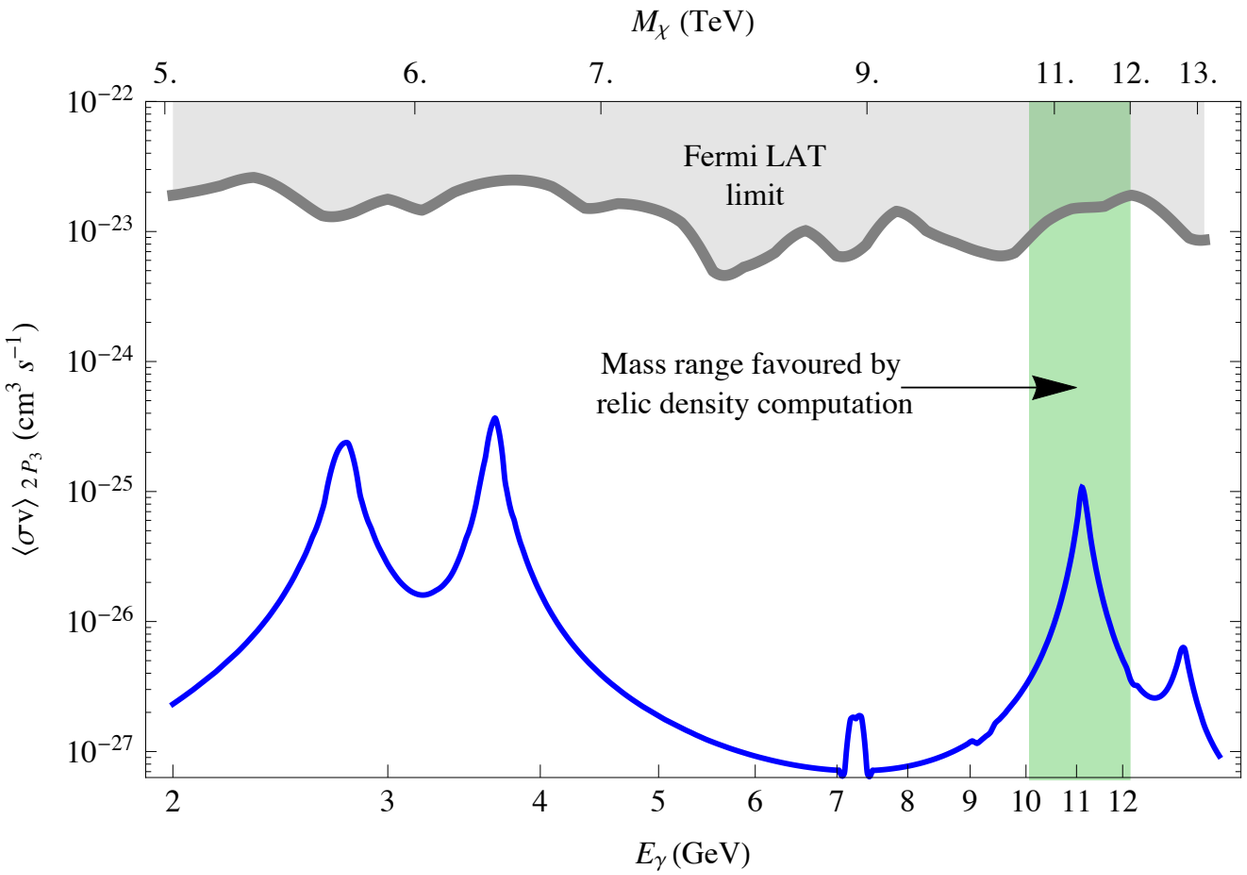
Probing the Heavy





The cross sections confronted with Fermi LAT searches

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Scalar

Dark Matter: The Higgs Portal

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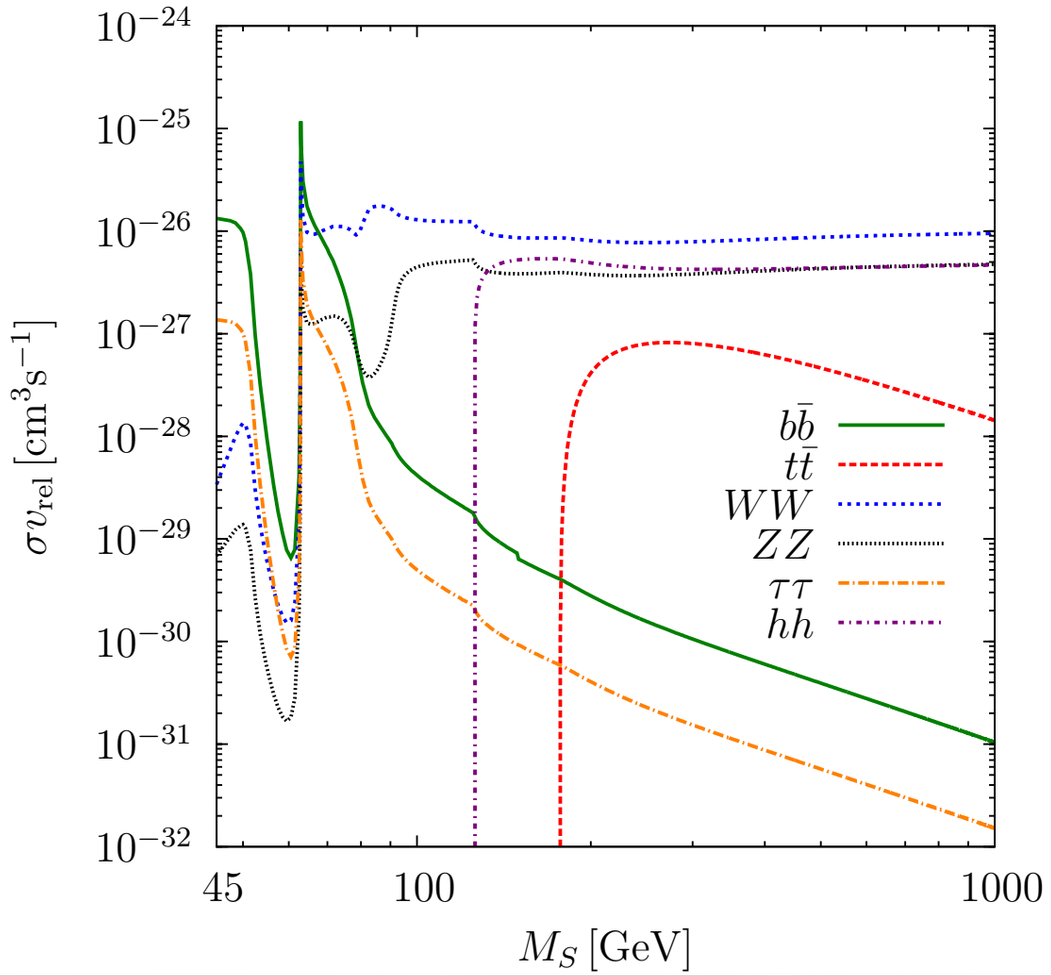
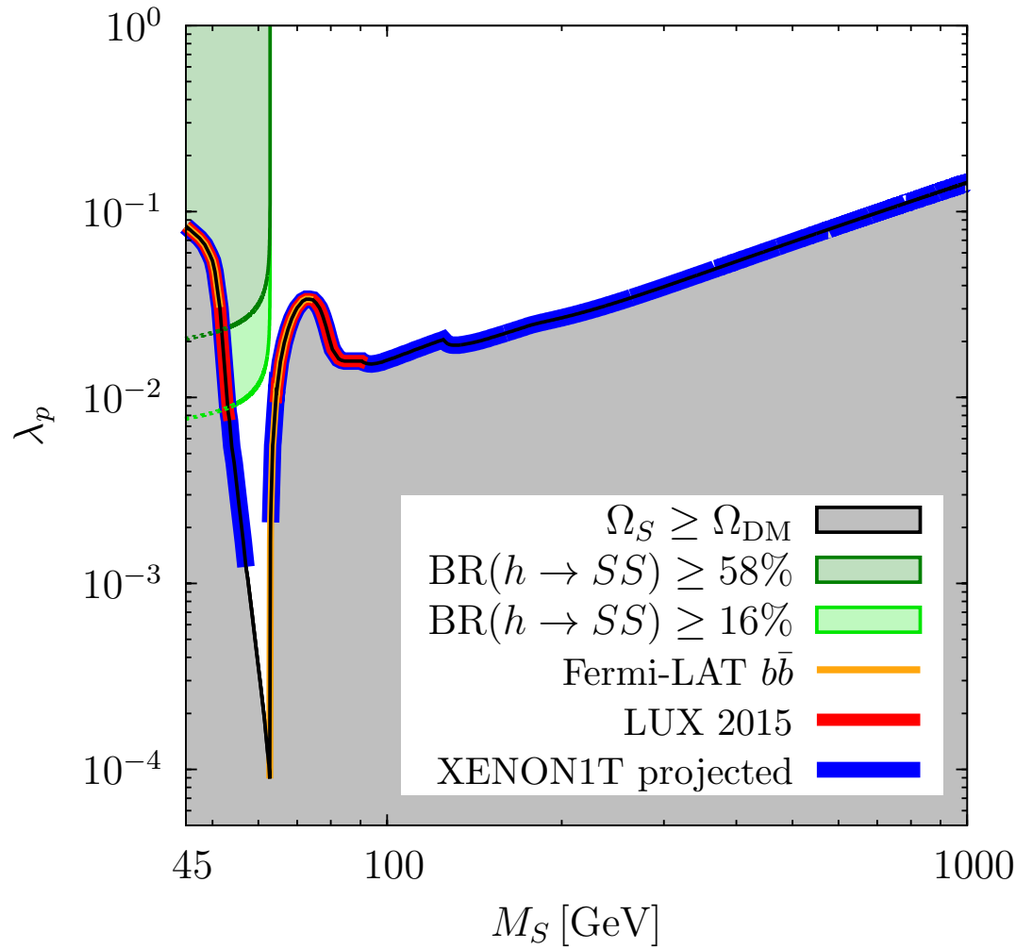
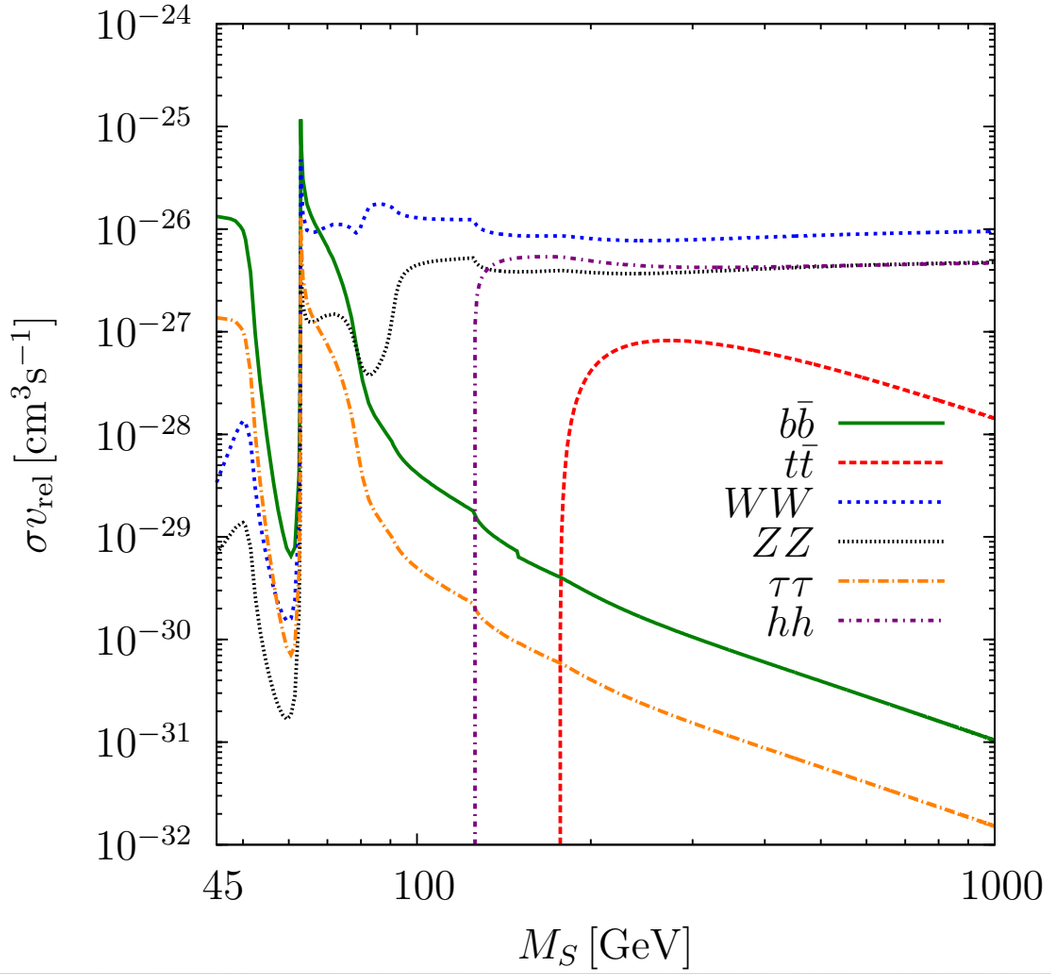
The Higgs Portal



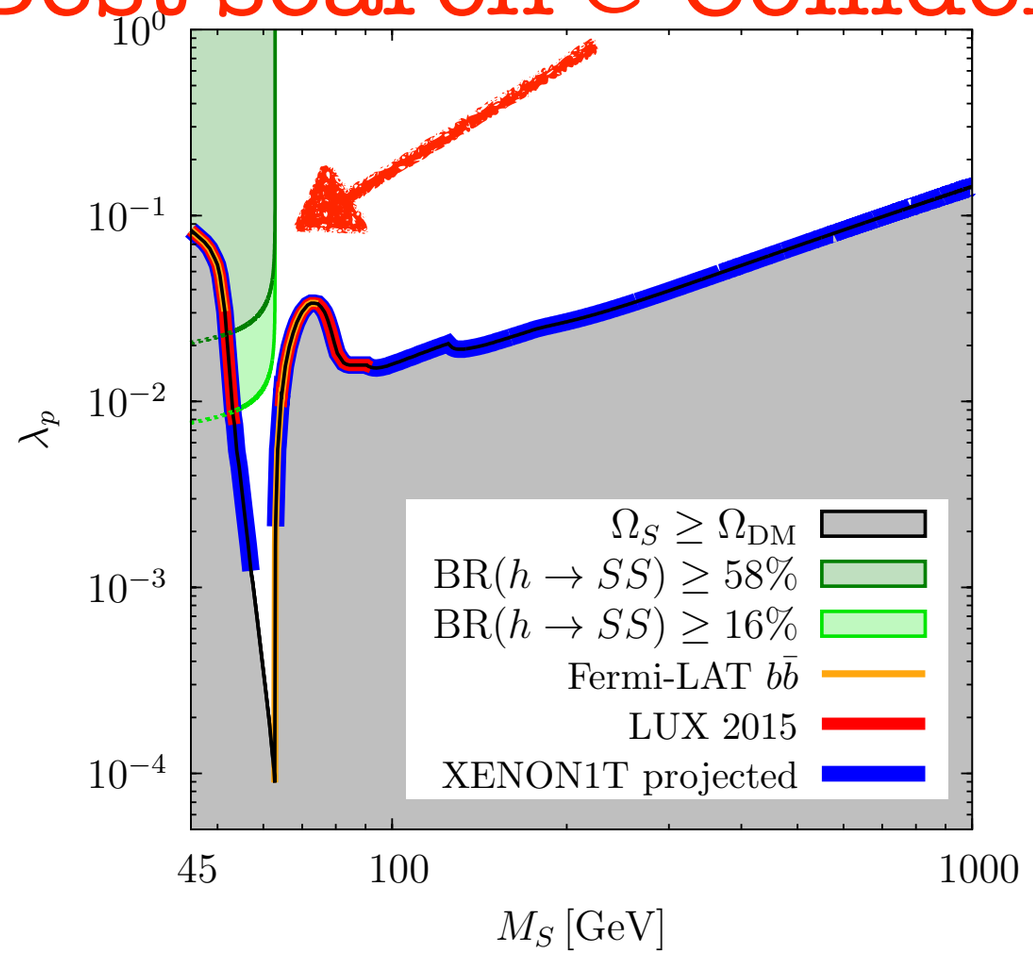


$$\mathcal{L}_{\rm SDM} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2}m_S^2 S^2 - \lambda_S S^4 - \lambda_p H^\dagger H S^2,$$

The Higgs Portal



Best search @ Collider



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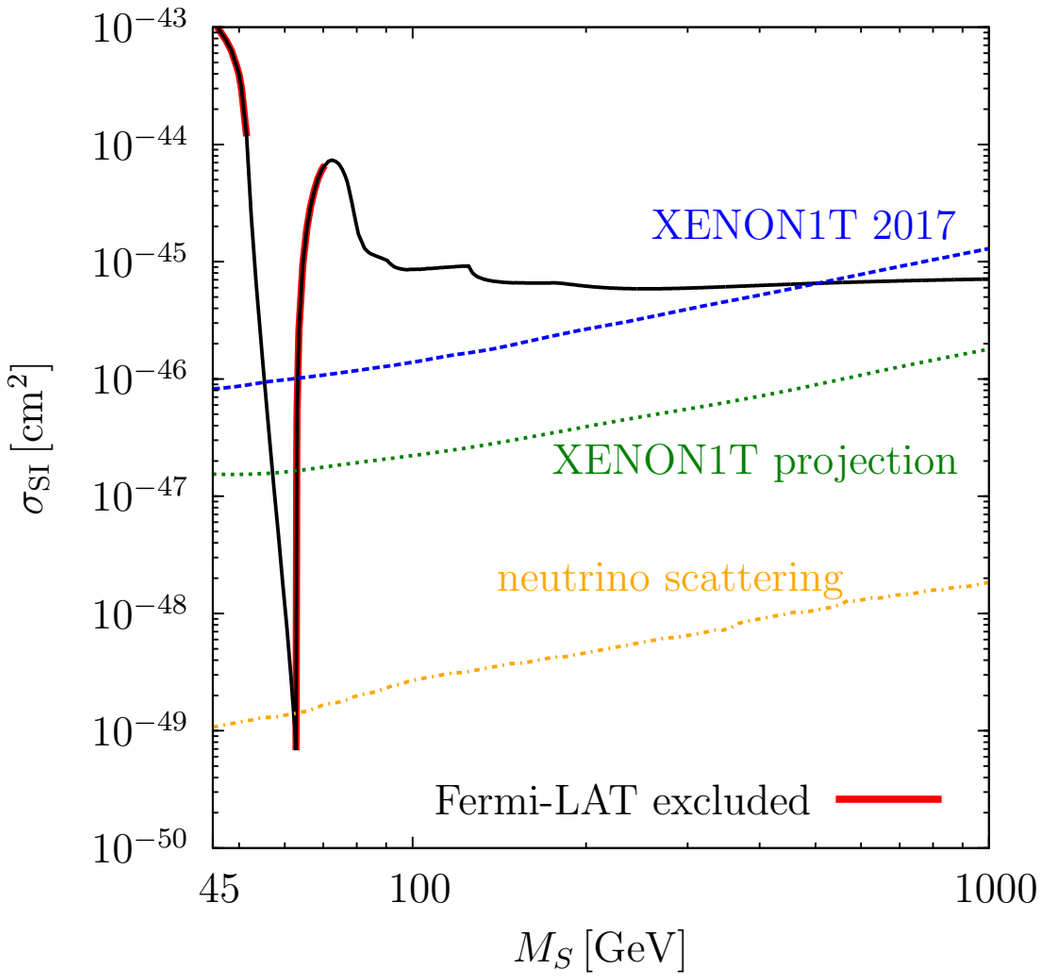
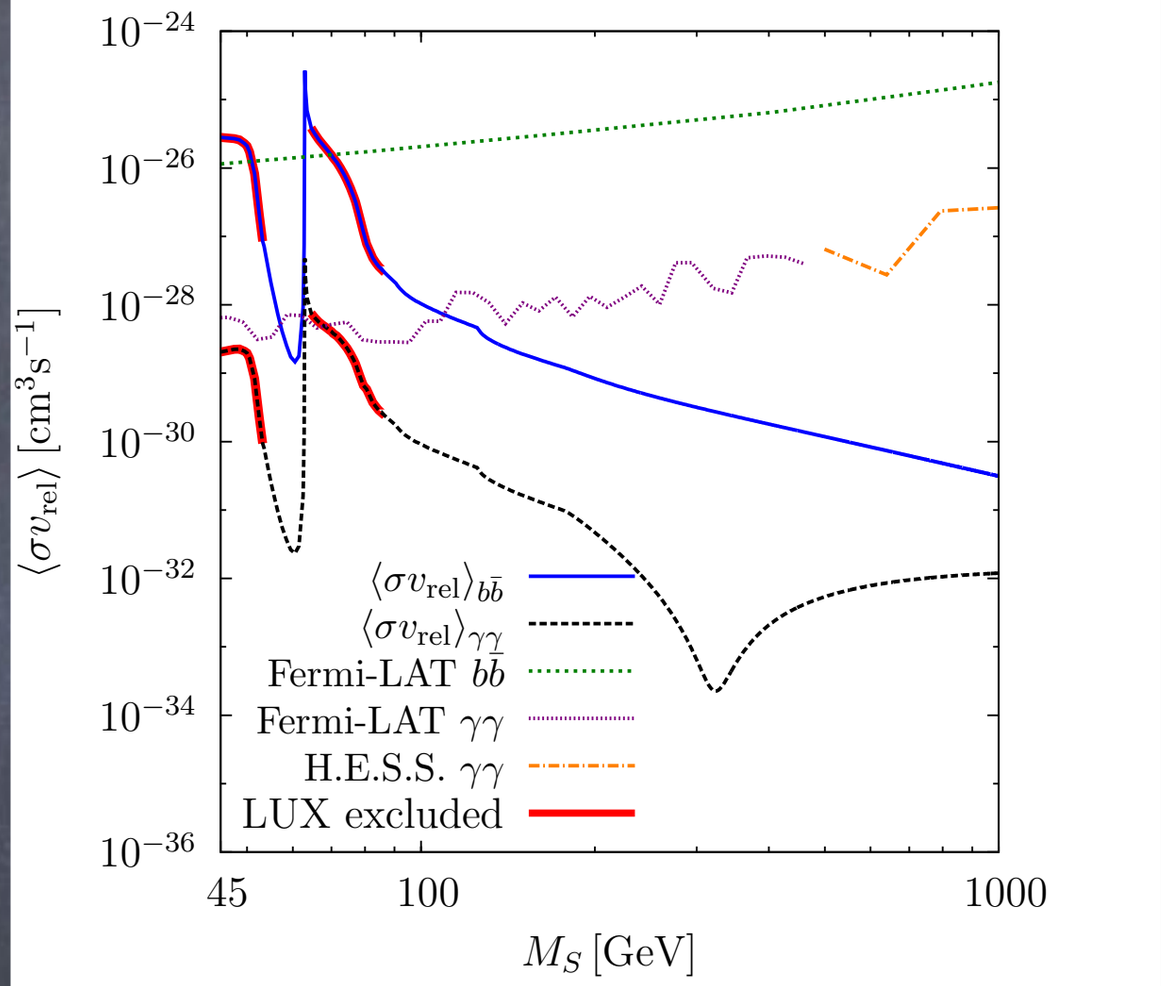
Constraints and Future Prospects

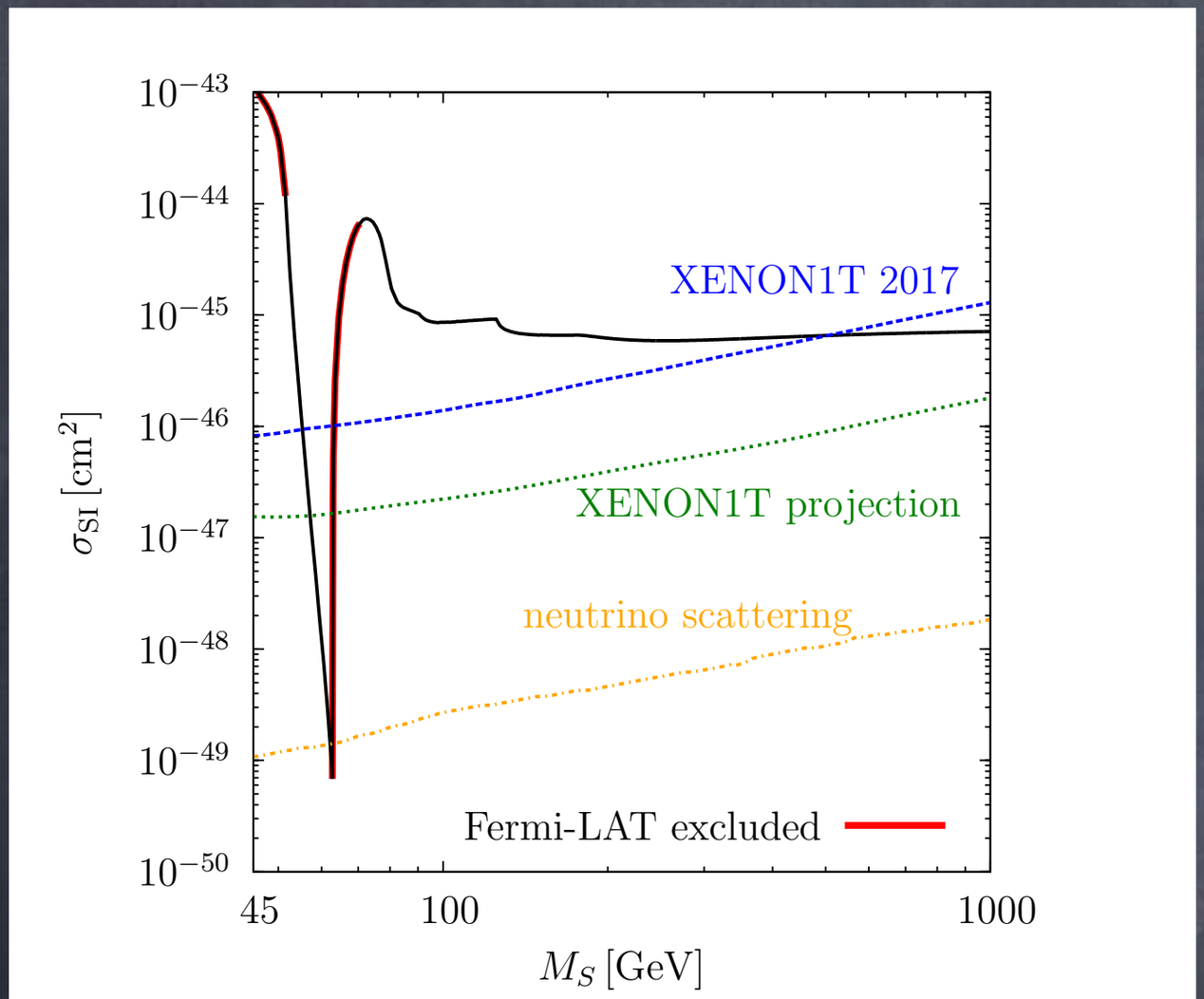


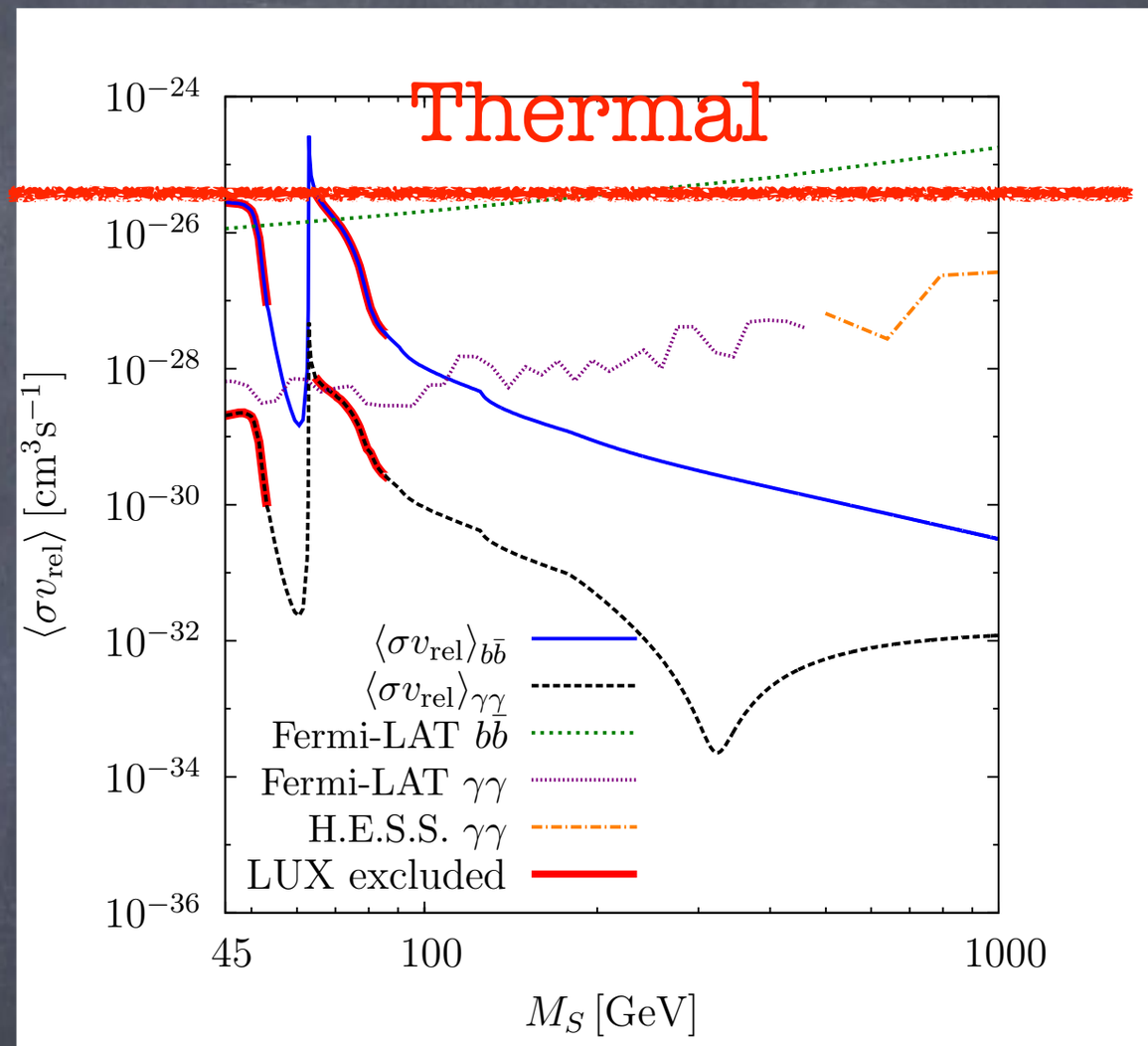


- At the resonance indirect searches might be the only chance in near future
- Above the resonance direct detection is taking over!

M. Duerr, P. Fileviez Perez, J. Smirnov 1509.04282 , 1508.04418

Constraints and Future Prospects





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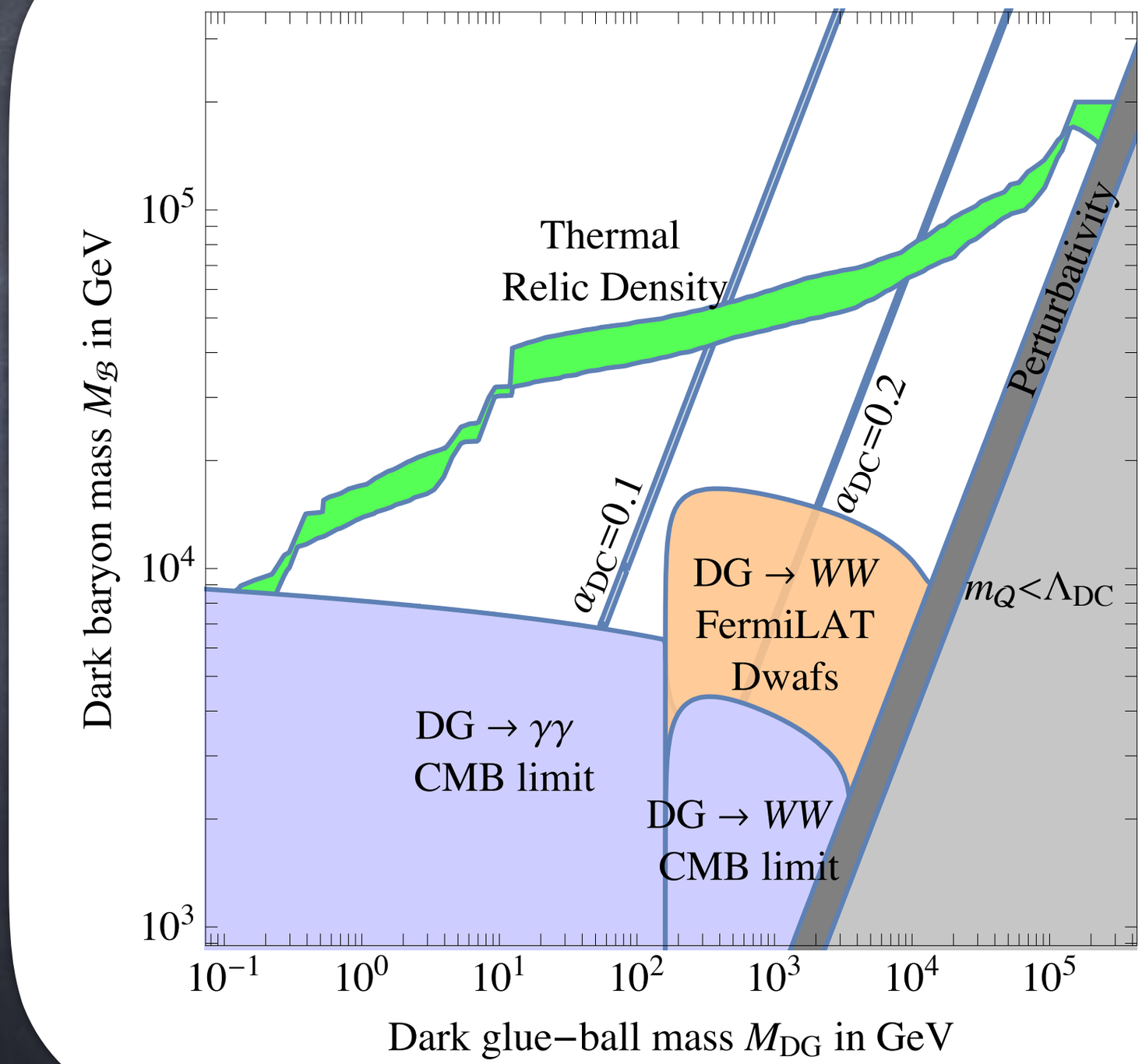
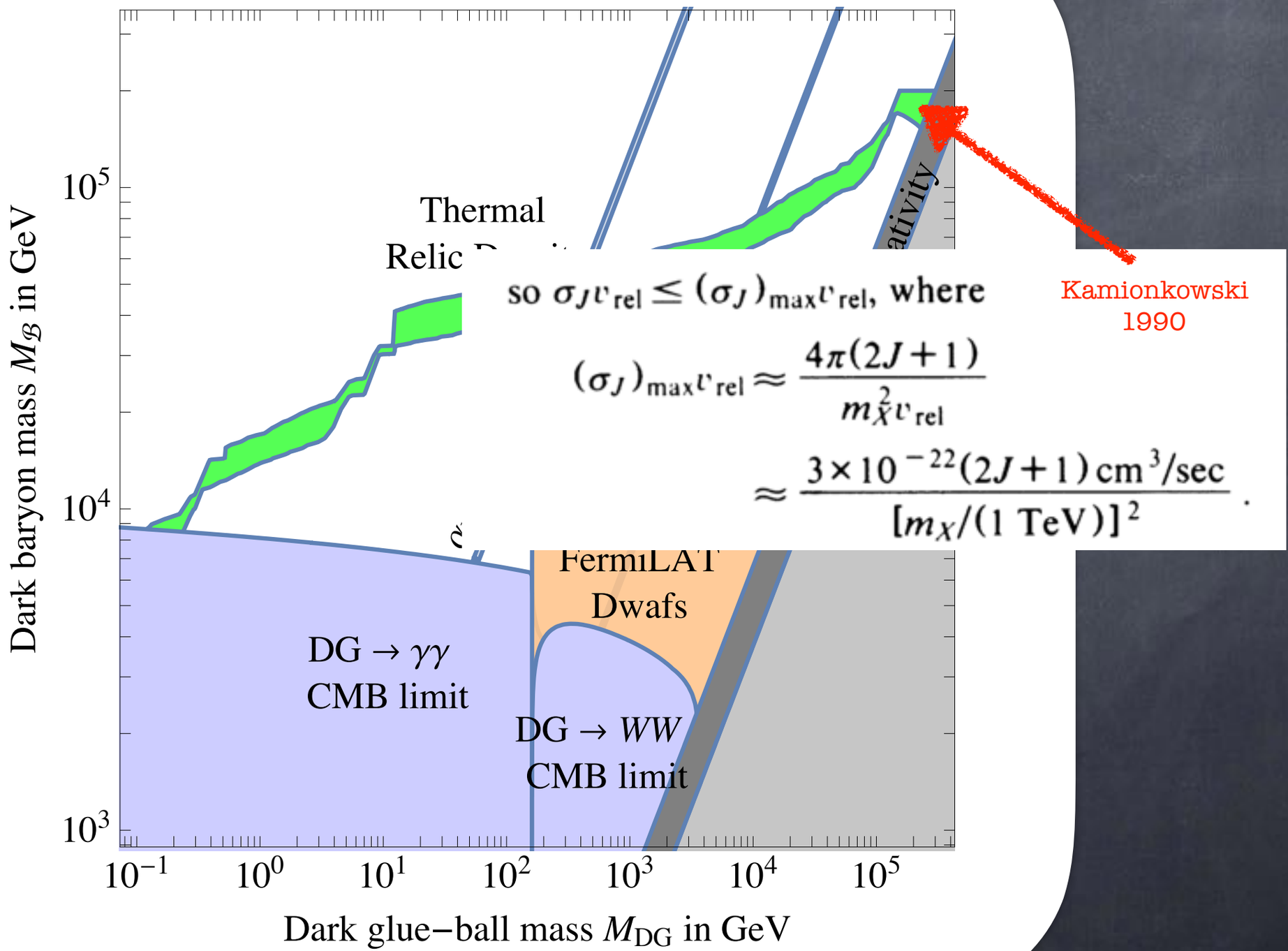
Full Thermal Mass Range



Full Thermal Mass Range



so $\sigma_J v_{rel} \leq (\sigma_J)_{max} v_{rel}$, where

$$(\sigma_J)_{max} v_{rel} \approx \frac{4\pi(2J+1)}{m_X^2 v_{rel}}$$

$$\approx \frac{3\times 10^{-22}(2J+1)\,\mathrm{cm}^3/\mathrm{sec}}{[m_X/(1\ \mathrm{TeV})]^2}\,.$$

Kamionkowski 1990

Summary

- The Thermal Hypothesis is a well defined testable statement
- The unitarity bound sets an upper bound on the dark matter mass in the freeze-out
- 100 TeV is the desired range to test the full thermal region
- At the moment indirect detection seems to be the best way to go towards this goal

Thank you!

Juri Smirnov, INFN Florence division