Dark matter stability and unification without supersymmetry

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MF & Thomas Hambye, arXiv: 0912.1545 [hep-ph]

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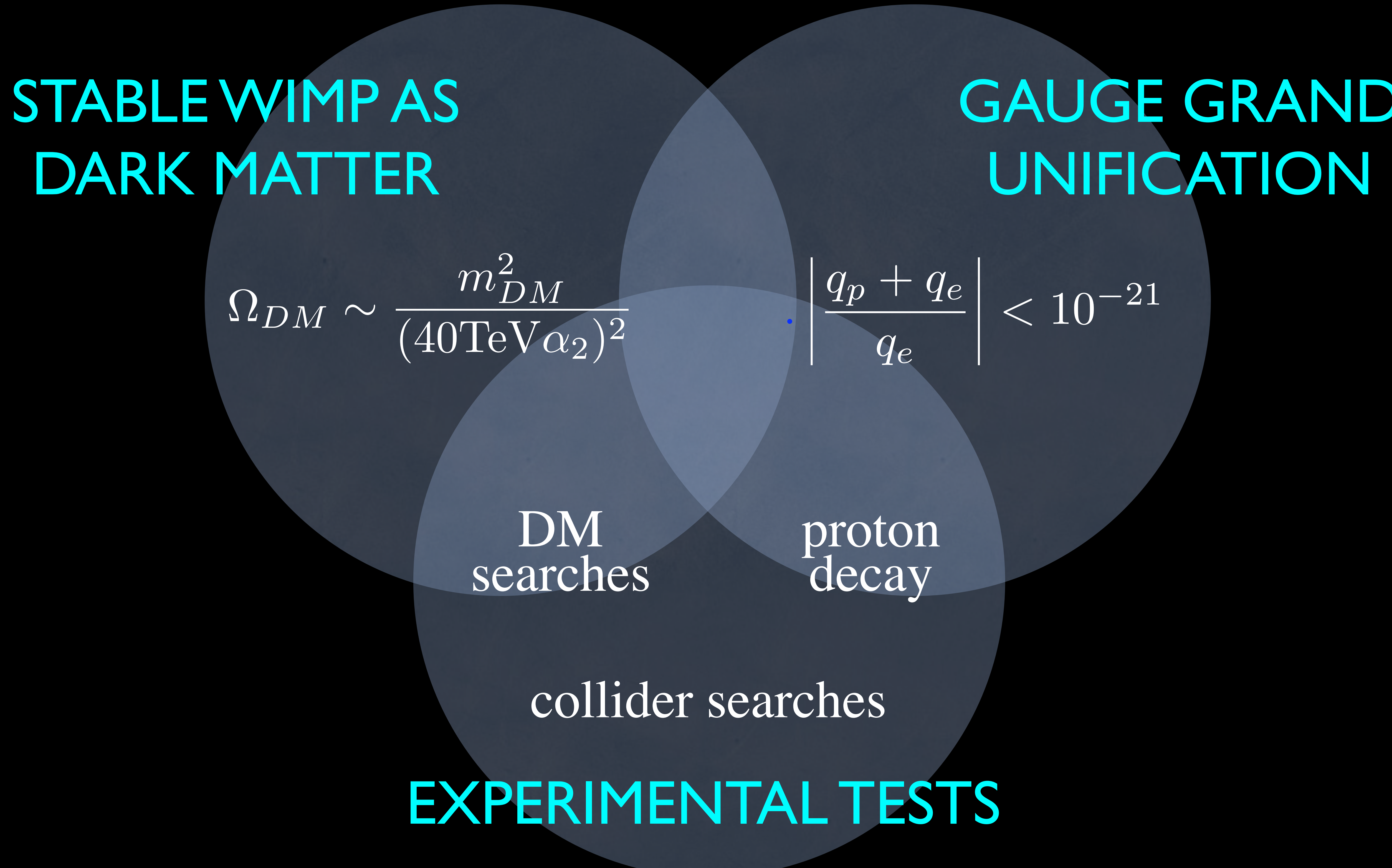
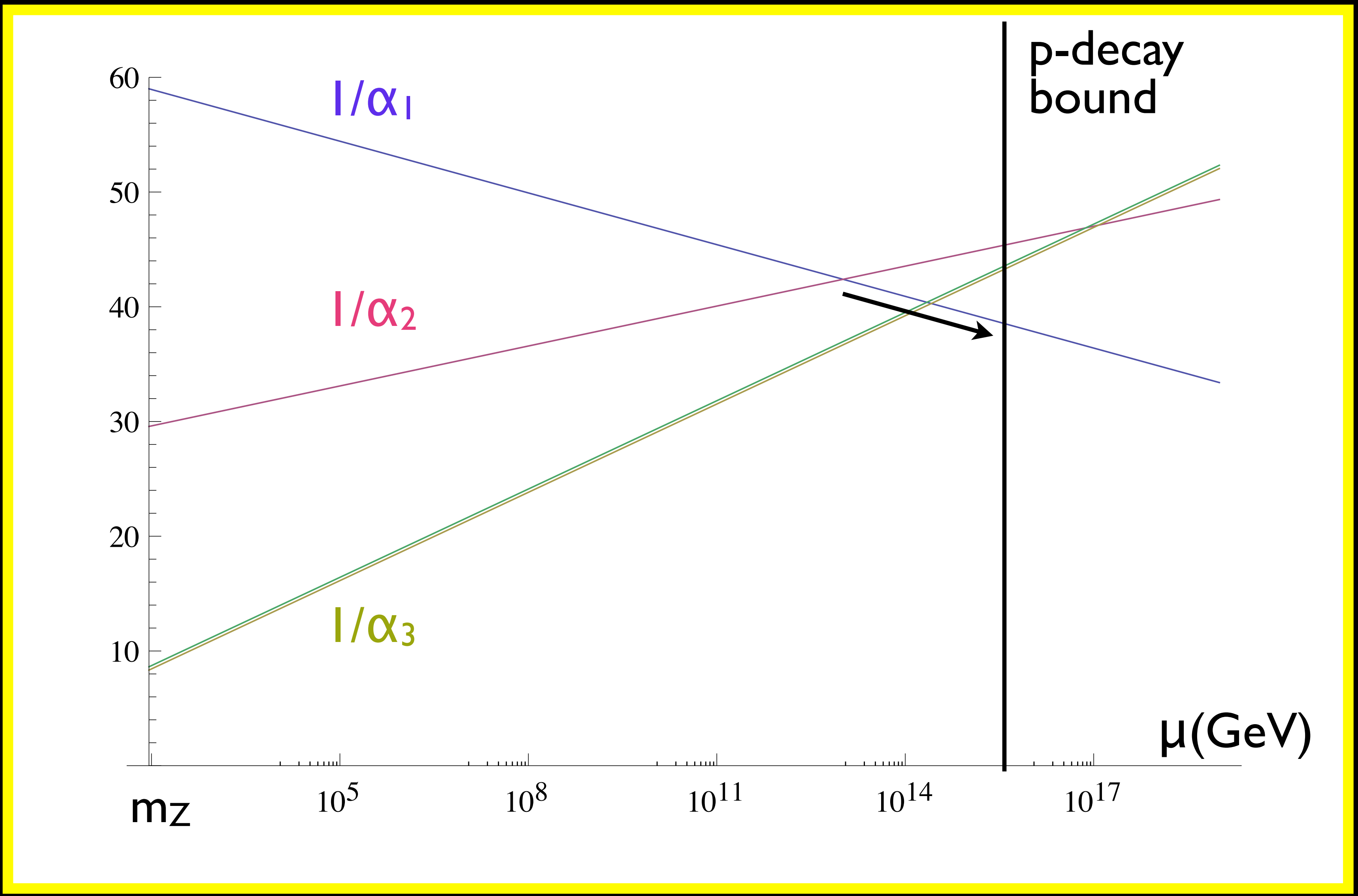
Presently, no direct indications of new physics at the TeV scale, despite the hierarchy problem. In fact, stringent constraints come from electroweak precision tests and flavour observables.



Gauge coupling unification

$$\frac{1}{\alpha_i(m_Z)} = \frac{1}{\alpha_{GUT}} + \frac{b_i^{SM}}{2\pi}\log\frac{M_{GUT}}{m_Z} + \frac{b_i^{DM}}{2\pi}\log\frac{M_{GUT}}{m_{DM}}$$



In the SM, α_1 and α_2 cross at 10^{13} GeV.
But, $p \to e^+\pi^0$ is too fast for $M_{GUT} < 4\ 10^{15}$ GeV.

Weakly interacting particles needed to raise the scale where $\alpha_1 = \alpha_2$.
The DM is the most motivated one.

To unify above 10^{15} and below 10^{19} GeV:

$$-2.6 < b_1^{DM} - b_2^{DM} < -1.1$$

Automatic DM stability

- DM is stable on cosmological time scales: need to forbid DM decays into SM particles

- The GUT gauge symmetry can be sufficient to guarantee the DM stability

$$G_{GUT} = SO(10) \supset U(1)_{B-L} \supset P_M \equiv (-1)^{3(B-L)}$$

- The matter parity P_M is preserved if the fields breaking SO(10) have even B-L

- SM fermions ($16_{1,2,3}$) are odd; SM higgs (10) is even: a new odd scalar or even fermion could not decay into SM particles

Unified DM

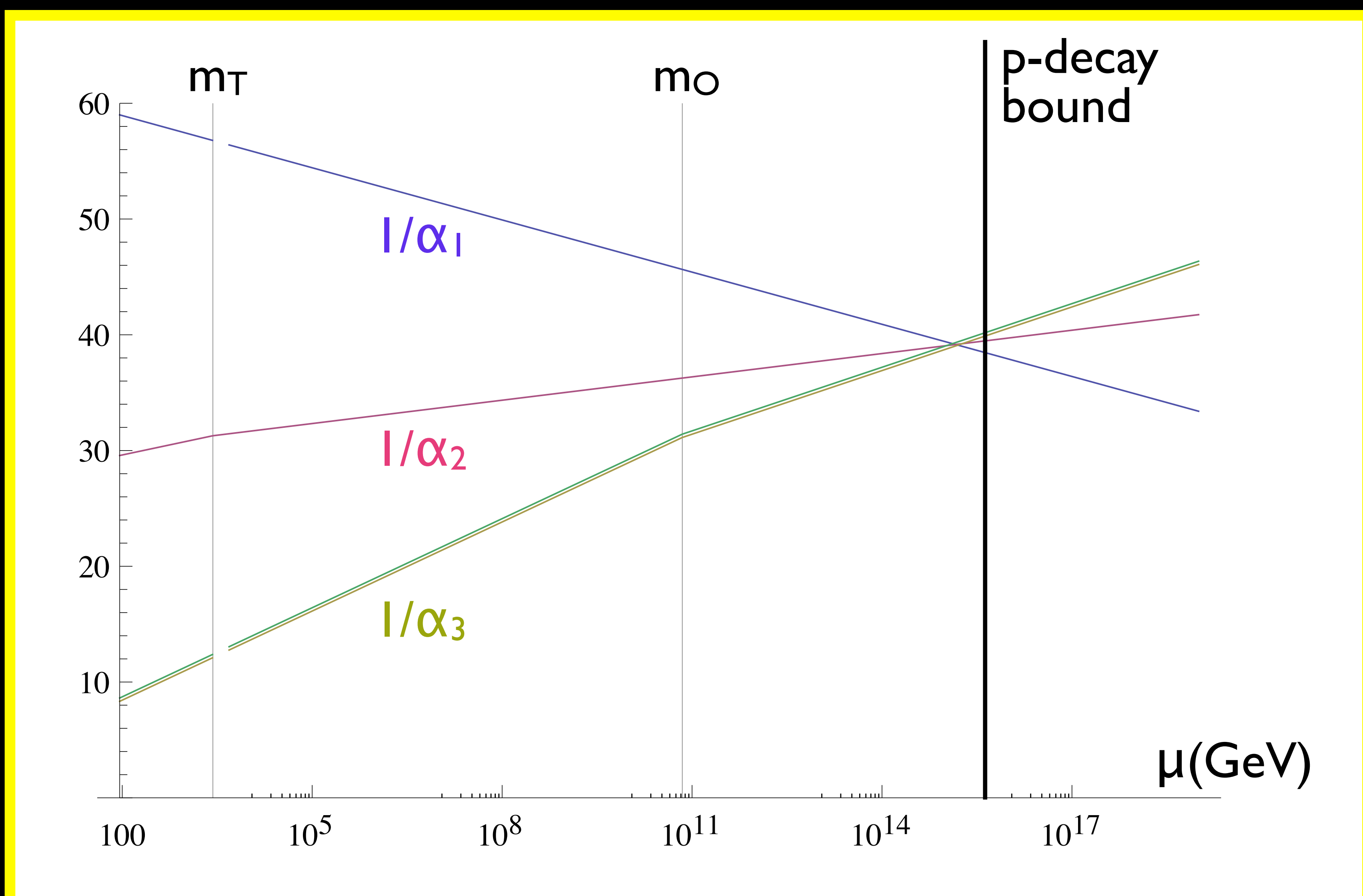
The DM candidate should be neutral, colourless, weakly interacting, stable because of P_M and should raise M_{GUT} to suppress p-decay ($-2.6 < b_1^{DM} - b_2^{DM} < -1.1$)

A unique simple possibility: a fermion triplet of $SU(2)_L$ with $Y = 0$: $T = (T^+, T^0, T^-)$. It is a W-ino without all other superpartners.

	fermions		scalars	
DM multiplet	even $SO(10)$ multiplet	$b_1^{DM} - b_2^{DM}$	odd $SO(10)$ multiplet	$b_1^{DM} - b_2^{DM}$
1_0	45	0	16	0
$2_{\pm 1/2}$	10	$-4/15$	16	$-1/15$
3_0	45	$-20/15$	144	$-5/15$
$3_{\pm 1}$	54	$-4/15$	144	$-1/15$
$4_{\pm 1/2}$	$210'$	$-88/15$	560	$-22/15$
$4_{\pm 3/2}$	$210'$	$+8/15$	720	$+2/15$
5_0	660	$-100/15$	2640	$-25/15$
...	...	...	...	...

Unifying DM

The DM triplet T has only $SU(2)_L$ gauge interactions. They lead to $m(T_0) < m(T_+)$ and fix $<\sigma_{ann}v> = (37g^4)/(96\pi\, m_T^2)$, so that the experimental value of Ω_{DM} determines $m_T = (2.75 \pm 0.15)$ TeV.



T alone is sufficient to raise M_{GUT} close to the present bound from p-decay.

α_3 can be fixed by much heavier particles, e.g. the colour octet O, part of the same 45 as T.

Collider searches

- If produced, T would leave long-lived charged tracks in the detector:

$$\tau(T^+ \to T^0 \pi^+) \simeq 5.5 \text{ cm}$$

- However, T is too heavy to be produced at LHC:

$$q\bar{q}' \to W^* \to T^+ T^0$$

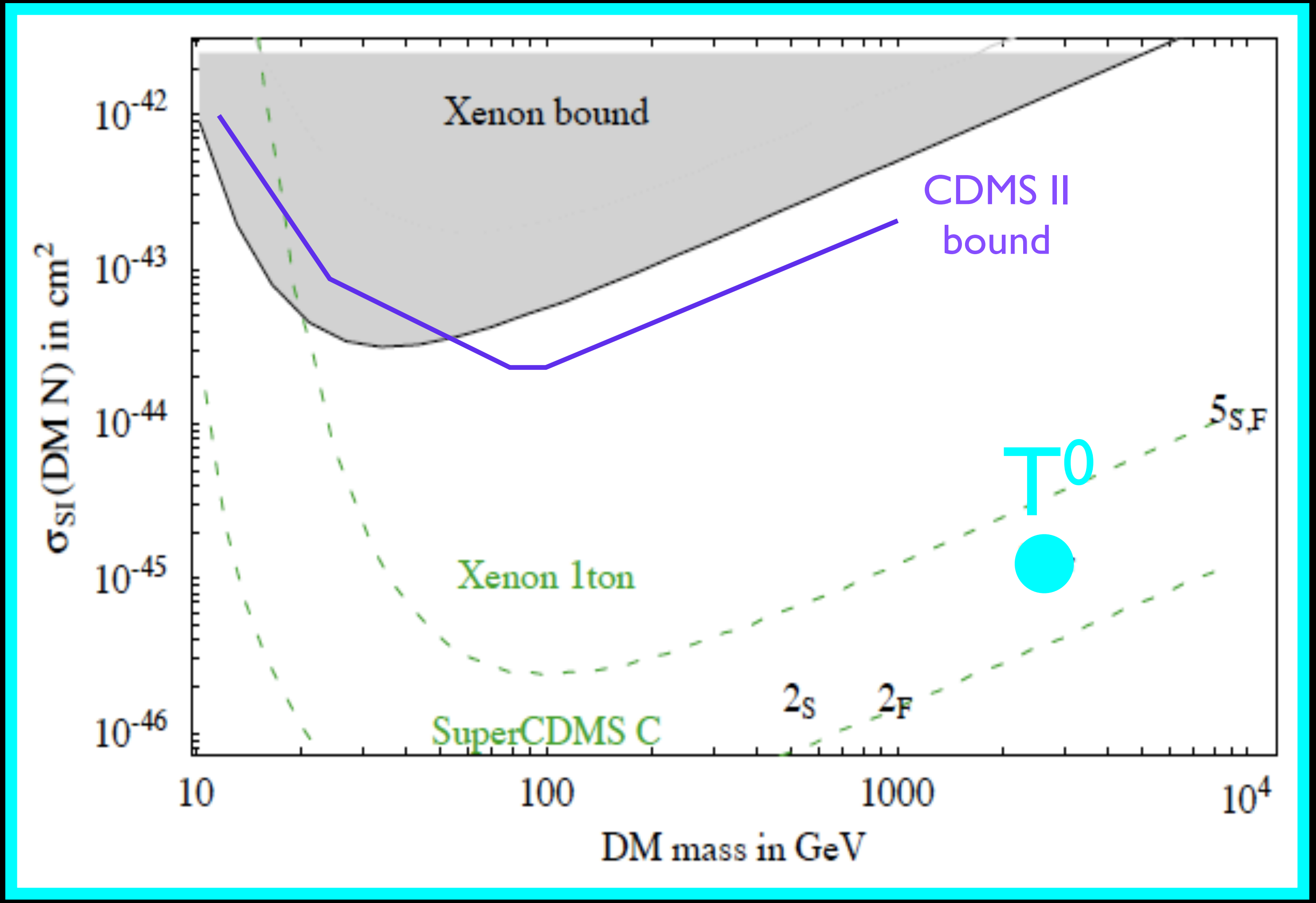
With 100 fb^{-1} only one event for m_T = 2.7 TeV (50 events for m_T = 1 TeV).

- Can one conceive T to be lighter? Only if there are other DM components or non-thermal production ...

(In)Direct DM searches

DIRECT: T^0 elastically scatters on nucleons through 2 virtual W's with $\sigma_{SI} \sim 10^{-45}\text{cm}^2$

Cirelli, Strumia, Tamburini



INDIRECT: T^0 annihilates at tree level to $W^\pm$ and at one loop to $\gamma\gamma$, γZ, ZZ. Large Sommerfeld enhancement (~10^2) since $m_T \sim m_W/\alpha_2$. Still, positron and antiproton fluxes below the astrophysical background.

Monochromatic gamma lines within the reach of, e.g., MAGIC could allow to measure m_T :

$$\langle\sigma(T^0T^0 \to \gamma\gamma)v\rangle \sim 10^{-25}\ \text{cm}^3/s$$

Proton decay searches

- The strongest constraint comes from p-decay mediated by the SO(10) gauge bosons V's

$$\tau(p \to \pi^0 e^+) > 8.2 \cdot 10^{33} \text{ years at } 90\% \text{ C.L.}$$

- This bound implies $M_V > 4.3\ 10^{15}$ GeV while, in the SM+T with $m_T = 2.7$ TeV, α_1 and α_2 cross at $M_{GUT} = 1.5\ 10^{15}$ GeV
- However, these numbers do not account for [i] two-loop RGEs; [ii] GUT thresholds; [iii] realistic (non-minimal) Yukawa couplings : a precise prediction is model-dependent

TeV scale DM from M_{GUT}

- Without SUSY, the lightness of the Higgs w.r.t. M_{GUT} requires a fine-tuning: the hierarchy problem.
  A light scalar DM would require an extra fine-tuning.

- On the contrary, the lightness of a fermion like T can be justified by a chiral symmetry, that is recovered in the limit $m_T \to 0$:

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + i\bar{T} D T - (m_T T T + \text{h.c.})$$

- To split the T (and O) mass from the other components of the 45 multiplet of SO(10) requires some model-building, analogously to the doublet-triplet splitting in SUSY models.

Summary

- Perhaps the strongest phenomenological indication of new physics at the TeV scale is a WIMP candidate for DM
- With no other TeV scale new physics, we investigated whether DM can improve gauge coupling unification and whether its stability can follow from the GUT symmetry
- There is a unique simple possibility: a fermion isotriplet T with no hypercharge and mass about 2.7 TeV
- T is accessible to near future DM searches and $p \to e^+ \pi^0$ is expected close to the experimental limit