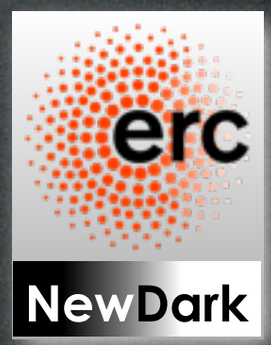
1 December 2016
Journée Matière Sombre France, APC Paris

Dark Matter DD 'theory'

Or of why one should not trash WIMPs (yet)

Marco Cirelli
(CNRS LPTHE Jussieu Paris)



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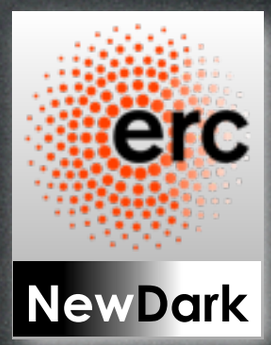

Executive summary

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- DM exists

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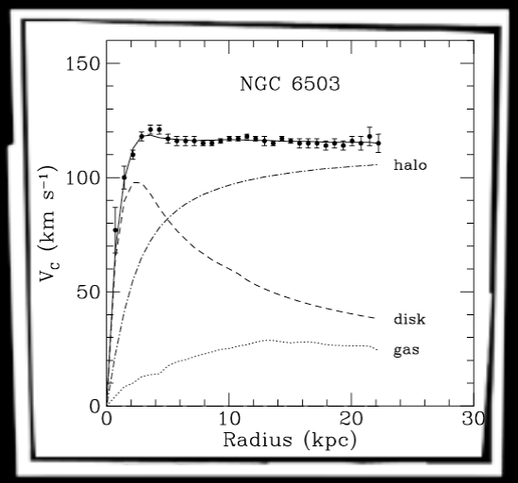
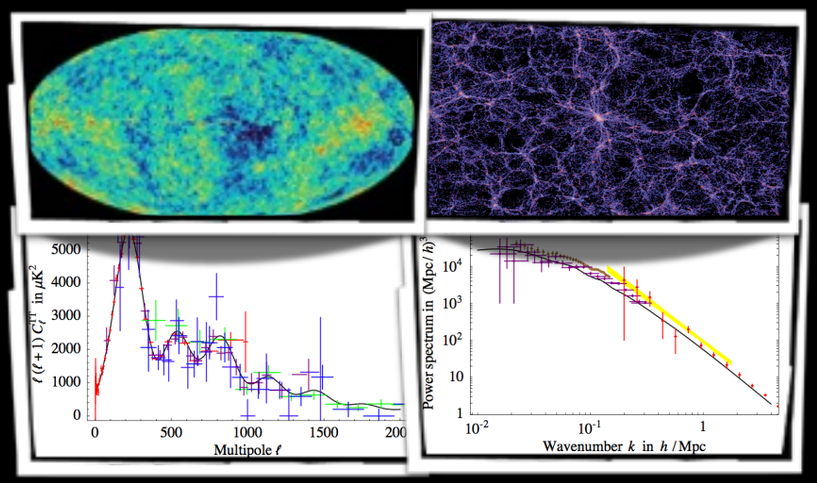


galactic rotation curves

weak lensing (e.g. in clusters)



'precision cosmology' (CMB, LSS)

Executive summary

- DM exists
- it's a new, unknown corpuscule

dilutes as $1/a^3$ with universe expansion

Executive summary

- DM exists
- it's a new, unknown particle

no SM particle can fulfil

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Executive summary

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- makes up 26% of total energy
  82% of total matter

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$$\Omega_{\rm DM} h^2 = 0.1199 \pm 0.0027$$

(notice error!)

[Planck 2015, 1502.01589]

Executive summary

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Mass??

Charge??
Interactions??

Candidates

The Dark Matter theory space:

Candidates

The Dark Matter theory space:

SuSy DM

Non SuSy DM

Candidates

The Dark Matter theory space:

SuSy DM

Non SuSy DM

?

Candidates

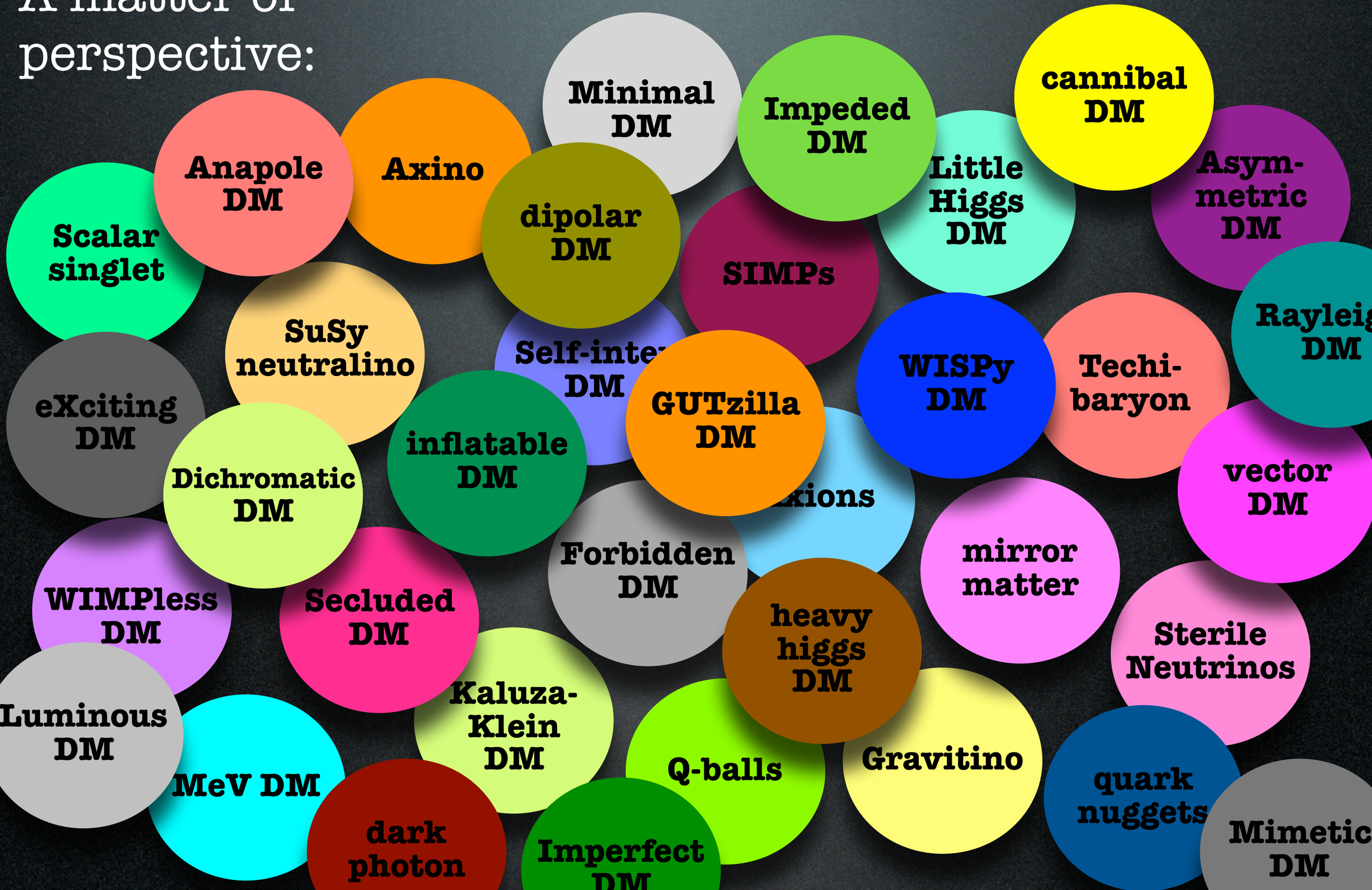
The Dark Matter theory space:

SuSy neutralino

other exotic candi-dates

Candidates

A matter of perspective:



Candidates

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Candidates

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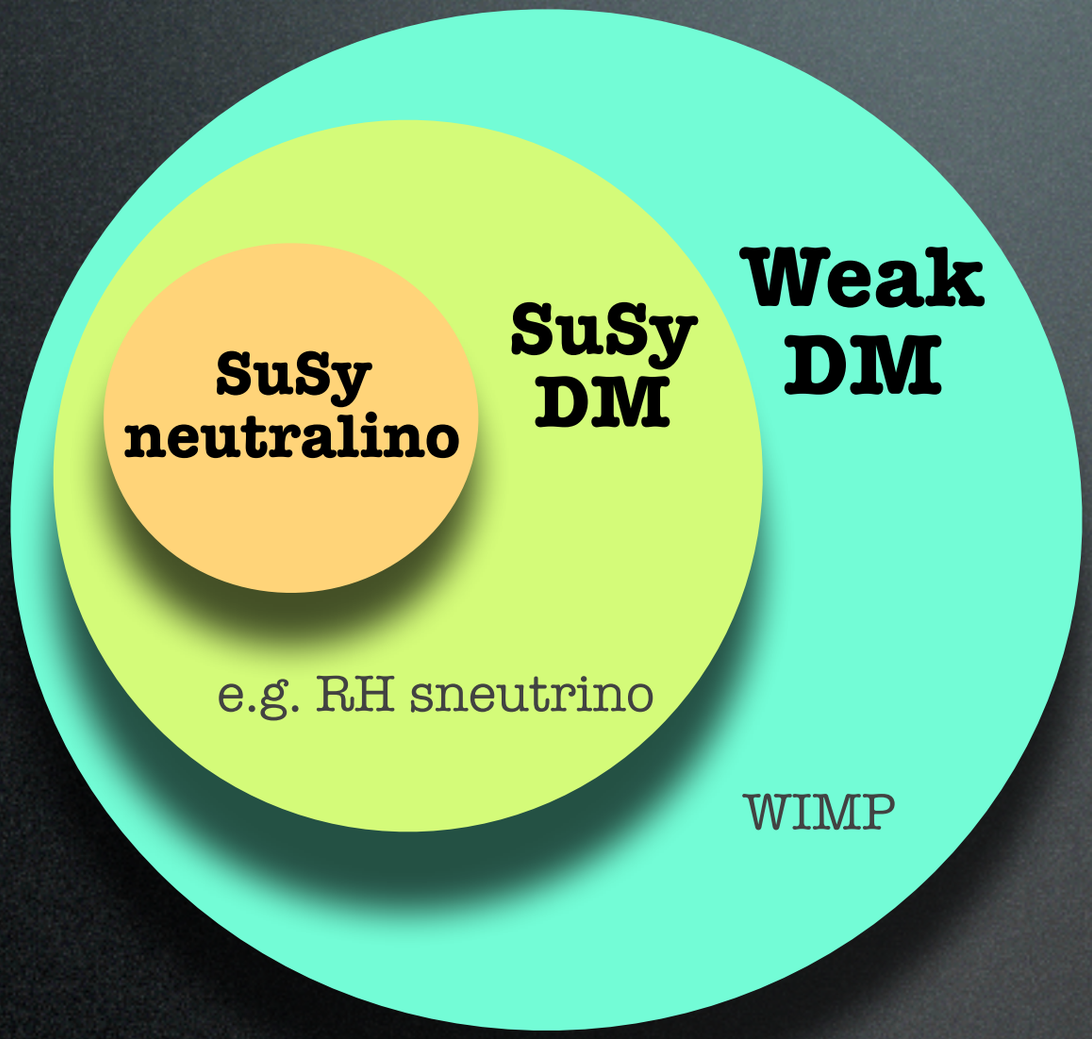

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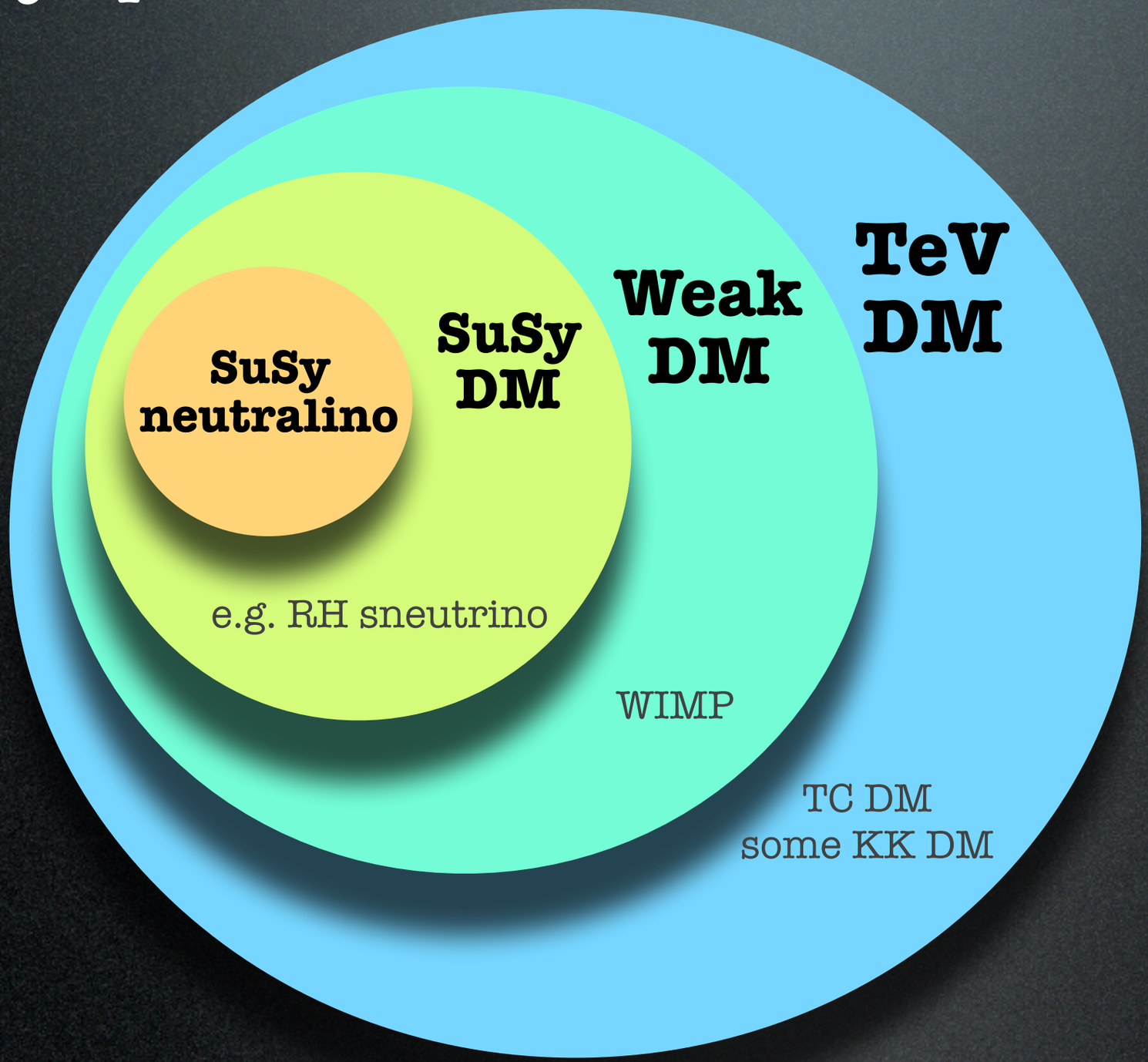

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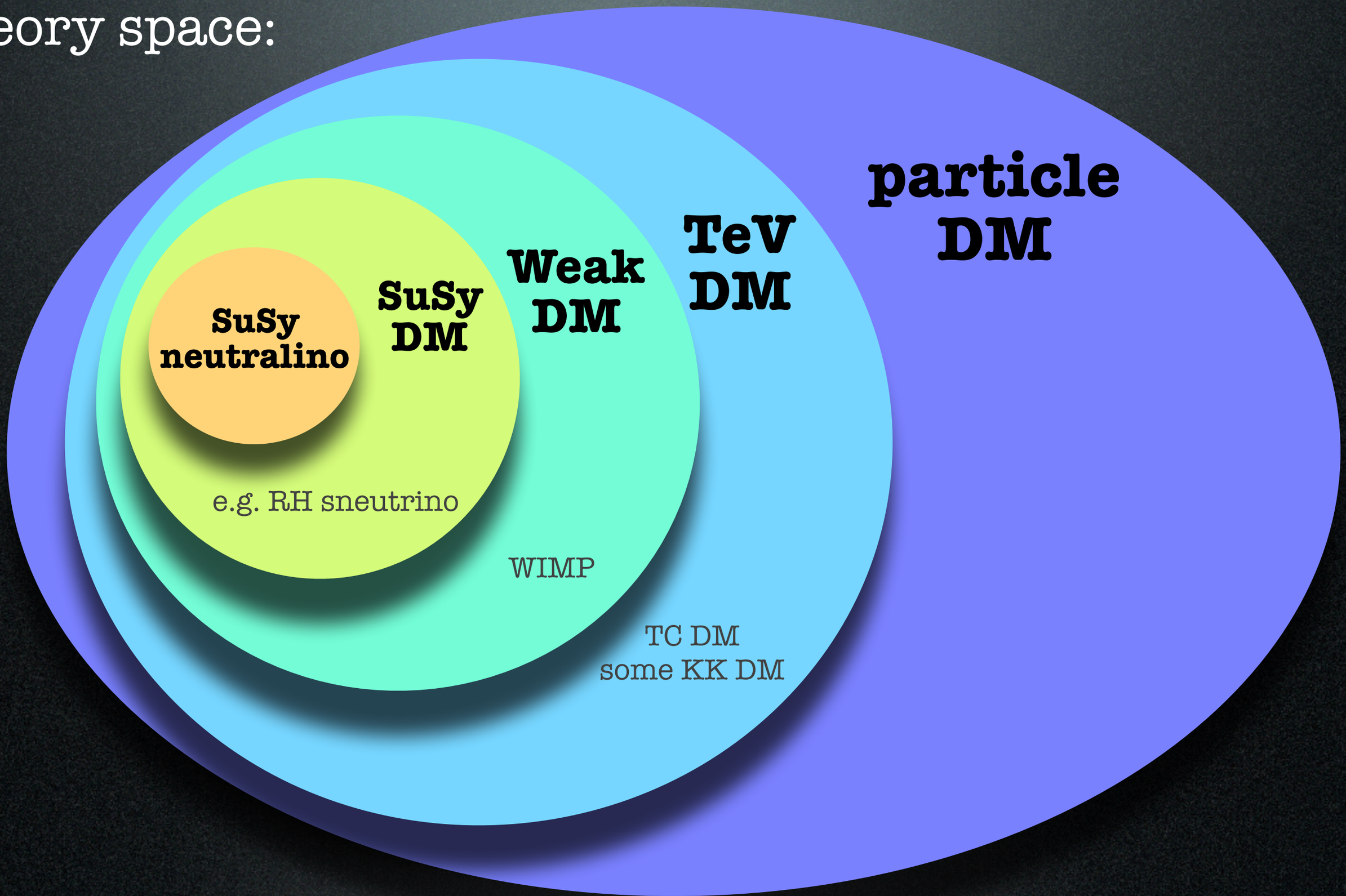

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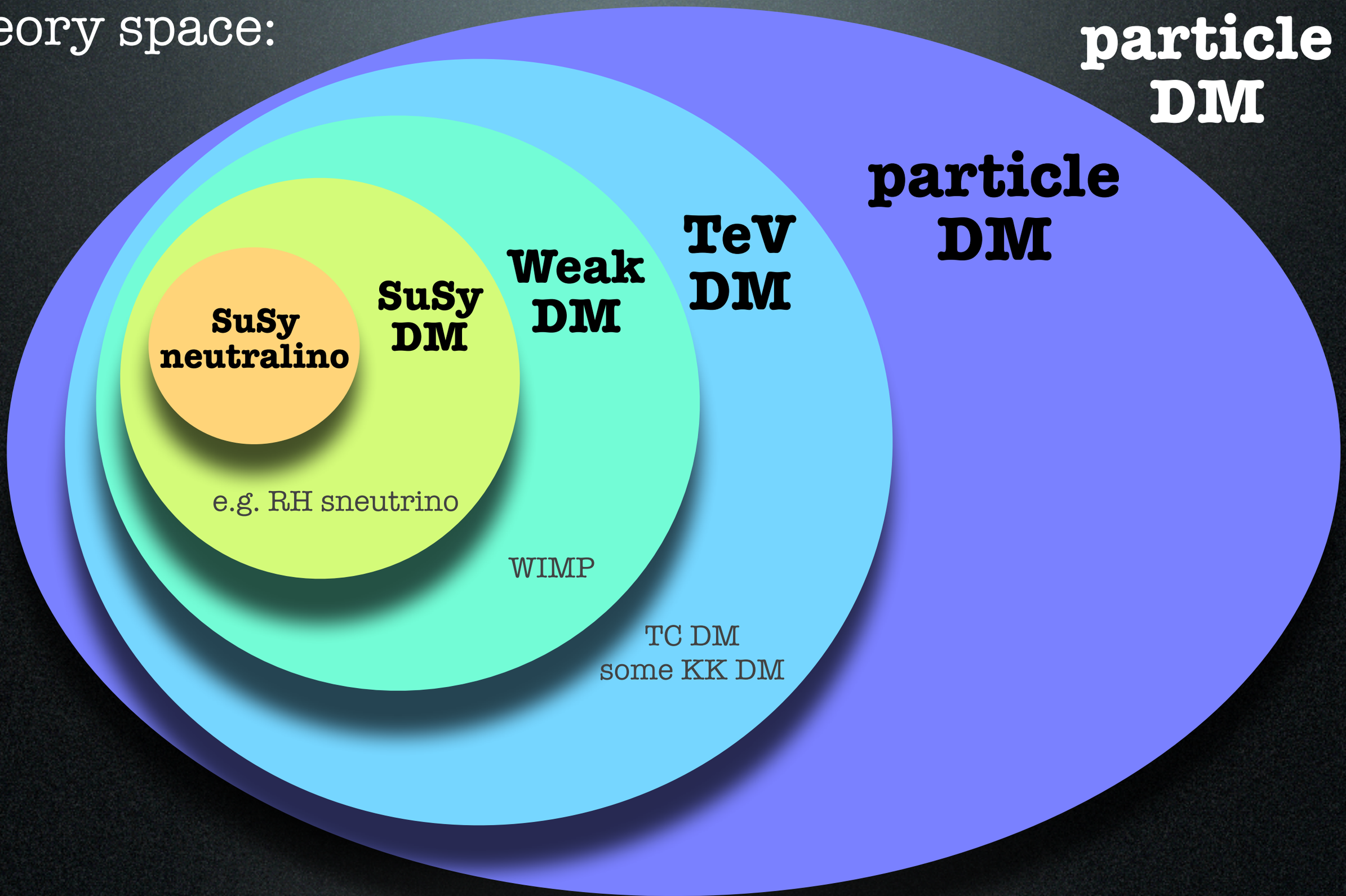
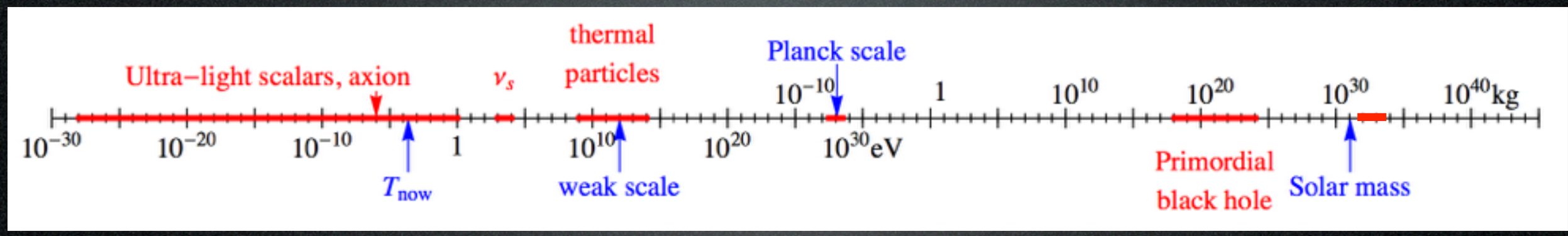


Candidates

A matter of perspective: plausible mass ranges



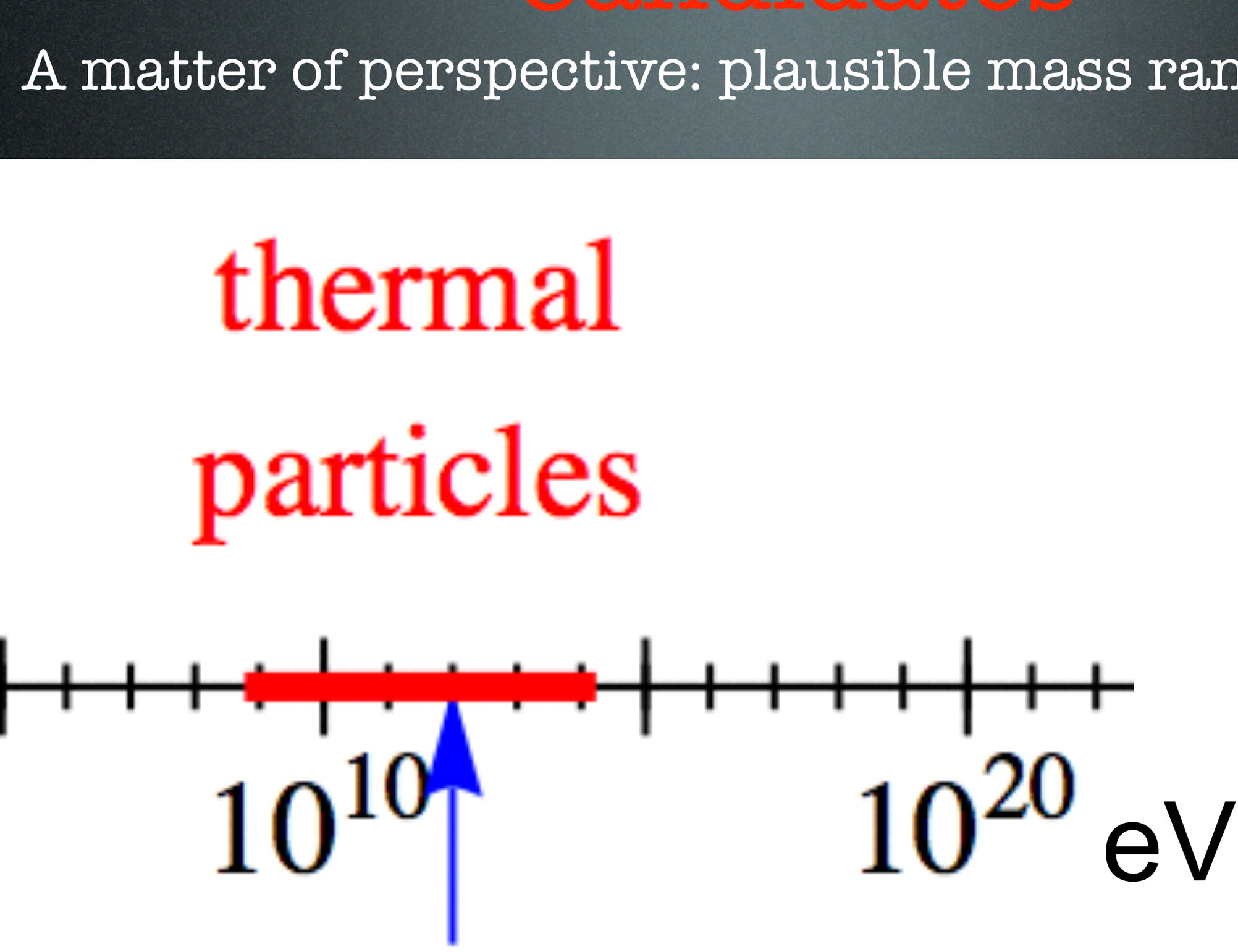
‘only’ 90 orders of magnitude!

Candidates

A matter of perspective: plausible mass ranges

thermal

particles



Candidates

WIMPs

Candidates

new physics at the TeV scale

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WIMPs

LHC

AMS, Fermi, CTA
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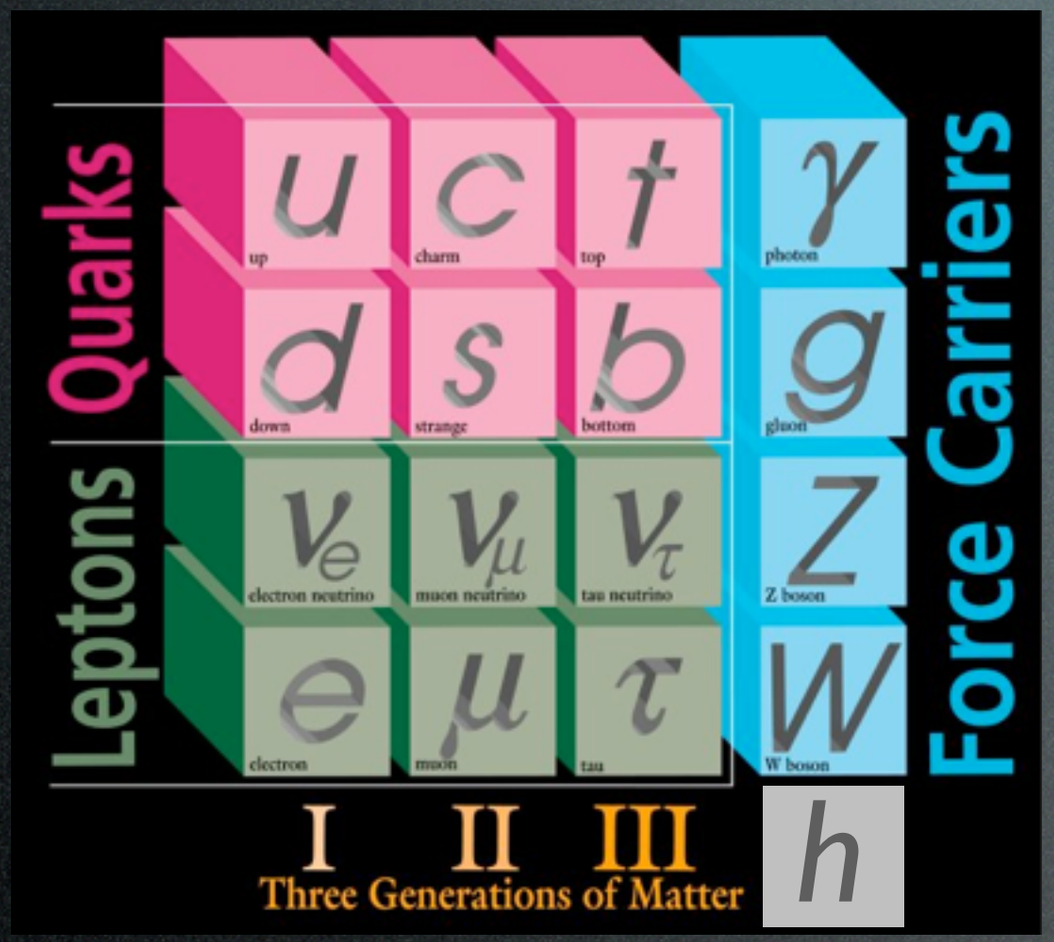
Direct Detection

SuSy DM in 2 minutes



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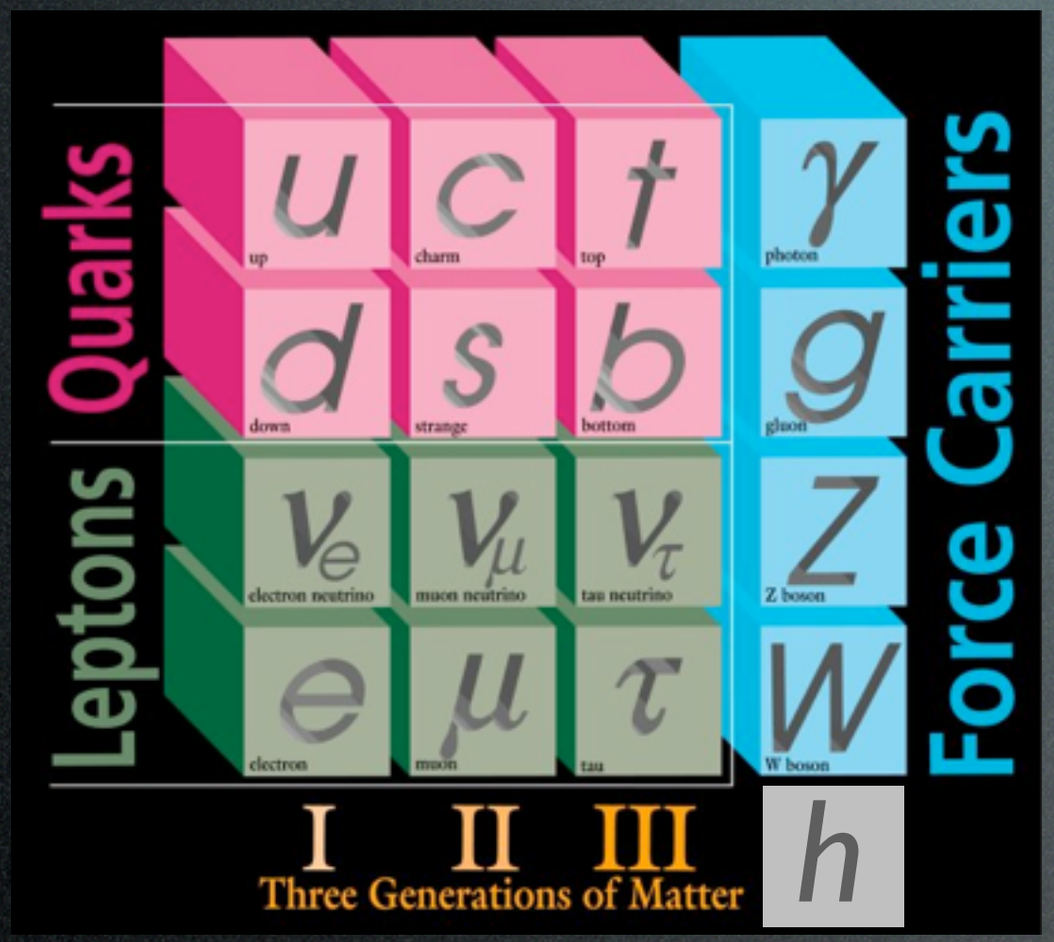
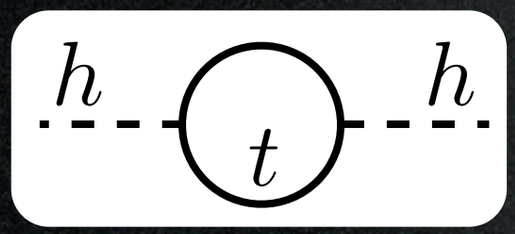


$m_{\rm h} \simeq 125$ GeV



$\Delta m_{\rm h} \propto 10^{19}$ GeV

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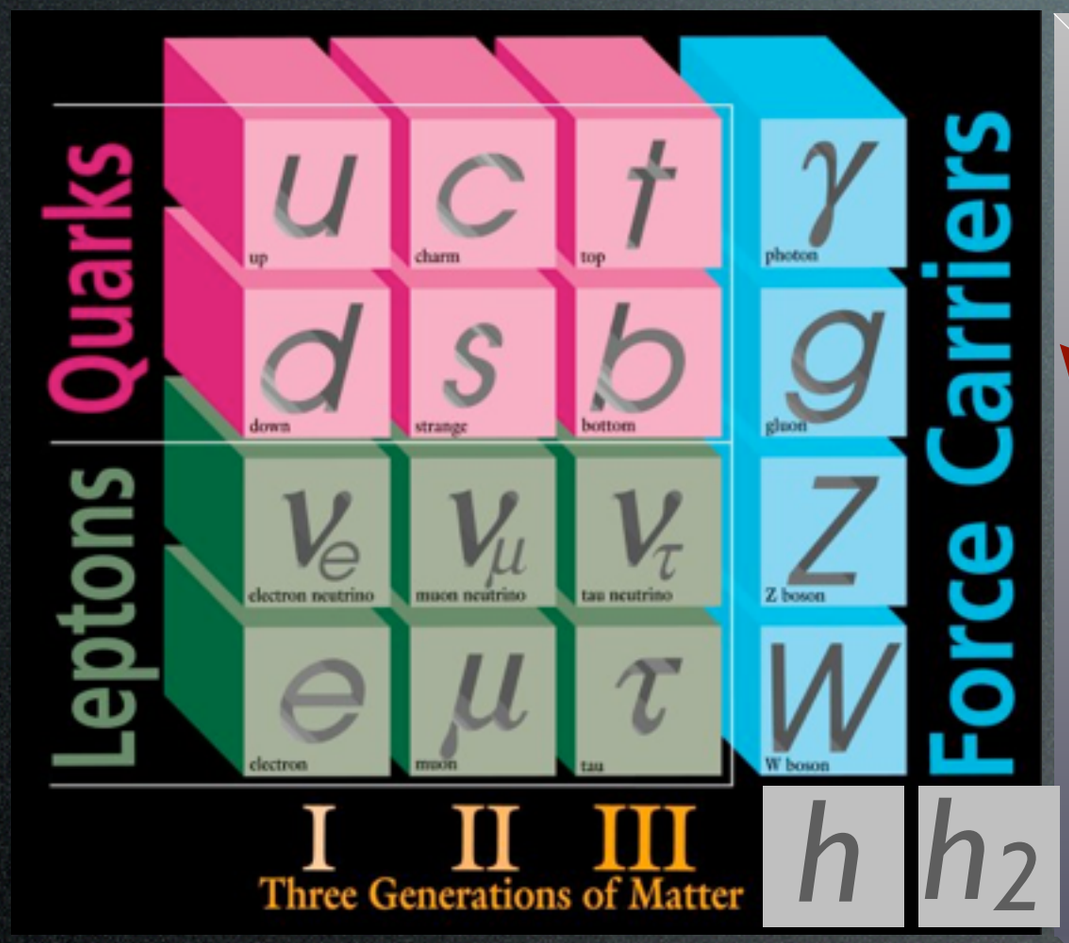
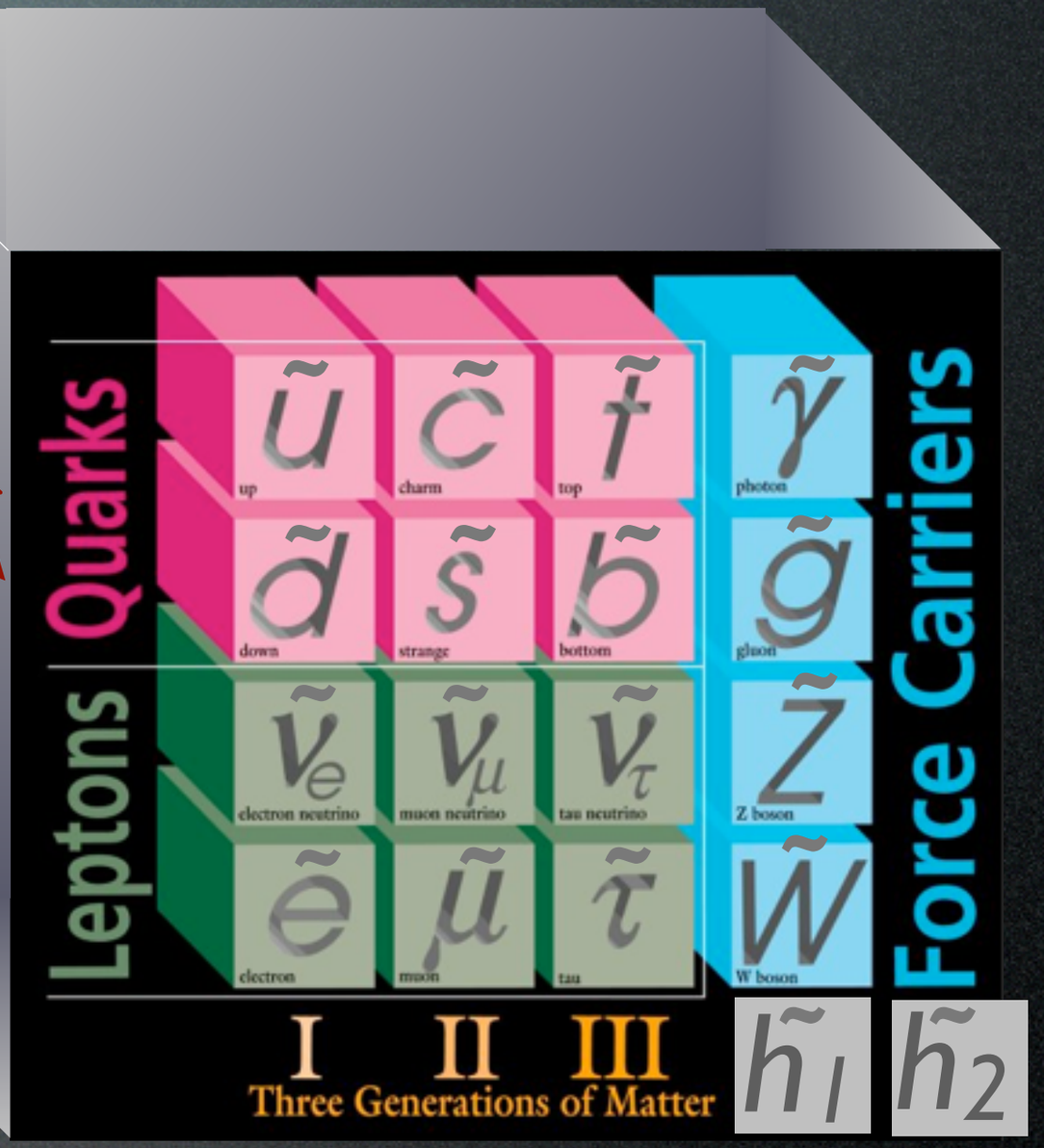


200 GeV



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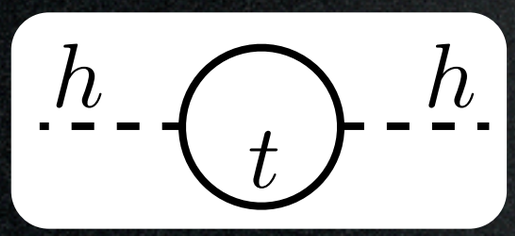

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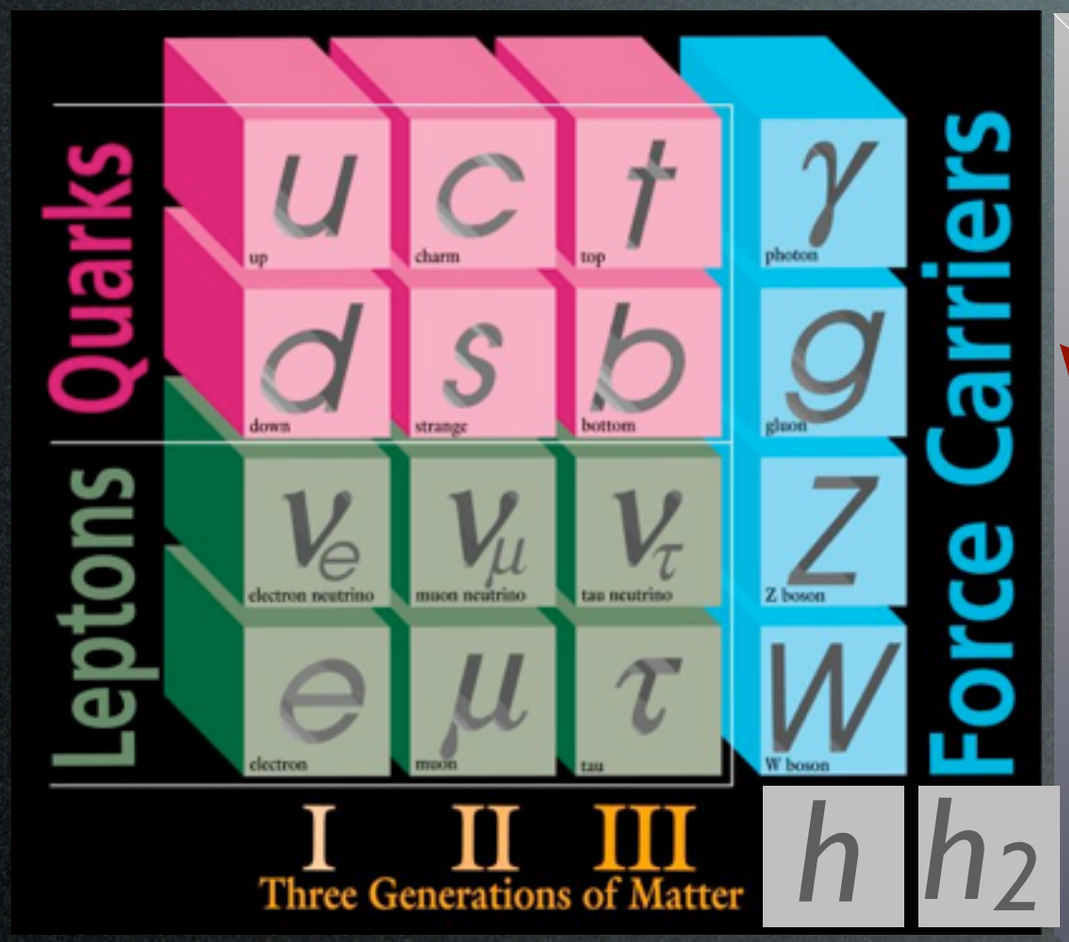

$R = +1$

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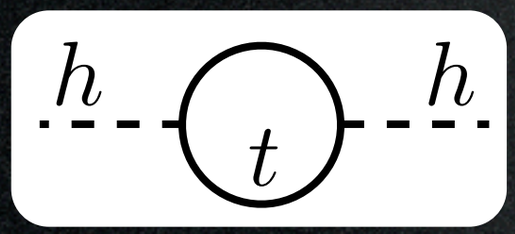

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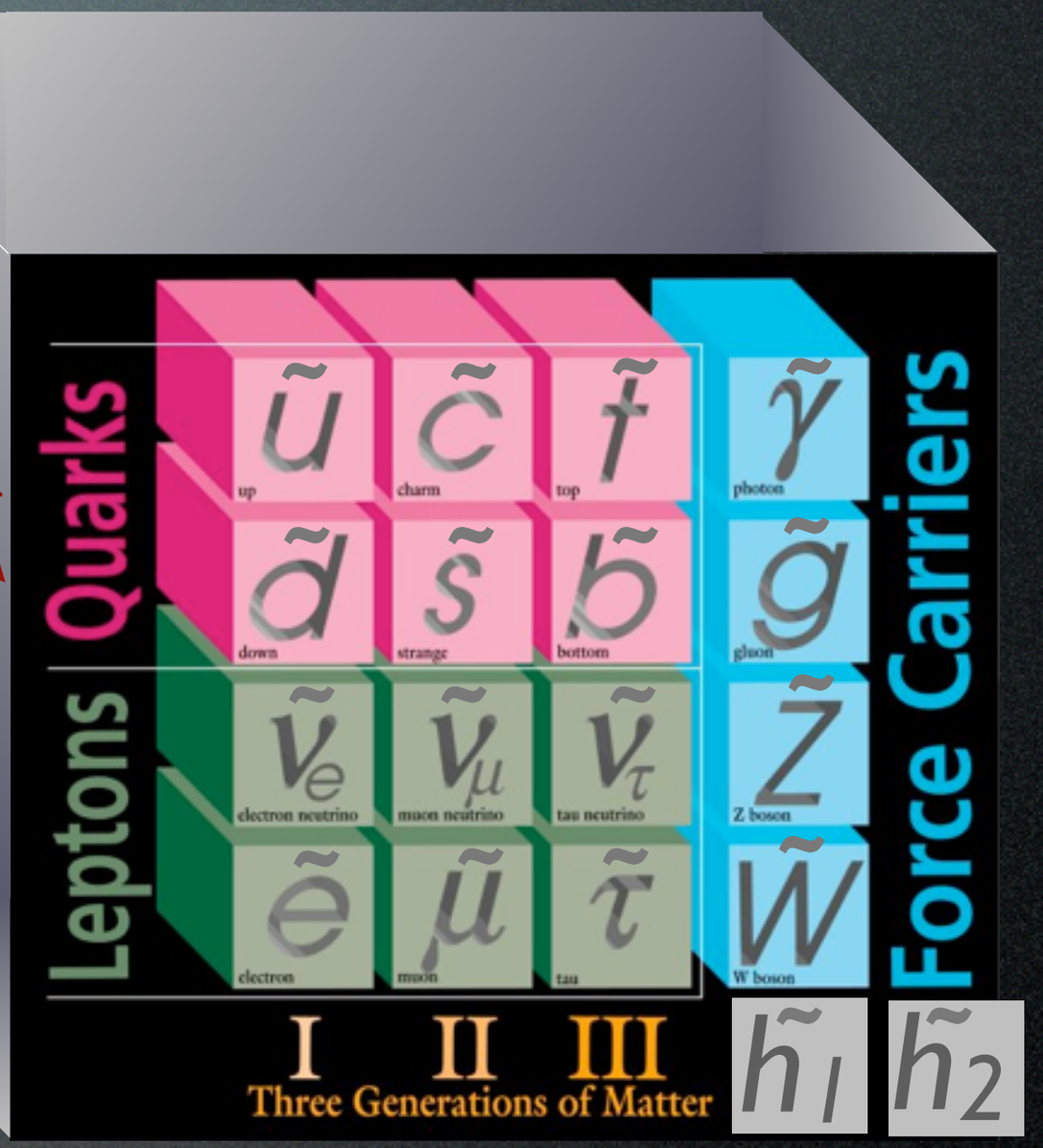

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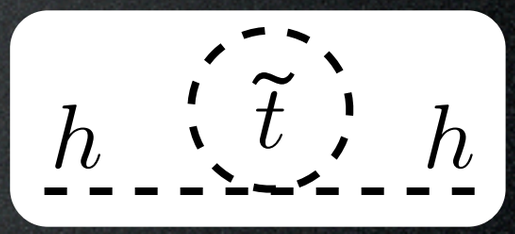

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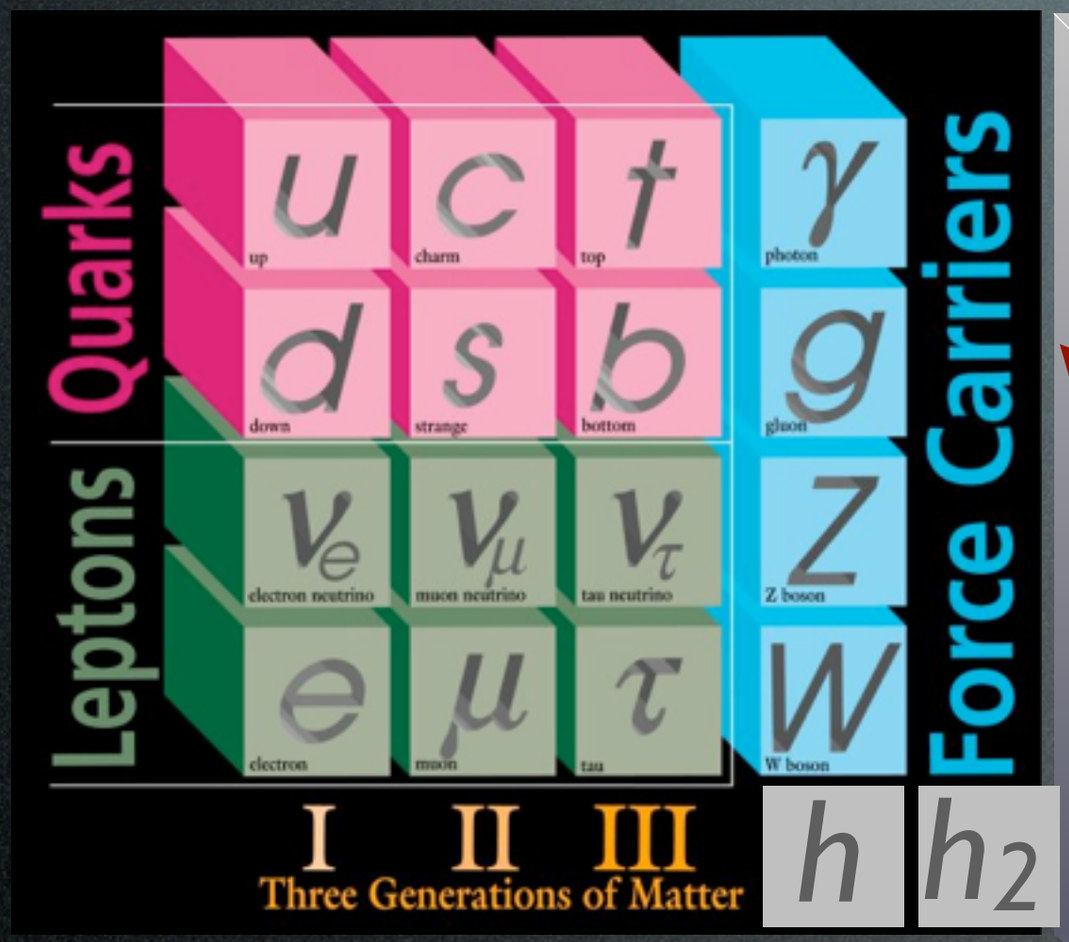

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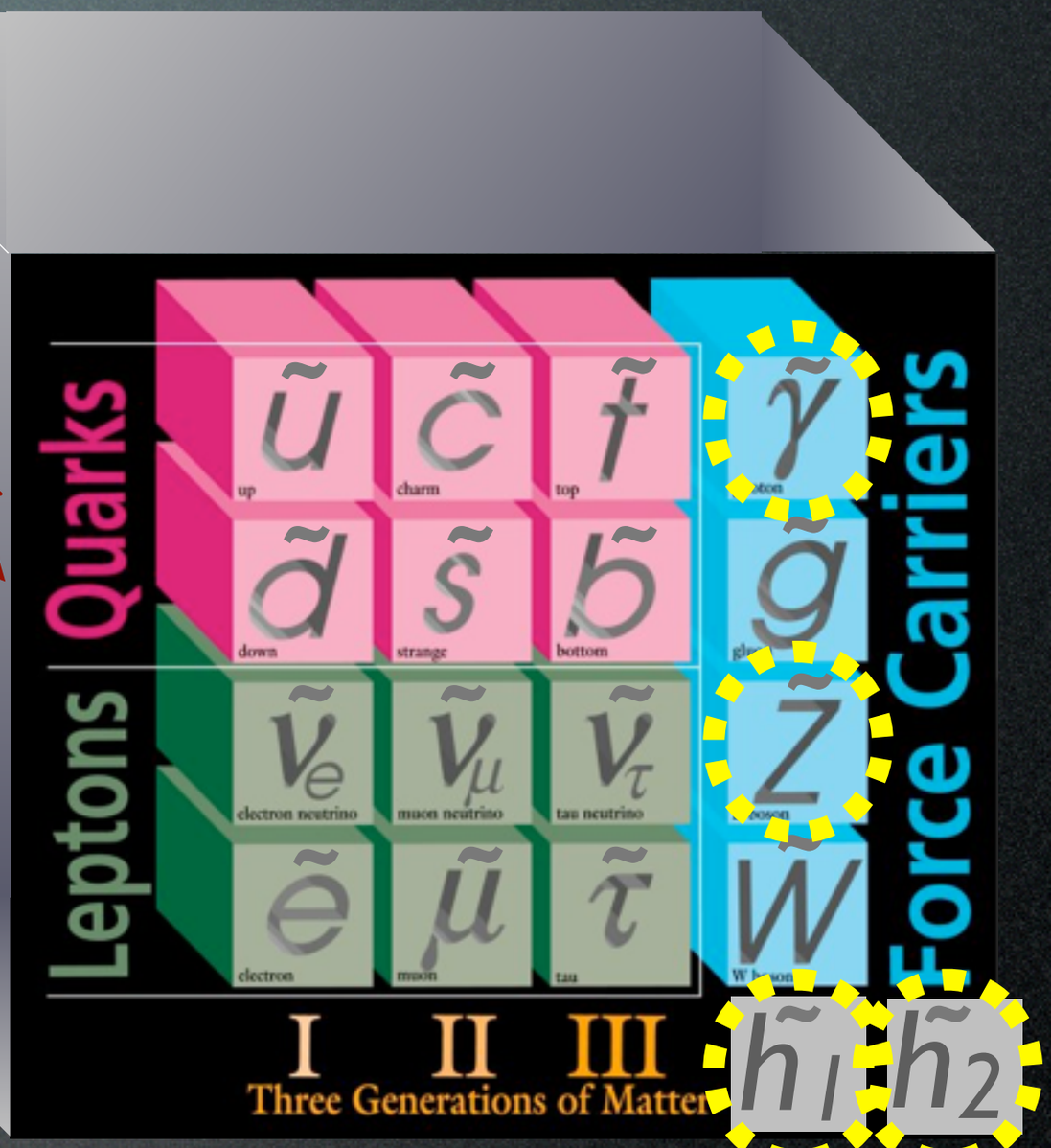

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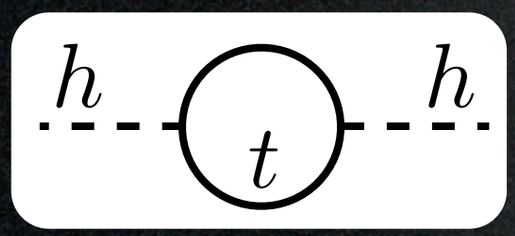

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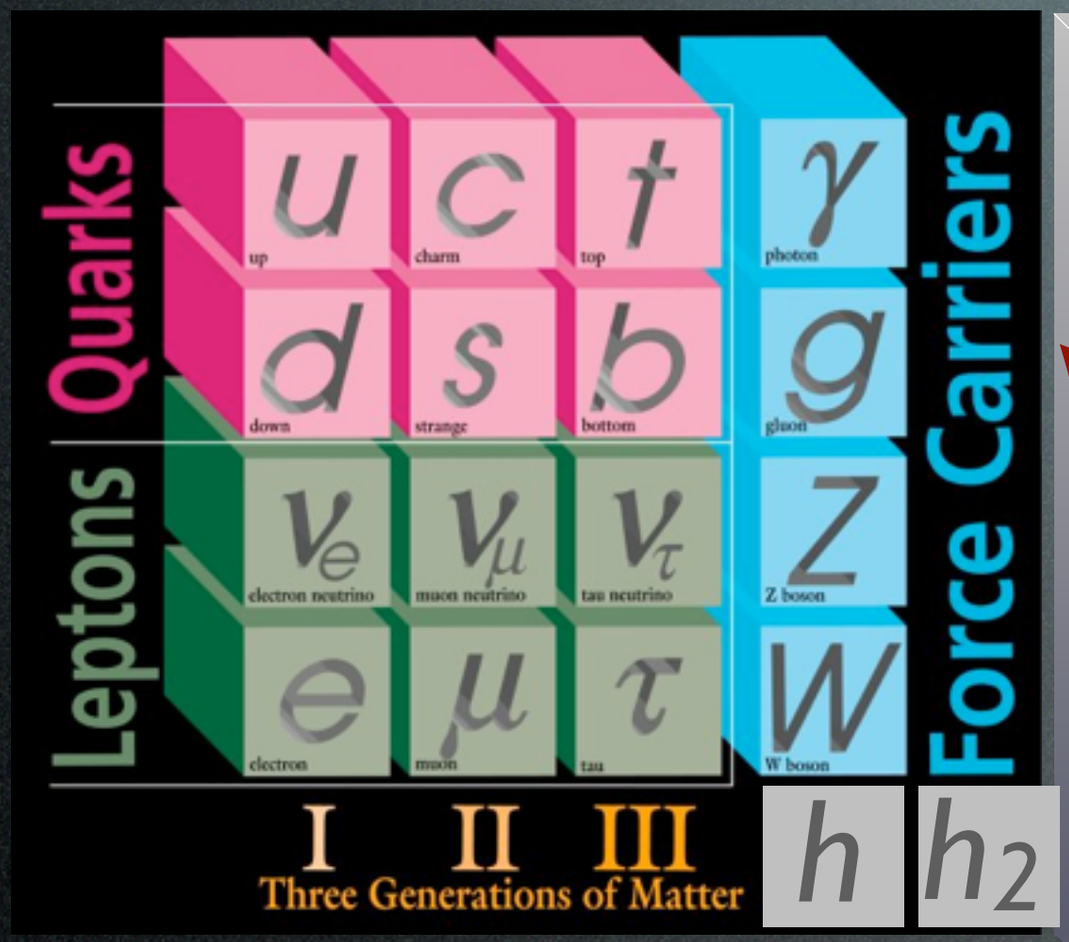

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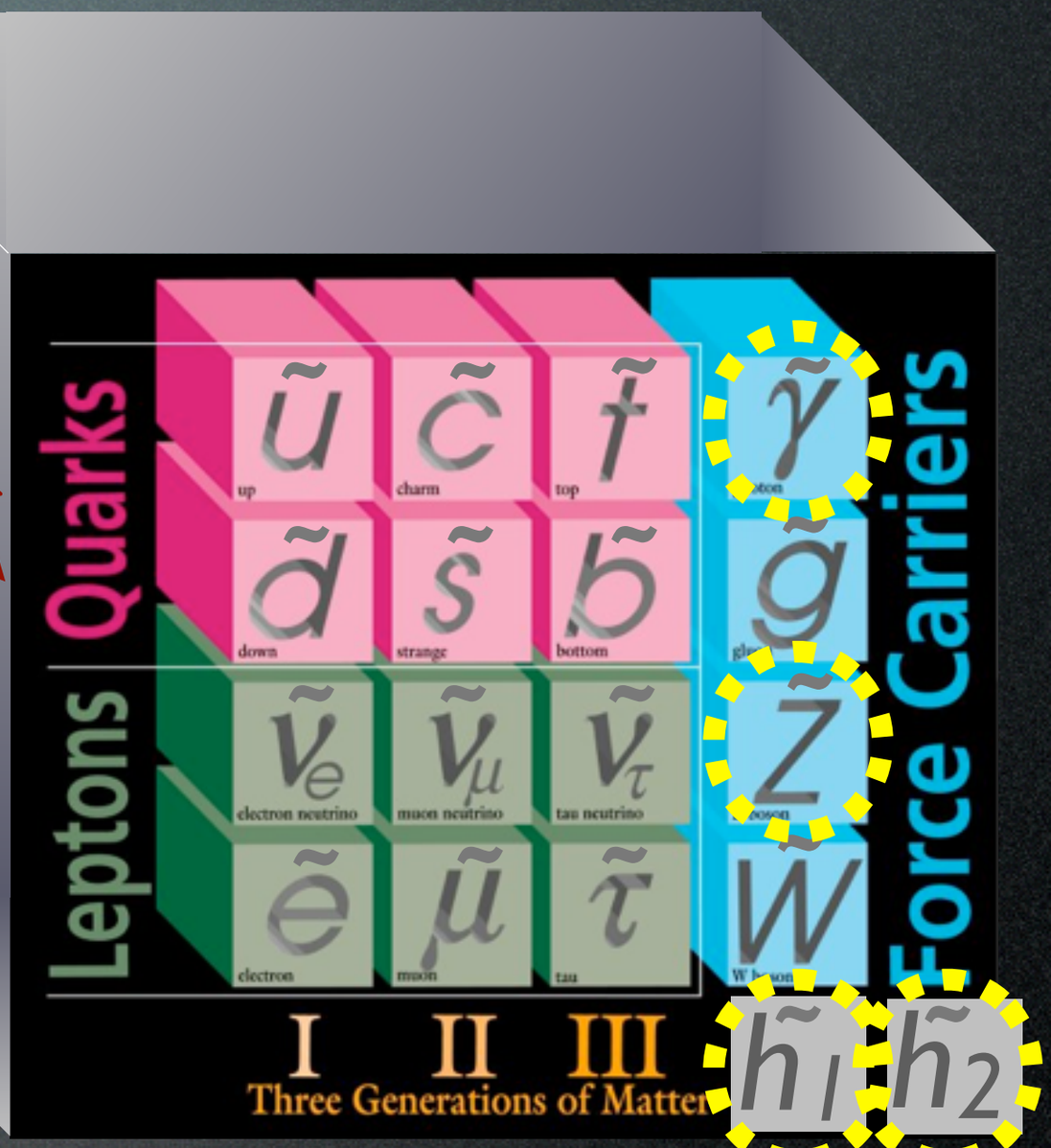

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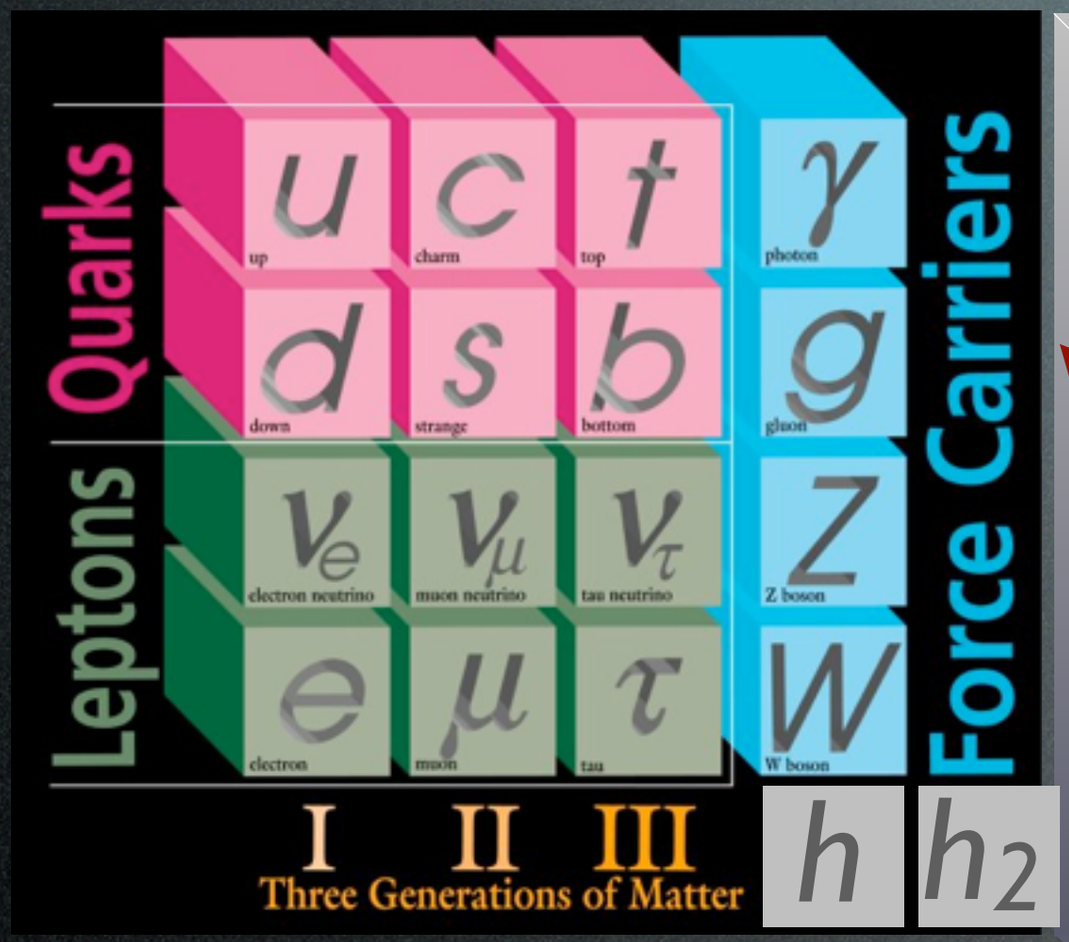

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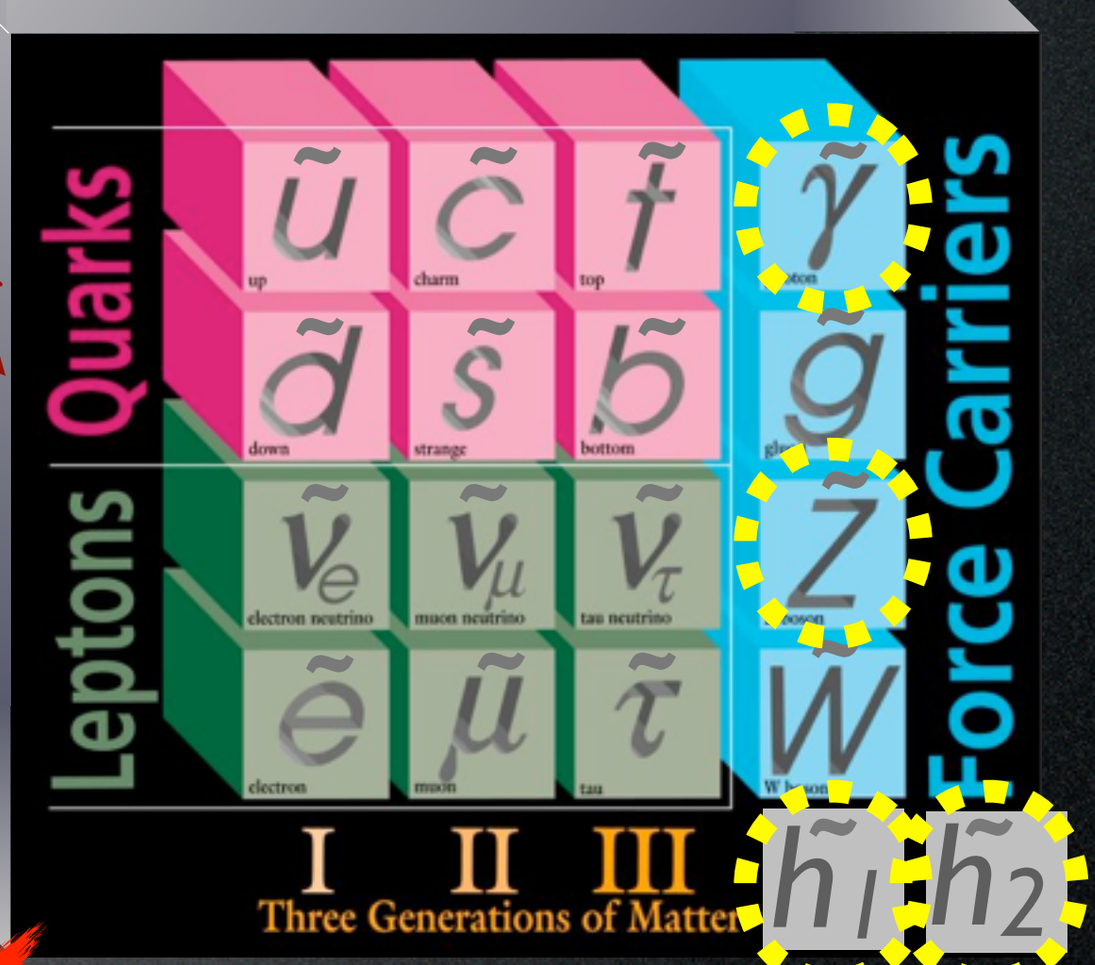

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prevent
proton decay

Candidates

new physics at the TeV scale

thermal freeze-out

WIMPs

LHC

AMS, Fermi, CTA
Antares, Icecube

Direct Detection

DM as a thermal relic from the Early Universe

Boltzmann equation in the Early Universe:

$$\Omega_X \approx \frac{6\ 10^{-27}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle\sigma_{\mathrm{ann}} v\rangle}$$

Relic $\Omega_{\mathrm{DM}} \simeq 0.23$ for

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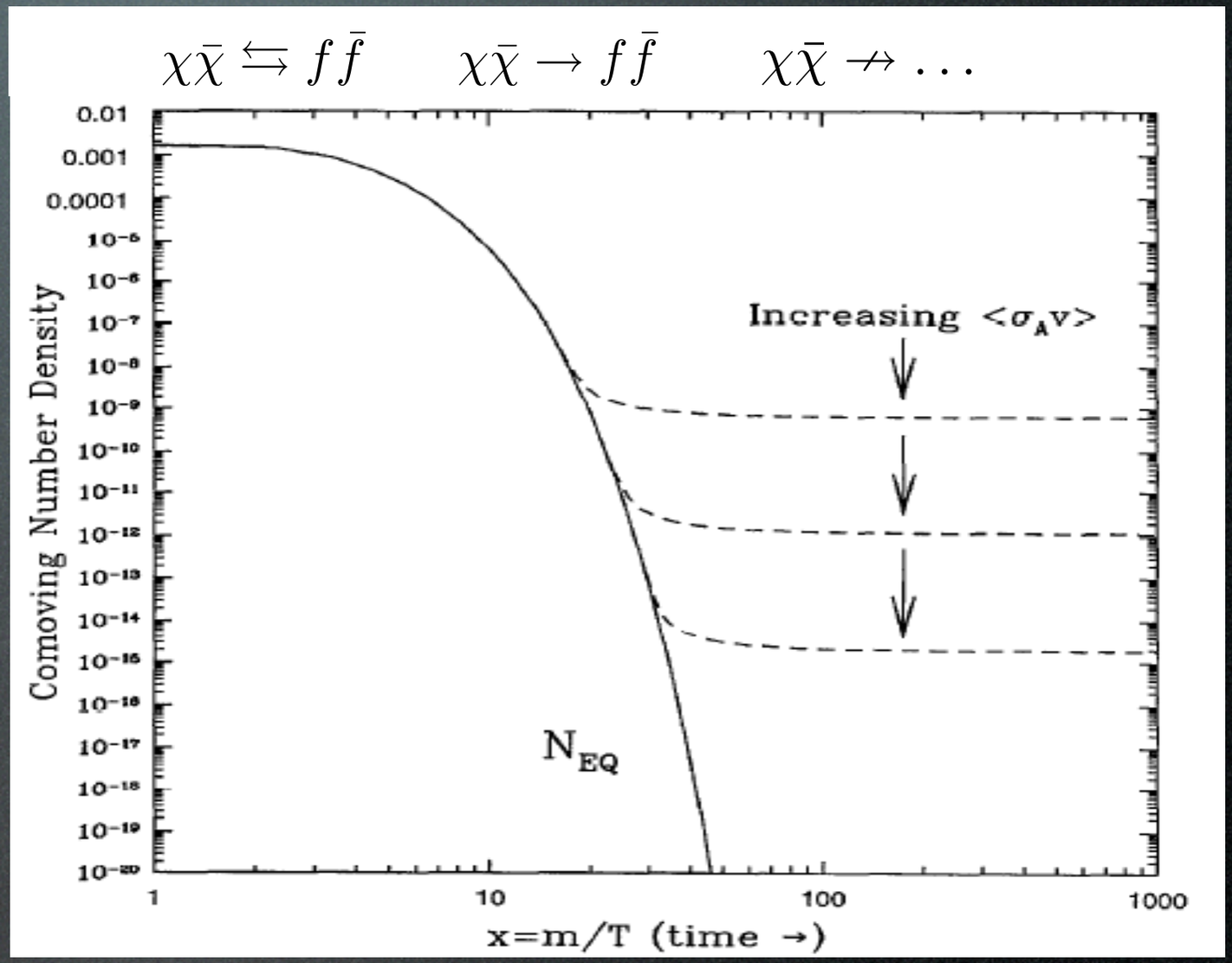

Kolb,Turner, The Early Universe, 1995

Weak cross section:

$$\langle\sigma_{\mathrm{ann}} v\rangle \approx \frac{\alpha_w^2}{M^2} \approx \frac{\alpha_w^2}{\mathbf{1\,TeV^2}} \Rightarrow \Omega_X \sim \mathcal{O}(\text{few } 0.1)$$

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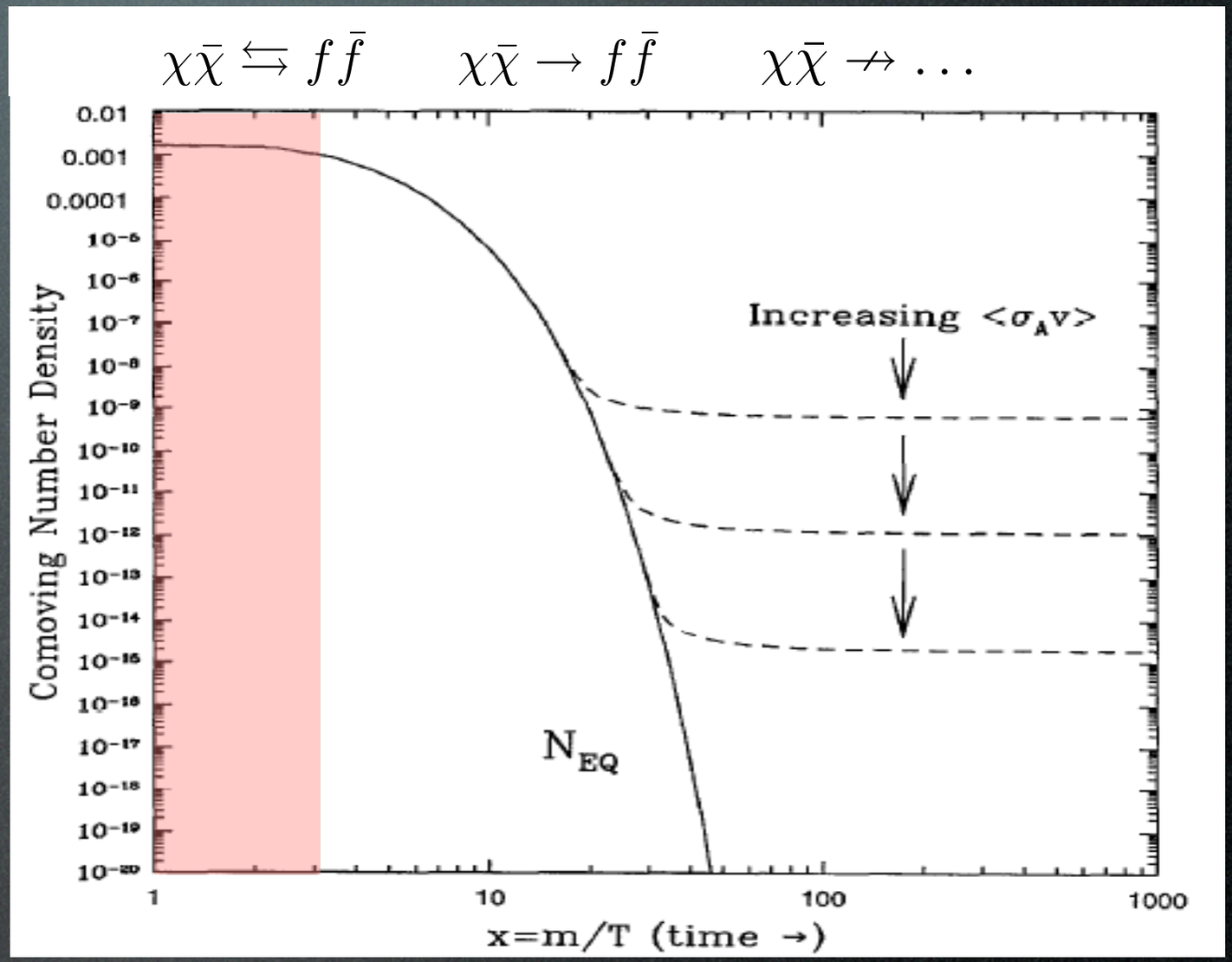

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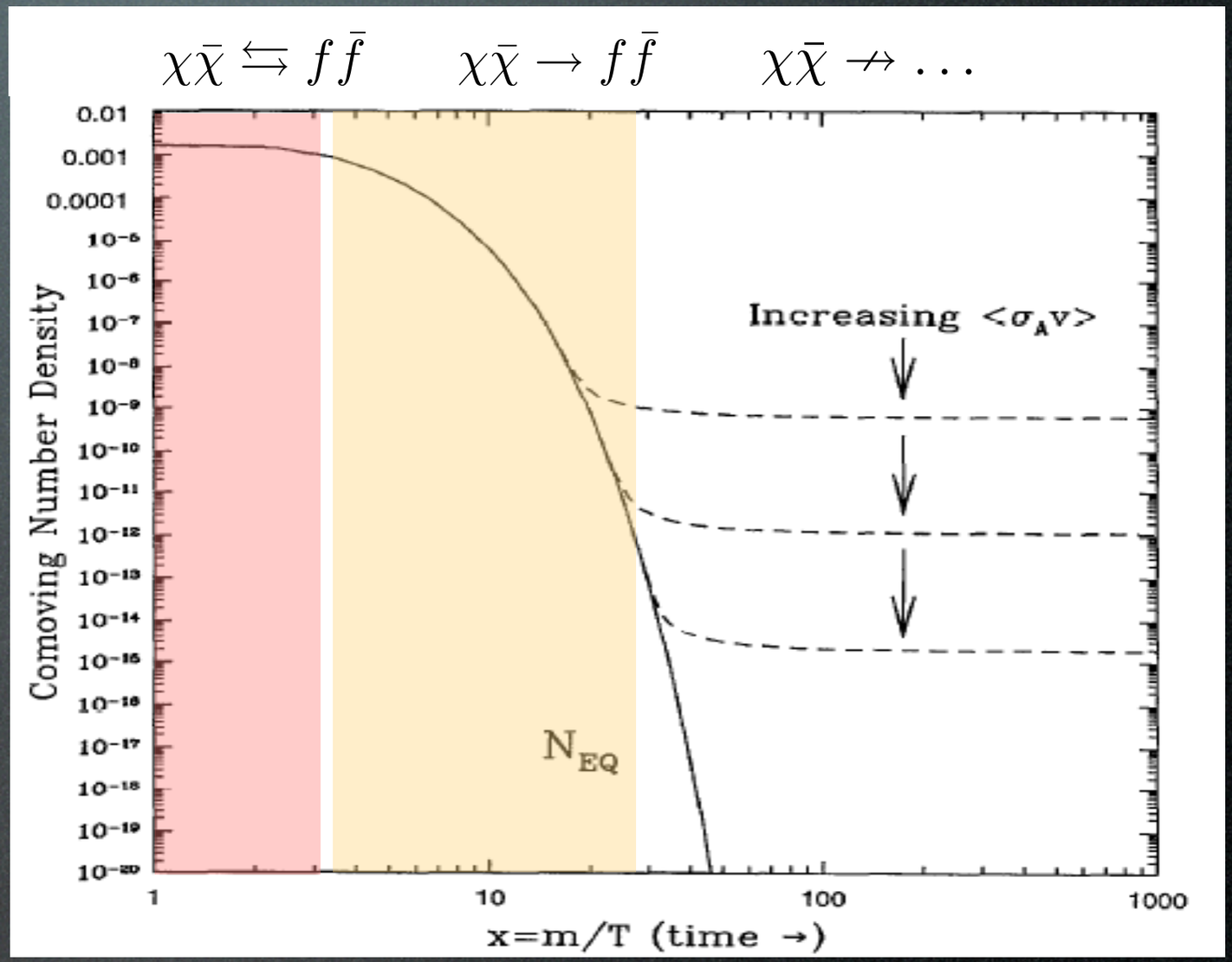

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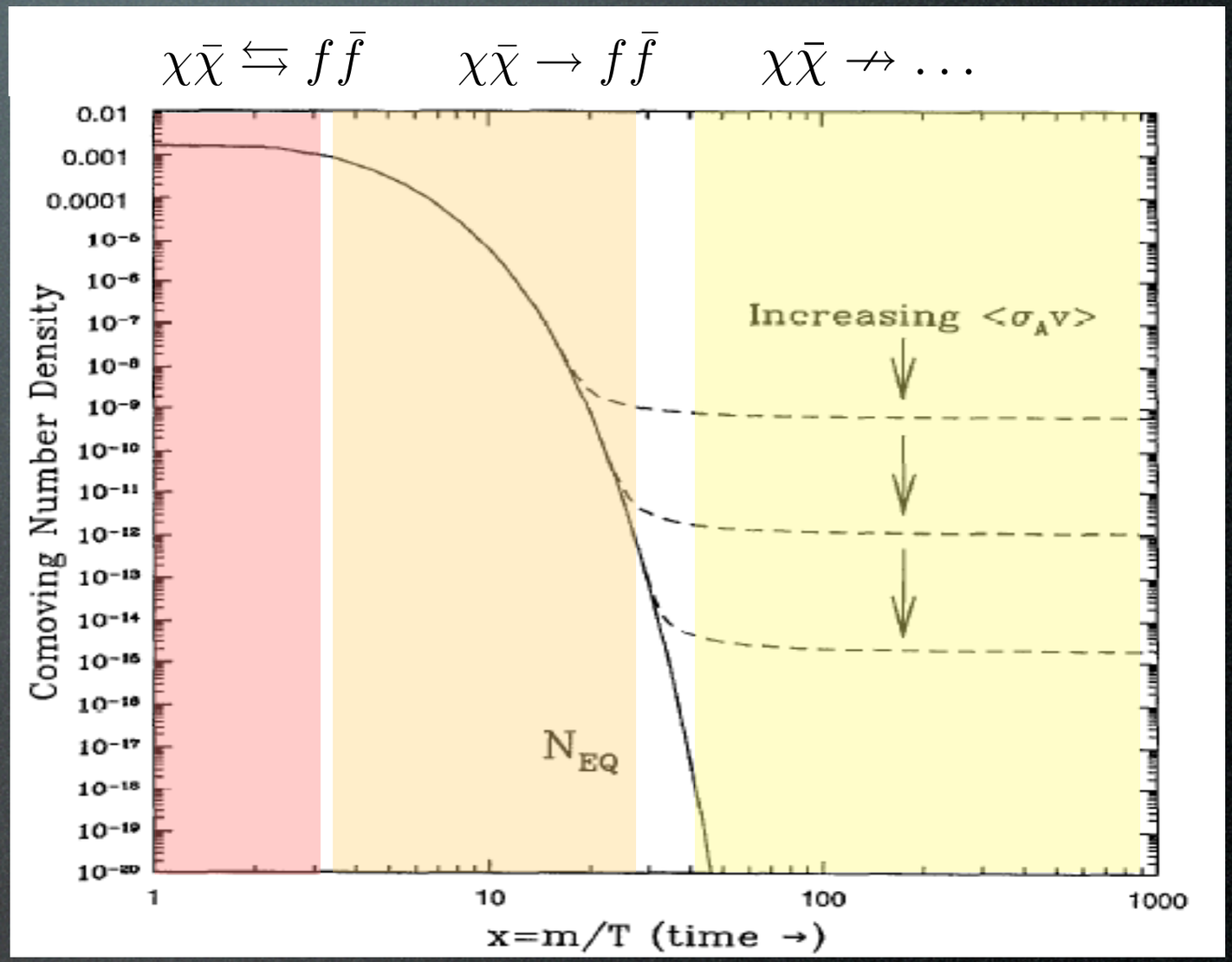

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new physics at the TeV scale

thermal freeze-out

WIMPs

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Direct Detection

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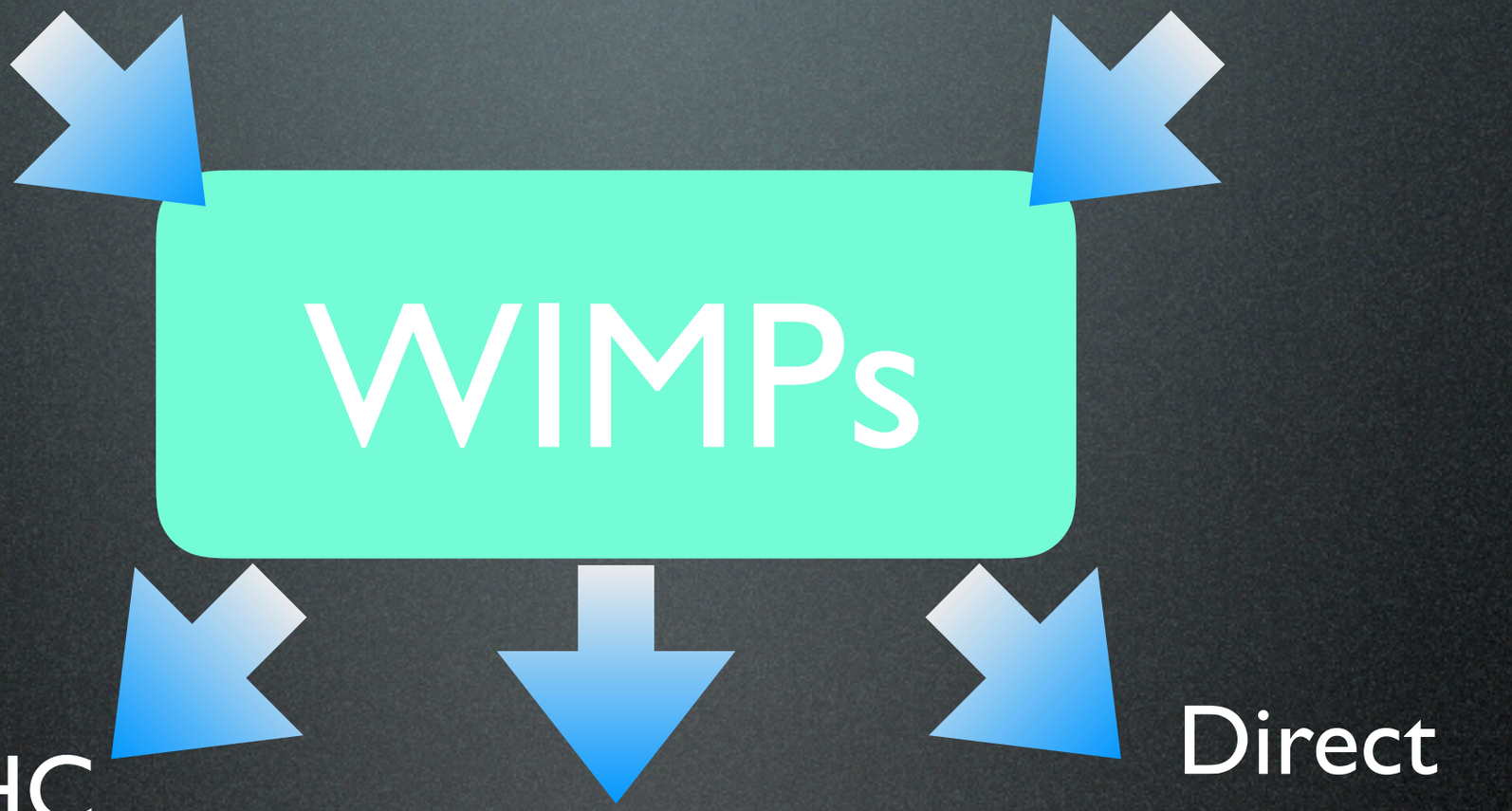

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Direct Detection

1.
2.

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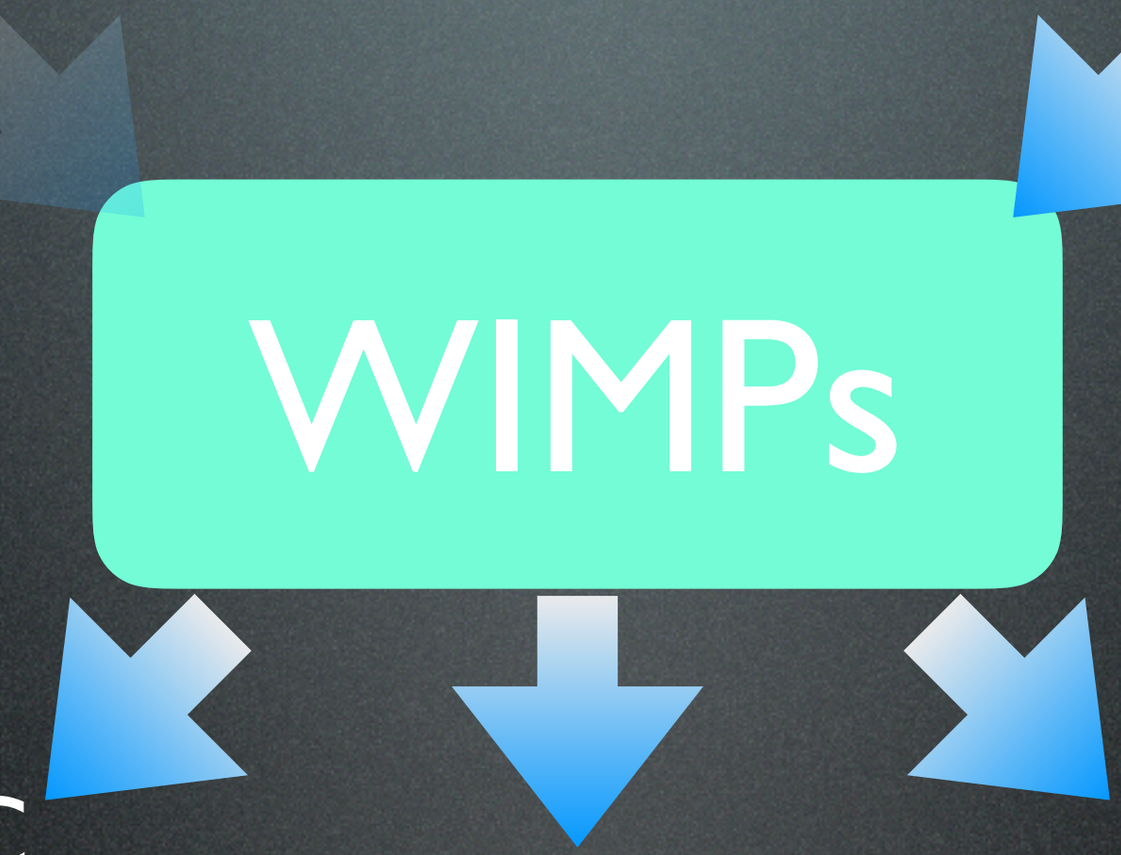

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Direct Detection

1. even without a larger framework, WIMPs are still appealing
2.

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Direct Detection

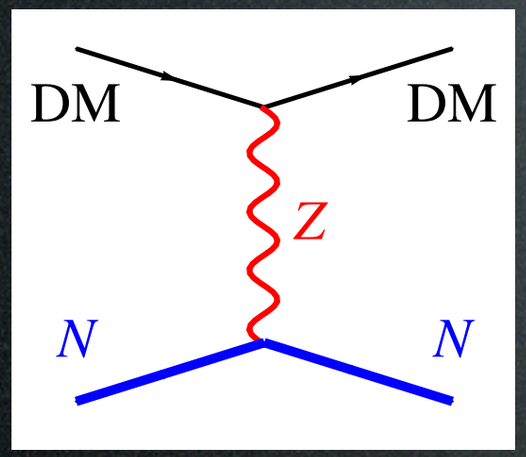
1. even without a larger framework, WIMPs are still appealing
2. the three search strategies are complementary

WIMP DD: '**theory**'

SM weak scale SI interactions

WIMP DD: 'theory'

SM weak scale SI interactions

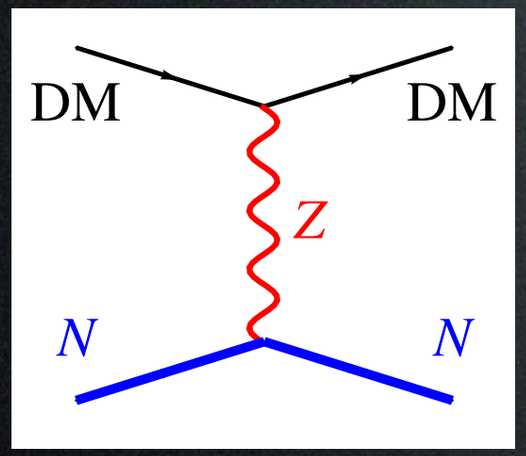


tree level, vector

$$\sigma_{\rm SI} \sim \frac{\alpha^2 \ m_N^2}{M_Z^4}$$

WIMP DD: 'theory'

SM weak scale SI interactions



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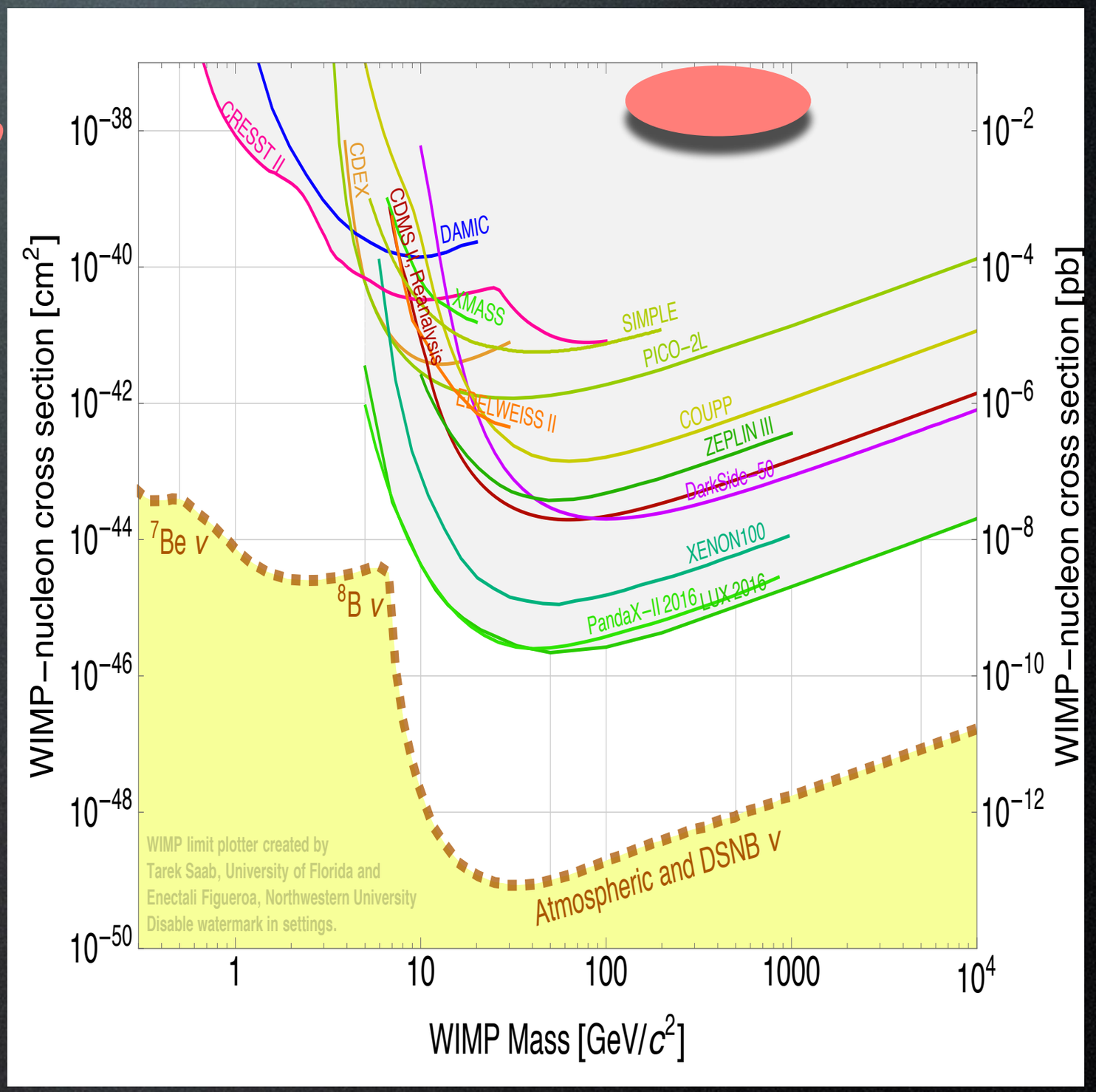

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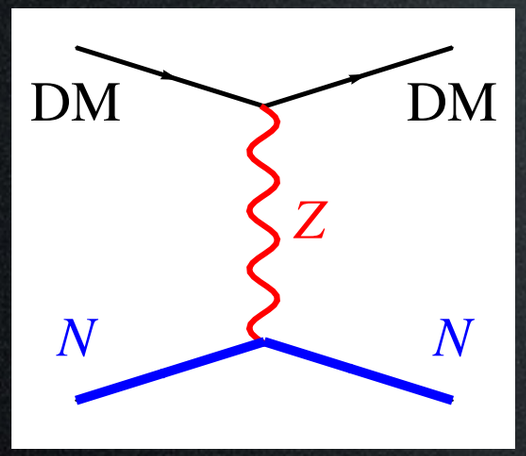

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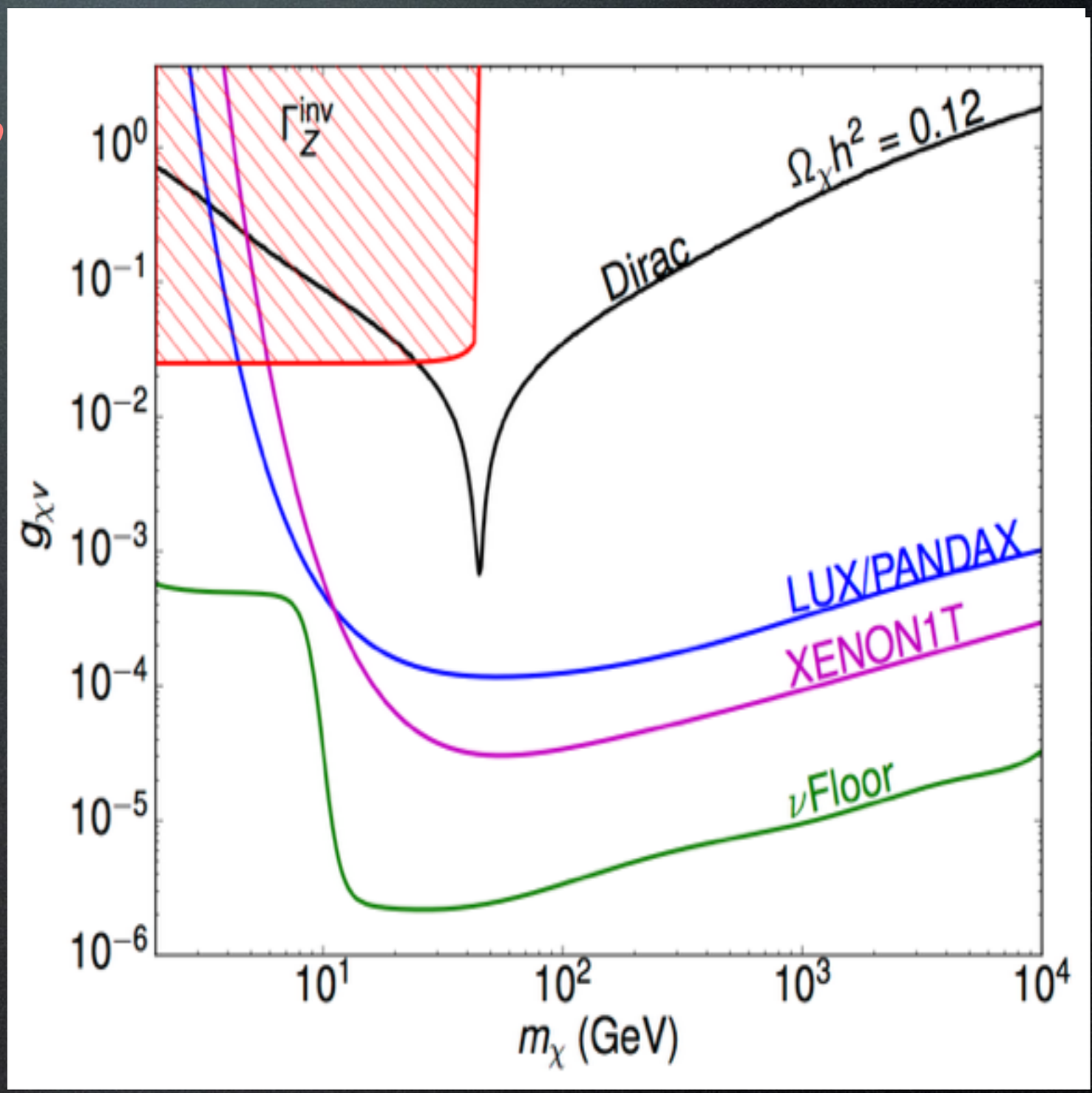
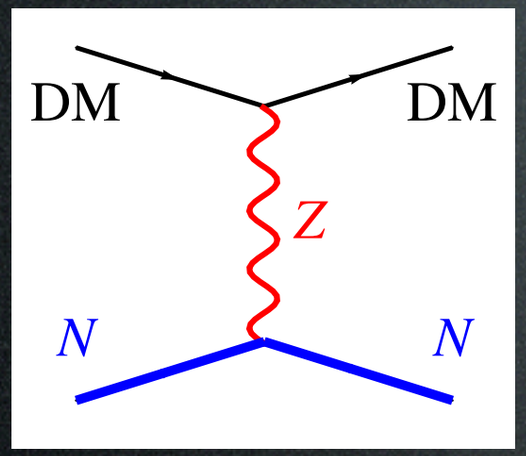


Escudero, Berlin, Hooper, Lin 1609.09079

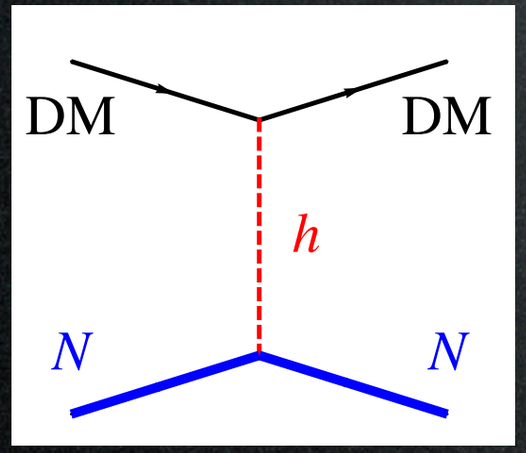
WIMP DD: 'theory'

SM weak scale SI interactions



tree level, vector

$$\sigma_{\rm SI} \sim \frac{\alpha^2 \ m_N^2}{M_Z^4}$$

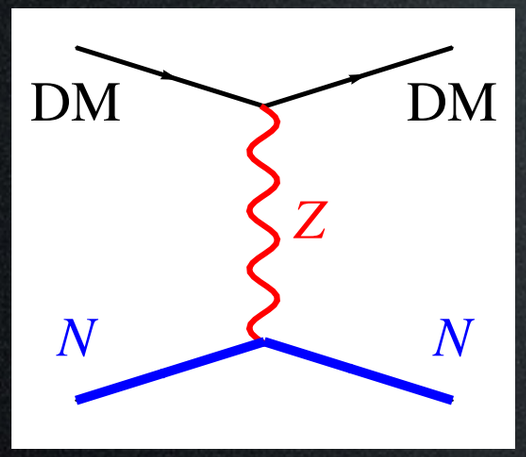


tree level, scalar

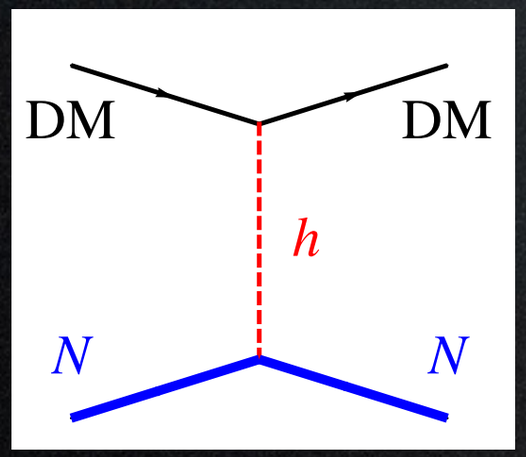
$$\sigma_{\rm SI} \sim \frac{\alpha^2 \ m_N^4}{M_h^6}$$

WIMP DD: 'theory'

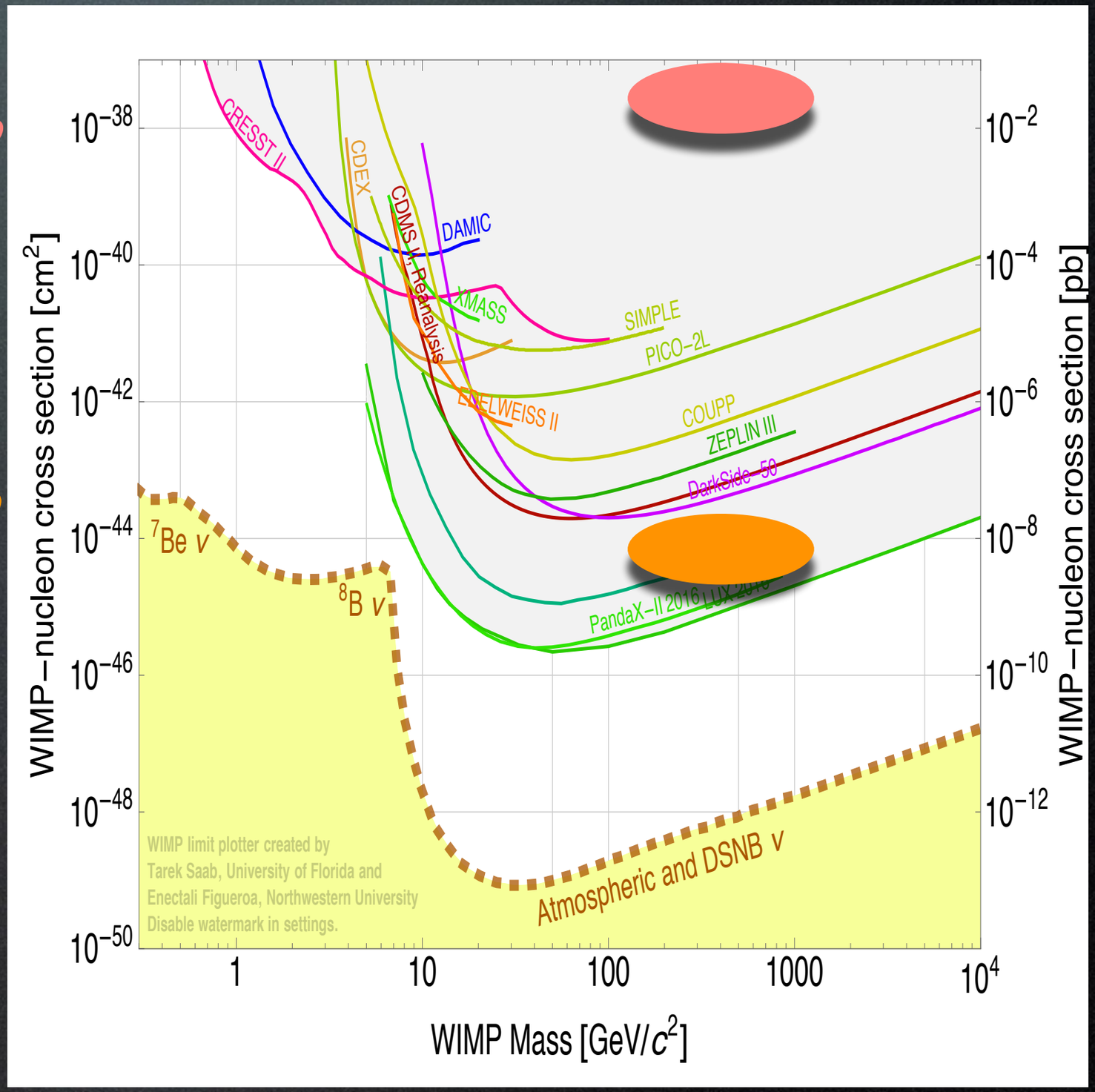
SM weak scale SI interactions



tree level, vector

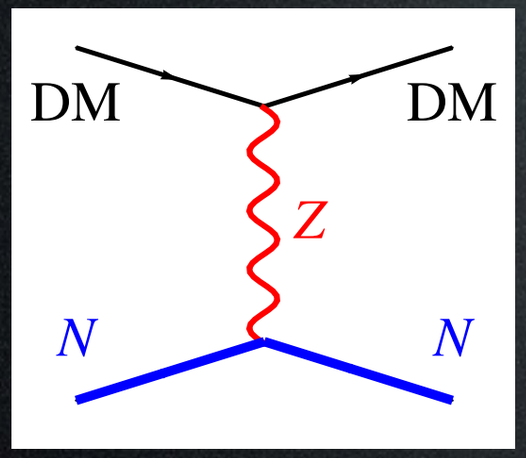


tree level, scalar

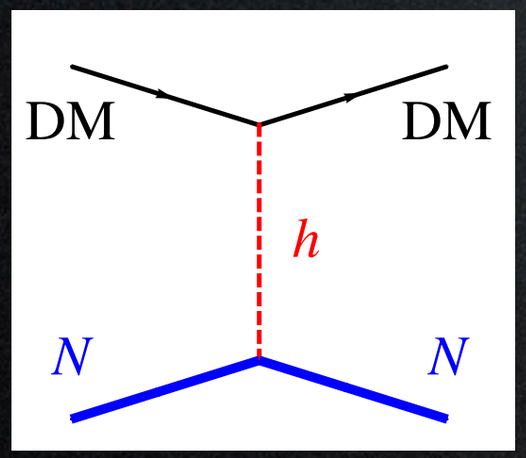


WIMP DD: 'theory'

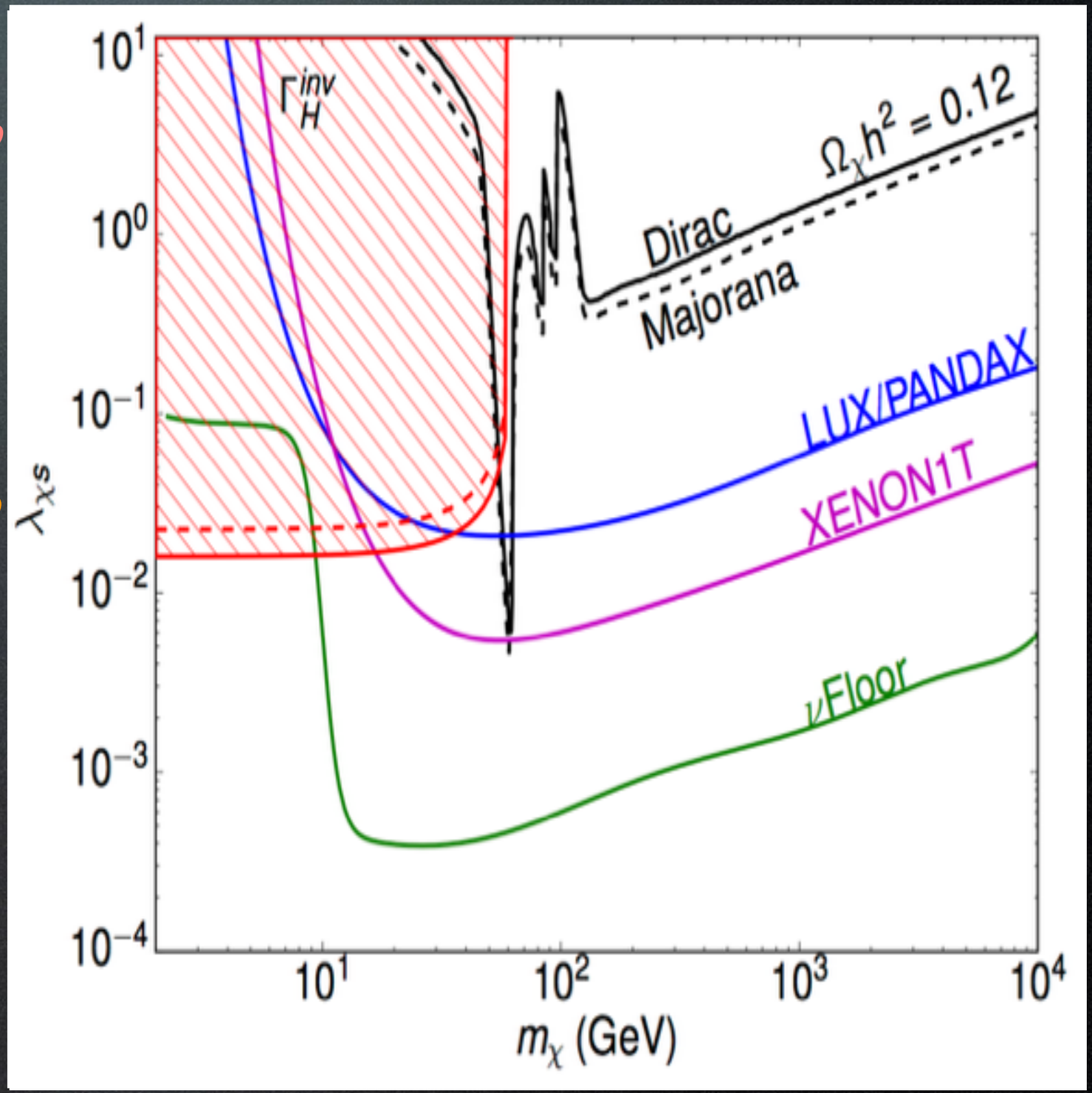
SM weak scale SI interactions



tree level, vector



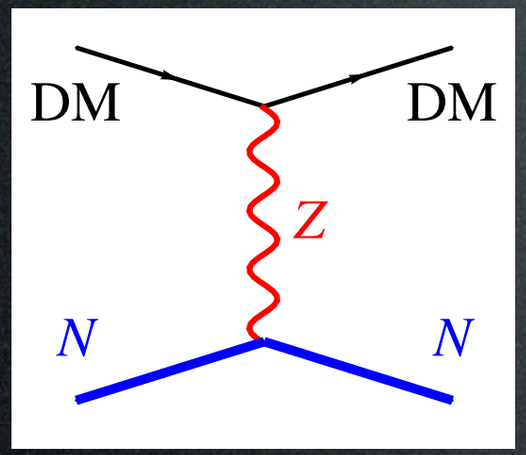
tree level, scalar



Escudero, Berlin, Hooper, Lin 1609.09079

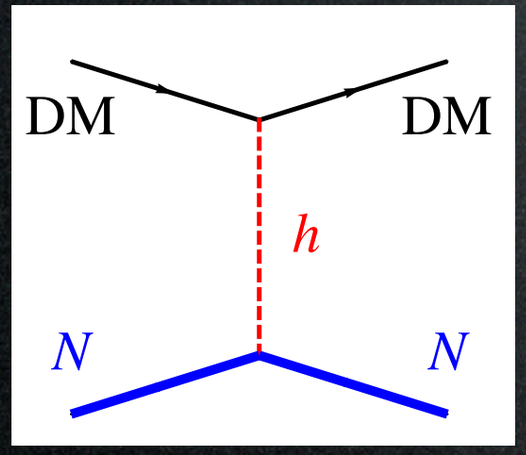
WIMP DD: 'theory'

SM weak scale SI interactions



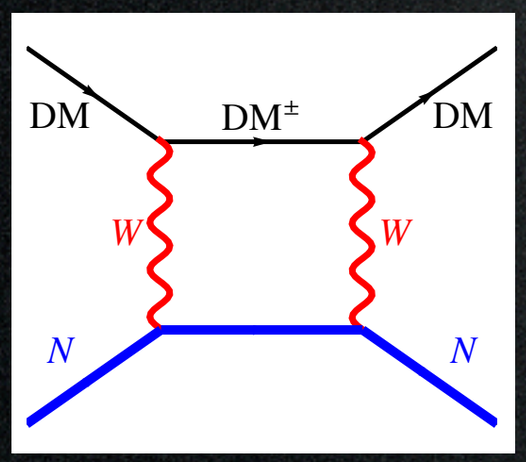
tree level, vector

$$\sigma_{\rm SI} \sim \frac{\alpha^2 \ m_N^2}{M_Z^4}$$



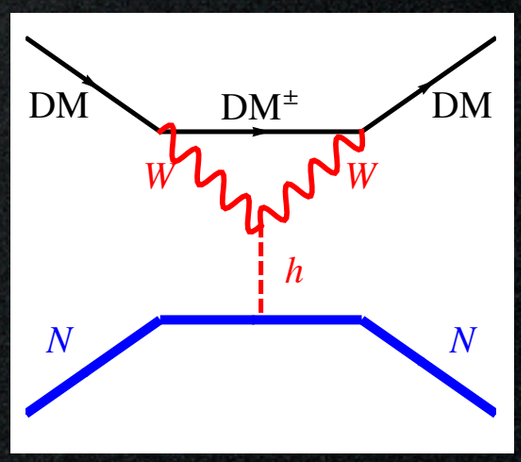
tree level, scalar

$$\sigma_{\rm SI} \sim \frac{\alpha^2 \ m_N^4}{M_h^6}$$



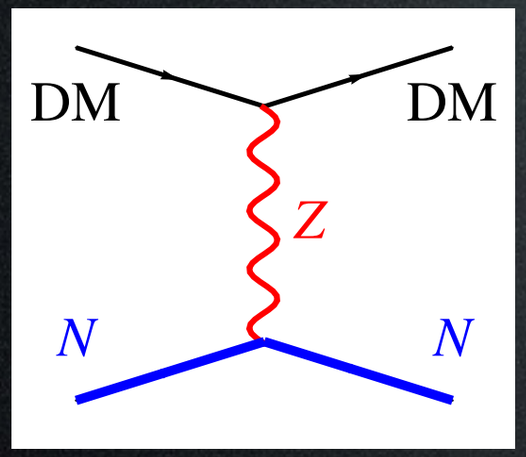
one loop

$$\sigma_{\rm SI} \sim \frac{\alpha^4 \ m_N^4}{M_W^6}$$

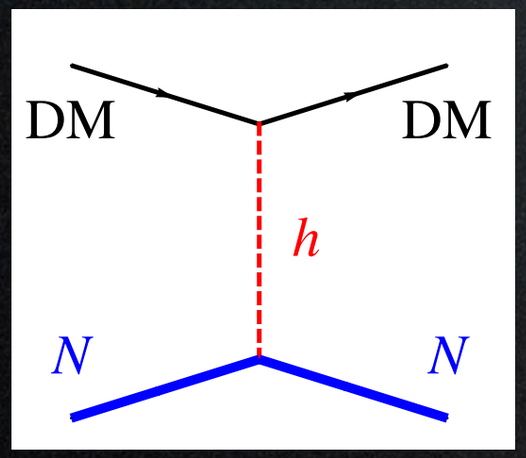


WIMP DD: 'theory'

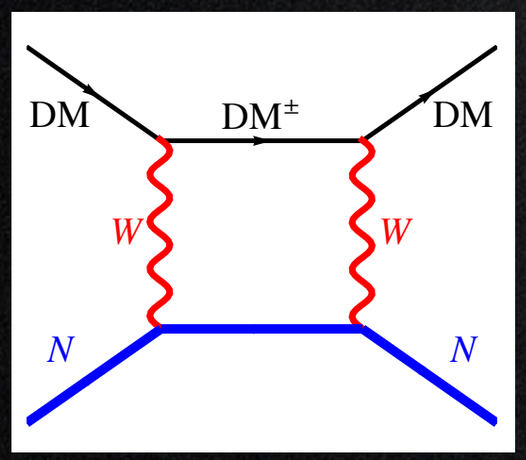
SM weak scale SI interactions



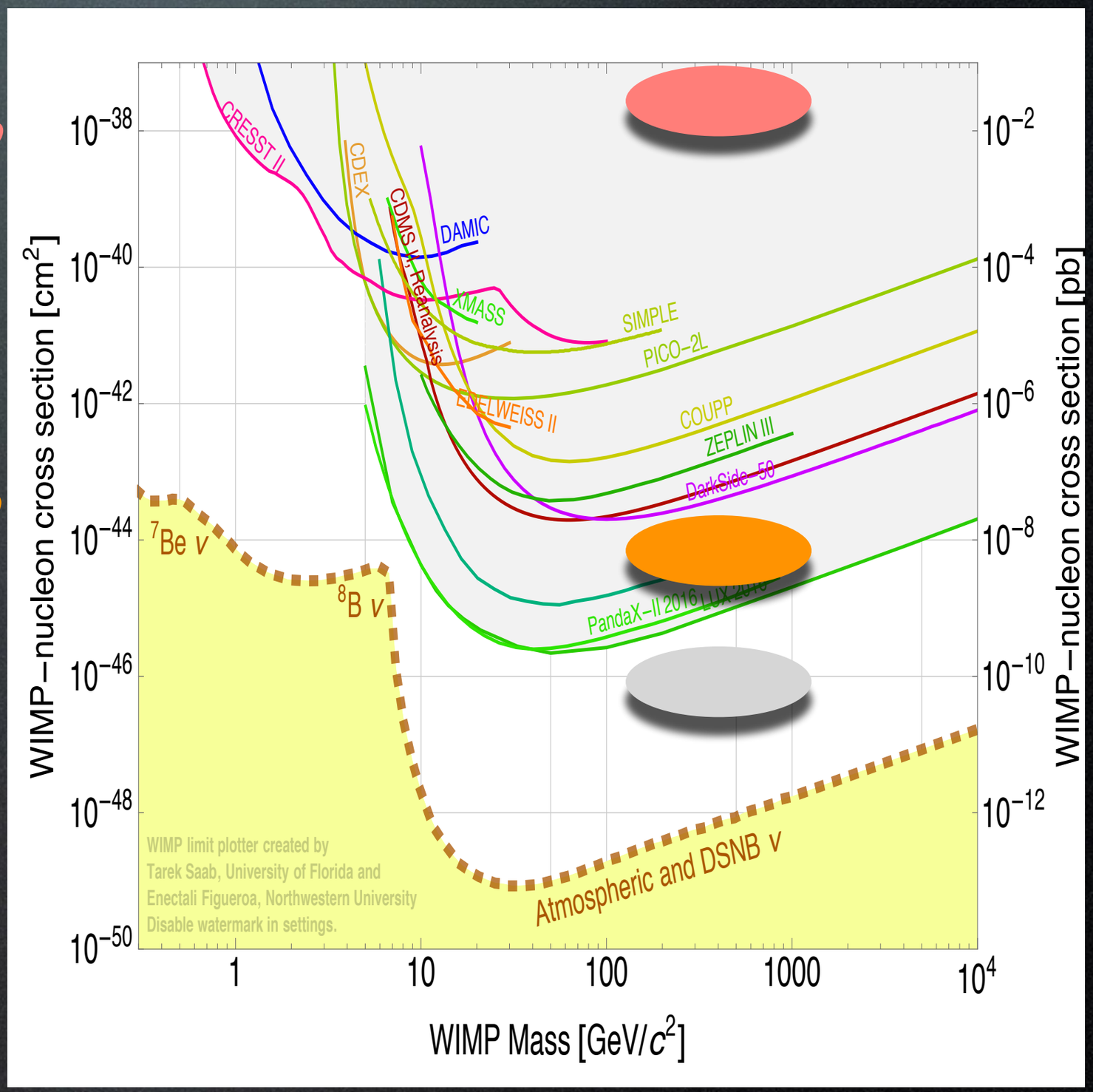
tree level, vector



tree level, scalar

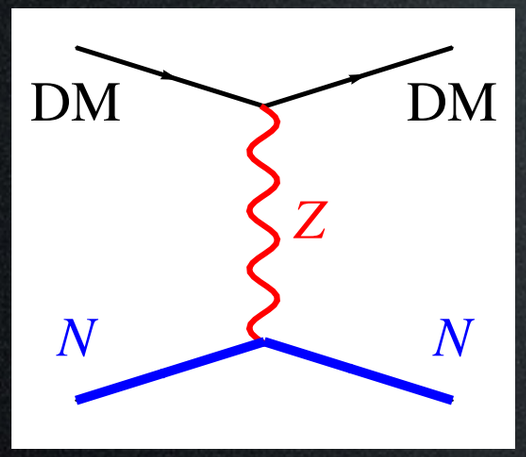


one loop

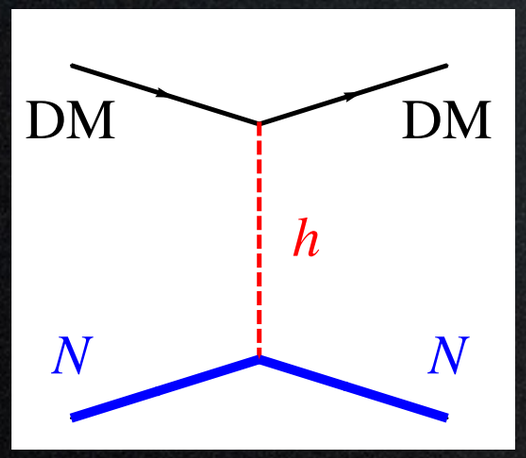


WIMP DD: 'theory'

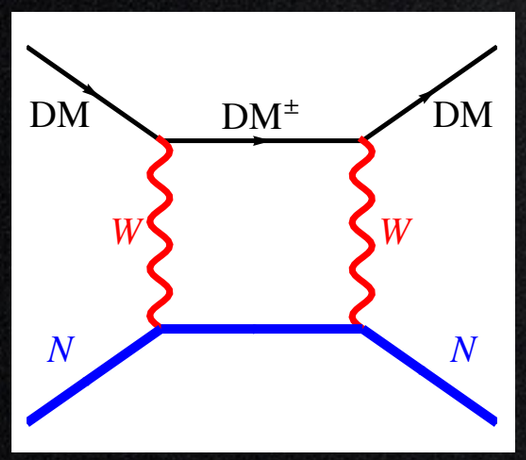
SM weak scale SI interactions



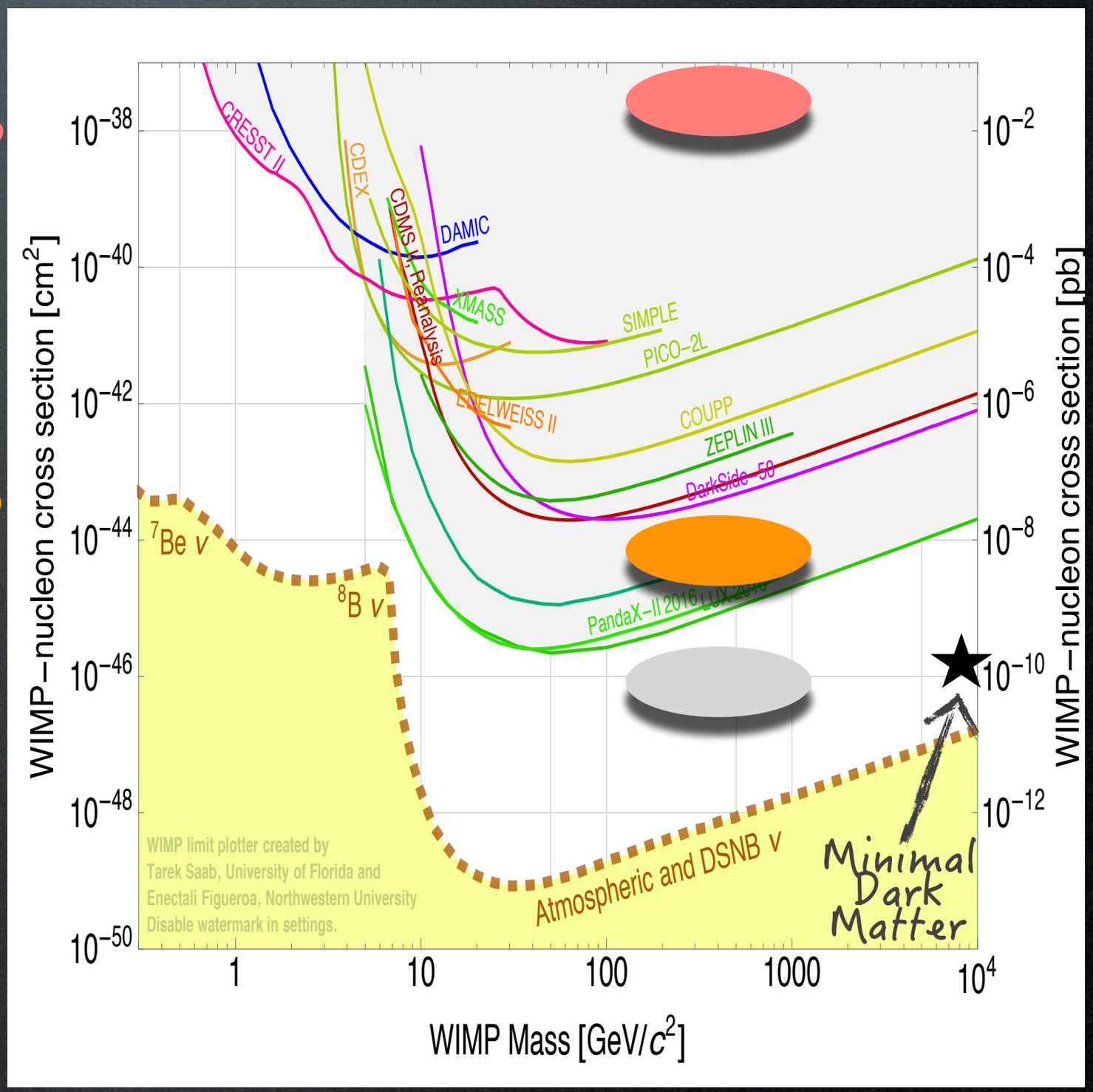
tree level, vector



tree level, scalar



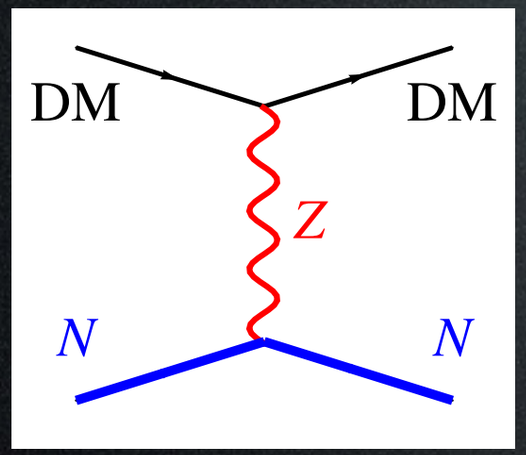
one loop



Cirelli, Fornengo, Strumia hep-ph/0512090

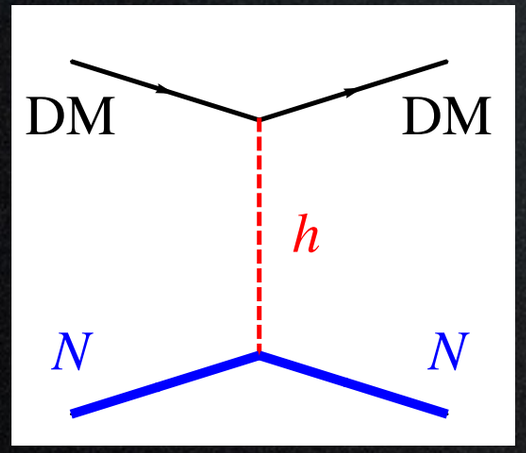
WIMP DD: 'theory'

SM weak scale SI interactions

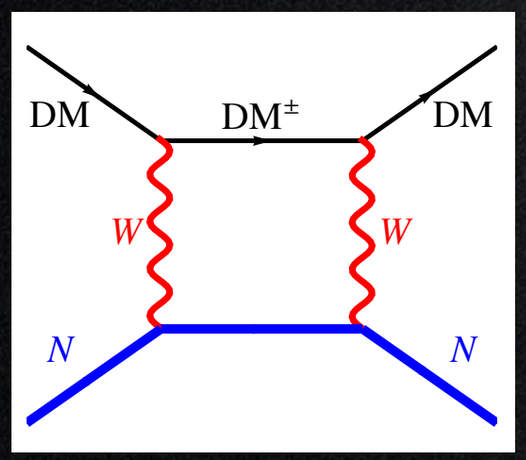


tree level, vector

Still viable under which conditions?



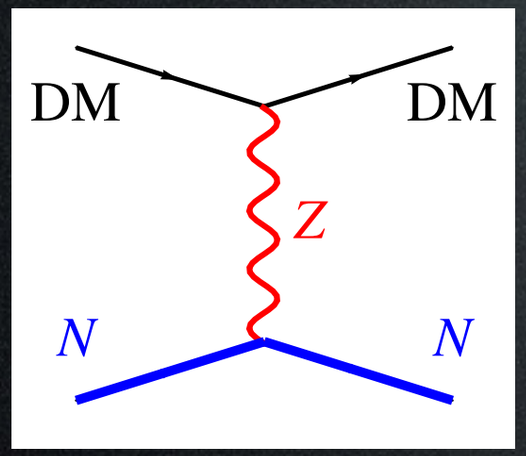
tree level, scalar



one loop

WIMP DD: 'theory'

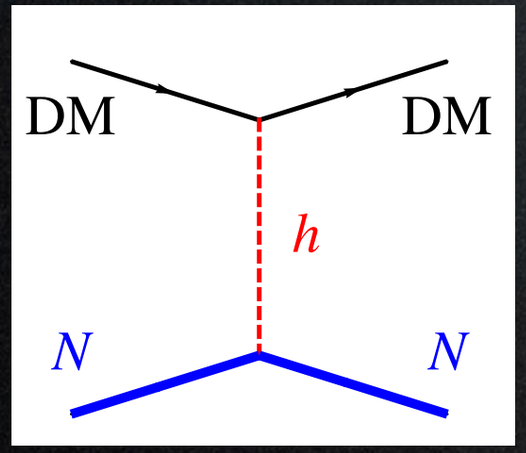
SM weak scale SI interactions



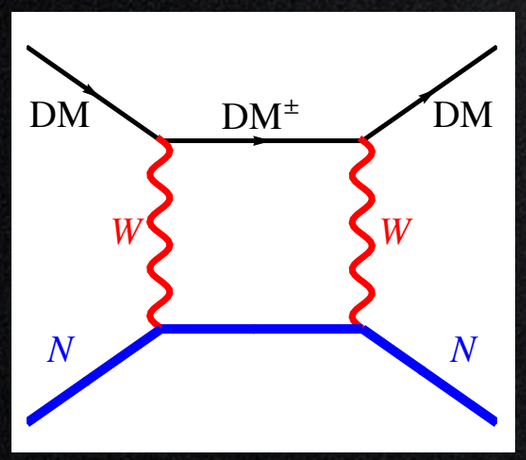
tree level, vector

Still viable under which conditions?

- real particle
  (Majorana fermion, real scalar)



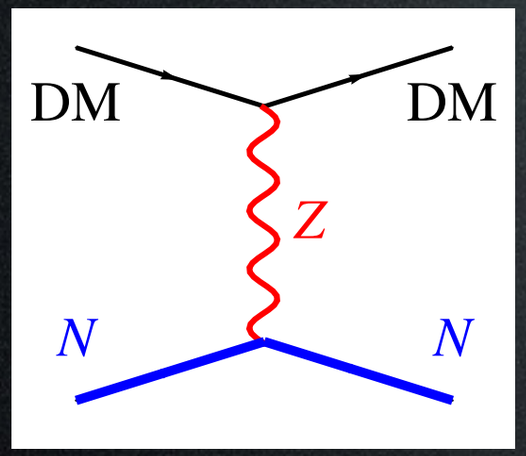
tree level, scalar



one loop

WIMP DD: 'theory'

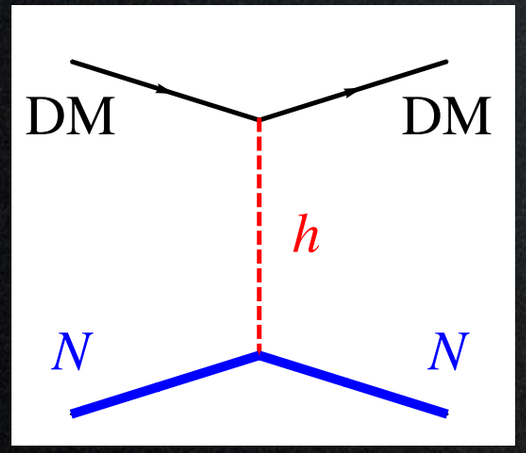
SM weak scale SI interactions



tree level, vector

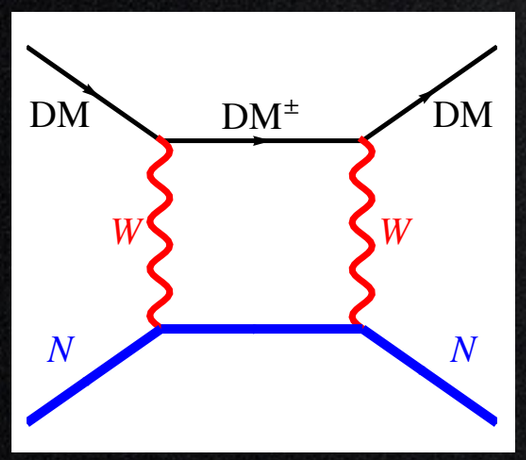
Still viable under which conditions?

- real particle
  (Majorana fermion, real scalar)



tree level, scalar

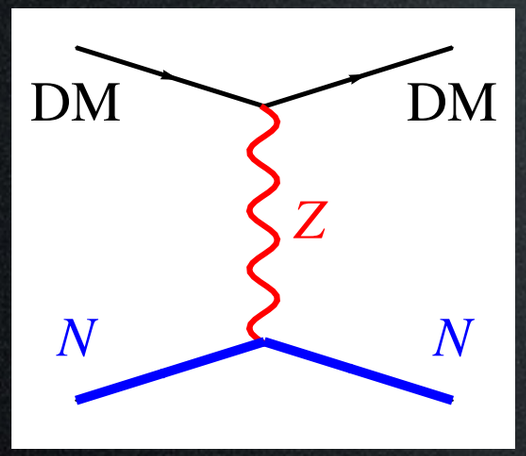
- hypercharge $Y = 0$



one loop

WIMP DD: 'theory'

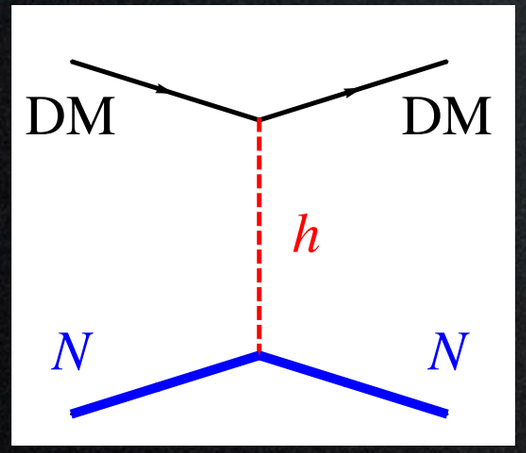
SM weak scale SI interactions



tree level, vector

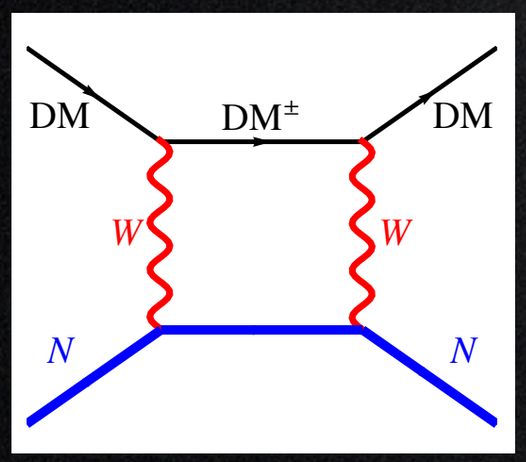
Still viable under which conditions?

- real particle
  (Majorana fermion, real scalar)

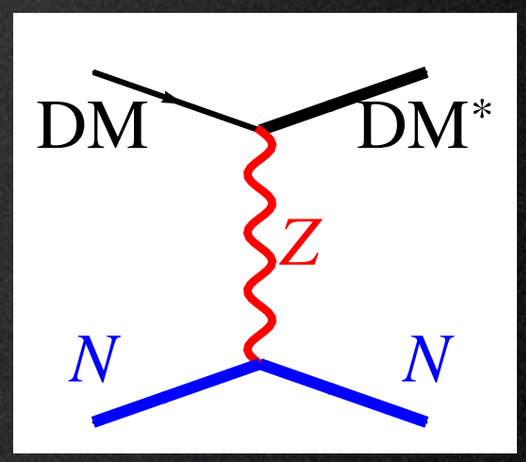


tree level, scalar

- hypercharge $Y = 0$
- SD interactions only
- inelastic scattering



one loop



Conclusions

new physics at the TeV scale

thermal freeze-out

WIMPs

LHC

AMS, Fermi, CTA
Antares, Icecube

Direct Detection

1. even without a larger framework, WIMPs are still appealing
2. the three search strategies are complementary