25 Octobre 2018
Conseil Scientifique IN2P3

(A theorist's view of)

The physics of rare events

Marco Cirelli

(CNRS LPTHE Jussieu Paris)

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DM DD **0νββ**

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Dark Matter factsheet

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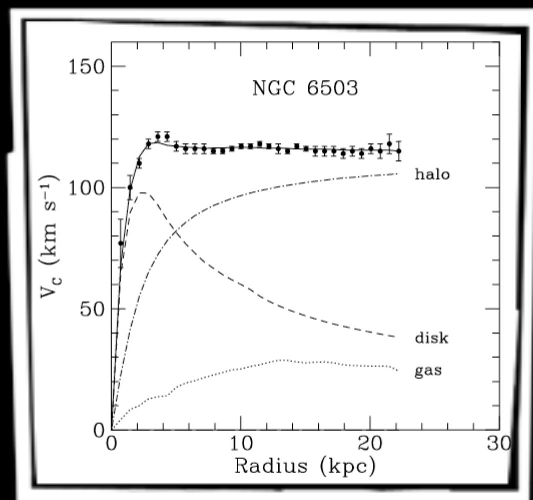
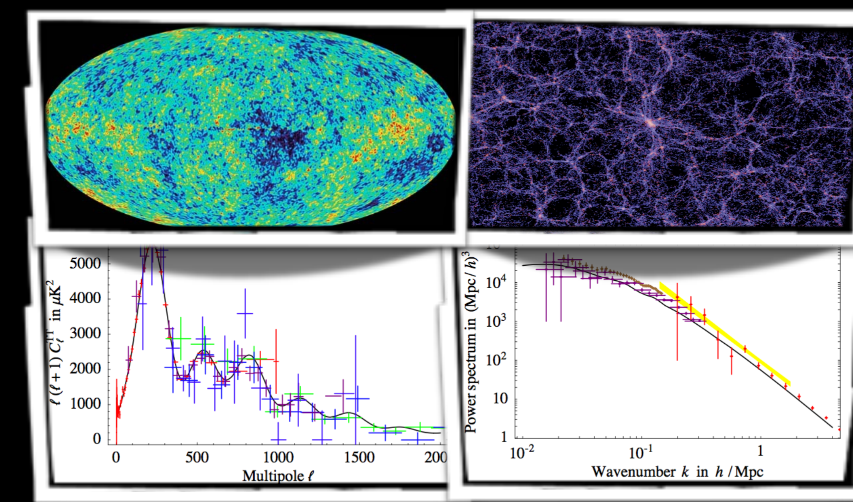


galactic rotation curves

weak lensing (e.g. in clusters)



‘precision cosmology’ (CMB, LSS)

Dark Matter factsheet

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

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

Dark Matter factsheet

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no SM particle can fulfill

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(notice error!)

[Planck 2015, 1502.01589]

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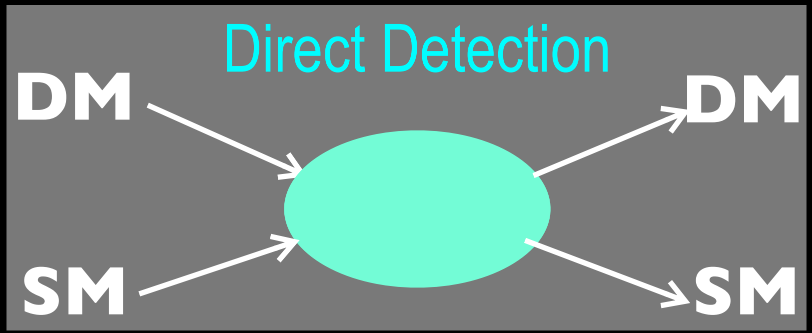

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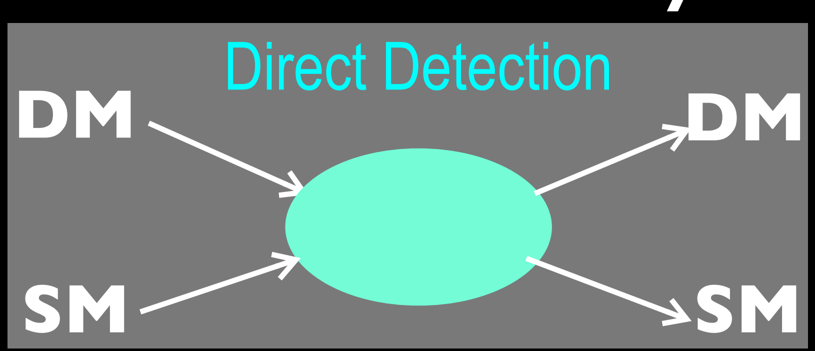

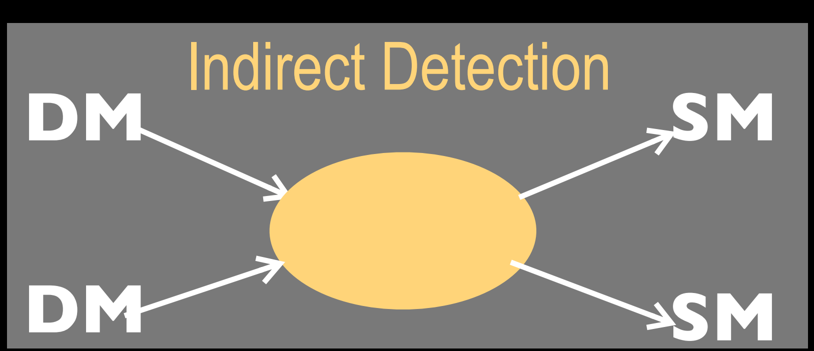

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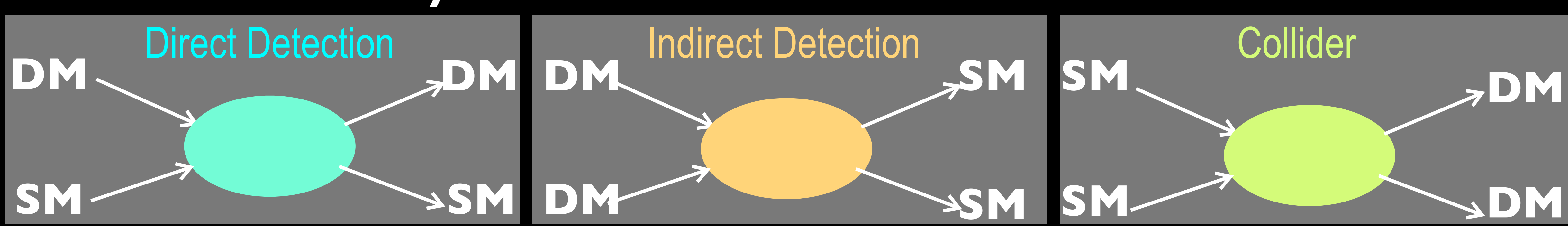

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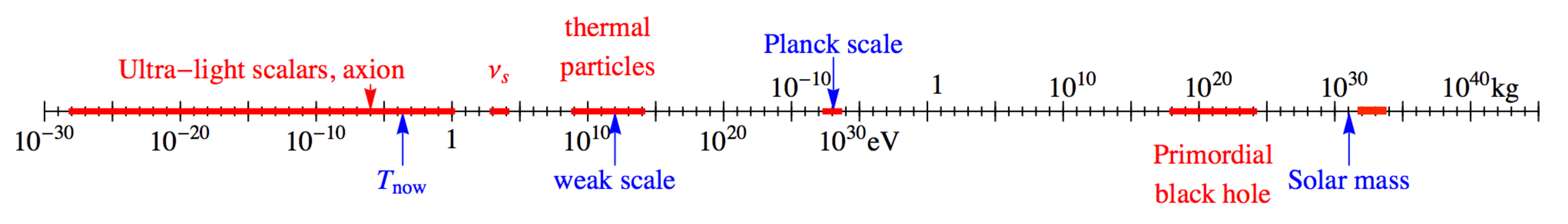
Mass??

Charge??
Interactions??

Candidates

A matter of perspective: plausible mass ranges



'only' 90 orders of magnitude!

Candidates

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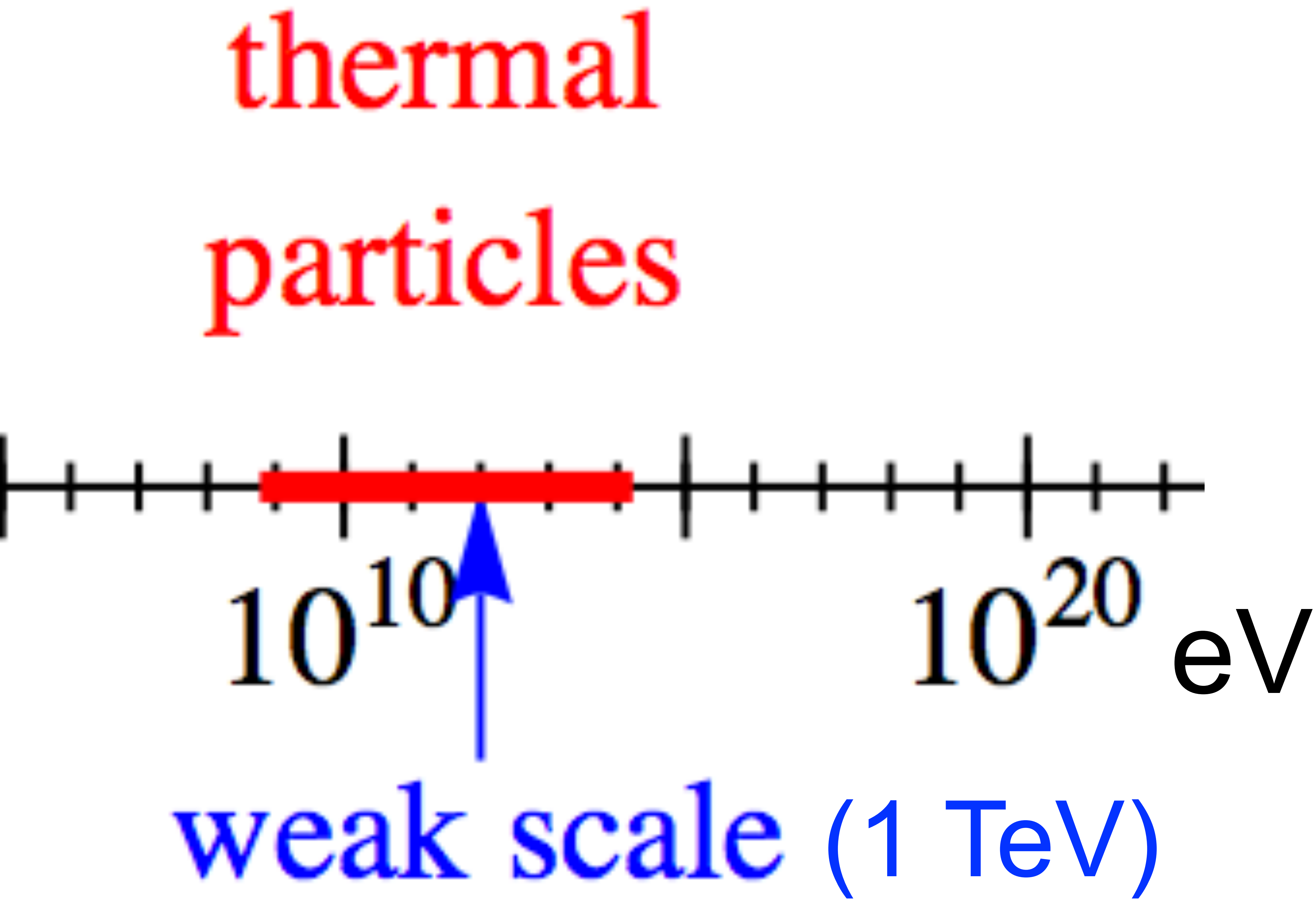
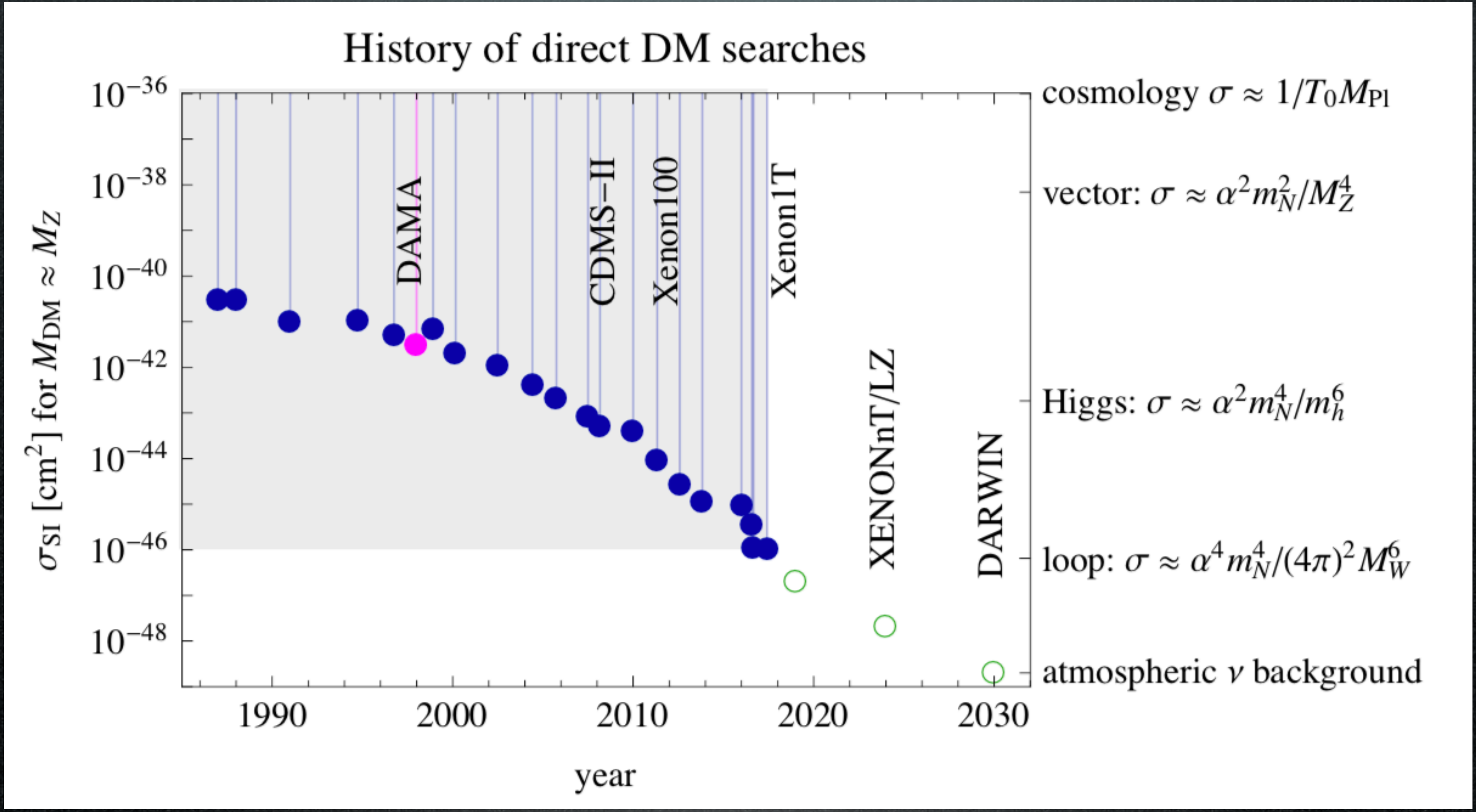


Candidates

A matter of perspective: plausible cross sections



Candidates

WIMPs

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new physics at the TeV scale

thermal freeze-out

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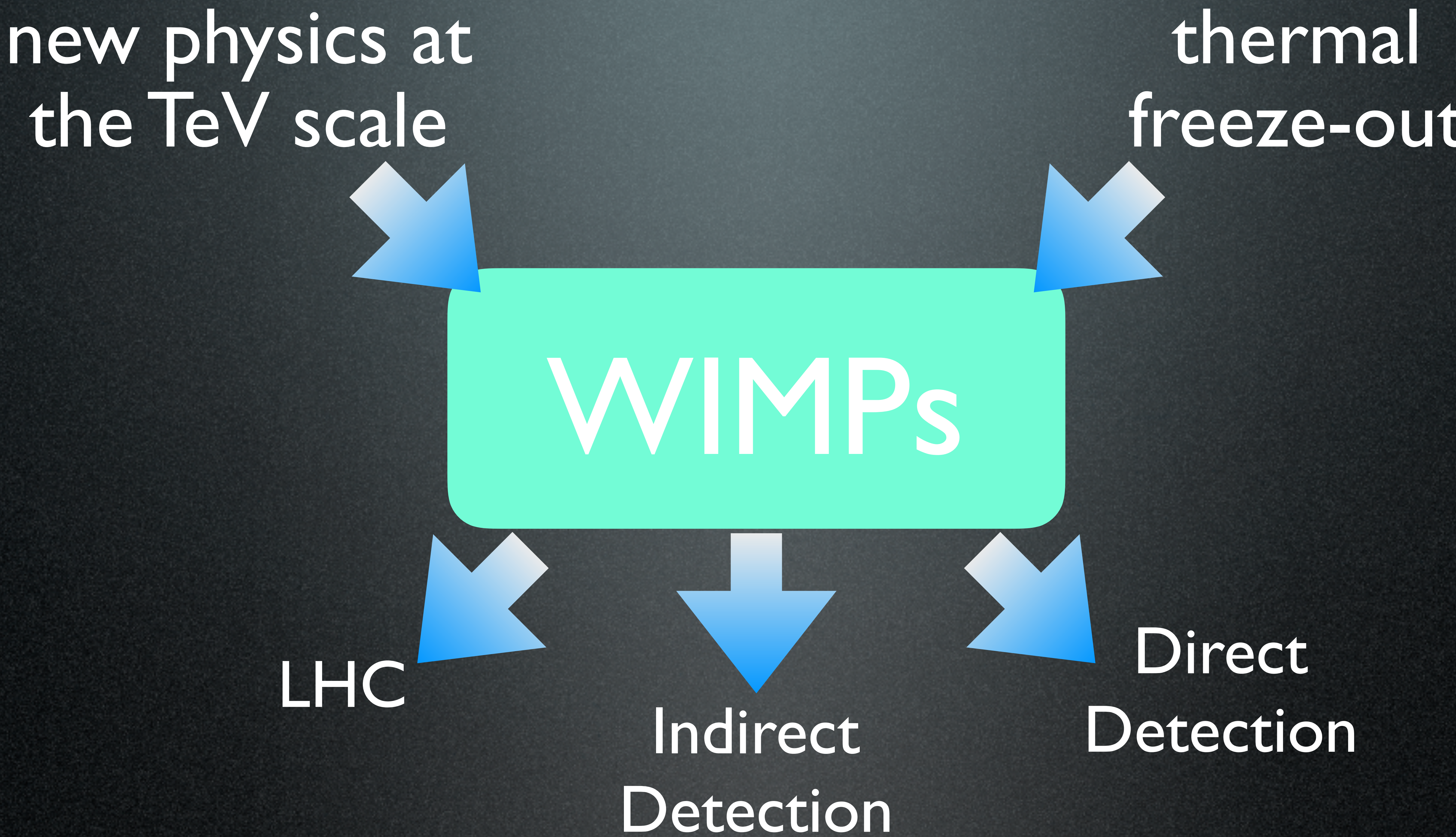
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LHC
Indirect
Detection
Direct
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DM as a thermal relic from the Early Universe

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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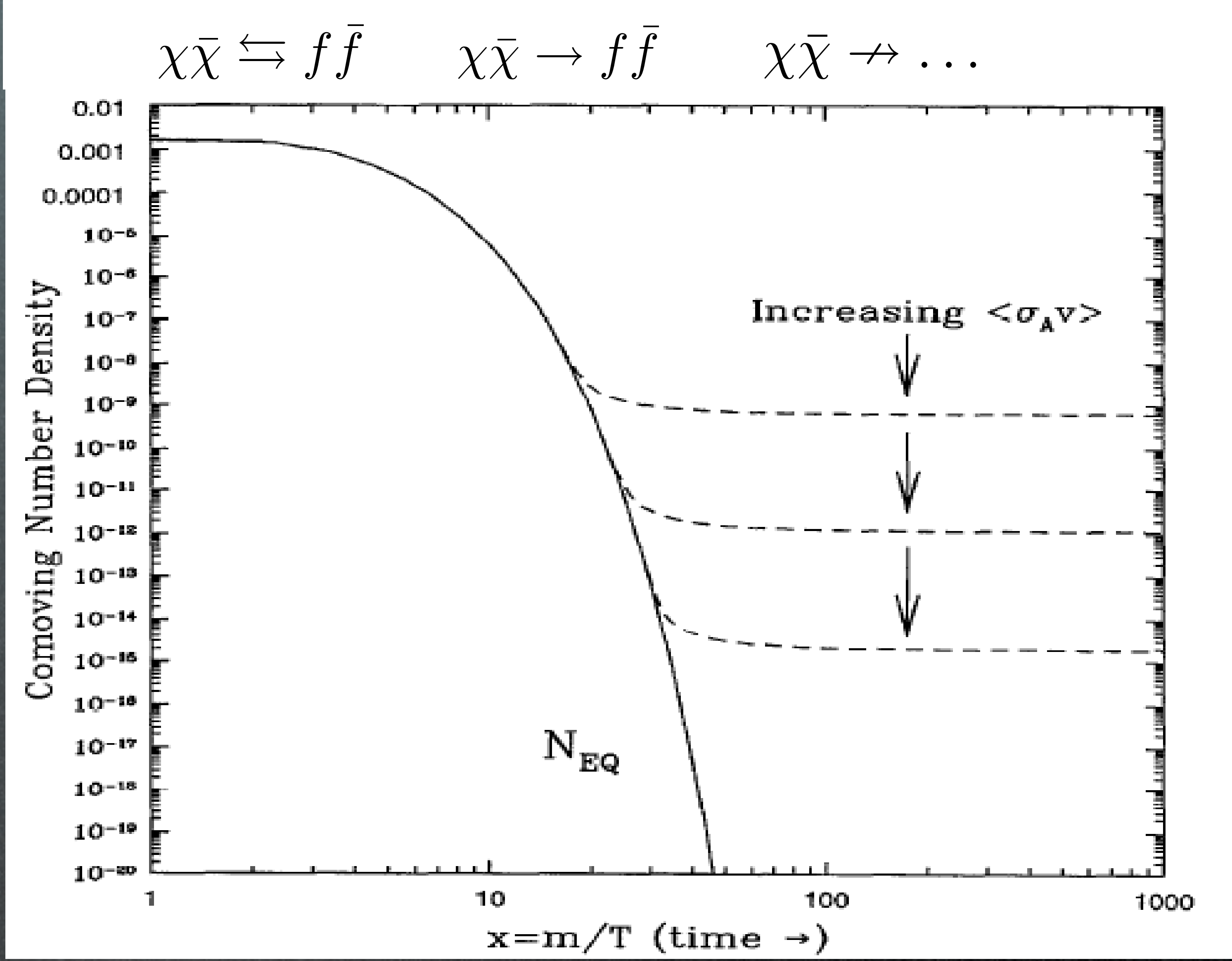

Kolb,Turner, The Early Universe, 1995

Weak cross section:

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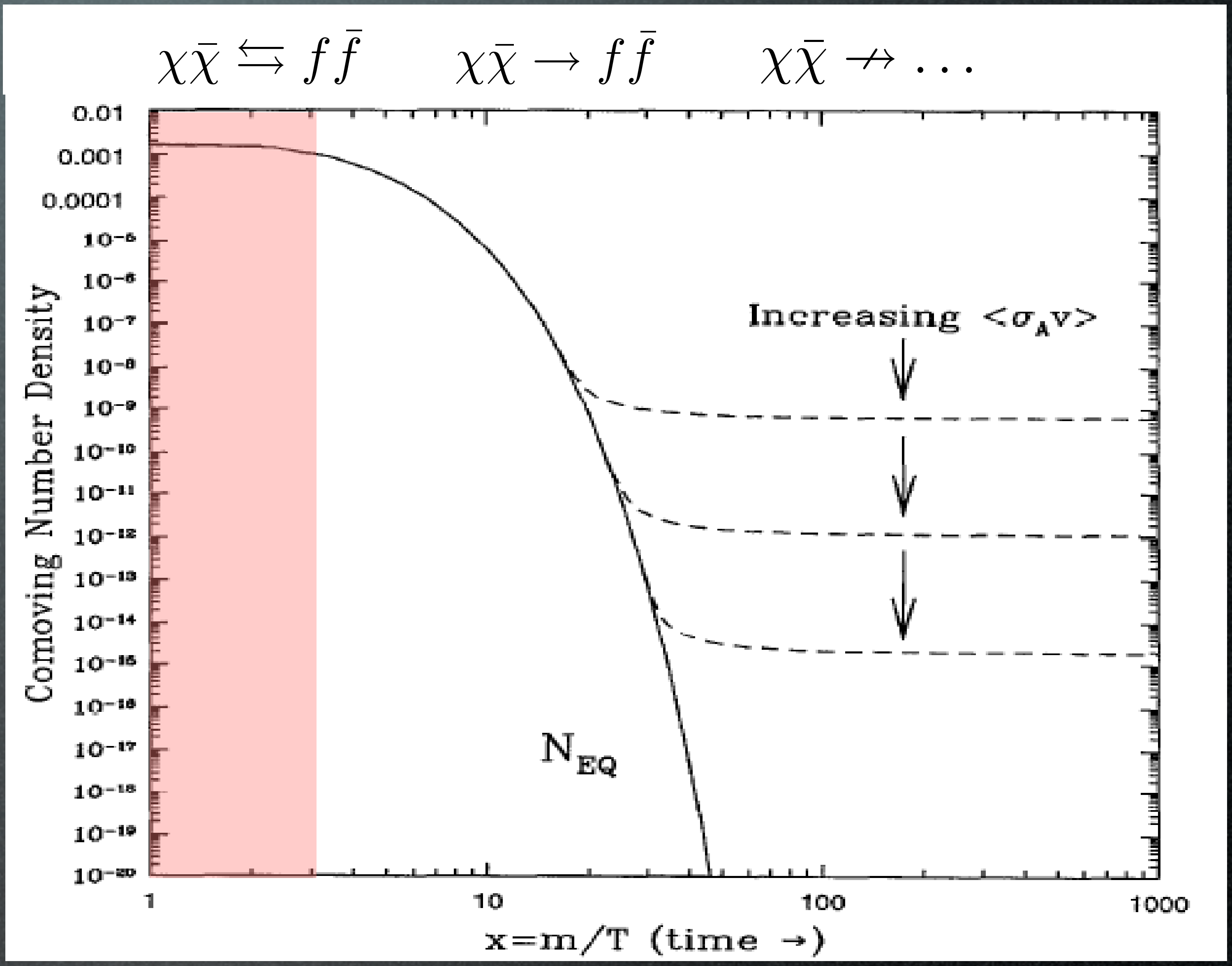

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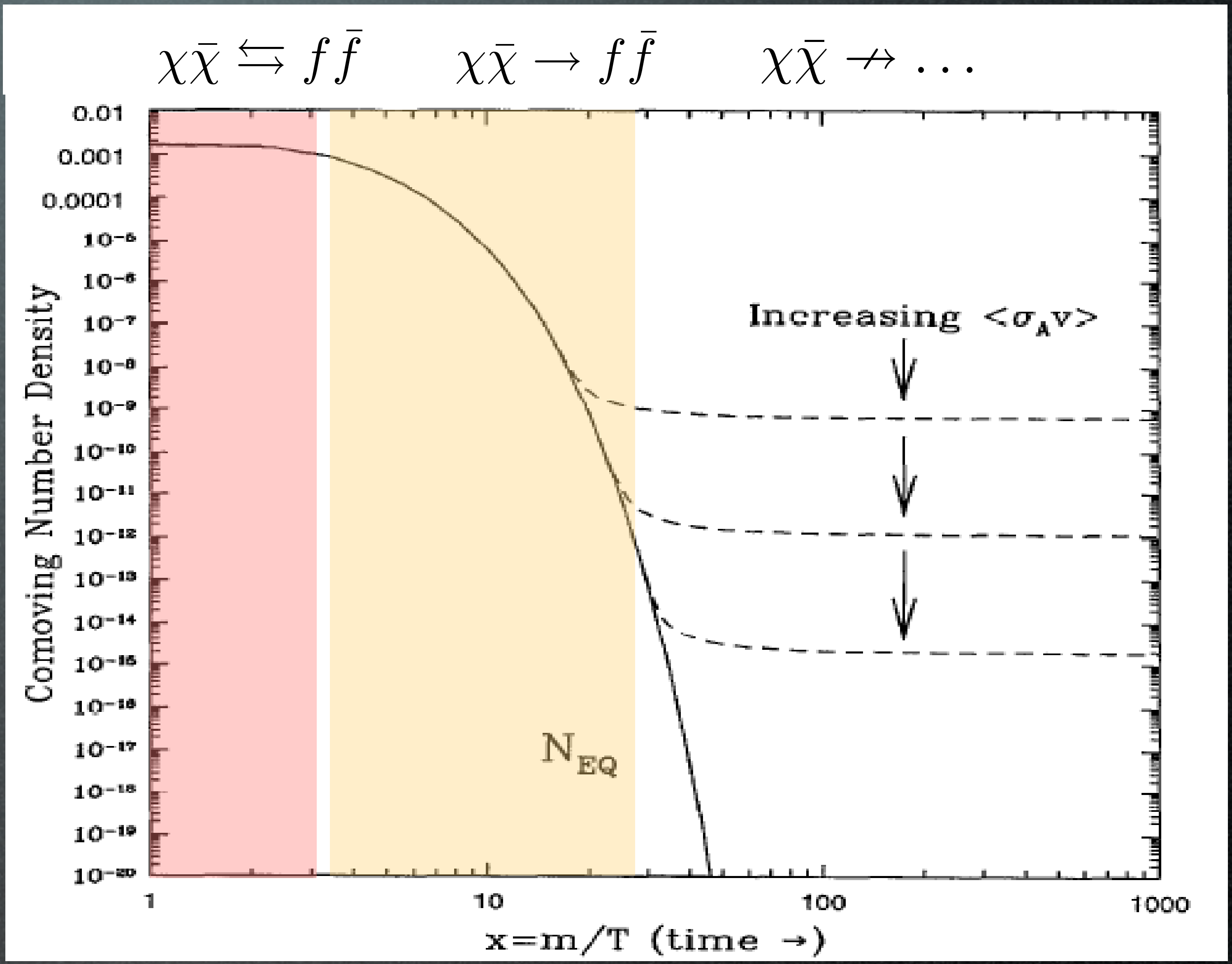

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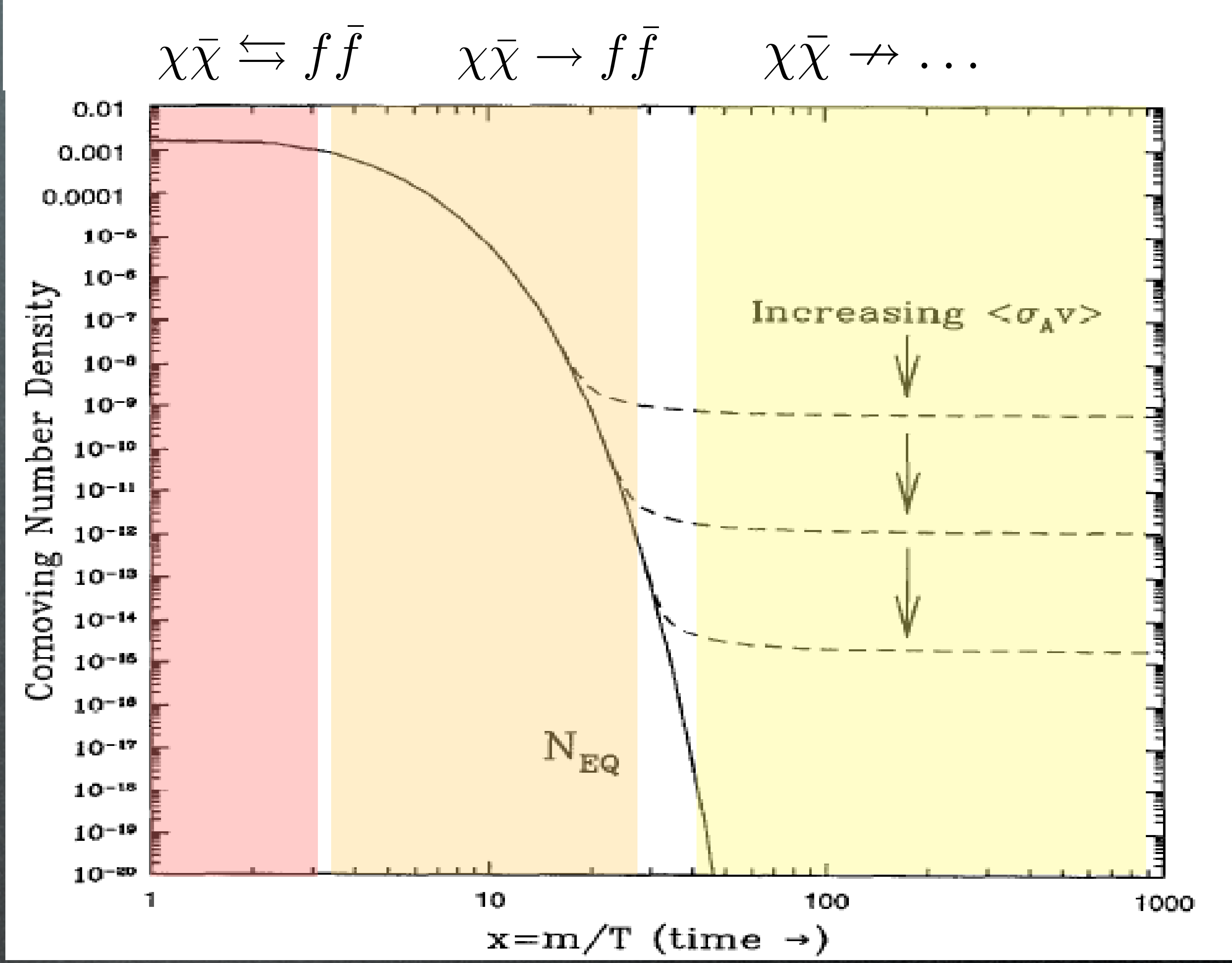

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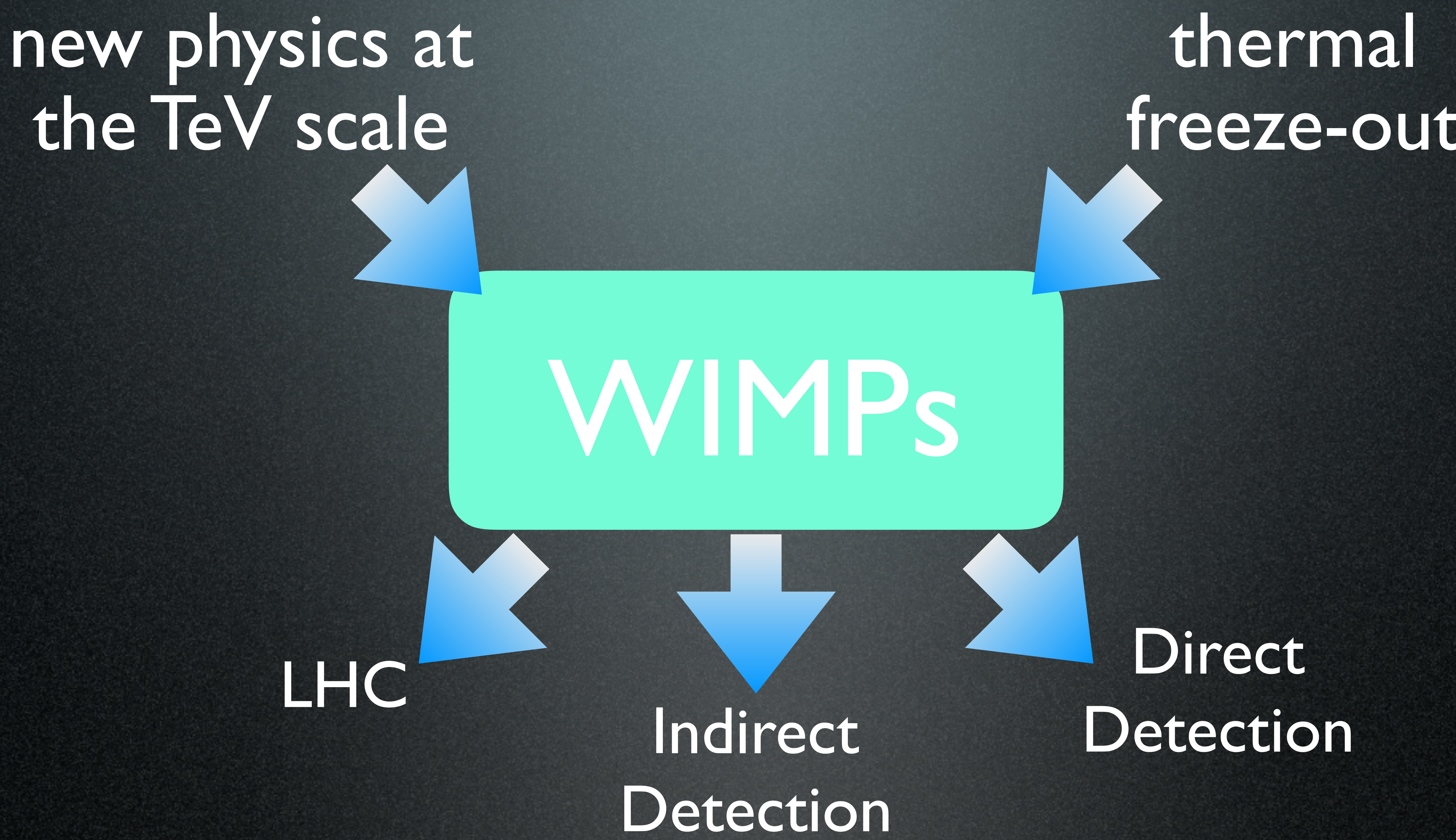
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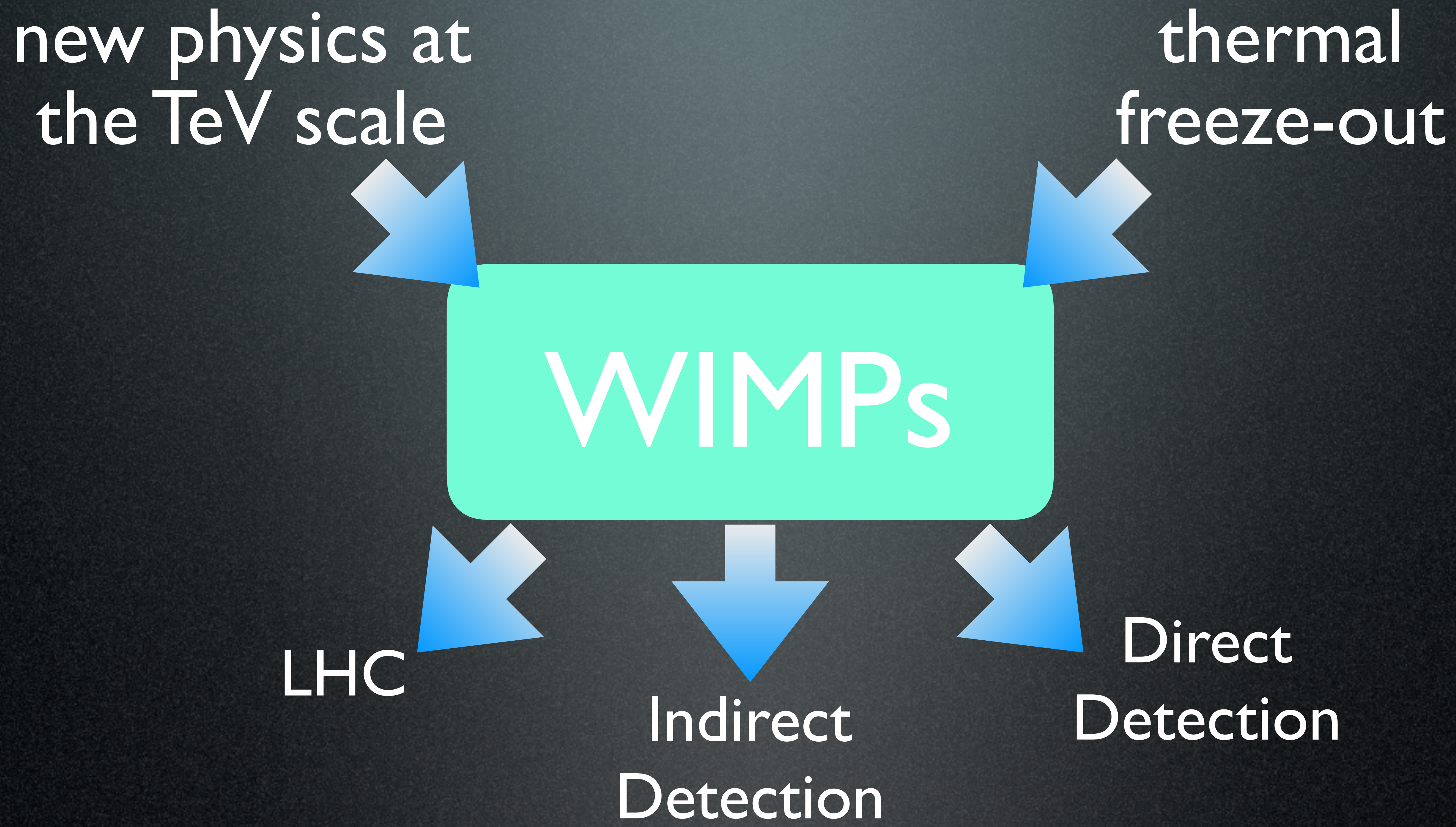
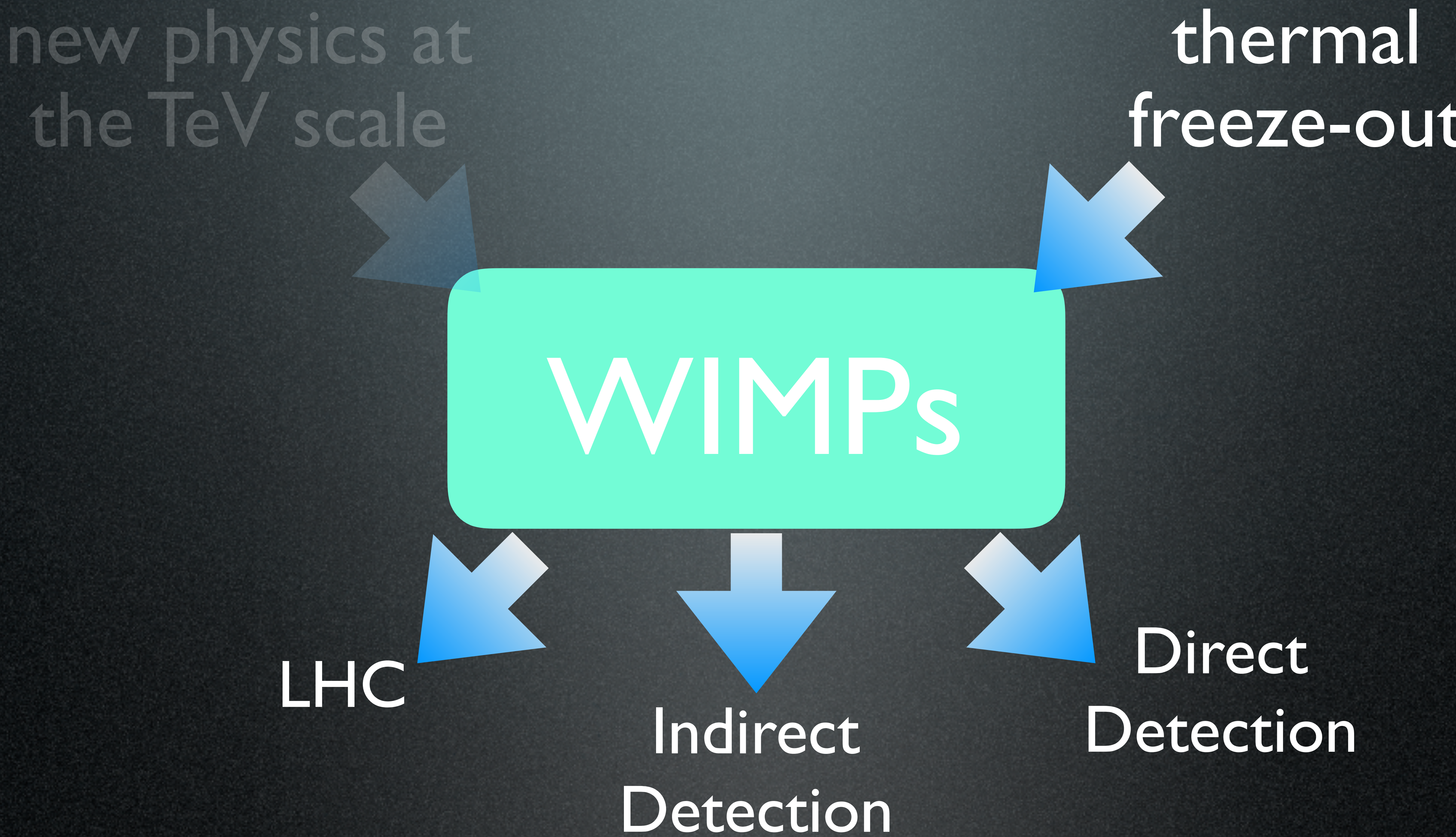


1.
2.

Candidates



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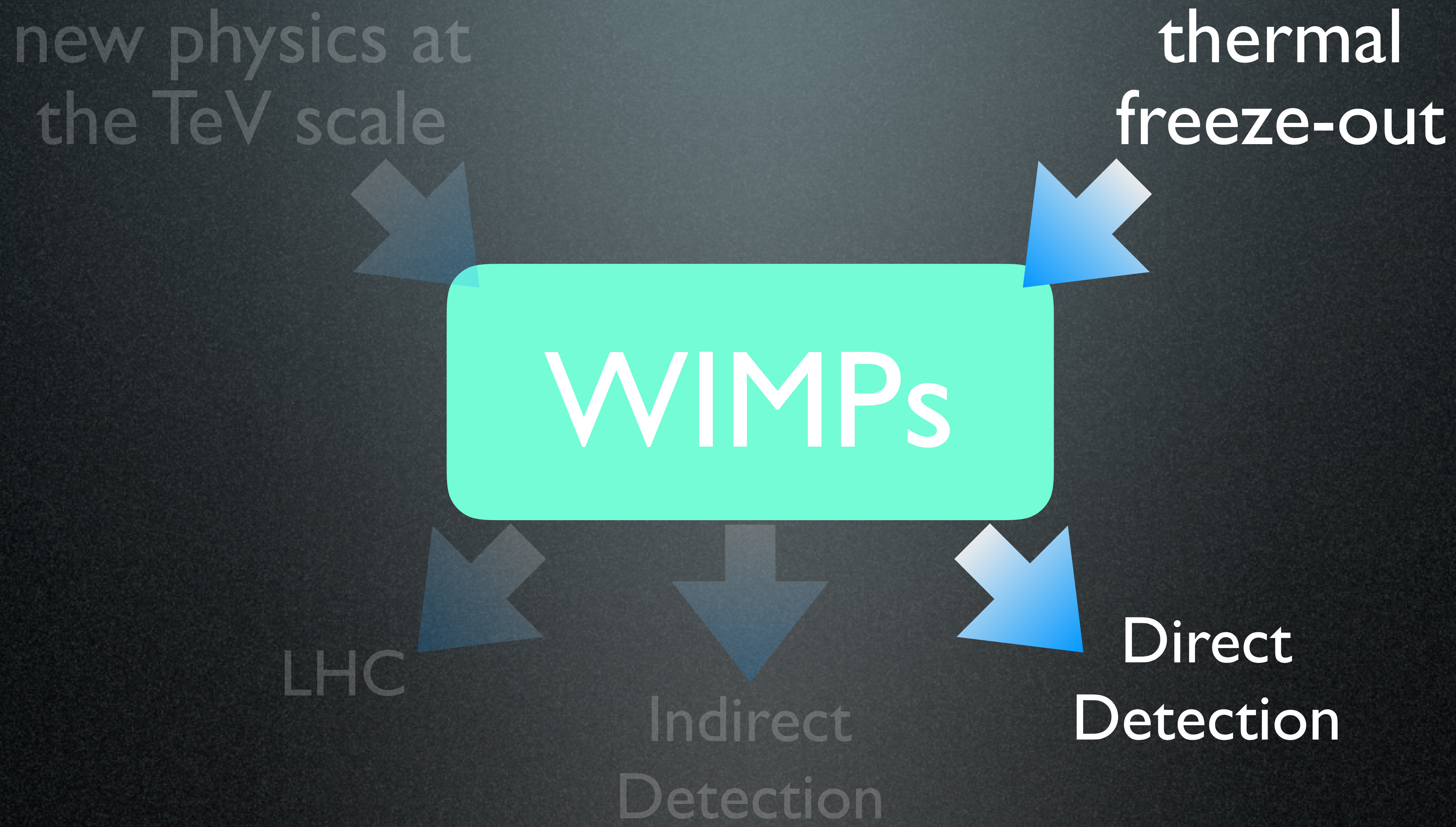

1. even without a larger framework, WIMPs are still appealing
2. the three search strategies are complementary

WIMP DD: ‘**theory**’

SM weak scale SI interactions

WIMP DD: 'theory'

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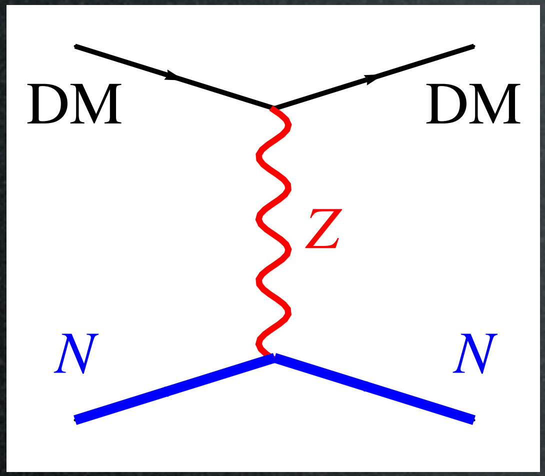

tree level, vector

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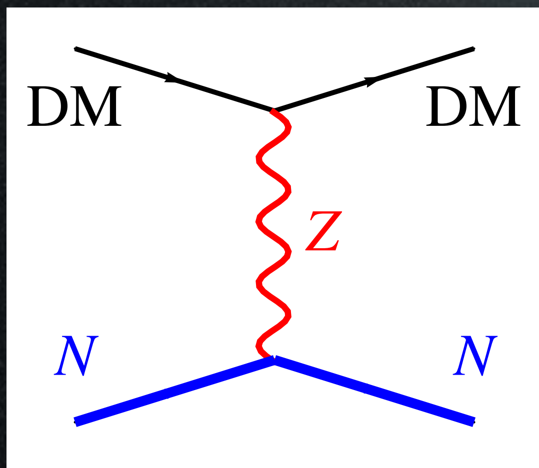

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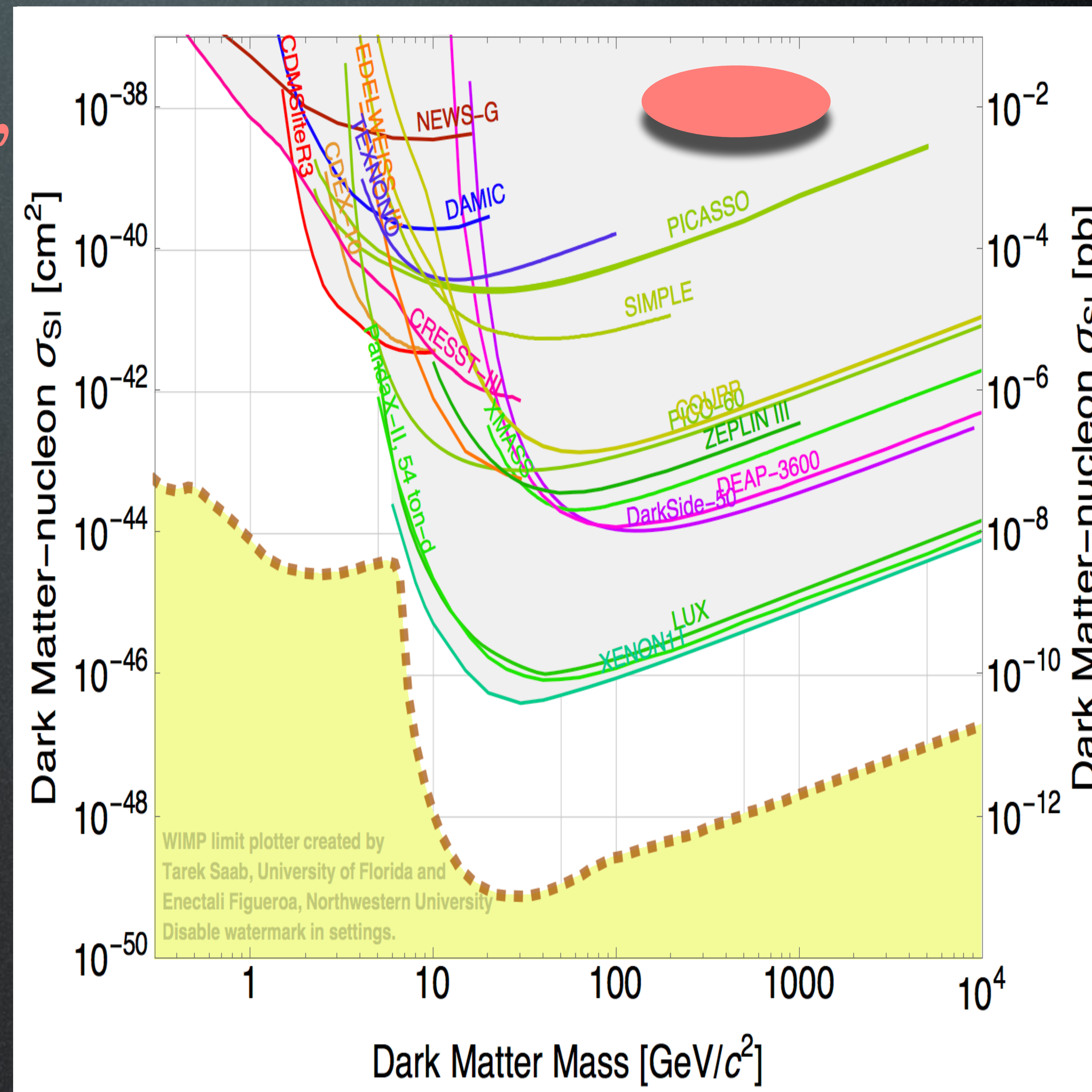

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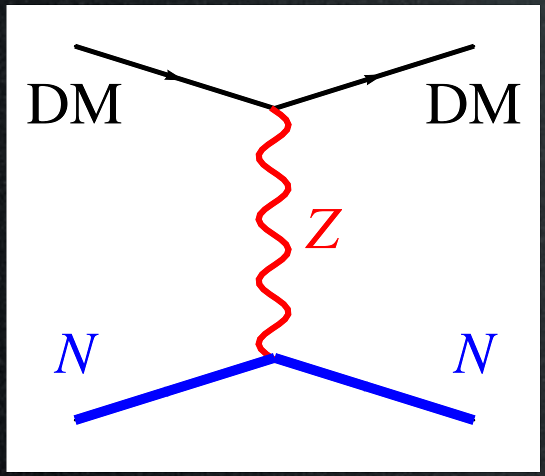

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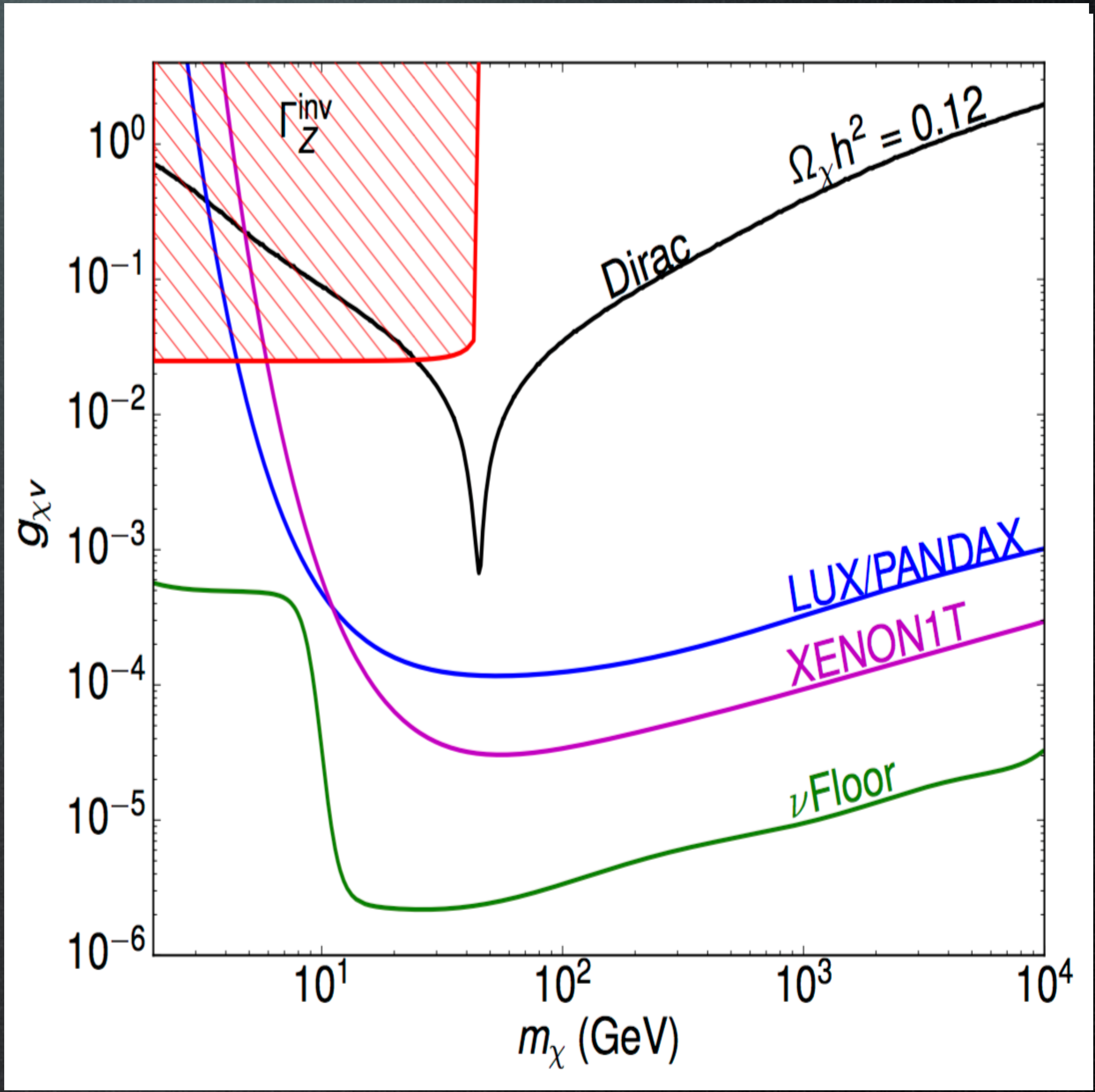

Escudero, Berlin, Hooper, Lin 1609.09079

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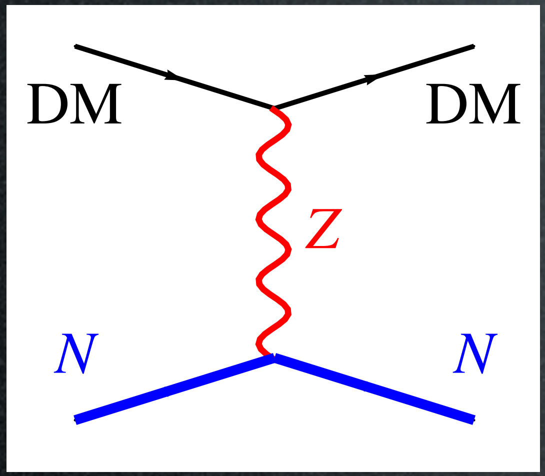

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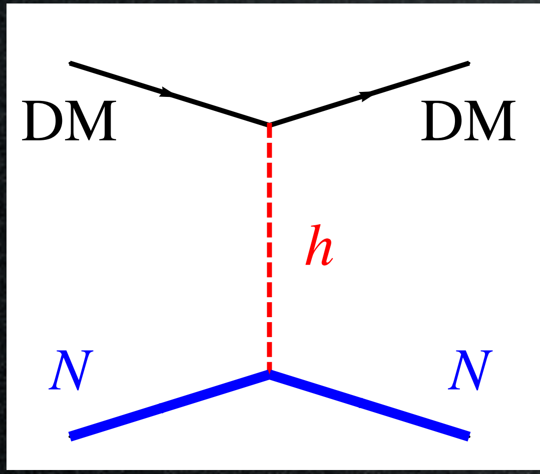

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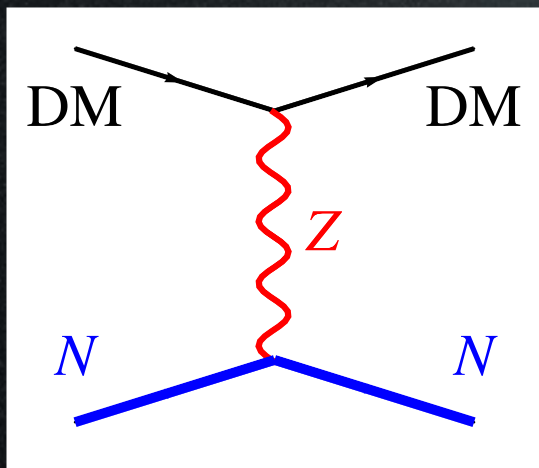

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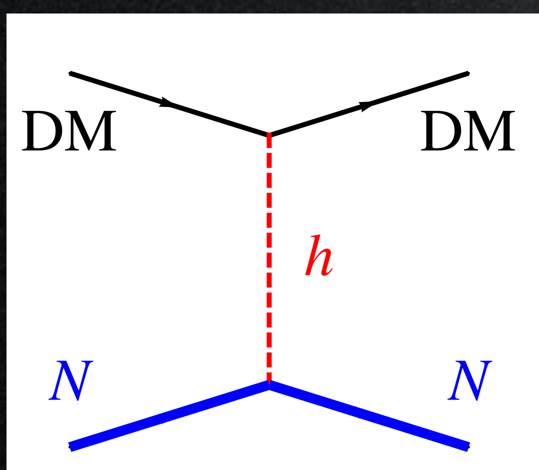

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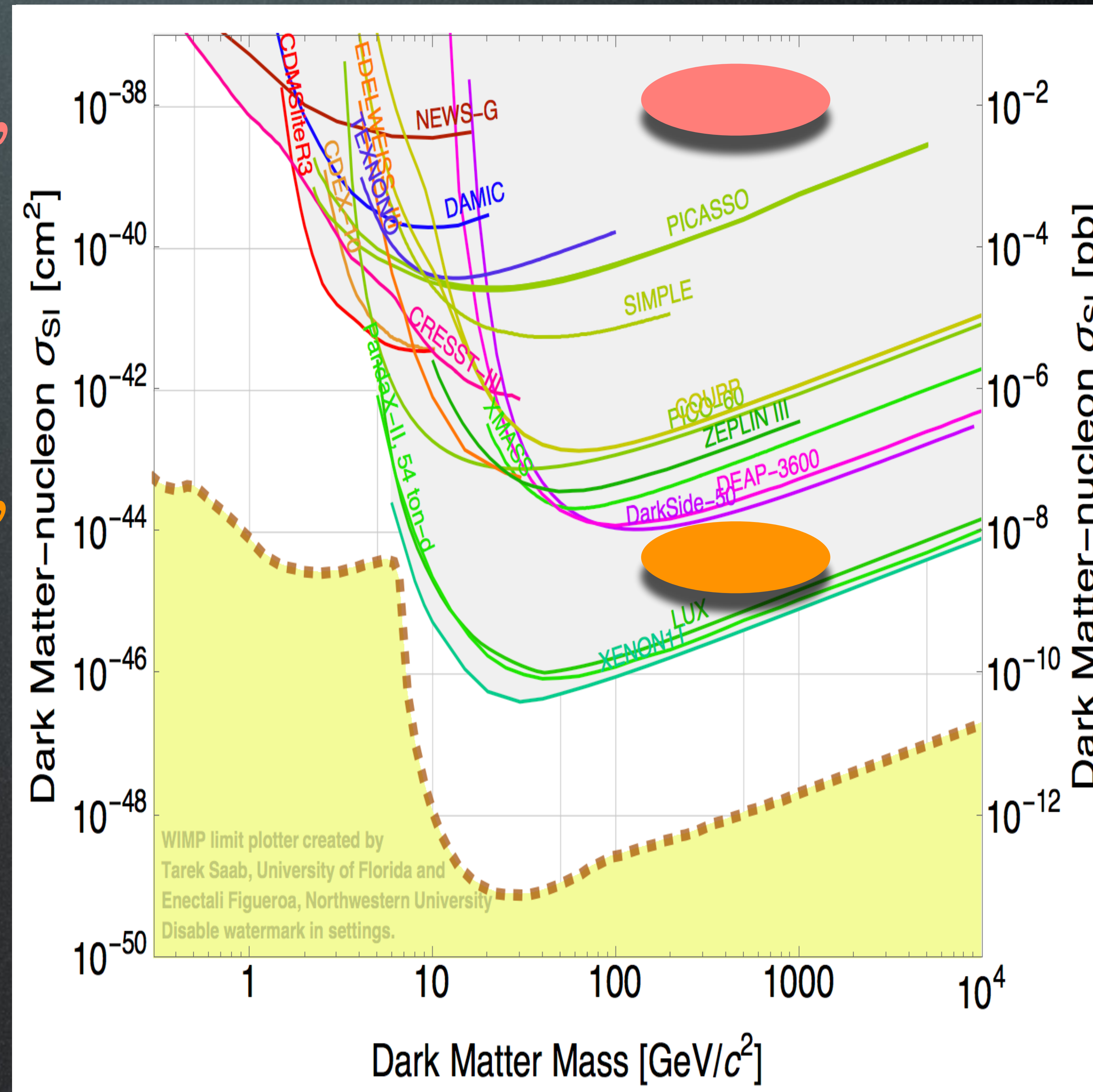

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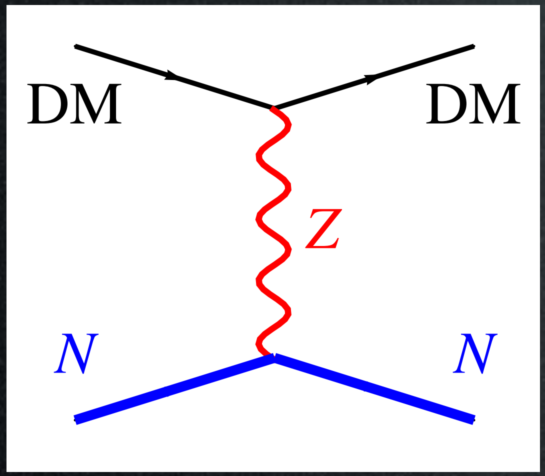

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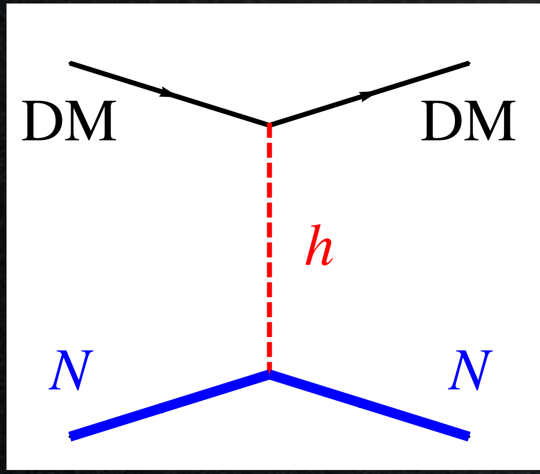

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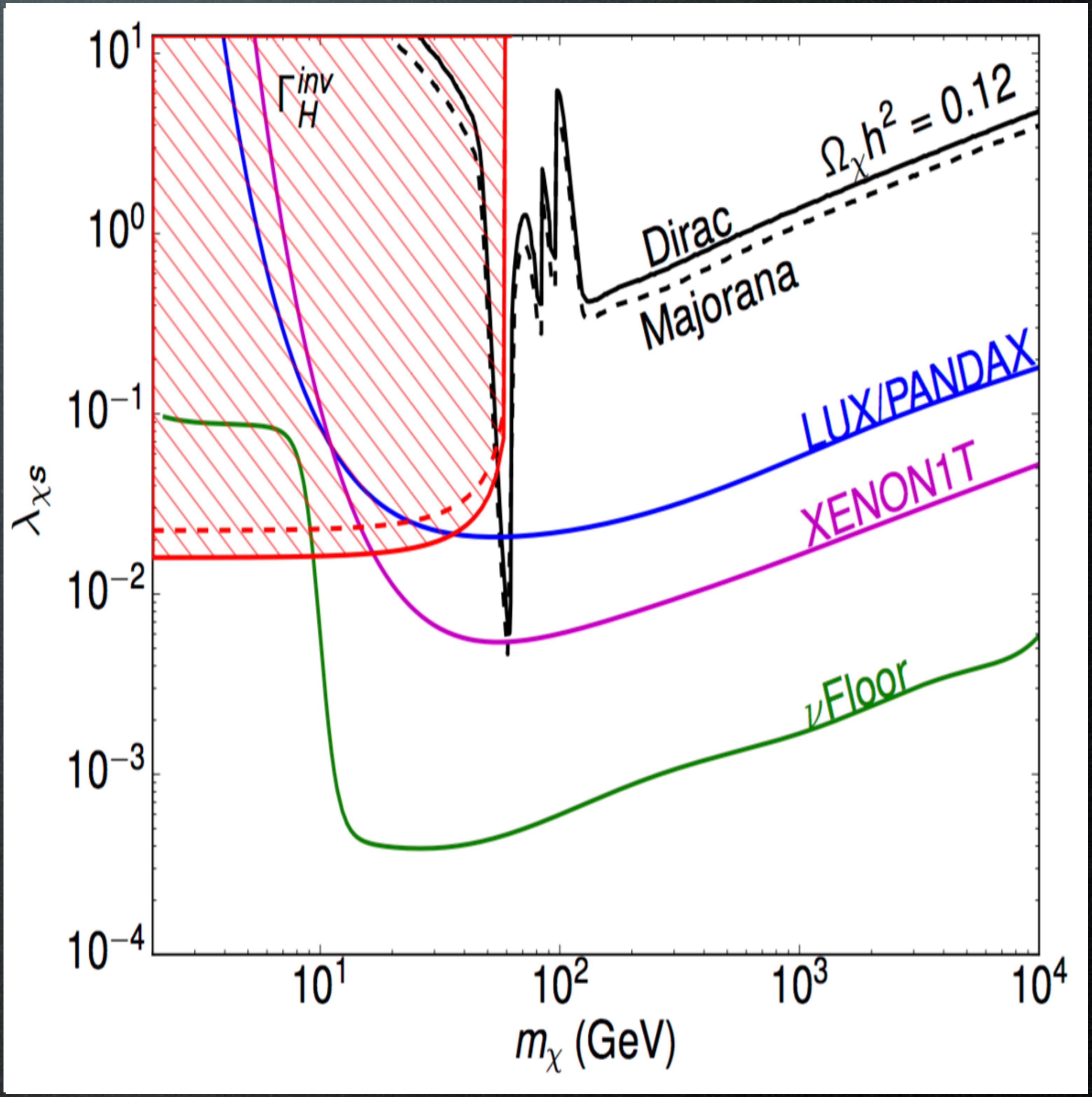

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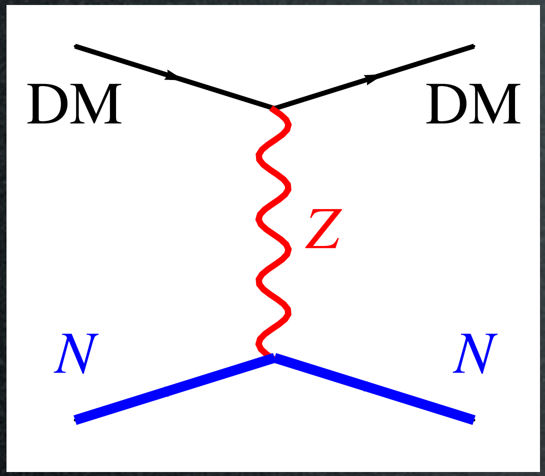

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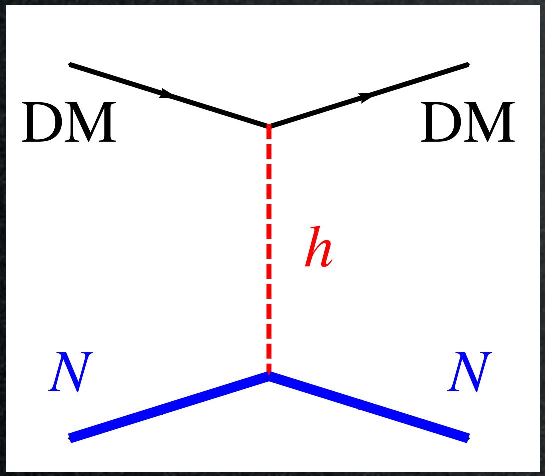

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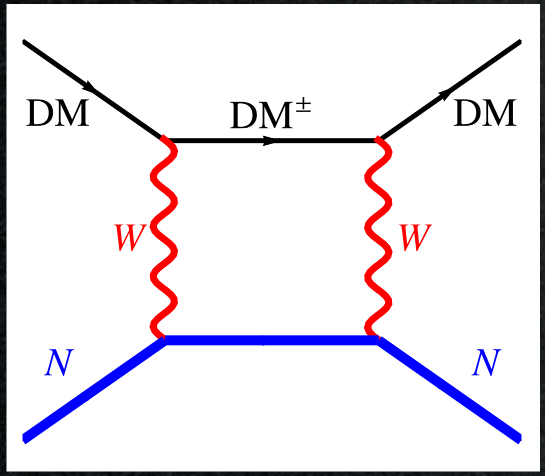

one loop

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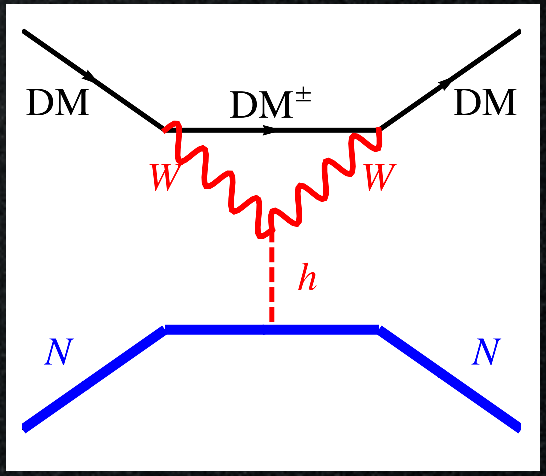

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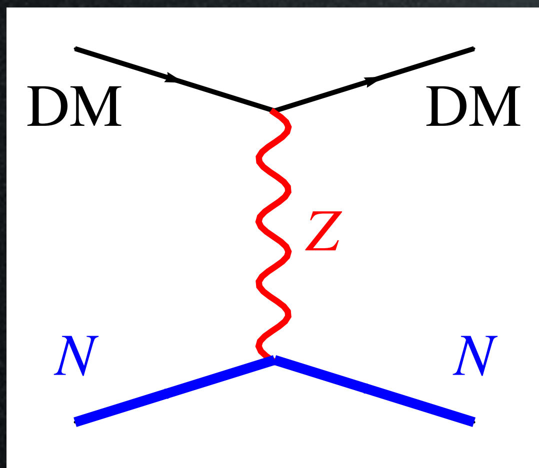

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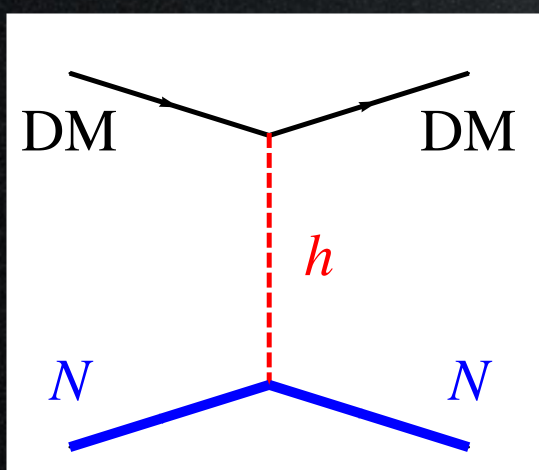

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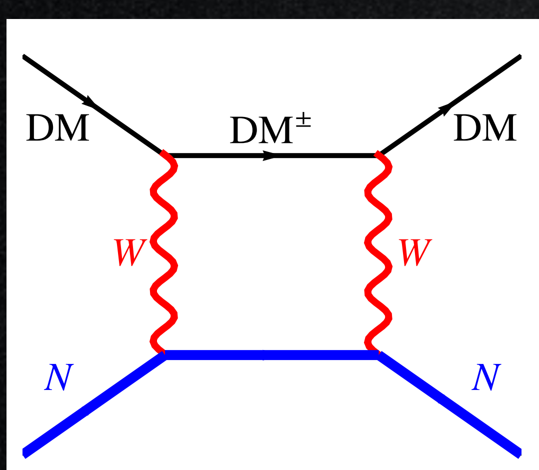

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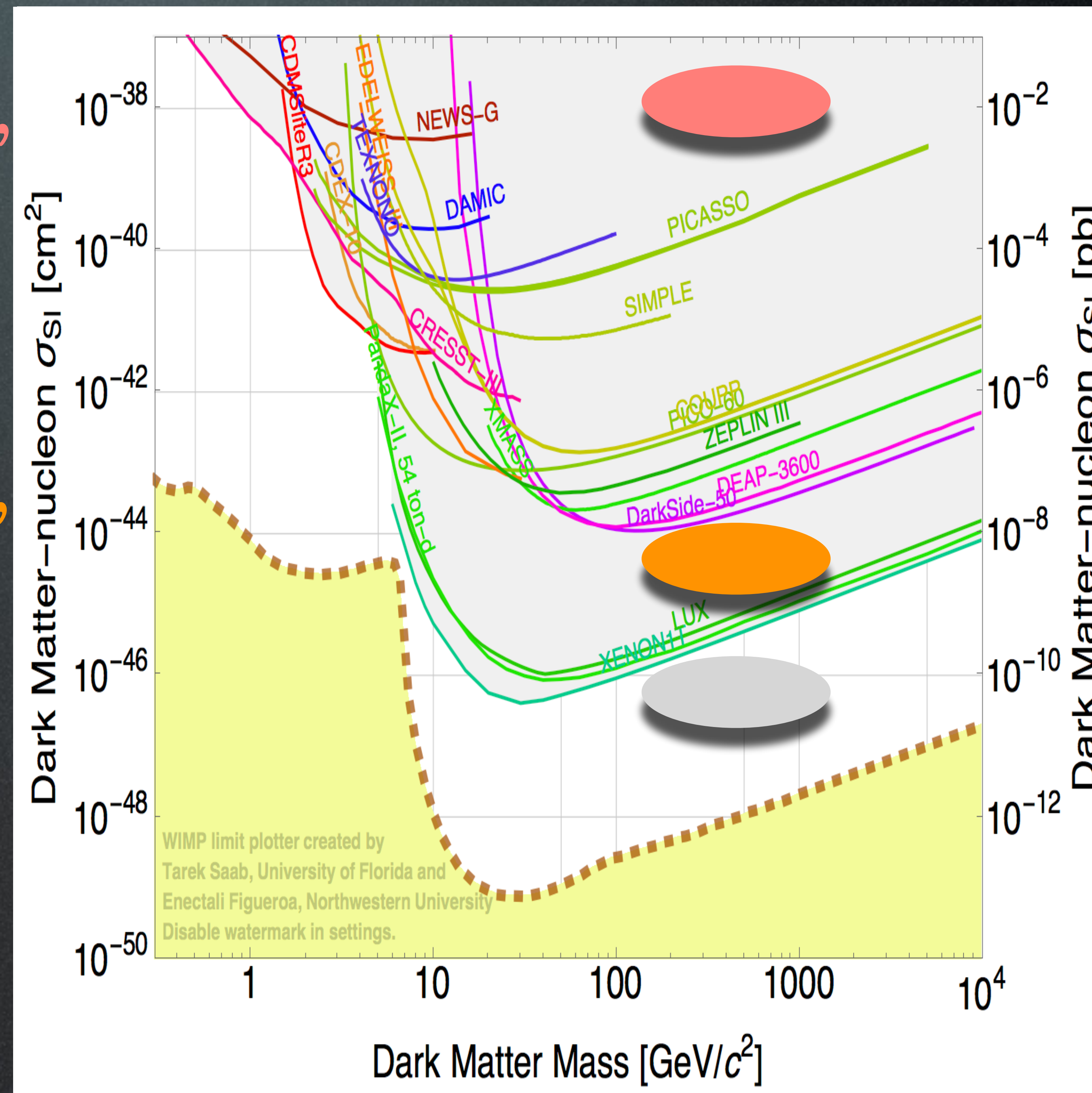

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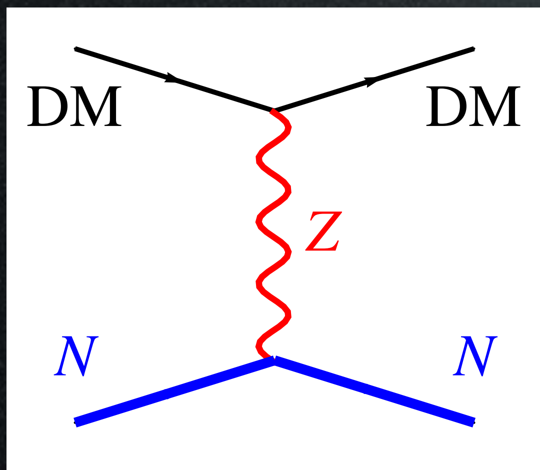

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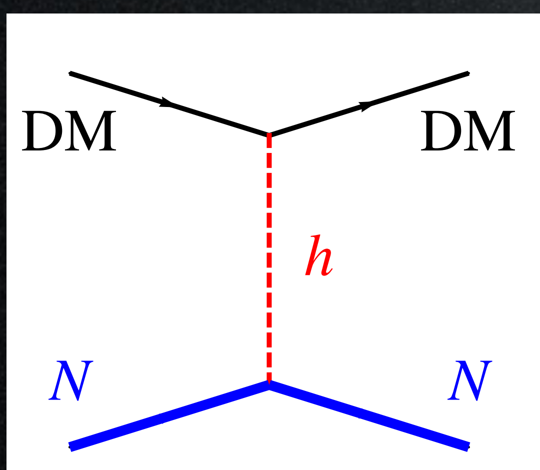

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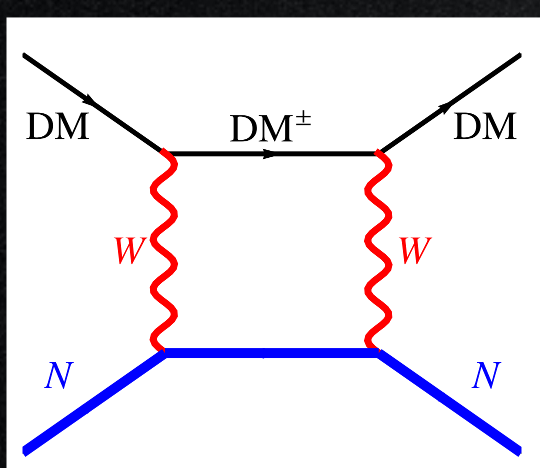

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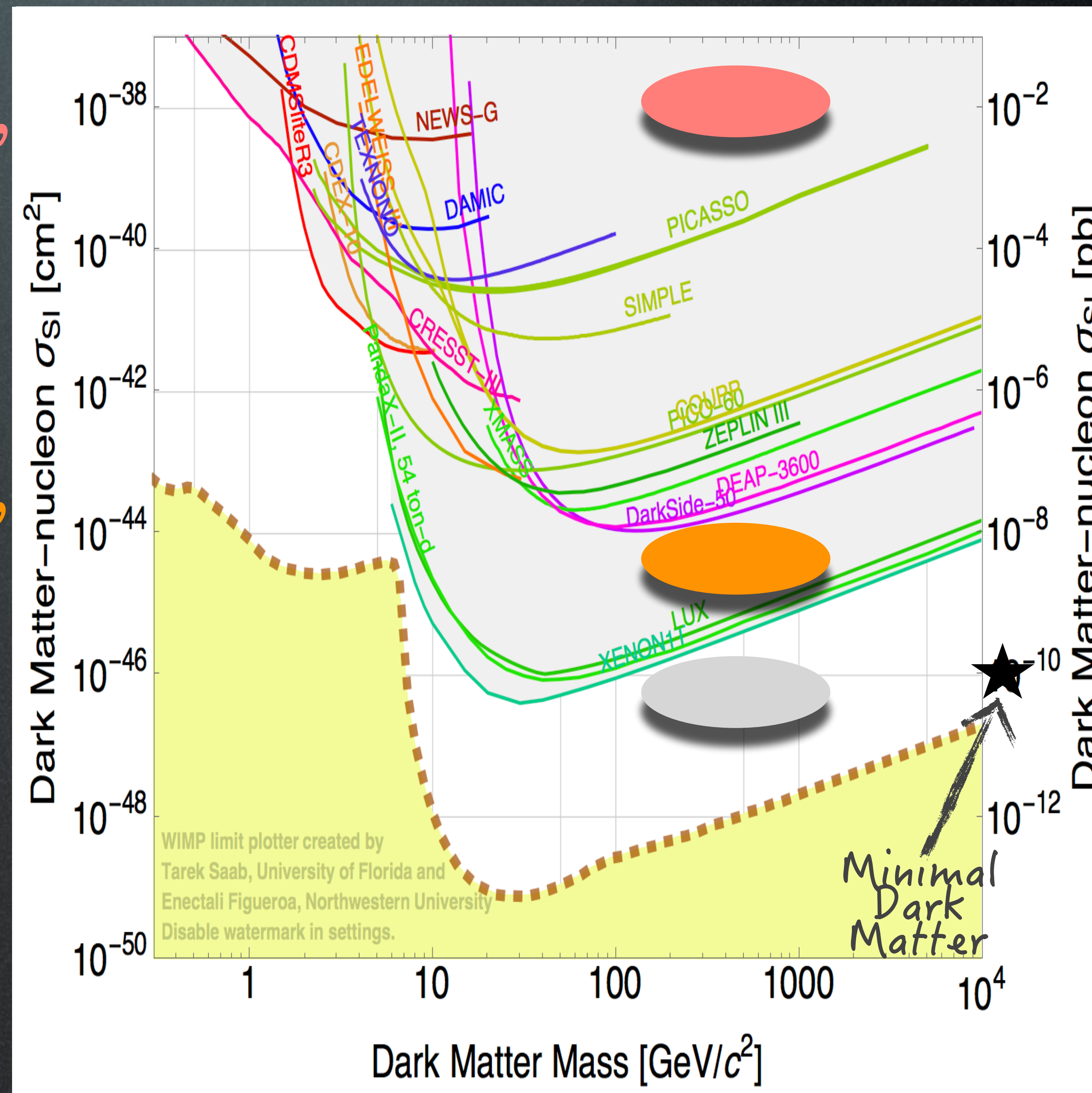

Cirelli, Fornengo, Strumia hep-ph/0512090

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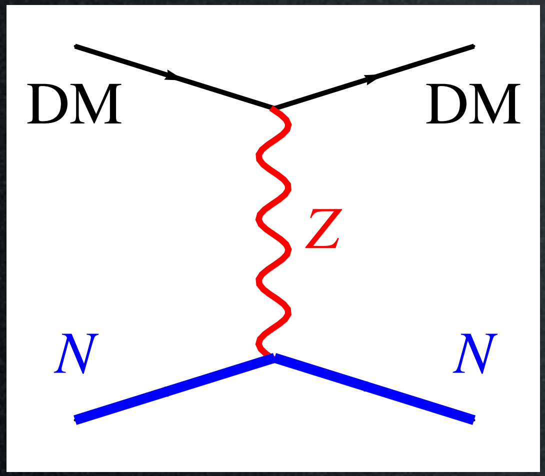
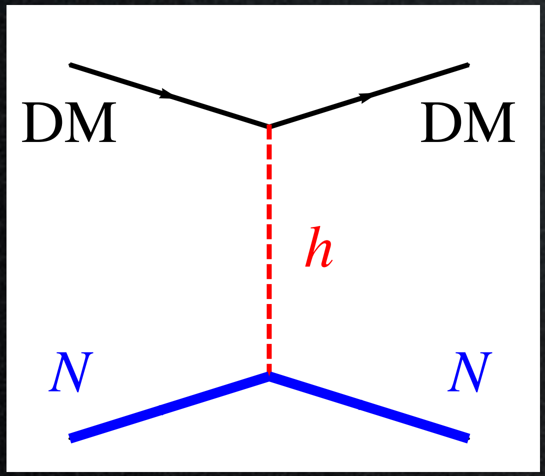
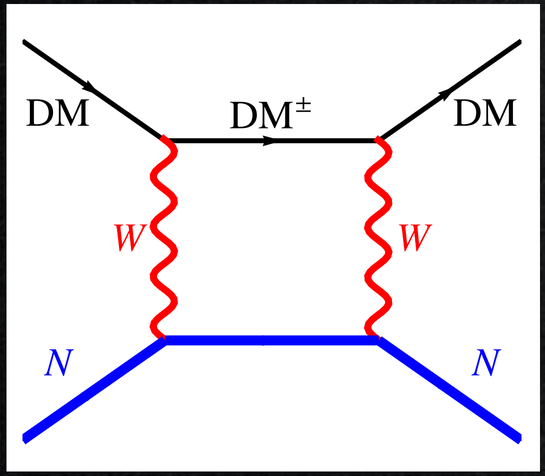
Still viable under which conditions?



tree level, vector



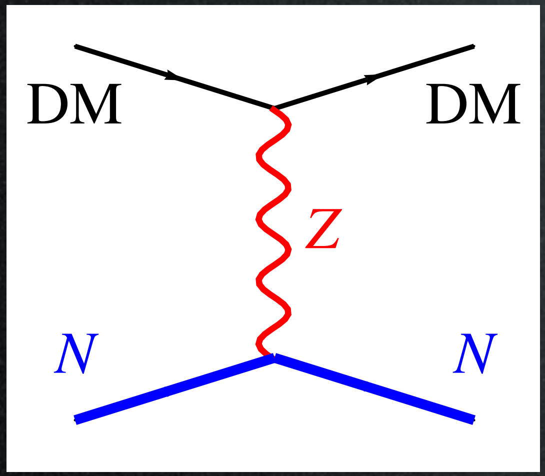
tree level, scalar



one loop

WIMP DD: 'theory'

SM weak scale SI interactions



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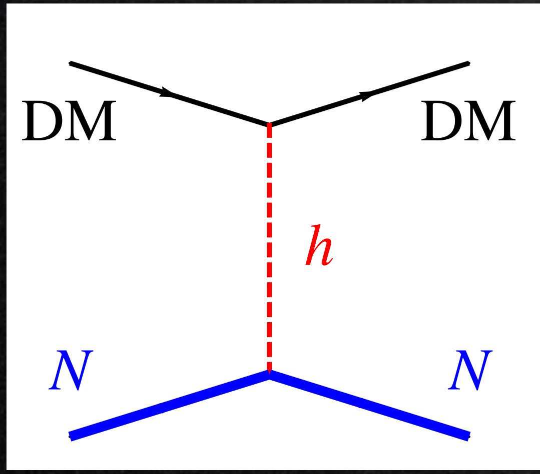
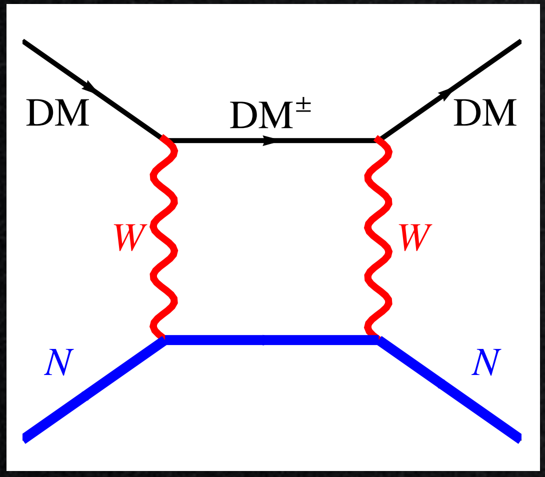


tree level, scalar



one loop

Still viable under which conditions?

- real particle
  (Majorana fermion, real scalar)

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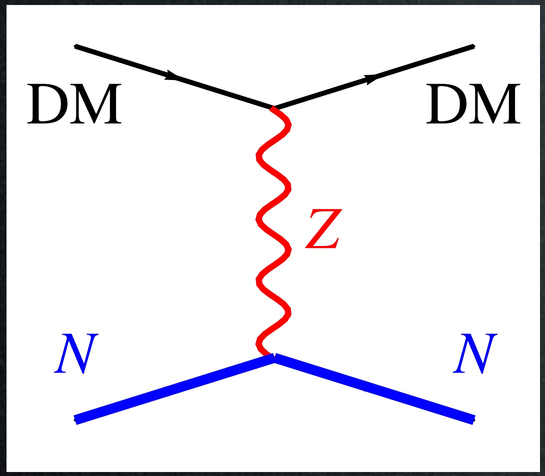

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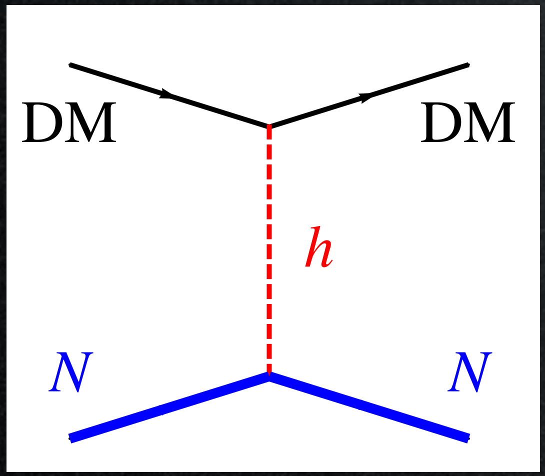

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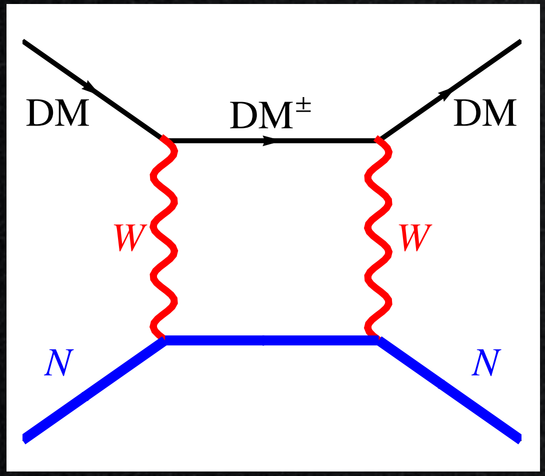

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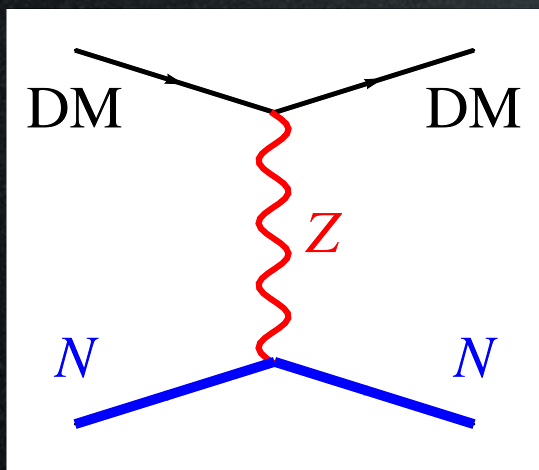

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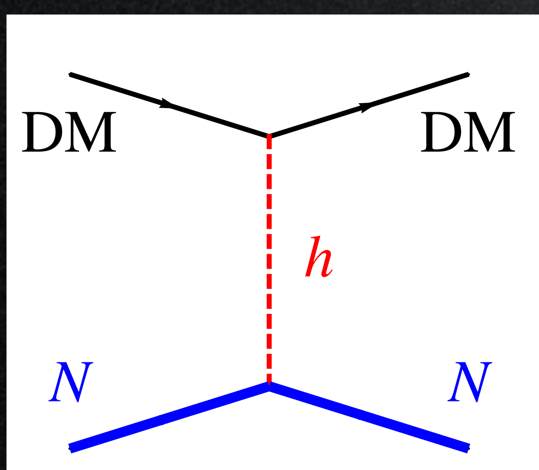
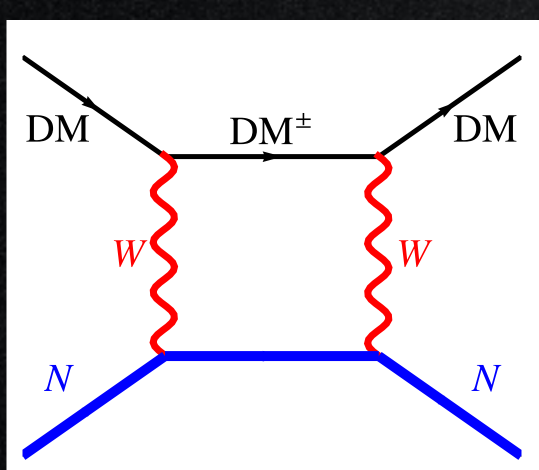


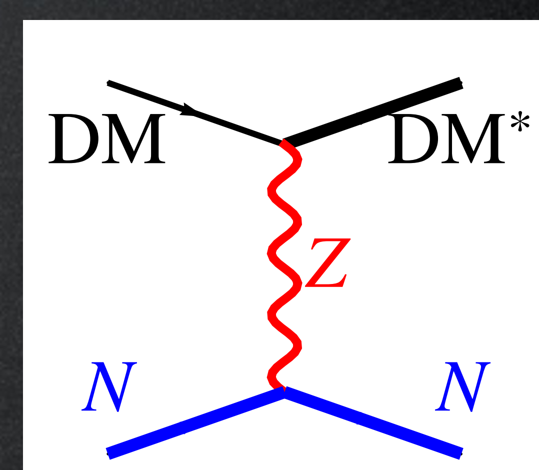
tree level, scalar



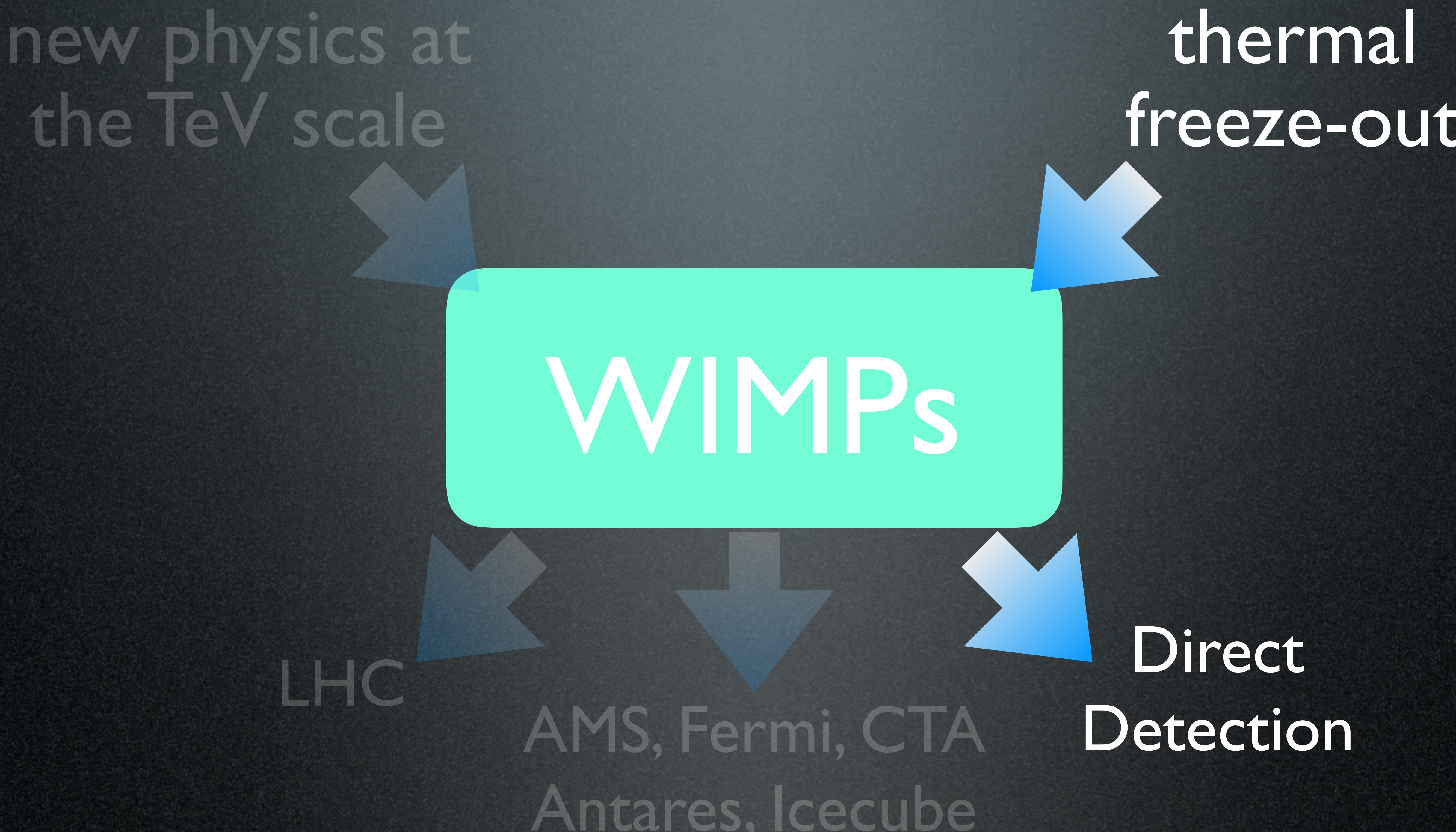
one loop

Still viable under which conditions?

- real particle
  (Majorana fermion, real scalar)
- hypercharge $Y = 0$
- SD interactions only
- inelastic scattering



Candidates

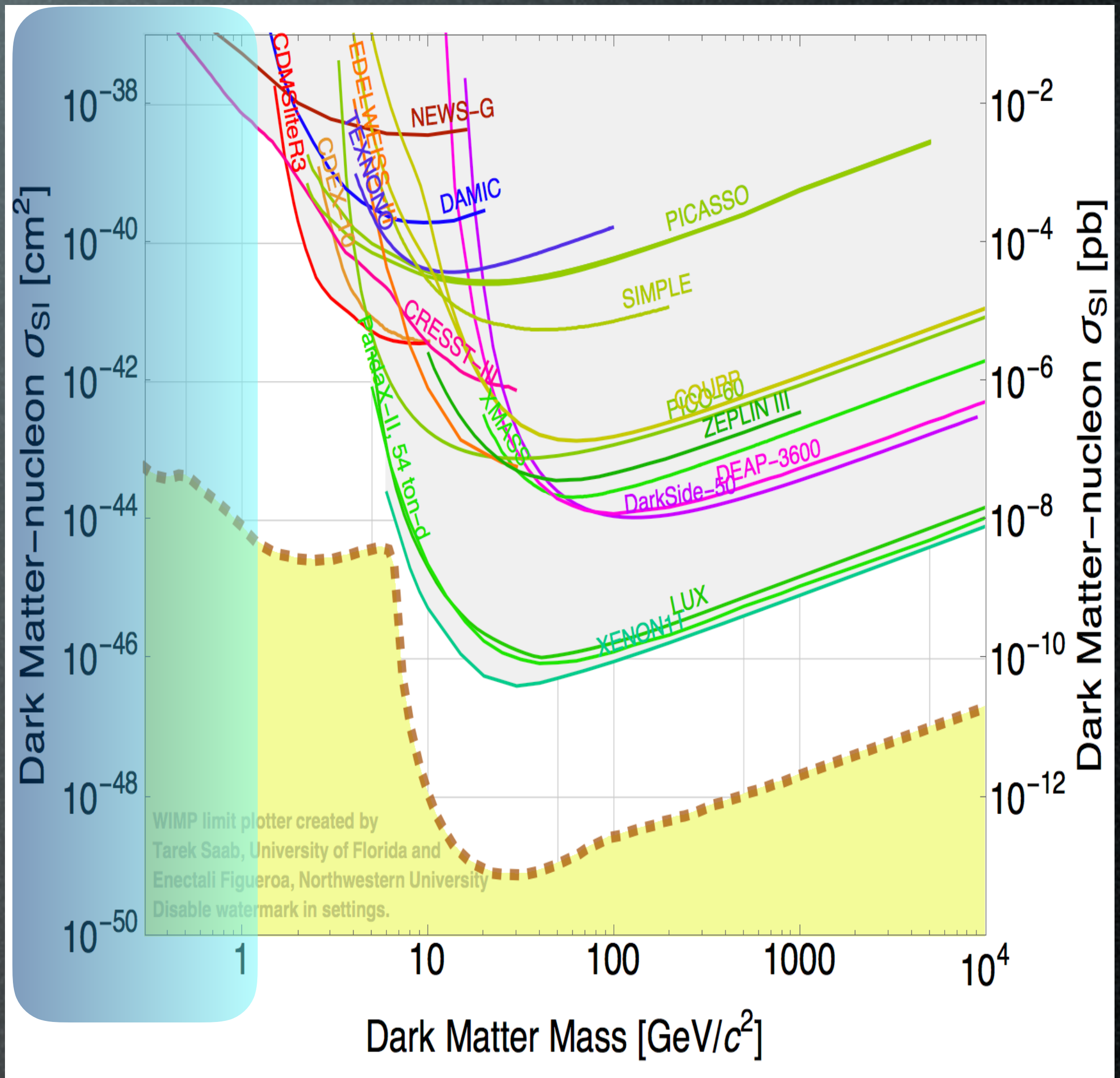


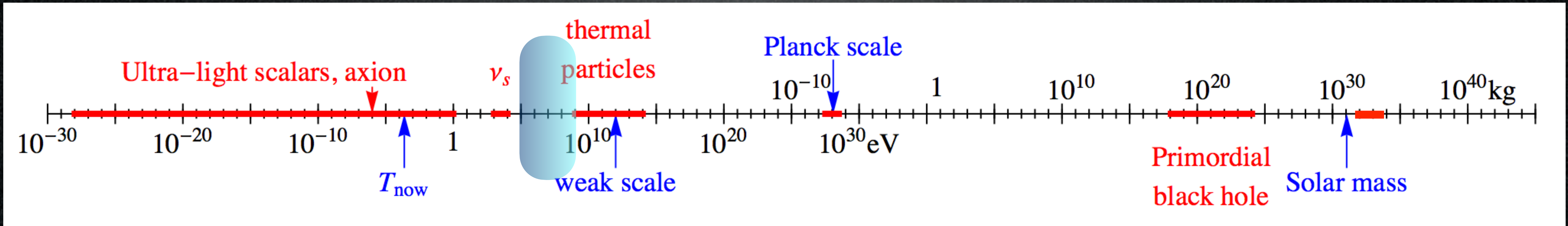
1. even without a larger framework, WIMPs are still appealing
2. the three search strategies are complementary

Candidates

A matter of perspective: plausible mass ranges

Sub-GeV DM?





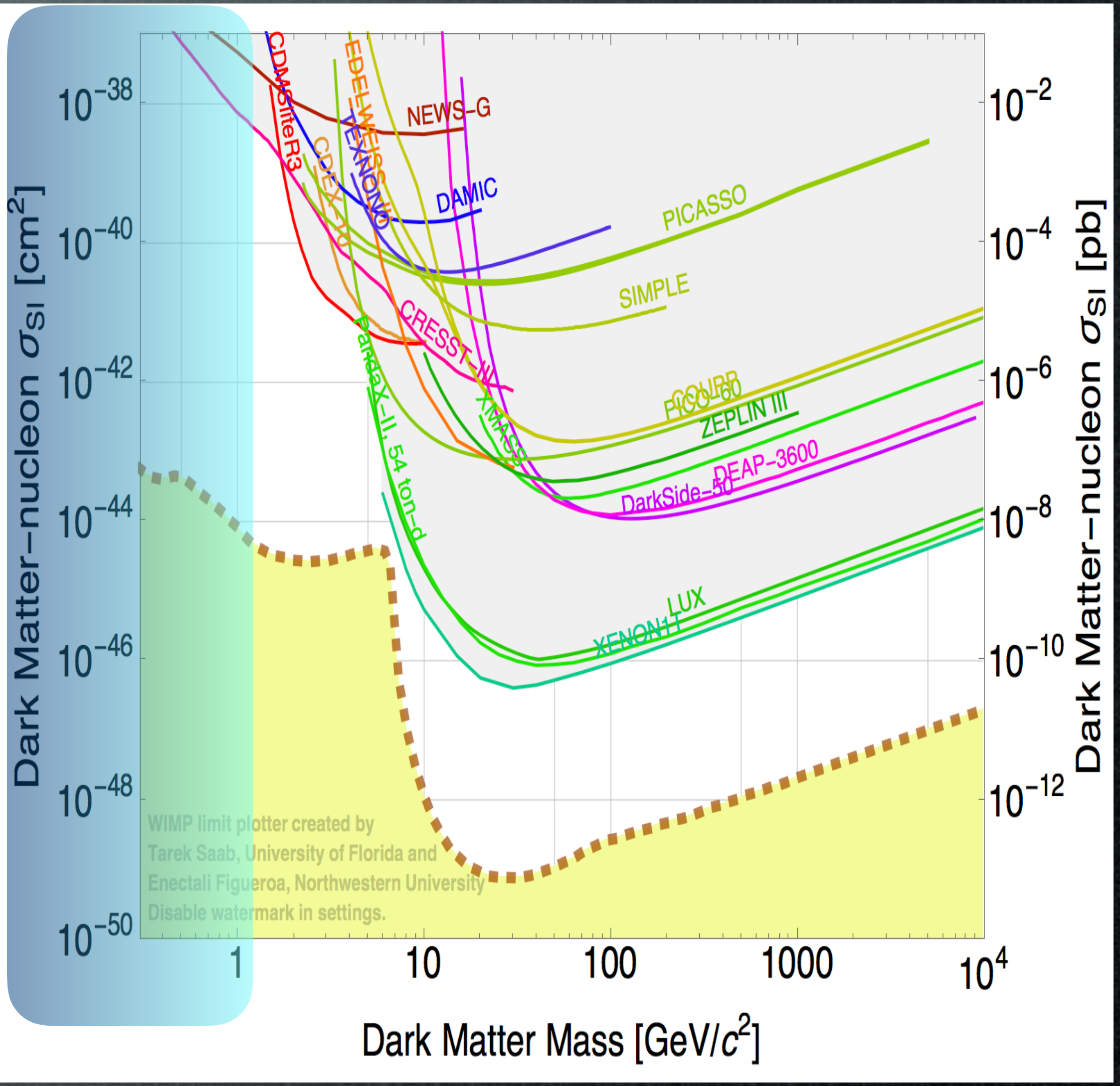
'only' 90 orders of magnitude!

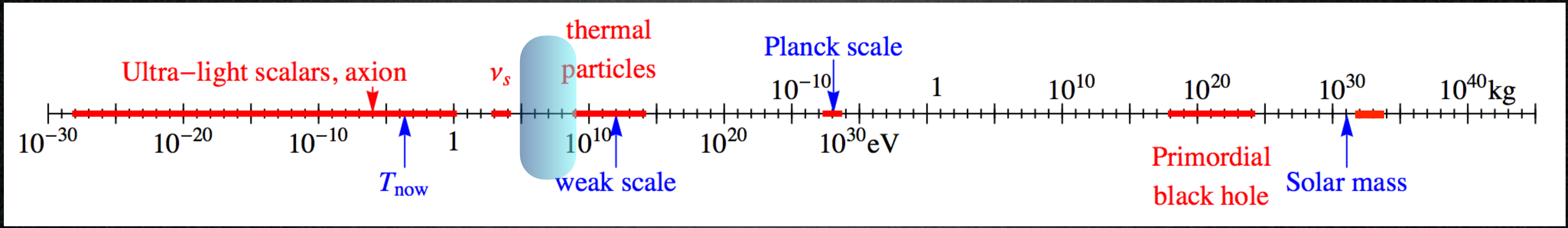
Candidates

A matter of perspective: plausible mass ranges

Sub-GeV DM?

Why not!





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Neutrinos factsheet

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- progress in the past 2 decades:

Parameter	best-fit	3σ
Δm^2_{21} $[10^{-5}$ eV $^2]$	7.37	6.93 – 7.96
$\Delta m^2_{31(23)}$ $[10^{-3}$ eV $^2]$	2.56 (2.54)	2.45 – 2.69 (2.42 – 2.66)
$\sin^2\theta_{12}$	0.297	0.250 – 0.354
$\sin^2\theta_{23}$, $\Delta m^2_{31(32)} > 0$	0.425	0.381 – 0.615
$\sin^2\theta_{23}$, $\Delta m^2_{32(31)} < 0$	0.589	0.384 – 0.636
$\sin^2\theta_{13}$, $\Delta m^2_{31(32)} > 0$	0.0215	0.0190 – 0.0240
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Nakamura & Petcov, PDG 2018

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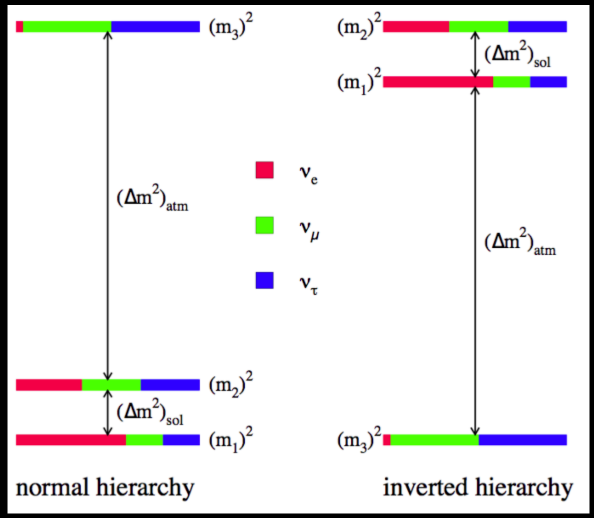
  - Majorana or Dirac?
  - absolute mass scale?
  - mass ordering?



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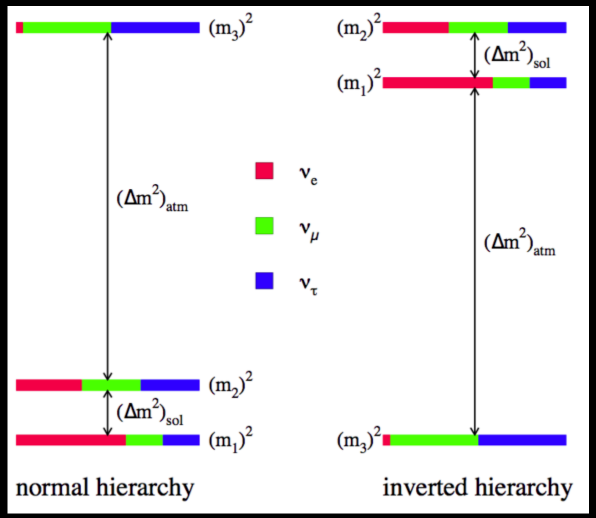
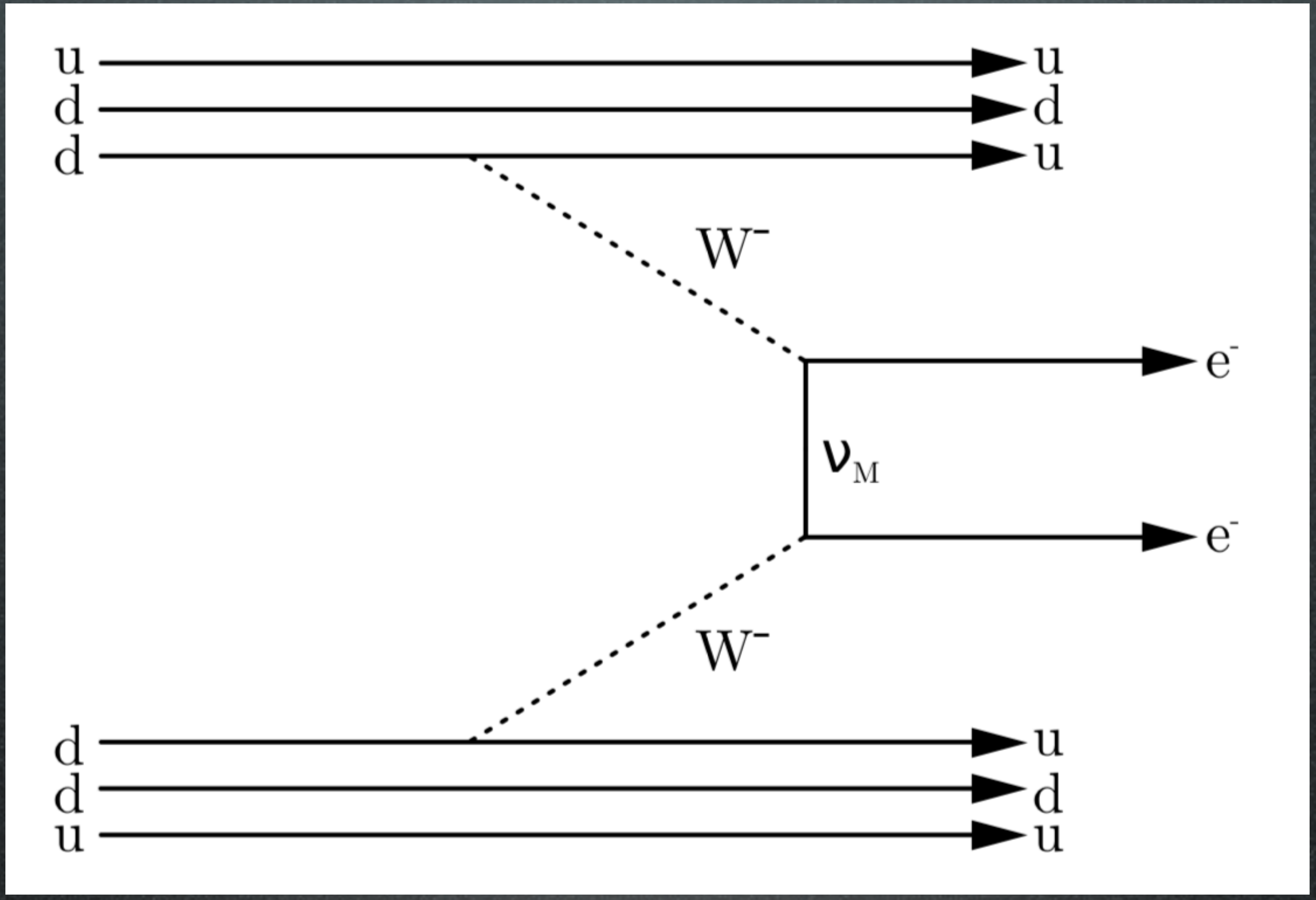
$0\nu\beta\beta$



0νββ

If neutrinos are Majorana, 0νββ can happen

$$(A, Z) \rightarrow (A, Z+2) + 2e^-$$



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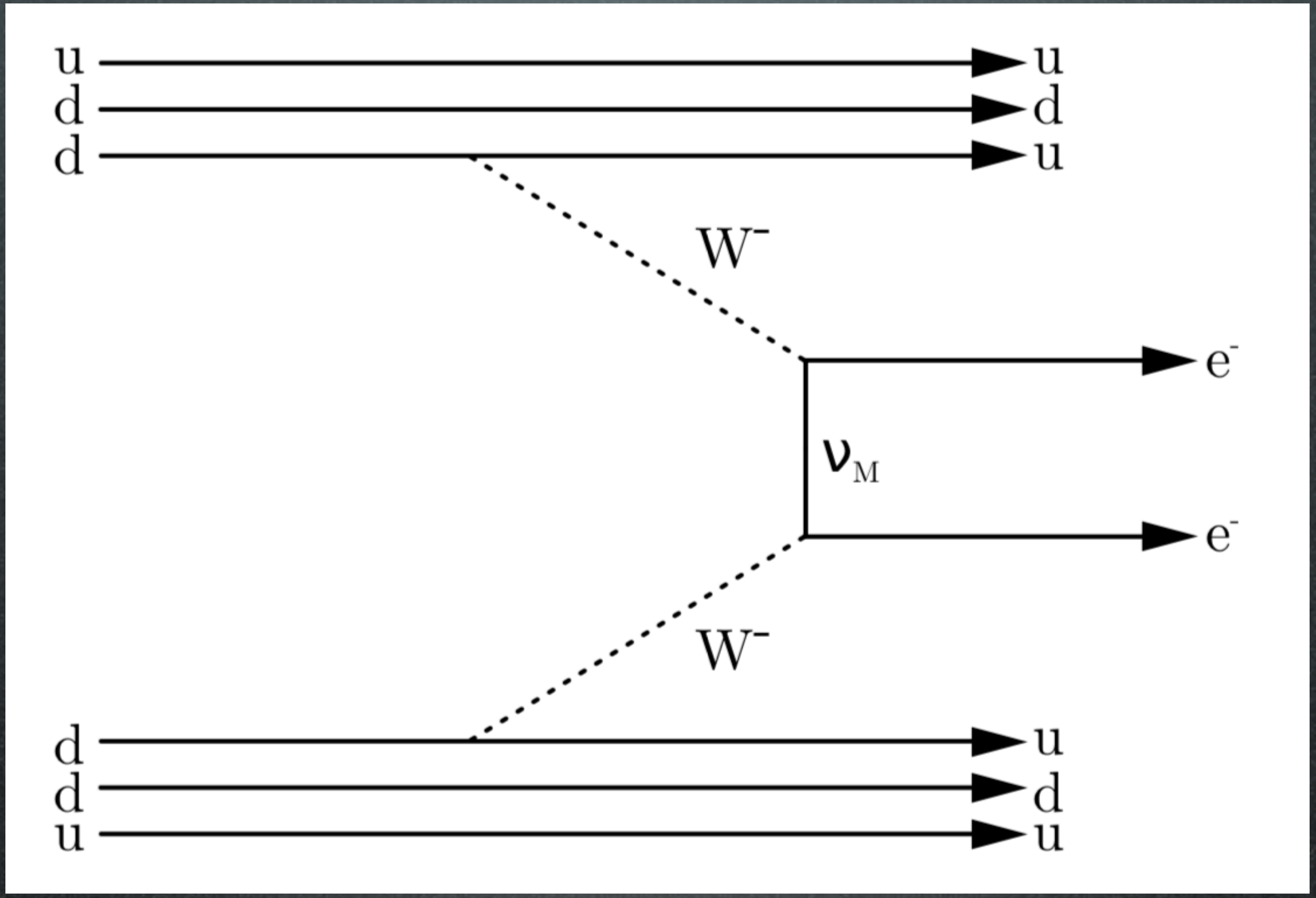

0νββ violates the (total) lepton number → BSM!

$0\nu\beta\beta$

Effective Majorana mass $m_{\beta\beta}$

$$m_{\beta\beta} = \left| \sum_{i=1,2,3} U_{ei}^2 \, m_i \right|$$

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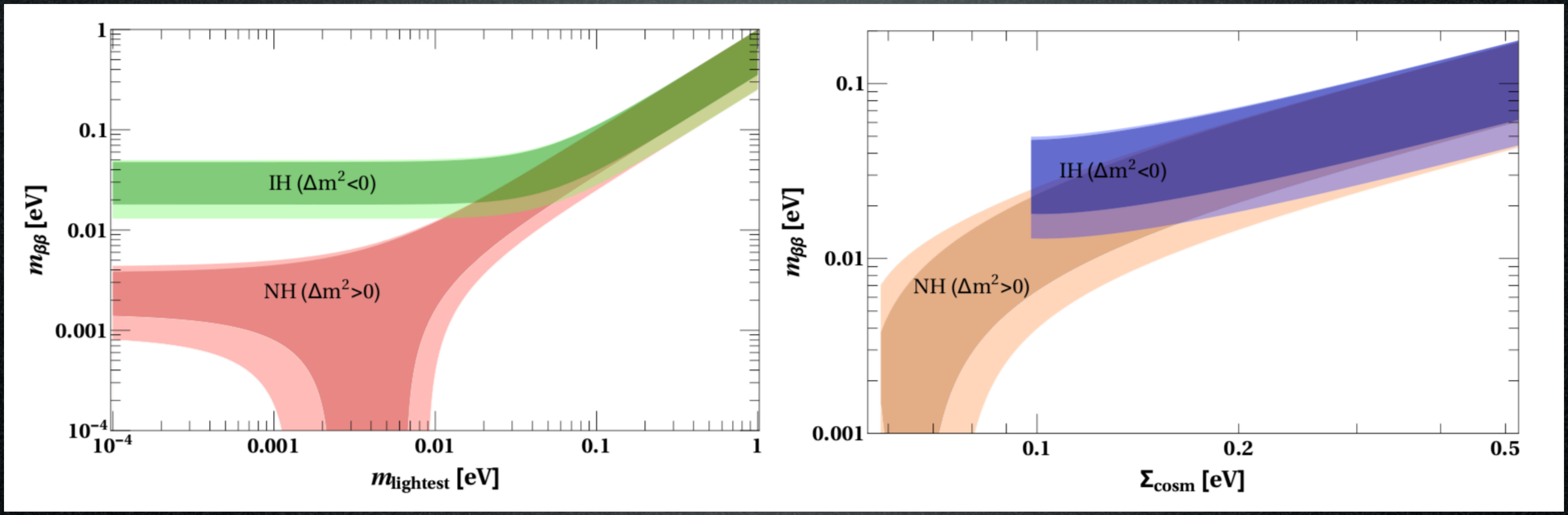
$m_{\beta\beta}$ is connected to absolute mass and ordering



Dell'Oro et al., arXiv:1404.2616

Conclusions

The physics of rare events (DM DD and $0\nu\beta\beta$) is in an experiment driven phase

Theory can (does) point to preferred directions, but actually too many...