11 October 2017
7th Amsterdam-Paris-Stockholm meeting, Kasteel Woerden

The motivation for and status of WIMPs

Or: how we fell in love with WIMPs and should not dump them (yet)

Marco Cirelli
(CNRS LPTHE Jussieu Paris)

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Candidates

WIMPs

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$SU(2)_L$

Candidates

new physics at the TeV scale

thermal freeze-out

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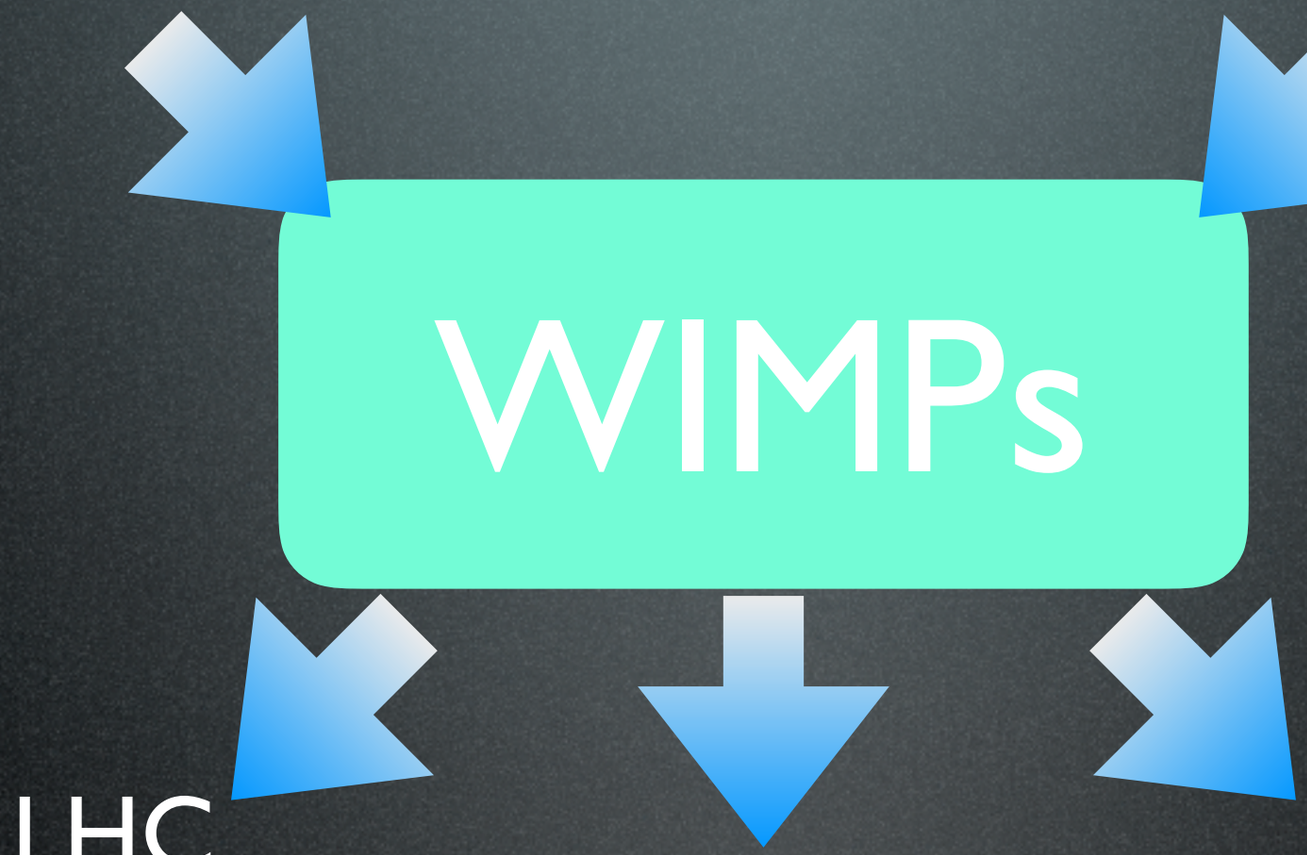
thermal freeze-out

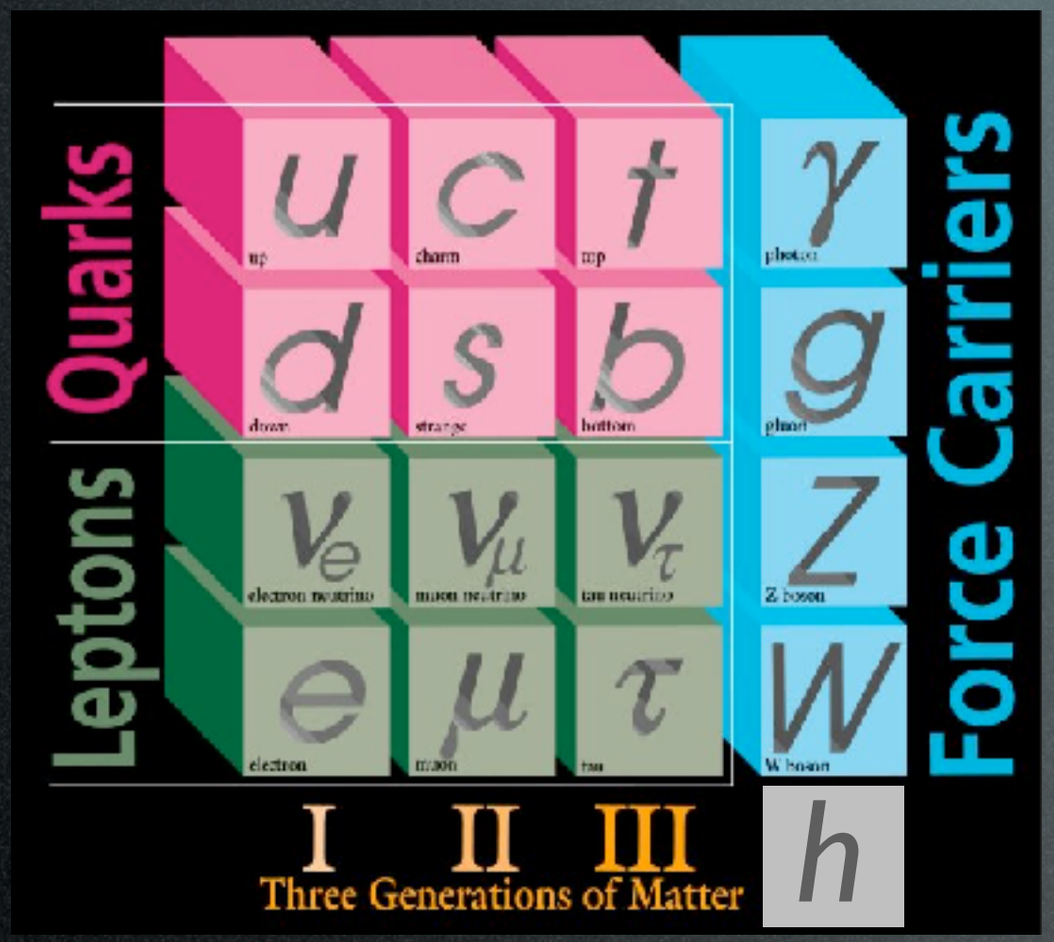


LHC

AMS, Fermi, CTA
Antares, Icecube

Direct Detection

SuSy DM in 2 minutes



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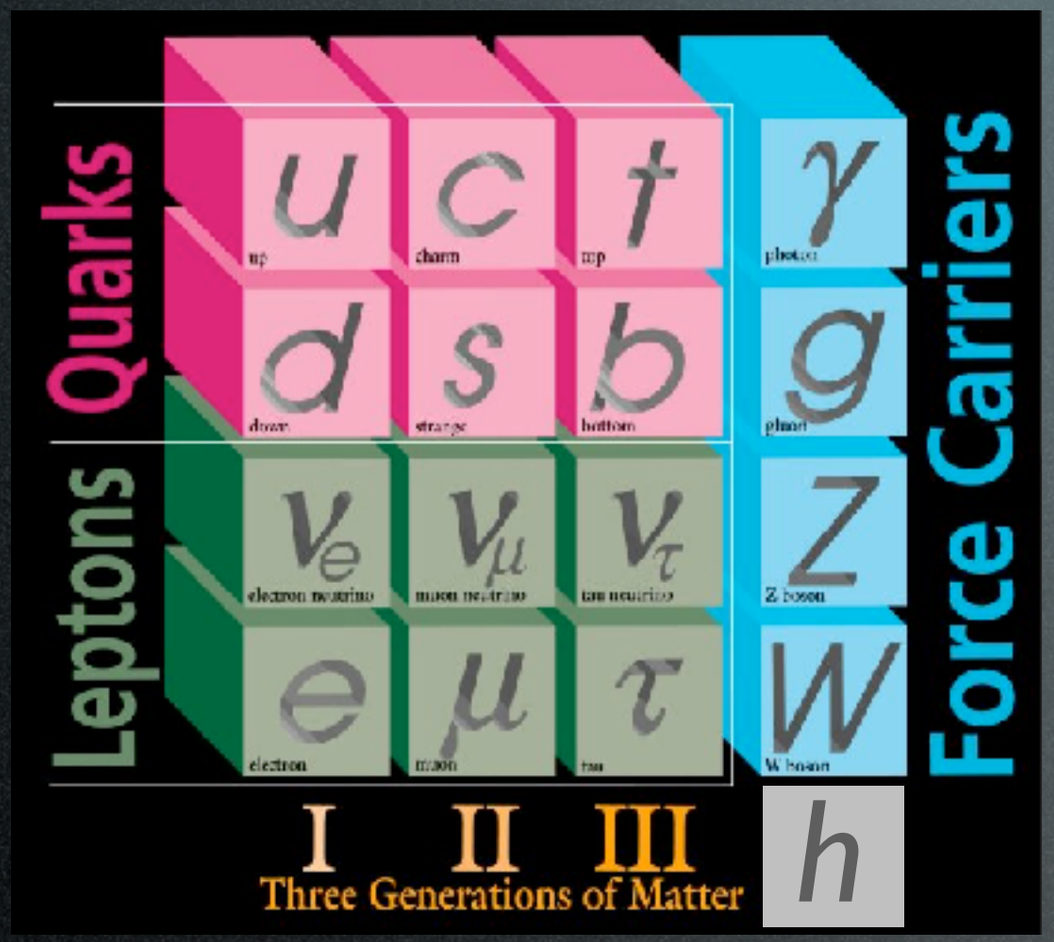
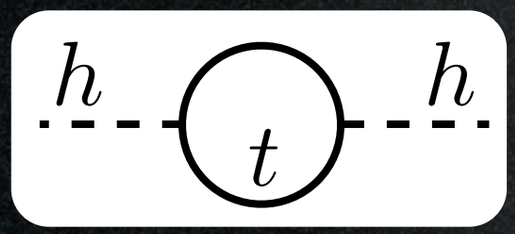


$m_{\rm h} \simeq 125$ GeV



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

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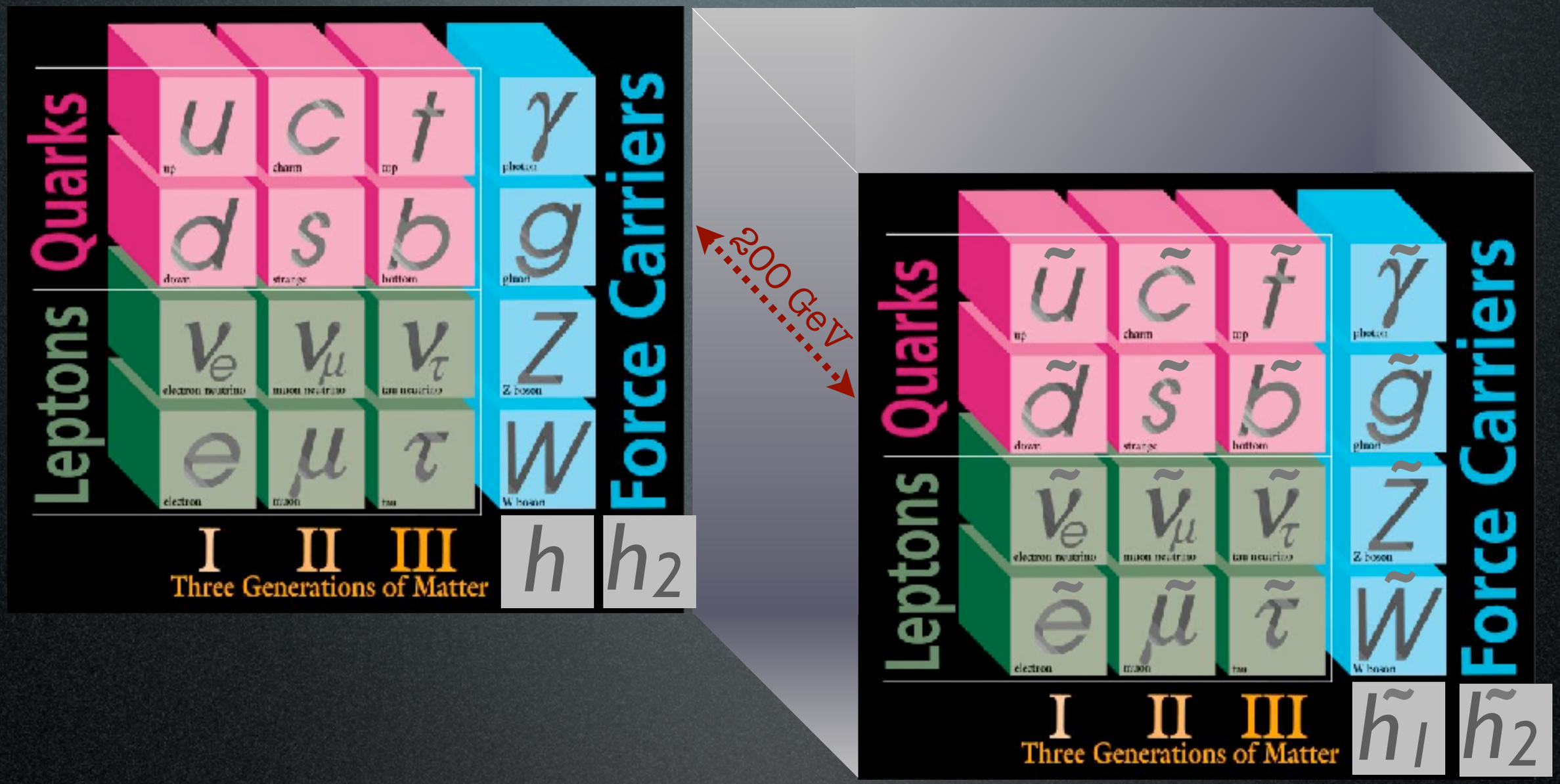

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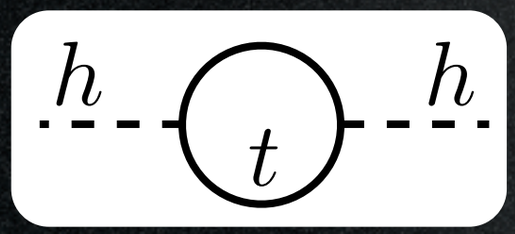

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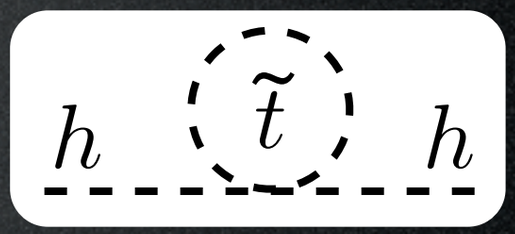

$\Delta m_{\rm h} \propto -10^{19}$ GeV

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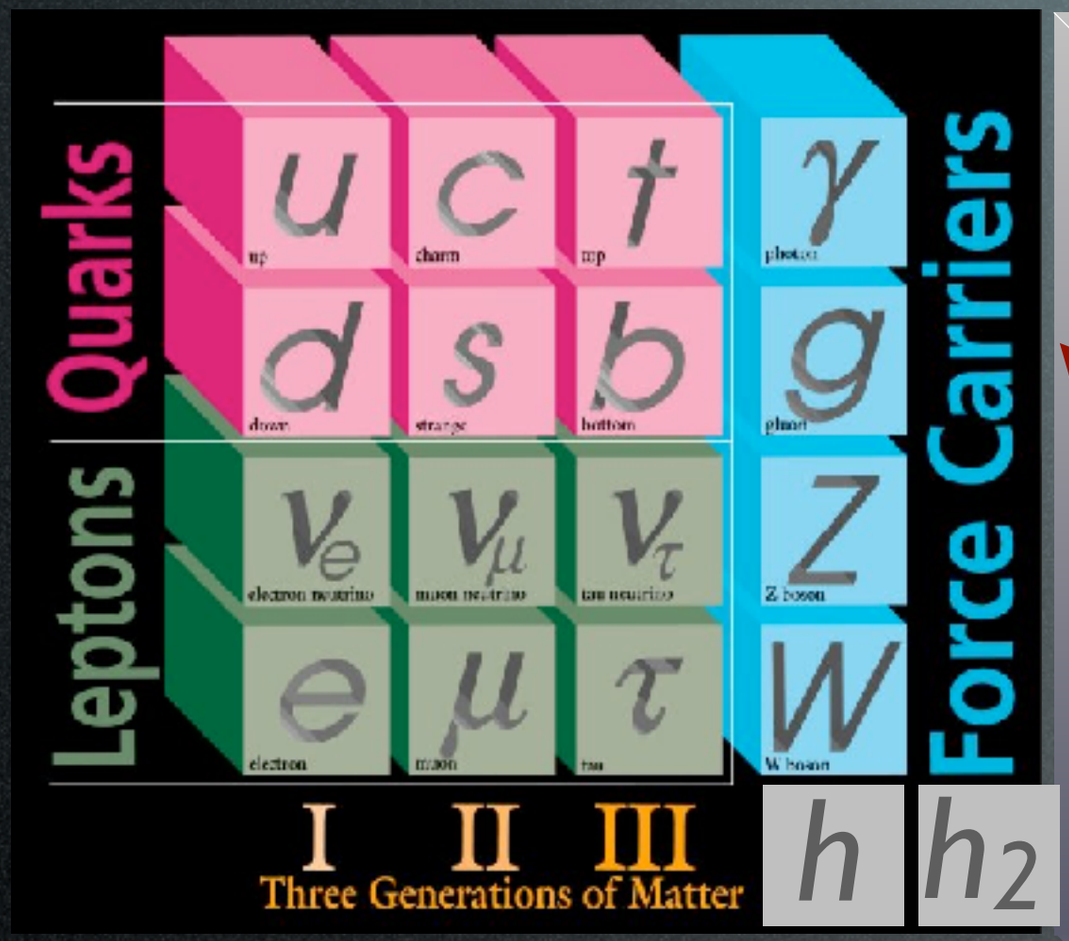
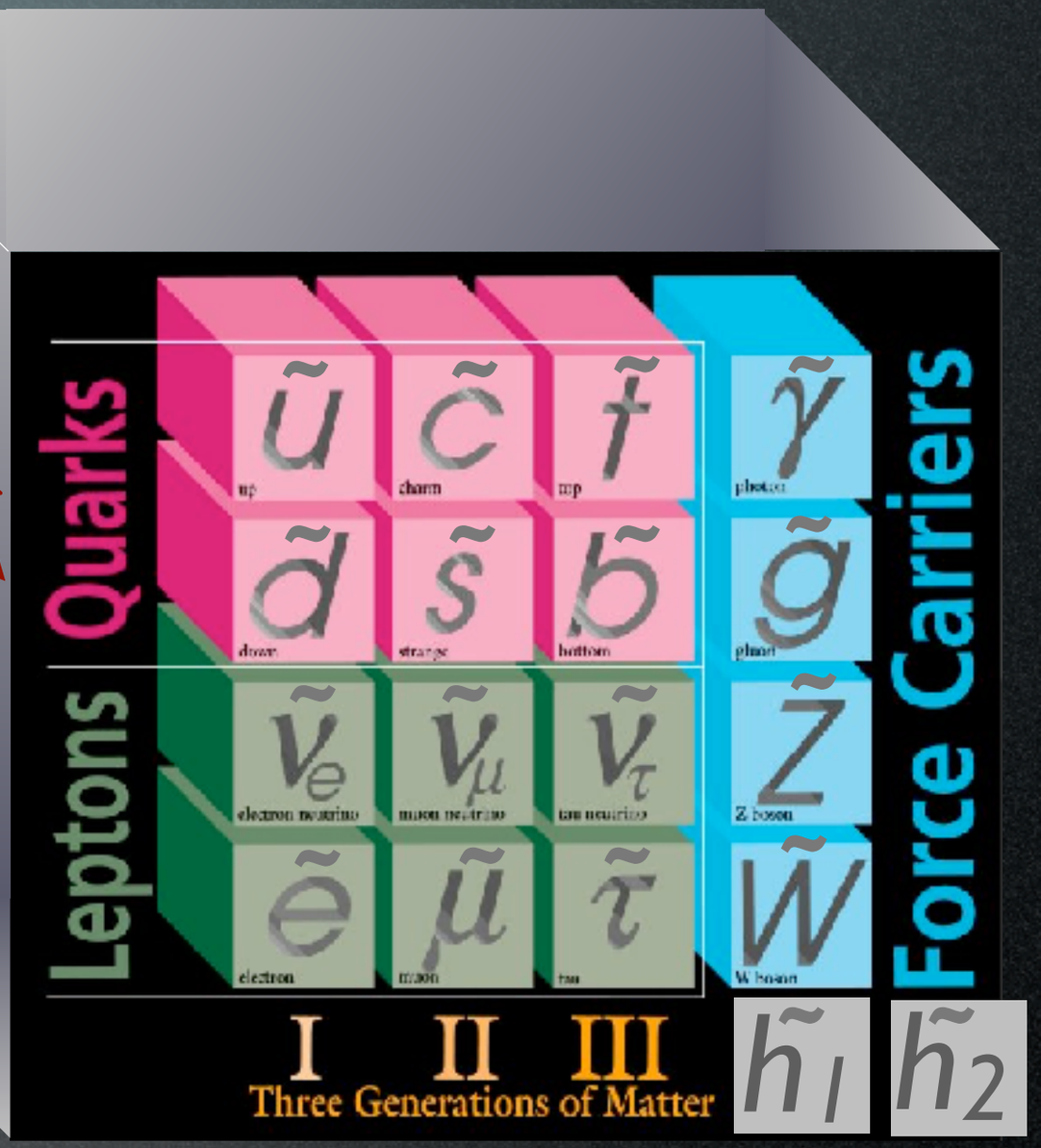


200 GeV



$$R = +1$$

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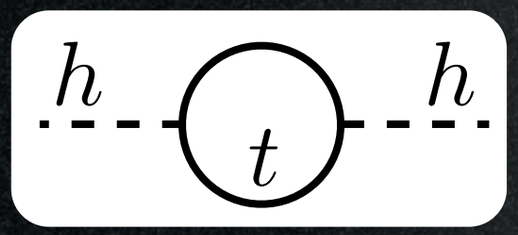

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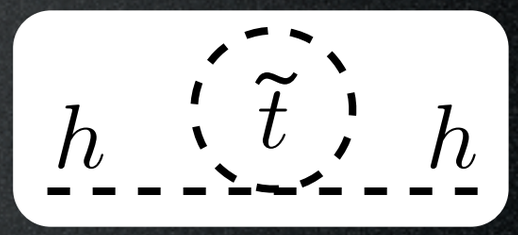

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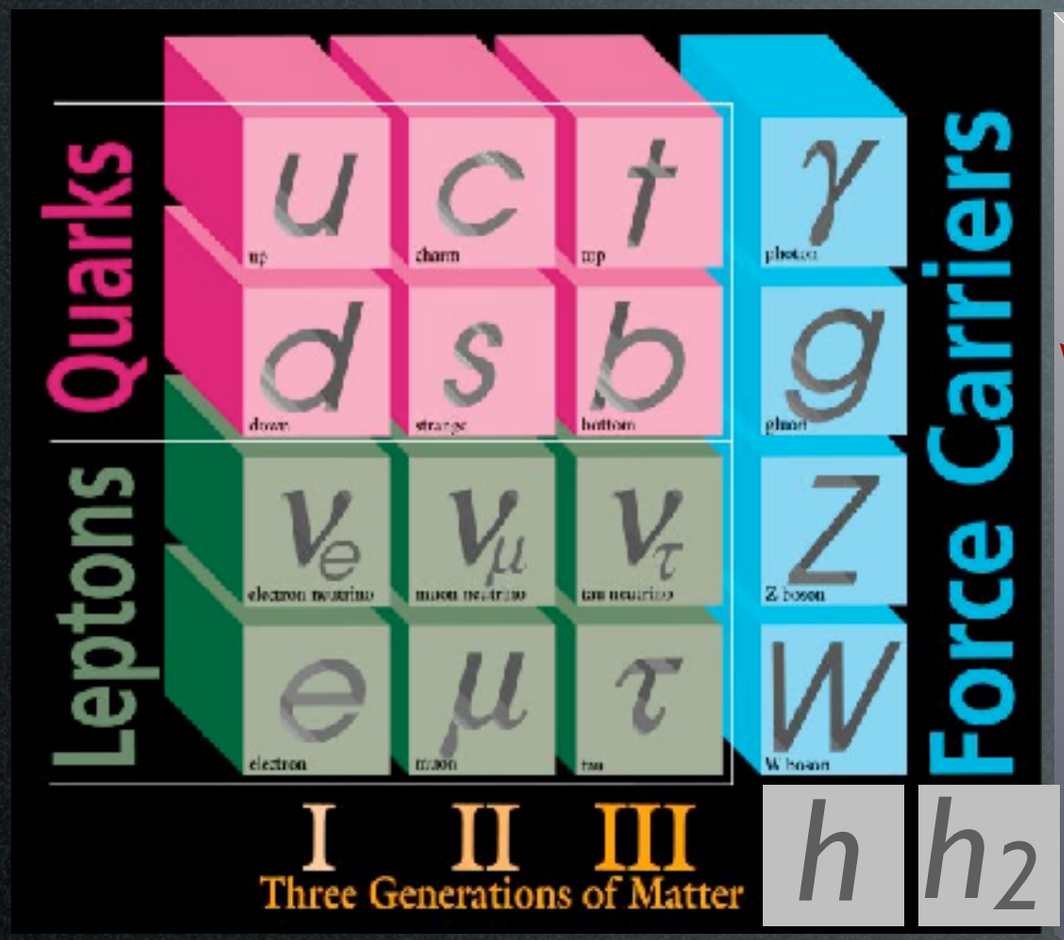

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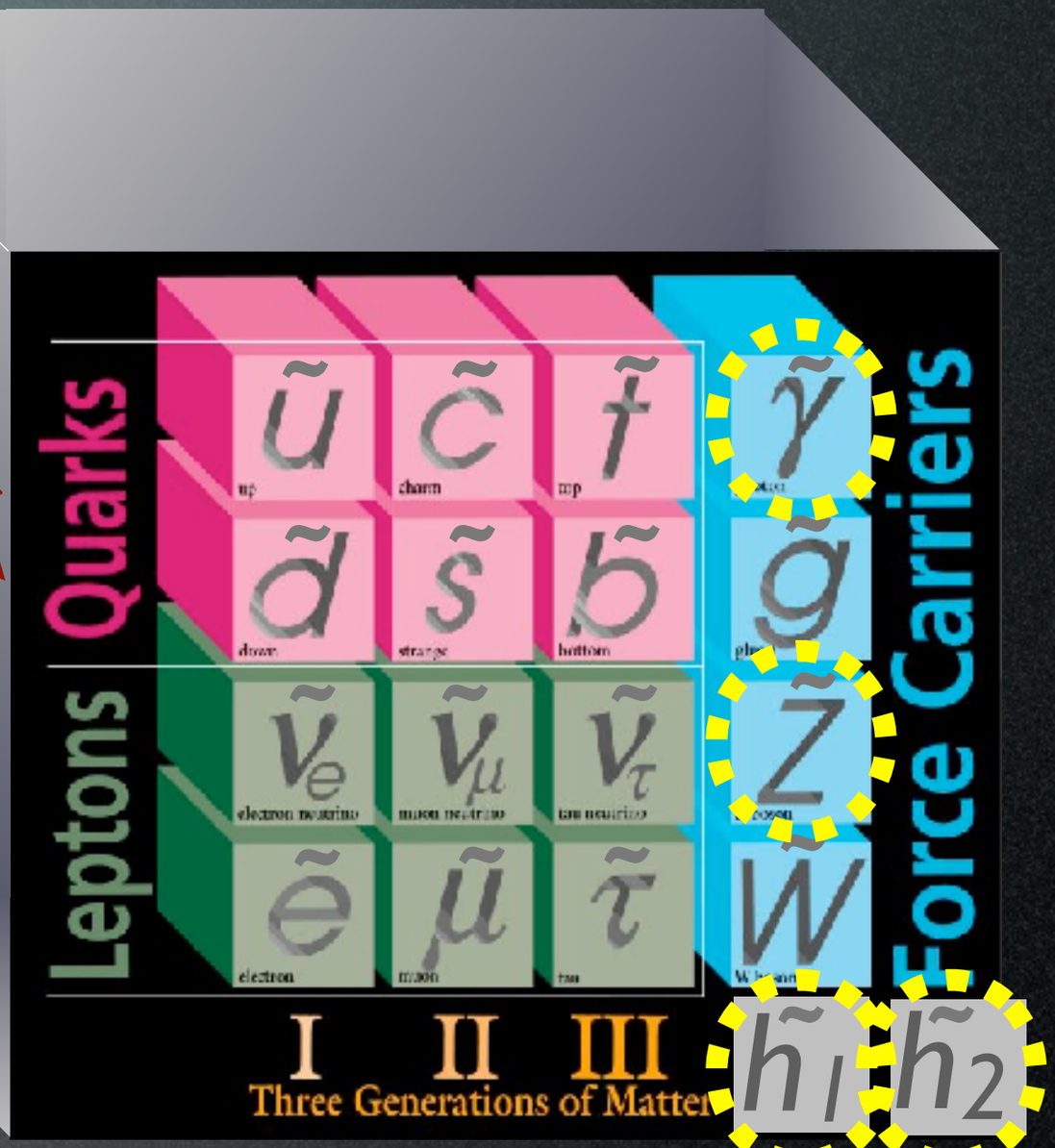

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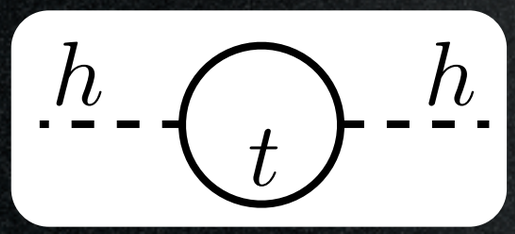

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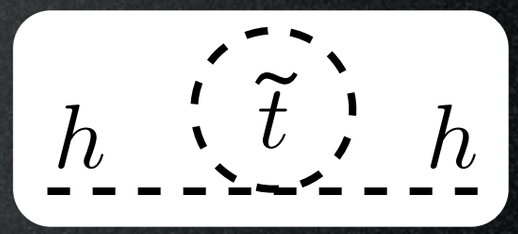

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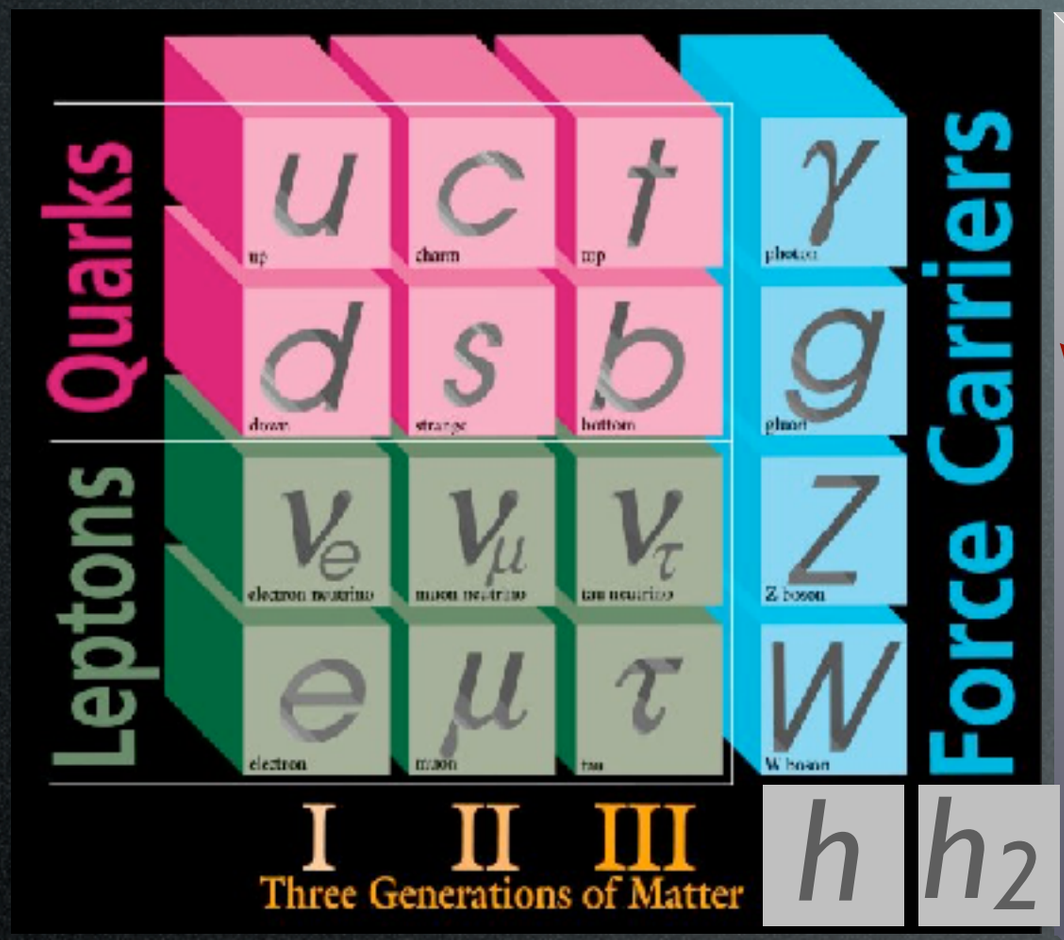

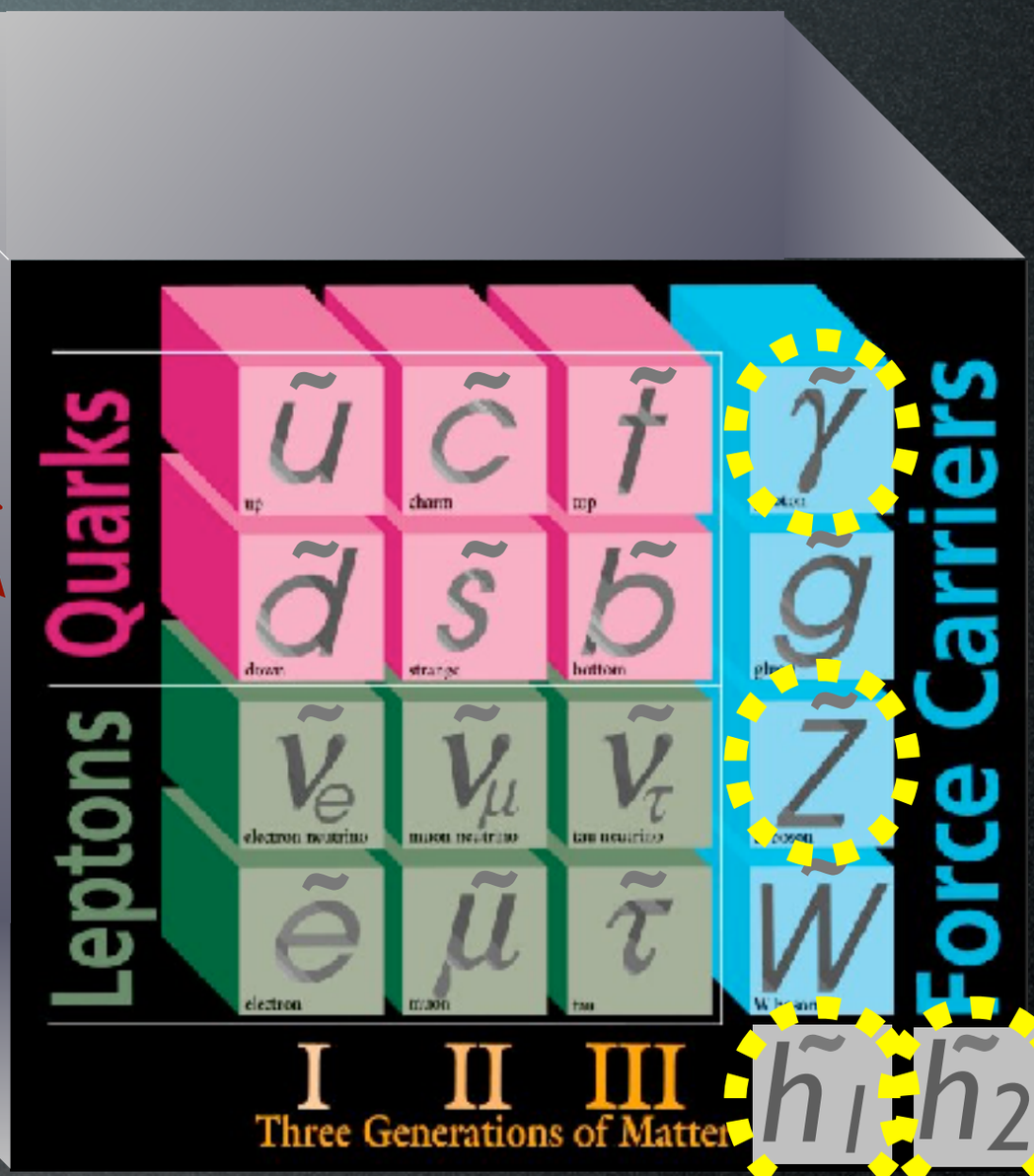

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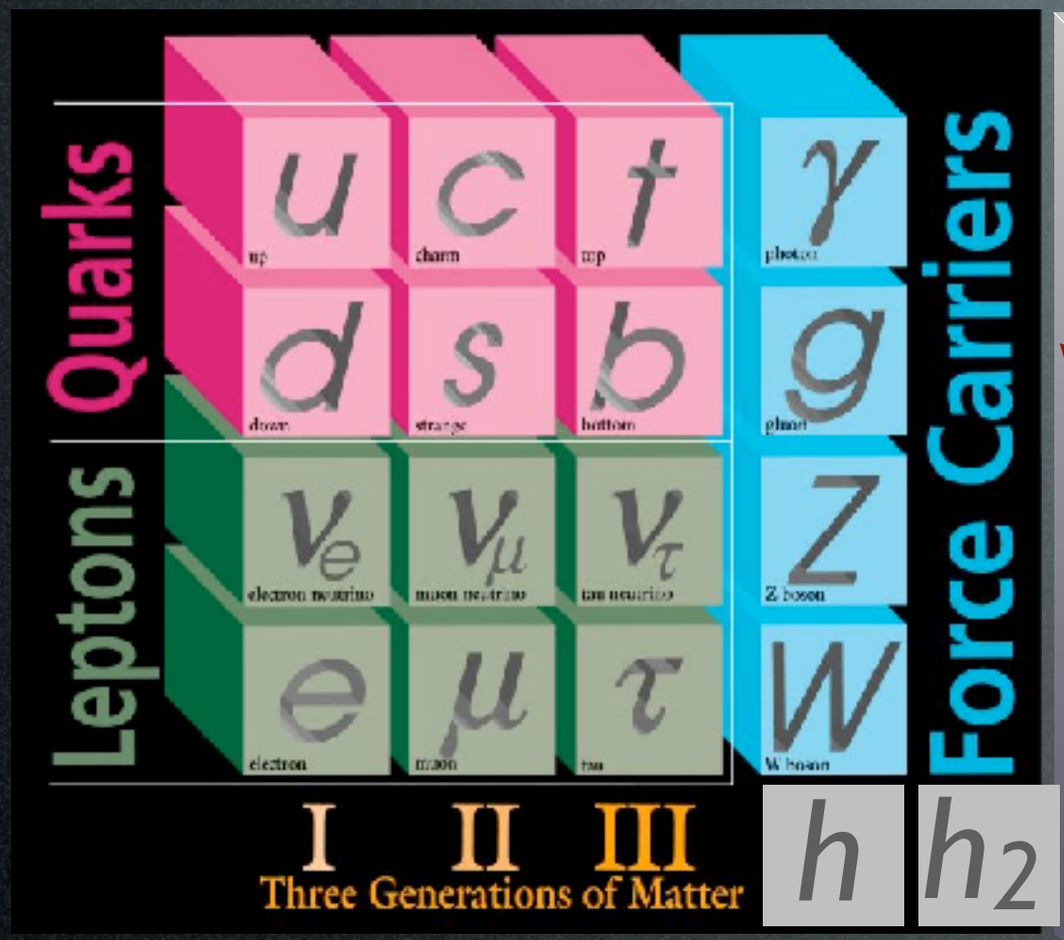

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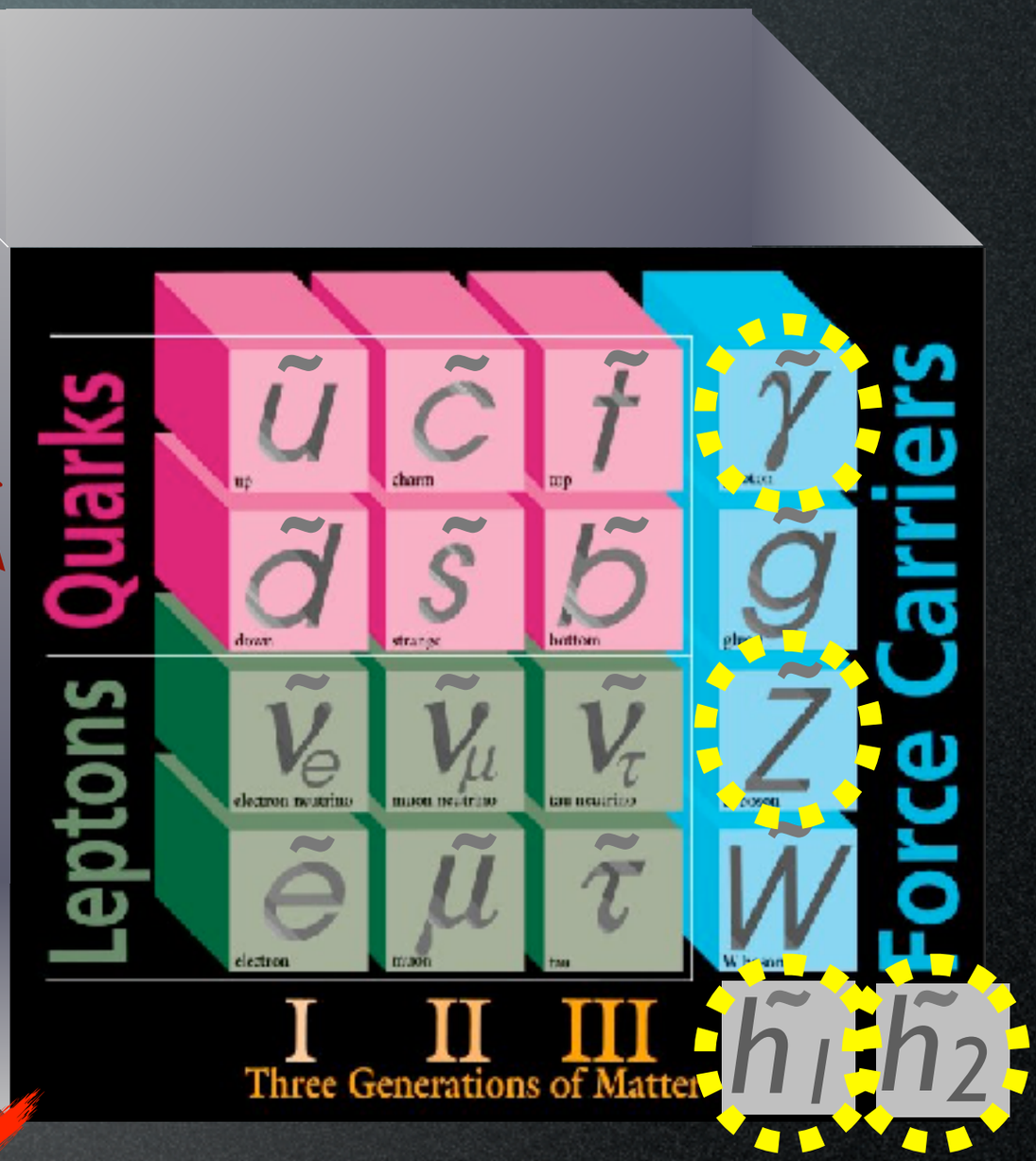

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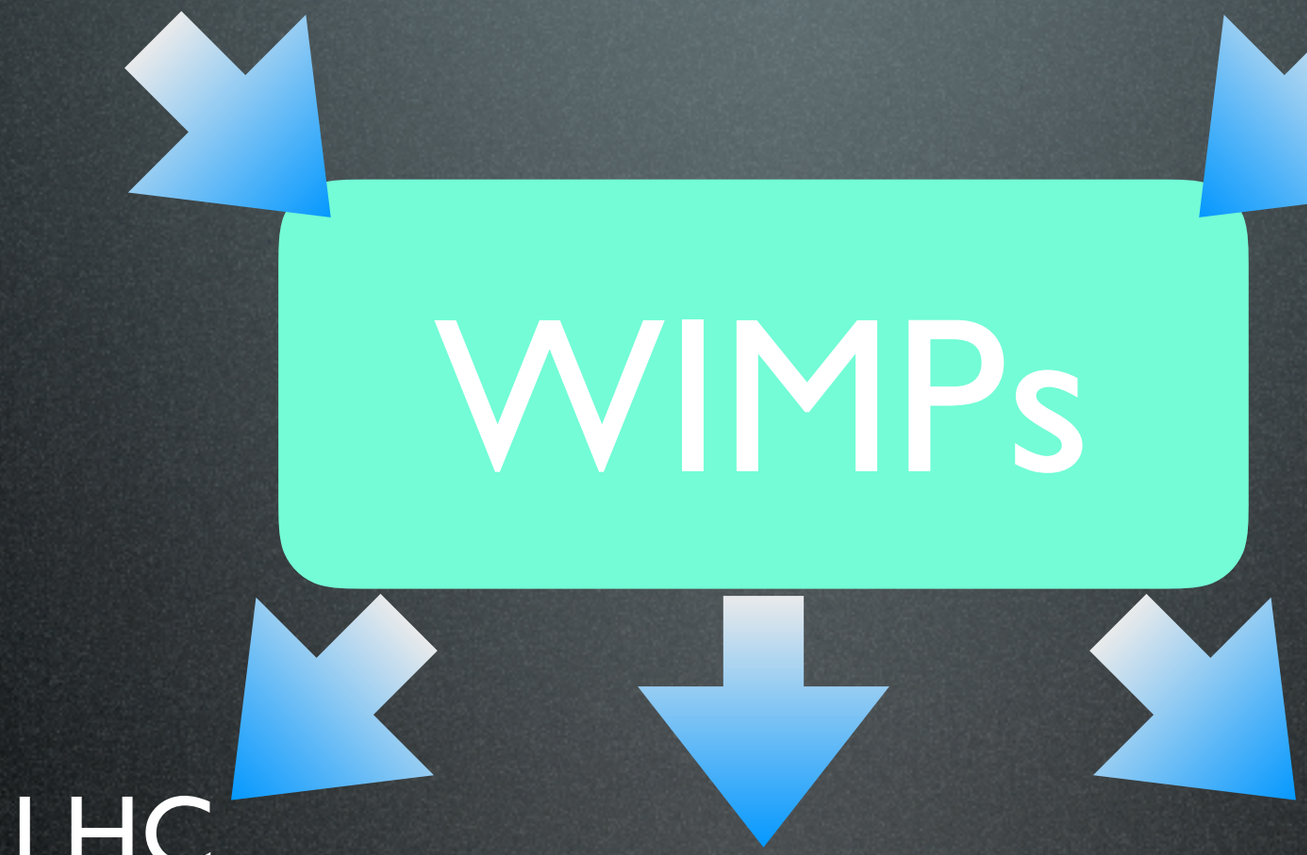
prevent
proton decay

Candidates

new physics at the TeV scale

thermal freeze-out



LHC

AMS, Fermi, CTA
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Direct Detection

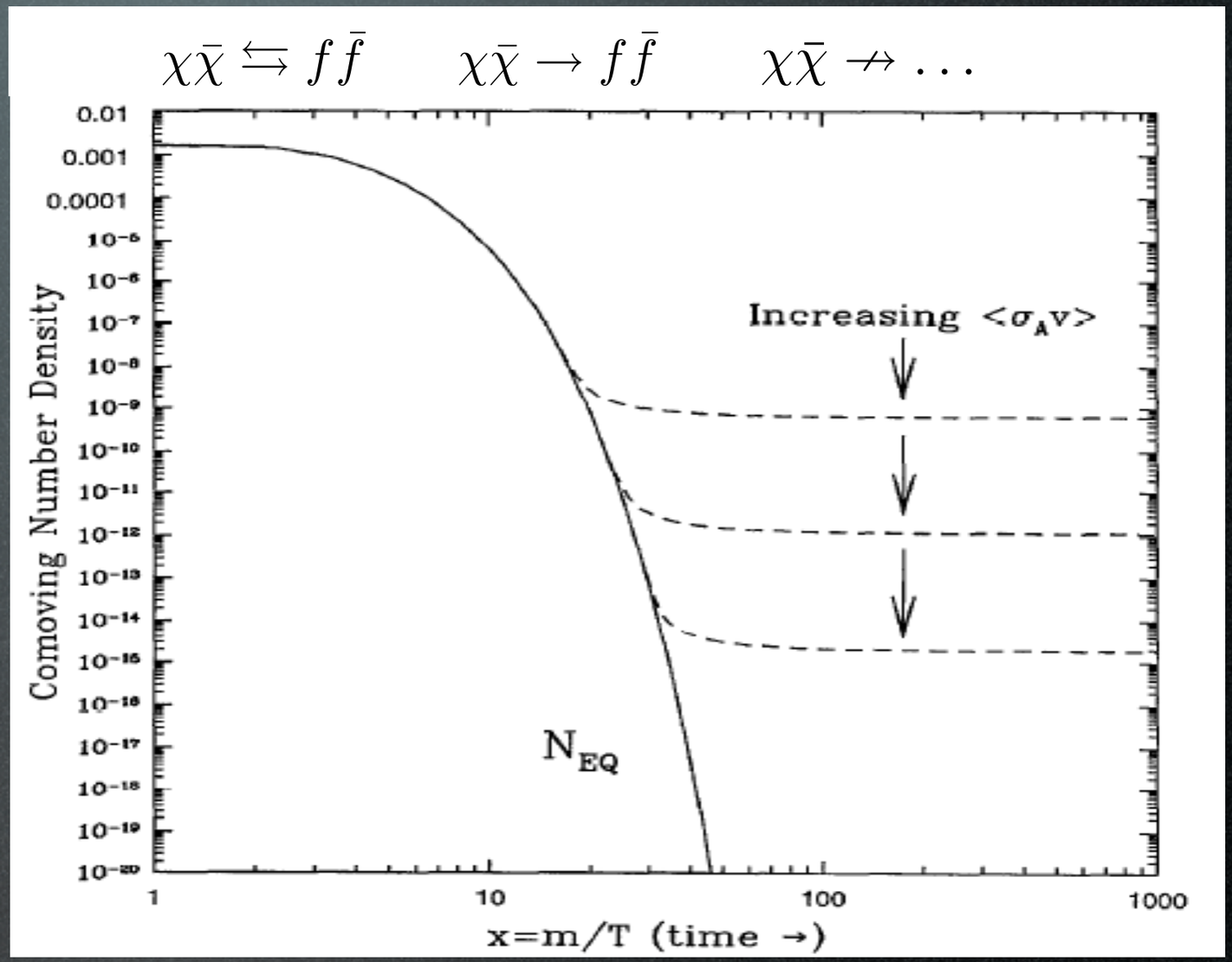
DM as a thermal relic from the Early Universe

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

$$\langle\sigma_{\mathrm{ann}}v\rangle = 3\cdot 10^{-26}\mathrm{cm}^3/\mathrm{sec}$$



Kolb,Turner, The Early Universe, 1995

Weak cross section:

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

(WIMP)

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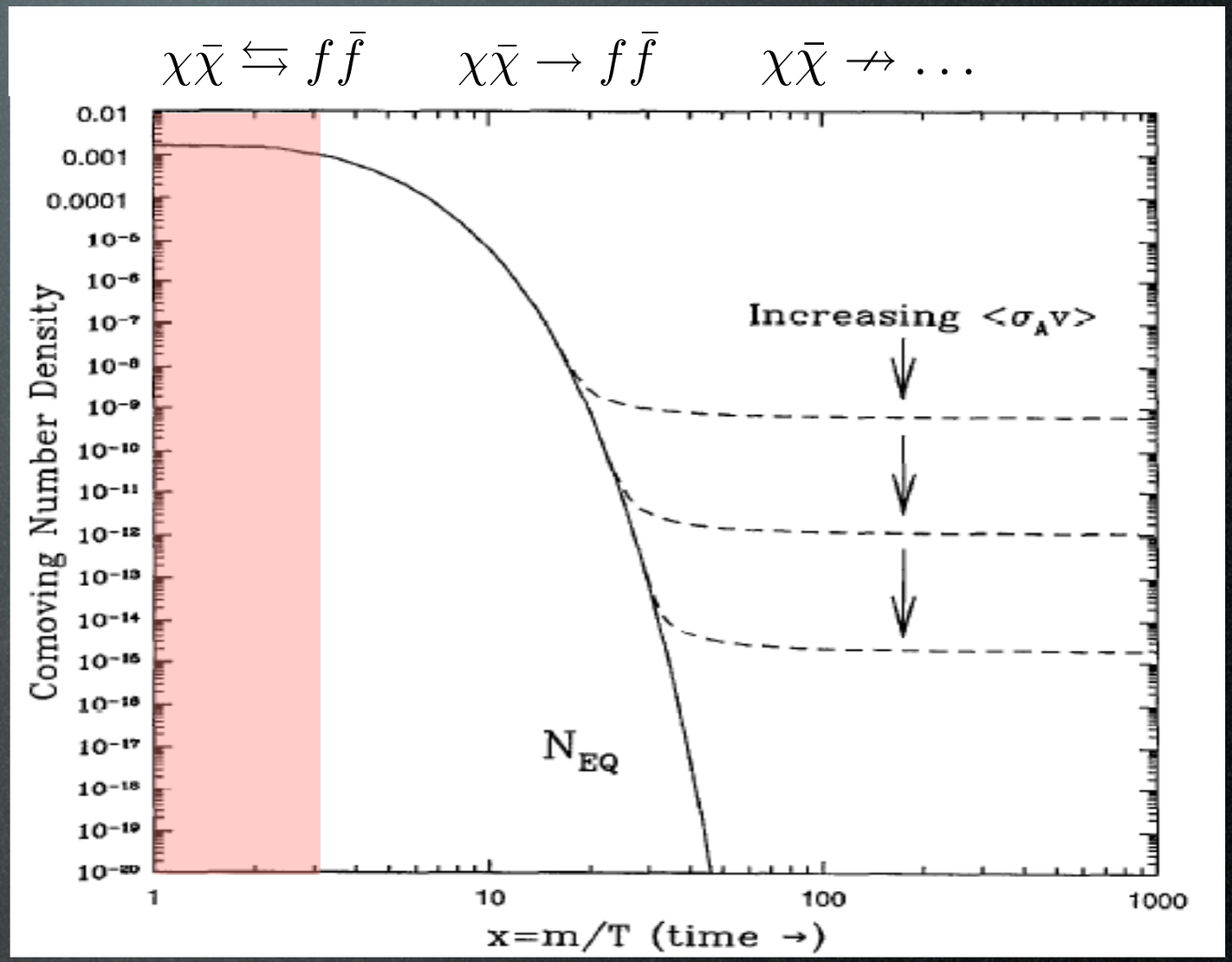

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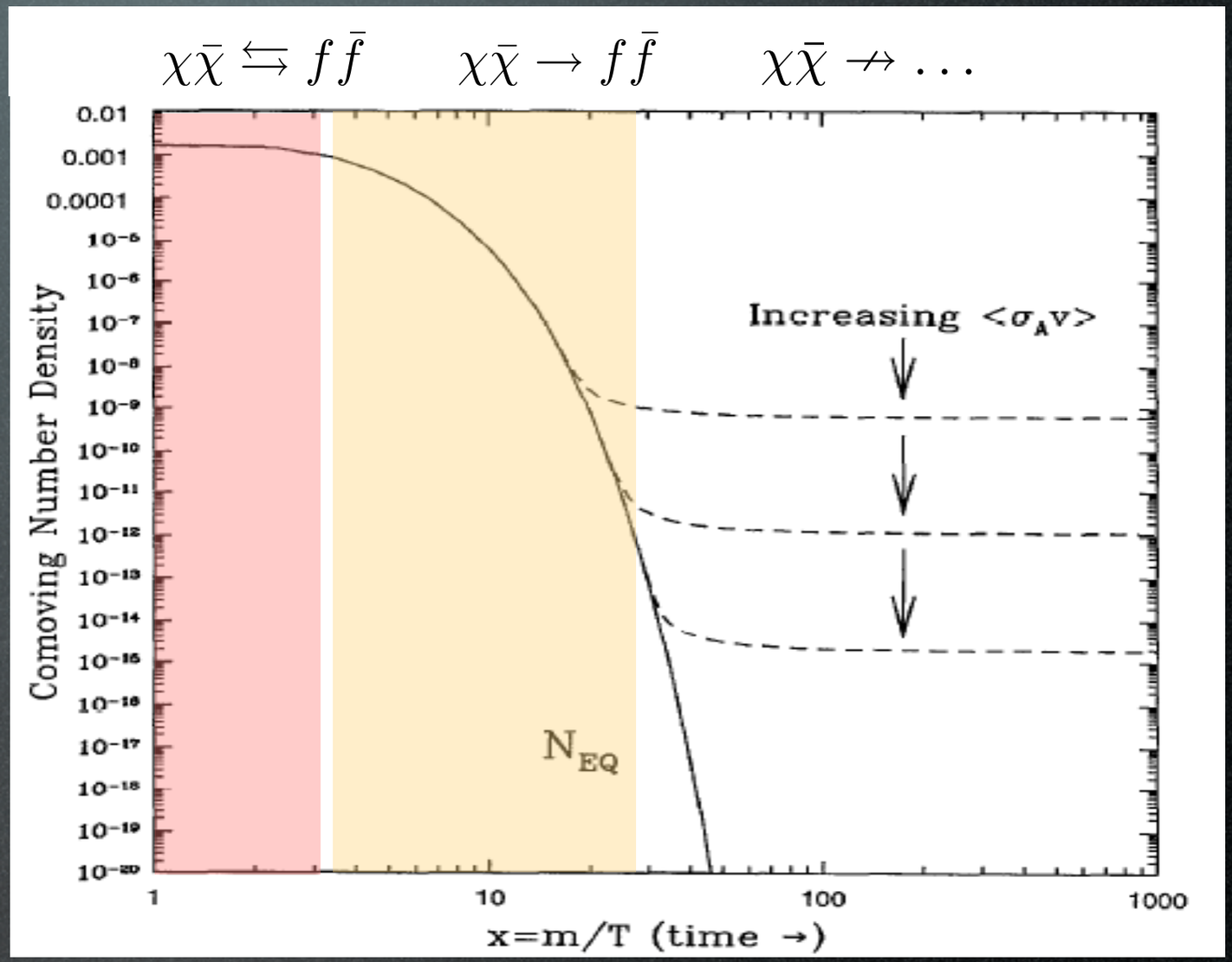

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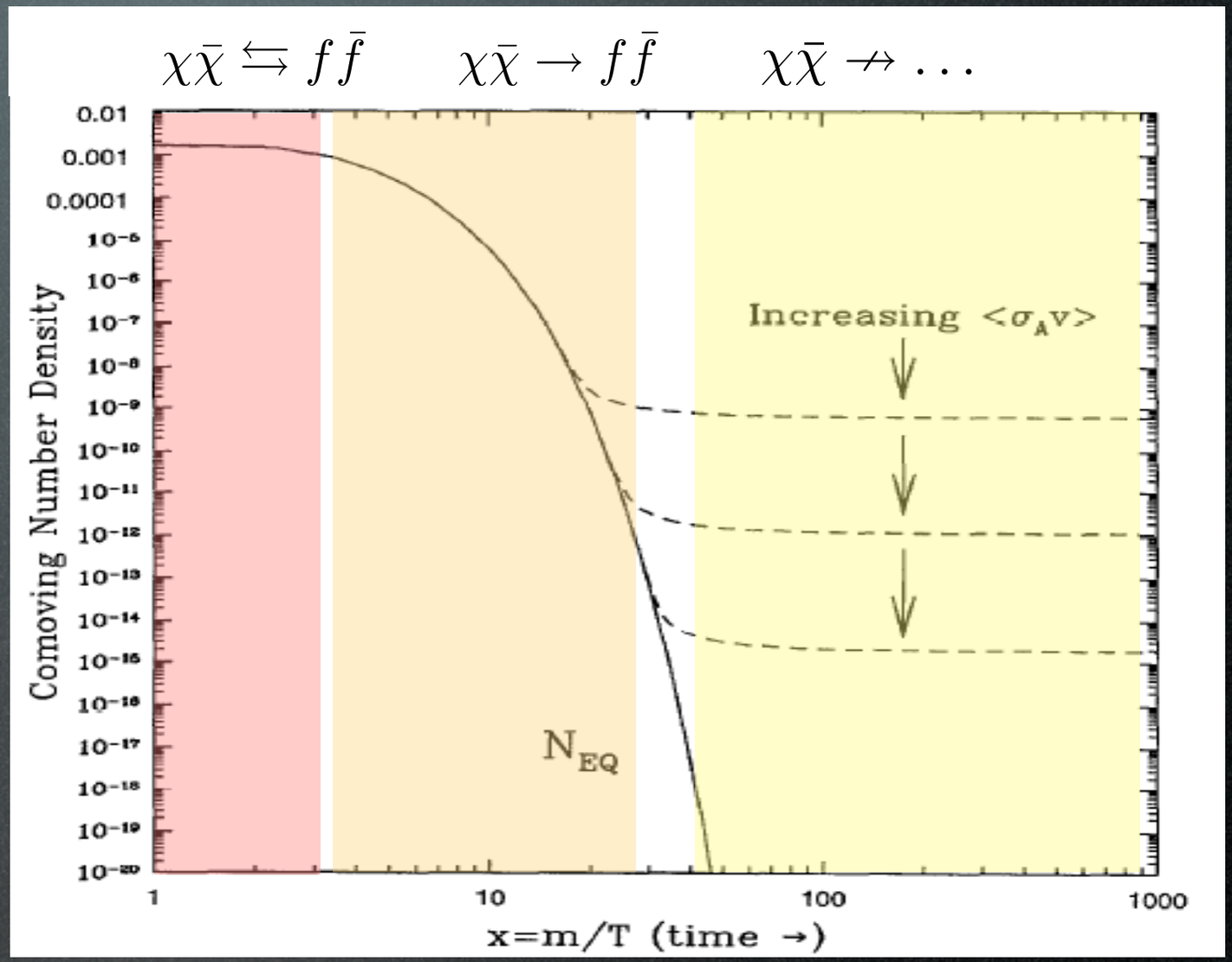

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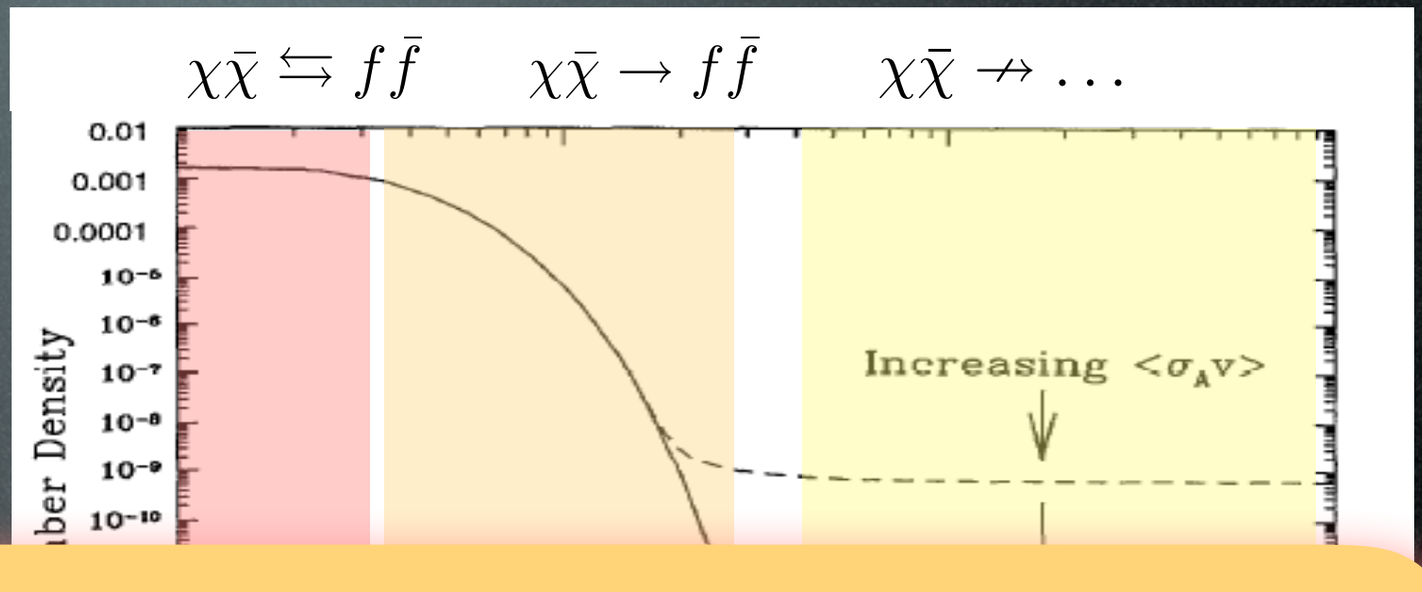

Universe, 1995

WIMPs naturally have **multi-TeV** masses.
Actually, pure WIMPs **necessarily** so.
E.g.:

- pure WIMP doublet (aka pure higgsino): ~1 TeV
- pure WIMP triplet (aka pure wino): 2.7 TeV
- pure WIMP 5plet (aka Minimal DM): ~9.4 TeV

Weak cross section:

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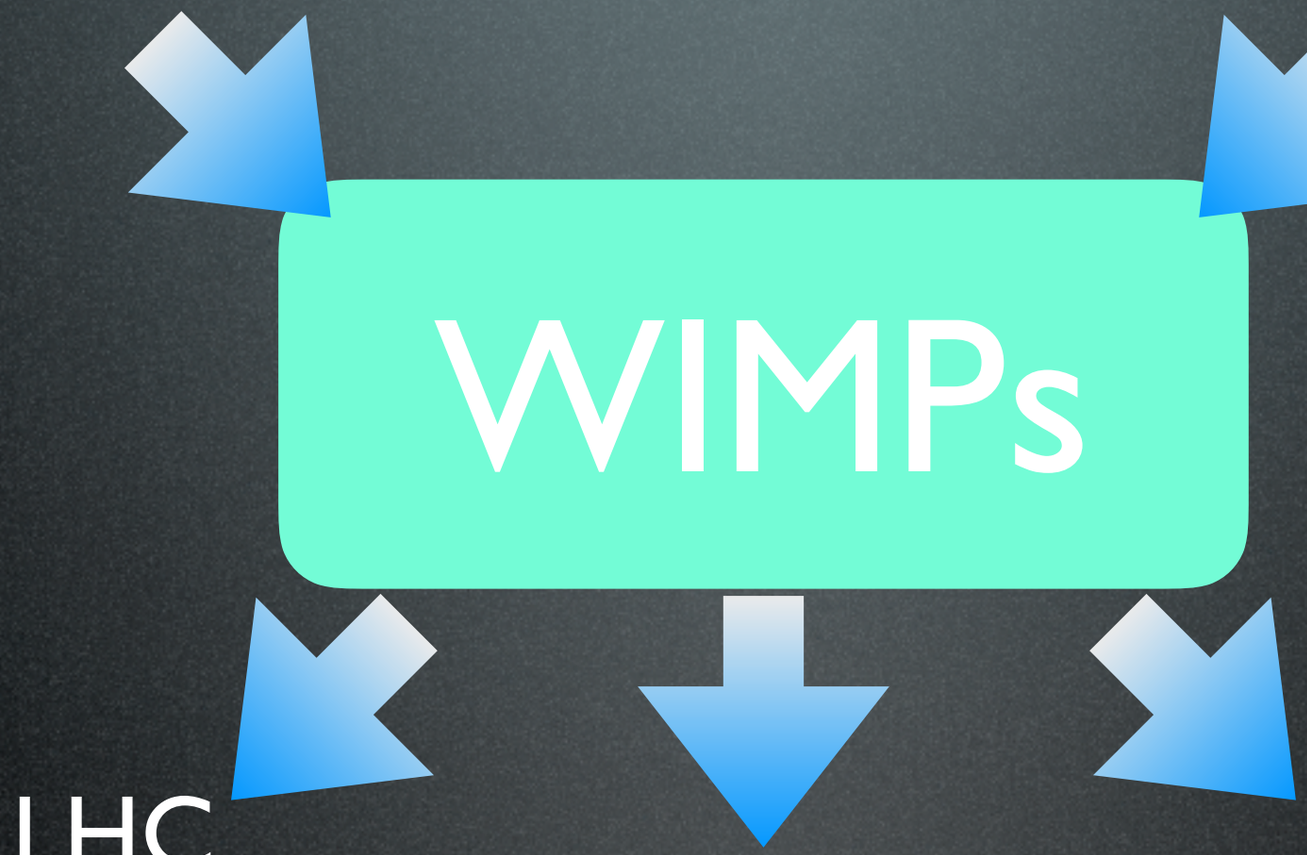

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Direct Detection

1.
2.
3.

Candidates

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WIMPs

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Direct Detection

1. even without a larger framework, WIMPs are still appealing
2.
3.

Candidates

new physics at the TeV scale

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Direct Detection

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

new physics at the TeV scale

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Direct Detection

1. even without a larger framework, WIMPs are still appealing
2. the frontier is multi-TeV
3. searches are complementary and still have ground to cover

WIMP DD: '**theory**'

SM weak scale SI interactions

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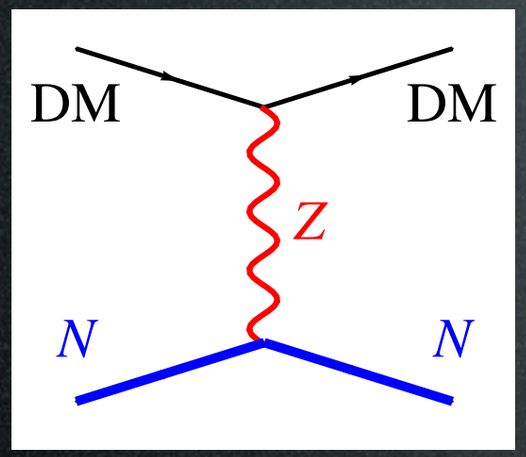

tree level, vector

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

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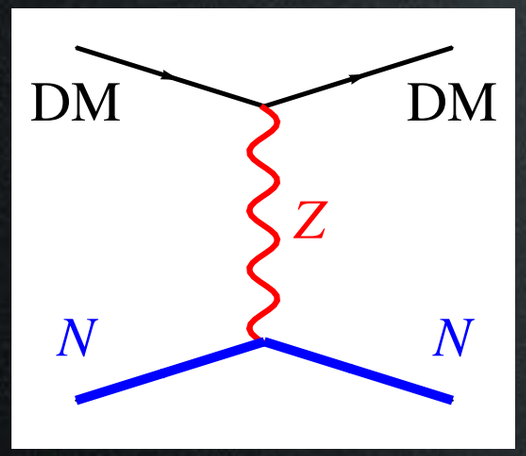

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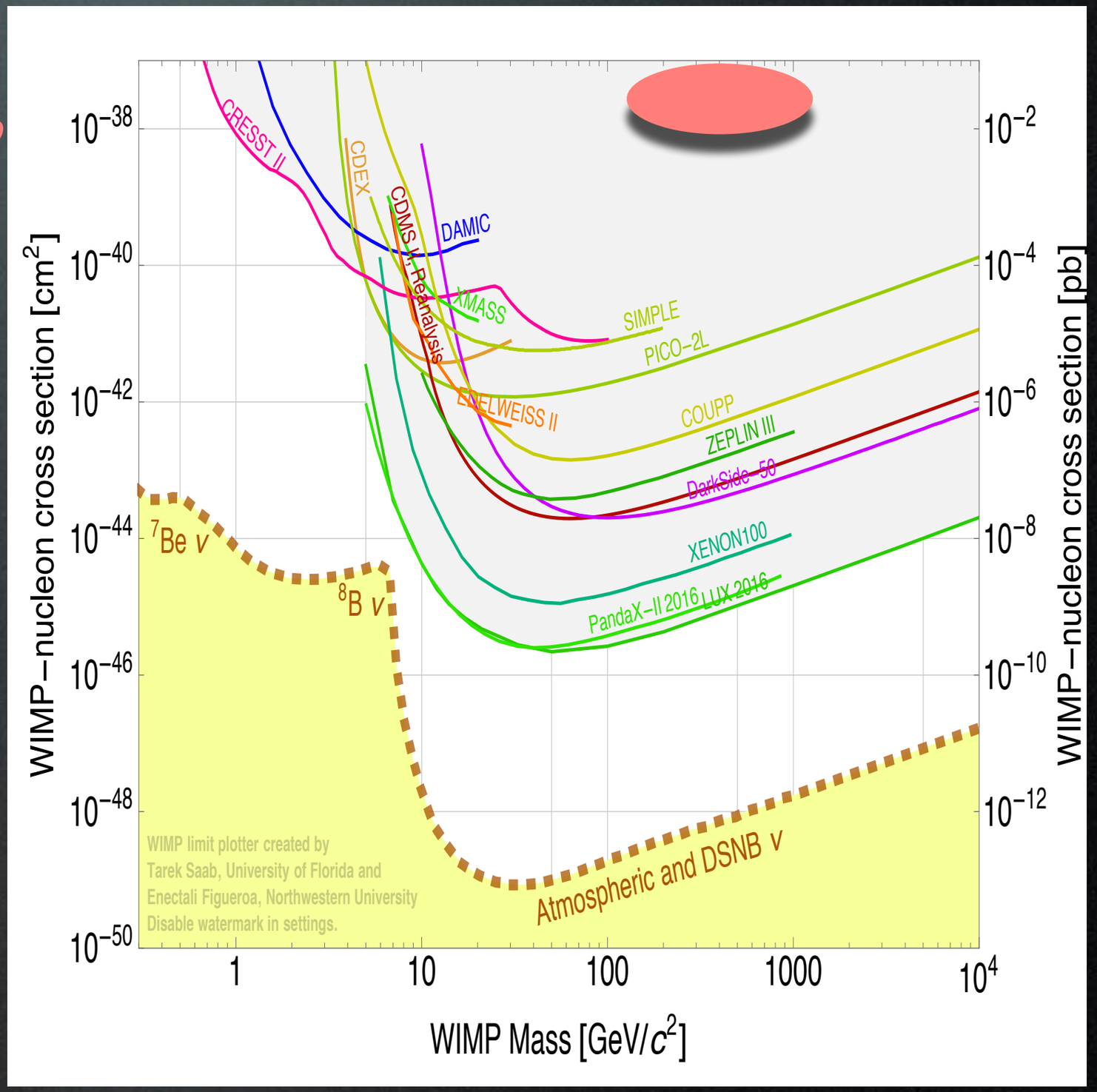

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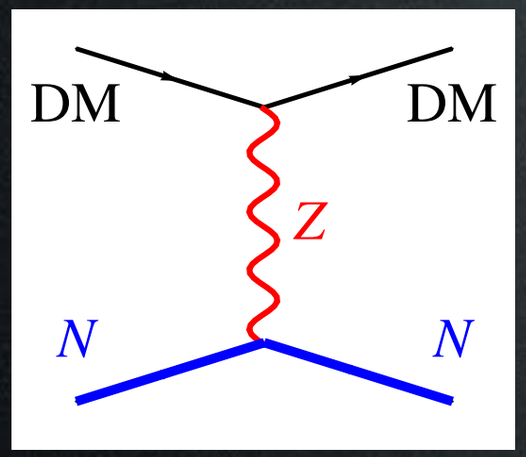

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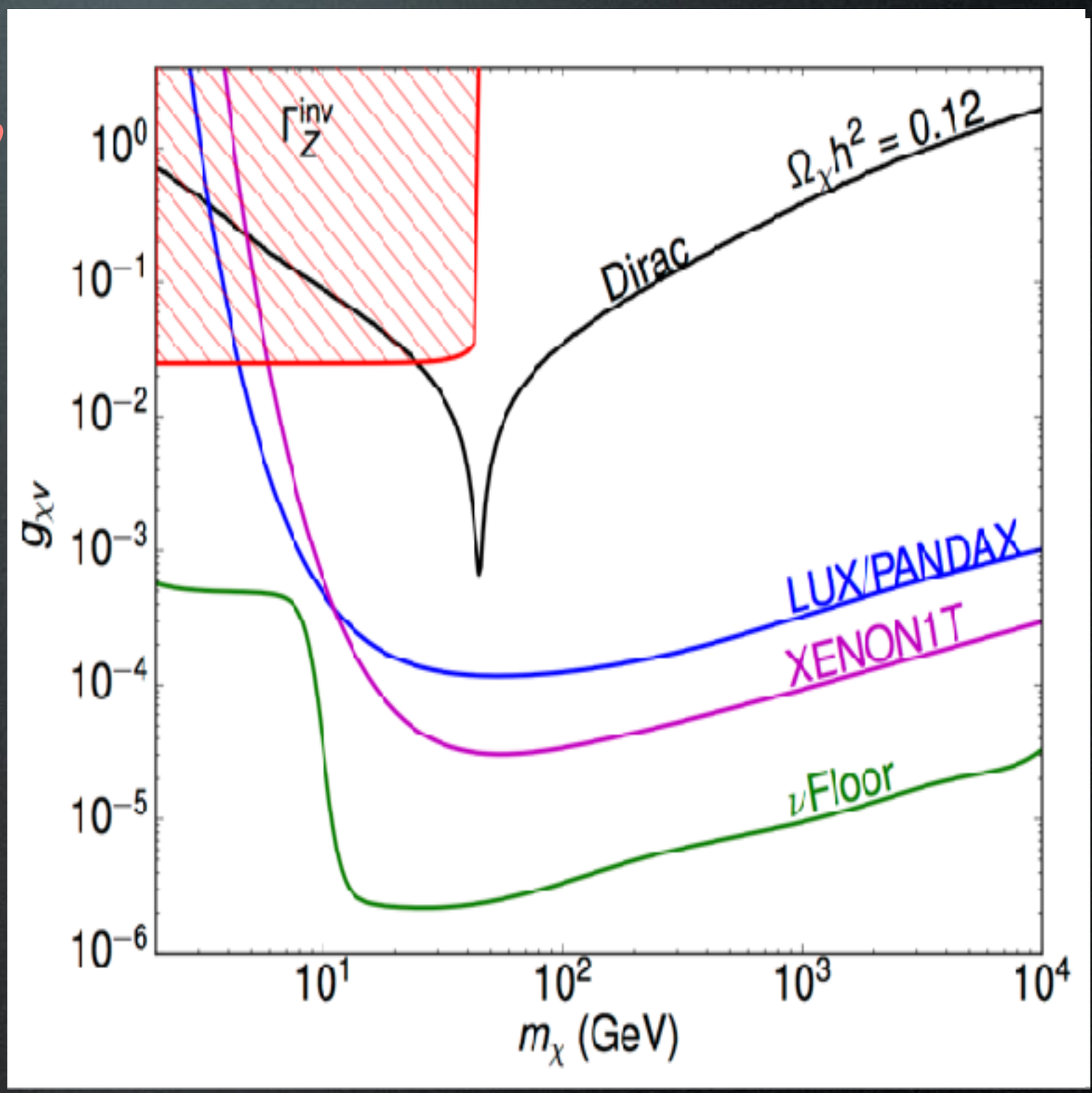

Escudero, Berlin, Hooper, Lin 1609.09079

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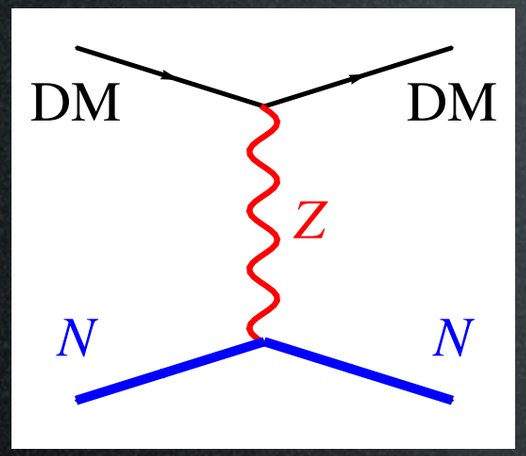

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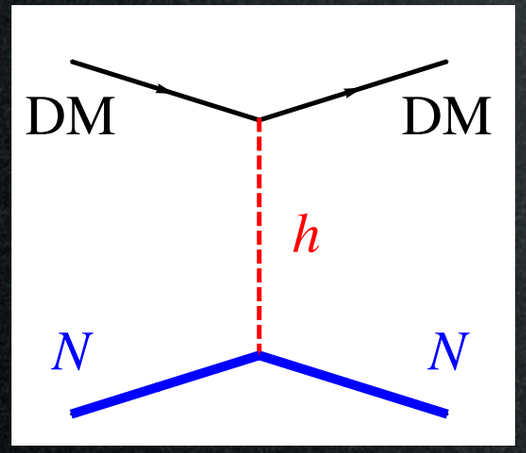

tree level, scalar

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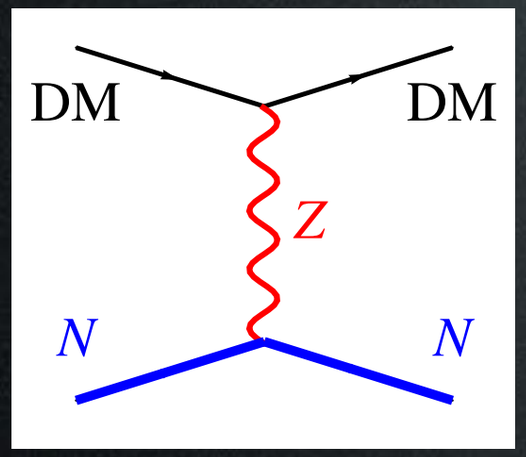

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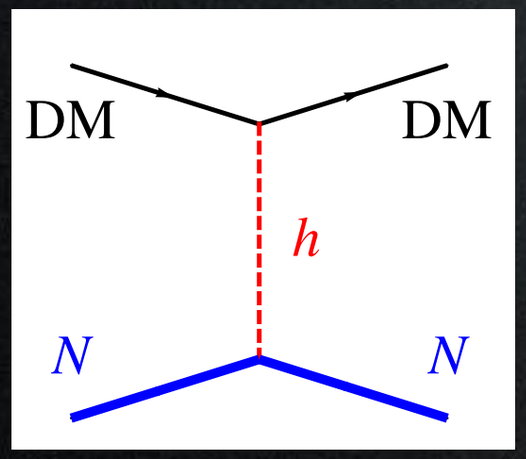

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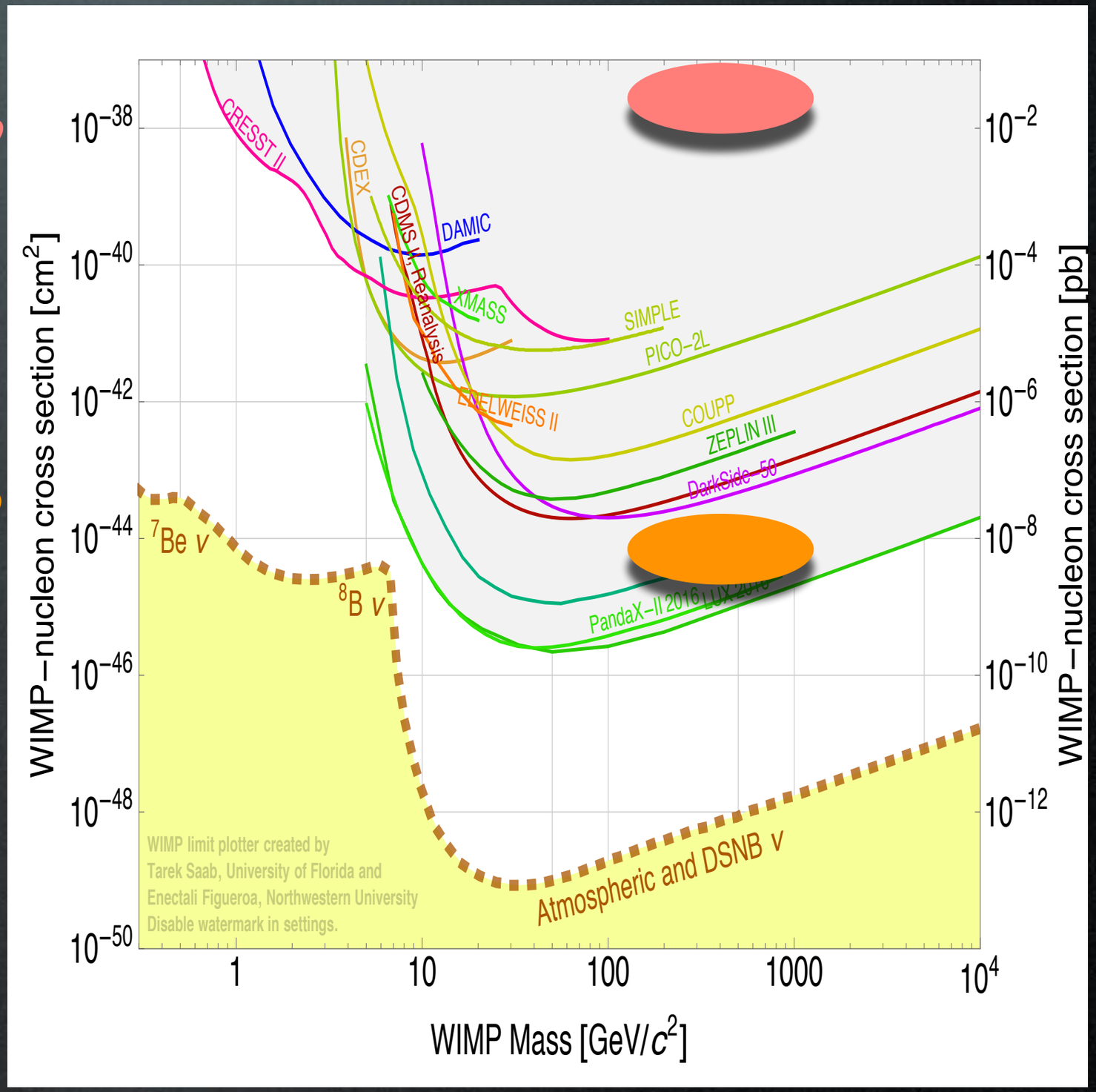

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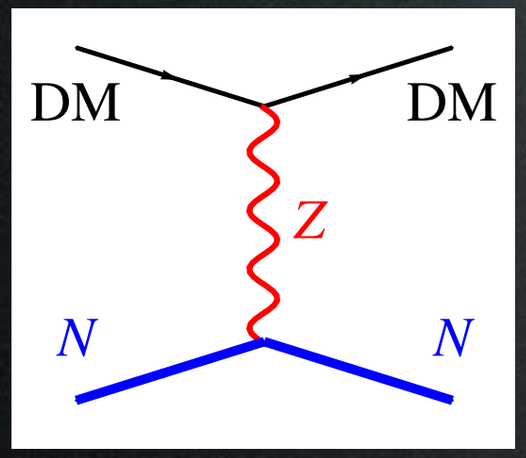

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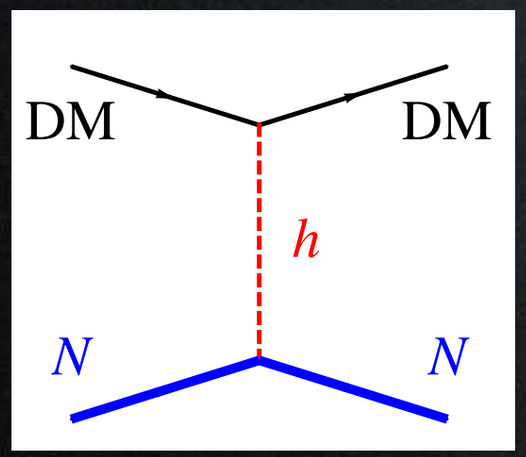

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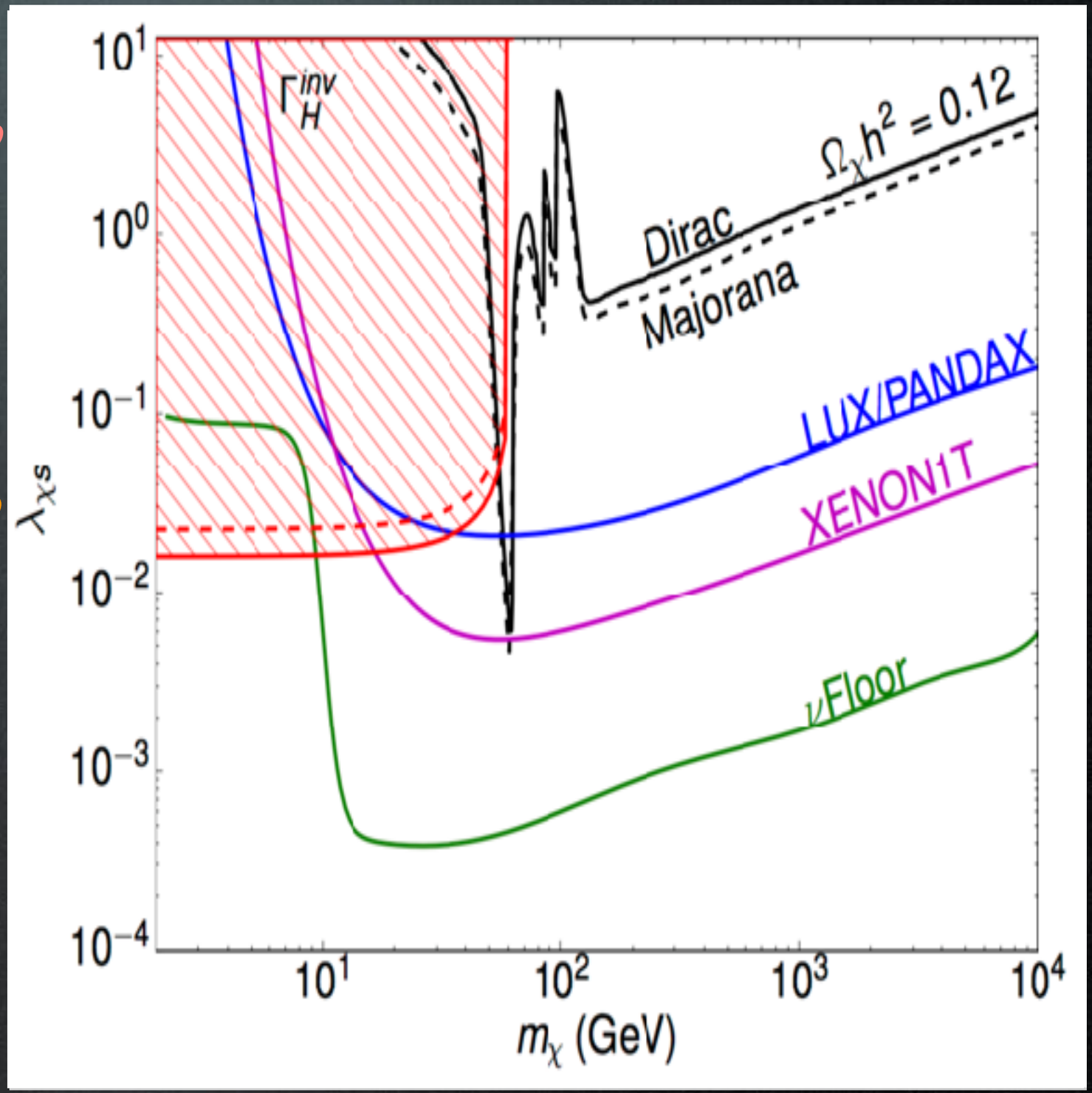

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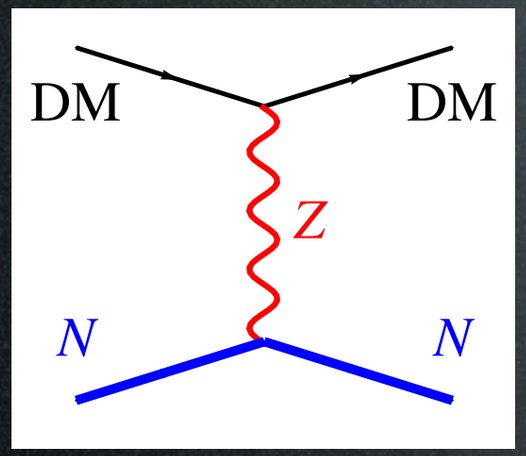

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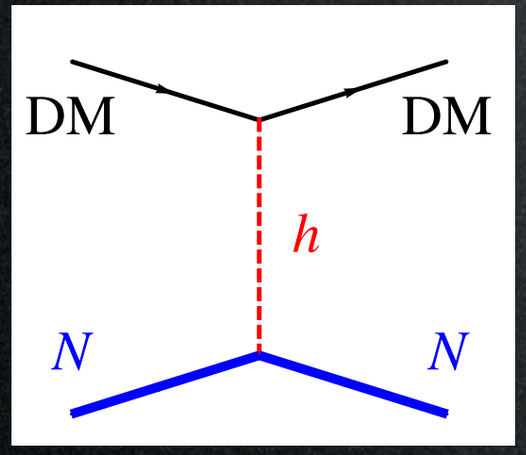

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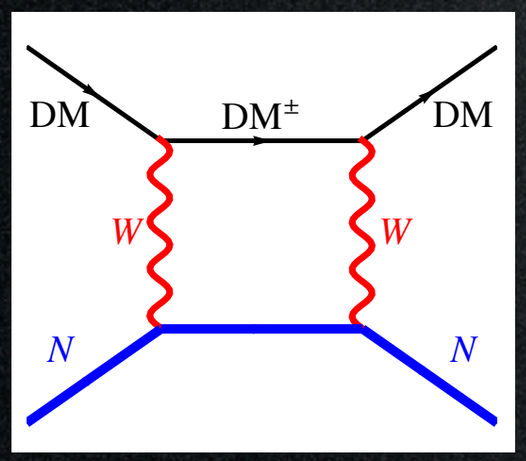

one loop

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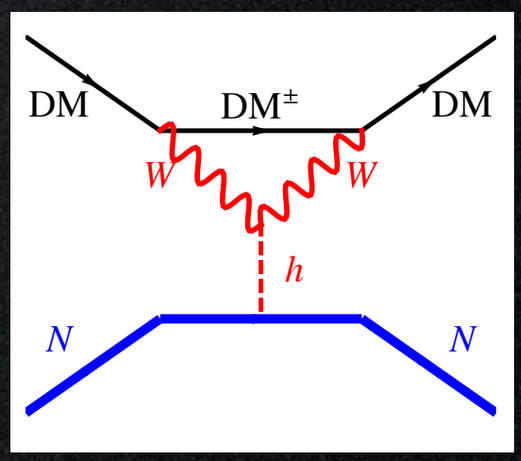

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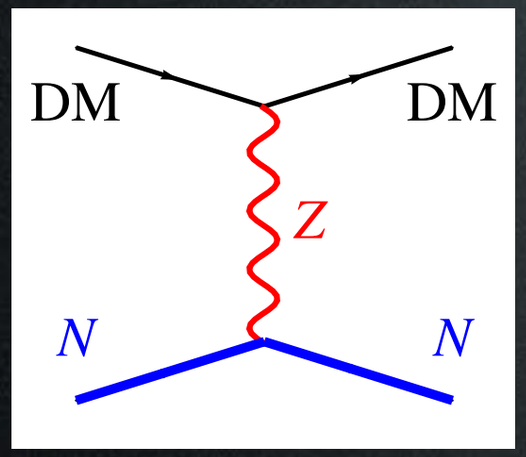
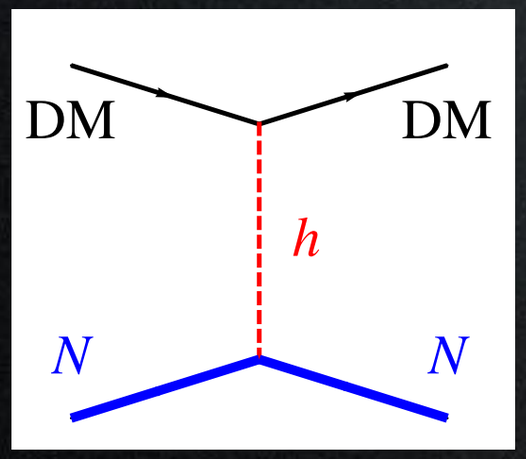
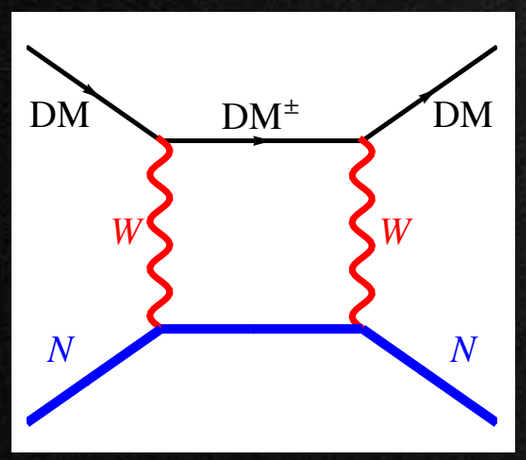


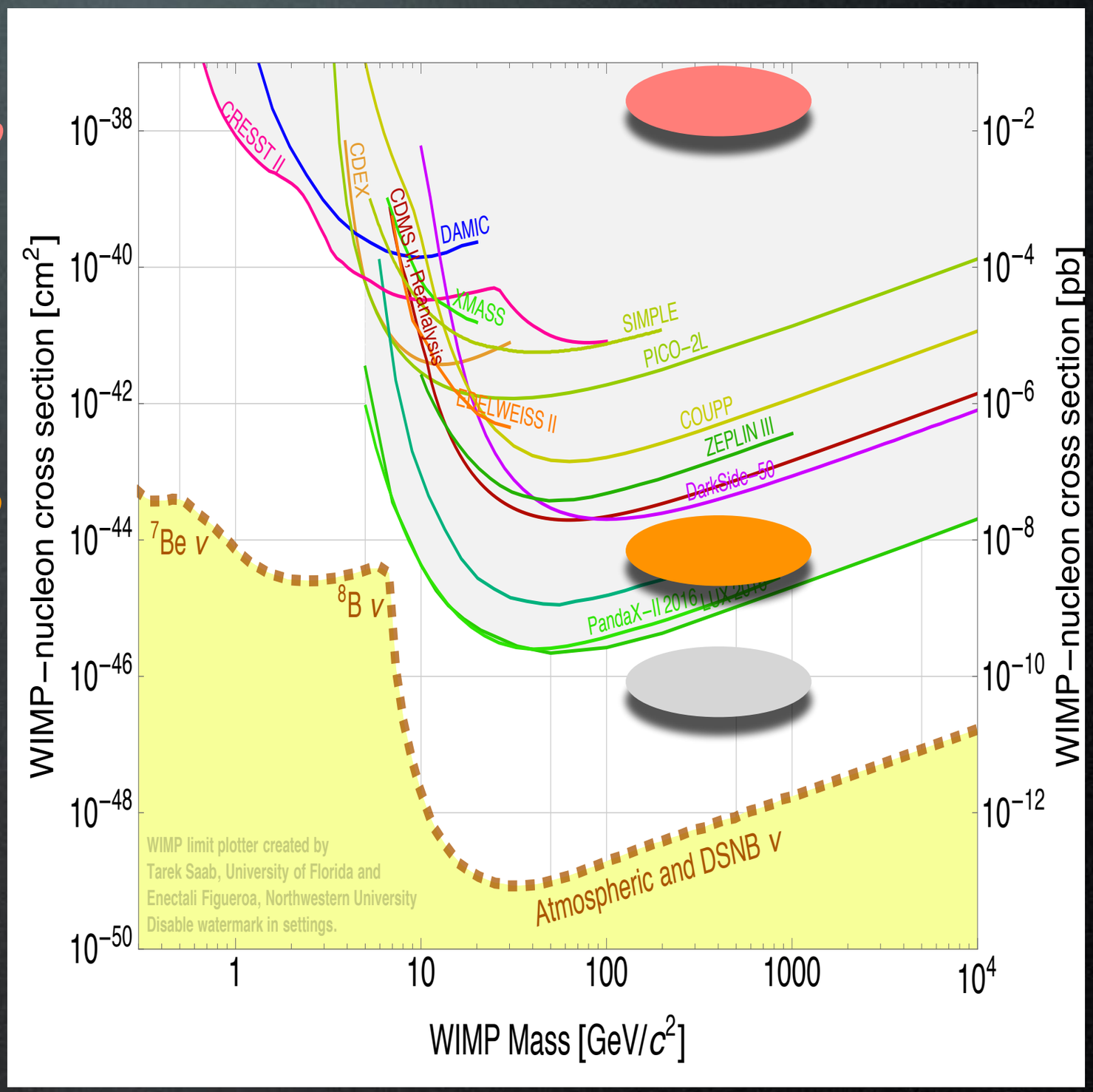
tree level, vector



tree level, scalar



one loop



WIMP DD: 'theory'

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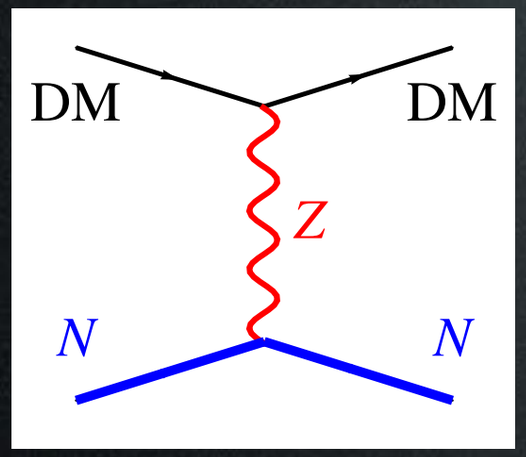

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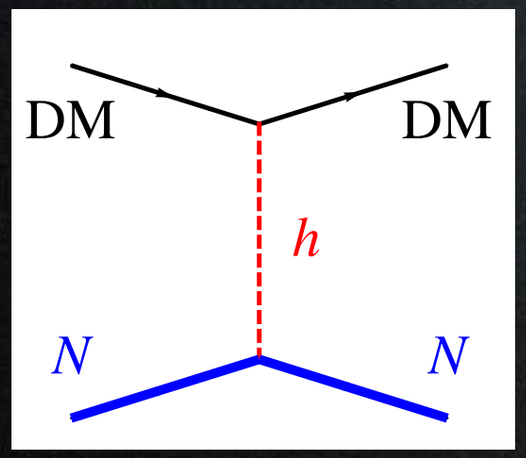

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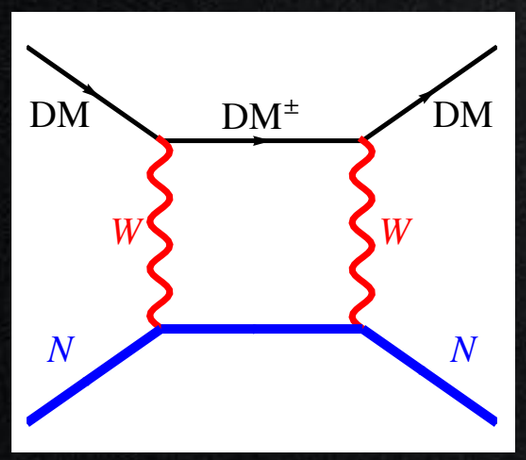

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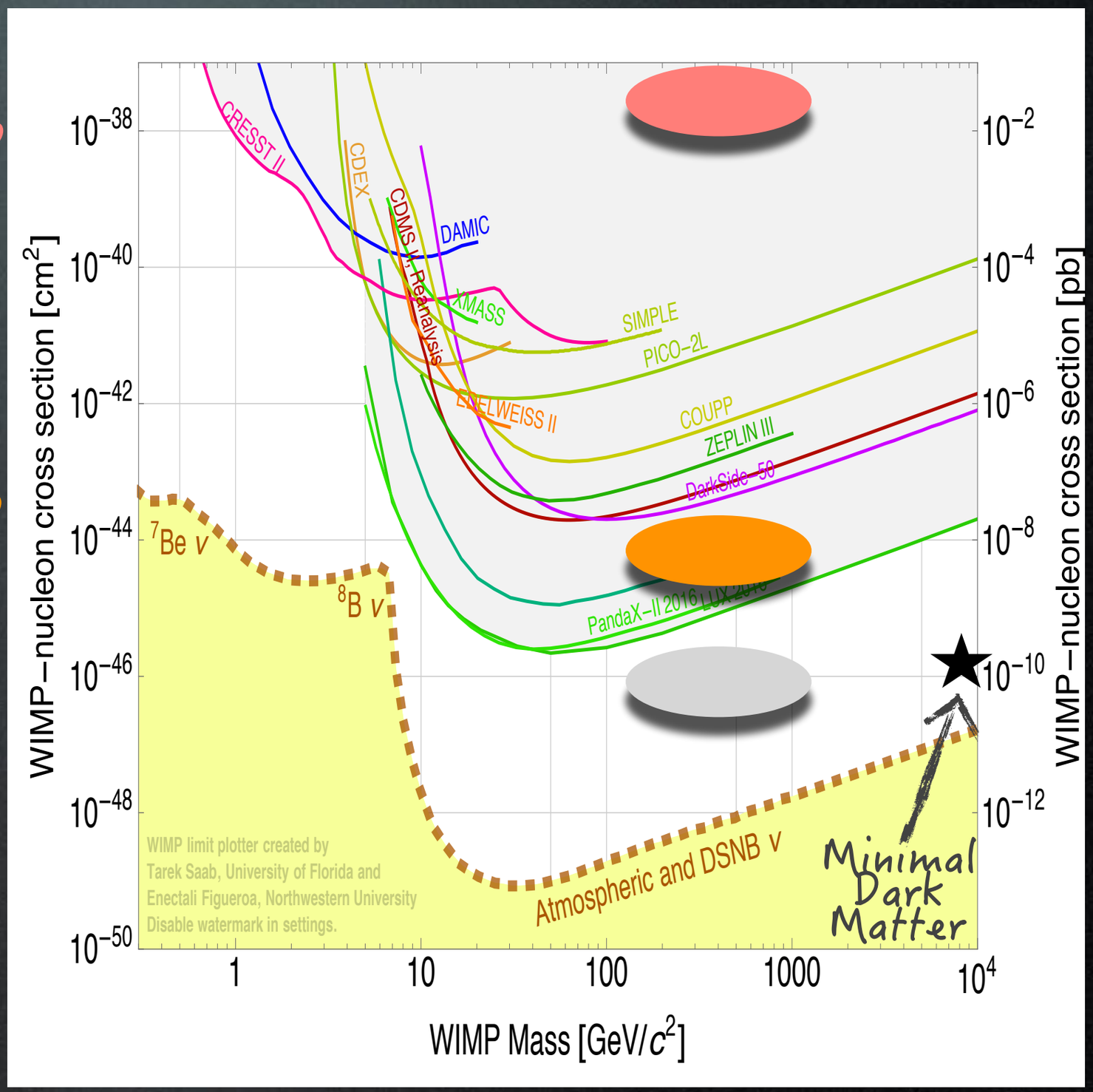

Cirelli, Fornengo, Strumia hep-ph/0512090

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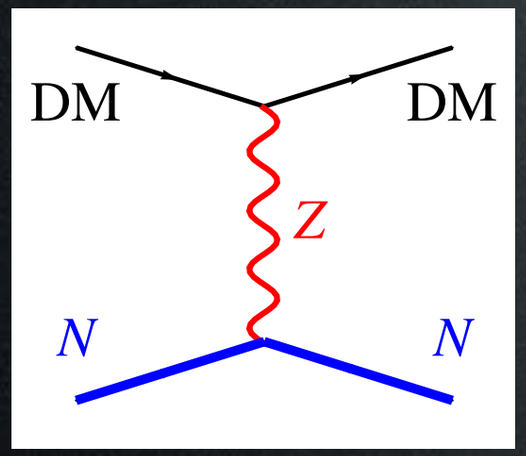

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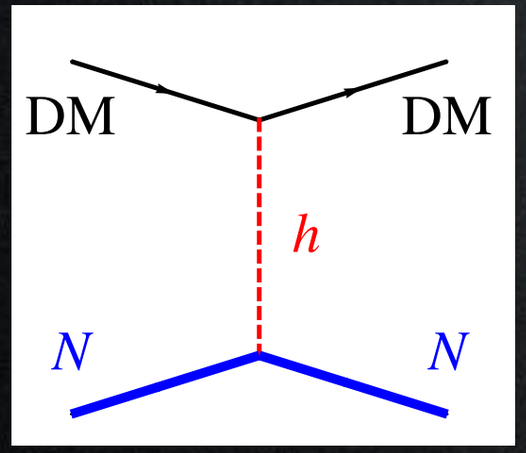

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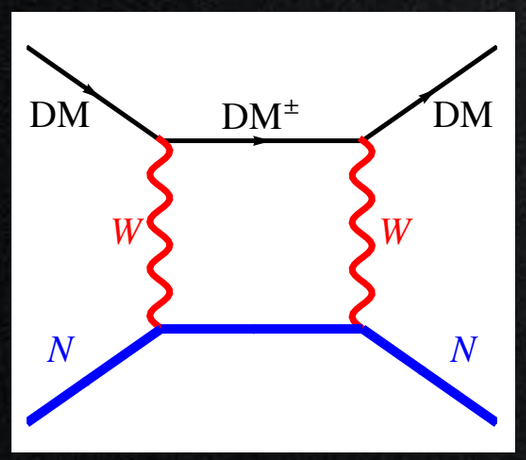

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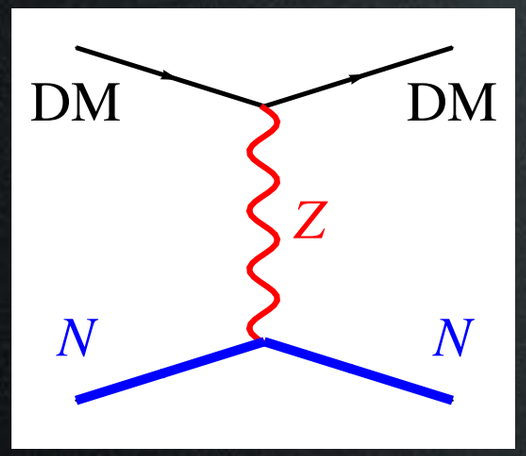

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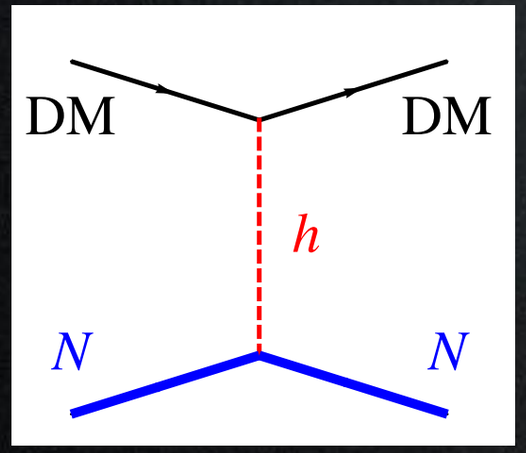

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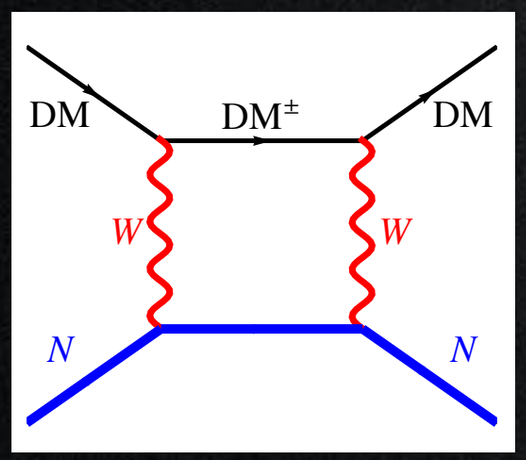

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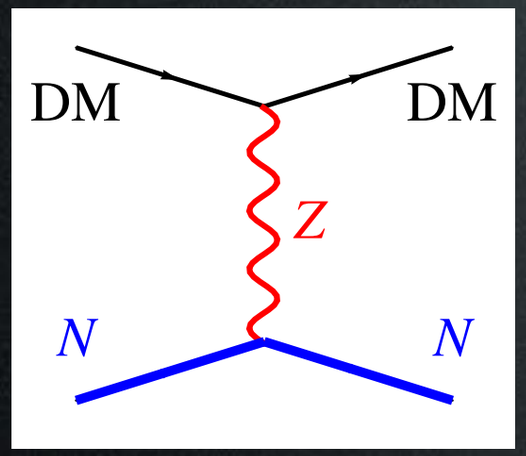

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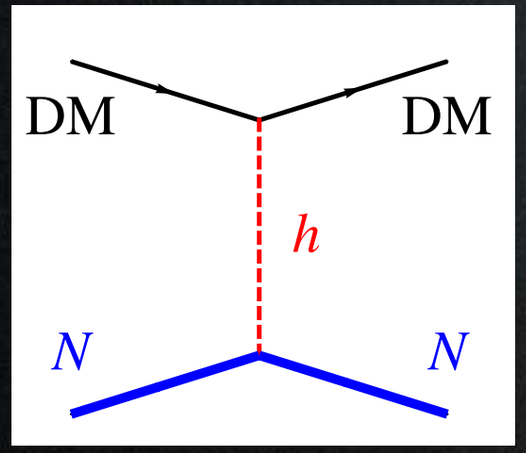

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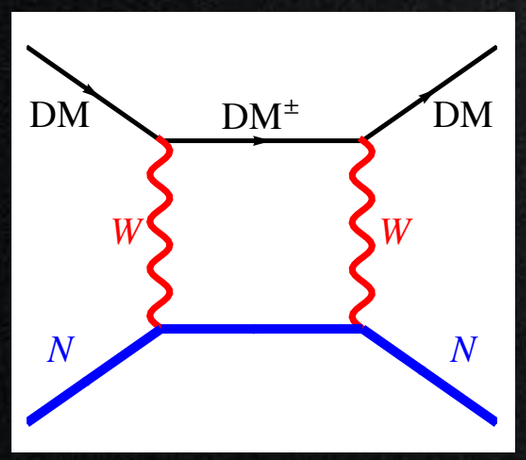

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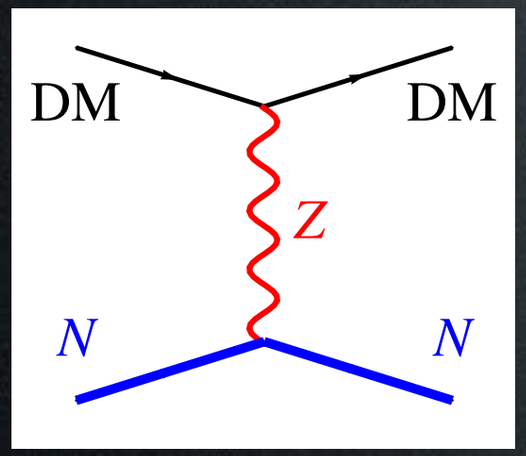

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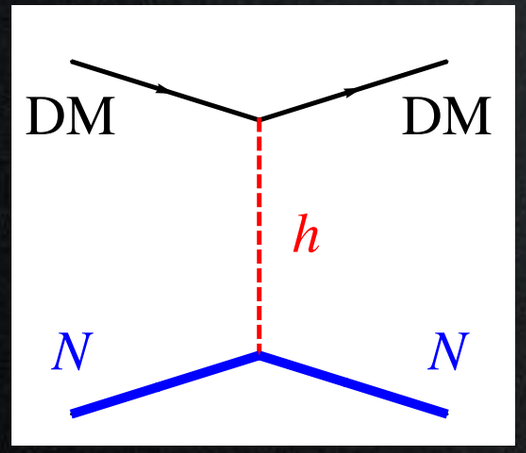
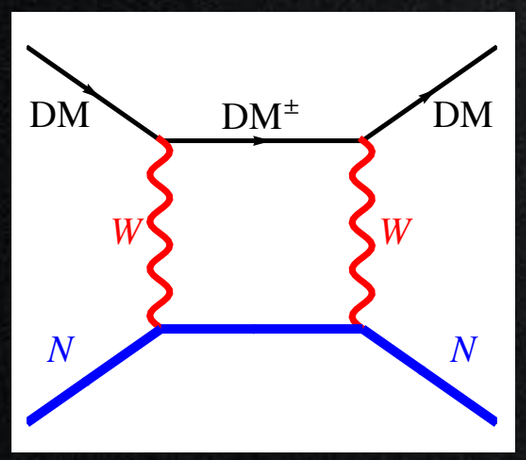


~~tree level, scalar~~

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



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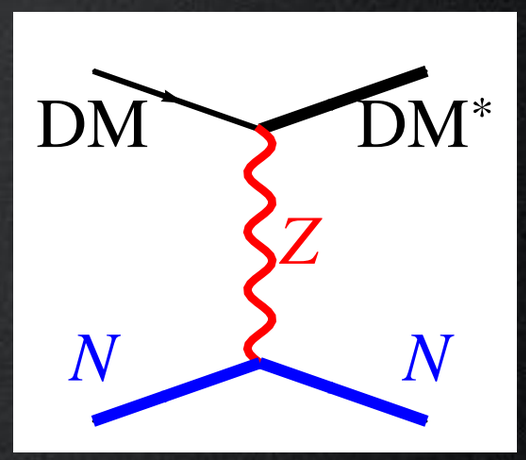

Candidates

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 frontier is multi-TeV
3. searches are complementary and still have ground to cover

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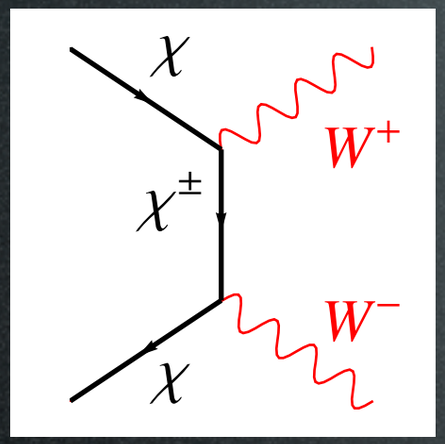
γ from MDM annihilations



$$+ \quad W^\pm, Z \to \bar{p}, e^+, \gamma \ldots$$

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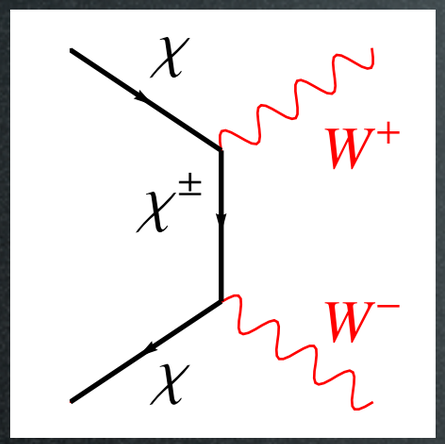

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continuum

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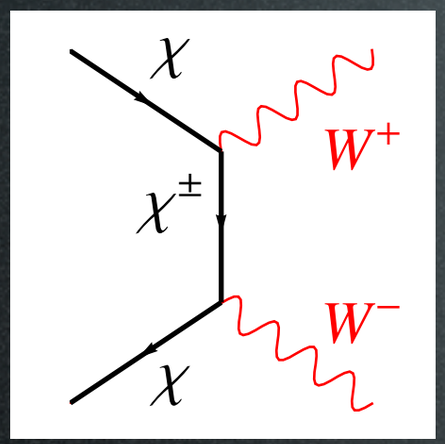

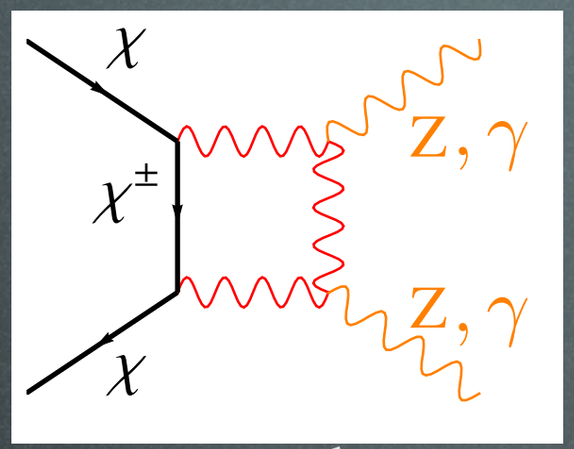

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(channels for MDM with Y=0)

continuum

line(s)
(+ continuum)

Indirect Detection

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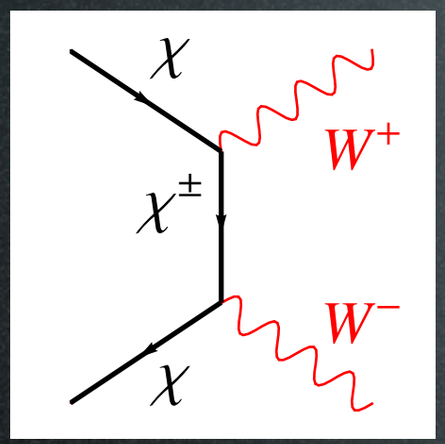

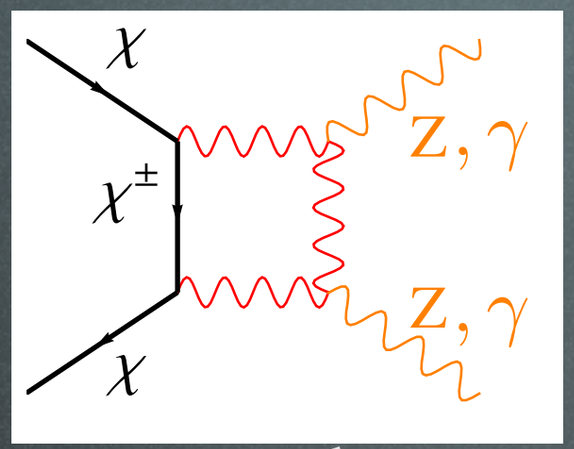

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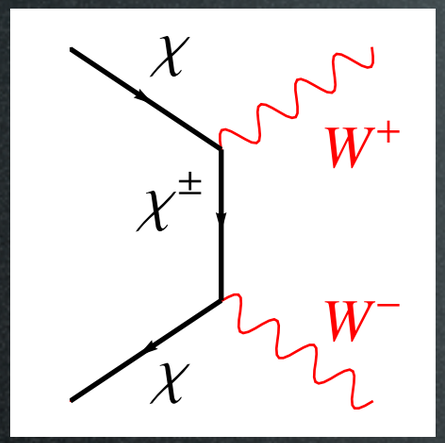
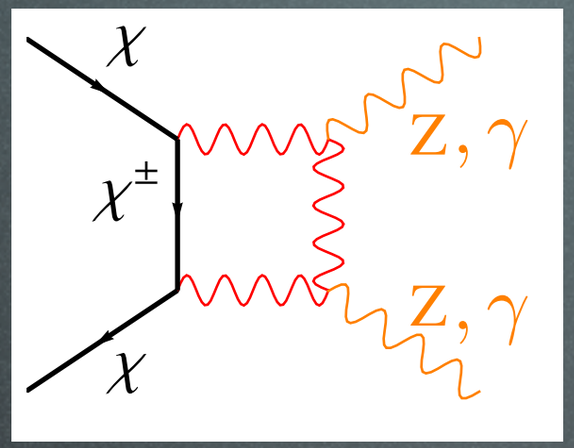
γ from MDM annihilations





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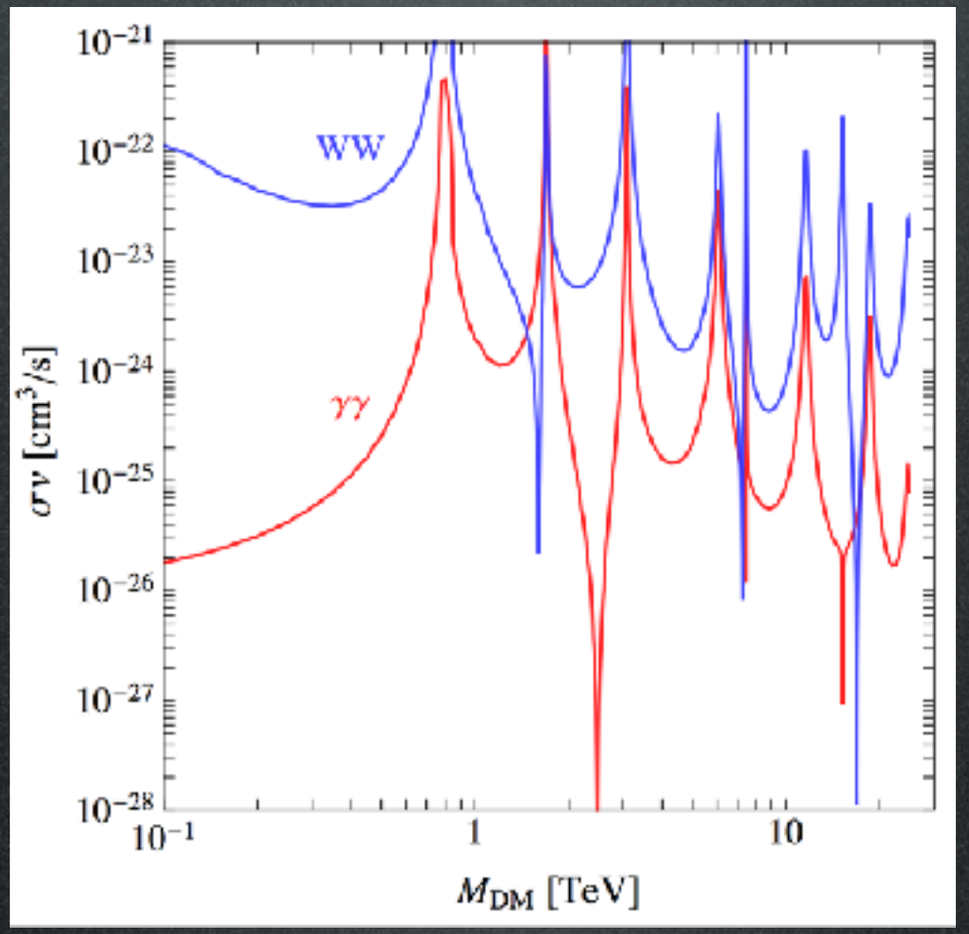
Enhanced cross section due to 'Sommerfeld corrections'

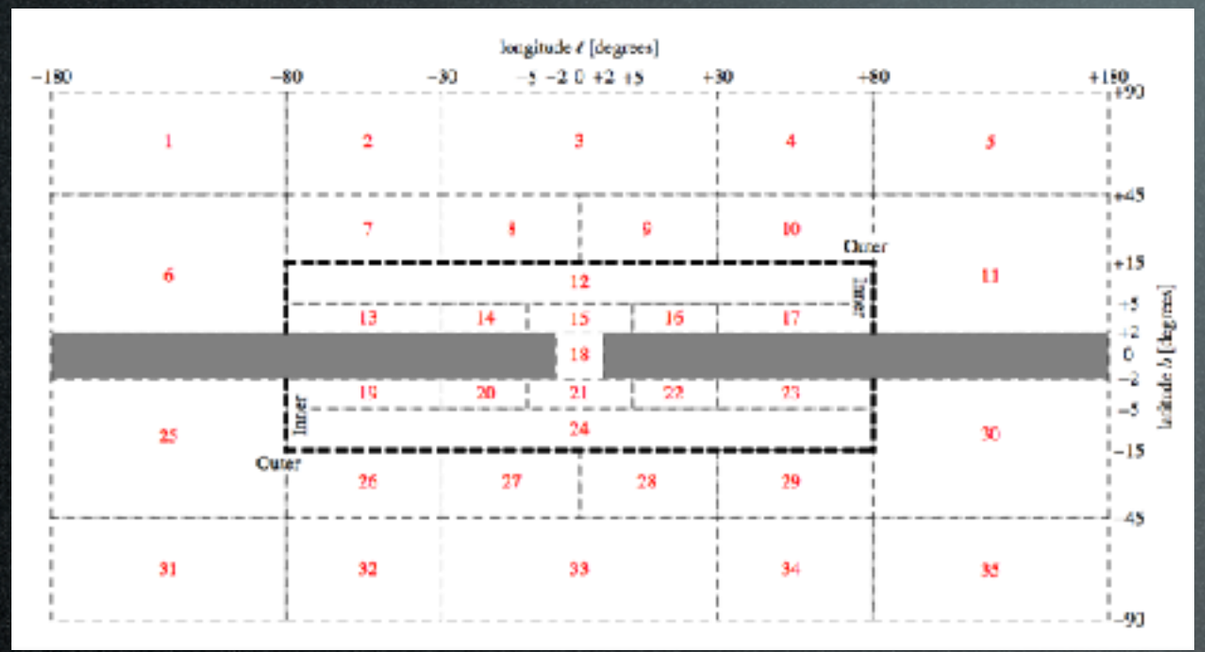
Hisano et al., 2004, 2005
Cirelli, Strumia, Tamburini 2007

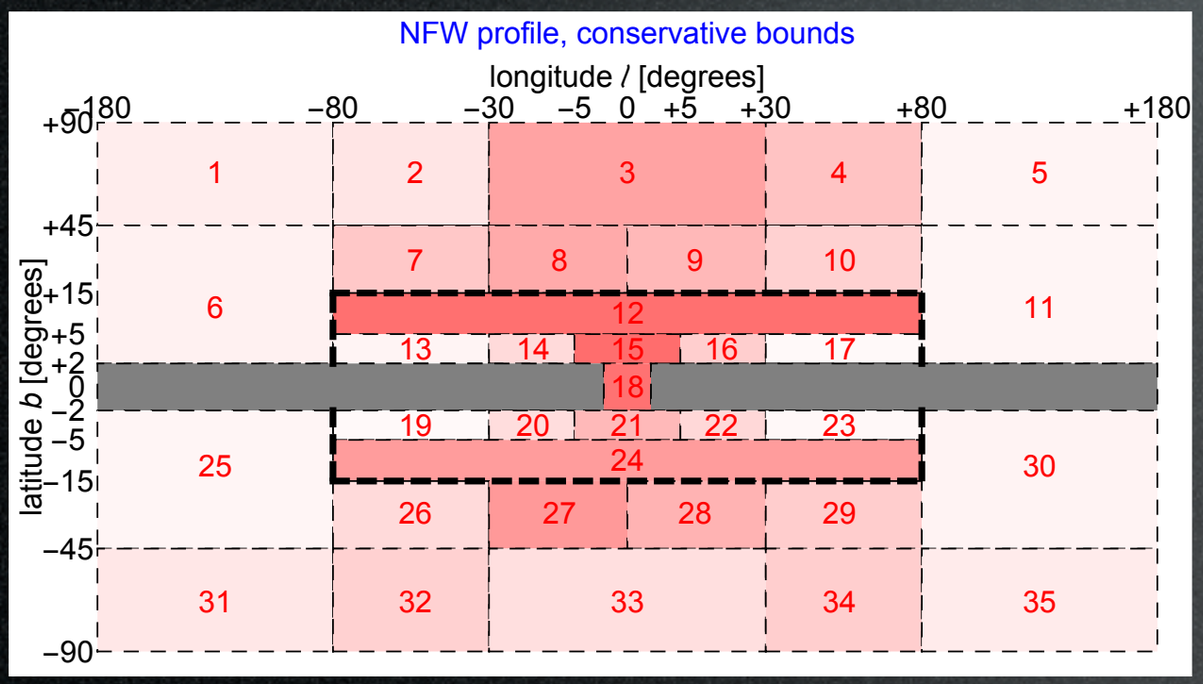


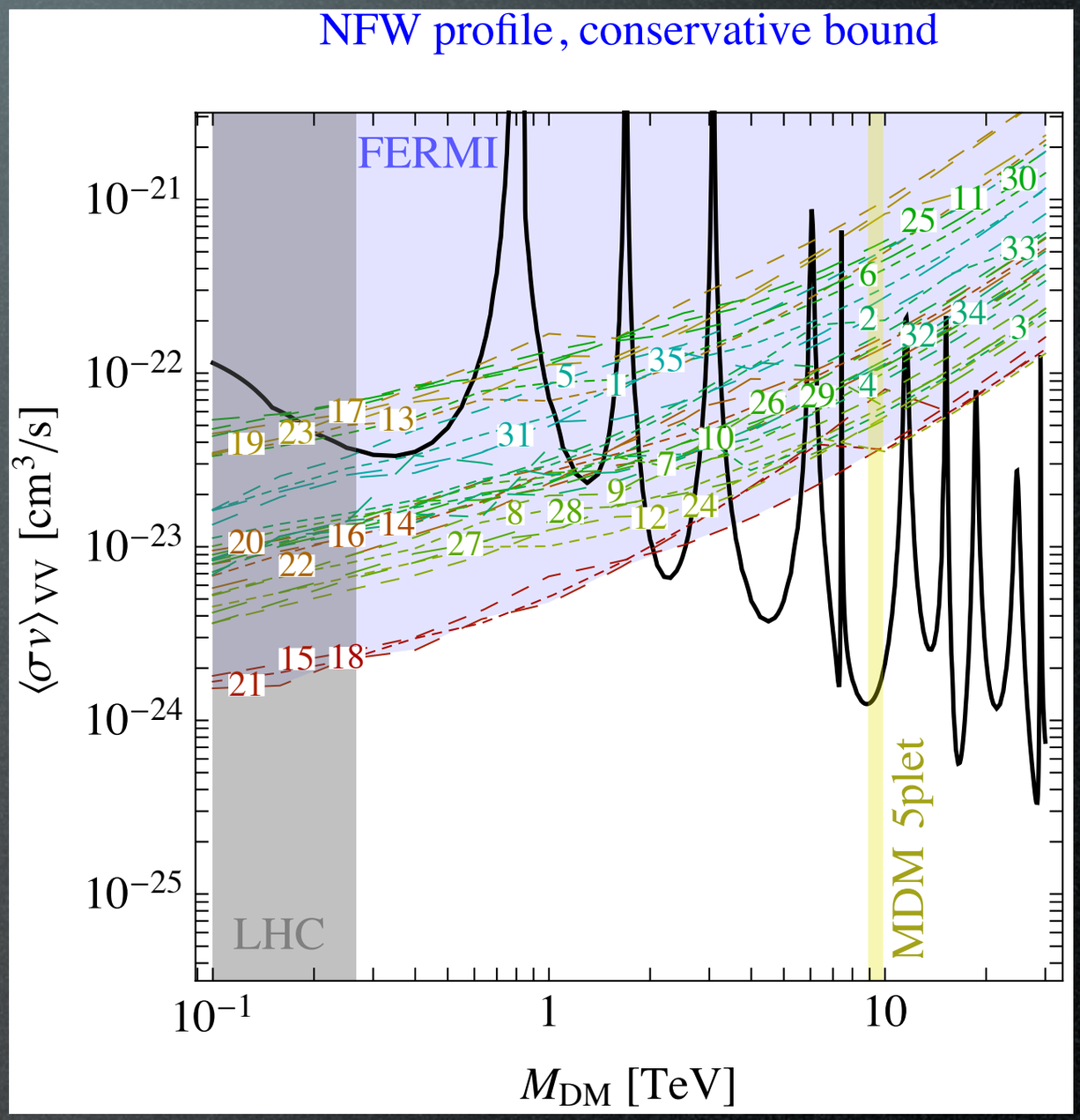
Cirelli, Hambye, Panci, Sala, Taoso
1507.05519

Indirect Detection

FERMI diffuse galactic:





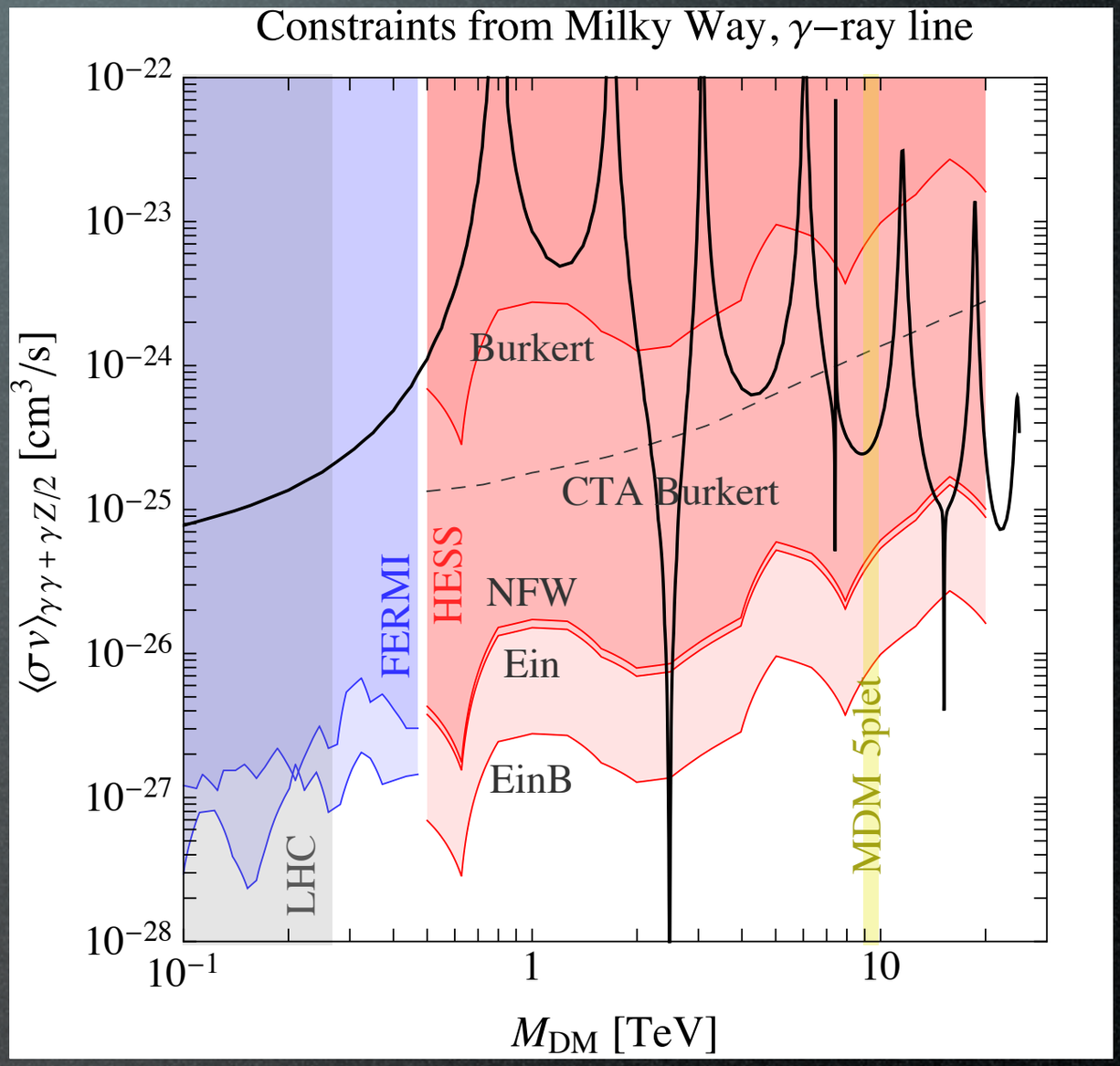


Indirect Detection

MW center area, search for γ-ray lines:

FERMI: 1506.00013

HESS: 1301.1173



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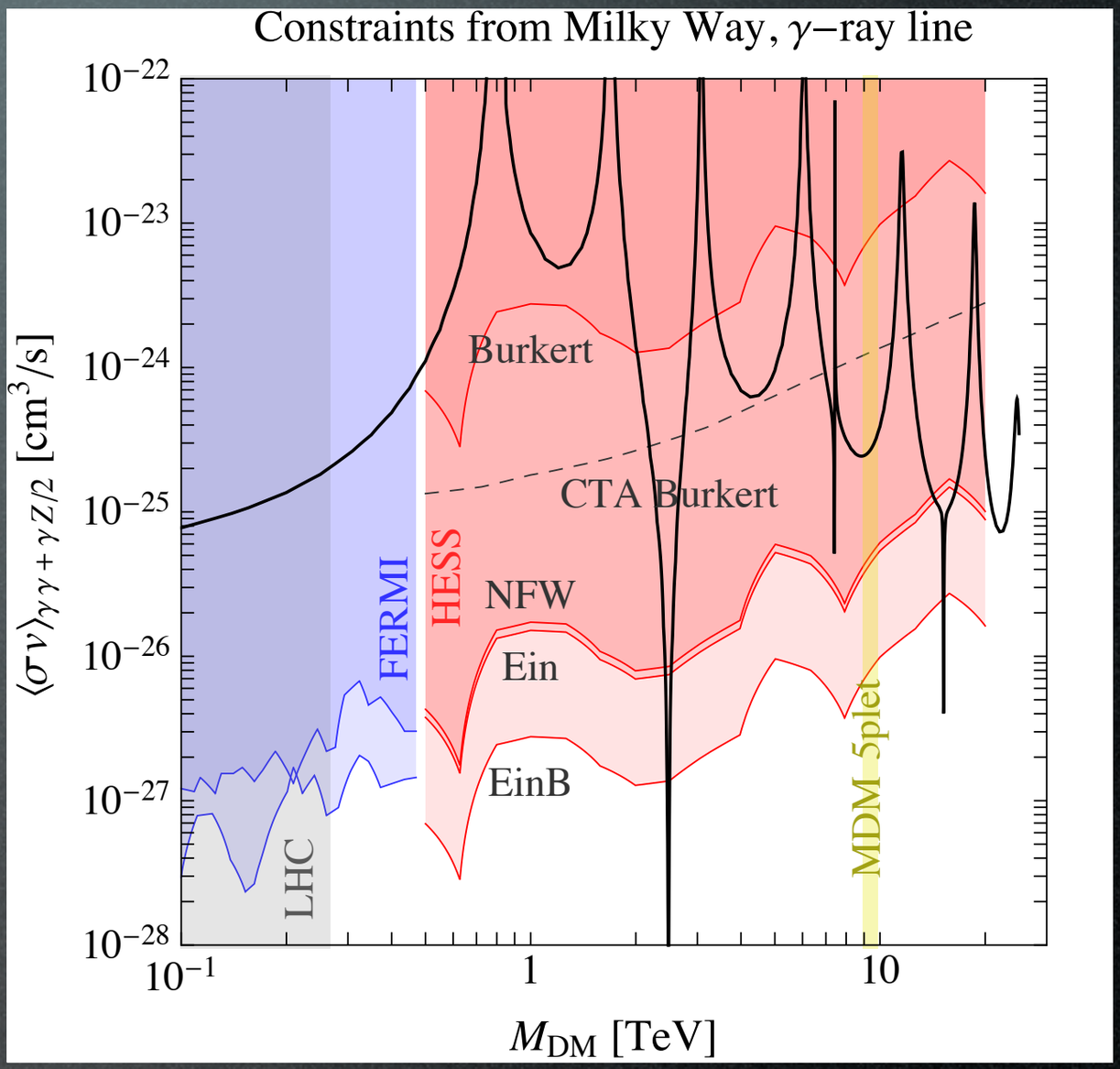
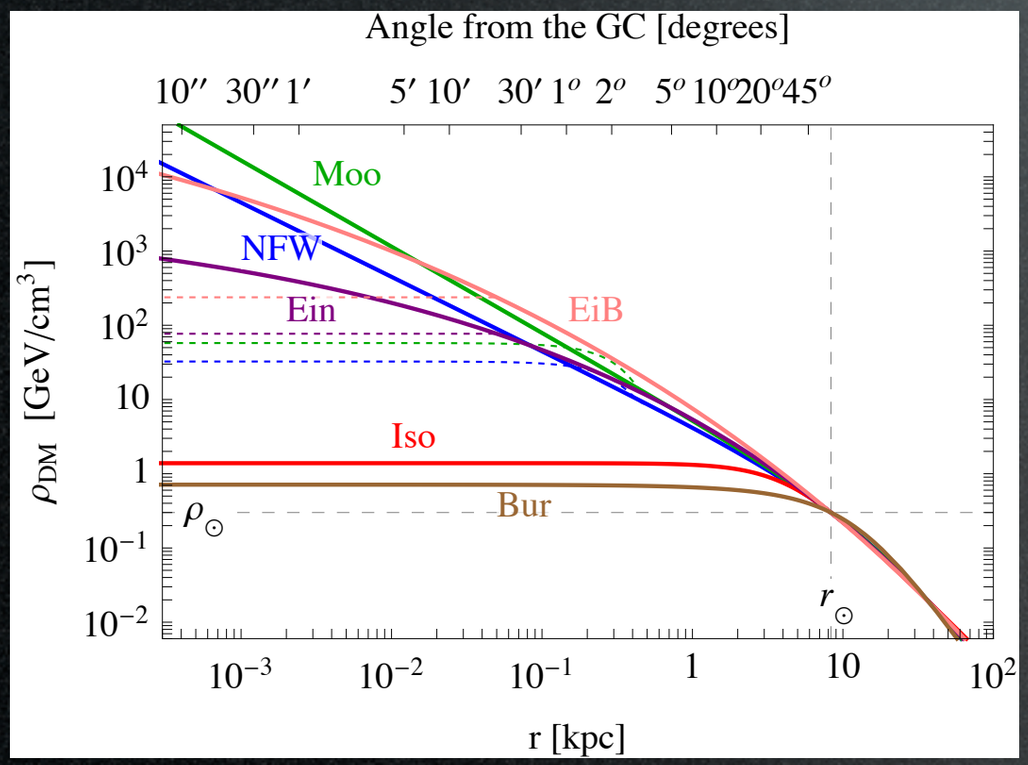


Uncertainties in DM profile:



e.g. Cirelli et al., 1012.4515

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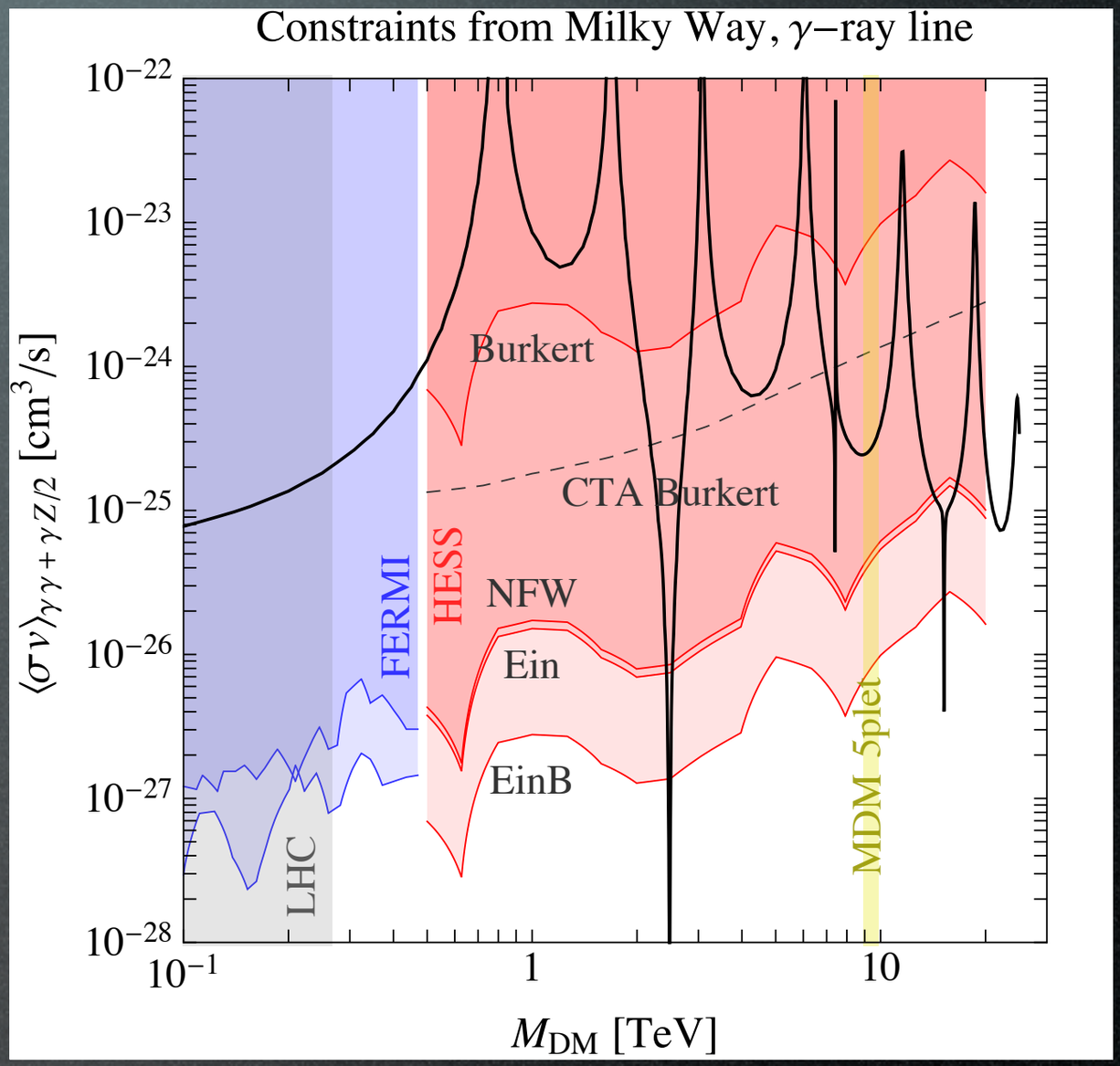

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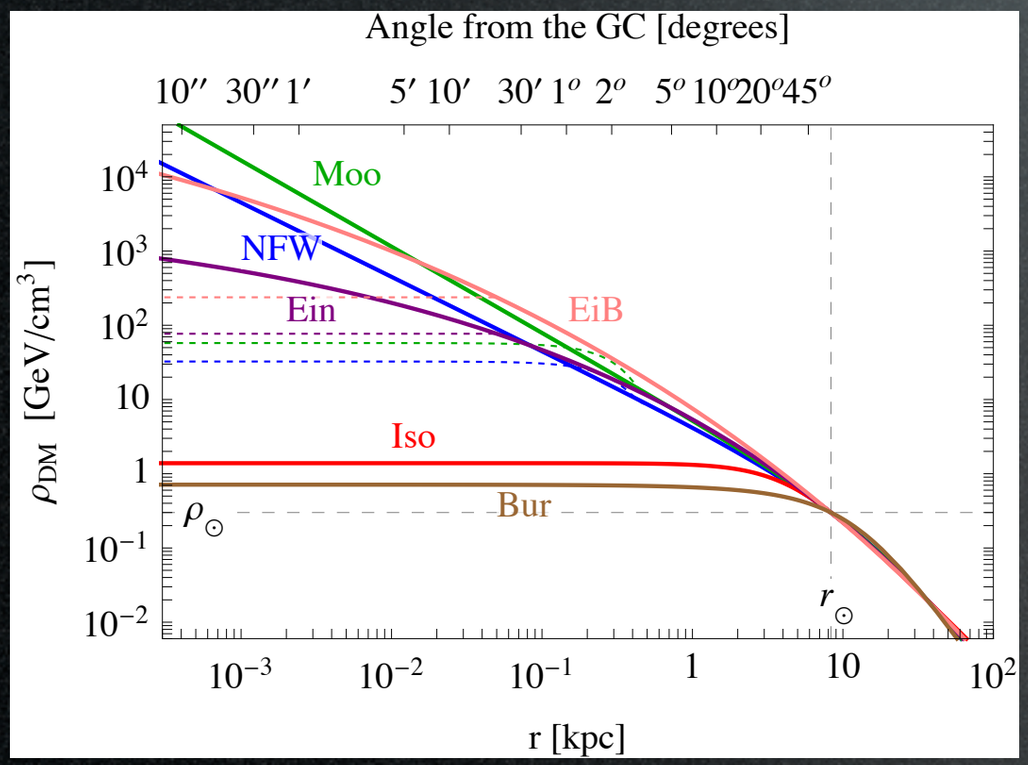

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MDM excluded if cuspy

MDM not probed if cored

Consistent conclusions in: Garcia-Cely et al. 1507.05536

Post scriptum

Bound state formation is relevant

Pospelov, Ritz 2009
March-Russell, West 2009
Shepherd, Tait, Zaharijas 2009
K.Petraki+, 2014+

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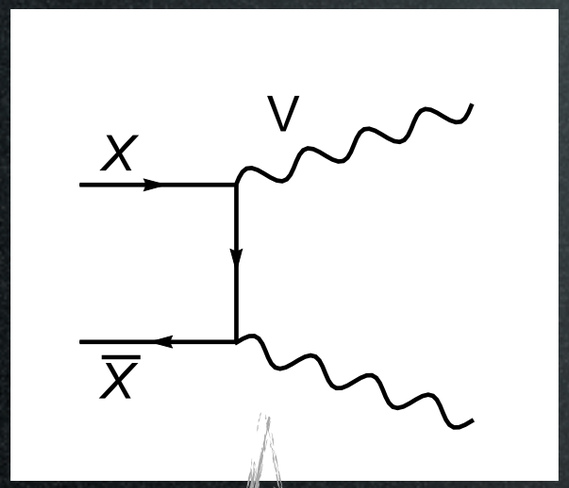

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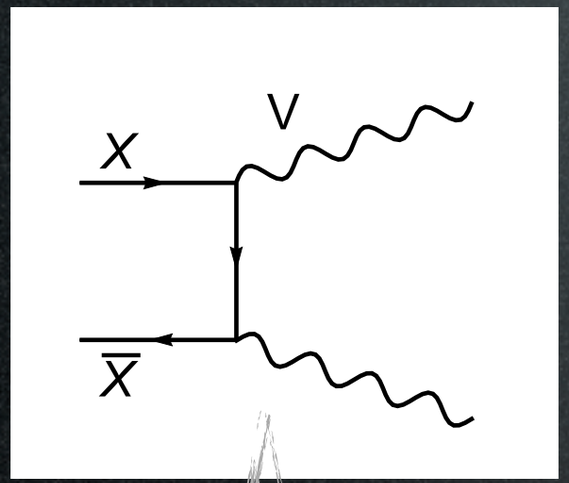

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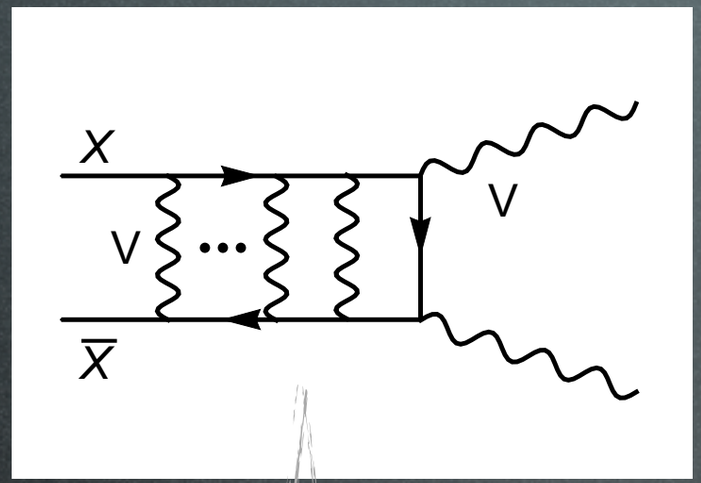

size of the XX system

If $\alpha M/m_V \gtrsim 1$, the force is long range:

range

Sommerfeld enhanced

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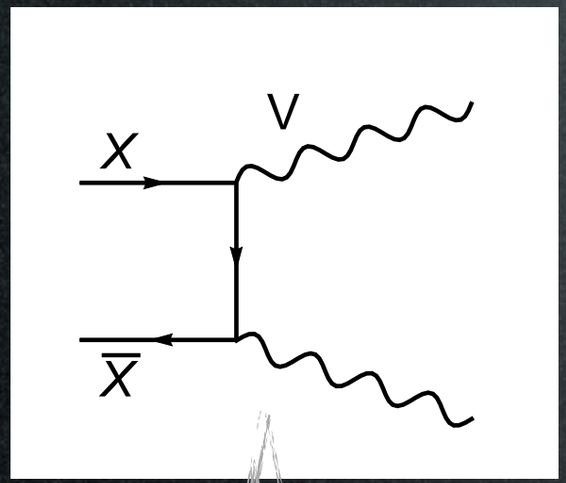

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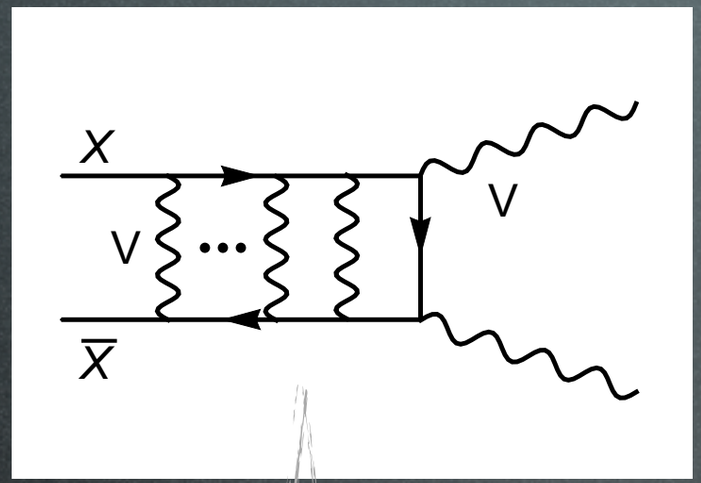

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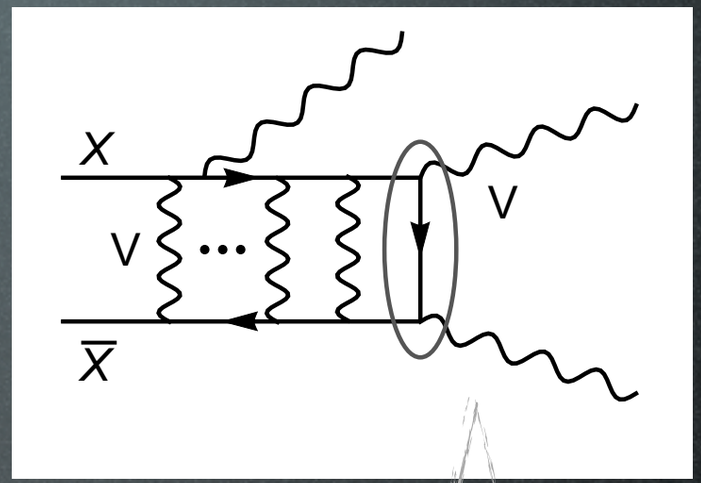

binding energy of the XX system

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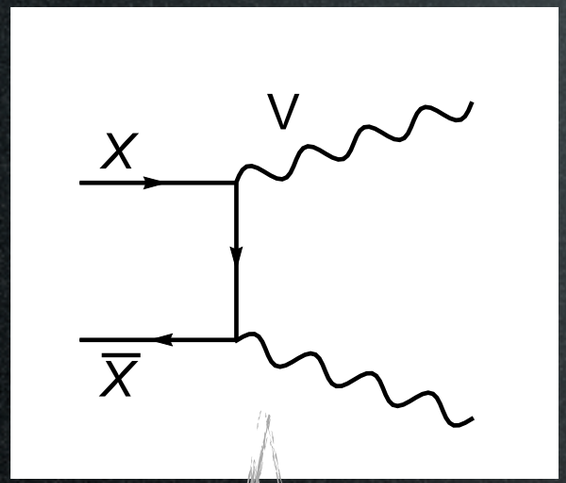

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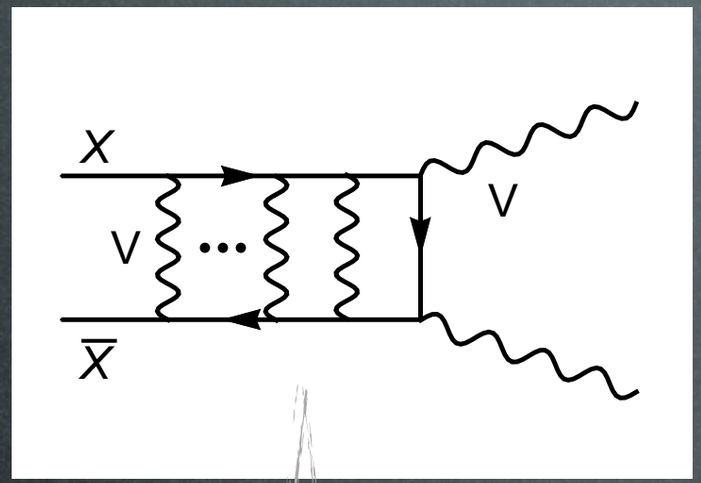

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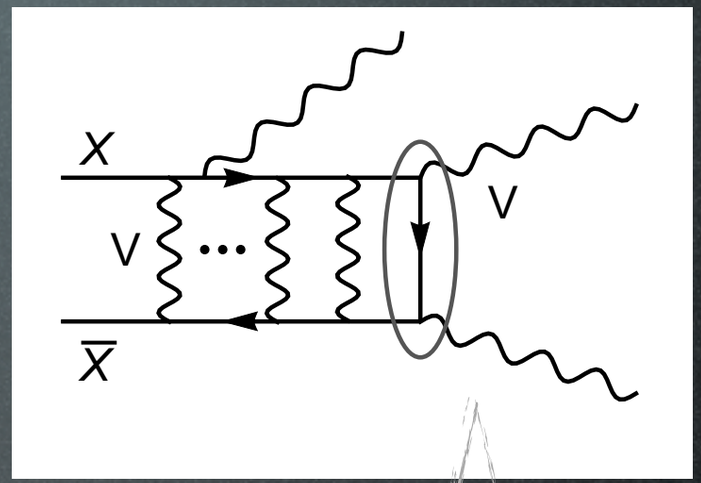

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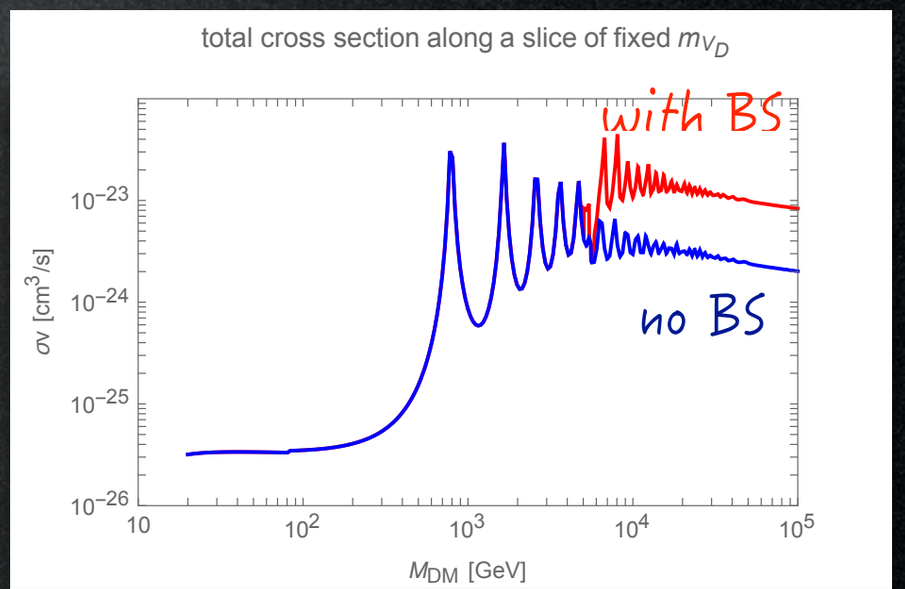

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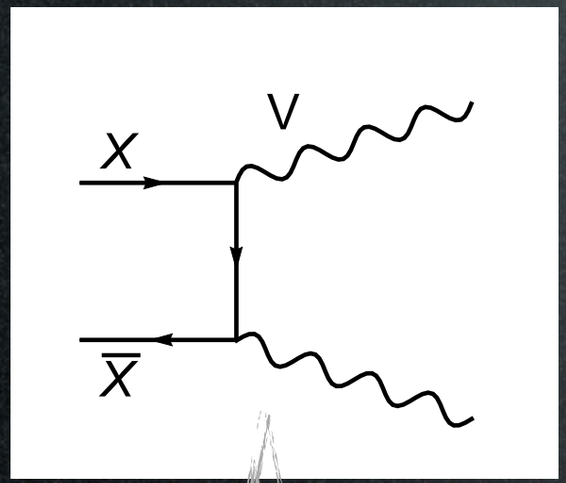

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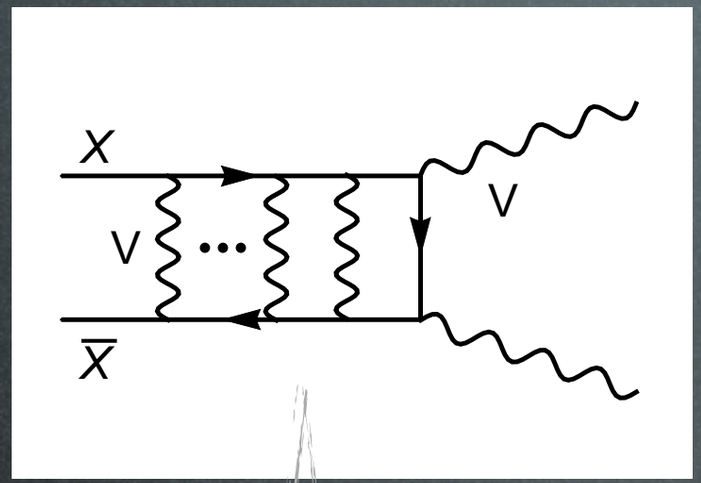

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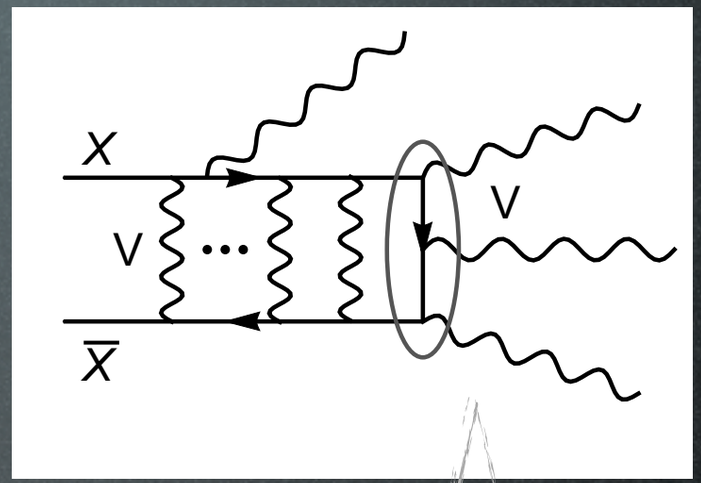
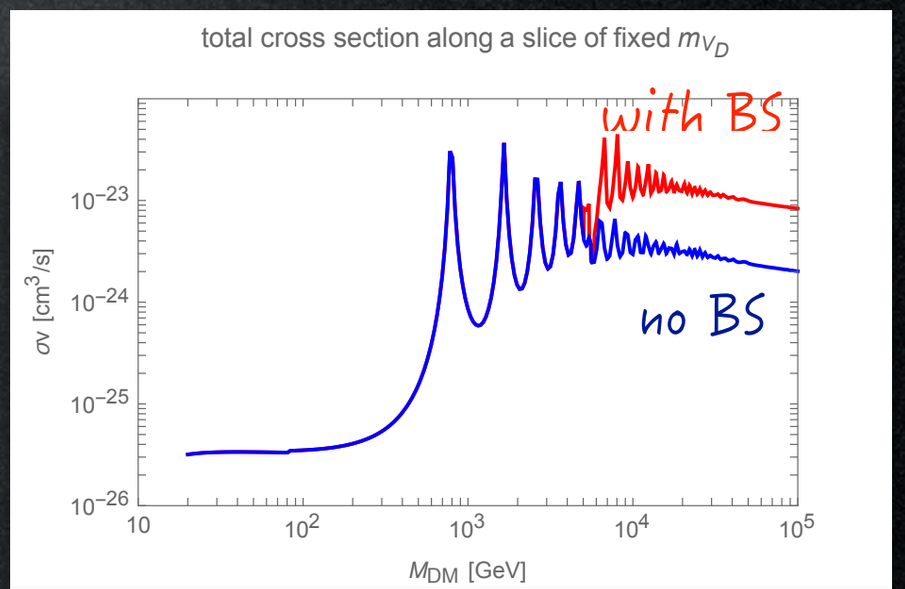


binding energy of the XX system

If $\alpha^2 M/2m_V \gtrsim 1$, bound states form

emitted mediator

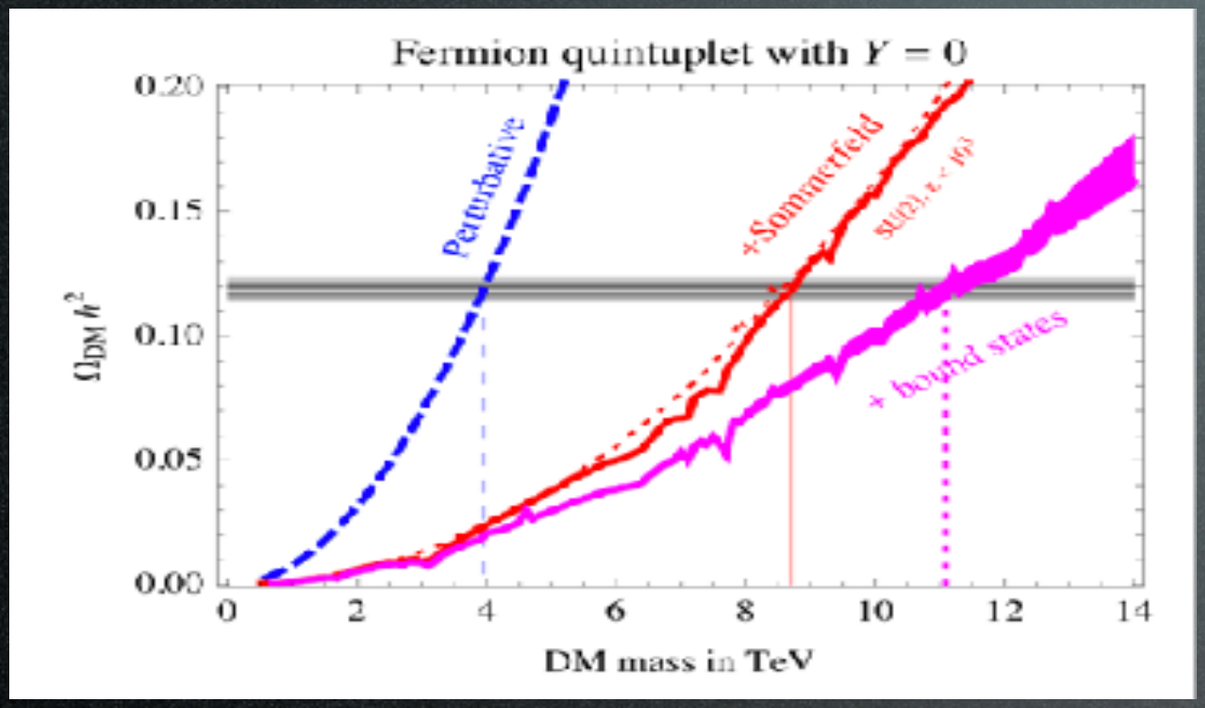


Post scriptum

Bound state formation

Mitridate, Redi, Smirnov, Strumia 1702.01141

impact on thermal mass and indirect detection



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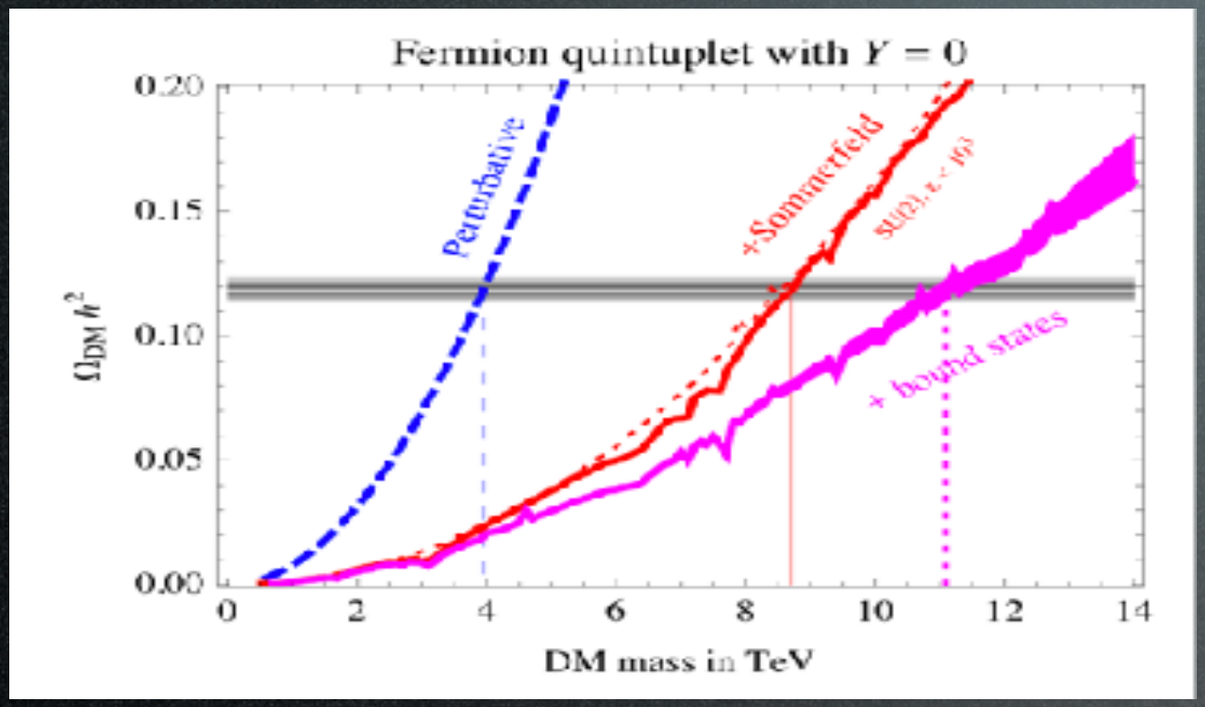

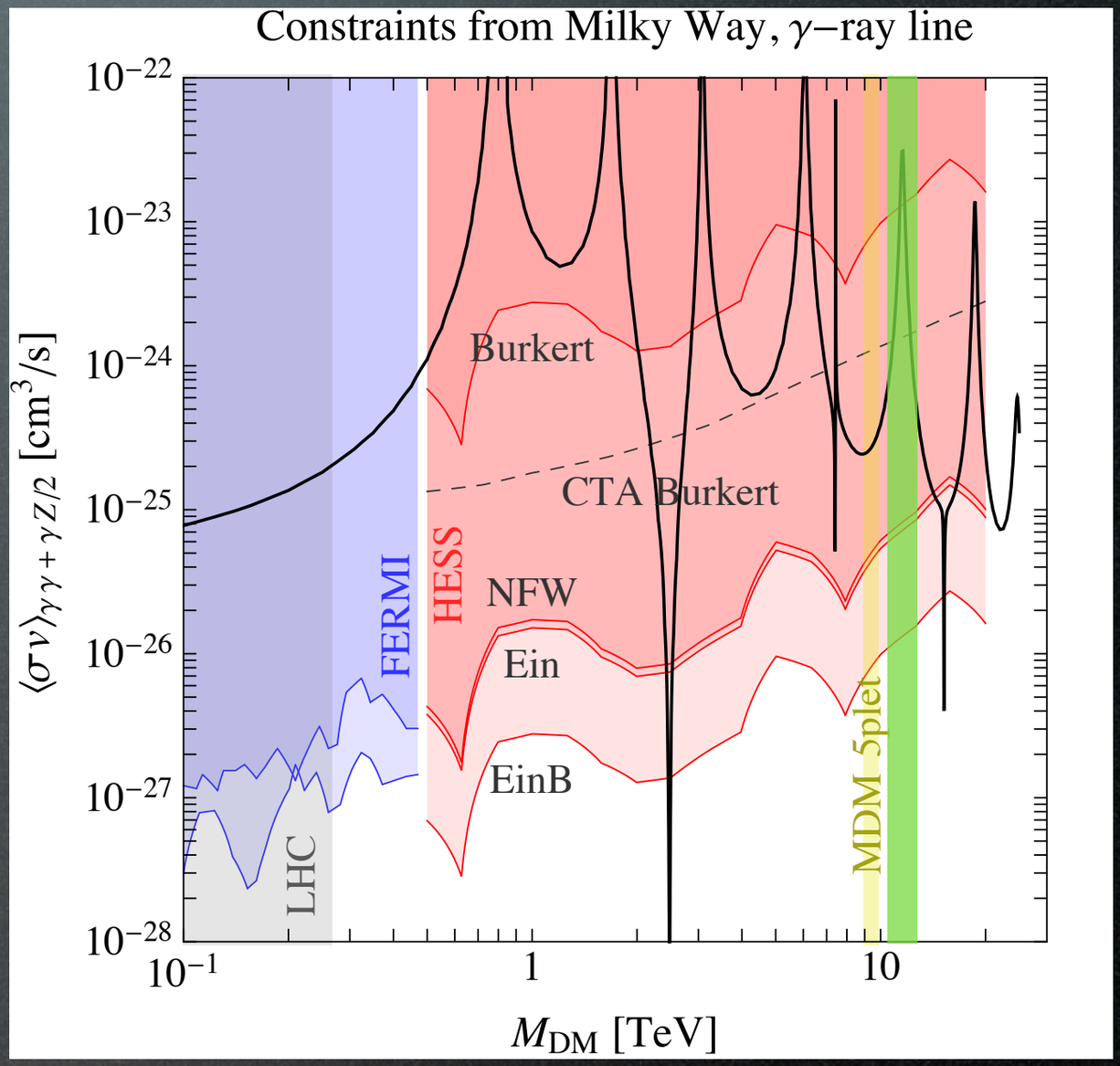

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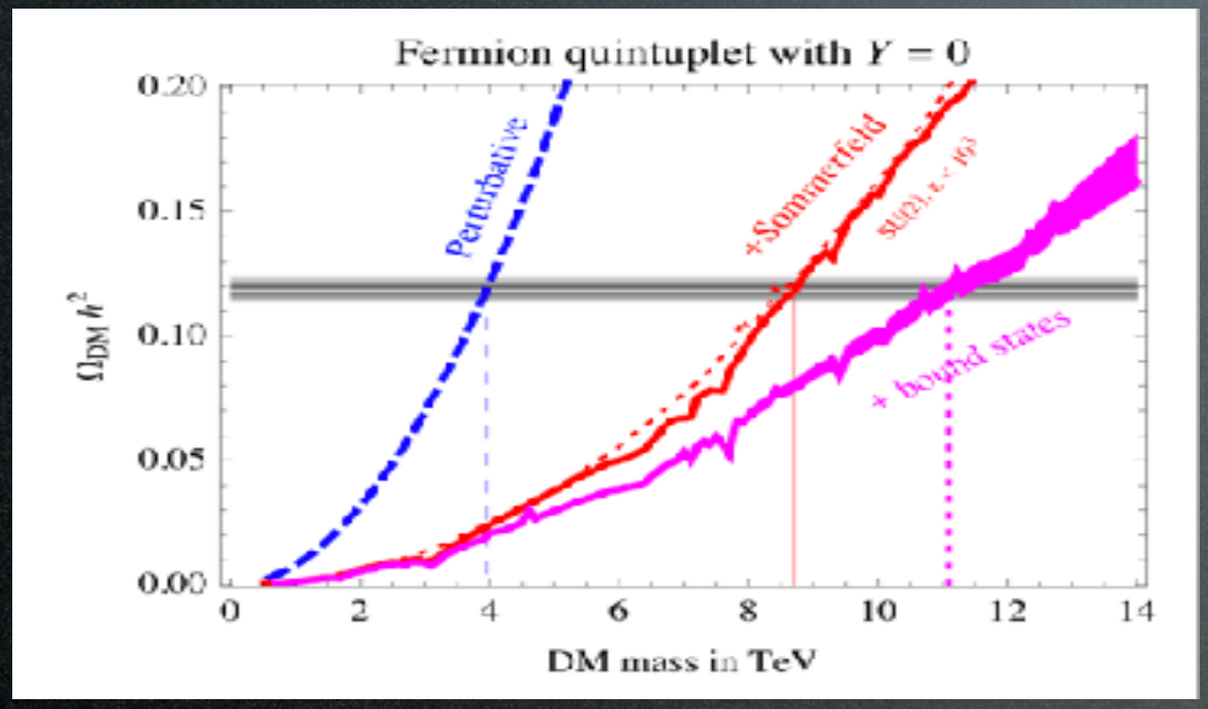

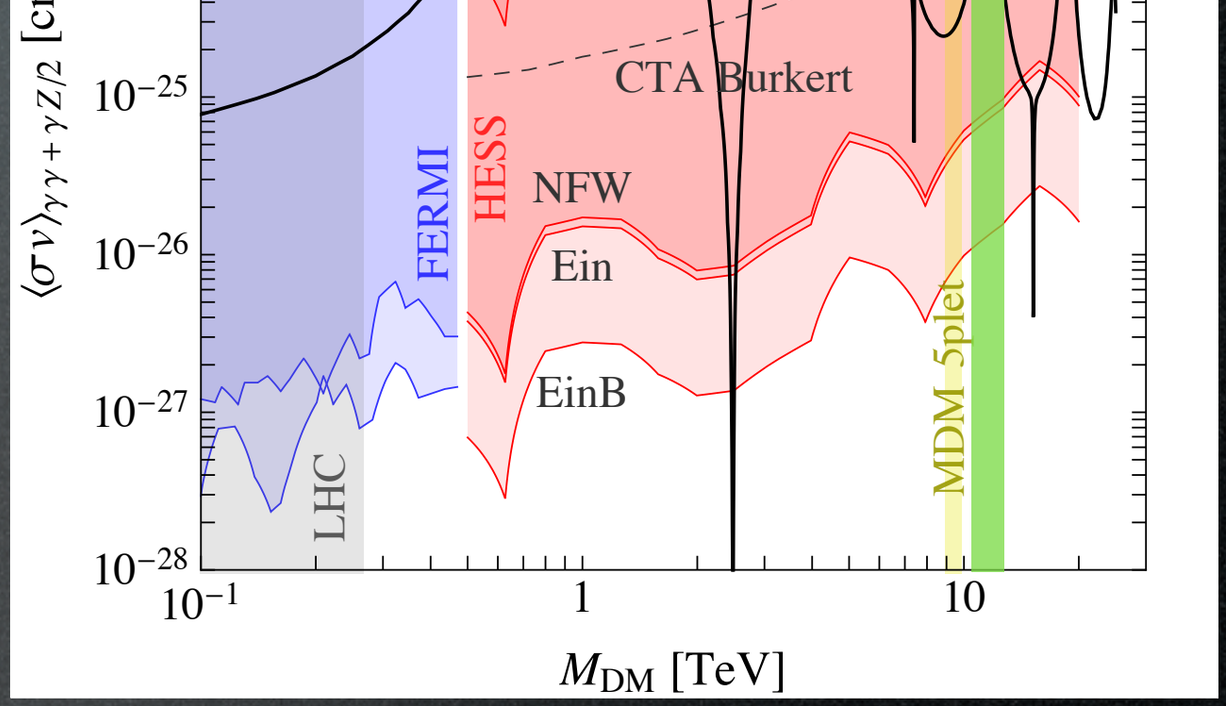

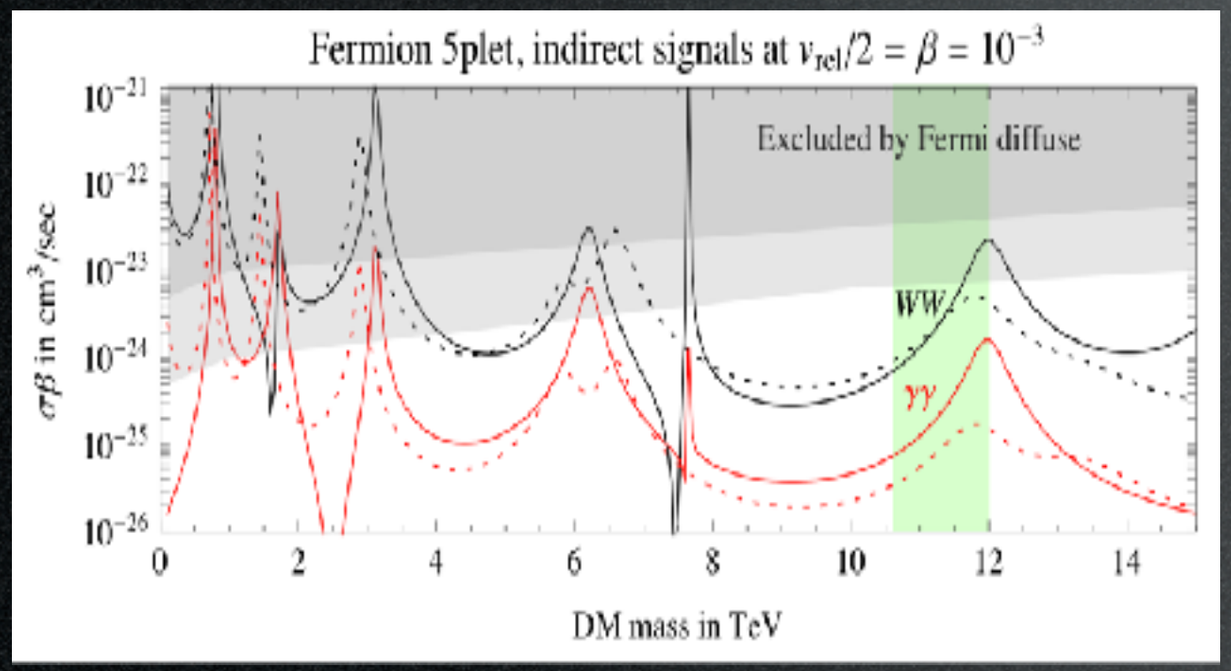

<— Mitridate, Redi, Smirnov, Strumia 1702.01141**v2**

Candidates

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
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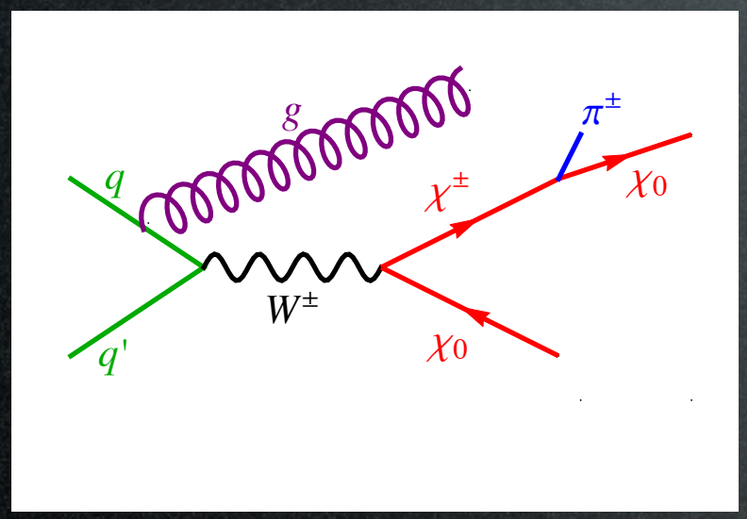
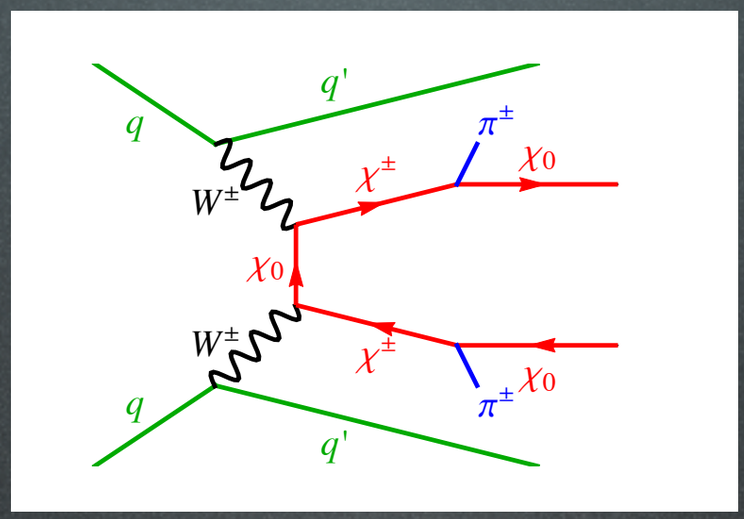
Collider searches

EW processes:

Mono-X

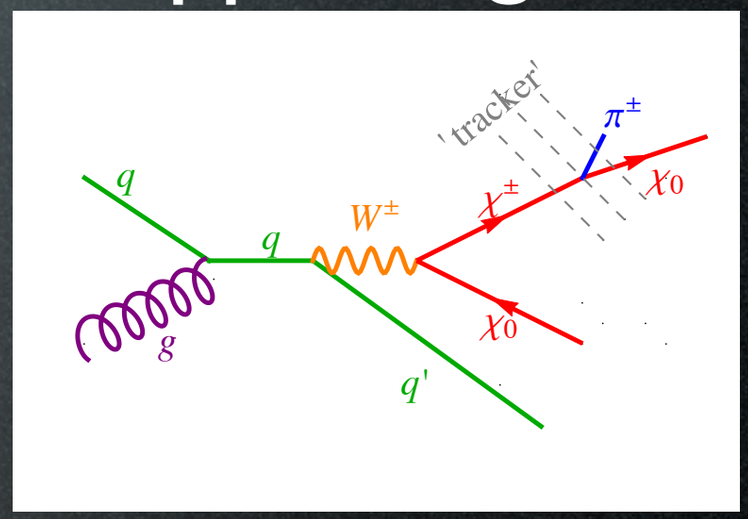


VBF



di-jets + MET

Disappearing tracks



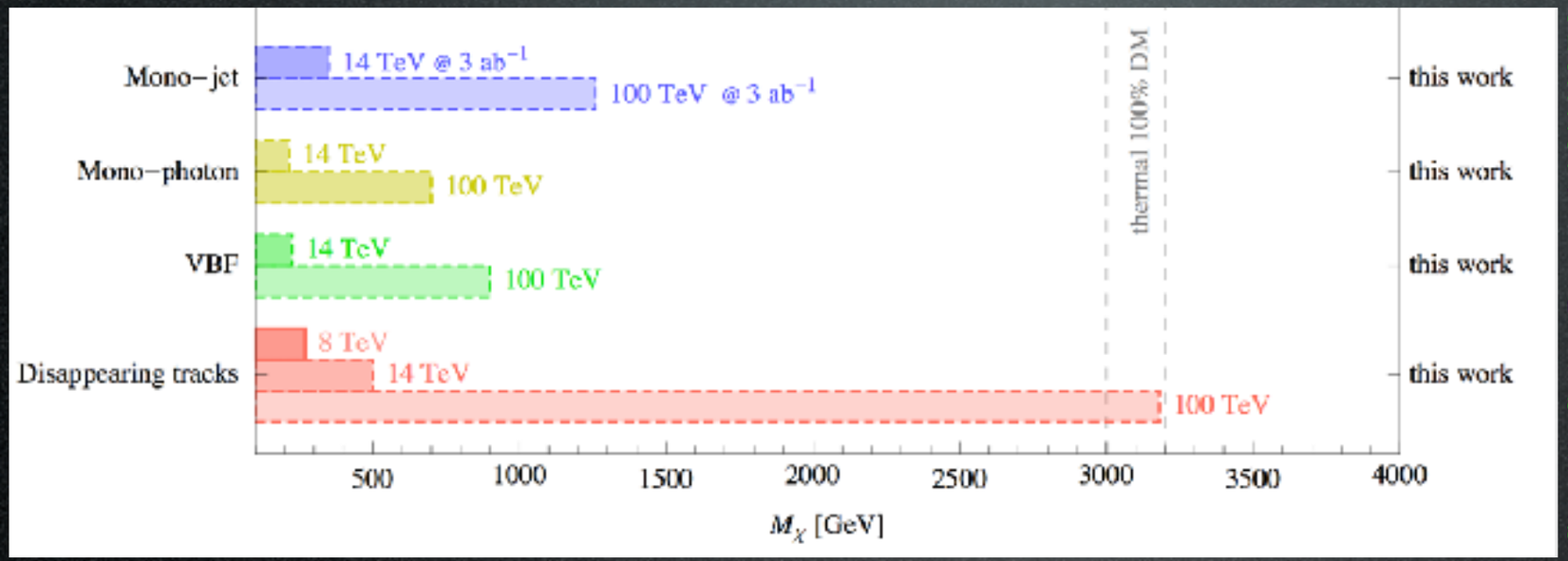
or: indirect searches

Collider searches

EW processes:

everything depends on the DM mass

For triplet WIMP (a.k.a. pure wino DM)



Cirelli, Sala, Taoso 1407.7058

For 5plet MDM

Model	$\sqrt{s} = 8$ TeV				$\sqrt{s} = 14$ TeV					
	ATLAS		CMS		Exclude			Discover		
	Expected	Observed	Expected	Observed	500%	100%	20%	500%	100%	20%
Wino	224	238	203	195	354	483	635	287	394	514
Majorana Fiveplet	256	267	234	226	410	524	668	340	448	576
Dirac Fiveplet	283	293	259	251	465	599	743	381	503	639

Ostdiek, 1506.03445

Collider searches

Indirect searches at a future Linear Collider:

Collider searches

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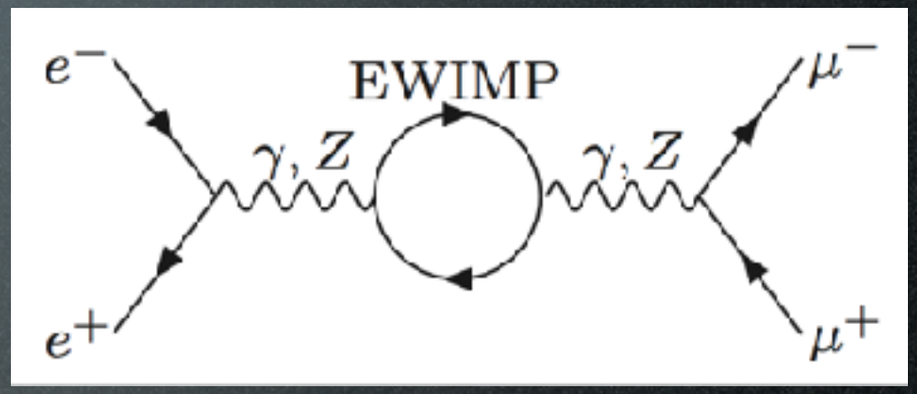
Harigaya, Ichikawa, Matsumoto..., 1504.03402

Even if $\sqrt{s} < M_{\rm DM}$, one can see the effects in precision measurements



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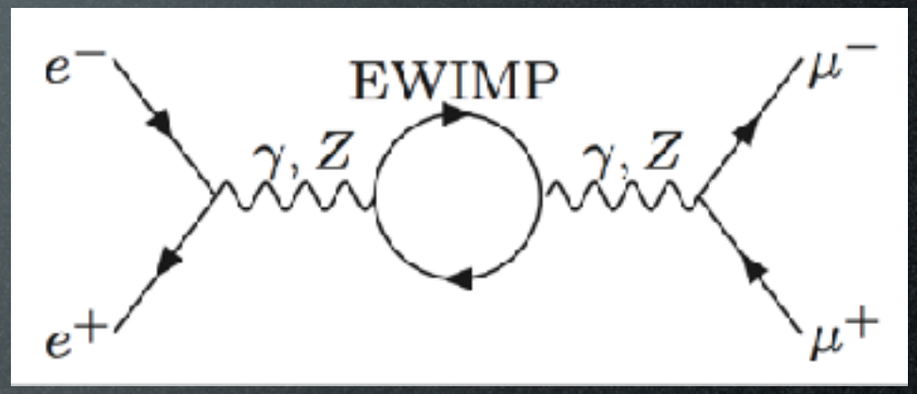
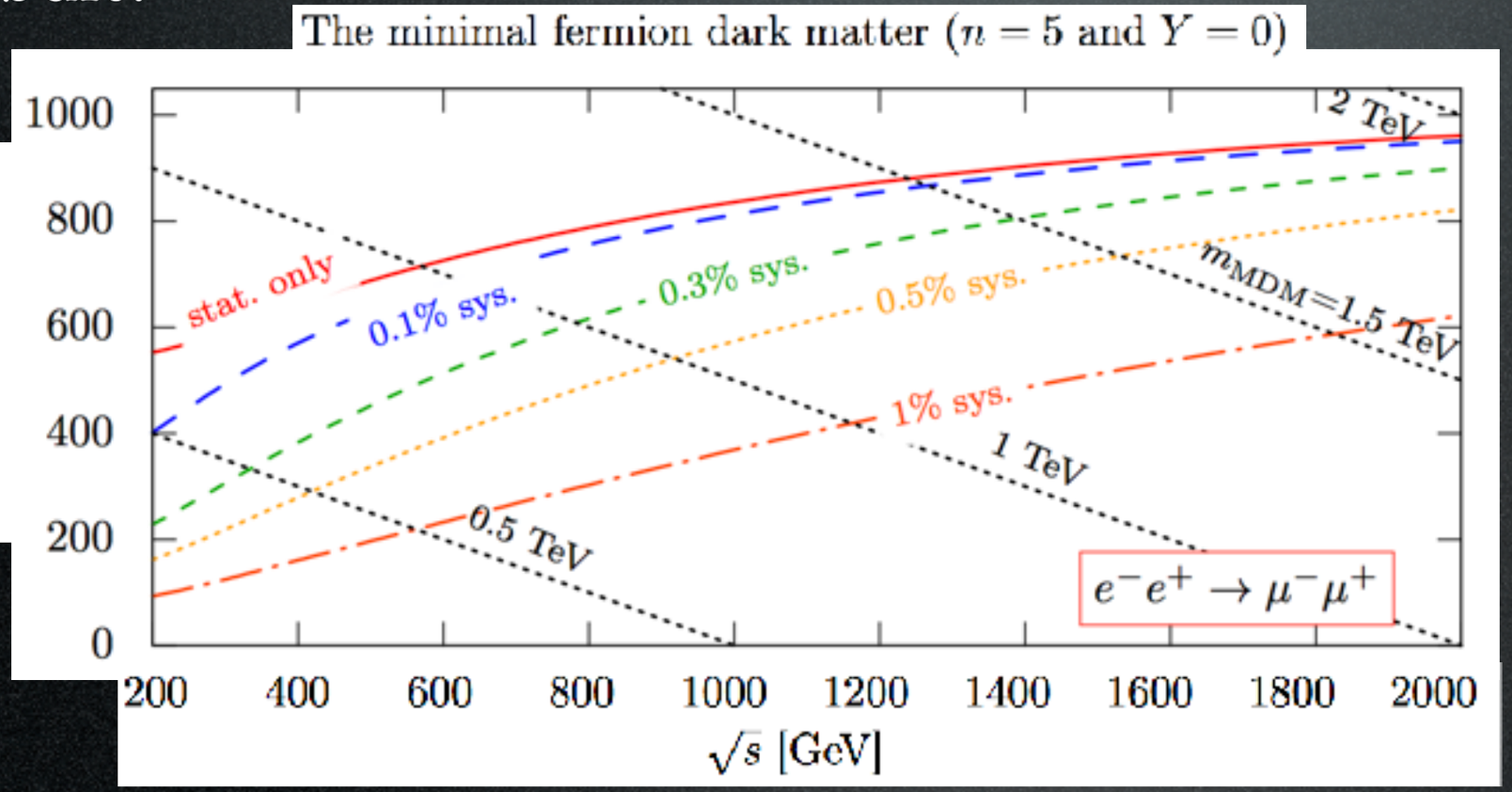


Result:



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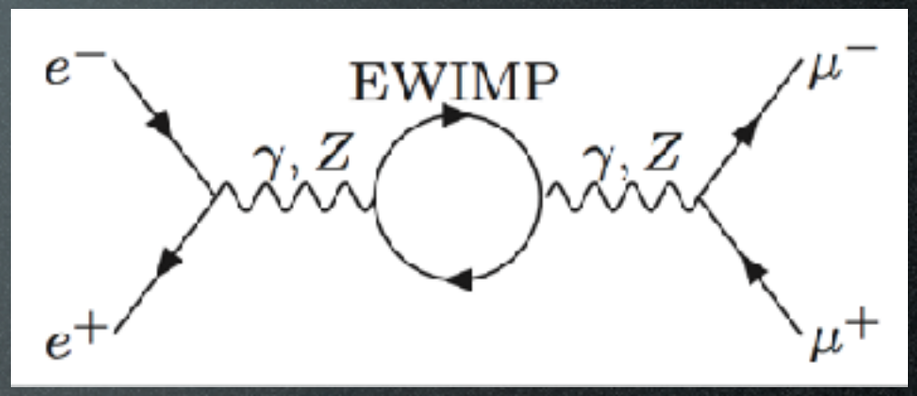

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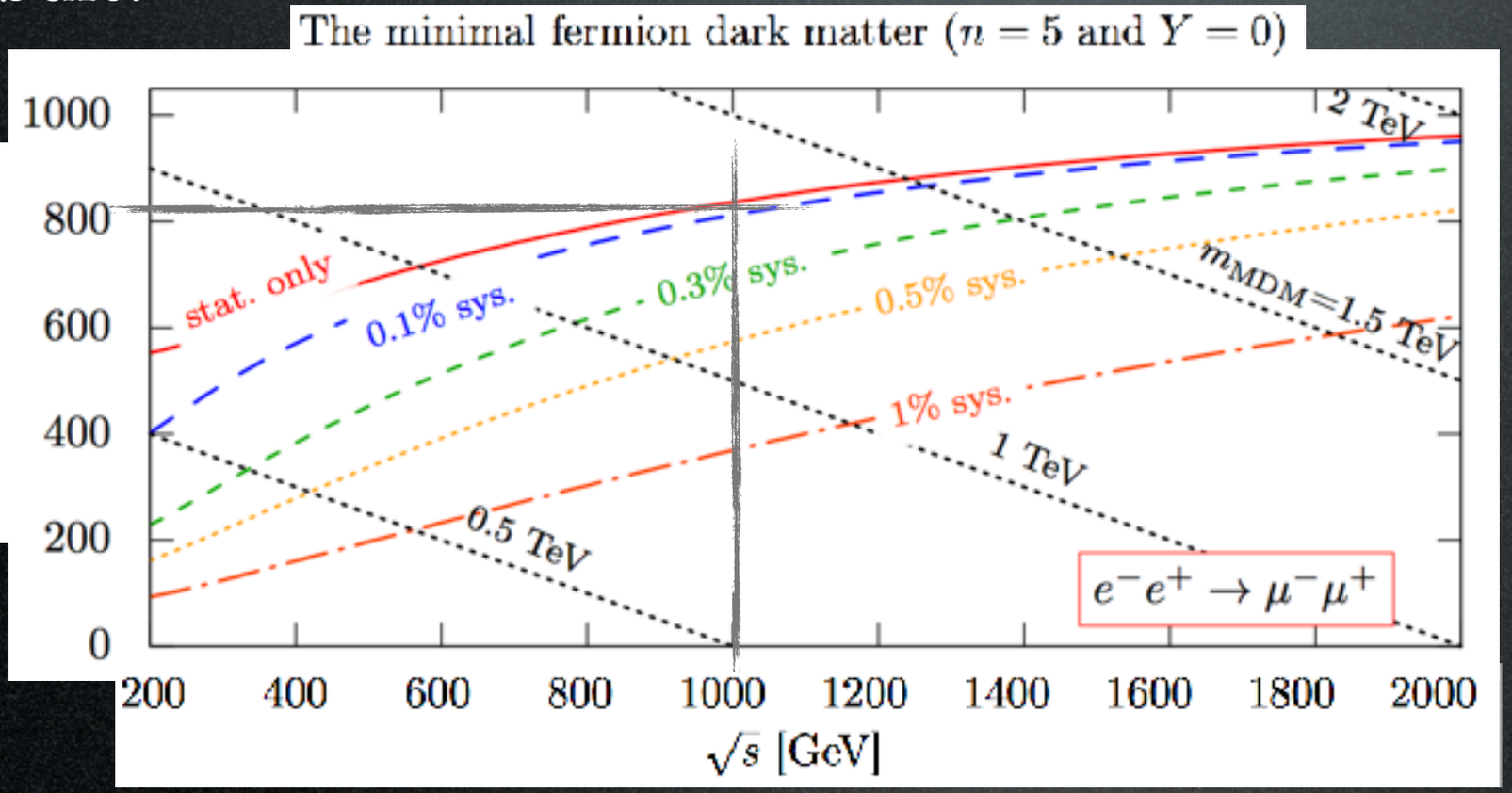

How to read the plot:
a LC with $\sqrt{s}$ = 1 TeV,
assuming only stat uncertainties,
will be sensitive to m_{DM} - $\sqrt{s}/2$ ~ 800 GeV
i.e. m_{DM} ~ 1.3 TeV (indeed see the dotted isocontours of the DM mass)

similar plots for other channels
& for other candidates

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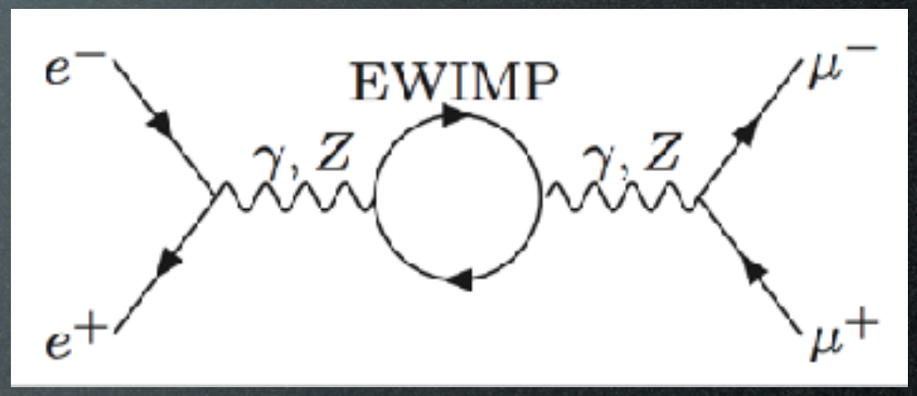

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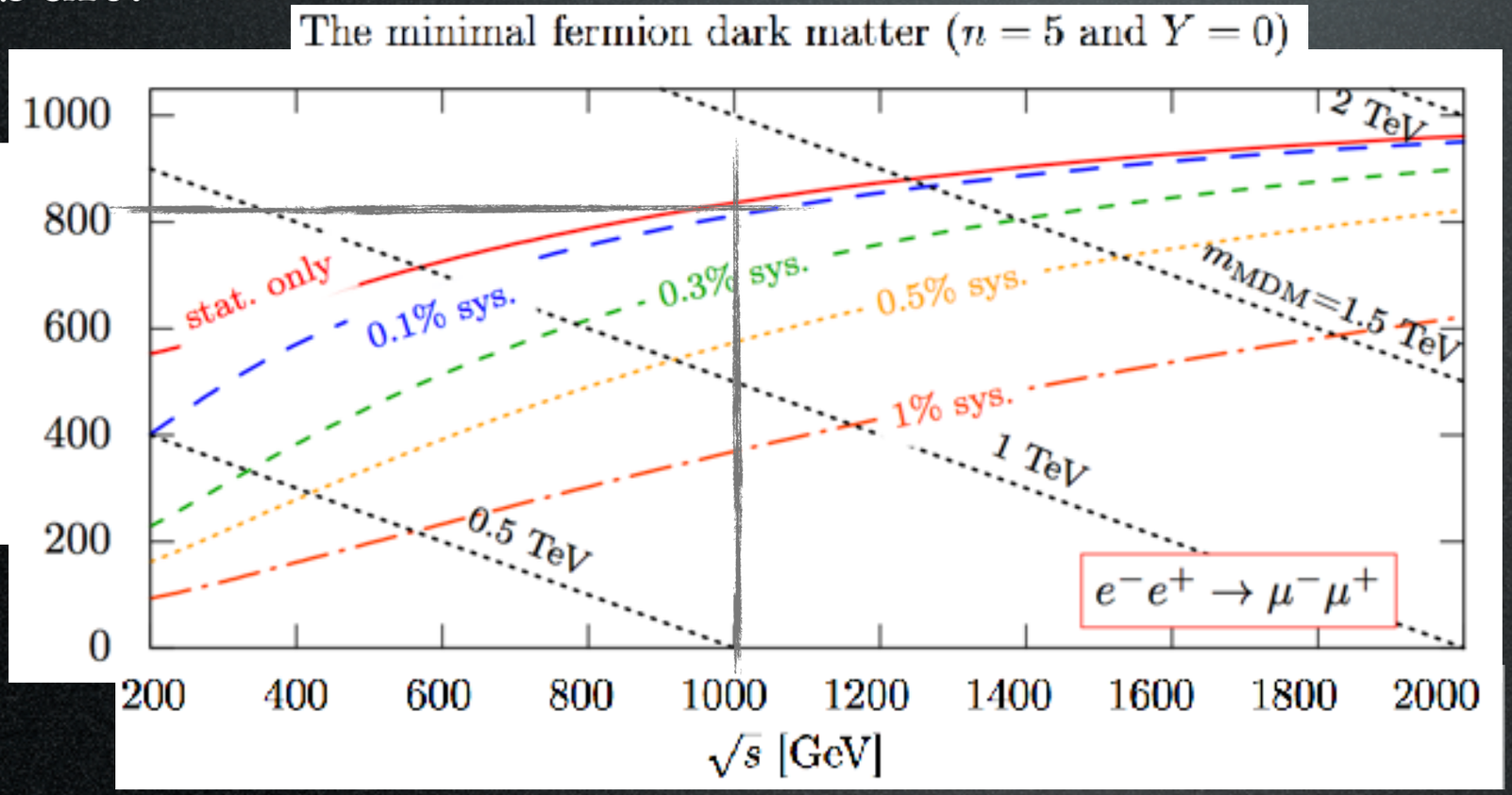

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one can go beyond the collider energy, but not by much

Conclusions

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