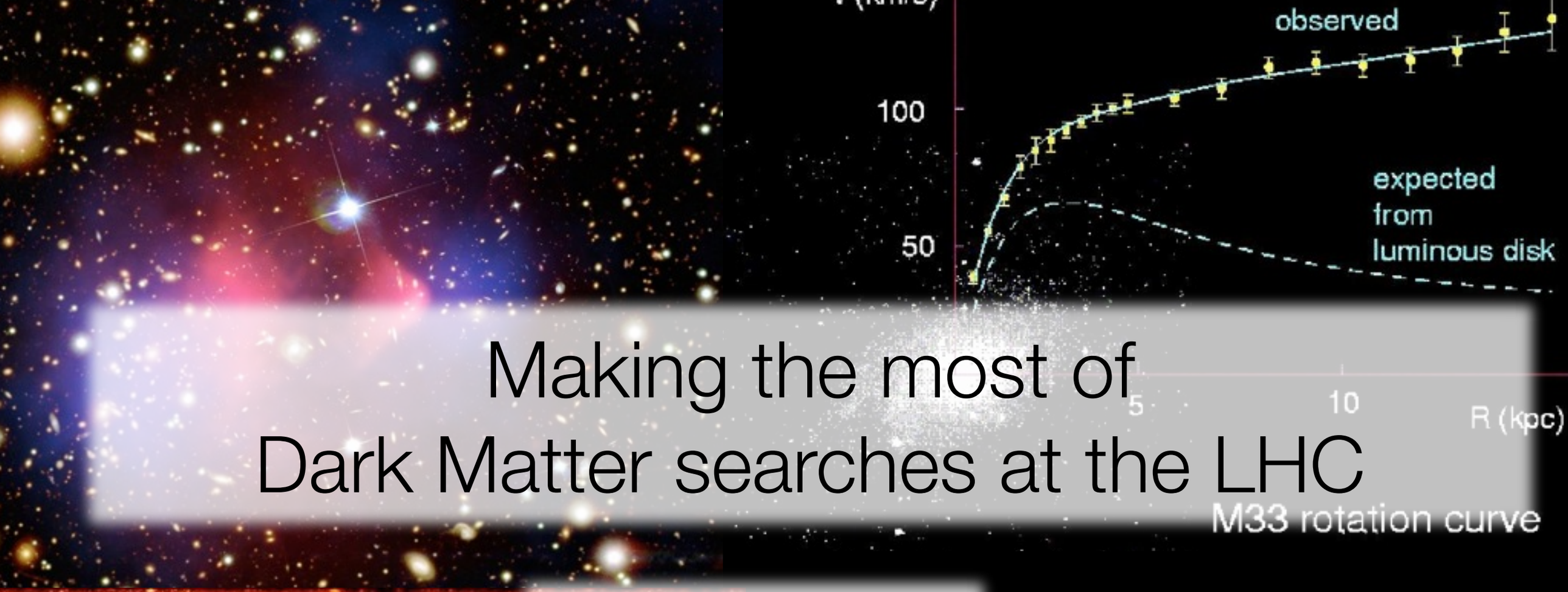


Making the most of Dark Matter searches at the LHC

Thomas Jacques

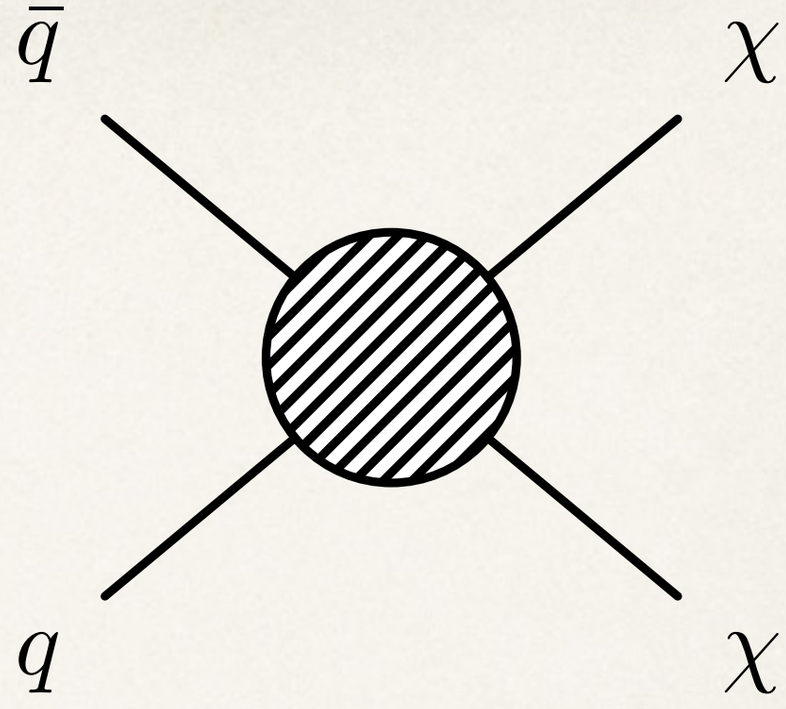
2015-06-23
Invisibles 2015

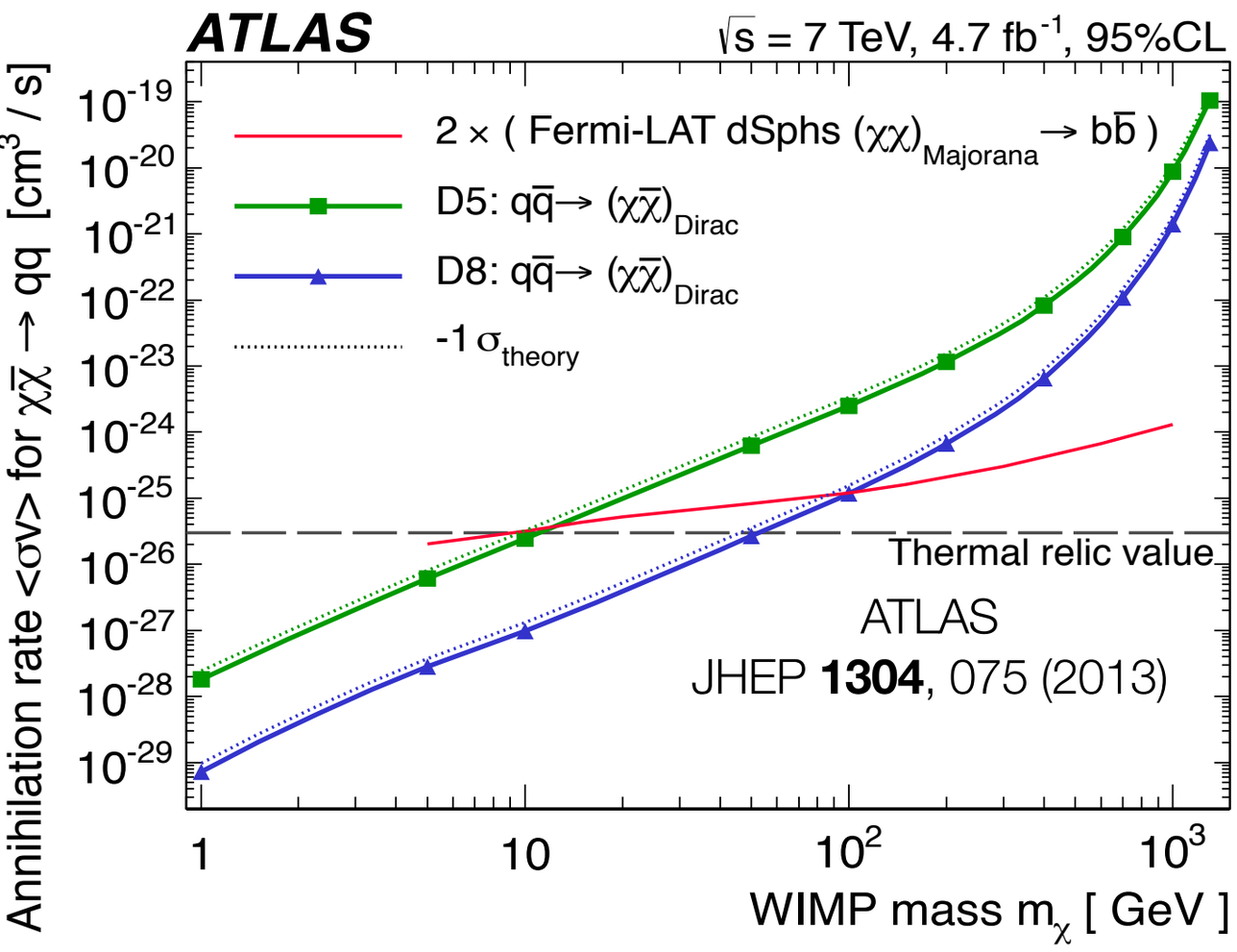
UNIVERSITÉ DE GENÈVE

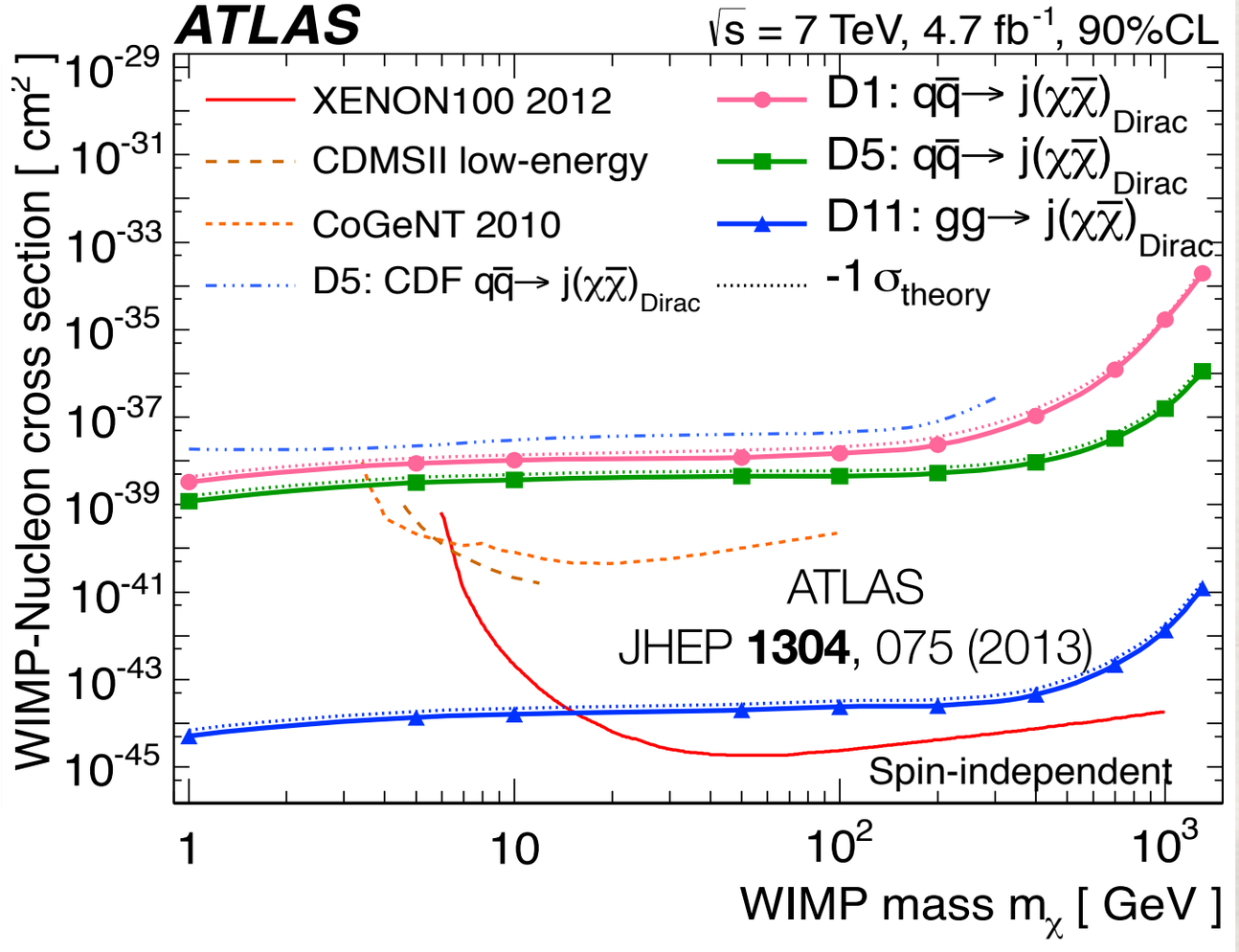
Center for Astroparticle Physics
GENEVA

Effective Field Theories

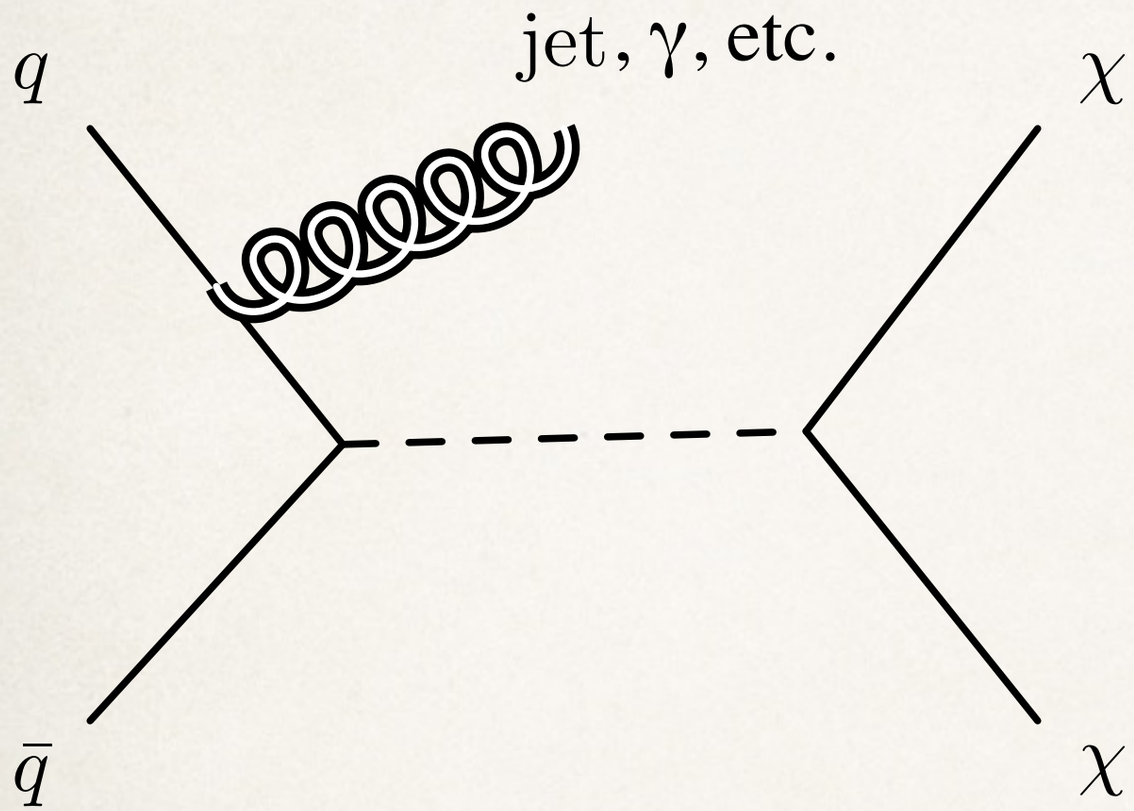
- Integrate out the mediator
- Reduce parameters to m_{DM}, M^* for each operator
- Limited number of operators

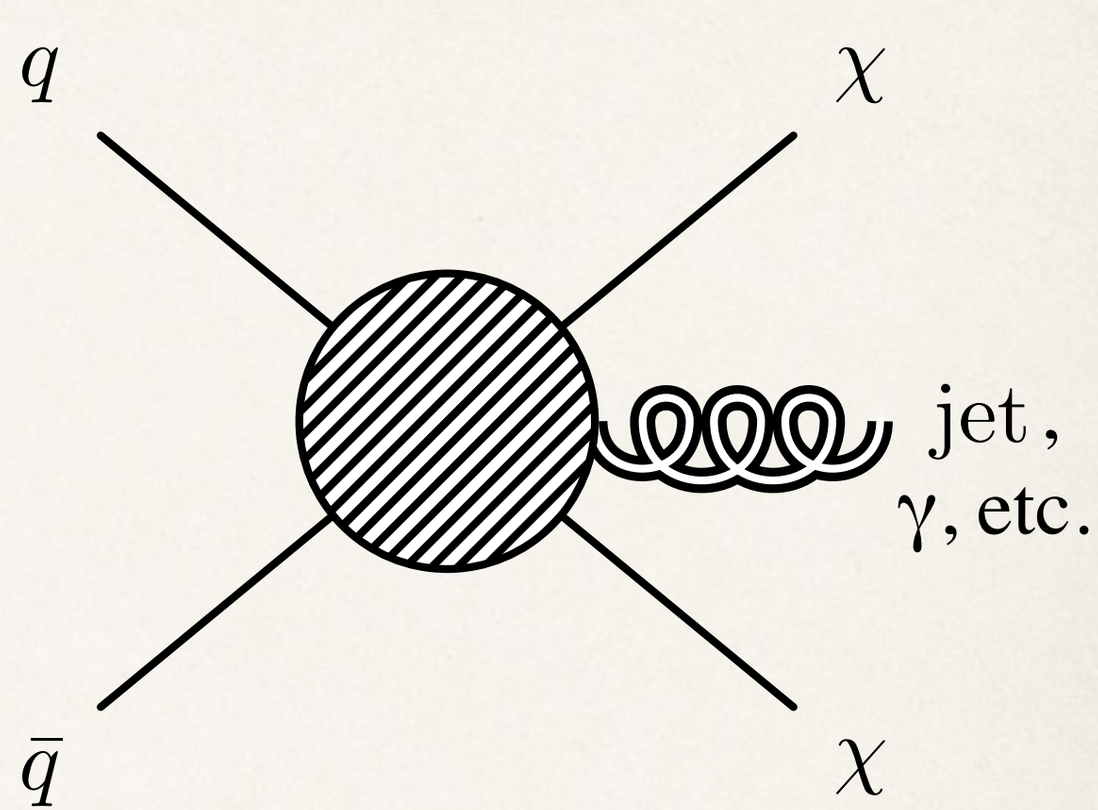






Effective Field Theories

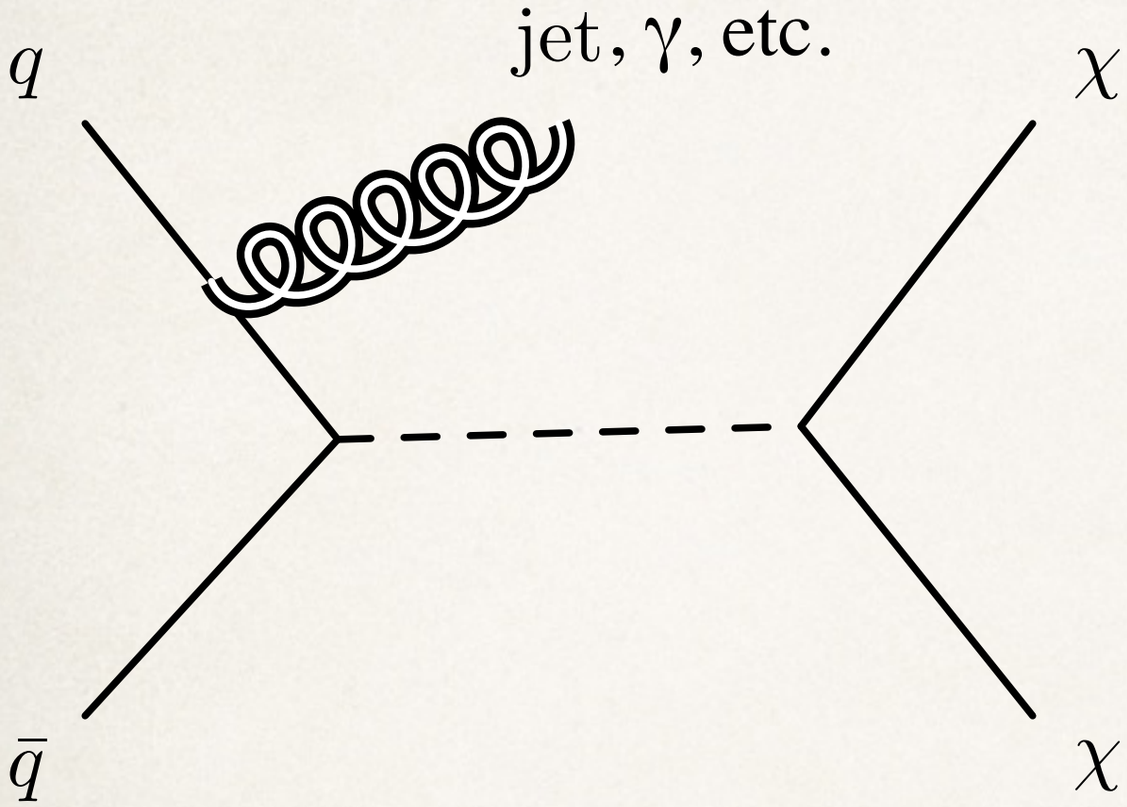


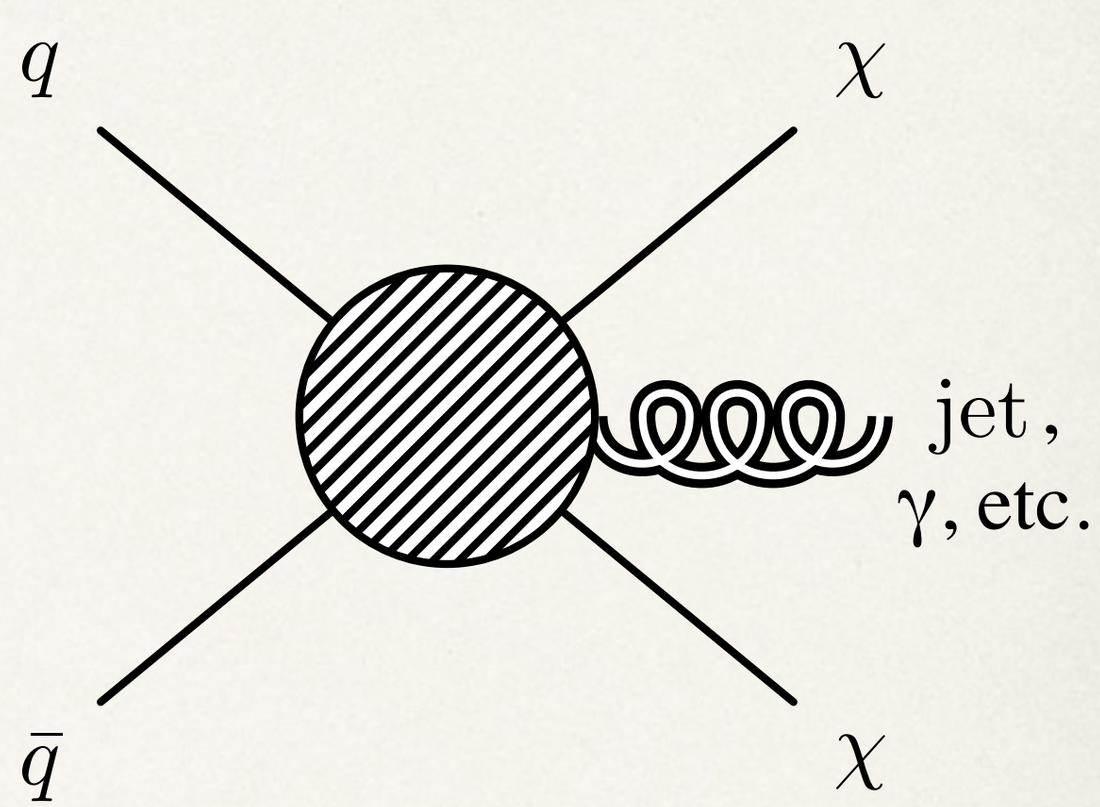


$$\frac{g_q g_\chi}{M^2 - Q_{\rm tr}^2} = \frac{g_q g_\chi}{M^2}\left(1 + \frac{Q_{\rm tr}^2}{M^2} + \mathcal{O}\left(\frac{Q_{\rm tr}^4}{M^4}\right)\right) \simeq \frac{1}{M^{*2}}$$

$$M^* \gtrsim \frac{m_{\rm DM}}{2\pi}$$

Effective Field Theories





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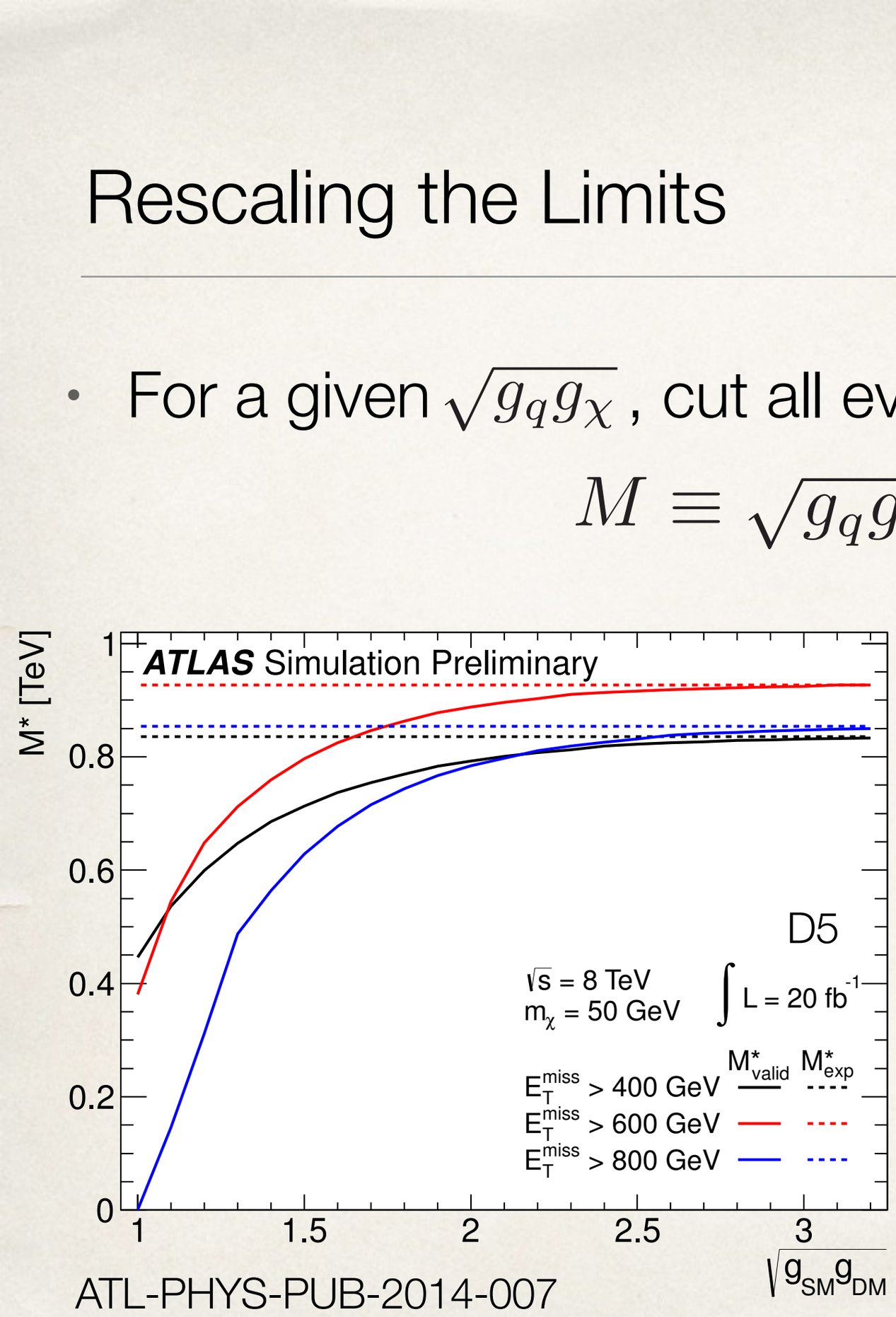
~~$M^* \gtrsim \frac{m_{\rm DM}}{2\pi}$~~

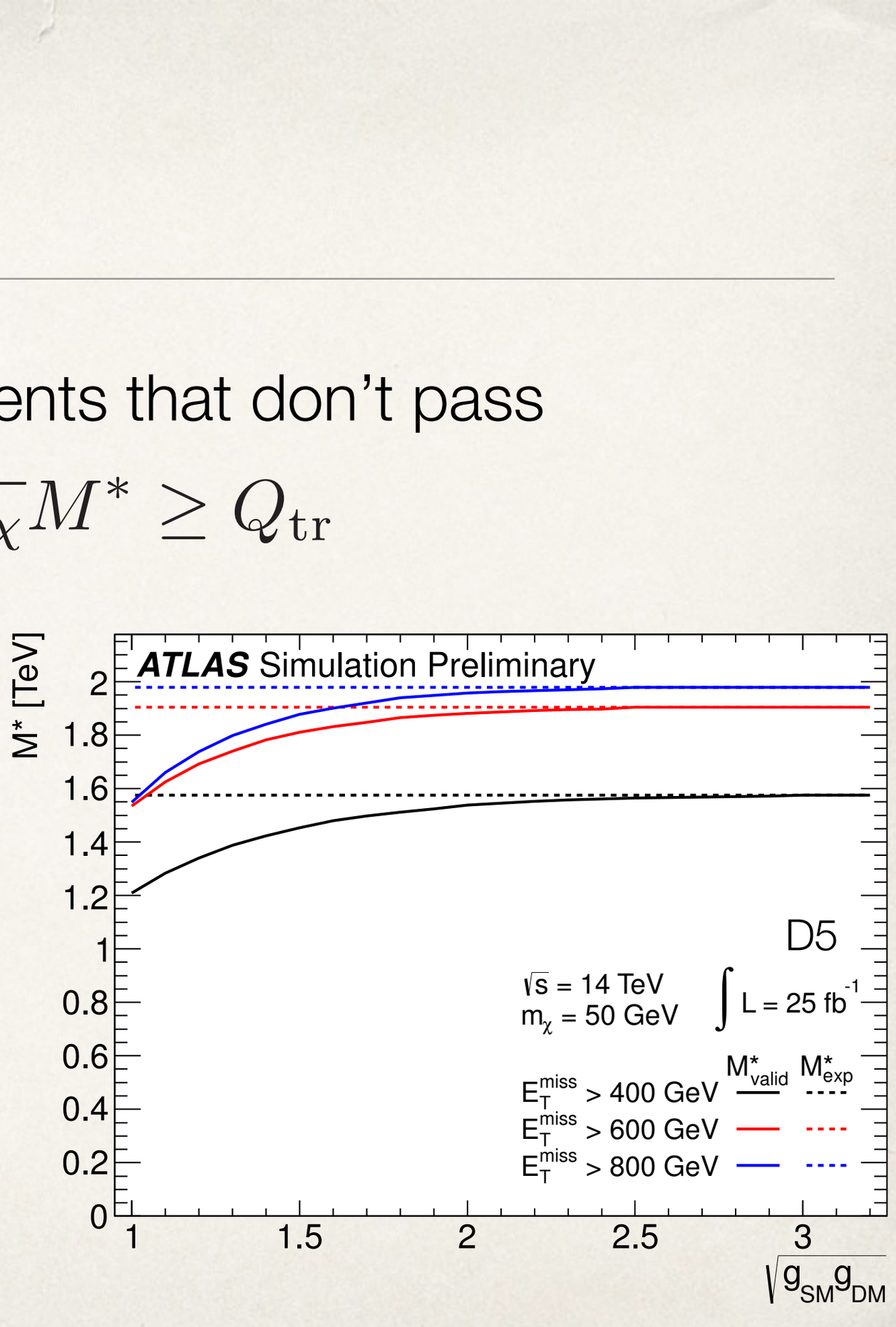
$$Q_{\rm tr} < M \equiv g M^*$$

Rescaling the Limits

- For a given $\sqrt{g_q g_\chi}$, cut all events that don't pass

$$M \equiv \sqrt{g_q g_\chi} M^* \geq Q_{\mathrm{tr}}$$





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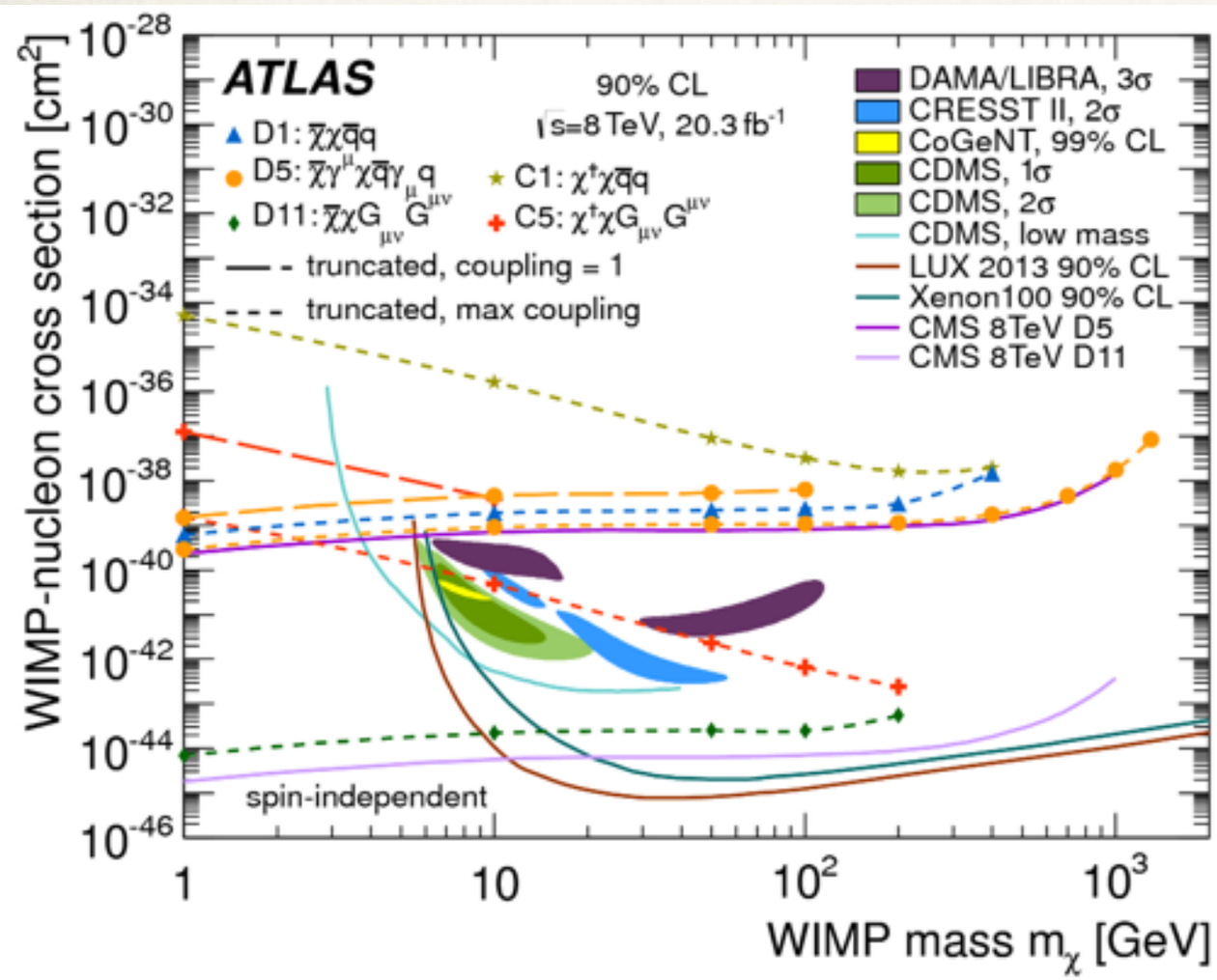
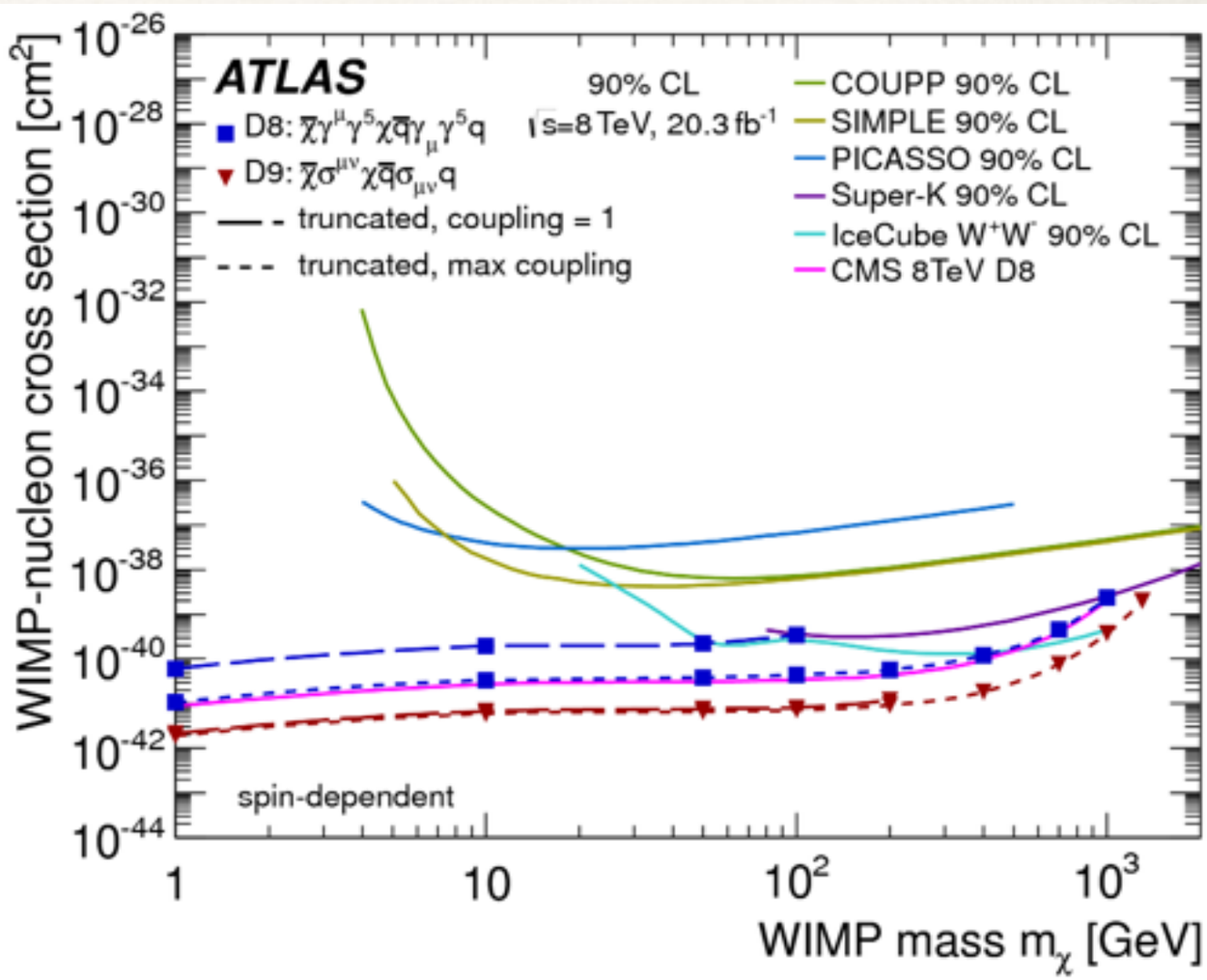
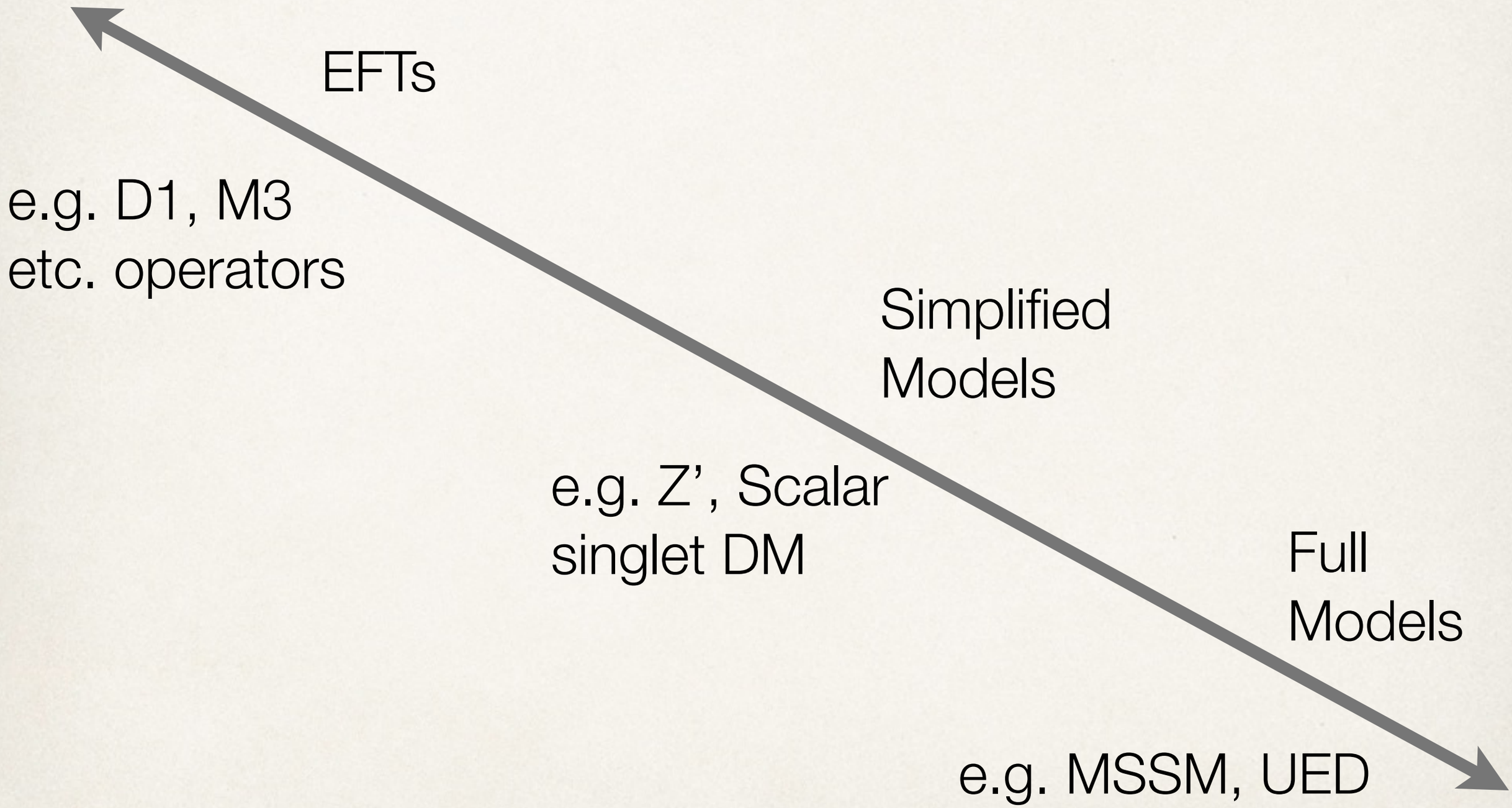




Moving on from EFTs



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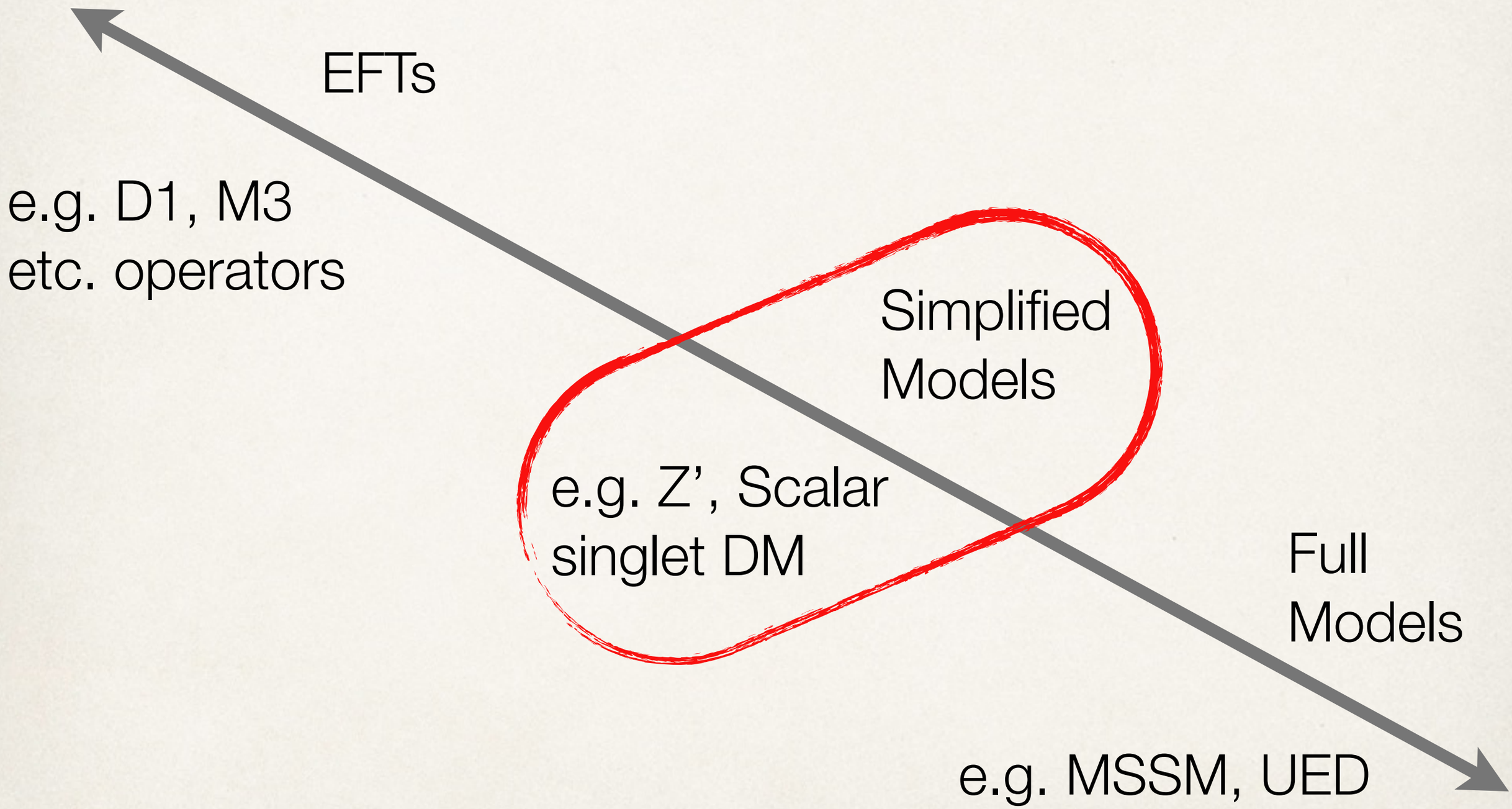
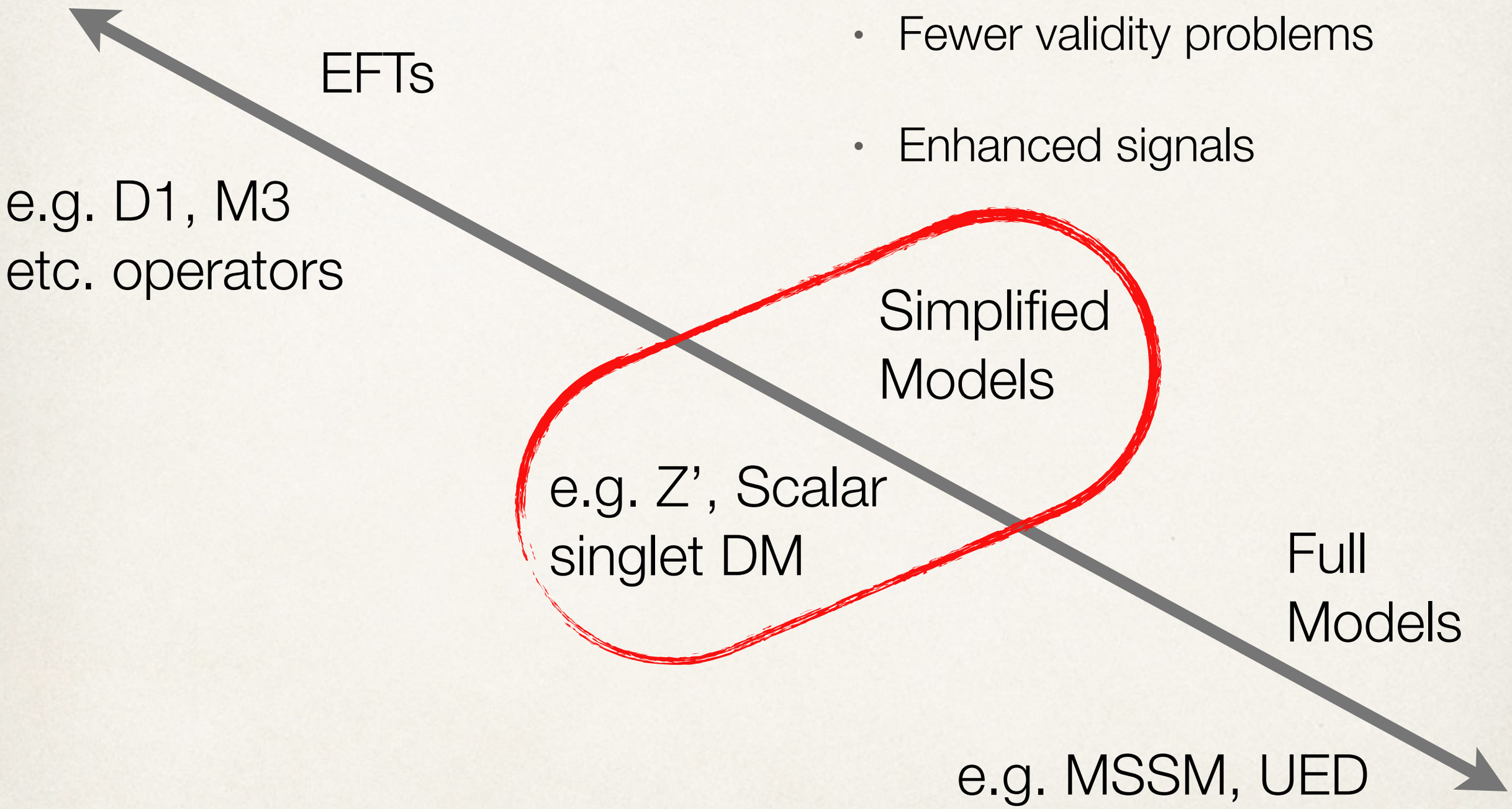


Moving on from EFTs

- Closer approximation to a physical model
- Fewer validity problems
- Enhanced signals



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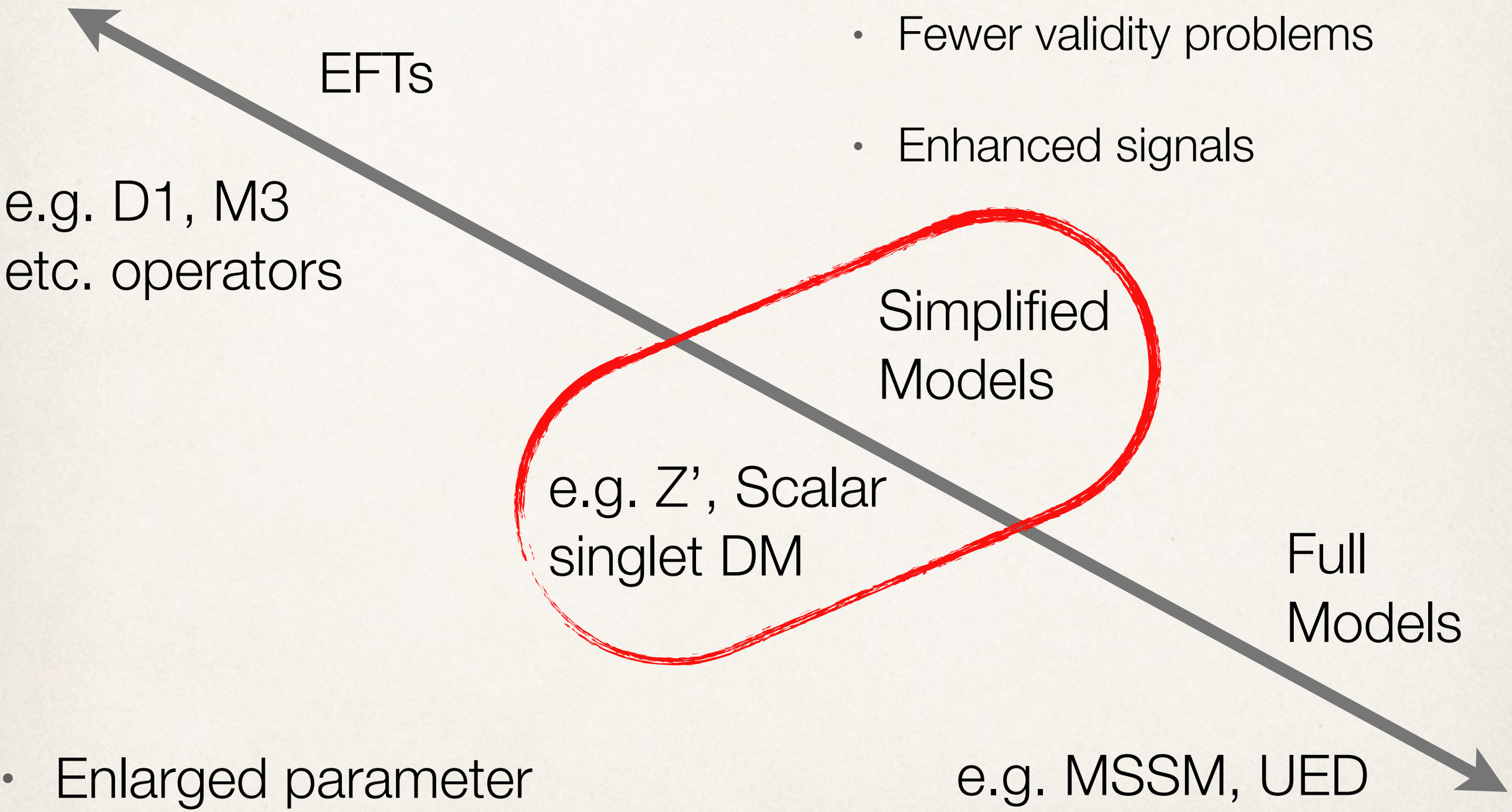
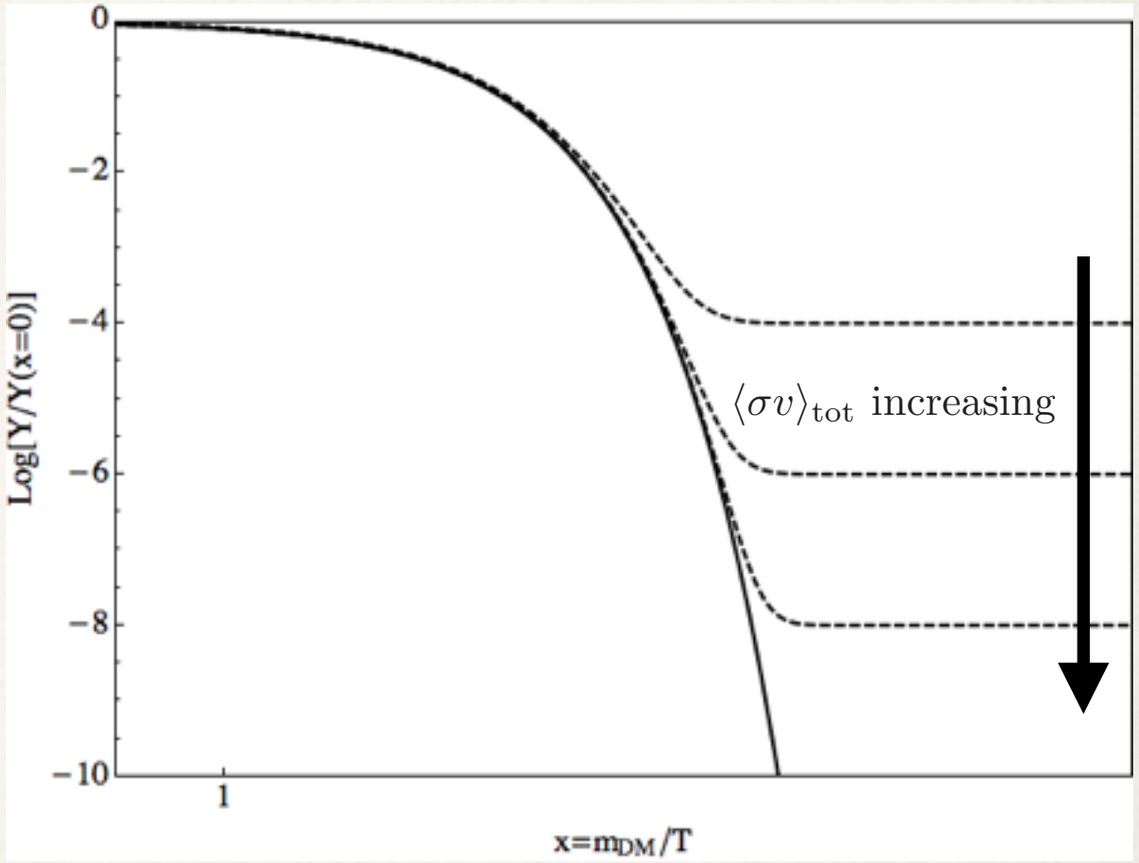


- Enlarged parameter space and list of models

Thermal Relic Dark Matter

- Dark matter in thermal equilibrium at large T
- When $m_{DM} > T$, comoving abundance drops exponentially
- As universe expands, abundance freezes out
- Annihilation rate controls abundance at freezeout



$$\langle \sigma v \rangle_{\rm tot} \simeq \frac{4.8 \times 10^{-10}\,{\rm GeV}^{-2}}{\Omega_{\rm DM} h^2}$$

Not a constraint, but a good starting point!

Relating WIMP searches to DM

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1. DM is a thermal relic, so that relic density goes like

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4. The DM candidate makes up 100% of the DM of the universe

Can be relaxed

3 & 4. Annihilation Range

Allowing DM to couple to either just one generation of quarks, or all fermions, gives a range for the annihilation rate

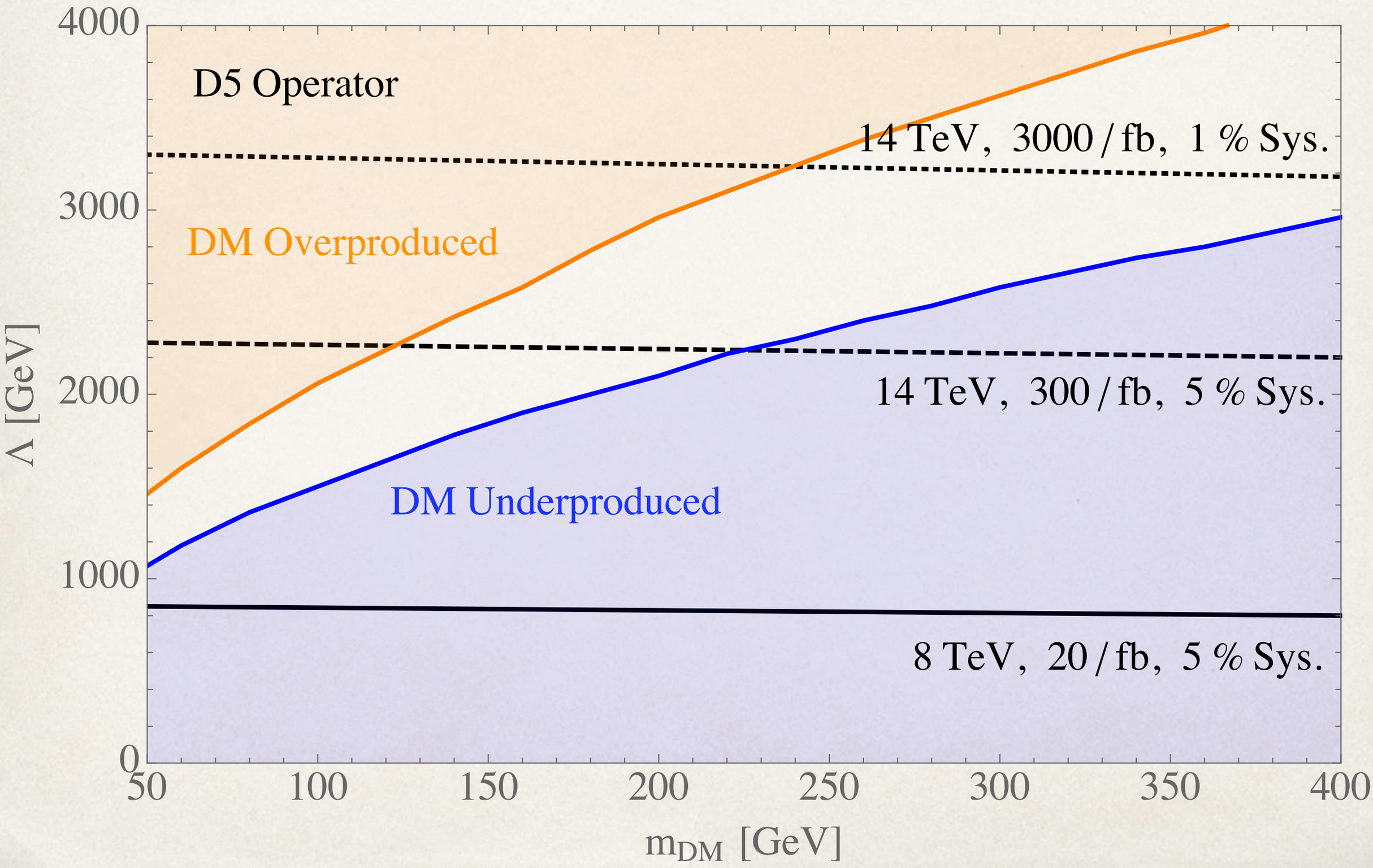
3: $$\langle \sigma v \rangle_{\rm ann} \geq \langle \sigma v \rangle_{\chi\bar{\chi}\to u\bar{u}} + \langle \sigma v \rangle_{\chi\bar{\chi}\to d\bar{d}} \equiv \langle \sigma v \rangle_{\rm min}$$

4: $$\langle \sigma v \rangle_{\rm ann} \leq \sum_{\rm quarks} \langle \sigma v \rangle_{\rm min} + \sum_{\rm leptons} \frac{1}{3} \langle \sigma v \rangle_{\rm min}$$

$$1.0 \times 10^{-9}\,{\rm GeV}^{-2} \lesssim \langle \sigma v \rangle_{\rm min} \lesssim 4.0 \times 10^{-9}\,{\rm GeV}^{-2}$$

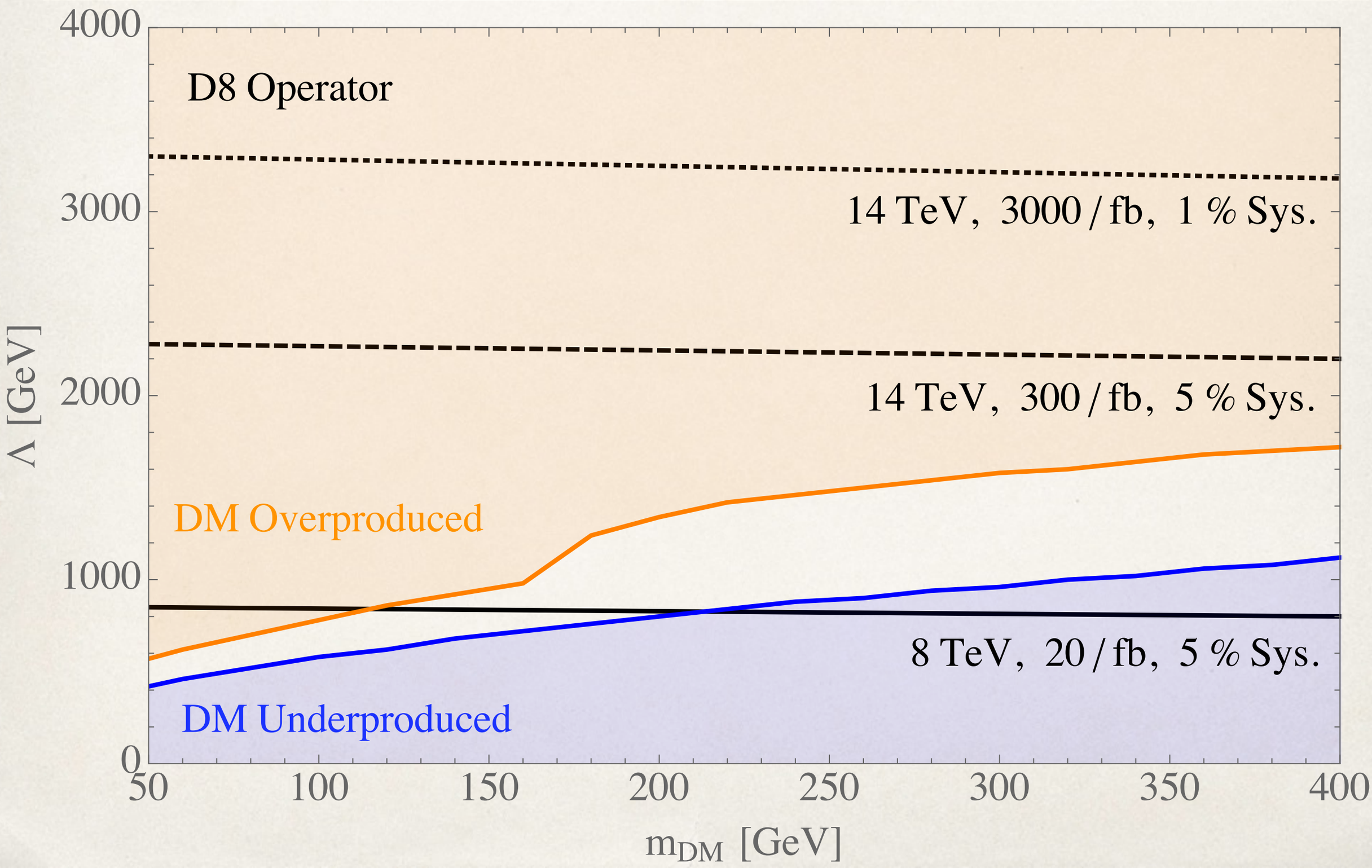
Effective operator results

$$\mathrm{D5} = \frac{1}{\Lambda^4}(\bar{\chi}\gamma^\mu\chi)(\bar{q}\gamma_\mu q)$$

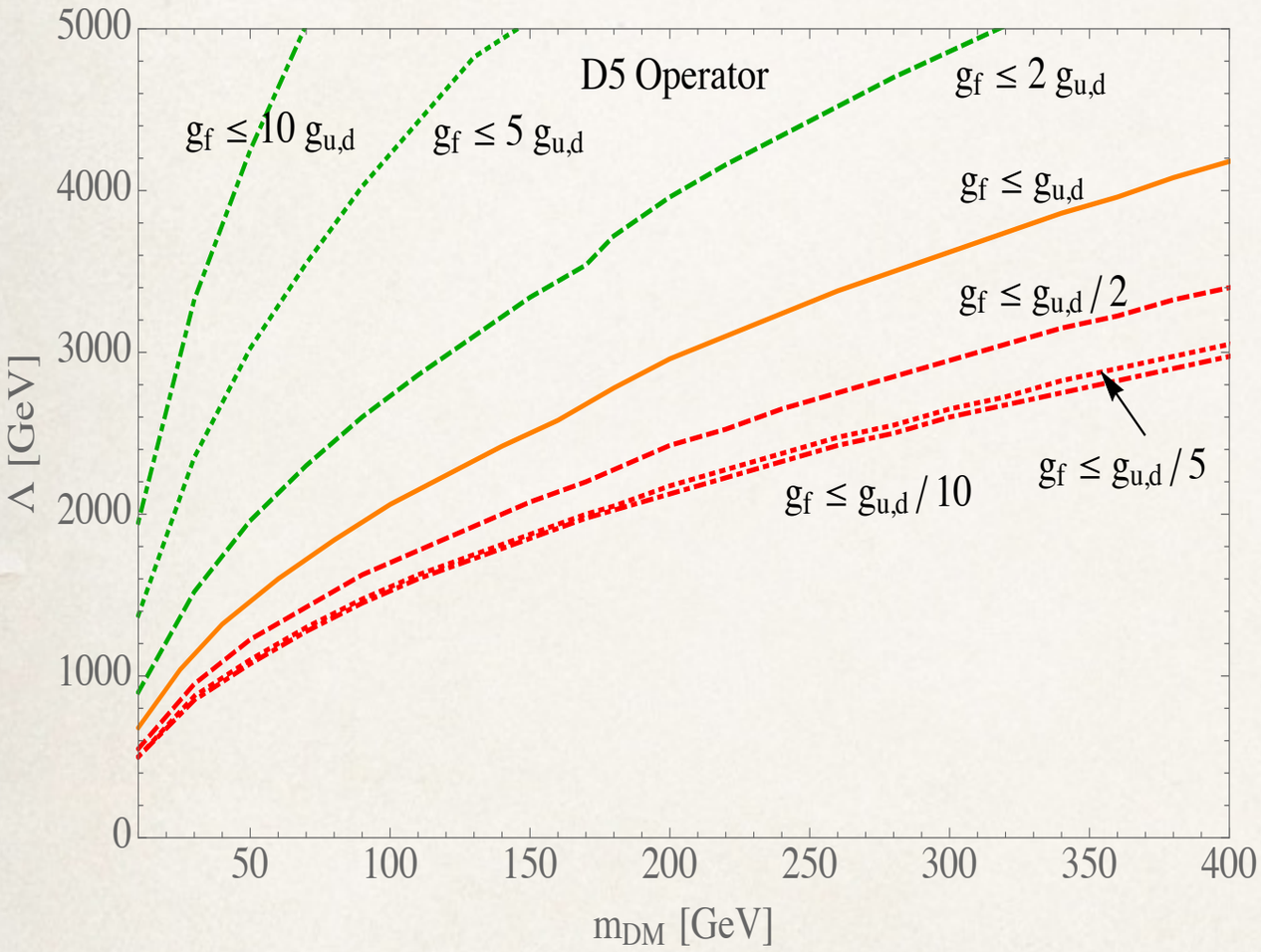


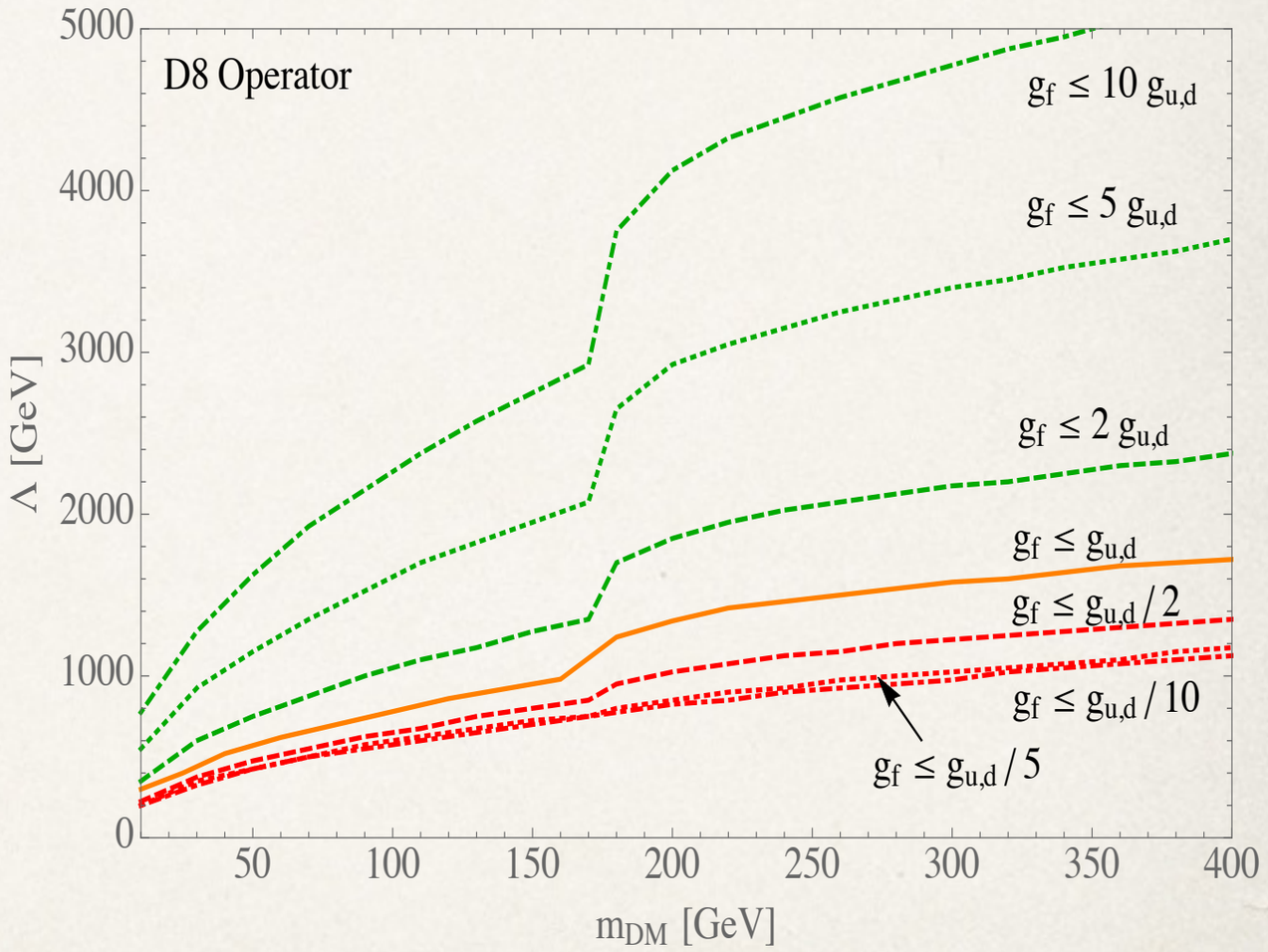
Effective operator results

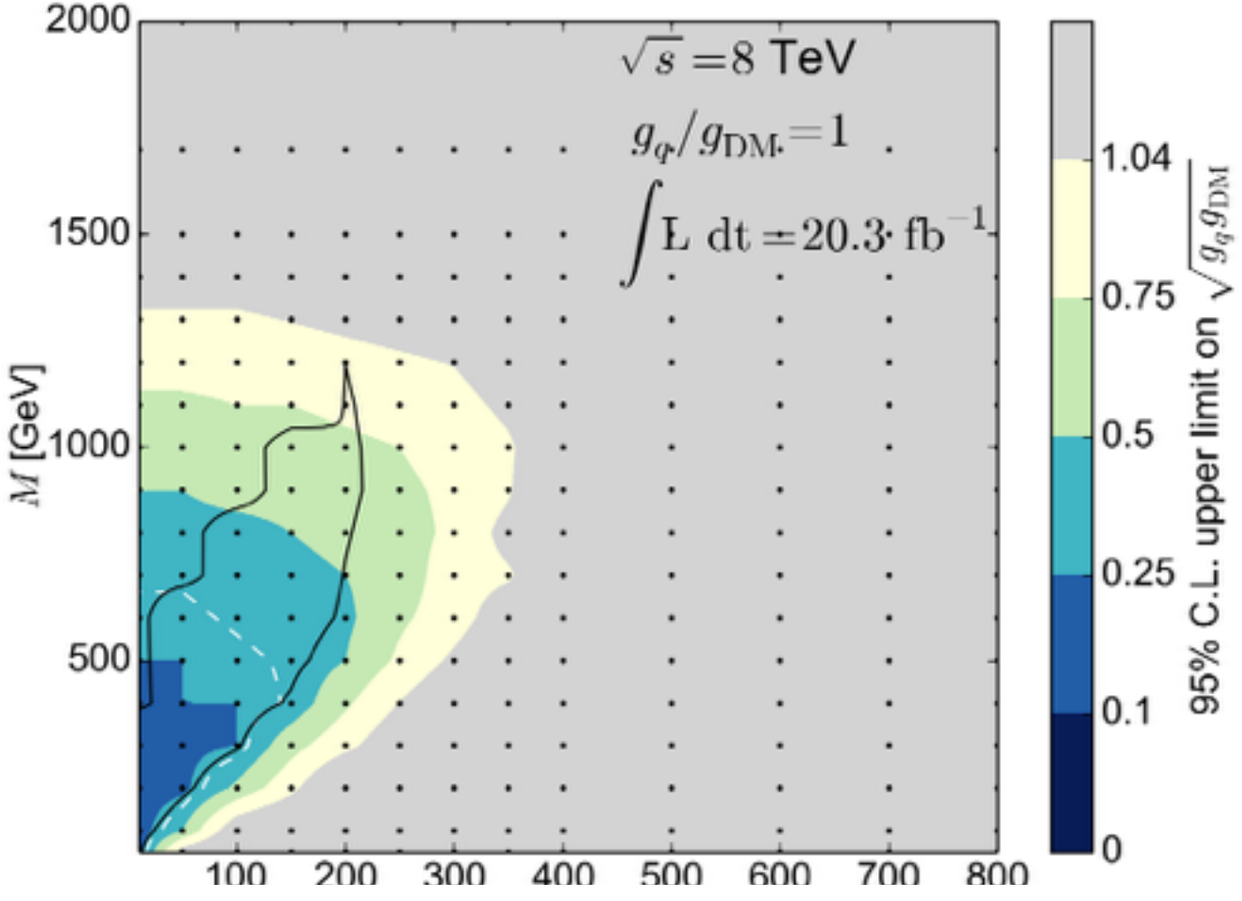
$$\mathrm{D8} = \frac{1}{\Lambda^4}(\bar{\chi}\gamma^\mu\gamma^5\chi)(\bar{q}\gamma_\mu\gamma^5 q)$$

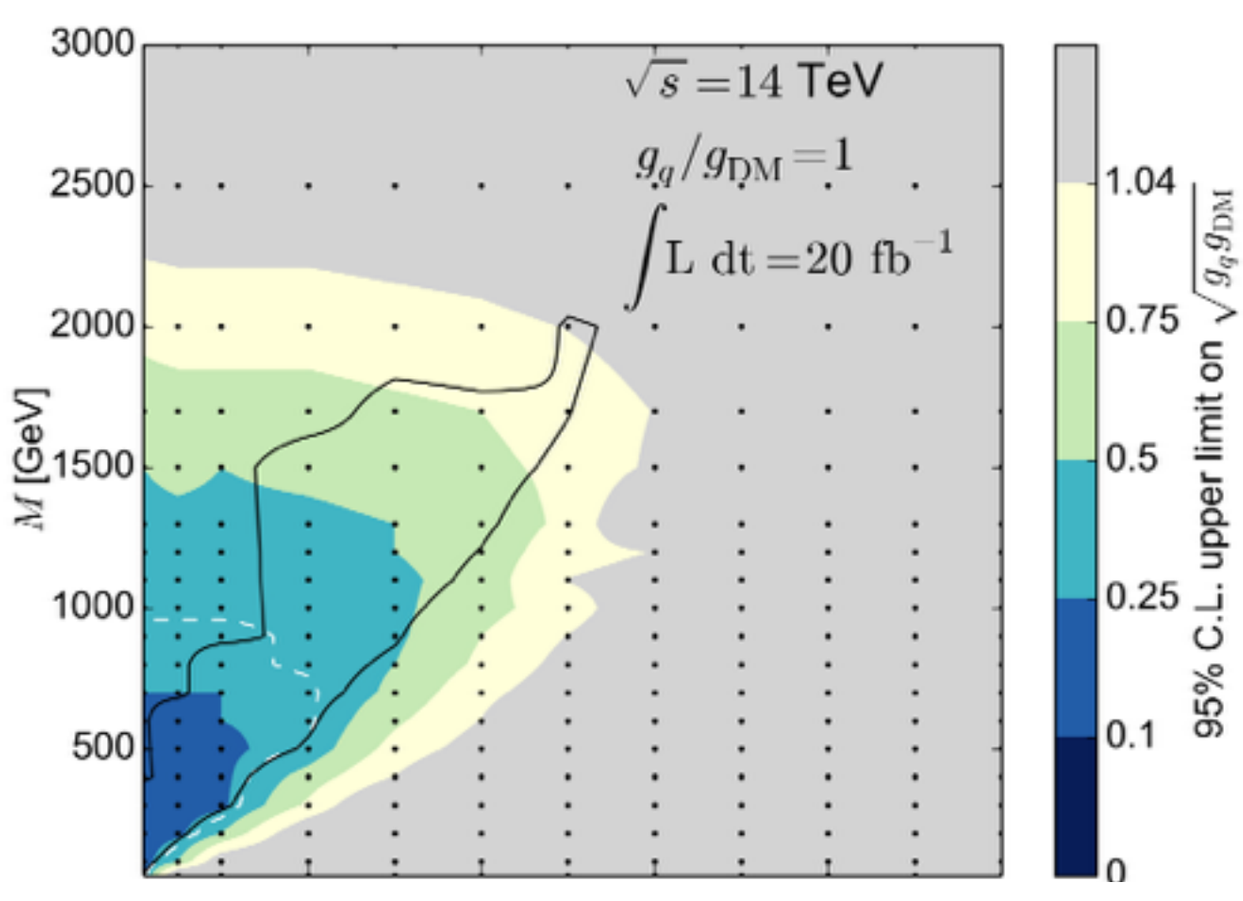


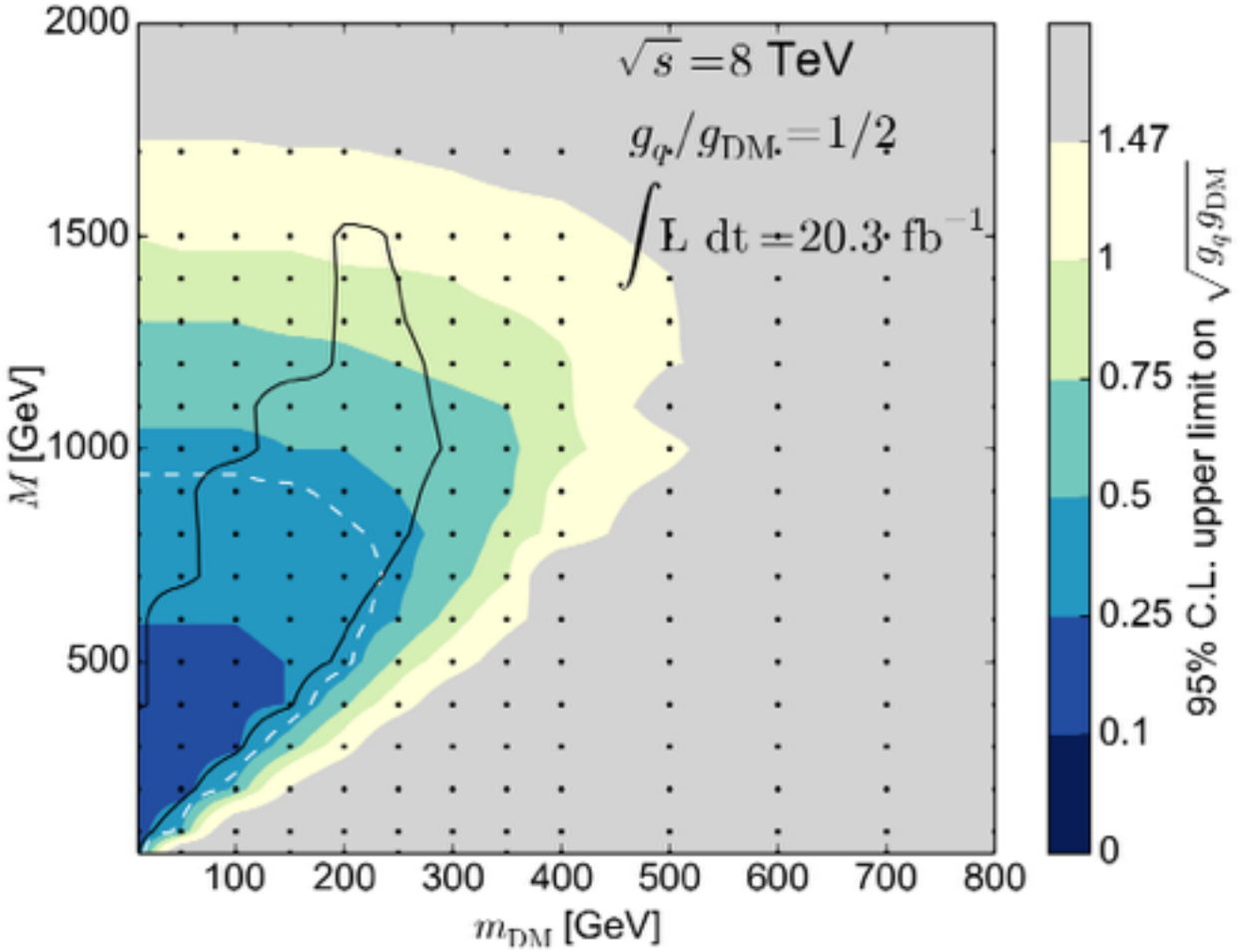
Relaxing the final assumption

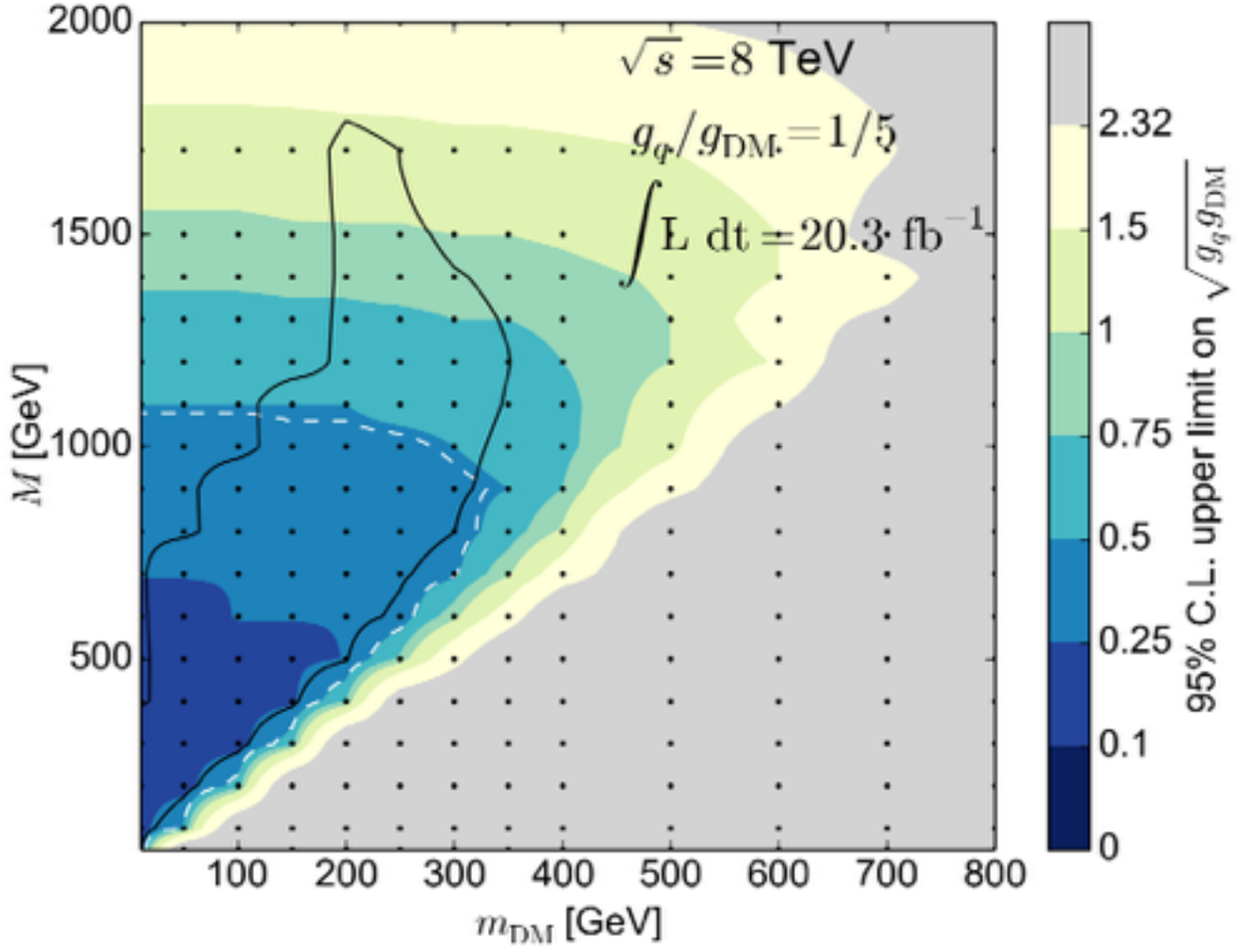





$\sqrt{s}$ =8 TeV
g_q/g_{DM}=1
$\int$L dt=20.3 fb^{-1}
M [GeV]
95% C.L. upper limit on $\sqrt{g_q g_{DM}}$
1.04
0.75
0.5
0.25
0.1
0
2000
1500
1000
500
100
200
300
400
500
600
700
800


$\sqrt{s}$ =14 TeV
g_q/g_{DM}=1
$\int$L dt=20 fb^{-1}
M [GeV]
95% C.L. upper limit on $\sqrt{g_q g_{DM}}$
1.04
0.75
0.5
0.25
0.1
0
3000
2500
2000
1500
1000
500


$\sqrt{s}$ =8 TeV
g_q/g_{DM}=1/2
$\int$L dt=20.3 fb^{-1}
M [GeV]
m_{DM} [GeV]
95% C.L. upper limit on $\sqrt{g_q g_{DM}}$
1.47
1
0.75
0.5
0.25
0.1
0
2000
1500
1000
500
100
200
300
400
500
600
700
800


$\sqrt{s}$ =8 TeV
g_q/g_{DM}=1/5
$\int$L dt=20.3 fb^{-1}
M [GeV]
m_{DM} [GeV]
95% C.L. upper limit on $\sqrt{g_q g_{DM}}$
2.32
1.5
1
0.75
0.5
0.25
0.1
0
2000
1500
1000
500
100
200
300
400
500
600
700
800

Conclusion

- At LHC energies, EFTs are a powerful tool, but range of validity is limited to large couplings

- EFTs remain useful, but only if accompanied by searches for more complex models

- Dark Matter considerations can help focus the search for simplified WIMP models