On the Validity of Effective Field Theories for Dark Matter Searches

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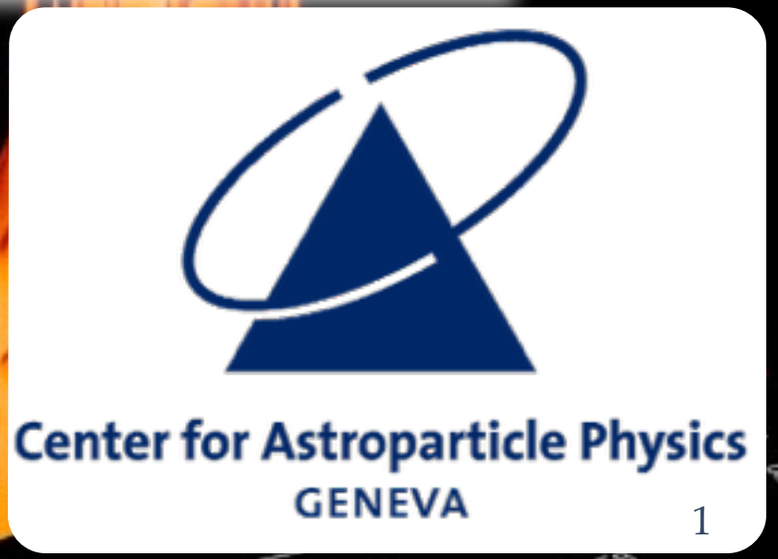
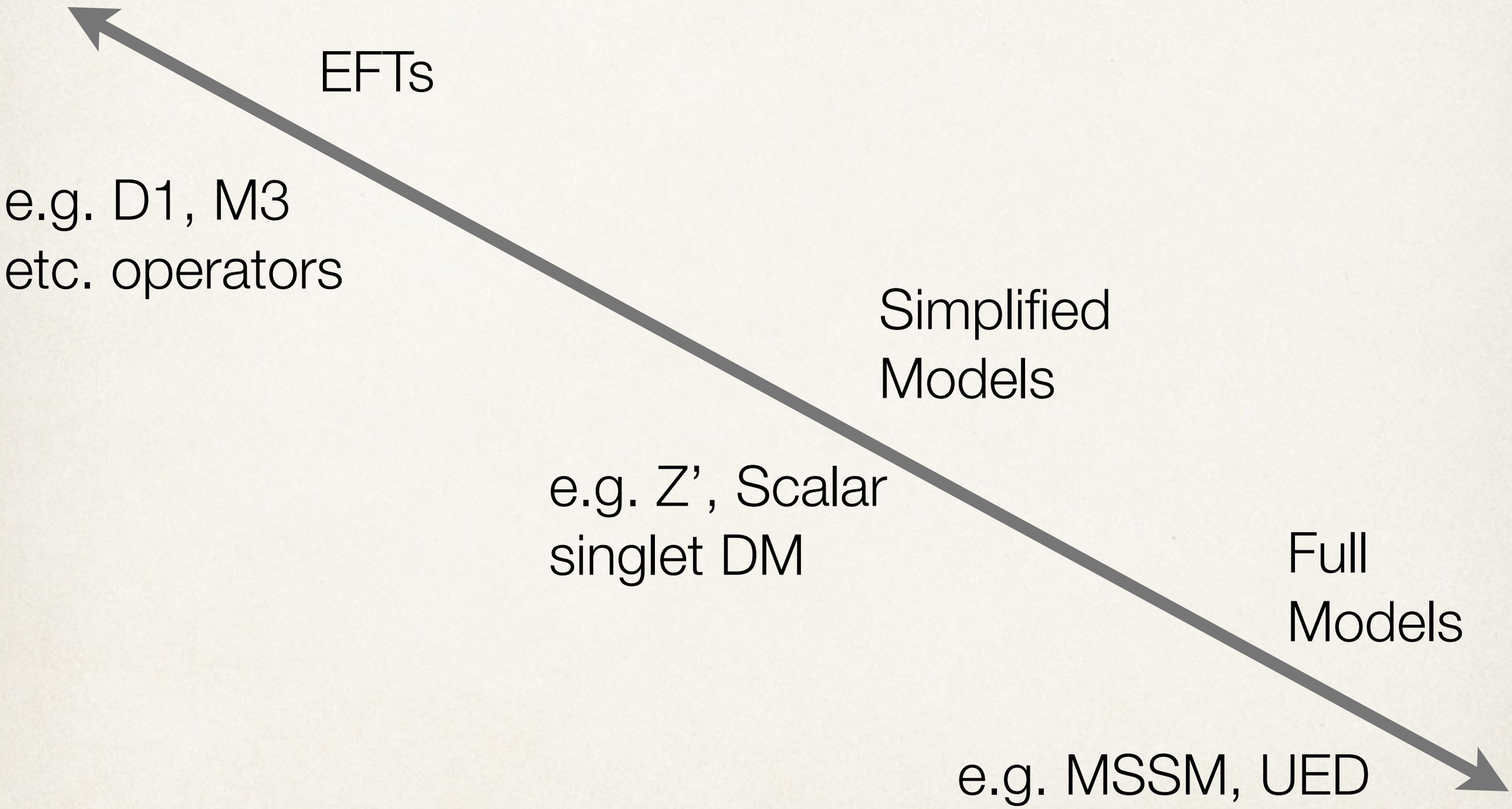
1405.3101 Busoni, De Simone, TDJ, Morgante, Riotto
1402.1275 Busoni, De Simone, Gramling, Morgante, Riotto
1307.2253 Busoni, De Simone, Morgante, Riotto

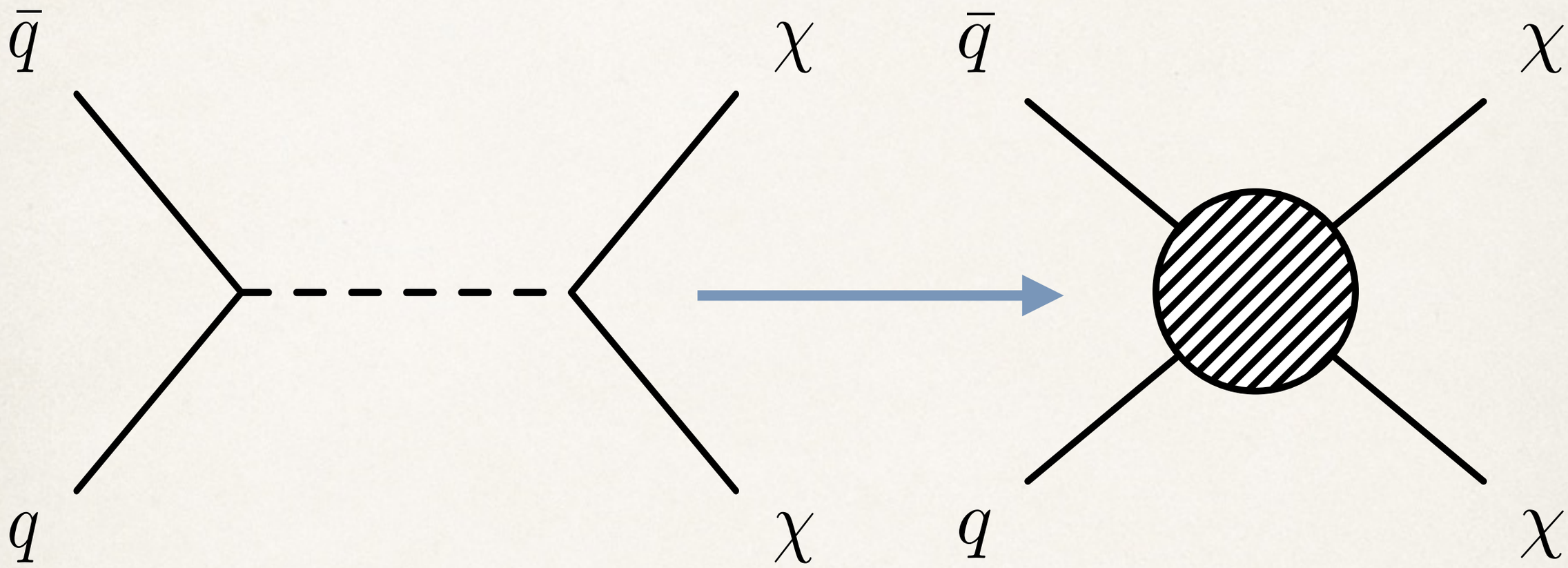
2014-03-12
Dark Matter Forum, CERN



What to constrain?



Effective Field Theories



$$\frac{g_a g_b}{Q_{\rm tr}^2 - M^2} = -\frac{g_a g_b}{M^2}\left(1 + \frac{Q_{\rm tr}^2}{M^2} + \mathcal{O}\left(\frac{Q_{\rm tr}^4}{M^4}\right)\right) \simeq -\frac{1}{\Lambda^2}$$

$$\mathrm{D1} = (\bar{\chi}\chi)(\bar{q}q) \qquad \mathrm{M1} = (\chi\chi)(\bar{q}q)$$

$$\mathrm{D5} = (\bar{\chi}\gamma^\mu\chi)(\bar{q}\gamma_\mu q) \qquad \mathrm{C1} = (\chi^\dagger\chi)(\bar{q}q)$$

Complementarity

$q\bar{q} \to \chi\chi$

$N\chi \to N\chi$

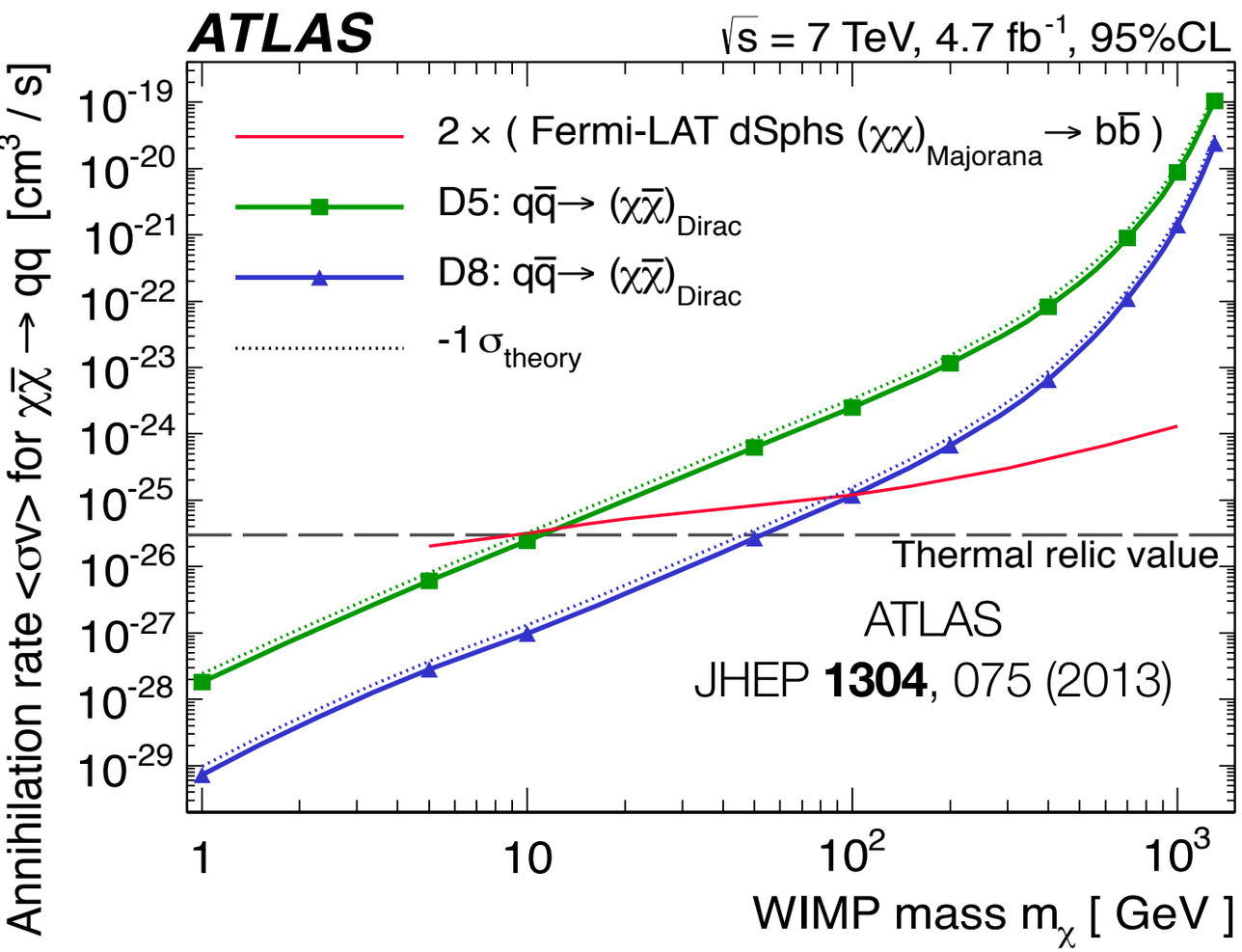
$\chi\chi \to q\bar{q}$

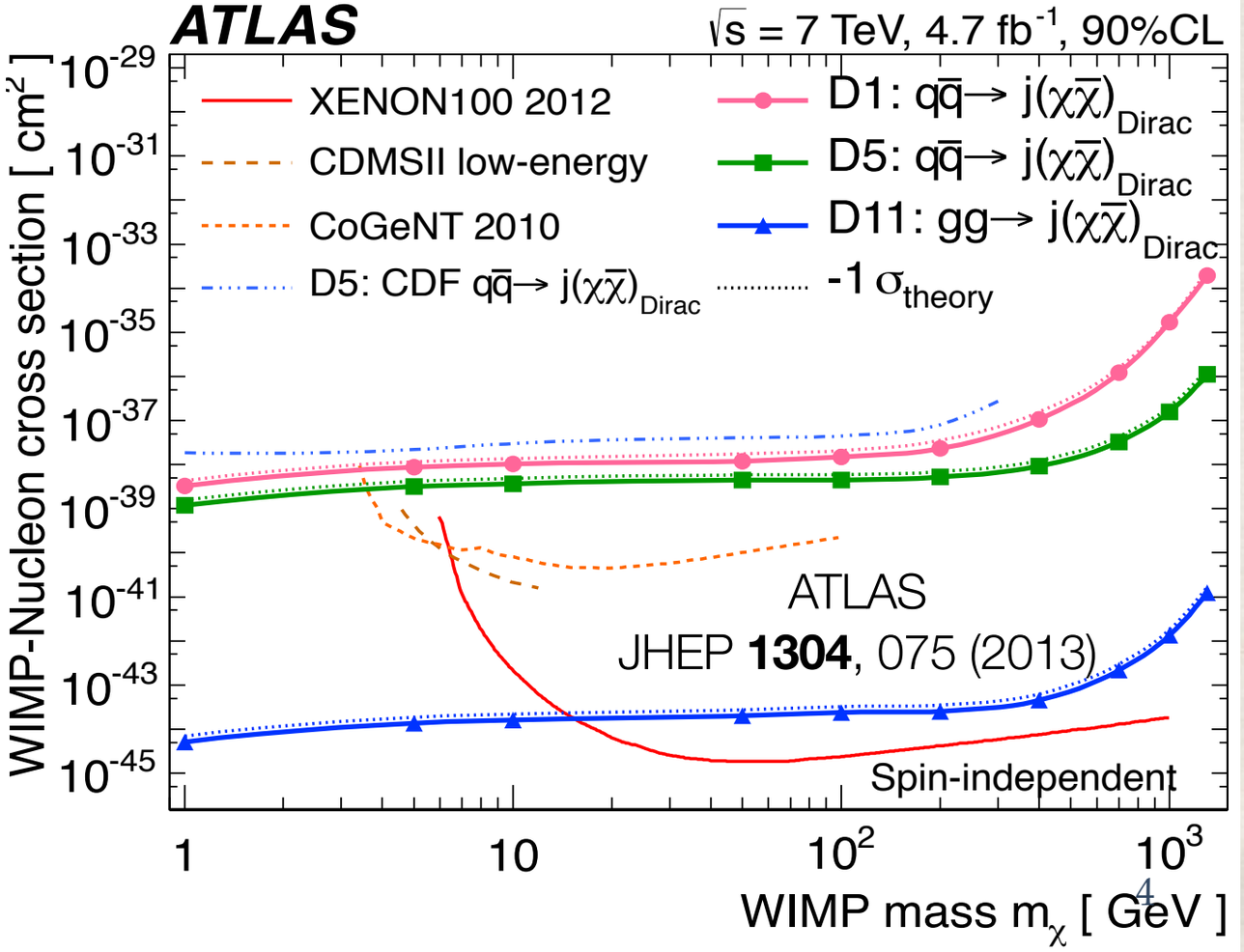
Λ

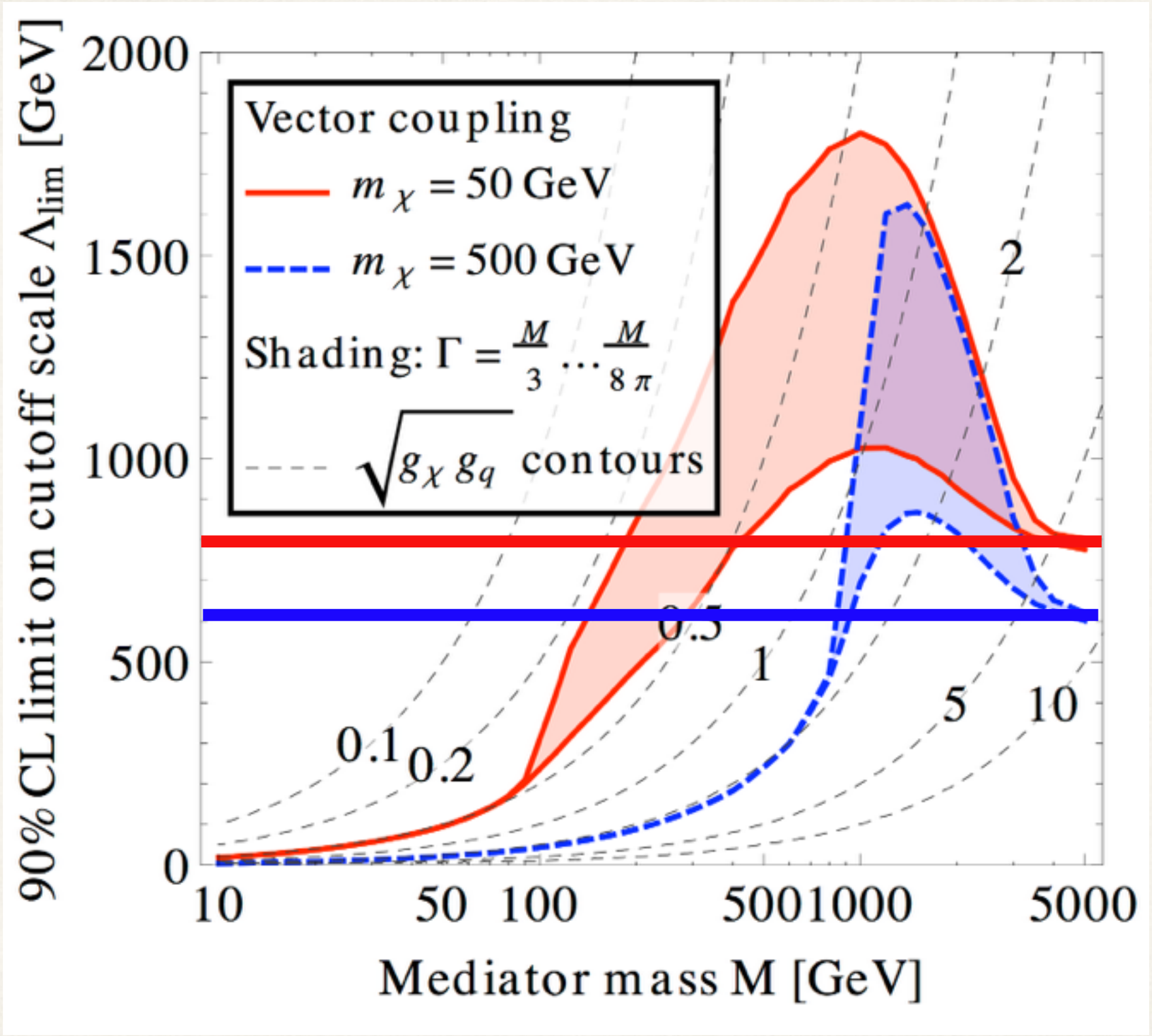
$\sigma_{q\bar{q}\to\chi\chi}$

$\sigma_{N\chi\to N\chi}$

$\sigma_{\chi\chi\to q\bar{q}}$







Fox, Harnik, Kopp, Tsai, arXiv:1109.4398

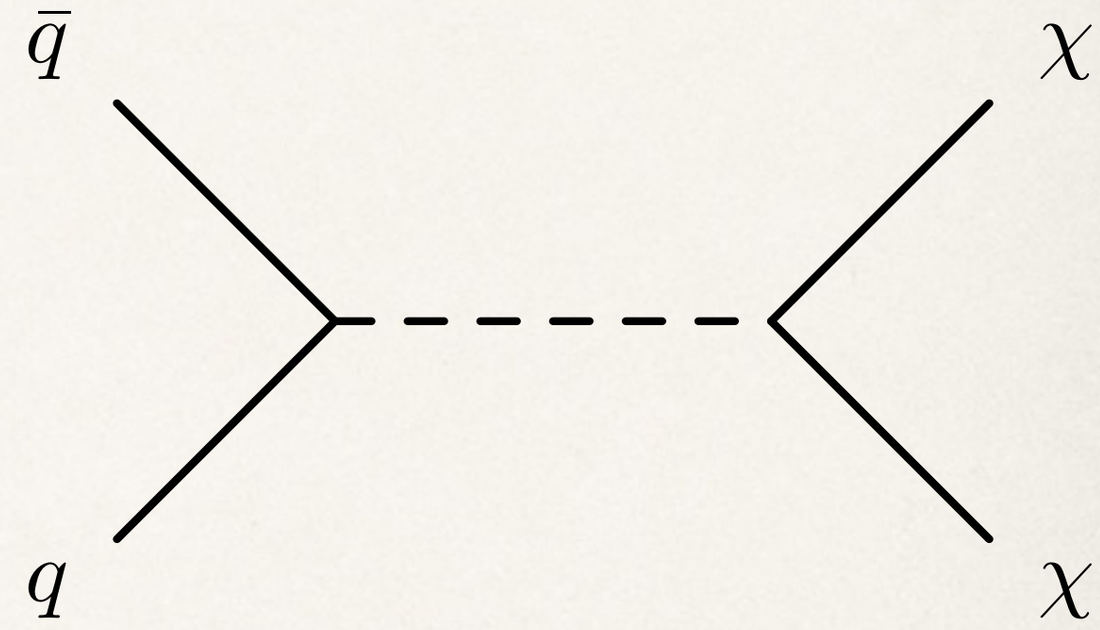
Fundamental Limit to Validity

- In s-channel:

1) $Q_{\rm tr} > 2m_{\rm DM}$

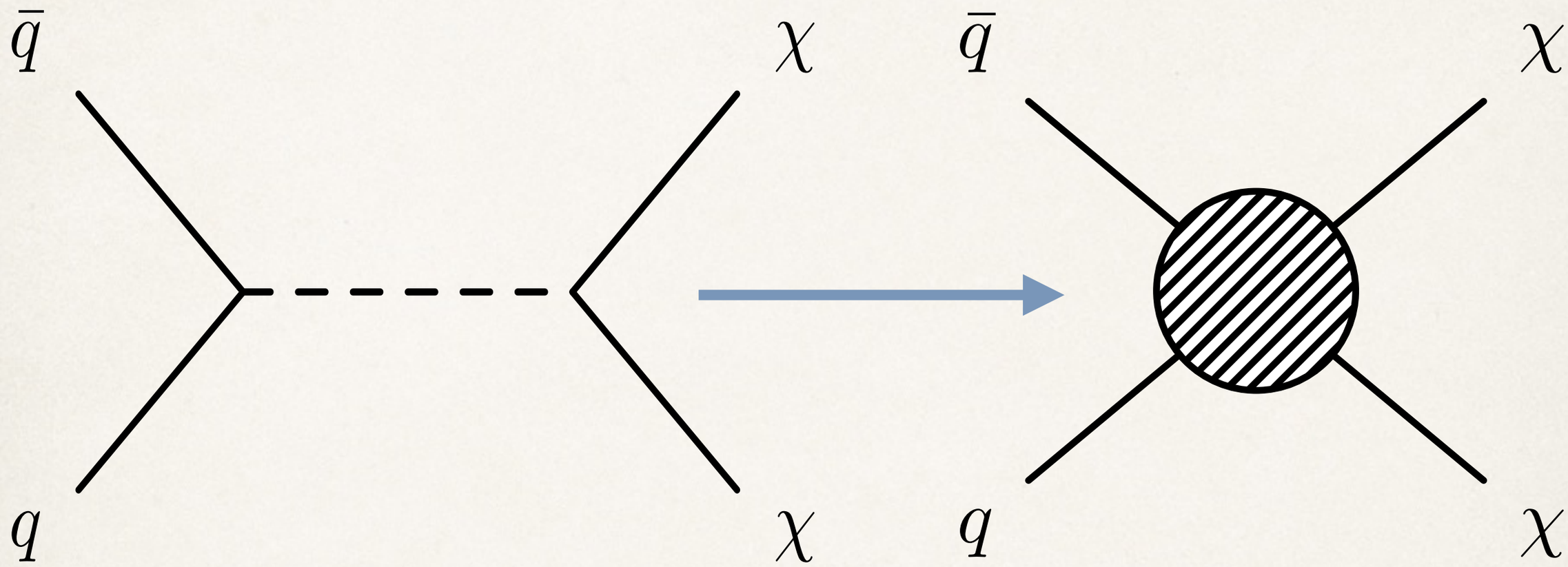
$\rightarrow M > 2m_{\rm DM}$

2) $\Lambda = \dfrac{M}{\sqrt{g_a g_b}} \geq \dfrac{M}{4\pi}$



$$\Lambda \gtrsim \frac{m_{\rm DM}}{2\pi}$$

Measuring the Validity



$$\frac{g_a g_b}{Q_{\rm tr}^2 - M^2} = -\frac{g_a g_b}{M^2}\left(1 + \frac{Q_{\rm tr}^2}{M^2} + \mathcal{O}\left(\frac{Q_{\rm tr}^4}{M^4}\right)\right) \simeq -\frac{1}{\Lambda^2}$$

~~$\Lambda \gtrsim \frac{m_{\rm DM}}{2\pi}$~~

$$Q_{\rm tr} < M$$

Measuring the Validity

- If we want to measure the validity as a fn of $\mathbf{\Lambda}$, the $Q_{\rm tr} < M$ condition means choosing a model-dependent relationship between $\mathbf{M}$ and $\mathbf{\Lambda}$: e.g.

$$\frac{M^2}{g_a g_b} \equiv \Lambda^2$$

- Best case scenario:

$$\sqrt{g_a g_b} \simeq 4\pi, \;\; Q_{\rm tr} \lesssim 4\pi\Lambda$$

- Starting choice for coupling:

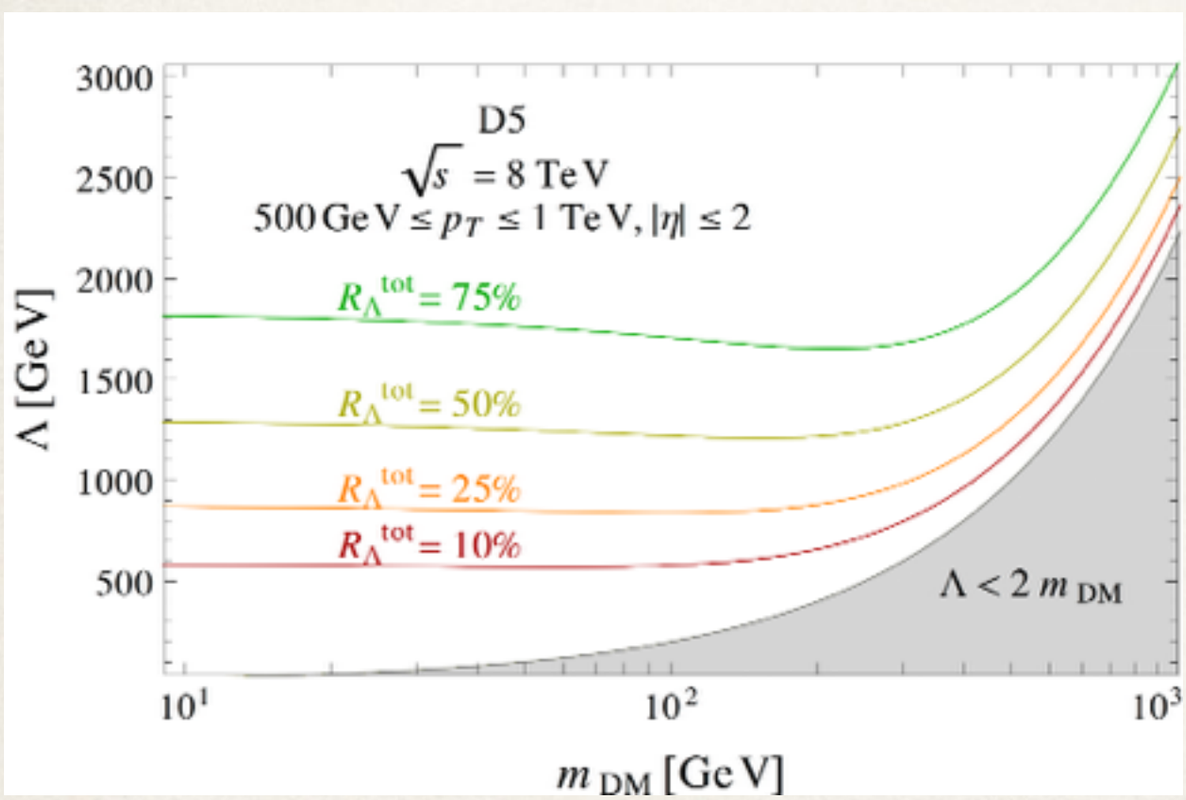
$$g_a g_b \simeq 1, \boxed{Q_{\rm tr} \lesssim \Lambda}$$

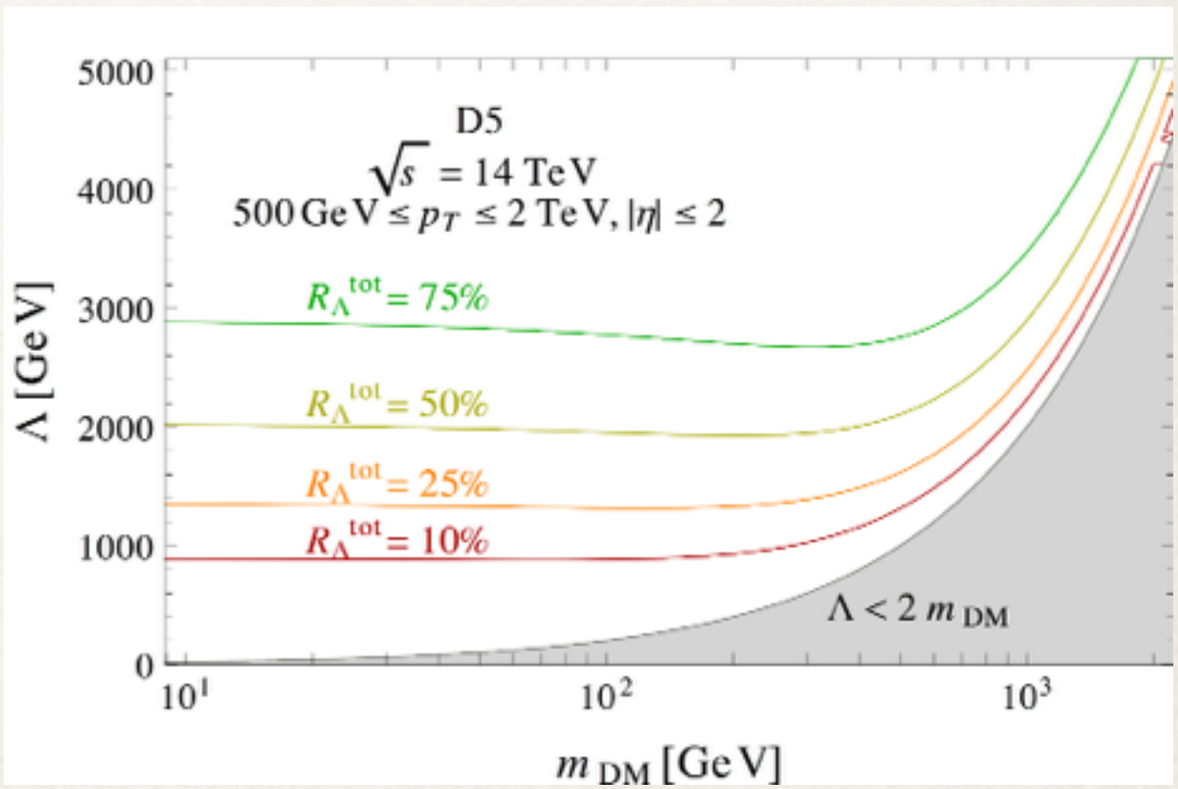
Measuring the Validity

Calculate or measure the fraction of events that pass the condition $\mathrm{Q_{tr}} < \Lambda$, for a given choice of Λ and $\mathrm{m_{DM}}$

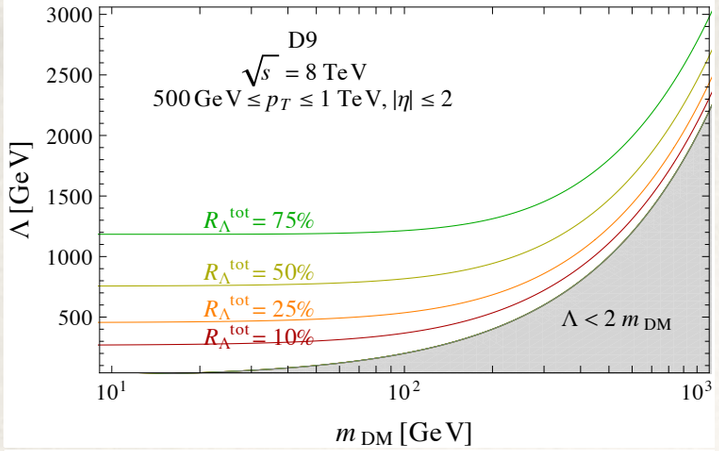
$$R_\Lambda^{\mathrm{tot}} = \frac{\sigma_{\mathrm{eff}}\big|_{\Lambda > Q_{\mathrm{tr}}}}{\sigma_{\mathrm{eff}}}$$

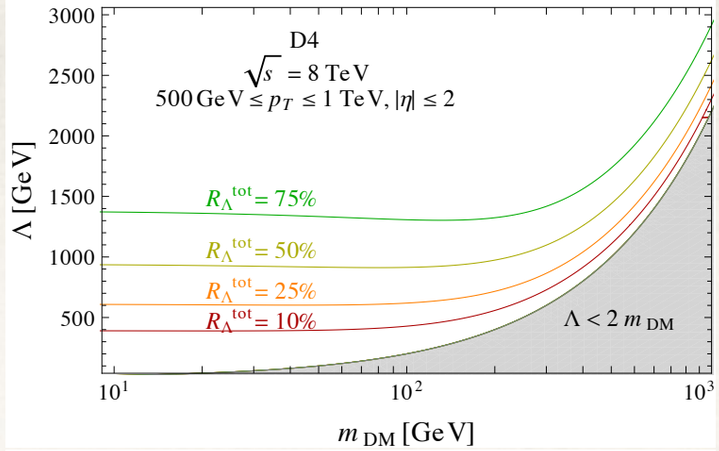
$$\mathrm{D5} = (\bar{\chi}\gamma^\mu\chi)(\bar{q}\gamma_\mu q) \qquad q\bar{q} \to \chi\chi + \mathrm{jet}$$

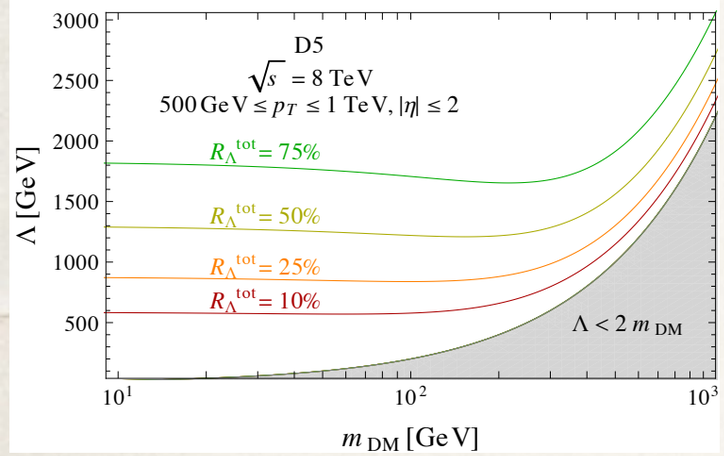


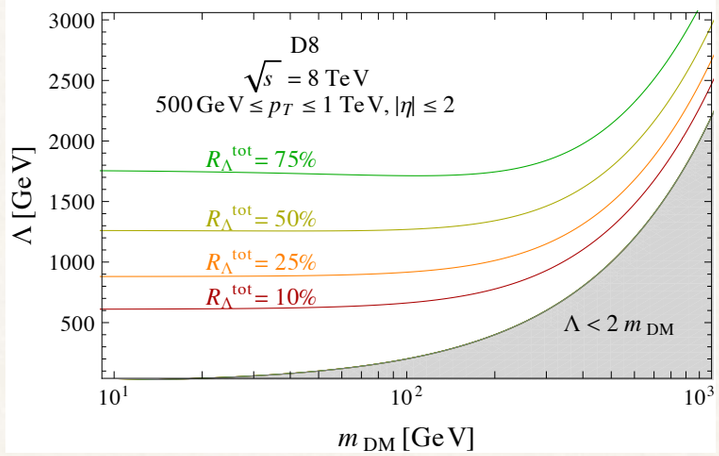


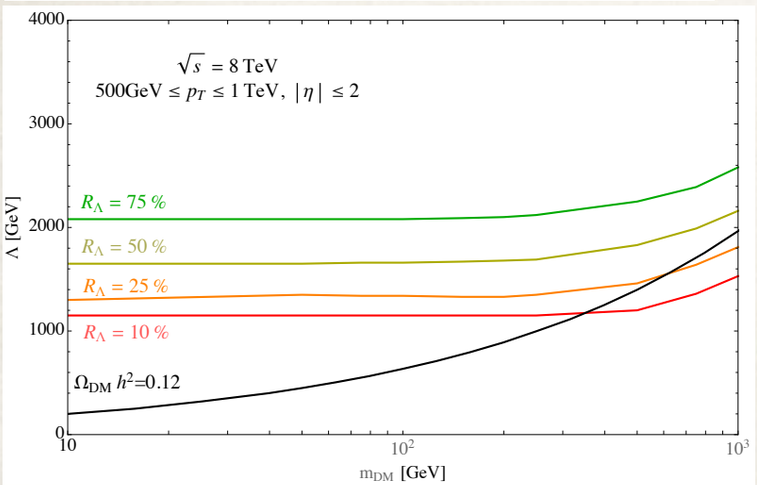
G. Busoni, A. De Simone, J. Gramling, E. Morgante, A. Riotto
arXiv:1402.1275, JCAP 1406 (2014) 060









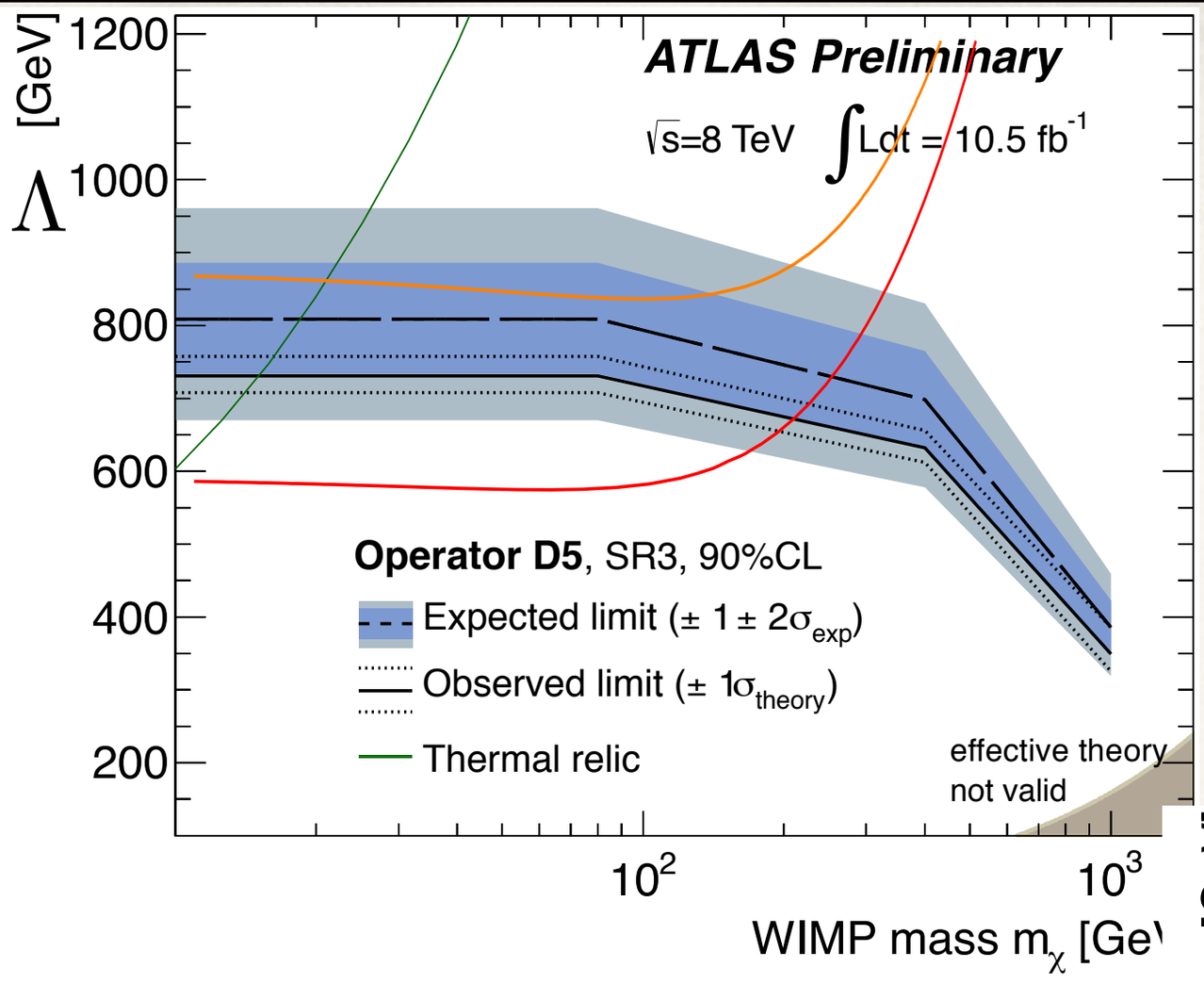


Extension to other operators

- Calculated for a representative set of effective operators
- Qualitatively similar to first operator

G. Busoni, A. De Simone, J. Gramling, E. Morgante, A. Riotto, arXiv:1402.1275 JCAP 1406 (2014) 060

G. Busoni, A. De Simone, T. Jacques, E. Morgante, A. Riotto, arXiv:1405.3101 JCAP 1409 (2014) 022

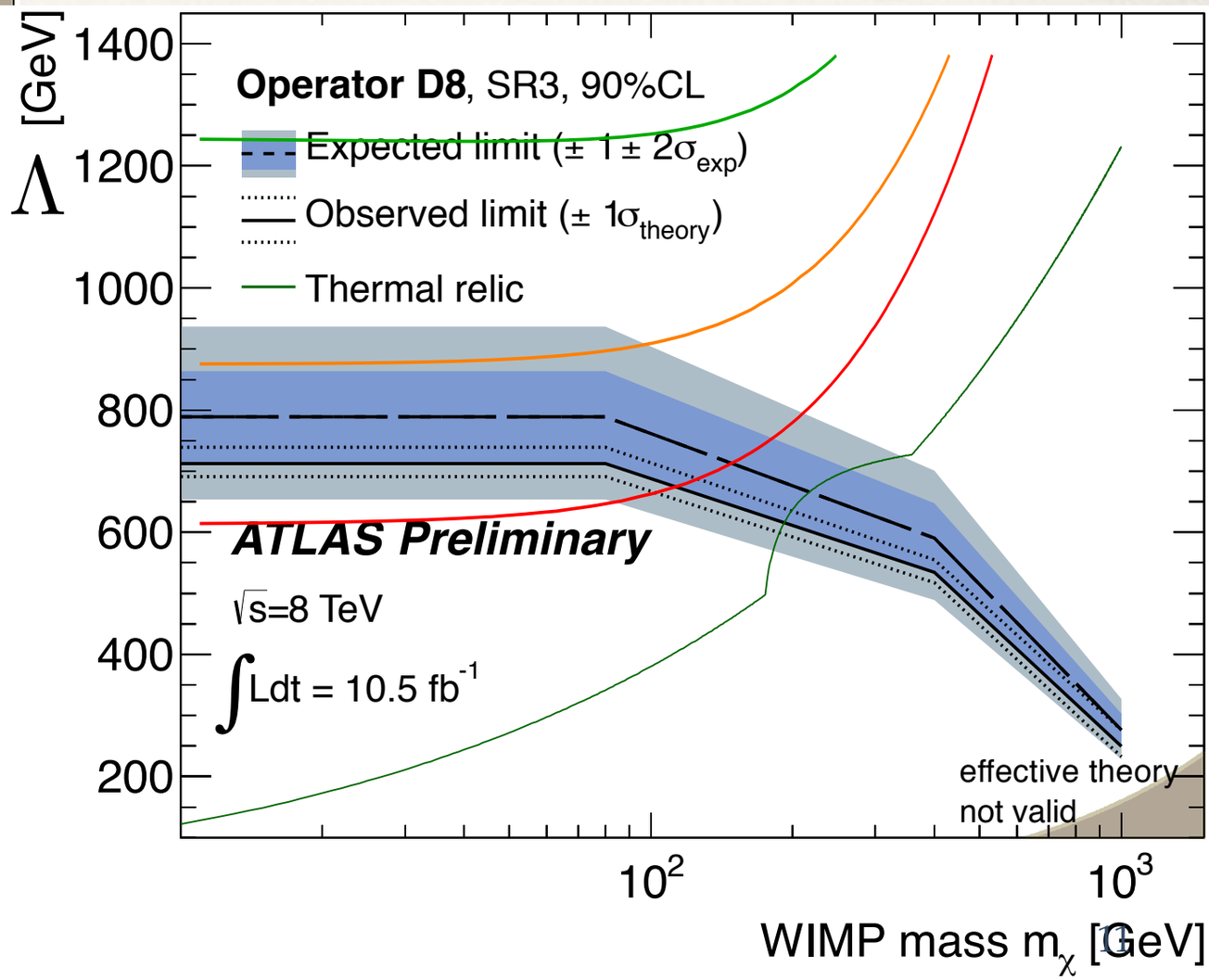


Measuring the Validity

$R_\Lambda = 10\%$	
$R_\Lambda = 25\%$	
$R_\Lambda = 50\%$	

$$R_\Lambda^{\text{tot}} = \frac{\sigma_{\text{eff}}\big|_{\Lambda > Q_{\text{tr}}}}{\sigma_{\text{eff}}}$$

ATLAS-CONF-2012-147



Summary

- Effective Field Theories are a powerful tool allowing comparisons between different classes of experiment.

- At LHC energies, the approximation begins to break down, and remains fully valid only for very large couplings and values of Λ.

- More on the implementation of the truncation, and dependence on the UV completion & couplings from Steven next.