APP14
Amsterdam - 26 June 2014

Beyond EFT for DM@LHC

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Based on:
DS, Giudice, Strumia
arXiv:1402.6287, JHEP 06(2014)081

Outline

. EFT approach (see T. Jacques' talk)

- limited validity
- not entirely model-independent, but still rather general

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"you can't score if you don't have the ball"

[J. Cruyff]

Outline

. EFT approach (see T. Jacques' talk)

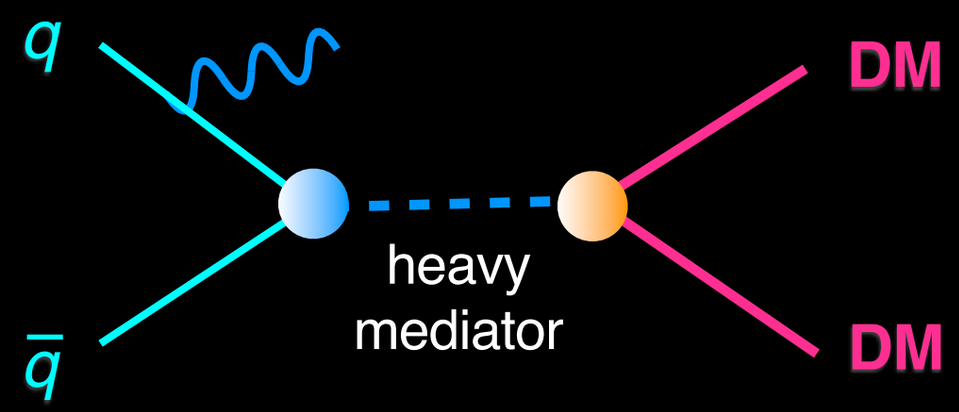
- limited validity
- not entirely model-independent, but still rather general

. How to go beyond that (but keeping generality), in view of LHC Run II?

- Simplified Models
- Selected benchmarks cases ⟵

Simplified Models

correspondence
eff ops ⟷ simple toy models



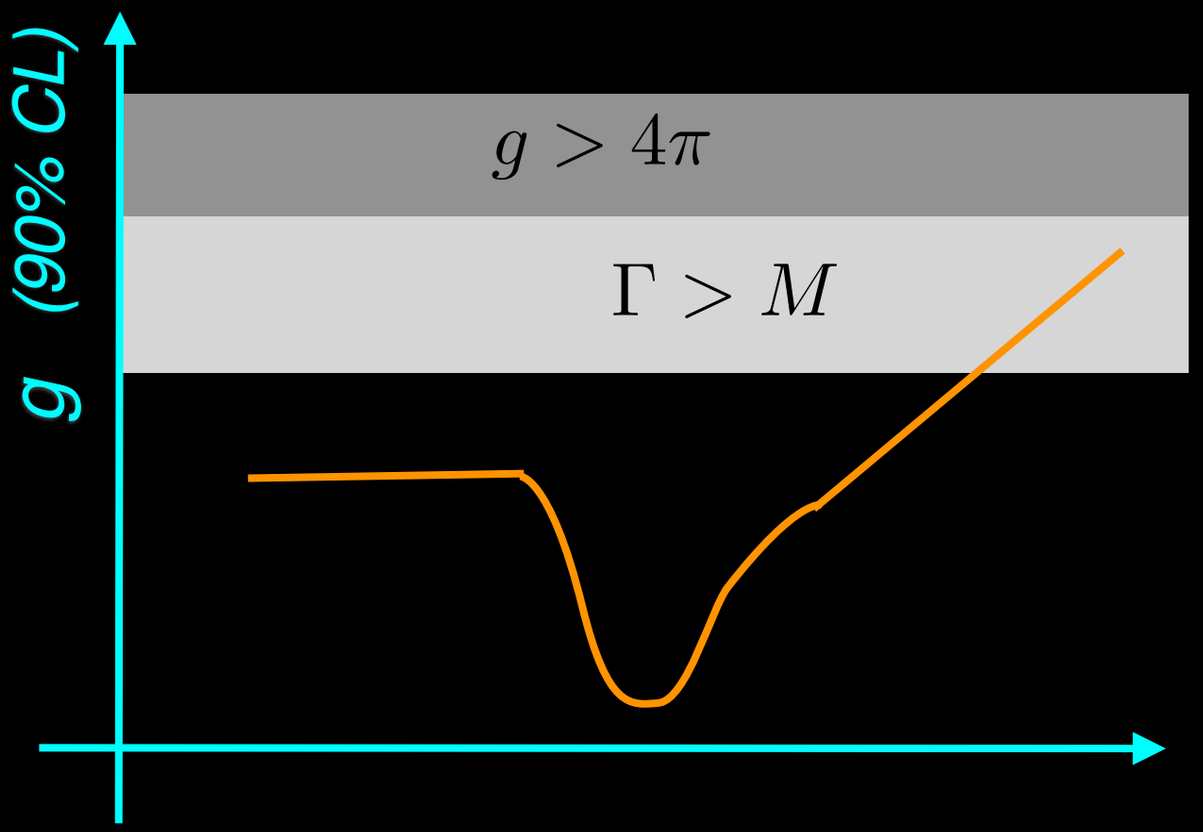
✘ 1 or 2 more parameters (g's)
✘ direct detection limits must be re-expressed

✓ exploit other searches for mediators (e.g. di-jet), <u>complementary</u> to mono-jet
✓ theoretically consistent, no worries about EFT, widths, etc.

provide upper limits on g (or M/g)

- for each simplified model
- for given m_{DM}

⟶ complete and reliable information



Benchmarks

Some benchmark cases offering prospects for DM discovery
(alternative to EFT or simplified models):

1. DM co-annihilating with a coloured partner

2. DM annihilating through a SM mediator

- DM coupled to the Z
- DM coupled to the Higgs

3. DM near Z/h thresholds

1. CO-ANNIHILATIONS WITH A COLOURED PARTNER

- DM accompanied by a nearby coloured state

DM' - - - - - - - $M_{DM} + \Delta M$

DM ——— M_{DM}

- Situation fully characterised (model-independently) by:
  - DM' quantum numbers (spin,color)
  - M_{DM}
  - ΔM

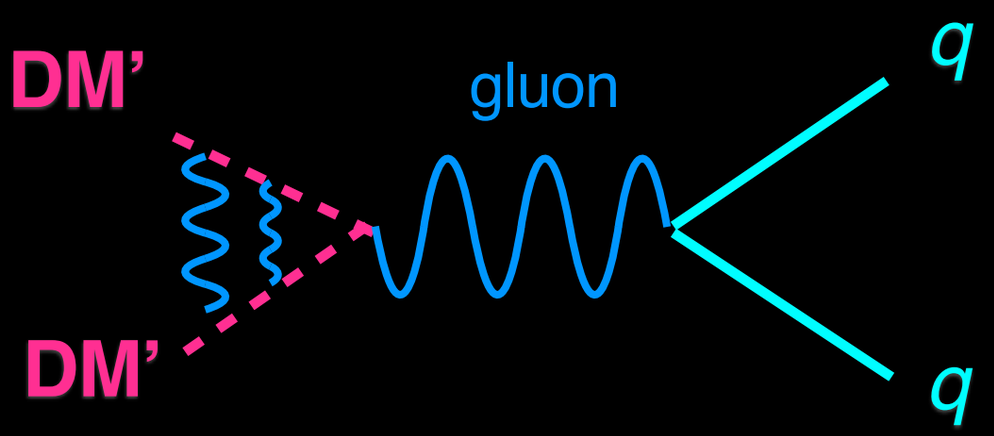
- 4 cases of interest:

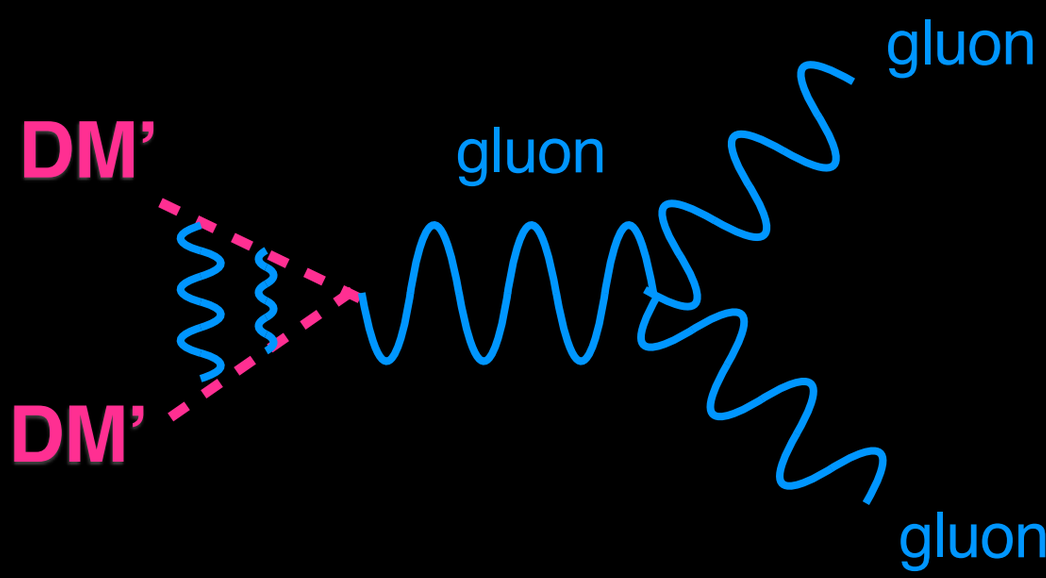
DM'	Colour triplet	Colour octet
Scalar	S3	S8
Fermion	F3	F8

S3 → stop

F8 → gluino

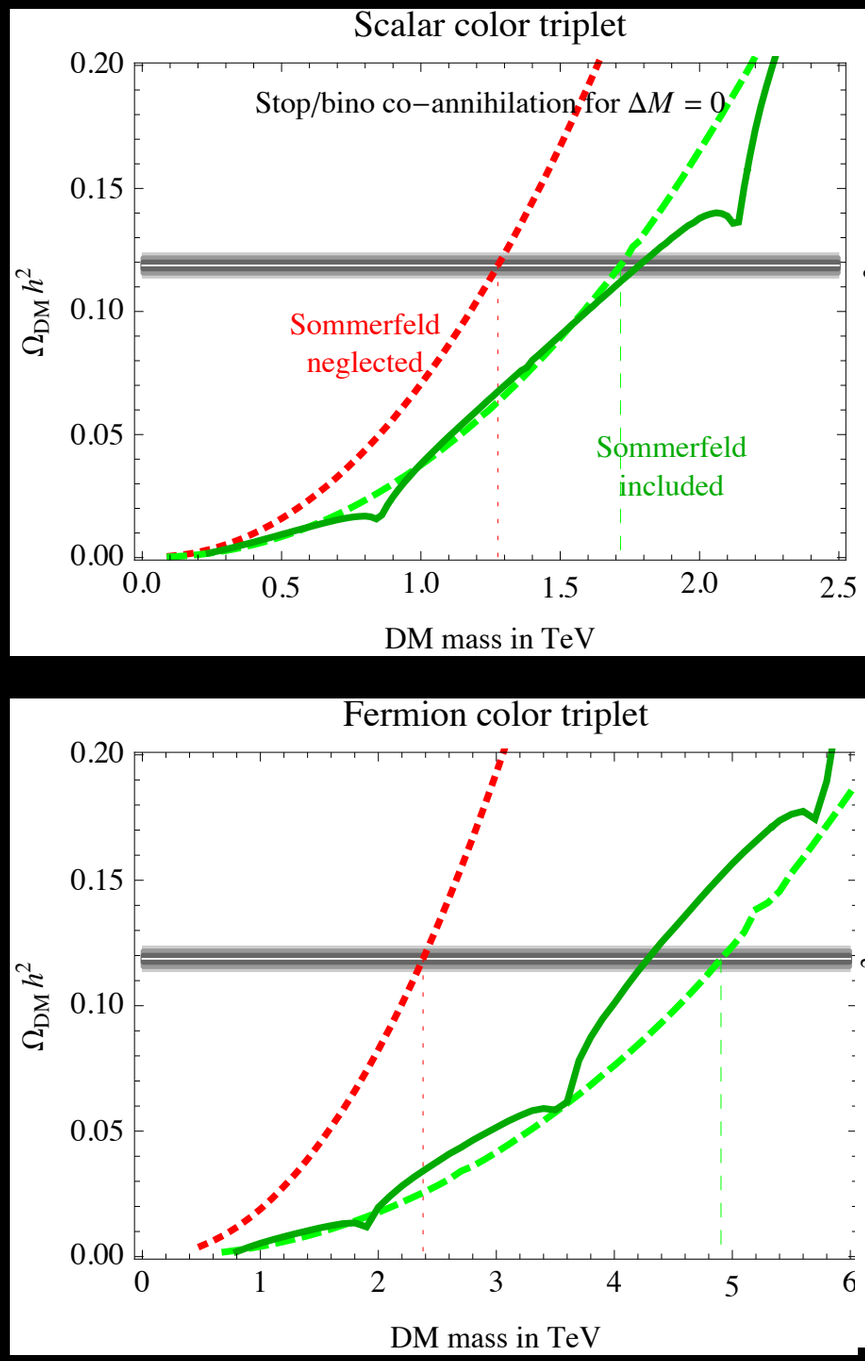
- Relic density from co-annihilations in the early Universe (with Sommerfeld enhancement)



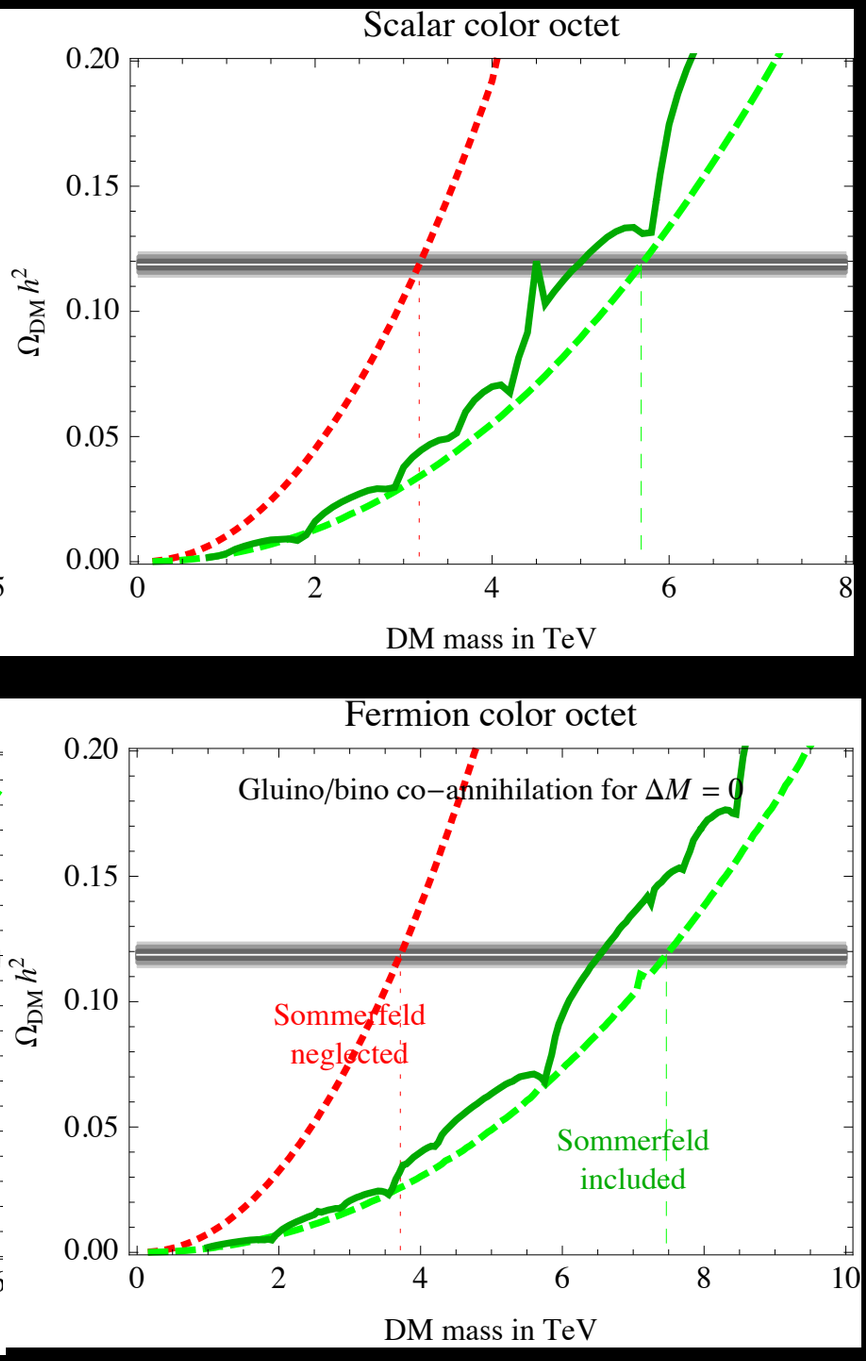


Relic density in the limit of mass degeneracy *ΔM = 0.*

S3



S8



F3

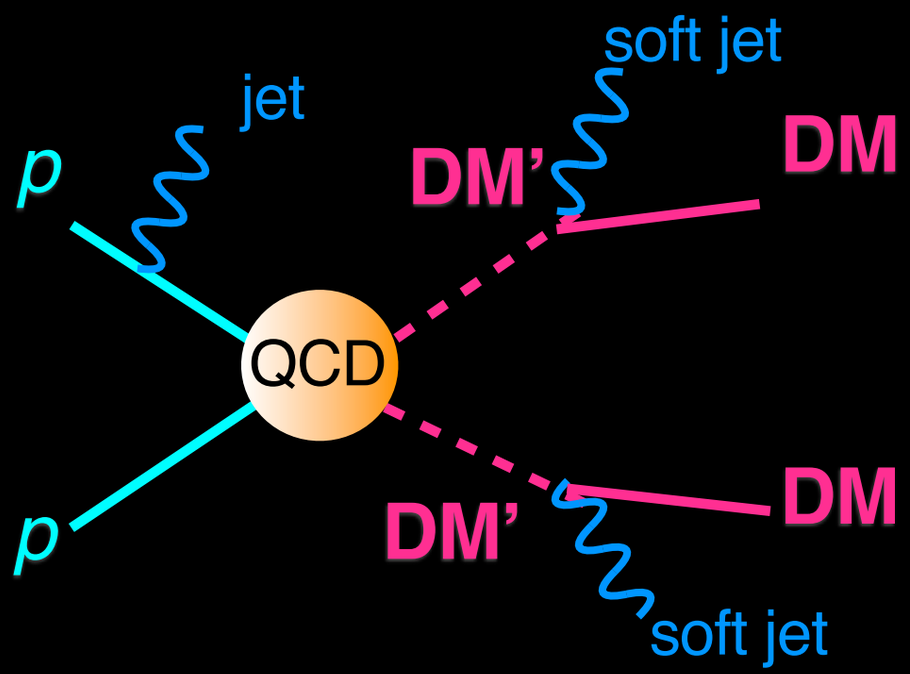
F8

substantial effect of Sommerfeld corrections

1. CO-ANNIHILATIONS WITH A COLOURED PARTNER

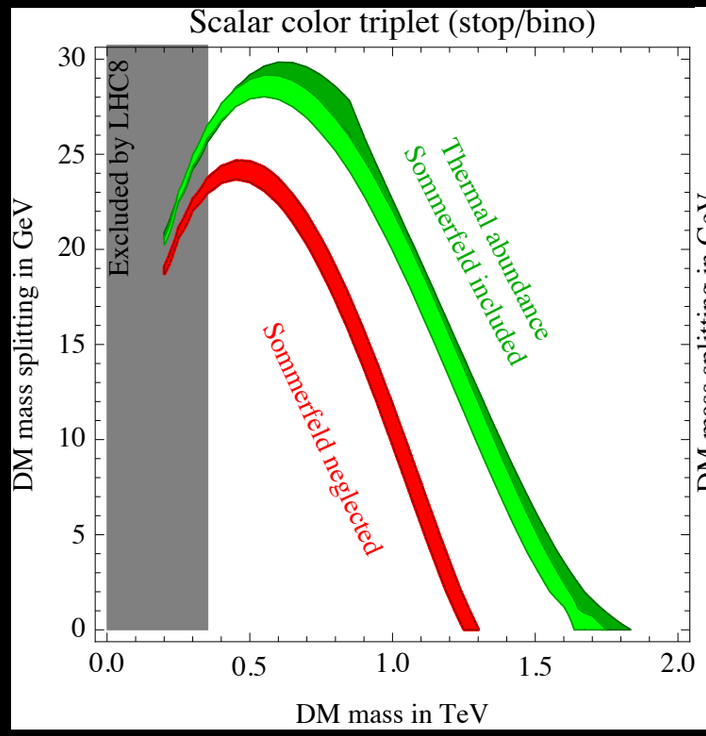
large QCD cross section:

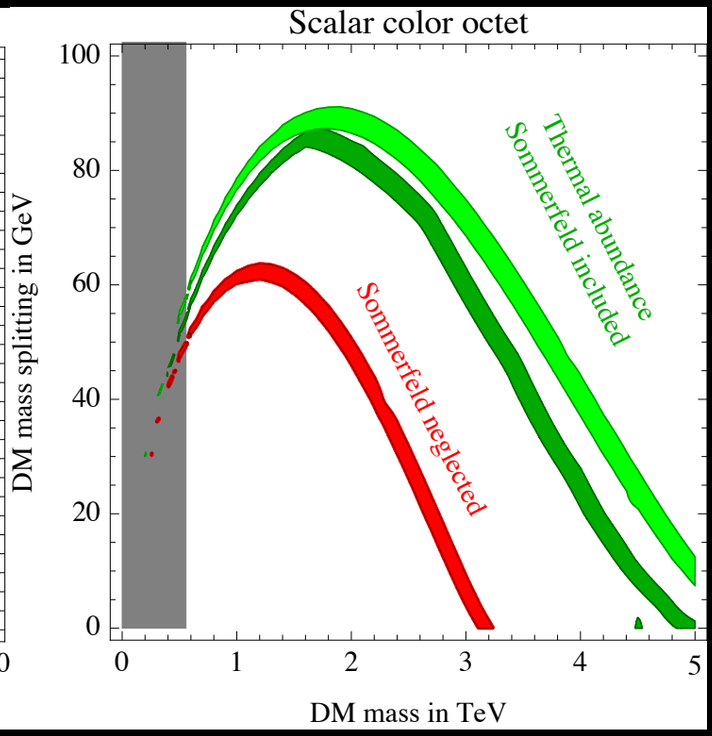
$$pp \to \mathrm{DM'\,DM'} + \mathrm{jet}$$

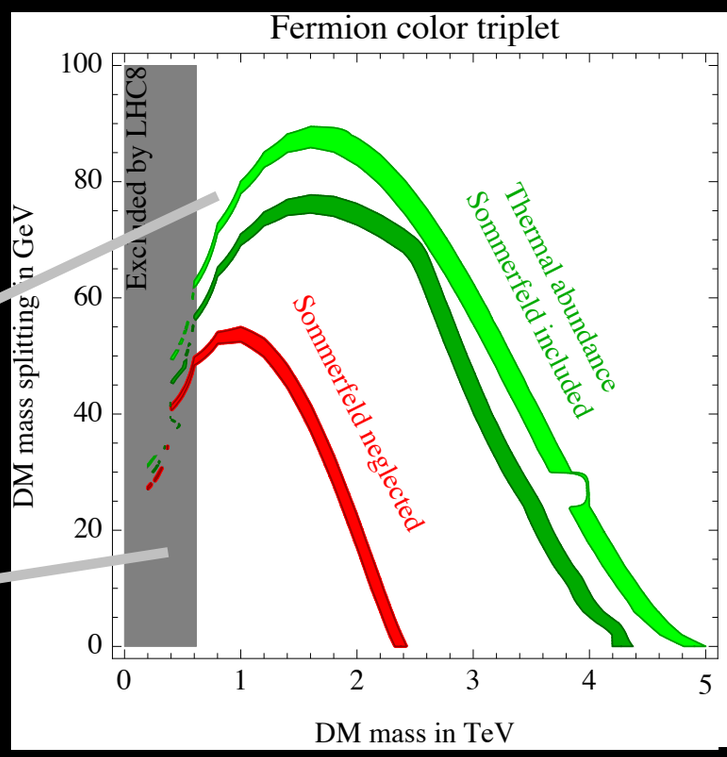


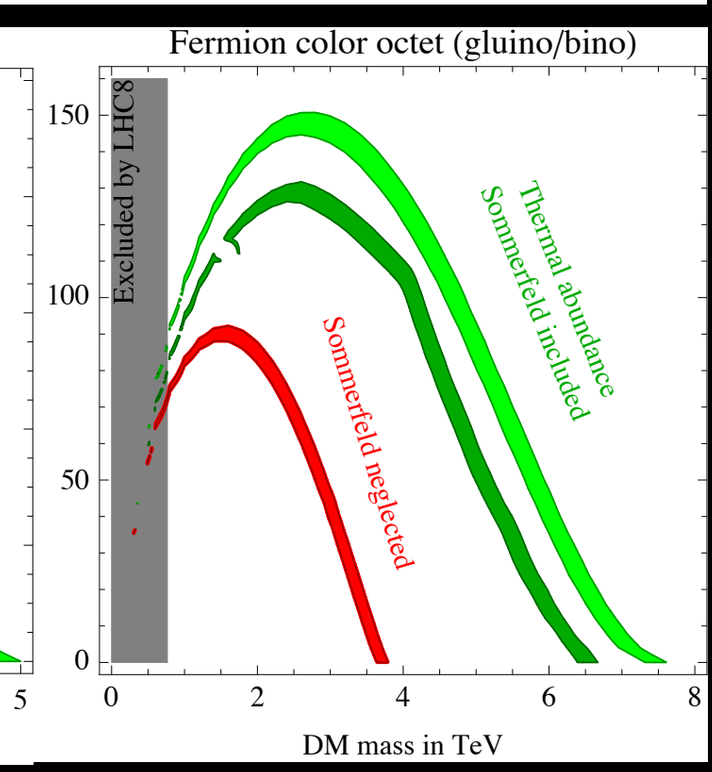
large-enough splitting
to tag soft jet?

90%CL exclusion
$\sqrt{s} = 8$ TeV
L=19.6 / fb







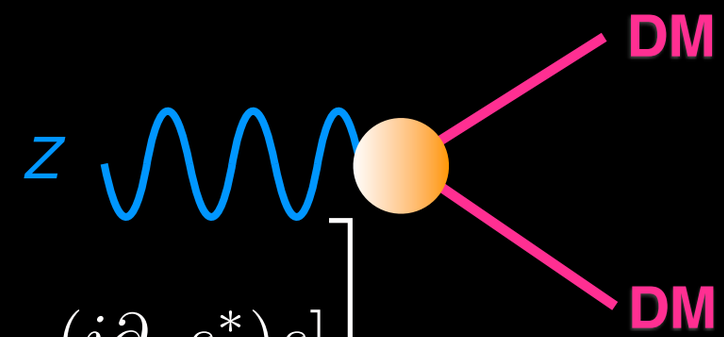


LHC will not probe the entire parameter space, $\sqrt{s} \sim 100$ TeV will.

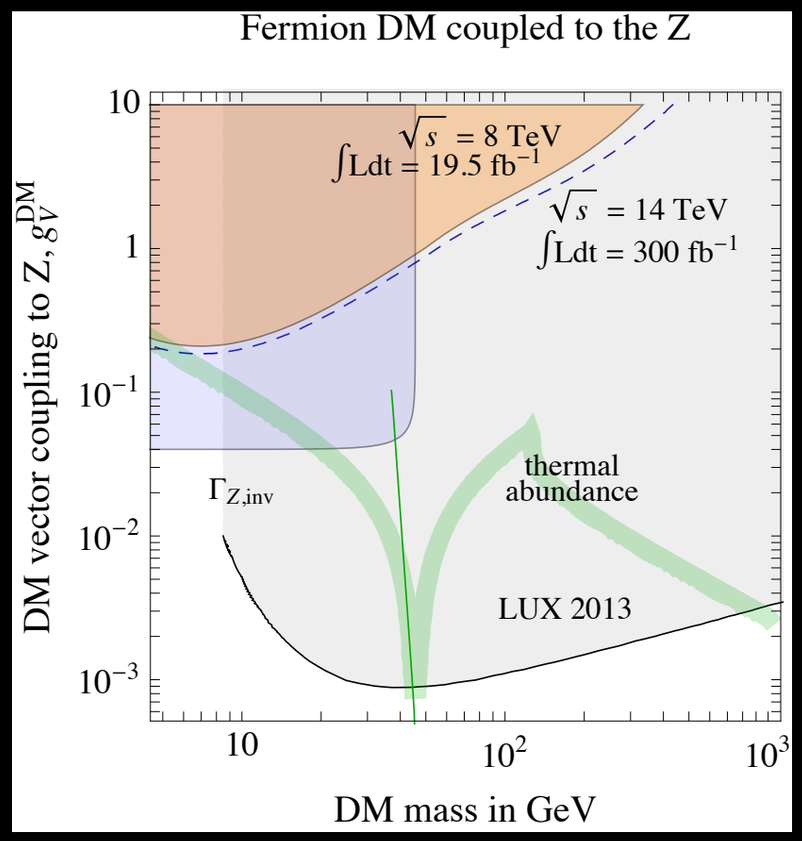
2. Annihilations through SM mediator

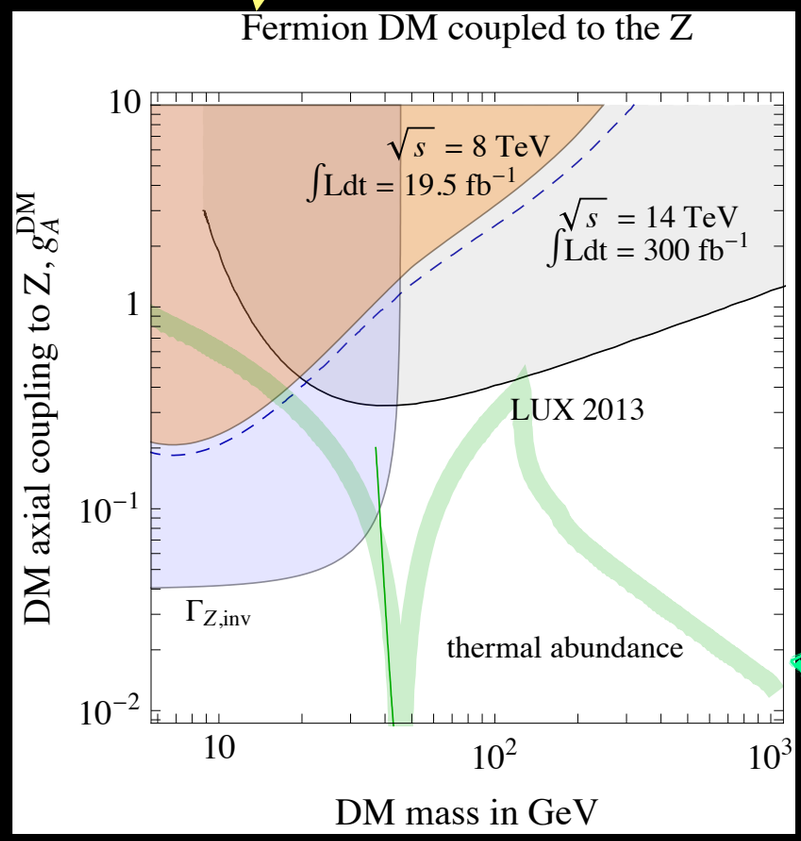
The DM-quarks interactions are mediated by a SM particle (Z or H)

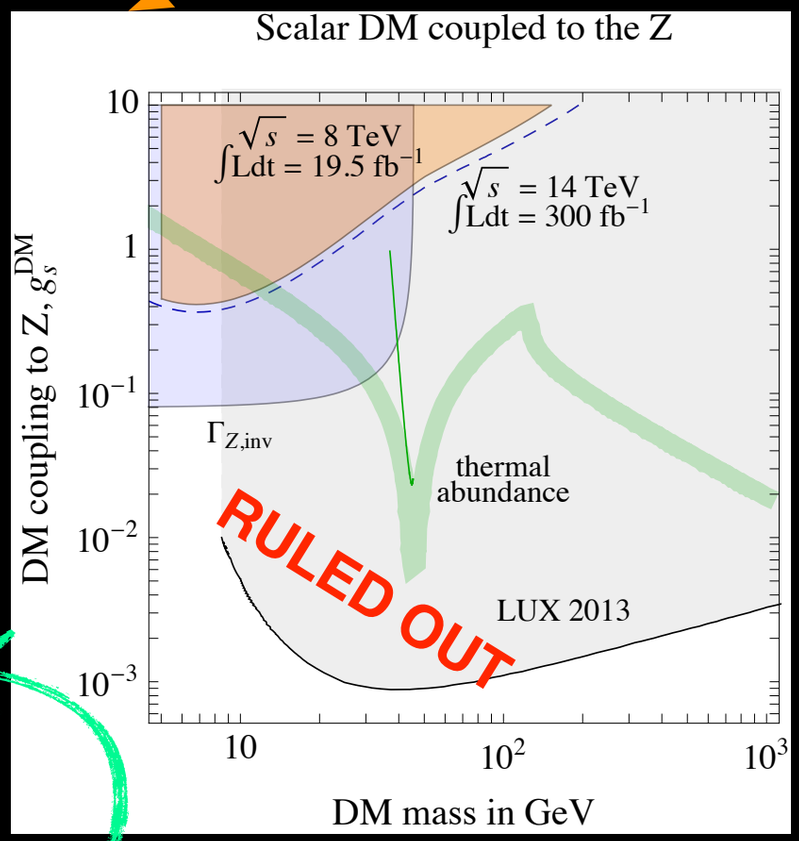
DM coupled to the Z



$$\mathcal{L} = -Z_\mu \frac{g_2}{\cos\theta_W}\left[\sum_f [\bar{f}\gamma_\mu(g_V^f + \gamma_5 g_A^f)f] + \sum_s g_s[s^*(i\partial_\mu s) - (i\partial_\mu s^*)s]\right]$$

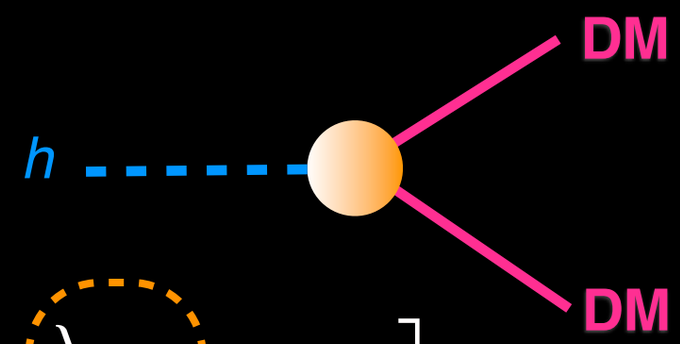




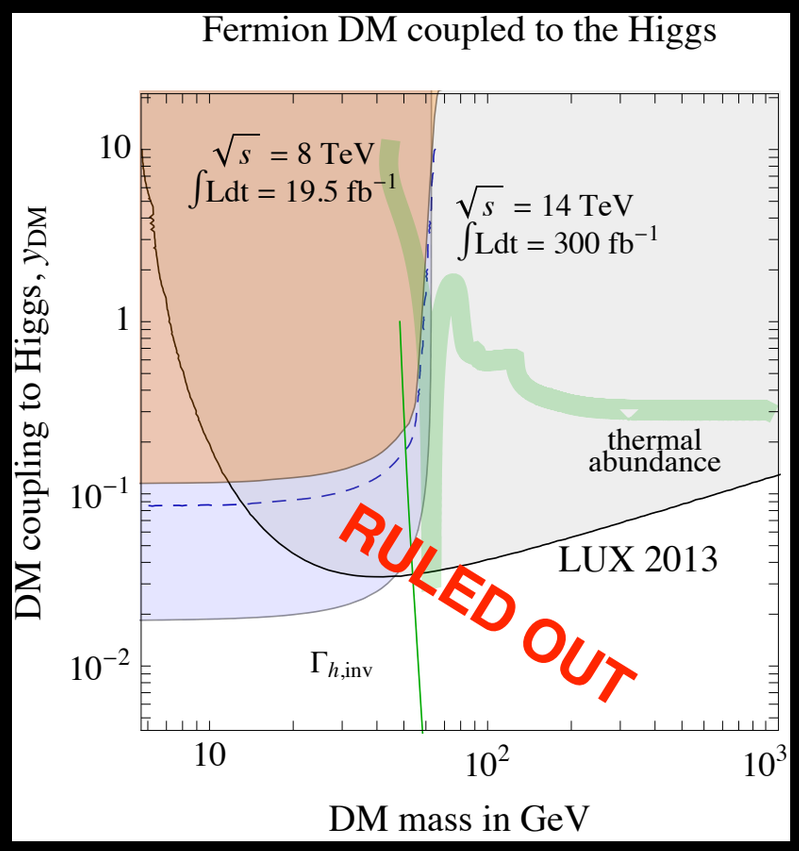


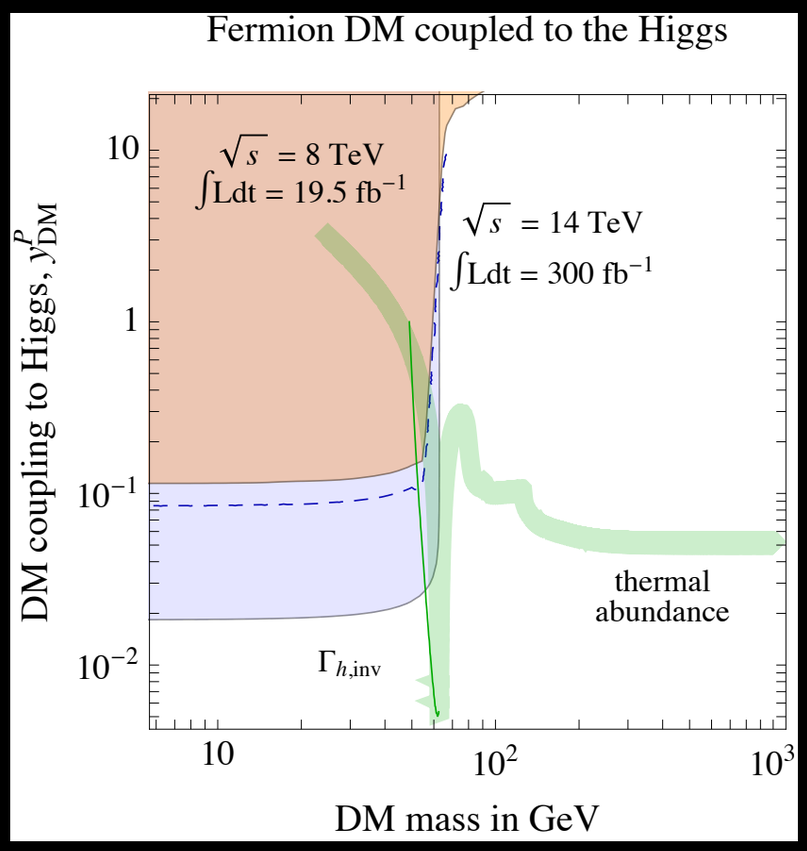
some regions still allowed for axial couplings of fermion DM
(SD cross section is less constrained)

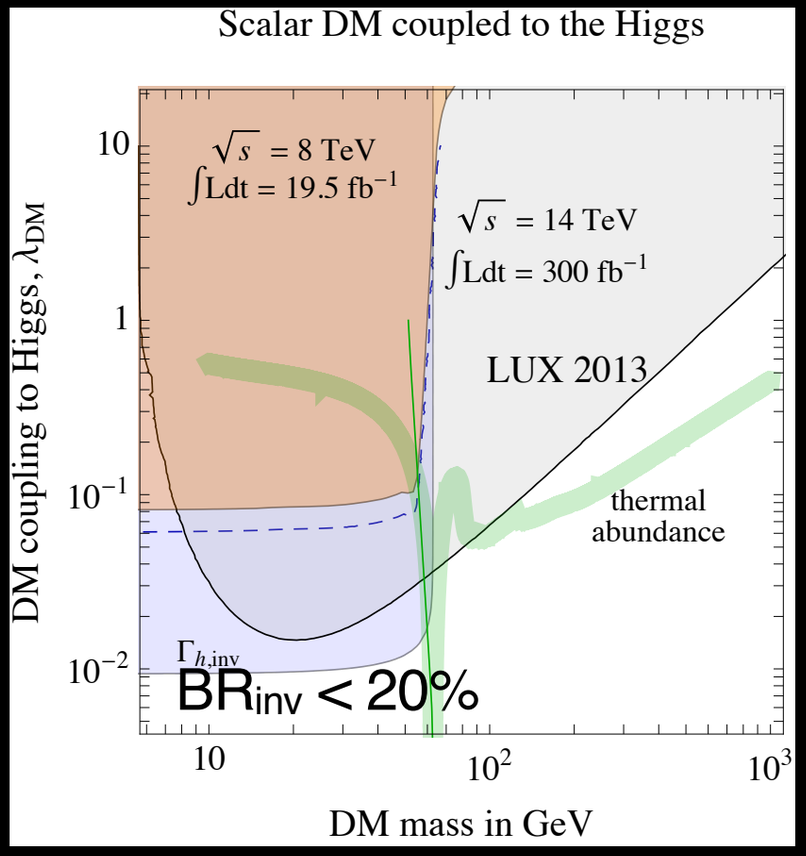
DM coupled to the Higgs



$$\mathcal{L} = -h\frac{1}{\sqrt{2}}\left[\sum_f y_f \bar{f} f + \bar{\psi}_{\rm DM}(y_{\rm DM} + i y^P_{\rm DM}\gamma_5)\psi_{\rm DM} + \frac{\lambda_{\rm DM} v}{2} s^2_{\rm DM}\right]$$

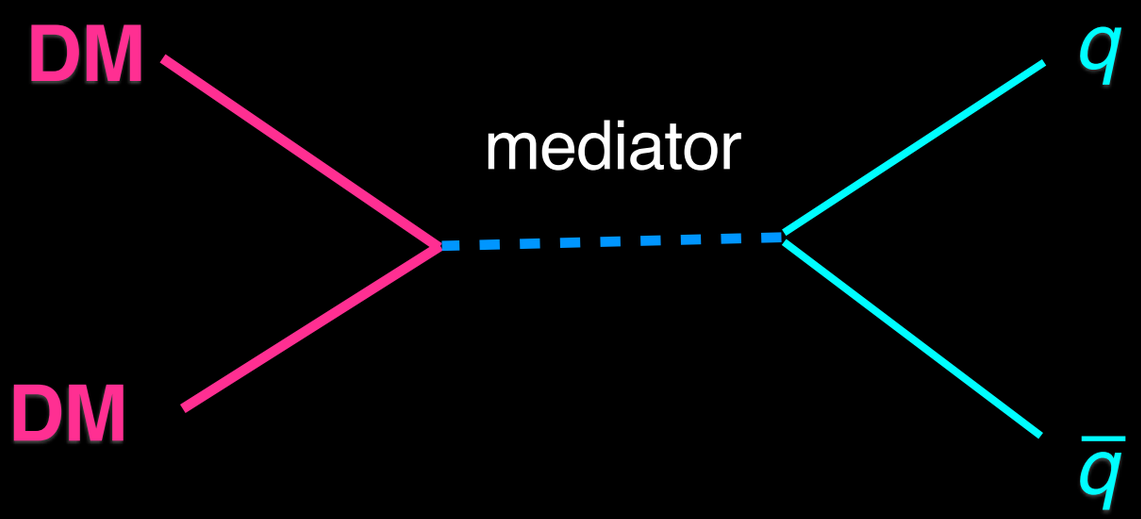






some regions still allowed for scalar DM (M>100 GeV)
and fermion DM with axial couplings

in the early Universe:
DM annihilations with s-channel exchange of a mediator



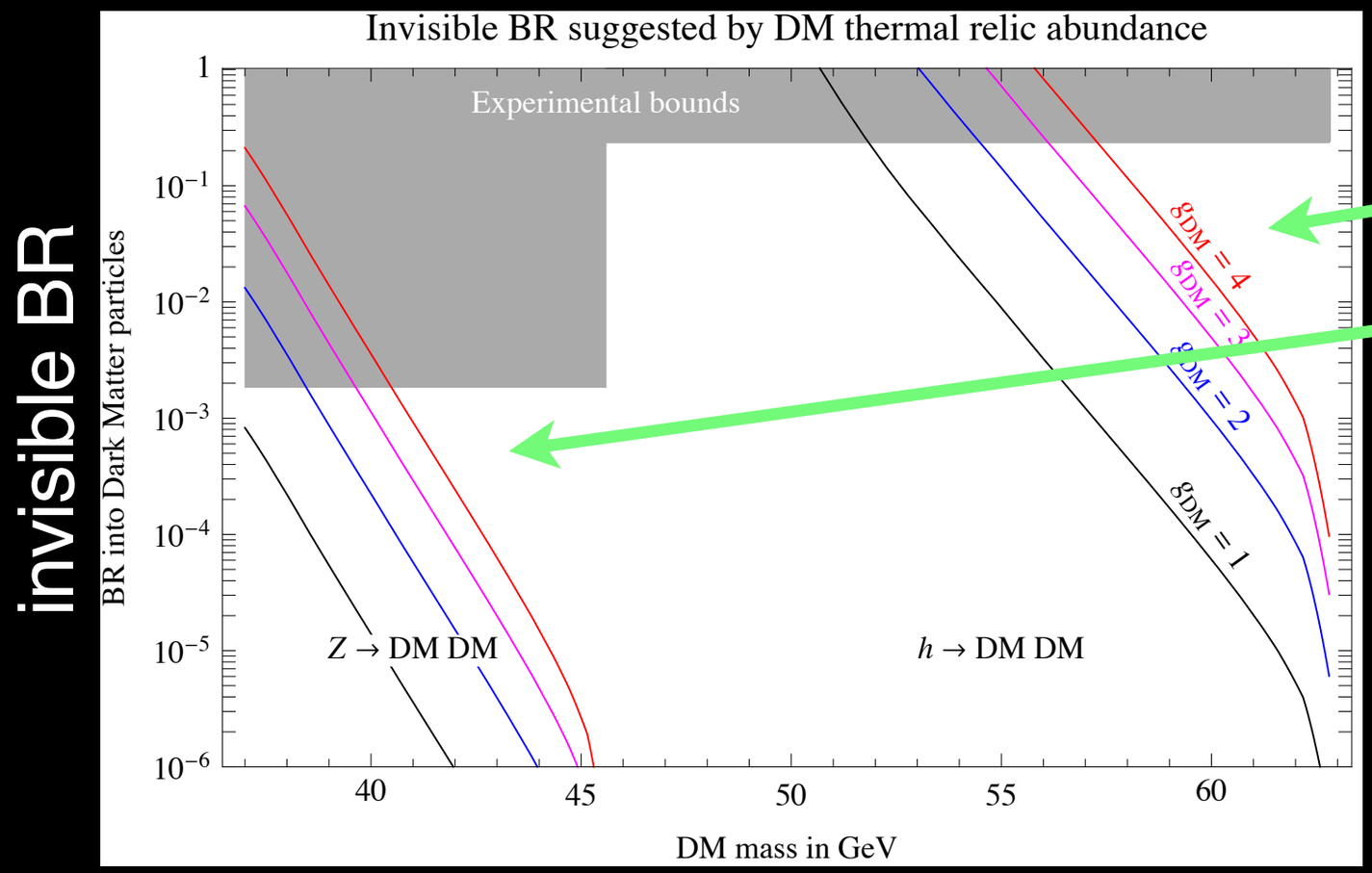
Near resonance ($M_{\rm med} - 2M_{\rm DM} \lesssim 2\Gamma_{\rm med\to DM}$), the annihilation cross section is driven by the on-shell term, which is model-independent (Breit-Wigner)

The relic abundance is determined model-independently by the width: $\Gamma_{\rm med\to DM}$

DM freezes out via decays

Simple situation when the mediator is Z or H.

Curves for correct DM relic abundance:



invisible BR

DM mass

room for improvement, exploring invisible widths of Z and h

(LHC, future Higgs factories, GigaZ...)

Conclusions

- Need to explore <u>new avenues</u> for DM searches @ LHC

  - *beyond EFT*

  - *as model-independent as possible*

- Proposed some benchmark cases for DM discovery:

1. DM co-annihilating with a coloured partner
   - identification of soft jets, tag extra-jets

2. DM annihilations via SM mediator (Z, h)
   - LHC searches not competitive, but good to improve MET channels (e.g. non-thermal production)

3. DM near Z/h thresholds
   - motivation to improve on Z/h invisible BRs