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Collider DM searches BEYOND the LHC

Björn Penning

Imperial College London

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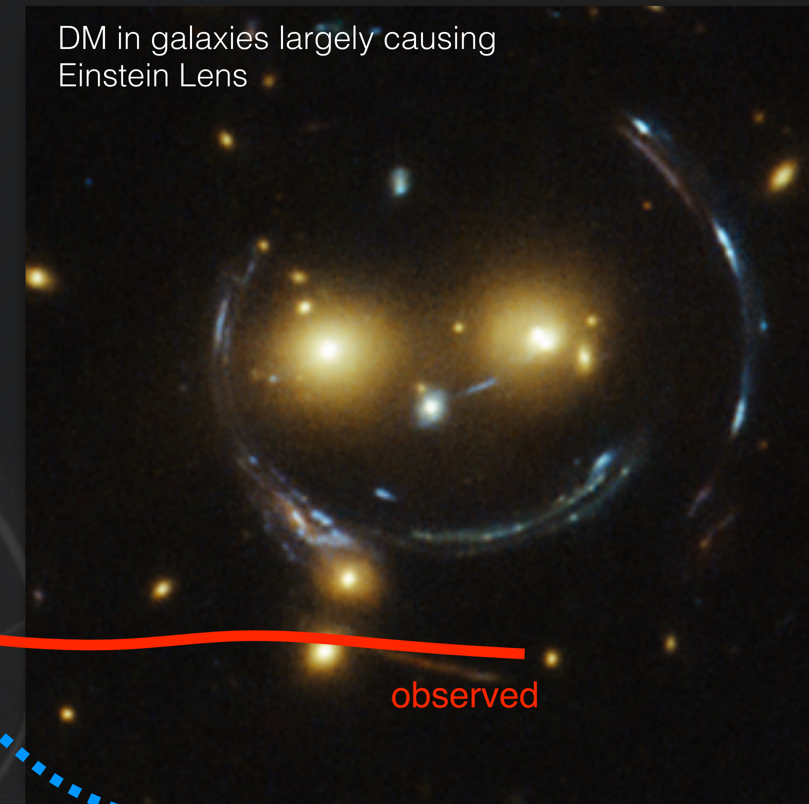
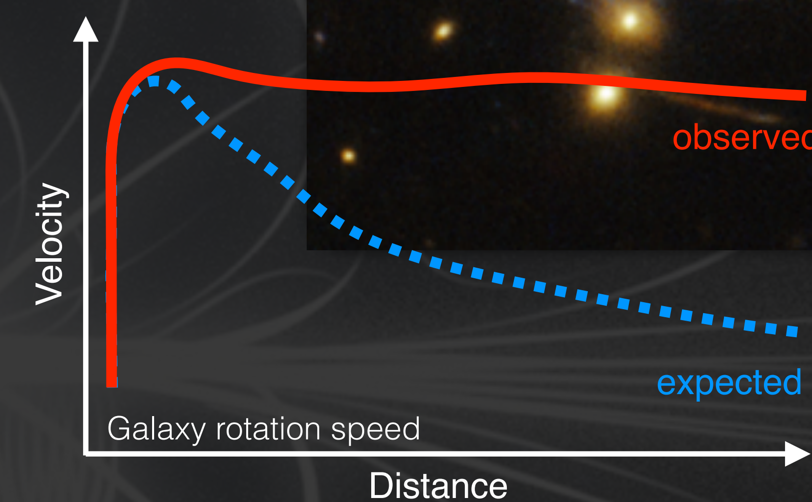
Overview

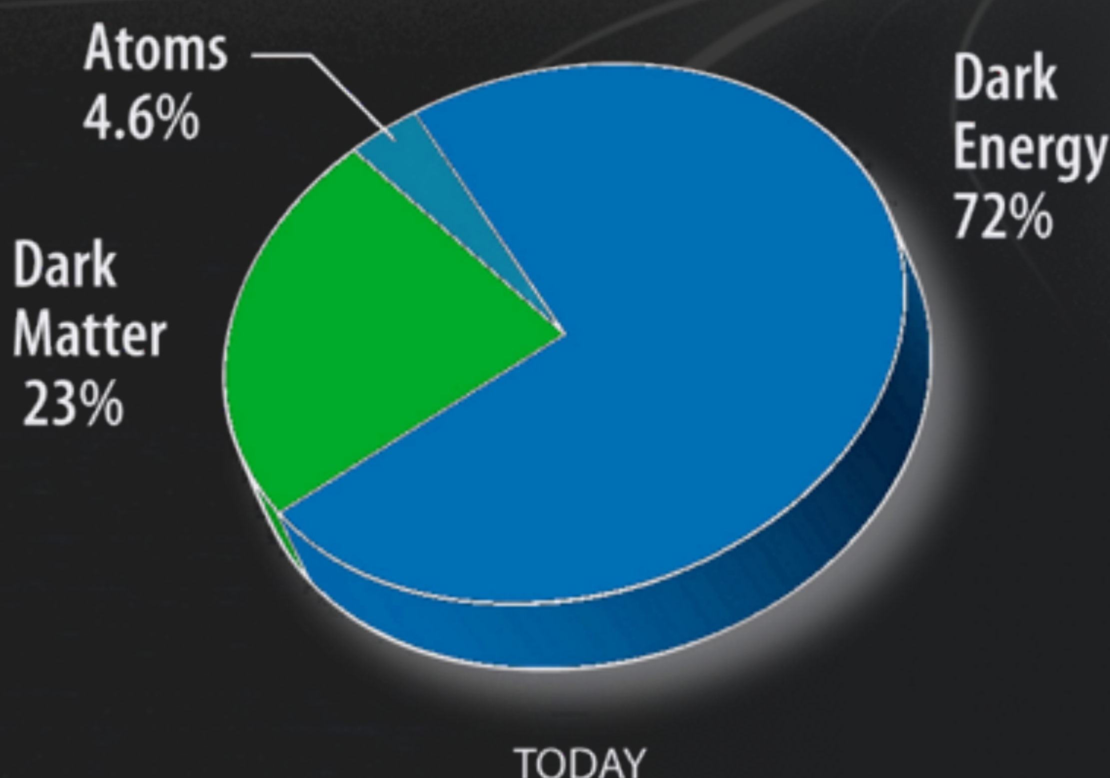
- DM detection and model dependency
- Pseudoscalar models and Fermi-LAT
- Precision (VBF) measurements and generic scalar models
- Axial-Vector projections
- Conclusion

Introduction



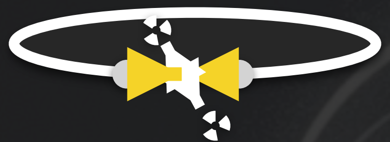
- Dark Matter (DM) one of the greatest puzzles in physics
- Many independent observations only gravitationally
- Weakly interacting massive particle (WIMP)
- Five times as much DM as regular matter in the Universe





- The hunt for dark matter is an inter-disciplinary effort
- Potentially accessible at experiments that are just starting

Complementarity of searches

	Interaction			
EWK style	**Vector**	low mass	high mass	
	Axial-Vector	low mass	high mass	
mass based	**Scalar**	low mass	high mass	
	Pseudo-Scalar	low mass		large range

- Different types of DM searches probe different parameter space
- An eventual discovery has to be confirmed in more than one experiment and only a combination can truly identify and measure DM

Evolution of collider models

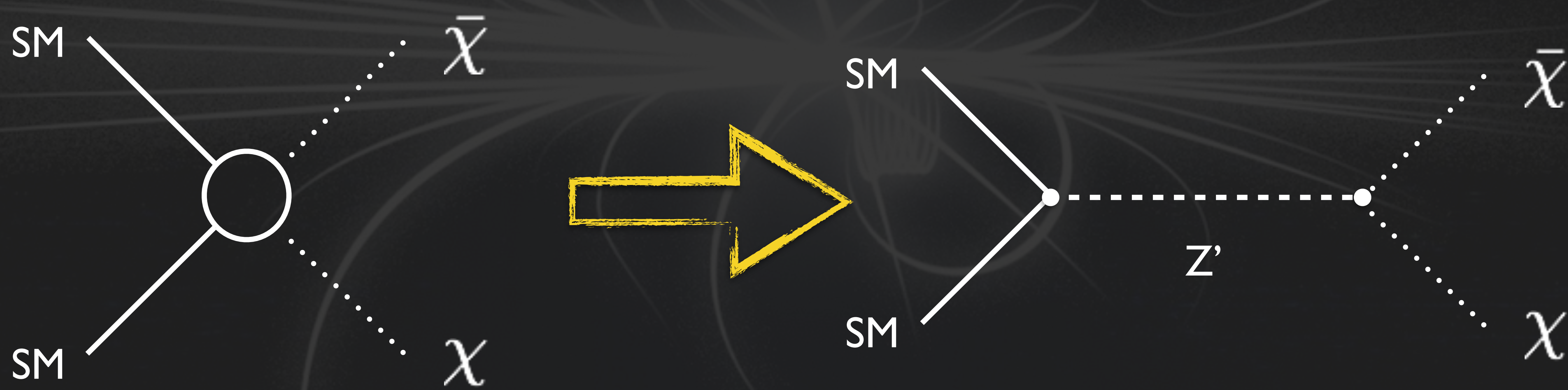
Simplified Models

Effective Models

$$\frac{1}{M^*} = \frac{\sqrt{g_{\mathrm{DM}} g_{\mathrm{SM}}}}{m_\Phi}$$

Simplified Model

$$\frac{m_\chi^2 g^2}{(m_\Phi^2 + m\chi^2)^2}$$



Using (mostly) scalar simplified models to study advantages of more complete models and complementary impact

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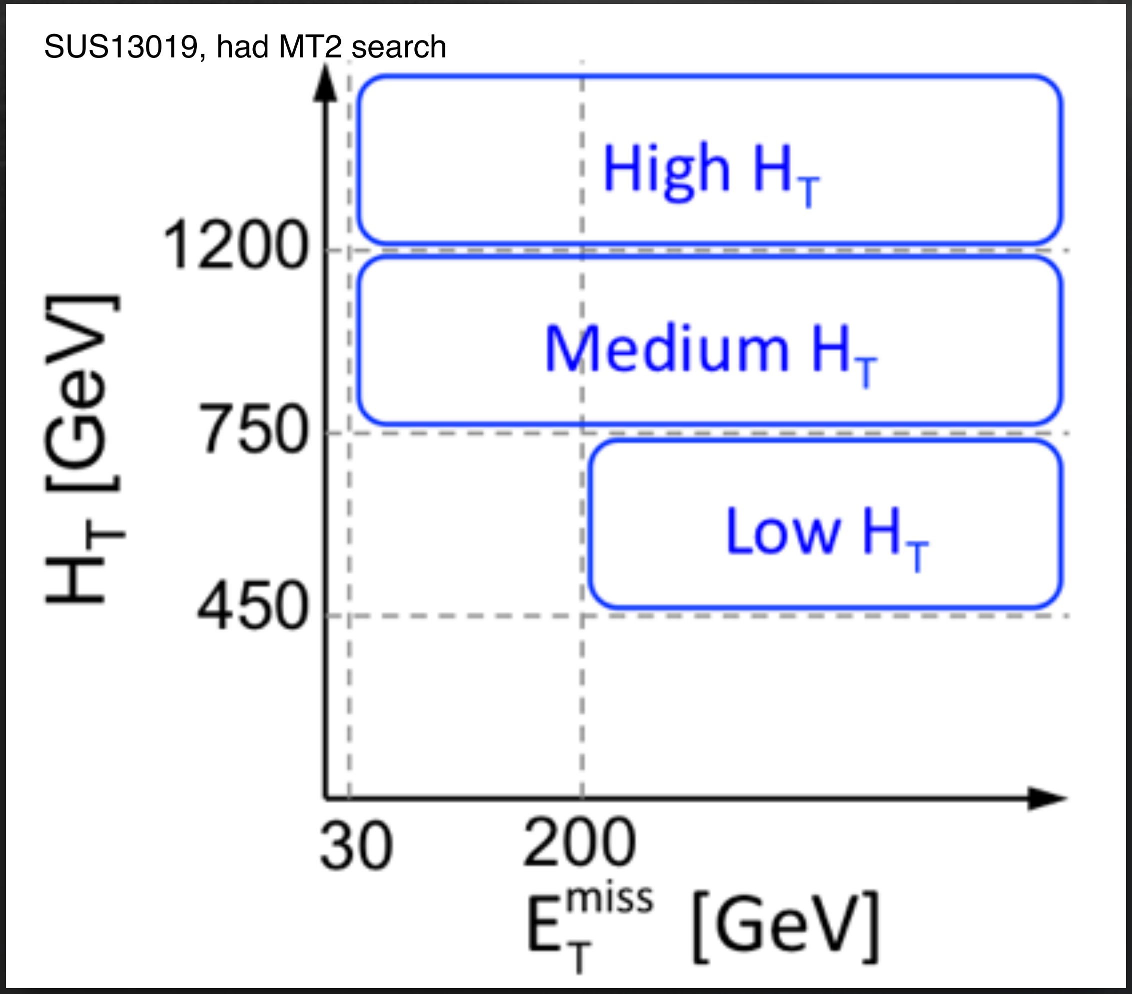
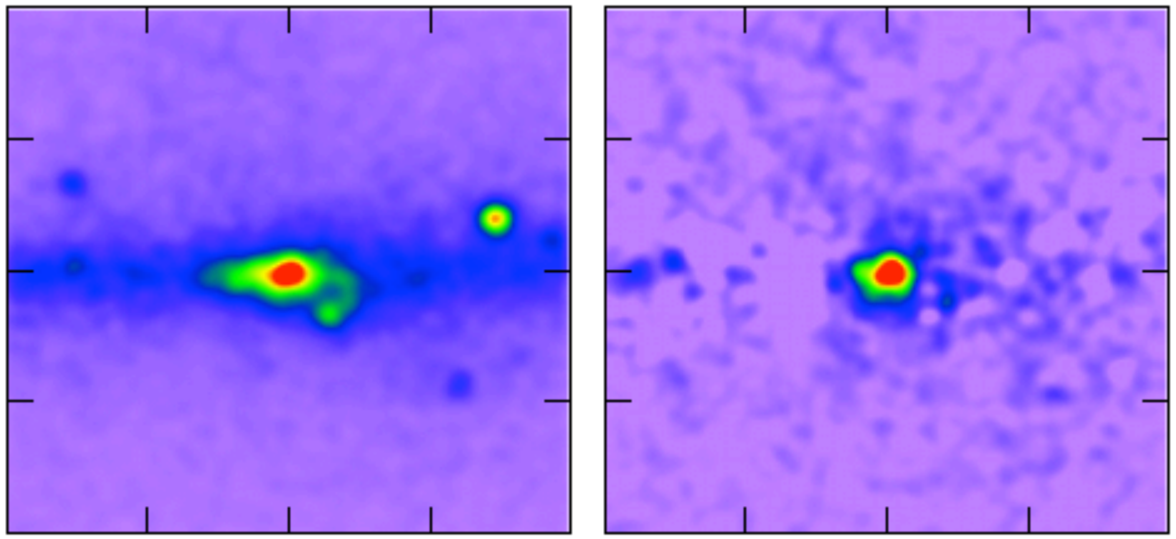
Sensitivity for GC with 8 TeV data

- Example: GC excess as pseudoscalar mediator
- Monojet searches probe mostly dominantly resonantly enhanced region: $m_A \sim 2m_{DM}$
- MT2 search categories are designed so that final states with differing jet-multiplicity have a similar sensitivity





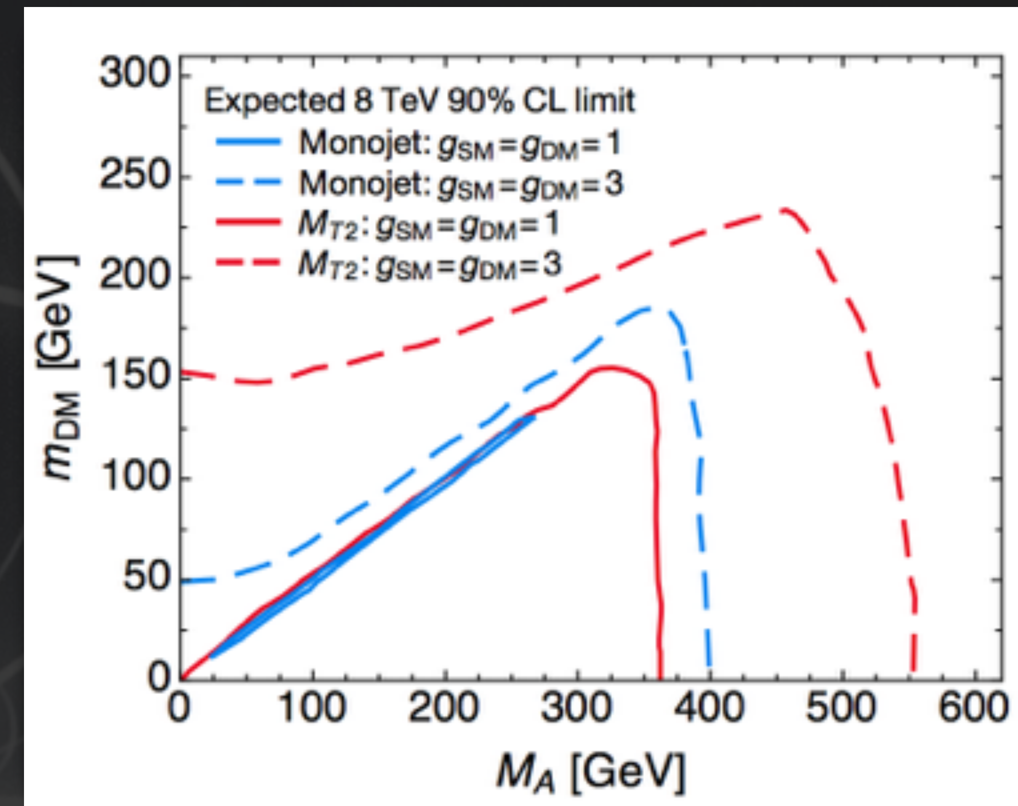
Potential signal from annihilating DM arXiv:1402.6703

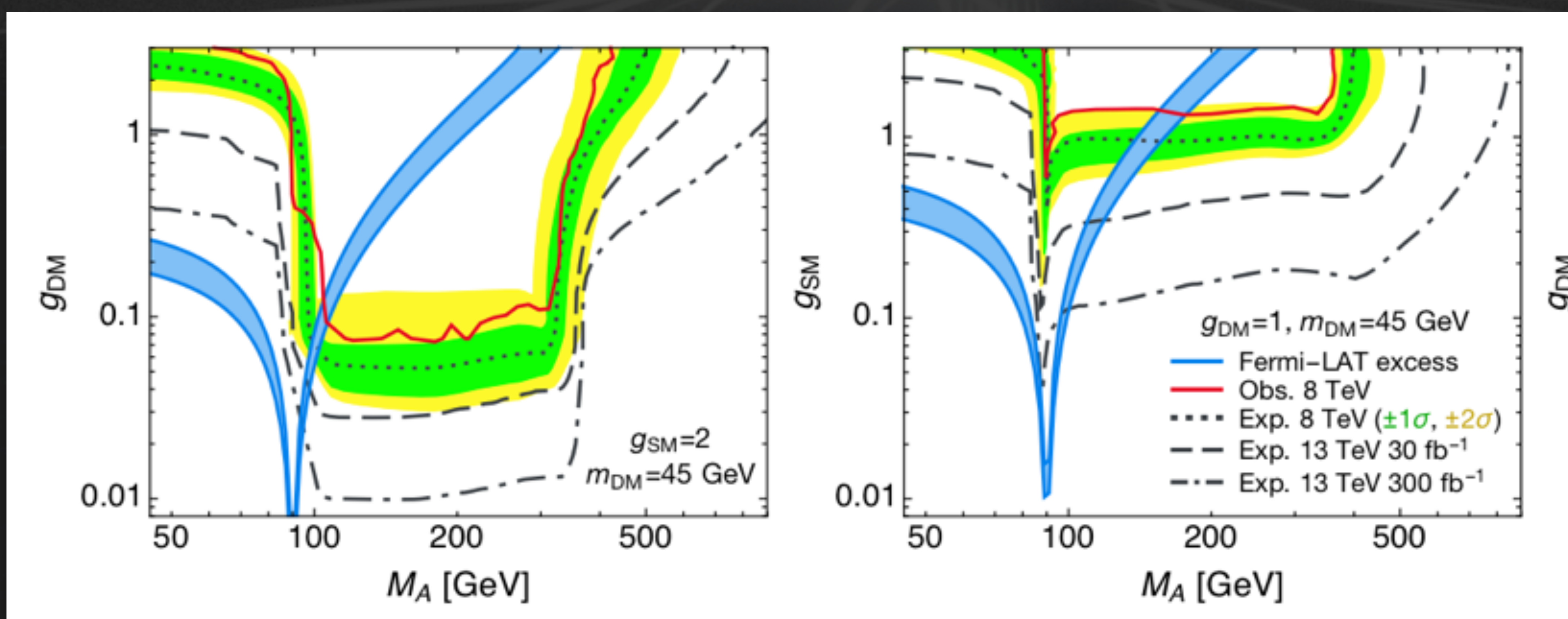
- Many models dominated by gluon fusion → large jet multiplicities
- Inclusive SUSY searches such as a_T, MT2, Razor, MHT-HT place fewer constraints on phase space

Improving & Connecting Searches

arXiv:1505.07826
Penning et al (PRL)

- Testing Fermi-LAT excess and inclusive analyses using collider data
- Inclusive search has significantly better expected sensitivity
- Excluding already part of the phase space
- More 13 TeV data will be very exciting





Improving & Connecting Searches

arXiv:1505.07826
C. McCabe, S. Malik, BP

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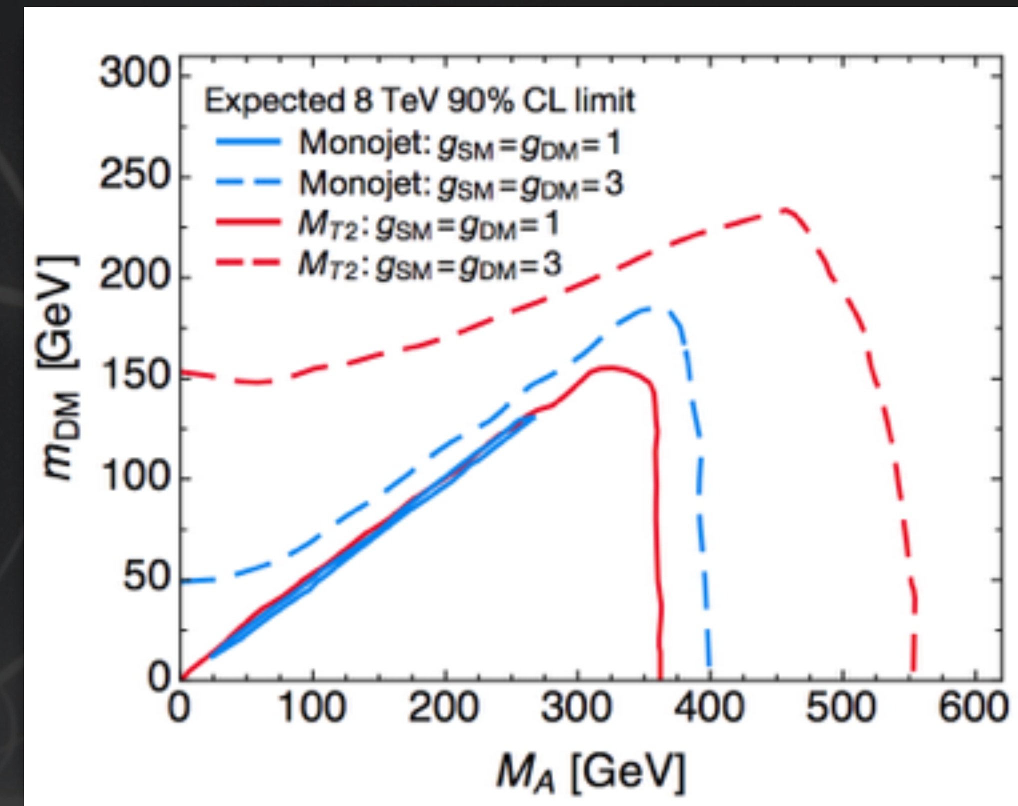

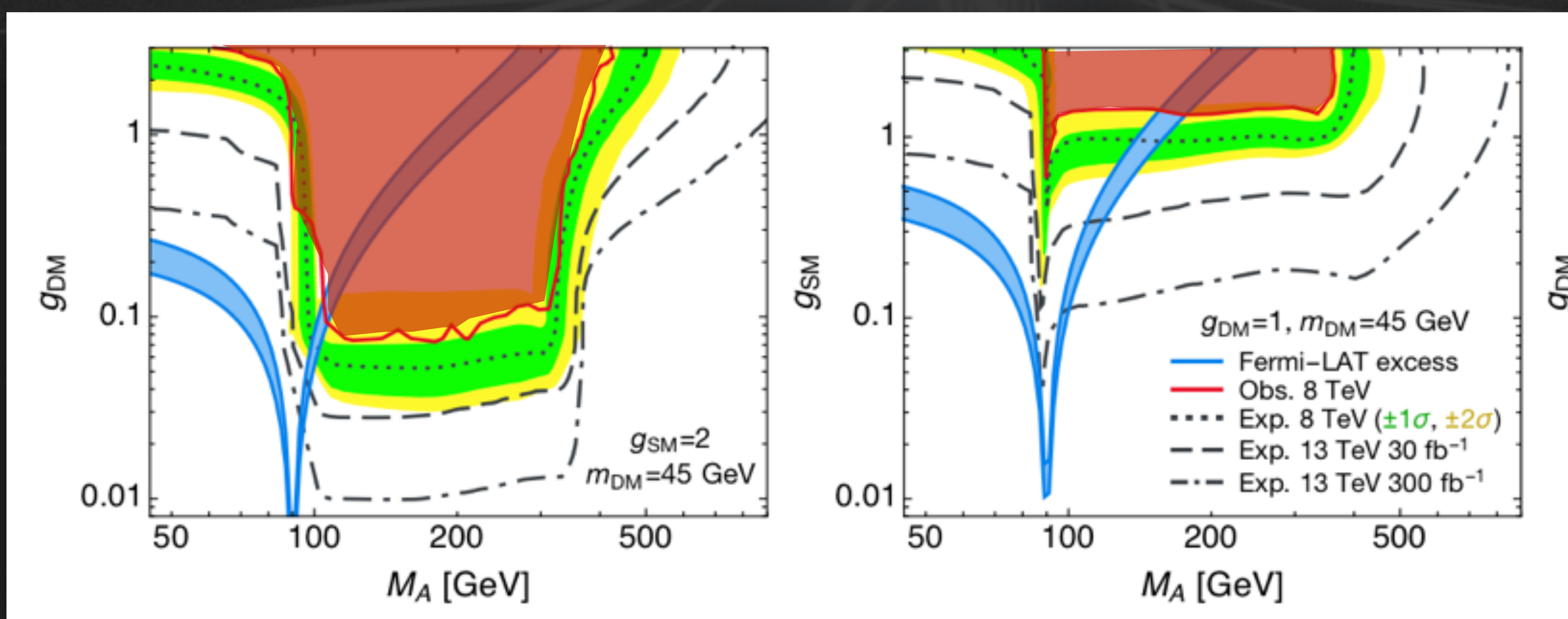

Precision measurements

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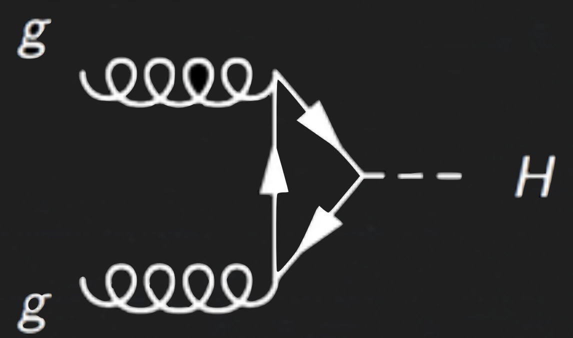
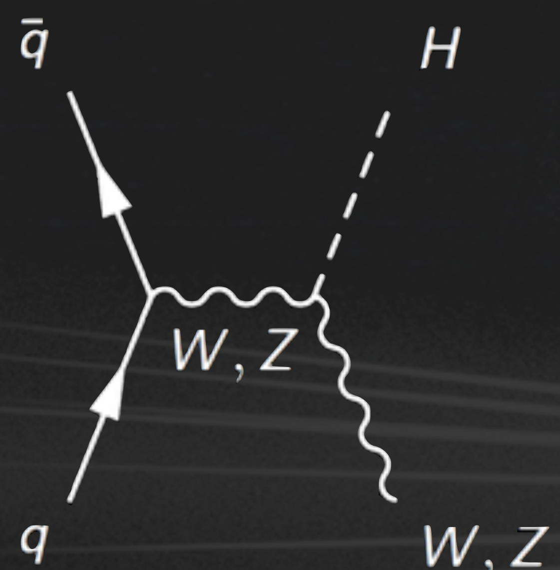
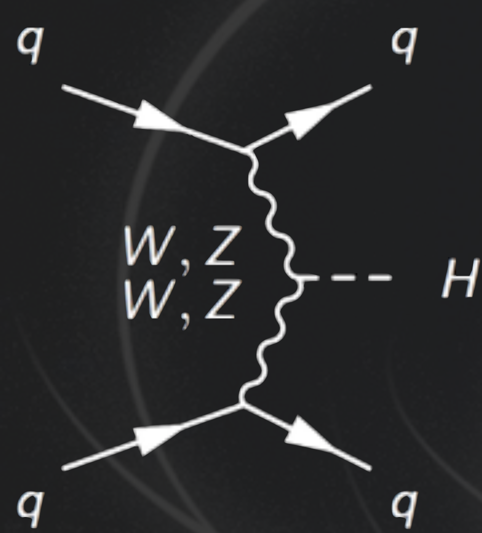
VBF Searches

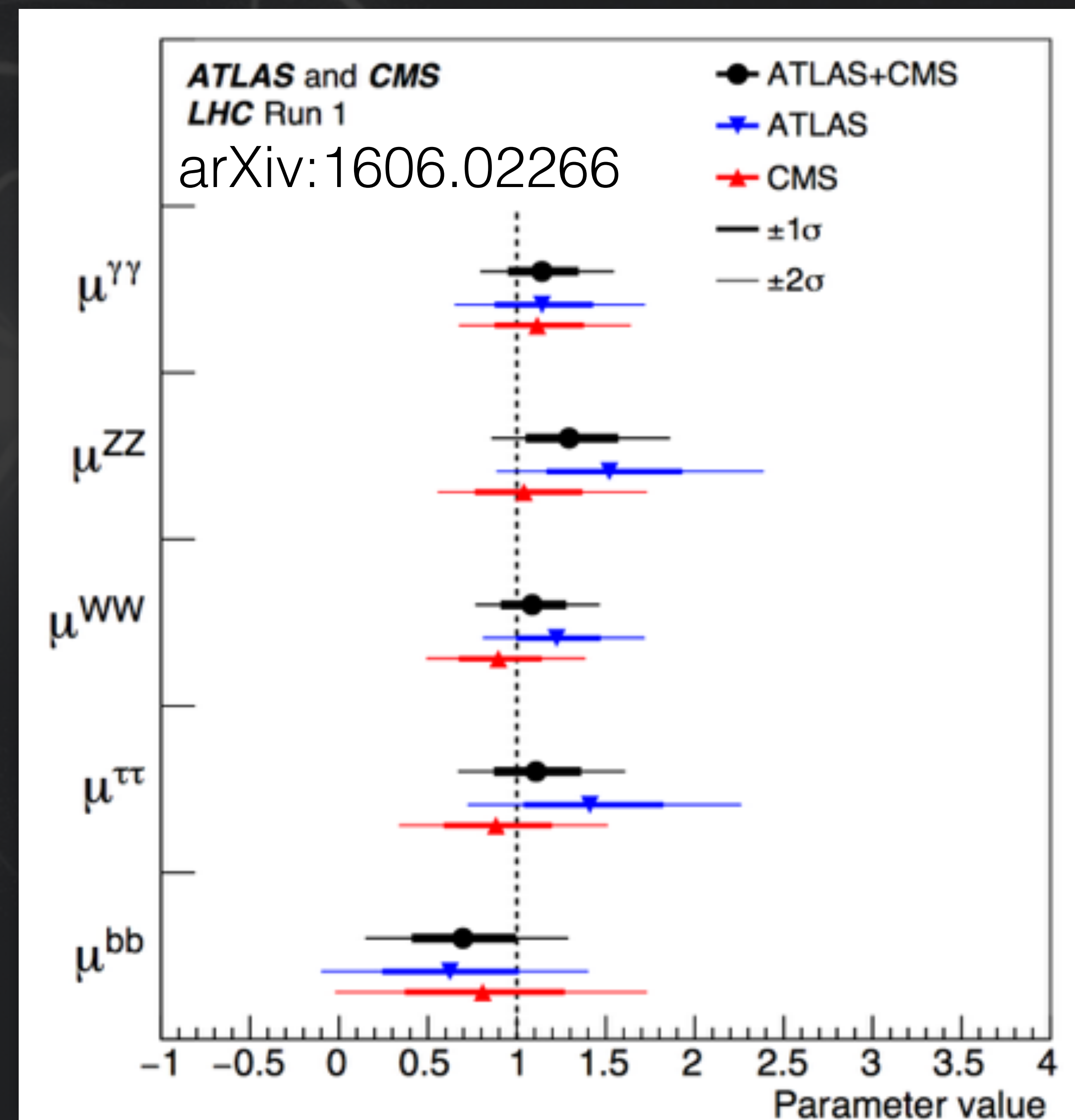






VBF

- The Higgs boson is a natural messenger into the ‘dark world’
- 3 main production modes: ggF, VH, VBF



- Measurements of the Higgs boson’s properties are already very impressive:
    - Mass measured within 0.2% uncertainty
- Many parameters relatively unconstrained: Indirect limit on width is ~$4\Gamma_{SM}$

$$BR_{\rm BSM} = \frac{\Gamma_{\rm H} - \Gamma_{\rm vis}}{\Gamma_{\rm H}}$$

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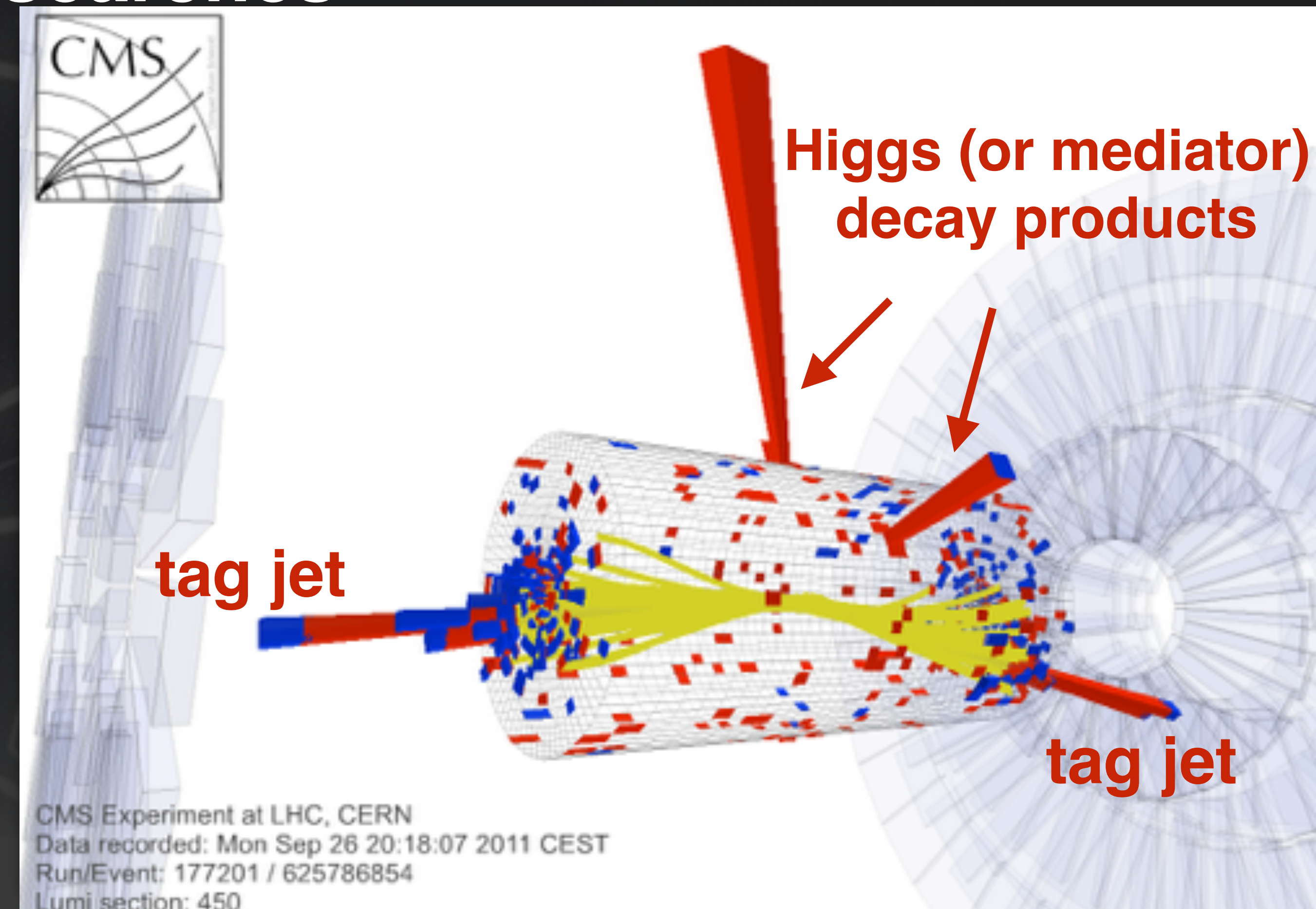
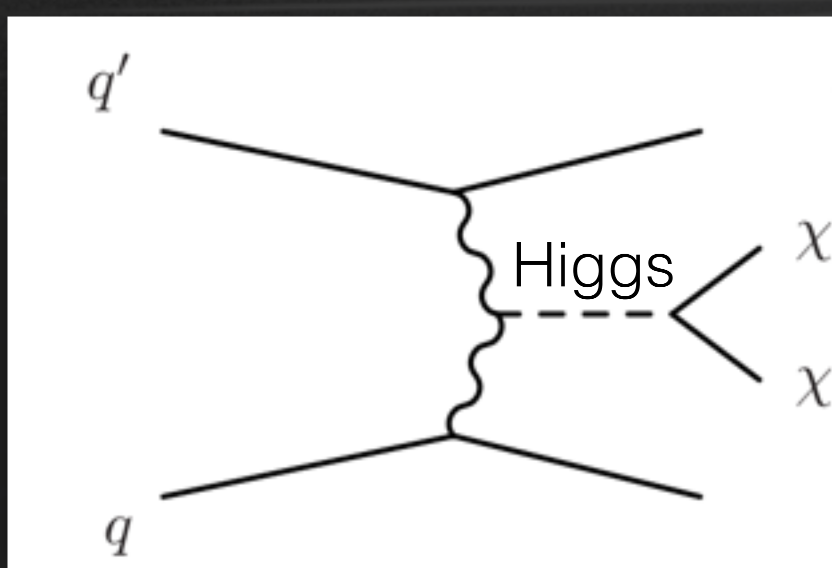
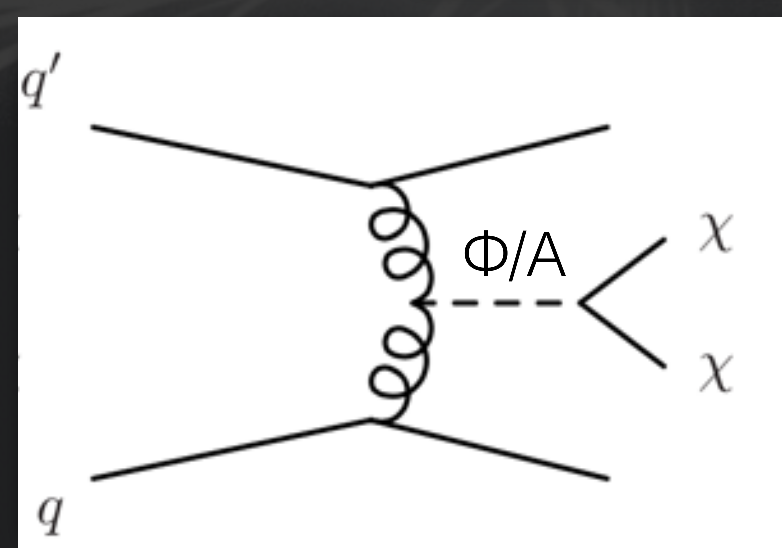
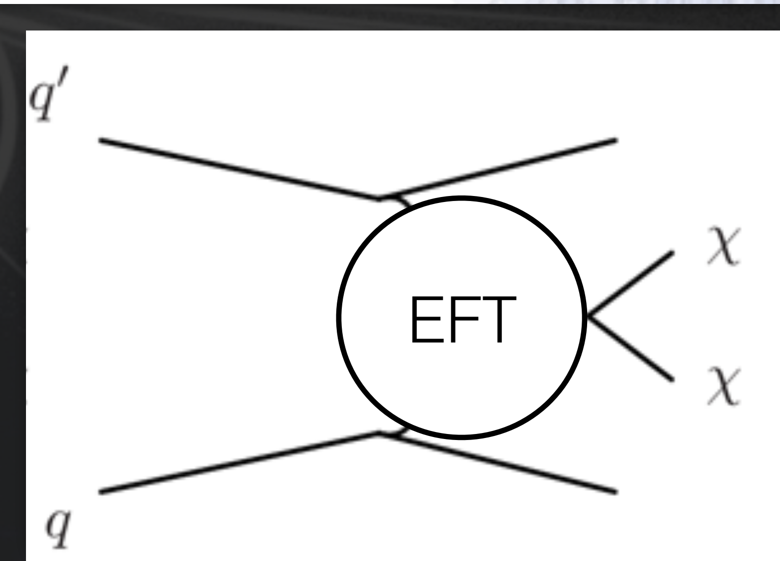
VBF DM searches

- VBF is the most important channel in H→inv. searches
  - Large rapidity gap between jets
  - Litte reliance on E_T^{miss} trigger
- Large xsec for scalar type processes









- SM Higgs
- Particular powerful for on-shell decay

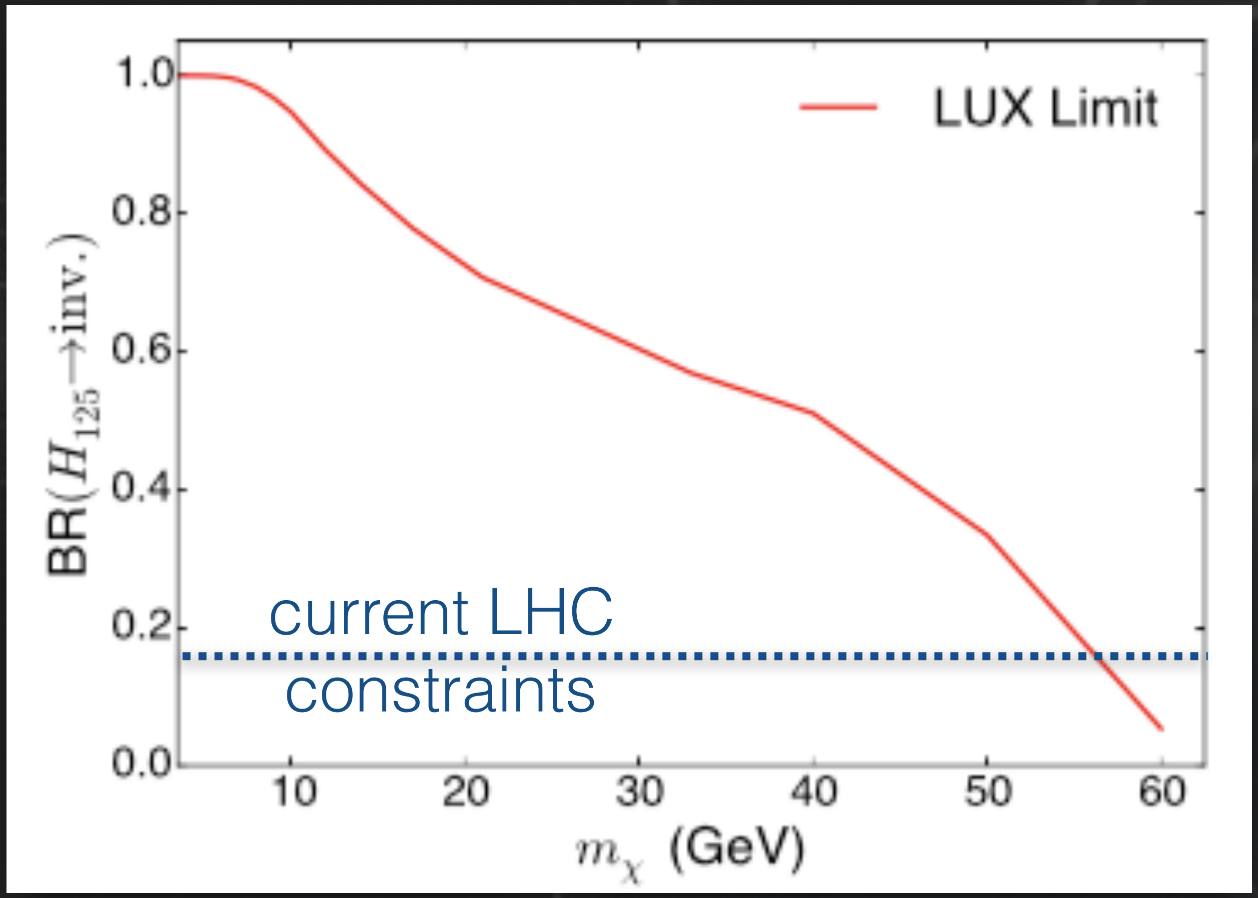
- Generic heavy spin 0/1 particle

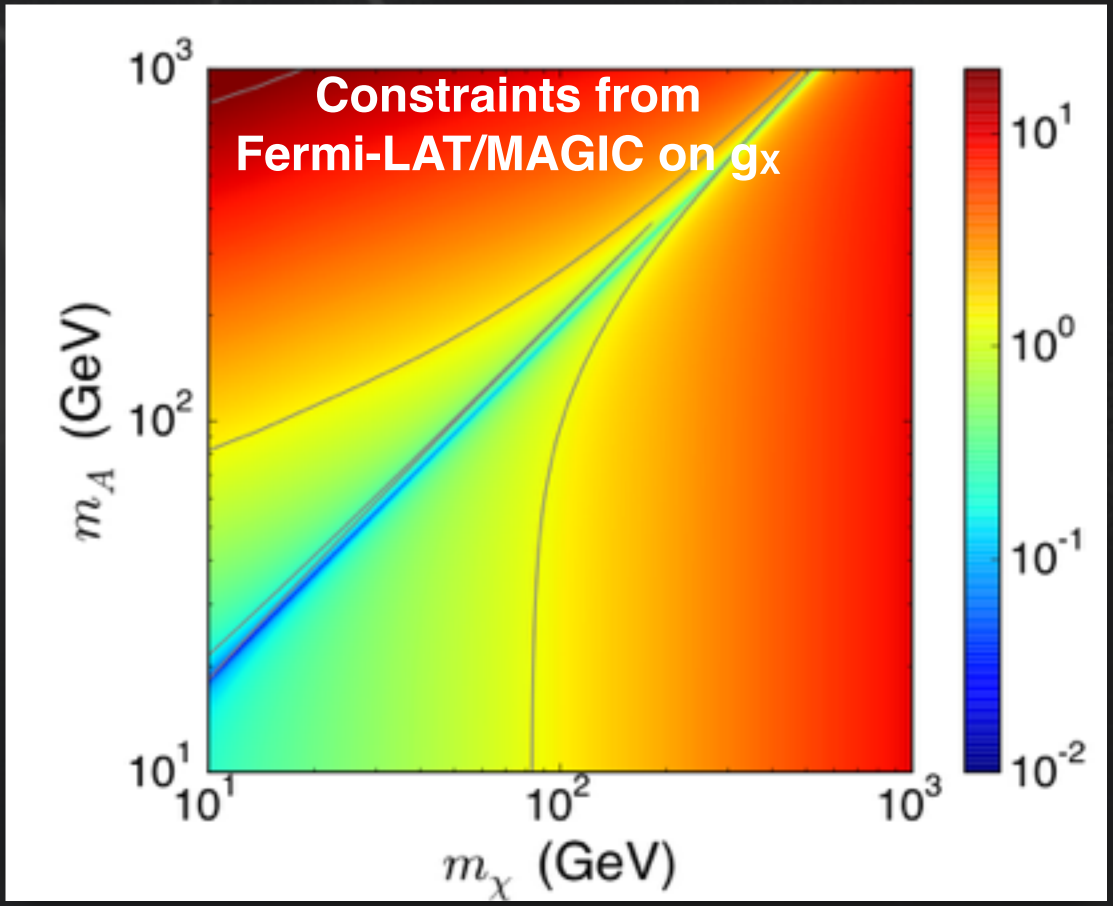
- Dim 5 - 7 EFT models with different Lorentz-Structure

Non-Collider constraints

arXiv:1603.07739
M. Buckley, P. Dunne, J. Brooke,
M. Zgubič, J. Tamanas, B.P

- We can use non-LHC results to constrain these results
  - Higgs is scalar → spin-independent (SI) direct detection cross sections
  - e.g direct / indirect detection constraints scalar/pseudoscalar models





- Typically constrain operators scales O(100-1000) GeV for DM masses O(10-1000) GeV

SM Higgs projections

arXiv:1603.07739
M. Buckley, P. Dunne, J. Brooke,
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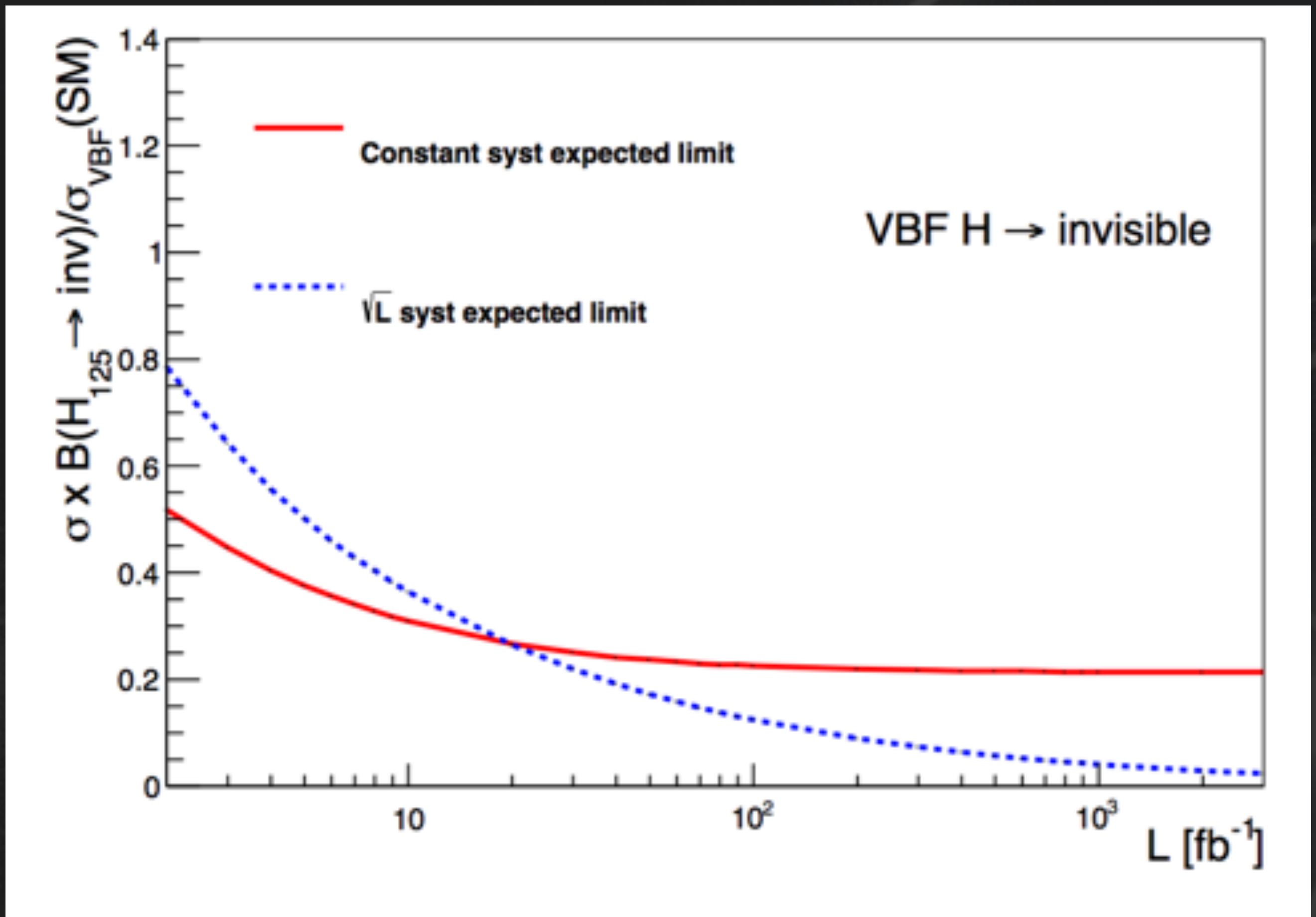
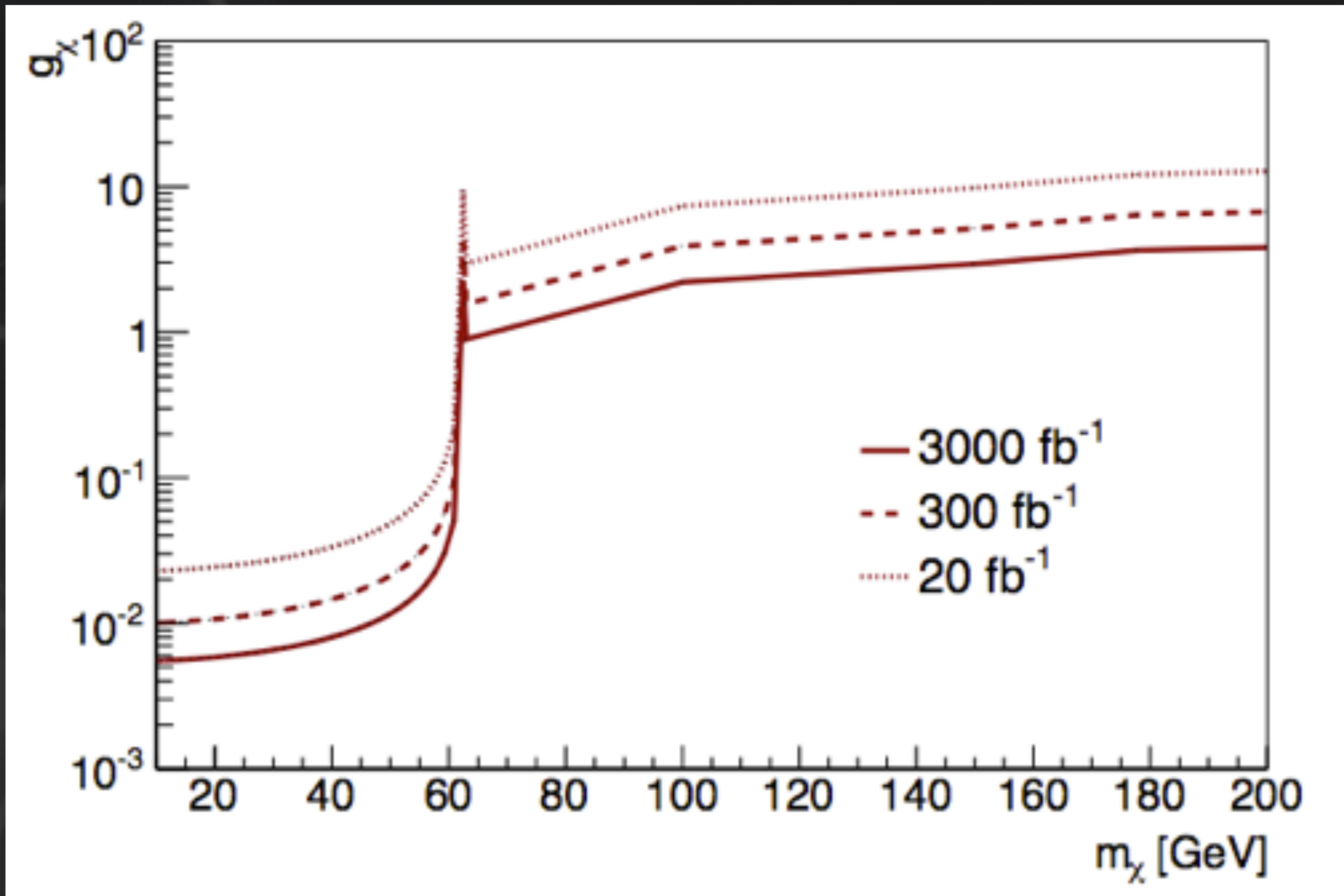


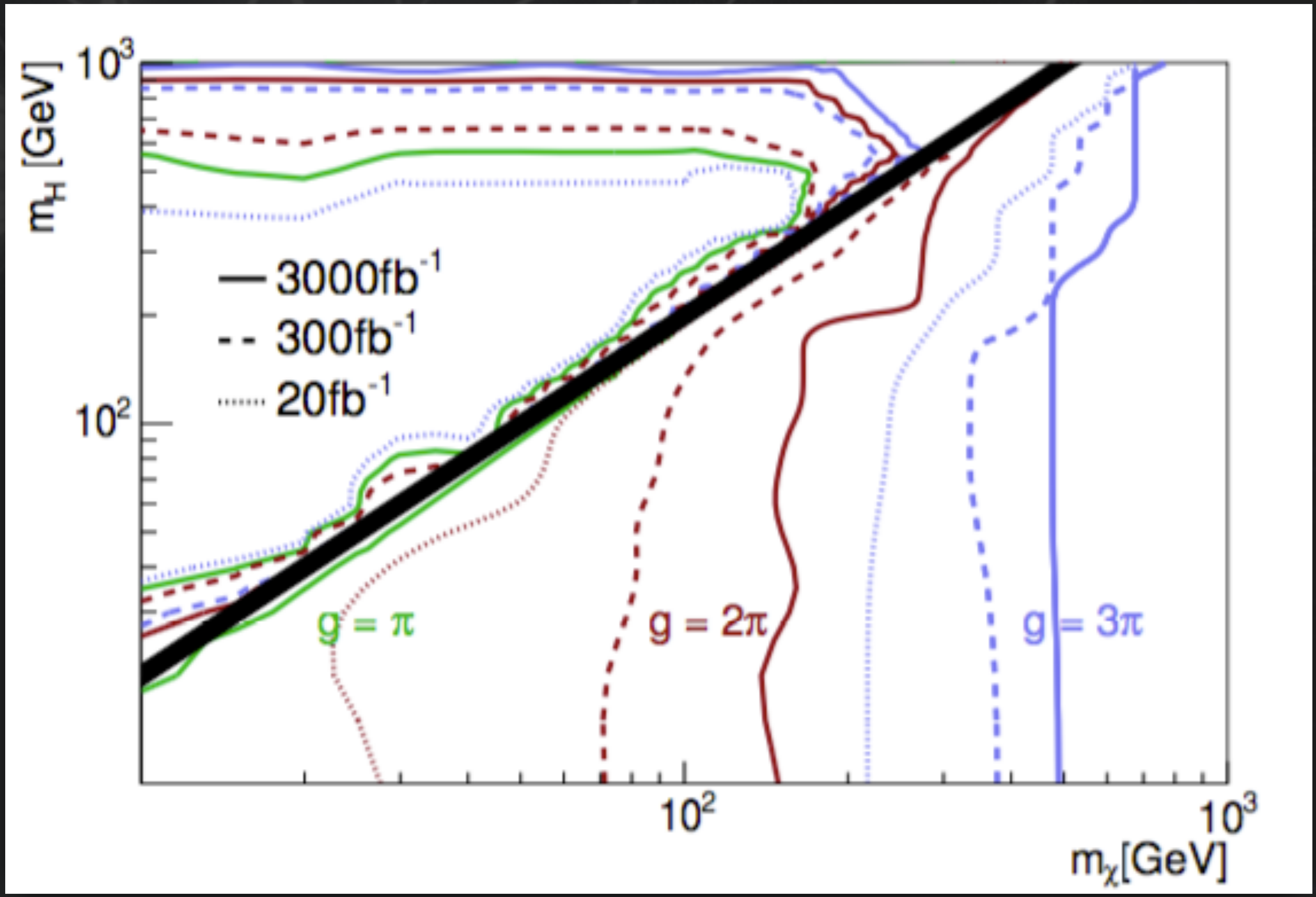


- Using realistic detector modeling to perform projections
  - 20/fb (this year)
  - 300/fb (Run 2/3)
  - 2/ab (full LHC run)
- Projected limits on B(H→inv.)~10-20% from VBF by the end of LHC Run 2 and 5% by end of LHC running assuming systematics scale as $\sqrt{\mathcal{L}}$

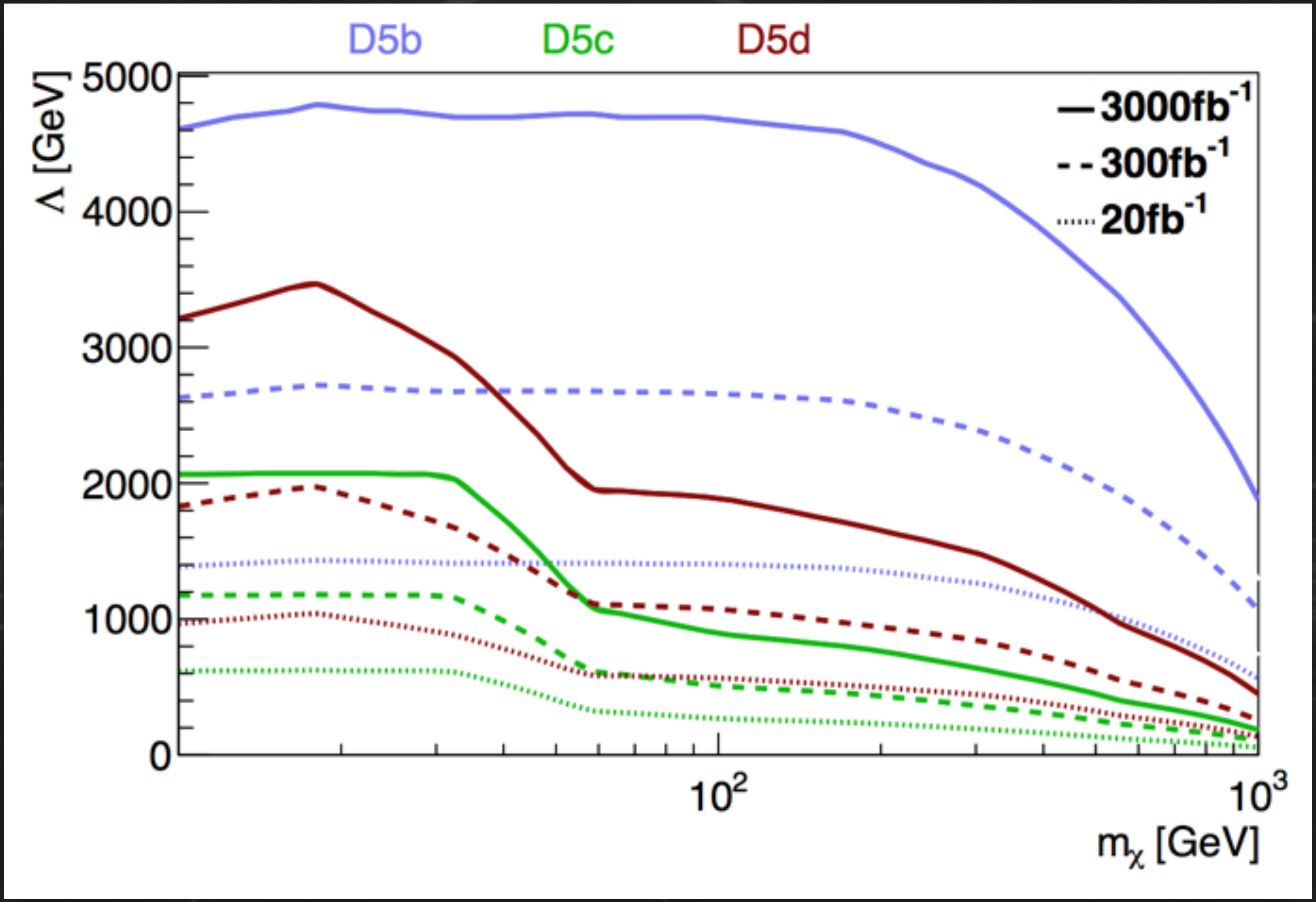
General mediator projections

- Collider can set the strongest bounds in on-shell region
- In off-shell region indirect (for pseudoscalars) and direct (for scalar) constraints more stringent than the projected collider limits.

- Quick decline of cross sections for off-shell production
  - Can lead to non-perturbative width
  - Addressable e.g. by extending the models, e.g addition decay products



EFT projections



- EFT mostly valid, hence VBF EFT is somewhat an outlier among mono-X searches
- Generally decreasing sensitivity to Λ as the dimensionality of the operators increases
  - Exceptions if DM produce via Z boson →more central jets → failing selection criteria

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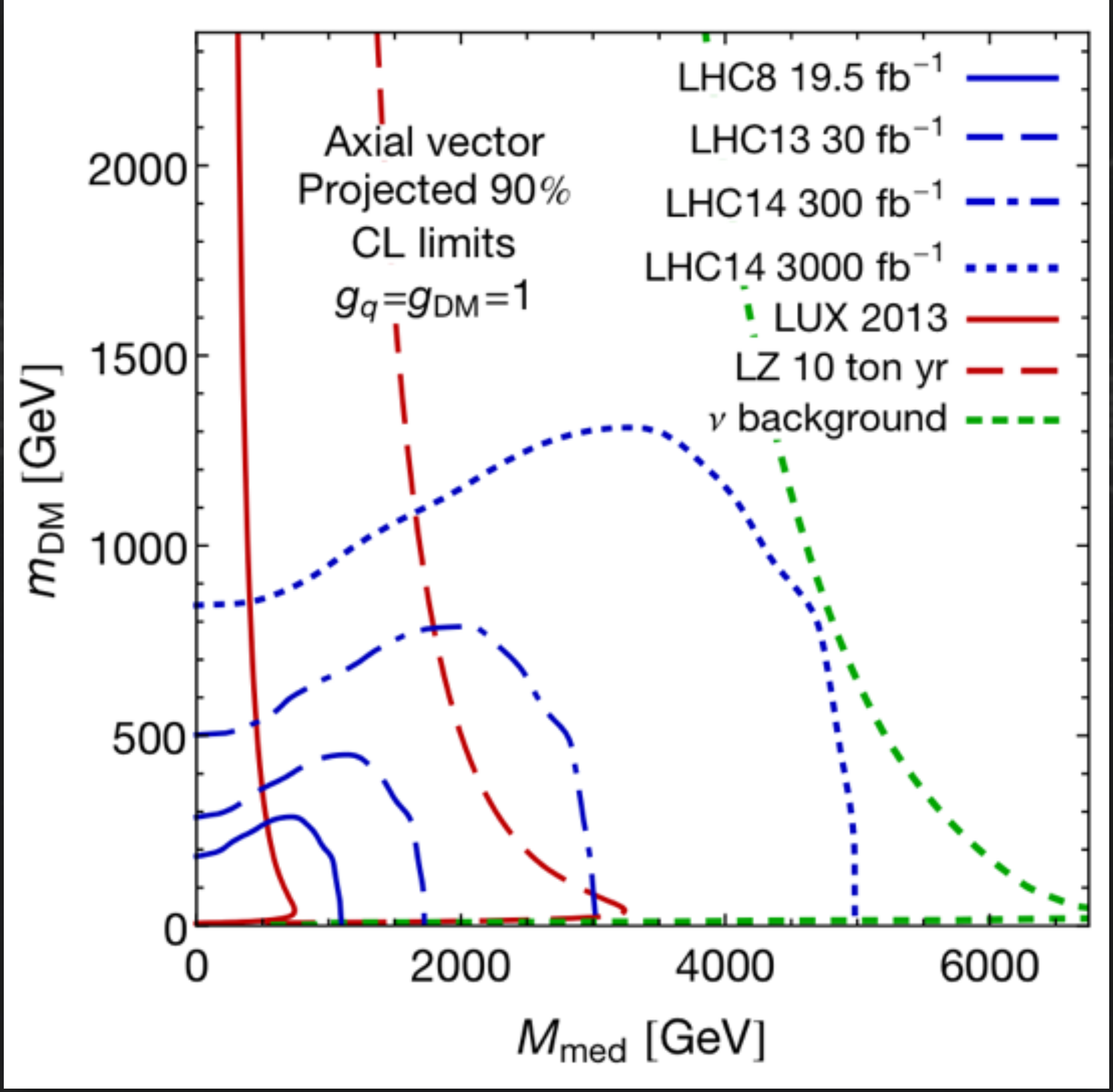
Future combined reach

V/A projections

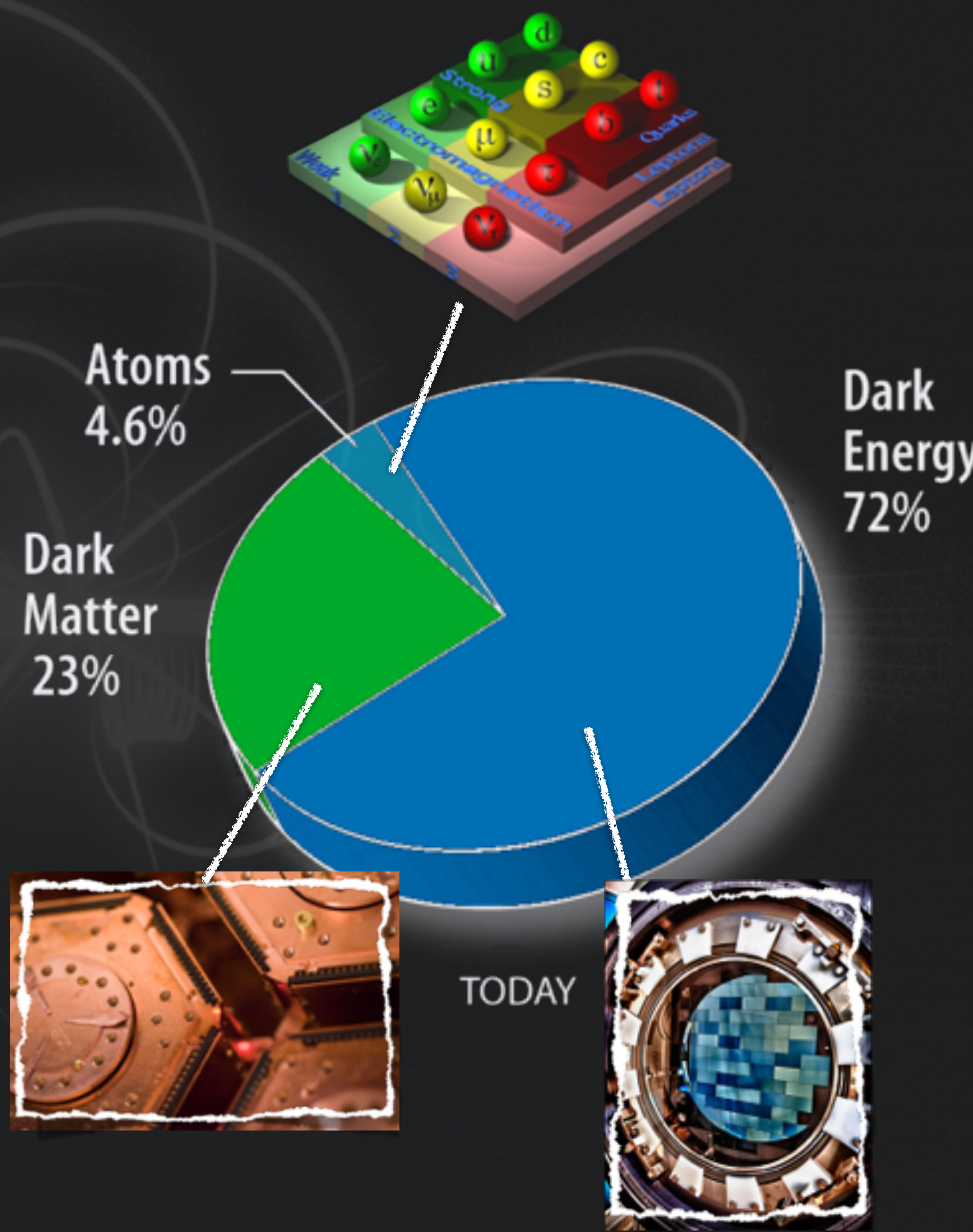
arXiv:1407.8257
Buchmueller et al

- Similar considerations possible for (axial-vector) searches
- Extrapolate reach of (axial-)vector models DD



Summary

- DM searches truly interdisciplinary field
  - DM has to be discovered in several fields to be confirmed and measured
- Example of scalar DM to demonstrate:
  - Improved collider searches to improve/ maintain acceptance
  - Importance of precision measurements
  - Complementarity of DM search approaches
- Collider contribute particularly at low masses
- Improve simplified models necessary: mixing, t-channel, etc
- Only combination will be able to exploit full potential



Backup

V/A projections

arXiv:1407.8257
Buchmueller et al

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