Simplified Dark Matter Models with Spin-2 Mediator @ LHC

Ursula Laa
LPSC Grenoble & LAPTh Annecy

based on [1701.07008]

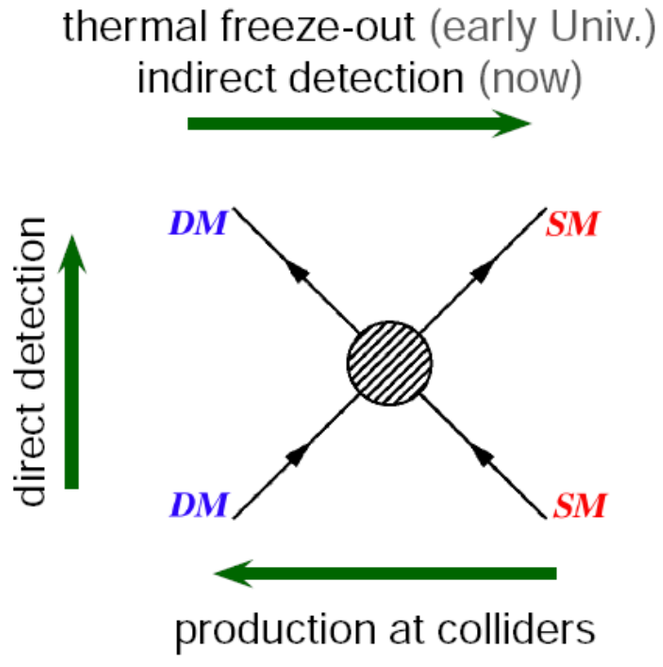
with Sabine Kraml, Kentarou Mawatari, Kimiko Yamashita

Open Questions in Particle Physics and Cosmology
April 2017

Dark Matter Searches

Searching for WIMPs

- Direct Detection
- Indirect Detection
- Production at Collider



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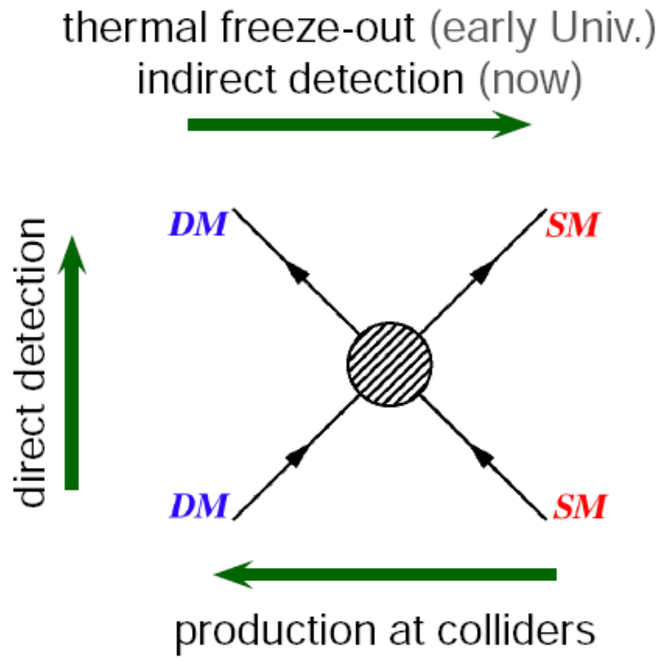

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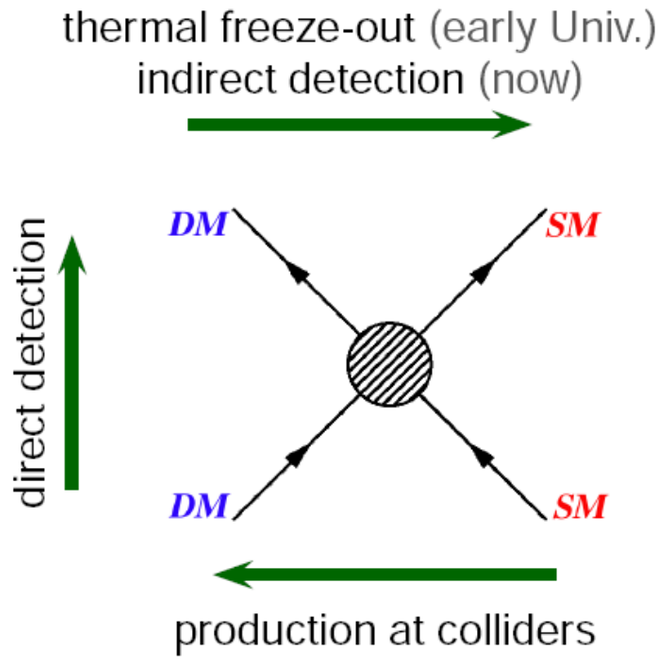

LHC Searches

- SUSY searches: many new particles, cascade decay to DM candidate (jets and/or leptons + missing energy)
- Minimal dark matter searches: DM candidate (missing energy) + Initial State Radiation (monojet, monophoton)

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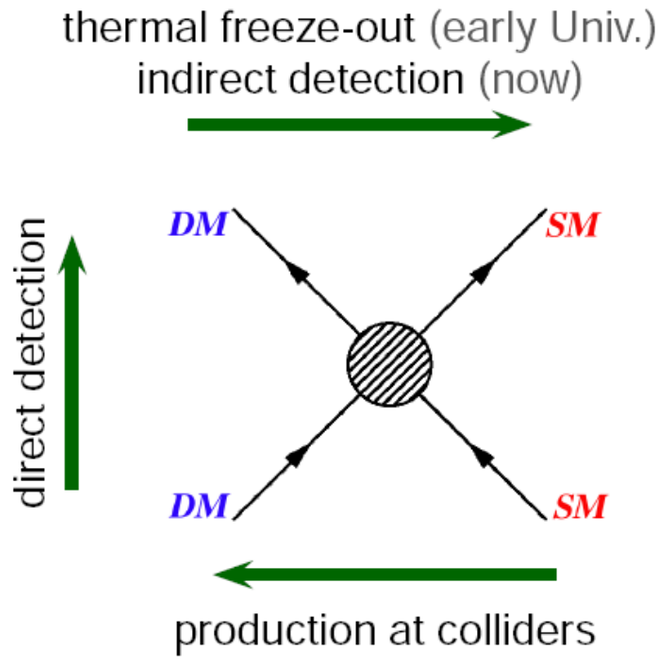

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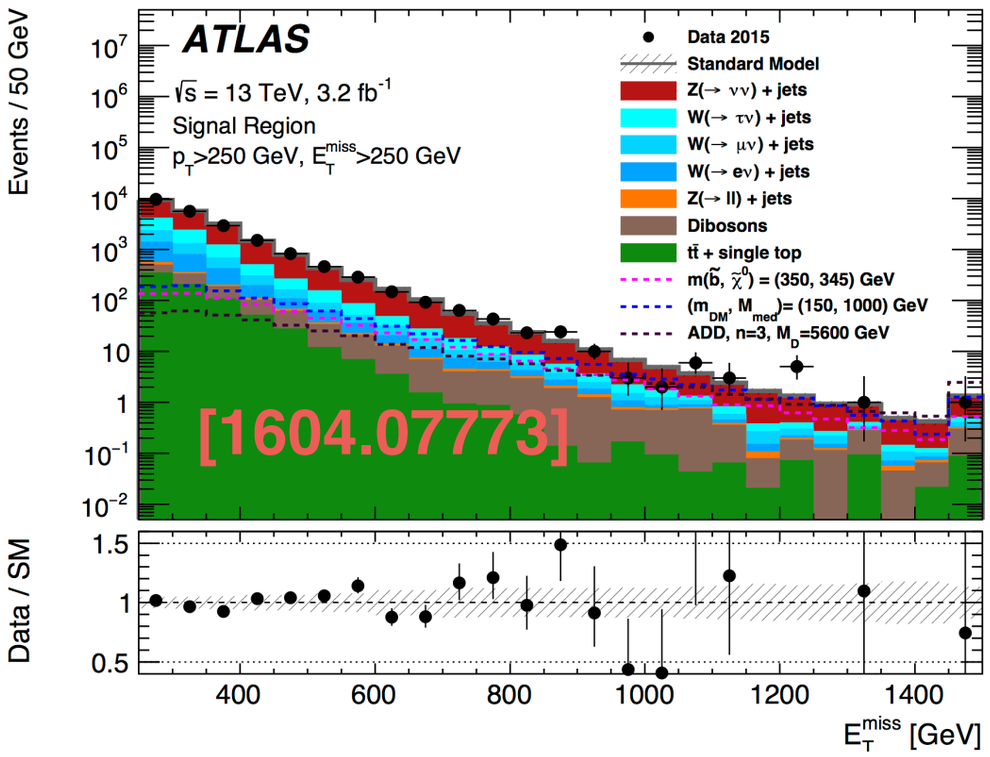
Interpretation of Minimal DM searches



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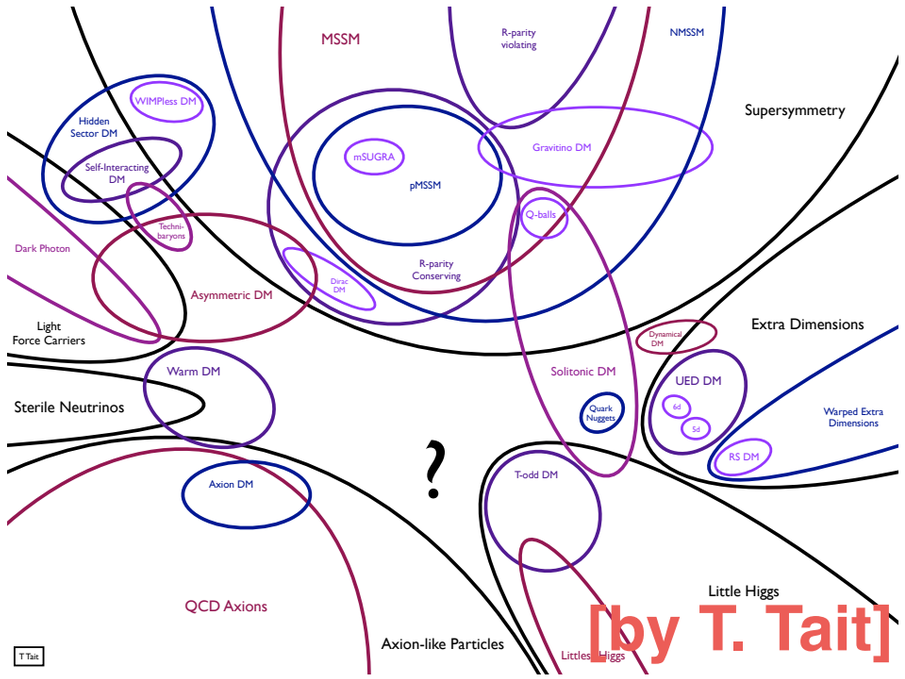
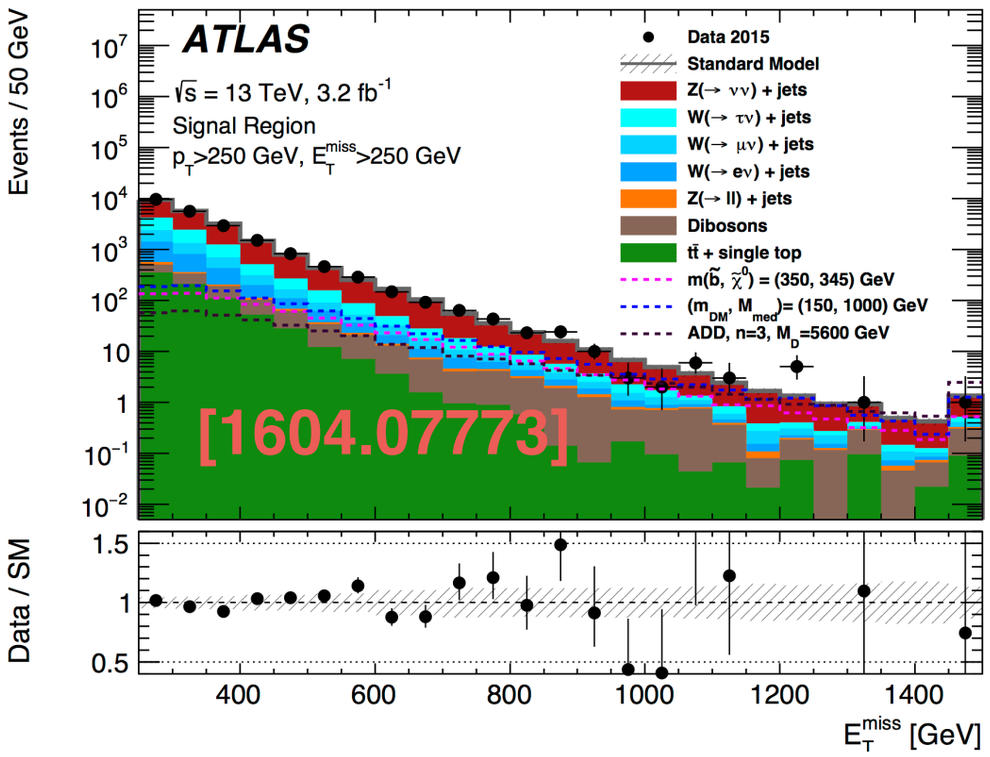


Need “sketch” of models to

- efficiently design and tune search strategies
- compare results from different searches
- derive limits that are meaningful in generic models (without introducing large model dependence)
- (help identify the underlying description)

Interpretation of Minimal DM searches



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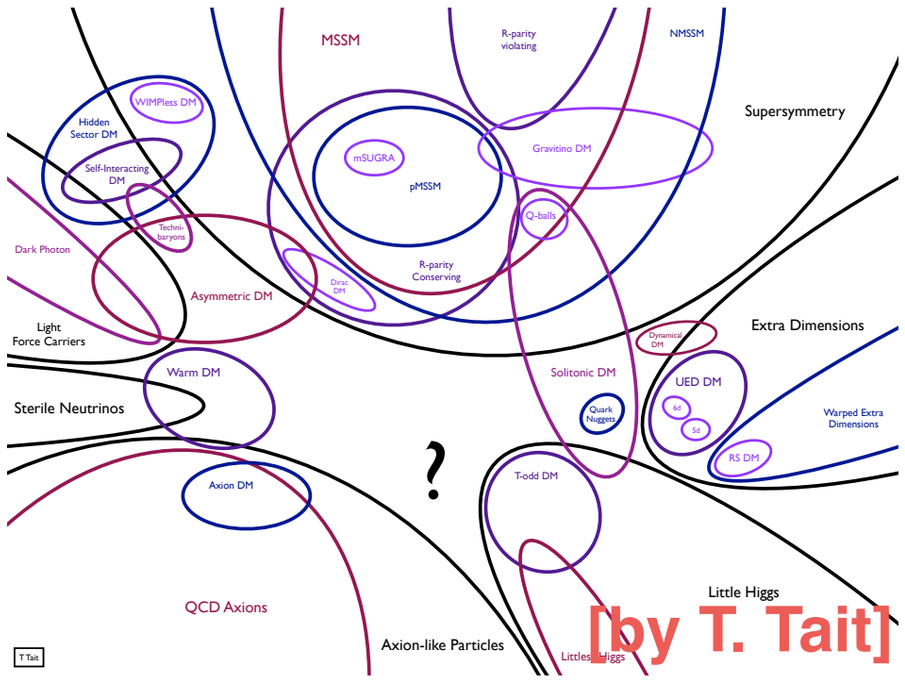
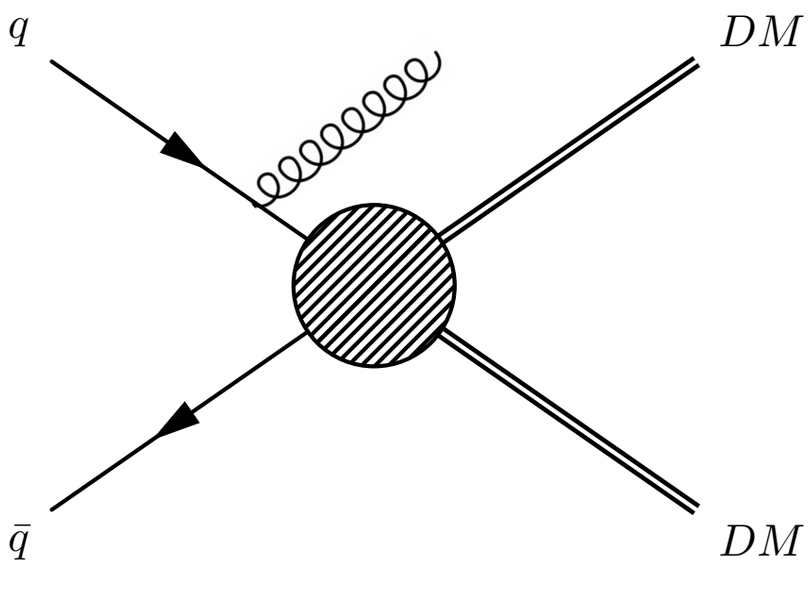


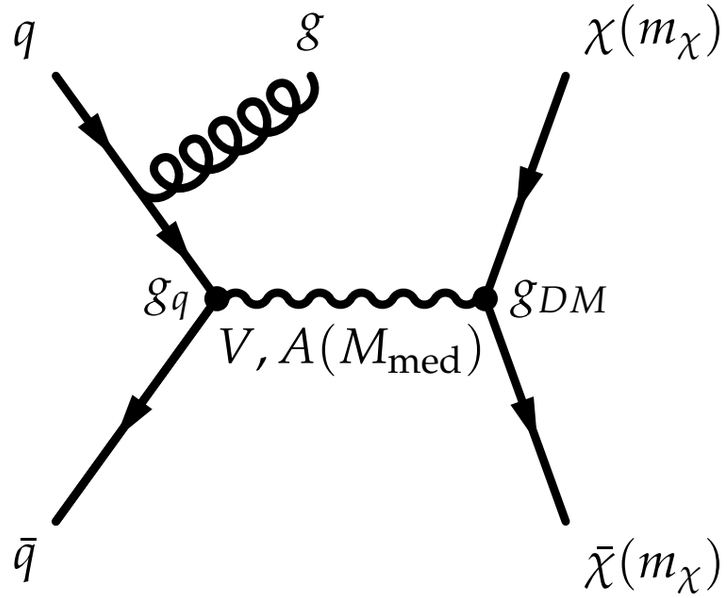
- Need model that
  - has small parameter space
  - parameters are phenomenological
  - captures key kinematics relevant at the LHC

- Minimal approach: contact interaction (EFT)
- More complete: Simplified Model with explicit mediator

EFT vs Simplified Model

for the example of (axial) vector coupling / s-channel mediator





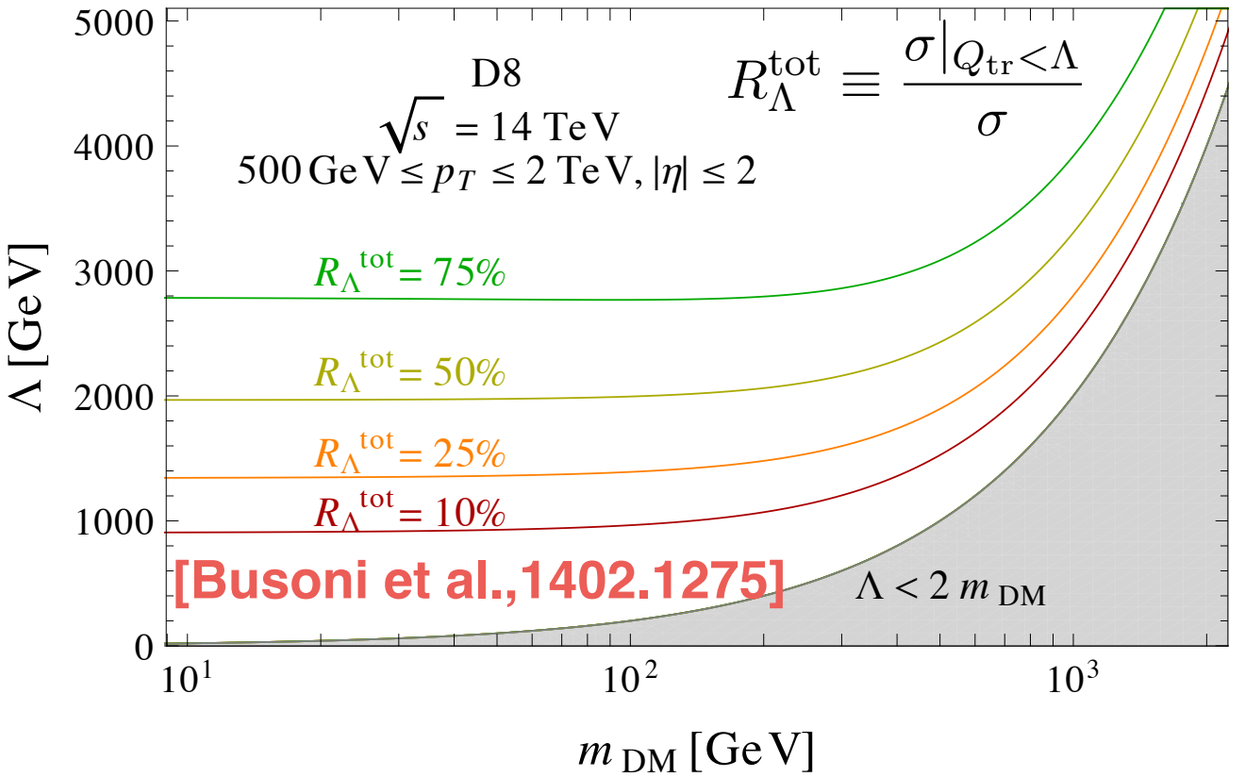
$$\text{vector}: \quad \frac{\bar{\chi}\gamma_\mu\chi\,\bar{q}\gamma^\mu q}{\Lambda^2}$$

$$\text{axial-vector}: \quad \frac{\bar{\chi}\gamma_\mu\gamma^5\chi\,\bar{q}\gamma^\mu\gamma^5 q}{\Lambda^2}\,.$$

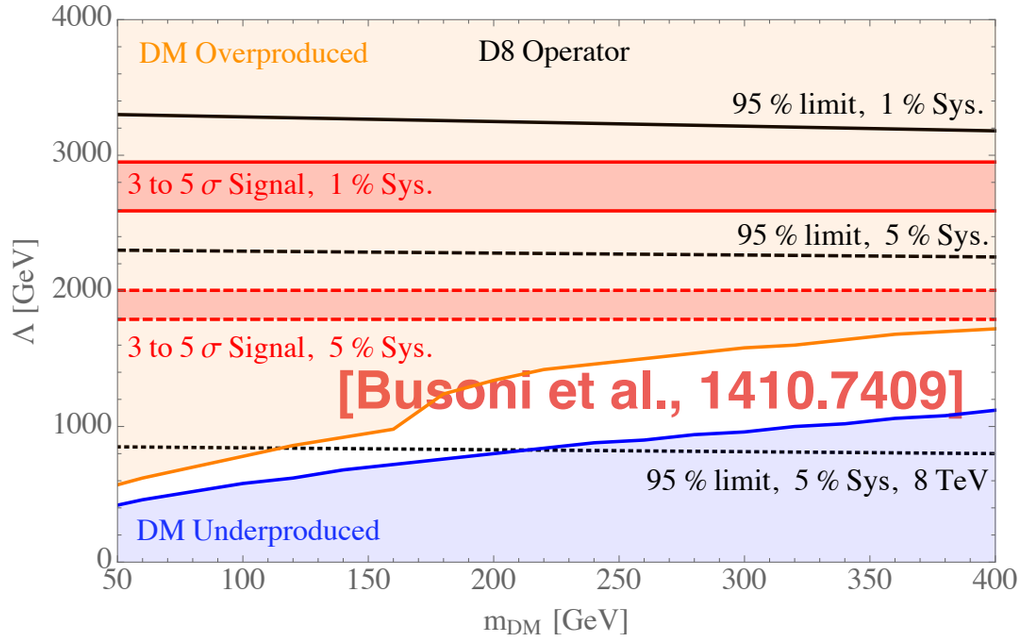
$$\mathcal{L}_{\rm vector} = g_{\rm q}\sum_{q=u,d,s,c,b,t} Z'_\mu\bar{q}\gamma^\mu q + g_\chi Z'_\mu\bar{\chi}\gamma^\mu\chi$$

$$\mathcal{L}_{\rm axial-vector} = g_{\rm q}\sum_{q=u,d,s,c,b,t} Z'_\mu\bar{q}\gamma^\mu\gamma^5 q + g_\chi Z'_\mu\bar{\chi}\gamma^\mu\gamma^5\chi.$$

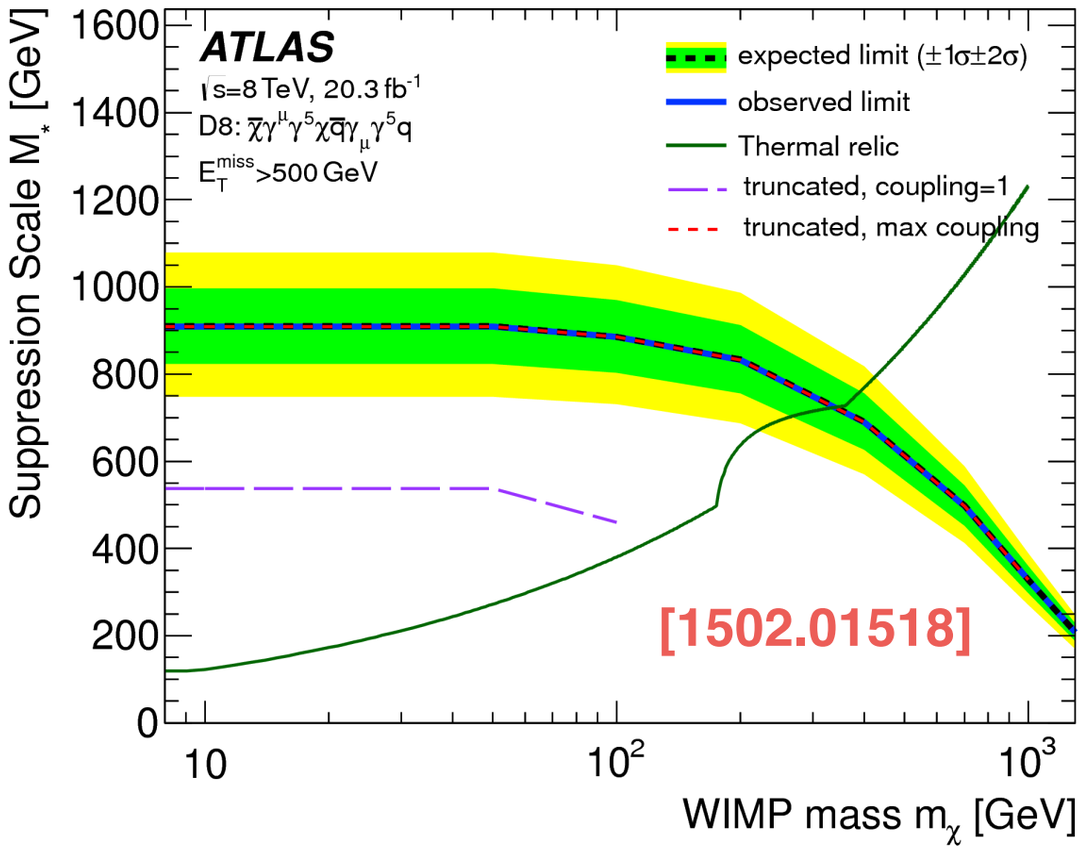
When is the EFT approximation valid?
Does it describe a viable thermal DM candidate?
Does the EFT description capture the relevant kinematics?



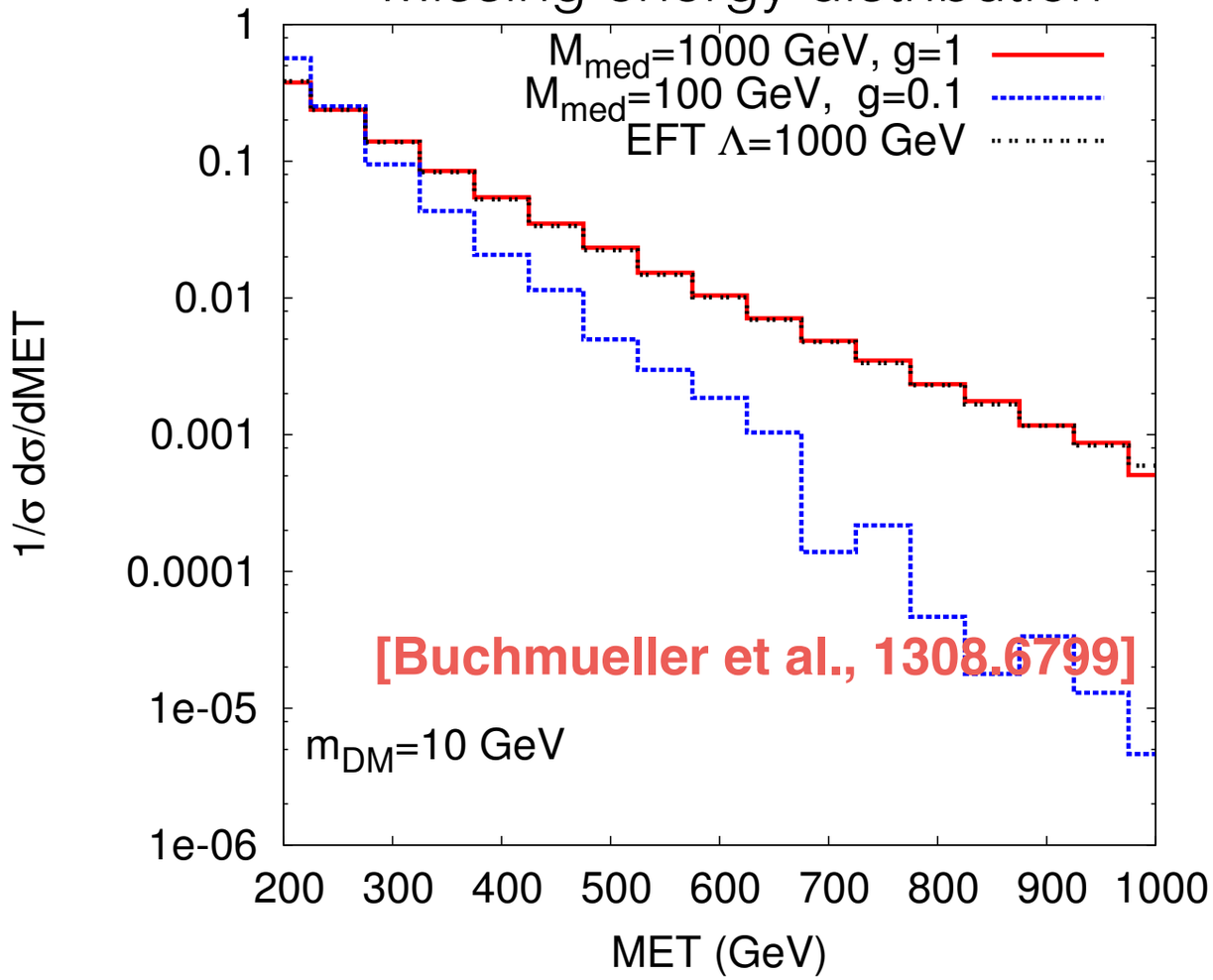
Relic density consideration



Typical limits from ATLAS

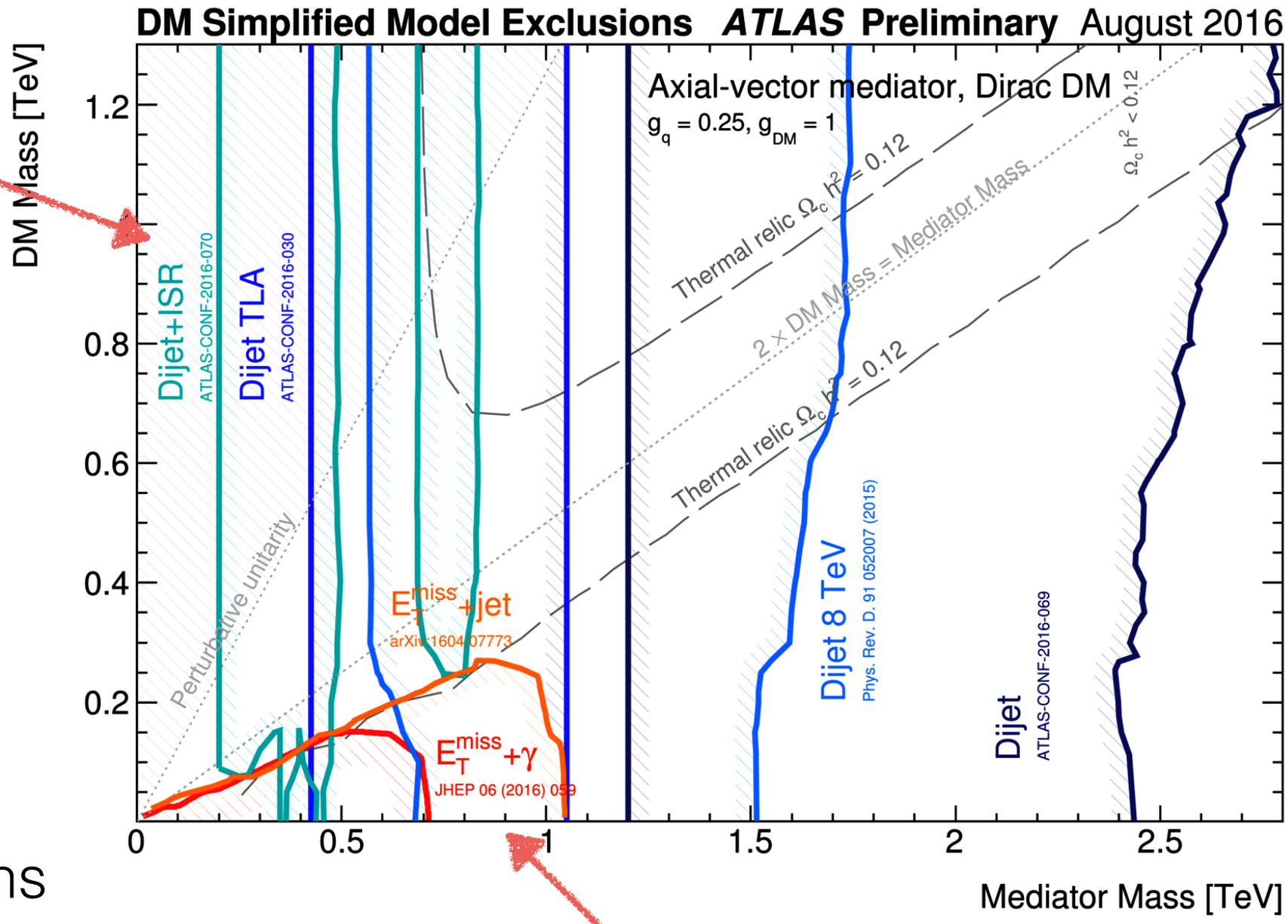


Missing energy distribution



Presentation of Simplified Model Interpretation

Searches for Mediator decays to jets (depend mainly on mediator mass, new techniques to constrain light resonances)



Searches for DM production, Run 2 (mostly constraining on-shell region)

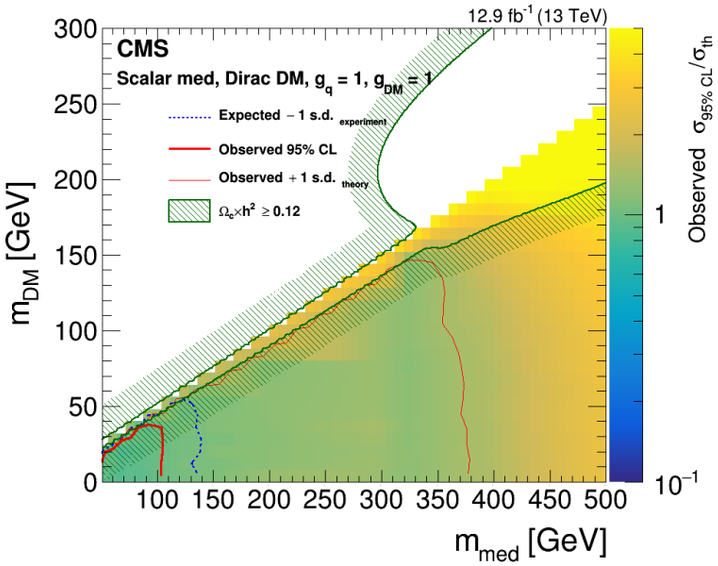
Coupling to leptons should also be considered, see e.g.

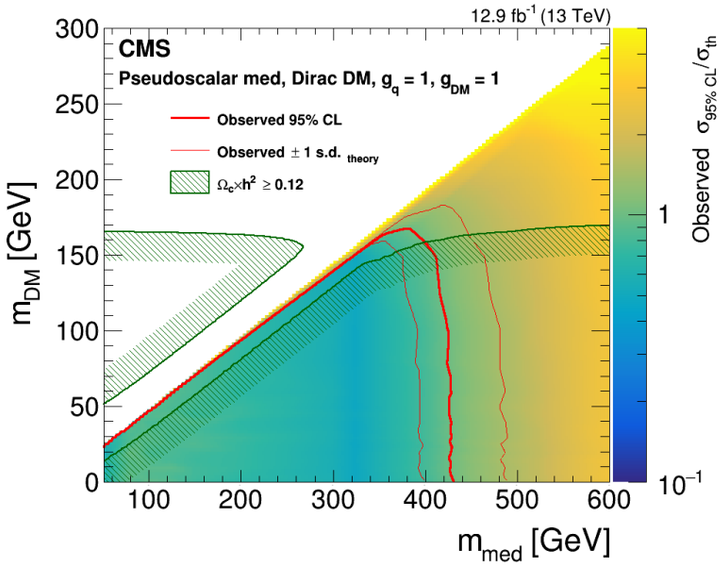
[LHC DMWG, 1703.05703]

Simplified Model Interpretations by CMS Jet(s) + MET search

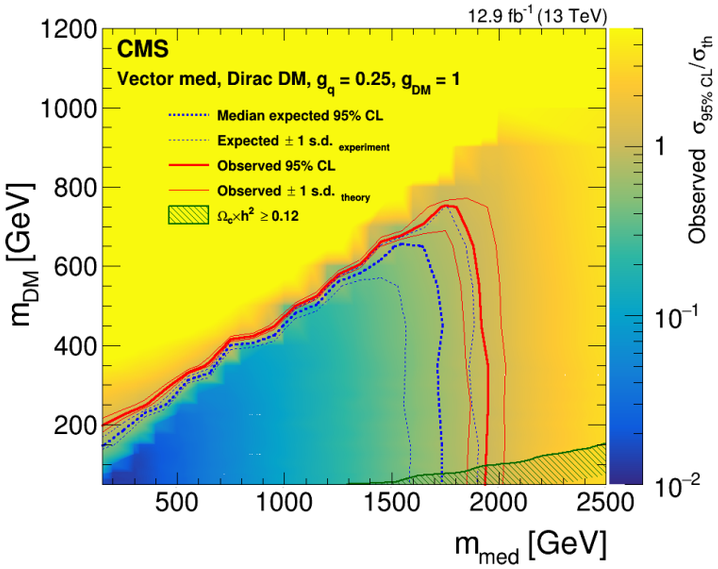
[1703.01651]

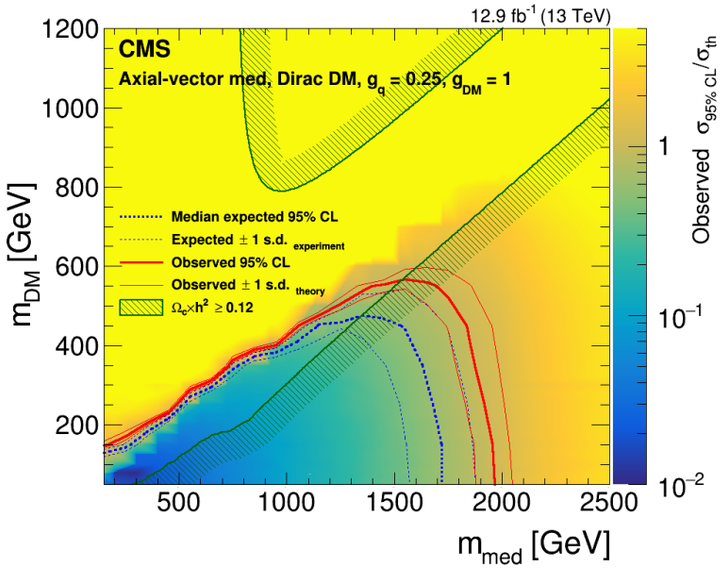
Spin-0





Spin-1





- Covering (pseudo)scalar and (axial)vector s-channel mediator scenarios
- What about **Spin-2** s-channel mediator? ➡ this work

Gravity Mediated Dark Matter

[Lee, Park, Sanz 1306.4107]

Consider warped extra dimension models

* KK graviton or radion can mediate interactions between SM and DM
* in 4-D the effective Lagrangian is given as

$$\mathcal{L}_{\rm KK} = -\frac{c_i^G}{\Lambda} G_{\mu\nu}\, T_i^{\mu\nu} + \frac{c_i^r}{\sqrt{6}\Lambda} r\, T_i$$

with

* Λ the compactification scale related to the geometry
* the couplings $c_i^{G,r}$ are determined by the overlap of the wave functions in the bulk

→ the parameters are strongly model dependent, instead we consider a phenomenological Simplified Model

Simplified Model with Spin-2 Mediator

Spin-2 mediator Y_2 couples to scalar/fermionic/vector dark matter X as

$$\mathcal{L}_X^{Y_2} = -\frac{1}{\Lambda} g_X^T \, T_{\mu\nu}^X Y_2^{\mu\nu}$$

and to SM particles

$$\mathcal{L}_{\rm SM}^{Y_2} = -\frac{1}{\Lambda} \sum_i g_i^T \, T_{\mu\nu}^i Y_2^{\mu\nu}$$

Considering universal coupling to all SM particles we have 4 free parameters

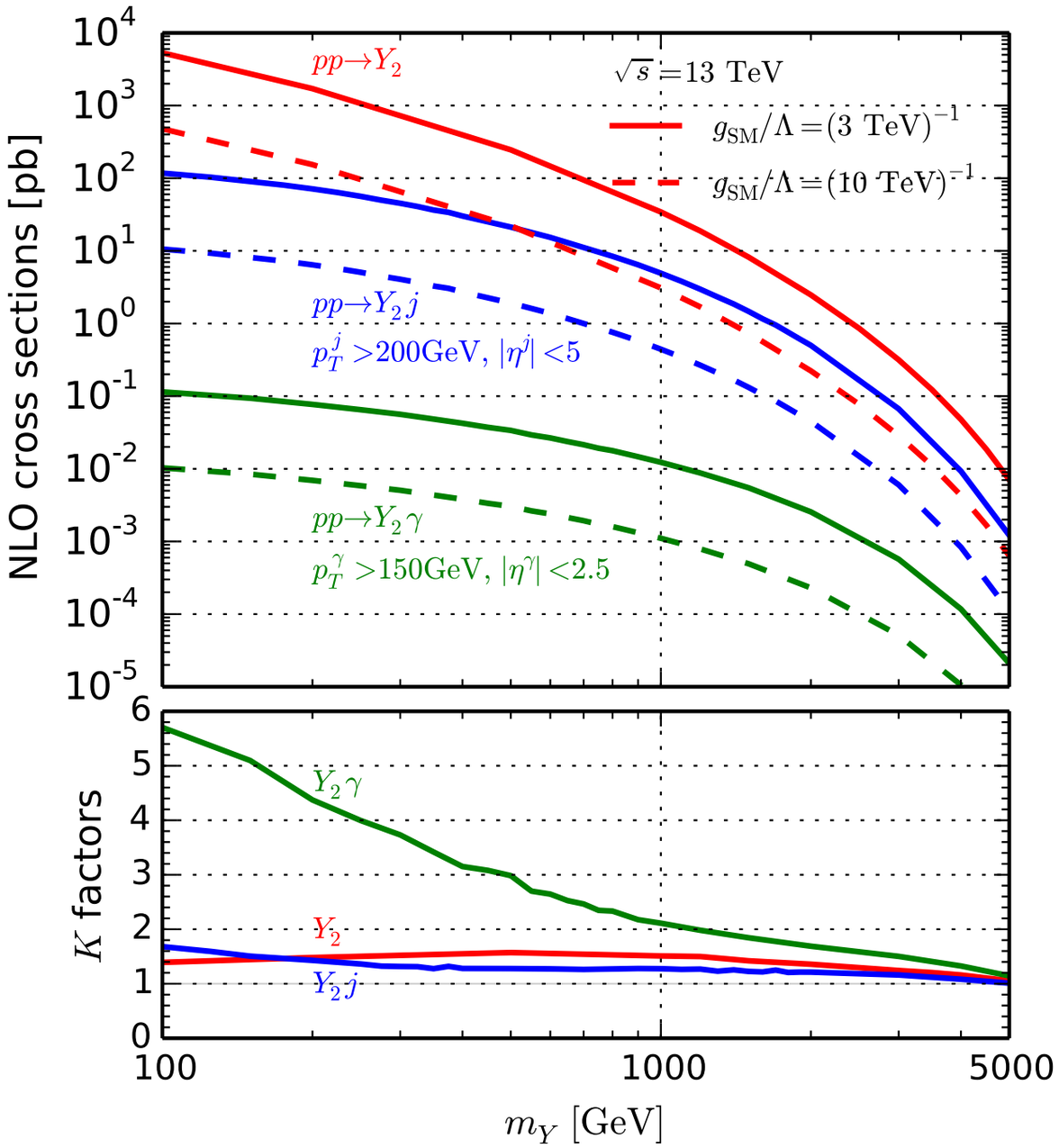
$$\{m_X,\, m_Y,\, g_X/\Lambda,\, g_{\rm SM}/\Lambda\}$$

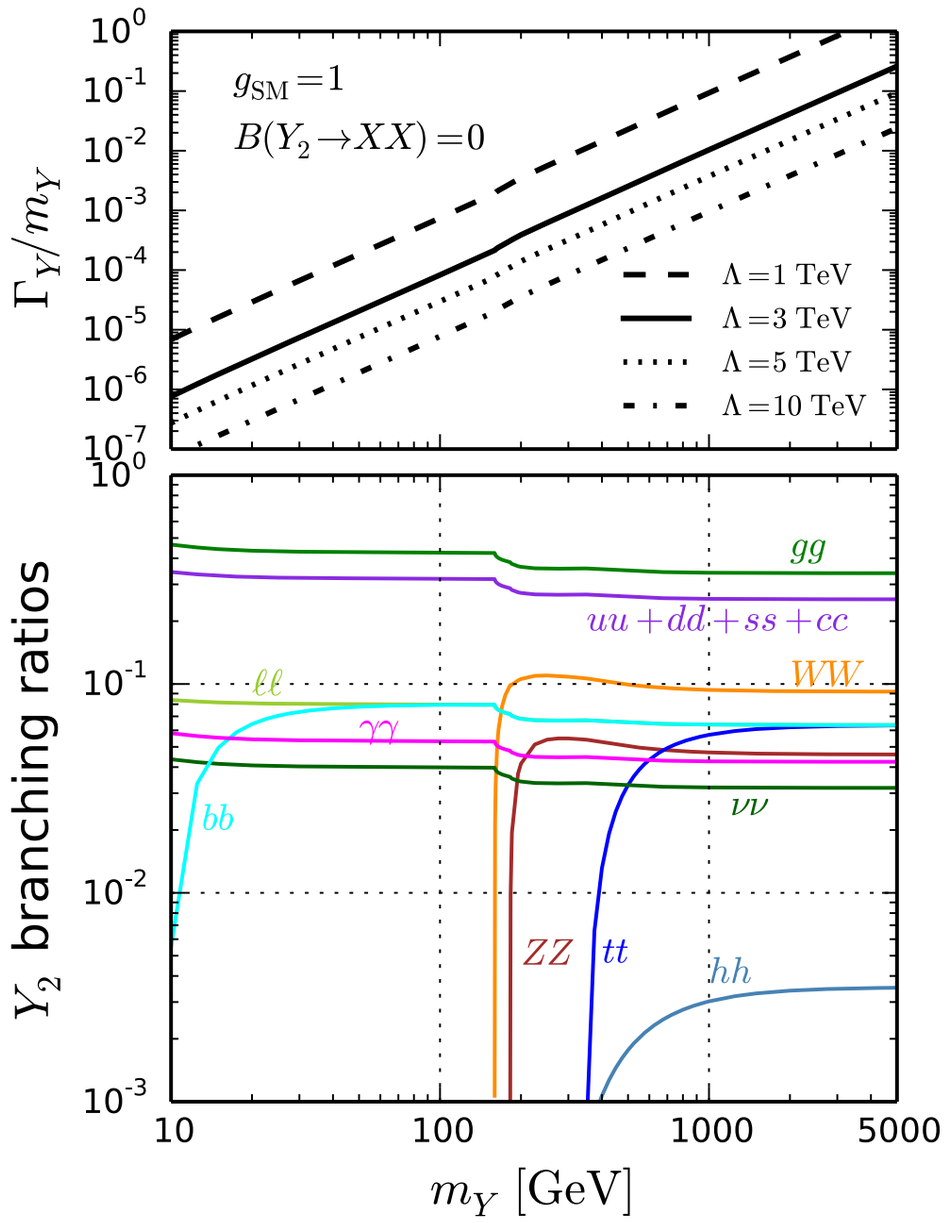
rescaling parameter, not EFT cutoff scale!

How is this set of parameters constrained by LHC searches?

Y_2 Production and Decay

using K factors according to [Das et al., 1605.09359]

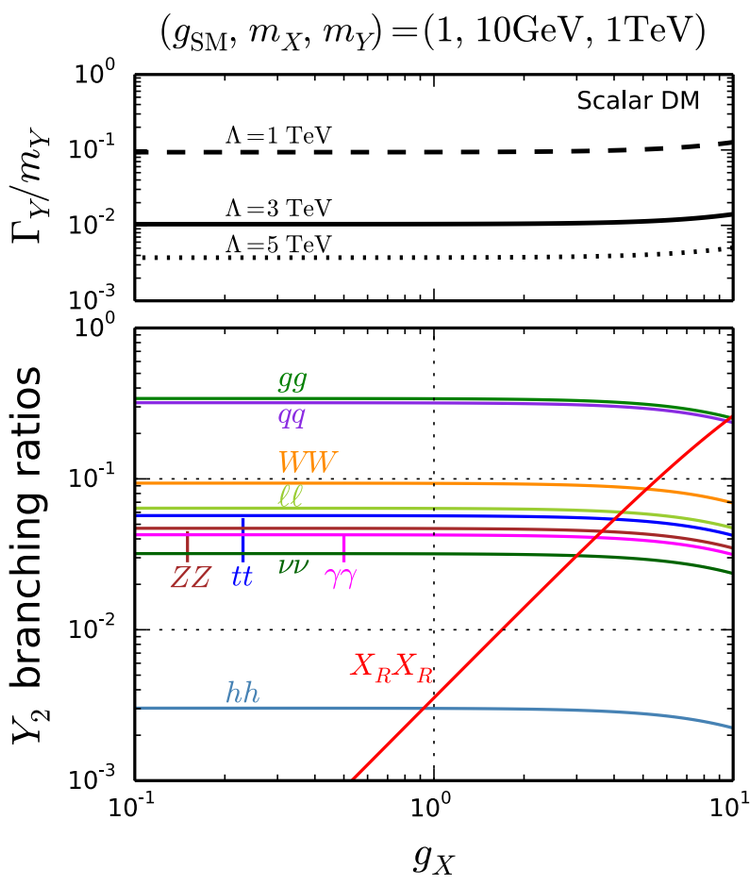




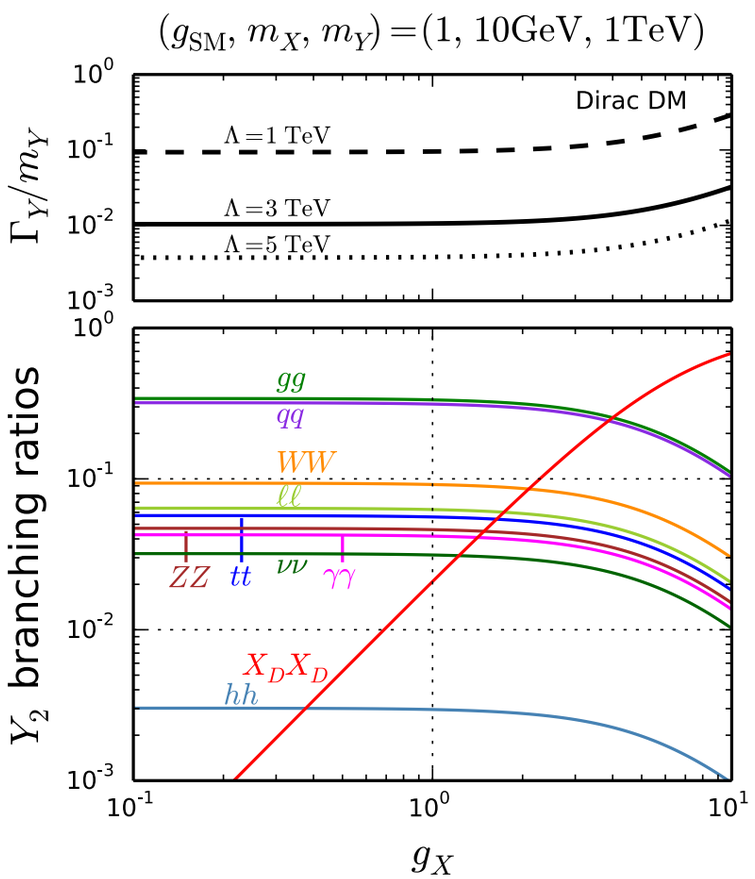
- Cross sections scale as $(g_{SM}/\Lambda)^2$
- $Y_2\gamma$ suppressed (dominantly gluon initial state)
- Narrow width for $\Lambda \geq 3\text{TeV}$

Y_2 Decay with DM

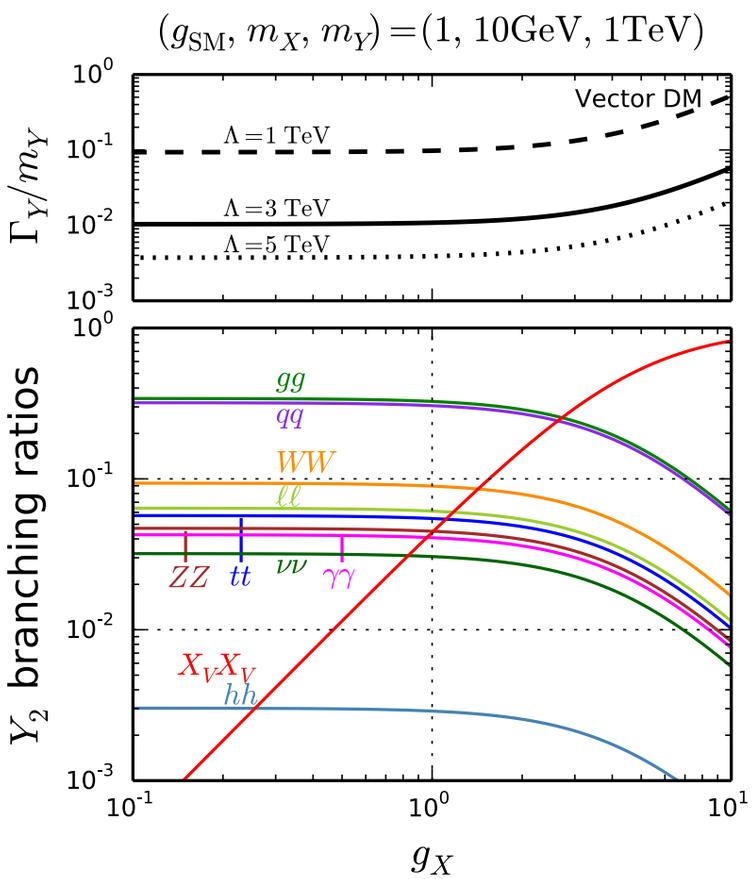
Scalar DM



Dirac DM



Vector DM



- Branching ratio into DM strongly depends on the nature of the DM particle
- Decay into neutrinos similar/more important for small g_X
- Decays into SM particles suppressed for very large g_X

Constraints from LHC DM Searches

- Consider jet(s)+MET searches at 13 TeV (3.2 fb^{-1})
- High hadronic activity → similar sensitivities in monojet or multijet + MET searches, we consider the ATLAS searches
  - **Monojet + MET** [1604.07773]
    - Up to 4 hard jets, requiring $p_T(j_1) > 250\text{GeV}$
    - Signal regions defined by different MET cuts
  - **Multijet + MET** [1605.03814]
    - e.g. SR 2jm:

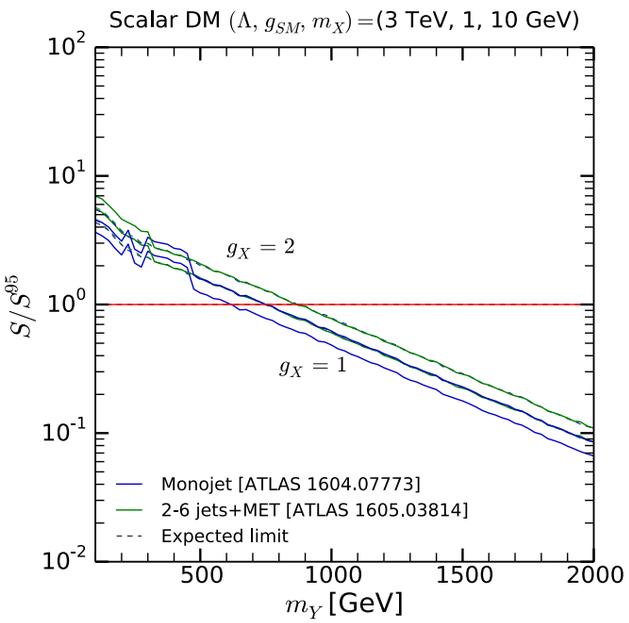
$$p_T(j_1) > 300\text{GeV} \quad E_T^{miss} > 200\text{GeV}$$
$$p_T(j_2) > 50\text{GeV}$$

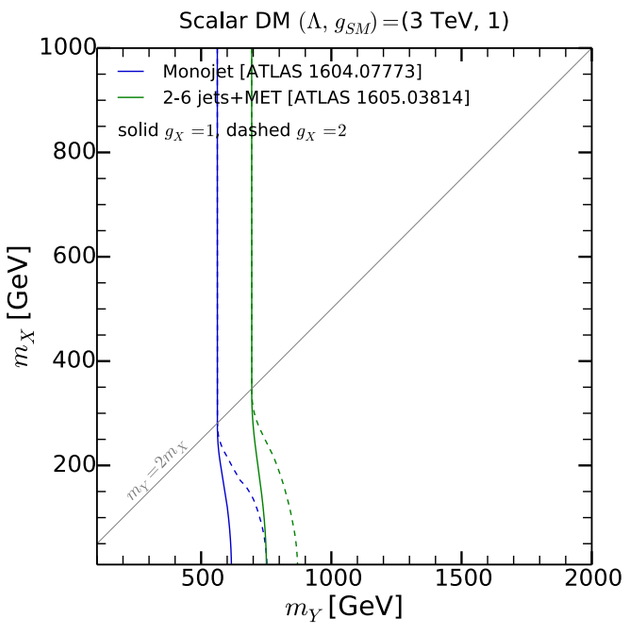
- Consider both DM and neutrino contributions
- Generate events with up to two matrix element jets in MG5
- Use CheckMATE2 (+Delphes and Fastjet) for the recasting

Results $(\Lambda, g_{SM}) = (3\ \mathrm{TeV}, 1)$

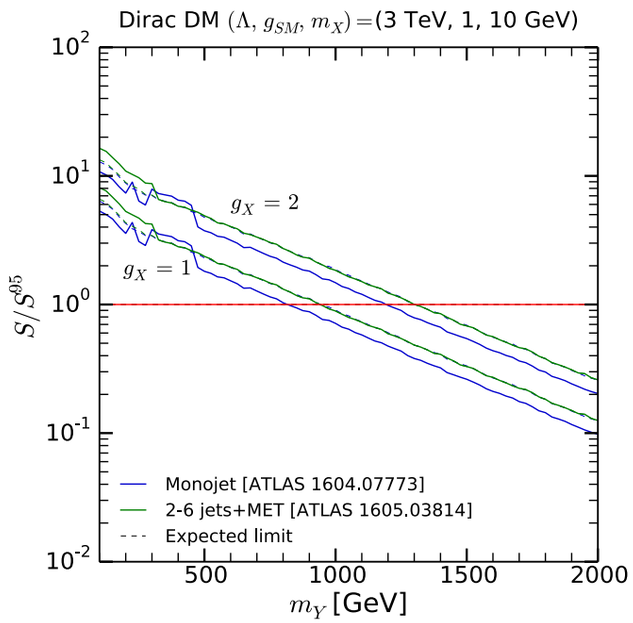
obtained with CheckMATE2

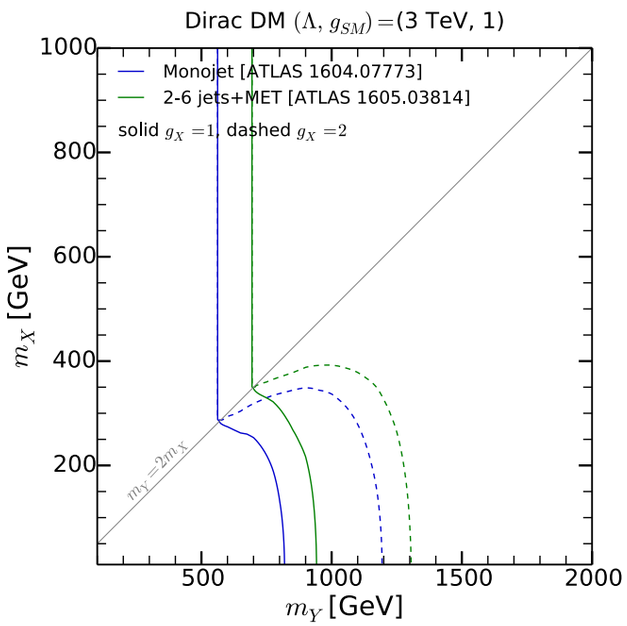
Scalar DM





Dirac DM





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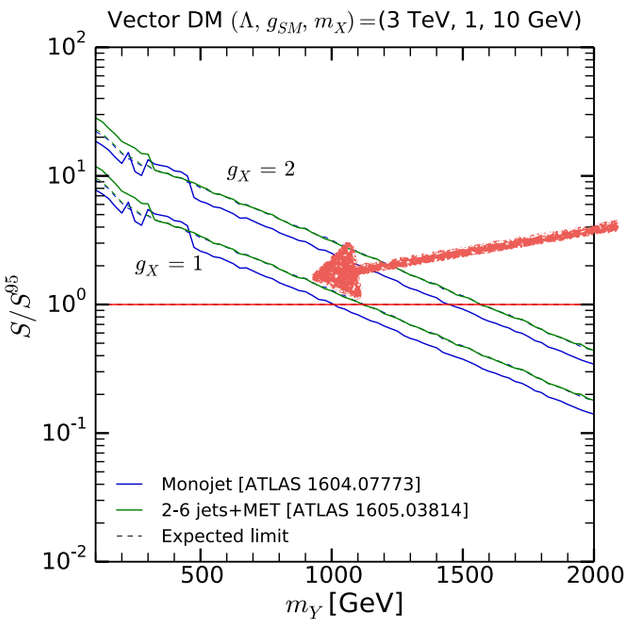
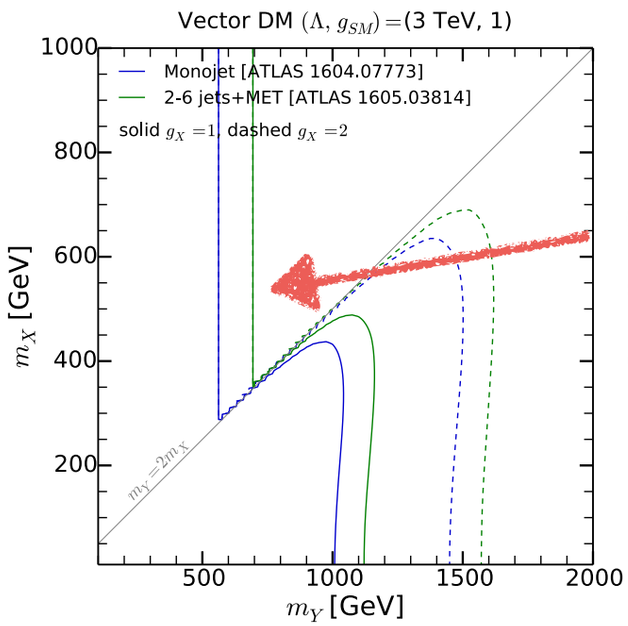
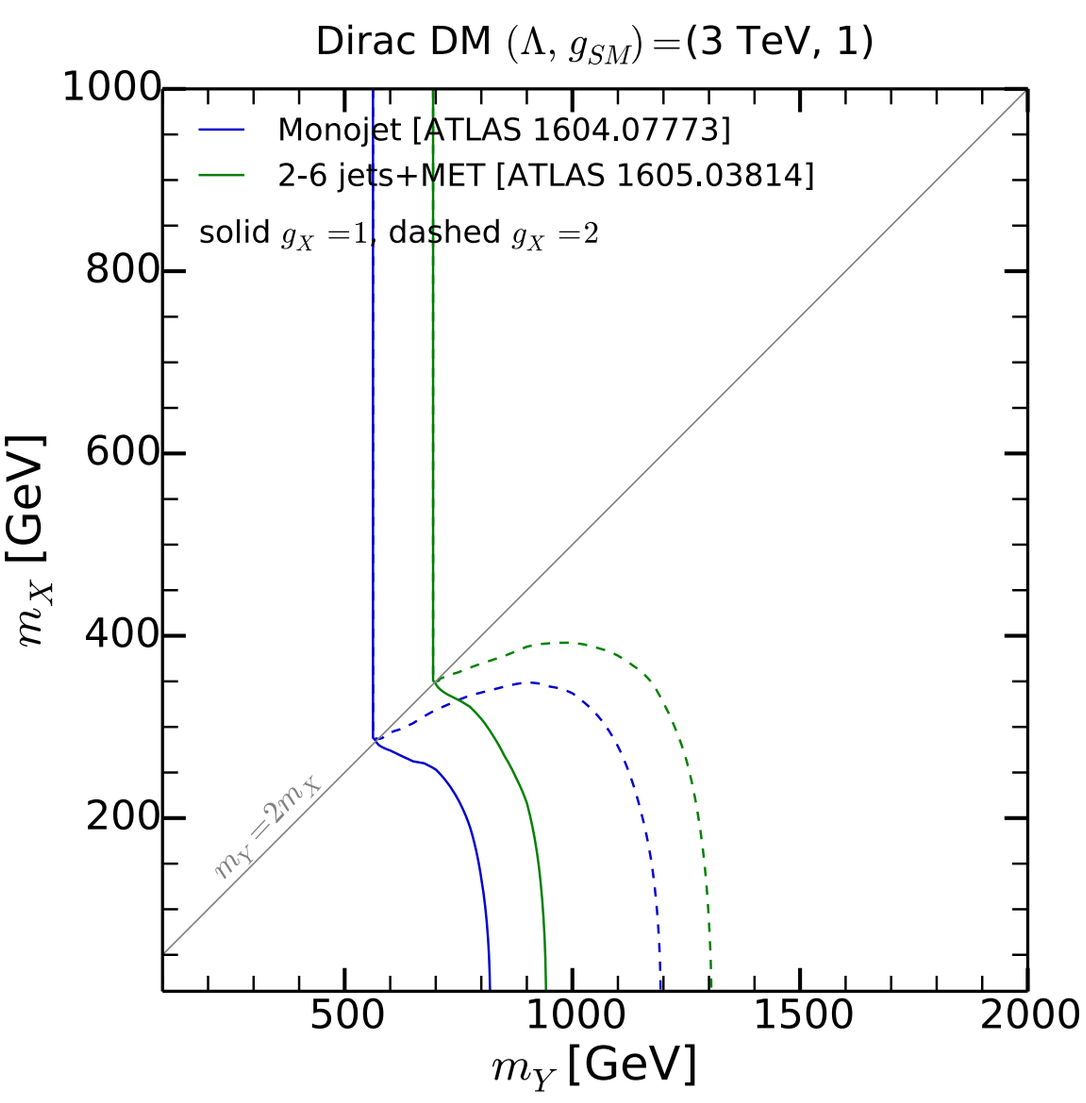




similar expected limits from monojet and multijet search!

off-shell region constrained from decays to neutrinos

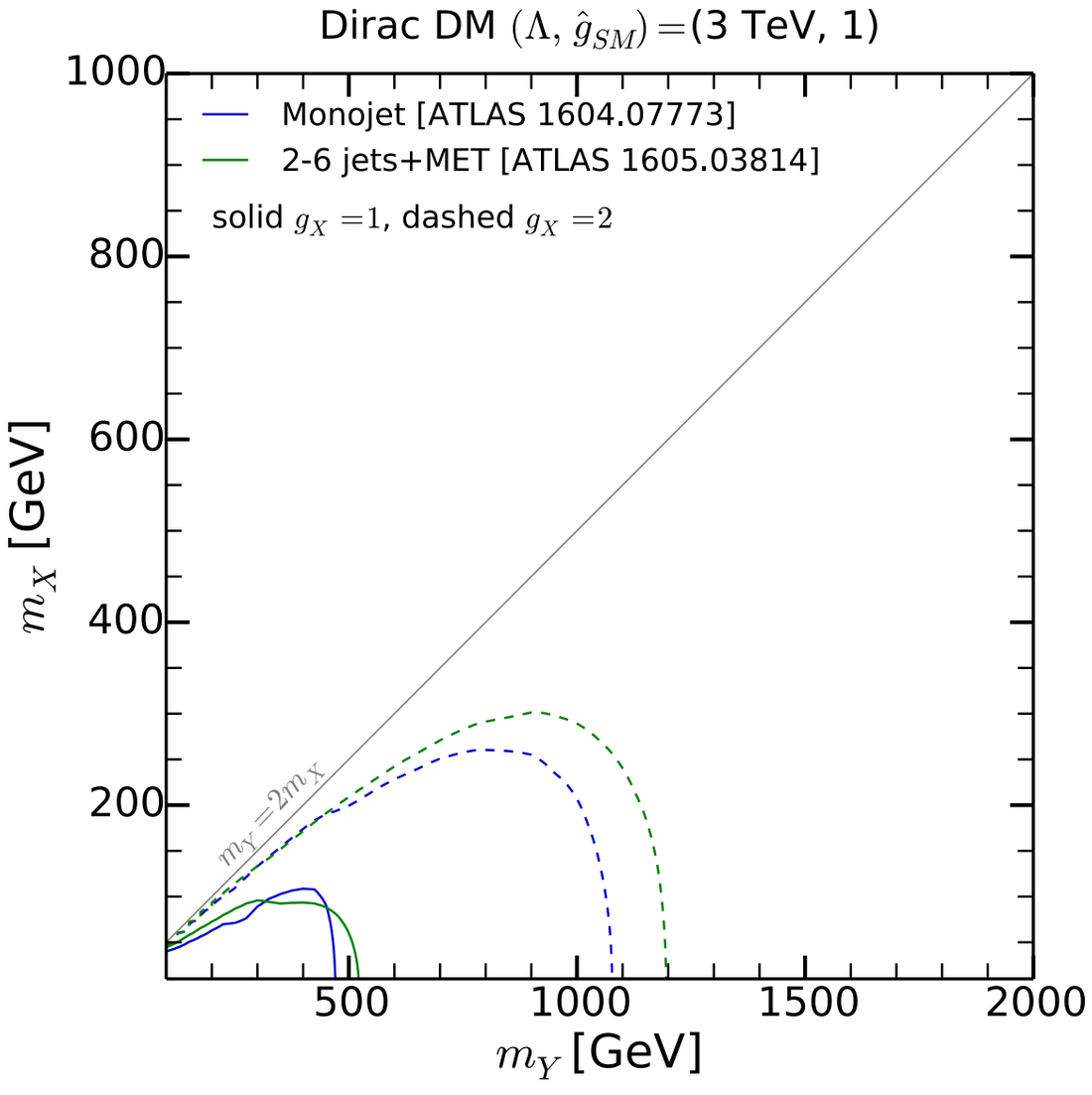
Universal vs Leptophobic coupling (Dirac DM)



Universal coupling

$$\left[g_{\text{SM}} \equiv g_H^T = g_q^T = g_\ell^T = g_g^T = g_W^T = g_B^T \right]$$

$$(\Lambda, g_{SM}) = (3\ \text{TeV}, 1)$$



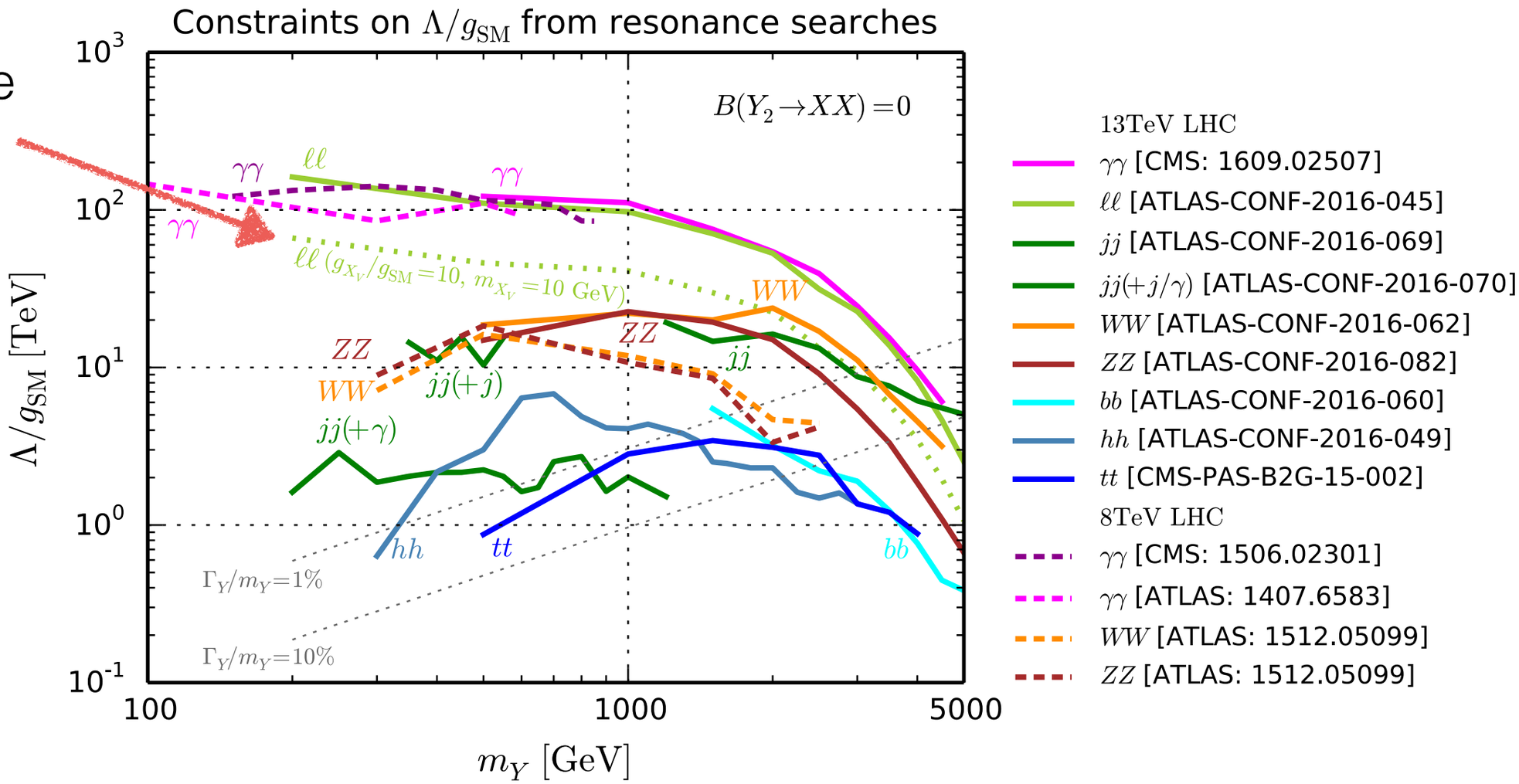
Leptophobic coupling

$$\left[g_\ell^T \ll \hat{g}_{\text{SM}} \equiv g_H^T = g_q^T = g_g^T = g_W^T = g_B^T \right]$$

$$(\Lambda, \hat{g}_{SM}) = (3\ \text{TeV}, 1)$$

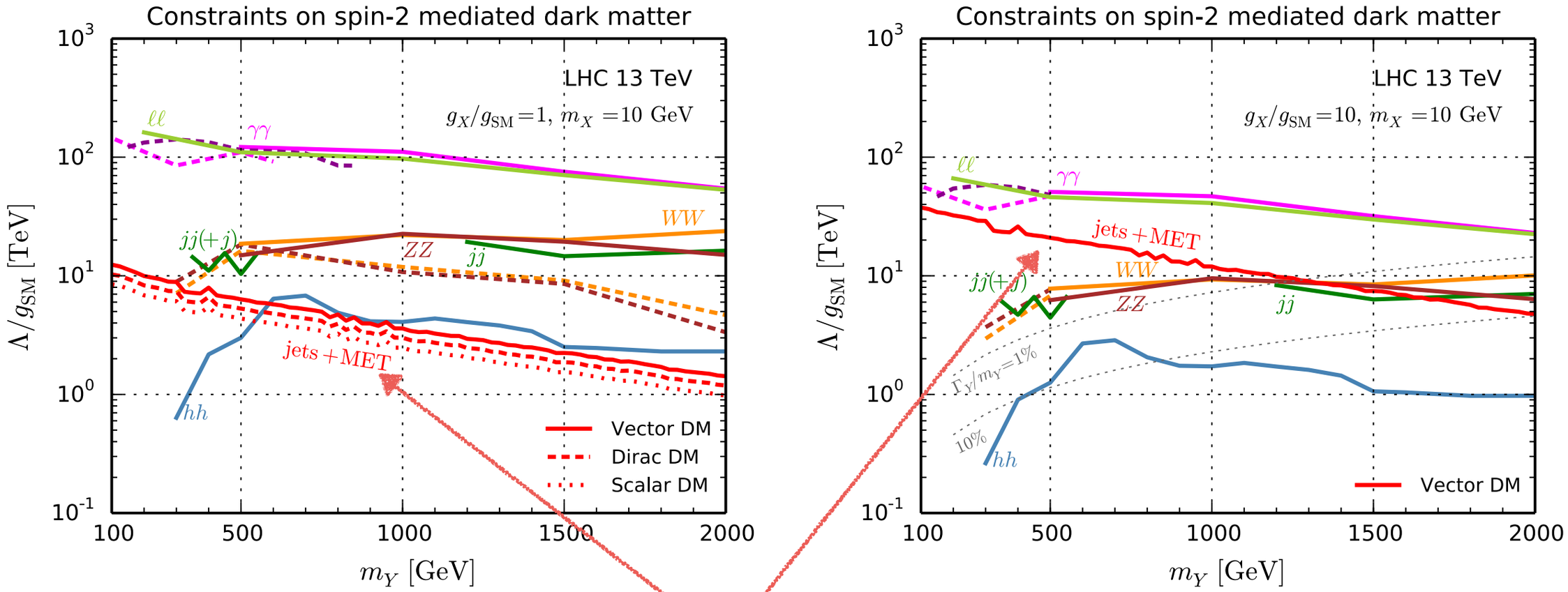
Constraints from Resonance searches

Reduced BR in scenario with large coupling to vector DM



- Diphoton and dilepton searches give strong constraints
- Universal coupling scenarios: Λ pushed to high scales

Summary



Rescaled to $\mathcal{L} = 15\text{fb}^{-1}$

- Univ. coupling scenario: MET searches are not competitive, dilepton & diphoton constraints push the limits to high scales
- Conclusions change if decays to leptons and photons are suppressed (e.g. bulk RS), but expect lower production

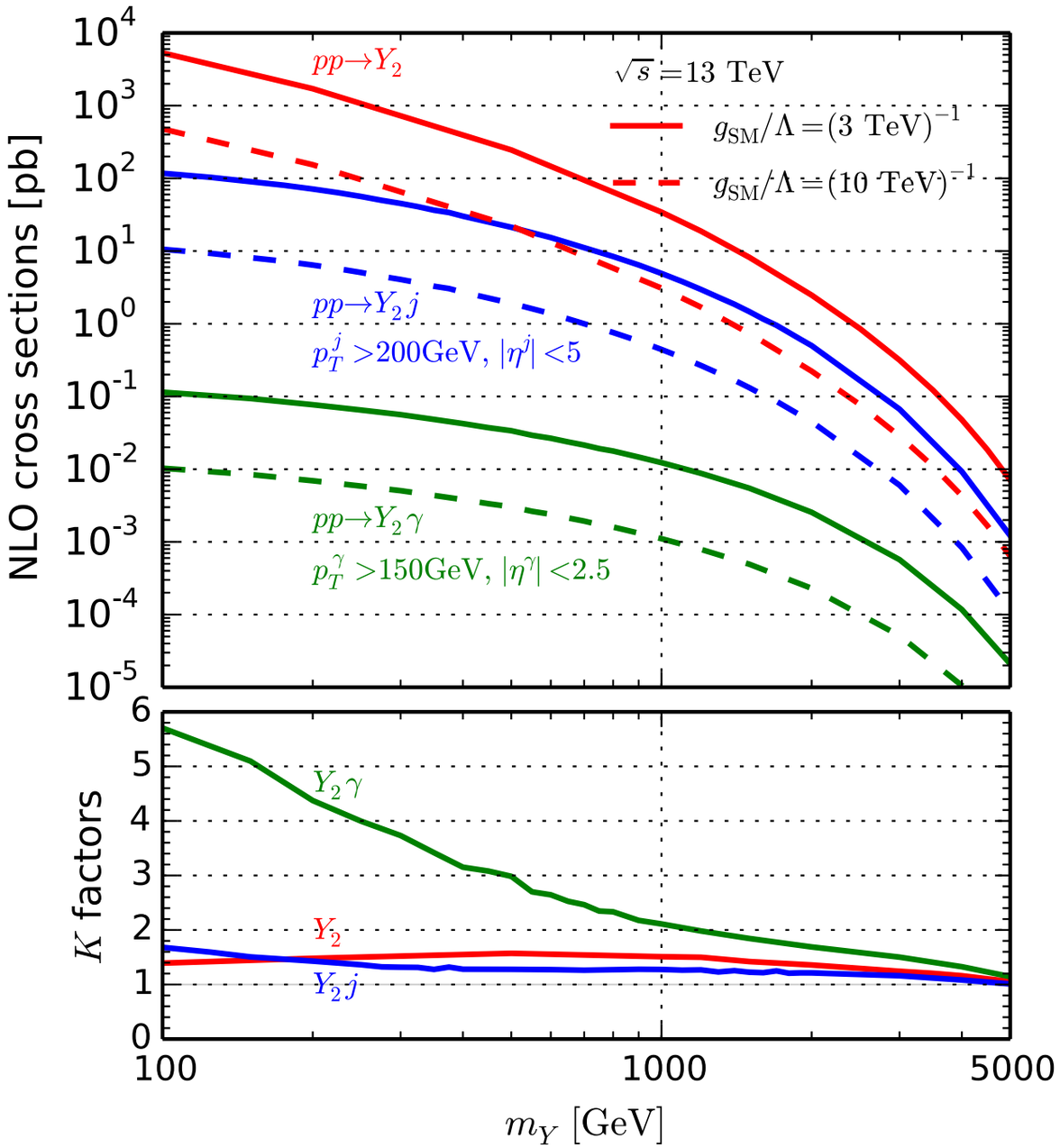
Comments on Reinterpretation

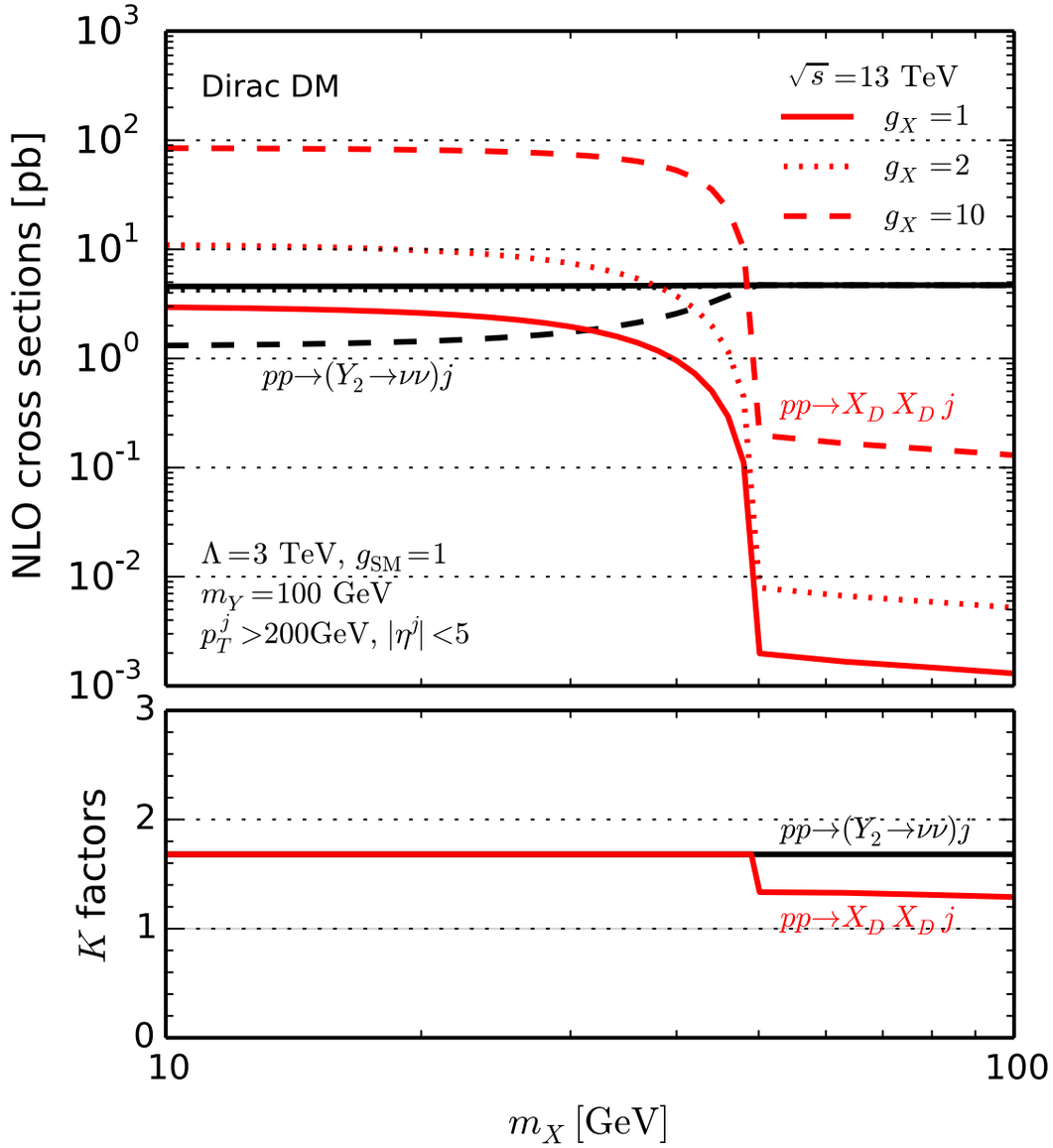
- Model Files (UFO) online at
  - http://feynrules.irmp.ucl.ac.be/wiki/DMsimp
- We digitised many of the resonant search (preliminary) results, digitised format shared at
  - https://hepmdb.soton.ac.uk/phenodata/
- We also share efficiencies for the MET searches at
  - http://lpsc.in2p3.fr/projects-th/recasting/spin2mediator/
- We used CheckMATE to evaluate efficiencies, cross checks with MadAnalysis5 and Rivet show agreement within ~20% uncertainty

BACKUP

Y_2 Production

using K factors
according to [1605.09359]





- cross sections scale as $(g_{\rm SM}/\Lambda)^2$
- $Y_2\gamma$ suppressed
- neutrinos dominant in off-shell region, even for large g_X