Simplified dark matter models with a spin-2 mediator at the LHC

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(LPSC Grenoble)

Reference: arXiv:1701.07008

LHCTheory ERC meeting

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Universite Catholique de Louvain

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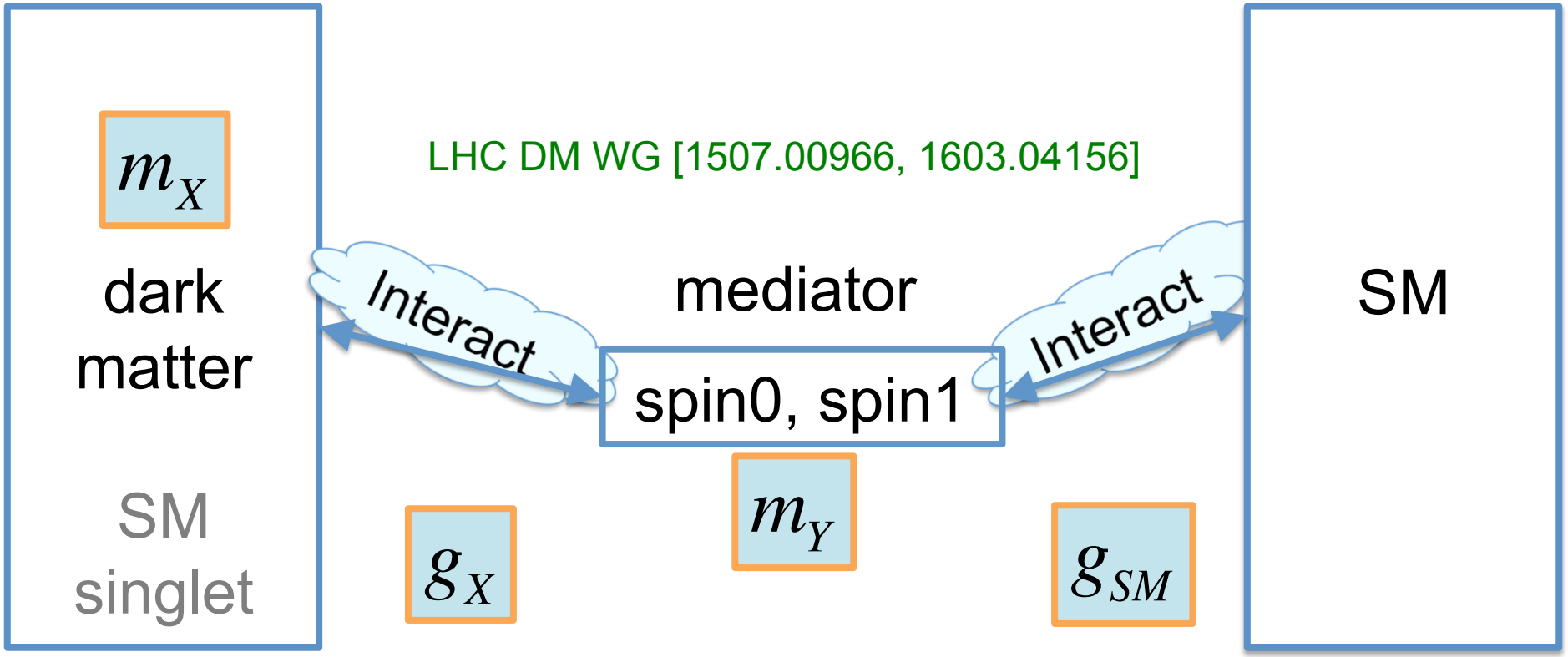
s-channel simplified DM models

Model Parameter: m_X, m_Y, g_X, g_{SM}



Gravity-mediated DM: Lee, Park, Sanz [1306.4107, 1401.5301]

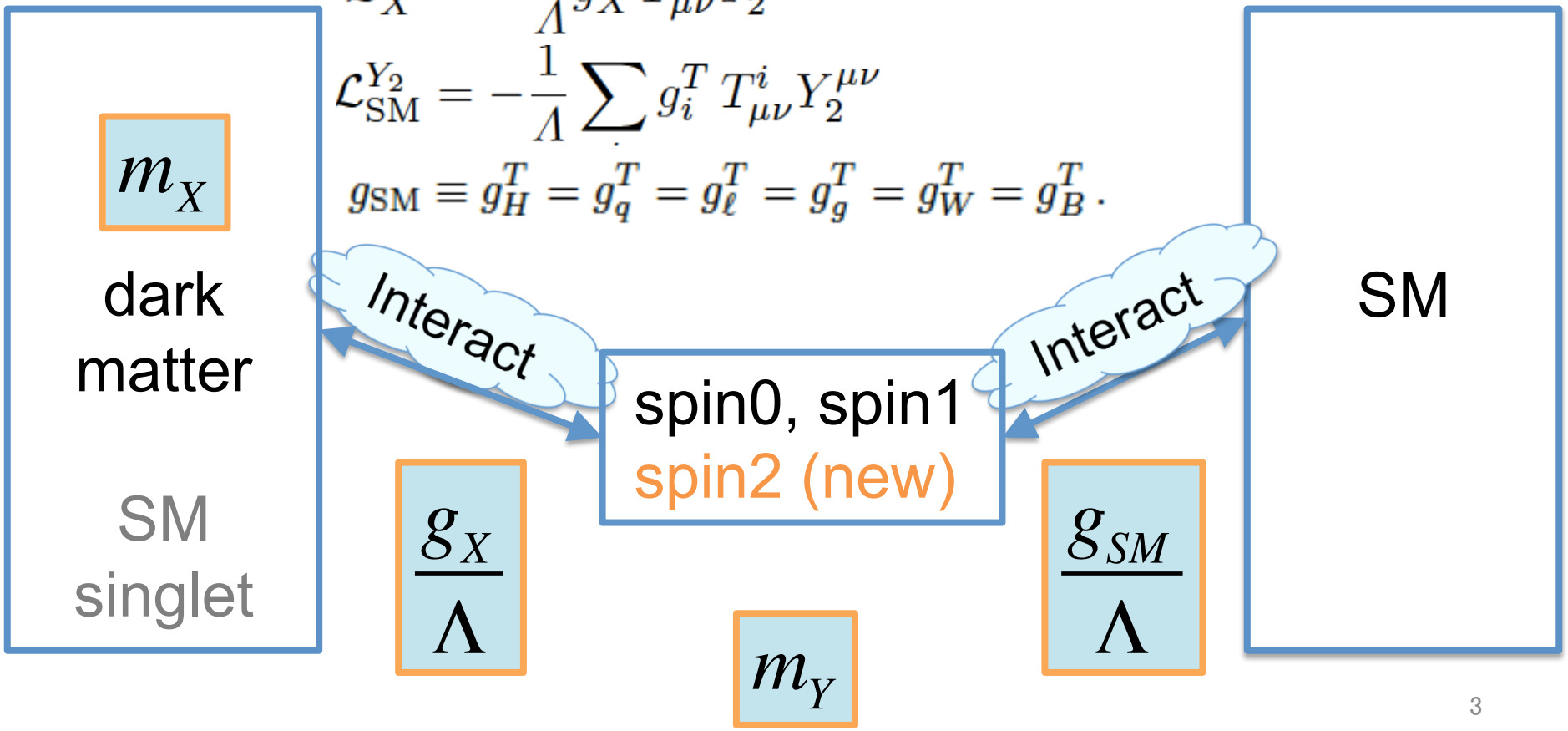
spin2-mediated simplified DM model

Model Parameter: m_X, m_Y, $\frac{g_X}{\Lambda}$, $\frac{g_{SM}}{\Lambda}$

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

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

$$g_{\rm SM} \equiv g_H^T = g_q^T = g_\ell^T = g_g^T = g_W^T = g_B^T \,.$$



http://feynrules.irmp.ucl.ac.be/wiki/DMsimp

Simplified DM models (DMsimp)

Authors

- s-channel (spin-0 and spin-1)
  - Antony Martini (Université catholique de Louvain) & Kentarou Mawatari (LPSC Grenoble)
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- s-channel (spin-0 and spin-1 electroweak)
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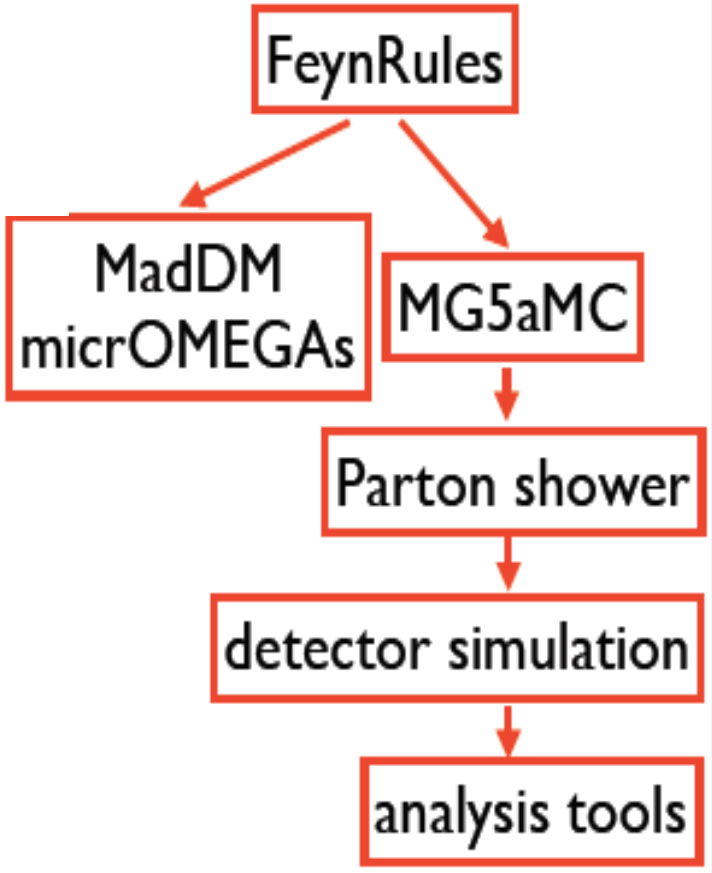
Description of the model

This is simplified dark matter models for NLO.

- Xr (real scalar DM)
- Xc (complex scalar DM)
- Xd (Dirac spinor DM)
- Xm (Majorana spinor DM) [to be done.]
- Xv (vector DM)
- ...

and different types of mediators:

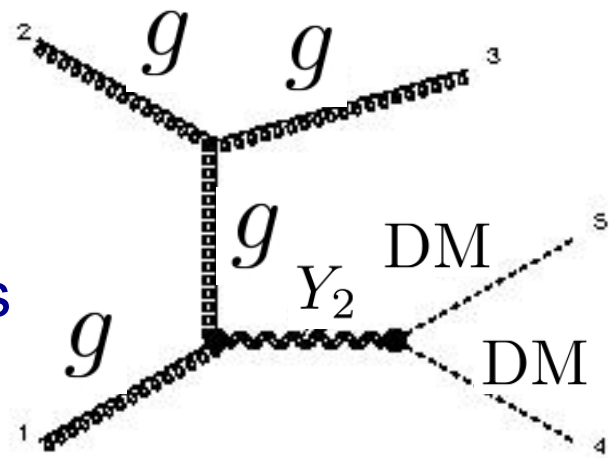
- s-channel
  - Y0 (spin-0)
  - Y1 (spin-1)
  - Y2 (spin-2)



LHC search

- monojet/multijet + missing E_T (DM search)

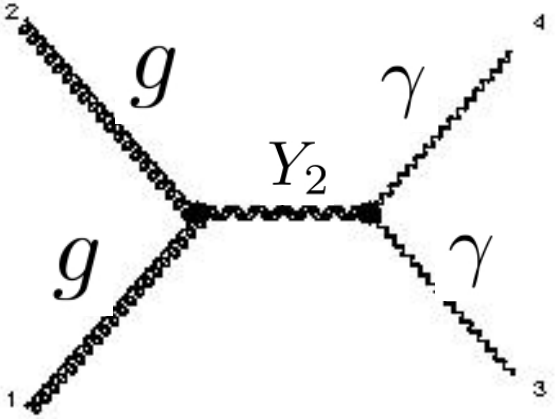
Y2 decay
into DM/neutrinos



- resonance search

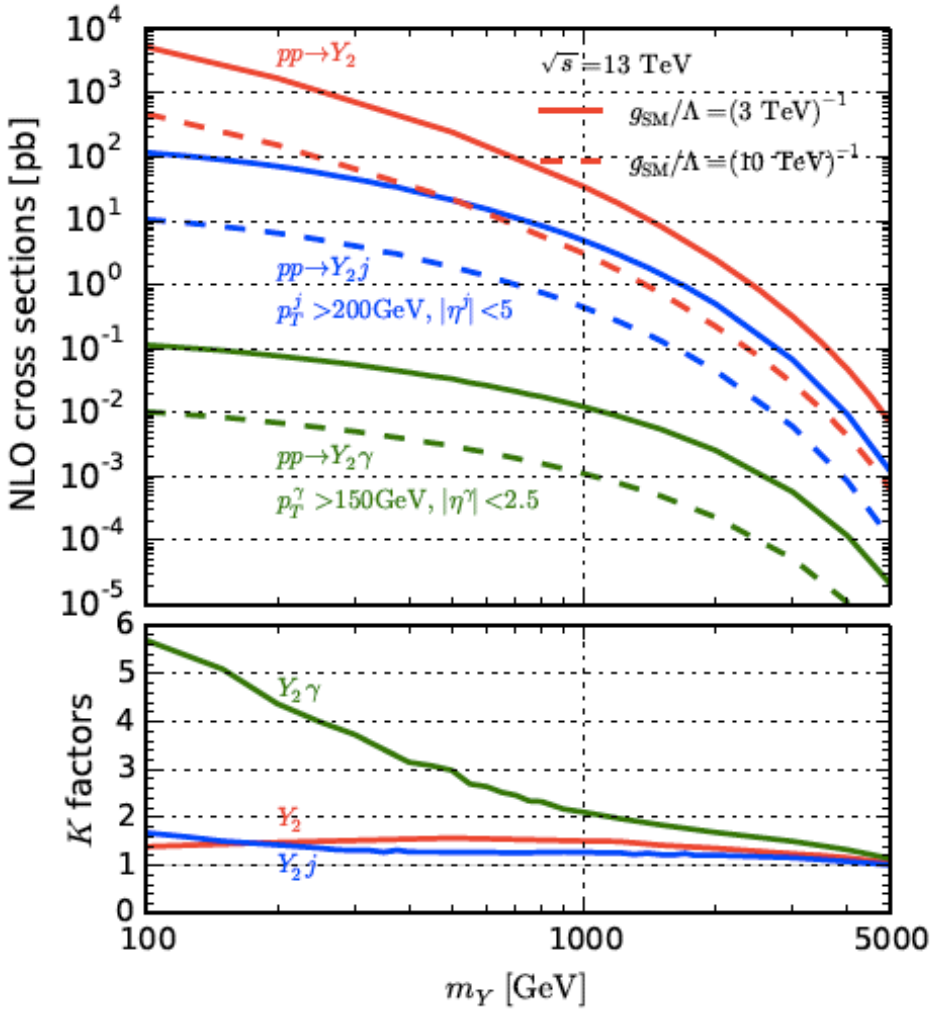
  Resonance: 2 photons, 2 leptons, 2 jets, 2 jets(+j/gamma)
  2W, 2Z, 2 bottom, 2 higgs, 2 top

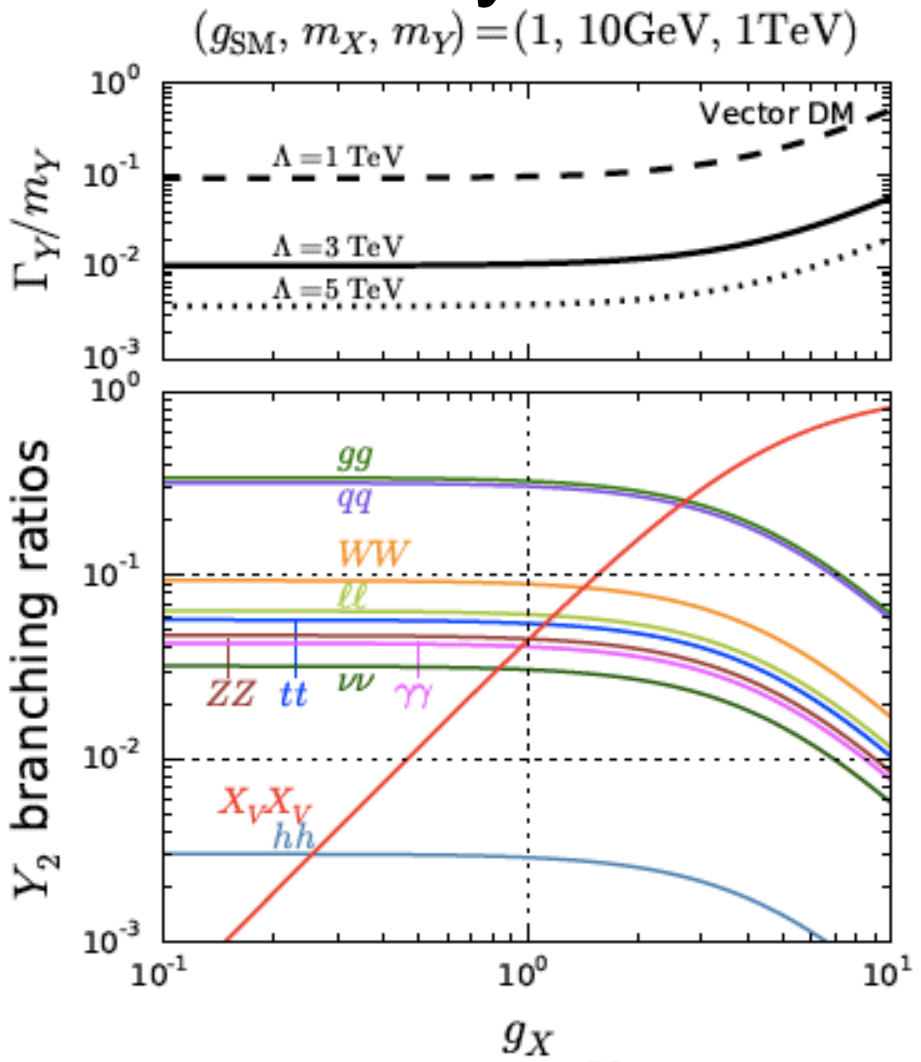
Y2 decay
into SM



We used the NLO UFO model by Das, Degrande, Hirschi, Maltoni, Shao [1605.09359]

Y_2 production and decay





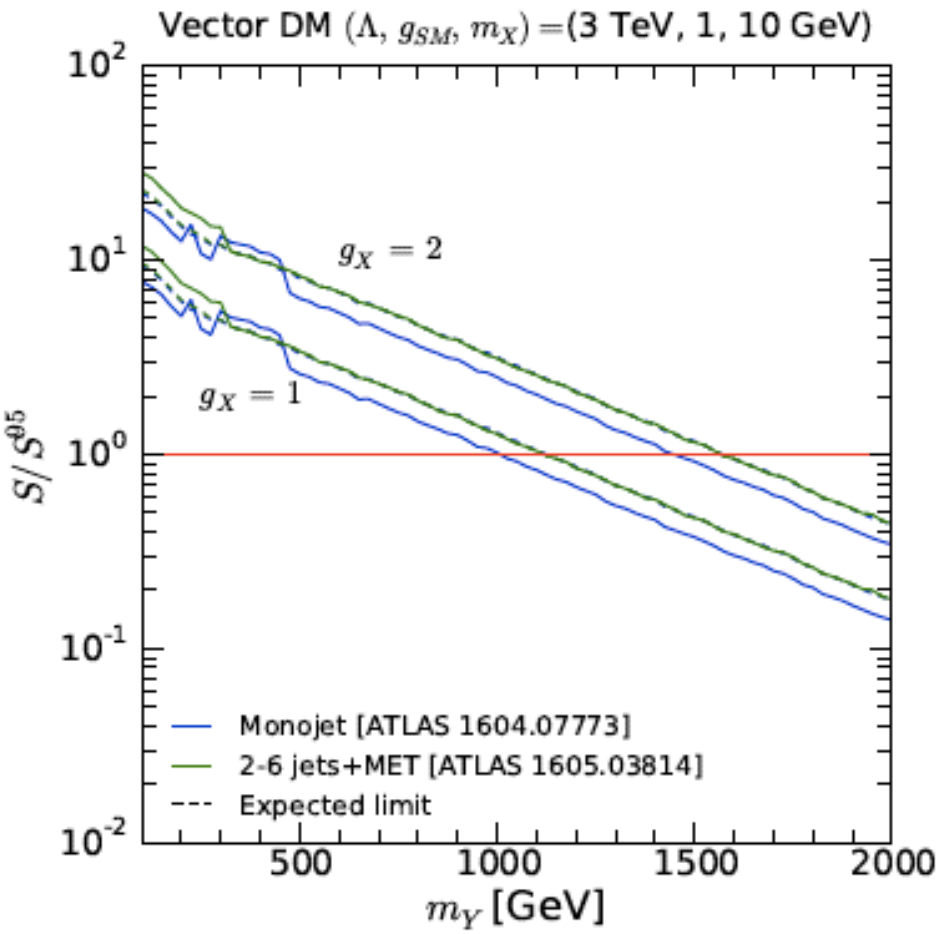
$$\Gamma_S = \frac{g_S^2 m_Y^3}{960\pi\Lambda^2}\beta_S^5\,,\ \Gamma_F = \frac{g_F^2 N_\nu N_C^F m_Y^3}{160\pi\Lambda^2}\beta_F^3\left(1+\frac{8}{3}r_F\right),\ \Gamma_V = \frac{g_V^2 N_s N_C^V m_Y^3}{40\pi\Lambda^2}\beta_V\, f(r_V)$$

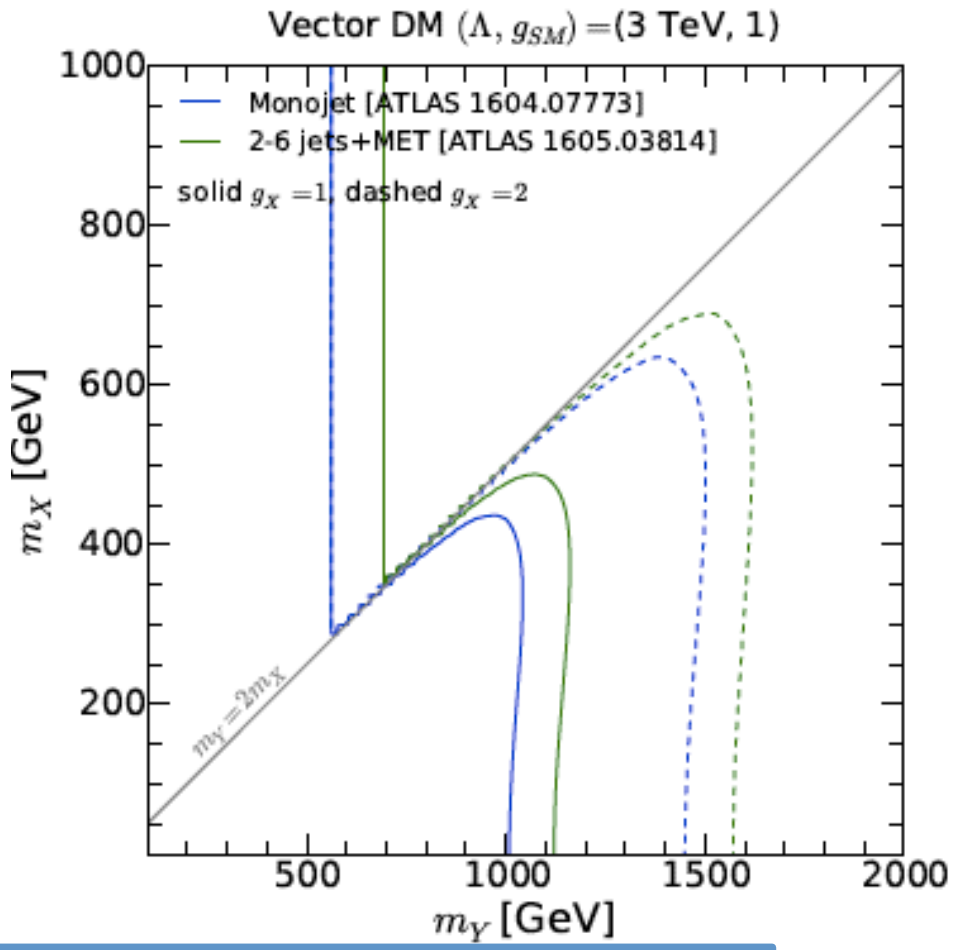
where $\beta_i = \sqrt{1-4r_i}$ with $r_i = m_i^2/m_Y^2$

by CheckMATE (validation: MadAnalysis5 and Rivet)

Constraints from missing E_T searches (1/2)

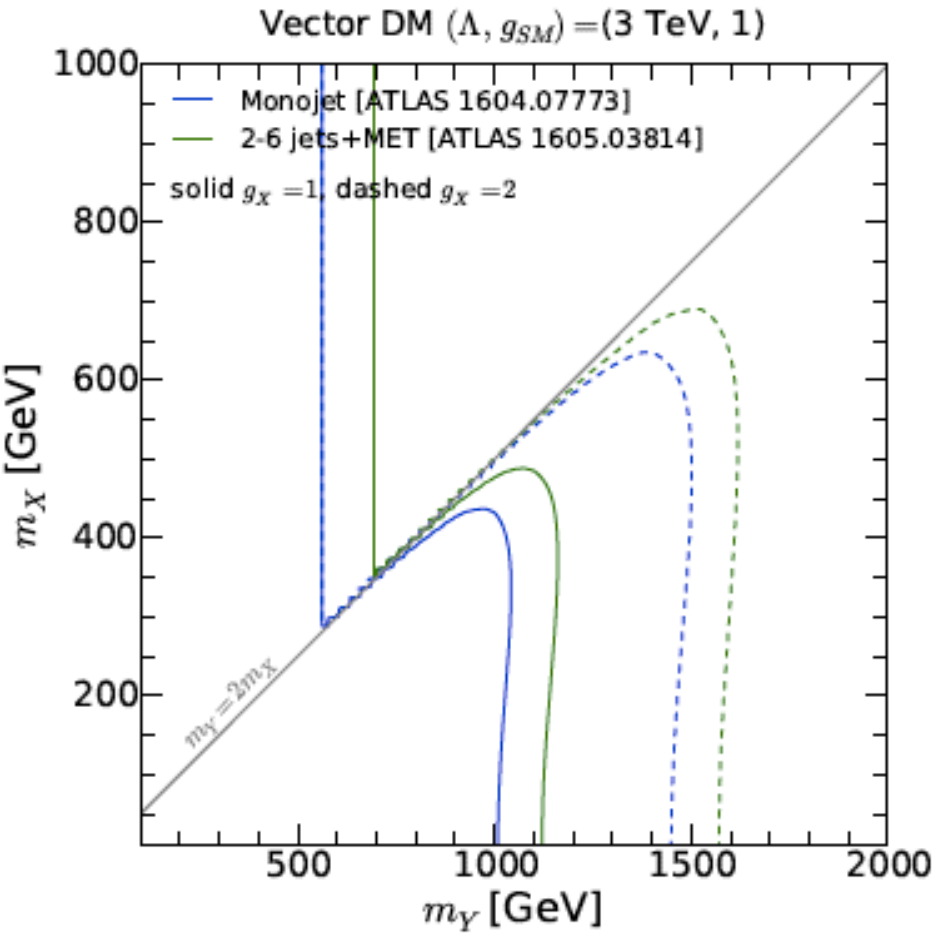
13 TeV LHC with 3.2/fb



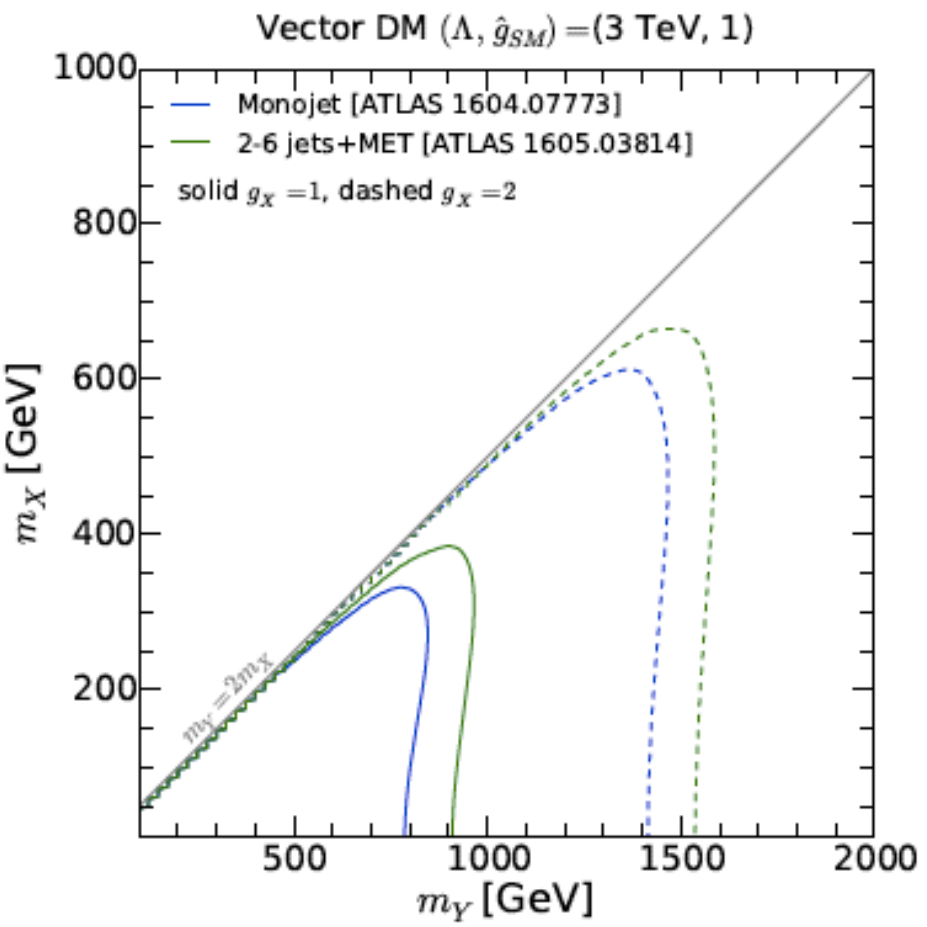


universal g_{SM} $\quad g_{\rm SM} \equiv g_H^T = g_q^T = g_\ell^T = g_g^T = g_W^T = g_B^T \,.$

Constraints from missing E_T searches (2/2)



universal g_{SM}

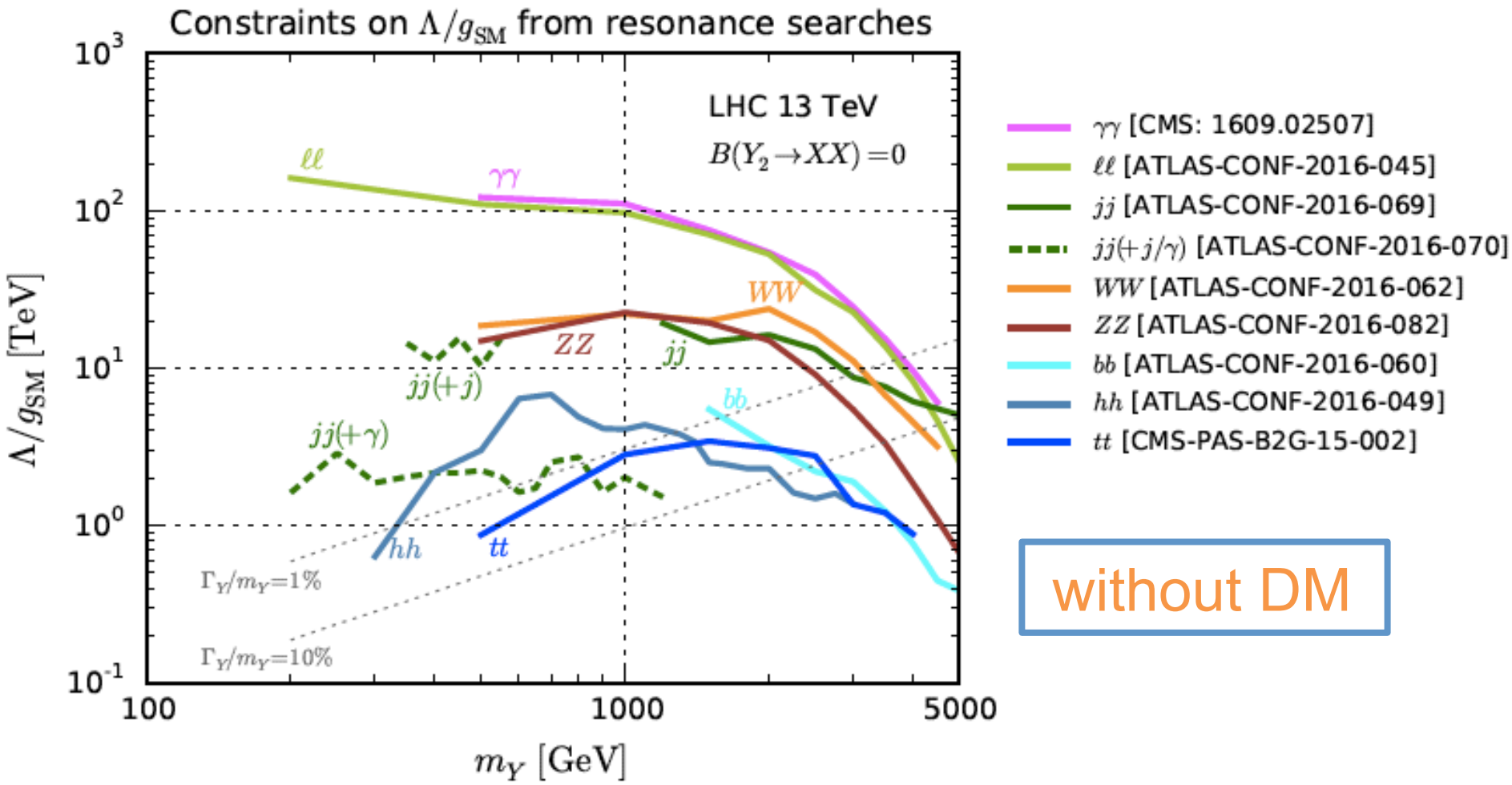


leptophobic

$$g_{\rm SM} \equiv g_H^T = g_q^T = g_\ell^T = g_g^T = g_W^T = g_B^T \,.$$

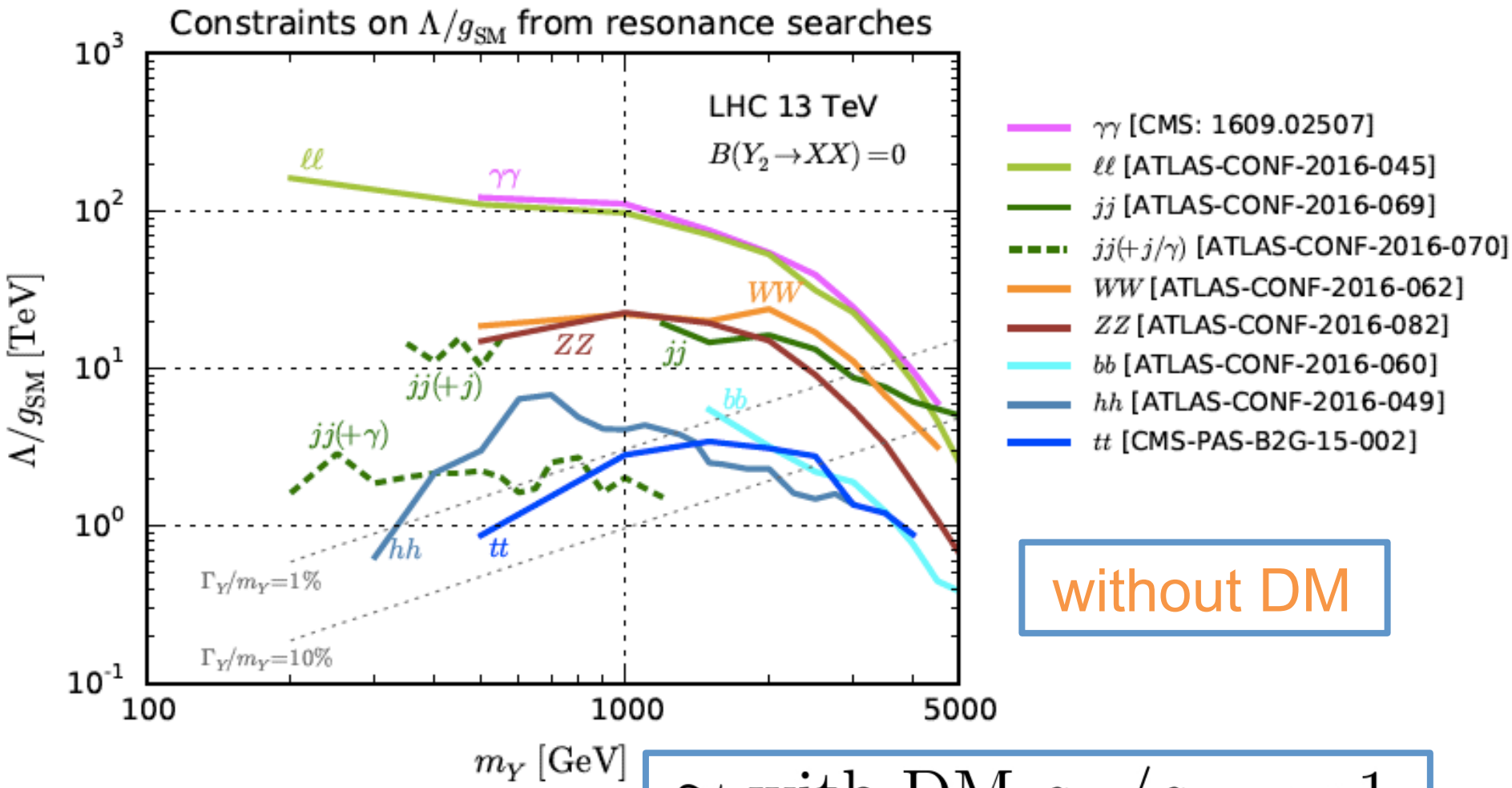
$$g_\ell^T \ll \hat{g}_{\rm SM} \equiv g_H^T = g_q^T = g_g^T = g_W^T = g_B^T$$

Constraints from resonance searches (1/2)



without DM

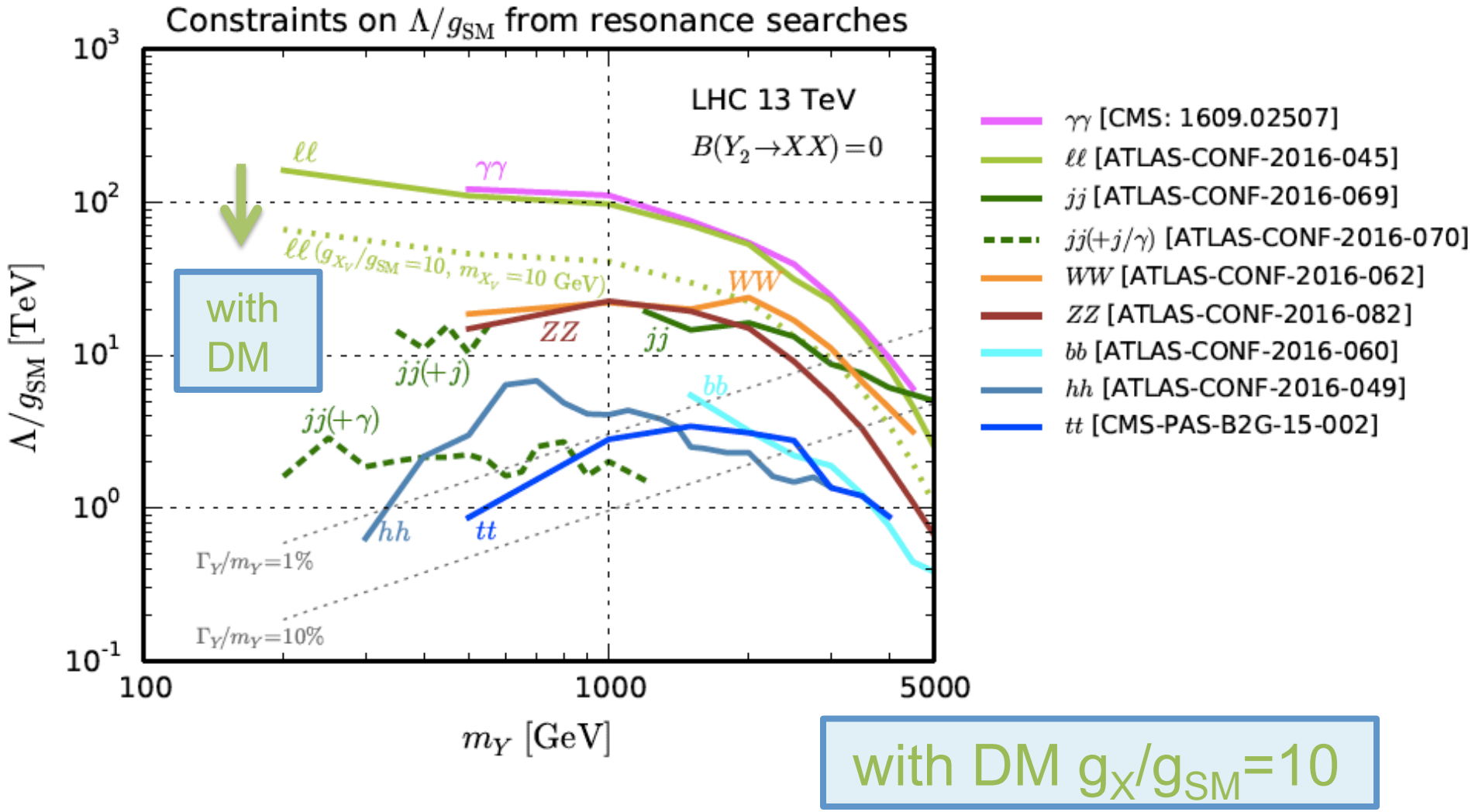
Constraints from resonance searches (1/2)



without DM

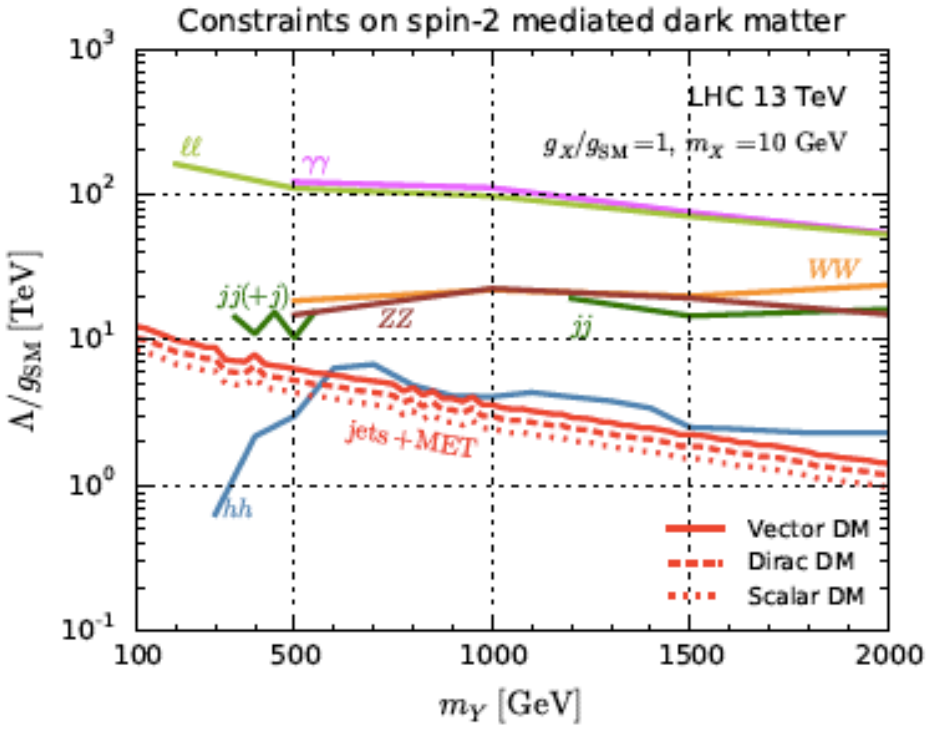
$\approx$ with DM $g_X/g_{\rm SM} = 1$

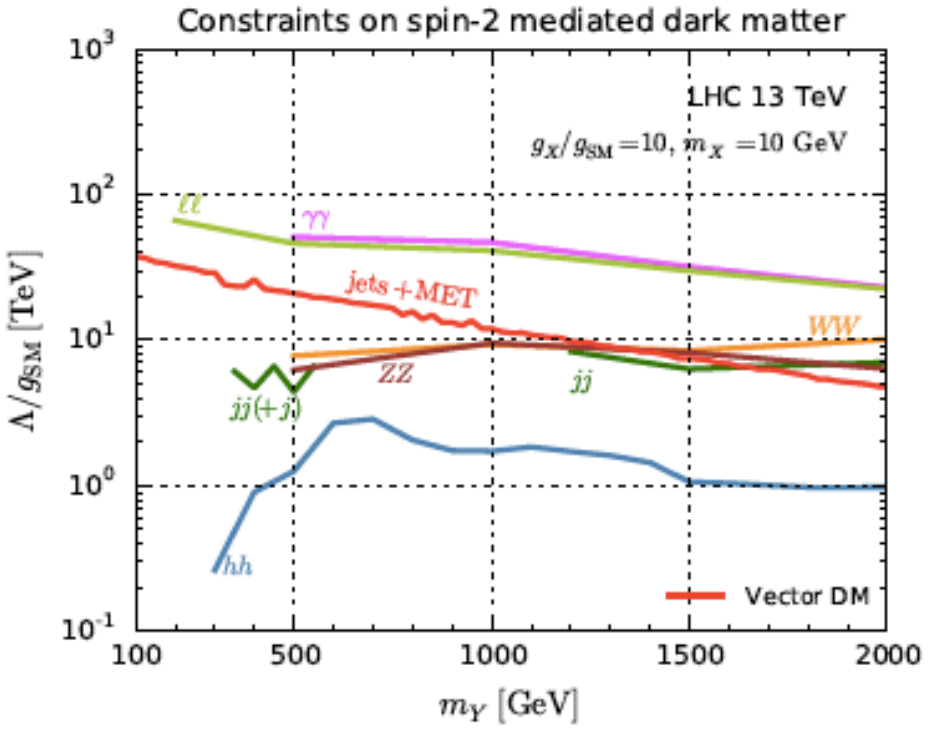
Constraints from resonance searches (2/2)



with DM $g_X/g_{SM}=10$

Comparison between MET & resonance searches





$$g_X = g_{\rm SM} = 1$$

$$g_X = 10$$
$$g_{\rm SM} = 1$$

Summary (1/2)

1. We considered spin2-mediated simplified DM Model, and studied the current LHC constraints:
   - monojet/multijet + missing E_T
   - resonance searches

2. We show the complementarity among different searches
   - dilepton/diphoton resonance searches
     -> strongest constraint for $m_{Y2} > 200/500$ GeV
   - Missing E_T searches
     -> competitive only in the low-mass region
     -> leptophobic scenario/larger g_X (DM coupling) give important role for this searches

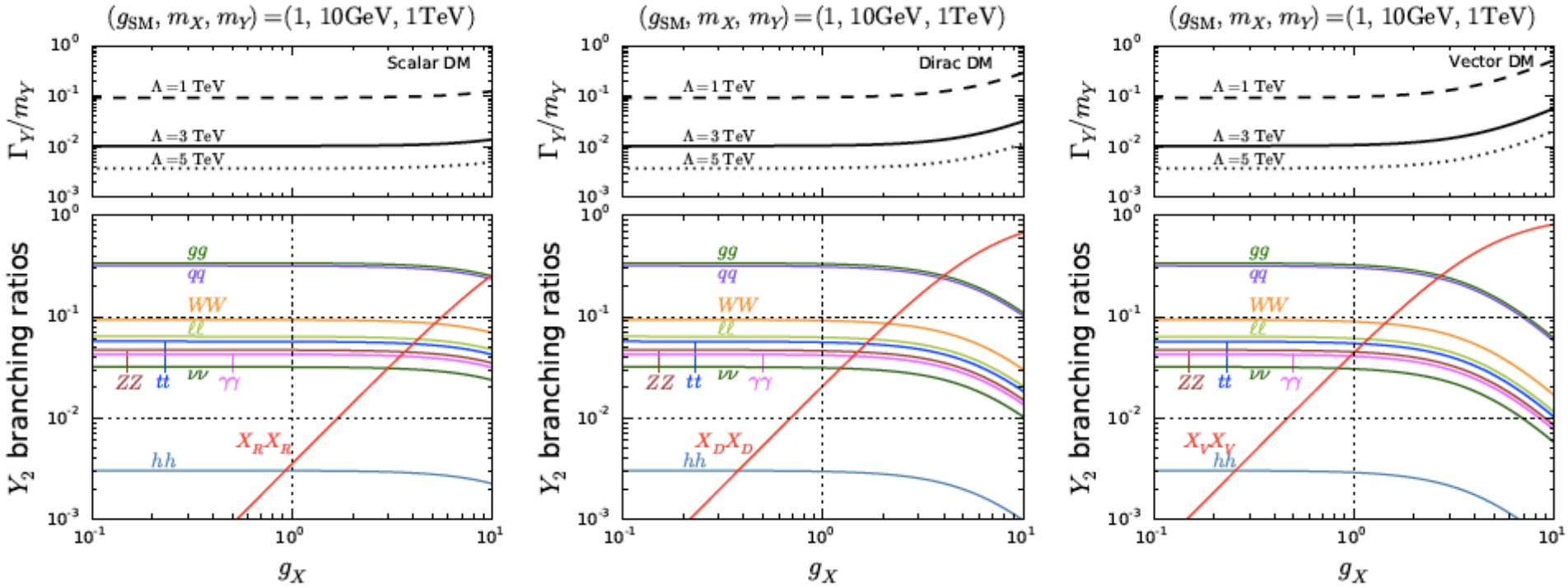
Summary (2/2)

3. DMsimp s-channel spin- 0,1,2 NLO UFO models are publicly available : http://feynrules.irmp.ucl.ac.be/wiki/DMsimp

4. Efficiencies and MadGraph5 aMC@NLO & Pythia6 run cards for monojet and 2-6jets + MET searches, Digitized limits from resonance searches are publicly available : http://lpsc.in2p3.fr/projects-th/recasting/spin2mediator/

Backup

Y_2 decay: Scalar, Dirac, Vector DM

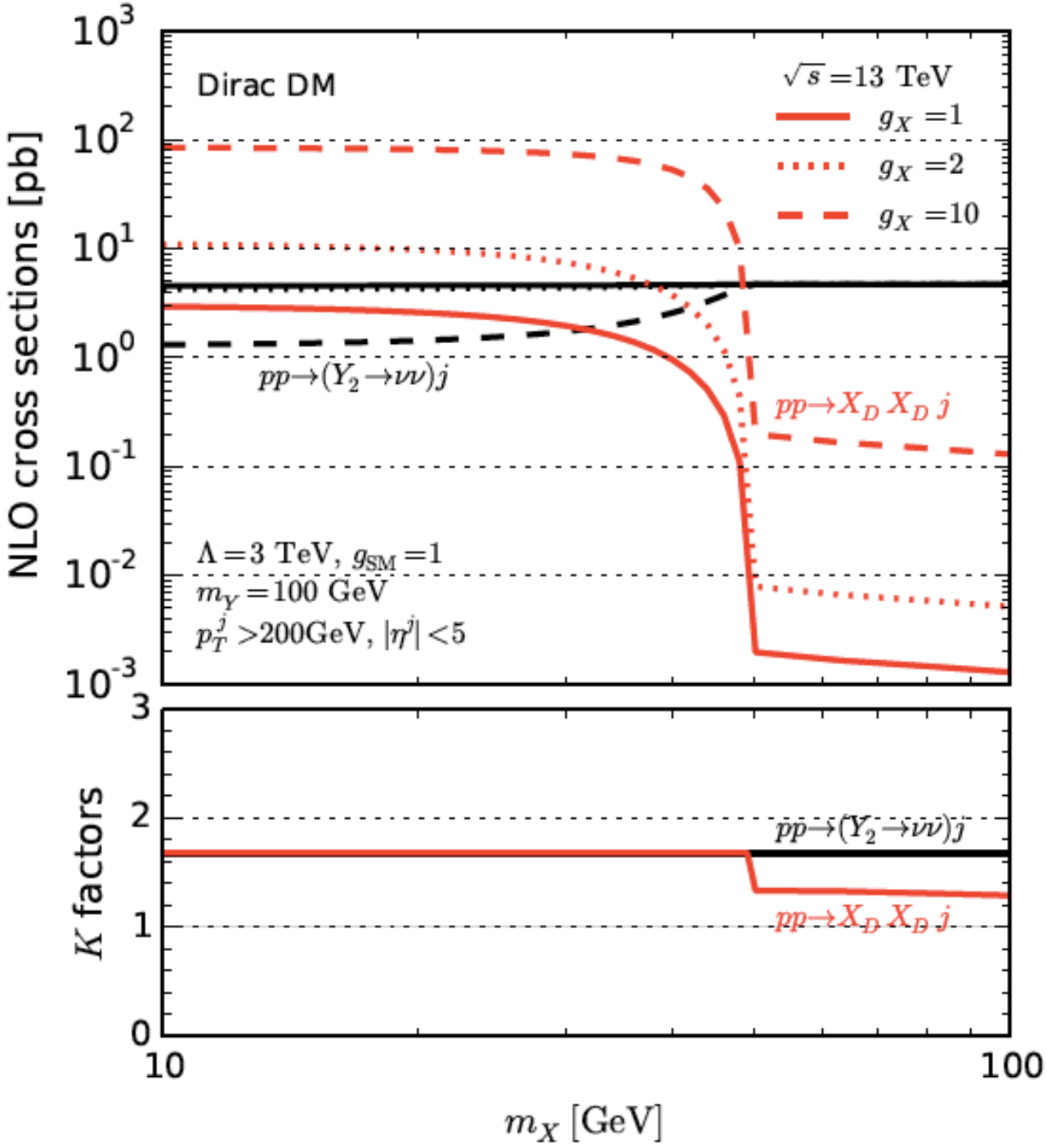


$$\Gamma_S = \frac{g_S^2 m_Y^3}{960\pi\Lambda^2}\,\beta_S^5\,,$$

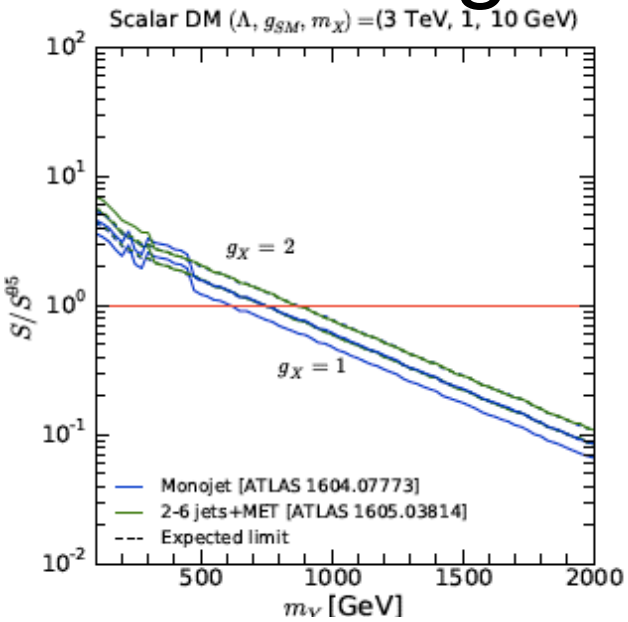
$$\Gamma_F = \frac{g_F^2 N_\nu N_C^F m_Y^3}{160\pi\Lambda^2}\,\beta_F^3\,(1+\frac{8}{3}r_F)\,,$$

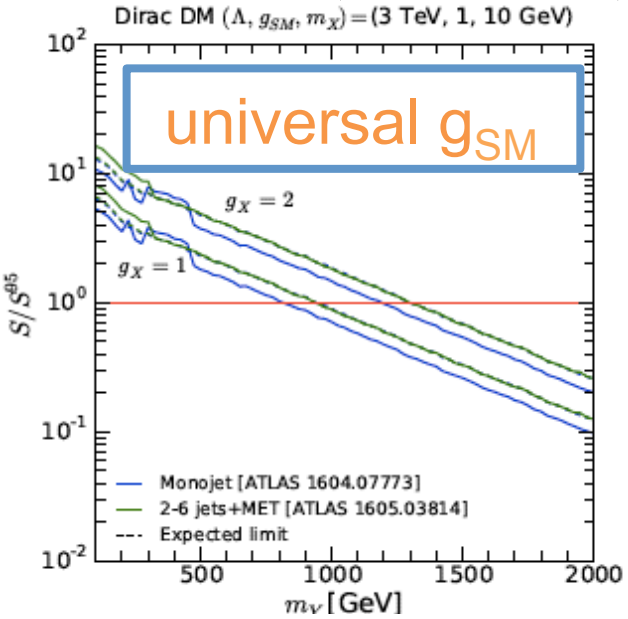
$$\Gamma_V = \frac{g_V^2 N_s N_C^V m_Y^3}{40\pi\Lambda^2}\,\beta_V\,f(r_V)\,,$$

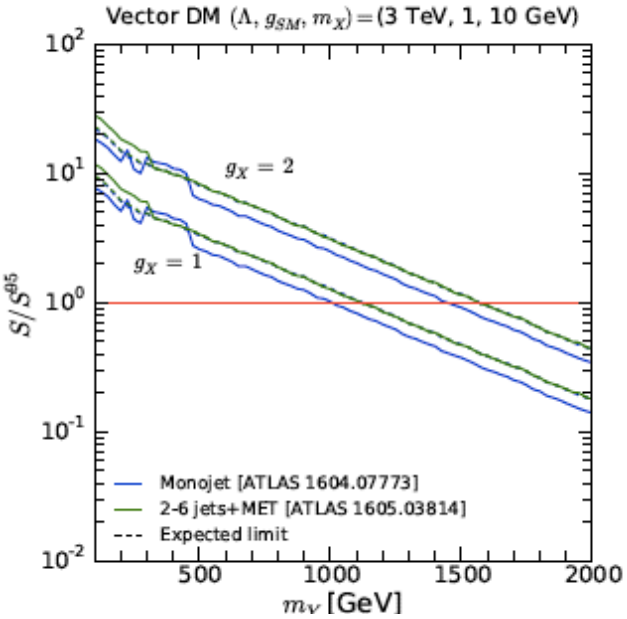
where $\beta_i = \sqrt{1-4r_i}$ with $r_i = m_i^2/m_Y^2$

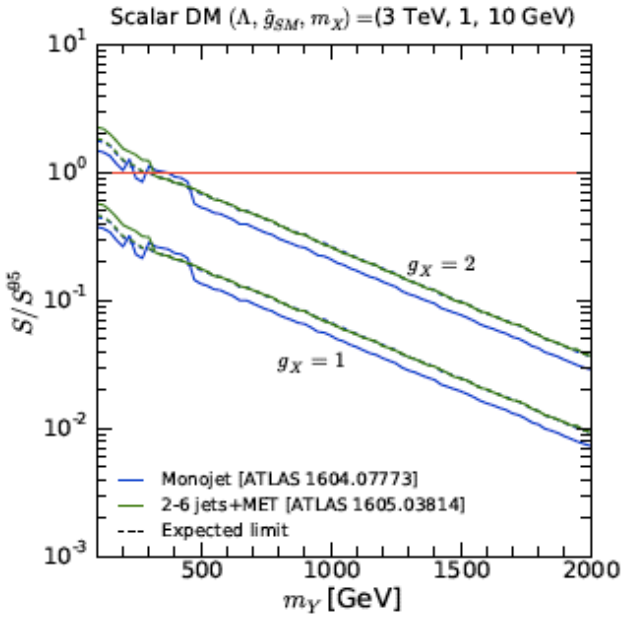

Dirac DM
$\sqrt{s}$ =13 TeV
g_X =1
g_X =2
g_X =10
$pp \to (Y_2 \to \nu\nu) j$
$pp \to X_D X_D j$
Λ =3 TeV, g_{SM} =1
m_Y =100 GeV
p_T^j >200GeV, $|\eta^j|$ <5
NLO cross sections [pb]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
K factors
3
2
1
0
10
100
m_X [GeV]

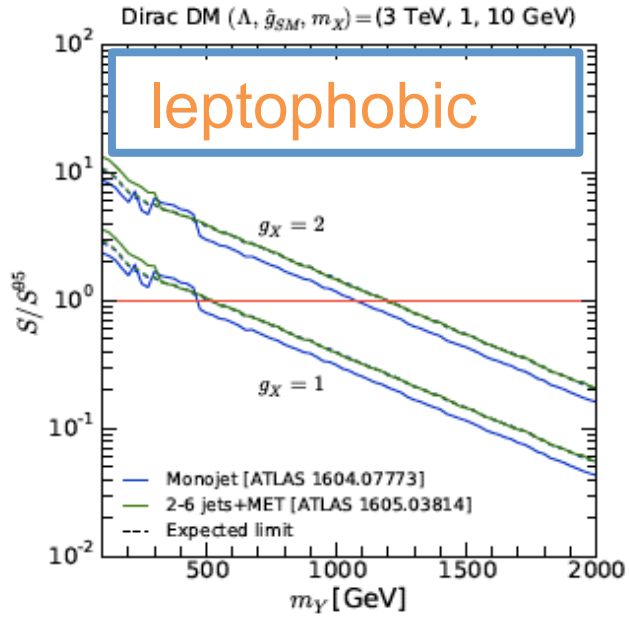
missing ET: Scalar, Dirac, Vector DM

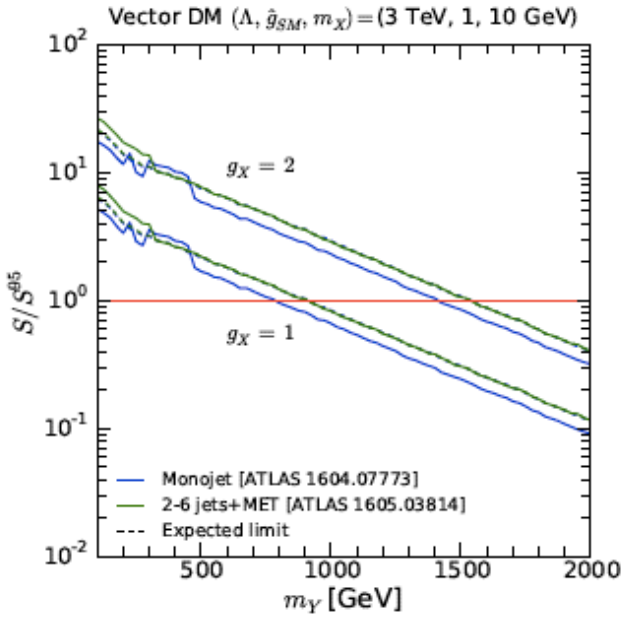




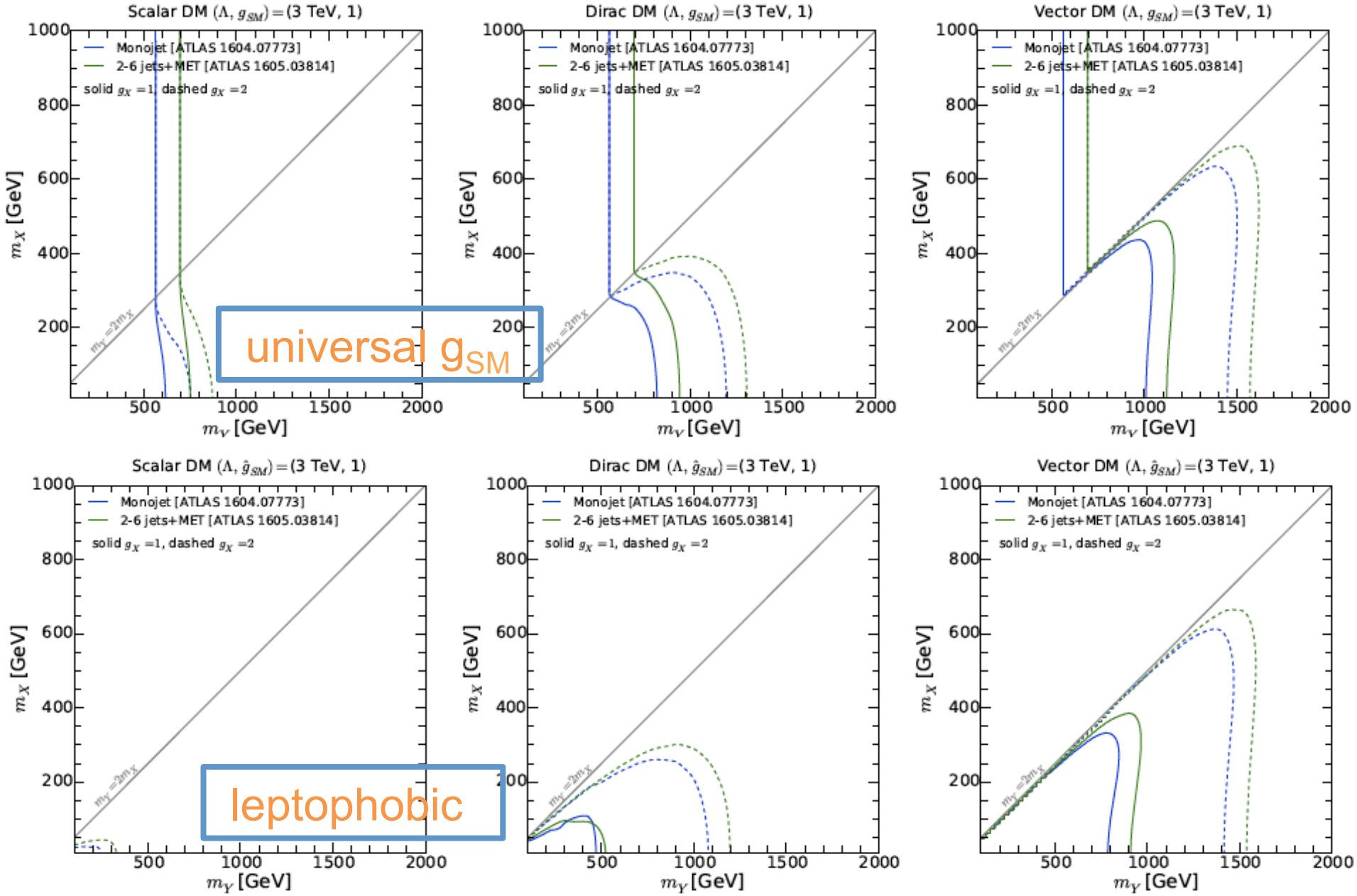




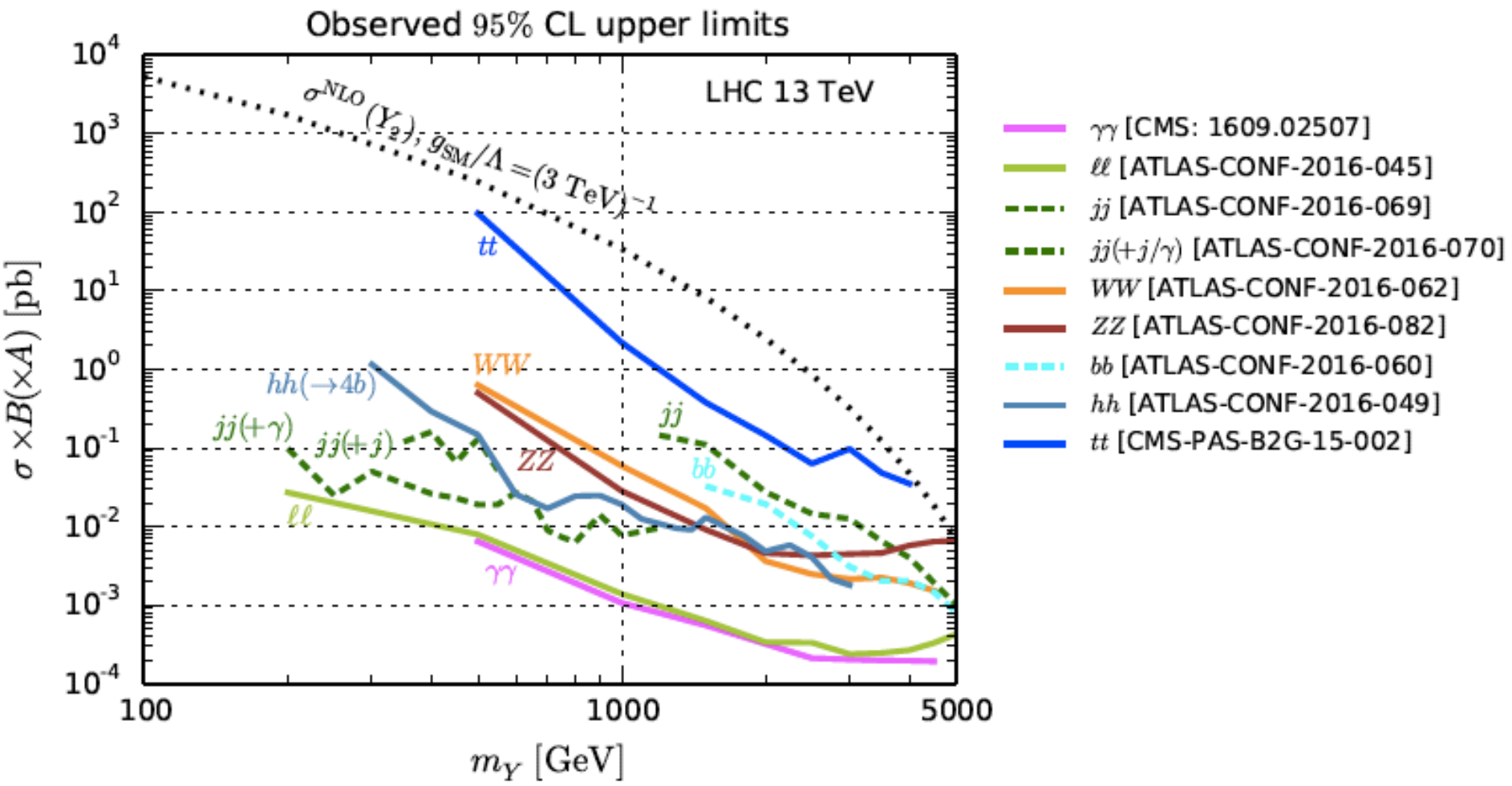




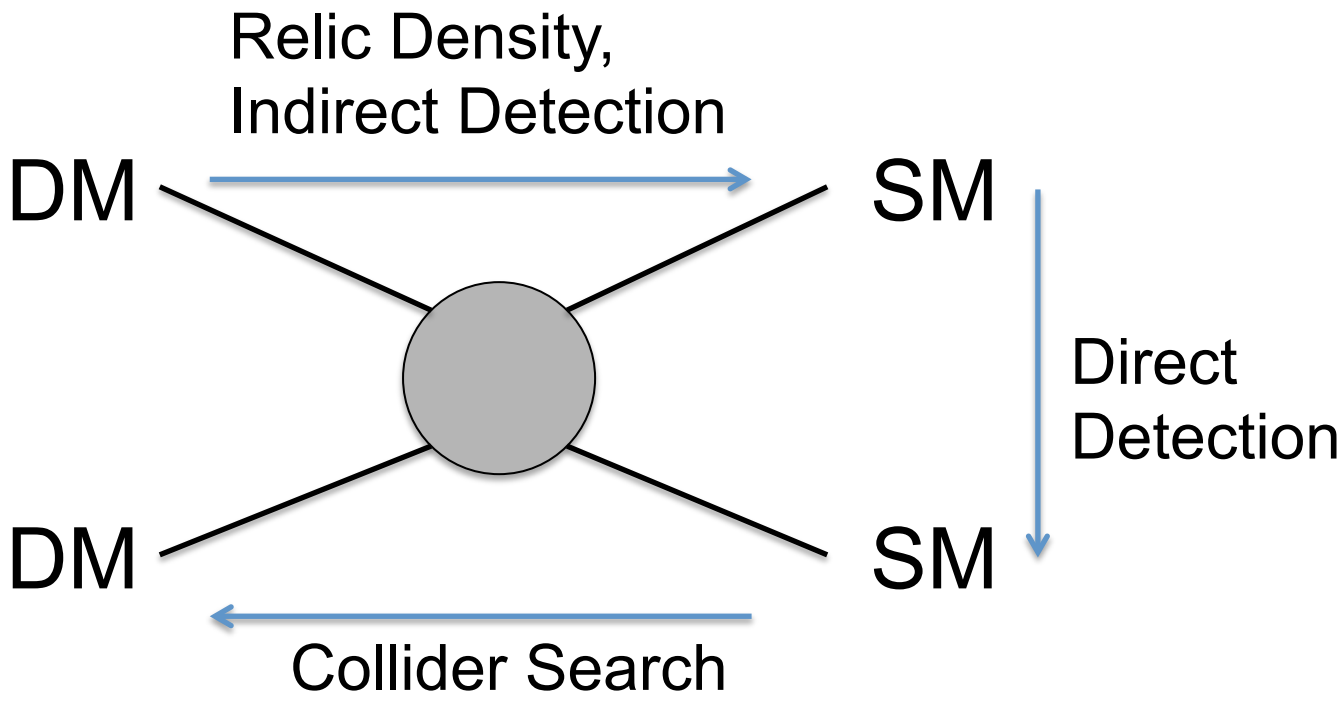
missing ET: Scalar, Dirac, Vector DM



Observed 95% CL upper limits



Dark Matter: LHC search



In this talk: LHC search

Randall and Sundrum, PRL83, 3370

RS model 5-dimensional model

1. Metric

$ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$, where

k : Ads curvature ~ M_{pl} , kr_c ~ 12

2. Interaction of Kaluza-Klein(KK) gravitons

$$-\frac{1}{\Lambda_\pi}T^{\alpha\beta}(x)\sum_{n=1}^{\infty}h_{\alpha\beta}^{(n)}(x)$$, where $\Lambda_\pi = e^{-kr_c\pi}\bar{M}_{pl}$ ~ TeV

$\bar{M}_{pl} = \frac{M_{pl}}{\sqrt{8\pi}}$,

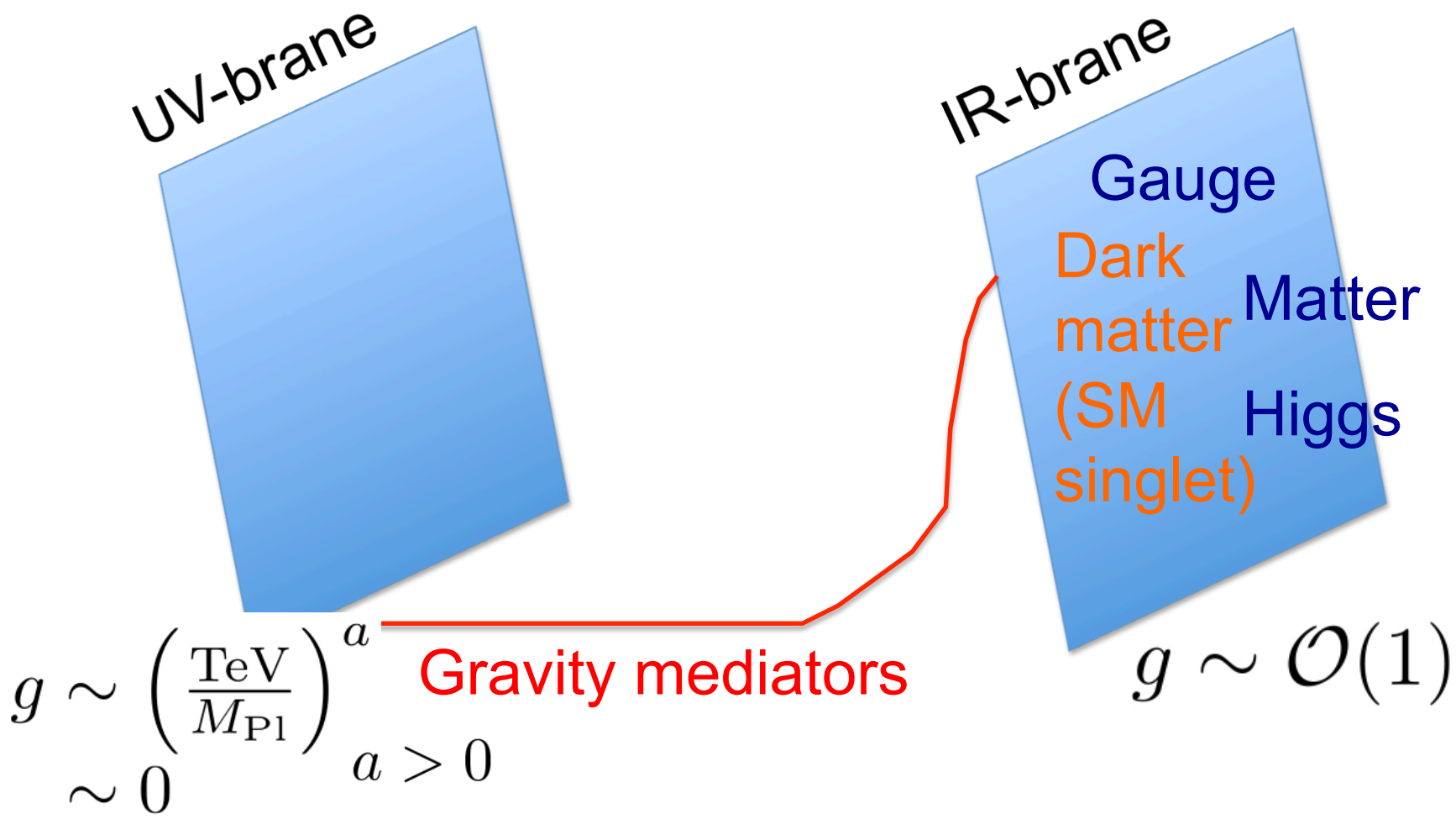
All the massive KK gravitons are suppressed by Λ_π ~ TeV

3. Model parameters

(m_G, $\frac{k}{\bar{M}_{pl}}$), where $m_G = kx_1e^{-kr_c\pi}(x_1 \cong 3.83)$

m_G : mass of the 1st KK graviton excitation state

Gravity-mediated Dark Matter



SM boson ⇆ KK graviton ⇆ Dark matter

RS model & gauge hierarchy problem

$$m_H = \widetilde{m} \cdot e^{-\pi \cdot k \cdot R}$$
$$m_G = x_1 \cdot k \cdot e^{-\pi \cdot k \cdot R}$$

Reference:

Arun, *etal*, arXiv:1410.5591

$$\frac{m_G}{m_H} = x_1 \cdot \frac{k}{\widetilde{m}}$$

m_H: 126 GeV; x_1: 3.83; $\widetilde{m}$: planck scale: $\overline{M}_{\mathrm{pl}}$

$$0.01 \leq \frac{k}{\overline{M}_{\mathrm{pl}}} \leq 1$$

$$m_G \leq 126\mathrm{GeV} \cdot 3.83 \cdot 1 = 480 \text{ GeV}$$

$(m_G, \frac{k}{\overline{M}_{pl}})$ =(1.25 TeV, 0.01) ➡ m_H => 33 TeV