Searching for dark matter at colliders

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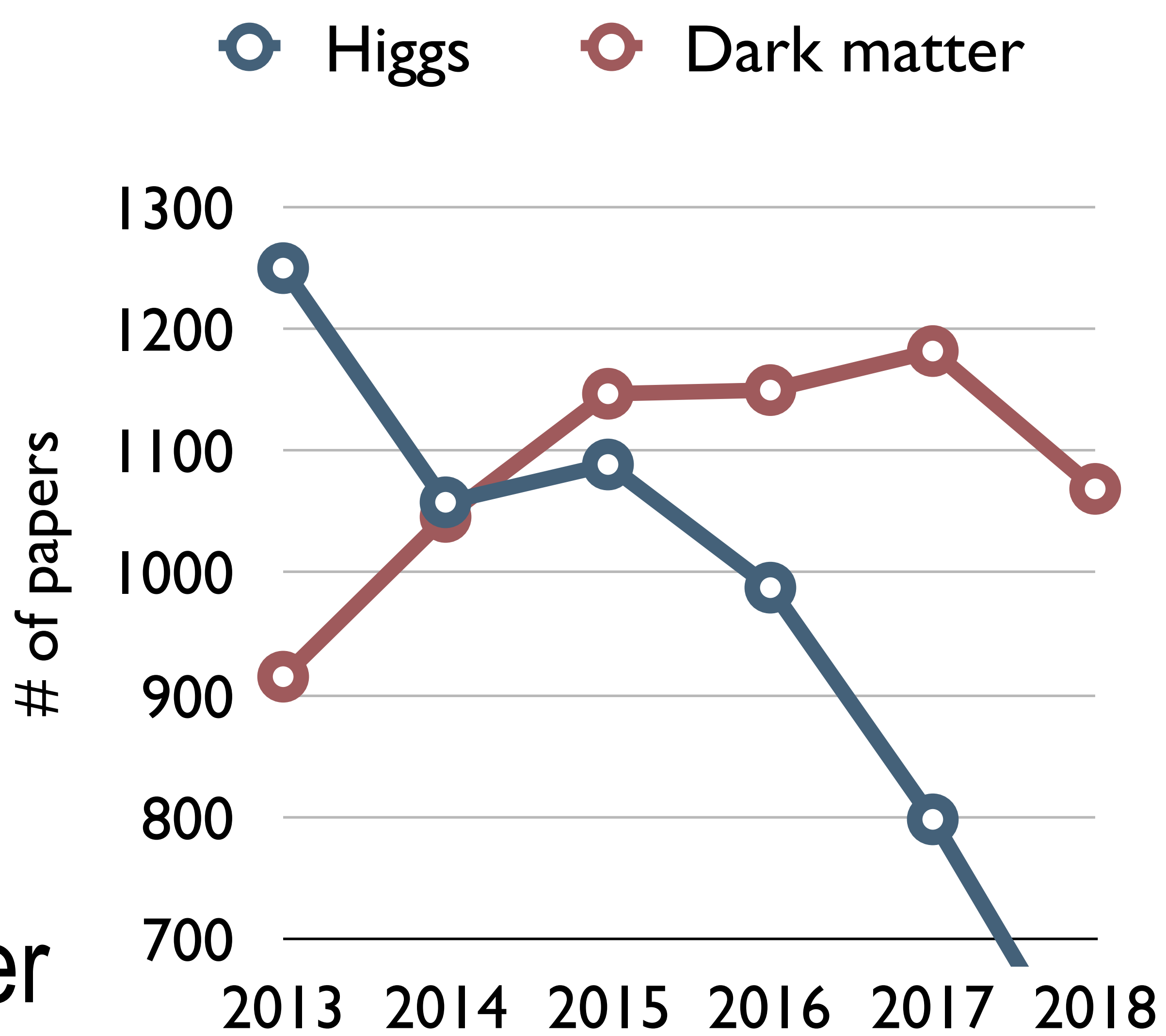
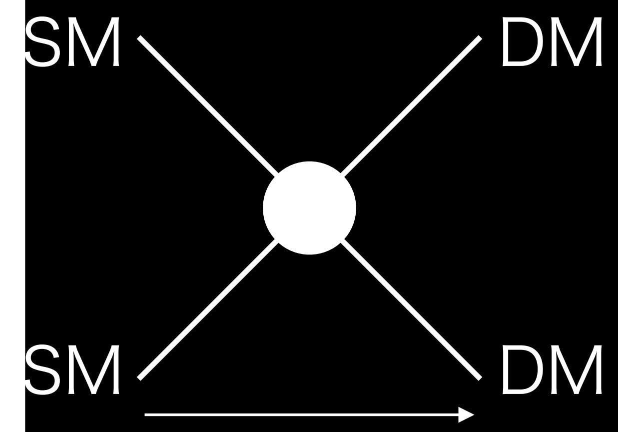
My main research field is collider phenomenology

- the Higgs sector
- dark matter (DM)

- inSPIRE
  - find title higgs
  - find title dark matter

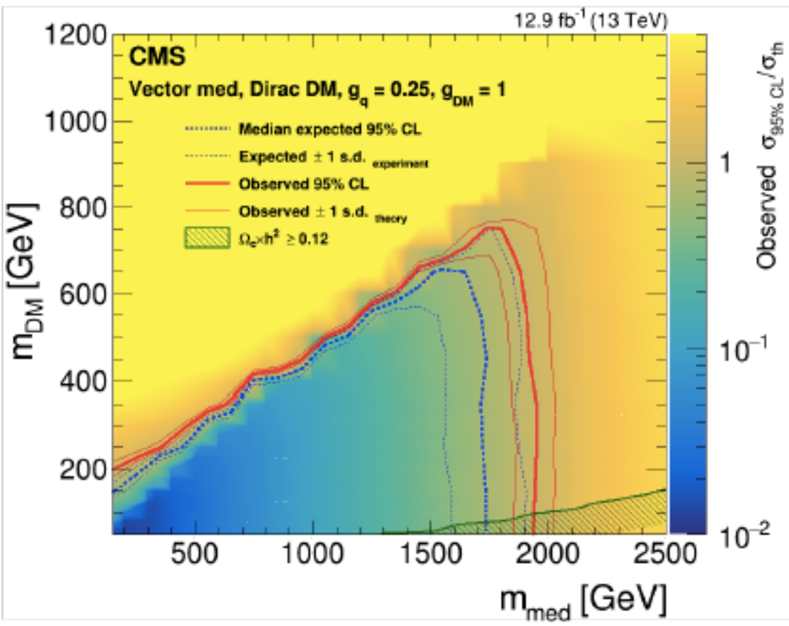


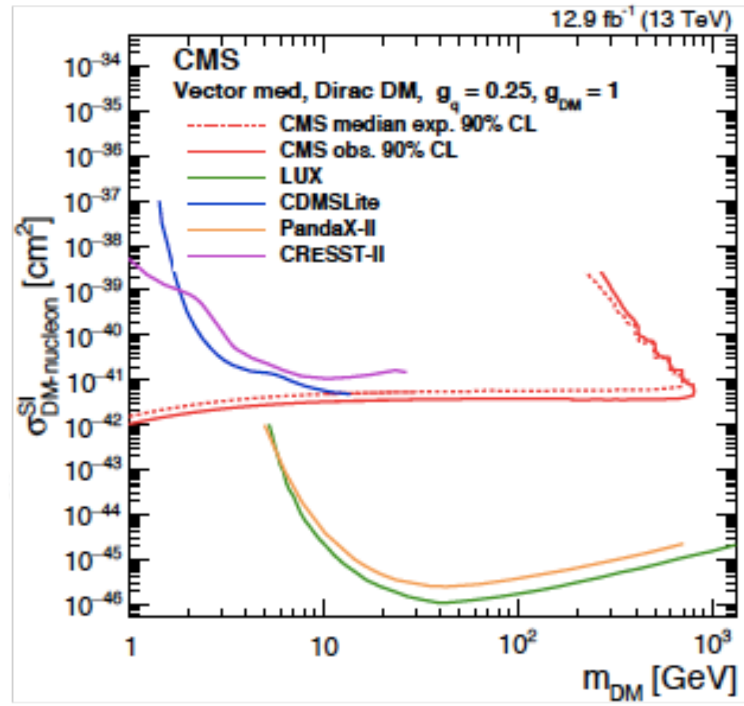


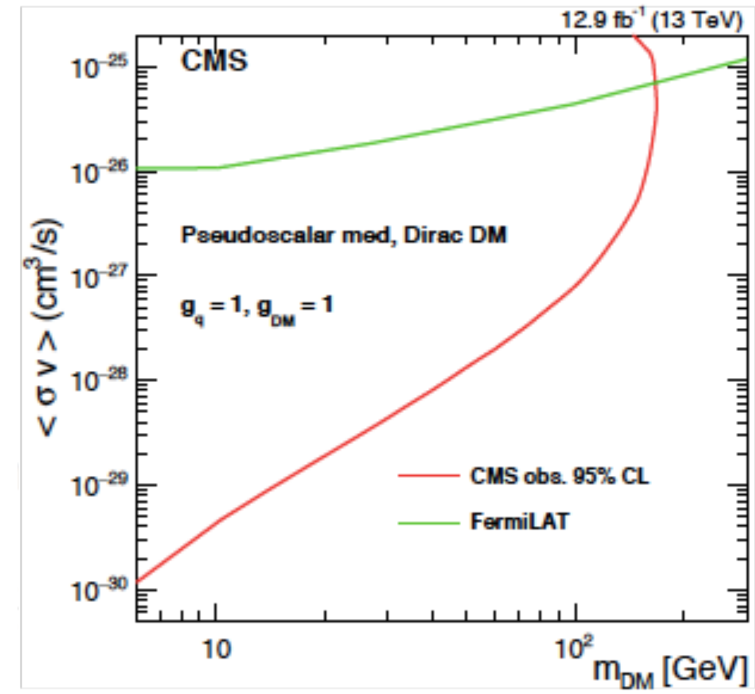
production (LHC)

Search for dark matter produced with an energetic jet or a hadronically decaying W or Z boson at $\sqrt{s} = 13$ TeV

The CMS Collaboration*



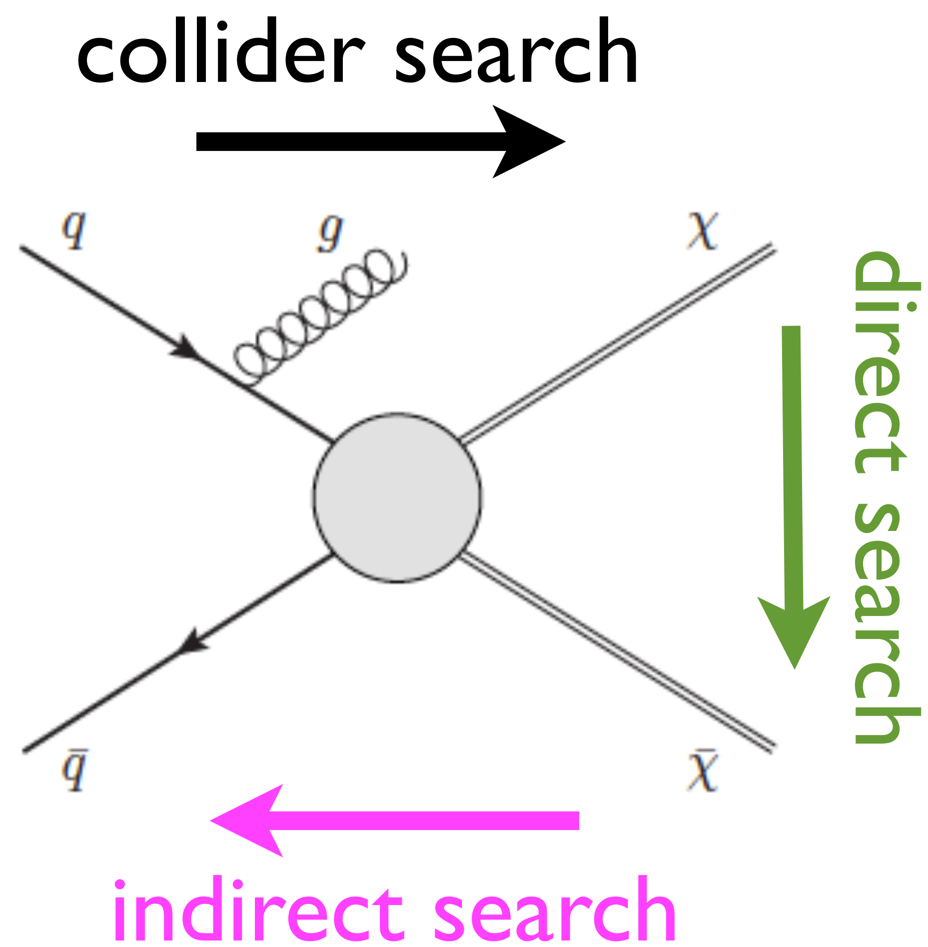




ing fraction. The results of this search provide the strongest constraints on the dark matter pair production cross section through vector and axial-vector mediators at a particle collider. When compared to the direct detection experiments, the limits obtained from this search provide stronger constraints for dark matter masses less than 5, 9, and 550 GeV, assuming vector, scalar, and axial-vector mediators, respectively. The search yields stronger constraints for dark matter masses less than 200 GeV, assuming a pseudoscalar mediator, when compared to the indirect detection results from Fermi–LAT.

Looking for dark matter

- If dark matter has non-gravitational interactions with ordinal matter, we can observe it directly and/or indirectly.
- Indeed, many types of dark matter search experiments are currently on-going all over the world.

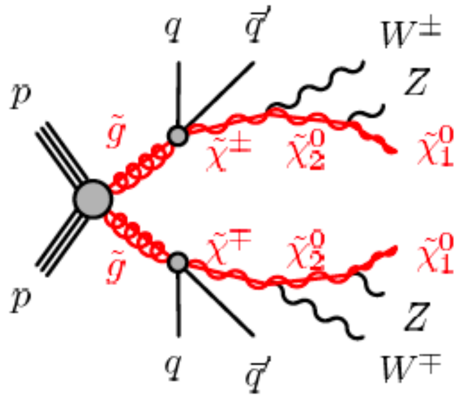


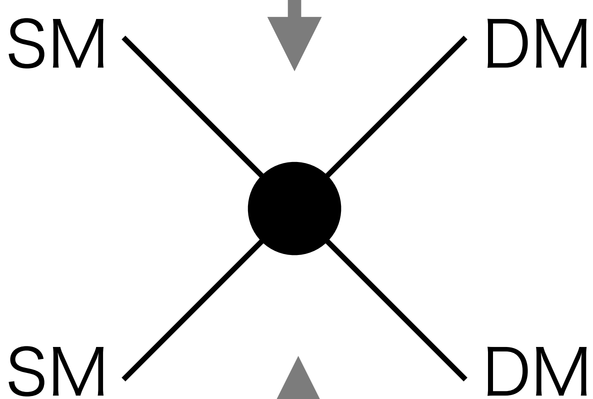
DM (or MET) searches at LHC Run-I

Top-down approach

UV model : SUSY, ExtraDim, $\cdots$

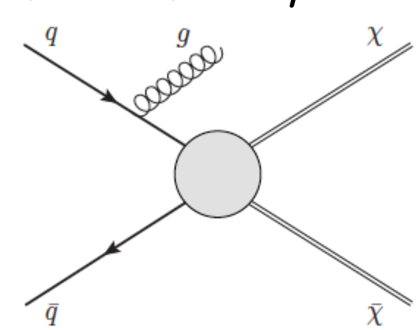
$$\{\mathcal{L}; m_{\rm DM}, m_1, m_2, \cdots, g_1, g_2, \cdots\}$$





EFT : SM + DM particles

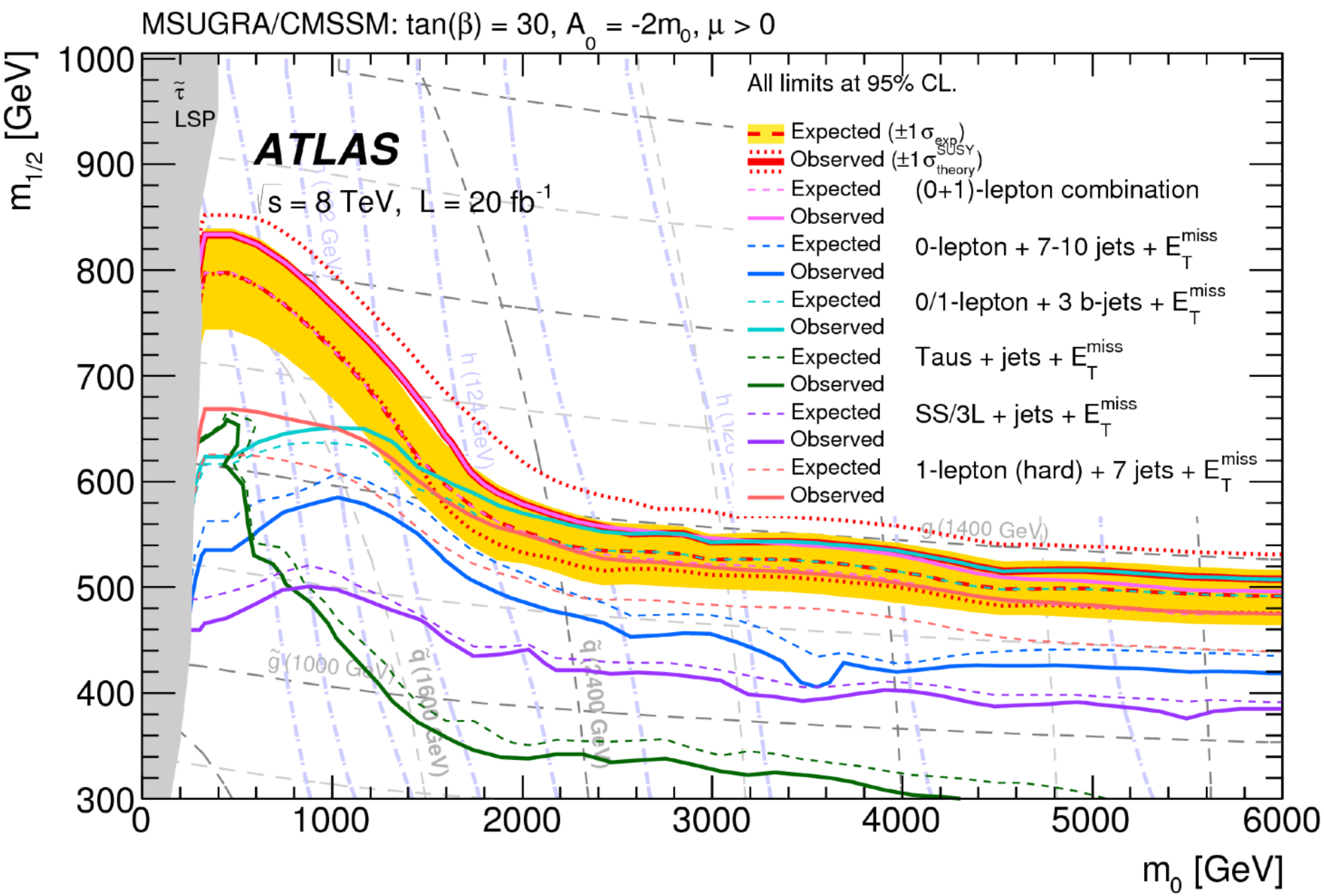
$$\{\mathcal{L}; m_{\rm DM}, M_*\} \qquad \mathcal{L} = \frac{1}{M_*^2}\bar{\chi}\Gamma^\mu\chi\,\bar{q}\Gamma_\mu q$$



Bottom-up approach

$\tilde{\chi}_1^0$

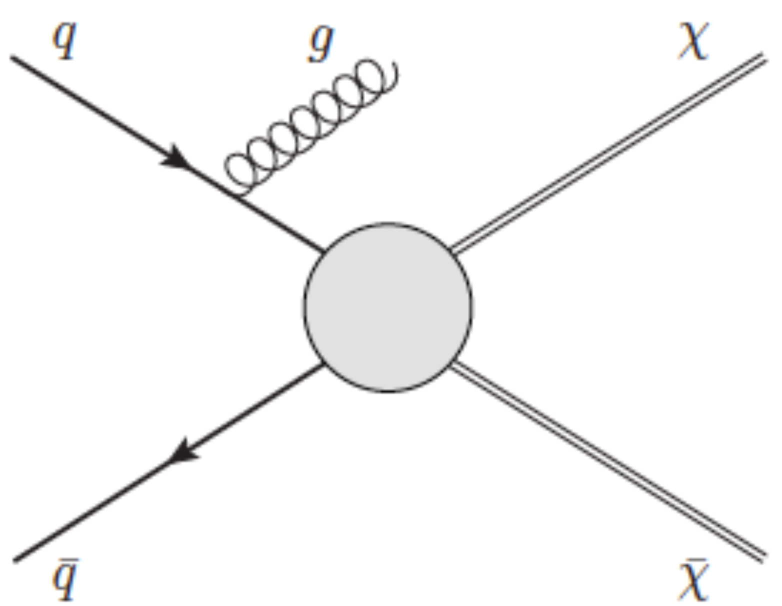
DM (or MET) searches at LHC Run-I: top-down (e.g. Supersymmetry)



predictive, but many parameters and many final states…

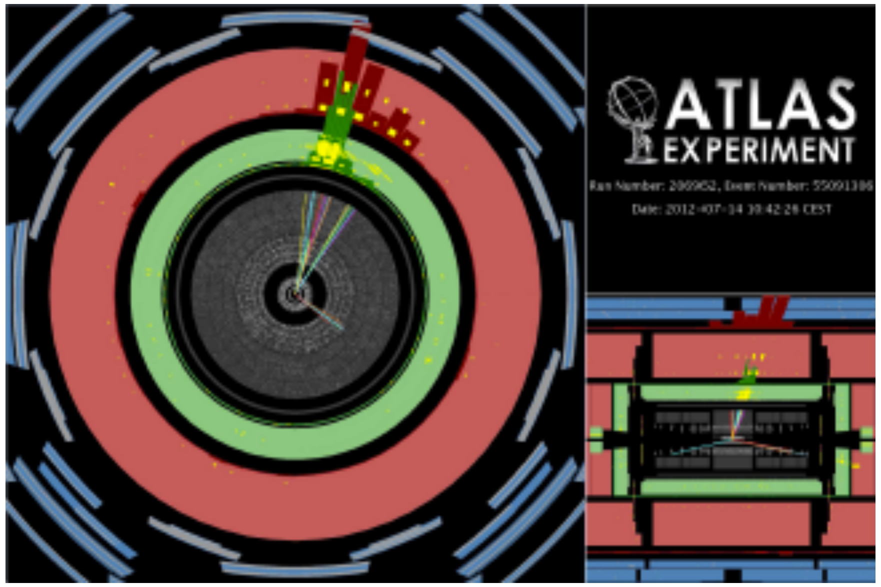
DM (or MET) searches at LHC Run-I: bottom-up (Effective field theory)

mono-X search



- employed contact interaction operators in EFTs (effective field theories).
- vector $\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$

  axial-vector $\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
- The signal is determined by the Lorentz structure, the DM mass, and the overall coupling (or the cutoff scale).
- Simple final states
- easy interpretation to non-collider DM searches

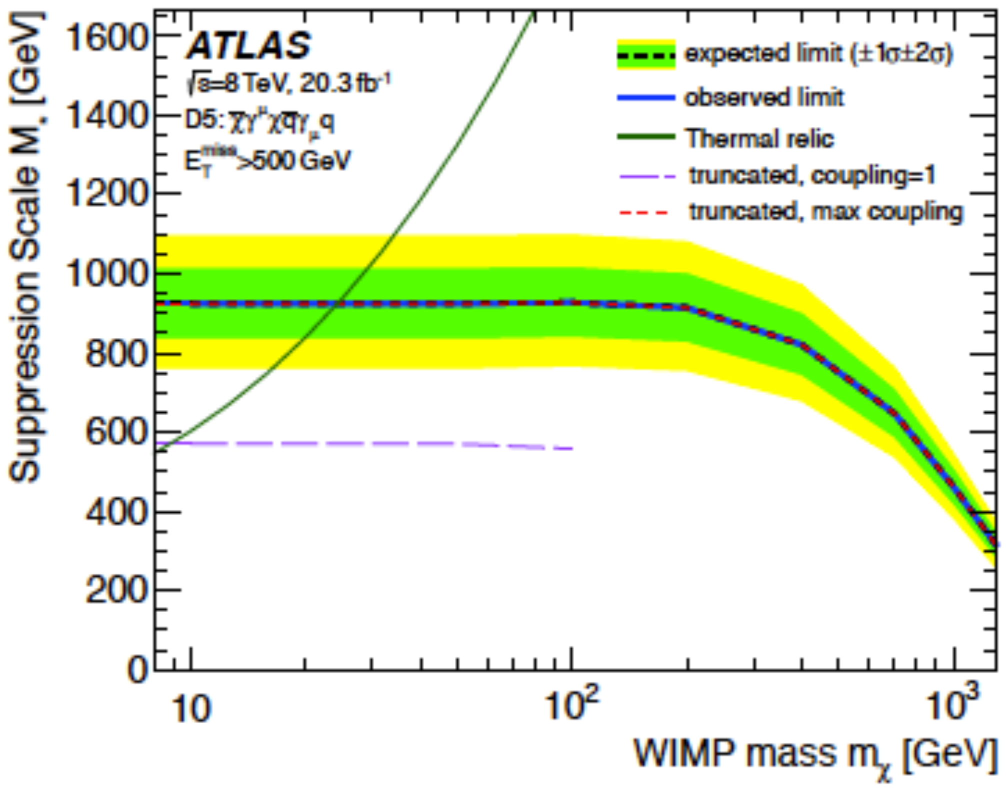


DM (or MET) searches at LHC Run-I: bottom-up (Effective field theory)

- employed contact interaction operators in EFTs (effective field theories).
- vector $\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$

  axial-vector $\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
- The signal is determined by the Lorentz structure, the DM mass, and the overall coupling (or the cutoff scale).
- Simple final states
- easy interpretation to non-collider DM searches
- EFT validation; $M_\star \leqq$ (LHC accessible energy)

[1502.01518]



First open meeting of the LHC Dark Matter WG

by M. Mangano

CERN, Dec 10-11 2015

The WG activity builds on the experience of the previous ATLAS-CMS Dark Matter Forum, whose findings are documented in http://arxiv.org/abs/1507.00966

The WG

- brings together theorists and experimentalists to define guidelines and recommendations for the benchmark models, interpretation, and characterisation necessary for broad and systematic searches for dark matter at the LHC.
- develops and promotes well-defined signal models, specifying the assumptions behind them and describing the conditions under which they should be used.
- works to improve the set of tools available to the experiments, such as higher-precision calculations of the backgrounds.
- assists theorists with understanding and making use of LHC results.
- develops and maintains close connections with theorists and other experimental particle DM searches (e.g. Direct and Indirect Detection experiments) in order to help verify and constrain particle physics models of astrophysical excesses, to understand how collider searches and non-collider experiments complement one another, and to help build a comprehensive understanding of viable dark matter models.

LHC DMWG documents

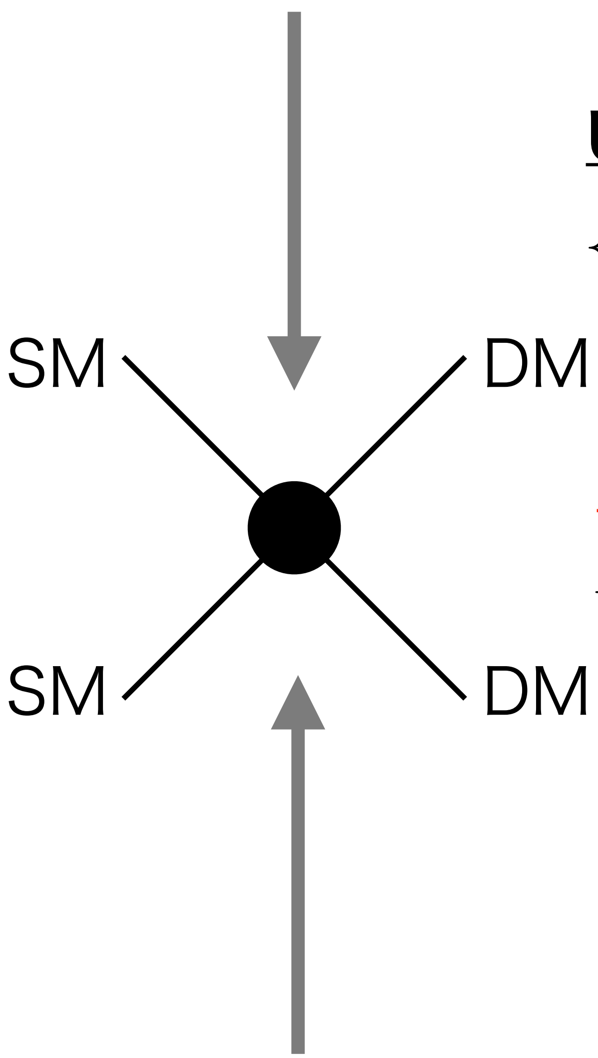
- arXiv:1507.00966
  "DM benchmark models for early LHC Run-2"
  (Report of the ATLAS/CMS Dark Matter Forum)
- arXiv:1603.04156
  "Recommendations on presenting LHC searches for MET signals using simplified s-channel models of DM"
- arXiv:1703.05703
  "Comparing LHC searches for heavy mediators of DM production in visible and invisible decay channels"
- arXiv:1705.04664
  "Precise predictions for V+jets DM backgrounds"

Summary of the LHC DMWG activities

- develops well-defined benchmark models
- provides (accurate) simulation tools for signal and background
- defines guidelines for presentation and interpretation of the LHC results

DM (or MET) searches at LHC Run-II

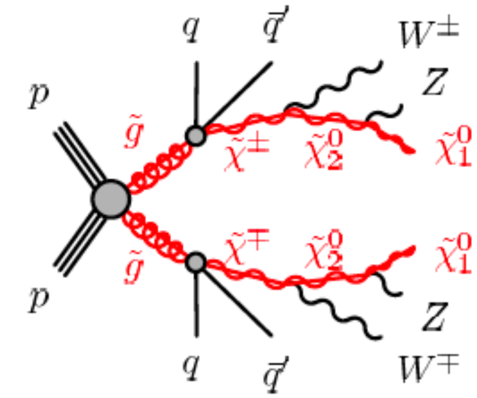
Top-down approach



Bottom-up approach

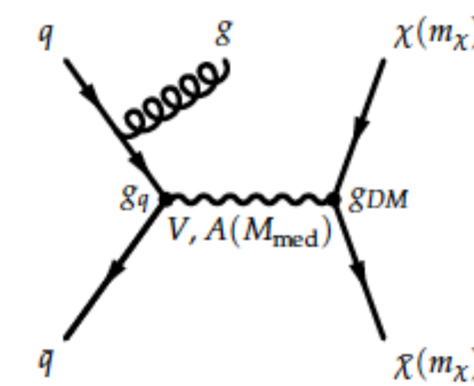
UV model : SUSY, ExtraDim, ⋯

$$\{\mathcal{L}; m_{\rm DM}, m_1, m_2, \cdots, g_1, g_2, \cdots\}$$



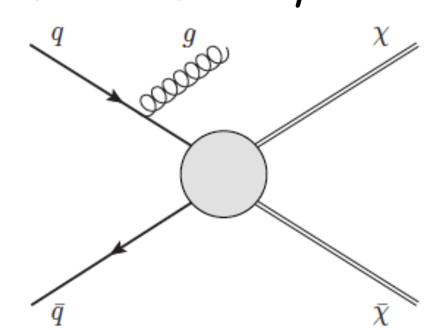
Simplified model : SM + DM + Mediator particles

$$\{\mathcal{L}; m_{\rm DM}, m_{\rm med}, g_{\rm DM}, g_q\} \quad \mathcal{L} = g_{\rm DM} Z'_\mu \bar{\chi}\gamma^\mu\chi + g_q Z'_\mu \bar{q}\gamma^\mu q$$



EFT : SM + DM particles

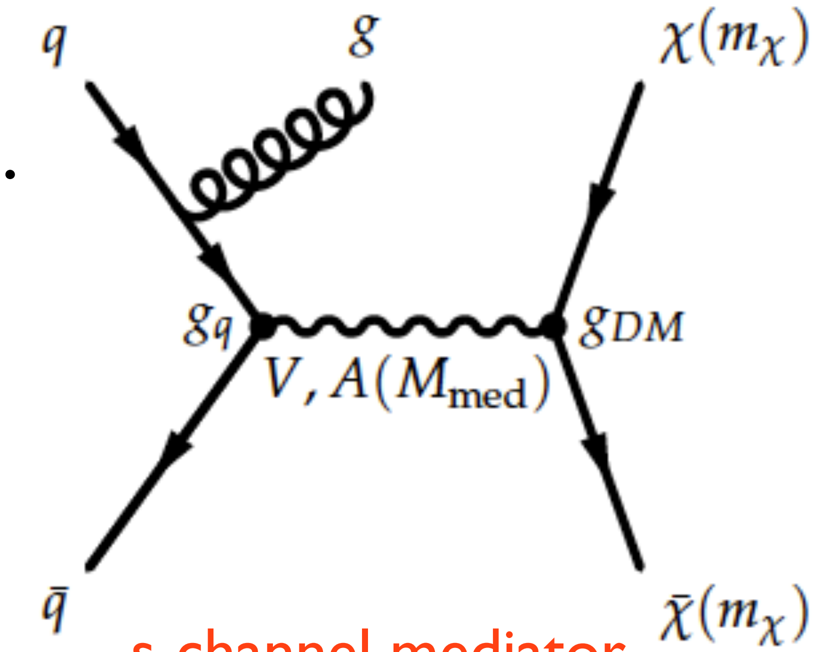
$$\{\mathcal{L}; m_{\rm DM}, M_*\} \quad \mathcal{L} = \frac{1}{M_*^2}\bar{\chi}\Gamma^\mu\chi\,\bar{q}\Gamma_\mu q$$



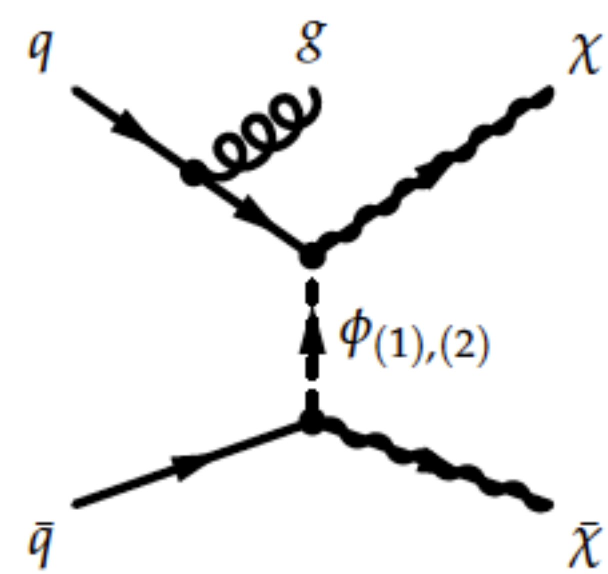
Simplified DM models

DM Forum [1507.00966]

- Run-II is employing simplified DM models.
- $$\mathcal{L}_{\text{vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu \chi$$
  $$\mathcal{L}_{\text{axial-vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu \gamma^5 q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu \gamma^5 \chi$$
- The signal is determined by the mediator type, the DM and mediator masses, and one or two coupling(s).
- Richer phenomenology
- Interpretations to non-collider DM searches are more complicated.



s-channel mediator



t-channel mediator

s-channel simplified models: spin-0, 1

DM Forum [1507.00966]

- Simplified DM models (s-channel):
  - spin-1 mediator

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

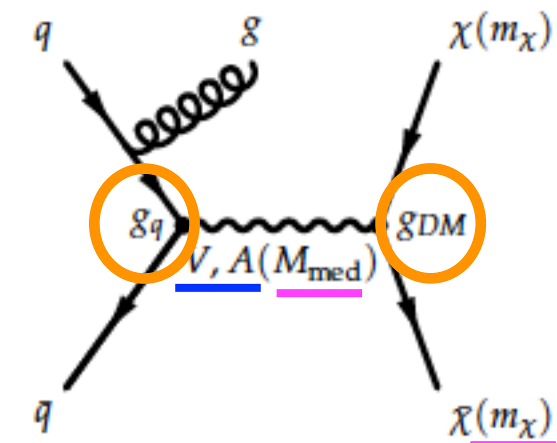
$$\mathcal{L}_{\text{axial-vector}} = -g_{\text{DM}} Z'_\mu \bar{\chi}\gamma^\mu \gamma_5 \chi - g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu \gamma_5 q\,.$$

  - spin-0 mediator

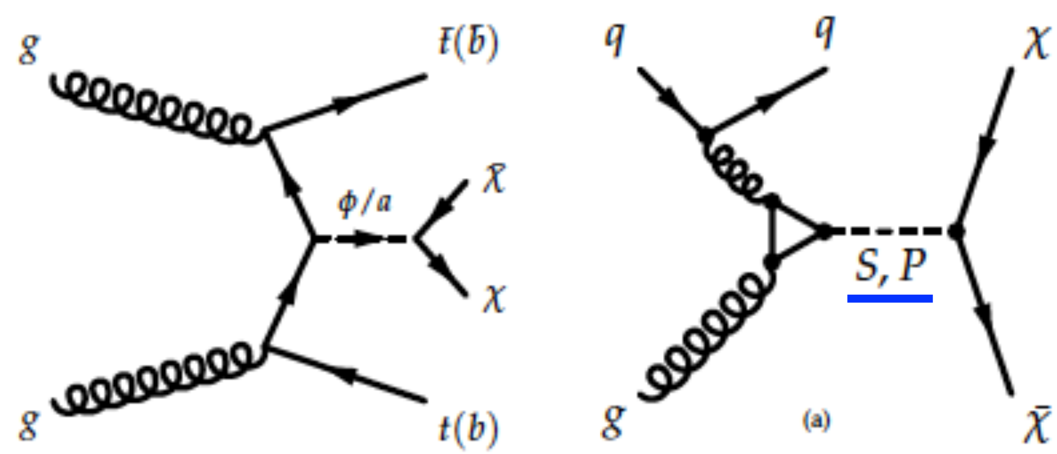
$$\mathcal{L}_{\text{scalar}} = -g_{\text{DM}}\, \phi \bar{\chi}\chi - g_q \frac{\phi}{\sqrt{2}} \sum_{q=u,d,s,c,b,t} y_q \bar{q} q\,,$$

$$\mathcal{L}_{\text{pseudo-scalar}} = -i g_{\text{DM}}\, \phi \bar{\chi}\gamma_5 \chi - i g_q \frac{\phi}{\sqrt{2}} \sum_{q=u,d,s,c,b,t} y_q \bar{q}\gamma_5 q\,,$$

- The signal is determined by
  - the mediator type (V, A, S, P)
  - the DM and mediator masses
  - the two couplings



spin-1 mediator



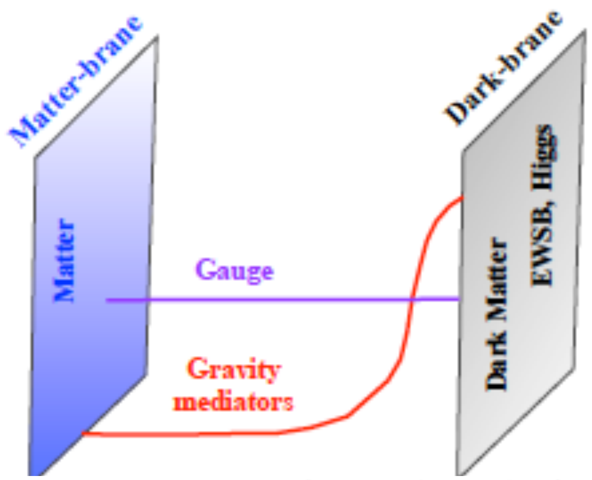
spin-0 mediator

👉 Top-philic DM models

s-channel simplified models: spin-2

Gravity-mediated DM:
  Lee, Park, Sanz [1306.4107, 1401.5301]
  Rueter, Rizzo, Hewett [1706.07540]

Das, Degrande, Hirschi, Maltoni, Shao [1605.09359]
Kraml, Laa, KM, Yamashita [1701.07008, EPJC]

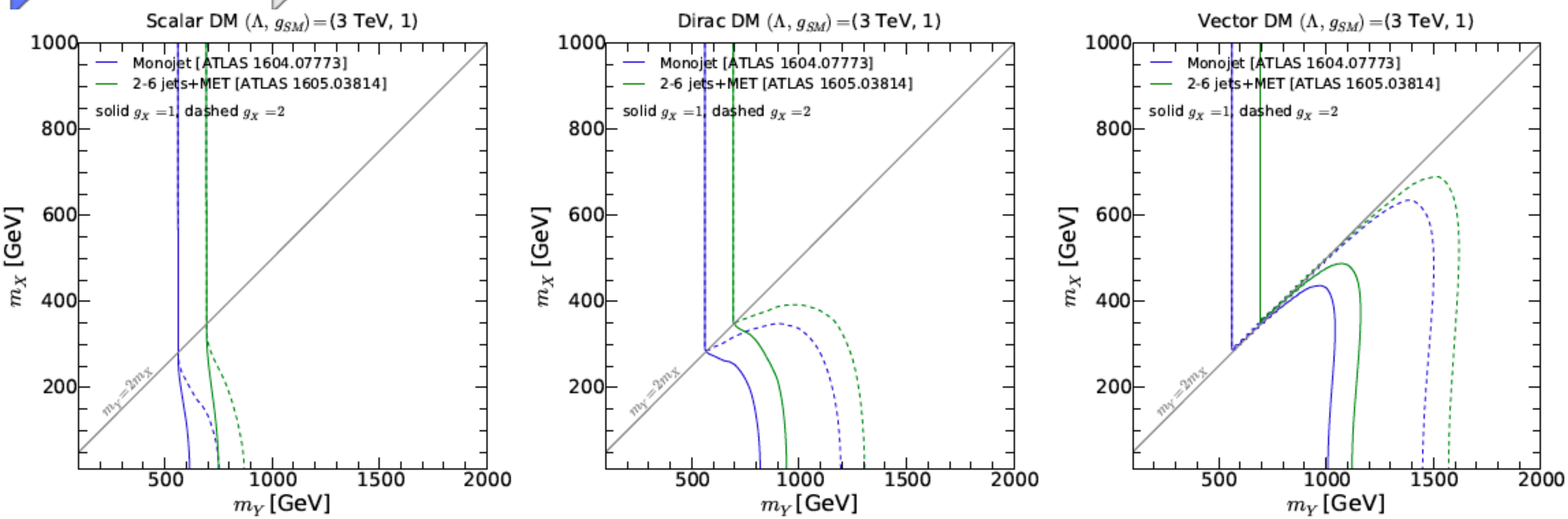


$$\mathcal{L}_X^{Y_2} = -\frac{1}{\Lambda} g_X^T \, T_{\mu\nu}^X Y_2^{\mu\nu}$$

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

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

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

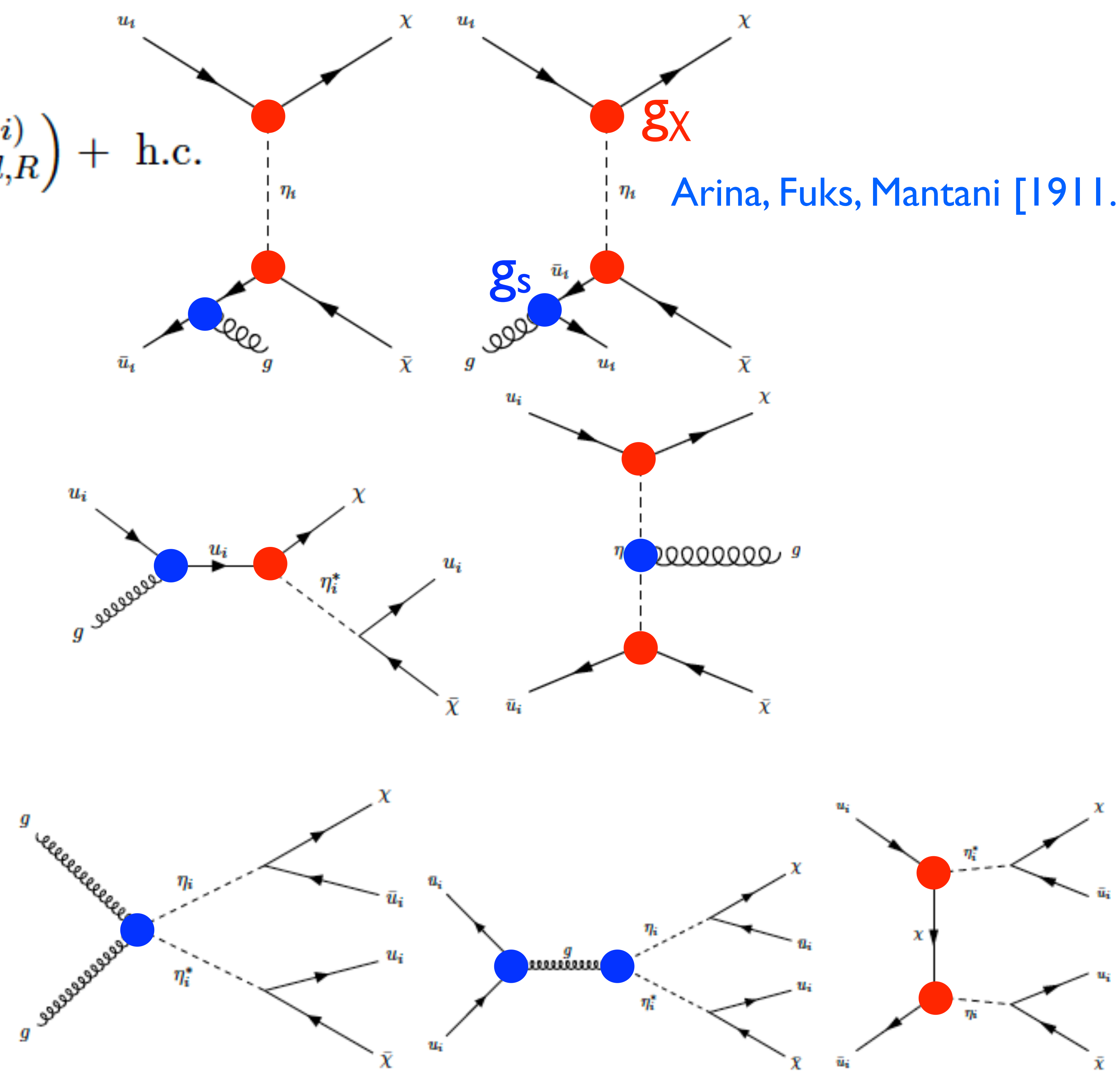


t-channel simplified models: colored scalar

See, e.g., De Simone, Jacques [1603.08002, EPJC]

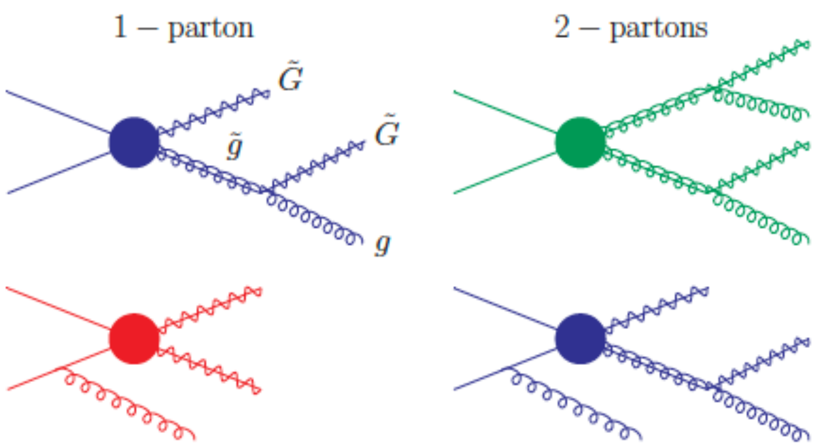
$$\mathcal{L} = \sum_{i=1,2,3} g_i \, \chi \left(\bar{Q}_L^{(i)} \eta_L^{(i)} + \bar{u}_R^{(i)} \eta_{u,R}^{(i)} + \bar{d}_R^{(i)} \eta_{d,R}^{(i)} \right) + \text{ h.c.}$$

$$\{m_\chi, M, g\}$$



Arina, Fuks, Mantani [1911.?????]

Gravitino production at the LHC
Maltoni, Martini, KM, Oexl [1502.01637, JHEP]



ME+PS merging,
proper treatment of resonances,
...

Summary of the LHC DMWG activities

- develops well-defined benchmark models
- provides (accurate) simulation tools for signal and background
- defines guidelines for presentation and interpretation of the LHC results

CMS [1712.02345]

Search for new physics in final states with an energetic jet or a hadronically decaying W or Z boson and transverse momentum imbalance at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

3 Simulated samples

To model the SM backgrounds, simulated Monte Carlo (MC) samples are produced for the Z+jets, W+jets, γ+jets, and quantum chromodynamics (QCD) multijet processes at leading order (LO) using the MADGRAPH5_aMC@NLO 2.2.2 [56] generator and are generated with up to four additional partons in the matrix element calculations. The samples for the $t\bar{t}$ and single top quark background processes are produced at next-to-leading order (NLO) using POWHEG 2.0 and 1.0, repectively [57, 58], and the set of diboson (WW, WZ, ZZ) samples is produced at LO with PYTHIA 8.205 [59].

Vector and axial-vector monojet and mono-V dark matter signals are simulated at NLO using the DMSIMP models [60, 61] with the MADGRAPH5_aMC@NLO generator. Both scalar and pseudoscalar monojet production contain gluon-initiated loop processes. These samples are generated at LO with one or two additional partons in the matrix element calculations, taking into account finite top mass effects using the MADGRAPH5_aMC@NLO generator in conjunction with the DMSIMP models.

ATLAS [1903.01400]

Constraints on mediator-based dark matter and scalar dark energy models using $\sqrt{s}$ = 13 TeV pp collision data collected by the ATLAS detector

The ATLAS Collaboration

Table 4: Details of the generation setup and Universal FeynRules Output (UFO) model used for the spin-1 mediator simplified models, for each signature considered in this paper.

Model and Final State	UFO	Generator and Parton Shower	Cross-section	Additional details
$Z'(\chi\bar{\chi})+j$	DMV [26, 215]	POWHEG-BOX v2 [216] + PYTHIA 8.205 [217]	NLO	Particle-level rescaling of leptophobic Z'_A scenario of Ref. [26] (see Appendix A.1)
$Z'(\chi\bar{\chi})+\gamma$	DMSimp [116, 218]	MG5_AMC@NLO 2.4.3 (NLO) [213] + PYTHIA 8.212	NLO	Leptophobic Z'_A scenario simulated, other scenarios obtained by cross-section rescaling (see Appendix A.1)
$Z'(\chi\bar{\chi})+V$	DMSimp	MG5_AMC@NLO 2.5.3 (NLO) + PYTHIA 8.212	NLO	Particle-level rescaling of LO samples of Ref. [20] to each of the four NLO scenarios (see Appendix A.1)
$Z'(qq)$ or $Z'(qq)$+ISR	DMSimp	MG5_AMC@NLO 2.2.3 (NLO) + PYTHIA 8.210	NLO	Leptophobic Z'_A scenario simulated, other scenario obtained by Gaussian resonance limits and cross-section rescaling [214]
$Z'(b\bar{b})$	DMSimp	MG5_AMC@NLO 2.2.3 (NLO) + PYTHIA 8.210	NLO	Leptophobic Z'_A scenario simulated, other scenario obtained by Gaussian resonance limits and cross-section rescaling [214]

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

Simplified dark matter models

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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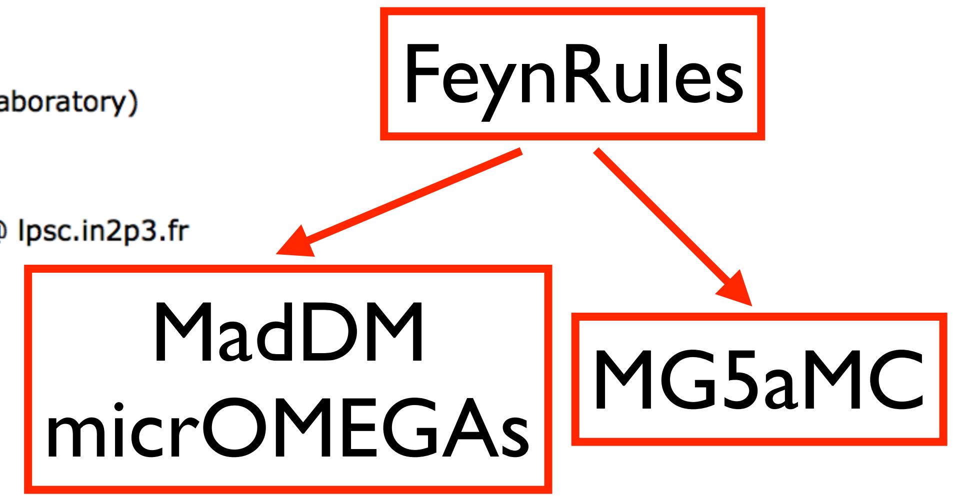
    - Emails: cenzhang @ bnl.gov
- s-channel (spin-2)
  - Goutam Das (Saha Inst.), Celine Degrande (CERN) & Kentarou Mawatari (LPSC Grenoble)
    - Emails: goutam.das @ saha.ac.in, celine.degrande @ cern.ch, kentarou.mawatari @ lpsc.in2p3.fr



Description of the model

This is simplified dark matter models for NLO. Our lagrangian consists of different types of DM:

- 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)
  - ...
- t-channel [to be done.]

See more details in

- 1508.00564 : O. Mattelaer, E. Vryonidou, "Dark matter production through loop-induced processes at the LHC: the s-channel mediator case" (EPJC75(2015)436).
- 1508.05327 : M. Backovic, M. Kramer, F. Maltoni, A. Martini, K. Mawatari, M. Pellen, "Higher-order QCD predictions for dark matter production at the LHC in simplified models with s-channel mediators" (EPJC75(2015)482).
- 1509.05785 : M. Neubert, J. Wang, C. Zhang, "Higher-order QCD predictions for dark matter production in mono-Z searches at the LHC" (JHEP1602(2016)082).
- 1605.09359 : G. Das, C. Degrande, V. Hirschi, F. Maltoni, H. Shao, "NLO predictions for the production of a spin-two particle at the LHC"
- 1701.07008 : S. Kraml, U. Laa, K. Mawatari, K. Yamashita, "Simplified dark matter models with a spin-2 mediator at the LHC".

1-min MadGraph5_aMC@NLO tutorial

```
./bin/mg5_aMC
>import model DMsimp_s_spin1
>generate p p > xd xd~ j [QCD]
>output
>launch
```

- Start the MG5_aMC shell
- Import the model
- Generate the process
- Write the code (including html)
- Generate the LO/NLO events

param_card.dat

```
##################################
## INFORMATION FOR DMINPUTS
##################################
Block dminputs
    1 0.000000e+00 # gVXc
    2 1.000000e+00 # gVXd
    3 0.000000e+00 # gAXd
    4 2.500000e-01 # gVd11
    5 2.500000e-01 # gVu11
    6 2.500000e-01 # gVd22
    7 2.500000e-01 # gVu22
    8 2.500000e-01 # gVd33
    9 2.500000e-01 # gVu33
   10 0.000000e+00 # gAd11
   11 0.000000e+00 # gAu11
   12 0.000000e+00 # gAd22
   13 0.000000e+00 # gAu22
   14 0.000000e+00 # gAd33
   15 0.000000e+00 # gAu33
```

$$\mathcal{L}_{X_D}^{Y_1} = \bar{X}_D\gamma_\mu(g^V_{X_D} + g^A_{X_D}\gamma_5)X_D\, Y_1^\mu$$

$$\mathcal{L}_{\rm SM}^{Y_1} = \sum_{i,j}\left[\bar{q}_i\gamma_\mu(g^V_{q_{ij}} + g^A_{q_{ij}}\gamma_5)q_j\right]Y_1^\mu$$

```
##################################
## INFORMATION FOR MASS
##################################
Block mass
    6 1.720000e+02 # MT
   15 1.777000e+00 # MTA
   23 9.118760e+01 # MZ
   25 1.250000e+02 # MH
   51 1.000000e+01 # MXc
   52 1.000000e+01 # MXd
   55 1.000000e+03 # MY1
 5000001 1.000000e+01 # MXr
```

run_card.dat

```
#*********************************************************************
# Collider type and energy
#*********************************************************************
  1    = lpp1    ! beam 1 type (0 = no PDF)
  1    = lpp2    ! beam 2 type (0 = no PDF)
 6500  = ebeam1  ! beam 1 energy in GeV
 6500  = ebeam2  ! beam 2 energy in GeV
#*********************************************************************
# PDF choice: this automatically fixes also alpha_s(MZ) and its evol.
#*********************************************************************
 nn23nlo  = pdlabel  ! PDF set
 230000   = lhaid    ! if pdlabel=lhapdf, this is the lhapdf number
#*********************************************************************
# Include the NLO Monte Carlo subtr. terms for the following parton
# shower (HERWIG6 | HERWIGPP | PYTHIA6Q | PYTHIA6PT | PYTHIA8)
# WARNING: PYTHIA6PT works only for processes without FSR!!!!
#*********************************************************************
  HERWIG6   = parton_shower
```

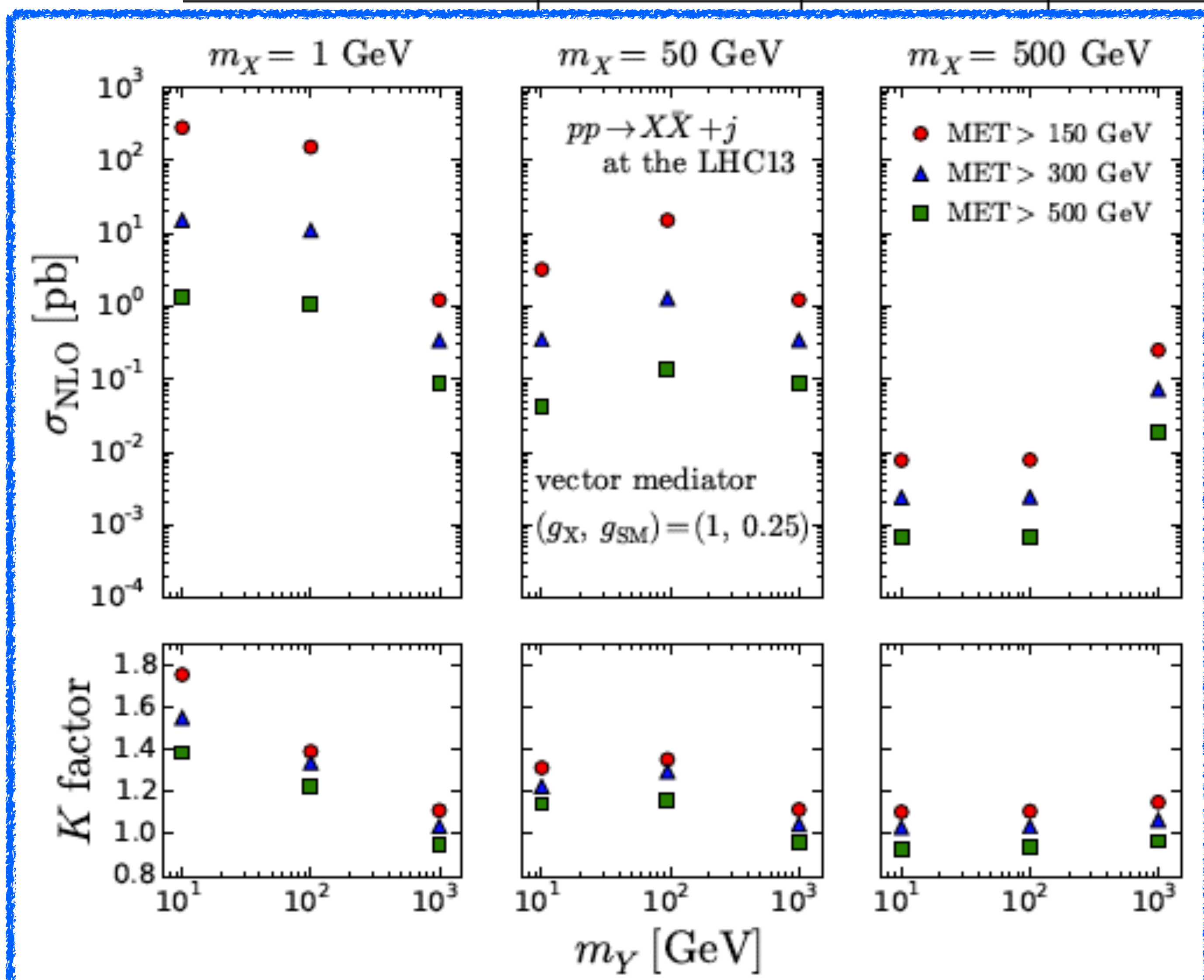
DMsimp(spin-0,1): Backovic, Kramer, Maltoni, Martini, KM, Pellen [1508.05327, EPJC]

Cross sections for mono-j at LHC13

(m_Y, m_X) [GeV]			MET > 150 GeV	MET > 300 GeV
(100, 1)	$m_Y > 2m_X$	$\sigma_{\rm LO}$ [pb] $\sigma_{\rm NLO}$ [pb] K factor	$1.100 \times 10^2\,{}^{+10.6}_{-9.3} \pm 1.5\,\%$ $1.530 \times 10^2\,{}^{+6.5}_{-5.7} \pm 0.5\,\%$ 1.39	$0.822 \times 10^1\,{}^{+14.4}_{-12.0} \pm 1.1\,\%$ $1.100 \times 10^1\,{}^{+7.4}_{-7.2} \pm 0.6\,\%$ 1.34
			$10^1\,{}^{+11.0}_{-9.6} \pm 1.5\,\%$ $10^1\,{}^{+6.0}_{-5.5} \pm 0.5\,\%$	$0.988 \times 10^0\,{}^{+14.7}_{-12.2} \pm 1.1\,\%$ $1.281 \times 10^0\,{}^{+6.8}_{-6.8} \pm 0.6\,\%$ 1.30
			$10^{-3}\,{}^{+17.4}_{-14.0} \pm 4.3\,\%$ $10^{-3}\,{}^{+5.3}_{-6.4} \pm 2.2\,\%$	$2.329 \times 10^{-3}\,{}^{+18.9}_{-15.0} \pm 4.6\,\%$ $2.411 \times 10^{-3}\,{}^{+5.5}_{-6.8} \pm 2.3\,\%$ 1.04

PDF uncertainty

scale (renormalization and factrorization) uncertainty

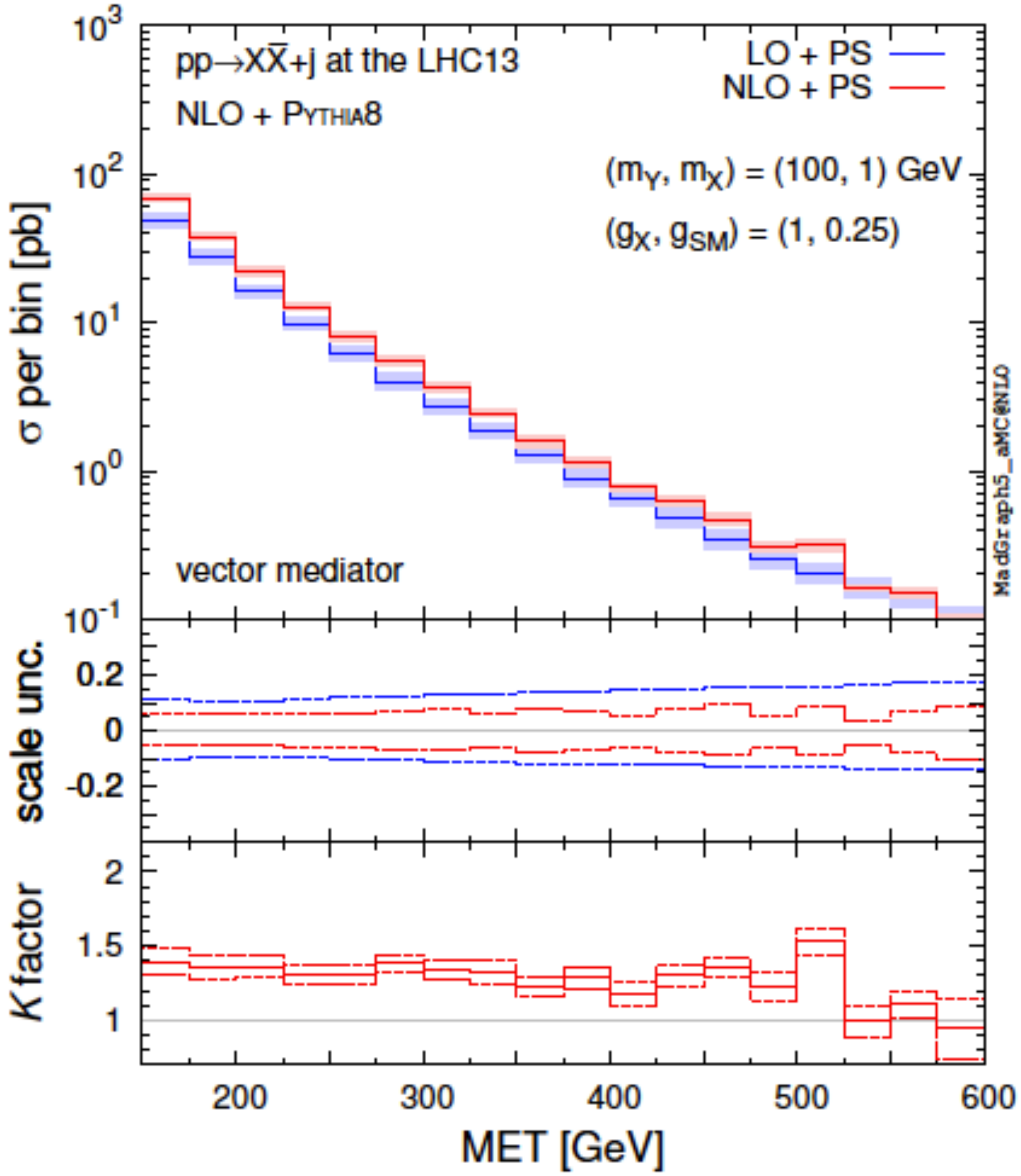


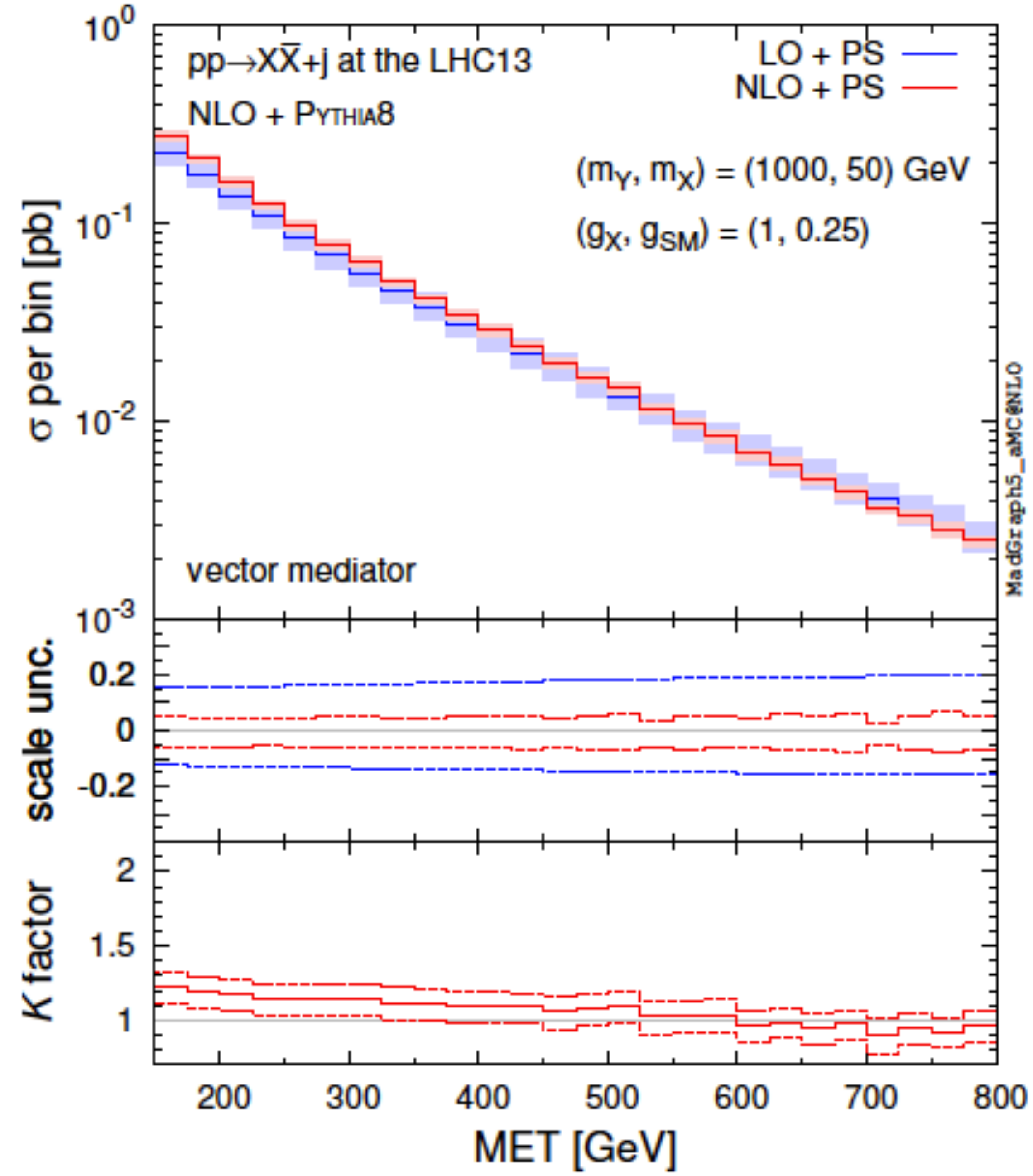
NLO corrections

- strongly depends on the mass spectrum and the kinematical cuts.
- sizeably reduces of the scale and PDF uncertainties.

DMsimp(spin-0,1): Backovic, Kramer, Maltoni, Martini, KM, Pellen [1508.05327, EPJC]

DM production at NLO+PS

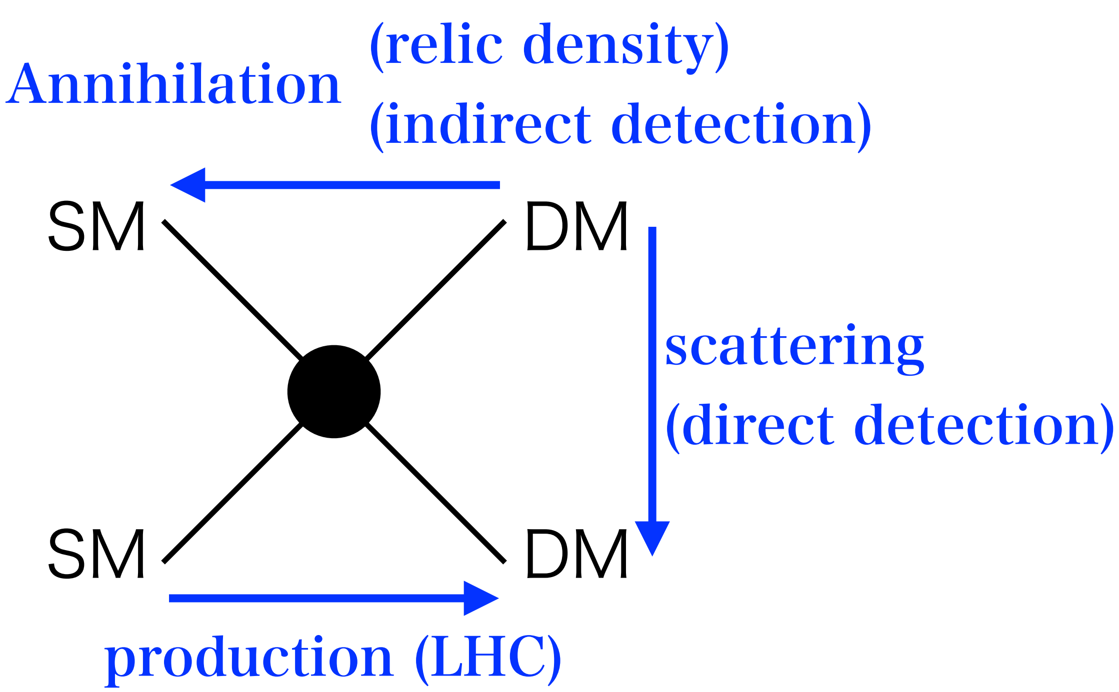


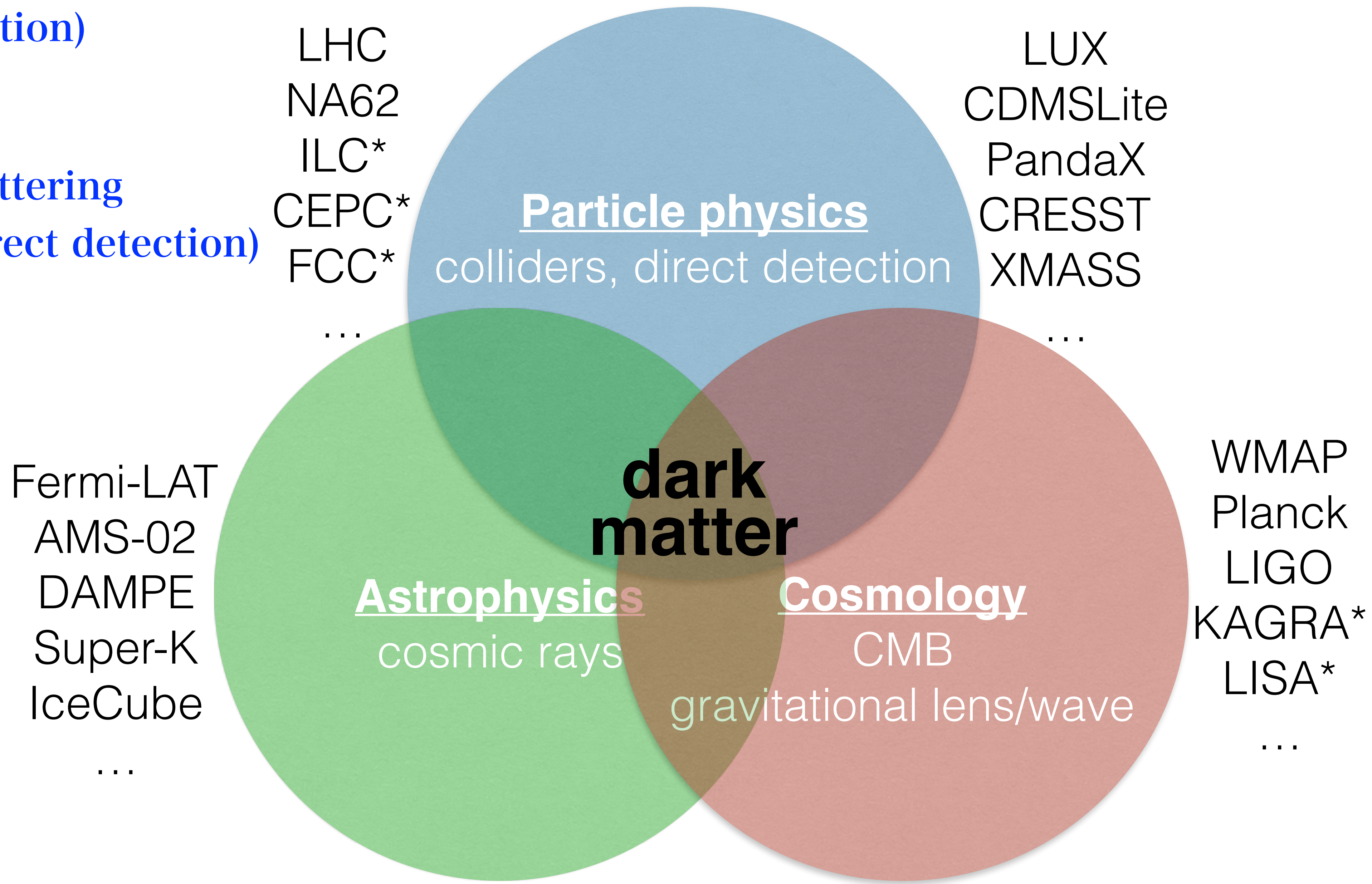


Summary of the LHC DMWG activities

- develops well-defined benchmark models
- provides (accurate) simulation tools for signal and background
- defines guidelines for presentation and interpretation of the LHC results

Interpretation of the LHC MET search

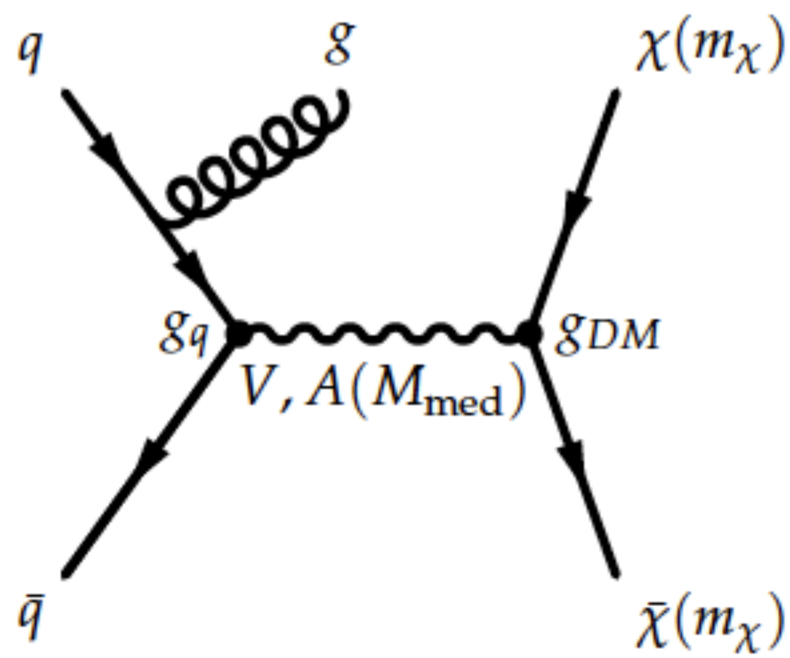




Signatures of simplified DM models

LHC DMWG [1603.04156, 1703.05703]

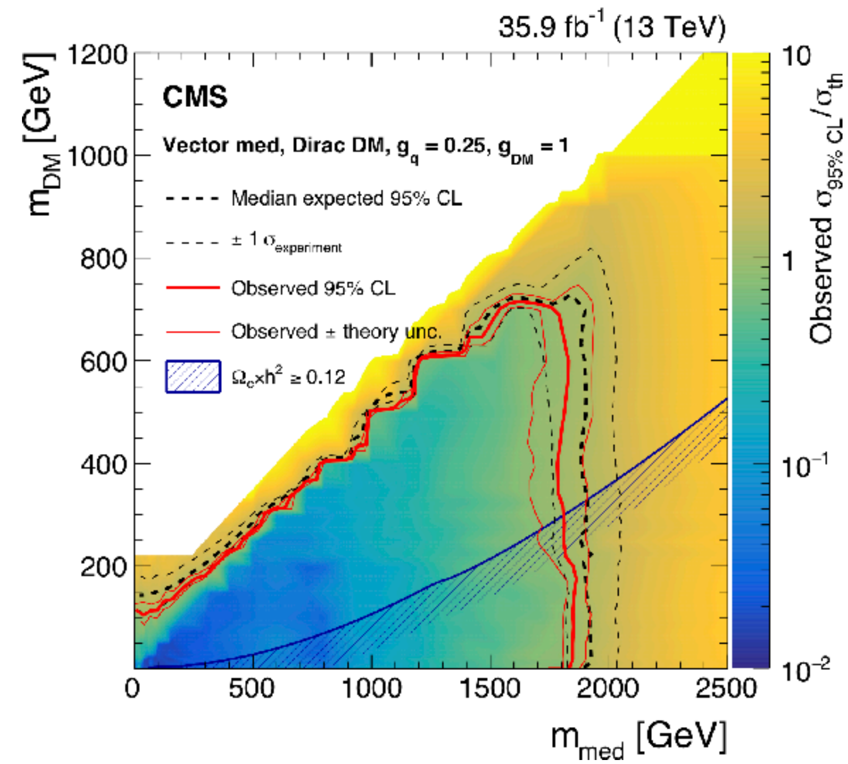
missing-energy search →



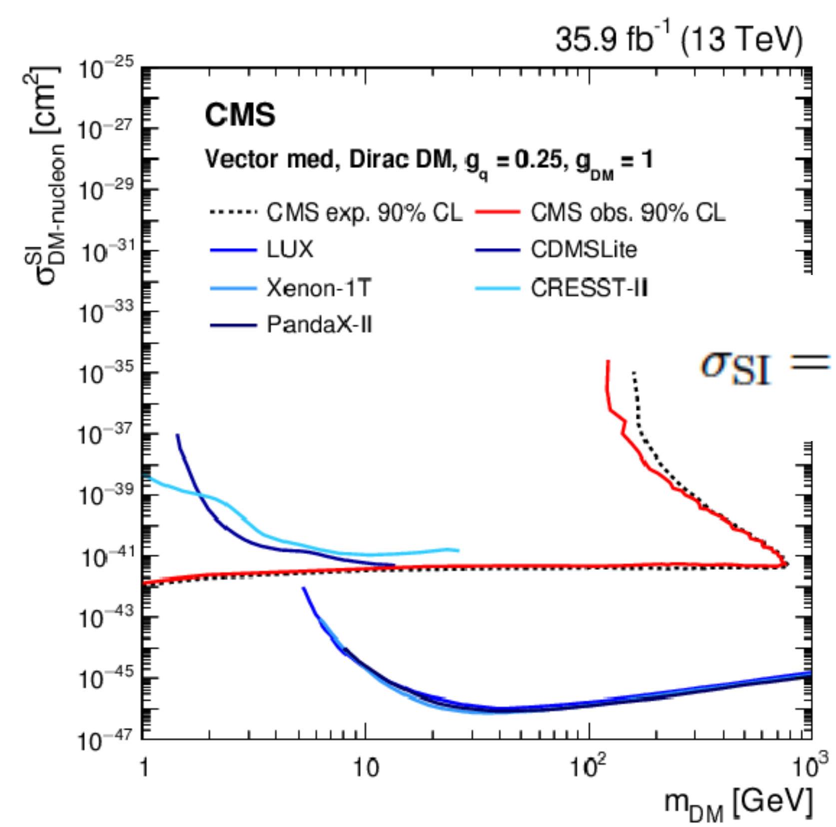
direct detection ↓

← relic density

indirect detection



[1712.02345]

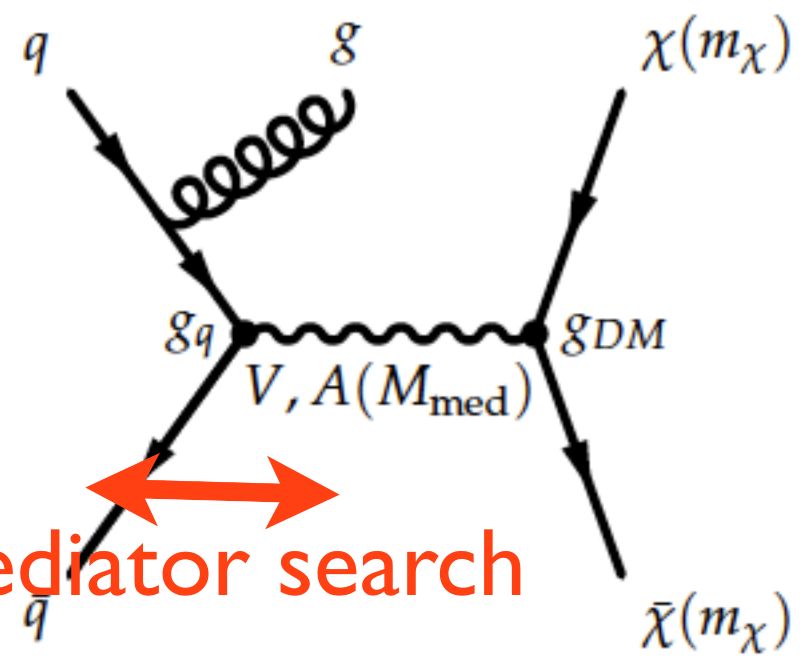


$$\sigma_{\rm SI} = \frac{f^2(g_q) g_{\rm DM}^2 \mu_{n\chi}^2}{\pi M_{\rm med}^4}$$

Signatures of simplified DM models

LHC DMWG [1603.04156, 1703.05703]

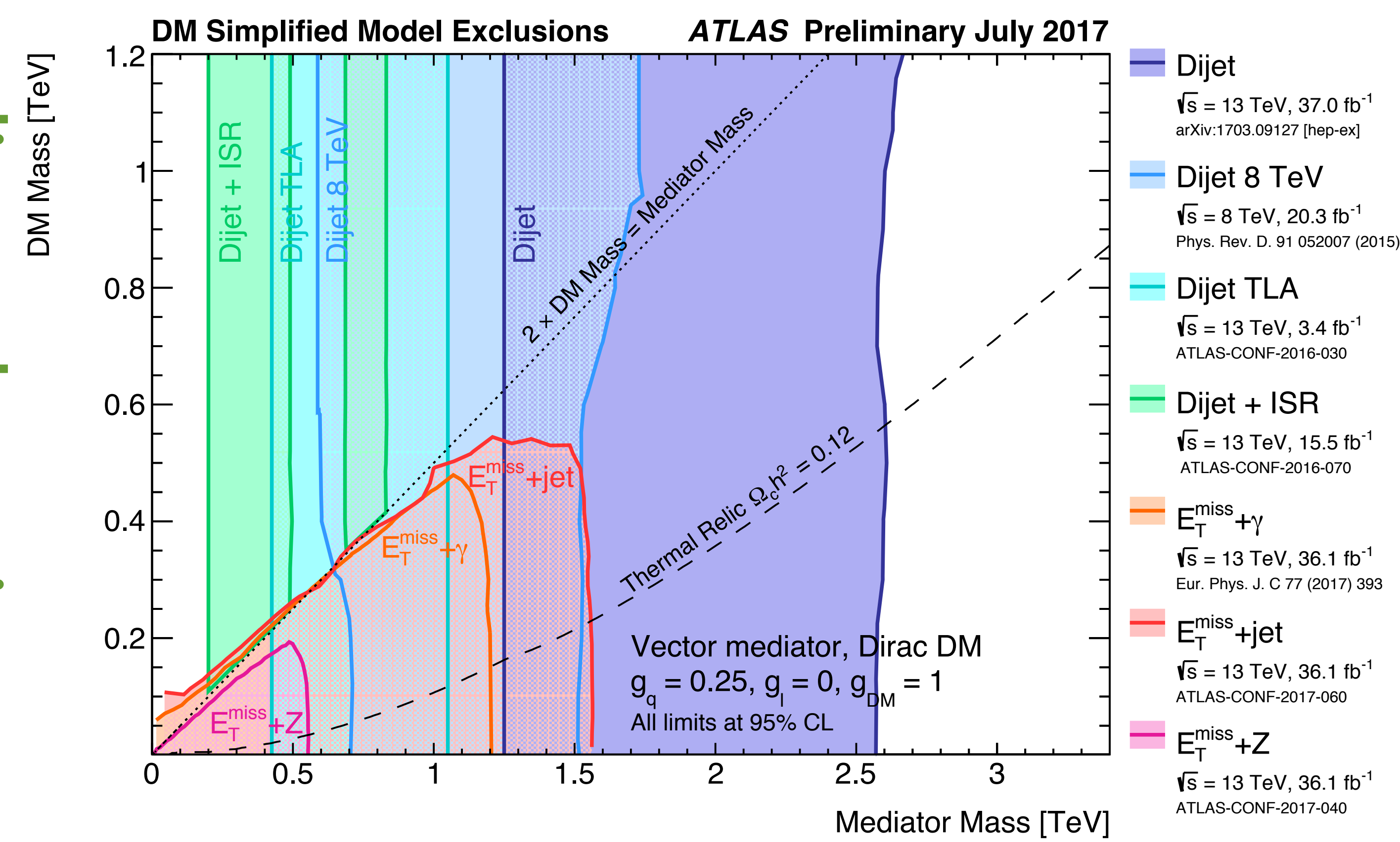
missing-energy search



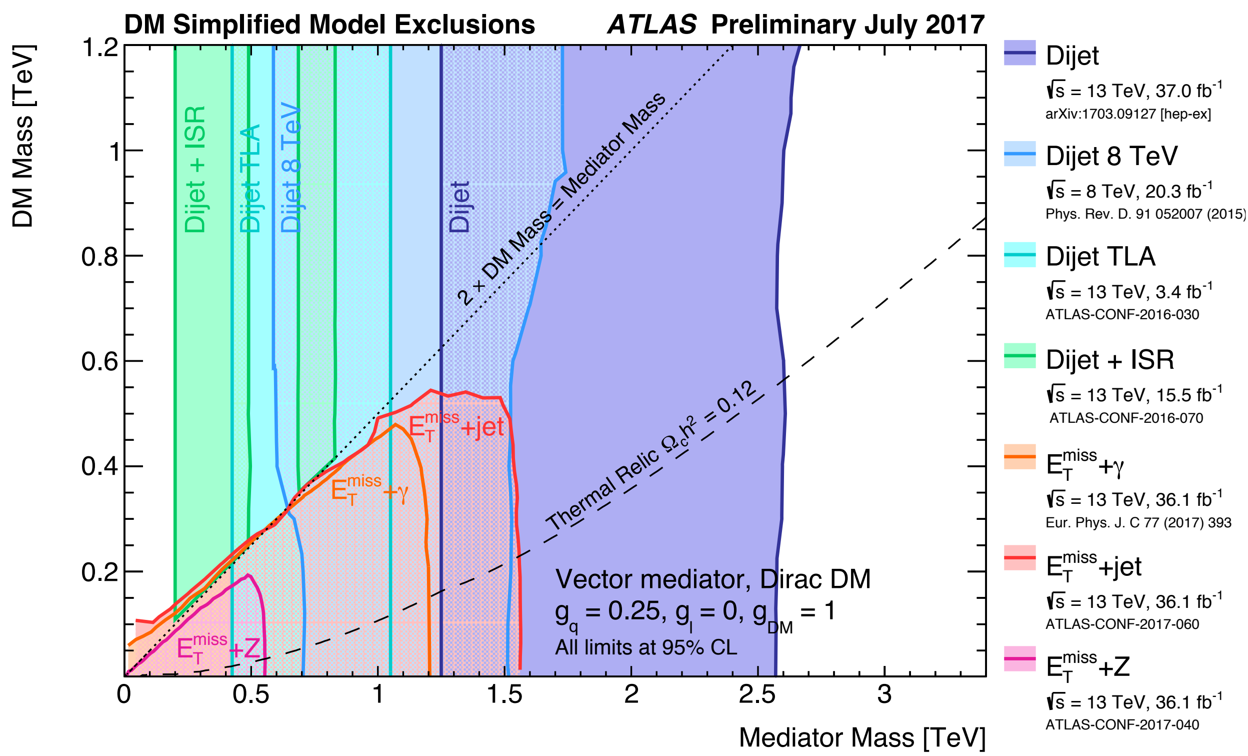
direct detection

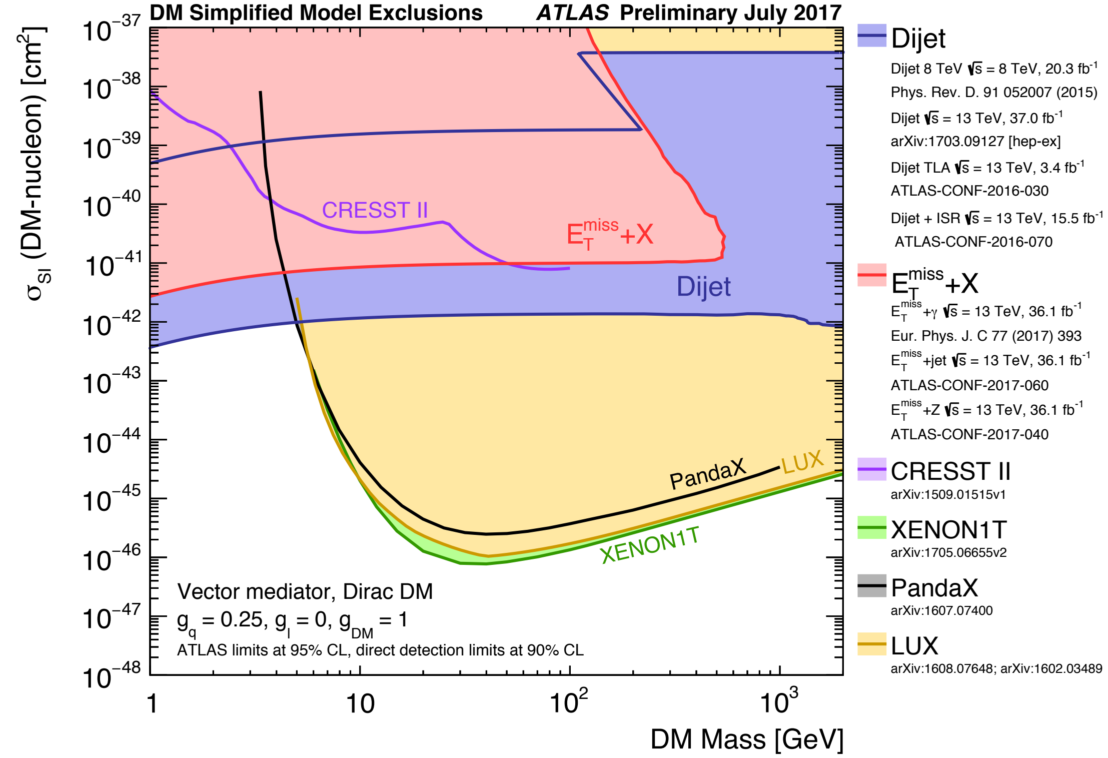
mediator search

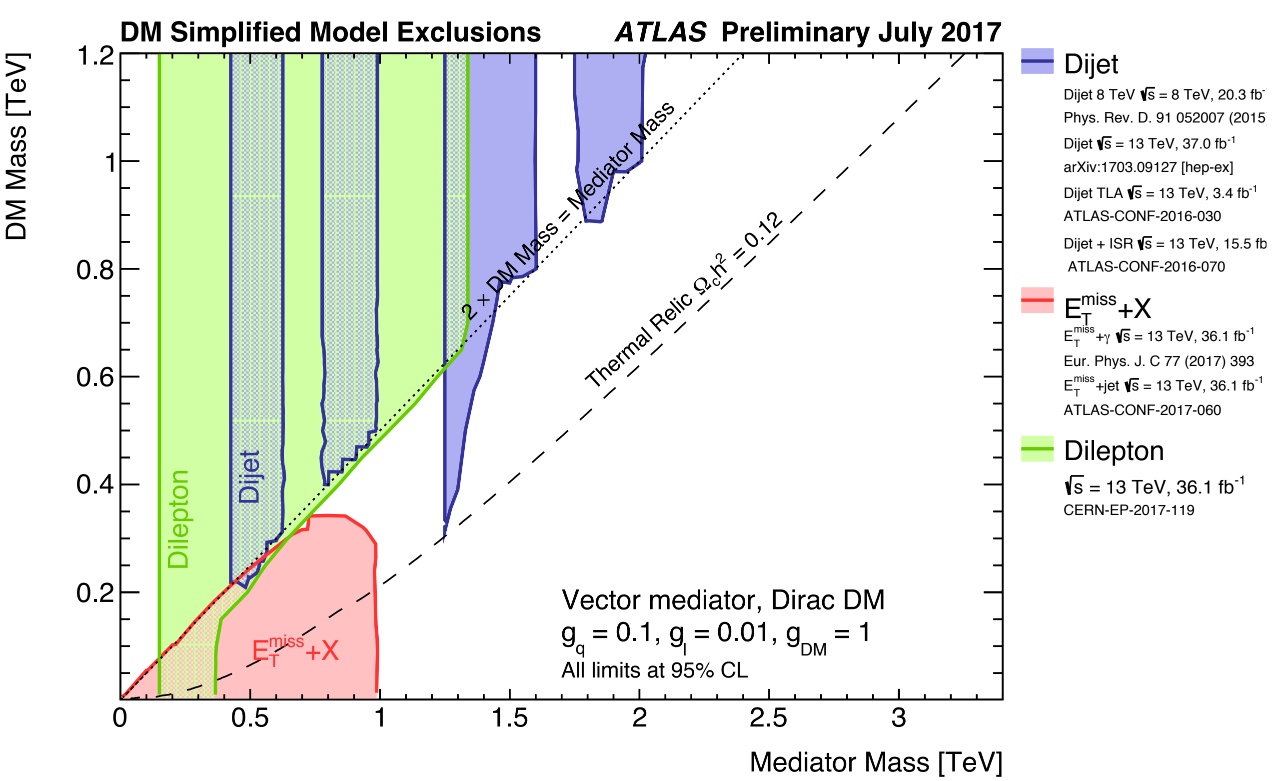
relic density
indirect detection

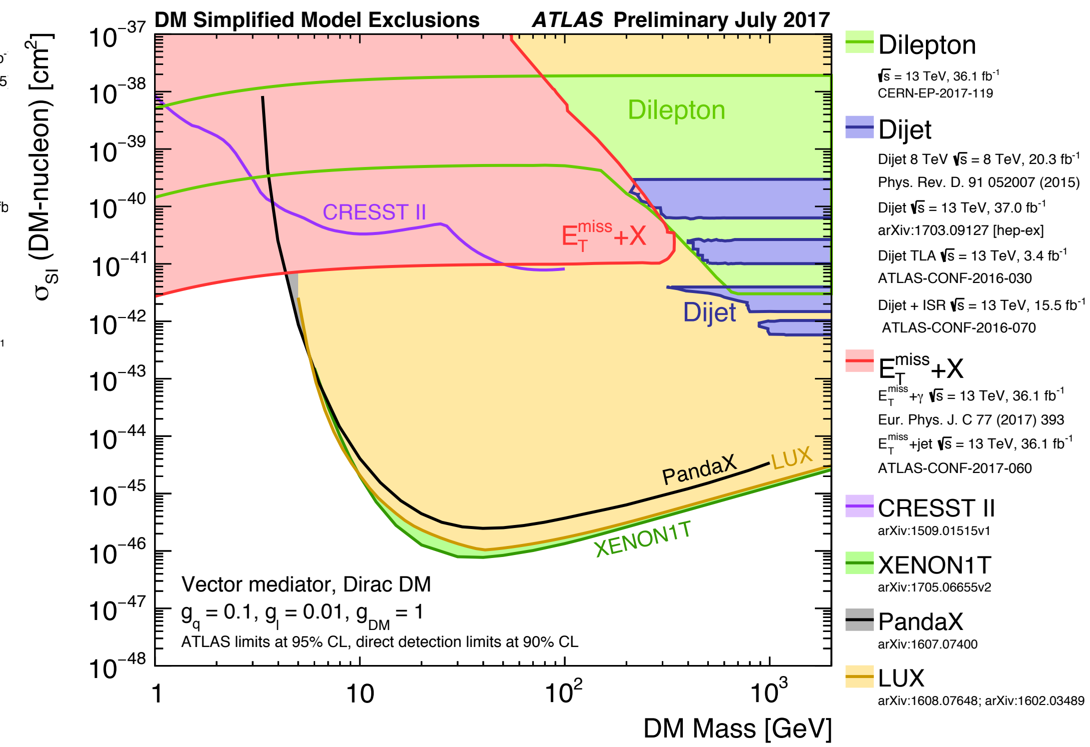


Interpretation of the LHC searches



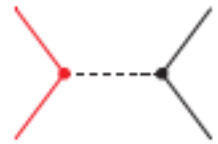
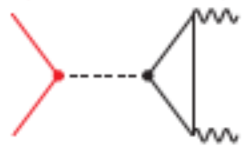
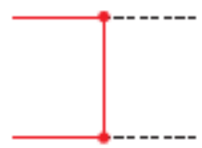
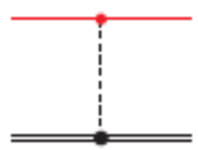
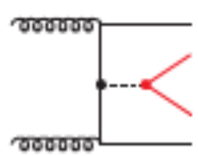
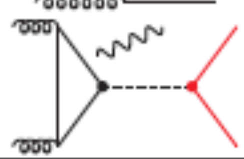
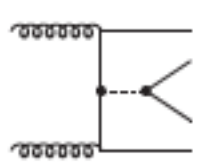
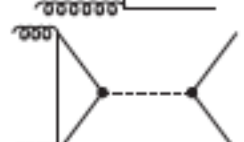


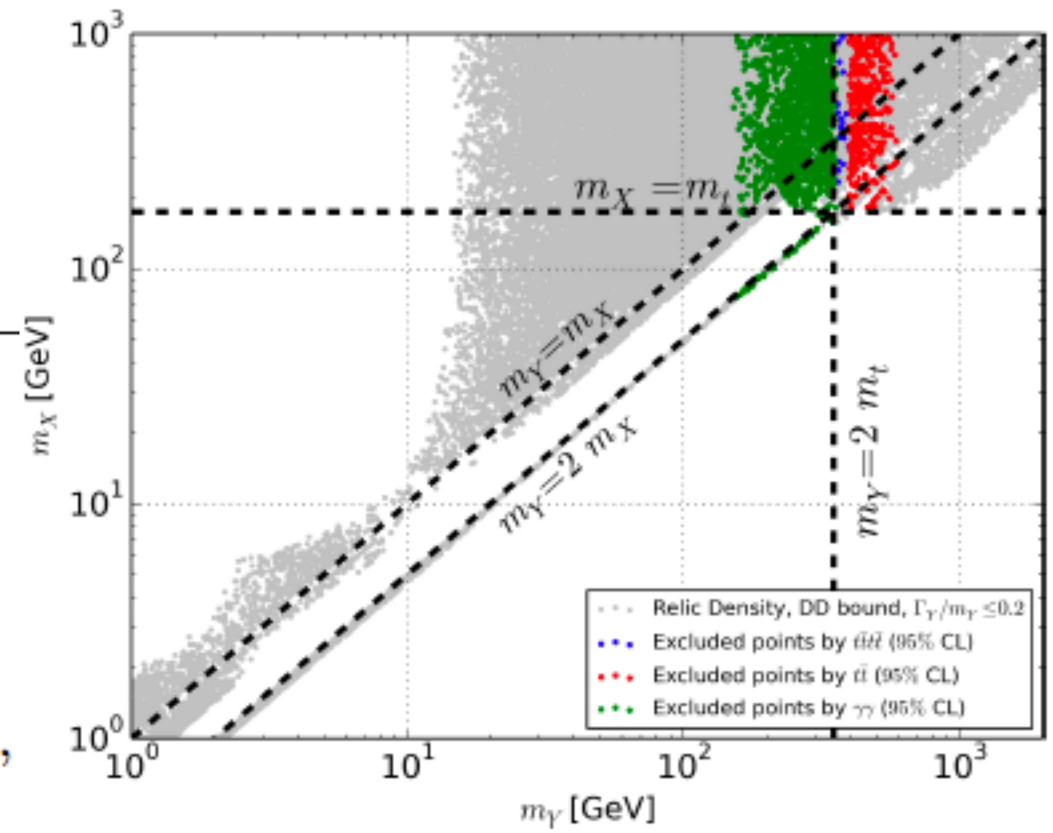




A comprehensive simplified DM study: s-channel spin-0

Arina, Backovic, Conte, Fuks, Guo, Heisig, Hespel, Kraemer, Maltoni, Martini, KM, Pellen, Vryonidou [1605.09242, JHEP]

Cosmology	relic		$m_X > m_t$	
	indirect		$m_X < m_t$	Planck, FermiLAT
Astrophysics			$m_X > m_Y$	
	direct		$m_X > 1$ GeV	LUX, CDMSLite
Colliders	$\not{E}_T$		$m_Y > 2m_X$	
			$m_Y > 2m_X$	
	no $\not{E}_T$		$m_Y > 2m_t$	
			$m_Y > 2m_t$	
			$m_Y < 2m_X$,	



$$\mathcal{L}^{Y_0}_{t,X} = -\left(g_t \frac{y_t}{\sqrt{2}} \bar{t}t + g_X \bar{X}X\right) Y_0$$

X=DM
Y=mediator

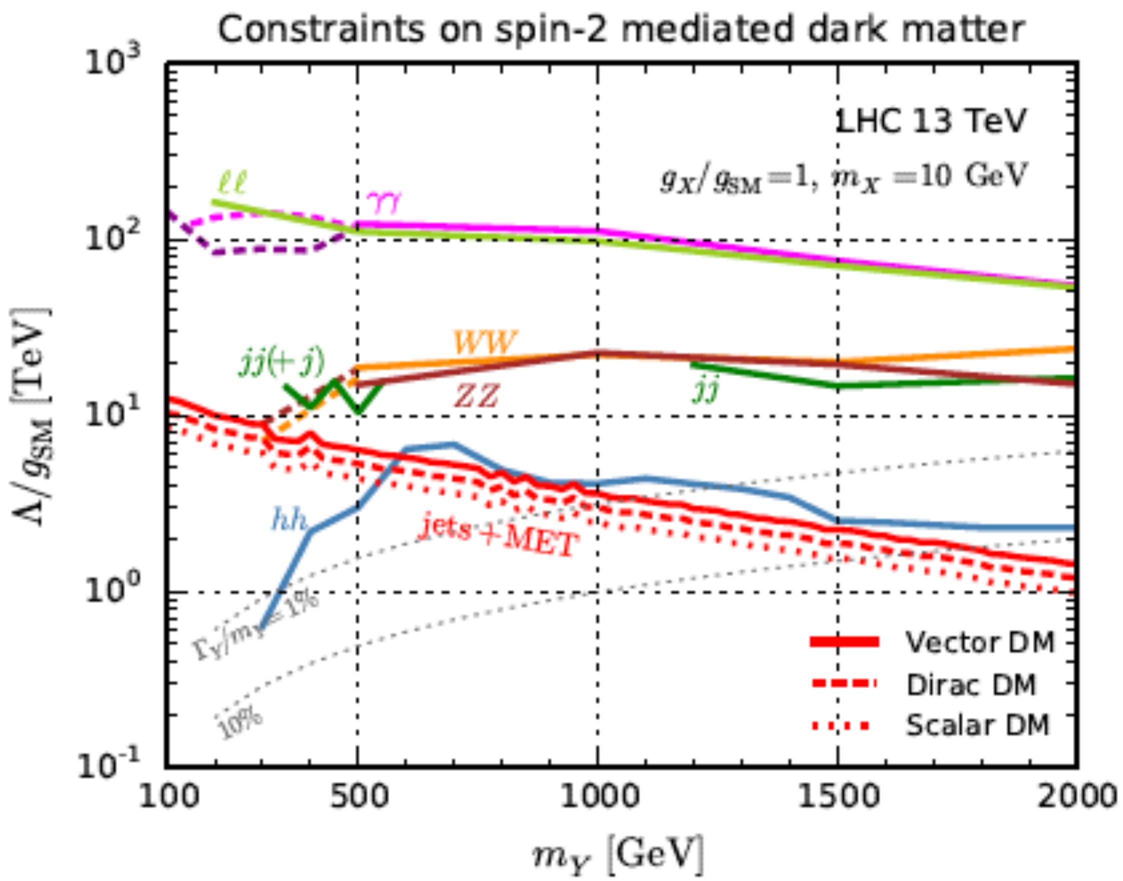
Spin-2 model: MET vs. resonance searches

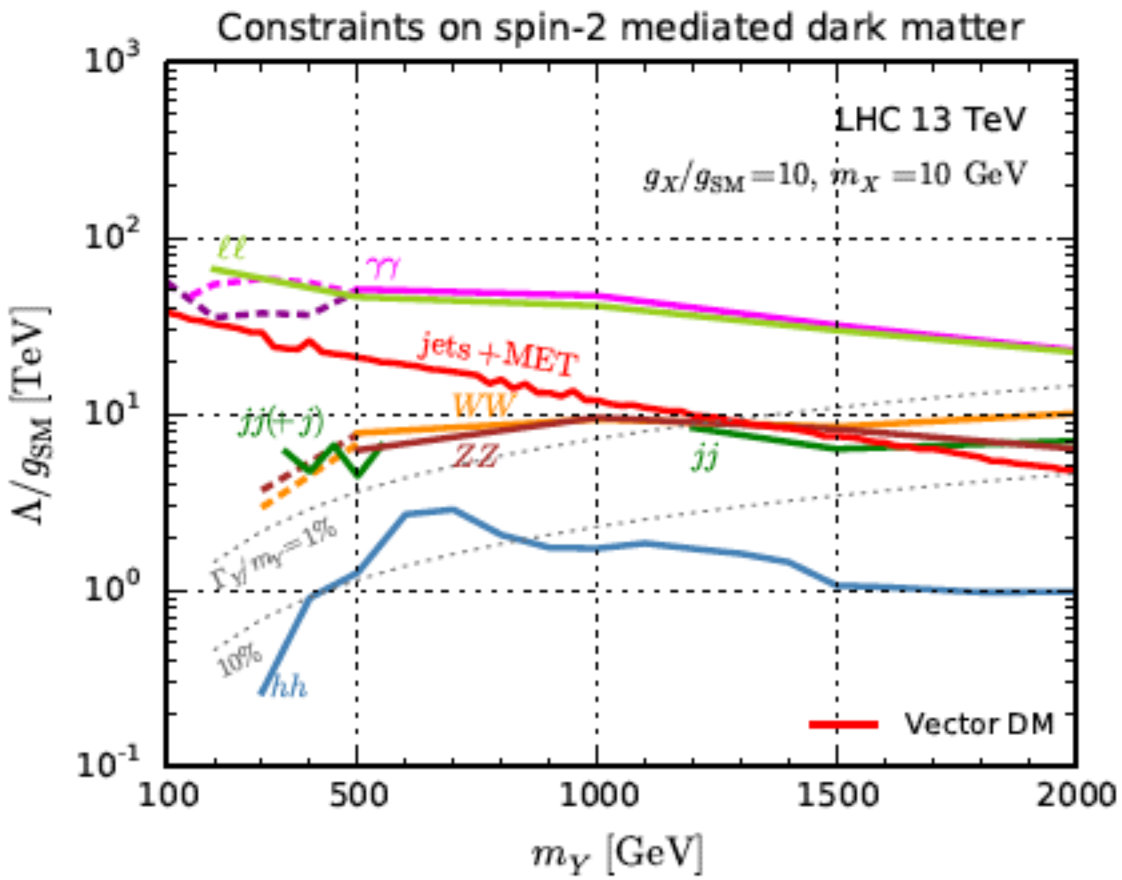
Kraml, Laa, KM, Yamashita [1701.07008, EPJC]

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

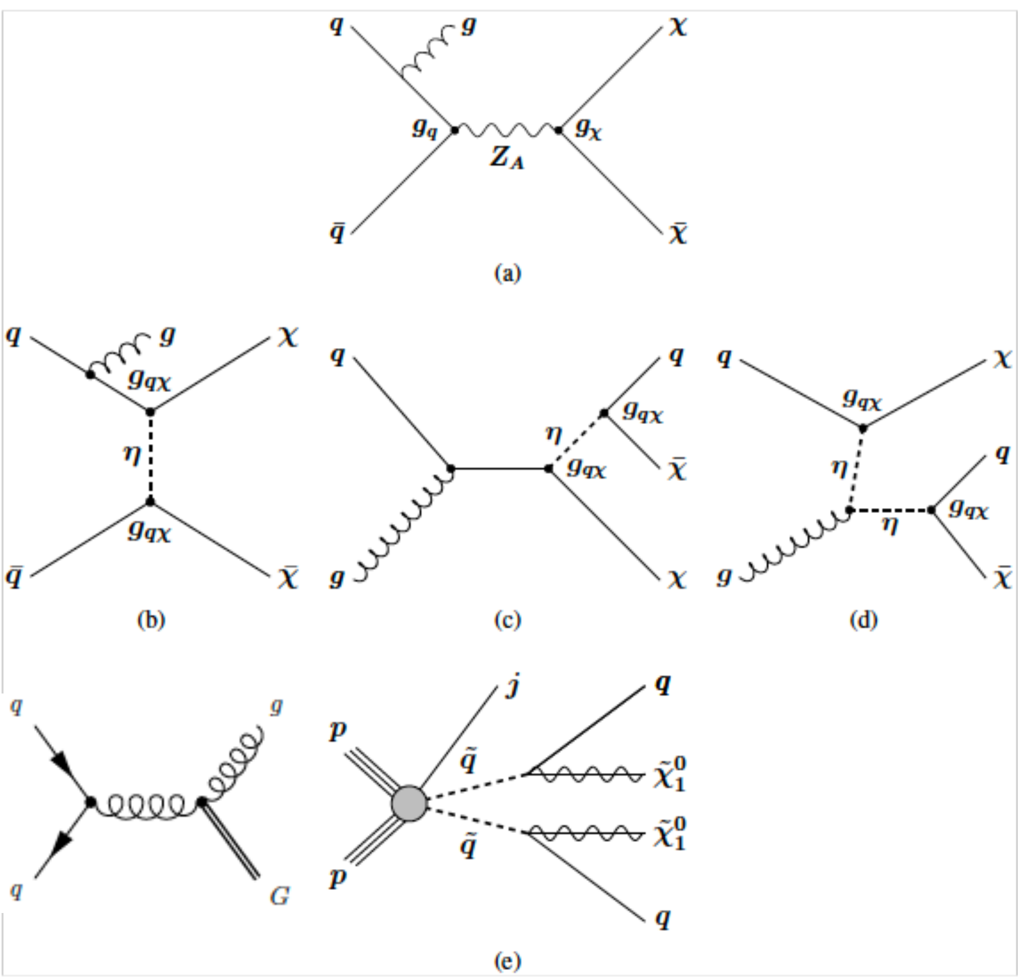
$$g_{\rm SM} \equiv g_H^T = g_q^T = g_\ell^T = g_g^T = g_W^T = g_B^T$$

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





Search for dark matter and other new phenomena in events with an energetic jet and large missing transverse momentum using the ATLAS detector

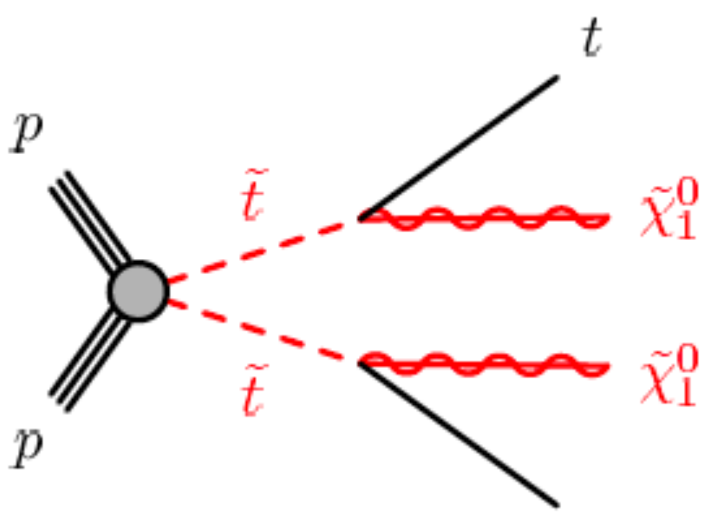


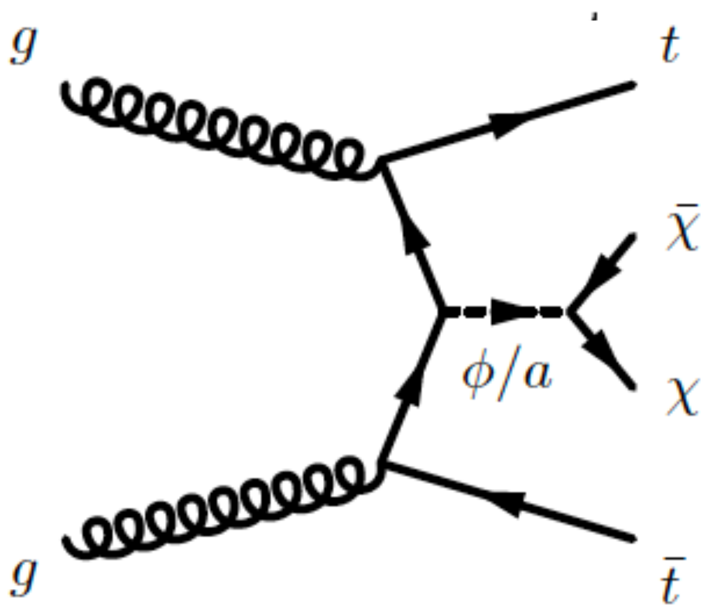
ATLAS Collaboration

enomena in final states with an energetic jet and large e reported. The search uses proton–proton collision data minosity of 36.1 fb^{-1} at a centre-of-mass energy of 13TeV the ATLAS detector at the Large Hadron Collider. Events jet with a transverse momentum above 250GeV and no egions are considered with increasing requirements on the bove 250GeV. Good agreement is observed between the dard Model predictions. The results are translated into exclusion limits in models with pair-produced weakly interacting dark-matter candidates, large extra spatial dimensions, and supersymmetric particles in several compressed scenarios.

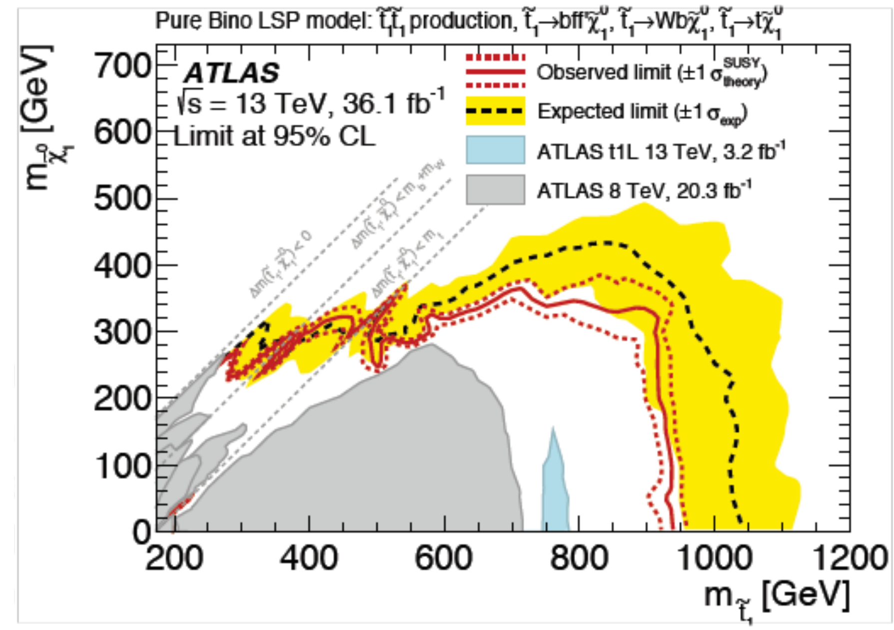
Search for top-squark pair production in final states with one lepton, jets, and missing transverse momentum using 36 fb^{-1} of $\sqrt{s}$ = 13 TeV pp collision data with the ATLAS detector

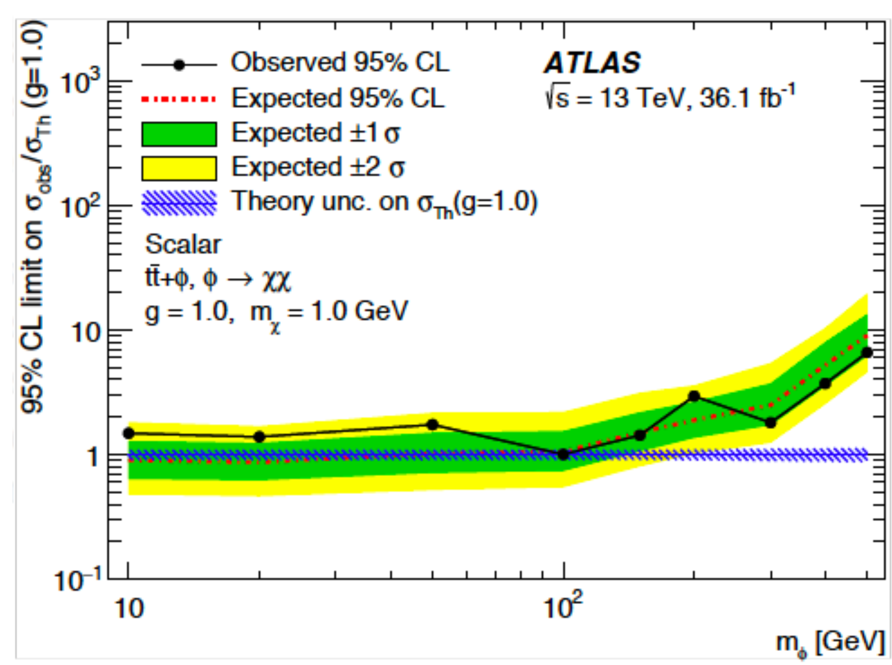
The ATLAS Collaboration





e direct pair production of top squarks
tes with one isolated electron or muc
um are reported. The analysis also tar
into a pair of dark-matter particles ar
The search uses data from proton–pr
in 2015 and 2016 at a centre-of-m
S detector, corresponding to an integ
enarios with different mass-splittin
possible intermediate supersymmet
V bosons or the top quarks produce
over the Standard Model prediction
its at 95% confidence level in severa
top-squarks decaying into top quar
ingent exclusion limits are also deri
top-squark decay scenarios. For the spin-0 mediator models, upp
cross-section.





Summary of the LHC DMWG activities

[Discussions]

- develops well-defined benchmark models

  Are the simplified models too simple/complicated?

- provides (accurate) simulation tools for signal and background

  Are the current available tools satisfactory?

- defines guidelines for presentation and interpretation of the LHC results

  Are the current experimental informations enough for reinterpretation/recasting?

Summary and outlook

- Dark matter is one of the biggest mysteries in our world.
- The systematic simulation framework for dark matter searches have been developed not only for LHC but also for non-collider experiments.
- Higher-order predictions not only provide reliable rate but also reduce the theoretical uncertainty.
- A single model can be constrained by many different LHC searches and also by non-collider searches.
- Recasting business becomes more and more important.