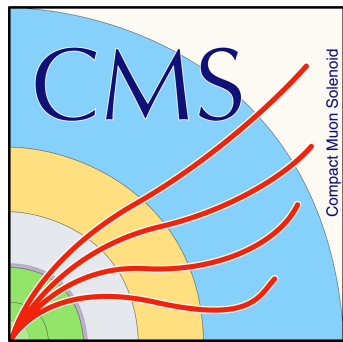
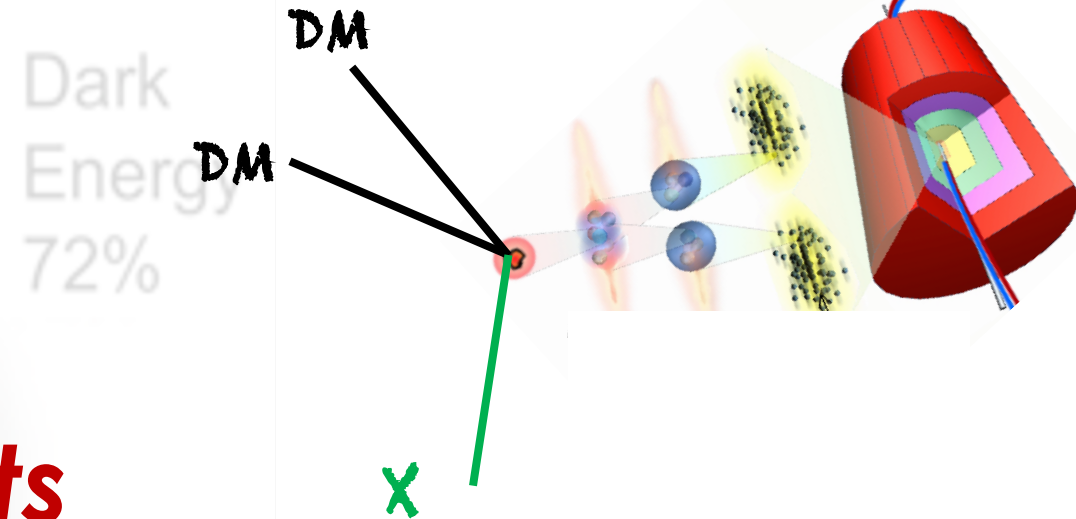


# ***Mono-jet/V searches for new physics at ATLAS & CMS experiments***

Varun sharma

University of Wisconsin – Madison, USA

on behalf of the ATLAS & CMS Collaboration



# Introduction

[ATLAS Results](#)

[CMS Results](#)



- Search for new physics in the **mono-jet (AK4 jets)** and **mono-V (AK8 jets)** final state with Run-2 data
- New results with about 4 times more data, improvements in signal selection, background estimation and systematic uncertainties
- Results are interpreted in several new physics theoretical models
- **CMS Results:** Analyses 101 fb<sup>-1</sup> (2017-2018) of data combined with 36 fb<sup>-1</sup> (2016) data, categorically divided into mono-jet and mono-V events
- **ATLAS Results:** Analyses 139 fb<sup>-1</sup> (2016-2018) of data in mono-jet category.
  - Mono-V results with 36 fb<sup>-1</sup> (2016) data only

# Signal model interpretations

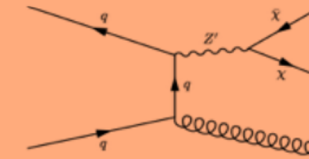
[ATLAS Results](#)

[CMS Results](#)

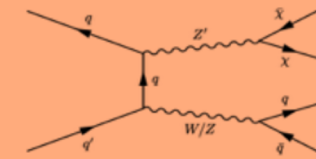


## Dark Matter Simplified Model

- Color-neutral, s-channel mediators – Scalar, Vector, Axial-vector, pseudo-scalars
- Parameters based on [LHC DM Forum](#)
- Candidate: Dirac WIMPs

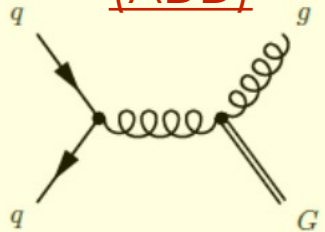


mono-jet



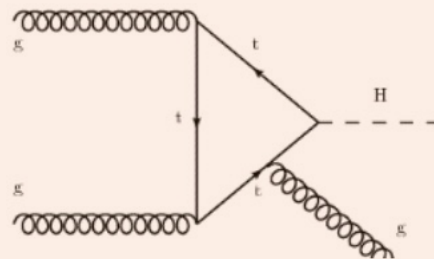
mono-V

## Large Extra Dimensions (ADD)



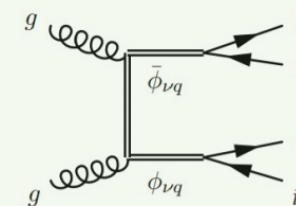
- N-extra spatial dimensions size R leads to a fundamental Planck scale
- Produce Gravitons that interact weakly

## Higgs Portal



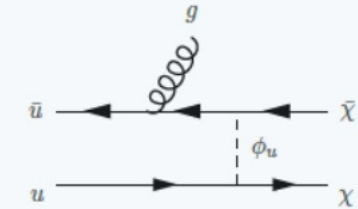
- SM-like Higgs decay into BSM invisible particles
- Exclusion on SM Higgs invisible branching fraction

## Lepto-quarks



- Couples to up-quarks and electron neutrinos
- Exclusion as a function of LQ mass and coupling constant

## Fermion Portal (t-channel)



- Mediator couples to q and DM
- Couplings assumed to be 1

**CMS**

# Signal model interpretations

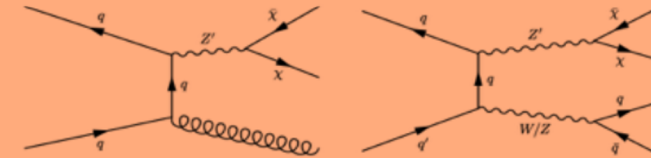
[ATLAS Results](#)

[CMS Results](#)



## Dark Matter Simplified Model

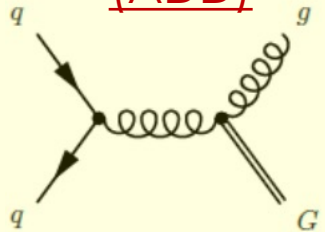
- Color-neutral, s-channel mediators – Scalar, Vector, Axial-vector, pseudo-scalars
- Parameters based on [LHC DM Forum](#)
- Candidate: Dirac WIMPs



mono-jet

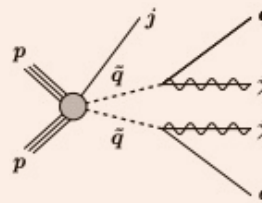
mono-V

## Large Extra Dimensions (ADD)



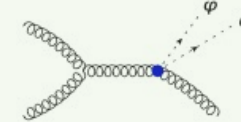
- N-extra spatial dimensions size R leads to a fundamental Planck scale
- Produce Gravitons that interact weakly

## SUSY Candidates



- R-parity conservation
- LSP: neutralino
- Simplified models with small mass differences

## Dark Energy



- EFT implementation of Horndeski theories
- New DE scalar field  $\varphi$ , governed by effective Mass  $M_2$  and coupling
- $\varphi$  is pair produced, stable, undetected

## Axion-Like Particle

- New Pseudoscalar bosons breaking of additional U(1) symmetries
- Address strong CP problem
- ALP decays are suppressed

ATLAS

# Analysis Strategy

[ATLAS Results](#)

[CMS Results](#)

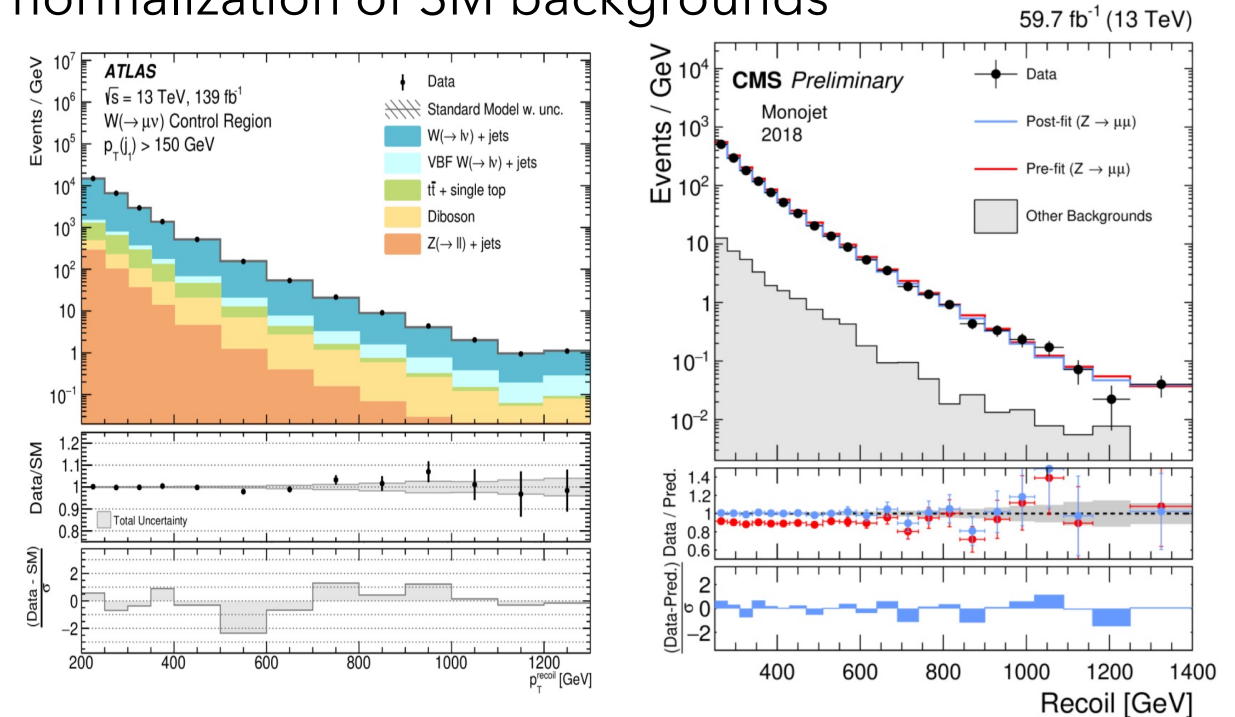


Signal Region: **Jets + MET**

Background: **Z/W+jet, top, dibosons, multijet**

- At least one high  $p_T$  central jet
- Veto events with leptons ( $e, \mu, \tau$ ) and photons  $\gamma$
- MET (Hadronic Recoil) > 250 (200) GeV: **CMS** (**ATLAS**)
- Events are broadly categorized in mono-jet and mono-V based on leading jet  $p_T$ 
  - **Mono-V:** Jet  $p_T$  (AK8) > 250 GeV
  - **Mono-jet:** Jet  $p_T$  (AK4) > **100** (**150**) GeV

Both ATLAS and CMS employ semi-data driven technique, supported by statistically independent control regions (**1e/μ, 2e/μ, t, γ**), to constrain the normalization of SM backgrounds



Data/background predictions in Control Regions



# Analysis Strategy

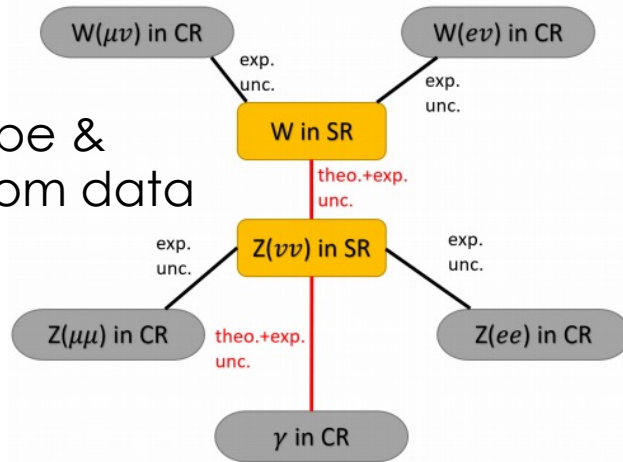
[ATLAS Results](#)

[CMS Results](#)



Simultaneous maximum likelihood fit

Bkg shape & norm. from data



$W/Z$ +jets processes, their MC predictions were reweighted to account for higher-order QCD and electroweak corrections

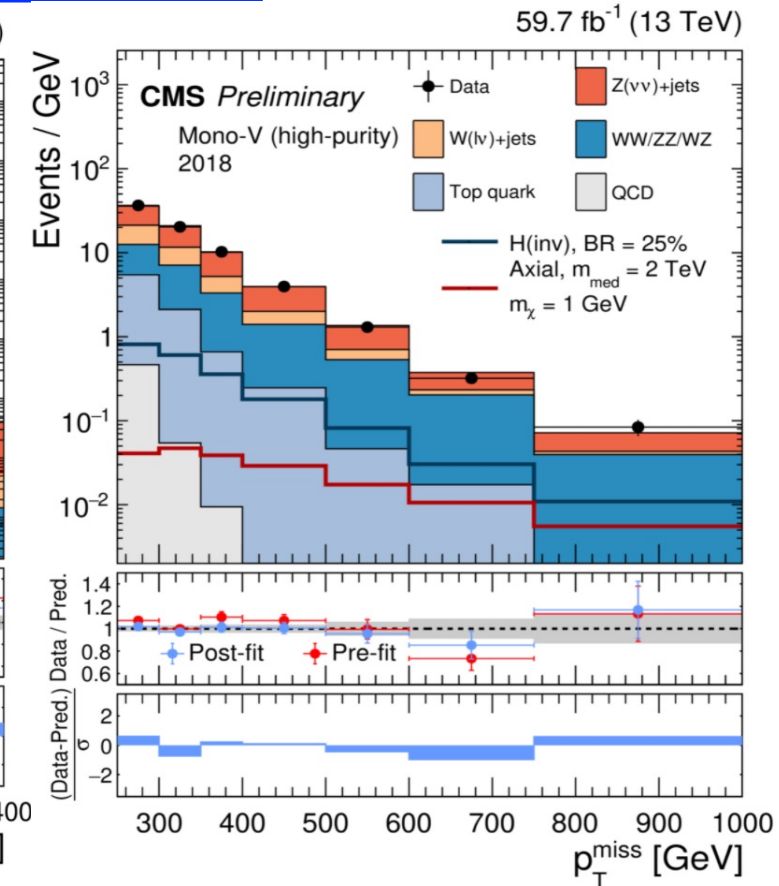
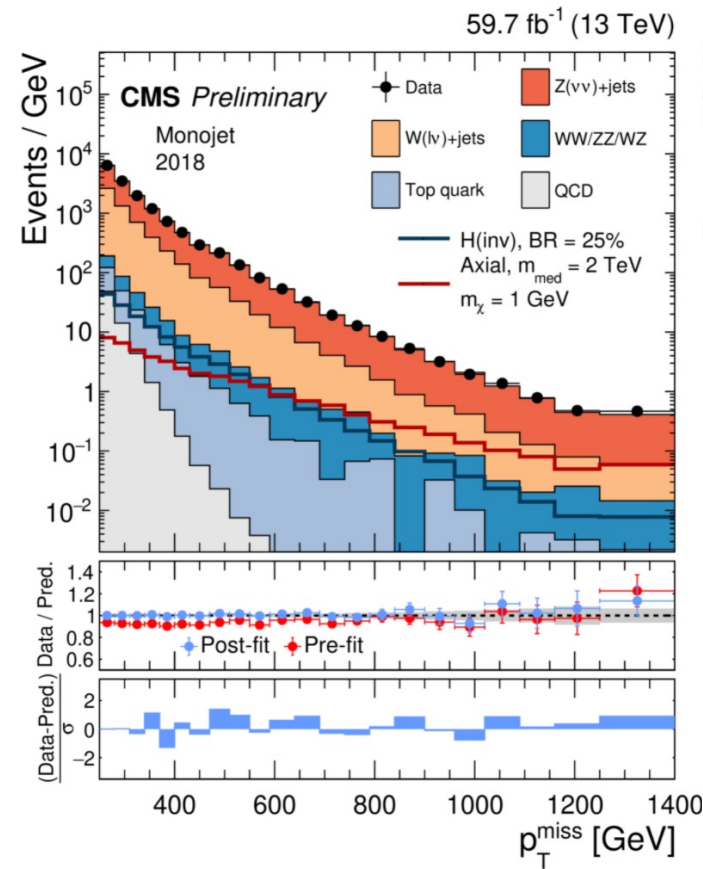
These prescriptions allows constrain the  $Z$ +jets in the SR

Mono-Jet

Signal Region

[CMS PAS EXO-20-004](#)

Mono-V



Good agreement between Data and SM predictions

# Analysis Strategy

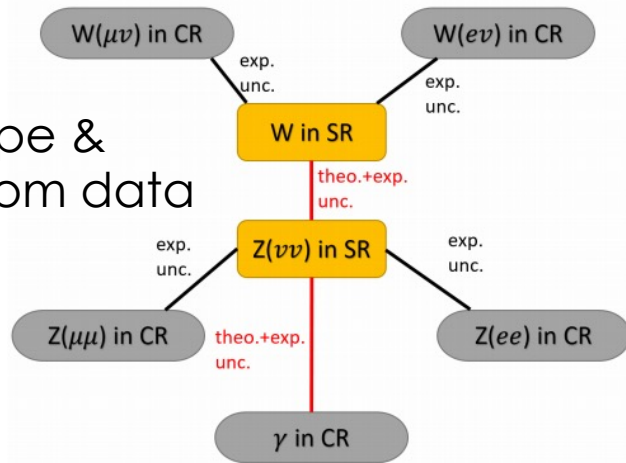
[ATLAS Results](#)

[CMS Results](#)



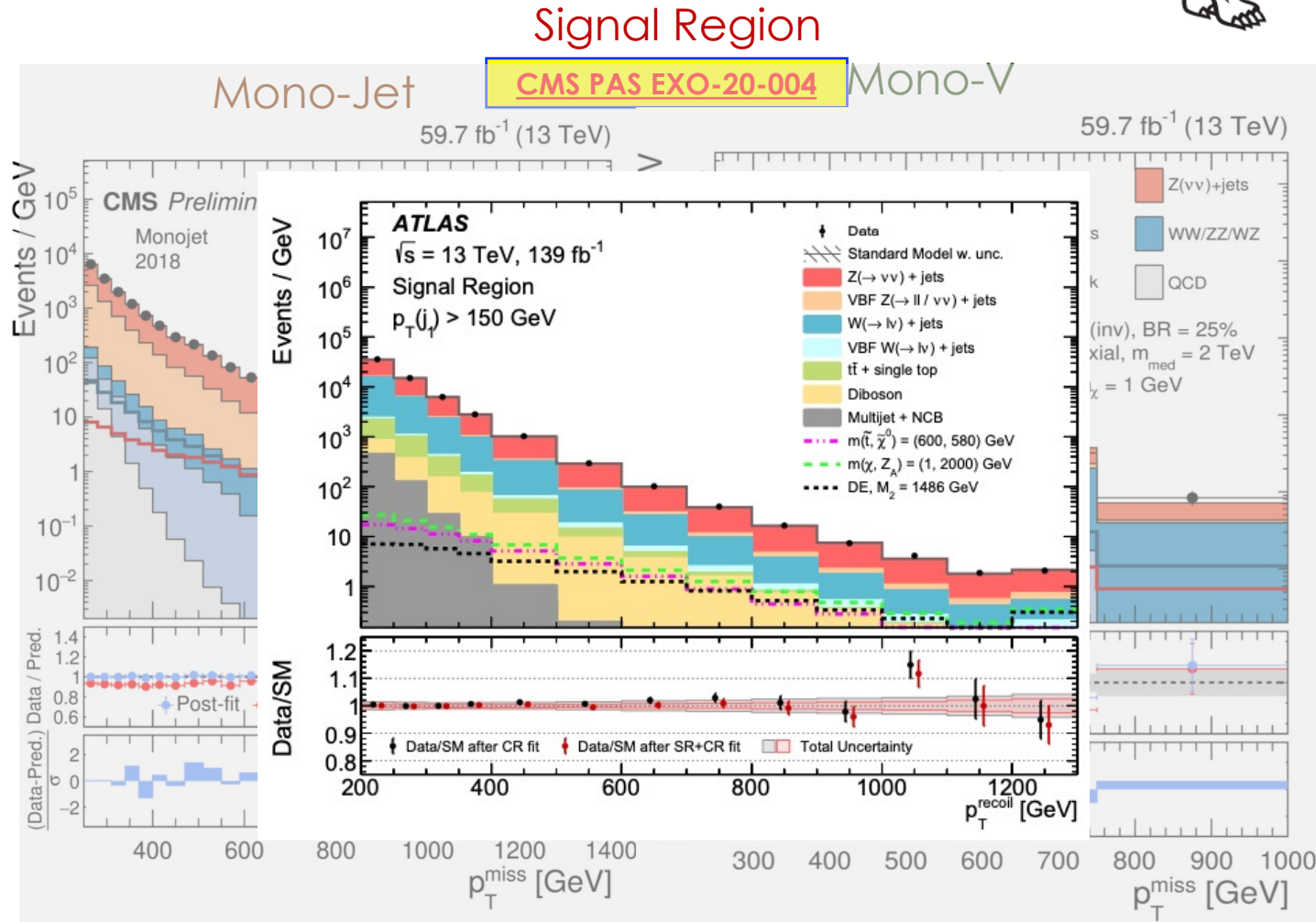
Simultaneous maximum likelihood fit

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$W/Z$ +jets processes, their MC predictions were reweighted to account for higher-order QCD and electroweak corrections

These prescriptions allows constrain the Z+jets in the SR



Good agreement between Data and SM predictions

# Systematic uncertainties

ATLAS Results

CMS Results



The inputs to the ML fit are subject to various experimental and theoretical uncertainties

Systematic uncertainties are incorporated in the likelihood function as nuisance parameters

All the possible correlations between experimental systematic uncertainties in signal and background predictions are taken into account

Results from Simultaneous fit are used to set observed and expected 95% CL exclusion limits on the parameters of the different models under consideration

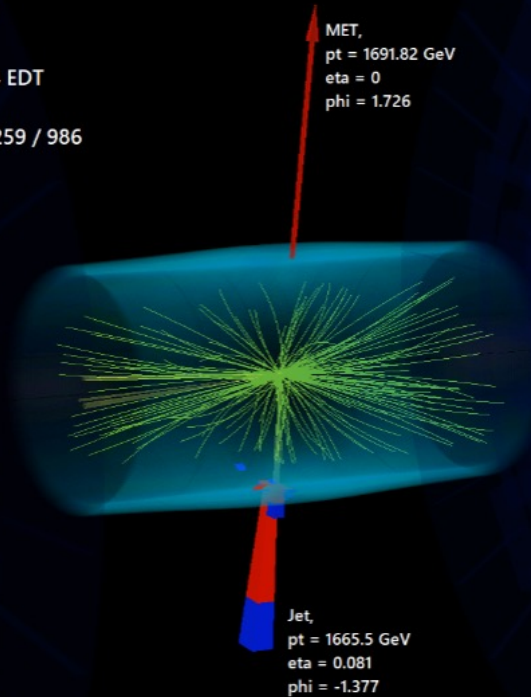
Source	Process	Uncertainty
Electron trigger	$W_{SR}/W_{e\nu}, Z_{SR}/Z_{ee}$	1%
$E_T^{\text{miss}}$ trigger	$W_{SR}/W_{e(\mu)\nu}$	1-2% (shape)
	$Z_{SR}/Z_{\mu\mu}$	2-3% (shape)
Photon trigger	$Z_{SR}/\gamma_{CR}$	2%
Photon $p_T$ scale	$Z_{SR}/\gamma_{CR}$	< 4% (shape)
Muon-reco efficiency per muon	$W_{SR}/W_{\mu\nu}, Z_{SR}/Z_{\mu\mu}$	1%
Muon-ID efficiency per muon	$W_{SR}/W_{\mu\nu}, Z_{SR}/Z_{\mu\mu}$	1%
Muon-iso. efficiency per muon	$W_{SR}/W_{\mu\nu}, Z_{SR}/Z_{\mu\mu}$	1%
Electron-reco efficiency per ele.	$W_{SR}/W_{e\nu}, Z_{SR}/Z_{ee}$	1%
Electron-ID efficiency per ele.	$W_{SR}/W_{e\nu}, Z_{SR}/Z_{ee}$	3%
Photon-ID efficiency	$Z_{SR}/\gamma_{CR}$	4 – 13% (shape)
Muon veto	$W_{SR}/W_{e(\mu)\nu}, Z_{SR}/W_{SR}$	< 1% (shape)
Electron veto	$W_{SR}/W_{e(\mu)\nu}, Z_{SR}/W_{SR}$	2% (shape)
Tau veto	$W_{SR}/W_{e(\mu)\nu}, Z_{SR}/W_{SR}$	1–2% (shape)
Prefiring	$Z_{SR}/Z_{CR}, W_{SR}/W_{CR}$	< 1% (shape)

CMS

Source of uncertainty and effect on the total SR background estimate [%]			
Flavor tagging	0.1 – 0.9	$\tau$ -lepton identification efficiency	0.1 – 0.07
Jet energy scale	0.17 – 1.0	Luminosity	0.01 – 0.05
Jet energy resolution	0.15 – 1.3	Noncollision background	0.2 – 0.0
Jet JVT efficiency	0.01 – 0.03	Multijet background	1.0 – 0.0
Pileup reweighting	0.4 – 0.24	Diboson theory	0.01 – 0.22
$E_T^{\text{miss}}$ resolution	0.34 – 0.04	Single-top theory	0.13 – 0.28
$E_T^{\text{miss}}$ scale	0.5 – 0.25	$t\bar{t}$ theory	0.06 – 0.7
Electron and photon energy resolution	0.01 – 0.08	V+jets $\tau$ -lepton definition	0.04 – 0.16
Electron and photon energy scale	0.3 – 0.7	V+jets pure QCD corrections	0.24 – 1.1
Electron identification efficiency	0.5 – 1.0	V+jets pure EW corrections	0.17 – 2.2
Electron reconstruction efficiency	0.15 – 0.2	V+jets mixed QCD–EW corrections	0.02 – 0.7
Electron isolation efficiency	0.04 – 0.19	V+jets PDF	0.01 – 0.7
Muon identification efficiency	0.03 – 0.9	VBF EW V+jets backgrounds	0.02 – 1.1
Muon reconstruction efficiency	0.4 – 1.5	Limited MC statistics	0.05 – 1.9
Muon momentum scale	0.1 – 0.7		
Total background uncertainty in the Signal Region: 1.5%–4.2%			

ATLAS





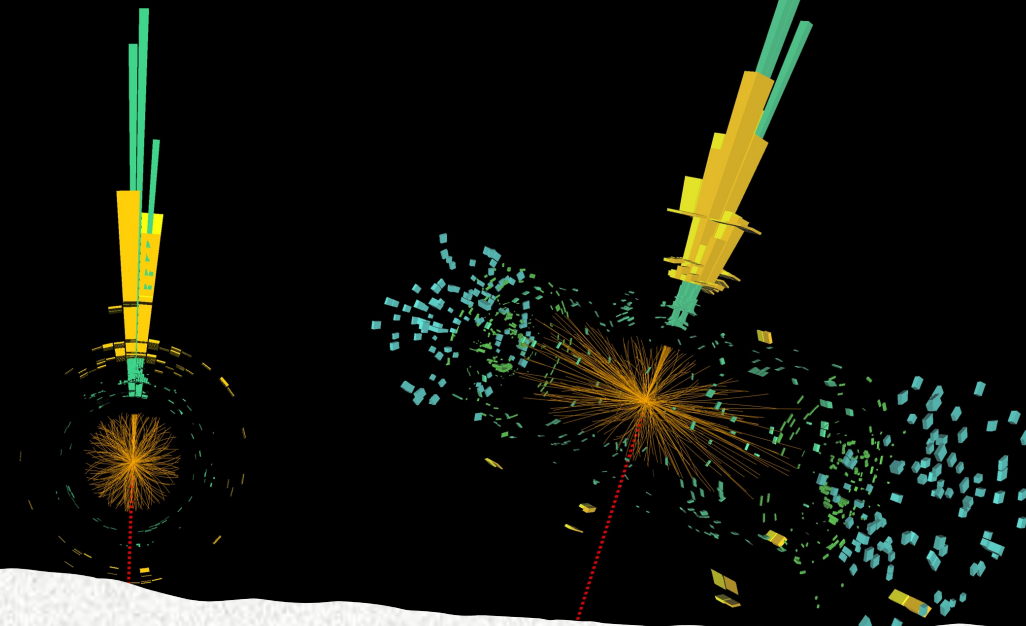
Run: 337215

Event: 2546139368

2017-10-05 10:36:30 CEST

$E_T^{\text{miss}} = 1.9 \text{ TeV}$

jet  $p_T = 1.9 \text{ TeV}$



# Results

ATLAS & CMS

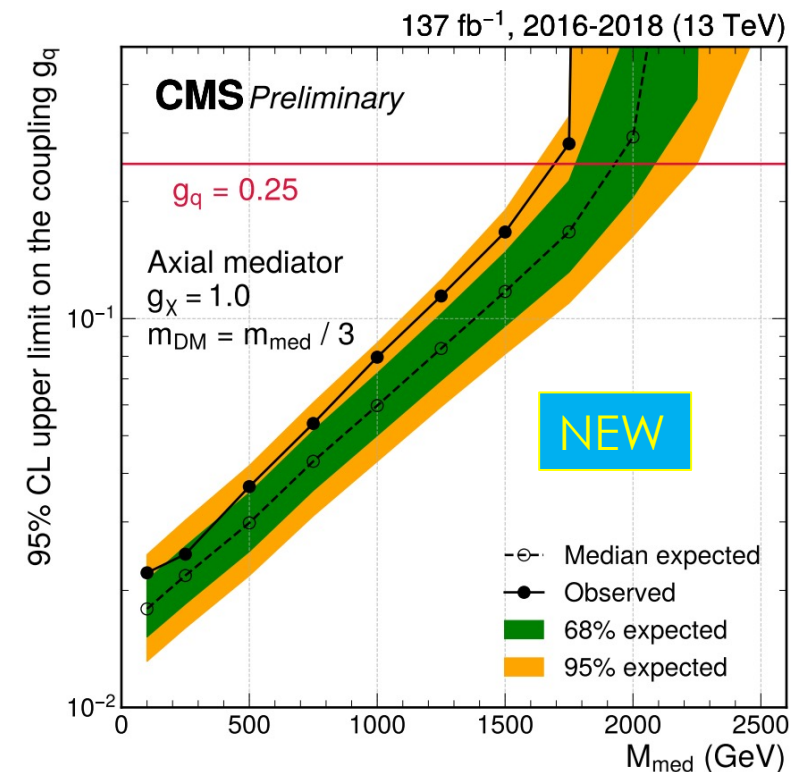
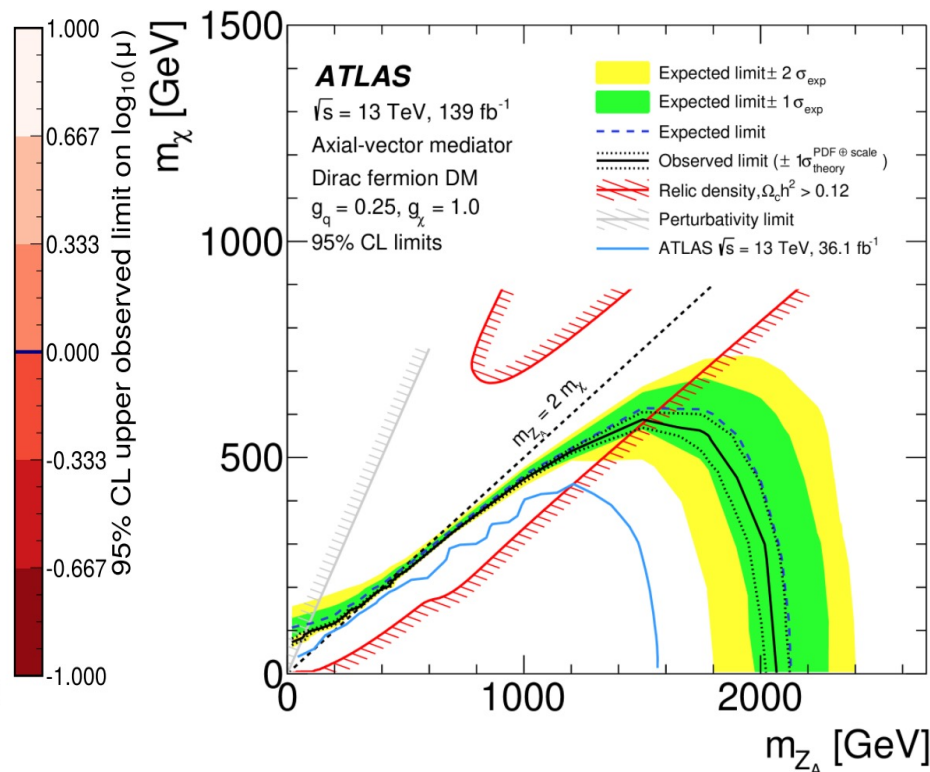
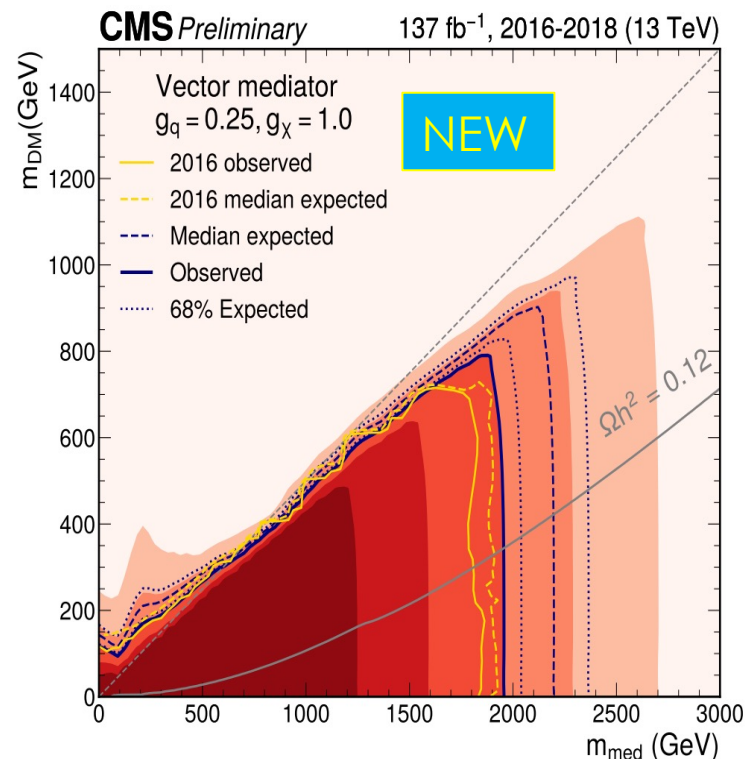
# Simplified Dark Matter (Spin-1)

CMS PAS EXO-20-004

ATLAS: arXiv:2102.10874



Simplified models with the exchange of a vector or an axial-vector in the s-channel



Exclude DM mediator for 1 GeV DM particle  $< \sim 2 \text{ TeV}$  as compared to expectations of  $\sim 2.2 \text{ TeV}$   
(Similar exclusions for both CMS and ATLAS)

Exclusion on couplings for axial-vector mediator

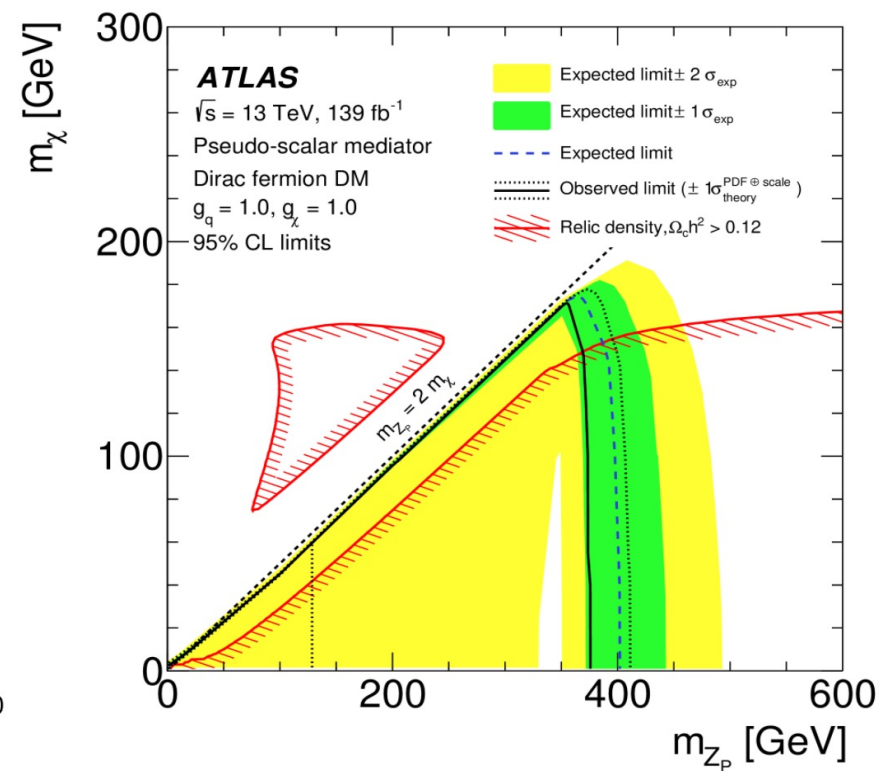
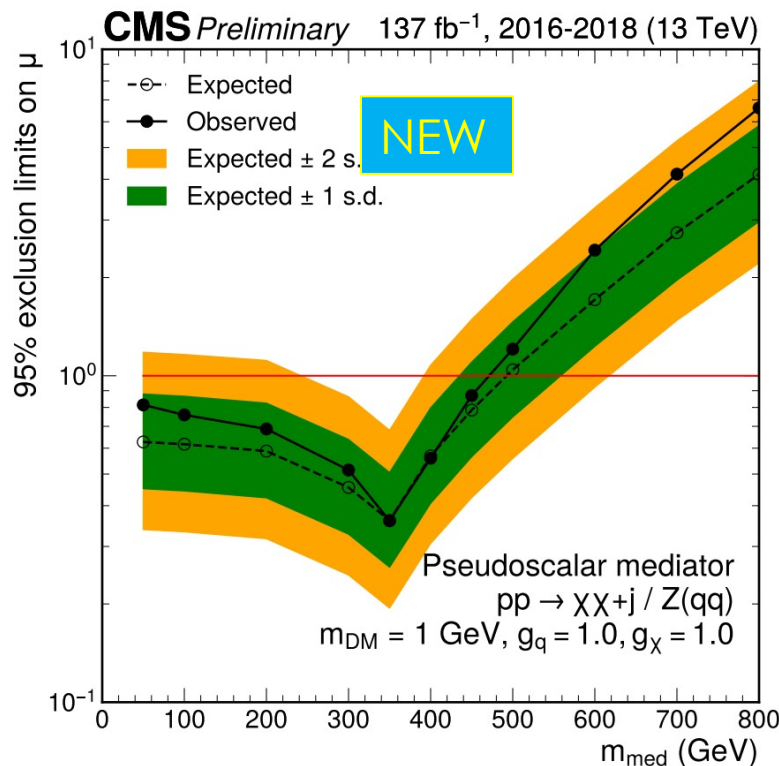
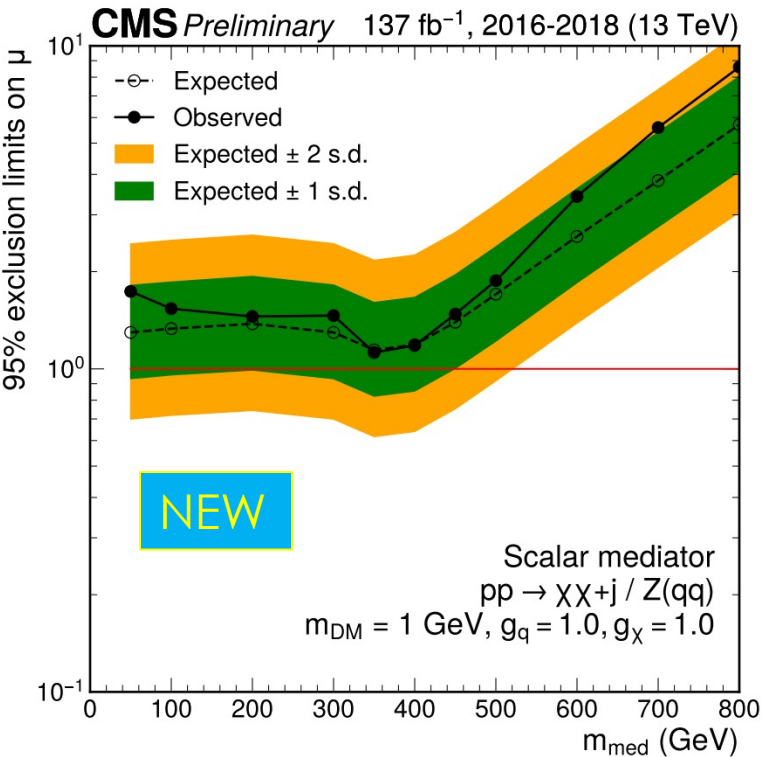
# Simplified Dark Matter (Spin-0)

CMS PAS EXO-20-004

ATLAS: arXiv:2102.10874



Simplified models with the exchange of a scalar or pseudo scalar in the s-channel



**CMS:** No exclusion for scalar mediator while Pseudo-scalar mediator  $< 480 \text{ GeV}$  excluded for  $m_{DM} = 1 \text{ GeV}$

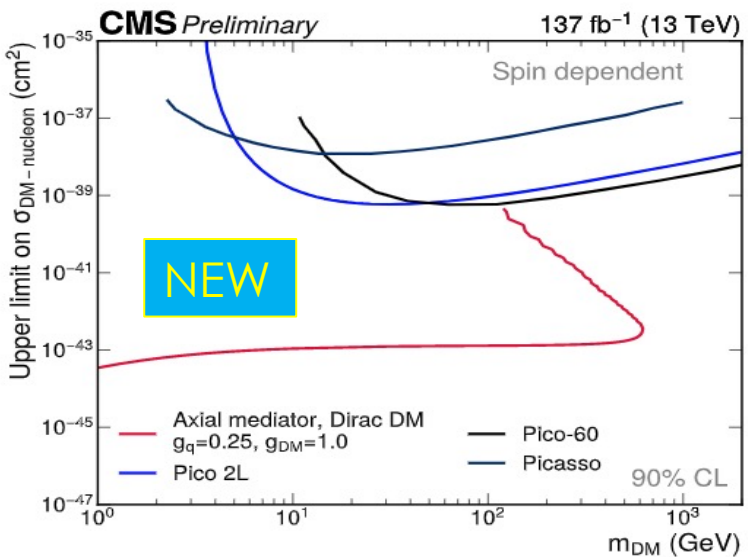
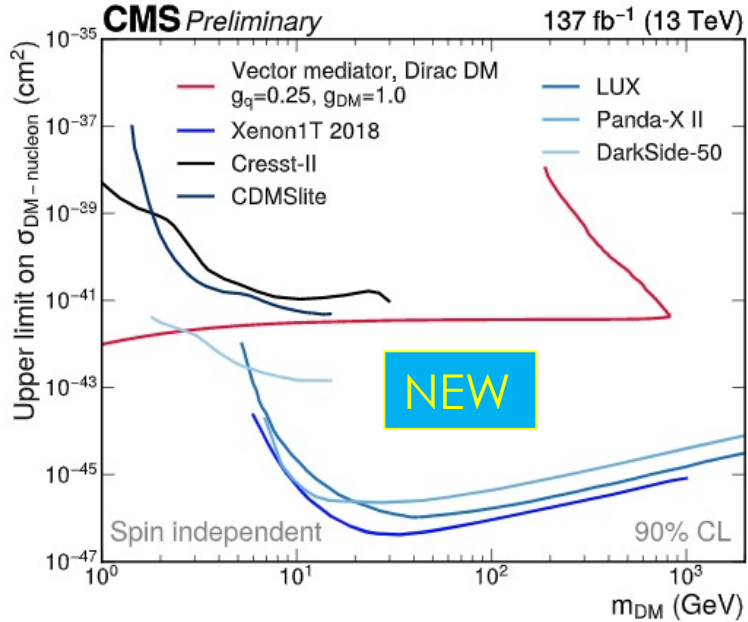
**ATLAS:** Mediator masses below  $376 \text{ GeV}$  are excluded for very light WIMP candidates



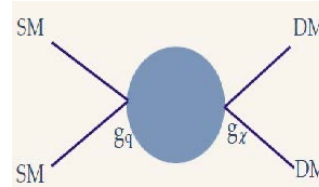
# Direct detection Comparison

CMS PAS EXO-20-004

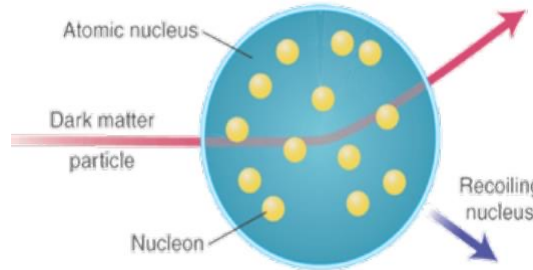
ATLAS: arXiv:2102.10874



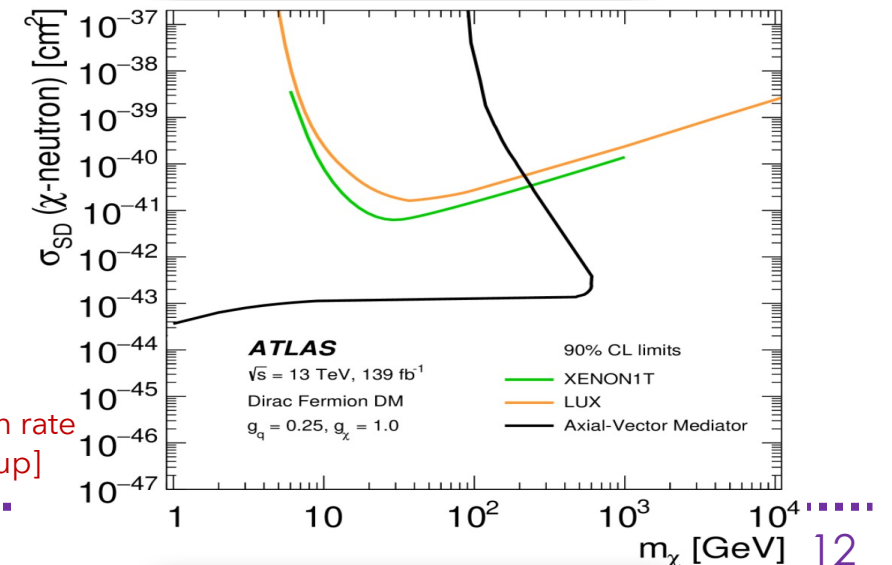
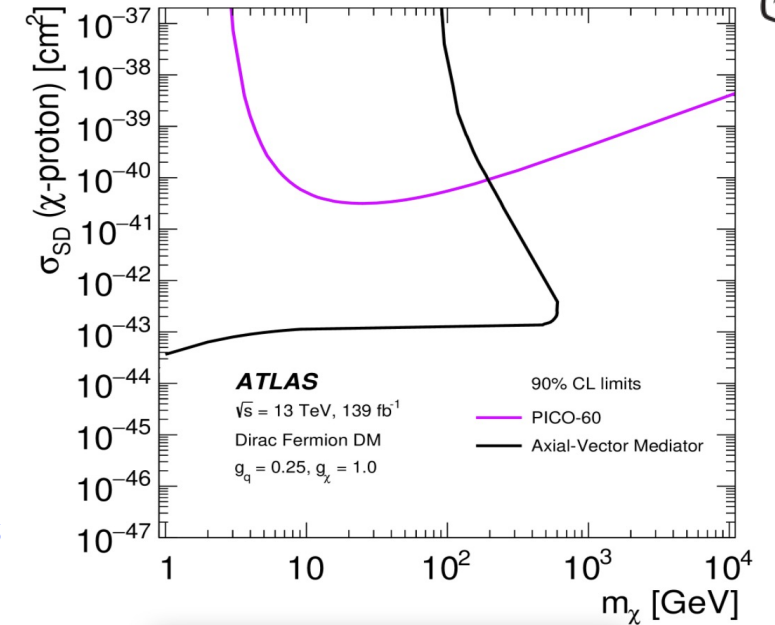
## Comparison to direct detection experiments



Axial-vector mediator results are translated into 90% CL exclusion limits on the spin-dependent WIMP–nucleon scattering cross section  $\sigma_{\text{SD}}$  as a function of the WIMP mass



ATLAS provides WIMP annihilation rate as a function of WIMP mass [backup]





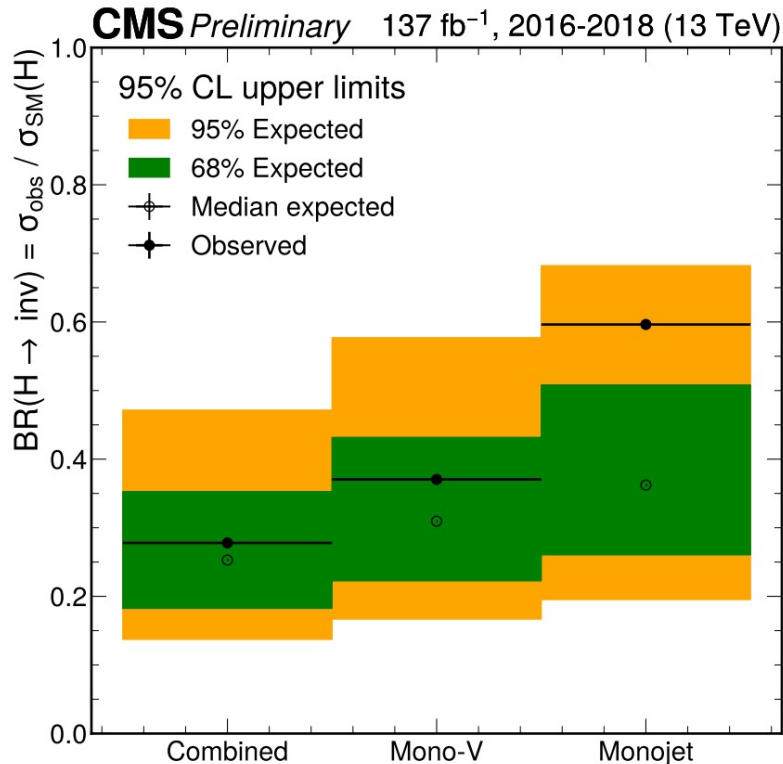
# Other Interpretations (CMS)

CMS PAS EXO-20-004

ATLAS: arXiv:2102.10874

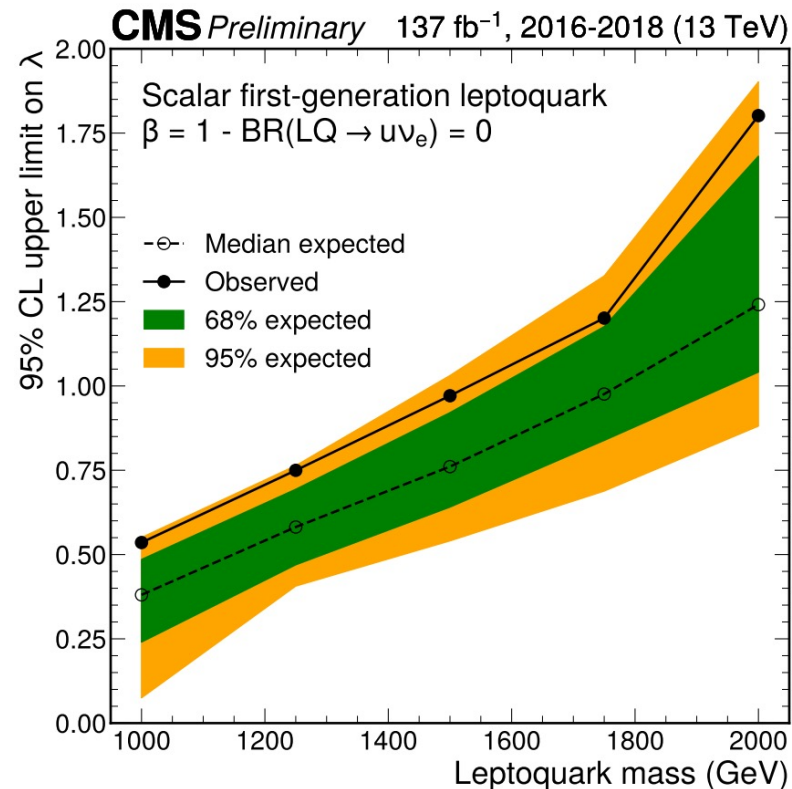


NEW



## Higgs Portal

$$B(H \rightarrow \text{inv}) < 27.8 \text{ (25.3)}$$

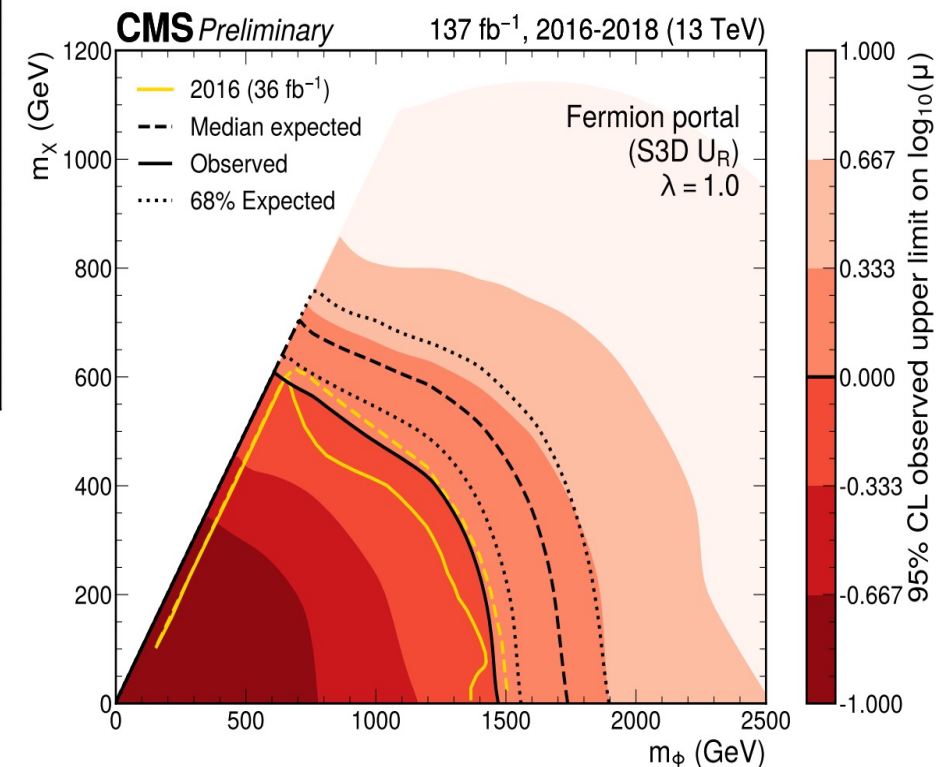


## Lepto-quark

Pair production: dominates below  $\lambda < 1$  TeV while single above 1 TeV

## Fermion Portal: DM t-channel

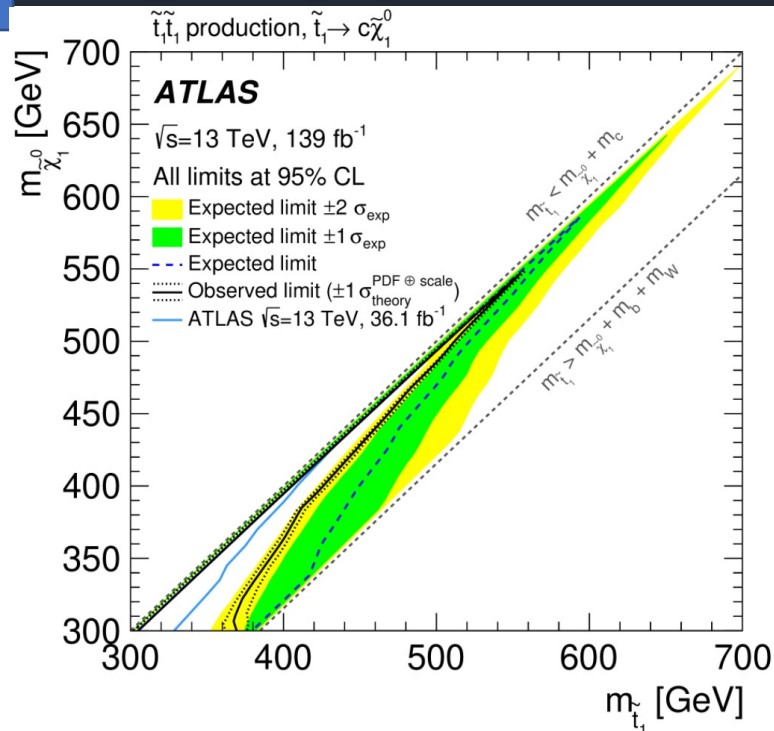
Mediator mass below  $\sim 1.5$  TeV  
excluded for  $m_{\text{DM}} = 1$  TeV



# Other Interpretations (ATLAS)

CMS PAS EXO-20-004

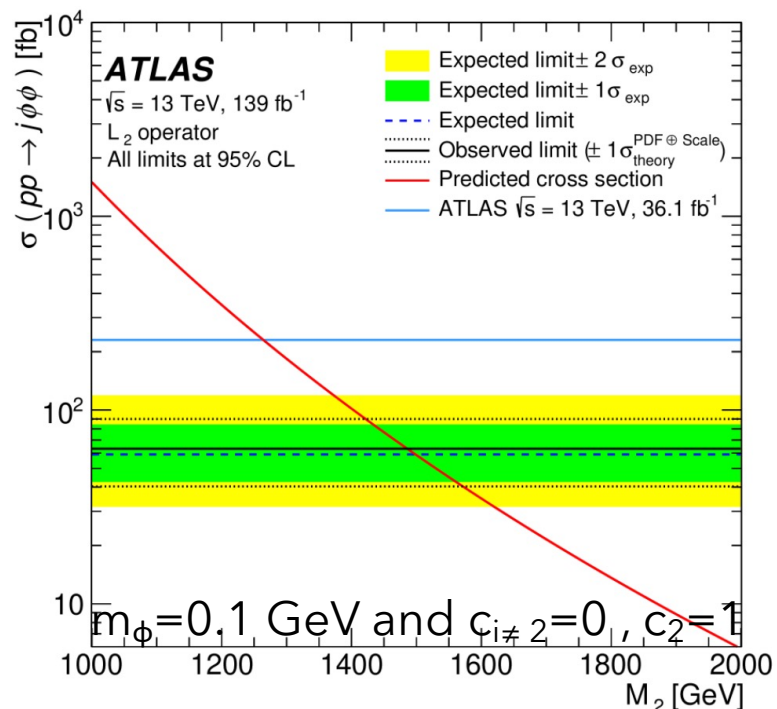
ATLAS: arXiv:2102.10874



## Squark-pair production

Excluded regions at 95% CL in the channel:  $\tilde{t}_1 \rightarrow c + \tilde{\chi}_1^0$  (B=100%)

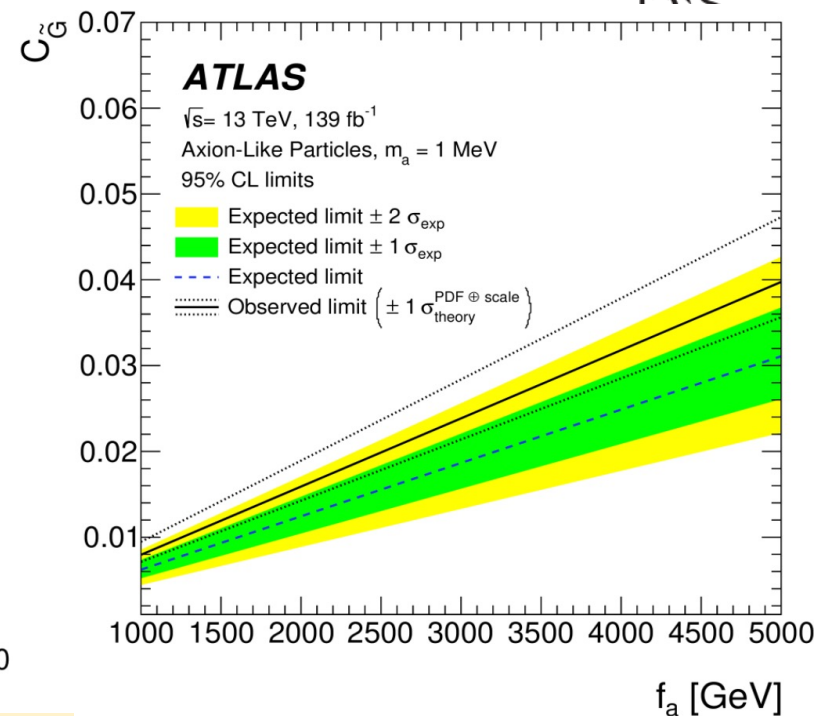
Other channels in back-up



## Horndeski Dark Energy Model

Signal acceptance independent as a function of the suppression scale  $M_2$

Values for  $M_2 < 1.486$  excluded



## Axion-like Particle

Exclusion does not depend on axion mass significantly

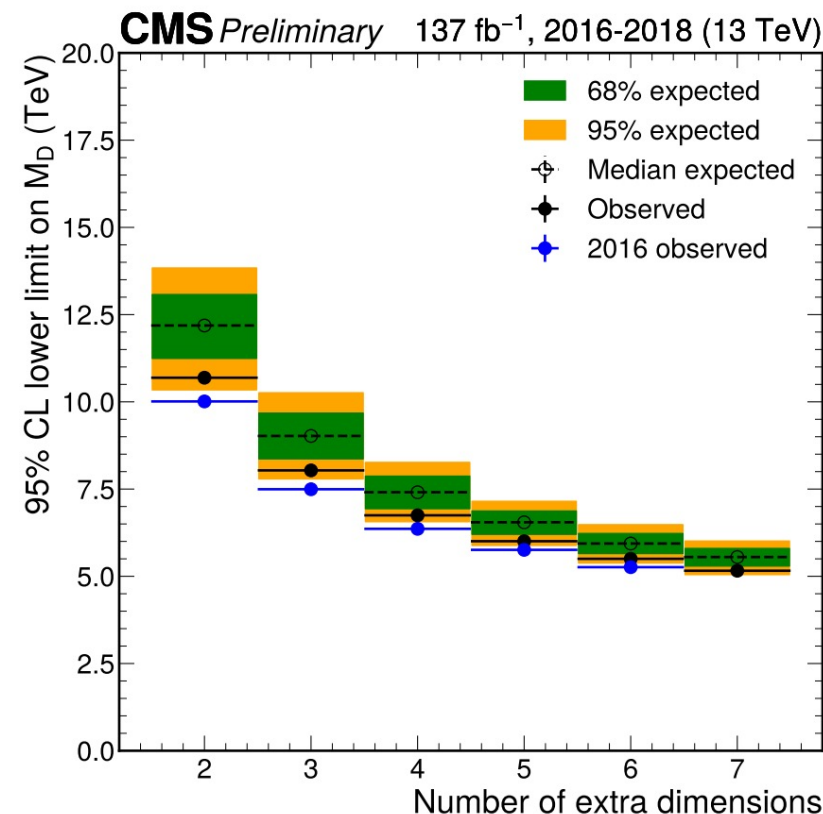
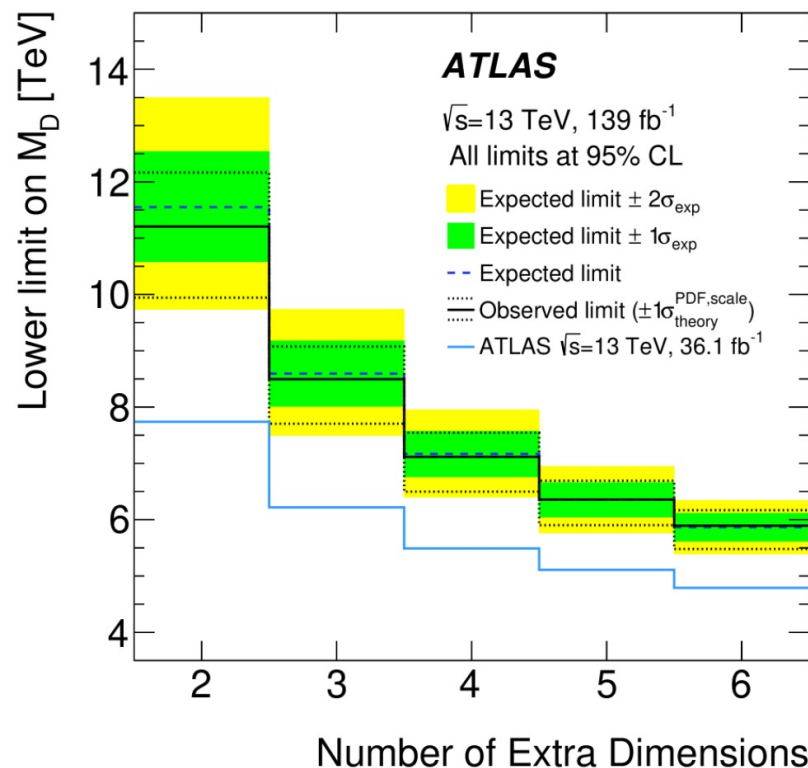
$f_a = 1$  TeV:  $C > 0.008$  excluded

ATLAS provides also model-independent limits on visible cross-sections

# Large Extra Dimensions

CMS PAS EXO-20-004

ATLAS: arXiv:2102.10874



Lower limits on the fundamental Planck scale  $M_D$  for the number of extra dimensions  $d$

For the lowest number of extra dimensions considered,  $d = 2$ ,  $M_D$  values of up to **10.8** (**11.2**) TeV are excluded as compared to expected value of **12.1** (**11.6**) TeV.

# Conclusion

[CMS PAS EXO-20-004](#)

[ATLAS: arXiv:2102.10874](#)

[ATLAS Results](#)

[CMS Results](#)



Data agrees to SM predictions mono-jet/V final state with full Run-2 (2016-2018) data for ATLAS and CMS

Results are interpreted in several theoretical models – significant improvement in exclusions

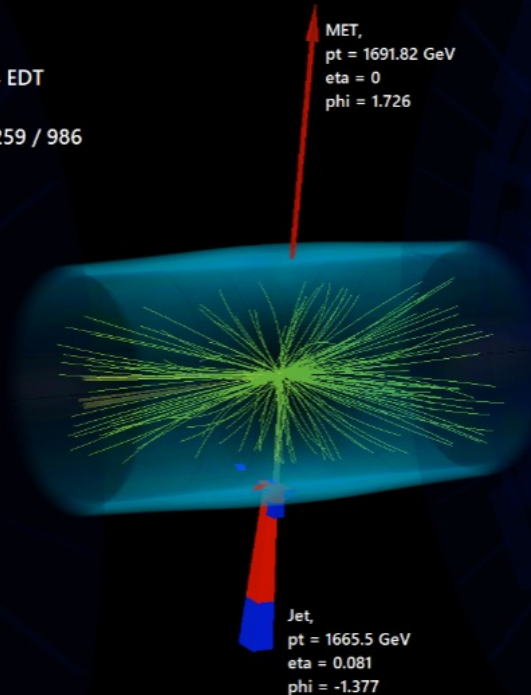
Ample supplementary material is made public by both CMS & ATLAS

ATLAS provides set of auxiliary material for re-interpretability (e.g. signal cutflows, bin by bin tables with bkg components, detailed systematic impacts table etc.)

CMS will also make public:

- HEPData entry with simplified likelihood, signal cutflows, generator cards etc.
- Mono-jet category in MadAnalysis for re-interpretation





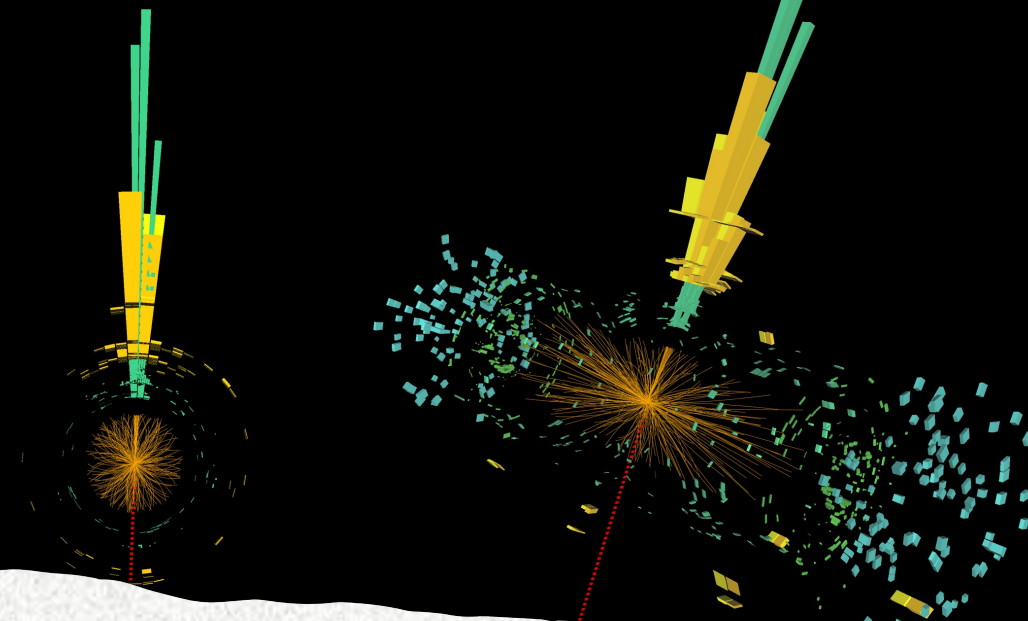
Run: 337215

Event: 2546139368

2017-10-05 10:36:30 CEST

$E_T^{\text{miss}} = 1.9 \text{ TeV}$

jet  $p_T = 1.9 \text{ TeV}$



धन्यवाद

Thank You

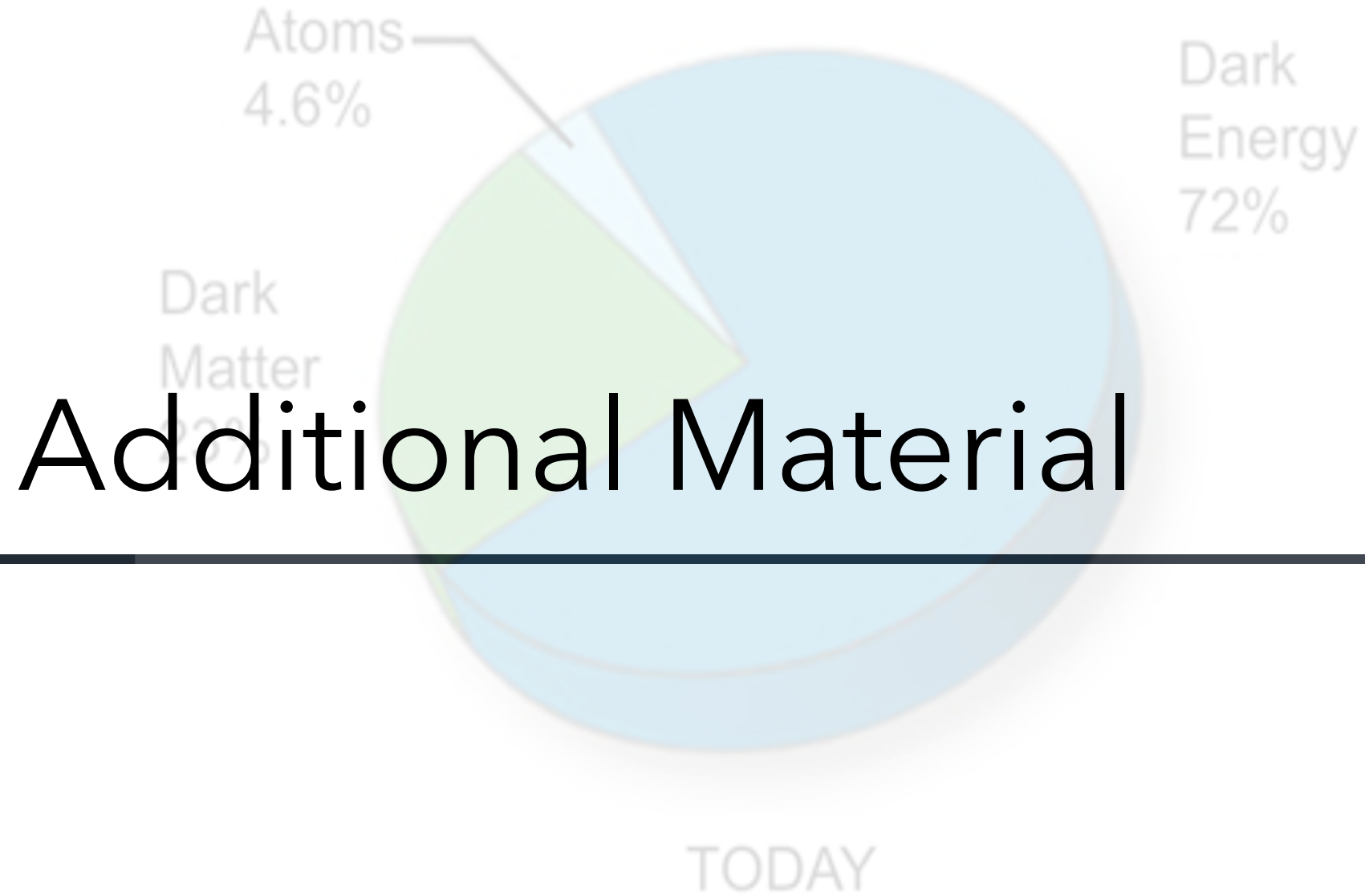
<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2018-06/>

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2016-23/>

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2016-28/>

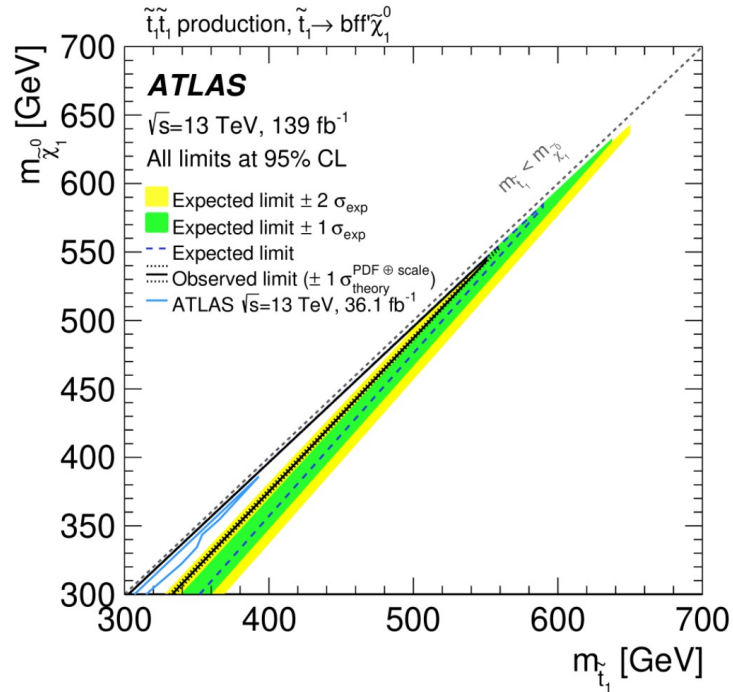
Monojet search @ CMS & ATLAS -- Varun Sharma

<http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/EXO-20-004/index.html>



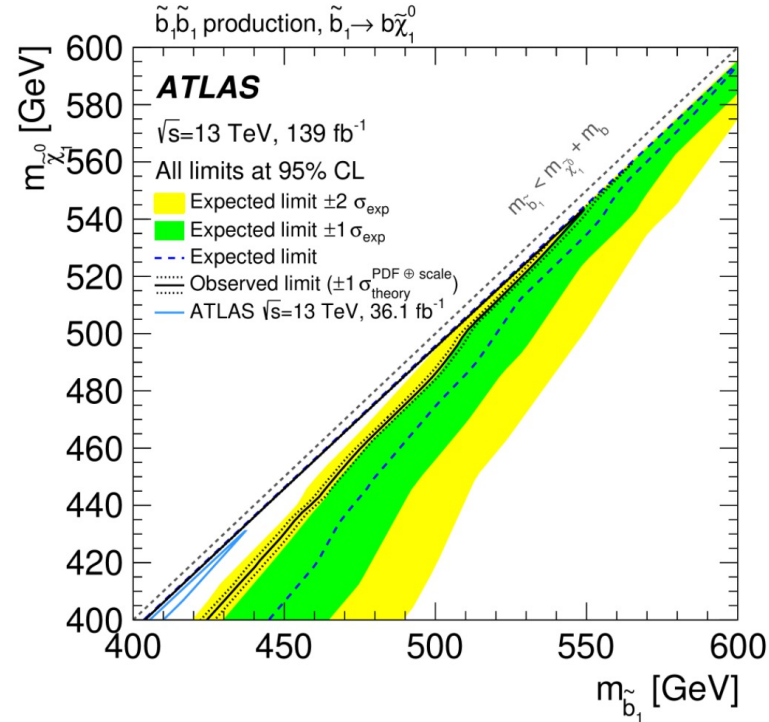
# Additional Material

# ATLAS: SUSY Scenarios



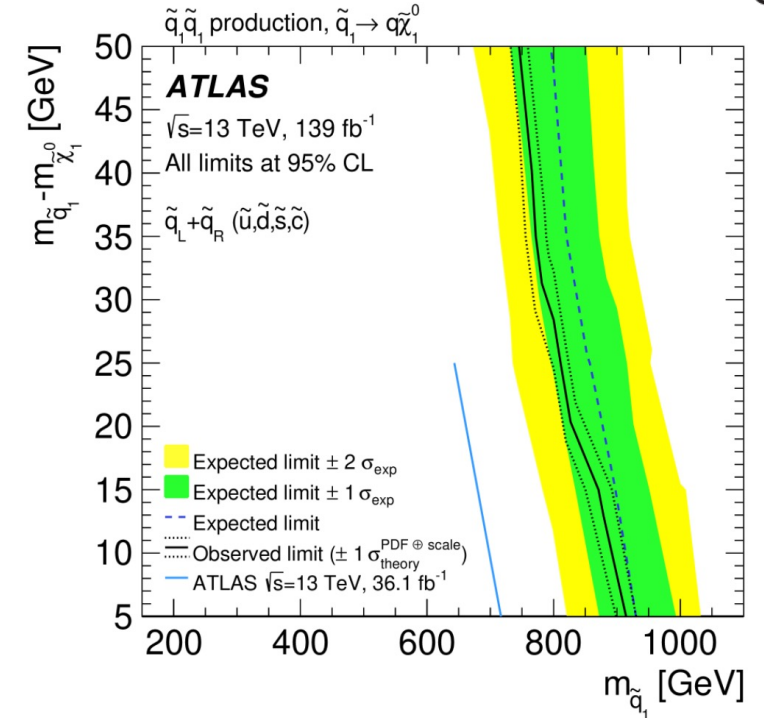
Excluded regions at the 95% CL in the channel:

$$\tilde{t}_1 \rightarrow b + f\bar{f}' + \tilde{\chi}_1^0 \quad (B=100\%).$$



Exclusion plane at 95% CL as a function of sbottom and neutralino masses for the decay channel

$$\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0 \quad (B=100\%)$$

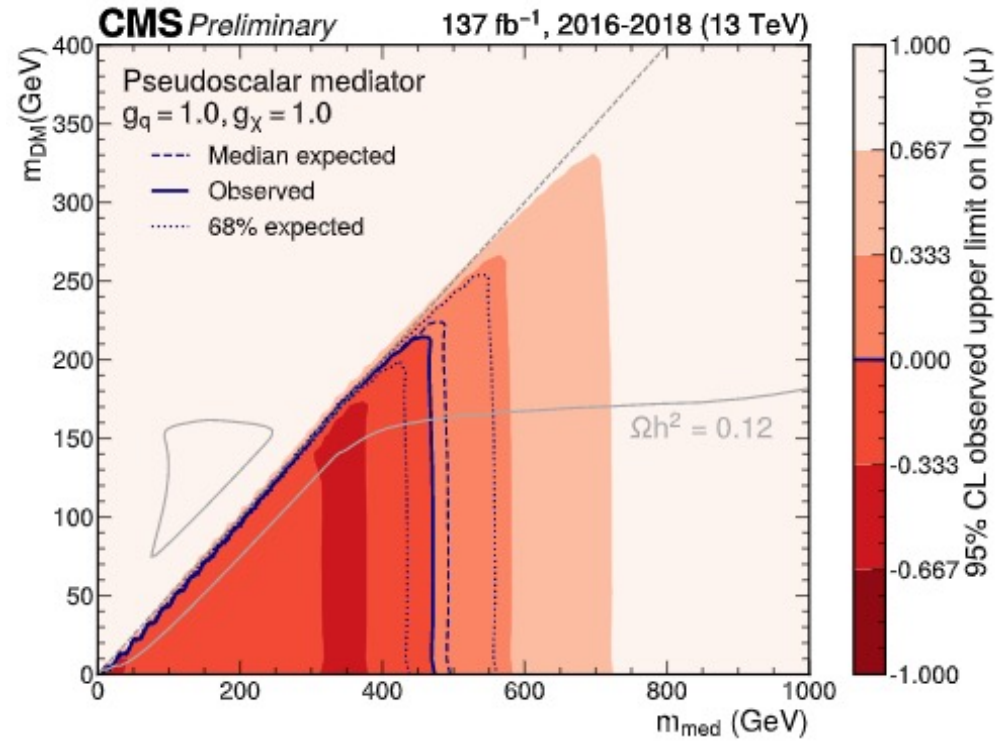


Exclusion region at 95% CL as a function of squark mass and the squark--neutralino mass difference for

$$\tilde{q} \rightarrow q + \tilde{\chi}_1^0 \text{ and } \tilde{q}_L + \tilde{q}_R \text{ with } (u, d, c, s)$$

BACK-UP

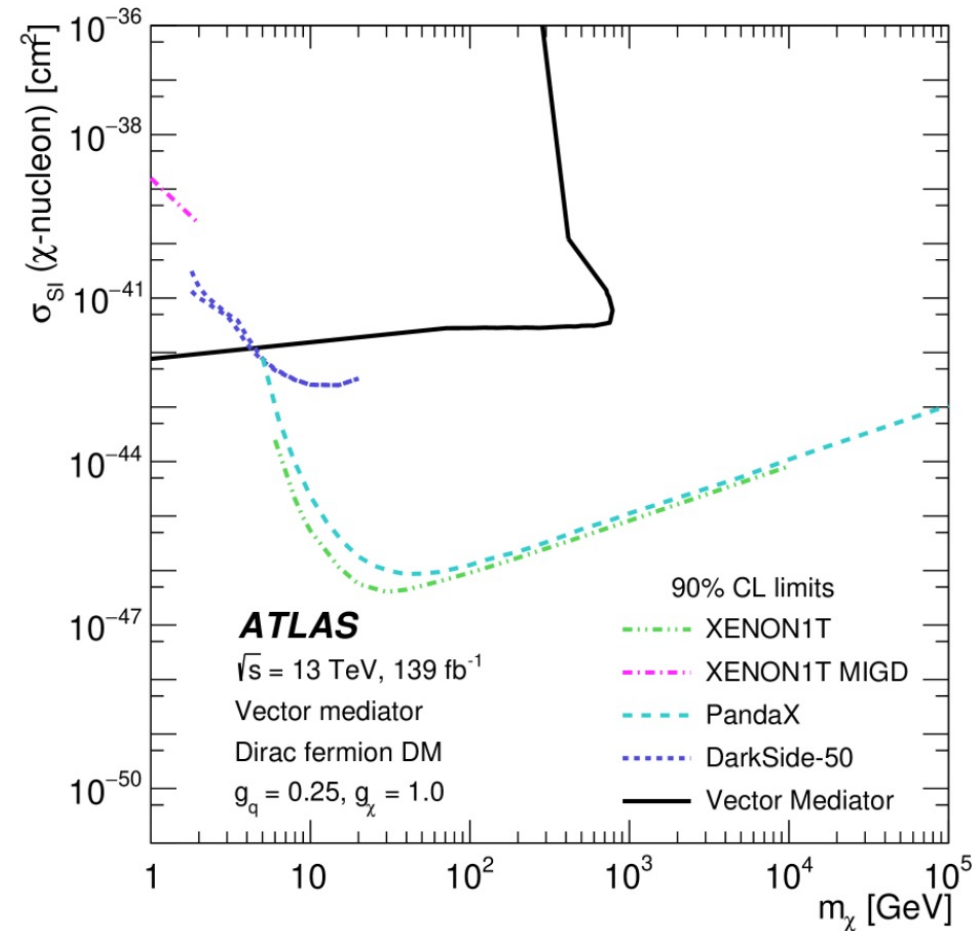
# Simplified Dark Matter (Spin-0)



A pseudoscalar mediator



# Direct detection comparison



WIMP annihilation rate as a function of WIMP mass