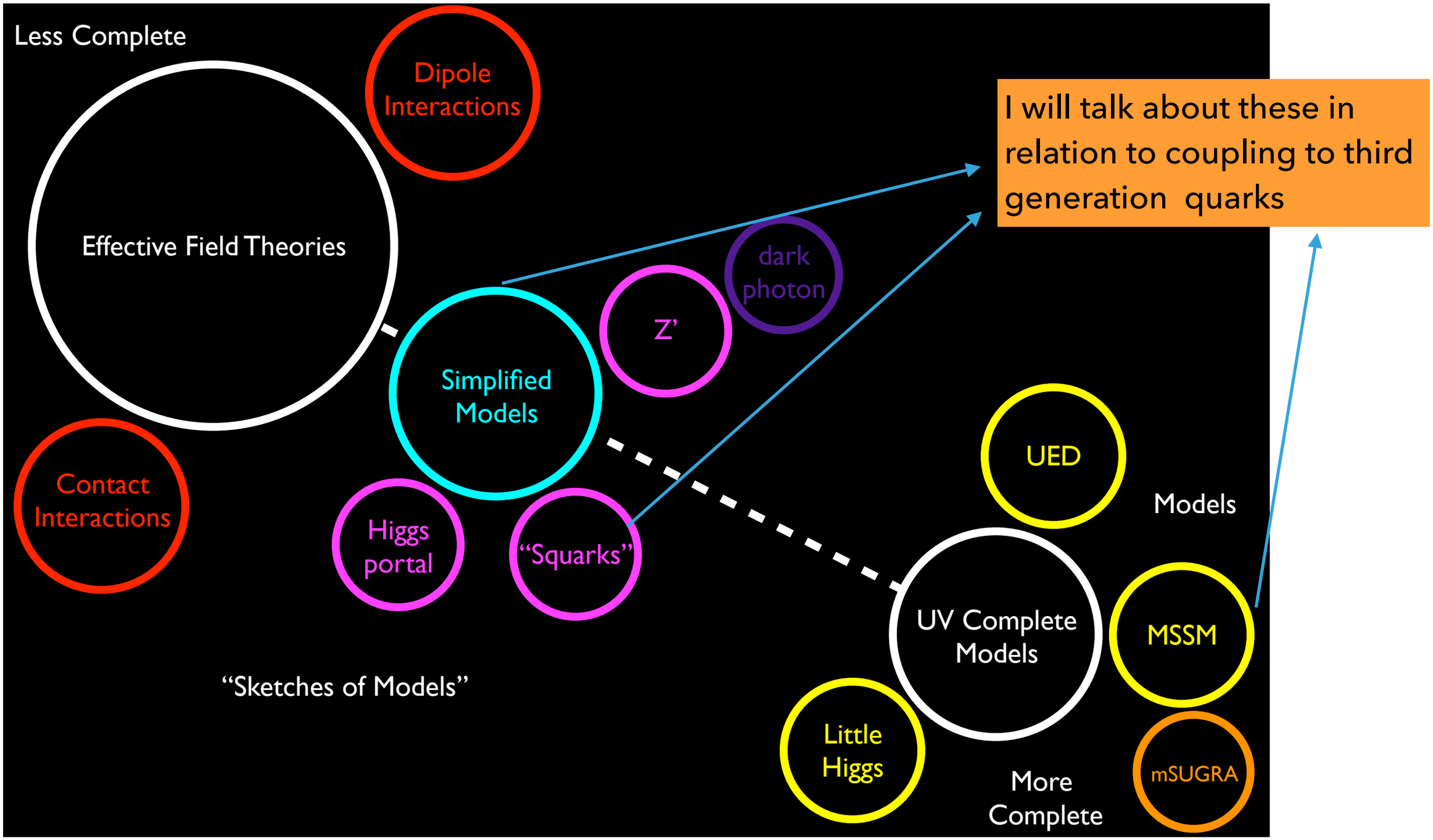
Image credit: https://www.particlezoo.net/products/ (accessed 2/8/19)

MATT ANTHONY,
ON BEHALF OF THE ATLAS COLLABORATION

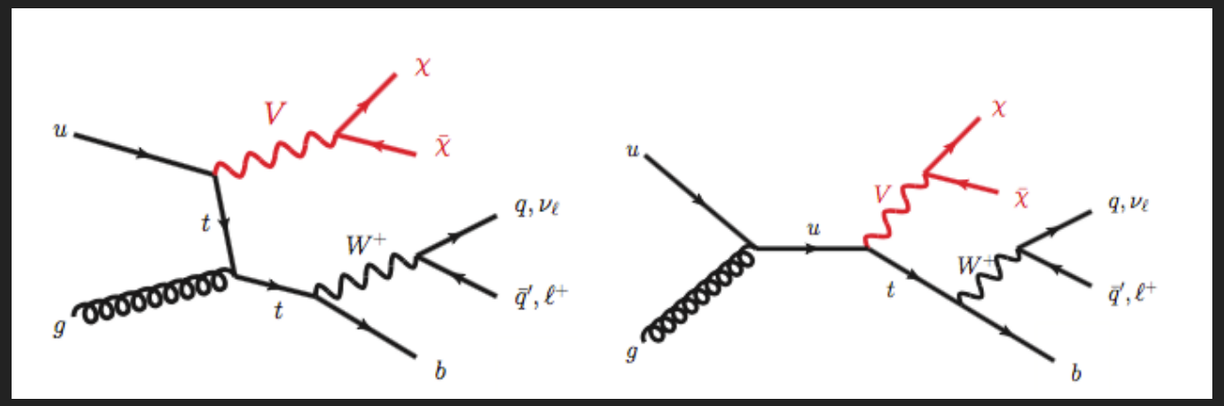
SEARCH FOR DARK MATTER IN THIRD GENERATION QUARKS IN ATLAS

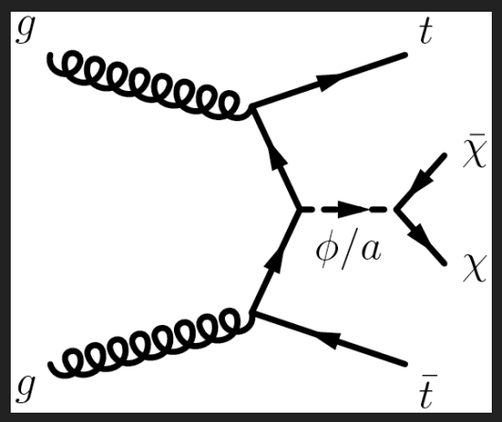
THEORETICAL MODELS

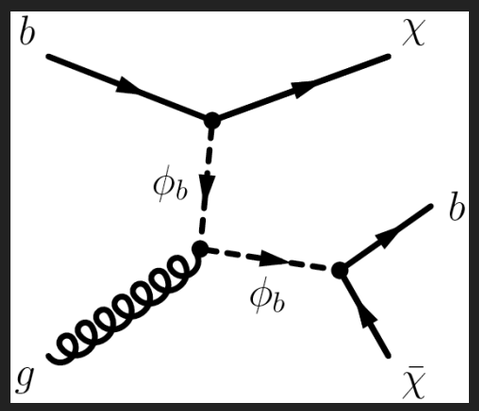


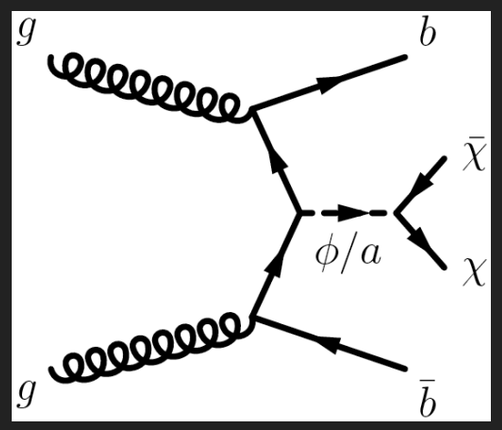
Credit: "Perspectives on Dark Matter Interactions", Tim Tait, DM@LHC2013

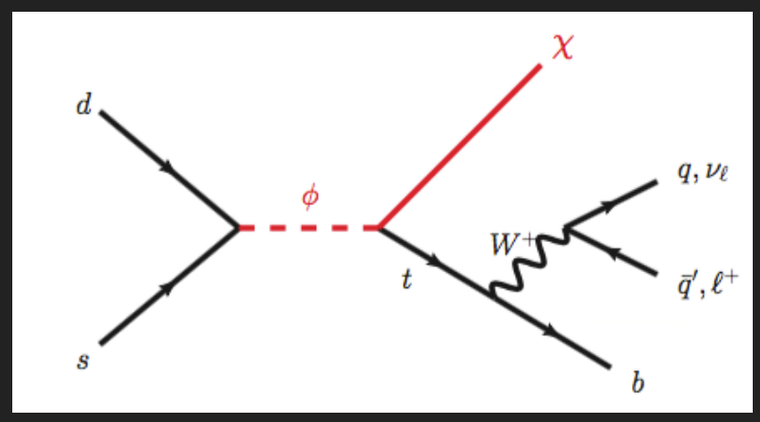
SIMPLIFIED MODELS: DEDICATED DM MODEL SEARCHES











DM+TT (0,2L)

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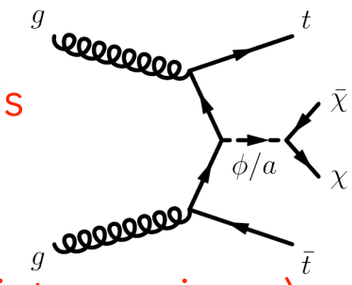
- 3 signal regions (2 hadronic, 1 dileptonic):
  SRt1: Low mass [Pseudo]scalar mediator models

  $M(\phi/a) < 100$ GeV

  SRt2: High mass [Pseudo] scalar mediator
  SRt3: Dileptonic top (both [Pseudo] scalar mediator regimes)



- Key discriminating variables:

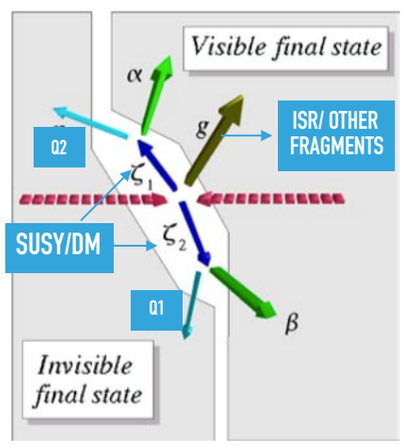
  Hadronic Channel:
  Reclustered R=1.2 jets, E_T^{miss} , MET significance

  Dileptonic Channel:

$$\xi^+ = m_{\mathrm{T2}}^{\ell\ell} + 0.2 \cdot E_{\mathrm{T}}^{\mathrm{miss}}$$

$m_{\mathrm{T2}}^{\ell\ell}$ [GeV] → Stransverse mass of the two leptons

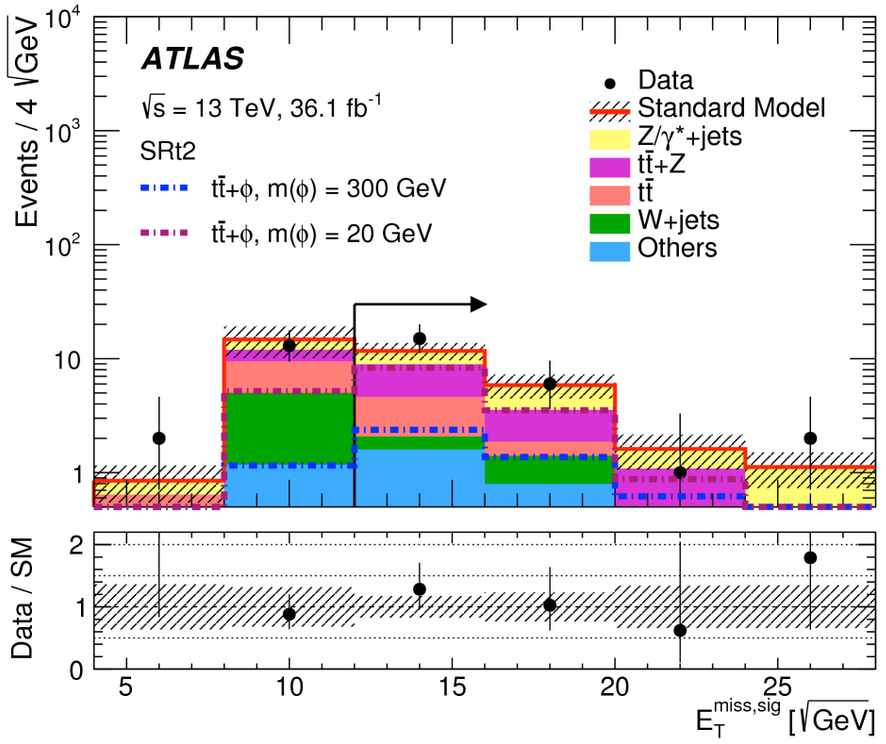
See JHEP02(2017)131 for more motivation for this choice of linear combination

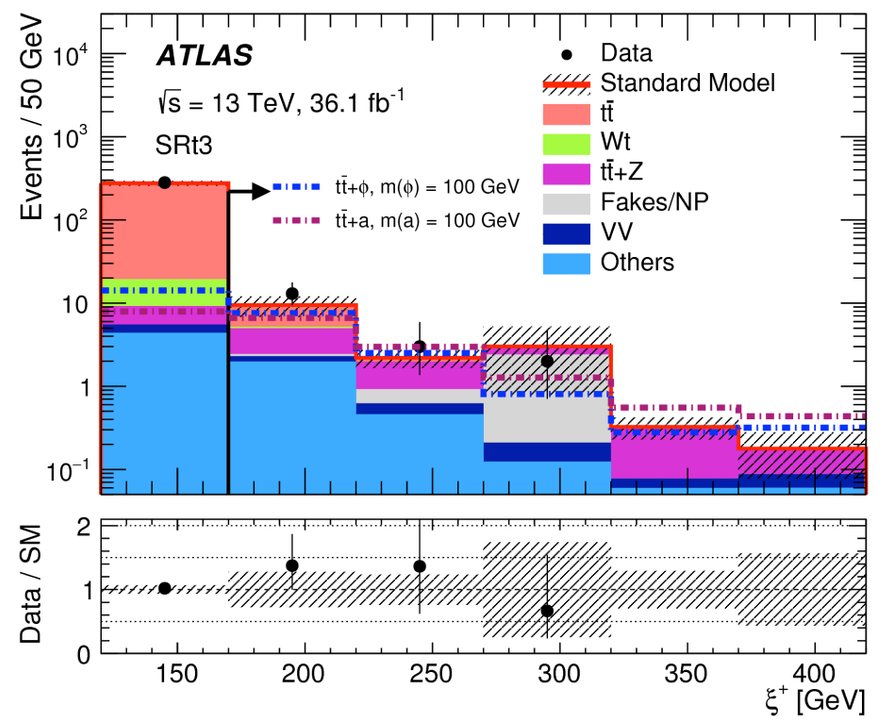


Popular variable in RPC SUSY searches!

$$\min_{\not{q}_T^{(1)}+\not{q}_T^{(2)}=\not{p}_T}\left[\max\left\{m_T^2\left(\mathbf{p}_T^{\pi^{(1)}},\not{q}_T^{(1)};m_{\chi_1^0}\right),m_T^2\left(\mathbf{p}_T^{\pi^{(2)}},\not{q}_T^{(2)};m_{\chi_1^0}\right)\right\}\right],$$

Example derived from C1->Pi + N1
In di-lepton case, replace pi with leptons, and M(N1) =0 10.1088/0954-3899/29/10/304





- Key backgrounds:

$t\bar{t}$ (all channels) ,Z+jets (Hadronic only), $t\bar{t} + Z(\rightarrow \nu\nu)$ (all channels), Fake leptons (Dileptonic only)

DM+BB (0L)

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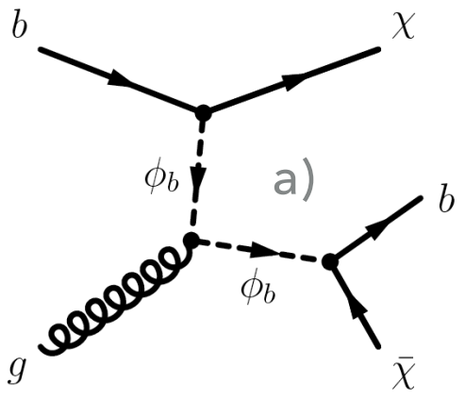
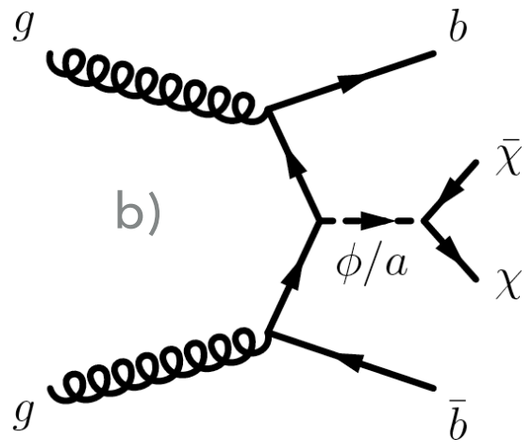




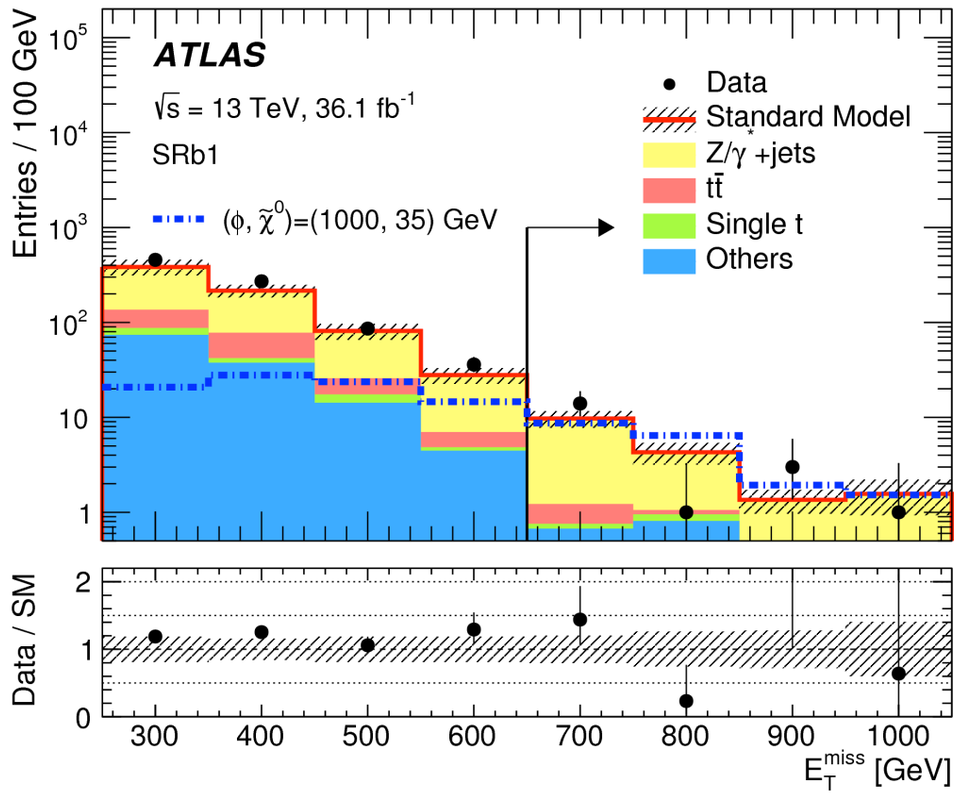
- 0 Lepton topology with 2 signal regions.

SRb1 topology:

>=2 jets, >=1b-jets, $E_T^{\text{miss}} > 650$ GeV

large jet pT, Multi-jet rejection criteria applied

Diagram a)



- SRb2 topology:

2 or 3 jets, >=2 b-jets, $E_T^{\text{miss}} > 180$ GeV ,

large leading jet pT, Multi-jet rejection criteria applied

Diagram b)

- Key discriminant variables:

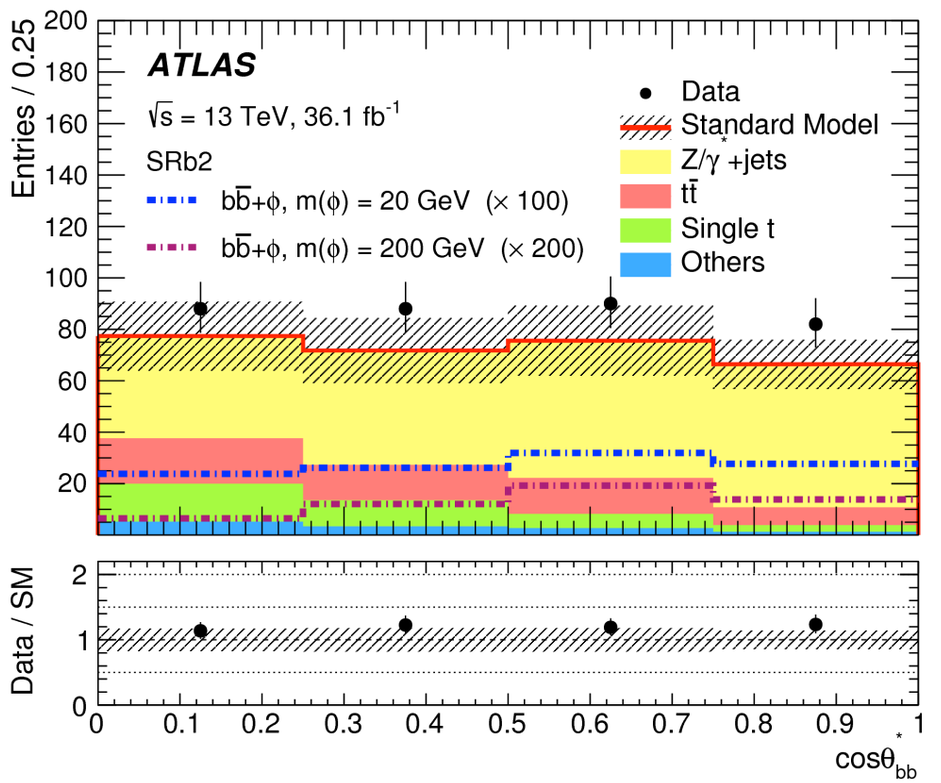
SRb1: H_{T3} HT of all jets excluding leading & sub-leading

SRb2:

$$\cos\theta^*_{bb} = \left|\tanh\left(\frac{\Delta\eta_{bb}}{2}\right)\right|$$

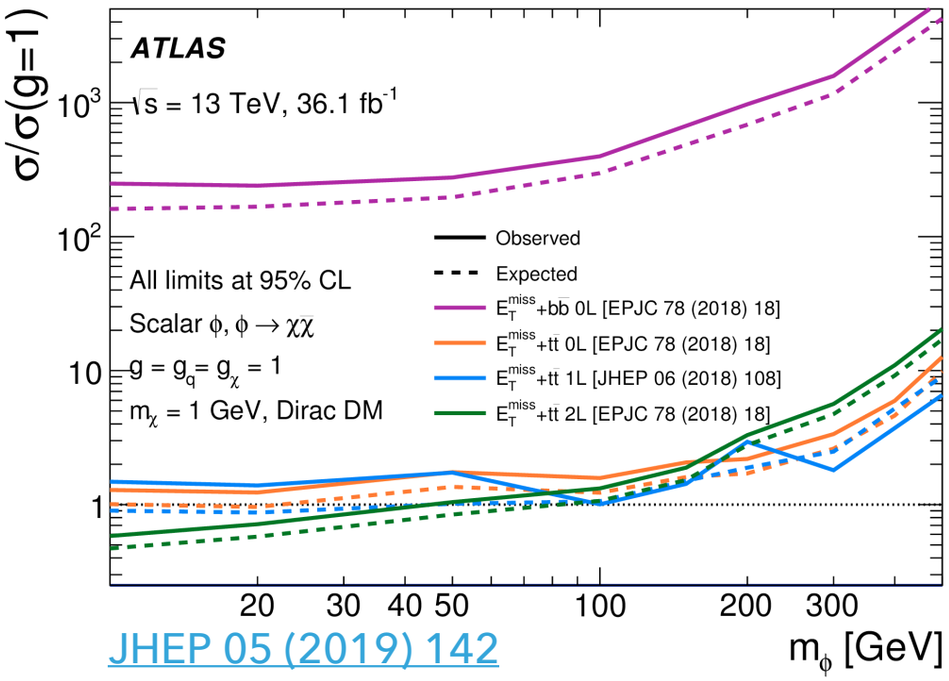
Used to discriminate between Z+jets and signal

Angular information of the jets, MET and b-jets in the event



EXCLUSION LIMITS

Colour independent Scalar mediator to DM



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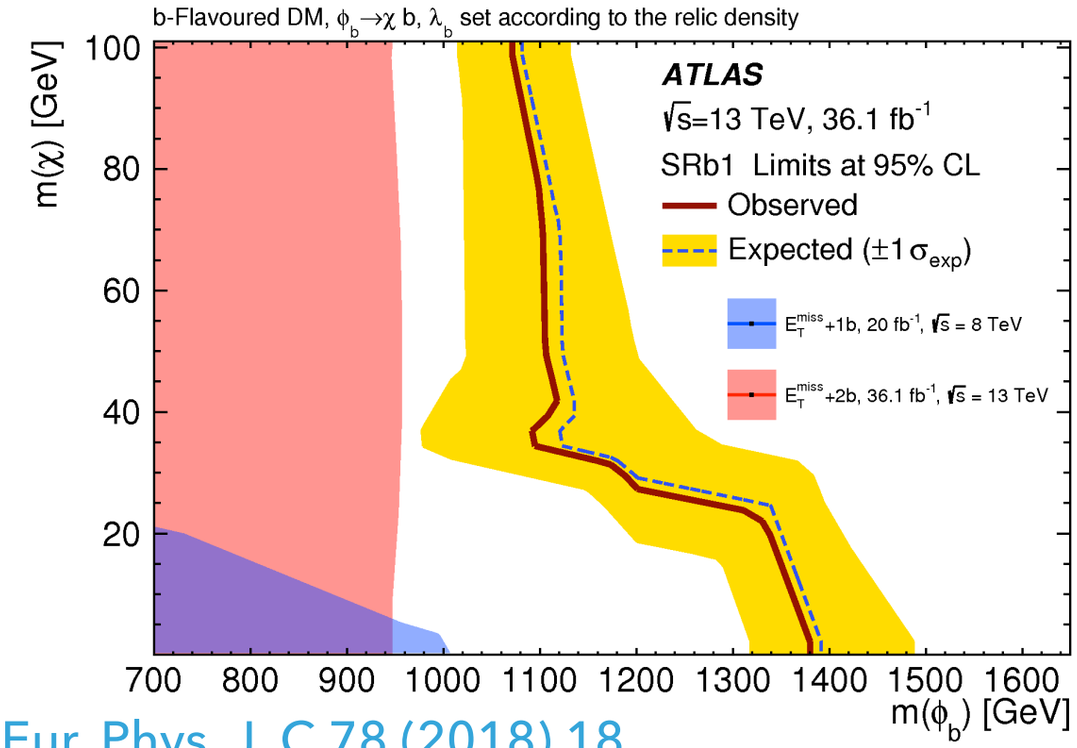
Colour charged scalar mediator to DM+b



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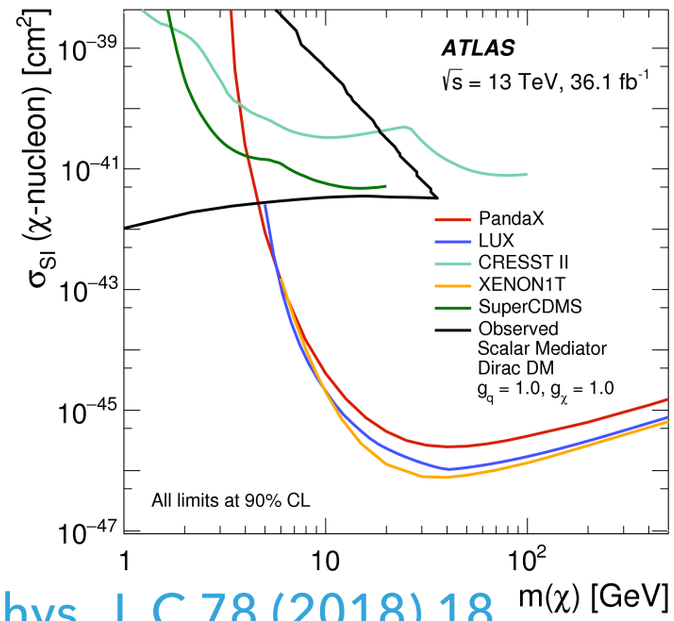
Colour independent Pseudo scalar mediator models to DM covered in backup

Spin independent cross section limits in context of other experiments



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Model dependent limit is complementary with direct detection experiments

DM: MONO TOP +DM

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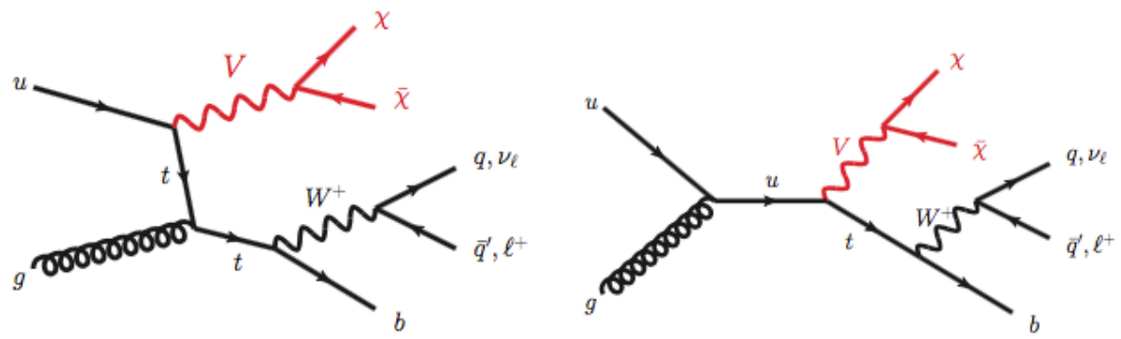
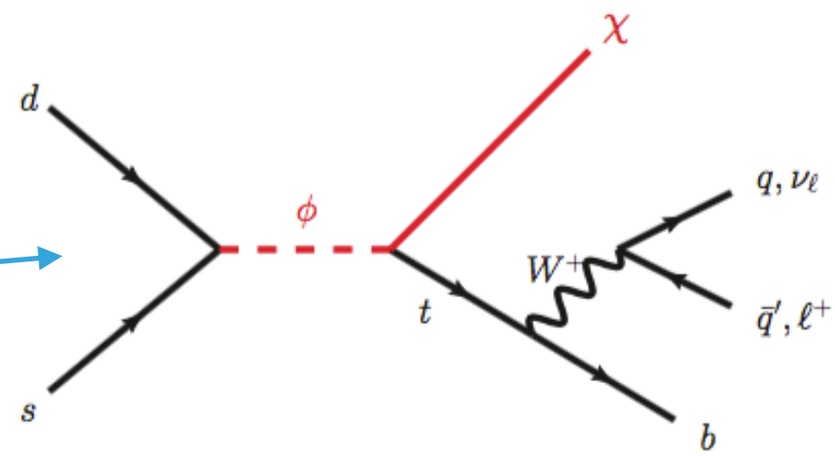
- Signal models targeted:
  Non-Resonant DM interaction:
  Colour charged Vector mediator.



Complementary models (Mediator->Visible) can be probed by the dilepton (same sign) + b analysis
(JHEP 05 (2019) 142) - see backup.

Resonant DM production models:
Charged Scalar mediator



- Two channels considered: all-hadronic and semi-leptonic channel

- Key backgrounds:
  Hadronic channel: $t\bar{t}$, W/Z+jets, Multi-jet (important in CR)
  Semi-leptonic channel: $t\bar{t}$,W+jets

DM: MONO TOP +DM

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No statistically significant excess observed

- Signal regions:

  Key discriminants:

Leptonic channel:

1jet, which is b-tagged, MET>50 GeV, dPhi(Lepton,b=jet)

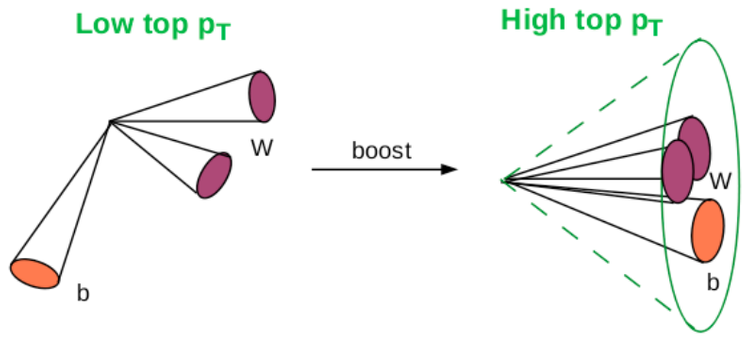
$$m_{\mathrm{T}}^{W} = \sqrt{2p_{\mathrm{T}}(\ell)E_{\mathrm{T}}^{\mathrm{miss}}(1-\cos\Delta\phi(p_{\mathrm{T}}(\ell), E_{\mathrm{T}}^{\mathrm{miss}}))},$$

Hadronic channel:

>=1 R=1.0 jets,

$$\Delta\phi(\mathbf{p}_T^{\mathrm{miss}}, R=1.0\ \mathrm{Jet})$$

$$\Delta\phi(\mathbf{p}_T^{\mathrm{miss}}, R=0.4\ \mathrm{Jets})$$



Source: https://www.quantumdiaries.org/tag/top-quark/ (accessed 8/8/19)

Top Tagging:

pT(R=1.0) > 400 GeV,

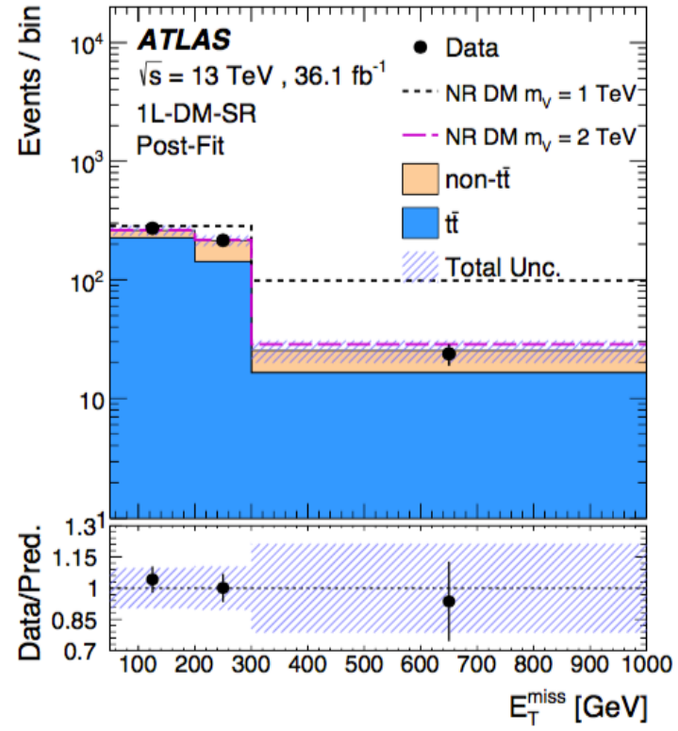
Uses small R (R=0.2) sub-jets inside the R=1.0 jets.

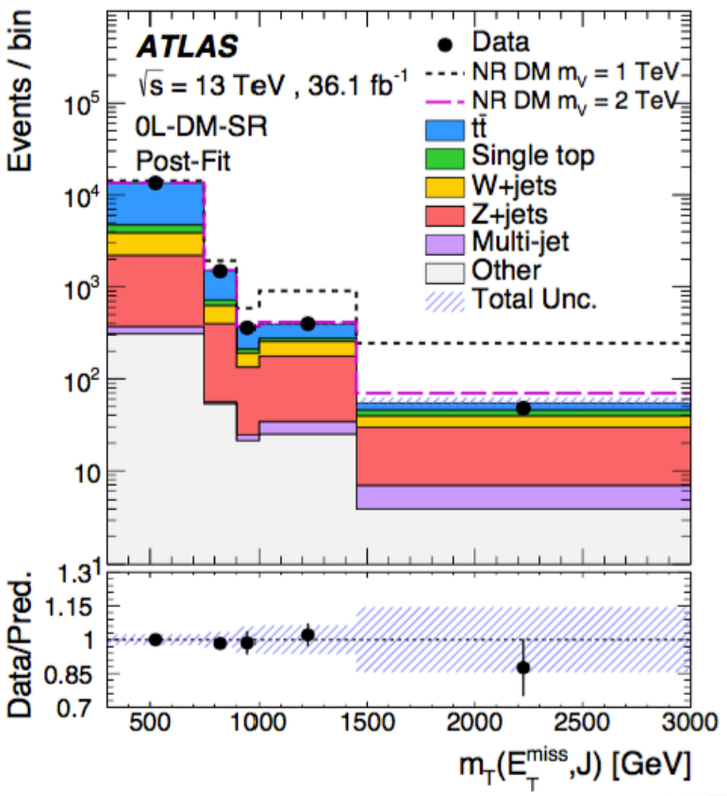
Tagging using n-subjettiness + Calibrated jet mass, with a fixed identification efficiency of ~80%

Nsubjettiness: Extent to which an R=1.0 jet is built from N sub-jets (in our case 2 or 3).

$$\tau_N = \frac{1}{d_0}\sum_k p_{T,k}\min\{\Delta R_{1,k}, \Delta R_{2,k}, \cdots, \Delta R_{N,k}\} \qquad d_0 = \sum_k p_{T,k}R_0$$

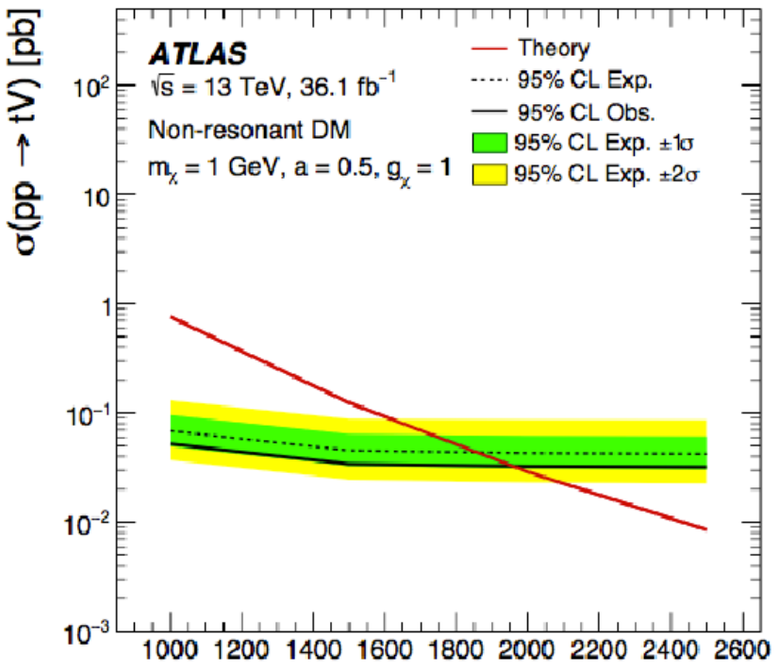
Equations from JHEP 1103:015,2011

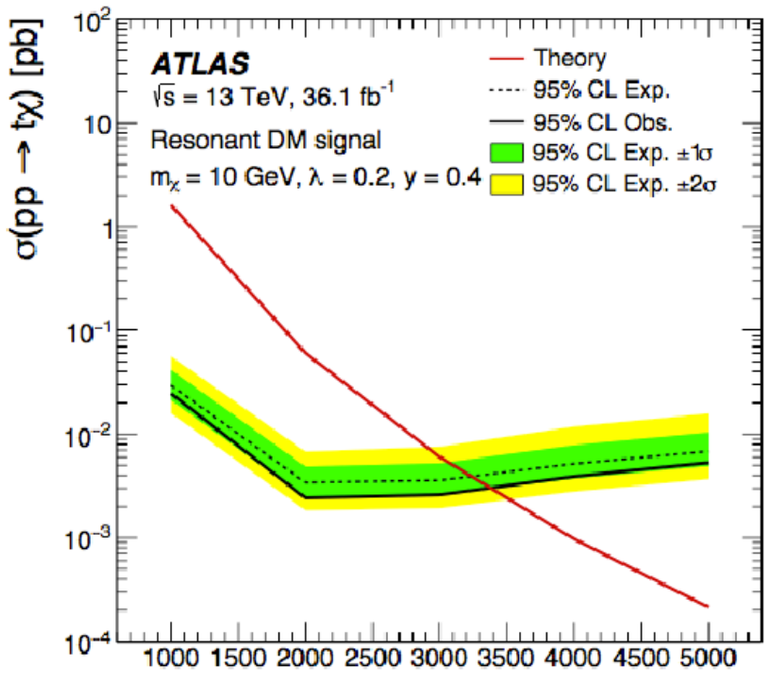




DM: MONO TOP EXCLUSION LIMITS

Exclusion limits of the resonant & non-resonant DM models





See backup for limits on individual simplified model parameters + complementary case

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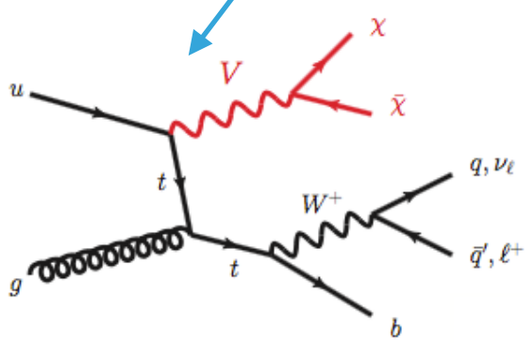

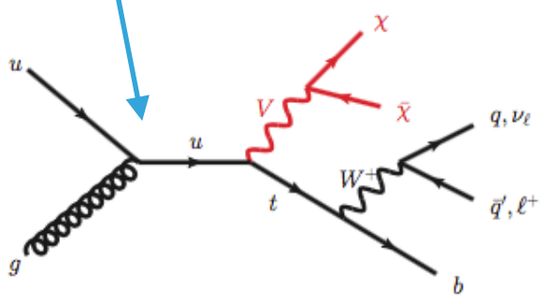

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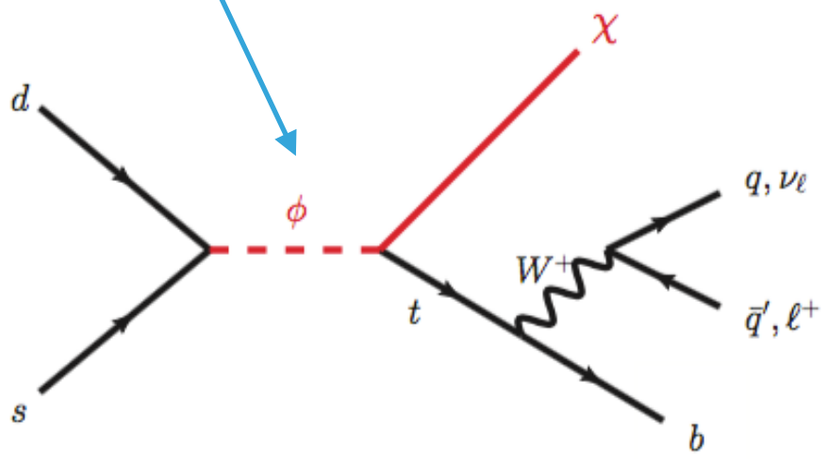
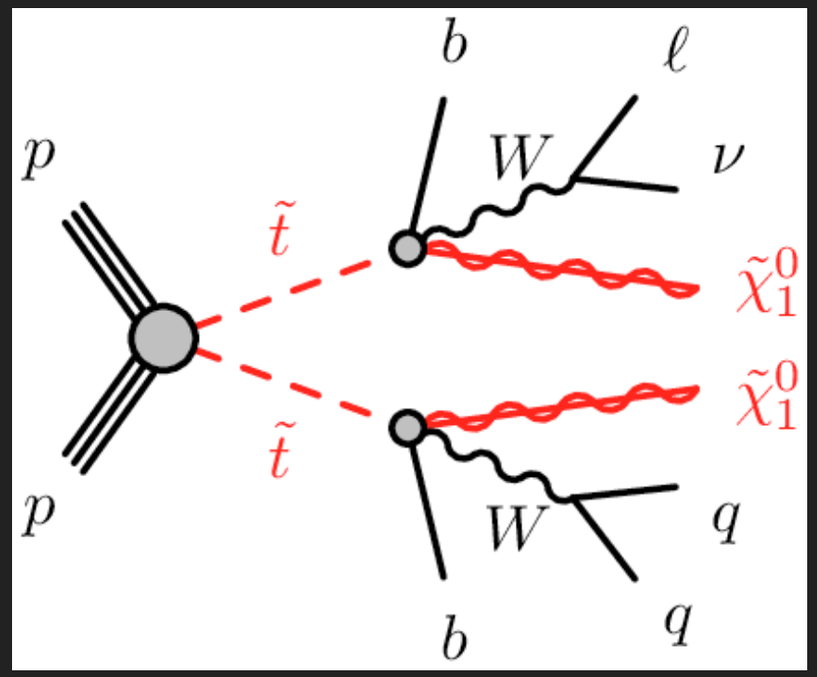


SIMPLIFIED MODELS: SUSY SEARCHES



SUSY: TT+MET (1L) - 3 BODY

ATLAS-CONF-2019-017

- Preselection:

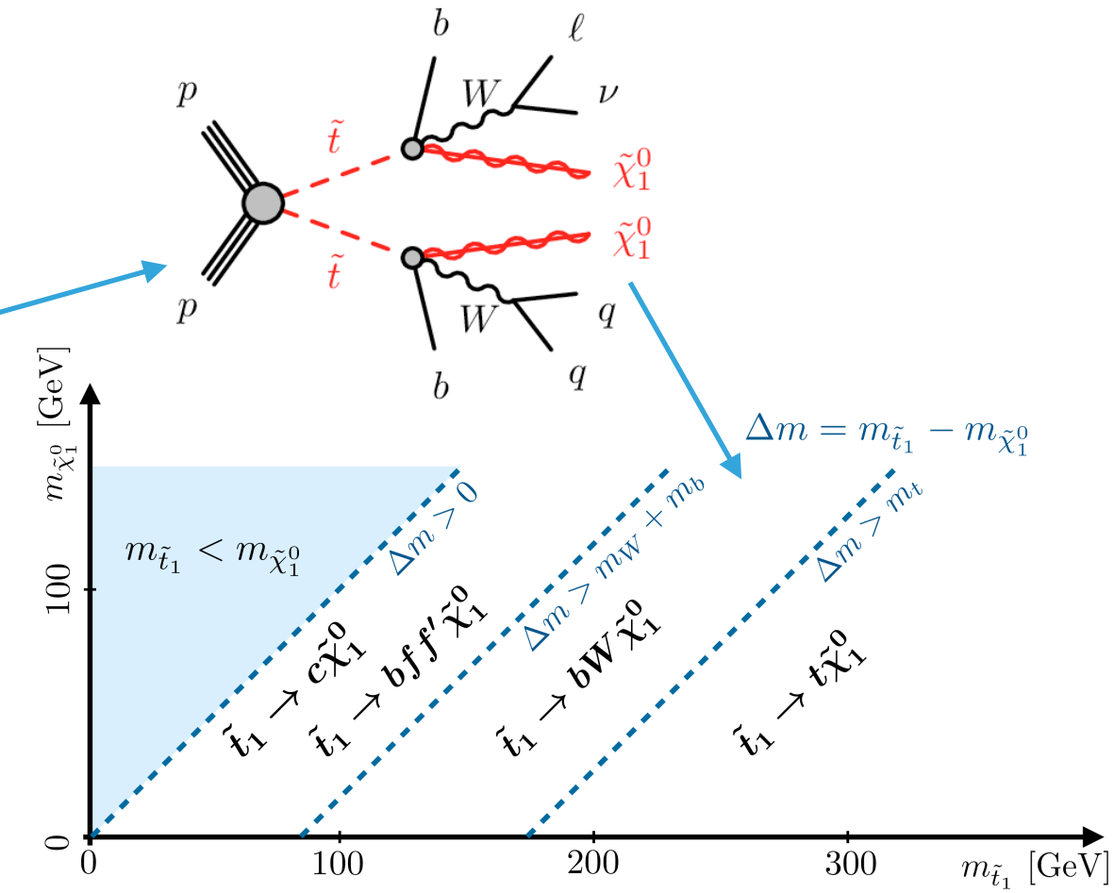
  1 Lepton ,>=4 Jets,>=2 b-jets,
  $M_T(\ell, \mathbf{p}_T^{\text{miss}})$ > 110 GeV

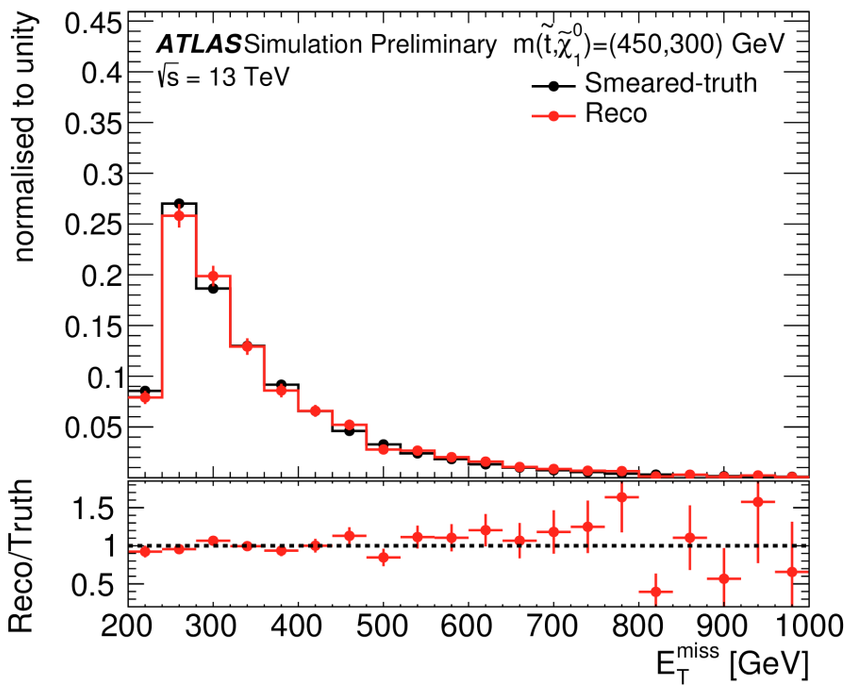
- Model targeted: Semi-leptonic 3 body stop decay (100% BR)

- Neural network defined signal region

  Input variables:
  E_T^{miss} ,
  $M_T(\ell, \mathbf{p}_T^{\text{miss}})$,
  lepton kinematics,
  leading b-jet kinematics,
  Jet kinematics

- Neural Network is trained on smeared truth level events from signal and background MC to increase statistics in the training set.





SUSY: TT+MET 1L (3BODY) ATLAS-CONF-2019-017

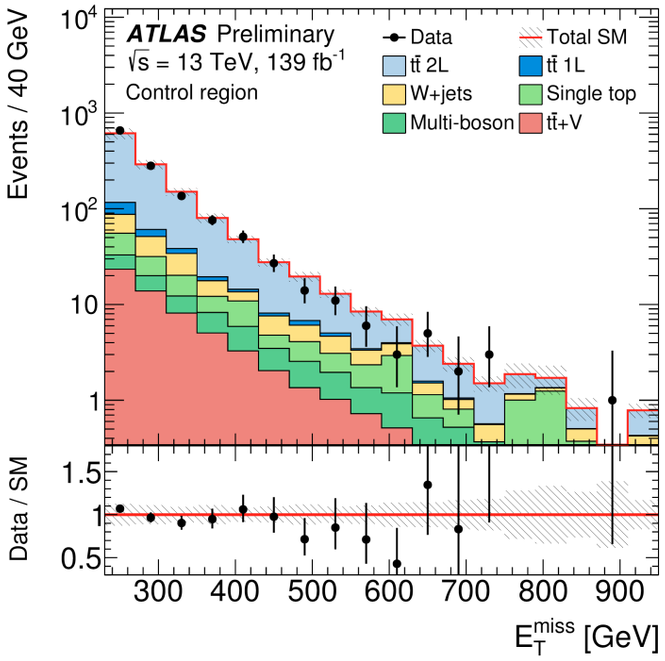
- Discovery Regions: Region chosen to maximise expected significance in the given region.

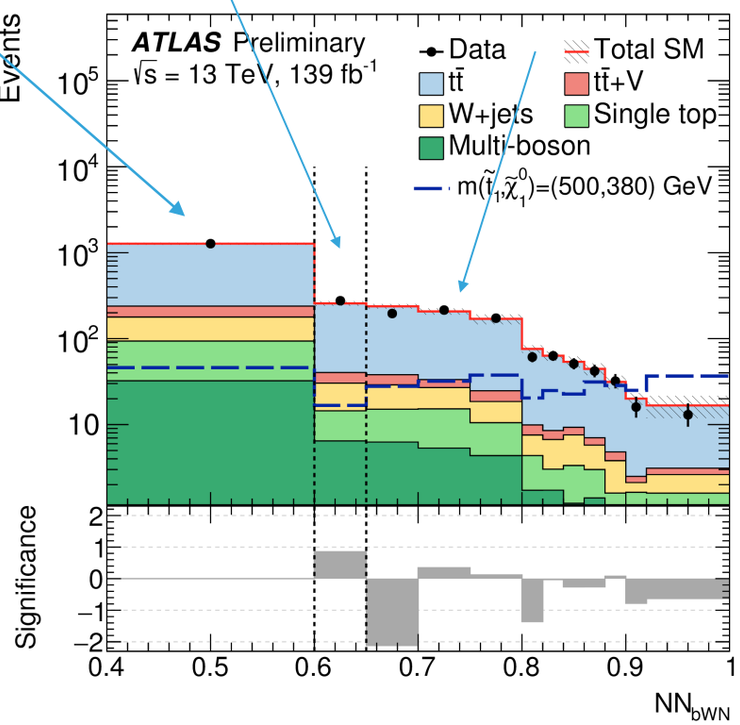
Scenario	SR and its binning
Discovery	$NN_{bWN} > 0.9$
Exclusion	$NN_{bWN} \in [0.65^*, 0.7^*, 0.75^*, 0.8, 0.82, 0.84, 0.86, 0.88, 0.9, 0.92, 1]$

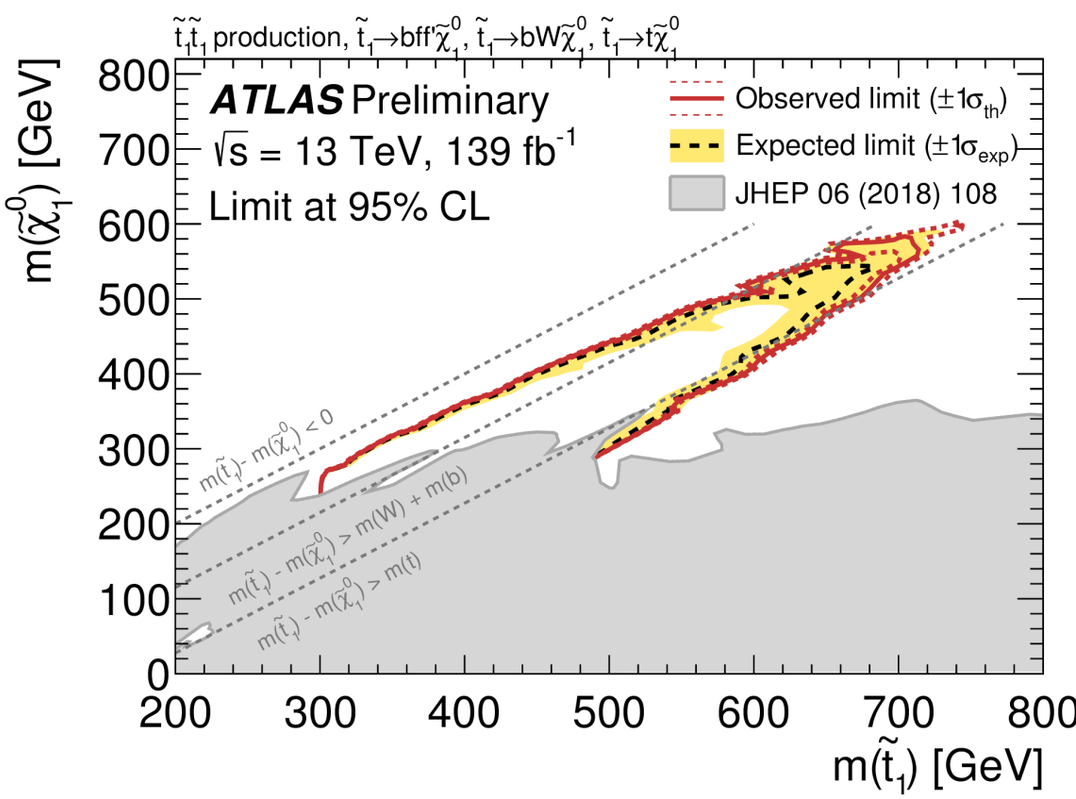
Exclusion Regions: Binned simultaneous fit on the NN output, chosen to maximise the excluded parameter space.

- $t\bar{t}$ control Region: NN score in range [0.40,0.60] with $M_T(\ell, \mathbf{p}_T^{\text{miss}})$ >150 GeV selection

Control Region (CR)	Validation Region (VR)	Signal Region (SR) (all bins)	No significant excess over the standard model is observed.







Substantial improvement over previous limit!!

European Research Council

CONCLUSION

- In this talk I have shown:
  Spin independent cross section limits as a function of DM mass which are complementary with direct DM detection experiments

  Limits which substantially expanded the excluded class of simplified DM phase spaces in models relating to top and bottom quark couplings

  Imposed new limits extended by ~250 GeV over the 2015/16 result in stop mass along the 3 body diagonal in the case of RPC stop decaying to b+W+MET

A better photo than any I could get: Accessed: https://www.istockphoto.com/photos/seattle (Accessed 12/08/19)

Source: https://looneytunes.fandom.com/wiki/That%27s_all_Folks (accessed 1/8/19)

BACKUP

DM MODELS

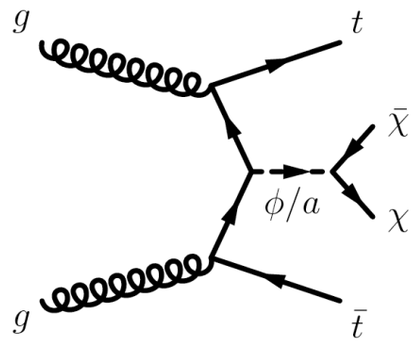
1. Colour neutral scalar (“Phi”) or Colour neutral pseudo scalar mediator (“a”) -> MET + top pair.

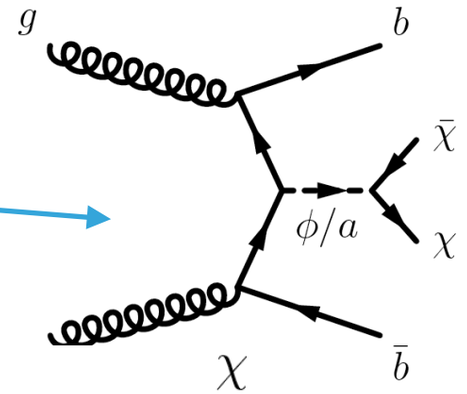
2. Colour-neutral scalar/pseudoscalar -> MET + bottom pair

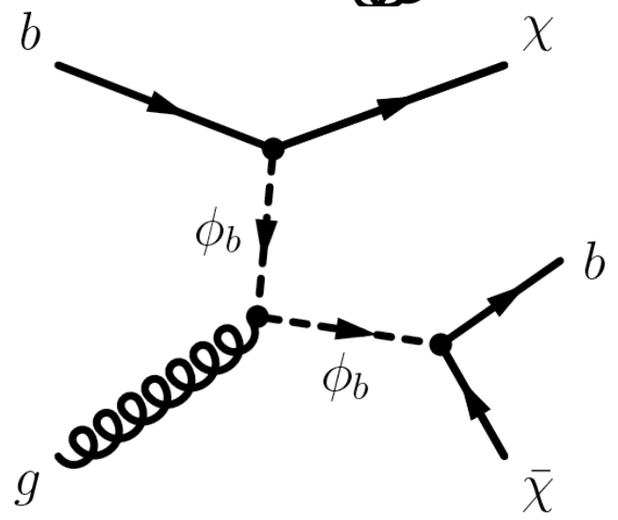
3. Colour charged scalar mediator decaying to b + DM

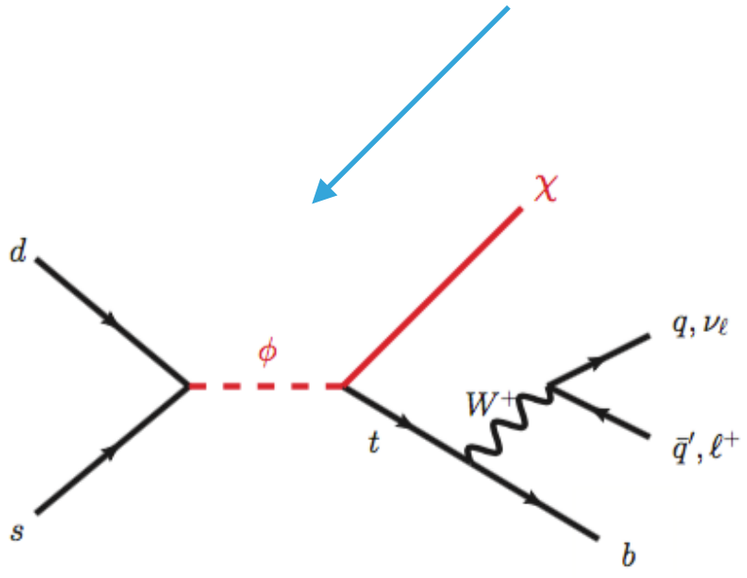
4. Non Resonant interactions:
   Single top + Colour charged vector mediator -> DM

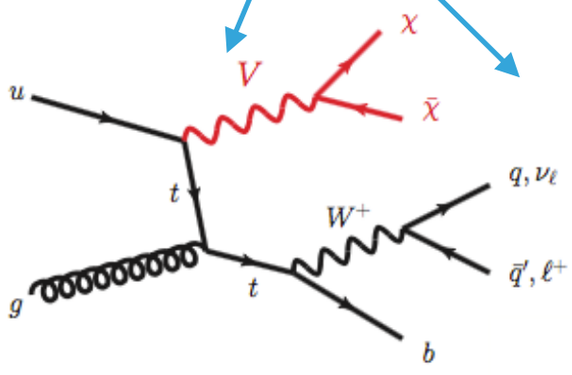
5. Resonant interactions:
   Charged scalar mediator decaying into top +DM

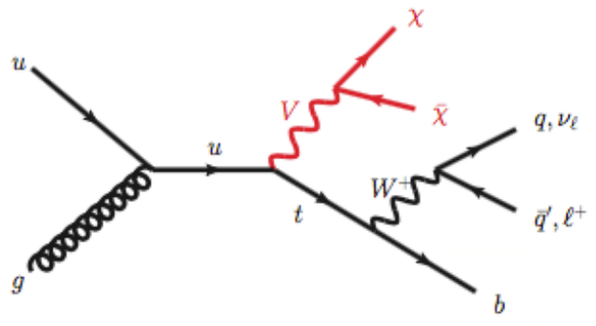






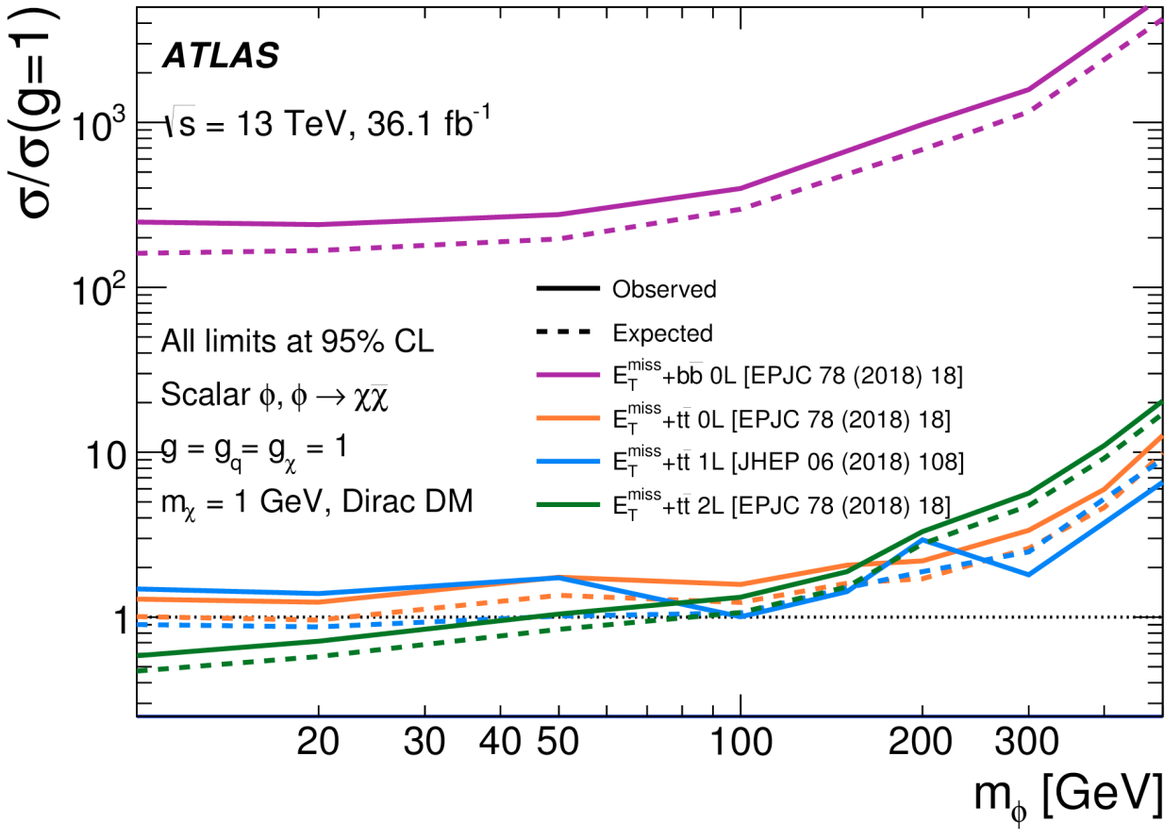






LIMITS: DM+TT/BB

- Colour neutral scalar



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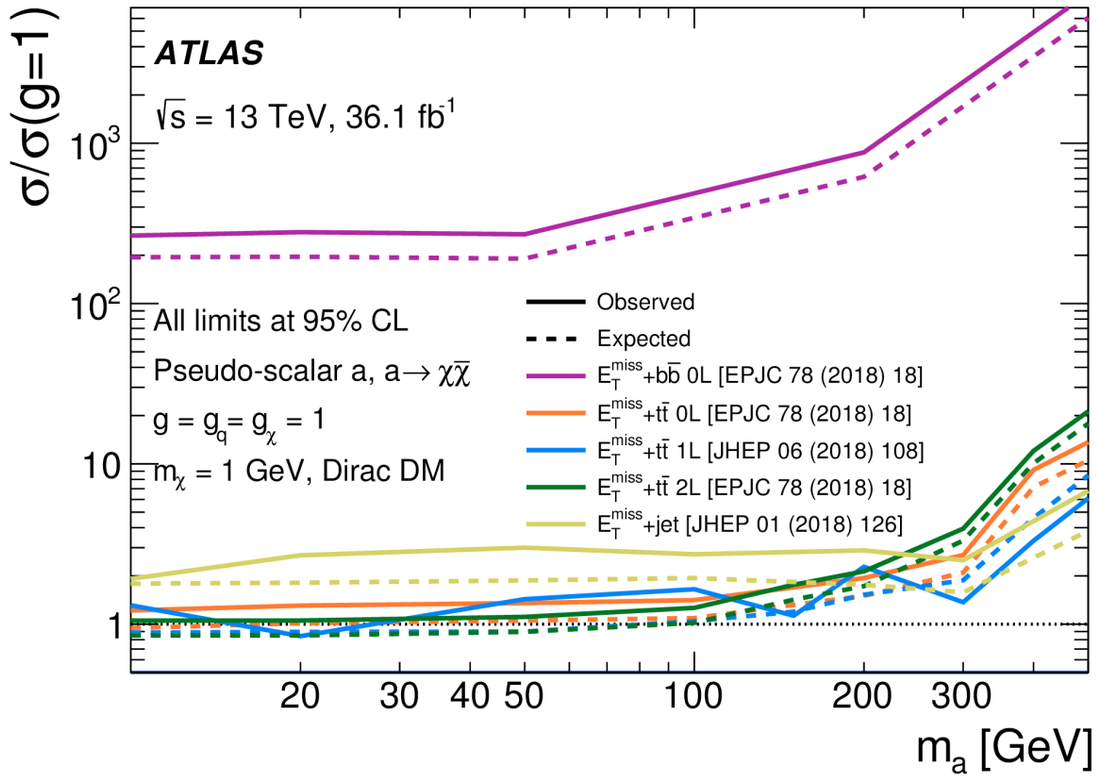
- Colour Neutral Pseudoscalar



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MONO TOP EXCLUSION LIMITS

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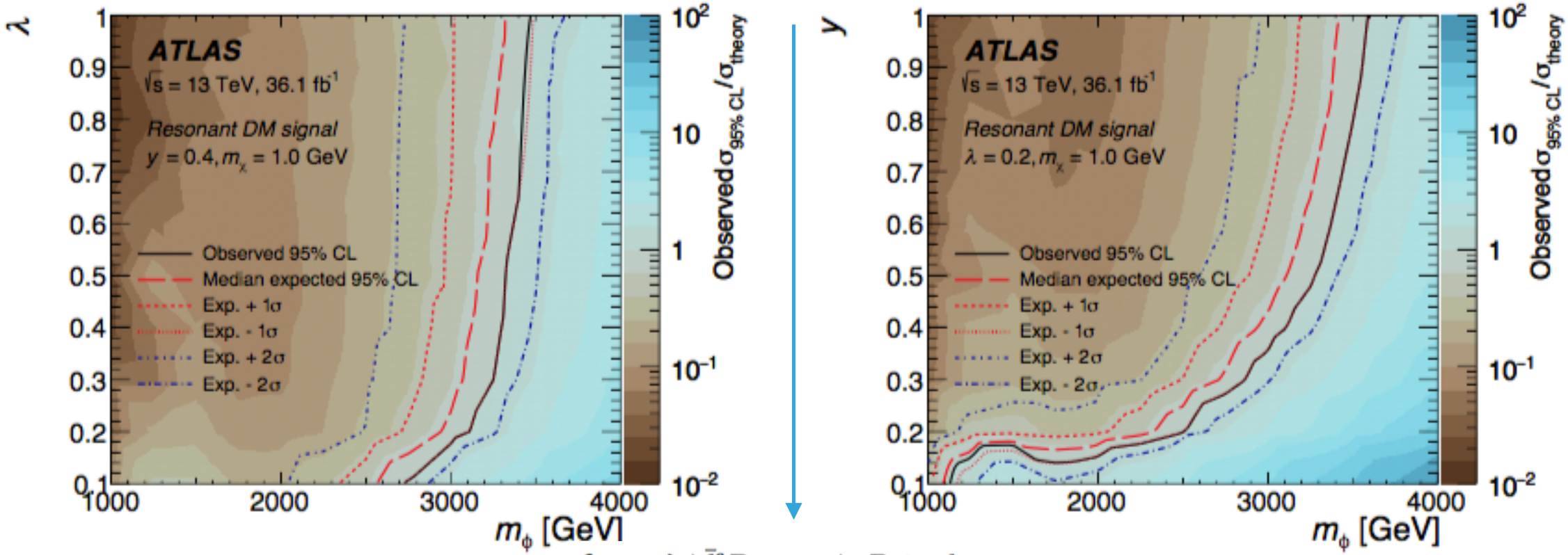
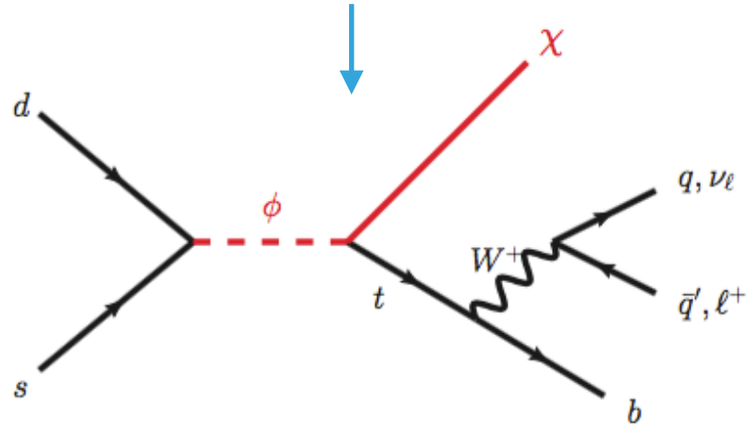
Resonant DM signals as a function of either the scalar DM mass, the coupling to d & s quarks (Lambda) or the coupling t to DM and top quark "y"



$$\mathcal{L}_{\text{int}} = \lambda\phi\bar{d}^c P_{\text{R}} s + y\phi\bar{\chi} P_{\text{R}} t + \text{h.c.}\,,$$



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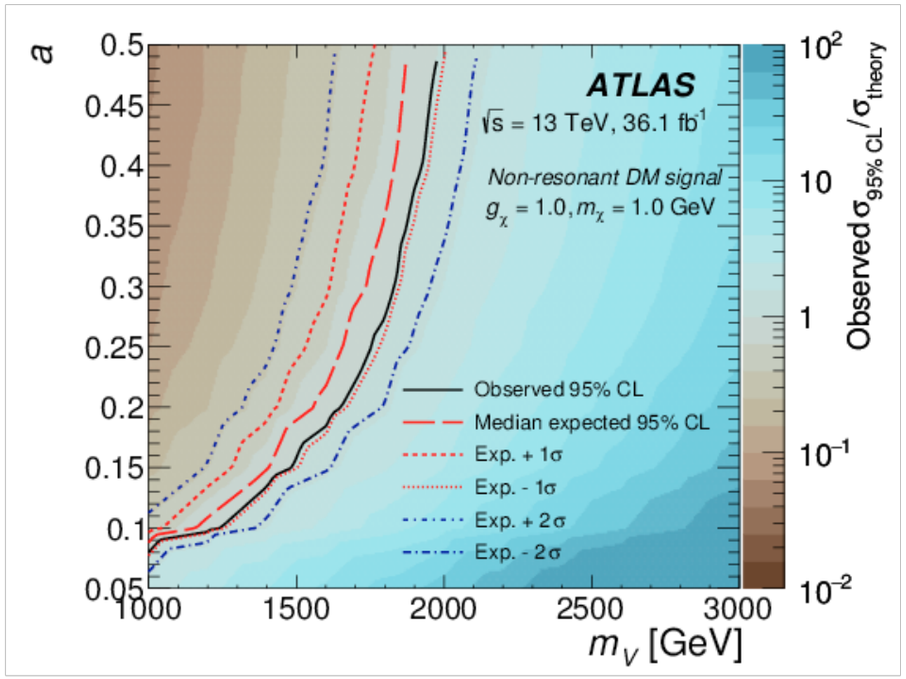
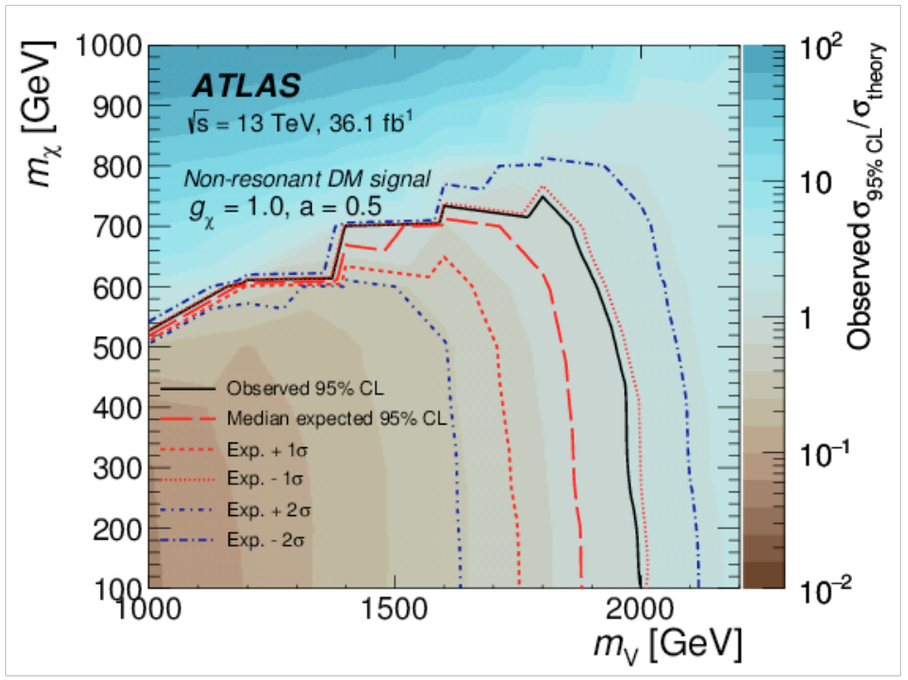
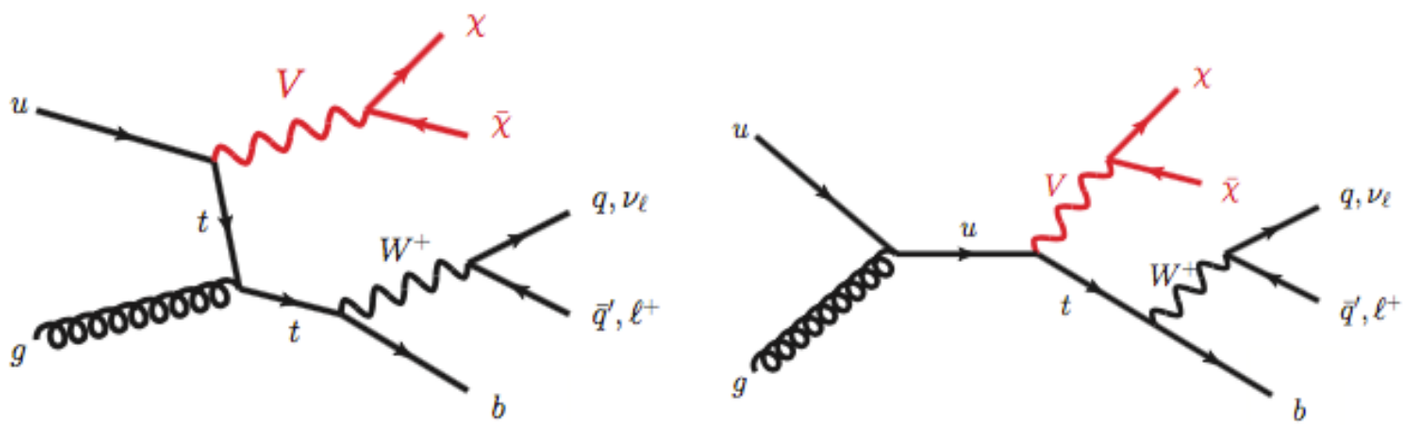
DM: MONO-TOP +DM

Non-Resonant DM signals as a function of either the Vector DM mass, the coupling to quarks "a", and the mass of the DM final state





$$\mathcal{L}_{\text{int}} = aV_\mu \bar{u}\gamma^\mu P_{\text{R}} t + g_\chi V_\mu \bar{\chi}\gamma^\mu \chi + \text{h.c.}\,,$$



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COMPLEMENTARY NON RESONANT DM+TOP

Complementary exclusion limits: Combining the same sign dilepton+ b search and the DM+Mono-Top

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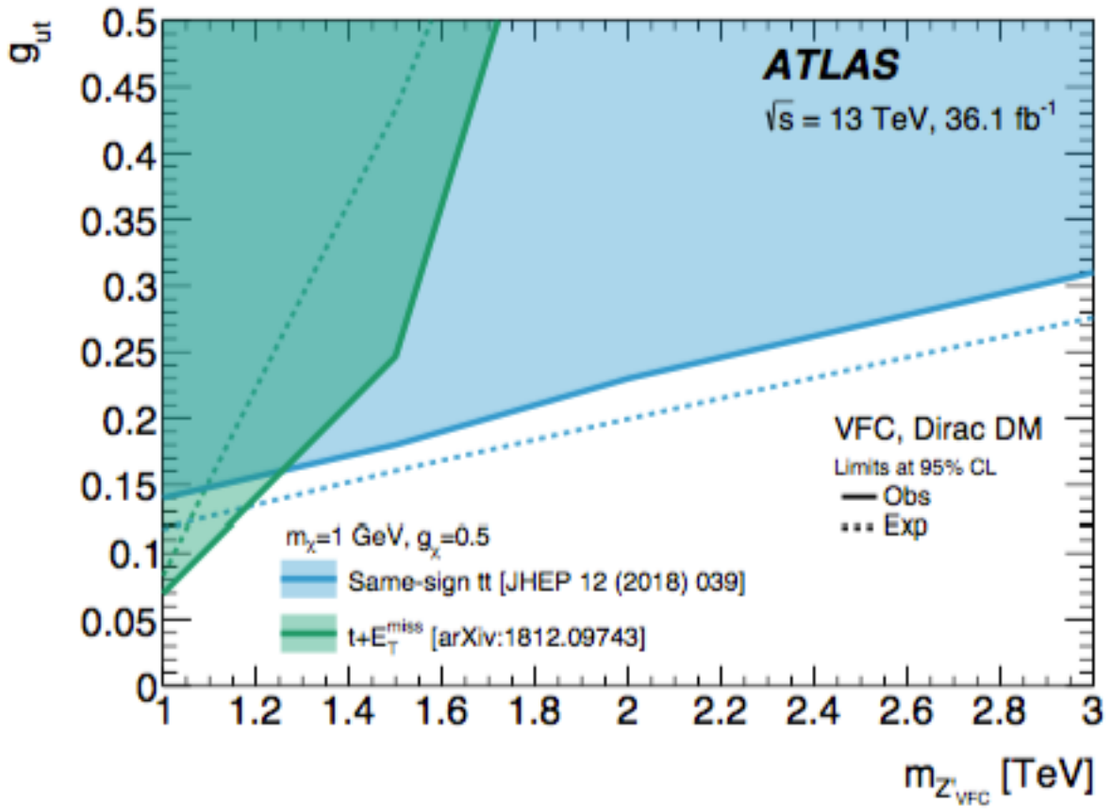
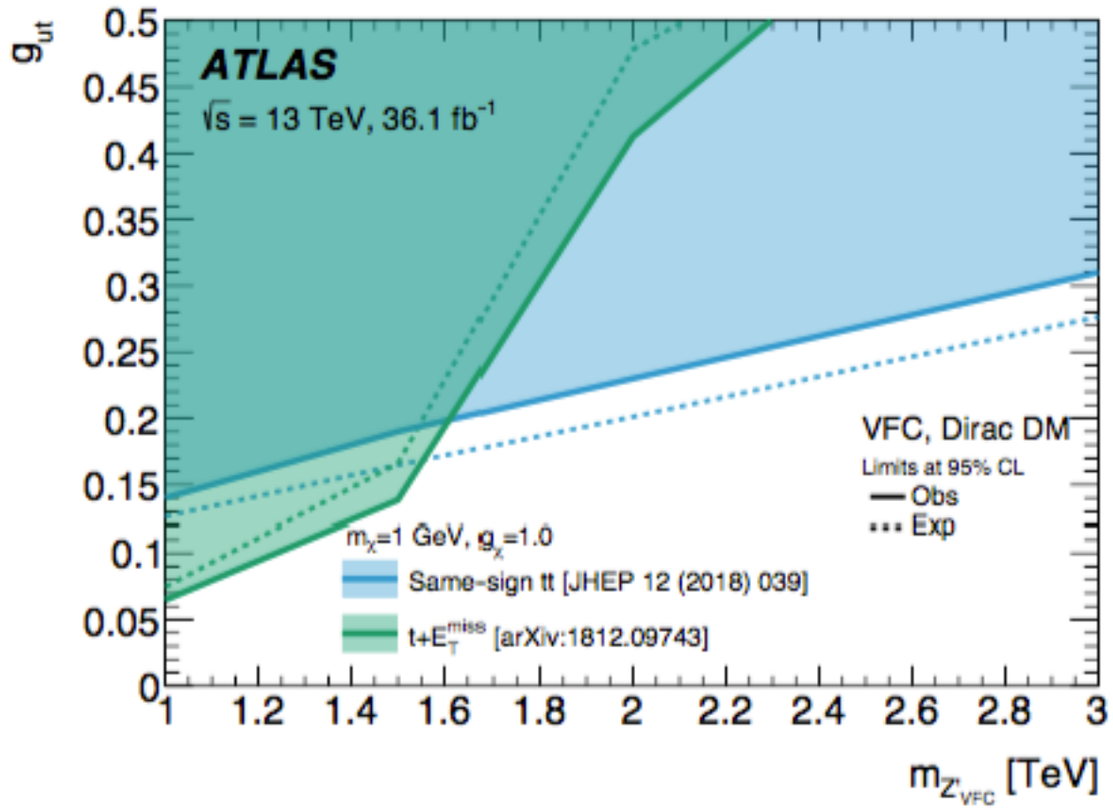
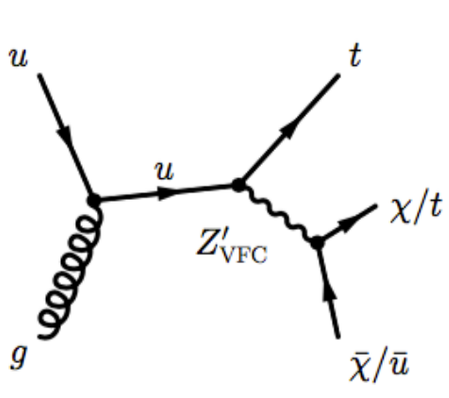
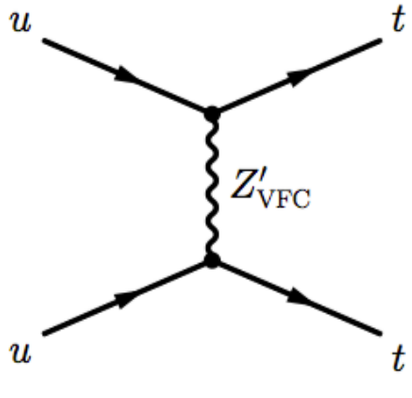
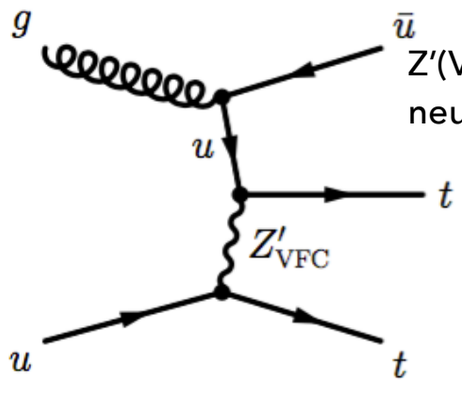










Z'(VFC) = Vector Flavour Changing neutral current (DM mediator)

ATLAS FIT STRATEGY

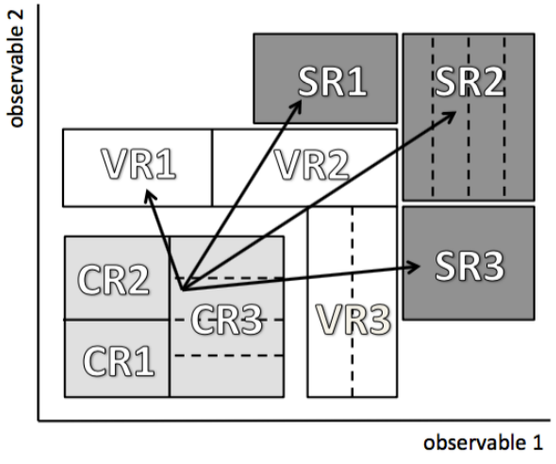
1. Identify key backgrounds present in signal region, after optimisation for signal topology

2. Define a region kinematically orthogonal to signal region that is enriched in the background of interest (Control region), and is not contaminated by signal, but is sufficiently similar in kinematic distribution to the signal region.

3. 3) Define validation regions close to signal region, but orthogonal to both signal and control regions with some enrichment in given background where possible.

4. Use profile likelihood fit on all control regions for all samples, retrieving the maximal likelihood estimator (MLE) of the normalisation, including systematics as nuisance parameters

5. Apply the MLE estimators of the background normalisations to signal/validation regions (when a background only hypothesis is considered: this is a “background-only” fit). Validation regions are used to check the validity of the MLE of the normalisation and



A nice schematic diagram from:
arXiv:1410.1280

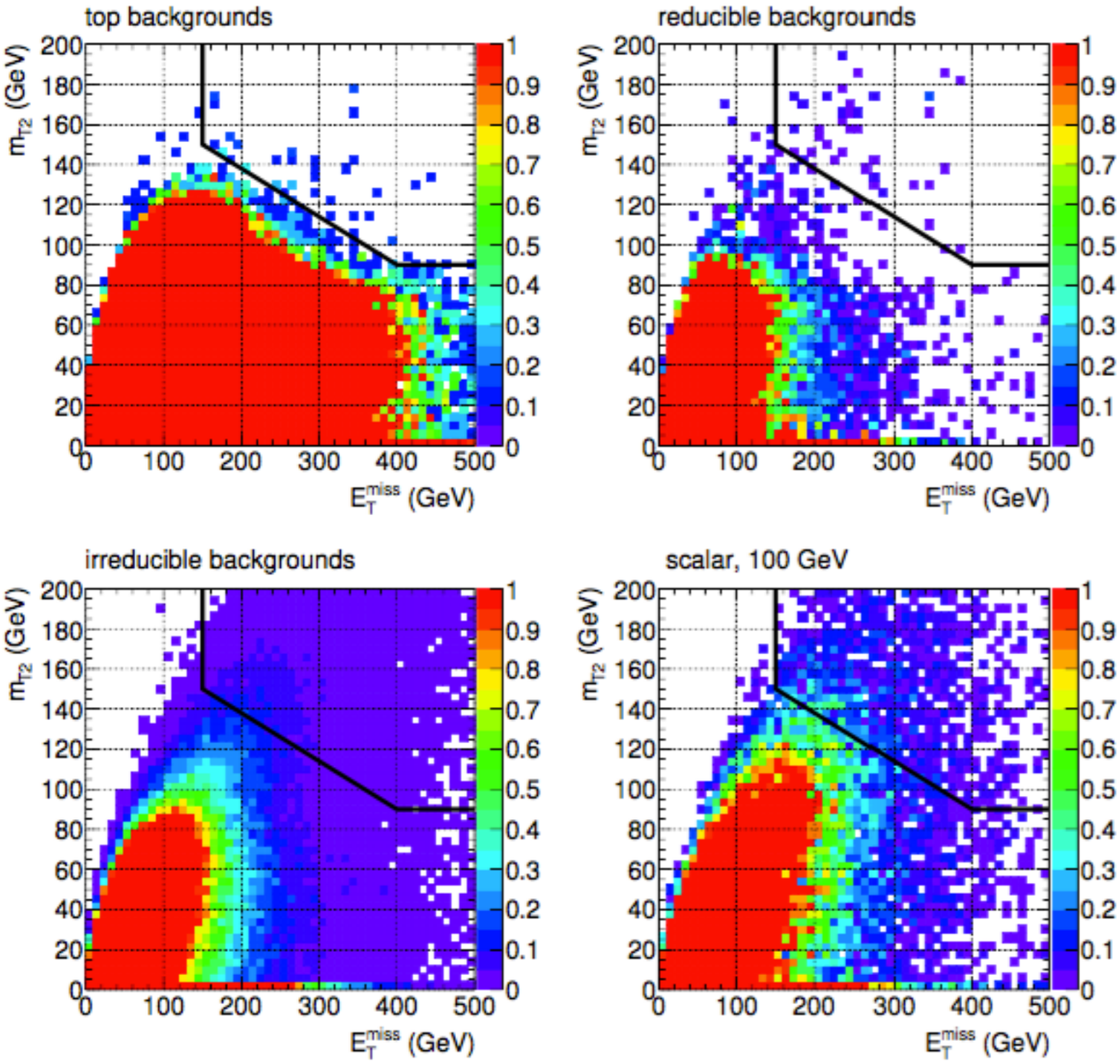
SUSY: TT 1L NEURAL NETWORK CONFIGURATION

Input variable	Description
$E_{\mathrm{T}}^{\mathrm{miss}}$	Missing transverse energy
$\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	Azimuthal angle of the $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$
m_{T}	Transverse mass
$\Delta\phi(\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	Azimuthal angle between $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ and lepton
m_{bl}	Invariant mass of leading b-tagged jet and lepton
$p_{\mathrm{T}}^{b_{jet}}$	Transverse momentum of the leading b-tagged jet
n_{jet}	Jet multiplicity
$n_{b-\mathrm{tag}}$	Number of b-tagged jets @ 77%
$p_{\mathrm{T}}(\ell)$	Transverse momentum of lepton
$\eta(\ell)$	Pseupdorapidity of lepton
$\phi(\ell)$	Azimuthal angle of lepton
$E(\ell)$	Energy of lepton

Also includes LSTM RNN output based on jet 4-vectors as an NN input.

Training: 200K signal, 300K background events, with 30% of the total held as a test set

BACKUP: WHY THE XI+ COMBINATION



JHEP02(2017)131. The area above the black line is that bounded by the signal region in both MT2 and MET for this analysis. The diagonal sector is the definition of the Xi+ variable.

BACKGROUND ESTIMATION

- DM+tt analysis:
  0L:
  Z+jets: Di-lepton
  ttZ: Uses ttGamma to model ttZ.
  ttbar: 1L

  2L:
  ttbar: dilepton, invert Xi+ cut.
  ttZ: trilepton CR, one of which OSSF.
  Data Driven fake estimate.

- DMbb
  b1: Zjets: 2L CRs
  b2: Zjets, 2L CR ttbar: 1L CR.

- Mono top:
  Hadronic channel:
  ttbar CR: 0L CR, orthogonal to CR via 0.2<dphimin(MET,R=0.4jets)<1.0
  V+jets: 0L CR, orthogonal based on selection of number of b-tagged track jets.
  Leptonic Channel:
  ttbar: 1L CR, 60<MT(W)<100, ==2jets, ==2 b-tags.
  W+jets: 1LCR, 60<MT(W)<100, ==1jet, ==1 b-tag.

- 3body stop decay: Single bin 1L ttbar CR based on the NN output.

- Key systematics in analyses presented today:
  DM+bb/tt:
  DMtt: ttbar modelling & theory uncertainties, MC stat uncertainties (SRt2 is the main contributor to the limit for both models due to ttbar modelling uncertainties in SRt1).
  DMbb: Z+jets Theory, normalisation & modelling, JES

Mono top +DM:
Hadronic SR: Multi-jet modelling
Leptonic SR: ttbar modelling & modelling of other backgrounds.

SUSY:
Stop1L (3body): ttbar hadronisation/fragmentation, JES/