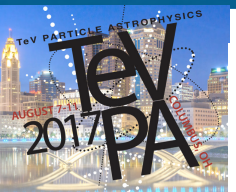
Searches for dark matter beyond mono-jets at the ATLAS experiment

Rui Wang
Argonne National Laboratory
On behalf of the ATLAS Collaboration

TeVPA 2017, August 11th, 2017



ATLAS EXPERIMENT

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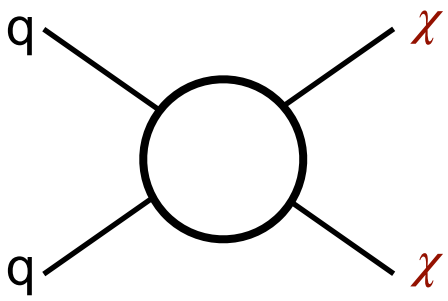
DM models used at ATLAS

1507.00966

details in Wendy Taylor's talk

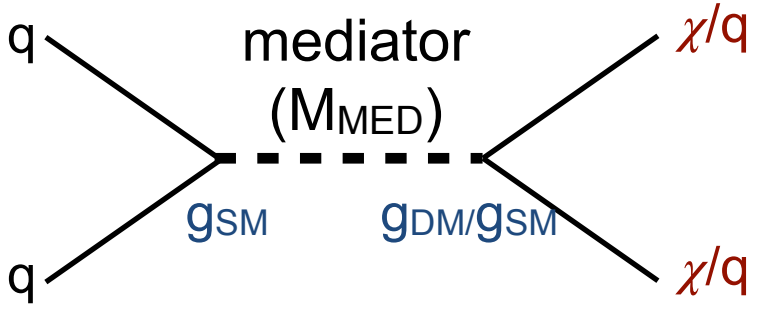
Effective field Theory

- m_{DM}, M*, underlying coupling type, DM types
- Valid when mediator of the interaction between SM and DM particles are very heavy



Simplified model

- Standardized for ATLAS&CMS Run2
- Relatively light mediator (TeV-scale)
- Mediator has minimal decay width
- Minimal flavor violation
- Minimal set of parameters
  - Coupling structure, M_{MED}, m_{DM}, g_{SM} (g_q), g_{DM}



LHC DM forum and working group

— Antonio Boveia's talk

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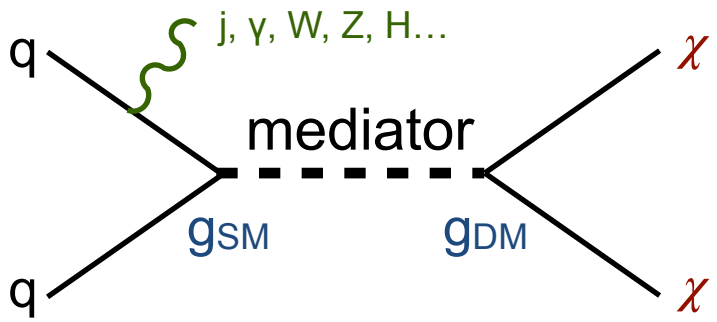
DM search in Mono-X

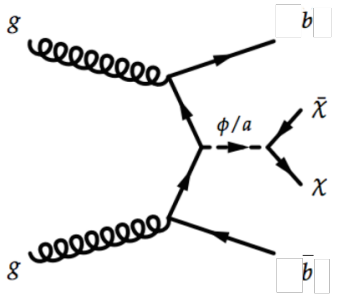
- Directly produced Dark Matter (g_q & g_{DM})
  - Pair production of DMs
  - Mono-X signature
    - MET + bb, tt, Z(ll) covered by this talk
      - Using control regions to constrained background from known processes
      - Further suppress the backgrounds



MET + γ, W/Z(had), Higgs in Wendy Taylor's talk

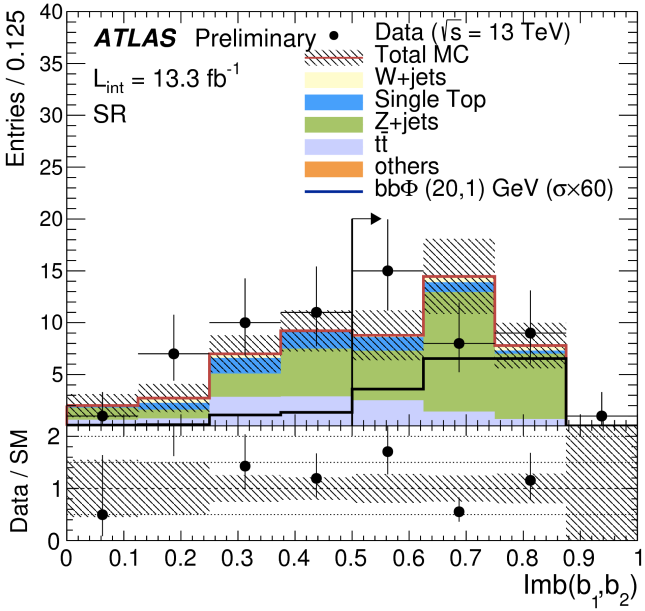
MET+bb

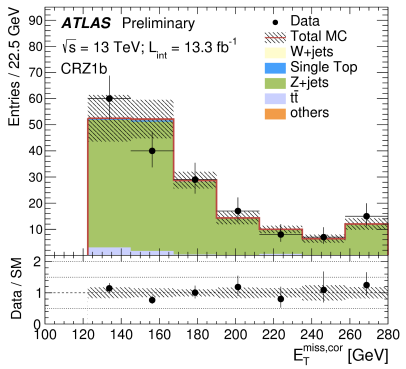
ATLAS-CONF-2016-086

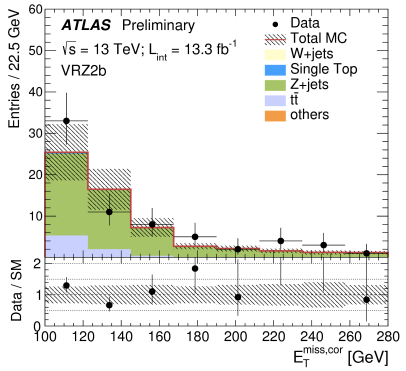


- Motivation to a search in association with Heavy Flavour quarks
- Mediator is a (pseudo-) scalar, DM is a dirac fermion
  - Assumes Yukawa-like couplings between mediator and SM fermions
- Events with E_{miss}^{T}> 150 GeV, two b-tagged jets

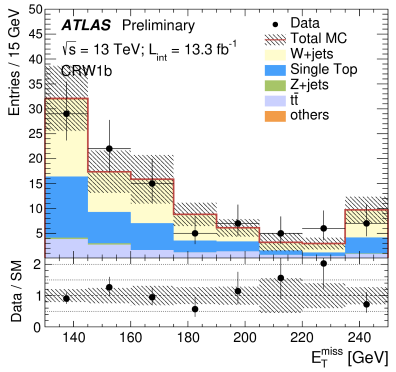
$N_{obs.}$ in the CRs are used in combined profile likelihood fit to determine the expected SM background yields in the SR







Orthogonal to the SR



Likelihood function is build to describe $N_{obs.}$ and $N_{exp.}$ in each CR

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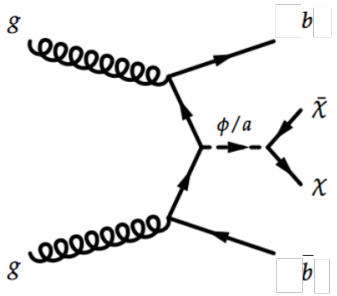
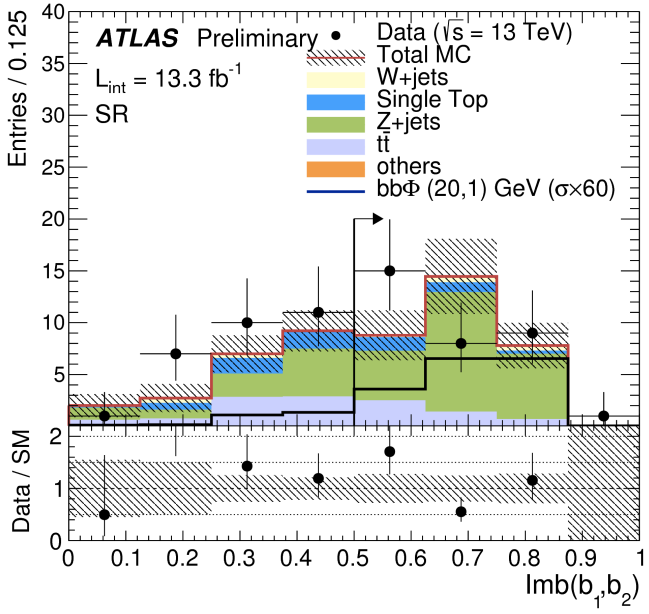
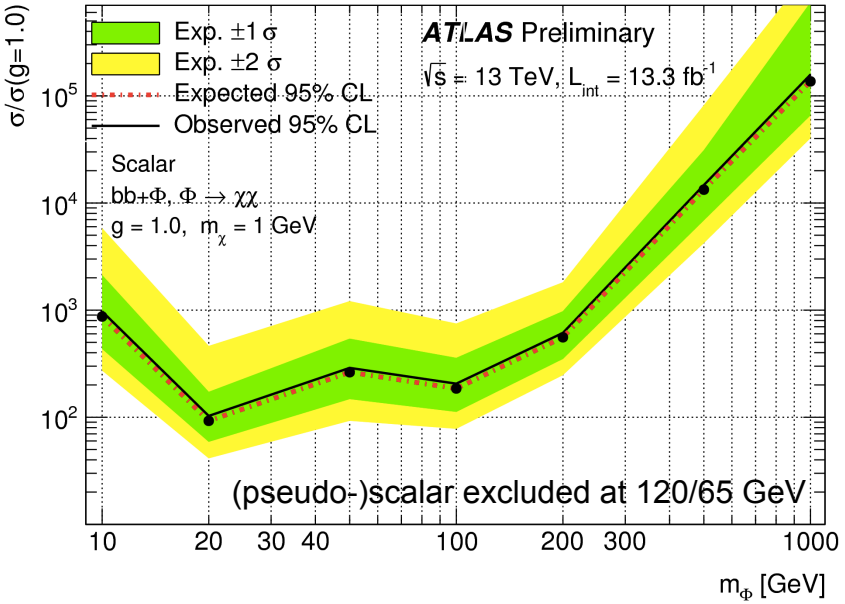
MET+bb

ATLAS-CONF-2016-086



- Motivation to a search in association with Heavy Flavour quarks
- Mediator is a (pseudo-) scalar, DM is a dirac fermion
  - Assumes Yukawa-like couplings between mediator and SM fermions
- Events with E_{miss}^{T}> 150 GeV, two b-tagged jets
- Background dominated by Z->vv
  - large dR between jets (>2.8)
  - lmb(b1, b2) =(pT(b1) − pT(b2)) / (pT(b1) + pT(b2))> 0.5





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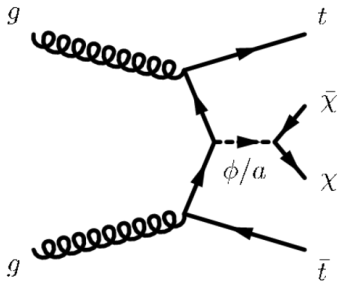
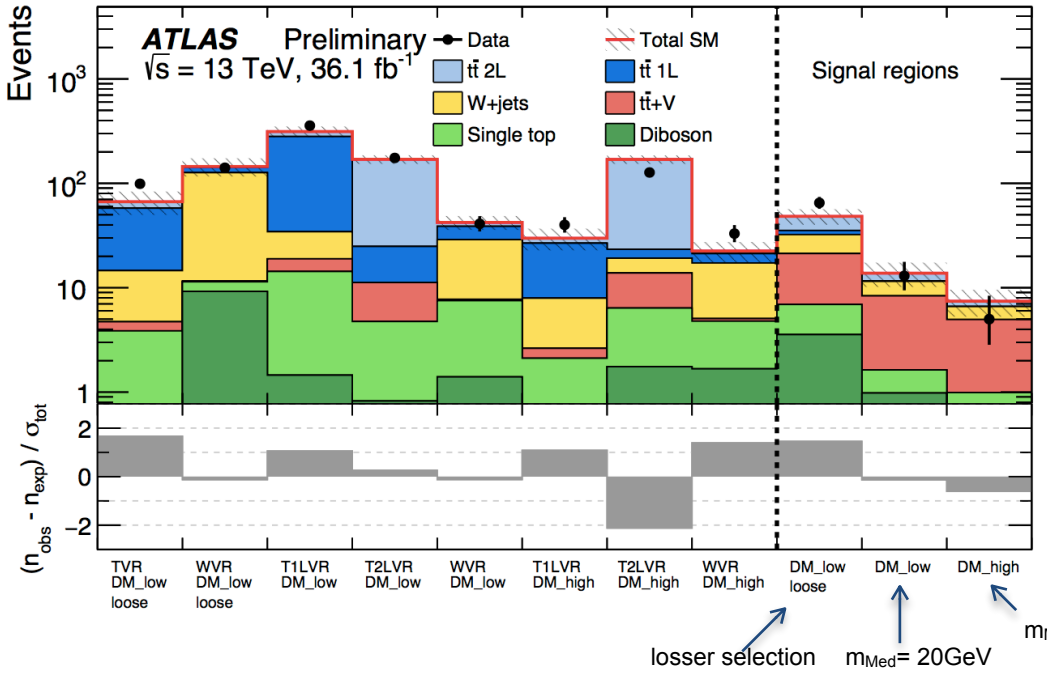
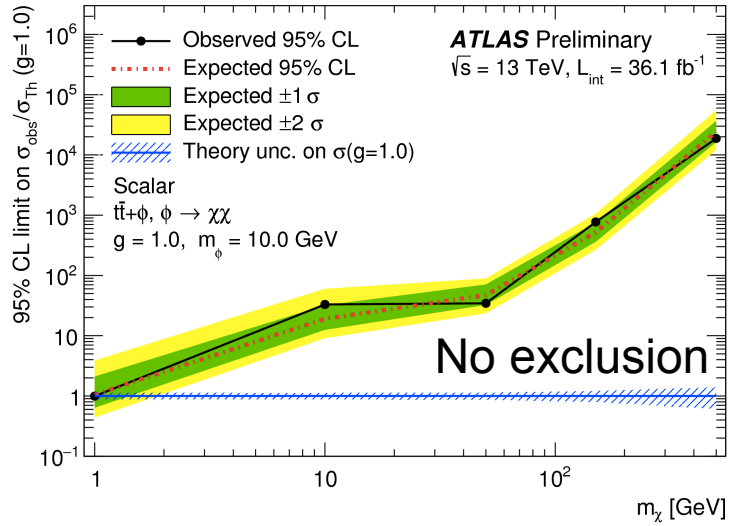
MET+tt

ATLAS-CONF-2017-037

- Motivation to a search in association with Heavy Flavour quarks
- Similar DM model as MET+bb
- Events with MET+tt(had, 1L, 2L)
  - Same final state as for SUSY 1-lepton EW searches







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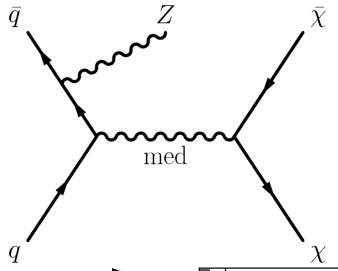
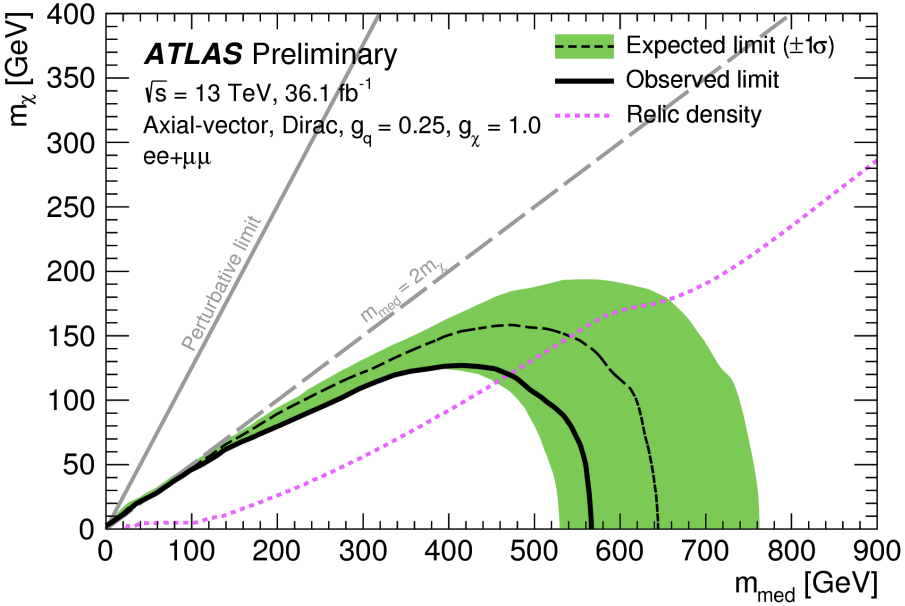
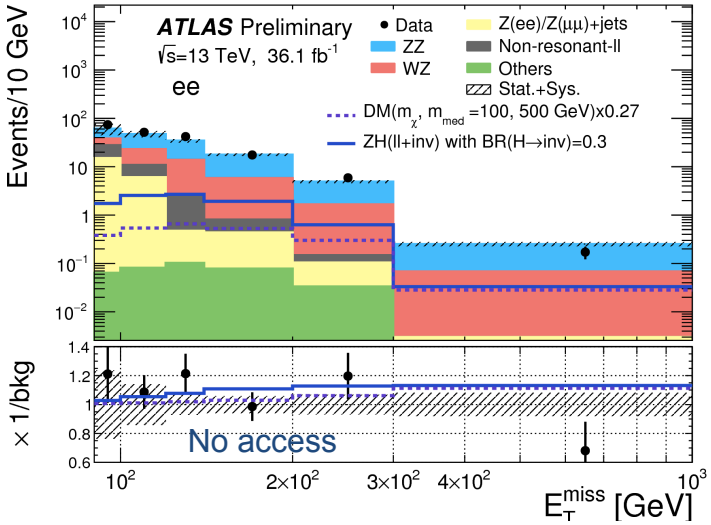
MET+Z(ll)

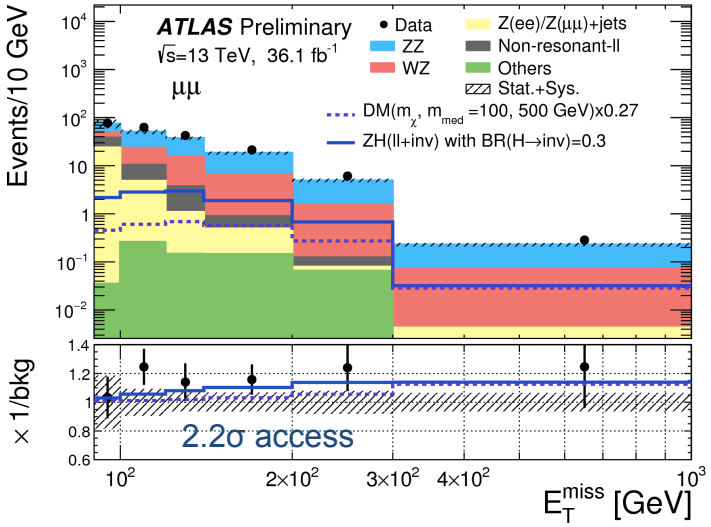


ATLAS-CONF-2017-040

- Axial-vector mediator , DM is a dirac fermion
- Events with a boosted Z (ee/μμ pair) back-to-back with MET
  - MET > 90 GeV, MET/H_T>0.6
  - ΔΦ(Z, MET) > 2.7, ΔR(ll) < 1.8, b-veto
- Background dominated by ZZ and WZ







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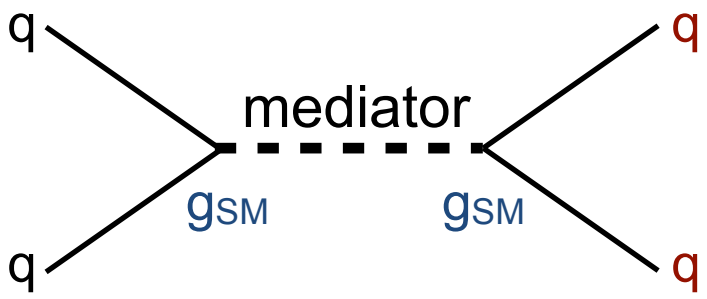
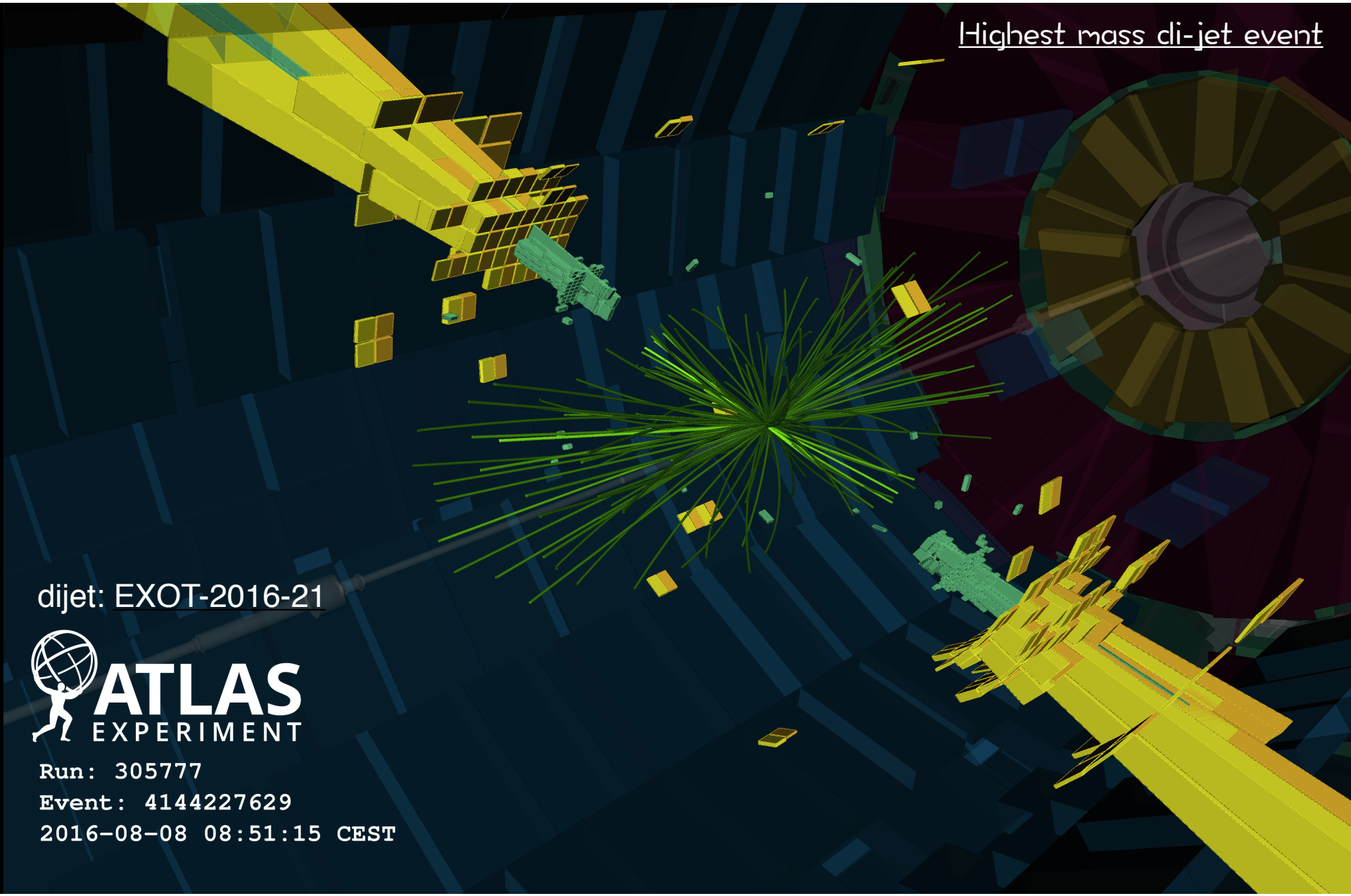
DM search in Di-X

- Search for mediator (g_q & g_q)
  - Pair production of SM final state
  - di-jet, di-b-jet, tt, di-lepton covered by this talk



  - Probing TeV resonances generically
  - Mediator mass search usually limited by the trigger threshold
    - Special treatment needed to go to lower mass



Ref: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2016-21/figaux_11.png

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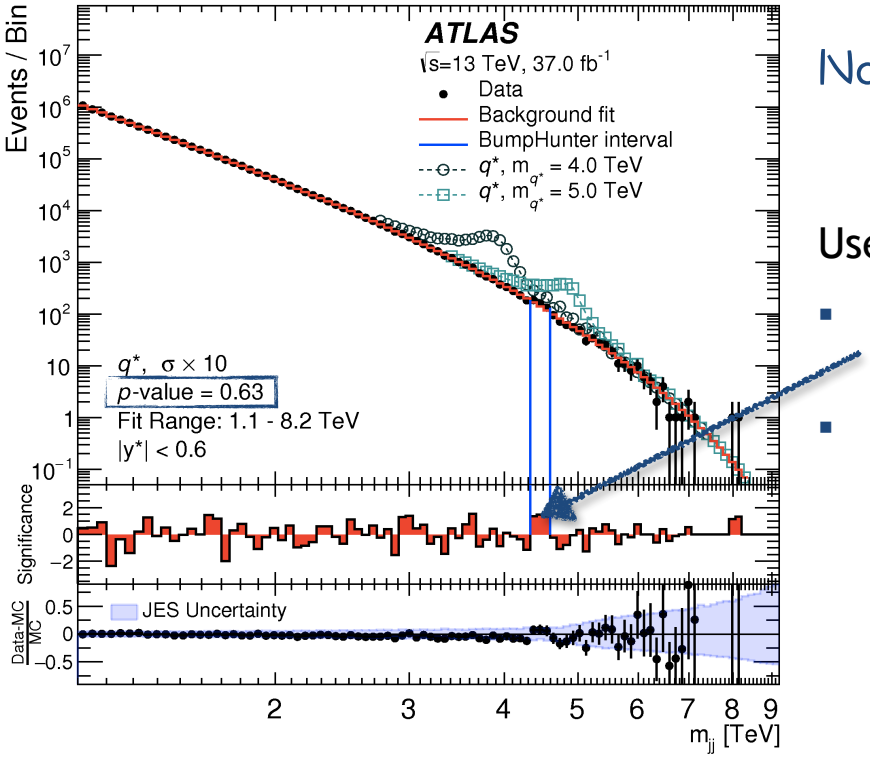
Di-jet

EXOT-2016-21

- Narrow resonance search above 1.1 TeV
  - Signal jet trigger
  - $p_{T,1}$ ($p_{T,2}$) > 440 (60) GeV
  - |y*|<0.6, y*= (y1-y2)/2



Narrow peak on top of the smooth falling QCD background

Use ***Bumphunter*** to search for possible excess

- Looking for the most significant deviation from the background spectrum
- Bump hunter p-value reflects the bins that have the smallest probability of arising from a background fluctuation (assuming poisson statistics)

Di-jet

EXOT-2016-21

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  - Signal jet trigger
  - $p_{T,1}$ ($p_{T,2}$) > 440 (60) GeV
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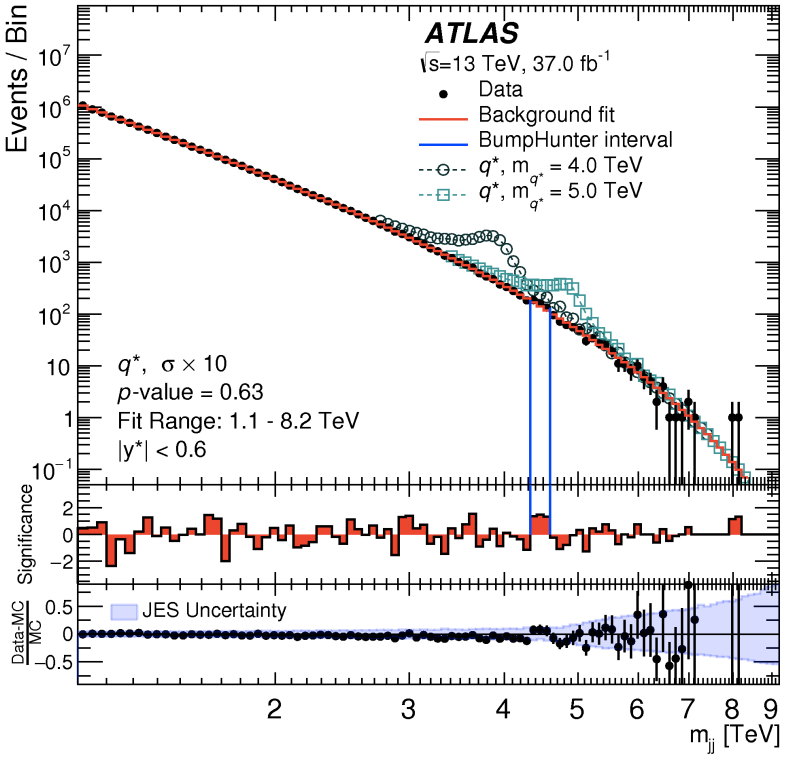
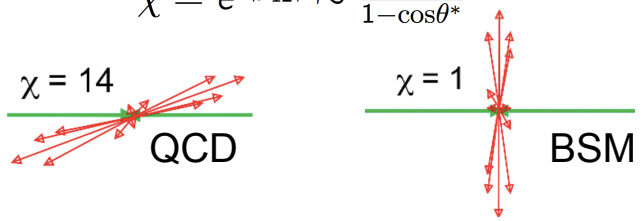
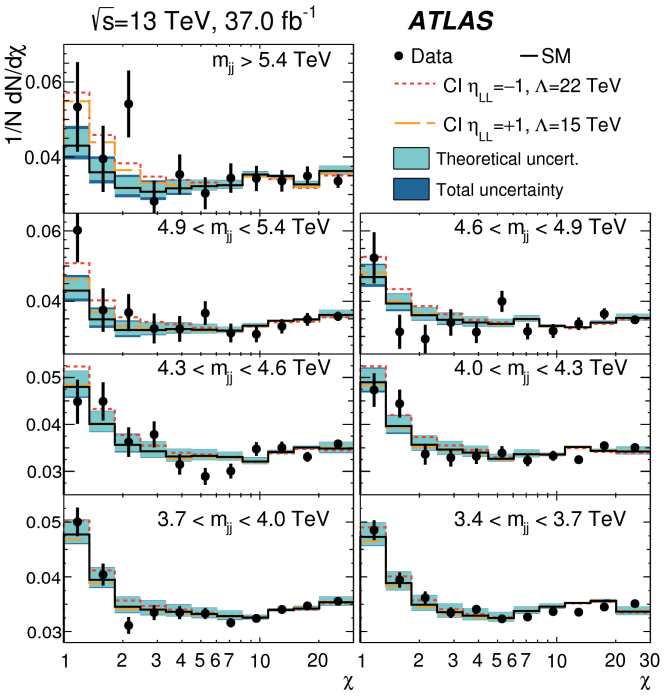


- Angular search — sensitive to wide mediators or non-resonant signature

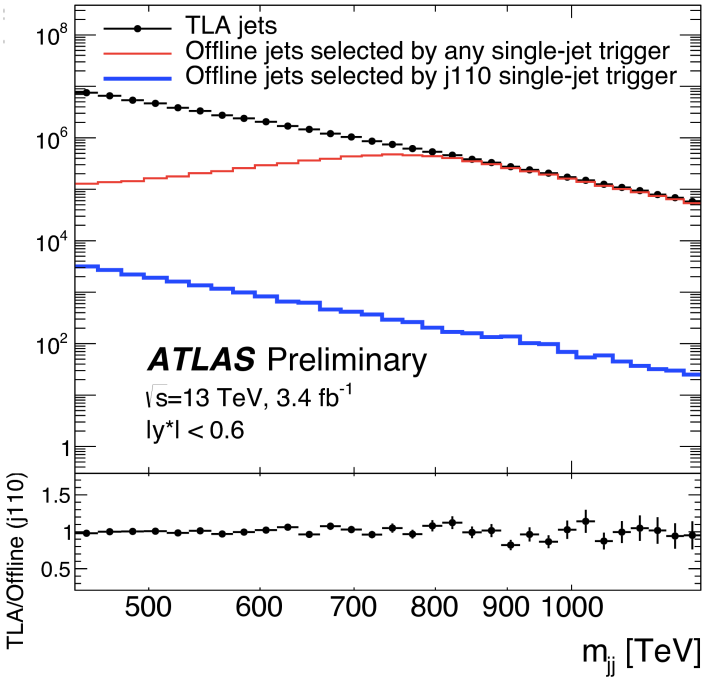
$$\chi = e^{2|y^*_{12}|} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

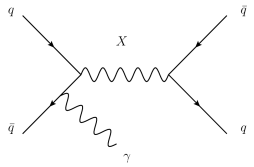


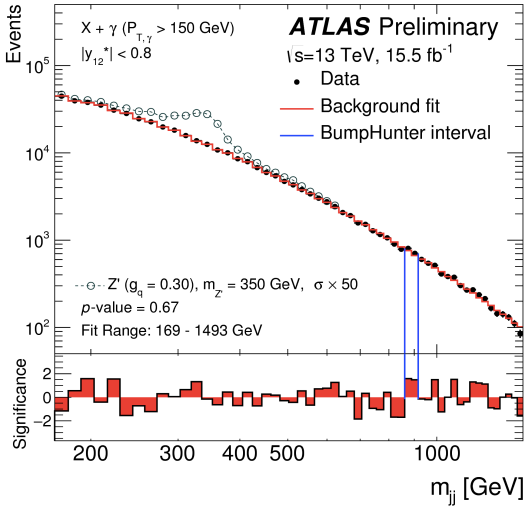


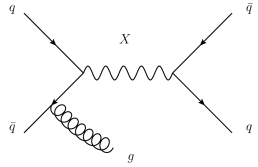
TLA + di-jet ISR — Expand to lower m_{jj}

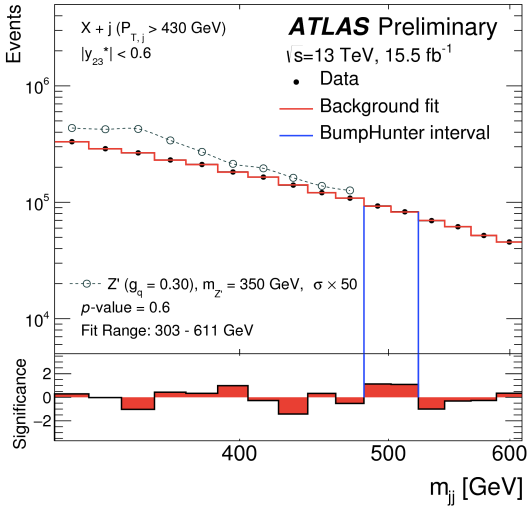
- TLA (trigger level analysis) — use Data Scouting stream
  - Stores partial event informations (~ 5% of full event)
  - dedicated jet calibration for trigger level (TL) jets
- Trigger selection on ISR objects
  - Jets p_T > 25 GeV, $|\eta|$ < 2.8
  - γ+JJ : γ p_T > 150 GeV, $|y^*_{12}|$ < 0.8, $\Delta R_{\gamma,closest}$ > 0.85
  - J+JJ : $p_{T,1}$ > 430 GeV, $|y^*_{23}|$ < 0.6











ATLAS-CONF-2016-030

ATLAS-CONF-2016-070

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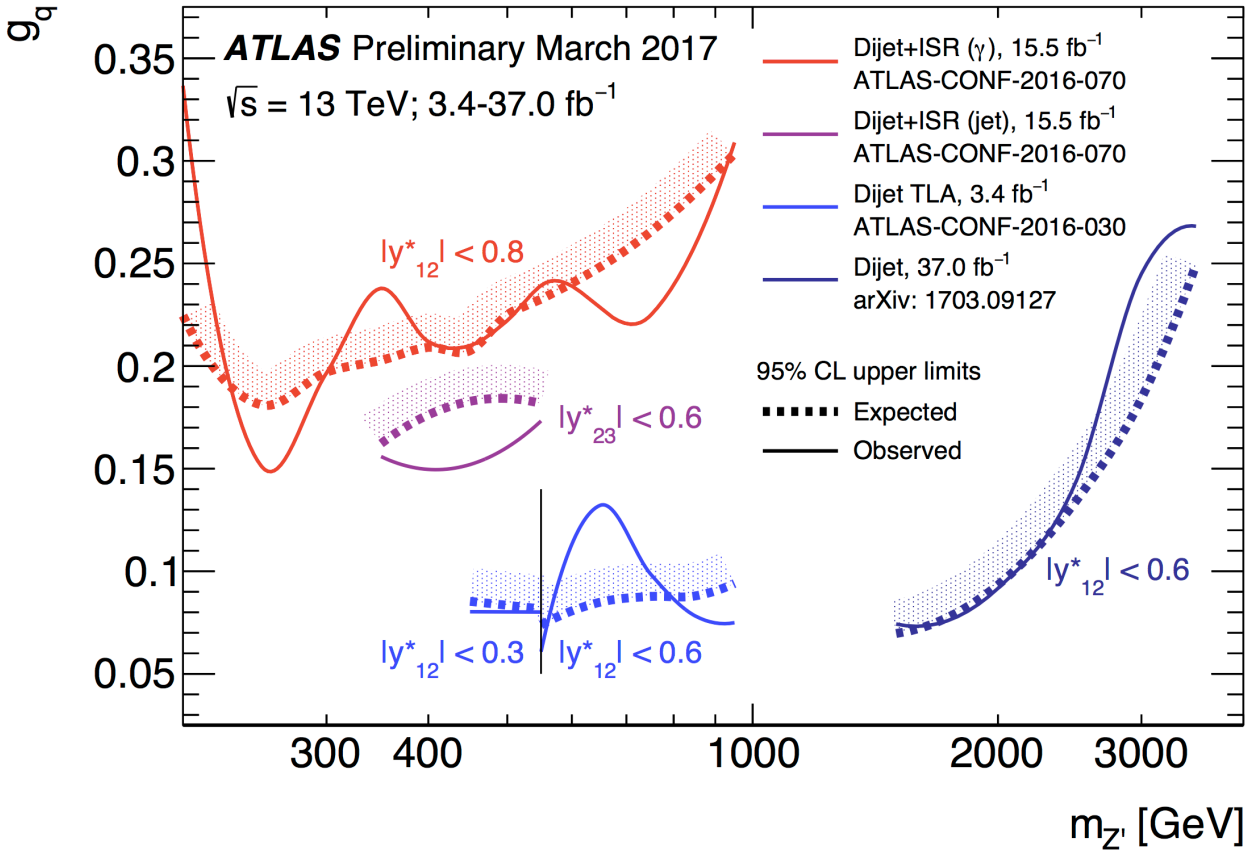
Di-jet limits

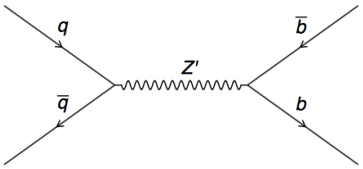
- ATLAS bounds in the coupling-mediator mass plane of leptophobic Z' DM mediator from di-jet searches using 2015 and 2016 data



Ref: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/ATLAS_DarkMatterCoupling_Summary/ATLAS_DarkMatterCoupling_Summary.png

Di-b-jet — couple preferentially to b-quark

- Narrow resonance search with b-tagged jets
- Low mass - 570<m_{jj}<1200 GeV
  - $p_{T,1}$ ($p_{T,2}$) > 250 (60) GeV
  - |y*|<0.6, y*= (y1-y2)/2
  - b-tagged trigger + offline 2 b-tag
- High mass — m_{jj}>1380 GeV
  - $p_{T,1}$ ($p_{T,2}$) > 430 (60) GeV
  - |y*|<0.6, y*= (y1-y2)/2
  - Offline 2 b-tag



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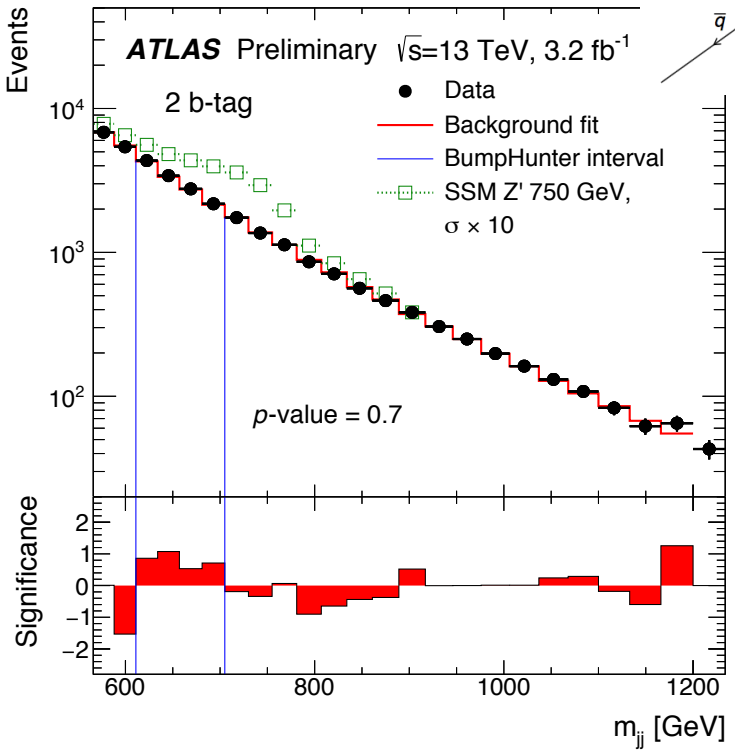

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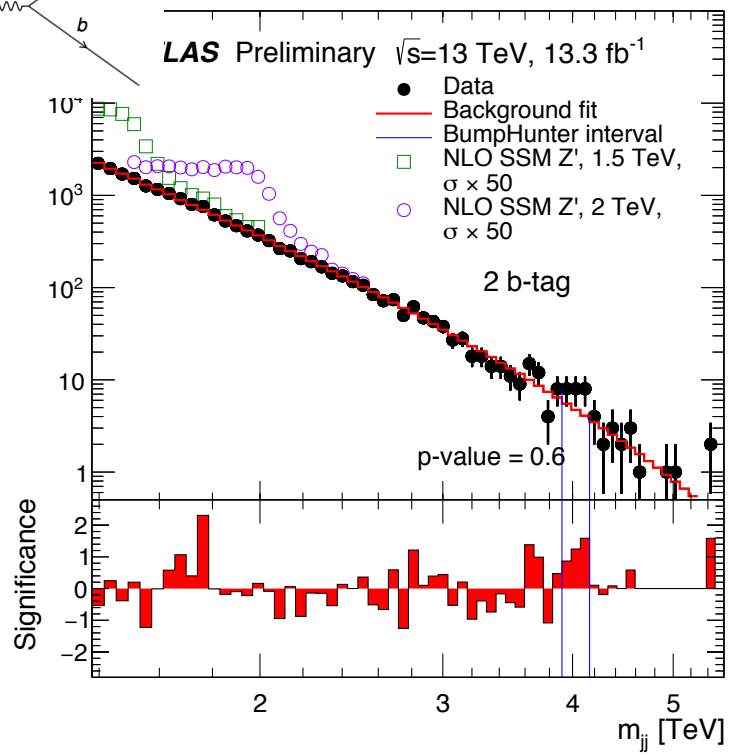
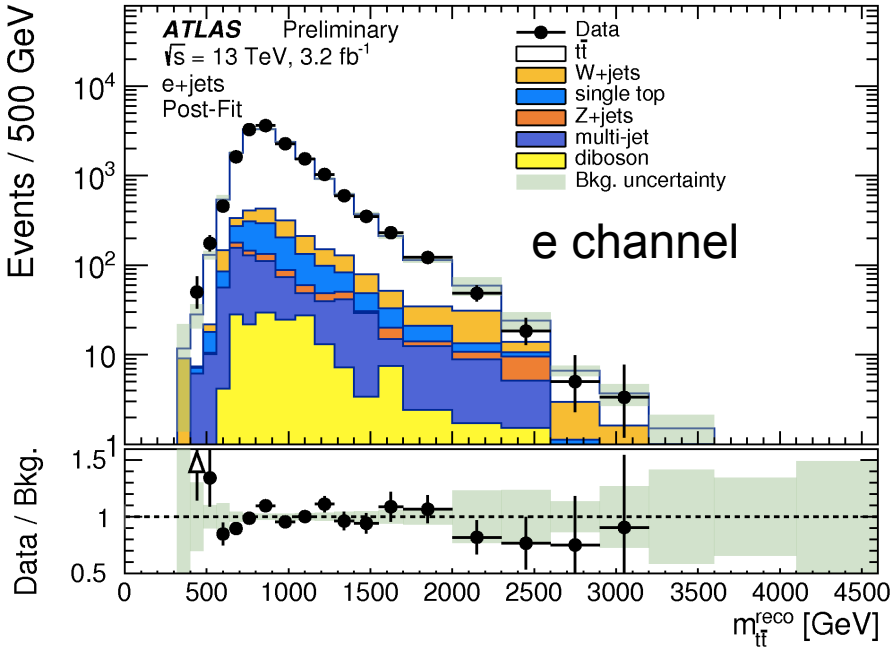
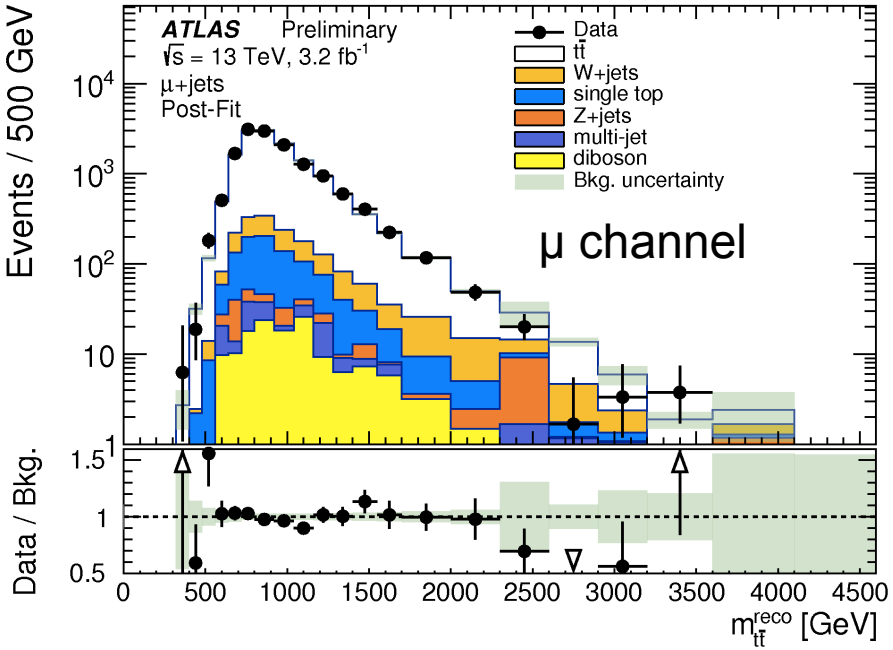


ttbar resonance search

ATLAS-CONF-2016-014

- DM couple preferentially to t-quark
- Events with exactly 1 electron or muon,
  - MET > 20 GeV, MET + MWT> 60 GeV ($MWT = \sqrt{p_T^{lep}.MET.2(1 - cos\Delta\Phi(MET, lepton))}$)
  - top-tagged large-R jets
  - 1 b-tagged track jet

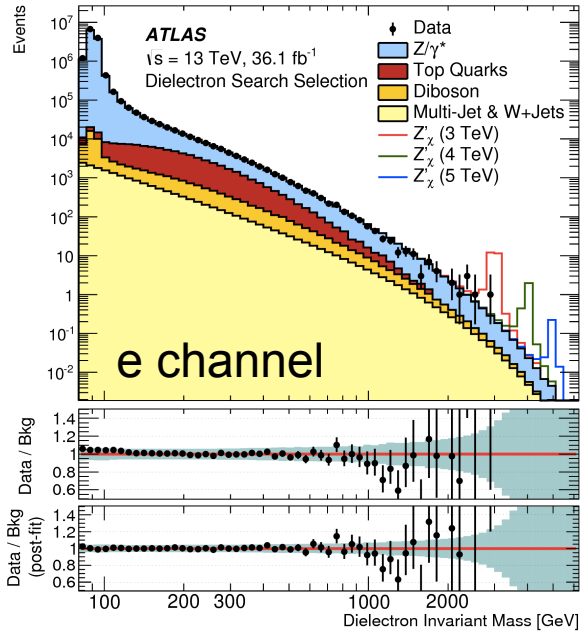


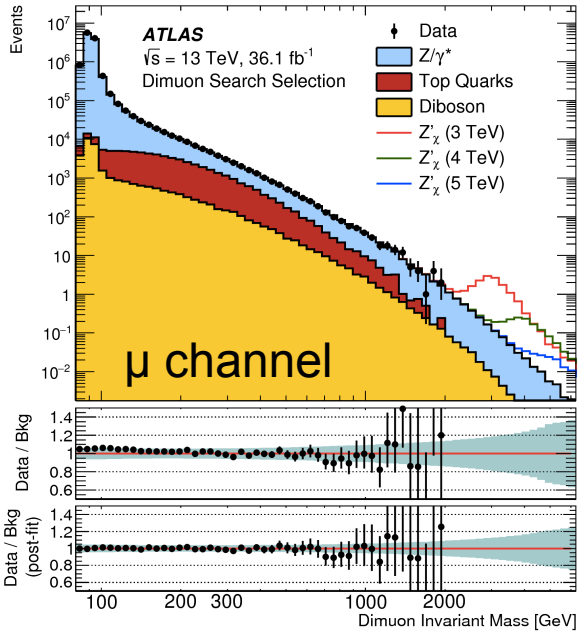


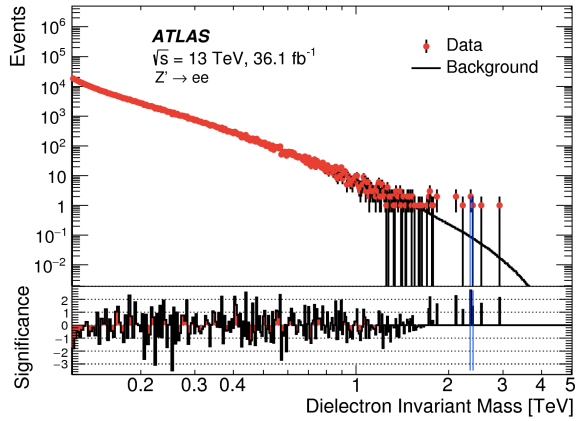
Di-lepton resonance search

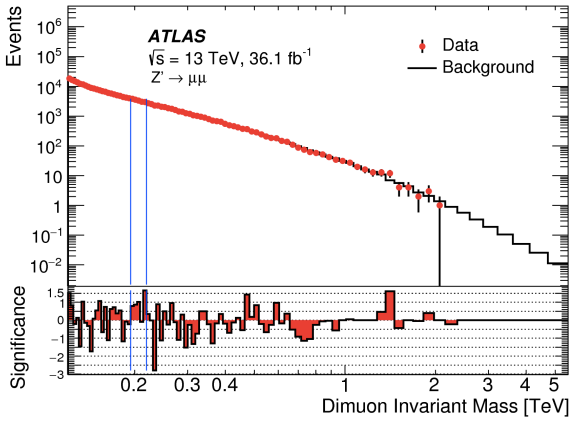
EXOT-2016-05

- Events with one pair of isolated e/μ with pT>30 GeV









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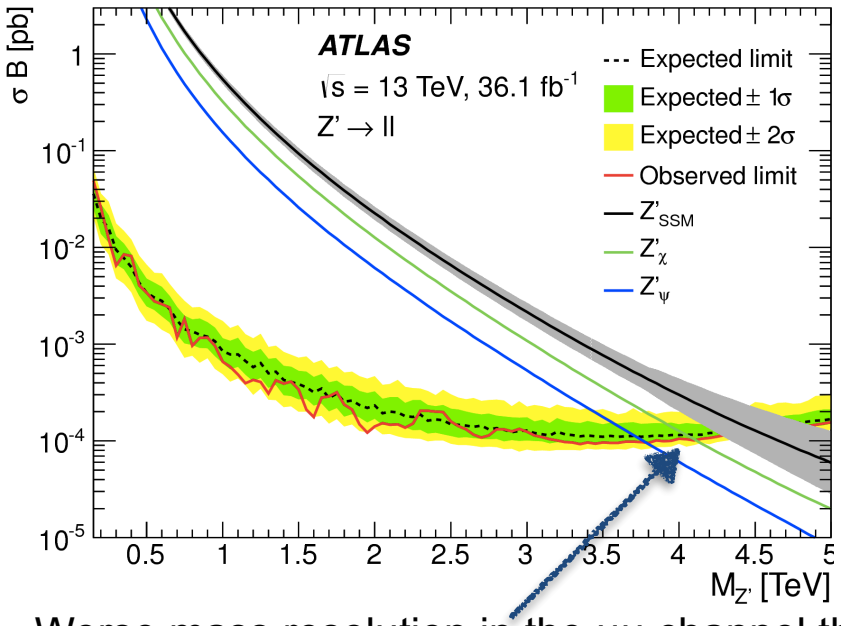
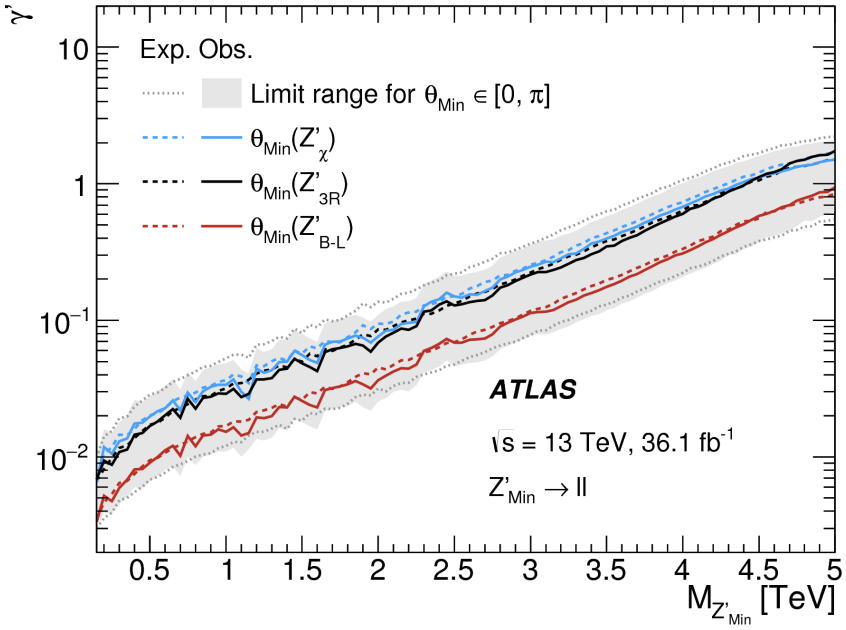
Di-lepton resonance search

EXOT-2016-05

- Events with one pair of isolated e/μ with pT>30 GeV

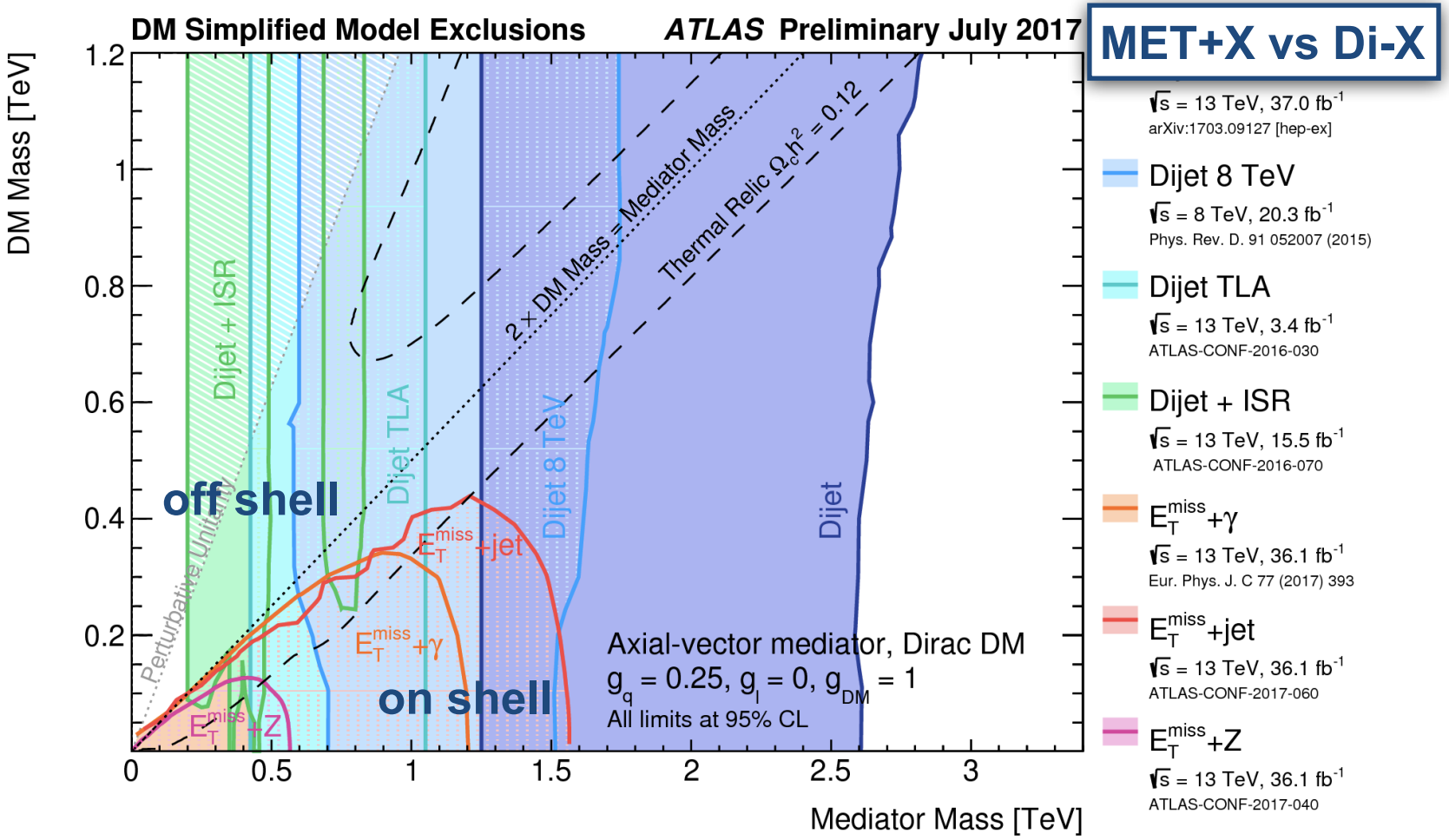




- Worse mass resolution in the μμ channel than in the ee channel.
  - Rapidly falling signal cross-section
  - Increase of the off-shell production in the low-mass tail, and the natural width of the resonance
- Selection efficiency slowly decrease at very high pole masses (subdominant)

limits on the ratio of coupling strengths between the Z' boson and the Z boson, as a function of the Z' mass in the context of minimal Z' models

Summary



- Extensive DM search program ongoing at ATLAS
- ATLAS is a telescope for new physics in multiple final states

Ref: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/ATLAS_DarkMatter_Summary/ATLAS_DarkMatter_Summary.png

Backup

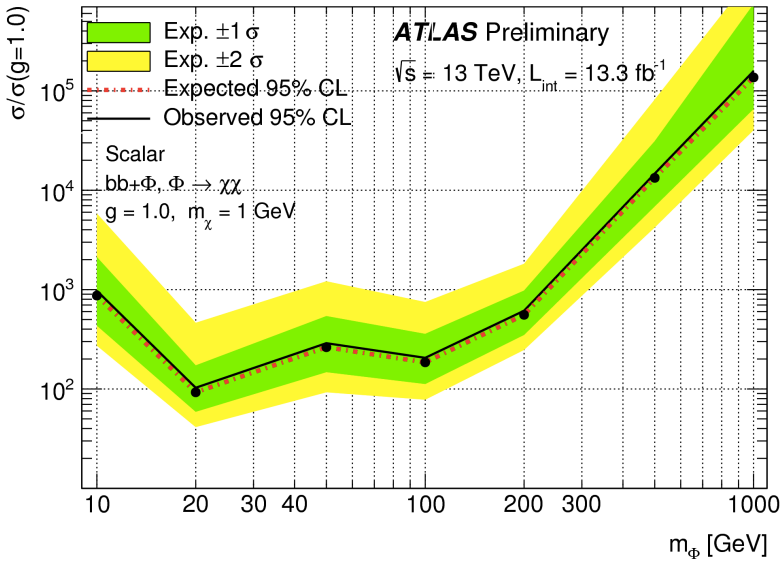
MET+bb selection criterial

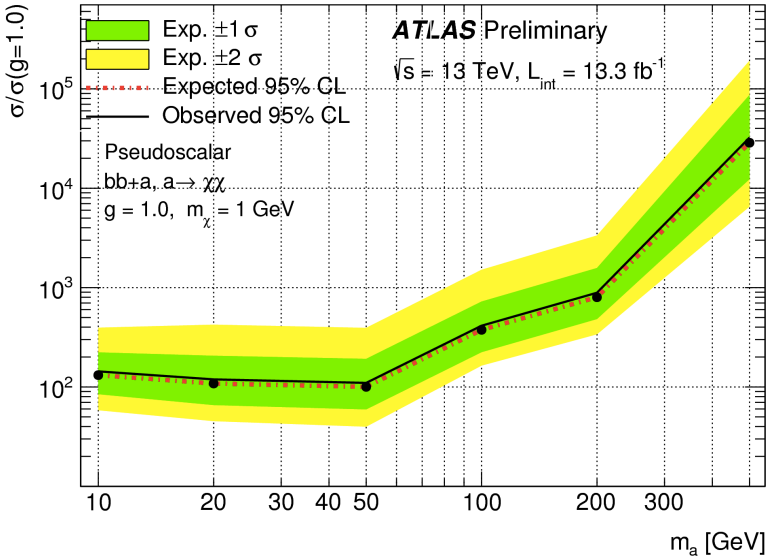
ATLAS-CONF-2016-086

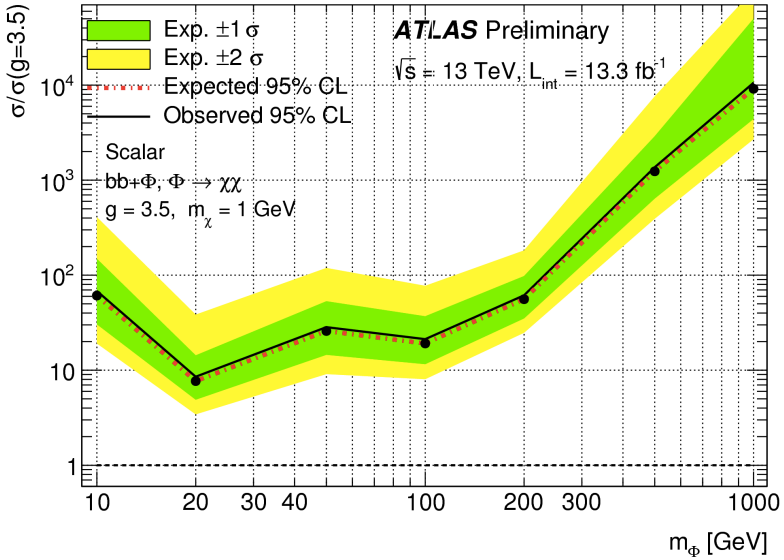
Quantity	SR	CRZ1b	VRZ2b	CRW1b	VRW1b	CRW2b	VRLR
$\mathcal{N}_{lepton}$ (baseline)	0	2 (SFOS)	2 (SFOS)	1	1	1	0
$\mathcal{N}_{lepton}$ (high-purity)	0	2 (SFOS)	2 (SFOS)	1	1	1	0
$\Delta\phi^{j}_{\mathrm{min}}$	> 0.4	> 0.4	> 0.4	> 0.4	> 0.4	> 0.4	> 0.4
$\mathcal{N}_{jets}$	$2-3$	$2-3$	$2-3$	$2-3$	$2-3$	$2-3$	$2-3$
$\mathcal{N}_{bjets}$	$= 2$	$= 1$	$= 2$	$= 1$	$= 1$	$= 2$	$= 2$
jet 1 p_{T} [GeV]	> 100	> 100	> 85	> 100	> 100	> 100	> 100
jet 2 p_{T} [GeV]	> 20	> 20	> 20	> 30	> 30	> 20	> 20
jet 3 p_{T} [GeV]	< 60	< 60	< 60	< 60	< 60	< 60	< 60
$p_{\mathrm{T}}^{\text{b-jet1}}$ [GeV]	> 50	> 50	> 50	> 50	> 50	> 50	> 50
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	< 100	< 80	> 130	> 150	> 120	> 150
$E_{\mathrm{T}}^{\mathrm{miss,cor}}$ [GeV]	-	> 120	> 100	-	-	-	-
ΔR_{min}	> 2.8	> 2.8	> 2.8	> 2.5	> 2.8	> 2.8	< 2.5
$\Delta\eta(b_1, b_2)$	> 0.5	-	-	-	> 0.5	-	> 0.5
$Imb(b_1, b_2)$	> 0.5	-	-	-	-	-	> 0.5
m_{T}^{lep}	-	-	-	$[30, 100]$	$[30, 100]$	> 30	-
$m_{\ell\ell}$	-	$[75, 105]$	$[80, 100]$	-	-	-	-
lepton 1 p_{T} [GeV]	-	> 30	> 30	> 30	> 30	> 30	-
lepton 2 p_{T} [GeV]	-	> 25	> 25	-	-	-	-
$\Delta\phi(b_1, b_2)$	> 2.2	> 2.2	-	$[1, 2.2]$	> 2.2	> 2.2	> 2.2

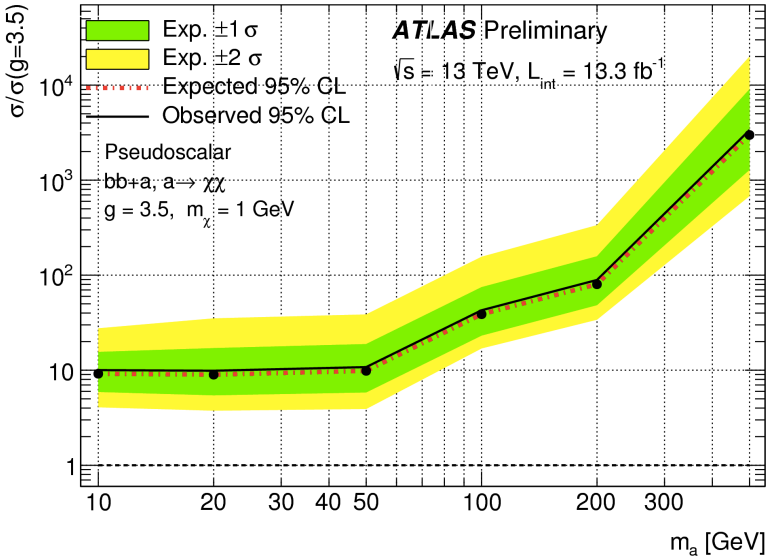
MET+bb limits

ATLAS-CONF-2016-086









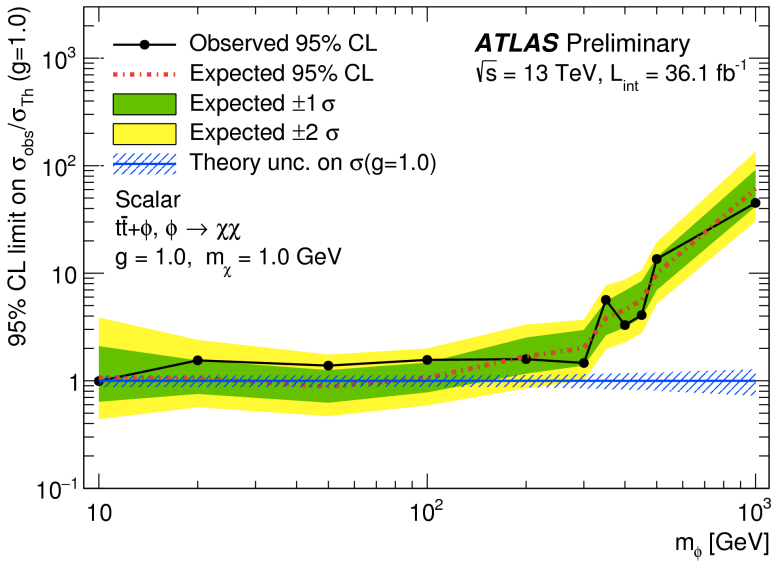
MET+tt signal selection criterial

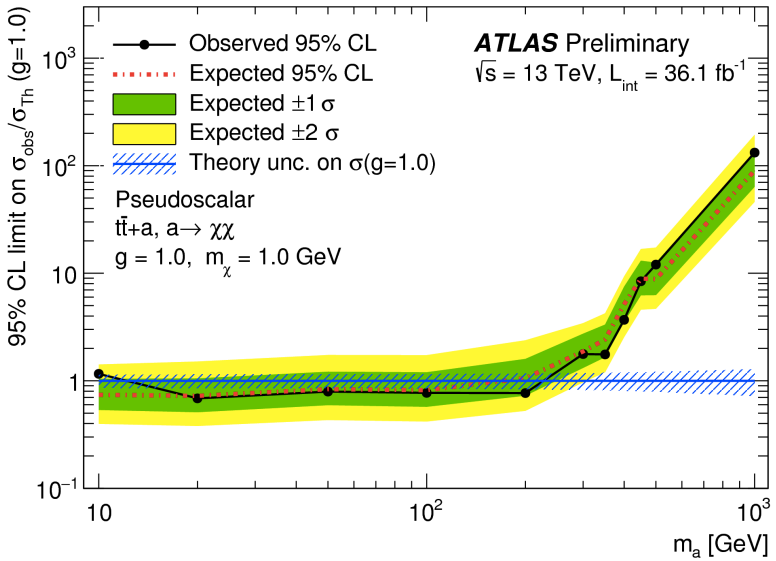
ATLAS-CONF-2017-037

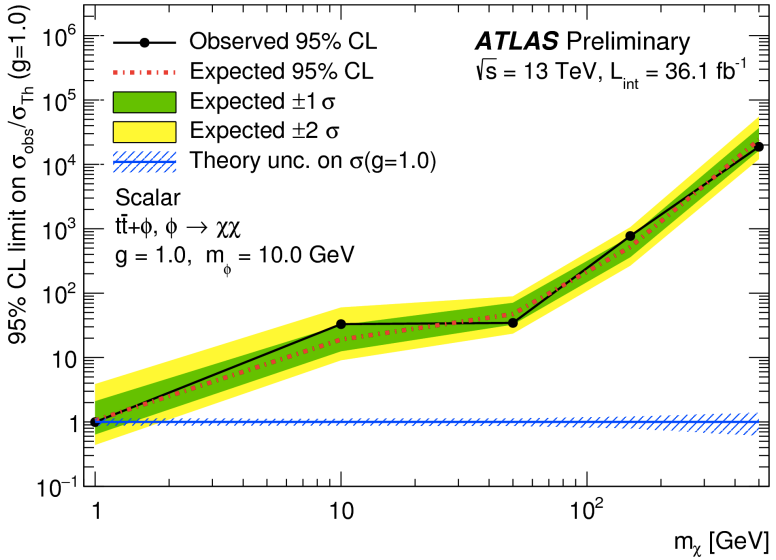
Signal region	DM_low_loose	DM_low	DM_high
Preselection	high-$E_{\mathrm{T}}^{\mathrm{miss}}$ preselection		
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet p_{T} [GeV]	$> (60,\ 60,\ 40,\ 25)$	$> (120,\ 85,\ 65,\ 25)$	$> (125,\ 75,\ 65,\ 25)$
b-tagged jet p_{T} [GeV]	–	> 60	–
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 300	> 320	> 380
m_{T} [GeV]	> 120	> 170	> 225
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 14	–
am_{T2} [GeV]	> 140	> 160	> 190
$m_{\mathrm{top}}^{\mathrm{reclustered}}$ [GeV]	–	> 130	> 130
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \ell)$	> 0.8	> 1.2	> 1.2
$\lvert\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$	> 1.4	> 1.0	> 1.0
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$		> 0.4	
m_{T2}^{τ} based τ-veto [GeV]		> 80	
exclusion technique	cut-and-count	cut-and-count	cut-and-count

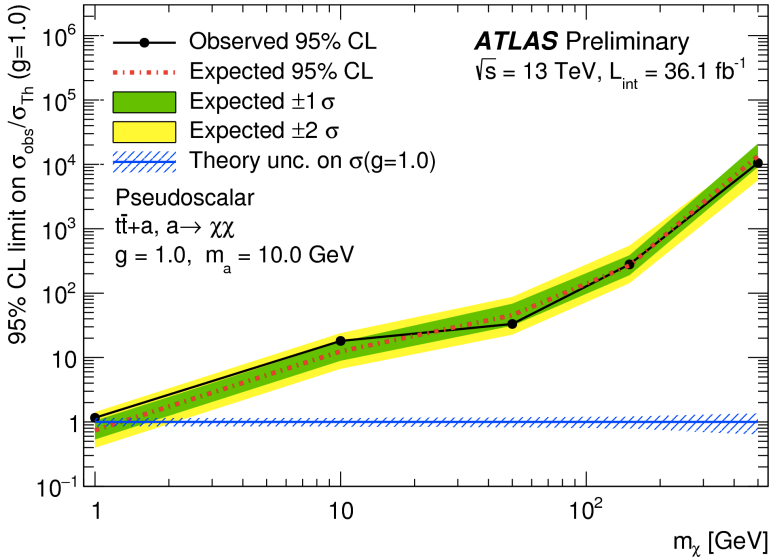
MET+tt limits

ATLAS-CONF-2017-037





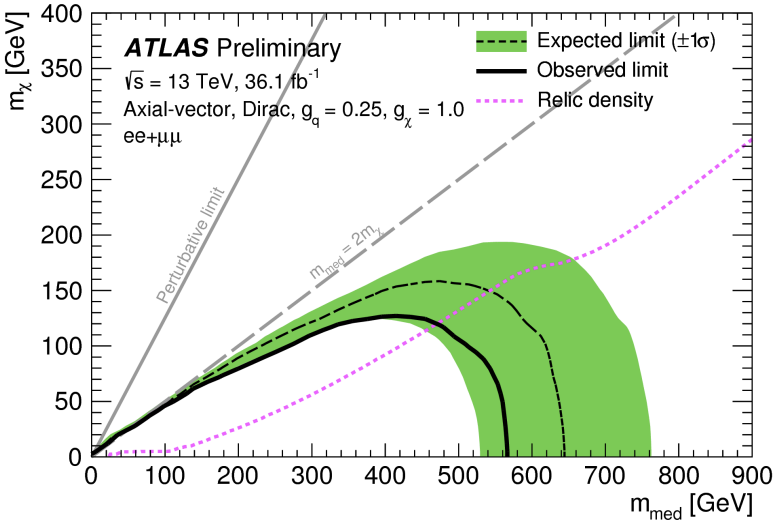


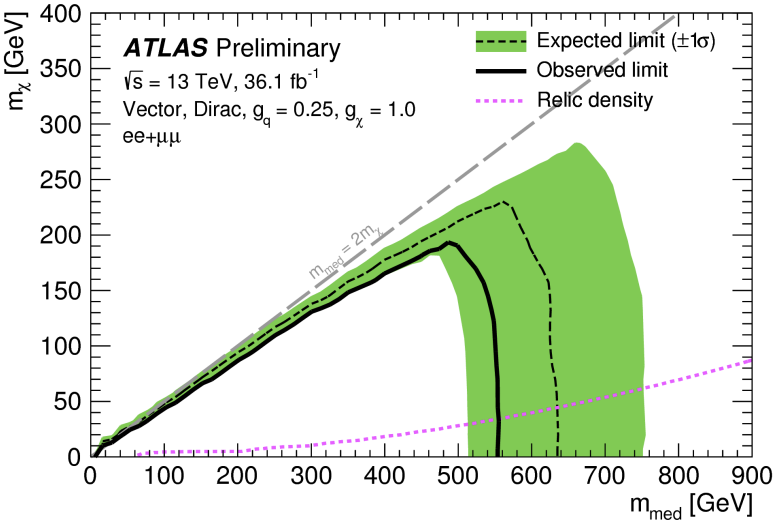


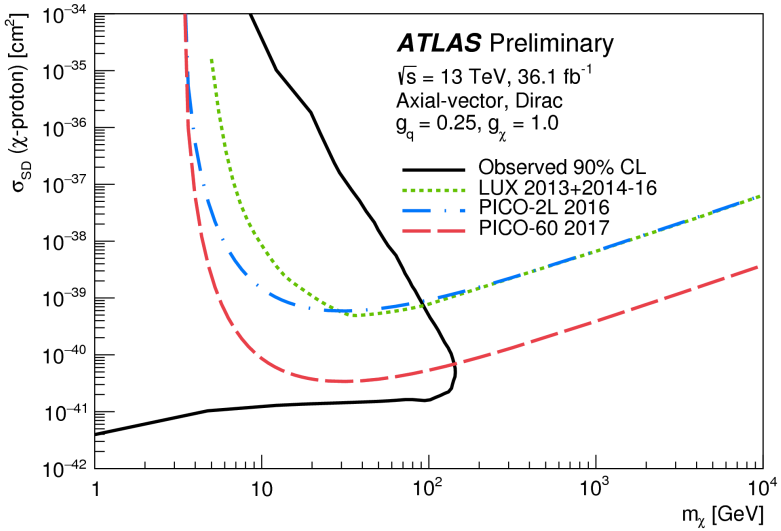
MET+Z(ll) limits

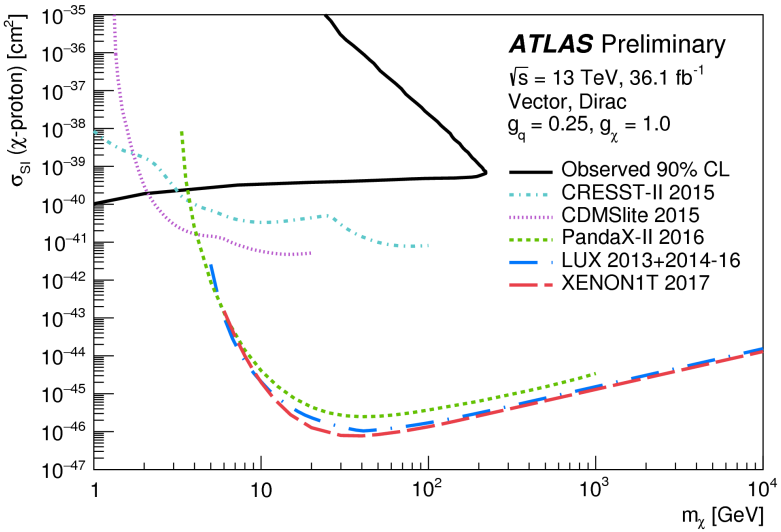
ATLAS-CONF-2017-040

m_{Med} excluded at 560 GeV for light DM, m_{DM} excluded at 130 GeV for m_{Med} = 400 GeV





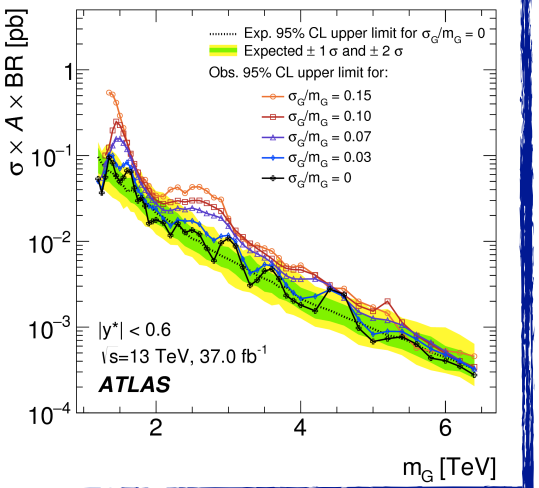




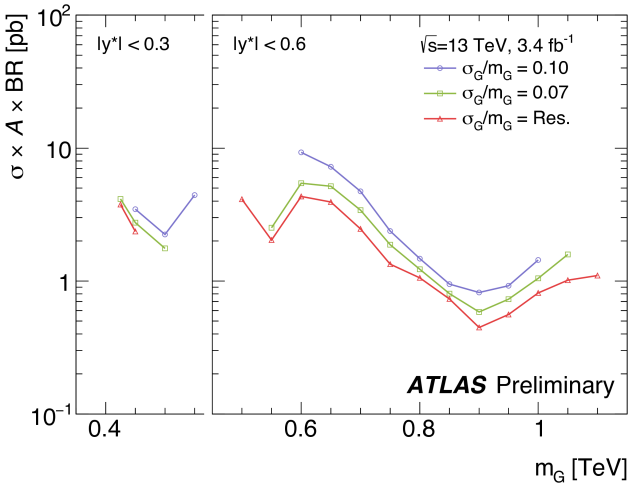
Generaical Gaussian limits

EXOT-2016-21
ATLAS-CONF-2016-030
ATLAS-CONF-2016-070

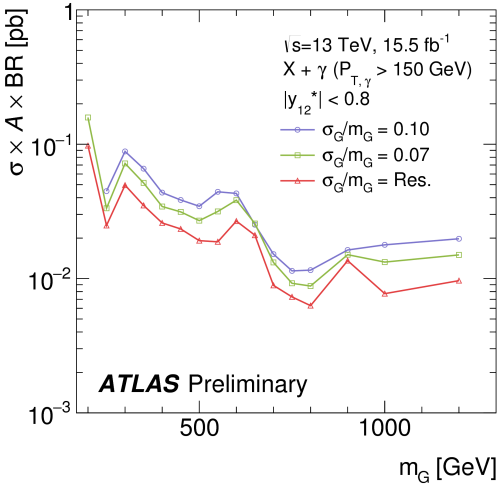
Di-jet resonance search

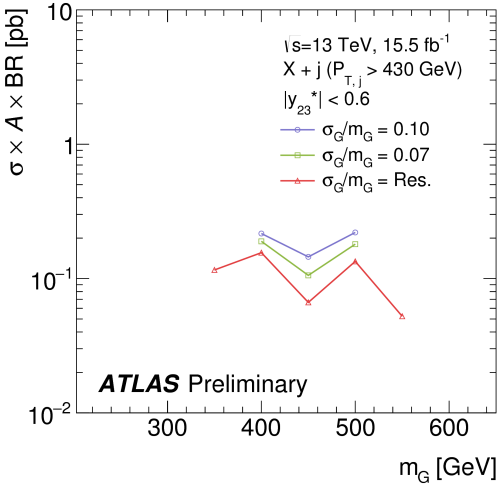


TLA



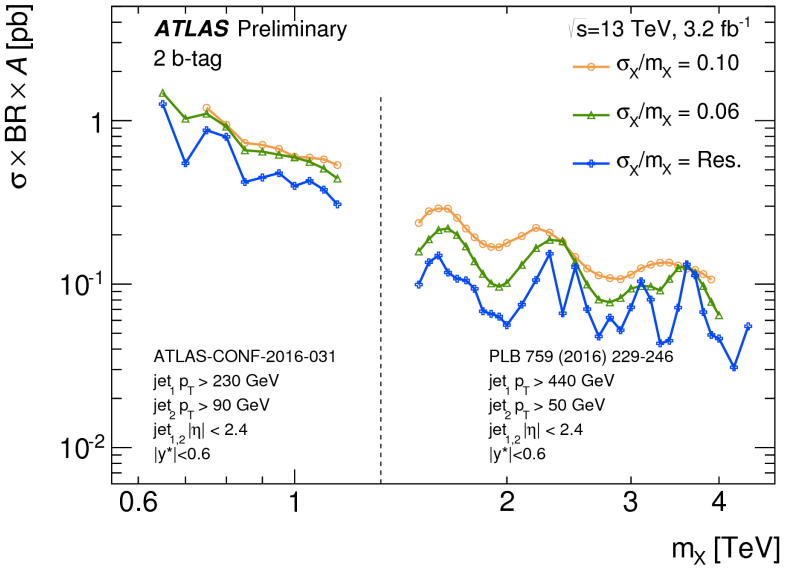
Di-jet+ISR





Di-b-jet search

Ref: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/ATLAS_Dibjet_GeneralLimit_Summary/ATLAS_Dibjet_GeneralLimit_Summary.png



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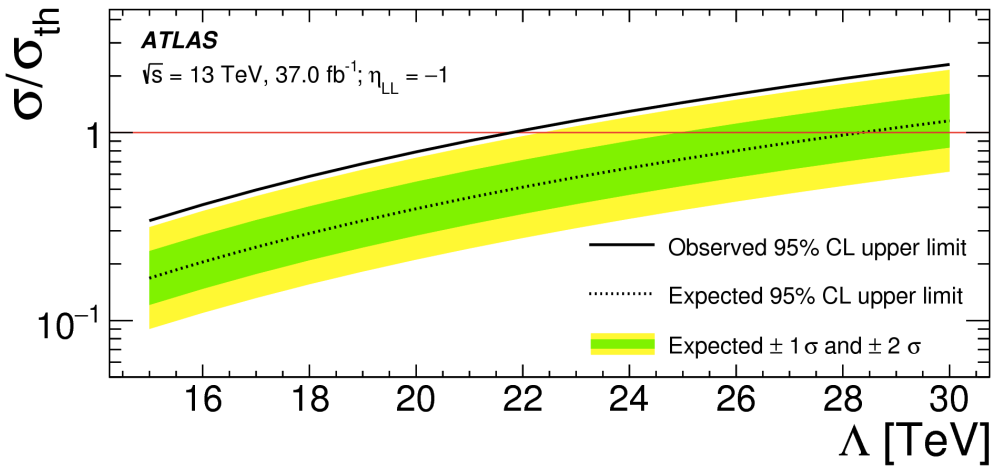
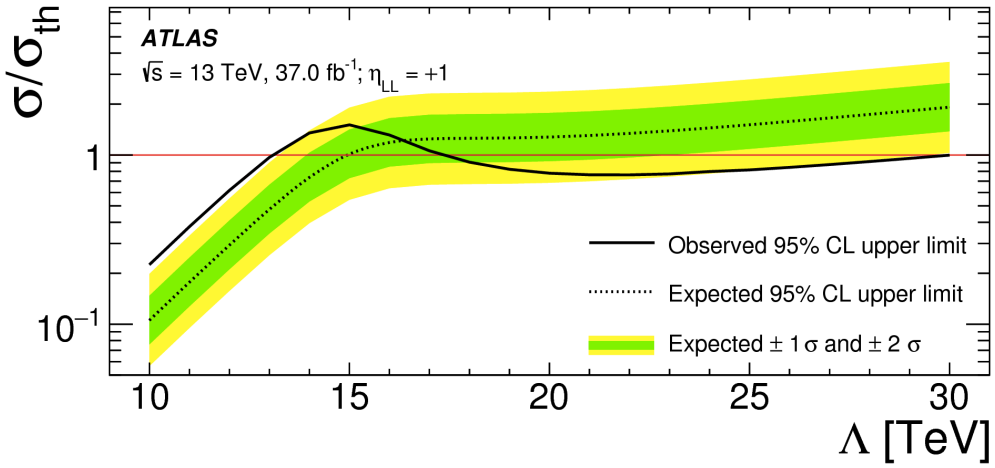
EXOT-2016-21
EXOT-2016-05

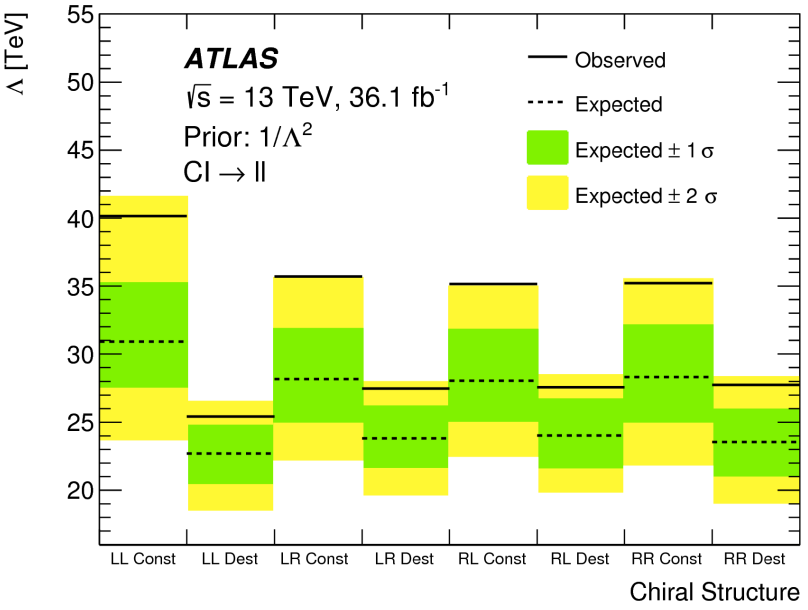
contact interaction limits

Dijet angular search





dilepton search



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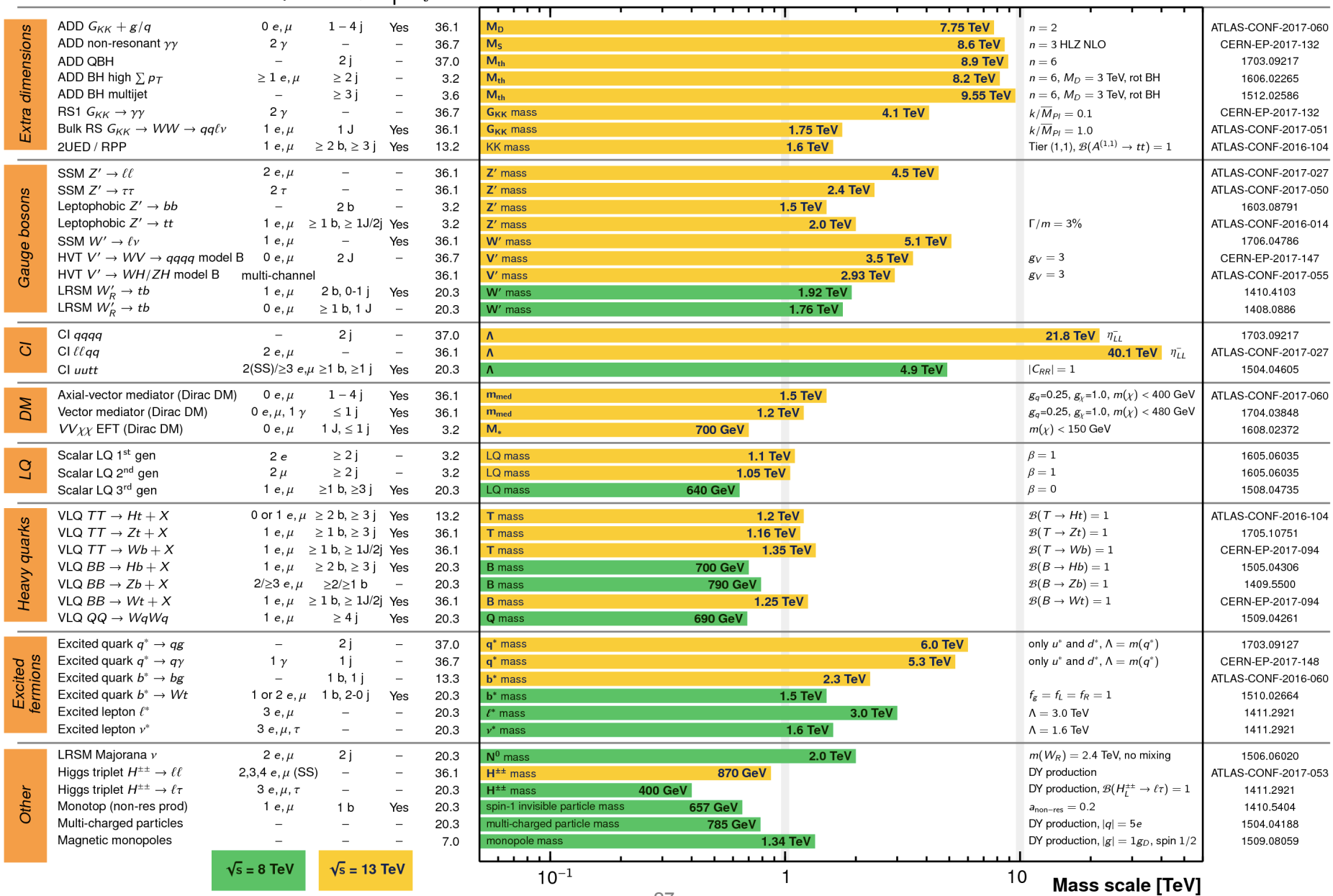
ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 37.0)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

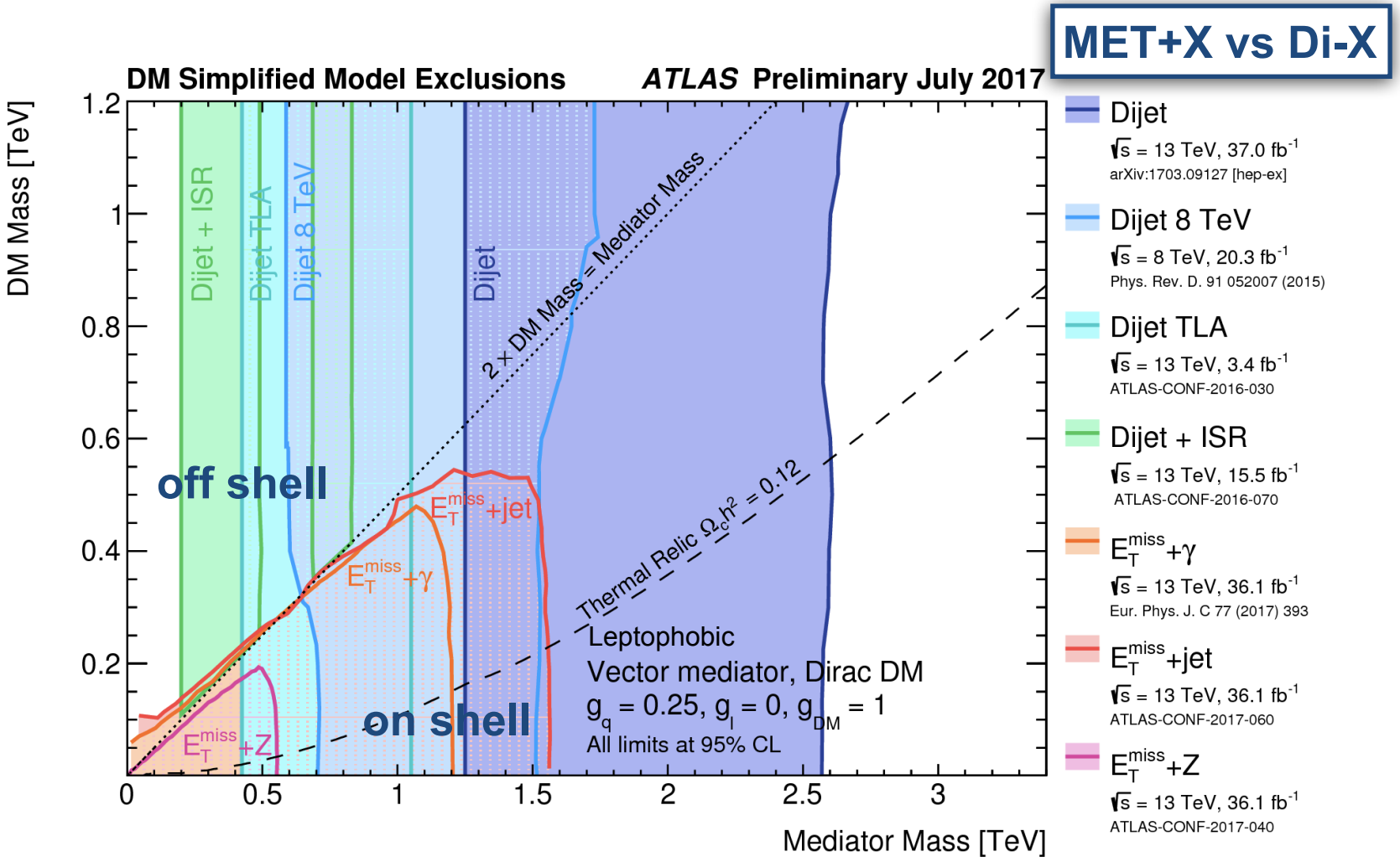


*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

Ref: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/ATLAS_Exotics_Summary/ATLAS_Exotics_Summary.png

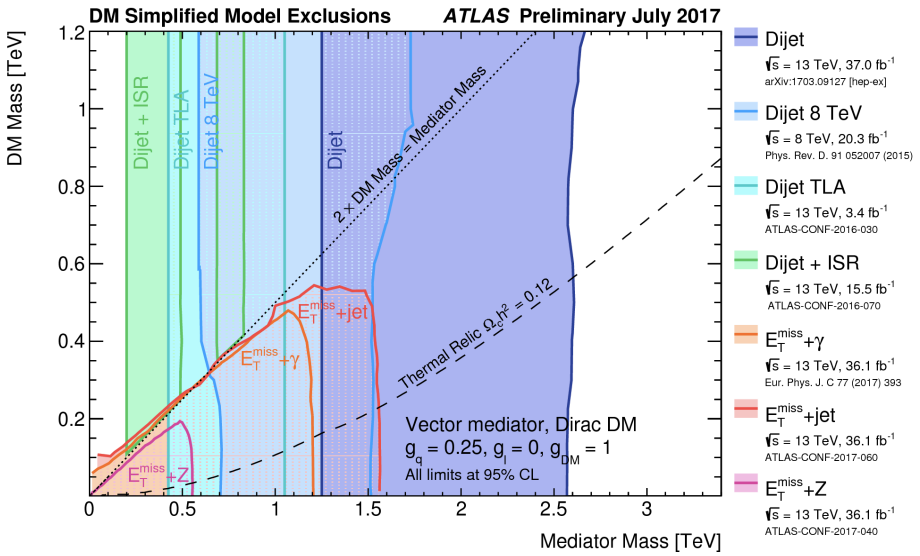
ATLAS limit on vector mediator



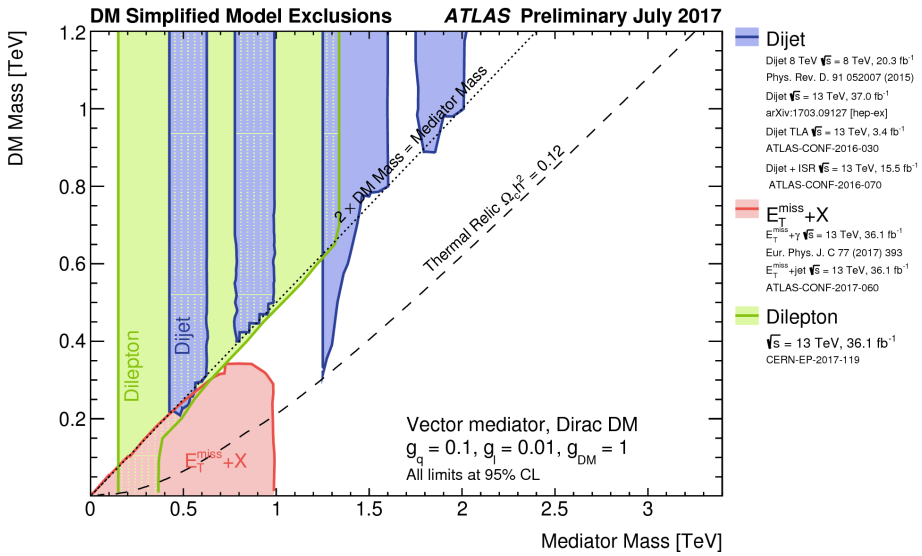
Ref: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/ATLAS_DarkMatter_Summary/ATLAS_DarkMatter_Summary.png

ATLAS limit on vector mediator

g_q=0.25, q_l=0,q_{DM}=1



g_q=0.1, q_l=0.01,q_{DM}=1



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Ref: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/ATLAS_DarkMatter_Summary_Vector_ModifiedCoupling/ATLAS_DarkMatter_Summary_Vector_ModifiedCoupling.png