Recent results from Susy and Exotic signatures with the ATLAS experiment

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on behalf of the ATLAS Collaboration

Outline

- ATLAS has a wide programme of analyses focusing on hints of New Physics, with new scenarios Beyond the Standard Model (BSM)
  - Supersimmetry, dark-sector models, extended Higgs sectors and many others
  - The detector potential can be exploited for detecting new signatures (i.e. long-lived particles, heavy resonances, spartcles…) also making use of **dedicated reconstruction techniques and trigger algorithms**
  - Some of the analyses updates previous searches at 7 TeV and 8 TeV
  - Results are interpreted both in terms of specific models and **model-independent signatures**
  - See talk by Masahiro Morinaga for a more complete view for ATLAS and CMS results

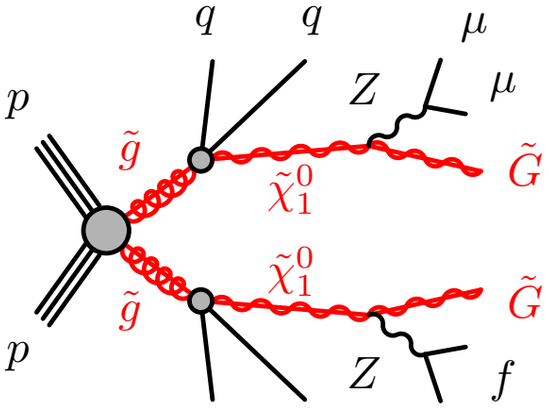
- Highlights on **some of the most recent results** of BSM signatures in SUSY and Exotics searches are given, also exploiting the **~80fb^{-1} collected at 13 TeV since 2015**
  - analyses shown here differ for the number of leptons/jets (also b-tagged)/missing transverse momenta (E_T^{miss}) in the final state

Search for long-lived particles in final states with displaced non-collimated muons (1/2)

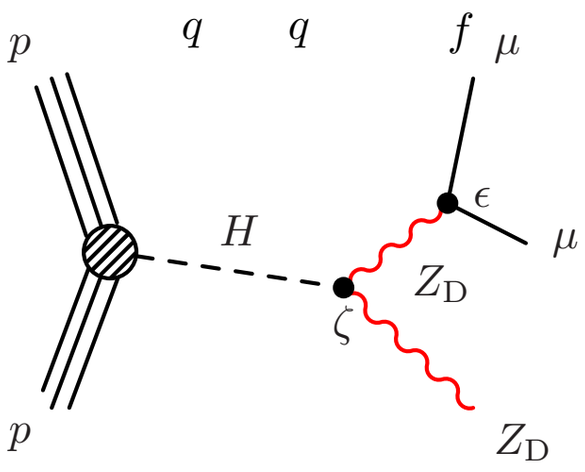
arXiv 1808.03057

33 fb^{-1} (2016) at 13 TeV

displaced vertices: 2 opposite sign (OS) muons



Gauge-mediated (GGM) SUSY with long-lived neutralino as NLSP. Neutralino masses in the 300 – 1000 GeV range.



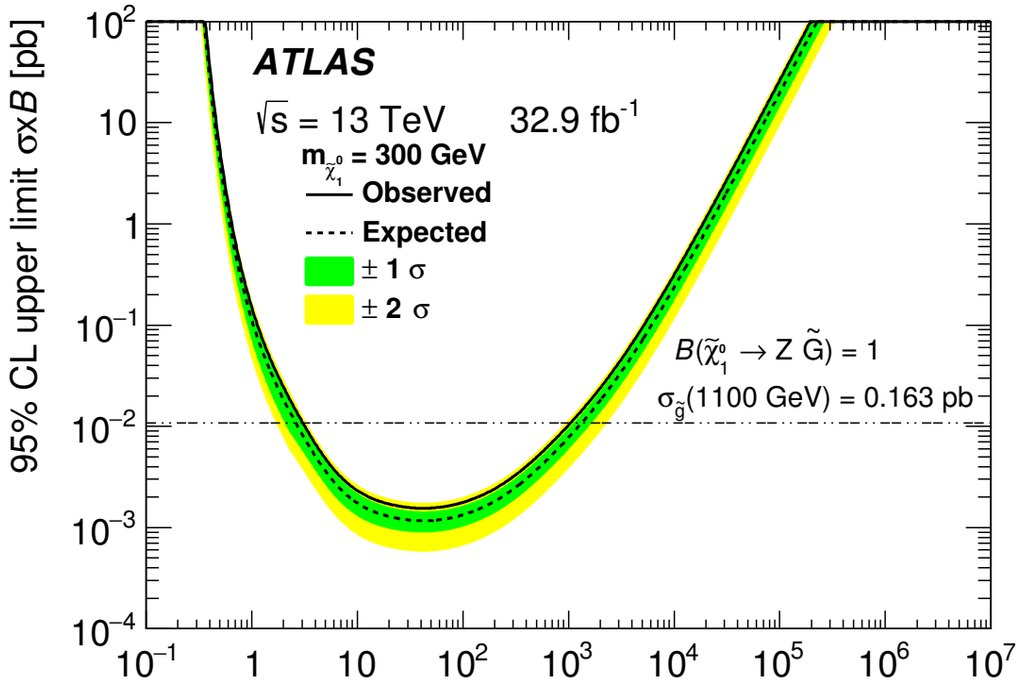
Dark-sector gauge boson model (DS) with long-lived dark-photon, in the mass range 20 – 60 GeV.

Selection	Low mass	High mass
p_{T}^{μ} [GeV]	> 10	> 20
$m_{\mu\mu}$ [GeV]	15–60	> 60
Dimuon transverse boost	–	> 2
	$\mathrm{SR_{low}}$	$\mathrm{SR_{high}}$
Muon candidates	both MSonly	both MSonly
Muon candidate charge	opposite charge	opposite charge

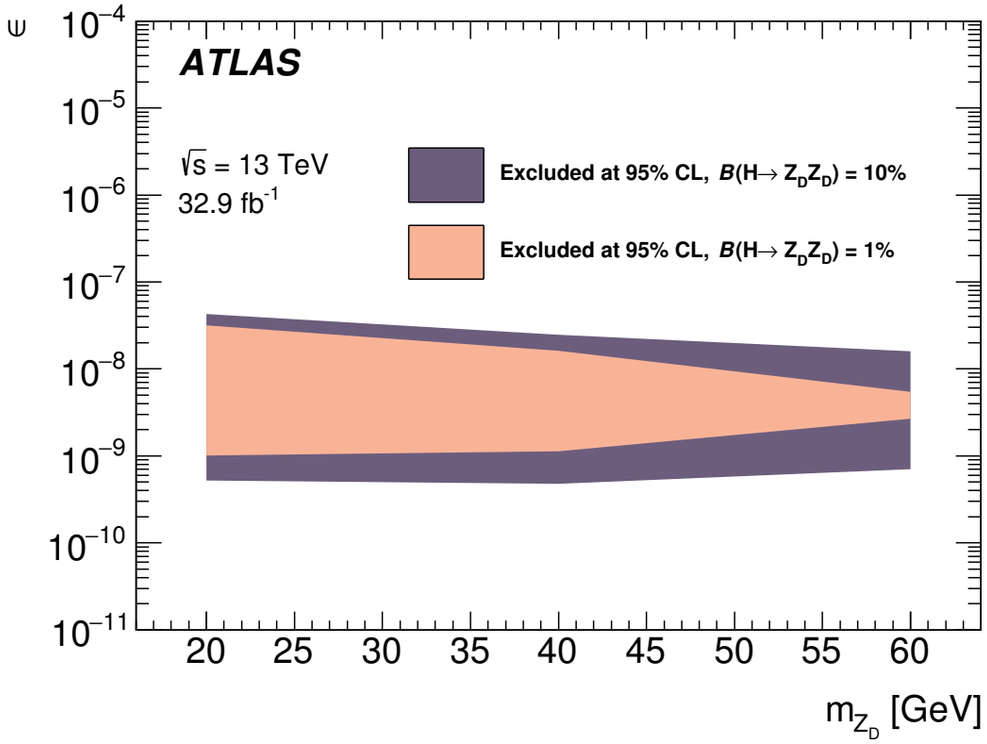
- single muon trigger efficiency decreases with large impact parameter (70%->10% at 400 cm)
  - recovered by large E_T^{miss} and by **collimated muon pair trigger (developed for long-lived searches** JINST 8 (2013) P07015**)**
- still good efficiency for **muon p_T > 10 GeV** with **impact parameter up to 200 cm**
- Displaced vertices (several centimetres from the IP)
  - leading and sub-leading muons with **opening angle > 0.1 (non-collimated)**
  - **$m_{\mu\mu}$ > 15 GeV** remove SM di-muon bkg
  - **MS-only muons**
- Non-prompt vertices: r_{vtx} > 1 cm
  - muon pairs from cosmics, BIB, pions and kaons
- Prompt vertices: r_{vtx} < 1 cm
  - SM processes as decay of b/c-hadrons

Search for long-lived particles in final states with displaced non-collimated muons (2/2)

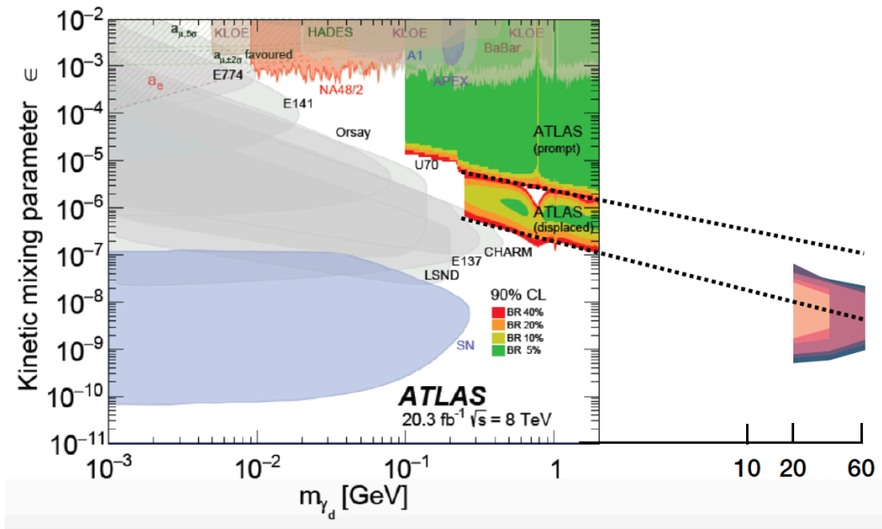
arXiv 1808.03057



- No significant excess is found above the predicted background in the signal regions.
- Upper limits on the signal yield are set **as a function of the proper lifetime** for the long-lived particle.
  - In GGM model with benchmark masses, excluded $c\tau$ range from 2.6 cm to 1800 cm.
  - In DS models excluded $c\tau$ range from 0.3 cm to 2400 cm.



- Limits on dark-photon Z_D set at 8 TeV by complementary analyses, (i.e. DS models with prompt and displaced Lepton-Jets JHEP02(2016)062, JHEP 11 (2014) 088)



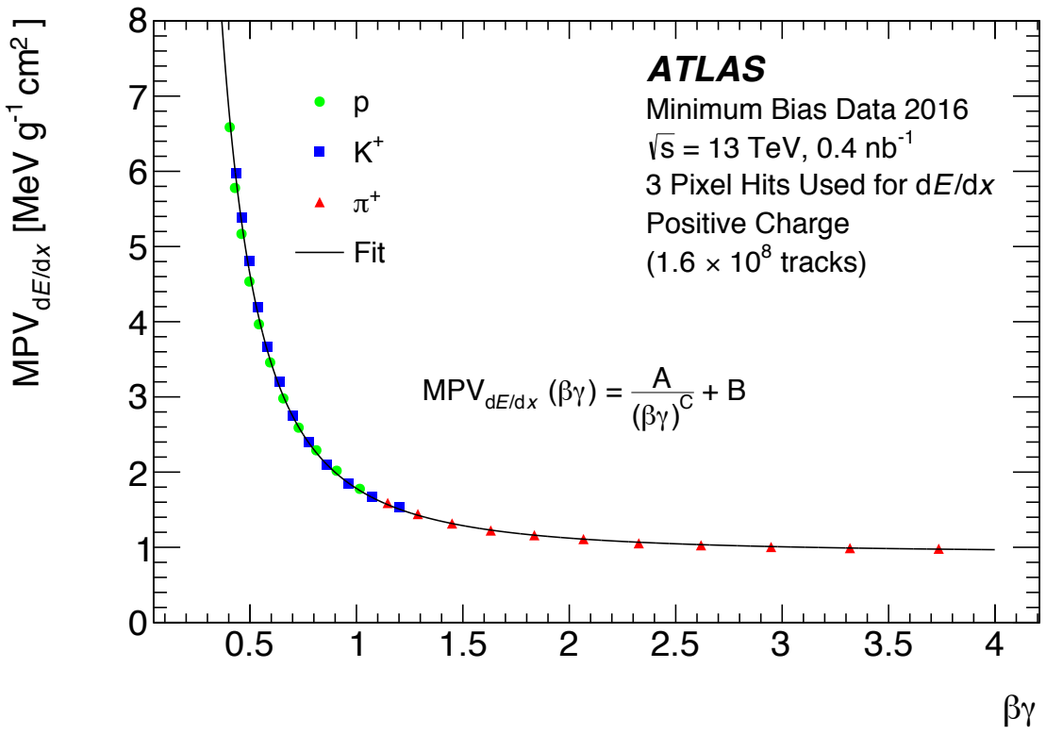
Filling new regions in the exclusion plane of dark-photon mixing parameter VS mass

figure by Nathan Bernard

Search for heavy charged long-lived particles (1/3)

arXiv 1808.04095

- Search for **excess in the mass** distribution of reconstructed tracks with **high p_T and large dE/dx**
- Production of **massive particles with lifetimes > 1 ns** (mini-split SUSY, AMSB models).
  - LLPs are expected to be slow and, if charged, with a specific larger ionisation.



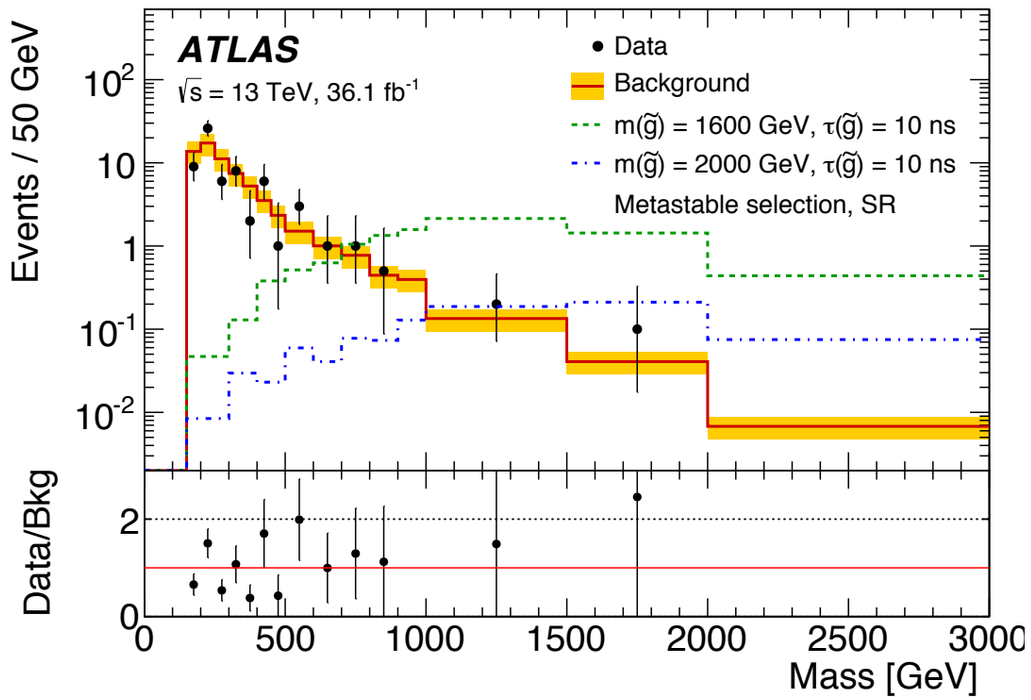
- **36 fb^{-1} collected in 2015 + 2016**
  - Selection for **metastable** R-hadrons with lifetimes from 1 ns to 50 ns ($\tilde{g}$ -> $q\bar{q}\tilde{X}_1^0$, $\tilde{g}$ 400 – 3000 GeV + 100 GeV $\tilde{X}_1^0$)
  - Selection for **stable** R-hadrons decaying outside the ATLAS volume.
- From **Pixel** measurement of $MPV_{dE/dx}$ to LLP's $\beta\gamma$ to LLP's mass
- highest-pT (> 50 GeV) isolated track
  - low impact parameter
  - transverse mass (track + E_T^{miss}) > 130 GeV
  - dE/dx > 1.8 MeV g^{-1} cm^2
  - muon veto for meta-stable search
- high E_T^{miss} (trigger + offline cuts)

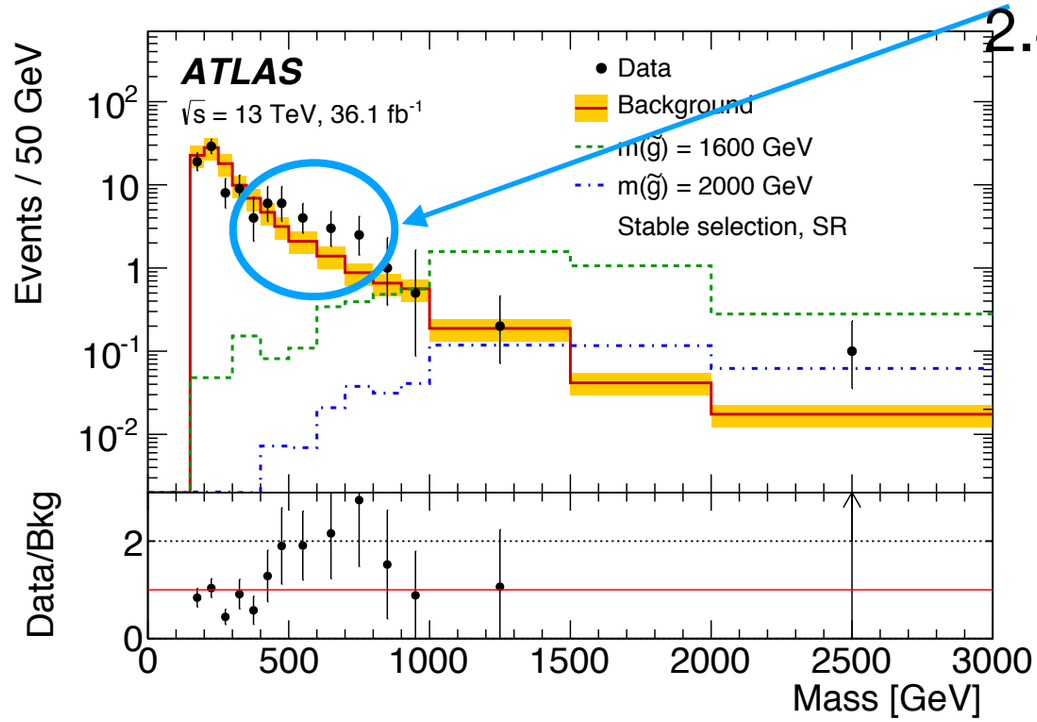
Search for heavy charged long-lived particles (2/3)

arXiv 1808.04095

- Expected bkg from:
  - tracks from vector bosons, top-quark, multi-jet production
  - overlapping particles, spurious pixel hits
- Data-driven CRs from inverted cuts
  - random p and dE/dx pairs to build the expected mass distribution (m < 160 GeV from previous exclusion of signal)

Region	Sample	Pred. Bkg ($\pm$ stat. $\pm$ syst.)	Exp. Signal	Data
			$m(\tilde{g}) = 1600\ GeV$, $\tau(\tilde{g}) = 10$ ns	
Metastable	p-CR	-	12.0 ± 0.9	7397
	dE/dx-CR	-	7.2 ± 0.6	110019
	VR	$140 \pm 4 \pm 28$	0.3 ± 0.03	130
	SR	$71 \pm 2 \pm 14$	52.1 ± 4.2	72
			$m(\tilde{g}) = 1600\ GeV$, stable	
Stable	p-CR	-	8.0 ± 1.6	13108
	dE/dx-CR	-	10.3 ± 2.1	272723
	VR	$168 \pm 5 \pm 32$	0.2 ± 0.04	138
	SR	$107 \pm 3 \pm 28$	36.0 ± 7.2	107



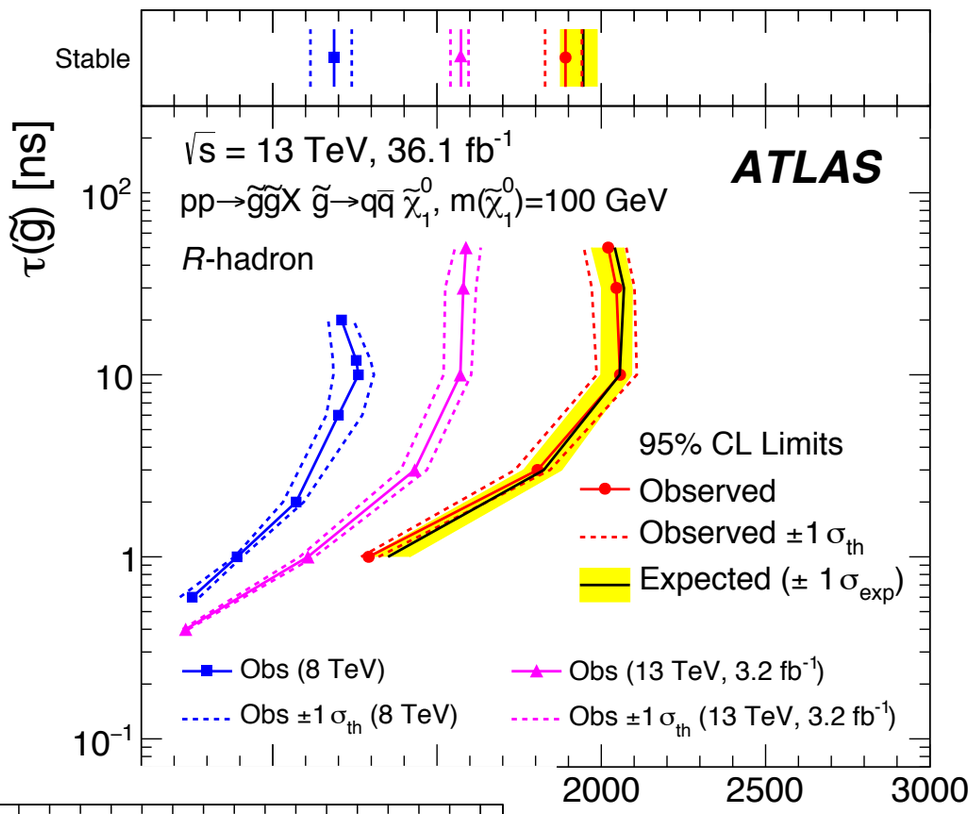


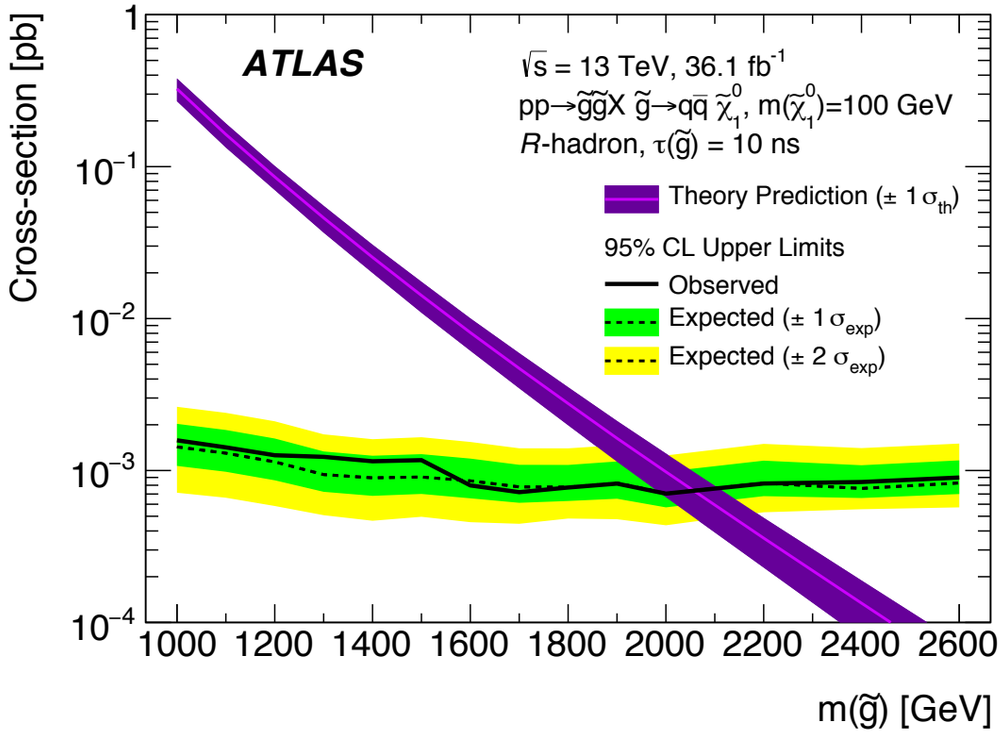
Mild excess
2.4 sigma only

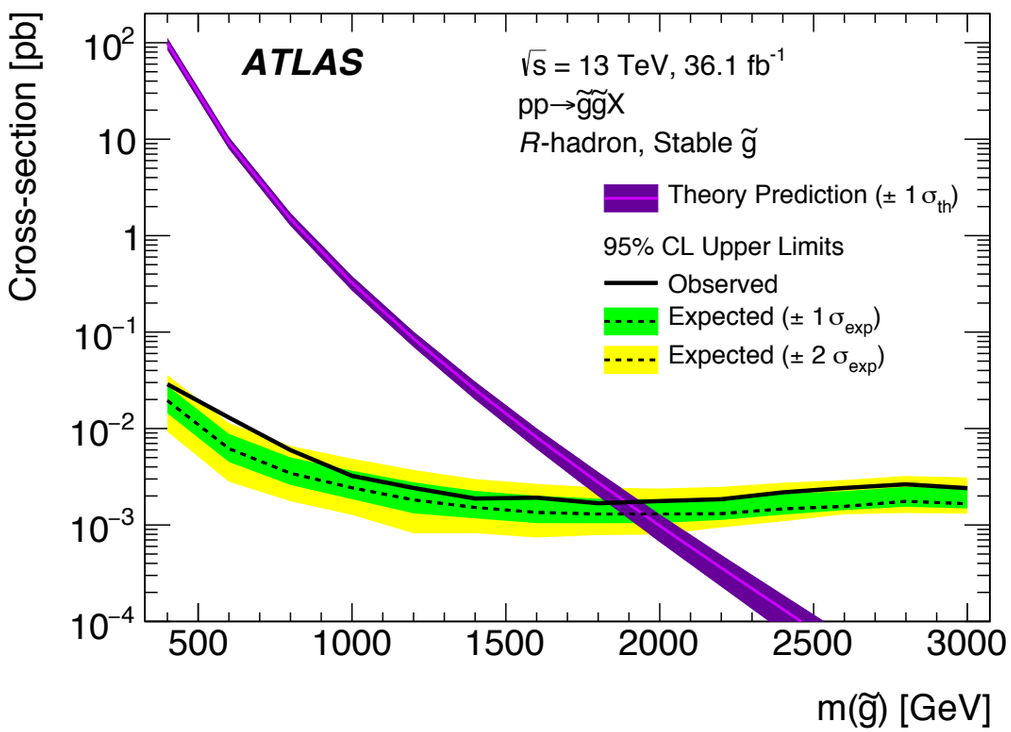
Search for heavy charged long-lived particles (3/3)

arXiv 1808.04095

- No significant excess
  - Upper limits on the cross-section as a function of mass for $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ and for detector-stable gluinos.
  - Maximum sensitivity for metastable gluinos with lifetime of 10 ns:
    - **< 2060 GeV** excluded at 95% CL
  - **Stable gluinos < 1890 GeV** excluded at 95% CL





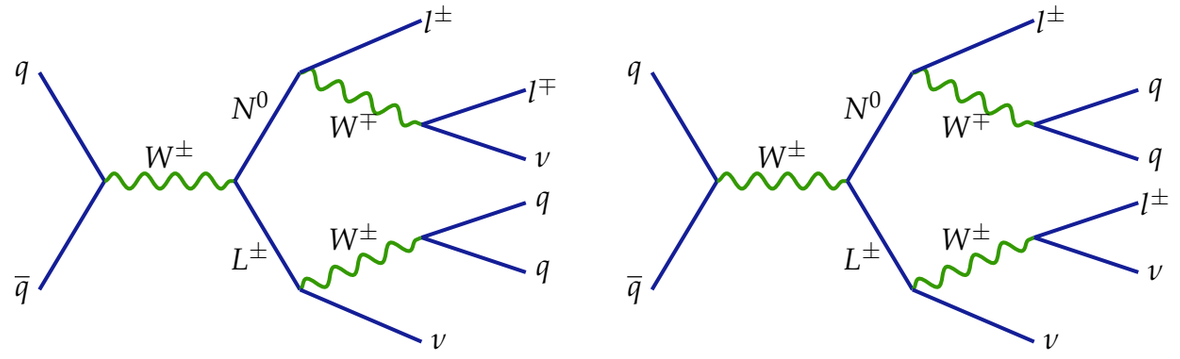


Search for type-III seesaw heavy leptons (1/2)

ATLAS-CONF-2018-020

80 fb^{-1} (2015-2017) at 13 TeV

- 2 final-state charged leptons (electrons or muons) of same/opposite sign and same/different flavour
- large E_T^{miss}
- >= 2 jets



Type III seesaw model can explain neutrino masses through a new heavy-lepton triplet where all particles mainly decay to W

- a Majorana particle N^0
- 2 opposite sign $L^{\pm}$

	OS ($\ell^+\ell^- = e^+e^-, e^\pm\mu^\mp, \mu^+\mu^-$)				**SS** ($\ell^\pm\ell^\pm = e^\pm e^\pm, e^\pm\mu^\pm, \mu^\pm\mu^\pm$)			
	Top CR	Z+jets VR	m_{jj} VR	SR	Z+jets VR	m_{jj} VR	m_{jj} CR	SR
N(jet)	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2
$N(b$-jet)	$\geq \mathbf{2}$	0	0	0	0	0	0	0
m_{jj} [GeV]	$[60, 100)$	$[60, 100)$	$\mathbf{[35, 60) \cup [100, 125)}$	$[60, 100)$	$[60, 100)$	$\mathbf{[0, 60) \cup [100, 300)}$	$\mathbf{[0, 60) \cup [100, 300)}$	$[60, 100)$
$m_{\ell\ell}$[GeV]	$[110, \infty)$	$\mathbf{[70, 110)}$	$[110, \infty)$	$[110, \infty)$	$\mathbf{[70, 100)}$	$[100, \infty)$	$[100, \infty)$	$[100, \infty)$
Sig($E_{\mathrm{T}}^{\mathrm{miss}}$)	≥ 5	≥ 5	$\geq \mathbf{10}$	$\geq \mathbf{10}$	≥ 5	≥ 5	≥ 5	$\geq \mathbf{7.5}$
$\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, l)_{\mathrm{min}}$				$\geq \mathbf{1}$				
$p_{\mathrm{T}}(jj)$ [GeV]				$\mathbf{[100, \infty)}$				$\mathbf{[60, \infty)}$
$p_{\mathrm{T}}(\ell\ell)$ [GeV]				$\mathbf{[100, \infty)}$				$\mathbf{[100, \infty)}$
$H_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	$[300, \infty)$	$[300, \infty)$	$[300, \infty)$	$[300, \infty)$		$\mathbf{[500, \infty)}$	$\mathbf{[300, 500)}$	$[300, \infty)$

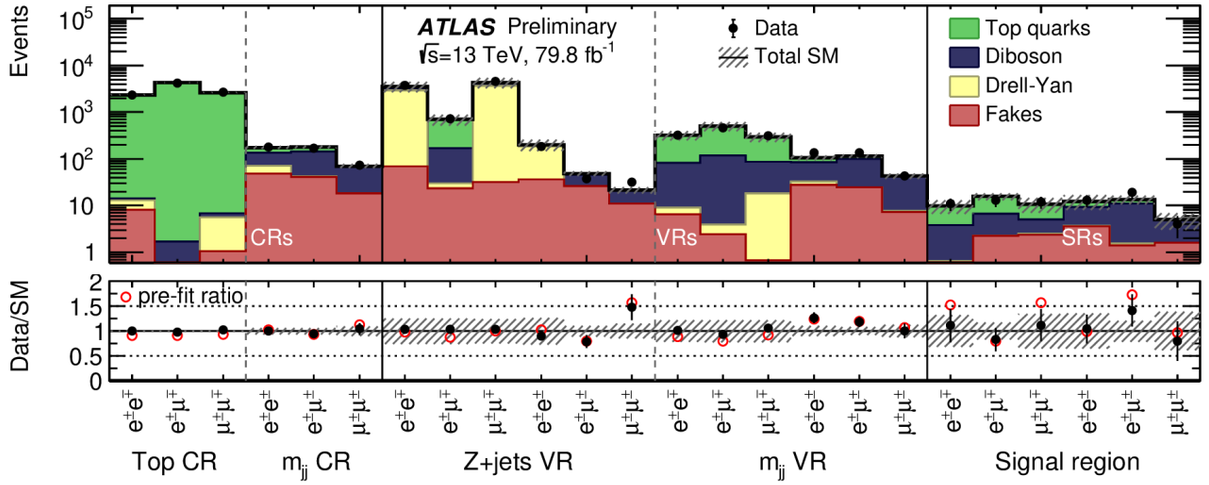
- >= 2 jets, m_{jj} around W mass
- $m_{\ell\ell}$ lower bound, to remove DY Z->ee peak

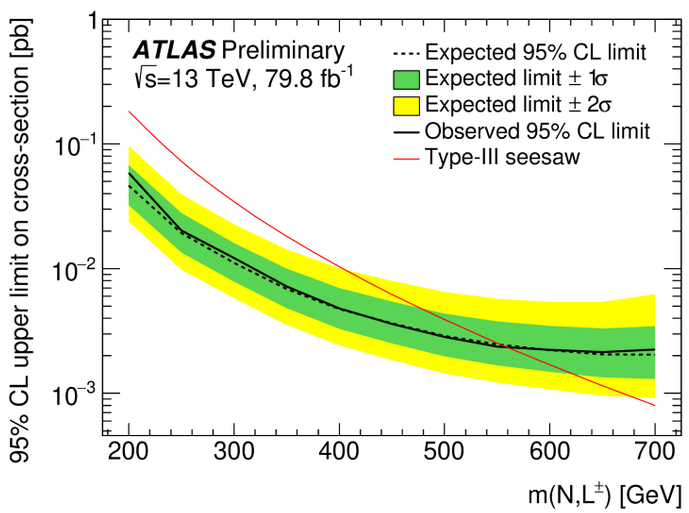
- final state with high-pT leptons, jets and neutrinos
  - large E_T^{miss} + H_T (scalar sum of transverse momenta)

Search for type-III seesaw heavy leptons (2/2)

ATLAS-CONF-2018-020

- Corrections applied for electron charge-flip
- **Fake-factor** for non-prompt electrons/muons background estimated
  - e reconstructed as jets, e from photon conversion, in-flight decays of mesons inside jets
  - b-jet veto already reduces significantly leptons from heavy-flavour decay
- Binned maximum-likelihood fit of the $H_T + E_T^{miss}$ to estimate final yields and bkg
  - validated on VRs





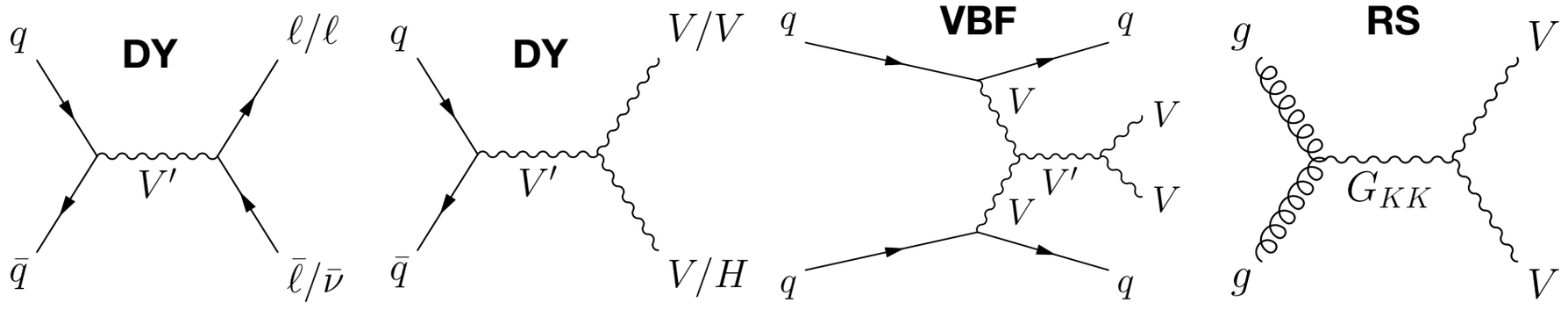
Expected and observed final yield in control/validation/ signal regions

- **No significant excess above the SM prediction has been found.**
- Limits were set on the type-III seesaw heavy lepton masses, using the simplified type-III seesaw model and assuming branching fractions to all lepton flavours to be equal.
- **Heavy leptons < 560 GeV are excluded at the 95% C.L.**

More details in the talk by B. Wynne

Combined searches for heavy resonances decaying into bosonic and leptonic final states (1/3)

arXiv 1808.02380v1



36 fb^{-1} (2015-2016) at 13 TeV

- Combined searches for new heavy resonances decaying into different pairings of W, Z, or Higgs bosons, or directly into leptons
  - qqqq, $\nu\nu$qq, $\ell\nu$qq, $\ell\ell$qq, $\ell\nu\ell\nu$,$\ell\ell\nu\nu$, $\ell\nu\ell\ell$, $\ell\ell\ell\ell$, qqbb, $\nu\nu$bb, $\ell\nu$bb, $\ell\ell$bb or $\ell\nu$, $\ell\ell$.
- Results interpreted in heavy triplet (HVT) model, Randall-Sundrum (RS) model, new heavy scalar resonance decaying into VV.

Model \ Decay mode	WW	WZ	ZZ	WH	ZH	$\ell\nu$	$\ell\ell$
HVT	Z'	W'		W'	Z'	W'	Z'
Bulk RS	G_{KK}		G_{KK}				
Scalar	Scalar		Scalar				

- single/multiple electron/muon pairs, E_T^{miss}, high-jet pT (depending on the signature)
- AntiKt small-R 0.4 (**j**) and large-R 1.0 (**J**) jets
  - pile-up jet removal and b-tagging
  - exploiting jet substructure by D_2 variable (energy correlation functions)

See talk by M. Morinaga

Combined searches for heavy resonances decaying into bosonic and leptonic final states (2/3)

arXiv 1808.02380v1

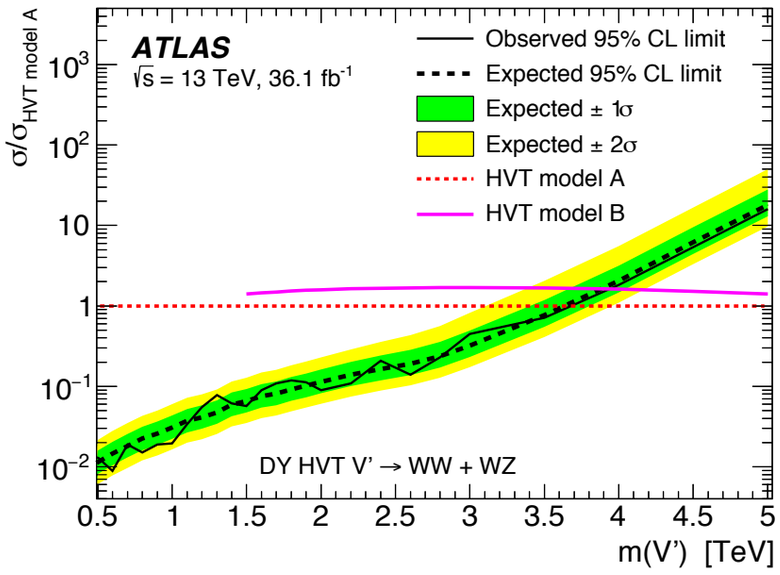
Channel	Diboson state	Selection				VBF cat.
		Leptons	$E_{\mathrm{T}}^{\mathrm{miss}}$	Jets	b-tags	
$qqqq$	$WW/WZ/ZZ$	0	veto	2J	–	–
$\nu\nu qq$	WZ/ZZ	0	yes	1J	–	yes
$\ell\nu qq$	WW/WZ	$1e, 1\mu$	yes	2j, 1J	–	yes
$\ell\ell qq$	WZ/ZZ	$2e, 2\mu$	–	2j, 1J	–	yes
$\ell\ell\nu\nu$	ZZ	$2e, 2\mu$	yes	–	0	yes
$\ell\nu\ell\nu$	WW	$1e{+}1\mu$	yes	–	0	yes
$\ell\nu\ell\ell$	WZ	$3e$, $2e{+}1\mu$, $1e{+}2\mu$, 3μ	yes	–	0	yes
$\ell\ell\ell\ell$	ZZ	$4e$, $2e{+}2\mu$, 4μ	–	–	–	yes
$qqbb$	WH/ZH	0	veto	2J	1, 2	–
$\nu\nu bb$	ZH	0	yes	2j, 1J	1, 2	–
$\ell\nu bb$	WH	$1e, 1\mu$	yes	2j, 1J	1, 2	–
$\ell\ell bb$	ZH	$2e, 2\mu$	veto	2j, 1J	1, 2	–
$\ell\nu$	–	$1e, 1\mu$	yes	–	–	–
$\ell\ell$	–	$2e, 2\mu$	–	–	–	–

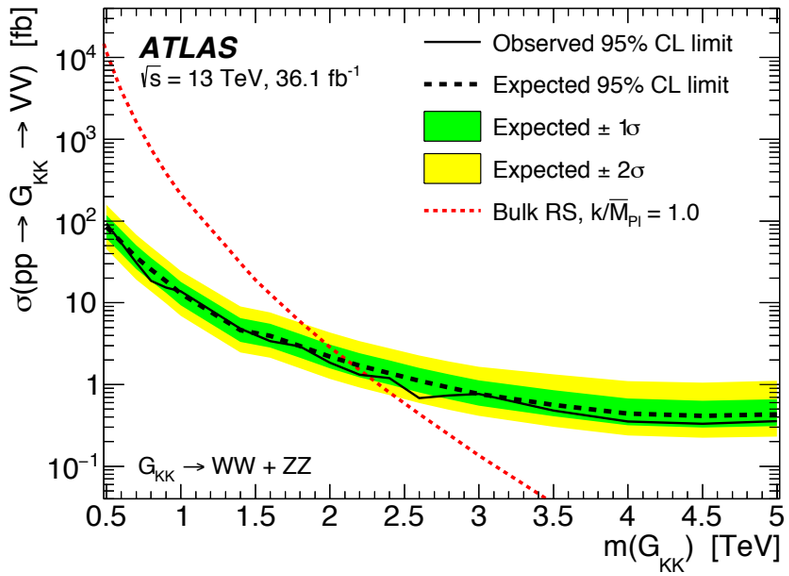
- Discriminating variable:
  - invariant mass of the VV/VH/$\ell\ell$ candidates
  - if two neutrinos or the W -> $\ell\nu$ final state, transverse mass of final-state particles
- Background:
  - fake leptons for charged lepton final states
  - multi-jets, V+jets, ttbar, VV, DY

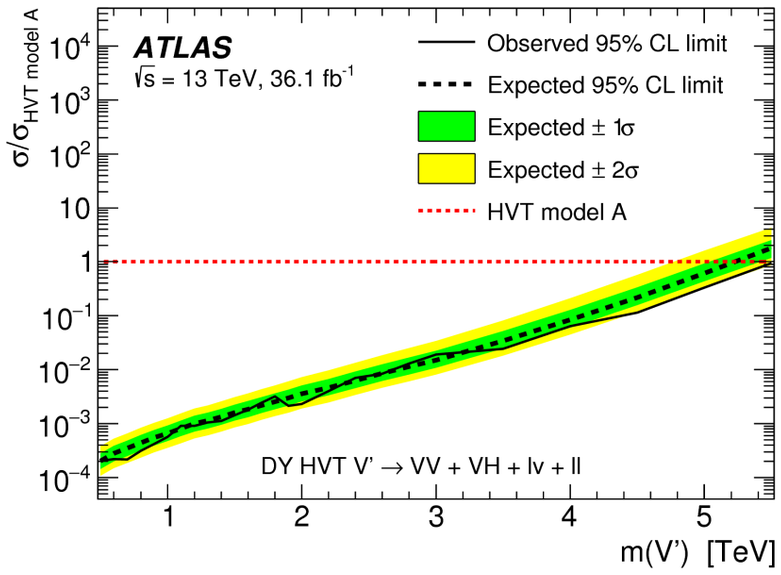
- Orthogonal searches
- **fully hadronic VV**:explores the mass range between **1.1 and 5.0 TeV; sensitive at high resonance mass.**
- **semi-leptonic VV**: used in the mass range 0.3 – 5 TeV; sensitive to **mid-high resonance mass**
- **fully leptonic VV**:0.2 – 5 TeV (depending on the VV pair and production mechanism)
- **fully hadronic VH**: highly boosted collimated VH (1 J); focus on mass > 1 TeV
- **semi-leptonic VH**: focus on mass > 0.5 TeV
- $\ell\nu, \ell\ell$ final states: high sensitivity in a wide range of resonance mass 0.2 – 5.5 TeV

Combined searches for heavy resonances decaying into bosonic and leptonic final states (3/3)

arXiv 1808.02380v1







- 1D upper limits on cross section x BR
- 2D limits on coupling strength
- **Each of the channel presented contributes uniquely to the search.** Results obtained by their combination extend the reach beyond that of the individual searches.

95% CL lower limit on:

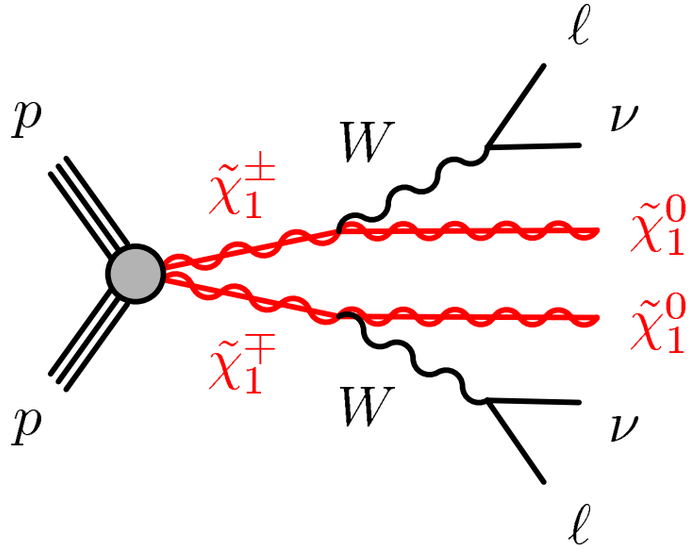
- V' mass resonance is:
  - 5.5 TeV for the weakly coupled HVT A
  - 4.5 TeV for the strongly coupled HVT B
- G_{KK} mass in the bulk RS model is 2.3 TeV
- New scalar in empirical heavy scalar model:
  - 0.3 – 3 TeV in ggF
  - 0.5 – 3 TeV in VBF

Direct chargino pair production with W-boson mediated decays in events with 2 leptons and missing energy (1/2)

ATLAS-CONF-2018-042

80 fb^{-1} (2015-2017) at 13 TeV

- 2 OS leptons (electrons or muons)
- large E_T^{miss} (neutrinos + neutralinos)
- 0/1 non-b-tagged jets



Each chargino decays to LSP via emission of a SM W boson which itself decays leptonically

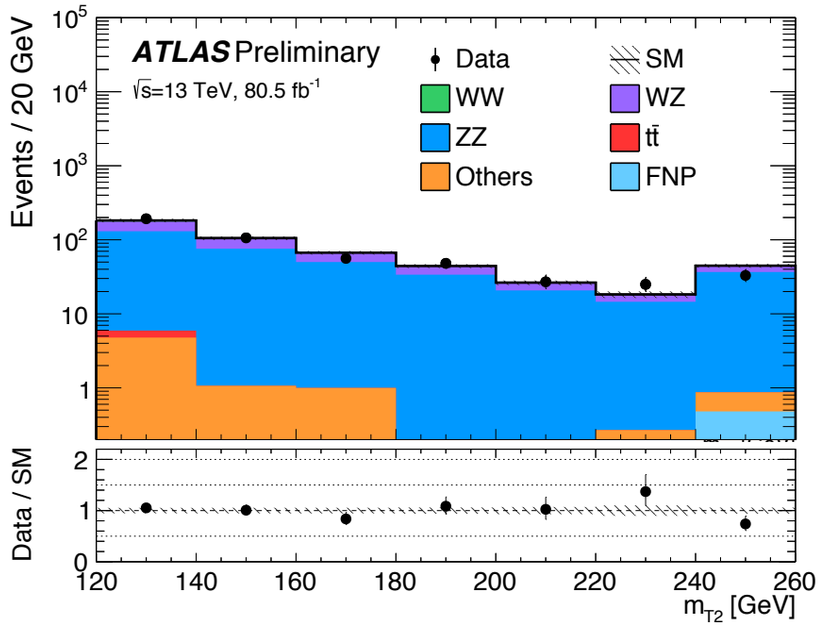
Signal regions:

- **2 OS p_T > 25 GeV leptons**
- same/different flavour (SF/DF) events
- **0 / 1 non-b-tagged jets**
- high m_{T2} (stransverse mass) separates signal from SM bkg (where m_{T2} is up to W mass)
- $m_{\ell\ell}$ > 25 GeV + |mZ - $m_{\ell\ell}$| > 30 GeV (SF only)
- **E_T^{miss} > 110 GeV**

Signal region (SR)	SR-DF-0J	SR-DF-1J	SR-SF-0J	SR-SR-1J
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$	$= 1$	$= 0$	$= 1$
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	–		>30	
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>110			
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	>10			
Binned SRs				
m_{T2} [GeV]	$\in [100,105]$ $\in [105,110]$ $\in [110,120]$ $\in [120,140]$ $\in [140,160]$ $\in [160,180]$ $\in [180,220]$ $\in [220,\infty]$			
Inclusive SRs				
m_{T2} [GeV]	$\in [100,\infty]$ $\in [160,\infty]$ $\in [100,120]$ $\in [120,160]$			

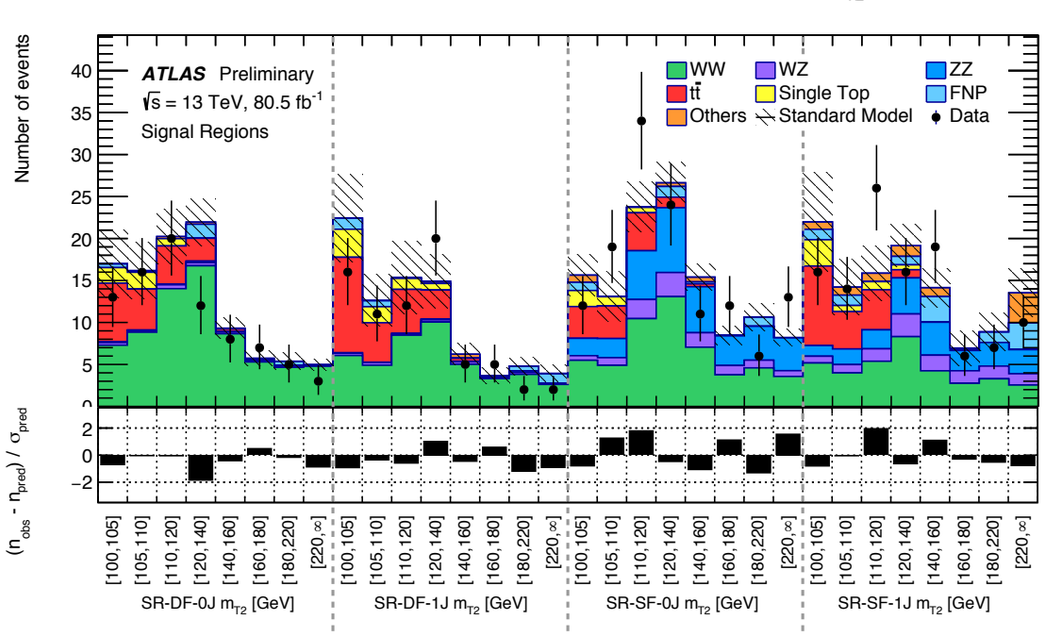
Direct chargino pair production with W-boson mediated decays in events with 2 leptons and missing energy (2/2)

ATLAS-CONF-2018-042

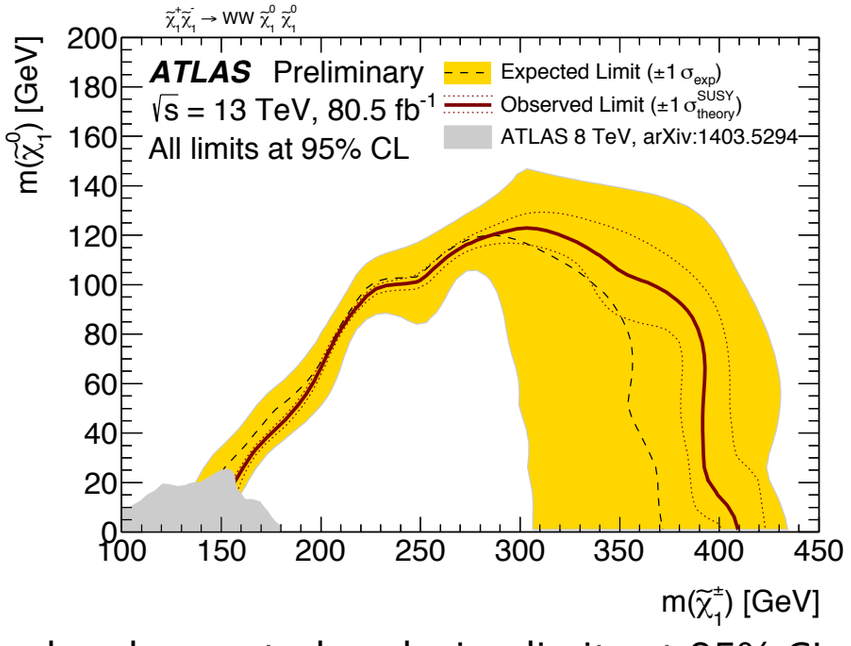


Control regions: some inverted cut or complementary mass region to estimate bkg from VZ, WW, top (very well modelled by MonteCarlo)

Fake non-prompt leptons estimated by matrix-method (data driven)



observed number of events
and the expected SM backgrounds
for each of the binned SRs



Observed and expected exclusion limits at 95% CL.

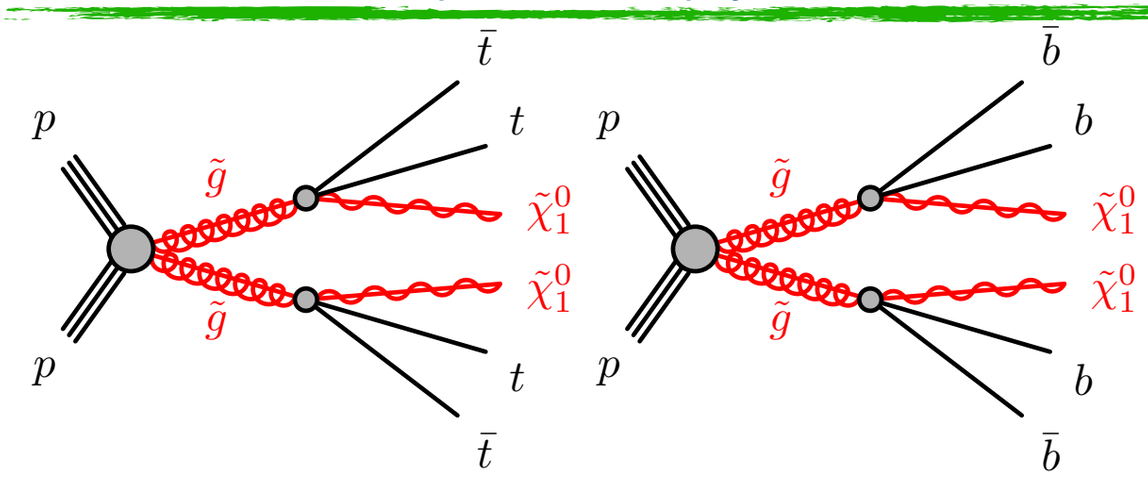
No excess above SM expectations.

For a massless LSP,

chargino masses up to 410 GeV are excluded.

Gluino pair production in final states with missing energy and multiple b-jets (1/2)

ATLAS-CONF-2018-041



Simplified models "Gbb" and "Gtt": gluino pair production with off-shell stop and sbottom squarks

80 fb^{-1} (2015-2017) at 13 TeV

- multiple b-jets*
- large E_T^{miss}
- 0/1 isolated electron or muon

* b-tagging: 77% efficient in simulated ttbar

- overlap removal between objects
- small-R reclustered to large-R (0.8)
- p_T > 100 GeV

Signal regions (SR):

- E_T^{miss} > 200 GeV
- at least 4 jets with at least 3 b-jets
- 0/1 leptons

$\Delta\phi_{\min}^{4j} = \min(|\phi_1 - \phi_{E_{\mathrm{T}}^{\mathrm{miss}}}|, \ldots, |\phi_4 - \phi_{E_{\mathrm{T}}^{\mathrm{miss}}}|)$ *QCD suppression*

minimum ΔΦ between leading 4 jets and MET **> 0.4**

$m_{\mathrm{eff}}^{\mathrm{incl}} = \sum_{i \le n} p_{\mathrm{T}}^{j_i} + \sum_{j \le m} p_{\mathrm{T}}^{\ell_j} + E_{\mathrm{T}}^{\mathrm{miss}}$ *Only signal objects used*

Inclusive effective mass **typically higher than SM bkg**

$m_{\mathrm{T,min}}^{b-\mathrm{jets}} = \min_{i \le 3} \sqrt{\left(E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}^{j_i}\right)^2 - \left(E_{\mathrm{T}}^{\mathrm{miss}}{}_x + p_x^{j_i}\right)^2 - \left(E_{\mathrm{T}}^{\mathrm{miss}}{}_y + p_y^{j_i}\right)^2}$

to reduce top semileptonic-decay bkg

Transverse mass of MET and *b*-jets *(leading 3 b-jets)*

$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos\Delta\phi\left(E_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{lepton}\right)\right)}$ *Regions with ≥1 lepton*

Transverse mass leptonic W **to reduce W leptonic-decay bkg**

$M_J^{\Sigma,4} = \sum_{i \le 4} m_{J,i}$ *Sum of 4 leading reclustered jets*

Total jet mass

$|\Delta\phi(j_1, E_{\mathrm{T}}^{\mathrm{miss}})|$ *Helps select high pT ISR jets in Gbb*

dPhi jet MET

figure by Giordon Stark

Gluino pair production in final states with missing energy and multiple b-jets (2/2)

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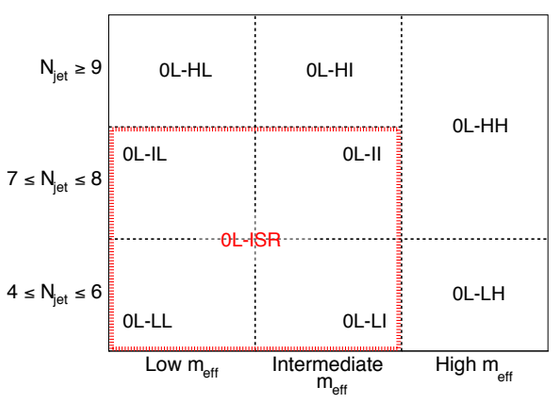
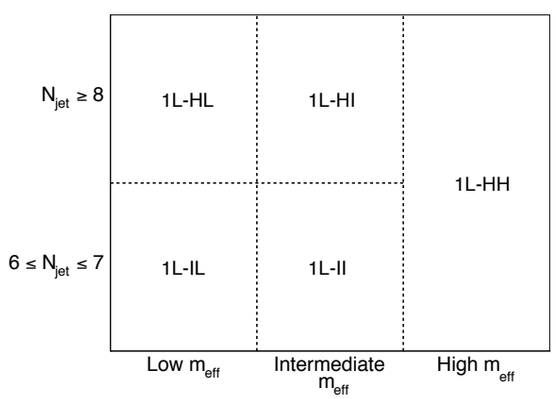
Cut-and-count analysis

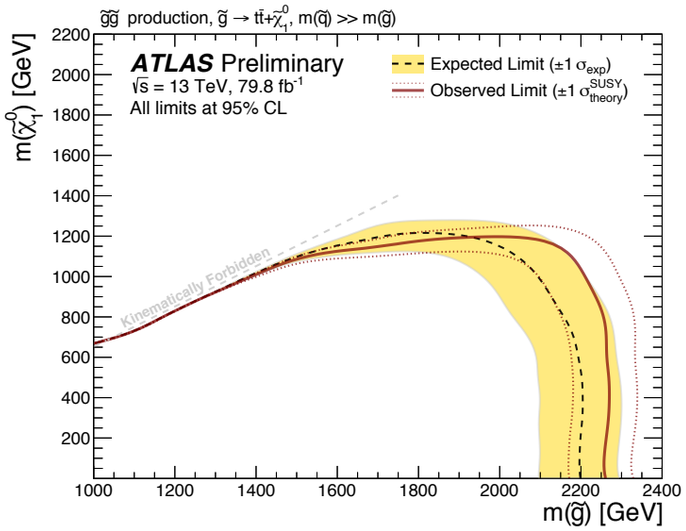
- maximises discovery for benchmark models, allows re-interpretation
- SRs optimised for $\tilde{g}$ and $\tilde{\chi}_1^0$ mass difference (< 0.3 up to > 1.5 TeV)

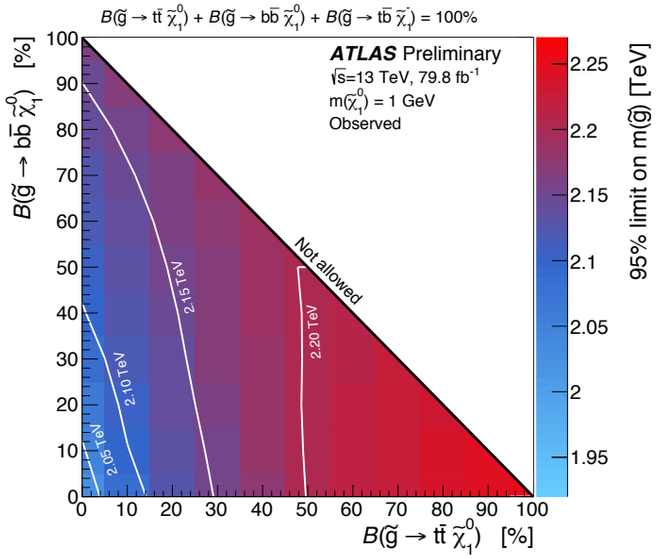
Multi-bin analysis

- optimized for SUSY exclusion
- Several orthogonal signal regions to be statistically combined to produce a strong model dependent exclusion









- **No significant excess is found above the predicted background in any of the signal regions.**
- Model-independent limits are set on the visible cross-section for new physics processes.
- Exclusion limits are set on gluino and LSP masses in two simplified models where the gluino decays exclusively as $\tilde{g} \rightarrow b\bar{b}\tilde{X}_1^0$ or $\tilde{g} \rightarrow t\bar{t}\tilde{X}_1^0$
- **For LSP masses below approximately 800 GeV, gluino masses of less than 2.2 TeV are excluded at the 95% CL** for the simplified models.
- The results are also interpreted in a model with variable gluino branching ratios to $\tilde{g} \rightarrow b\bar{b}\tilde{X}_1^0$, $\tilde{g} \rightarrow t\bar{t}\tilde{X}_1^0$, $\tilde{g} \rightarrow t\bar{b}\tilde{X}_1^0$

Summary

- A collection of **most recent results** of BSM signatures in SUSY and Exotics searches have been presented
  - focus on different leptonic signatures
  - + combination of (fully) hadronic searches
  - + missing transverse momenta related to lightest neutral and/or very long-lived particles

- **No excess beyond SM expectations** has been observed so far, but **stronger limits and constraints** are set on new particles' masses, coupling constants etc…
  - Results are interpreted both in terms of specific models and **model-independent signatures**

- The ATLAS programme for BSM searches is very wide and the Collaboration is very active.
  - The detector is performing extremely well
  - Many searches updating their results with more and more integrated luminosity
  - Stay tuned for upcoming news!!!