ATLAS results on searches for exotic new particles

Sara Alderweireldt
on behalf of the ATLAS Collaboration

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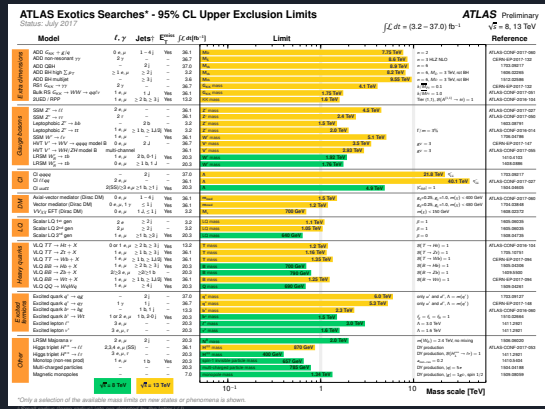
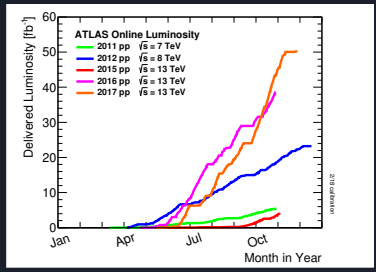
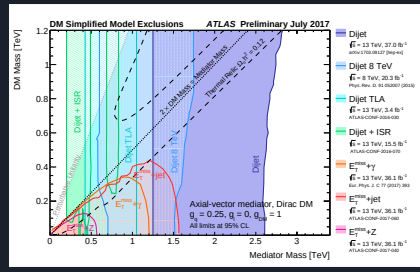
Introduction

- Many BSM theories:
  - Grand Unification Theory
  - Sequential Standard Model
  - Dark sector extensions
  - Two-Higgs-doublet model
  - Triplets
  - Extra dimensions
  - Gravitons
  - …
- Many final states and many regions of phase space to consider
  - Search for any deviation from the SM prediction
- Pushing limits both at high and low mass
- 2015+2016 dataset: 36.1 fb^{-1}







Overview

Search for Higgs decays to beyond the standard model light gauge bosons in **four-lepton events** with the ATLAS detector at $\sqrt{s}$ = 13 TeV	$H(125) \rightarrow XX \rightarrow 4l$	EXOT-2016-22	leptonic	low mass
Search for doubly charged Higgs boson production in **multi-lepton final states** with the ATLAS detector using proton–proton collisions at $\sqrt{s}$ = 13 TeV	$pp \rightarrow H^{++}H^{--}$ $\rightarrow l^+l^+l^-l^-$	EXOT-2016-07	leptonic	high mass
Search for heavy resonances decaying into a W or Z boson and a Higgs boson in final states with **leptons and b-jets** in 36 fb^{-1} of $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector	$V' \rightarrow VH$ $\rightarrow (lv/ll/vv)bb$	EXOT-2016-10	semi-leptonic	intermediate/ high mass
Search for WW/WZ resonance production in $lvqq$ **final states** in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$X \rightarrow WV \rightarrow lvqq$	EXOT-2016-28	semi-leptonic	intermediate/ high mass
Search for light resonances decaying to **boosted quark pairs** and produced **in association with a photon or a jet** in proton–proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$ISR(\gamma/j)$ $+$ *boosted* jj	EXOT-2017-01	hadronic	low mass
Search for dark matter and other new phenomena in events with an **energetic jet and large missing transverse momentum** using the ATLAS detector	$jet + E_T^{miss}$	EXOT-2016-27	hadronic	high mass
Search for pair production of up-type vector-like quarks and 4t-quark events in **final states with multiple b-jets** with the ATLAS detector	$T\overline{T} \rightarrow \ Ht + X$	EXOT-2016-13	hadronic	high mass
Search for $W' \rightarrow tb$ **decays in the hadronic final state** using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$W' \rightarrow tb$	EXOT-2017-02	hadronic	high mass
A search for high-mass resonances **decaying to** $\tau\nu$ in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$W' \rightarrow \tau\nu$	EXOT-2017-06	hadronic	high mass

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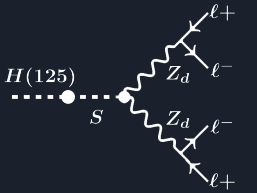
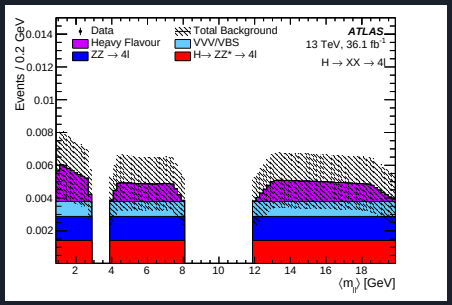
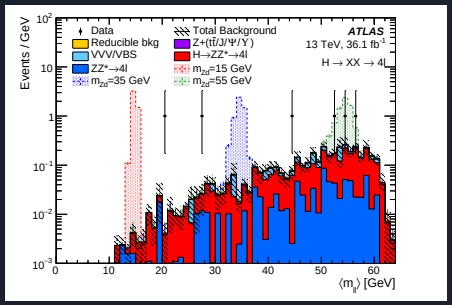
Higgs decays to light bosons $H(125) \to XX \to 4l$



- **motivation:** higgs portal models, hidden sectors, dark matter
  → setting upper limits on the Higgs boson branching ratio to BSM particles
- three analysis regions targetting different processes
  - H(125)→ZX→4l (2l2e and 2l2μ)
  - H(125)→XX→4l, m(X) ∈ [15,60] GeV (4e, 2e2μ and 4μ)
  - H(125)→XX→4l, m(X) ∈ [1,15] GeV (4μ)
- X is new vector boson Z_d or pseudoscalar a with low mass

EXOT-2016-22 – leptonic





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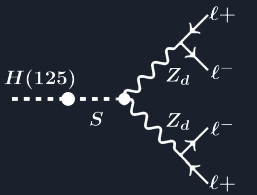
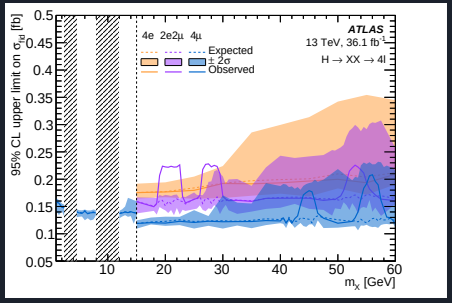
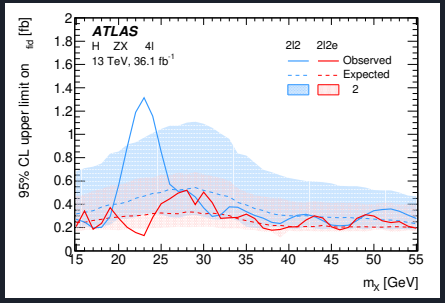


- set 95% CL upper limits on the fiducial cross section for H→ZX→4l & H→XX→4l (model independent)
- upper limits are applicable to any model with H(125) decays to 4 leptons via two intermediate, on-shell, narrow, promptly-decaying bosons

leptonic – EXOT-2016-22



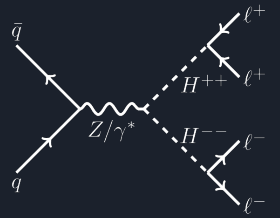
H(125)→XX→4l



H(125)→ZX→4l

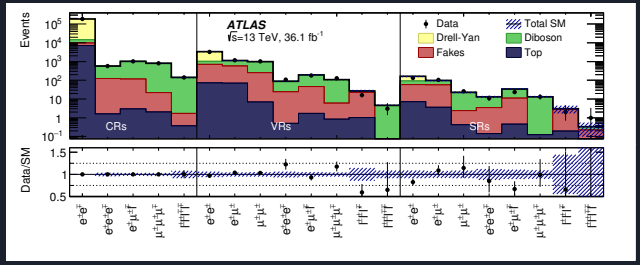
Doubly Charged Higgs

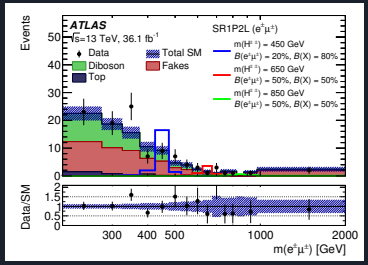
$pp \to H^{++}H^{--} \to l^+l^+l^-l^-$



- dedicated 2-, 3-, and 4-lepton channels to optimize signal acceptance
- fit invariant mass
  - invariant mass of same-charge lepton pair in 2- and 3-lepton channels
  - average mass in 4-lepton channel
- dominant systematic uncertainties
  - fake leptons
  - charge misidentification
  - background estimation

leptonic – EXOT-2016-07





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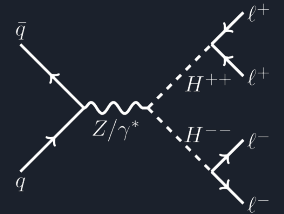
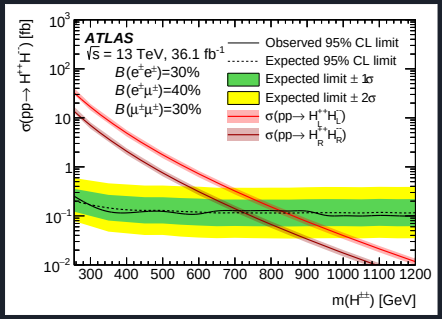
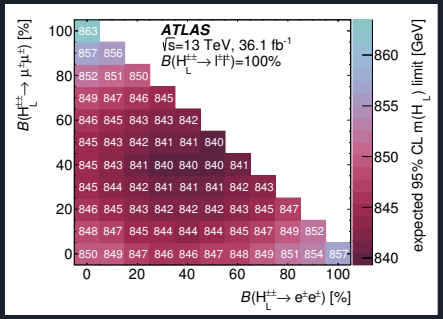


- set lower limit on m($H^{\pm\pm}$) at 95% CL
- B($H^{\pm\pm}\to e^{\pm}e^{\pm}$) + B($H^{\pm\pm}\to e^{\pm}\mu^{\pm}$) + B($H^{\pm\pm}\to \mu^{\pm}\mu^{\pm}$) = B($H^{\pm\pm}\to l^{\pm}l^{\pm}$)
- mass limit derived for all combinations of the partial branching ratios
  - lower limit above 770 (450) GeV for B($H^{\pm\pm}\to l^{\pm}l^{\pm}$) = 100(10)% for $H_L^{\pm\pm}$
  - lower limit above 670 (320) GeV for B($H^{\pm\pm}\to l^{\pm}l^{\pm}$) = 100(10)% for $H_R^{\pm\pm}$





leptonic – EXOT-2016-07

Doubly Charged Higgs

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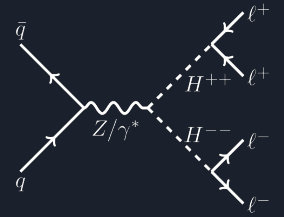

- the muon channel is the most powerful, but the differences are small
- minimum limit as a function of $B(H^{\pm\pm} \to l^{\pm}l^{\pm})$
- limits derived for $H_L^{\pm\pm}$ and $H_R^{\pm\pm}$
  - lower limit above 770 (450) GeV for $B(H^{\pm\pm} \to l^{\pm}l^{\pm}) = 100(10)\%$ for $H_L^{\pm\pm}$
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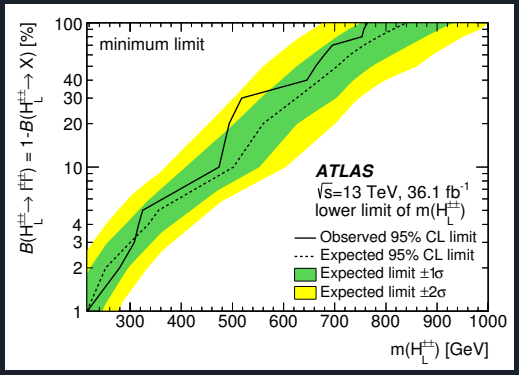
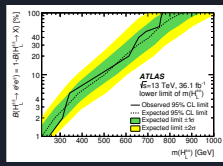
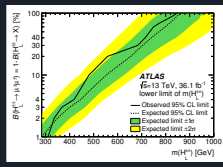
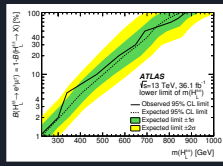




$e^{\pm}e^{\pm}$



$\mu^{\pm}\mu^{\pm}$



$e^{\pm}\mu^{\pm}$

leptonic – EXOT-2016-07

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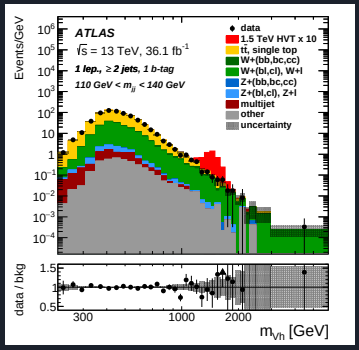
Heavy resonance → VH in semi leptonic decays

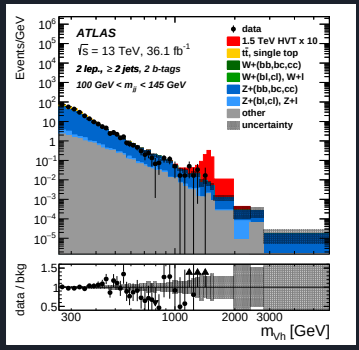
$W'/Z'/ggF\ A/bbA \rightarrow\ VH \rightarrow\ (l\nu/ll/\nu\nu)bb$

- **motivation:** heavy resonances, 2HDM, heavy vector triplets, …
- analysis setup using dedicated categories
  - 0-2 lepton channels
  - resolved or merged bb regimes *(small- and large-R jets)*
  - various multiplicities of main and additional b-jets
- reconstructed resonance mass dependent on channel: m_{Vh} and $m_{T,Vh}$

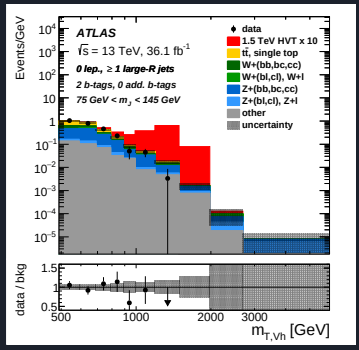
semi-leptonic – EXOT-2016-10



resolved, 1 lep, 2+ jets, 1 b-tag



resolved, 2 lep, 2+ jets, 2 b-tags

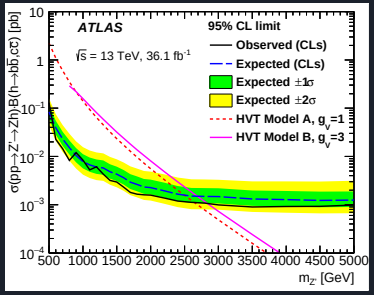


merged, 0 lep, 1+ large-R jet, 2+0 b-tags

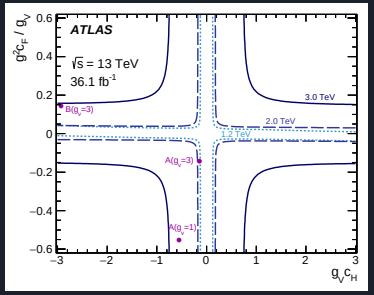
Heavy resonance → VH in semi leptonic decays

$W'/Z'/ggF\ A/bbA \rightarrow\ VH \rightarrow\ (l\nu/ll/\nu\nu)bb$

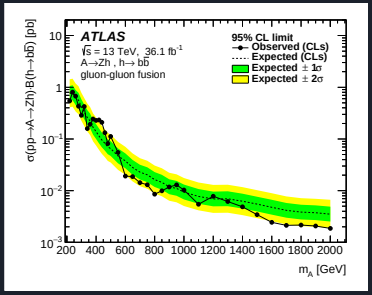
- 95% CL upper limits for Z′→Zh & W′→Wh production
- observed exclusion contours in the HVT parameter space
- 95% CL upper limits for A→Zh with h→bb
- interpretations following various models available in the paper



Z′→Zh



HVT exclusion contours



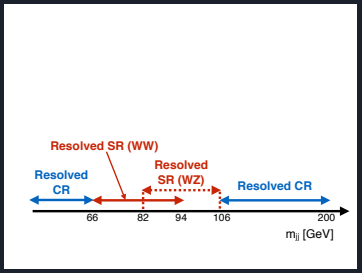
A→Zh with h→bb

Heavy resonance → WV in semi leptonic decays

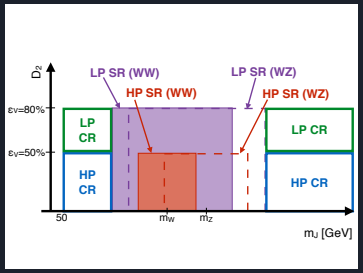
$X \to WV \to lvqq$

- **motivation:** composite H, extra dimensions, heavy vector triplets, …
- analysis using dedicated categorization
  - merged (lvJ) or resolved (lvjj) quark pair
  - low- or high purity boson tagging (D_2)
  - WW or WZ signal
  - DY or VBF production

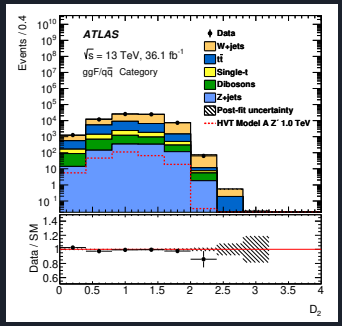
semi-leptonic – EXOT-2016-28



resolved



merged



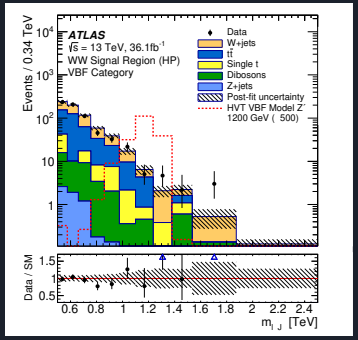
D_2 variable

Heavy resonance → WV in semi leptonic decays

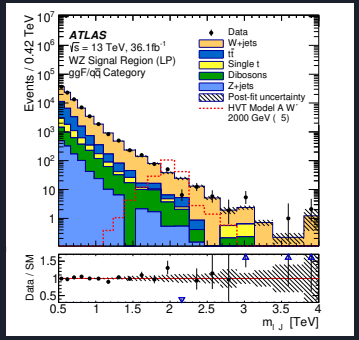
$X \to WV \to lvqq$

- **motivation:** composite H, extra dimensions, heavy vector triplets, …
- analysis using dedicated categorization
  - merged (lvJ) or resolved (lvjj) quark pair
  - low- or high purity boson tagging (D_2)
  - WW or WZ signal
  - DY or VBF production
- perform simultaneous binned ML fit to m(WV) distributions

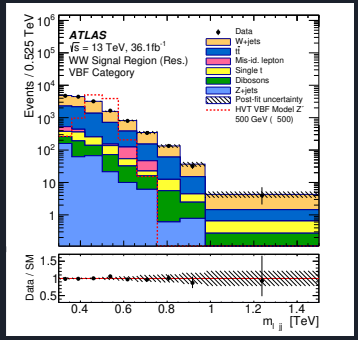
semi-leptonic – EXOT-2016-28



merged, VBF, WW, high-purity



merged, ggF, WZ, low-purity

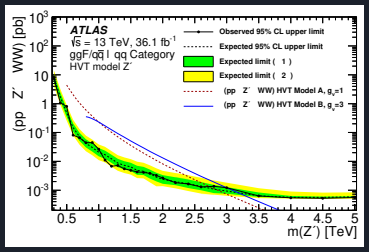


resolved, VBF, WW

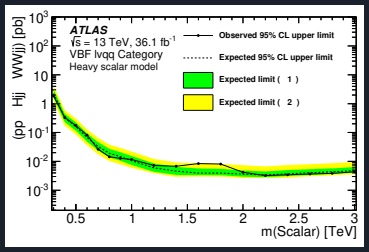
Heavy resonance → WV in semi leptonic decays

$X \to WV \to lvqq$

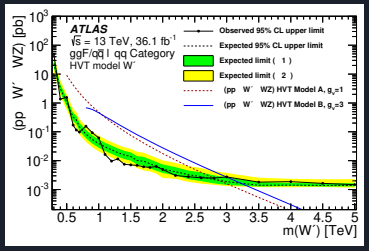
- 95% CL upper limits for various models; more in the paper
- largest excess 2.7σ local



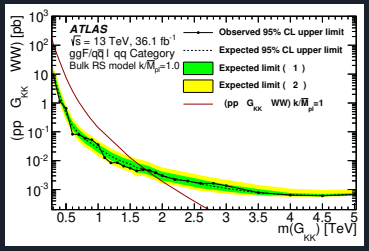
VBF, HVT model Z′



VBF, Heavy-scalar model



ggF, HVT model W′



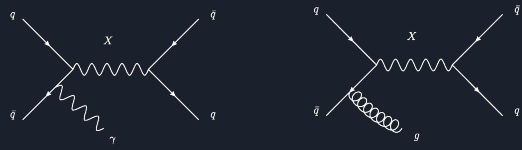
ggF, graviton model

Overview

Search for Higgs decays to beyond the standard model light gauge bosons in **four-lepton events** with the ATLAS detector at $\sqrt{s}$ = 13 TeV	$H(125) \rightarrow XX \rightarrow 4l$	EXOT-2016-22	leptonic	low mass
Search for doubly charged Higgs boson production in **multi-lepton final states** with the ATLAS detector using proton–proton collisions at $\sqrt{s}$ = 13 TeV	$pp \rightarrow H^{++}H^{--}$ $\rightarrow l^+l^+l^-l^-$	EXOT-2016-07	leptonic	high mass
Search for heavy resonances decaying into a W or Z boson and a Higgs boson in final states with **leptons and b-jets** in 36 fb^{-1} of $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector	$V' \rightarrow VH$ $\rightarrow (lv/ll/vv)bb$	EXOT-2016-10	semi-leptonic	intermediate/ high mass
Search for WW/WZ resonance production in $lvqq$ **final states** in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$X \rightarrow WV \rightarrow lvqq$	EXOT-2016-28	semi-leptonic	intermediate/ high mass
Search for light resonances decaying to **boosted quark pairs** and produced **in association with a photon or a jet** in proton–proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$ISR(\gamma/j)$ + boosted jj	EXOT-2017-01	hadronic	low mass
Search for dark matter and other new phenomena in events with an **energetic jet and large missing transverse momentum** using the ATLAS detector	$jet + E_T^{miss}$	EXOT-2016-27	hadronic	high mass
Search for pair production of up-type vector-like quarks and 4t-quark events in **final states with multiple b-jets** with the ATLAS detector	$T\overline{T} \rightarrow Ht + X$	EXOT-2016-13	hadronic	high mass
Search for $W' \rightarrow tb$ **decays in the hadronic final state** using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$W' \rightarrow tb$	EXOT-2017-02	hadronic	high mass
A search for high-mass resonances **decaying to** $\tau\nu$ in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$W' \rightarrow \tau\nu$	EXOT-2017-06	hadronic	high mass

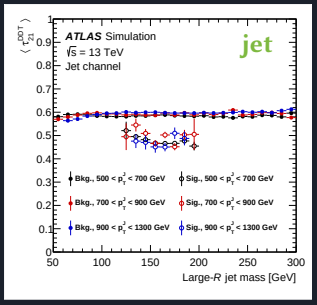
Light resonances decaying to boosted quark pairs

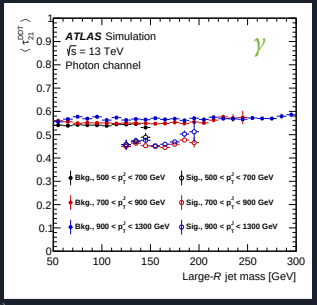
- **motivation:** many models with mediators coupling to quarks & gluons
  - look at lower mass with ISR *($m_{Z'} < 200$ GeV)*
  - ISR allows highly efficient triggering at lower masses
    (compared to regular triggering on the resonance decay products)



- **topologies:**
  - 1 isolated γ + 1 large-R jet
  - 1 small-R jet + 1 large-R jet
- making use of τ_{21} substructure variable and Designed Decorrelated Tagger
  (DDT;removing dependence of τ_{21} on jet mass and p_T)
  - τ_N a measure of a jet's compatibility with being fully aligned along N axes
  - $\tau_{21} = \tau_2/\tau_1$ differentiates two-particle jets from the decay of a boosted resonance & a single-particle jet
  - aim to separate large-R signal jets and QCD γ+jet background
- background estimate using transfer factor method

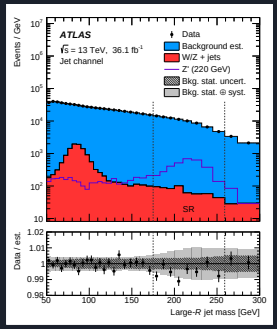
ISR(γ/j) + boosted jj

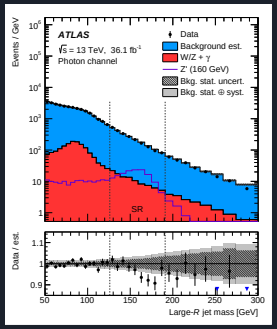




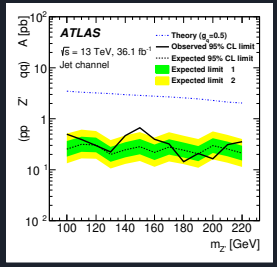
Light resonances decaying to boosted quark pairs

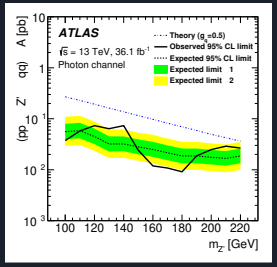
ISR(γ/j) + boosted jj

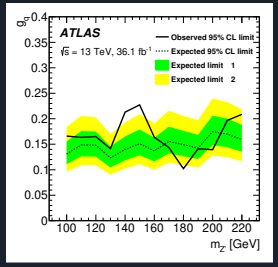




- fit of large-R jet mass in jet & photon channels
  - background estimated separately per candidate mass
- 95% CL limits on the Z′ cross section
- channels combined for limit on coupling g_q
- largest excess in the jet (γ) channel at $m_{Z'}$ = 150 (140) GeV with local significance 2.5 (2.2)σ







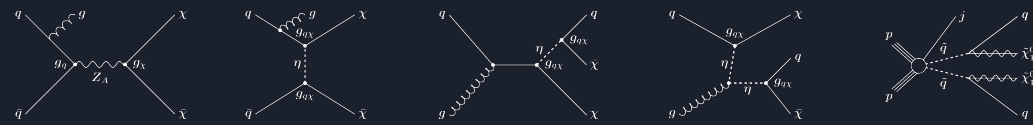
Monojets and missing transverse momentum

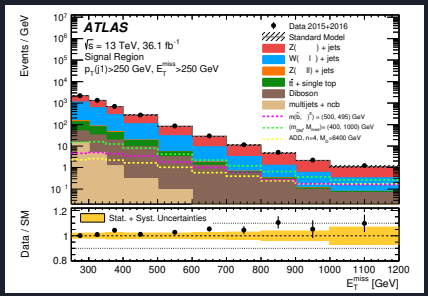
jet + E_T^{miss}

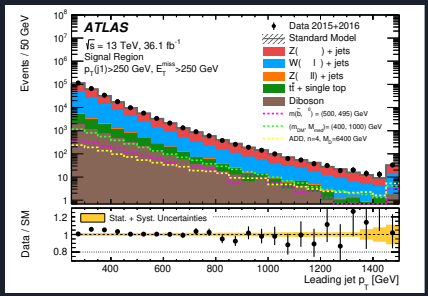
- **motivation:** dark matter, compressed SUSY, extra dimensions, …
  - many possible diagrams
- **requiring:** large missing transverse energy + 1 high-p_T jet + ≤3 more jets (p_T >30 GeV) + no leptons
- background is constrained using a likelihood fit to the E_T^{miss} distribution in a set of control regions, taking into account systematic uncertainties

EXOT-2016-27

hadronic –



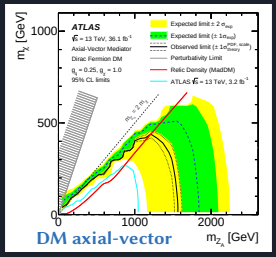




Monojets and missing transverse energy

monojet + E_T^{miss}

- setting model-independent limits using inclusive signal regions
- providing exclusion limits for a wide range of models (more in the paper)



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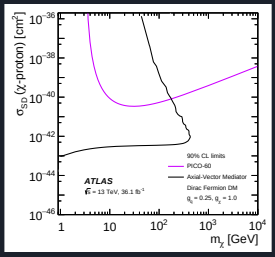
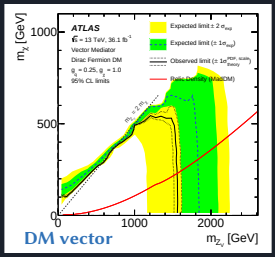
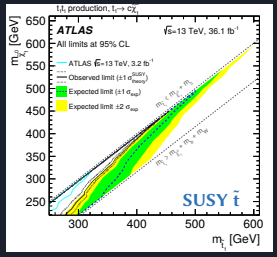
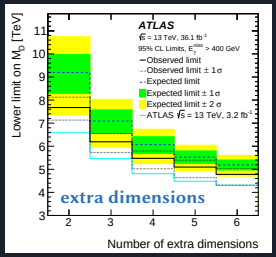


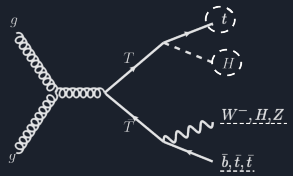






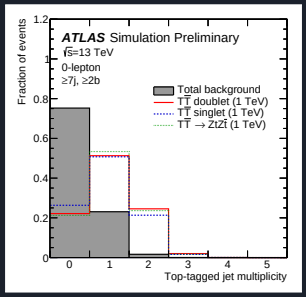
Pair production of vector like quarks

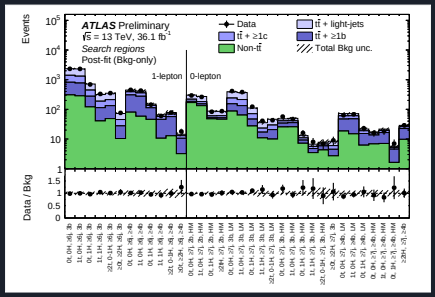
$T\bar{T} \rightarrow Ht + X$

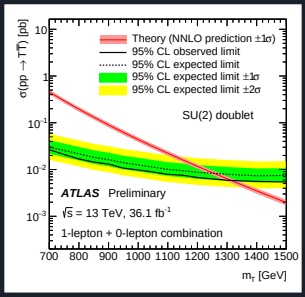


- **motivation:** alternative for 4th generation quarks; hierarchy problem
  decays to vector bosons and 3rd generation quarks
- **approach: 0/1-lepton + (many) jets, some b-tagged**
  - 1-lepton = lepton + jets: sensitive to $T \rightarrow tH(bb)$ (12 regions)
  - 0-lepton = jets + MET: sensitive to $T \rightarrow tZ(\nu\nu)$ (22 regions)
- make use of Higgs and top tagging: categorize using N(H), N(t), N(b), N(j) multiplicities
- ML fit of effective mass
- derive 95% CL limit on production cross section

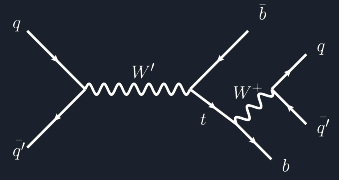
hadronic – EXOT-2016-13





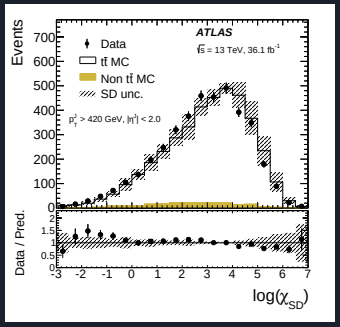


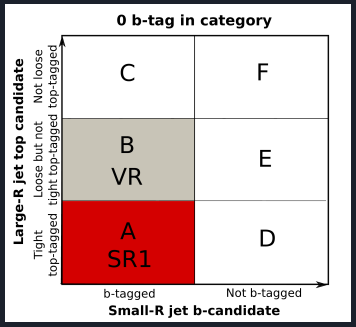
Hadronic $W' \to tb$

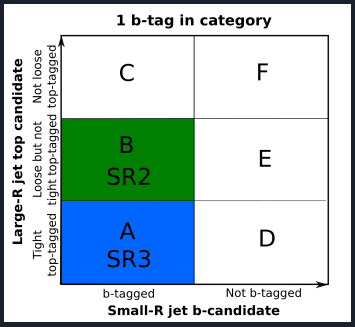


- **motivation:** universal extra dimensions, little Higgs, top assisted technicolor, Kaluza-Klein gravitons, …
  - tb final state sensitive to right handed W's
- **topology:** 1 high-p_T *b-jet* + 1 large-R *top-jet* (bqq)
- **categorize:**
  - 0 or 1 b-tag
  - 6 regions each based on b- and top tagging criteria
- making use of shower deconstruction top tagger

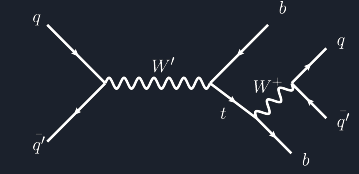
[1] https://journals.aps.org/prd/abstract/10.1103/PhysRevD.84.074002
[2] https://journals.aps.org/prd/abstract/10.1103/PhysRevD.87.054012



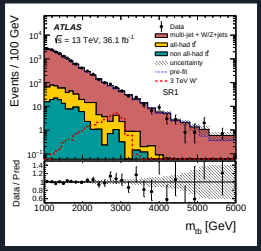


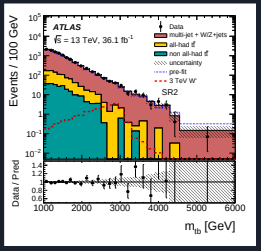


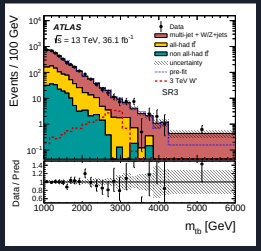
Hadronic $W' \to tb$

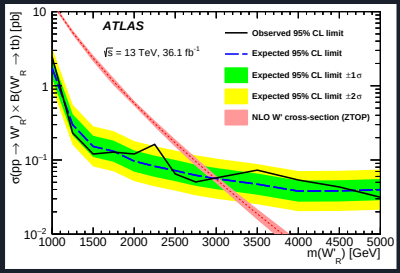


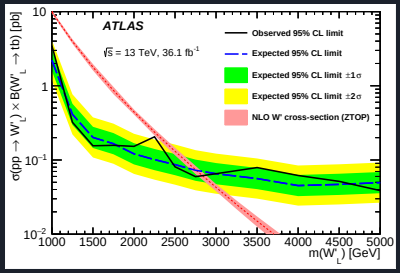
- fit reconstructed m_{tb} in signal and validation regions
- derived 95% CL limits on the cross section
- largest excess at m = 2.25 TeV with local significance of 2.0σ









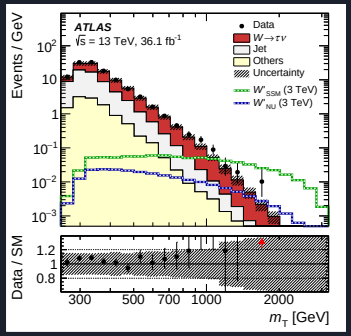


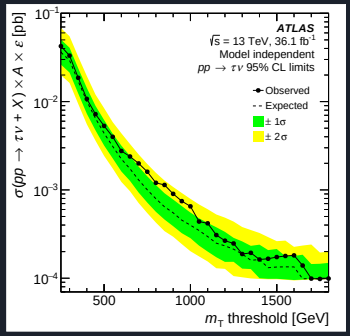
Heavy resonances decaying to taus

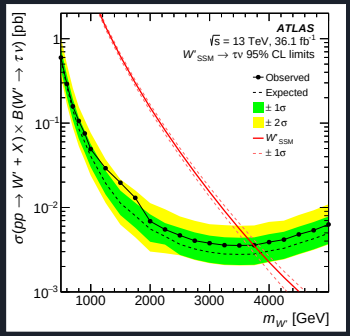
$W' \to \tau\nu$

hadronic – EXOT-2017-06

- **motivation:** W′ preferential coupling to 3rd gen as explanation for anomalies, mass hierarchy, …
  - might not appear in e/μ final states and therefore requires targetted τ search
- selecting events with taus and large missing transverse energy
- deriving model-independent 95% CL limits
- interpretations in SSM and non-universal G(221)







Summary

- presented 9 recent ATLAS exotics searches using the 2015+2016 dataset (36.1 fb^{-1})
- results covering many final states and a wide range of masses
- derivation of model-independent limits as well as interpretations testing a large number of models
- no hints of new physics yet

Search for Higgs decays to beyond the standard model light gauge bosons in **four-lepton events** with the ATLAS detector at $\sqrt{s}$ = 13 TeV	$H(125) \to XX \to 4l$	EXOT-2016-22	leptonic	low mass
Search for doubly charged Higgs boson production in **multi-lepton final states** with the ATLAS detector using proton–proton collisions at $\sqrt{s}$ = 13 TeV	$pp \to H^{++}H^{--}$ $\to l^{+}l^{+}l^{-}l^{-}$	EXOT-2016-07	leptonic	high mass
Search for heavy resonances decaying into a W or Z boson and a Higgs boson in final states with **leptons and b-jets** in 36 fb^{-1} of $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector	$V' \to VH$ $\to (l\nu/ll/\nu\nu)bb$	EXOT-2016-10	semi-leptonic	intermediate/ high mass
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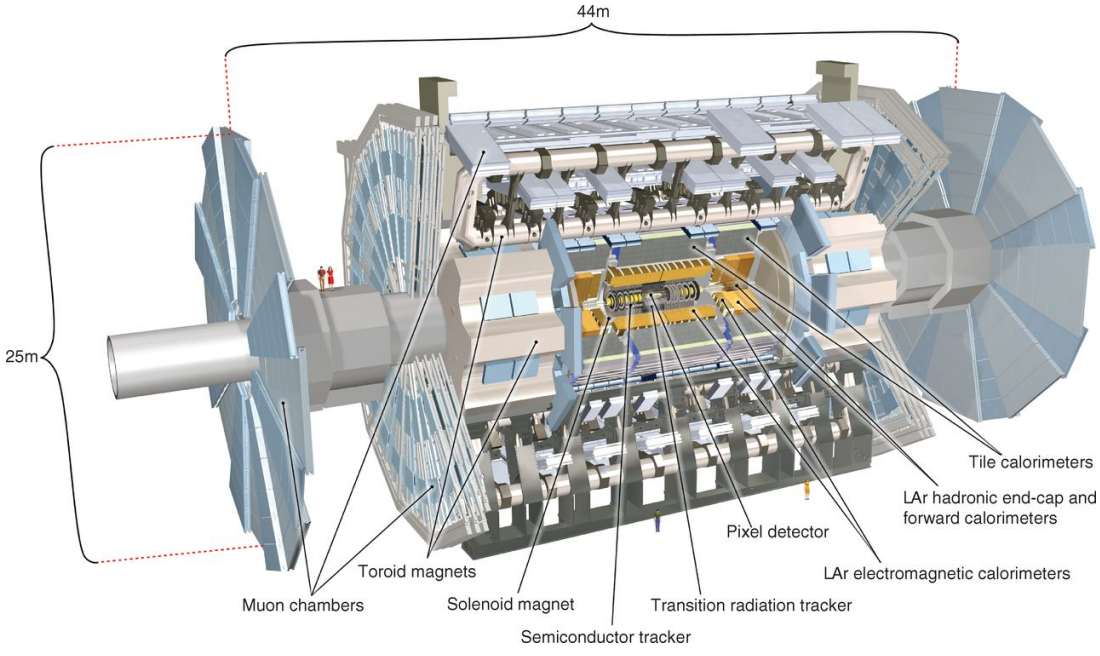
Search for pair production of up-type vector-like quarks and 4t-quark events in **final states with multiple b-jets** with the ATLAS detector	$T\overline{T} \to Ht + X$	EXOT-2016-13	hadronic	high mass
Search for $W' \to tb$ **decays in the hadronic final state** using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$W' \to tb$	EXOT-2017-02	hadronic	high mass
A search for high-mass resonances **decaying to** $\tau\nu$ in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	$W' \to \tau\nu$	EXOT-2017-06	hadronic	high mass

- for the future
  - more data to be analysed (2017+2018)
  - several more results in the pipeline
  - all public results at: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

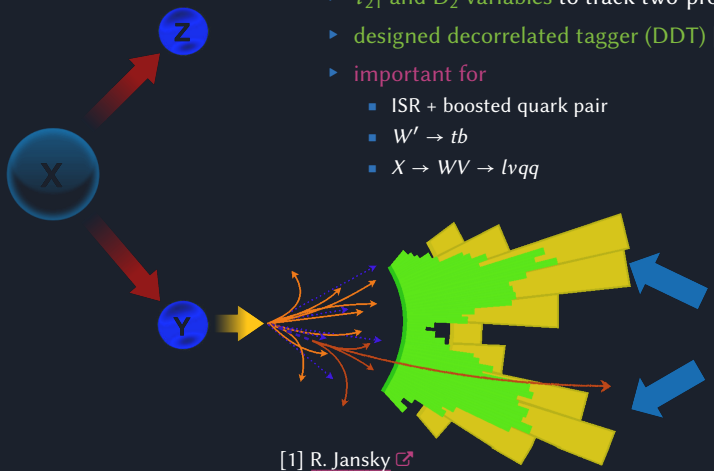
Backup

ATLAS

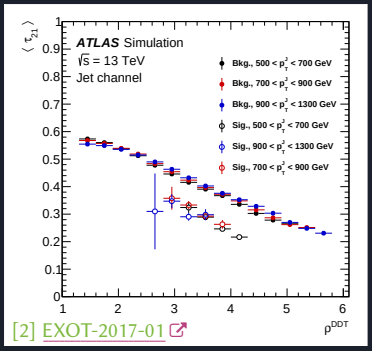

44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

Jet substructure

- crucial tool in searches for resonances decaying to highly boosted
  - quark pairs, SM bosons, top quarks
- τ_{21} and D_2 variables to track two-pronged signal jets [2],[3]
- designed decorrelated tagger (DDT) [4] to remove dependence on mass & p_T
- important for
  - ISR + boosted quark pair
  - $W' \to tb$
  - $X \to WV \to lvqq$



[1] R. Jansky

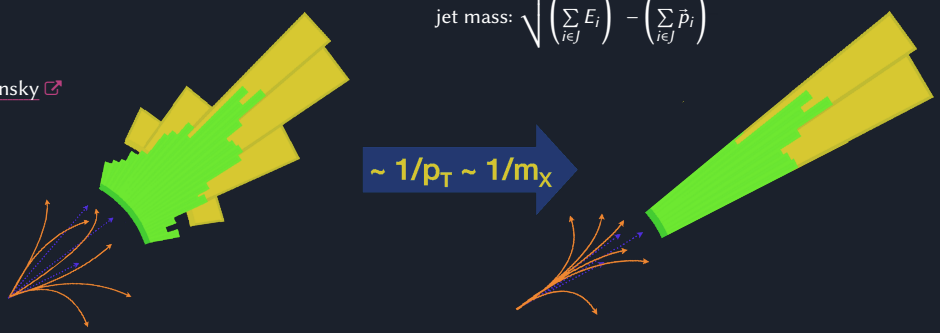


[2] EXOT-2017-01

Jet substructure

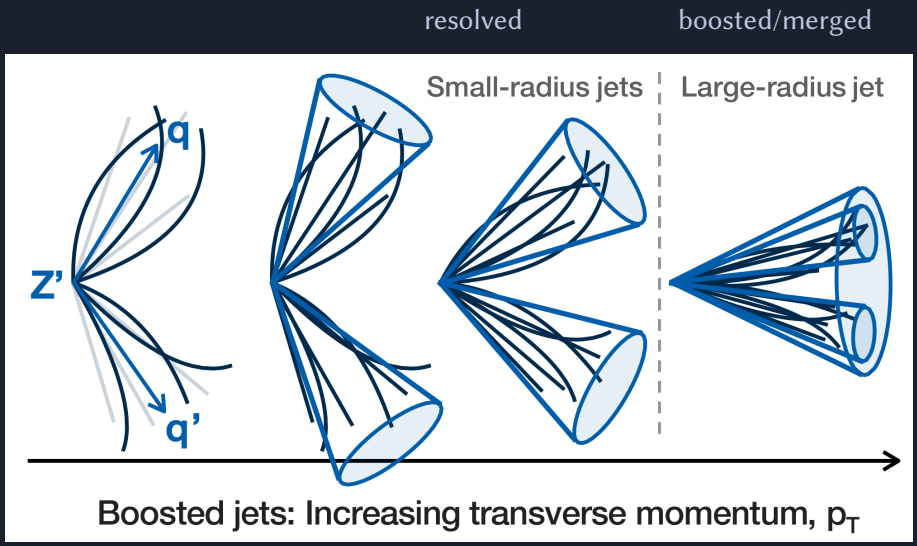
jet mass: $\sqrt{\left(\sum_{i\in J} E_i\right)^2 - \left(\sum_{i\in J} \vec{p}_i\right)^2}$

[1] R. Jansky



- currently mostly using calorimeter-based jet substructure
- gain from including tracker information in substructure measurements

Jets



[1] R. Jansky