Searches for new heavy resonances in hadronic final states with the ATLAS detector

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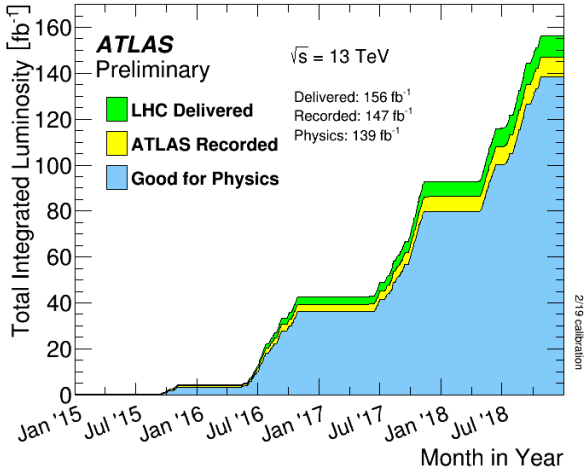
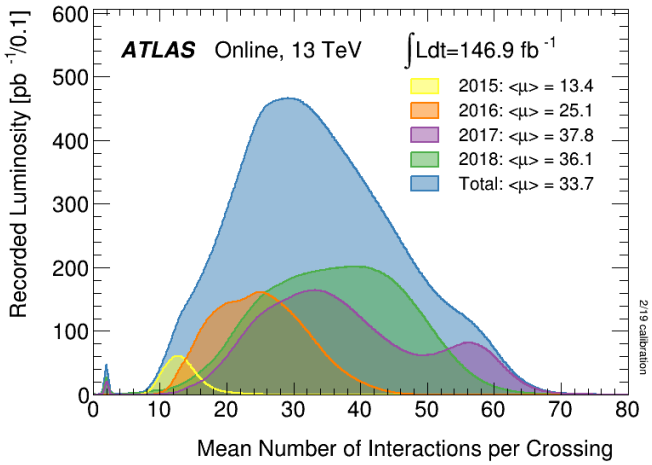
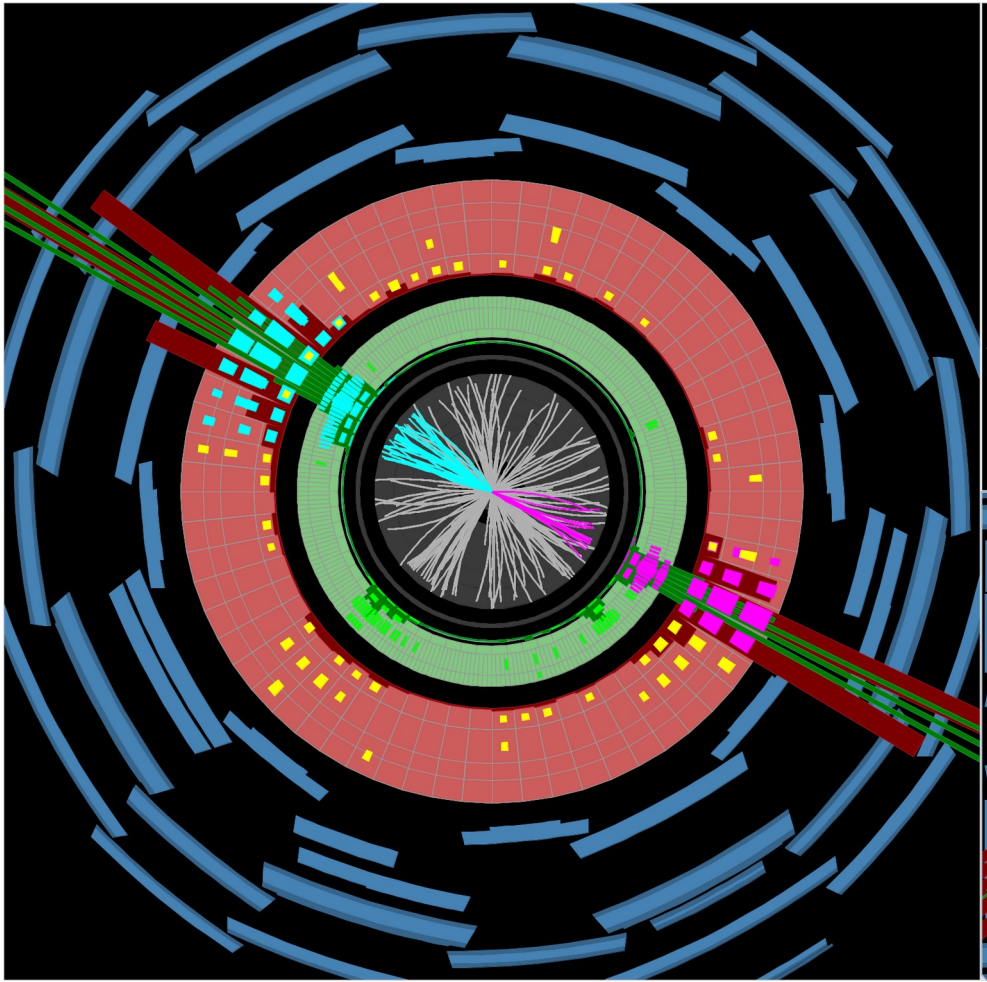
On Behalf of the ATLAS Collaboration

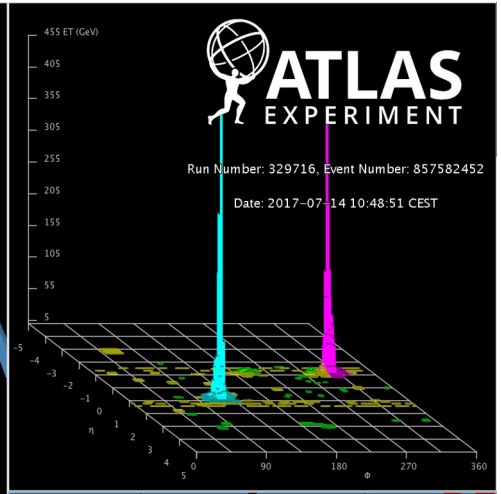
The Run-2 Legacy

- During Run-2 ATLAS recorded 147 fb^{-1} of 13 TeV pp data
  - With **139 fb^{-1}** (95%) Good for Physics
  - Average of 33.7 proton-proton interactions per bunch crossing
    - Well above detector design luminosity
- This large data set is now being used for the Run-2 legacy physics program
  - Additional improvements in Jet Calibration and Flavor Tagging performance has enabled more precise results
    - Jet Performance – E. Hanson





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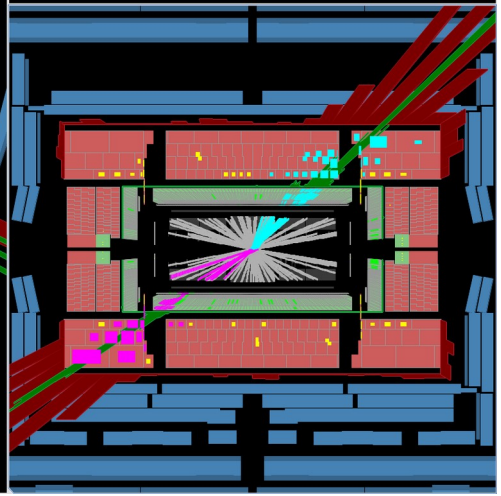

Search for Di-jet Resonances

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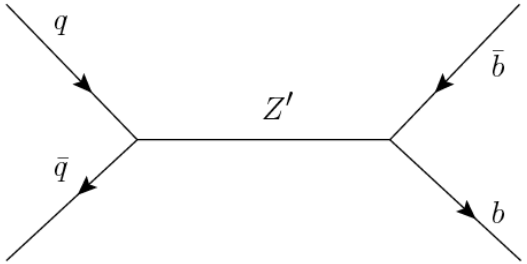

- Legacy Run-2 result searching for resonances in the invariant mass spectrum of leading pairs of jets
  - Results in the inclusive spectrum and those identified as coming from b-quarks
    - Searching in the b-tagged spectrum improves sensitivity to new physics in the 3rd generation and DM models
- This result includes new models and a comparison to the analysis techniques of the previous paper
- Analysis uses a single jet trigger with a threshold of 420 GeV
  - The lowest m_{jj} the analysis can test is determined by this trigger threshold

Category	Inclusive		1b	2b
Jet p_T	> 150 GeV			
Jet ϕ	$\lvert\Delta\phi(jj)\rvert > 1.0$			
Jet $\lvert\eta\rvert$	—		< 2.0	
$\lvert y^*\rvert$	< 0.6	< 1.2	< 0.8	
m_{jj}	> 1100 GeV	> 1717 GeV	> 1133 GeV	
b-tagging	no requirement		$\geqslant 1$ b-tagged jet	2 b-tagged jets
Signal	DM mediator Z' W' q^* QBH Generic Gaussian	W^*	b^* Generic Gaussian	DM mediator Z' $(b\bar{b})$ SSM Z' $(b\bar{b})$ graviton $(b\bar{b})$ Generic Gaussian

Statistical Treatment & Search Phase

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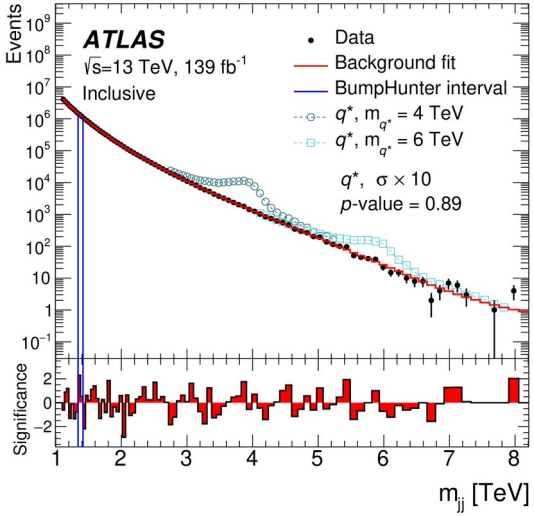
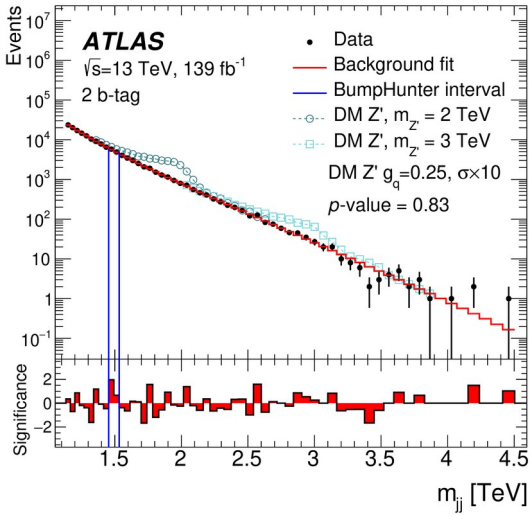
- Invariant mass spectrum of leading jets is fit with an analytic function

$$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x} \qquad \text{where} \qquad x = m_{jj}/\sqrt{s}$$

- BumpHunter algorithm used to test consistency of the fit with the observed data to search for excesses
  - Inclusive: 1.4 TeV (5 TeV) |y*| < 0.6 (1.2) with p-value of 0.89 (0.88)
  - B-tagged: 1.8 TeV (1.5 TeV) >1 (2) b-tag category with p-value of 0.69 (0.83)
- No significant excesses in any channel





Systematic Uncertainties

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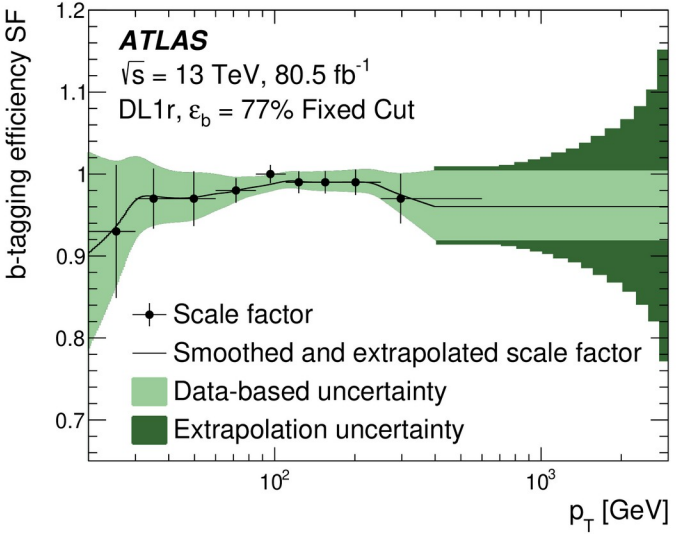
- Experimental systematic uncertainties on the background modeling are from the choice of analytic function and limited size of the data sample
  - Evaluated using pseudo-experiments of Poisson fluctuations of the observed data and alternative functions
    - Impact is 30-40% for the high mass tails but only 0.1% at 2 TeV
- The main systematic uncertainties on signal MC are Jet Energy Scale(JES), Jet Energy Resolution(JER), and flavor-tagging uncertainty
  - JES is 2% for m_{jj} < 5 TeV and 4% above
  - JER varies from 3-6% across the m_{jj} range
  - Flavor tagging uncertainty varies from 2% at jet-p_T of 90 GeV up to 20% for jet-p_T of 3



Limits Set

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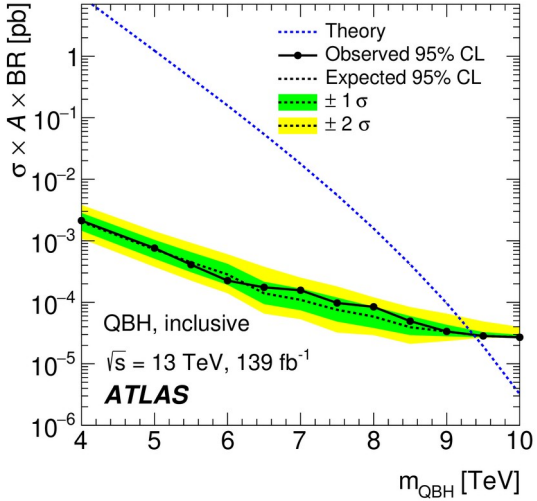
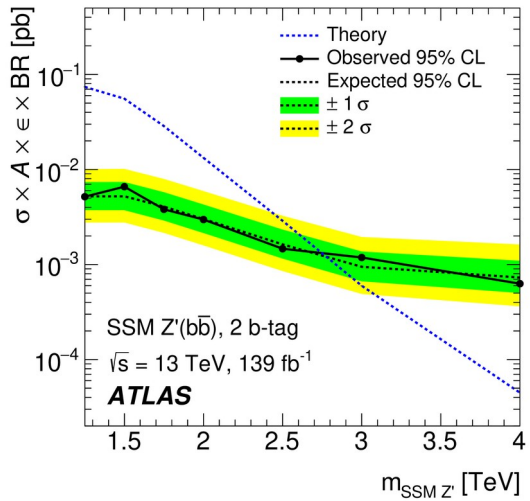
- 95% Confidence Level limits set on many BSM models
  - Inclusive: Quantum Black Holes > 9.4 TeV
  - B-tag: SSM Z' excluded below 2.7 TeV
- For Dark Matter signals inclusive limits out perform b-tagged due to loss of efficiency at high mass
  - For leptophobic DM models limits are consistent

Category	Model	Lower limit on signal mass at 95% CL	
		Observed	Expected
Inclusive	q^*	6.7 TeV	6.4 TeV
	QBH	9.4 TeV	9.4 TeV
	W'	4.0 TeV	4.2 TeV
	W^*	3.9 TeV	4.1 TeV
	DM mediator Z', $g_q = 0.20$	3.8 TeV	3.8 TeV
	DM mediator Z', $g_q = 0.50$	4.6 TeV	4.9 TeV
$1b$	b^*	3.2 TeV	3.1 TeV
$2b$	DM mediator Z' $g_q = 0.20$	2.8 TeV	2.8 TeV
	DM mediator Z', $g_q = 0.25$	2.9 TeV	3.0 TeV
	SSM Z',	2.7 TeV	2.7 TeV
	graviton, $k/\overline{M}_{PL} = 0.2$	2.8 TeV	2.9 TeV





Flavor Tagging Improvements

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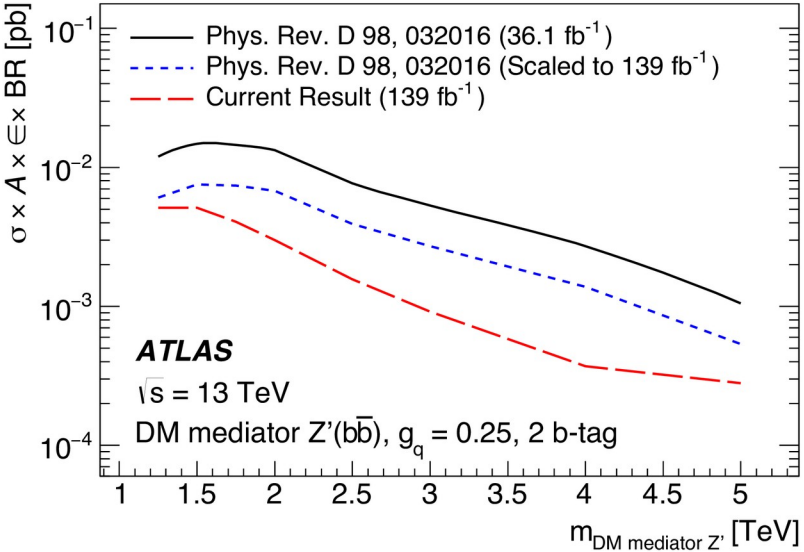
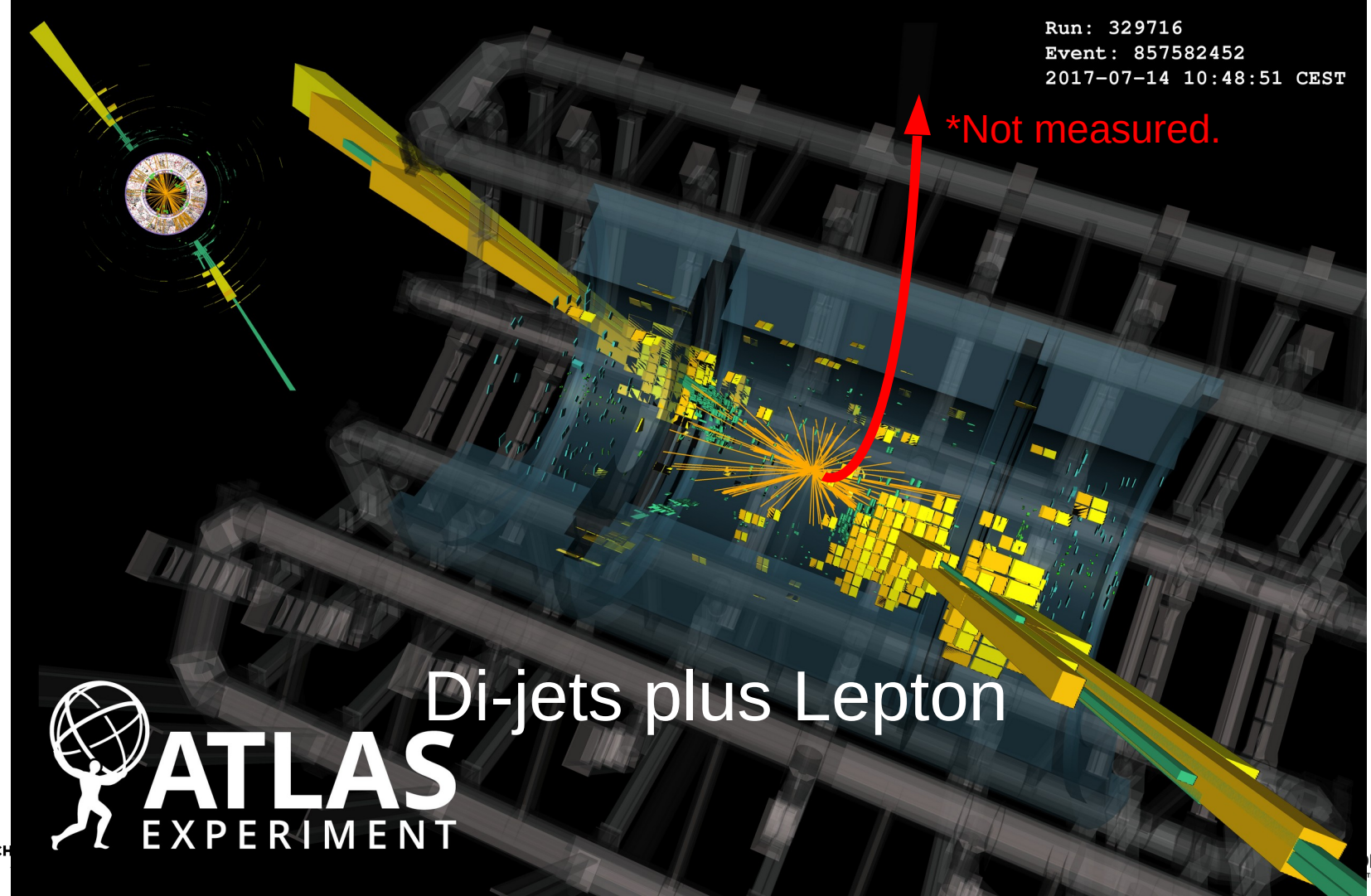
- A new Deep Learning algorithm (DL1r tagger) is used to identify jets containing B-hadrons
  - Inputs from features of b-quarks: secondary vertices, impact parameters, etc.
  - Additionally a recurrent neural network trained on tracks to exploit the correlations in jets with B-hadrons
- Analysis performed a detailed study to quantify the impact of the new DL1r tagger
  - Found significant improvement over full mass range
    - Even when accounting for increased luminosity
  - DL1r provides an additional improvement by up to **3.5x**

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Di-jets plus Lepton
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EXPERIMENT

Di-jet Resonances in Events with Isolated Leptons

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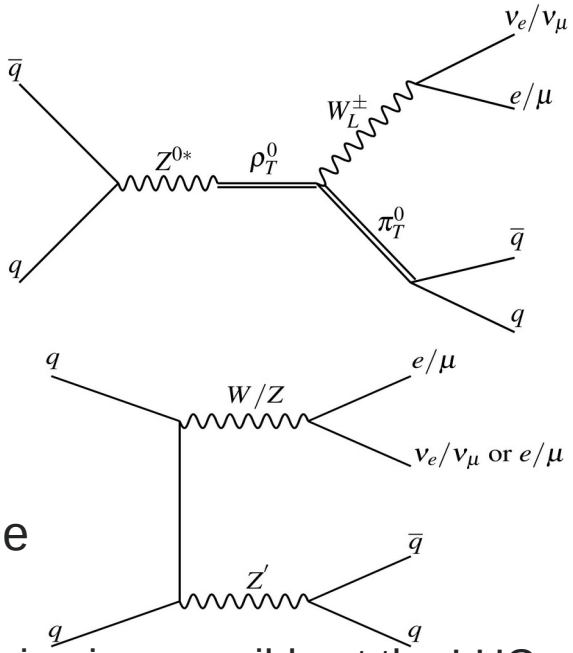
- Search for hadronic resonances in events with isolated leptons
  - Motivated by cascade decays or associated production
    - Sensitive to various BSM models:
      - technicolor
      - New heavy gauge bosons (SSM Z'/W')
      - Charged Higgs
      - Simplified Dark Matter models with couplings to vector bosons



- Requiring a lepton reduces backgrounds making it possible to search for resonances with $m_{jj} < 1$ TeV
  - Rate of multi-jet events at low m_{jj} makes this kinematic region inaccessible at the LHC without using the lepton trigger or a Trigger Level Analysis

Event Selection & Background Modeling

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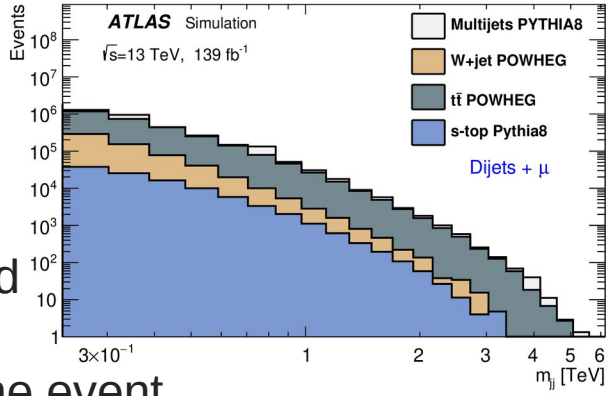

- An unprescaled single lepton trigger is used
  - Threshold of 26 (24) GeV for electrons (muons)
  - Require two jets with p_T > 20 GeV, |η| <2.4
    - At least 60% of jet energy must be associated with the event's most energetic vertex
  - M_{jj} reconstructed from the two leading p_T jets in the event
- Dominant background contributions come from Multi-jet, W+jet, and ttbar processes
- MC simulation of QCD processes in this final state is challenging so Control Regions are identified to quantify backgrounds
  - Three jet control region – a 60 GeV jet replaces the isolated lepton
    - Used to improve statistics in QCD MC studies and compare with data
  - Loose Electron control region – identify 'loose' but not 'tight' quality electrons
    - Used in data to compare with QCD MC, and perform background fit studies

Statistical Treatment & Search Phase

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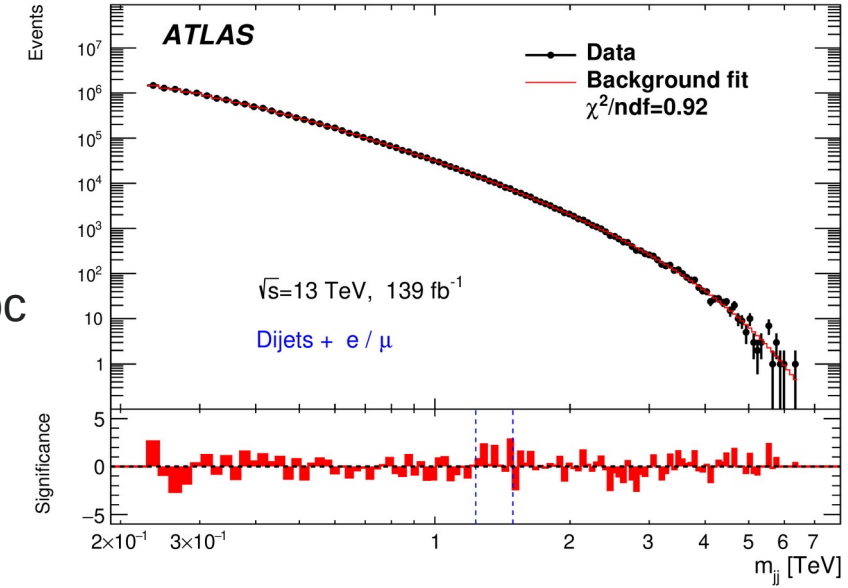
- Observed data is fit with a five parameter analytic function

$$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x + p_5 \ln^2 x} \quad \text{where} \quad x \equiv m_{jj}/\sqrt{s}$$

  - Fitting between 0.22 TeV – 6.3 TeV
    - Result has a χ^2/ndf = 0.92

- BumpHunter algorithm is used to search for significant excesses
  - Largest deviation at 1.3 TeV with a loc significance of 2.8σ and **1.3σ global**
  - Consistent with the background only hypothesis



Limits Set

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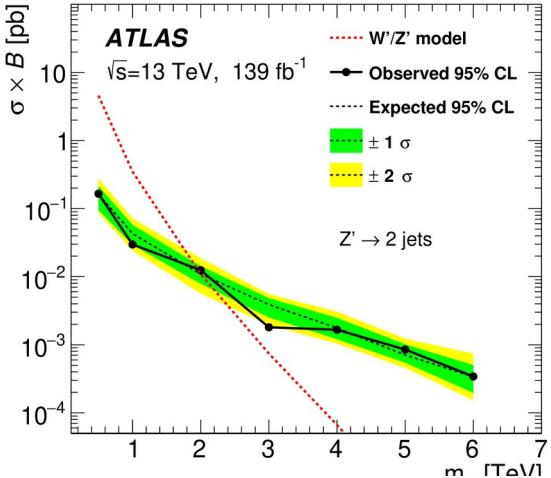
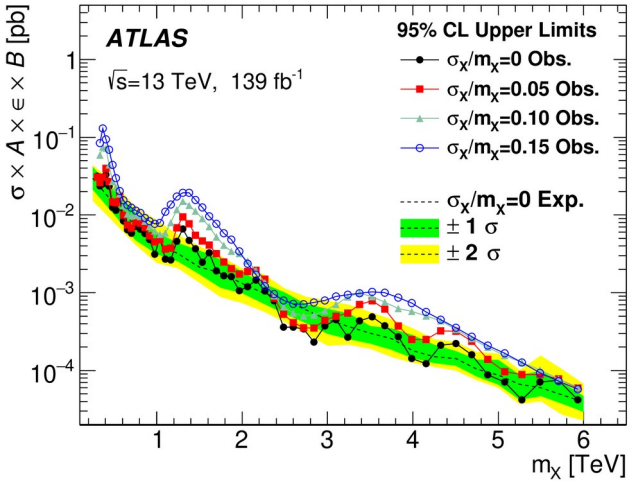
- 95% Confidence Level limits were set for BSM resonances
  - SSM Z’ mass below **2 TeV**
    - For Z’/W’ mass splitting of 250 GeV
  - Techni-pion masses below **350 GeV**
  - Charged Higgs H^+ mass below **1.2 TeV**
    - For tanβ = 0.5
  - Simplified DM Leptophobic Z’ mass excluded below **1.2 TeV**
- Cross section limits set on model independent Gaussian signals with widths between 0 and 15% of signal mass





Summary & Conclusions

- ATLAS is publishing Run-2 legacy papers with the full 13 TeV pp dataset of 139 fb^{-1}
  - In addition to the larger data set making use of advanced techniques such as more precise calibrations and improved algorithms
    - Deep learning trained b-tagging algorithm improved sensitivity by up to 3.5x for resonances decaying to b-quarks
- Results shown for ATLAS's searches for resonances decaying to hadronic final states
  - Resonances decaying to jet pairs are signals from many BSM models
    - Highest limits set exclude QBH below 9.4 TeV
  - New analysis searching for di-jet resonances in events with isolated leptons
    - Excluding SSM Z' below 2 TeV
- More exciting results still to come