Search for high mass resonances with ATLAS

Marianna Testa
LNF-INFN
On behalf of the ATLAS Collaboration

Rencontre de Moriond: QCD and High Energy Interactions
La Thuile 25 March-1 April 2017

Introduction

- After Higgs discovery, the Standard Model (SM) is a self-consistent theory
- So far in good agreement with data

- Many ***experimental*** observations not explained in the SM
  - Nature of Dark Matter/Energy
  - Baryon asymmetry
  - neutrino masses

- ***Theory*** problems:
  - Hierarchy problem: $m_{EW}/M_{Pl} \sim 10^{-16}$
  - How to accomodate qravity
  - Unexplained hierarchical structure of Yukawa couplings

Model and ideas to address them:

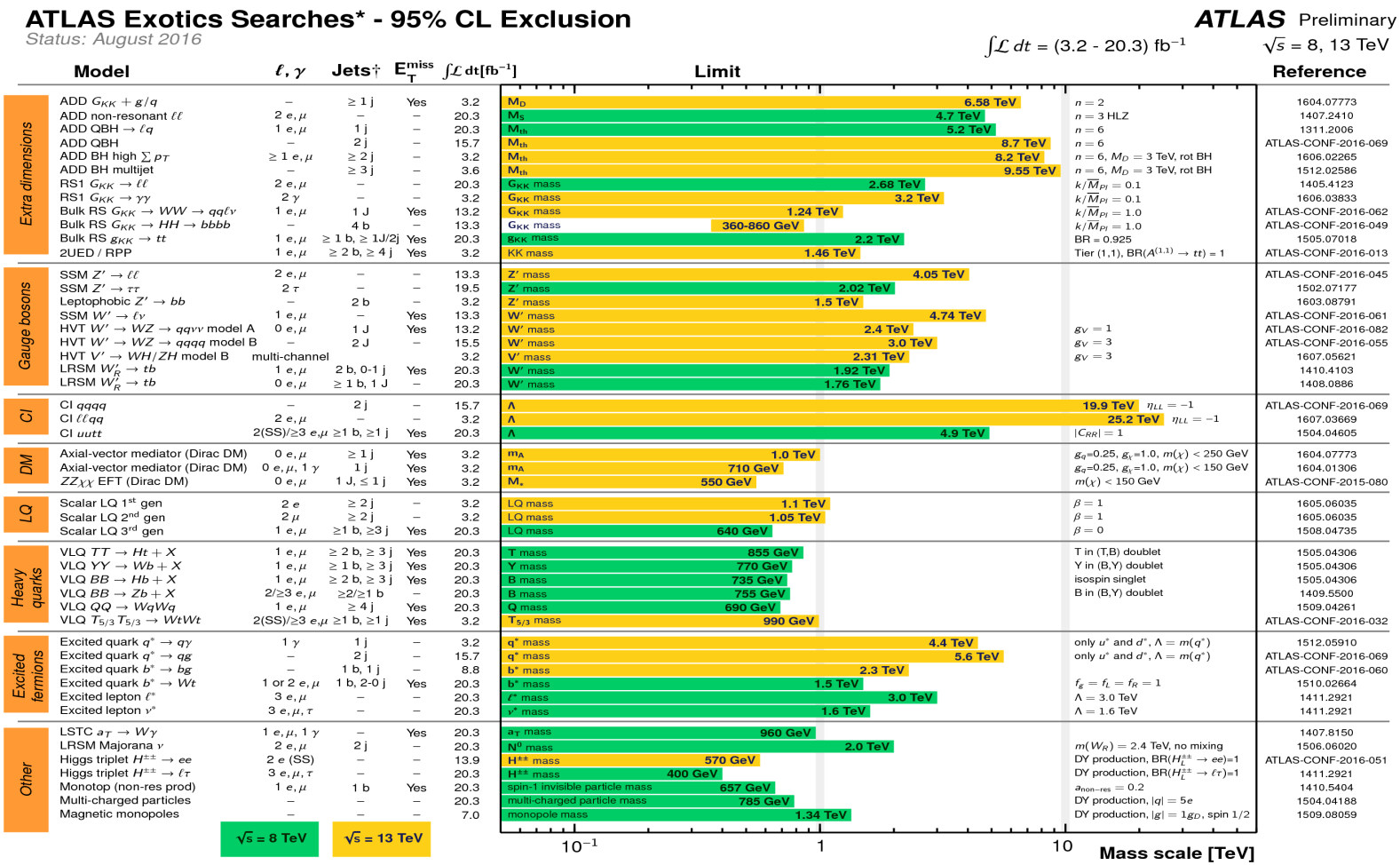
- SUSY
- (*) Compositeness, Extra dimensions
- Extended Higgs Sector
- Top Partner
- (*) W'/Z'
- Minimal Dark Matter
- Hidden Sectors

(*) in this talk

Search of physics beyond the SM is well motivated

Introduction

ATLAS has an extensive search program to prove or discard models



(*)

(*)

(*)

(*)

ATLAS_Exotics_Summary

(*) models tested in this talk

Outline

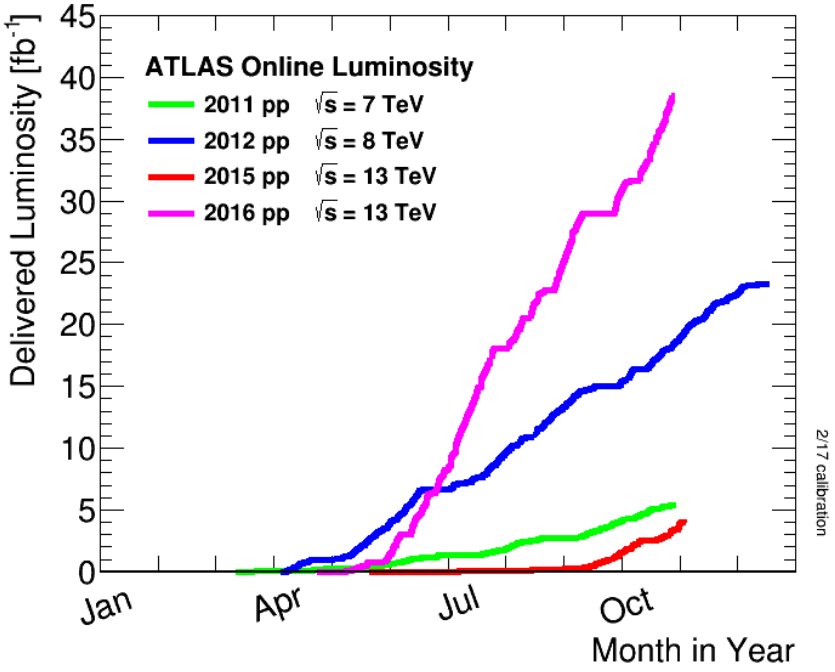
- Searches of new phenomena with di-jet final states
  full 2015+2016 dataset

NEW

- Search for new resonances decaying to a charged lepton and a neutrino
  full 2015+2016 dataset

NEW

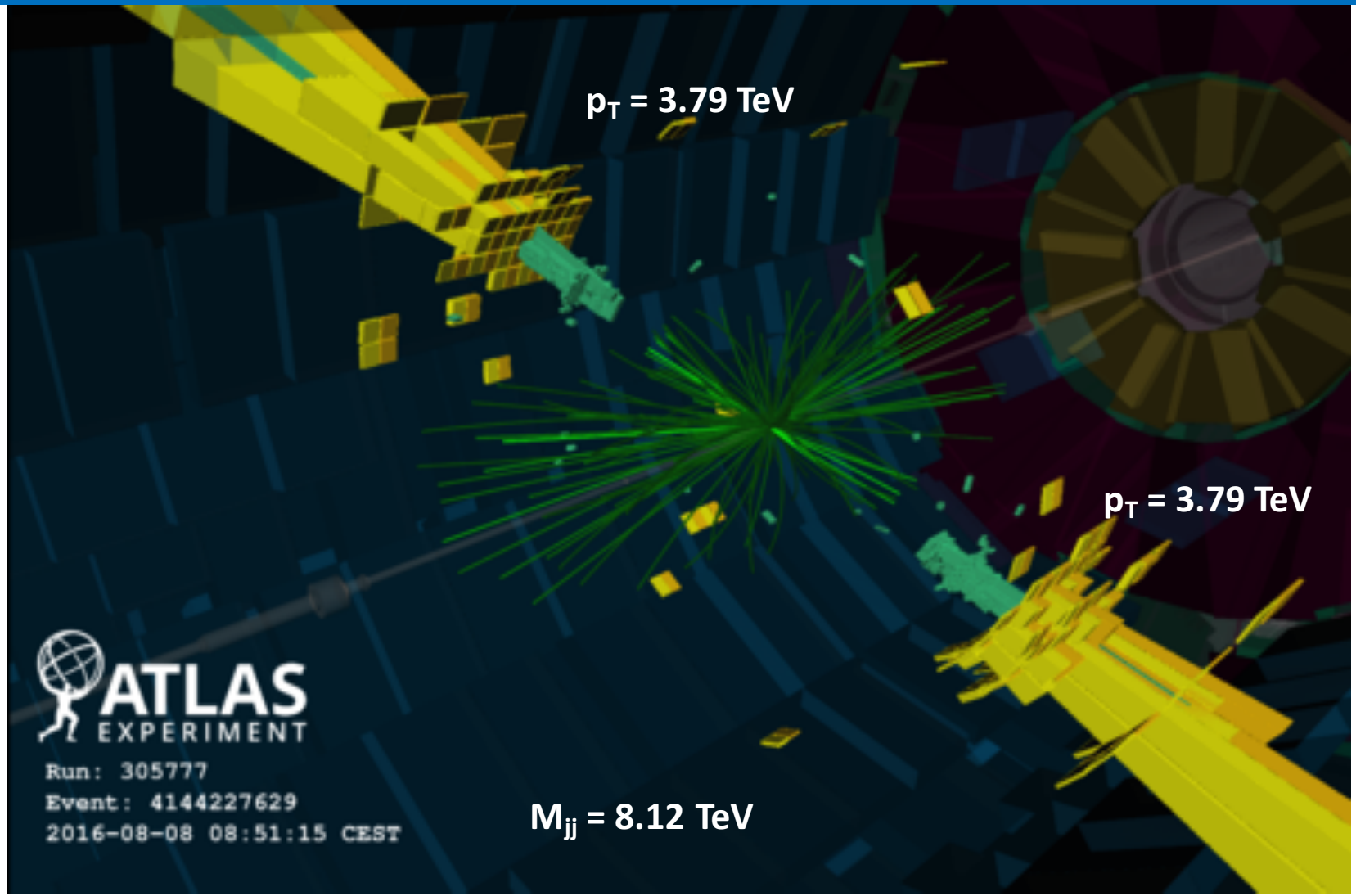
- Search for new high-mass resonances in the dilepton final state with 13.3 fb^{-1} and 3.2 fb^{-1}



Excellent performance of LHC in Run 2:

- Center-of-mass energy: √s =13 TeV
- Collected good data: 36.1 fb^{-1}
  3.2 fb^{-1} in 2015, 32.9 fb^{-1} in 2016

Search for new phenomena in di-jets

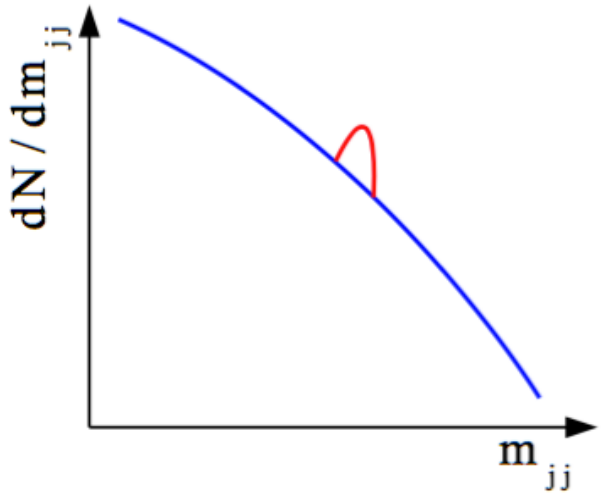


arXiv:1703.09127

Search for new phenomena in di-jets

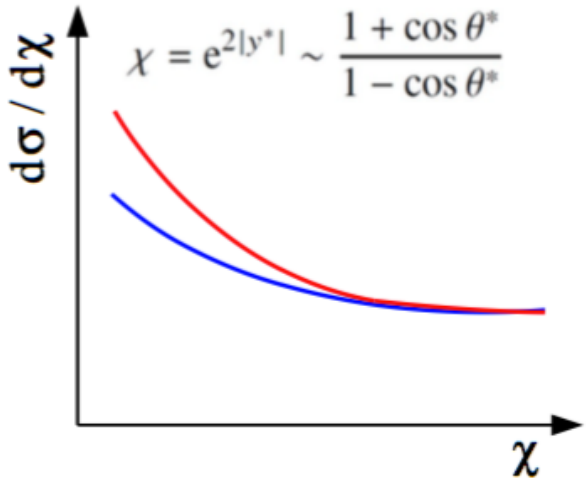
Di-jets final states sensitive to a broad class of new phenomena, through **generic** features of Beyond Standard Models (BSM) signals

Resonances searches



- localized excess in the m_{jj} distribution
- Sensitive to narrow resonance:
  - Quantum Black Hole (QBH), Excited quark (q*), W', excited W*

Di-jets angular distributions anomalies:

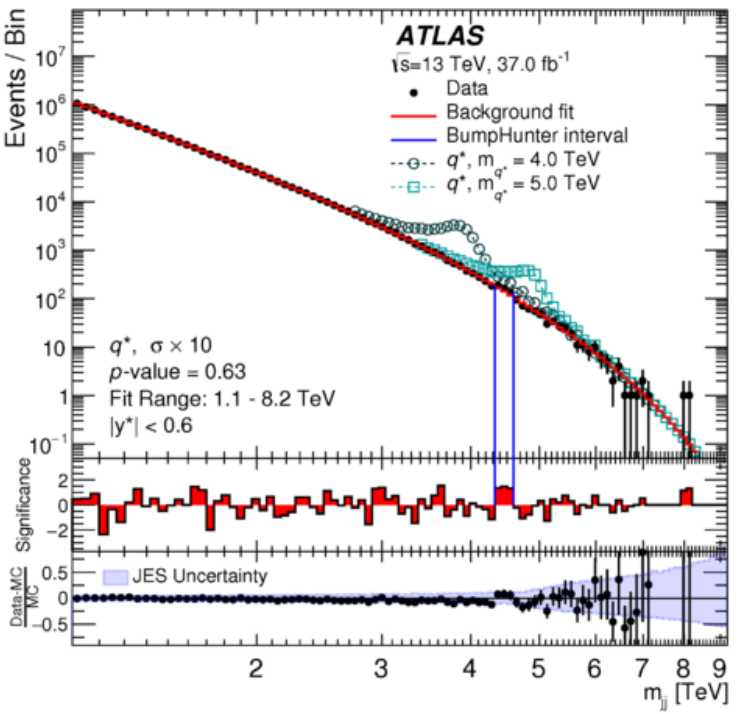


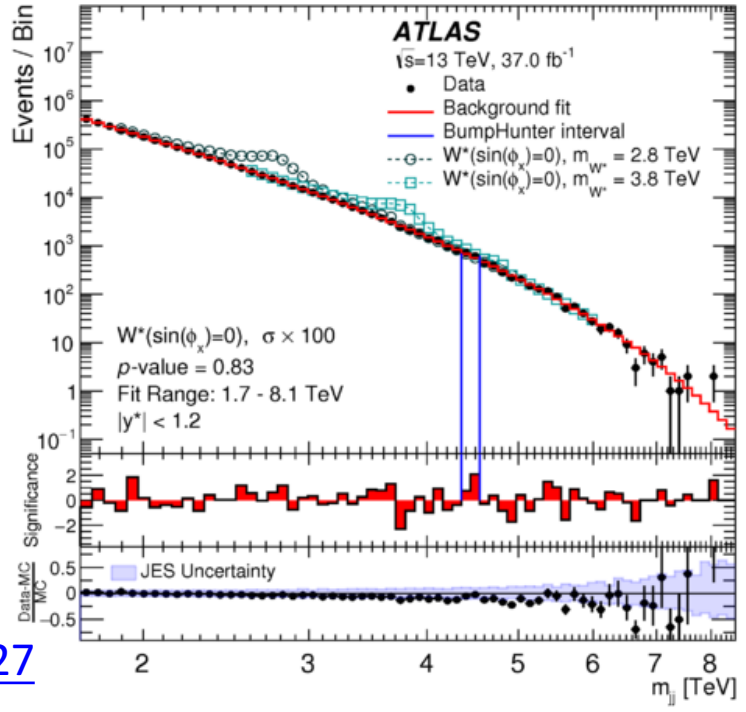
- BSM give more isotropic signature wrt to QCD
- More Sensitive to non-resonant signals
  - Contact interactions at compositeness scale Λ

Resonance Search in di-jets

- Single jet trigger $p_T > 380$ GeV
- $p_T^{lead(sub)} > 440\ (60)$ GeV
- To suppress t-channel scattering:
  - $y^* < 0.6(1.2)$, $y^* = |\ y_{lead} - y_{sublead}\ | / 2$
  - $m_{jj} > 1.1(1.7)$ TeV (for W*)
    - fully efficient trigger selection
  - Smooth QCD background from a Sliding Window Fit
- BumpHunter algorithm to scan for excesses
  - Most discrepant interval: 4326 – 4595 GeV
  - global significance of 0.63 (0.83 for W*)

No evidence of a localized contribution from BSM phenomena





arXiv:1703.09127

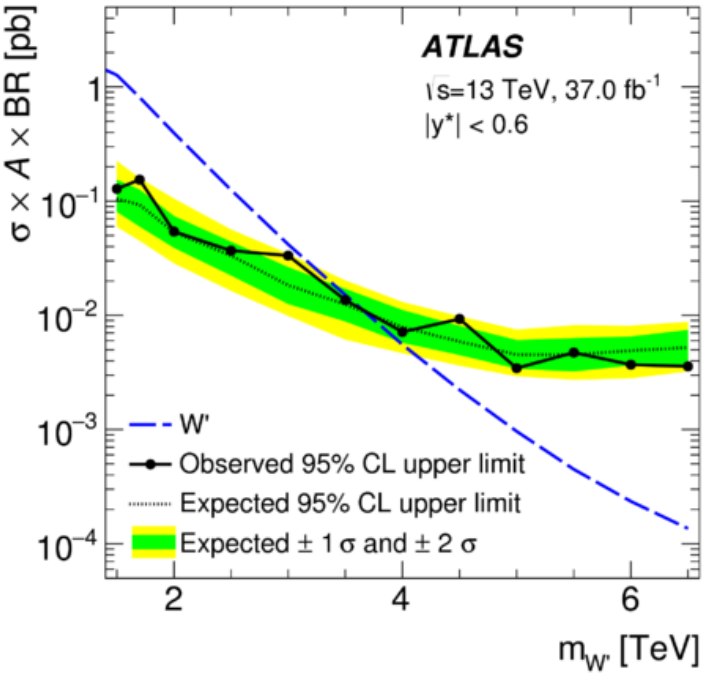
Resonance Search in di-jets: Exclusion limits

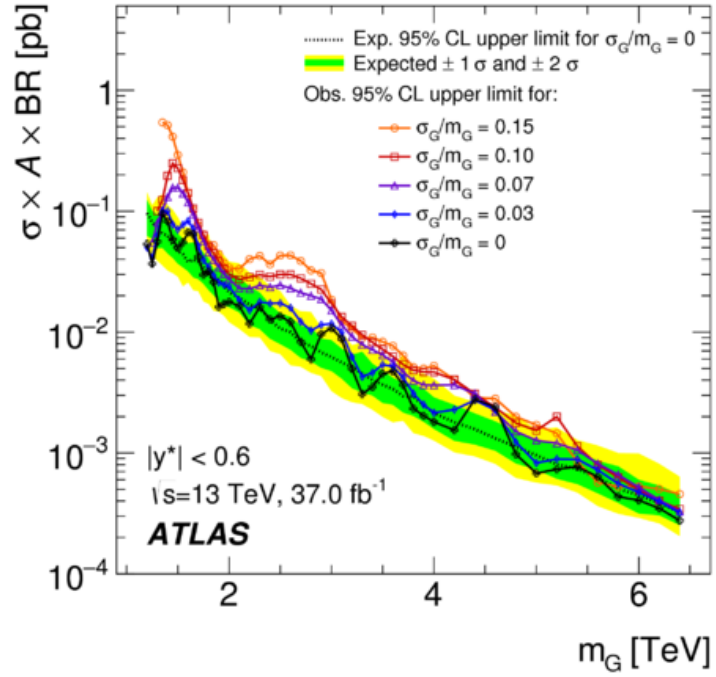
95 %CL exclusion limit		
Model	Observed	Expected
Quantum Black Hole, ADD	8.9 TeV	8.9 TeV
Excited quark	6.0 TeV	5.8 TeV
W’	3.7 TeV	3.7 TeV
W*	3.4 TeV, 3.8-3.9 TeV	3.6 TeV

Improved limits from 7% to 40% wrt analysis based on 3.2 fb^{-1}

Limits on generic Gaussian signals

- can be re-interpreted with various signal models
- MC-based folding methods to factorize physics & detector effects
- Excluded at 95% CL effective cross-sections from 20–50 fb at $m_G < 2$ TeV to 0.2-0.4 fb for $m_G > 6$ TeV





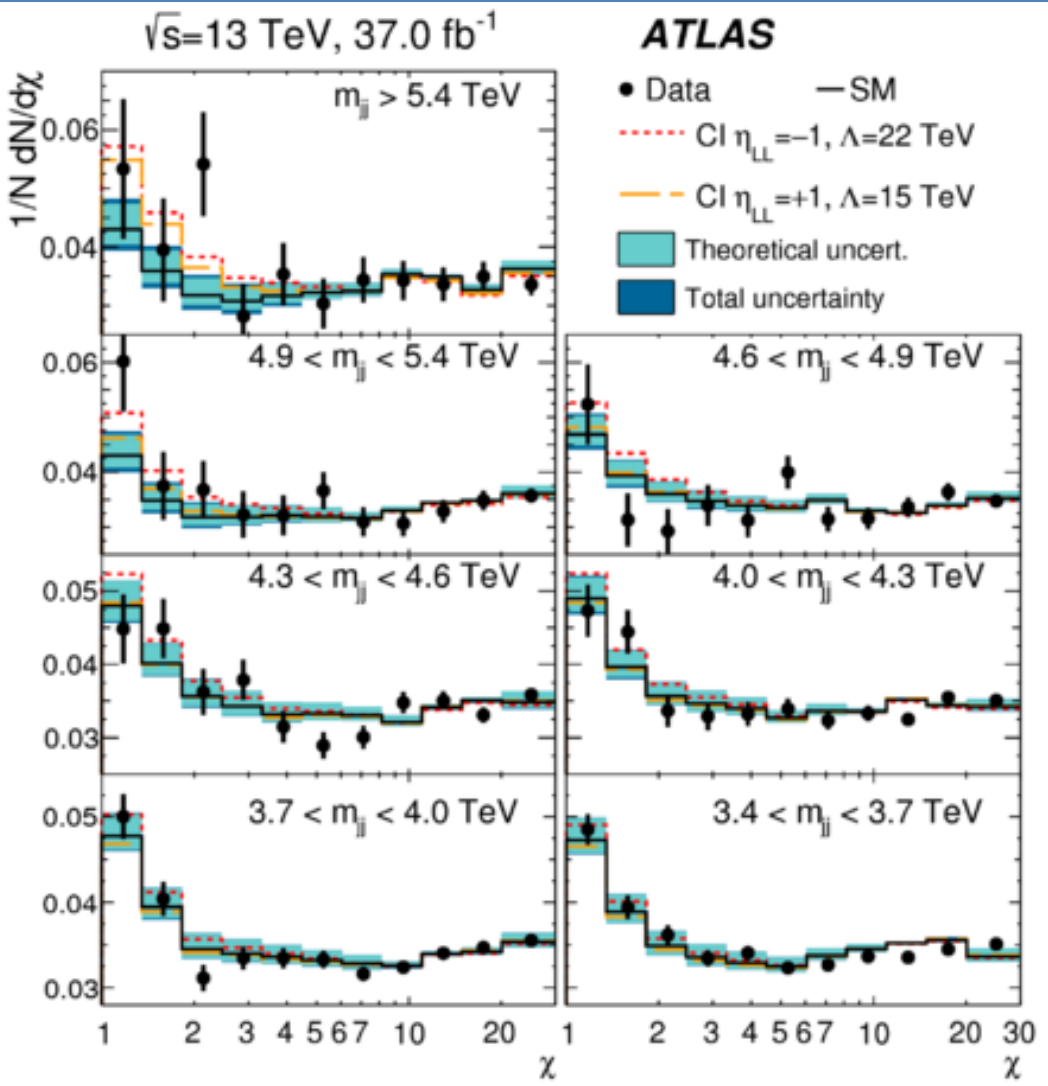
Angular Searches in di-jets

- Single jet trigger $p_T > 380$ GeV, $p_T^{lead(sub)} > 440(60)$ GeV
- $y^* < 1.7$, $y_B < 1.1$, $m_{jj} > 2.5$ TeV, y_B semi-sum of rapidities

- Signal: Contact interactions at compositeness scale Λ

$$L_{qq} = \frac{2\pi}{\Lambda^2}[\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L) + \eta_{RR}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_R\gamma_\mu q_R) + 2\eta_{RL}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_L\gamma_\mu q_L)],$$

$\eta_{LL} = \pm 1$, $\eta_{RR} = \eta_{RRL} = 0$



- QCD background described by MC, normalized to data in each m_{jj} bin

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

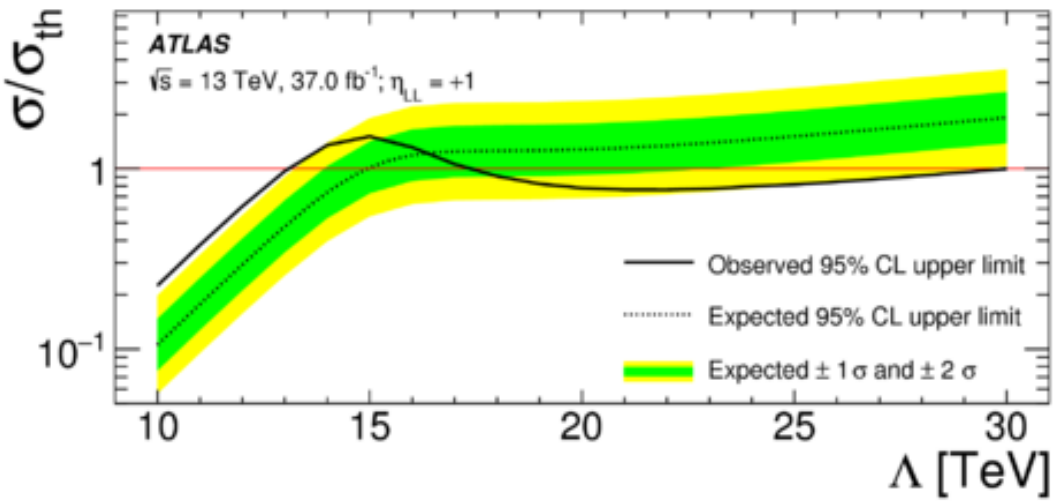
- Dominant Uncertainty:
  - Jet energy scale (exp) and renormalization/factorization scales (theory)

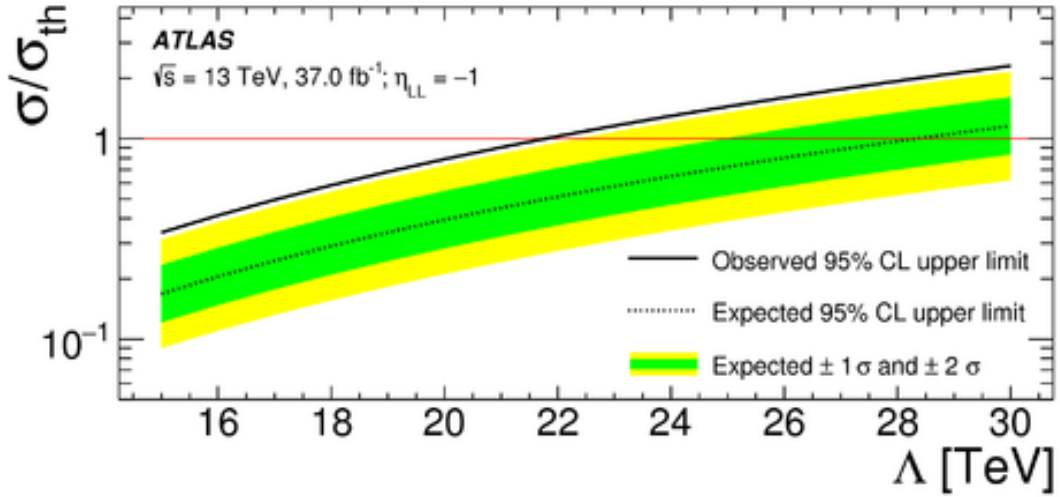
Angular Searches in di-jets: Exclusion limits on contact interactions

No deviations from background expectations

95 %CL exlusion limit on Λ		
Model	Observed	Expected
η_{LL}=-1	21.8 TeV	28.3 TeV
η_{LL}=+1	13.1 TeV 17.4-29.5 TeV	15.0 TeV

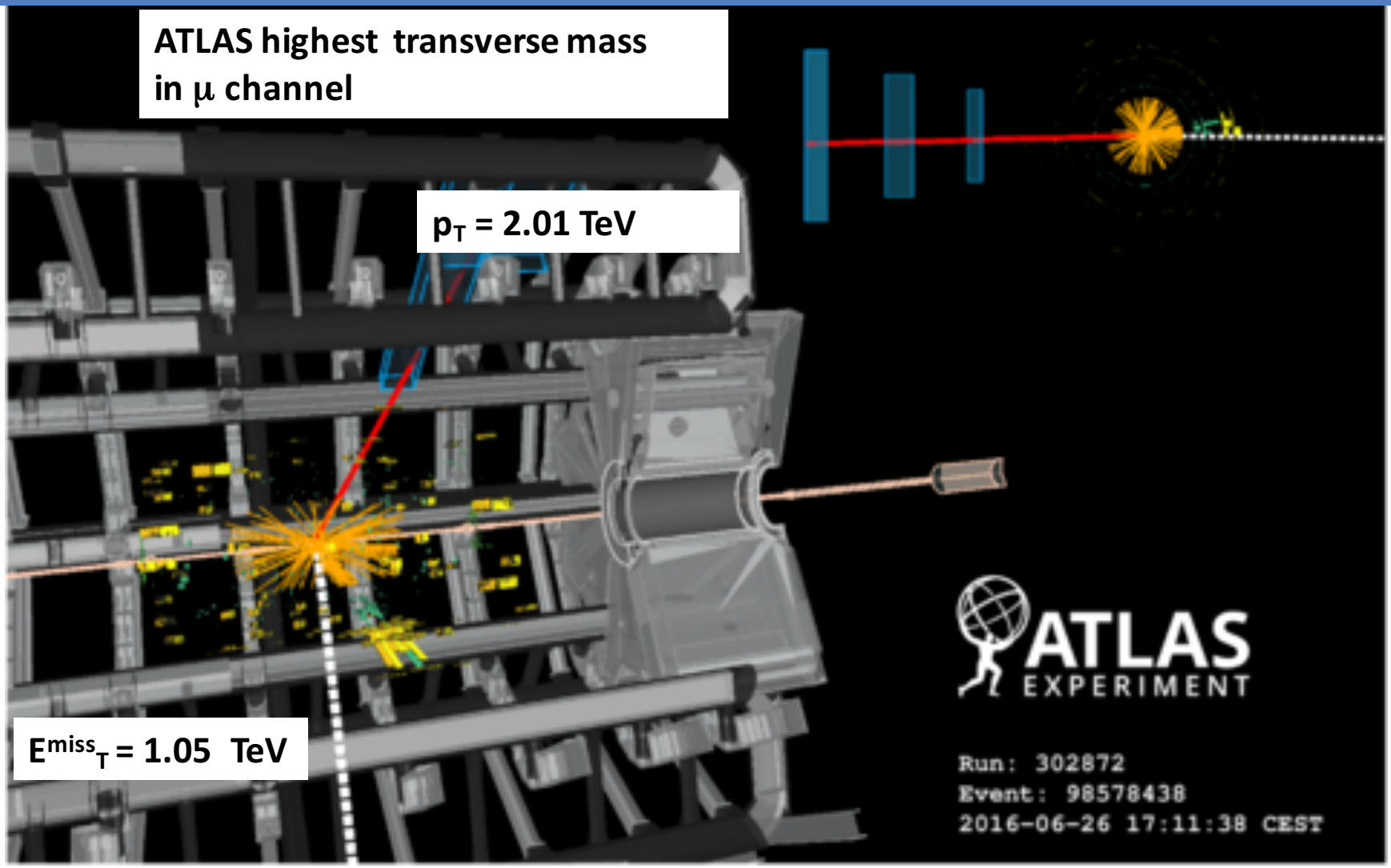
-10% less sensitivity to other benchmark models compared to resonance search





Negative (positive) interference of signal model η_{LL} = +1(-1) with SM QCD

Search for new resonances decaying to a charged lepton and a neutrino



ATLAS-CONF-2017-016

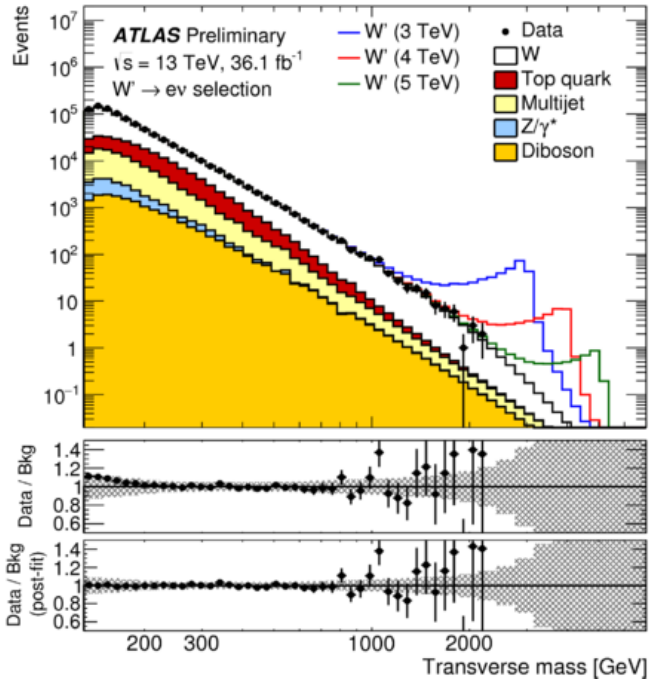
Search for new resonances decaying to a charged lepton and a neutrino

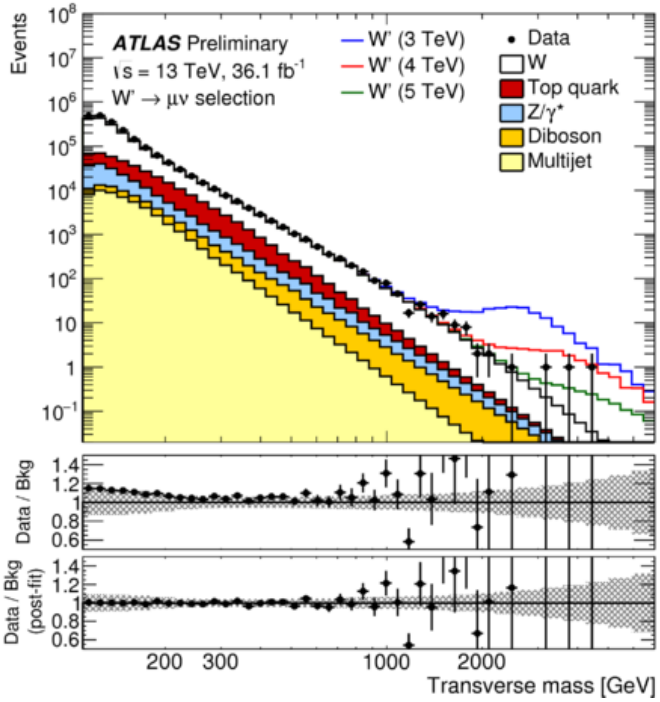
- BSM models introduce new heavy charged Spin-1 gauge-bosons W'
- W' → lν experimental signature

- Benchmark model: Sequential Standard Model (SSM)
  - Same fermion coupling as the SM W
  - no coupling to W,Z
  - Interference between W and W' neglected

- Analysis Strategy:
  - exactly one high- p_T lepton and large missing transverse energy
  - Compare transverse mass distribution to SM predictions

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



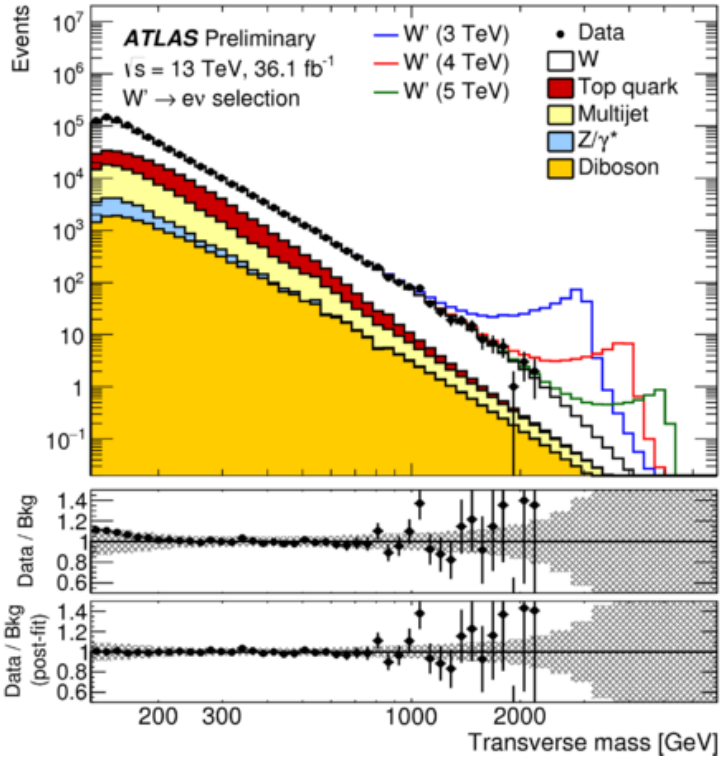


ATLAS-CONF-2017-016

Search of W' → e ν: event yield

- Tight ID electron p_T > 65 GeV
- E_T^{miss} > 65 GeV, m_T > 130 GeV
- Bkg with "real" leptons estimated with MC
  - Largest from W Drell-Yan production
- Bkg from misidentified objet: data-driven
- Acc × ε = 81% (77%) @ $m_{W'}$ = 2 TeV (4 TeV)

m_{ll} (TeV)	0.6-1	1-2	2-3	3-7
Obs	1931	246	4	0
Exp SM	1960±140	224±23	5.7±1.4	0.4±0.4
SM+ W' 2 TeV	2260± 160	3930 ±80	380±80	1.4±0.4



- Syst. Uncertainty for Bkg and Signal: 7% (115%) and 21% (10%) m_T = 2 TeV (4 TeV)

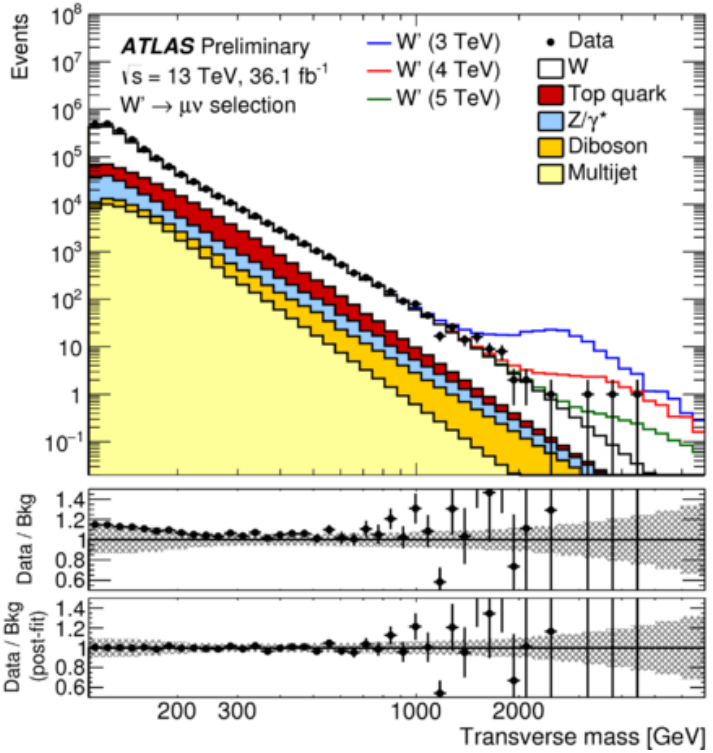
No significant excess is observed

most significant excess at $m_{W'}$ = 1.1 TeV: local (global) significance of 2.3 (0.6)

Search of W' → μ ν: event yield

- Tight ID muon p_T > 55 GeV
- E_T^{miss} > 55 GeV, m_T > 130 GeV
- Bkg with "real" leptons estimated with MC
  - Largest from W Drell-Yan production
- Bkg from misidentified objet: data-driven
- Acc × ε = 50% (46%) @ $m_{W'}$ = 2 TeV (4 TeV)

m_{ll} (TeV)	0.6-1	1-2	2-3	3-7
Obs	1392	177	3	3
Exp SM	1320±90	150±13	4.7±0.6	0.63±0.13
SM+ W' 2 TeV	1740±100	1870±90	374±28	18±4

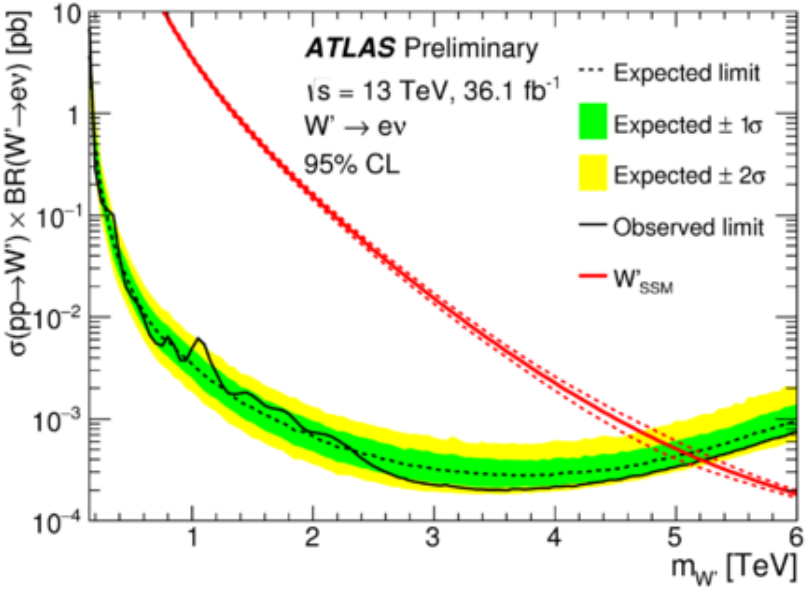


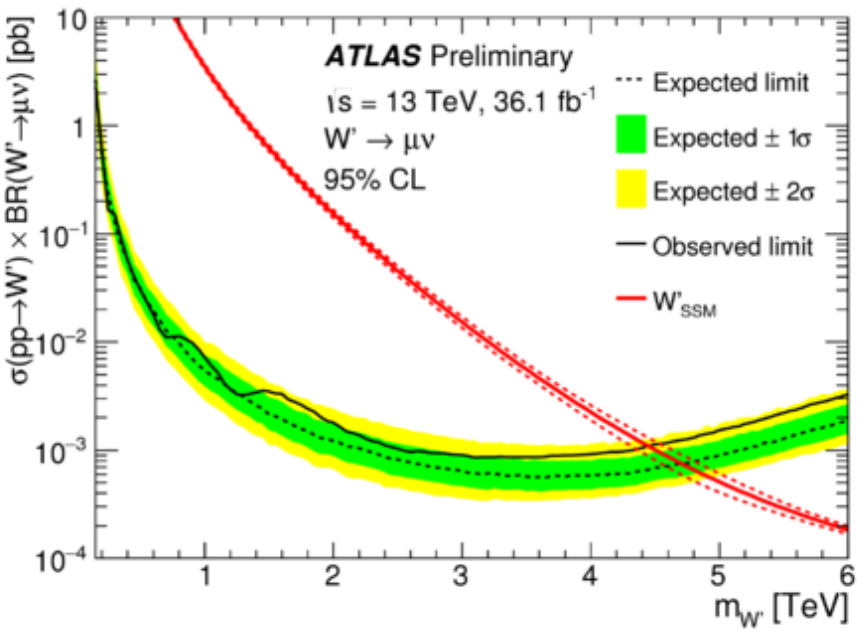
- Syst. Uncertainty for Bkg and Signal: 12% (21%) and 6% (8%) m_T = 2 TeV (4 TeV)

No significant excess is observed

most significant excess at $m_{W'}$ ~ 5 TeV: local (global) significance of 1.8 (0.1)

Search of W' → lν: Limits on σ ·BR

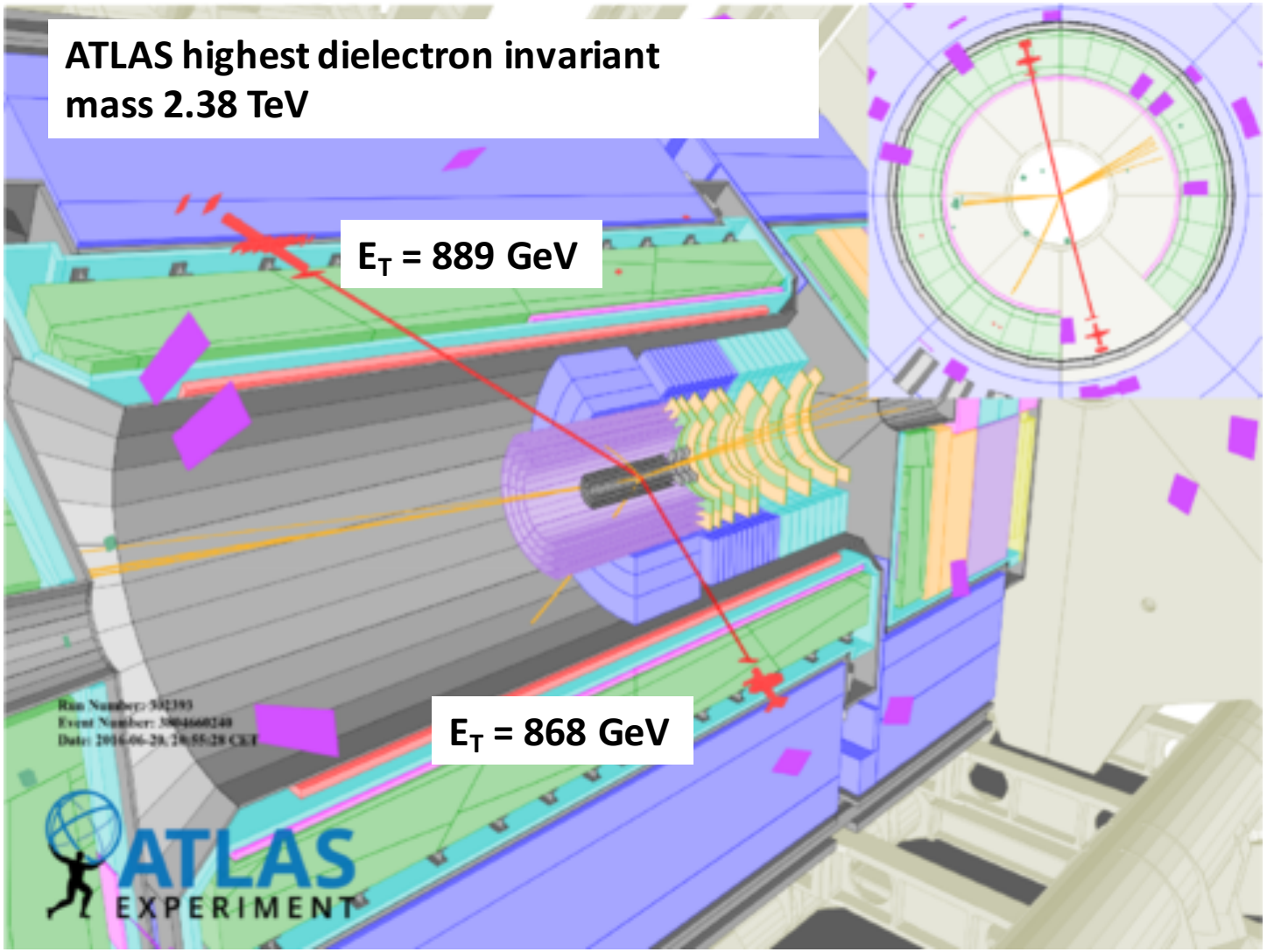




- **Observed (Exp) limits on m W'$_{SSM}$**
  - **5.22 (5.10) TeV for e channel**
  - **4.45 (4.71) TeV for μ channel**
  - **5.11 (5.24) TeV combined**

Limits improved by ~ 1 TeV wrt previous analysis based on 3.2 fb^{-1}

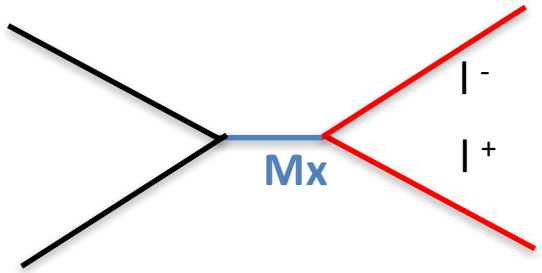
Search of high-mass resonances in the dilepton final state



ATLAS-CONF-2016-045

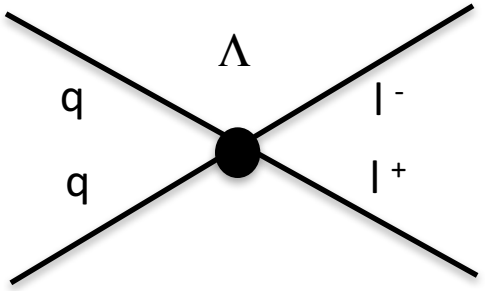
Search of high-mass resonances in the dilepton final state

Di-lepton final states sensitive to a broad class of new phenomena



1. **Direct search** of narrow new heavy resonances
   - Sequential Standard Model (SSM):
     Z' with same couplings to fermions as Z
   - Grand unified Theories (GUT) inspired E6 gauge group:
     - predicts two neutral gauge bosons mixing to
       $Z'(\theta_{E6}) = Z'_{\psi} \cos(\theta_{E6}) + Z'_{\chi} \sin(\theta_{E6})$
     - Signals considered for 6 values of θ_{E6}

2. **Non-resonant** deviations from predicted SM dilepton mass spectrum.
   - new interactions or compositeness in $qq \rightarrow l^+l^-$
   - contact interaction rappresentation

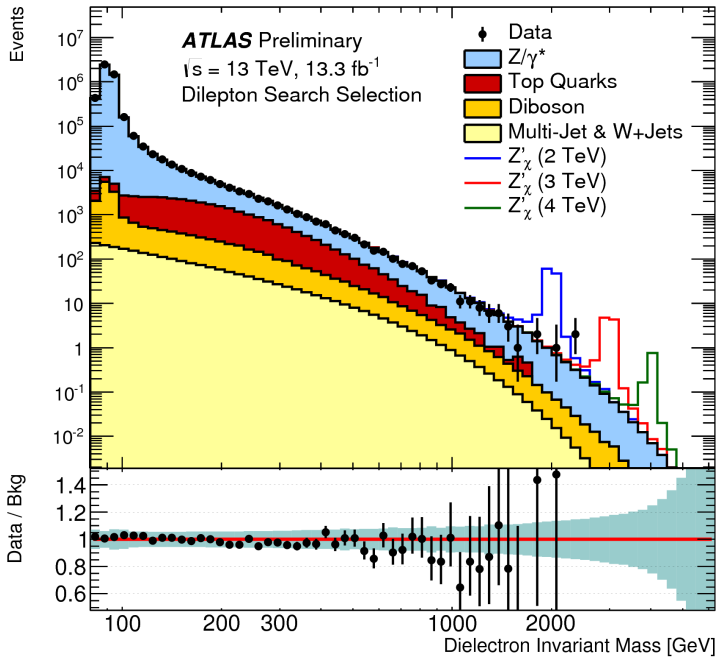


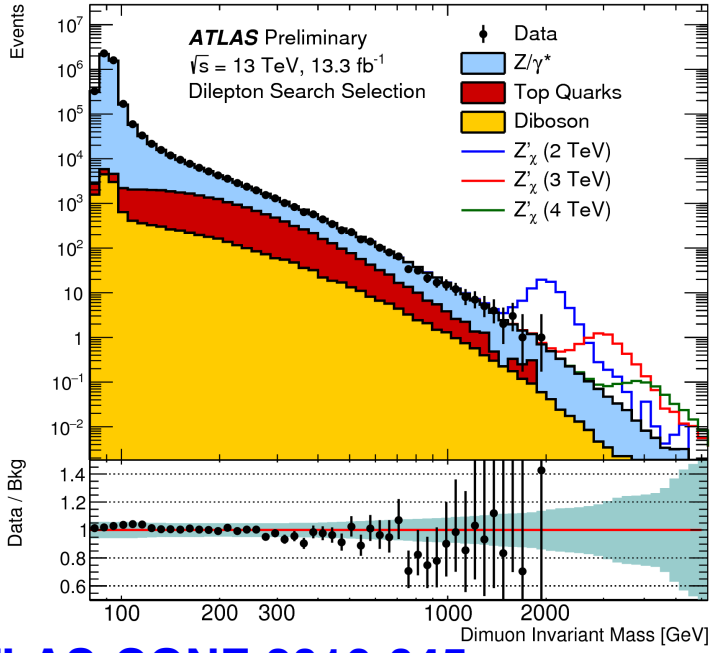
Search of Z' → ll: Analysis strategy

- Trigger: 2e with $E_T > 17$ GeV
  1 μ –iso $p_T > 26$ GeV OR 1 μ $p_T > 50$ GeV
- Selection:
  - ≥ e (μ) with E_T (p_T) > 30 GeV
  - Isolation and quality criteria
  - ε^{tot} = 73% (44%) for ee (μμ) channel for $m_{Z'}$ = 3 TeV

- Backgrounds with two real leptons:
  - Drell-Yan (dominant), $t\bar{t}$, single-top, WW, WZ, and ZZ by MC
- Background due to jet faking electrons:
  - W +jets and multi-jet events estimated from data

- Syst. Uncertainties for bkg at m_{ll} ~4 TeV:
  - e (μ) efficiency: 5% (17%)
  - e or μ energy scale and resolution: ~10%



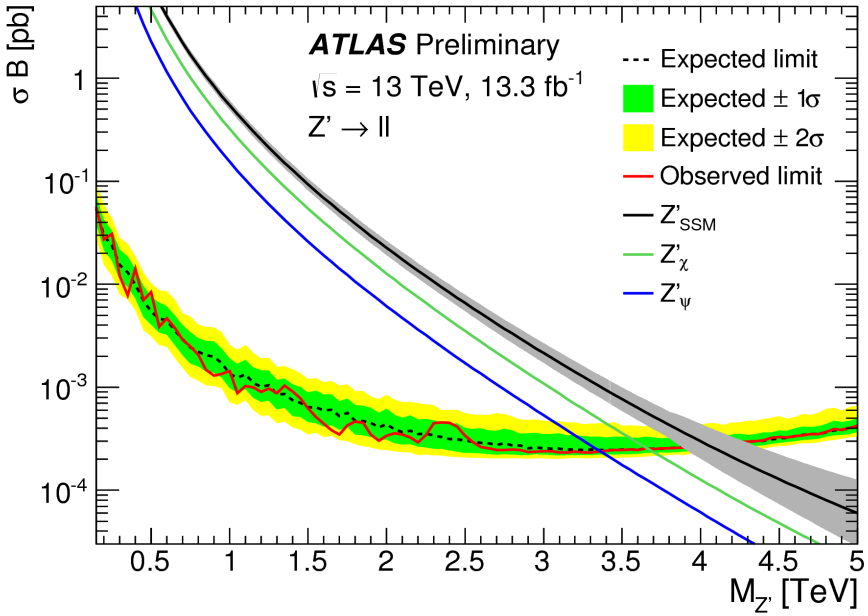


ATLAS-CONF-2016-045

Search of Z' → ll: Limits on σ · BR

No significant excess is observed

Limit increased by 700 GeV wrt limit obtained with 3.2 fb^{-1}

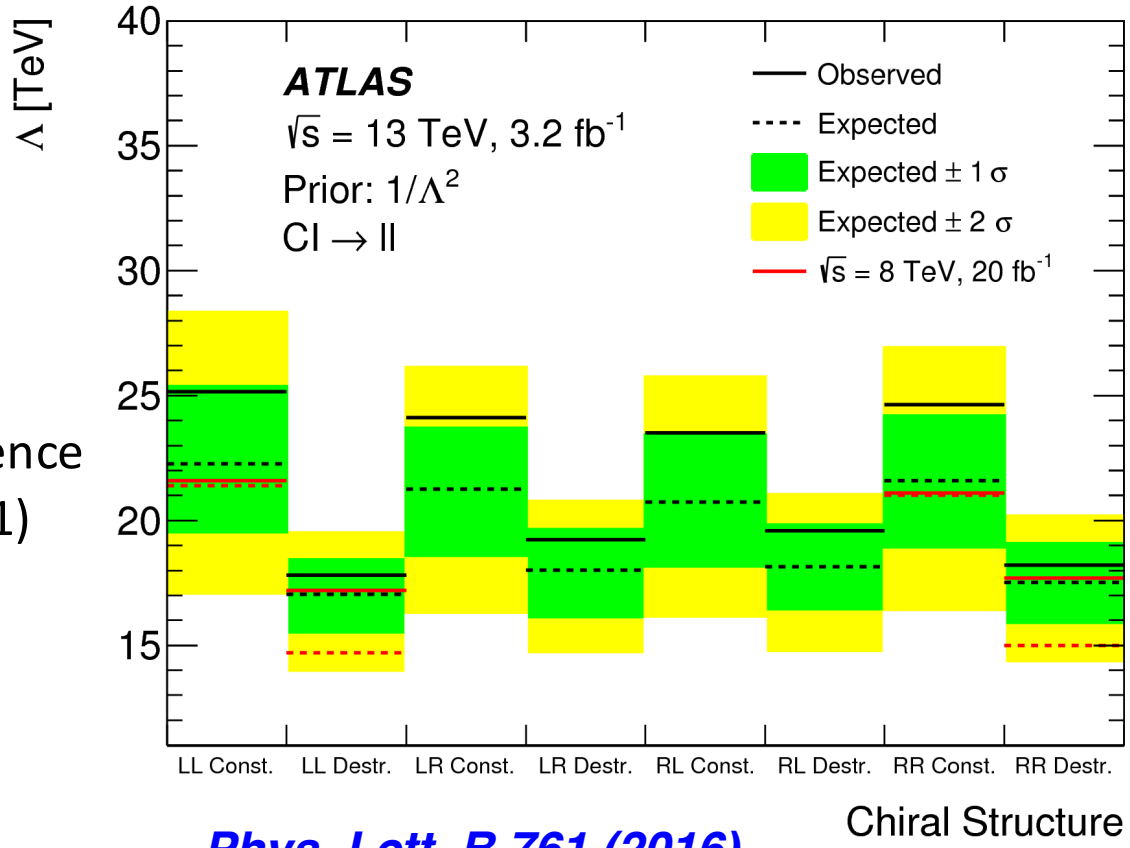


Model	Width [%]	θ_{E_6} [Rad]	Lower limits on $m_{Z'}$ [TeV]					
			ee		$\mu\mu$		$\ell\ell$	
			Obs	Exp	Obs	Exp	Obs	Exp
Z'_{SSM}	3.0	-	3.85	3.86	3.49	3.53	4.05	4.06
Z'_{χ}	1.2	0.50	3.48	3.49	3.18	3.19	3.66	3.67
Z'_{S}	1.2	0.63 π	3.43	3.44	3.14	3.14	3.62	3.61
Z'_{I}	1.1	0.71 π	3.37	3.37	3.08	3.08	3.55	3.55
Z'_{η}	0.6	0.21 π	3.25	3.25	2.96	2.94	3.43	3.42
Z'_{N}	0.6	-0.08 π	3.23	3.23	2.95	2.94	3.41	3.41
Z'_{ψ}	0.5	0 π	3.18	3.18	2.90	2.88	3.36	3.35

Search of Z' → ll: Exclusion limits on contact interactions

- Based on only 3.2 fb^{-1} of data collected in 2015
- Different chiral structures tested:
  - Left-right ,left-left, right-rights
    - $\eta_{LR\,(RL)} = \pm 1$
    - $\eta_{LL(RR)} = \pm 1$
    - the others to zero
- (con)destructive interference of signal model $\eta_{ij} = -1(+1)$ with SM QCD
- Limits on Λ between 16.7 and 25.2 TeV

$$\mathcal{L} = \frac{g^2}{\Lambda^2}[\eta_{LL}(\bar{q}_L\gamma_\mu q_L)(\bar{\ell}_L\gamma^\mu \ell_L) + \eta_{RR}(\bar{q}_R\gamma_\mu q_R)(\bar{\ell}_R\gamma^\mu \ell_R) + \eta_{LR}(\bar{q}_L\gamma_\mu q_L)(\bar{\ell}_R\gamma^\mu \ell_R) + \eta_{RL}(\bar{q}_R\gamma_\mu q_R)(\bar{\ell}_L\gamma^\mu \ell_L)]$$



Phys. Lett. B 761 (2016)

Conclusions

Search for new physics has been performed using full 2015+2016 dataset

No deviations from SM expectations are observed

- **Di-jets final states**
  - Limits on resonances masses between 3.4 and 8.9 TeV
  - contact interactions scale Λ > 13 - 29 TeV
  - New techniques to fit background and new folding methods
- **lepton+neutrino final state:** $M_{W'}$ > 5.1 TeV
- **dilepton final state:**
  - $M_{Z'}$ > 3.4 - 4.1 TeV
  - contact interactions scale Λ > 17-25 TeV

Improved limits on many signal scenarios compared to previous results

Backup

Limits on Z’

Z’ model:
axial-vector couplings to al
SM quarks and to Dirac
fermion dark matter

Assume decay to DM
negligible:

→ rate and resonance
width depend only on the
coupling to quarks, gq, an
the mass of the resonance
$m_{Z'}$