# Recent ATLAS results on Composite Dynamics and Dark Matter

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### Outline

ATLAS and the LHC in 2016

• Detector operation and performance

The physics program of ATLAS is broad so I'll only cover some fraction of the more relevant analyses

- Dark Matter searches
- Resonance searches
- SUSY searches









# A Toroidal LHC ApparatuS

OR

# A Terribly Lame Acronym, Sorry







Position (momentum)

Energy

http://atlas.c

### **The ATLAS experiment**



- Solenoidal magnetic field (2T) in the central region – momentum measurement
- Energy meas. down to 1° to the beamline
- High resolution silicon detectors
  - 6M strip channels (80µmx12cm)
  - 80M pixel channels
     (50μmx400μm) space
     resolution ~15μm
- Independent muon spectrometer (superconducting toroidal magnet)







### **The ATLAS experiment**

New detectors in Run-2:

- Innermost pixel layer IBL, 3.4cm from interaction point
- Forward proton detectors (one arm in 2016, 210m from IP)

In addition, various consolidations provide improved running at high luminosities and rates





**AFP** 



#### **Data Samples**

Exceptional LHC performance in 2016 following 13 TeV commissioning in 2015 (2015: 4.2 fb<sup>-1</sup> delivered, 3.9 fb<sup>-1</sup> collected) Results reported so far in 2016 with 3-15 fb<sup>-1</sup>



140

120

100

80

ATLAS Online, √s=13 TeV





Ldt=22.4 fb

2015: <µ> = 13.7

2016: <µ> = 23.2

Total:  $<\mu> = 21.4$ 

50



6



### LHC: More than nominal Luminosity



#### Many challenges

- Detectors (occupancies, SEUs ...)
- Trigger (thresholds, rates)
- Readout (bandwidth)
- Offline (Tier-0, Grid)

ATLAS has risen to meet these challenges!

LHC design:  $L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ 

Achieved:  $L = 1.2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ 



Pileup often above LHC design in 2016





## **Searches**







Precision measurements of boson, ttbar, single top and di-boson cross sections



Standard Model Total Production Cross Section Measurements Status: July 2014



Crucial to demonstrate detector performance and measure Standard Model to great accuracy







....keep increasing the energy....

# 2011 -> 2012 -> 2015+ 7 TeV -> 8TeV -> **13TeV**





#### Standard Model Total Production Cross Section Measurements Status:

Status: August 2016

11

ATLAS





#### **Standard Model Production Cross Section Measurements**

Status: August 2016











Standa	rd Model Total Production	Cross S	ection Measure	ements Status: August 2016	∫£ dt [fb <sup>−1</sup> ]	Reference
	$\sigma = 96.07 \pm 0.18 \pm 0.91$ mb (data)				50×10 <sup>-8</sup>	arXiv:1607.06605
рр	$\sigma = 95.35 \pm 0.38 \pm 1.3 \text{ mb (data)}$		6		8×10 <sup>-8</sup>	Nucl. Phys. B, 486-548 (2014)
	$\sigma = 190.1 \pm 0.2 \pm 6.4 \text{ nb} (\text{data})$		Ļ ,		0.081	PLB 759 (2016) 601
VV	$\sigma = 94.51 \pm 0.194 \pm 3.726 \text{ nb (data)}$		¢ '	d	0.035	PRD 85, 072004 (2012)
7	$\sigma = 58.8 \pm 0.2 \pm 1.7 \text{ nb} (\text{data})$		¢	þ	0.081	PLB 759 (2016) 601
Z	$\sigma = 27.94 \pm 0.178 \pm 1.096 \text{ nb (data)}$ FEWZ+HERAPDET 5 NNI O (theory)		¢ '	<b>d</b>	0.035	PRD 85, 072004 (2012)
	$\sigma = 818.0 \pm 8.0 \pm 35.0 \text{ pb (data)}$ top++ NNLO+NLL (theory)	. ¢		<b></b>	3.2	arXiv:1606.02699 [hep-ex]
tŦ	$\sigma = 242.4 \pm 1.7 \pm 10.2 \text{ pb (data)}$ top++ NNLO+NNLL (theory)	4		4	20.3	EPJC 74: 3109 (2014)
	$\sigma = 182.9 \pm 3.1 \pm 6.4$ pb (data) top++ NNLO+NNLL (theory)	<b>o</b>		•	4.6	EPJC 74: 3109 (2014)
	$\sigma = 229.0 \pm 48.0 \text{ pb} (\text{data})$ NLO+NLL (theory)	Þ			3.2	ATLAS-CONF-2015-079
t <sub>t-chan</sub>	$\sigma = 82.6 \pm 1.2 \pm 12.0 \text{ pb} (\text{data})$ NLO+NLL (theory)	4			20.3	ATLAS-CONF-2014-007
	$\sigma = 68.0 \pm 2.0 \pm 8.0 \text{ pb} (\text{data})$ NLO+NLL (theory)	<b>•</b>			4.6	PRD 90, 112006 (2014)
	$\sigma = 142.1 \pm 5.4 \pm 13.3 \ {\rm pb} \ {\rm (data)} \ {\rm NNLO} \ {\rm (theory)}$	, Þ			3.2	ATLAS-CONF-2016-090
WW	$\sigma = 68.2 \pm 1.2 \pm 4.6 \text{ pb} \text{ (data)}$ NNLO (theory)	4	Theory		20.3	CERN-EP-2016-186
	$\sigma = 51.9 \pm 2.0 \pm 4.4  \mathrm{pb}  \mathrm{(data)}$ NNLO (theory)	<b>¢</b>		p	4.6	PRD 87, 112001 (2013)
	$\sigma = 61.5 + 10.5 - 10.0 + 4.3 - 3.2 \text{ pb} (data)$ LHC-HXSWG YR4 (theory)	. P	LHC pp √s = 7 TeV		13.3	ATLAS-CONF-2016-081
Ц	$\sigma = 27.7 \pm 3.0 + 2.3 - 1.9 \text{ pb (data)}$ LHC-HXSWG YR4 (theory)	4	Data		20.3	EPJC 76, 6 (2016)
• •	$\sigma = 22.1 + 6.7 - 5.3 + 3.3 - 2.7 \text{ pb (data)}$ LHC-HXSWG YR4 (theory)		stat		4.5	EPJC 76, 6 (2016)
	$\sigma = 94.0 \pm 10.0 + 28.0 - 23.0 \text{ pb} \text{ (data)}$ NLO+NNLL (theory)	. <b>P</b>	$stat \oplus syst$		3.2	ATLAS-CONF-2016-065
Wt	$\sigma=23.0\pm1.3\pm3.4-3.7$ pb (data) NLO+NLL (theory)	4	LHC pp √s = 8 TeV	<b>↓</b>	20.3	JHEP 01, 064 (2016)
	$\sigma = 16.8 \pm 2.9 \pm 3.9 \mathrm{pb}$ (data) NLO+NLL (theory)	ב	Data		2.0	PLB 716, 142-159 (2012)
	$\sigma = 50.6 \pm 2.6 \pm 2.5 \text{ pb} (\text{data})$ MATRIX (NNLO) (theory)	, ¢	stat	<b>(</b>	3.2	arXiv:1606.04017 [hep-ex]
WZ	$\sigma = 24.3 \pm 0.6 \pm 0.9  \mathrm{pb}  (\mathrm{data}) \\ \mathrm{MATRIX}  (\mathrm{NNLO})  (\mathrm{theory})$	4	sial 🕁 sysi	4	20.3	PRD 93, 092004 (2016)
	$\sigma = 19.0 + 1.4 - 1.3 \pm 1.0 \text{ pb (data)} \\ \text{MATRIX (NNLO) (theory)}$	¢	LHC pp √s = 13 TeV	<b>0</b>	4.6	EPJC 72, 2173 (2012)
	$\sigma = 16.7 + 2.2 - 2.0 + 1.3 - 1.0 \text{ pb (data)}$ NNLO (theory)	2	Data		3.2	PRL 116, 101801 (2016)
ZZ	$\sigma = 7.1 + 0.5 - 0.4 \pm 0.4 \text{ pb (data)}$ NNLO (theory)		stat		20.3	ATLAS-CONF-2013-020
	$\sigma = 6.7 \pm 0.7 + 0.5 - 0.4 \text{ pb (data)}$		51at (± 5)51	<b>P</b>	4.6	JHEP 03, 128 (2013)
t <sub>s-chan</sub>	$\sigma = 4.8 \pm 0.8 + 1.6 - 1.3 \text{ pb (data)}$ NLO+NNL (theory)	ATLAS	Preliminary		20.3	PLB 756, 228-246 (2016)
++\/	$\sigma = 1.38 \pm 0.69 \pm 0.08 \text{ pb (data)} \\ \text{Madgraph5 + aMC@NLO (theory)} $				3.2	ATLAS-CONF-2016-003
LLVV	$\sigma = 369.0 + 86.0 - 79.0 \pm 44.0$ fb (data) MCFM (theory)	Run 1,2	$\sqrt{s} = 7, 8, 13 \text{ TeV}$		20.3	JHEP 11, 172 (2015)
++7	$\sigma = 0.92 \pm 0.29 \pm 0.08 \text{ pb} (\text{data})$ Madgraph5 + aMCNLO (theory)				3.2	ATLAS-CONF-2016-003
ιι <b>∠</b>	$\sigma = 176.0 + 52.0 - 48.0 \pm 24.0$ fb (data) HELAC-NLO (theory)				20.3	JHEP 11, 172 (2015)
	$10^{-1} 10^{-1} 10^{-2} 10^{-2} 10^{-1} 1 10^{-1}$	$10^{2} 10^{3}$	$10^{-1}$ $10^{-1}$ $10^{-1}$	0.5 I I.5 2 2.5		
			$\sigma$ [nh]	data/theory		
				sata troory		-









data/theory



Vector Boson +	X fid. Cross Section	<b>Neasurements</b>	Status: August 2016	∫£ dt [fb <sup>-1</sup> ]	Reference
24	$\sigma = 56.8 \pm 0.1 + 5.8 - 5.6$ nb (data) JETPHOX (theory)			20.2	arXiv: 1605.03495 [hep-e
7	$\sigma = 359.0 \pm 3.0 + 22.0 - 16.0 \text{ pb} (data)$ JETPHOX (theory)	0	Theory	4.6	PRD 89, 052004 (2014)
7	σ = 0.747 ± 0.001 ± 0.023 nb (data) DYNNLO + CT14NNLO (theory)			3.2	ATLAS-CONF-2016-046
$\Sigma \rightarrow ee, \mu\mu$	$\sigma = 479.0 \pm 3.0 \pm 17.0 \text{ pb} \text{ (data)}$ FEWZ+HERAPDF1.5 NNLO (theory)	0	LHC pp √s = 7 TeV	0.035	PRD 85, 072004 (2012)
_ <b>7</b> ⊥ >1 i	$\sigma = 118.1 \pm 0.2 \pm 9.1 \text{ pb (data)}$ Blackhat+Sherpa (theory)		Data	3.2	ATLAS-CONF-2016-046
-z+z j	$\sigma = 68.84 \pm 0.13 \pm 5.15$ pb (data) Blackhat (theory)	0	stat	4.6	JHEP 07, 032 (2013)
- <b>7</b> + >2;	$\sigma = 27.8 \pm 0.1 \pm 2.6 \text{ pb}$ (data) BlackHat+Sherpa (theory)		stat⊕ syst	3.2	ATLAS-CONF-2016-046
-z+22J	$\sigma = 15.05 \pm 0.06 \pm 1.51$ pb (data) Blackhat (theory)	0	LHC pp √s = 8 TeV	4.6	JHEP 07, 032 (2013)
7	$\sigma = 6.35 \pm 0.04 \pm 0.74 \text{ pb (data)}$ Blackhat+Sherpa (theory)		Data	3.2	ATLAS-CONF-2016-046
- <b>∠</b> + ≥3 J	$\sigma = 3.09 \pm 0.03 \pm 0.4 \text{ pb (data)}$ Blackhat (theory)	0	stat	4.6	JHEP 07, 032 (2013)
7	$\sigma = 1.53 \pm 0.02 \pm 0.22$ pb (data) Blackhat+Sherpa (theory)		stat ⊕ syst	3.2	ATLAS-CONF-2016-046
-∠+≥4J	$\sigma = 0.65 \pm 0.01 \pm 0.11 \text{ pb} \text{ (data)}$ Blackhat (theory)	0	LHC pp $\sqrt{s} = 13 \text{ TeV}$	4.6	JHEP 07, 032 (2013)
– <b>Z</b> + ≥1 b	$\sigma = 4820.0 \pm 60.0 + 360.0 - 380.0$ fb (data) MCFM (theory)		Data	4.6	JHEP 10, 141, (2014)
– <b>Z</b> + ≥2 b	$\sigma = 520.0 \pm 20.0 + 74.0 - 72.0$ fb (data) MCFM (theory)		stat	4.6	JHEP 10, 141, (2014)
$Z \rightarrow \tau \tau$	$\sigma = 1690.0 \pm 35.0 + 95.0 - 121.0$ (b (data) MC@NLO + HERAPDFNLO (theory)		stat ⊕ syst	4.6	PRD 91, 052005 (2015)
$Z \rightarrow bb$	$\sigma = 2.02 \pm 0.2 \pm 0.26 \text{ pb (data)}$ Powheg (theory)	A		19.5	PLB 738, 25-43 (2014)
$\mathbf{W} \rightarrow \mathbf{o} \mathbf{v}$	σ = 8.03 ± 0.01 ± 0.23 nb (data) DYNNLO + CT14NNLO (theory)	Þ		0.081	PLB 759 (2016) 601
$\mathbf{VV} \rightarrow \mathbf{e}\nu, \mu\nu$	$\sigma = 5.127 \pm 0.011 \pm 0.187 \text{ nb (data)}$ FEWZ+HERAPDF1.5 NNLO (theory)	0		0.035	PRD 85, 072004 (2012)
– W + ≥1 j	$\sigma = 493.8 \pm 0.5 \pm 45.1 \text{ pb (data)}$ Blackhat (theory)	0		4.6	EPJC 75, 82 (2015)
– W + ≥2 j	$\sigma = 111.7 \pm 0.2 \pm 12.2$ pb (data) Blackhat (theory)	<b>•</b>		4.6	EPJC 75, 82 (2015)
– W + ≥3 j	$\sigma = 21.82 \pm 0.1 \pm 3.23 \text{ pb} (data)$ Blackhat (theory)			4.6	EPJC 75, 82 (2015)
– W + ≥4 j	$\sigma = 4.241 \pm 0.056 \pm 0.885 \text{ pb} (\text{data})$ Blackhat (theory)			4.6	EPJC 75, 82 (2015)
– W + ≥5 j	$\sigma = 0.877 \pm 0.032 \pm 0.301 \text{ pb (data)}$ Blackhat (theory)			4.6	EPJC 75, 82 (2015)
$-W + 1b + \ge 1j$	$\sigma = 5.0 \pm 0.5 \pm 1.2 \text{ pb (data)}$ MCFM+D.FL (theory)			4.6	JHEP 06, 084 (2013)
– W +1b + ≥2 j	$\sigma = 2.2 \pm 0.2 \pm 0.5 \text{ pb} \text{ (data)}$ MCFM+D.P.I. (theory)			4.6	JHEP 06, 084 (2013)
W,Z → qq	$\sigma = 8.5 \pm 0.8 \pm 1.5 \text{ pb} \text{ (data)}$ MCFM (theory)			4.6	NJP 16, 113013 (2014)
$\sigma(M)/\sigma(7)$ (fid.)	$R_{atio} = 10.31 \pm 0.04 \pm 0.2 \text{ nb} (data)$ DYNNLO + CT14NNLO (theory)			0.081	PLB 759 (2016) 601
0 ( <b>vv</b> )/0 ( <b>z</b> ) (iid.)	Ratio = 10.7 ± 0.08 ± 0.11 (data) FEWZ+HERAPDF1.5 NNLO (theory)	•		0.035	PRD 85, 072004 (2012)
–≥1 j	Ratio = 8.54 ± 0.02 ± 0.25 (data) Blackhat (theory)	<b>D</b> ATLAS	Preliminary	4.6	EPJC 74: 3168 (2014)
-≥2 j	Ratio = 8.64 ± 0.64 ± 0.32 (data) Blackta (theory)		<u>,</u>	4.6	EPJC 74: 3168 (2014)
– ≥3 j	Ratio = 8.18 ± 0.08 ± 0.51 (data) Blackhat (theory)	Run 1.2	$\sqrt{s} = 7, 8.13$ TeV	4.6	EPJC 74: 3168 (2014)
– ≥4 j	Ratio = 7.62 ± 0.19 ± 0.94 (data)		, , . ,	4.6	EPJC 74: 3168 (2014)
$\sigma(t\bar{t})/\sigma(Z)$ (tot.)	$\sigma = 0.445 \pm 0.027 \pm 0.028 \text{ (data)} \\ \text{top++ NNLO+NLL, FEWZ+HERAPDF1.5 NNLO (theory)}$			0.085	ATLAS-CONF-2015-049





Diboson Cross Section Measurements         Status: August 2016				∫£ dt [fb <sup>-1</sup> ]	Reference		
$\gamma\gamma$	$\sigma = 44.0 + 3.2 - 4.2 \text{ pb (data)}$				4.9	JHEP 01, 086 (2013)	
$W_{\gamma \to \ell \nu \gamma}$	$\sigma = 2.77 \pm 0.03 \pm 0.36 \text{ pb (data)}$		<b>ATLAS</b> Prelimir	nary 🛛 🗄	4.6	PRD 87, 112003 (2013)	
$-[n_{iet} = 0]$	$\sigma = 1.76 \pm 0.03 \pm 0.22 \text{ pb (data)}$ $NNLO (theory)$	×× •	_	_	4.6	PRD 87, 112003 (2013)	
7	$\sigma = 1.507 \pm 0.01 + 0.083 - 0.078 \text{ pb} (\text{data})$		Run 1,2 $\sqrt{s} = 7$ ,	8, 13 TeV	20.3	PRD 93, 112002 (2016)	
$\Sigma\gamma \rightarrow i i \gamma$	$\sigma = 1.31 \pm 0.02 \pm 0.12$ pb (data) NNLO (theory)	Xo L	,		4.6	PRD 87, 112003 (2013) arXiv:1407 1618 [hep-ph]	
[n - 0]	$\sigma = 1.189 \pm 0.009 + 0.073 - 0.067  \mathrm{pb}  \mathrm{(data)}$ NNLO (theory)	Č <u>A</u> Č			20.3	PRD 93, 112002 (2016)	
$-[\Pi_{jet} = 0]$	$\sigma = 1.05 \pm 0.02 \pm 0.11$ pb (data) NNLO (theory)	Ŏ			4.6	PRD 87, 112003 (2013)	
7	$\sigma = 68.0 \pm 4.0 + 33.0 - 32.0$ fb (data) NNLO (theory)				20.3	PRD 93, 112002 (2016)	
$- \mathbf{z}_{\mathbf{y}} \rightarrow \mathbf{v} \mathbf{v}_{\mathbf{y}}$	$\sigma = 0.133 \pm 0.013 \pm 0.021 \text{ pb (data)} \\ \text{MCFM NLO (theory)}$				4.6	PRD 87, 112003 (2013)	
WV→ℓvqq	$\sigma = \begin{array}{l} 1.37 \pm 0.14 \pm 0.37 \text{ pb (data)} \\ \text{MC@NLO (theory)} \end{array}$				4.6	JHEP 01, 049 (2015)	
	$\sigma = 137.0 \pm 6.0 \pm 13.2 \text{ pb} \text{ (data)}$ NNLO (theory)				3.2	ATLAS-CONF-2016-090	
WW	$\sigma = 68.2 \pm 1.2 \pm 4.6 \text{ pb} \text{ (data)}$ NNLO (theory)				20.3	ATLAS-STDM-2015-24	
	$\sigma = 51.9 \pm 2.0 \pm 4.4 \text{ pb (data)}$ NNLO (theory)				4.6	PRD 87, 112001 (2013) PRL 113, 212001 (2014)	
	$\sigma = 530.0 \pm 23.0 \pm 51.0 \text{ fb (data)}$ NNLO (theory)				3.2	ATLAS-CONF-2016-090	
$-WW \rightarrow e\mu$ , [n <sub>jet</sub> = 0]	$\sigma = 374.0 \pm 7.0 + 26.0 - 24.0$ fb (data) approx. NNLO (theory)				20.3	arXiv:1603.01702 [hep-ex]	
	$\sigma = 262.3 \pm 12.3 \pm 23.1 \text{ fb (data)}$ MCFM (theory)				4.6	PRD 87, 112001 (2013)	
$-WW \rightarrow e\mu, [n_{jet} \geq 0]$	$\sigma = 563.0 \pm 28.0 + 79.0 - 85.0$ fb (data) MCFM (theory)			NNLO QCD	4.6	PRD 91, 052005 (2015)	
$-WW \rightarrow e\mu$ , $[n_{jet} = 1]$	$\sigma = 136.0 \pm 6.0 \pm 14.3$ tb (data) NLO (theory)				20.3	ATLAS-STDM-2015-24	
	$\sigma = 50.6 \pm 2.6 \pm 2.5 \text{ pb} \text{ (data)}$ MATRIX (NNLO) (theory)			NLO QCD	3.2	arXiv:1604.08576[hep-ph]	
WZ	$\sigma = 24.3 \pm 0.0 \pm 0.9 \text{ pb} (\text{data})$ MATRIX (NNLO) (theory)	× ^			20.3	arXiv:1604,08576 [hep-ph]	
	$\sigma = 19.0 + 1.4 - 1.5 \pm 1.0 \text{ pb (data)}$ MATRIX (NNLO) (theory) $\sigma = 252.8 \pm 13.2 \pm 12.0 \text{ fb (data)}$		I HC nn	√s = 7 TeV	4.6	arXiv:1604.08576 [hep-ph]	
$-WZ \rightarrow \ell \nu \ell \ell$	$\sigma = 252.6 \pm 15.2 \pm 12.0$ b (data) MCFM NLO (theory) $\sigma = 140.4 \pm 2.8 \pm 4.6$ fb (data)		Lito pp		3.2	arXiv:1606.04017 [hep-ex]	
	MCFM NLO (theory) m = 167 + 2.2 - 2.0 + 1.3 - 1.0 pb (data)		•	Dala stat	20.3	PRD 93, 092004 (2016) PRI 116 101801 (2016)	
	$\sigma = 71 \pm 0.5 = 0.4 \pm 0.4$ pb (data)			stat ⊕ syst	3.2	PLB 735 (2014) 311 ATLAS-CONE-2013-020	
	$\sigma = 67 \pm 0.7 \pm 0.5 \pm 0.4 \text{ pb (data)}$			$\sqrt{c} = 8 \text{ TeV}$	20.3	FLEP 03. (2014) 311	
	NNLO (theory) $\sigma = 107.0 + 9.0 + 5.0$ fb (data)		спо рр	VS - O TEV	4.6	PLB 735 (2014) 311	
– <b>ZZ→4</b> ℓ, (tot.)	Powheg (theory) $\sigma = 76.0 \pm 18.0 \pm 4.0$ fb (data)	×		Data	20.3	PRL 112, 231806 (2014)	
	Powheg (theory) $\sigma = 29.7 + 3.9 - 3.6 + 2.0 - 1.5$ fb (data)			stat ⊕ syst	4.5	PRL 112, 231000 (2014)	
77 . 10	MCFM (theory) $\sigma = 20.7 + 1.3 - 1.2 \pm 1.0$ fb (data)			$\sqrt{c} = 12 \text{ ToV}$	3.2	ATLAS CONF 2012 000	
$- \mathbf{\Sigma} \mathbf{\Sigma} \rightarrow 4 \mathbf{i}$	MCFM (theory) $\sigma = 25.4 + 3.3 - 3.0 + 1.6 - 1.4$ fb (data)		Life pp	γs = 13 lev	20.3	ATLAS-CONF-2013-020	
77 . 00	PowhegBox & gg2ZZ (theory) $\sigma = 12.7 + 3.1 - 2.9 \pm 1.8$ fb (data)			Data	4.0	IHEP 03, 128 (2013)	
	PowhegBox & gg2ZZ (theory) $\sigma = 73.0 \pm 4.0 \pm 5.0$ fb (data)			stat ⊕ svst	4.0	PLB 753 552-572 (2016)	
-ZZ*→4ℓ	PowhegBox norm. to NNLO & gg2ZZ (theory) $\sigma = 29.8 + 3.8 - 3.5 + 2.1 - 1.9$ fb (data)				20.5	JHEP 03, 128 (2013)	
	PownegBox & gg2ZZ (theory)		<b>.</b>		4.0	0.121 00, 120 (2010)	
	0.2 0.4 0.6 0	0.8 1.0 1.2	1.4 1.6 1.8 2	.0 2.2 2.4			
ratio to best theory							





AS









#### The reaction from CERN Restaurant 1











But YOU said there would be new physics!!!



















#### Searches 0 - Standard Model 'a lot'

- The standard model is standing up to intense scrutiny
- A variety of precision measurements show excellent agreement with calculations at several collision energies
- Almost all searches we perform have some amount of model dependence i.e. you search for a specific signal topology
- But....
- We DO NOT KNOW what new physics will look like (...and we want to cast a wide net)









Higgs boson

## **Dark Matter**







2(



#### **Properties of dark matter**



Approximately Cold / non-relativistic

Modified gravity difficult and lacks other evidence

Massive AstrophysiCal Halo Objects (MACHOs) cannot\* account for observed density

Particle dark matter: but properties inconsistent with any Standard Model particle











#### **Searches for New Physics**







Dijet

2.5

#### **Searches for New Physics => Searches for Dark Matter**









# Spectrum of Theory Space



Conta

Focus on general WIMP searches emphasizing complementarity between searches for dark matter
assume an effective baryon coupling: scattering off nuclei and production in pp collisions
do signature-based searches applicable to broad classes of possible models



#### **Searching for collider stable Weakly interacting particles**







### Mono-jet



Inclusive and Exclusive signal regions with successively larger MET requirements











One key challenge of the mono-jet analysis is modeling Z+jets and W+jets background at very high boson pT.

Check with visible W and Z decays, photon+jet (invisible decays of the Z occurs 6x more often than visible).







#### **Mono-jet**







### **13 TeV Monojet results: Constraints on DM Simplified Models**

Axial-vector simplified model:

$${\cal L}_{
m axial-vector}=-g_{
m DM}Z'_{\mu}ar{\chi}\gamma^{\mu}\gamma_5\chi-g_q\sum_{q=u,d,s,c,b,t}Z'_{\mu}ar{q}\gamma^{\mu}\gamma_5q$$





Translation from simplified model to nucleon-WIMP cross section described in arXiv:1603.04156













Representative distributions for the three control regions of the analysis. Backgrounds are normalised to the fit results. The dominant post-fit systematic uncertainties are included in the systematic band.

#### ATLAS-CONF-2016-086

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### Higgs+MET

#### ATLAS-CONF-2016-019









#### **Mono-photon**



Similar strategy to mono-jet search:

- 1 and 2 electron/muon CRs used to estimate W/Z +jets background
- Use missing transverse momentum and photon pT as key discriminators
- No evidence for signal above predicted background •







90% CL limit on xx-proton scattering cross section in a simplified model of dark matter production involving an axial-vector operator

 $10^{4}$ 





#### Mono-W/Z



### If instead we consider a hadronically decaying W or Z boson

The missing transverse momentum (no muons) distribution of the events in the tt, Z and W CRs. The total background prediction before the fit is shown as a dashed line.







35 🔘



### **Resonance searches**




#### **ATLAS Exotics Searches\* - 95% CL Exclusion**

Status: August 2016

	Model	<i>ℓ</i> ,γ	Jets†	$\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}$	∫£ dt[fb	- <sup>1</sup> ] Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$ ADD non-resonant $\ell\ell$ ADD QBH $\rightarrow \ell q$ ADD QBH ADD QBH ADD BH high $\sum p_T$ ADD BH multijet RS1 $G_{KK} \rightarrow \ell\ell$ RS1 $G_{KK} \rightarrow \gamma\gamma$ Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$ Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$ Bulk RS $g_{KK} \rightarrow tt$ 2UED / RPP	$ \begin{array}{c} - \\ 2 e, \mu \\ 1 e, \mu \\ - \\ 2 e, \mu \\ 2 \gamma \\ 1 e, \mu \\ - \\ 1 e, \mu \\ 1 e, \mu \\ 1 e, \mu \\ \end{array} $	$\geq 1 j$ $-$ $2 j$ $\geq 2 j$ $\geq 3 j$ $-$ $-$ $1 J$ $4 b$ $\geq 1 b, \geq 1 J h$ $\geq 2 b, \geq 4$	Yes    Yes j Yes	3.2 20.3 20.3 15.7 3.2 3.6 20.3 3.2 13.2 13.3 20.3 3.2	Mp         6,58 TeV         n = 2           Ms         4.7 TeV         n = 3 HLZ           M <sub>b</sub> 5.2 TeV         n = 6           M <sub>th</sub> 8.7 TeV         n = 6           M <sub>th</sub> 8.2 TeV         n = 6           M <sub>th</sub> 8.2 TeV         n = 6, M <sub>D</sub> = 3 TeV, rot BH           M <sub>th</sub> 9,55 TeV         n = 6, M <sub>D</sub> = 3 TeV, rot BH           M <sub>th</sub> 9,55 TeV         n = 6, M <sub>D</sub> = 3 TeV, rot BH           G <sub>KK</sub> mass         3.2 TeV         k/M <sub>P</sub> = 0.1           G <sub>KK</sub> mass         1.24 TeV         k/M <sub>P</sub> = 1.0           G <sub>KK</sub> mass         2.2 TeV         BR = 0.925           KK mass         1.46 TeV         Tier (1,1), BR(A^{(1,1)} \rightarrow tt) = 1	1604.07773 1407.2410 1311.2006 ATLAS-CONF-2016-069 1606.02265 1512.02586 1405.4123 1606.03833 ATLAS-CONF-2016-062 ATLAS-CONF-2016-049 1505.07018 ATLAS-CONF-2016-013
Gauge bosons	$\begin{array}{l} \operatorname{SSM} Z' \to \ell\ell \\ \operatorname{SSM} Z' \to \tau\tau \\ \operatorname{Leptophobic} Z' \to bb \\ \operatorname{SSM} W' \to \ell\nu \\ \operatorname{HVT} W' \to WZ \to qq\nu\nu \mbox{ model } B \\ \operatorname{HVT} W' \to WZ \to qqqq \mbox{ model } B \\ \operatorname{HVT} V' \to WH/ZH \mbox{ model } B \\ \operatorname{LRSM} W'_R \to tb \\ \end{array}$	2 e, μ 2 τ - 1 e, μ 3 - multi-channe 1 e, μ 0 e, μ	- 2 b - 1 J 2 J el 2 b, 0-1 j ≥ 1 b, 1 J	- Yes Yes - Yes -	13.3 19.5 3.2 13.3 13.2 15.5 3.2 20.3 20.3	Z' mass     4.05 TeV       Z' mass     2.02 TeV       Z' mass     1.5 TeV       W' mass     4.74 TeV       W' mass     2.4 TeV       W' mass     3.0 TeV       Y' mass     2.31 TeV       W' mass     1.92 TeV       W' mass     1.76 TeV	ATLAS-CONF-2016-045 1502.07177 1603.08791 ATLAS-CONF-2016-061 ATLAS-CONF-2016-062 ATLAS-CONF-2016-055 1607.05621 1410.4103 1408.0886
CI	Cl qqqq Cl ℓℓqq Cl uutt	_ 2 e,μ 2(SS)/≥3 e,	2 j _ µ ≥1 b, ≥1 j	_ _ Yes	15.7 3.2 20.3	Λ         19.9 TeV         η <sub>LL</sub> = -1           Λ         25.2 TeV         η <sub>LL</sub> = -1           Λ         4.9 TeV         Ι/L_R = 1	ATLAS-CONF-2016-069 1607.03669 1504.04605
DM	Axial-vector mediator (Dirac DM) Axial-vector mediator (Dirac DM) $ZZ_{\chi\chi}$ EFT (Dirac DM)	0 e, μ 0 e, μ, 1 γ 0 e, μ	≥1j 1j 1J,≤1j	Yes Yes Yes	3.2 3.2 3.2	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	eV 1604.07773 eV 1604.01306 ATLAS-CONF-2015-080
ΓØ	Scalar LQ 1 <sup>st</sup> gen Scalar LQ 2 <sup>nd</sup> gen Scalar LQ 3 <sup>rd</sup> gen	2 e 2 μ 1 e,μ	≥ 2 j ≥ 2 j ≥1 b, ≥3 j	– – Yes	3.2 3.2 20.3	LQ mass         1.1 TeV $\beta = 1$ LQ mass         1.05 TeV $\beta = 1$ LQ mass         640 GeV $\beta = 0$	1605.06035 1605.06035 1508.04735
Heavy quarks	$ \begin{array}{l} VLQ \ TT \rightarrow Ht + X \\ VLQ \ YY \rightarrow Wb + X \\ VLQ \ BB \rightarrow Hb + X \\ VLQ \ BB \rightarrow Zb + X \\ VLQ \ BB \rightarrow Zb + X \\ VLQ \ QQ \rightarrow WqWq \\ VLQ \ T_{5/3} \ T_{5/3} \rightarrow WtWt \end{array} $	1 <i>e</i> , μ 1 <i>e</i> , μ 1 <i>e</i> , μ 2/≥3 <i>e</i> , μ 1 <i>e</i> , μ 2(SS)/≥3 <i>e</i> ,	$ \begin{array}{l} \geq 2 \ {\rm b}, \geq 3 \\ \geq 1 \ {\rm b}, \geq 3 \\ \geq 2 \ {\rm b}, \geq 3 \\ \geq 2/{\geq}1 \ {\rm b} \\ \geq 4 \ {\rm j} \\ \mu \geq 1 \ {\rm b}, \geq 1 \ {\rm j} \end{array} $	j Yes j Yes j Yes - Yes Yes	20.3 20.3 20.3 20.3 20.3 20.3 3.2	T mass         855 GeV         T in (T.B) doublet           Y mass         770 GeV         Y in (B, Y) doublet           B mass         735 GeV         isospin singlet           B mass         755 GeV         B in (B, Y) doublet           B mass         755 GeV         B in (B, Y) doublet           T sr,3 mass         990 GeV         B in (B, Y) doublet	1505.04306 1505.04306 1505.04306 1409.5500 1509.04261 ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \rightarrow q\gamma$ Excited quark $q^* \rightarrow qg$ Excited quark $b^* \rightarrow bg$ Excited quark $b^* \rightarrow Wt$ Excited lepton $\ell^*$ Excited lepton $\nu^*$	1 γ - 1 or 2 e, μ 3 e, μ 3 e, μ, τ	1 j 2 j 1 b, 1 j 1 b, 2-0 j –	- - Yes -	3.2 15.7 8.8 20.3 20.3 20.3	q* mass     4.4 TeV     only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ q* mass     5.6 TeV     only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ b* mass     2.3 TeV     only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ b* mass     1.5 TeV $f_g = f_L = f_R = 1$ $\ell^*$ mass     3.0 TeV $\Lambda = 3.0$ TeV $v^*$ mass     1.6 TeV $\Lambda = 1.6$ TeV	1512.05910 ATLAS-CONF-2016-069 ATLAS-CONF-2016-060 1510.02664 1411.2921 1411.2921
Other	LSTC $a_T \rightarrow W\gamma$ LRSM Majorana $v$ Higgs triplet $H^{\pm\pm} \rightarrow ee$ Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$ Monotop (non-res prod) Multi-charged particles Magnetic monopoles	$\frac{1}{1} \frac{1}{e, \mu, 1} \frac{1}{\gamma} \frac{1}{2} \frac{1}{e, \mu} \frac{1}{2} \frac{1}{e, \mu} \frac{1}{2} \frac{1}{e, \mu} \frac{1}{e, \mu}$	_ 2 j - 1 b - - -	Yes   Yes  - 3 TeV	20.3 20.3 13.9 20.3 20.3 20.3 7.0	ar mass     960 GeV       N <sup>0</sup> mass     2.0 TeV       M <sup>±x</sup> mass     570 GeV       H <sup>±±</sup> mass     570 GeV       H <sup>±±</sup> mass     657 GeV       multi-charged particle mass     657 GeV       multi-charged particle mass     785 GeV       monopole mass     1.34 TeV	1407.8150 1506.06020 ATLAS-CONF-2016-051 1411.2921 1410.5404 1504.04188 1509.08059
						Mass scale [Te	V

\*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded. †Small-radius (large-radius) jets are denoted by the letter j (J).





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ATLAS Preliminary  $\int \mathcal{L} dt = (3.2 - 20.3) \text{ fb}^{-1}$ 

 $\sqrt{s}$  = 8, 13 TeV

## Early Searches for Exotic New Phenomena









## **Di-jet resonance**





Run: 280673 Event: 1273922482 2015-09-29 15:32:53 CEST





### **Di-Jets**

- Update on Dijet resonance search 15.7fb<sup>-1</sup>
- Dijet search for a peaking signal in invariant mass spectrum
- Models: Sensitive to Quantum Black Holes, excited quarks, W' and Z'
- Backgrounds: Using simple analytic fit function
- Using *Bump Hunter* technique to identify the most significant excess (global p-value of 70%). *No significant excess found*



#### Limits on QBH at ~9TeV at 95% CL with 2016 data





### Di-Jets – low mass

Use dijet events with an extra photon (left) or • jet(right) from ISR – with 15.5fb<sup>-1</sup>





X + j (P<sub>T i</sub> > 430 GeV)

-  $\odot$  - Z' (g<sub>a</sub> = 0.30), m<sub>z'</sub> = 350 GeV,  $\sigma \times 50$ 

400

ATLAS Preliminary

400

300

|y<sub>23</sub>\*| < 0.6

p-value = 0.6

Fit Range: 303 - 611 GeV

Events

10

10

10<sup>4</sup>

Significance 2

450

500

550

600 m<sub>z'</sub> [GeV]

× BR [pb]

A

×

ь

10

 $10^{-2}$ 



ATLAS Preliminary

\s=13 TeV, 15.5 fb<sup>-1</sup>

Background fit

500

\s=13 TeV, 15.5 fb<sup>-1</sup>

 $--- \sigma_{c}/m_{c} = 0.10$ 

 $--- \sigma_{\rm G}/m_{\rm G} = 0.07$ 

 $--- \sigma_G/m_G = \text{Res.}$ 

500

600

m<sub>G</sub> [GeV]

|y<sub>23</sub>\*| < 0.6

X + j (P<sub>T i</sub> > 430 GeV)

600

m<sub>ii</sub> [GeV]

BumpHunter interval

Data





## Photon-Jet Event

High Mass Photon-Jet  $ET_1 = 1.23 \text{ GeV } ET_2 = 1.26 \text{ GeV}$  $m_{yJ} = 2.9 \text{TeV}$ 



Run: 280862 Event: 2810917867 2015-10-03 01:08:53 CEST

## Search for new phenomena in Photon-Jet events



Search for q\* or QBH decaying to a photon and a parton

 Background estimated using a simple fit function similar to dijet search and extrapolate in the high mass domain

$$f_{bkg}(x \equiv m_{\gamma j} / \sqrt{s}) = p_0 (1 - x)^{p_1} x^{-p_2 - p_3 \log x}$$

 Background modeling systematics estimated using the *spurious signal* method similarly to the diphoton Higgs channel









## Search for new phenomena in Multi-Jet events

**Search for thermal black holes** in multijet events (in 3-8 jets signal regions), signal at high HT

- Fit low HT and validate and choose in medium
   HT (among 10 functions)
- **Bootstrap**: use incremental datasets to define Control Regions (6.5pb-1, 74pb-1, 440pb-1 and 3.0 fb-1)











## **Di-lepton Resonances (LFC)**

- Search for Z' in dilepton (LFC)
  - Main background DY is taken from MC



 Backgrounds taken from MC except for multi-jet in dielectron which uses Matrix method (based on electron ID)



Highest dielectron mass at 2.2TeV

Highest dimuon mass at 2TeV



No excesses found! 95% CL limit on SSM Z' at 4TeV (2.9TeV from Run 1)







#### ATLAS-CONF-2016-045

## Di-lepton Resonances (LFC and LFV)

- Search for Z' in dilepton (LFC)
  - Main background DY is taken from MC
  - Top and diboson extrapolated at very high masses using a functional form
  - Backgrounds taken from MC except for multi-jet in dielectron which uses Matrix method (based on electron ID)



No excesses found! 95% CL limit on SSM Z' at 4TeV (2.9TeV from Run 1)









## **Di-Electron Event**

High Mass Dielectron ET<sub>1</sub> = 370 GeV ET<sub>2</sub> = 246 GeV m<sub>ee</sub> = 1.8 TeV



Run: 280319 Event: 472098394 2015-09-25 16:25:21 CEST Z' to 2e candidate Event

- Search for Resonant Lepton-MET
  - Primarily a search for W'
  - Top and diboson extrapolated at very high masses using a functional form
  - Backgrounds taken from MC except for multi-jet which is estimated using Matrix method (based on electron ID)









ATLAS-CONF-2016-061

## W' -> ev candidate



Run: 301973 Event: 370829290 2016-06-13 06:52:57 CEST





## **Di-boson resonance searches**





## **Exotics:** Run1 - diboson resonances with boson-tagged jets





Local  $p_0$ 



Exotics: Run1 - diboson resonances with boson-tagged jets











#### Searches for VV or VH resonances in several topologies involving boson (W, Z and H) tagging

#### Nominal boson tagging algorithm

- Anti-kT R=1.0
- Trimming: fcut = 5% and Rsub = 0.2
- pT dependent (energy correlation ratio) D2 selections for W and Z separately (Multijet reduction by 40 – 70)

#### Boson tagging at work

W and Z peak in the data from dijet events applying the nominal boson tagging algorithm







## Searches for Resonance in Di-Boson VV Final States

ZV (with Z to vv)



#### ZV (with Z to dilepton)





#### Backgrounds

Z-jets, W-jets and top are main backgrounds, these are estimated using CRs with 1 or 2 muons and one b-tag for the Top CR.

#### Backgrounds

Z-jets is the main background, estimated using MC and normalised to mJ sidebands Diboson and top from MC

**Background** Estimated using a functional form









## Searches for Resonance in Di-Boson ZV Final States



With no excess, we place limits on a variety of scenarios with limits at 95% CL ranging up to 2TeV.





## Searches in Di-Boson in VH final states

- Search in Diboson VH final
- Analysis strategy: distinct signal regions for 1L-MET and 2L with at least two jets with 1 or 2 btags (2 btags harder to distinguish against at high pT)
- Analysis strategy: perform a global fit to all the regions simultaneously (similar to SM VH analysis in Run-1)







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## Searches in Di-Boson Fully hadronic final state

- Search in Fully hadronic Diboson final state with JJ
  - Modest excess in Run1: 2.5σ global
  - Analysis strategy: maintain synergy with Run-1 functional fit of smoothly falling background shape





 No excess observed – now with sensitivity to the 2TeV region where the Run-1 excess was seen. Limits set at 95% CL on several models









ATLAS-CONF-2016-055

## Searches in Di-Boson Fully hadronic final state

- Search in Fully hadronic Diboson final state with JJ
  - Modest excess in Run1: 3.4σ local / 2.5σ global
  - Analysis strategy: maintain synergy with Run-1 functional fit of smoothly falling background shape



 No excess observed – now with sensitivity to the 2TeV region where the Run-1 excess was seen. Limits set at 95% CL on several models





ATLAS-CONF-2016-055

VV to JJ





## Searches in Di-Boson Fully hadronic final state

EXPERIMENT

Run: 299584 Event: 563621388 2016-05-20 08:26:49 CEST M(JJ)=2.40 TeV





AS















#### SUSY



#### If weak-scale SUSY existed, it could ...

- Moderate the hierarchy problem by cancelling quadratic divergence of SM scalar
- Equalise the number of fermionic and bosonic degrees of freedom, render existence of scalar particles natural
- Realise grand unification of the gauge couplings
- Provide a suitable dark matter candidate





slide by Andreas Hoecker









illustration by M-H Genest





SUSY





Franz Anthony Winner of 'Collision 2015'





SUSY

SUSY ~duplicates spectrum of particle states wrt. Standard Model

Sparticle decays produce SM objects: (**b**/**c**-)jets, leptons,  $\tau$ ,  $\gamma$ , invisible (MET), ...

Cancellation of the top loop correction to the Higgs mass requires (relatively) light susy...perhaps particularly third generation squarks

But, direct production cross section is relatively small compared to light squark and gluino

Dedicated searches required

The early focus of Run2 is on strong production with squarks/ gluinos







## SUSY: Strong Production

### Squark and Gluino mediated light jets











#### Gluino mediated third generation







### HOWTO search for SUSY

# SUSY searches rely primarily on the <u>understanding of the SM backgrounds</u>



Combined fit of all regions and backgrounds and incl. systematic exp. and theor. uncertainties as nuisance parameters

#### Reducible backgrounds

Determined from data Backgrounds and methods depend on analyses

#### Irreducible backgrounds

Dominant sources: normalise MC in data control regions Subdominant sources: MC

#### Validation

Standard Model

Top, multijets V, VV, VVV, Higgs & combinations of these

Validation regions used to cross check SM predictions with data

Signal regions





blinded

blinded

## **SUSY: Strong Production**

Squark and Gluino mediated light jets. The workhorse of the SUSY group – if you predict an excess in many/most channels you often have to reconcile it with the results here.

No excess observed so far in 2015/2016!





## *Always caveats!* Be careful making blanket interpretations of any SUSY search

2000

m<sub>ã</sub> [GeV]







## SUSY: Recursive Jigsaw Reconstruction



#### Application to open final states

- Apply a *decay tree* to decompose information event-by-event
- Partition the MET using a series of *jigsaw rules*
- Extract a basis of variables sensitive to mass scales, but also properties of particles (decay angles, ratios of scales etc)
- Construct signal regions sensitive to mass splittings





Application to compressed scenarios ( 25 GeV <  $\Delta m$  < 200 GeV)

- Leverage large pT ISR system, simple additional complementary variables
- Apply a dedicated decay tree to categorize jets as ISR-like or not
- Improved sensitivity for light squark, stop and gluino pair-production





## **SUSY: Strong Production**

#### Squark and Gluino mediated light jets: 7-10 jets and 0 leptons





As we increase the number of steps in the decay chain we increase the number of objects











## SUSY: Strong Production – multi b-jet signatures

**Search for gluino** production in 8 signal regions with multiple b-jets aiming at decays with b and top quarks



#### Signal categories

- OL and 1L (specific for multi-top signals)
- Number of jets, b-jets and MET

#### Improvements to the analysis

Use of boosted tops, New selection cuts

#### Backgrounds

Top background (dominant) from CRs (in MET) Other backgrounds from MC







**SUSY: Strong Production** 








## 3<sup>rd</sup> generation searches – Summary





fractions alter the limits severely





#### **SUSY: Electroweak Production**











### SUSY Summary

#### ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: August 2016

	Model	$e, \mu, \tau, \gamma$	Jets	$E_{T}^{mbss}$	∫£ dt[fb <sup>-</sup>	Mass limit	√% = 7, 8 TeV	$\sqrt{s} = 13 \text{ TeV}$	Reference	
Inclusive Searches	$\begin{array}{l} \text{MSUGRA/CMSSM} \\ \begin{array}{c} \widetilde{\varphi}_{1}^{2}, \widetilde{\varphi} \rightarrow \varphi_{1}^{C} \\ \widetilde{\varphi}_{1}^{2}, \widetilde{\varphi} \rightarrow \varphi_{1}^{C} \\ \widetilde{z}_{2}^{2}, \widetilde{z} \rightarrow \varphi_{1}^{C} \\ \widetilde{z}_{2}^{2}, \widetilde{z} \rightarrow \varphi_{1}^{C} \\ \widetilde{z}_{2}^{2}, \widetilde{z} \rightarrow \varphi_{1}^{2} \\ \widetilde{z}_{1}^{2}, \widetilde{z} \rightarrow \varphi_{1}^{2} \\ z$	$\begin{array}{c} 0.3 \ e, \mu/1-2 \ \tau \\ 0 \\ mono-jet \\ 0 \\ 3 \ e, \mu \\ 2 \ e, \mu \ (SS) \\ 1-2 \ r + 0-1 \ \ell \\ 2 \ \gamma \\ \gamma \\ 2 \ e, \mu \ (Z) \\ 0 \end{array}$	2-10 jets/3 2-6 jets 1-3 jets 2-6 jets 2-6 jets 4 jets 0-3 jets 0-2 jets 2 jets 2 jets mono-jet	6 Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes	20.3 13.3 13.3 13.3 13.2 13.2 13.2 3.2 20.3 13.3 20.3 20.3	.š 1. 008 GeV 1. 900 GeV 4/2 scale 905 GeV	1.45 TeV m(i)]=n   35 TeV m(i <sup>2</sup> <sub>1</sub> )<2   1.85 TeV m(i <sup>2</sup> <sub>1</sub> )<2   1.85 TeV m(i <sup>2</sup> <sub>1</sub> )   1.85 TeV m(i <sup>2</sup> <sub>1</sub> )   1.7 TeV m(i <sup>2</sup> <sub>1</sub> )   1.05 TeV m(i <sup>2</sup> <sub>1</sub> )	(g) 00 GeV, m[1 <sup>4</sup> gen, ä]=m(2 <sup>m1</sup> gen, ä)  k <sub>1</sub> <sup>n</sup>  <5 GeV 0 GeV 400 GeV, m(k <sup>2</sup> )=0.5[m(k <sub>1</sub> <sup>0</sup> )+m(g)] 400 GeV 500 GeV P]<0.1mm 950 GeV, cr[NLSP]<0.1mm, µ<0 880 GeV, cr[NLSP]<0.1mm, µ>0 P]<430 GeV 1.8 × 10 <sup>-4</sup> eV, m(g)-m(g)=1.5 TeV	1507.05525 ATLAS-CONF-2016-078 1604.07773 ATLAS-CONF-2016-078 ATLAS-CONF-2016-078 ATLAS-CONF-2016-037 ATLAS-CONF-2016-037 1807.05979 1806.09150 1507.05403 ATLAS-CONF-2016-068 1503.03200 1502.01518	
3 <sup>rd</sup> gen. <u>8</u> med.	<u>22</u> , 2→bāξ <sup>0</sup> 22, 2→aīξ <sup>1</sup> 22, 2→bīξ <sup>1</sup> 22, 2→bīξ <sup>1</sup>	0 Ο-1 e,μ Ο-1 e,μ	3 b 3 b 3 b	Yes Yes Yes	14.8 14.8 20.1	1	1.89 TeV m( $\tilde{\ell}_{1}^{4}$ )- 1.89 TeV m( $\tilde{\ell}_{1}^{4}$ )- 37 TeV m( $\tilde{\ell}_{1}^{2}$ )<	DGeV DGeV 300GeV	ATLAS-CONF-2016-062 ATLAS-CONF-2016-062 1407.0600	
$\mathcal{F}^d$ gen. squarks direct production	$\begin{array}{l} b_1 b_1, b_1 \rightarrow h \tilde{\chi}_1^0 \\ b_1 b_1, b_1 \rightarrow h \tilde{\chi}_1^0 \\ \tilde{\chi}_1 \tilde{\chi}_1, \tilde{\chi}_1 \rightarrow \tilde{\chi}_1^0 \\ \tilde{\chi}_1 \tilde{\chi}_1, \tilde{\chi}_1 \rightarrow \tilde{\chi}_1^0 \\ \tilde{\chi}_2 \tilde{\chi}_2, \tilde{\chi}_2 \rightarrow \tilde{\chi}_1 + X \\ \tilde{\chi}_2 \tilde{\chi}_2, \tilde{\chi}_2 \rightarrow \tilde{\chi}_1 + K \end{array}$	0 2 e, $\mu$ (SS) 0 · 2 e, $\mu$ 0 · 2 e, $\mu$ 0 2 e, $\mu$ (Z) 3 e, $\mu$ (Z) 1 e, $\mu$	2 & 1 & 1 -2 & -2 jets/1-2 mono-jet 1 & 1 & 1 & 5 jets + 2 &	Yes Yes Yes Yes Yes Yes Yes Yes	3.2 13.2 .7/13.3 3.2 20.3 13.3 20.3	940 GeV 325-685 GeV 90-198 GeV 90-323 GeV 90-323 GeV 150-600 GeV 290-700 GeV 320-620 GeV	$\pi(\ell_1^2) \le \pi(\ell_1^2) $	100 GeV 150 GeV, m(k <sup>2</sup> <sub>1</sub> ) = m(k <sup>2</sup> <sub>1</sub> ) + 100 GeV 2 m(k <sup>2</sup> <sub>1</sub> ), m(k <sup>2</sup> <sub>1</sub> ) = 55 GeV 1 GeV 150 GeV 150 GeV 300 GeV 0 GeV	1806.03772 ATLAS-CONF-2016-037 1209.2102, ATLAS-CONF-2016-077 1508.06818, ATLAS-CONF-2016-077 1904.07773 1904.07773 1403.5222 ATLAS-CONF-2016-038 1506.03816	
EW direct	$ \begin{array}{c} \tilde{t}_{1,\mathbf{R}}\tilde{t}_{1,\mathbf{R}},\tilde{t} \rightarrow \tilde{t}_{1}^{*}\tilde{t}_{1}^{*}\\ \tilde{x}_{1}^{*}\tilde{t}_{1}^{*},\tilde{x}_{1}^{*}\rightarrow\tilde{t}_{1}\tau(p)\\ \tilde{x}_{1}^{*}\tilde{x}_{1}^{*},\tilde{x}_{1}^{*}\rightarrow\tilde{t}_{1}\tau(p)\\ \tilde{x}_{1}^{*}\tilde{x}_{2}^{*}\rightarrow\tilde{t}_{1}\tau\tilde{x}_{1}^{*}\tau(p), \ell\tilde{\tau}\tilde{t}_{1}\ell(p)\\ \tilde{x}_{1}^{*}\tilde{x}_{2}^{*}\rightarrow\tilde{w}_{1}^{*}\tilde{t}_{2}\tilde{t}_{1}^{*}\\ \tilde{x}_{1}^{*}\tilde{x}_{2}^{*}\rightarrow\tilde{w}_{1}^{*}\tilde{t}_{1}\tilde{x}_{1}^{*},k\rightarrow\tilde{t}\tilde{t}_{1}ww/r\\ \tilde{x}_{2}^{*}\tilde{x}_{2}^{*},\tilde{x}_{23}^{*}\rightarrow\tilde{t}_{R}\ell\\ \tilde{t}_{2}^{*}\tilde{t}_{2}^{*},\tilde{x}_{23}^{*}\rightarrow\tilde{t}_{R}\ell\\ GGM (bino NLSP) weak prod\\ GGM (bino NLSP) weak prod\\ \end{array}$	$2 \epsilon, \mu$ $2 \epsilon, \mu$ $2 \tau$ $3 \epsilon, \mu$ $2 \cdot 3 \epsilon, \mu$ $2 \cdot 3 \epsilon, \mu$ $\epsilon, \mu, \gamma$ $4 \epsilon, \mu$ $1 \epsilon, \mu + \gamma$ $2 \cdot \gamma$	0 - 0-2 jets 0-2 <i>j</i> 0-2 <i>j</i> 0 - -	Yes Yes Yes Yes Yes Yes Yes Yes	20.3 20.3 20.3 20.3 20.3 20.3 20.3 20.3	90-335 GeV 140-475 GeV 355 GeV 715 GeV 425 GeV 35 425 GeV 635 GeV 530 GeV 590 GeV	$\begin{array}{c} m(\xi_1^{0}) =\\ m(\xi_1^{0}) =\\ m(\xi_1^{0}) =\\ m(\xi_1^{0}) =\\ m(\xi_1^{0}) =m(\xi_2^{0}), m(\\ m(\xi_1^{0}) =m(\xi_1^{0}), \\ m(\xi_2^{0}) =m(\xi_2^{0}), \\ cr < 1m\\ cr < 1m \\ cr < 1m \end{array}$	$\begin{array}{l} 0 \; \text{GeV} \\ 0 \; \text{GeV} \; m[\tilde{\ell},\tilde{r}]{=}0.5(m[\tilde{\ell}_1^{-1}]{+}m[\tilde{\ell}_1^{0}]) \\ 0 \; \text{GeV}, \; m[\tilde{\ell},\tilde{r}]{=}0.5[m[\tilde{\ell}_1^{-1}]{+}m[\tilde{\ell}_1^{0}]) \\ 0 \; \text{GeV}, \; m[\tilde{\ell},\tilde{r}]{=}0.5(m[\tilde{\ell}_1^{-1}]{+}m[\tilde{\ell}_1^{0}]) \\ m[\tilde{\ell}_1^{0}]{=}0.5(m[\tilde{\ell}_1^{0}]{+}m[\tilde{\ell}_1^{0}]) \\ m[\tilde{\ell}_1^{0}]{=}0.7[\tilde{\ell}]{+}0.5(m[\tilde{\ell}_2^{0}]{+}m[\tilde{\ell}_1^{0}]) \\ m[\tilde{\ell}_1^{0}]{=}0.7[\tilde{\ell}]{+}0.5(m[\tilde{\ell}_2^{0}]{+}m[\tilde{\ell}_1^{0}]) \\ m \\ m \end{array}$	1403 5294 1403 5294 1407 0350 1402 7029 1403 5294, 1402 7029 1501 07110 1405 5068 1507 05493	
Long-lived particles	$\begin{array}{l} \text{Direct} \ \widehat{k}_1^+ \widehat{k}_1^- \ \text{prod., long-lived.} \\ \text{Direct} \ \widehat{k}_1^+ \widehat{k}_1^- \ \text{prod., long-lived.} \\ \text{Stable, stopped } \widehat{g} \ \mathbb{R}^+ \text{hadron} \\ \text{Stable} \ \widehat{g} \ \mathbb{R}^+ \text{hadron} \\ \text{Metastable } \widehat{g} \ \mathbb{R}^+ \text{hadron} \\ \text{GMSB, stable} \ \widehat{\tau}, \ \widehat{k}_1^0 \rightarrow \forall \widehat{c}, \widehat{\mu}) + \\ \text{GMSB, } \ \widehat{k}_1^0 \rightarrow \forall \mathcal{C}, \ \text{long-lived} \ \widehat{k}_1^0 \\ \ \widehat{g} \ \mathcal{R}_1^0 \rightarrow \forall \mathcal{C}, \ \text{long-lived} \ \widehat{k}_1^0 \\ \ \overline{g} \ \mathcal{R}_1^0 \rightarrow \forall \mathcal{C}, \ \text{long-lived} \ \mathcal{R}_1^0 \end{array}$	$ \begin{array}{l} \widehat{\mathfrak{r}}_1^+ & \operatorname{Disapp.trk}\\ \mathfrak{l}_1^+ & \operatorname{dE/dxtrk}\\ & o\\ & \operatorname{trk}\\ \operatorname{dE/dxtrk}\\ \mathfrak{r}(x,\mu) & 1{\cdot}2\mu\\ & 2\gamma\\ \operatorname{displ.ex/ept/\mu}\\ \operatorname{displ.vtx} + \operatorname{jet} \end{array} $	1 jet - 1-5 jets - - - - ts	Yes Yes · · Yes ·	20.3 18.4 27.9 3.2 19.1 20.3 20.3 20.3	270 GeV 495 GeV 850 GeV 537 GeV 440 GeV 1.0 TeV 1.0 TeV	rr(č <sup>1</sup> <sub>1</sub> )+ rr(č <sup>1</sup> <sub>1</sub> )+ 1.57 TeV 1.57 TeV 10 ctan 1 < ct <sup>2</sup> <sub>1</sub> )= 10 ctan 1 < ct <sup>2</sup> <sub>1</sub> 10 ctan	n[k <sup>2</sup> <sub>1</sub> ] - 180 MeV, τ(k <sup>2</sup> <sub>1</sub> ) = 0.2 na n[k <sup>2</sup> <sub>1</sub> ] - 180 MeV, τ(k <sup>2</sup> <sub>1</sub> ) < 15 na 100 GeV, 10 μs <τ(g) < 1000 a 100 GeV, τ>10 na μ<50 )<3 na, SPS8 model <sup>2</sup> <sub>1</sub> ] < 740 mm, m(g) = 1.3 TeV <sup>2</sup> <sub>1</sub> ] < 450 mm, m(g) = 1.1 TeV	1310.3675 1506.05332 1310.6584 1606.05120 1804.04520 1411.6705 1409.5542 1504.05182 1504.05182	
RPV	$ \begin{array}{l} LFV pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow ap(e\tau) \mu \\ Binear \ RPV \ CMSSM \\ \tilde{x}_1^* \tilde{x}_1^* , \tilde{x}_1^* \rightarrow W_1^{\tilde{x}_1} \tilde{x}_1^0 \rightarrow aev, e\muv; \\ \tilde{x}_1^* \tilde{x}_1^* , \tilde{x}_1^* \rightarrow W_1^{\tilde{x}_1} \tilde{x}_1^0 \rightarrow arv, e\muv; \\ \tilde{x}_2^* \tilde{x}_1^* , \tilde{x}_1^* \rightarrow W_1^{\tilde{x}_1} \tilde{x}_1 \rightarrow arv_k, e\tauv; \\ \tilde{x}_2^* \tilde{x}_2^* \rightarrow q\bar{q}_1^* \tilde{x}_1^* \rightarrow a\bar{q}q \\ \tilde{x}_2^* \tilde{x}_2^* \rightarrow q\bar{q}_1^* \tilde{x}_1^* \rightarrow b\bar{x}_2 \\ \tilde{x}_1^* \tilde{x}_1 , \tilde{x}_1 \rightarrow b\bar{x}_2 \\ \tilde{x}_1^* \tilde{x}_1 , \tilde{x}_1 \rightarrow b\bar{x}_2 \\ \tilde{x}_1^* \tilde{x}_1 , \tilde{x}_1 \rightarrow b\bar{x} \end{array} $	$\tau = e^{i\mu_e e_{\tau} \mu_e T}$ $2 e, \mu (SS)$ $\mu\mu\nu = 4 e, \mu$ $\nu_{\tau} = 0 = 4$ 0 = 4 $2 e, \mu (SS)$ 0 $2 e, \mu$	- 0-3 b - 5 large- R ju 0-3 b 2 jets + 2 b 2 b	Yes Yes Yes ets ts Yes	3.2 20.3 13.3 20.3 14.8 14.8 13.2 15.4 20.3	2 450 GeV 1.08 Te 410 GeV 410 GeV 0.4-1.0 TeV 0.4-1.0 TeV	1.9 TeV λ'm =   1.45 TeV rr(ĝ)=n   reV rr(ĝ1)=n   v BR(r)=1   1.55 TeV rr(ĝ1)   .3 TeV rr(ĝ1)   BR(r)=1 BR(r)=1	2.11, λ <sub>122/123/22</sub> =0.07 (β), cr <sub>222</sub> =1 mm 4000;cV, λ <sub>122</sub> =0 (k = 1, 2) 0.2em(k <sup>2</sup> ), λ <sub>122</sub> =0 (k 380/b;cBR(c)=0% 880 GeV 750 GeV Arr(μ):>20%	1807.08079 1404.2500 ATLAS-CONF-2016-075 1406.5068 ATLAS-CONF-2016-067 ATLAS-CONF-2016-067 ATLAS-CONF-2016-087 ATLAS-CONF-2016-087 ATLAS-CONF-2015-015	
Other	Scalar chann, $\tilde{\epsilon} \rightarrow \varsigma \tilde{\ell}_1^0$	0	2 c	Yes	20.3	510 GeV	rn( $\tilde{t}_{1}^{*}$ )<	200 GeV	1501.01325	
*On sta	*Only a selection of the available mass limits on new 10 <sup>-1</sup> 1 Mass scale [TeV]									







**ATLAS** Preliminary  $\sqrt{s} = 7, 8, 13 \text{ TeV}$ 

# Summary

#### • The Past:

- Hundreds of searches performed with 7TeV and 8TeV data lay the groundwork for higher energy runs
- 13TeV collisions since mid-2015

#### • The Present:

- Incredible LHC performance so far in 2016
- Lots of results produced in the last ~6 weeks
- Much more to come by the end of the year
- We anticipate another harvest of results toward the end of the year with publications being prepared in early 2017 (ready for Moriond timescale)

### • The Future:

- ~100fb<sup>-1</sup> of 13TeV pp collisions by the end of the current run
- With further upgrades to LHC/ATLAS we will continue running deep into the 2020's
- The LHC physics program is still very much in it's infancy





# **Backup Slides**





Mono-W/Z: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2015-08/

Mono-photon: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2015-05/

VLQ Wb: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-072/

VLQ top: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-013/





# **Vector-Like Quarks: single production decaying to Wb**

VLQ - Spin 1/2, coloured, charged particles with both left- and right-handed coupling to charged currents.

- pair production: through QCD dominant in low mass
- single production through EWK coupling dominant at high mass (model dependent)





# **VLQ: single production decaying to Wb**



#### Post-fit distributions agree well with SM predictions

#### ATLAS-CONF-2016-072









Theoretical cross sections (NNLO +NNLL) for QQ production in pp collisions at  $\sqrt{s}=8$  TeV and 13 TeV, as a function of mQ.

Branching ratios for the different decay modes of a vector-like T quark as a function of the heavyquark mass, separately for an SU(2) singlet and an SU(2) doublet.





Representative leadingorder Feynman diagram for TT production probed by this search.







Good discrimination between signal and backgd for variables considered

Due to richness of the final state several signal regions are defined

Post-fit results show excellent agreement with all final state topologies considered.







With no evidence of BSM physics we proceed to place limits on the models considered.  $M_T > 900 GeV @ 95\% CL$ although altering BF's relaxes this constraint.









Representative leading-order Feynman diagrams for four-top-quark production within (a) the SM and several BSM scenarios (see text for details): (b) via an effective four-top-quark interaction in an effective field theory model, and (c) via cascade decays from Kaluza–Klein excitations in a universal extra dimensions model with two extra dimensions compactified using the geometry of the real projective plane.





**SUSY: Strong Production** 









### 3<sup>rd</sup> SUSY generation topologies







### Scalar bottom searches – still no excess at 13TeV



$$m_{CT}^{2}(v_{1}, v_{2}) = [E_{T}(v_{1}) + E_{T}(v_{2})]^{2} - [p_{T}(v_{1}) - p_{T}(v_{2})]^{2}$$

$$H_{T,3} = \sum_{i=4}^{n} (p_T^{\text{jet}})_i$$

 $\begin{array}{ll} 0 \ \text{lepton}+2 \ \text{b-jets}+\text{MET} \\ \text{Primary signature for direct sbottom production} \\ \text{Direct Stop sensitivity for small} & \Delta\mathbf{m}(\tilde{\chi}^{\pm},\tilde{\chi}^{\mathbf{0}}) \\ \text{in } \tilde{t}_1 \rightarrow b\tilde{\chi}^{\pm} \end{array}$ 

#### Analysis method:

- Trigger: E<sub>T</sub><sup>miss</sup>
- Selection: E<sub>T</sub><sup>miss</sup>, 2-b-jets, lepton veto
- Large  $\Delta m(b_1, \chi^0_1)$ : large  $m_{CT}$ ,  $m_{bb} > 200 GeV$ ,  $3^{rd}$  jet veto
- Small  $\Delta m(b_1, \chi^0_1)$ : require an anti- b-tagged ISR jet, large  $H_{T,3}$  and  $E_T^{miss}$
- Main backgrounds: Z(vv)+bjets, W+bjets, tt



from single lep or e/ μ control region





