ARC Centre of Excellence for Particle Physics at the Terascale

LHC searches and status

March 9th, 2016
In celebration of Tony William's 60th birthday 'New Directions in Subatomic Physics'

Paul Jackson
University of Adelaide

Outline

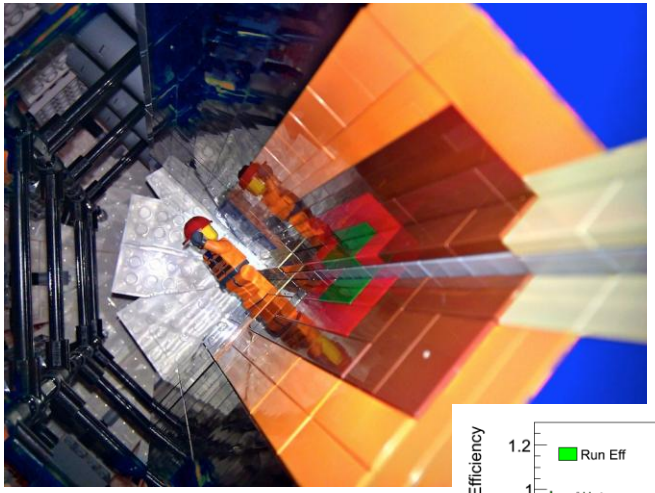
- The datasets and the physics programs
- Part I: Higgs
  - SM constraints
  - BSM searches
- Part II: SUperSYmmetry
  - 0/1-lepton
  - 2-leptons: including Z
  - Third generation and Electroweak
- Part III: Exotica Resonances:
  - Dijet, Dilepton, Diphoton
  - Boosted objects
  - All others
- Hints? Excesses? Anomalies? What might they all mean
- Are there any common themes to look out for?
- What might 2016 bring?

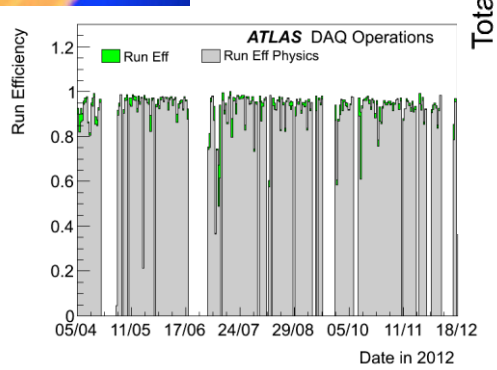
There is an almost complete bias in what I show as it's almost entirely about ATLAS……other results touched on where appropriate

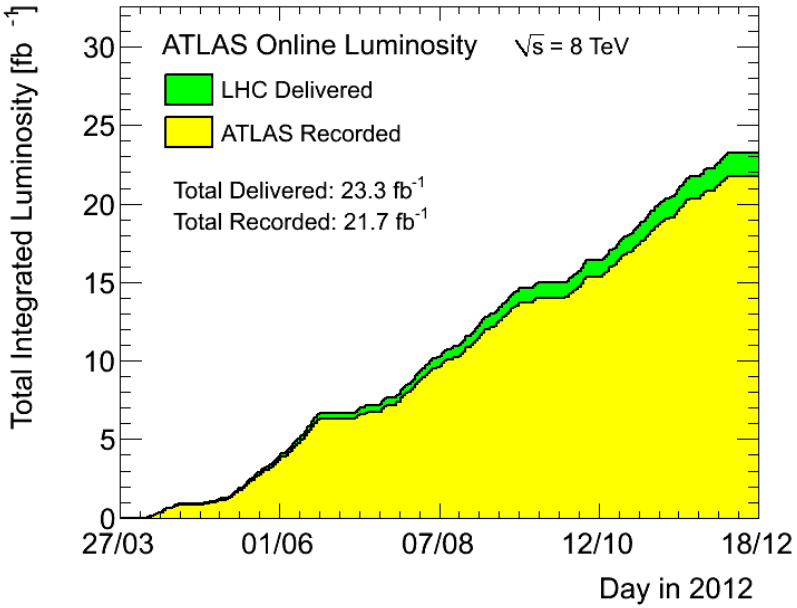
(Maybe obvious) statements about "Searches"

- Any new physics will either be produced in conjunction with/or decay to Standard Model particles - ***these are what we measure***
  - Whether performing a search or not we measure Standard Model objects
  - To search for something new there has to be a difference, or differences, between the new physics and the Standard Model
  - Exploiting the differences as efficiently as possible is what makes one analysis better than another
- We DO NOT KNOW what new physics will look like!!!
  - The searches we perform are based on our prejudices and we interpret them in only a specific number of signal scenarios
- The *partitioning* of many analyses within ATLAS/CMS is *largely arbitrary* and often not based on physics principles
  - Example "Y" -> W^+W^- -> $l^+\nu\, l^-\nu$ (+X) => is it SM/Exotics/Higgs/SUSY?

ATLAS data-taking in 2012 @ 8TeV







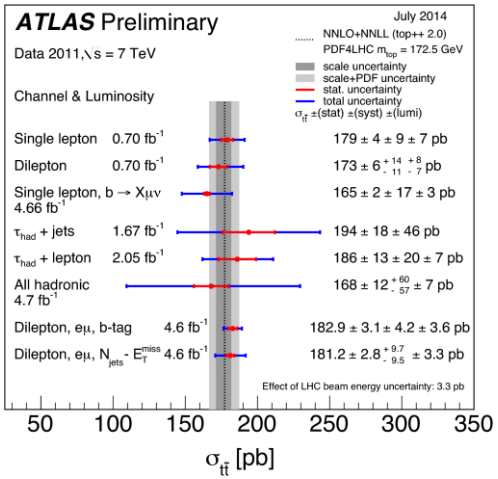
All detectors operating with high efficiency

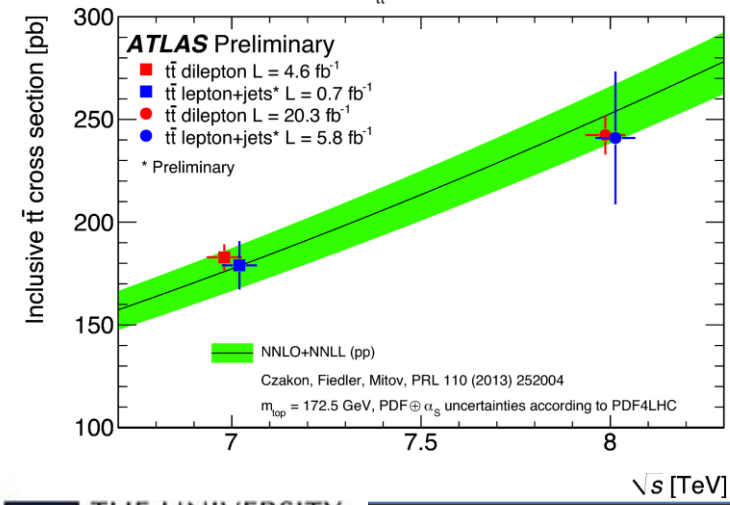
Peak Lumi	$7.48 \times 10^{33} cm^{-2} s^{-1}$
Peak Events/BX	35.87
Delivered Ready (pb^{-1})	22322.5
Recorded Ready (pb^{-1})	21279.6
LAr Ready Fraction of All Good	99.79%

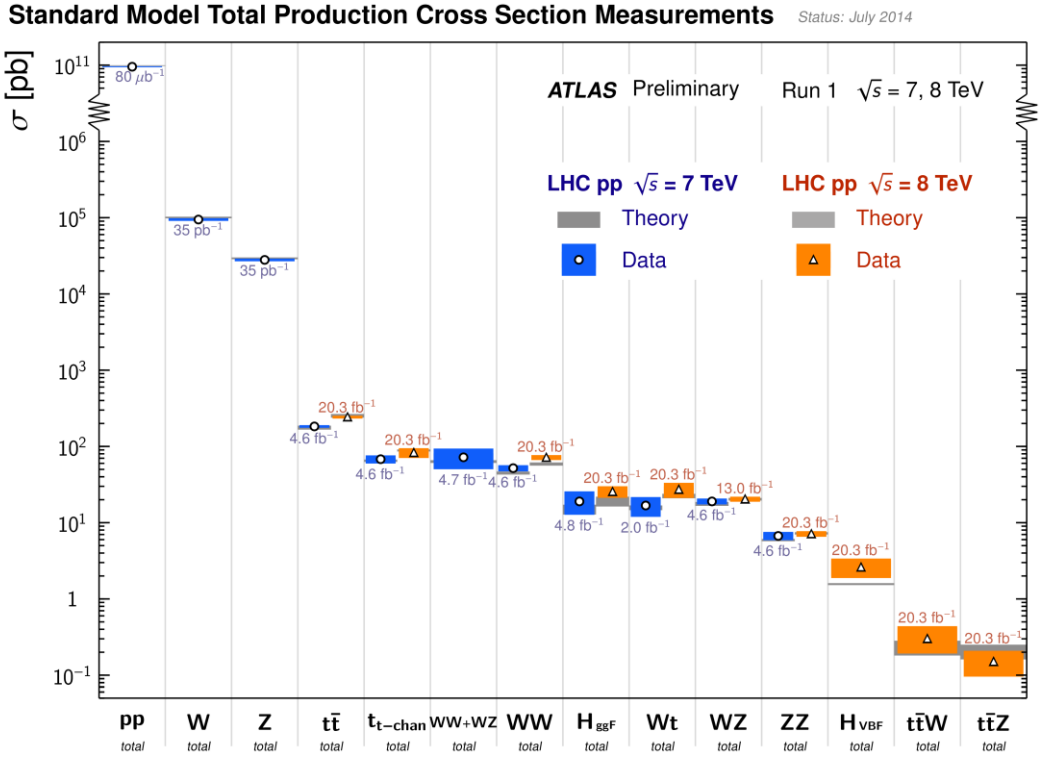
CP and Physics				Inner Detector		Calorimeters		Muon Detectors		Trigger, Lumi & Magnets	
Jet/MET	95.7	Tracking	97.5	Pixel	99.9	LAr	99.1	MDT	99.6	L1	99.8
Egamma	96.8	MCP	96.7	SCT	99.1	Tile	99.6	RPC	99.8	HLT	100.0
B-Jet	96.9	Tau	96.8	TRT	99.8			CSC	100.0	LUMI	99.8
All Good	95.5	Tight	59.8					TGC	99.6	Sol.	99.8
Atlas Ready	99.8									Tor	99.5

Understanding the Standard Model Backgrounds

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







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

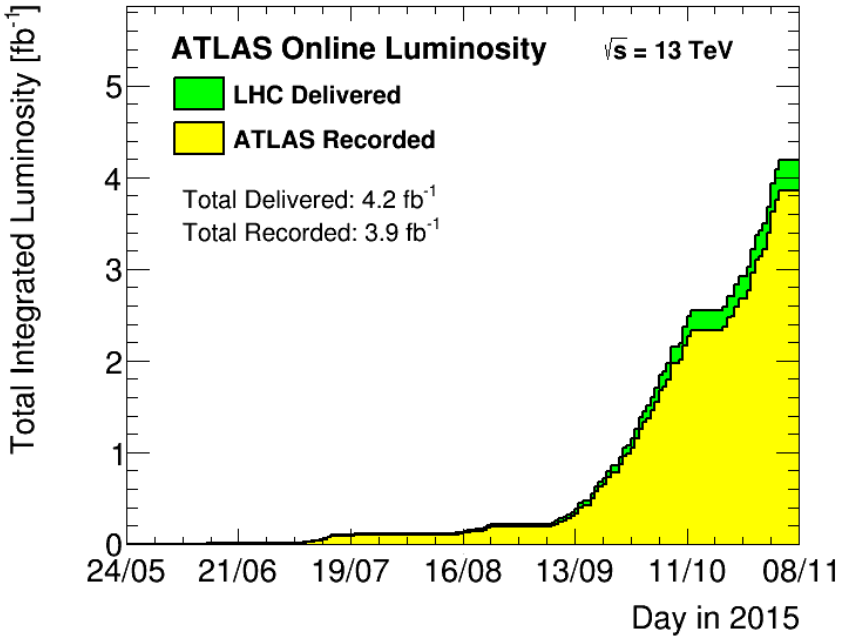
If {no discoveries of new physics} then……

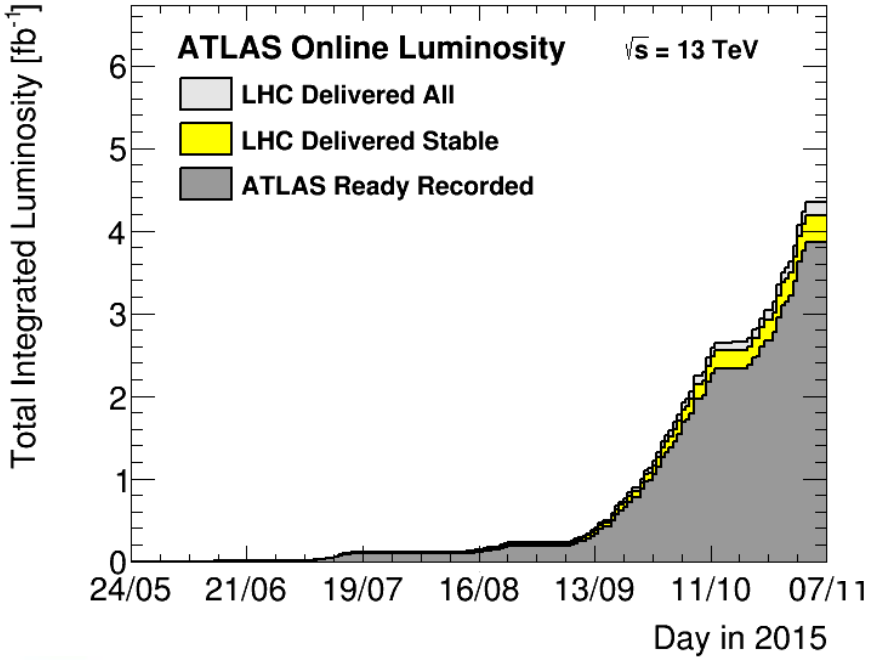
….keep increasing the energy….

2011 -> 2012 -> 2015+

7 TeV -> 8 TeV -> **13 TeV**

ATLAS data-taking in 2015 @ 13TeV

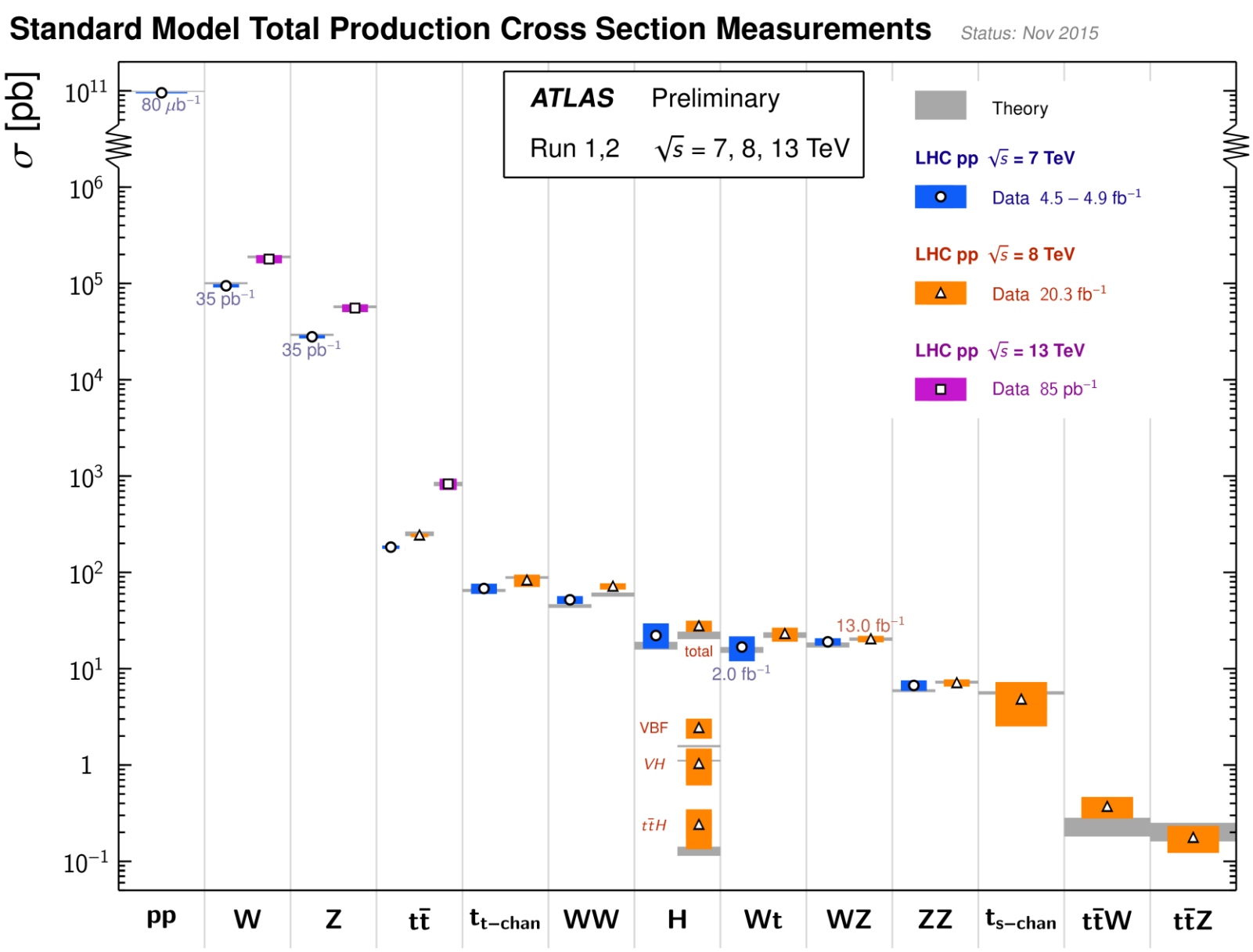




Peak Stable Lumi	5.02×10^{33} cm^{-2} s^{-1}	
Peak Events/BX	40.5	
Peak <Events>/BX	28.1	
Avg <Events>/BX	13.6	
	Lumi (fb^{-1})	Percent
Physics Beams Del.	4.193	100.0%
ATLAS Ready Del.	4.128	98.5%
ATLAS Ready Rec.	3.859	92.0%
Del. after Warmstop	0.023	0.5%

All detectors and machine continue to operate with high efficiency

Understanding the Standard Model Backgrounds



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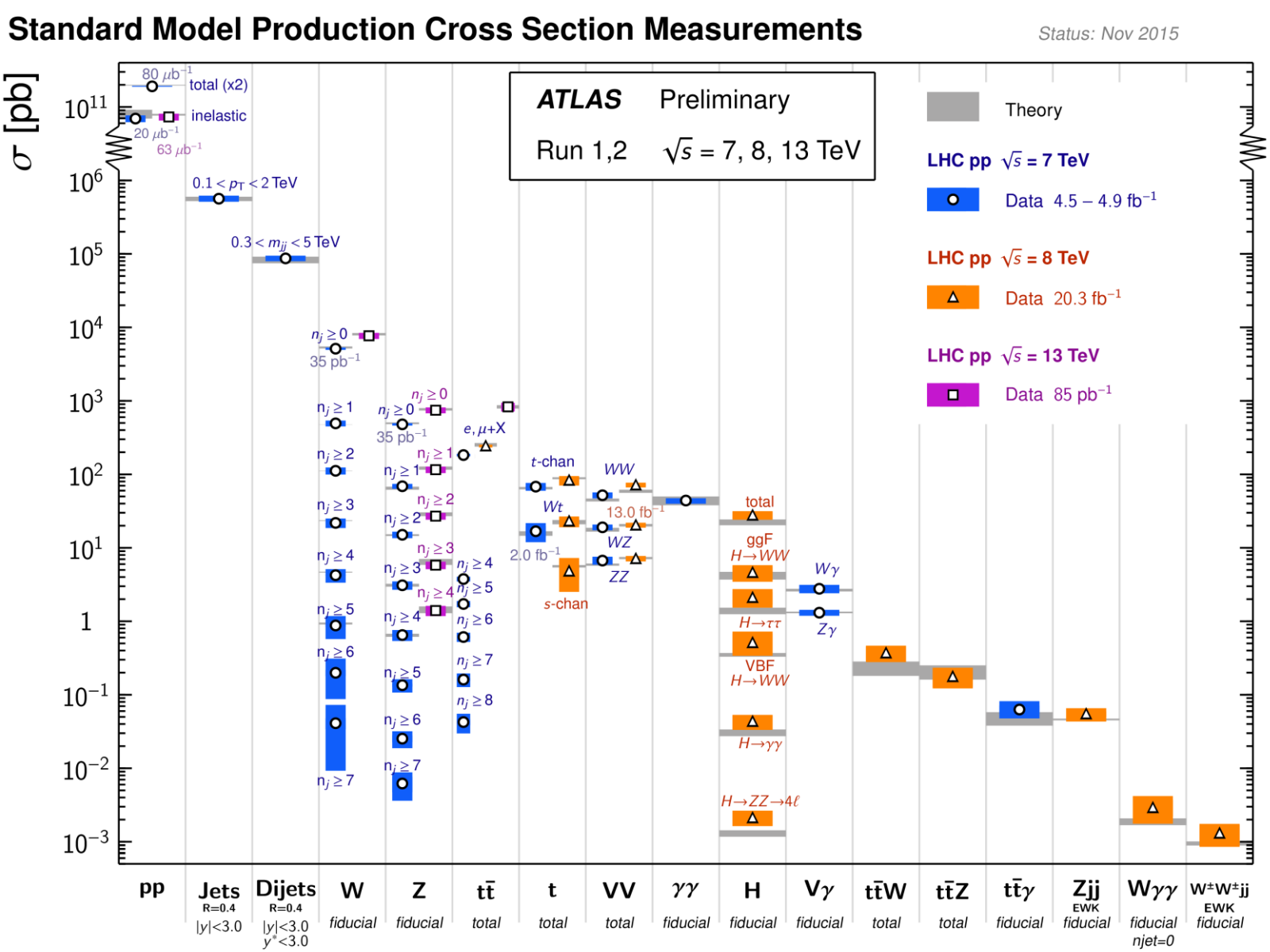

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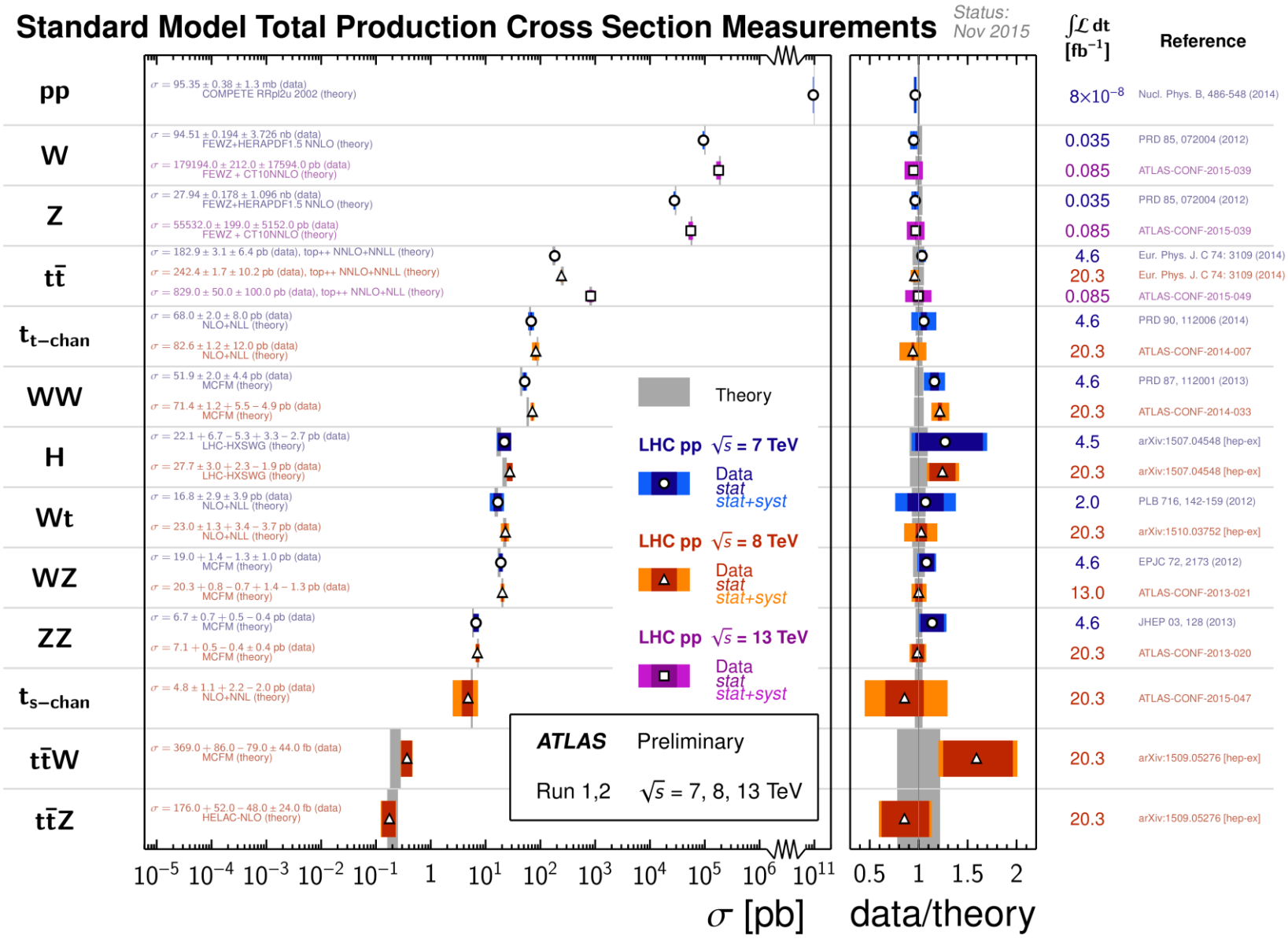
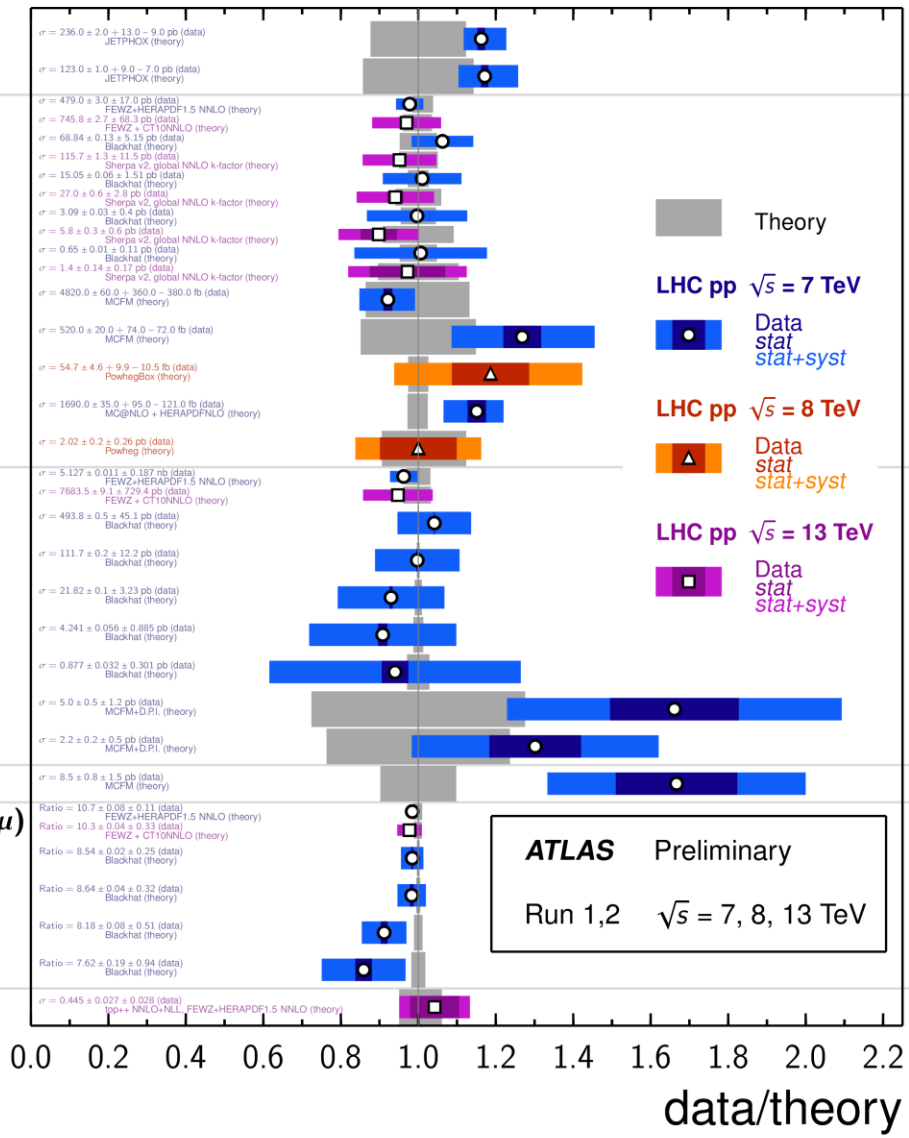


Understanding the Standard Model Backgrounds



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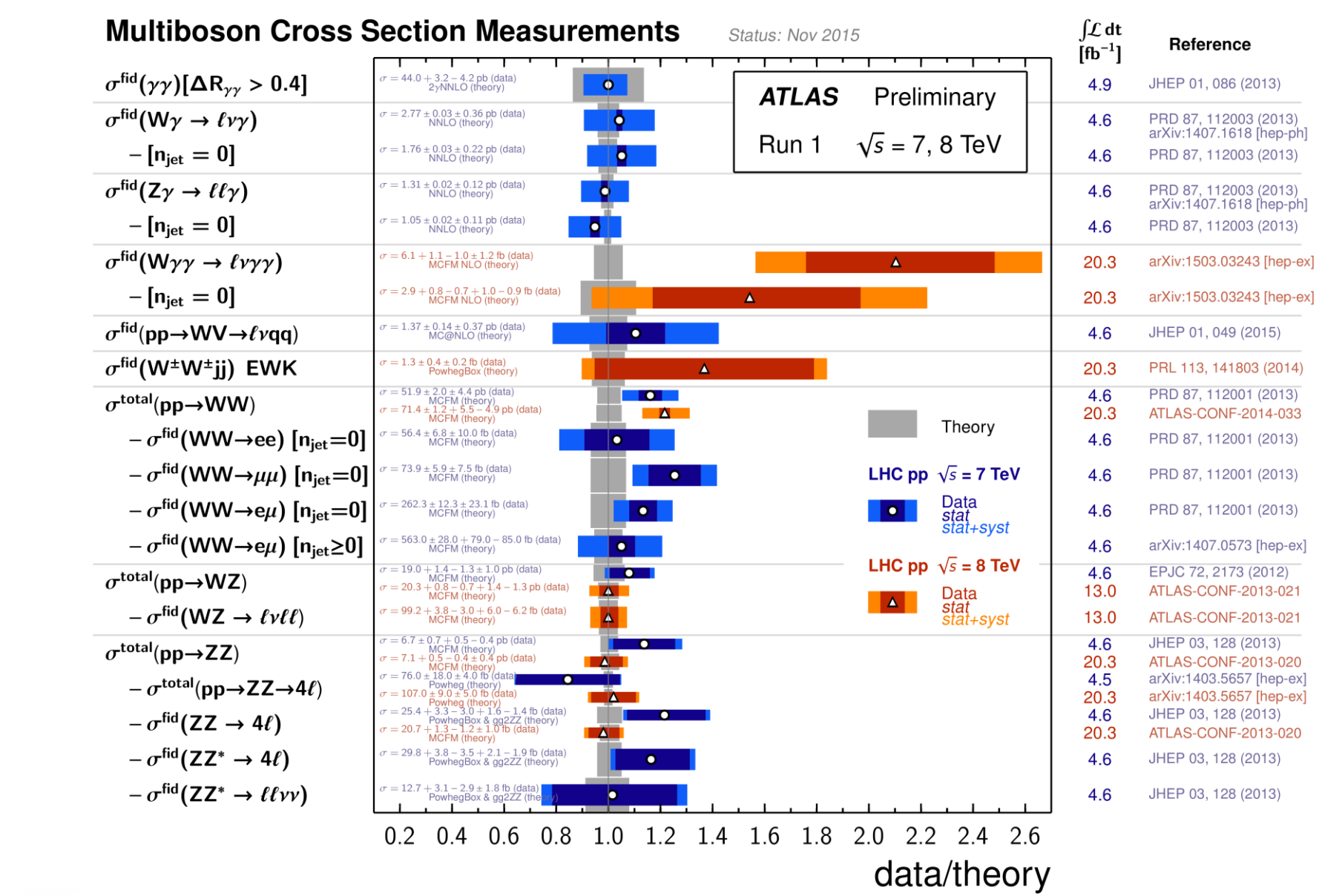
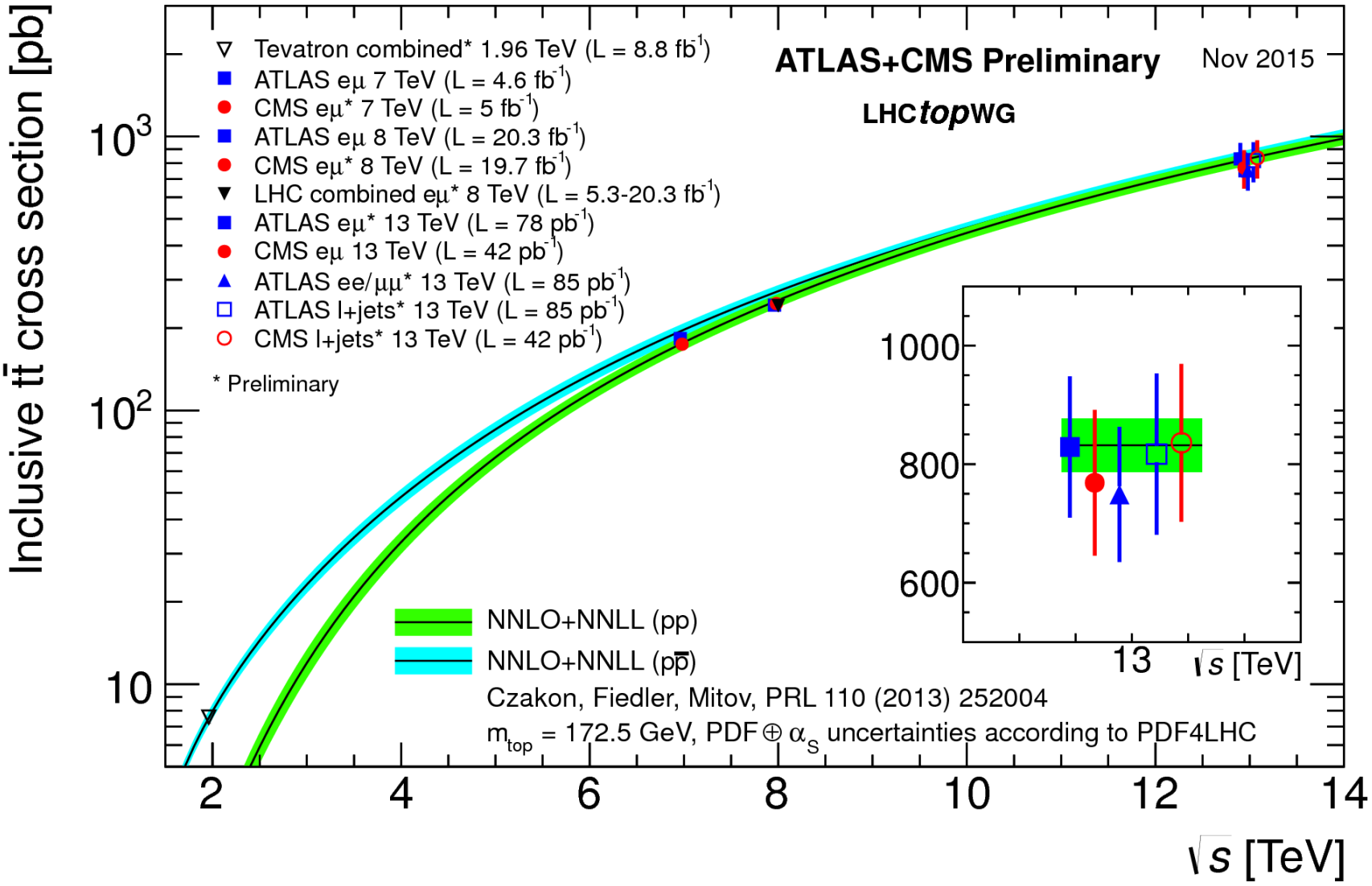
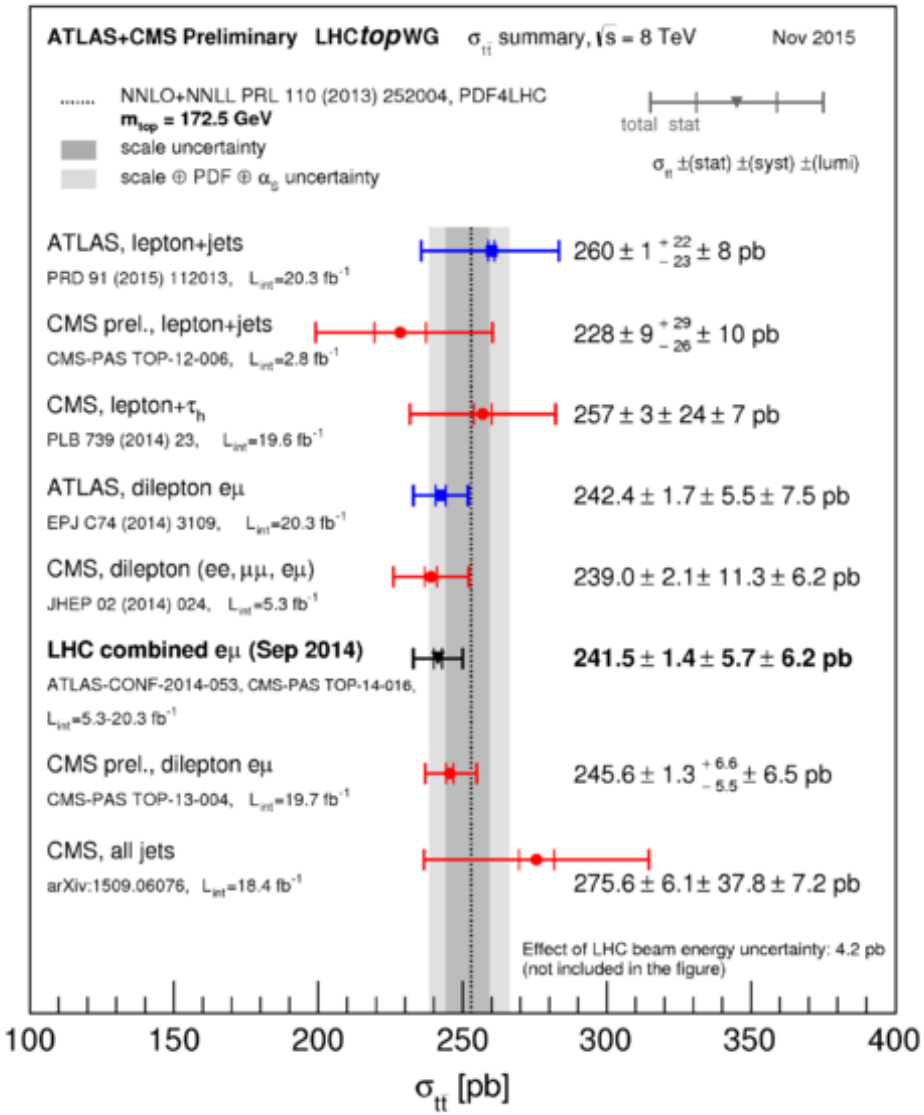
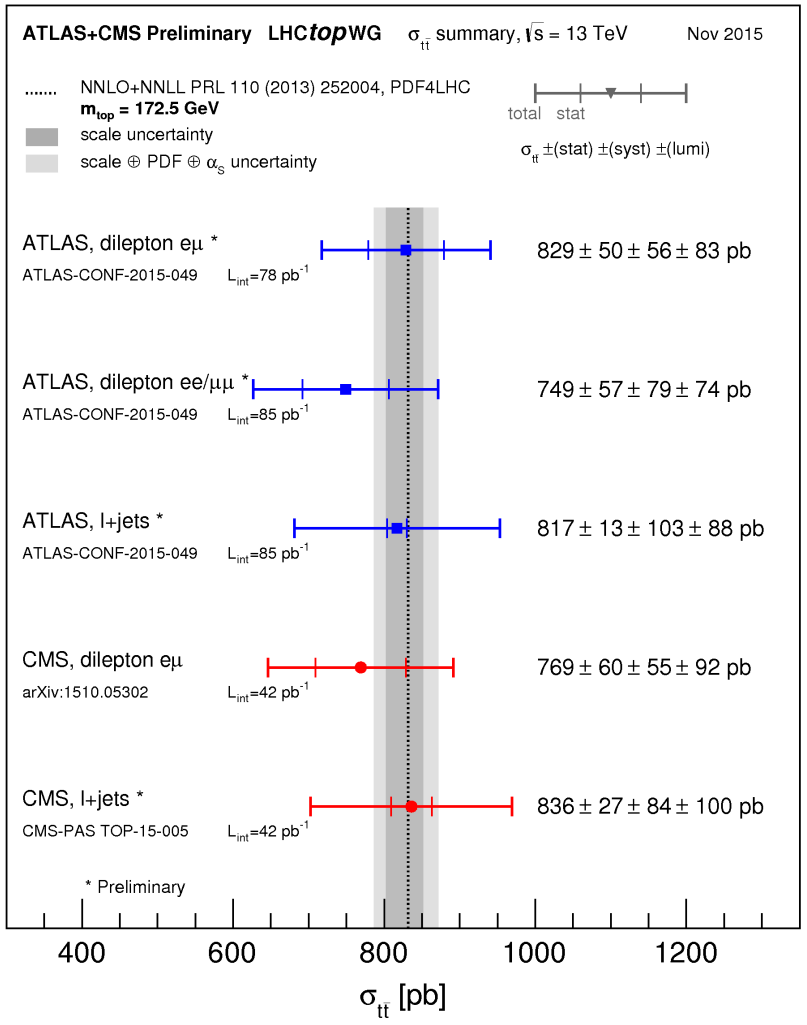


Understanding the Standard Model Backgrounds



Understanding the Standard Model Backgrounds





The reaction from CERN Restaurant 1





But YOU said there would be ***new*** physics!!!





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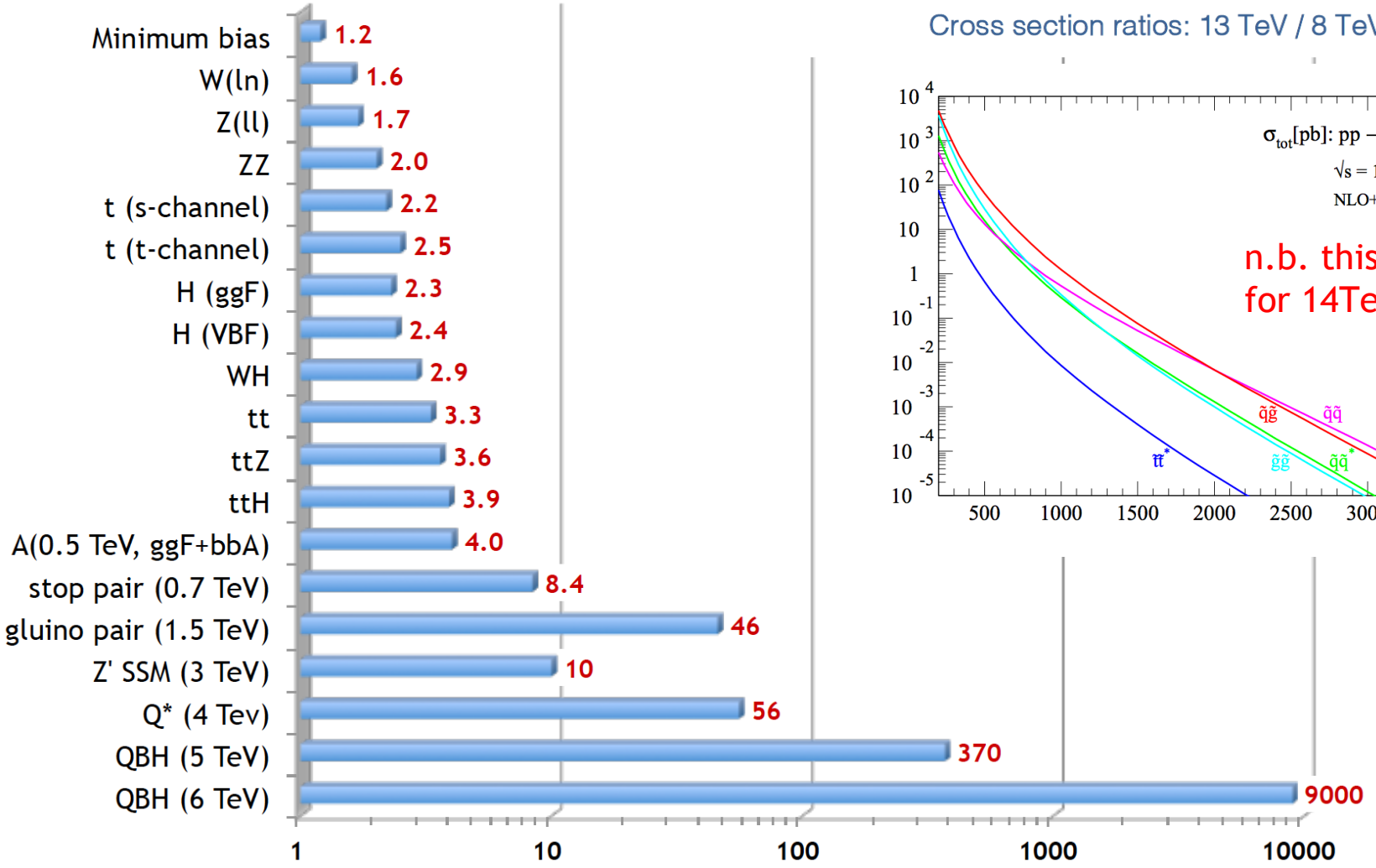
CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

- Almost all searches we perform have some amount of model dependence i.e. one searches for a specific signal topology
- **We DO NOT KNOW what new physics will look like**
- We want to cast a wide net – the wider the net we cast the larger the probability of seeing a significant excess in a channel (because statistics is a thing)

SEARCHES…..do not despair

Hugely increased potential for discovery of heavy particles at 13 TeV

But life may also become harder for states lighter than tt



Cross section ratios: 13 TeV / 8 TeV

slide by Andreas Hoecker

HIGGS

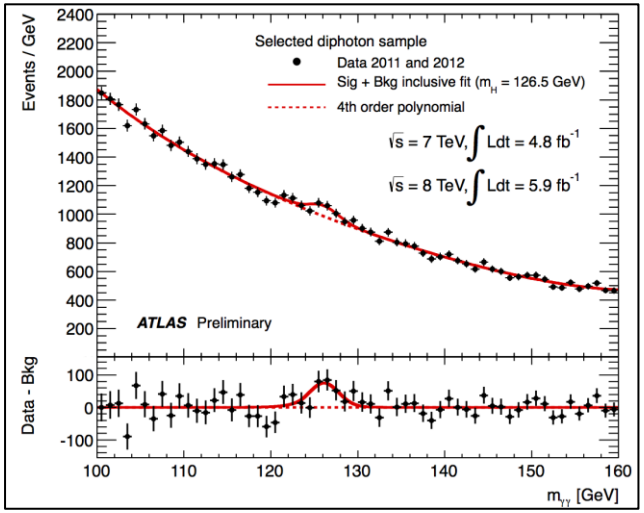
Higgs *Searches*

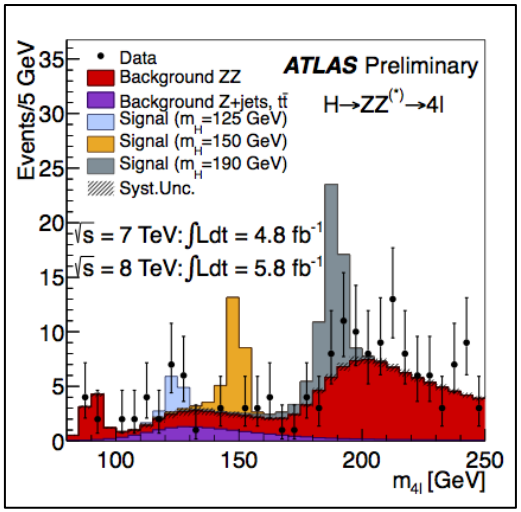
- We've discovered the Higgs – can't search for it anymore
- If you're working on Higgs physics you are either:
  a) Making as precise a measurement as possible of the Standard Model (both ***production***: ttH, VH and ***decay:*** H->WW, H->ττ, H->μμ, H->Zγ etc)
  b) Searching for BSM Higgs
     - $H^+ \to \tau^+ \nu$ or $H^+ \to tb$ (charged Higgs)
     - H->τe or τμ (Lepton Flavour Violation)
     - H/h/A->f fbar (where f is 'fermion')
     - H/h/A-> B Bbar (where B is 'boson')
- For the most part there's overlap with the exotics program here

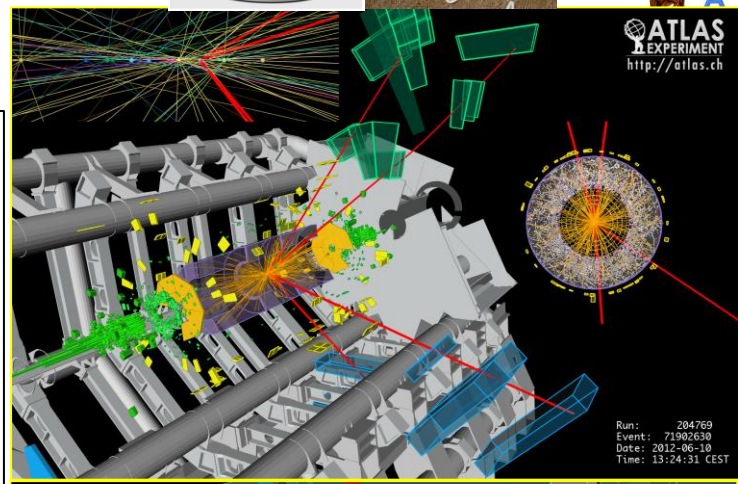
LHC Run 1 Higgs Results

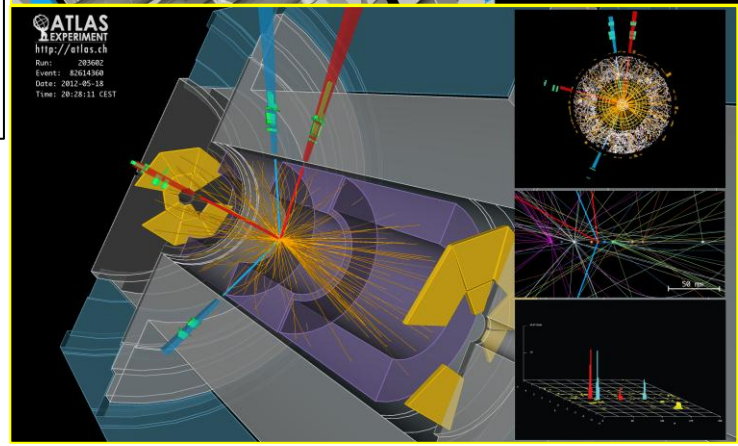

Run 1 highlights!!

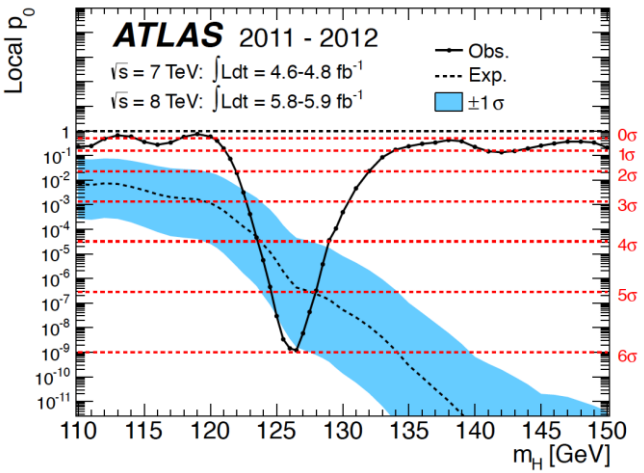
Higgs Boson discovered!











Francois Englert and Peter Higgs shared the 2013 Nobel Prize for the discovery

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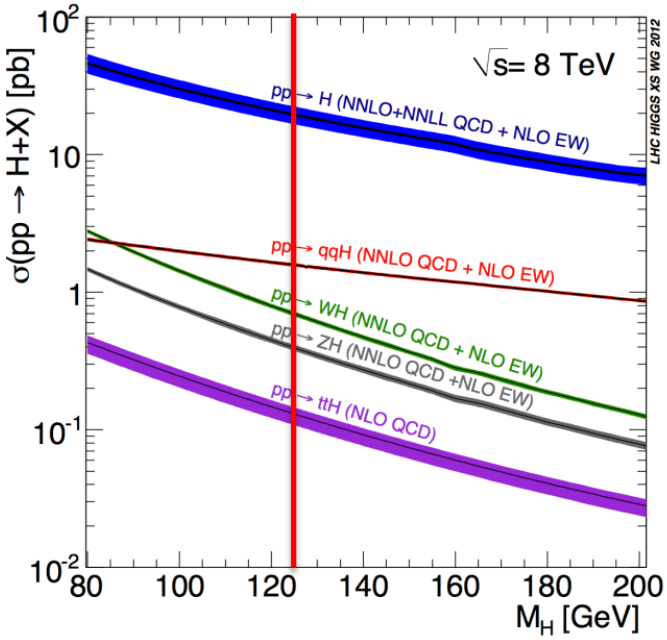
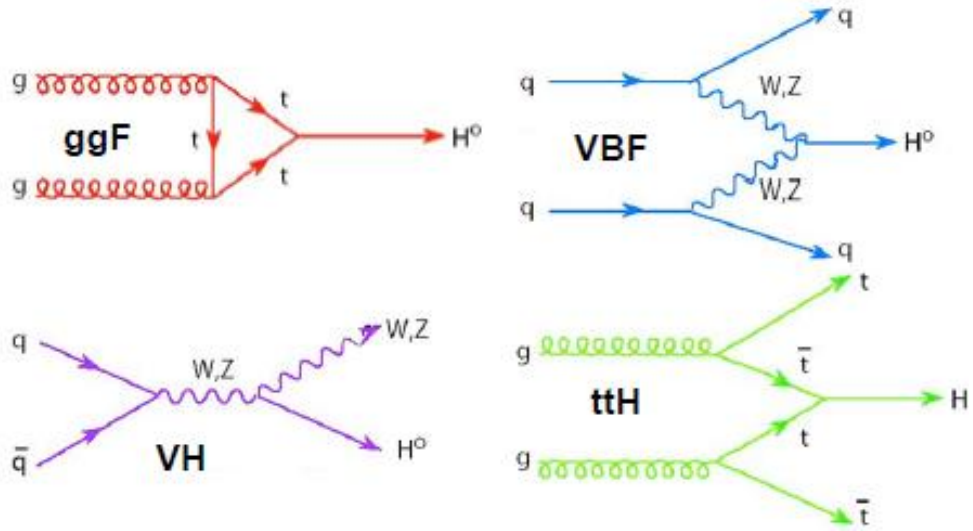
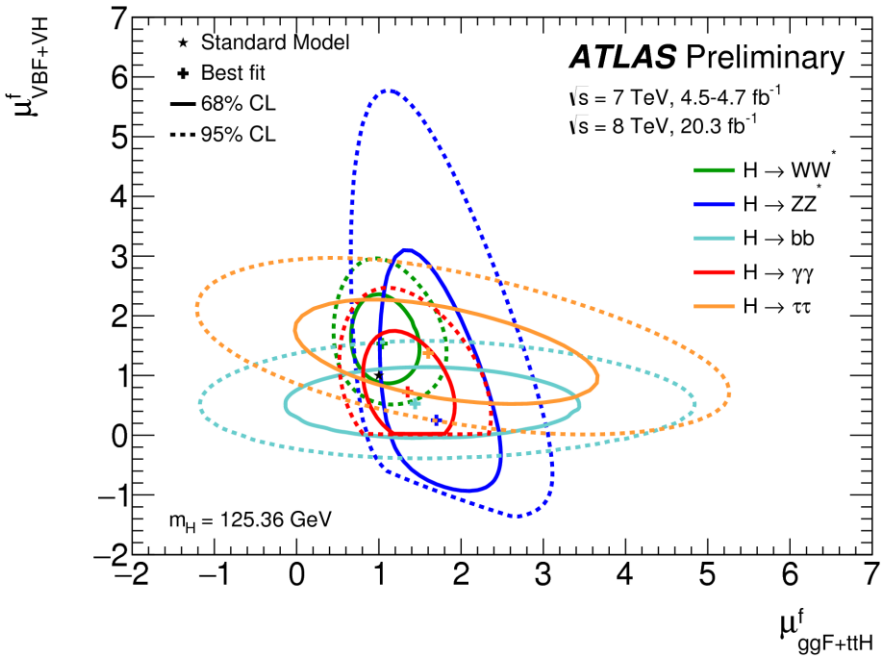
The Higgs Boson - Production modes



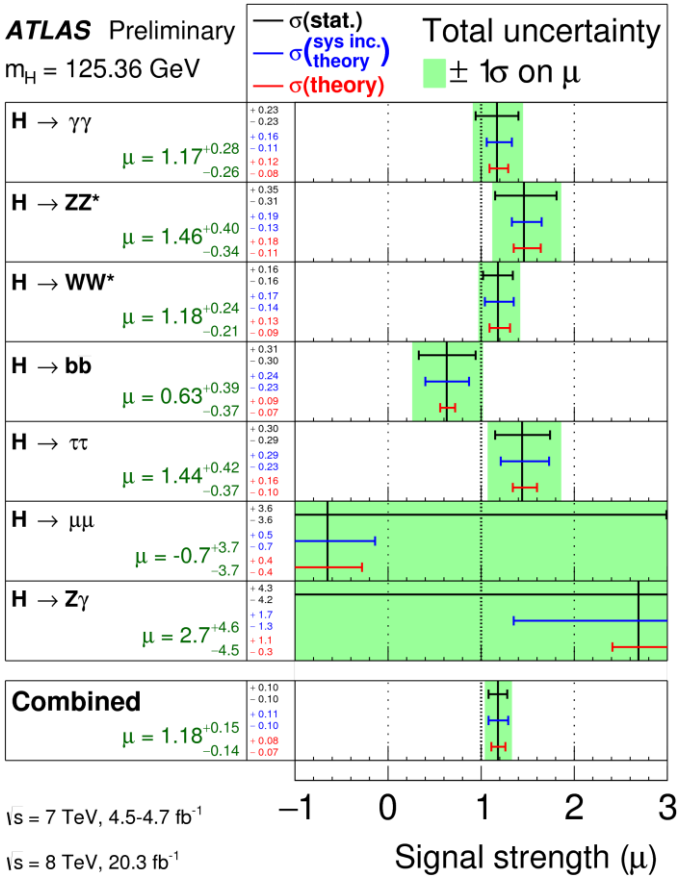


- gluon-gluon fusion (ggF) dominant
- Several measurements of vector-boson fusion (VBF)
- Data not yet very sensitive to VH and ttH

- Combine VBF and VH (both scale with V-H coupling)
- Combine ggF and ttH (both scale with t-H coupling)



The Higgs Boson – Run 1 summary



Analysis	Signal		$\int \mathcal{L}dt$ (fb^{-1})	
Categorisation or final states	Strength	Significance [σ]	7 TeV	8 TeV
$H \to \gamma\gamma$ [12]	1.17 ± 0.27	5.2 (4.6)	4.5	20.3
ttH: leptonic, hadronic			✓	✓
VH: one-lepton, dilepton, E_T^{miss}, hadronic			✓	✓
VBF: tight, loose			✓	✓
ggF: 4 p_{Tt} categories			✓	✓
$H \to ZZ^* \to 4\ell$ [13]	$1.44^{+0.40}_{-0.33}$	8.1 (6.2)	4.5	20.3
VBF			✓	✓
VH: hadronic, leptonic			✓	✓
ggF			✓	✓
$H \to WW^*$ [14, 15]	$1.16^{+0.24}_{-0.21}$	6.5 (5.9)	4.5	20.3
ggF: (0-jet, 1-jet) $\otimes$ $(ee + \mu\mu,\ e\mu)$			✓	✓
ggF: $\geq$ 2-jet and $e\mu$				✓
VBF: $\geq$ 2-jet $\otimes$ $(ee + \mu\mu,\ e\mu)$			✓	✓
VH: opposite-charge dilepton, three-lepton, four-lepton			✓	✓
VH: same-charge dilepton				✓
$H \to \tau\tau$ [17]	$1.43^{+0.43}_{-0.37}$	4.5 (3.4)	4.5	20.3
Boosted: $\tau_{lep}\tau_{lep}, \tau_{lep}\tau_{had}, \tau_{had}\tau_{had}$			✓	✓
VBF: $\tau_{lep}\tau_{lep}, \tau_{lep}\tau_{had}, \tau_{had}\tau_{had}$			✓	✓
$VH \to Vb\bar{b}$ [18]	0.52 ± 0.40	1.4 (2.6)	4.7	20.3
0ℓ ($ZH \to \nu\nu bb$): $N_{jet} = 2, 3$, $N_{btag} = 1, 2$, $p_T^V >$ and < 120 GeV			✓	✓
1ℓ ($WH \to \ell\nu bb$): $N_{jet} = 2, 3$, $N_{btag} = 1, 2$, $p_T^V >$ and < 120 GeV			✓	✓
2ℓ ($ZH \to \ell\ell bb$): $N_{jet} = 2, 3$, $N_{btag} = 1, 2$, $p_T^V >$ and < 120 GeV			✓	✓

The Higgs Boson is no longer a discovery – it is a precision measurement!

The Higgs Boson – ATLAS + CMS combined

Combined Measurement of the Higgs Boson Mass in *pp* Collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS Experiments

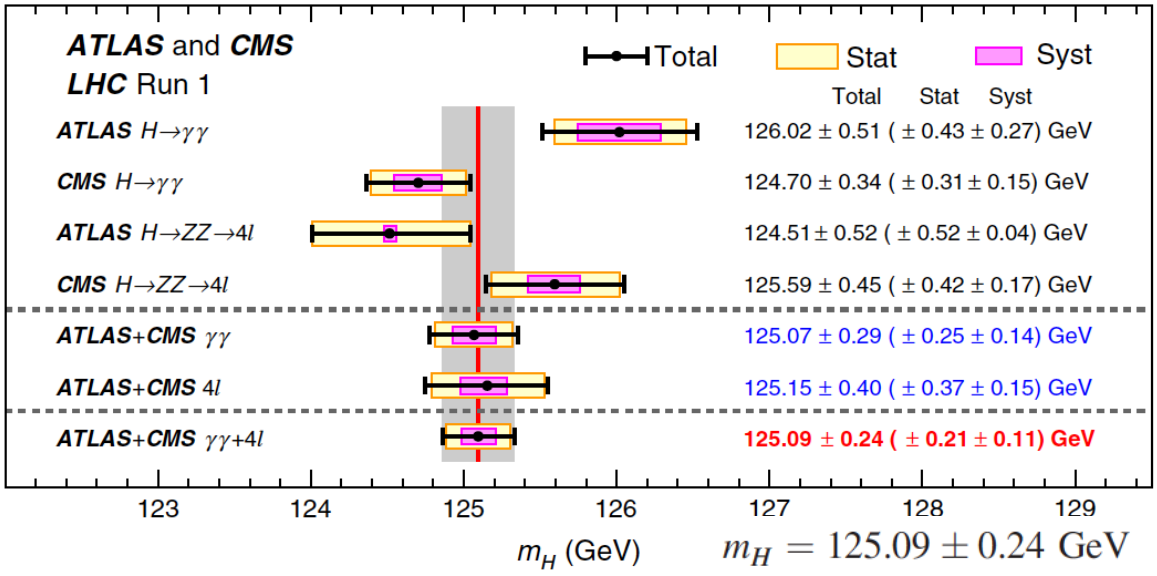
G. Aad *et al.*[*]

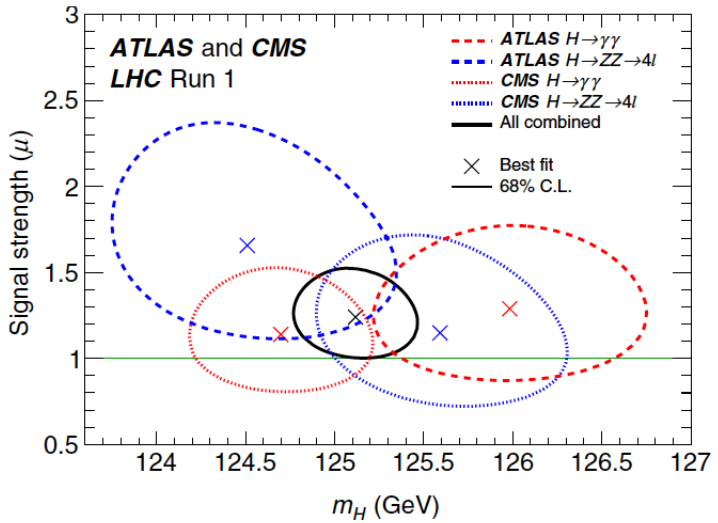
(ATLAS Collaboration)[†]
(CMS Collaboration)[‡]

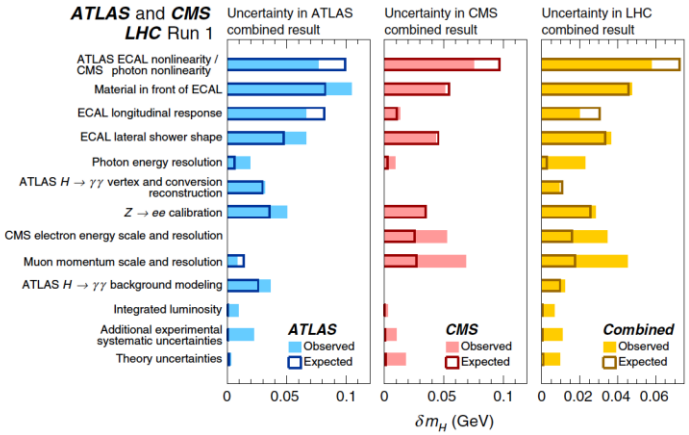
(Received 25 March 2015; published 14 May 2015)

A measurement of the Higgs boson mass is presented based on the combined data samples of the ATLAS and CMS experiments at the CERN LHC in the $H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$ decay channels. The results are obtained from a simultaneous fit to the reconstructed invariant mass peaks in the two channels and for the two experiments. The measured masses from the individual channels and the two experiments are found to be consistent among themselves. The combined measured mass of the Higgs boson is $m_H = 125.09 \pm 0.21\,(\text{stat}) \pm 0.11\,(\text{syst})$ GeV.

…only 5,154 authors!
Adelaide lead institution ☺



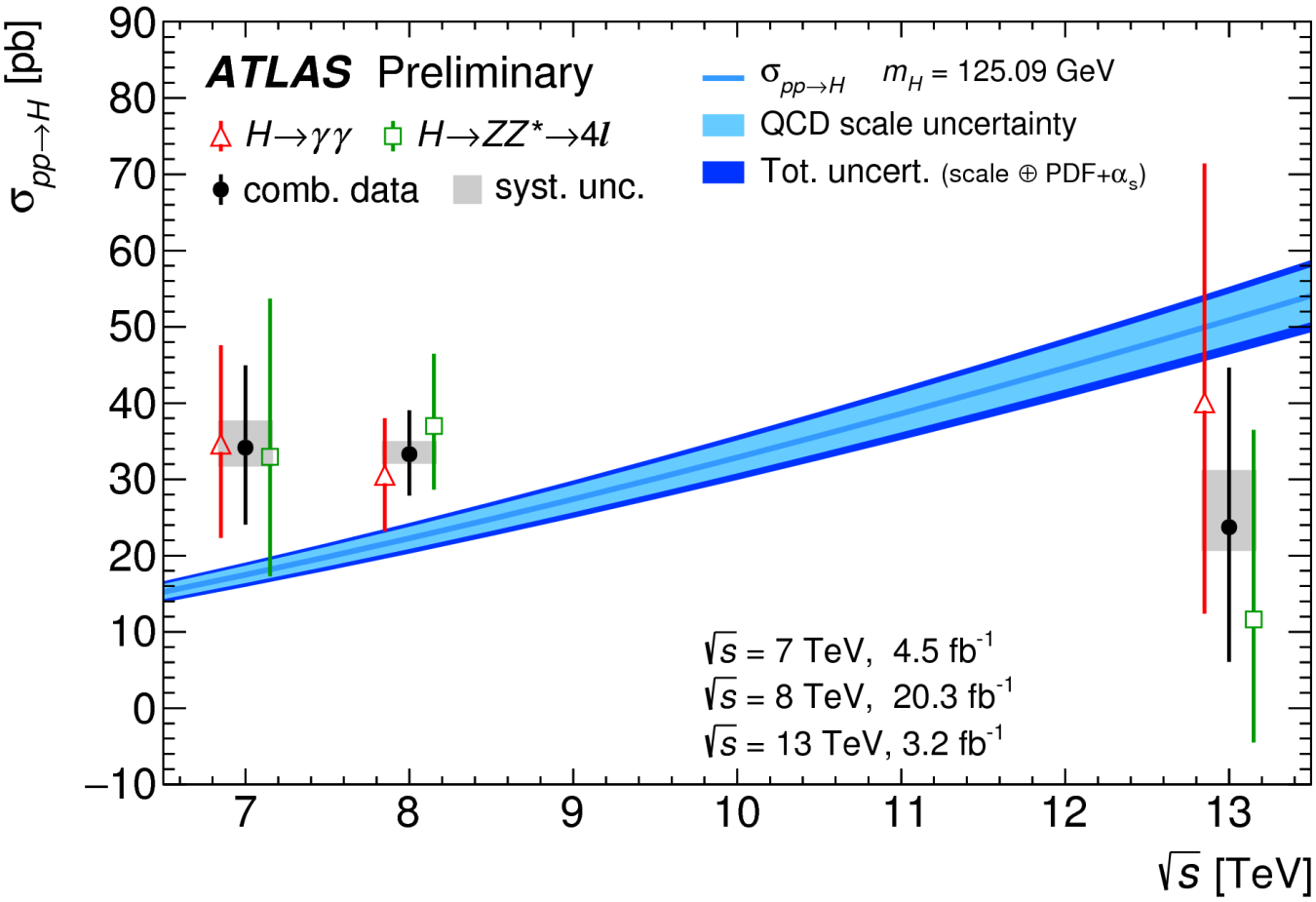




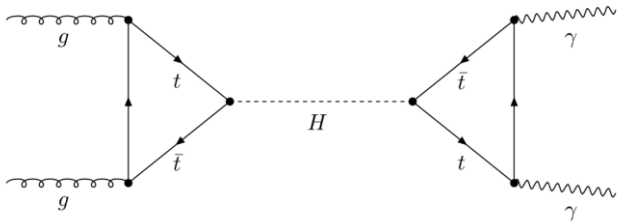
$$m_H = 125.09 \pm 0.24 \text{ GeV}$$
$$= 125.09 \pm 0.21\,(\text{stat}) \pm 0.11\,(\text{syst}) \text{ GeV}$$

The Higgs Boson is no longer a discovery – it is a precision measurement!

Higgs in 2015 @ Run2



Higgs has fluctuated a little low at 13 TeV…
…..bad news if you wanted to see early effects of something showing up in loops



SUPERSYMMETRY

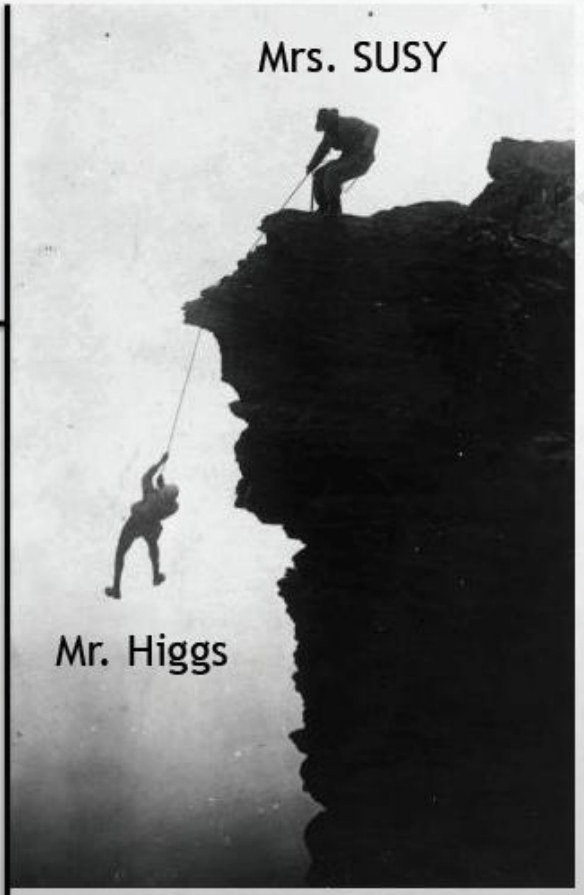
SUSY

The scalar precipice

EW scale^{-1}

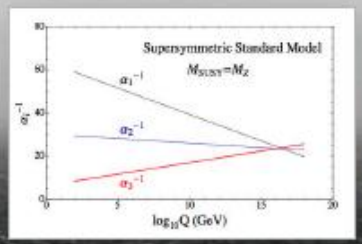
GUT scale^{-1}

Fundamental scalar length scale



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

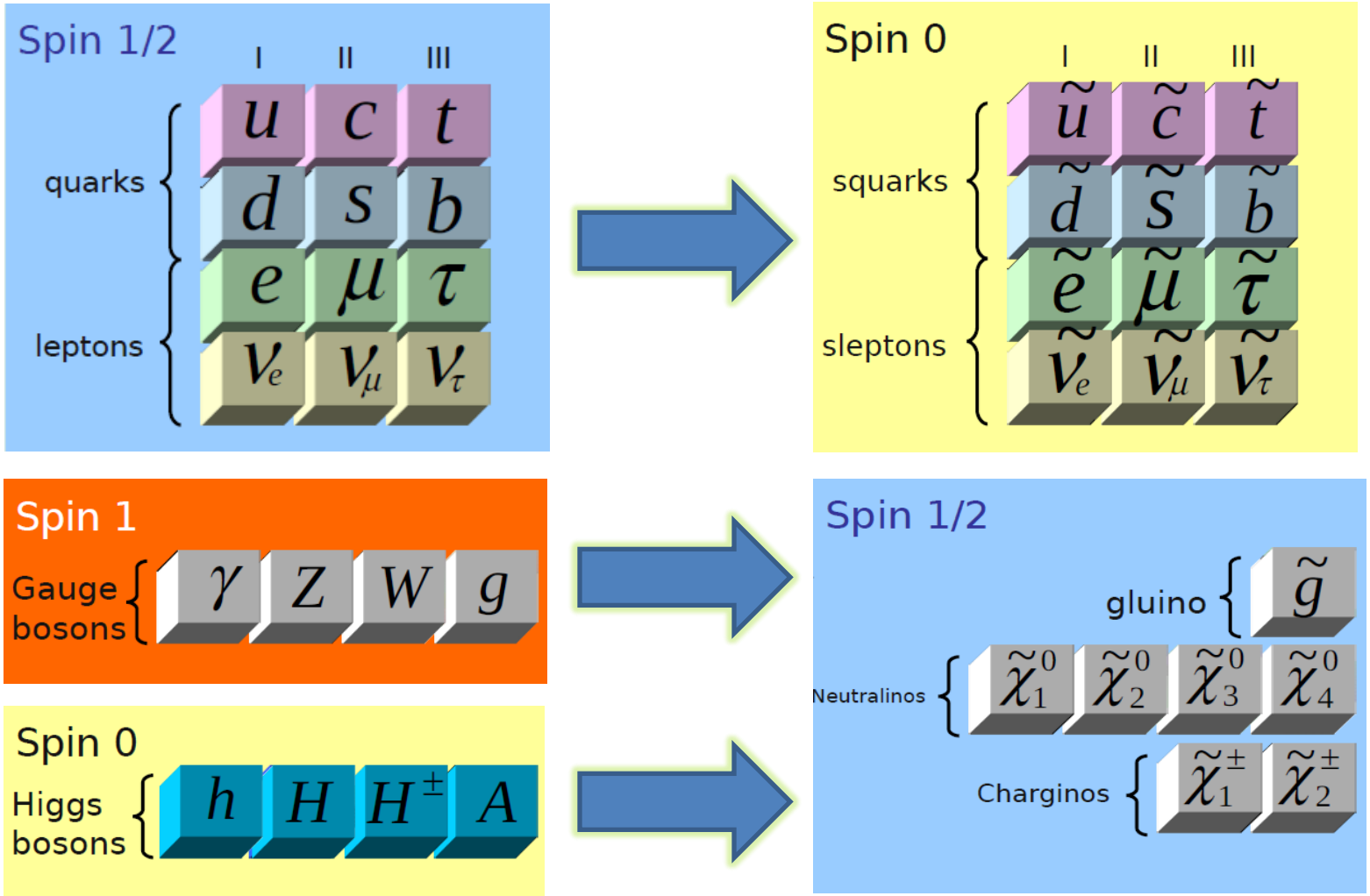


illustration by M-H Genest

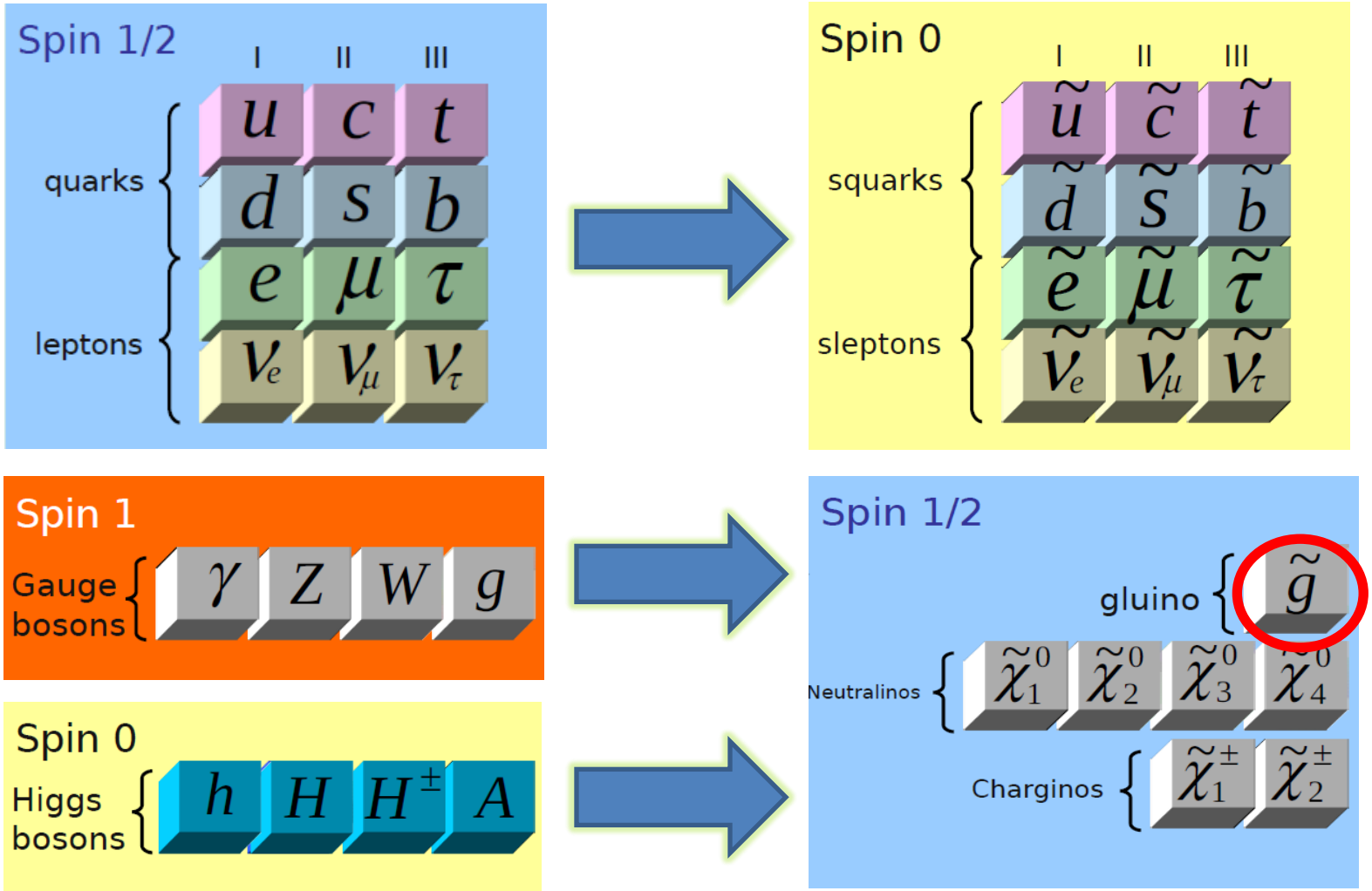


illustration by M-H Genest


MAKE GLUINOS
GREAT AGAIN
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Franz Anthony Winner of ‘Collision 2015’

SUSY – ATLAS Run1 Summary

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: July 2015

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

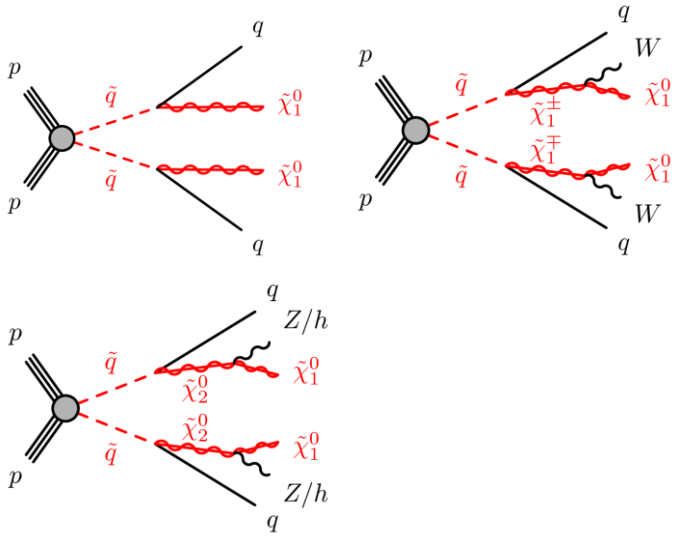
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Mass limit ($\sqrt{s}$ = 7 TeV / $\sqrt{s}$ = 8 TeV)		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e, μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.8 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$	100-440 GeV	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)<10 GeV	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$	780 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1503.03290
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0-1 e, μ	2-6 jets	Yes	20	$\tilde{g}$	1.26 TeV	m($\tilde{\chi}_1^0$)<300 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	1507.05525
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20	$\tilde{g}$	1.32 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$	1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$	1.29 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}_1^0$)<900 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$	1.25 TeV	m($\tilde{\chi}_1^0$)<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	1507.05493
	GGM (higgsino NLSP)	2 e, μ (Z)	2 jets	Yes	20.3	$\tilde{g}$	850 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	865 GeV	m($\tilde{G}$)>1.8 × 10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.25 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	m($\tilde{\chi}_1^0$) <350 GeV	1308.1841
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	m($\tilde{\chi}_1^0$)<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$	275-440 GeV	m($\tilde{\chi}_1^\pm$)=2 m($\tilde{\chi}_1^0$)	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e, μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$ 110-167 GeV	230-460 GeV	m($\tilde{\chi}_1^\pm$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$ 90-191 GeV	210-700 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV		m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-580 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$	290-600 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp, \tilde{\chi}_1^\pm\to\tilde{\ell}\nu(\tilde{\ell}\nu)$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$	140-465 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp, \tilde{\chi}_1^\pm\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$	100-350 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1407.0350
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	700 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	420 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	250 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	620 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
	GGM (wino NLSP) weak prod.	1 $e, \mu + \gamma$	-	Yes	20.3	$\tilde{W}$	124-361 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	270 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^\pm$)=0.2 ns	1310.3675
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^\pm$	482 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^\pm$)<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	832 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$	1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$	537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$	435 GeV	2<τ($\tilde{\chi}_1^0$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to eev/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV	7 <$c\tau$($\tilde{\chi}_1^0$)< 740 mm, m($\tilde{g}$)=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV	6 <$c\tau$($\tilde{\chi}_1^0$)< 480 mm, m($\tilde{g}$)=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$	1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.35 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.3	$\tilde{\chi}_1^\pm$	750 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{121}\neq 0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$	450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133}\neq 0$	1405.5086
	$\tilde{g}\tilde{g}, \tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to q\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	870 GeV	m($\tilde{\chi}_1^0$)=600 GeV	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$	850 GeV		1404.250
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$	100-308 GeV		ATLAS-CONF-2015-026
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\ell$	2 e, μ	2 b	-	20.3	$\tilde{t}_1$	0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$	490 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

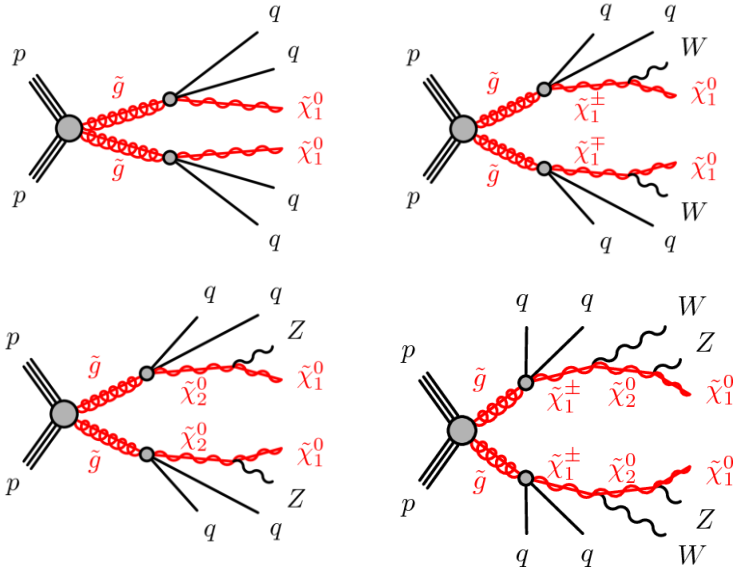
10^{-1} 1 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

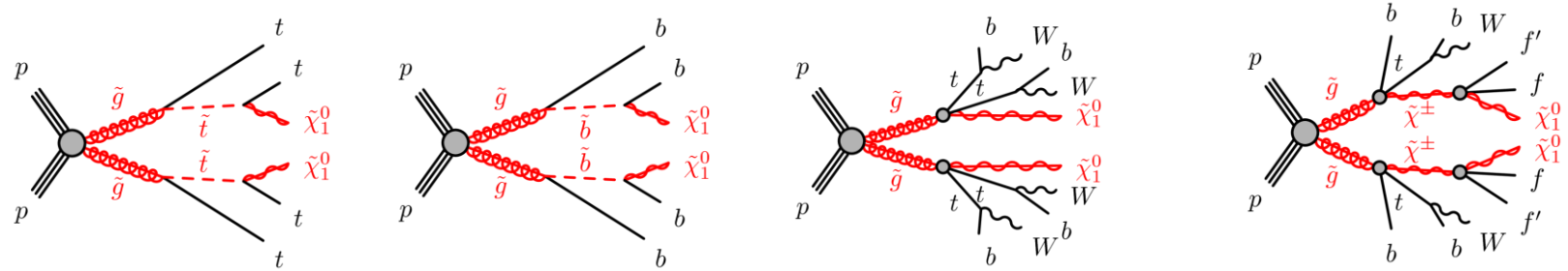
SUSY: Strong Production

Squark and Gluino mediated light jets





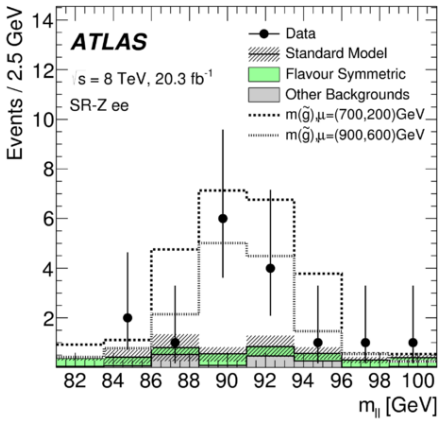
Gluino mediated third generation

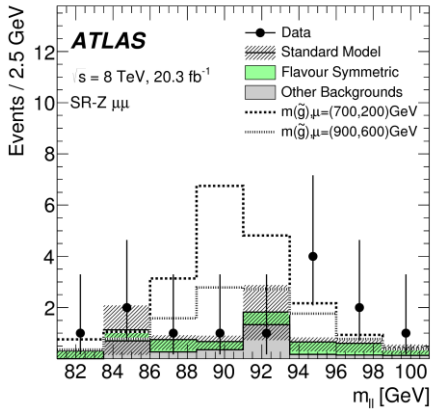


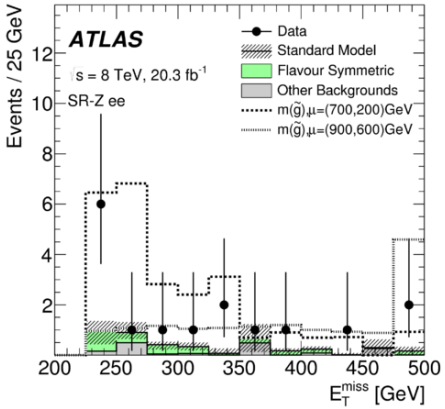
Searches in Run 1 – anomalies….there was one!

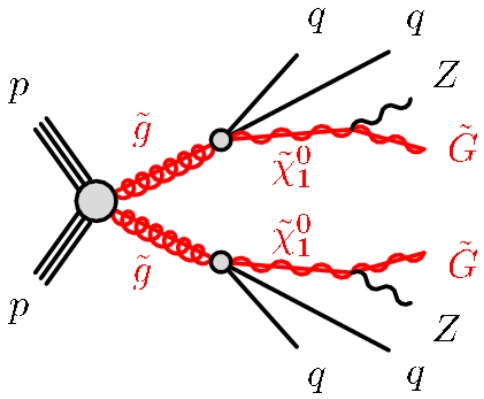
Z+jets+MET

….excess of events above the expected Standard Model background is observed, with a significance of 3 standard deviations









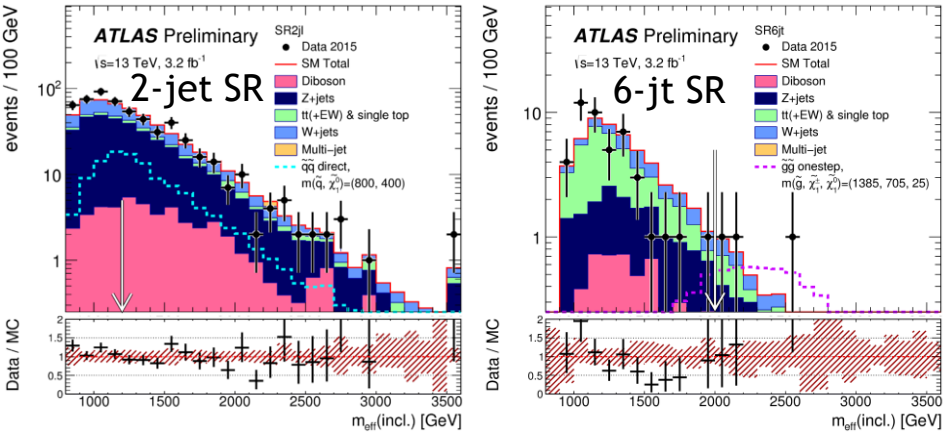
An anomaly => but it looks fishy….

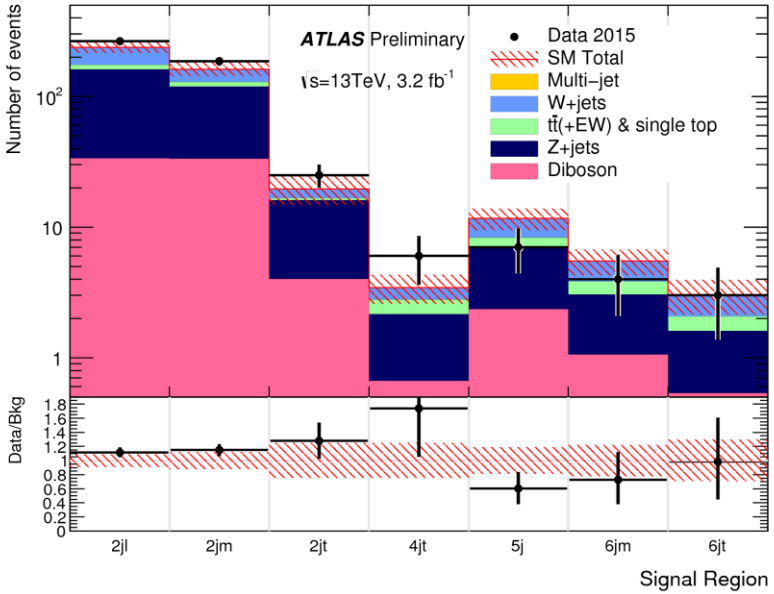
More events in electrons than muons,
Doesn't look much like the signal they proposed.
We'll have to see what Run 2 brings...

SUSY: Strong Production

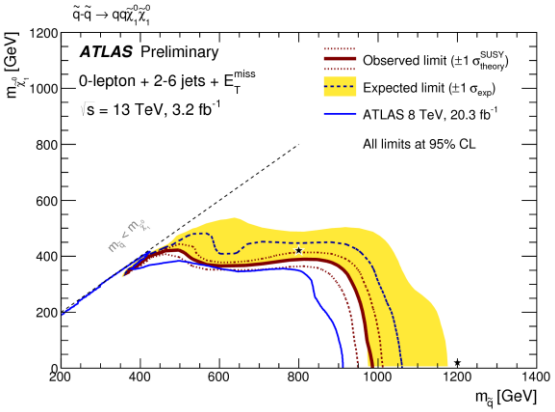
Squark and Gluino mediated light jets. The workhorse of the SUSY group – if you predict an excess in many/most channels you often have to reconcile it with the results here.

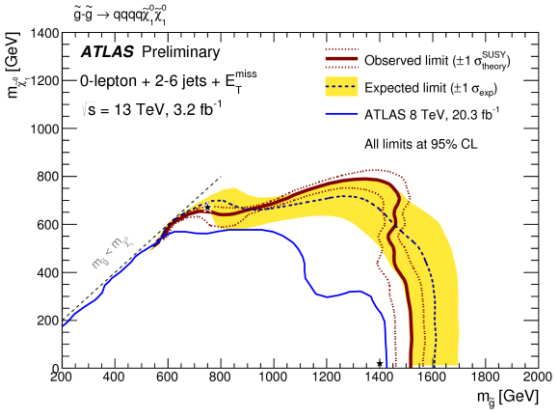
No excess observed so far in 2015!

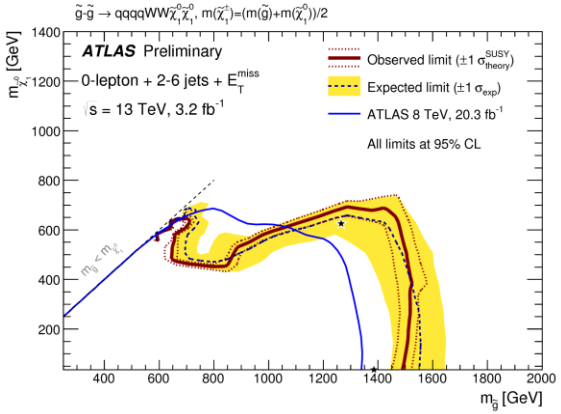




Always caveats! Be careful making blanket interpretations of any SUSY search







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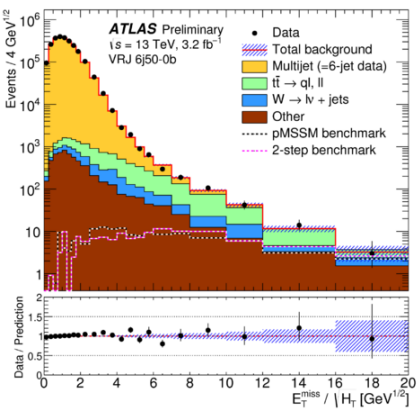
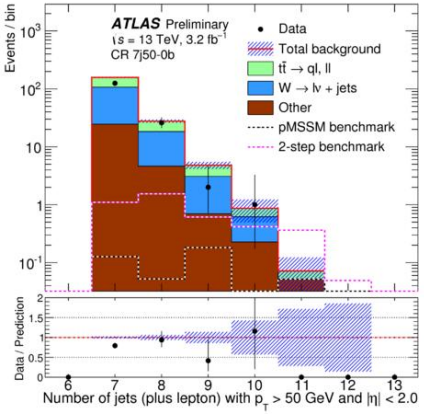
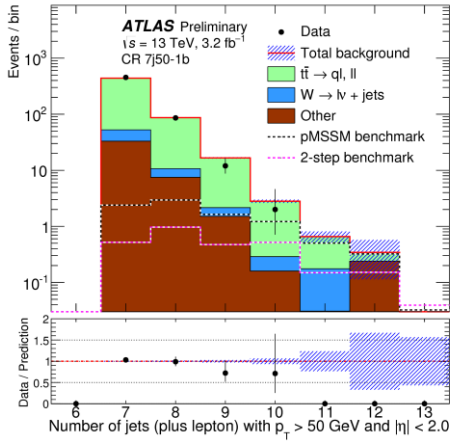
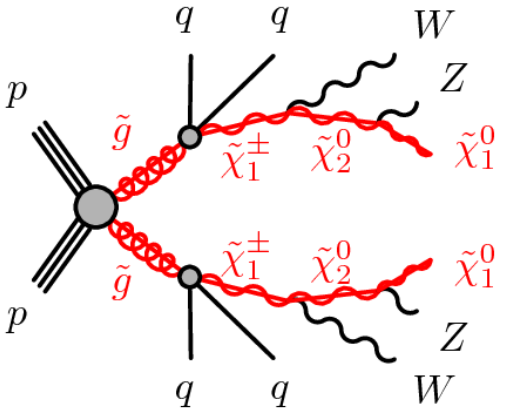
SUSY: Strong Production

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

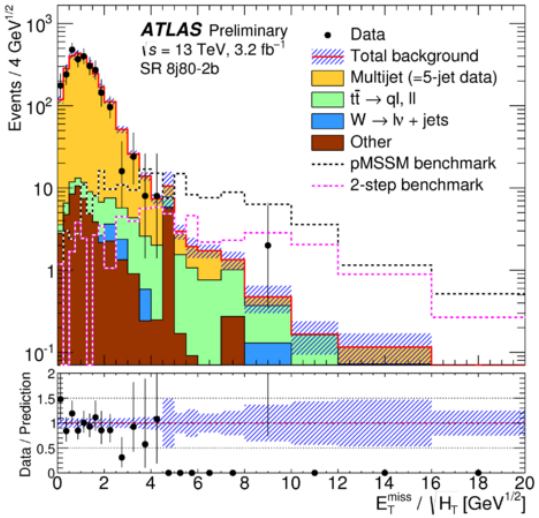


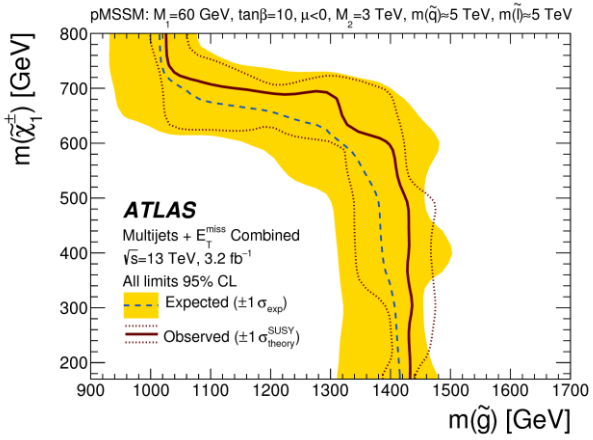


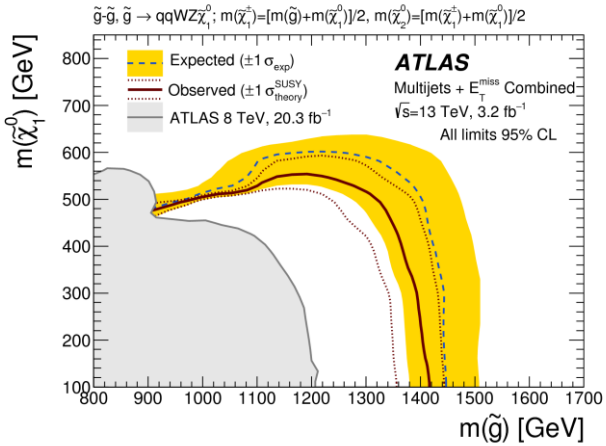




As we increase the number of steps in the decay chain we increase the number of objects

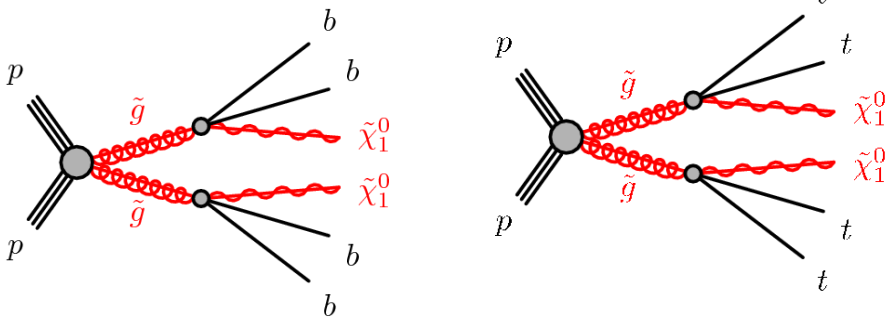


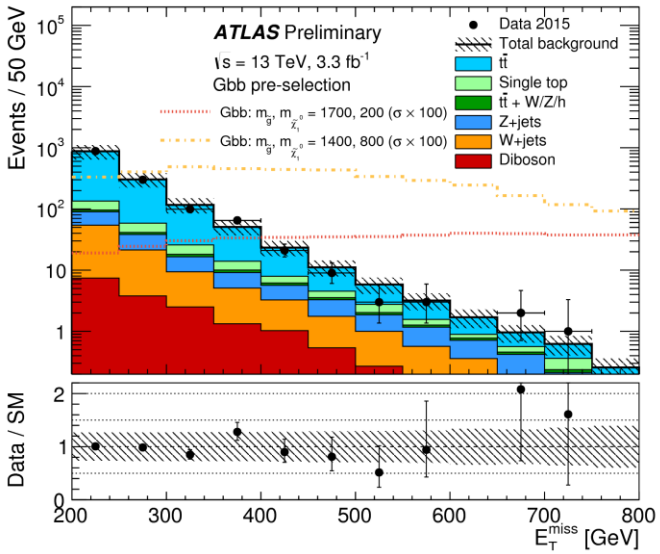




SUSY: Strong Production – multi b-jet signatures

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





Signal categories

- 0L and 1L (specific for multi-top signals)
- Number of jets, b-jets and MET

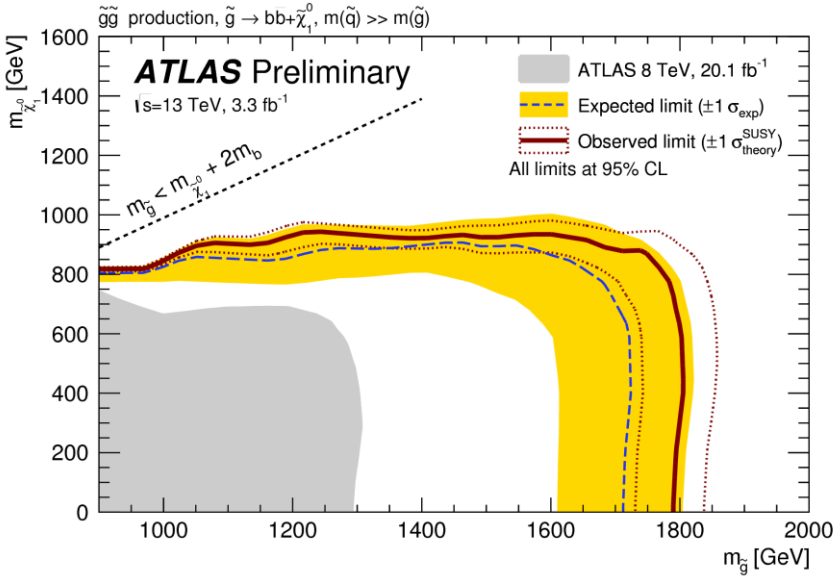
Improvements to the analysis

Use of boosted tops, New selection cuts

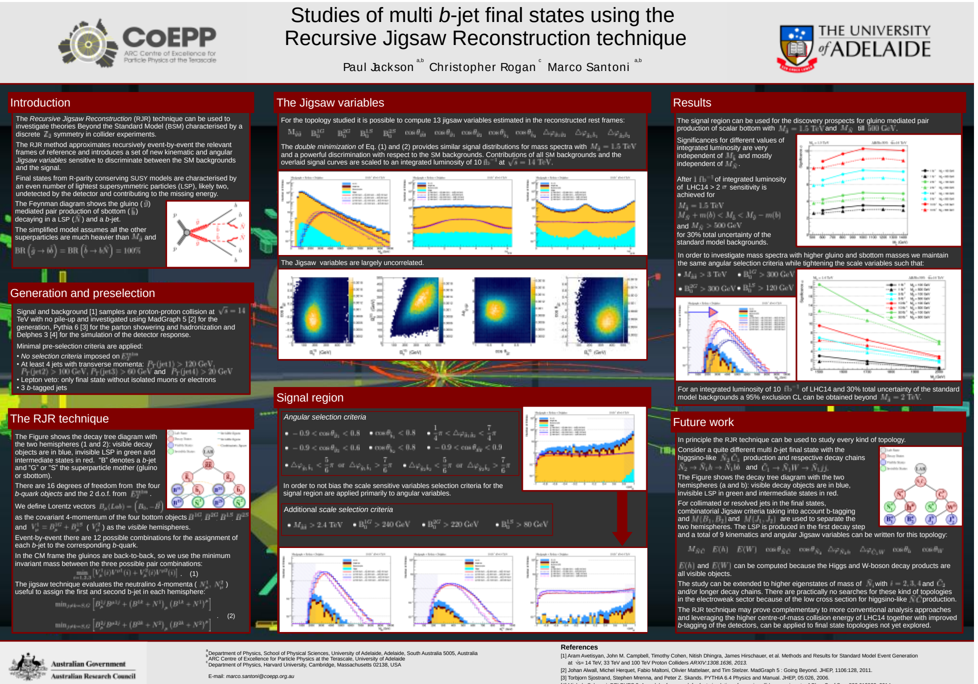
Backgrounds

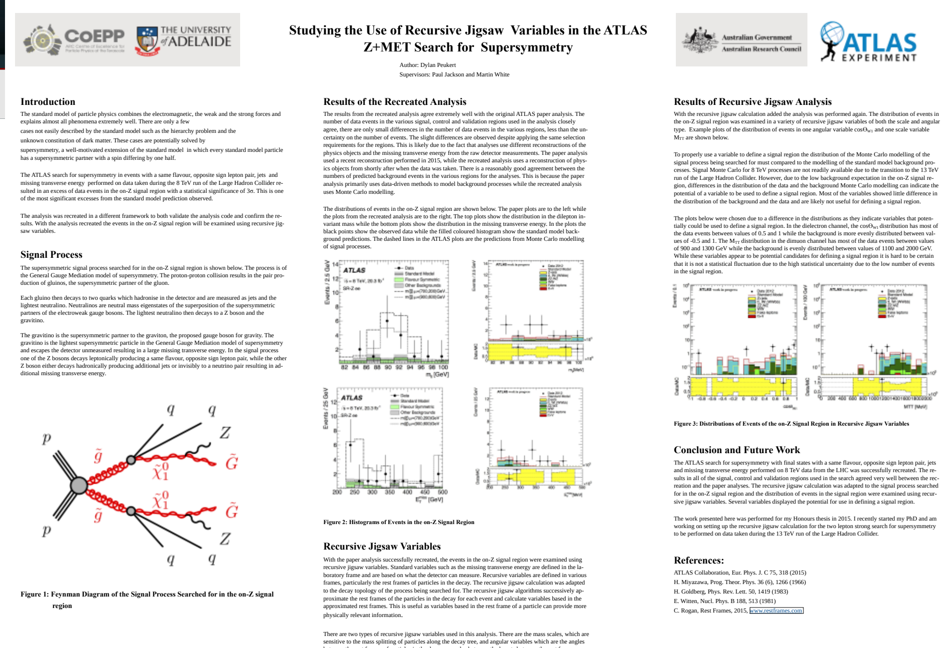
Top background (dominant) from CRs (in MET)

Other backgrounds from MC



SUSY: Strong Production

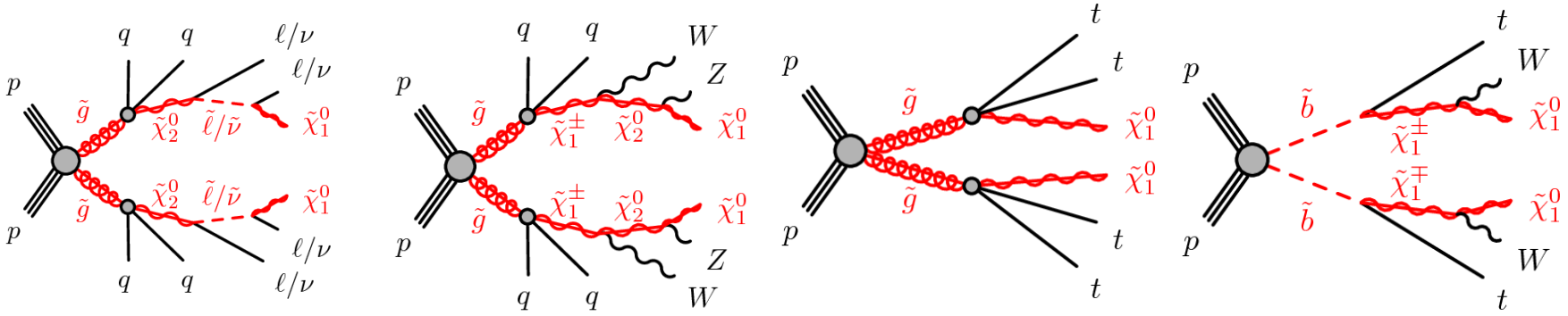




Recent posters at the CoEPP workshop from Adelaide students studying these important channels

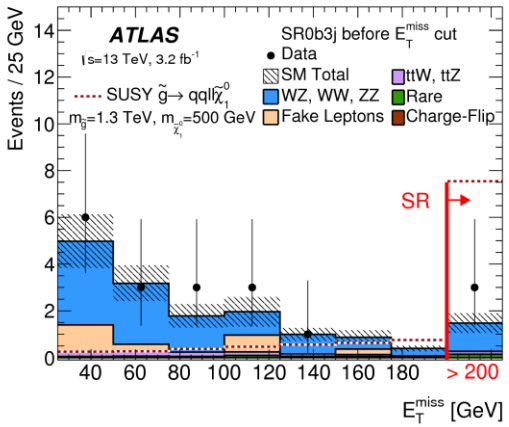
SUSY: Strong Production

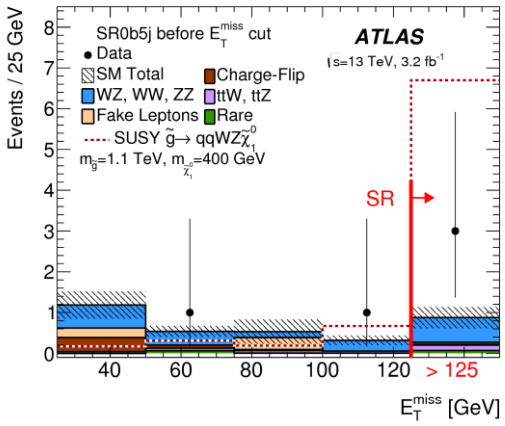
Squark and Gluino search in SS dilepton and 3-lepton

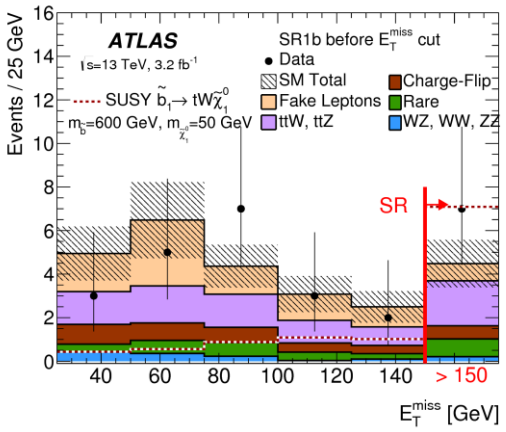


Signal region	$N_{\text{lept}}^{\text{signal}}$	$N_{b-\text{jets}}^{20}$	N_{jets}^{50}	$E_{\text{T}}^{\text{miss}}$ [GeV]	m_{eff} [GeV]
SR0b3j	≥ 3	$=0$	≥ 3	>200	>550
SR0b5j	≥ 2	$=0$	≥ 5	>125	>650
SR1b	≥ 2	≥ 1	≥ 4	>150	>550
SR3b	≥ 2	≥ 3	-	>125	>650

Various signal regions probe different processes we may be sensitive to



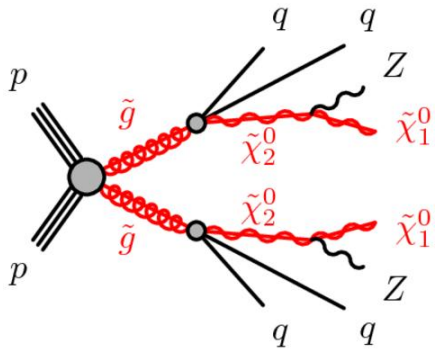


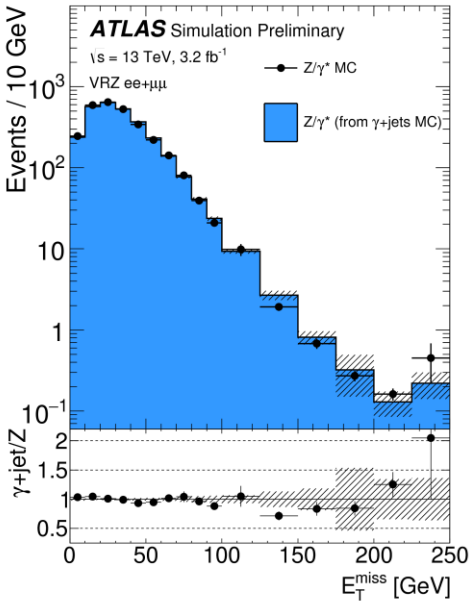


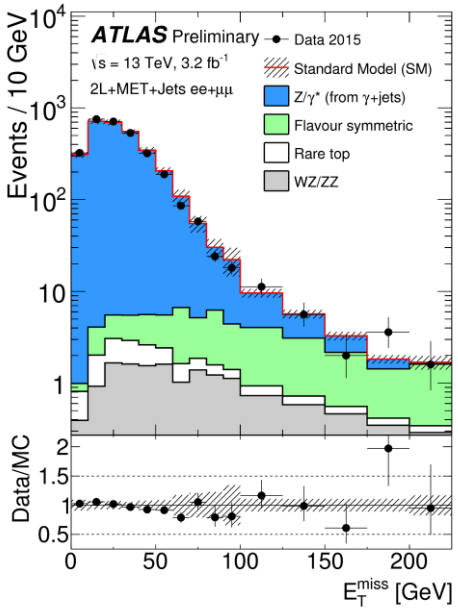
SUSY: Strong Production: Z+MET

Squark and Gluino mediated 2lep+MET+jets

Region	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	H_{T} [GeV]	n_{jets}	$m_{\ell\ell}$ [GeV]	SF/DF	$\Delta\phi(\mathrm{jet}_{12}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})$	$m_{\mathrm{T}}(\ell_3, E_{\mathrm{T}}^{\mathrm{miss}})$ [GeV]	$n_{\mathrm{b\text{-}jets}}$
Signal regions								
SRZ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
Control regions								
Z normalisation	< 60	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
CR-FS	> 225	> 600	≥ 2	$61 < m_{\ell\ell} < 121$	DF	> 0.4	-	-
CRT	> 225	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	> 0.4	-	-
Validation regions								
VRZ	< 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
VRT	100–200	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	> 0.4	-	-
VRS	100–200	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
VR-FS	100–200	> 600	≥ 2	$61 < m_{\ell\ell} < 121$	DF	> 0.4	-	-
VR-WZ	100–200	-	-	-	3ℓ	-	< 100	0
VR-ZZ	< 100	-	-	-	4ℓ	-	-	0
VR-3L	60–100	> 200	≥ 2	$81 < m_{\ell\ell} < 101$	3ℓ	> 0.4	-	-





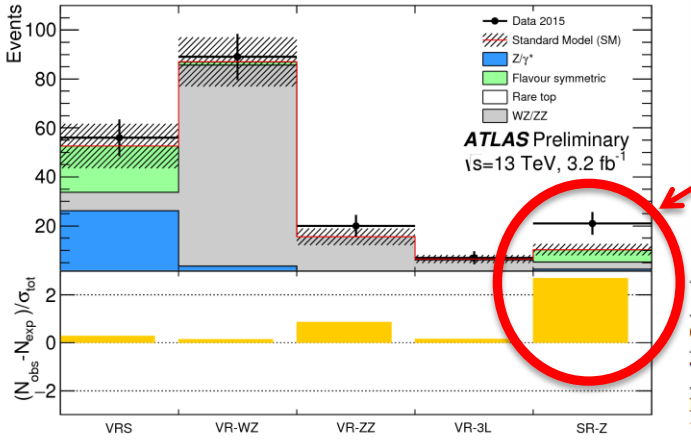


	VRS	VR-WZ	VR-ZZ	VR-3L
Observed events	56	89	20	7
Total expected background events	52.6 ± 9.1	87 ± 10	15.5 ± 3.4	6.5 ± 1.6
Flavour symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	18.9 ± 4.8	1.3 ± 0.4	0	0.3 ± 0.2
WZ/ZZ events	7.5 ± 1.7	82 ± 10	15.5 ± 3.4	4.9 ± 1.6
Z/γ^* + jets events	24.8 ± 7.6	2.7 ± 2.8	0	0.2 ± 0.2
Rare top events	1.4 ± 0.2	0.9 ± 0.4	0.04 ± 0.02	1.0 ± 0.1

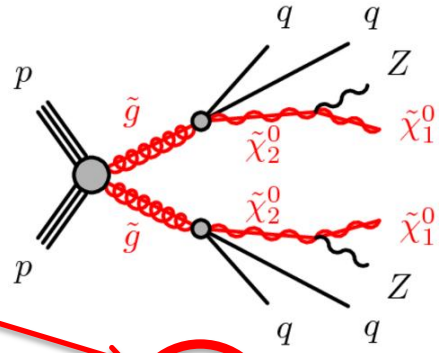
Control regions look good.

SUSY: Strong Production

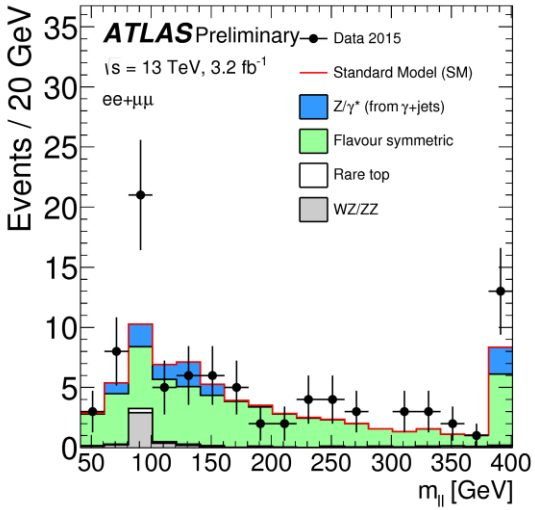
Squark and Gluino mediated 2lep+MET+jets

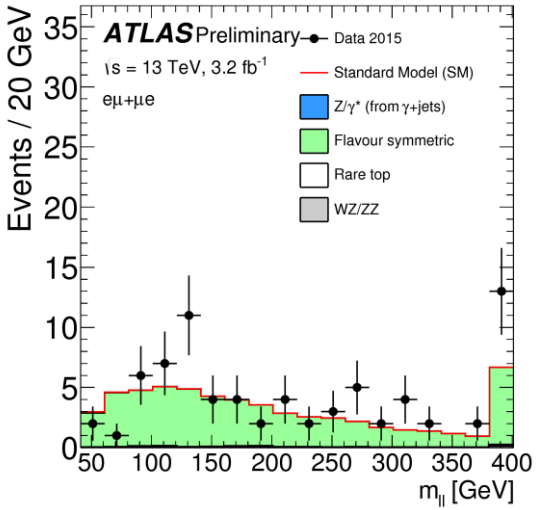


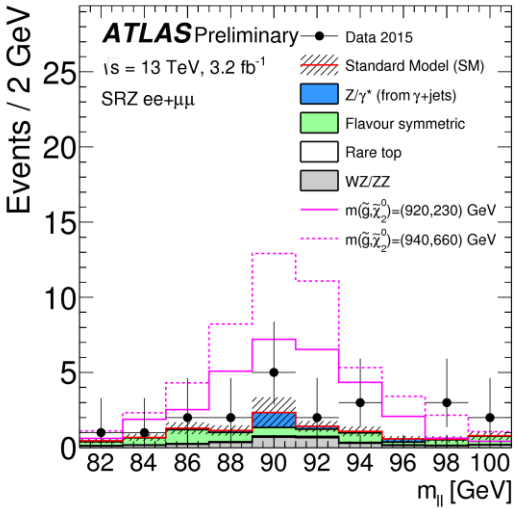
But wait!!



	SRZ
Observed events	21
Total expected background events	10.3 ± 2.3
Flavour symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	5.1 ± 2.0
WZ/ZZ events	2.9 ± 0.8
Z/γ^* + jets events	1.9 ± 0.8
Rare top events	0.4 ± 0.1
p-value	0.013
Significance	2.2
Observed (Expected) S^{95}	20.0 (10.2$^{+4.4}_{-3.0}$)

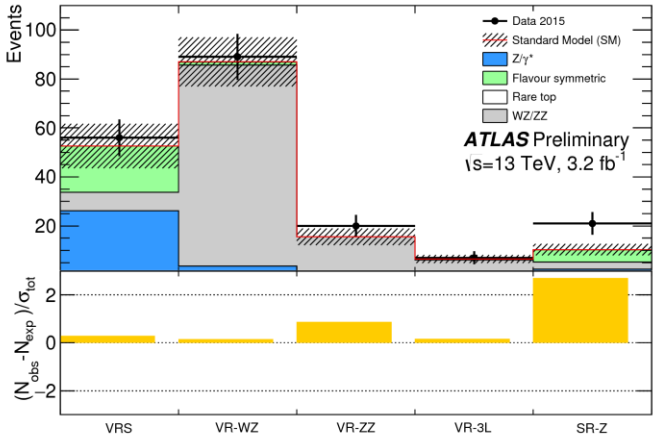


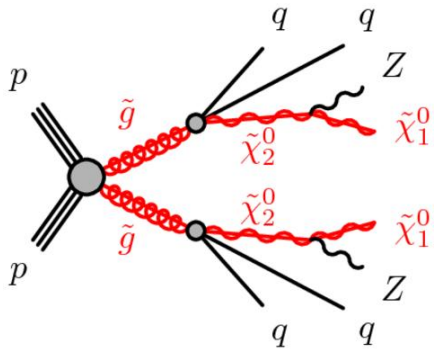




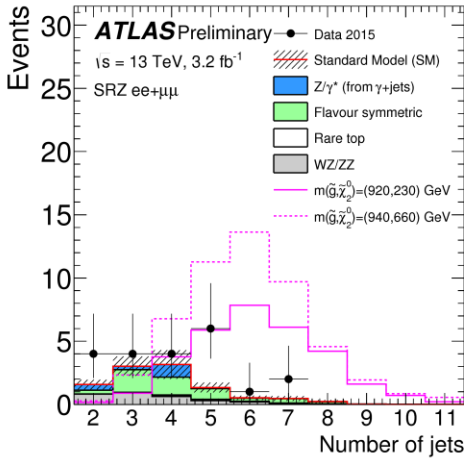
SUSY: Strong Production

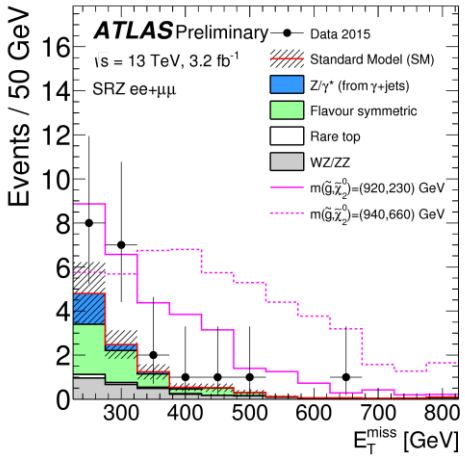
Squark and Gluino mediated 2lep+MET+jets

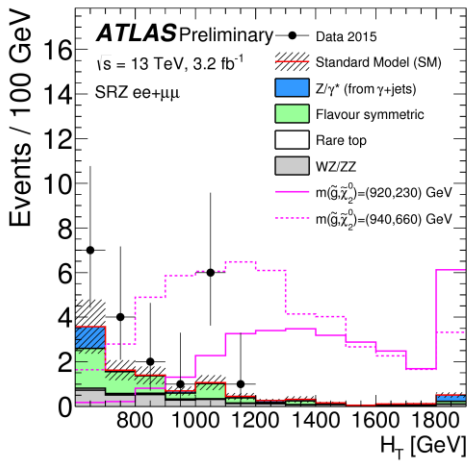


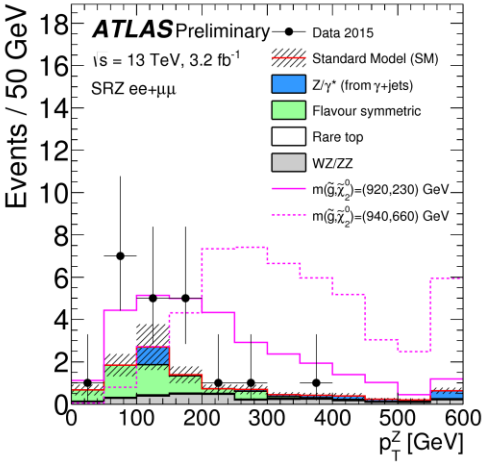


Maybe an excess – but it isn't this particular signal process. Otherwise >=8 jets and 0 leptons would see it!
Unless (trigger, too little MET etc etc)...



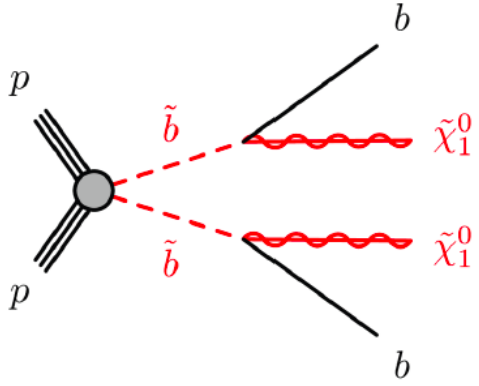


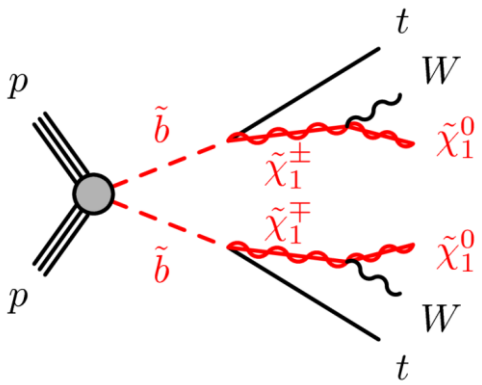




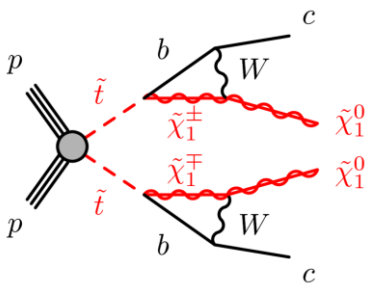
3rd SUSY generation topologies

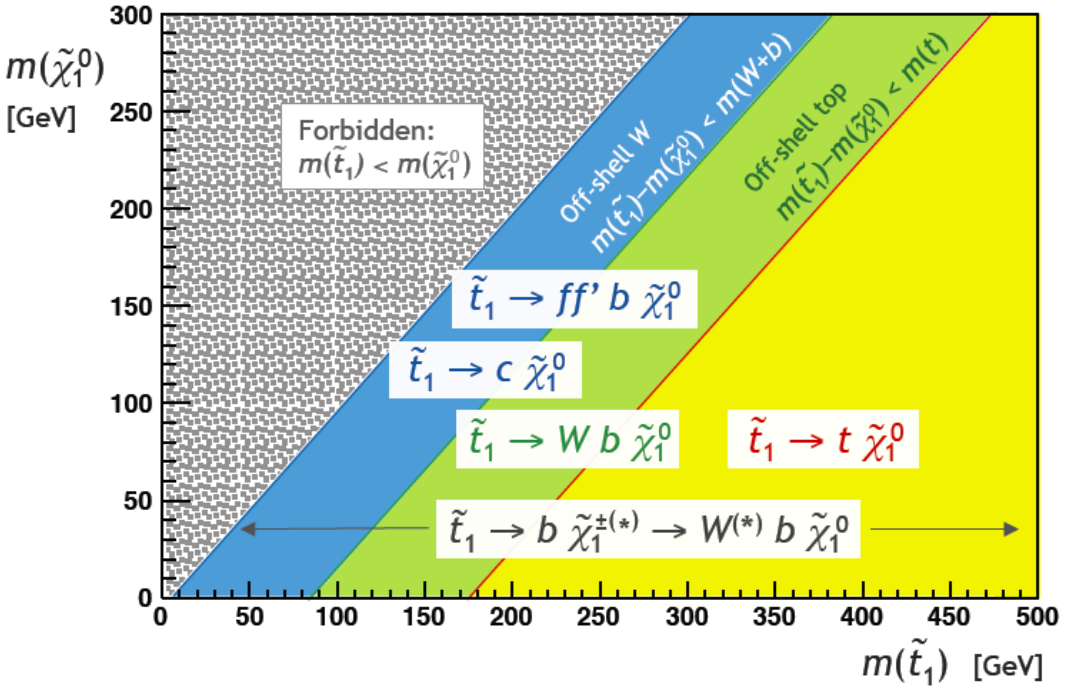
scalar bottom searches

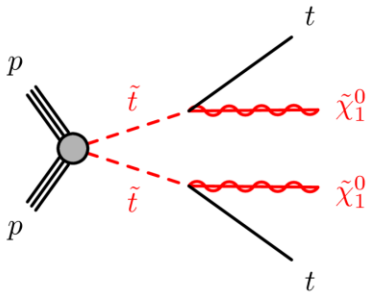


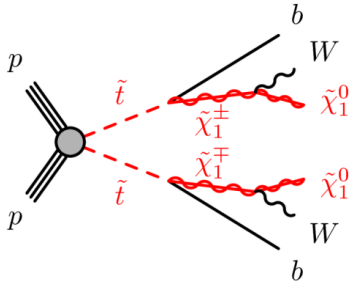


scalar top searches

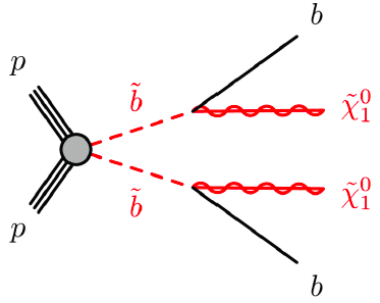






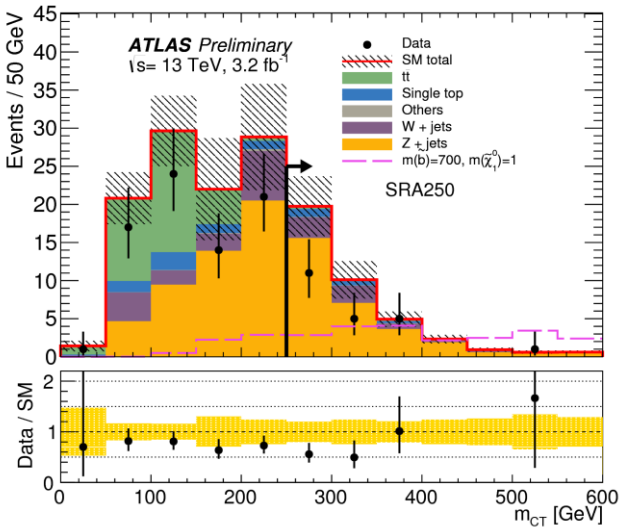


Scalar bottom searches – still no excess at 13TeV



$$m_{CT}^2(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [p_T(v_1) - p_T(v_2)]^2$$

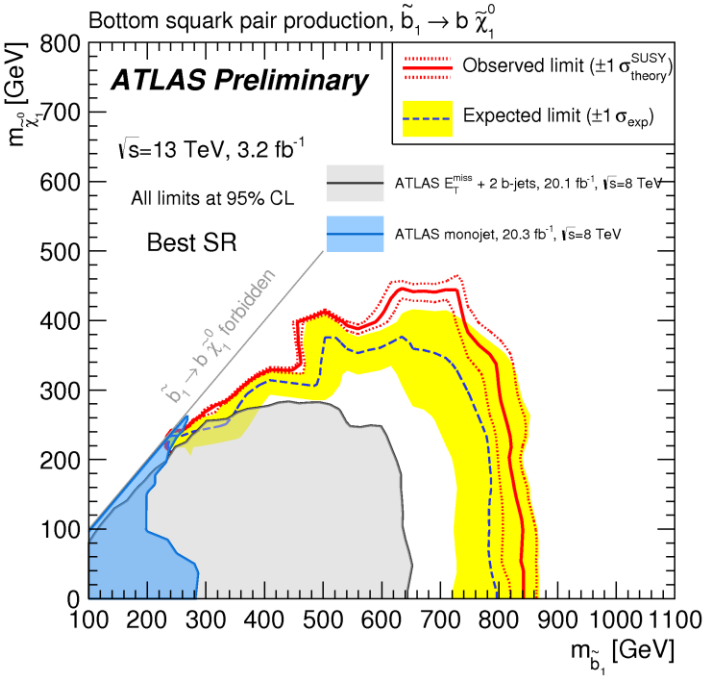
$$H_{T,3} = \sum_{i=4}^{n} (p_T^{\text{jet}})_i$$



0 lepton + 2 b-jets + MET

Primary signature for direct sbottom production

Direct Stop sensitivity for small $\Delta m(\tilde{\chi}^{\pm}, \tilde{\chi}^{0})$ in $\tilde{t}_1 \to b\tilde{\chi}^{\pm}$



Analysis method:

- Trigger: E_T^{miss}
- Selection: E_T^{miss}, 2-b-jets, lepton veto
- Large $\Delta m(b_1,\chi^0_1)$: large m_{CT}, m_{bb} > 200GeV, 3rd 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 Z(ll)+bjets control region

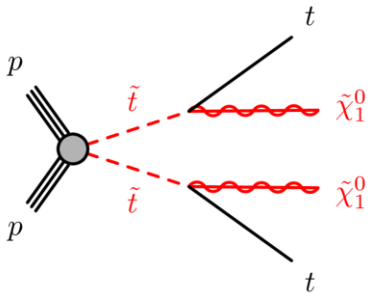
from single lep or e/μ control region

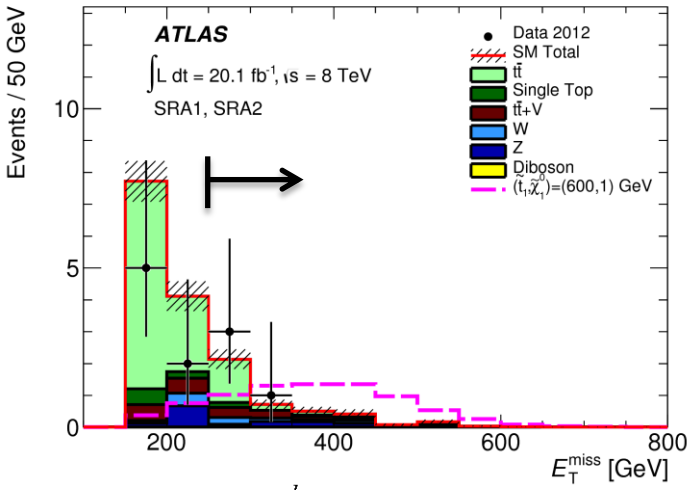
0lepton + 6 jets (2 b-jets) +E_T^{miss} analyses

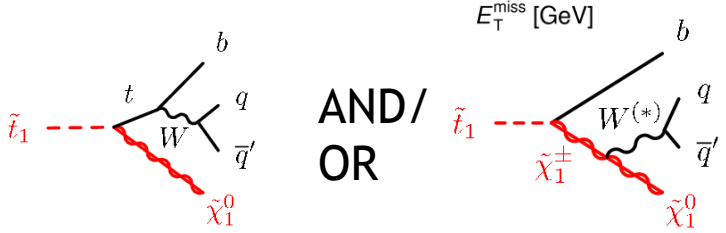
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$
N_{lep}	0
b-tagged jets	≥ 2
$E_{\mathrm{T}}^{\mathrm{miss}}$	$> 150GeV$
$\left\|\Delta\phi\left(\mathrm{jet}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}\right)\right\|$	$> \pi/5$
$\left\|\Delta\phi\left(\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss,track}}\right)\right\|$	$< \pi/3$
$m_{\mathrm{T}}^{b,\,\mathrm{min}}$	> 175 GeV

	SRA1	SRA2	SRA3	SRA4
anti-k_t $R = 0.4$ jets	≥ 6, $p_{\mathrm{T}} > 80, 80, 35, 35, 35, 35$ GeV			
m_{bjj}^0	< 225 GeV		[50,250] GeV	
m_{bjj}^1	< 250 GeV		[50,400] GeV	
$\min[m_{\mathrm{T}}(\mathrm{jet}^i, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})]$	–		> 50 GeV	
τ veto	yes			
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150 GeV	> 250 GeV	> 300 GeV	> 350 GeV

One example of selection showing fully resolved signal regions



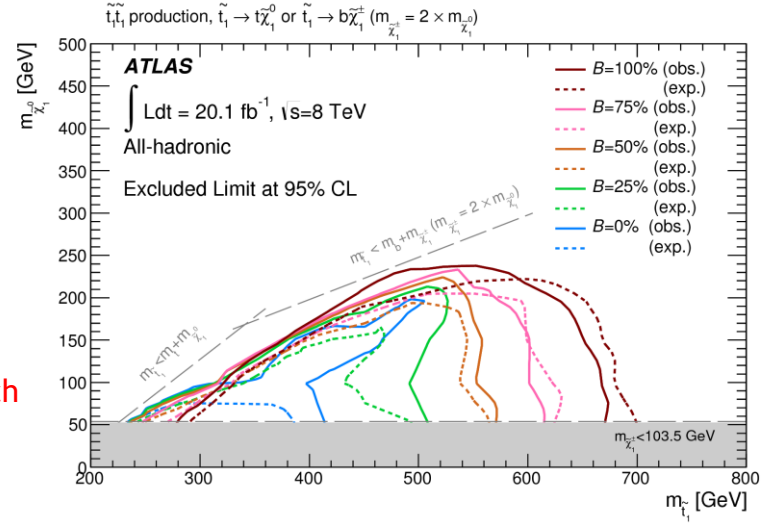




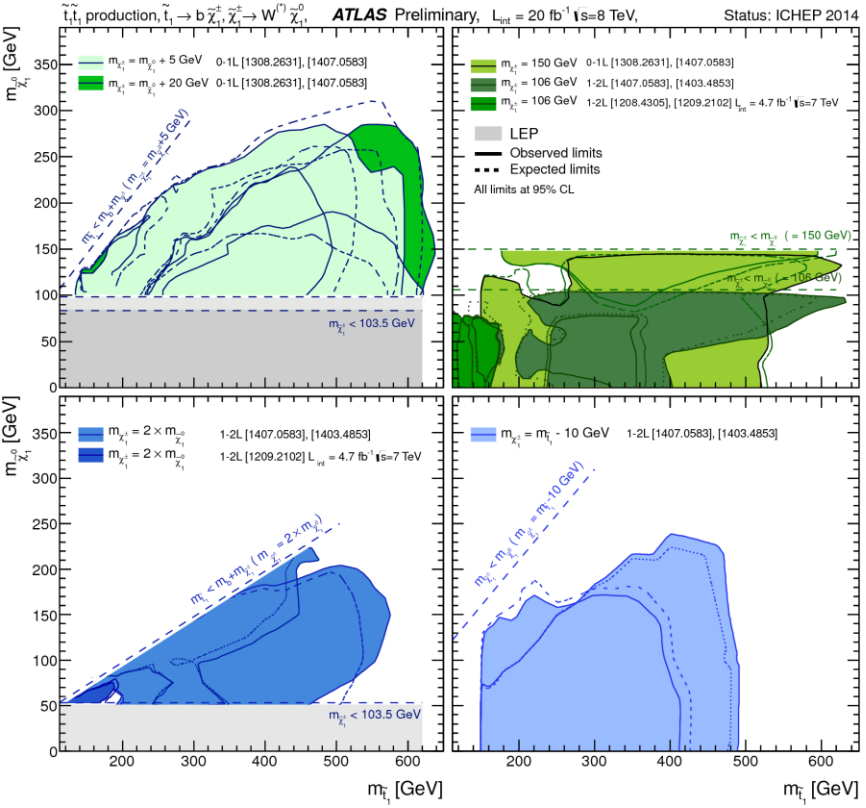
Main Backgrounds

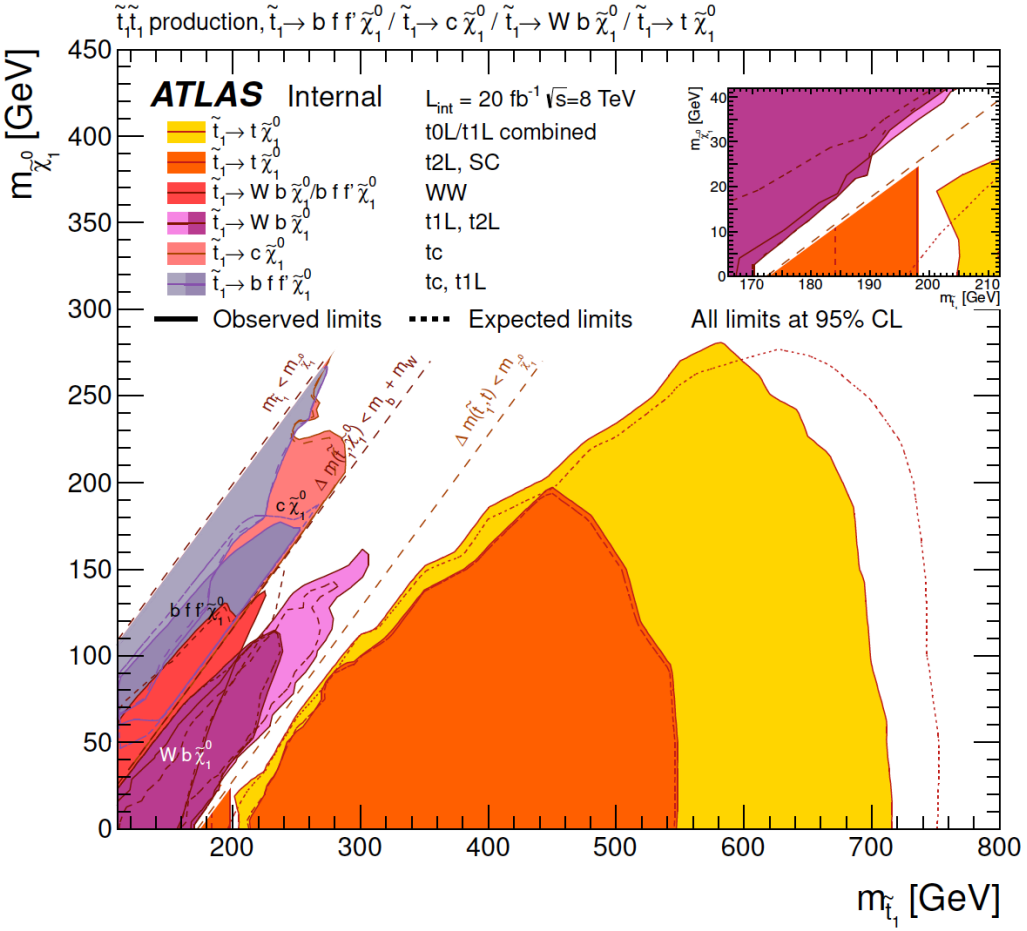
- Semileptonic tt with one missing (or hadronic tau) lepton: normalise with 1-lepton control region (CR) in data
- Z(vv)+j normalise with Z(ll) CR
- tt + W/Z taken from MC

Challenging fully hadronic search exploiting large MET regime, sensitive to t+LSP decays

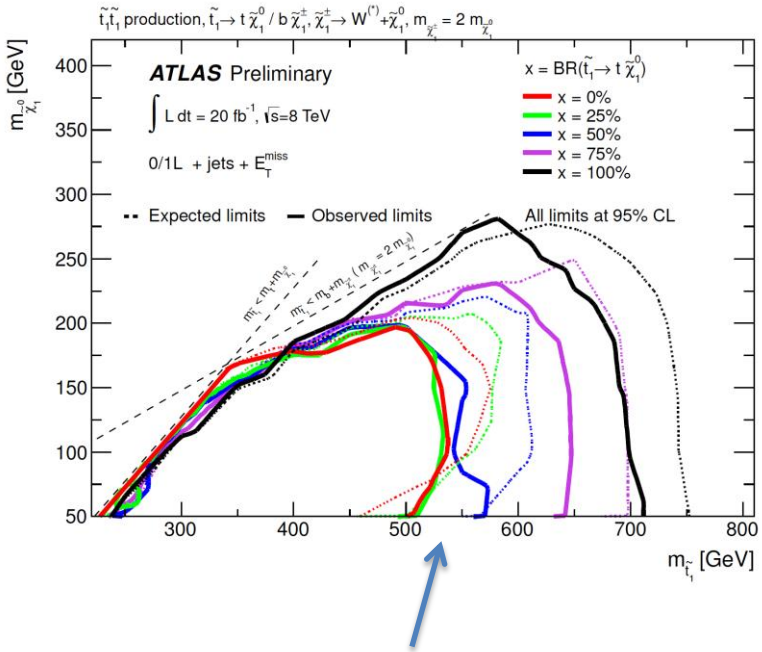


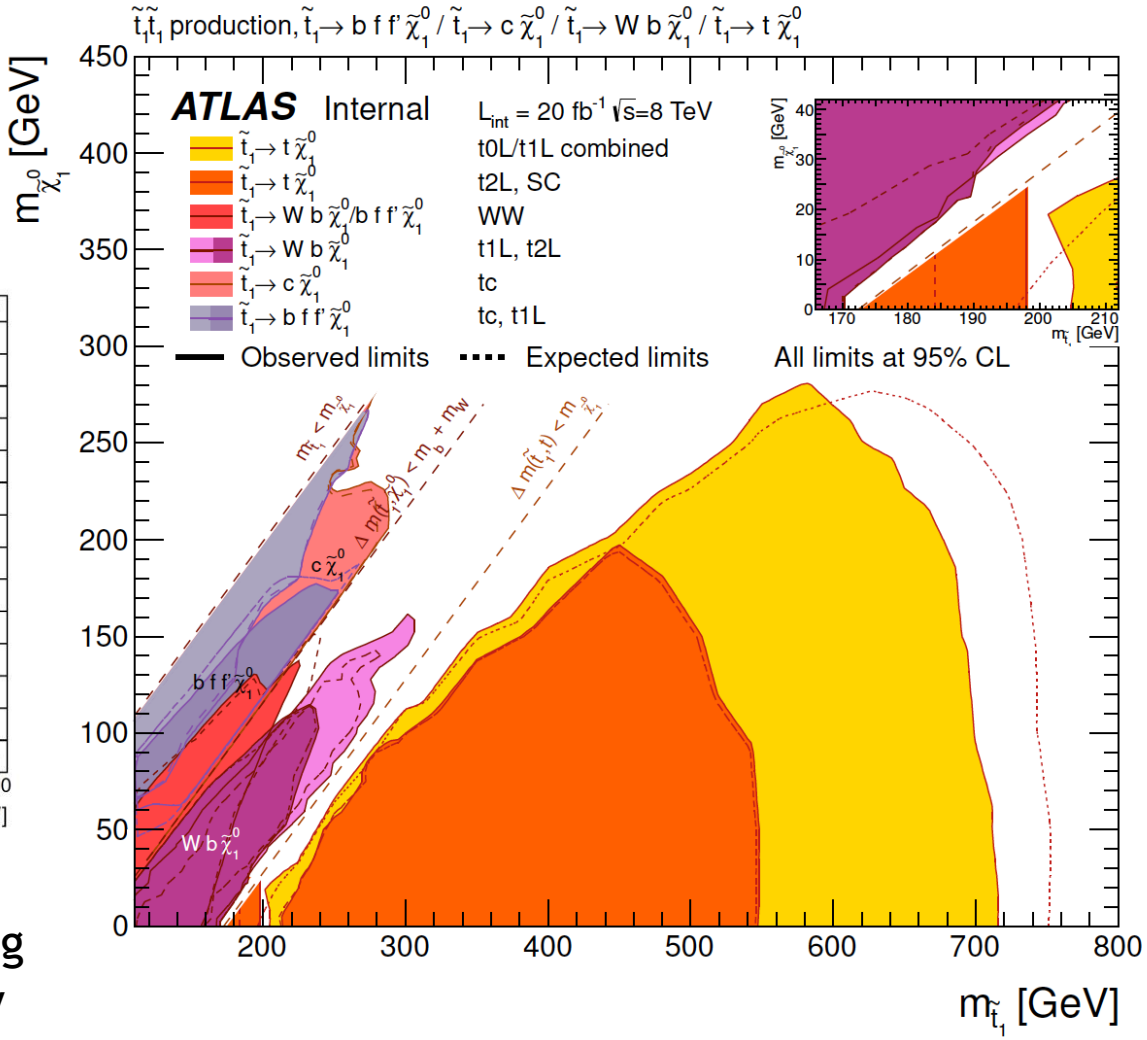
Stop searches - summary





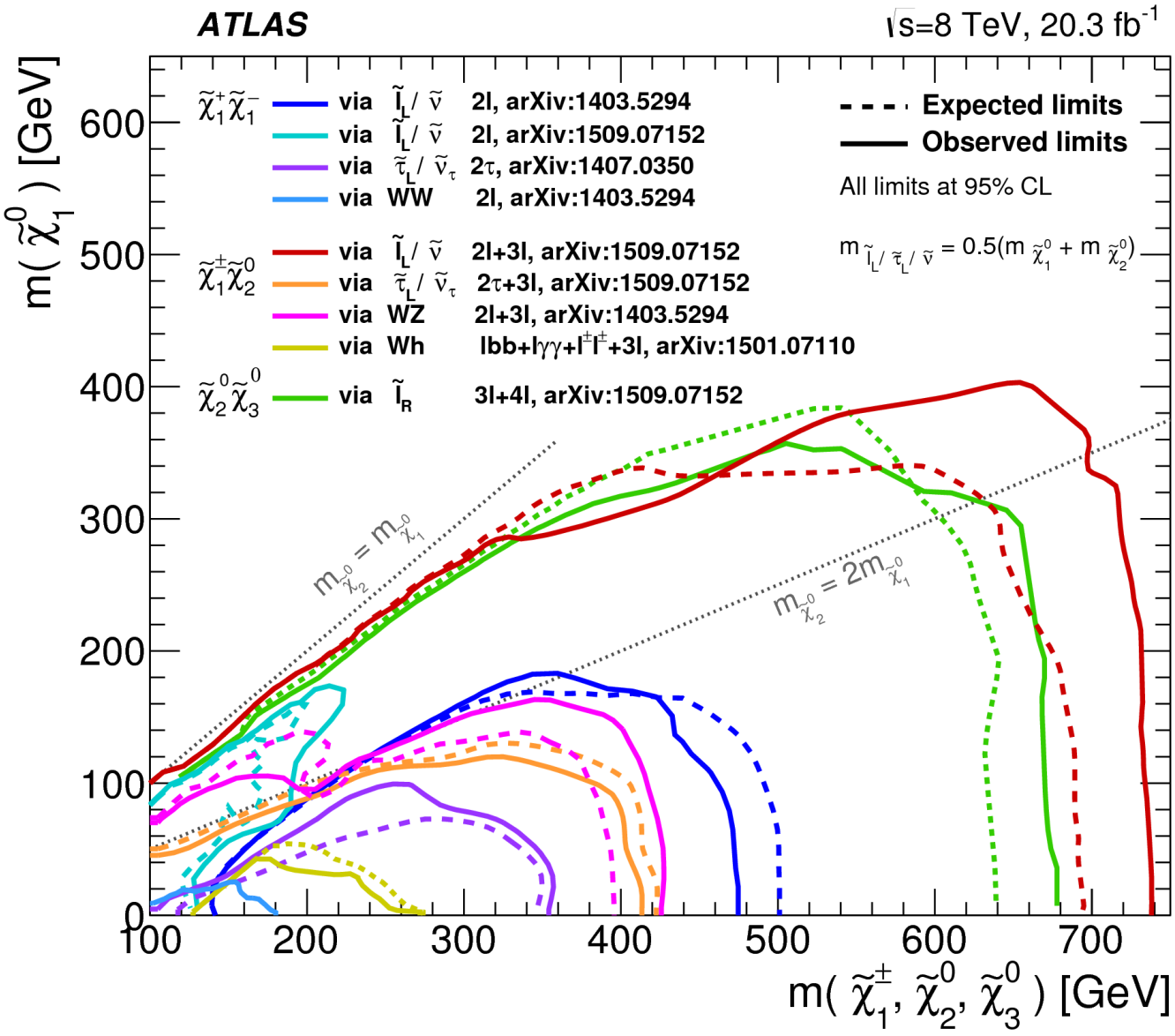
3rd generation searches – Run 1 summary



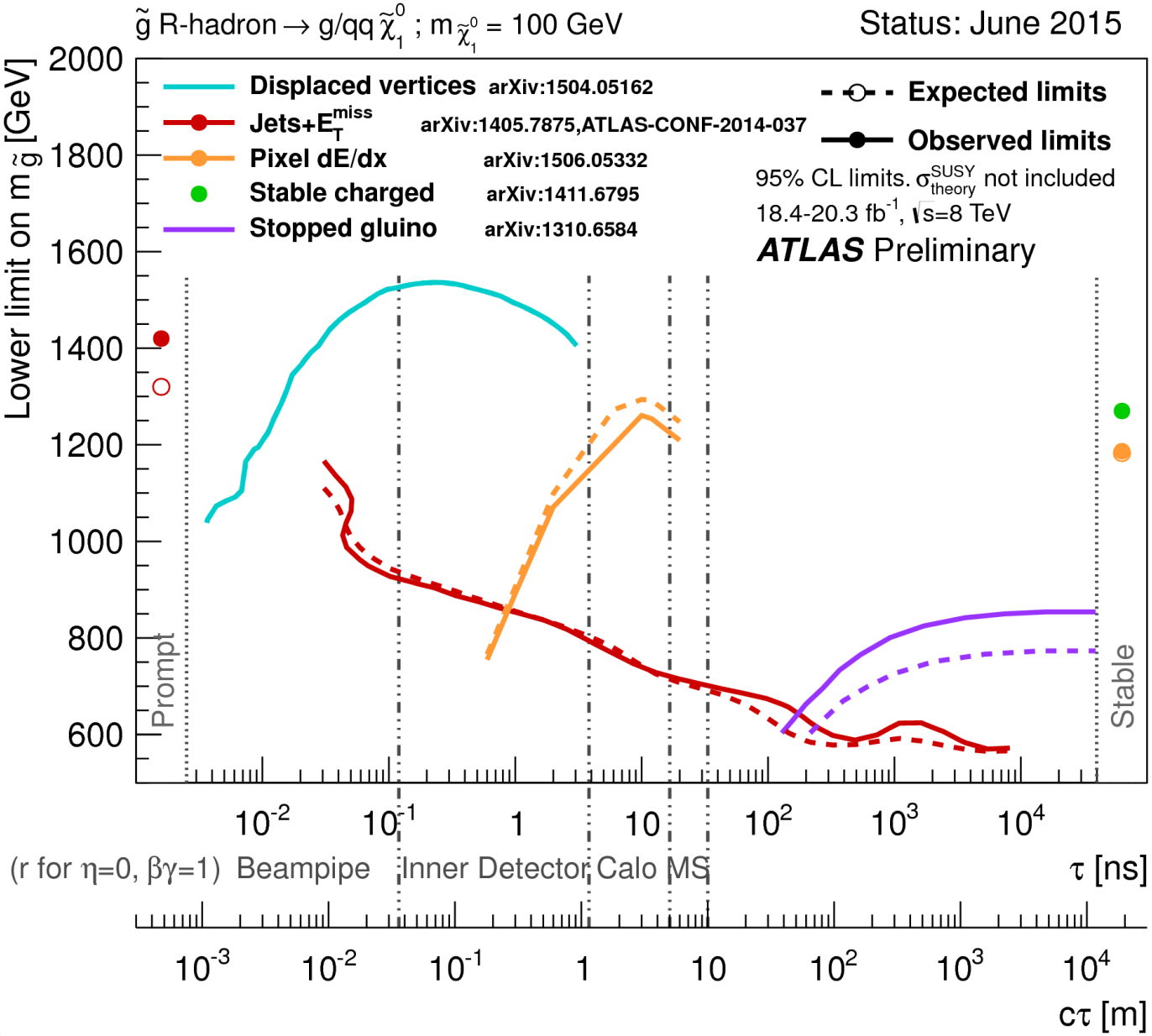


Simply altering the stop branching fractions alter the limits severely

SUSY: Electroweak Production



SUSY: Long-lived particles



EXOTICA

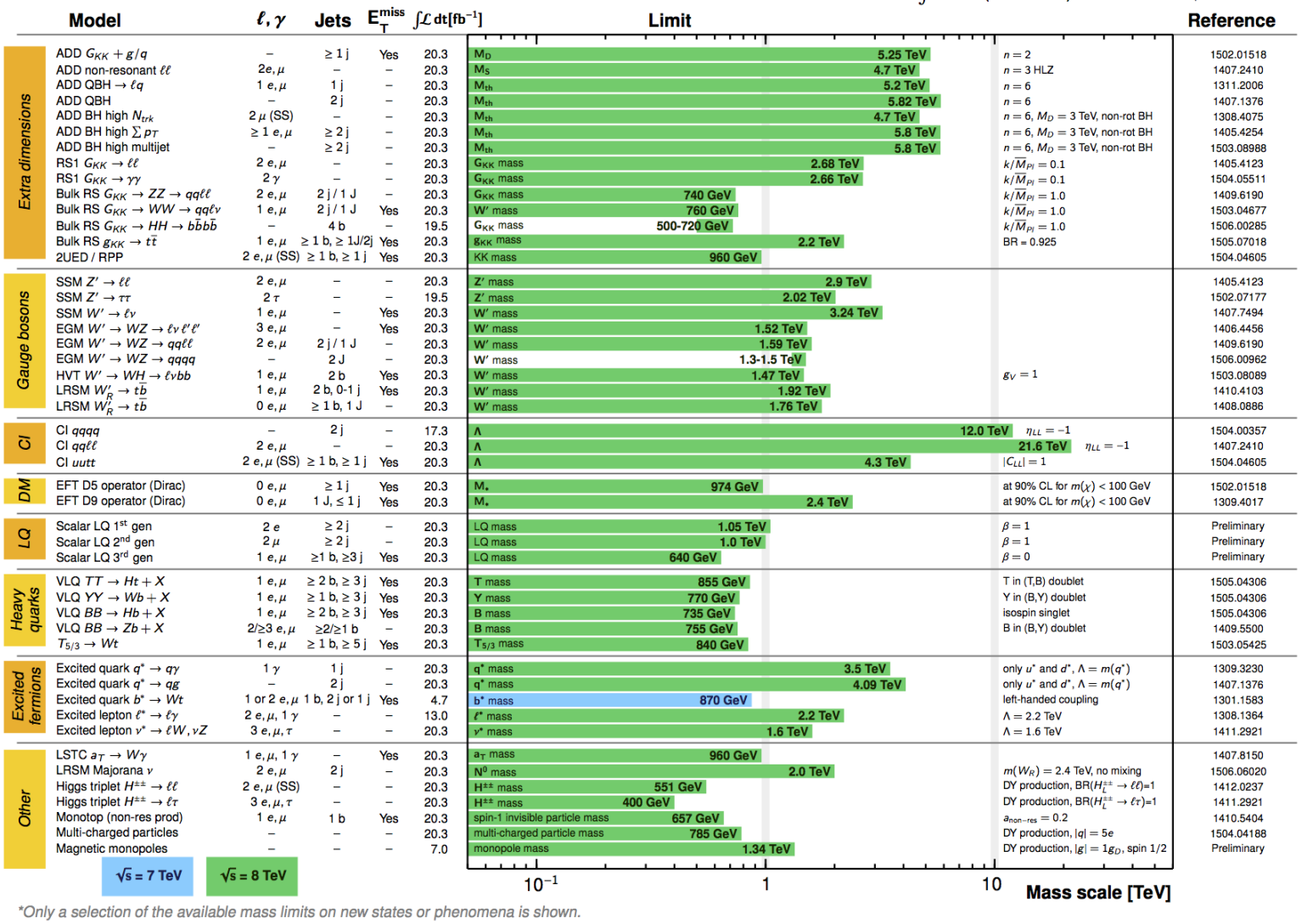
Gratuitous Tony Williams Coffee Joke Slide

New Physics

Exotics

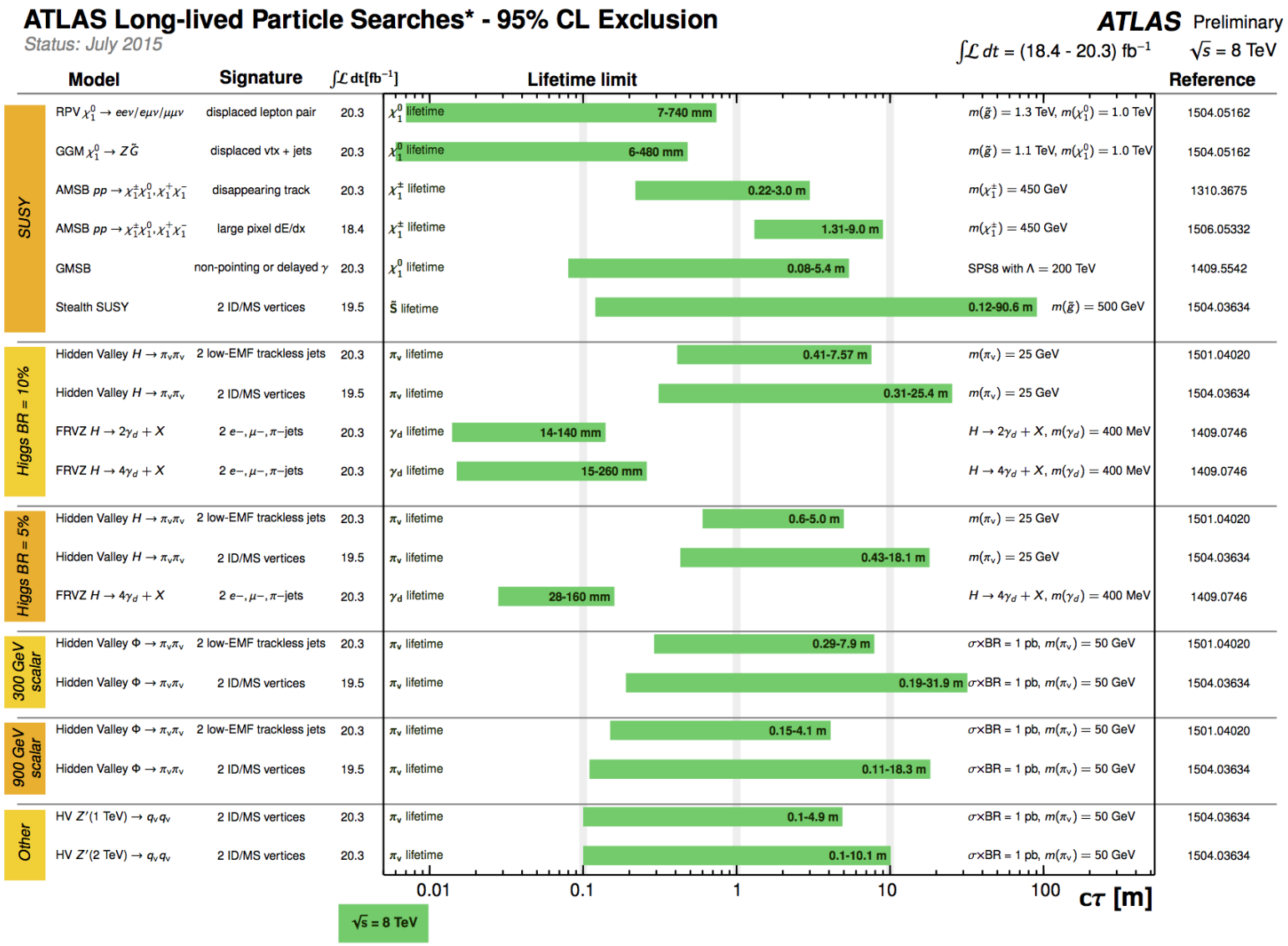
- What makes something “Exotic”?
- If ≠ SUSY .and. ≠ HIGGS .then. EXOTICA!
- More generally SUSY tends to have large missing momentum and Exotics doesn’t necessarily (although RPV and Long-lived SUSY mess with this paradigm)
- Also, Exotics is the place where non-SM resonance searches are performed (although they overlap with BSM Higgs)
- Take >=2 SM objects, plot the invariant mass and look for a bump - Easy ☺ (Maybe 😐)

Exotics: Run1 summary



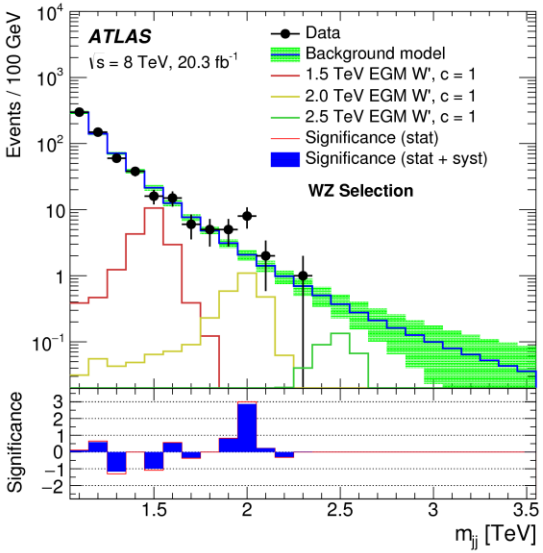
*Only a selection of the available mass limits on new states or phenomena is shown.

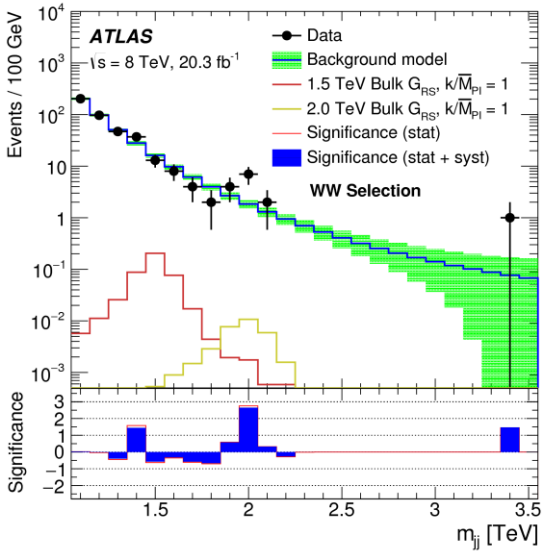
Long-lived particle searches: Run1 summary

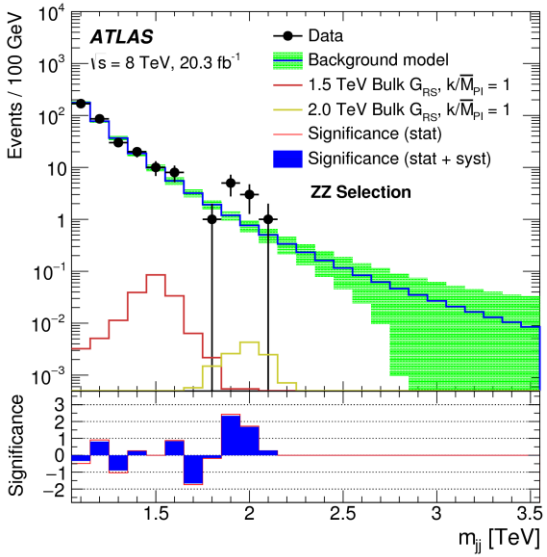


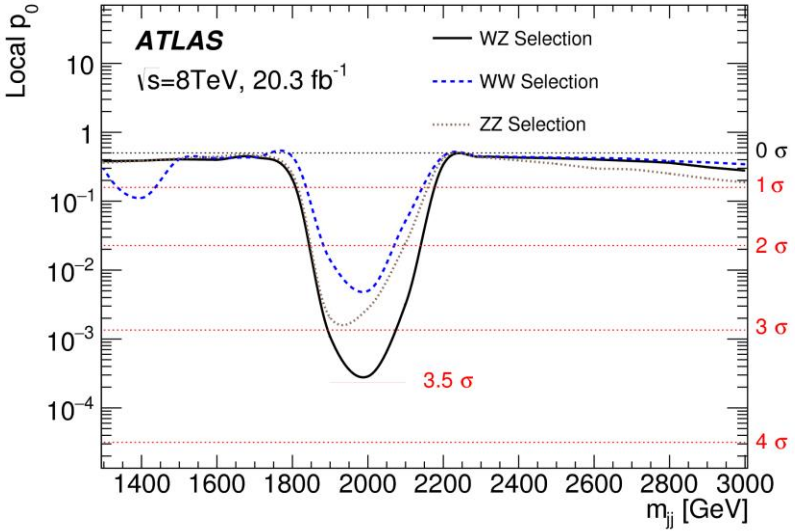
*Only a selection of the available lifetime limits on new states is shown.

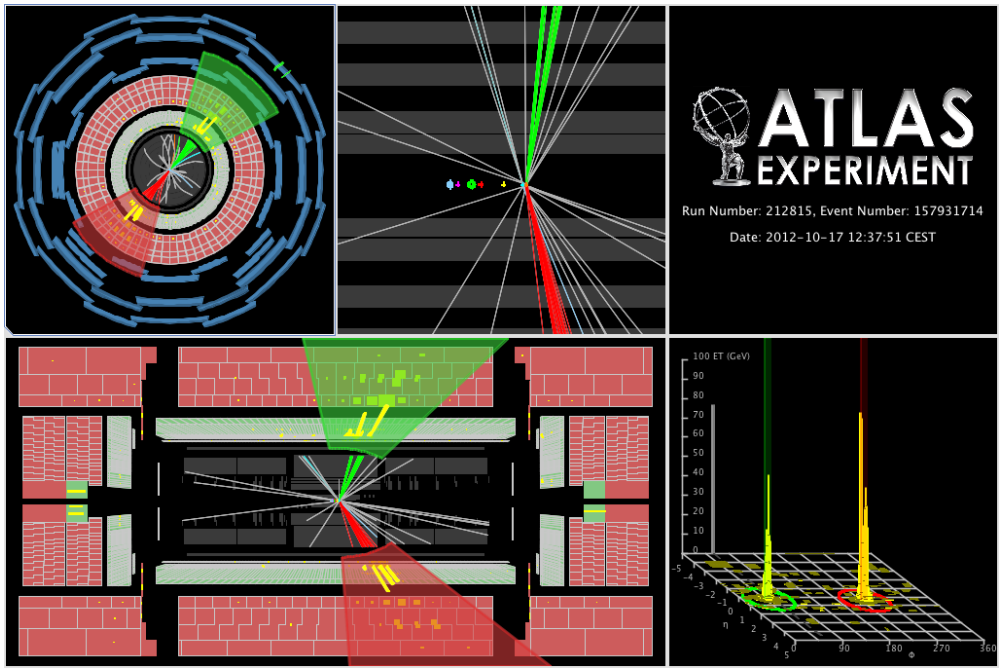
Exotics: Run1 - diboson resonances with boson-tagged jets









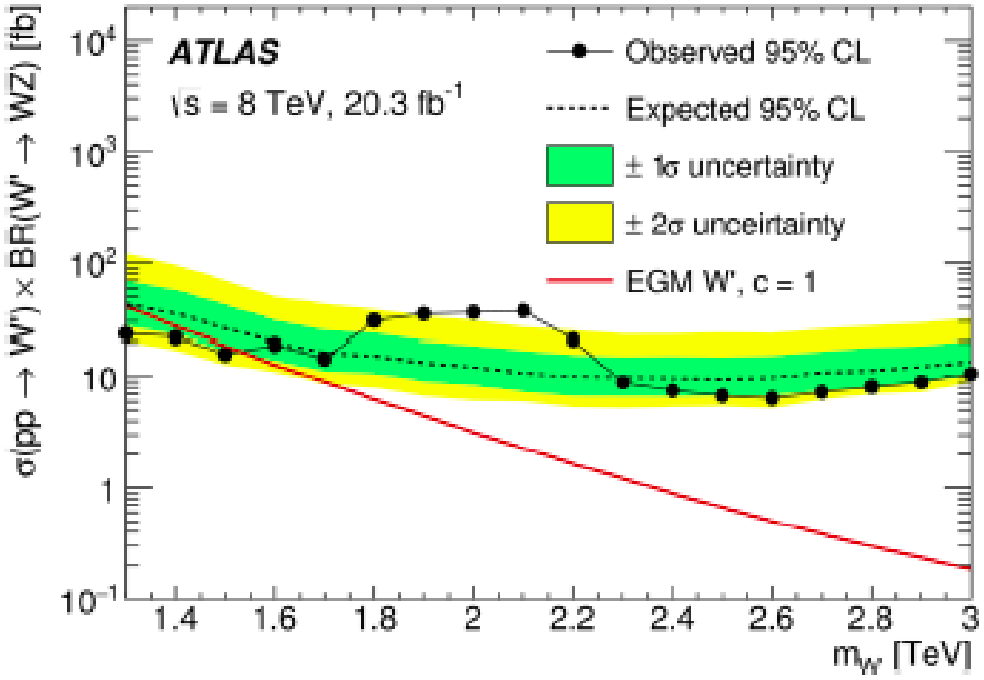


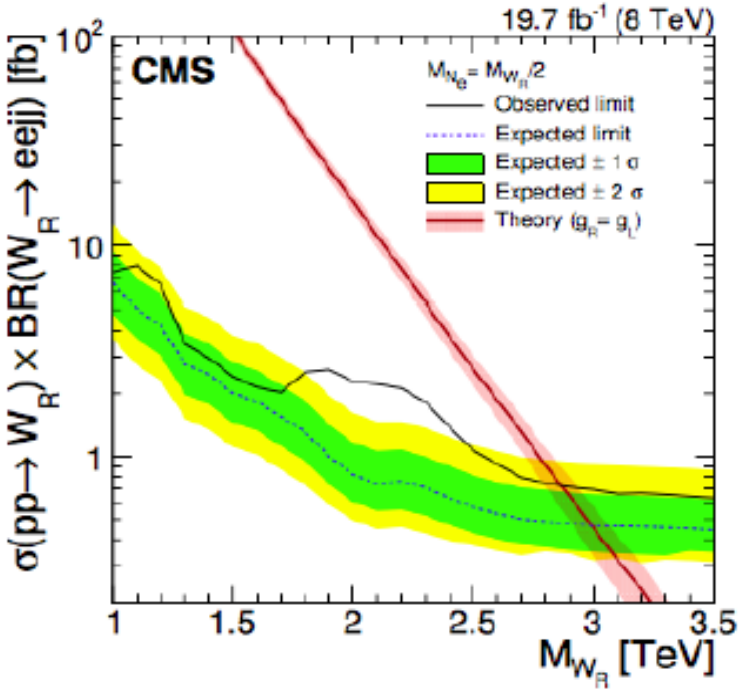
THE UNIVERSITY of ADELAIDE

CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

Exotic High-Mass Anomalies

- Diboson "bump": VV ➔jjjj around 2 TeV?
  - 3.5σ local significance, 2.5σ global significance

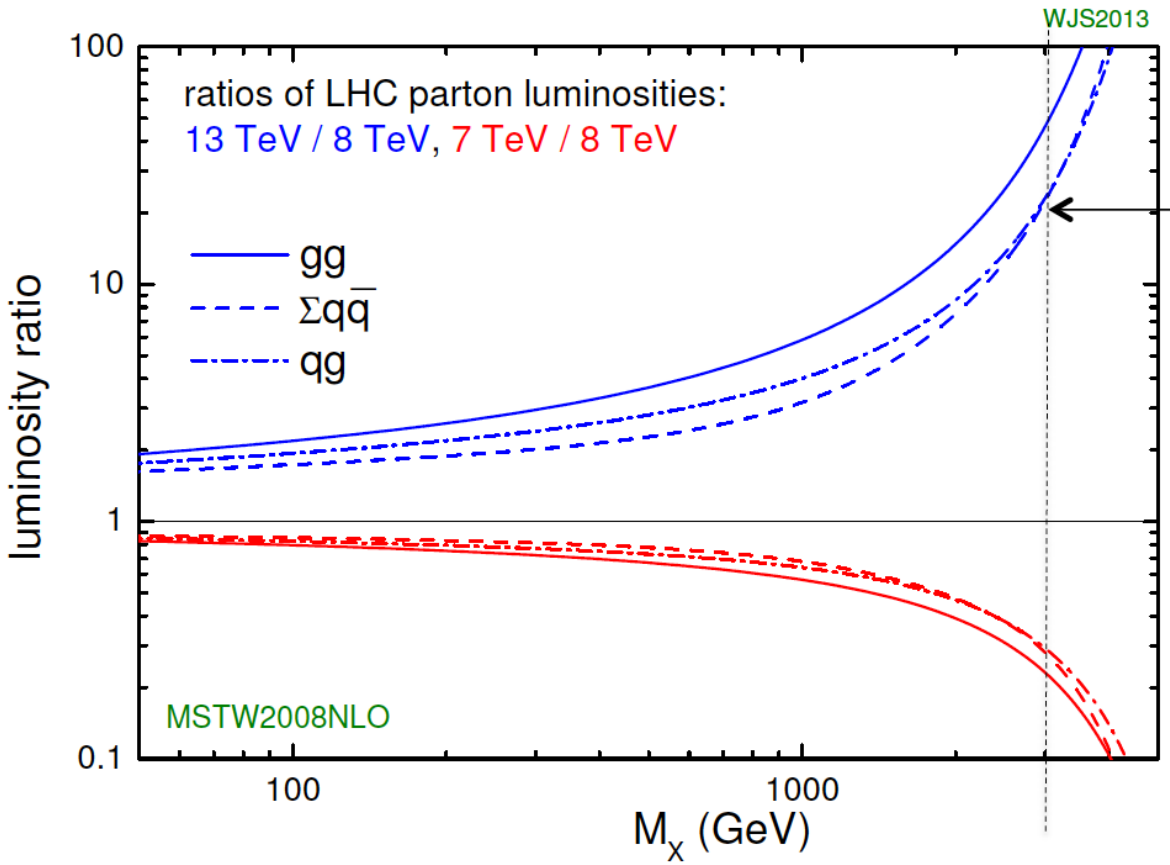




Seen at both ATLAS and CMS!

Exciting @ Run 2!

Early Searches for Exotic New Phenomena

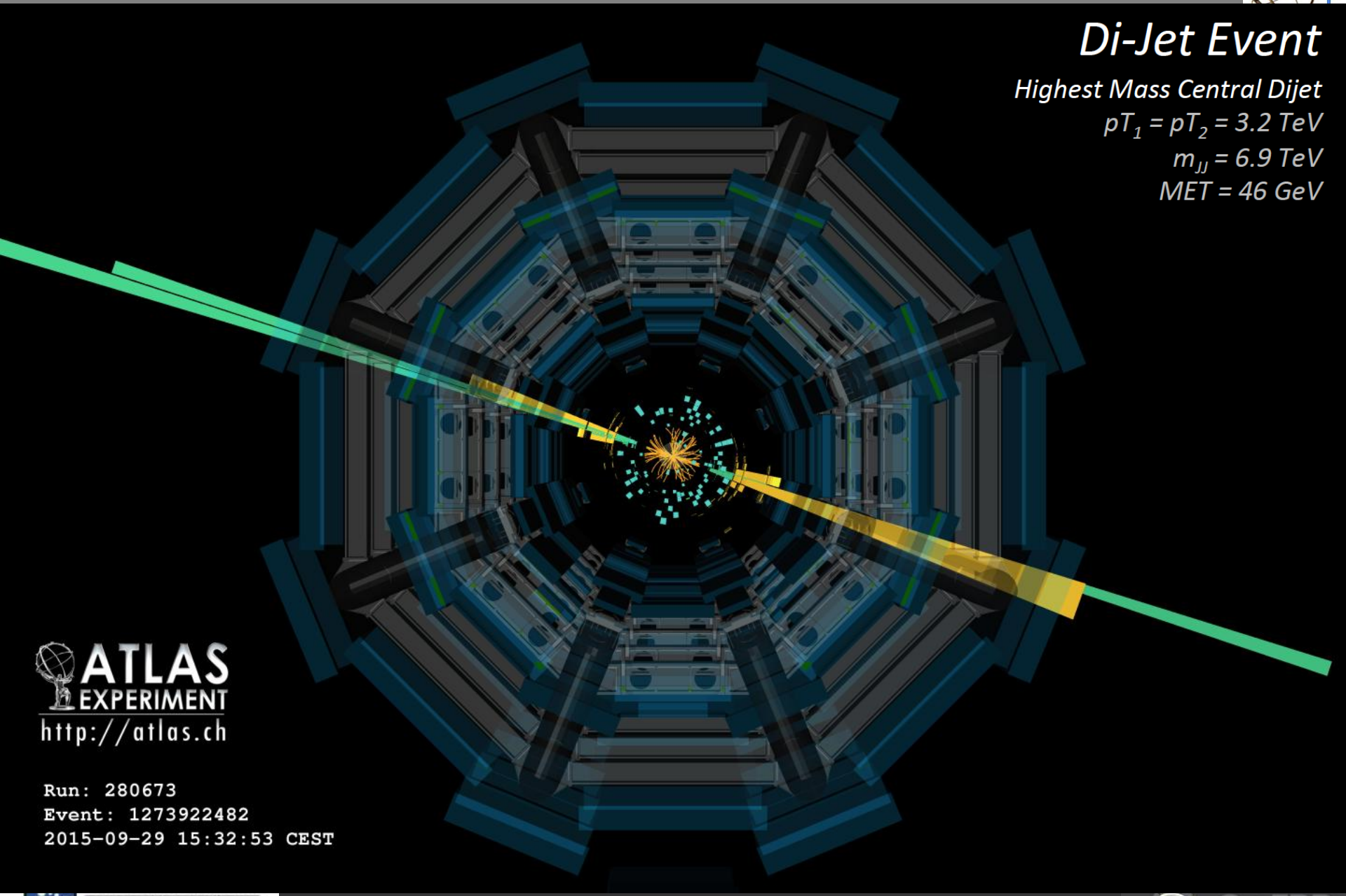


Ratio of 13 TeV / 8 TeV

Cross sections:

- Z' at 3 TeV: **20**
- q* at 4 TeV: **56**
- QBH at 5 TeV: **370**
- QBH at 6 TeV: **9000**

Di-Jets

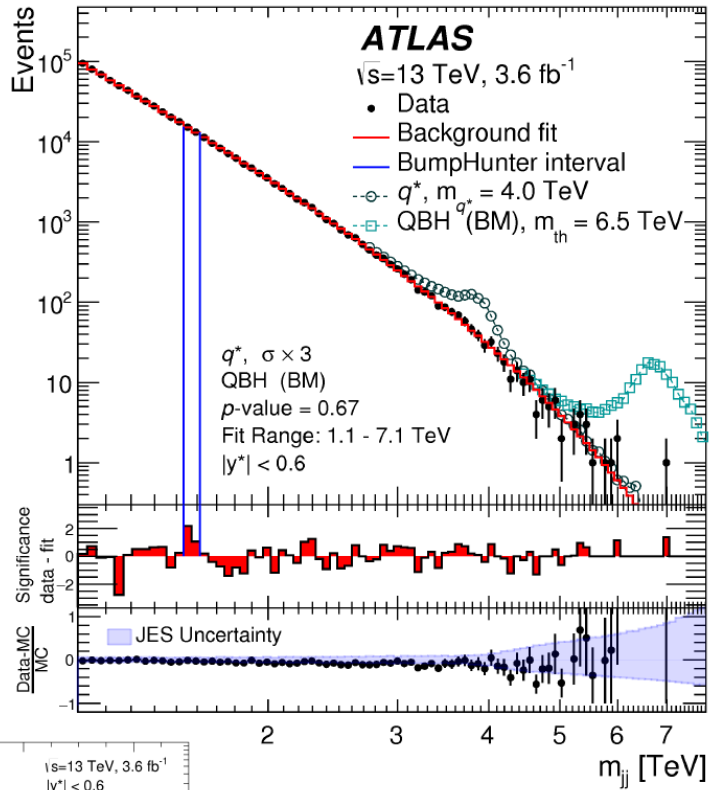

Di-Jet Event
Highest Mass Central Dijet
$pT_1 = pT_2 = 3.2$ TeV
$m_{JJ} = 6.9$ TeV
MET = 46 GeV
ATLAS EXPERIMENT
http://atlas.ch
Run: 280673
Event: 1273922482
2015-09-29 15:32:53 CEST

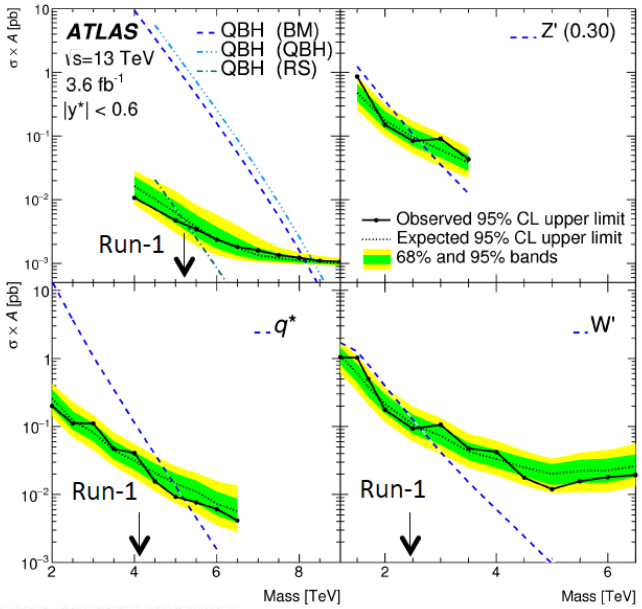
Update on **Dijet Resonant** Searches

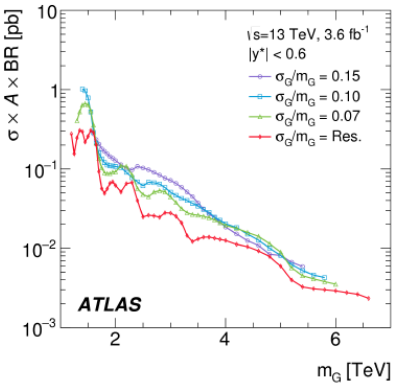
1512.01530

Dijet search for a peaking signal in invariant mass spectrum

- **Models**: Sensitive to Quantum Black Holes (Close to Mass Scale), Excited quarks, W' and Z'
- **Background**: Using simple analytic fit function
- Using Bump Hunter technique to identify most significant excess (global p-value of 70%)
  No significant excess found







Model independent limits (based on Gaussian signal shape)

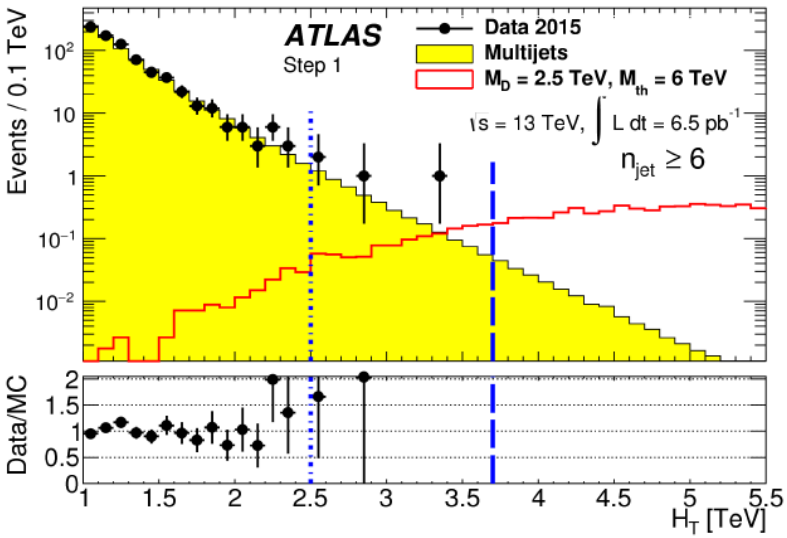
Limits on QBH reaching 8 TeV

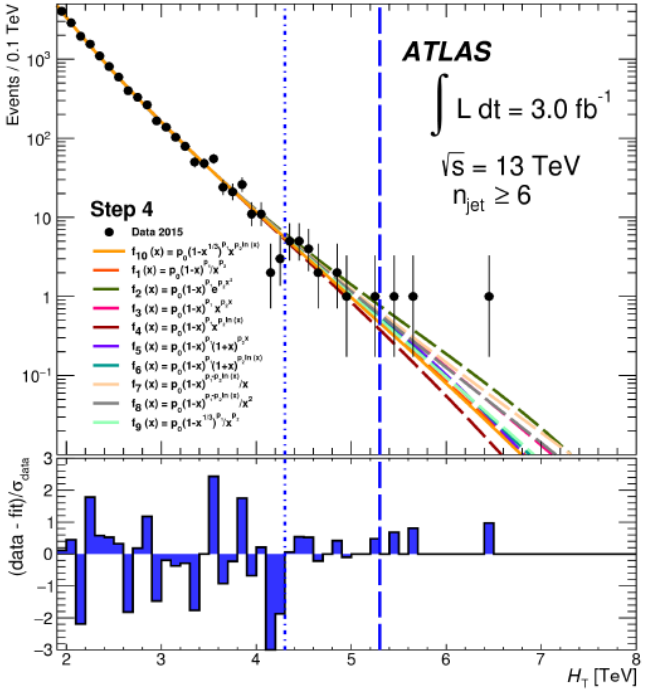
Search for new phenomena in Multi-Jet events

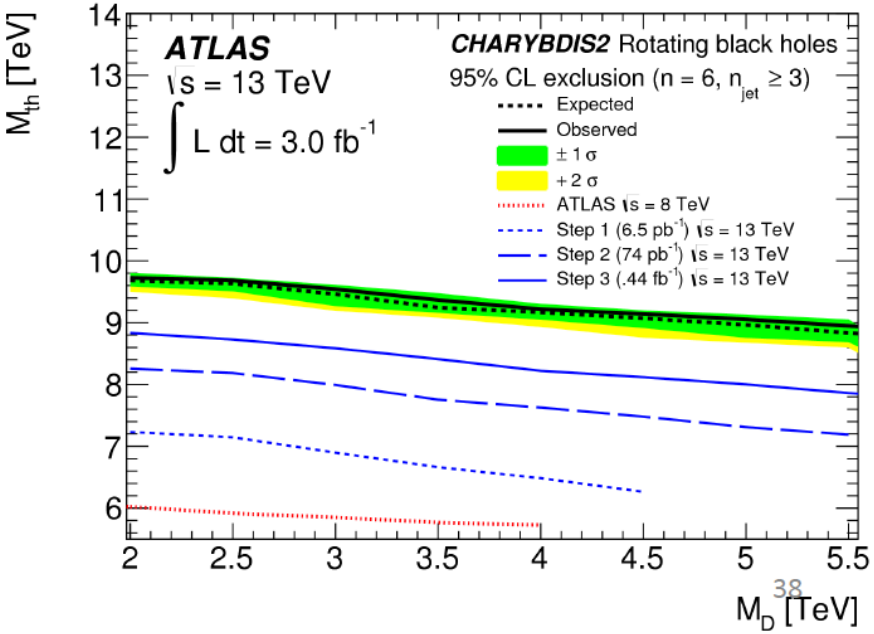
1512.02586

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)







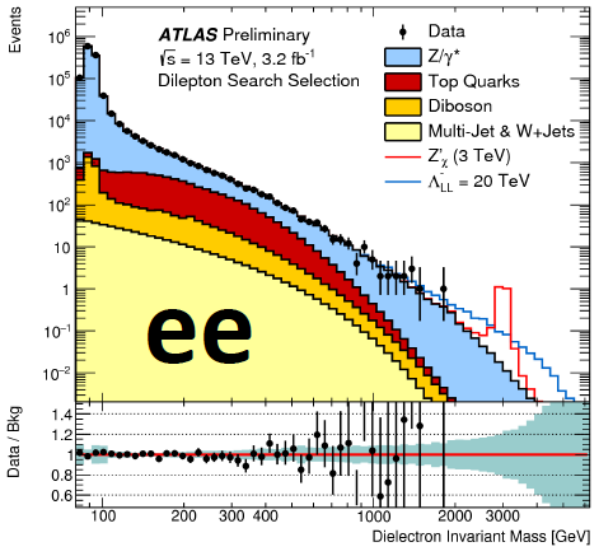
Di-lepton Resonances (LFC and LFV)

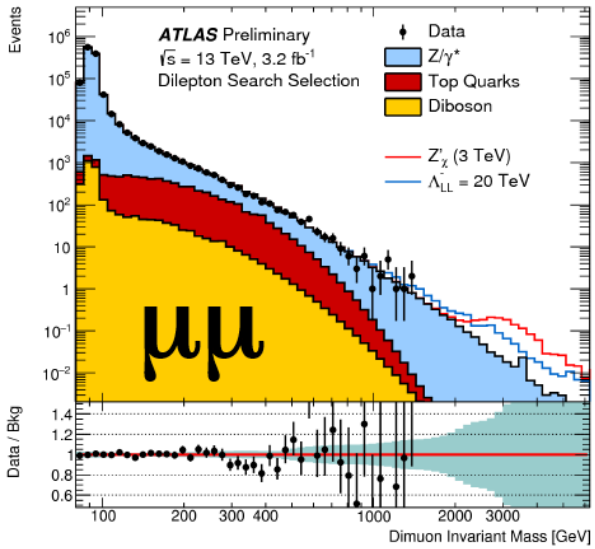
Search for Z' in dilepton (LFC) and (LFV) *(in eμ decays)*

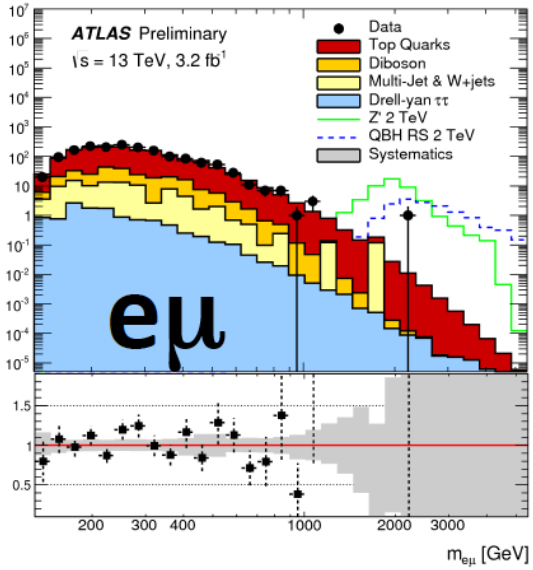
ATLAS-CONF-2015-070

ATLAS-CONF-2015-072

- Main background DY is taken from MC
- Top and diboson extrapolated at very high masses using a functional form
- Background from MC except for MJ in dielectron uses Matrix method (based on electron ID)







Highest di-electron mass event at 1.8 TeV

Highest di-muon mass event at 1.4 TeV

Highest eμ mass event at 2.1 TeV

No Excess found !

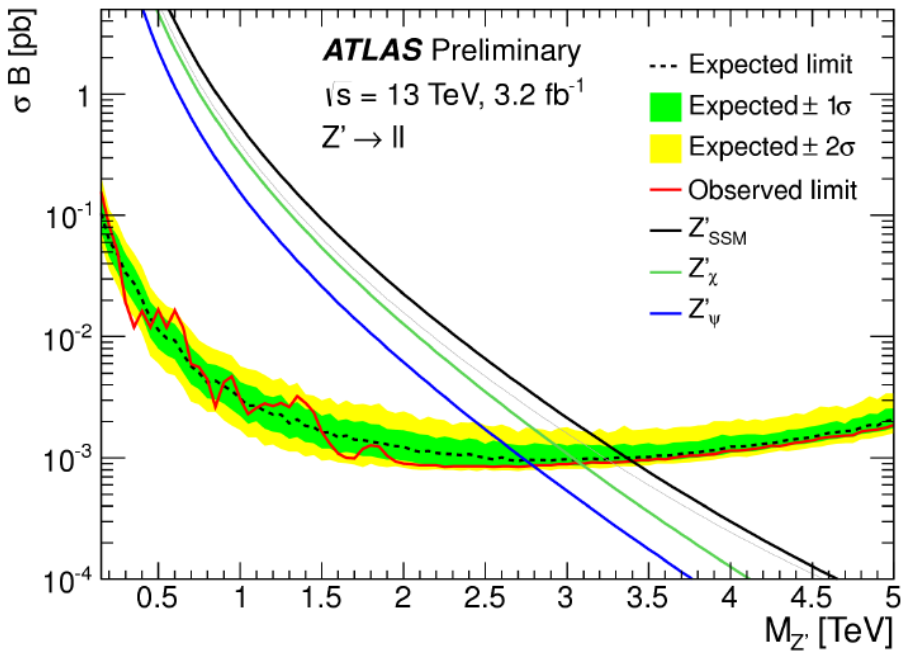
95% CL Limit on SSM Z' at 3.4 TeV (2.9 TeV from Run-1)

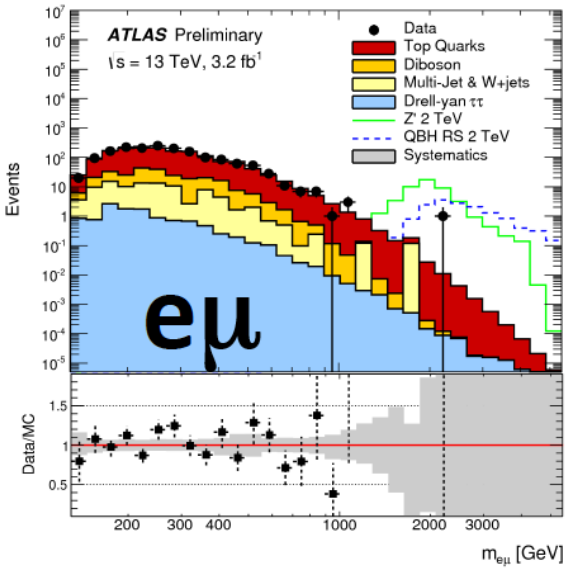
95% CL Limit on SSM LFV Z' at 3.0 TeV (2.5 TeV from Run-1)

Di-lepton Resonances (LFC and LFV)

Search for Z' in dilepton (LFC) and (LFV) *(in eμ decays)*

- Main background DY is taken from MC
- Top and diboson extrapolated at very high masses using a functional form
- Background from MC except for MJ in dielectron uses Matrix method (based on electron ID)





Highest eμ mass event at 2.1 TeV

No Excess found !

95% CL Limit on SSM Z' at 3.4 TeV (2.9 TeV from Run-1)

95% CL Limit on SSM LFV Z' at 3.0 TeV (2.5 TeV from Run-1)

Di-lepton Resonances (LFC and LFV)

Z' mass limits and the naturalness of supersymmetry

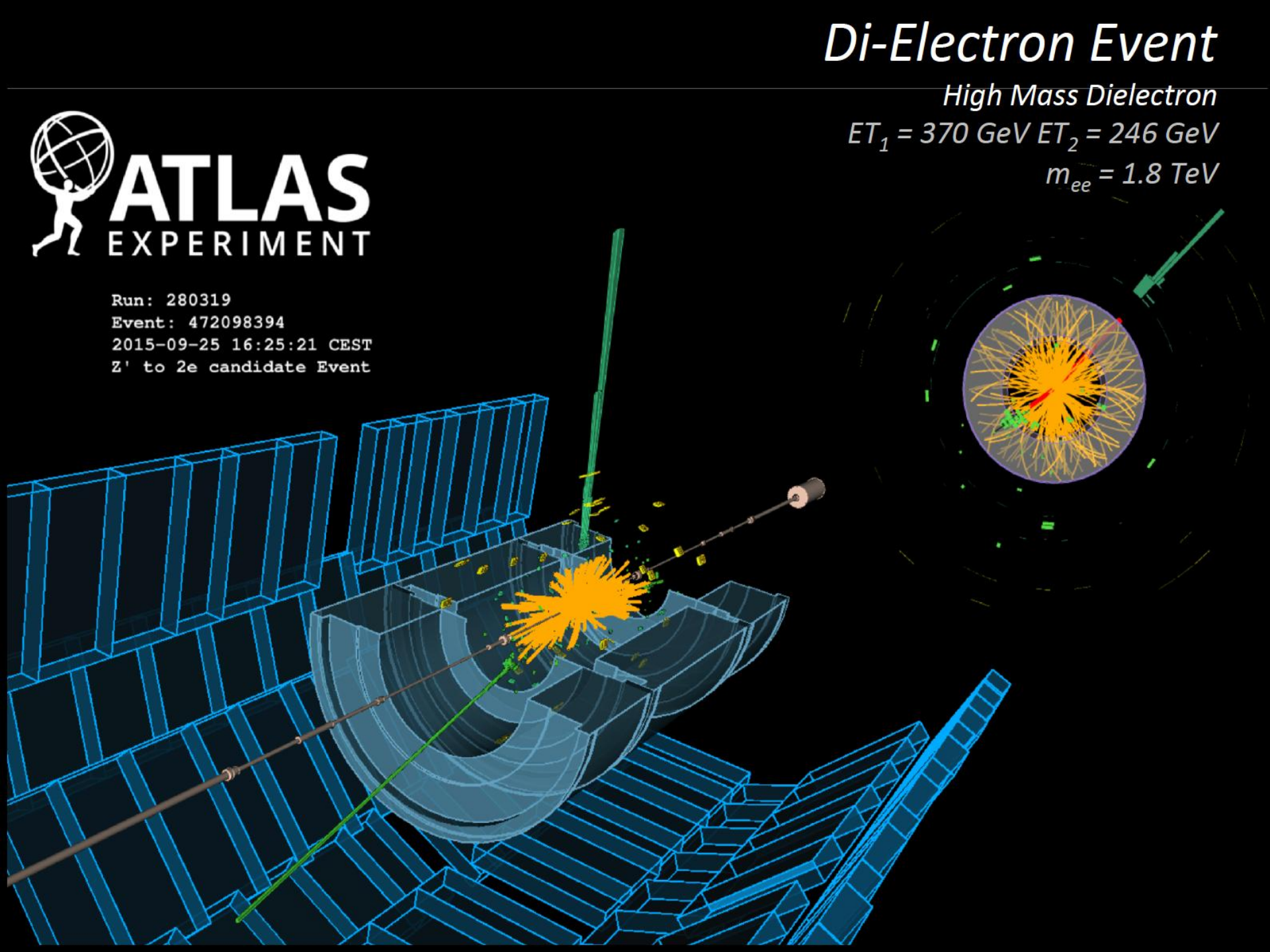
P. Athron,[1,*] D. Harries,[2,†] and A. G. Williams[2,‡]

[1] *ARC Centre of Excellence for Particle Physics at the Terascale, School of Physics, Monash University, Melbourne VIC 3800, Australia*

[2] *ARC Centre of Excellence for Particle Physics at the Terascale, Department of Physics, The University of Adelaide, Adelaide, South Australia 5005, Australia*

(Dated: June 24, 2015)

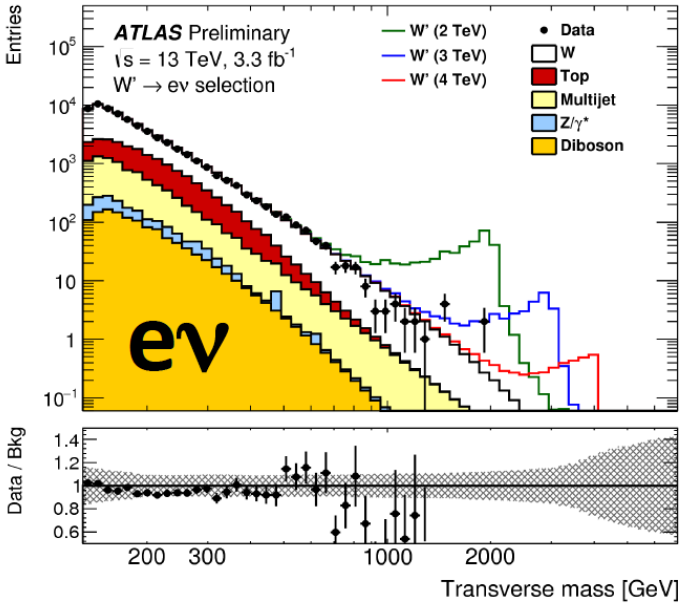
Di-Electron Event

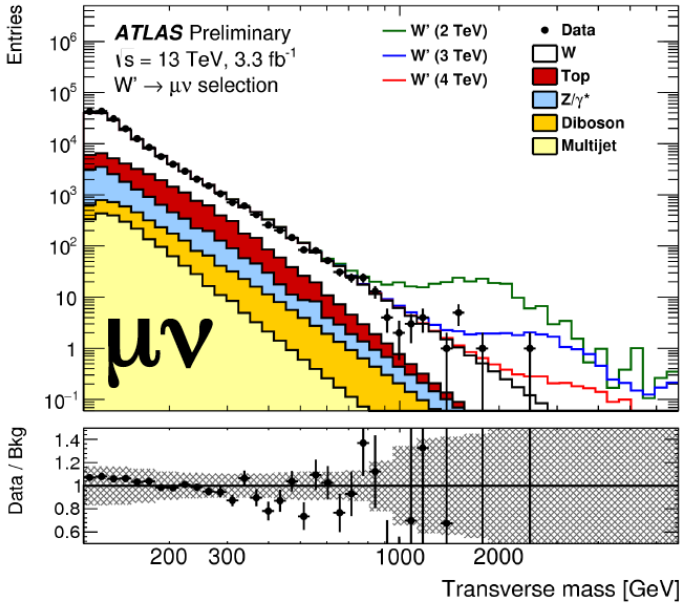


Search for Resonant Lepton+MET

ATLAS-CONF-2015-063

- Search for W' in lepton-MET final states
- Background from MC except for Multijet estimated with matrix method
- Top and diboson extrapolated at very high masses using a functional form





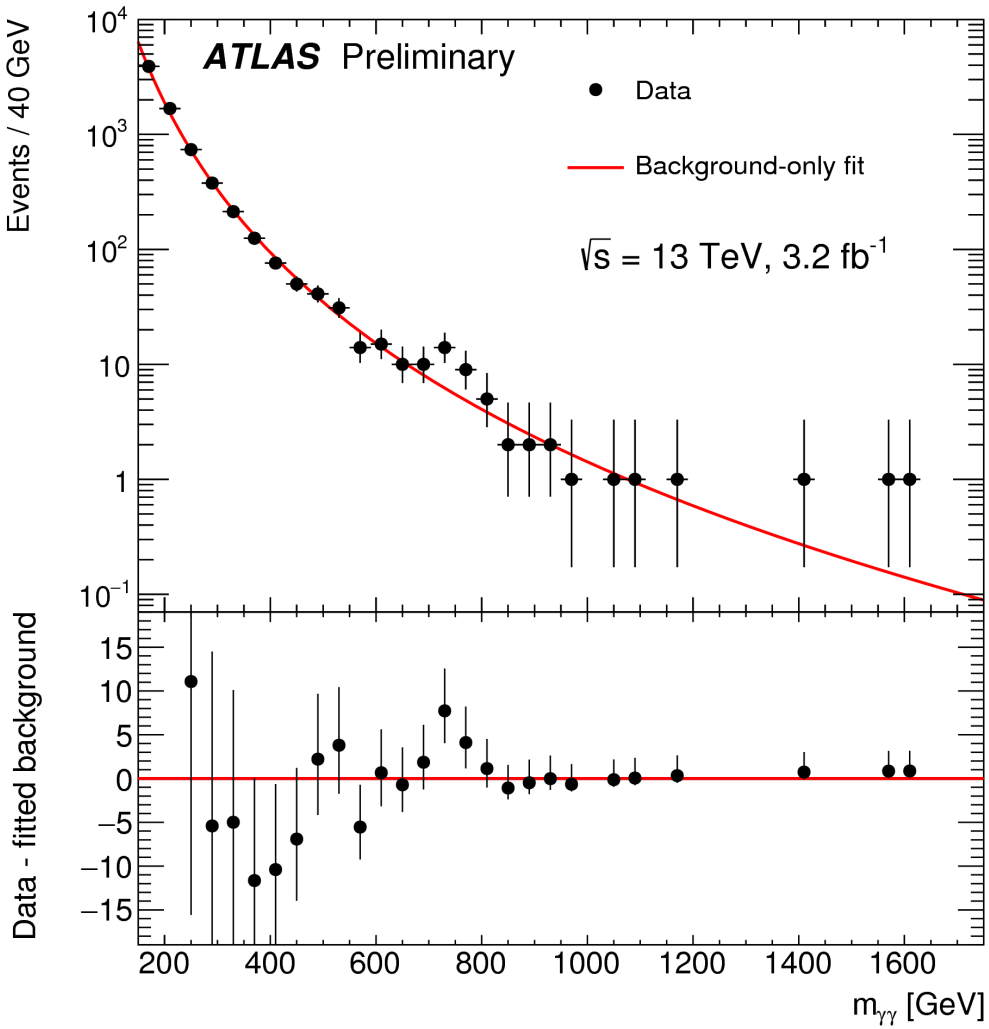
Highest electron-MET mass event at 1.95 TeV

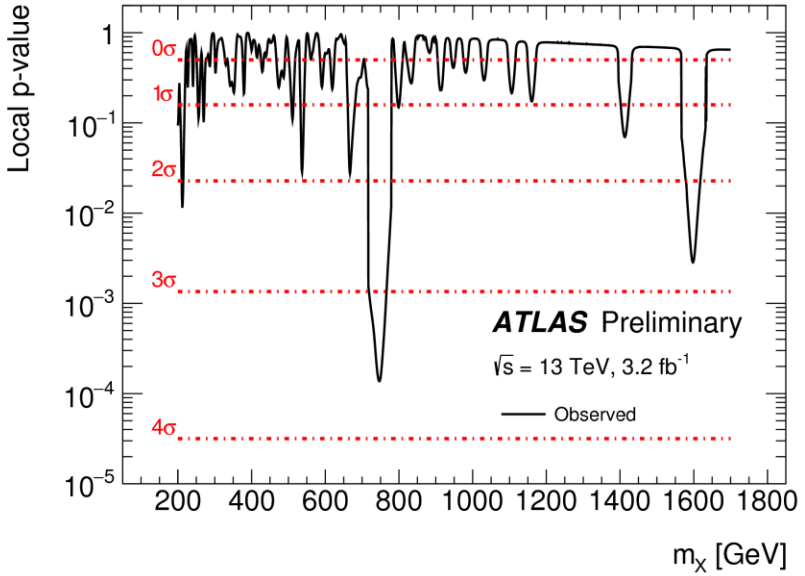
Highest muon-MET mass event at 2.2 TeV

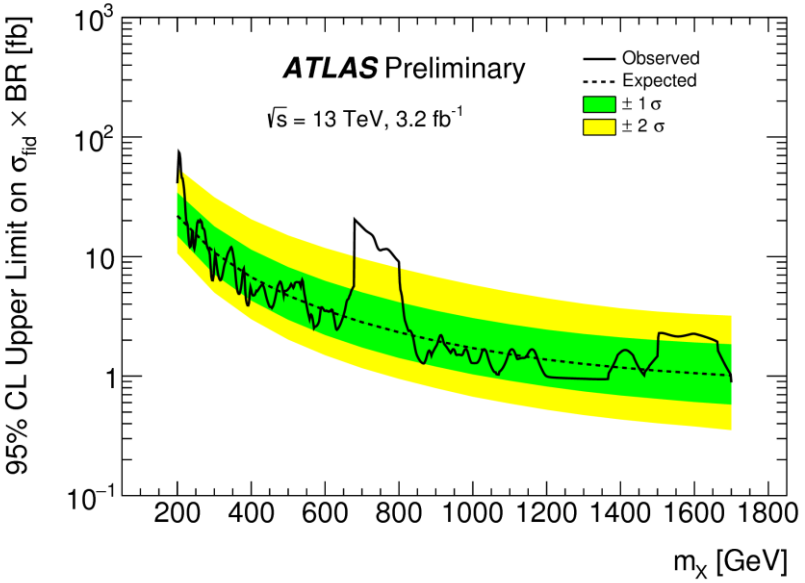
No Excess found !

95%CL Limit on SSM W' at 4.1 TeV (3.2 TeV at Run-1)

“Things that go bump in the light”

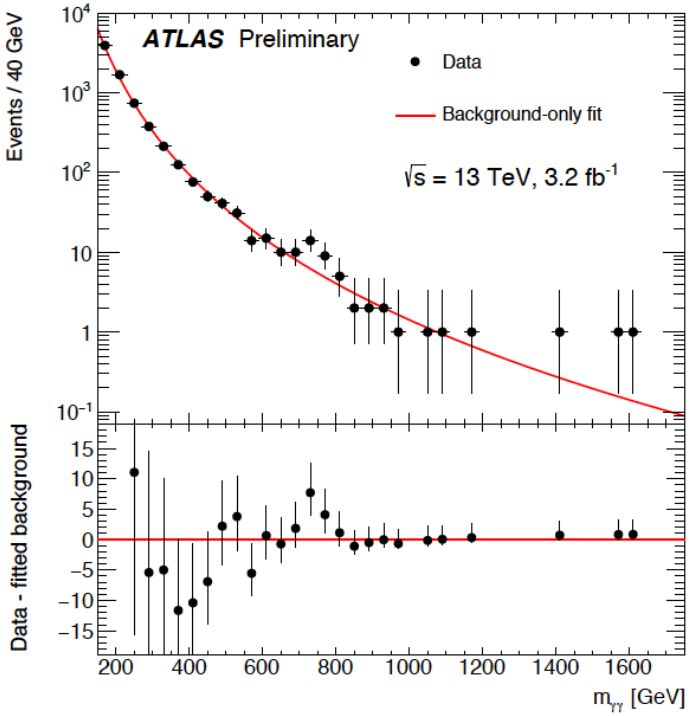






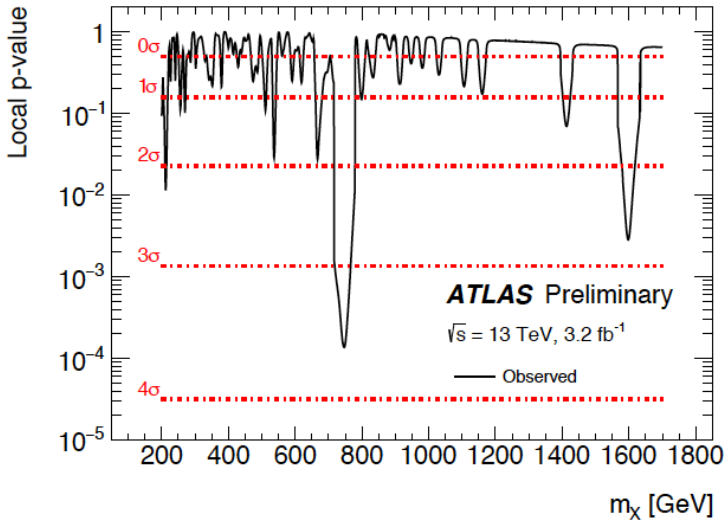
“Things that go bump in the light”

Results: Events with mass in excess of 200 GeV are included in **unbinned fit**



- **In the NWA search**, an excess of **3.6σ** (local) is observed at a mass hypothesis of minimal p_0 of 750 GeV

- Taking a LEE in a mass range (fixed before unblinding) **of 200 GeV to 2.0 TeV** the global significance of the excess is **2.0σ**



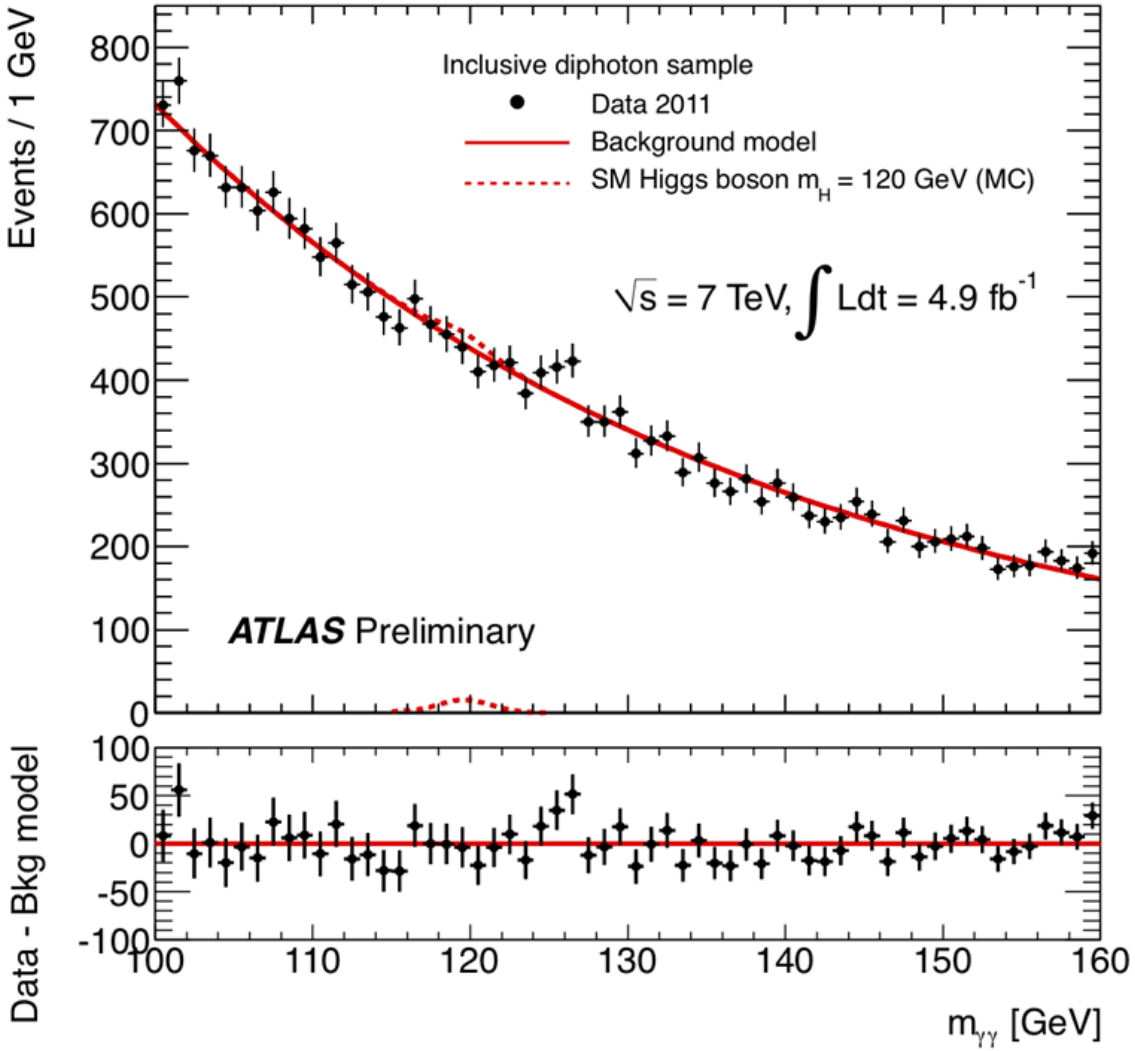
In the NWA fit the resolution uncertainty is profiled in the NWA fit and is pulled by 1.5σ

The data was then fit under a **LW hypothesis** yielding a width of approximately 45 GeV
(Approx. 6% of the best fit mass of approximately 750 GeV)

- As expected the local significance increases to **3.9σ**

- Taking into account a LEE in mass and width of up to **10%** of the mass hypothesis of **2.3σ** (Note: upper range in resolution fixed after unblinding)

“Things that go bump in the light”



A little history lesson:
This is what the H->γγ “signal” looked like back in 2011.

It looks eerily similar to this bump at 750GeV today

The beauty of a resonance signal is that simply by integrating more data we can answer the question

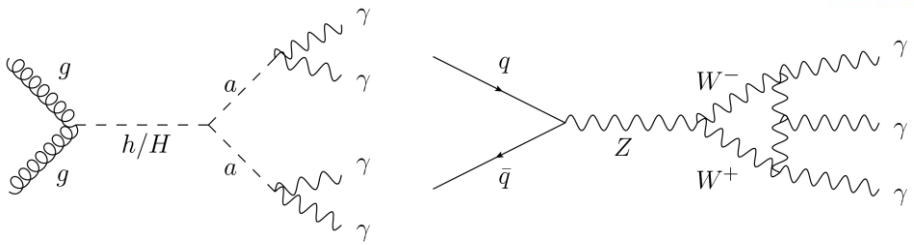
Other "Higgs" results….

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Eur. Phys. J. C.

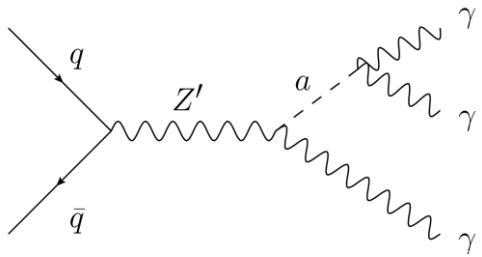
CERN-PH-EP-2015-187
18th September 2015

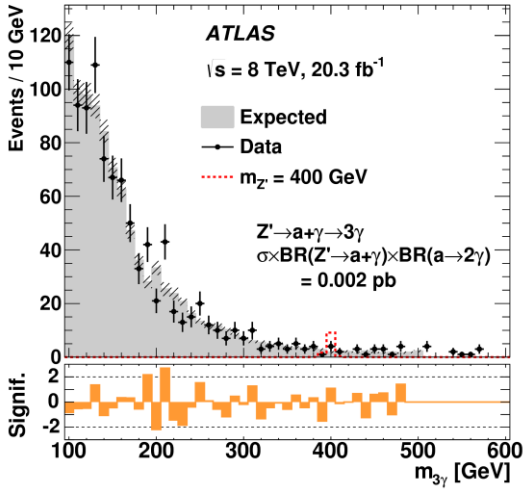
Consider several channels

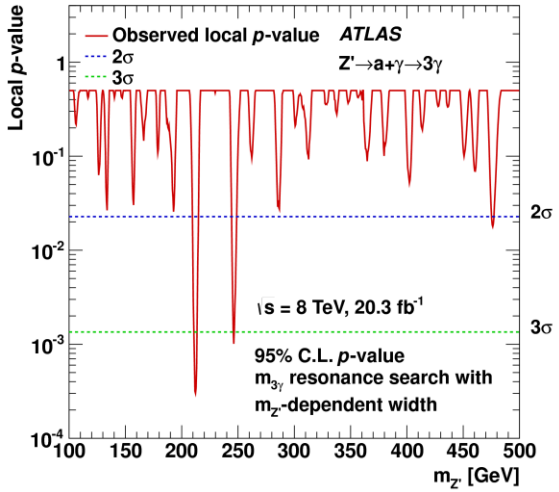


http://arxiv.org/abs/1509.05051

Search for new phenomena in events with at least three photons collected in *pp* collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector







If you do enough searches you should see 3σ excesses….

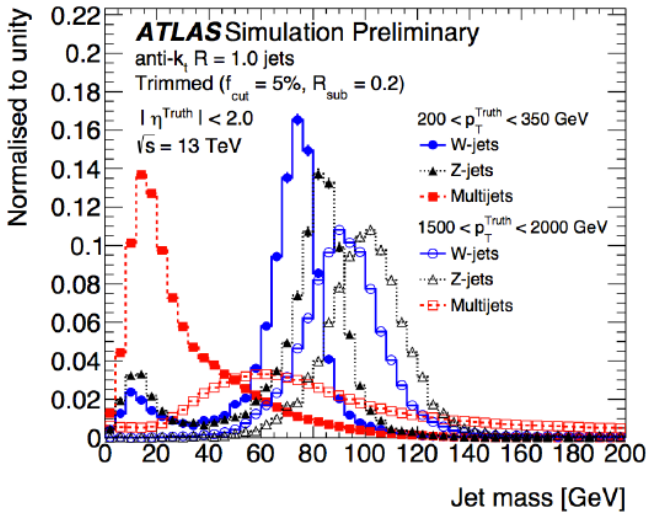
Searches for VV or VH resonances in several topologies involving boson (W, Z and H) tagging

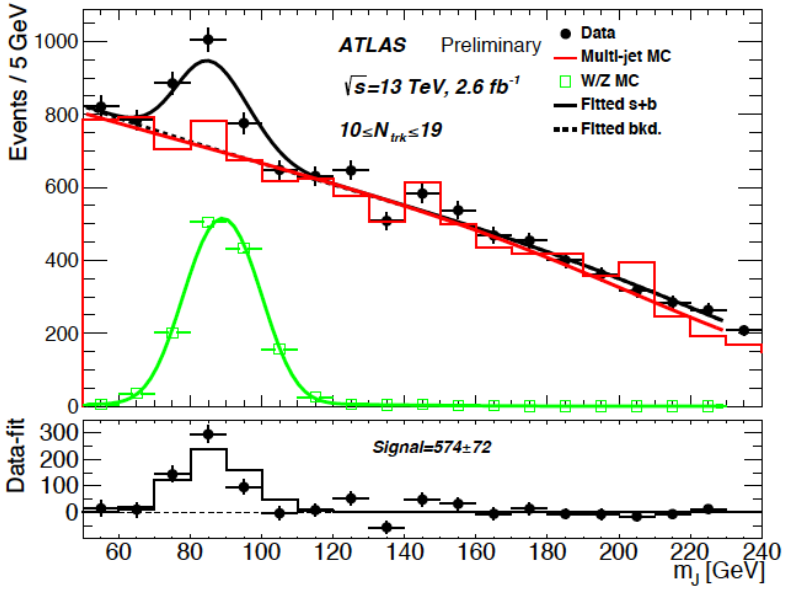
Nominal boson tagging algorithm

- 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

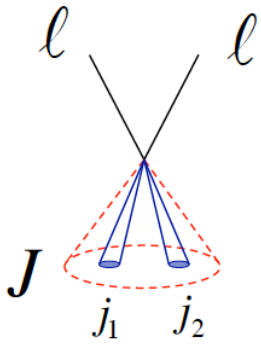
W and Z peak in the data from dijet events applying the nominal boson tagging algorithm





Searches for Resonance in Di-Boson VV Final States

ZV (with Z to **dilepton**)

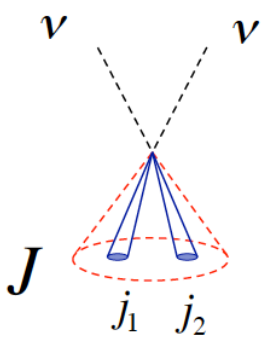


Backgrounds

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

Diboson and top from MC

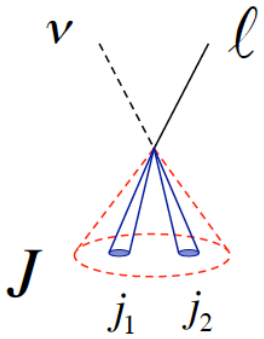
ZV (with Z to **νν**)



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.

WV (with W to **lν**)



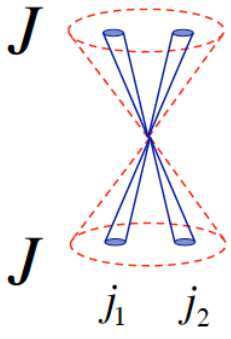
Backgrounds

Z, W and top shapes from MC

Diboson fully from MC

Multijet shape from loose lepton ID

VV to **JJ**

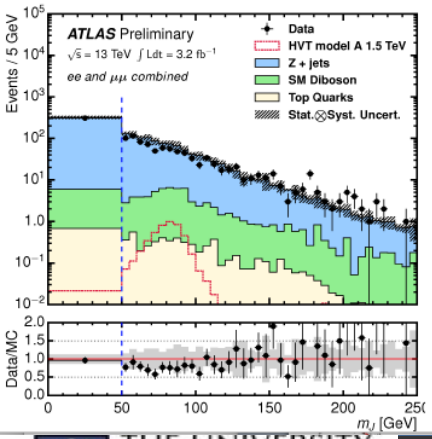


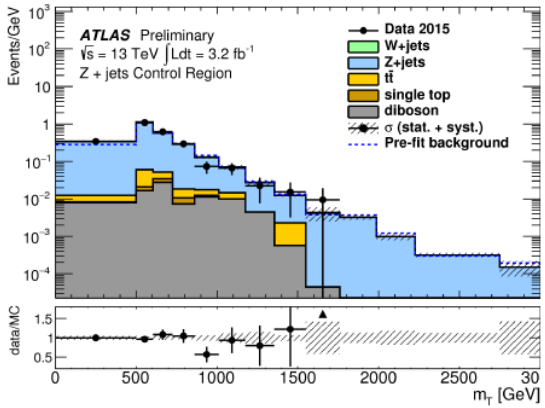
Modest excess Run-1

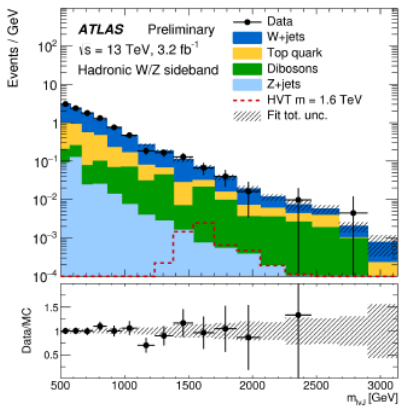
observed at Run 1 to be checked

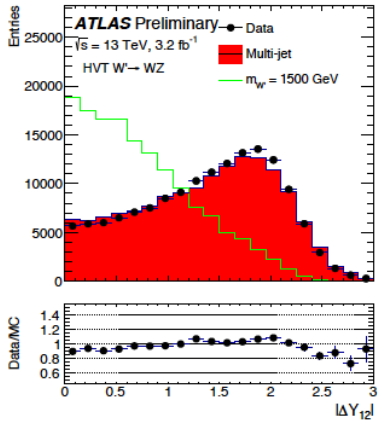
Background

Estimated using a functional form



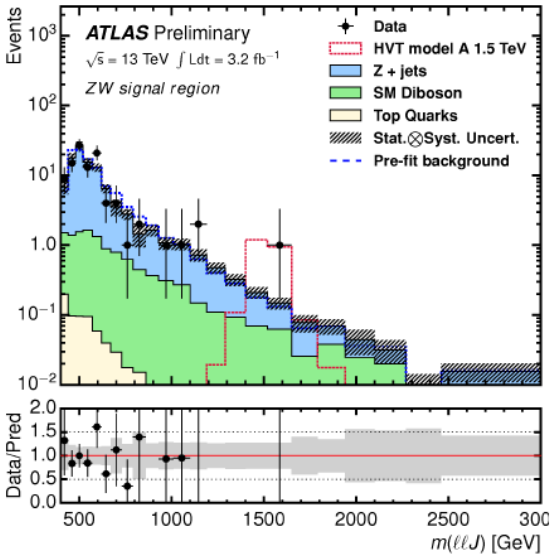




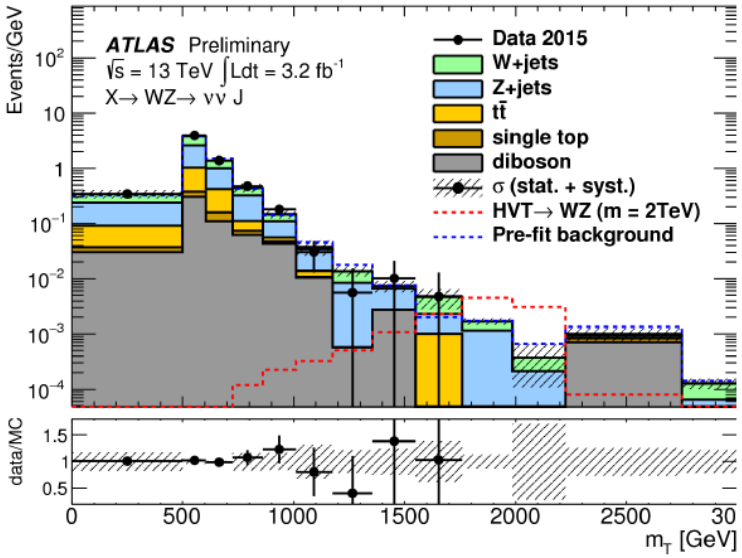


Searches for Resonance in Di-Boson VV Final States

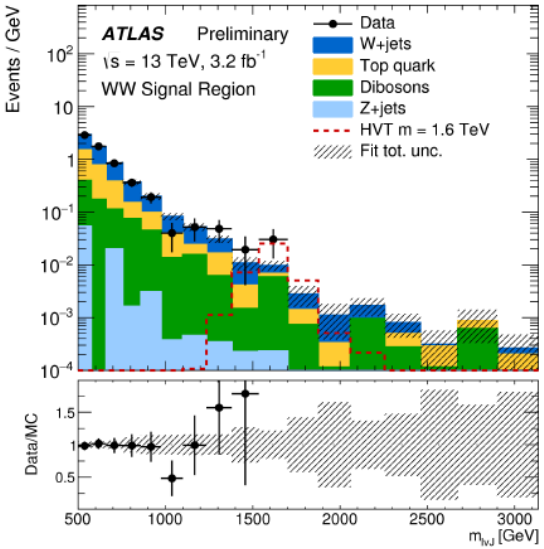
ZV (with Z to **dilepton**)



ZV (with Z to **νν**)



WV (with W to **lν**)

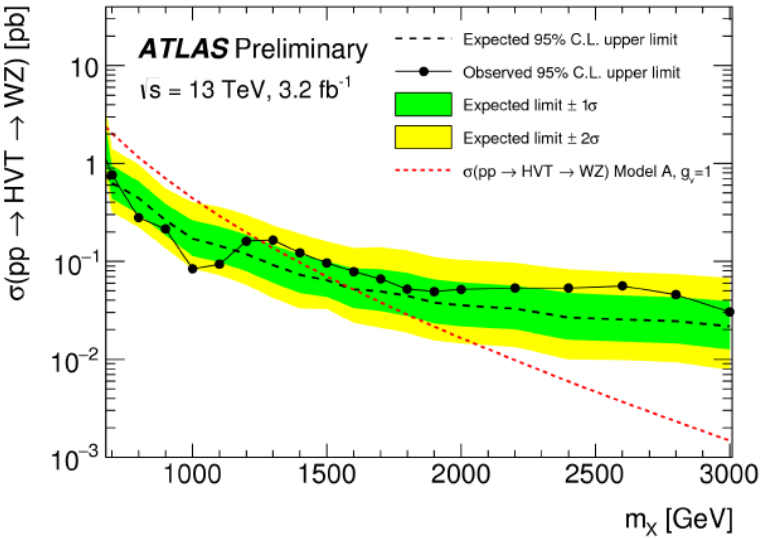


Results

All analyses have similar sensitivities ranging between **1.4 TeV** and **1.6 TeV** for HVT additional vector bosons

- No significant excess observed, limits are set in these scenarios

- Interpretations also in Higgs and Graviton hypotheses



Searches in Di-Boson Fully hadronic final state

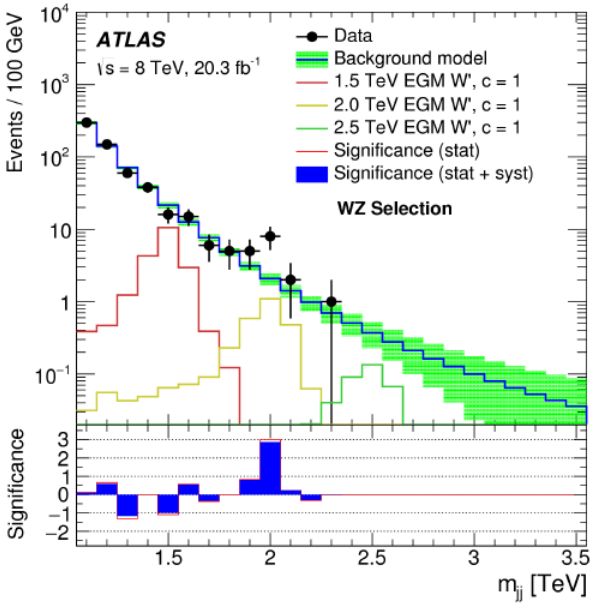
ATLAS-CONF-2015-073

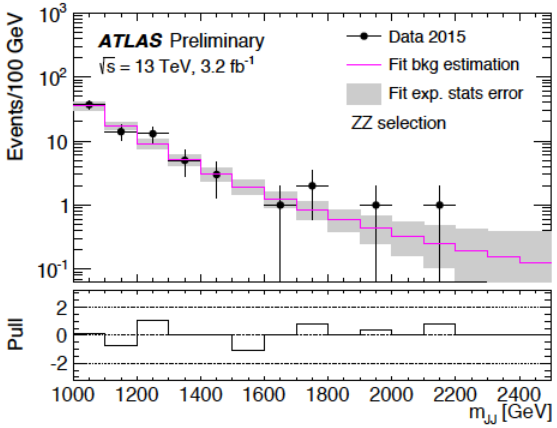
A lot of excitement about this during 2015

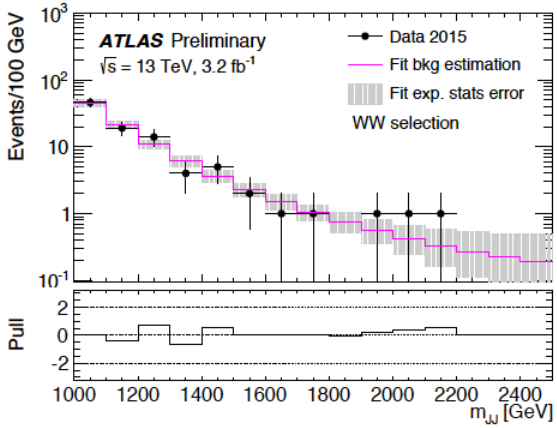
- **Modest excess at Run-1**: **3.4σ** local / **2.5σ global**
- **Analysis very similar to Run 1**, with functional fit of the background

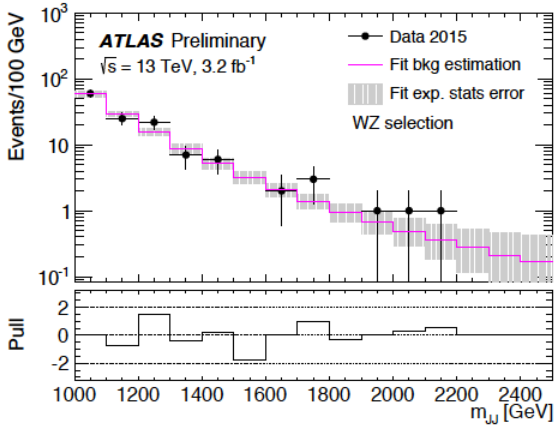
- **No significant excess is observed**
  however sensitivity not high enough for conclusive probe of the Run 1 excess

Run-1







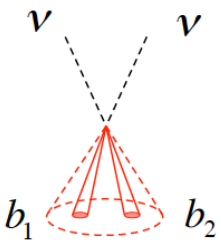


Searches in Di-Boson in VH final states

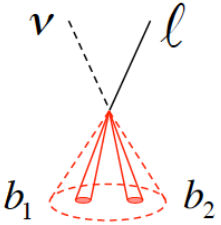
ATLAS-CONF-2015-074

Analysis Strategy: 6 regions 0L, 1L-MET and 2L-MET with at least two jets and 1 or 2 b-tags (2 b-tags harder to distinguish at high pT)

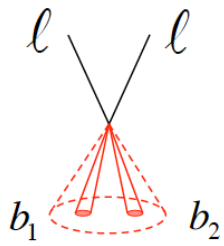
Analysis Strategy: Global fit of 6 regions simultaneously (similar to SM VH analysis at Run-1)



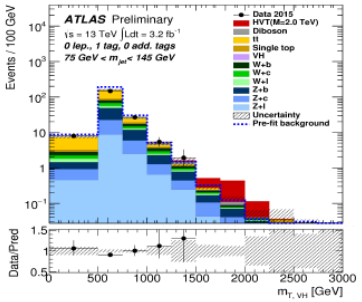
ZH (with **Z to vv**)

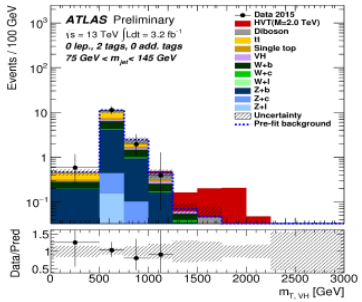


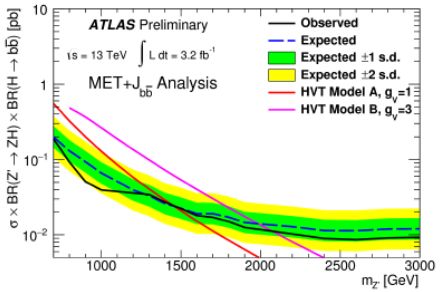
WH (with **W to lv**)

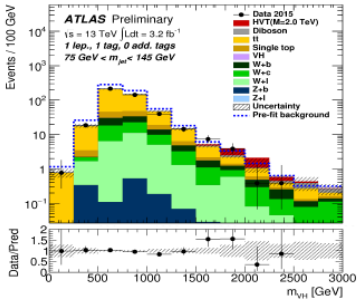


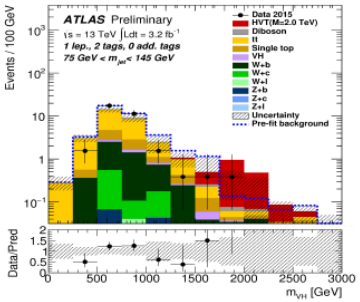
ZH (with **Z to dilepton**)

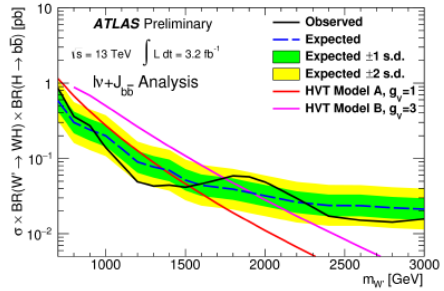


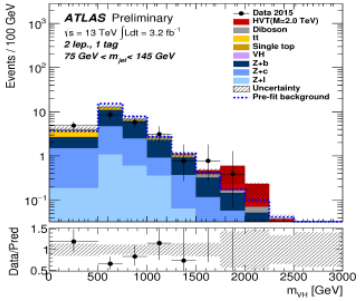


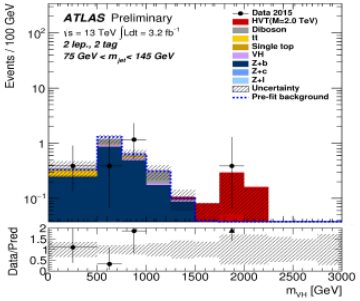


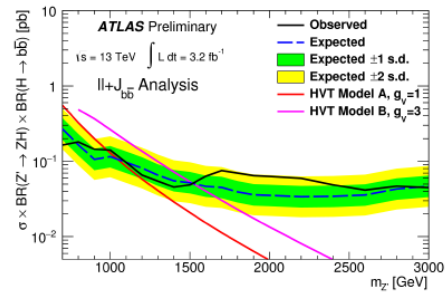












THE UNIVERSITY of ADELAIDE

CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

WHAT DOES IT ALL MEAN?

Anomalies/Hints/Excesses – We do have a few ☺

- X(750)->γγ (Run2….not seen in Run1)
  - not seen in Run1? Why?
  - why no di-jet bump at 750GeV?

- X(2000) -> WW/WZ/ZZ (Run1…not yet in Run2)
  - don't see this in other diboson channels….yet? That's weird!

- Z(ll)+jets+MET: Run1 and Run2 excess
  - hints from ATLAS and CMS
  - Not as trivial as a resonance to pin down
  - Z+jets background? Jet flavour composition?
  - Why no excess in jets+MET analyses?
  - Excess on Z peak or in 'edge' analysis

* In all of these channels CMS sees some hints of excess too! (although not entirely clear at the moment)

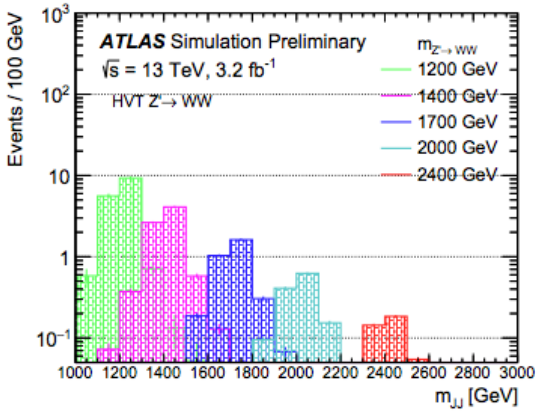
Summary

- There *ARE* anomalies in the LHC data (and beyond) that cannot be reconciled with the Standard Model alone – but no clear discovery *yet.*
- Some of these are well motivated (additional heavy resonances) but one would expect them to decay in multiple channels, as the Higgs does.
- Remember that the LHC design energy was/is 14TeV!
- So we are just getting started!! We'll be taking data for the next 10-20 years (depending on other machines)
- The beauty of a search is that there can be discovery at any time.

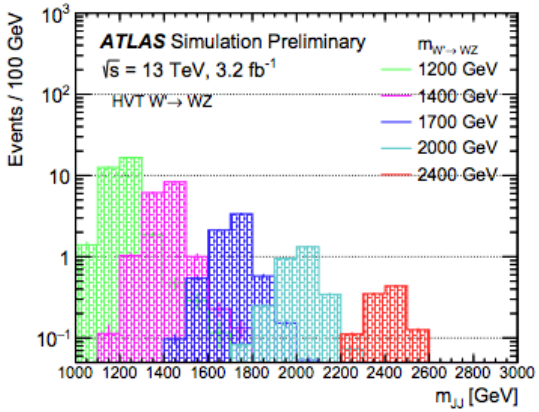
Thanks! Some backup slides may follow

p.jackson@adelaide.edu.au

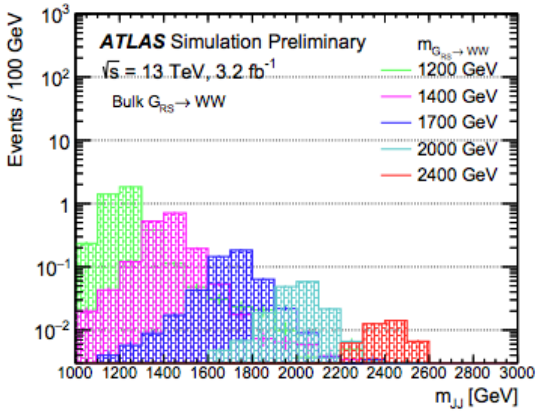
Searches in Di-Boson Fully hadronic final state



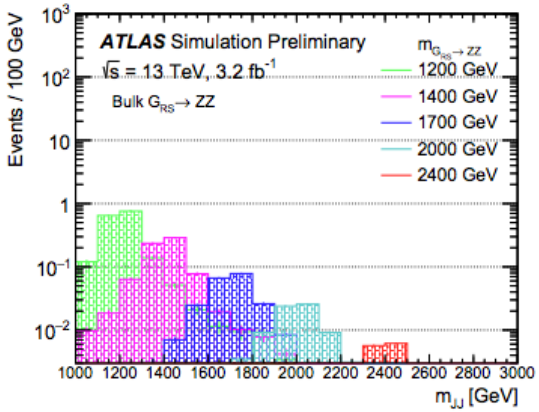
(a)



(b)



(c)



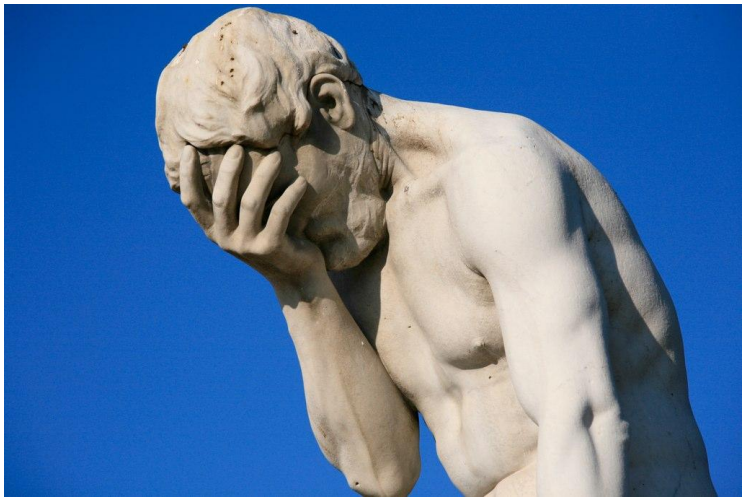
(d)

Figure 4: Distribution of the reconstructed dijet invariant-mass for benchmark signals. The signals yields are normalized to an integrated luminosity of 3.2 fb^{-1}. Five signal distributions are shown in each figure, with resonance masses between 1.2 TeV and 2.4 TeV. The models shown are the HVT in (a) the WW and (b) the WZ channels, and the RS graviton through (c) the WW and (d) the ZZ analyses.

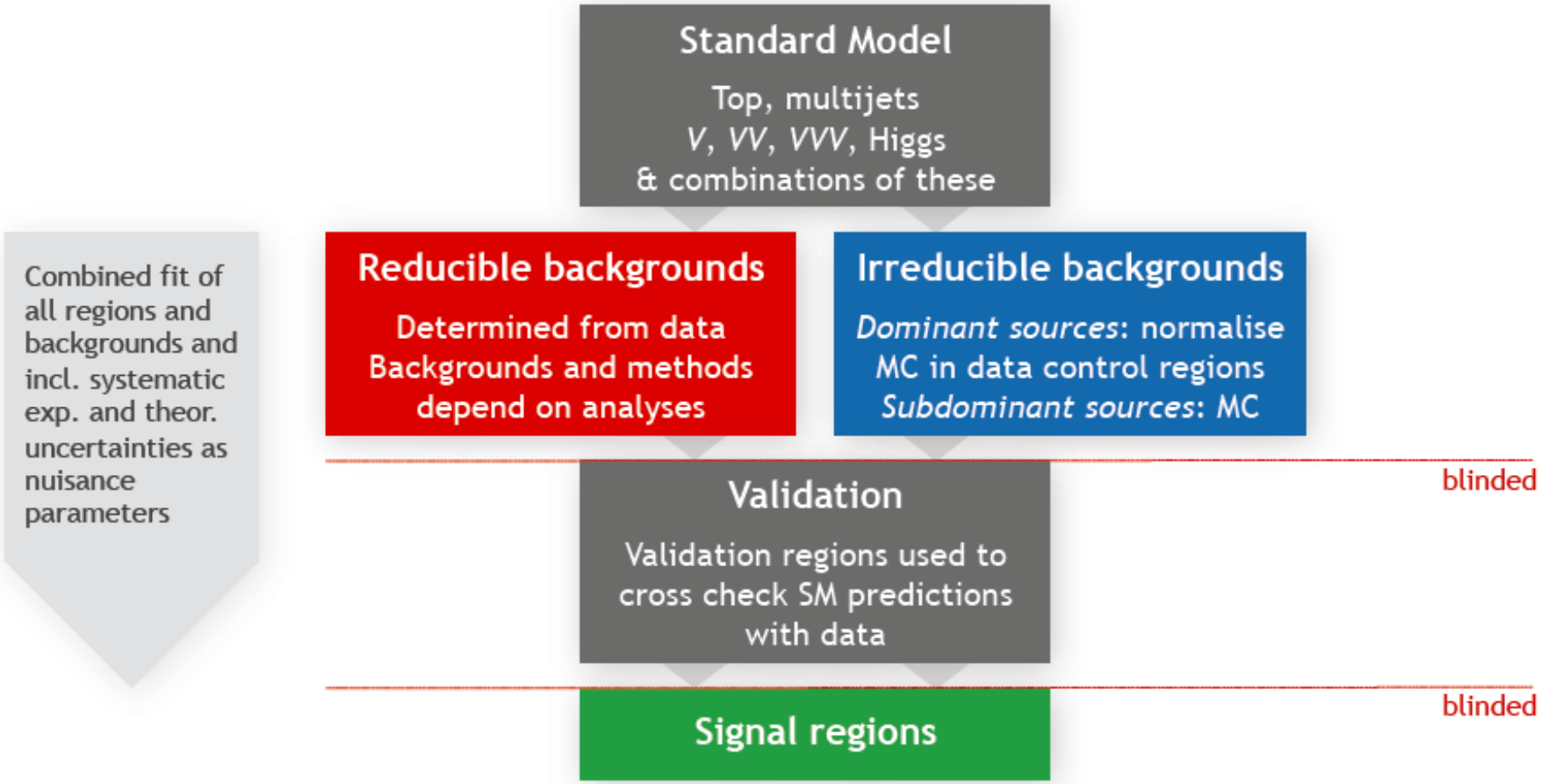
SEARCHES

Objects	Multiplicity	Resonance	Analysis Techniques
jets	0-10	Yes and no	α_T, H_T, M_{eff}, M_{T2},Razor,RJR
b-jets	0-4		
electrons	0-4		
muons	0-4		
taus	0-3		
photons	0-3		
W	0-3		
Z	0-3		
MET	Yes/no		
Boosted Jets	Yes/no		
Boosted Bosons	Yes/no		
Higgs	Yes/no (maybe?)		
charm-tagged jets	0-2		
Top-tagged jets	0-2		

- Essentially you can search for any number and combination of any of these objects
- There are always multiple variables and ways to do the same analysis
- Some of these aren't really a search though but as we'll see one persons measurement can be another persons search
- Not even mentioned displaced vertices, long-lived, multi-charged, monopoles etc etc



SUSY searches rely primarily on the understanding of the SM backgrounds



Main Improvements for the Run-2

Important changes in all areas of the experiment

Detector

- 4th innermost layer of pixels (3.3 cm, 2nd layer at 5.05 cm)
- Consolidation: Complete muon coverage, Luminosity detectors, Repairs (LAr and Tile), Beam Condition. Monitors

Infrastructure

New Beam Pipe, Magnets and Cryogenic system, Muon Chamber shielding, New pixel services

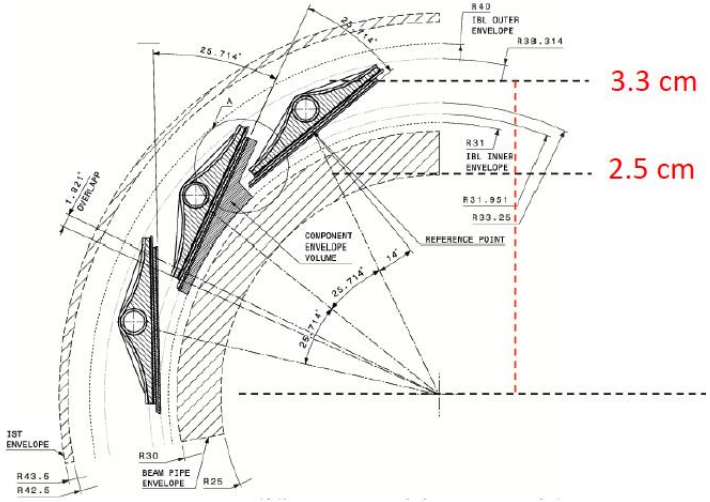
Trigger/DAQ

- Increase max L1 rate from 75kHz to 100kHz
- New Central Trigger Processor
- Merge L2 and HLT farms, Additional SFOs allowing for higher output rate (limited by storage capacity to **1.1-1.5 kHz**)

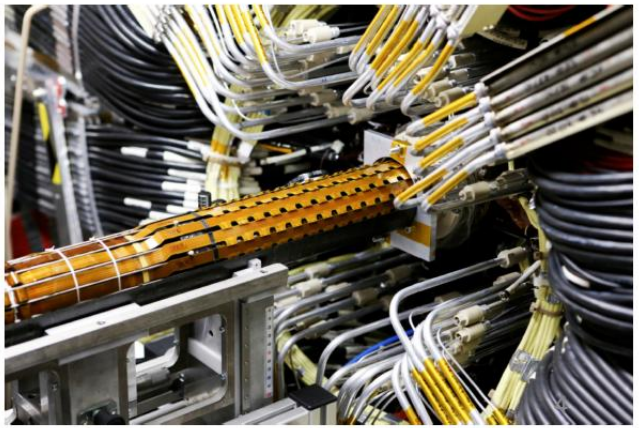
Software and Computing

Improved reconstruction software, New analysis framework with new data format

For a complete ATLAS Status: see A. Polini talk at LHCC Open Session (Dec 2, 2015) http://indico.cern.ch/event/460278



IBL TDR: http://cds.cern.ch/record/1291633



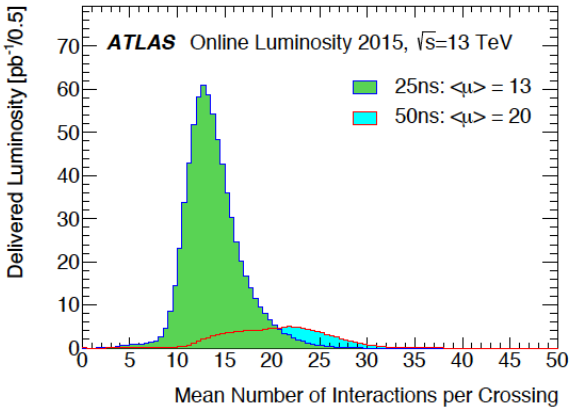
2015 Brief Year in Review

13 TeV pp 2015 Dataset

- **50 ns data**: 100 pb-1 good for physics *(mu ~ 20)*
- **25 ns data**: 4 fb-1 recorded *(mu ~ 13)*
- **Highest instantaneous Luminosity**

  reached 5.1 10^{33} cm^2s^{-1} *(Run 1: 7-8 10^{33} cm^2s^{-1})*

- **Special runs**:
  - 90m elastic run with 10 μb-1 collected
  - 170 μb-1 of "low mu" data (special runs with LHCf)
- **Heavy Ion** running with 680 μb^{-1} collected and corresponding pp reference at 5 TeV with 27 pb^{-1} (mu~1.5)

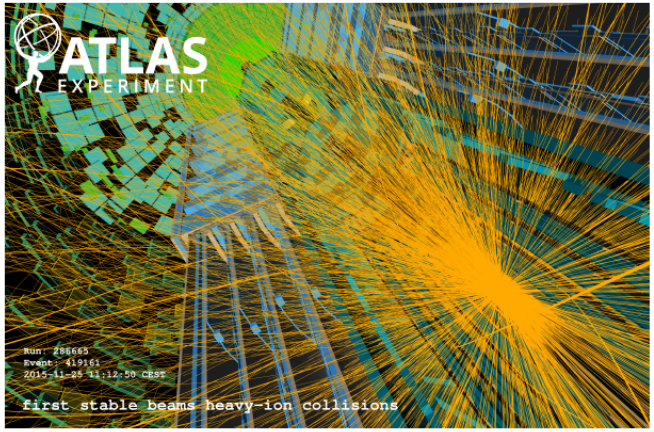


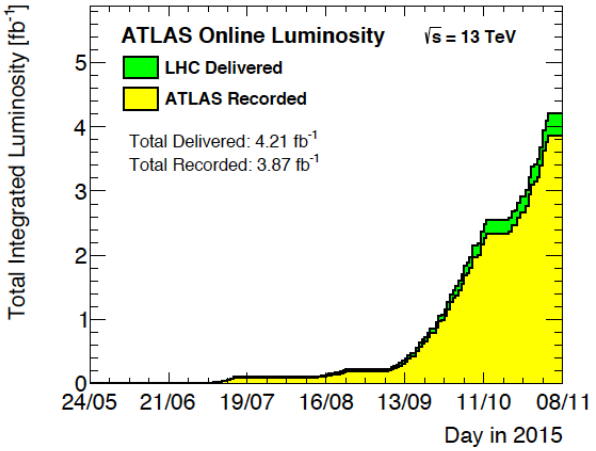
***Run 1**: 8 TeV (mu~21) and 7 TeV (mu~9)*

***ATLAS**: Pileup at Run-2 less difficult than at Run-1*

PbPb Collision at **1.1 PeV**

Events with charged track multiplicities of up to 10k tracks





Data taking efficiency of 92%

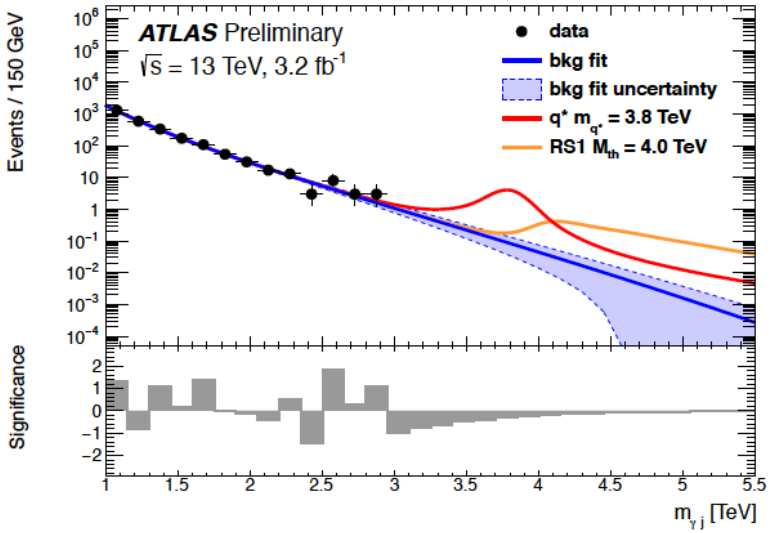
Search for new phenomena in Photon-Jet events

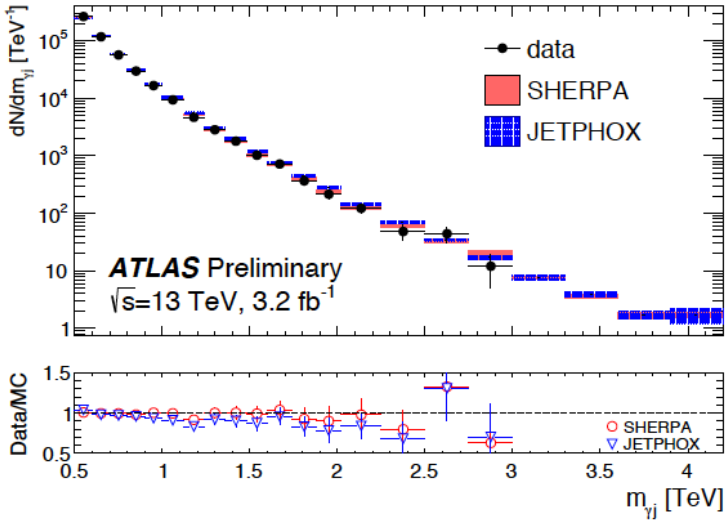
Search for q* or **QBH** decaying to a photon and a parton

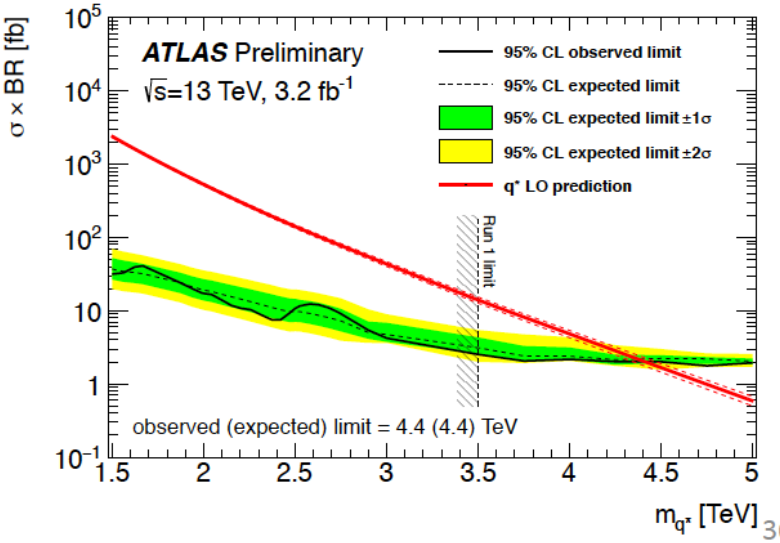
- **Background** estimated using a simple fit function similar to dijet search and extrapolate in the high mass domain

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

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







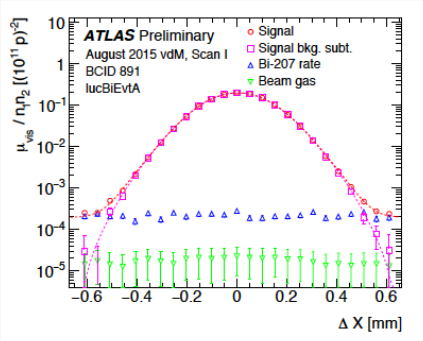
Data Quality Efficiencies, Luminosity and Trigger

Data Quality efficiency

- Average 93% (Run 1 Average 94%)
- Requiring IBL as well 87%

Luminosity Measurement

- Preliminary uncertainty from complete scan (Valid for entire 2015 dataset) **5%**



"All Good" dataset :

$3.2 \pm 0.2 \ fb^{-1}$

With IBL Off runs

$3.5 \pm 0.2 \ fb^{-1}$

Trigger

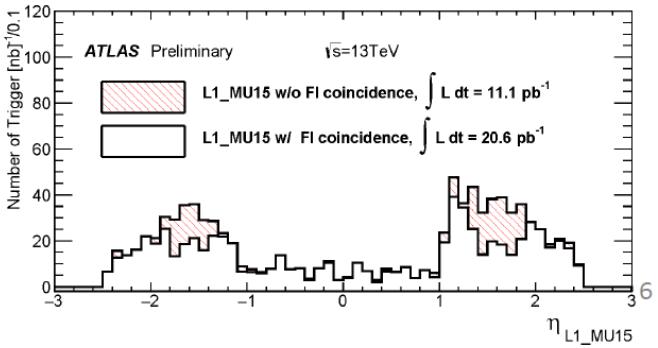
- **Run-2 Menu**: Approximately 1500 HLT selections seeded by about 400 L1 items
  - Primary triggers, typically unprescaled;
  - Numerous other triggers for Support, Background, Alternative algorithms, Backup and Calibration
- **Continued excellent performance** and stability of trigger throughout the run
- Rates for typical lowest unprescaled single object triggers:

Trigger	p_T Threshold (GeV)		Rate (Hz) *	
	Run 1	Run 2	Run 1	Run 2
Inclusive e	24	24	70	97
Inclusive μ	24	20	45	130
E_T^{mis}	80	70	18	55

Improvements at Run-2

L1 Calo Per bunch baseline subtraction large reduction in MET trigger rates

L1 Muon triggering Use of FI coincidences **50%** **Rate reduction** (in $1.0 < \eta < 1.9$ at p_T 20 GeV)



Inclusive search for two photon resonance
(optimized for a scalar resonance)

- Selection of two photons with pT/m thresholds of 0.3 and 0.4 and pT dependent calorimeter and track isolation criteria
- Typical prompt photon purity 90%

Background from a functional

Similar to the dijet search but chosen using the Fisher F-test and the spurious signal method measured in events from Sherpa, Diphox and Jetphox:

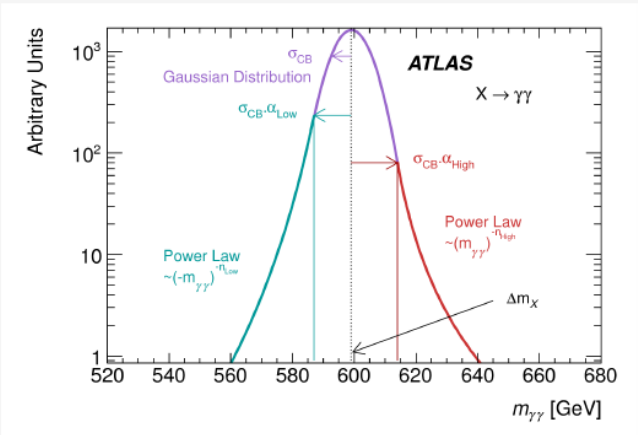
$$f_{bkg}(x;b,\{a_k\}) = (1-x^{1/3})^b \, x^{\sum_{j=0}^{k} a_j \log(x)^j}$$

$$x \equiv \frac{m_{\gamma\gamma}}{\sqrt{s}}$$

Here a simple form with k=0 is used

Signal Model

- **NWA**: Use Double Sided Crystal Ball function
- **LW**: Use DSCB fitted from simulated samples with different widths with up to 25% of the resonance mass



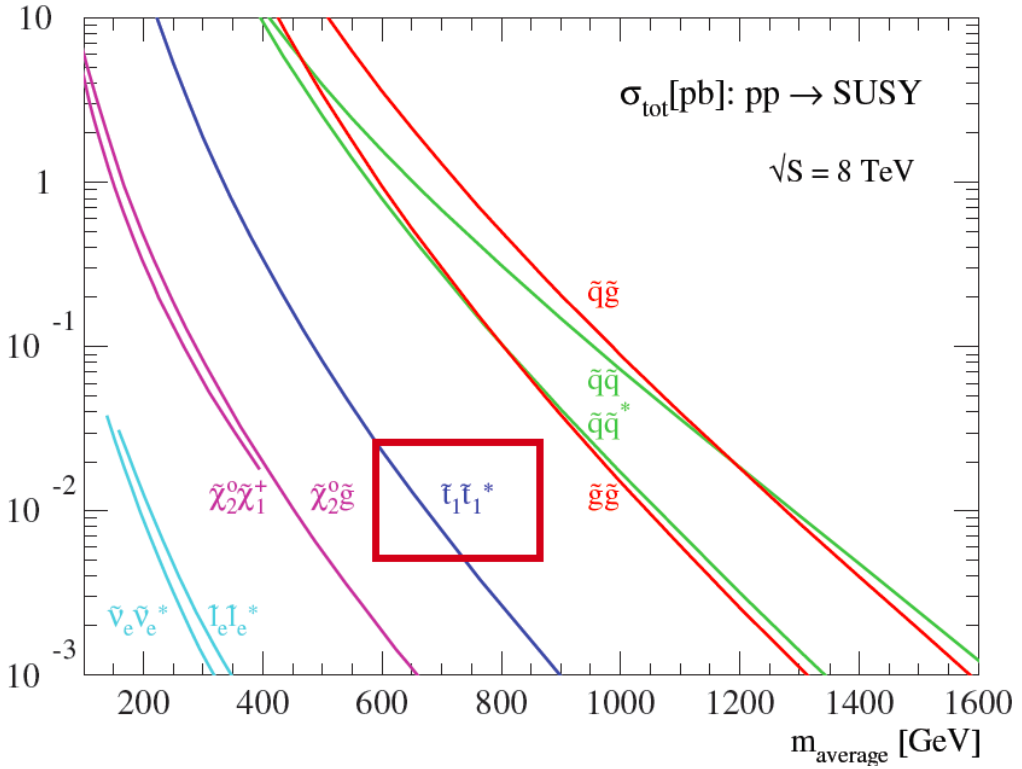
SUSY ~duplicates spectrum of particle states wrt. Standard Model

Sparticle decays produce SM objects: (b/c-)jets, leptons, τ, γ, invisible (MET), …

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

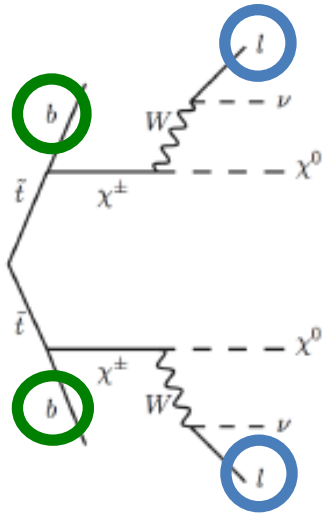
But, direct production cross section is relatively small compared to light squark and gluino

Dedicated searches required



Early focus of Run2 is on strong production with squarks/ gluinos

2lepton (+jets) +E_T^{miss} analyses



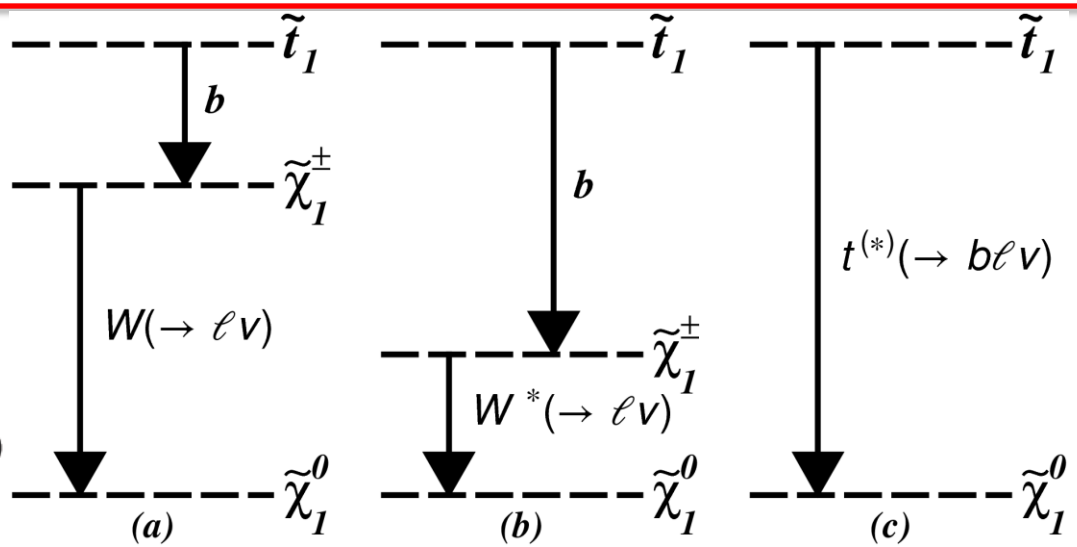
- For pair-produced particles with identical decay chains the variable

$$m_{T2}^2(p_T^{\alpha}, p_T^{\beta}, p_T^{miss}) = \min_{\mathbf{q}_T^{(1)}+\mathbf{q}_T^{(2)}=p_T^{miss}} \left[\max\left(M_T^2(\mathbf{p}_T^{\alpha}, \mathbf{q}_T^{(1)}; m_{\alpha}, m_{\chi}), M_T^2(\mathbf{p}_T^{\beta}, \mathbf{q}_T^{(2)}; m_{\beta}, m_{\chi})\right)\right]$$

is bounded from above by the parent mass.

$m_{T2}(l_1, l_2, E_T^{Miss})$ bounded by W mass for WW, Wt, $t\bar{t}$

$m_{T2}(b_1, b_2, l_1 + l_2 + E_T^{Miss})$ bounded by top mass for $t\bar{t}$



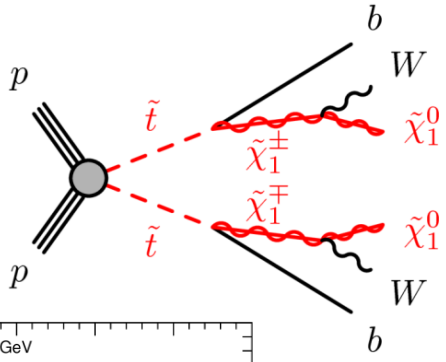
- Asks for large $m_{T2}(l_1, l_2, E_T^{Miss})$
- Four signal regions, one without jets: sensitive also to small $m(\tilde{t}) - m(\tilde{\chi}_1^{\pm})$
- Asks for 2 b-jets and large $m_{T2}(b_1, b_2, l_1 + l_2 + E_T^{Miss})$

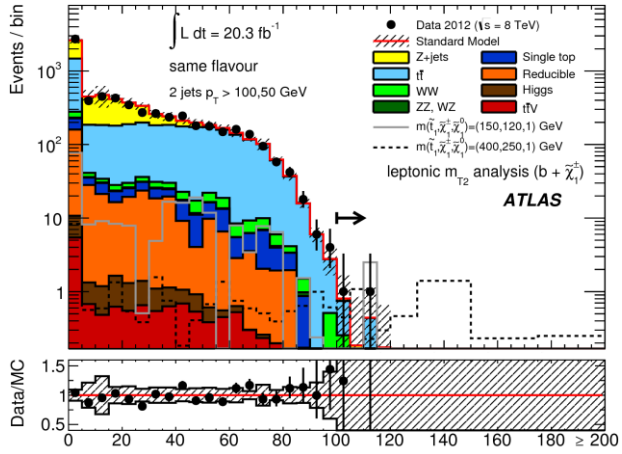
2lepton + (b) jets + E_T^{miss} analyses

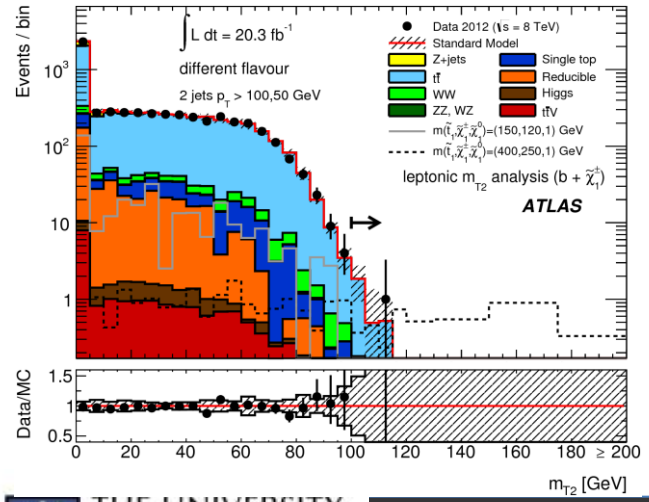
2 leptons (+jets) + MET

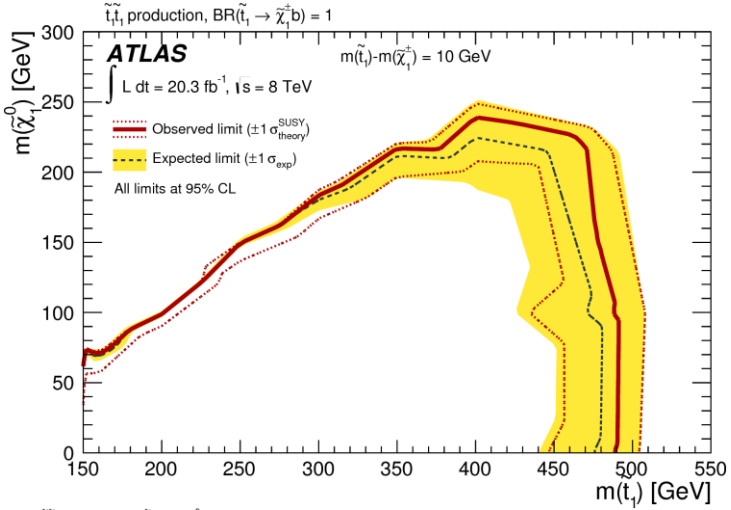
Analysis mainly targets $\tilde{t}_1 \rightarrow b\tilde{\chi}^{\pm}$

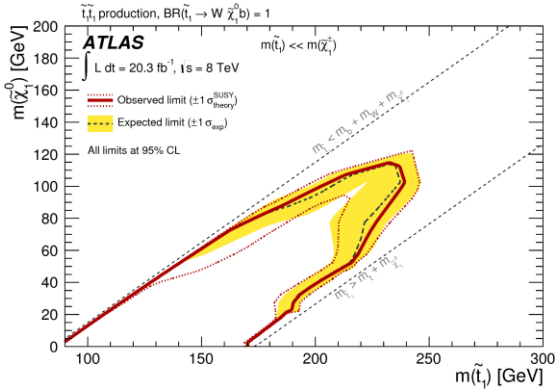
Complements bb + E_T^{miss} analysis for large $\Delta m(\tilde{\chi}^{\pm}, \tilde{\chi}^{0})$

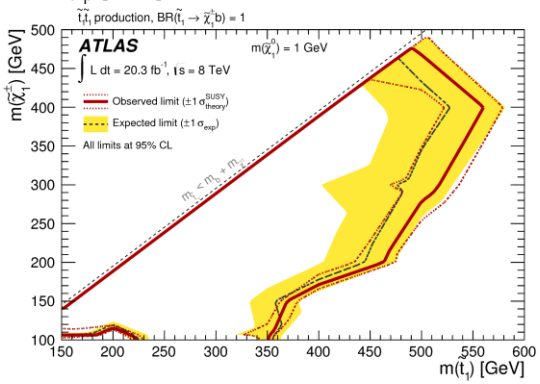












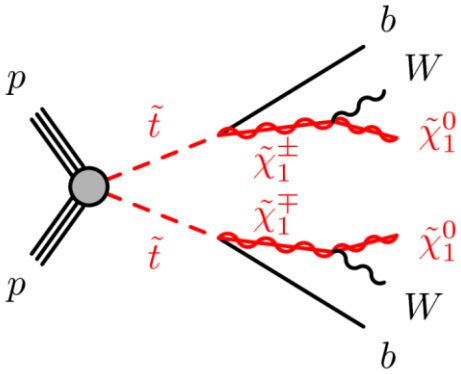
Limits placed in various kinematic scenarios

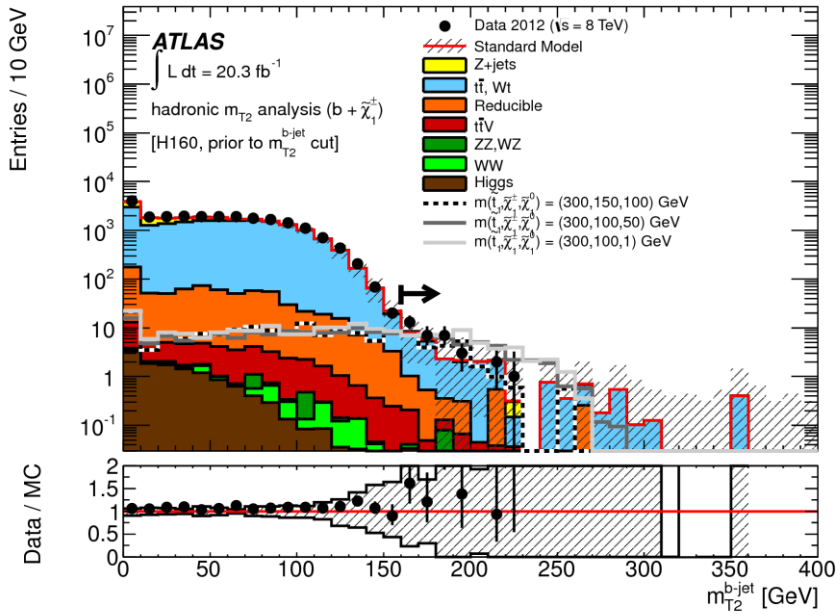
2lepton + (b) jets + E_T^{miss} analyses

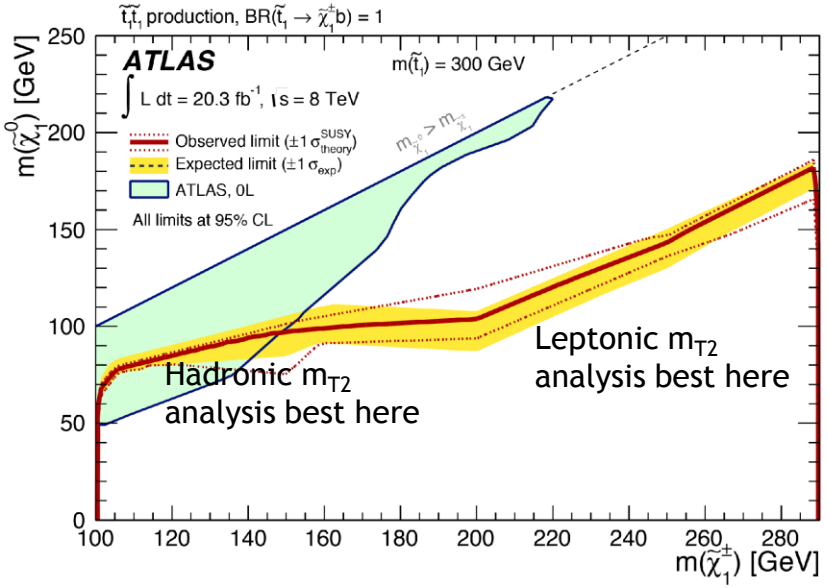
Selections:

- 2leptons and 2 b-jets
- Leading lepton p_T < 60 GeV
- $m_{T2}(ll, E_T^{miss})$ < 90 GeV
- $m_{T2}(bb,l_1+l_2+E_T^{miss})$ > 160 GeV

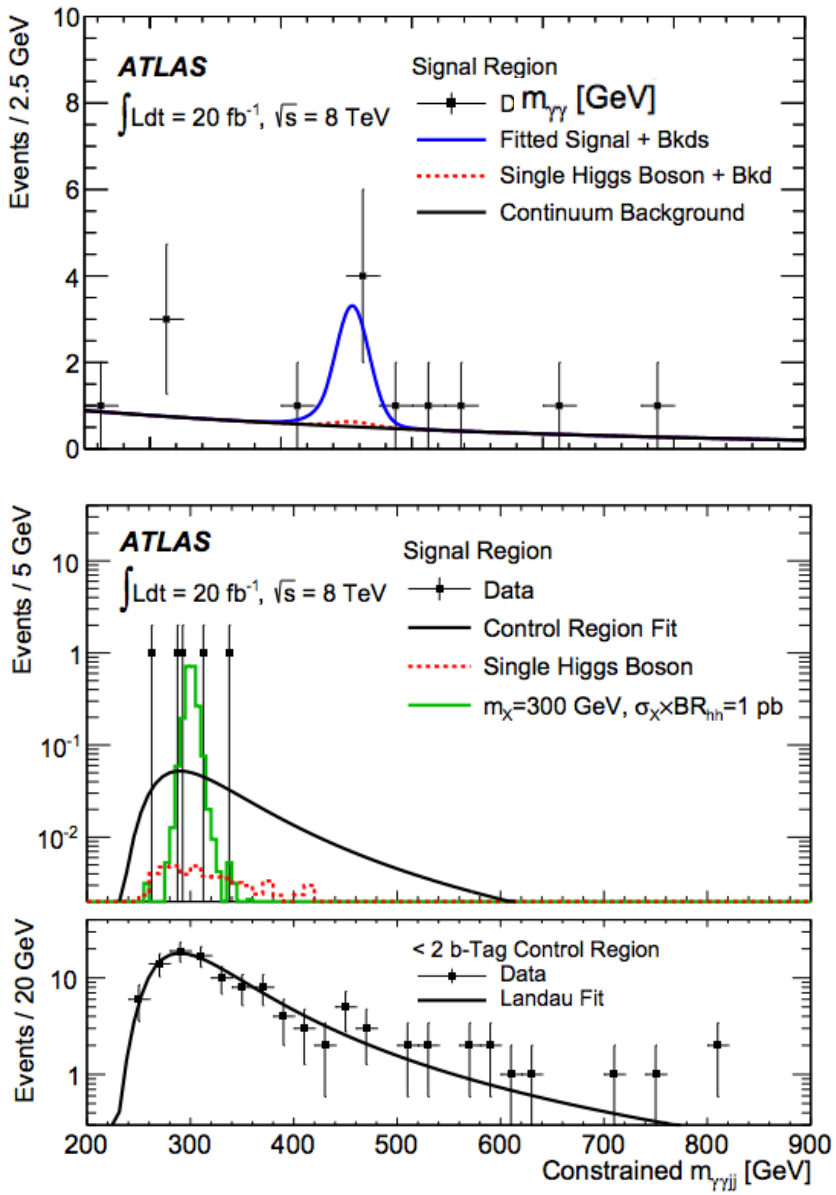
- Main backgrounds (single top and top pairs) normalized in dedicated 1b control region







Higgs *Searches*



HH -> γγbb

…excess on the order of 2.4σ at a m_X = 300GeV

Others channels investigated as well

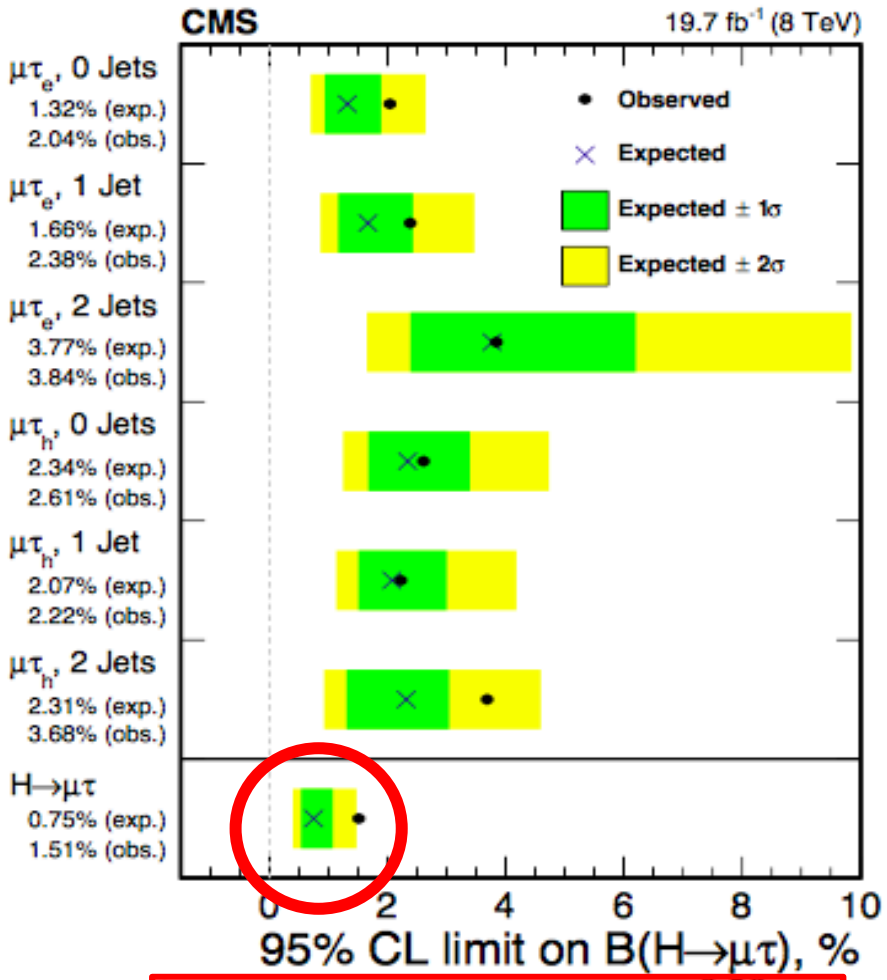
One thing is clear - with many hundreds of searches ***we should*** be seeing anomalies purely from a statistical viewpoint.

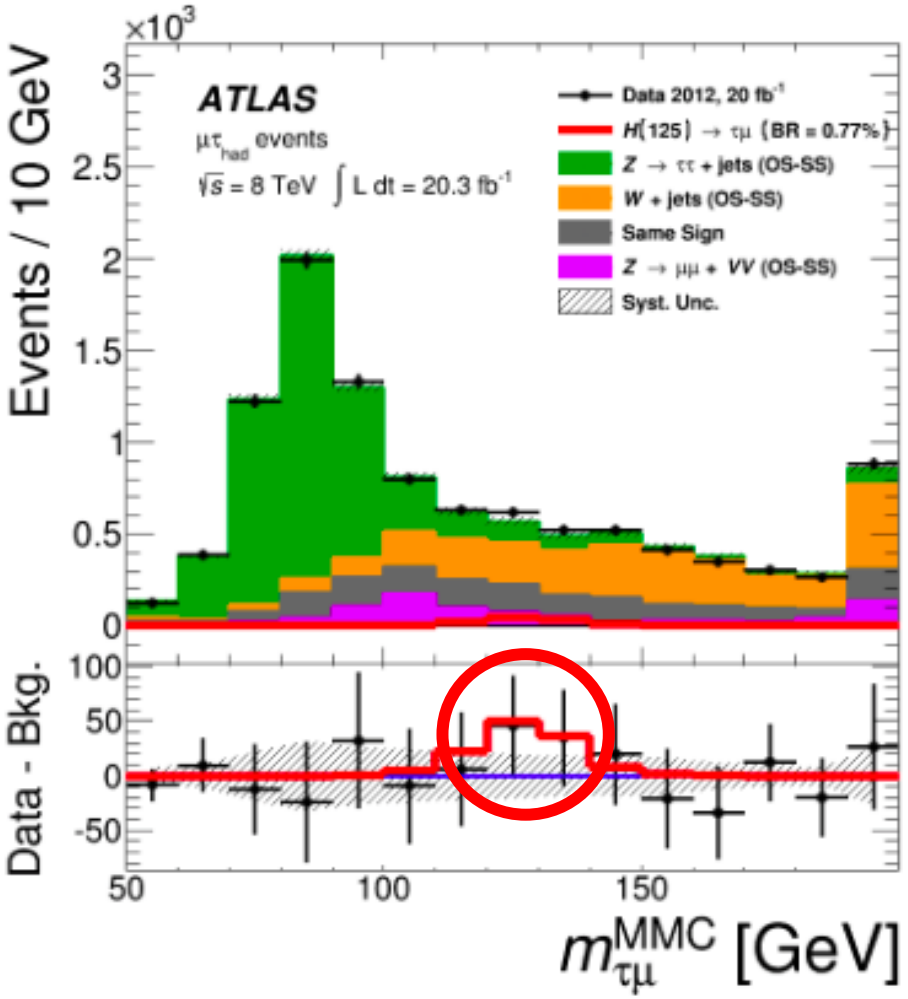
If anything there ***should be more*** 2-3σ deviations but we tend to be overly conservative and inflate systematic uncertainties on occasions…personal view ☺

More later….

Beyond SM Higgs?

Higgs *Searches – Hint from Run1*





$$\mathcal{B}(\mathrm{H} \to \mu\tau) = (0.84^{+0.39}_{-0.37})\%$$

Also: BR(eτ) < 0.69%, BR(eμ) < 0.036%

$$\mathrm{Br}(H \to \mu\tau) = (0.77 \pm 0.62)\%$$