Recent ATLAS results on Composite Dynamics and Dark Matter

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LIO, September 5-8, 2016

Outline

ATLAS and the LHC in 2016

- Detector operation and performance

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

- Dark Matter searches
- Resonance searches
- SUSY searches

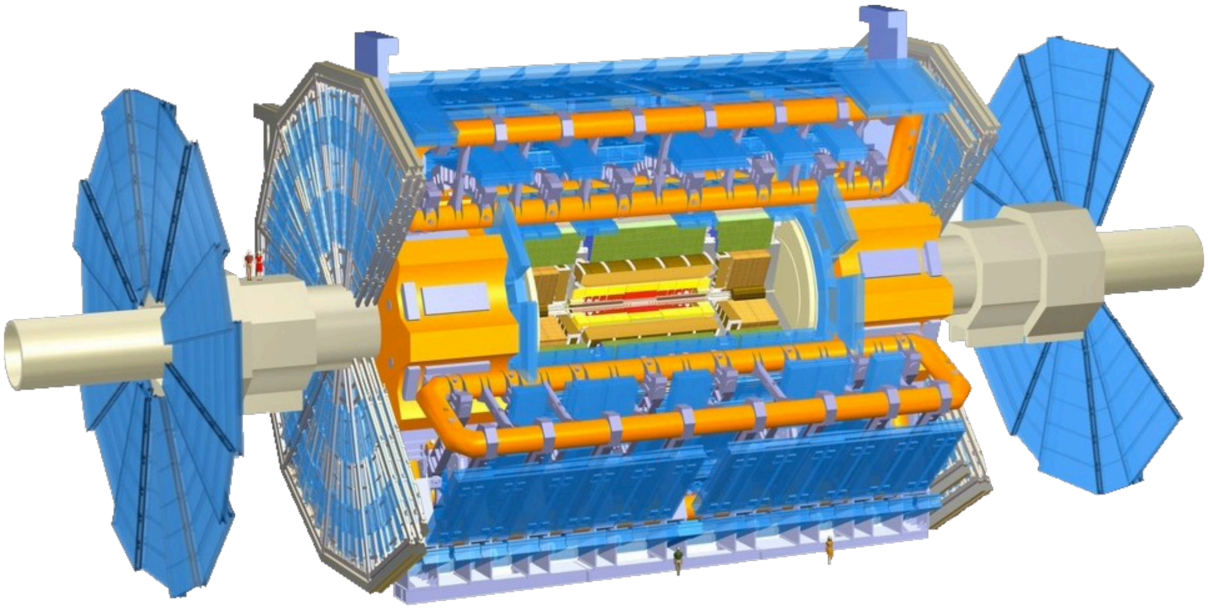
The ATLAS experiment

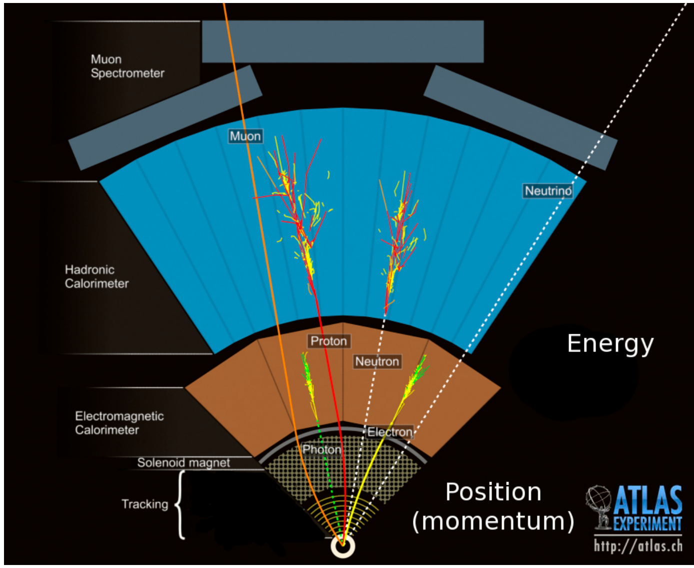
A **T**oroidal **L**HC **A**pparatu**S**

OR

A **T**erribly **L**ame **A**cronym, **S**orry

The ATLAS experiment





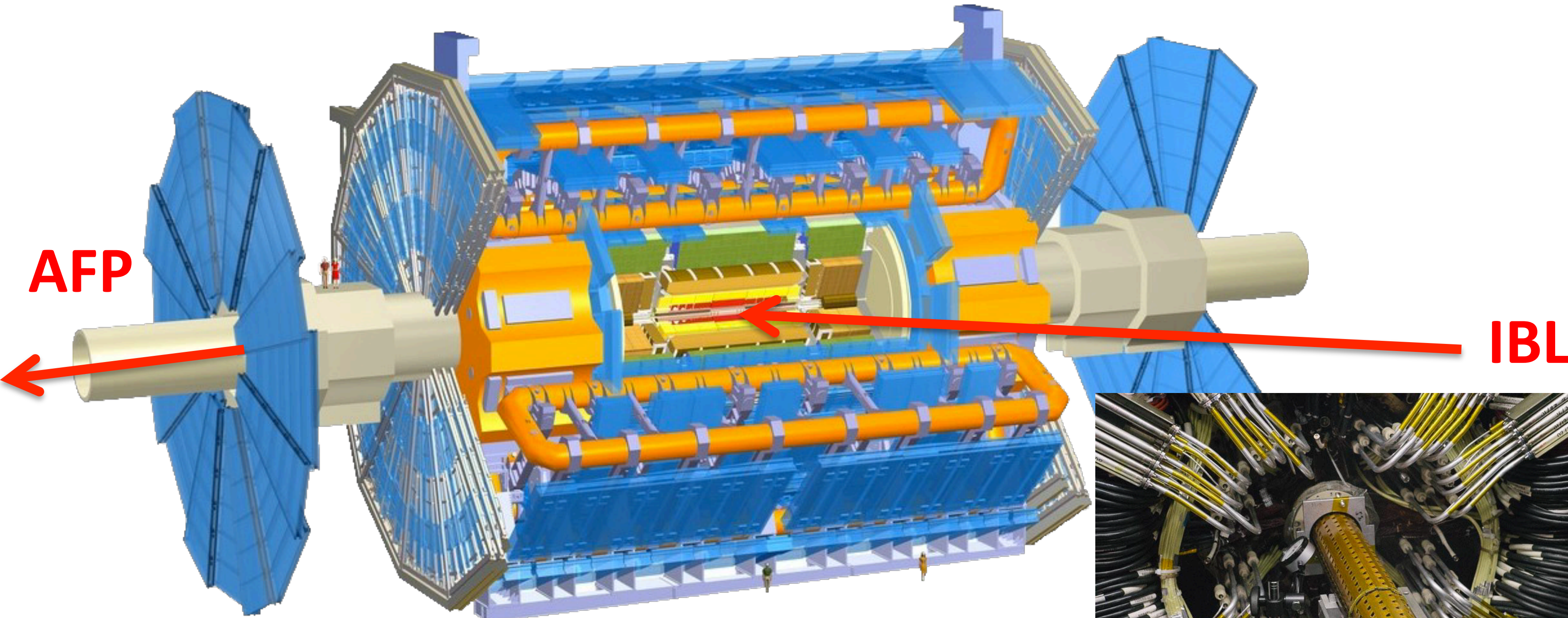
- Solenoidal magnetic field (2T) in the central region – momentum measurement
- Energy meas. down to 1° to the beamline

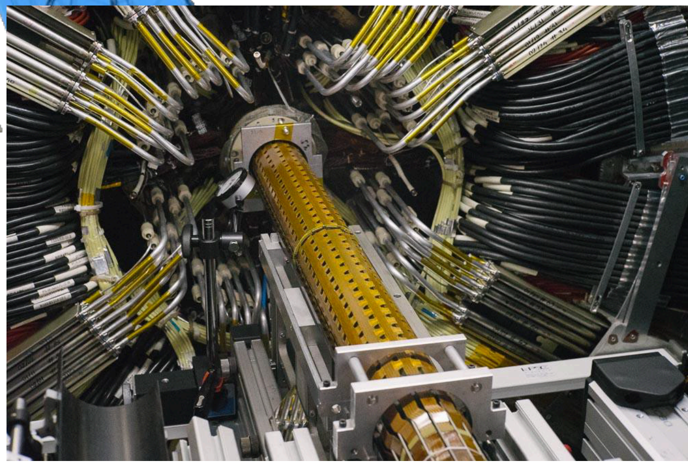
- High resolution silicon detectors
  - 6M strip channels (80µmx12cm)
  - 80M pixel channels (50µmx400µm) space resolution ~15µm

- Independent muon spectrometer (superconducting toroidal magnet)

The ATLAS experiment

New detectors in Run-2:
- Innermost pixel layer IBL, 3.4cm from interaction point
- Forward proton detectors (one arm in 2016, 210m from IP)

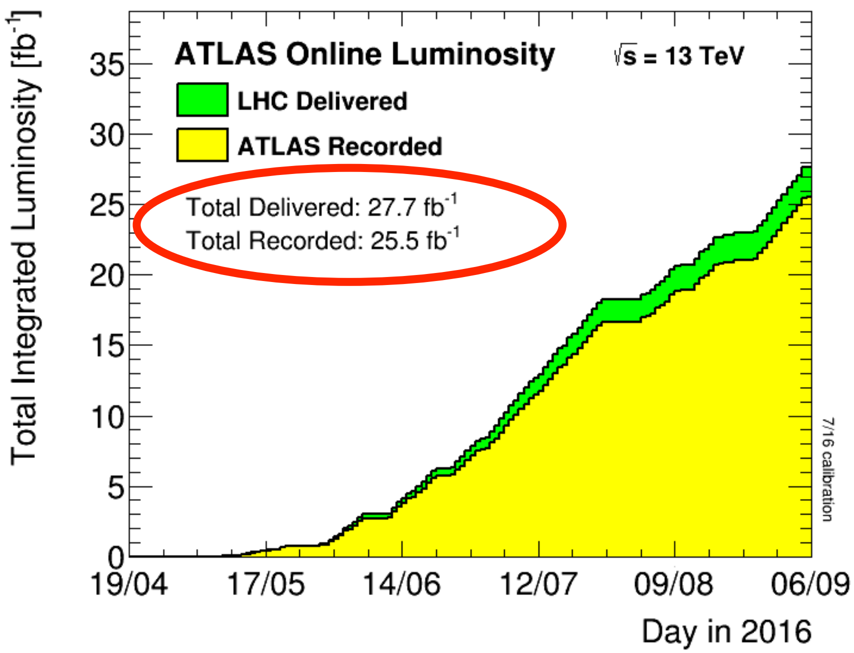


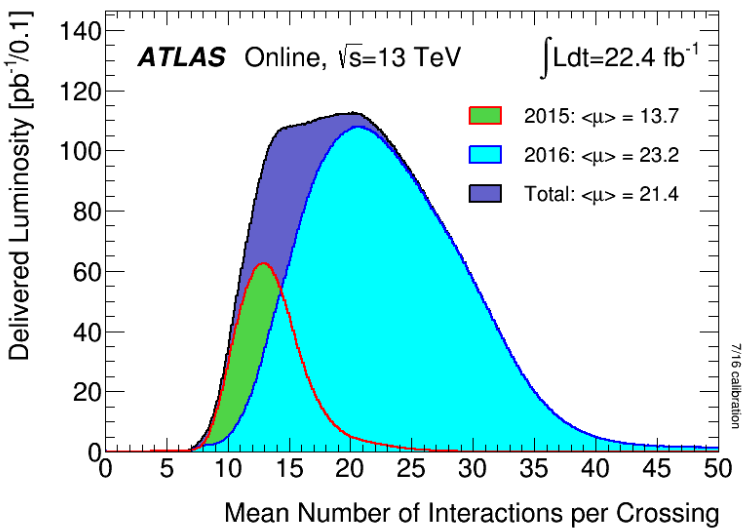


In addition, various consolidations provide improved running at high luminosities and rates

Data Samples

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

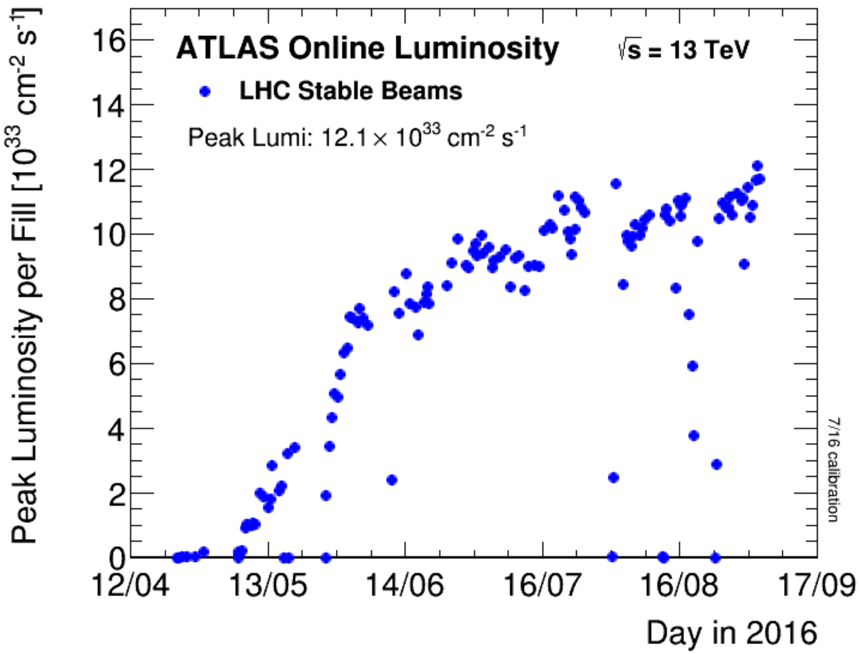




Luminosity uncertainty
- ±2.1% (2015)
- ±3.7% (2016, preliminary)
- ±2.9% (2015+2016, prel)

Data quality in 2016:
- >90% of data collected usable for analysis

LHC: More than nominal Luminosity



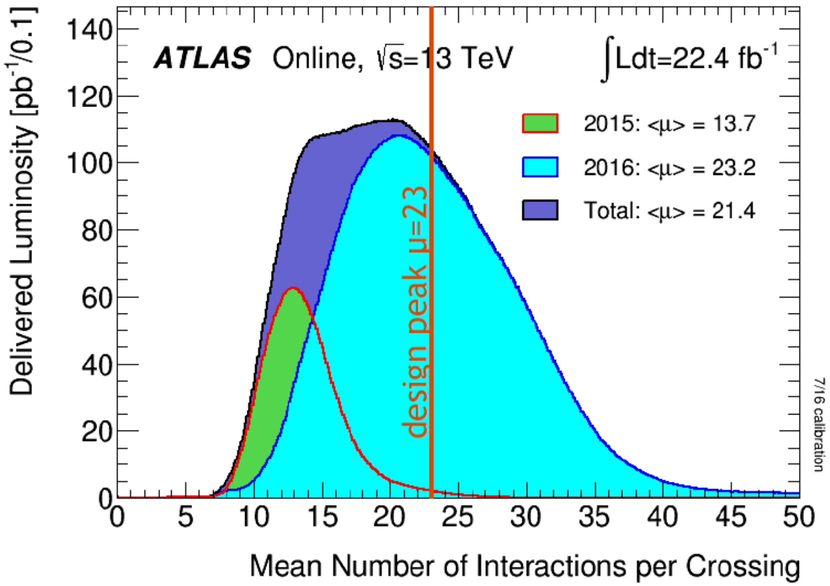
LHC design: $L = 10^{34}\ cm^{-2}\ s^{-1}$

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

Many challenges

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

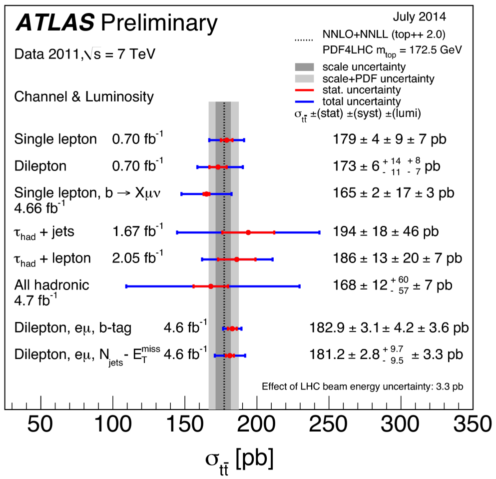
ATLAS has risen to meet these challenges!

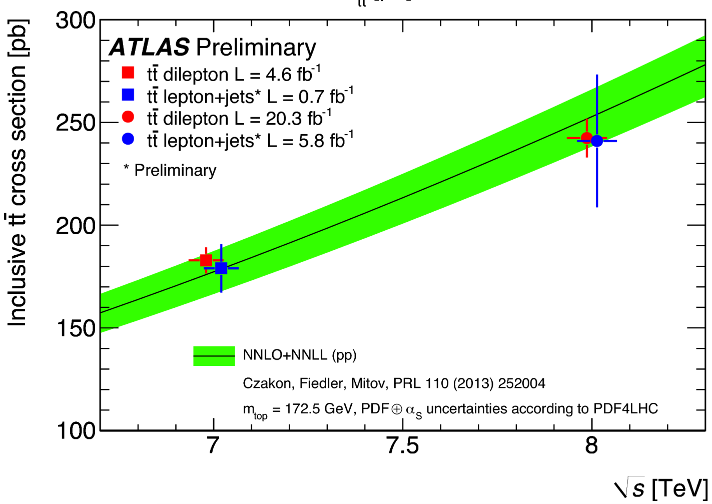


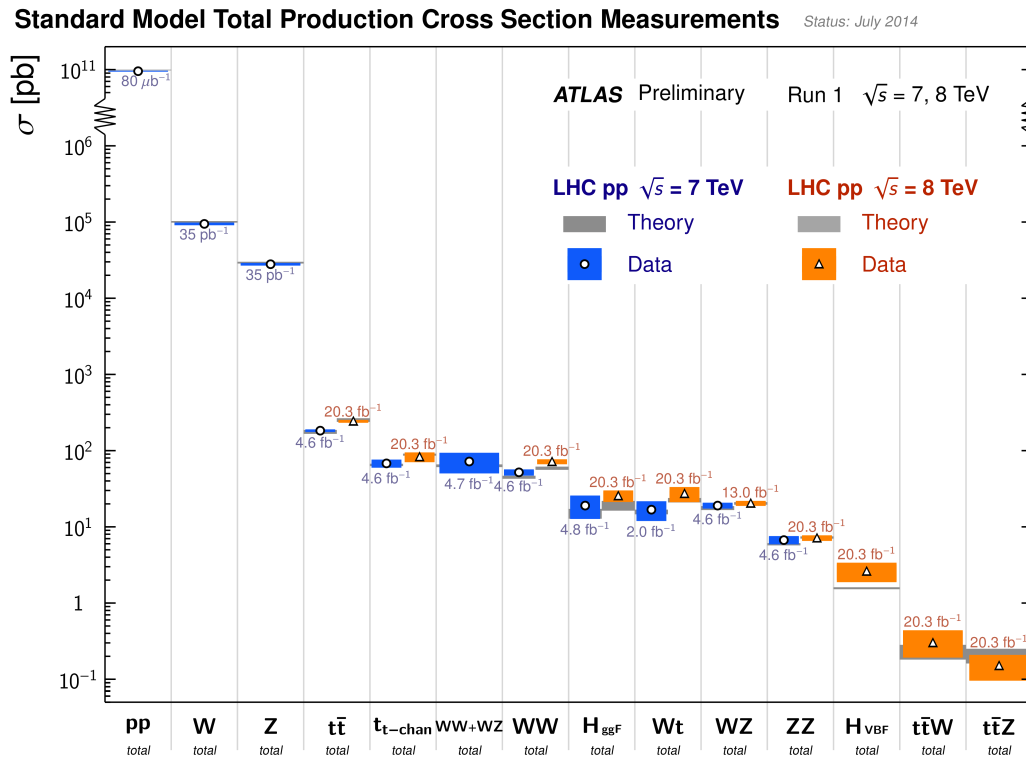
Pileup often above LHC design in 2016

Searches

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







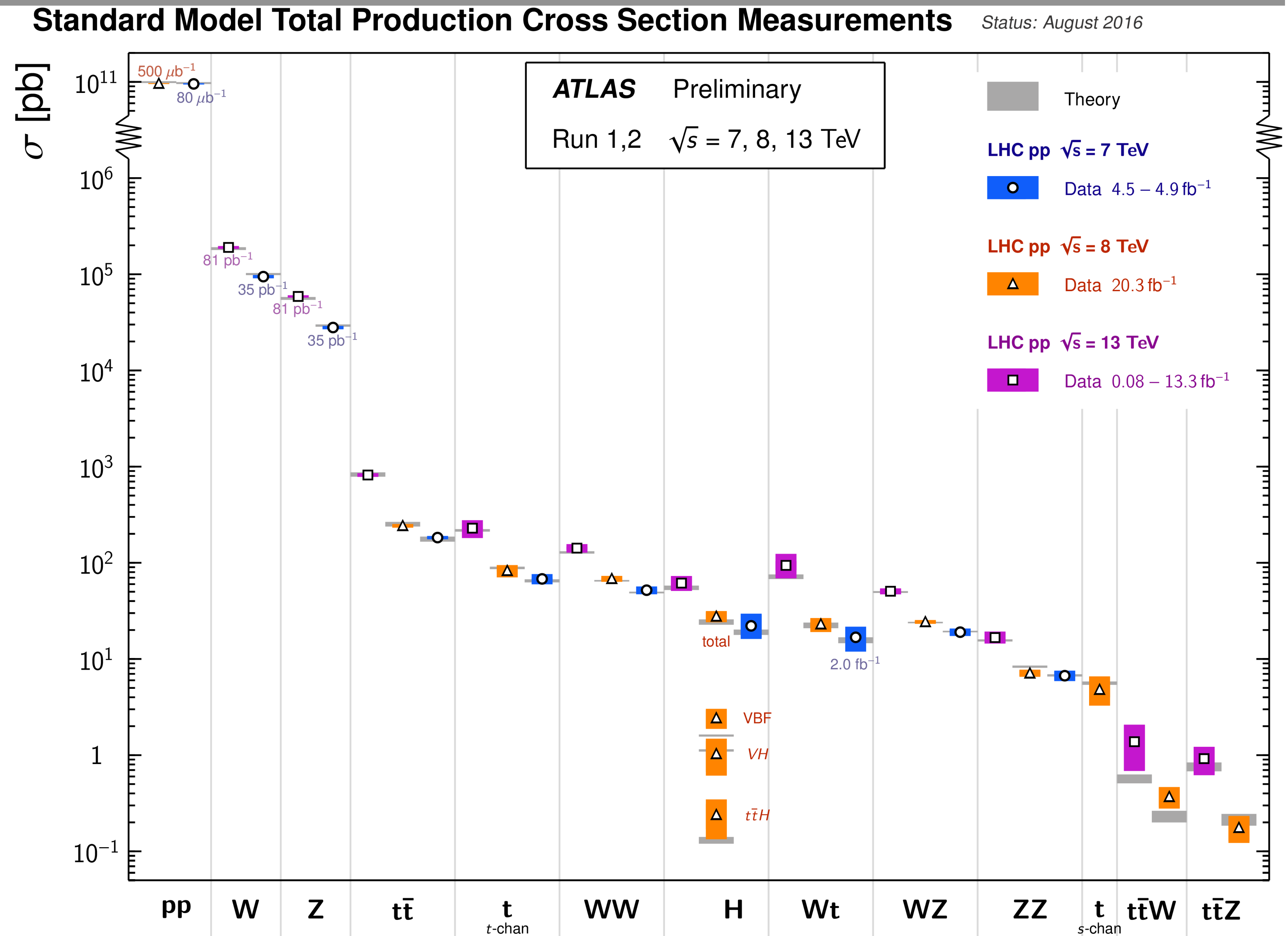
Crucial to demonstrate detector performance and measure Standard Model to great accuracy

….keep increasing the energy….

2011 -> 2012 -> 2015+

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

Understanding the Standard Model Backgrounds



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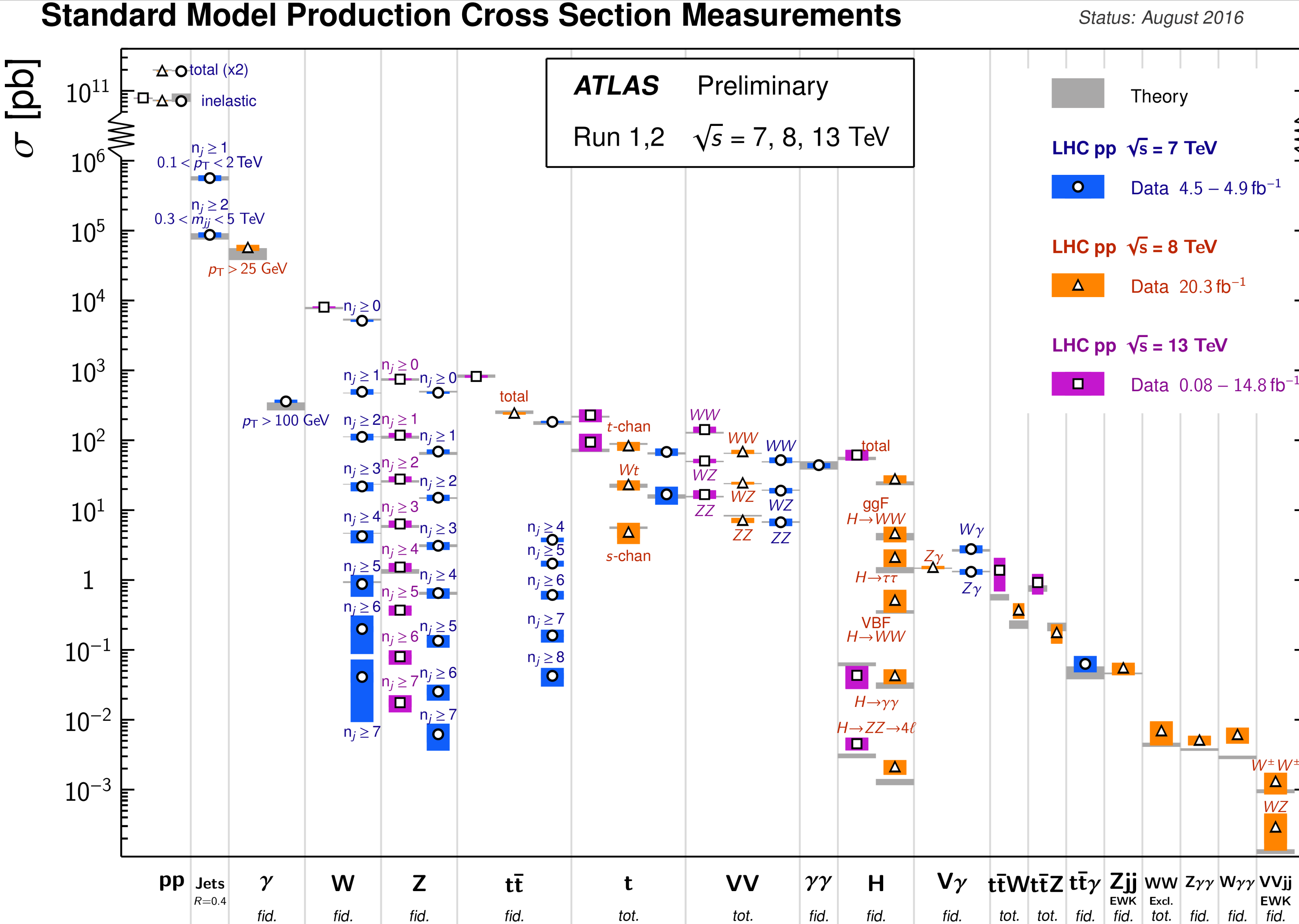
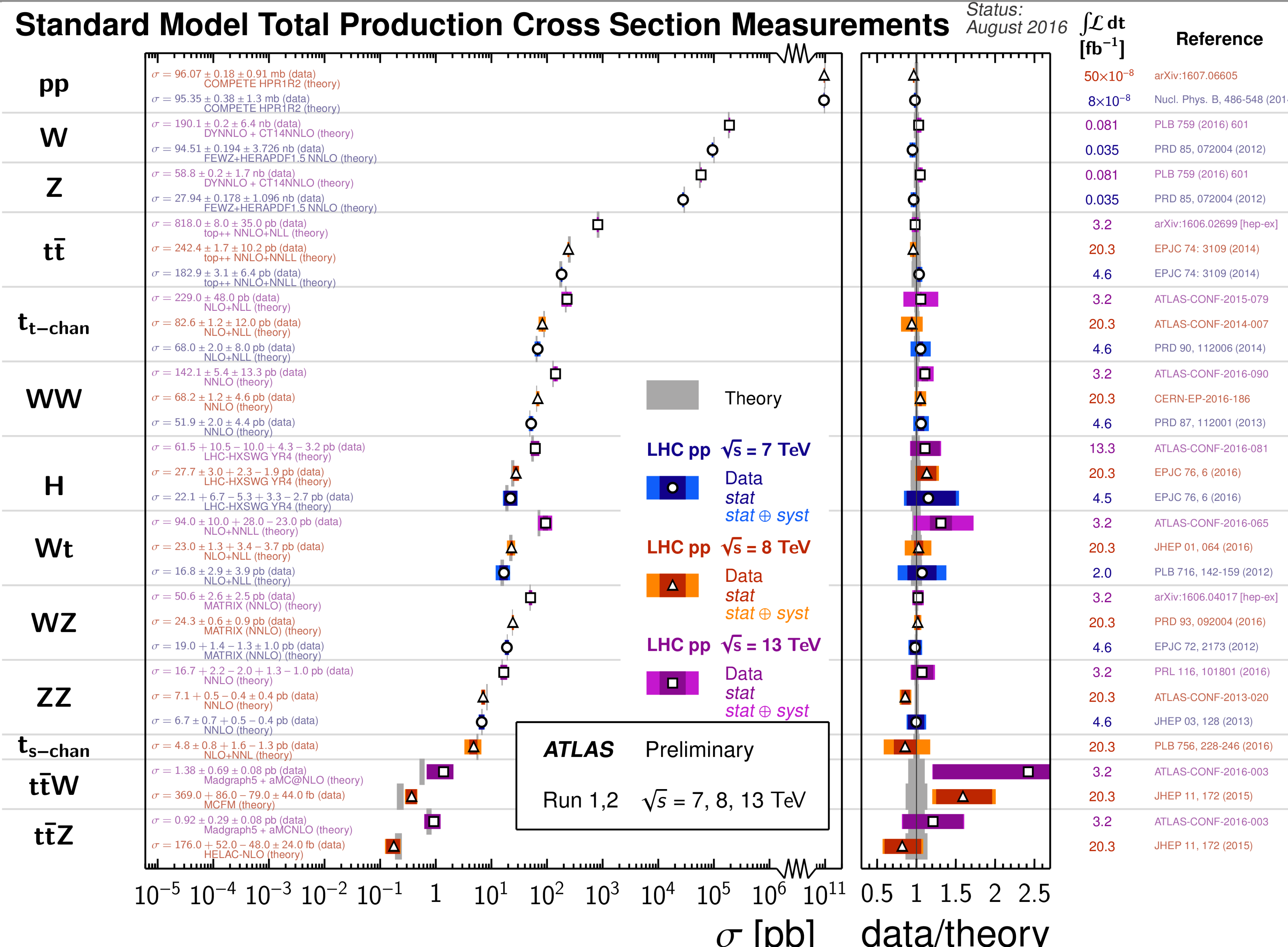
Understanding the Standard Model Backgrounds



Understanding the Standard Model Backgrounds



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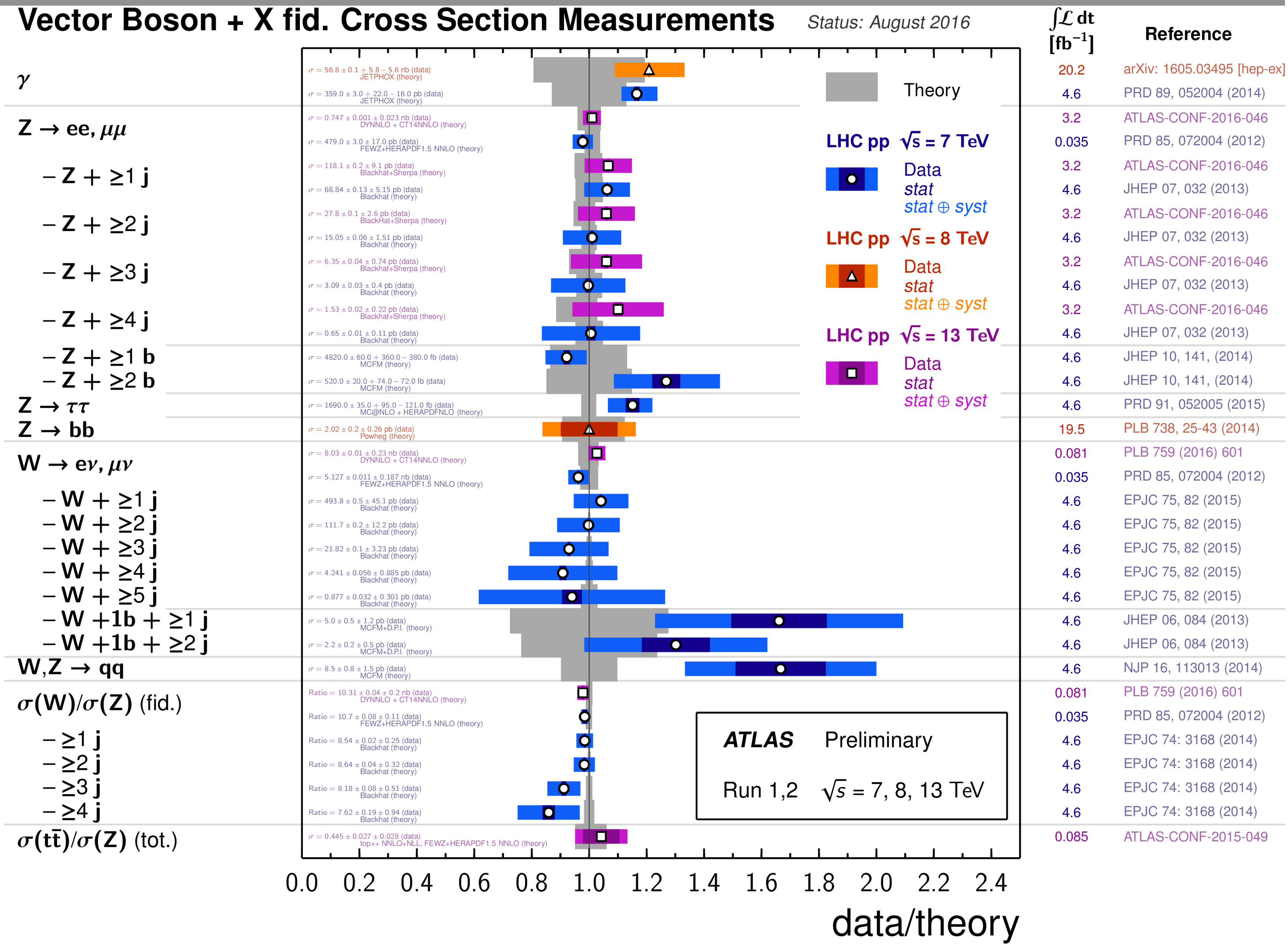
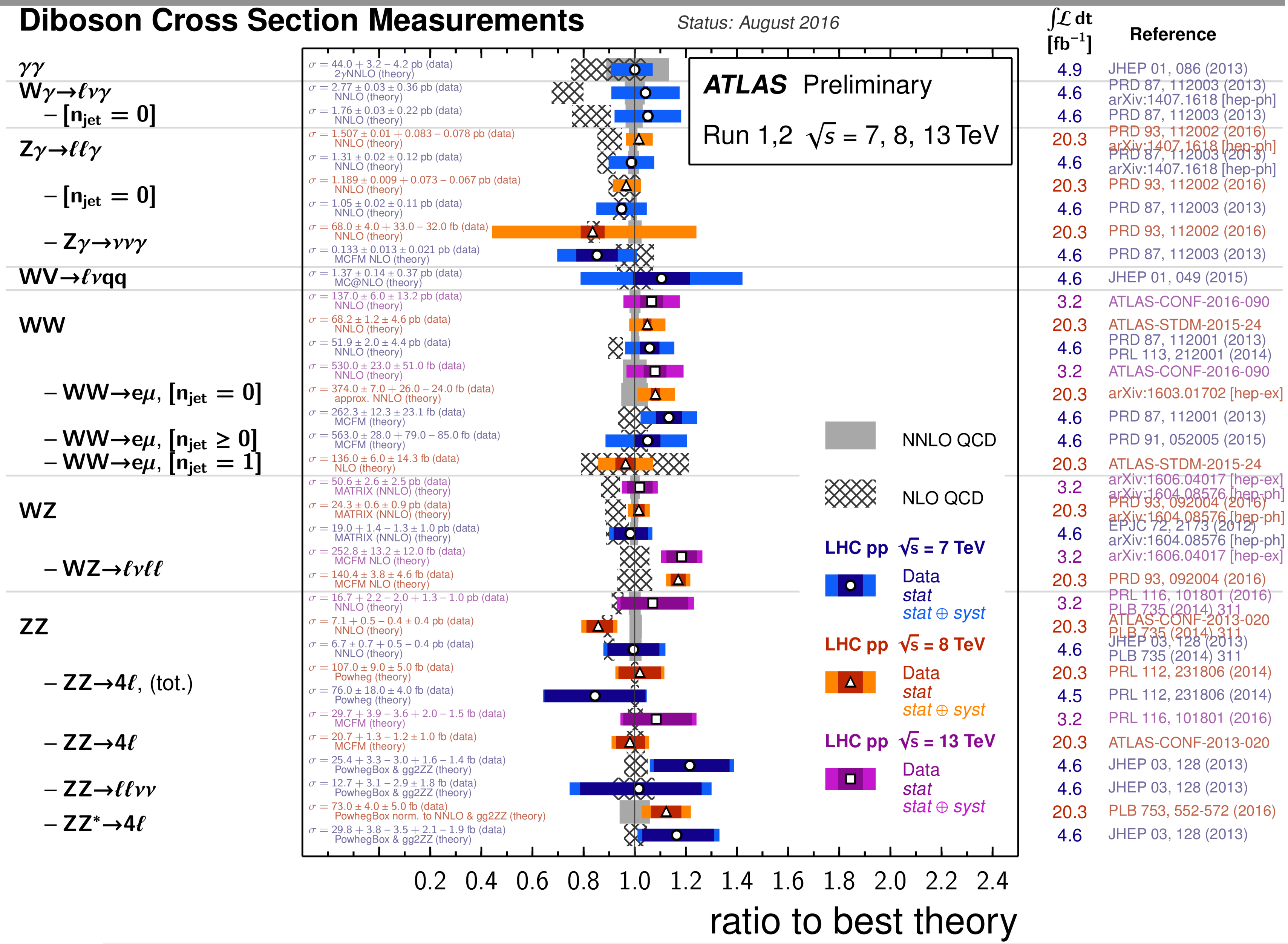


Understanding the Standard Model Backgrounds



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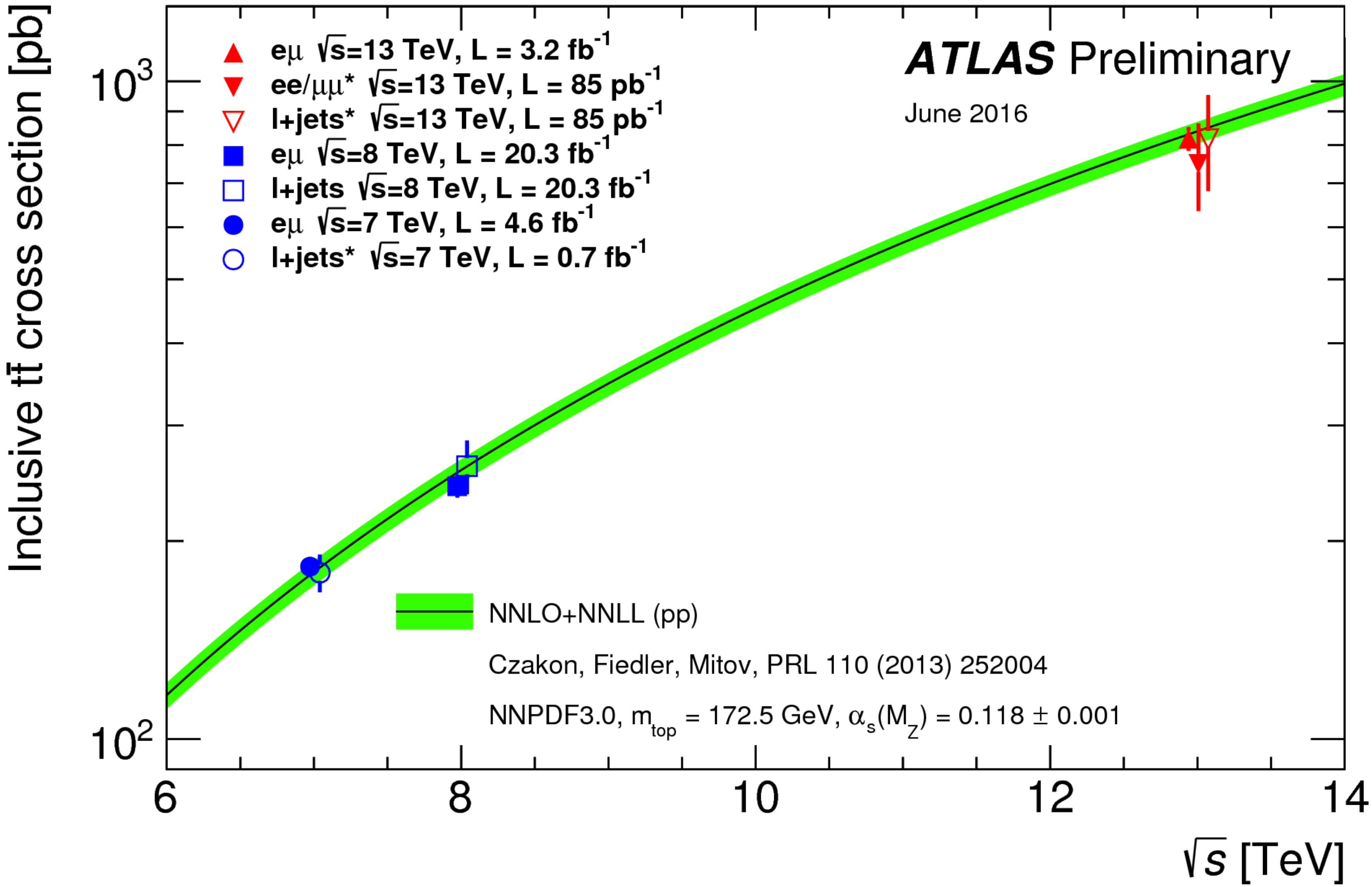
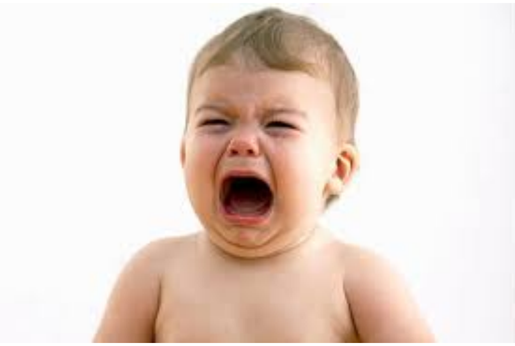


ATLAS Preliminary
June 2016
eμ √s=13 TeV, L = 3.2 fb-1
ee/μμ* √s=13 TeV, L = 85 pb-1
l+jets* √s=13 TeV, L = 85 pb-1
eμ √s=8 TeV, L = 20.3 fb-1
l+jets √s=8 TeV, L = 20.3 fb-1
eμ √s=7 TeV, L = 4.6 fb-1
l+jets* √s=7 TeV, L = 0.7 fb-1
NNLO+NNLL (pp)
Czakon, Fiedler, Mitov, PRL 110 (2013) 252004
NNPDF3.0, m_top = 172.5 GeV, α_s(M_Z) = 0.118 ± 0.001
Inclusive tt̄ cross section [pb]
10^3
10^2
6
8
10
12
14
√s [TeV]

The reaction from CERN Restaurant 1





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



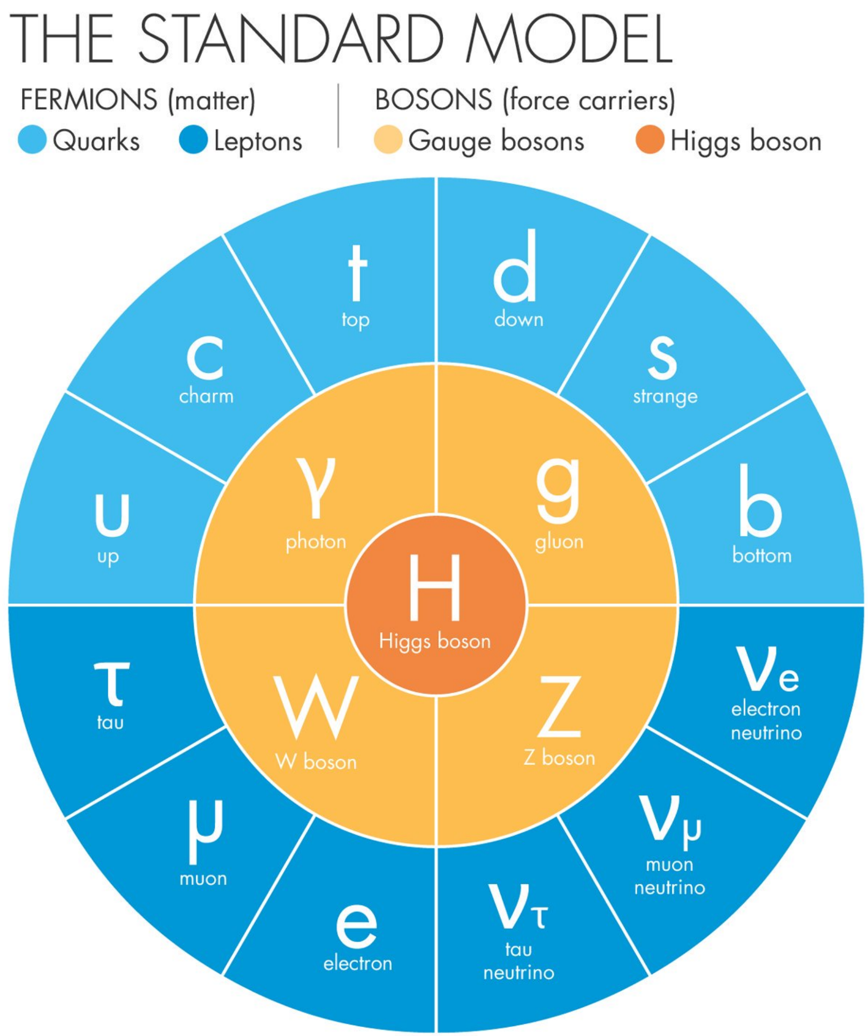


- The standard model is standing up to intense scrutiny

- A variety of precision measurements show excellent agreement with calculations at several collision energies

- Almost all searches we perform have some amount of model dependence i.e. you search for a specific signal topology

- **But…..**
- **We DO NOT KNOW what new physics will look like (…and we want to cast a wide net)**



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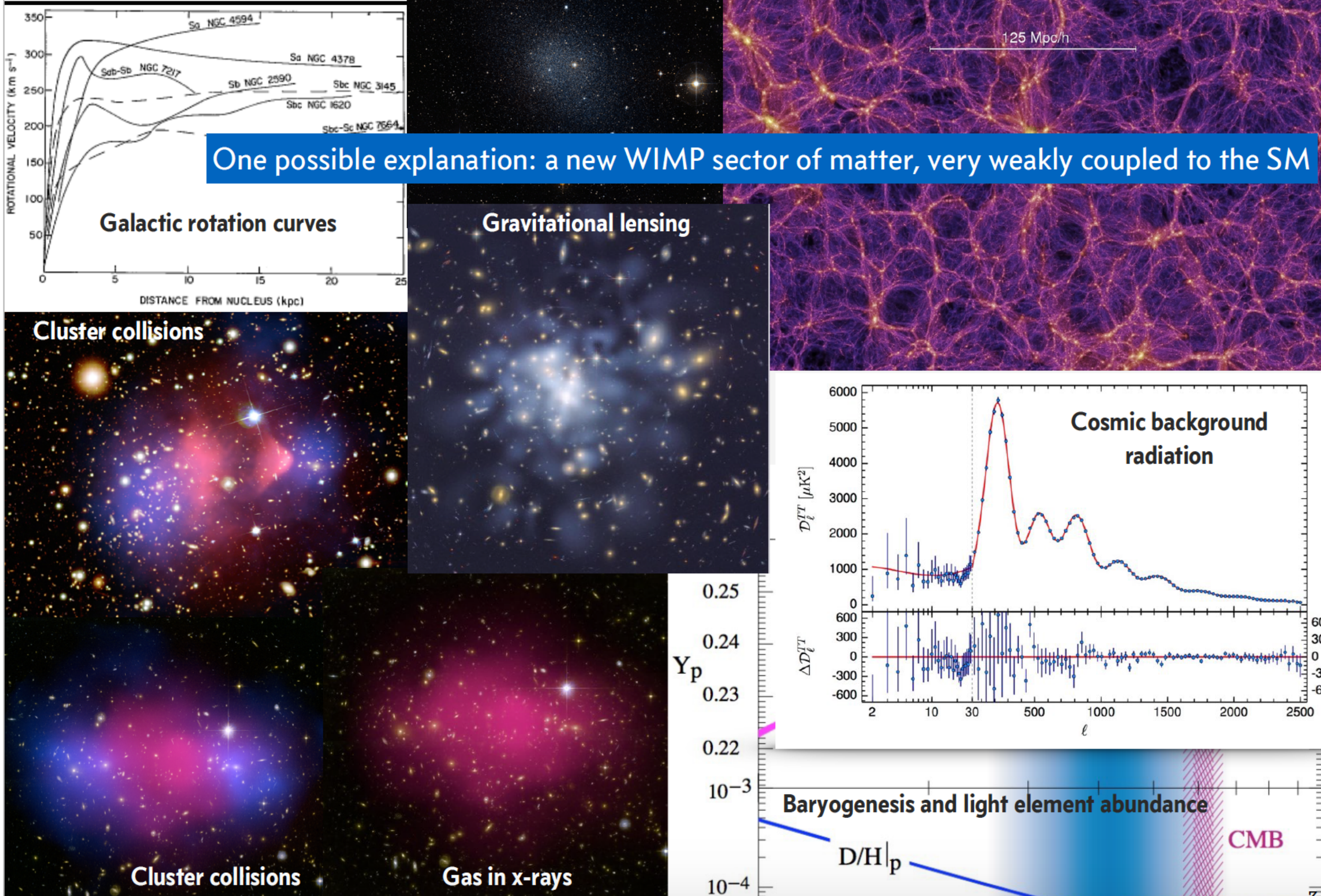
Dark Matter

Evidence for Dark Matter



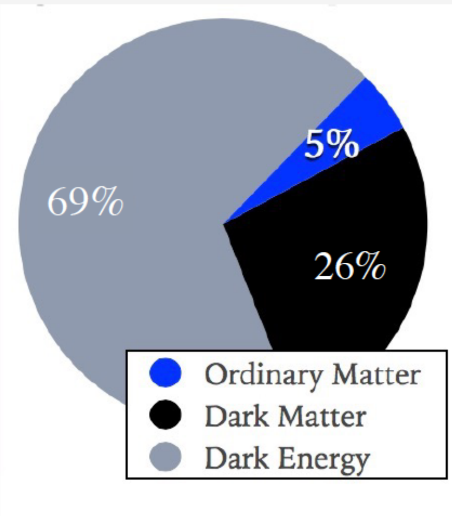
One possible explanation: a new WIMP sector of matter, very weakly coupled to the SM

Properties of dark matter

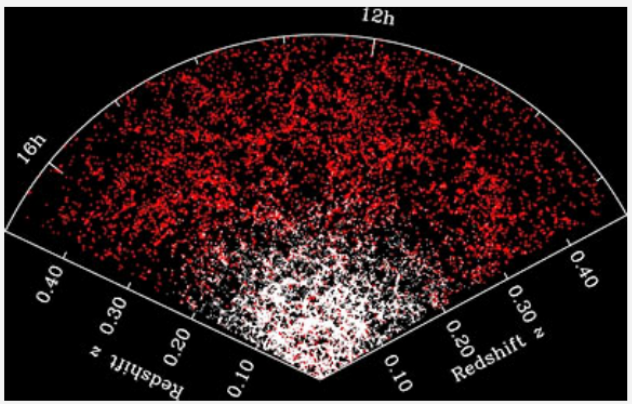
Interacts gravitationally

Dark

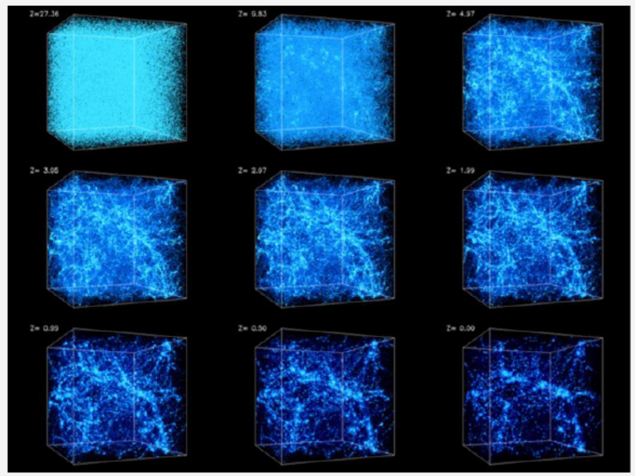
(other effective couplings to SM are zero or small)



5x as much DM as SM



Cosmologically stable

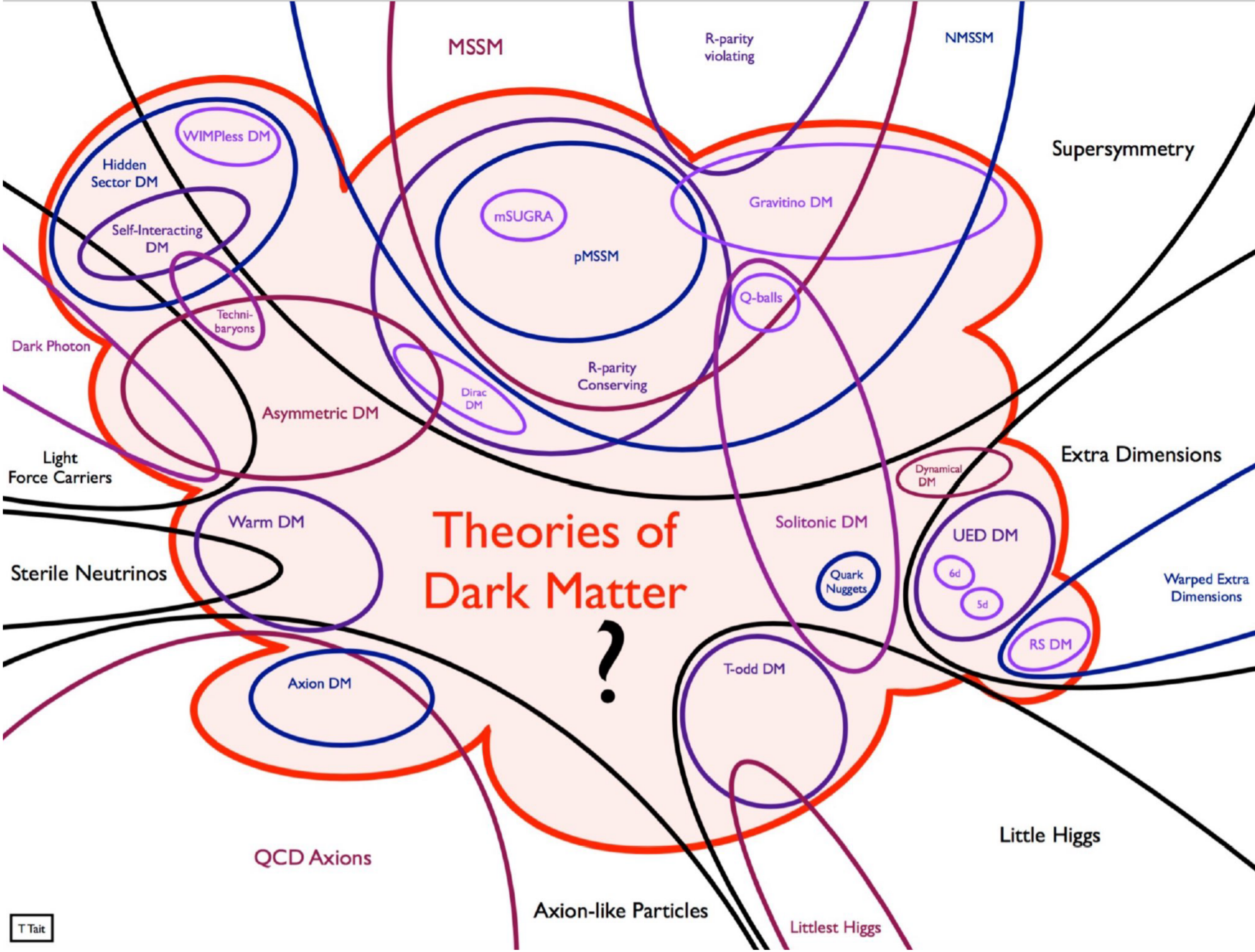


Approximately Cold / non-relativistic

Modified gravity difficult and lacks other evidence

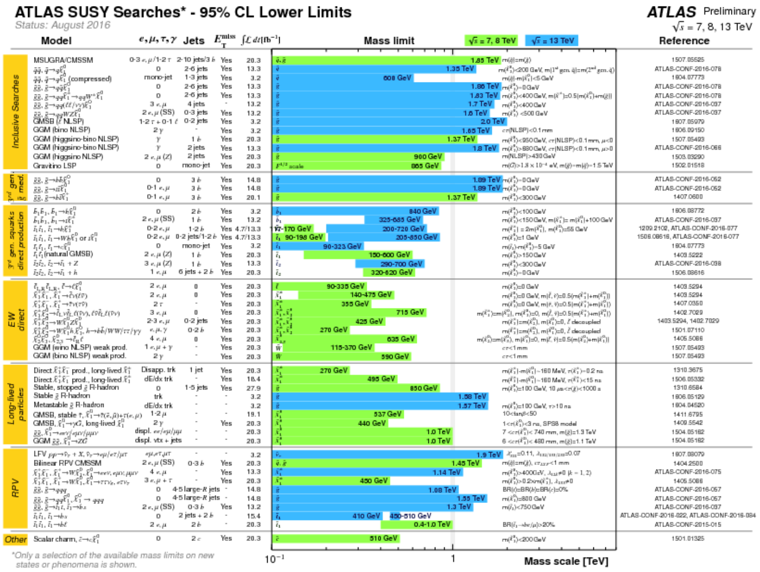
Massive AstrophysiCal Halo Objects (MACHOs) cannot* account for observed density

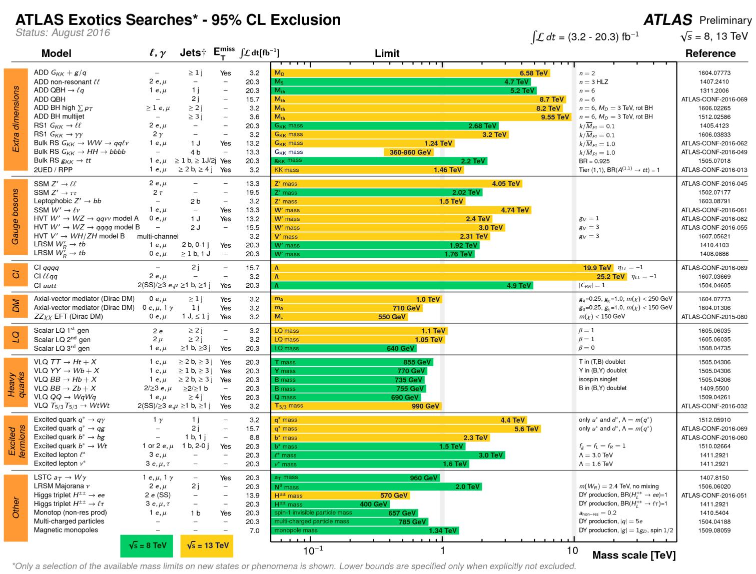
Particle dark matter: but properties inconsistent with any Standard Model particle

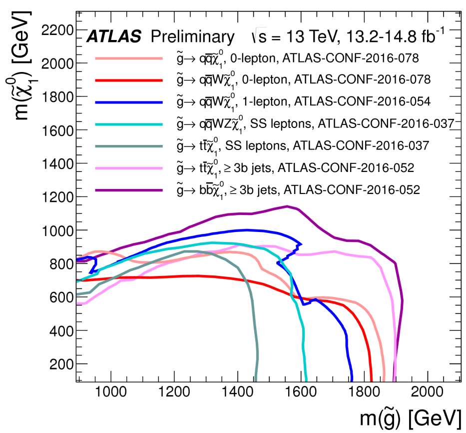


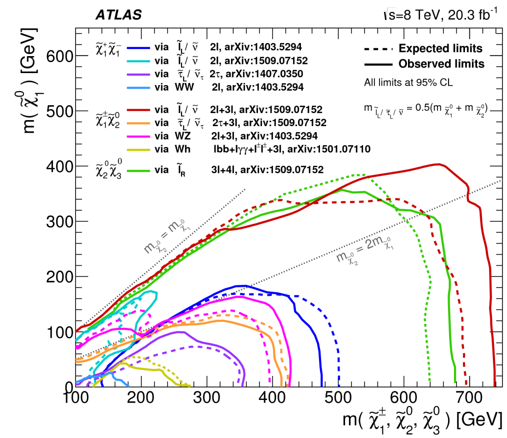
Theories of Dark Matter
?
MSSM
R-parity violating
NMSSM
Supersymmetry
WIMPless DM
Hidden Sector DM
Self-Interacting DM
Techni-baryons
mSUGRA
pMSSM
Gravitino DM
Q-balls
Dark Photon
Asymmetric DM
Dirac DM
R-parity Conserving
Light Force Carriers
Extra Dimensions
Dynamical DM
Warm DM
Solitonic DM
UED DM
6d
5d
Quark Nuggets
Sterile Neutrinos
Warped Extra Dimensions
RS DM
Axion DM
T-odd DM
Little Higgs
QCD Axions
Axion-like Particles
Littlest Higgs
T Tait

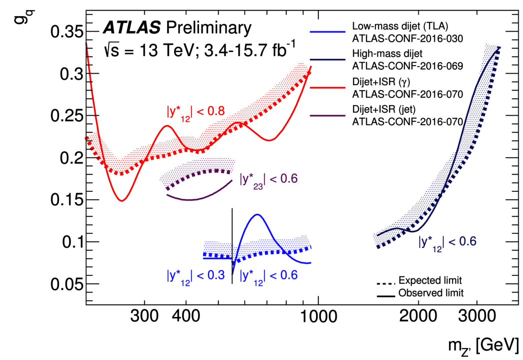
Searches for New Physics

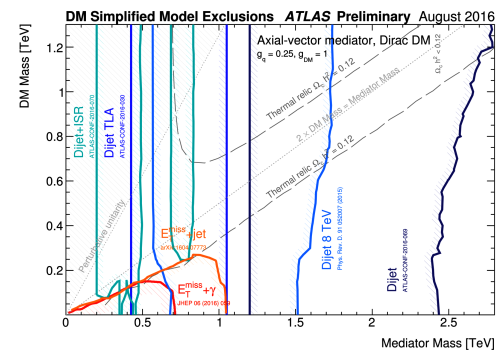




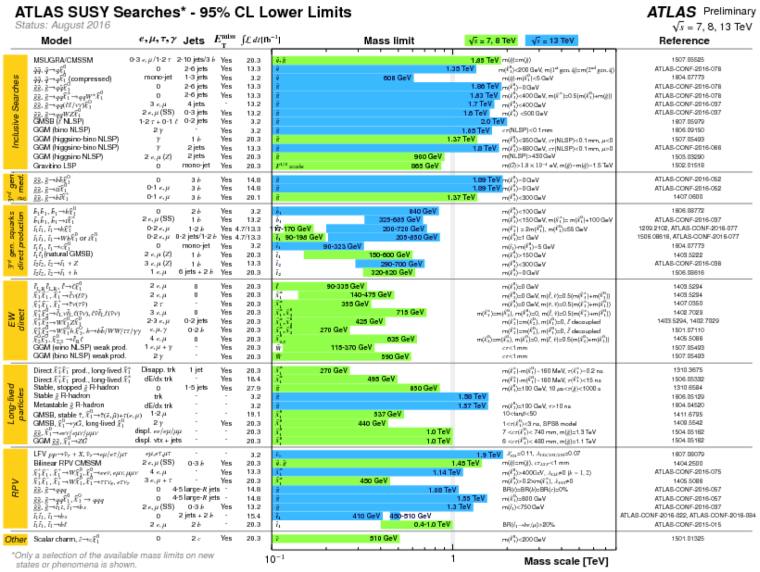


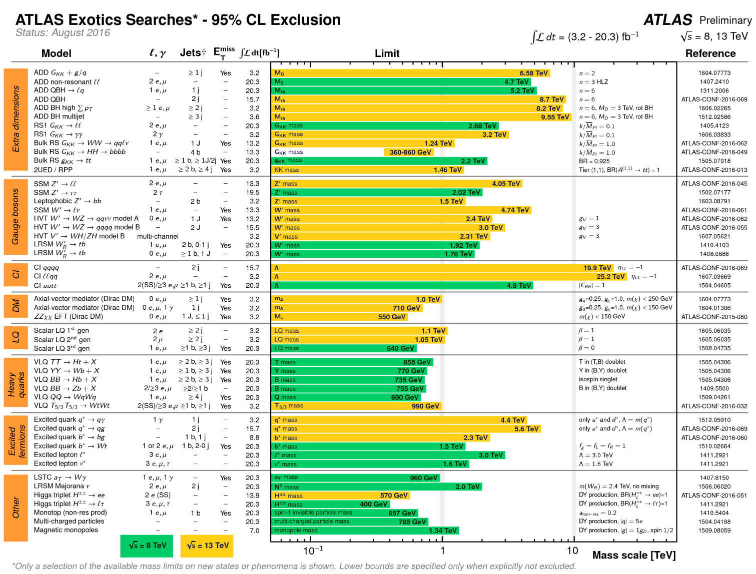


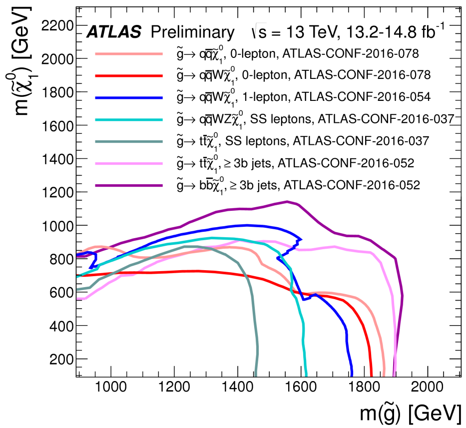


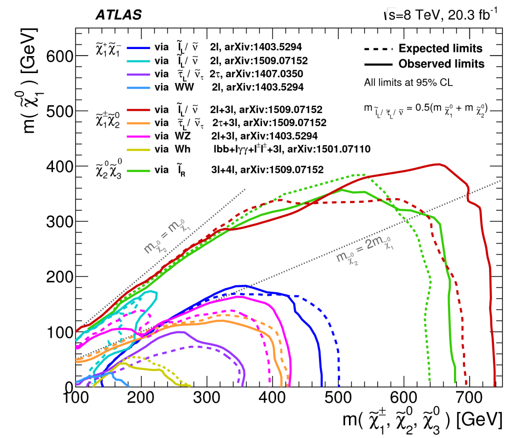


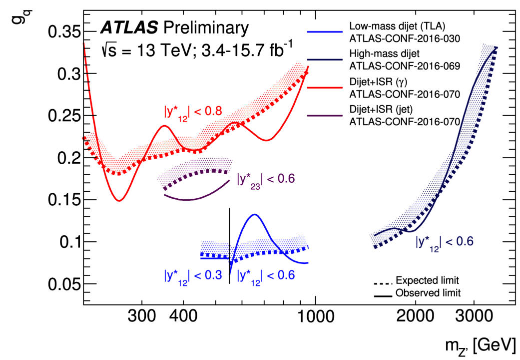
Searches for New Physics => Searches for Dark Matter

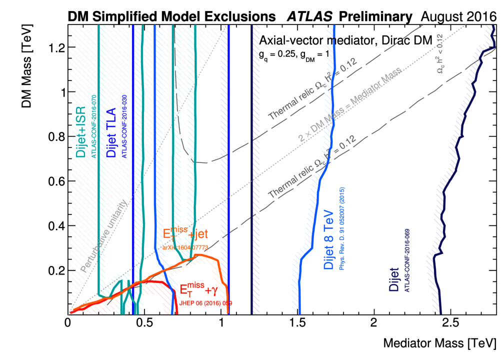










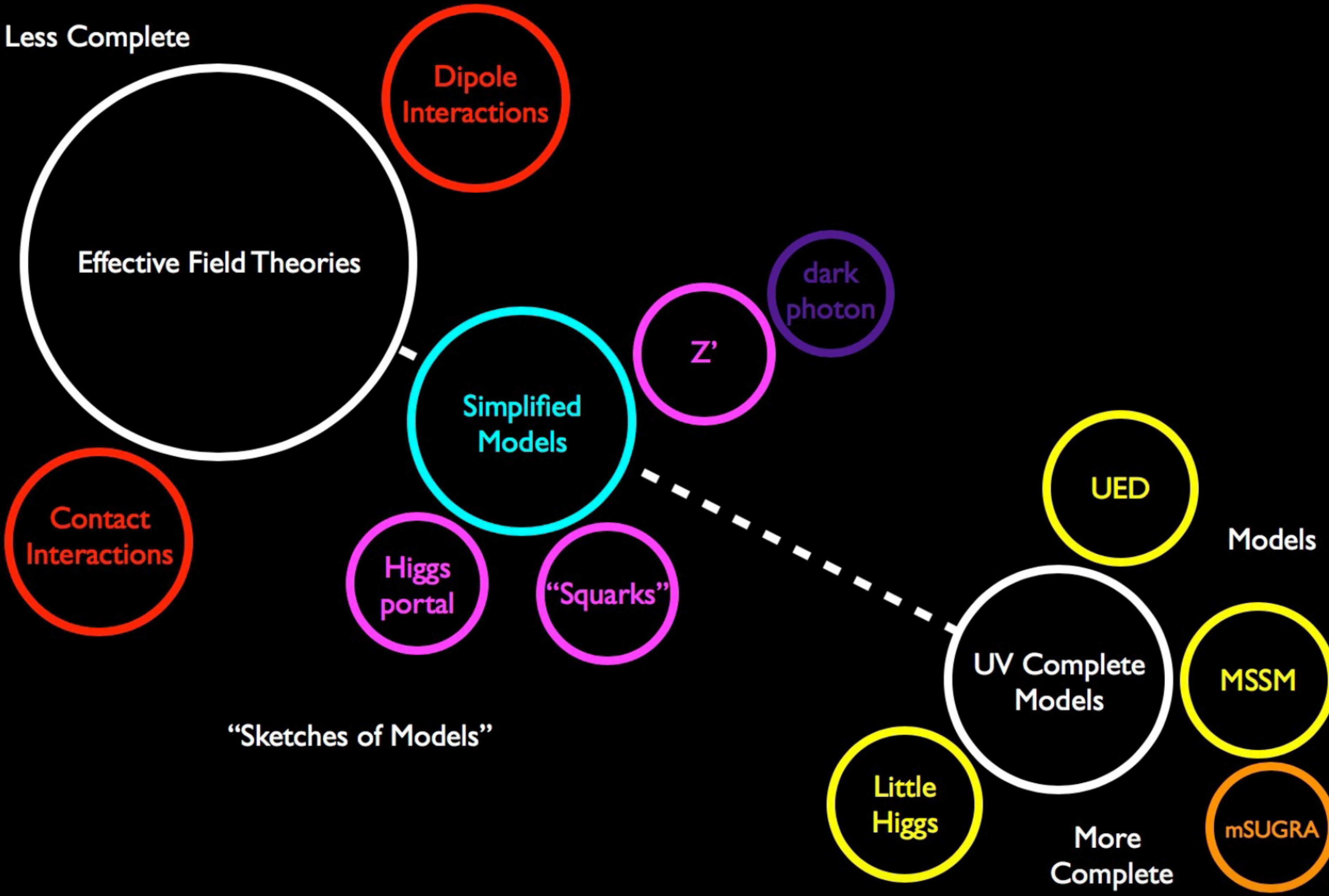


Most models already have a DM candidate, or can be easily modified to provide one

So how do we map these searches onto DM searches… and what are we missing?

Spectrum of Theory Space

Tim M.P. Tait



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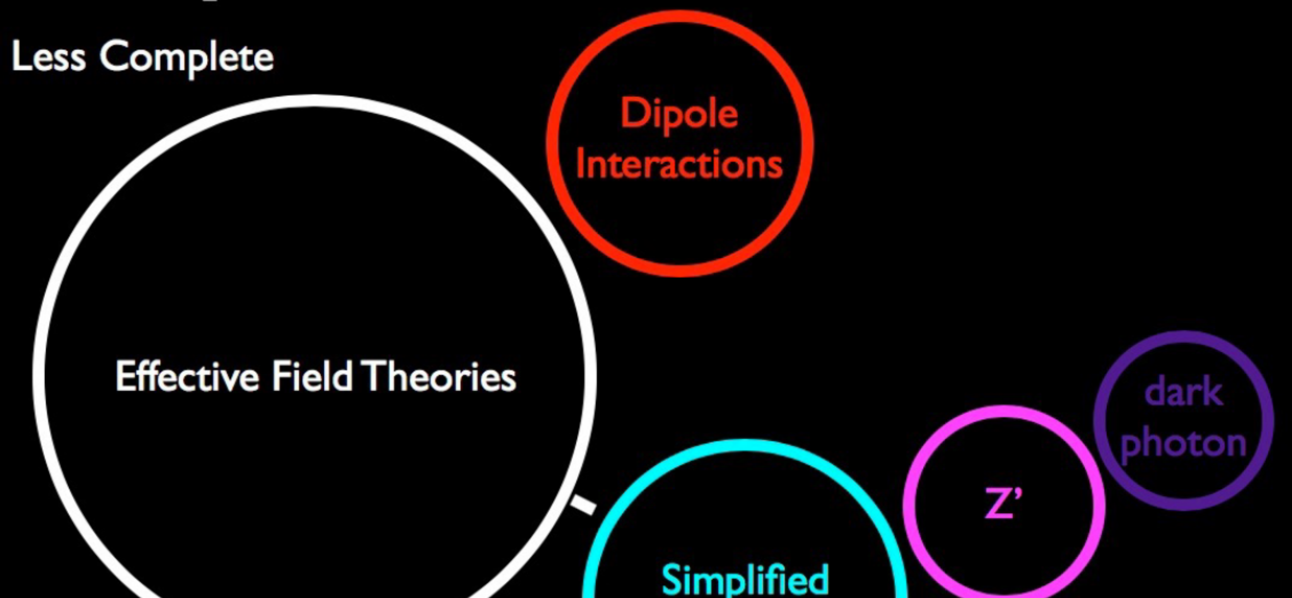
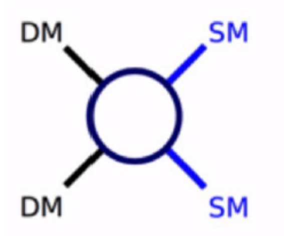
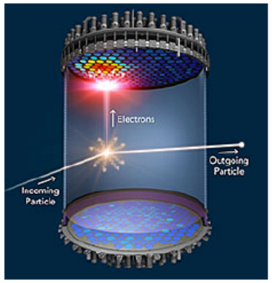


Focus on general WIMP searches **emphasizing complementarity between searches for dark matter**
- assume an **effective baryon coupling**: scattering off **nuclei** and production in **pp collisions**
- do **signature-based searches** applicable to broad classes of possible models

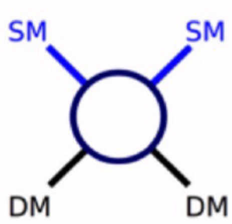
Break it!



Indirect Detection

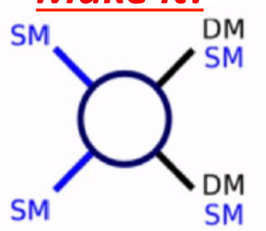


Shake it!

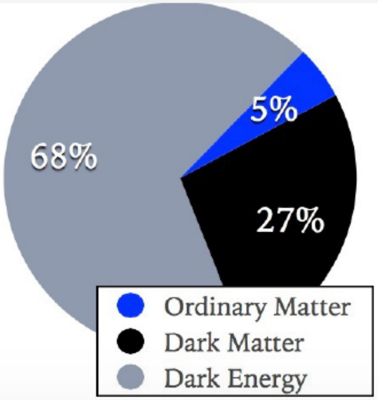


Direct Detection

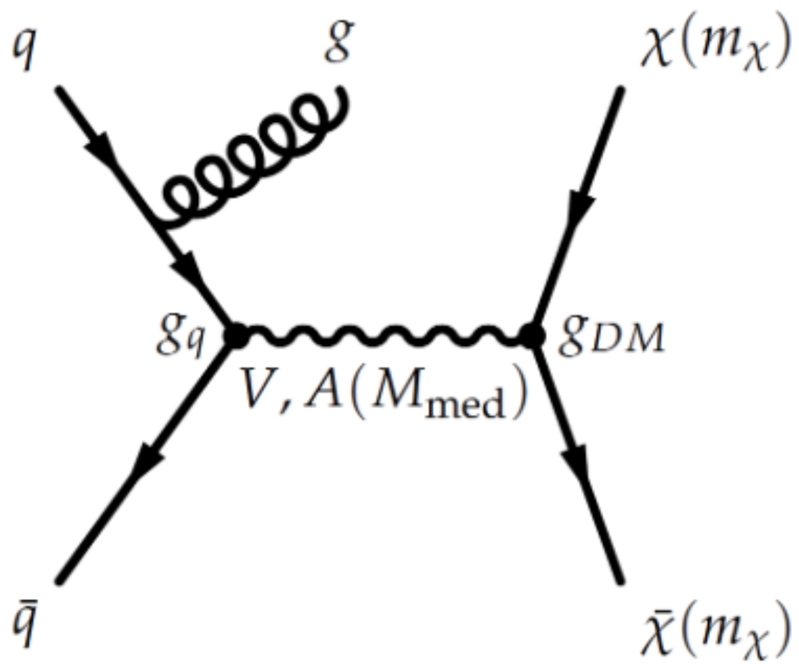
Make it!



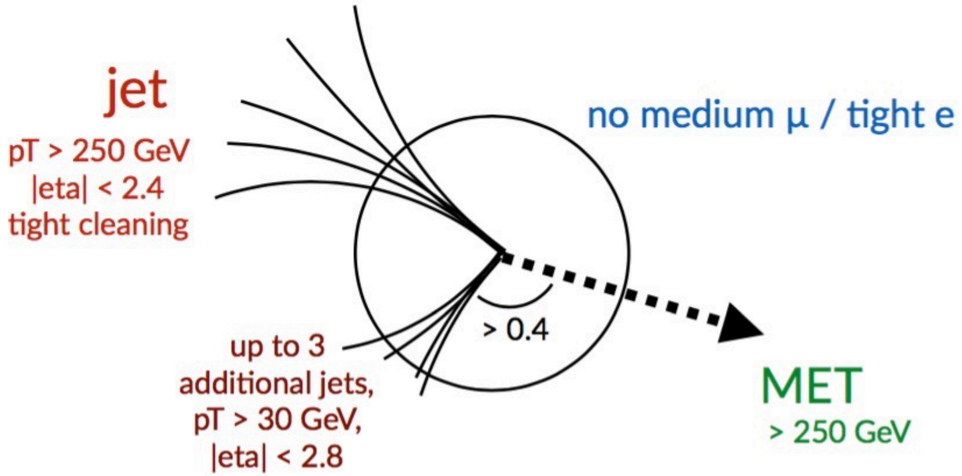
Colliders



Searching for collider stable Weakly interacting particles

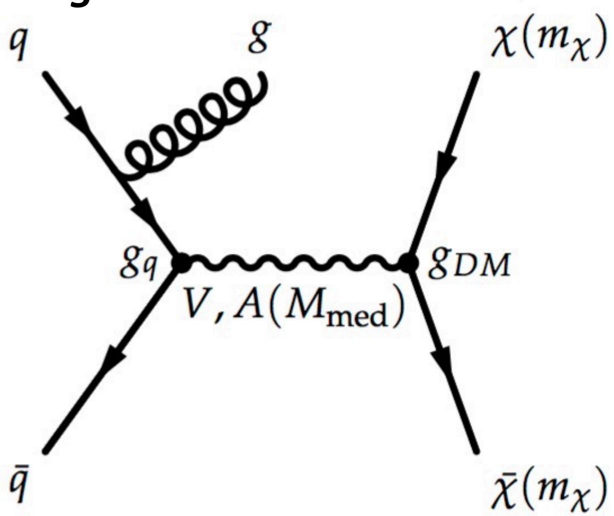


Mono-jet

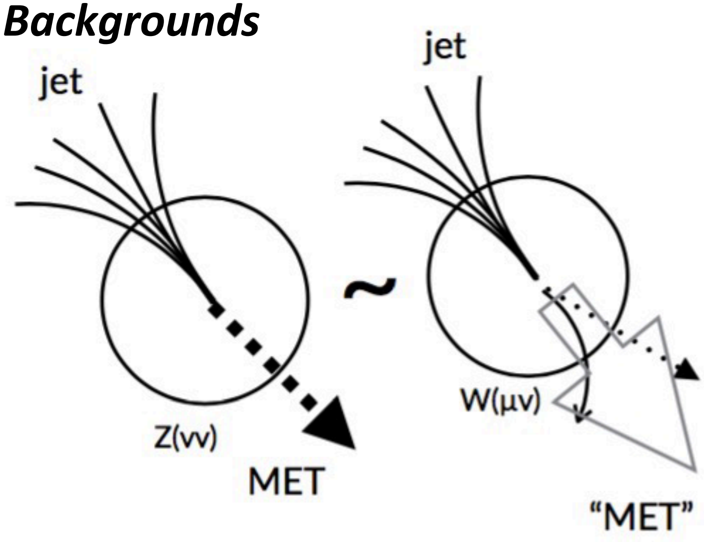


Inclusive and Exclusive signal regions with successively larger MET requirements

Signals

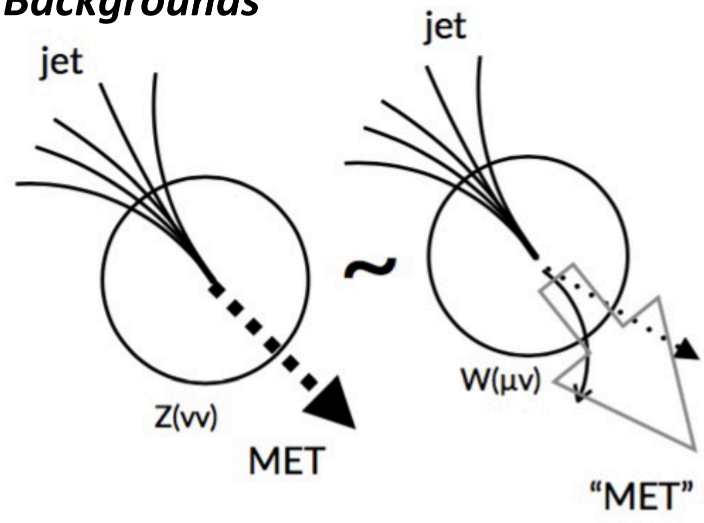


Backgrounds

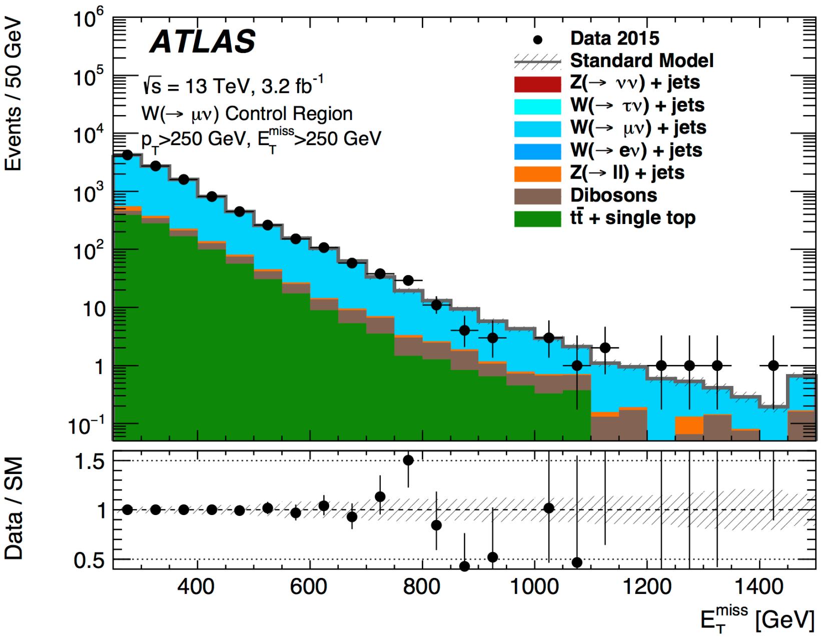


Mono-jet

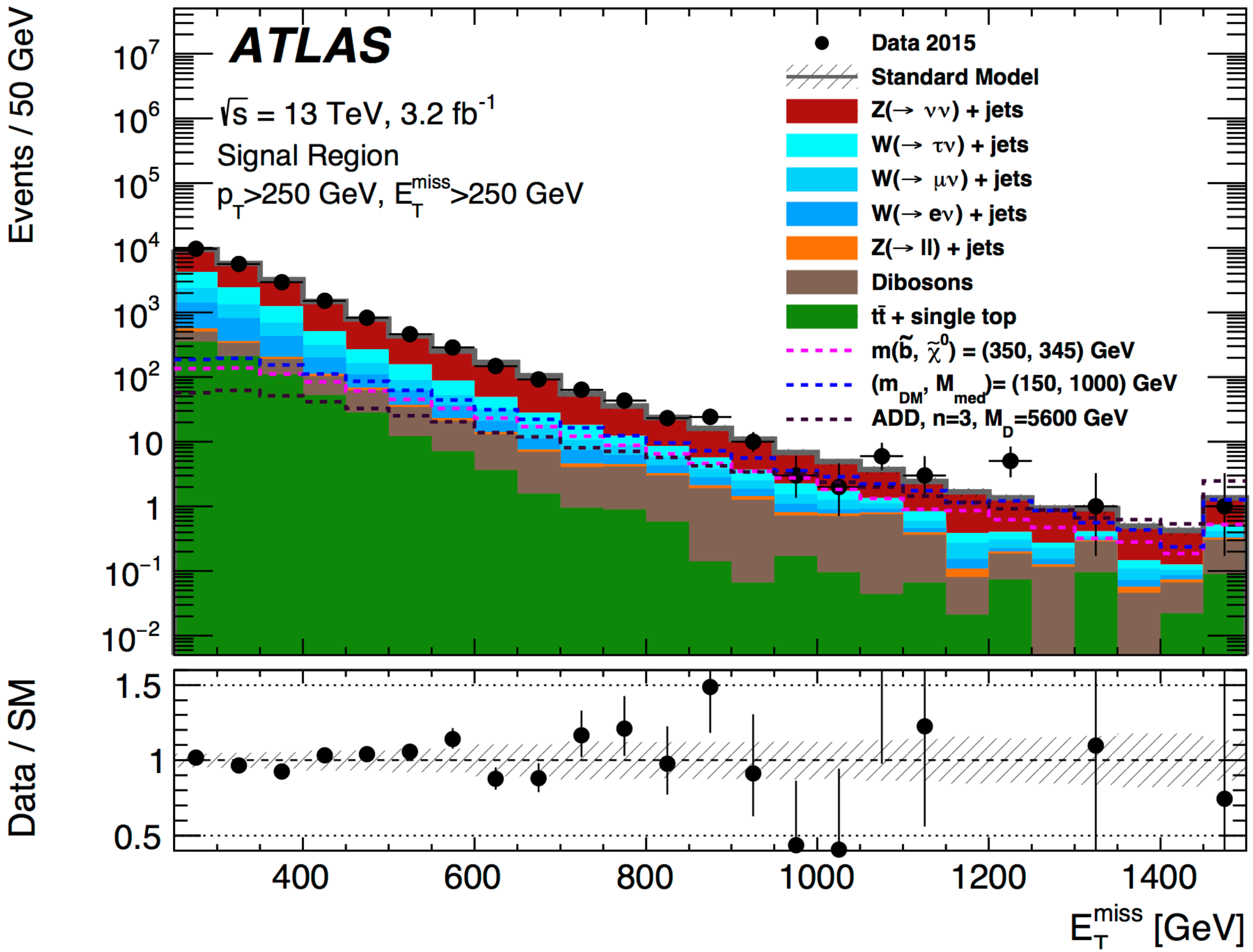
Backgrounds



One key challenge of the mono-jet analysis is modeling Z+jets and W+jets background at very high boson pT.
Check with visible W and Z decays, photon+jet (invisible decays of the Z occurs 6x more often than visible).



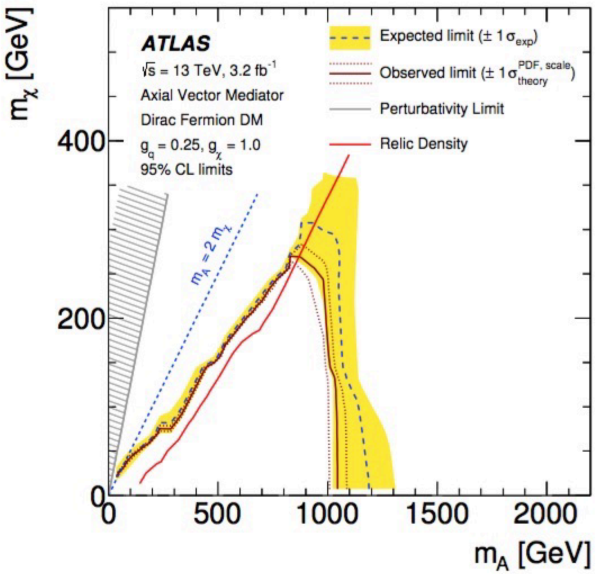
Mono-jet

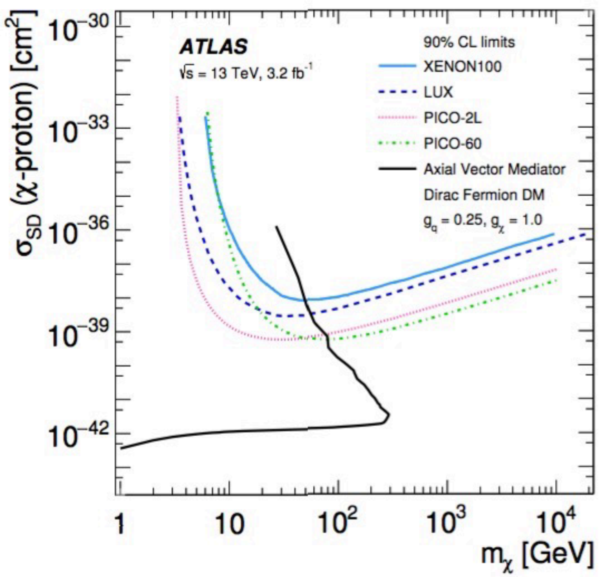

ATLAS
$\sqrt{s}$ = 13 TeV, 3.2 fb^{-1}
Signal Region
p_T>250 GeV, E_T^{miss}>250 GeV
Data 2015
Standard Model
Z(→ νν) + jets
W(→ τν) + jets
W(→ μν) + jets
W(→ eν) + jets
Z(→ ll) + jets
Dibosons
$t\bar{t}$ + single top
m($\tilde{b}$, $\tilde{\chi}^0$) = (350, 345) GeV
(m_{DM}, M_{med})= (150, 1000) GeV
ADD, n=3, M_D=5600 GeV
Events / 50 GeV
Data / SM
E_T^{miss} [GeV]

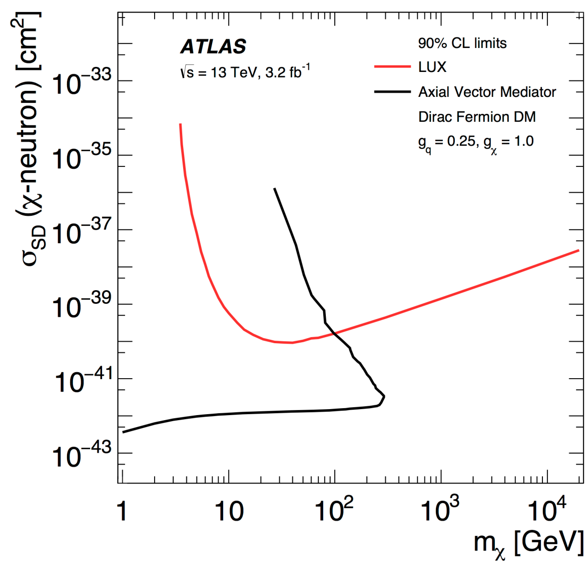
13 TeV Monojet results: Constraints on DM Simplified Models

Axial-vector simplified model:

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

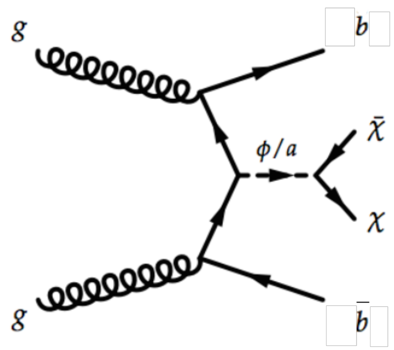




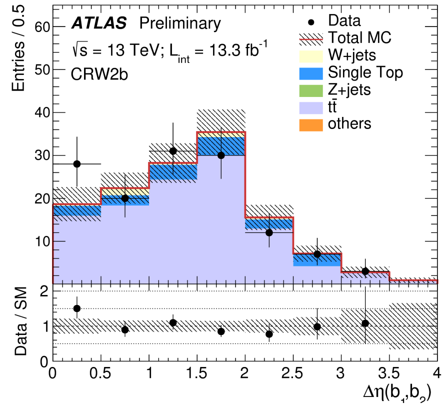


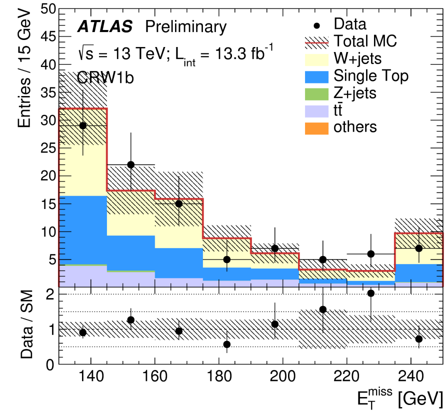
Translation from simplified model to nucleon-WIMP cross section described in arXiv:1603.04156

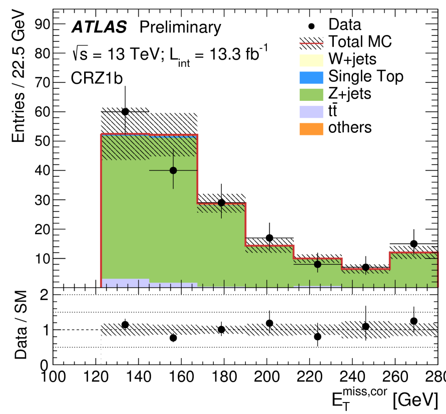
bjets+MET



Lowest order for spin-0 mediator production

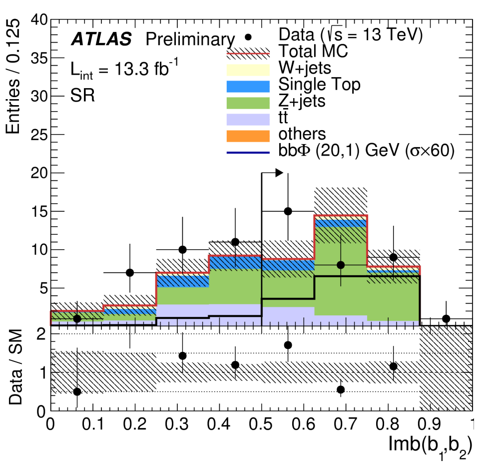


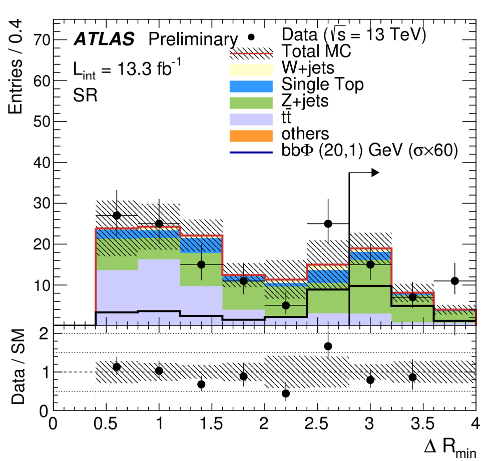


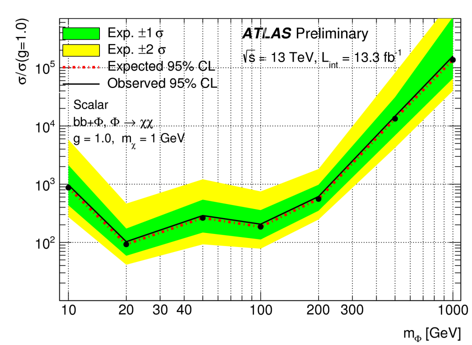


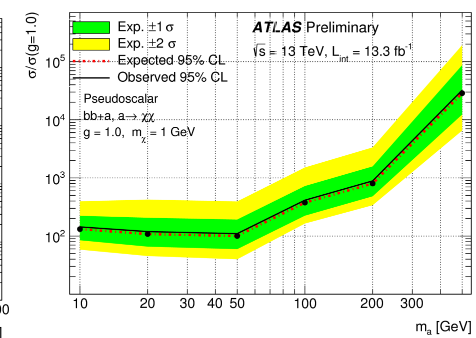
Representative distributions for the three control regions of the analysis. Backgrounds are normalised to the fit results.
The dominant post-fit systematic uncertainties are included in the systematic band.

[ATLAS-CONF-2016-086]()









Limits on scalar and pseudoscalar mediators

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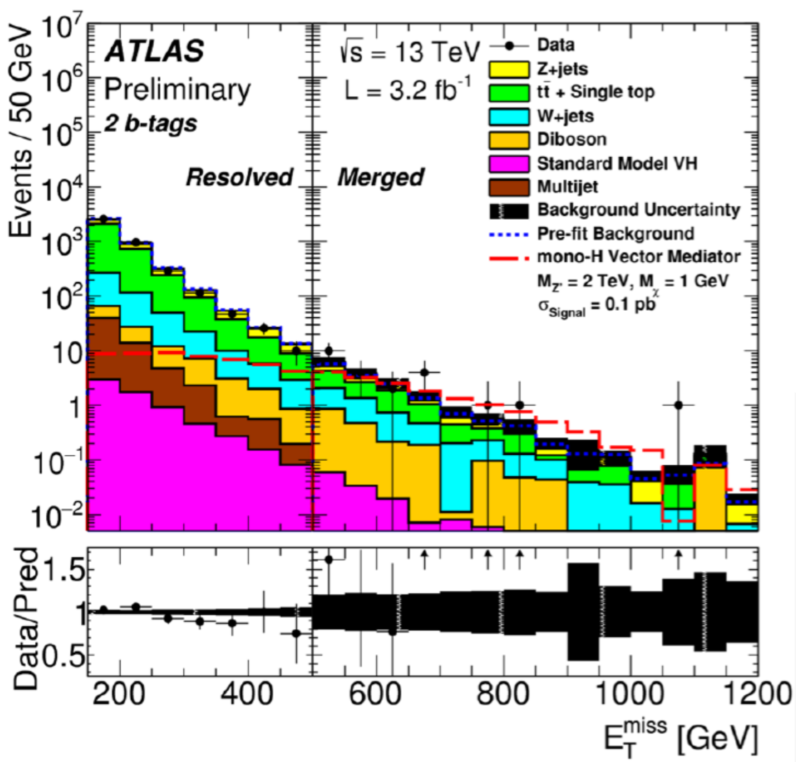
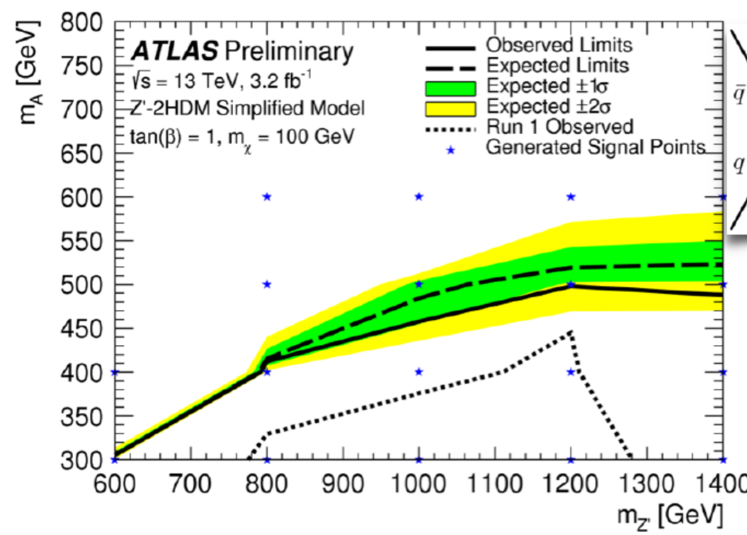
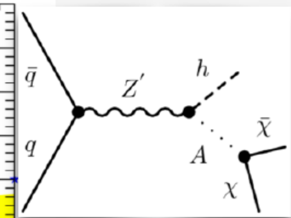
Higgs+MET

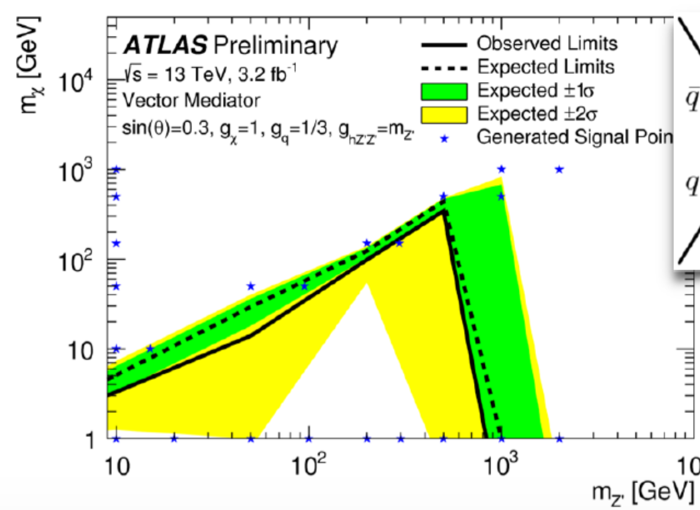
ATLAS-CONF-2016-019

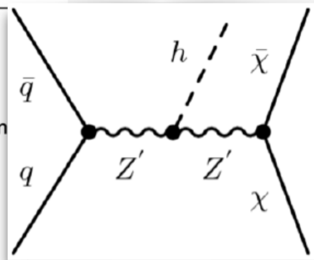
Higgs boson decaying to b quarks



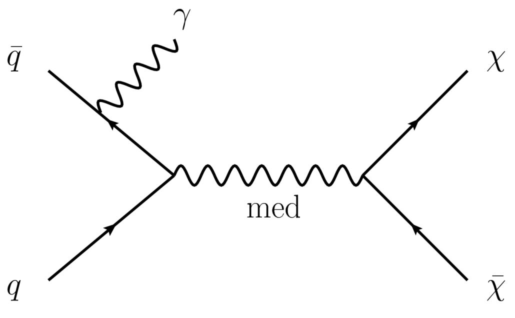


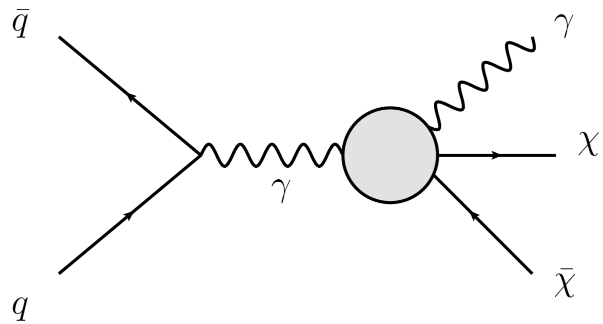


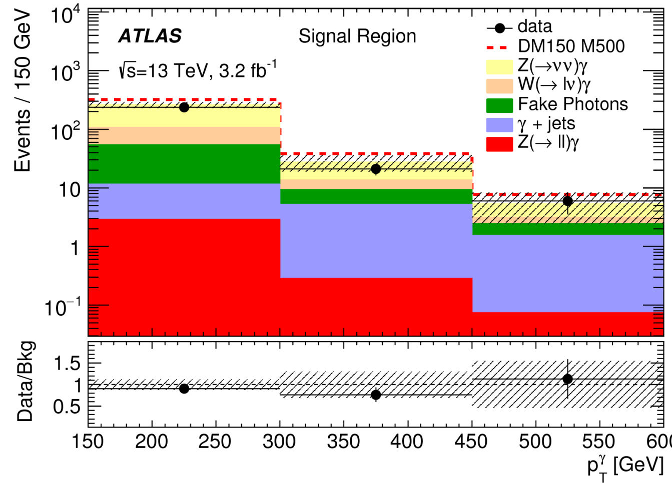


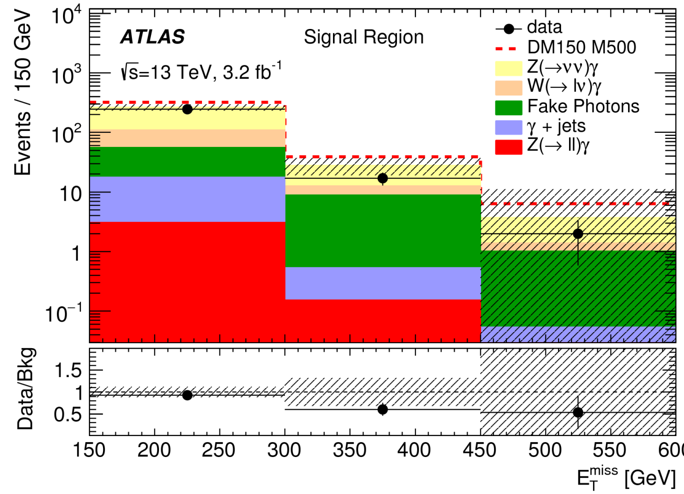


Mono-photon



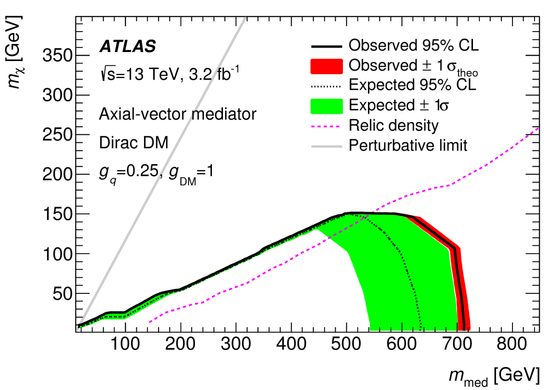


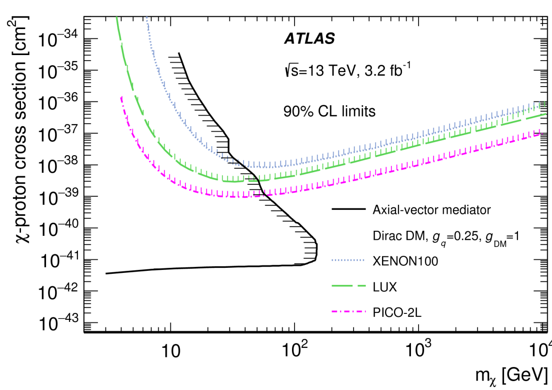




Similar strategy to mono-jet search:

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





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

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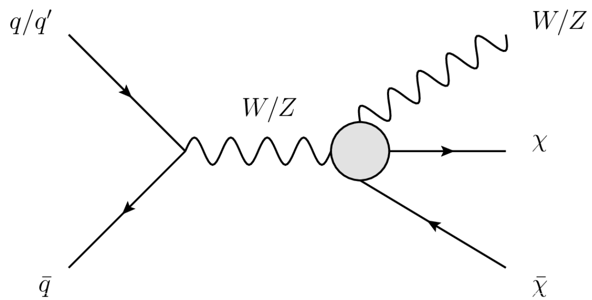
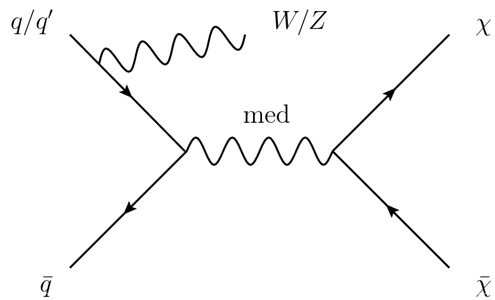
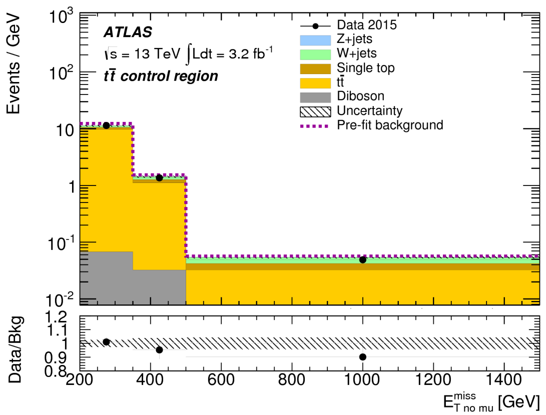
Mono-W/Z

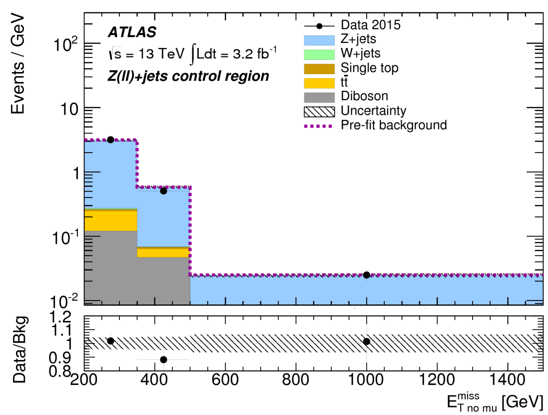


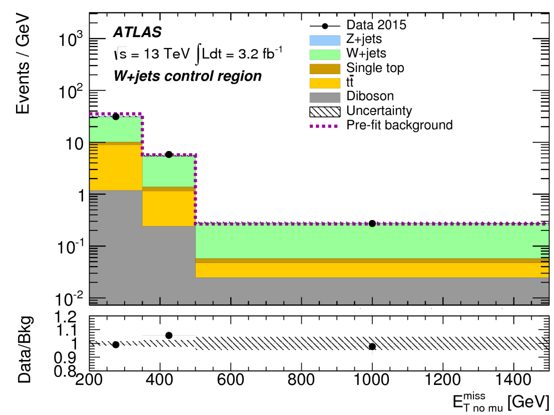


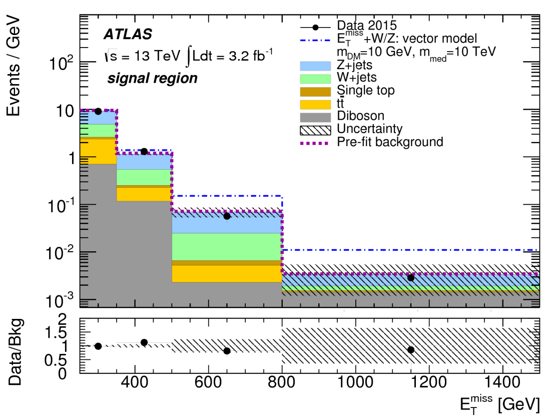
If instead we consider a hadronically decaying W or Z boson

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

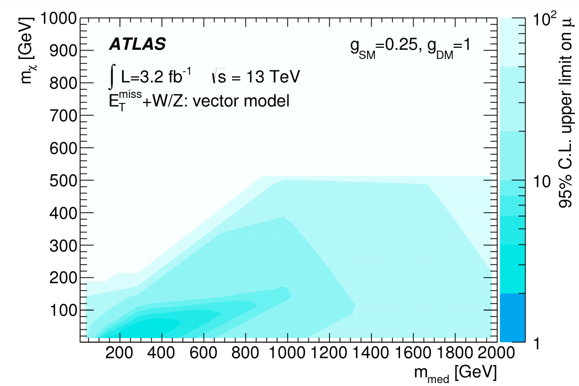








No excess leads us to set limits on the signal strength in the dark matter mass vs mediator mass plane



Resonance searches

ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 20.3)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

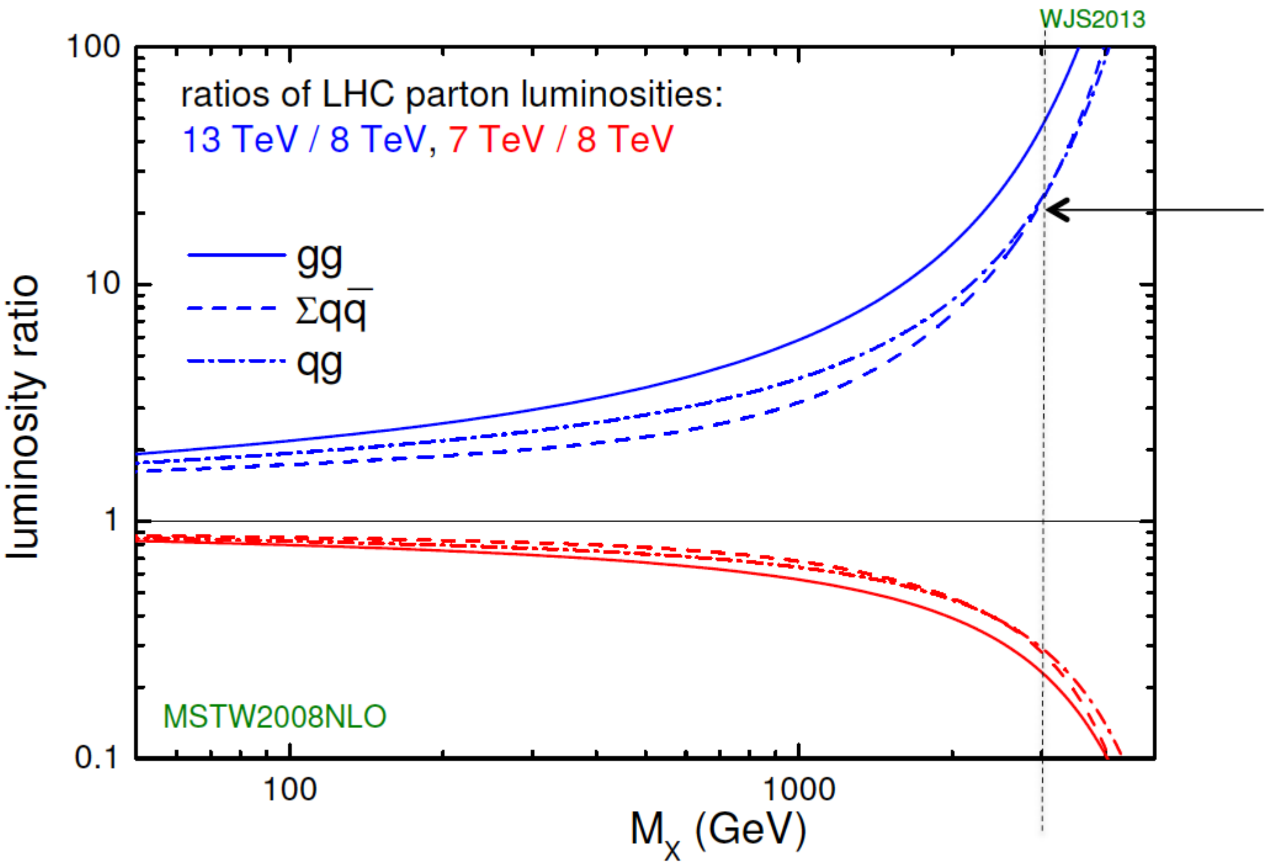
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt [\text{fb}^{-1}]$	$\sqrt{s}$	Limit		Reference
Extra dimensions	ADD $G_{KK}+g/q$	–	≥ 1 j	Yes	3.2	13 TeV	M_D 6.58 TeV	$n=2$	1604.07773
	ADD non-resonant $\ell\ell$	2 e,μ	–	–	20.3	8 TeV	M_S 4.7 TeV	$n=3$ HLZ	1407.2410
	ADD QBH $\to \ell q$	1 e,μ	1 j	–	20.3	8 TeV	M_{th} 5.2 TeV	$n=6$	1311.2006
	ADD QBH	–	2 j	–	15.7	13 TeV	M_{th} 8.7 TeV	$n=6$	ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	≥ 1 e,μ	≥ 2 j	–	3.2	13 TeV	M_{th} 8.2 TeV	$n=6$, $M_D=3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	13 TeV	M_{th} 9.55 TeV	$n=6$, $M_D=3$ TeV, rot BH	1512.02586
	RS1 $G_{KK}\to\ell\ell$	2 e,μ	–	–	20.3	8 TeV	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl}=0.1$	1405.4123
	RS1 $G_{KK}\to\gamma\gamma$	2 γ	–	–	3.2	13 TeV	G_{KK} mass 3.2 TeV	$k/\overline{M}_{Pl}=0.1$	1606.03833
	Bulk RS $G_{KK}\to WW\to qq\ell\nu$	1 e,μ	1 J	Yes	13.2	13 TeV	G_{KK} mass 1.24 TeV	$k/\overline{M}_{Pl}=1.0$	ATLAS-CONF-2016-062
	Bulk RS $G_{KK}\to HH\to bbbb$	–	4 b	–	13.3	13 TeV	G_{KK} mass 360-860 GeV	$k/\overline{M}_{Pl}=1.0$	ATLAS-CONF-2016-049
	Bulk RS $g_{KK}\to tt$	1 e,μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	8 TeV	g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e,μ	≥ 2 b, ≥ 4 j	Yes	3.2	13 TeV	KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)}\to tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z'\to\ell\ell$	2 e,μ	–	–	13.3	13 TeV	Z' mass 4.05 TeV		ATLAS-CONF-2016-045
	SSM $Z'\to\tau\tau$	2 τ	–	–	19.5	8 TeV	Z' mass 2.02 TeV		1502.07177
	Leptophobic $Z'\to bb$	–	2 b	–	3.2	13 TeV	Z' mass 1.5 TeV		1603.08791
	SSM $W'\to\ell\nu$	1 e,μ	–	Yes	13.3	13 TeV	W' mass 4.74 TeV		ATLAS-CONF-2016-061
	HVT $W'\to WZ\to qq\nu\nu$ model A	0 e,μ	1 J	Yes	13.2	13 TeV	W' mass 2.4 TeV	$g_V=1$	ATLAS-CONF-2016-082
	HVT $W'\to WZ\to qqqq$ model B	–	2 J	–	15.5	13 TeV	W' mass 3.0 TeV	$g_V=3$	ATLAS-CONF-2016-055
	HVT $V'\to WH/ZH$ model B	multi-channel			3.2	13 TeV	V' mass 2.31 TeV	$g_V=3$	1607.05621
	LRSM $W'_R\to tb$	1 e,μ	2 b, 0-1 j	Yes	20.3	8 TeV	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R\to tb$	0 e,μ	≥ 1 b, 1 J	–	20.3	8 TeV	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	15.7	13 TeV	Λ 19.9 TeV	$\eta_{LL}=-1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	2 e,μ	–	–	3.2	13 TeV	Λ 25.2 TeV	$\eta_{LL}=-1$	1607.03669
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	8 TeV	Λ 4.9 TeV	$\lvert C_{RR}\rvert=1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e,μ	≥ 1 j	Yes	3.2	13 TeV	m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi)$ < 250 GeV	1604.07773
	Axial-vector mediator (Dirac DM)	0 e,μ, 1 γ	1 j	Yes	3.2	13 TeV	m_A 710 GeV	g_q=0.25, g_χ=1.0, $m(\chi)$ < 150 GeV	1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e,μ	1 J, ≤ 1 j	Yes	3.2	13 TeV	M_* 550 GeV	$m(\chi)$ < 150 GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	13 TeV	LQ mass 1.1 TeV	$\beta=1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	13 TeV	LQ mass 1.05 TeV	$\beta=1$	1605.06035
	Scalar LQ 3rd gen	1 e,μ	≥1 b, ≥3 j	Yes	20.3	8 TeV	LQ mass 640 GeV	$\beta=0$	1508.04735
Heavy quarks	VLQ $TT\to Ht+X$	1 e,μ	≥ 2 b, ≥ 3 j	Yes	20.3	8 TeV	T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY\to Wb+X$	1 e,μ	≥ 1 b, ≥ 3 j	Yes	20.3	8 TeV	Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB\to Hb+X$	1 e,μ	≥ 2 b, ≥ 3 j	Yes	20.3	8 TeV	B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB\to Zb+X$	2/≥3 e,μ	≥2/≥1 b	–	20.3	8 TeV	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ\to WqWq$	1 e,μ	≥ 4 j	Yes	20.3	8 TeV	Q mass 690 GeV		1509.04261
	VLQ $T_{5/3}T_{5/3}\to WtWt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	3.2	13 TeV	$T_{5/3}$ mass 990 GeV		ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^*\to q\gamma$	1 γ	1 j	–	3.2	13 TeV	q^* mass 4.4 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1512.05910
	Excited quark $q^*\to qg$	–	2 j	–	15.7	13 TeV	q^* mass 5.6 TeV	only u^* and d^*, $\Lambda=m(q^*)$	ATLAS-CONF-2016-069
	Excited quark $b^*\to bg$	–	1 b, 1 j	–	8.8	13 TeV	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^*\to Wt$	1 or 2 e,μ	1 b, 2-0 j	Yes	20.3	8 TeV	b^* mass 1.5 TeV	$f_g=f_L=f_R=1$	1510.02664
	Excited lepton ℓ^*	3 e,μ	–	–	20.3	8 TeV	ℓ^* mass 3.0 TeV	$\Lambda=3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e,μ,τ	–	–	20.3	8 TeV	ν^* mass 1.6 TeV	$\Lambda=1.6$ TeV	1411.2921
Other	LSTC $a_T\to W\gamma$	1 e,μ, 1 γ	–	Yes	20.3	8 TeV	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e,μ	2 j	–	20.3	8 TeV	N^0 mass 2.0 TeV	$m(W_R)=2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm}\to ee$	2 e (SS)	–	–	13.9	13 TeV	$H^{\pm\pm}$ mass 570 GeV	DY production, BR($H_L^{\pm\pm}\to ee$)=1	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm}\to\ell\tau$	3 e,μ,τ	–	–	20.3	8 TeV	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm}\to\ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e,μ	1 b	Yes	20.3	8 TeV	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}}=0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	8 TeV	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert=5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	8 TeV	monopole mass 1.34 TeV	DY production, $\lvert g\rvert=1g_D$, spin 1/2	1509.08059

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

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

*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

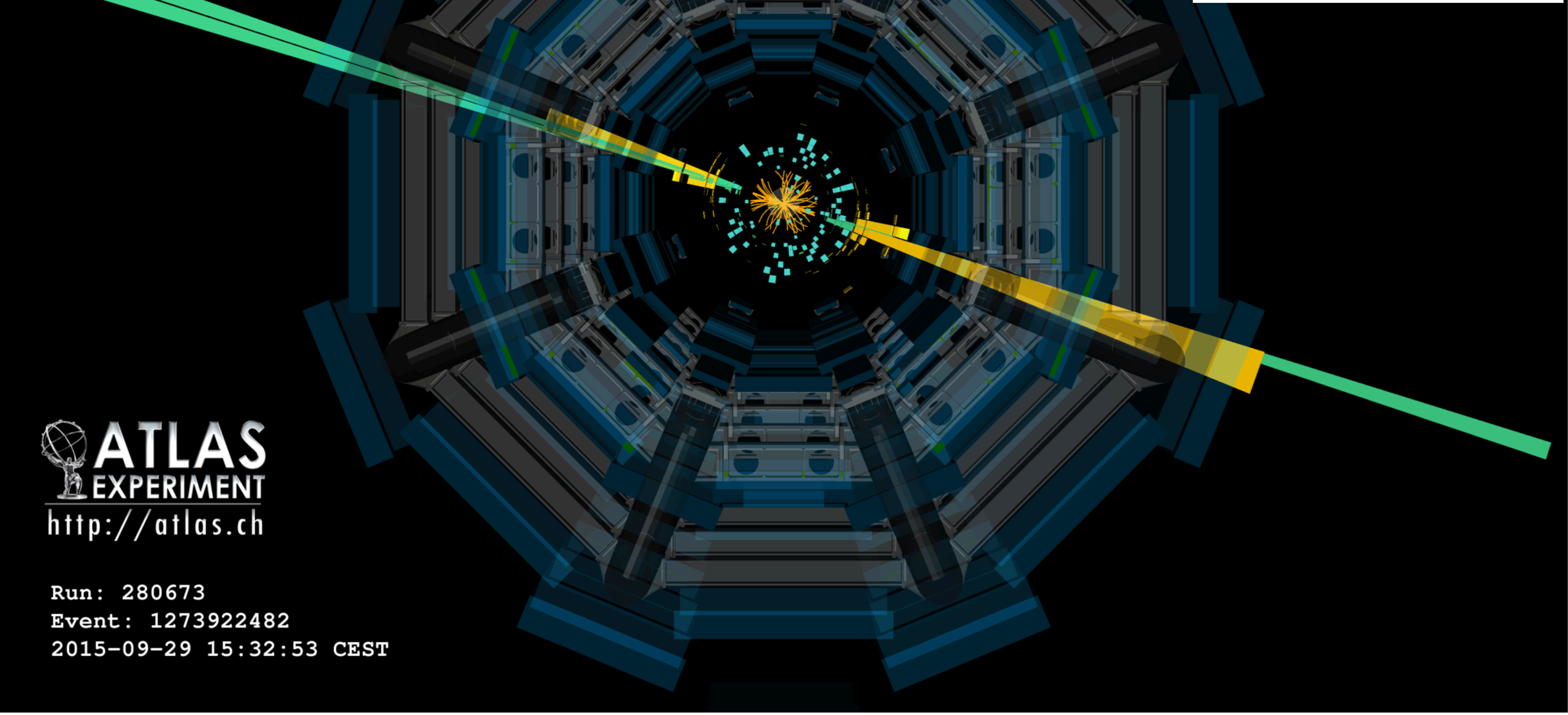
†Small-radius (large-radius) jets are denoted by the letter j (J).

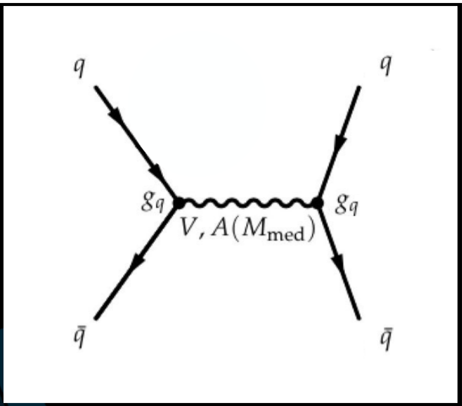


Ratio of 13 TeV / 8 TeV Cross sections:

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

Di-jet resonance

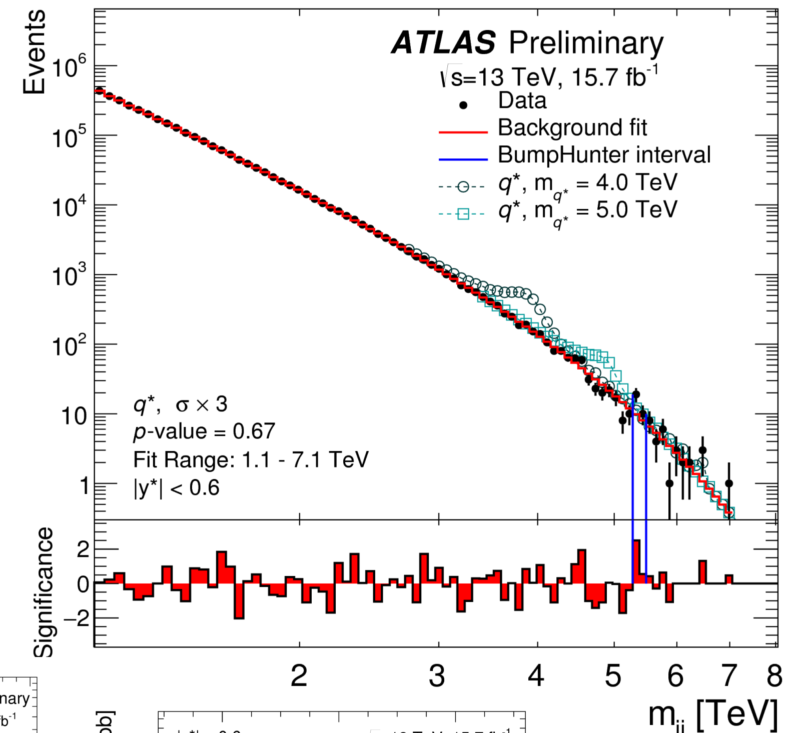


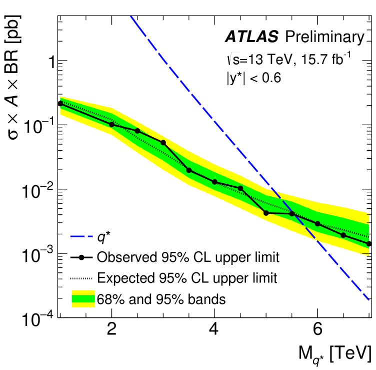


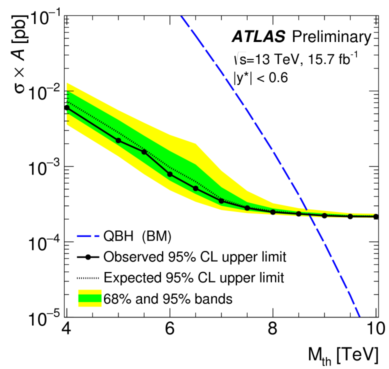
Di-Jets

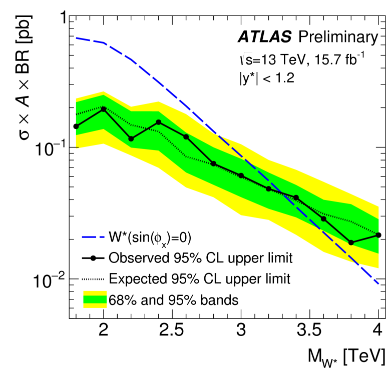
- **Update on Dijet resonance search – 15.7fb^{-1}**
- Dijet search for a peaking signal in invariant mass spectrum
- Models: Sensitive to Quantum Black Holes, excited quarks, W' and Z'
- Backgrounds: Using simple analytic fit function
- Using *Bump Hunter* technique to identify the most significant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

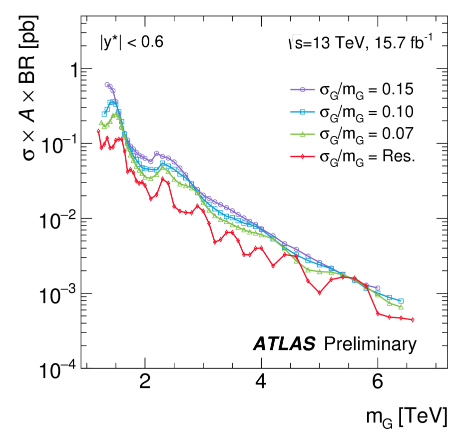
ATLAS-CONF-2016-069









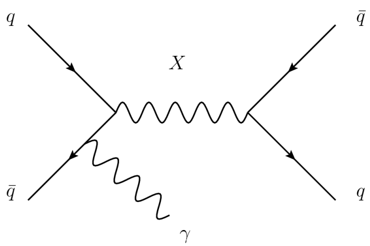


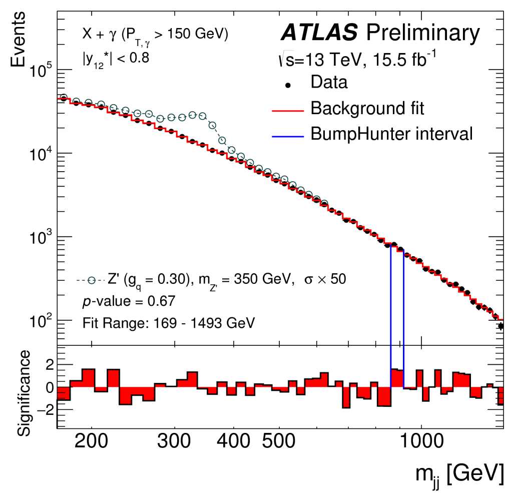
Limits on QBH at ~9TeV at 95% CL with 2016 data

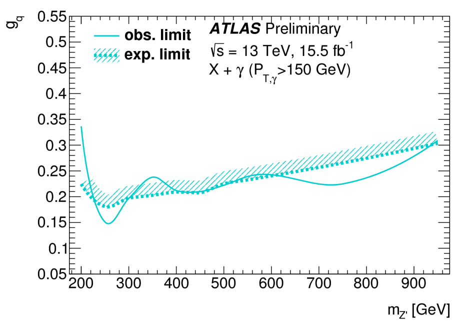
Di-Jets – low mass

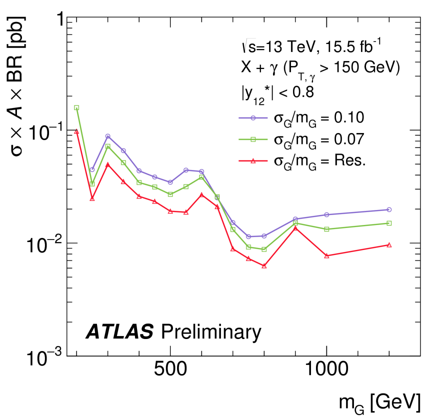
- Use dijet events with an extra photon (left) or jet(right) from ISR – with 15.5fb^{-1}

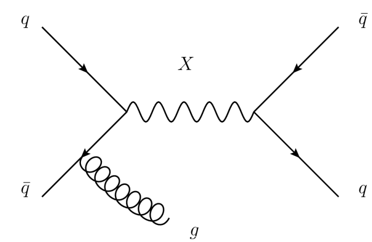
ATLAS-CONF-2016-070

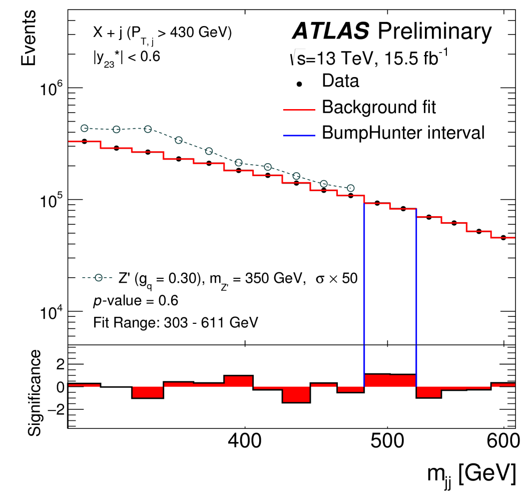


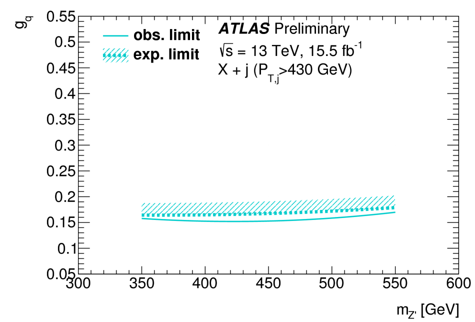


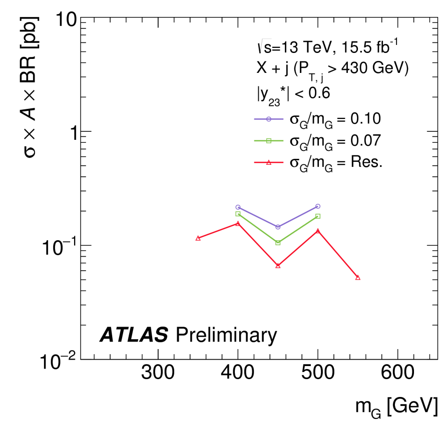










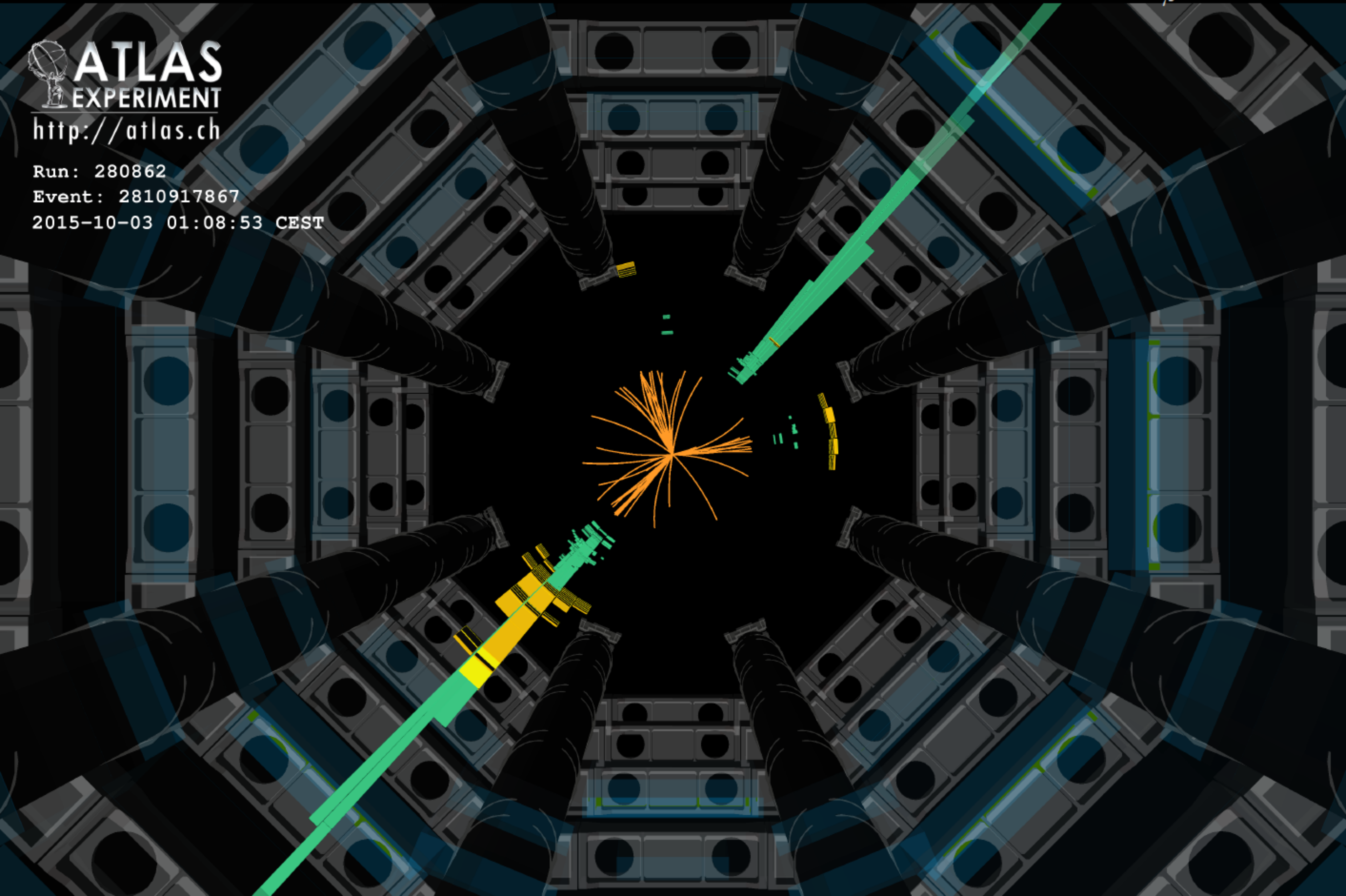


Photon-Jet Event

High Mass Photon-Jet

ET_1 =1.23 GeV ET_2 = 1.26 GeV

$m_{\gamma J}$ = 2.9TeV

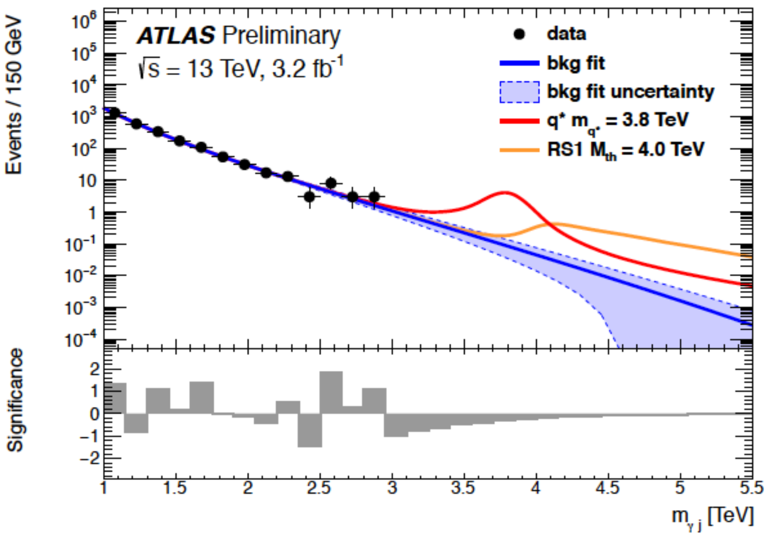


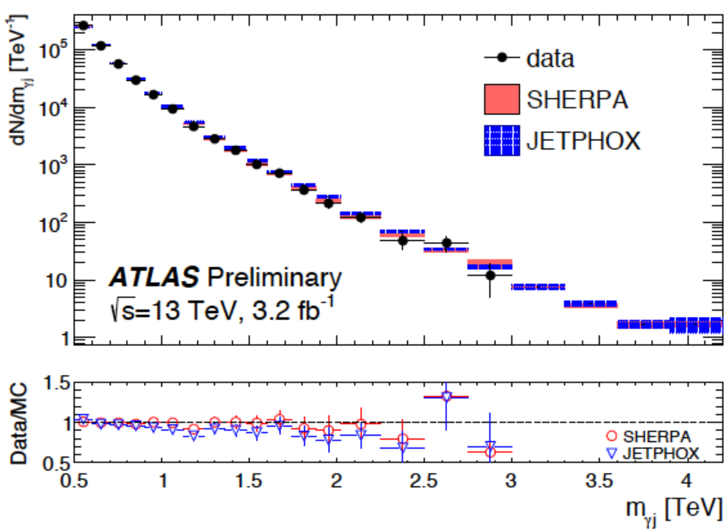
Search for q* or **QBH** decaying to a photon and a parton

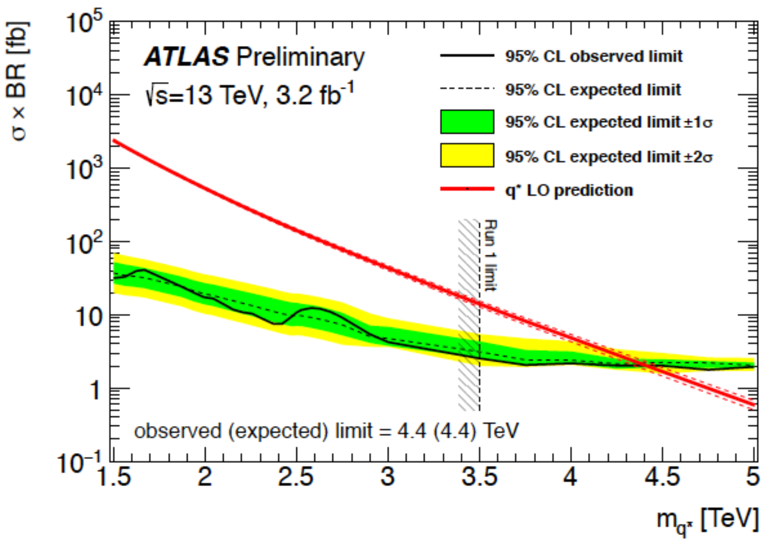
- **Background** estimated using a simple fit function similar to dijet search and extrapolate in the high mass domain

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

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







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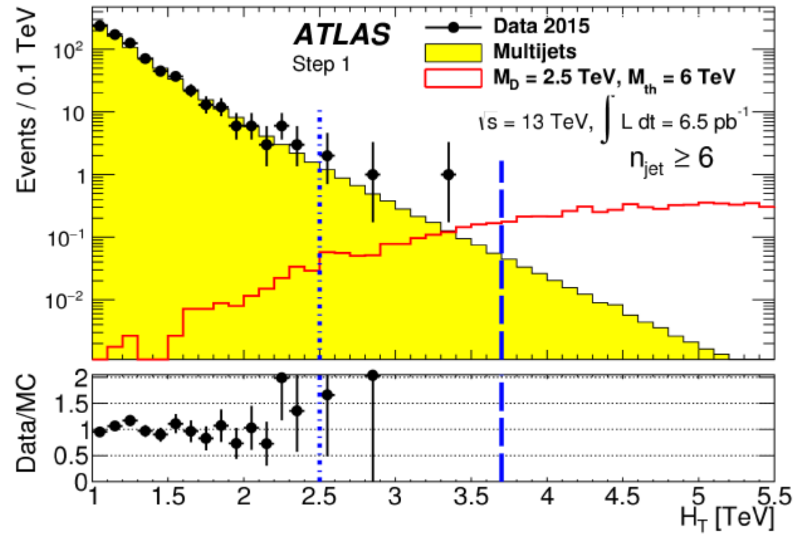
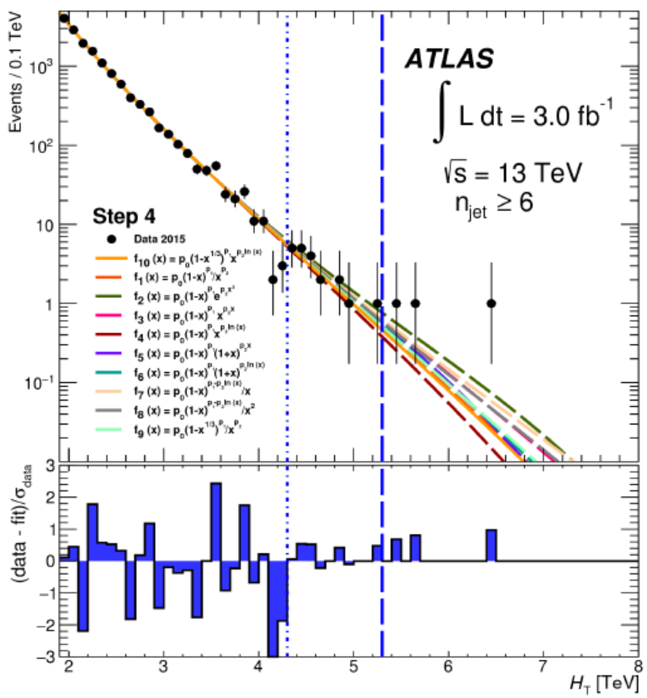
Search for new phenomena in Multi-Jet events

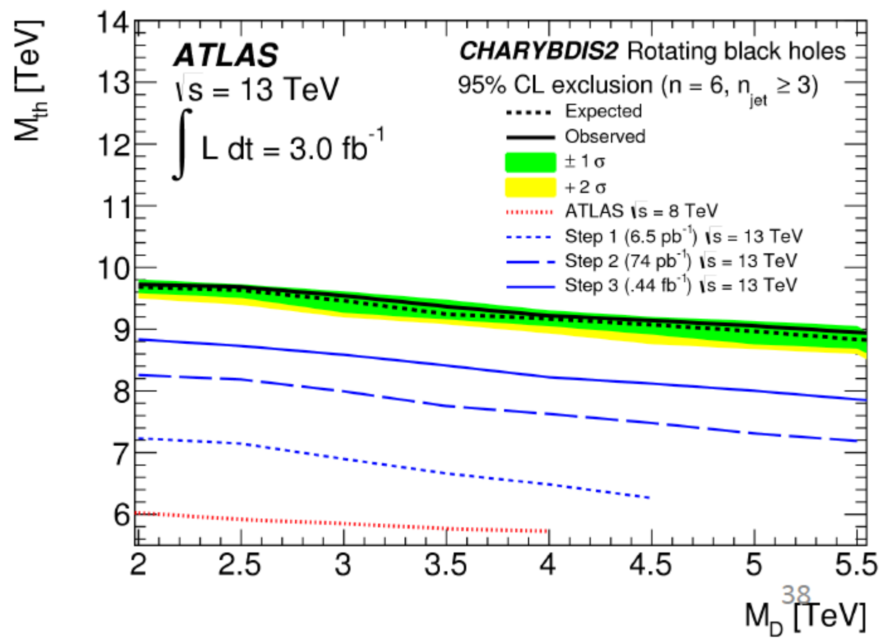
1512.02586

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)

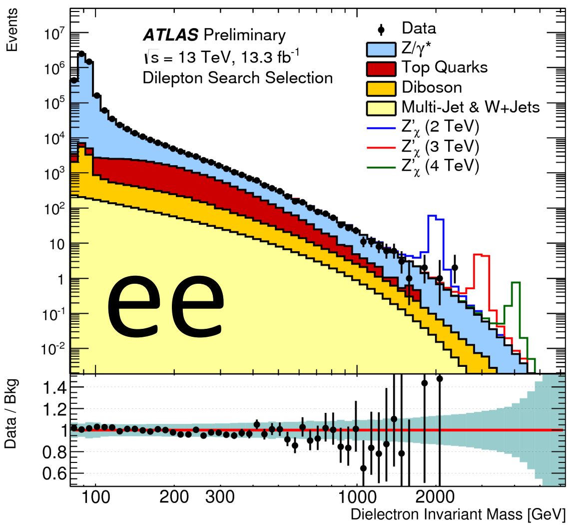


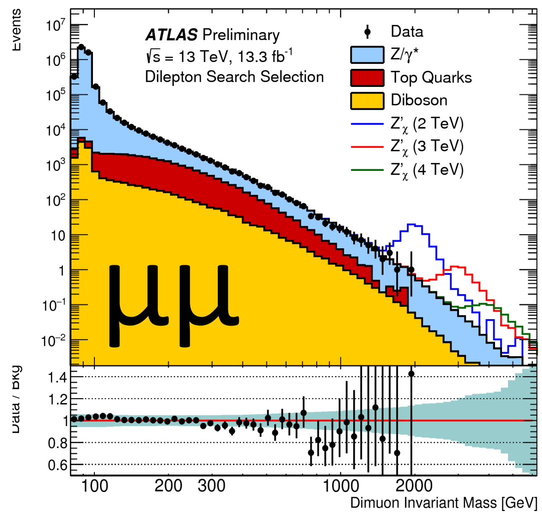


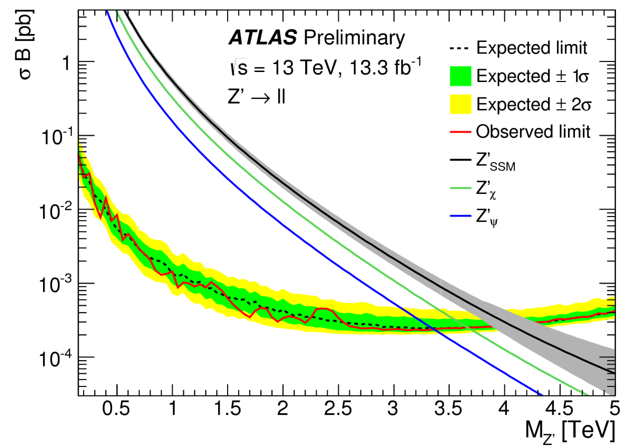


Di-lepton Resonances (LFC)

- Search for Z' in dilepton (LFC) ATLAS-CONF-2016-045
  - Main background DY is taken from MC
  - Top and diboson extrapolated at very high masses using a functional form
  - Backgrounds taken from MC except for multi-jet in dielectron which uses Matrix method (based on electron ID)







Highest dielectron mass at 2.2TeV

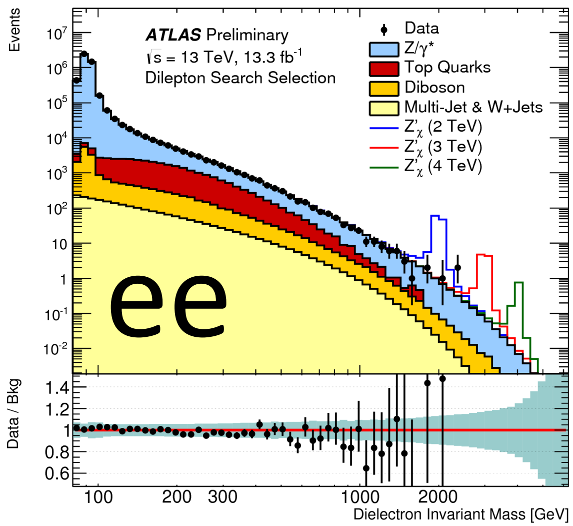
Highest dimuon mass at 2TeV

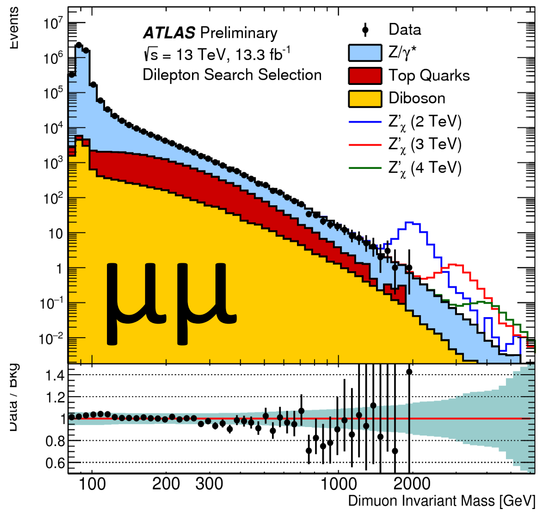
No excesses found!

95% CL limit on SSM Z' at 4TeV (2.9TeV from Run 1)

Di-lepton Resonances (LFC and LFV)

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



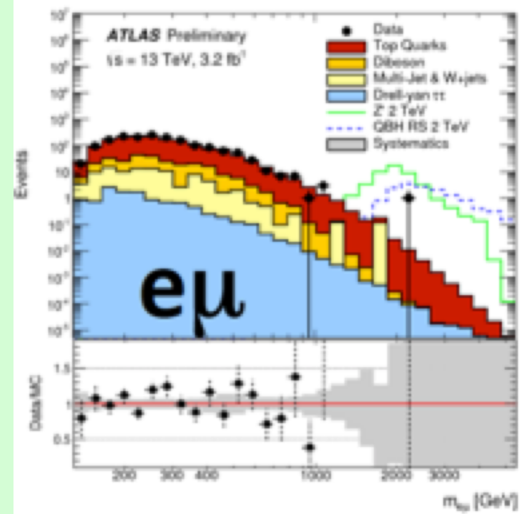


Highest dielectron mass at 2.2TeV

Highest dimuon mass at 2TeV

No excesses found!

95% CL limit on SSM Z' at 4TeV (2.9TeV from Run 1)



Highest eμ mass event at 2.1 TeV

95% CL Limit on SSM LFV Z' at 3.0 TeV (2.5 TeV from Run-1) 40

THE UNIVERSITY of ADELAIDE

CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

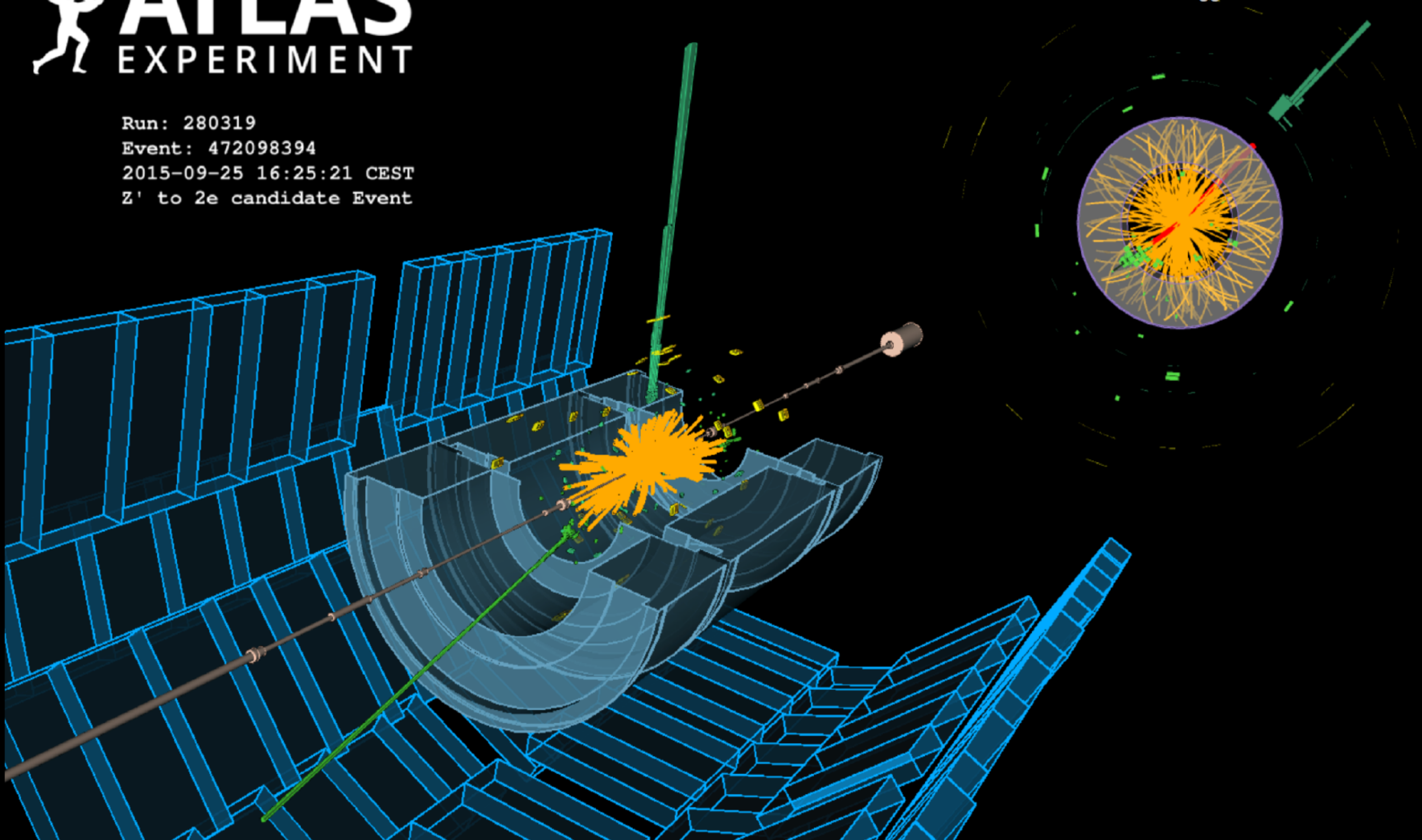
Di-Electron Event

High Mass Dielectron

$ET_1 = 370$ GeV $ET_2 = 246$ GeV

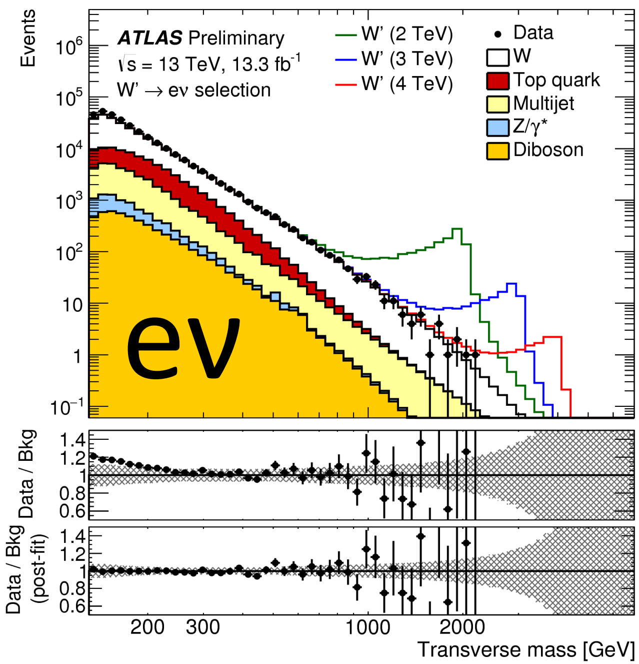
$m_{ee} = 1.8$ TeV

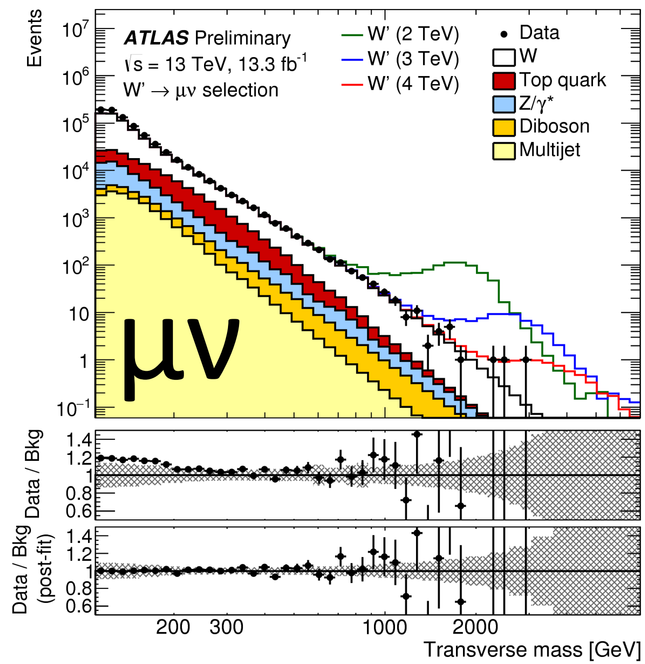
ATLAS EXPERIMENT

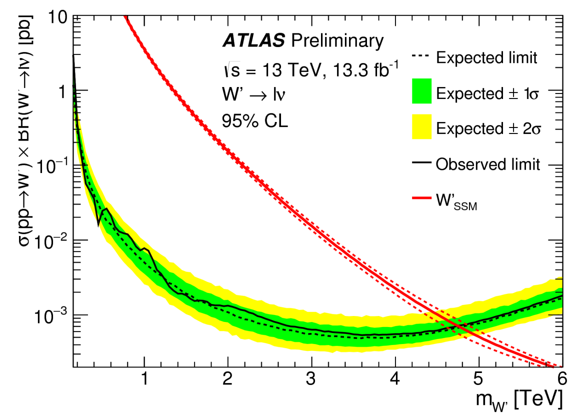


Search for Resonant Lepton+MET

- Search for Resonant Lepton-MET [ATLAS-CONF-2016-061]
  - Primarily a search for W'
  - Top and diboson extrapolated at very high masses using a functional form
  - Backgrounds taken from MC except for multi-jet which is estimated using Matrix method (based on electron ID)



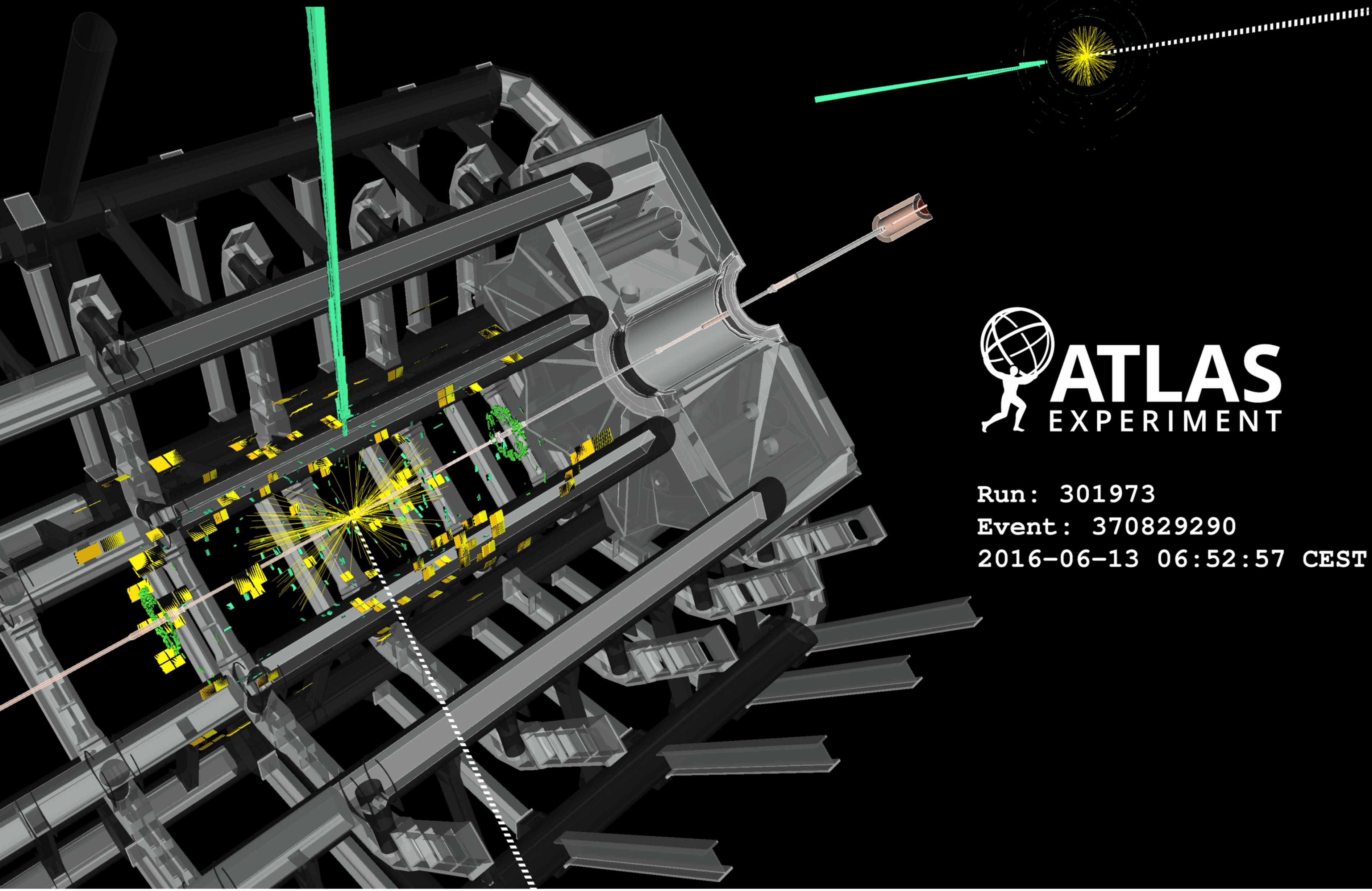




No excesses found!

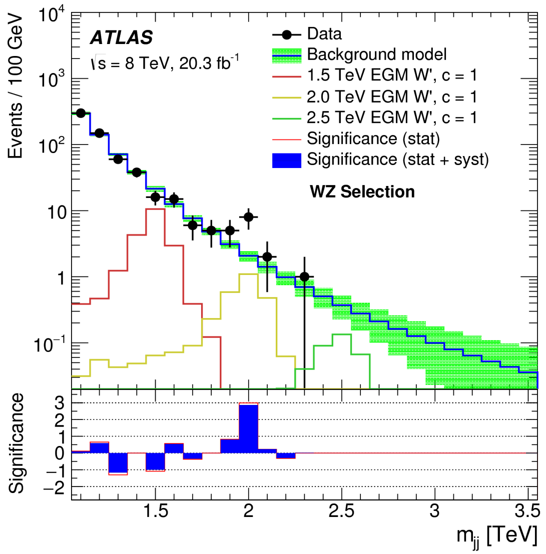
95% CL limit on SSM Z' at 4.7TeV (3.2TeV from Run 1)

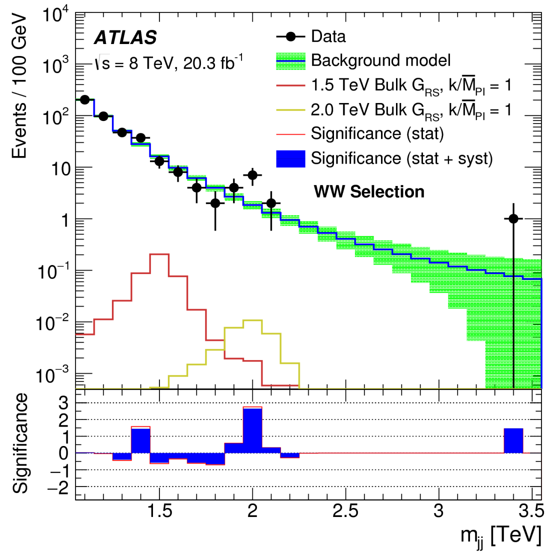
W’ -> eν candidate

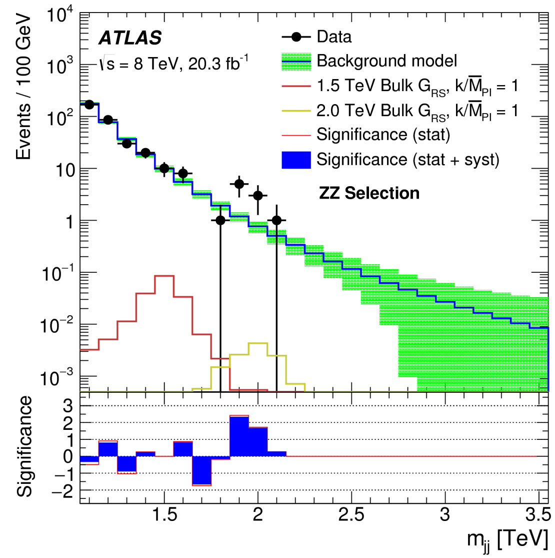


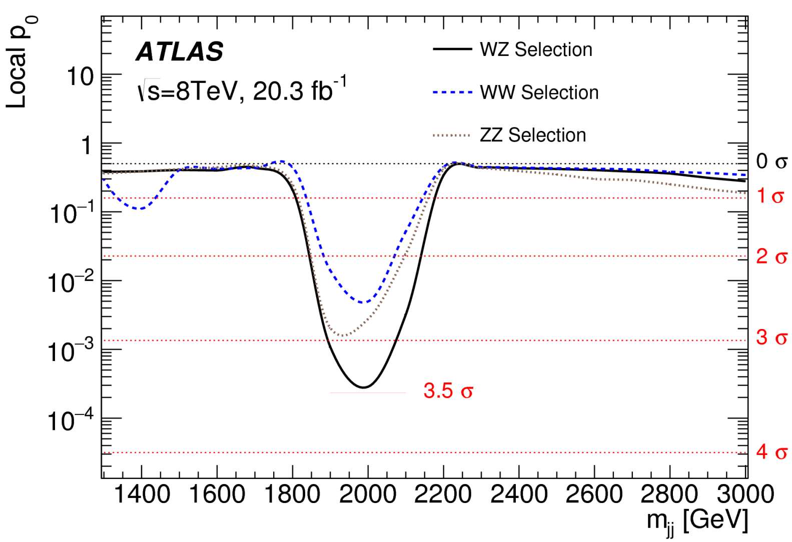
Di-boson resonance searches

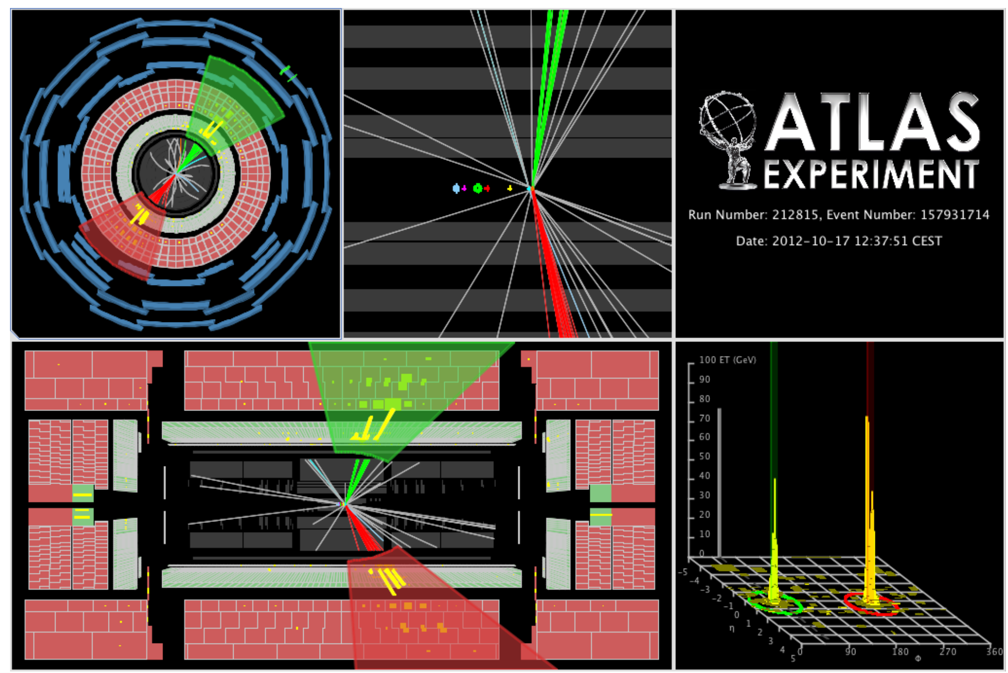
Exotics: Run1 - diboson resonances with boson-tagged jets





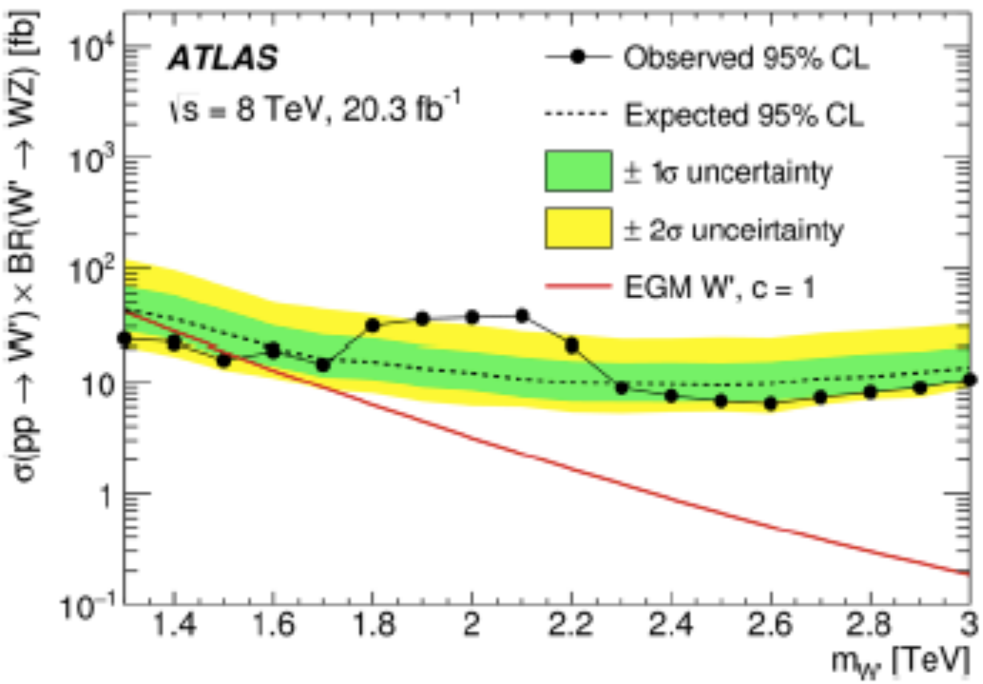


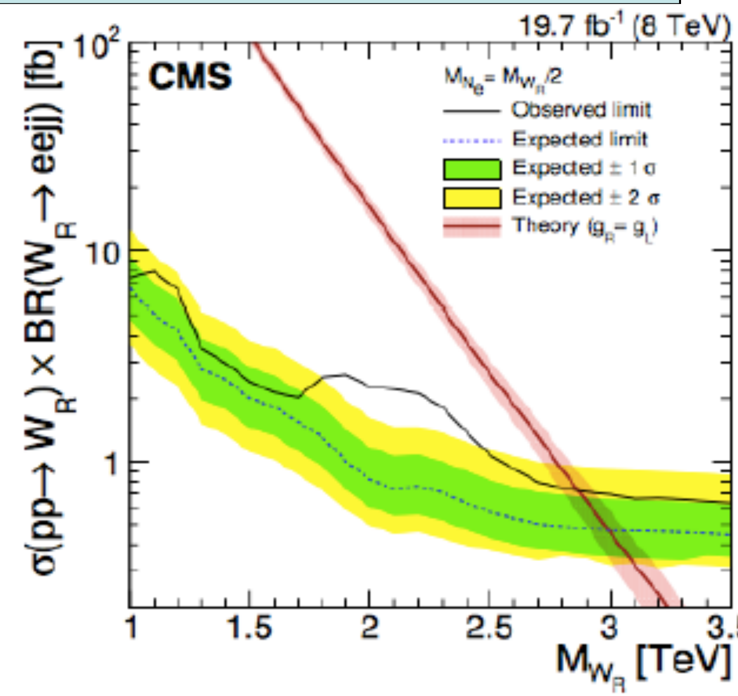




Exotics: Run1 - diboson resonances with boson-tagged jets

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





Seen at both ATLAS and CMS!

From J Ellis, LP15

Exciting @ Run 2!

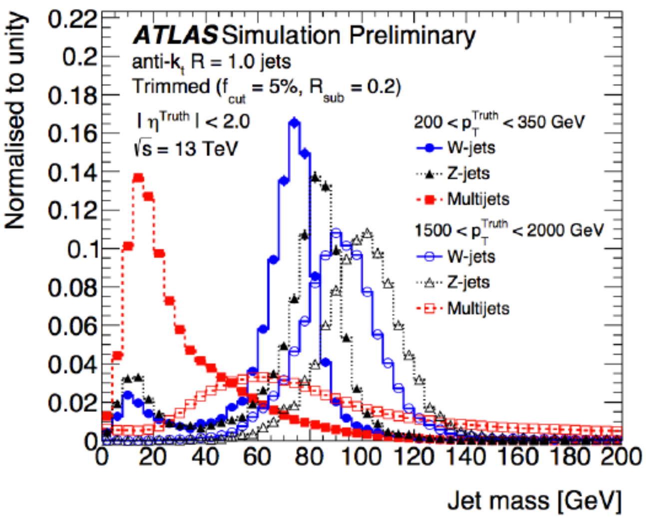
Searches for VV or VH resonances in several topologies involving boson (W, Z and H) tagging

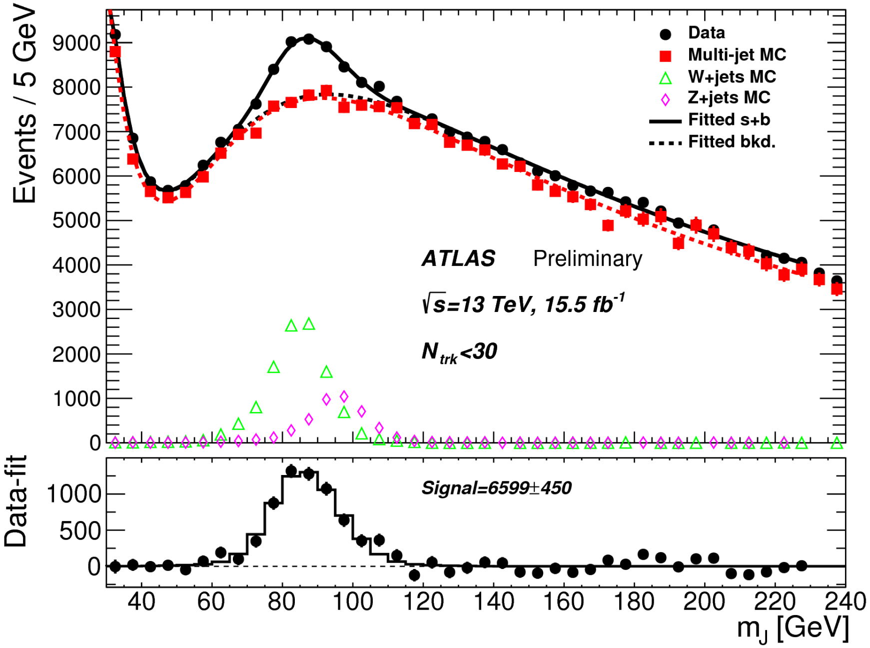
Nominal boson tagging algorithm

- 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

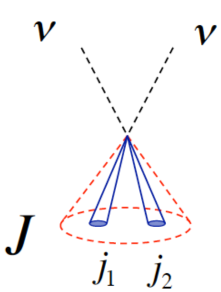
W and Z peak in the data from dijet events applying the nominal boson tagging algorithm





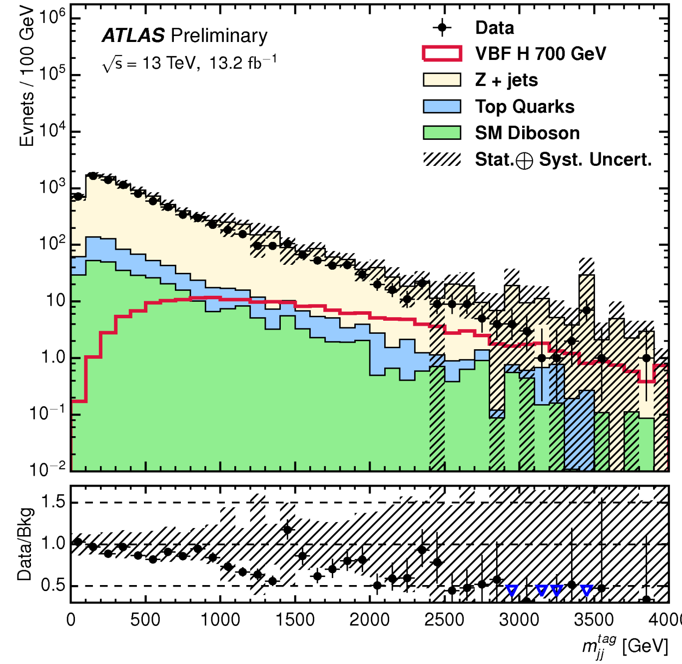
Searches for Resonance in Di-Boson VV Final States

ZV (with Z to **νν**)

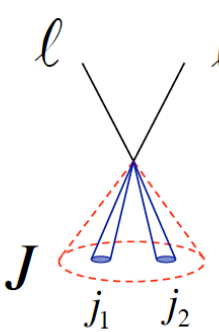


Backgrounds

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.



ZV (with Z to **dilepton**)

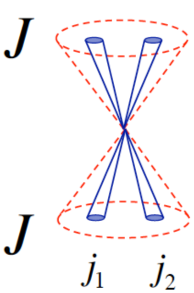


Backgrounds

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

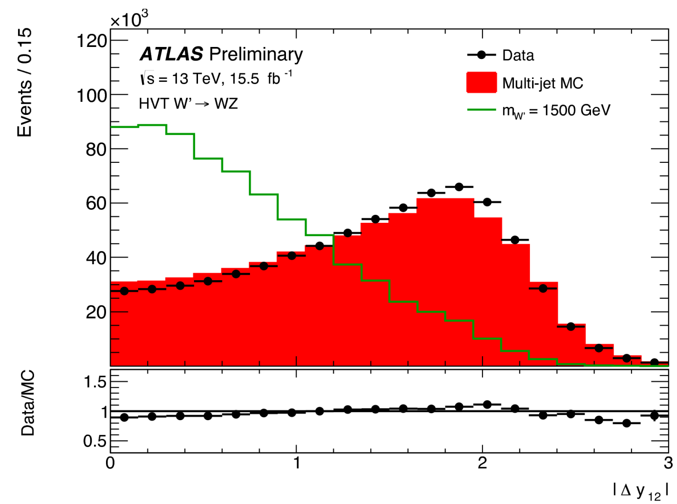
Diboson and top from MC

VV to JJ



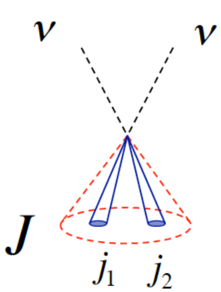
Background

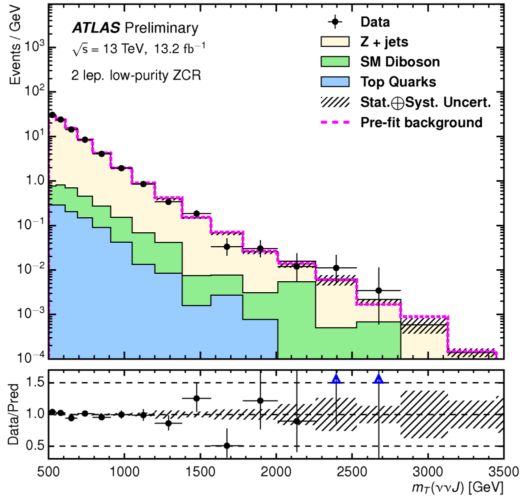
Estimated using a functional form

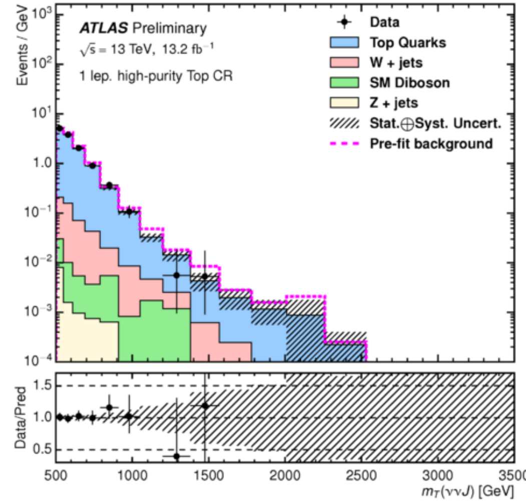


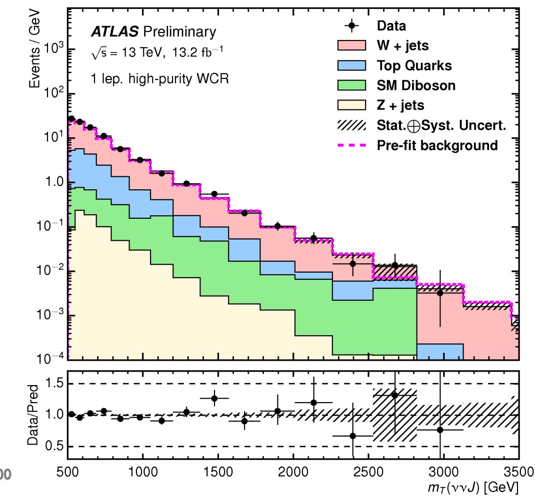
Searches for Resonance in Di-Boson ZV Final States

ZV (with Z to **νν**)

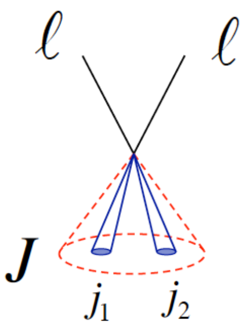




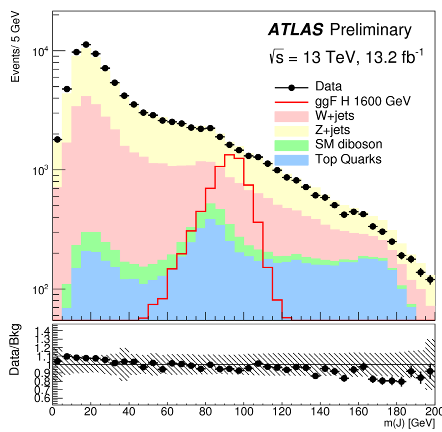


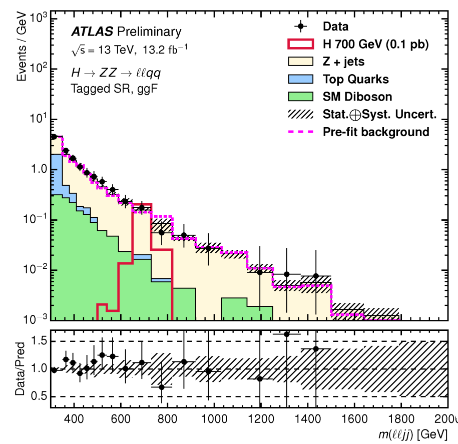


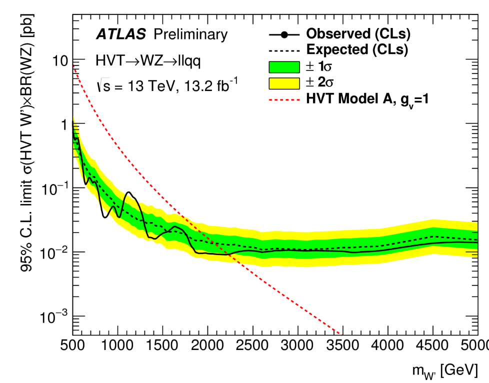
ZV (with Z to **dilepton**)



Z, Top and W Control Regions show good agreement with background predictions.





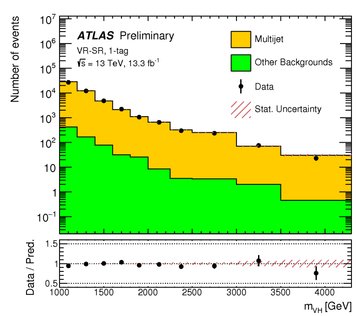


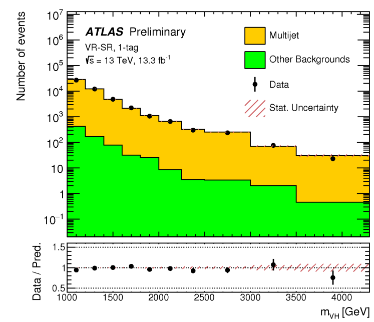
With no excess, we place limits on a variety of scenarios with limits at 95% CL ranging up to 2TeV.

Searches in Di-Boson in VH final states

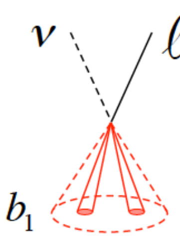
- Search in Diboson VH final
- Analysis strategy: distinct signal regions for 1L-MET and 2L with at least two jets with 1 or 2 btags (2 btags harder to distinguish against at high pT)
- Analysis strategy: perform a global fit to all the regions simultaneously (similar to SM VH analysis in Run-1)

Validation regions for 1- and 2-btags in good agreement

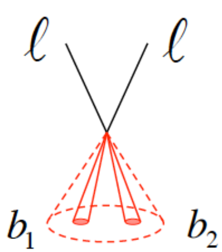




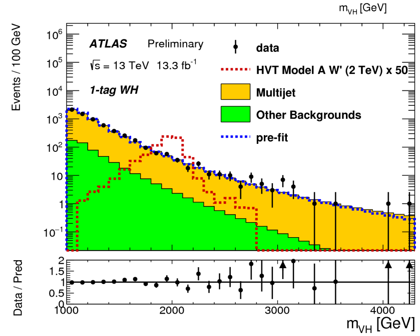
[ATLAS-CONF-2016-083]

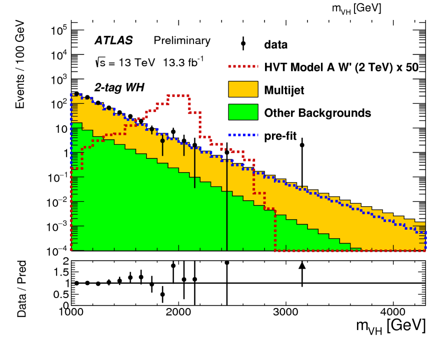


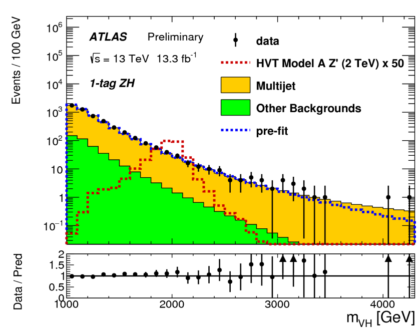
WH (with **W to lv**)

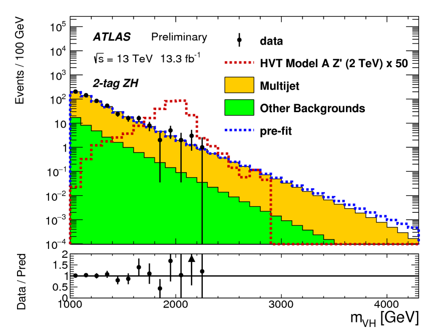


ZH (with **Z to dilepton**)

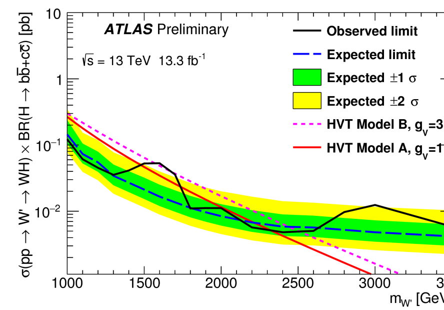


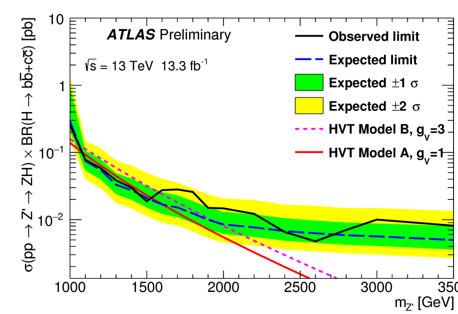






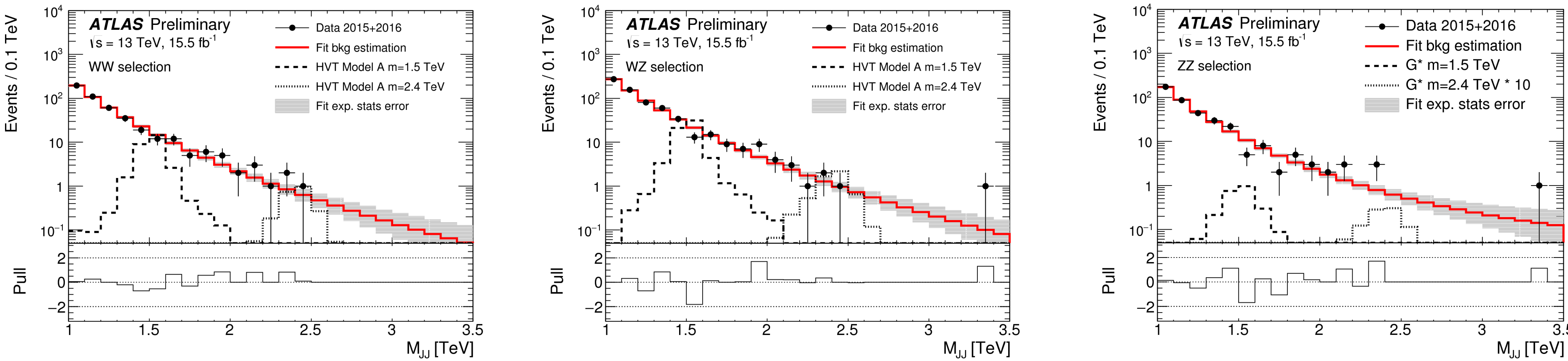
No excess. Set 95% CL limits on HVT models





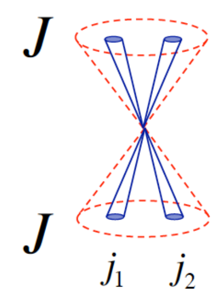
- Search in Fully hadronic Diboson final state with JJ
  - Modest excess in Run1: 2.5σ global
  - Analysis strategy: maintain synergy with Run-1 – functional fit of smoothly falling background shape

[ATLAS-CONF-2016-055]



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

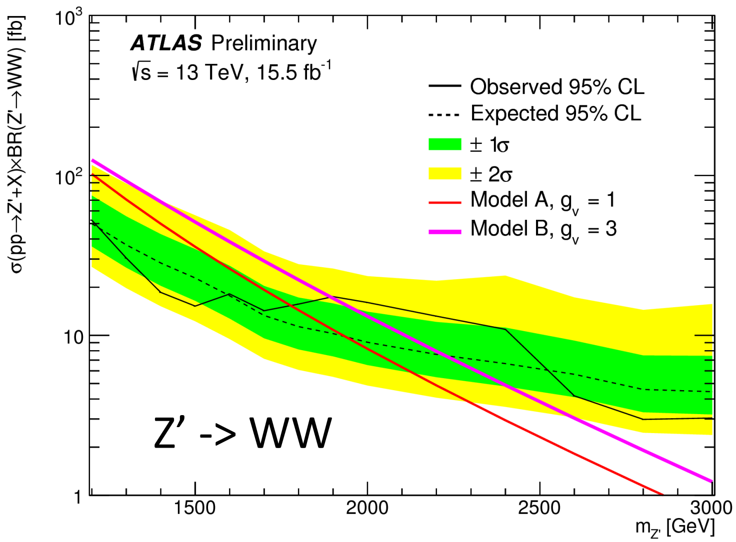
VV to JJ

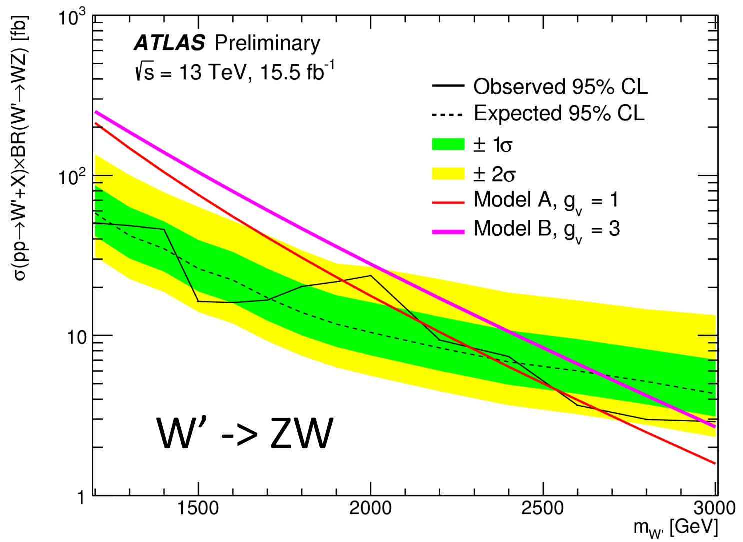


Searches in Di-Boson Fully hadronic final state

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

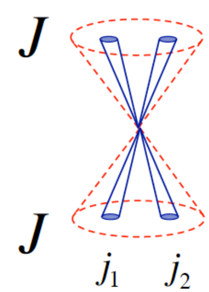
ATLAS-CONF-2016-055



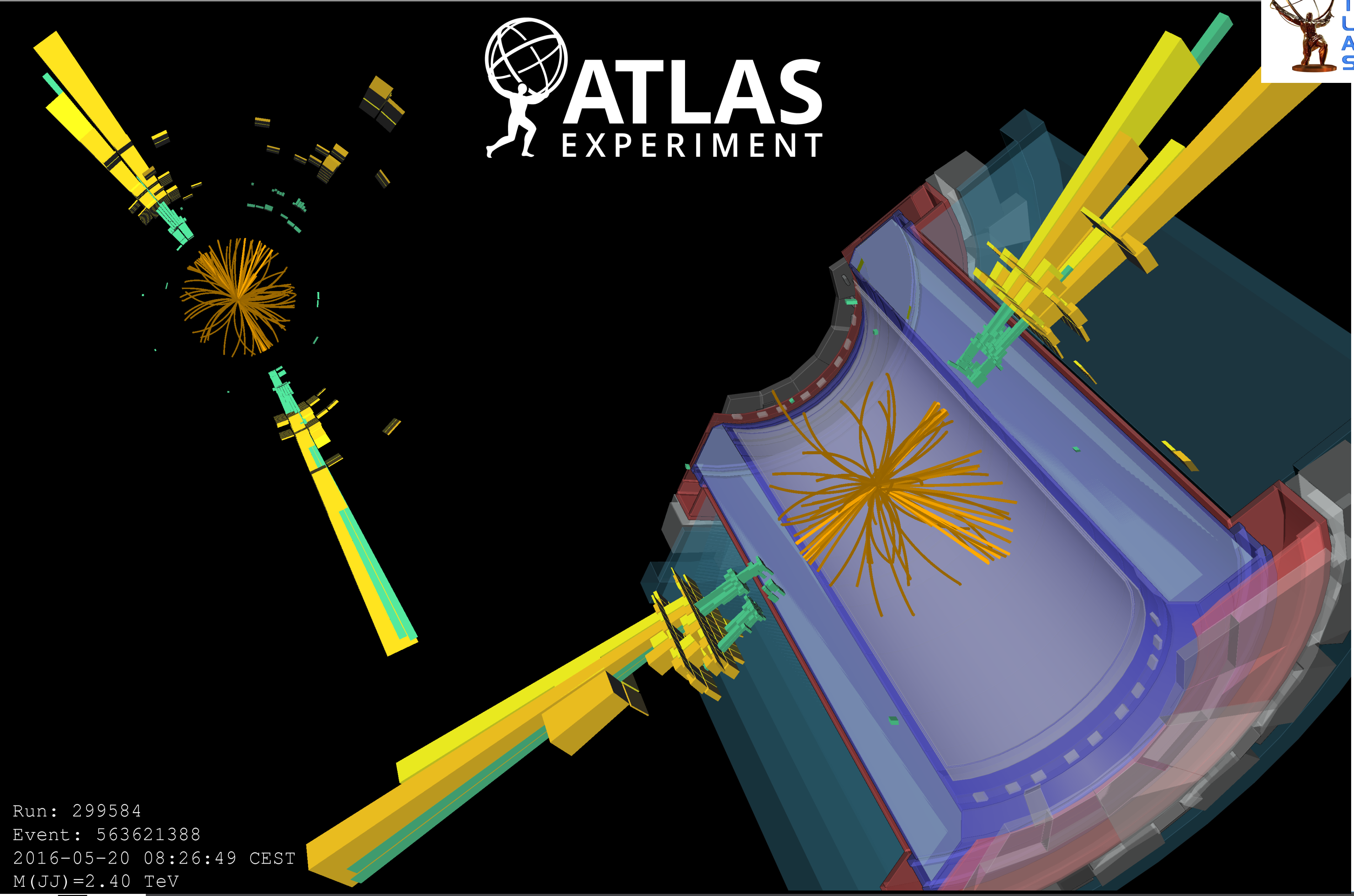


- No excess observed – now with sensitivity to the 2TeV region where the Run-1 excess was seen. Limits set at 95% CL on several models

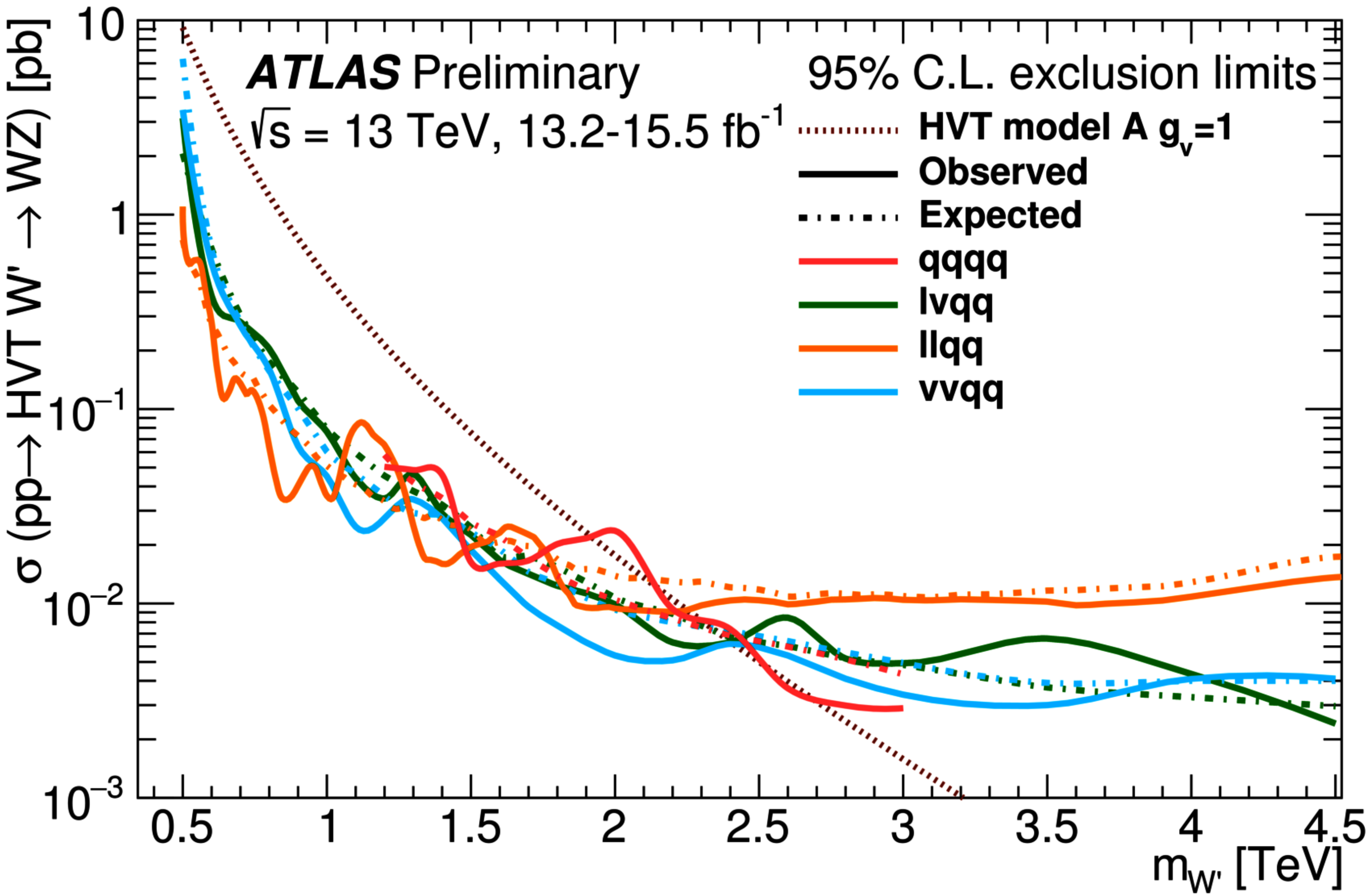
VV to JJ



Searches in Di-Boson Fully hadronic final state



Diboson resonances summary plot

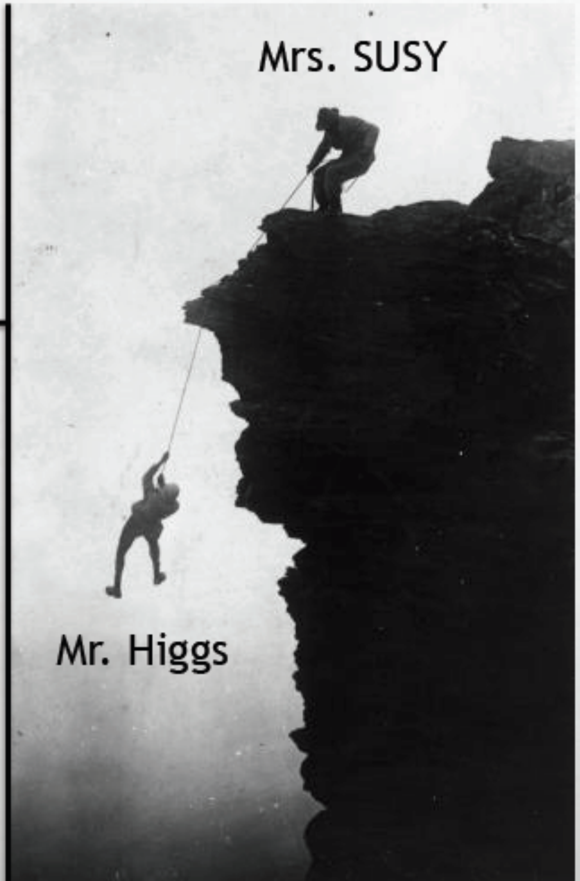


SUSY

SUSY

The scalar precipice

EW scale^{-1}

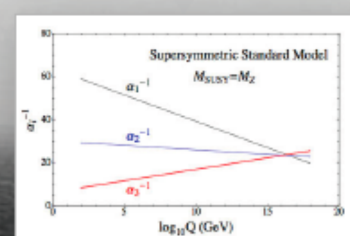


GUT scale^{-1}

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

SUSY

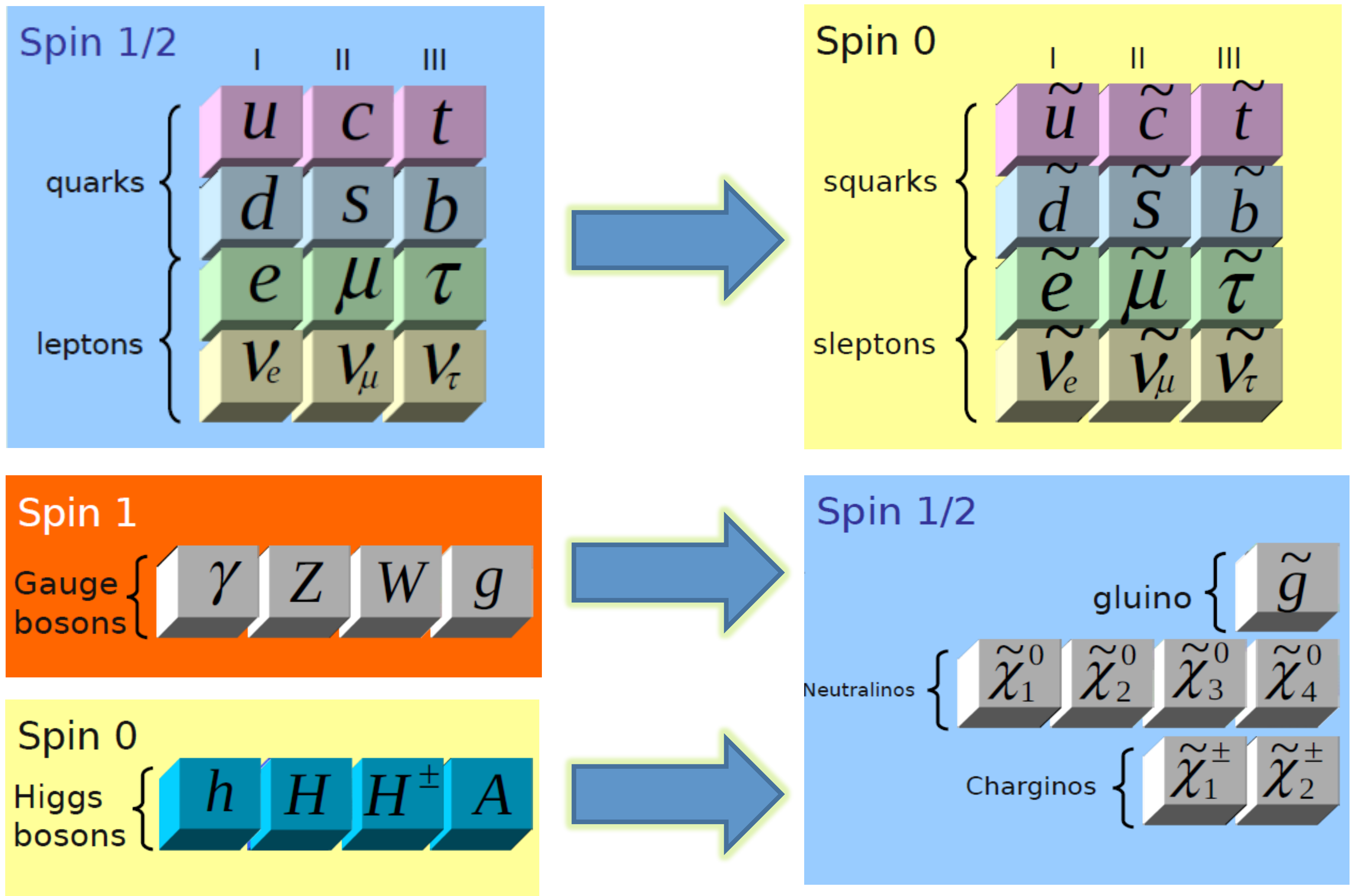


illustration by M-H Genest

Franz Anthony Winner of ‘Collision 2015’

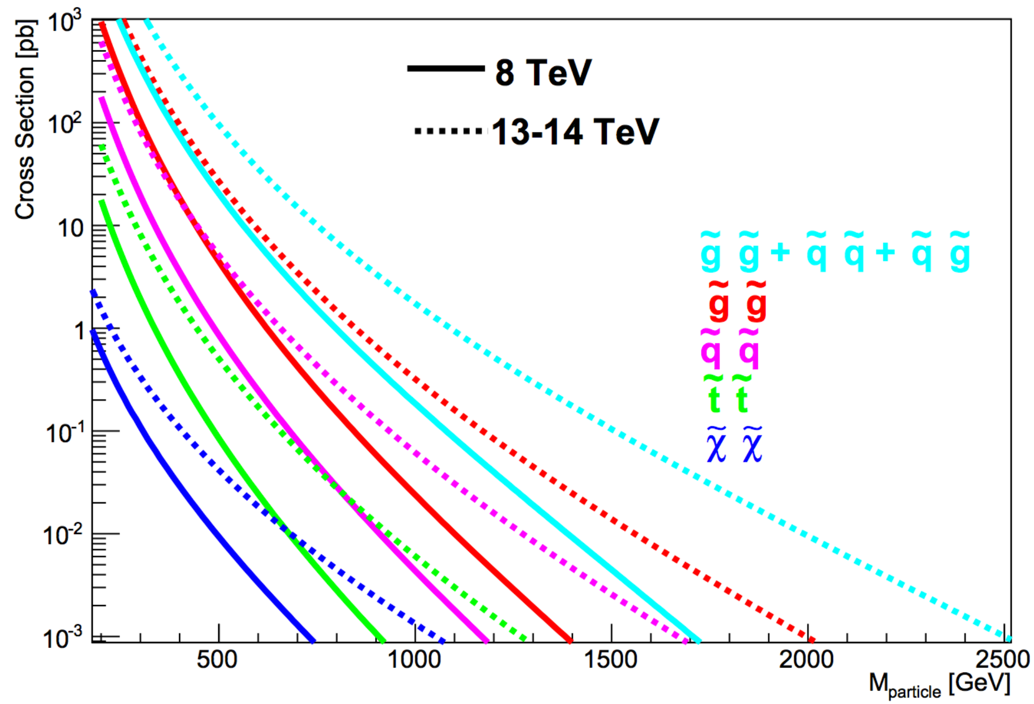
SUSY ~duplicates spectrum of particle states wrt. Standard Model

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

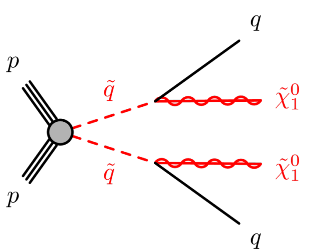
Dedicated searches required

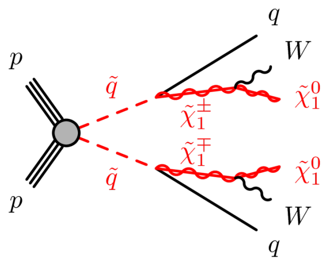


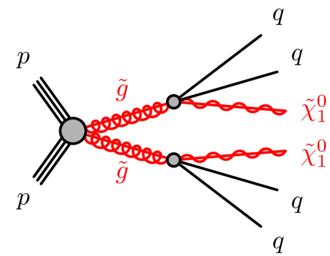
The early focus of Run2 is on strong production with squarks/ gluinos

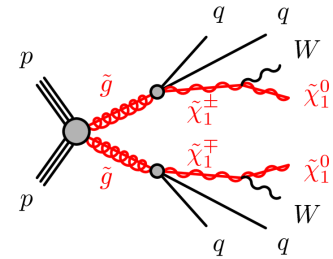
ATLAS

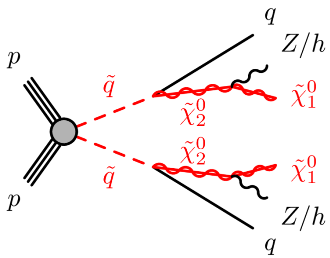
Squark and Gluino mediated light jets

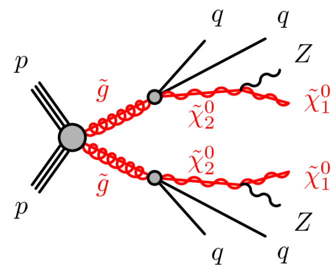




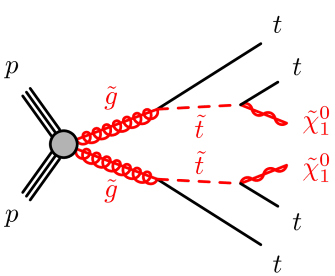


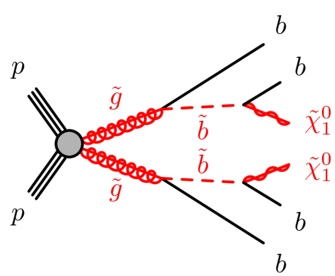


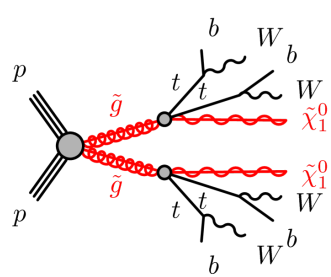


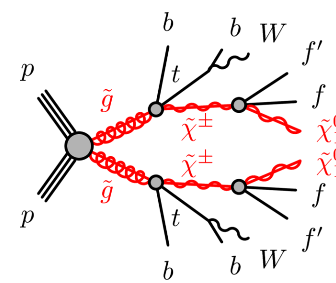


Gluino mediated third generation

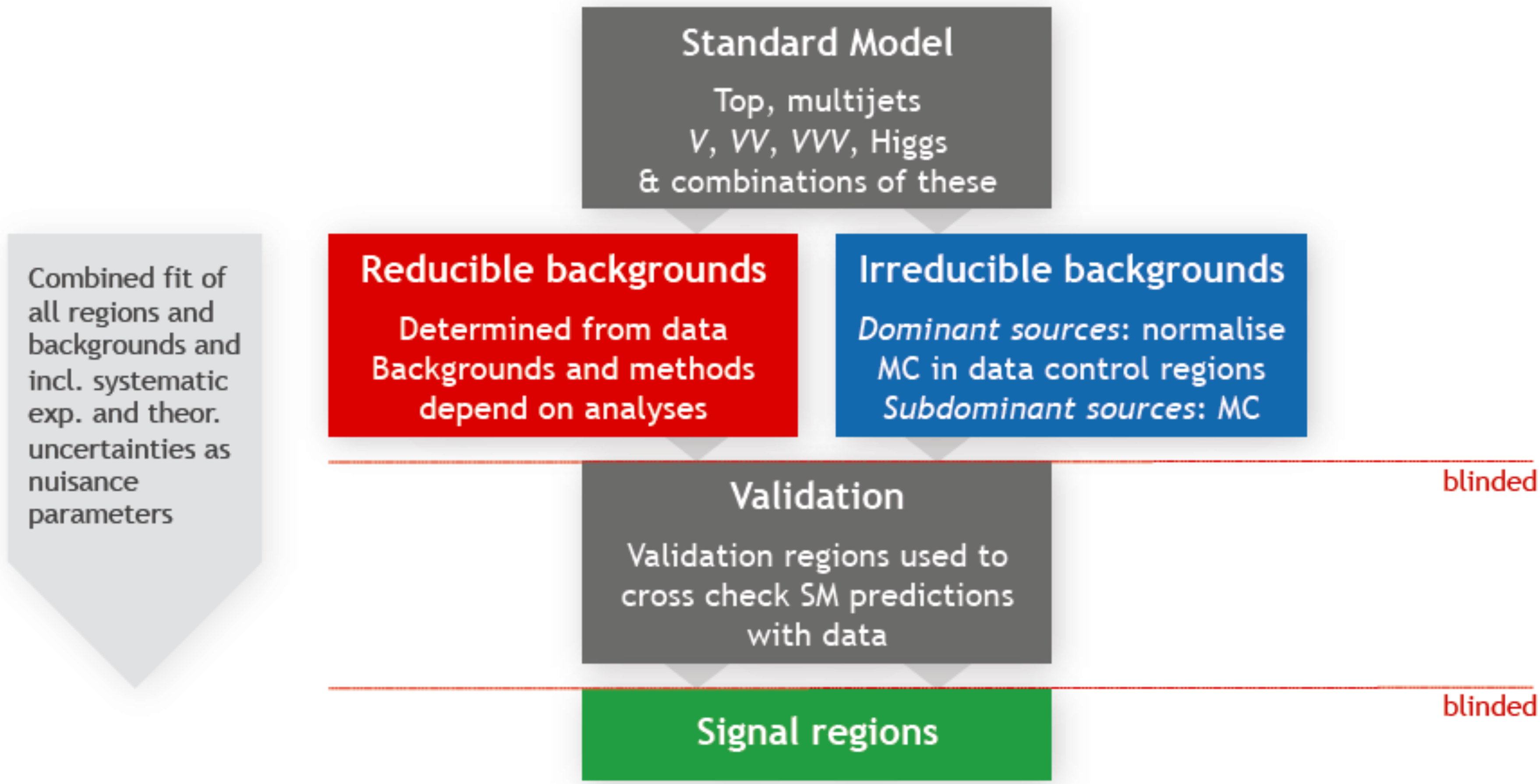








SUSY searches rely primarily on the understanding of the SM backgrounds

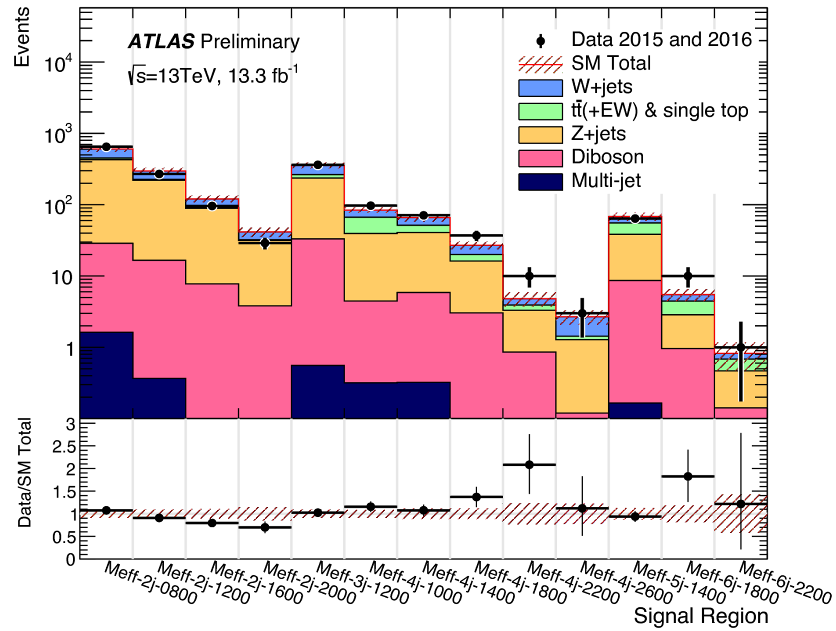


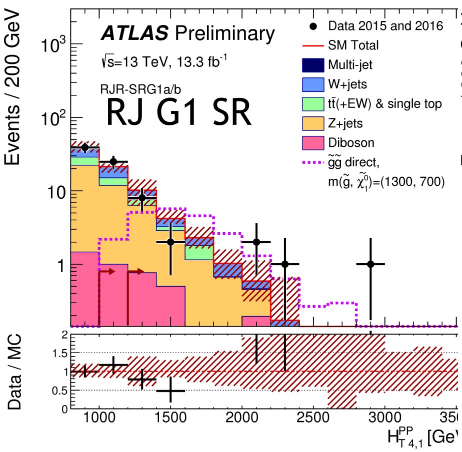
SUSY: Strong Production

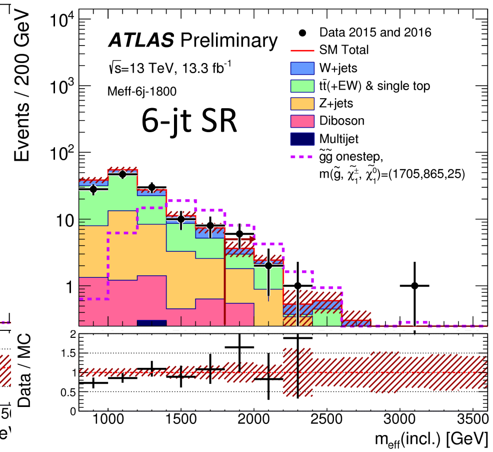
Squark and Gluino mediated light jets.

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

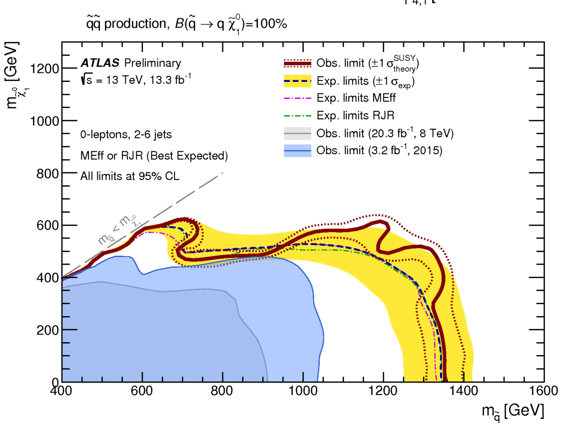
No excess observed so far in 2015/2016!

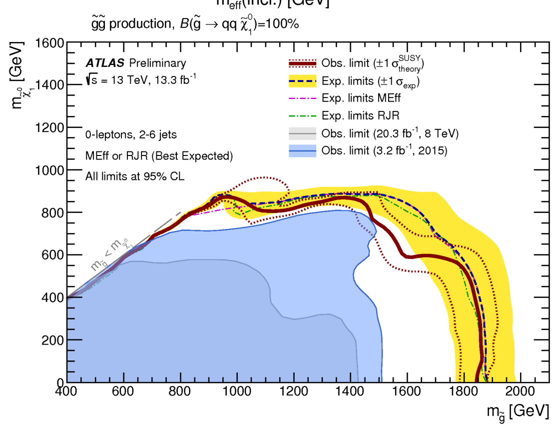


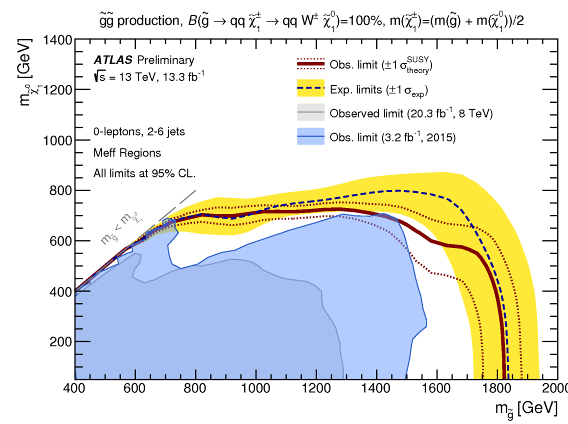


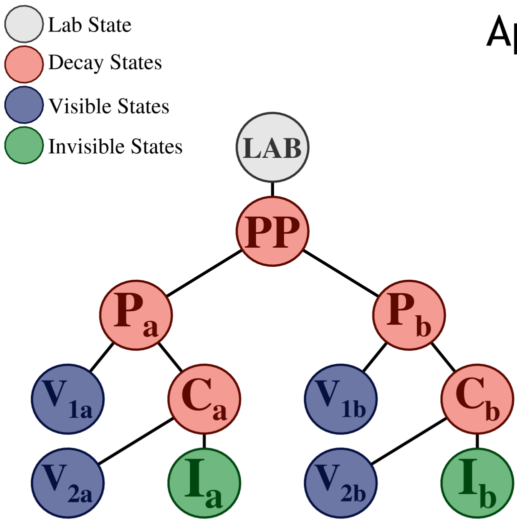


Always caveats! Be careful making blanket interpretations of any SUSY search



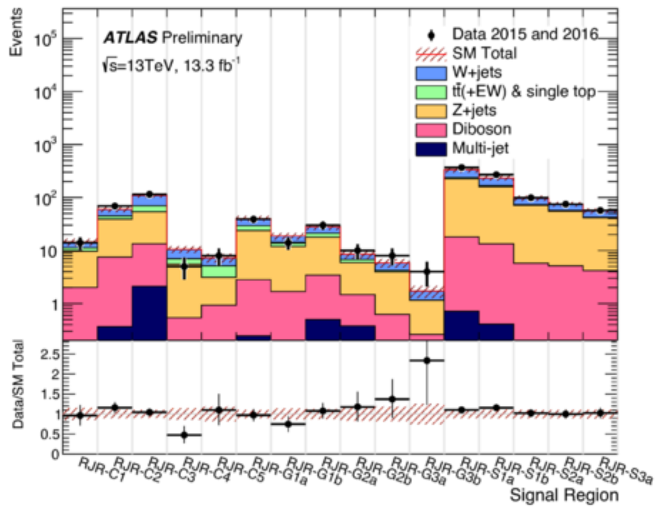


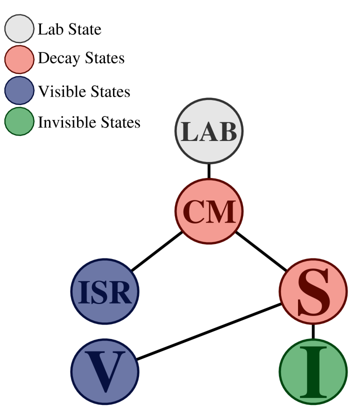




Application to open final states

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



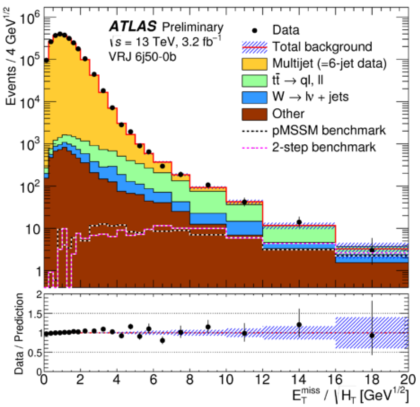


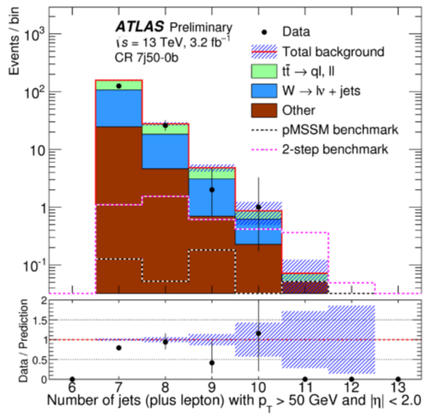
Application to compressed scenarios (25 GeV < Δm < 200 GeV)

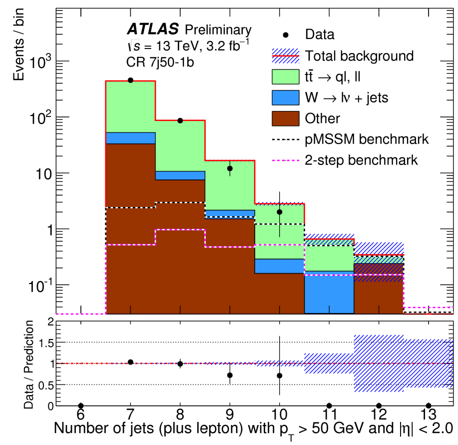
- Leverage large pT ISR system, simple additional complementary variables
- Apply a dedicated decay tree to categorize jets as ISR-like or not
- Improved sensitivity for light squark, stop and gluino pair-production

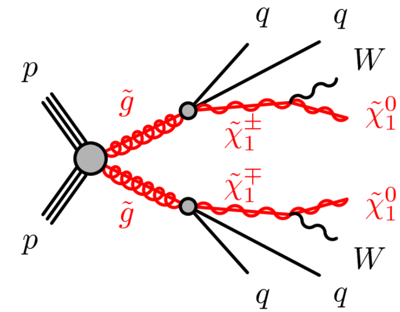
SUSY: Strong Production

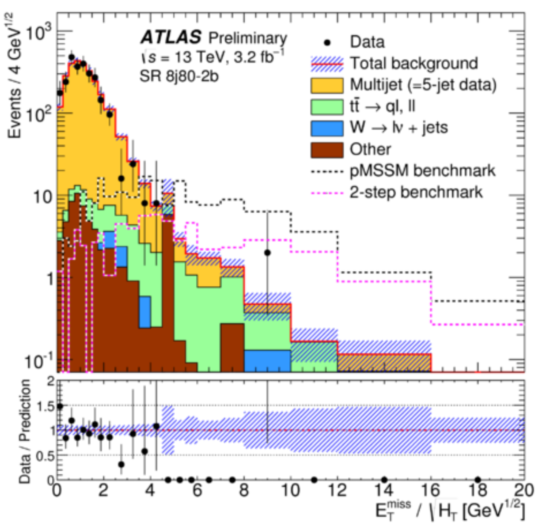
Squark and Gluino mediated light jets: 7-10 jets and 0 leptons



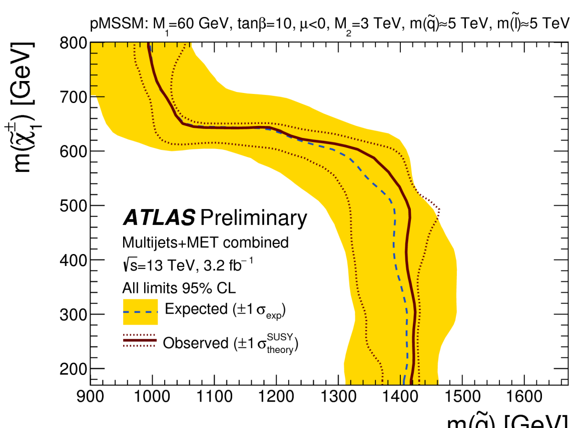


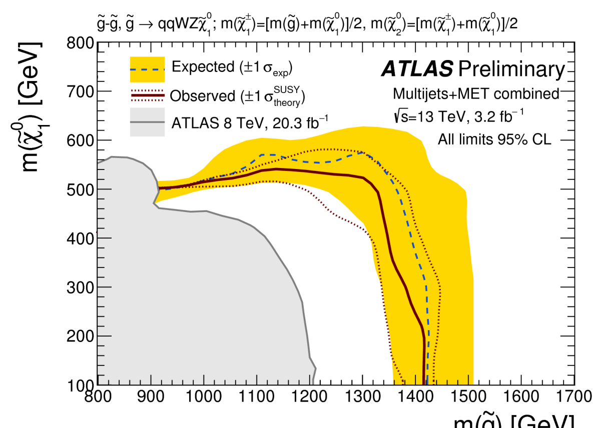




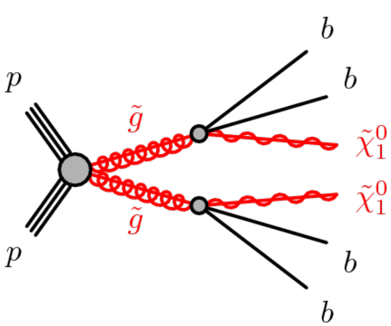


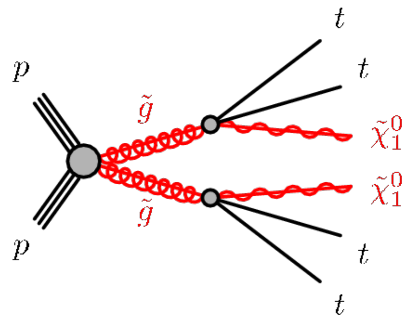
As we increase the number of steps in the decay chain we increase the number of objects

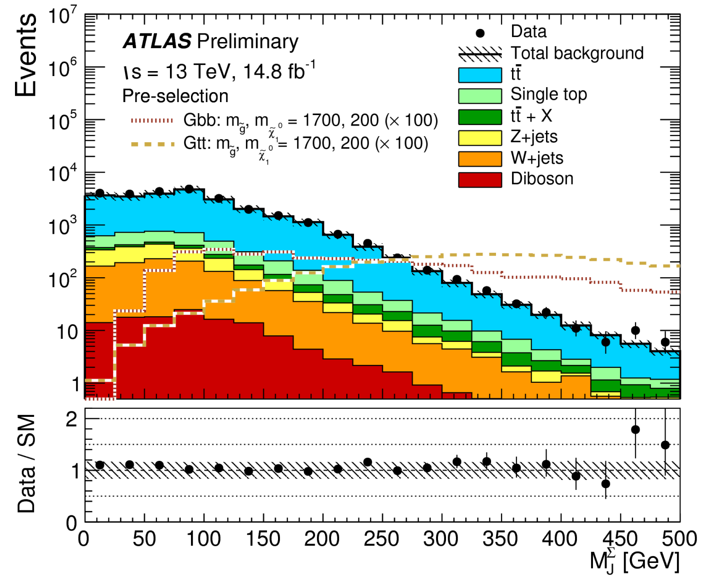




Search for gluino production in 8 signal regions with multiple b-jets aiming at decays with b and top quarks







Signal categories

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

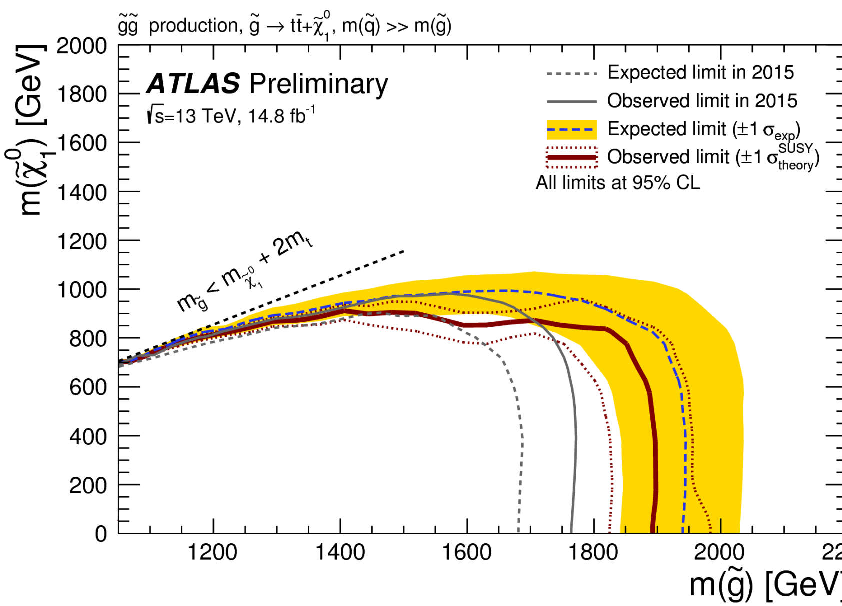
Improvements to the analysis

Use of boosted tops, New selection cuts

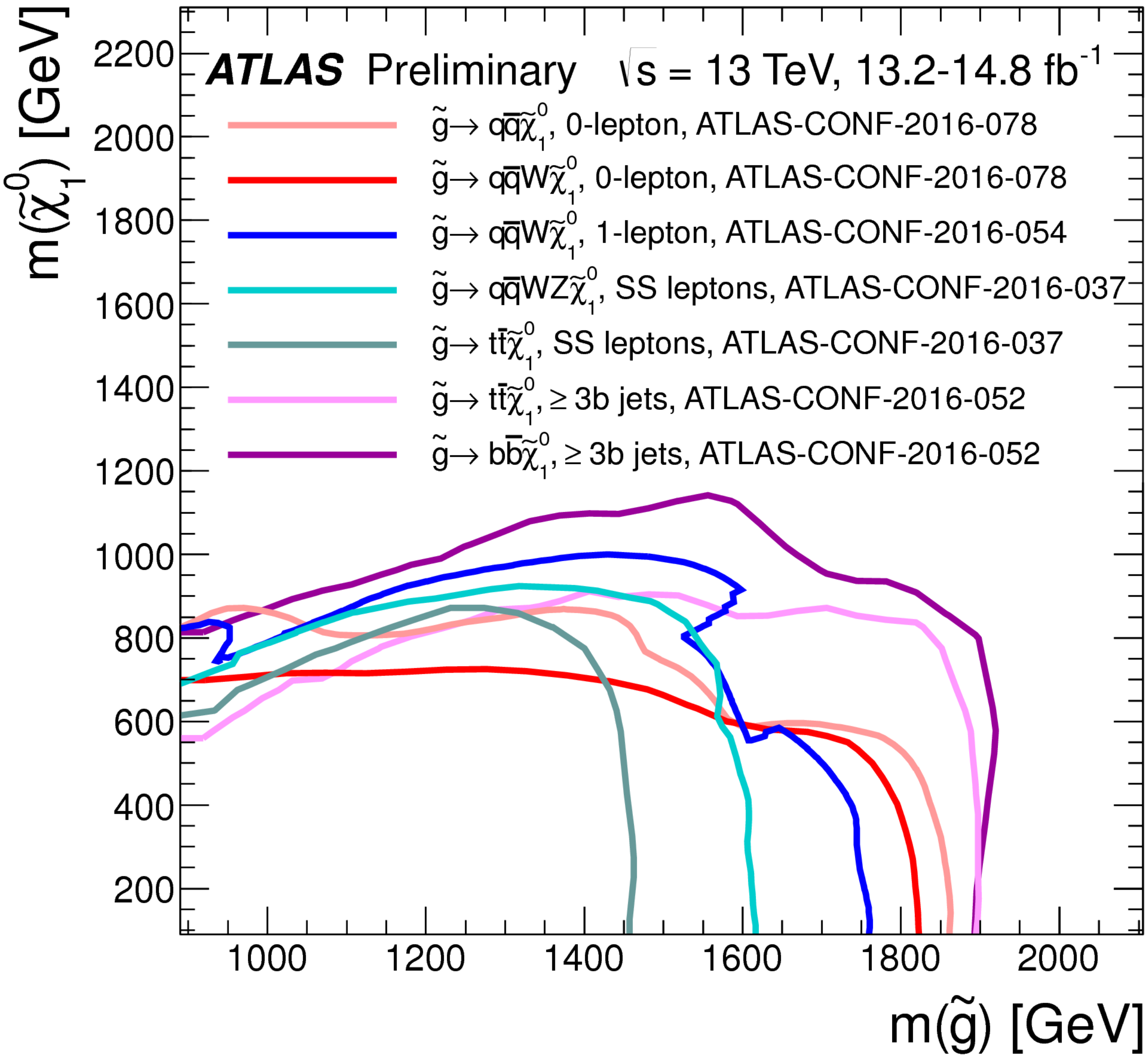
Backgrounds

Top background (dominant) from CRs (in MET)

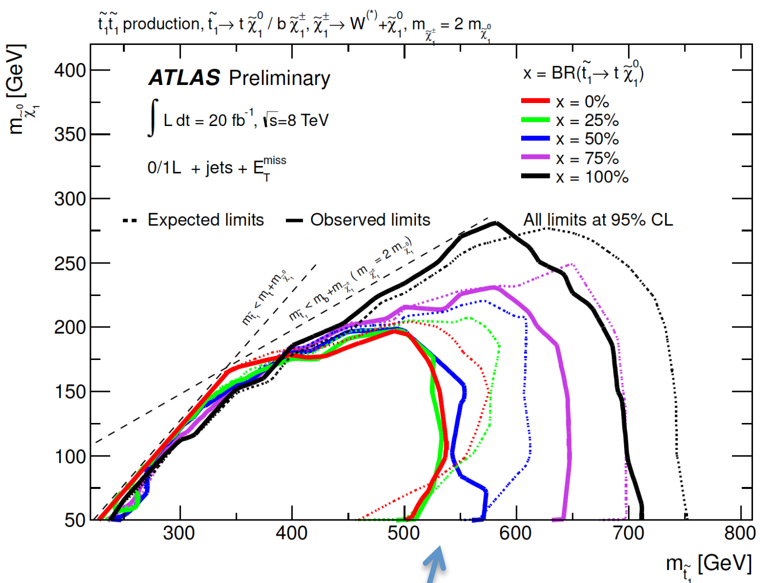
Other backgrounds from MC

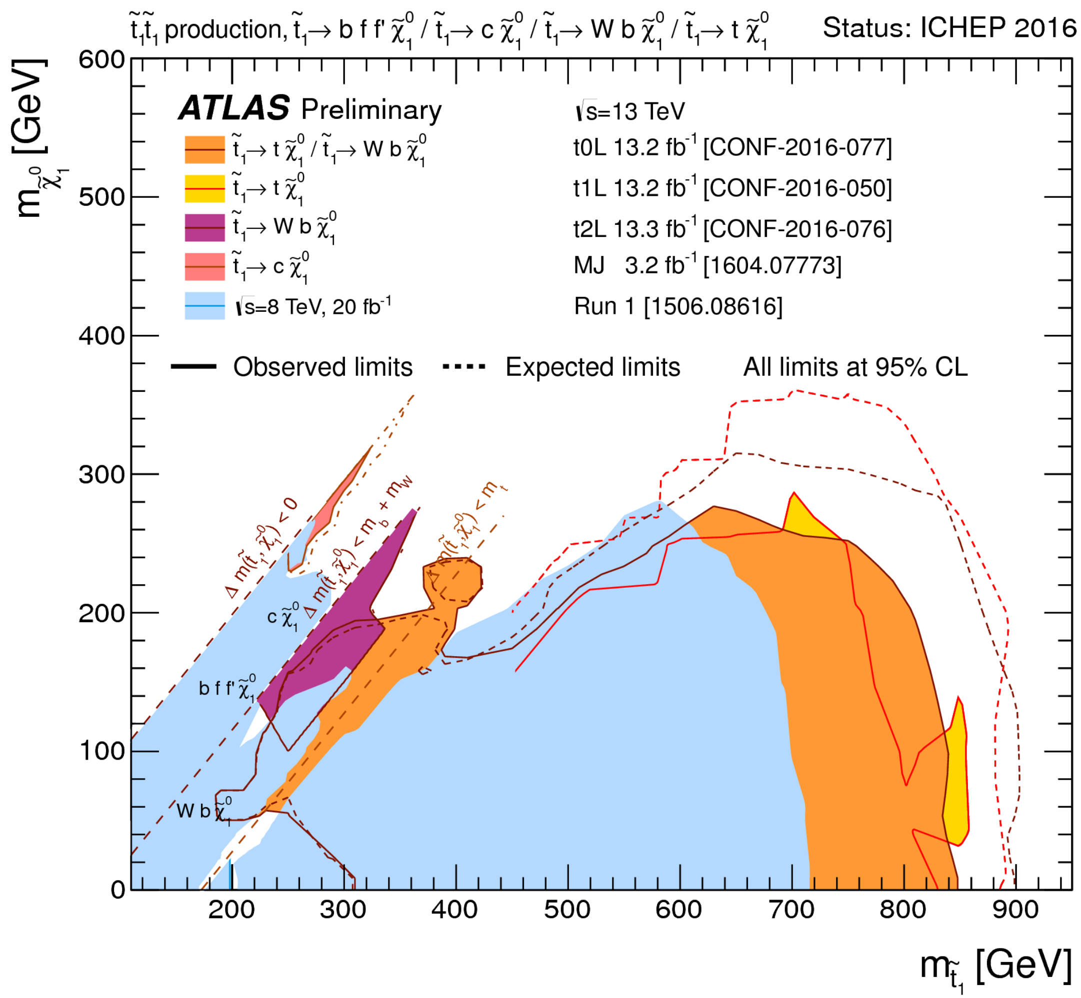


SUSY: Strong Production



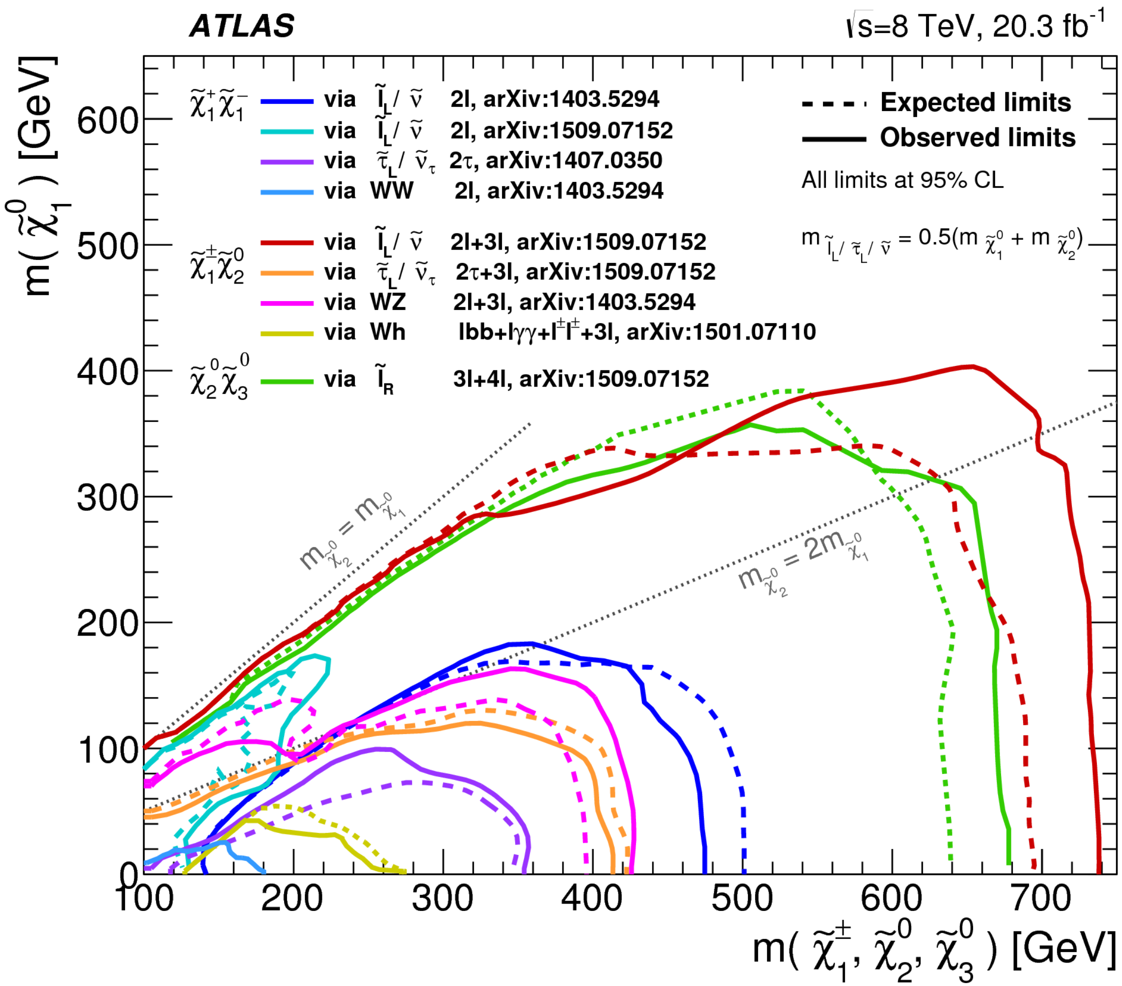
3^{rd} generation searches – Summary

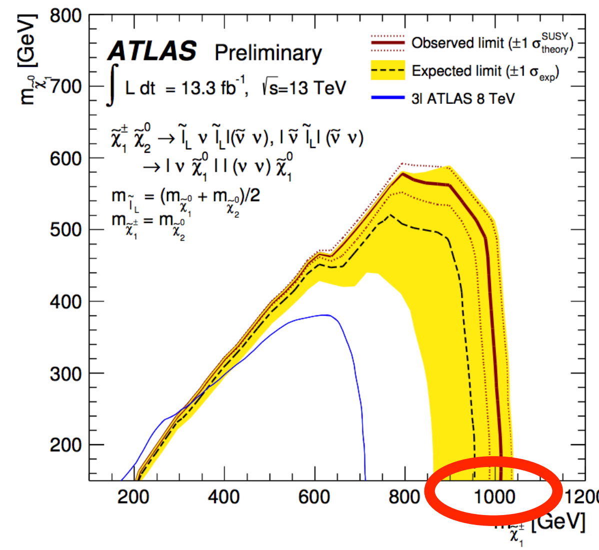


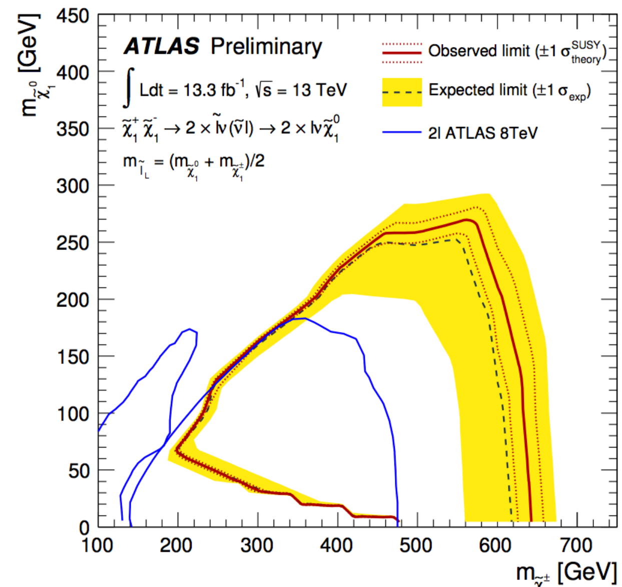


Simply altering the stop branching fractions alter the limits severely

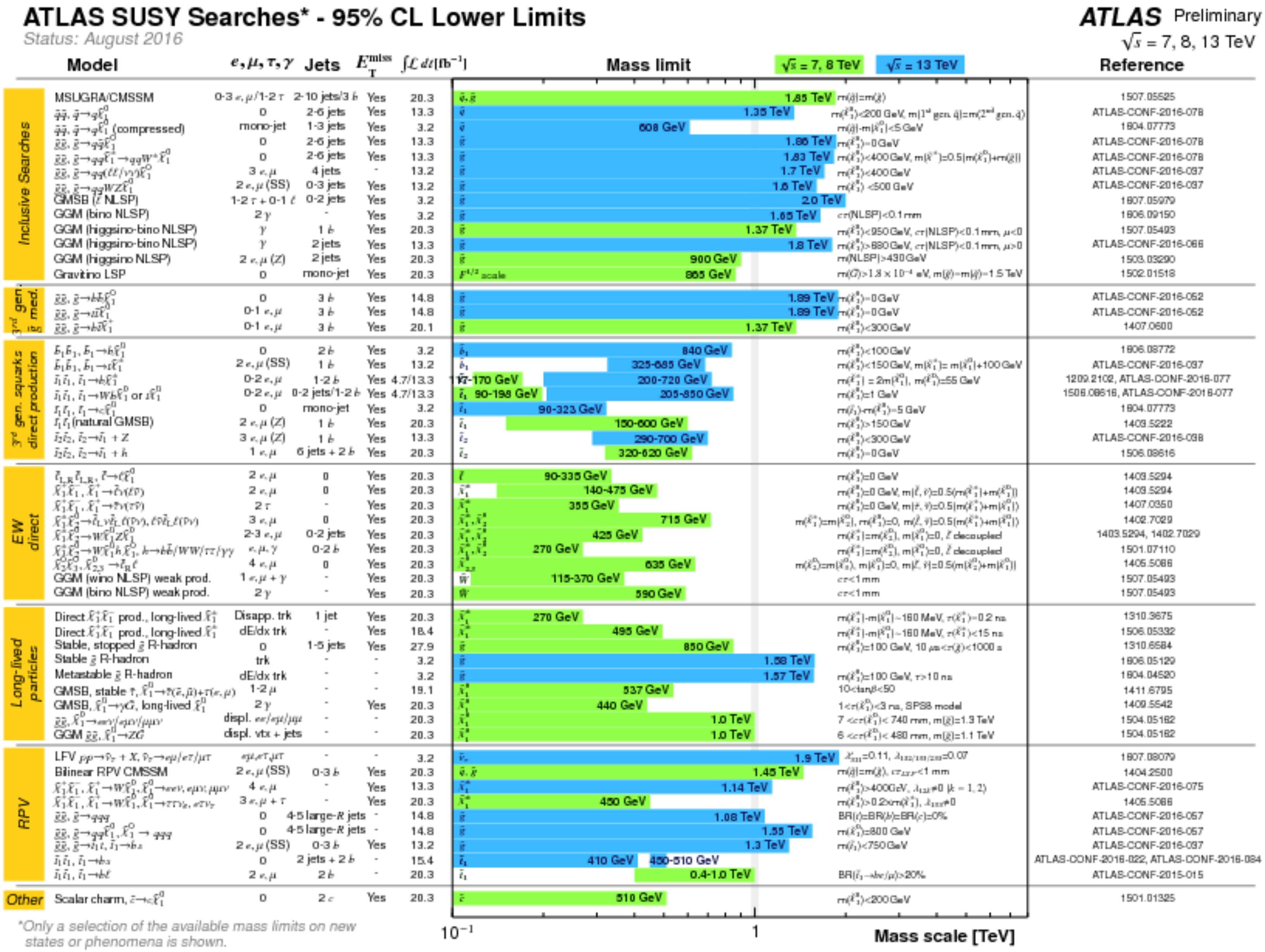
SUSY: Electroweak Production







SUSY Summary



Summary

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

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

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

Backup Slides

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

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

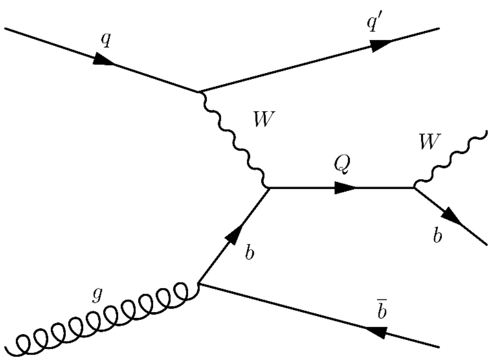
VLQ Wb:
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-072/

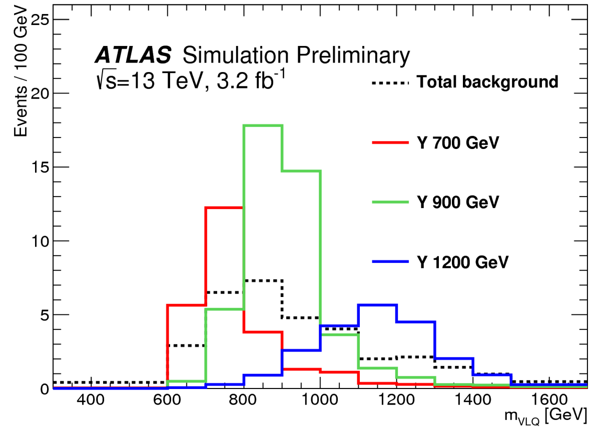
VLQ top:
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-013/

Vector-Like Quarks: single production decaying to Wb

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

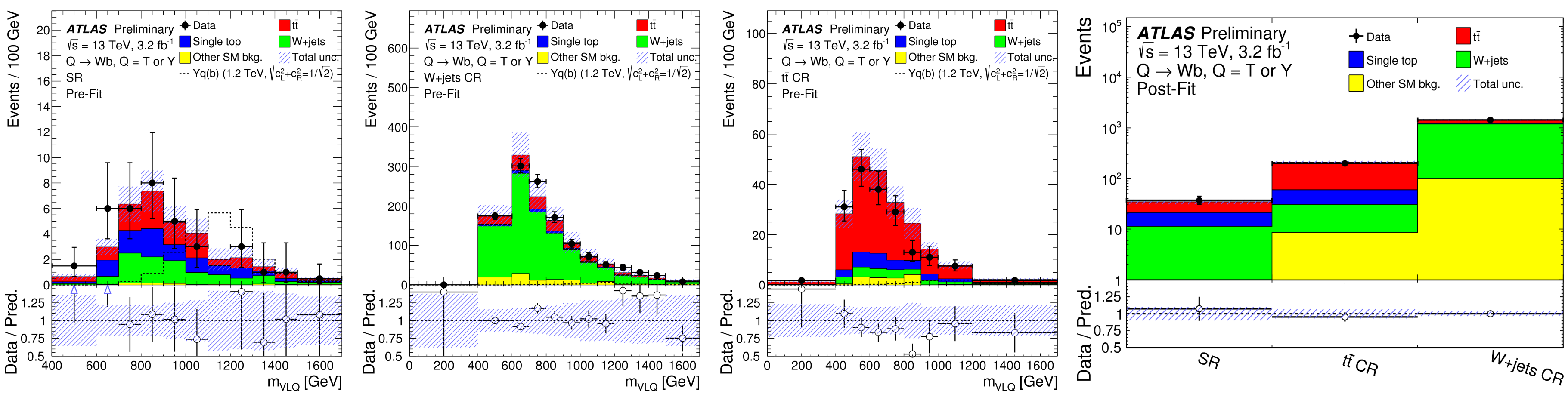
- pair production: through QCD - dominant in low mass
- single production through EWK coupling – dominant at high mass (model dependent)



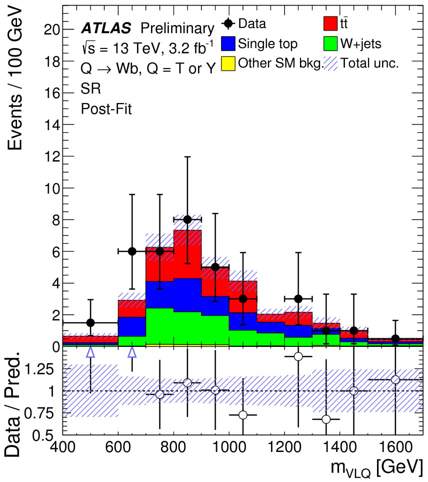


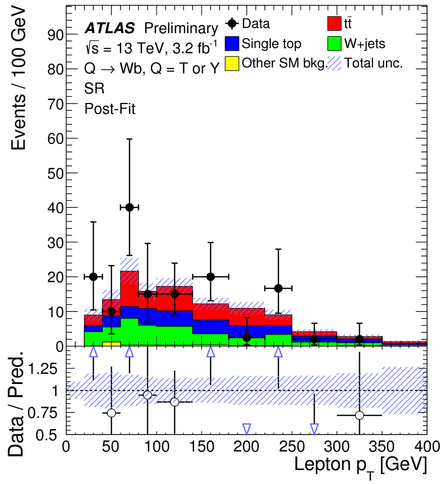
Essentially closed final state so we can resolve the mass

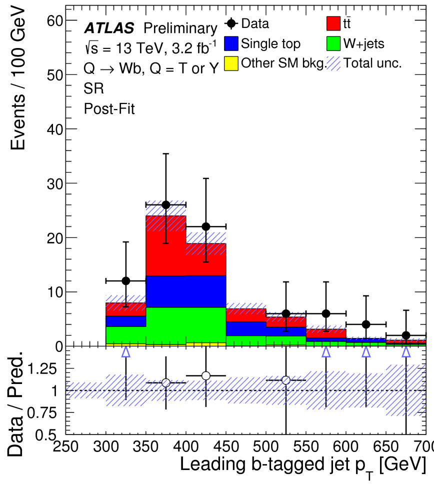
ATLAS-CONF-2016-072



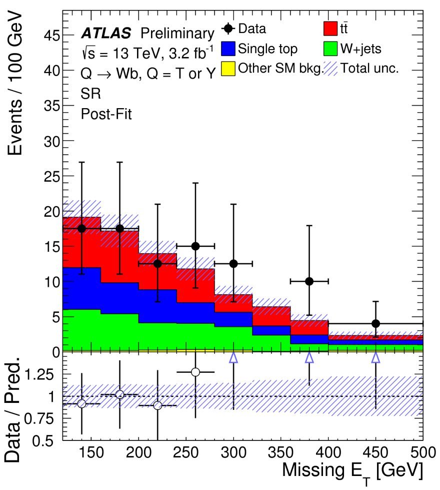
VLQ: single production decaying to Wb

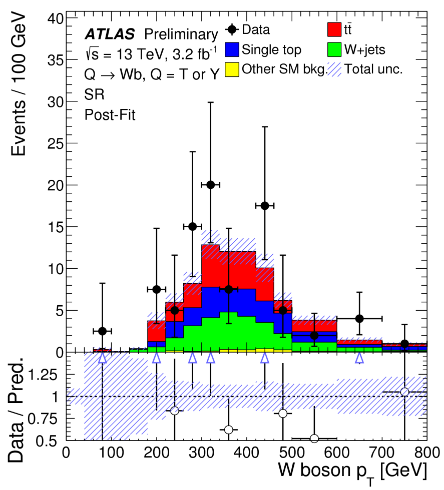




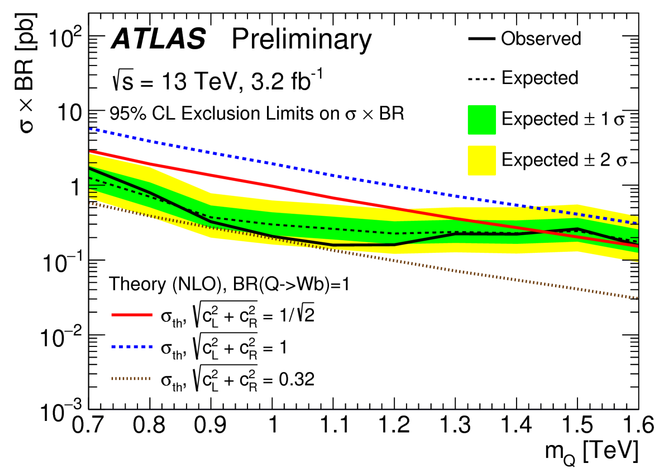


Post-fit distributions agree well with SM predictions





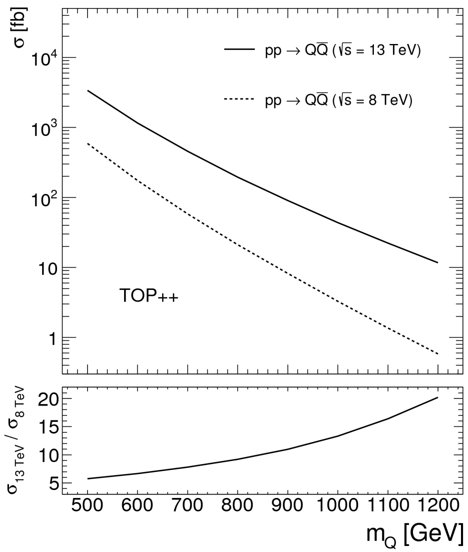
ATLAS-CONF-2016-072



THE UNIVERSITY of ADELAIDE

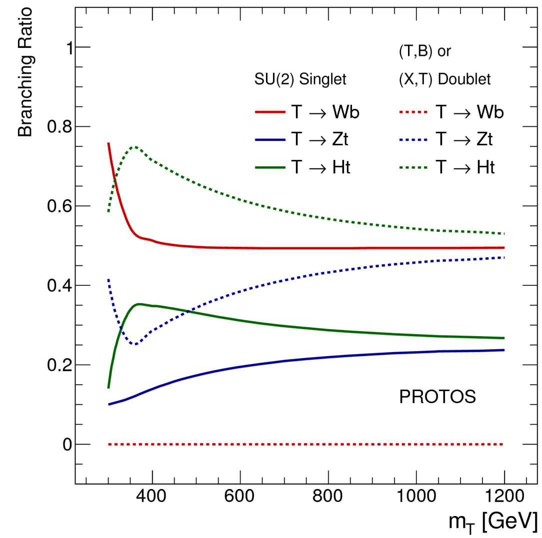
CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

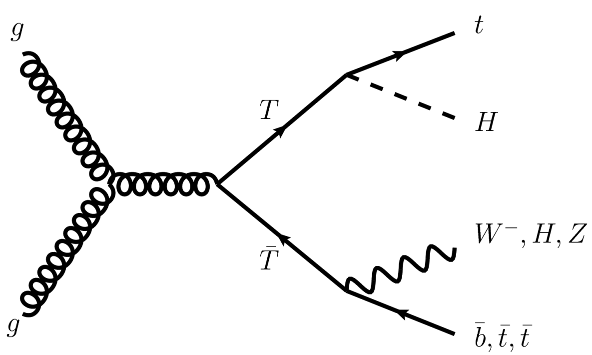
VLQ: pair-production



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

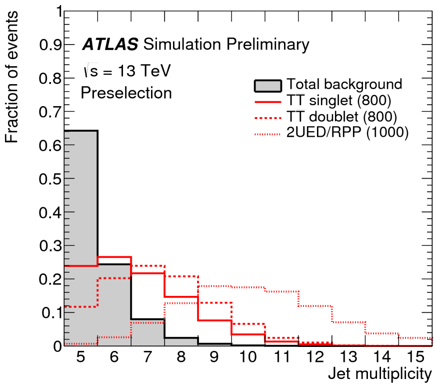
Branching ratios for the different decay modes of a vector-like T quark as a function of the heavy-quark mass, separately for an SU(2) singlet and an SU(2) doublet.

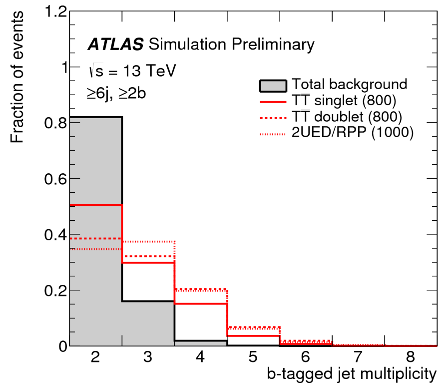


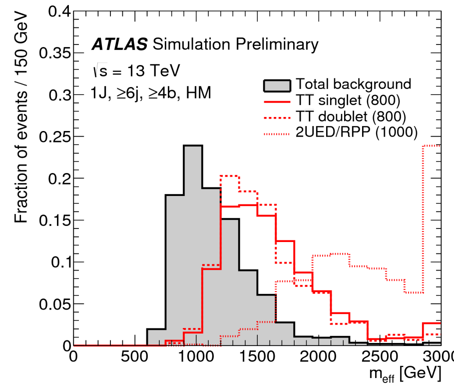


Representative leading-order Feynman diagram for TT production probed by this search.

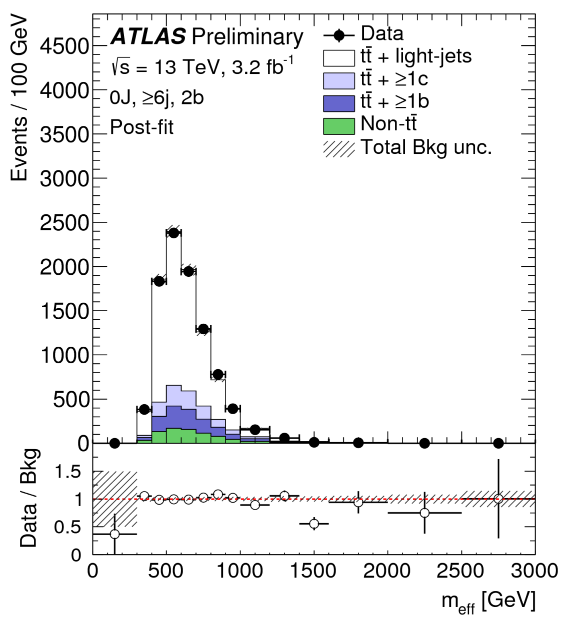
VLQ: pair-production

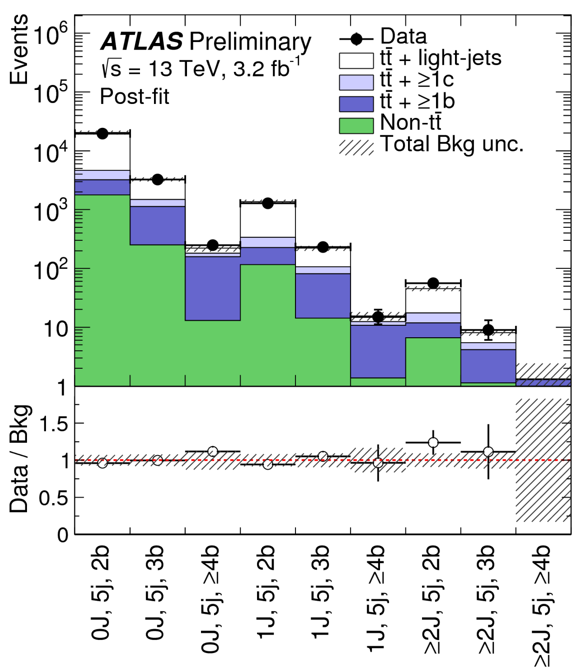






Good discrimination between signal and backgd for variables considered

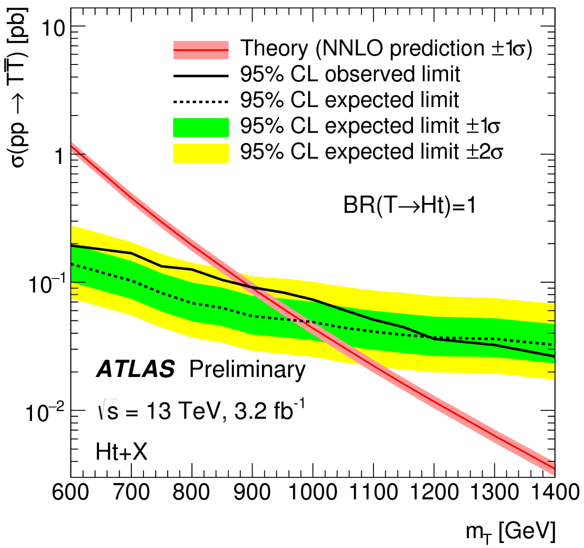


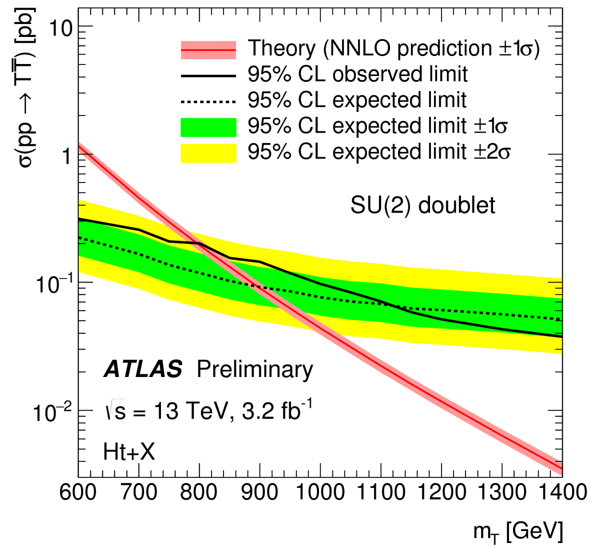


Due to richness of the final state several signal regions are defined

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

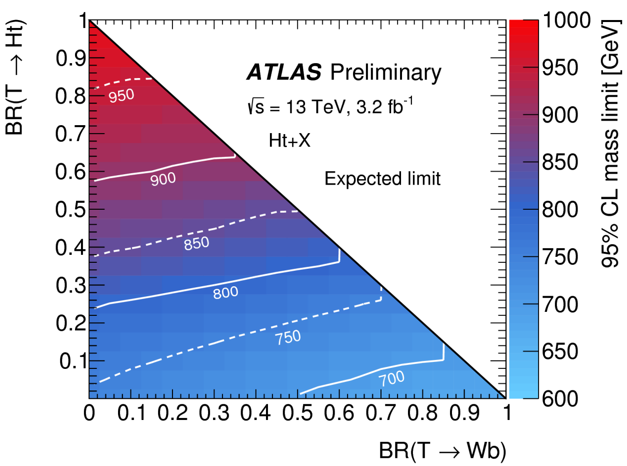
VLQ: pair-production

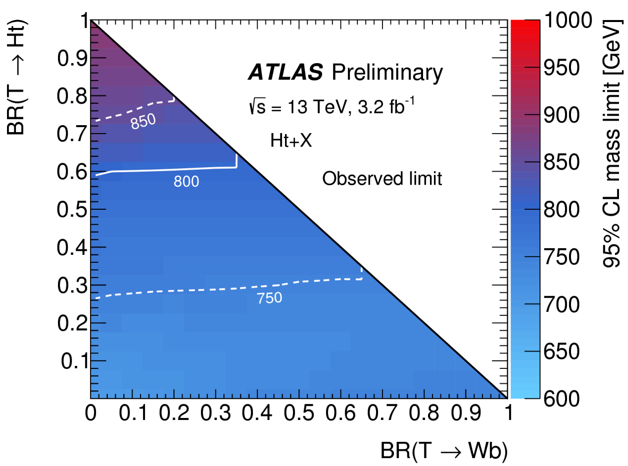


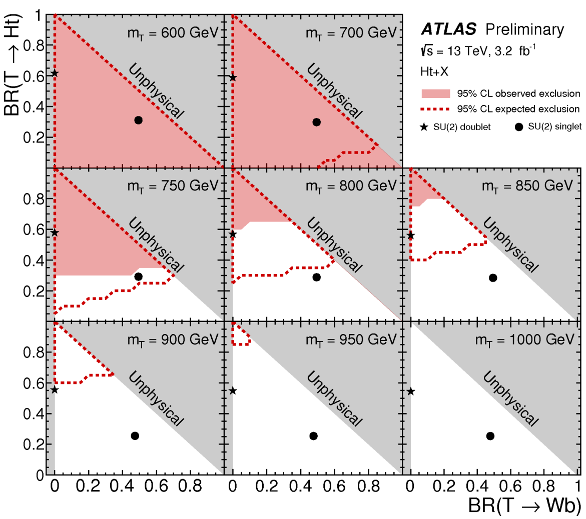


With no evidence of BSM physics we proceed to place limits on the models considered.

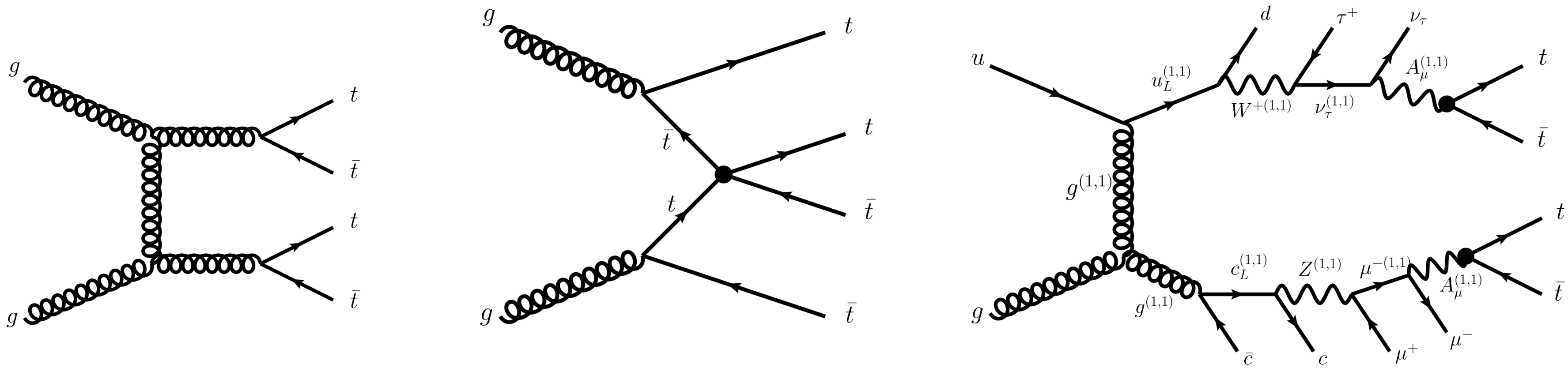
M_T >~900GeV @ 95% CL although altering BF's relaxes this constraint.





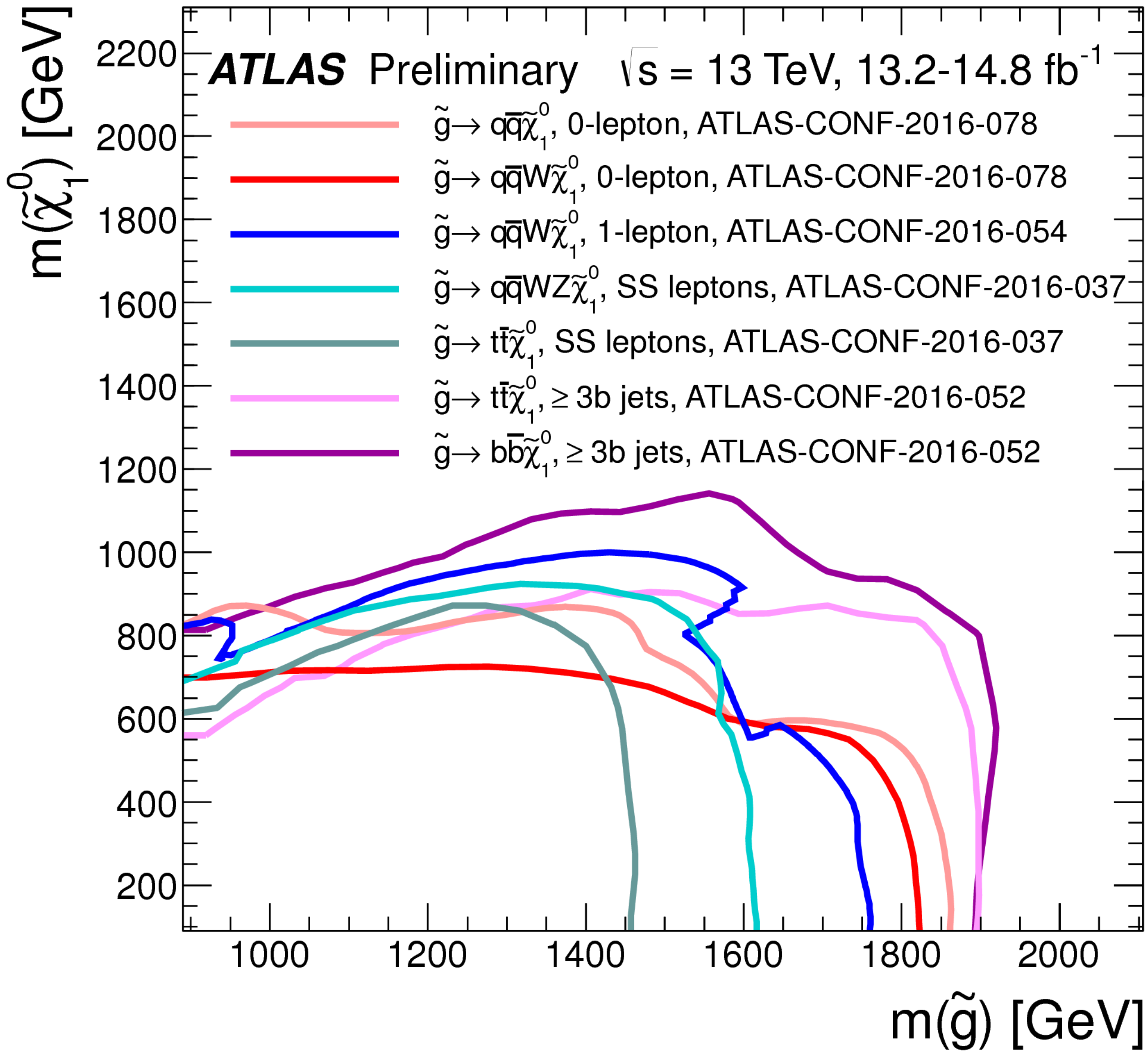


VLQ: pair-production



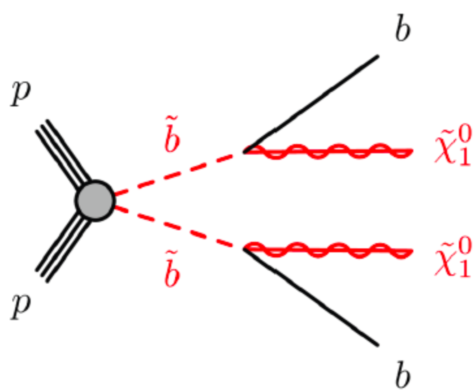
Representative leading-order Feynman diagrams for four-top-quark production within (a) the SM and several BSM scenarios (see text for details): (b) via an effective four-top-quark interaction in an effective field theory model, and (c) via cascade decays from Kaluza–Klein excitations in a universal extra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

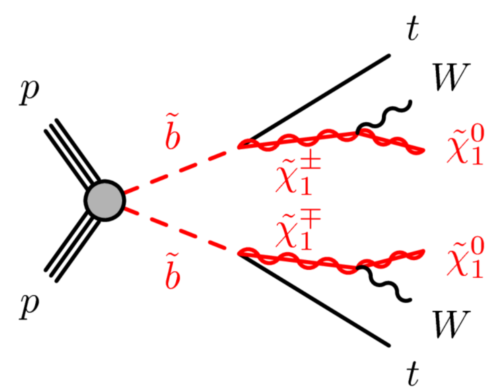
SUSY: Strong Production



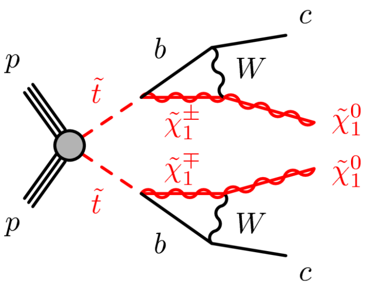
3rd SUSY generation topologies

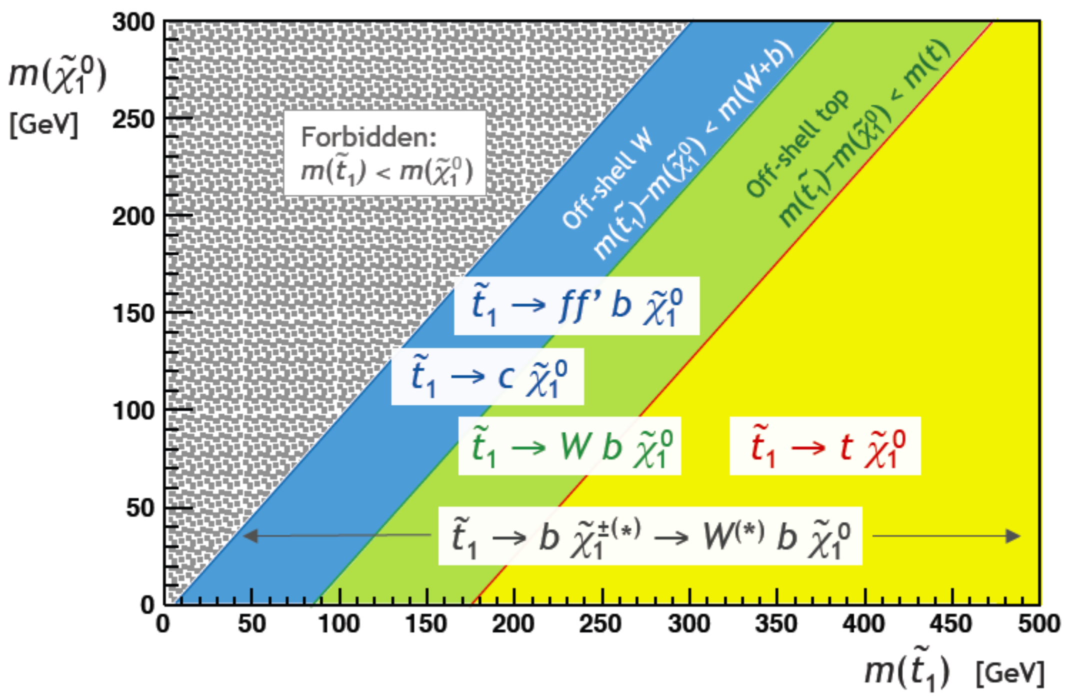
scalar bottom searches

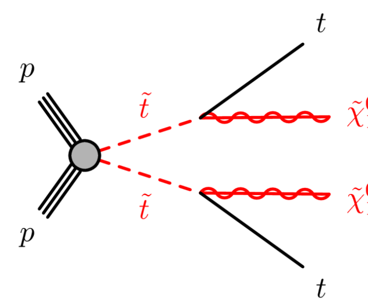


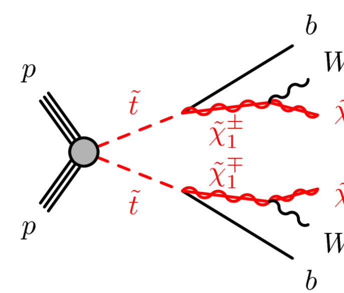


scalar top searches

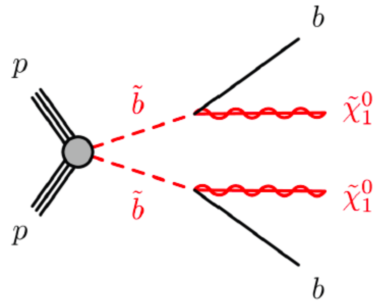






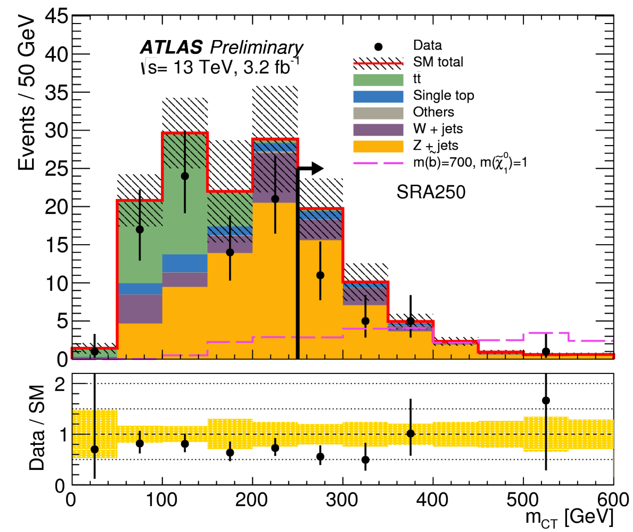


Scalar bottom searches – still no excess at 13TeV

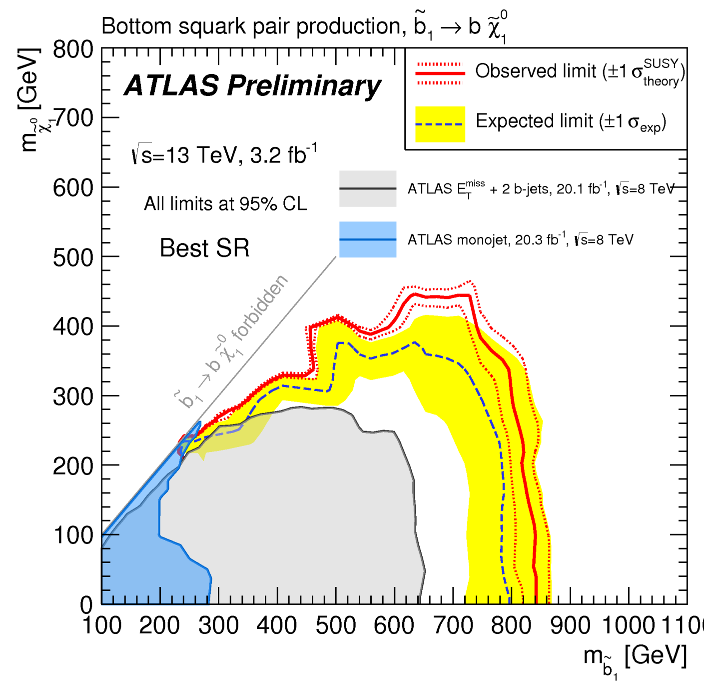


$$m_{CT}^2(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [p_T(v_1) - p_T(v_2)]^2$$

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



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



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, 3^{rd} jet veto
- Small $\Delta m(b_1,\chi^0_1)$: require an anti- b-tagged ISR jet, large $H_{T,3}$ and E_T^{miss}
- Main backgrounds: Z(νν)+bjets, W+bjets, tt

from Z(ll)+bjets control region

from single lep or e/μ control region

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