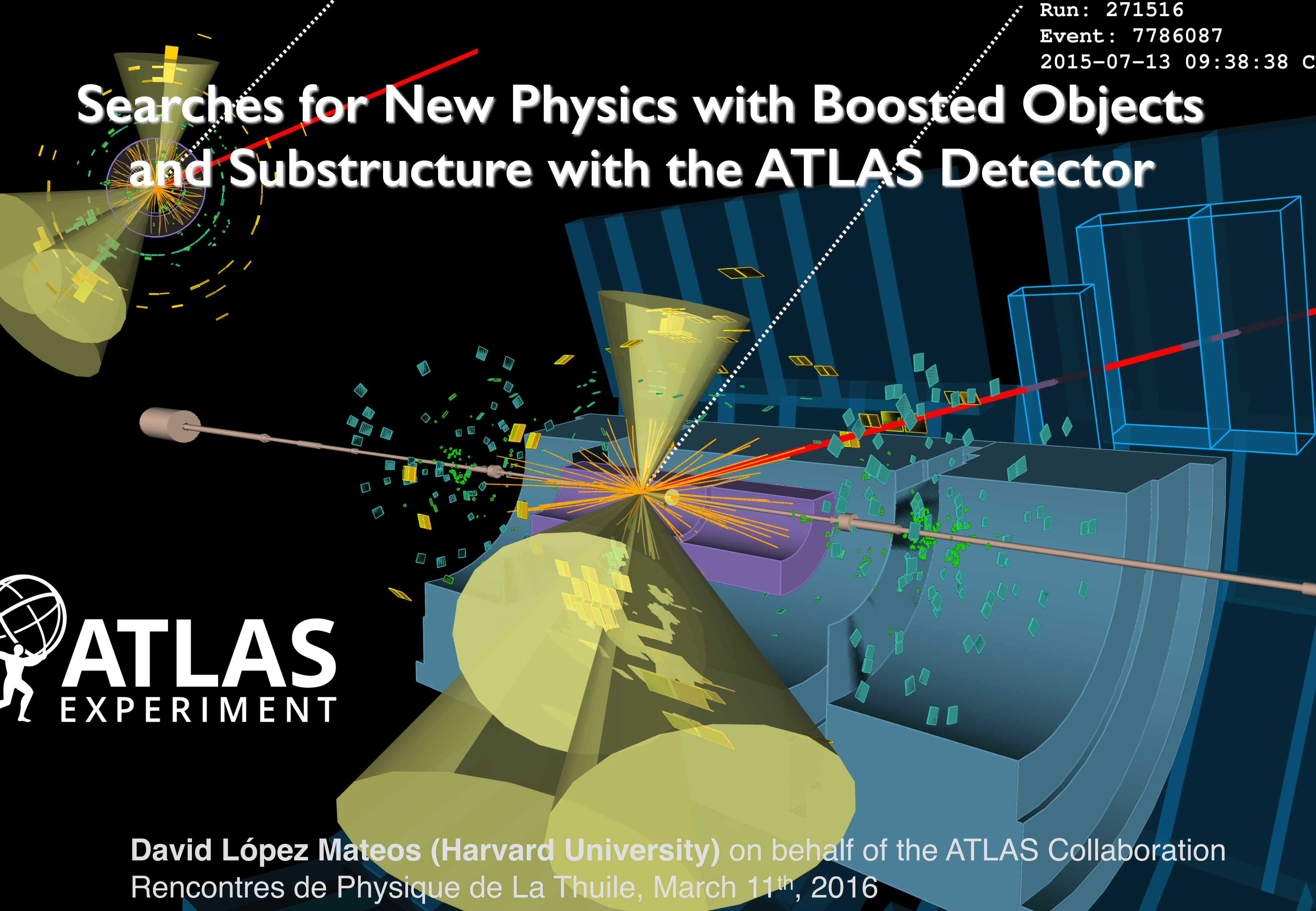
Searches for New Physics with Boosted Objects and Substructure with the ATLAS Detector

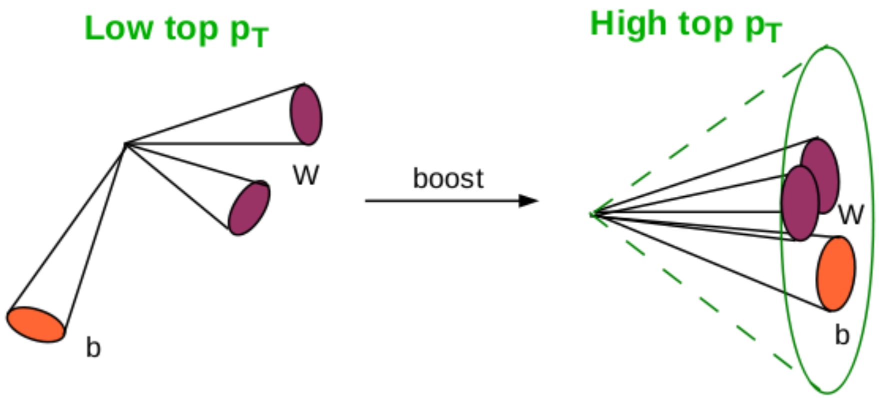


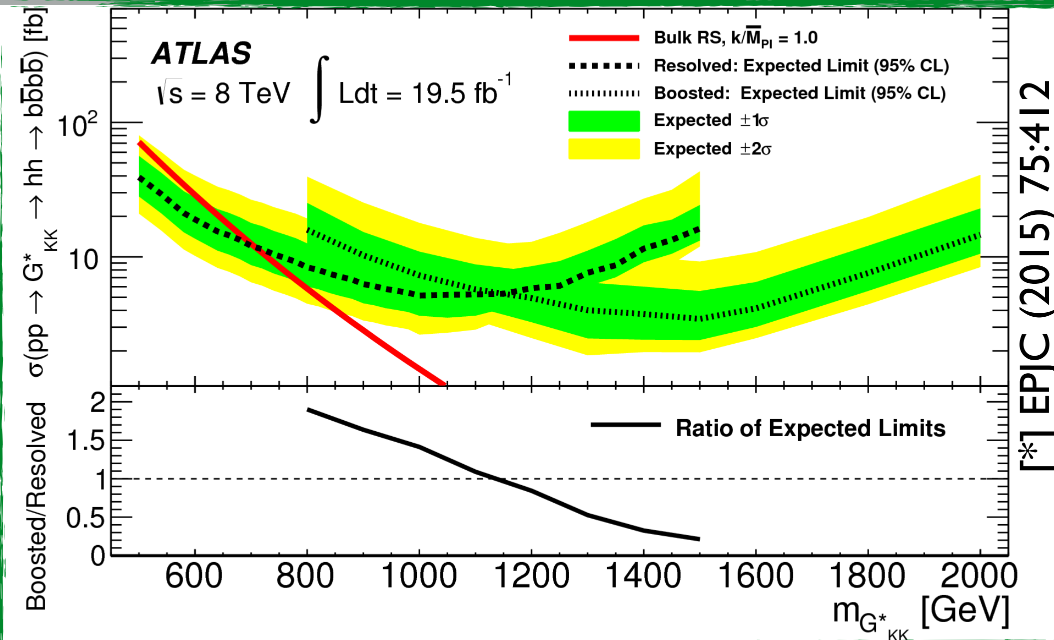
ATLAS EXPERIMENT

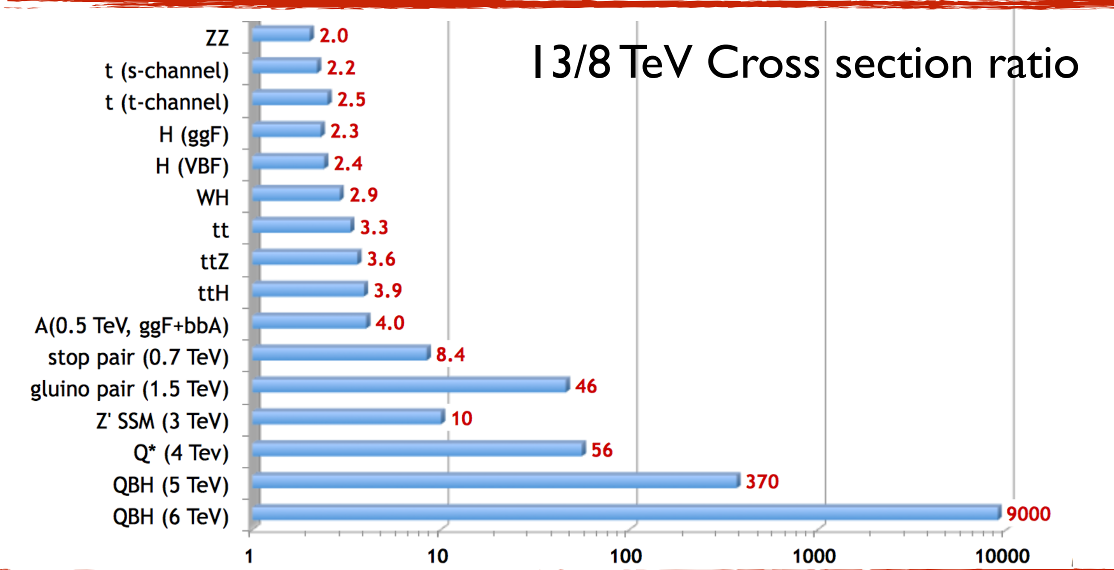
David López Mateos (Harvard University) on behalf of the ATLAS Collaboration

Rencontres de Physique de La Thuile, March 11th, 2016

Why Boost Your Search for New Physics

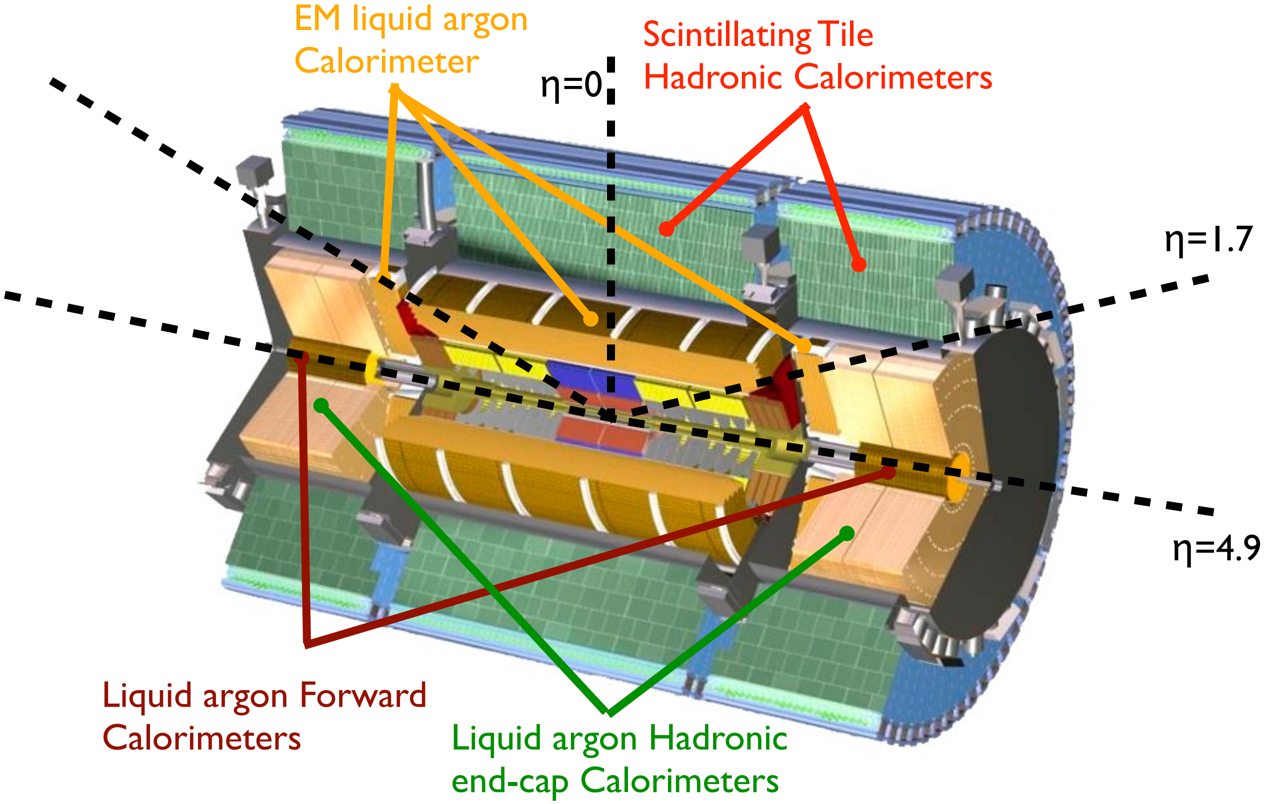


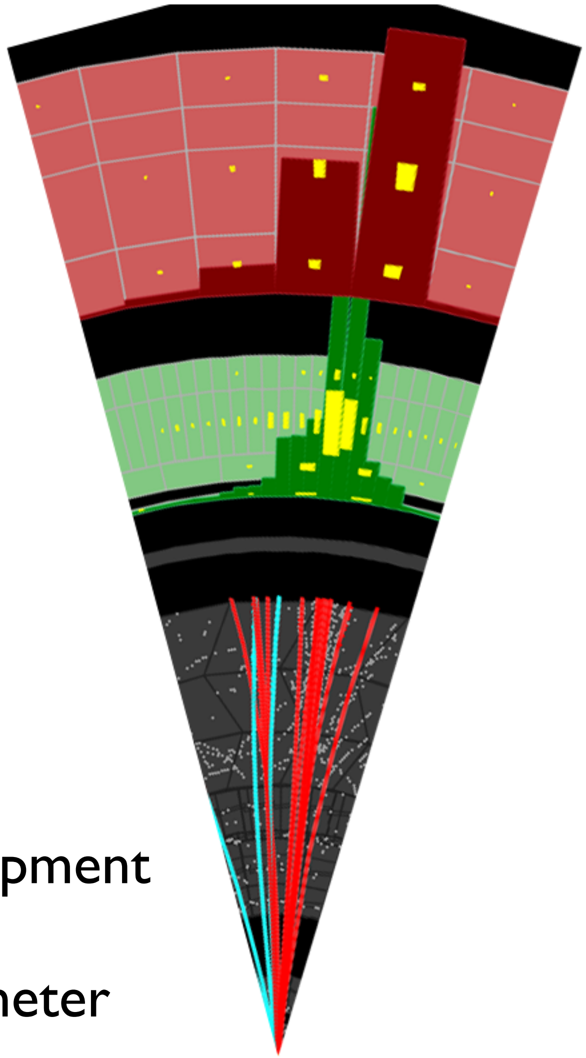




- Hadronic final states dominate branching ratios of bosons/tops
- Power of new techniques to reconstruct these final states demonstrated in Run 1
- Increase in cross section of boosted processes in Run 2!

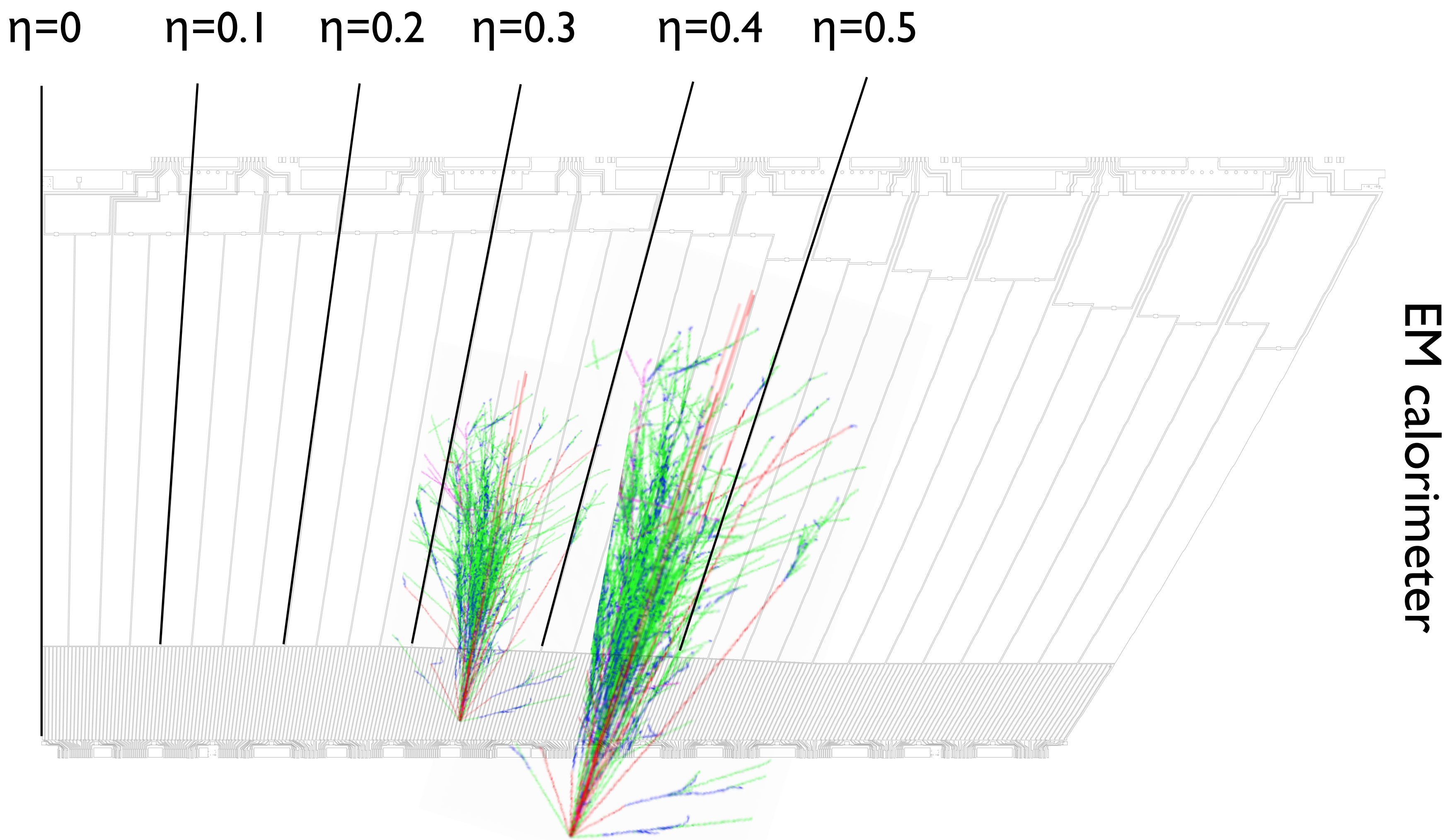
The ATLAS Detector and Calorimeters





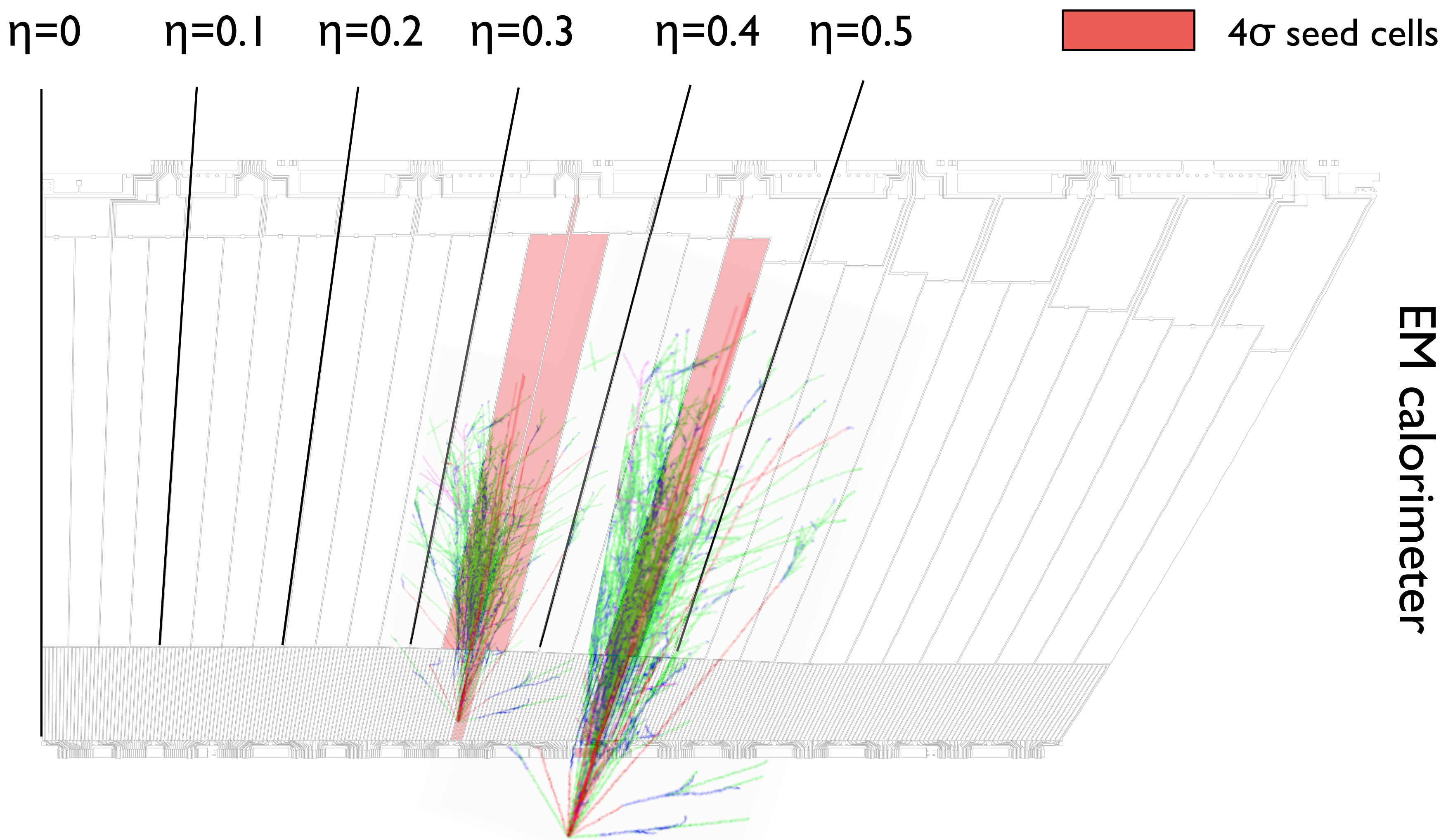
- Read-out in several segments along shower development
- Fine position resolution in electromagnetic calorimeter

ATLAS Clusters: the Inputs to Substructure



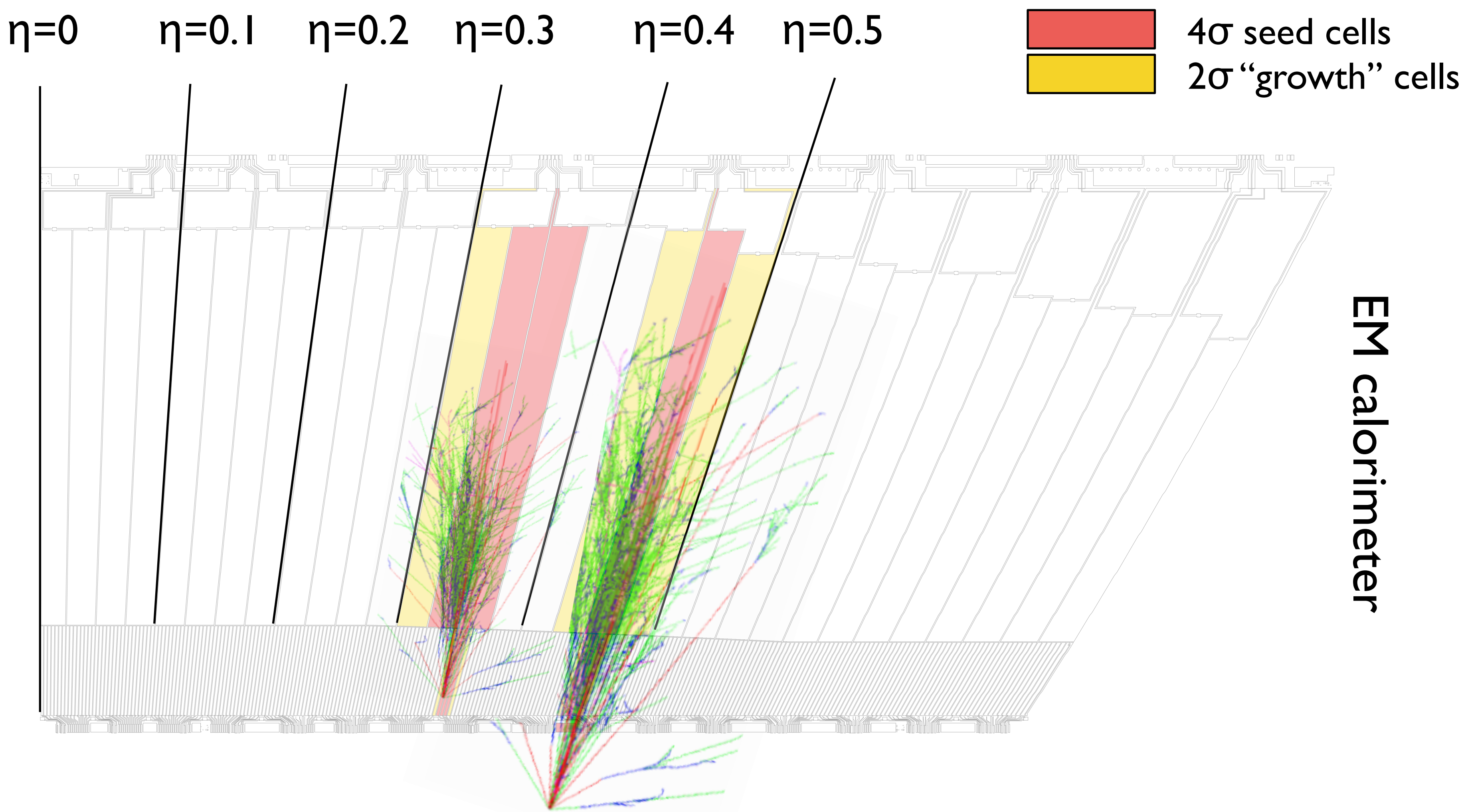
- Clusters are built starting from the fine readout granularity of the ATLAS calorimeter (above the EM calorimeter in the central region)

ATLAS Clusters: the Inputs to Substructure



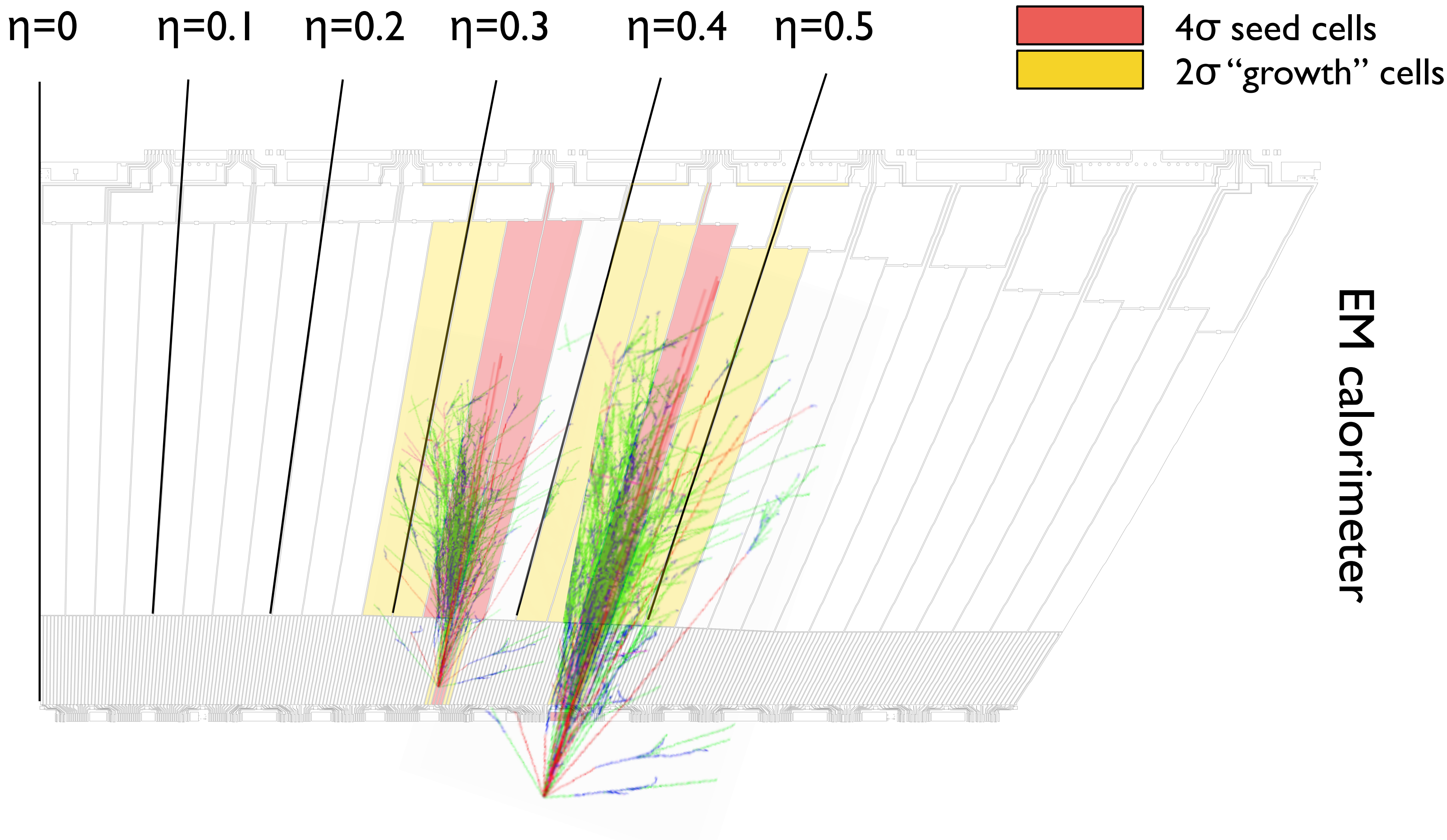
- Seeds are taken from cells that are above 4 standard deviations of the noise
- Noise includes electronic noise and average energy readings from pile-up
- Each cell has its value of noise stored in a database and that value is validated in data

ATLAS Clusters: the Inputs to Substructure



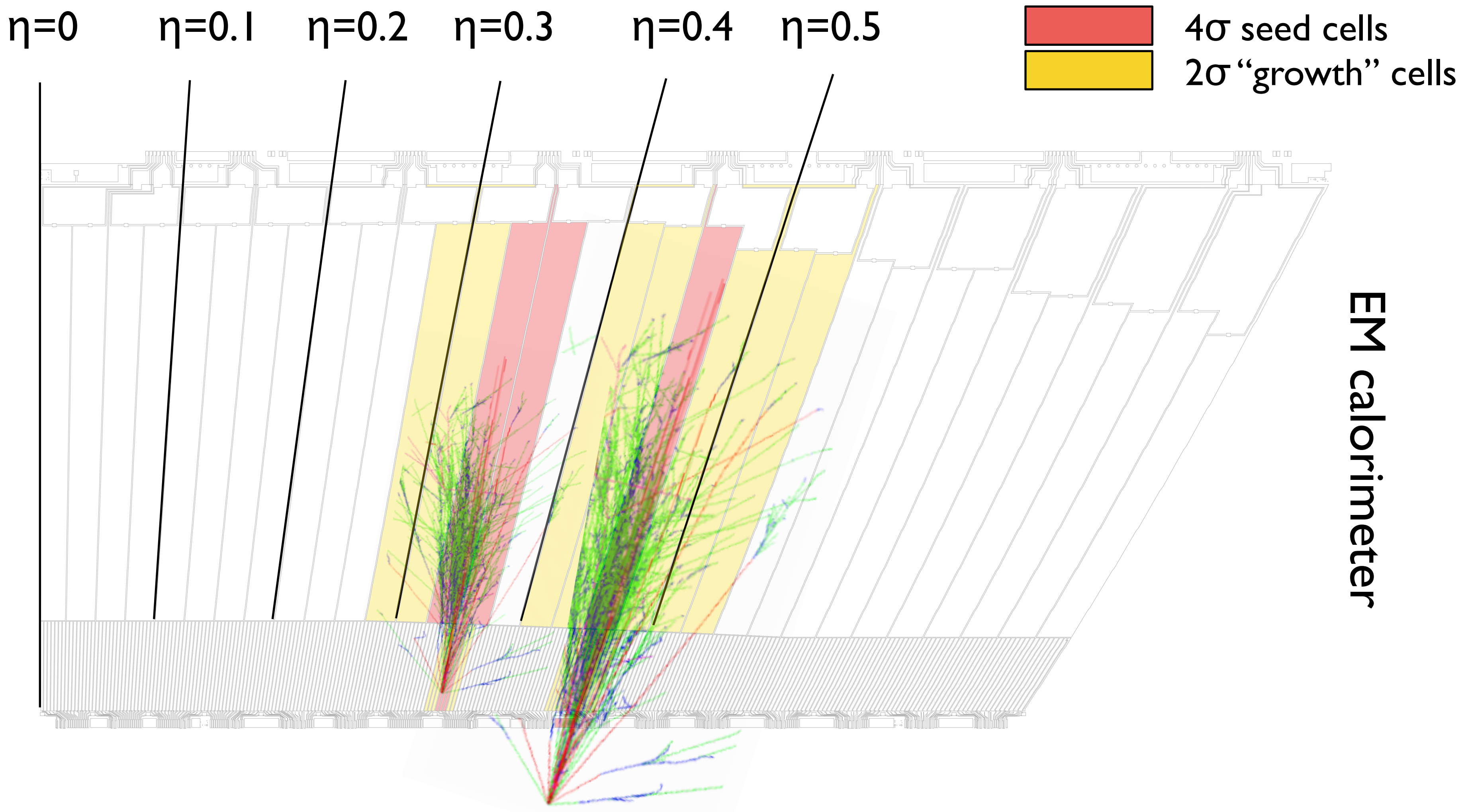
- Cluster grows (in 3 dimensions) into adjacent cells where a deposition >2σ is found

ATLAS Clusters: the Inputs to Substructure



- Cluster grows (in 3 dimensions) into adjacent cells where a deposition >2σ is found
- Growth continues while adjacent cells with >2σ are found

ATLAS Clusters: the Inputs to Substructure



- Cluster grows (in 3 dimensions) into adjacent cells where a deposition >2σ is found
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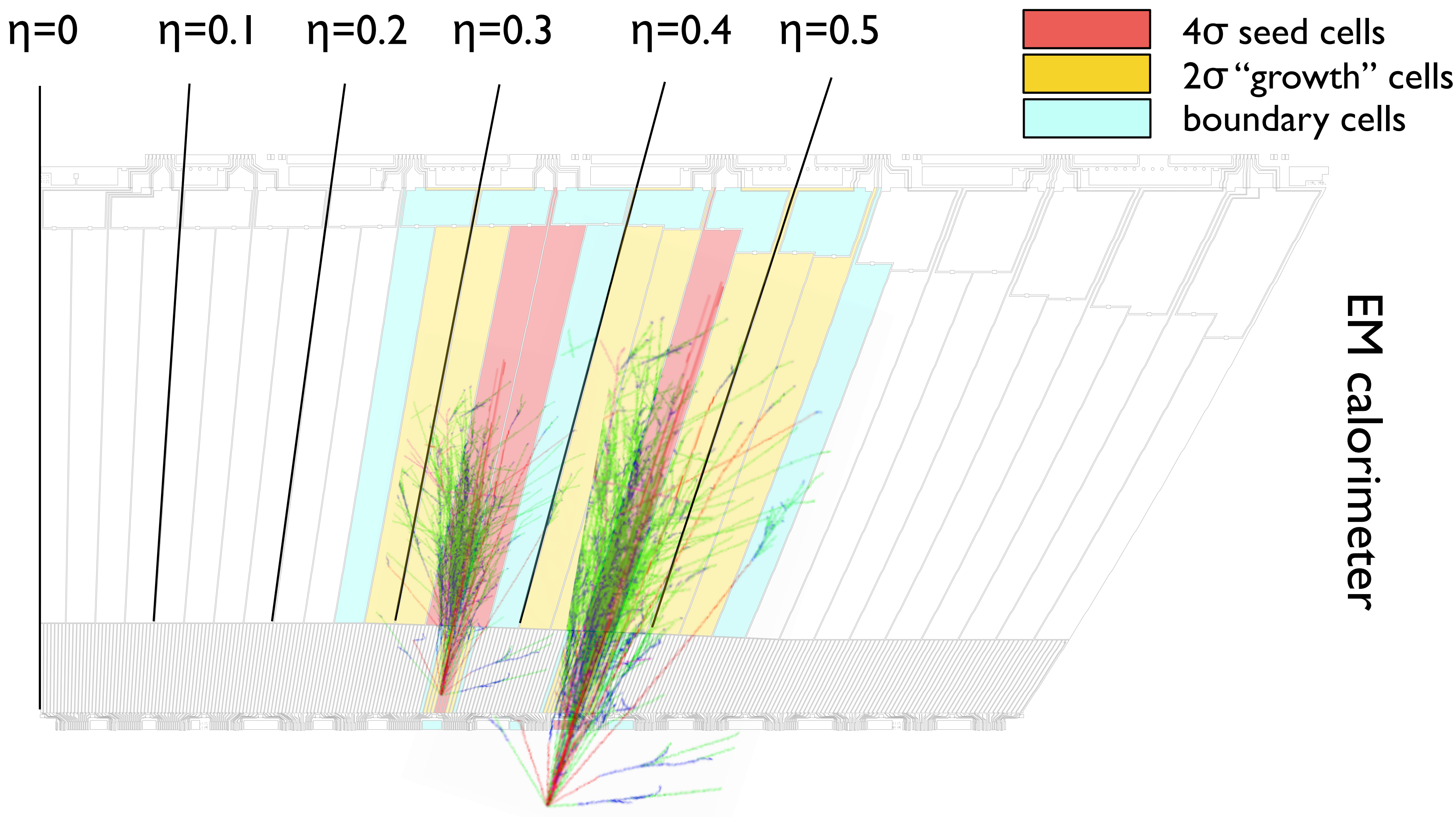
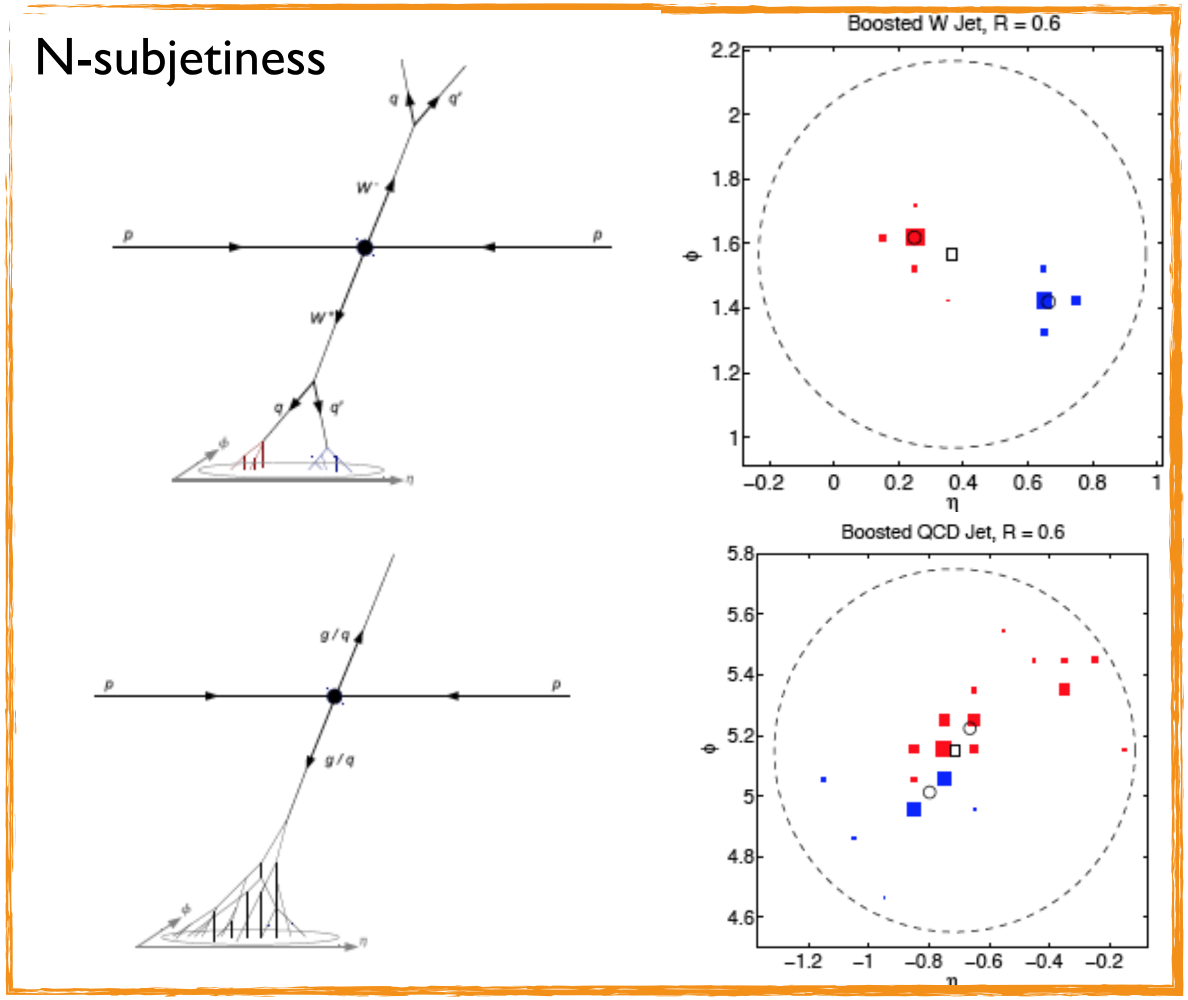
ATLAS Clusters: the Inputs to Substructure



- Once growth is no longer possible, an additional set of boundary cells is added (irrespective of their energy)

Looking Inside Jets: A Few Definitions

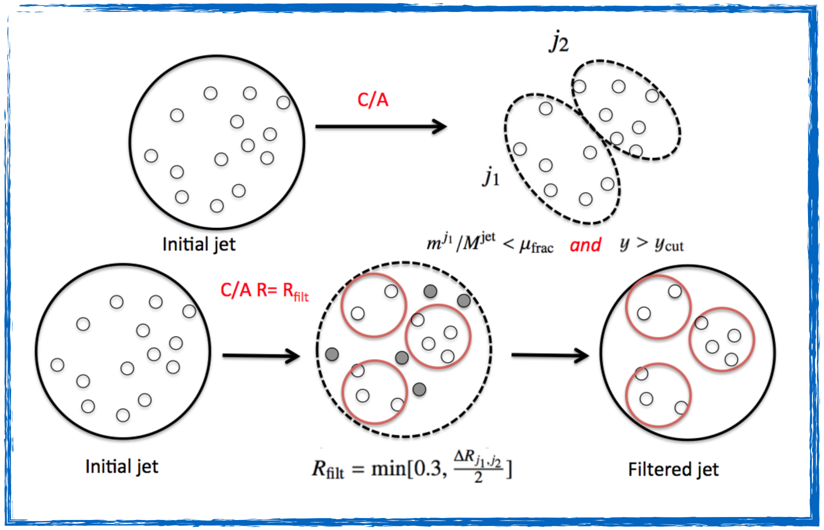
- Track multiplicities
- N-subjetiness
- Jet mass
- Jet charge
- k_t splitting scales
- Volatiliy
- Planar flow
- Jet pull
- Angularities (and EEC angularities)

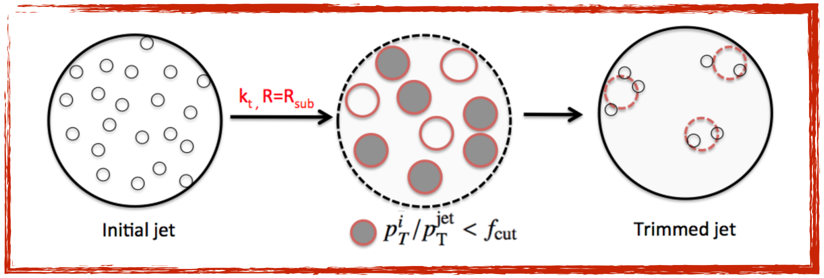


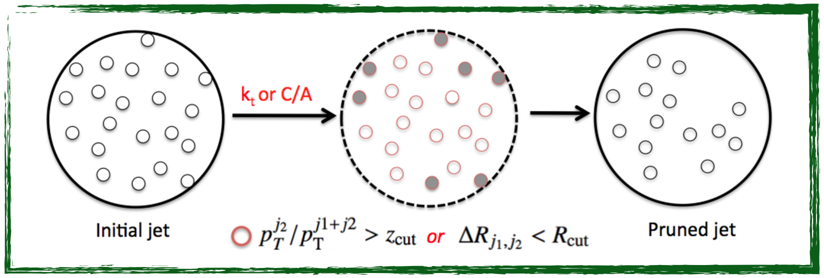
⇒Wealth of variables studied with different taggers as motivation; often used with groomers

Grooming

- Split-filtering, trimming and pruning studied in detail with 2011 and 2012 data







Grooming

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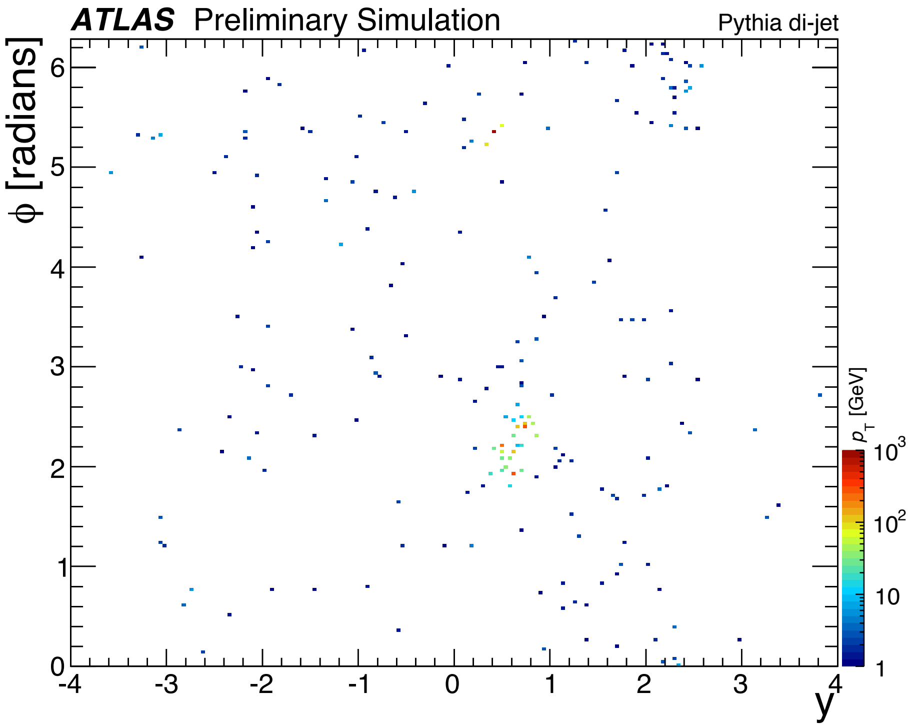
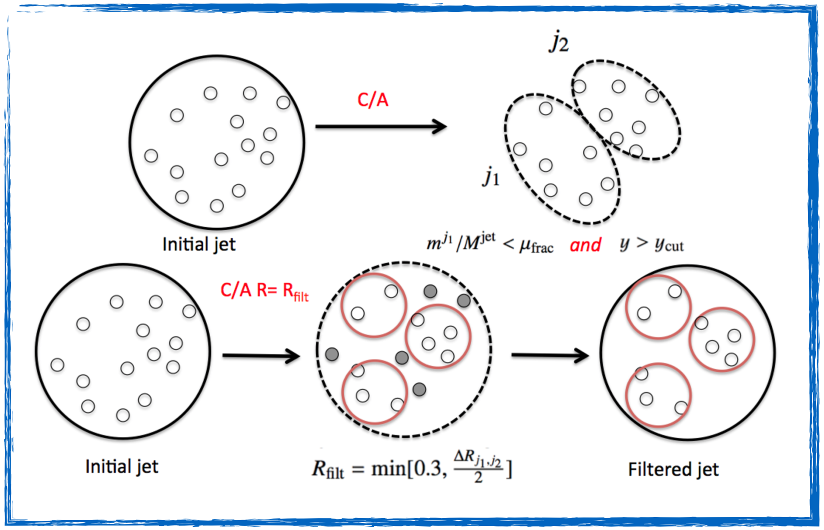
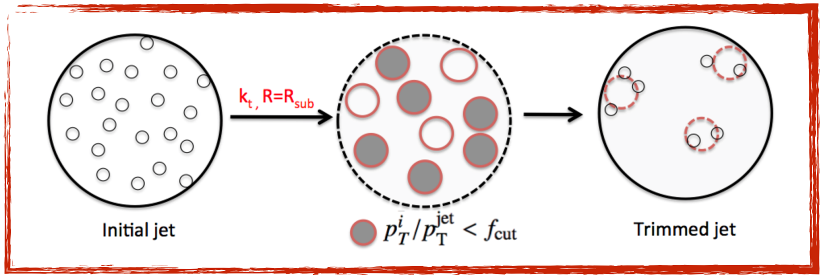
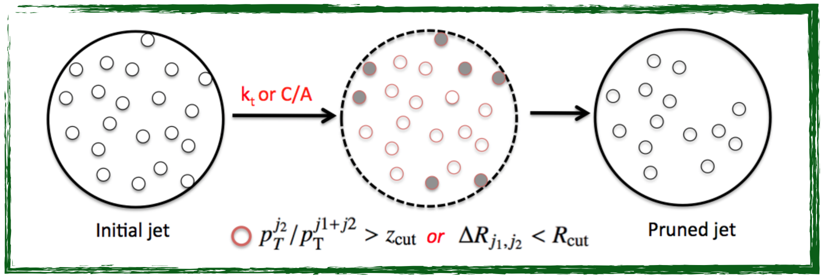


Trimming in action







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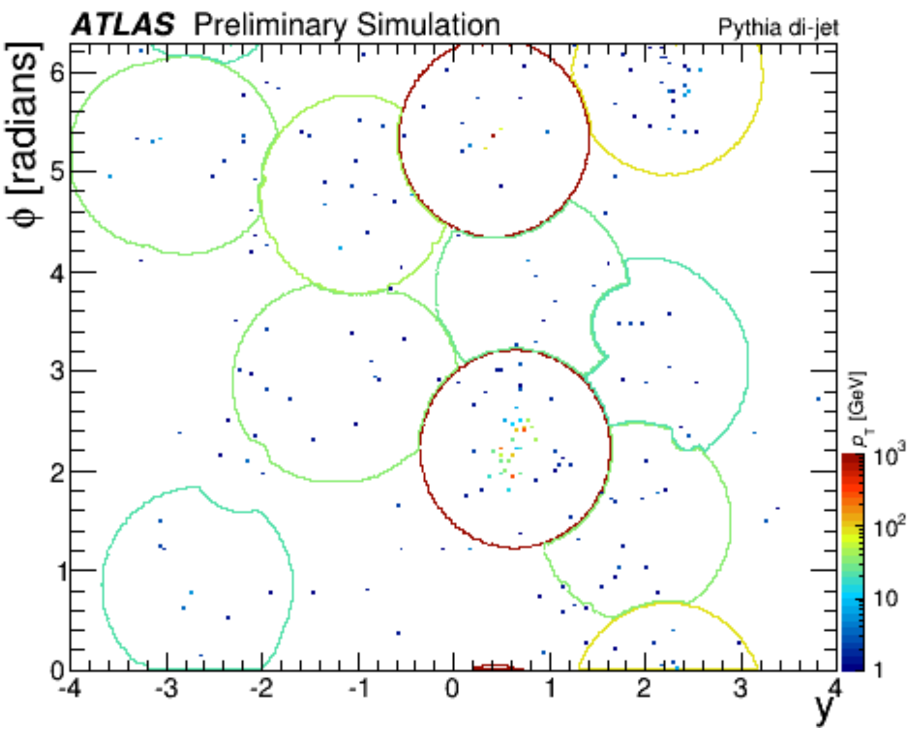
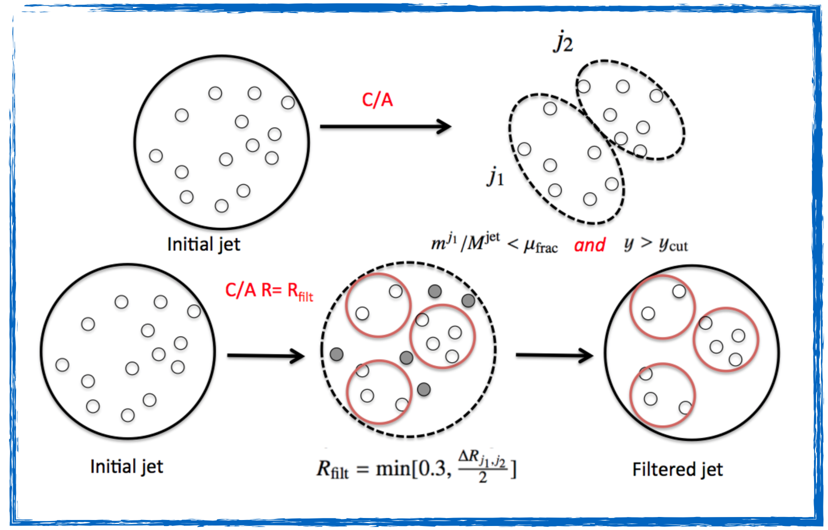
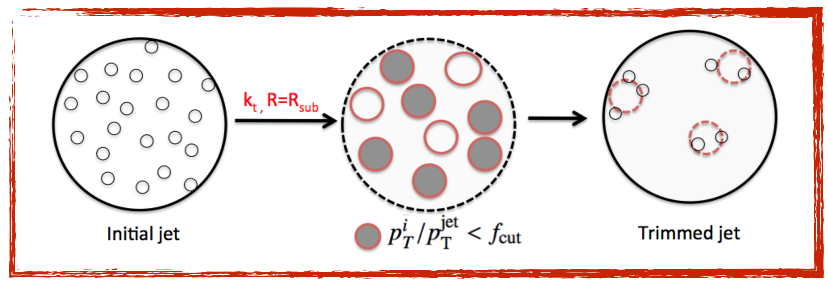
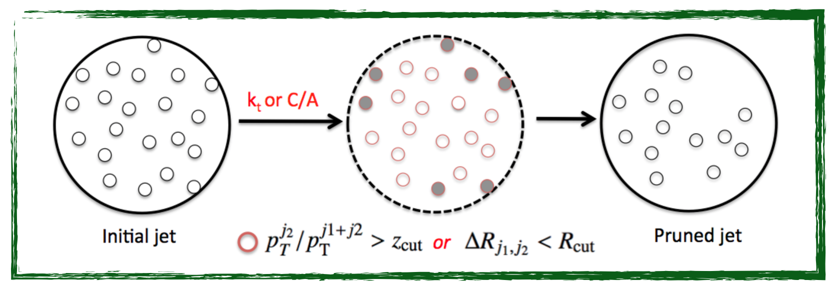


anti-k_t R=1.0 jets







Trimming in action

Grooming

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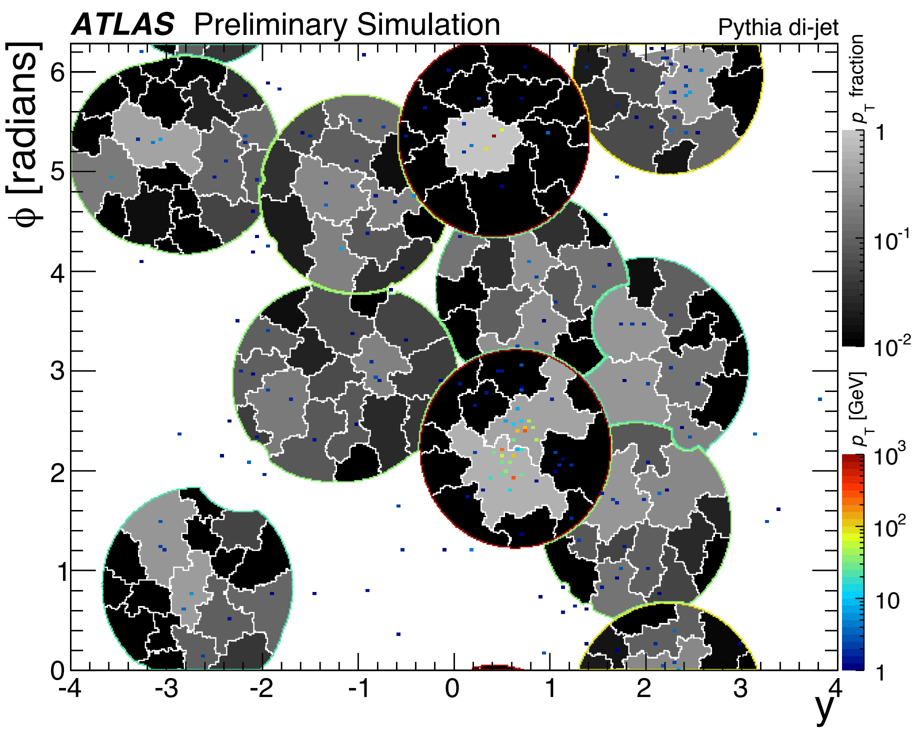
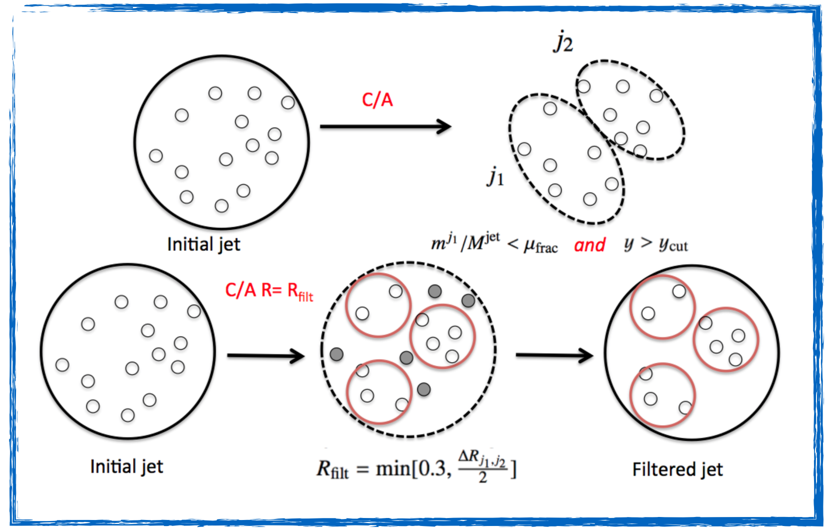
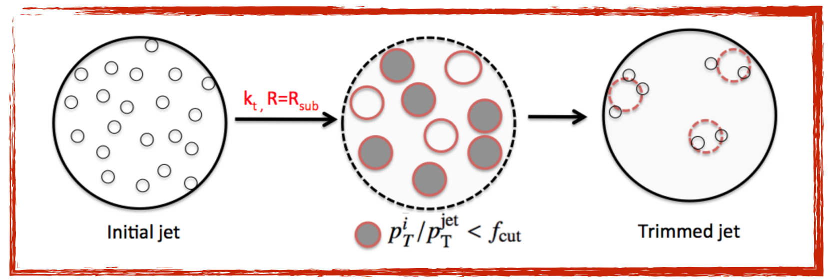
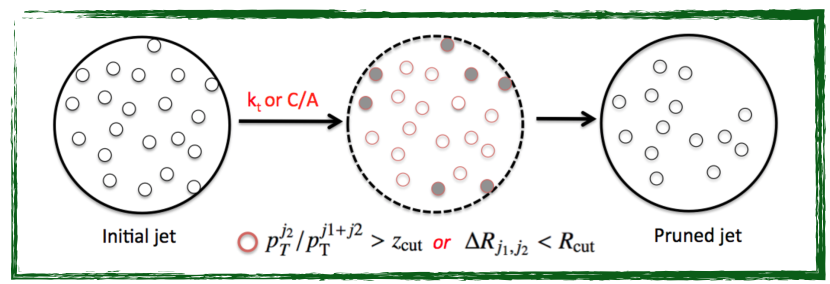


anti-k_t $R=1.0$ jets
k_t $R=0.3$ subjets

Trimming in action







Grooming

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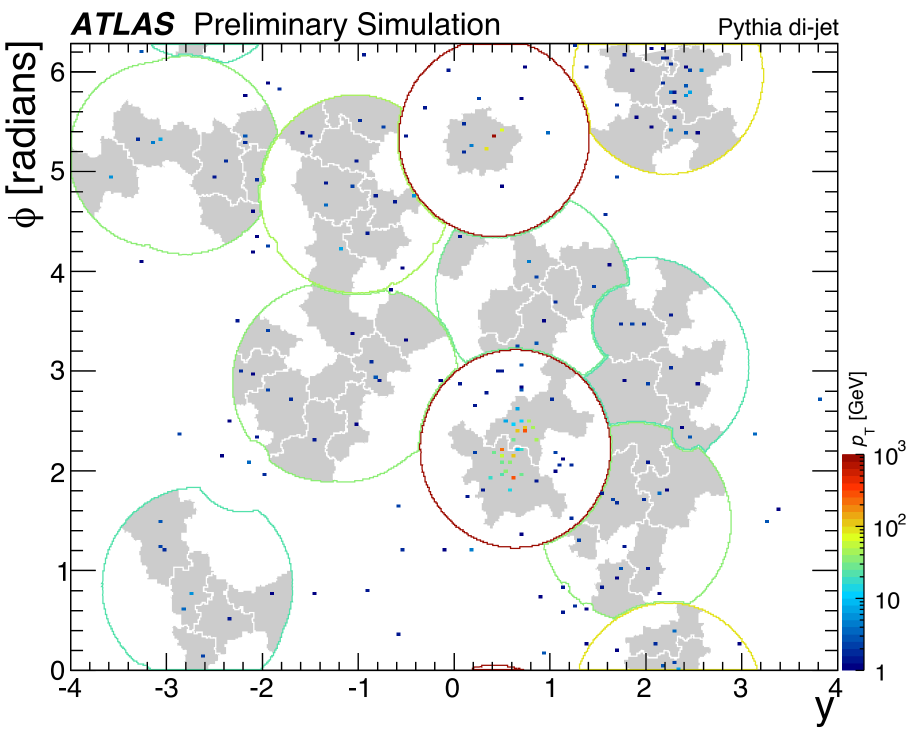
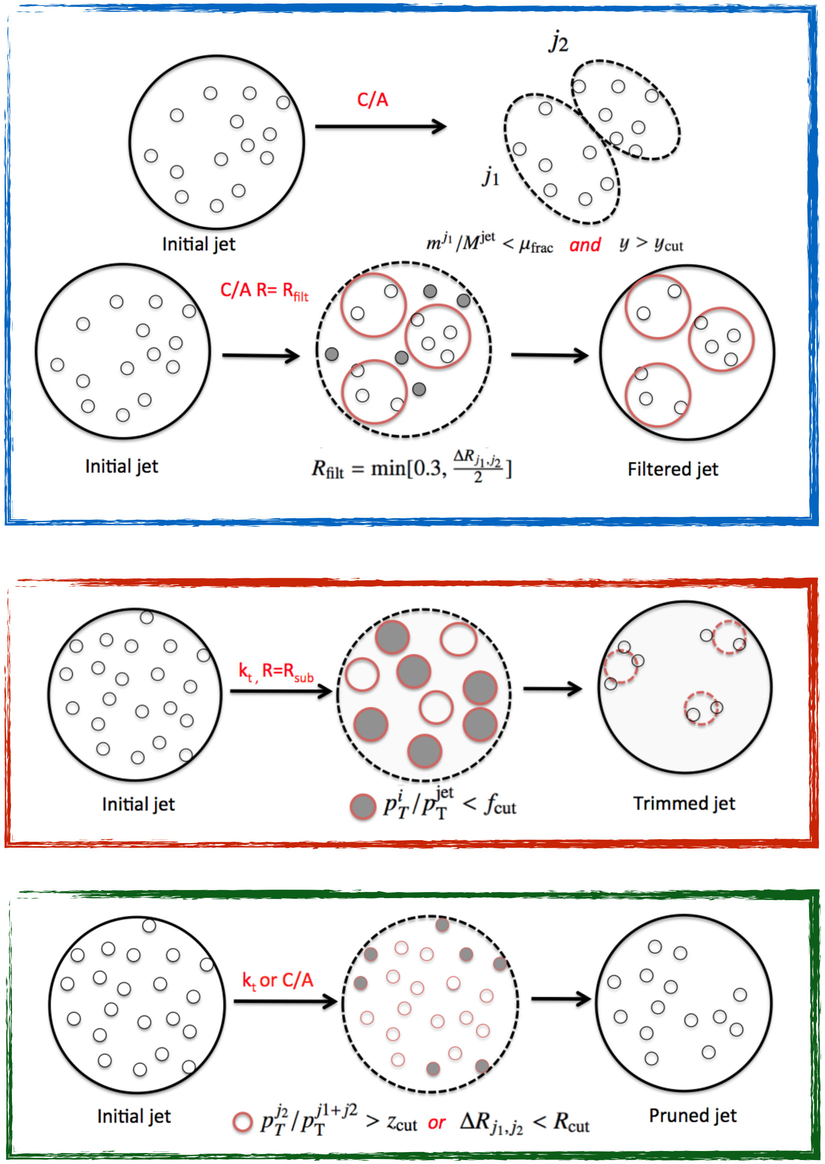
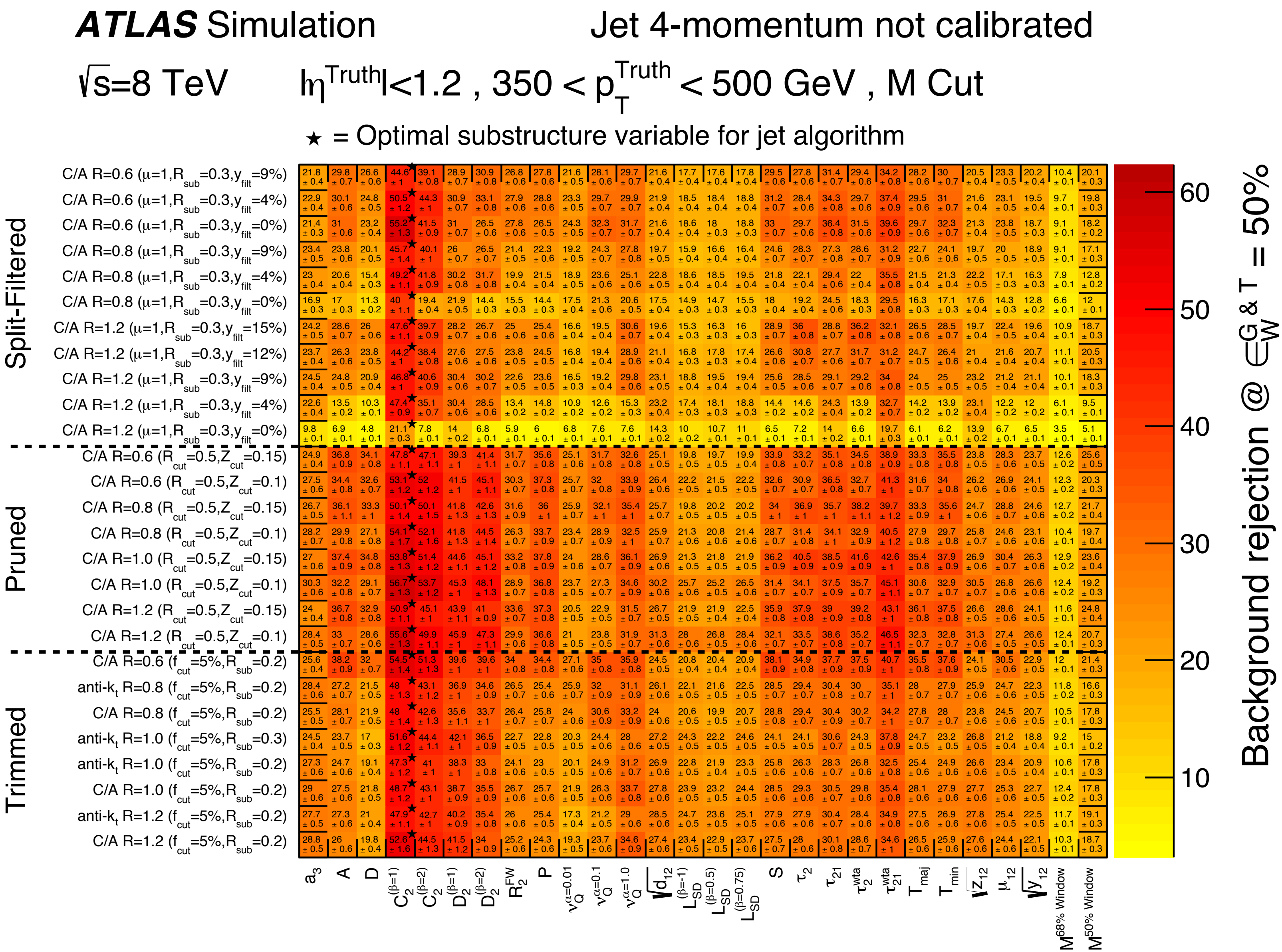


anti-k_t R=1.0 jets
k_t R=0.3 subjets
f_{cut}=0.05

Trimming in action

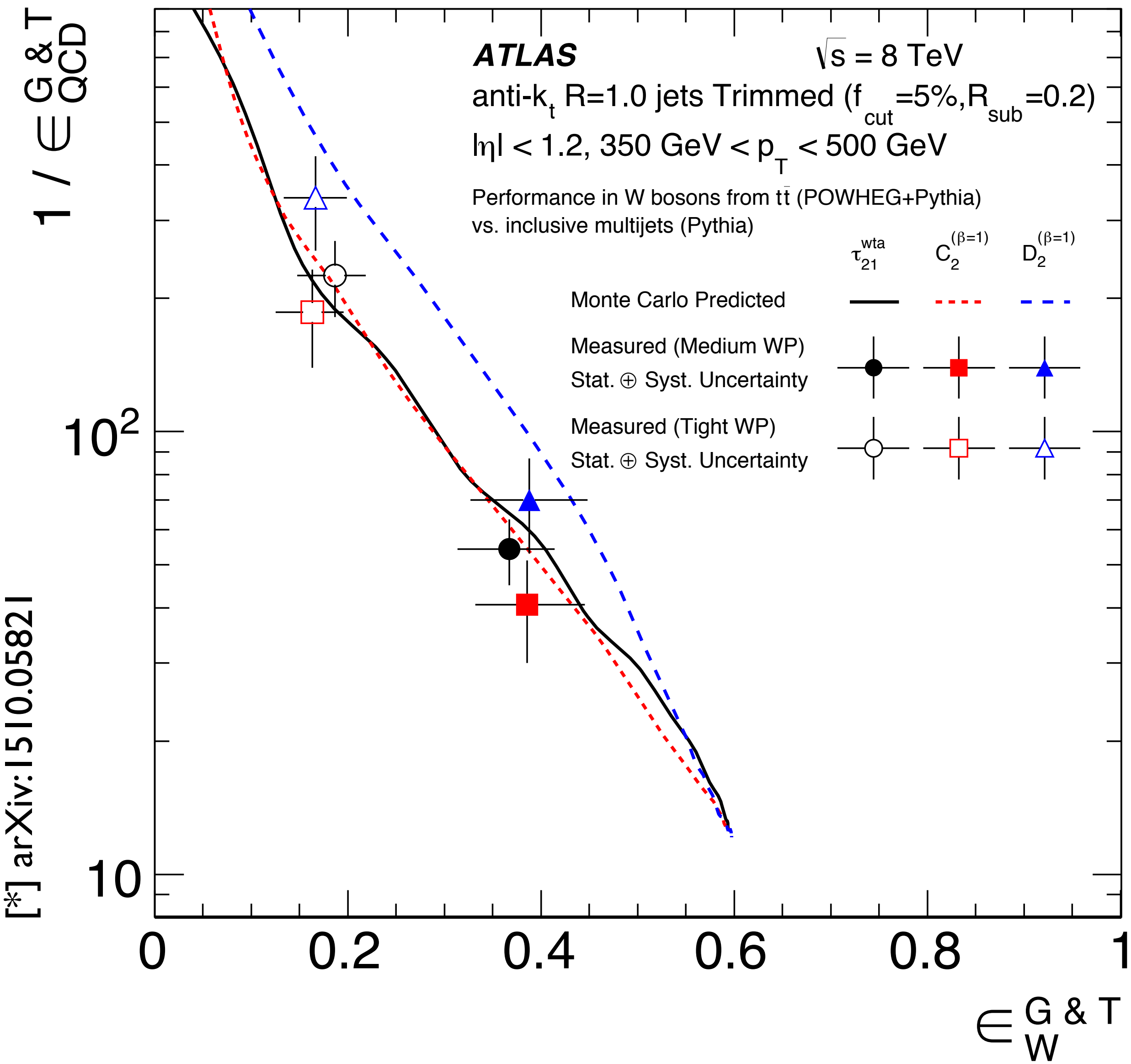


W/Z-tagging in Run 1



[*] arXiv:1510.05821

W/Z-tagging in Run 1

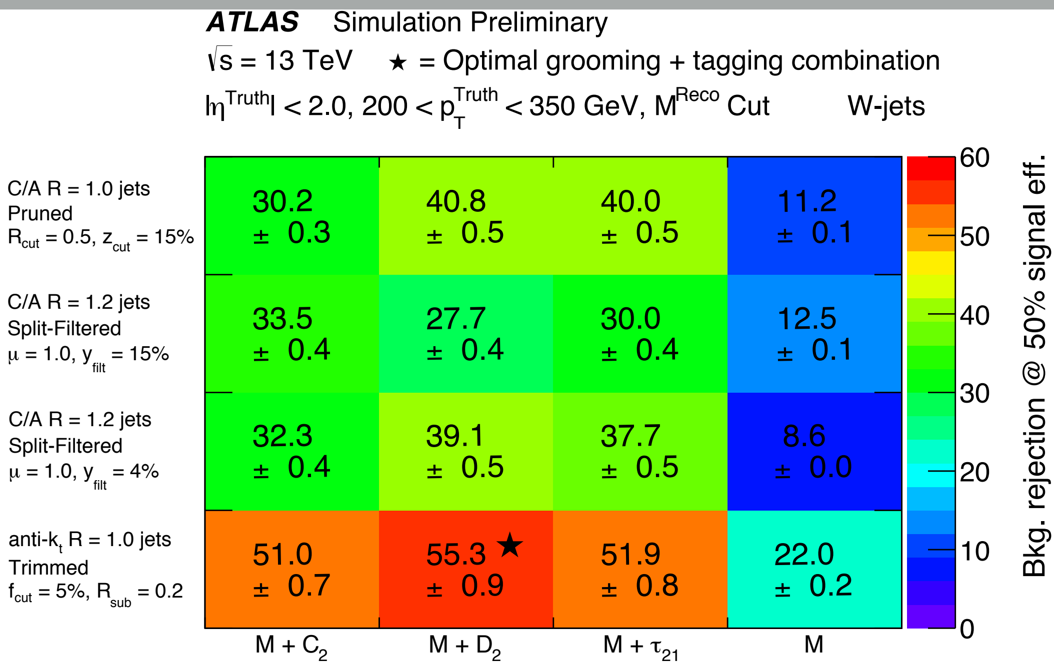


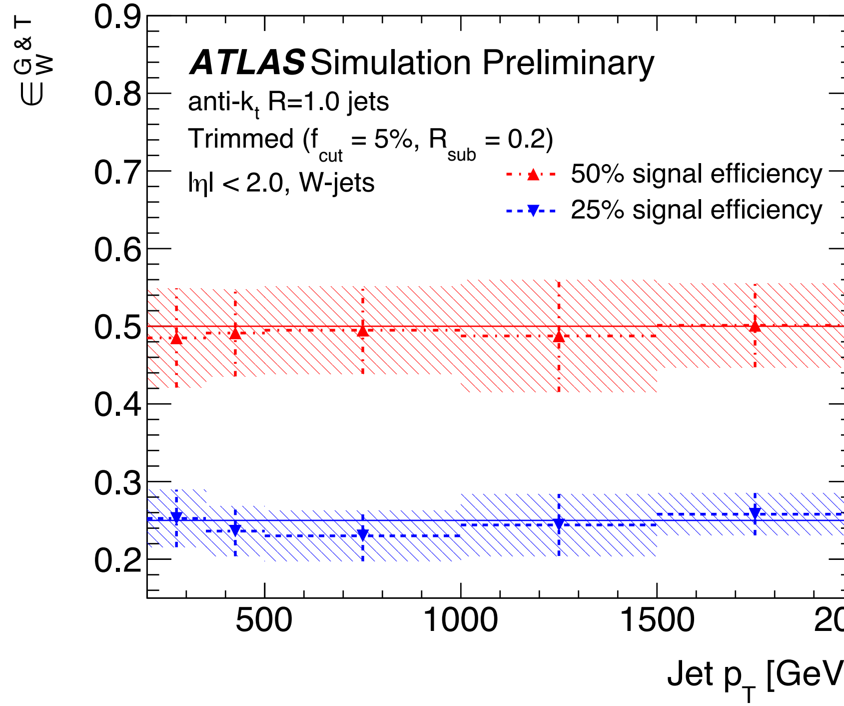
[*] arXiv:1510.05821

- Detailed comparison of 2-variable taggers with many jet reconstructions/groomers
- Used data to measure the efficiency for signal and background

➡ Good agreement between data and performance predicted in MC simulations

W/Z-tagging in Run 2

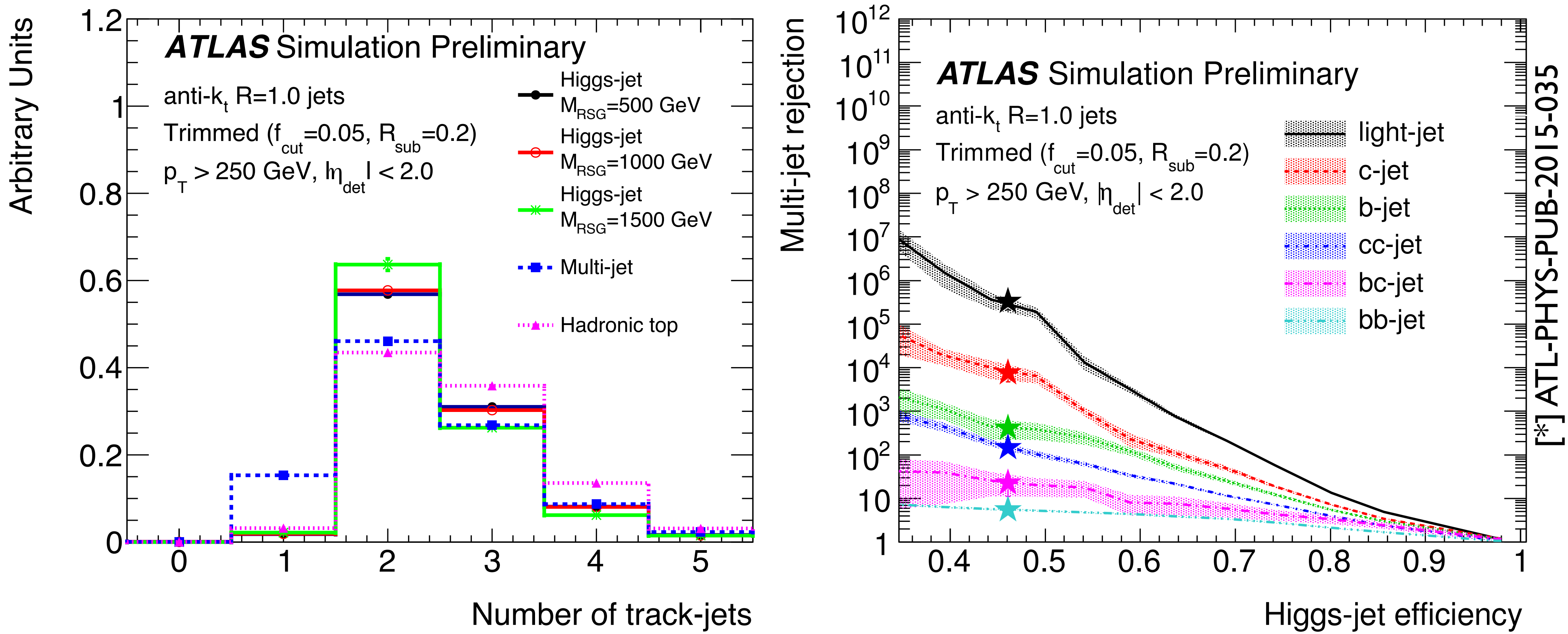




[*] ATL-PHYS-PUB-2015-033

- Run 1 studies give us confidence to do the same thing in Run 2 and establish systematic uncertainties

H→bb Tagging



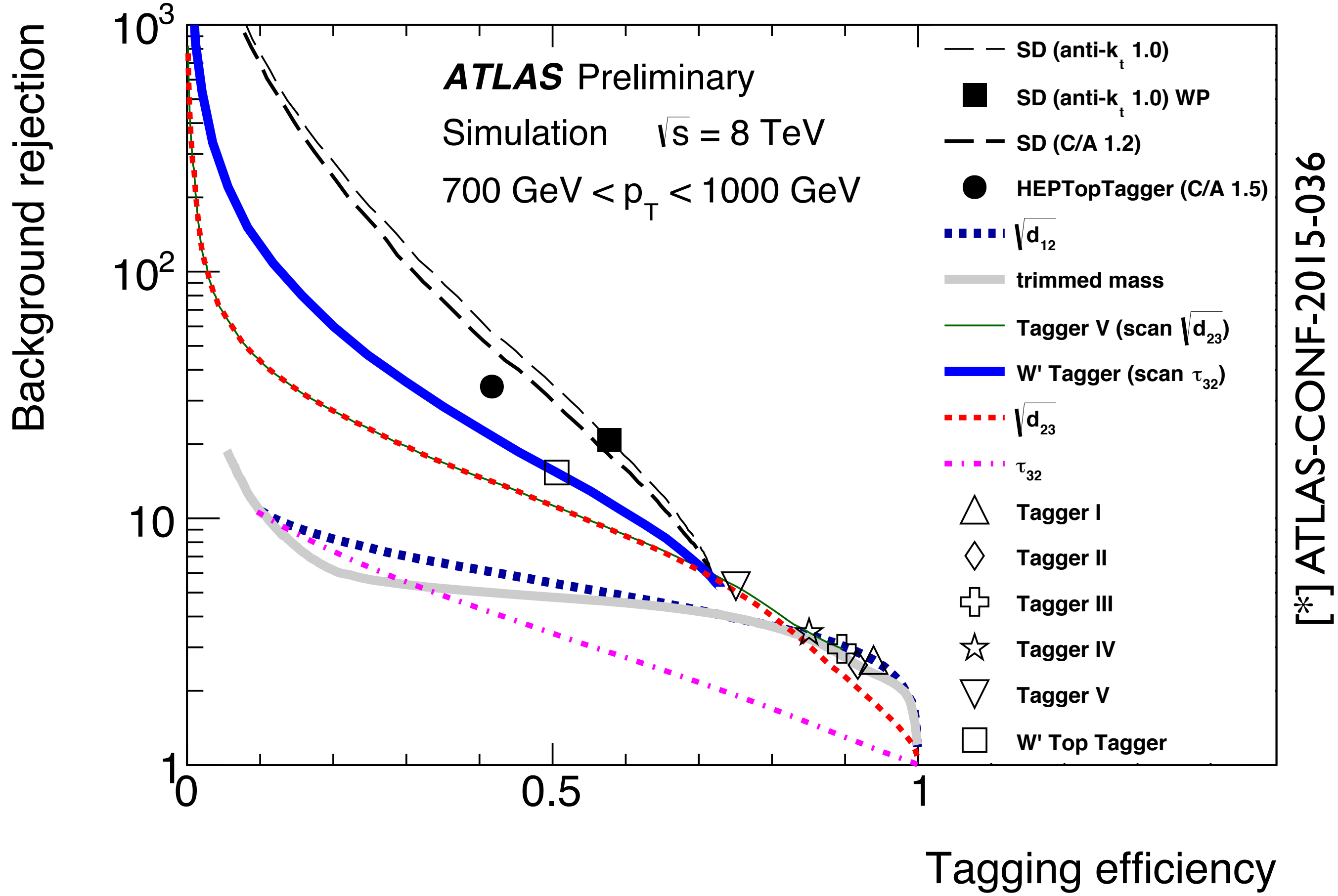
- Exploit two b-tags inside the jet
- Tag small (R=0.3 or 0.2) jets made of tracks (charged particles)
- Uncertainties driven by b-tagging (calibrated in Run 1 using ttbar events)

Simple taggers

- 1-D or 2-D cuts on mass and substructure variables
- Used when backgrounds are small

Complex taggers

- Use more complex combinations of the substructure kinematics
- Used when higher rejection is needed (at lower efficiencies)



- Both types thoroughly validated using data-driven techniques with 2012 data

Analyses Using Substructure in Run 1 and 2

Run 1

SUSY stop search	JHEP 1409 (2014) 015, JHEP 1411 (2014) 118	Back-up
X→$t\bar{t}$ search	JHEP 1301 (2013) 116, JHEP 1508 (2015) 148	Discussed here
W'→tb search	EPJC 75 (2015) 4, 165	Back-up
DM searches	PRL 112 (2014) 041802, arXiv:1510.06218	See A. Cortes's talk
ttbar differential x-section	arXiv:1510.03818	Not shown (measurement)
Vector-like quark searches	PRD 92 (2015) 11, 112007, arXiv:1510.02664	Back-up
W'→WZ search	EPJC (2015) 75:69 (209), JHEP 1512 (2015) 055	Discussed here
Hadronic W cross section	NJP 16 (2014) 11, 113013	Not shown (measurement)
HH→4b search	EPJC 75 (2015) 9, 412	Discussed here

Run 2

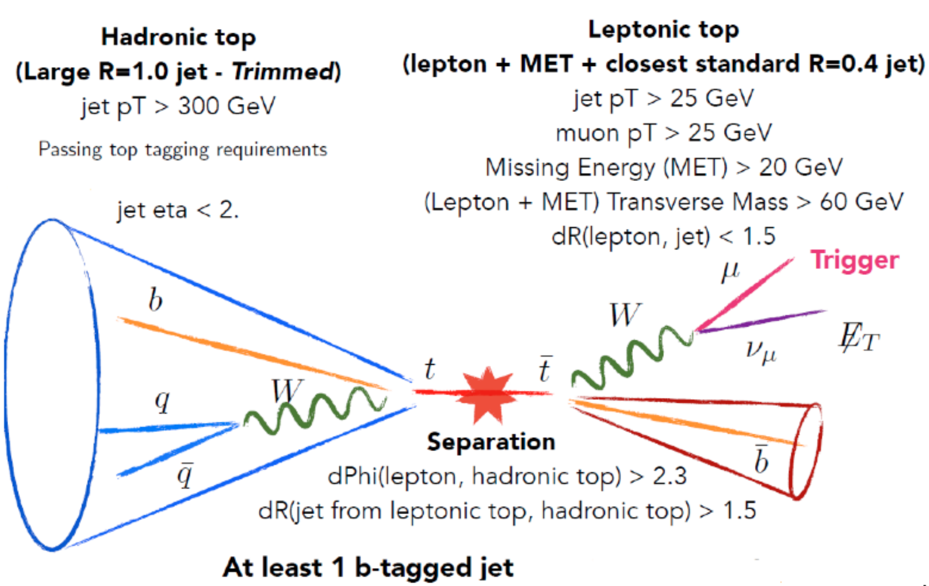
Diboson searches	ATLAS-CONF-2015-068, 71, 73, 75	Discussed here
High mass W/Z+H search	ATLAS-CONF-2015-074	Discussed here
Dark matter search	ATLAS-CONF-2015-080	See A. Cortes's talk
SUSY stop search	ATLAS-CONF-2015-067	See C. Ohm's talk

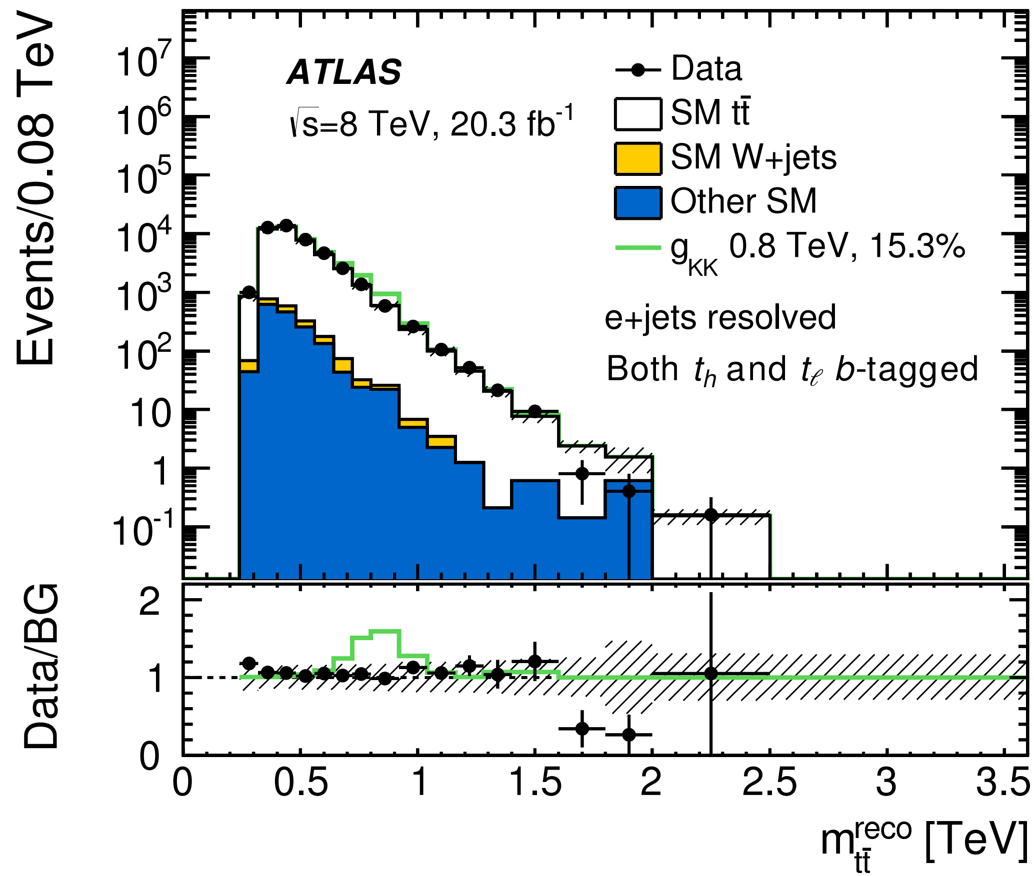
- Many early analyses already making use of boosted objects!
- I will discuss those performed in Run 2 and some representative analyses from Run 1

Top Resonance Searches with Simple Taggers

X→$t\bar{t}$→lepton+jets

- Low backgrounds other than $t\bar{t}$
- No advantage in cutting hard on substructure variables





[*] JHEP 1508 (2015) 148

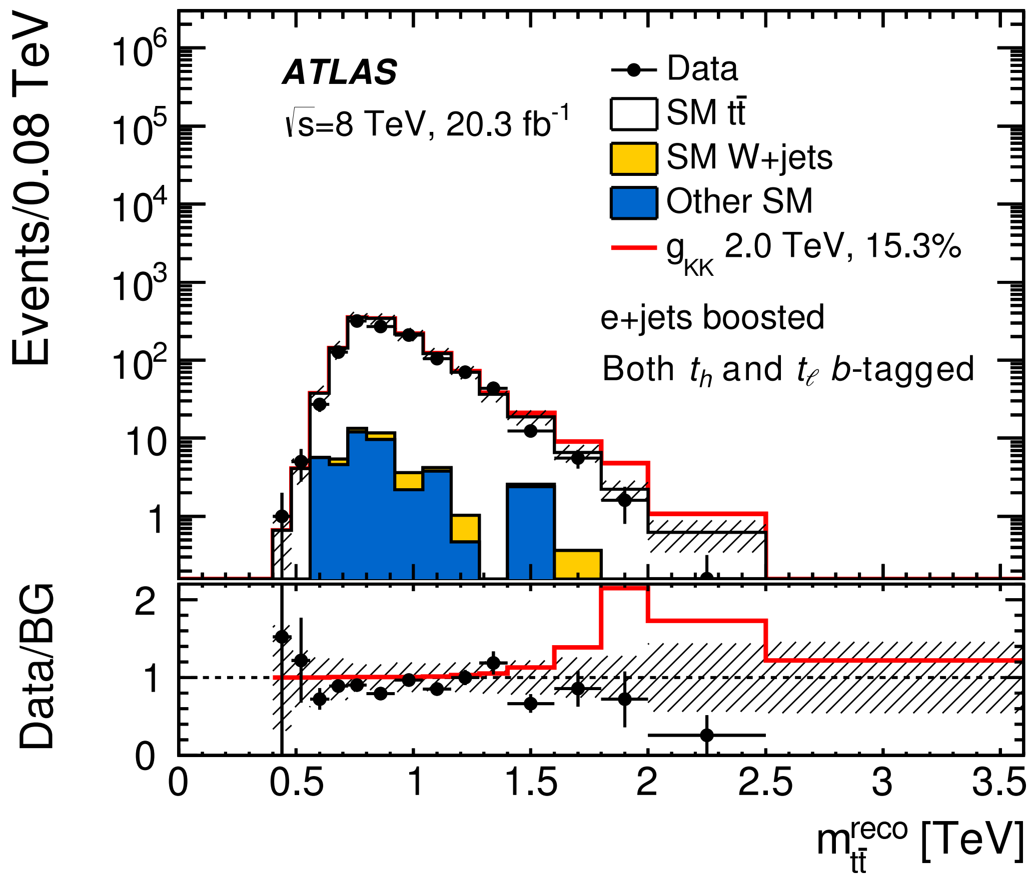
Top Resonance Searches with Simple Taggers

X→$t\bar{t}$→lepton+jets

- Low backgrounds other than ttbar

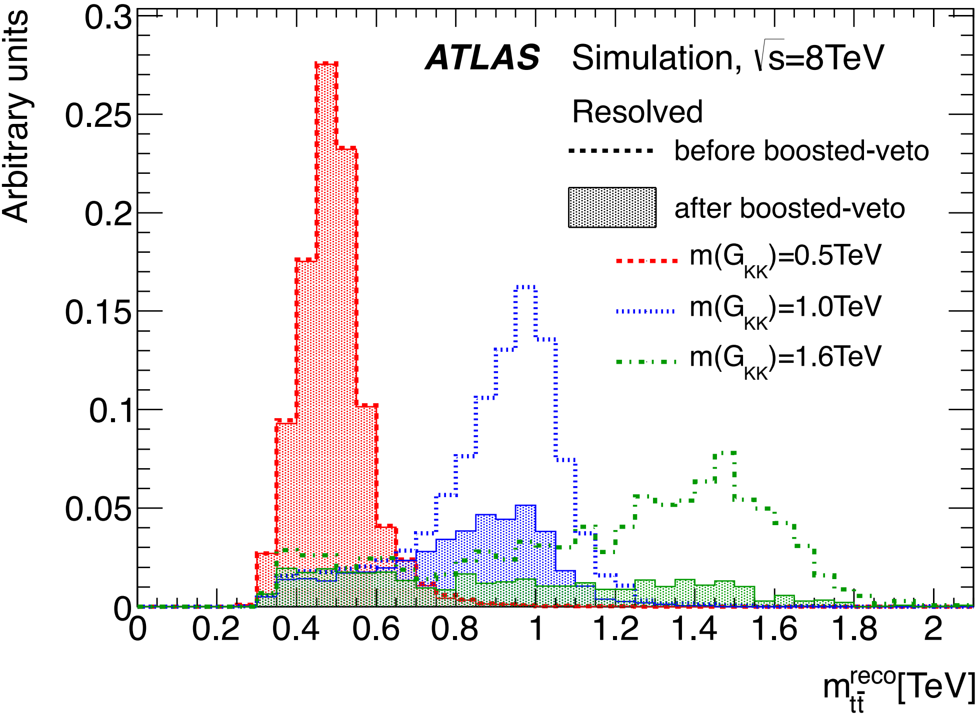
- No advantage in cutting hard on substructure variables

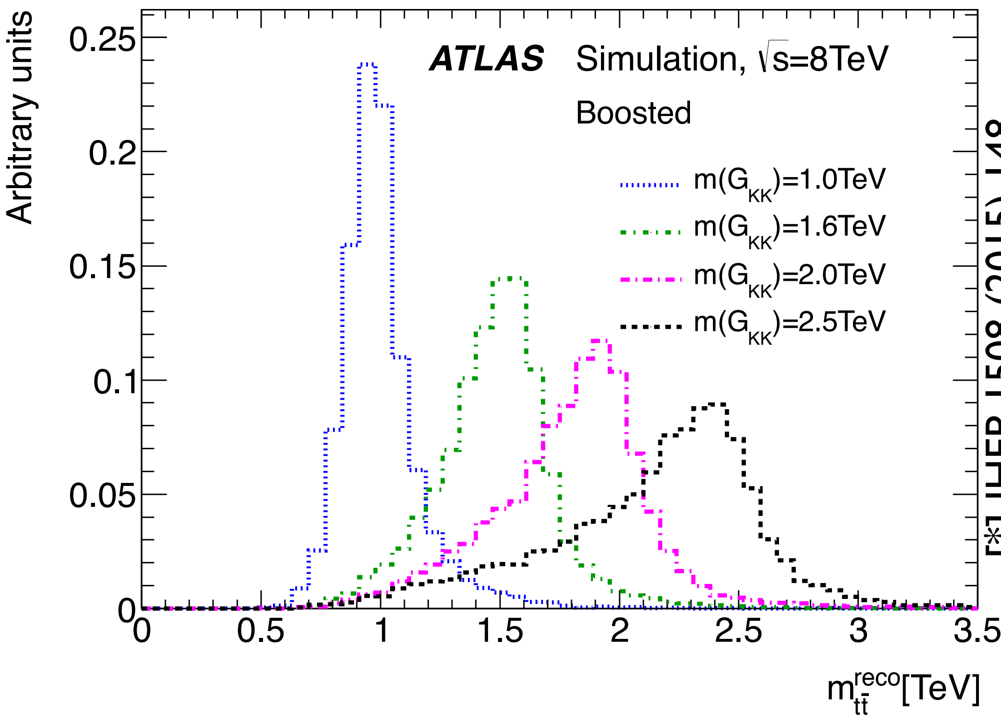
- A simple cut on the first k_t splitting scale (>40 GeV), m_{top}>100 GeV



[*] JHEP 1508 (2015) 148

Top Resonance Searches with Simple Taggers

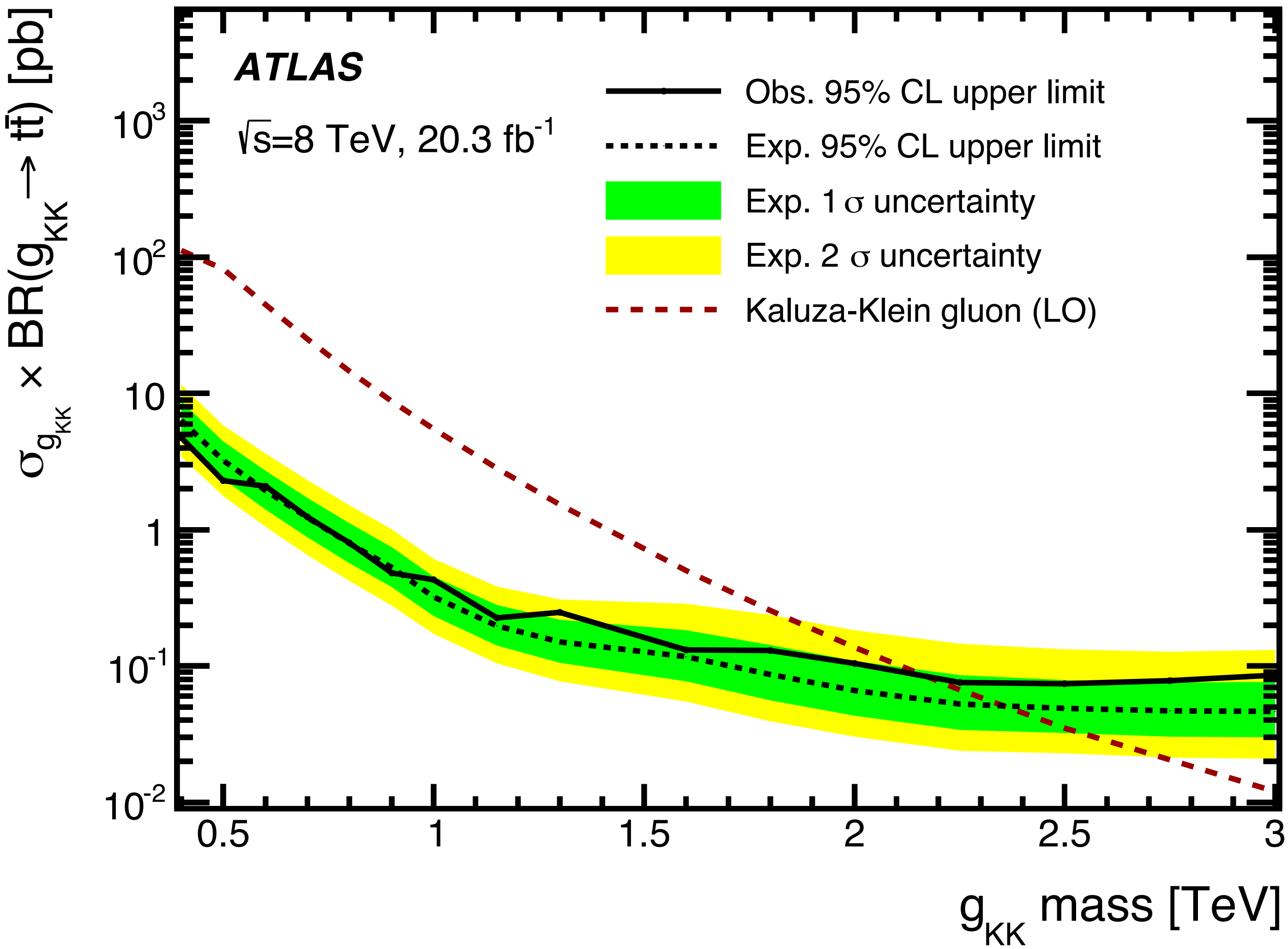




[*] JHEP 1508 (2015) 148

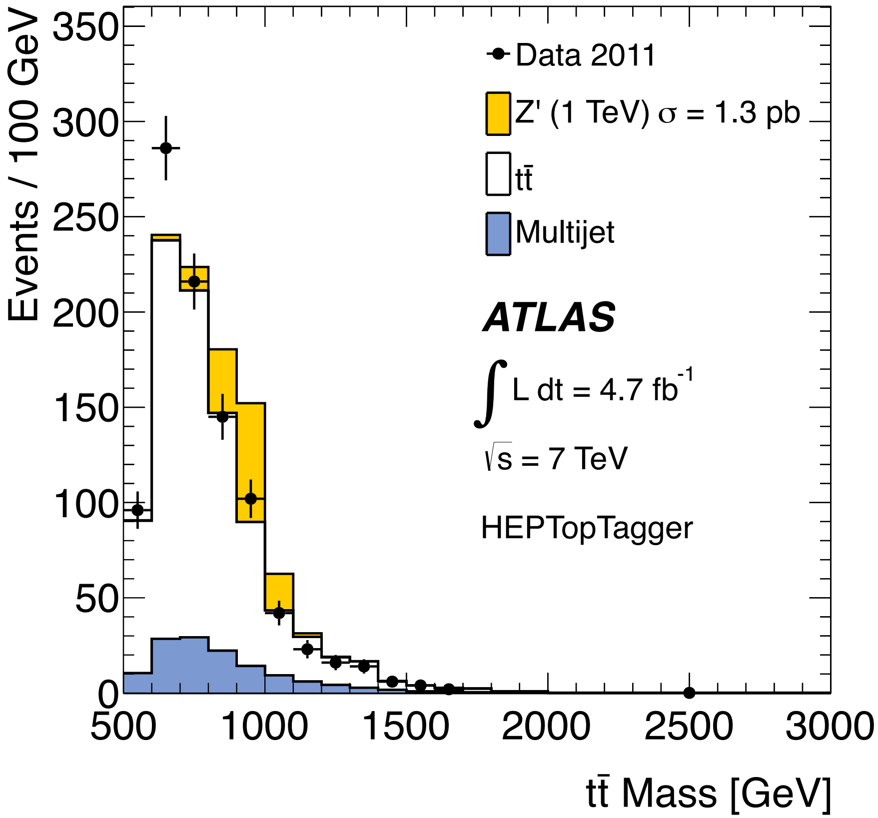
- Clear improvement in reconstruction using large-R jets as we go to high masses

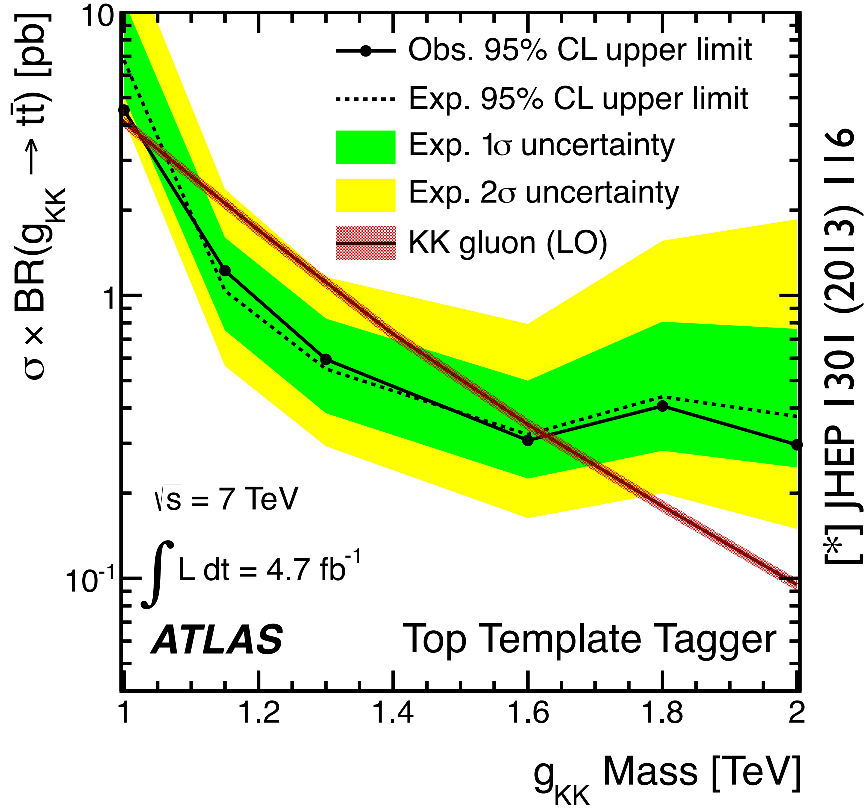
Top Resonance Searches with Simple Taggers



[*] JHEP 1508 (2015) 148

Top Resonance Searches with Complex Taggers





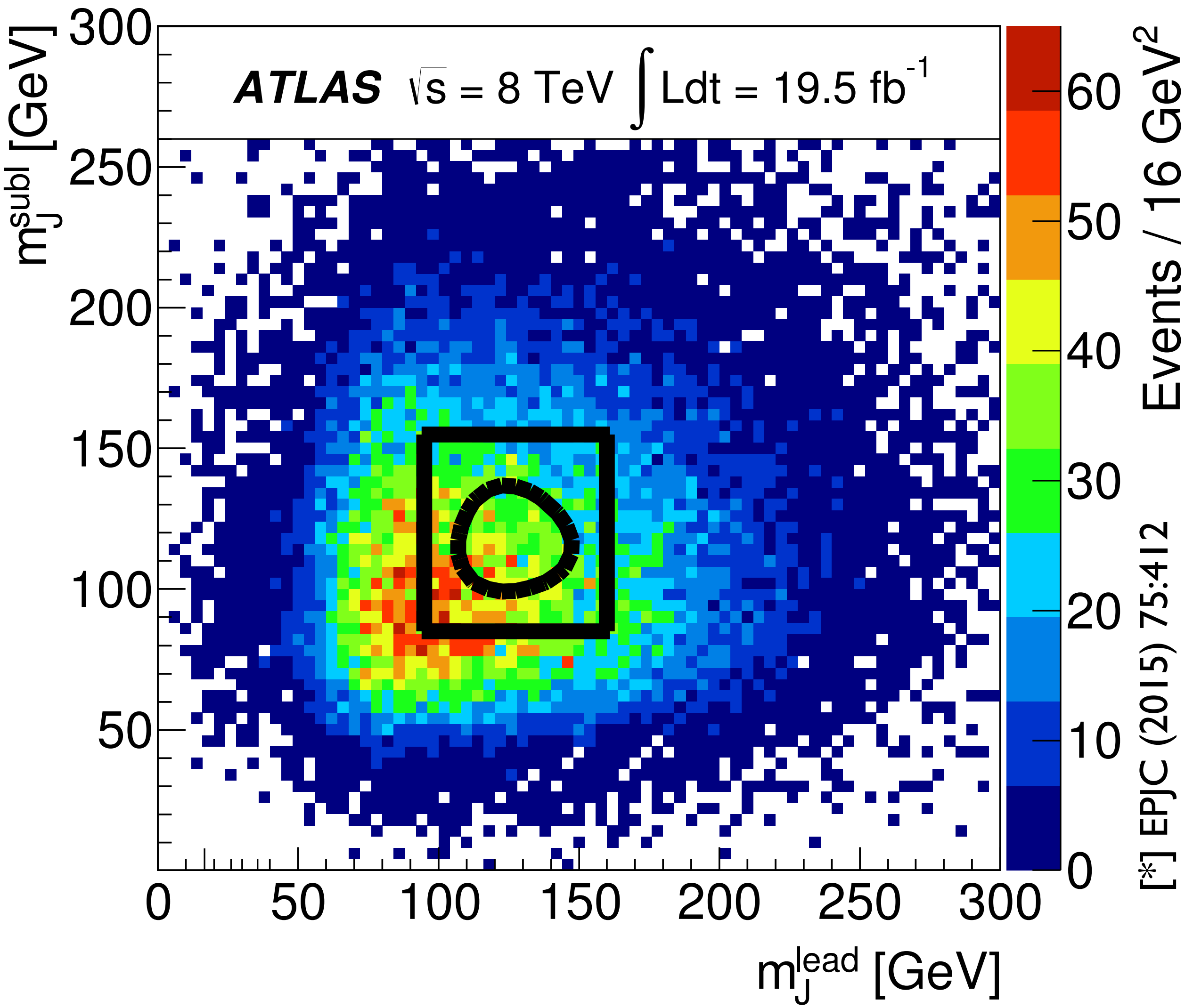
$X \to t\bar{t} \to$ jets

- Large multijet background
- Use HEPTopTagger at about 40% efficiency to reject multisite backgrounds

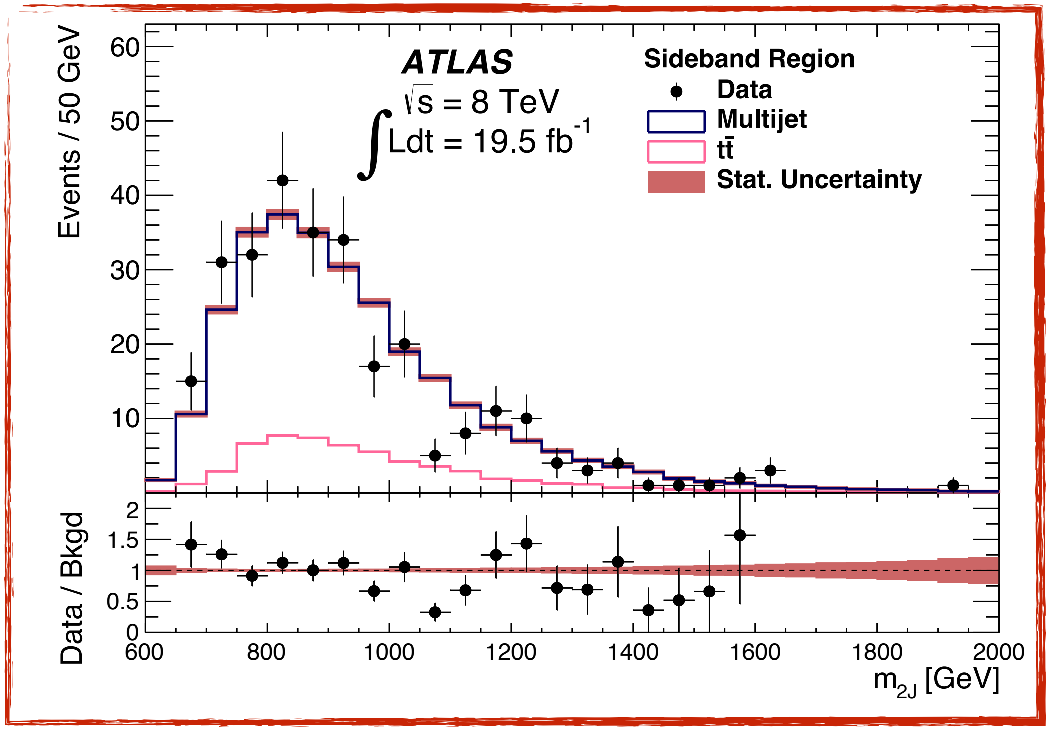
Di-Higgs Searches

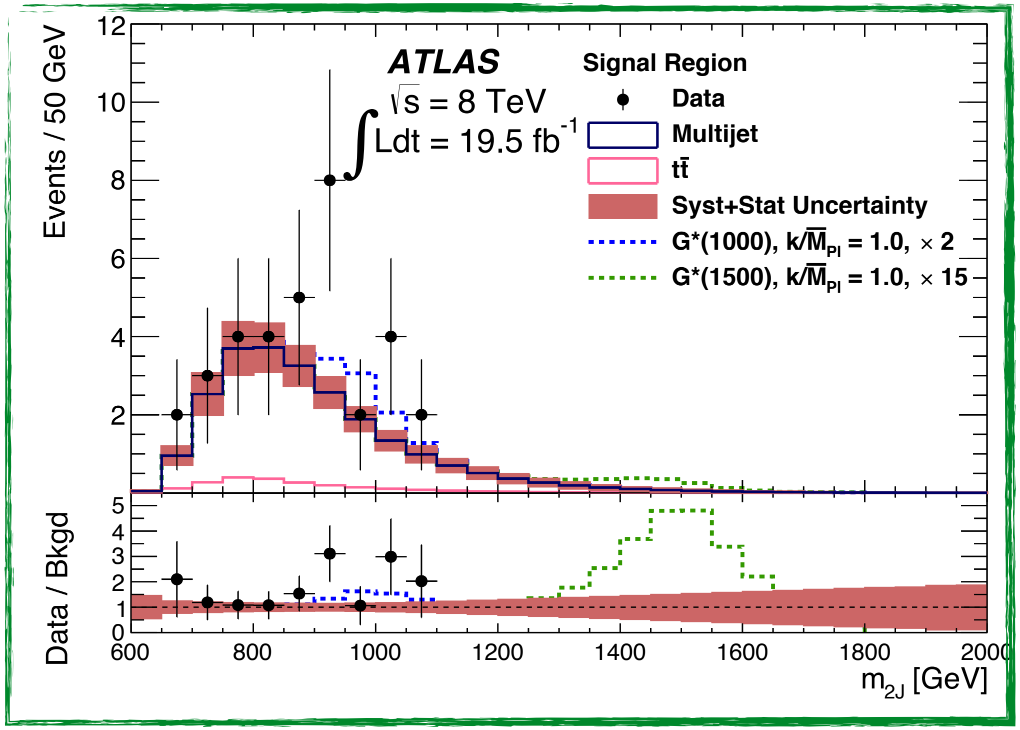
HH→4b

- Large multijet background
- 2 b-tags used
- Sideband control regions heavily used for validation and background estimation



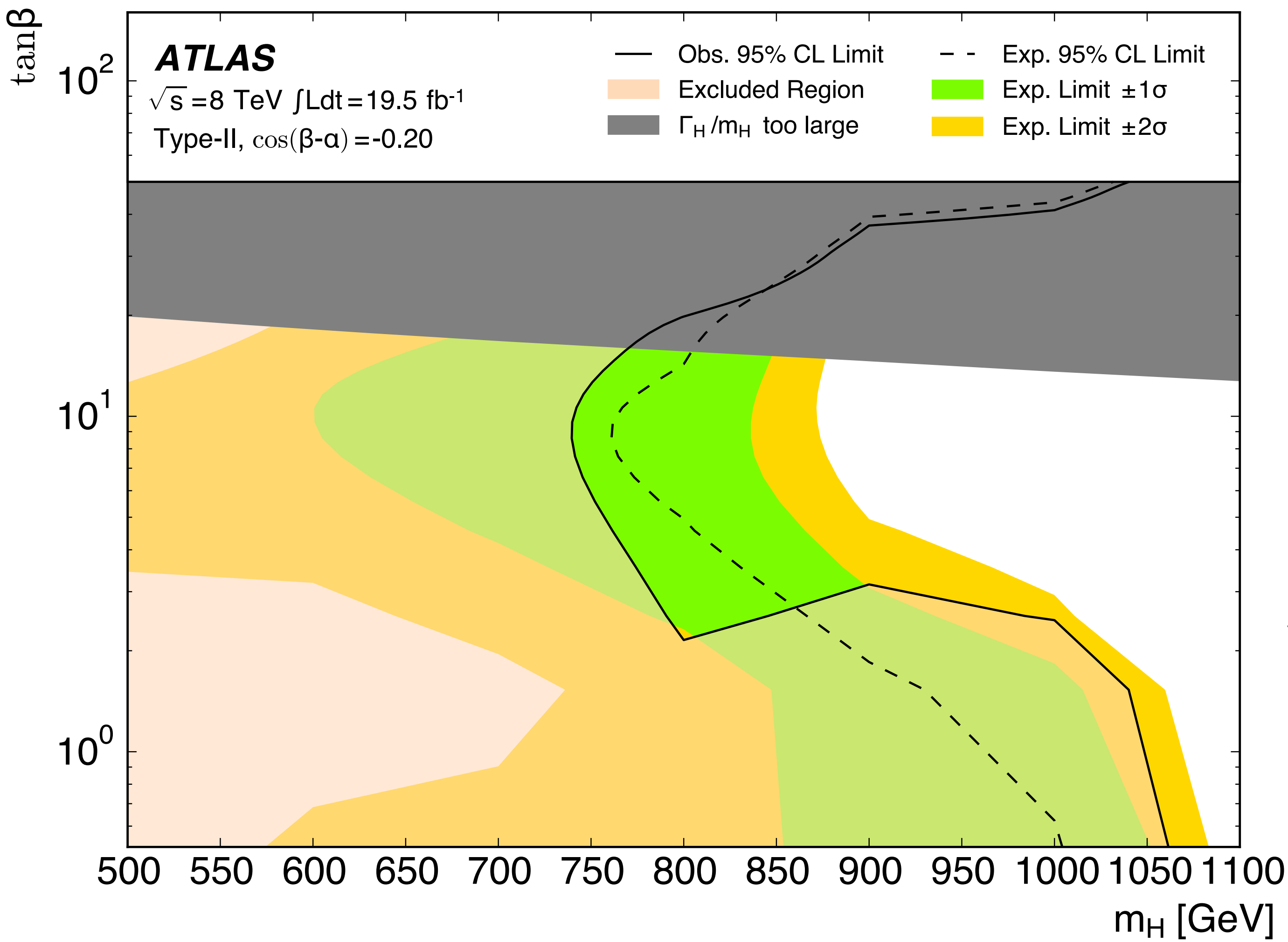
Di-Higgs Searches





- Good agreement between data and MC in sidebands
- Multijet remains the most dominant background in the signal region

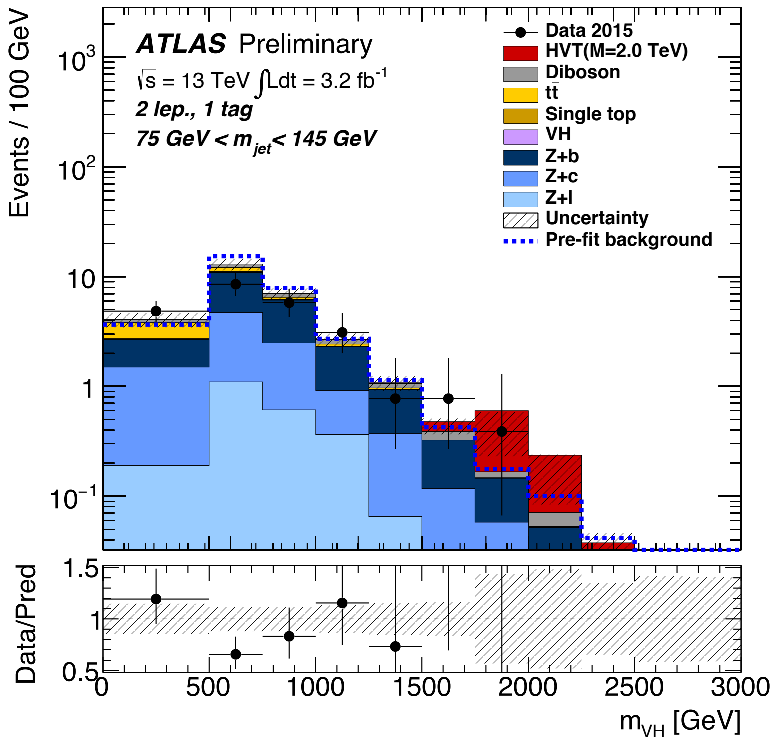
Di-Higgs Searches

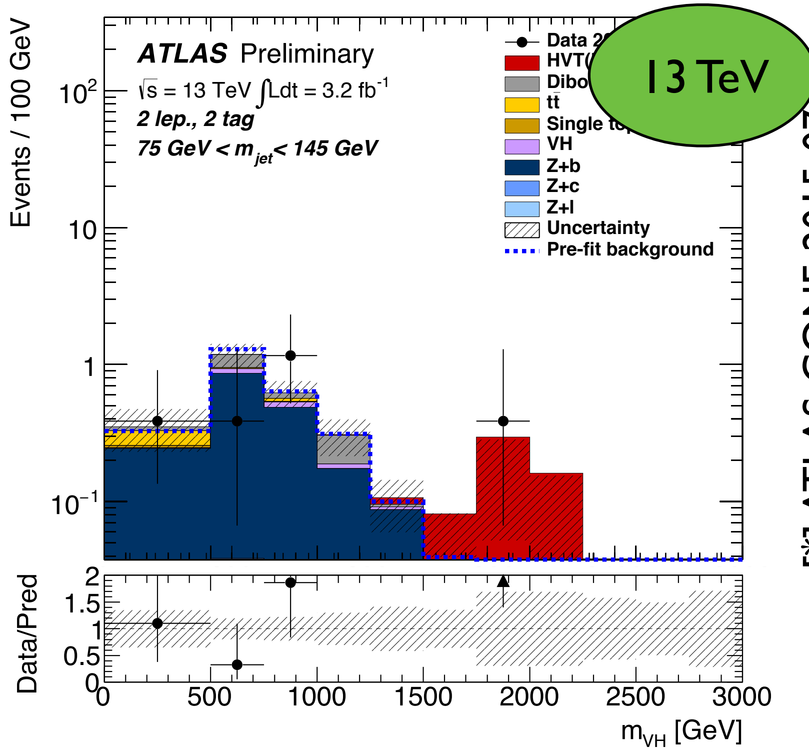


[*] EPJC (2015) 75:412

- Power to constrain also 2HDM models (SUSY or others)

High-Mass Higgs Searches





[*] ATLAS-CONF-2015-074

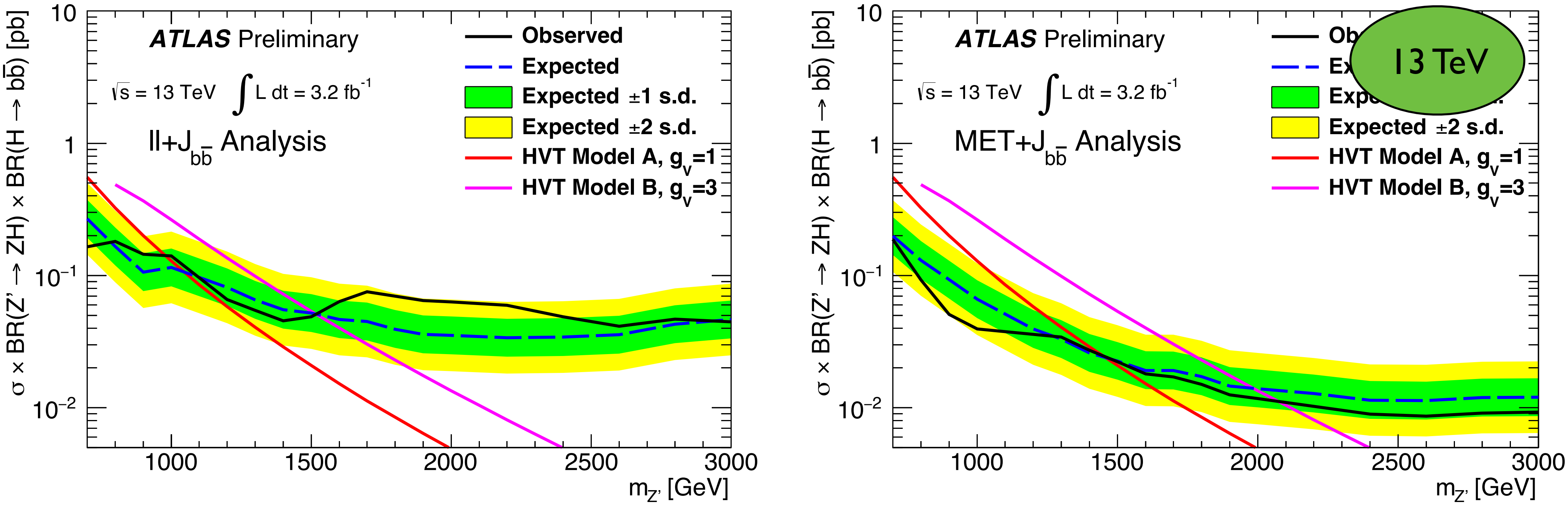
HVT→W/Z H

- Only looking at the boosted regime, obvious wins with respect to Run 1

- Several analysis regions (signal and control) help constrain many different backgrounds

- Looking at 3 channels: $\ell\ell bb$, $\ell\nu bb$ and $\nu\nu bb$

High-Mass Higgs Searches

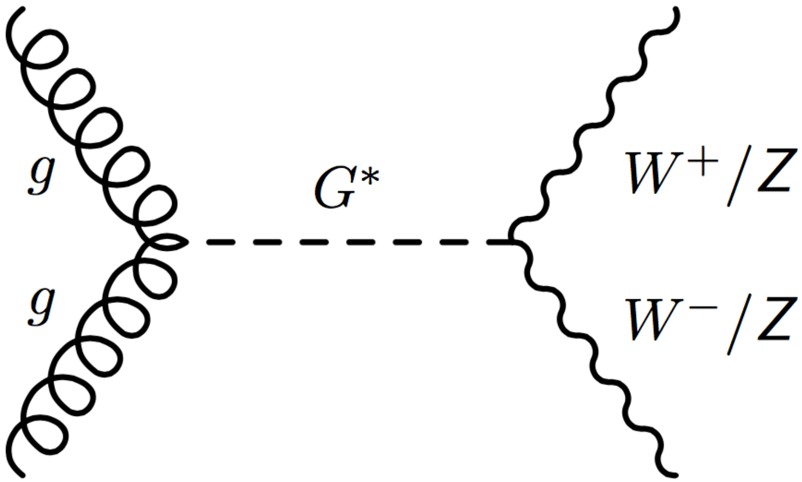


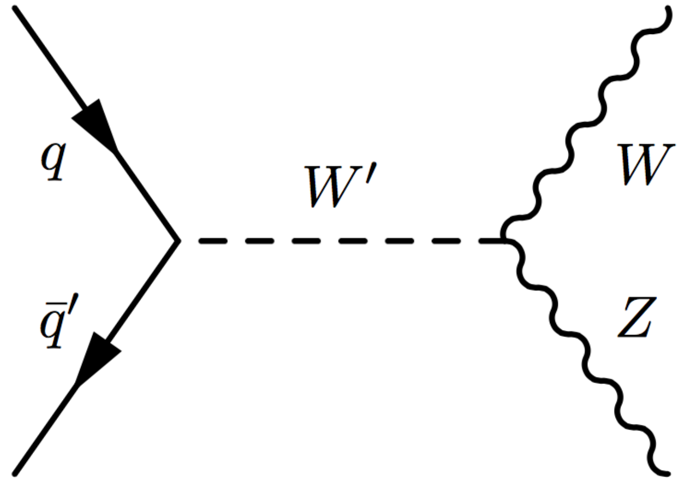
HVT→W/Z H

- Only looking at the boosted regime, obvious wins with respect to Run 1

- Several analysis regions (signal and control) help constrain many different backgrounds

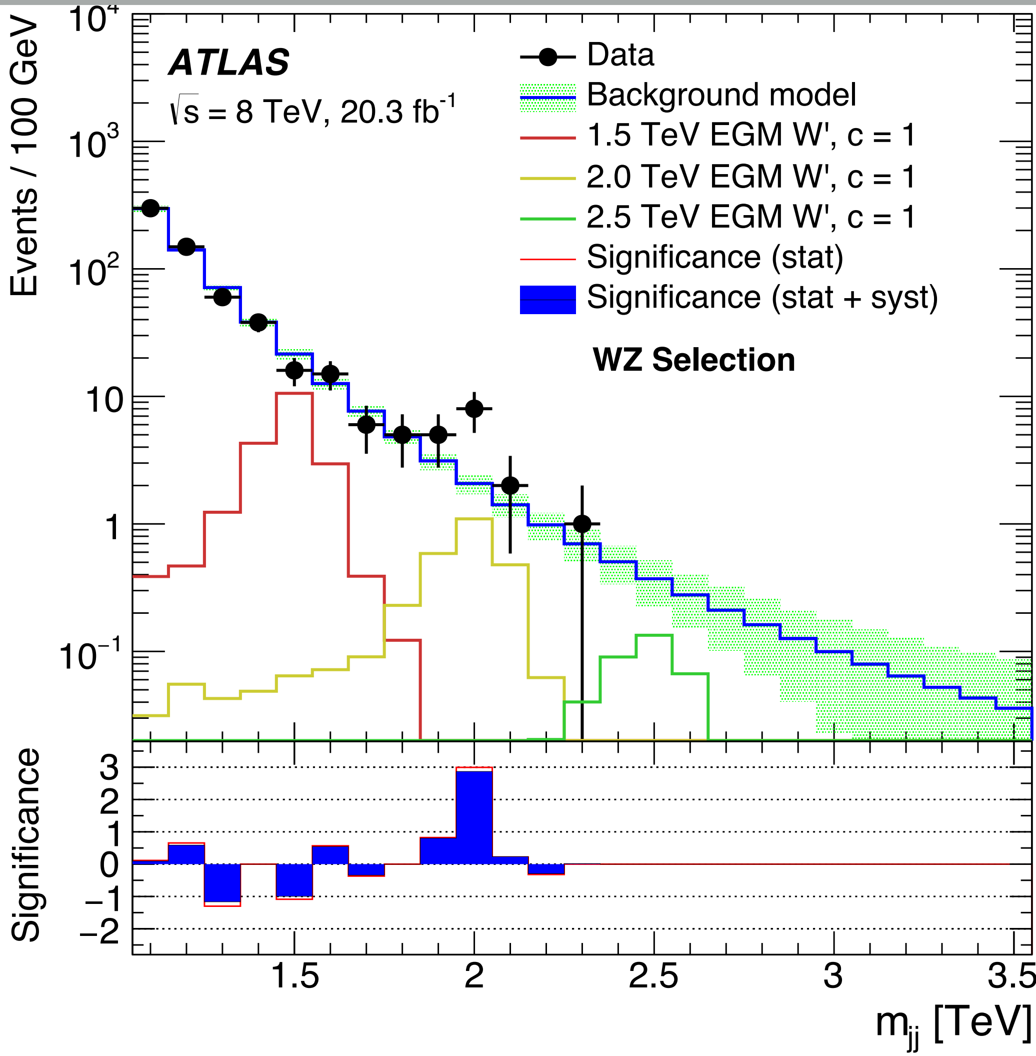
- Power to exclude Z' up to about 1.5 TeV, small excess seen around 2 TeV



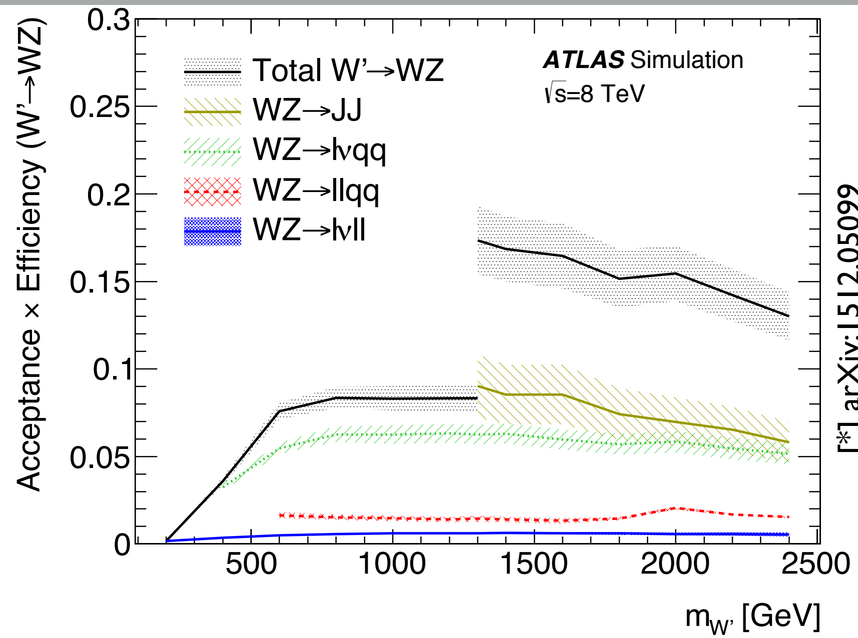


- Three analyses combined looking for these resonances
  - ZW/ZZ→$\ell\ell$qq (resolved and boosted regime)
  - WZ/WW→$\ell\nu$qq (resolved and boosted regime)
  - WW/WZ/ZZ→qqqq (only boosted regime)
  - ZW/ZZ→$\nu\nu$qq (only boosted, only Run 2)

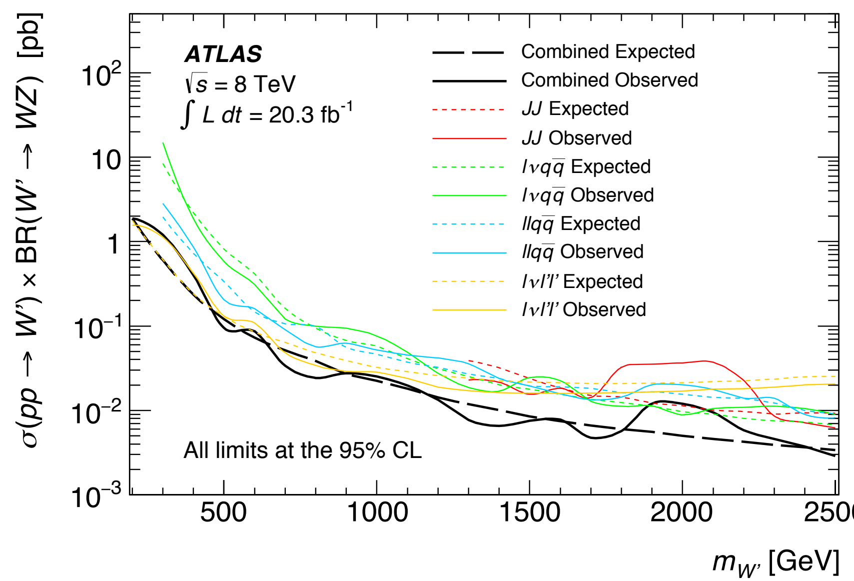
Diboson Searches in Run 1



[*] JHEP 1512 (2015) 055

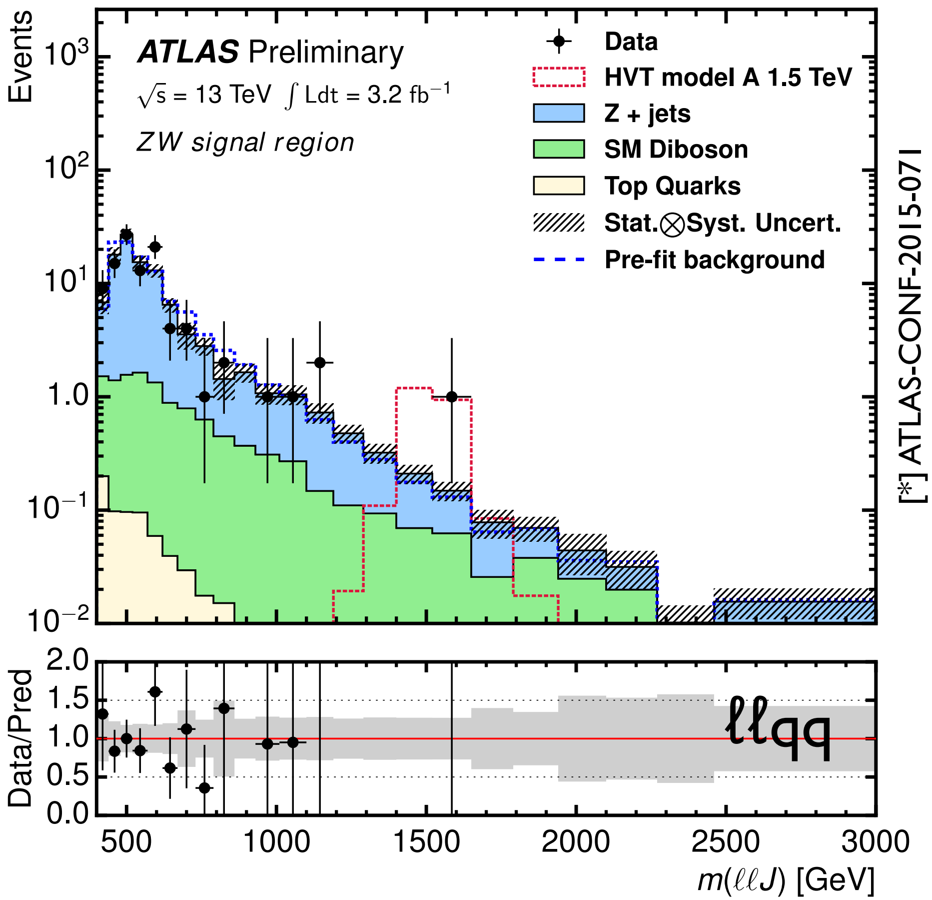


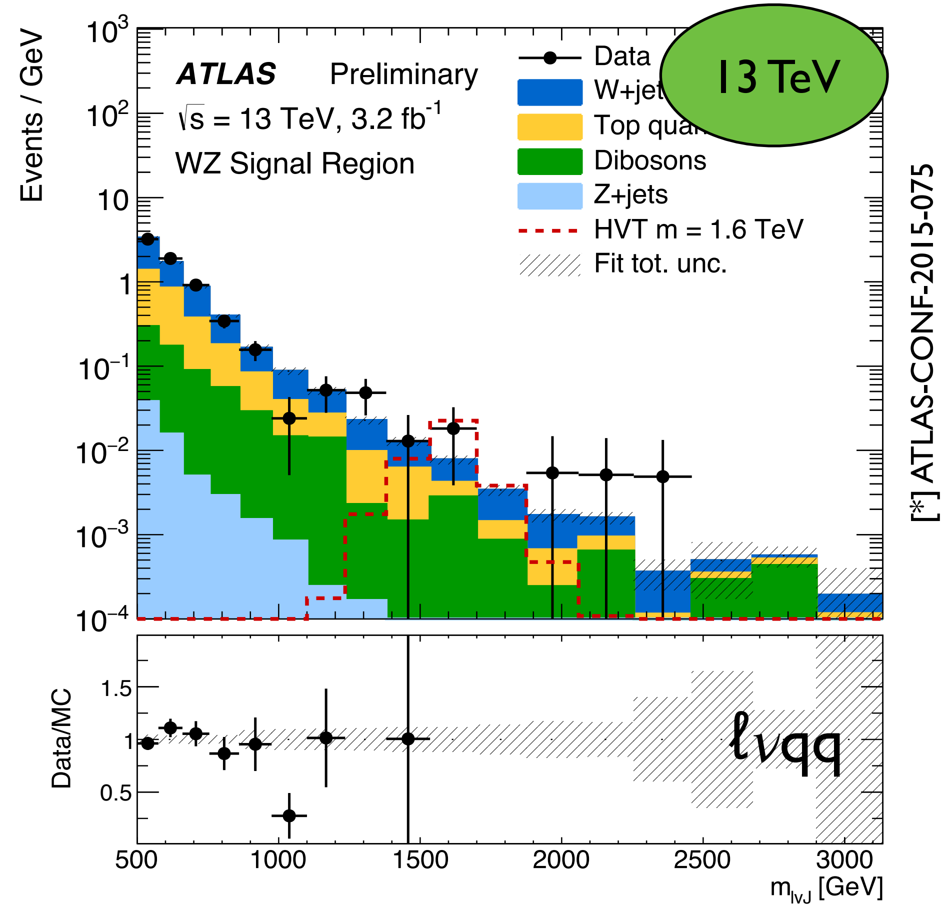
[*] arXiv:1512.05099



- Small excess in boosted all-hadronic search

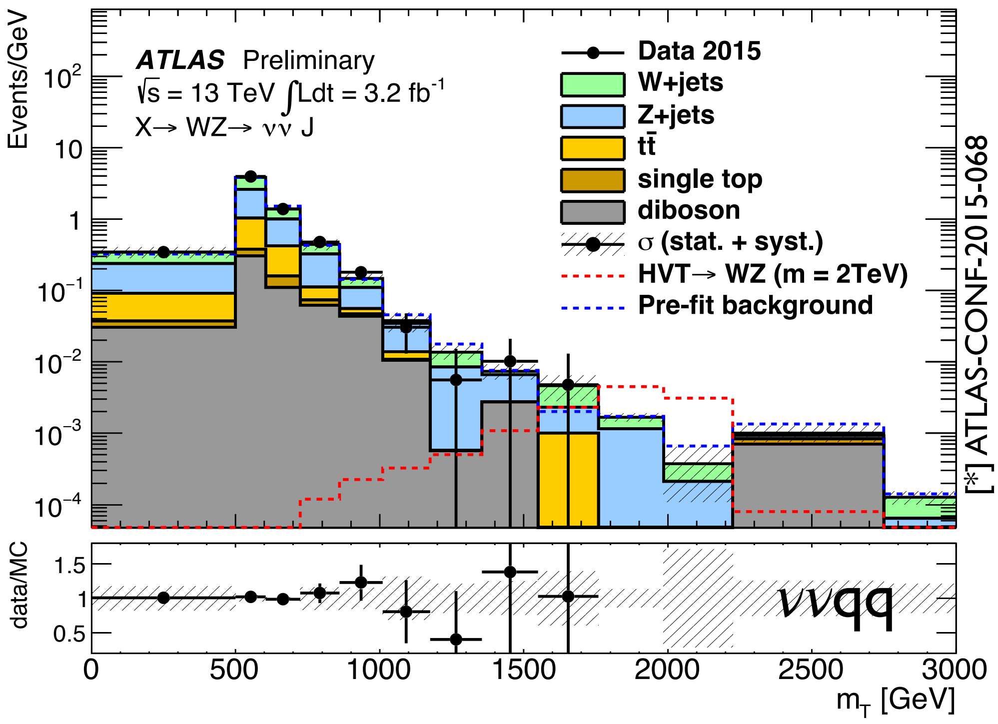
Diboson Searches in Run 2

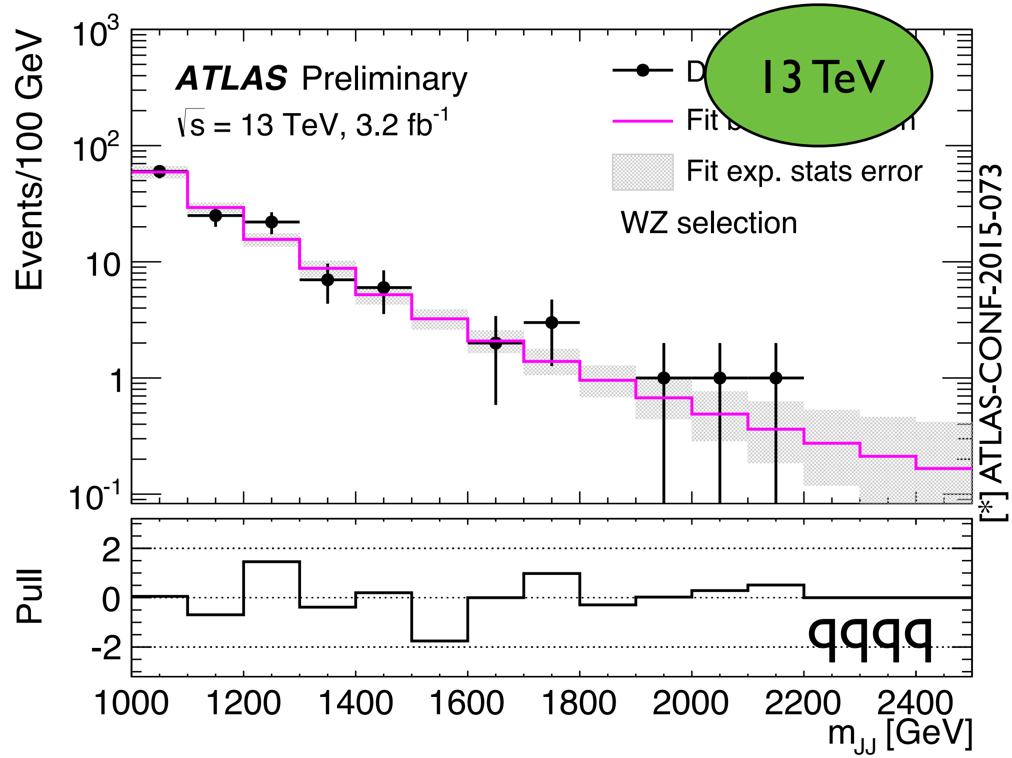




- In early data focus on high-mass region: only substructure-based analyses!
- Same tagging cuts applied by all analyses

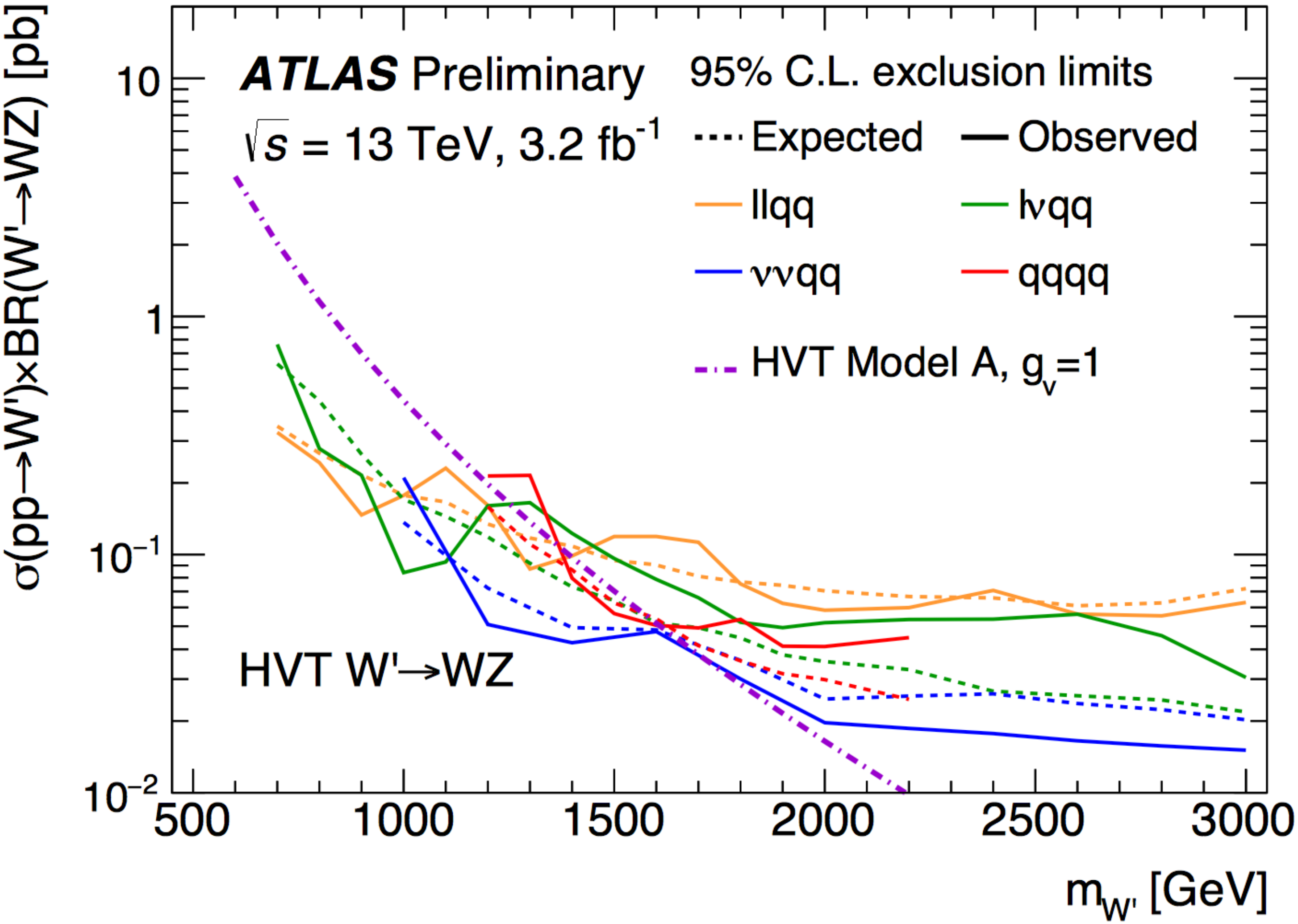
Diboson Searches in Run 2





- In early data focus on high-mass region: only substructure-based analyses!
- Same tagging cuts applied by all analyses
- Additional tagging cut applied for all-hadronic channel (for stronger background suppression)

Diboson Searches in Run 2



13 TeV

➡ Only barely sensitive to ~2 TeV region, if bump present, not as strong as in 2012 dataset

Conclusions and Outlook

- Techniques developed during Run 1 to look into very high-p_T physics are now mature

- 2015 saw many Run 1 papers and Run 2 results using these new techniques, and many more are to come

- Searches in the boosted regime cover exotic physics, Higgs physics and Supersymmetry

- 2015 did not give us enough data to settle the diboson excess observed in boosted searches at the end of Run 1, but if signal present, weaker than in 2012

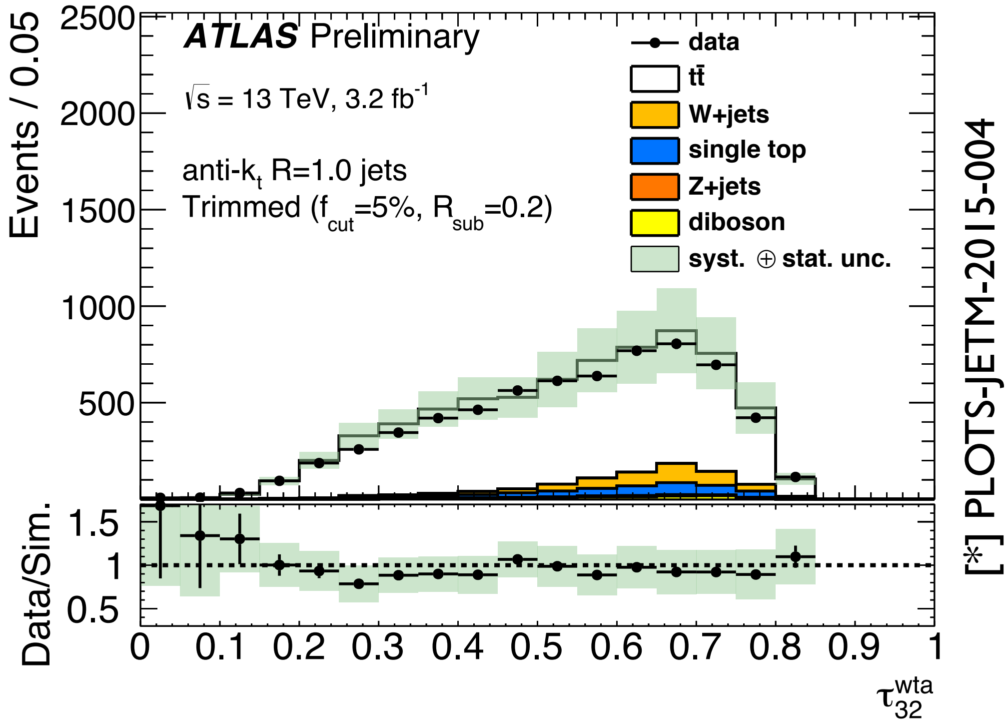
➡ Our exploration of the new LHC energy regime with hadronic physics is ongoing at a faster rate than ever!

BACK-UP SLIDES

Looking Inside Jets: A Few Definitions

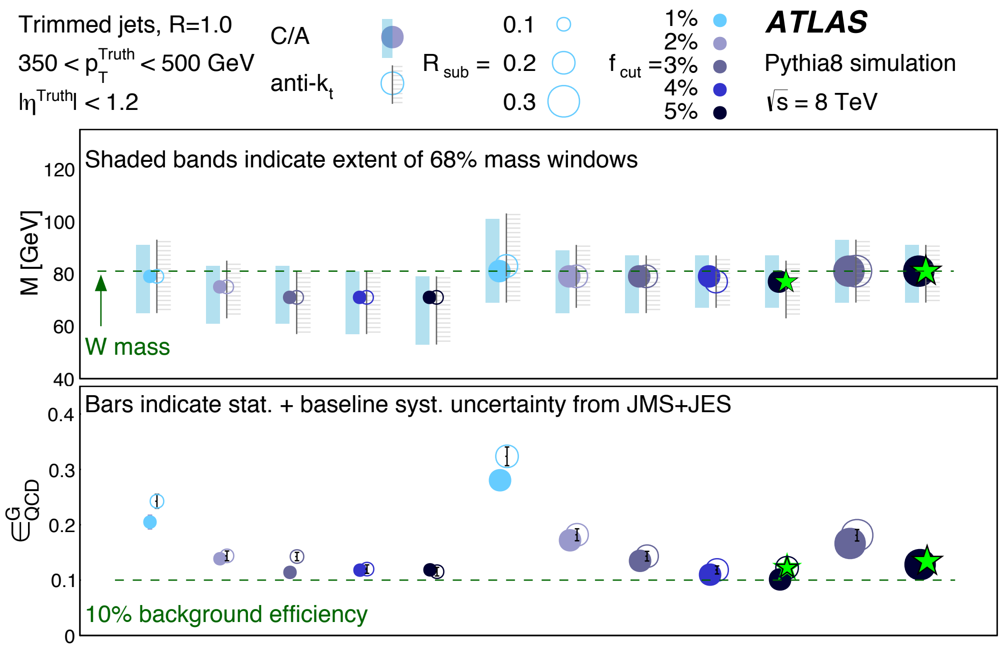
- Track multiplicities
- N-subjetiness
- Jet mass
- Jet charge
- k_t splitting scales
- Volatiliy
- Planar flow
- Jet pull
- Angularities (and EEC angularities)

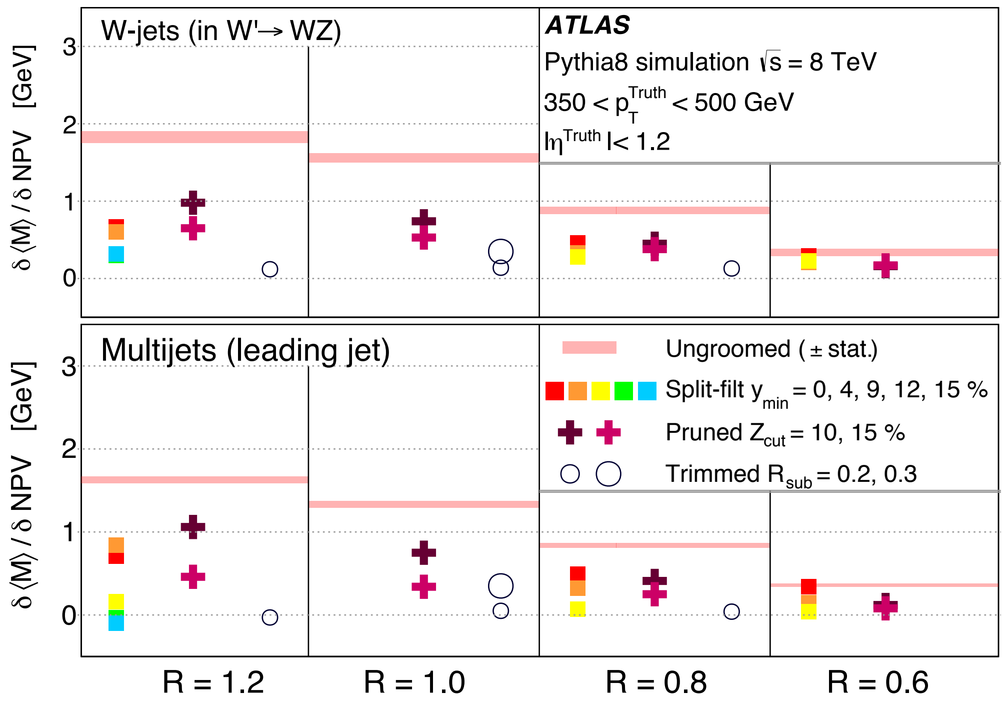
N-subjetiness



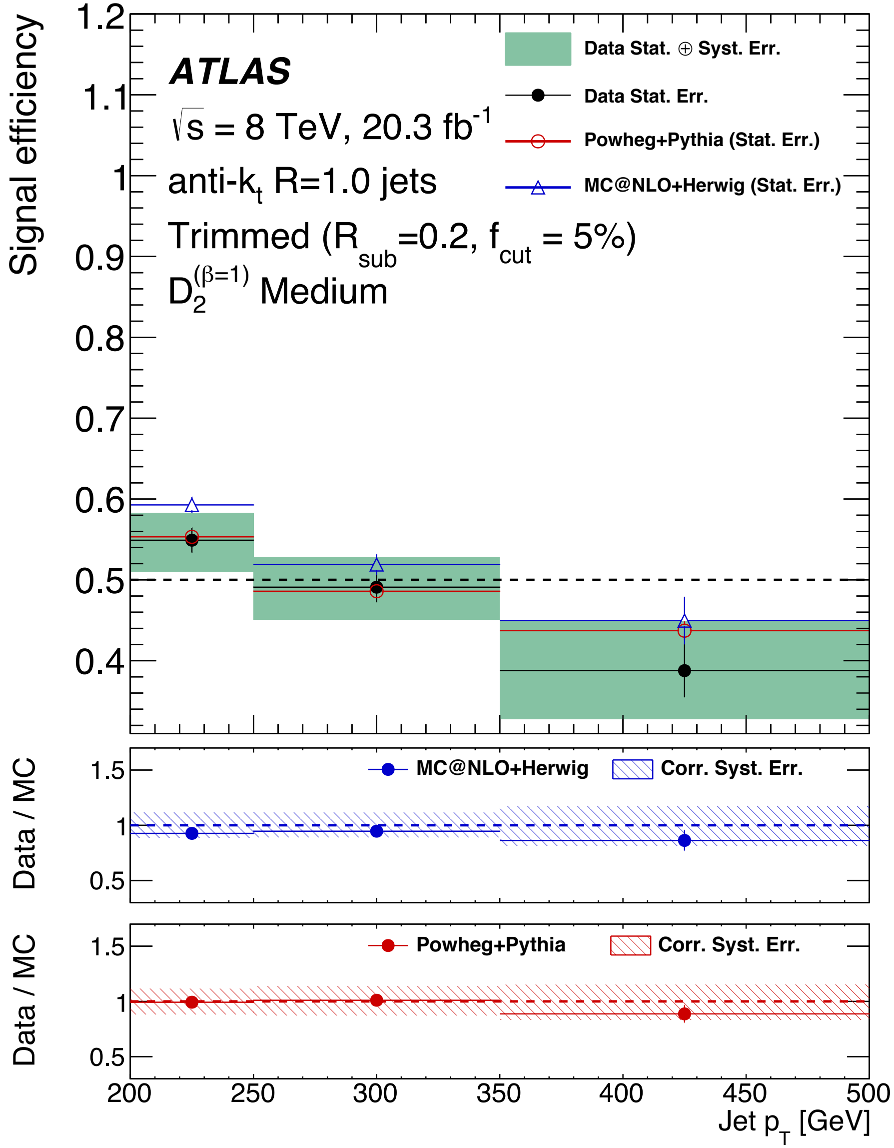
⇒Wealth of variables studied with different taggers as motivation; often used with groomers

Additional W-tagger Studies



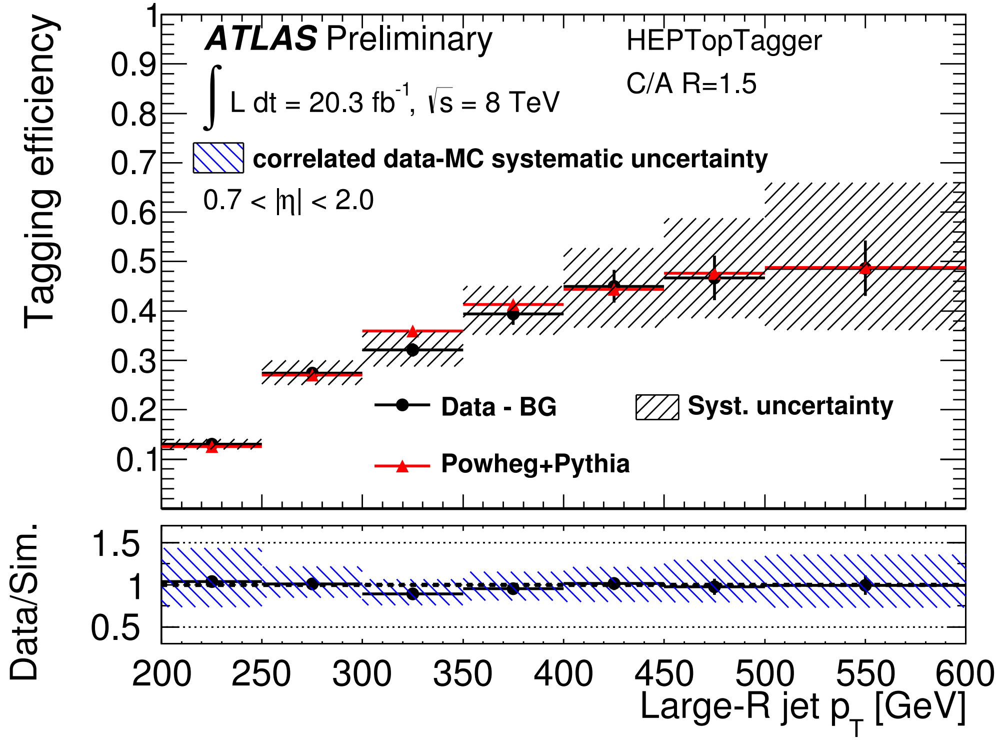


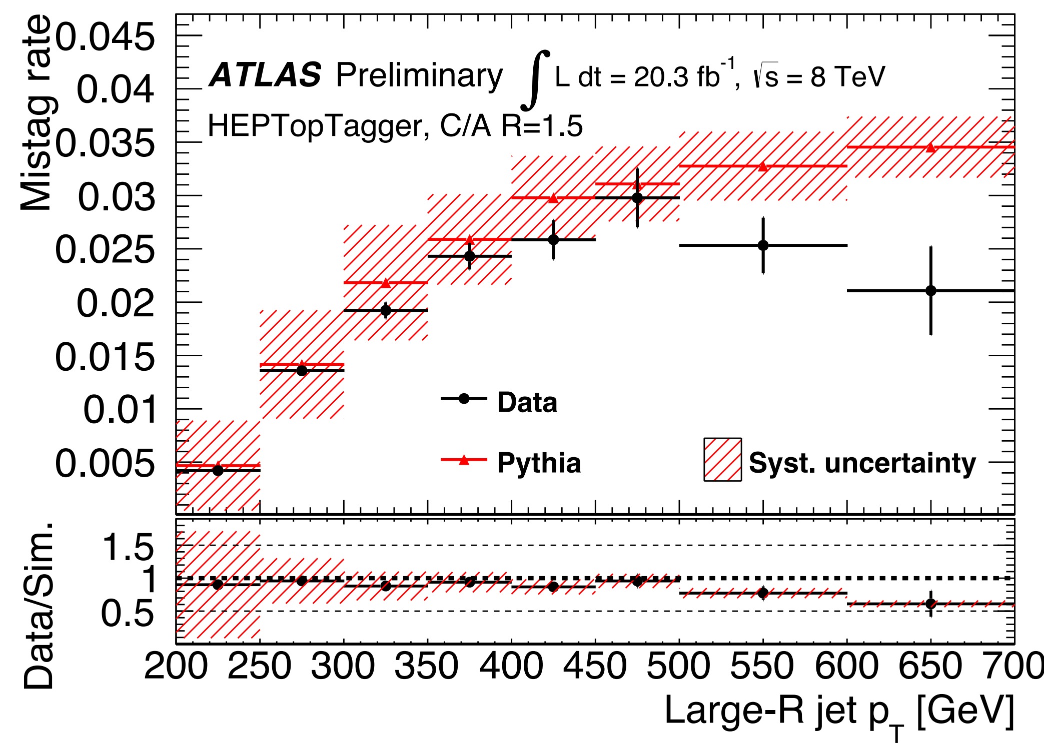
Additional W-tagger Studies



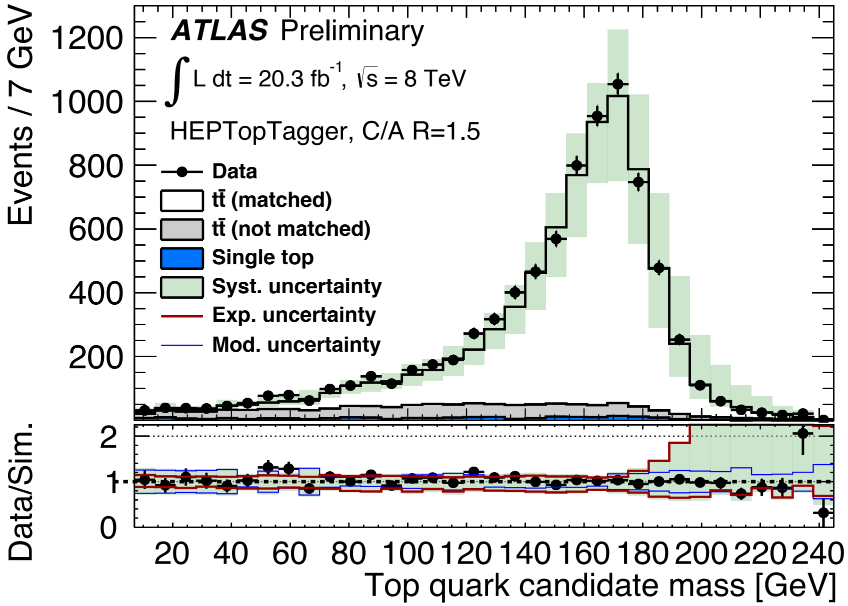
Source	p_T range [GeV]		
	200–250	250–350	350–500
JMS	+1.1	+1.1	+9.6
JES	−3.5 / +3.6	−1.7 / +2.5	+1.6 / −2.3
JER	−0.1	+1.0	+1.0
JMR	+2.7	+3.7	+4.3
JSS ($D_2^{(\beta=1)}$)	+4.3 / −2.9	+4.2 / −4.5	+5.1 / −4.8
MC generator	−0.9	+1.9	−3.2
ISR/FSR	+1.6 / −2.2	+2.7 / −4.0	+4.4 / −5.6
Multijet normalisation	−0.4 / +0.4	−0.3 / +0.3	+0.1 / −0.1
Single-top normalisation	−0.1 / +0.1	−0.1 / +0.1	−0.1 / +0.1
$t\bar{t}$ normalisation	0.6 / −0.5	+0.6 / −0.6	+0.5 / −0.5
W+jets normalisation	−0.3 / +0.3	−0.4 / +0.4	−0.5 / +0.4
MC statistics	−1.0	−1.5	−3.5
Total	+6.6 / −5.4	+7.3 / −6.6	+13.1 / −13.2

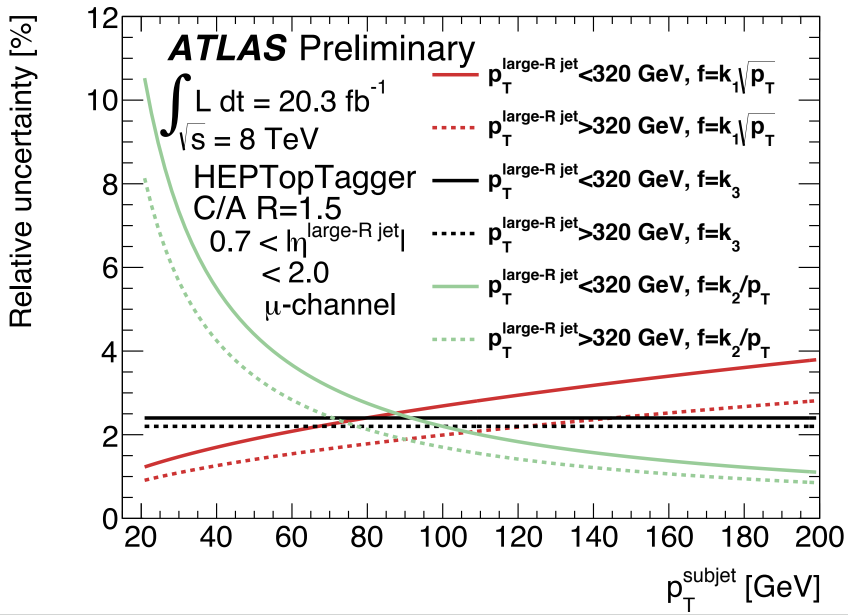
Additional top-tagger Studies

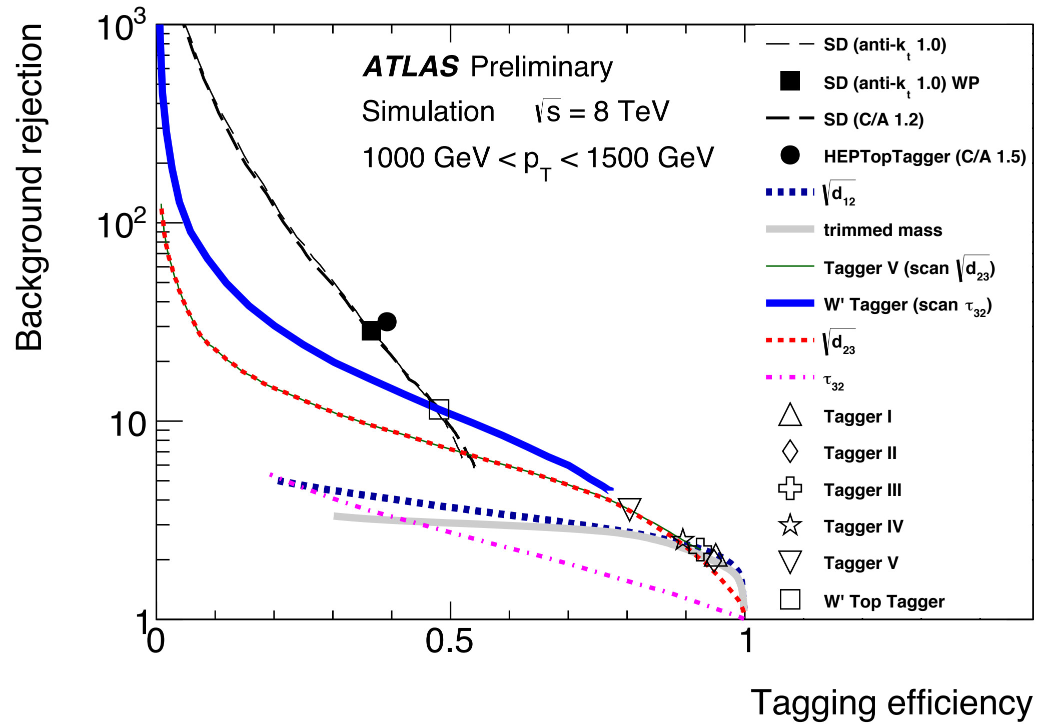




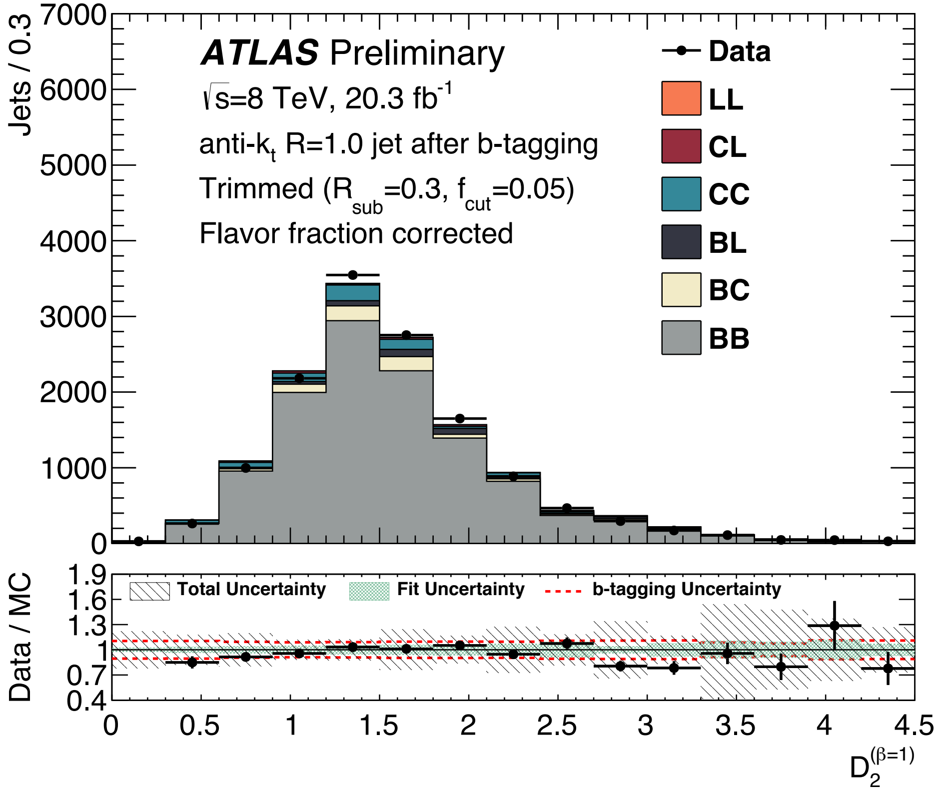
Additional top-tagger Studies

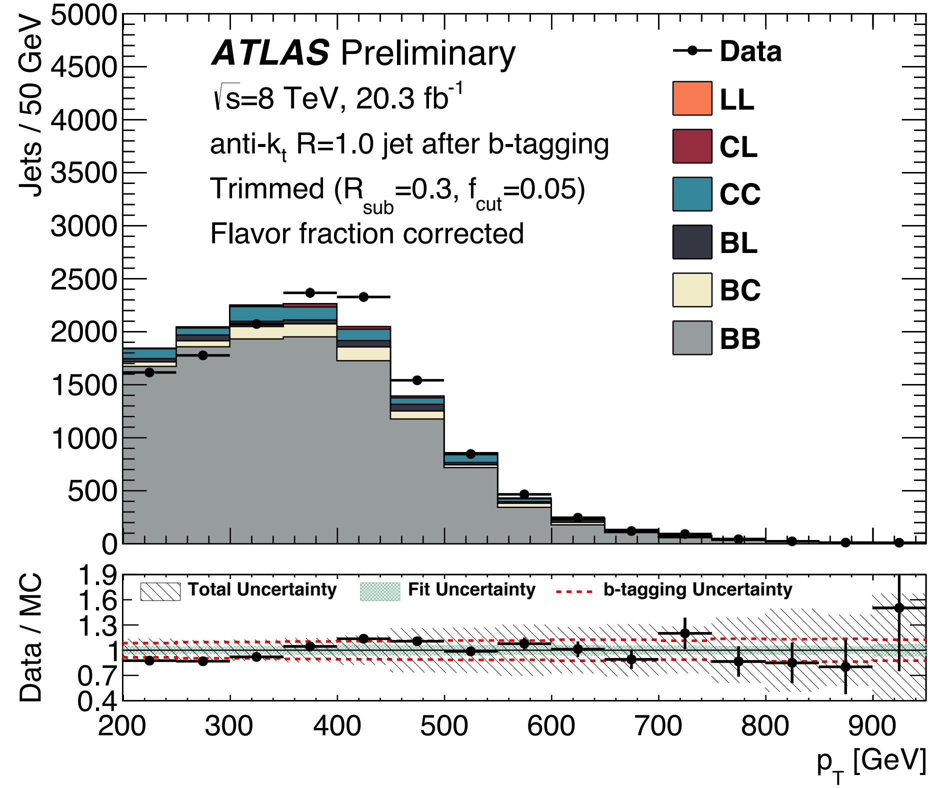






g→bb Validation for H→bb taggers





Top Resonance with Simple Tagger: Bkg

- ttbar from MC, multijet using the matrix method, for W+jets:
  - Relax selection criteria (b-tagging, $\Delta\varphi$ and d_{12} cut)

$$N_{W^+} + N_{W^-} = \left(\frac{r_{\mathrm{MC}} + 1}{r_{\mathrm{MC}} - 1}\right)(D_{\mathrm{corr}+} - D_{\mathrm{corr}-})$$

$$\begin{pmatrix} C_{\mathrm{A}} \cdot (N^{b\bar{b}}_{\mathrm{MC},W^-} + N^{c\bar{c}}_{\mathrm{MC},W^-}) & C_{\mathrm{A}} \cdot N^{c}_{\mathrm{MC},W^-} & C_{\mathrm{A}} \cdot N^{\mathrm{light}}_{\mathrm{MC},W^-} \\ (f_{b\bar{b}} + f_{c\bar{c}}) & f_c & f_{\mathrm{light}} \\ C_{\mathrm{A}} \cdot (N^{b\bar{b}}_{\mathrm{MC},W^+} + N^{c\bar{c}}_{\mathrm{MC},W^+}) & C_{\mathrm{A}} \cdot N^{c}_{\mathrm{MC},W^+} & C_{\mathrm{A}} \cdot N^{\mathrm{light}}_{\mathrm{MC},W^+} \end{pmatrix} \cdot \begin{pmatrix} K_{b\bar{b},c\bar{c}} \\ K_c \\ K_{\mathrm{light}} \end{pmatrix} = \begin{pmatrix} D_{W^-} \\ 1.0 \\ D_{W^+} \end{pmatrix}$$

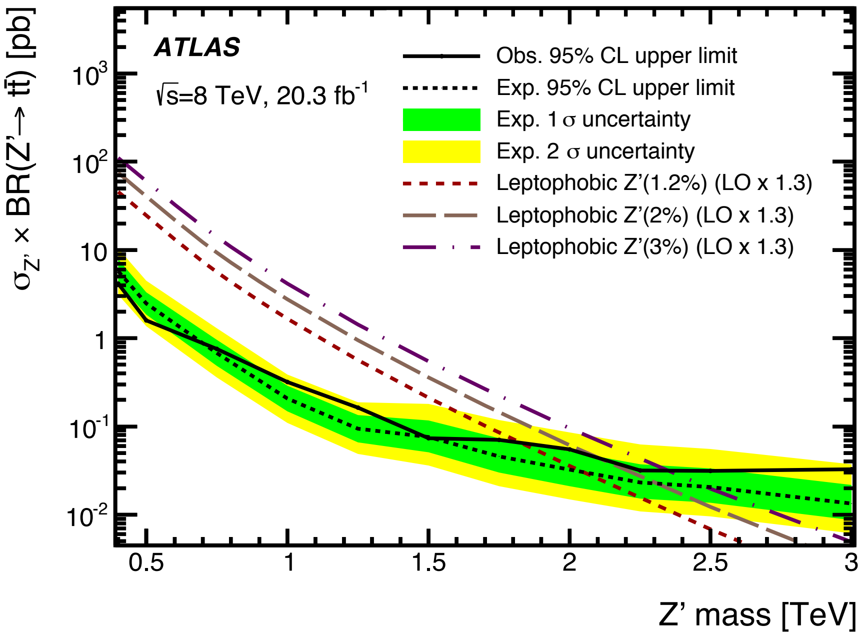
- K_{bb}(e,μ)=1.36±0.07, 1.51±0.08; K_c(e, μ)=0.71±0.03, 0.66±0.03; K_l(e,μ)=0.934±0.005, 0.873±0.004

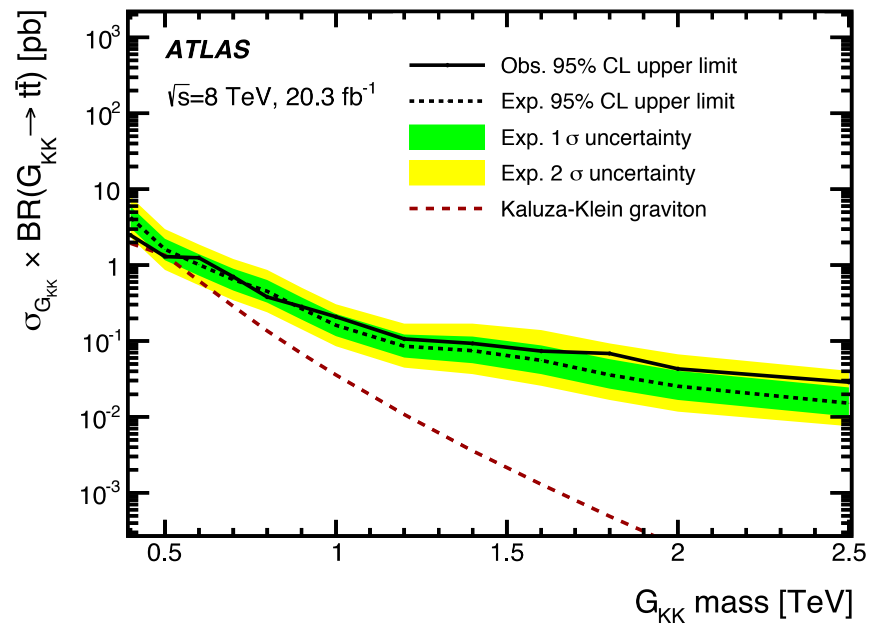
- C_A(e,μ)=0.89±0.06, 0.81±0.05

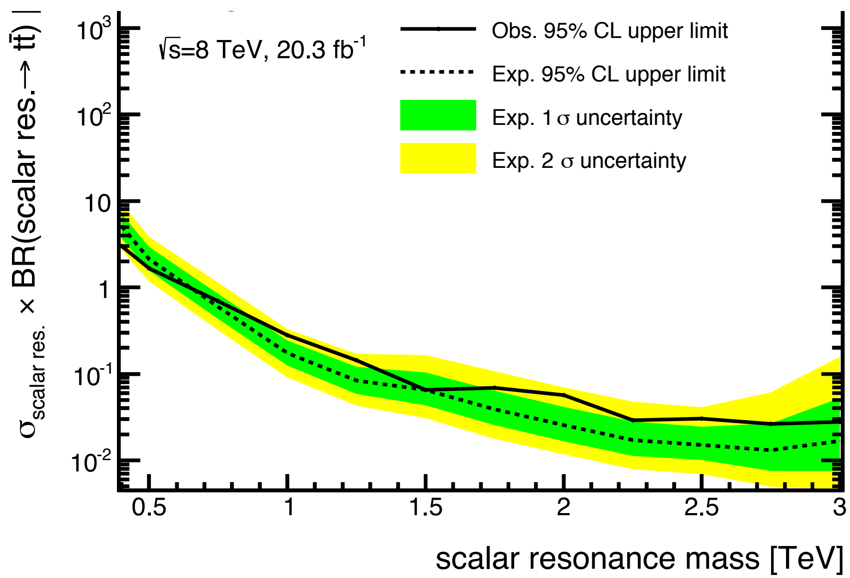
Top Resonance with Simple Tagger: Systematics

Systematic Uncertainties	Resolved selection yield impact [%] total bkg.	Resolved selection yield impact [%] Z'	Boosted selection yield impact [%] total bkg.	Boosted selection yield impact [%] Z'
Luminosity	2.5	2.8	2.6	2.8
PDF	2.4	3.6	4.7	2.3
ISR/FSR	3.7	–	1.2	–
Parton shower and fragmentation	4.8	–	1.5	–
$t\bar{t}$ normalisation	5.3	–	5.5	–
$t\bar{t}$ EW virtual correction	0.2	–	0.5	–
$t\bar{t}$ generator	0.3	–	2.6	–
$t\bar{t}$ top quark mass	0.6	–	1.4	–
W+jets generator	0.3	–	0.1	–
Multi-jet normalisation, e+jets	0.5	–	0.2	–
Multi-jet normalisation, μ+jets	0.1	–	< 0.1	–
JES+JMS, large-radius jets	0.1	2.1	9.7	2.8
JER+JMR, large-radius jets	< 0.1	0.3	1.0	0.2
JES, small-radius jets	5.6	2.6	0.4	1.4
JER, small-radius jets	1.8	1.4	< 0.1	0.2
Jet vertex fraction	0.8	0.8	0.2	< 0.1
b-tagging b-jet efficiency	1.1	2.0	2.9	17.1
b-tagging c-jet efficiency	0.1	0.7	0.1	2.1
b-tagging light-jet efficiency	< 0.1	< 0.1	0.5	0.2
Electron efficiency	0.3	0.6	0.6	1.3
Muon efficiency	0.9	1.0	1.0	1.1
MC statistical uncertainty	0.4	6.0	1.3	1.8
All systematic uncertainties	10.8	8.8	13.4	18.0

Top Resonance w/ Simple Tagger: Interpretation





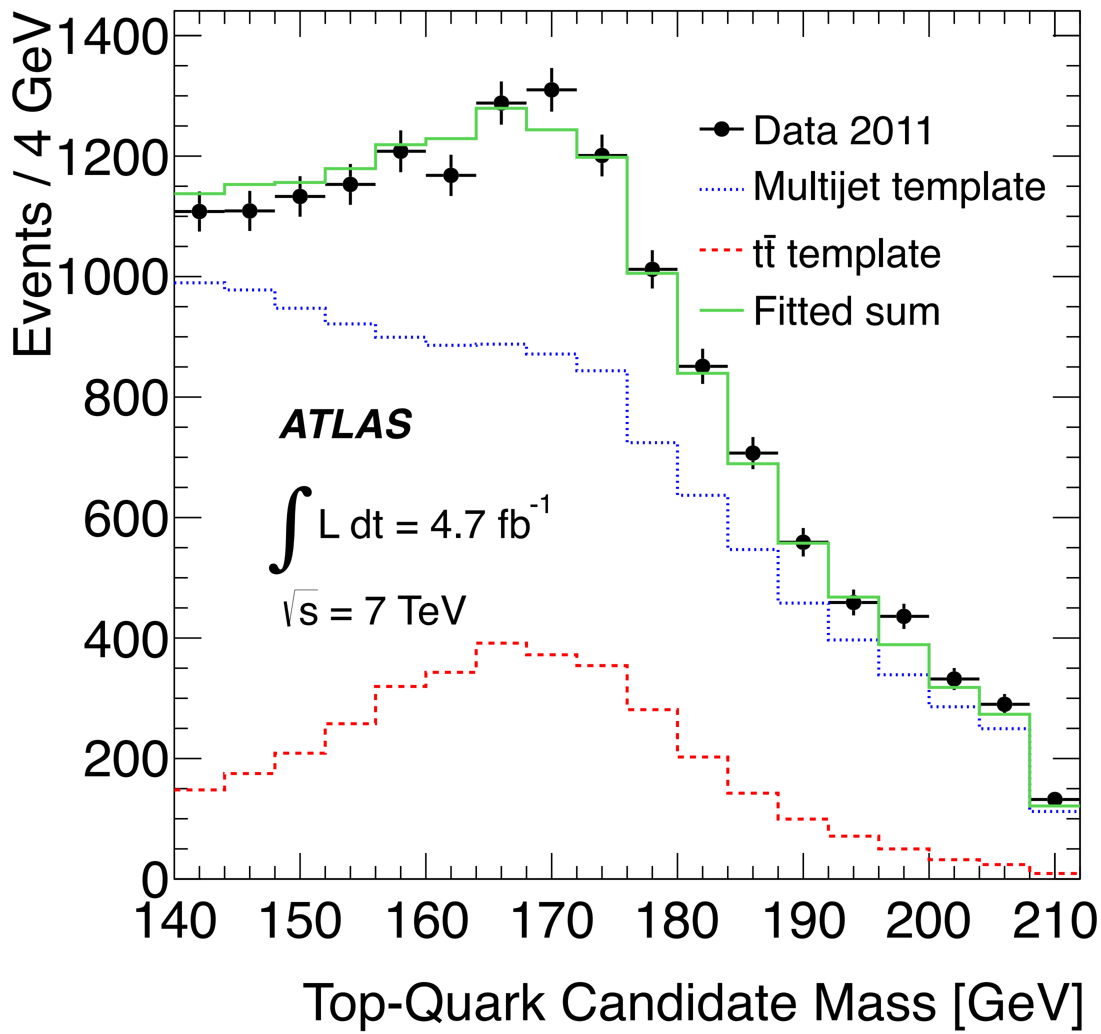


Top Resonance with Complex Tagger: Bkg

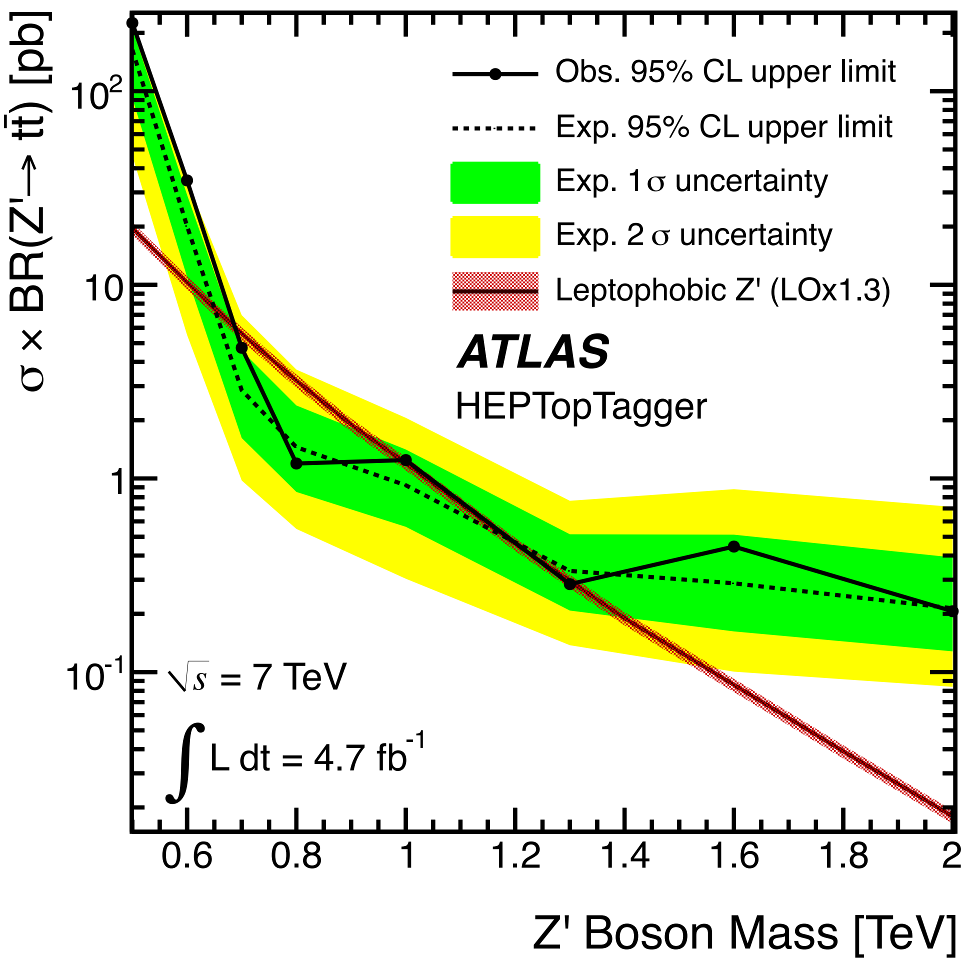
	1 top-tag	≥ 2 top-tags
no b-tag	U(0.3%)	V(2.4%)
1 b-tag	W(3.2%)	X(24.3%)
≥ 2 b-tags	Y(22.5%)	$\boxed{\text{Z(80.9\%)}}$

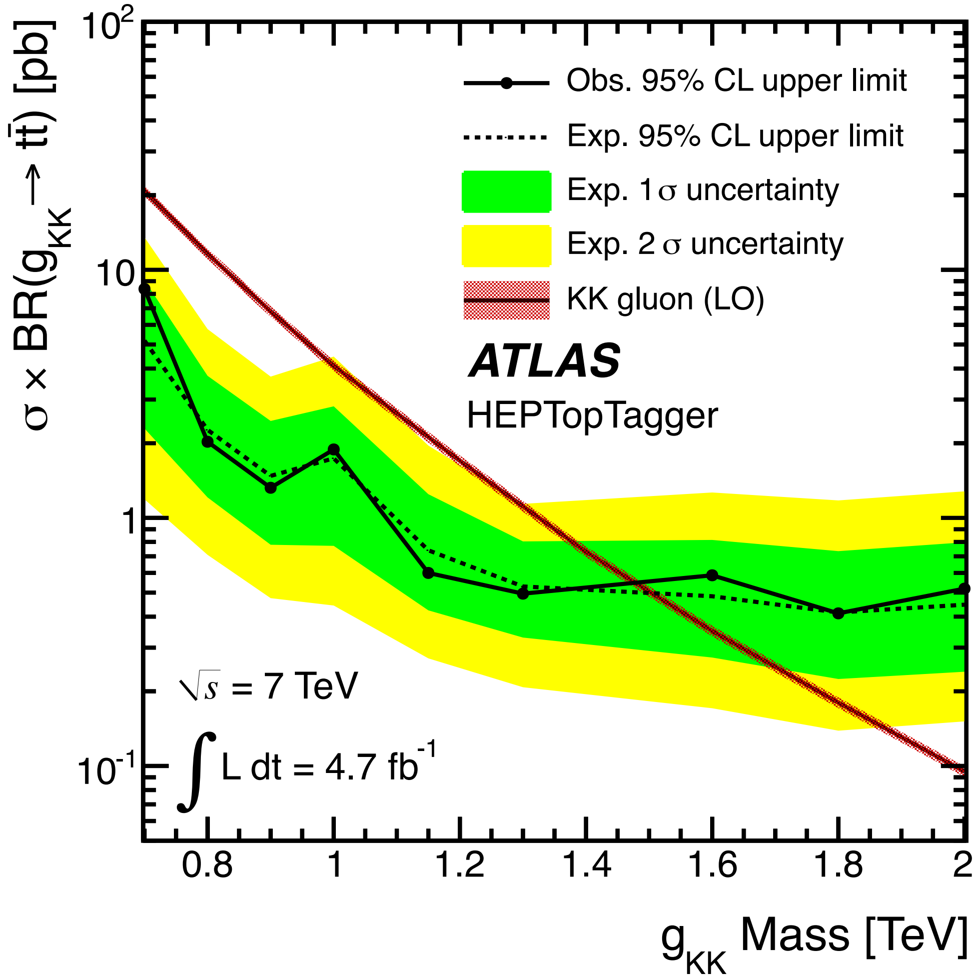
SR

$$\frac{dn_Z}{dm_{t\bar{t}}} = \left(\frac{1}{n_U} \times \frac{dn_V}{dm_{t\bar{t}}} + \frac{1}{n_W} \times \frac{dn_X}{dm_{t\bar{t}}}\right) \times \frac{n_Y}{2}$$



Top Resonance w/ Complex Tagger: Interpret





Di-Higgs Search: Backgrounds

- Multijet estimated in sidebands and extrapolating from 2-tag region

$$\mu_{\mathrm{QCD}} = \frac{N_{\mathrm{QCD}}^{4-\mathrm{tag}}}{N_{\mathrm{QCD}}^{2-\mathrm{tag}}} = \frac{N_{\mathrm{data}}^{4-\mathrm{tag}} - N_{t\bar{t}}^{4-\mathrm{tag}} - N_{Z}^{4-\mathrm{tag}}}{N_{\mathrm{data}}^{2-\mathrm{tag}} - N_{t\bar{t}}^{2-\mathrm{tag}} - N_{Z}^{2-\mathrm{tag}}}$$

- Kinematics in 2-tag reweighed to match 4-tag region

- ttbar normalization calculated from data, shape from MC

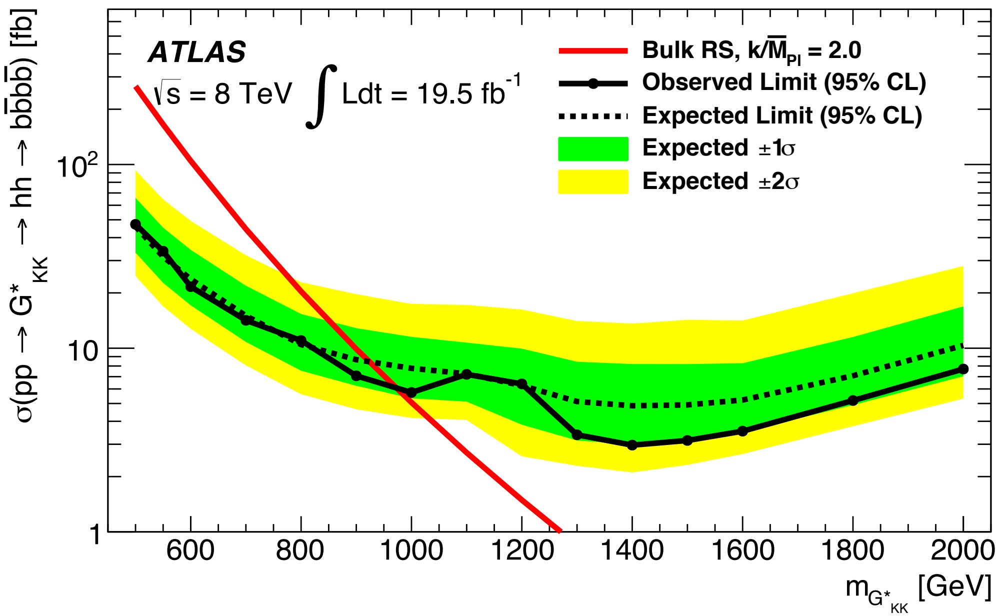
- ttbar CR defined by inverting top veto, efficiency of veto calculated in semileptonic top sample

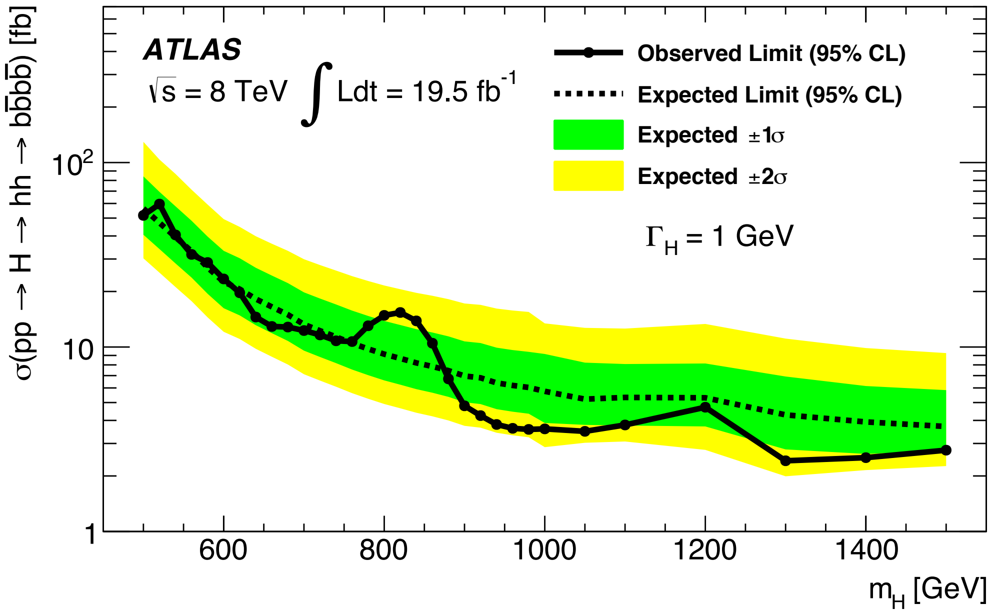
$$X_{tt} = \sqrt{\left(\frac{m_W - \tilde{m}_W}{\sigma_{m_W}}\right)^2 + \left(\frac{m_t - \tilde{m}_t}{\sigma_{m_t}}\right)^2}$$

Di-Higgs Search: Systematics

Source	Bkgd	G^*_{KK} $k/\bar{M}_{\mathrm{Pl}} = 1$	G^*_{KK} $k/\bar{M}_{\mathrm{Pl}} = 2$	H
Luminosity	0.2	2.8	2.8	2.8
JER	0.9	0.1	0.2	0.1
JES	0.4	0.1	2.5	0.1
JMR	4.3	13	13	12
JMS	1.3	18	17	16
b-tagging	-	21	20	21
Theoretical	-	2.0	2.0	2.0
Multijet	12	-	-	-
$t\bar{t}$	2.5	-	-	-
Bkgd stat.	8.9	-	-	-
Total	15.9	33	28	30

Di-Higgs Search: Interpretations





High-mass Higgs Searches: Backgrounds and Sys

- Combined likelihood fit for each channel using CRs enriched in each background

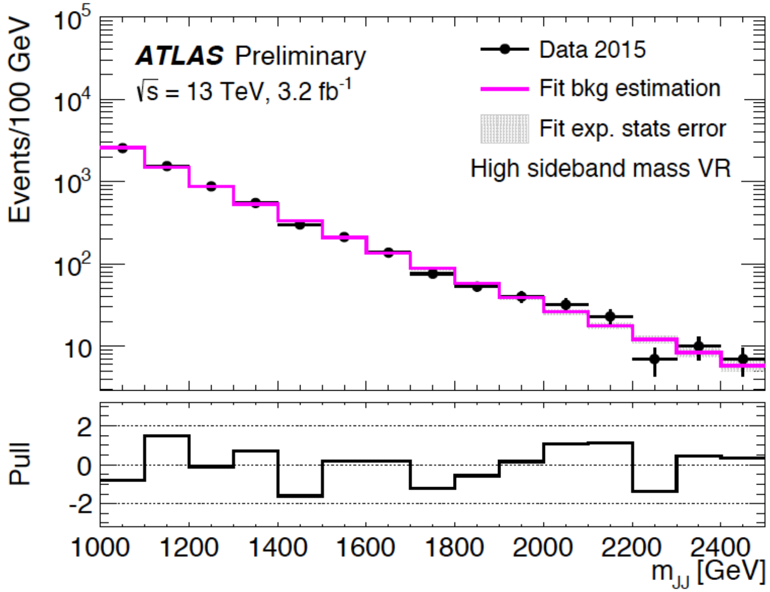
- Low (W/Z+jets) and high sidebands (ttbar) used as CRs, in 1-tag and 2-tag events for the low sidebands (W/Z+c vs W/Z+b)

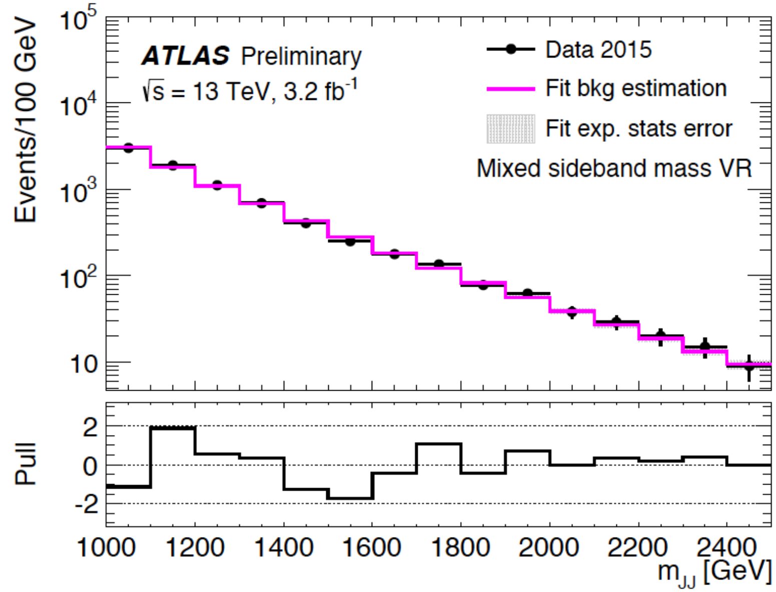
- Constraints within systematics included in a maximum likelihood fit

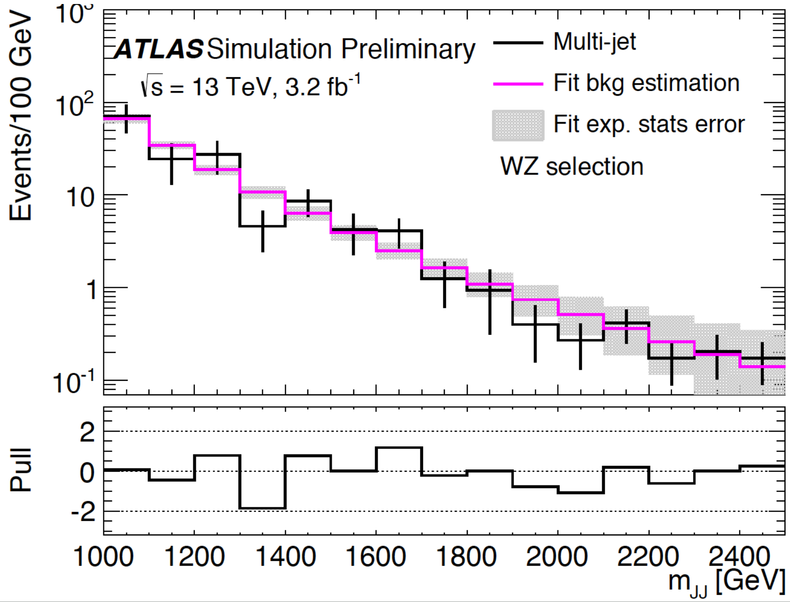
- Theoretical prior systematics from MC comparisons:
  - W/Z+light: 10%
  - W/Z+c: 30%
  - W/Z+b: 30%
  - ttbar and single top: 30%
  - Diboson: 11%

- Additional uncertainties on invariant mass shape

VV→JJ Backgrounds



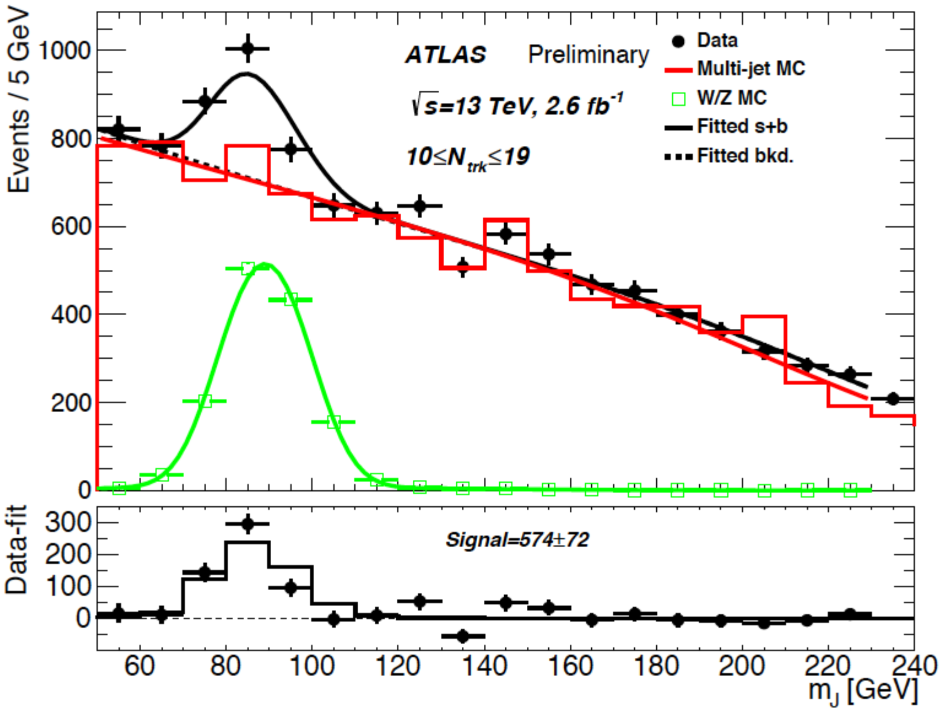


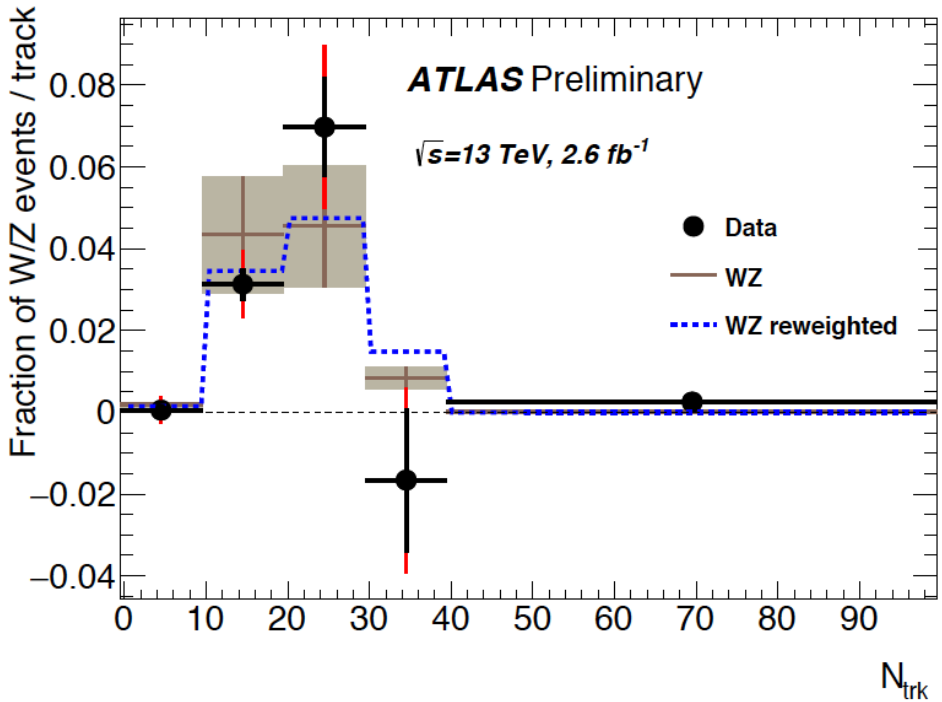


$$\frac{dn}{dx} = p_1(1-x)^{p_2+\xi p_3} x^{p_3}$$

Sample	$\chi^2/\mathrm{n_{DOF}}$	Probability
Pythia dijet events tagged	18.2/14	0.20
Data in high-high VR	14.1/14	0.44
Data in low-high VR	14.6/15	0.48

VV→JJ Systematics



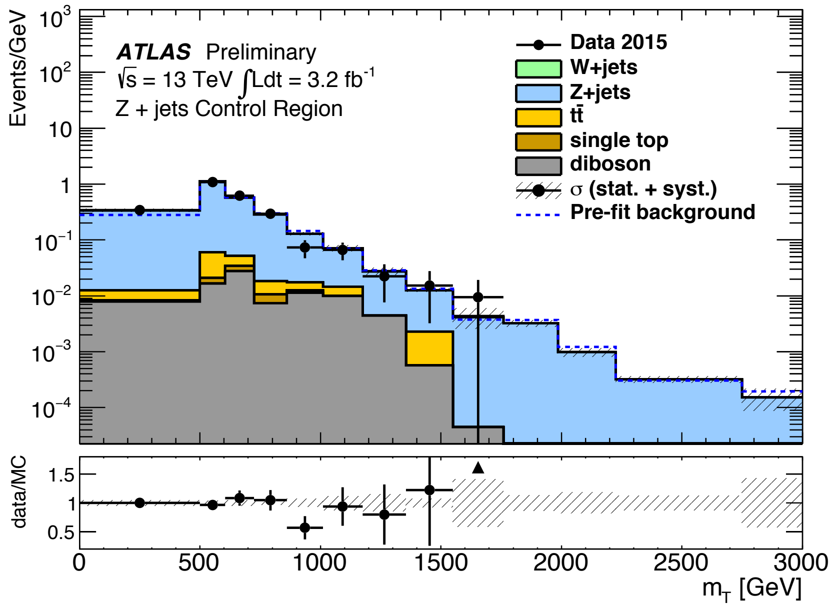


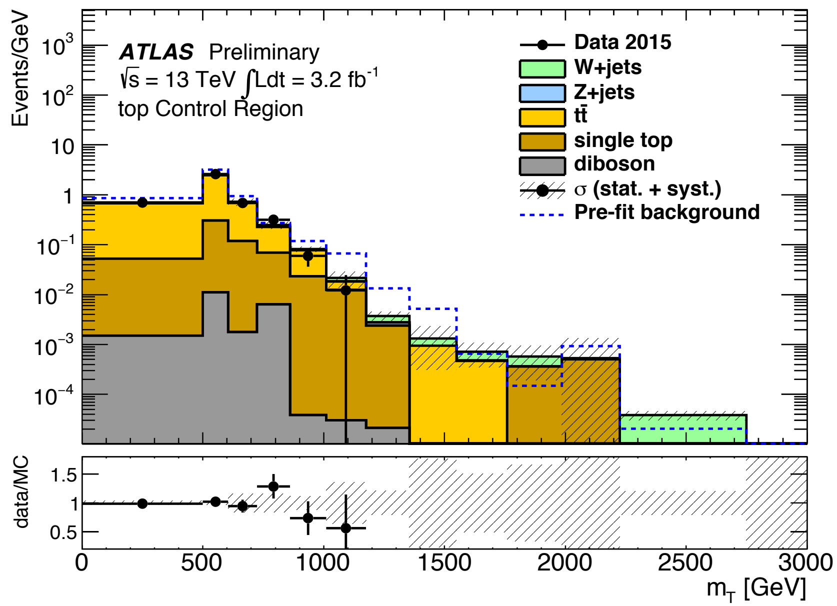
VV→ννJ Backgrounds and Systematics

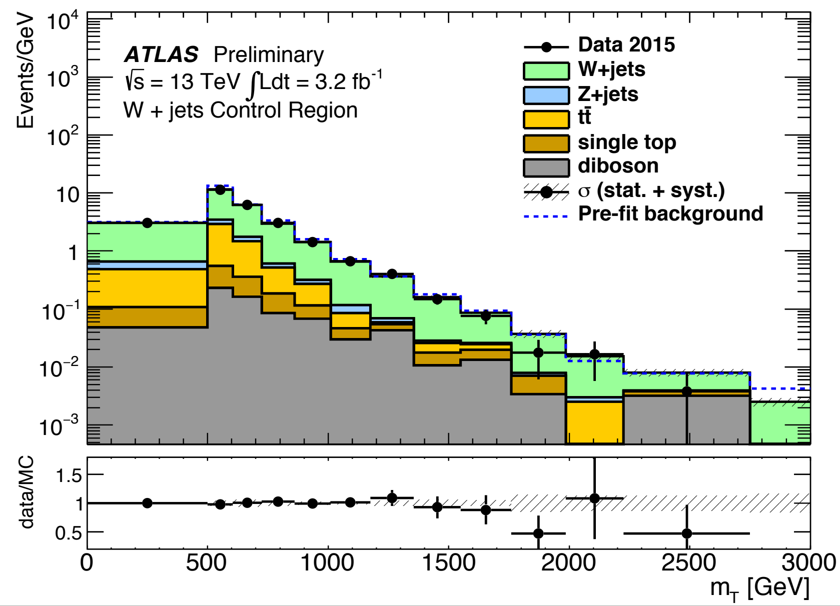
- Z+jets, W+jets and ttbar are all important backgrounds
- Studied requiring muons in the final state and building E_T^{miss} including those muons
- Background modeling uncertainties from MCs input to the fit that includes in these regions
  - W+jets: 10% throughout all m_T
  - Z+jets: 1% at low m_T, 10% at high m_T
  - ttbar: 10% at low m_T, 40% at high m_T

Process	SF from the WZ signal region	SF from the ZZ signal region
$W+$ jets	1.04 ± 0.14	1.07 ± 0.13
$Z+$ jets	1.13 ± 0.13	1.12 ± 0.11
$t\bar{t}$	0.82 ± 0.11	0.80 ± 0.10

VV→ννJ Backgrounds and Systematics







VV→ℓνJ Backgrounds and Systematics

- W+jets and ttbar are the most important backgrounds

- Normalizations taken from a fit to data using CRs:
  - ttbar: b-tagged events
  - W+jets: invert invariant mass cut on large-R jet

- Multijet taken from data changing lepton identification requirements

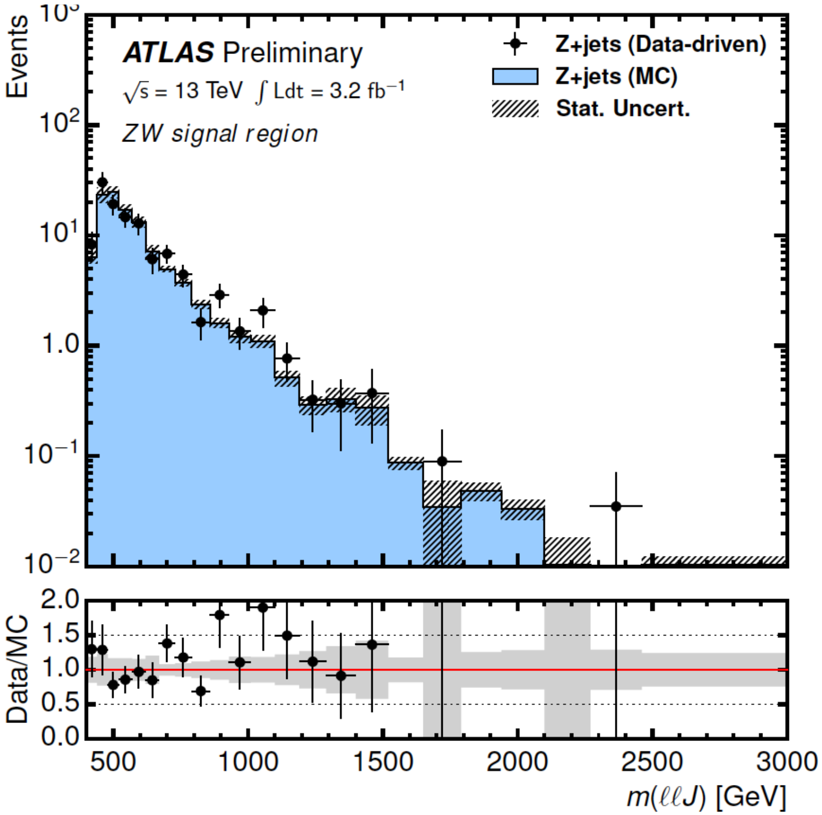
- Diboson taken from MC, as well as shape uncertainties

VV→ℓℓJ Backgrounds and Systematics

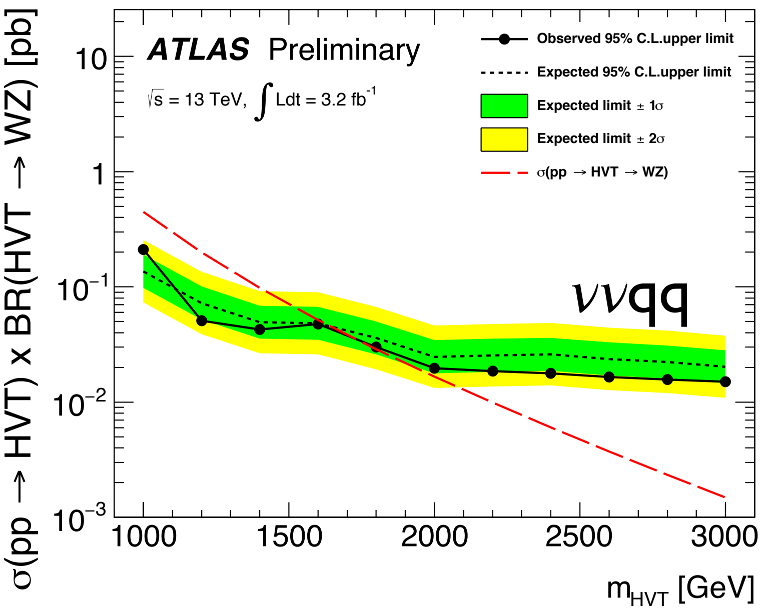
- Z+jets is the main background, using a CR to validate inverting the mass cuts of the jet

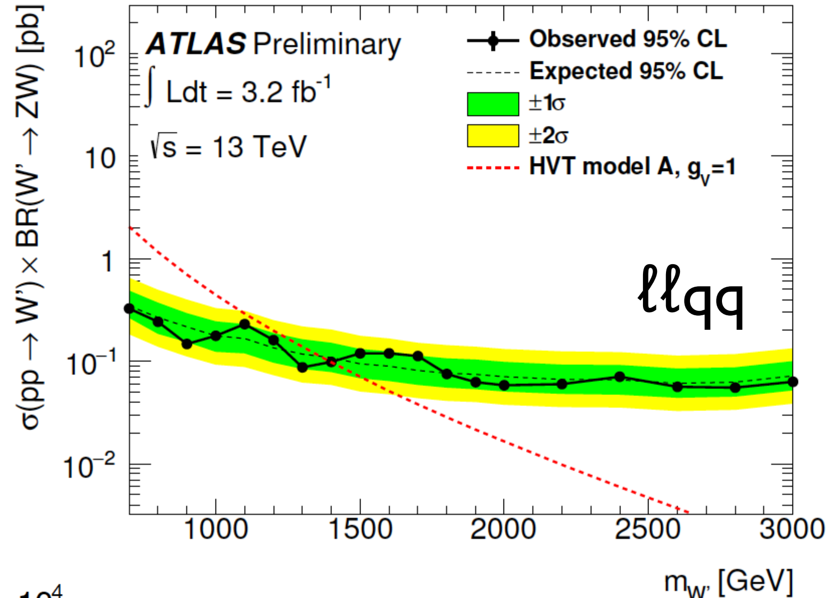
$$N_{\mathrm{SR}}^{Z+\mathrm{jets}}(m_i) = N_{\mathrm{CR}}^{\mathrm{Data}}(m_i) \times \alpha_{\mathrm{MC}}(m_i) = N_{\mathrm{CR}}^{\mathrm{Data}}(m_i) \times \left(\frac{N_{\mathrm{SR}}(m_i)}{N_{\mathrm{CR}}(m_i)}\right)_{\mathrm{MC}}$$

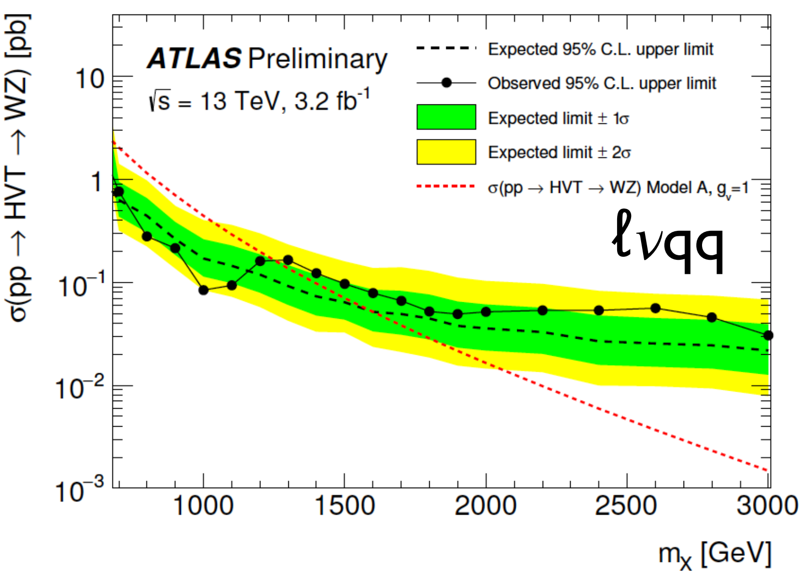
- Uncertainties on this background comparing data-driven estimate and MC for diboson (6%) and ttbar (10%), using MCs

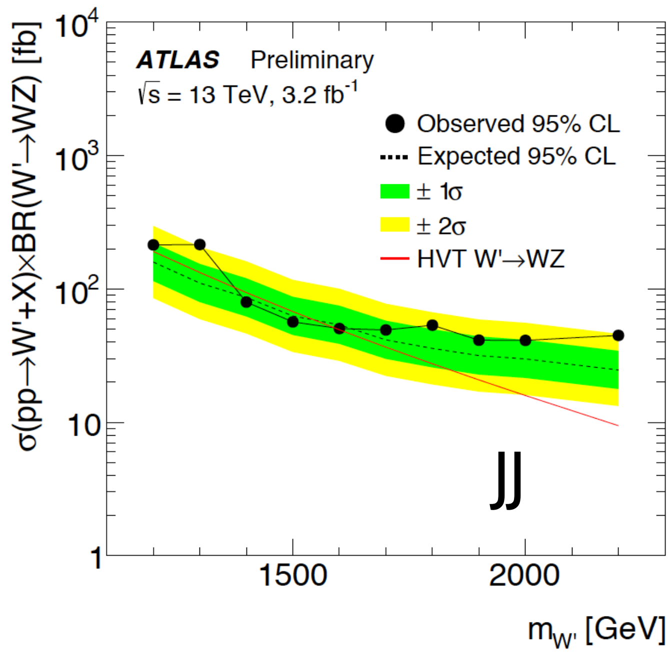


Individual Diboson Limits

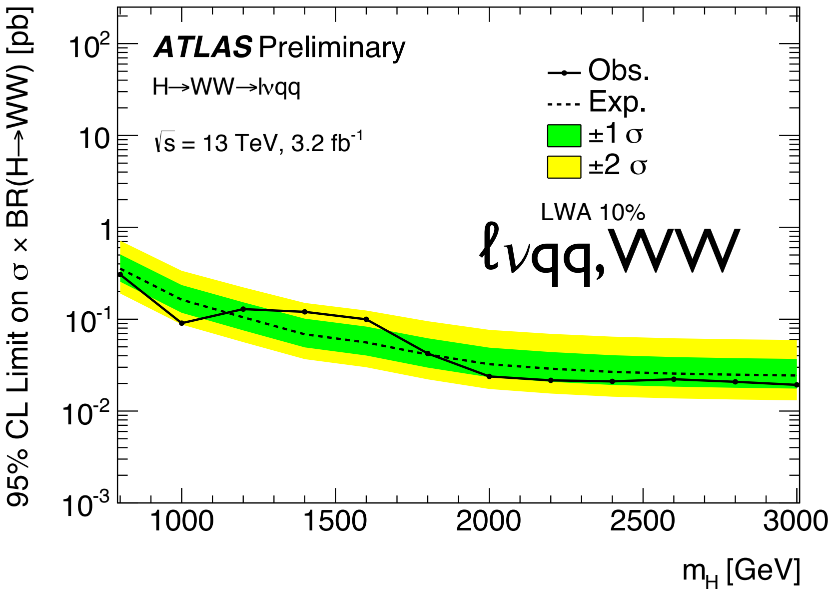


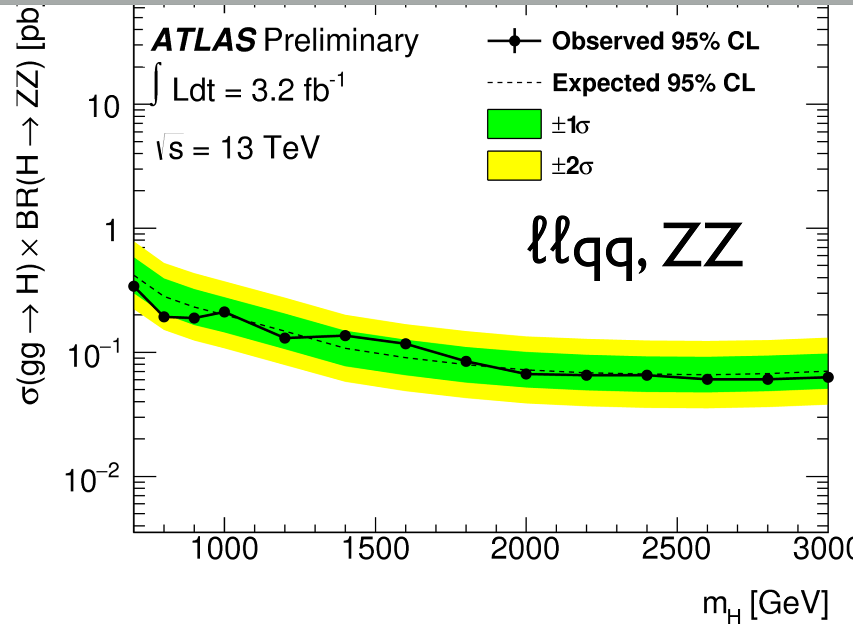




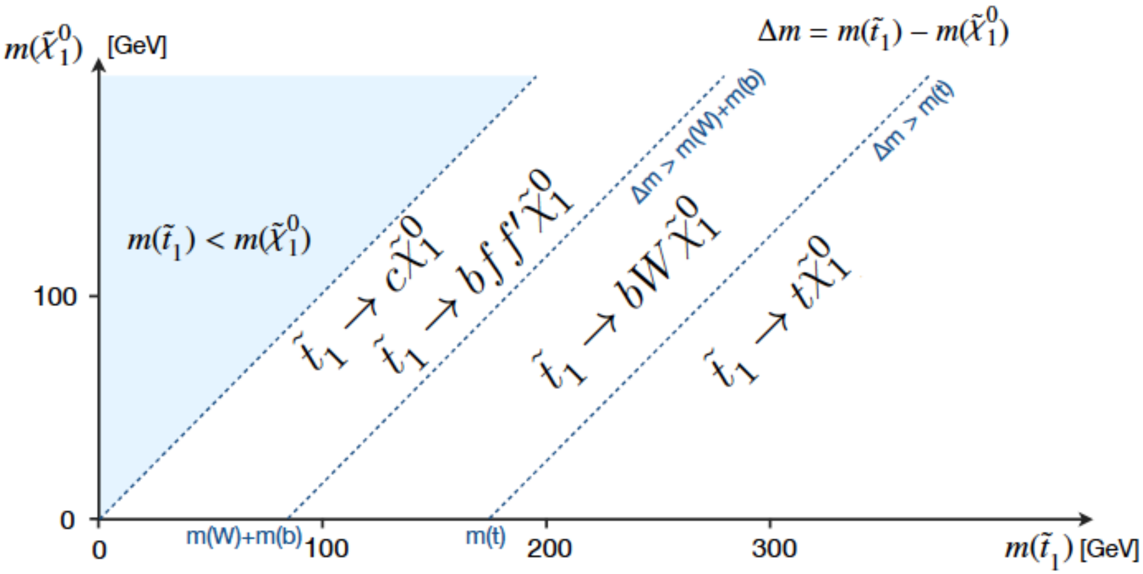


Individual Diboson Limits (WW, ZZ)



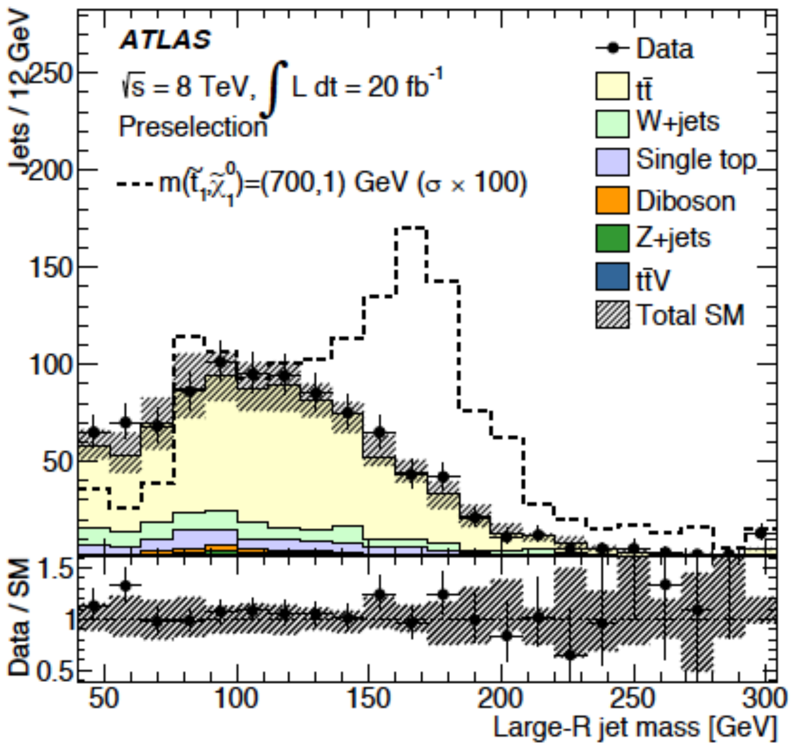


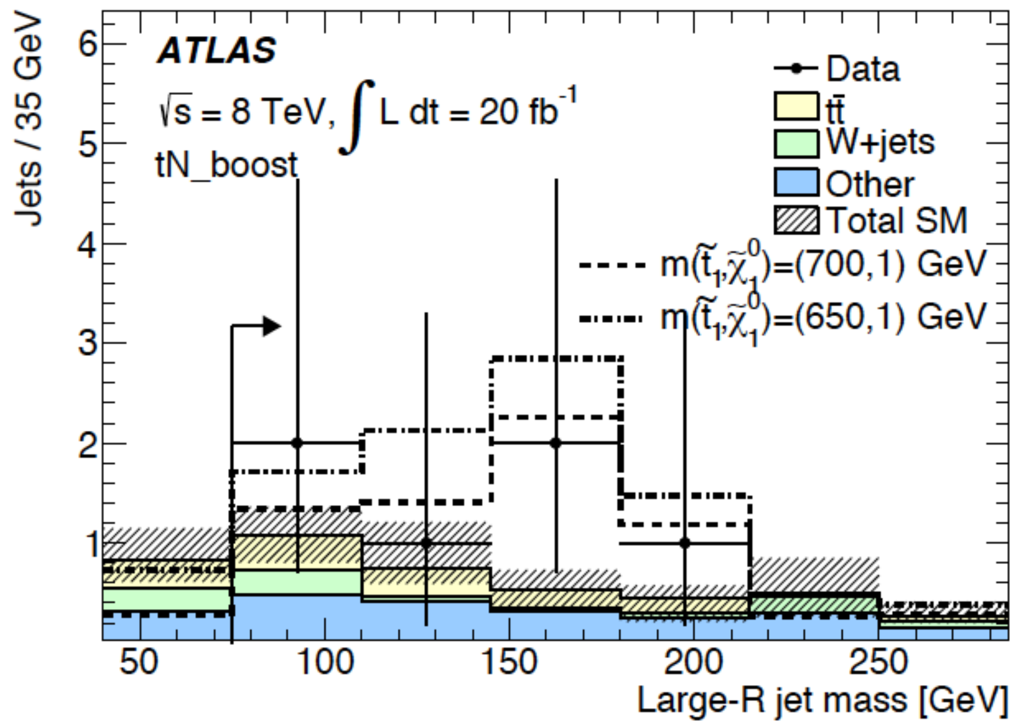
8 TeV Stop Searches and Boosted Objects



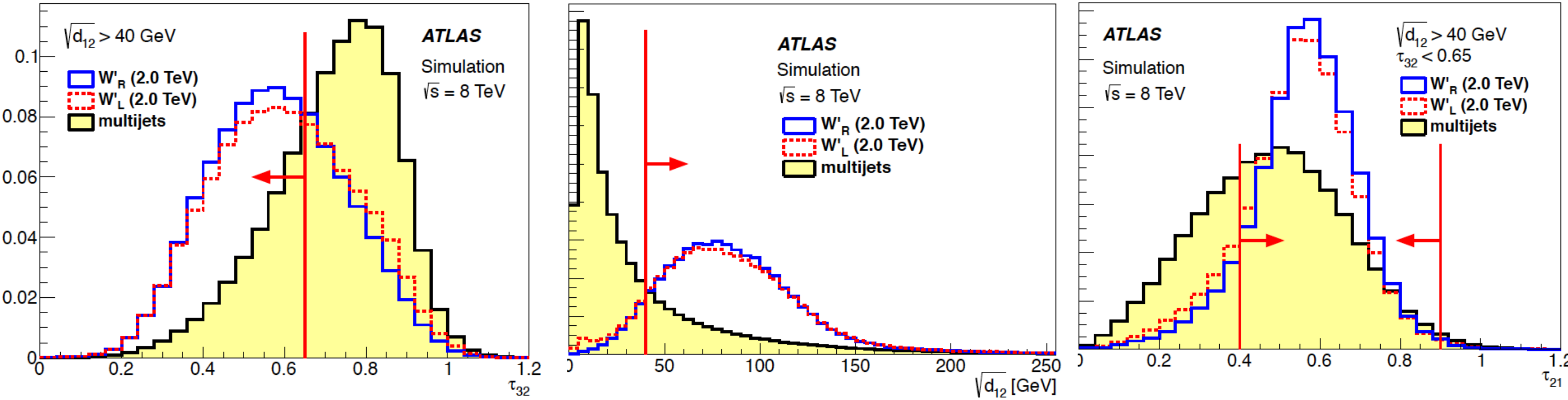
	tN_diag	tN_med	tN_high	tN_boost
Preselection	Default preselection criteria, cf. table 3.			
Lepton	= 1 lepton			
Jets	≥ 4 with $p_T >$ 60, 60, 40, 25 GeV	≥ 4 with $p_T >$ 80, 60, 40, 25 GeV	≥ 4 with $p_T >$ 100, 80, 40, 25 GeV	≥ 4 with $p_T >$ 75, 65, 40, 25 GeV
b-tagging	≥ 1 b-tag (70% eff.) amongst four selected jets			
large-R jet	–			≥ 1, $p_T > 270$ GeV and $m > 75$ GeV
$\Delta\phi(\mathrm{jet}_2^{\text{large-}R}, \vec{p}_T^{\text{miss}})$	–			> 0.85
E_T^{miss}	> 100 GeV	> 200 GeV	> 320 GeV	> 315 GeV
m_T	> 60 GeV	> 140 GeV	> 200 GeV	> 175 GeV
am_{T2}	–	> 170 GeV	> 170 GeV	> 145 GeV
m_{T2}^{τ}	–	–	> 120 GeV	–
topness	–	–	–	> 7
$m_{\text{had-top}}$	$\in$ [130, 205] GeV	$\in$ [130, 195] GeV	$\in$ [130, 250] GeV	
τ-veto	tight	–	–	modified, see text.
$\Delta R(b\text{-jet}, \ell)$	< 2.5	–	< 3	< 2.6
$E_T^{\text{miss}}/\sqrt{H_T}$	> 5 GeV$^{1/2}$	–		
$H_{T,\text{sig}}^{\text{miss}}$	–	> 12.5		> 10
$\Delta\phi(\mathrm{jet}_i, \vec{p}_T^{\text{miss}})$	> 0.8 $(i = 1, 2)$	> 0.8 $(i = 2)$	–	$> 0.5, 0.3$ $(i = 1, 2)$
Model-dependent selection:				
	shape-fit in m_T and E_T^{miss}, cf. figure 6.	cut-and-count		
Model-independent selection:				
	test 4 most signal-sensitive bins one-by-one.	cut-and-count		

8 TeV Stop Searches and Boosted Objects



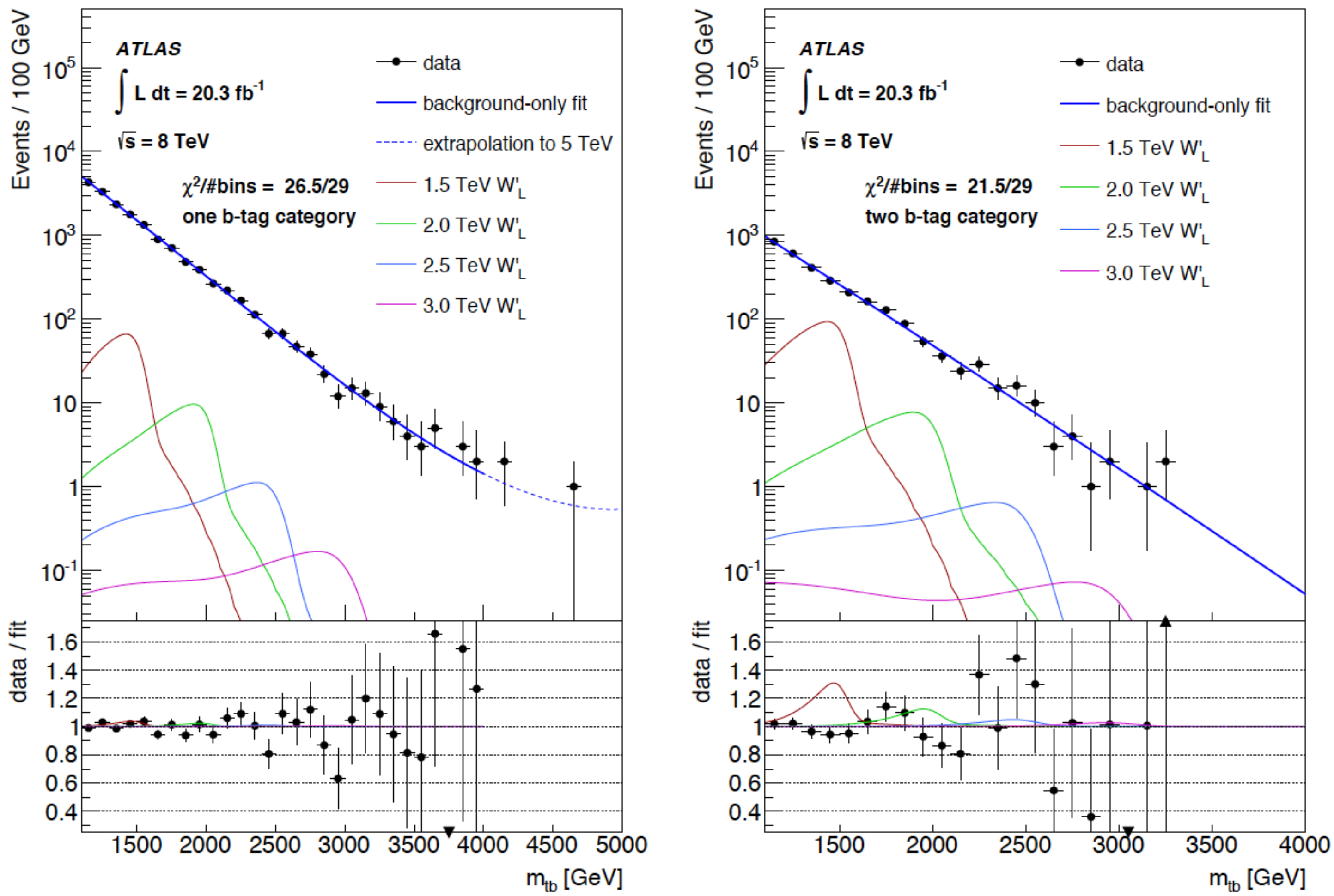


8 TeV W'→tb Search and Boosted Objects

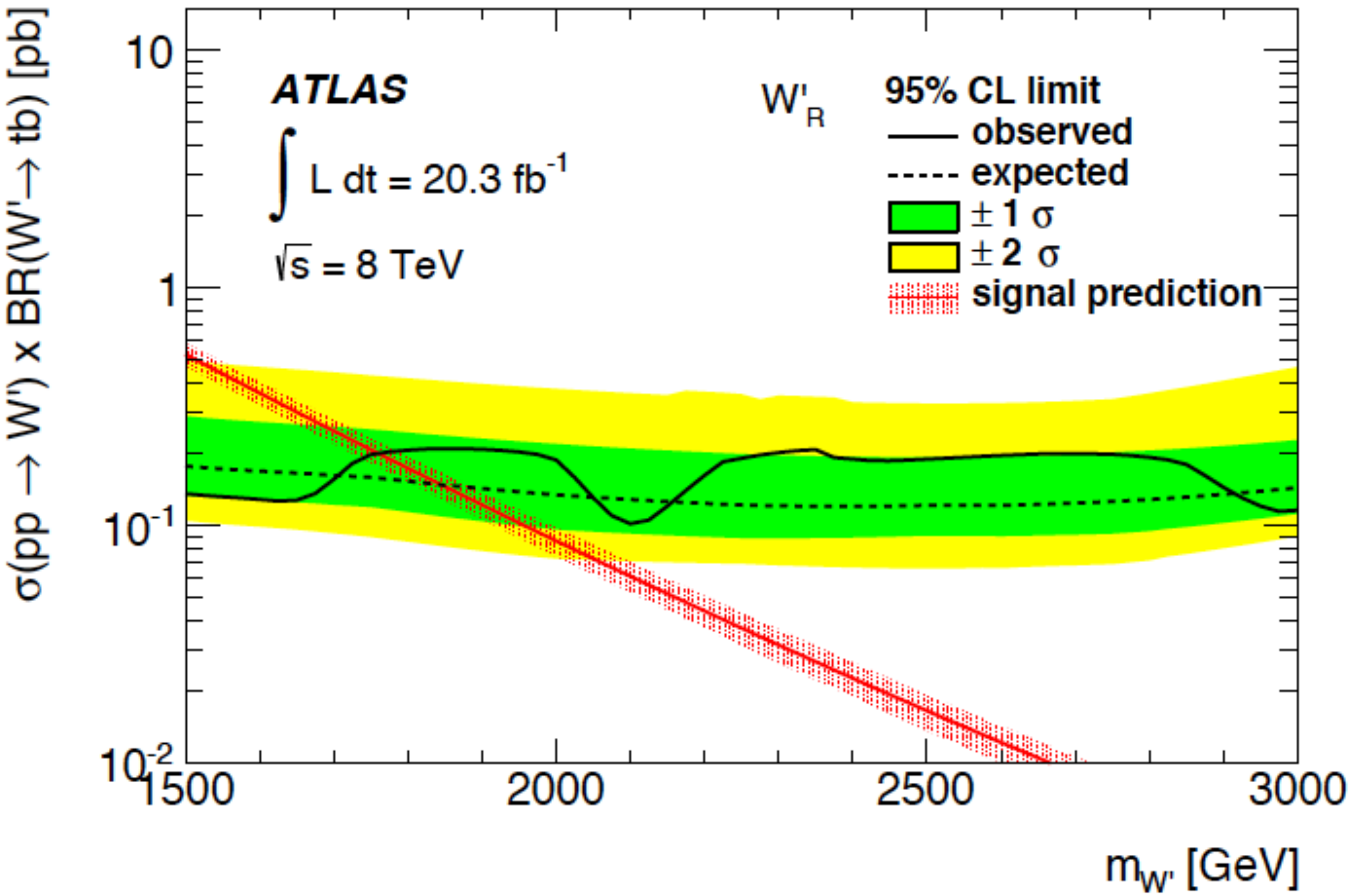


- Tagger pushing the limits of cut-based taggers, but rather good performance

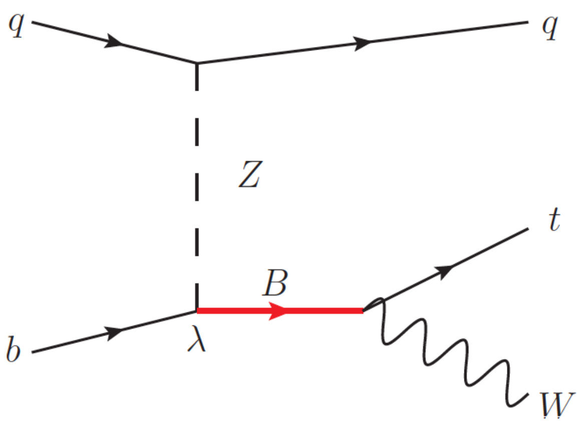
8 TeV W'→tb Search and Boosted Objects

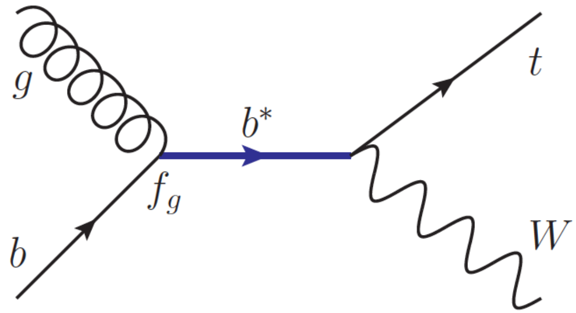


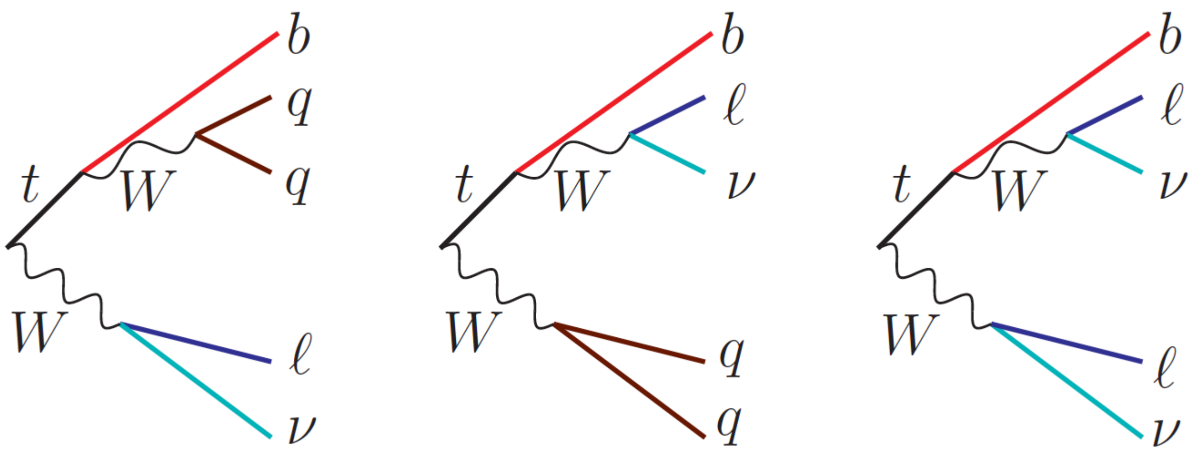
8 TeV W'→tb Search and Boosted Objects



8 TeV VLQ Search and Boosted Objects







- No tagger used, just large-R jet reconstruction if lepton is far from large-R jet
- Better mass resolution in this case

8 TeV VLQ Search and Boosted Objects