Probing new physics at the LHC: searches for heavy top-like quarks with the ATLAS experiment

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Four questions, one dissertation

- **Why?** bother with "new physics"

Four questions, one dissertation

- **Why?** bother with "new physics"
- **Where?** is all happening

Four questions, one dissertation

- **Why?** bother with "new physics"
- **Where?** is all happening
- **What?** are we looking at

Four questions, one dissertation

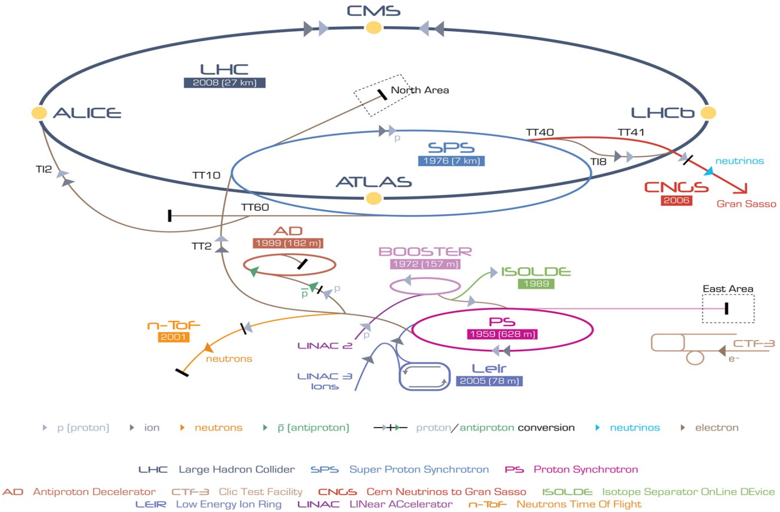
- Why? bother with “new physics”
- Where? is all happening
- What? are we looking at
- How?

Outline

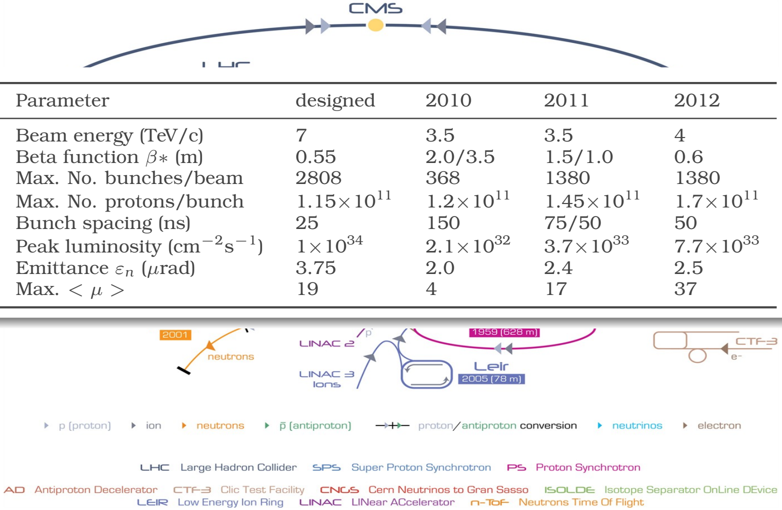
Standard Model as an effective theory

Outline

The LHC complex

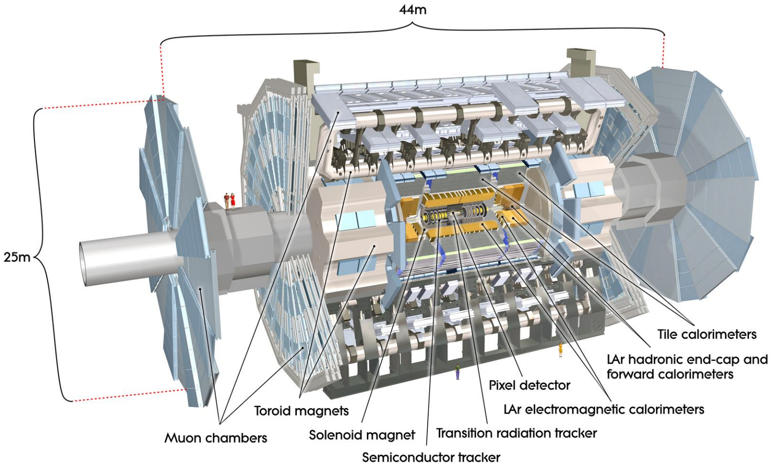


The LHC complex



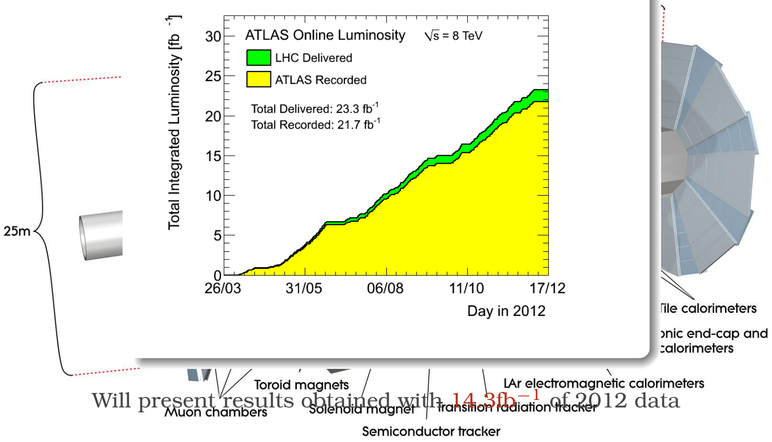
Parameter	designed	2010	2011	2012
Beam energy (TeV/c)	7	3.5	3.5	4
Beta function $\beta*$ (m)	0.55	2.0/3.5	1.5/1.0	0.6
Max. No. bunches/beam	2808	368	1380	1380
Max. No. protons/bunch	1.15×10^{11}	1.2×10^{11}	1.45×10^{11}	1.7×10^{11}
Bunch spacing (ns)	25	150	75/50	50
Peak luminosity (cm^{-2}s^{-1})	1×10^{34}	2.1×10^{32}	3.7×10^{33}	7.7×10^{33}
Emittance ε_n (μrad)	3.75	2.0	2.4	2.5
Max. $<\mu>$	19	4	17	37

The ATLAS Detector



The ATLAS Detector

In 2012 21.7fb^{-1} collected at $\sqrt{s} = 8$ TeV!

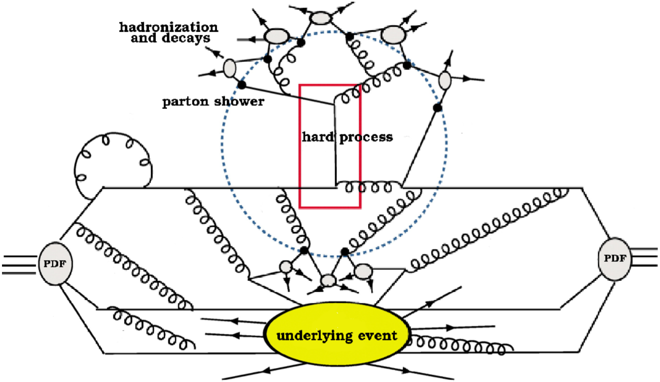


Will present results obtained with 14.3fb^{-1} of 2012 data

Outline

Modelling of hadron collisions

want to do physics at hadron colliders?
need a good understanding of incoming hadrons



Modelling of hadron collisions

Drawings from [1]

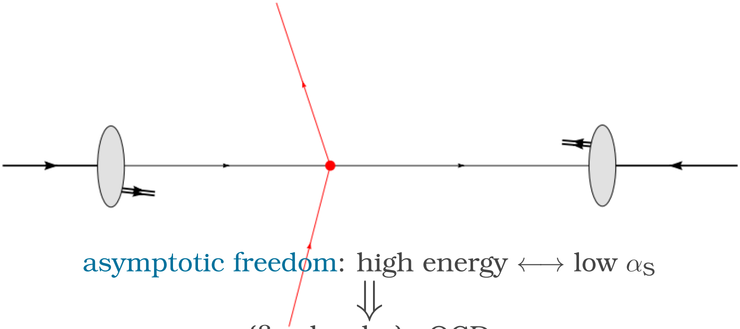
$E(p_1) = 4$ TeV $E(p_2) = 4$ TeV

Quarks are distributed according to PDFs inside the proton

$\Downarrow$

intial energy unknown

Hard scattering of two partons

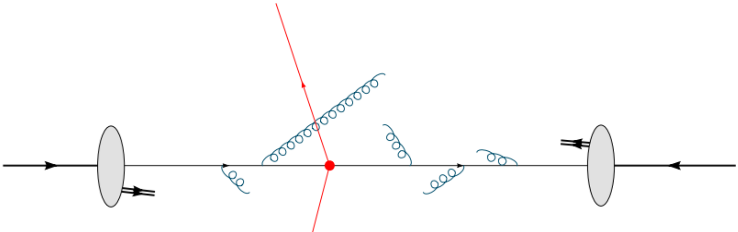


asymptotic freedom: high energy $\longleftrightarrow$ low α_S

$\Downarrow$

(fixed order) pQCD

Parton showering

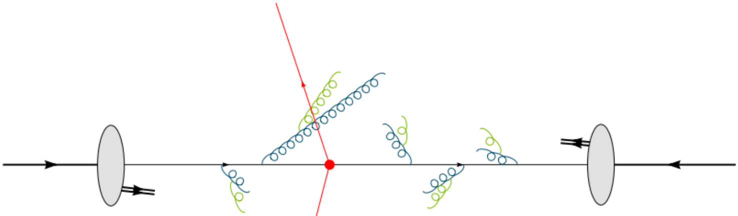


QCD emission: $q \to gq$, $g \to gg$, $g \to q\bar{q}$

$\Downarrow$

higher-order corrections

Parton showering

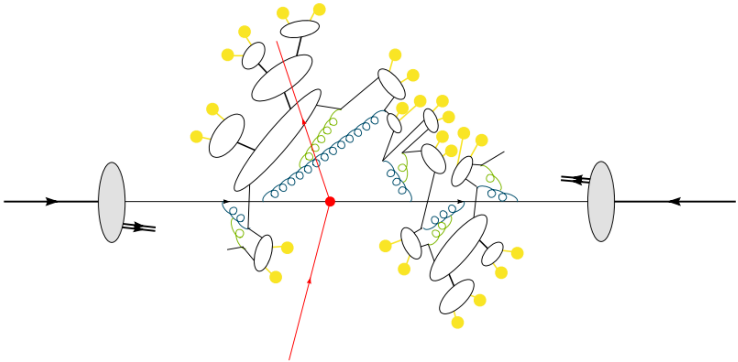


QCD emission: $q \rightarrow gq$, $g \rightarrow gg$, $g \rightarrow q\bar{q}$

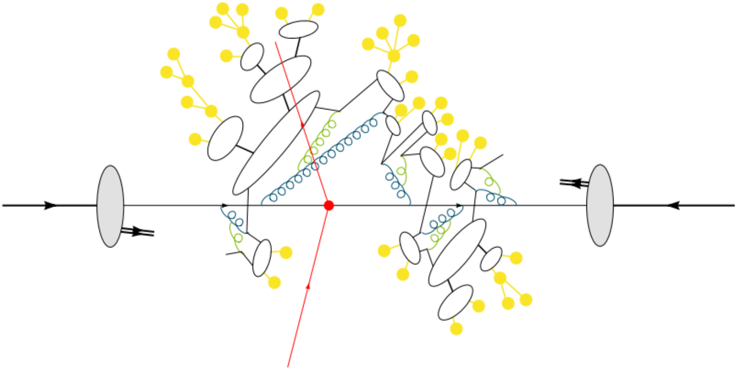
$$\Downarrow$$

higher-order corrections

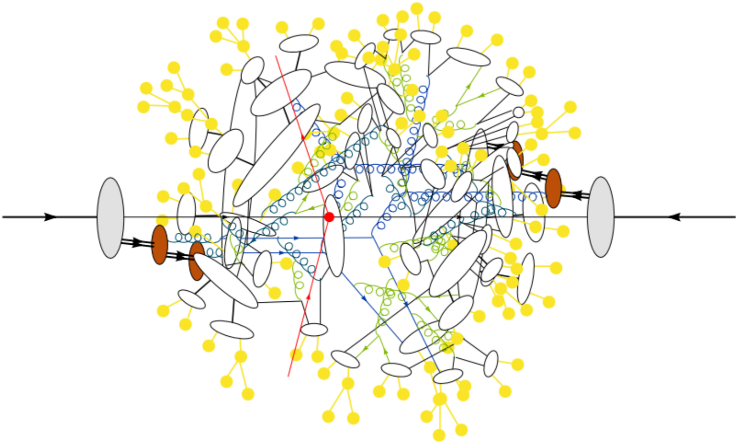
Hadronization



Final particle decays

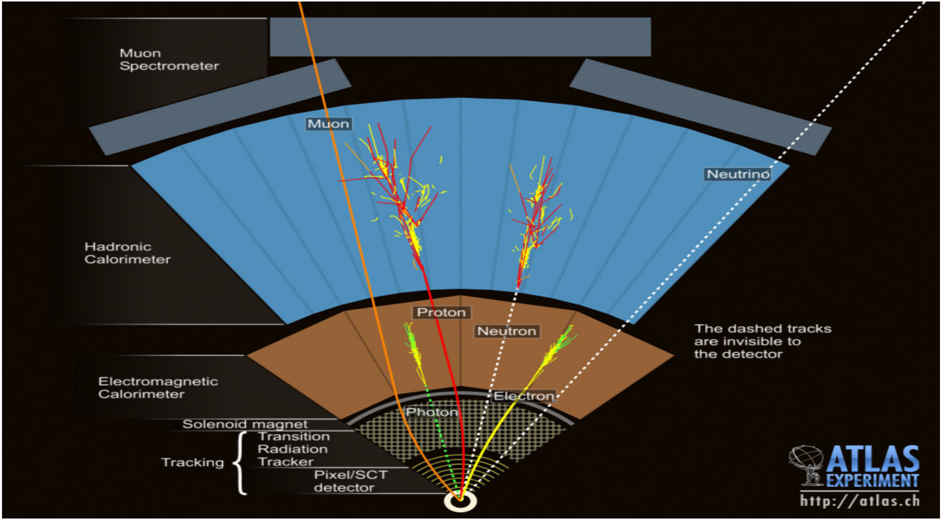


Underlying event simulation



Outline

Physics objects puzzle



One lepton

Many jets

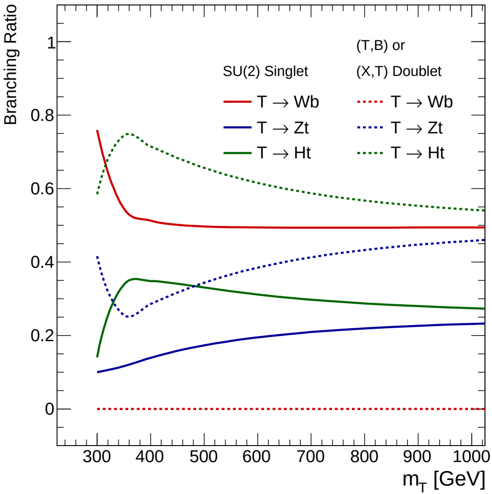
Missing transverse energy

Outline

Allowed decay modes

Singlet	Decay modes
$T(+2/3)$	W^+b, Ht, Zt
$B(-1/3)$	W^-t, Hb, Zb
$X(+5/3)$	W^+t
$Y(-4/3)$	W^-b

Doublet	Decay modes
$\begin{pmatrix} T \\ B \end{pmatrix}$	W^+b, Ht, Zt W^-t, Hb, Zb
$\begin{pmatrix} T \\ X \end{pmatrix}$	Ht, Zt W^+t
$\begin{pmatrix} B \\ Y \end{pmatrix}$	Hb, Zb W^-b

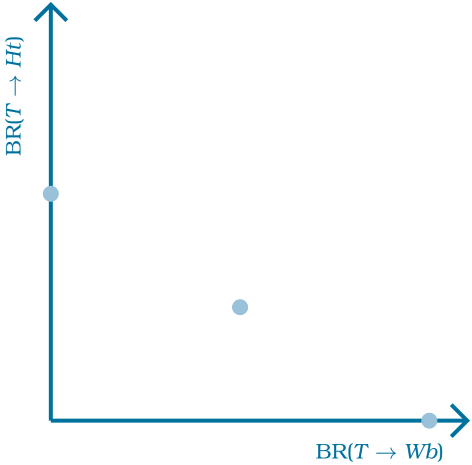


Model Independent Strategy

- Build a 2-dim plane to scan model mixing

BR($T \to Wb$)

Model Independent Strategy



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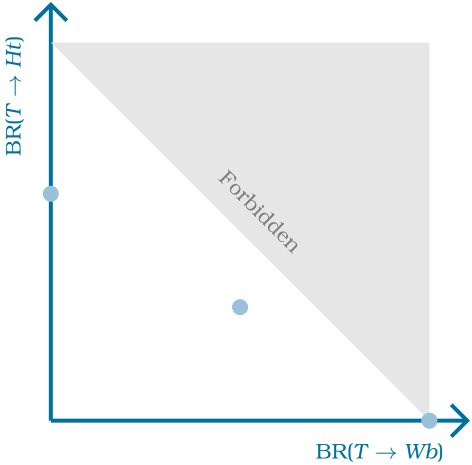
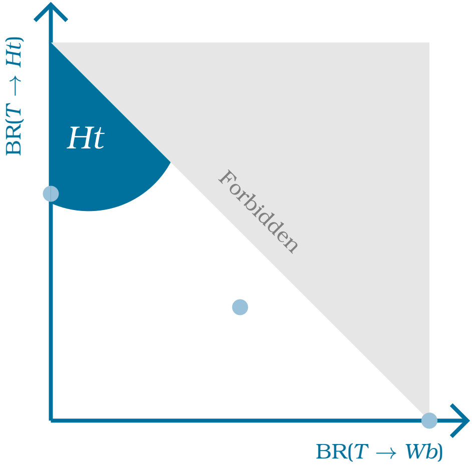


- Build a 2-dim plane to scan model mixing
- Sum of BRs is 1[a]

[a] BR($T \to Zt$) = 1 - BR($T \to Ht$) - BR($T \to Wb$)

Model Independent Strategy



- Build a 2-dim plane to scan model mixing
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- Different analyses are sensitive to different areas

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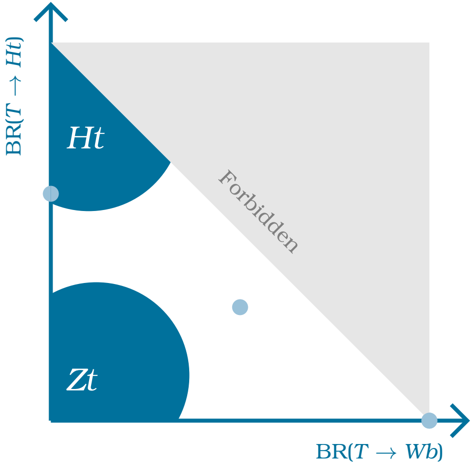

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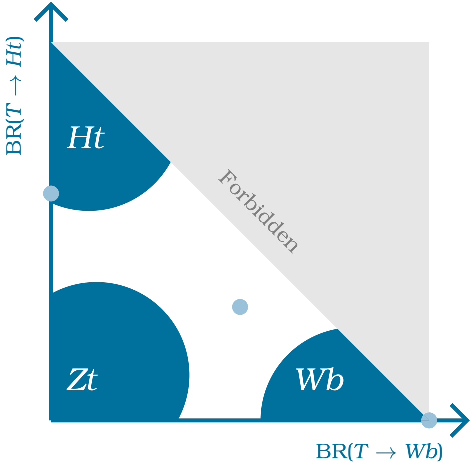

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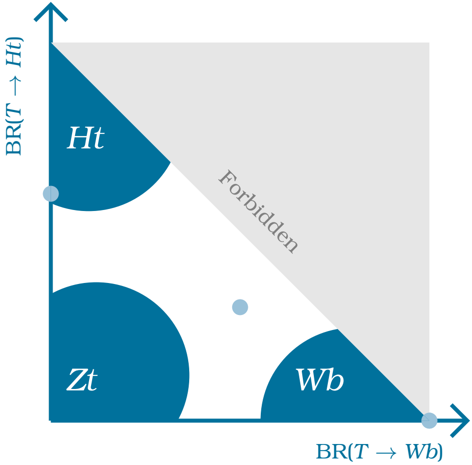

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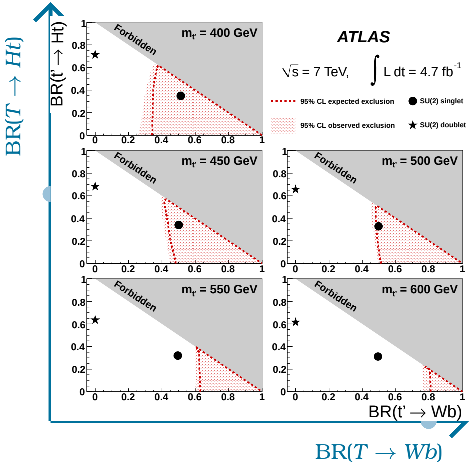
Model Independent Strategy



- Build a 2-dim plane to scan model mixing
- Sum of BRs is 1[a]
- Different analyses are sensitive to different areas
- Set exclusion using CL_s technique [2, 3]
- First published results at 7 TeV *Phys.Lett.* **B718** (2012) [4]

[a] BR($T \to Zt$) = 1 - BR($T \to Ht$) - BR($T \to Wb$)

Preselection

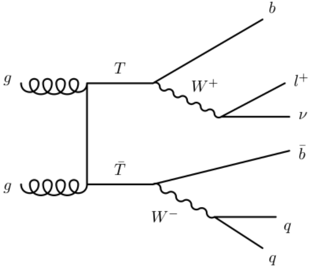
Two searches using common analysis framework:

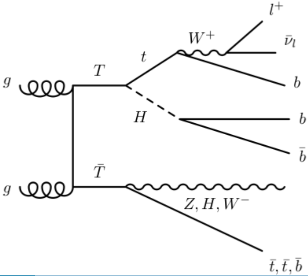
- $T\bar{T} \to Wb + X$ — ATLAS-CONF-2013-060 [5]
- $T\bar{T} \to Ht + X$ — ATLAS-CONF-2013-018 [6]

Preselection stage	Requirements
Single lepton	One electron or muon matching trigger
QCD rejection	$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV $E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}} > 60$ GeV
Jet multiplicity	≥ 4 jets ≥ 1 b-tagged jets

orthogonality requirements:

- $T\bar{T} \to Wb + X$: reject events with $\geq$6 jets and $\geq$3 b-jets
- $T\bar{T} \to Ht + X$: reject events in the low b-tags channel with $H_{\mathrm{T}} < 700$ GeV





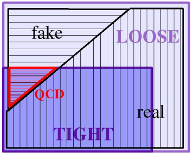
Background and signal modelling

Yields in the preselection region "blinded" as: $H_T^{4j} < 800$ GeV (*)

	≥ 4 jets, ≥ 1 b-tags
Multi-jet	6264 ± 74
Single top	14375 ± 107
Diboson	548 ± 12
Z+jets	5804 ± 146
W+jets	35921 ± 525
$t\bar{t}$V	680 ± 2
$t\bar{t}$H (125)	220 ± 1
$t\bar{t}$ MC@NLO	202042 ± 285
Tot Bkg w/ MC@NLO	265854 ± 629
$T\bar{T}$ (600) chiral	36 ± 2
Data	256993 ± 507

(*) $H_T^{4j} = p_{\mathrm{T}}(l) + E_{\mathrm{T}}^{\mathrm{miss}} + \sum_{j=1}^{4} p_{\mathrm{T}}(j)$

- QCD multi-jet events have high cross-section
- Data-drive estimation
- Matrix-method



$$N_{\text{fake}}^{\text{tight}} = \frac{\epsilon_{\text{fake}}}{\epsilon_{\text{real}} - \epsilon_{\text{fake}}} (N^{\text{loose}} \epsilon_{\text{real}} - N^{\text{tight}})$$

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(*) $H_T^{4j} = p_T(l) + E_T^{miss} + \sum_{j=1}^{4} p_T(j)$

- s-channel and Wt production generated with `MC@NLO+HERWIG`
- t-channel generated with `ACERMC+PYTHIA`
- $m_t = 172.5$ GeV
- NNLO theoretical cross sections

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- Diboson production generated with `HERWIG`
- NLO theoretical cross section

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- Z boson production in association with jets generated with up to five additional partons with ALPGEN+HERWIG
- Samples generated separately for Z+light jets, $Zb\bar{b}$+jets, and $Zc\bar{c}$+jets
- Inclusive NNLO theoretical cross section

Background and signal modelling

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(*) $H_T^{4j} = p_{\mathrm{T}}(l) + E_{\mathrm{T}}^{\mathrm{miss}} + \sum_{j=1}^{4} p_{\mathrm{T}}(j)$

- W boson production in association with jets generated with up to five additional partons with ALPGEN+HERWIG
- Samples generated separately for W+light jets, $Wb\bar{b}$+jets, $Wc\bar{c}$+jets, and Wc+jets
- Normalized to data-driven prediction

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- $t\bar{t}$ produced in association with a W or Z boson generated with MADGRAPH+PYTHIA
- $m_t = 172.5$ GeV
- NLO theoretical cross section

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(*) $H_T^{4j} = p_{\mathrm{T}}(l) + E_{\mathrm{T}}^{\mathrm{miss}} + \sum_{j=1}^{4} p_{\mathrm{T}}(j)$

- $t\bar{t}$ produced in association with a Higgs boson generated with PYTHIA
- $m_t = 172.5$ GeV, $m_H = 125$ GeV
- Higgs decay modes considered: $H \to b\bar{b}$, $c\bar{c}$, gg, W^+W^-
- NLO theoretical cross section

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- $t\bar{t}$ pair production in association with jets generated with `MC@NLO+HERWIG`
- $m_t = 172.5$ GeV
- NNLO theoretical cross section

but

`MC@NLO` does not model well high-jet multiplicity regions!

- Additional samples generated with `ALPGEN+HERWIG`
- Separate samples are generated for $t\bar{t}$+light jets with up to three additional light partons, and for $t\bar{t}$+heavy-flavour jets including $t\bar{t}b\bar{b}$ and $t\bar{t}c\bar{c}$
- $m_t = 172.5$ GeV
- NNLO theoretical cross section

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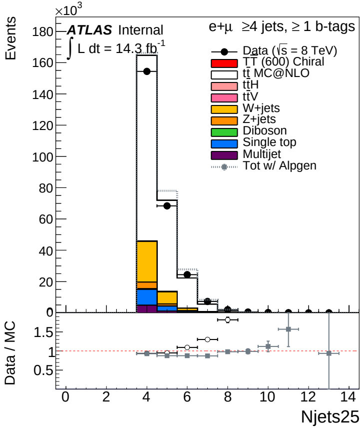
Yields for $t\bar{t}$ predicted with ALPGEN are ~3-8% higher than MC@NLO



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(*) $H_T^{4j} = p_T(l) + E_T^{miss} + \sum_{j=1}^{4} p_T(j)$

- $T\bar{T}$ singlet production generated with PROTOS+PYTHIA
- Branching ratio to each decay mode (Wb, Zt and Ht) is set to 1/3
- Events are reweighted at the analysis level in order to reproduce any desired branching ratio configuration
- m_T values generated from 350 GeV to 850 GeV in steps of 50 GeV
- $m_H = 125$ GeV, all Higgs boson decay modes are considered
- NNLO theoretical cross section

m_T (GeV)	$BR(T \to Wb)$	$BR(T \to Zt)$	$BR(T \to Ht)$
		Singlet	
600	0.494	0.194	0.312
		Doublet	
600	0.000	0.383	0.617

Systematic uncertainties - Shape and Norm

Systematic uncertainty	$T\bar{T} \rightarrow Wb + X$		$T\bar{T} \rightarrow Ht + X$	
	Status	Components	Status	Components
Luminosity	N	1	N	1
Lepton ID+reco+trigger	N	1	N	1
Jet vertex fraction efficiency	SN	1	SN	1
Jet energy scale	SN	1	SN	8
Jet energy resolution	SN	1	SN	1
b-tagging efficiency	SN	9	SN	9
c-tagging efficiency	SN	5	SN	5
Light jet-tagging efficiency	SN	1	SN	1
$t\bar{t}$ cross section	N	1	N	1
$t\bar{t}V$ cross section	N	1	N	1
$t\bar{t}H$ cross section	-	-	N	1
Single top cross section	N	1	N	1
Dibosons cross section	N	1	N	1
W+jets normalization	N	5	-	-
Z+jets normalization	N	1	-	-
V+jets normalization	-	-	N	1
Multijet normalization	-	-	N	1
$t\bar{t}$ modelling	SN	3	SN	3
V+jets modelling	SN	1	-	-
$t\bar{t}$+heavy-flavour fractions	-	-	N	1

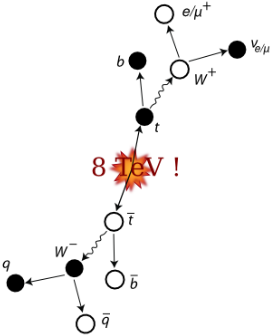
Outline

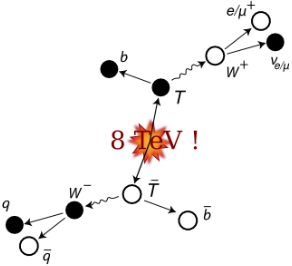
Strategy

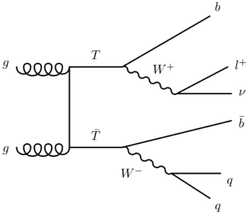
$T\bar{T} \to WbWb$

like

$t\bar{t} \to WbWb$







different boosted kinematics

$\Downarrow$

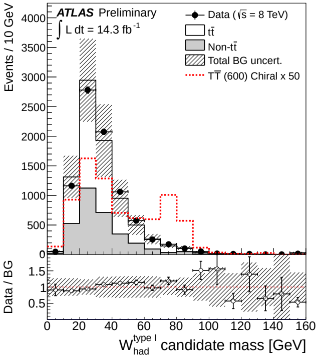
reconstruct the W boson from hadronic decay

merged jets $W_{\text{had}}^{\text{type I}}$

close-by jets $W_{\text{had}}^{\text{type II}}$

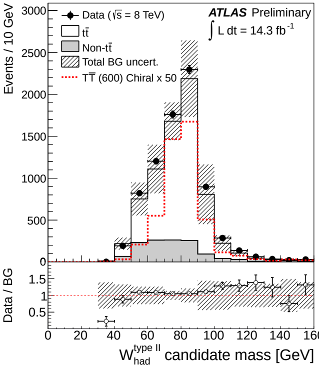
W boson reconstruction

$W_{\text{had}}^{\text{type I}}$



one jet
$p_{\mathrm{T}} > 250$ GeV
$60 < M < 120$ GeV

$W_{\text{had}}^{\text{type II}}$

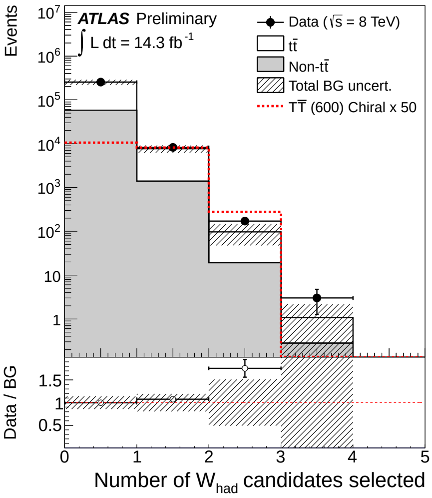


no $W_{\text{had}}^{\text{type I}}$
di-jet system
$\Delta R(j,j) < 0.8$
$p_{\mathrm{T}} > 200$ GeV
$60 < M < 120$ GeV

W_{lep} reconstructed using lepton and “neutrino”:
p_X, p_Y from $E_{\mathrm{T}}^{\text{miss}}$, p_Z from $M_W^2 = (P_l + P_\nu)^2$

Event selection

	LOOSE selection	
SR0	Preselection	
SR1	+	≥ 1 W_{had} candidates
SR2	+	$H_T^{4j} > 800$ GeV
SR3	+	$p_T(b_1) > 160$ GeV
SR4	+	$p_T(b_2) > 80$ GeV
SR5	+	$\Delta R(\ell,\nu) < 1.2$
	TIGHT selection	
SR5	LOOSE selection	
SR6	+	$\min\Delta R(\ell,b) > 1.4$
SR7	+	$\min\Delta R(W_{\text{had}},b) > 1.4$



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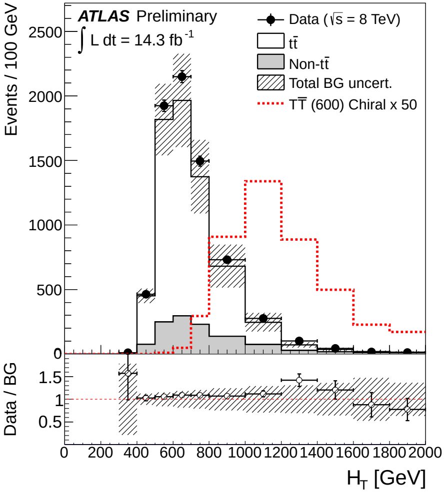

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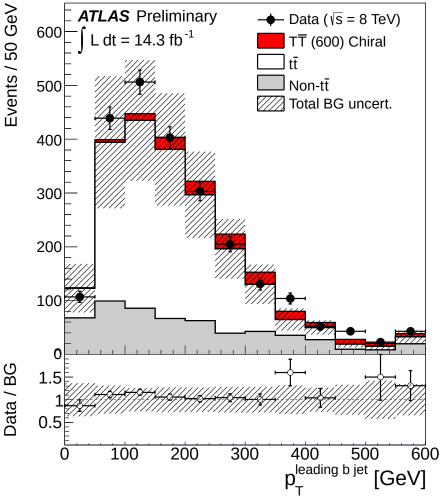

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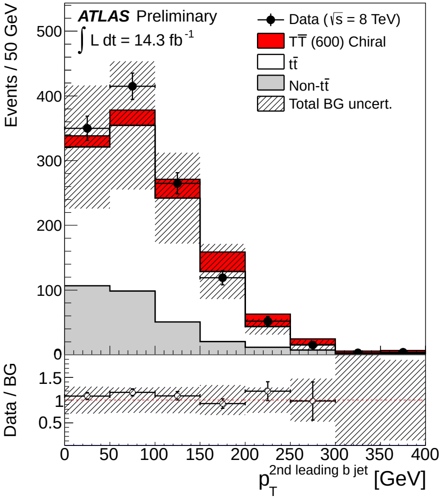

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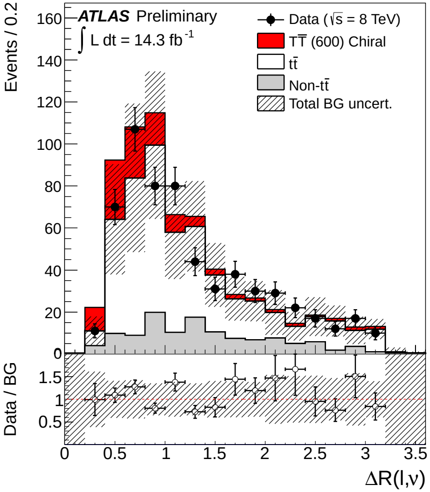

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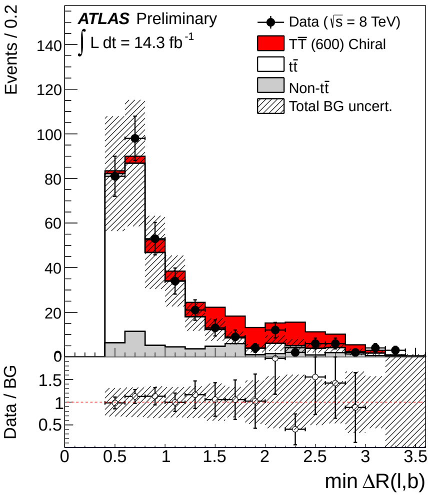

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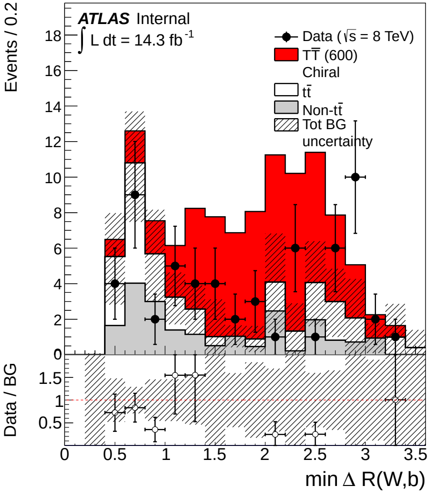


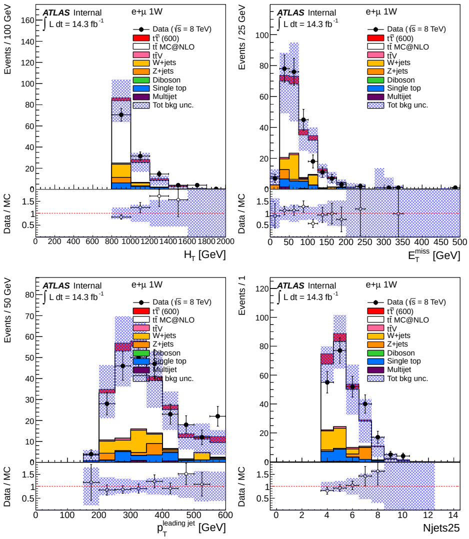
Comparison data vs prediction

Check agreement between data and background prediction

$\Downarrow$

Define regions depleted in signal

	Loose but $\Delta R(\ell, \nu) > 1.2$
$t\bar{t}'$ (600 GeV)	$18.47 \pm 1.48\ ^{+1.09}_{-1.64}$
$t\bar{t}$	$173.13 \pm 8.82\ ^{+46.92}_{-48.59}$
W+jets	$30.64 \pm 9.78\ ^{+13.74}_{-12.43}$
Z+jets	$11.68 \pm 5.93\ ^{+5.89}_{-6.96}$
Diboson	$0.29 \pm 0.19\ ^{+0.17}_{-0.17}$
Single top	$21.46 \pm 2.54\ ^{+2.60}_{-2.54}$
$t\bar{t}V$	$4.21 \pm 0.16\ ^{+1.33}_{-1.33}$
Multijet	$0.49 \pm 0.91 \pm 0.25$
Total bkg.	$241.90 \pm 14.70\ ^{+53.57}_{-55.95}$
Data	250



Yields in signal region

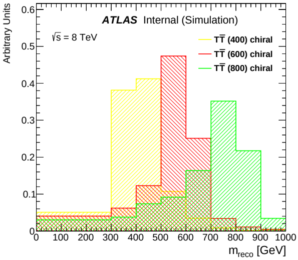
	Loose	Tight
$t\bar{t}$	264 ± 80	10 ± 6
$t\bar{t}V$	5.1 ± 1.8	0.5 ± 0.2
W+jets	16 ± 11	6 ± 5
Z+jets	1.1 ± 1.4	0.2 ± 0.5
Single top	30 ± 7	4.4 ± 1.6
Dibosons	0.21 ± 0.15	0.06 ± 0.05
Tot.Bkg.	317 ± 90	21 ± 9
Data	348	37
$T\bar{T}$(600 GeV)		
Chiral t'	88 ± 10	54 ± 7
T Singlet	41 ± 4	20.3 ± 2.2

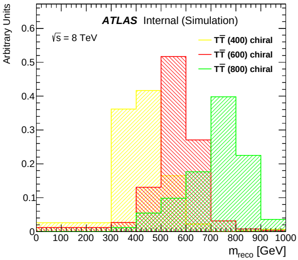
merged

Discriminating variable $\Rightarrow$ T reconstructed mass

$\Downarrow$

Pair b-jets and W boson candidates in order to get $\min\Delta(M_{\text{lep}}, M_{\text{had}})$





Reconstructed mass

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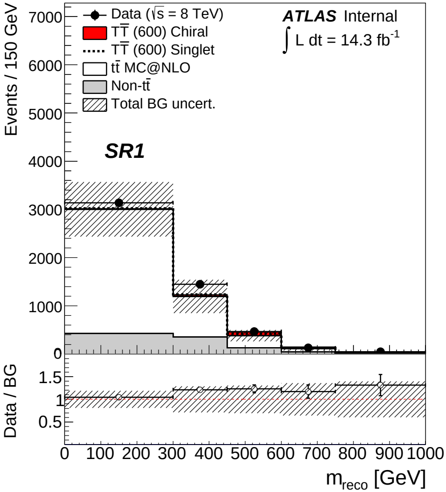

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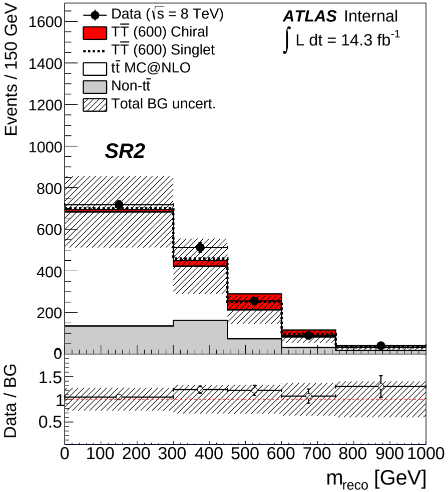

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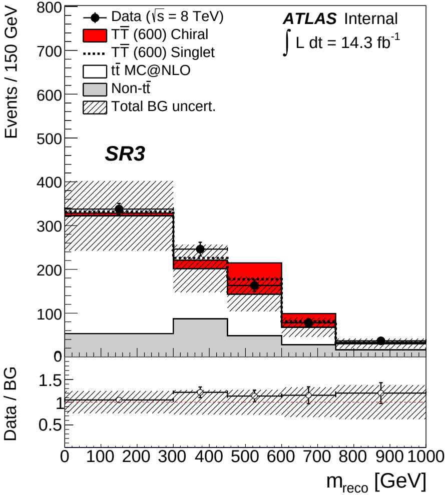

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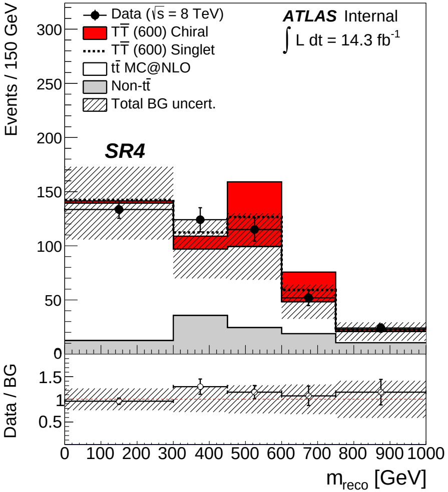

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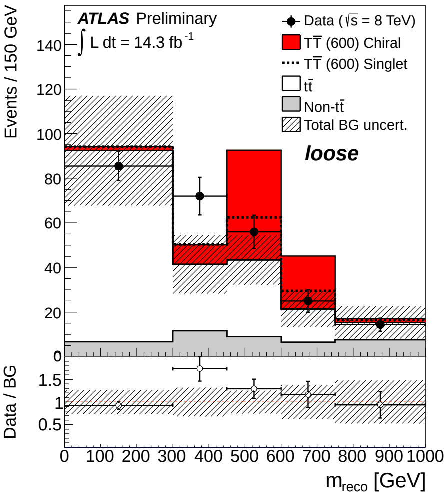

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SR5	LOOSE selection	
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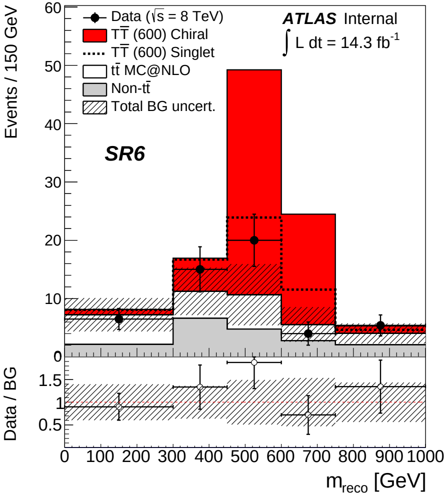

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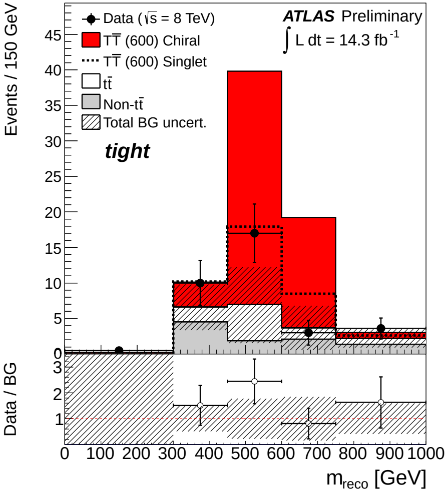
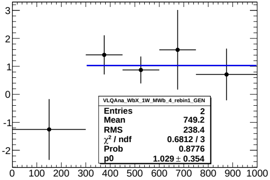
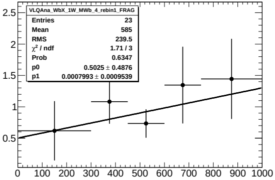
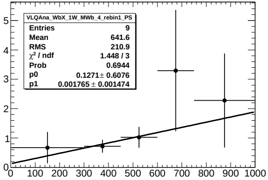


Most relevant systematic uncertainties

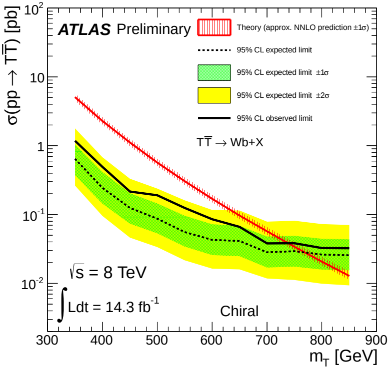
	$T\bar{T}$ (600 GeV)	$t\bar{t}$	Non-$t\bar{t}$
Total [%]	+14/-15	+59/-59	+42/-35
Main contributions [%]			
Jet energy scale	+6.6/-8.4	+15/-15	+33/-22
$t\bar{t}$ modelling: NLO MC generator	–	+48/-48	–
$t\bar{t}$ modelling: PS and fragm	–	+25/-25	–
$t\bar{t}$ modelling: ISR/FSR	–	+8.8/-8.8	–



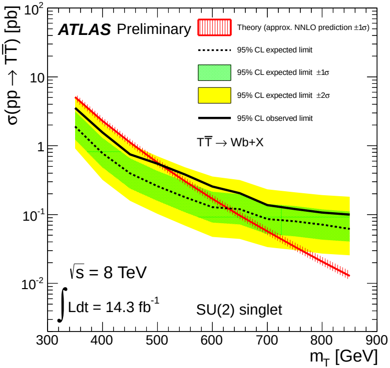




Results



ATLAS Preliminary
Theory (approx. NNLO prediction ±1σ)
95% CL expected limit
95% CL expected limit ±1σ
95% CL expected limit ±2σ
95% CL observed limit
TT̄ → Wb+X
√s = 8 TeV
∫Ldt = 14.3 fb^-1
Chiral
σ(pp → TT̄) [pb]
m_T [GeV]



ATLAS Preliminary
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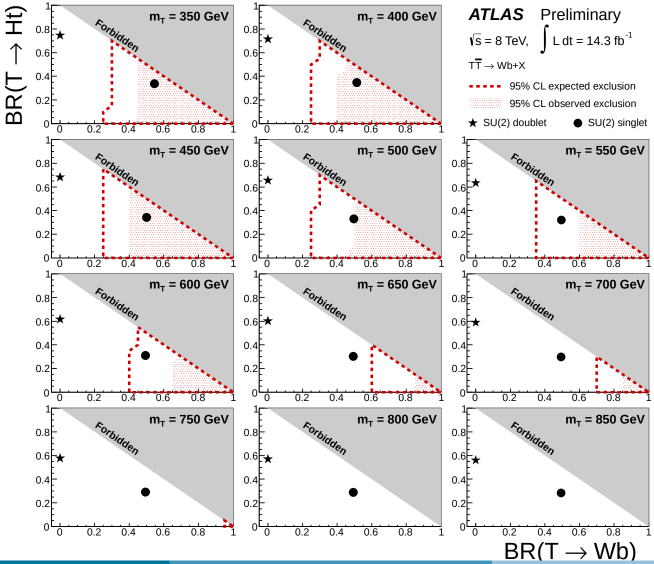
95% CL expected limit
95% CL expected limit ±1σ
95% CL expected limit ±2σ
95% CL observed limit
TT̄ → Wb+X
√s = 8 TeV
∫Ldt = 14.3 fb^-1
SU(2) singlet
σ(pp → TT̄) [pb]
m_T [GeV]

Results



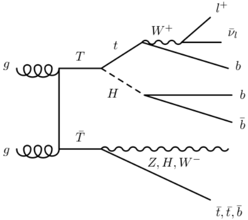
ATLAS Preliminary
√s = 8 TeV, ∫ L dt = 14.3 fb^-1
TT̄ → Wb+X
95% CL expected exclusion
95% CL observed exclusion
SU(2) doublet
SU(2) singlet
m_T = 350 GeV
m_T = 400 GeV
m_T = 450 GeV
m_T = 500 GeV
m_T = 550 GeV
m_T = 600 GeV
m_T = 650 GeV
m_T = 700 GeV
m_T = 750 GeV
m_T = 800 GeV
m_T = 850 GeV
Forbidden
BR(T → Ht)
BR(T → Wb)

Outline

Strategy

$$T \to Ht \begin{matrix} \nearrow bbWb \to bbbl\nu \\ \searrow WWWb \to qqqqbl\nu \end{matrix} \quad + \bar{T} \to Wb/Zt/Ht$$

$T\bar{T} \to Ht + X$



SM Higgs boson
w/ $m_H = 125$ GeV

$\Downarrow$

BR($H \to bb$) = 60%

BR($H \to WW$) = 20%

as a minimum 6 total jets in the event ($T\bar{T} \to HtWb$)

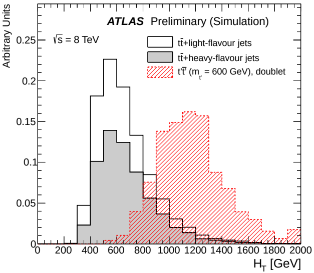
$\Downarrow$

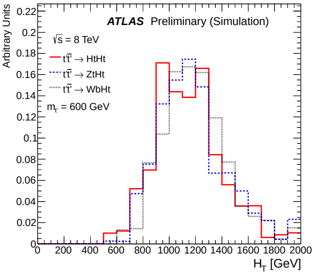
$$H_{\mathrm{T}} = p_{\mathrm{T}}(l) + E_{\mathrm{T}}^{\mathrm{miss}} + \sum_{j=1}^{\mathrm{Njets}} p_{\mathrm{T}}(j)$$

peak $\sim 2m_T$

good signal/bkg discriminant

for all $Ht + X$ modes





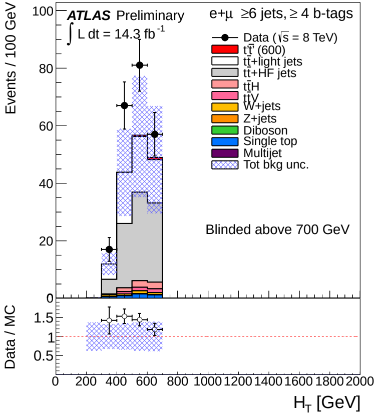
$\geq$ 6 jets, $\geq$ 4 b-jets

Event selection

maximize signal acceptance

"2 b-TAGGED JETS"	$\geq$ 6 jets =2 b-tagged jets orthogonality cut: $H_\mathrm{T} < 700$ GeV
"3 b-TAGGED JETS"	$\geq$ 6 jets =3 b-tagged jets
"$\geq$4 b-TAGGED JETS"	$\geq$ 6 jets $\geq$ 4 b-tagged jets

$\rightarrow$ b-tagging by TRF in MC $\leftarrow$



heavy flavor component not well predicted

$\Downarrow$

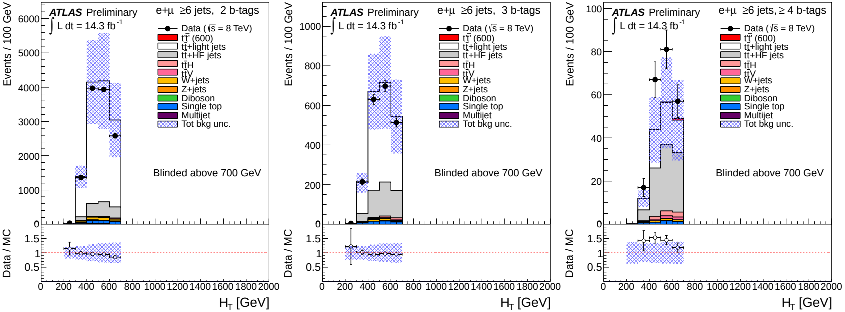
simultaneous fit to data of H_T variable

(good to have background enriched channels)

Scale of $t\bar{t}$ components

$t\bar{t}$+light: 0.87 ± 0.02 (stat.) $t\bar{t}$+HF: 1.35 ± 0.11 (stat.)

before. . .

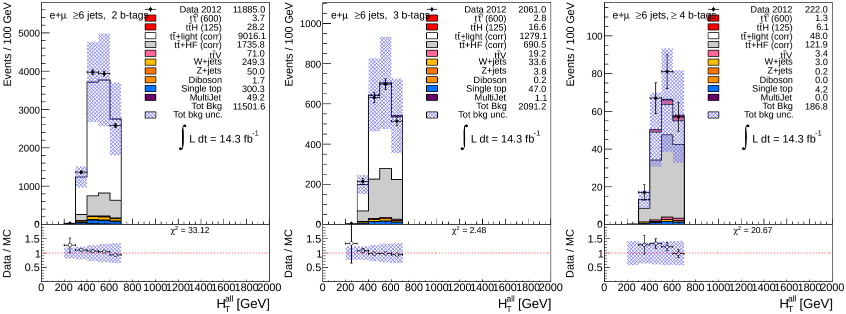


Maximum yields discrepancy below 5%

Scale of $t\bar{t}$ components

$t\bar{t}$+light: $0.87 \pm 0.02\,(\text{stat.})$ $t\bar{t}$+HF: $1.35 \pm 0.11\,(\text{stat.})$

...after



Maximum yields discrepancy below 5%

Comparison data vs prediction

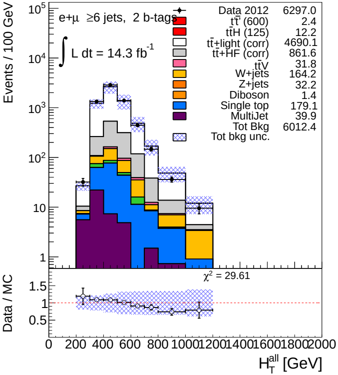
Blinding cut: $H_{\mathrm{T}} < 700$ GeV

$\Downarrow$

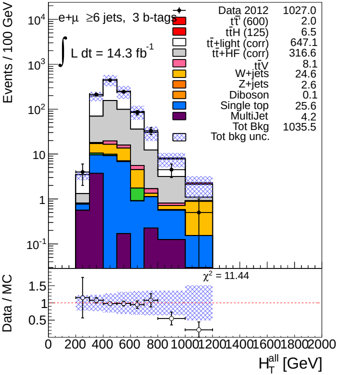
Define special blinded regions to check H_{T} modeling:

at most two jets with $p_{\mathrm{T}} > 60$ GeV, $H_{\mathrm{T}} < 1.2$ TeV

2 b-tagged jets

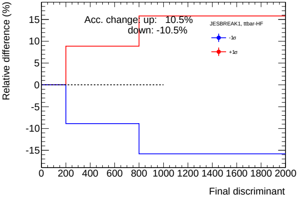


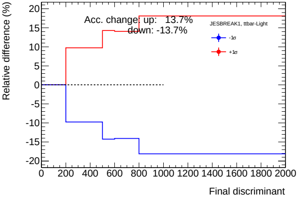
3 b-tagged jets



Most relevant systematic uncertainties

	$T\bar{T}$	$t\bar{t}$H (125)	$t\bar{t}$-HF	$t\bar{t}$-Light	W+jets	Z+jets	Single top	Diboson	$t\bar{t}V$	Multijet
Total [%]	+21.9/-24.0	+25.2/-30.0	+57.3/-58.4	+42.0/-44.1	+60.0/-61.0	+65.2/-66.2	+31.7/-32.9	+68.2/-70.2	+37.6/-38.8	+50.0/-50.0
					Main contributions [%]					
BTAGBREAK8	+20.4/-22.7	+18.7/-21.6	+15.8/-17.8	+12.2/-13.1	+13.5/-15.0	+13.0/-13.9	+15.9/-17.8	+22.0/-27.4	+16.4/-18.6	–
JES “baseline”	+3.1/-3.1	+7.3/-7.3	+10.5/-10.5	+13.7/-13.7	+18.1/-18.1	+18.2/-18.2	+19.9/-19.9	+5.2/-5.2	+8.4/-8.4	–
ttbar iqopt2	–	–	+6.9/-6.9	+20.1/-20.1	–	–	–	–	–	–
ttbar ktfac	–	–	+7.5/-9.2	+13.8/-17.0	–	–	–	–	–	–
ttbar qfac	–	–	+0.7/-0.7	+1.6/-1.6	–	–	–	–	–	–
ttbarHF	–	–	+50.0/-50.0	+13.0/-13.0	–	–	–	–	–	–



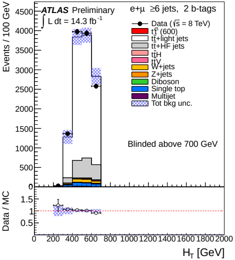


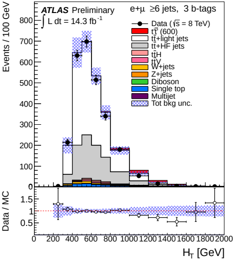
Introduce the scaling factors as nuisance parameters

$\Downarrow$

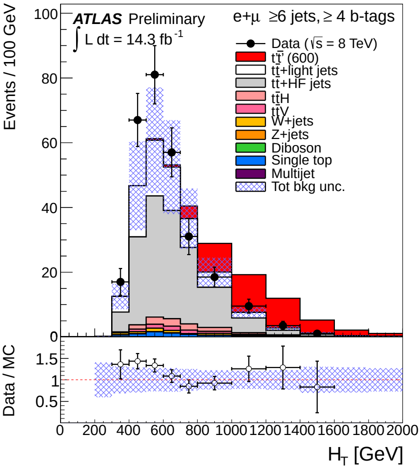
total uncertainty on $t\bar{t}$+HF reduced by $\sim$ 20%

Yields in signal regions



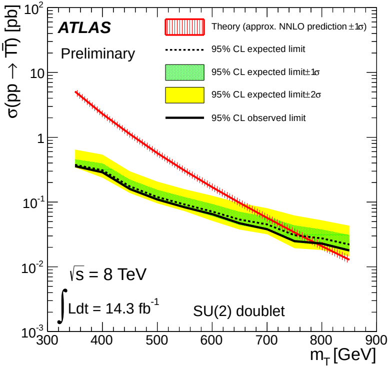


	2 b-tags	3 b-tags	$\geq$ 4 b-tags
$t\bar{t}$+HF	1500 ± 900	900 ± 400	170 ± 70
$t\bar{t}$+LF	9600 ± 1000	1900 ± 350	75 ± 22
W+jets	250 ± 130	50 ± 30	5 ± 3
Z+jets	50 ± 40	9 ± 6	0.5 ± 0.9
Single top	300 ± 70	75 ± 18	7 ± 3
Diboson	1.7 ± 0.6	0.3 ± 0.1	0.03 ± 0.03
$t\bar{t}V$	70 ± 20	36 ± 12	7 ± 3
$t\bar{t}H$	28 ± 4	31 ± 6	12 ± 3
Multijet	49 ± 23	1.7 ± 0.8	0.15 ± 0.06
Tot.Bkg.	11860 ± 260	2990 ± 210	270 ± 60
Data	11885	2922	318
$T\bar{T}$ (600)			
doublet	4.3 ± 1.2	94 ± 7	79 ± 18
singlet	2.3 ± 0.4	61 ± 7	36 ± 9



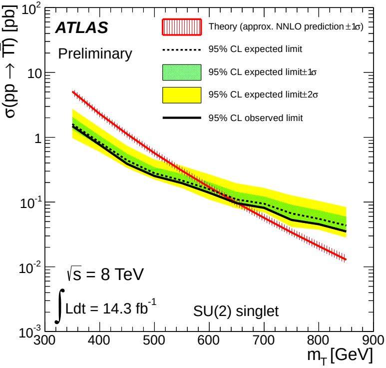
Benchmark results

Doublet



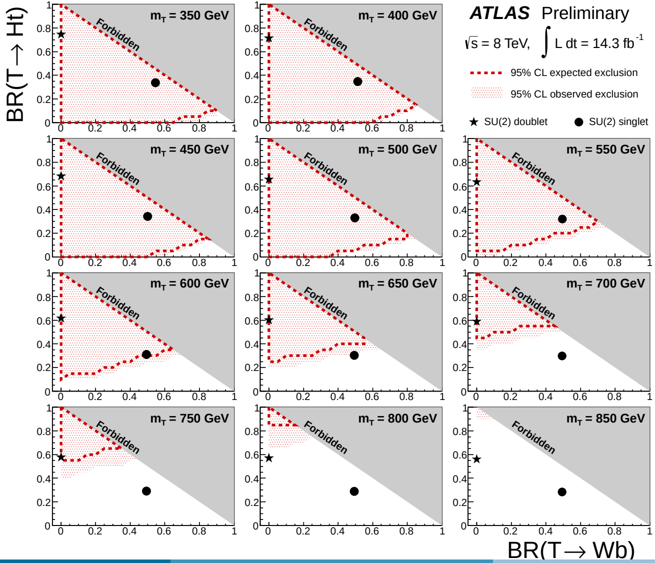
observed (expected) 95% CL limit
$m_T > 790\,(745)$ GeV

Singlet



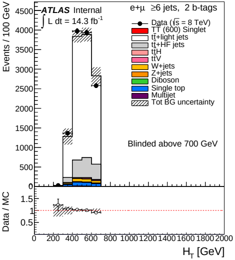
observed (expected) 95% CL limit
$m_T > 640\,(615)$ GeV

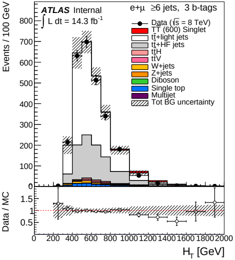
Model independent results

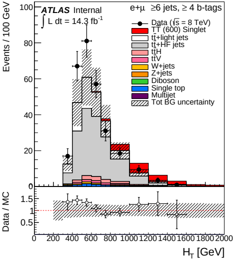


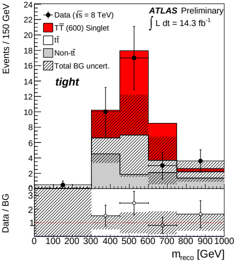
Outline

Combination of $T\bar{T} \to Wb + X$ and $T\bar{T} \to Ht + X$







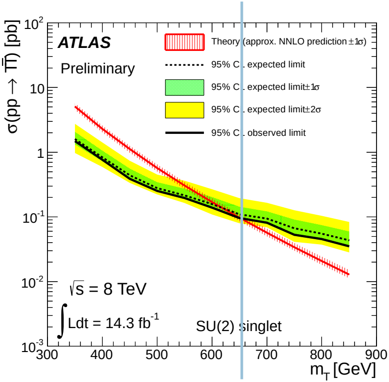


The search channels do not overlap

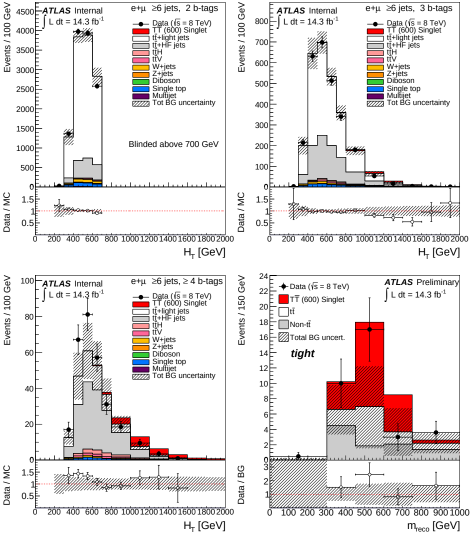
$\Downarrow$

can be combined in the statistical analysis (consistent syst unc treatment)

$T\bar{T} \to Ht + X$ only: 640 GeV



Combination of $T\bar{T} \to Wb + X$ and $T\bar{T} \to Ht + X$



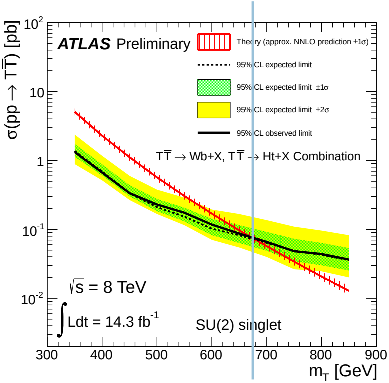
The search channels do not overlap

⇓

can be combined in the statistical analysis

(consistent syst unc treatment)

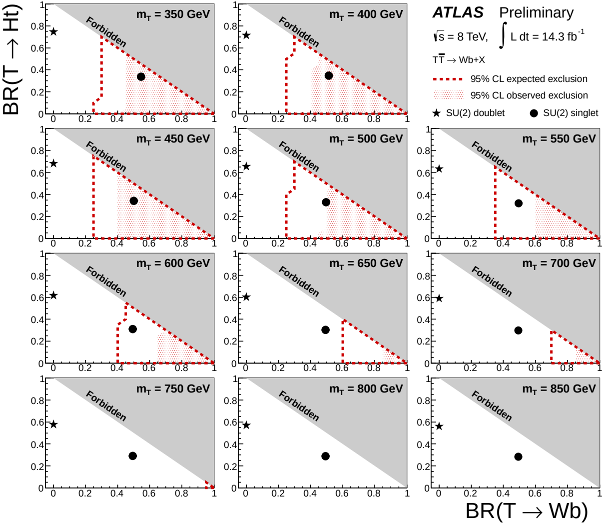
combination: 670 GeV



Combined results

Individual analyses probe different areas

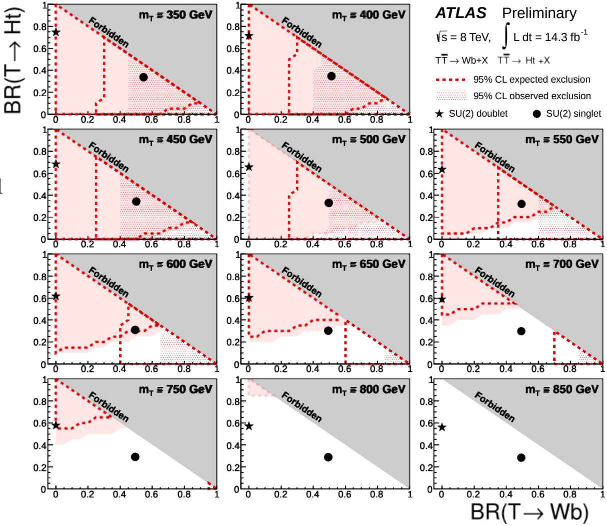
- $T\bar{T} \rightarrow Wb + X$ analysis alone very optimized for the bottom right corner



Combined results

Individual analyses probe different areas

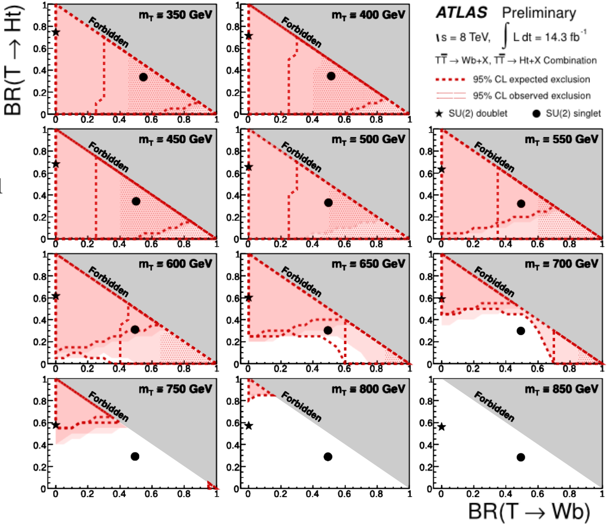
- $T\bar{T} \to Wb + X$ analysis alone very optimized for the bottom right corner
- $T\bar{T} \to Ht + X$ gives general good coverage, brings complete exclusion up to 450 GeV and almost excludes 650 GeV singlets



Combined results

Individual analyses probe different areas

- $T\bar{T} \to Wb + X$ analysis alone very optimized for the bottom right corner
- $T\bar{T} \to Ht + X$ gives general good coverage, brings complete exclusion up to 450 GeV and almost excludes 650 GeV singlets
- full combination reaches complete exclusion up to almost 600 GeV and excludes 650 GeV singlets

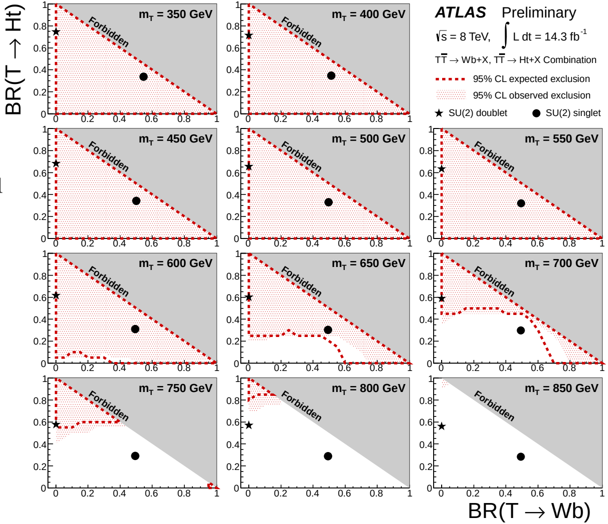


Combined results

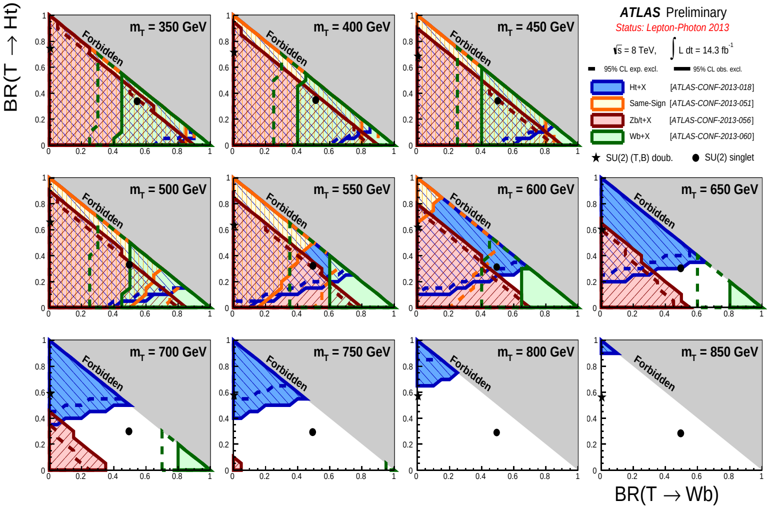
Individual analyses probe different areas

- $T\bar{T} \to Wb + X$ analysis alone very optimized for the bottom right corner
- $T\bar{T} \to Ht + X$ gives general good coverage, brings complete exclusion up to 450 GeV and almost excludes 650 GeV singlets
- full combination reaches complete exclusion up to almost 600 GeV and excludes 650 GeV singlets

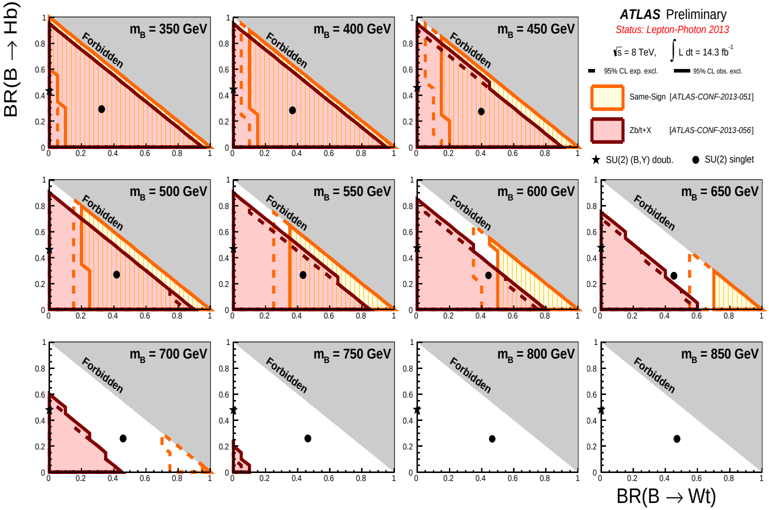
. . . but there's more from ATLAS Exotics!



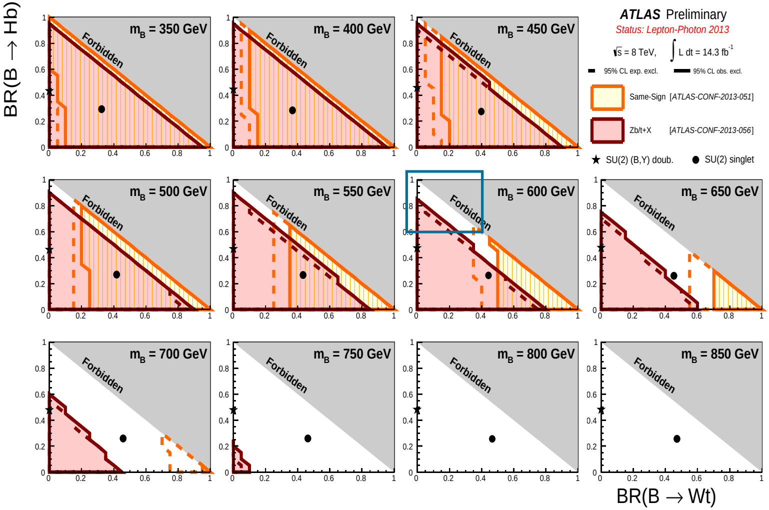
ATLAS “worst case scenario” coverage



ATLAS “worst case scenario” coverage

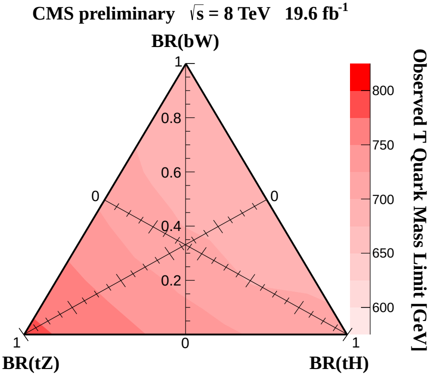


ATLAS “worst case scenario” coverage



Comparison to CMS results

Inclusive $T\bar{T}$ searches CMS-PAS-B2G-12-015 [7]



Scenario	Branching Fractions T→bW	T→tH	T→tZ	expected limit (GeV)	observed limit (GeV)
(0)	0.5	0.25	0.25	773	696
(1)	0.0	0.0	1.0	813	782
(2)	0.0	0.2	0.8	798	766
(3)	0.0	0.4	0.6	790	747
(4)	0.0	0.6	0.4	783	731
(5)	0.0	0.8	0.2	773	715
(6)	0.0	1.0	0.0	770	706
(7)	0.2	0.0	0.8	794	758
(8)	0.2	0.2	0.6	786	739
(9)	0.2	0.4	0.4	777	717
(10)	0.2	0.6	0.2	767	698
(11)	0.2	0.8	0.0	766	694
(12)	0.4	0.0	0.6	786	734
(13)	0.4	0.2	0.4	776	705
(14)	0.4	0.4	0.2	766	693
(15)	0.4	0.6	0.0	762	690
(16)	0.6	0.0	0.4	779	703
(17)	0.6	0.2	0.2	771	693
(18)	0.6	0.4	0.0	769	687
(19)	0.8	0.0	0.2	779	695
(20)	0.8	0.2	0.0	777	689
(21)	1.0	0.0	0.0	785	700

"doublet" 790 obs

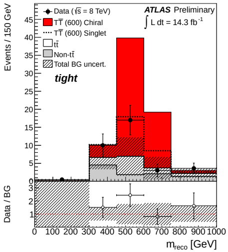
"singlet" 670 obs

"chiral" 740 obs

Outline

Conclusions and outlook

both searches are being updated with the full $20\ fb^{-1}$ statistics



↘ poor MC bkgs statistical population in the TIGHT channel

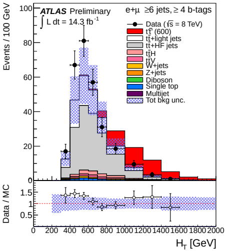
↗ larger MC samples available
↗ possible optimization of the H_T^{4j} cut
↗ explorable option: larger anti-k_t jets

Best up-to-date 95% CL obs limit on chiral T and vector-like Y (740 GeV)

↘ poor modeling of $t\bar{t}$+HF by ALPGEN
↘ b-tagging calibration sub-optimal for analyses with high-p_T objects

↗ $t\bar{t}$-based calibrations being developed
↗ potential high gain in sensitivity with profiling
↗ easily optimizable for a $B\bar{B} \to Hb + X$ analysis

Best up-to-date 95% CL obs limit on doublet T



Outlook

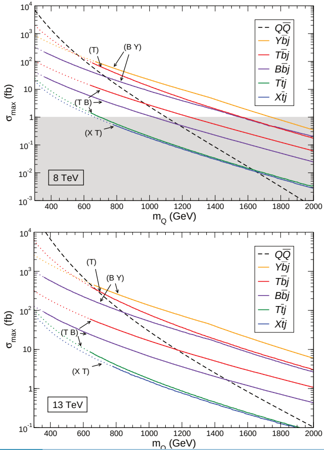
all four ATLAS searches are being updated
with the full 20 fb^{-1} statistics,
plus two new channels: $B\bar{B} \to Wt + X$ and $B\bar{B} \to Hb + X$

LHC Run-II:

↗ $\sqrt{s}$=14 TeV
↗ $\sim$ 100fb^{-1} in 3 years
↘ higher pile-up

To-do:

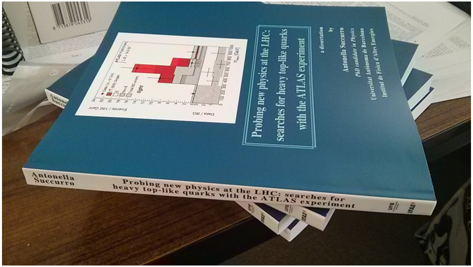
- continue on the road of full combination
- design searches for single production



plots from [8]

Thank you!

Thank you for your attention!



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Parton shower monte carlos.

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Presentation of search results: The CL(s) technique.
J.Phys., G28:2693–2704, 2002.

[4] ATLAS Collaboration.
Search for pair production of heavy top-like quarks decaying to a high-p_{T} W boson and a b quark in the lepton plus jets final state at $\sqrt{s} = 7$ TeV with the ATLAS detector.
Phys.Lett., B718:1284–1302, 2012.

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[5] ATLAS Collaboration.
Search for pair production of heavy top-like quarks decaying to a high-p_{T} W boson and a b quark in the lepton plus jets final state in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector.
ATLAS-CONF-2013-060, Jun 2013.

[6] ATLAS collaboration.
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ATLAS-CONF-2013-018, Mar 2013.

[7] Inclusive search for a vector-like T quark by CMS.
Technical Report CMS-PAS-B2G-12-015, CERN, Geneva, 2013.

[8] J.A. Aguilar-Saavedra, R. Benbrik, S. Heinemeyer, and M. Perez-Victoria.
A handbook of vector-like quarks: mixing and single production.
2013.

[9] M. Lamont.
The First Years of LHC Operation for Luminosity Production.
in Proceedings of 4th International Particle Accelerator Conference (IPAC 2013), 2013.

BACKUP SLIDES

LHC parameters

Parameter	designed	2010	2011	2012
Beam energy (TeV/c)	7	3.5	3.5	4
Beta function $\beta*$ (m)	0.55	2.0/3.5	1.5/1.0	0.6
Max. No. bunches/beam	2808	368	1380	1380
Max. No. protons/bunch	1.15×10^{11}	1.2×10^{11}	1.45×10^{11}	1.7×10^{11}
Bunch spacing (ns)	25	150	75/50	50
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.1×10^{32}	3.7×10^{33}	7.7×10^{33}
Emittance ε_n (μrad)	3.75	2.0	2.4	2.5
Max. $<\mu>$	19	4	17	37

Table: Overview of some parameters for the LHC performance comparing the design values with their time evolution during the first long run operation in 2010-2013 [9].

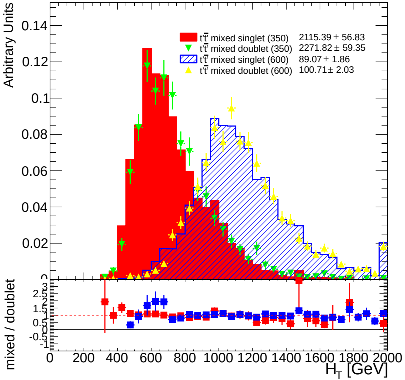
$T\bar{T} \rightarrow Wb + X$ 7 TeV vs 8 TeV

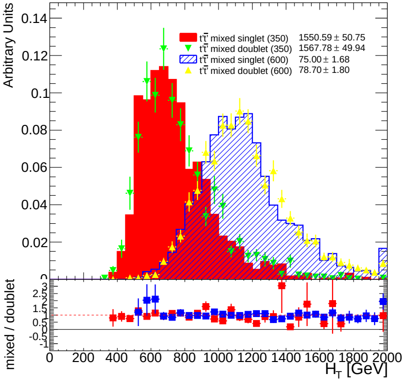
Selection		7 TeV	8 TeV
Preselection		One electron or muon$^{(+)}$	
		$E_{\mathrm{T}}^{\mathrm{miss}} > 35(20)$ GeV for electron (muon) channel	$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV
		$E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}} > 60$ GeV	
		≥ 3 jets for $W_{\mathrm{had}}^{\mathrm{type\ I}}$ ≥ 4 jets for $W_{\mathrm{had}}^{\mathrm{type\ II}}$	≥ 4 jets$^{(*)}$
		≥ 1 b-tagged jets$^{(**)}$	
			orthogonality cut reject events with $\geq$ 6 and ≥ 3 b-tagged je
LOOSE selection		Preselection ≥ 1 W_{had} candidates$^{(\mathrm{x})}$	
		$H_T^{4j} > 750$ GeV	$H_T^{4j} > 800$ GeV

Doublet vs singlet

MC simulated for singlet T with BR = 1/3 for every decay mode

- Mixing between SM quarks and T is left-handed for singlets, right-handed for doublets





Discrepancies in yields below 5% in "$\geq$4 b-TAGGED JETS"

Treatment of sys unc in combination

	Systematic uncertainty	$T\bar{T} \to Wb + X$ Status	Components	$T\bar{T} \to Ht + X$ Status	Components
Fully Correlated	Luminosity	N	1	N	1
	Lepton ID+reco+trigger	N	1	N	1
	Jet vertex fraction efficiency	SN	1	SN	1
	Jet energy resolution	SN	1	SN	1
	b-tagging efficiency	SN	9	SN	9
	c-tagging efficiency	SN	5	SN	5
	Light jet-tagging efficiency	SN	1	SN	1
	$t\bar{t}$ cross section	N	1	N	1
	$t\bar{t}V$ cross section	N	1	N	1
	$t\bar{t}H$ cross section	-	-	N	1
	Single top cross section	N	1	N	1
	Dibosons cross section	N	1	N	1
	W+jets normalization	N	5	-	-
	Z+jets normalization	N	1	-	-
	V+jets normalization	-	-	N	1
	Multijet normalization	-	-	N	1
Uncorrelated	$t\bar{t}$ modelling	SN	3	SN	3
	V+jets modelling	SN	1	-	-
	$t\bar{t}$+heavy-flavour fractions	-	-	N	1
Correlate JES w/ BASELINE	Jet energy scale	SN	1	SN	8