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

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Bellaterra, 28th of February, 2014

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

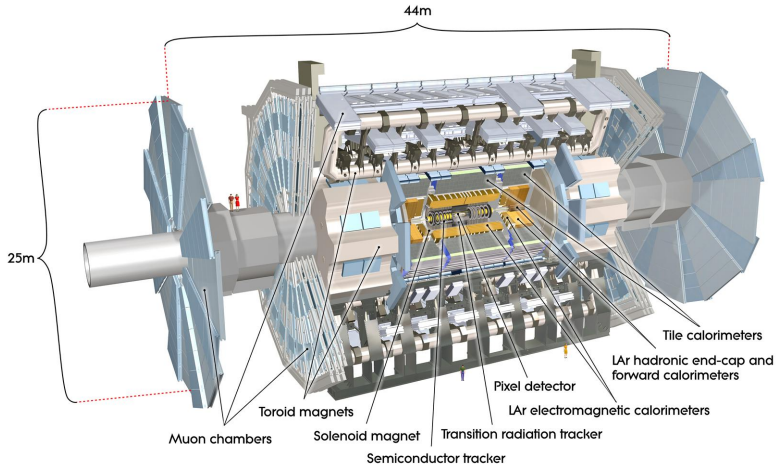| Parameter	designed	2010	2011	2012
Beam energy (TeV/c)	7	3.5	3.5	4
Beta function $\beta*$ (m)	0.55	2.0/3.5	1.5/1.0	0.6
Max. No. bunches/beam	2808	368	1380	1380
Max. No. protons/bunch	1.15×10^{11}	1.2×10^{11}	1.45×10^{11}	1.7×10^{11}
Bunch spacing (ns)	25	150	75/50	50
Peak luminosity (cm^{-2}s^{-1})	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

▸ p (proton)   ▸ ion   ▸ neutrons   ▸ p̄ (antiproton)   →+→ proton/antiproton conversion   ▸ neutrinos   ▸ electron

LHC Large Hadron Collider   SPS Super Proton Synchrotron   PS Proton Synchrotron
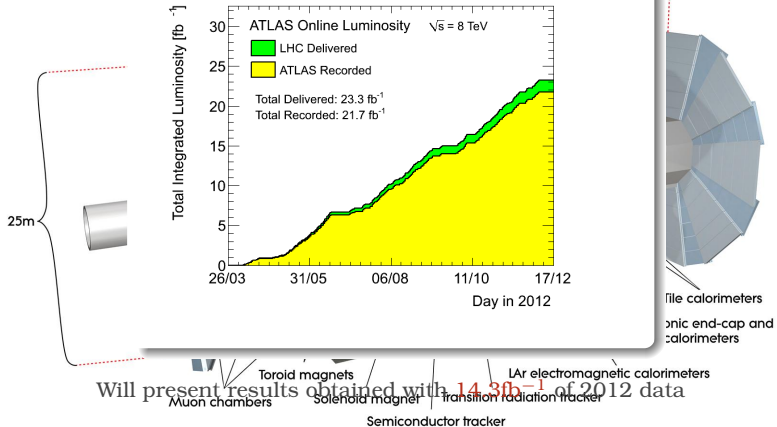
AD Antiproton Decelerator   CTF-3 Clic Test Facility   CNGS Cern Neutrinos to Gran Sasso   ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring   LINAC LINear ACcelerator   n-ToF Neutrons Time Of Flight

The ATLAS Detector

44m

25m

Tile calorimeters

LAr hadronic end-cap and forward calorimeters

Pixel detector

LAr electromagnetic calorimeters

Transition radiation tracker

Semiconductor tracker

Solenoid magnet

Toroid magnets

Muon chambers

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

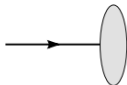# Outline

Modelling of hadron collisions

want to do physics at hadron colliders?
need a good understanding of incoming hadrons
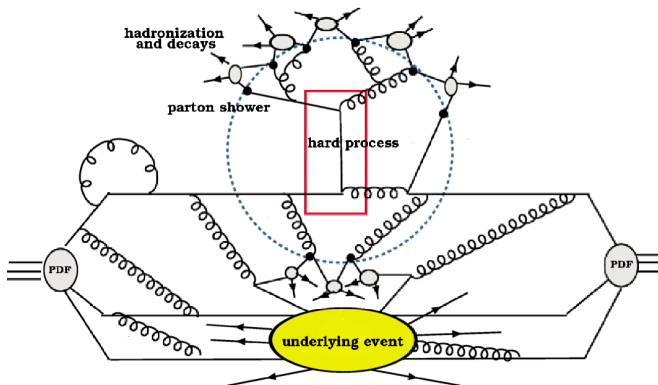
Modelling of hadron collisions
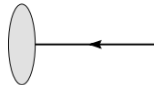
Drawings from [1]

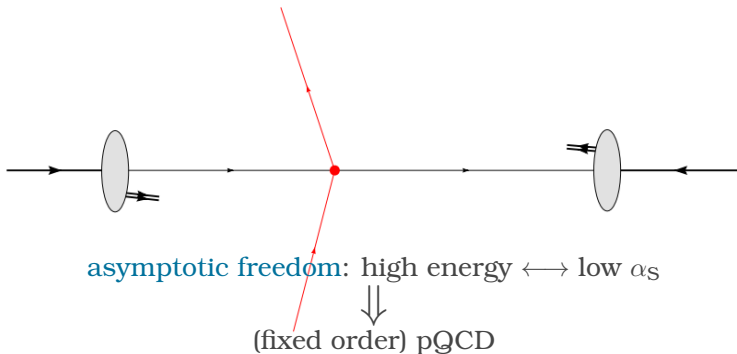$E(p_1) = 4$ TeV $\qquad\qquad\qquad E(p_2) = 4$ TeV

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

$\Downarrow$
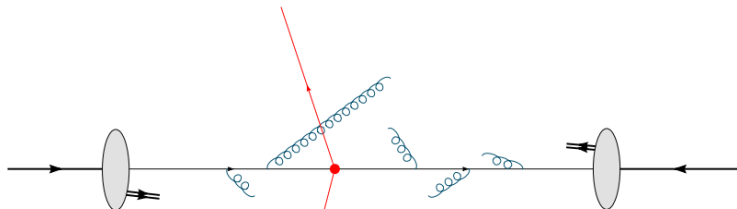
higher-order corrections

Parton showering

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

$\Downarrow$

higher-order corrections
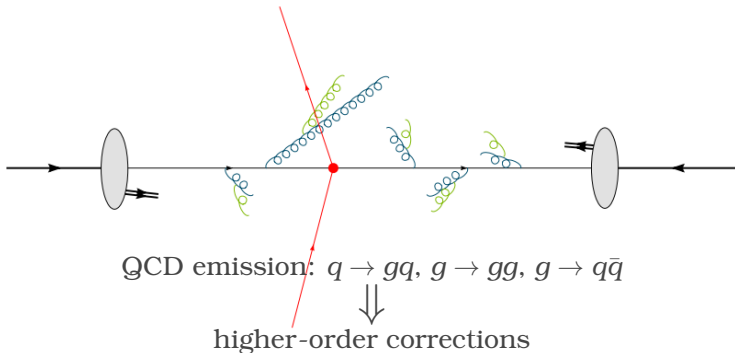
Hadronization
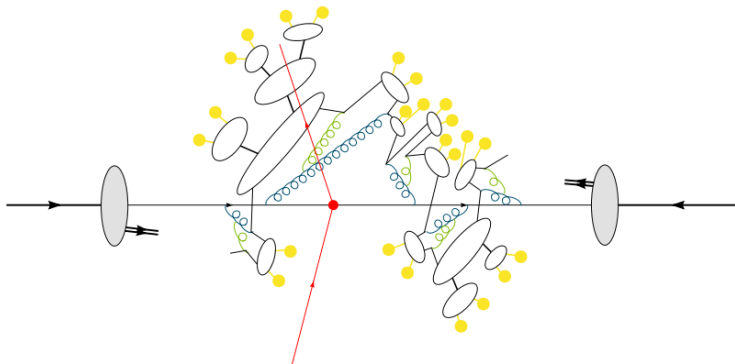
Final particle decays
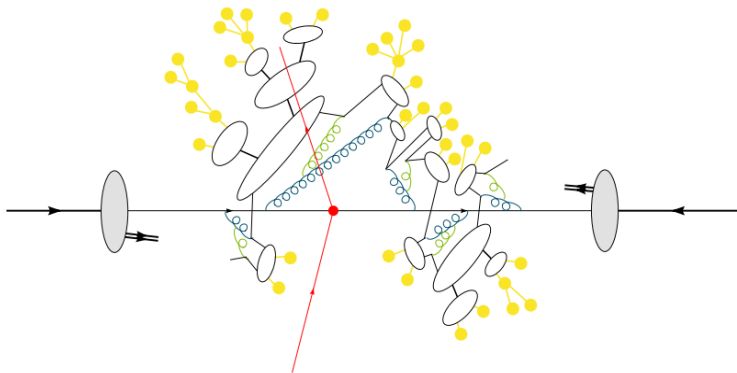
Underlying event simulation
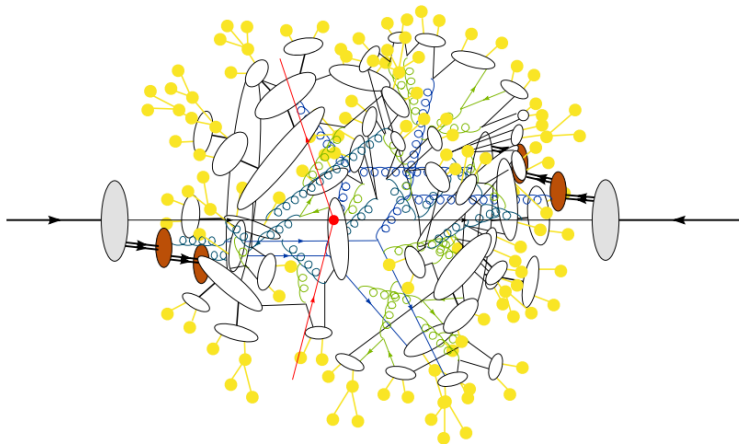
Outline

Physics objects puzzle
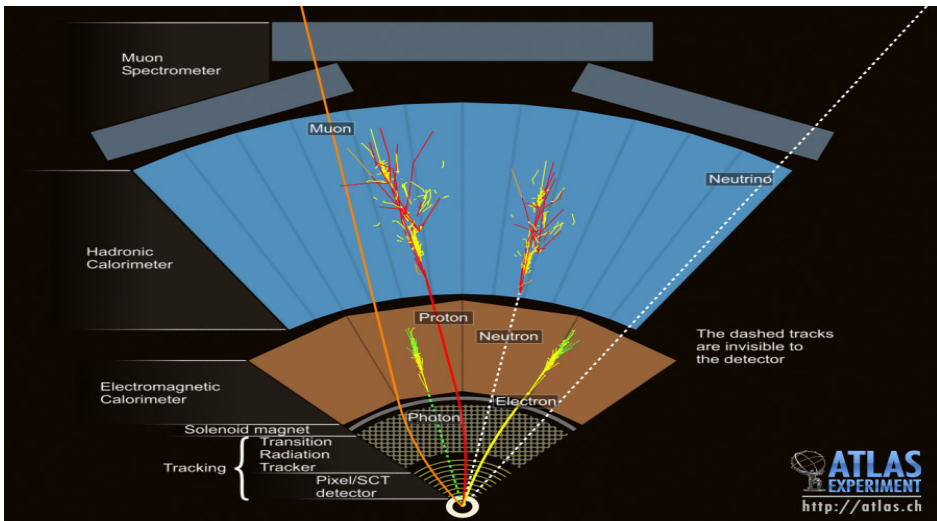
One lepton

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
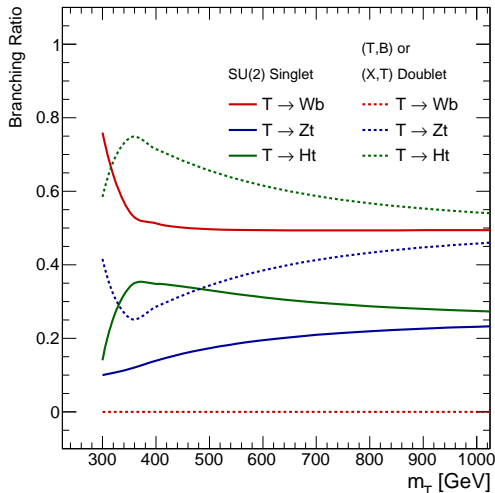
BR($T \to Wb$)

Model Independent Strategy

- Build a 2-dim plane to scan model mixing

Model Independent Strategy
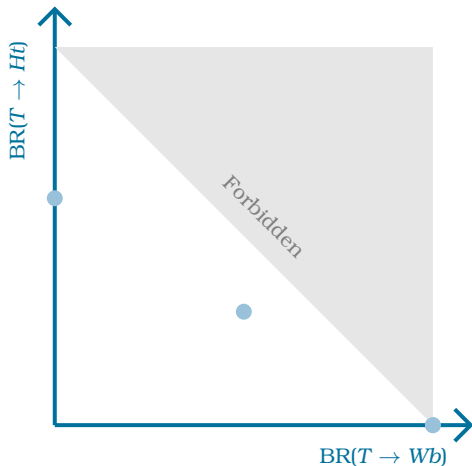
- Build a 2-dim plane to scan model mixing
- Sum of BRs is $1^{(a)}$

[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
- Sum of BRs is 1[a]
- Different analyses are sensitive to different areas

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

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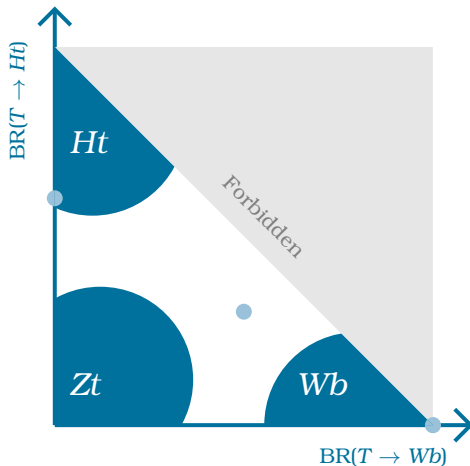
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Model Independent Strategy

- Build a 2-dim plane to scan model mixing
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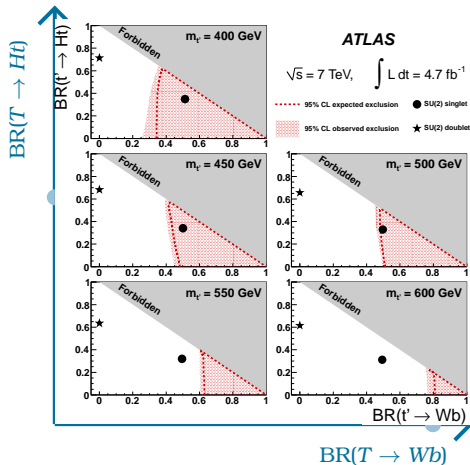
Model Independent Strategy

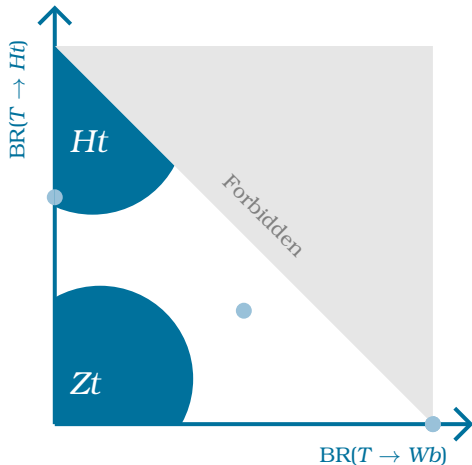

- Build a 2-dim plane to scan model mixing
- Sum of BRs is $1^{(a)}$
- Different analyses are sensitive to different areas
- Set exclusion using CL_s technique [2, 3]
- First published results at 7 TeV *Phys.Lett.* **B718** (2012) [4]

$^{(a)}$BR($T \to Zt$) = 1 - BR($T \to Ht$) - BR($T \to Wb$)

Preselection

Two searches using common analysis framework:

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

ATLAS-CONF-2013-060 [5]   ATLAS-CONF-2013-018 [6]

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

orthogonality requirements:

▶ $T\bar{T} \to Wb + X$: reject events with ≥ 6 jets and ≥ 3 b-jets

▶ $T\bar{T} \to Ht + X$: reject events in the low b-tags channel with $H_T < 700$ GeV

Background and signal modelling

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

	≥ 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

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

- ▶ QCD multi-jet events have high cross-section
- ▶ Data-drive estimation
- ▶ Matrix-method
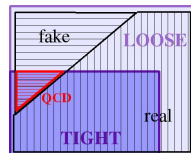
$$N_{\text{fake}}^{\text{tight}} = \frac{\epsilon_{\text{fake}}}{\epsilon_{\text{real}} - \epsilon_{\text{fake}}}(N^{\text{loose}}\epsilon_{\text{real}} - N^{\text{tight}})$$

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▶ 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

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

Background and signal modelling

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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

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

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

Background and signal modelling

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

▶ $t\bar{t}$ produced in association with a W or Z boson generated with `MADGRAPH`+`PYTHIA`

▶ $m_t = 172.5$ GeV

▶ NLO theoretical cross section

Background and signal modelling

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

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Multi-jet	6264 ± 74
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(*) $H_T^{4j} = p_T(l) + E_T^{\text{miss}} + \sum_{j=1}^{4} p_T(j)$

- ▶ $t\bar{t}$ 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

Background and signal modelling

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

- ▶ $t\bar{t}$ 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
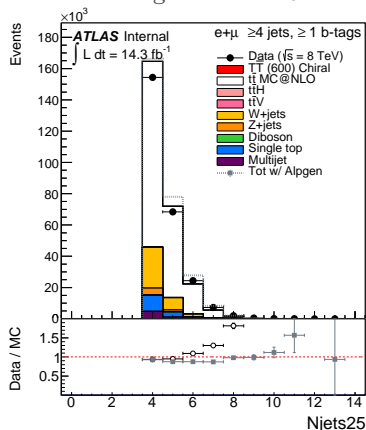- ▶ NNLO theoretical cross section

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

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

Background and signal modelling

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

$t\bar{t} \to WbWb$

8 TeV !

8 TeV !
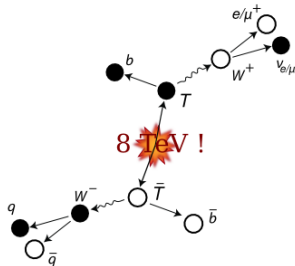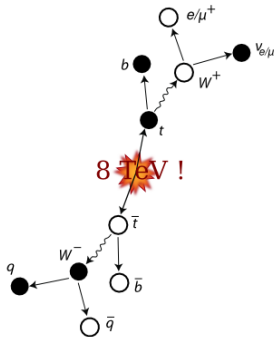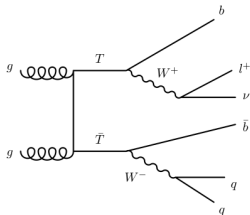
different boosted kinematics

$\Downarrow$

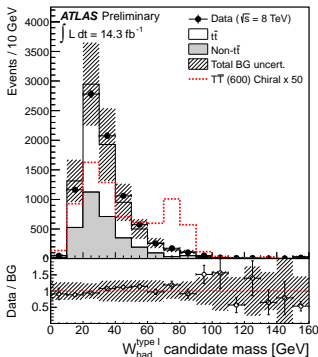reconstruct the W boson from hadronic decay

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

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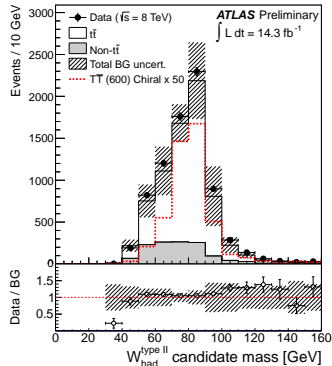
W boson reconstruction

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

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

one jet
$p_T > 250$ GeV
$60 < M < 120$ GeV

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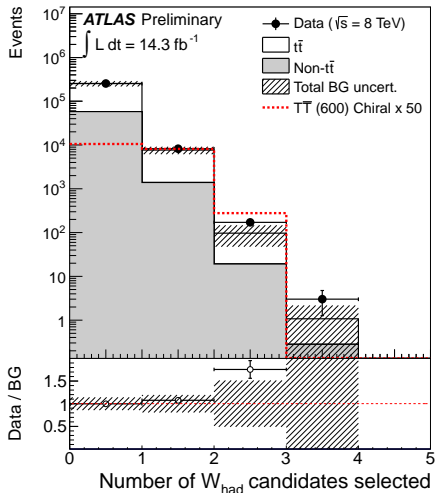$\Delta R(j,j) < 0.8$
$p_T > 200$ GeV
$60 < M < 120$ GeV

W_{lep} reconstructed using lepton and "neutrino":
p_X, p_Y from E_T^{miss}, p_Z from $M_W^2 = (P_l + P_\nu)^2$

Event selection

	LOOSE selection	
SR0	Preselection	
SR1	+	$\geq 1\ W_{\text{had}}$ 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	+	$\min \Delta R(W_{\text{had}}, b) > 1.4$

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	+	$\min \Delta R(W_{\mathrm{had}}, b) > 1.4$

Event selection

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

Comparison data vs prediction

Check agreement between data and
background prediction
⇓
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 ± 0.25	
Total bkg.	241.90 ± 14.70	$^{+53.57}_{-55.95}$	
Data	250		
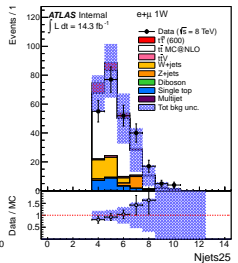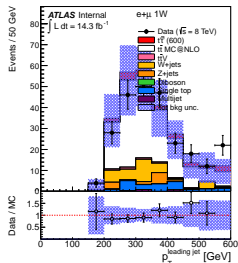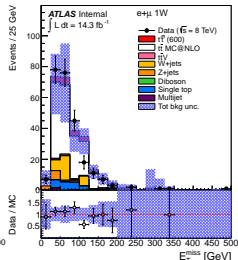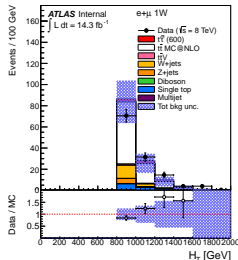
Yields in signal region

	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
$T\bar{T}(600\ \mathrm{GeV})$		
Chiral t'	88 ± 10	54 ± 7
T Singlet	41 ± 4	20.3 ± 2.2

merged (bracket spanning $t\bar{t}$ through Dibosons)

Discriminating variable $\Rightarrow$ *T reconstructed mass*
$$\Downarrow$$
Pair b-jets and W boson candidates in order to get
$$\min\Delta(M_{\mathrm{lep}}, M_{\mathrm{had}})$$

Reconstructed mass

	LOOSE selection	
SR0	Preselection	
SR1	+	$\geq 1\ W_{\text{had}}$ 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	+	$\min \Delta R(W_{\text{had}}, b) > 1.4$

Reconstructed mass

	Loose selection	
SR0	Preselection	
SR1	+	$\geq 1\ W_{\text{had}}$ candidates
SR2	+	$H_T^{4j} > 800$ GeV
SR3	+	$p_{\text{T}}(b_1) > 160$ GeV
SR4	+	$p_{\text{T}}(b_2) > 80$ GeV
SR5	+	$\Delta R(\ell, \nu) < 1.2$

	Tight selection	
SR5	Loose selection	
SR6	+	$\min \Delta R(\ell, b) > 1.4$
SR7	+	$\min \Delta R(W_{\text{had}}, b) > 1.4$

Reconstructed mass

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	TIGHT selection	
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SR7	+	$\min \Delta R(W_{\mathrm{had}}, b) > 1.4$

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	–
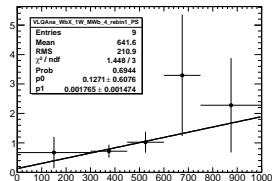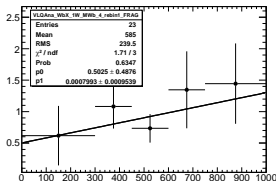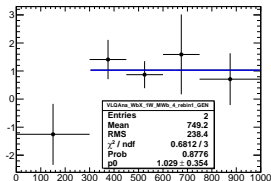
Results
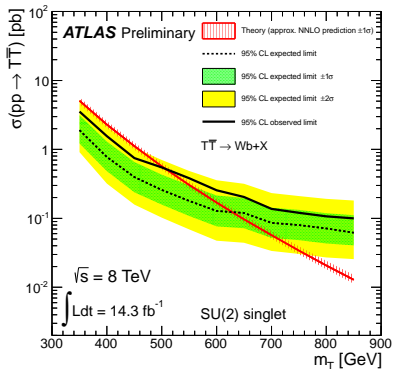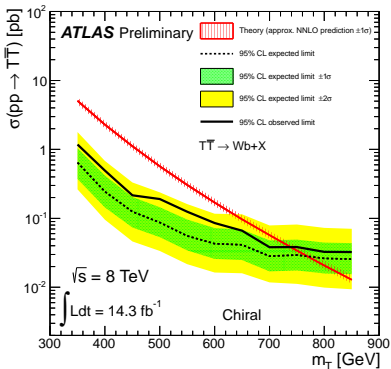
Results
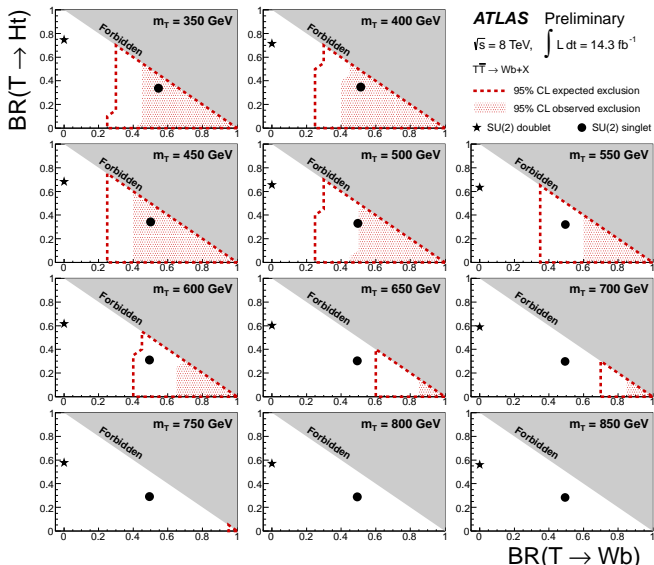
Outline

Strategy

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

$T \to Ht \nearrow bbWb \to bbbl\nu$ $\quad + \bar{T} \to Wb/Zt/Ht$
$\searrow WWWb \to qqqqbl\nu$
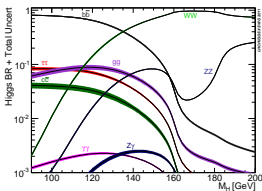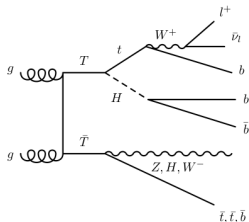
as a minimum 6 total jets in the event ($T\bar{T} \to HtWb$)

$$\Downarrow$$

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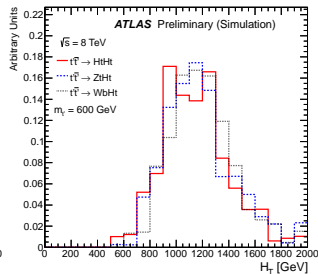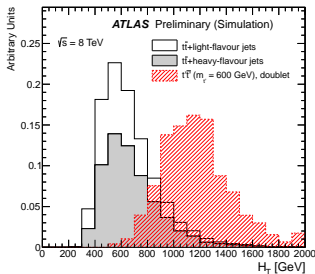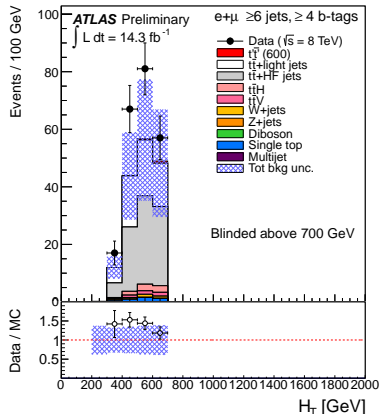

≥ 6 jets, ≥ 4 b-jets

Event selection

maximize signal acceptance

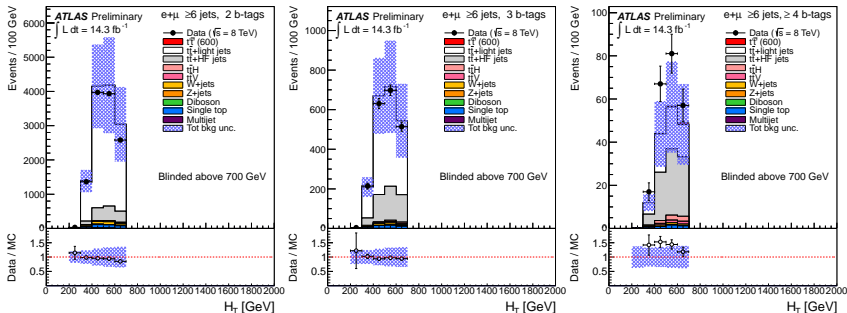| "2 b-TAGGED JETS"	≥ 6 jets $=2$ b-tagged jets orthogonality cut: $H_T < 700$ GeV
"3 b-TAGGED JETS"	≥ 6 jets $=3$ b-tagged jets
"≥ 4 b-TAGGED JETS"	≥ 6 jets ≥ 4 b-tagged jets

bad modeling $\Rightarrow$ Simultaneous fit to data of H_T variable

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

. . . after

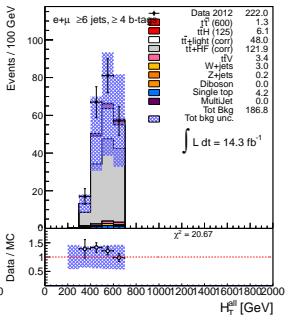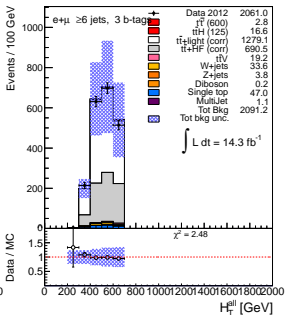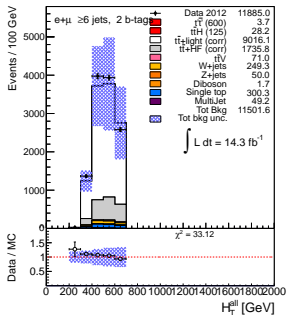Maximum yields discrepancy below 5%

Scale of $t\bar{t}$ components

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

final
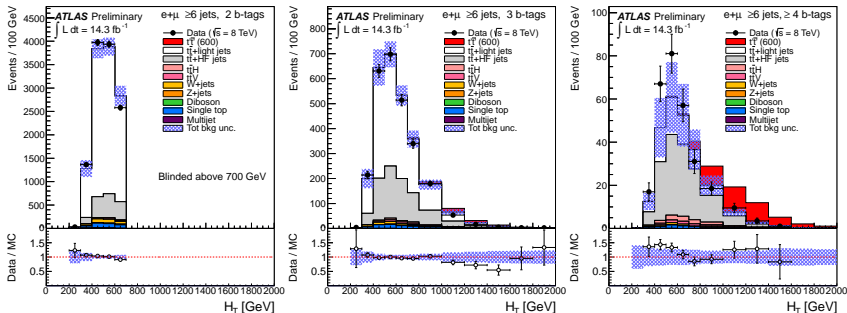
Maximum yields discrepancy below 5%

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

Yields in signal regions

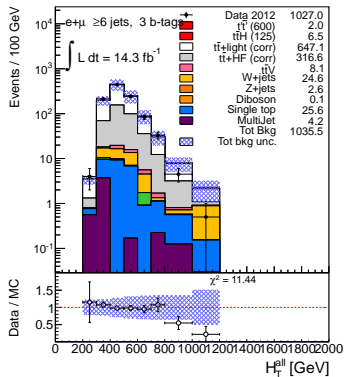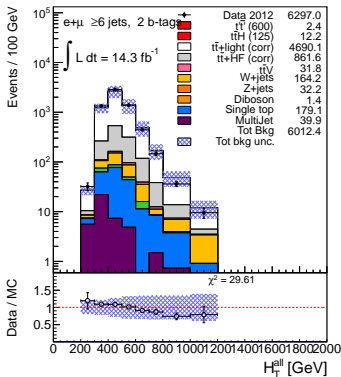|	2 b-tags	3 b-tags	$\geq$ 4 b-tags
$t\bar{t}$+HF	1500 ± 900	900 ± 400	170 ± 70
$t\bar{t}$+LF	9600 ± 1000	1900 ± 350	75 ± 22
W+jets	250 ± 130	50 ± 30	5 ± 3
Z+jets	50 ± 40	9 ± 6	0.5 ± 0.9
Single top	300 ± 70	75 ± 18	7 ± 3
Diboson	1.7 ± 0.6	0.3 ± 0.1	0.03 ± 0.03
$t\bar{t}V$	70 ± 20	36 ± 12	7 ± 3
$t\bar{t}H$	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
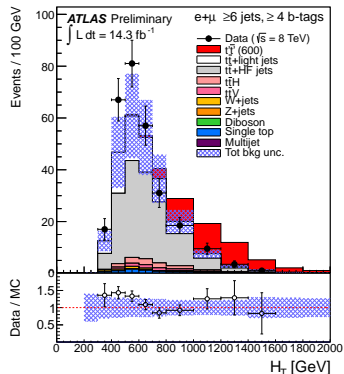
Introduce the scaling factors as nuisance parameters

Most relevant systematic uncertainties

. . . before fitting the nuisance parameters

	$T\bar{T}$	$t\bar{t}$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	–	–	–	–	–	–
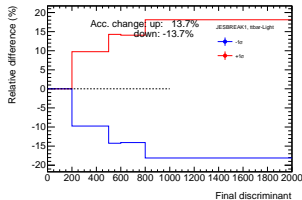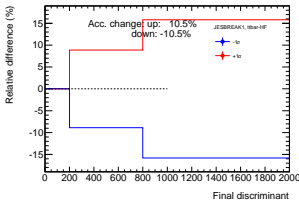
Results
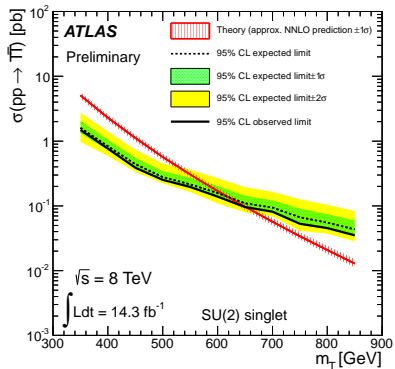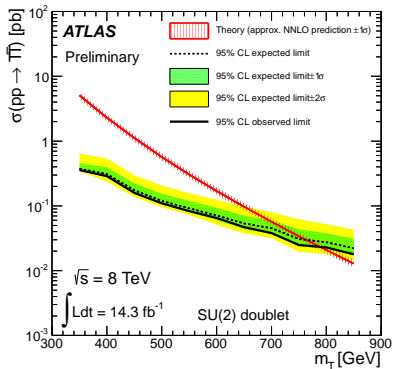
Results

Outline

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)

$T\bar{T} \to Ht + X$ only: 640 GeV
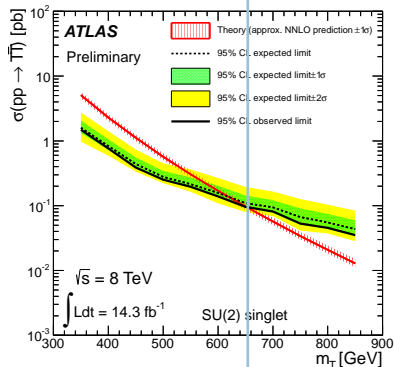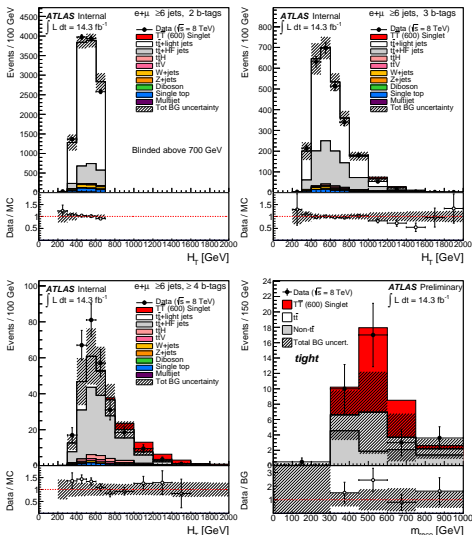
Combination of $T\bar{T} \rightarrow Wb + X$ and $T\bar{T} \rightarrow Ht + X$

The search channels do not overlap
⇓
can be combined in the statistical analysis
(consistent syst unc treatment)

combination: 670 GeV
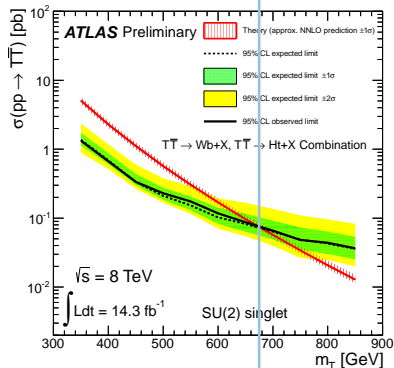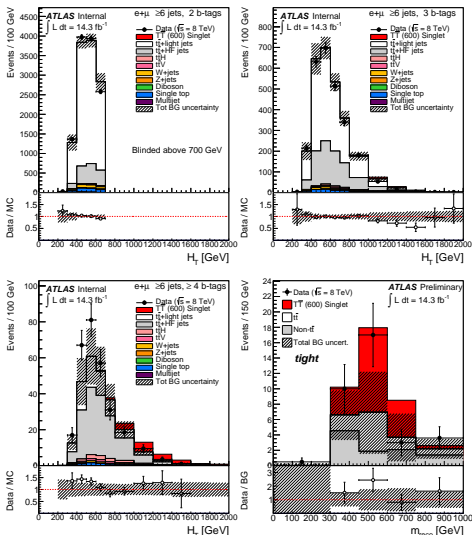
Combined results

Individual analyses probe different areas

▶ $T\bar{T} \to Wb + X$ 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

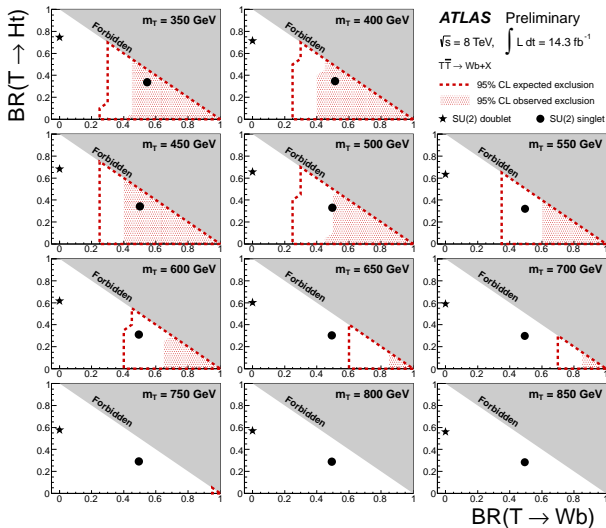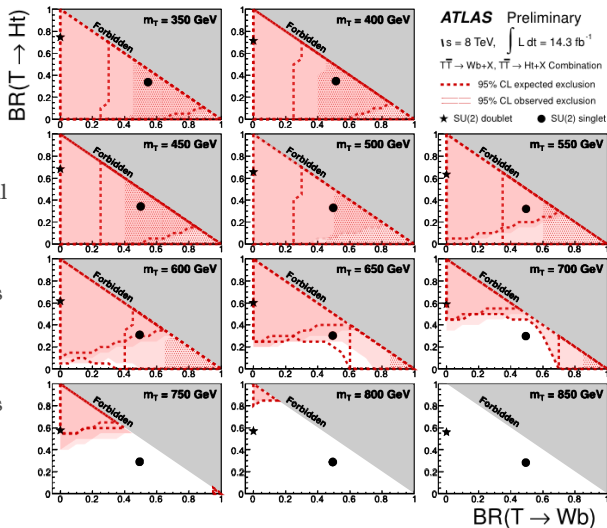- $T\bar{T} \to Wb + X$ analysis alone very optimized for the bottom right corner

- $T\bar{T} \to Ht + X$ 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!
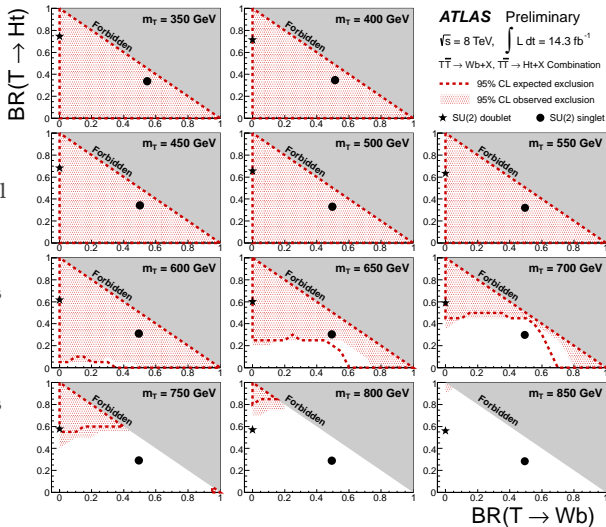
ATLAS Preliminary

$\sqrt{s}$ = 8 TeV, $\int$ L dt = 14.3 fb^{-1}

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

----- 95% CL expected exclusion

95% CL observed exclusion

★ SU(2) doublet ● SU(2) singlet

BR(T → Ht) [y-axis] BR(T → Wb) [x-axis]

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

ATLAS "worst case scenario" coverage
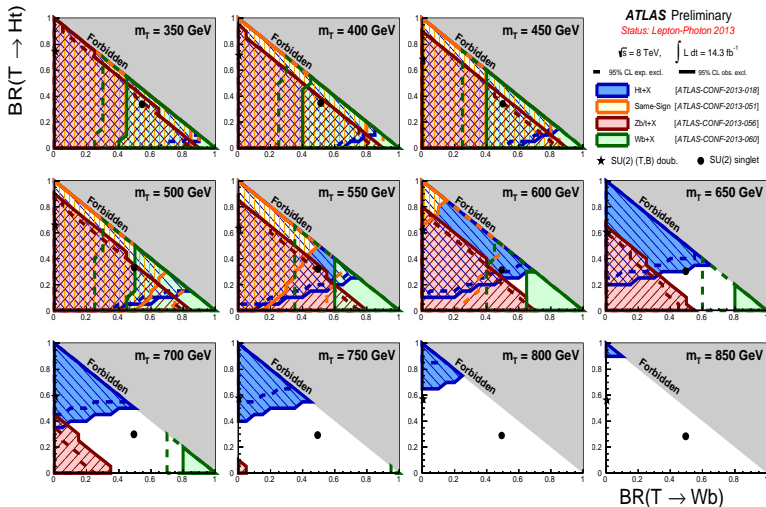
ATLAS "worst case scenario" coverage
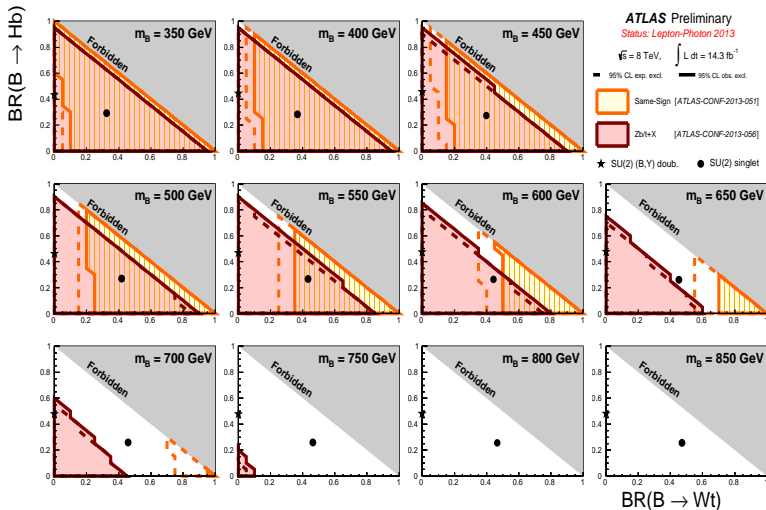
ATLAS "worst case scenario" coverage

Comparison to CMS results

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

CMS preliminary $\sqrt{s} = 8$ **TeV** **19.6 fb⁻¹**

BR(bW)
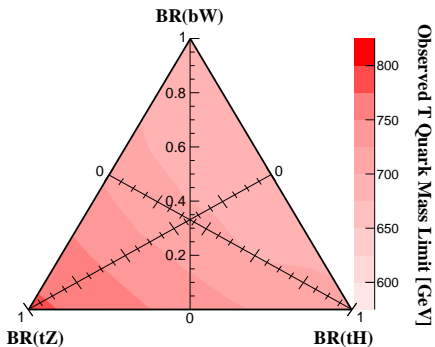
"doublet"
790 obs

"singlet"
670 obs

"chiral"
740 obs

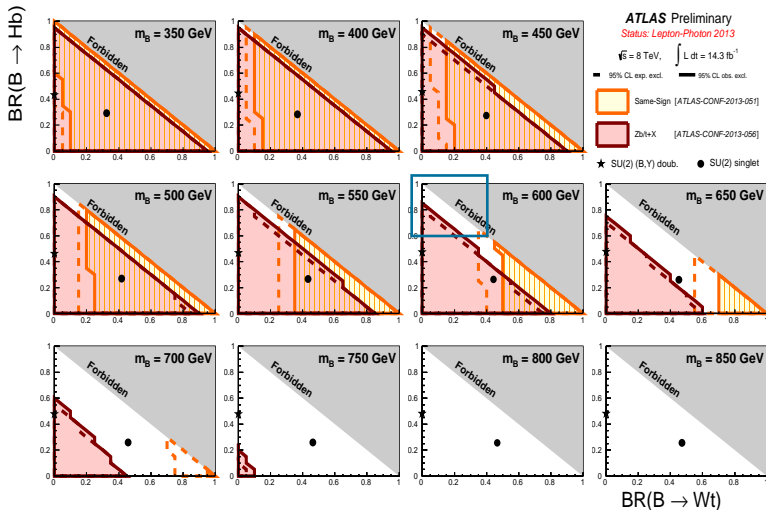| Scenario	Branching Fractions			expected	observed
	T→bW	T→tH	T→tZ	limit (GeV)	limit (GeV)
(0)	0.5	0.25	0.25	773	696
(1)	0.0	0.0	1.0	813	782
(2)	0.0	0.2	0.8	798	766
(3)	0.0	0.4	0.6	790	747
(4)	0.0	0.6	0.4	783	731
(5)	0.0	0.8	0.2	773	715
(6)	0.0	1.0	0.0	770	706
(7)	0.2	0.0	0.8	794	758
(8)	0.2	0.2	0.6	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

Outline

Conclusions and outlook

both searches are being updated with the full 20 fb^{-1} statistics
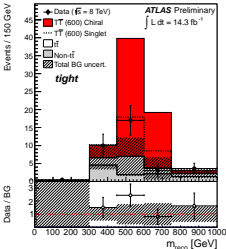
↘ poor MC bkgs statistical population in the TIGHT channel

↗ 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
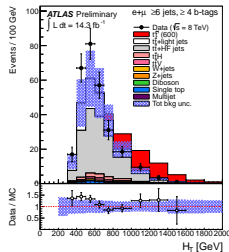
Outlook

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]
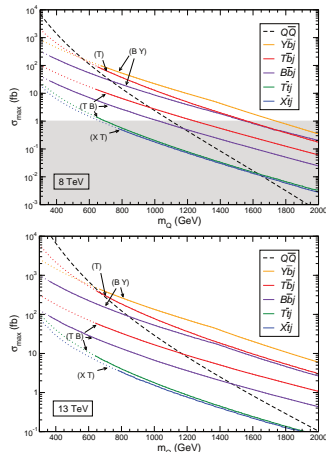
Thank you!

Thank you for your attention!
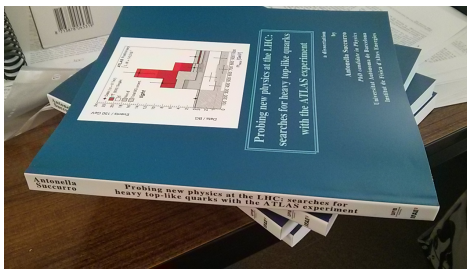
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Presentation of search results: The CL(s) technique.
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Search for pair production of heavy top-like quarks decaying to a high-p_T W boson and a b quark in the lepton plus jets final state at $\sqrt{s} = 7$ TeV with the ATLAS detector.
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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.
Search for heavy top-like quarks decaying to a higgs boson and a top quark in the lepton plus jets final state in pp collisions at $\sqrt{s} = 8$ tev with the atlas detector.
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].

$T\bar{T} \to Wb + X$ 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 ≥ 6 and ≥ 3 b-tagged je
LOOSE selection	Preselection	
	≥ 1 W_had candidates[x]	
	$H_T^{4j} > 750$ GeV	$H_T^{4j} > 800$ GeV

Treatment of sys unc in combination

	Systematic uncertainty	$T\bar{T} \to Wb + X$		$T\bar{T} \to Ht + X$	
		Status	Components	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