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

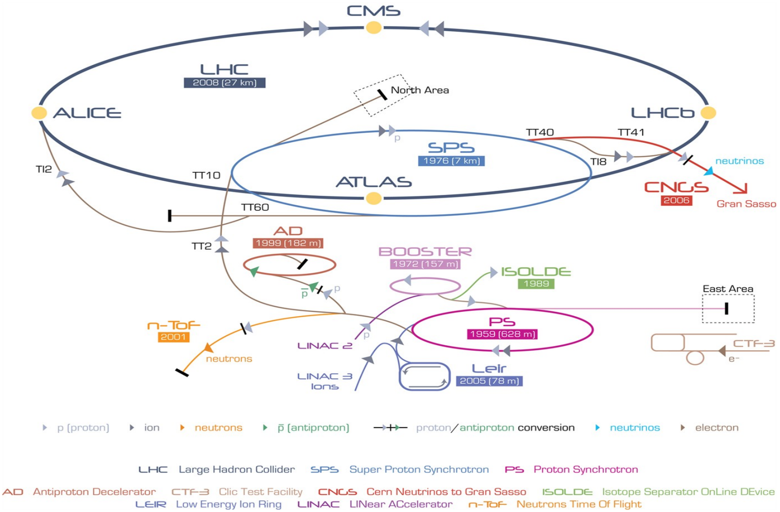
- **Why?** bother with “new physics”
- **Where?** is all happening
- **What?** are we looking at
- **How?**

Outline

Standard Model as an effective theory

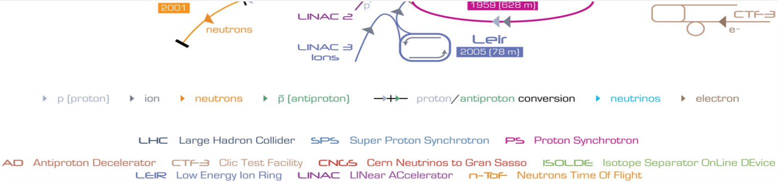
Outline

The LHC complex

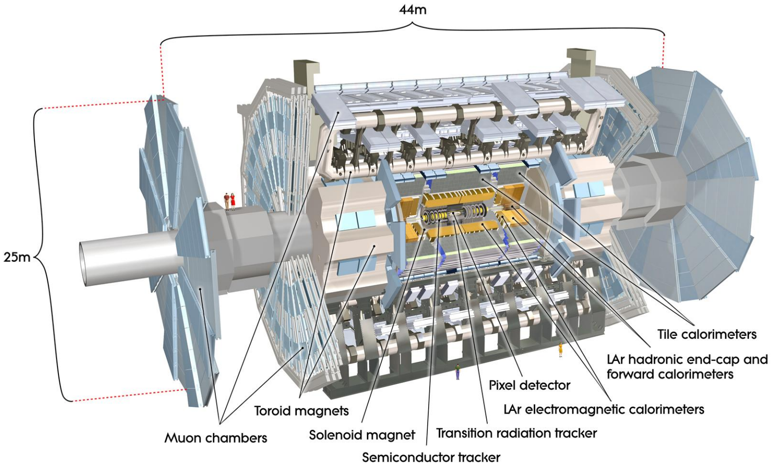


The LHC complex

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

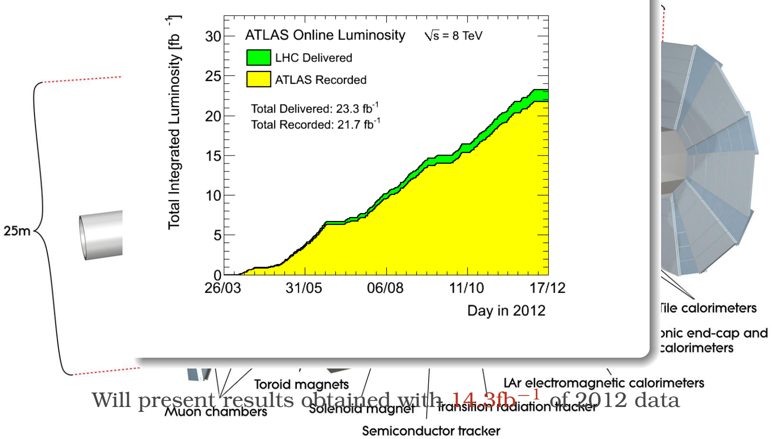


The ATLAS Detector



The ATLAS Detector

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

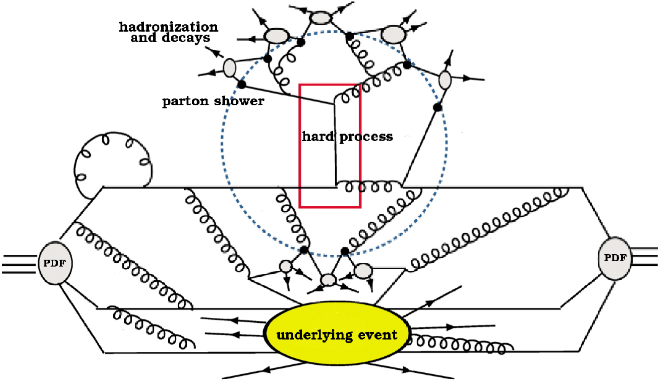


Will present results obtained with 14.3fb^{-1} of 2012 data

Outline

Modelling of hadron collisions

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

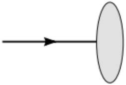


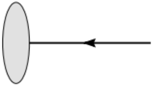
Modelling of hadron collisions

Drawings from [1]

$E(p_1) = 4$ TeV

$E(p_2) = 4$ TeV



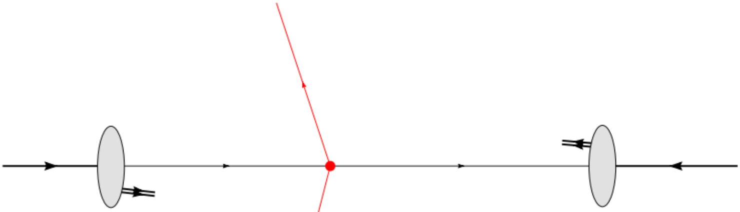


Quarks are distributed according to PDFs inside the proton

$\Downarrow$

intial energy unknown

Hard scattering of two partons

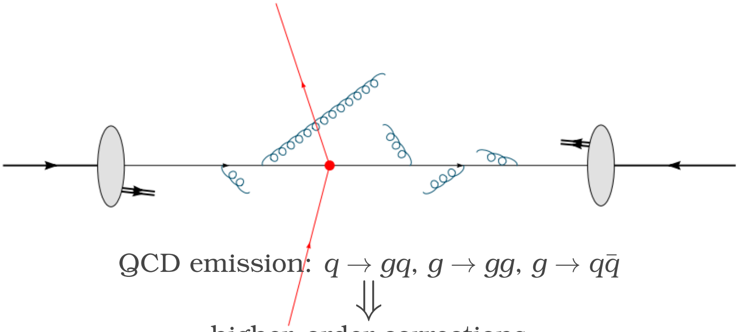


asymptotic freedom: high energy $\longleftrightarrow$ low α_S

$$\Downarrow$$

(fixed order) pQCD

Parton showering

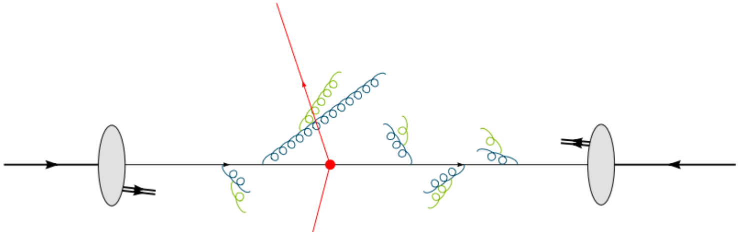


QCD emission: $q \rightarrow gq$, $g \rightarrow gg$, $g \rightarrow q\bar{q}$

$\Downarrow$

higher-order corrections

Parton showering

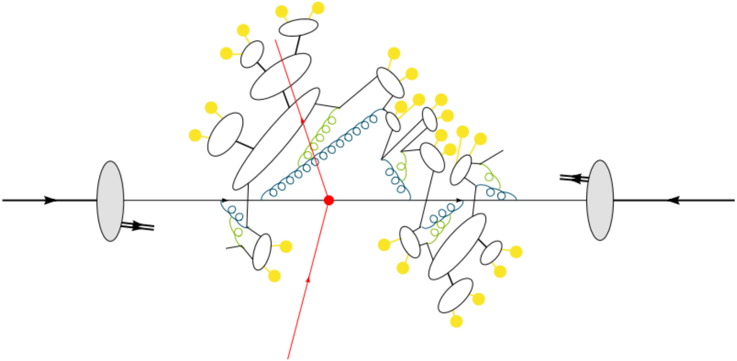


QCD emission: $q \to gq$, $g \to gg$, $g \to q\bar{q}$

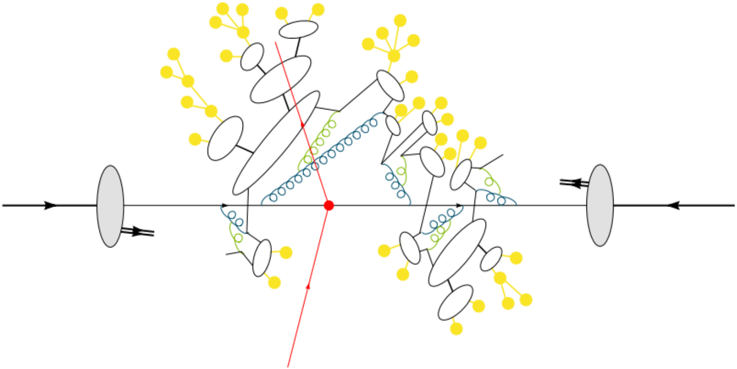
$\Downarrow$

higher-order corrections

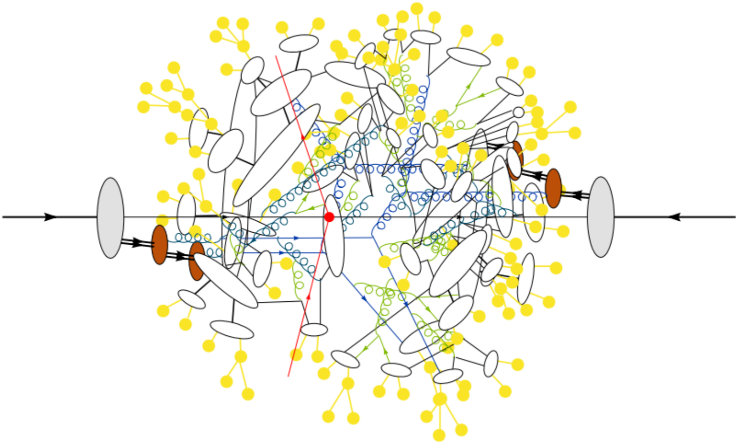
Hadronization



Final particle decays

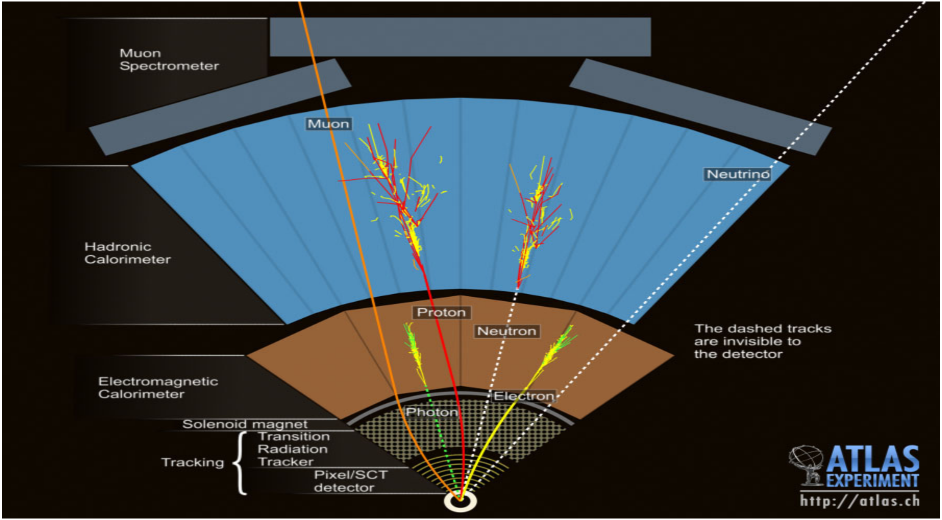


Underlying event simulation



Outline

Physics objects puzzle



One lepton

Many jets

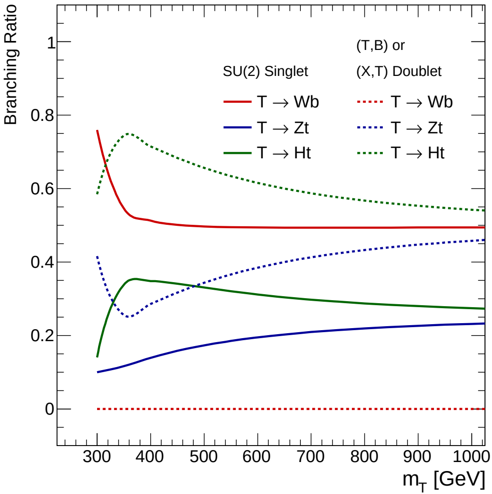
Missing transverse energy

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

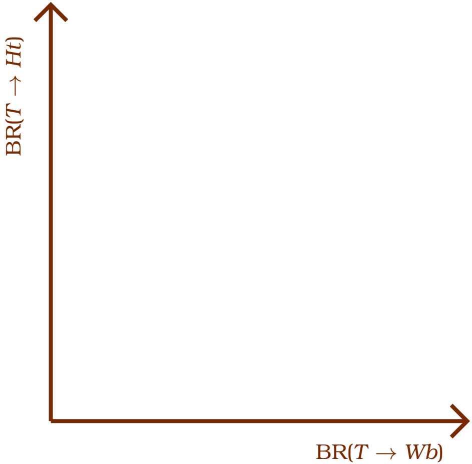


Model Independent Strategy

- Build a 2-dim plane to scan model mixing

BR($T \rightarrow Wb$)

Model Independent Strategy



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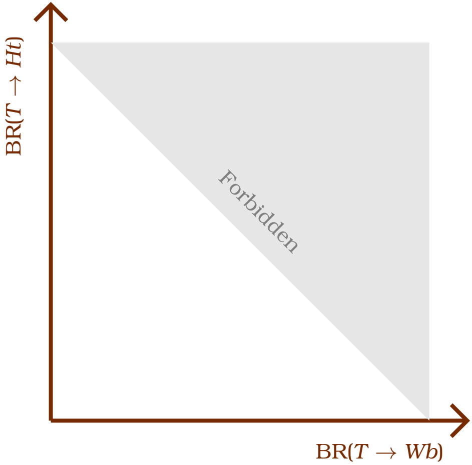
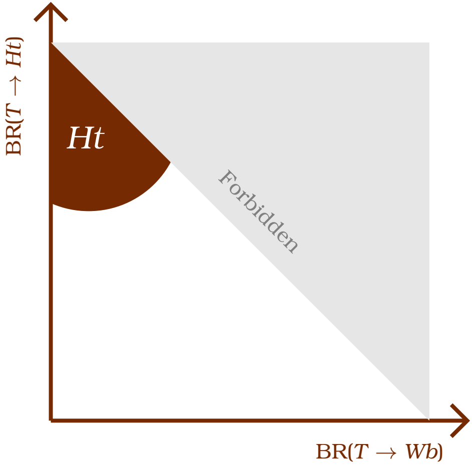
Model Independent Strategy



- 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

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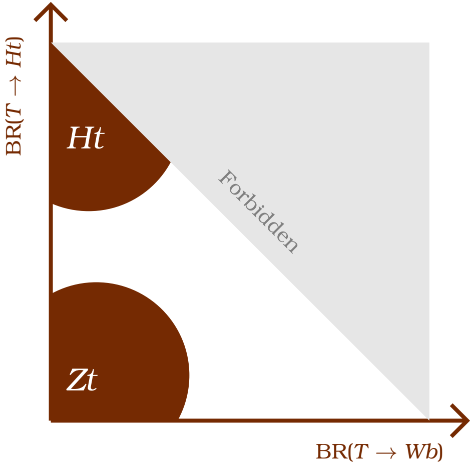
Model Independent Strategy



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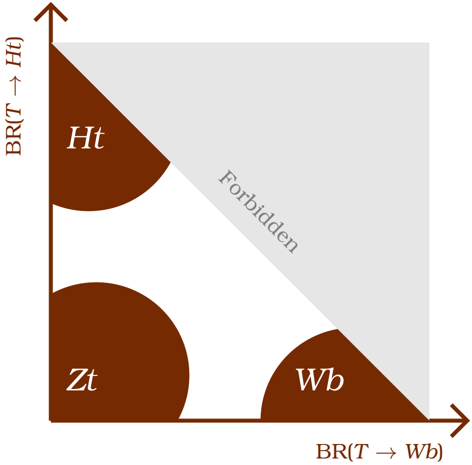

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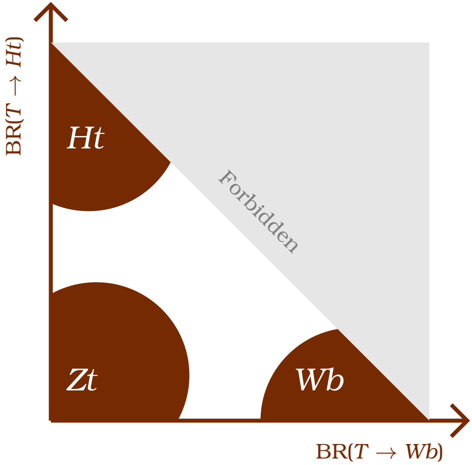

- Build a 2-dim plane to scan model mixing
- Sum of BRs is 1[(a)]
- Different analyses are sensitive to different areas
- Set exclusion using CL_s technique [2, 3]

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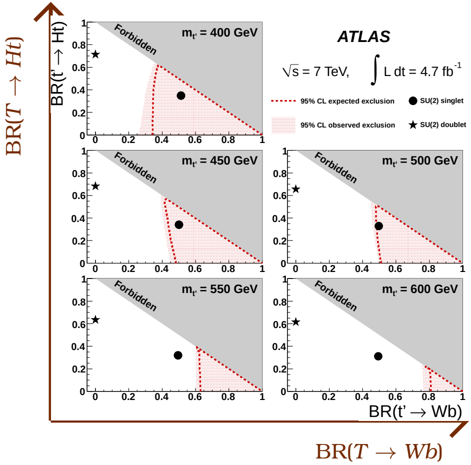
Model Independent Strategy



- 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

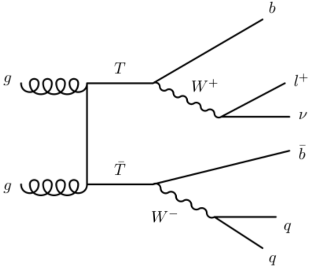
Two searches using common analysis framework:

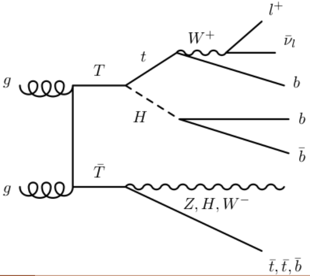
- $T\bar{T} \to Wb + X$ ATLAS-CONF-2013-060 [5]
- $T\bar{T} \to Ht + X$ ATLAS-CONF-2013-018 [6]

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





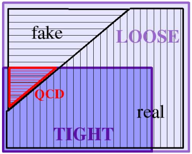
Background and signal modelling

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

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

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



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

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

- 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

Background and signal modelling

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

Background and signal modelling

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

- 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

Background and signal modelling

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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

Background and signal modelling

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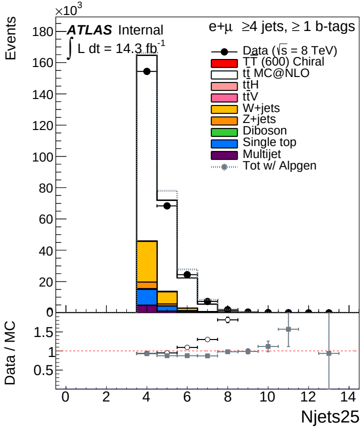
Yields for $t\bar{t}$ predicted with ALPGEN are ~3-8% higher than MC@NLO



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

- $T\bar{T}$ 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)	$BR(T \rightarrow Wb)$	$BR(T \rightarrow Zt)$	$BR(T \rightarrow Ht)$
		Singlet	
600	0.494	0.194	0.312
		Doublet	
600	0.000	0.383	0.617

Outline

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References I

[1] S. Gieseke.
Parton shower monte carlos.

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Confidence level computation for combining searches with small statistics.
Nucl.Instrum.Meth., A434:435–443, 1999.

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[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.

References II

[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.

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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] 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

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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 ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	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 [7].