Review of New Phenomena Searches in the Top Quark Sector with the ATLAS detector

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on behalf of the ATLAS Collaboration

Laboratoire de Physique Corpusculaire
Clermont-Ferrand – France

Lyon Institute of Origin Conference

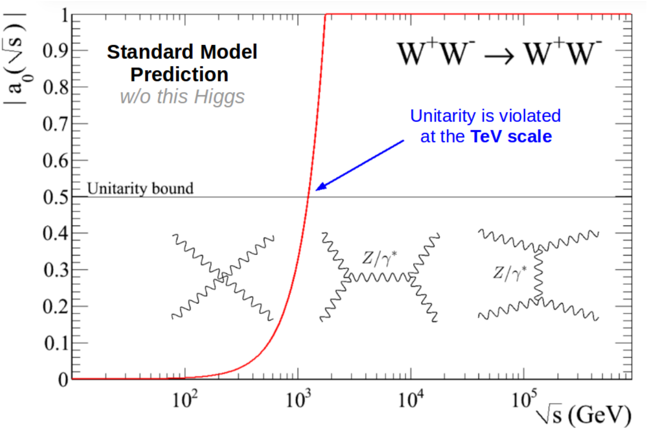
– 5th of September 2016 –

Preamble

Why New Physics <u>at the TeV scale</u>?

from the point of view of a naive experimentalist ...

Before the Higgs Discovery

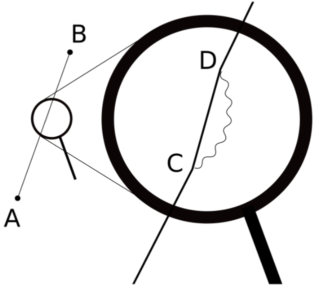


New physics **had** to appear at the TeV scale to restore predictive power of the theory, whatever its nature (Higgs field of course, but not only)

After the Higgs Discovery

$$\left(M_H^{\mathrm{obs}}\right)^2 = \left(M_H^0\right)^2 + \delta_{\mathrm{SM}}$$

Correction, depending on the scale with which we "look" at it



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$$\boxed{\sim 10^4\,\text{GeV}^2}$$

$$\boxed{\sim \frac{3y_t^2}{8\pi^2}\Lambda_{\text{SM}}^2}$$

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$$\delta_{\text{SM}} \rightarrow \boxed{\sim \frac{3y_t^2}{8\pi^2}\Lambda_{\text{SM}}^2}$$

$$\Lambda_{\text{SM}} \sim 100\,\text{TeV}$$

Hierarchy between the bare mass (10^{10}) and physical mass (10^4)

$$\Rightarrow \left(M_H^0\right)^2 \sim 10\,000\,010\,000\,\text{GeV}^2$$

After the Higgs Discovery

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Small change in model parameter → ***Dramatic change*** in physics prediction (EW scale !)

This is what people call **un-naturalness** (rather a *guide* than a theorem-based argument)

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$$\boxed{\delta_{\text{SM}} + \delta_{\text{BSM}} \sim 10^4\,\text{GeV}^2}$$

Extend the SM: How?

The Higgs boson is the **only** elementary scalar in the theory, suffering from this mass instability essentially coming from the **top quark's peculiar mass**. Three main ideas allow to workaround this unwanted feature.

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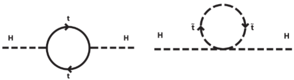
Supersymmetry

Coleman-Mandula Theorem : additional space-time symmetry must change the spin

$$|b\rangle = \mathcal{Q}\,|f\rangle$$

And **fermion mass** protected by **chiral symmetry**



But simplest SUSY extension(s) of SM are quite strongly constrained by current observations

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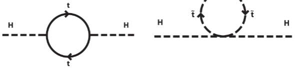

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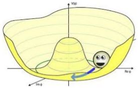
Little Higgs



$\mathcal{G}$ — Larger symmetry (approximate), broken @ high energy

$SU(2)_L \times U(1)_Y$ — Remaining invariance: (pseudo) goldstone bosons, massless (light)

$U(1)_{em}$ — EWSB via Higgs mechanism, with a light Higgs boson

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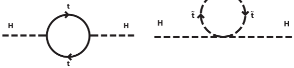

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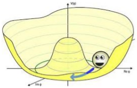

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Little Higgs models predict heavy fermions that couple to the top (**Vector-Like Quarks**). SUSY searches will not be discussed in this review.

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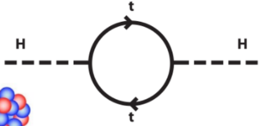

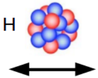

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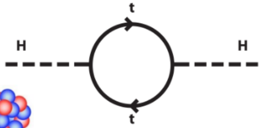

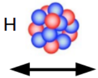

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The Higgs-top couplings will change for $\Lambda > \Lambda_{\mathrm{comp}}$

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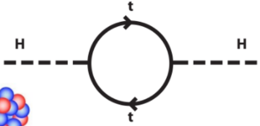

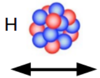

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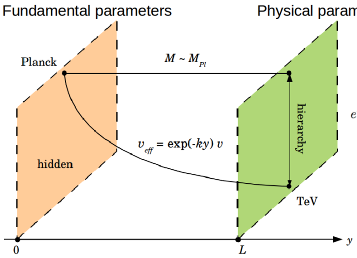

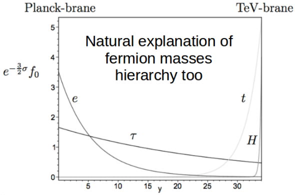

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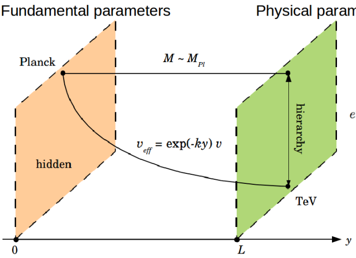
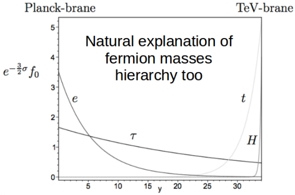




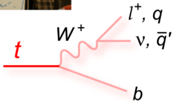
Models based on extra-dimensions also predict extra heavy fermions coupled to the top (**Vector-Like Quarks**), as well as Kaluza-Klein excitations (when compactified).

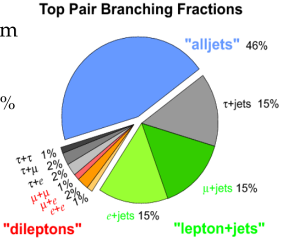
Overview

The Top Quark as Seen by the Detector

$$d = \gamma\, c\, \tau_{\text{top}} \sim 0.5\,\text{fm}$$
$$(p = 300\,\text{GeV})$$

$$\mathcal{BR}(t \to Wb) \approx 100\%$$





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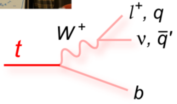

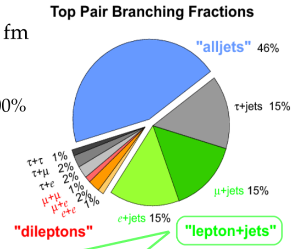

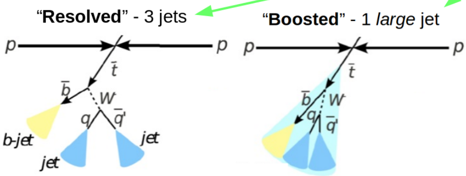

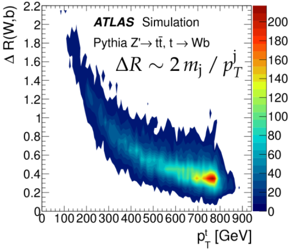

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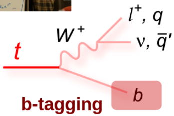
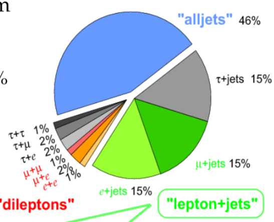
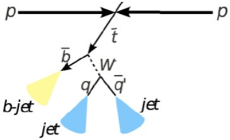


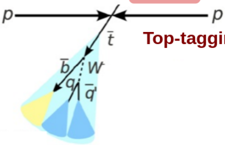
Top Pair Branching Fractions



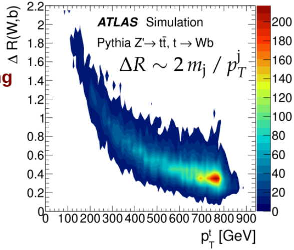
"Resolved" - 3 jets



"Boosted" - 1 *large* jet

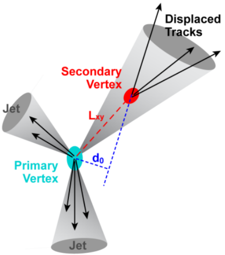


Top-tagging



b-jet Identification

- Impact parameter based algorithm
- Inclusive secondary vertex reconstruction algorithm
- Decay chain multi-vertex reconstruction algorithm



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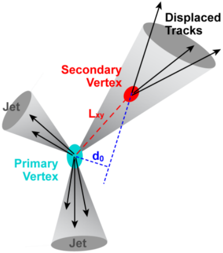

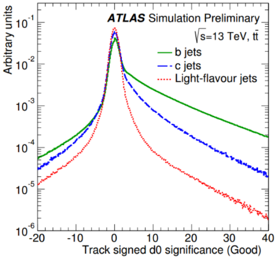

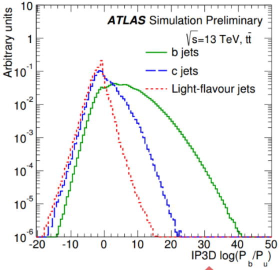

PDFs → likelihood of ligh/b-jet hypothesis

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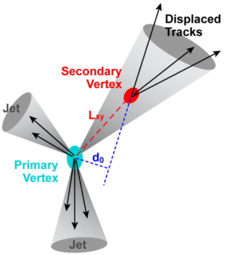

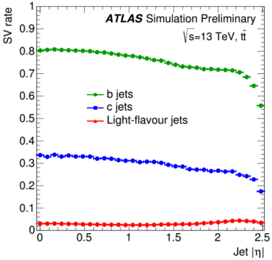

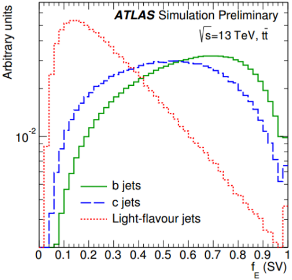

Exploit full properties of the secondary vertex
(mass, energy fraction, number of tracks, etc ...)

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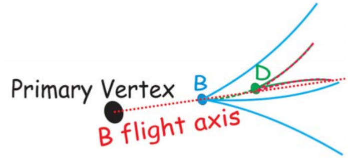
$$b \to Wc \qquad c \to Ws$$

Inclusive secondary vertex reconstruction



Decay chain multi-vertex reconstruction

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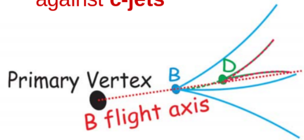
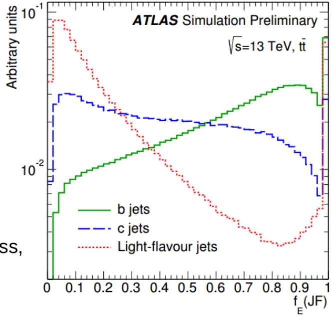
Adding a nice separation against **c-jets**





Exploit full properties of the vertices chain (mass, energy fraction, number of tracks, etc ...)

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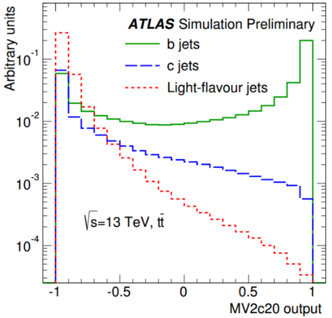
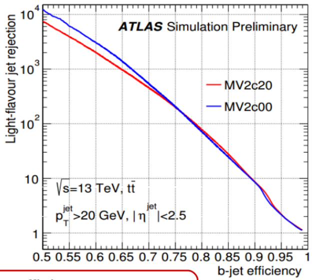
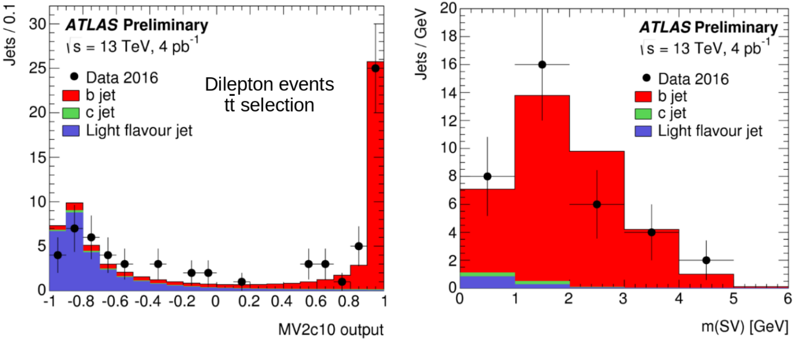
Combination of 24 input variables from the **3 algorithms** in a **MVA** (BDT)





b-jet efficiency ~ 77%
light jet suppression ~ 140

b-jet Identification



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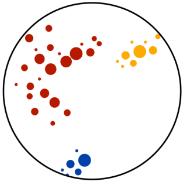

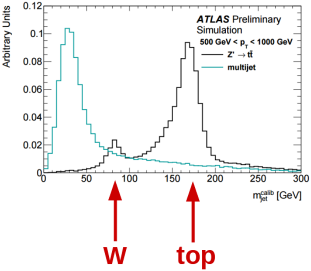

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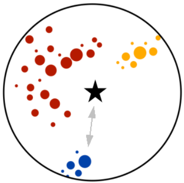

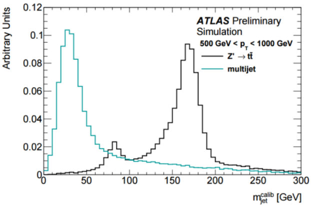

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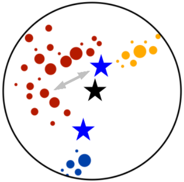
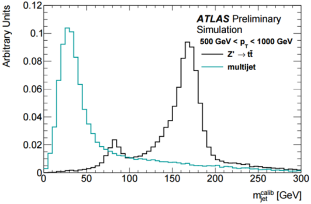
τ_1

τ_2



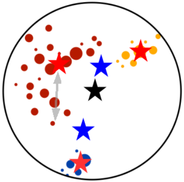


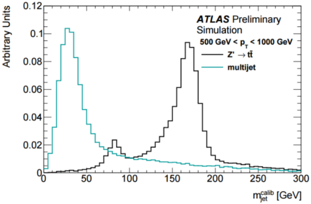
Top-jet Identification

Jet substructure and top quark tagging is an entire field with many on-going developments. Just presenting few key ideas here, like N-subjettiness.

$$\tau_N = \frac{1}{d_0} \sum_k p_{\mathrm{T}k} \times \min(\delta R_{1k}, \delta R_{2k}, \ldots, \delta R_{Nk})$$

τ_1
τ_2
τ_3





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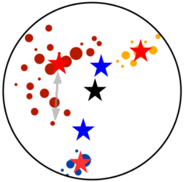

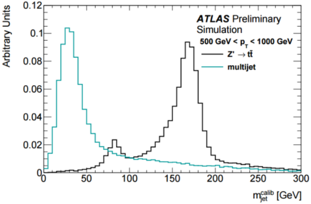

$$\tau_{32} \equiv \frac{\tau_3}{\tau_2} < 1$$

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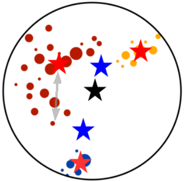
τ_1

τ_2

τ_3



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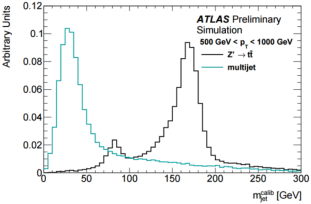

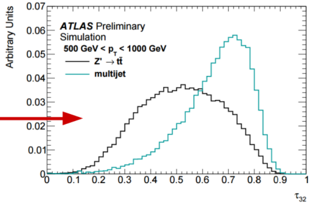

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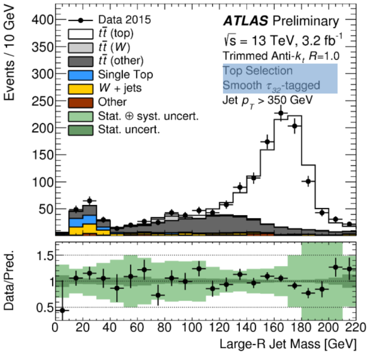

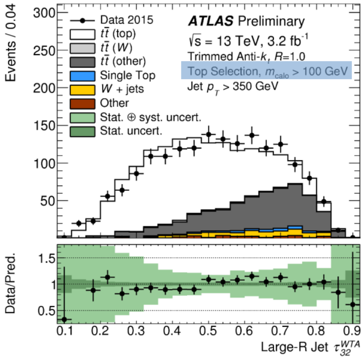

Wide spectrum of performances (see slide 44)

Overview

Overview of Searches

Final state	Targeted process	Class of models
jets (all hadronic) Large BR's but large background	$X \to t\bar{t}$	Extra-dimensions
$\ell +$ jets (single lepton) Good compromise BR/ background	$X \to t\bar{b}$	Additional symmetry
$\ell^{\pm}\ell^{\mp}$ (dilepton - OS) Clean signature but low BR's, perfect for Z's	$X \to t\varphi_{\text{inv}}$	Vector-like Quarks
$\ell^{\pm}\ell^{\pm}/3\ell$ (dilepton - SS) Very low background (and mostly instrumental), needs several tops	$t\bar{t}t\bar{t}$	Compositeness
	tt	Alternative EWSB
	$Q \to V\,q$	FCNC
	$Q\bar{Q} \to V\,q\,V'\,q'\,V$	
	$t \to Hq \quad t \to Zq \quad gq \to t$	

Overview of Searches

Final state

- jets (all hadronic)
  Large BR's but large background
- $\ell +$ jets (single lepton)
  Good compromise BR/ background
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Targeted process

- $X \to t\bar{t}$
- $X \to t\bar{b}$
- $X \to t\varphi_{\text{inv}}$
- $t\bar{t}t\bar{t}$
- tt
- $Q \to V\,q$
- $Q\bar{Q} \to V\,q\,V'\,q'\,V$
- $t \to Hq \quad t \to Zq \quad gq \to t$

Class of models

- Extra-dimensions
- Additional symmetry
- Vector-like Quarks
- Compositeness
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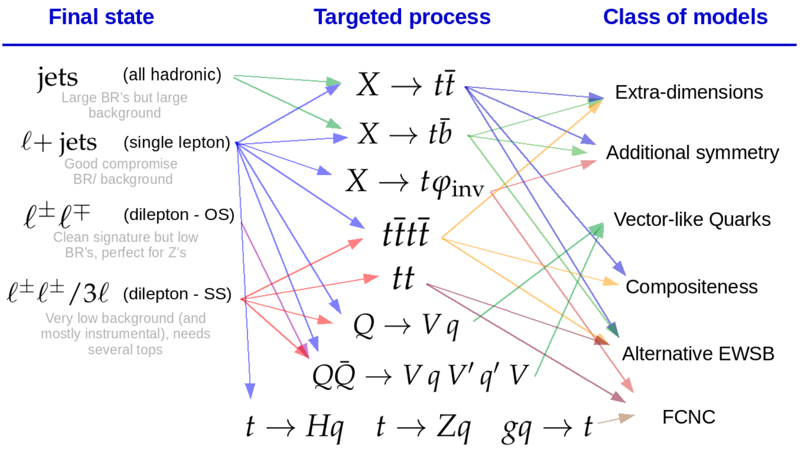
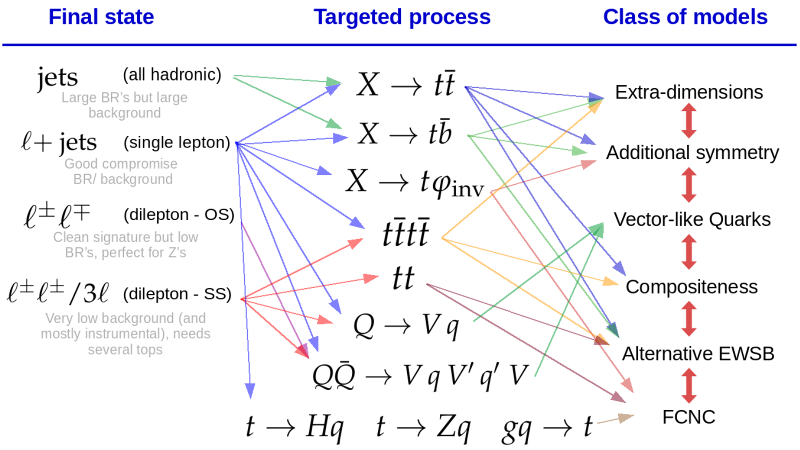
Overview of Searches



Overview of Searches



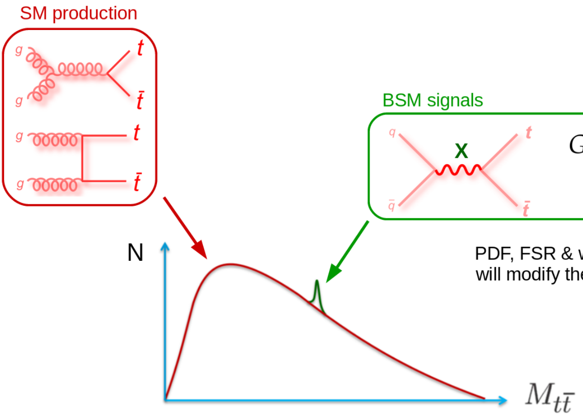
Overview of Searches

New results are in blue - since Moriond 2016.

Final state	8 TeV	13 TeV	Signal type
ℓ+jets boosted	JHEP 08 (2015) 148	ATLAS-CONF-2016-014	$X \to t\bar{t}$
ℓ+jets resolved	JHEP 08 (2015) 148	-	$X \to t\bar{t}$
ℓ+jets resolved	ATLAS-CONF-2016-073	-	$H/A \to t\bar{t}$, interferences
ℓ+jets	PLB 743 (2015) 235-255	-	$X \to t\bar{b}$
full had	EPJC (2015) 75:165	-	$X \to t\bar{b}$
full had $\oplus$ ℓ+jets	JHEP 03 (2016) 127	-	$H^+ \to t\bar{b}$
ℓ+jets	EPJC (2015) 75:79	-	$X \to t\varphi_{\text{inv}}$
ℓ+jets	JHEP 08 (2015) 105	-	$t\bar{t}t\bar{t}$, $Q\bar{Q} \to V\,q\,V'\,q'$
ℓ+jets boosted	-	ATLAS-CONF-2016-013	$t\bar{t}t\bar{t}$, $Q\bar{Q} \to V\,q\,V'\,q'$
ℓ+jets resolved	-	ATLAS-CONF-2016-020	$t\bar{t}t\bar{t}$
ℓ+jets	JHEP 08 (2015) 105	-	$Q\bar{Q} \to W\,b + X$
ℓ+jets	arXiv:1602.05606	ATLAS-CONF-2016-072	$Q \to W\,b$
$\ell^+\ell^-$	JHEP 11 (2014) 104	-	$Q\bar{Q} \to Z\,q\,V'\,q'$
$\ell^\pm\ell^\pm$	JHEP 10 (2015) 150	ATLAS-CONF-2016-032	tt, $t\bar{t}t\bar{t}$, $Q\bar{Q}$, $X_{5/3}\bar{X}_{5/3}$, $X_{5/3}$
ℓ+jets	JHEP 12 (2015) 061	-	$t \to Hq$
3ℓ	EPJC 76 (2016) 12	-	$t \to Zq$
ℓ+jets	EPJC 76 (2016) 55	-	$gq \to t$

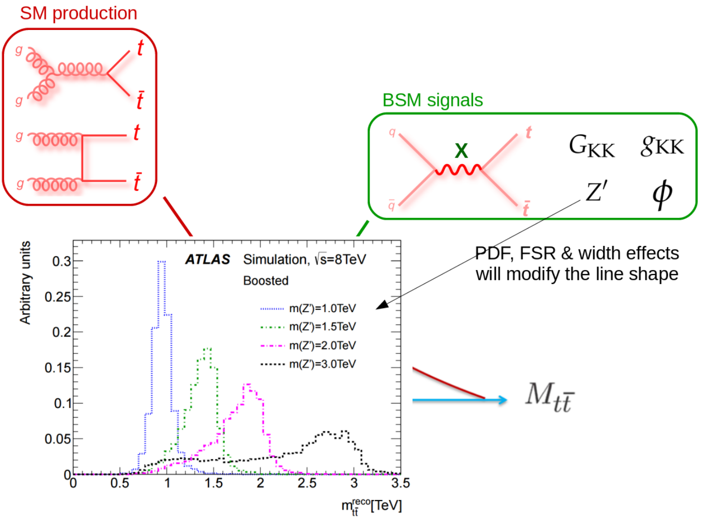
Overview

$X \rightarrow t\bar{t}$: Strategy & Challenges



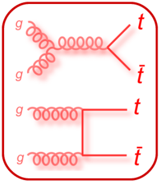
PDF, FSR & width effects will modify the line shape

$X \to t\bar{t}$: Strategy & Challenges

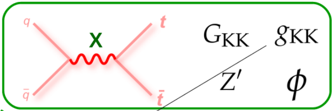


$X \to t\bar{t}$: Strategy & Challenges

SM production



BSM signals



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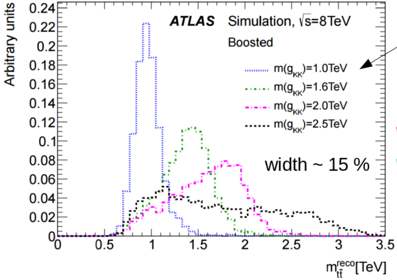
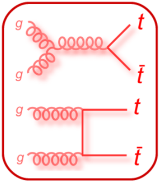


$M_{t\bar{t}}$

$X \rightarrow t\bar{t}$: Strategy & Challenges

SM production



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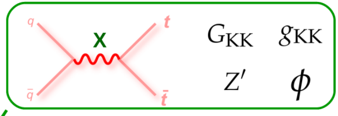
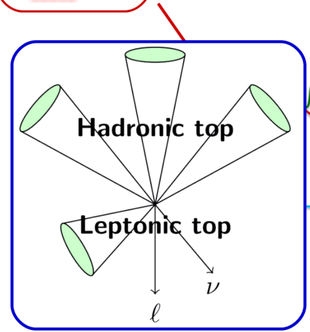
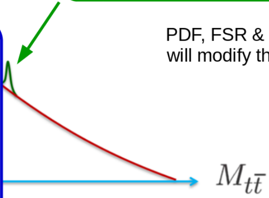






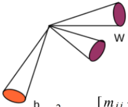
PDF, FSR & width effects will modify the line shape

Basic event selection

At leat one lepton (e/mu)
At least one b-tagged jet
MET> 20 GeV
P_z of neutrino extracted assuming a W

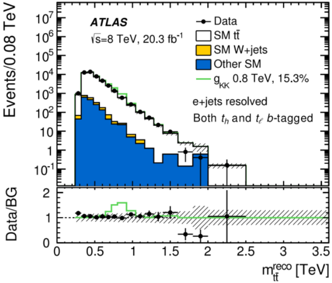
$X \to t\bar{t}$ @ 8 TeV

Resolved topology



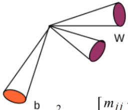
→ kinematic fit to infer compatibility of the jet system with a top quark

$$\chi^2 = \left[\frac{m_{jj} - m_W}{\sigma_W}\right]^2 + \left[\frac{m_{jjb} - m_{jj} - m_{t_h - W}}{\sigma_{t_h - W}}\right]^2 + \left[\frac{m_{j\ell\nu} - m_{t_\ell}}{\sigma_{t_\ell}}\right]^2 + \left[\frac{(p_{\mathrm{T},jjb} - p_{\mathrm{T},j\ell\nu}) - (p_{\mathrm{T},t_h} - p_{\mathrm{T},t_\ell})}{\sigma_{\mathrm{diff}\,p_\mathrm{T}}}\right]^2 .$$



$X \to t\bar{t}$ @ 8 TeV

Resolved topology



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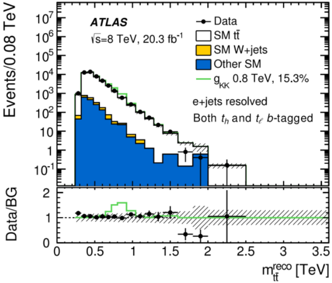
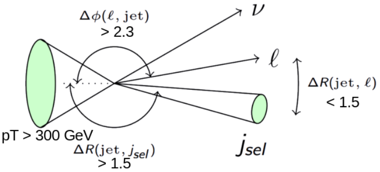
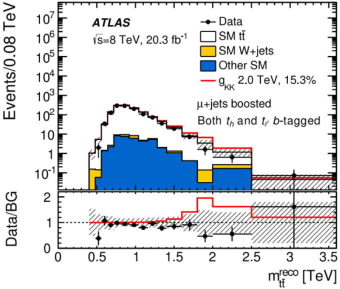
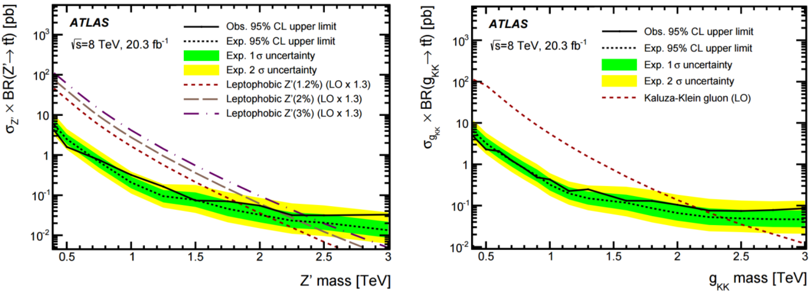


Boosted topology





$X \rightarrow t\bar{t}$ @ 8 TeV

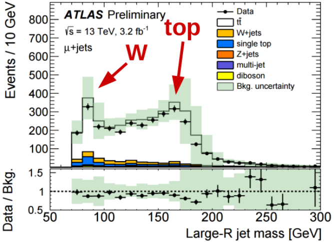


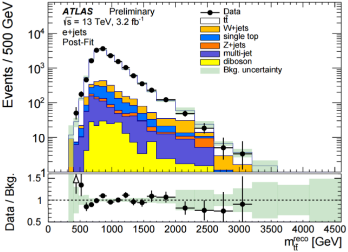
Typical excluded mass scale $\sim$ 2 TeV

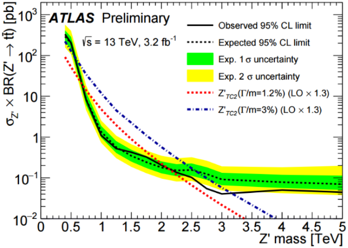
$X \to t\bar{t}$ @ 13 TeV

Update with 13 TeV pp colllisions

- 3.2 fb^{-1}
- only boosted regime has public results (for now)
- only one signal benchmark (for now)







$H/A \rightarrow t\bar{t}$ - interfering with $gg \rightarrow t\bar{t}$

Until now, interferences with SM non-resonant process were neglected, but it can dramatically change the expected signature for signal at medium mass.

First investigation of this effect in 2HDM model - aligned type-II (arXiv:1505.00291) with 8 TeV data, resolved topology only.

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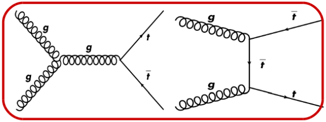
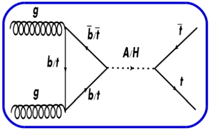
$|\mathcal{A}_b|e^{i\varphi_b}$



$|\mathcal{A}_s|e^{i\varphi_s}$



$$|\mathcal{A}_{\text{tot}}|^2 = |\mathcal{A}_b|^2 + \boxed{|\mathcal{A}_s|^2 + 2|\mathcal{A}_b||\mathcal{A}_s|\cos(\Delta\varphi)}$$

S+I contribution

$$\Delta\varphi \to f(m_{t\bar{t}}, \tan\beta)$$

can induce significant shape distortion, depending on parameter values

$H/A \rightarrow t\bar{t}$ - interfering with $gg \rightarrow t\bar{t}$

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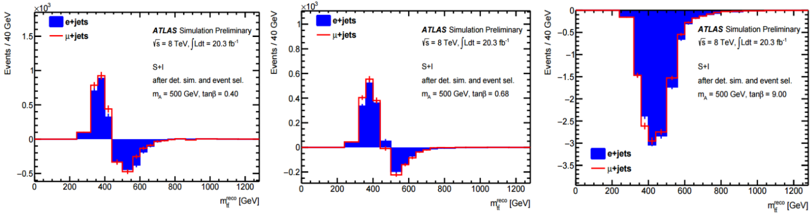
How the S+I contribution evolves with tanβ (m_A=500 GeV) – partonic level



$H/A \rightarrow t\bar{t}$ - interfering with $gg \rightarrow t\bar{t}$

How to properly set a limit? Few (related) issues:

1. meaning of signal strength μ ($\equiv \sigma_{\text{sig}}/\sigma_{\text{sig}}^{\text{ref}}$) - since $\sigma_{\text{sig}}^{(\text{ref})}$ is not defined?
2. interference pattern changes with μ
3. a simple μ scale doesn't work for $I \propto \sqrt{\mu}$ (unlike $S \propto \mu$)

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Re-parametrization of $N(\mu) = \mu S + B$: $\sqrt{\mu}$ is the new parameter of interest

$$N = \mu S + \sqrt{\mu} I + B = \sqrt{\mu}(S + I) + (\sqrt{\mu}^2 - \sqrt{\mu})S + B$$

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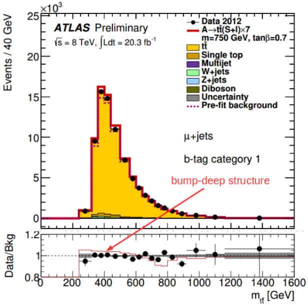
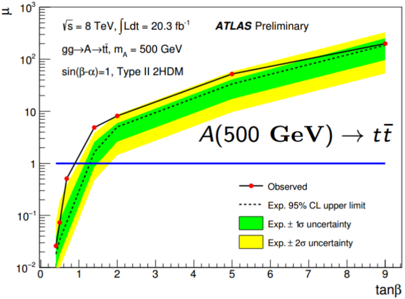
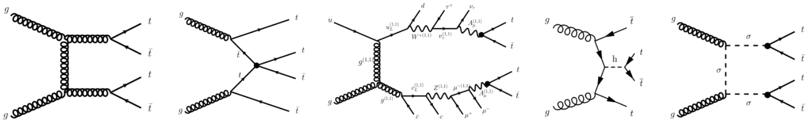




Overview

$t\bar{t}t\bar{t}$ Strategy & Challenges



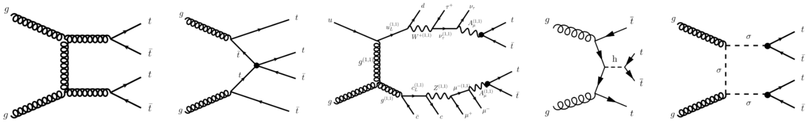
Standard Model | Effective theory | 2UED signature | BSM Higgs | Scalar gluon

4 top quarks final state

→ 4 W bosons

→ 4 b-jets

$t\bar{t}t\bar{t}$ Strategy & Challenges



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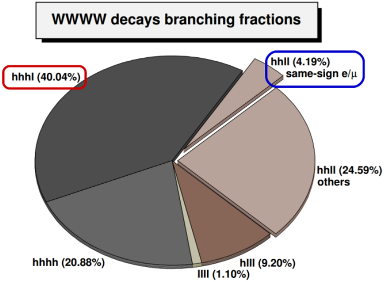


l+jets

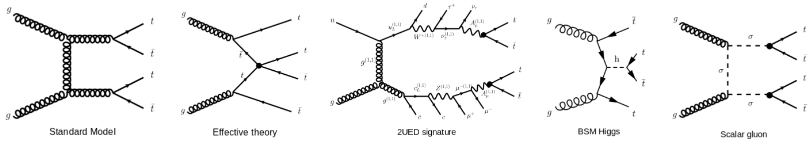
Large statistics, but large background

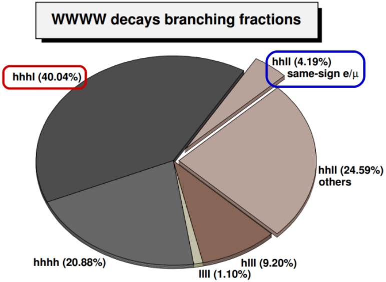
Exploit (b-)jet multiplicity to extract the signal

Main background: $t\bar{t}$ + $b\bar{b}$

Key signature: large detector activity (H_T)

$t\bar{t}t\bar{t}$ Strategy & Challenges





Same-sign dilepton

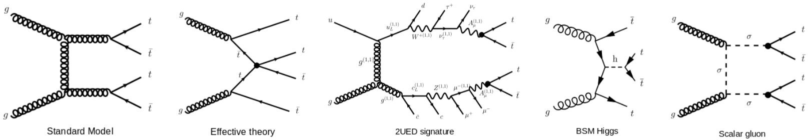
Low statistics, but low background

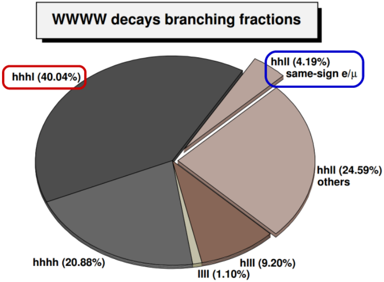
Challenging: *instrumental* backgrounds

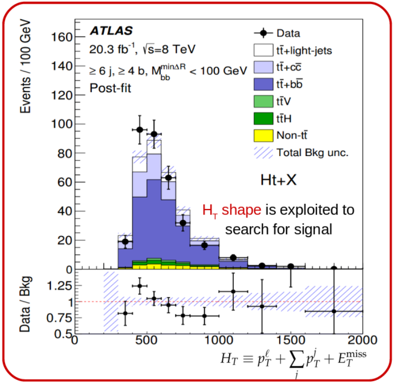
Main background: $t\bar{t}$ + V

Key signature: large detector activity (H_T)

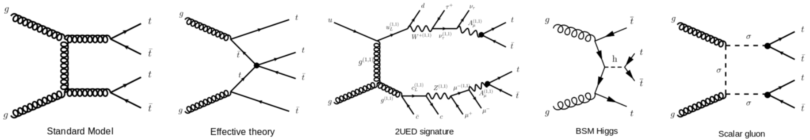
$t\bar{t}t\bar{t}$ @ 8 TeV

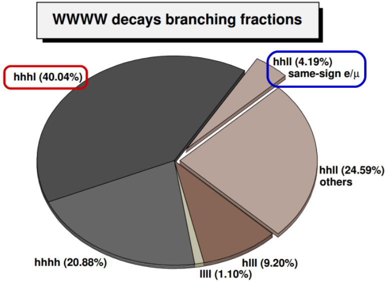


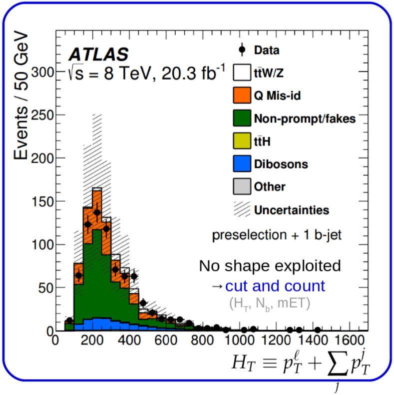




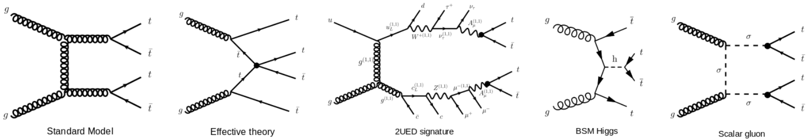
$t\bar{t}t\bar{t}$ @ 8 TeV

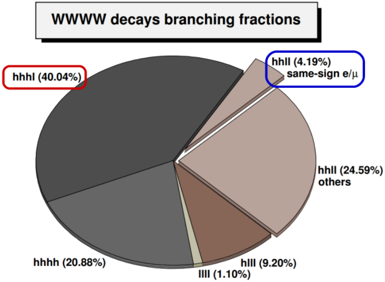


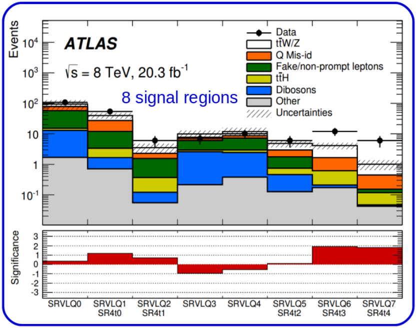




$t\bar{t}t\bar{t}$ @ 8 TeV





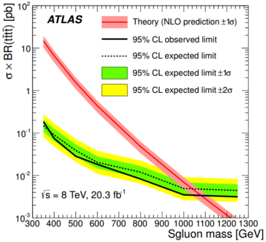


$t\bar{t}t\bar{t}$ @ 8 TeV

$\sigma_{SM}(t\bar{t}t\bar{t}) < 23$ (32) fb (32xSM)

$\sigma_{EFT}(t\bar{t}t\bar{t}) < 12$ (16) fb

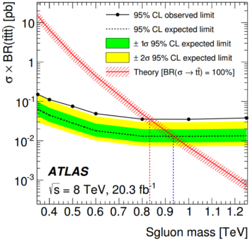
$|C_{4t}|/\Lambda^2 < 6.6\ \mathrm{TeV}^{-2}$

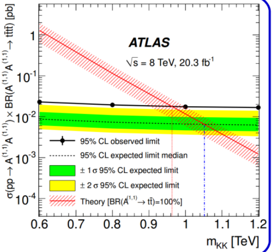


$\sigma_{SM}(t\bar{t}t\bar{t}) < 70$ (27) fb (103xSM)

$\sigma_{EFT}(t\bar{t}t\bar{t}) < 61$ (22) fb

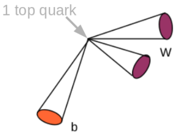
$|C_{4t}|/\Lambda^2 < 15.1\ \mathrm{TeV}^{-2}$





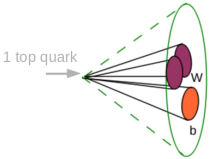
$t\bar{t}t\bar{t}$ @ 13 TeV – ℓ+jets

l+jets resolved



4 top quarks in l+jets resolved final state
→ 6 light jets (3 W_{had})
→ 4 b-jets
→ 1 lepton (1 W_{lep})
→ mET (neutrino from W_{lep})

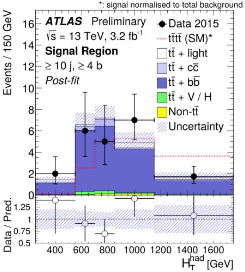
l+jets boosted

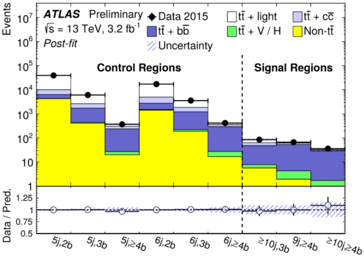


4 top quarks in l+jets boosted final state
→ 1, 2 or 3 top-tagged jets
→ 4, 2 or 0 light jets
→ 3, 2 or 1 b-jets
→ 1 lepton (1 W_{lep})
→ mET (neutrino from W_{lep})

$t\bar{t}t\bar{t}$ @ 13 TeV – ℓ+jets

l+jets resolved

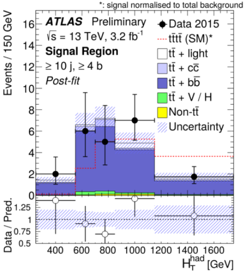


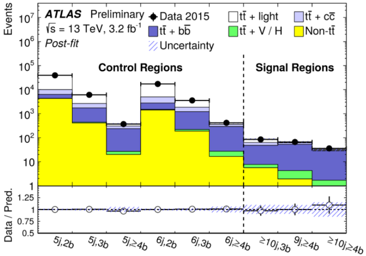


l+jets boosted

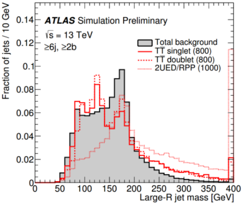
$t\bar{t}t\bar{t}$ @ 13 TeV – ℓ+jets

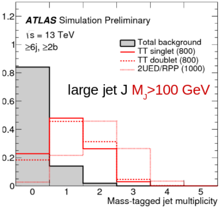
l+jets resolved

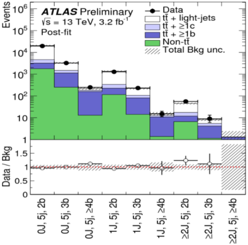




l+jets boosted







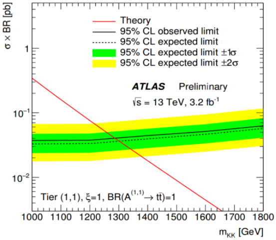
$t\bar{t}t\bar{t}$ @ 13 TeV – ℓ+jets

l+jets resolved

$\sigma_{SM}(t\bar{t}t\bar{t}) < 190\ (143)$ fb (21xSM)

$\sigma_{EFT}(t\bar{t}t\bar{t}) < 148\ (115)$ fb

$|C_{4t}|/\Lambda^2 < 5.0\ \text{TeV}^{-2}$

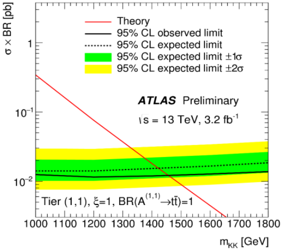


l+jets boosted

$\sigma_{SM}(t\bar{t}t\bar{t}) < 370\ (180)$ fb (40xSM)

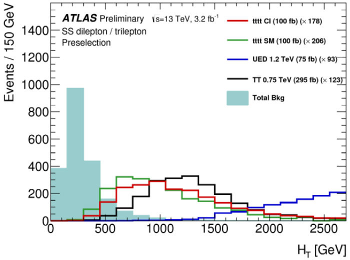
$\sigma_{EFT}(t\bar{t}t\bar{t}) < 140\ (99)$ fb

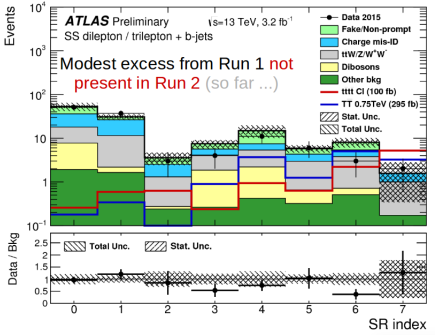
$|C_{4t}|/\Lambda^2 < 4.8\ \text{TeV}^{-2}$



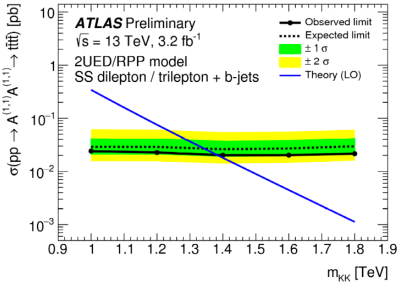
$t\bar{t}t\bar{t}$ @ 13 TeV – same-sign leptons

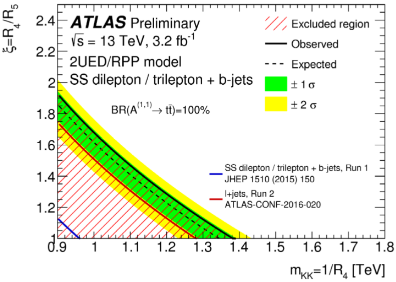
Same strategy as the Run 1 analysis





$t\bar{t}t\bar{t}$ @ 13 TeV – same-sign leptons



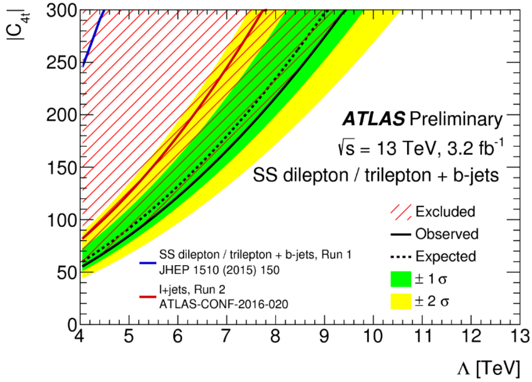


$t\bar{t}t\bar{t}$ @ 13 TeV – same-sign leptons

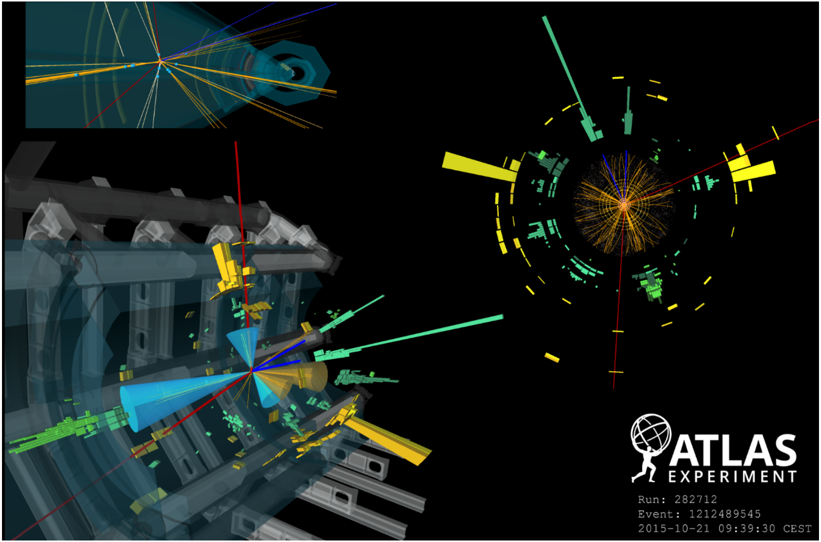
$\sigma_{SM}(t\bar{t}t\bar{t}) < 95\ (107)$ fb (10xSM)

$\sigma_{EFT}(t\bar{t}t\bar{t}) < 67\ (79)$ fb

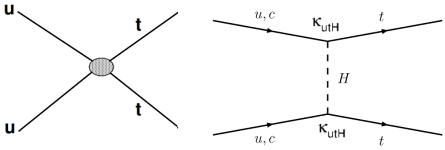
$|C_{4t}|/\Lambda^2 < 3.5\ \mathrm{TeV}^{-2}$

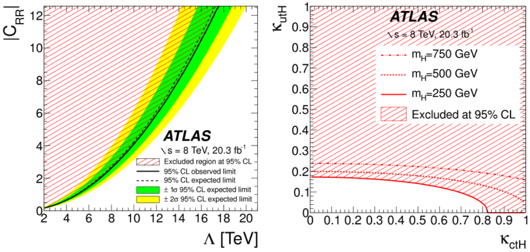


$t\bar{t}t\bar{t}$ @ 13 TeV – same-sign leptons



tt @ 8 TeV – same-sign leptons





Generic approaches for FCNC
Connection with $t\bar{t}$ asymmetry
arXiv:1104.1385

Signal showing up only
in same-sign lepton

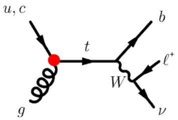
Modest N_b and H_T than 4
top quarks signal

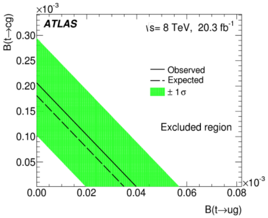
$$BR(t \to uH) < 0.01$$

Rare Top Quark Decay @ 8 TeV

$$gq \to t$$

Single top final state,
Neural network to
extract the signal





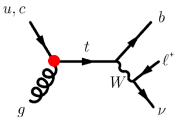
Rare Top Quark Decay @ 8 TeV

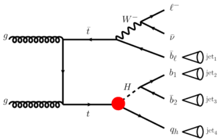
$gq \to t$

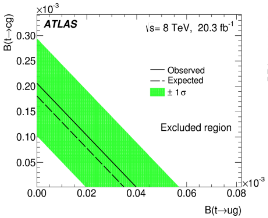
Single top final state,
Neural network to
extract the signal

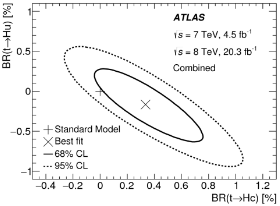
$t \to Hq$

lepton+jets final state,
discriminant based on
jet-pairing, M_W, M_H, M_t



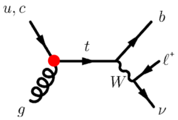


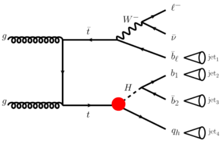


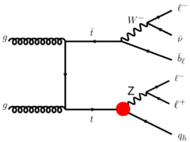


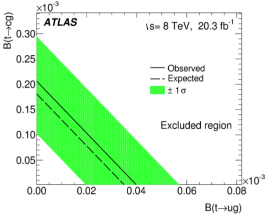
Rare Top Quark Decay @ 8 TeV

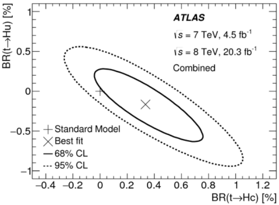
$gq \to t$	$t \to Hq$	$t \to Zq$
Single top final state, Neural network to extract the signal	lepton+jets final state, discriminant based on jet-pairing, M_W, M_H, M_t	trilepton final state, reconstruction of the W and the Z boson

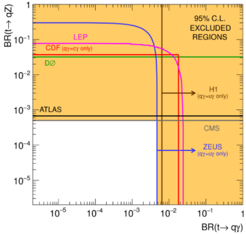










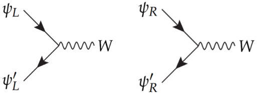


Overview

Vector-Like Quarks Overview

1. What? Spin-1/2 fermions having ψ_L and ψ_R in the same SU(2) representation.

$$SU(3)_c \times SU(2) \times U(1)_Y$$



$$\mathcal{L}_{\text{mass}} = M_Q \; (\bar{\psi}_L \psi_R + \bar{\psi}_R \psi_L)$$

Gauge-invariant mass term
(*impossible* to have for SM fields)

Vector-Like Quarks Overview

1. **What?** Spin-1/2 fermions having ψ_L and ψ_R in the same SU(2) representation.
2. **Why?** Fermions predicted in many theories addressing naturalness

Vector-Like Quarks Overview

1. **What?** Spin-1/2 fermions having ψ_L and ψ_R in the same SU(2) representation.
2. **Why?** Fermions predicted in many theories addressing naturalness
   - Based on general assumptions, mostly 7 possible SU(2) representations heavily constraining the dynamics

X,Y : exotic charges
→ **no mixing** with SM fields

$$\text{(singlets)} \longrightarrow T^0_{L,R}\,,\quad B^0_{L,R}$$

$$\text{(doublets)} \longrightarrow (X\,T^0)_{L,R}\,,\quad (T^0\,B^0)_{L,R}\,,\quad (B^0\,Y)_{L,R}$$

$$\text{(triplets)} \longrightarrow (X\,T^0\,B^0)_{L,R}\,,\quad (T^0\,B^0\,Y)_{L,R}$$

Vector-Like Quarks Overview

1. What? Spin-1/2 fermions having ψ_L and ψ_R in the same SU(2) representation.

2. Why? Fermions predicted in many theories addressing naturalness

- Based on general assumptions, mostly 7 possible SU(2) representations heavily constraining the dynamics
- Modify observable physics via a mixing with SM quarks (3^{rd} generation)

$$\underbrace{\begin{pmatrix} t_{L,R} \\ T_{L,R} \end{pmatrix}}_{\text{Propagating states}} = \underbrace{\boxed{\begin{pmatrix} \cos\theta^u_{L,R} & -\sin\theta^u_{L,R} e^{i\phi_u} \\ \sin\theta^u_{L,R} e^{-i\phi_u} & \cos\theta^u_{L,R} \end{pmatrix}}}_{\text{Mixing matrix}} \underbrace{\begin{pmatrix} t^0_{L,R} \\ T^0_{L,R} \end{pmatrix}}_{\text{SU(2) states}}$$

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   - Compatible with existing observations
     - 1^{st} *generation*: mixing constrained by parity violation in atomic physics (neutral current $u, d \leftrightarrow e^-$)
     - 2^{nd} *generation*: mixing constrained by R_c (LEP)
     - 3^{rd} *generation*: mixing allowed but constrained by R_b (LEP) and (S, T) "oblique" parameters

       $\rightarrow$ Much less constrained, and most relevant for hierarchy problem.

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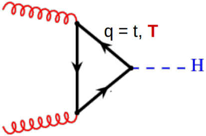
   - Heavy fermions compatible with $\sigma(gg \to H)$ production



Flat loop function for $m_X >> m_H$
the two components t and T give the same amplitude: a rotation doesn't change the total amplitude

$$F_q = \sum_i Y_{ii} A_{1/2}\left(\frac{M_H^2}{4m_i^2}\right)$$

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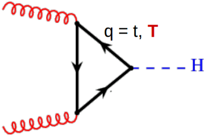

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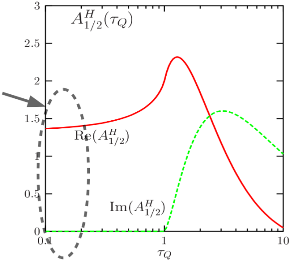

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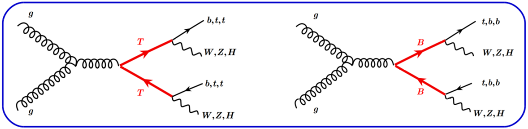
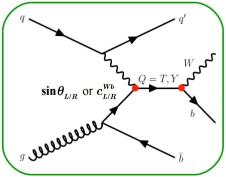
3. How? Rich and reachable signatures at the LHC



Pair production (model **independent** – driven by QCD)



Single production / decay (model **dependent** – driven by EW)

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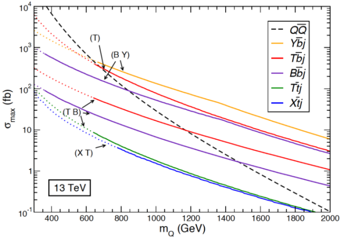

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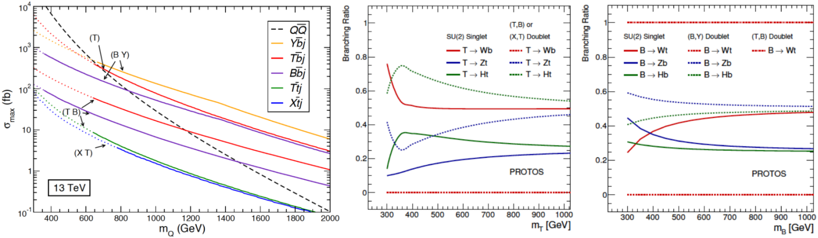
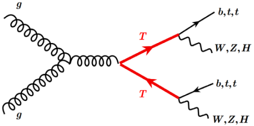
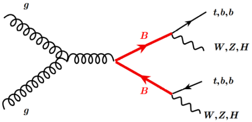
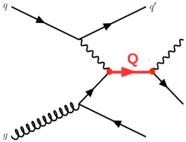
3. How? Rich and reachable signatures at the LHC



Many ATLAS VLQ searches

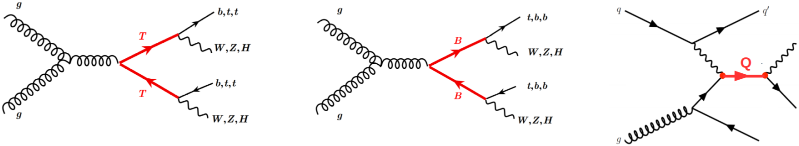






Final state	8 TeV	13 TeV	VLQ Signal type
ℓ+jets	JHEP 08 (2015) 105	-	$T\bar{T} \to Wb + X/Ht + X$, $B\bar{B} \to Hb + X$
ℓ+jets	JHEP 08 (2015) 105	TOP2016	$T\bar{T} \to W\,b + X$
ℓ+jets boosted	-	ATLAS-CONF-2016-013	$T\bar{T} \to Ht + X$
ℓ+jets	arXiv:1602.05606	ATLAS-CONF-2016-072	$Y_{-4/3} \to W^- b$, $T \to W^- \bar{b}$
$\ell^+\ell^-$	JHEP 11 (2014) 104	TOP2016	$T\bar{T}(B\bar{B}) \to Z\,t(b) + X$
$\ell^\pm\ell^\pm$	JHEP 10 (2015) 150	ATLAS-CONF-2016-032	$T\bar{T}$, $B\bar{B}$, $X_{5/3}\bar{X}_{5/3}$, $X_{5/3}$

Many ATLAS VLQ searches



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In the next slides:

- Summary of 8 TeV results
- Results split for pair and single production
- Update with 13 TeV collisions

Summary of 8 TeV Results

How to cover the largest parameter space?

$\rightarrow$ Determine excluded Q mass for all possible $\mathcal{BR}$ scenarios

$$\mathcal{BR}(T \rightarrow Ht) + \mathcal{BR}(T \rightarrow Zt) + \mathcal{BR}(T \rightarrow Wb) = 1$$
$$\mathcal{BR}(B \rightarrow Hb) + \mathcal{BR}(B \rightarrow Zb) + \mathcal{BR}(B \rightarrow Wt) = 1$$

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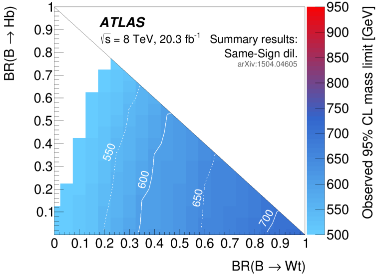
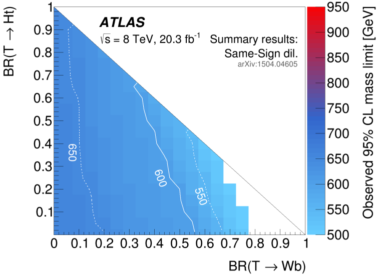


Vector-like T



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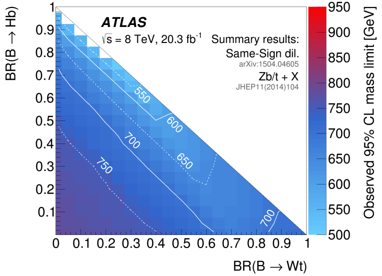

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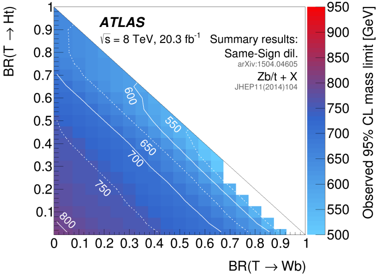

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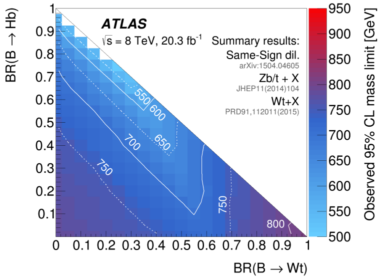

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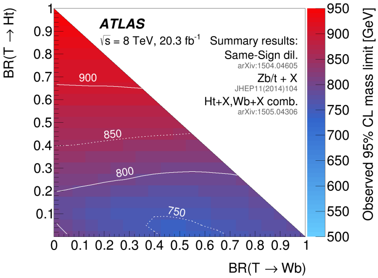

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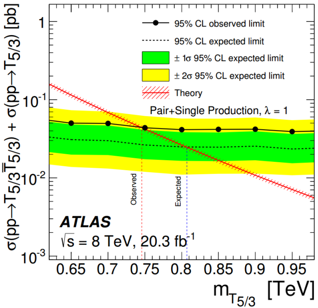

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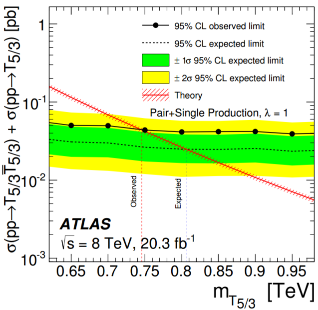

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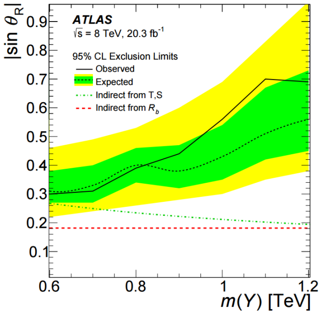
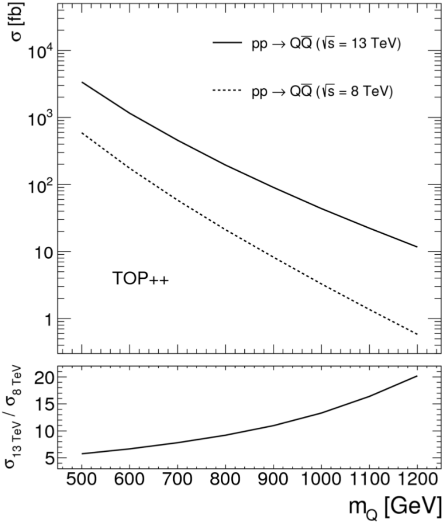
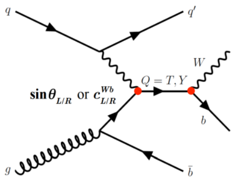


VLQs: From 8 to 13 TeV ...

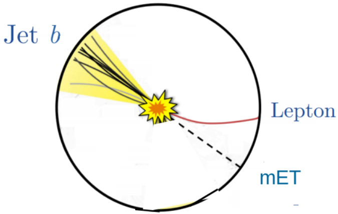


VLQ @ 13 TeV: Single Production



Why?
→ higher sensitivity than pair production, at high mass

Signature:
- 1 lepton + mET (W_{lep}), with mET>120 GeV
- high pT b-jet (>300 GeV)
- *forward* jets (t-channel)
- lepton back-to-back with b-jet



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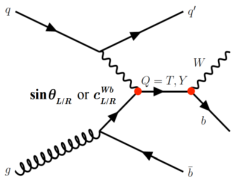

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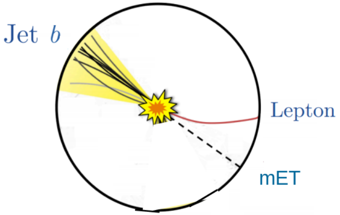
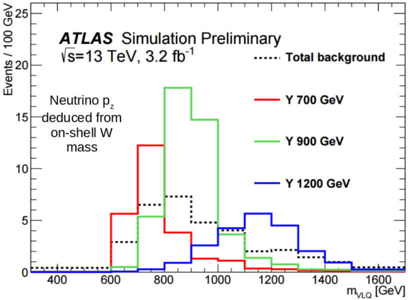


$$m^2_{\mathrm{VLQ}} \equiv (p_\ell + p_\nu + p_b)^2$$

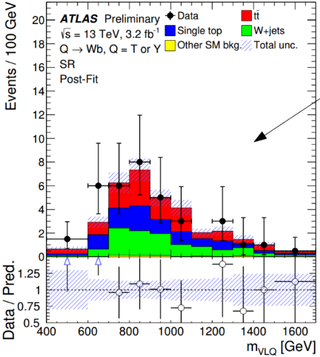


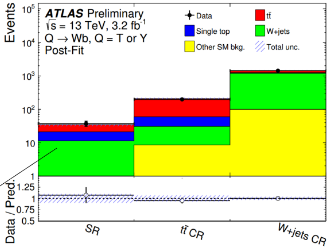
VLQ @ 13 TeV: Single Production

Main backgrounds

- W+jets (high pT region)
- top quark pair/single production

→ constrained using a simultaneous fit over SR and CRs





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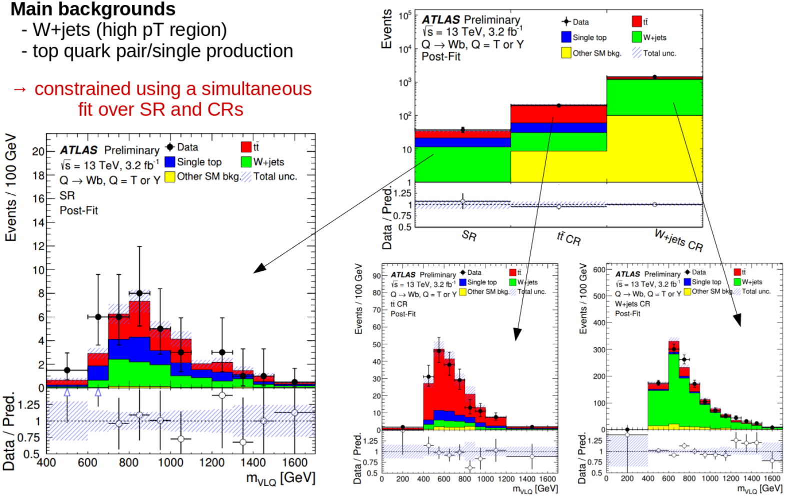

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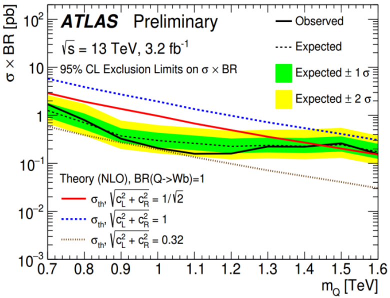
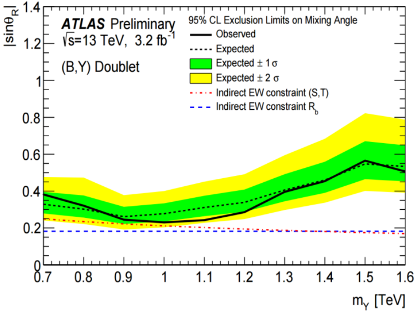




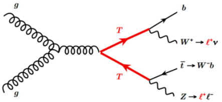
Direct LHC searches reach constraints similar to LEP & WE precision indirect constraints !

VLQ @ 13 TeV: Pair Production – same-sign

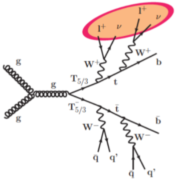
$T\bar{T}, B\bar{B}$

$B \rightarrow Wt, Zb, Hb$

$T \rightarrow Wb, Zt, Ht$



$T_{5/3}\bar{T}_{5/3}$ (doublet)



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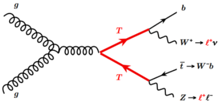

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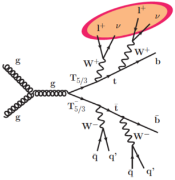
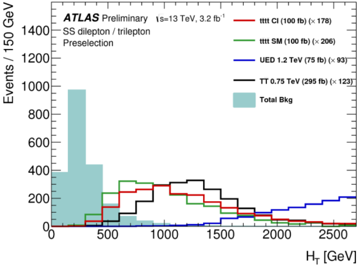


8 signal regions based on N_b, H_T and mET



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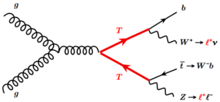

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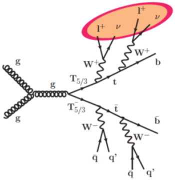

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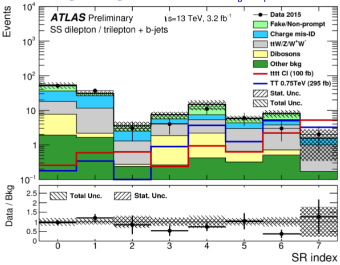

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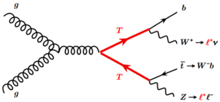

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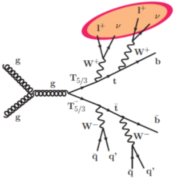

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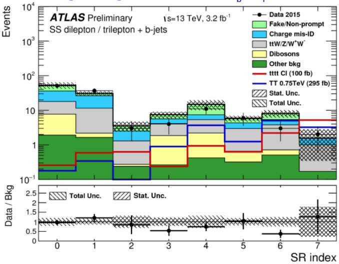

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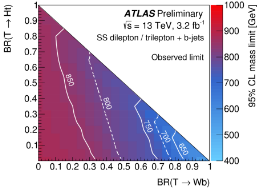

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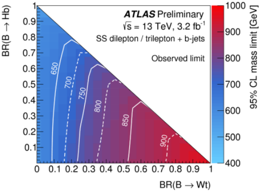

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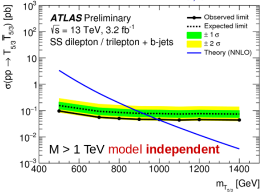
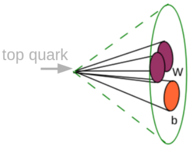
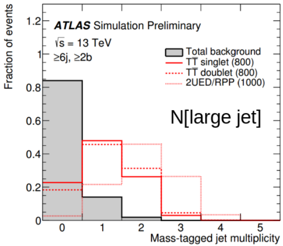


VLQ @ 13 TeV: Pair Production – ℓ+jets

l+jets boosted topology





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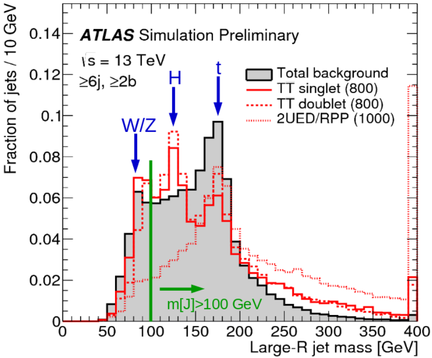

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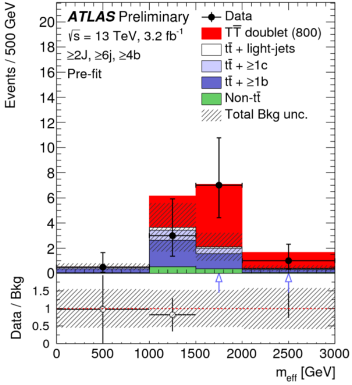
l+jets boosted topology

$$m_{\text{eff}} \equiv p_T^{\ell} + \sum_j p_T^j + E_T^{\text{miss}}$$



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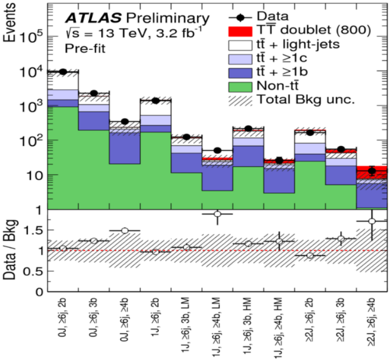

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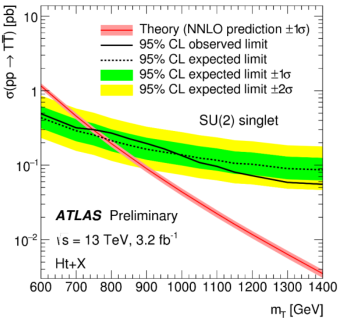
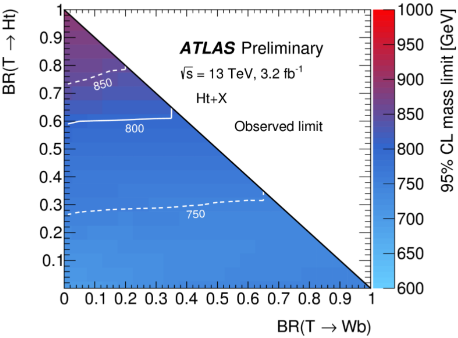




Overview

Summary and outlooks

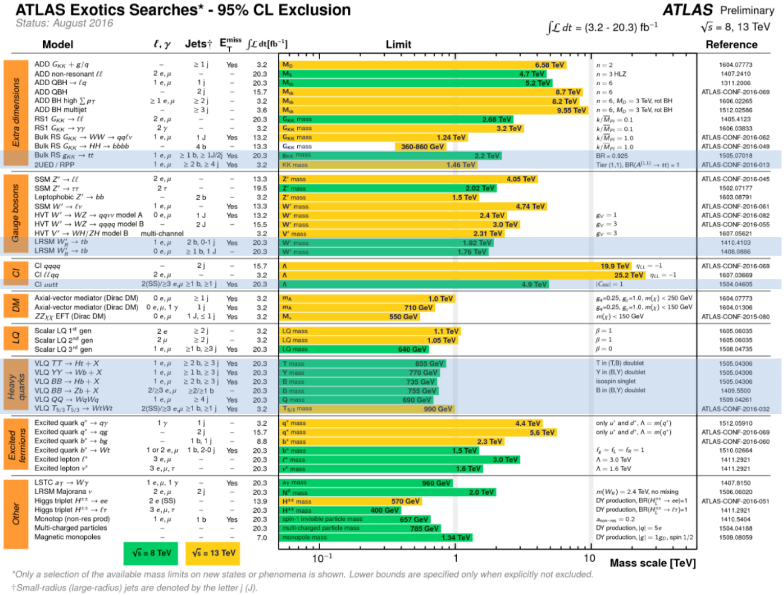
The top quark represents a very promising sector to discover new phenomena. A wide spectrum of ATLAS searches is performed and many updates are to come.

Summary:

- Large number of final states and models scrutinized
- Typical constraints: $M > 1 - 3$ TeV, $\mathcal{BR} \lesssim 10^{-3}$
- Updates of results using 13 TeV collisions
- Investigation of interferences: new type of signatures

Outlooks:

- Many analyses are being done using the unique 2016 dataset.
- Stay tuned and start to bet on what the Nature has to say: new boson, new fermion, extra-dimension ...?

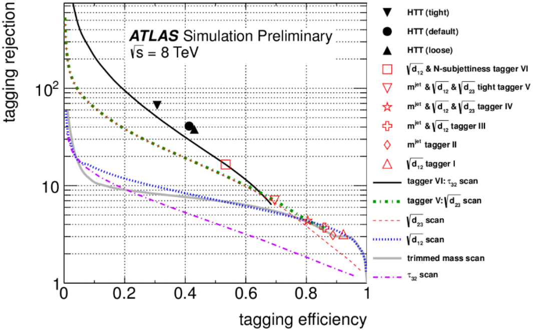

ATLAS Exotics Searches* - 95% CL Exclusion
Status: August 2016
ATLAS Preliminary
∫ℒ dt = (3.2 - 20.3) fb⁻¹
√s = 8, 13 TeV
Model
ℓ, γ
Jets†
E_T^miss
∫ℒ dt[fb⁻¹]
Limit
Reference
Extra dimensions
ADD G_KK + g/q – ≥1 j Yes 3.2 M_D 6.58 TeV n = 2 1604.07773
ADD non-resonant ℓℓ 2 e, μ – – 20.3 M_S 4.7 TeV n = 3 HLZ 1407.2410
ADD QBH → ℓq 1 e, μ 1 j – 20.3 M_th 5.2 TeV n = 6 1311.2006
ADD QBH – 2 j – 15.7 M_th 8.7 TeV n = 6 ATLAS-CONF-2016-069
ADD BH high Σp_T ≥1 e, μ ≥2 j – 3.2 M_th 8.2 TeV n = 6, M_D = 3 TeV, rot BH 1606.02265
ADD BH multijet – ≥3 j – 3.6 M_th 9.55 TeV n = 6, M_D = 3 TeV, rot BH 1512.02586
RS1 G_KK → ℓℓ 2 e, μ – – 20.3 G_KK mass 2.68 TeV k/M̄_Pl = 0.1 1405.4123
RS1 G_KK → γγ 2 γ – – 3.2 G_KK mass 3.2 TeV k/M̄_Pl = 0.1 1606.03833
Bulk RS G_KK → WW → qqℓν 1 e, μ 1 J Yes 13.2 G_KK mass 1.24 TeV k/M̄_Pl = 1.0 ATLAS-CONF-2016-062
Bulk RS G_KK → HH → bbbb – 4 b – 13.3 G_KK mass 360-860 GeV k/M̄_Pl = 1.0 ATLAS-CONF-2016-049
Bulk RS g_KK → tt 1 e, μ ≥1 b, ≥1J/2j Yes 20.3 g_KK mass 2.2 TeV BR = 0.925 1505.07018
2UED / RPP 1 e, μ ≥2 b, ≥4 j Yes 3.2 KK mass 1.46 TeV Tier (1,1), BR(A^(1,1) → tt) = 1 ATLAS-CONF-2016-013
Gauge bosons
SSM Z′ → ℓℓ 2 e, μ – – 13.3 Z′ mass 4.05 TeV ATLAS-CONF-2016-045
SSM Z′ → ττ 2 τ – – 19.5 Z′ mass 2.02 TeV 1502.07177
Leptophobic Z′ → bb – 2 b – 3.2 Z′ mass 1.5 TeV 1603.08791
SSM W′ → ℓν 1 e, μ – Yes 13.3 W′ mass 4.74 TeV ATLAS-CONF-2016-061
HVT W′ → WZ → qqνν model A 0 e, μ 1 J Yes 13.2 W′ mass 2.4 TeV g_V = 1 ATLAS-CONF-2016-082
HVT W′ → WZ → qqqq model B – 2 J – 15.5 W′ mass 3.0 TeV g_V = 3 ATLAS-CONF-2016-055
HVT V′ → WH/ZH model B multi-channel 3.2 V′ mass 2.31 TeV g_V = 3 1607.05621
LRSM W′_R → tb 1 e, μ 2 b, 0-1 j Yes 20.3 W′ mass 1.92 TeV 1410.4103
LRSM W′_R → tb 0 e, μ ≥1 b, 1 J – 20.3 W′ mass 1.76 TeV 1408.0886
CI
CI qqqq – 2 j – 15.7 Λ 19.9 TeV η_LL = −1 ATLAS-CONF-2016-069
CI ℓℓqq 2 e, μ – – 3.2 Λ 25.2 TeV η_LL = −1 1607.03669
CI uutt 2(SS)/≥3 e,μ ≥1 b, ≥1 j Yes 20.3 Λ 4.9 TeV |C_RR| = 1 1504.04605
DM
Axial-vector mediator (Dirac DM) 0 e, μ ≥1 j Yes 3.2 m_A 1.0 TeV g_q=0.25, g_χ=1.0, m(χ) < 250 GeV 1604.07773
Axial-vector mediator (Dirac DM) 0 e, μ, 1 γ 1 j Yes 3.2 m_A 710 GeV g_q=0.25, g_χ=1.0, m(χ) < 150 GeV 1604.01306
ZZχχ EFT (Dirac DM) 0 e, μ 1 J, ≤1 j Yes 3.2 M_* 550 GeV m(χ) < 150 GeV ATLAS-CONF-2015-080
LQ
Scalar LQ 1st gen 2 e ≥2 j – 3.2 LQ mass 1.1 TeV β = 1 1605.06035
Scalar LQ 2nd gen 2 μ ≥2 j – 3.2 LQ mass 1.05 TeV β = 1 1605.06035
Scalar LQ 3rd gen 1 e, μ ≥1 b, ≥3 j Yes 20.3 LQ mass 640 GeV β = 0 1508.04735
Heavy quarks
VLQ TT → Ht + X 1 e, μ ≥2 b, ≥3 j Yes 20.3 T mass 855 GeV T in (T,B) doublet 1505.04306
VLQ YY → Wb + X 1 e, μ ≥1 b, ≥3 j Yes 20.3 Y mass 770 GeV Y in (B,Y) doublet 1505.04306
VLQ BB → Hb + X 1 e, μ ≥2 b, ≥3 j Yes 20.3 B mass 735 GeV isospin singlet 1505.04306
VLQ BB → Zb + X 2/≥3 e, μ ≥2/≥1 b – 20.3 B mass 755 GeV B in (B,Y) doublet 1409.5500
VLQ QQ → WqWq 1 e, μ ≥4 j Yes 20.3 Q mass 690 GeV 1509.04261
VLQ T5/3 T5/3 → WtWt 2(SS)/≥3 e,μ ≥1 b, ≥1 j Yes 3.2 T5/3 mass 990 GeV ATLAS-CONF-2016-032
Excited fermions
Excited quark q* → qγ 1 γ 1 j – 3.2 q* mass 4.4 TeV only u* and d*, Λ = m(q*) 1512.05910
Excited quark q* → qg – 2 j – 15.7 q* mass 5.6 TeV only u* and d*, Λ = m(q*) ATLAS-CONF-2016-069
Excited quark b* → bg – 1 b, 1 j – 8.8 b* mass 2.3 TeV ATLAS-CONF-2016-060
Excited quark b* → Wt 1 or 2 e, μ 1 b, 2-0 j Yes 20.3 b* mass 1.5 TeV f_g = f_L = f_R = 1 1510.02664
Excited lepton ℓ* 3 e, μ – – 20.3 ℓ* mass 3.0 TeV Λ = 3.0 TeV 1411.2921
Excited lepton ν* 3 e, μ, τ – – 20.3 ν* mass 1.6 TeV Λ = 1.6 TeV 1411.2921
Other
LSTC a_T → Wγ 1 e, μ, 1 γ – Yes 20.3 a_T mass 960 GeV 1407.8150
LRSM Majorana ν 2 e, μ 2 j – 20.3 N⁰ mass 2.0 TeV m(W_R) = 2.4 TeV, no mixing 1506.06020
Higgs triplet H±± → ee 2 e (SS) – – 13.9 H±± mass 570 GeV DY production, BR(H±±_L → ee)=1 ATLAS-CONF-2016-051
Higgs triplet H±± → ℓτ 3 e, μ, τ – – 20.3 H±± mass 400 GeV DY production, BR(H±±_L → ℓτ)=1 1411.2921
Monotop (non-res prod) 1 e, μ 1 b Yes 20.3 spin-1 invisible particle mass 657 GeV a_non-res = 0.2 1410.5404
Multi-charged particles – – – 20.3 multi-charged particle mass 785 GeV DY production, |q| = 5e 1504.04188
Magnetic monopoles – – – 7.0 monopole mass 1.34 TeV DY production, |g| = 1g_D, spin 1/2 1509.08059
√s = 8 TeV
√s = 13 TeV
10⁻¹
1
10
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.
†Small-radius (large-radius) jets are denoted by the letter j (J).

Backup

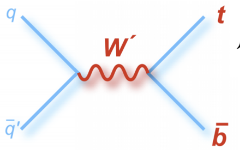
Comparison top tagger - 8 TeV

- substructure tagger I: $\sqrt{d_{12}} > 40$ GeV (labeled '$\sqrt{d_{12}}$ tagger I' in Figure 15)
- substructure tagger II: trimmed anti-k_t $R = 1.0$ mass $m^{\text{jet}} > 100$ GeV (labeled 'm^{jet} tagger II')
- substructure tagger III: $m^{\text{jet}} > 100$ GeV, $\sqrt{d_{12}} > 40$ GeV (labeled 'm^{jet} & $\sqrt{d_{12}}$ tagger III')
- substructure tagger IV: $m^{\text{jet}} > 100$ GeV, $\sqrt{d_{12}} > 40$ GeV, $\sqrt{d_{23}} > 10$ GeV (labeled 'm^{jet} & $\sqrt{d_{12}}$ & $\sqrt{d_{12}}$ tagger IV')
- substructure tagger V: $m^{\text{jet}} > 100$ GeV, $\sqrt{d_{12}} > 40$ GeV, $\sqrt{d_{23}} > 20$ GeV (labeled 'm^{jet} & $\sqrt{d_{12}}$ & $\sqrt{d_{12}}$ tagger V')
- substructure tagger VI: $\sqrt{d_{12}} > 40$ GeV, $0.4 < \tau_{21} < 0.9$, $\tau_{32} < 0.65$ (labeled '$\sqrt{d_{12}}$ & N-subjettiness tagger VI')

ATLAS-CONF-2013-084



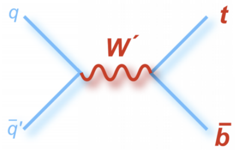
$X \to t\bar{b}$ @ 8 TeV



$$\mathcal{L}_{\text{eff}} = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma^\mu \left(g^R_{ij} P_R + g^L_{ij} P_L \right) W'_\mu f_j \; + \; \text{h.c.}$$

- Predicted in many BSM extensions
- Cover W' that doen't couple to leptons
- For g^L, interference with SM W boson

$X \to t\bar{b}$ @ 8 TeV



$$\mathcal{L}_{\text{eff}} = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma^\mu \left(g^R_{ij} P_R + g^L_{ij} P_L \right) W'_\mu f_j + \text{h.c.}$$

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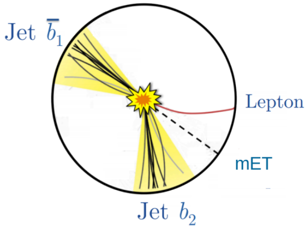
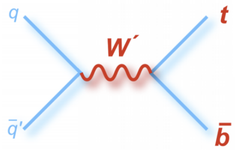


$X \to t\bar{b}$ @ 8 TeV



$$\mathcal{L}_{\text{eff}} = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma^\mu \left(g^R_{ij} P_R + g^L_{ij} P_L \right) W'_\mu f_j + \text{h.c.}$$

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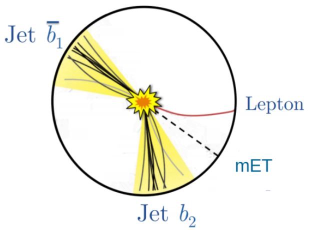
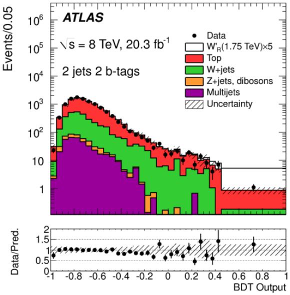
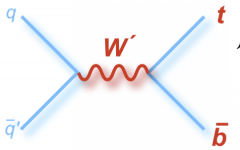


Variable
$m_{t\bar{b}}$
$p_T(top)$
$\Delta R(b_2, W)$
$\Delta\eta(lep, b_2)$
Aplanarity
Sphericity
$\Delta R(b_1, b_2)$
$\Delta R(lep, b_1)$
$p_T(lep)$
$E_T(b_2)$

BDT analysis



$X \to t\bar{b}$ @ 8 TeV



$$\mathcal{L}_{\rm eff} = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma^\mu \left(g^R_{ij} P_R + g^L_{ij} P_L \right) W'_\mu f_j + \text{h.c.}$$

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- Cover W' that doen't couple to leptons
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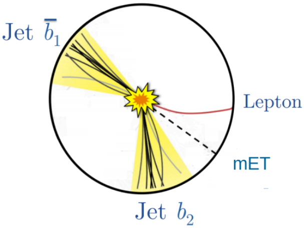
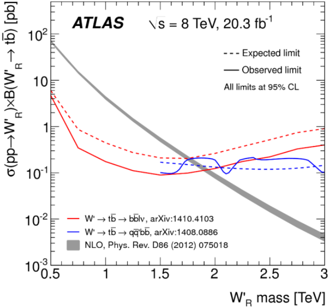
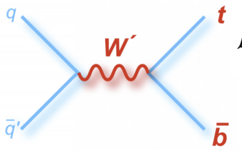




$X \to t\bar{b}$ @ 8 TeV



$$\mathcal{L}_{\text{eff}} = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma^{\mu} \left(g^R_{ij} P_R + g^L_{ij} P_L \right) W'_{\mu} f_j \; + \text{h.c.}$$

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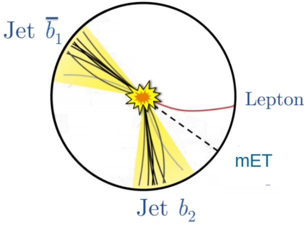
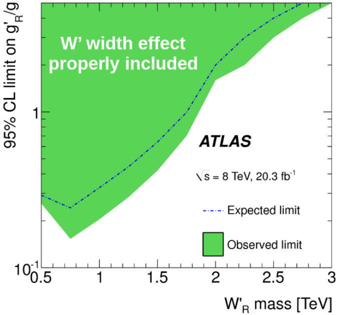
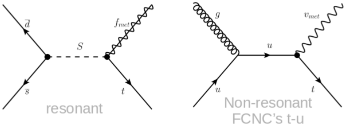
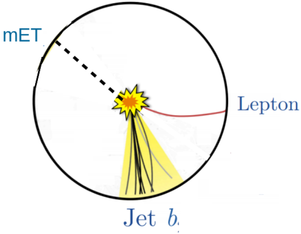




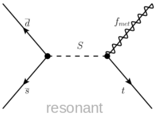
$X \to t\varphi_{\text{inv}}$ @ 8 TeV

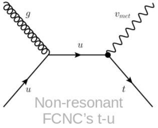


- Signal motivated by several models
- Use an effective Lagrangien approch
- Interesting interepretations in term of DM
- Unusual final state → good to search for NP !



$X \longrightarrow t\varphi_{\mathrm{inv}}$ @ 8 TeV





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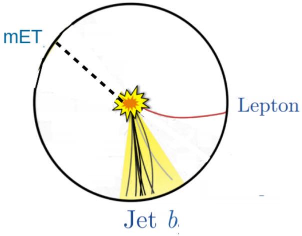
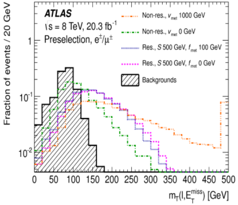
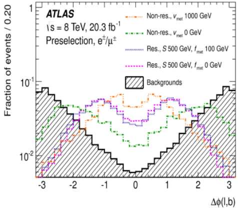
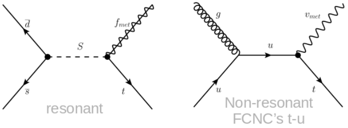


Dominant top background, reduced with these two kinematic variables





$X \rightarrow t\varphi_{\text{inv}}$ @ 8 TeV



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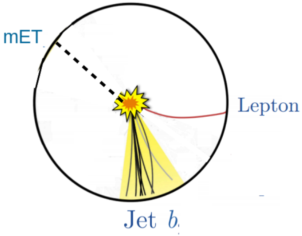
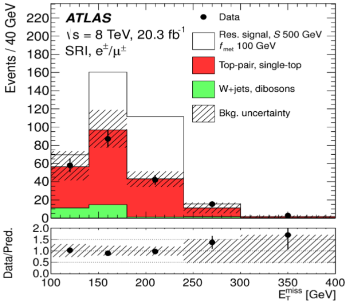
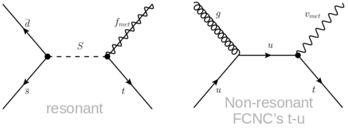




$X \rightarrow t\varphi_{\text{inv}}$ @ 8 TeV



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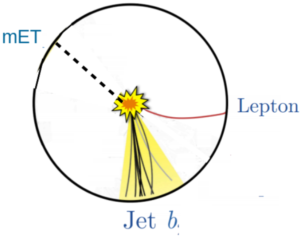

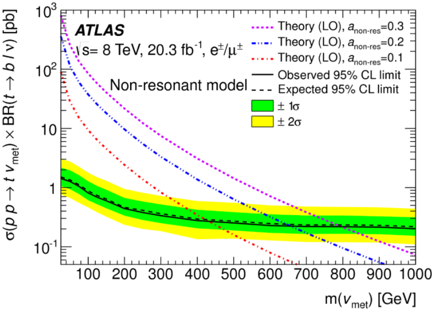

$X \rightarrow t\varphi_{\text{inv}}$ @ 8 TeV