Search for resonances in the $t\bar{t}$ production

Top LHC France 2017, Marseille

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On behalf of the ATLAS and CMS collaborations

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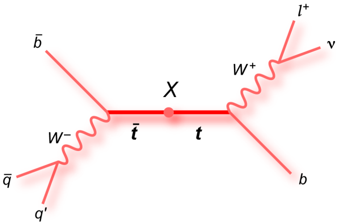
Plan

1. Boosted top quarks
2. Top selections
3. Improvement of leptonic top reconstruction in **ATLAS**
4. Results
5. Re-interpretation of 8 TeV results with interfering signal
6. Perspectives

Concept of the $t\bar{t}$ resonances searches

- Many BSM scenarios predict new particles (X) decaying into a pair of top quarks
  - Z' topcolor assisted technicolor
  - Randall Sundrum → gluon/graviton: g_{KK}/G_{KK}
  - 2 Higgs Doublet Models → heavy pseudoscalar/scalar A/H



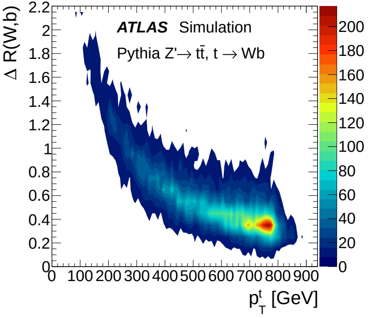
Analysis strategy :
Build a model independent analysis

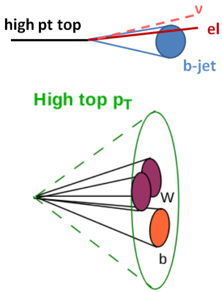
1. Select events
2. Reconstruct $t\bar{t}$ invariant mass
3. Scan $m_{t\bar{t}}$ to find an excess/deficit

- **ATLAS** results from ATLAS-CONF-2016-014
- **CMS** results from CMS-B2G-16-015

Context

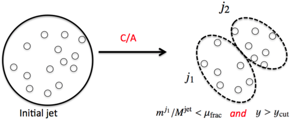
- $t\bar{t}$ resonance search are now sensitive to new particles with a mass $\mathcal{O}(TeV)$
- In such decay $\rightarrow$ the tops are produced with high momentum
- It leads to the collimation of the decay products
  - Merging of jets
  - Lepton-jet overlap



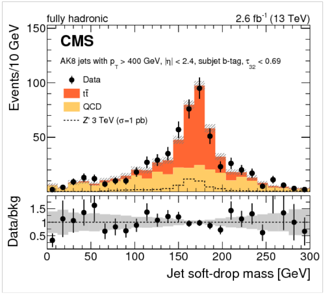


Boosted hadronic top selection : top tagging

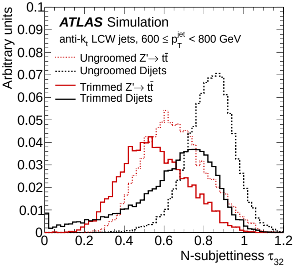
- Fat jet used to reconstruct boosted hadronic top
- Jet sub-structure used to differentiate QCD vs top fat jet



	CMS	ATLAS
large jet def	anti-kt (R=0.8)	anti-kt (R=1.0)
jet cleaning	Soft drop	Trimming
top tagger (t-tag)	$\tau_{32} < 0.69$ $110 < M_{SD} < 210$	τ_{32} and m_{jet} cut optimised to have 80% eff



Soft drop jets mass (M_{SD})



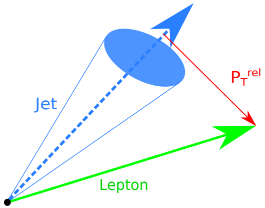
τ_{32}

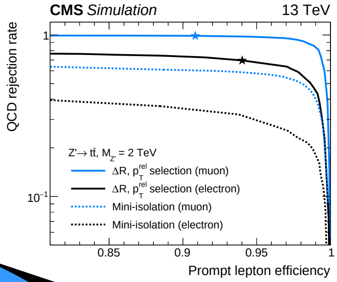
Boosted leptonic top selection

CMS strategy

- No isolation cut applied
- 2 dimentionnal cut :
- $\Delta R(l; jet) > 0.4$ or $p_{\mathrm{T}}^{rel} > 20\mathrm{GeV}$

  p_{T}^{rel} is the lepton p_T component relative to the jet axis
- $(p_T^{miss} + p_T^{l}) > 150\,GeV$
- Select jet in $\Delta R(lep; jet) < 1.2$
- Minimise χ^2 to find best combination





ATLAS strategy

- Isolation cut applied with p_T dependant cone (mini-isolation)
- Optimised in $\eta \times p_T$ to have 99% lepton selection efficiency
- leptonic b-jet : highest p_T jet within $\Delta R(let; jet) < 1.5$

Overlap removal impact in ATLAS

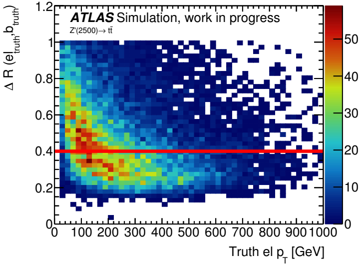
- In ATLAS, electrons and jets are reconstructed with the same calorimeter
- But with independent algorithms
- To avoid double counting and contamination of electron in jet

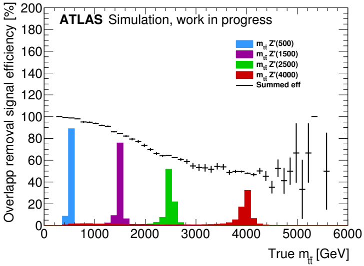
$\Rightarrow$ apply overlap removal procedure

- Basically an electron cannot be within a jet ie $\Delta R > 0.4$

But for boosted top , the prompt electron may fall within the top b-jet

- The higher is the mass of the signal, the worse is the effect



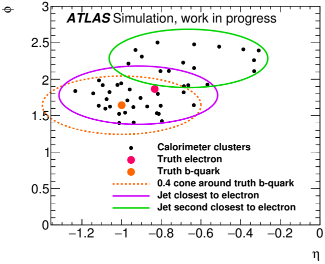


How to avoid such loss of efficiency while reconstructing correctly electrons and jets ?

The electron-in-jet removal method (ER)

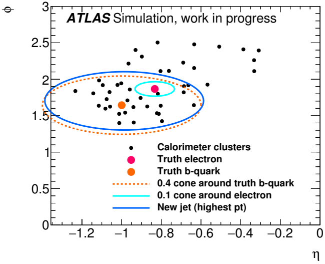
Basic Idea: remove electron cluster before defining jets

1. First select the electrons in the event via kinematics cuts (p_T,quality,eta)$\rightarrow$ intendt to select only top decay products
2. Match topoclusters to electron (radius=0.1)
3. The matched topocluster is removed if
   - 3.1 it falls within the calo crack region
   - 3.2 if the cluster has an $EM_{frac} > 0.8$
4. Apply jet algorithm on remaining topoclusters



Current reco w/o OR

→

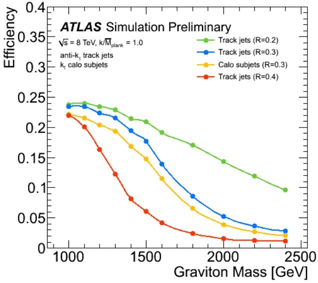


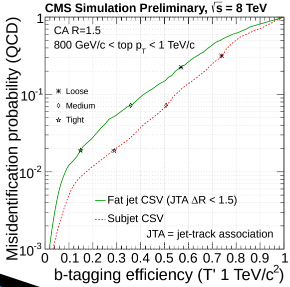
With el-in-jet removal

B-tagging in boosted topologies

ATLAS

- Track-jets (anti-kt R=0.2) are more efficiently b-tagged in boosted cases
- $t\bar{t}$ resonance search requires at least 1 b-tagged track-jet
- B-tagging algorithm WP has ≈ 70% efficiency
- Additionnal studies to optimise b-tagging between high and low $t\bar{t}$ mass



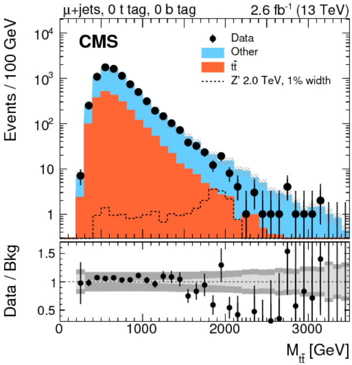


CMS

- B-tagging applied on soft-drop sub-jets
- In Run-2 the standard CMS algorithme CSV2 is applied on them
- Allows to reduce significantly the mis top-tag rate

Background estimation in boosted topologies (1)

- $t\bar{t}$ is the dominant bkg (modeled via Monte-Carlo)
- In 0 b-tag region the dominant background is W+jets:
- Shape well modeled
- Scaling needed to be corrected in data
  - **CMS** constrain it in the 0 b-tag control region
  - **ATLAS** rescale it via the difference of charge distribution
  - The scale is computed via :



$$N_{Data,W} = \left(\frac{r_{MC}+1}{r_{MC}-1}\right)\left(N^{+}_{Data} - N^{-}_{Data}\right)\text{ , with } r_{MC} = \frac{N_{MC,W^+}}{N_{MC,W^-}}$$

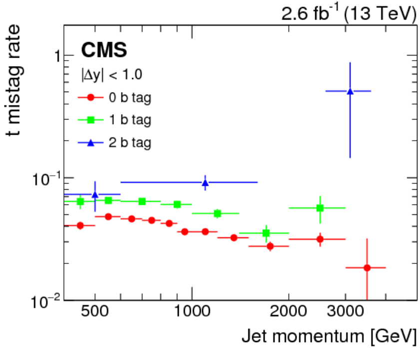
Background estimation in boosted topologies (2)

Multijet background (lepton+jets) :

- Strongly reduced by $p_t^{miss} > 120\text{GeV}$ cut in **CMS**
- Estimated in data using the matrix method in **ATLAS** :

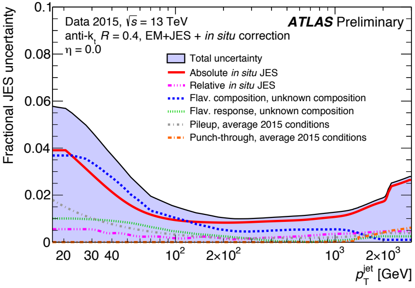
Multijet background (all hadronic) CMS:

- Measure the multijet background using anti-tag and probe method:
- Select the anti-tag by reverting t-tag cuts
- Determine the t-tag rate for the second jet

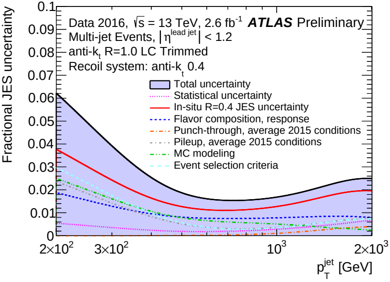


Important systematics

- Drawback of boosted topologies → large uncertainties on large R jets
- Here comparison of uncertainty of small vs large R jets in **ATLAS**



Small R jets

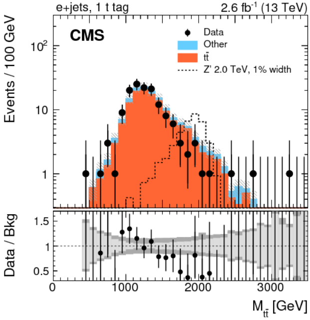


Large R jets

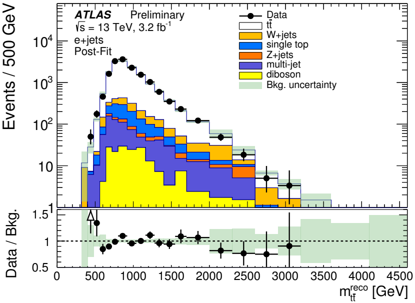
- In **CMS**:
  - The mistag rate uncertainty is in range [5 – 100%]
  - The mistag efficiency is estimated at 19%

Results in the lepton + jet channel

- **CMS** Split space in 6 region (e,μ)$\times$ (1 t-tag, 0 t-tag+1 b-tag, 0 t-tag+0 b-tag)
- **ATLAS** Use 2 regions (e, mu) with >1 t-tag and >1 b-tagged track-jet.



CMS e+jets
+ 1 t-tag selection

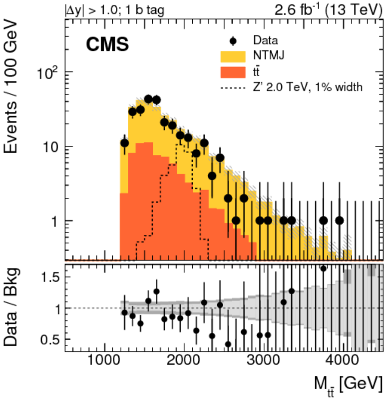


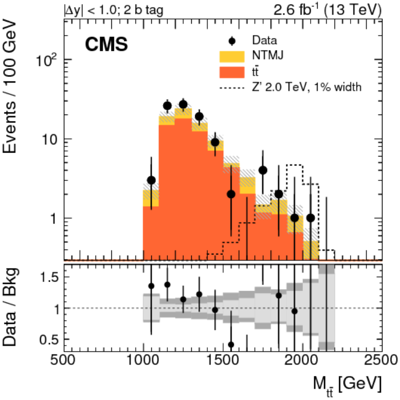
ATLAS e+jets selection

- No significant deviation found above background

Results in the fully hadronic channel in CMS

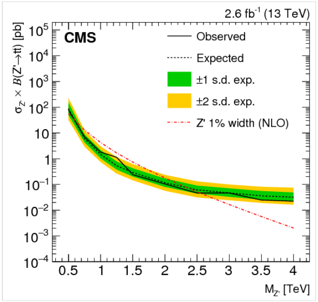
- The requirement of 2 t-tag fat jet highly supress the QCD background
- Remaining QCD background estimated in data
- Space splitted into ($y < |1|$, $|y| > 1.0$) $\times$ (0 b-tag, 1 b-tag, 2 b-tag)

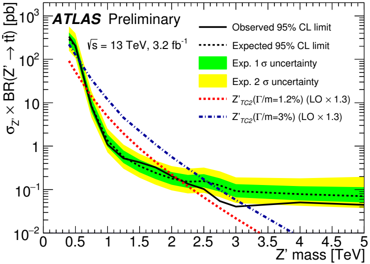




Limits setting

Exclusion for narrow with ($\Gamma/m \approx 1\%$) Z'





CMS
Obs Exclusion: 0.6-2.5 TeV

ATLAS
Obs Exclusion: 0.7-2.0 TeV

CMS exclusion presented for several width

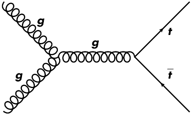
- Z' for 10% (0.5-3.9) TeV
- Z with 30% (0.5-4.0) TeV
- RS KK graviton (0.5-3.3) TeV

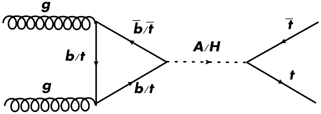
H/A $\to t\bar{t}$ case

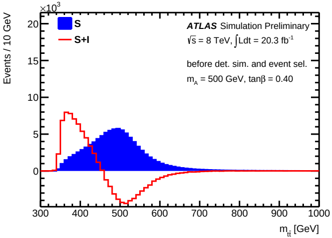
ATLAS-CONF-2016-073

Re-interpretation 8 TeV (20 fb^{-1}) $t\bar{t}$ resonances search

- 2HDM model predicts Scalar (H) or Pseudoscalar (A) decaying into $t\bar{t}$
- Large interference (I) with SM $gg \to t\bar{t}$ production
- It would require signal (S)+ (I) + background (B) simulation at parton level for each mass point





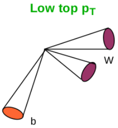


- Generator modified to produce only S+I
- $m_{t\bar{t}}$ Signal modeling at parton level versus Signal + Interference modeling.
- Validated with S+I+B generation for some parameter space points
- Difference treated as systematics uncertainties (0.4%)

Cross-section k-factor on (I) set as $k = k_{Signal}$
in the future $k = \sqrt{k_{background} \times k_{Signal}}$

$H/A \to t\bar{t}$ analysis setup and results

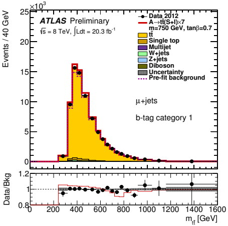
Resolved selection



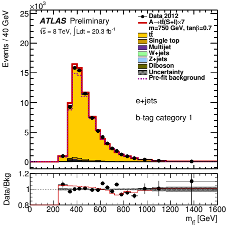
- Exactly 1 lepton (electron or muon)
- 4 jets (1 or 2 b-tags)
- Jet ambiguity solved by minimizing a χ^2 over jet combinations

Invariant mass

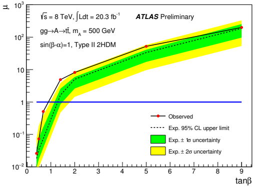
muon selection



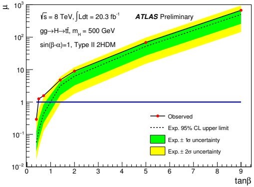
electron selection



Limit on the signal strength μ versus $\tan(\beta)$, $m_{H/A} = 500 GeV$



Pseudo scalar



Scalar

Perspectives

- $t\bar{t}$ resonance search performed both in **ATLAS** and **CMS**
- Probe TeV scale region without evidence of resonant signal

- In both experiments less than 10% of 13 TeV data are analysed
- Resolved channel will be studied but:
  - Higher QCD background
  - Stronger constrains due to high statistic at low mass
- Studies are ongoing to improve the top reconstruction and selection efficiencies

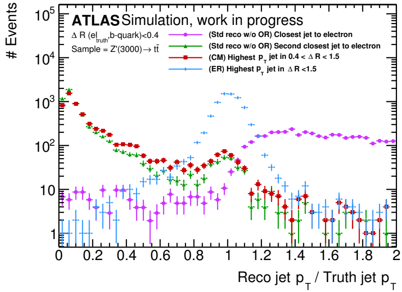
- Re-interpretaion of 8TeV data done for **ATLAS** and ongoing for **CMS**
- Limits set on low $tan(\beta)$ regions for mass of H/A = 500 and 750 GeV.

THANK YOU
QUESTIONS ?

BACKUP

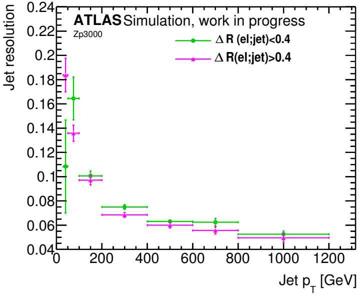
Jet selection boosted case

$\Delta R(el_{Truth}; b - quark) < 0.4$



Electron in jet removal is the only method reconstructing well jets

Compare jet resolution for above and below 0.4



Resolution is similar in both case

Top Tagging details

CMS Soft drop ref

- Fat jet is reclustered with C/A
- In the last step get j1 and j2 the 2 last subjets

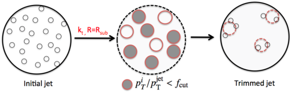
$$\frac{min(p_{T1}, p_{T2})}{p_{T1}+p_{T2}} > z_{cut} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$$

The parameter used are : $Z_{cut} < 0.1$, $\beta = 0$ and $R_0 = 0.8$

- Fat jet fullfill this condition -> OK kepts af SD jet
- Else, the highest pt subjet is taken and restart the procedure.

ATLAS Trimming

- Recluster with kt algorithm $R_{sub} = 0.2$
- Remove sub-jets with a fraction $pt_i/pt_jet < f_{cut} = 5\%$



Complex variables mentionned in this talk

τ_{32} is the ratio of τ_3/τ_2 and represent oth probility that a Fat jet is rather 3-prong than 2-prong

τ_N is the N-subjetiness and is computed as

$\tau_N = \frac{1}{d_0}\sum_k p_{\mathrm{Tk}} \times R_k^{min}, \mathrm{with\ d_0 = \sum_k p_{Tk} \times R}$

where k run over all the clusters and R is the characteristic size of sub-kt jets

am_{T2} target dilepton $t\bar{t}$ events. For such topology it has an end-point at $m_{top} = 175 GeV$. Derived from m_{T2} variables

m_T^W is teh w trasverse mass $m_T^W = \sqrt{2p_{\mathrm{T}}^{lep}E_{\mathrm{T}}^{miss}[1 - cos(\Delta\phi)]}$

CMS anlysis precisions

$$\chi = \left(\frac{M_{\boldsymbol{lep}} - \overline{M_{\boldsymbol{lep}}}}{\sigma_{M_{\boldsymbol{lep}}}}\right)^2 + \left(\frac{M_{\boldsymbol{had}} - \overline{M_{\boldsymbol{had}}}}{\sigma_{M_{\boldsymbol{had}}}}\right)^2$$

H/A anlysis precisions

Generator modification:
The modified generator is MadGraph5_aMC@NLO

Systematics

JES/JER (SM $t\bar{t}$)	6%
JES/JER (Signal S+I)	8%
JES/JER (Signal S)	4%
PDF on signal	12.3%
b-tag (bkg)	2%
b-tag (signal)	1%
$t\bar{t}$ cross section	6.5%
$t\bar{t}$ Parton Showering	5%
multijet bkg norm	20%
ST bkg norm	7.7 %
Z+jet bkg norm	48%
Signal remorm	7.5%
Inerference modeling	0.4%

To find better jet lepton combination
$\Rightarrow$ minimize χ^2

$$\chi^2 = \left[\frac{m_{jj} - m_W}{\sigma_W}\right]^2 + \left[\frac{m_{jjb} - m_{jj} - m_{th-W}}{\sigma_{th-W}}\right]^2 + \left[\frac{m_{j\ell\nu} - m_{tl}}{\sigma_{t\ell}}\right]^2 + \left[\frac{(p_{\mathrm{T},jjb} - p_{\mathrm{T},j\ell\nu}) - (p_{\mathrm{T},th} - p_{\mathrm{T},t\ell})}{\sigma_{diffp\mathrm{T}}}\right]^2$$

1. term constraint the W jet mass
2. term constraint the top-W mass
3. term constraint the top mass
4. term constraint the pt baance between leptonic and hadronic side

Multijet background estimation

- Multijet background is dominant at LHC
- Analysis design to supress it a maximum
- Not enough MC to run representative amound of QCD bkg
- Faking lepton is not well modeled (else it would have been corrected!)
- Measure QCD background in data direcly

Matrix method

- define Tight and Loose lepton selection
- Measure ϵ (f): the fraction of real(fake) lepton selected as tight lepton
- ϵ (f) is measured in a signal (background) enriched region

$\epsilon = N^{real}_{tight}/N^{real}_{loose}, \; f = N^{fake}_{tight}/N^{fake}_{loose}$

The system can be summarisez via : $\begin{pmatrix} N_{tight} \\ N_{loose} \end{pmatrix} = \begin{pmatrix} \epsilon & f \\ 1 & 1 \end{pmatrix} \times \begin{pmatrix} N^{loose}_{prompt} \\ N^{loose}_{fake} \end{pmatrix}$

By inverting the system it yield N_{prompt} and N_{fakes} in fuction of ϵ, f, N_{tight} and N_{loose}, the 2 latest being estimated directly in data.