BOOSTed Physics at ATLAS

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On behalf of the ATLAS collaboration

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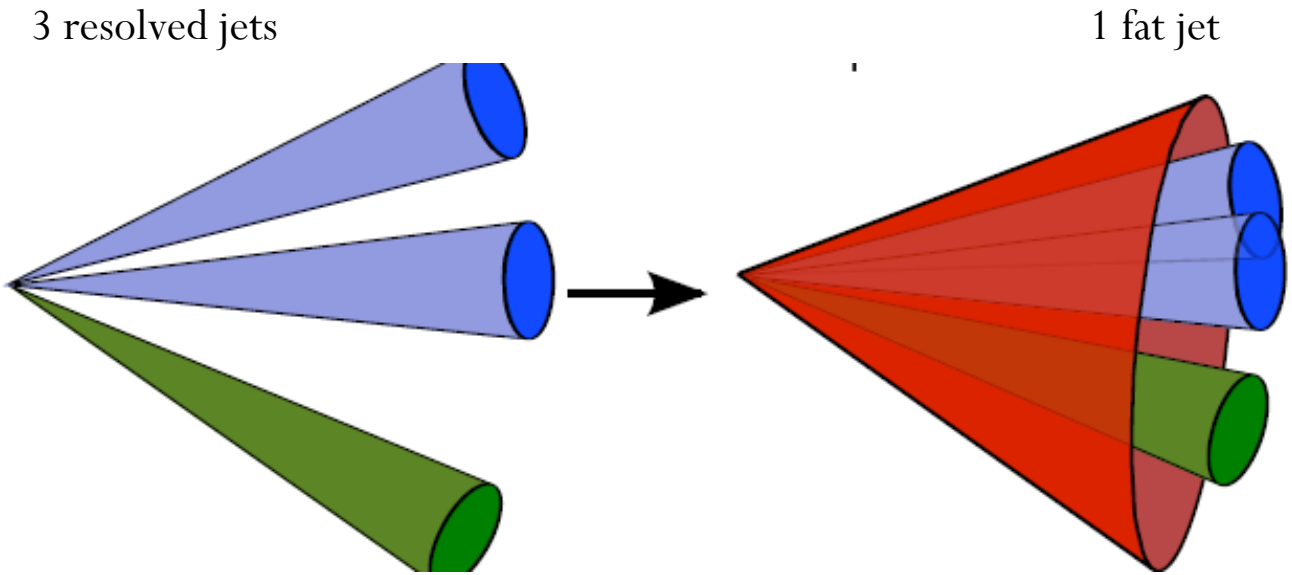
LHC days in SPLIT

Motivation

- With increasing c.m. energies, particles tends to be more boosted, and their decay products more collimated.
  - heavy particles produce naturally boosted objects as single massive jet
  - Standard reconstruction of the decays products inefficient
  - With the increasing luminosity, the number of observed boosted particle become significant in present LHC data



Motivation

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- To fully exploit potential signatures (at high mass) from new physics at LHC **novel reconstruction techniques to handle highly boosted objects**

- Simple Fat jet reconstruction or Jet substructure techniques to identify the hadronic decays of boosted particles.

  application to reconstruction of **W & top hadronic decays**

BOOSTED Physics

LHC explores the TeV scale :Hunting massive particles

Many studies dedicated to fat jets/ using jet substructure technique in ATLAS

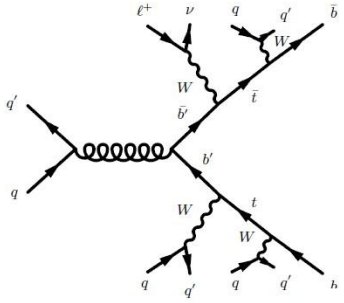
- Focusing on some recent results
  - **Heavy ttbar resonances (boosted tops)**
    - Many models of new physics BSM predict resonances in the TeV mass range that decay primarily into ttbar quark pairs
  - **4^{th} generation b' →Wt ,t' →Wb (boosted W)**
    - **Natural extension to the SM. Generic search for heavy up/down quarks**
- Other ongoing studies
  - **RPV gluino decay** to three overlapping jets **(boosted jet triplet)**
  - **…**

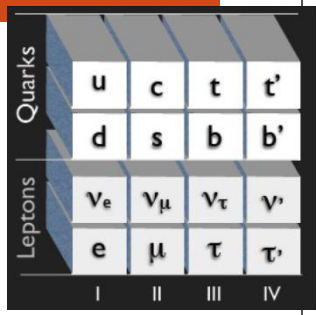
A simple approach

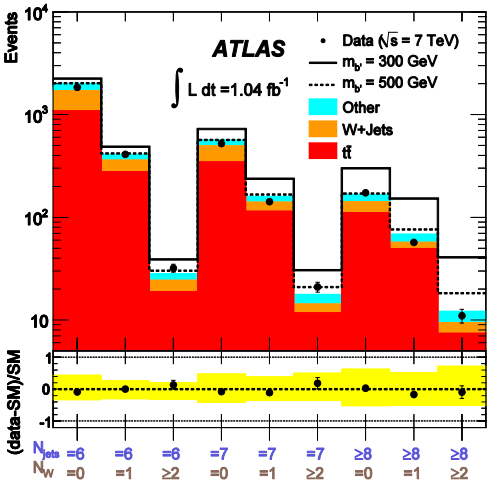
$b' \rightarrow Wt$

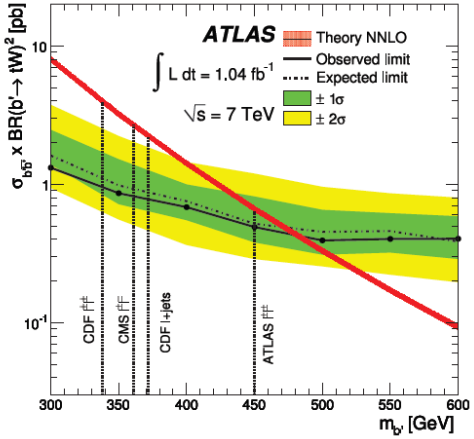
[arXiv:1202.6540]

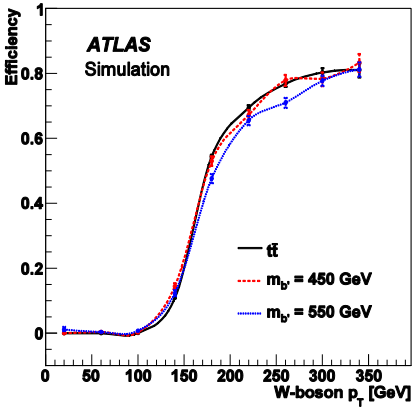
- $b'b' \rightarrow WtWt \rightarrow l\nu$+8jets, single lepton trigger
  - signature :lepton+MET+≥6 jets
- Boosted W Approach :
  - Semi-Boosted Ws
  - look at **jet pairs with small opening angle** and m_{jj} ~mW
  - up to 80% selection efficiency for high pT W











Main syst. : JES, ISR/FSR

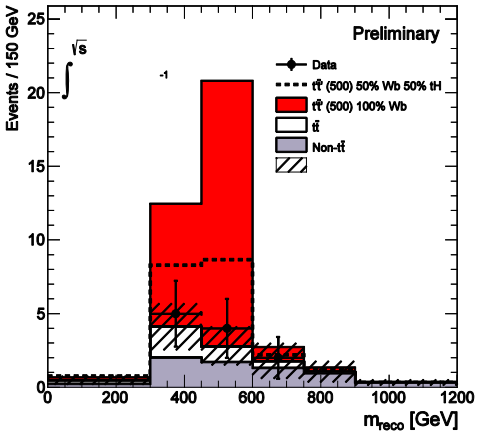
$M_{b'} > 480$ GeV @95%CL, BR(b'→Wt)=1

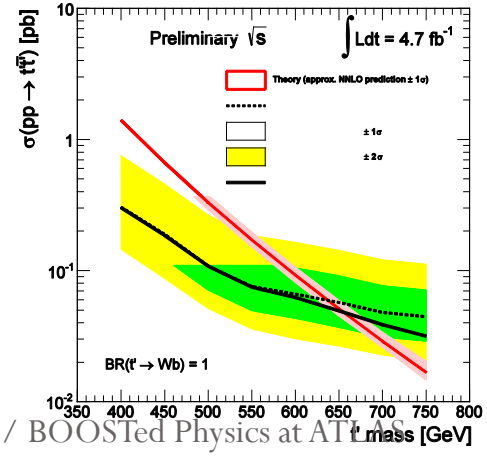
(non boosted analysis $M_{b'} > 450$ GeV)

A simple approach $t' \rightarrow Wb$

[NEW]

- $t't' \rightarrow Wb\,Wb \rightarrow l\nu$+4jets, single lepton trigger
  - signature :lepton+MET+≥3jets; ≥ 1b-tag jet
  - define as the 2 b-jets, the 2 jet with higest btag Prob
- Boosted W Approach :
  - exploit kinematics :Large $\Delta R(Wb)$ small $\Delta R(jj)_W$
  - Select candidates (≥1 fat jet+3 ≥ jets) or (≥4 jets+ ≥ 1 resolved W
  - Use kin to educe BKG: $\Delta R(Wb) > 1.4$ & $\Delta R(lb) > 1.4$
  - Choose W1b1W2b2 combination minimizing $MW_1\, b_1 - MW_2\, b_2$





$M_{t'} > 656$ GeV @95%CL, BR(t'→Wb)=1

A sophisticated approach

- $X \rightarrow t\bar{t} \rightarrow WbWb$
  - Two specific models that predict resonances with narrow and broad decay widths are used as benchmarks:
    - Leptophobic topcolour Z', spin 1 with $\Gamma/m = 1.2\%$

      Eur. Phys. J. **C72 (2012) 2072**
    - Kaluza-Klein (KK) gluons from RS models, spin 1 with $\Gamma/m = 15.3\%$

      Phys.Rev. **D76 (2007) 036006 ;** JHEP **0709 (2007) 074**

- Reconstruction with standard jets and by exploiting jet substructure
- Channels : lepton+jets, all-jets

channel	Resolved analysis	Boosted analysis
All-jets		4,7fb-1 ATL-CONF-2012-102
Lepton(e,μ)+jets	4,7fb-1 ATL-CONF-2012-136	4,7fb-1 ATL-CONF-2012-136

.

A sophisticated approach $t\bar{t}$ resonances

- $X \rightarrow t\bar{t} \rightarrow WbWb$?

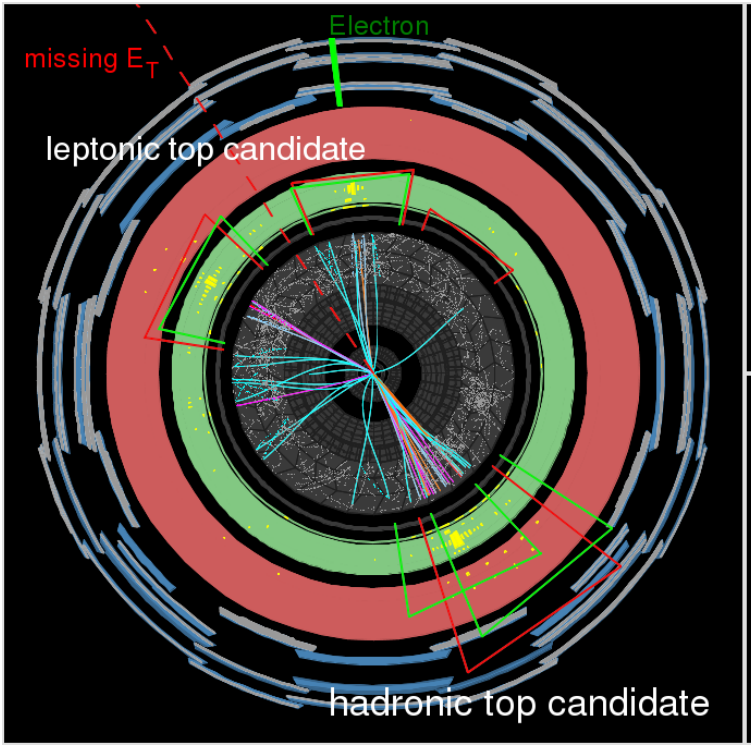
a $t\bar{t}$ candidate (m=2.5 TeV)

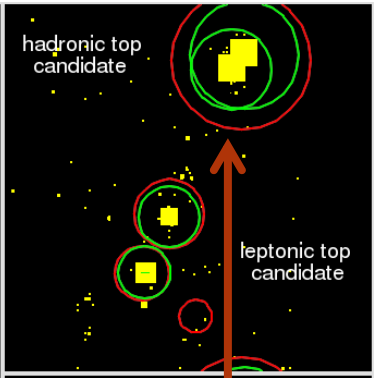
with a highly boosted hadronic top

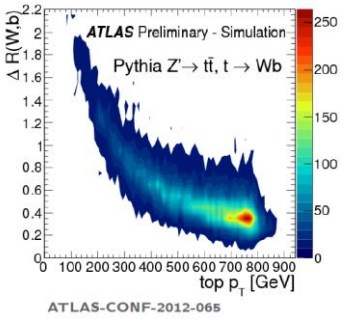
Jets reconstructed

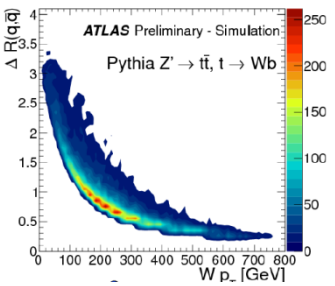
with R = 0.4 in green circles,

with R = 1.0 in red circles

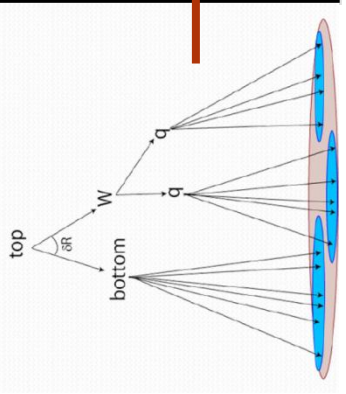








ATLAS-CONF-2012-065



A sophisticated approach

Boosted Techniques

$t\bar{t}$ resonances

- **Investigation of the substructure**
  - **Soft radiation, Underlying event & pile-up in the fat jet dilute substructure**

    "grooming" allows to extract substructure. Three main techniques :

    pruning [Ellis, Vermilion, Walsh; 2009]

    filtering [Butterworth, Davison, Rubin, Salam; 2008]

    Trimming [Krohn, Thaler, Wang; 2010]

  - ATLAS studies to gain confidence in subjet/boosted techniques

    [arXiv:1203.4606] jet mass and subjet variables

    [arXiv:1206.6369] properties of boosted jets

MC predictions are found broadly in agreement with data

ATLAS HEPToptagger for reconstruction and tagging specfic to Top quark

[atl-conf-2012-065] [atl-conf-2012-066]

  - **using filtering like approach**

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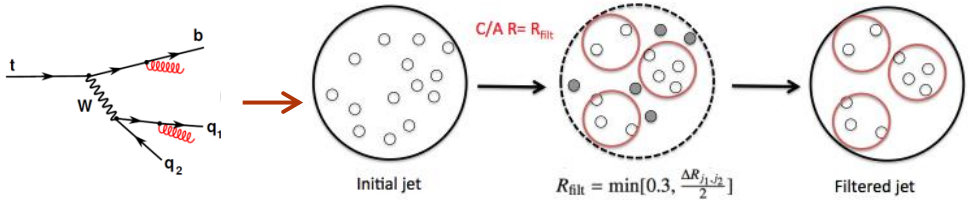
A sophisticated approach
HEPTopTagger

- **HEPToptagger for reconstruction and tagging specfic to Top quark**

Filtering :



- **Iterative clustering : seeks to isolate concentrations of energy within a jet by identifying relatively symmetric subjets, each with a significantly smaller mass than that of their sum**
  - Start from the two subjets of the fat jet from the last stage of clustering of C/A jet algorithm
  - Mass-drop: Decompose jets until $m_{ji} < 30$GeV with requirement $m_{ji} < \mu\, m_{fatjet}$ => at least 3 subjets
  - Filtering :re-cluster with Rfilt = min[0:3;ΔRj1; j2/2]
  - build exactly 3 subjets from the selected constituents with mass constraints

⇒ **Rejection of UE/pile-up deposits**

⇒ **Sub-jets reconstruction**

⇒ **Reclustering to 3 sub-jets with mass constraints**

A sophisticated approach

tt̄ resonances

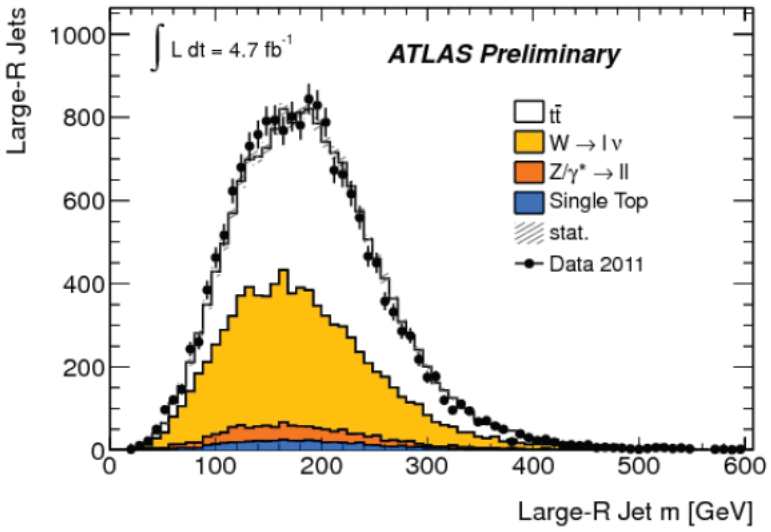
HEPTopTagger

- HEPTopTagger performance *[atl-conf-2012-065]*

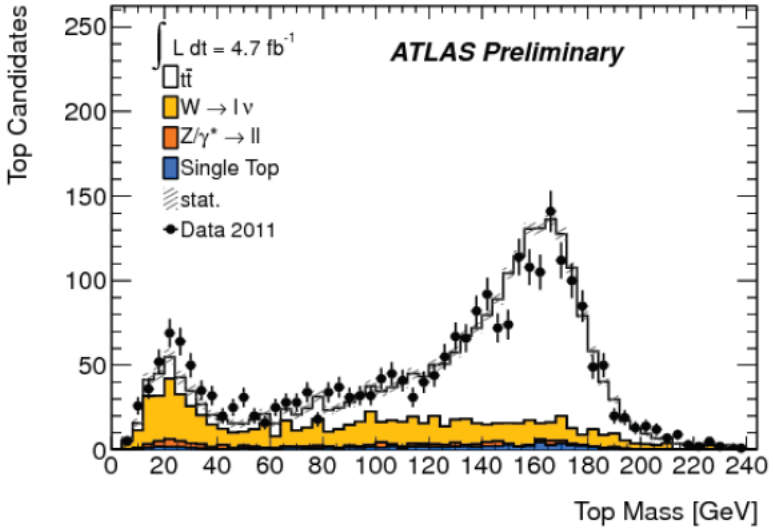
  using **tt̄ → WbWb → lν+4jets**

  Single muon trigger, ≥4 jets (AKT4), MET

jets with R=1.5 before HEPTopTagger



after HEPTopTagger



A sophisticated approach

$t\bar{t}$ resonances

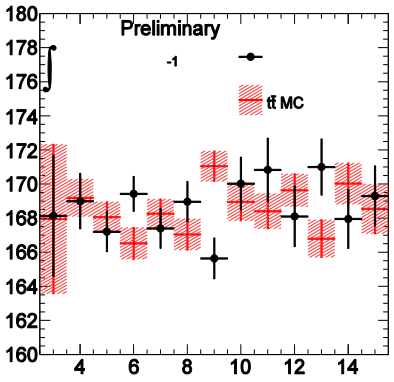
All-jet Channel

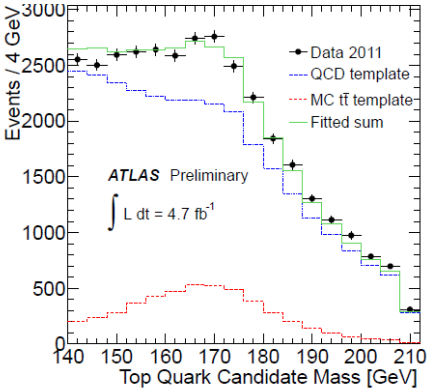
- $t\bar{t} \rightarrow WbWb \rightarrow 6$ jets

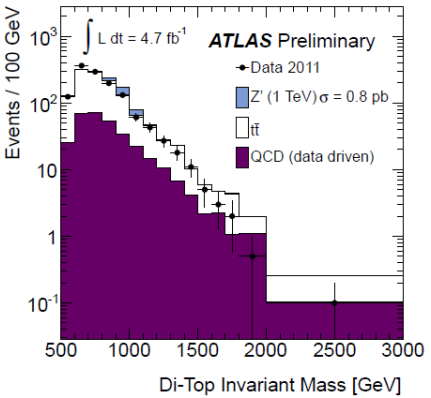
High pT jets trigger,

mini-isolation lepton veto, ≥2 fat jets(C/A,R=1.5) with pT>200GeV, ≥2 b-tag jets(AKT4)

- $t\bar{t}$ reconstruction
  - 2 jets HEPTOPtagger (Mt not impacted by PU)
  - Build Di-top invariant mass
  - SM top pairs normalisation from a fit in Control region
  - QCD multijet from control regions







No excess observed

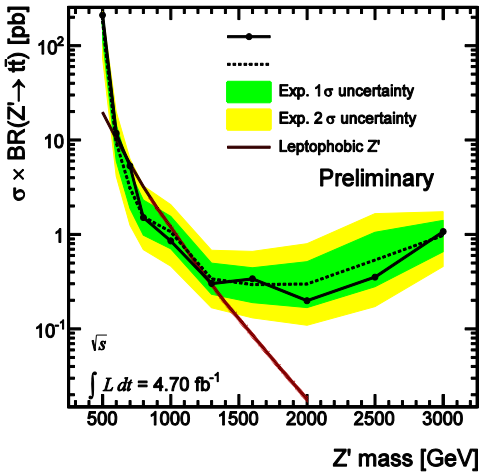
A sophisticated approach

All-jet Channel

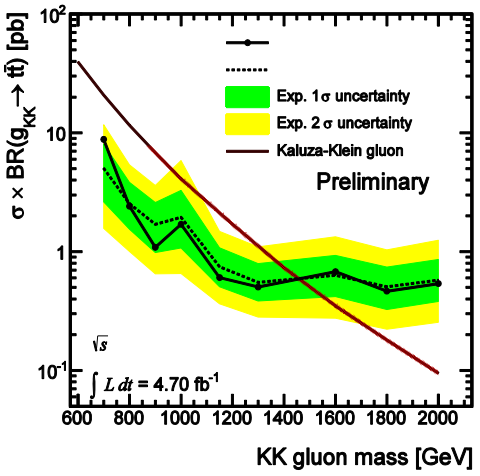
$t\bar{t}$ resonances

- Limits

limits for Z'



KK gluon



Exclusion range @95%CL

0.7 TeV $< m_{Z'} <$ 1.3 TeV

0.7 TeV $< m_{gKK} <$ 1.5 TeV

A sophisticated approach

Lepton+jet Channel

$t\bar{t}$ resonances

- $t\bar{t} \rightarrow WbWb \rightarrow l\nu$+4jets

Resolved : low tt mass range
Resolved semi-boosted: intermediate mass range
Boosted : high mass range

resolved: Single lepton trigger, ≥4 jets (AKT4), MET, ≥1 b-tag

resolved semi-boosted(W boosted) : Single lepton trigger, ≥3 jets (AKT4) with 1 jet m>60GeV, MET, ≥1 b-tag

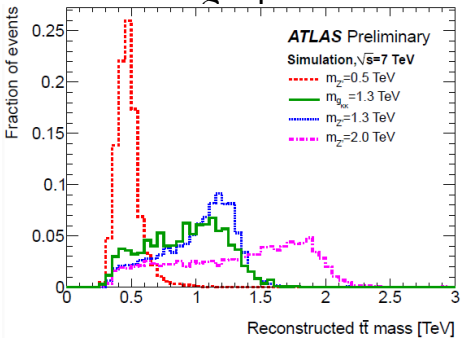
boosted: fat jet (AKT10) trigger, 1 lepton (mini-isolation), 1 leptonic jet (AKT4) ,

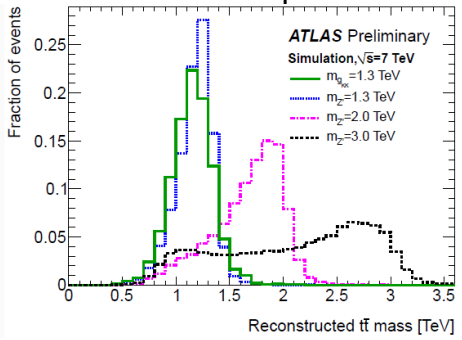
fat jet p_T >350 GeV, m>100Gev, $\sqrt{d_{12}}$>40GeV, ≥1 b-tag

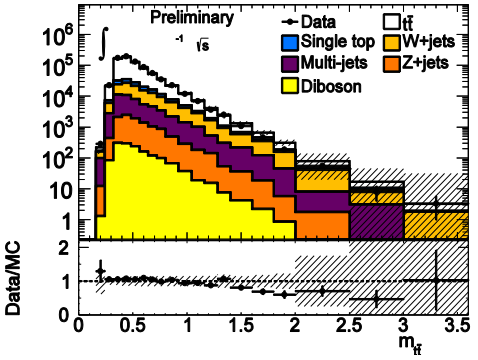
- $t\bar{t}$ reconstruction
  - neutrino momentum reconstruction using MET and M_W constraint

resolved: use combination with lowestχ^2 using M_W and M_{top} constraints

boosted: using lepton+neutrino + nearest from lepton AKT4 +AKT10 jet







No excess observed

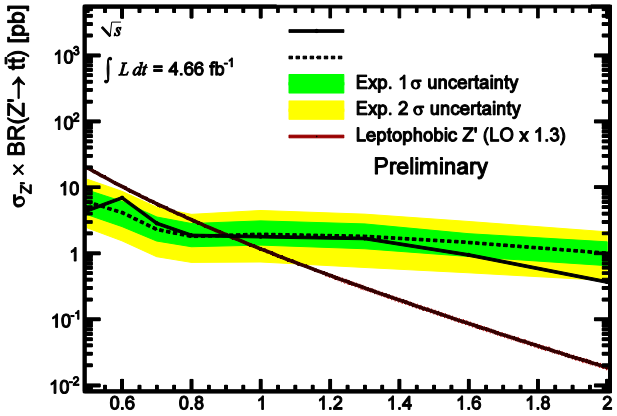
A sophisticated approach

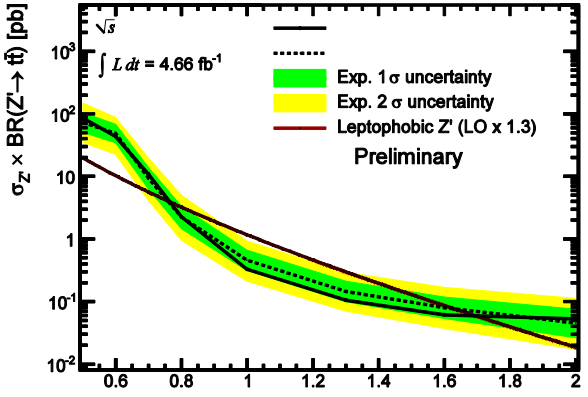
$t\bar{t}$ resonances

Lepton+jet Channel

- Limits
  - Use boosted reconstruction if event select by resolved & boosted
  - Some events at high mass from resolved reconstruction

limits for Z’ resolved boosted





Complementary approach, better sensitivity at low mass for resolved, at high mas for boosted

Combined limit of boosted+resolved

Exclusion range @95%CL

0.5 TeV $< m_{Z'} <$ 1.7TeV 0.7 TeV $< m_{gKK} <$ 1.9TeV

Summary

- Jet substructure techniques to identify the hadronic decays of boosted heavy particles demonstrated that they are key feature for massive particle search at LHC.

- With increasing c.m. energy and luminosity, Boosted techniques will gain in importance in the future

- No evidence for new physics in boosted physics found yet, but reached mass range increased significantly thanks to boosted techniques

A sophisticated approach

$t\bar{t}$ resonances

HEPTopTagger

- **Investigation of the substructure**

HEPToptagger for reconstruction and tagging specfic to Top quark

- **Soft radiation, Underlying event & pile-up in the fat jet dilute substructure**

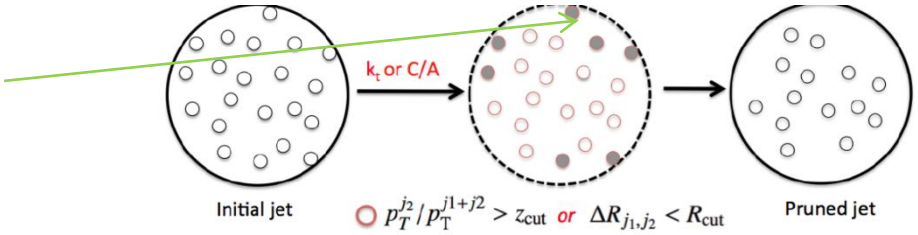
"grooming" allows to extract substructure. Three main techniques :

pruning [Ellis, Vermilion, Walsh; 2009]

filtering [Butterworth, Davison, Rubin, Salam; 2008]

Trimming [Krohn, Thaler, Wang; 2010]

Pruning : discard soft & wide angle particles



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A sophisticated approach
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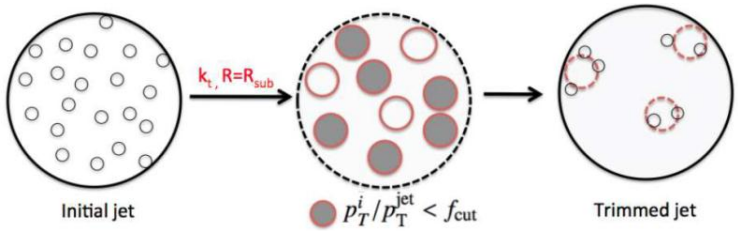
Trimming :



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