$t\bar{t}$ resonance searches with ATLAS

Gregor Kasieczka
(Universität Heidelberg, Germany)
for the ATLAS Collaboration,

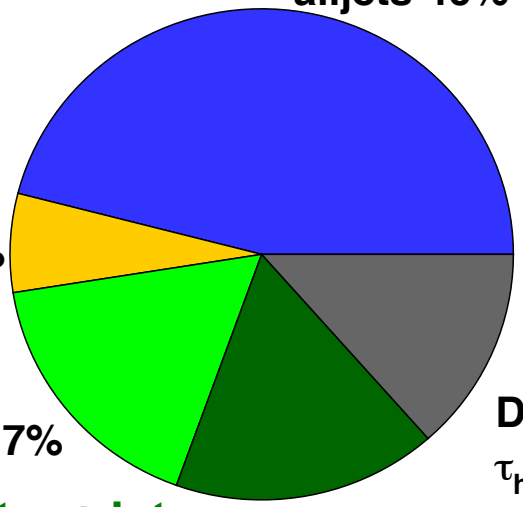
Boost2012 Valencia, Spain

22.07.-27.07.2012

Introduction

- The LHC provides many $t\bar{t}$ events at high di-top masses
- New Physics is expected to couple to the top quark

Fully-Hadronic:
ATLAS-CONF-2012-102



Dileptons:
arXiv:1205.5371

No dedicated search with hadronically decaying taus (leptonic tau decays included in e/mu branching fractions)

Lepton+Jets
arXiv: 1205.5371 (resolved)
arXiv: 1207.2409 (boosted)

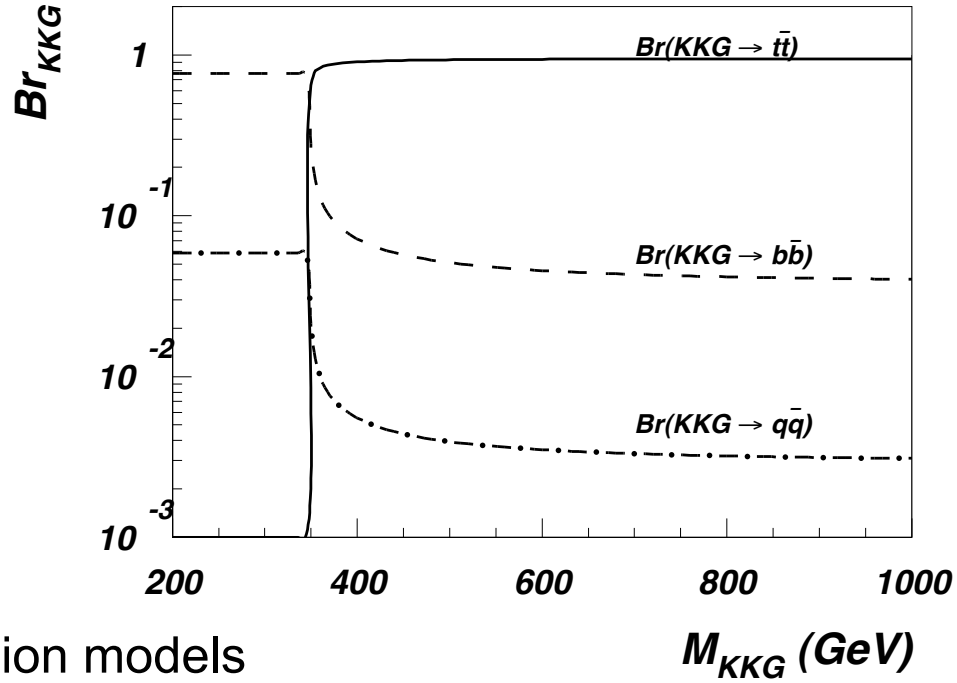
→ *Show results with 2011 pp data in all three channels…*

What are we looking for?

New particles decaying to $t\bar{t}$

Benchmark models:

- Z' boson
  - Leptophobic topcolor model
  - Narrow: $\Gamma/m = 1.2\%$
  - Phys. Rev. D 49 (1994) 4454
    arXiv:hep-ph/9911288
    arXiv:1112.4928
- Kaluza-Klein gluon (KKG)
  - Colored resonance
  - Randall-Sundrum extra dimension models
  - $\Gamma/m = 15.3\%$
  - Phys. Rev. D 77 (2008) 015003
    Phys. Rev. D 76 (2007) 115016
    JHEP 09 (2007) 074



KKG branching ratio
as a function of mass
[Phys. Rev. D 77 - 015003]

e+e, μ+μ and e+μ 6.5%

Dilepton final state

Object & event selection

- Electron (e):
  - p_T > 25 GeV
  - |η| <2.47 (exclude 1.37 <|η|<1.52)
- Muon (μ):
  - p_T > 25 GeV
  - |η| <2.5
- 2 isolated leptons (e or μ)
  - Opposite charge
- Single Lepton Trigger:
  - 20 GeV or 22 GeV for e
  - 20 GeV for μ

- ≥2 anti-k_T (R=0.4) jets
  - p_T>25 GeV
  - |η| <2.5
- $|m_{ll}-m_Z|$ > 10 GeV
- E_T^{miss}>40 GeV
- m_{ll}>10 GeV
- For e+μ:
  - $H_T=\sum p_T^{Leptons}+\sum_{i=1..2} p_{T,i}^{Jets}$
  - H_T > 130 GeV

Acceptance x efficiency: 1.5% for benchmark signal (KK gluon, 1100 GeV)
Only KKG signals are considered in this channel.

Background estimate

e+e, μ+μ and e+μ 6.5%

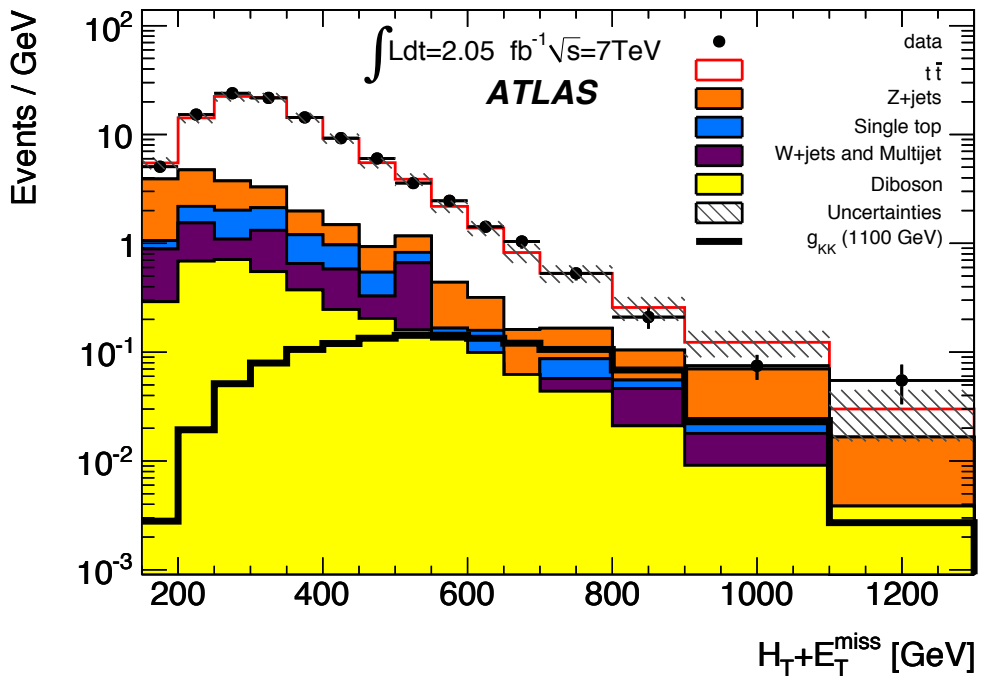
	Dilepton channel
$t\bar{t}$	4020 ± 470
Single top	210 ± 30
Z plus jets	570 ± 70
Diboson	185 ± 30
W plus jets and Multijet	190 ± 145
Total expected	5200 ± 500
Data observed	5304
$m_{g_{Z'}} = 800$ GeV	77
$m_{g_{KK}} = 1100$ GeV	75

- $t\bar{t}$, single top, Z+jets:
  - MC corrected from data
- Fake leptons:
  - Measured from data
- Diboson:
  - MC

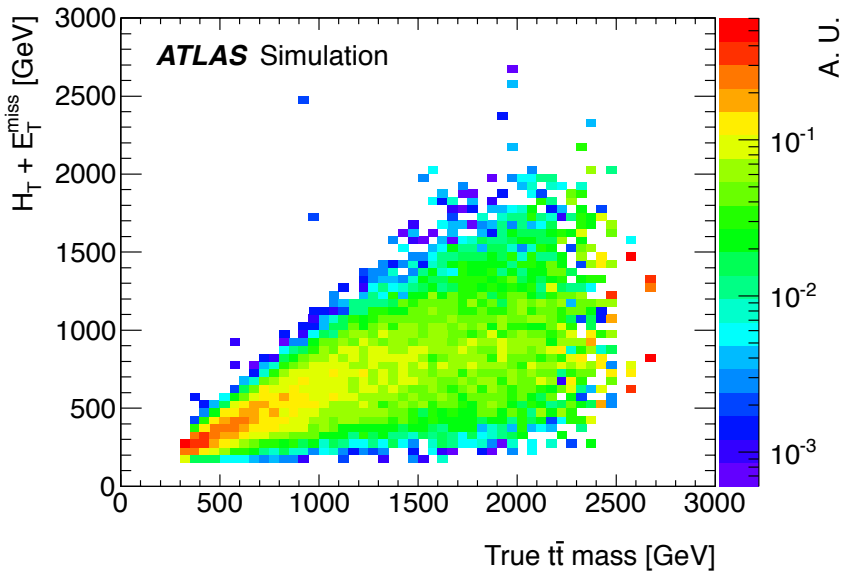
e+e, μ+μ
and e+μ 6.5%

Mass reconstruction

- Two neutrinos make mass reconstruction difficult
- Use effective mass: $H_T+E_T^{miss}$



Data and prediction for eff. mass in the signal region



Correlation of eff. mass with true di-top mass

e+e, μ+μ and e+μ 6.5%

Systematic uncertainties

Yield only:

- Luminosity (3.7%)
- Trigger & lepton reconstruction (≤1.5%)
- Background normalizations
  - $t\bar{t}(^{+7.0\%}_{-9.6\%})$
  - Single top (10%)
  - Diboson (5%)
  - Z+jets (12%)
  - W+jets & multijet (76%)

Yield and shape:

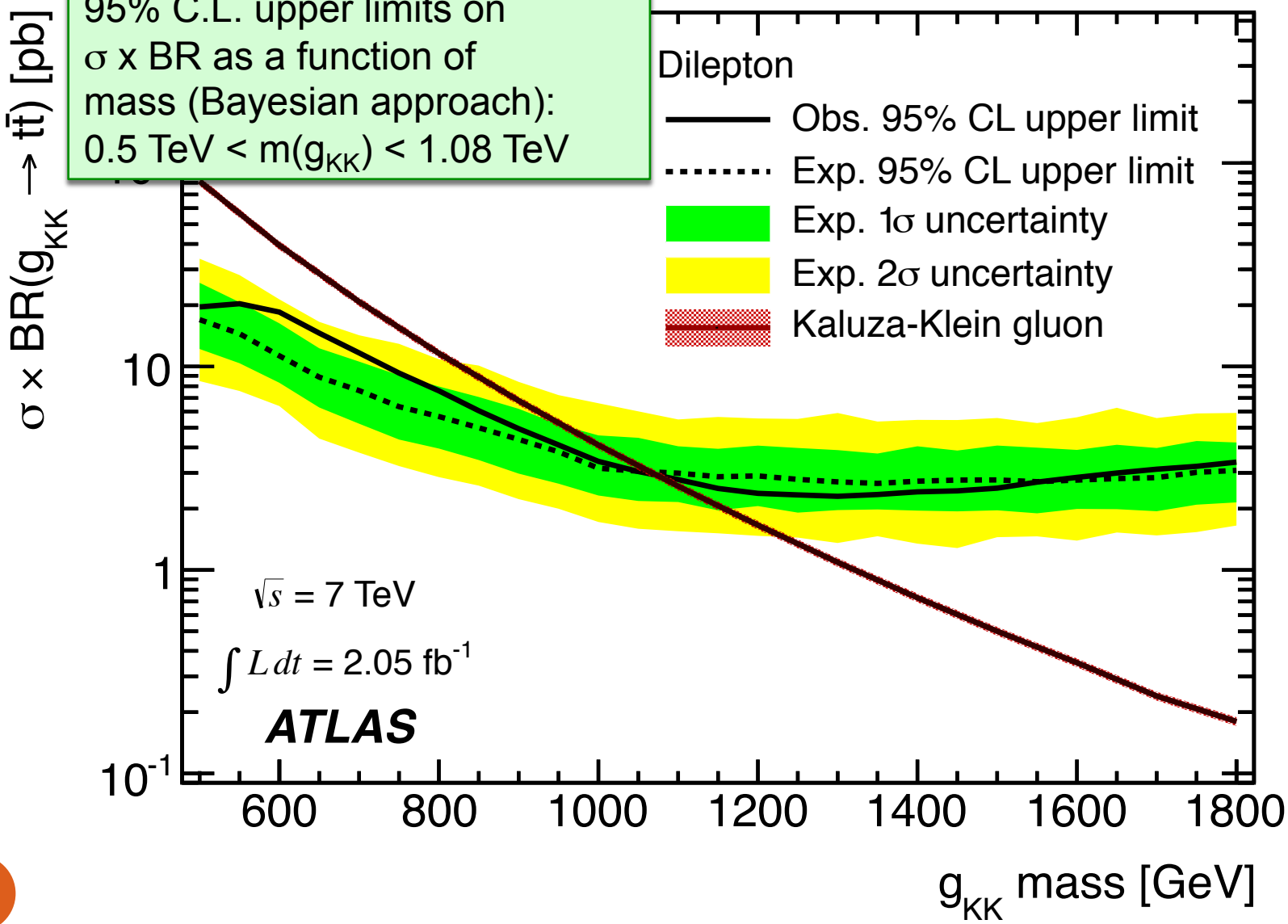
- Initial State/Final State Radiation
  1% / 5.1% (background / m_{GKK} = 1 TeV)
- Jet Energy Scale
  2.5% / 3.0%
- PDFs
  3.7% / 0.6%

- Negligible:
  - MC modelling
  - object reconstruction
  - momentum measurement

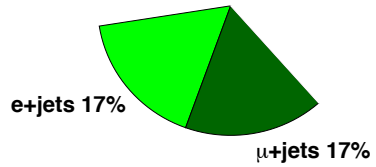
Exclusion limits

e+e, μ+μ and e+μ 6.5%

95% C.L. upper limits on σ x BR as a function of mass (Bayesian approach): 0.5 TeV < $m(g_{KK})$ < 1.08 TeV



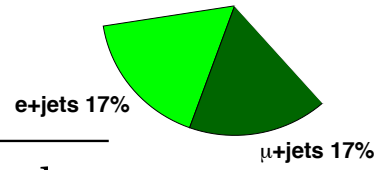
Lepton+jets (resolved)



Object & event selection

- Same trigger and lepton definition as di-lepton analysis
- exactly 1 isolated lepton (e or μ)
- e-channel:
  - E_T^{miss}>35 GeV
  - m_T>25 GeV
- μ-channel
  - E_T^{miss}>20 GeV
  - $E_T^{miss}+m_T$>60 GeV
- anti-k_T (R=0.4) jets (|η| <2.5):
  - Leading p_T > 60 GeV
  - ≥1 *b*-tagged jet (using lifetime, 60% eff. working point, light quark rejection of 345)
  - Either one m_j>60 GeV, ≥3 jets with p_T>25 GeV
  - Or ≥4 jets with p_T>25 GeV
- Acceptance x efficiency:
  - 7.3% KK gluon (1300 GeV)
  - 7.4% Z' (800 GeV)

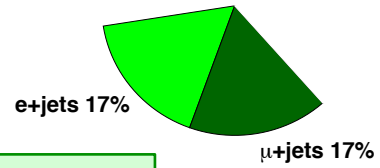
Background estimate



	Electron channel	Muon channel
$t\bar{t}$	7830 ± 750	10000 ± 960
Single top	470 ± 50	570 ± 60
W plus jets	1120 ± 540	1450 ± 700
Z plus jets	85 ± 40	90 ± 45
Diboson	18 ± 1	18 ± 1
Multijet	340 ± 170	470 ± 240
Total expected	9860 ± 940	12600 ± 1210
Data observed	9622	12706
$m_{g_{Z'}} = 800$ GeV	200	224
$m_{g_{KK}} = 1300$ GeV	59	65

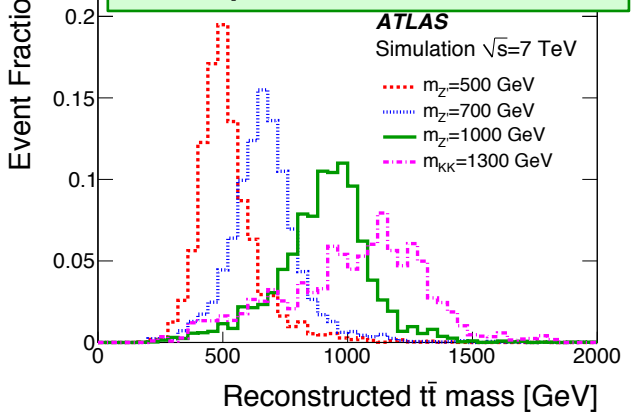
- $t\bar{t}$, single top, W+jets:
  - MC corrected from data
- QCD multijet:
  - Measured from data
- Everything else:
  - MC

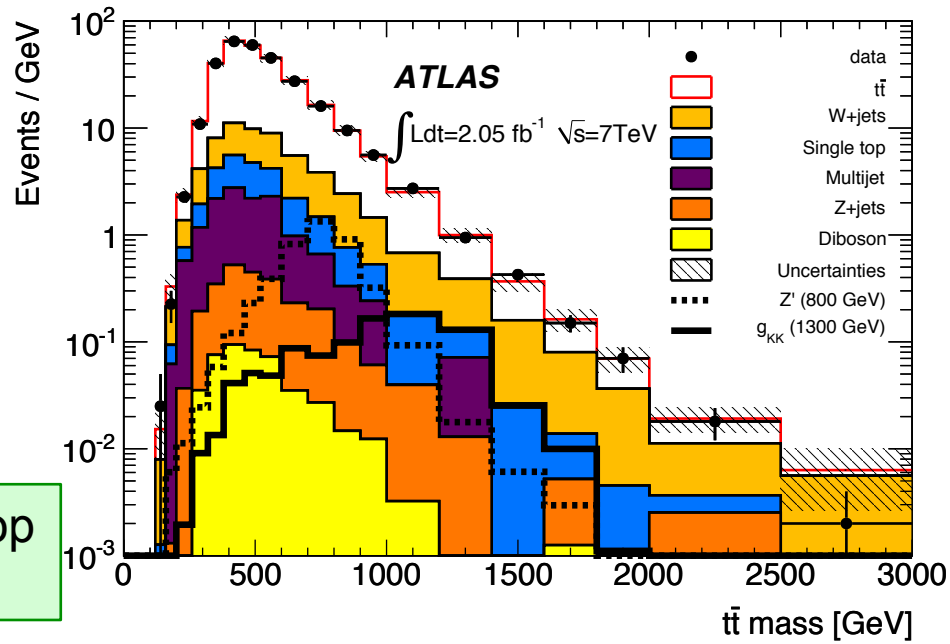
Mass reconstruction



- Determine neutrino p_z via W mass constraint
- Use jets with p_T>20 GeV
- If m_j>60 GeV:
  - Combine with closest jet (ΔR) for hadronic top candidate
  - Lepton+E_T^{miss}+closest jet for leptonic top candidate
- Otherwise:
  - Remove jets with large ΔR to other jets or lepton (Initial State Radiation)
  - Calculate di-top mass from leading 3 or 4 jets, E_T^{miss} and lepton

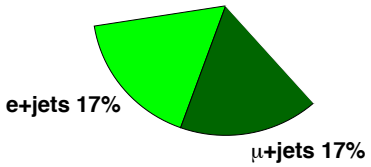
Di-top mass resolution





Data and prediction for di-top mass in the signal region

Systematic uncertainties



Yield only:

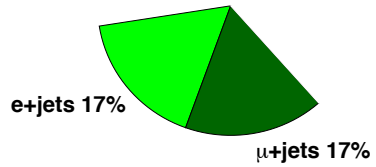
- Luminosity (3.7%)
- Trigger & lepton reconstruction (≤1.5%)
- Background normalizations
  - $t\bar{t}$ ($^{+7.0\%}_{-9.6\%}$)
  - Single top (10%)
  - Diboson (5%)
  - W+jets or Z+jets (48%)
  - multijet (50%)

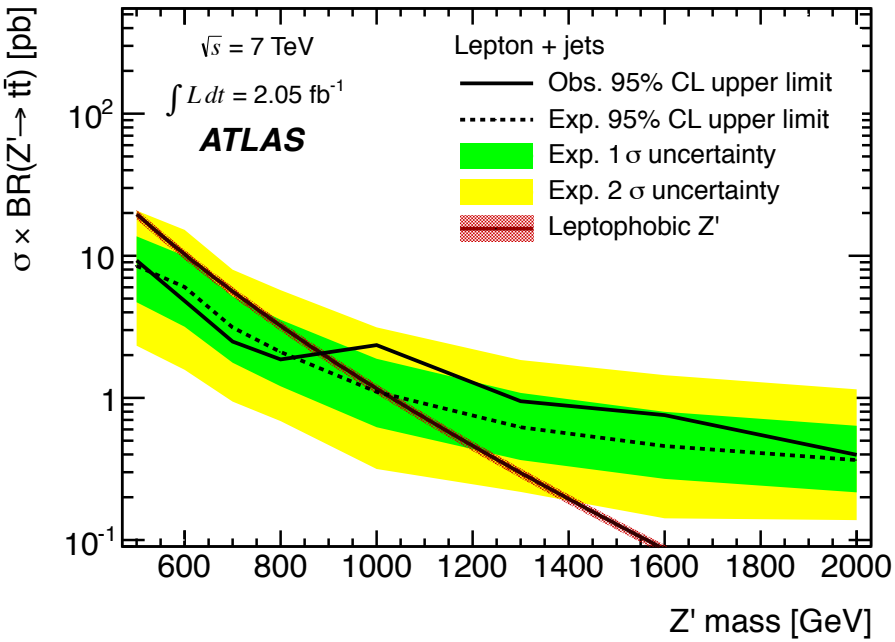
Yield and shape:

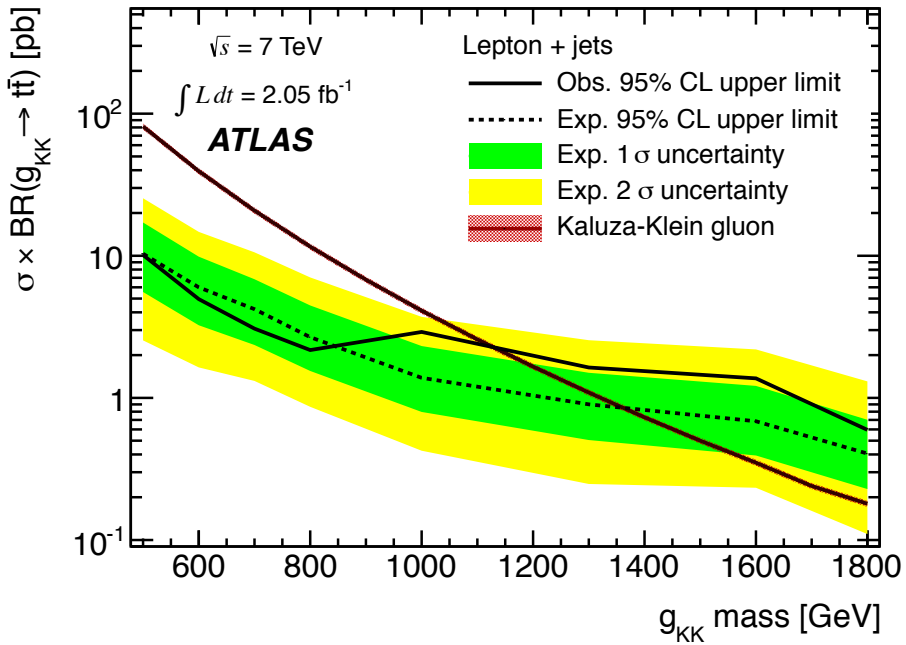
- *b*-tagging
  13% / 17% (background / $m_{Z'}$ = 0.8 TeV)
- Jet Energy Scale
  15% / 4%
- ISR/FSR
  7% / 6%

- Smaller effect from other MC modelling and object reconstruction and momentum measurement uncertainties

Results

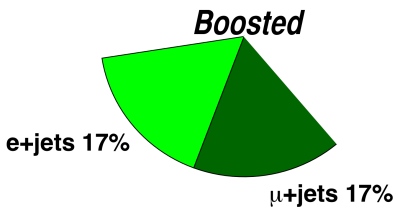






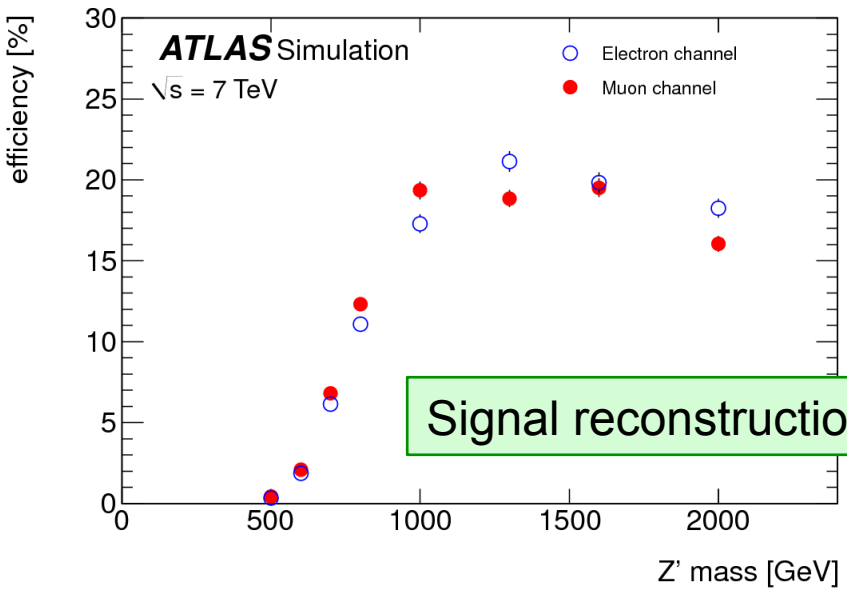
95% C.L. excluded mass ranges:
0.5 TeV < m(Z') < 0.88 TeV
0.5 TeV < m(g_{KK}) < 1.13 TeV

Lepton+jets (boosted)



Object & event selection

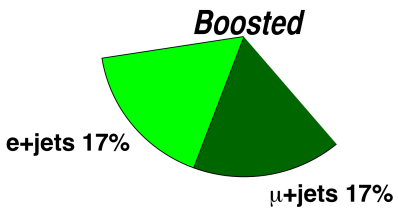
- Same e and μ and trigger requirements as resolved analysis
- **Leptonic** top candidate
  - Take closest jet with p_T>30 GeV with
    0.4 < ΔR(lepton,jet) <1.5
  - Use W mass hypothesis for neutrino p_Z



Signal reconstruction efficiency

- **Hadronic** top candidate
  - 1 anti-k_T (R=1.0) fat jet
  - Large distance to jet from leptonic top:
    ΔR(fat jet,leptonic top jet)>1.5
  - p_T>250 GeV, m_j>100 GeV
  - Recluster (using FastJet) with k_T-Algorithm and require last splitting scale
    $\sqrt{d_{12}}$ > 40 GeV

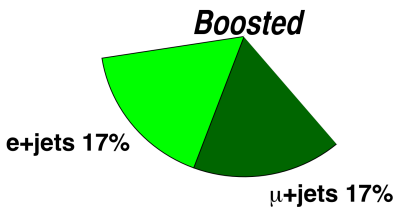
Background estimate

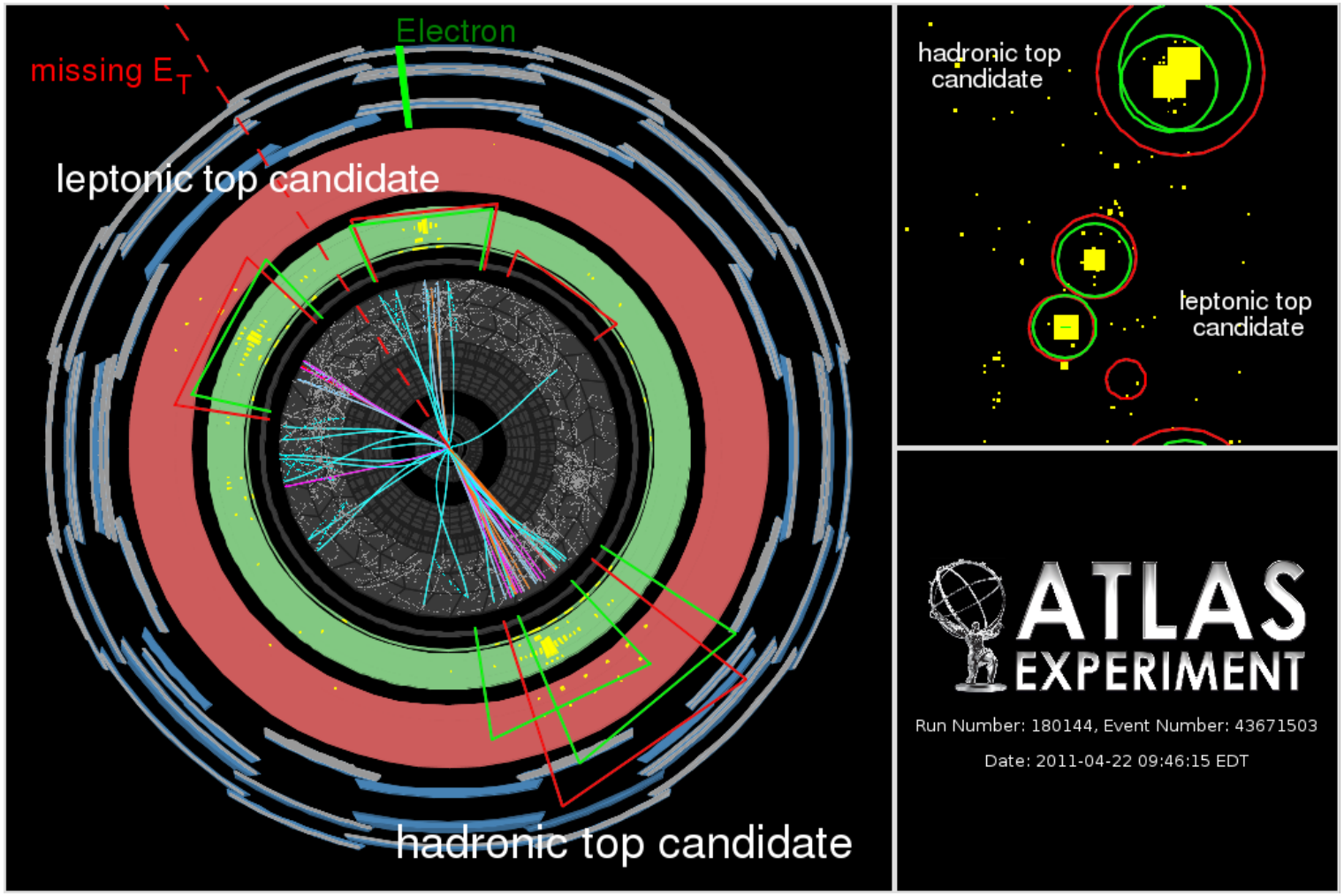


Type	e+jets	μ+jets	Sum
$t\bar{t}$	510 ± 40	620 ± 50	1130 ± 90
W+jets	202 ± 34	300 ± 50	500 ± 80
Multijets	45 ± 23	30 ± 15	75 ± 38
Z+jets	41 ± 20	34 ± 16	75 ± 36
Single top	21 ± 2	27 ± 3	48 ± 5
Dibosons	3.4 ± 0.2	4.5 ± 0.2	7.9 ± 0.4
Total	830 ± 60	1010 ± 70	1840 ± 130
Data	803	1034	1837

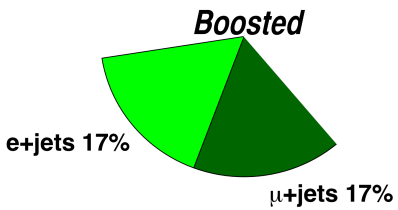
- W+jets:
  - MC normalized to data
- QCD multijet:
  - Measured in data
- Everything else:
  - MC

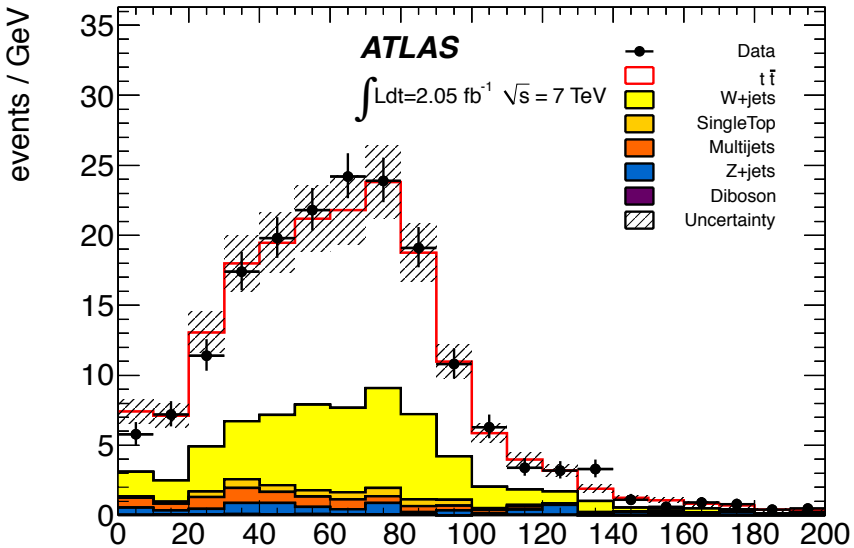
Event display



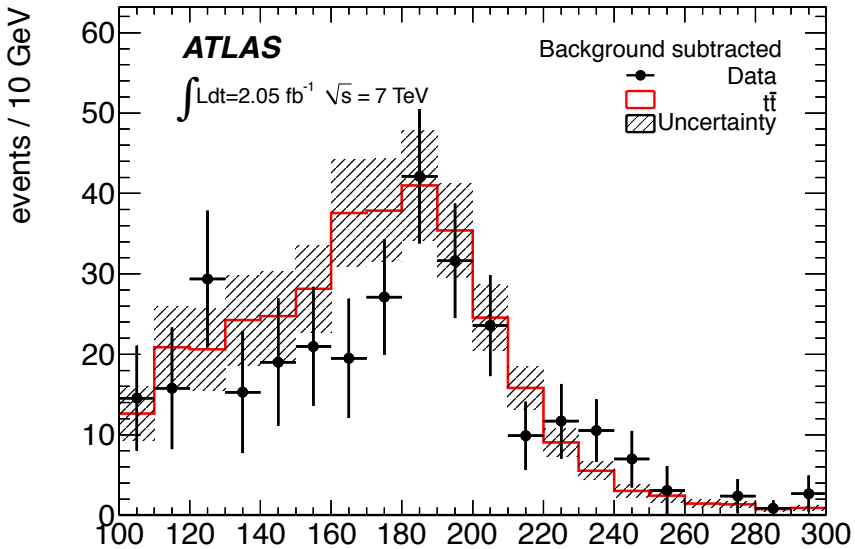


Control distributions

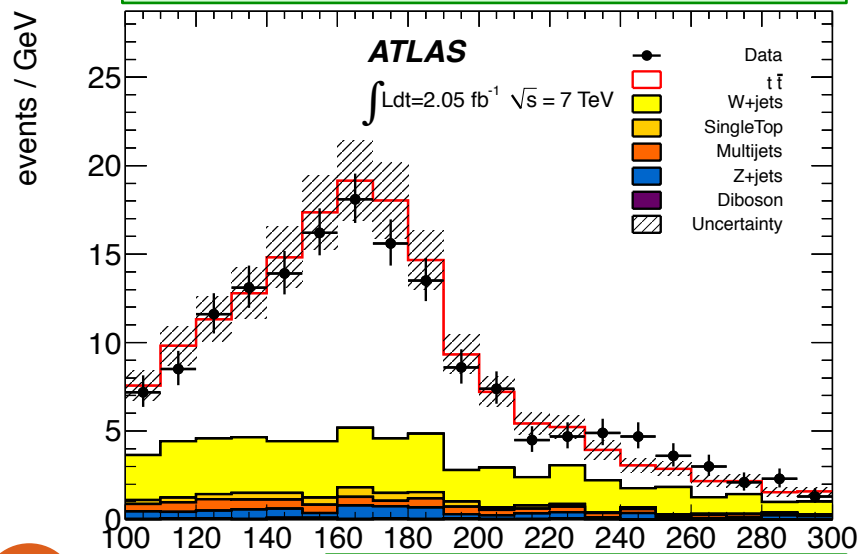




Leptonic W m_T(l,neutrino) [GeV]



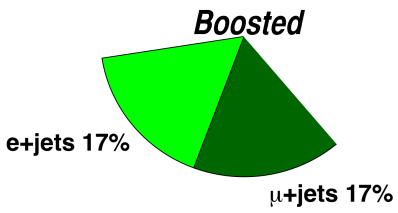
Hadronic Top m [GeV]



Leptonic Top m [GeV]

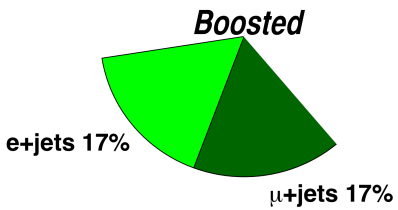
Good agreement for leptonic W and top confirms background estimation.
Hadronic top mass described reasonably well.

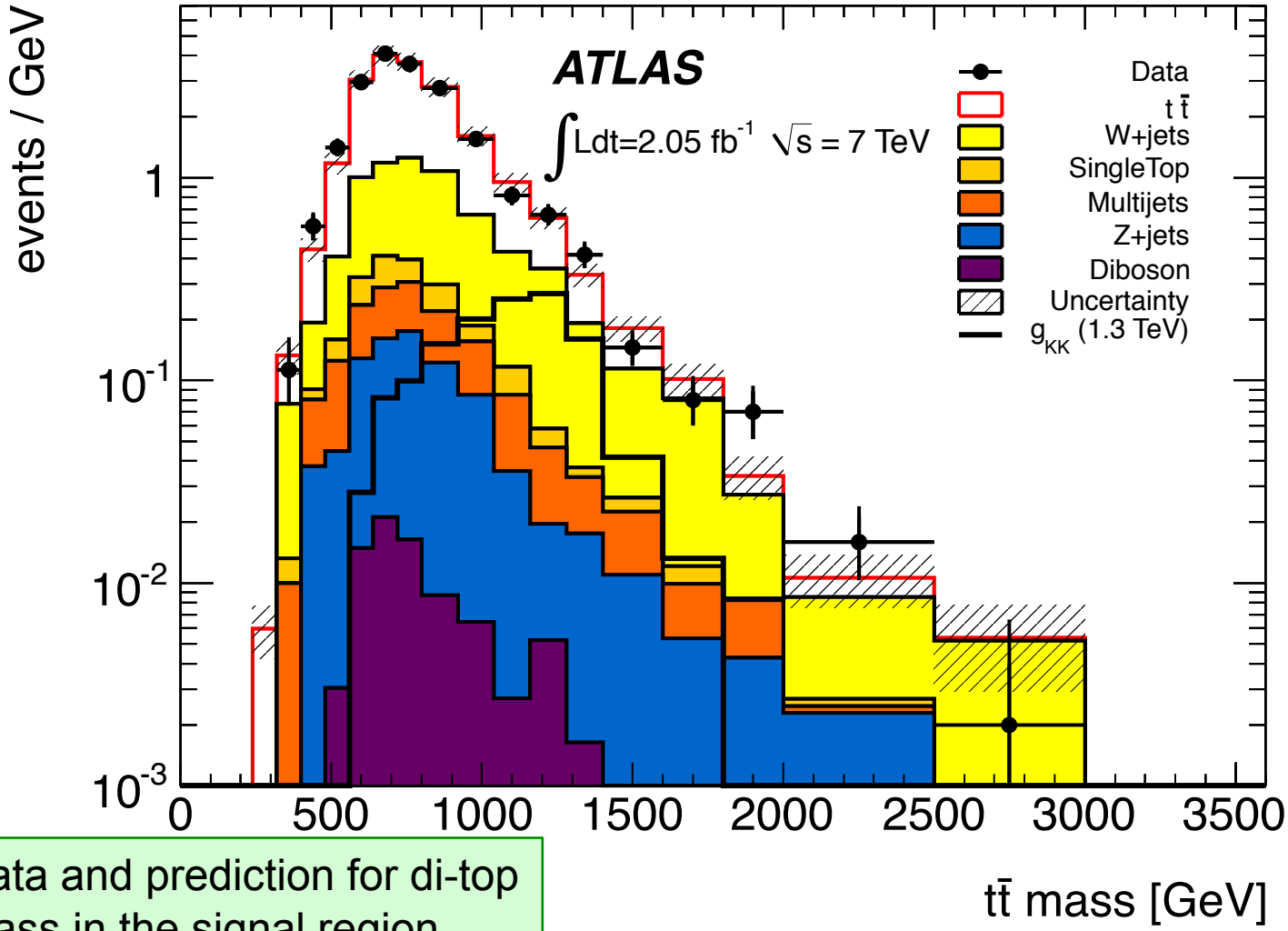
Systematic uncertainties



Systematic effect	Impact on yield [%]		Impact on
	background	Z'1.3 TeV	sensitivity [%]
Luminosity	2.5	3.7	0.4
PDF uncertainty	3.1	1.0	0.2
$t\bar{t}$ normalization	4.9	—	0.7
$t\bar{t}$ ISR, FSR	6.3	—	0.7
$t\bar{t}$ fragmentation & parton shower	3.4	—	0.9
$t\bar{t}$ generator dependence	2.8	—	2.2
$W+$ jets normalization	4.3	—	1.4
$W+$ jets shape	*norm.*	—	0.1
Multijets normalization	2.1	—	0.2
Multijets shape	*norm.*	—	1.1
$Z+$ jets normalization	2.0	—	0.5
Jet energy and mass scale	6.7	2.0	5.2
Jet energy and mass resolution	4.7	4.0	1.2
Electron ID and reconstruction	1.1	1.3	1.0
Muon ID and reconstruction	2.2	2.1	4.8

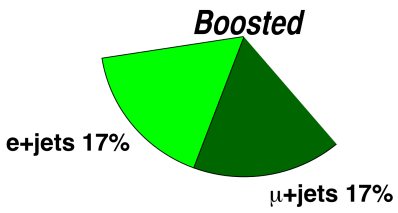
Results

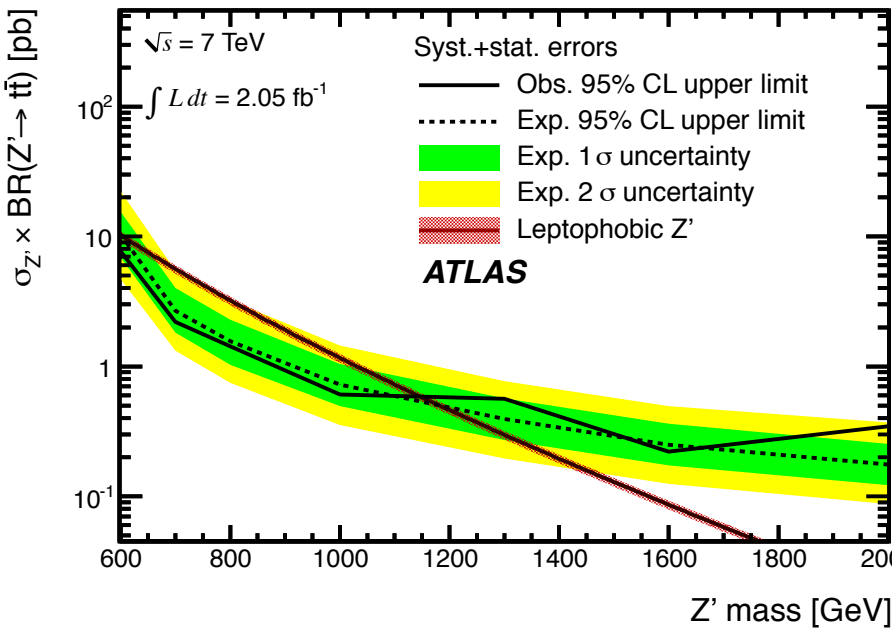


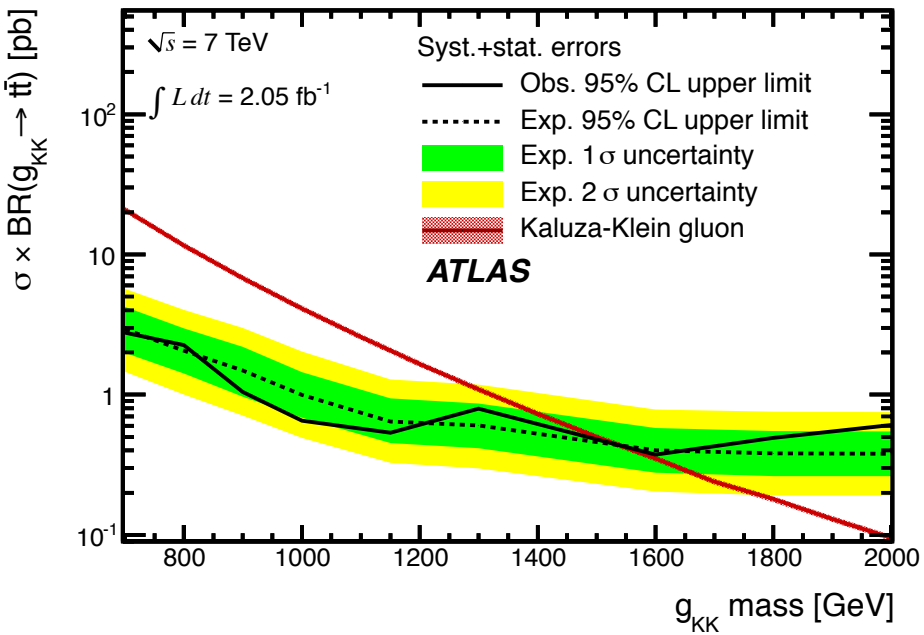


Data and prediction for di-top mass in the signal region

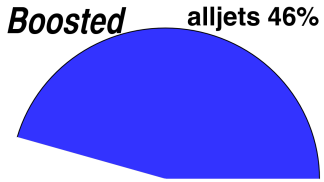
Exclusion limits







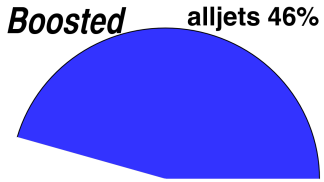
95% C.L. excluded mass ranges:
0.6 TeV < m(Z') < 1.15 TeV
0.7 TeV < m(g_{KK}) < 1.5 TeV



Fully-hadronic

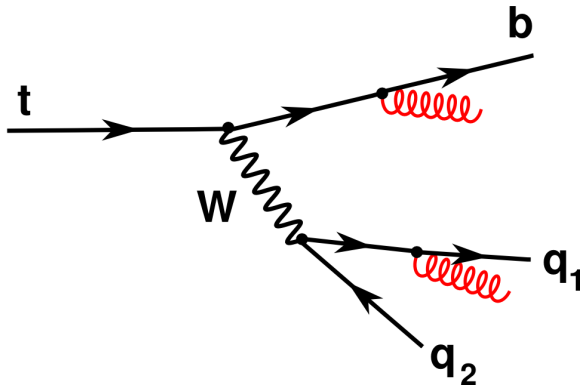
Object & event selection

- 0 isolated leptons (e or μ)
- Trigger:
  - Either:
    - ≥ 5 jets (anti-k_T, R=0.4) with E_T>30 GeV
  - Or:
    - 1 jet (anti-k_T, R=0.4) with E_T>100 GeV
    - and scalar sum of jet-E_T>350 GeV (400 GeV for late data-taking Periods)
- ≥2 Cambridge/Aachen (R=1.5) "fat" jets, p_T>200 GeV
  - Tagged as top quark using HEPTopTagger algorithm
  - Details on next slides
- ≥2 *b*-jets
  - anti-k_T (R=0.4)
  - p_T>25 GeV
  - ΔR(*b*-jet, fat jet)<1.4
  - Using neural network with impact parameter, secondary vertex and decay topology information, 70% eff. working point, light quark rejection of 140

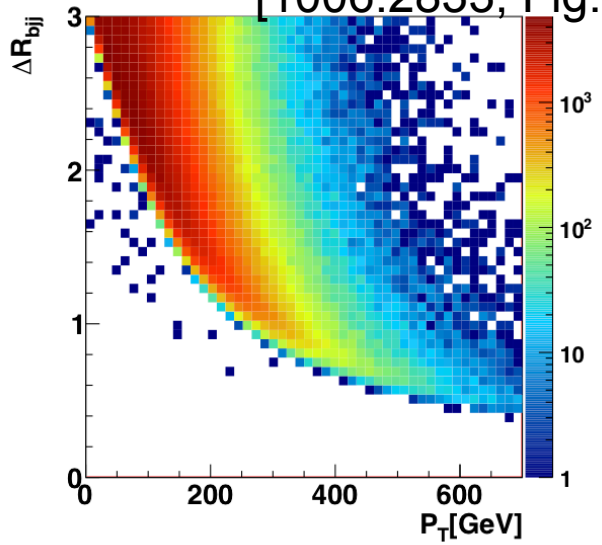


HEPTopTagger algorithm

- Algorithm by Plehn, Spannowsky, Takeuchi, Zerwas
  - *Stop Reconstruction with Tagged Tops, arxiv:*1006.2833
- Indentify top->hadron decays with p_T(top)>200 GeV
- Use substructure of R=1.5 Cambridge/Aachen jets (fat jets)
- Filtering against Underlying Event/Pile Up
- Identify top quark via mass ratios
- Calibrate subjets

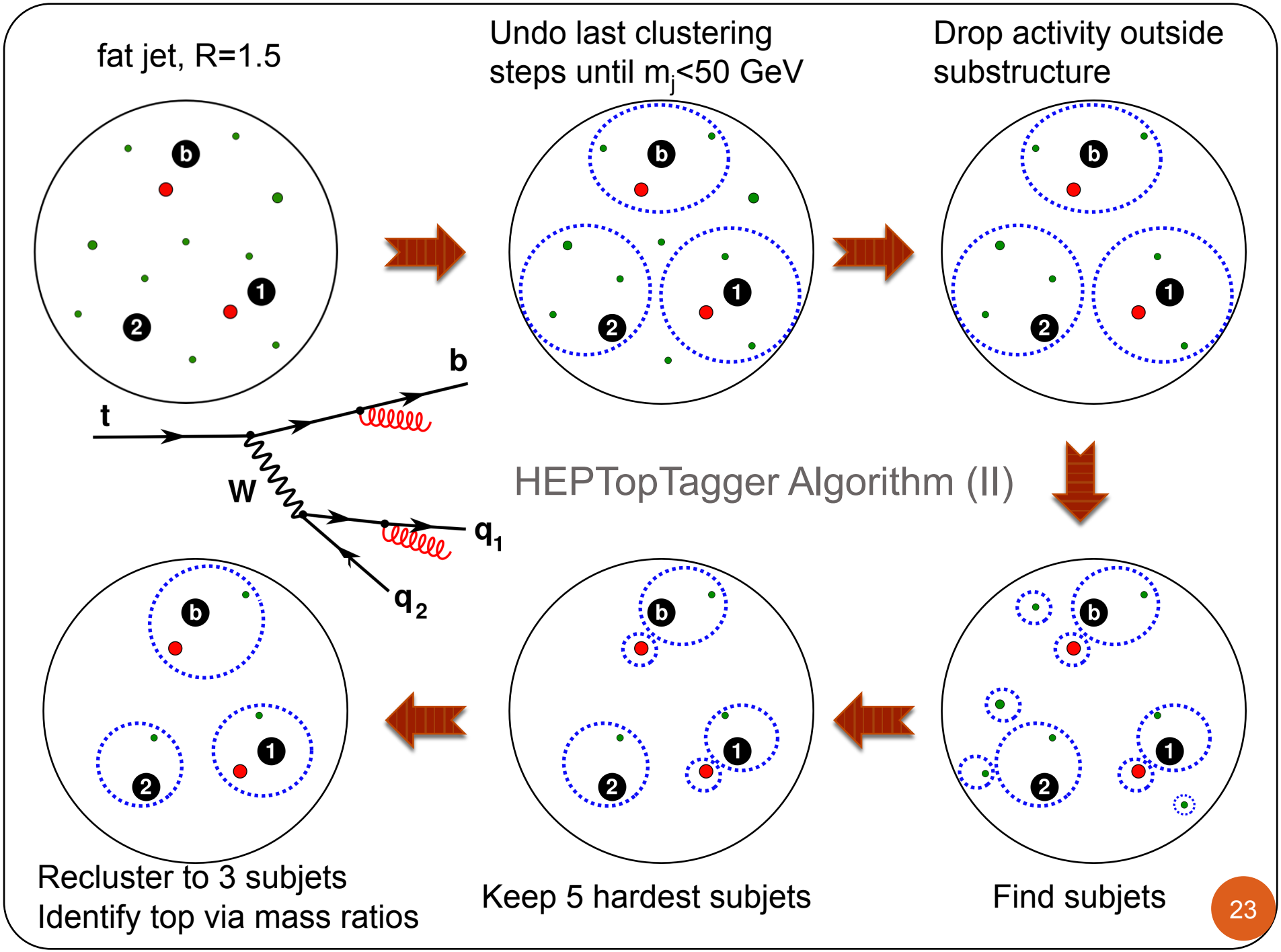


[1006.2833, Fig.2]

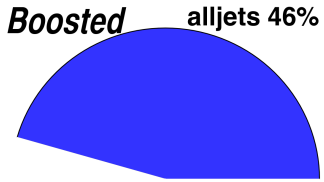


Top p_T>200 -> R=1.5

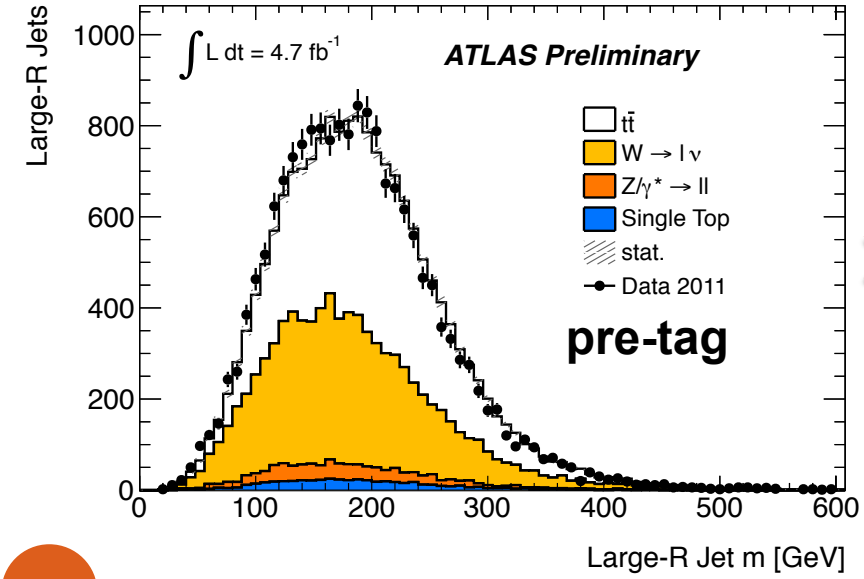
HEPTopTagger Algorithm (II)

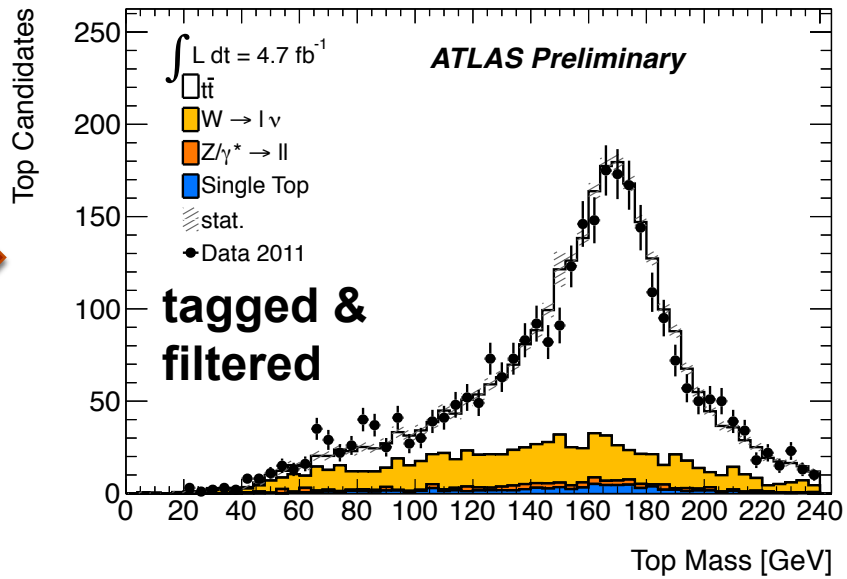


Tested in l+jets channel

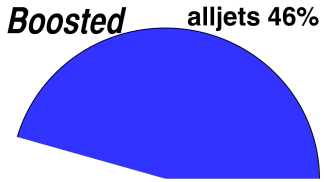


- Tested on 2011 data in semi-leptonic channel
- Good data/MC agreement before and after tagging
- Performance of large-R jets and jet substructure reconstruction with the ATLAS detector
  - ATLAS-CONF-2012-065
- Details in Sebastian's talk on Monday
- More on ATLAS substructure presented by Emily, Mishra & John



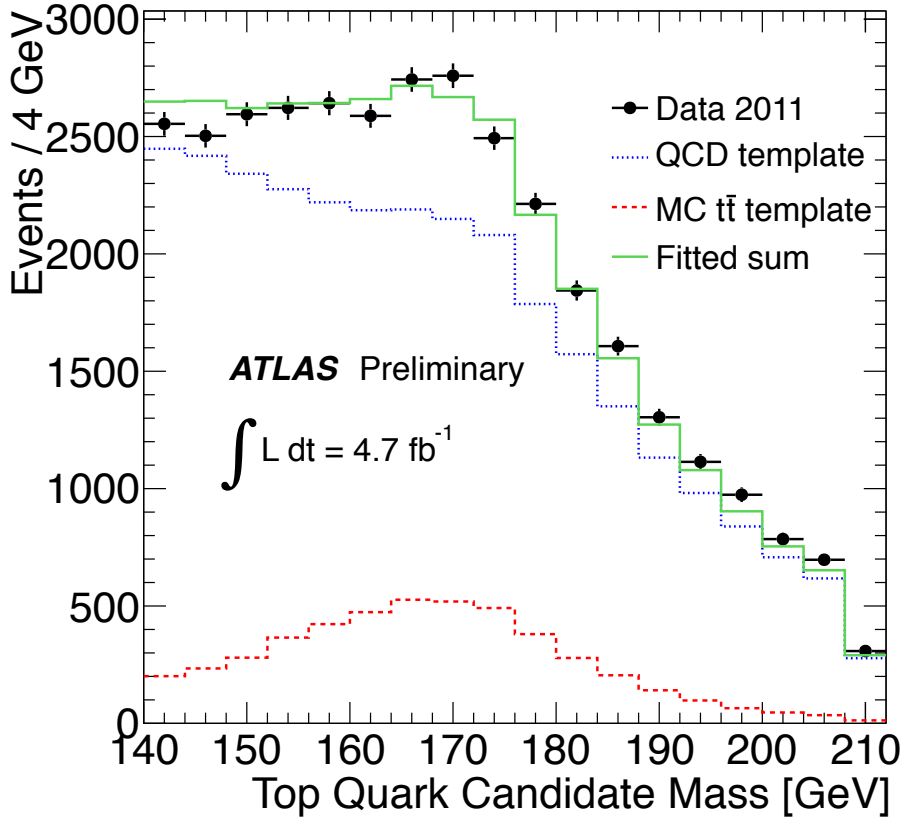


Backgrounds



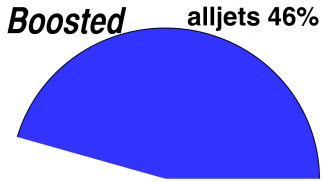
Backgrounds

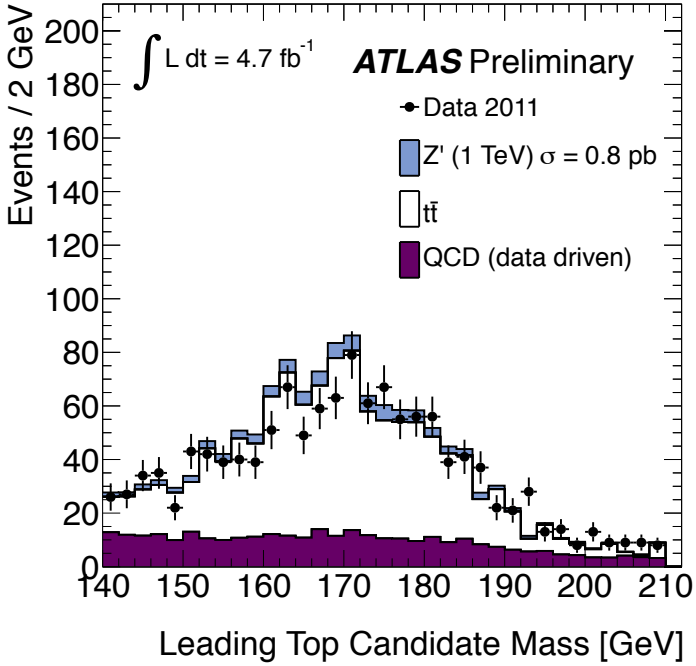
- $t\bar{t}$:
  - MC, measure normalisation in data
- QCD multijet:
  - estimate from data
  - ABCD method
  - also includes other negligible backgrounds like W+jets

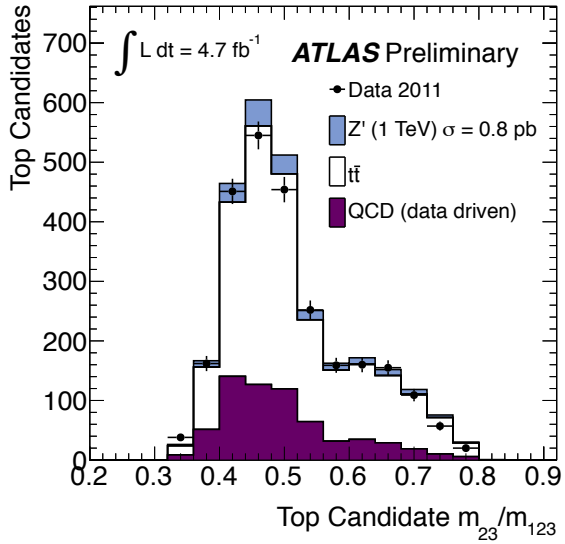


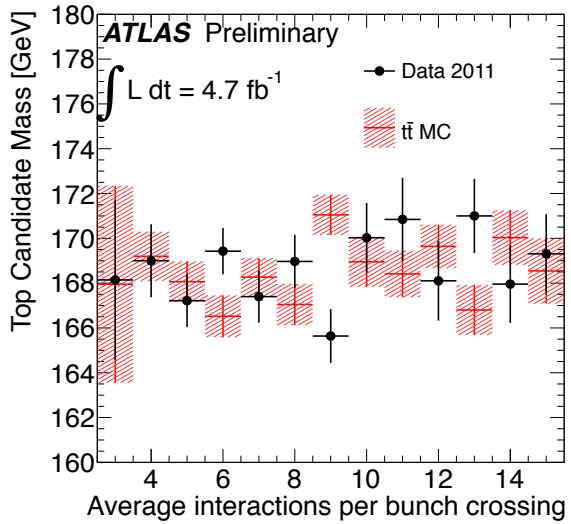
$t\bar{t}$ normalisation in control region

Fully-hadronic control plots







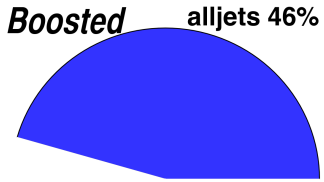


Hadronic top candidate mass is well reconstructed and supports background prediction.

Substructure variables $m_{23}/m_{123} \sim m_W/m_{top} \sim 0.46$ indicates that sub-leading and sub-sub-leading (in p_T) are W decays products

Top candidate mass robust against pile-up.

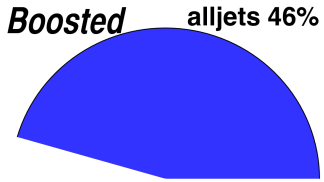
Systematic uncertainties

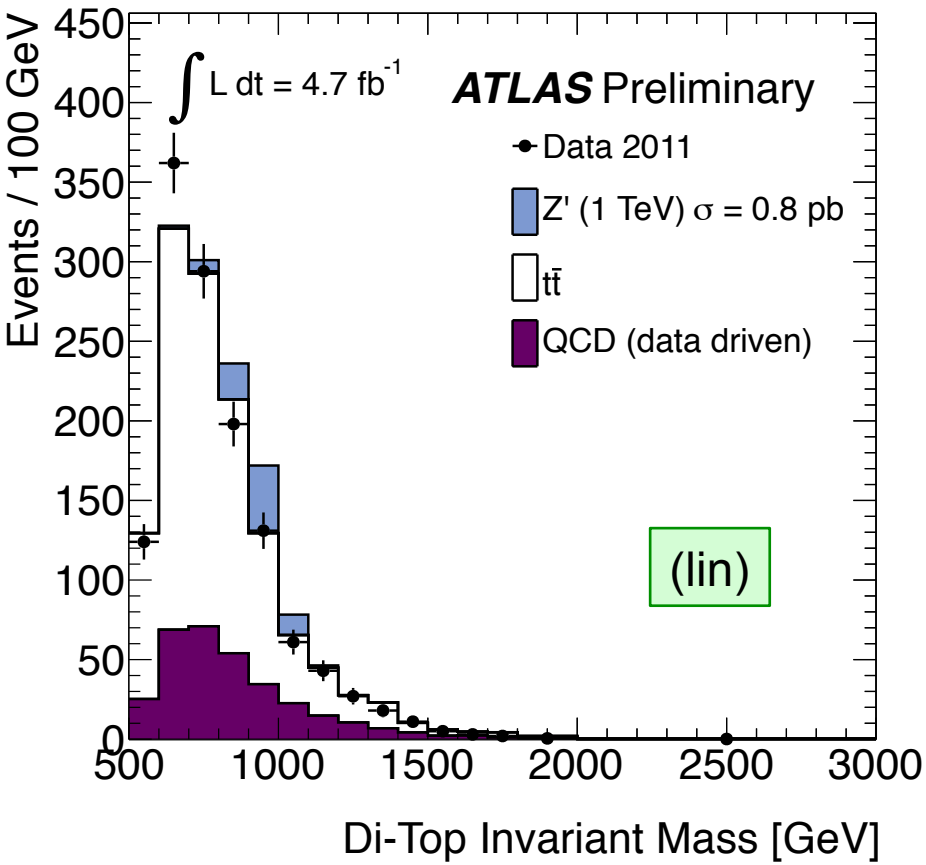


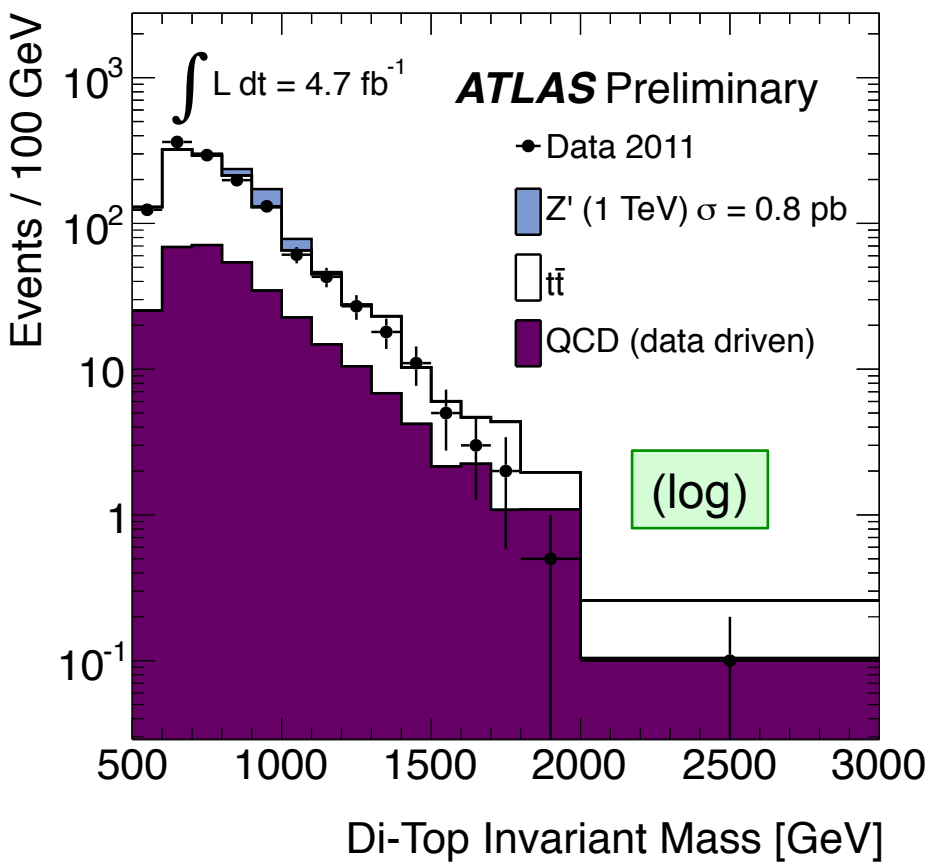
Uncertainty	Effect on Sensitivity (1.3 TeV Z')
b-tagging efficiency	15.9%
$t\bar{t}$ normalisation	9.3%
jet energy scale	3.5%
parton shower modelling	3.1%
$t\bar{t}$ generator	1.8%

The effect of other uncertainties
(PDF, QCD estimate, ISR/FSR) is below 1%

Results

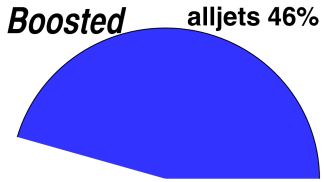


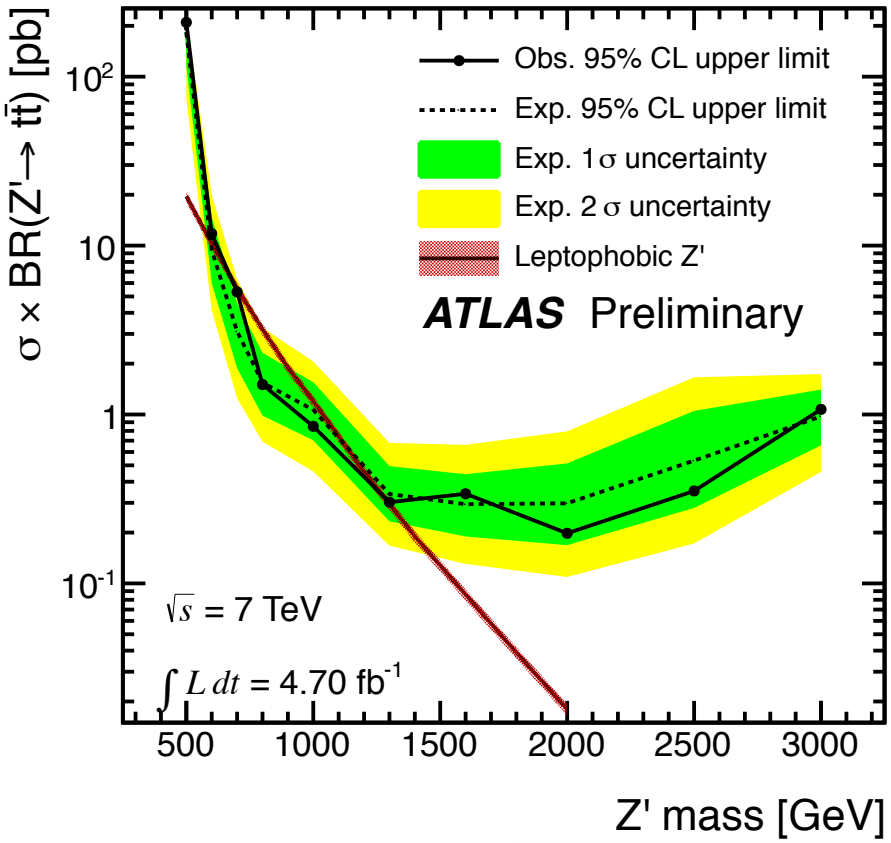


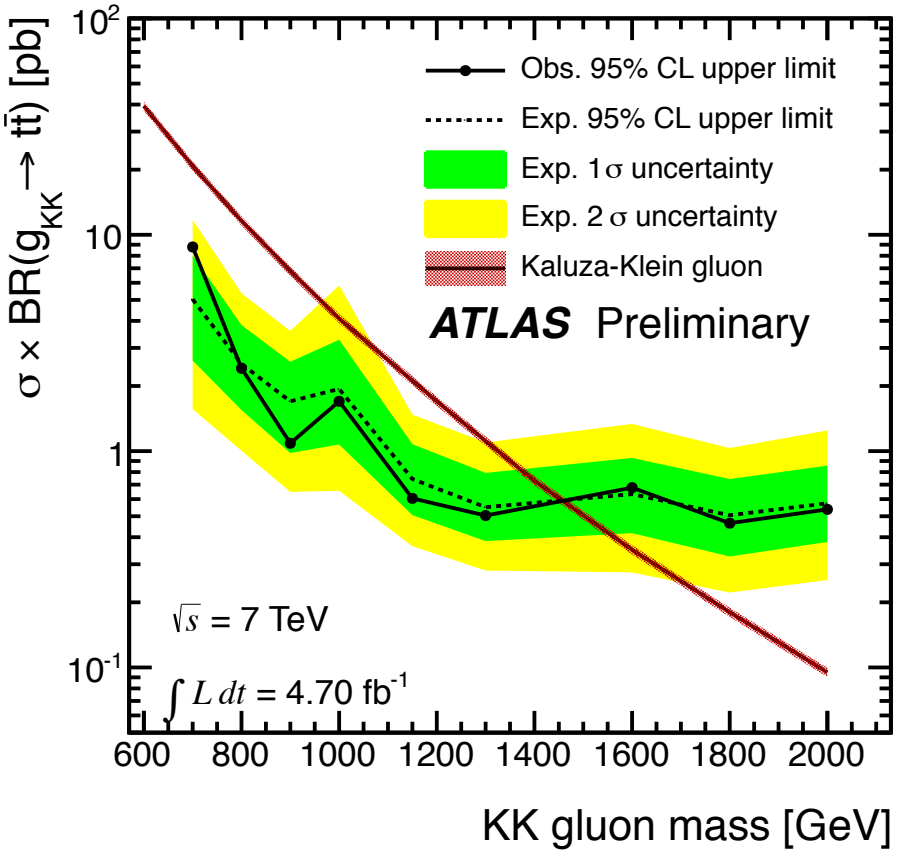


Data and prediction for di-top mass in the signal region

Limits

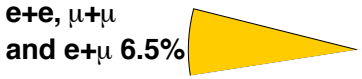
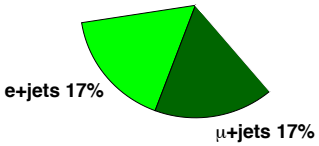
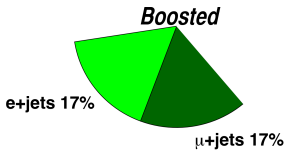
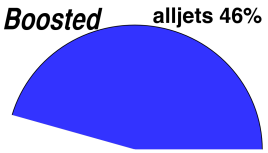






95% C.L. excluded mass ranges:
0.7 TeV < m(Z') < 1.3 TeV
0.7 TeV < $m(g_{KK})$ < 1.5 TeV

Summary

				
Article/ Note	**arXiv: 1205.5371**	**arXiv: 1205.5371**	**arXiv: 1207.2409**	**ATLAS-CONF-2012-102**
Integrated Luminosity	2 fb^{-1}	2 fb^{-1}	2 fb^{-1}	4.7 fb^{-1}
Z' limits $\Gamma/m = 1.2\%$	-	0.5-0.88 TeV	0.6-1.15 TeV	0.7-1.3 TeV
KKG limits $\Gamma/m = 15.3\%$	0.5-1.08 TeV	0.5-1.13 TeV	0.6-1.5 TeV	0.7-1.5 TeV

- Presented recent ATLAS results for all $t\bar{t}$ decay topologies
- Substructure methods are critical for extending reach
- Stay tuned, more to come!

Thank You!