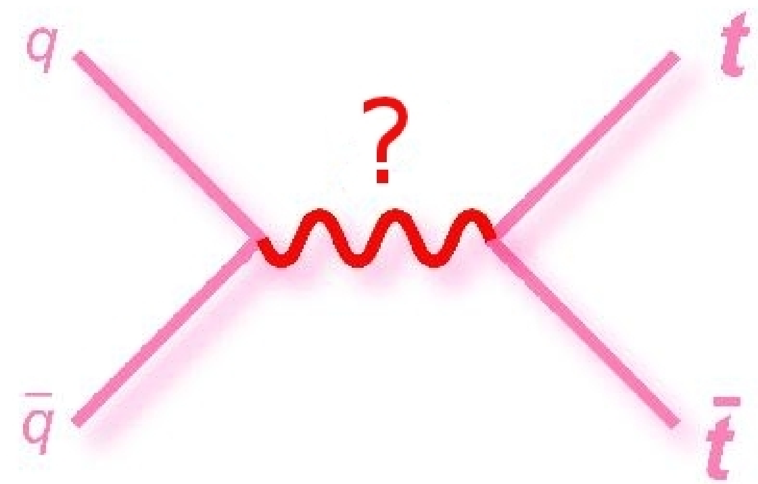


Searches for $t\bar{t}$ resonances in ATLAS

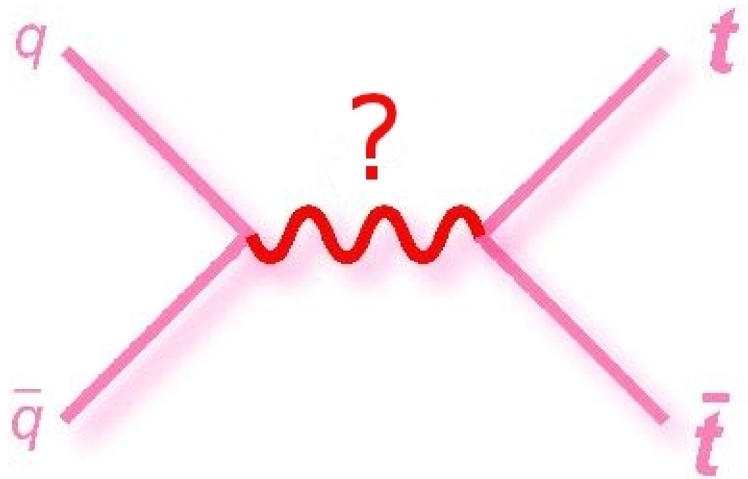
Beyond The Standard Model of Particle Physics
Rencontres du Vietnam

Reina Camacho Toro
LPC-Clermont Ferrand
on behalf of the ATLAS collaboration

Beyond The Standard Model of Particle Physics
Quy Nhon, Vietnam
July 15-21th 2012

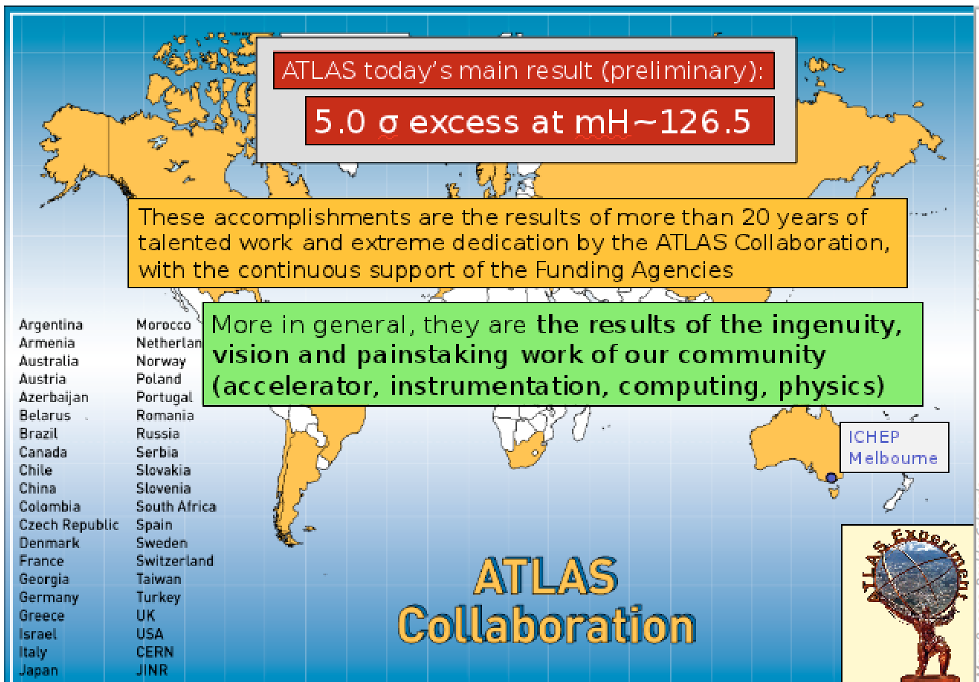
Overview

- Motivation
- Benchmark models
- Results in dilepton channel
- Results in lepton+jets channel: resolved and boosted topologies
- Summary



Overview

The Standard Model describes 3 of the 4 interactions between the known fundamental particles with high accuracy



F. Gianotti 04/07/2012
CERN/ICHEP 2012
"Status of SM Higgs searches in ATLAS"

J. Incandela 04/07/2012
CERN/ICHEP 2012
"Status of the CMS SM Higgs search"

But there are still some things missing...

- **Gravitation not included**
- **The hierarchy problem**
- **Does not account for neutrinos masses**
- **Neither dark matter nor dark energy nature are included**
- **Higgs boson?**

Top quark and new physics

Top quark: Identity card

- Discovered in 1995 at TEVATRON
- Electric charge: 2/3 e
- Spin: ½
- **Mass: 172.0±0.9±1.3 GeV/c^2**
- **LHC is a top factory**

→ σ = 165 pb (@7 TeV) :
20x larger than TEVATRON
→ 10 $t\bar{t}$ pairs/minute @10^{33} cm^{-2}s^{-1}

- **Large top mass could hint an intimately connection between the top and beyond the Standard Model (BSM) physics**

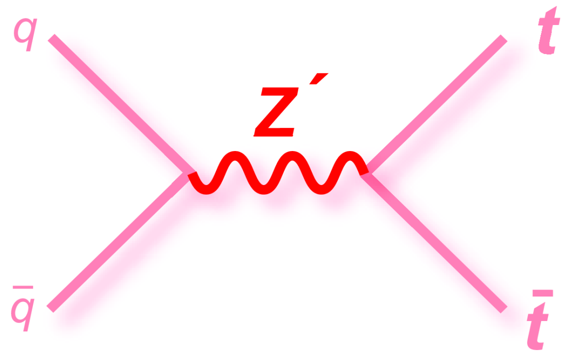
- Many models (e.g. Technicolor, extra dimensions models as Randall Sundrum (RS) or ADD, little Higgs...) predict the existence of new particles that couples preferentially to the top quark

- **$t\bar{t}$ production seems to be a good and natural place to look for new physics**

- Others possibilities to keep in mind: forward-backward asymmetry, top polarisation...

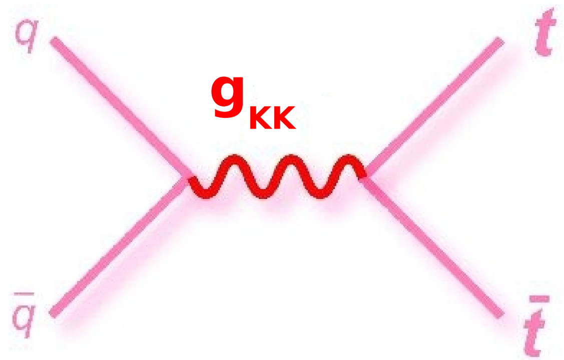
Benchmark models

- **Two different benchmark scenarios to quantify sensitivity:**
  - **Topcolor-assisted technicolor:** strong EWSB through top quark condensation (R. Harris et al. arXiv:hep-ph/9911288)



- Leptophobic and topophyllic **Z' boson**
- Spin-1, color singlet
- **Narrow resonance**: width 1.2% of the mass
- CDF excluded $m_{Z'}$<900 GeV (arXiv:1107.5063v3)
- σxBR(Z’ → $t\bar{t}$) ~ 1 pb ($m_{Z'}$=1 TeV)

  - **Randall Sundrum model** with a single extra warped extra dimension to explain the hierarchy problem (B. Lillie et al. arXiv:hep-ph/0701166)



- **RS Kaluza-Klein gluon g_{KK}**
- Spin-1, color octet
- **Broad resonance**: width ~15% of the mass
- Strongly coupled to the top
- σxBR(g_{KK} → $t\bar{t}$) ~ 4 pb (m_{gKK}=1 TeV)

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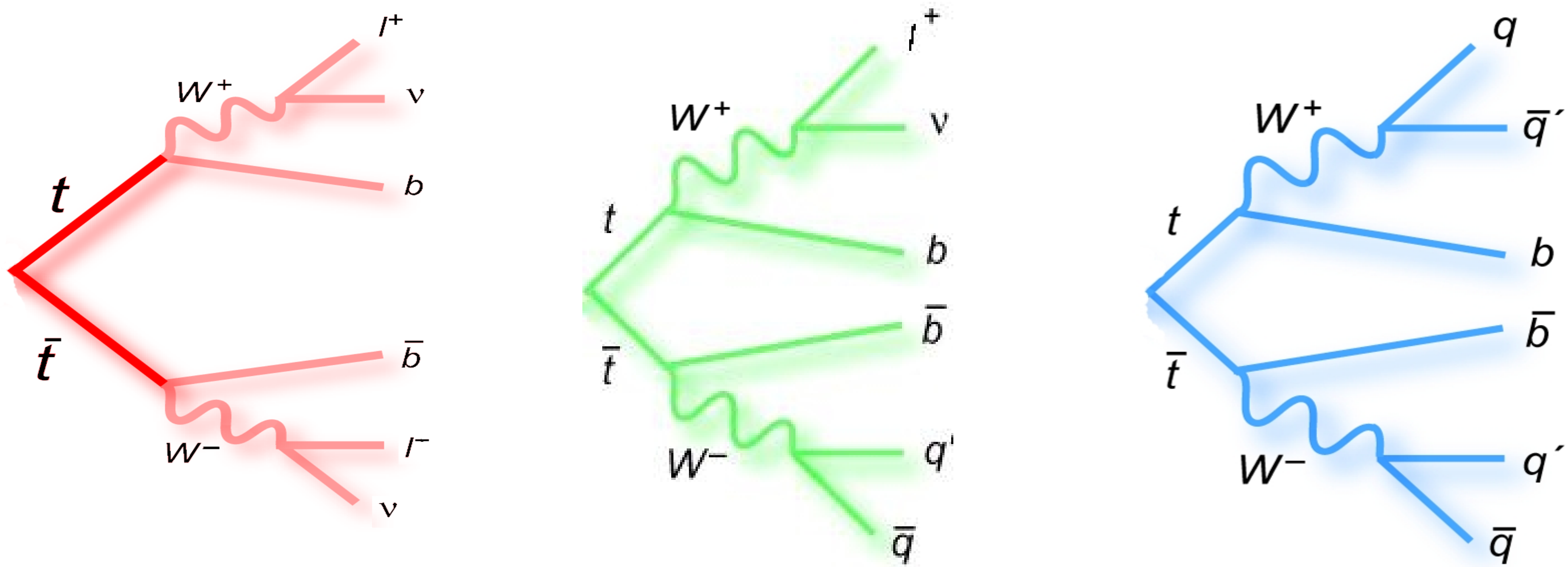
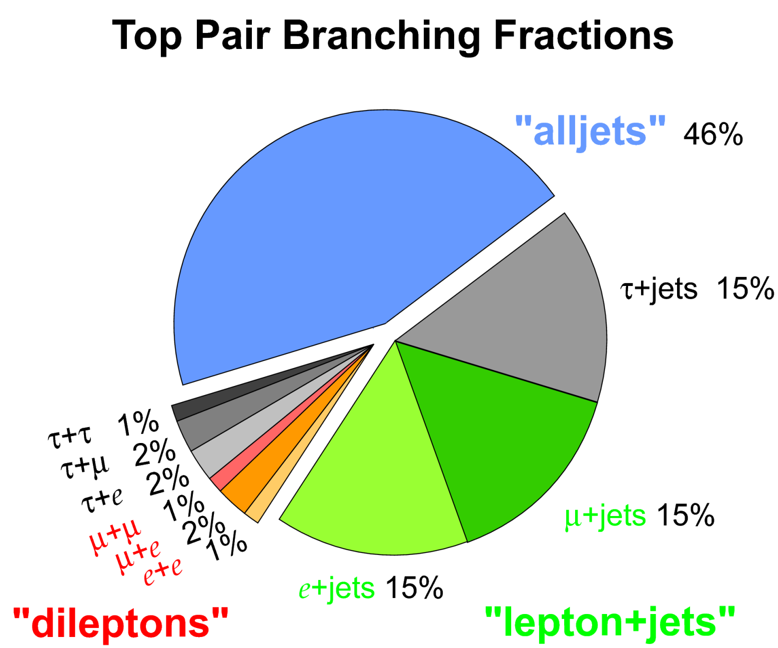
Top pair signatures



- **"Dileptons" l=e,μ:**
  - ➔ Very clear signature
  - ➔ Low branching fraction: 4.9%
- **"Lepton+jets" l=e,μ:**
  - ➔ Clear signature
  - ➔ Branching fraction: 29.6%
  - ➔ Reduced background (W+jets, multijet, single top, Z+jets, dibosons)
- **"All jets":**
  - ➔ Large branching fraction: 46%
  - ➔ Multijet background difficult to control



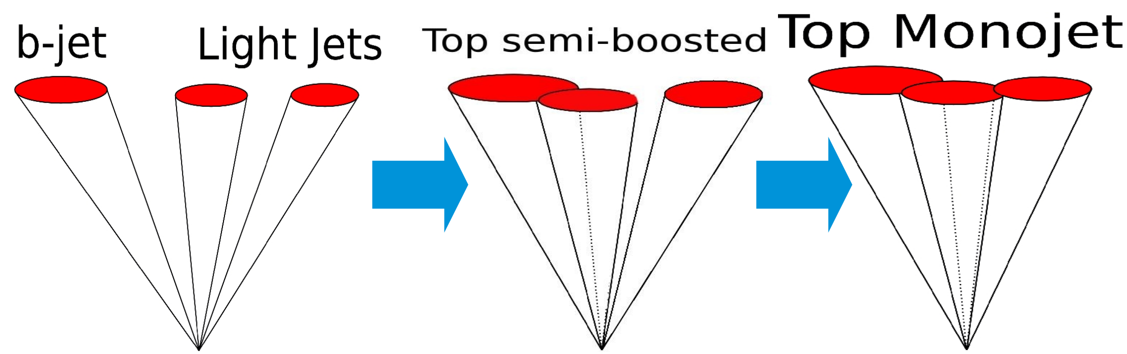
Top pair signatures: Boosted topology

- **At high $t\bar{t}$ mass:**

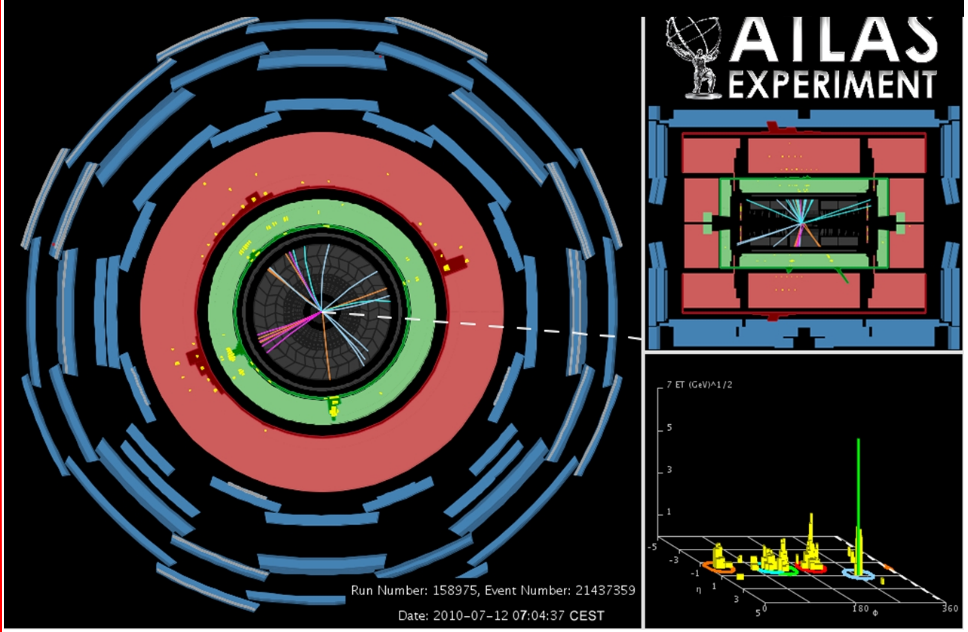
  ➔ Top gets more and more boosted
  ➔ **Objects (leptons and jets) merge into monojets**

- Standard reconstruction methods are no longer sufficient for boosted top quarks

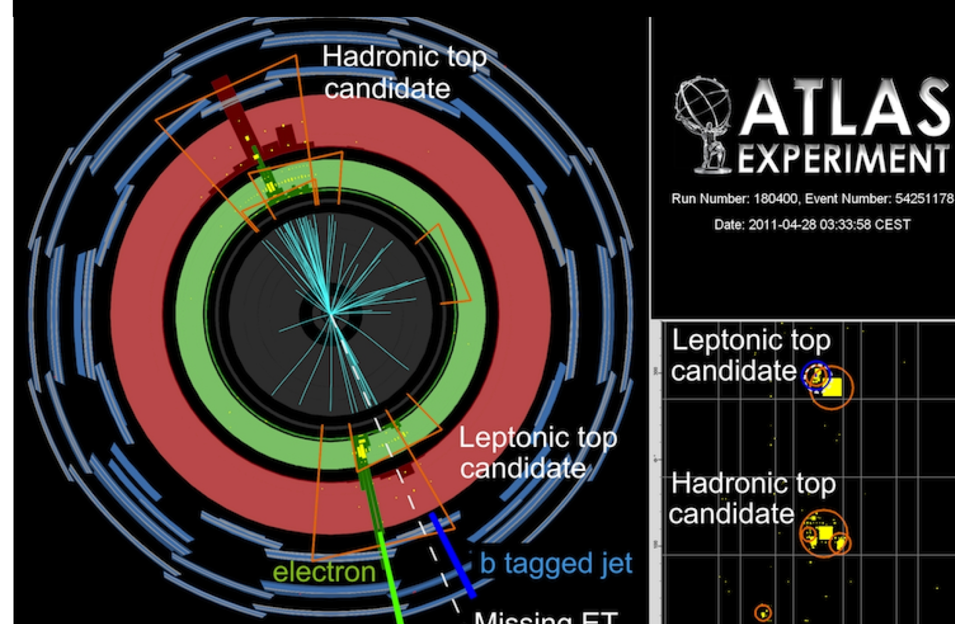
- Jet substructure needs to be studied



$t\bar{t}$ event candidate "l+jets" resolved topology ATLAS-CONF-2010-063



$t\bar{t}$ event candidate "l+jets" boosted topology ATLAS-CONF-2011-087



ATLAS (A Toroidal LHC ApparatuS)

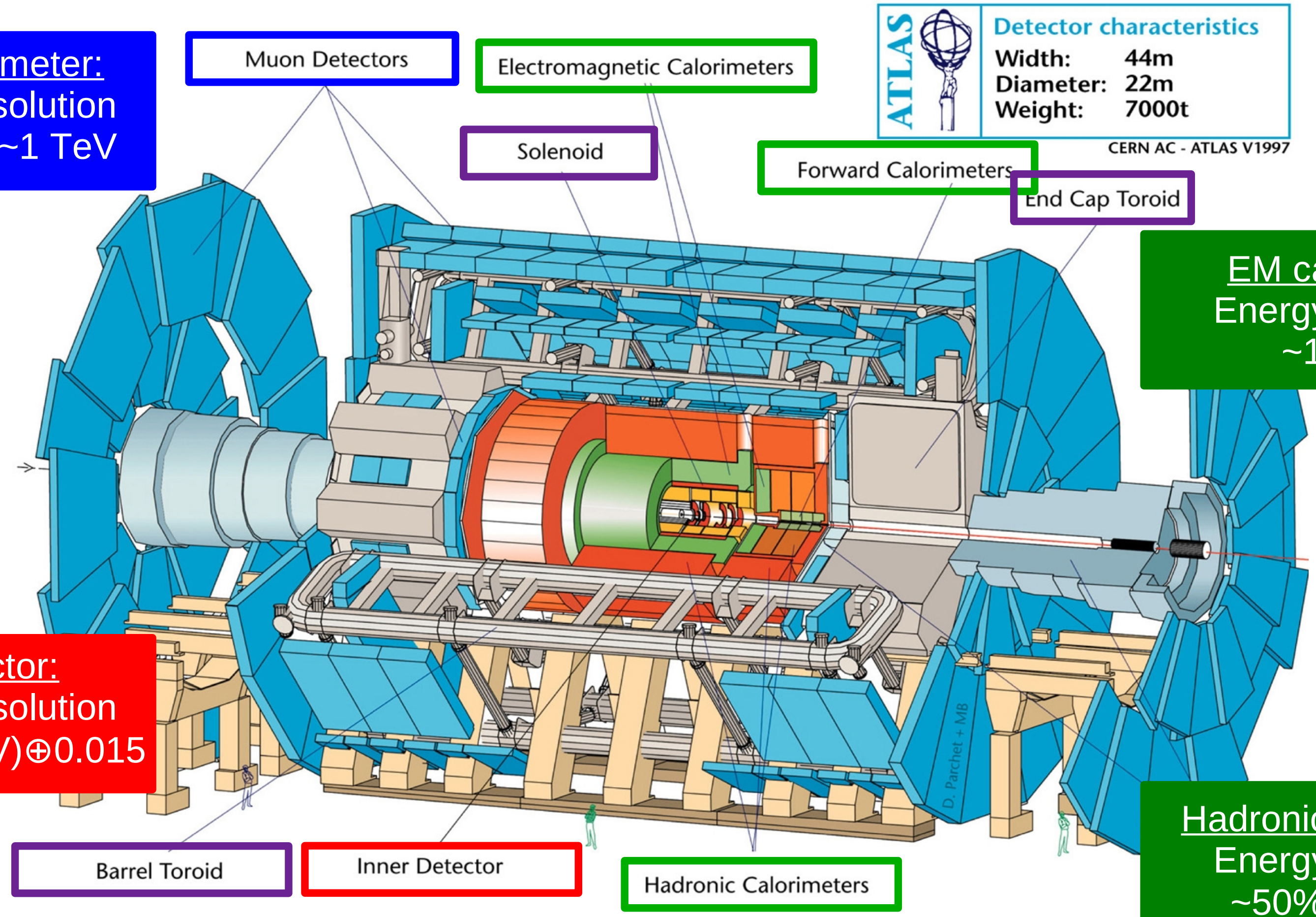
- ATLAS consists of a series of concentric sub-detectors around the interaction point
- Divided into 4 major parts: **the inner detector, the calorimeters, the muon spectrometer and the magnet systems**

Muon spectrometer:
Momentum resolution
<10% up to E_{μ}~1 TeV

Inner detector:
Momentum resolution
~$3.8\times10^{-4}\ p_T(\text{GeV})\oplus0.015$

EM calorimeter:
Energy resolution
~10%/√E

Hadronic calorimeter:
Energy resolution
~50%/√E⊕0.03



Good performance for all sub-systems is crucial for $t\bar{t}$ resonances searches

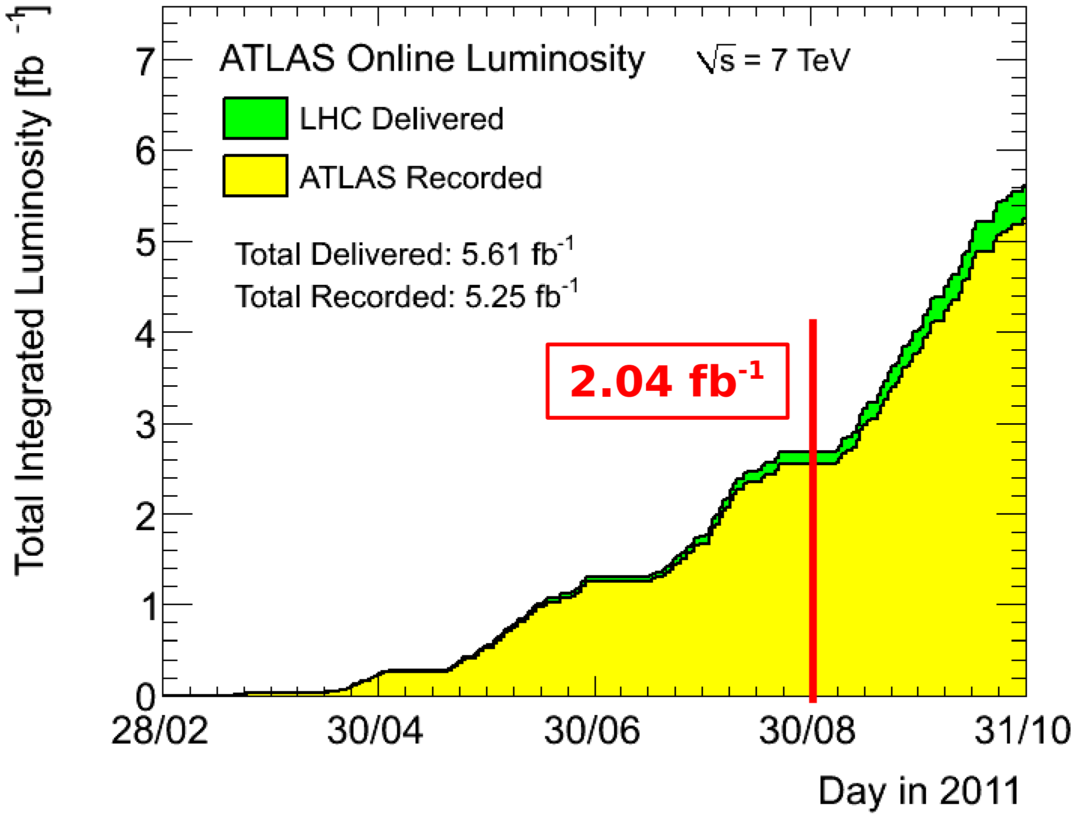
Analyses overview

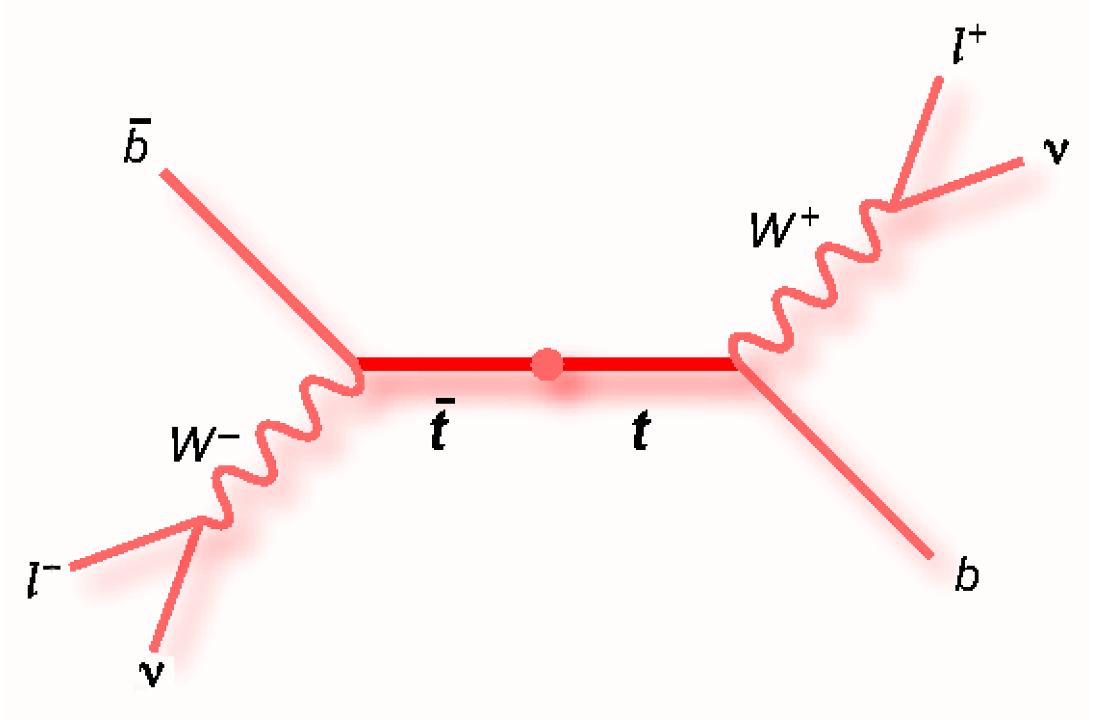
All analyses use 2.04 fb^{-1} of data collected at the beginning of 2011

Three channels:

- Dilepton channel (ee, μμ and eμ):
  Eur. Phys. J. C, arXiv:1205.5371
- Lepton+jets channel (e+jets and μ+jets):
  - Resolved topology
    ATLAS-CONF-2012-029
    Eur. Phys. J. C, arXiv:1205.5371
  - Boosted topology
    JHEP, arXiv:1207.2409v1

2011: 5.3 fb^{-1} @7 TeV
2012: 6.3 fb^{-1} @8 TeV



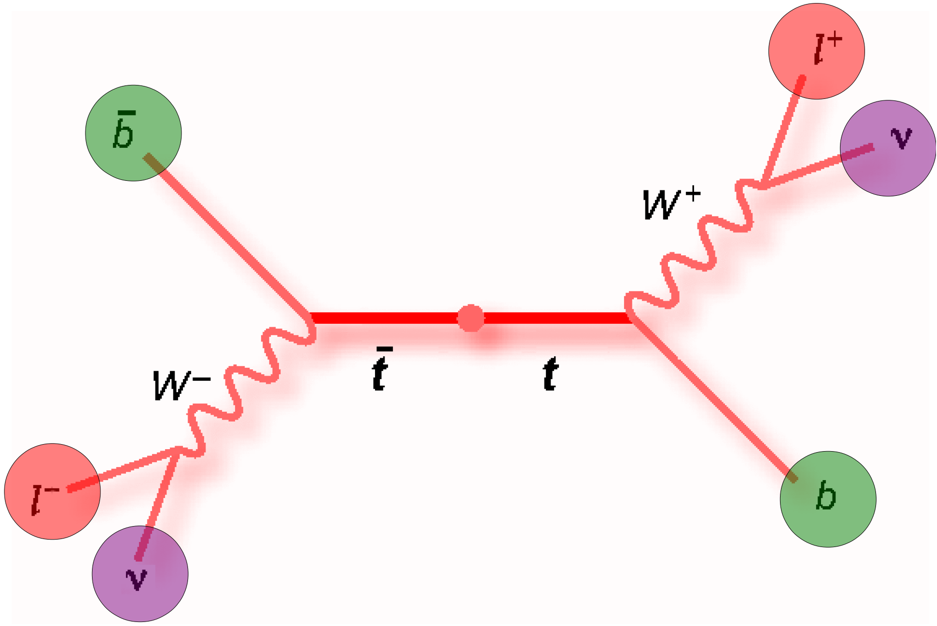


Dilepton channel

Event selection

- **Exactly 2 isolated leptons, opposite sign**
  - Electron: p_T > 25 GeV and |η| < 2.47
  - Muon: p_T > 25 GeV and |η| < 2.5
- **≥2 jets** anti-k_T R=0.4
  - p_T > 25 GeV and |η| < 2.5
- Z+jets background rejection ee and μμ channels:
  - **Z mass veto** ($|m_{ll}-m_Z|$>10 GeV)
  - **Missing transverse energy (MET)>40 GeV**
- Non-$t\bar{t}$ background rejection (mainly dibosons) in eμ channel:
  - **H_T ($=\Sigma p_T^{jets}+\Sigma p_T^{lept}$)>130 GeV**

Acceptance x efficiency x BR:
- 1.3% for a 800 GeV Z'
- 1.5% for a 1.3 TeV g_{KK}



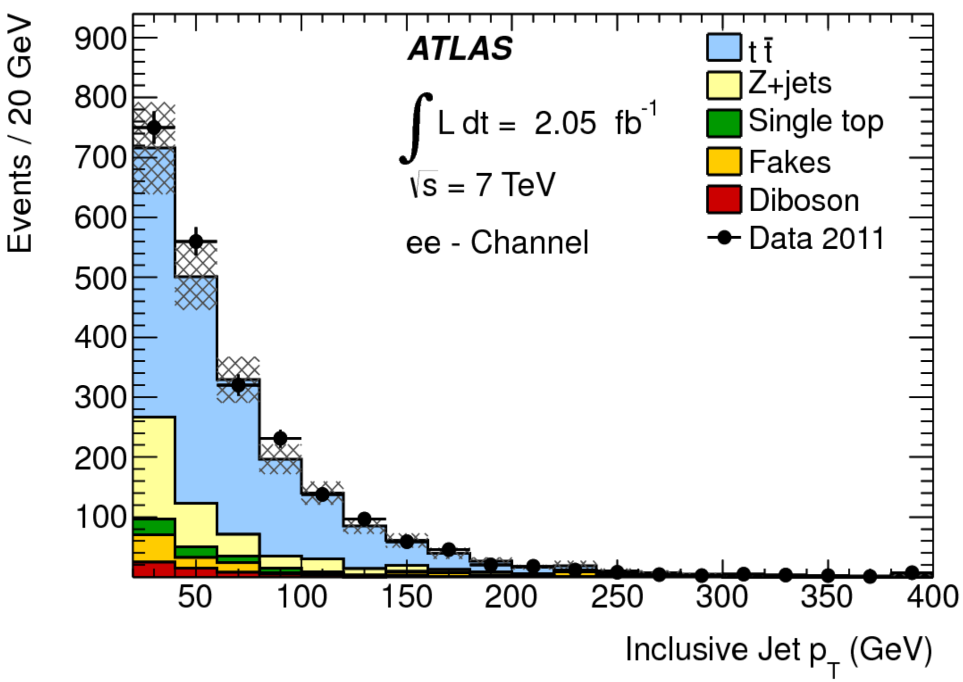
Backgrounds and data vs background expectation

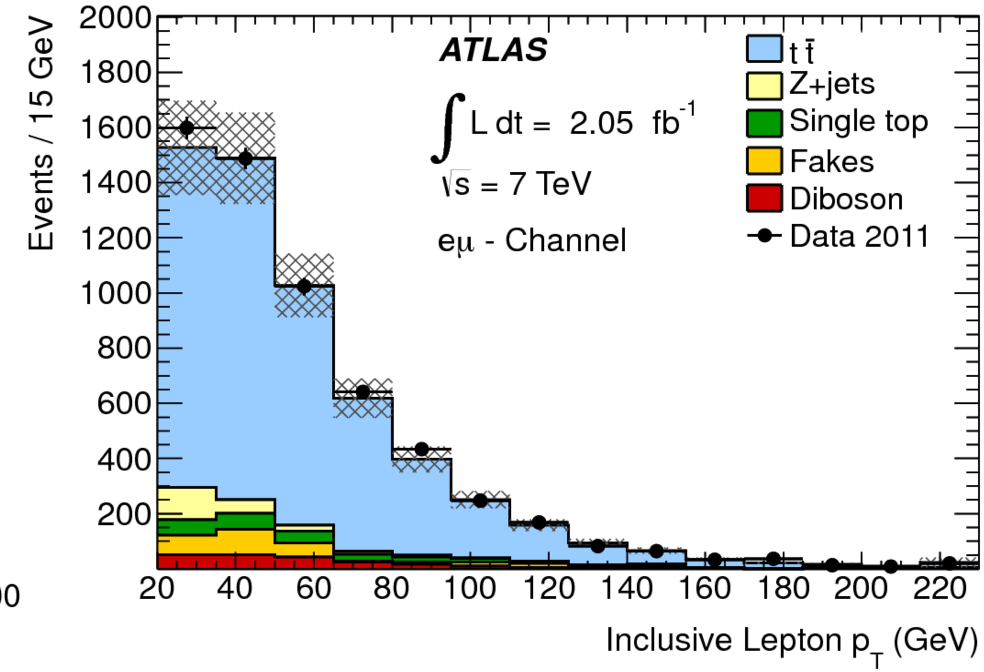
- **Z+jets/Drell-Yan MC normalized in a data** control sample orthogonal to the signal sample

- **W+jets** (one fake lepton) and **multijet** (two fake leptons) **estimated from data** using a technique called Matrix Method

- All other backgrounds are taken from simulation

SM $t\bar{t}$	~77%
Z+jets	~11%
Single top	~4%
W+jets and Multijet	~3.5%
Diboson	~3.5%

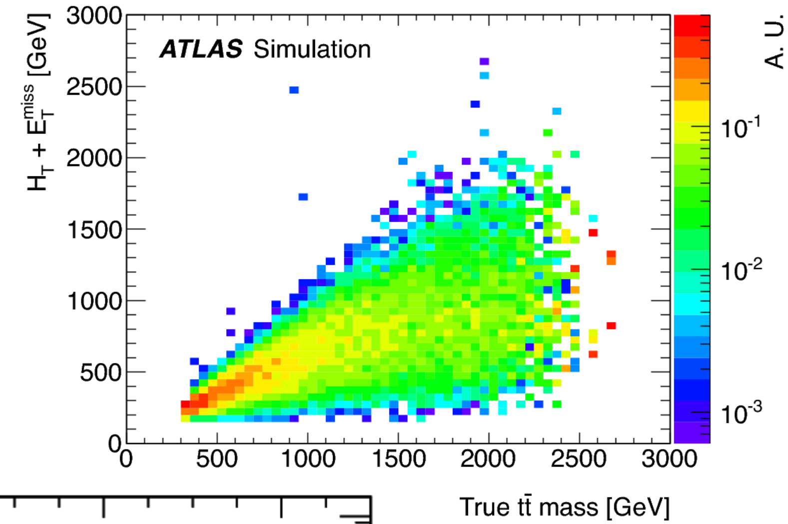


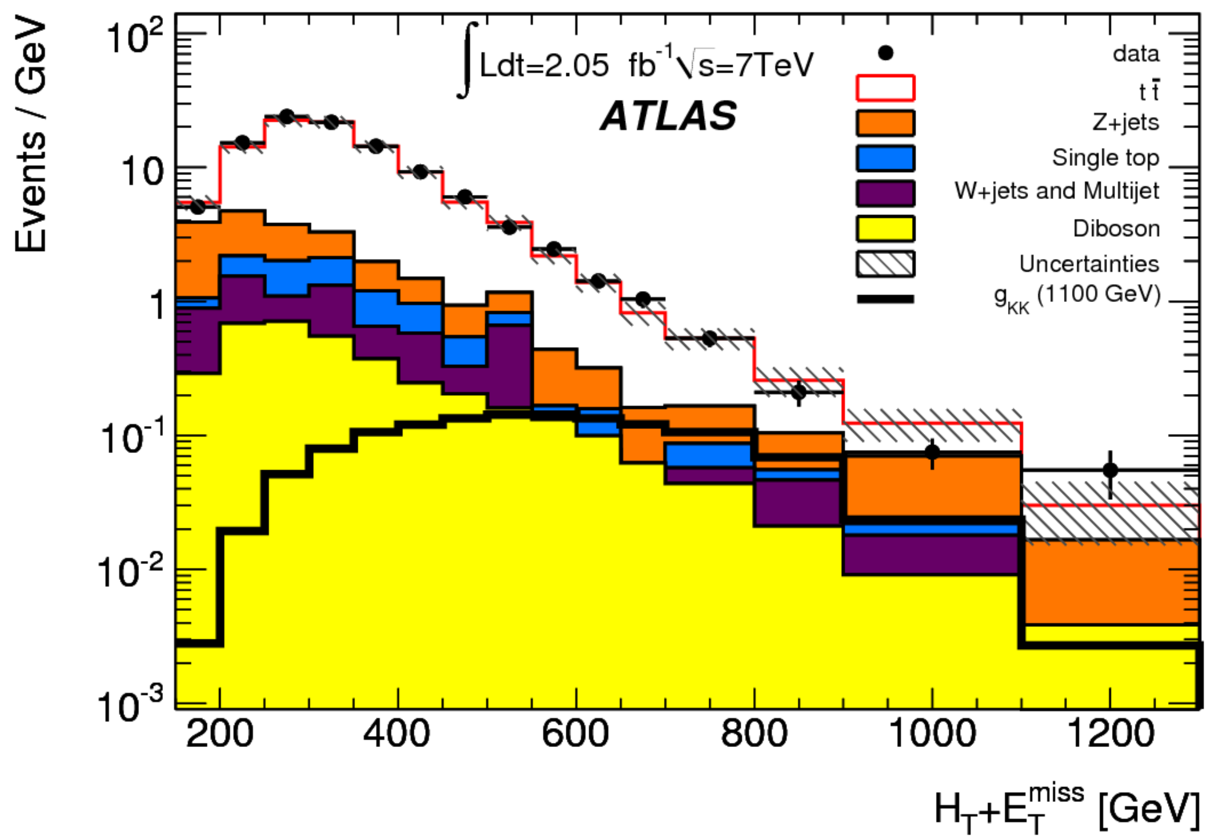


- The hatched areas correspond to the background normalization uncertainty

Discriminant variable

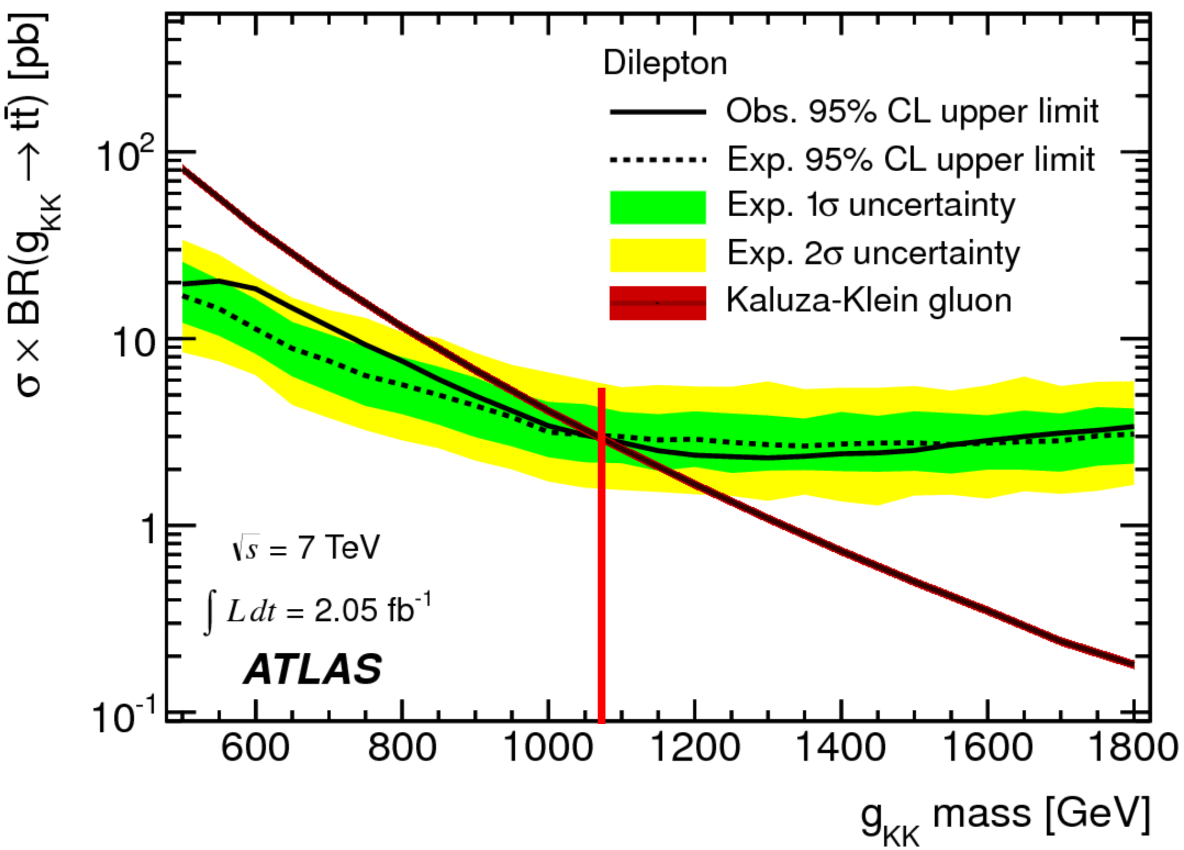
- $t\bar{t}$ mass reconstruction present ambiguities due to the presence of two neutrinos
- **Effective mass: H_T ($=\Sigma p_T^{jets}+\Sigma p_T^{lept}$) + MET used instead as discriminant variable**



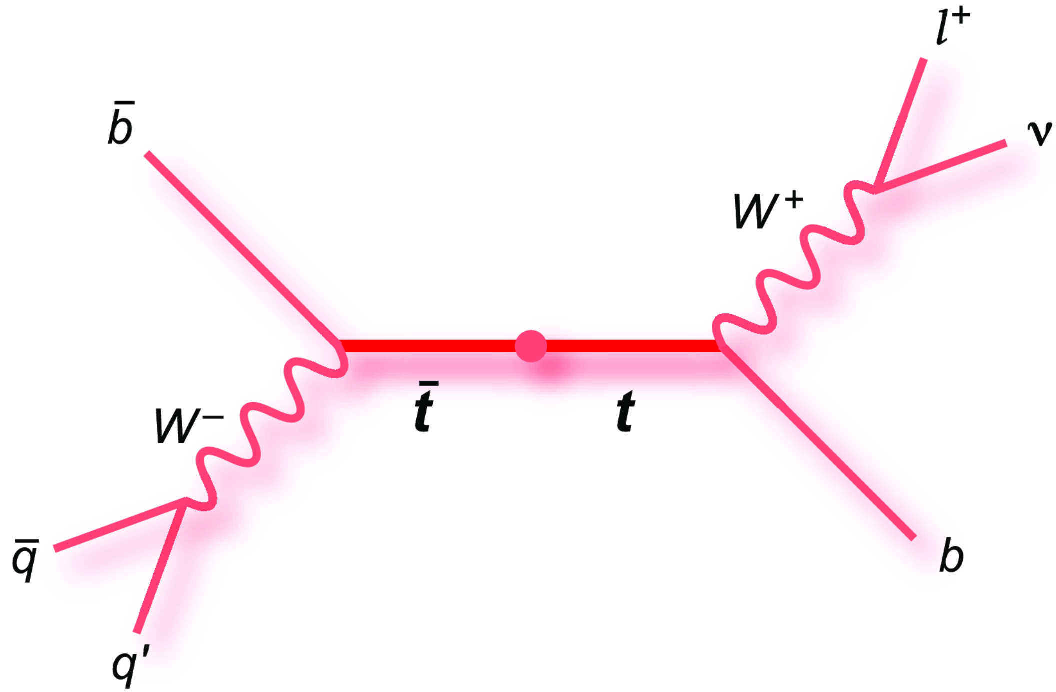


Results

- **No signs of new physics has been found**
- Bayesian approach used to set upper limits on σxBR at 95% CL
- Yield and shape systematic uncertainties are taken into account in the limit calculation by interpolation between the nominal and the shifted templates with a Gaussian prior
- **Exclusion: $500 < m_{gKK} < 1080$ GeV**



- **32 systematic uncertainties**
  - Each one has an impact <15% in the sensitivity
  - Sensitivity degraded by a factor of 3.0 (1.5) at low (high) mass
- **Shape systematic with biggest impact:**
  - **Jet energy scale**
  - **ISR/FSR**
  - **PDFs**

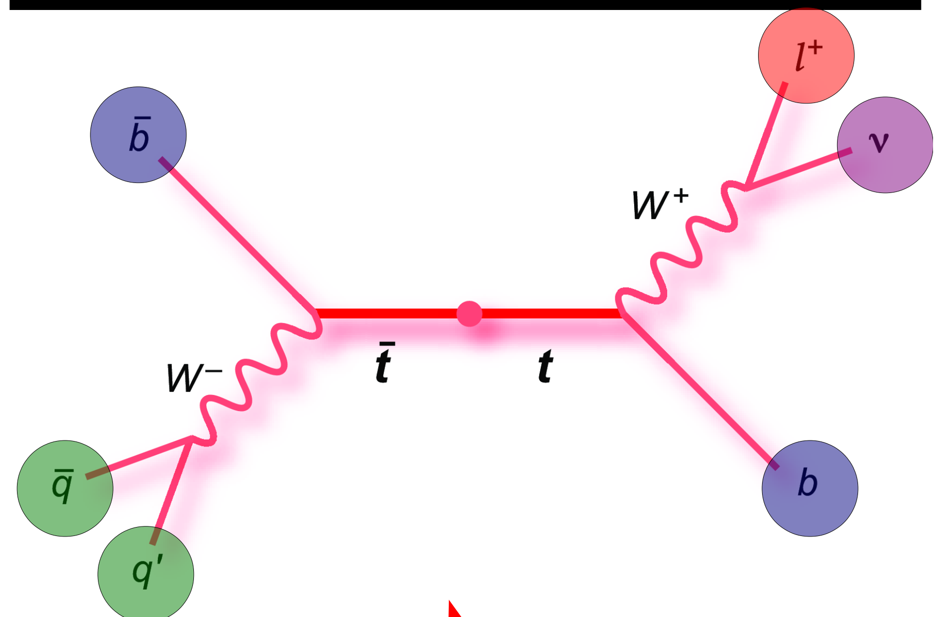


Lepton+jets channel (resolved)

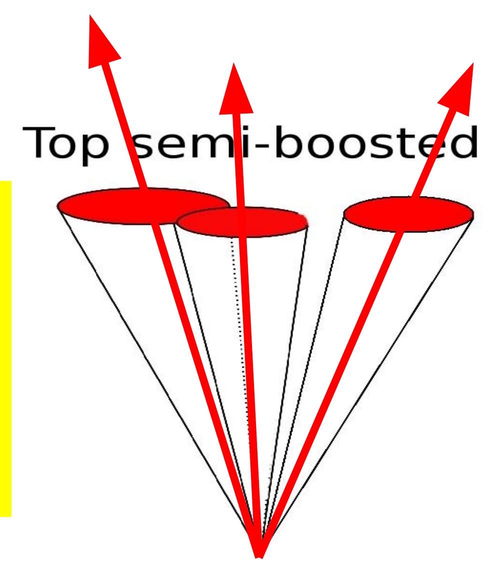
Event selection

- **Exactly 1 isolated lepton**
  - Electron: p_T > 25 GeV and $|\eta| < 2.47$
  - Muon: p_T > 25 GeV and $|\eta| < 2.5$
- **≥4 jets** anti-k_T R=0.4
  - p_T > 25 GeV and $|\eta| < 2.5$
- **Leading jet p_T>60 GeV**
- **Against multijet background:**
  - e channel: **MET>25 GeV and m_T^W>25 GeV**
  - μ channel: **MET>20 GeV and MET+m_T^W>60 GeV**
- **≥1 b-tagged jet** (impact parameter+decay chain)

Acceptance x efficiency x BR:
- 7.4% for a 800 GeV Z'
- 7.3% for a 1.3 TeV g_{KK}



Two of the jets from the hadronic top decay can be merged
→ **Semi-boosted regime**



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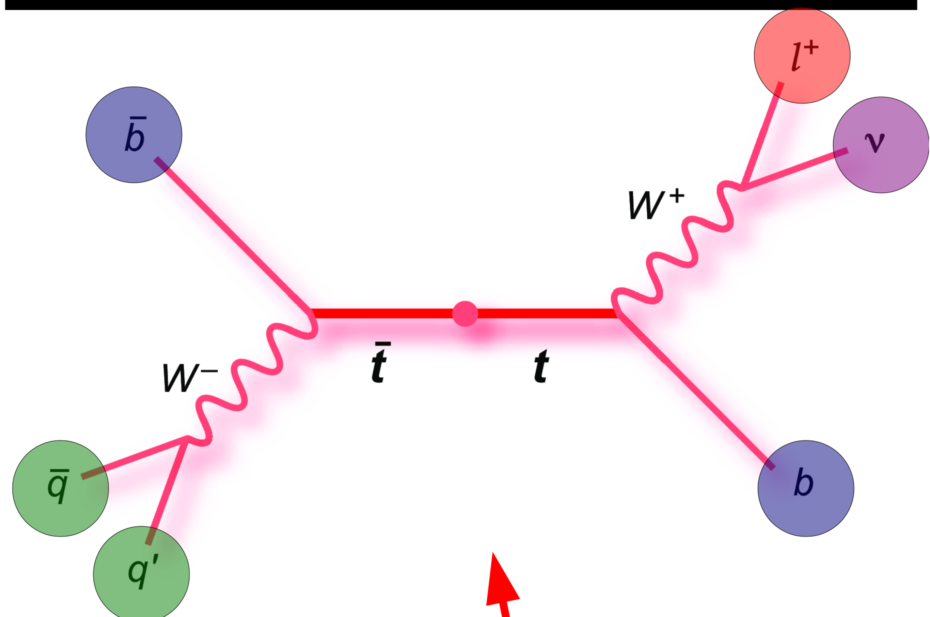
Event selection

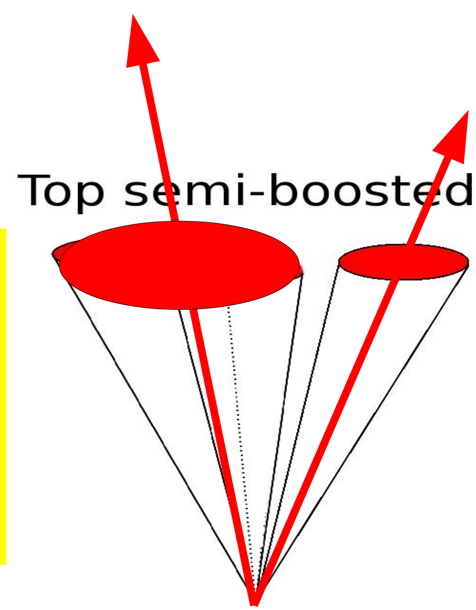
- **Exactly 1 isolated lepton**
  - Electron: p_T > 25 GeV and |η| < 2.47
  - Muon: p_T > 25 GeV and |η| < 2.5
- **≥4 jets** anti-k_T R=0.4
  - p_T > 25 GeV and |η| < 2.5
- **Leading jet p_T>60 GeV**
- **Against multijet background:**
  - e channel: **MET>25 GeV and m_T^W>25 GeV**
  - μ channel: **MET>20 GeV and MET+m_T^W>60 GeV**
- **≥1 b-tagged jet** (impact parameter+decay chain)

Acceptance x efficiency x BR:
- 7.4% for a 800 GeV Z'
- 7.3% for a 1.3 TeV g_{KK}



Two of the jets from the hadronic top decay can be merged
→ **Semi-boosted regime**

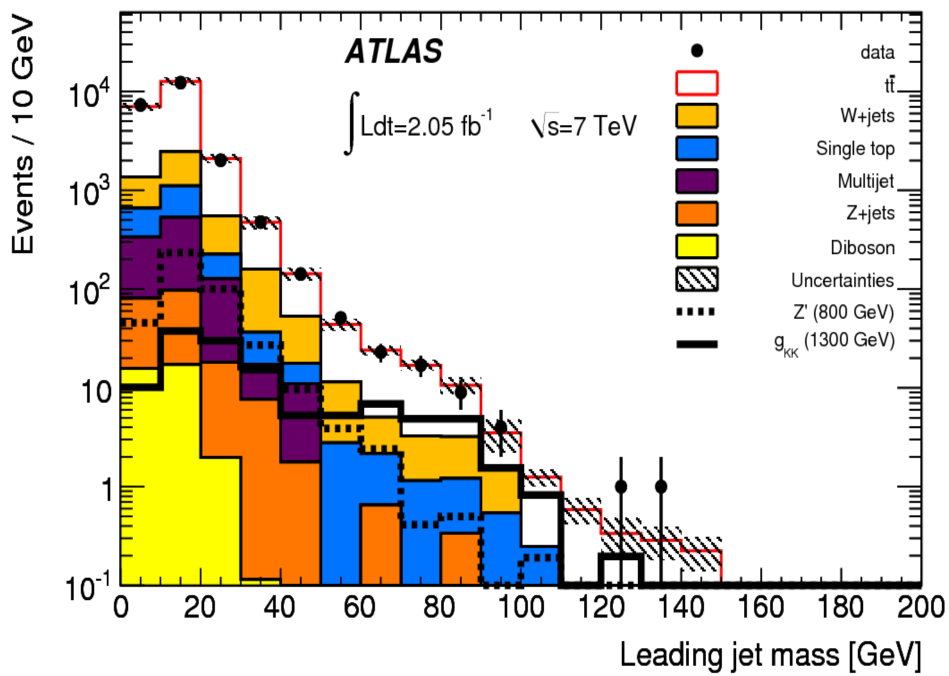
If one of the jets has a mass >60 GeV
→ ***Require ≥3 jets***

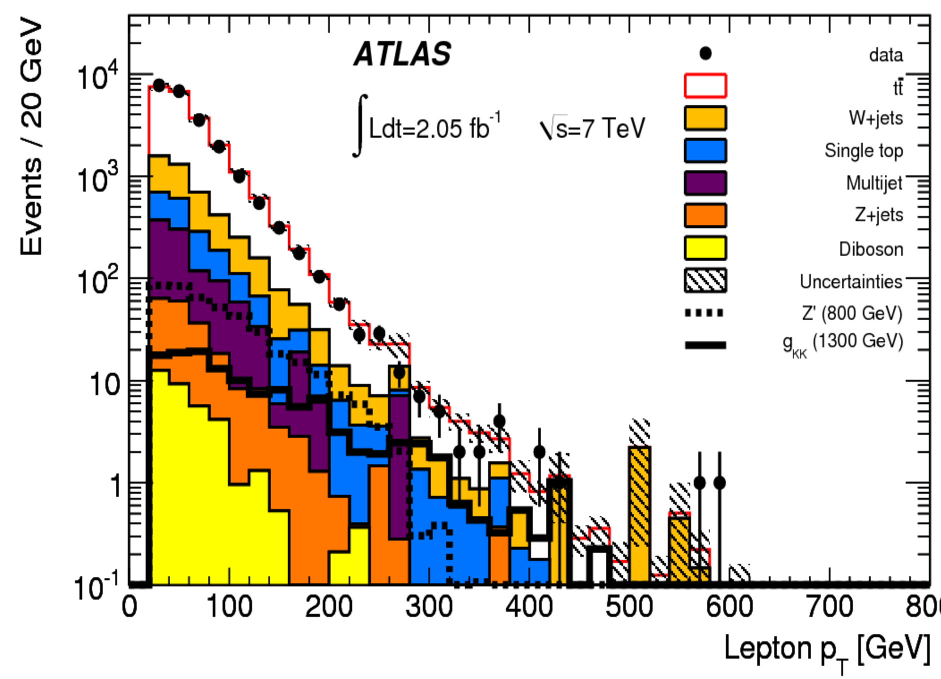


Backgrounds and data vs background expectation

- **Multijet from data** jet-triggered events with high EM fraction. Normalization from fit of MET distribution
- **W+jets normalization from data** based on tagged fractions and on charge asymmetry
- All other backgrounds are taken from simulation

SM $t\bar{t}$	**~79.4%**
W+jets	**~11%**
Single top	**~4.6%**
Multijet	**~3.6%**
Z+jets	**~0.7%**
Diboson	**~0.2%**





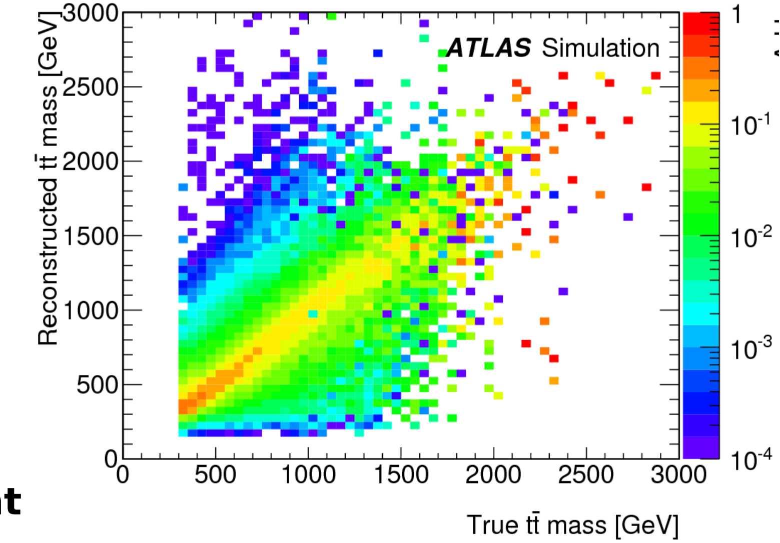
Discriminant variable

- **Discriminant variable: invariant mass of the reconstructed $t\bar{t}$ system mass**
  4(3) jets + lepton + neutrino

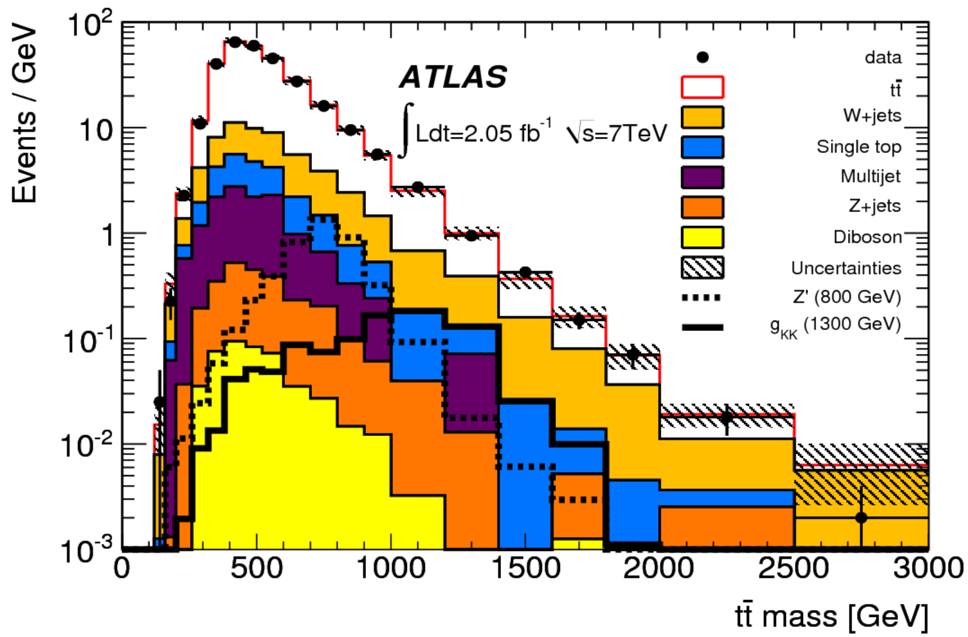
- Neutrino
  - MET identified with neutrino p_T
  - p_z from quadratic equation imposing W mass constraint

- No attempts are made to reconstruct each top

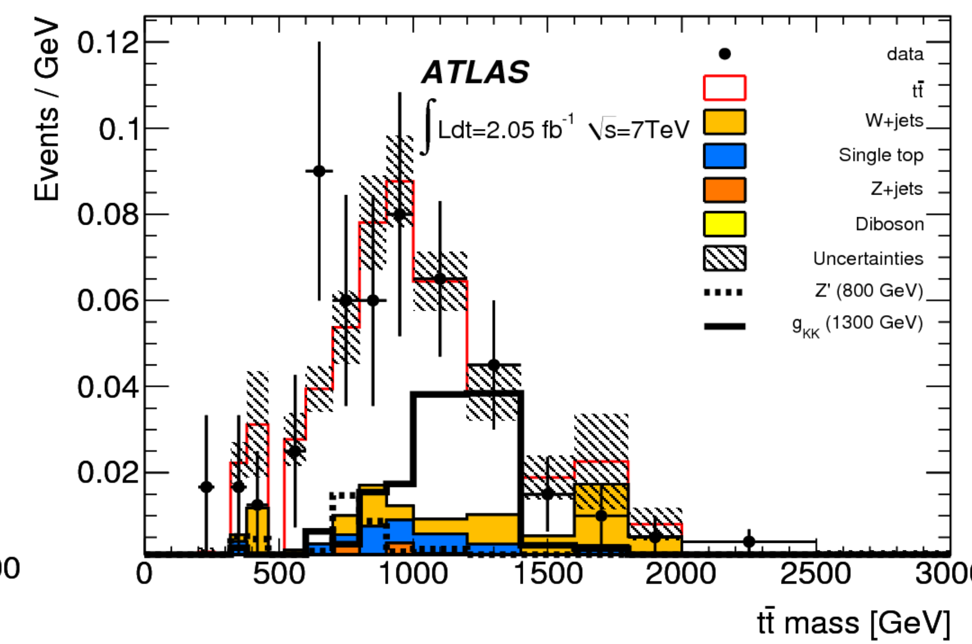
- **Use highest p_T jets close to other activity in the event**
  - ISR mitigation scheme



All selected events



Only events with a high mass jet



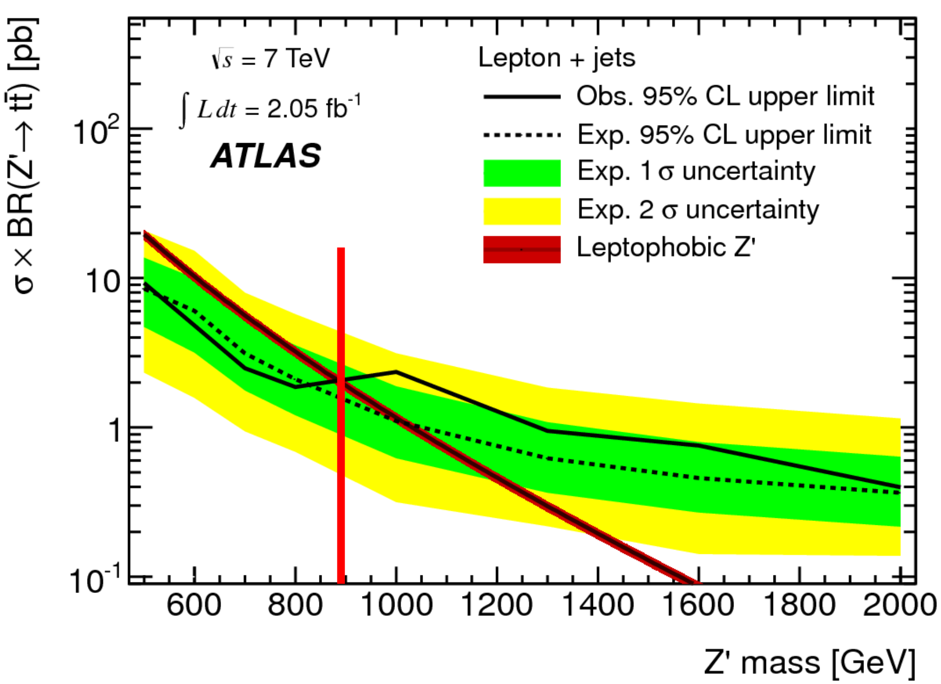
Results

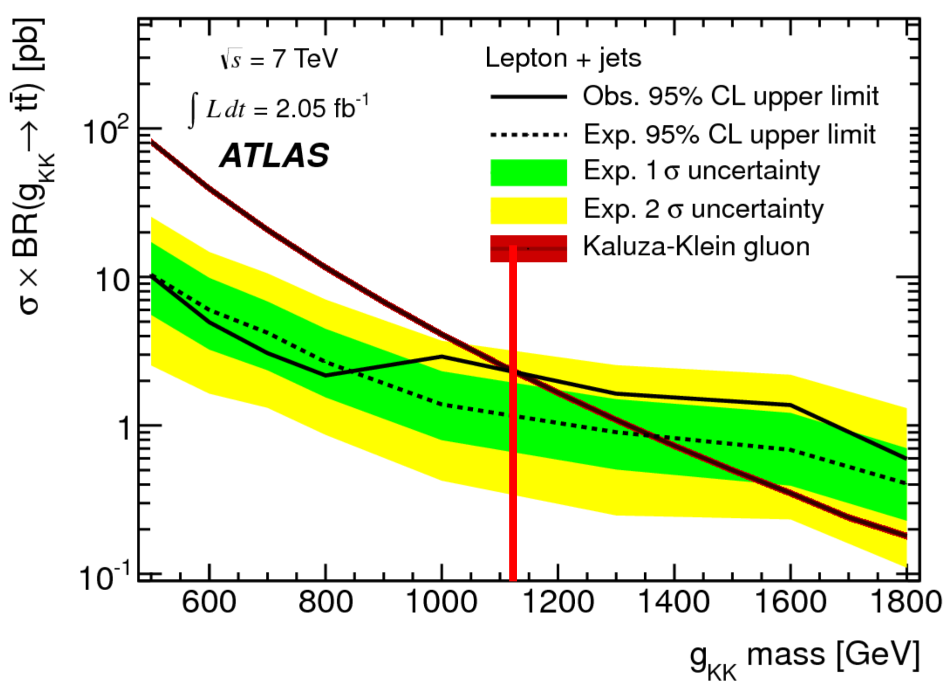
- **No significant deviations from the Standard Model**

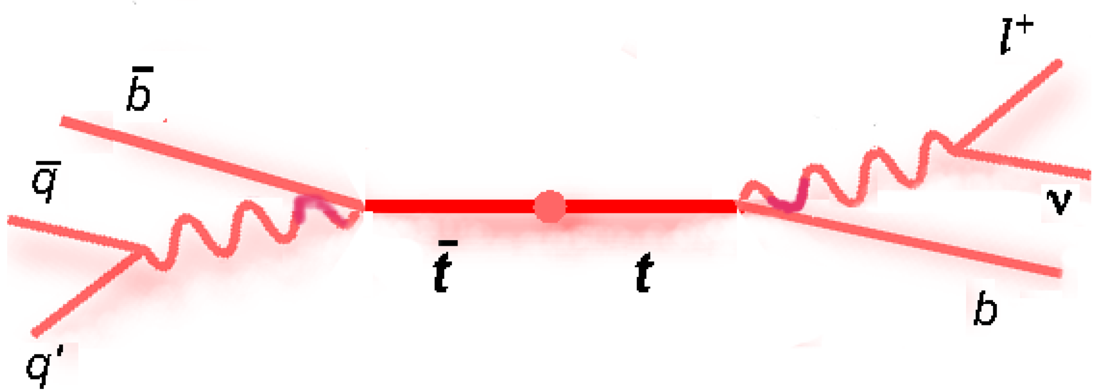
- Upper limits on σxBR at 95% CL has been set using the same tools as in the dileptonic analysis
- **Exclusion:**
  - **$500 < m_{Z'} < 880$ GeV**
  - **$500 < m_{gKK} < 1130$ GeV**

Enhanced sensitivity compared to the dilepton analysis

- **32 systematic uncertainties. Shape systematic with biggest impact:**
  - **b-tagging efficiency**
  - **Jet energy scale and resolution**
  - **ISR/FSR**





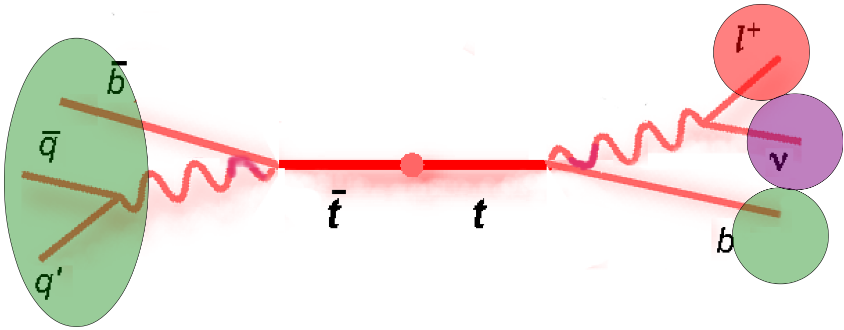


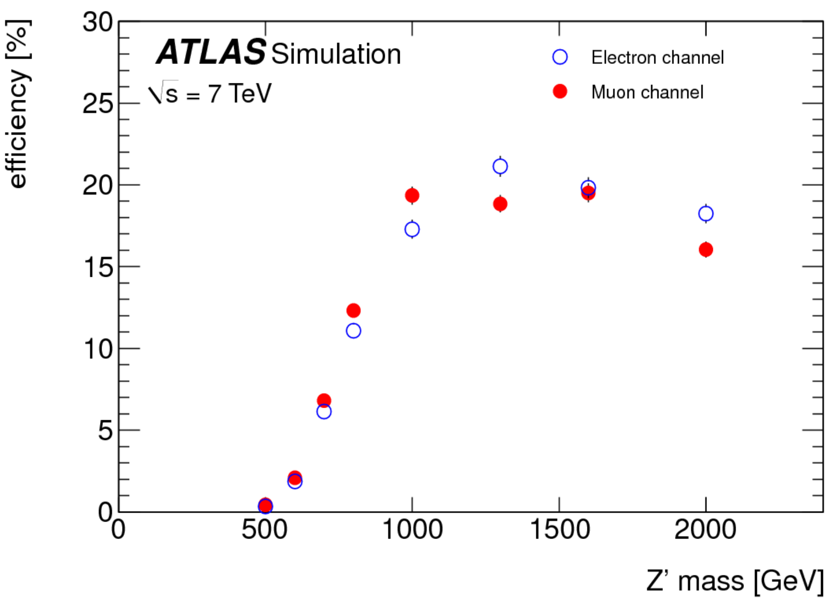
Lepton+jets channel (boosted)

Event selection

- **Lepton selection similar to previous analysis:** exactly 1 isolated lepton. Same criteria for selection and veto
  - Electron: p_T > 25 GeV and $|\eta|$ < 2.47
  - Muon: p_T > 20 GeV and $|\eta|$ < 2.5
- Mainly QCD background rejection:
  - e channel: **MET>25 GeV and m_T^W>25 GeV**
  - μ channel: **MET>20 GeV and MET+m_T^W>60 GeV**
- **Jet selection driven for the expected boosted topology:**
  - **1 jet close to the lepton** (0.4<ΔR(l,j)<1.5) with p_T > 30 GeV to **build the leptonic top**
  - **≥1 "fat" jet** anti-k_T **R=1.0** back-to-back to the previous jet (ΔR(j,j)>1.5)
    - p_T > 250 GeV
    - Mass >100 GeV
    - $\sqrt{d_{12}}$ >40 GeV (k_T last splitting scale of the jet constituents)
  - **The leading p_T fat jet is taken as the hadronic top candidate**
- No b-tagging condition

Assume all hadronic top decay products merge





-Turn on ~800 GeV
- Acceptance x efficiency degraded for >2 TeV due to lepton isolation

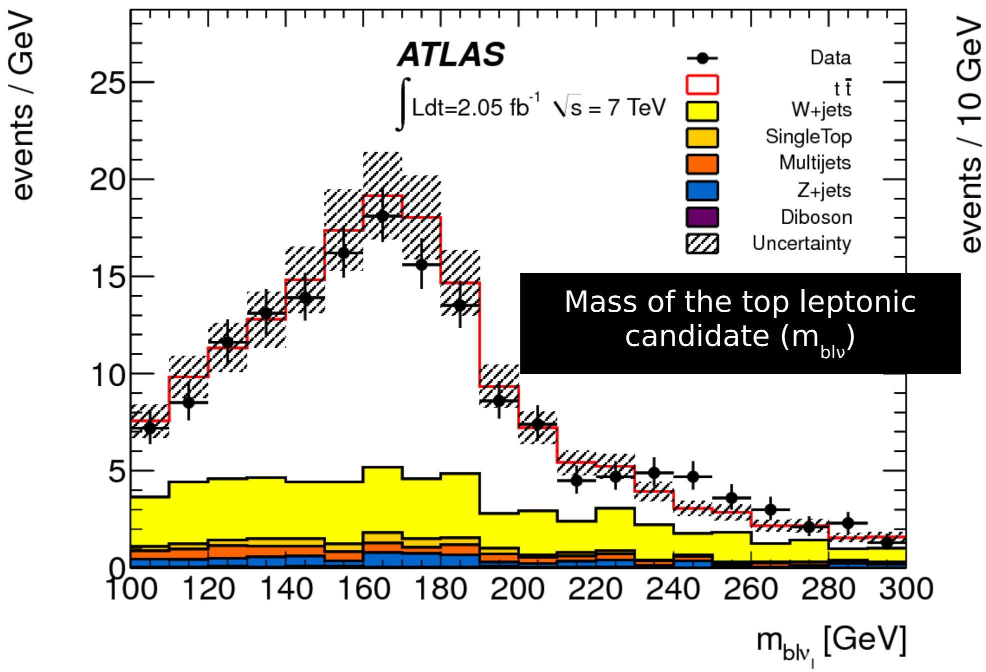
Backgrounds and data vs background expectation

- **Multijet estimated from data** using a technique called Matrix Method. Exploiting control region with low-quality leptons

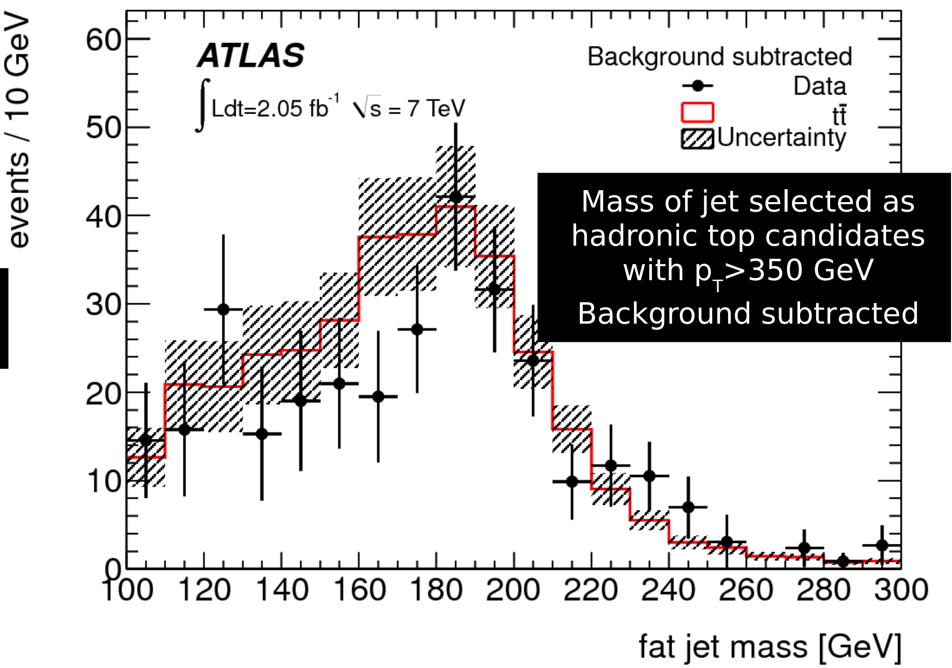
- **W+jets normalization from data** based on tagged fractions and on charge asymmetry.

- All other backgrounds are taken from simulation

SM $t\bar{t}$	~62%
W+jets	~27%
Z+jets	~4%
Multijet	~4%
Single top	~2.6%
Diboson	~0.5%



Mass of the top leptonic candidate ($m_{bl\nu}$)



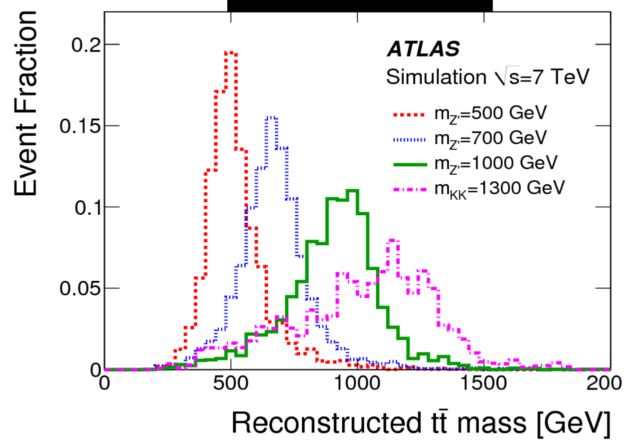
Mass of jet selected as hadronic top candidates with p_T>350 GeV
Background subtracted

Discriminant variable

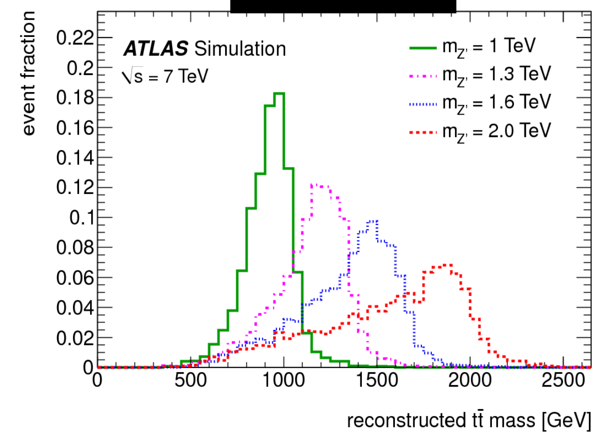
- **The $t\bar{t}$ invariant mass is used as discriminant variable**

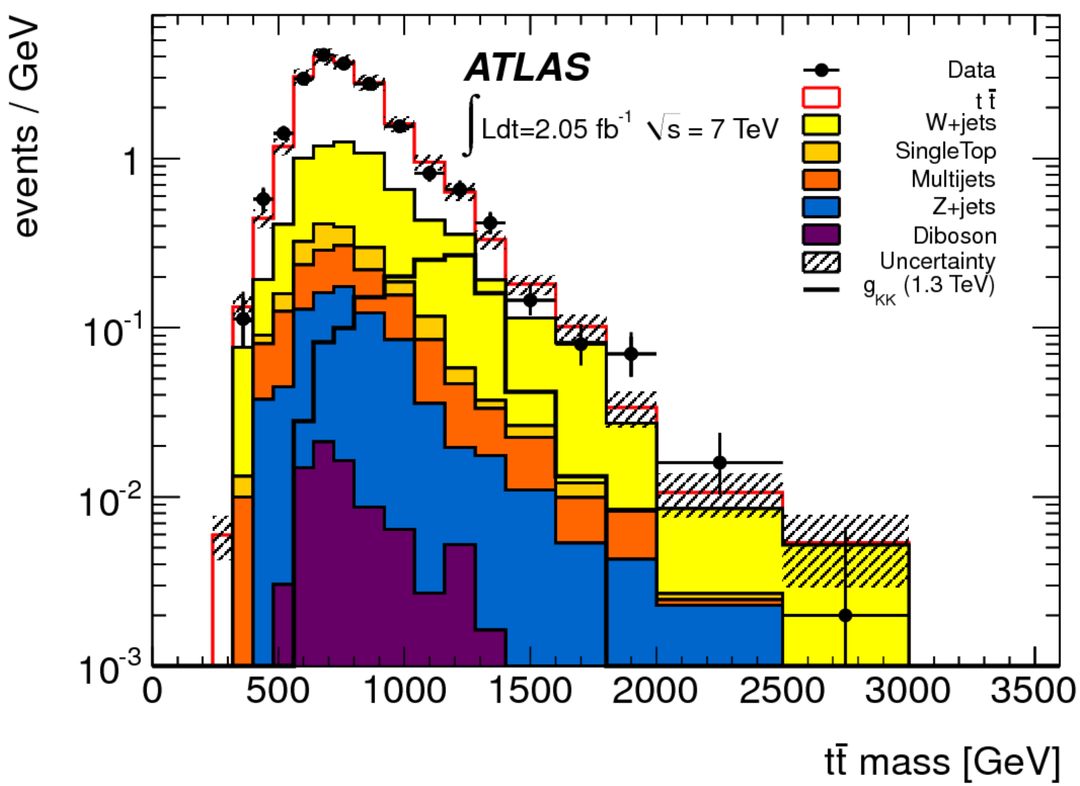
- The **$t\bar{t}$ system is reconstructed** adding the 4-momenta of:
  - **The top hadronic candidate** (fat jet)
  - **The top leptonic candidate** (neutrino+lepton+jet closest to lepton)

Resolved



Boosted





- Good agreement with background

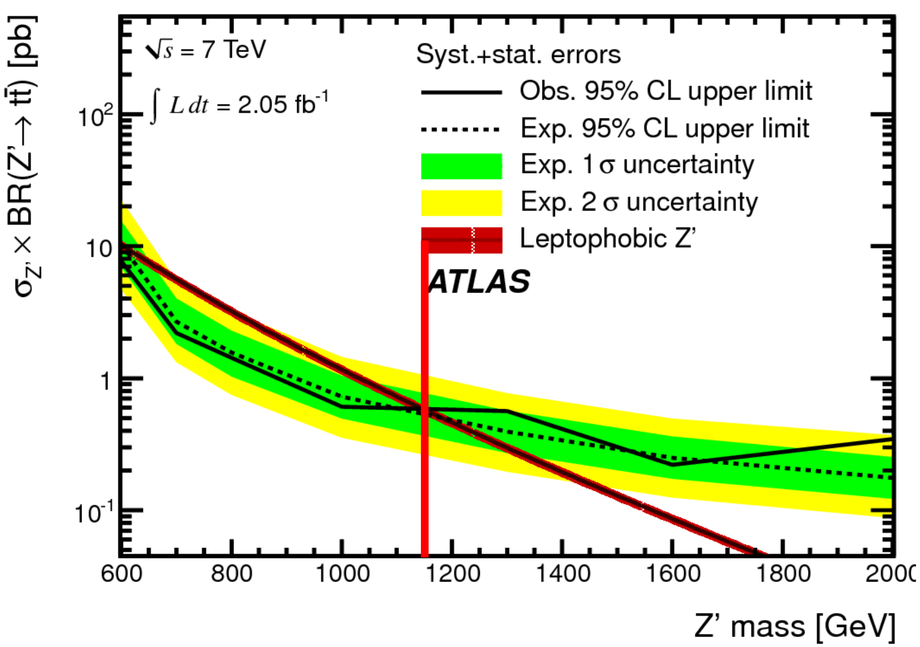
- The electron and muon channel have been added together

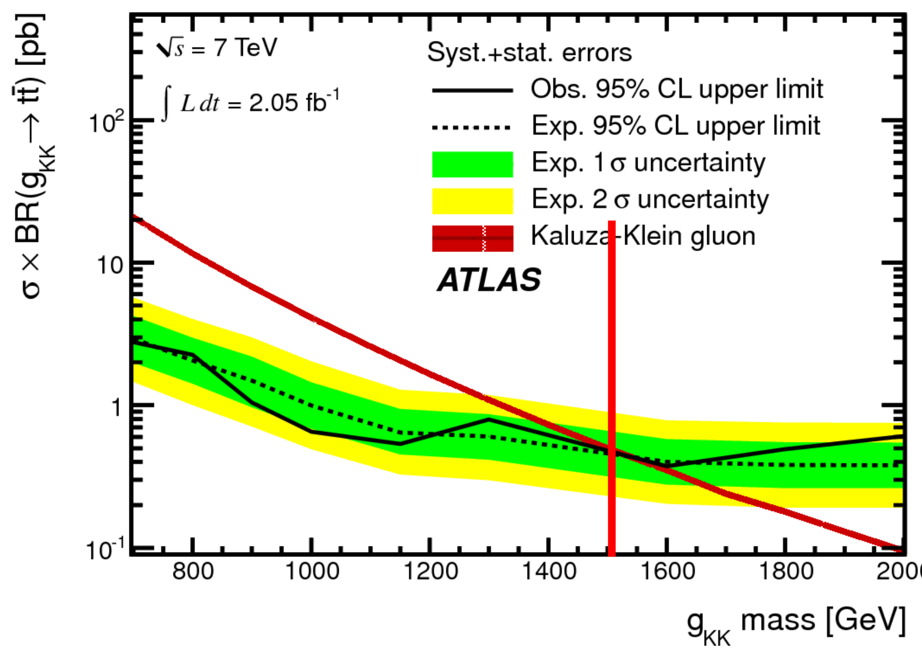
Results

- **No significant deviations from the Standard Model observed**
- Bayesian approach also used to set upper limits on σxBR at 95% CL
- **Exclusion:**
  - **600<$m_{Z'}$ < 1150 GeV**
  - **700<m_{gKK} < 1500 GeV**

Sensitivity: ~300 GeV higher than the resolved analysis

- **30 systematic uncertainties. Shape systematic with biggest impact:**
  - **Jet energy and mass scale**
  - **Jet energy and mass resolution**
  - **ISR/FSR**





Summary (I)

- So far, the search for a $t\bar{t}$ resonance done in ATLAS **does not show any evidence of a new physics signal**

- Limits on the mass for the leptophobic topcolor Z' model and KK gluon were set

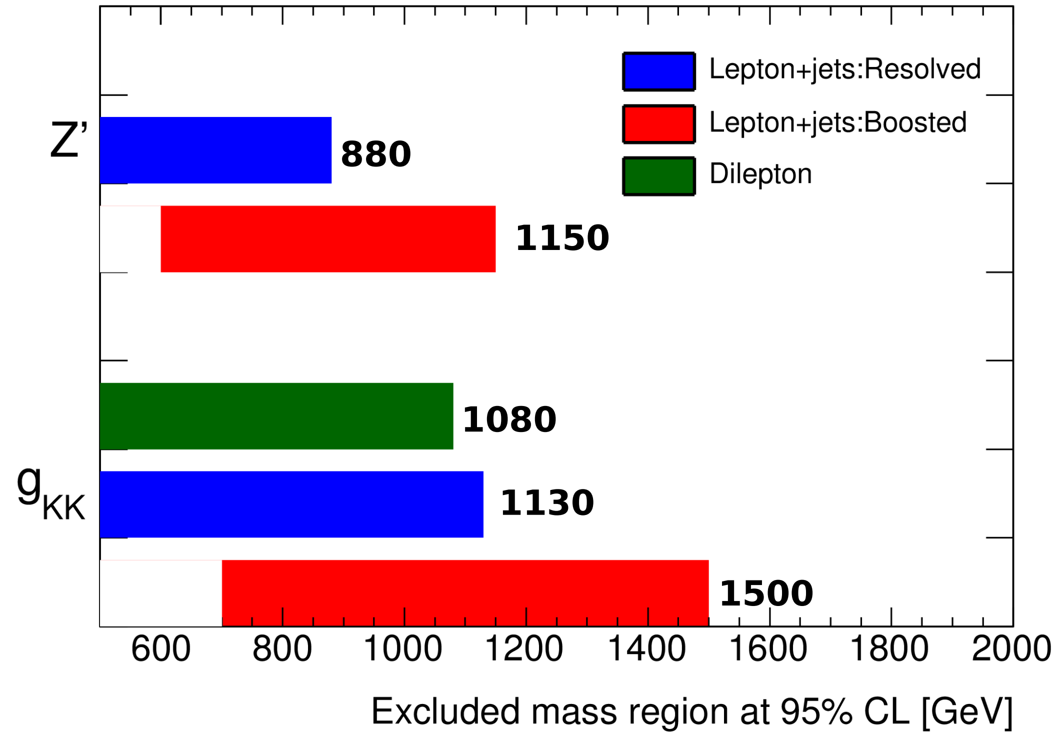
- **Exclusion (2.05 fb^{-1} @7 TeV):**
  - **$m_{Z'}$ < 1.15 TeV**
  - **m_{gKK} < 1.5 TeV**

Expected g_{KK} limit @ 600 GeV

Dilepton:	11.3 pb
Semileptonic resolved:	6.0 pb
Semileptonic boosted:	-

Expected g_{KK} limit @ 1.6 TeV

Dilepton:	2.8 pb
Semileptonic resolved:	0.68 pb
Semileptonic boosted:	0.40 pb



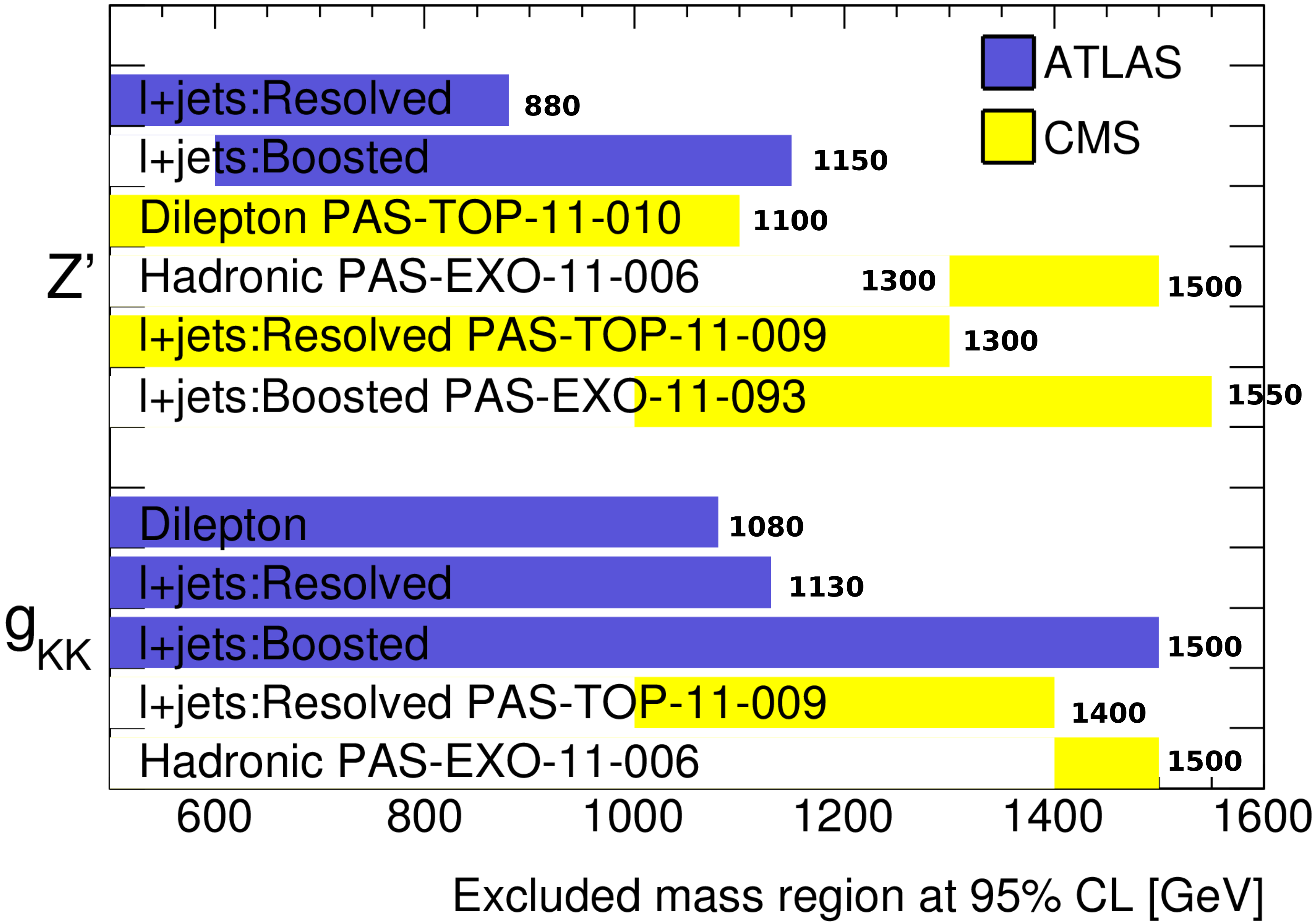
- **ATLAS analyses provide complementary sensitivity along the $t\bar{t}$ mass spectra**

Summary (II)

- Efforts between groups to develop orthogonal and more sophisticated analyses, that can be easily combined. In particular between resolved and boosted topologies
- New BSM signals to be tested
- **Looking forward for results with the whole 2011 and 2012 data**, which will allow to have access to a higher mass regime

Backup

Comparison: ATLAS and CMS



MC generators used

- **SM top-antitop:**
  - MC@NLO+HERWIG/JIMMY, CTEQ6.6, reweighted to MSTW2088nlo
  - Approximated NNLO cross-section: 165 pb
  - POWHEG+HERWIG/JIMMY and POWHEG+PYTHIA for systematics
  - AcerMC for ISR and FSR variations
- **Single top:**
  - MC@NLO+HERWIG/JIMM, CTEQ6.6, reweighted to MSTW2088nlo
  - Approximated NNLO cross-section: 65 pb (t-channel), 4.6 pb (s-channel), 15.7 pb (Wt-channel)
- **W/Z+jets:**
  - ALPGEN+HERWIG/JIMMY in parton multiplicity bins up to 5, CTEQ6L1
  - Normalized to the NNLO cross sections
- **Diboson:**
  - HERWIG/JIMMY, MRST2007LO*
  -
- **Z':**
  - PYTHIA, CTEQ6L1
  - Normalized to the NLO cross sections
- **gKK:**
  - MADGRAPH+PYTHIA, CTEQ6L1
  - LO cross sections

References

Tested models:

- g_{KK} arXiv:hep-ph/0612015v1
  arXiv:hep-ph/0701166v1
- Z' arXiv:hep-ph/941142
  arXiv:hep-ph/9911288v1

$t\bar{t}$ resonances search at ATLAS @7 TeV:

- **Dilepton channel (ee, μμ and eμ):**
  1.04/fb ATLAS-CONF-2011-123
  2.04/fb Eur. Phys. J. C, arXiv:1205.5371

- **Lepton+jets channel resolved (e+jets and μ+jets):**
  200/pb ATLAS-CONF-2011-087
  2.04/fb ATLAS-CONF-2012-029
  Eur. Phys. J. C, arXiv:1205.5371

- **Lepton+jets channel boosted (e+jets and μ+jets):**
  2.04/fb JHEP, arXiv:1207.2409v1

Statistical tools:

- BumpHunter arXiv:1101.0390 [physics.data-an].

- DØ Collaboration, I. Bertram et al., A Recipe for the construction of confidence limits, FERMILAB-TM-2104, Fermilab, 2000.

Matrix Method: Multijet estimation

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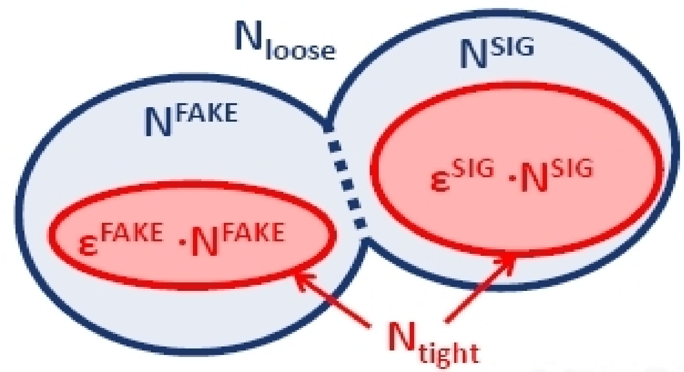
Matrix Method

Implementation of the Matrix Method:



- Define two samples N_{loose} and N_{tight} upon data with respect to a particular applied cut (here: muon isolation cut) → $N_{tight} \subset N_{loose}$:
- Determine signal and fake efficiencies.
- Solve matrix equation to obtain N^{FAKE}:

$$\begin{pmatrix} N_{loose} & = & N^{SIG} + N^{FAKE} \\ N_{tight} & = & \varepsilon^{SIG} N^{SIG} + \varepsilon^{FAKE} N^{FAKE} \end{pmatrix} \Rightarrow \begin{pmatrix} N_{loose} \\ N_{tight} \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ \varepsilon^{SIG} & \varepsilon^{FAKE} \end{pmatrix} \begin{pmatrix} N^{SIG} \\ N^{FAKE} \end{pmatrix}$$

Here:

$$\varepsilon^{SIG} = \frac{N^{SIG}_{tight}}{N^{SIG}_{loose}} \; ; \; \varepsilon^{FAKE} = \frac{N^{FAKE}_{tight}}{N^{FAKE}_{loose}}$$

- Loose selection: TopCommon selection without muon isolation.
- Tight selection: Loose + muon (etcone30 < 4 GeV & ptcone30 < 4 GeV).
- Determine ε^{SIG} with $Z \rightarrow \mu\mu$ Tag & Probe method.
- Determine ε^{FAKE} in low $M_T(W)$ and high d_0 significance control region.

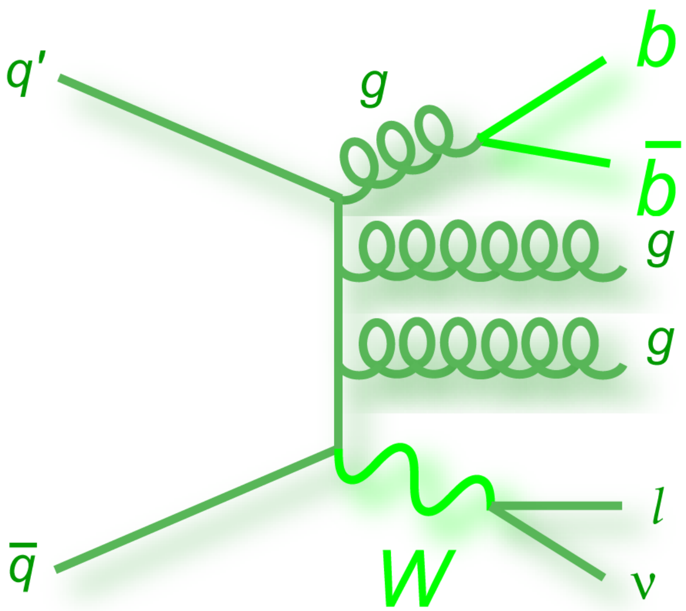
W+jets data-driven normalization

- Heavy flavour fraction determined from data based on the tagged fraction in W+2 jets events.

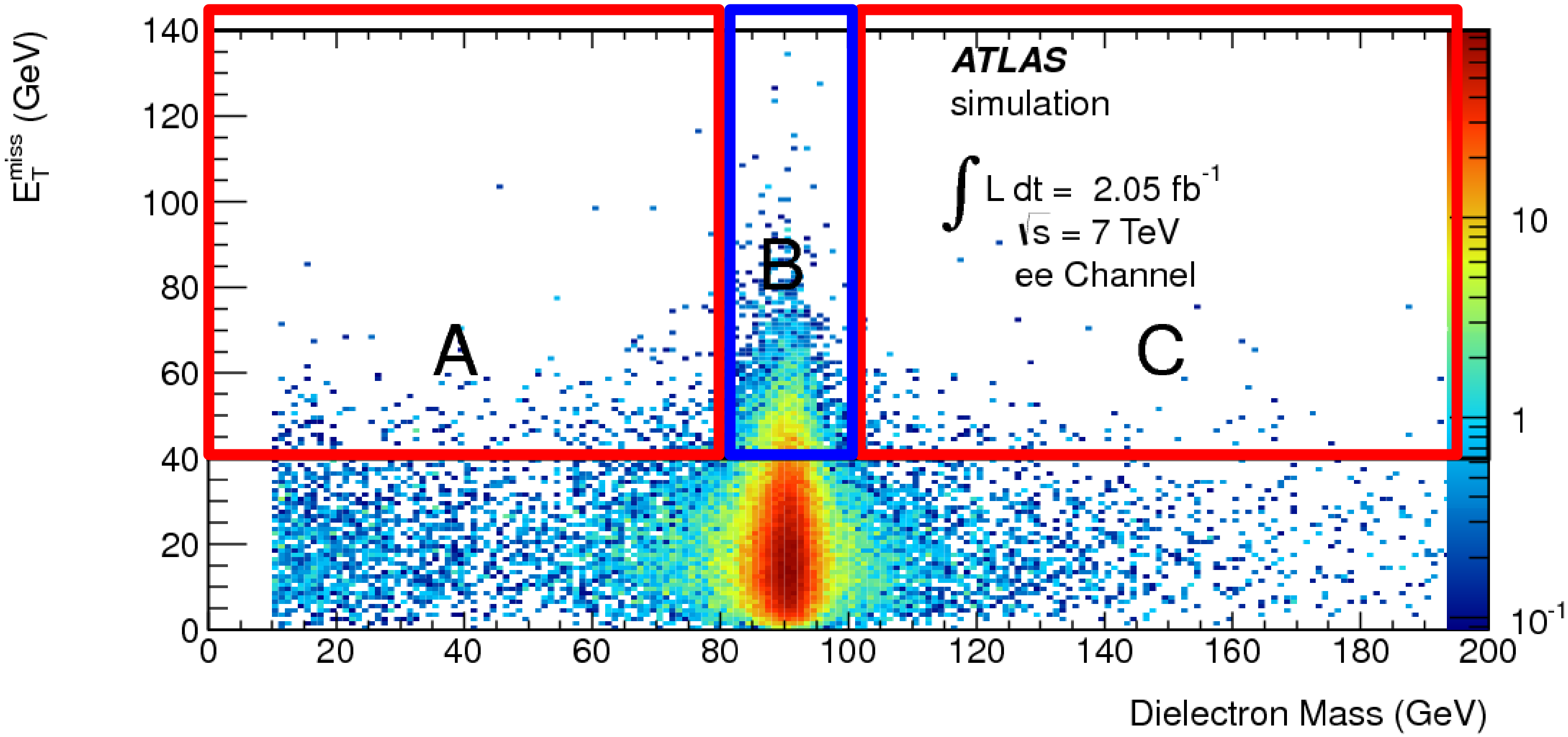
- Normalization factors determined from data based on the charge asymmetry for each jet multiplicity bin using the ratio: $r_{MC}=N_{W+}/N_{W-}$ from the simulation.

$$N_{W^+} + N_{W^-} = \left(\frac{r_{MC}+1}{r_{MC}-1}\right)(N_{W^+} - N_{W^-})$$

- Conservative uncertainty applied to the normalization, since this estimate is still preliminary.



Z+jets data-driven normalization



Data(SR) = Data(CR) * MC(SR) / MC(CR)

- Scale factors (ratio of data and MC events in the control region) used to extrapolate data to MC differences measured in the CR into the SR

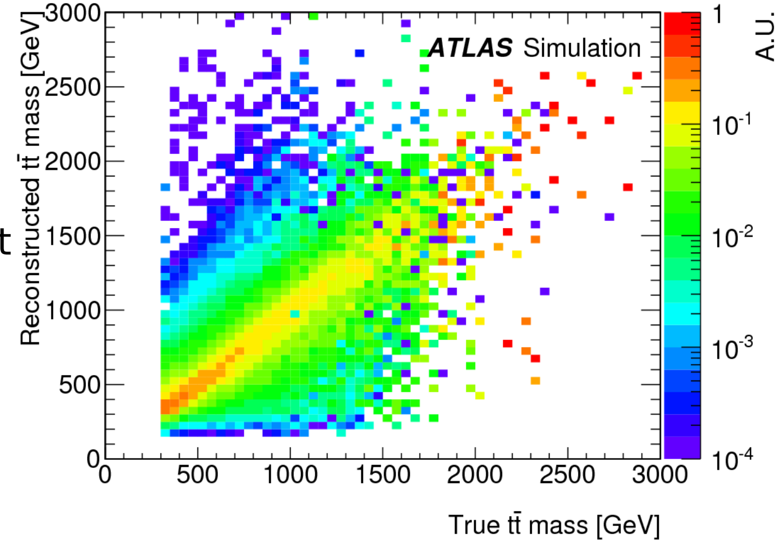
Lepton+jets channel resolved: $t\bar{t}$ mass reconstruction

- **tt mass=4(3) jets + lepton + neutrino**

- Neutrino
  - MET identified with neutrino p_T
  - p_z from quadratic equation imposing W mass constraint

- No attempts to reconstruct each top is done

- Two different reconstruction methods used whether or not there is a jet with mass > 60 GeV in the event:



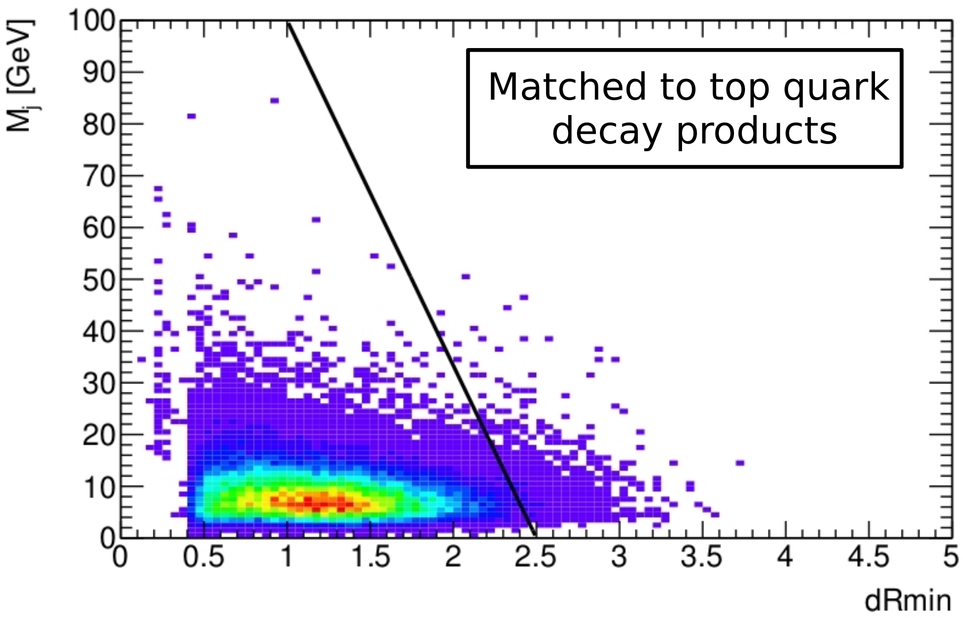
In case there is not:

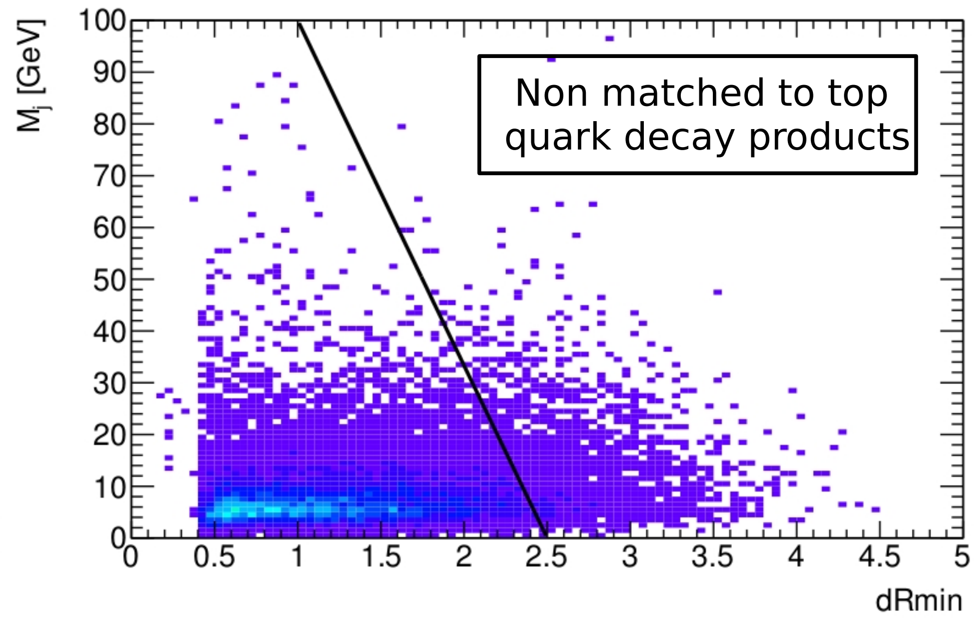
- Jets compatible with ISR excluded (far from other objects)
- Select 4 leading p_T jets
- Reject jet if minimal distance to other selected jets dRmin>2.5 – 0.015 mjet
- Iterate if 4 or more jets remain
- Selected 4(3) jets added to leptonic W

In case there is:

- Built top hadronic with closest jet to the massive one
- Built leptonic top with the closest jet to the lepton
- Allows to take into account events with significant boosted top quarks. This subsample represents 0.3% of the total
- *This analysis can be considered as a semi-boosted one*

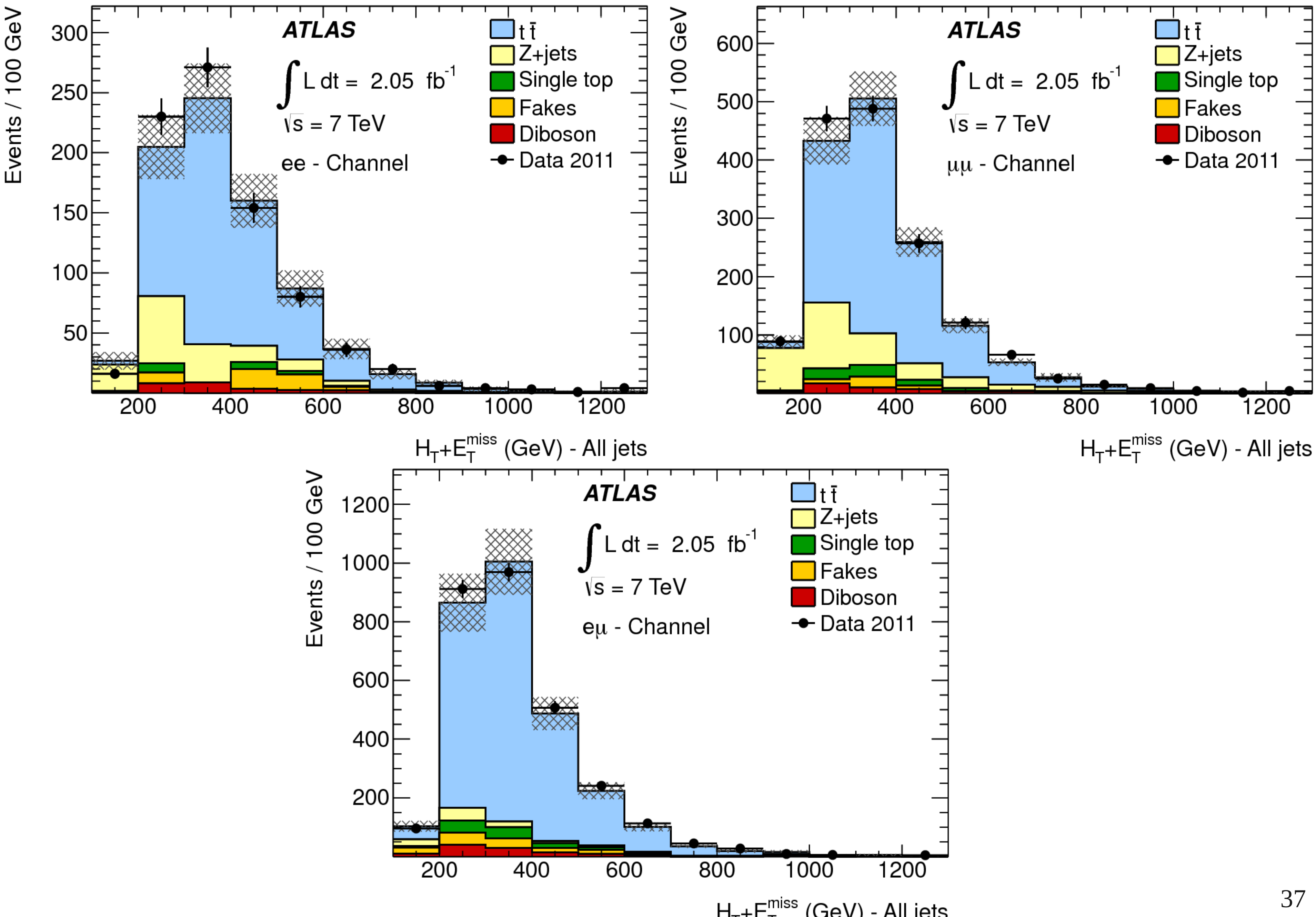
Lepton+jets channel resolved: $t\bar{t}$ mass reconstruction



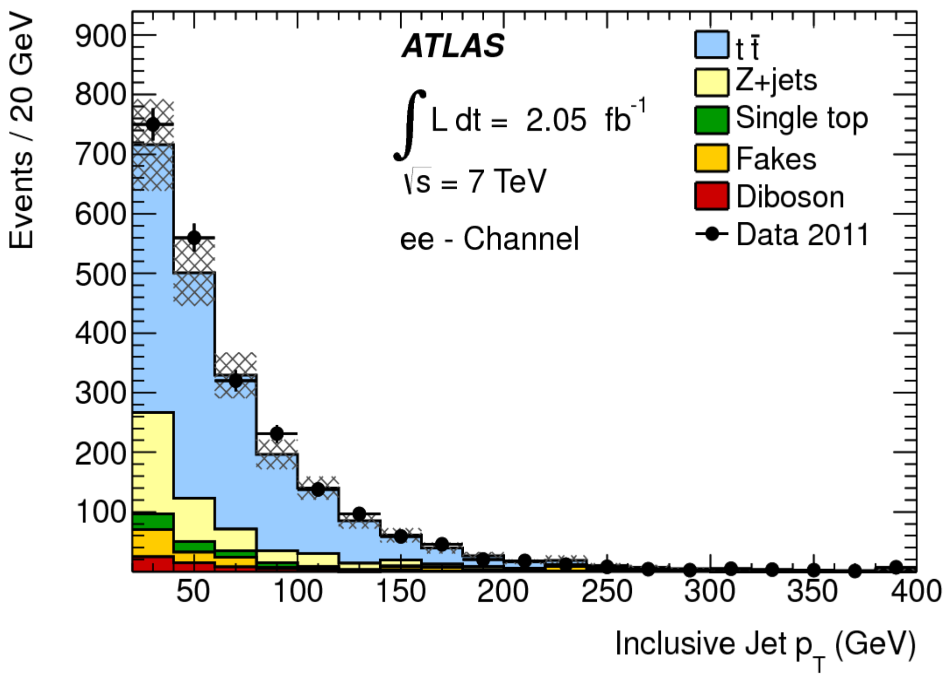


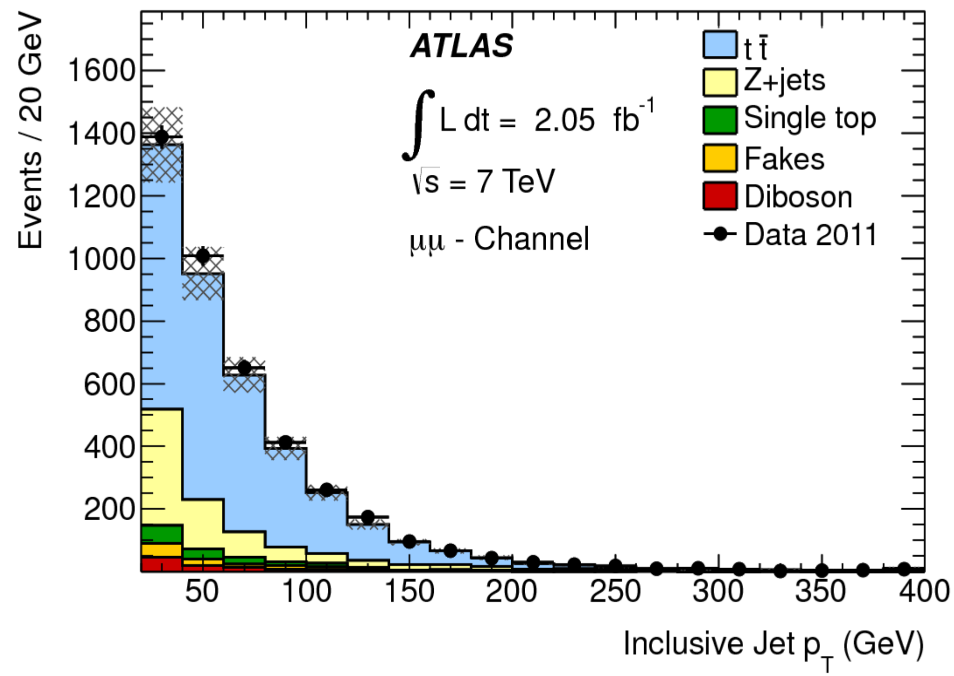
dRmin>2.5 – 0.015 Mj

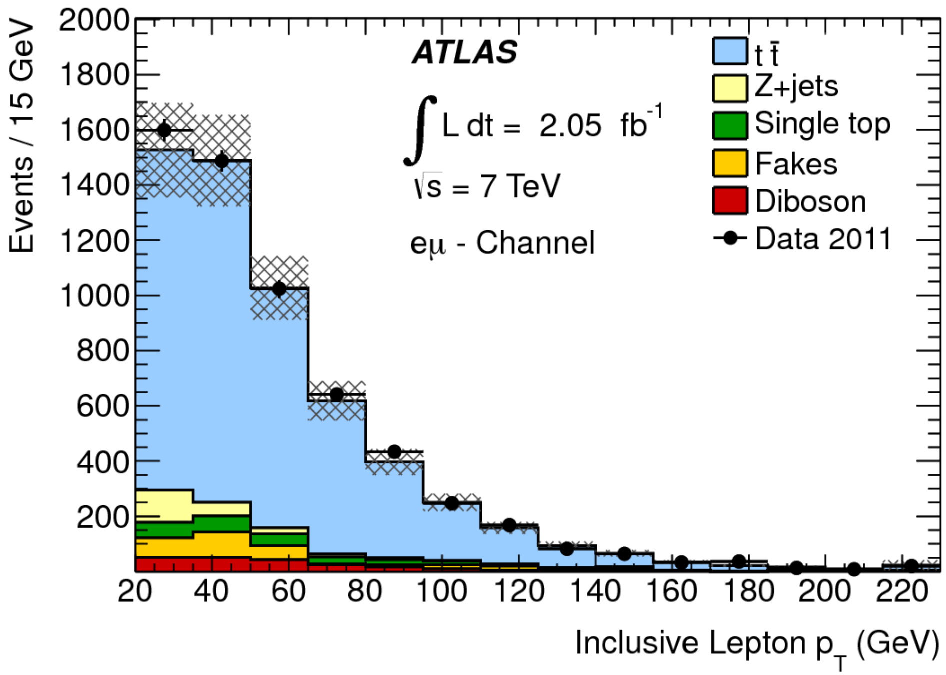
Dilepton channel: $t\bar{t}$ mass reconstruction

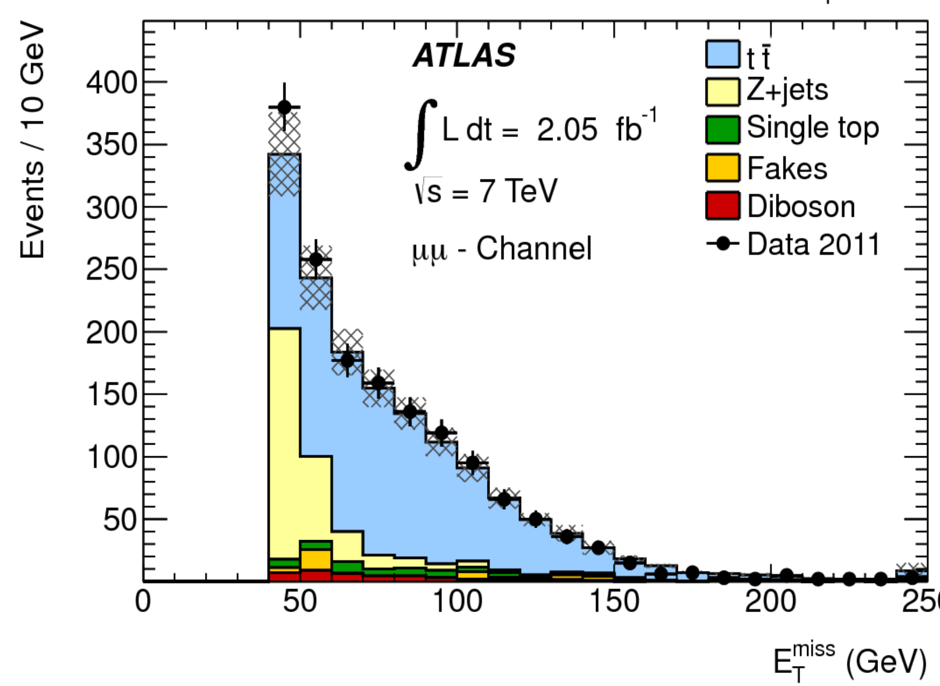


Dilepton channel: Data vs background expectation

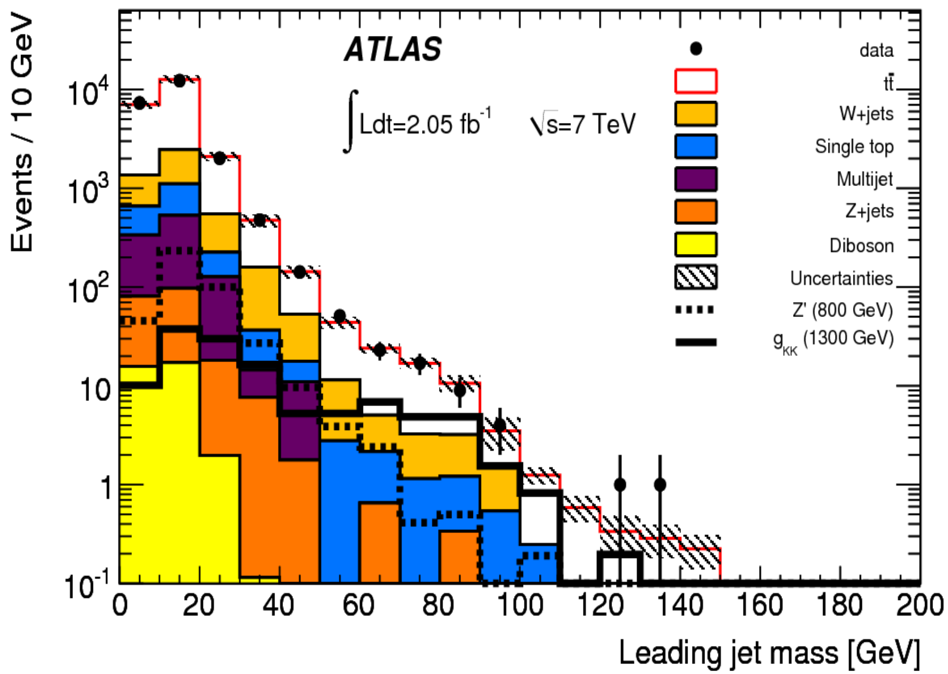


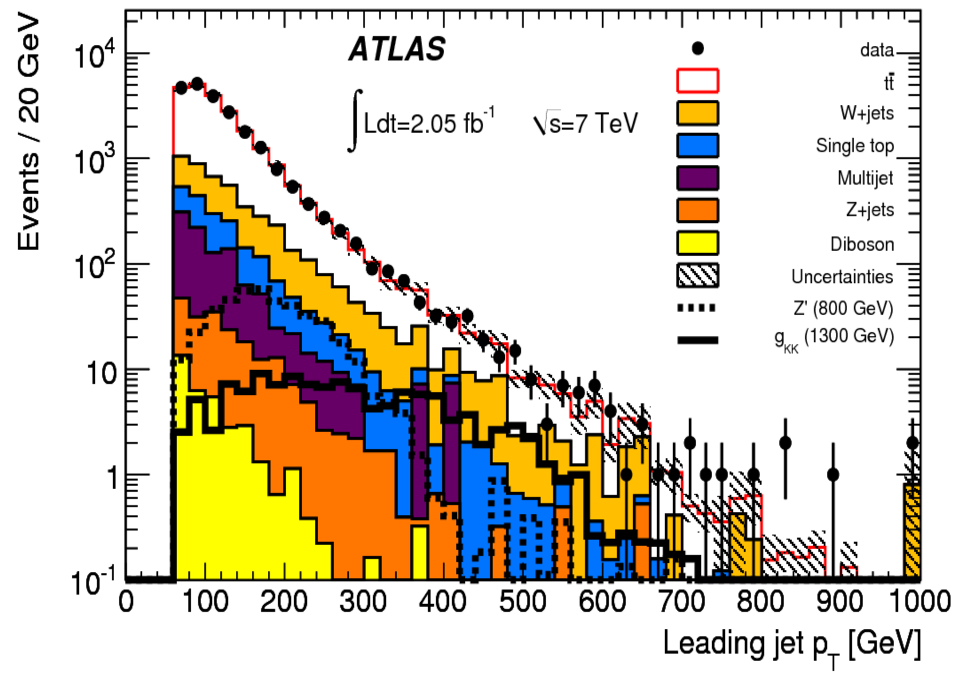


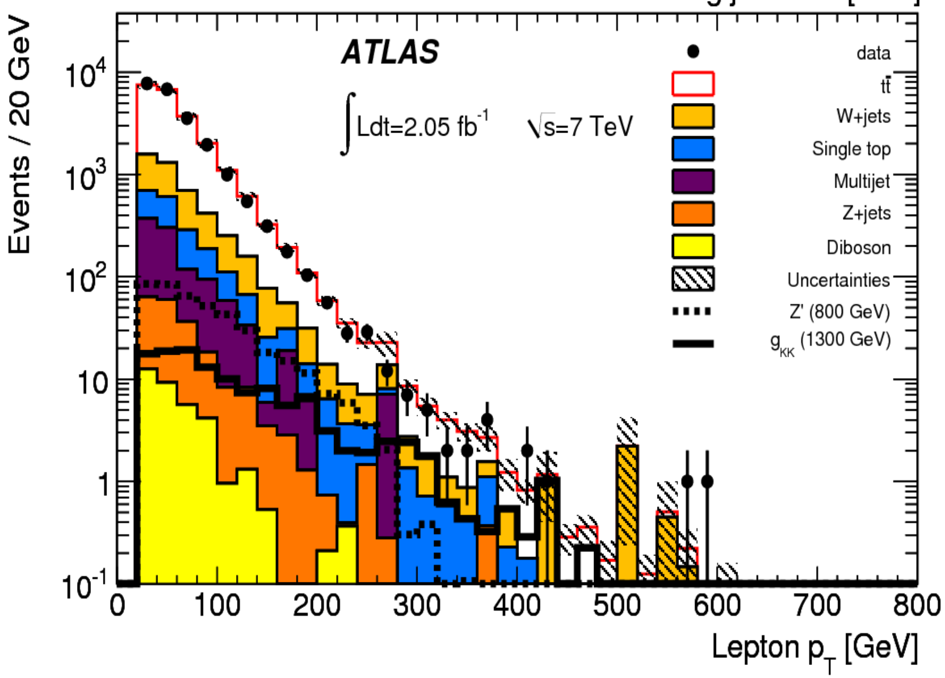


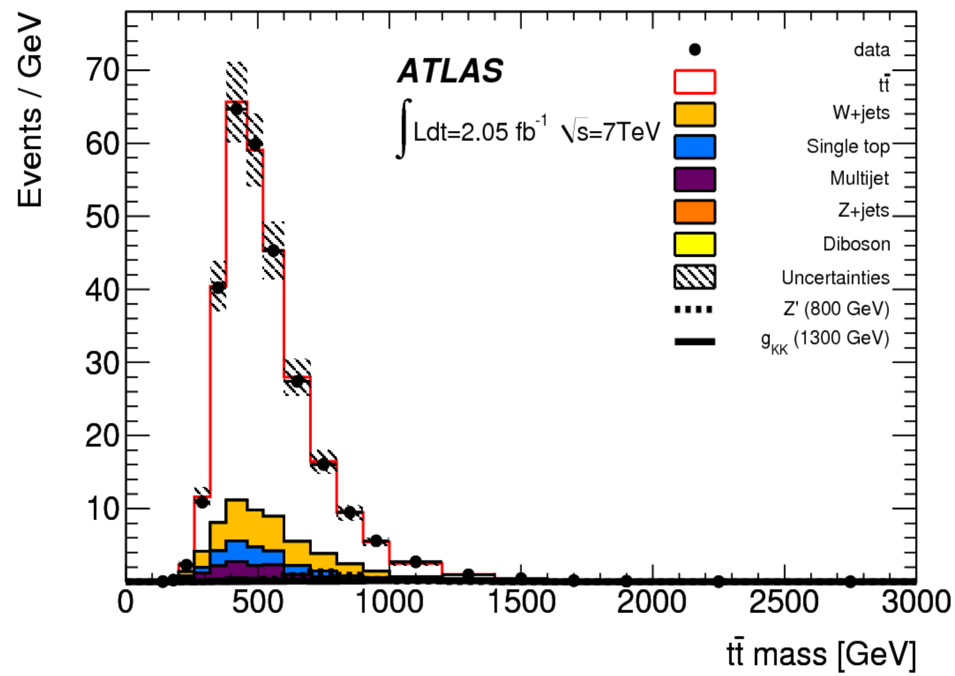


Lepton plus jets channel resolved: Data vs background expectation

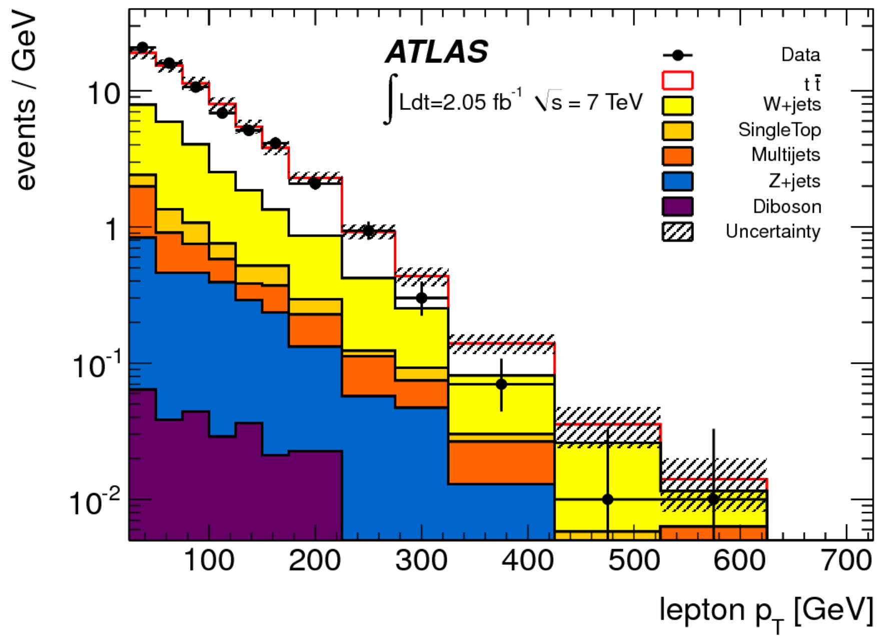


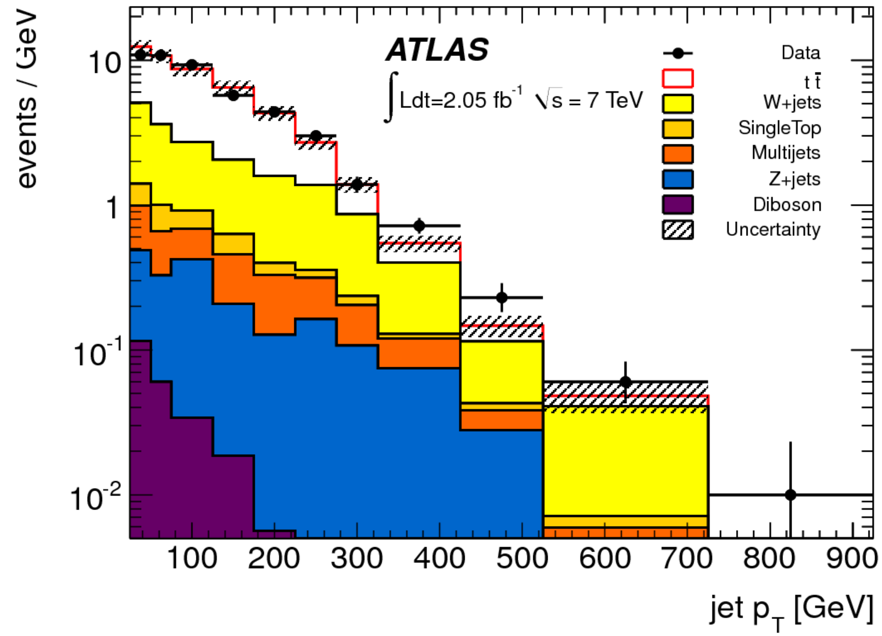


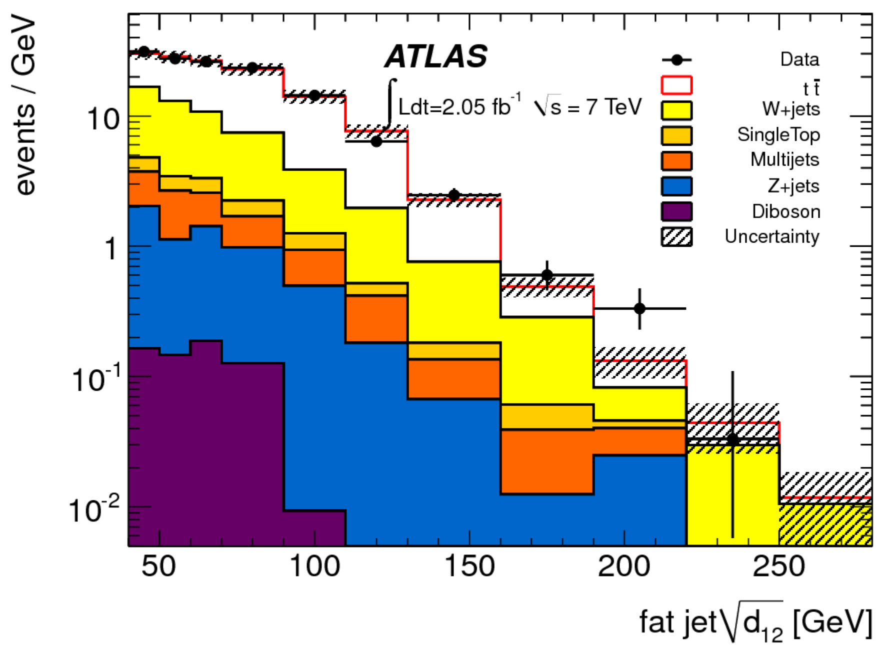


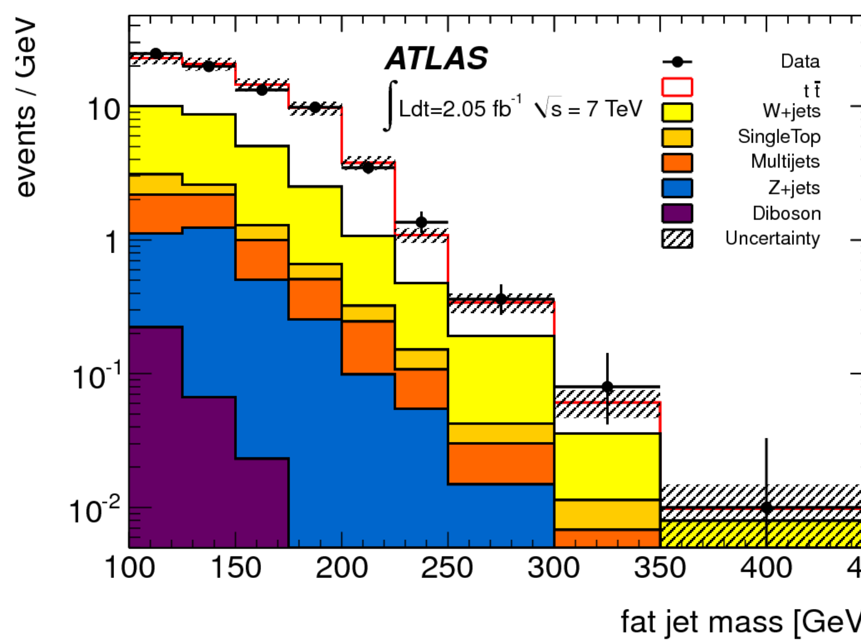


Lepton plus jets channel boosted: Data vs background expectation





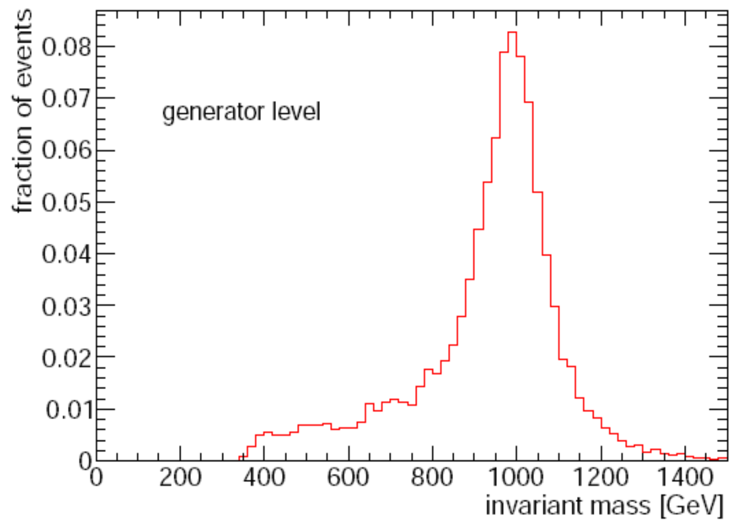




tt resonance @parton level

Beyond The Standard Model of Particle Physics
Quy Nhon, Vietnam July 15-21th, 2012

Width resonance effect

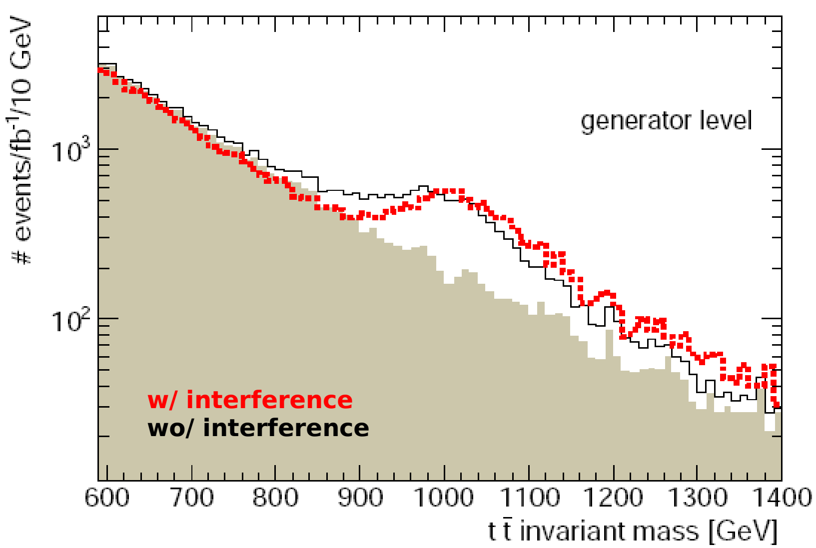


g_{KK} (m = 1 TeV)

ATL-COM-PHYS-2010-153

- Tail toward lower mass
- Due to the convolution of the quark PDF and the g_{KK} Breit-Wigner distribution
- Effect is more evident for higher masses
- This effect is combined with the detector resolution

Interference effect



- Destructive interference between SM processes and strongly coupled resonances leads to a reduction of the low mass tail
- Interference is not simulated in present studies since the SM bkg and signals are generated separately