A search for ttbar resonances in lepton plus jets events with ATLAS using 14 fb^{-1} of pp collisions at $\sqrt{s}$ = 8 TeV.

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Outline

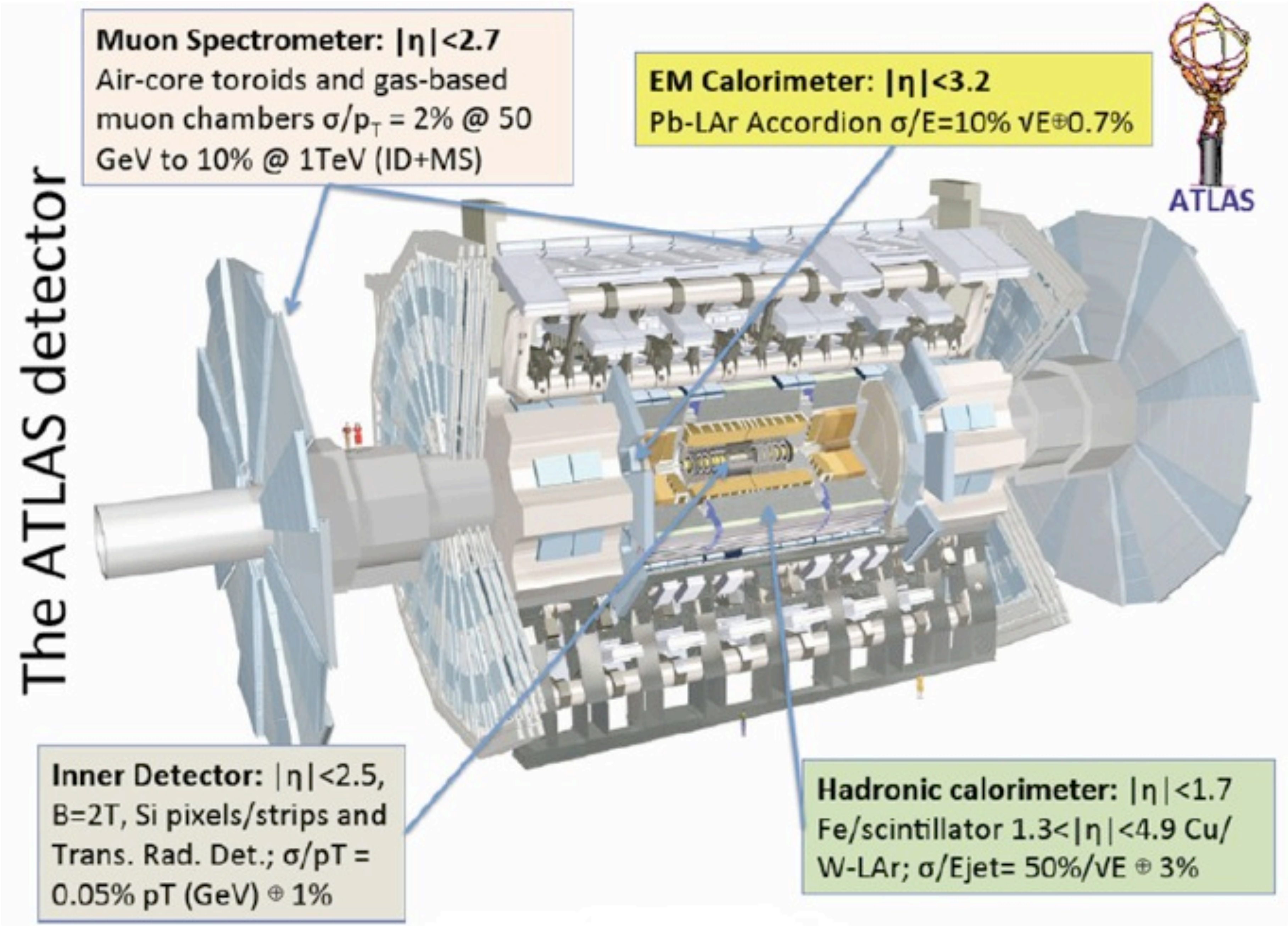
- Introduction.
  -- ATLAS detector.
  -- Motivation for top quark physics.
  -- Top quark production/decay.

- Top quark production measurements.
  -- Cross-section measurement.
  -- Charge asymmetry measurement.

- Analyzing the lepton plus jets decay channel.
  -- Benchmark models studied.
  -- Resolved vs boosted topology.
  -- Event Selection.
  -- Estimation of the backgrounds.
  -- Invariant mass reconstruction of top-antitop pair.
  -- Some kinematic distributions.
  -- Sources of Systematics.
  -- Limits.

- Conclusions.

The ATLAS Detector



Motivation

- Top quark is the heaviest of the known SM particle
  m_t =172.9 ± 1.1 GeV close to EW scale.

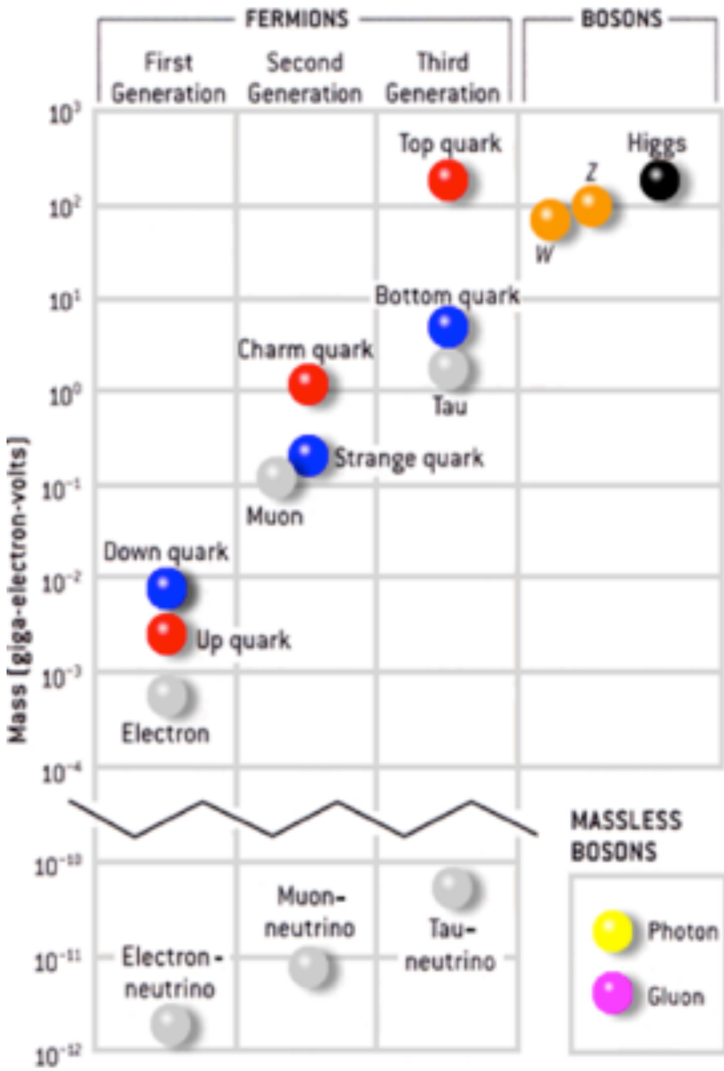
- Decay occurs before hadronization “bare quark”.
  width $\Gamma = 1.42$ GeV and lifetime $\tau = 4.5 \times 10^{-25}$ s $< \Lambda^{-1}_{QCD}$

- Due to its large mass, it offers a unique window
  to search for new physics at TeV scale.

- Many extensions of SM explain the large top mass
  by allowing the top to participate in new dynamics.

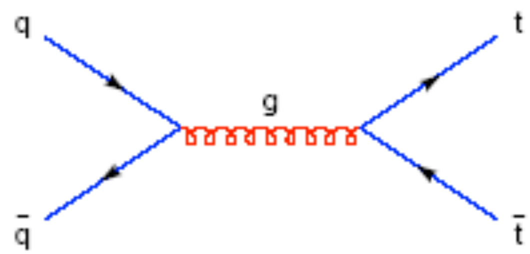
- To search for new physics :
  → Measure the production properties of top quark, and compare to the SM prediction. Any deviation hints new physics.

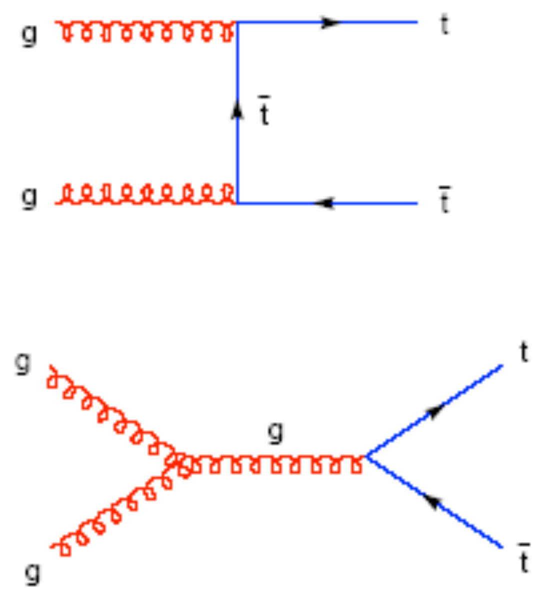
  → Directly search for new particles that couple to top quark.



Top quark pair production/decay

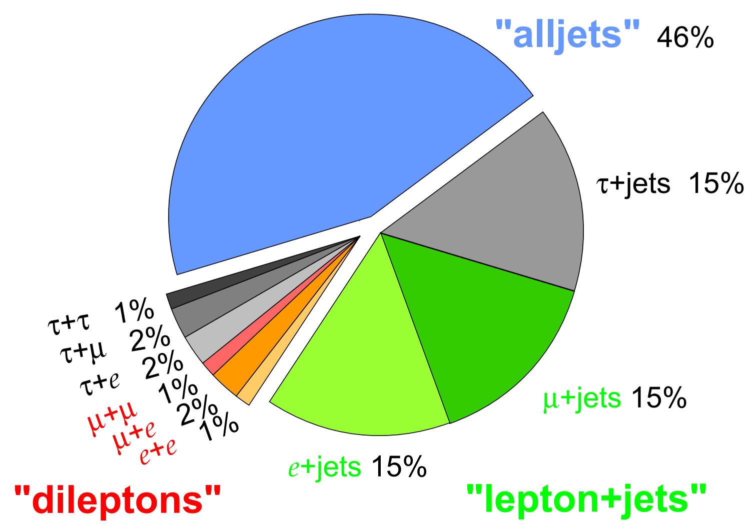
- LHC is a top factory, $\sigma(pp \to t\bar{t}) \sim 177$ pb
  - *-- $qq \to t\bar{t} \sim 10\%$*
  - *-- $gg \to t\bar{t} \sim 90\%$*





- Lepton plus jets is the most useful decay channel.
  - ***-- Dilepton channel - low B.R.***
  - ***-- Full hadronic - huge background.***

Top Pair Branching Fractions



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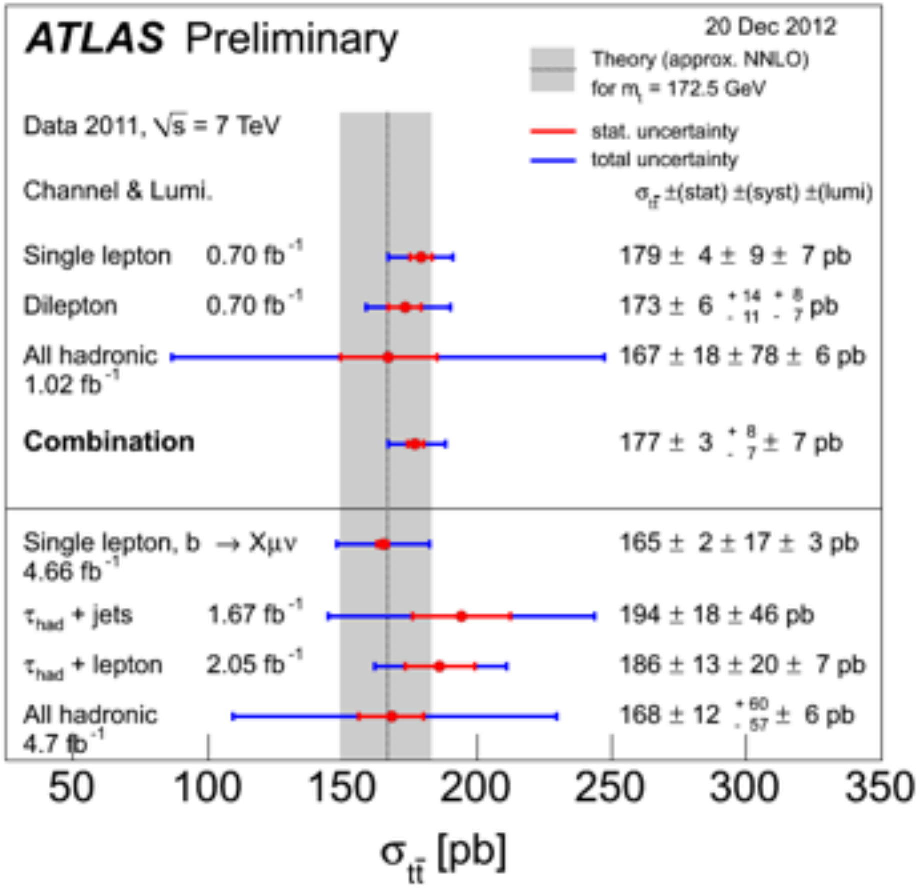
Top Quark Cross-section Measurement



ATLAS-CONF-2012-024

ATLAS-CONF-2012-131

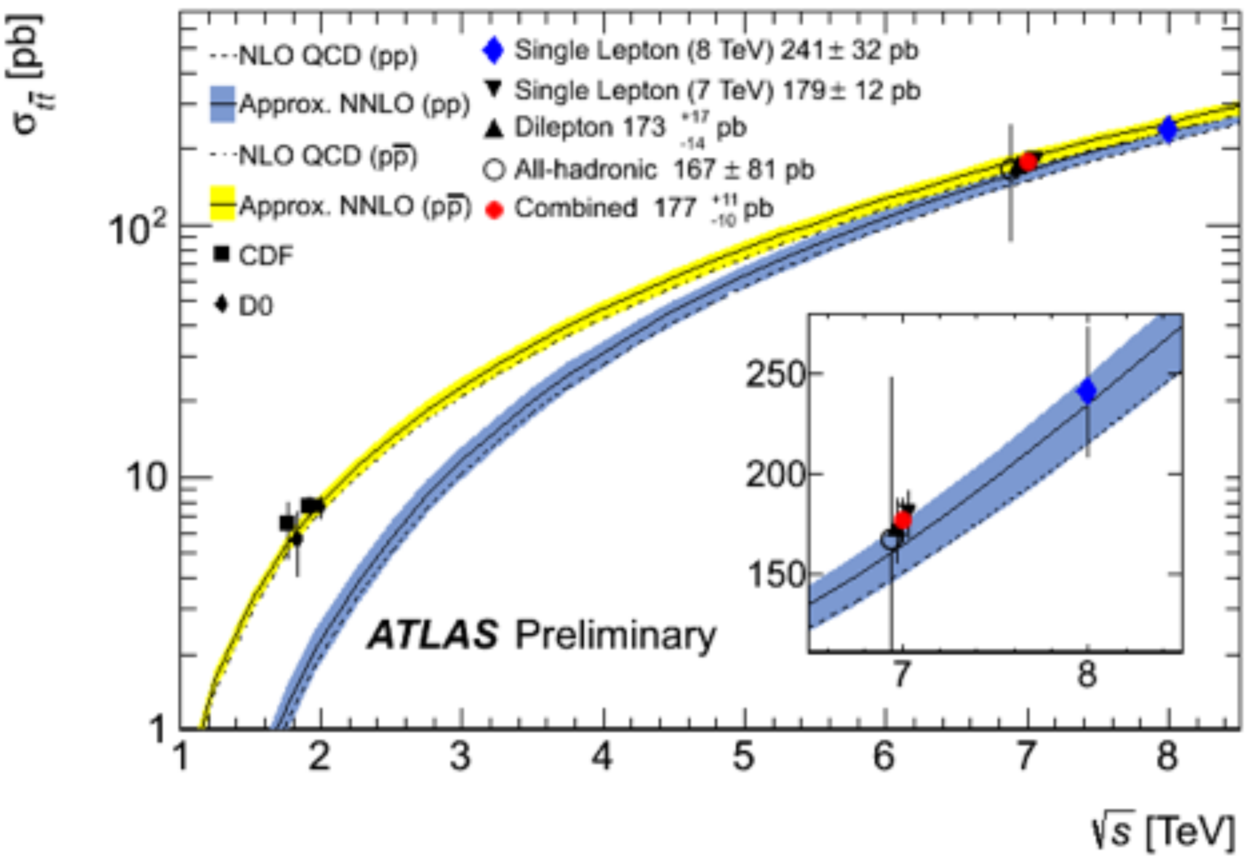
ATLAS-CONF-2012-031

- Summary of measurements compared to the corresponding theoretical expectation based on an approximate NNLO calculation (Hathor 1.2).

- The upper part of the figure shows measurements that are averaged to give the combined value shown.

- The lower part shows additional newer measurements not included in the combination.

Top Quark Cross-section Measurement



ATLAS-CONF-2012-024

ATLAS-CONF-2012-149

- Summary plot showing the top pair production cross section as a function of the LHC center of mass energy.
- The experimental results in the various top decay channels (and their combination) at 7 TeV and the recent result at 8 TeV are compared to an approximate NNLO QCD calculation based on Hathor 1.2.
- Some selected results from Tevatron are also shown.

Charge Asymmetry Measurement

- Interesting study since Tevatron measured a significantly larger forward backward asymmetry than the SM prediction.

- Observable is $\Delta|y| = |y_t| - |y_{\bar{t}}|$

$gg \to t\bar{t}$ production is symmetric where as $q\bar{q} \to t\bar{t}$ is asymmetric at NLO and $A_C^{SM} < 0$, $\bar{t}$ are produced more centrally than t

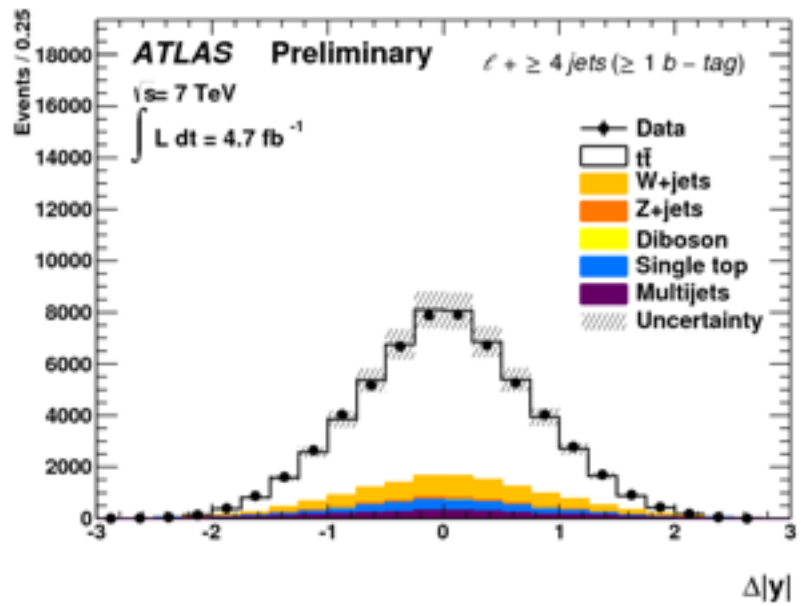
$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

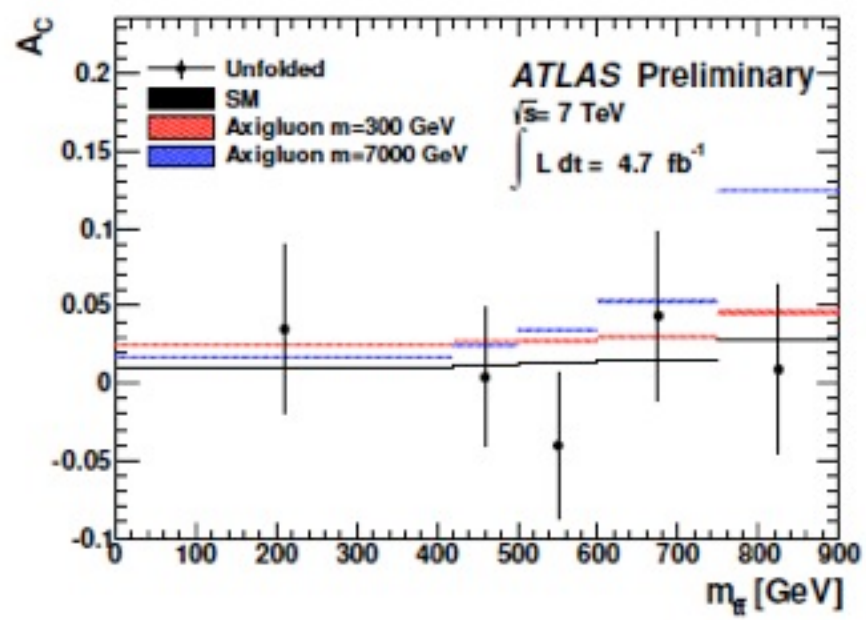
- The A_c fit results:

A_C	Data	Theory
Unfolded	0.006 ± 0.010	0.0123 ± 0.0005
Unfolded with $m_{t\bar{t}} > 600$ GeV	0.018 ± 0.022	$0.0175^{+0.005}_{-0.004}$
Unfolded with $\beta_{z,t\bar{t}} > 0.6$	0.011 ± 0.018	$0.0202^{+0.006}_{-0.007}$

- In good agreement with the SM!

ATLAS-CONF-2013-078





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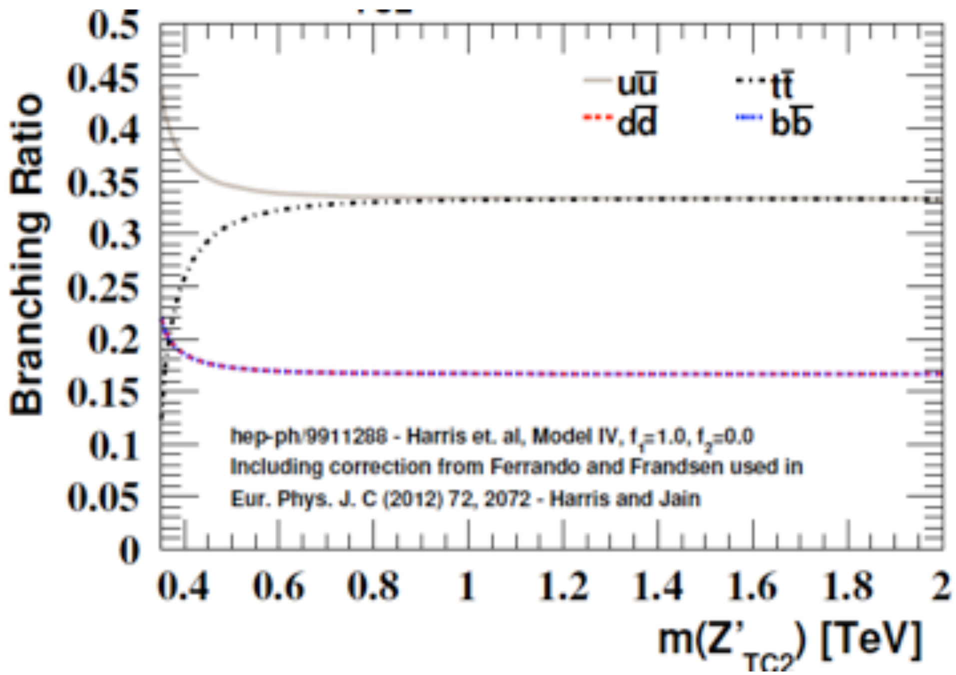
ATLAS-CONF-2013-052

Benchmark Models

- **Leptophobic topcolor Z'**

  Eur.Phys.J.C72 (2012) 2072

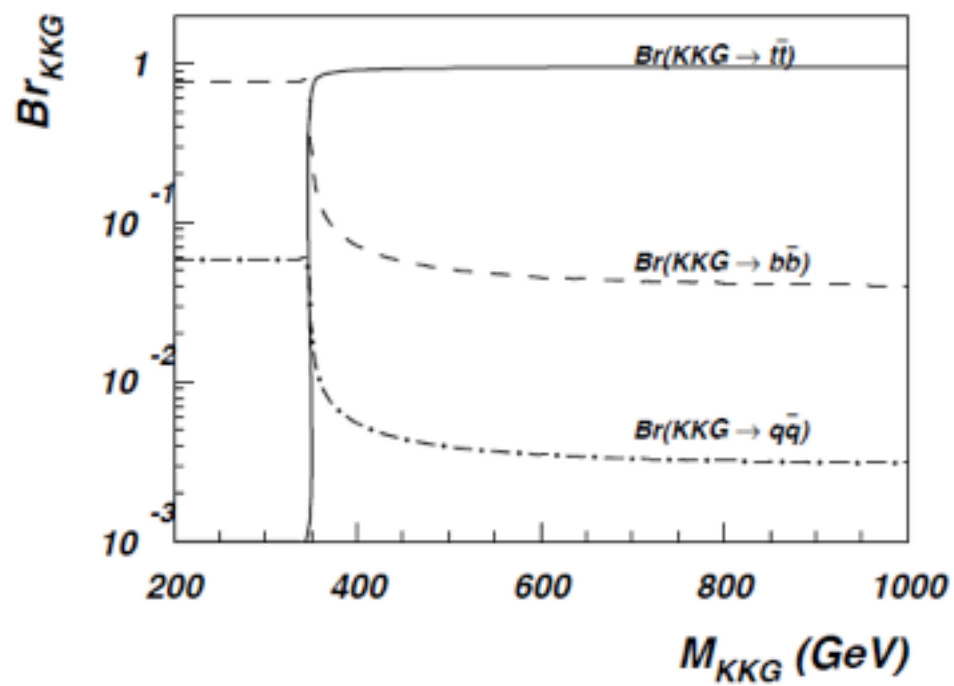
  - Explains the top quark mass and EWSB through a top quark condensate.
  - Z' couples only to the first and third generation of quarks.
  - Narrow resonance Γ/m ~1.2 %



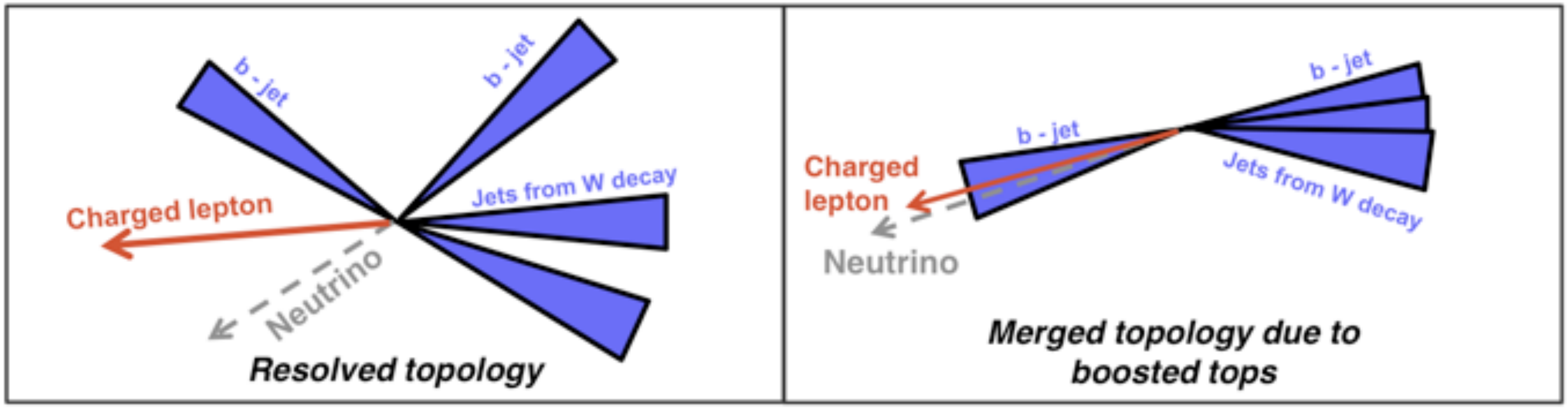
- **Kaluza Klein Gluons**

  Phys. Rev. D 77, 015003 (2008)

  - Predicted by the Randall-Sundrum model with warped extra dimension.
  - Strongly coupled to top quark.
  - Broad resonance Γ/m ~15 %



Boosted vs Resolved Topology



- **Resolved**: **No overlap between small radius (ΔR=0.4) jets or leptons.**
  - Useful for top quark pairs from low mass BSM particles.

- **Boosted**: **Large radius (ΔR=1.0) jets contain multiple partons and/or leptons.**
  - Merged Jets are reconstructed as “fat jets” with ΔR=1.0
  - Useful for top quark pairs from high mass BSM particles.

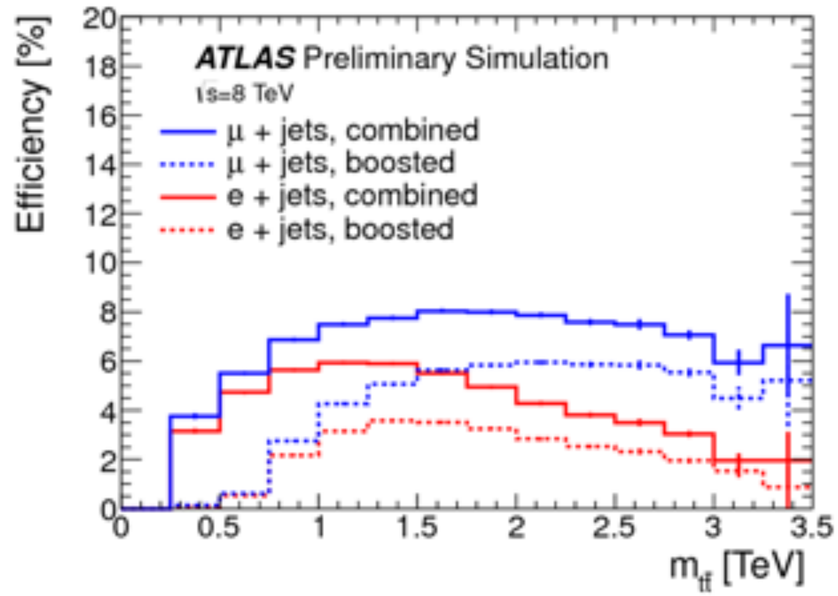
Event Selection

- One top decays hadronically, and the other semi-leptonically.
- At least 1 primary vertex with 4 or more associated tracks.
- Pass either single electron/muon trigger.
- Exactly one isolated lepton (e/μ) matching trigger.
- Missing E_T
  $E_T > 30/20$ GeV (e/μ channel)

- Transverse M_w
  $M_w > 30$ GeV (e channel)
  $M_w + E_T > 60$ GeV (μ channel)

- **Boosted Selection:**
  -- 1 high p_T R=1.0 jet with $m_{jet} > 100$ GeV
  and first K_T splitting scale $\sqrt{d_{12}} > 40$ GeV.
  -- 1 R= 0.4 jet closest to lepton
  -- ≥ 1 R=0.4 b-jet (can overlap with above jets)

- **Resolved Selection:**
  -- 3 or 4 R =0.4 jets with ≥ 1 b-jet



The selection efficiency as a function of the true $m_{t\bar{t}}$ for Z' resonances at various mass points.

Estimation of the Backgrounds

Major sources of backgrounds considered are:

- SM $t\bar{t}$ production
  - -- estimated using the MC@NLO
  - -- HERWIG for parton showering and hadronization.
  - -- JIMMY for modeling multiple parton scattering.
- W+jets
  - - Generated via ALPGEN + PYTHIA
  - - normalization derived from data
- Multi-Jet
  - - Data driven estimate
- Z+jets
  - - estimated using Alpgen + Pythia.
- Single Top
  - -- production in "s" channel is modeled with MC@NLO/HERWIG/JIMMY
  - -- production in "t" channel modeled with ACERMC/PYTHIA
- Diboson
  - - estimated using HERWIG and JIMMY.

Resolved selection			
Type	e+jets	μ+jets	Sum
$t\bar{t}$	94000 ± 15000	118000 ± 19000	211000 ± 33000
Single top	6800 ± 800	8400 ± 1100	15200 ± 1900
Multi-jet	3700 ± 1800	10000 ± 5000	14000 ± 6000
W+jets	16000 ± 4000	23000 ± 6000	39000 ± 10000
Z+jets	1800 ± 400	1800 ± 400	3600 ± 800
Di-bosons	230 ± 50	320 ± 60	550 ± 100
Total	121000 ± 17000	162000 ± 23000	283000 ± 39000
Data	119490	160878	280251

Boosted selection			
Type	e+jets	μ+jets	Sum
$t\bar{t}$	2100 ± 500	2800 ± 600	4900 ± 1100
Single top	71 ± 15	105 ± 22	176 ± 34
Multi-jet	39 ± 19	32 ± 16	71 ± 25
W+jets	170 ± 60	310 ± 90	480 ± 140
Z+jets	18 ± 11	33 ± 8	52 ± 15
Di-bosons	2.0 ± 0.8	1.5 ± 1.4	3.5 ± 1.8
Total	2400 ± 500	3300 ± 700	5600 ± 1200
Data	2177	2945	5122

Data Driven Background

The normalization for two important sources of background (W+jets /Multijet) is estimated using data.

- W+jets
  - Samples of simulated ALPGEN events are used to model the W+jets background including shape.
  - To determine the overall normalization, the asymmetry in the production of W^+/W^- bosons is exploited.

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

  - Charge symmetric contributions from various MC cancel out in the equation but the charge asymmetric contributions (single top) are estimated and subtracted.

  - Fits to data in jet/b-tag multiplicity bins provide the normalization factor.

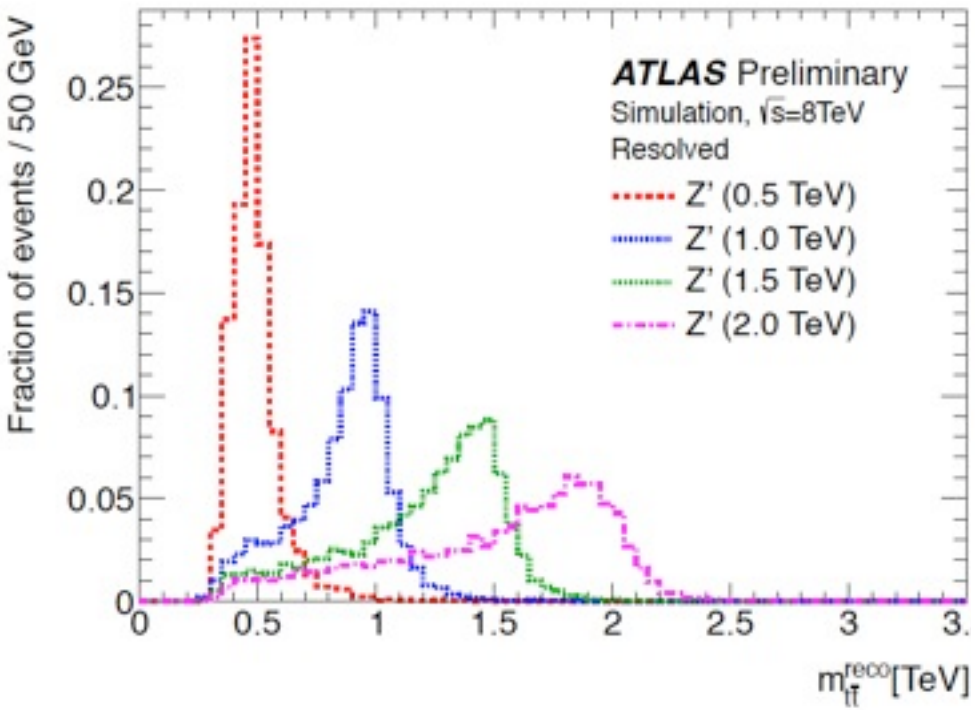
- Multi-Jet
  - The normalization as well as shape of the multijet background is estimated directly from data using a matrix method.
  - Enriched samples of multi-jet events with relaxed lepton identification criteria (eg. isolation requirement) are used.

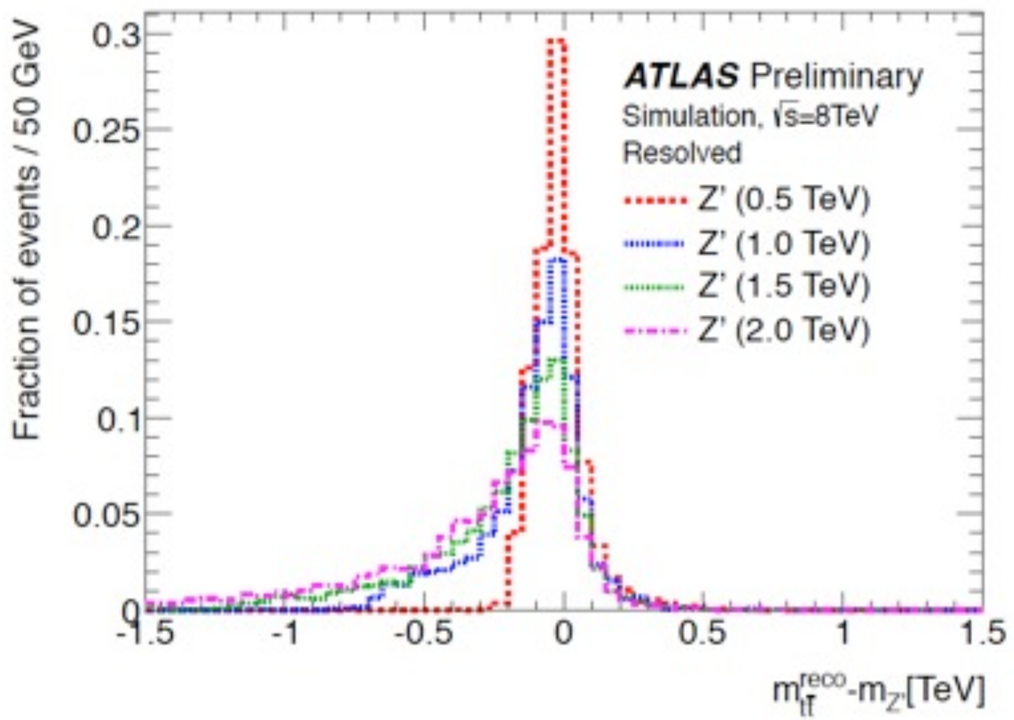
$M_{t\bar{t}}$ Reconstruction

The top quark pair invariant mass is computed from the four momenta of the physics object in the event.

- **Resolved Reconstruction:**

-- χ^2 algorithm is used to select the best assignment of jets to the hadronically and semi-leptonically decaying top quarks.
-- The algorithm uses reconstructed top quark and W masses as constraints.

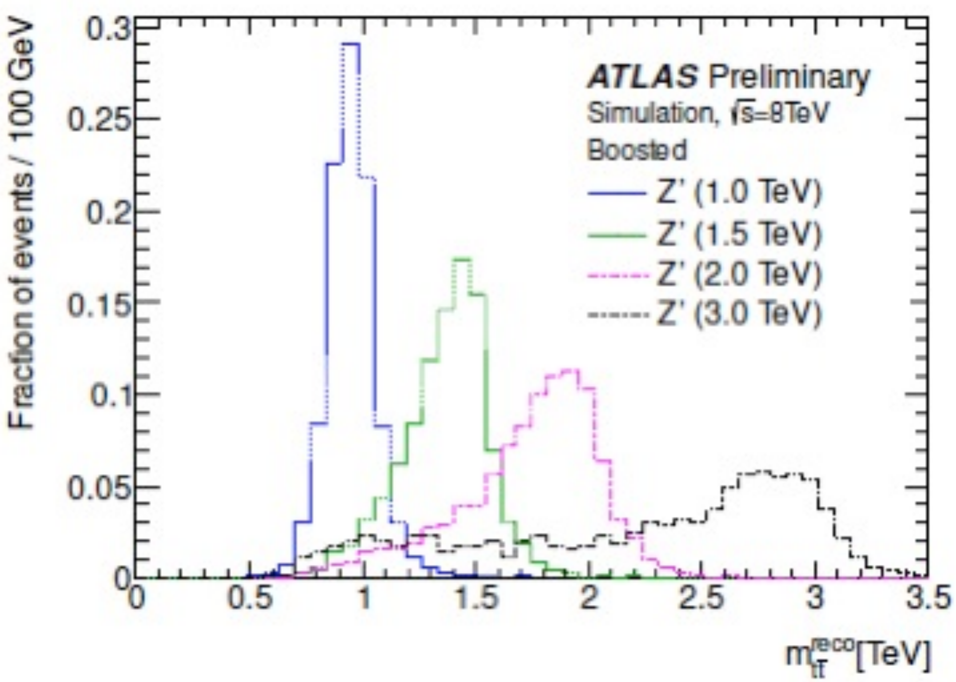


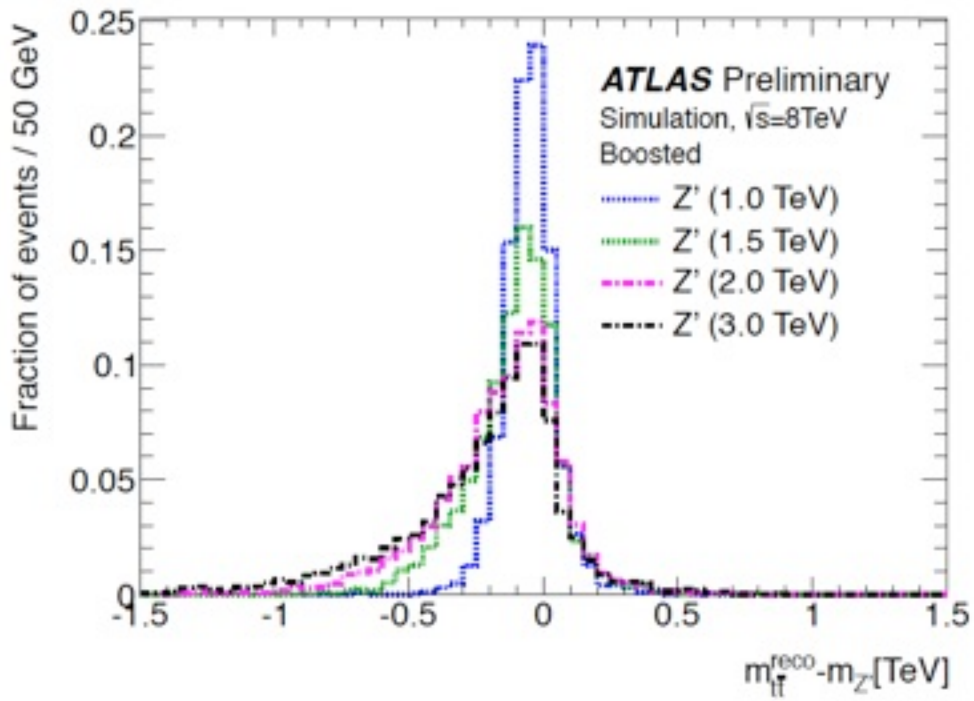


$M_{t\bar{t}}$ Reconstruction

- **Boosted Reconstruction:**

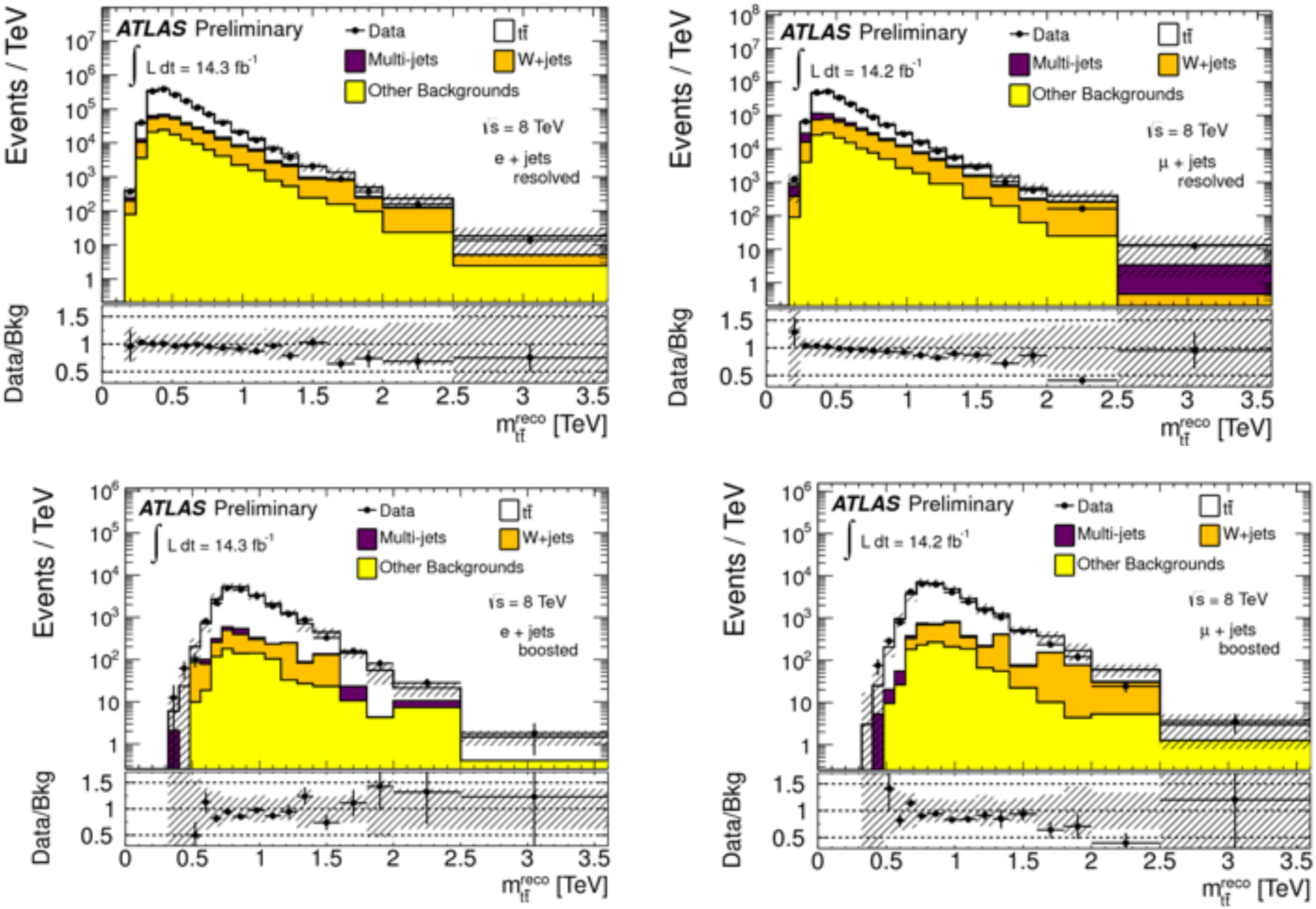
-- The four momenta of the hadronically decaying top is taken to be that of the large radius R=1.0 jet.
-- While for the semi-leptonically decaying top, use ν solution from the W boson, lepton and small radius R =0.4 jet.





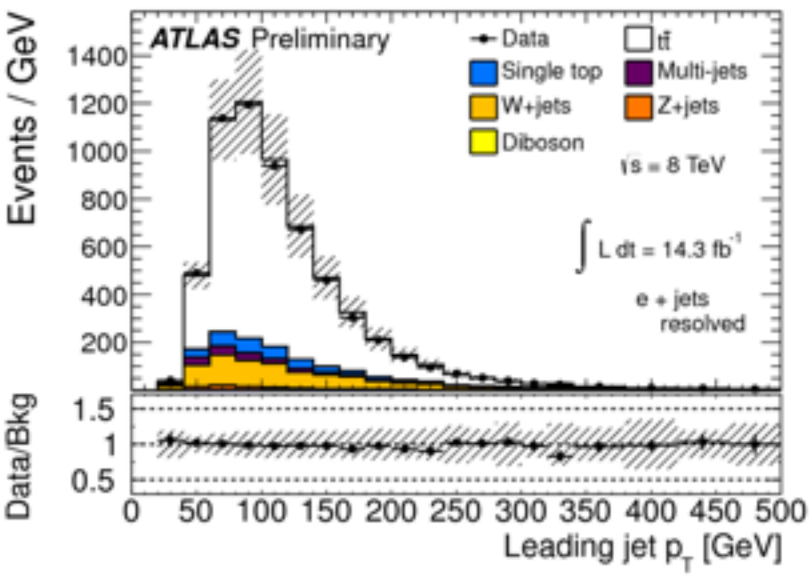
- **The produced top quark pair mass is used for the statistical analysis.**

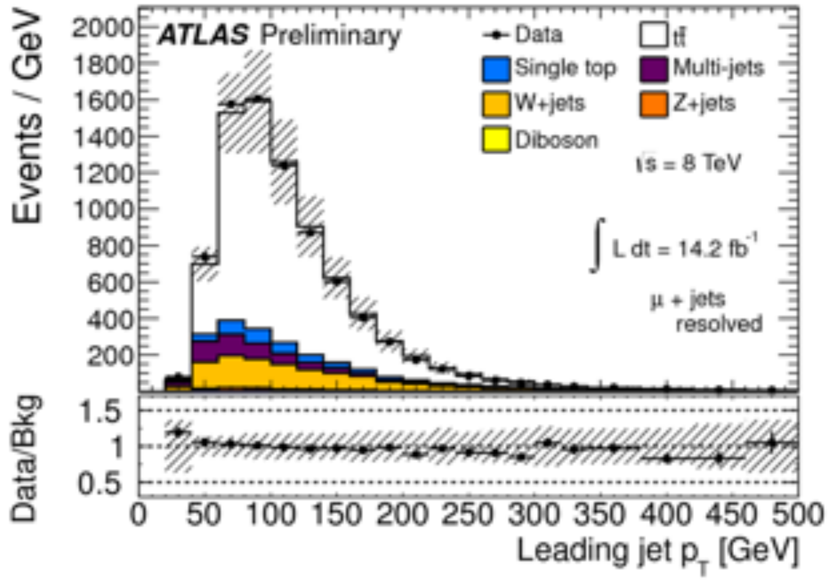
Reconstructed $M_{t\bar{t}}$ in Each Channel



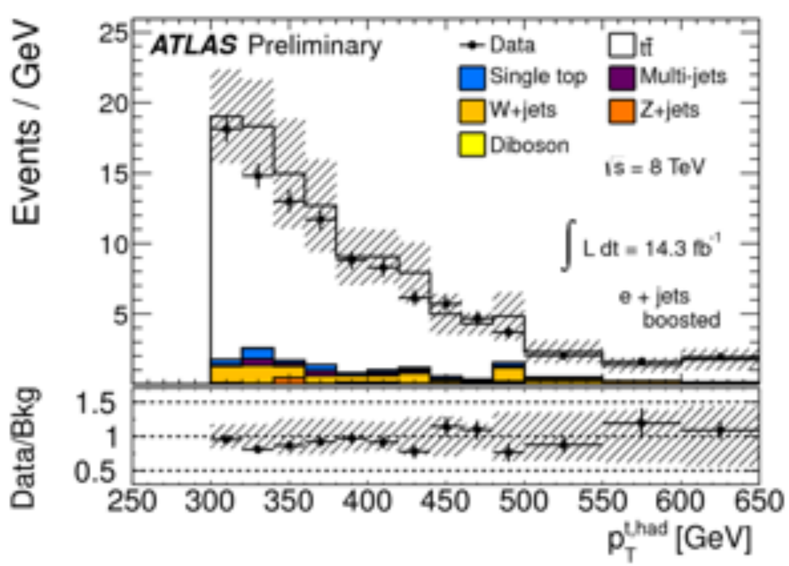
Some Kinematic Distributions (1)

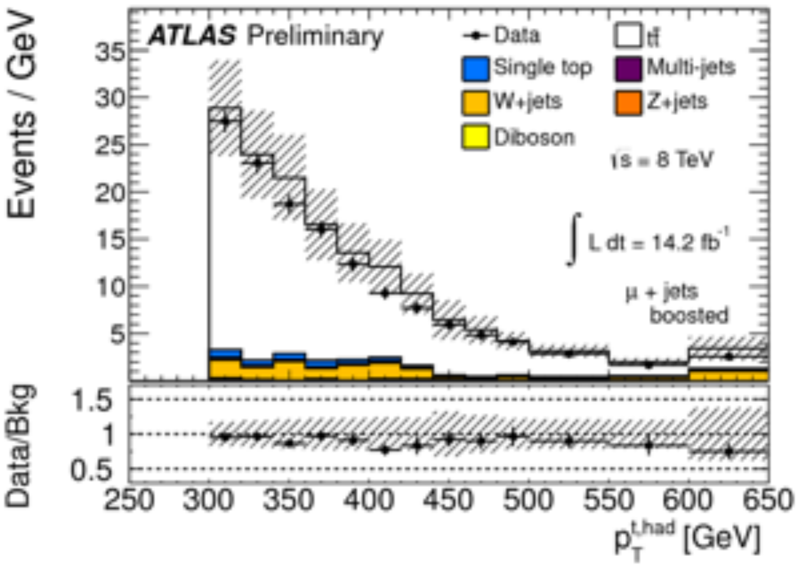
Leading jet p_T after the resolved selection.





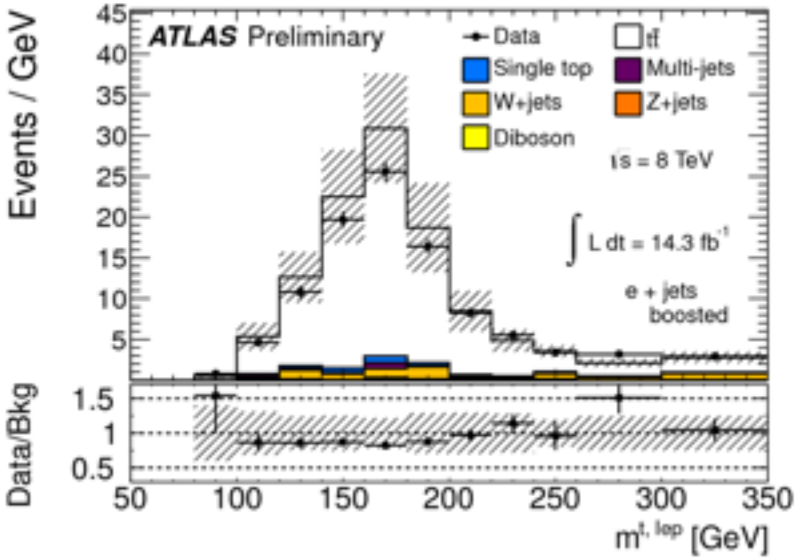
p_T of the hadronically decaying top quark candidate after the boosted selection.

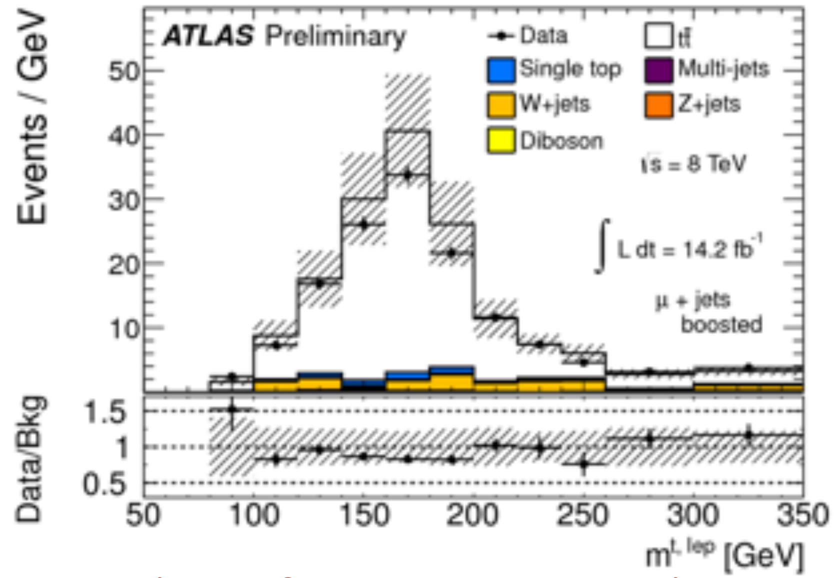




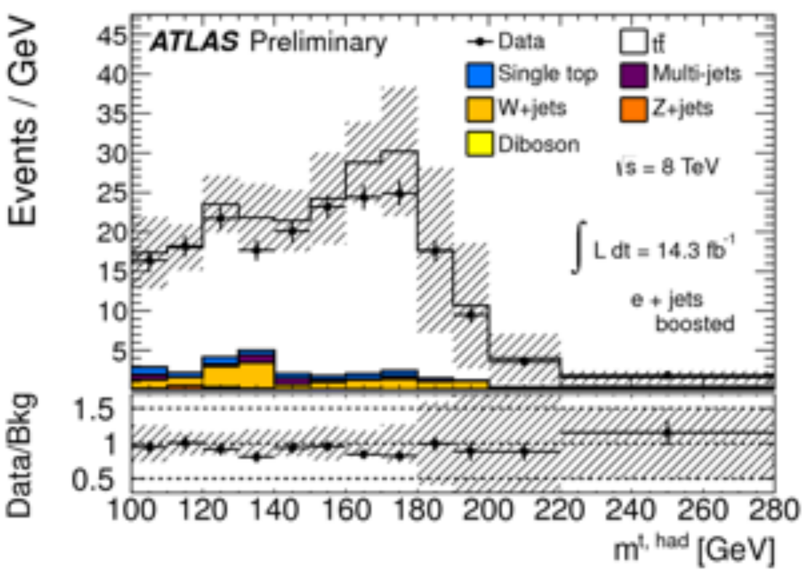
Some Kinematic Distributions (2)

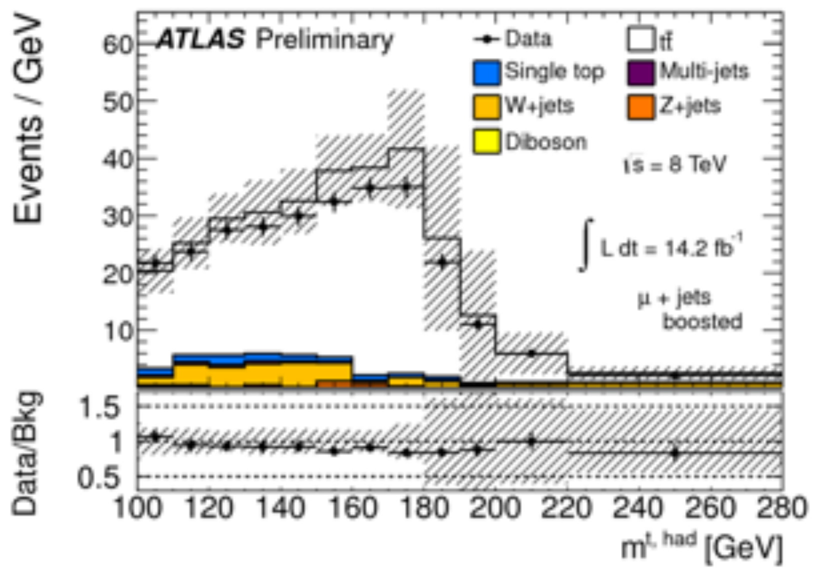
Invariant mass of the semi-leptonically decaying top quark candidate after the boosted selection.





Invariant mass of the hadronically decaying top quark candidate after the boosted selection.





Systematics

- The “uncertainty” or “error of measurement” is given by a range of values which enclose the true value. We can have two kinds of uncertainties:

  - **Statistical** - These sources of error are stochastic in nature and arise due to the fact that measurement is based on a finite set of events.
  - **Systematic** - These errors arise from uncertainty associated with nature of measurement apparatus, methods used for particle identification and so on.

- The analysis considers two cases of systematics :

  (1) Uncertainty that affect the reconstructed objects (jets..)

  (2) Uncertainty that affect modeling of the backgrounds or signals.

- Some of these can affect both the shape and normalization while some affect normalization only.

Systematics

- All values quoted here are % variation from nominal yields.

Dominant systematics on yields

Systematics	Resolved	Boosted
$t\bar{t}$ normalization	8.0%	9.0%
JES of R=0.4 jets	6.0%	0.70%
JES+JMS of R=1. jets	0.30%	17%
b-tag efficiency	4.0%	3.4%
PDF	2.9%	6.0%

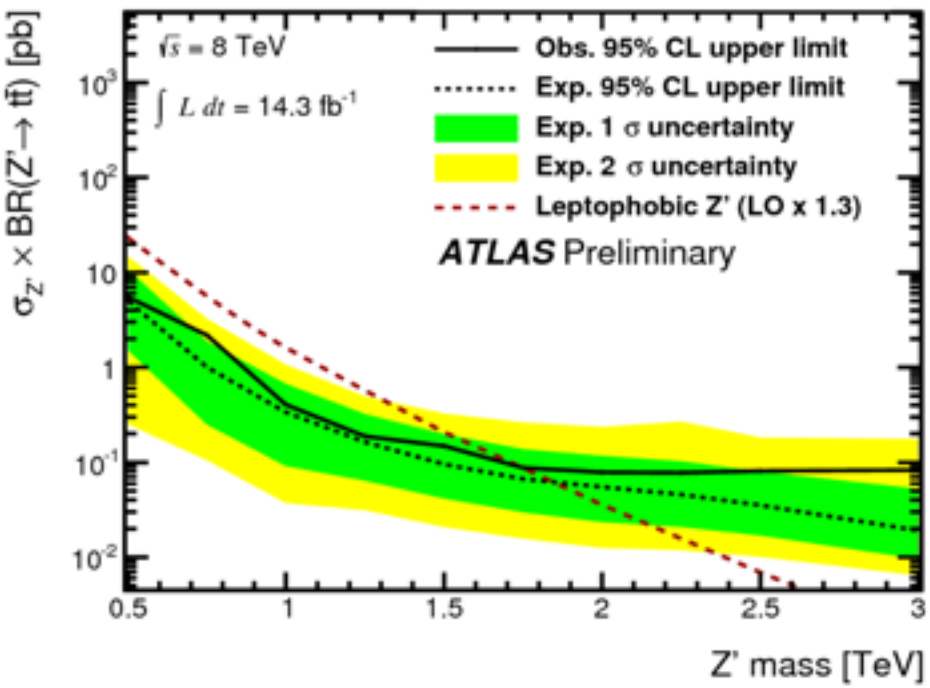
Systematic effect	Resolved selection yield impact [%] total bkg.	Resolved selection yield impact [%] Z'	Boosted selection yield impact [%] total bkg.	Boosted selection yield impact [%] Z'
Luminosity	2.9	3.6	3.3	3.6
PDF	1.6	4.6	5.8	2.9
ISR/FSR	0.2	–	0.7	–
Parton shower and fragm.	4.5	–	4.1	–
$t\bar{t}$ normalization	7.6	–	8.8	–
$t\bar{t}$ EW virtual correction	2.2	–	4.4	–
$t\bar{t}$ Generator	1.5	–	1.6	–
W+jets bb+cc+c vs. light	0.8	–	1.0	–
W+jets bb variation	0.2	–	0.4	–
W+jets c variation	1.1	–	0.6	–
W+jets normalization	2.1	–	1.0	–
Multi-jet norm, e+jets	0.6	–	0.3	–
Multi-jet norm, μ+jets	1.8	–	0.3	–
JES, small-radius jets	6.0	2.2	0.7	0.5
JES+JMS, large-radius jets	0.3	4.1	16.5	3.3
Jet energy resolution	1.6	0.4	0.6	0.7
Jet vertex fraction	1.7	2.3	2.1	2.4
b-tag efficiency	4.3	1.8	3.4	5.9
c-tag efficiency	1.4	0.3	0.7	0.9
Mistag rate	0.7	0.3	0.7	0.1
Electron efficiency	1.0	1.1	1.0	1.0
Muon efficiency	1.5	1.5	1.6	1.6

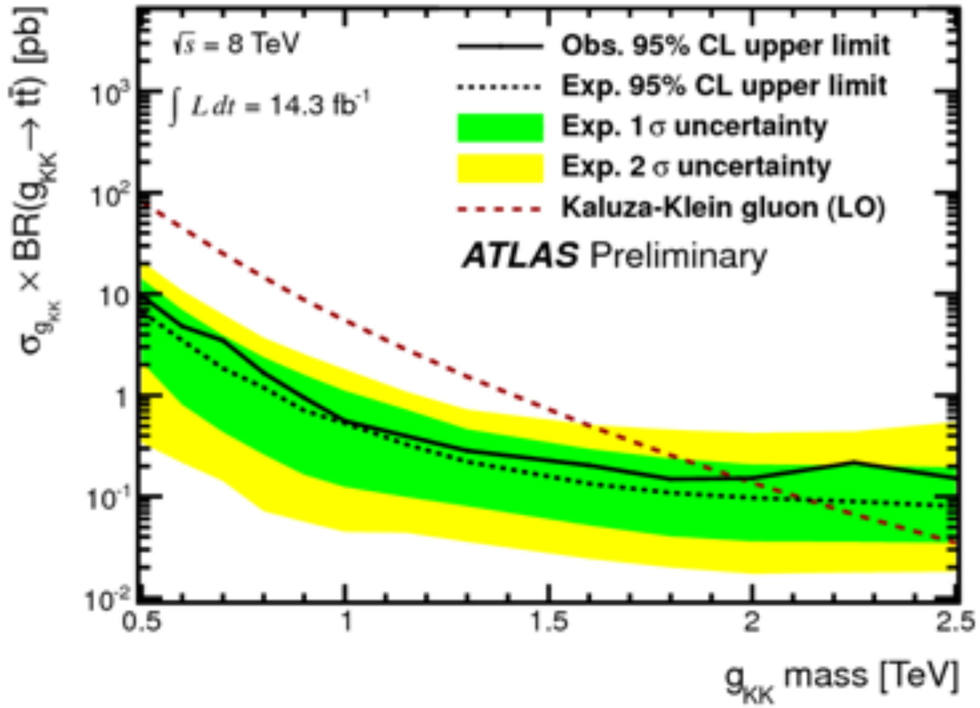
Limits (1)

After the $t\bar{t}$ mass reconstruction, data and expected background distributions are compared to search for new physics.

- A tool "BumpHunter" is used - it searches for local excesses or deficits in the data compared to the expected background, taking the look-elsewhere effect into account over the full mass spectrum.
- After accounting for systematics and statistical uncertainties, no excess is observed in data. -- Set upper limits!
- The limits are set on the $\sigma * B.R$ of Z' and KK gluon benchmark models using Bayesian techniques.
- In the combination, the four statistically uncorrelated spectra are used, corresponding to boosted and resolved selections, as well as **e**+jets and **μ**+jets decay channels.

Limits (2)





$14.3\ fb^{-1}$ @ 8TeV

Exclusion ranges	Observed
Z'	0.5-1.8TeV
KK gluon	0.5-2.0TeV

Limits (3)

Upper 95% CL cross section limits times branching ratio on a leptophobic topcolor Z'

Mass (TeV)	$\sigma \times$ BR $\times 1.3$ [pb]	Obs. (pb)	Exp. (pb)	-1σ (pb)	$+1\sigma$ (pb)
0.50	23.	5.30	4.99	1.50	10.7
0.75	5.6	2.17	1.00	0.249	1.87
1.00	1.6	0.406	0.335	0.091	0.674
1.25	0.57	0.187	0.160	0.064	0.323
1.50	2.1×10^{-1}	0.148	0.096	0.041	0.198
1.75		0.087	0.066	0.030	0.137
2.00	3.9×10^{-2}	0.078	0.055	0.023	0.117
2.25		0.078	0.045	0.021	0.103
2.50	6.9×10^{-3}	0.081	0.035	0.017	0.081
3.00	1.5×10^{-3}	0.083	0.019	0.010	0.053

Mass (TeV)	$\sigma \times$ BR [pb]	Obs. (pb)	Exp. (pb)	-1σ (pb)	$+1\sigma$ (pb)
0.50	82.	9.62	6.73	2.15	14.1
0.60	45.	4.79	3.48	0.813	6.98
0.70	25.	3.48	1.84	0.436	3.90
0.80	15.	1.66	1.19	0.262	2.37
0.90	8.8	0.948	0.711	0.165	1.60
1.00	5.5	0.561	0.529	0.125	1.11
1.15	2.8	0.394	0.329	0.100	0.720
1.30	1.5	0.282	0.221	0.081	0.464
1.60	0.50	0.204	0.134	0.052	0.296
1.80	0.26	0.149	0.109	0.041	0.237
2.00	0.14	0.153	0.097	0.036	0.209
2.25	0.067	0.218	0.089	0.036	0.203
2.50	0.035	0.152	0.080	0.035	0.196

Upper 95% CL cross section limits times branching ratio on a Kaluza–Klein gluon

Conclusions

- We searched for $t\bar{t}$ resonances in the lepton plus jets final state with 14 fb^{-1} of 8 TeV data.

- No significant excess of events was observed.

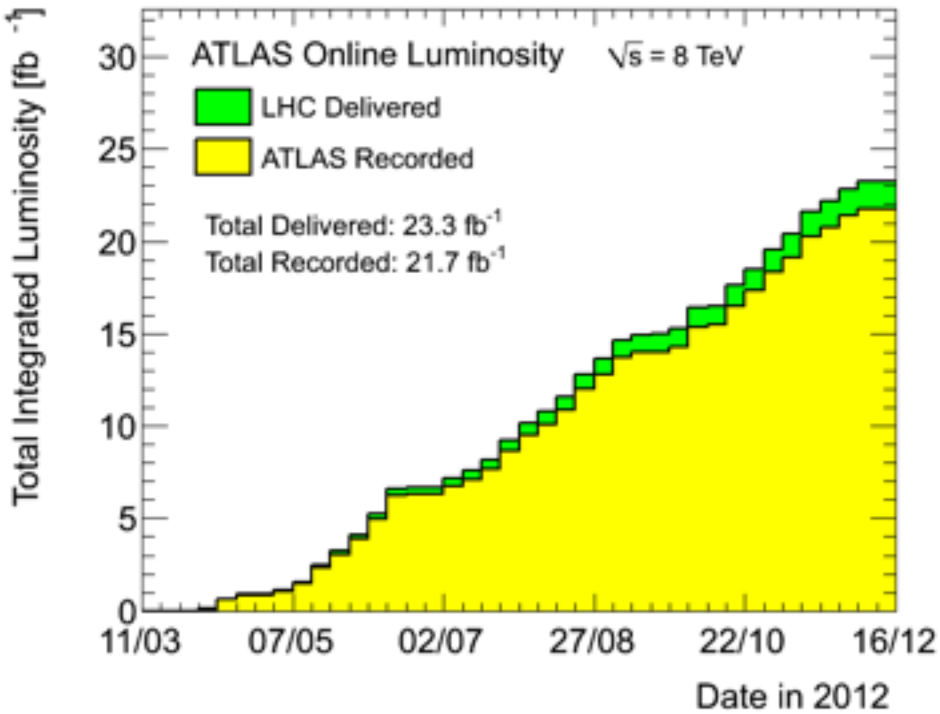
- Using 2 benchmark models, we set 95% C.L upper limits on mass of produced resonances.

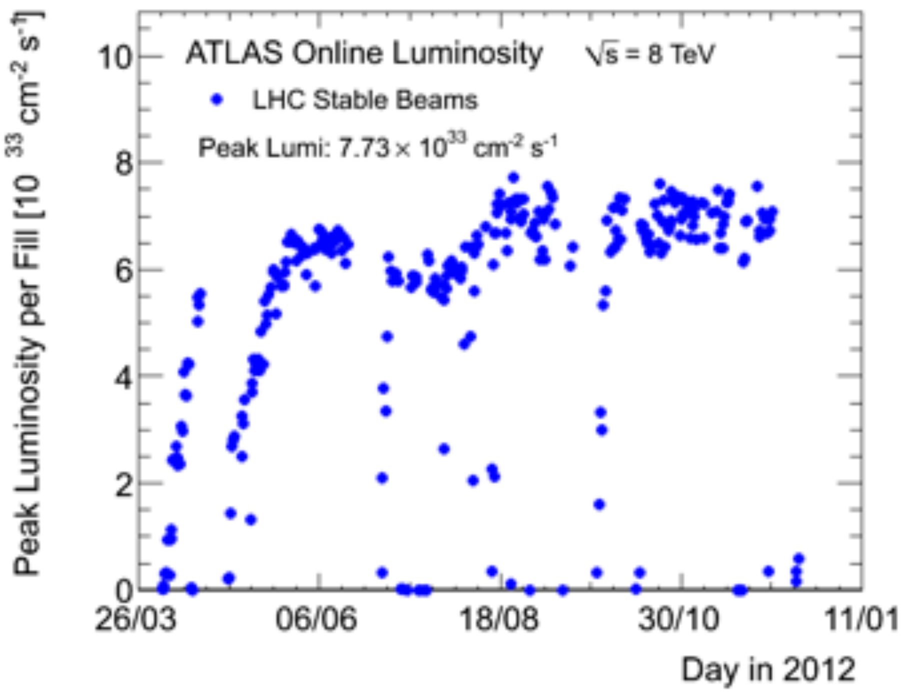
Exclusion ranges	Observed
Z'	0.5-1.8TeV
KK gluon	0.5-2.0TeV

- Re-optimization of 20 fb^{-1} of 8 TeV data is in progress and we expect new results by the end of the year.

Backup Slides

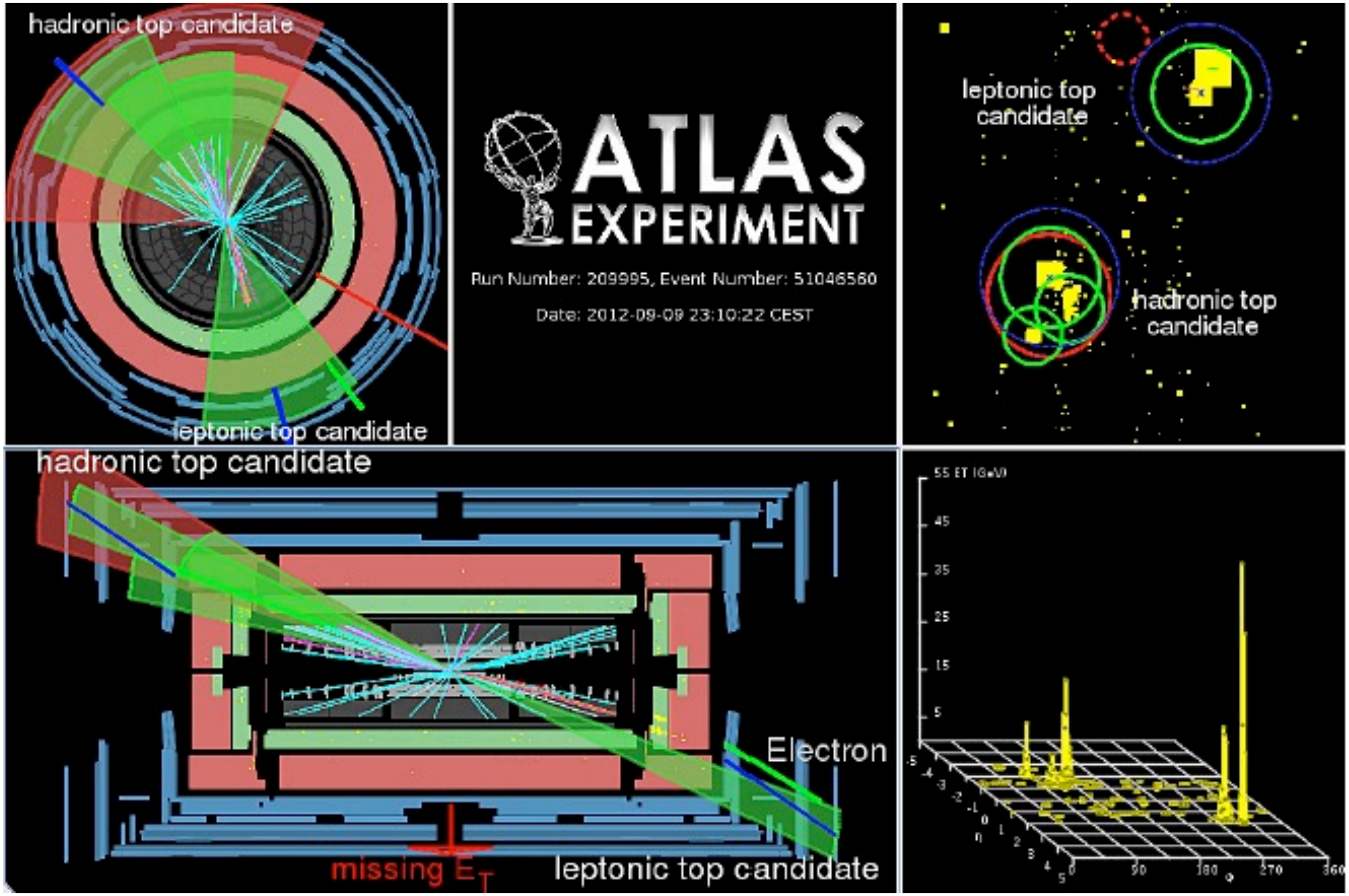
ATLAS Luminosity





Top Object Reconstruction

- Electrons:
  - Clusters of energy deposits in EM calorimeter are reconstructed and associated to charged particle tracks in the inner detector.
- Muons:
  - Track segments are reconstructed in the muon chambers (spectrometer) and segments are combined starting from the outermost layer. They are fitted to account for material effects.
  - Inner detector charged particle tracks are matched to the fitted spectrometer tracks.
- Jets:
  - Clusters of energy deposits in EM and hadronic calorimeter cells are combined using the Anti-k_T algorithm with distance parameter $R = 0.4$
- Missing E_T ($\not{E}_T$):
  - Formed using a vector sum of all jets, electron and muon candidates and all the unassigned cells in the calorimeter.


hadronic top candidate
leptonic top candidate
ATLAS
EXPERIMENT
Run Number: 209995, Event Number: 51046560
Date: 2012-09-09 23:10:22 CEST
leptonic top
candidate
hadronic top
candidate
hadronic top candidate
Electron
missing E_T
leptonic top candidate

e+jets event