Searches for resonances decaying to Standard Model third generation quarks and leptons

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On behalf of the ATLAS Collaboration

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Outline

- Presenting results from ATLAS @ 8 TeV for particle searches:

- $W' \rightarrow t\bar{b}$ (ATLAS-CONF-2013-050)

- $Z'/g_{KK} \rightarrow t\bar{t} \rightarrow W^{+} b\, W^{-} \bar{b}$ (ATLAS-CONF-2013-052)

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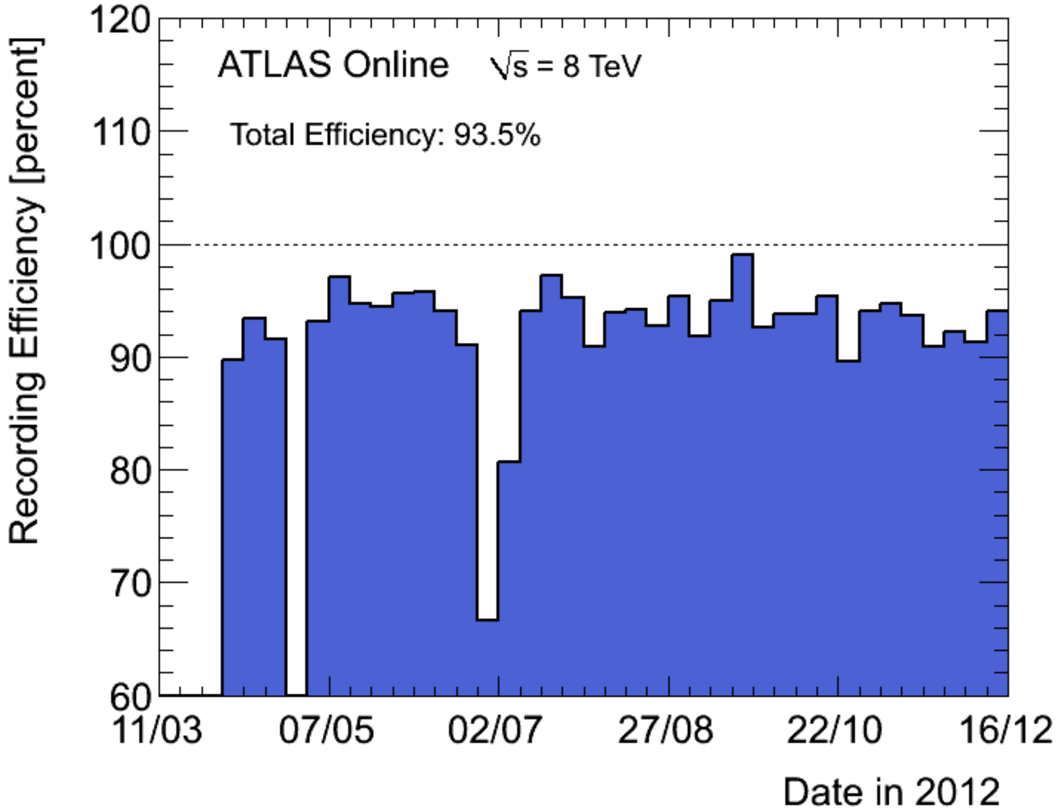
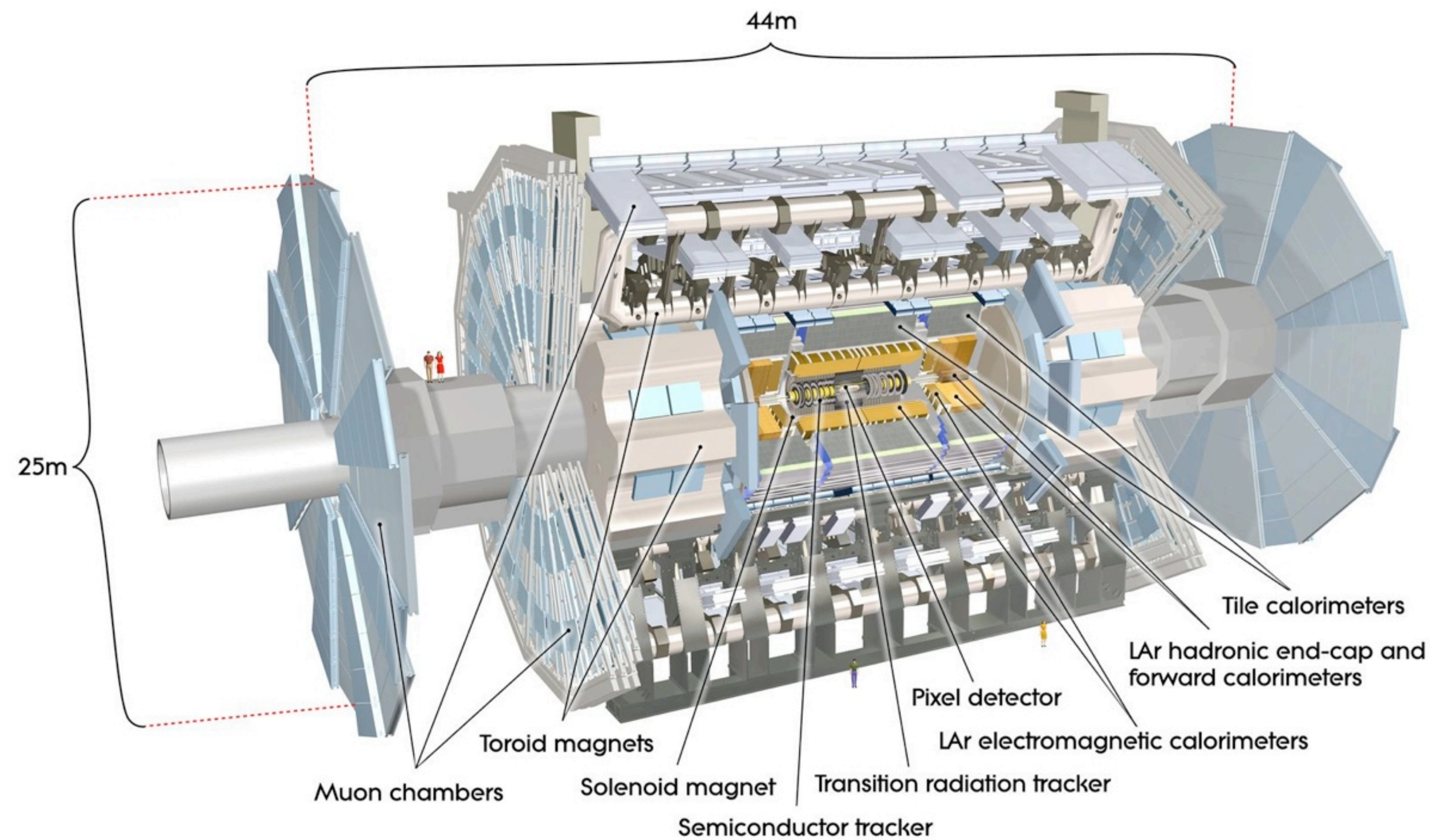
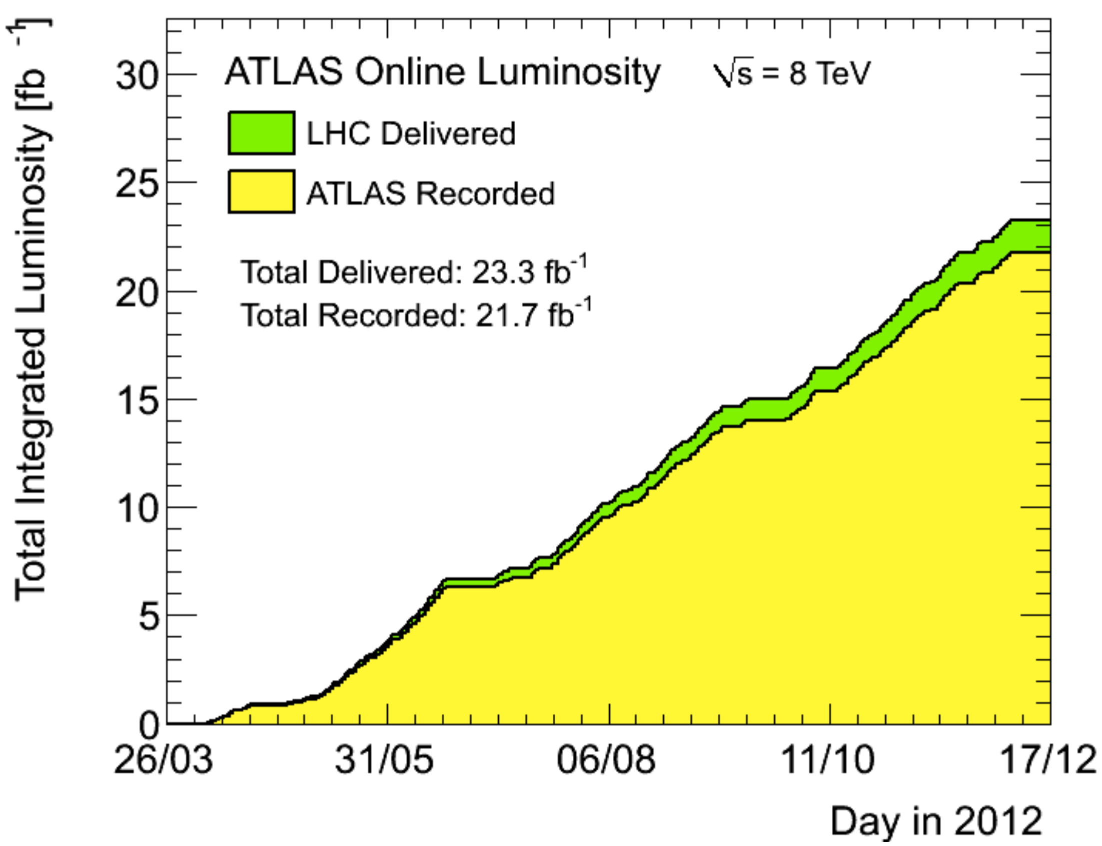
High-mass $Z'_{SSM} \rightarrow \tau_{had}\tau_{had}$ resonances (ATLAS-CONF-2013-066)

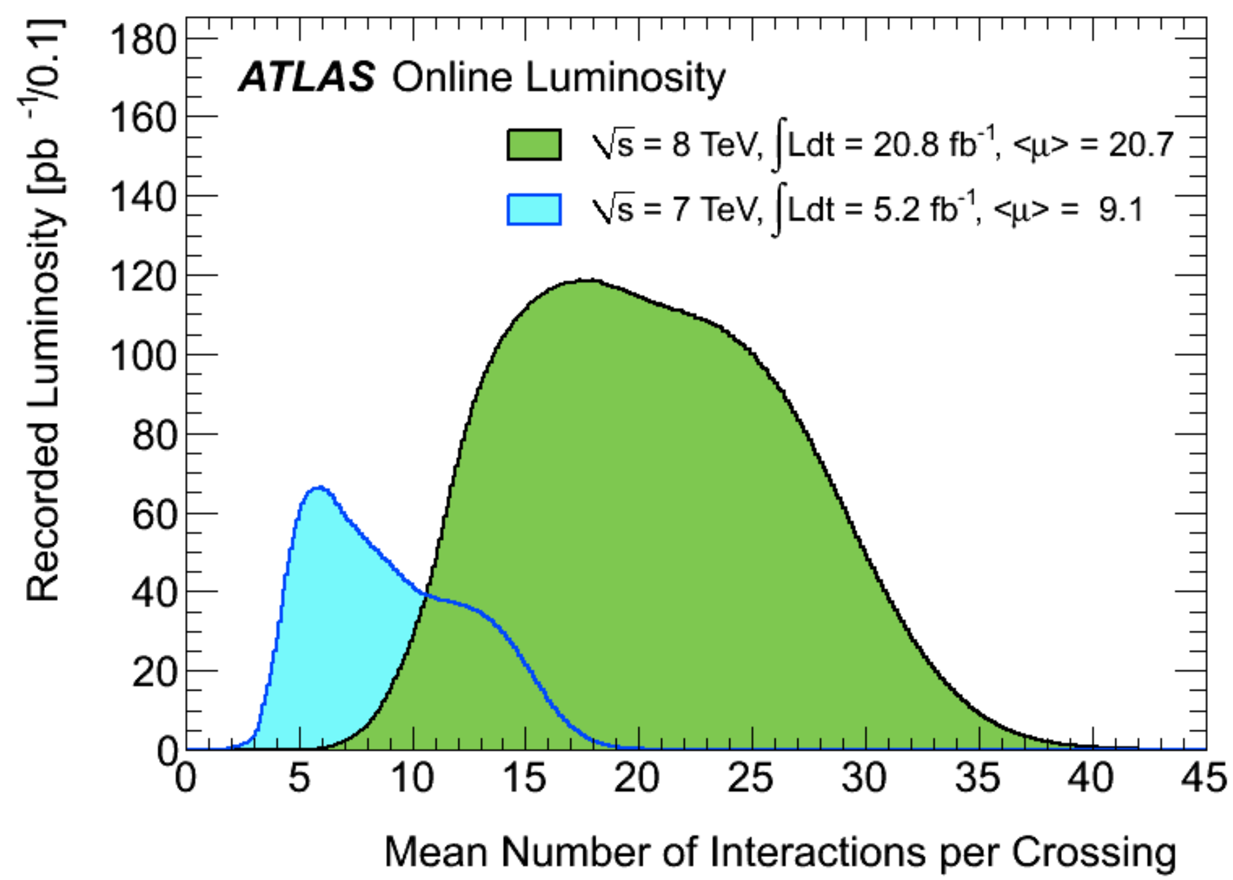
LHC luminosity & the ATLAS detector



All detectors/triggers good for physics: 95.8 %

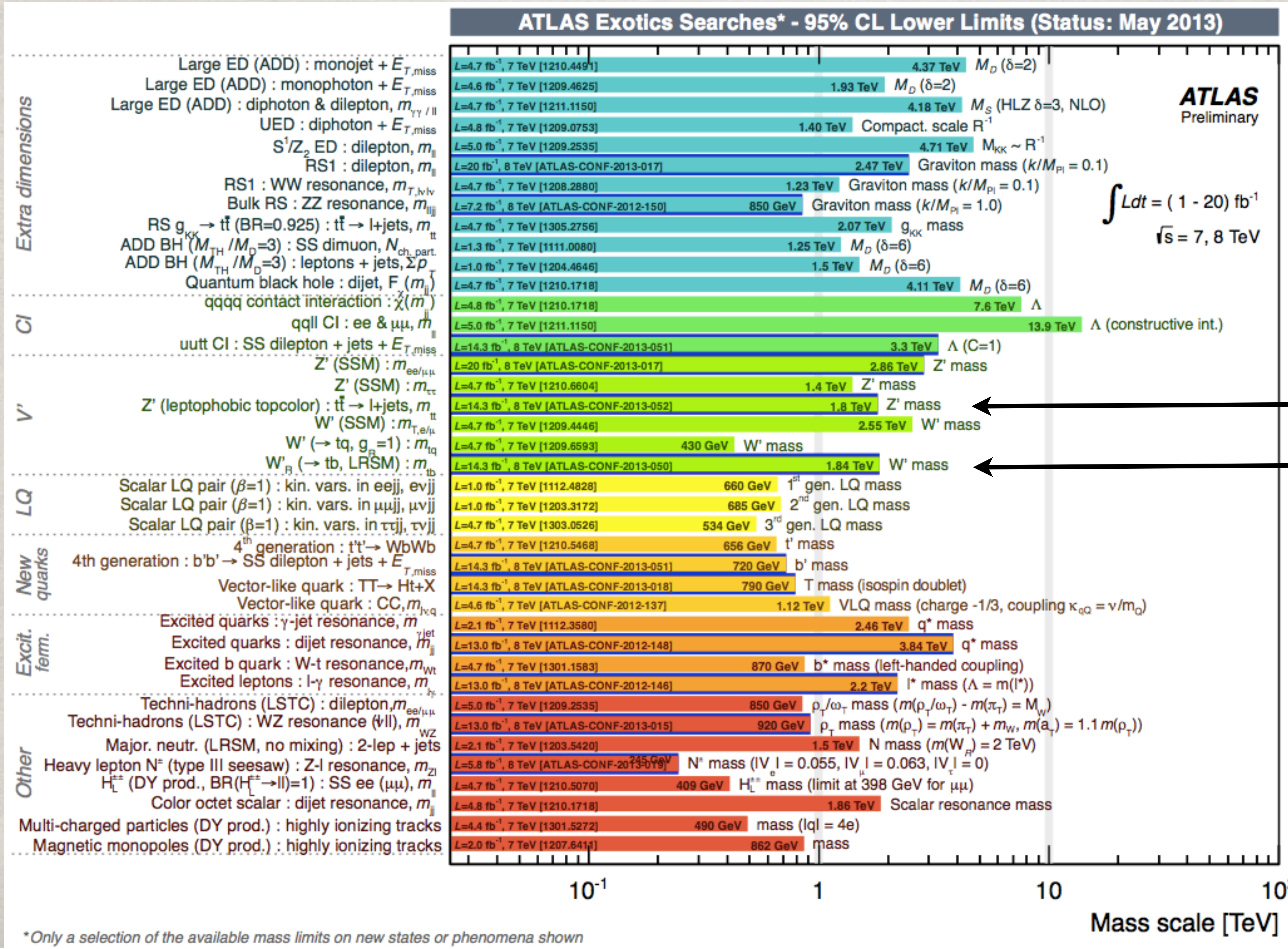






ATLAS exotic searches summary

- *Focusing on recent results with ~14 - 20 fb^{-1} (2012 data @ 8 TeV):*
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic



Searches with 3rd generation quarks & leptons

3rd generation quarks:

- Questions on mass hierarchy within SM
- top & bottom quarks → preferred final state in case of mass-dependent couplings

  Challenges:

  - Experimental identification of b-jets, especially at high p_T
  - Theory and modeling uncertainties in top physics
  - Substructure-based top-tagging & lepton isolation for boosted tops

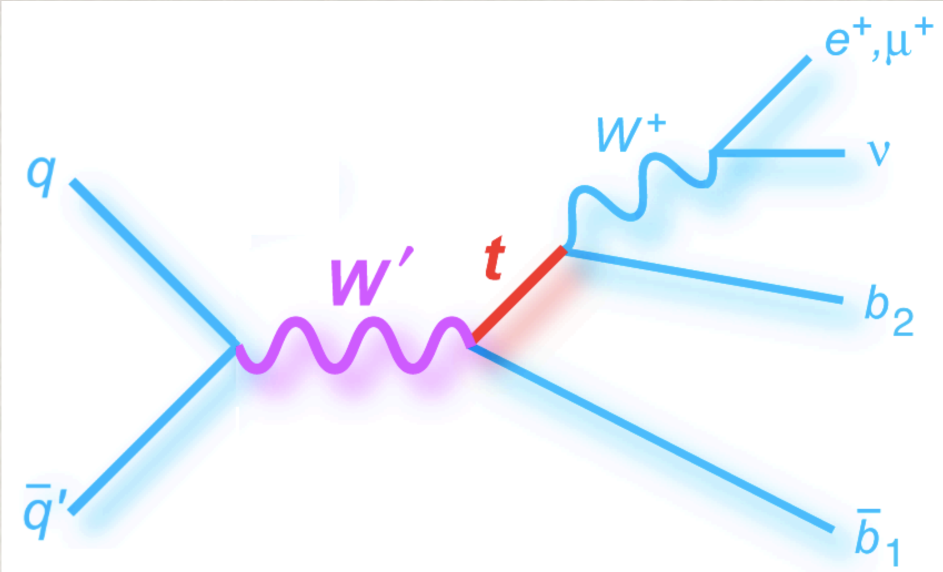
Tau Leptons:

- Backgrounds to leptons reduced w.r.t. hadronic signatures, thus smaller cross-sections can be probed
- Availability of known peaks to test background predictions and detector performance

  Challenges:

  - Small leptonic branching ratios at high masses
  - Soft leptons for some models → difficult detection
  - Jets faking leptons are not always well modeled

Search for $W' \to t\bar{b} \to l\nu b\bar{b}$ in pp collisions at $\sqrt{s}$ = 8 TeV



- This search uses $\mathcal{L}$ = 14.3 fb^{-1}and looks at final states with *electrons* or *muons*.
- Several BSM models predict *W'* bosons:
  - Kaluza-Klein excitations of the SM *W* boson, techni-colour models, Little Higgs
  - In many BSM theories the *W'* boson is expected to couple more strongly to the 3rd generation quarks than to the 1st or 2nd
  - Easier to look for t$\bar{b}$ final states than pure jj
- The analysis uses a multivariate method based on ***boosted decision trees*** (BDT)
- The search range covers 0.5 < $M_{W'}$ < 3.0 TeV, with R- or L-handed W′-boson chiralities.

Backgrounds, triggers & Event selection

- **Main contribution**: $t\bar{t}$ production, W+jets, W+light jets or $W+c/c\bar{c}$ $(b\bar{b})$ processes (possible misidentification of light-quarks as b jets)

- **Smaller contribution**: single top production (t-channel, Wt and s-channel), WW, WZ, ZZ, Z+jets events, multijet events

- **Triggers**:
  - electron object: $E_T > 60$ GeV, or $E_T > 24$ GeV with an isolation requirement
  - muon object: $p_T > 36$ GeV, or $p_T > 24$ GeV with an isolation criterion

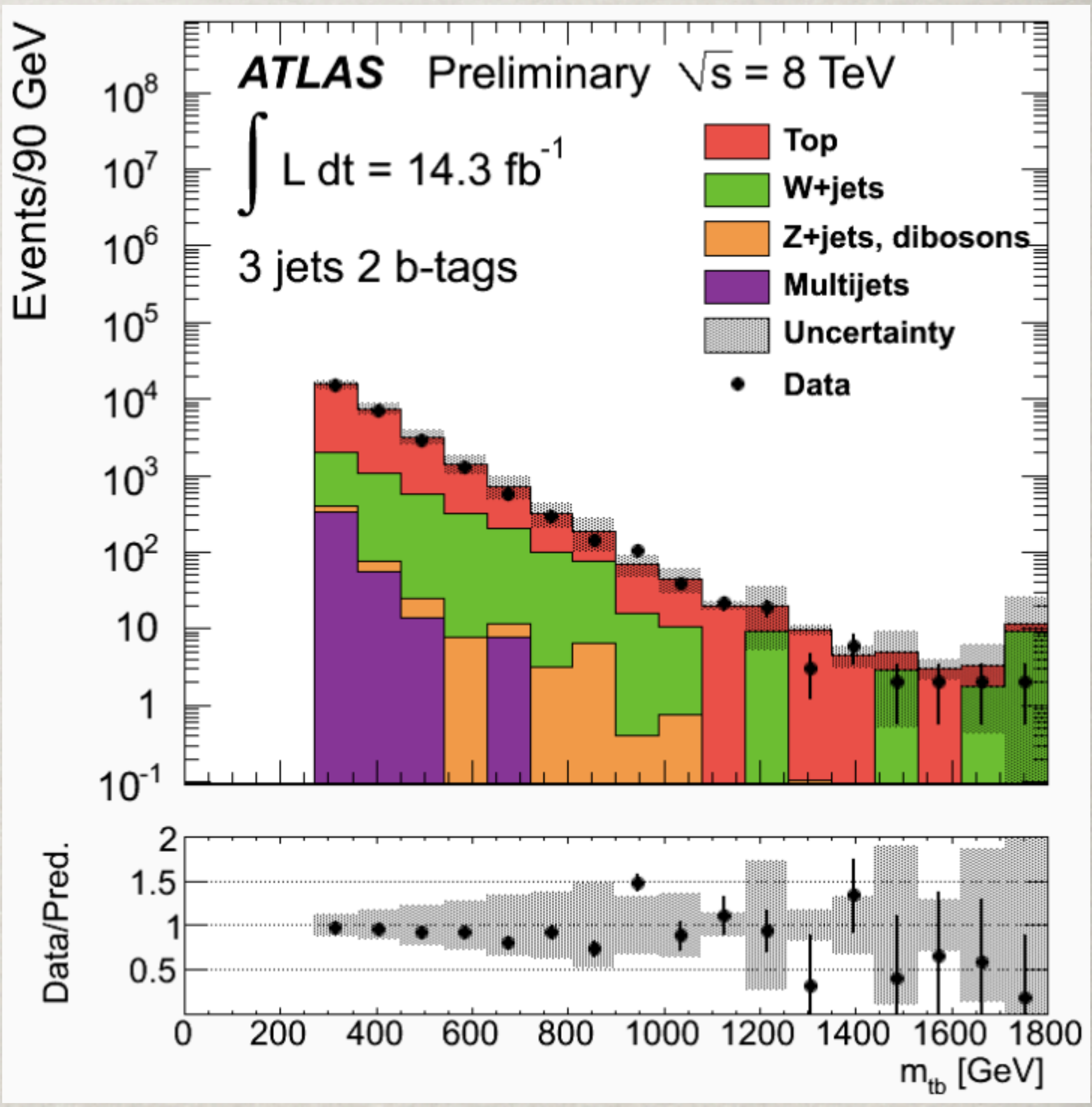
- **Event Selection:**

- Data-quality requirements (proper functioning of the detector and trigger subsystems, as well as LHC stable beam periods)

- Isolated electron candidates with $p_T > 30$ GeV, $|\eta| < 2.47$ excluding $1.37 < |\eta| < 1.52$; muon candidates should have a $p_T > 30$ GeV and $|\eta| < 2.5$

Event selection contd.

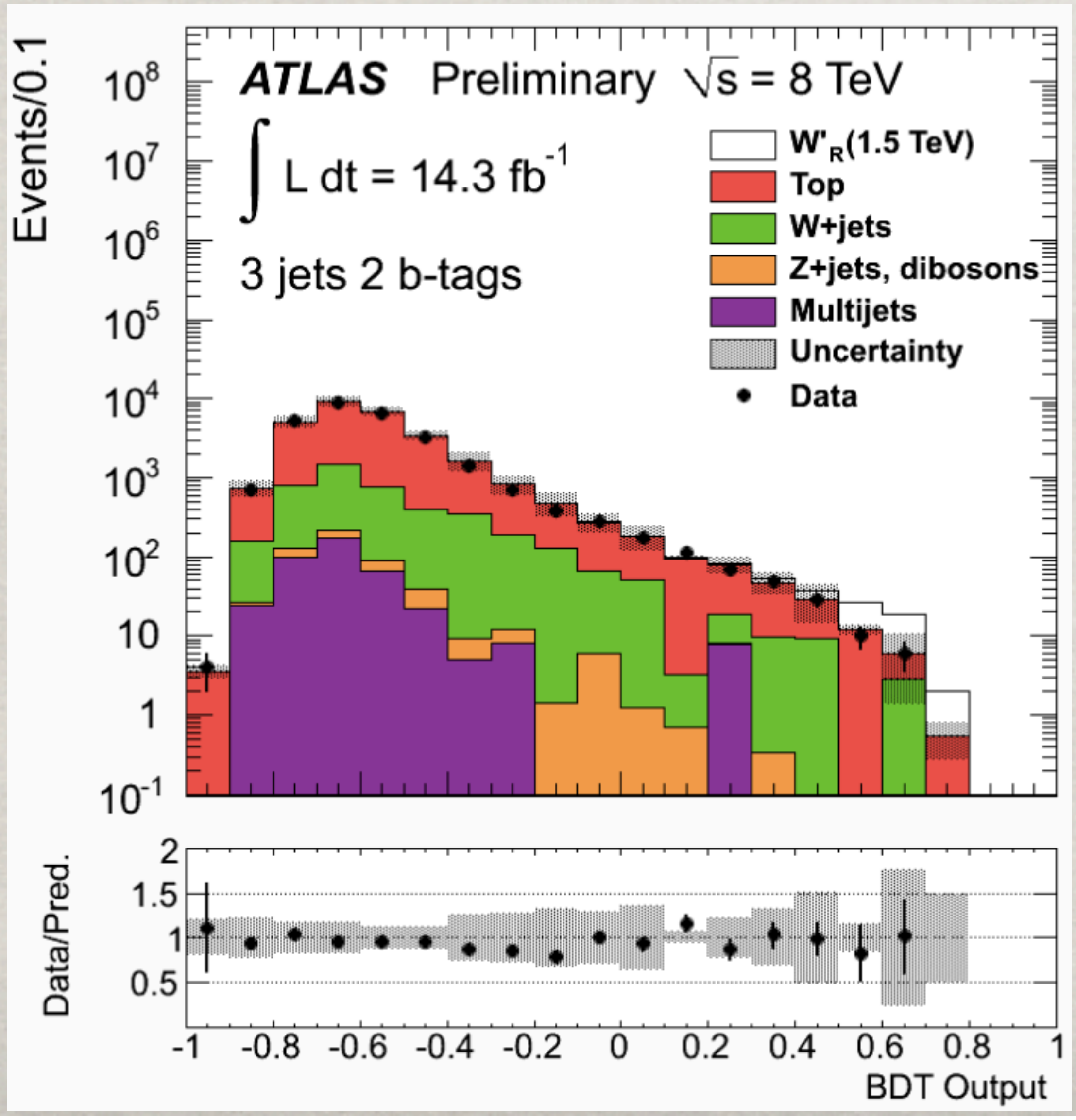
- Jets are reconstructed using the anti-k_t algorithm with R = 0.4, with $p_T > 25$ GeV and $|\eta| < 2.5$
- $E_T^{miss} > 35$ GeV (to reduce the multijet BG)
- *b*-jets identified using a NN-based *b*-tagger (70% eff. and light-jets rejection factor = 135)
- PV ≥ 1 with $N_{trk} \geq 5$ associated to it and with exactly one lepton (electron or muon), p_T^{miss}, and 2 or 3 jets with ≥ 1 *b*-jet
- Events must pass a selection criteria, defined as $E_T^{miss} + m_T(W) > 60$ GeV

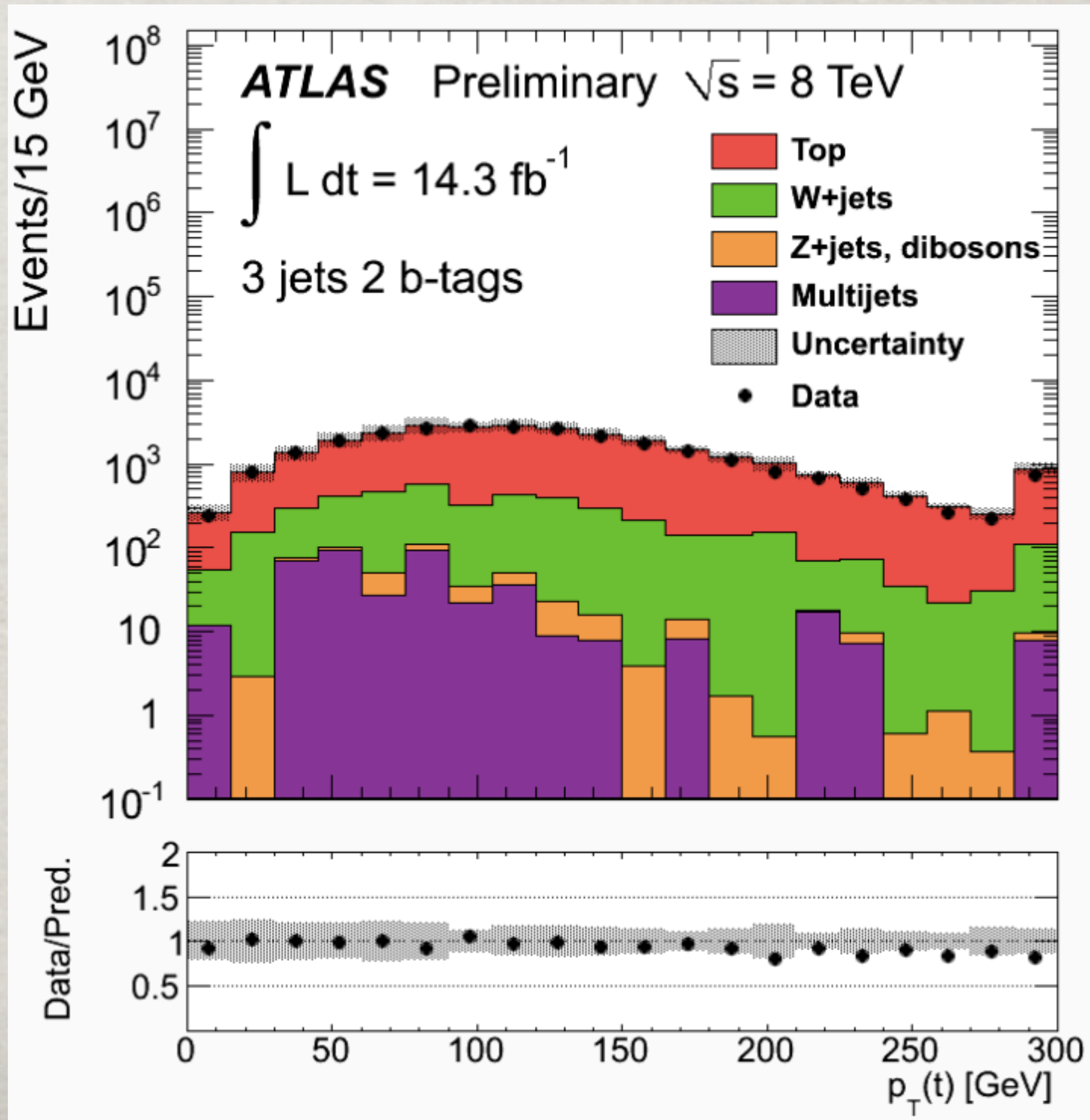


Analysis strategy

ATLAS-CONF-2013-050

- BDT is used for discrimination of signal to background
  - Main discriminants: m_{tb}, p_T(top) out of 14 variables (2-jet) / 13 variables (3-jet)
  - separation between lepton and b-jet
- BDT output and p_T spectrum for data, signal and background in a signal region with 2 b-jets

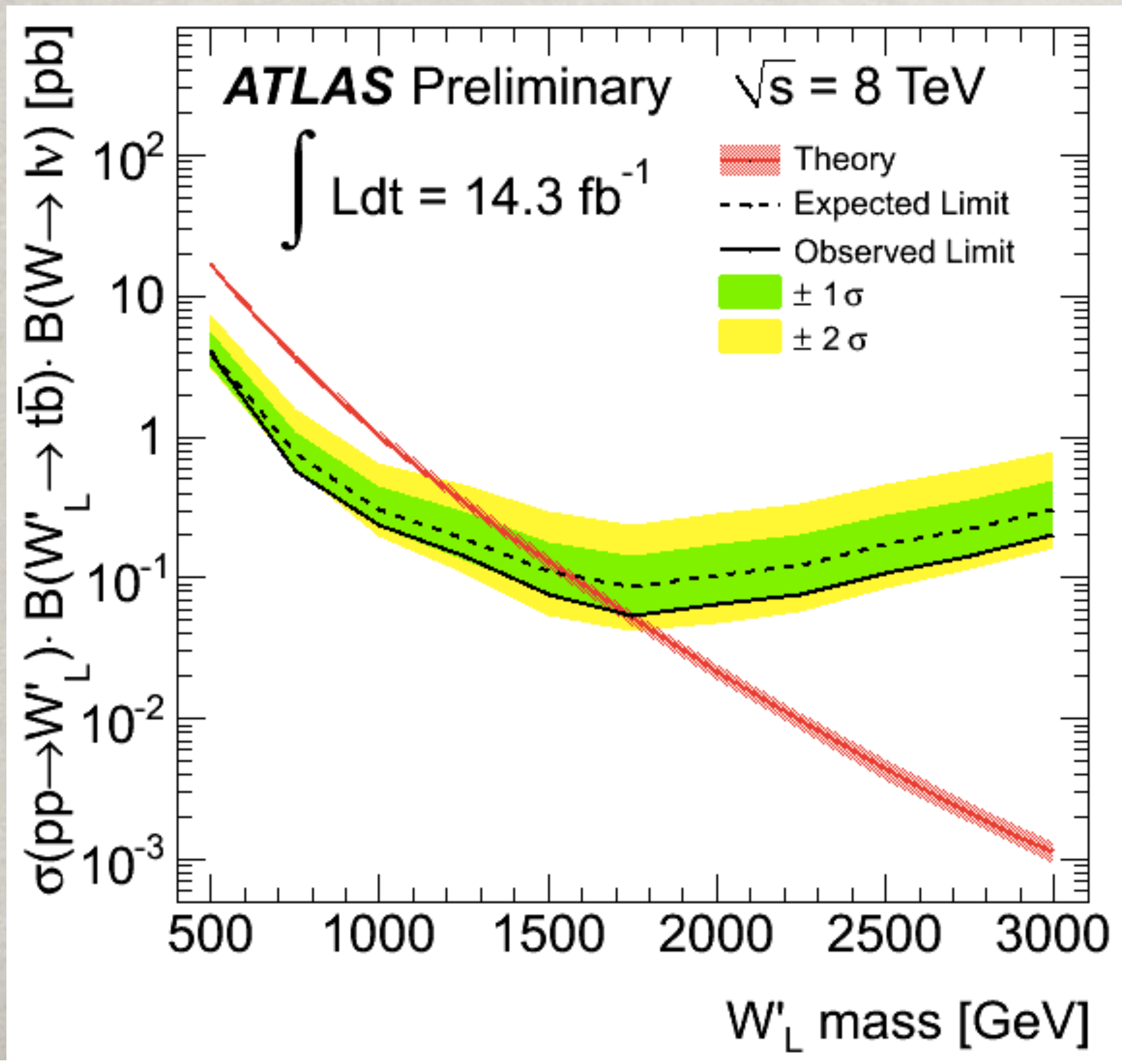


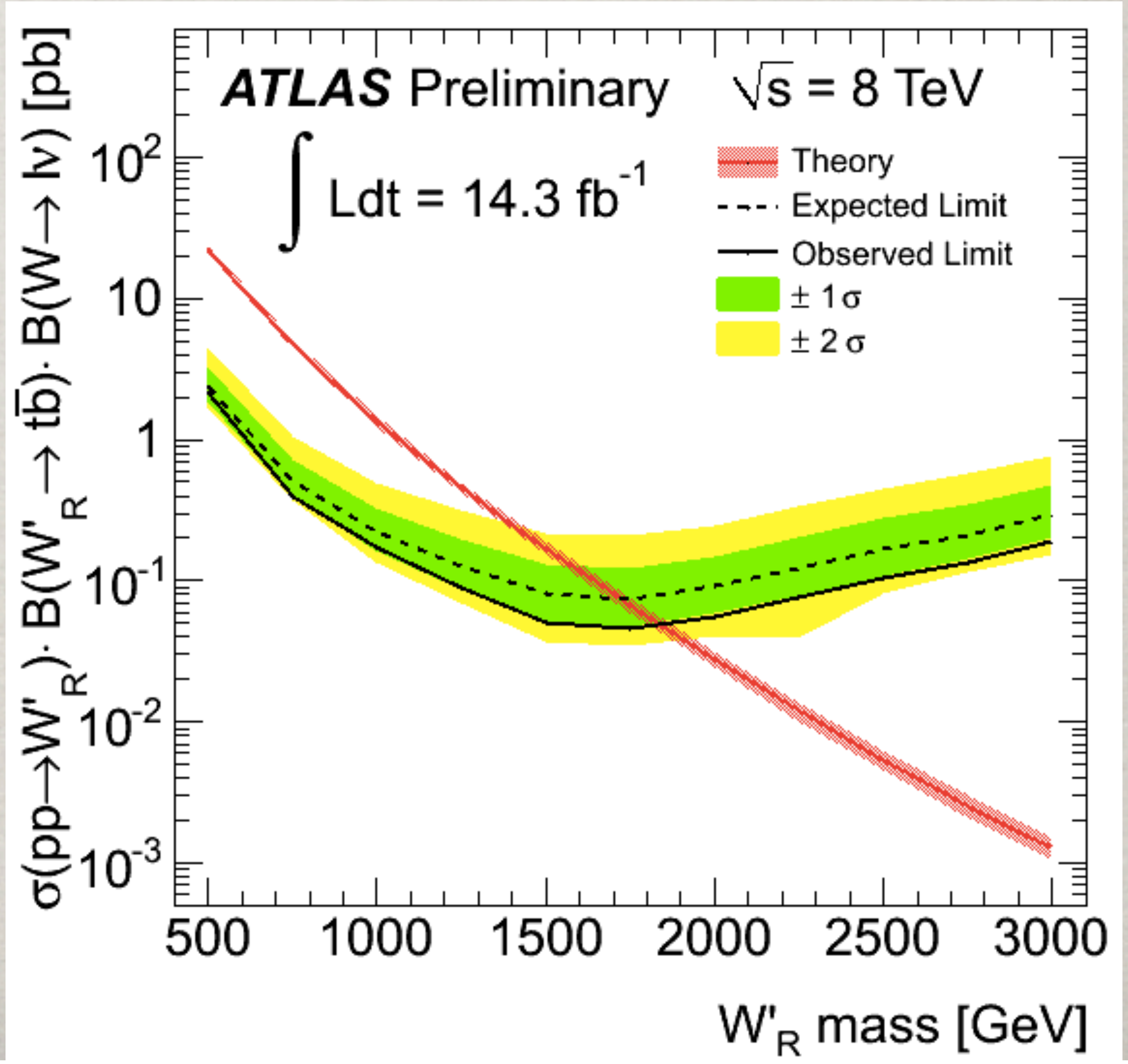


Results

- No data excess over the expected SM background is observed in the BDT output → set limits on W' with SM couplings (effective model) @ 95% CL:
    - **m(W'_L) > 1.74 TeV**
    - **m(W'_R) > 1.84 TeV**

W' mass (TeV)	W'_L Theory	W'_L Obs. limit	W'_R Theory	W'_R Obs. limit
0.5	17	4.0	23	2.2
1.0	1.0	0.24	1.4	0.17
1.5	0.13	0.075	0.17	0.051
2.0	0.022	0.064	0.028	0.056
2.5	0.0044	0.11	0.0054	0.10
3.0	0.0011	0.20	0.0013	0.19

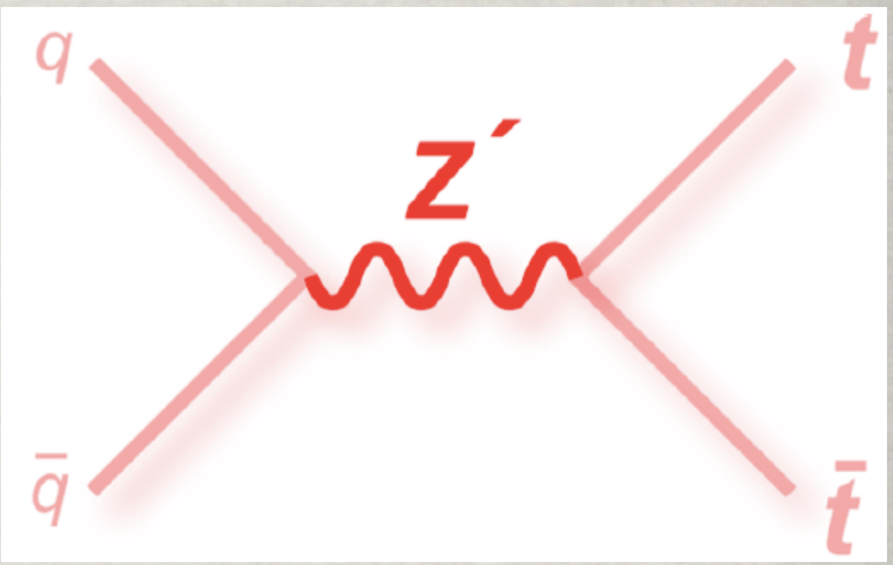




Search for $t\bar{t}$ resonances decaying to leptons and jets

Topcolor: introduces a new leptophobic Z-like boson: Z'.

- Narrow resonance: width 1.2% of the mass.
- Strong coupling to first and third generation of quarks.



- The model explains the top mass and EWSB.

Randall-Sundrum: Kaluza-Klein gluons arise in this model.

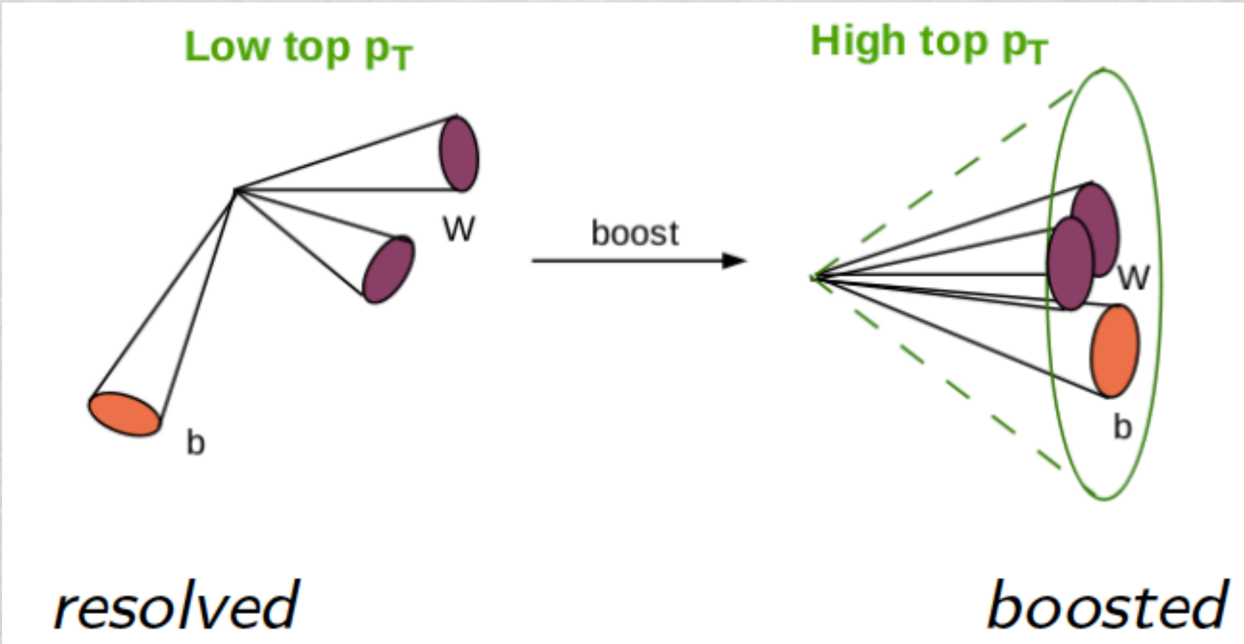
- Broad resonance: width 15% of the mass.
- Strongly coupled to the top quark.

- This model introduces a single warped extra dimension and explains the hierarchy problem.

Backgrounds & analysis strategy

ATLAS-CONF-2013-052

- **Data**: collected in 2012 @ 8 TeV with $\mathcal{L}$ = 14 fb^{-1}.
    - BG: SM $t\bar{t}$, W/Z + jets (shape), single top and di-boson → estimated from MC
    - W + jets normalization (charge-asymmetry of W) and multijet (matrix method)→ estimated from data
- **Event selection**: $t\bar{t}$ events are selected in the e or μ+jets channels using two different topologies: boosted and resolved.



- **Discriminant variable**: $t\bar{t}$ invariant mass
- **Limits**: computed using a Bayesian technique

ATLAS-CONF-2013-052

Event selection

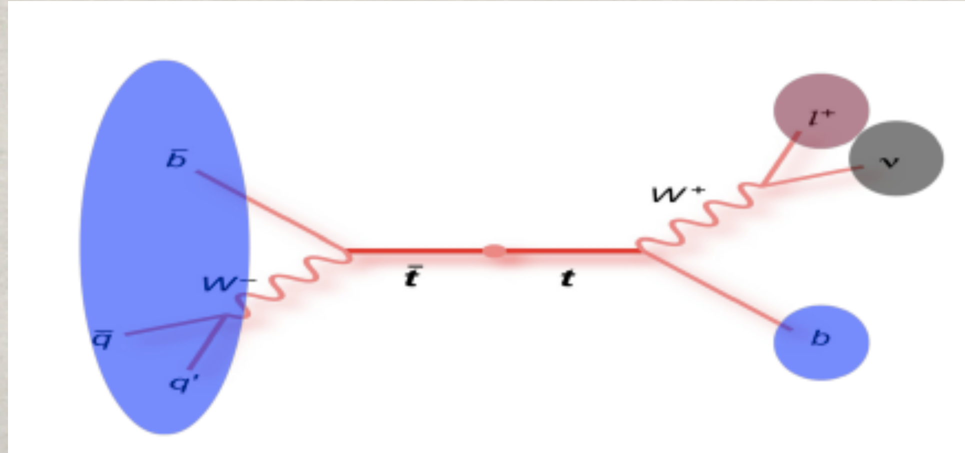
- **Lepton selection**: one isolated lepton
  - Electron: $E_T > 25$ GeV and $|\eta| < 2.47$ (excluding $1.37 < |\eta| < 1.52$)
  - Muon: $p_T > 25$ GeV and $|\eta| < 2.5$
- **<u>Multijet background rejected by</u>**:
  - e-channel: $E_T^{miss} > 30$ GeV and $m_T > 30$ GeV
  - μ-channel: $E_T^{miss} > 20$ GeV, $E_T^{miss} + m_T > 60$ GeV

$$m_T = \sqrt{2 p_T E_T^{\mathrm{miss}} (1 - \cos \Delta\phi)}$$

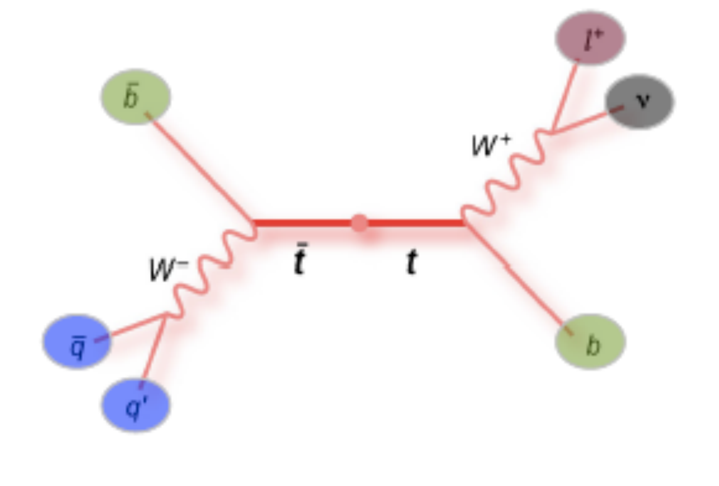
Jet selection

- **anti-k_t algorithm used**
  - **small-radius jets** (R = 0.4): $p_T > 25$ GeV, $|\eta| < 2.5$
  - **large-radius jets with trimming applied** (R = 1.0): $p_T > 300$ GeV and $|\eta| < 2.0$
- **Boosted**: ≥1 small-radius jet: highest p_T jet with $R(\ell; j_{0.4}) < 1.5$

  ≥1 large-radius jet: $m_{jet} > 100$ GeV, $\sqrt{d_{12}} > 40$ GeV, $\Delta R(j_{1.0}, j_{0.4}) > 1.5$ & $\Delta\Phi(j_{1.0}; \ell) > 2.3$
- or **resolved**: 4 small-radius jets: $p_T > 25$ GeV, $|\eta| < 2.5$
- or **3 small-radius jets**: accepted if $m_{jet} > 60$ GeV for one of these jets
  - Resolved topology is applied only if the boosted selection failed
- ≥ 1 b-tagged jet



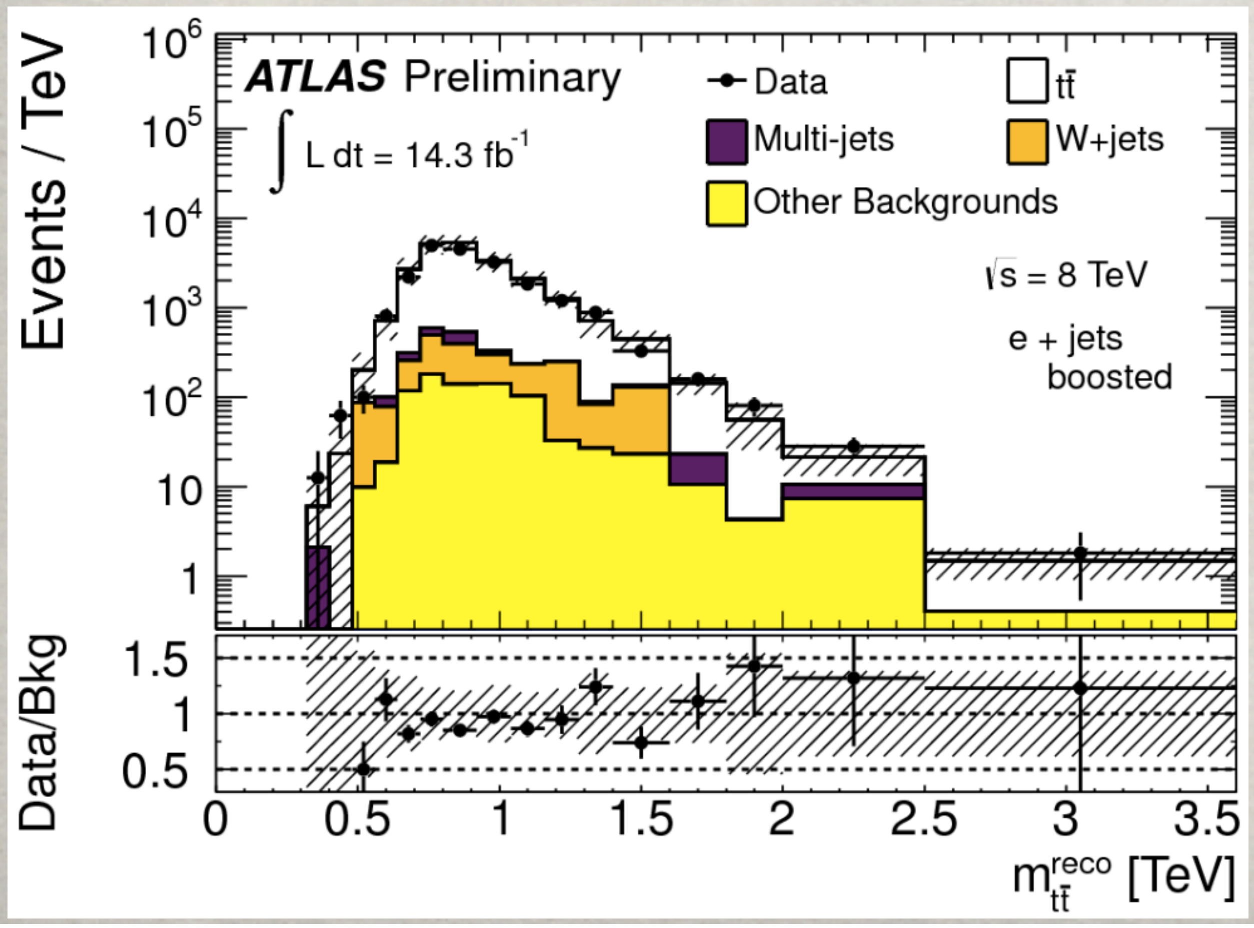
Boosted selection

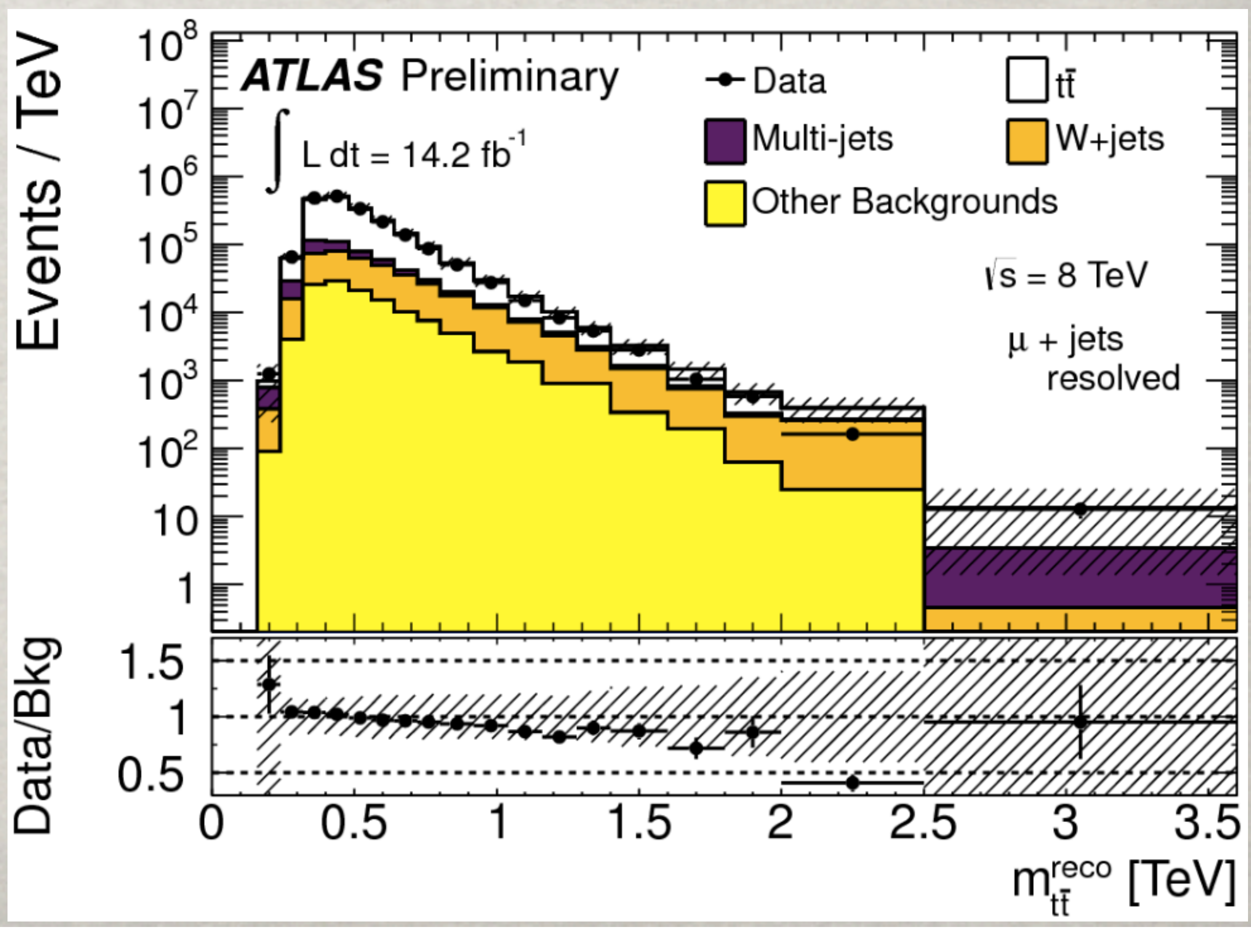


Resolved selection

Data & BG

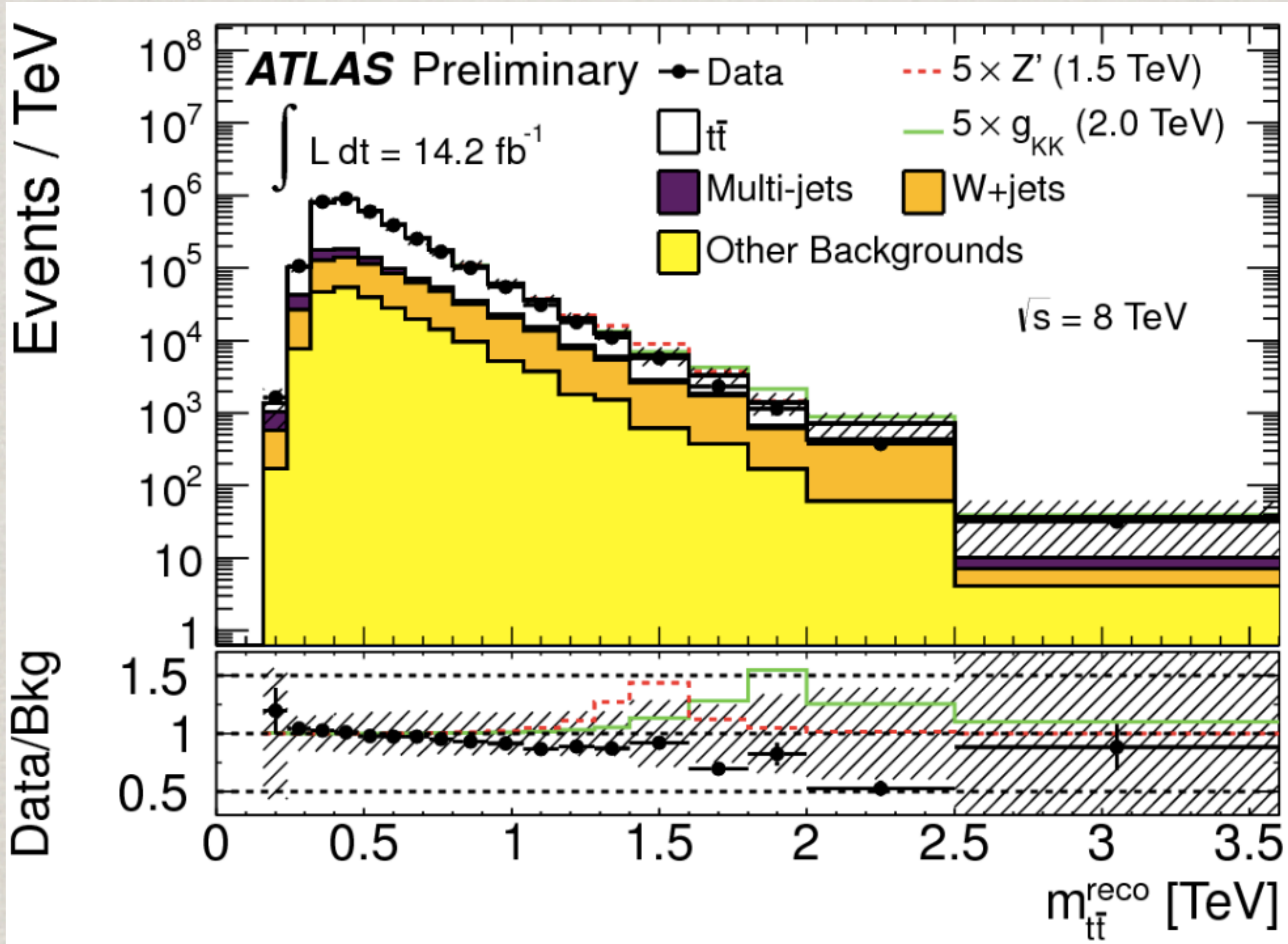
- $t\bar{t}$ invariant mass computed from the four-momenta of the objects in the event
  - **Resolved**: uses neutrino p_Z and a χ^2 algorithm to select the best assignment to jets
  - **Boosted**: no ambiguity in the assignment of jets
    - Hadronic decay → large radius jet
    - Semi-leptonic decay → Neutrino p_Z , high-p_T lepton and a small radius jet





ATLAS-CONF-2013-052

Resolved + boosted distributions



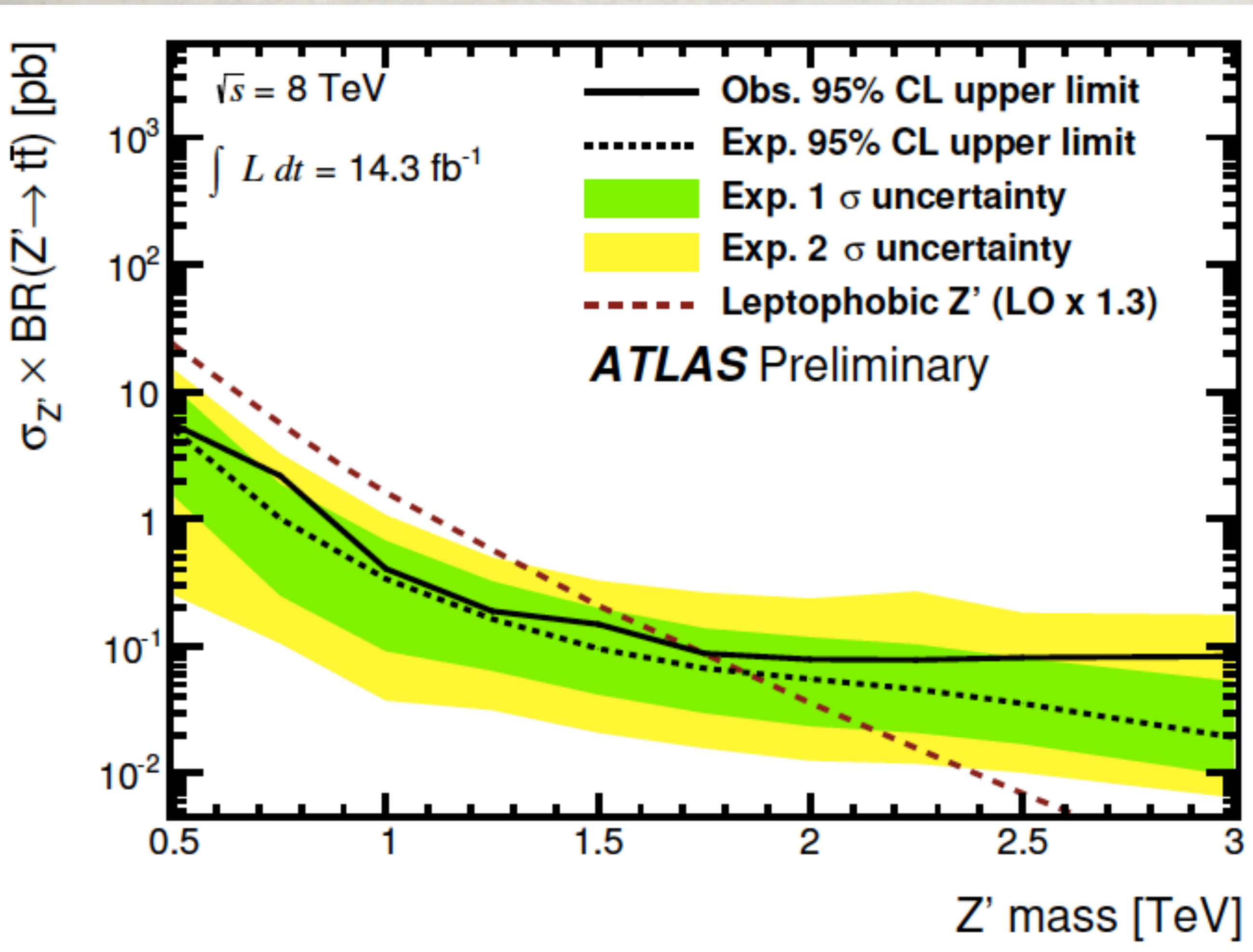
$e + \mu$	Resolved	Boosted
Predicted	$283\ 000 \pm 39\ 000$	$5\ 600 \pm 1\ 200$
Data	280 251	5 122

Observed and expected number of background events

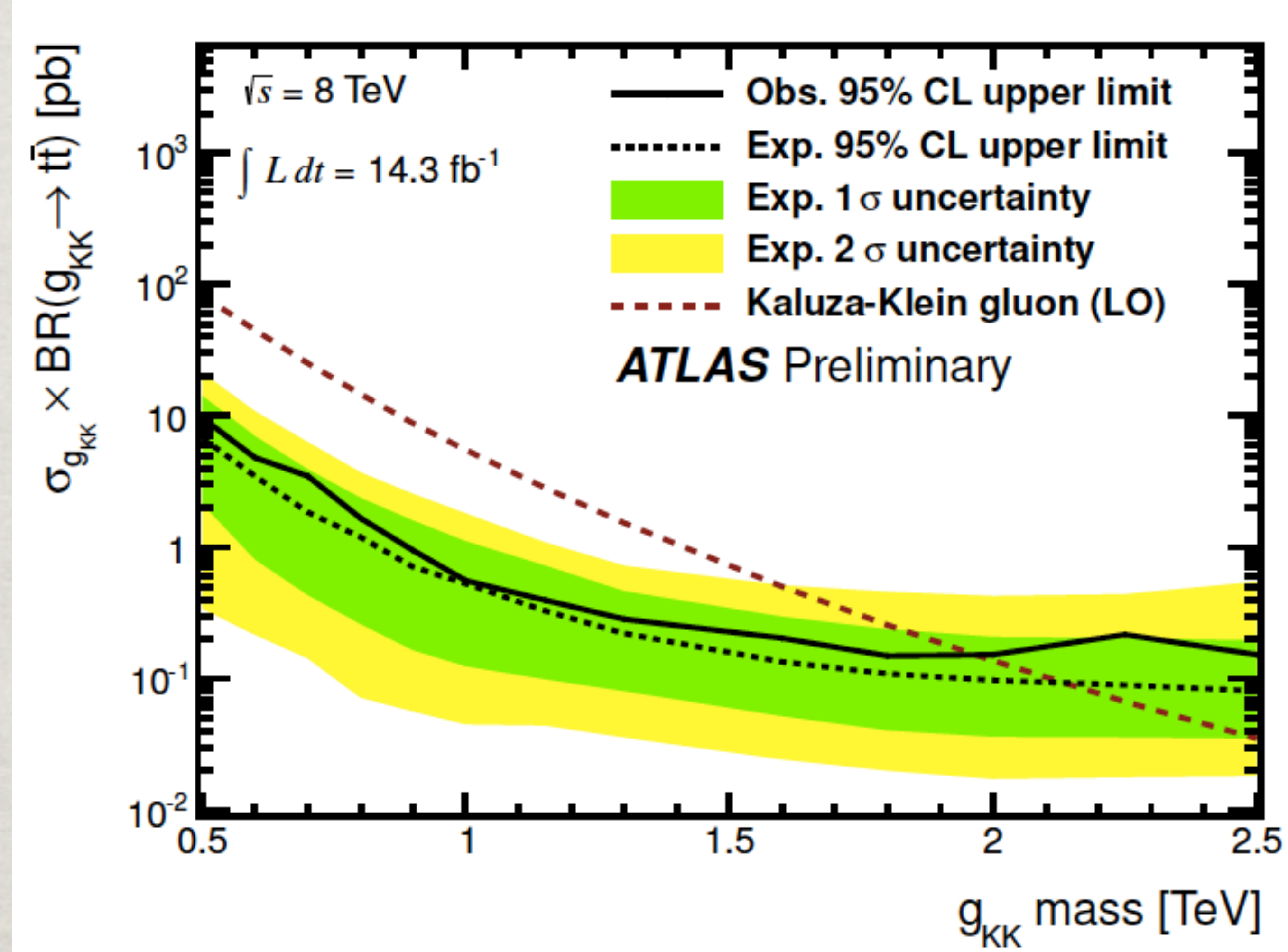
Good agreement between data and expected background within uncertainties

Limits on Z' and g_{KK}

- Exclusion ranges @ 95% C.L:



0.5 TeV $< m_{Z'} <$ 1.8 TeV



0.5 TeV $< g_{KK} <$ 2.0 TeV

Expected exclusion:
0.5 TeV $< m_{Z'} <$ 1.9 TeV

Expected exclusion:
0.5 TeV $< g_{KK} <$ 2.1 TeV

Search for high-mass $\tau_{had}\tau_{had}$ resonances

- Sequential Standard Model (*SSM*) is a benchmark model that contains a heavy neutral gauge boson, Z'_{SSM}, with the same couplings to fermions as the Z boson of the SM

- Most stringent limits on Z'_{SSM} in the e^+e^- and $\mu^+\mu^-$ decay channels combined are 2.79 TeV and $\tau_{had}\tau_{had}$ 1.4 TeV (5 fb^{-1}).

- In this analysis using integrated luminosity of 19.5 fb^{-1}.

- Tau leptons - good probe for new particles whose couplings increase with mass.

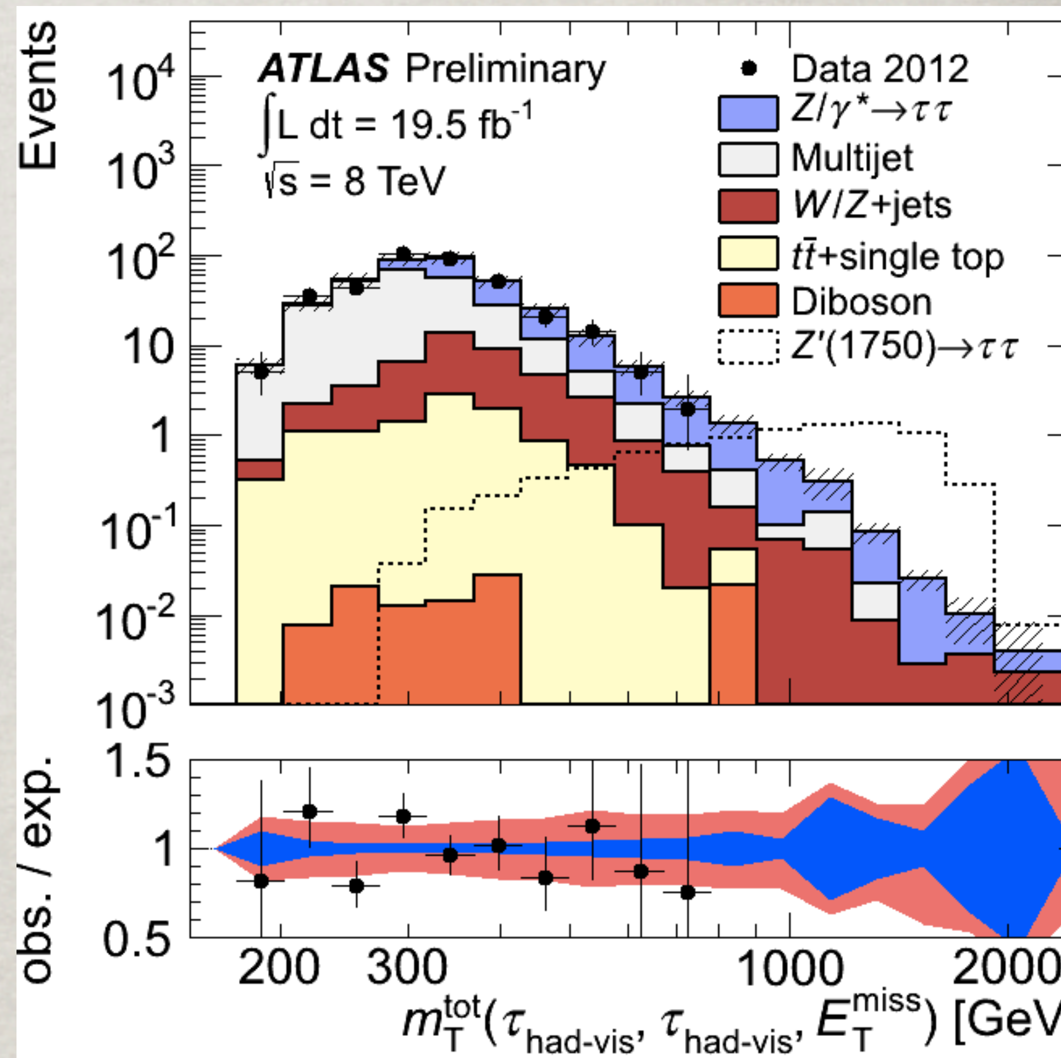
    - Single-tau trigger with E_T threshold of 125 GeV

    - Primary vertex with at least four associated tracks, each with $p_T > 0.5$ GeV

- BG: $Z/\gamma^* \rightarrow \tau\tau$, W+jets, $t\bar{t}$, diboson, Wt and s-channel single top events

Event selection

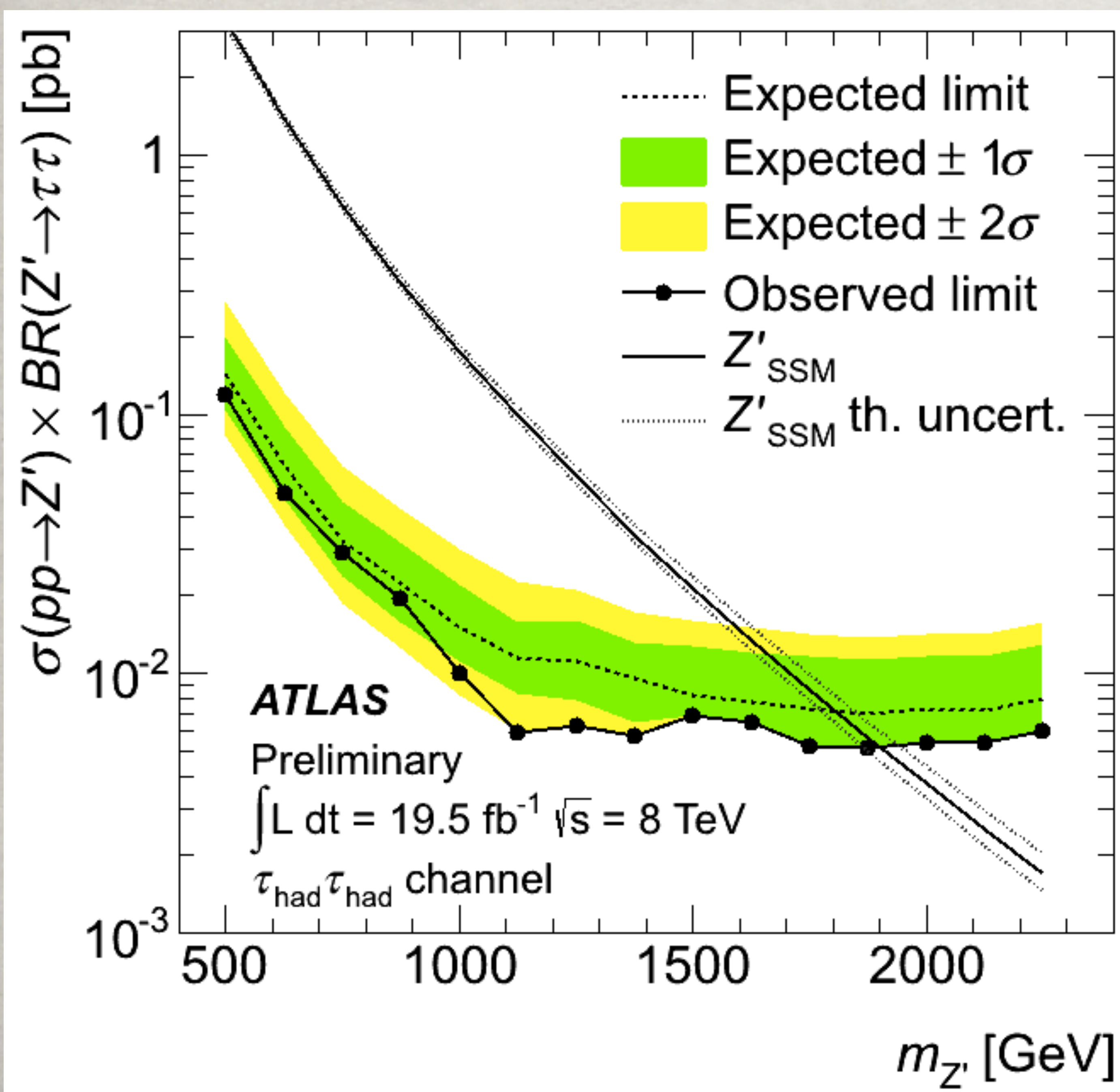
- ***Hadronic tau*** decays are defined as reconstructed jets with either **one** or **three** associated **tracks** reconstructed in the inner detector
- Hadronic tau decays are identified with a multivariate algorithm that employs BDTs to discriminate against quark and gluon-initiated jets using shower shape and tracking information; the taus must pass a loose BDT tau ID
- Tau candidates: $p_T \geq 50$ GeV & to be within $|\eta| < 2.47$ (with $1.37 < |\eta| < 1.52$ excluded)
- The analysis vetoes electrons and muons:
  - e-candidates: pass electron veto, $p_T > 15$ GeV and $|\eta| < 2.47$
  - μ-candidates: $p_T > 10$ GeV and $|\eta| < 2.5$
- Jets are reconstructed using the anti-k_t algorithm (R=0.4), $p_T > 30$ GeV and $|\eta| < 4.5$
- Events must contain ≥ 2 tau candidates and no electrons or muons, with the leading tau $p_T > 150$ GeV
- Taus are expected back-to-back with $\phi(\tau_1, \tau_2) > 2.7$.



Results

ATLAS-CONF-2013-066

- No significant excess observed
- A lower limit on the mass of a Z'_{SSM} decaying to $\tau_{had}\tau_{had}$ in the Sequential Standard Model is 1.90 TeV at 95% CL.



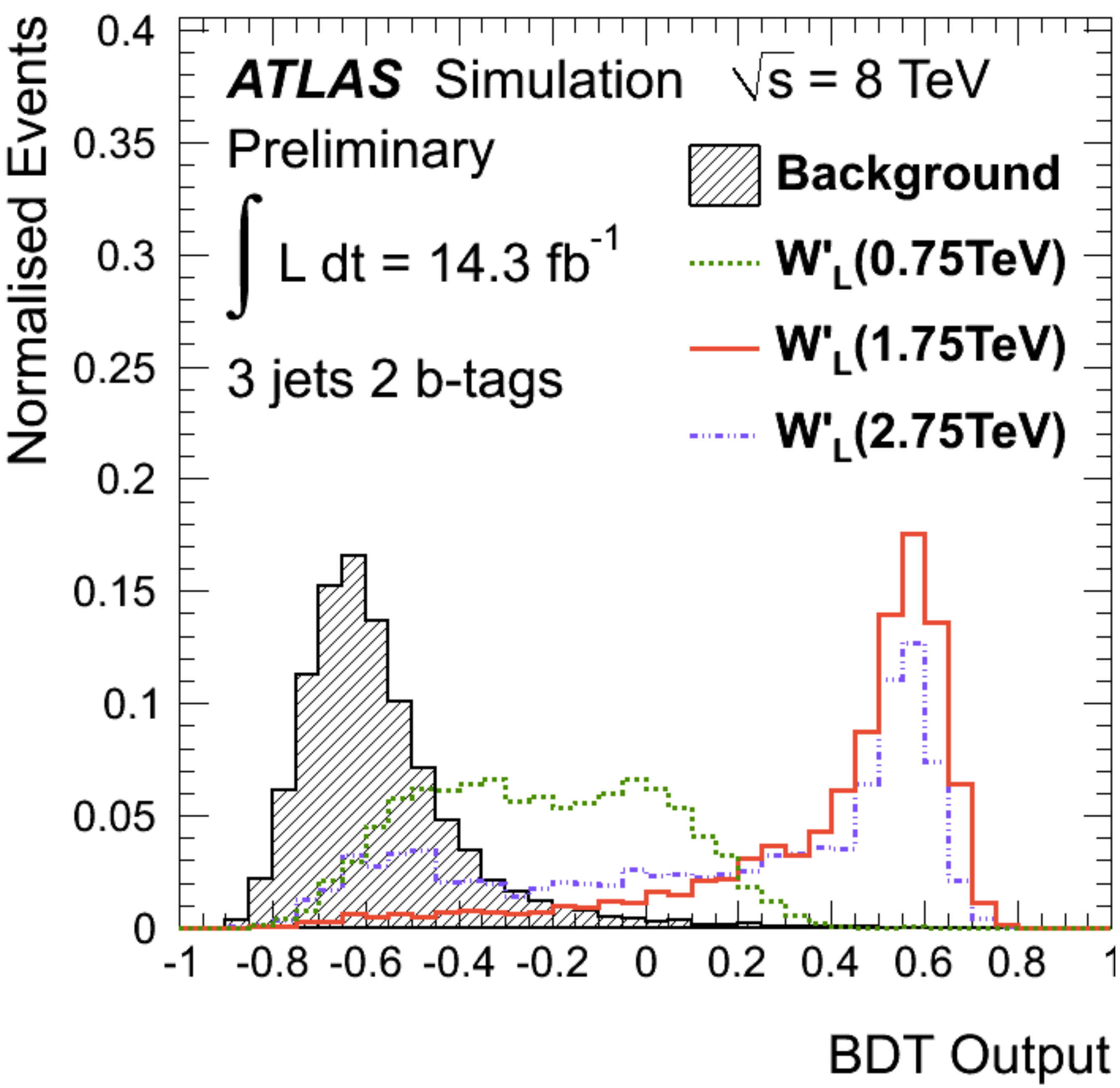
The earlier result in the hadronic tau channel for this search placed limits at 1.4 TeV.

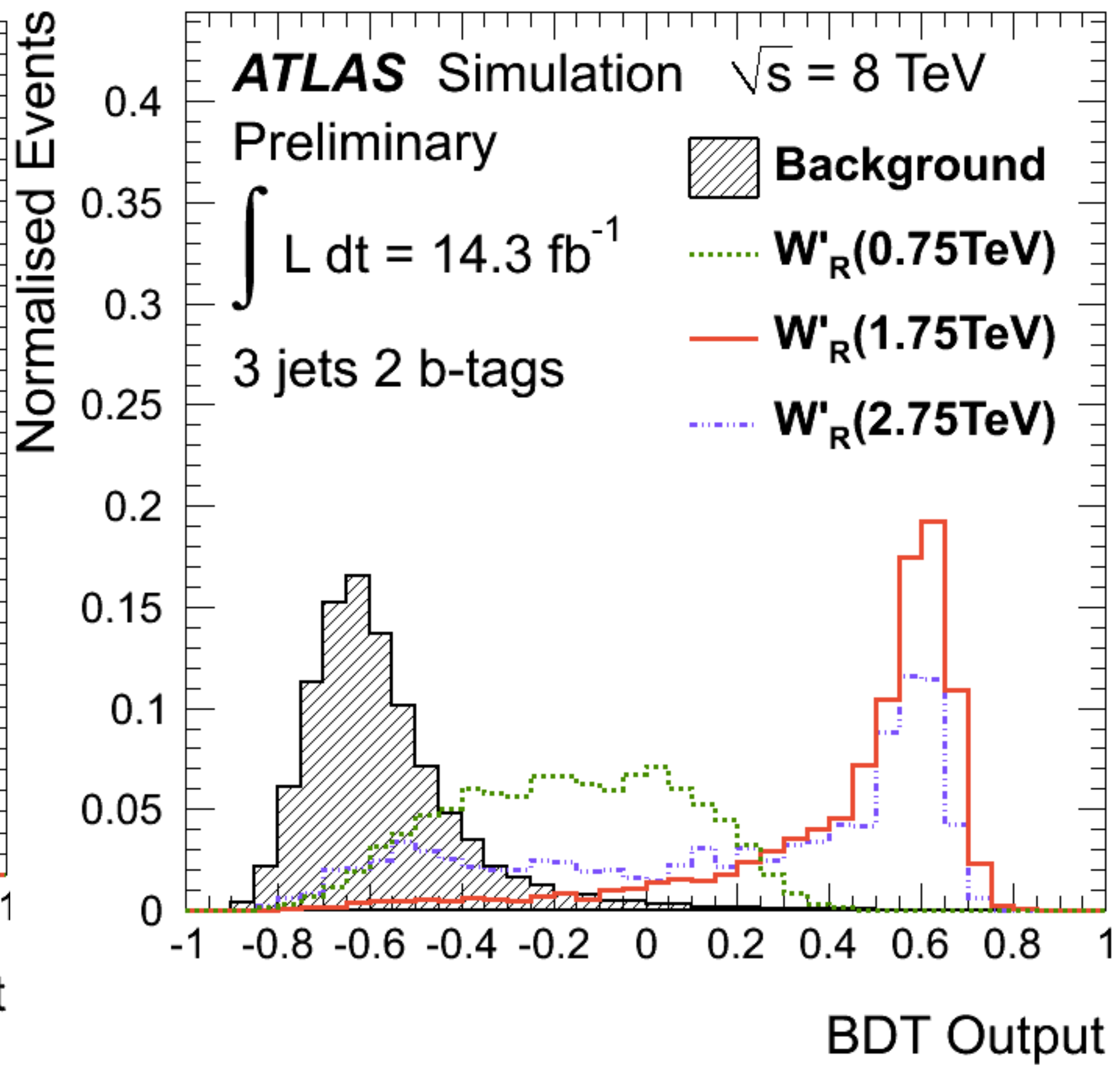
Summary

- No hints of new physics yet for resonances decaying to third generation leptons and quarks
  - We are pushing the limits into the multi-TeV scale with the current data set
- Latest results using the full luminosity from 2012 @ 8 TeV
- Run 2 will indeed be a very exciting period, with the increased beam energy and luminosity → expect surprises

Back-up Slides

• Expected BDT output distributions for the background and several W'_L/W'_R-boson processes in the 3-jet signal region (ATLAS-CONF-2013-050)

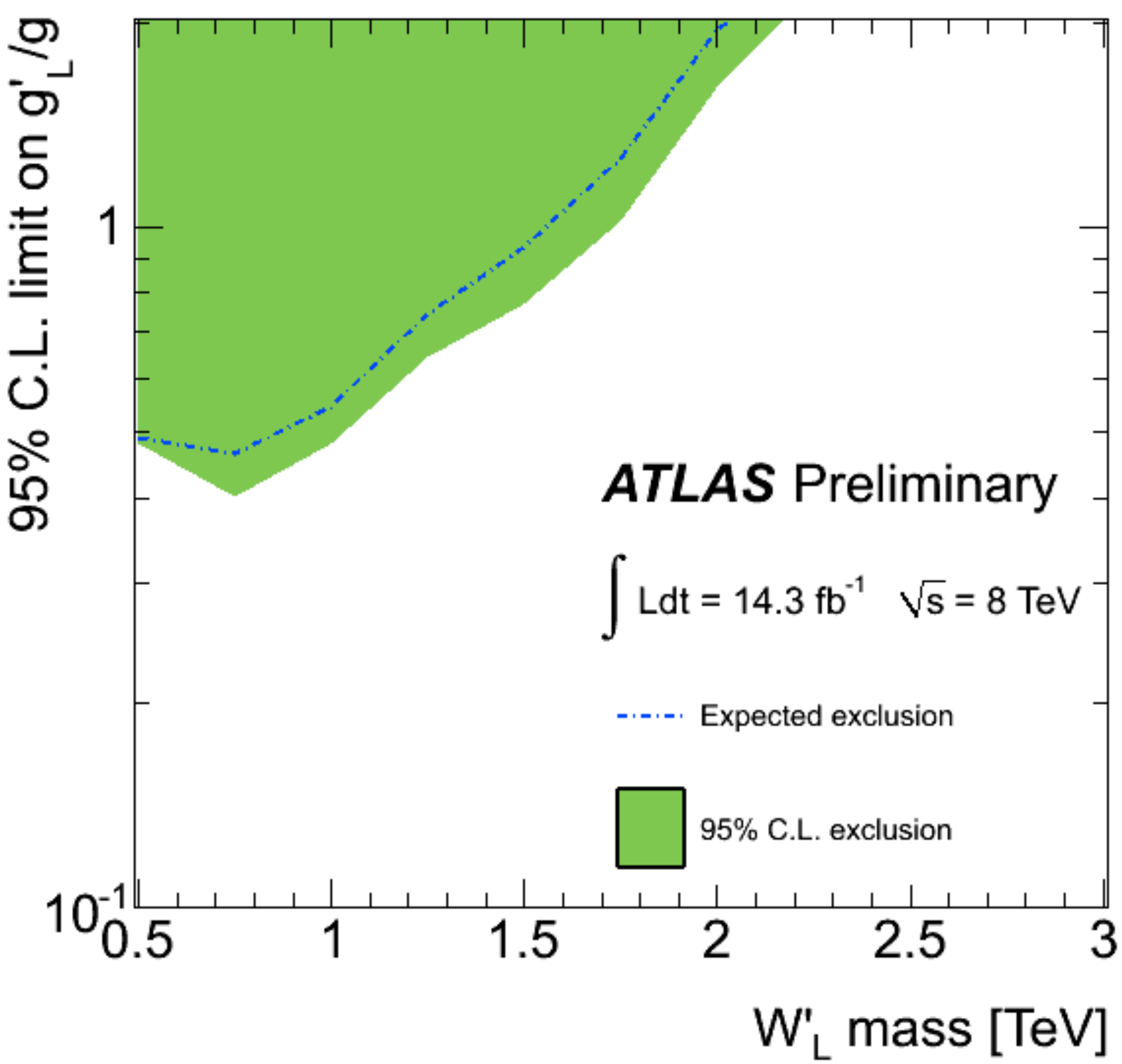


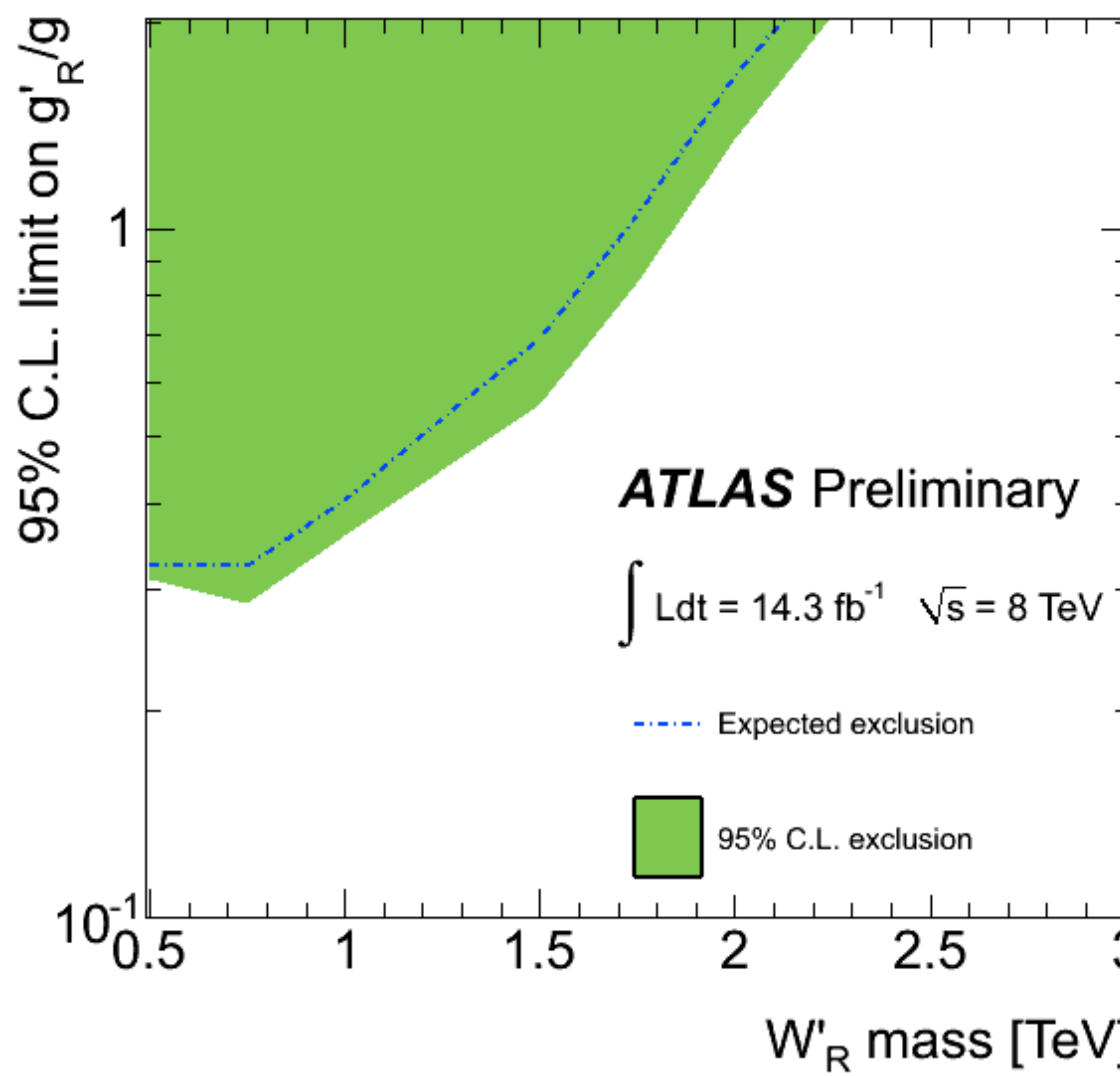


•Data and expected BG events in the signal region. Event yields for several mass hypotheses of the R-handed W' boson shown. The uncertainties account for all systematic effects. (**ATLAS-CONF-2013-050**)

	2-jet 2-tag channel	3-jet 2-tag channel
W'_R (0.5 TeV)	11800 ± 2700	8200 ± 1800
W'_R (1.0 TeV)	600 ± 150	660 ± 160
W'_R (1.5 TeV)	42 ± 11	56 ± 13
W'_R (2.0 TeV)	4.2 ± 1.1	6.2 ± 1.5
W'_R (2.5 TeV)	0.69 ± 0.17	0.87 ± 0.20
W'_R (3.0 TeV)	0.22 ± 0.06	0.25 ± 0.06
$t\bar{t}$	8300 ± 2100	22000 ± 5000
Single-top t-channel	1000 ± 270	1400 ± 400
Single-top Wt	400 ± 80	880 ± 170
Single-top s-channel	310 ± 90	160 ± 50
W+jets	3600 ± 1900	4000 ± 5000
Diboson	130 ± 60	80 ± 40
Z+jets	26 ± 20	42 ± 30
Multijets	710 ± 350	410 ± 210
Total bkg.	14400 ± 3100	29000 ± 7000
Data	14138	27759

• Observed and expected 95% CL limits on the ratio g'/g, as a function of the mass of the W' boson, for L- and R-handed W' bosons (ATLAS-CONF-2013-050)



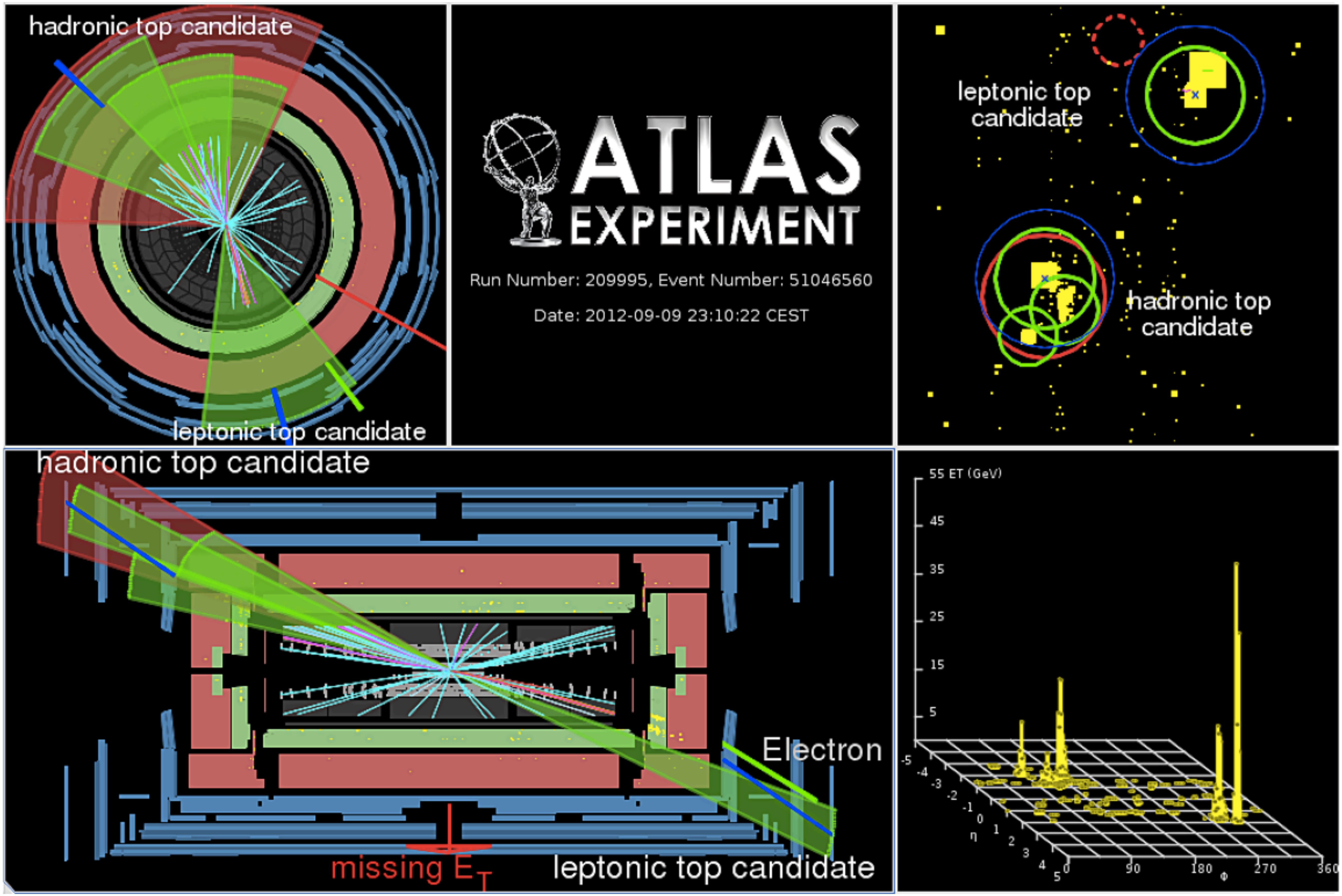


Data and expected background event yields after the resolved and boosted selections (ATLAS-CONF-2013-052)

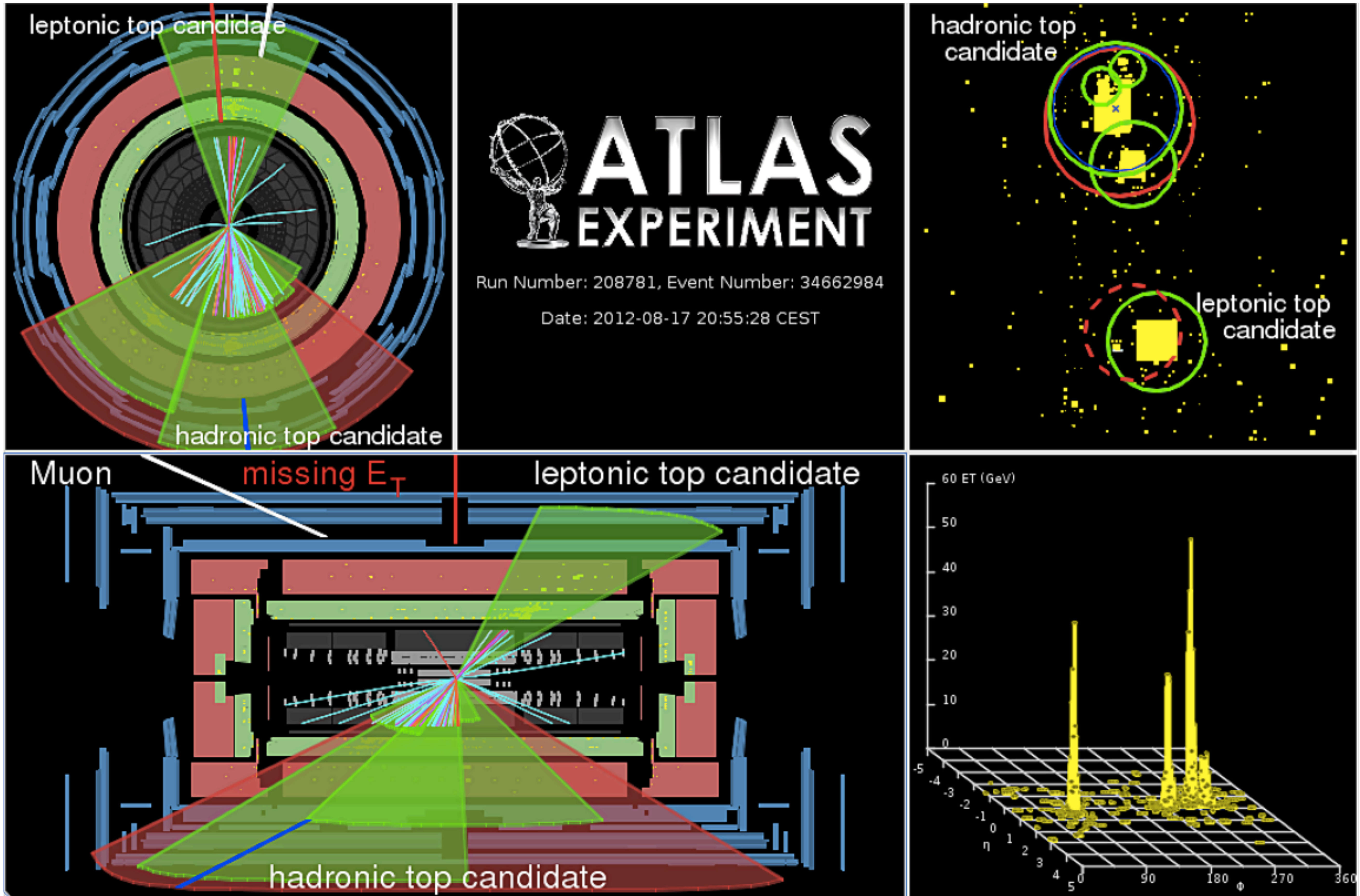
Resolved selection			
Type	e+jets	μ+jets	Sum
$t\bar{t}$	94000 ± 15000	118000 ± 19000	211000 ± 33000
Single top	6800 ± 800	8400 ± 1100	15200 ± 1900
Multi-jet	3700 ± 1800	10000 ± 5000	14000 ± 6000
W+jets	16000 ± 4000	23000 ± 6000	39000 ± 10000
Z+jets	1800 ± 400	1800 ± 400	3600 ± 800
Di-bosons	230 ± 50	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

Event display for $m_{tt}^{reco} = 2.6$ TeV e+jets $t\bar{t}$ candidate event



Event display for m_{tt}^{reco} = 2.5 TeV μ+jets $t\bar{t}$ candidate event



Systematic errors for the $\tau_{had}\tau_{had}$ resonance search

(ATLAS-CONF-2013-066)

	$Z/\gamma^* \to \tau\tau$	Multijet	W/Z+jets	Diboson	SM total	$Z'_{SSM}(1750)$
Expected Events	0.99 ± 0.02	0.17 ± 0.09	0.18 ± 0.03	0.02 ± 0.02	1.36 ± 0.10	5.58 ± 0.14
Theory Cross Section [%]	$^{+9}_{-6}$	–	± 28	± 13	$^{+7}_{-6}$	–
Luminosity [%]	± 2.8	–	± 2.8	± 2.8	± 2.5	± 2.8
Tau trigger [%]	± 10	–	< 1	–	± 7	± 10
Tau ID [%]	± 13	–	± 5	± 5	± 10	± 13
Tau 3-prong [%]	± 4	–	< 1	–	± 3	± 4
Jet-to-tau fake-rate [%]	< 1	–	± 61	± 60	± 9	< 1
Tau energy scale [%]	± 12	–	± 5	–	± 9	± 2
Jet energy scale [%]	< 1	–	$^{+1}_{-5}$	–	< 1	< 1
E_T^{miss} [%]	< 1	–	$^{-3}_{+0.2}$	–	< 1	< 1
Multijet fake-factor [%]	–	± 58	–	–	± 7	–