Search for 4th generation quarks with same-sign dilepton events in $4.7\,\mathrm{fb}^{-1}$ pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ with the ATLAS detector

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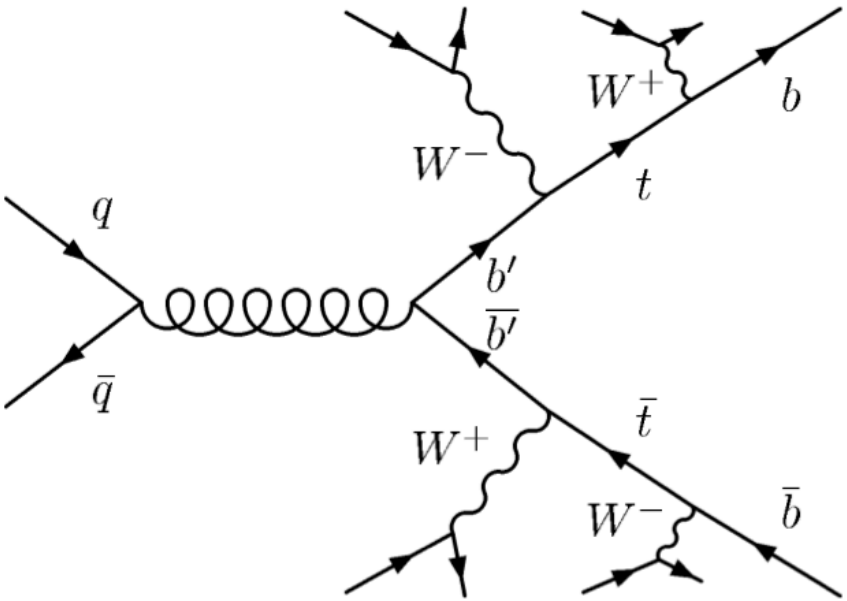
FSP 101 ATLAS

GRADUIERTEN KOLLEG
Masse-Spektrum-Symmetrie

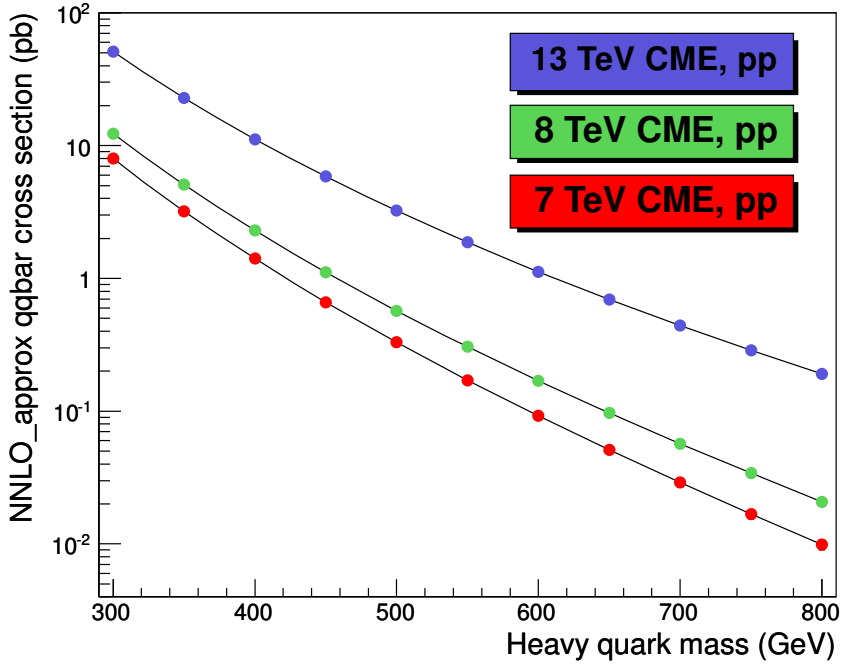
Contents

Fourth generation down-type quark (b')

- Looking for pair production of chiral 4th generation quarks as simple SM extension
- Consider decay: $b' \to tW^- \to bW^+W^-$ (100% BR)
- Could play interesting role in EW symmetry breaking
- Allows for gauge coupling unification in non-SUSY GUT



Production and decay



Production cross-section (HATHOR)
Comput.Phys.Commun.182:1034-1046,2011

- We study events with two same-sign charged leptons in the final state
  $\hookrightarrow$ rare SM signature
  $\hookrightarrow$ possible contributions from BSM physics

The considered decay $b' \to tW \to bWW$ leads to final states involving top quarks and can result in events with

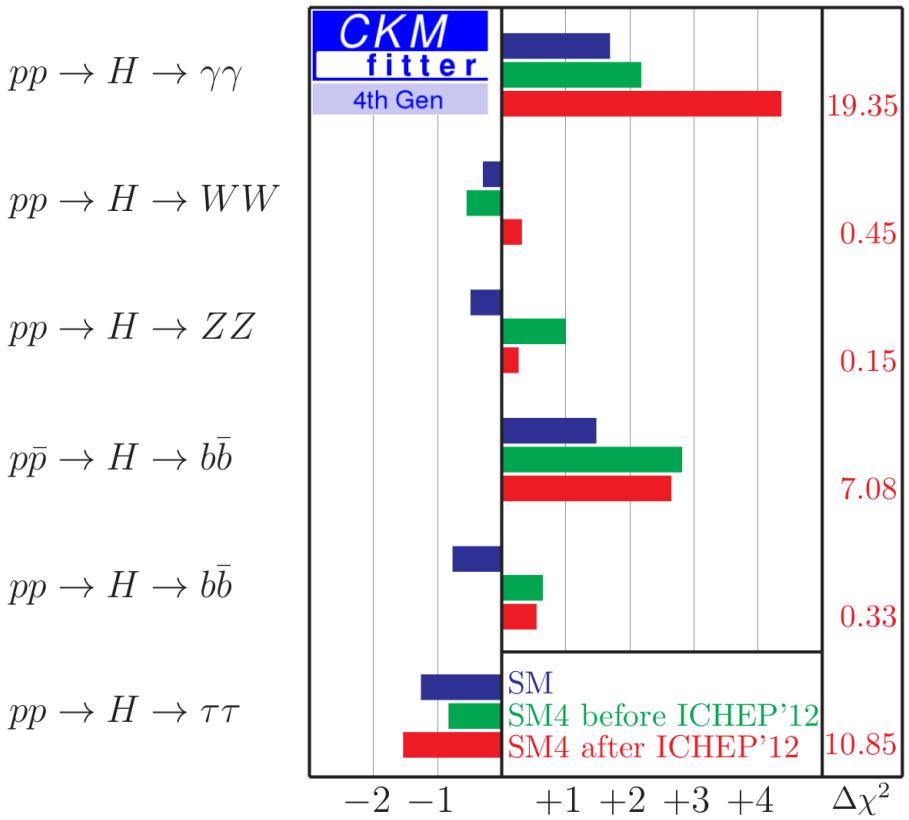
- two same-sign charged leptons
- 2 or more jets (and b-jets)
- high $\not{E}_T$ and H_T ($H_T = \sum P_T^{\text{Leptons}} + \sum P_T^{\text{Jets}}$)

- The analysis is perfomed on the **full 2011 data set ($4.7\,\text{fb}^{-1}$)**
- Part of CONF note (ATLAS-CONF-2012-130):
  "Search for exotic same-sign dilepton signatures (b′ quark, $\mathbf{T_{5/3}}$ and 4-tops production) in $4.7\,\text{fb}^{-1}$ of pp collisions at $\sqrt{s} = 7\,\text{TeV}$ with the ATLAS detector"

Implications from Higgs searches

- Within SM4: would observe
  - different Higgs decay BF
  - higher Higgs production cross section in gluon fusion (factor ≈ 9)

- $\hat{\mu}_{\text{exp/fit}}$:
  Measured/fitted signal strength assuming SM3 or SM4 (before/after ICHEP12)
- Shown: $\left[\frac{\hat{\mu}_{\text{exp}} - \hat{\mu}_{\text{fit}}}{\Delta\hat{\mu}_{\text{exp}}}\right]$
- All channels combined:
  SM4 excluded at 5.3σ!



arXiv:1209.1101 (accepted by PRL)

Search topology still interesting

- 4th generation still possible with other models, e.g. 2-Higgs doublet
- VLQ has similar topology
  $\rightarrow$ same search strategy

Background processes with same-sign dileptons in the final state:

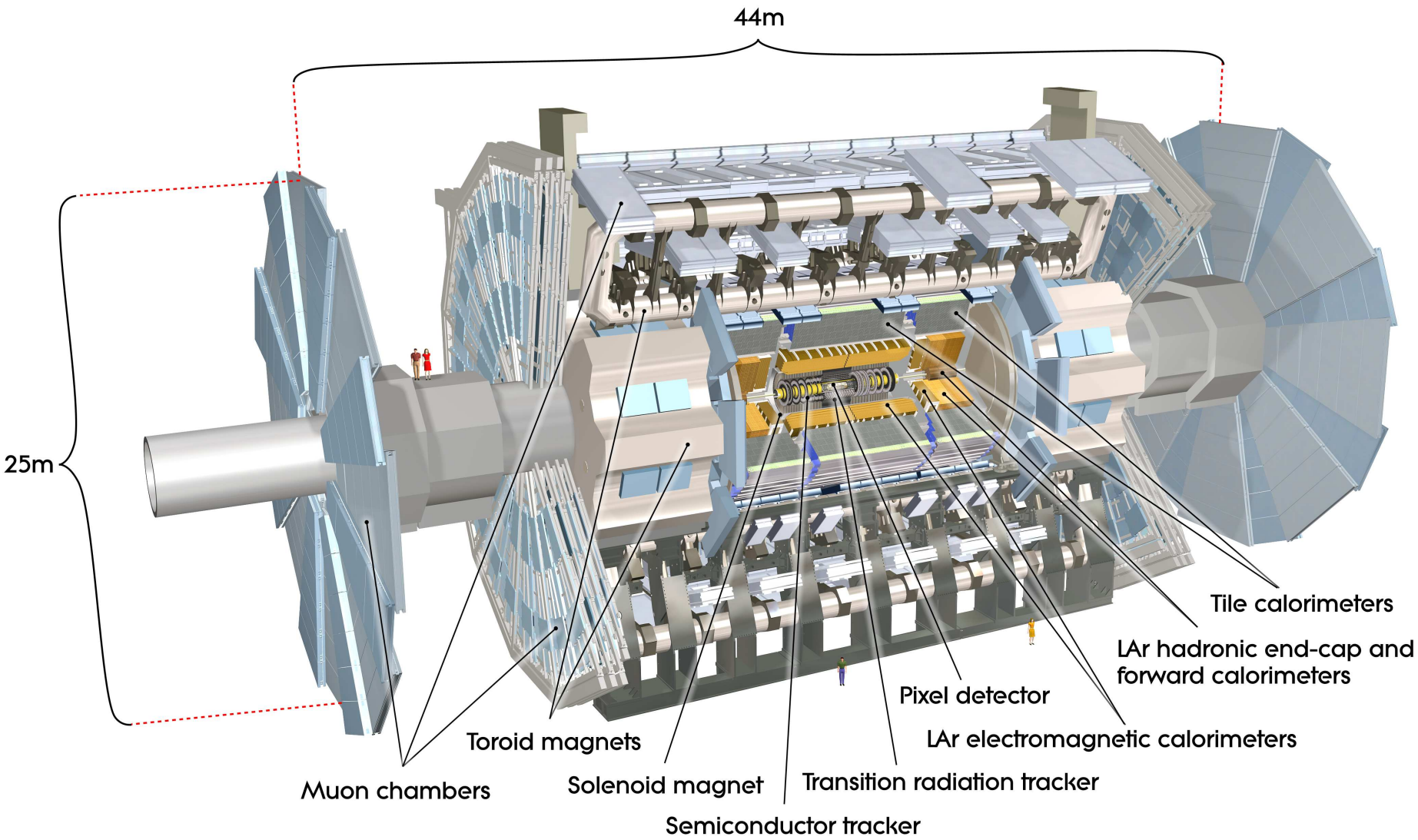
Irreducible backgrounds (MC)

- Diboson WZ/ZZ+jets (Alpgen)
- Diboson $W^{\pm}W^{\pm}$+jj (MadGraph)
- $t\bar{t} + W(+\text{j})$, $t\bar{t} + Z(+\text{j})$, $t\bar{t} + WW$ (MadGraph)

Charge MisId and lepton fakes (data-driven)

- Electron charge mis-identification (Charge MisId)
  - measuring Charge MisId rate in same-sign events within Z-peak
  - reweight OS events and treat as SS
- Lepton mis-reconstruction (Fakes)
  - using "matrix-method"
  - measuring fake efficiencies in fake enriched control regions

$\rightarrow$ more information in backup


44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Transition radiation tracker
Muon chambers
Solenoid magnet
Semiconductor tracker

Electrons

- $p_t > 25\,\mathrm{GeV}$
- $0 < \eta < 2.47$, excluding $1.37 < |\eta| < 1.52$
- Cluster based reconstruction algorithm
- Reject electrons with $\Delta R(e, jet) < 0.4$
- Isolated
- Recalibration + smearing

Muons

- $p_t > 20\,\mathrm{GeV}$ and $|\eta| < 2.5$
- Combined muon (ID+MS)
- Reject cosmic muons
- Remove muons with $\Delta R(\mu, jet) < 0.4$
- Isolated
- Smearing

Jets

- Anti-k_T Topo jets ($\Delta R = 0.4$)
- $p_t > 25\,\mathrm{GeV}$ and $|\eta| < 2.5$
- Remove the closest jet to an accepted electron.
- Recalibration (+ smearing for MC).

Event preselection

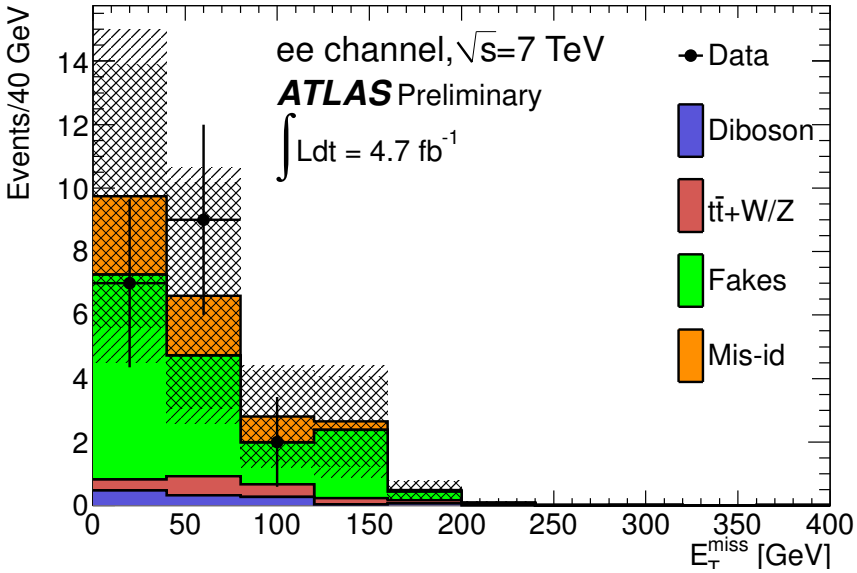
- Single lepton trigger & Good Run List (data)
- Primary vertex with at least 5 tracks ($P_T \geq 400\,\mathrm{MeV}$)
- Cosmic rejection and e/μ overlap rejection
- Invariant mass ($ee/\mu\mu$ events)
  - Z-veto: $|m_{inv} - m_Z| > 10\,\mathrm{GeV}$
  - $m_{inv} \geq 15\,\mathrm{GeV}$
- At least one trigger match

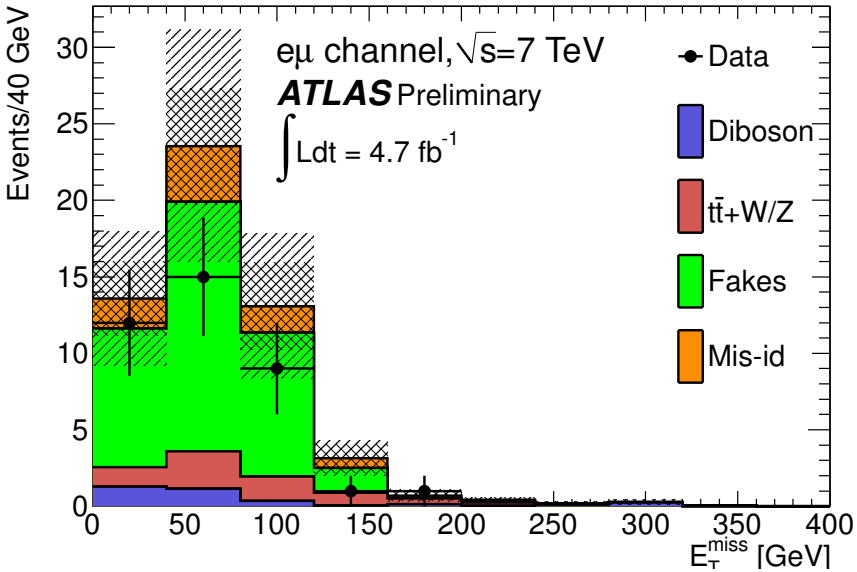
Additional selection (optimized, based on expected limit)

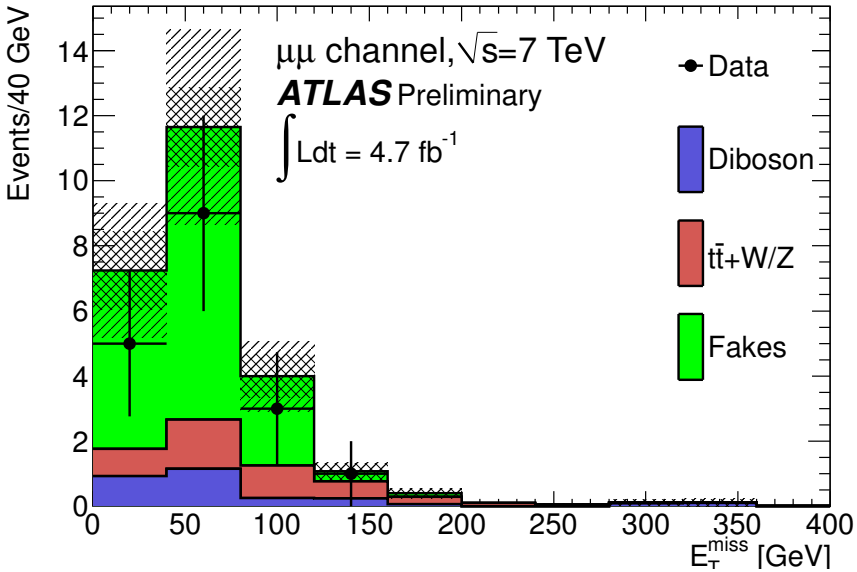
- At least two same-sign leptons, one with $P_T \geq 25\,\mathrm{GeV}$
  - Classification ($ee/e\mu/\mu\mu$) based on highest P_T pair
- $\not{E}_T \geq 40\,\mathrm{GeV}$, $H_T \geq 550\,\mathrm{GeV}$ ($H_T = \sum P_T^e + P_T^\mu + P_T^{\mathrm{Jets}}$)
- $N_{\mathrm{Jets}} \geq 2$, $N_{\mathrm{bJets}} \geq 1$ (b-tagging)

Control region

- **Same-sign dileptons**
- Event preselection
- No H_T cut
- No $\not{E}_T$ cut
- $N_{\text{Jets}} \geq 2$, $N_{\text{bJets}} \geq 1$







Considered systematics

- Electrons: energy scale/resolution, SF ($< 5\%$)
- Muons: energy scale/resolution, SF ($< 4\%$)
- Jets: JES ($< 16\%$), JER, reco eff., JVF SF, b-tag SF ($< 5\%$)
- $\not{E}_T$: Cell, PileUp ($< 1\%$)

- Luminosity: 3.7%
- Diboson (WZ/ZZ+jets) cross-section: 34%
- $W^{\pm}W^{\pm}$+2jets cross-section: 50%
- $t\bar{t} + W + j$ cross-section: 30%
- $t\bar{t} + Z + j$ cross-section: 50%
- $t\bar{t} + WW$ cross-section: $+35\%/-24\%$

- b' cross-section: HATHOR ($< 20\%$)
- PDF: $+1\%/-0.9\%$ estimated from reweighting method
- Parton shower: 6% estimated from More/Less PS samples

- Lepton fakes: $50\%/40\%/30\%$ ($ee/e\mu/\mu\mu$)
- QMisId: 12% estimated from difference between QMisId methods yields

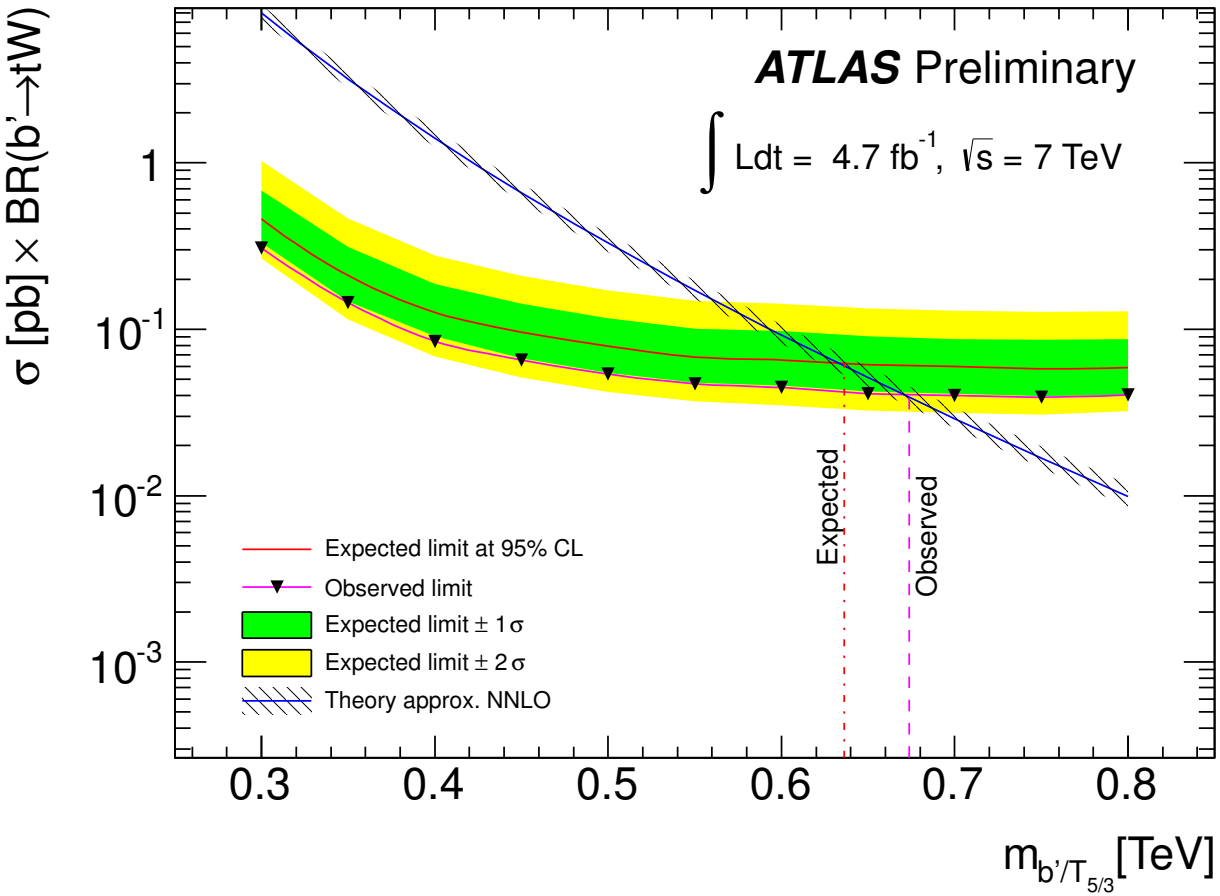
Expected yields and observed data in signal region

Samples	Channel		
	ee	eμ	$\mu\mu$
Mis-id	$0.13 \pm 0.04 \pm 0.02$	$0.23 \pm 0.04 \pm 0.03$	—
Fakes	$0.52 \pm 1.12 \pm 0.26$	$0.82 \pm 1.05 \pm 0.33$	$0.13 \pm 0.13 \pm 0.04$
Diboson			
• WZ/ZZ+jets	$0.19 \pm 0.20 \pm 0.07$	$0.34 \pm 0.21 \pm 0.13$	$0.28 \pm 0.22 \pm 0.10$
• $W^{\pm}W^{\pm}$+jj	$0.06 \pm 0.03 \pm 0.03$	$0.07 \pm 0.03 \pm 0.03$	$0.03 \pm 0.02 \pm 0.03$
$t\bar{t} + W/Z$			
• $t\bar{t}W$(+jet)	$0.23 \pm 0.02 \pm 0.07$	$0.79 \pm 0.04 \pm 0.24$	$0.57 \pm 0.04 \pm 0.18$
• $t\bar{t}Z$(+jet)	$0.17 \pm 0.02 \pm 0.09$	$0.61 \pm 0.03 \pm 0.31$	$0.33 \pm 0.02 \pm 0.17$
• $t\bar{t}W^{\pm}W^{\mp}$	$0.008 \pm 0.001 \pm 0.002$	$0.023 \pm 0.001 \pm 0.007$	$0.016 \pm 0.001 \pm 0.005$
Total	$1.31 \pm 1.14 \pm 0.29$	$2.88 \pm 1.07 \pm 0.53$	$1.36 \pm 0.26 \pm 0.27$
$b'(600\,\mathrm{GeV})$	1.78 ± 0.08	5.09 ± 0.14	3.29 ± 0.11
Observed	2	2	0

- Uncertainties shown (BG): yield $\pm$ stat. $\pm$ syst.
- Uncertainties shown (Signals): yield $\pm$ stat.

Limit determination

- CL_S method implemented in *MCLimit (Nucl.Instrum.Meth. A434,435 (1999))*
- Event yields from cut and count as input



$m_{b'} \geq 0.67\,\mathrm{TeV}$ (expected: $m_{b'} \geq 0.64\,\mathrm{TeV}$)

Summary

- Presented search for 4th generation b' quarks in same-sign dilepton final states
- Assuming decay $b' \to tW$ (100% BR)
- Using 2011 data set ($\mathcal{L} = 4.7\,\mathrm{fb}^{-1}$) at $7\,\mathrm{TeV}$
- Observed no excess $\to$ setting limit on b' mass:
  Expected: $m \geq 0.64\,\mathrm{TeV}$, Observed $m \geq 0.67\,\mathrm{TeV}$
- Analysis with 2012 data set has started

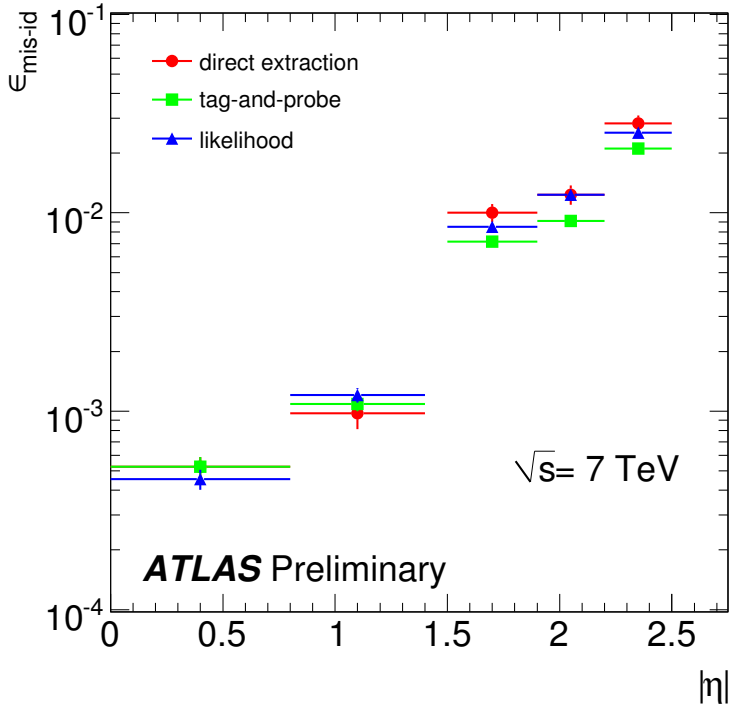
CONF note: ATLAS-CONF-2012-130

Backup slides

Charge mis-identification

Estimated by measuring the charge misidentification rate ϵ reconstructing a Z peak using 2 same-sign electrons in data.

- ϵ is computed as a function of $|\eta|$ bins for three different methods:
  1. Tag and Probe method.
  2. Direct extraction method.
  3. Likelihood method.
- A side-band method is used for the background subtraction:
  - The Z peak is divided in 3 parts: A, B, C on [61-81], [81-101] and [101-121] GeV.
  - Background is estimated in the A an C regions and interpolated to the region B.
- The number of signal events is $N_B^S = N_B - (N_A + N_C)/2$



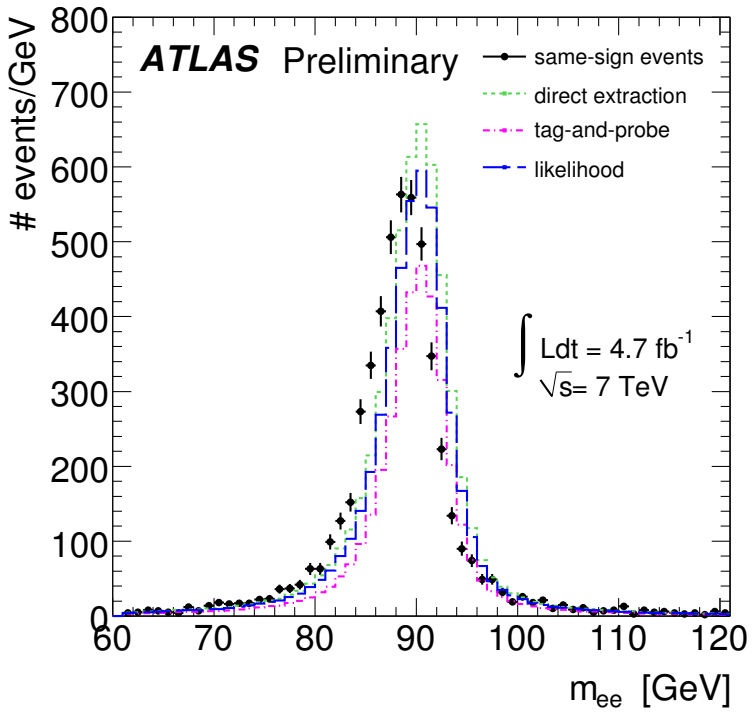
Differences on the rates comes from the kinematic selection

Charge mis-identification

- We take the $M_{e^+e^-}$ distribution for the opposite sign electrons.
- Each event is weighted with:

$$\omega(i,j) = \frac{\epsilon_i + \epsilon_j}{(1-\epsilon_i)(1-\epsilon_j)} \qquad (1)$$

  ϵ_i is the charge flip rate in the η bin i.
- The final same-sign distribution is obtained from $M_{e^+e^-}$ weighted with $\omega(i,j)$.
- Method validated by Egamma Working Group.
- Likelihood method is used to extract the event.
- The other two methods are used to compute the systematics.



Likelihood method gives the best agreement!

Lepton fakes

The matrix method is used to determine the magnitude of the mis-reconstructed leptons (from leptons or jets) in the dilepton signal regions.

- Electron and Muon real and fake rates are provided by LLMatrixMethodB and MuJetsMatrixMethodA from Top Group FakeMacros tools.

Two sets of leptons selection criteria are defined: Loose and Tight .

- Electrons:
  - Loose: isEM (MediumPP) + not match photons conversion + isolation.
  - Tight: Same definition than in the analysis.
- Muons:
  - Loose: TopCommon selection without muon isolation.
  - Tight: Same definition than in the analysis.

The probabilities r and f that a real or fake "Loose" lepton pass the "Tight" criteria is measured using purified control regions.

Lepton fakes

The composition of the signal samples is extracted by inverting the following matrix:

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

relating the "true" composition of the sample in terms of real and fake leptons to Tight and Loose leptons.

- Electrons: rates parametrized as a function of η and P_T of the electron.
- Muons: rates parametrized as a function of η of the muon and P_T of the leading jet.

Events that tend to have a charge misidentified electron (trident electrons) tend to also be identified as fakes in the matrix method:

The overlap between the charge misidentification and fakes ($\approx 22\%$) is measured, and this amount is used to rescale the final mis-id estimate.

Lepton fakes

- Electrons rate:
  - Signal efficiencies: determined with a Tag & Probe $Z^0 \to ee$ method with same cleaning as for top studies + overlap removal procedure applied with Loose leptons.
  - Fakes efficiencies: estimated in a sample with at least 1 jet ($P_T > 25$ GeV) and 1 Loose lepton + ΔR(leading jet, lepton)> 0.7 + overlap removal performed with loose electrons + $\not{E}_T < 20\,\mathrm{GeV}$.
- Muons rate:
  - Signal efficiencies: determined with a Tag & Probe $Z^0 \to \mu\mu$ method by selecting prompt muons from the Z decay.
  - Fake efficiencies: determined from data in a low transverse W mass region with an inverted triangular cut $M_T(W) < 20$ GeV, $\not{E}_T + M_T(W) < 60$ GeV.

Event selection optimisation

Cut optimisation

Starting with our preselection, we performed various studies to increase our sensitivity. We varied various parameters of our selection criteria with the goal of establishing a set of cuts that would give us strong expected limits for all signals.

- Optimised event selection cuts based on expected limit
- Investigated cuts on H_T and N_{Jets}

Event selection optimization

b' cut optimization

- Optimization based on expected mass limit
- Varied cuts on H_T and N_{Jets}
- Using full systematics in limit determination (listed later)

H_T [GeV] \ N_{Jets}	≥ 2	≥ 3	≥ 4	≥ 5
≥ 350	—	—	591.58	591.70
≥ 400	592.52	595.39	599.34	–
≥ 450	608.19	609.51	612.12	608.37
≥ 500	622.69	621.44	615.57	—
≥ 550	636.26	636.61	621.22	—
≥ 600	629.67	628.83	609.60	—
≥ 650	638.66	637.26	617.26	—

Expected b' mass limits in GeV
ATLAS work in progress

Event selection optimisation

Summary of optimised cuts

- $H_T \geq 550\,\mathrm{GeV}$
- $N_{\mathrm{Jets}} \geq 2$
- $N_{\mathrm{bJets}} \geq 1$

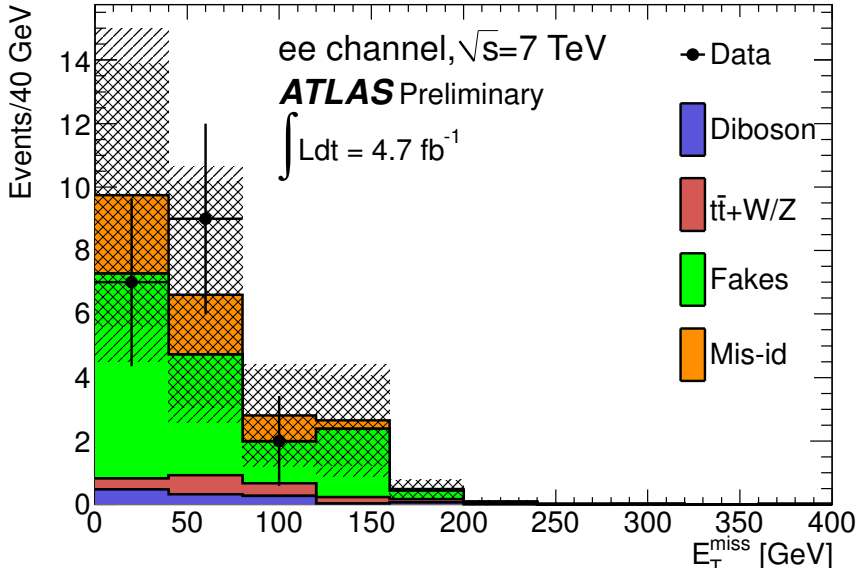
Control regions

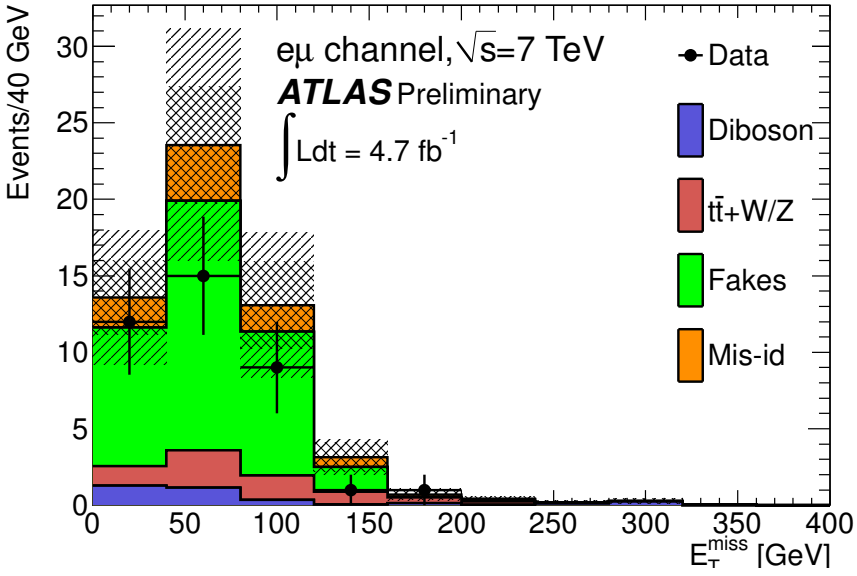
Control region 1

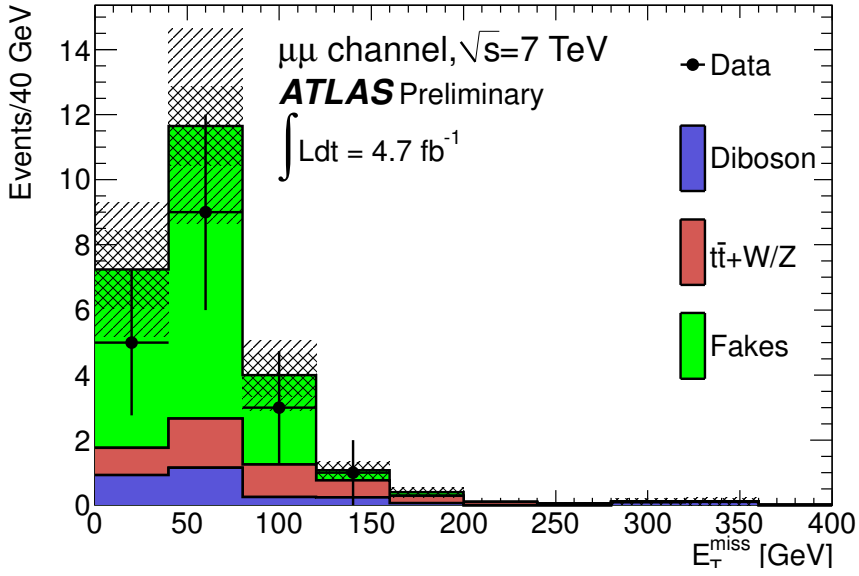
- Event preselection
- Same-sign dileptons
- $N_{\text{Jets}} \geq 2$, $N_{\text{bJets}} \geq 1$
- No cut on H_T (Loosened relative to signal region)
- No cut on $\not{E}_T$ (Loosened relative to signal region)

Control region 1

- **Same-sign dileptons**
- No H_T cut
- No $\not{E}_T$ cut
- $N_{\text{Jets}} \geq 2,\ N_{\text{bJets}} \geq 1$







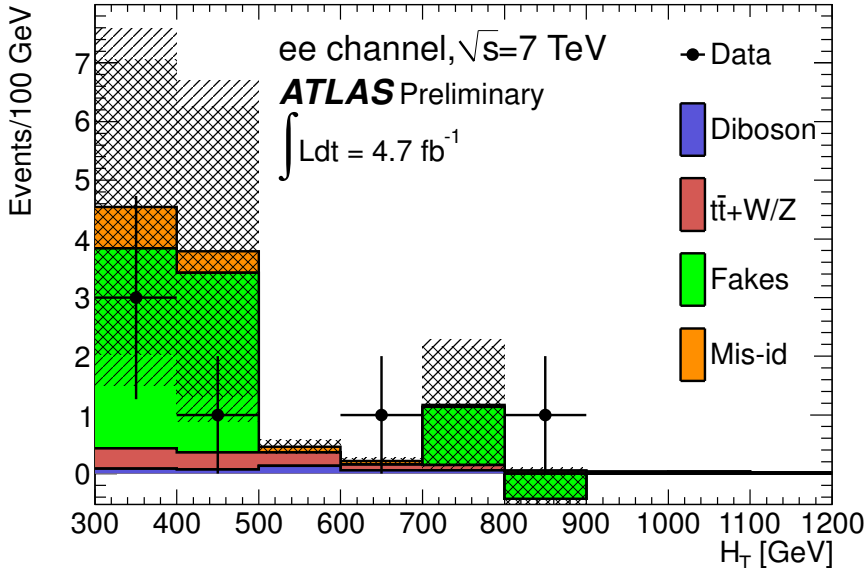
Control regions

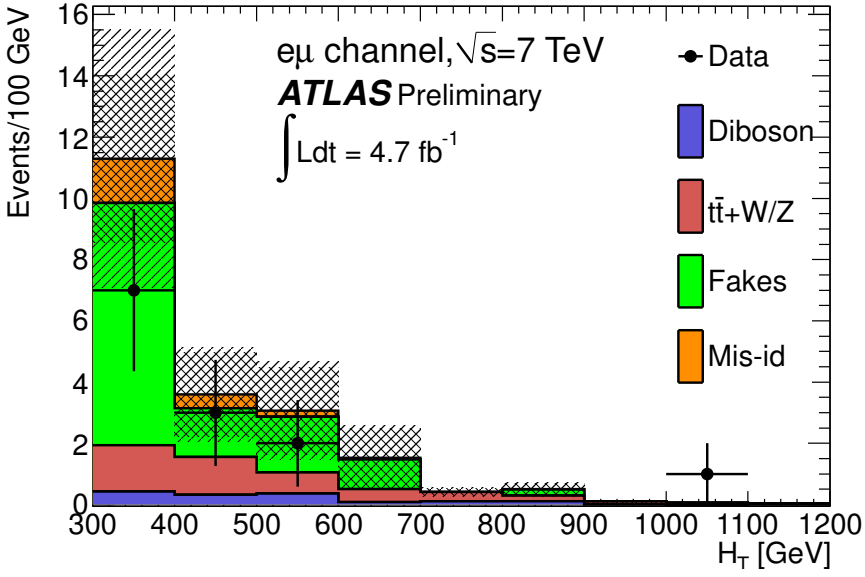
Control region 2

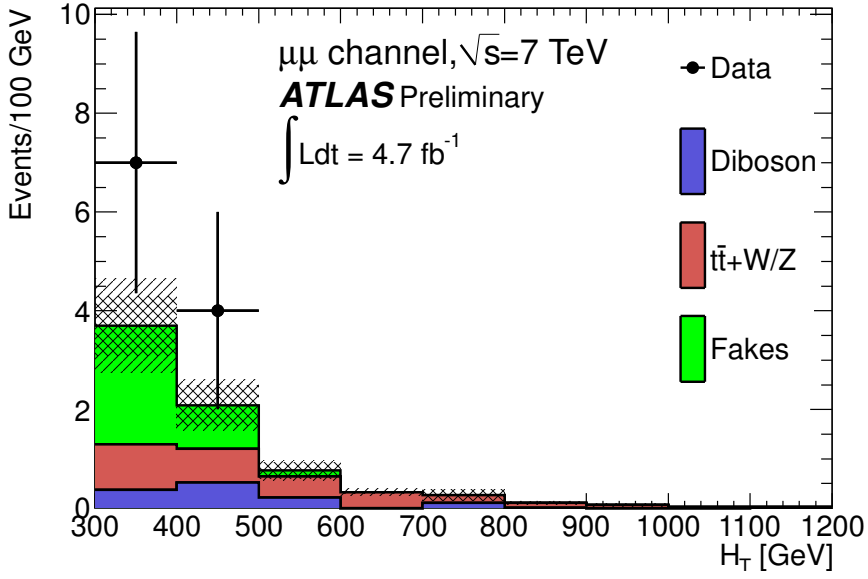
- Event preselection
- Same-sign dileptons
- $N_{\text{Jets}} \geq 2$, $N_{\text{bJets}} \geq 1$
- No cut on H_T (Loosened relative to signal region)
- $\not{E}_T \geq 40\,\text{GeV}$

Control region 2

- **Same-sign dileptons**
- No H_T cut
- $\not{E}_T \geq 40\,\mathrm{GeV}$
- $N_{\mathrm{Jets}} \geq 2,\ N_{\mathrm{bJets}} \geq 1$







Largest object systematics (Uncertainties in %)

Sys.	b' 500	550GeV $\lambda = 1$	FourTops	ttbar_W	ttbar_Z	ttbar_WW	WZ_ZZ	WWjj
				ee				
JES	3.0/-4.8	2.2/-2.8	4.2/-1.4	9.3/-10.4	6.3/-7.7	3.2/-8.1	15.9/-14.4	6.0/-6.0
BJET	0.0/-1.6	0.8/-0.3	1.3/0.0	3.5/-3.8	1.7/-3.7	0.0/-2.1	0.0/0.0	0.0/-3.4
JVF	2.9/-2.9	2.9/-2.9	4.0/-3.9	2.6/-2.6	2.8/-2.7	2.9/-2.8	1.7/-1.7	1.7/-1.7
MuTSF	0.1/-0.2	0.2/-0.3	0.2/-0.3	0.1/-0.2	0.0/-0.1	0.1/-0.2	0.0/0.0	0.0/0.0
ElIDSF	4.7/-4.7	4.7/-4.7	4.7/-4.7	4.7/-4.6	5.5/-5.4	4.7/-4.7	5.2/-5.1	4.5/-4.5
Others	2.2/2.6	2.3/2.2	3.7/2.3	3.1/4.9	2.9/2.6	2.7/2.6	3.6/3.4	2.0/2.0
				$e\mu$				
JES	3.4/-3.4	3.0/-2.7	0.8/-2.4	8.1/-8.8	10.8/-8.3	9.7/-8.0	13.4/-12.6	6.3/-7.9
BJET	0.7/-0.7	0.8/-1.0	1.0/-0.8	3.6/-2.6	1.9/-2.3	1.2/-1.5	0.0/0.0	0.0/0.0
JVF	3.0/-3.0	3.0/-2.9	4.0/-3.9	2.6/-2.5	2.7/-2.7	3.0/-2.9	1.6/-1.7	1.6/-1.6
MuTSF	1.5/-1.6	1.5/-1.6	1.4/-1.5	1.4/-1.5	1.6/-1.7	1.4/-1.5	1.8/-1.9	1.3/-1.4
ElIDSF	2.4/-2.5	2.4/-2.5	2.4/-2.5	2.3/-2.4	2.8/-2.8	2.3/-2.4	2.8/-2.9	2.2/-2.3
Others	1.6/1.4	1.5/1.5	1.4/1.5	1.7/1.6	2.1/2.0	1.5/1.4	3.9/2.8	1.8/1.3
				$\mu\mu$				
JES	2.2/-4.6	1.4/-1.3	0.0/-1.1	8.1/-9.9	5.4/-6.9	5.1/-4.0	6.0/-2.7	0.5/-10.9
BJET	0.0/-0.6	0.6/-0.8	0.0/-0.5	4.1/-0.9	1.8/-3.0	0.5/-1.8	0.0/0.0	0.0/0.0
JVF	2.9/-2.8	3.0/-3.0	4.0/-3.9	2.6/-2.6	2.6/-2.6	2.9/-2.9	1.7/-1.7	1.6/-1.6
MuTSF	2.8/-2.9	2.8/-2.8	2.8/-2.8	2.6/-2.7	3.4/-3.4	2.7/-2.7	3.5/-3.5	2.4/-2.5
ElIDSF	0.2/-0.4	0.2/-0.3	0.1/-0.2	0.1/-0.2	0.0/-0.1	0.2/-0.3	0.0/0.0	0.0/0.0
Others	1.7/1.9	1.7/1.7	1.7/1.8	2.4/1.8	2.5/2.6	1.8/1.8	6.7/4.9	3.5/3.4

ATLAS work in progress

Expected b' yields

Expected signal yields

Signal parameter	Channel		
Mass [GeV]	ee	$e\mu$	$\mu\mu$
b' pair production			
300	16.75 ± 2.17	77.78 ± 4.97	57.84 ± 4.33
350	16.78 ± 1.44	64.50 ± 2.88	36.20 ± 2.21
400	12.30 ± 0.83	41.85 ± 1.54	28.19 ± 1.29
450	8.05 ± 0.46	26.18 ± 0.85	16.25 ± 0.66
500	4.72 ± 0.20	15.84 ± 0.38	9.71 ± 0.30
550	2.83 ± 0.14	8.88 ± 0.25	6.34 ± 0.22
600	1.78 ± 0.08	5.09 ± 0.14	3.29 ± 0.11
650	0.98 ± 0.04	3.06 ± 0.08	2.00 ± 0.07
700	0.57 ± 0.03	1.84 ± 0.05	1.15 ± 0.04
750	0.36 ± 0.02	1.07 ± 0.03	0.66 ± 0.02
800	0.20 ± 0.01	0.61 ± 0.02	0.39 ± 0.01

- Uncertainties due to Monte-Carlo statistics are shown.

MCLimit

Limit determination

- CL_S method implemented in *MCLimit*
- Most suitable for low statistics

- Log-likelihood ratio (LLR) as test-statistic:

$$LLR = -2 \ln \frac{L_{s+b}}{L_b}$$

- Generation of pseudo-experiments (PSE)
- Considering uncertainties:
  - statistical fluctuations according to Poisson statistics
  - Gaussian fluctuations describing effect of systematic uncertainties
- CL_{s+b} and CL_b defined by PSE with $LLR > LLR_{\text{exp/obs}}$
- Signal cross sections are excluded at 95%CL for which

$$CL_S = \frac{CL_{s+b}}{CL_b} < 0.05$$