Measurement of the total *ZZ* production cross section in the four-lepton channel using 4.7 fb^{-1} of ATLAS data

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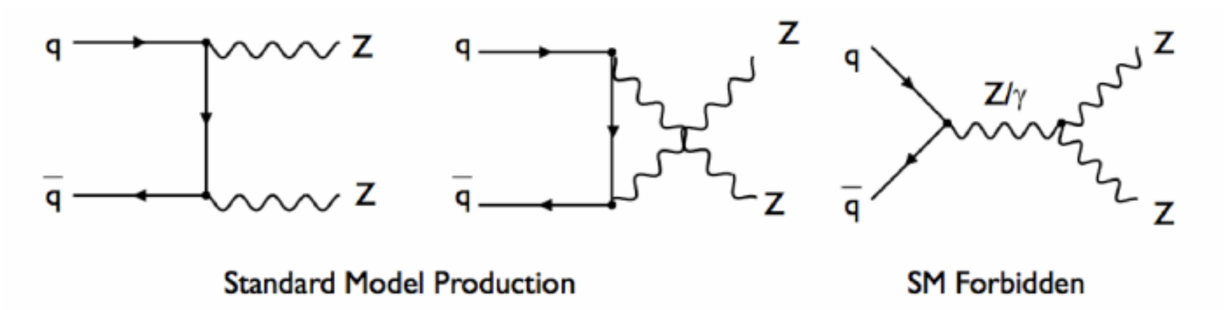
Introduction

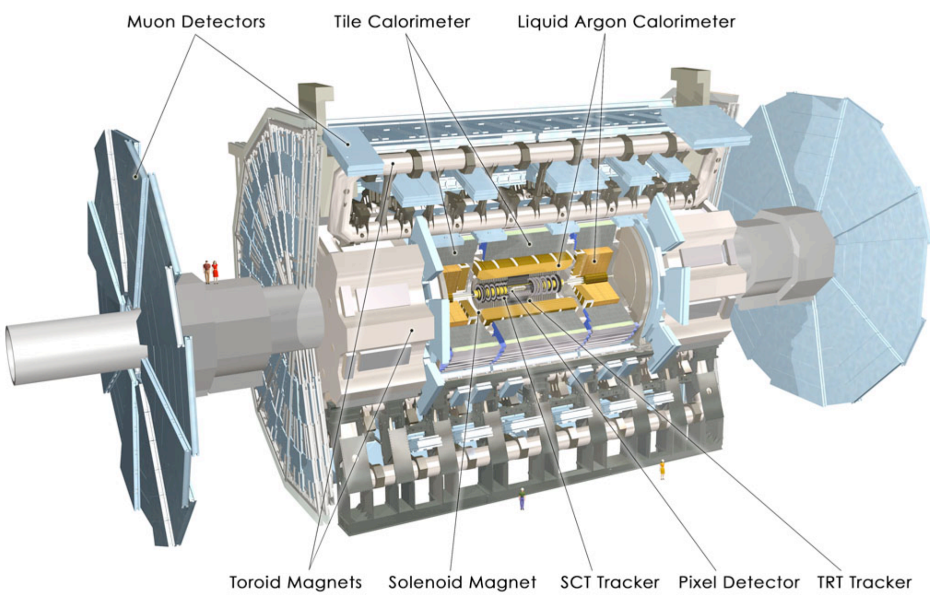
- ZZ production is a rare process but with striking signature and low background.
- An important probe of the structure of electroweak sector.
- The irreducible background to H->ZZ.
- Standard Model predicted cross section in the on-shell approximation is $6.5^{+0.3}_{-0.2}$ pb .
- I describe today a ZZ production cross section measurement in the four lepton (electron, muon) channel using the full dataset of 4.7fb^{-1} collected by ATLAS in 2011.
- The two LO SM diagrams are shown below left. Gluon-gluon fusion also contributes 6.3% of the cross section.



1fb^{-1} measurement: Phys. Rev. Lett. 108, 041804 (2012) http://arxiv.org/abs/1110.5016
4.7fb^{-1} measurement: ATLAS-CONF-2012-026 https://cdsweb.cern.ch/record/1430735

Detector and object selection

- Important detector systems for this measurement are the muon spectrometer, the inner tracking detector and the electromagnetic calorimeters.



Muons

- Combine Muon Spectrometer track or track segment with Inner Detector track.
- Kinematic acceptance: $|\eta| < 2.7$, $p_T > 7$ GeV

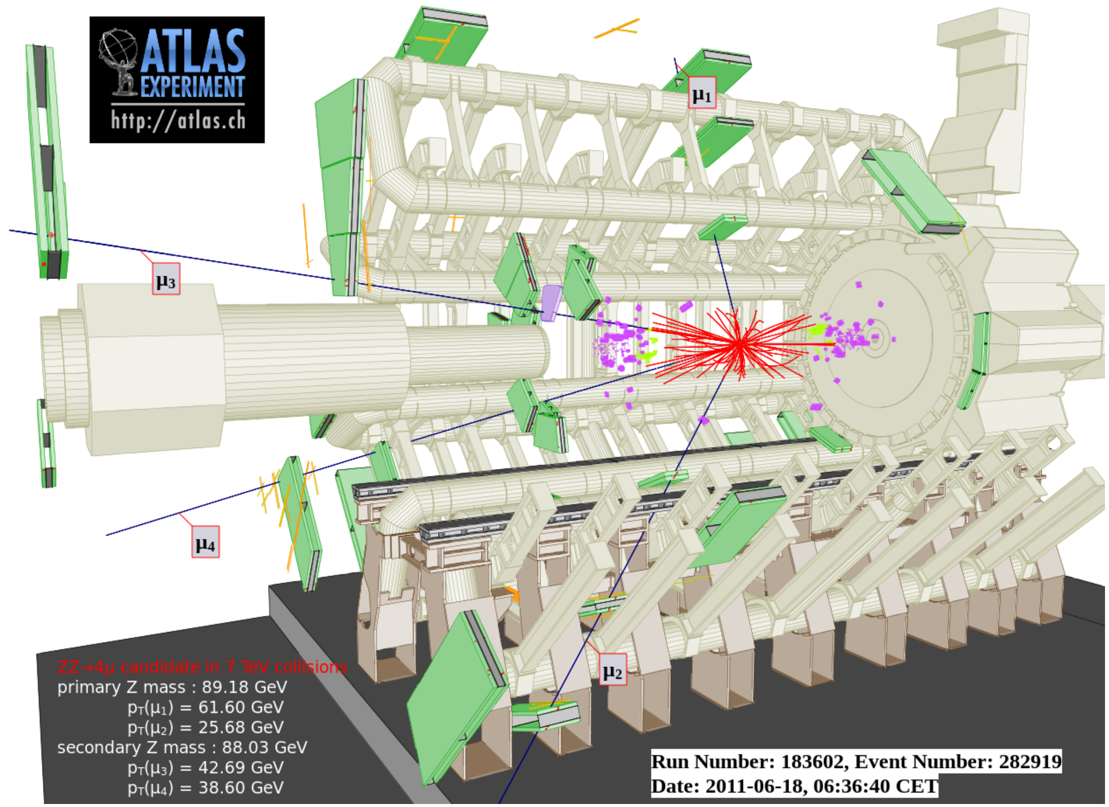
Electrons

- Combine EM Calorimeter cluster with Inner Detector track.
- Inner Detector tracks are fitted using a Gaussian Sum Filter to account for bremsstrahlung.
- Kinematic acceptance: $|\eta| < 2.47$, $p_T > 7$ GeV.

- Apply requirements to leptons on ID track isolation, calorimeter isolation and longitudinal and transverse impact parameters to reject fake leptons.
- Leading lepton must have $p_T > 25$ (20) GeV for electrons (muons).

Event Selection

- Trigger using single electron and muon triggers, with p_T thresholds 18-22 GeV.
- Select events with exactly four leptons passing the object selection described previously.
- Form two opposite-flavour same-sign pairs, choosing the pairing which minimises sum of distances from Z mass: $|m_{12}\text{-}m_Z|+|m_{34}\text{-}m_Z|$.
- Both pairs required to be on-shell: **66 < m_Z < 116 GeV**.



Display of a selected ZZ-> $\mu^+\mu^-\mu^+\mu^-$ event with $m^{4\mu}$ = 249.7 GeV and $p_T^{4\mu}$ = 22.0 GeV

Updates from 1fb^{-1} analysis

- Increase in statistics: 1fb^{-1} measurement extremely statistically limited:

$$\sigma_{ZZ}^{\mathrm{tot}} = 8.5^{+2.7}_{-2.3}(\mathrm{stat})^{+0.4}_{-0.3}(\mathrm{syst}) \pm 0.3(\mathrm{lumi})\ \mathrm{pb.}$$

- Reduced p_T threshold on the 2nd, 3rd and 4th leptons from 15 GeV to 7 GeV.
- Increased muon acceptance from $|\eta| < 2.5$ to $|\eta| < 2.7$
  - ✓ Increased signal acceptance by 6% overall.
- Moved to using electrons with tracks fitted using Gaussian Sum Filter to account for bremsstrahlung
  - ✓ Improves resolution of parameters in the bending plane.
- Used a re-optimised electron identification algorithm giving higher efficiency for similar fake rejection.
- Tightened impact parameter cuts
  - ✓ Increases heavy flavour background rejection with minimal loss of signal efficiency.

✓ Overall, signal acceptance increased by approximately 30%.

Background Estimate

- Main backgrounds are Z->l^+l^- with additional jets or photons, t-tbar, single-top and other diboson processes (WW, WZ). All involve one or more **fake leptons**.

In reality there are **True Leptons (T)** and objects that can **Fake Leptons (F)**, with a probability **f** for the fake object to be identified as a lepton.
The background is: $N_{4\ell}^{\text{fake}} = N_{TTFF} \times f \times f + N_{TTTF} \times f$

We can only actually *measure* the number of selected leptons (L) and number of lepton-like jets that fail one or two of the lepton ID cuts (J). We can measure *FF*, the ratio of "selected" leptons to "lepton-like" jets in data. The background estimate is then:

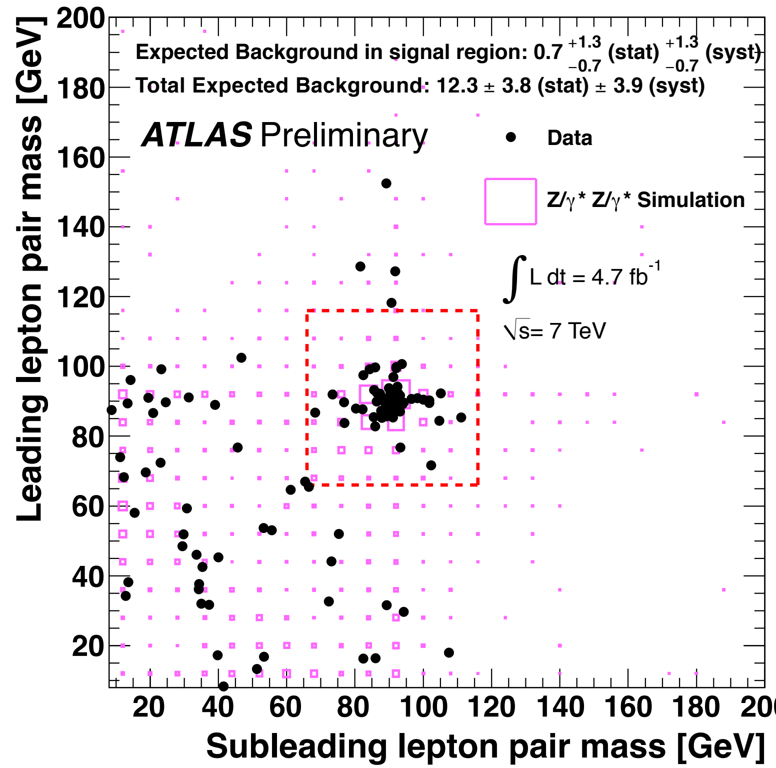
$$N_{4\ell}^{\text{fake}} = (N_{LLLJ} - N_{LLLJ}^{ZZ}) \times FF - N_{LLJJ} \times FF^2$$

<u>Fake factors are measured using a Z-tag method:</u>

- Tag an event by finding a good Z candidate
- Look for additional leptons in the event , categorize as **L** or **J**,
- Subtract the quantity of "real" leptons from WZ events using MC estimates.
- Parameterise *FF* in p_T and η .

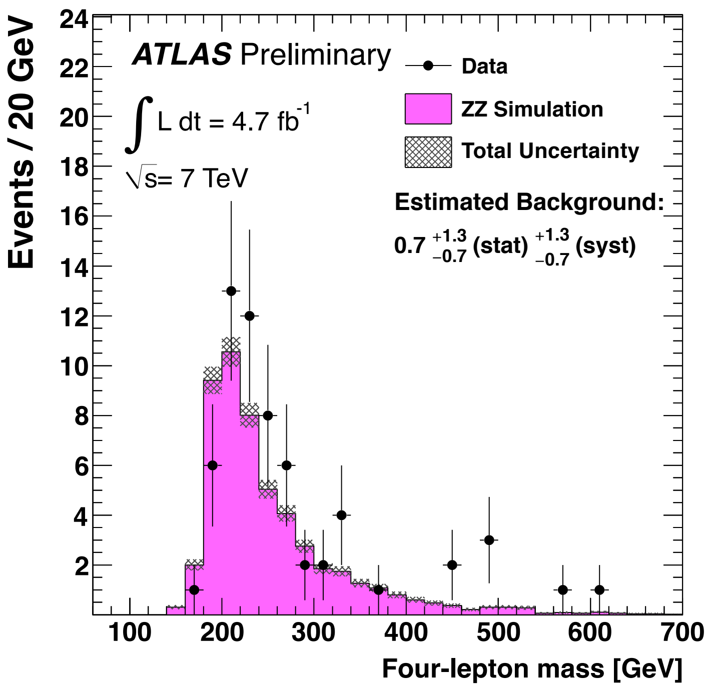
Observed Events

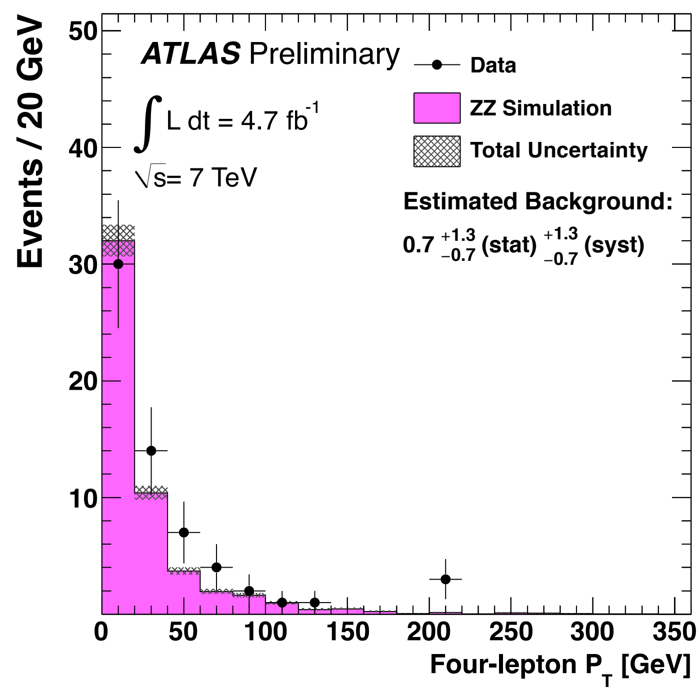
- We observe 62 events in $4.7 fb^{-1}$ of data.
  - Predicted background: $0.7^{+1.3}_{-0.7}$ (stat) $^{+1.3}_{-0.7}$ (syst)
  - Predicted signal (MC): 53.2 +1.1 (stat) ± 1.9 (syst)
- Sherpa (LO) used for signal predictions, scaled to predicted cross section of MCFM (NLO).
  - Cross checked with Pythia and gg2ZZ and found to be consistent.
- Dominant systematics arise from uncertainty on lepton identification efficiencies.
  - Evaluate using Tag and Probe measurements on large samples of Z->ll events.



Candidate distributions

- Invariant mass (left) and transverse momentum (right) of the four lepton system.
- Good agreement between data and Monte-Carlo.





Cross Section Measurement

- We first calculate a "fiducial cross section" in a phase space close to the experimental selection.
- This is extracted combining all four lepton channels and using a profile likelihood method, with systematic uncertainties included as nuisance parameters.
- We then extrapolate to the total cross section in the on-shell approximation, correcting for the acceptance of the fiducial cuts estimated using the MCFM NLO generator and the Z->ll branching ratios.

Fiducial Phase Space

- ZZ -> $l^+ l^- l^+ l^-$ (l= e, μ)
- 66 < m_{01} < 116 GeV
- 66 < m_{23} < 116 GeV
- p_T (lepton) > 7 GeV
- | η (lepton) | < 2.7

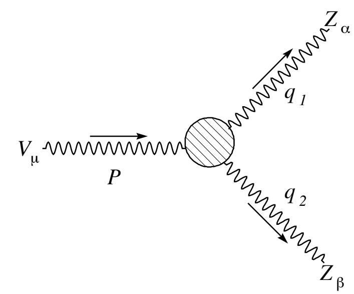
$$\sigma^{\text{fid}}_{ZZ\to\ell^+\ell^-\ell^+\ell^-} = 21.2^{+3.2}_{-2.7}\,(\text{stat})\,^{+1.0}_{-0.9}\,(\text{syst})\ \pm 0.8\,(\text{lumi})\ \text{fb}$$

$$\sigma^{\text{tot}}_{ZZ} = 7.2^{+1.1}_{-0.9}\,(\text{stat})\,^{+0.4}_{-0.3}\,(\text{syst})\ \pm 0.3\,(\text{lumi})\ \text{pb}$$

- Observed total cross section is consistent with the Standard Model cross section, calculated with MCFM and PDF set MSTW2008, of $6.5^{+0.3}_{-0.2}$ pb.

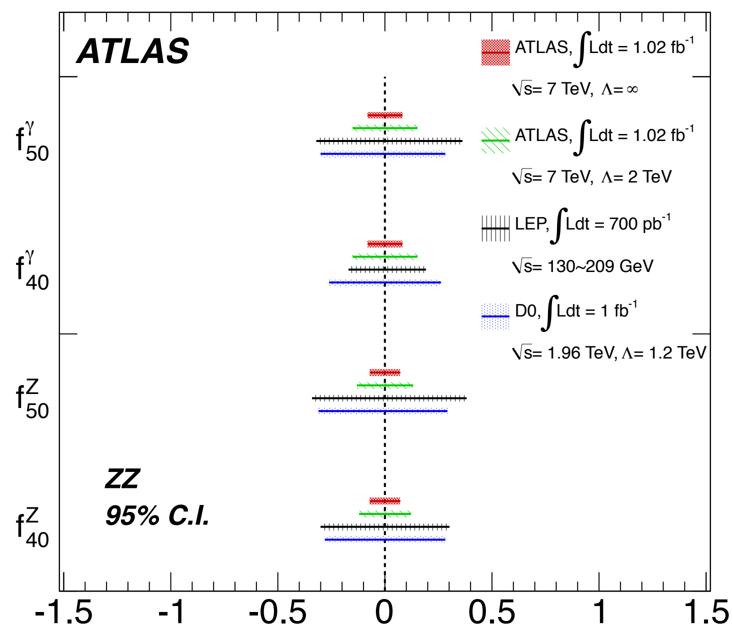
aTGC limits

$$\mathcal{L} = \frac{e}{m_Z^2}\left[f_4^V(\partial_\mu V^{\mu\beta})Z_\alpha(\partial^\alpha Z_\beta) + f_5^V(\partial^\sigma V_{\sigma\mu}\tilde{Z}^{\mu\beta}Z_\beta)\right]$$



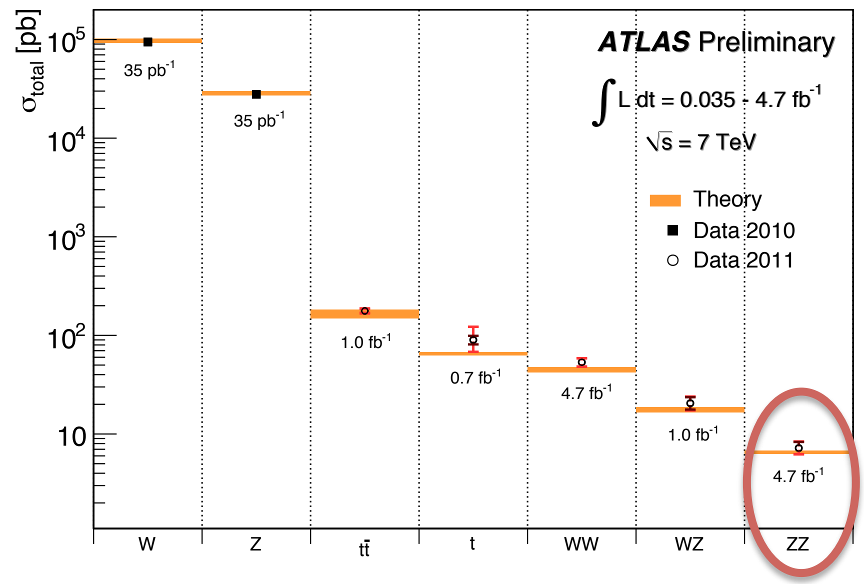
$= ie\Gamma^{\alpha\beta\mu}(q_1,q_2,P)$

- Search for general ZZV couplings where V = (Z, γ), introduced using an effective Lagrangian given above.
- Couplings paramaterised by two CP-violating ($f^V{}_4$) and two CP-conserving ($f^V{}_5$) complex parameters. All are zero in the SM.
- Signature for aTGCs is enhanced cross section at high energies and at large scattering angles => observables proportional to M^{ZZ}, $P_T{}^{ZZ}$ sensitive to aTGCs.
- Limits on aTGCs set using ZZ->4l cross section measured with the first 1fb-1 of the 2011 dataset using the observed number of events only.
- Limits are comparable with, or tighter than, those derived with measurements from LEP and the Tevatron.



Conclusions

- ZZ cross section measurement pushes the lower boundary of ATLAS Standard Model cross section measurements.
- Cross section measured using full 2011 dataset and found to be consistent with Standard Model prediction.
- Limits on aTGCs set using cross-section measured with $1 fb^{-1}$ of the dataset; no deviation from SM prediction.



Future Plans

- Differential cross-section measurements.
- Update aTGC limits using full dataset and differential distributions.
- Push detector acceptance even further using forward electrons and calorimeter tagged muons.

Extra Slides

Observed Events by lepton channel

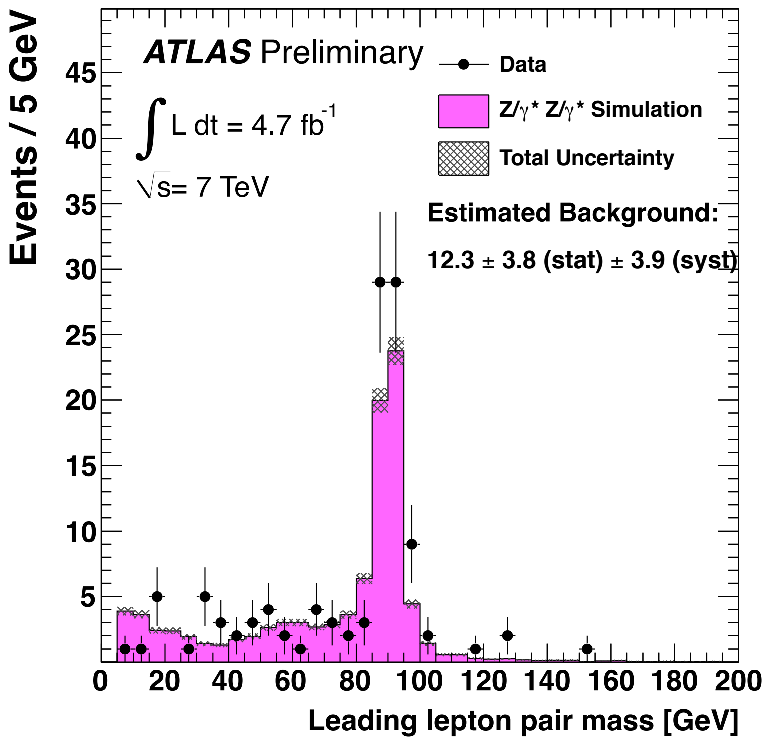
- Table shows number of observed events, predicted signal from Monte Carlo, and predicted background from MC using both the date driven technique and a Monte Carlo estimation, split by four lepton final states.

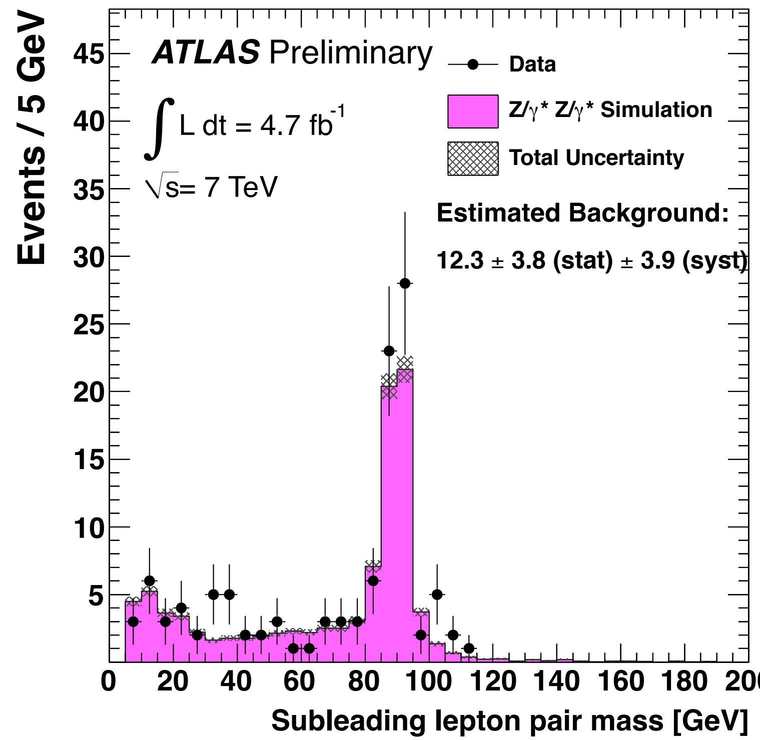
Final state	$eeee$	$\mu\mu\mu\mu$	$ee\mu\mu$	combined ($\ell\ell\ell\ell$)
Observed	15	21	26	62
Signal(MC)	$9.9 \pm 0.5 \pm 0.8$	$16.6 \pm 0.6 \pm 0.3$	$26.8 \pm 0.8 \pm 1.0$	$53.2 \pm 1.1 \pm 1.9$
Bkg(d.d.)	$0.6^{+0.7+0.8}_{-0.6-0.6}$	$< 0.3^{+0.5}_{-0.2}$	$0.3^{+0.9+0.8}_{-0.3-0.3}$	$0.7^{+1.3+1.3}_{-0.7-0.7}$
Bkg(MC)	0.3 ± 0.3	< 0.8	0.6 ± 0.6	1.0 ± 0.6

- Fiducial cross section by channel:
  - eeee: $6.6^{+2.0}_{-1.6}$ (stat) $^{+0.8}_{-0.5}$ (syst) $^{+0.3}_{-0.2}$ (lumi) fb
  - $\mu\mu\mu\mu$: $5.5^{+1.3}_{-1.1}$ (stat) $^{+0.2}_{-0.1}$ (syst) $^{+0.3}_{-0.2}$ (lumi) fb
  - ee$\mu\mu$: $9.1^{+2.1}_{-1.7}$ (stat) $^{+0.5}_{-0.4}$ (syst) $^{+0.4}_{-0.3}$ (lumi) fb

Observed Events

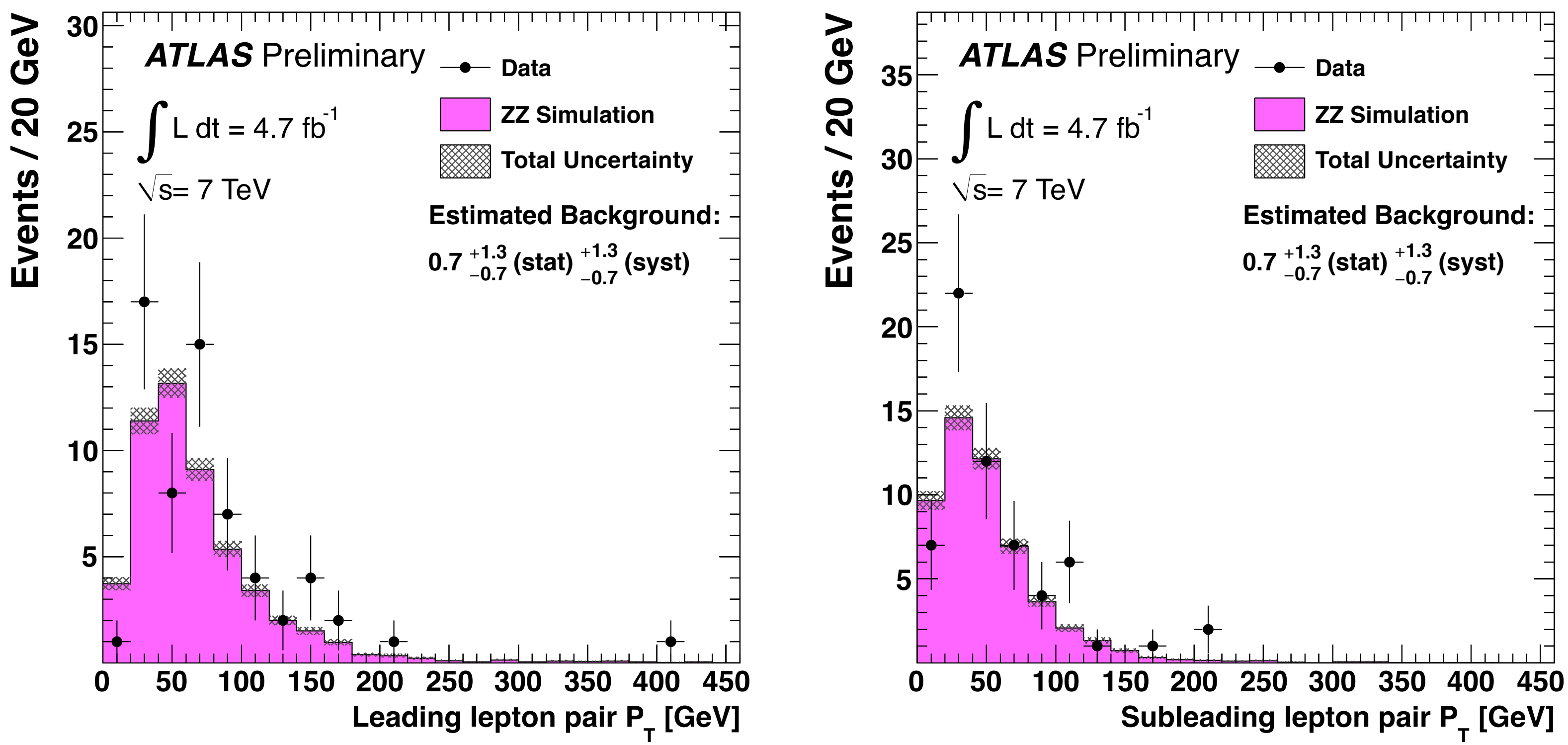
- Mass distributions of the leading and subleading lepton pair.





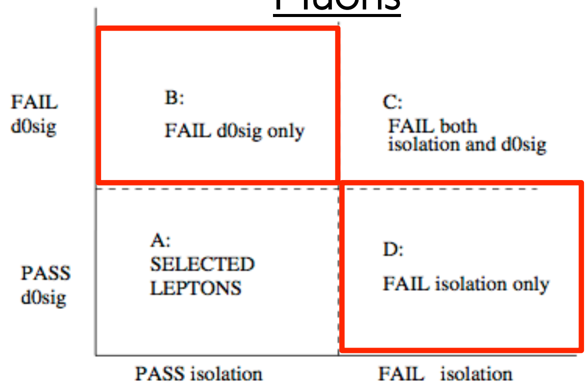
Observed Events

- Transverse momentum of the leading and subleading lepton pair.

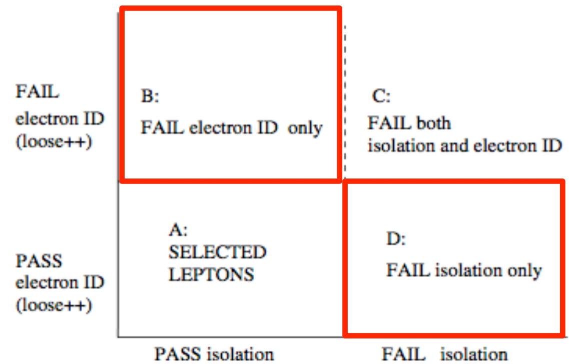


Lepton Like Jet definitions

Muons



Electrons



- **Lepton like jets (J)** are objects that fall into either area B or D – fail **either impact parameter significance** (d0sig) **or** isolation (muons) / fail **either** Loose++ **or** isolation (electrons).
- **Selected Leptons (L)** fall into area A – pass all cuts.
- We only want to extrapolate from control regions close to the signal, so only allow a "lepton-like" jet J to fail one of the requirements (so exclude region C)

	Selected leptons	Lepton-like jets
Muons	Track iso < 0.15 and Calo iso < 0.30 and d_0-significance < 3.5	(d_0-significance > 3.5 and Track iso < 0.15 and Calo iso < 0.30) or (d_0-significance < 3.5 and (Track iso > 0.15 or Calo iso > 0.30))
Electrons	Track iso < 0.15 and Calo iso < 0.30 and Loose++	(!Loose++ and Track iso < 0.15 and Calo iso < 0.30) or (Loose++ and Track iso > 0.15 and Calo iso > 0.30)