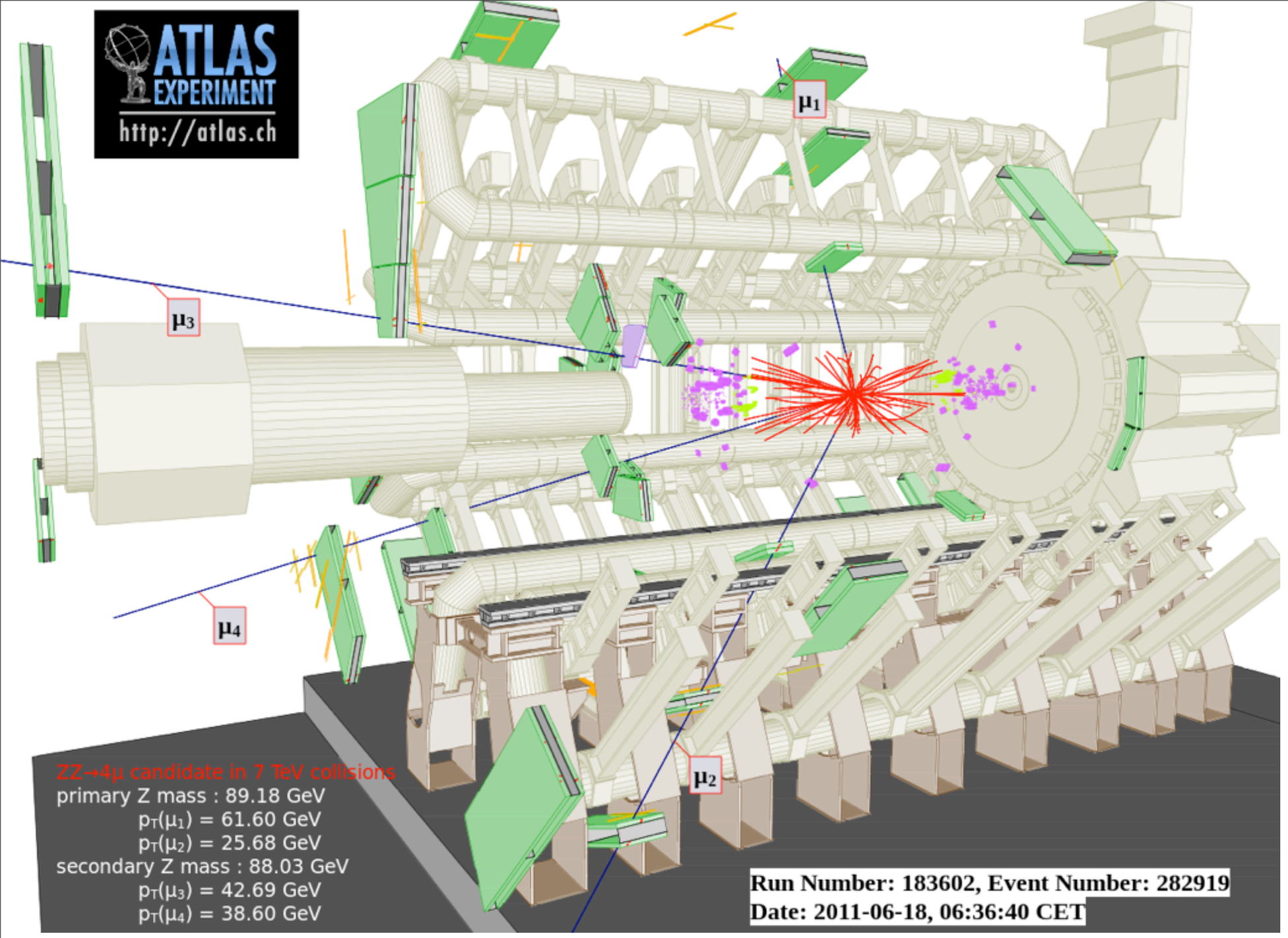

ZZ cross section measurement at 8TeV

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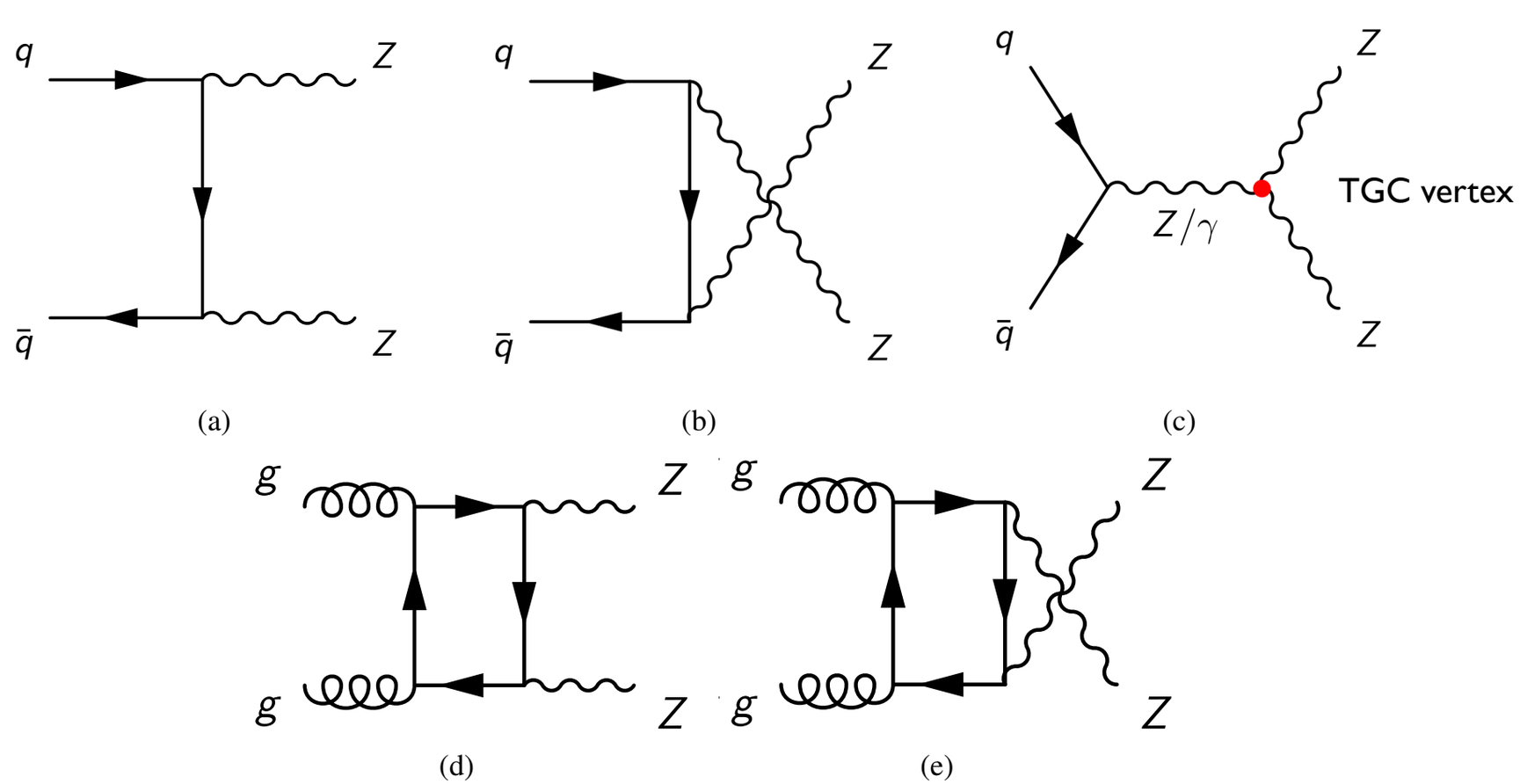
Physics Motivation

- Provide direct high energy test of Standard Model (SM) predictions
- Probe for new physics through deviations from SM expectation
  e.g. anomalous TGCs
- Irreducible background for Higgs measurements



How do we measure the cross section?

1. Measure the cross section in the detector fiducial region

$$\sigma_{ZZ}^{fid} = \frac{N_{obs} - N_{bkg}}{L \cdot C_{ZZ}}$$

fiducial volume definition

$p_T^{\ell} > 7$GeV, $|\eta^{\ell}| < 2.7$

$\min(\Delta R(\ell,\ell)) > 0.2$,

$66 < m_{\ell\ell} < 116$ GeV

2. then extrapolate to the full phase space

efficiency correction for detector effects obtained from Monte Carlo and corrected by efficiencies measured in data

$$\sigma_{ZZ}^{tot} = \frac{N_{obs} - N_{bkg}}{L \cdot BR(ZZ) \cdot A_{ZZ} \cdot C_{ZZ}}$$

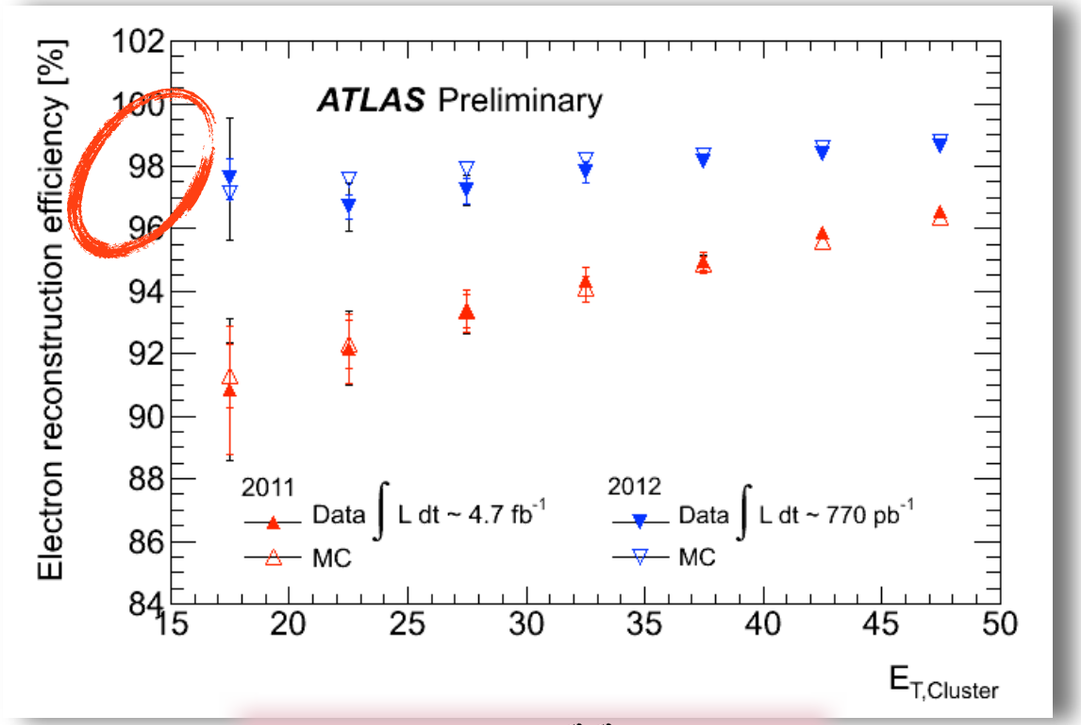
correction for $ZZ \to 4\ell$ Branching Ratio

acceptance correction for kinematic and geometric selection criteria

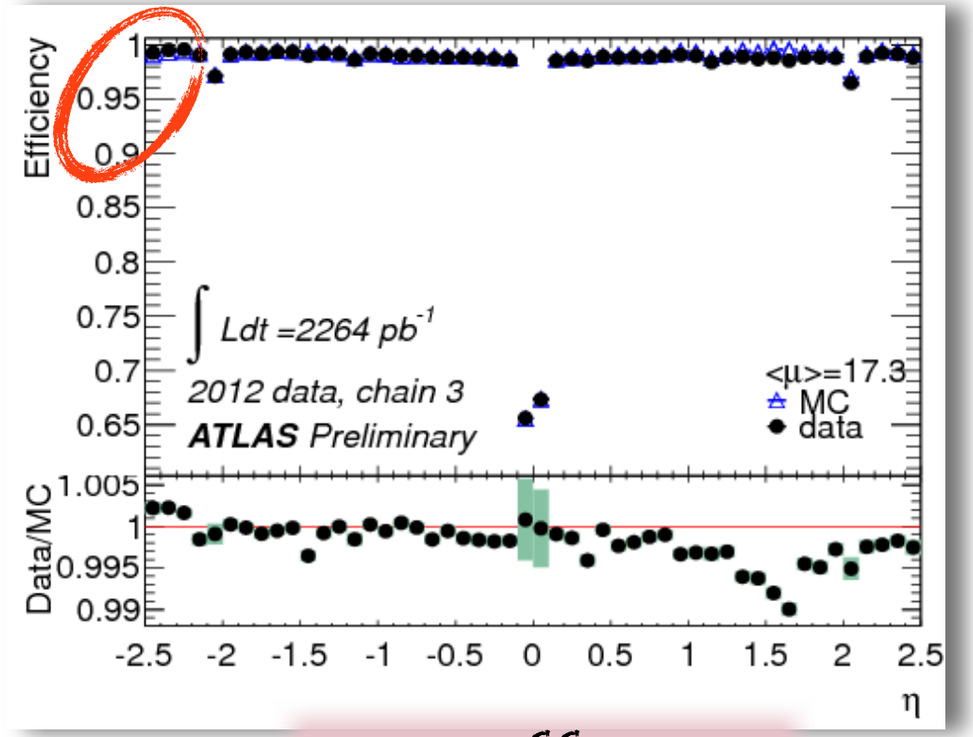
ZZ event selection

- Single lepton (electron or muon) trigger
- Leading lepton in the event with transverse momentum pT > 25 GeV
- 4 isolated leptons with high transverse momentum (pT > 7GeV)
- Opposite sign same flavor lepton pairs - $e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$, $e^+e^-\mu^+\mu^-$
- Mass range of each 2 lepton pair: $66 < m_{\ell\ell} < 116$ GeV
- All selected leptons are separated by $\Delta R(\ell,\ell) > 0.2$

tau contribution: 0.30% ±0.02% of selected ZZ events estimated from simulation



electron efficiency

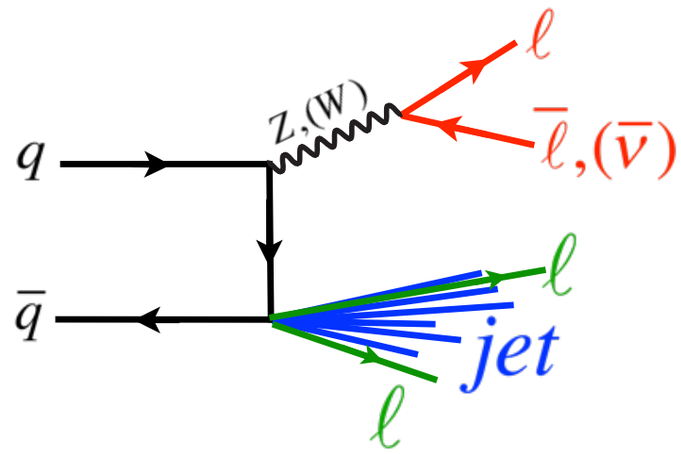


muon efficiency

Background Estimate

Sources of background:

- ***Z/W+X* (jets or photons)**
- $t\bar{t}$ or single top
- Other di-boson final states



Estimated with data-driven method

- Build control regions (data samples enriched in background events)
  - select 4 lepton events where 1 or 2 leptons fail isolation criteria
- Obtain the fraction of fakes *(f)* from Z + lepton candidates
- Extrapolate the background yield from the control region to the signal region

$$N_{4\ell}^{\text{fake}} = N_{TTFF} \times f \times f + N_{TTTF} \times f$$

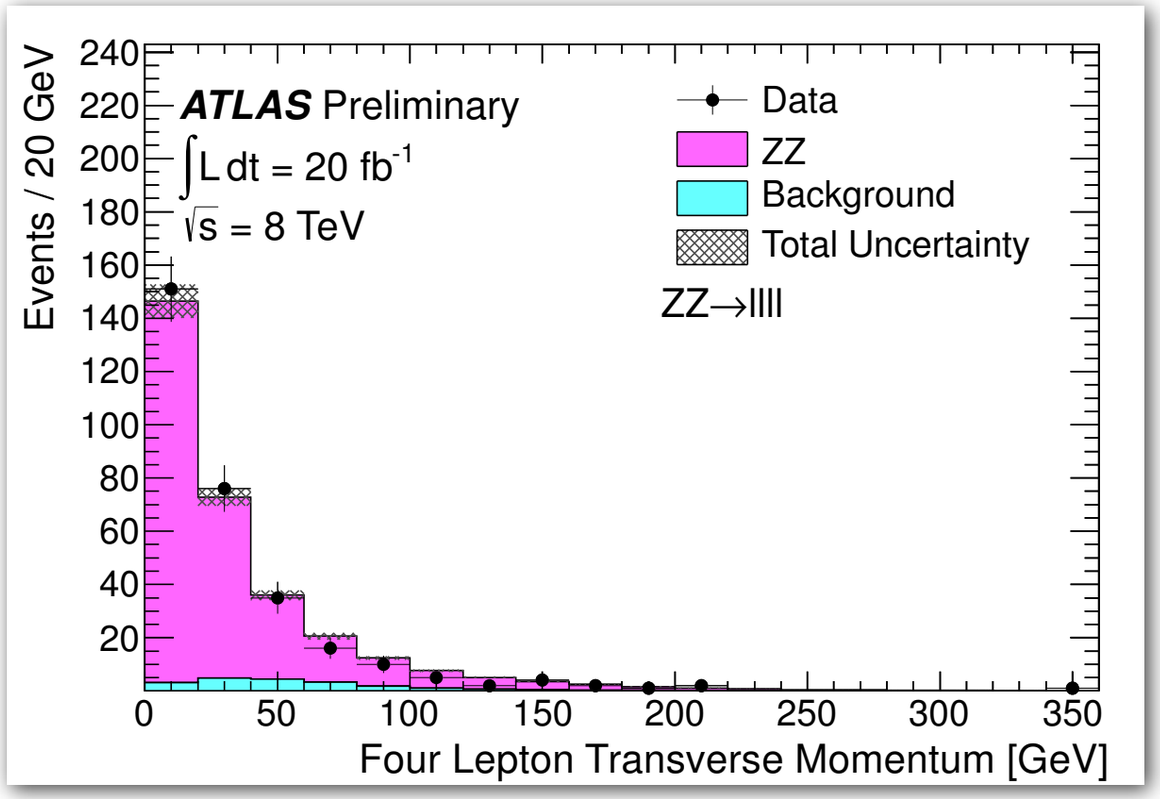
- Irreducible background $Z+t\bar{t}$, ZZZ, ZWW (estimated from simulation)

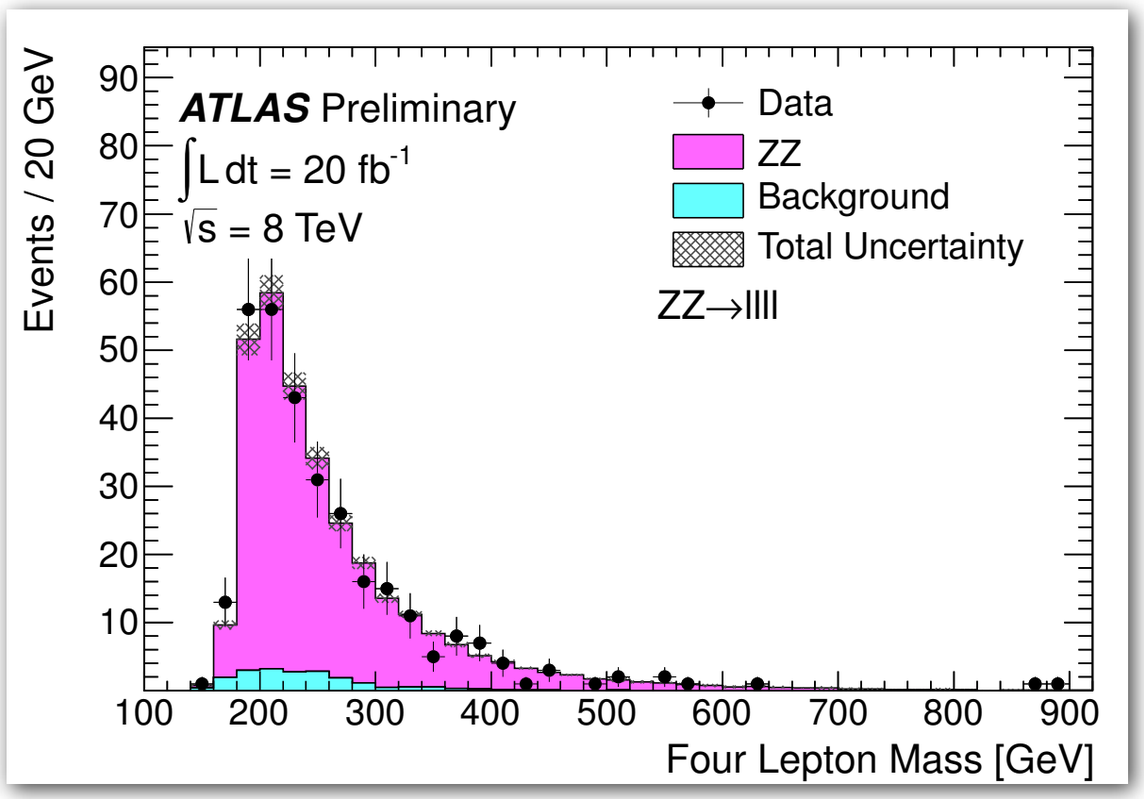
T: true isolated leptons

F: fake leptons

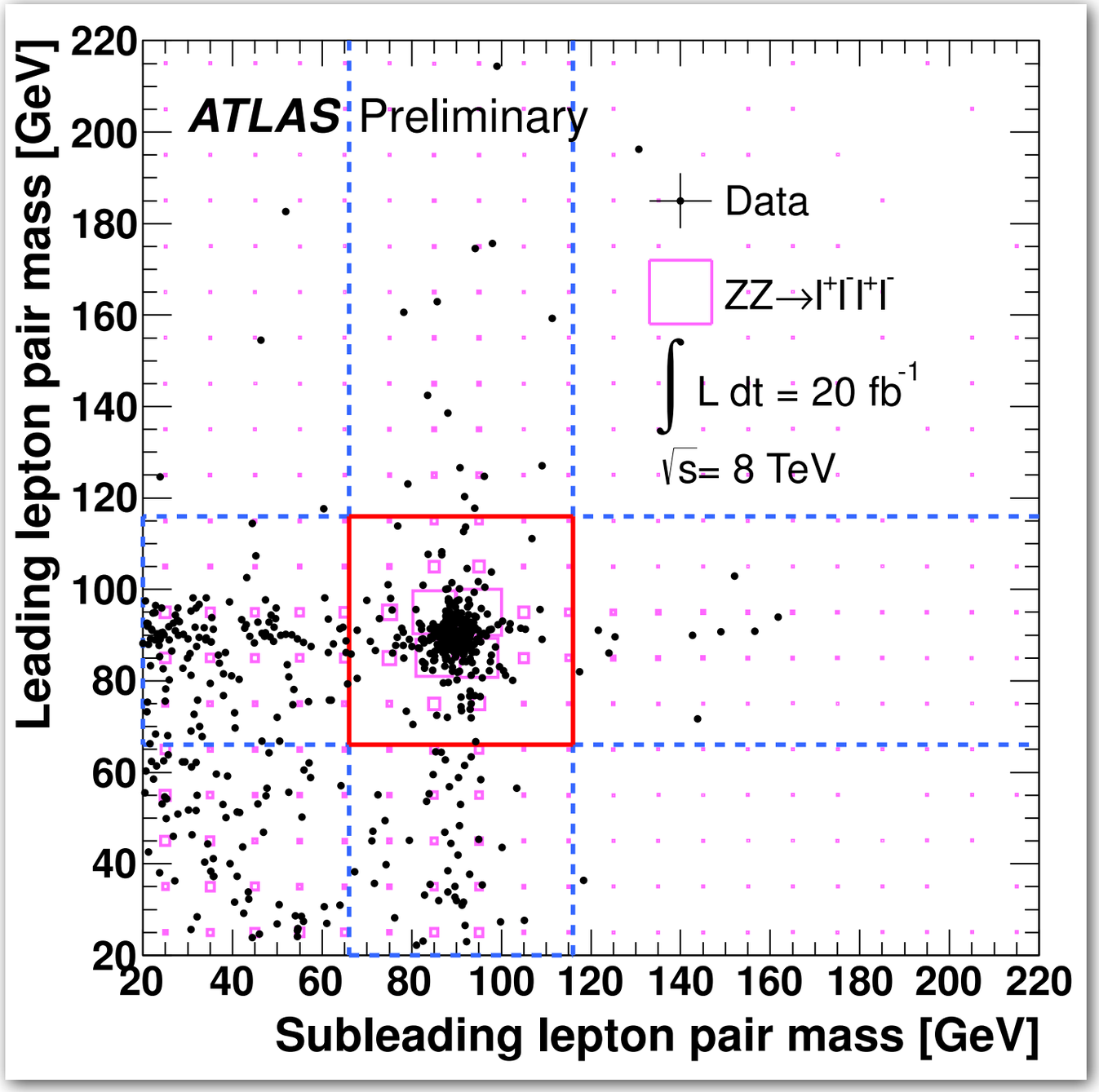
ZZ Candidate Events

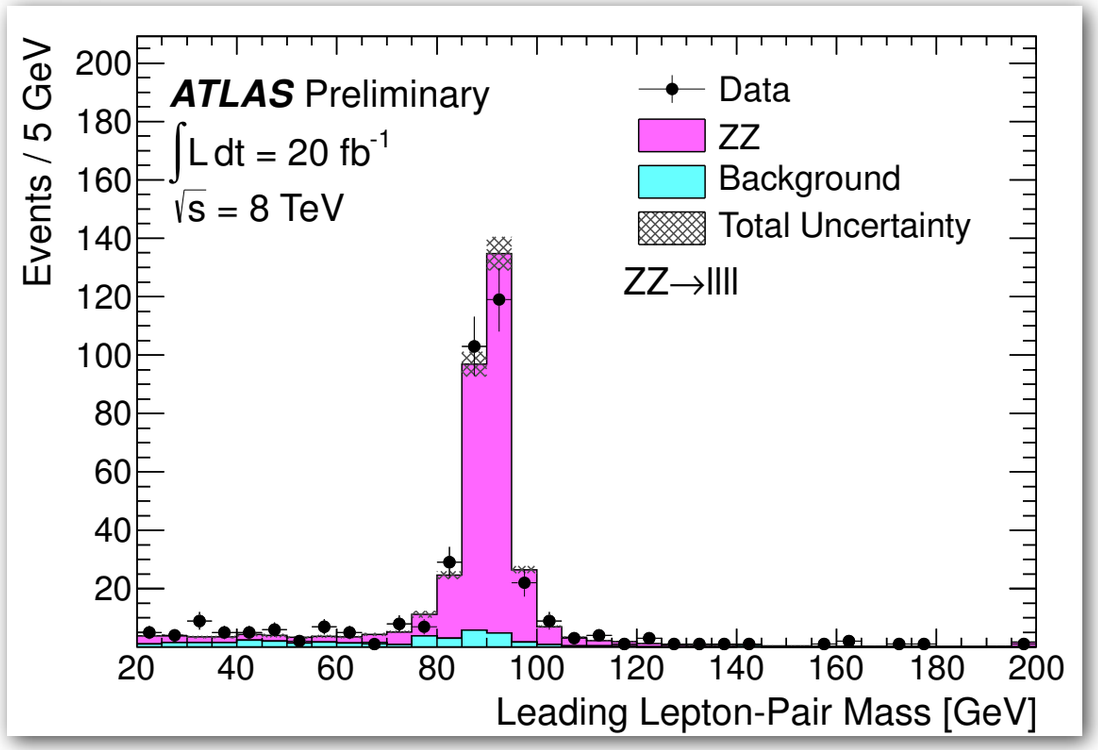
Final state	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell'^+\ell'^-$
Observed	62	85	158	305
Signal (MC)	59.5±4.0	90.2±2.7	142.7±5.6	292.5±10.6
Background	10.0±1.8±1.4	1.1±1.4±0.5	9.3±2.1±3.1	20.4±2.9±5.0
C_{ZZ}	0.55±0.04	0.83±0.03	0.66±0.03	0.68±0.02

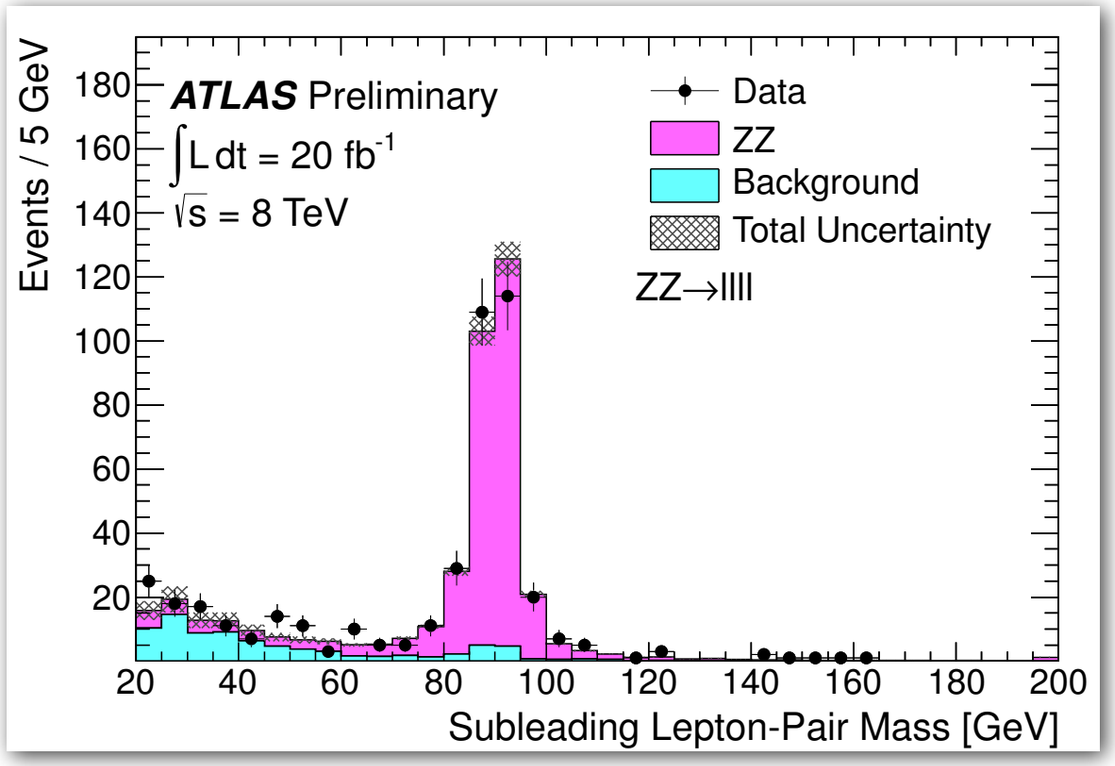




ZZ Candidate Events







Final Result

Fiducial cross section

$$\sigma^{\text{fid}}_{ZZ\to\ell\ell\ell'\ell'} = 20.7^{+1.3}_{-1.2}(\text{stat.}) \pm 0.8(\text{syst.}) \pm 0.6(\text{lumi.})\ \text{fb}$$

NLO SM prediction (MCFM, PDF set CT10)

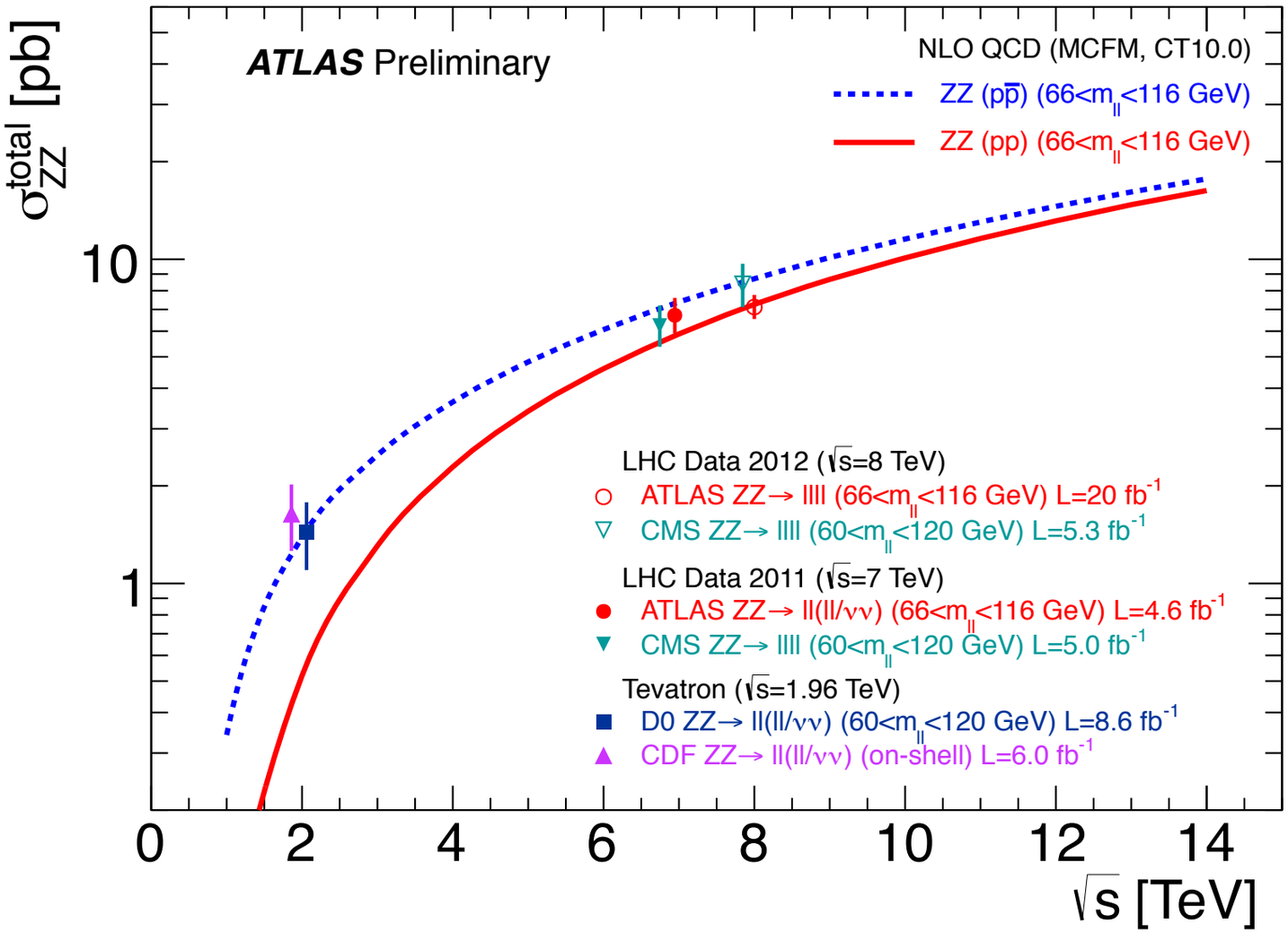
$$\sigma^{fid}_{ZZ\to ll'l'} = 21.1^{+0.9}_{-0.7} fb$$

Total cross section

$$\sigma^{\text{tot}}_{ZZ} = 7.1^{+0.5}_{-0.4}(\text{stat.}) \pm 0.3(\text{syst.}) \pm 0.2(\text{lumi.})\ \text{pb}$$

NLO SM prediction (MCFM, PDF set CT10)

$$\sigma^{tot}_{ZZ} = 7.2^{+0.3}_{-0.2} pb$$



- ✓ **Statistical uncertainty dominates the measurement**
- ✓ **Systematic uncertainties originate from:**
  - ✓ **luminosity (2.8%)**
  - ✓ **background estimate (1.6%)**
  - ✓ **reconstruction efficiencies (3.3%)**

Back up slides

Lepton Selection Criteria

Requirement	$\ell^+\ell^-\ell'^+\ell'^-$ final state
Standard Muons	
1. μ: type	"loose" STACO muons, Combined or SegmentTagged
2. μ: p_{T} and η	$p_{\mathrm{T}} > 7$ GeV, $\lvert\eta\rvert < 2.5$
3. μ: ID hits	MCP recommendation, see Sec.8
4. μ: $z_0 * sin(\theta)$	$\lvert z_0 * sin(\theta)\rvert < 0.5$ mm
5. μ: d_0	$\lvert d_0\rvert/\sigma(d_0) < 3.0$
6. μ: track iso	$\Sigma p_{\mathrm{T}}(\Delta R < 0.2)/p_{\mathrm{T}} < 15\%$
Forward Muons	
1. μ: type	"loose" STACO muons, Combined or StandAlone
2. μ: p_{T} and η	$p_{\mathrm{T}} > 10$ GeV, $2.5 < \lvert\eta\rvert < 2.7$
3. μ: ID hits	MCP recommendation, see Sec.8
4. μ: $z_0 * sin(\theta)$	$\lvert z_0 * sin(\theta)\rvert < 0.5$ mm
5. μ: d_0	$\lvert d_0\rvert/\sigma(d_0) < 3.0$
7. μ: calo iso	calo $\Sigma E_T(\Delta R < 0.2)/p_{\mathrm{T}} < 15\%$
Calorimeter-tagged Muons	
1. μ: type	Calorimeter Tagged muons
2. μ: p_{T} and η	$p_{\mathrm{T}} > 20$ GeV, $\lvert\eta\rvert < 0.1$
3. μ: ID hits	MCP recommendation, see Sec.8
4. μ: $z_0 * sin(\theta)$	$\lvert z_0 * sin(\theta)\rvert < 0.5$ mm
5. μ: d_0	$\lvert d_0\rvert/\sigma(d_0) < 3.5$
6. μ: track iso	$\Sigma p_{\mathrm{T}}(\Delta R < 0.2)/p_{\mathrm{T}} < 15\%$
8. Quality Cuts	`CaloMuonIDTag` > 10 || `CaloLRLikelihood` > 0.9
9. Overlap Removal	Remove if overlaps with a standard muon in $\Delta R < 0.1$

Table 4: Muon selection requirements.

Requirement	$\ell^+\ell^-\ell'^+\ell'^-$ final state
Central Electron Selection:	
1. e: Type	`author==1 or 3`
2. e: Quality	`(OQ AND 1446 == 0)`
3. e: ID cut	`Loose++`
4. e: η	$\lvert\eta\rvert < 2.47$ (include crack: $1.37 < \lvert\eta_{Cluster}\rvert < 1.52$)
5. e: E_T	$E_T > 7$ GeV
6. e: $z_0 * sin(\theta)$	$\lvert z_0 * sin(\theta)\rvert < 0.5$ mm
7. e: d_0	$\lvert d_0\rvert/\sigma(d_0) < 6$
8. e: Track isolation	Σp_{T} $(\Delta R < 0.2)/p_{\mathrm{T}} < 15\%$
10. e: Overlap removal	a) Remove e if $\Delta R < 0.1$ from μ
	b) Remove lowest E_T e in $\Delta R < 0.1$ from another e

Table 5: Electron selection requirements.

Summary of Systematics

Source	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell'^+\ell'^-$
Reconstruction Uncertainties				
Lepton identification and reconstruction	6.2%	1.2%	3.1%	2.8%
Lepton energy/momentum	0.4%	<0.1%	0.2%	0.1%
Lepton isolation and impact parameter	1.8%	2.6%	1.5%	1.6%
Trigger efficiency	<0.1%	0.2%	0.1%	0.1%
Total Reconstruction Uncertainty (C_{ZZ})	6.4%	2.8%	3.4%	3.3%
Theoretical Uncertainties				
PDF & Scale (C_{ZZ})	0.1%	0.1%	<0.1%	<0.1%
MC Generator Difference (C_{ZZ})	1.7%	0.9%	1.8%	1.5%
PDF & Scale (A_{ZZ})	1.0%			
MC Generator Difference (A_{ZZ})	0.8%			
Total for C_{ZZ}	6.6%	3.0%	3.9%	3.6%
Total for A_{ZZ}	1.3%			
Luminosity	2.8%			