ZZ production cross-section measurements and neutral Trilinear Gauge Coupling limits in ATLAS

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Reference document: ATLAS-CONF-2011-107

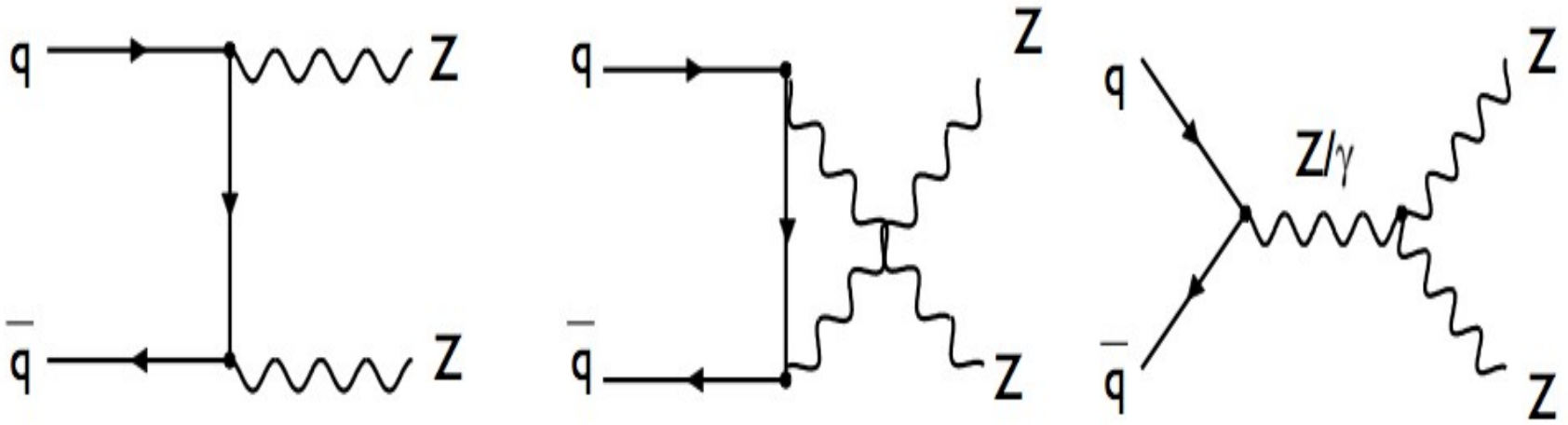
Motivation

Signature

Four isolated charged leptons with small backgrounds.

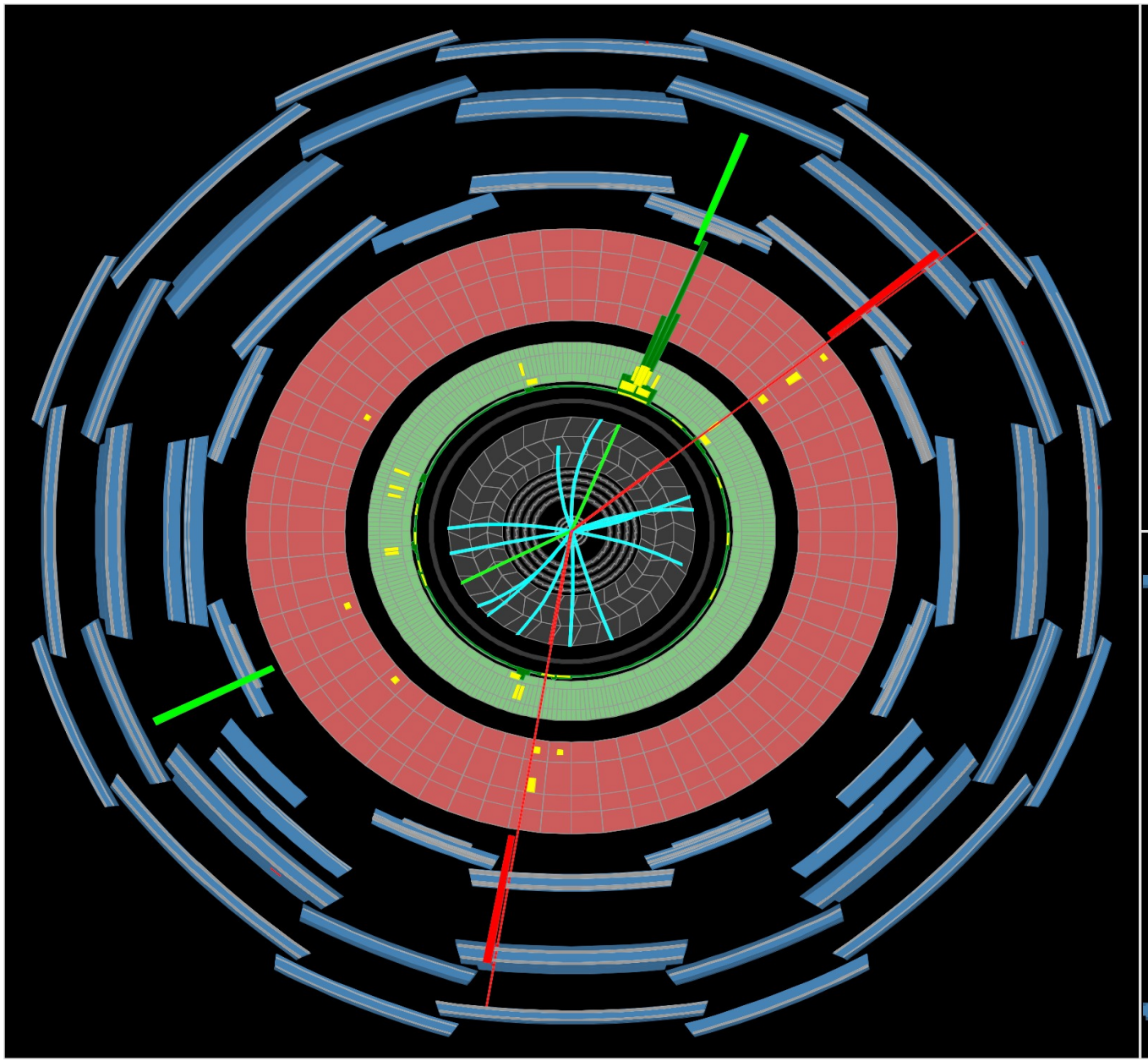
Foundation for later work

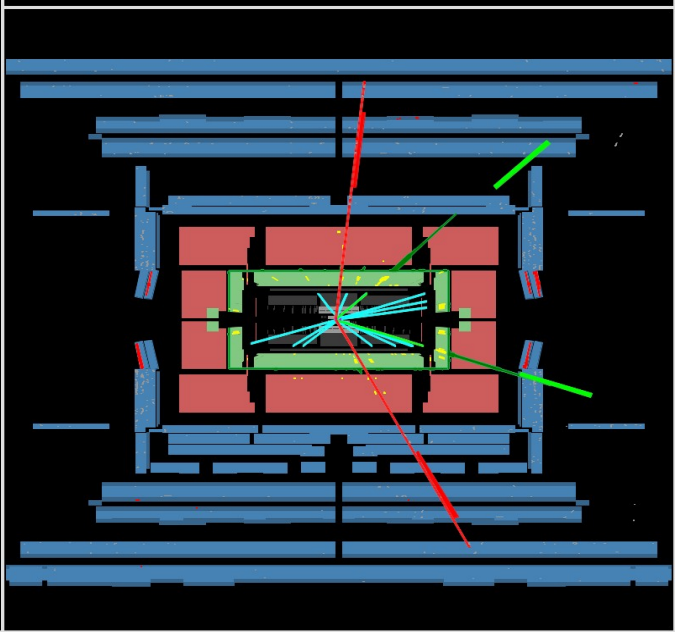
- The only significant background for H → ZZ searches
- Probe anomalous triple gauge (TGC) coupling (in this talk)
- Search for new physics (e.g. G → ZZ)



Footnote: Z in this talk refers to Z/γ*

ATLAS Detector and a 2e2μ Candidate





Object and Event Selections

Objects Selections:

Trigger : Offline selection on plateau of trigger efficiency, at least one electron E_T > 25 GeV or muon p_T > 20 GeV

Electron: E_T>15GeV,|eta|<2.47

Muon : p_T>15 GeV,|eta|<2.5

Track Isolation: $\Sigma\, p_{T,trk}(\Delta R(trk,lep)<0.2)/p_{T,lep}$ <0.15
Insensitive to pile-up effects

Event Selections:

- 4 and only 4 leptons
  Tau leptonic decay contribution is 0.3 %
- min (|mZ_{01}-91.25| + |mZ_{23}-91.25|)
- 66-116 GeV mass requirement on both Z candidates

Signal Yield and Selection Efficiency

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Channels	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell'^+\ell'^-$
Cuts	$N_{ZZ}/C_{ZZ}(\%)$	$N_{ZZ}/C_{ZZ}(\%)$	$N_{ZZ}/C_{ZZ}(\%)$	$N_{ZZ}/C_{ZZ}(\%)$
Four leptons	1.84 / 49	3.61 / 94	5.3 / 67	11 / 69
Trigger Match	1.83 / 49	3.60 / 94	5.3 / 67	11 / 69
Two pairs	1.78 / 47	3.60 / 94	5.1 / 66	11/ 68
Mass cut on leading Z	1.68 / 45	3.33 / 87	4.8 / 61	9.8 / 64
Mass cut on subleading Z	1.57 / 41	3.09 / 81	4.5 / 57	9.1 / 59

- Yields predictions N_{ZZ} at 1.02 fb^{-1}
- Event reconstruction efficiency C_{ZZ} is defined with respect to truth fiducial volume

$$C_{ZZ\to\ell\ell'\ell'} = \frac{N^{\text{MC Pass All Cuts}}_{\text{Reconstructed } ZZ\to\ell\ell'\ell'} \times \text{SF}}{N^{\text{MC Fiducial Volume}}_{\text{Generated } ZZ\to\ell\ell'\ell'}}$$

Truth Fiducial Volume:

- $(Z/\gamma^*)(Z/\gamma^*) \to \ell^+\ell^-\ell^+\ell^-, \ell = e, \mu$;
- $|m(Z/\gamma*) - m_{\text{PDG}}(Z)| < 25$ GeV;
- $p_{\text{T}}^{\ell} > 15$ GeV;
- SF: MC efficiency scale factor correction

Systematics on Acceptance

Systematics uncertainty is dominated by the lepton reconstruction and ID efficiency determined from data-driven method

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Source %	*eeee*	*μμμμ*	*eeμμ*	combined
μ reconstruction efficiency	-	2.0	1.0	1.2
μ p_T smearing	-	0.1	< 0.1	< 0.1
μ trk isolation	-	0.1	0.1	0.1
μ d0Sig	-	0.2	0.1	0.2
μ z0	-	0.1	0.1	0.1
e reconstruction efficiency	2.8	-	1.4	1.2
e identification efficiency	6.0	-	2.8	2.4
e energy scale	0.6	-	0.4	0.3
e energy smearing	< 0.1%			
e trk isolation	0.3	-	0.1	0.1
e d0Sig	0.5	-	0.2	0.2
e z0	0.2	-	0.1	0.1
trigger	< 0.1%			
$ZZ \to \tau$	0.3%			
Total	6.7	2.0	3.3	3.0
PDF	1.5			
Luminosity	3.7			

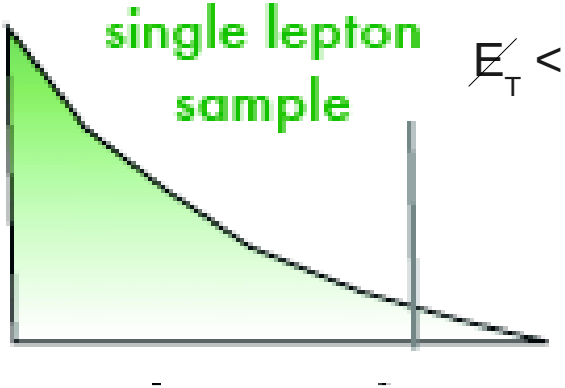
Data-Driven Fake Estimate

A pure data-driven technique is developed

To estimate all background processes containing at least one lepton-like jet background (Z+jets, Top, WZ, W+jets, QCD)

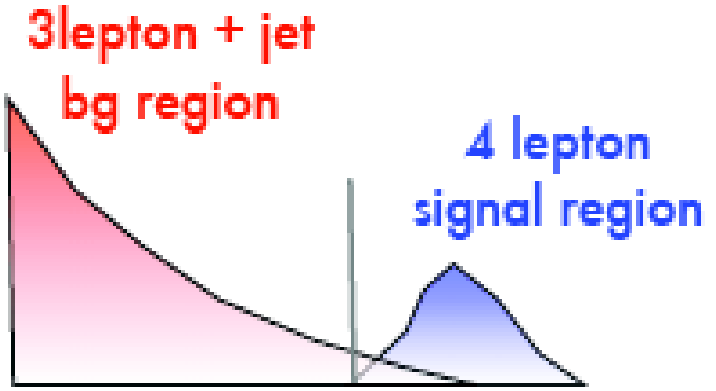
Extrapolation from QCD enriched regions via fake ratio, *f*

Discrepancy of *f* in MC/Data is included as systematics



Isolation or Identification variables

f = *N*(fail)/ *N*(pass)



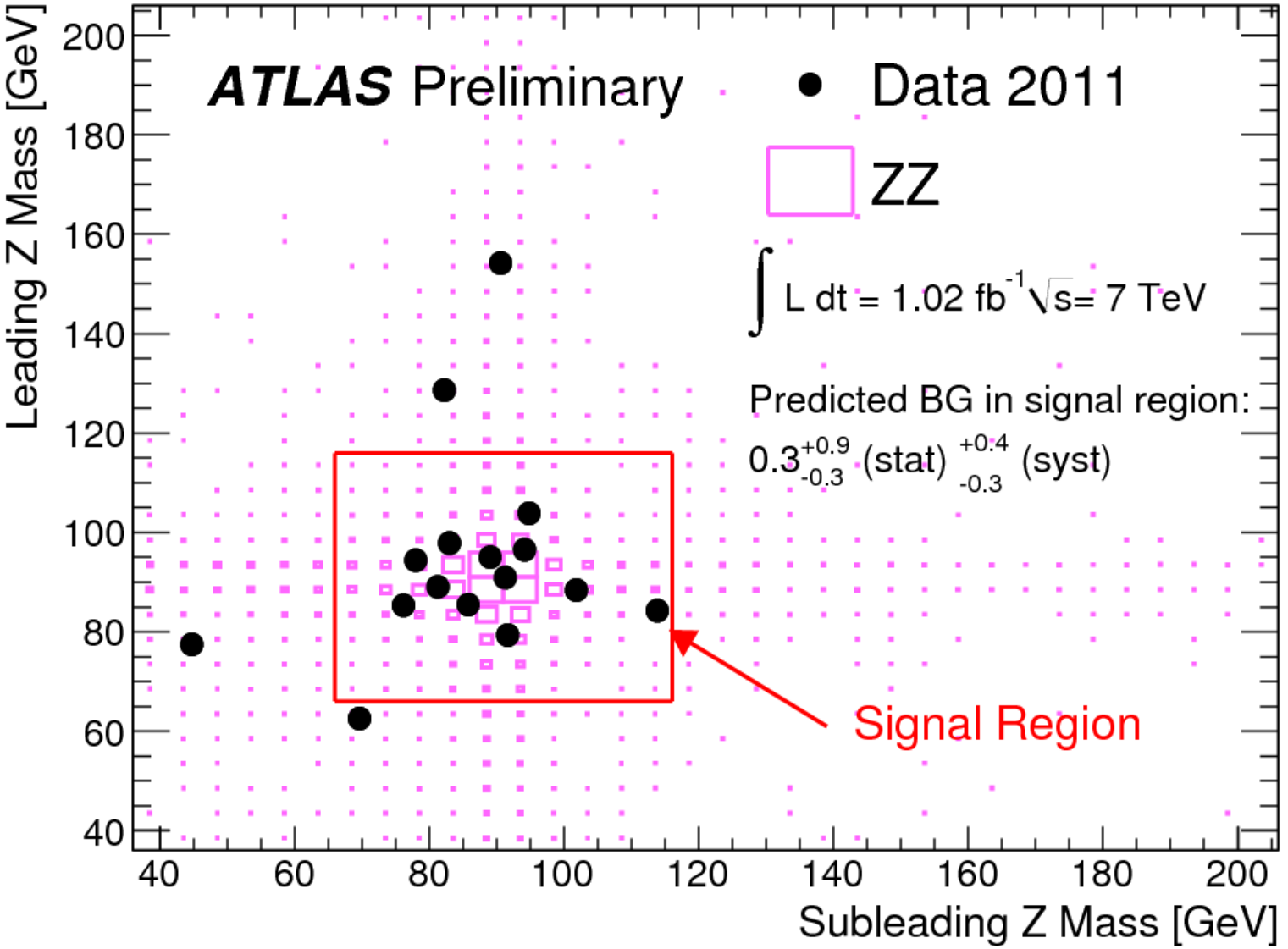
Isolation or Identification variables

***N*(3l+jet) X *f* = fake estimate**

Double counting removal

$$N(\text{background}) = N(\ell\ell\ell j) \times f - N(\ell\ell jj) \times f^2 - N(ZZ \text{ in control region}).$$

12 ZZ candidates are observed



Observed ZZ Yields

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Final State	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell^+\ell^-$
Observed	2	8	2	12
Bkg(data-driven)	$0.01^{+0.03+0.05}_{-0.01-0.01}$	$0.3^{+0.9}_{-0.3} \pm 0.3$	$< 0.01^{+0.03}_{-0.01}$	$0.3^{+0.9+0.4}_{-0.3-0.3}$
Expected ZZ	$1.57 \pm 0.03 \pm 0.11$	$3.09 \pm 0.04 \pm 0.06$	$4.5 \pm 0.1 \pm 0.2$	$9.1 \pm 0.1 \pm 0.3$

$$-2\ln Q = -2\ln\frac{L(s+b)}{L(b)}; \quad L(s+b) = \frac{e^{-(N_s+N_b)}(N_s+N_b)^{N_{obs}}}{N_{obs}!}, \quad L(b) = \frac{e^{-N_b}(N_b)^{N_{obs}}}{N_{obs}!},$$

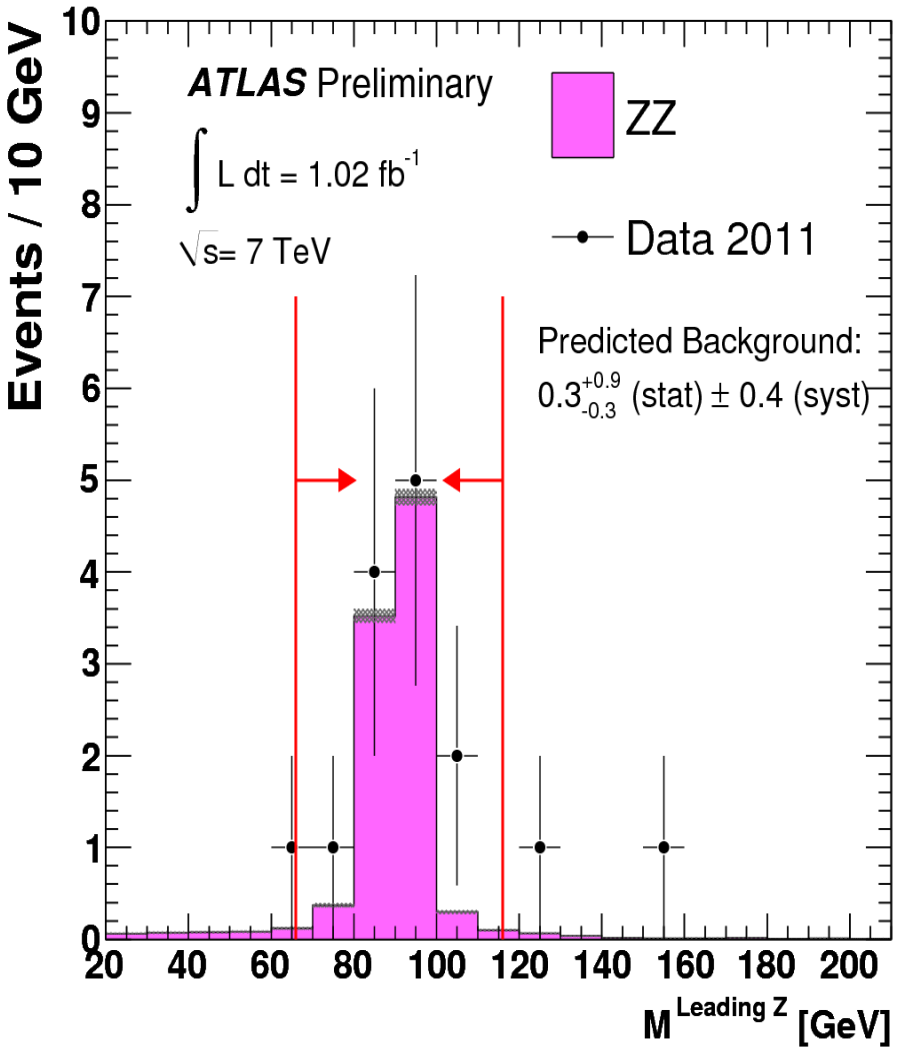
Number expected background $0.3^{+0.9}_{-0.3}(stat.)^{+0.4}_{-0.3}(syst.)$

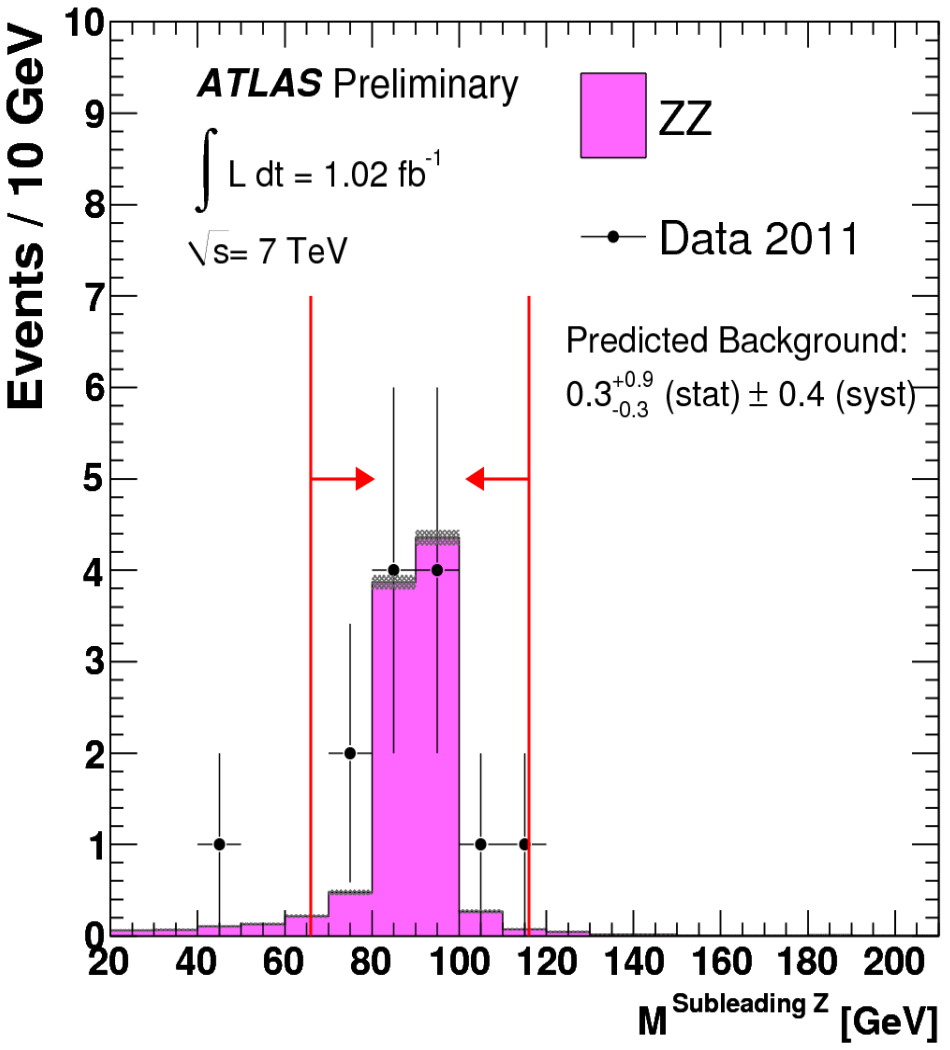
Expected p-value: 4.2×10^{-6} significance: 4.2 σ

Observed p-value: 3.4×10^{-6} Observed significance: 4.5 σ

Z Mass Plots

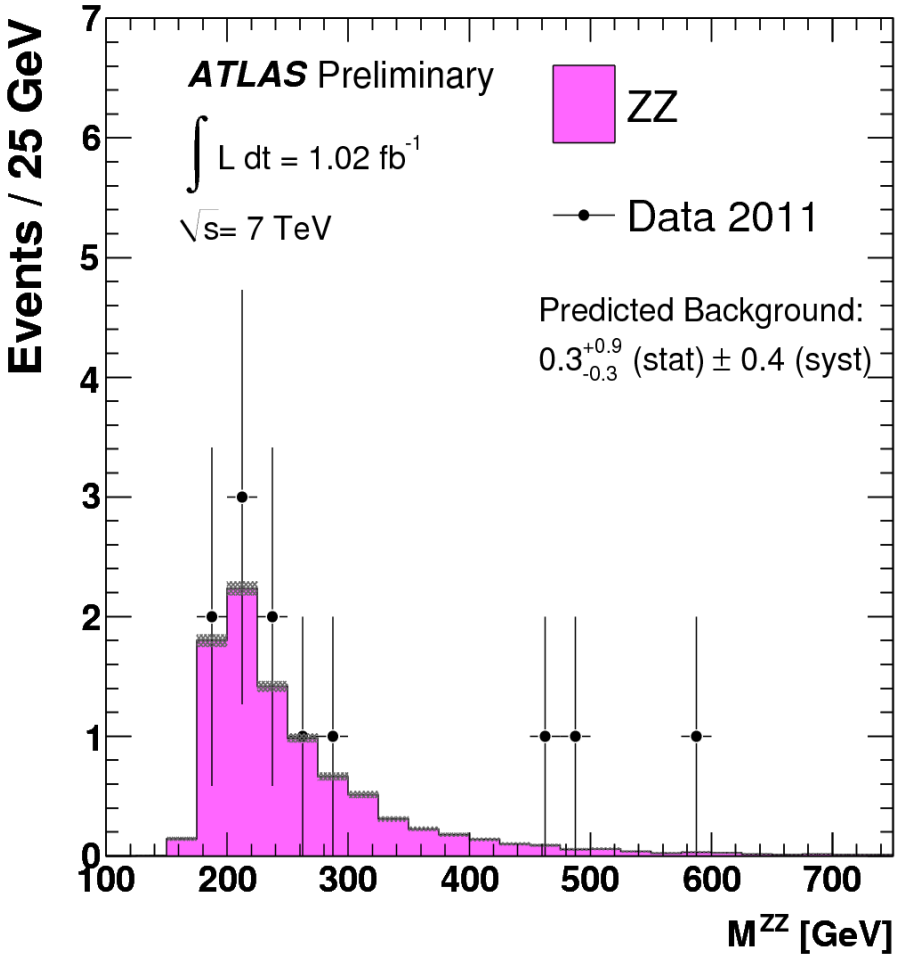
Nice agreement of the Z mass

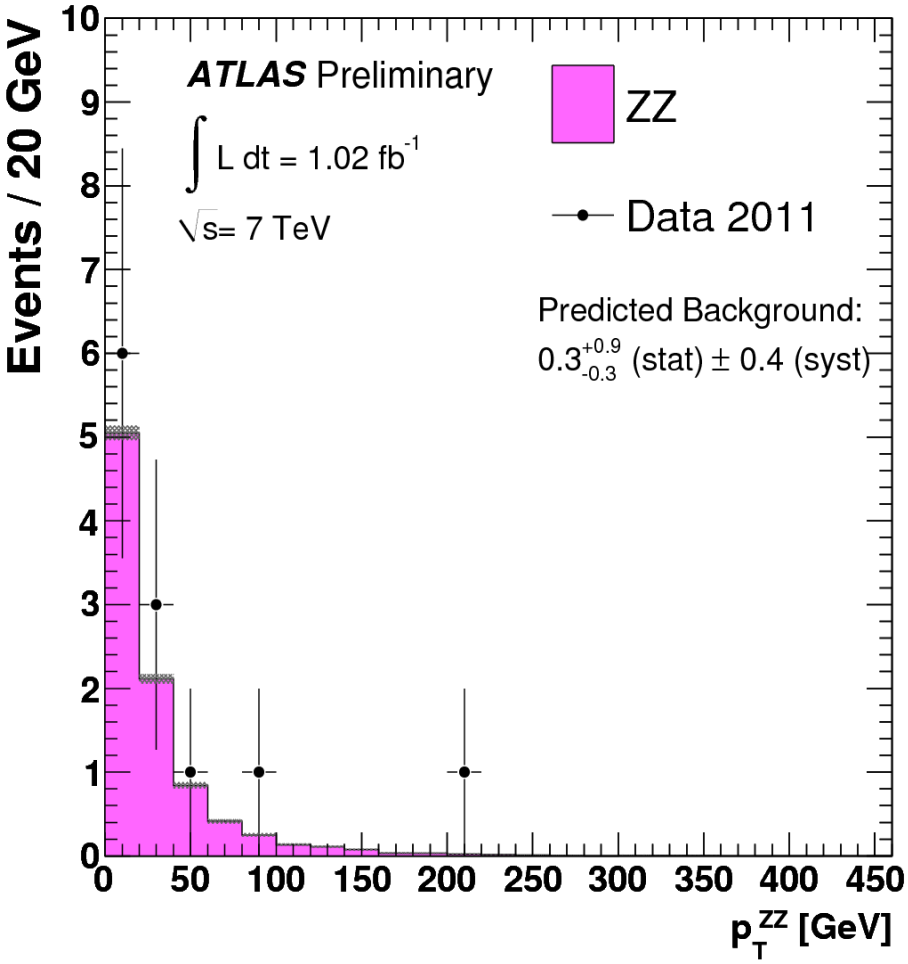




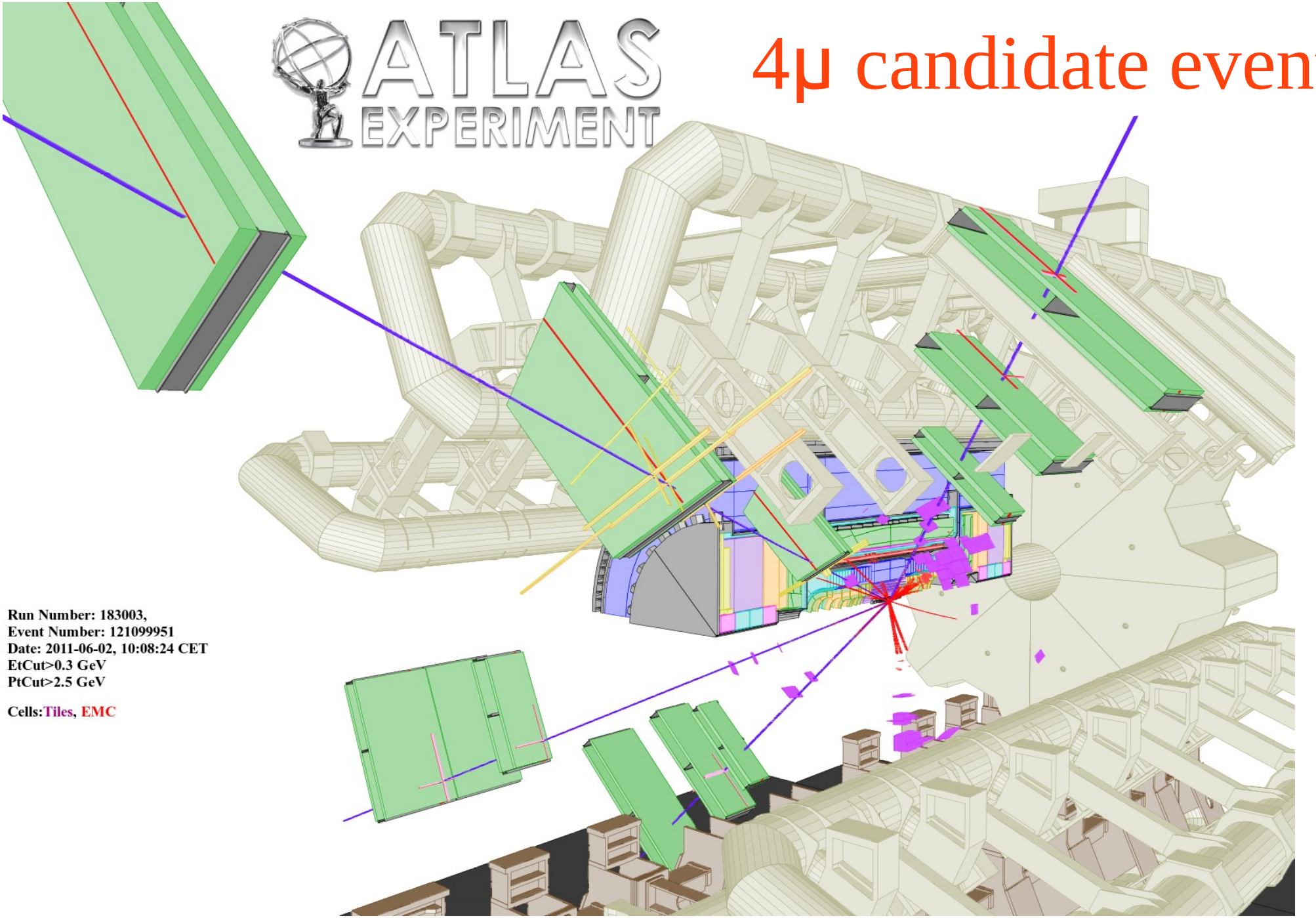
ZZ Kinematic Plots

Interesting to watch the tail evolution with more data accumulated in ATLAS





4μ candidate event



Cross-section Measurement

Fiducial cross-section:

Defined within fiducial volume to minimize theoretical acceptance extrapolation and L is luminosity.

$$\frac{N_{obs} - N_{bkg}}{C_{ZZ}\, BR(ZZ \to e, \mu)\, L}$$

Total cross-section:

Extrapolation to ZZ zero width approximation calculation

$$\frac{N_{obs} - N_{bkg}}{A_{ZZ} C_{ZZ}\, BR(ZZ \to e, \mu)\, L}$$

A_{ZZ} = σ(ZZ NLO fiducial)/σ(ZZ on-shell)

= 0.501

Fiducial volume:

with respect to on-shell Z

- $(Z/\gamma^*)(Z/\gamma^*) \to \ell^+\ell^-\ell^+\ell^-, \ell = e, \mu$;
- $|m(Z/\gamma*) - m_{PDG}(Z)| < 25$ GeV;
- $p_T^\ell > 15$ GeV;

Cross-Section Results

Fiducial cross-section results, where lepton is e or mu without tau contribution

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$$\sigma^{\text{fid}}_{ZZ\to\ell^+\ell^-\ell^+\ell^-} = 19^{+6}_{-5}\,(\text{stat})\,^{+1}_{-2}\,(\text{syst}) \pm 1\,(\text{lumi})\ \text{fb}$$

Total cross-section is extrapolated to ZZ on-shell Xsec:

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$$\sigma^{\text{tot}}_{ZZ} = 8.4^{+2.7}_{-2.3}\,(\text{stat})\,^{+0.4}_{-0.7}\,(\text{syst}) \pm 0.3\,(\text{lumi})\ \text{pb}.$$

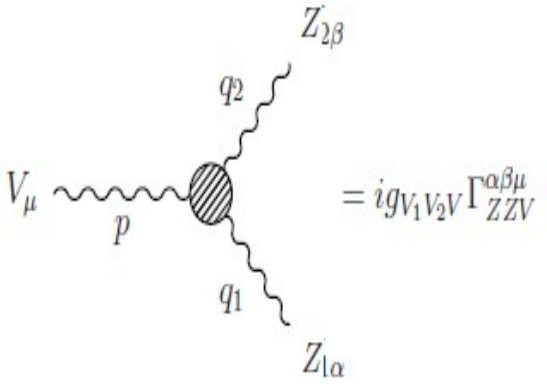
The results is consistent to NLO Calculation

Xsec (NLO) = $6.46\ ^{+0.2}_{-0.3}$ pb

ZZ Anomalous Triple Gauge Coupling

Two most generalized ZZV vertex, V=Z,γ

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



Form factor is introduced to preserve unitarity at high energy

$$f_i^V(s) = \frac{f_{i0}^V}{(1 + s/\Lambda_{FF}^2)^n}$$

Benchmark point (Exponent n=3, energy cut-off Λ=2 TeV) is chosen from the reference: Baur & Rainwater, PRD62 113011 (2000)

Neutral Trilinear Gauge Coupling Measurement

Total expected yield is parametrized as function of TGC parameter

$$s(\sigma_{\text{fiducial}}, C_{ZZ}, f_i^V) = (C_{\text{Sm}} + C_{f_i^V} \cdot f_i^V + C_{f_i^V; f_i^V} \cdot (f_i^V)^2) \cdot \mathcal{L} \cdot C_{ZZ}.$$

Profiling likelihood is used to include systematics uncertainty

$$\begin{aligned} L(\sigma, C_{ZZ}, b; \Delta_b, \Delta_{C_{ZZ}}, N) &= P(\sigma, C'_{ZZ}, b'; N) \cdot G(C'_{ZZ}; C_{ZZ}, \Delta_{C_{ZZ}}) \cdot G(b'; b, \Delta_b) \\ &\cdot G(C'_{SM}; C_{SM}, \Delta_{C_{SM}}) \cdot G(C'_{f_i^V}; C_{f_i^V}, \Delta_{C_{f_i^V}}) \cdot G(C'_{f_i^V f_i^V}; C_{f_i^V f_i^V}, \Delta_{C_{f_i^V f_i^V}}) \end{aligned}$$

Infinite energy-cut off results are also included as a reference

Coupling 95% CI	f_4^γ	f_4^Z	f_5^γ	f_5^Z
$\Lambda = 2$ TeV	$[-0.15, 0.15]$	$[-0.12, 0.12]$	$[-0.15, 0.15]$	$[-0.13, 0.13]$
$\Lambda = \infty$	$[-0.08, 0.08]$	$[-0.07, 0.07]$	$[-0.08, 0.08]$	$[-0.07, 0.07]$

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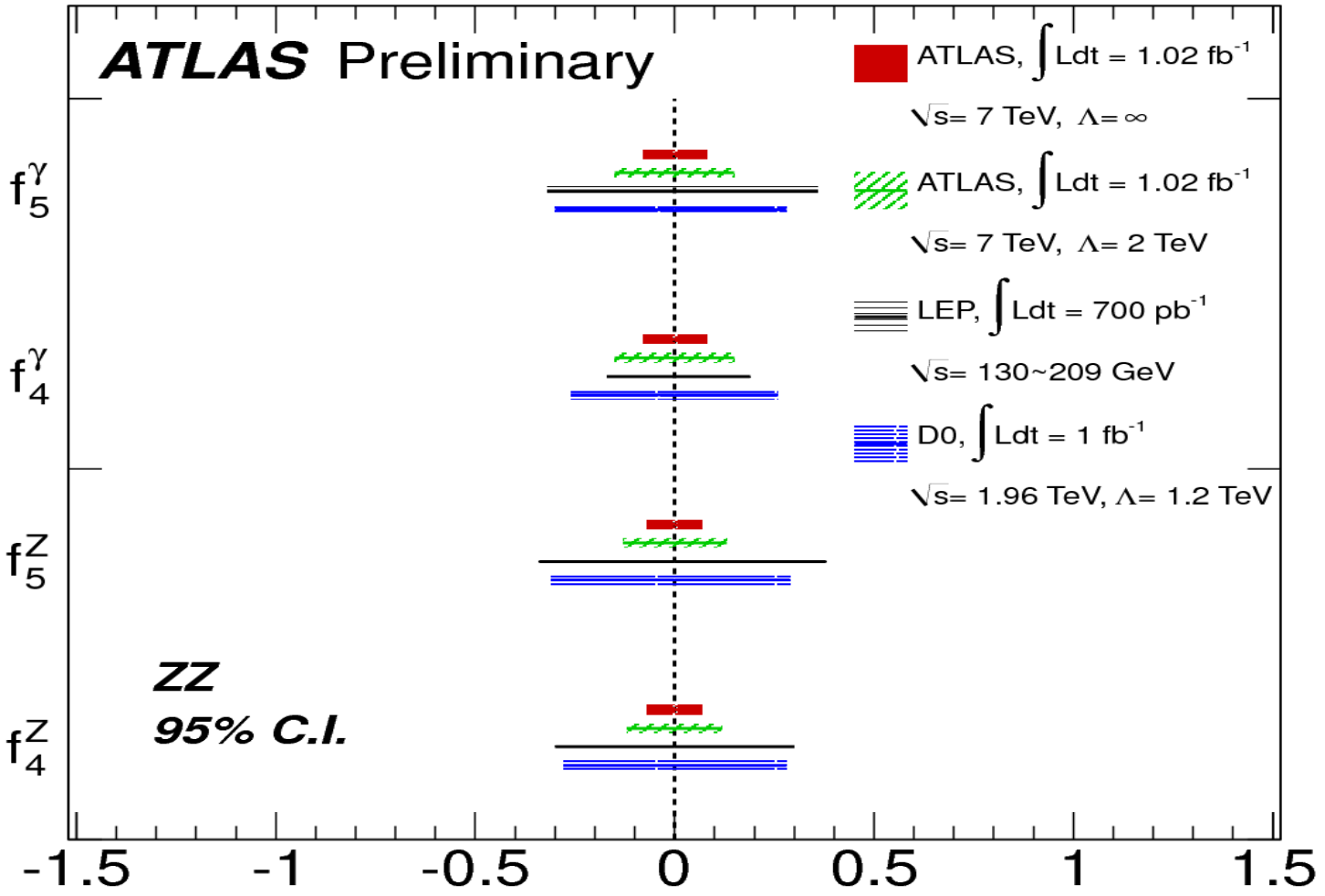
nTGC Results Comparisons

First nTGC results in 7 TeV pp collisions. The best limits with higher energy cut-off Λ



Summary

- **The first ZZ production cross-section in 7 TeV pp collisions is reported:**
  - Observed 12 candidates with background $0.3^{+0.9}_{-0.3}(stat.)^{+0.4}_{-0.3}(syst.)$ gives 4.5 σ significance
  - The measured cross-section is consistent with SM predictions 6.5 pb

$$\sigma_{ZZ}^{tot} = 8.4^{+2.7}_{-2.3}\,(\text{stat})\,^{+0.4}_{-0.7}\,(\text{syst}) \pm 0.3\,(\text{lumi})\,\text{pb}.$$

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- **The first nTGC limits are extracted in 7 TeV pp collision which provides the most stringent limits with higher cut-off**

- **More details can be found in ATLAS-CONF-2011-107:**
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-107/

Backup

Control Region Plots

Z performance shows reasonable agreement between MC and Data.