W,Z and Diboson physics at ATLAS

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On Behalf of the ATLAS Collaboration

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Introduction to W/Z physics

- W and Z bosons produced at high rate at the LHC, and are well known theoretically.
- Precision studies of W and Z bosons test Standard Model and pQCD in a new energy regime.
- Large statistics samples allow us to study rarer processes e.g. diboson production – stepping stones to discovery.

W/Z Measurements

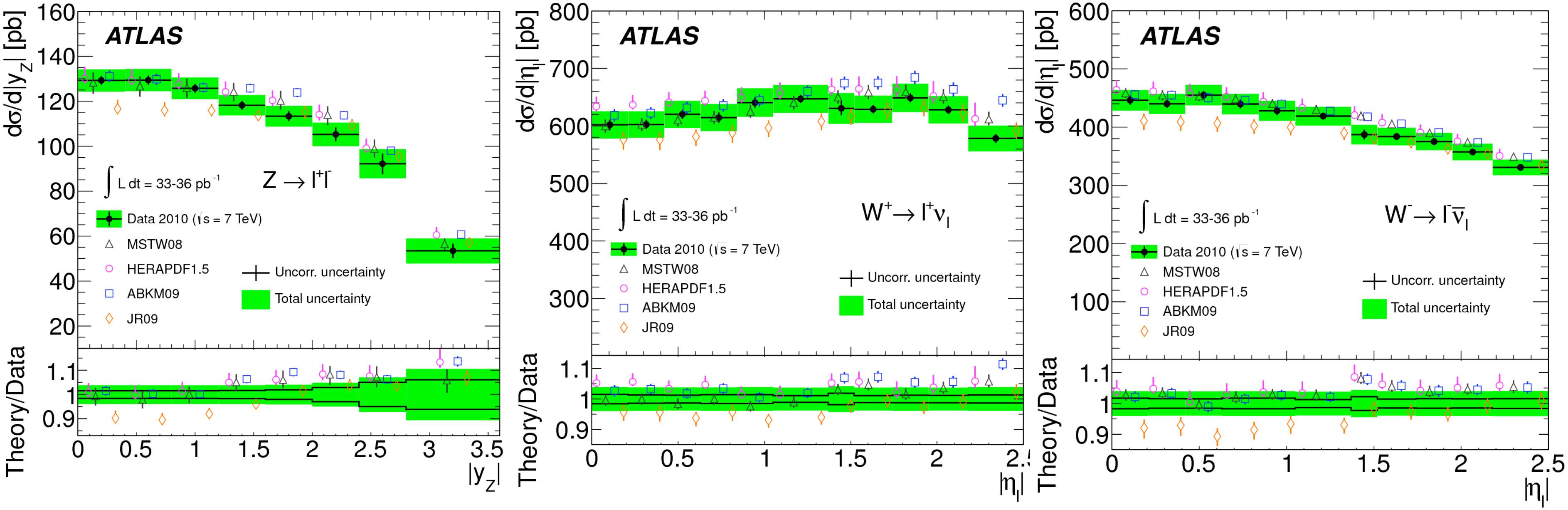
- W/Z differential cross sections
- Lepton Universality
- τ polarisation in W->$\tau\nu$
- Strange quark density

Diboson Measurements

- Wgamma/Zgamma + aTGC Limits
- WW->$l\nu l\nu$ + aTGC Limits
- WZ -> $lll\nu$ + aTGC Limits
- ZZ->$ll\nu\nu$
- ZZ -> llll + aTGC Limits

W/Z Differential Cross Sections

- W/Z cross-section measured differentially as a function of $|y_Z|$ for Z and $|\eta_l|$ for W using 33 – 36 pb^{-1} of data collected in 2010.
- Combination of electron and muon channels.
- Good agreements with NNLO predictions, though some discrepancies for some PDF sets.



http://prd.aps.org/abstract/PRD/v85/i7/e072004

Lepton Universality

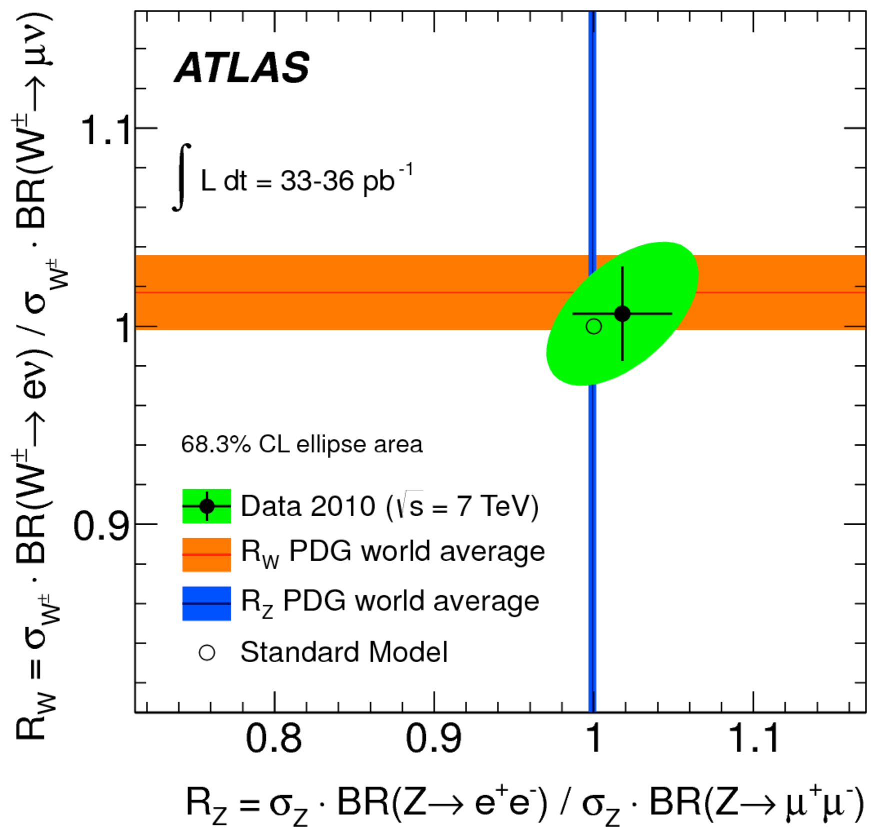
- Comparison of ratios of cross sections in electron and muon channels provides test of lepton universality.
- Production cross section independent of decay lepton flavour, so ratios of cross-sections give measurement of ratios of branching fractions.
- Results compatible with world average and with Standard Model prediction.

$$R_W = \frac{Br(W \to e\nu)}{Br(W \to \mu\nu)} = 1.006 \pm 0.024$$

World average: 1.017 ± 0.019

$$R_Z = \frac{Br(Z \to ee)}{Br(Z \to \mu\mu)} = 1.018 \pm 0.031$$

World average: 0.9991 ± 0.0024



Strange Quark Density

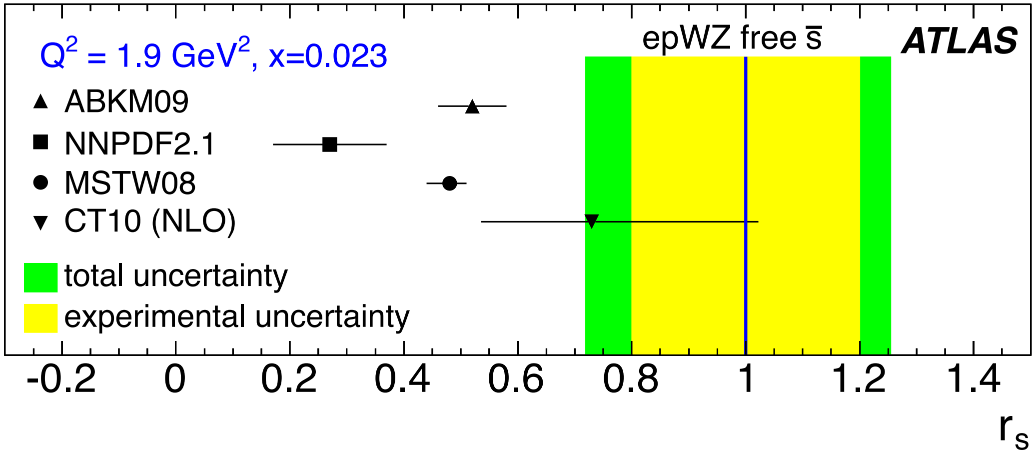
New!

- Flavour SU(3) symmetry suggests three light sea quark distributions equal, but strange quarks may be supressed due to their high mass.
- Ratio of the W± and Z cross-sections is sensitive to the strange quark fraction sensitive it contributes to σZ and σW through non-identical sub-processes $s\bar{s} \rightarrow Z$ and $sc \rightarrow W$.
- Measure $r_s = 0.5(s+\bar{s})/\bar{d}$ by a NNLO fit ATLAS data together with constraints from deep inelastic scattering from HERA using HERAFitter framework.
- Measured value at Q_2 =1.9 GeV , x=0.023 is:

$$r_s = 1.00 \pm 0.20_{\mathrm{exp}} \pm 0.07_{\mathrm{mod}}\,{}^{+0.10}_{-0.15}{}_{\mathrm{par}}\,{}^{+0.06}_{-0.07}{}_{\alpha_s} \pm 0.08_{\mathrm{th}}$$

- Consistent with prediction that the light quark see at low x is flavour symmetric.

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2011-43/

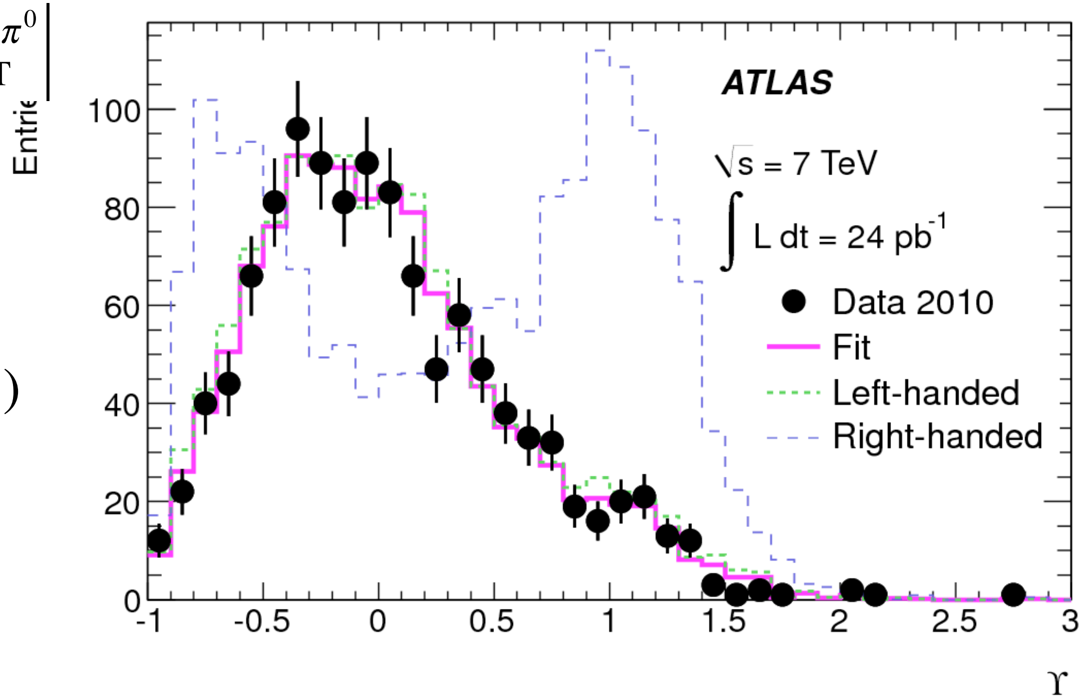


τ polarisation in W->τν decays

New!

- W^- expected to couple exclusively to left handed τ^-.
- Polarisation defined as: $P_\tau = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$ SM predicts $P_{\tau-} = -1$.
- Experimental observable in one prong tau decays sensitive to tau polarization:

$$\Upsilon = \left(E_T^{\pi^-} - E_T^{\pi^0}\right) \Big/ \left|\vec{P}_T^{\pi^-} + \vec{P}_T^{\pi^0}\right|$$



- Fit observed distribution to templates for left-handed and right-handed taus.

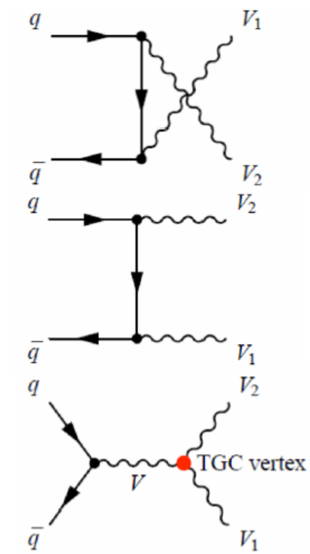
$$P_\tau = -1.06 \pm 0.04\,(stat)\,^{+0.05}_{-0.07}\,(syst)$$

- First τ polarisation measurement at a hadron collider.

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2011-46/

Diboson Physics

- Diboson production is an important test of the SM electroweak sector – relatively clean, rare signals.
- Sensitive to new phenomena such as resonant production of new massive particles.
- WW and ZZ production are irreducible backgrounds to the corresponding Higgs decay channels – crucial to understand.



Anomalous Triple Gauge Couplings

- Many new physics models lead to additional triple gauge couplings.
- aTGCs manifest as increased cross sections, especially at high p_T and high centre of mass energy.

Coupling	Parameters	Channel
$WW\gamma$	$\lambda_\gamma, \Delta\kappa_\gamma$	$WW, W\gamma$
WWZ	$\lambda_Z, \Delta\kappa_Z, \Delta g_1^Z$	WW, WZ
$ZZ\gamma$	h_3^Z, h_4^Z	$Z\gamma$
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
ZZZ	f_{40}^Z, f_{50}^Z	ZZ
$Z\gamma Z$	$f_{40}^\gamma, f_{50}^\gamma$	ZZ

Forbidden in SM

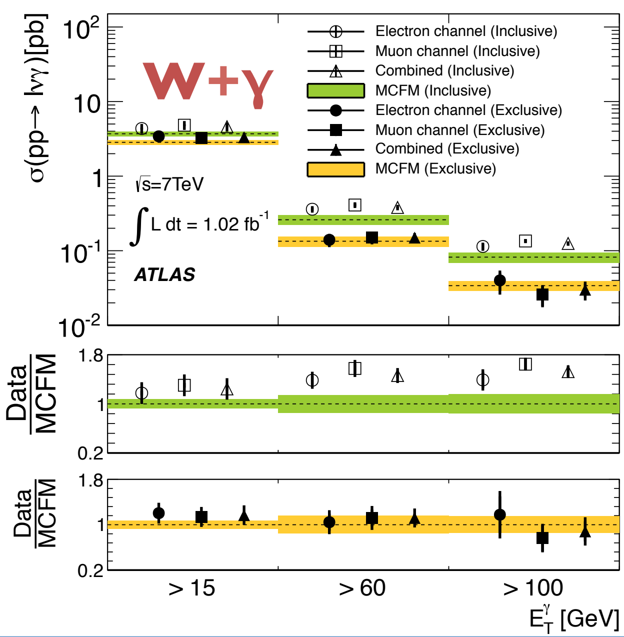
W/Z+γ

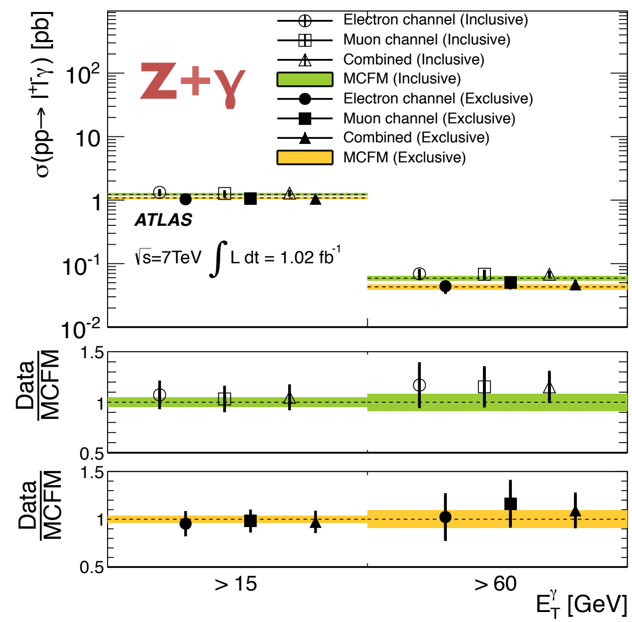
- Measure cross-sections as a function of photon E_T using 1fb^{-1} of 2011 data.
- Select events with isolated leptons with p_T > 25 GeV and isolated photon with E_T > 15 GeV, $\Delta R(l,\gamma)$ > 0.7
- **W+γ:** 1 lepton, E_T^{miss}>25GeV, M_T> 40 GeV , **Z+γ**: 2 isolated leptons, p_T > 25 GeV, M_{ll} > 40GeV
- Main background is W/Z+jets.

New!

Cross Section Measurements

- Exclusive: Veto events containing any jets with p_T > 30 GeV (YELLOW)
- Inclusive: No Jet Veto. (GREEN).



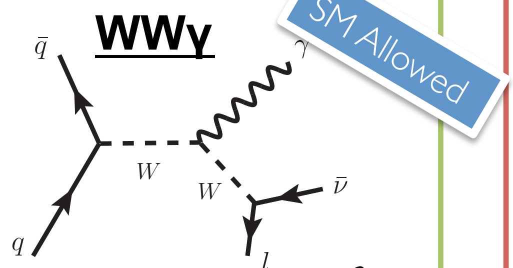


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2011-26/

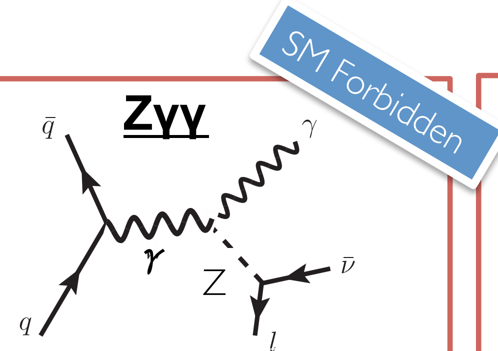
nTGC limits from W/Z+ γ

- Set limits using exclusive cross-sections in highest E_T bin: $E_T^{\gamma}>100$ GeV for W γ, $E_T^{\gamma}>60$ GeV for Z γ.

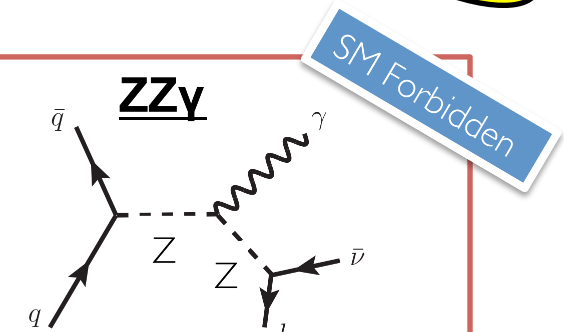
New!



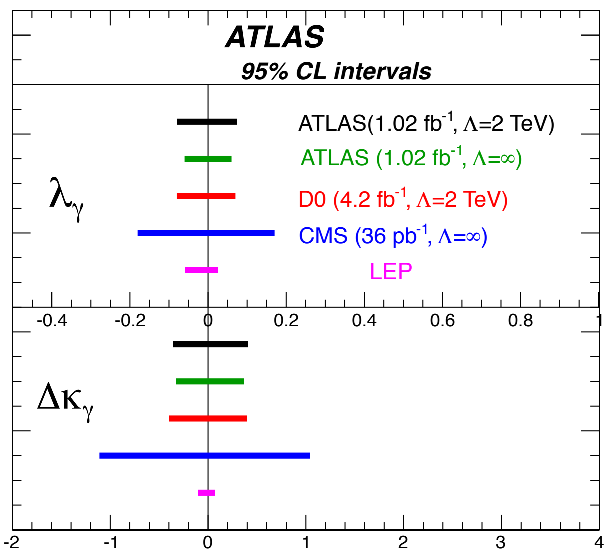
Parameters $\Delta\kappa_{\gamma}$, λ_{γ}

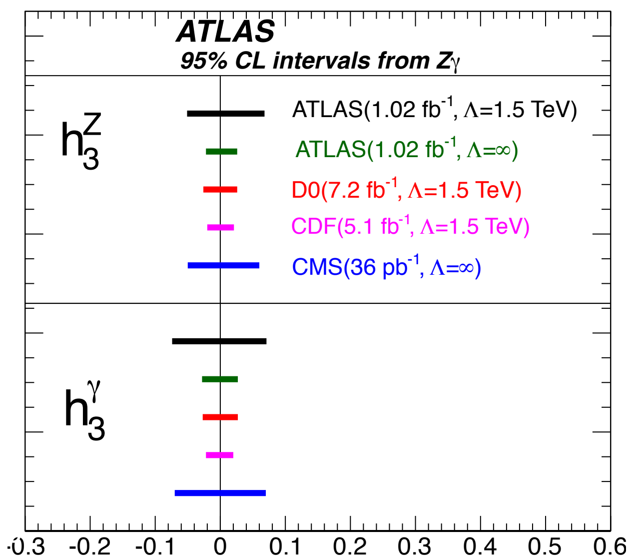


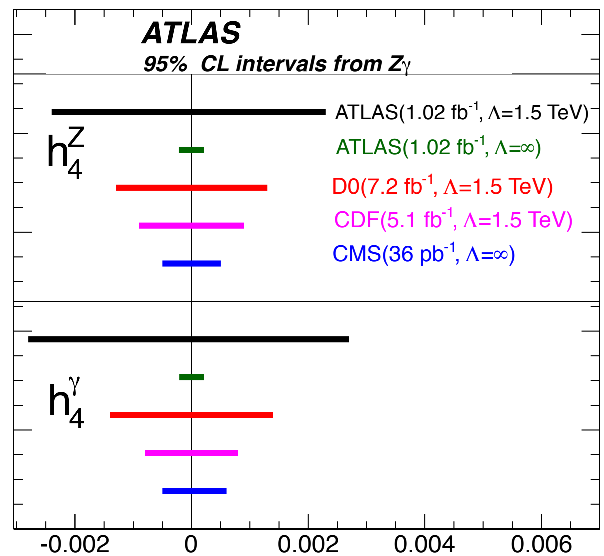
Parameters h_3^{γ}, h_4^{γ}



Parameters h_3^{Z}, h_4^{Z}





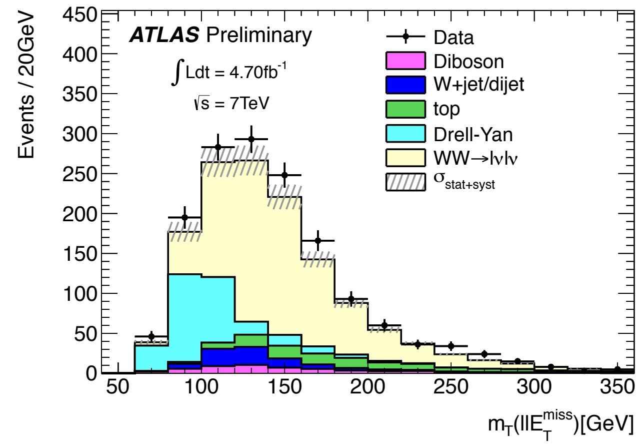


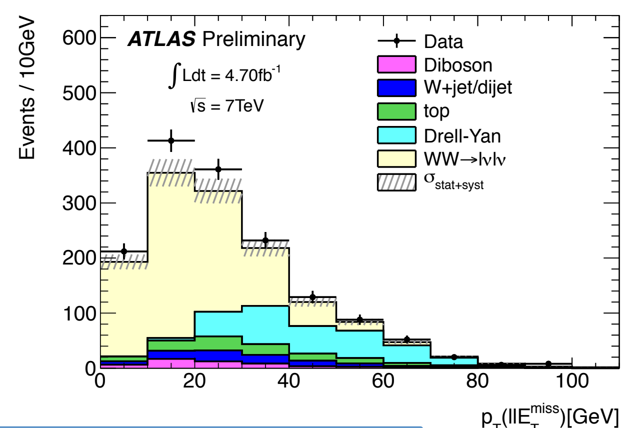
WW->lulu

- Measure cross section in 4.7fb^{-1} of 2011 data.
- Exactly 2 isolated leptons, p_T>25(leading) GeV, p_T>20(trailing) GeV
- Z/γ* / jet rejection:
  - M_{ll}>15GeV, $|M_{ll}-M_Z^{PDG}|$ >15 GeV (ee/$\mu\mu$)
  - M_{ll} > 10 GeV (eμ)
- $E_{T,rel}^{miss}$ > 55/50/25 GeV($\mu\mu$/ee/eμ)
- Veto events with a jet with p_T > 25 or a b-tagged jet with p_T> 20 GeV.
- Observe 1524 events with estimated background of 531.1±13.7±48.7.
- Measured cross section:
  - 53.4 ±2.1 (stat) ± 4.5 (syst) ± 2.1 (lumi) pb
- SM NLO prediction: 45.1 ± 2.8 pb.

New!

$$E_{\mathrm{T,\,Rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} \times \sin(\Delta\phi_{\ell,j}) & \text{if } \Delta\phi < \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2, \end{cases}$$

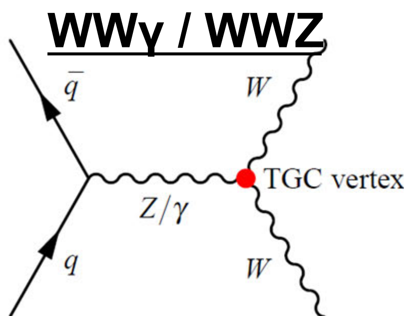




https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-025/

nTGC limits from WW->lνlν

SM Allowed

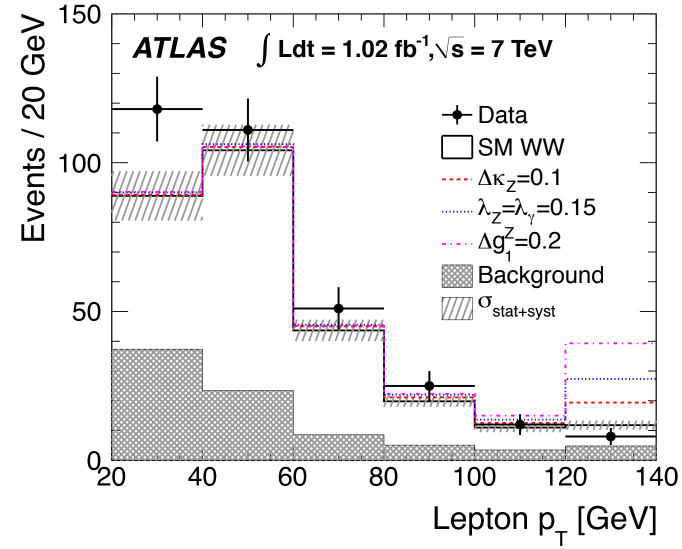


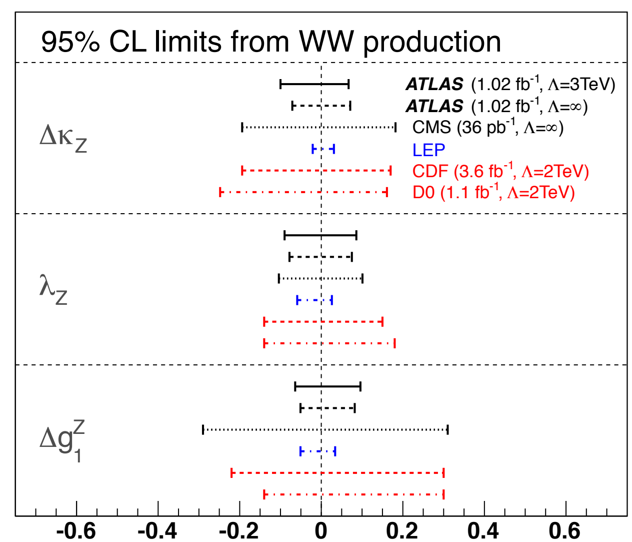
Parameters $\Delta\kappa_\gamma$, λ_γ, $\Delta\kappa_Z$, λ_Z, Δg_1^Z

- Limits set using 1fb-1 of 2011 data.
- Assume anomalous couplings arise from dimension-6 operators and EWSB occurs via a light SM Higgs ("LEP assumption", coupling parameterised by:
  - g^1_Z, κ_Z and λ_Z.
- Use leading lepton pT distribution to set limits with a binned likelihood fit.

Λ	Δg_1^Z	Δk_Z	λ_Z
3 TeV	[−0.064, 0.096]	[−0.100, 0.067]	[−0.090, 0.086]
∞	[−0.052, 0.082]	[−0.071, 0.071]	[−0.079, 0.077]

http://www.sciencedirect.com/science/article/pii/S0370269312005072





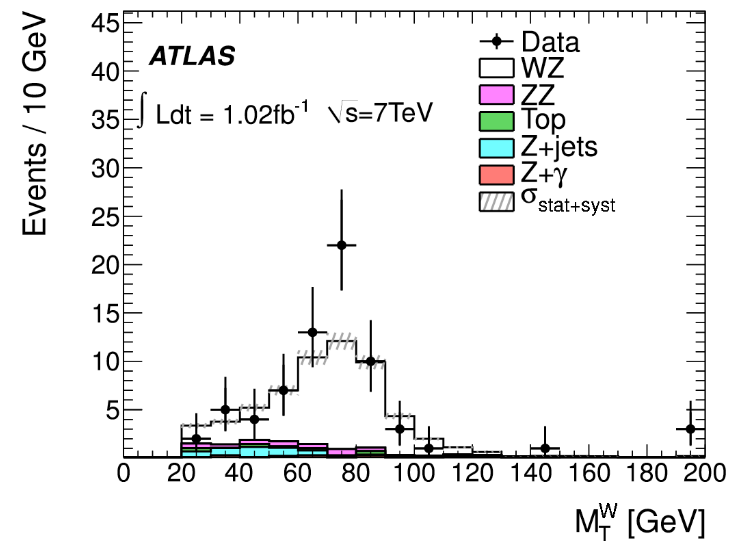
WZ->l ν ll

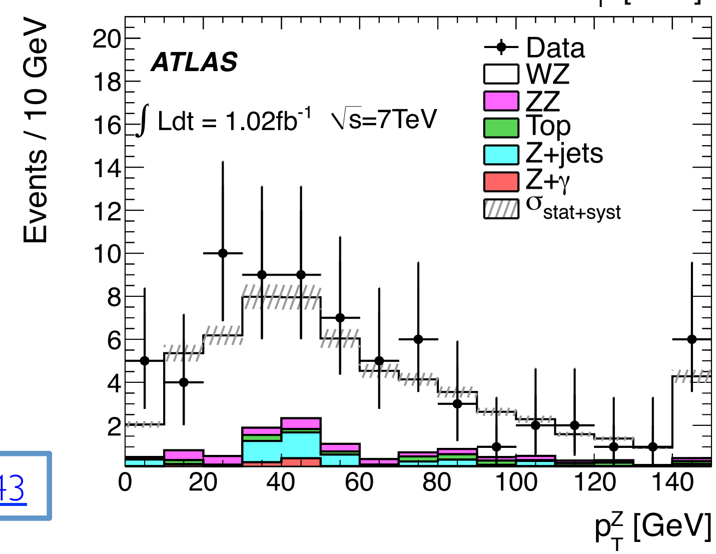
- Measured using $1.02 fb^{-1}$ of 2011 data.
  - 3 isolated leptons,
  - Z: 1st and 2nd leptons, $p_T>15$GeV $|M_{ll}-M_Z^{PDG}| < 10$GeV
  - W: 3rd lepton, $p_T>20$GeV, $m_T>20$GeV, $E_t^{miss} > 25$GeV
- Major backgrounds: Z+jets/ γ , ZZ, Top
- Observe 71 events, expected background of 12.1 ± 1.4 (syst) $^{+4.1}_{-2.0}$ (stat).
- Measured cross-section:

$$\sigma^{\rm fid}_{WZ\to\ell\nu\ell\ell} = 102^{+15}_{-14}({\rm stat.})^{+7}_{-6}({\rm syst.})^{+4}_{-4}({\rm lumi.})\ {\rm fb}$$

$$\sigma^{\rm tot}_{WZ} = 20.5^{+3.1}_{-2.8}({\rm stat.})^{+1.4}_{-1.3}({\rm syst.})^{+0.9}_{-0.8}({\rm lumi.})\ {\rm pb}.$$

- SM prediction: $17.3^{+1.3}_{-0.8}$ pb



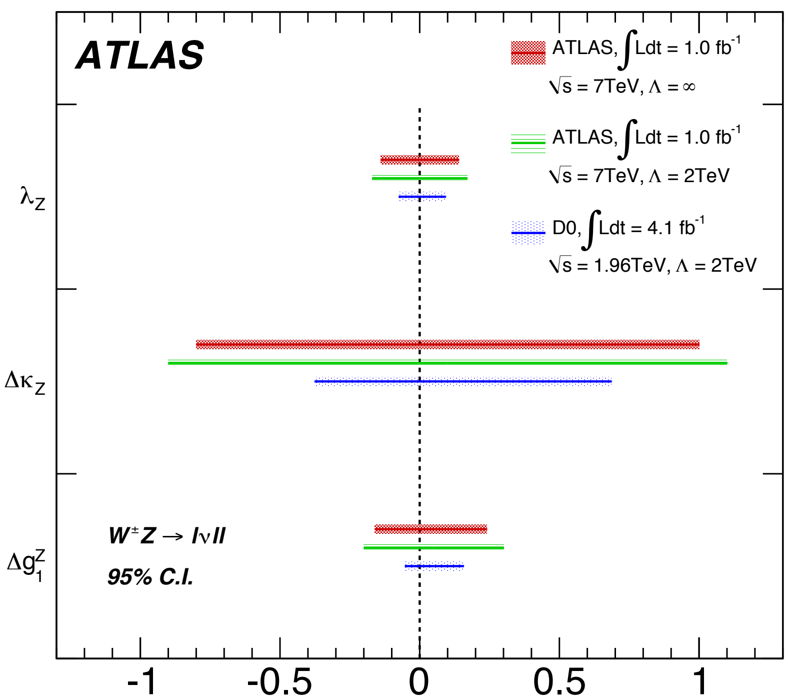


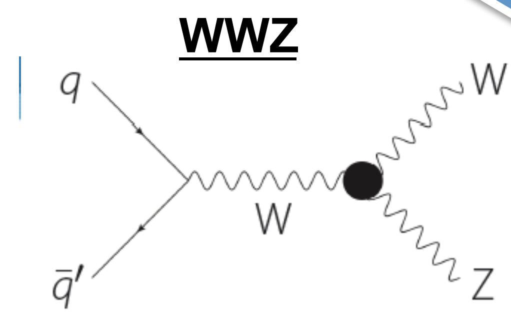
http://www.sciencedirect.com/science/article/pii/S0370269312001943

nTGC limits from WZ->lllυ

- Set limits of deviations from SM values using 1.02fb^{-1} cross section measurement.
- Limits set are compatible with SM.

SM Allowed





Parameters $\Delta g_1{}^Z$, $\Delta\kappa_Z$, λ_Z

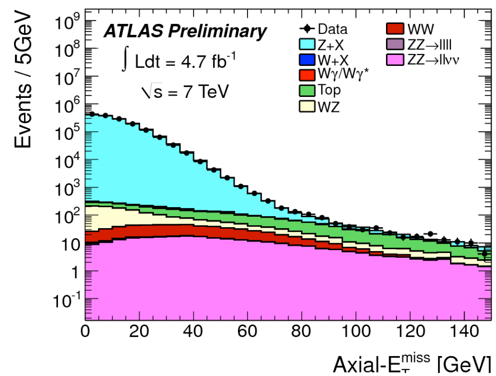
Coupling	Observed ($\Lambda = 2$ TeV)	Observed ($\Lambda = \infty$)	Expected ($\Lambda = \infty$)
Δg_1^Z	$[-0.20, 0.30]$	$[-0.16, 0.24]$	$[-0.12, 0.20]$
$\Delta\kappa_Z$	$[-0.9, 1.1]$	$[-0.8, 1.0]$	$[-0.6, 0.8]$
λ_Z	$[-0.17, 0.17]$	$[-0.14, 0.14]$	$[-0.11, 0.11]$

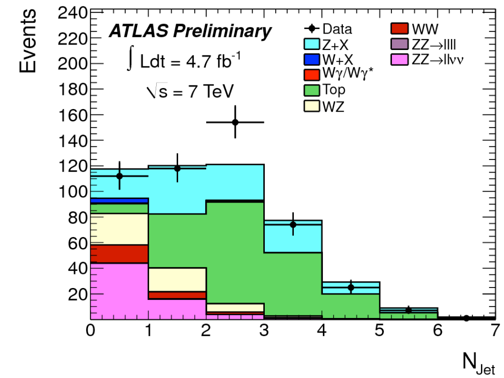
ZZ->llυυ

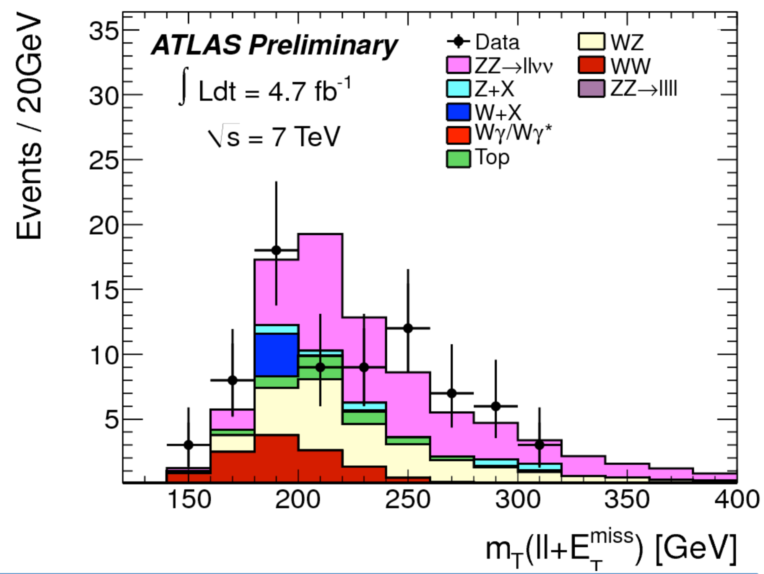
- Measure in 4.7fb-1 of 2012 data. Final states involving two isolated electrons and muons plus missing transverse energy.
- Lepton p_T > 20 GeV, $|M_{ll}-M^{Z}_{PDG}|<15$ GeV.
- No reconstructed jets with pT>25 GeV.
- Axial-E_T^{miss} > 80GeV (E_T^{miss} projection along Z pT)
- Fractional difference $|E_T^{miss} - p^Z_T|/p^Z_T < 0.6$.
- Observed 78 events with background estimated to be 40.7±4.3 (syst) ± 3.7 (stat)
- Measured total cross-section:

$$\sigma^{tot}_{ZZ} = 5.4^{+1.3}_{-1.2}(\text{stat.})^{+1.4}_{-1.0}(\text{syst.}) \pm 0.2(\text{lumi.})\ \text{pb}$$

- Consistent with SM prediction of $6.5^{+0.3}_{-0.2}$ pb.







https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-027/

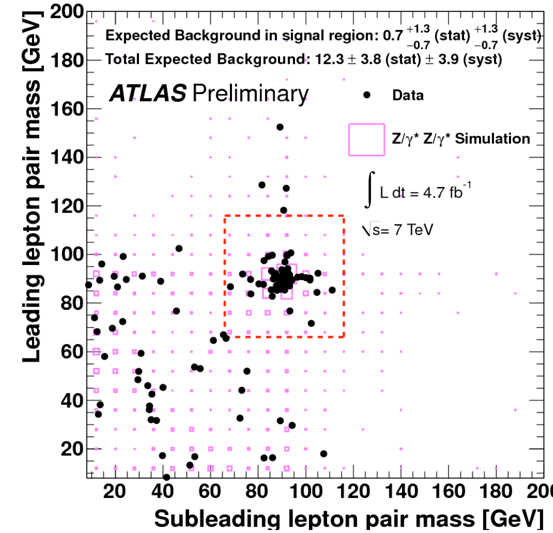
ZZ->llll

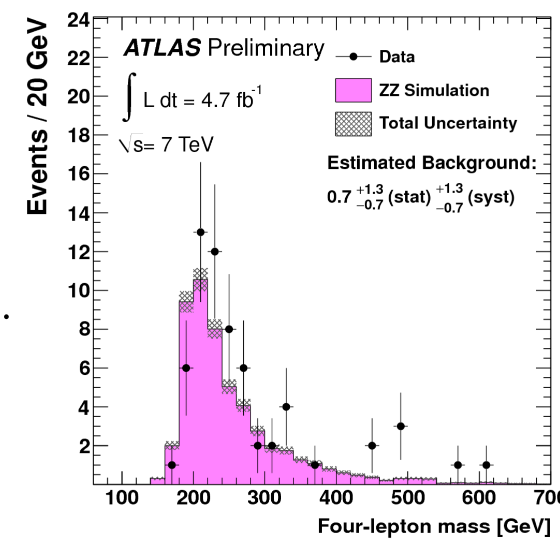
- 4.7fb-1 of 2012 data. Final states involving four isolated electrons and muons.
- Electron: pT > 7 GeV, |eta| < 2.47
- Muon: pT > 7 GeV, |eta|<2.7
- Both Z bosons 66 < m_Z < 116 GeV.
- Very low background:
  - Mainly Z+jets, ttbar, other diboson.
  - Data driven estimate 0.7+1.3-0.7 (syst) +1.3-0.7 (stat) events.
- Observed 62 events.
- Measured cross section:

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

- Consistent with SM NLO prediction of $6.5^{+0.3}_{-0.2}$ pb.

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-026/

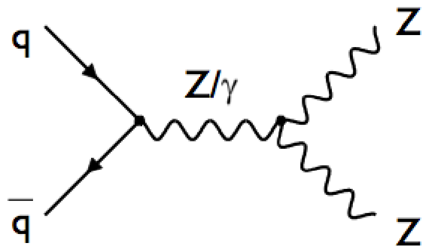




ZZ->llll nTGC limits

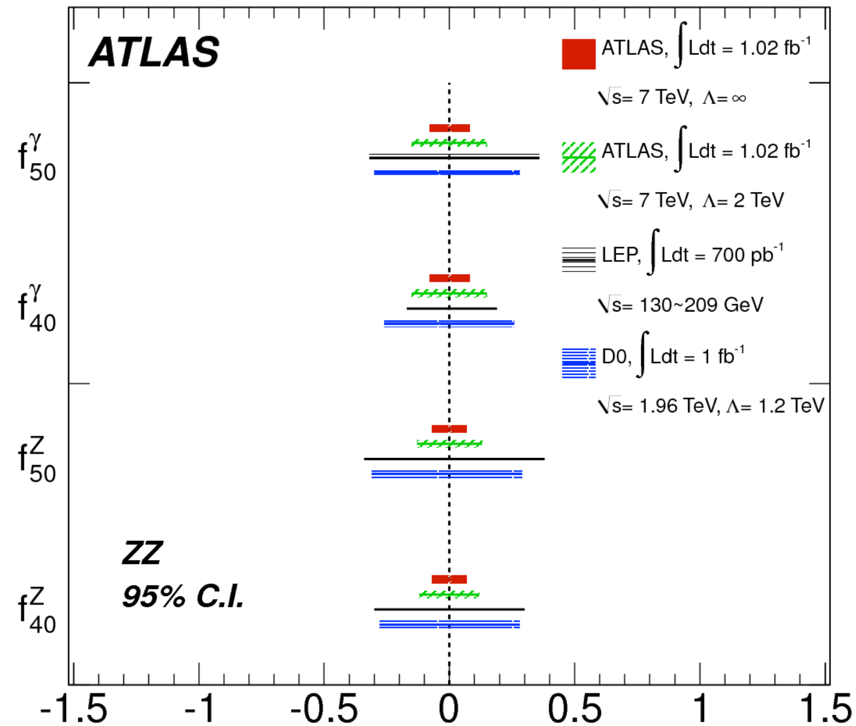
SM Forbidden

ZZZ / ZZγ



Parameters f_4^{γ}, f_5^{γ}, f_4^{Z}, f_5^{Z}

- Set using first 1.02 fb-1 of dataset.
- Limits set using total number of events only.
- Limits are comparable to, or tighter than previous limits from other experiments and compatible with SM expectation.

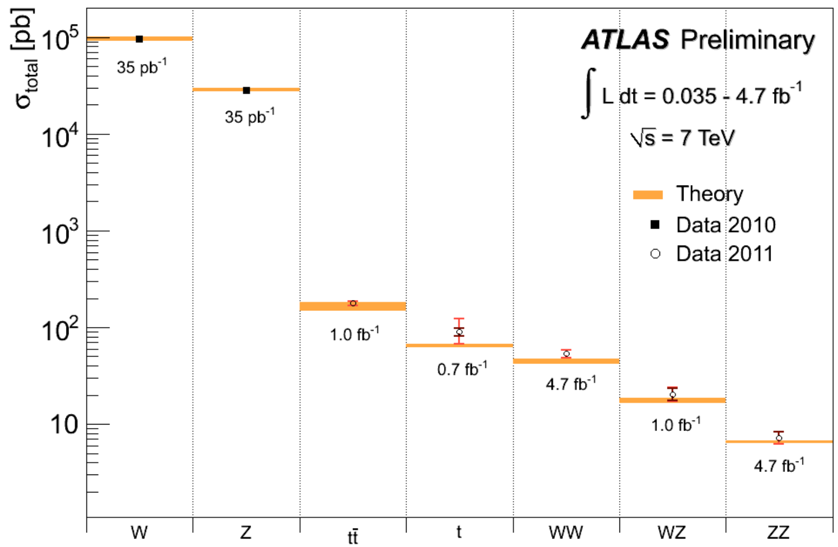


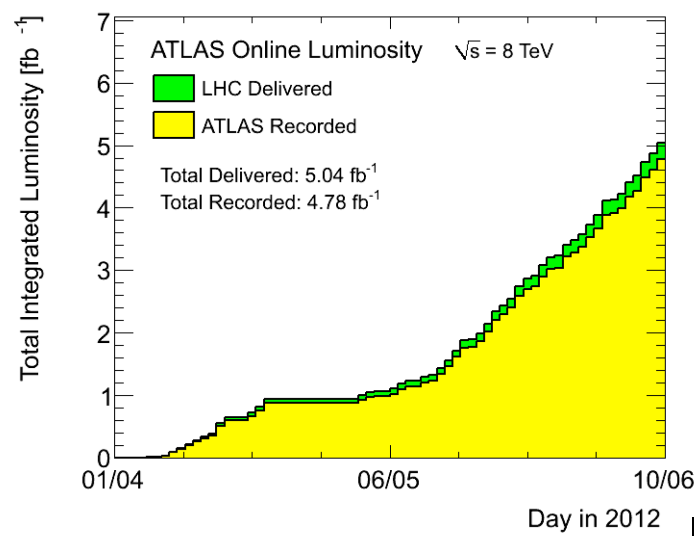
Λ	f_{40}^{γ}	f_{40}^{Z}	f_{50}^{γ}	f_{50}^{Z}
2 TeV	$[-0.15, 0.15]$	$[-0.12, 0.12]$	$[-0.15, 0.15]$	$[-0.13, 0.13]$
∞	$[-0.08, 0.08]$	$[-0.07, 0.07]$	$[-0.08, 0.08]$	$[-0.07, 0.07]$

http://prl.aps.org/abstract/PRL/v108/i4/e041804

Summary and Outlook

- Wide range of W/Z and diboson physics measurements performed by ATLAS giving rigorous tests of the Standard Model.
- Most W/Z measurements are based on 2010 data. The 2011 dataset gives more than 100 times more statistics – expect even more precise results soon.
- Diboson measurements based on 2011 data, but still much work ongoing with this dataset.
- 2012 data at 8 TeV accumulating fast!





Spare Slides

The ATLAS Experiment

- General purpose detector covering nearly entire solid angle around interaction point.
- Inner tracking detector in 2T axial magnet field provides charged particle tracking for $|\eta| < 2.5$.
- Electromagnetic and hadronic calorimeter system provide coverage for $|\eta| < 4.9$.
- Muon spectrometer provides coverage for $|\eta| < 2.7$ with separate trigger and high-precision tracking chambers.