

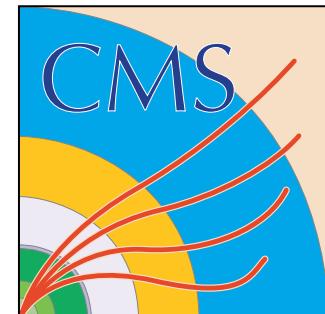
Electroweak Measurements at ATLAS & CMS

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On behalf of the ATLAS+CMS collaborations

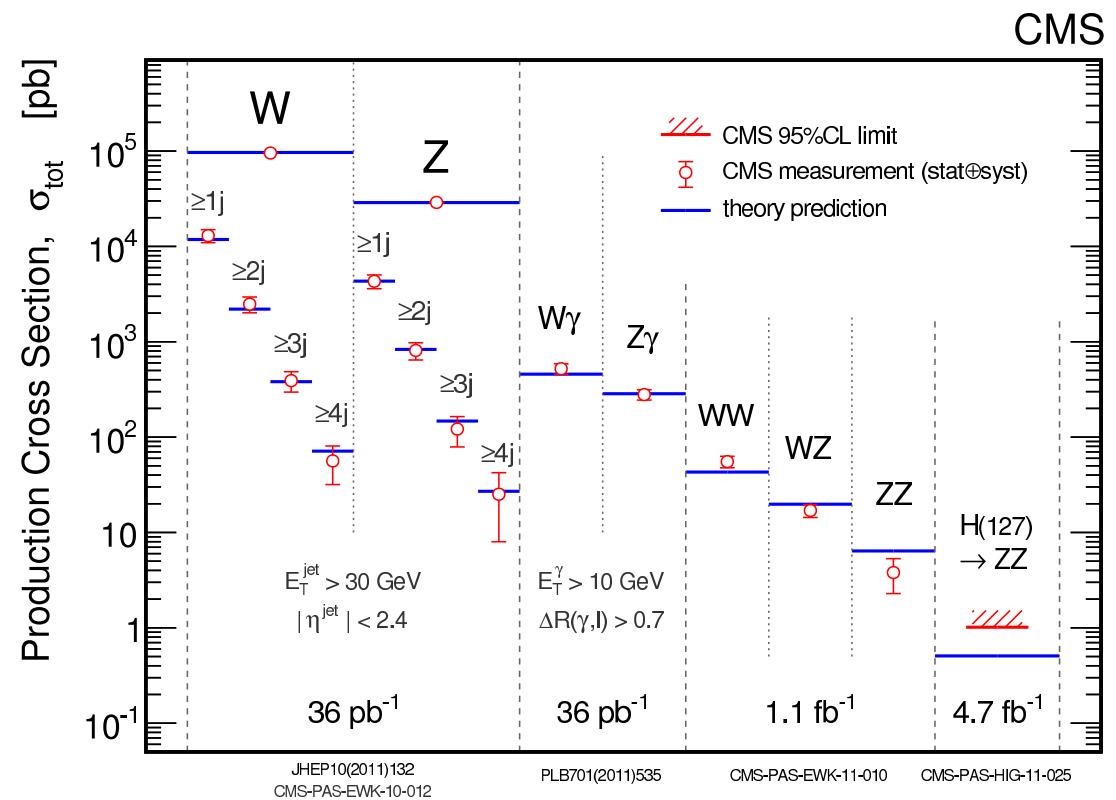
Moriond EW 2012, 7.3.2012



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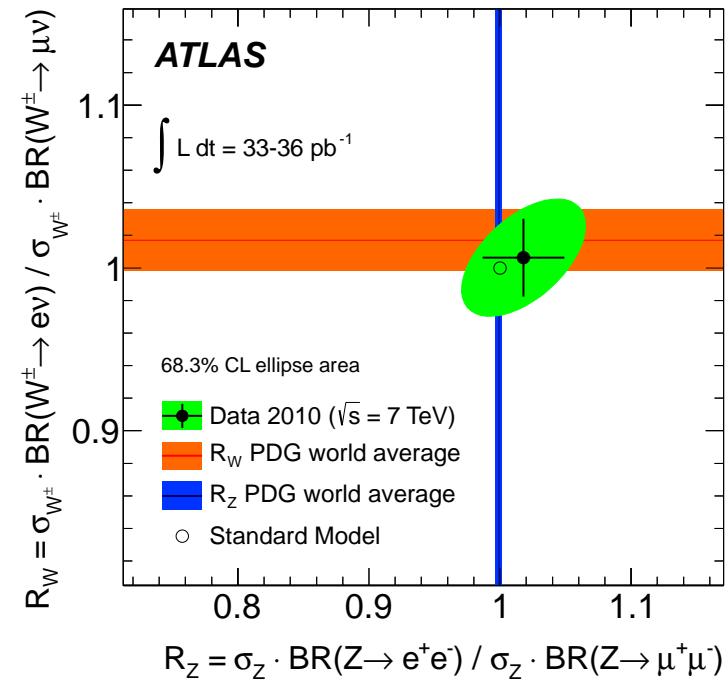
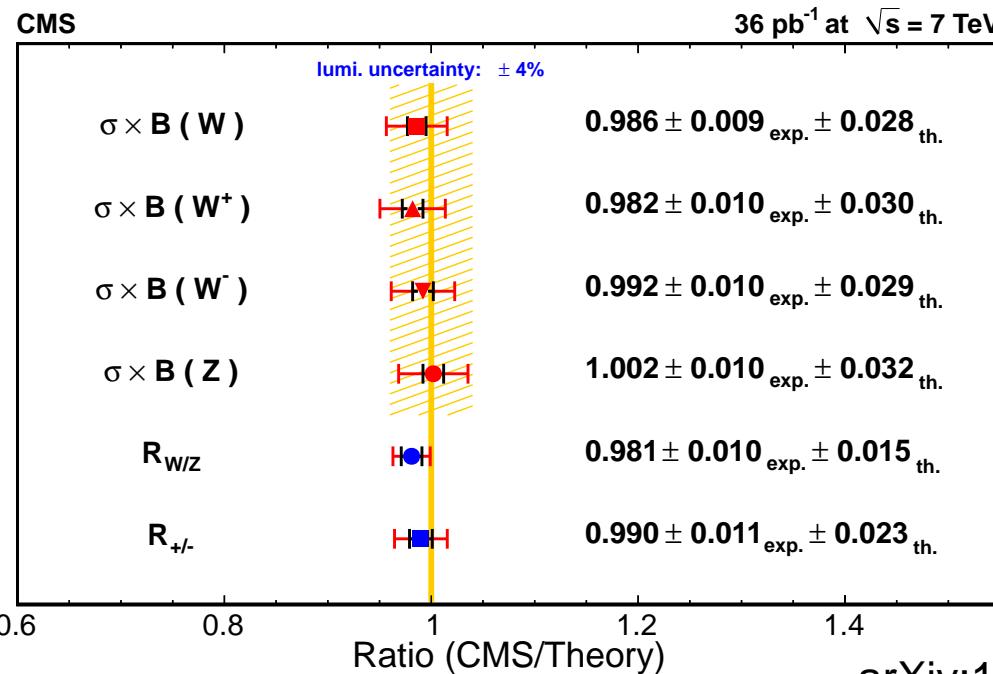
Electroweak measurements at LHC

- QCD sector
 - Proton structure (W, Z inclusive and +heavy flavours)
 - Higher order processes ($W, Z+jets$)
 - W polarisation
- Electroweak sector
 - Lepton universality
 - τ polarisation in $W \rightarrow \tau\nu$
 - Electroweak mixing angle $\sin^2 \theta$
 - Di-Boson production, triple gauge couplings



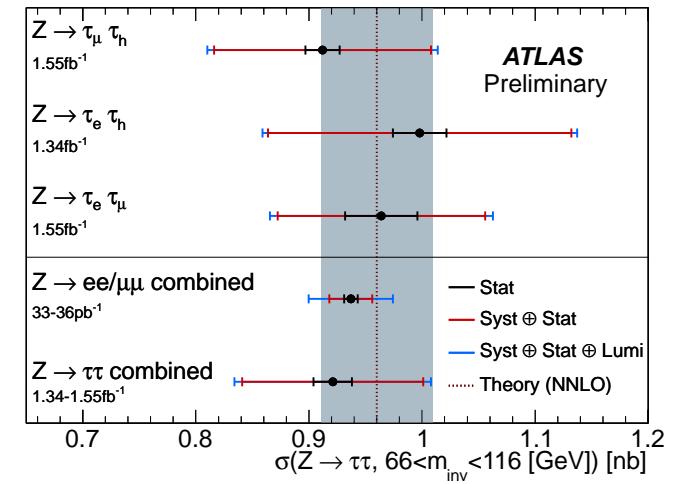
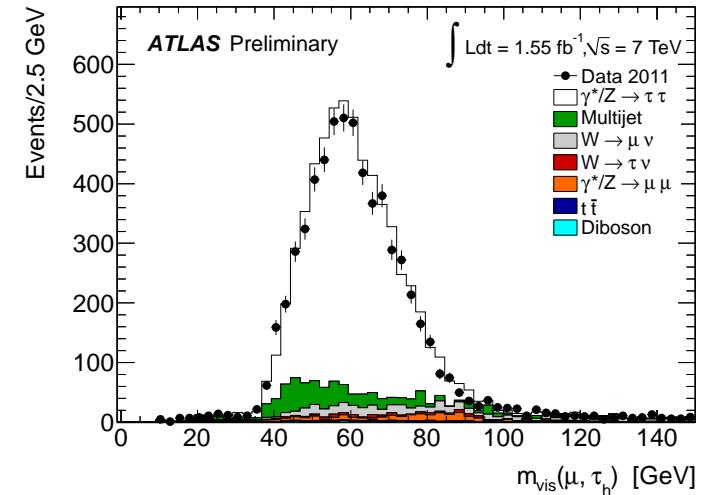
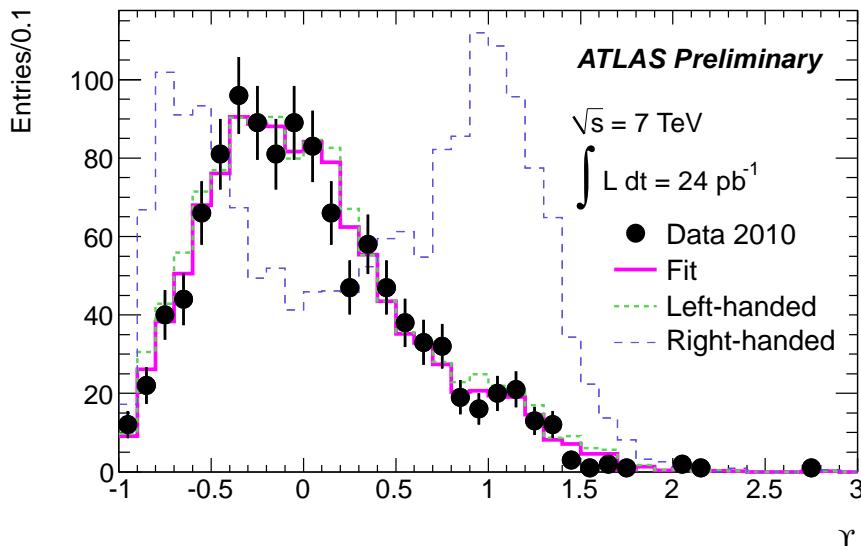
W and Z Production

- Cross section for inclusive production and leptonic decays, $W \rightarrow \ell\nu$ and $Z \rightarrow \ell\ell$ reached experimental accuracy of few % in $\ell = e, \mu$ channels with 2010 data
- QCD prediction at NNLO: precision test of proton PDFs and the SM
- Maximising sensitivity using ratios and correlation information; avoid extrapolation in theory comparison
- $e - \mu$ universality in W decays confirmed to 2%



$W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$

- W, Z cross sections measured in τ decays: latest result using $\mu\tau_h$, $e\tau_h$, and $e\mu$ channels with $\sim 10\%$ syst. unc.
- First measurement of τ polarisation in $W \rightarrow \tau_h\nu$ at hadron collider
- Using one-prong decays, energy sharing: $\Upsilon = (E_T^{\pi^-} - E_T^{\pi^0})/(E_T^{\pi^-} + E_T^{\pi^0})$
- $P_\tau = -1.06 \pm 0.04_{\text{stat}}^{+0.05}_{-0.07}$ syst
- Applications e.g. for $H \rightarrow \tau\tau$ ($P_\tau = 0$) and search for new physics



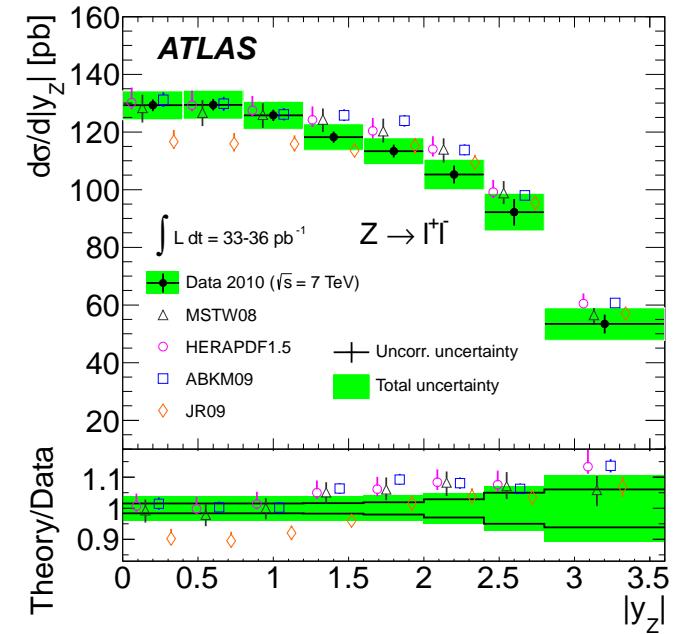
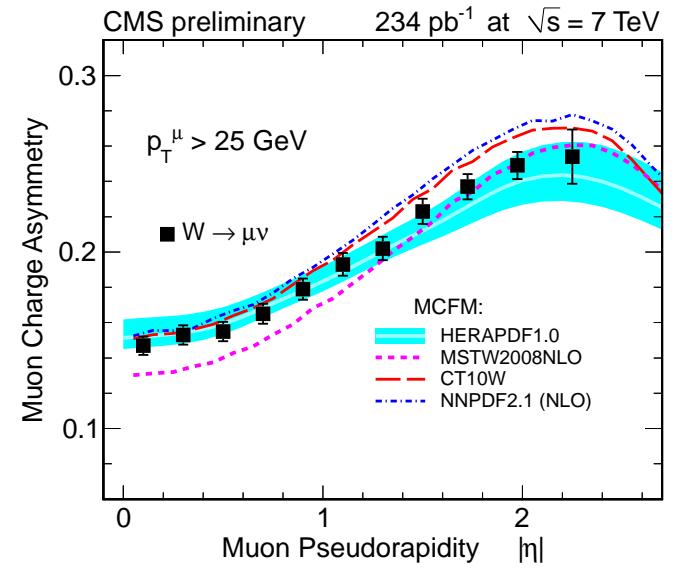
PRD 84 (2011) 112006; PLB 706 (2012) 276-294;
ATLAS-CONF-2012-006; ATLAS-CONF-2012-009;
JHEP 08 (2011) 117; CMS-PAS-EWK-11-019

W and Z Rapidity Differential Measurements

- Boson rapidity y directly linked to parton momentum fractions $x_{1,2} = M_{W,Z}/\sqrt{s} \cdot e^{\pm y}$
- W : charged lepton pseudo-rapidity η_ℓ used
- CMS:
 - W lepton charge asymmetry

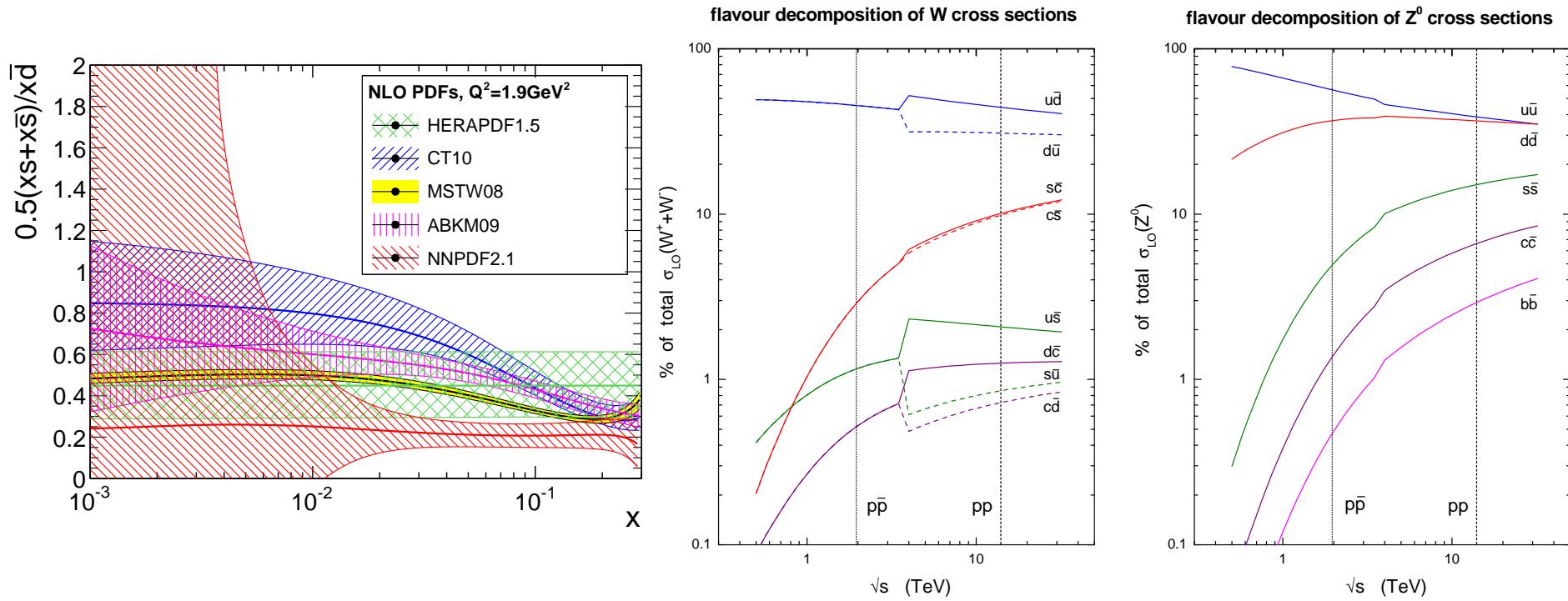
$$A(\eta) = (d\sigma^+(\eta) - d\sigma^-(\eta)) / (d\sigma^+(\eta) + d\sigma^-(\eta))$$
 - normalised Z rapidity $1/\sigma \cdot d\sigma/dy$
- ATLAS: absolute differential cross sections for Z, W^+, W^- with correlation information
- Comparison to theory at NLO and NNLO shows broad agreement, but also indicates sensitivity to PDFs

arXiv:1109.5141→PRD; arXiv:1110.4973→PRD;
JHEP04(2011)050; CMS PAS EWK-11-005



Strange quark PDF

- Little known about strange quark content of the proton at low x
- Ratio $r_s = 0.5 \cdot (xs(x) + x\bar{s}(x))/x\bar{d}(x)$ often assumed to be < 1 at low scale due to strange quark mass; large differences between PDFs
- Compared to Tevatron larger relevance of strange for W and Z prod.:
 - Knowledge important for e.g. W mass measurements
 - Constraints from new measurements: Z rapidity and W +charm

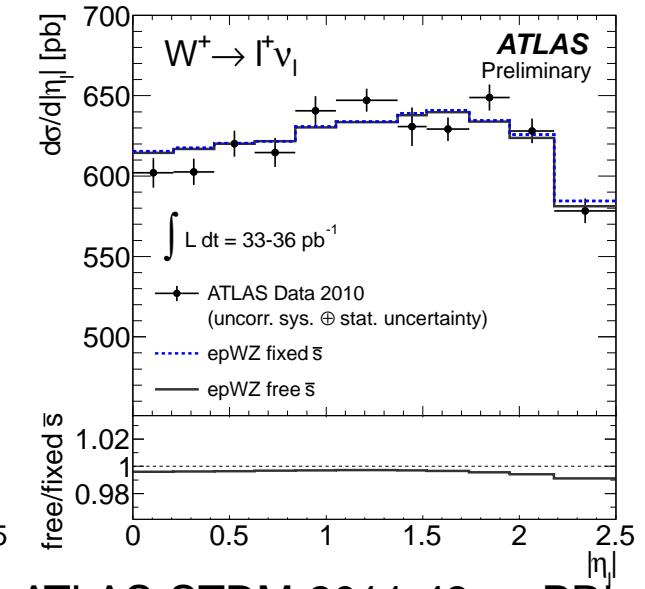
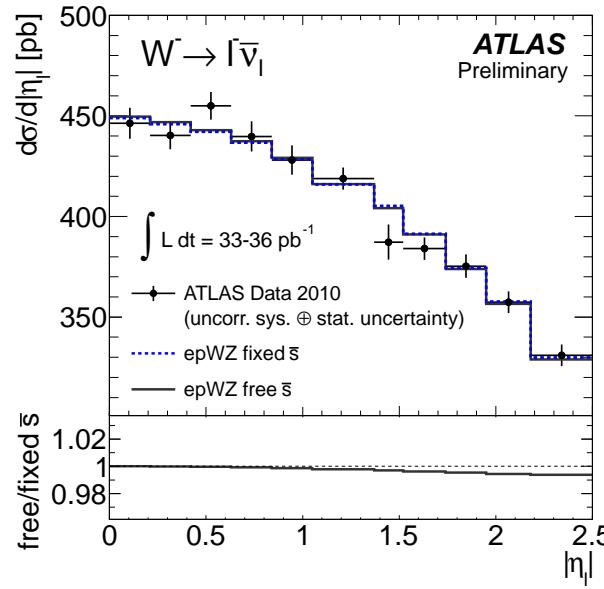
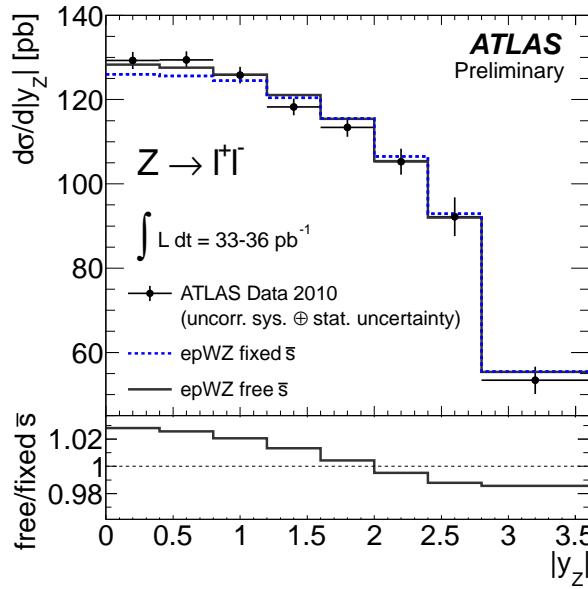
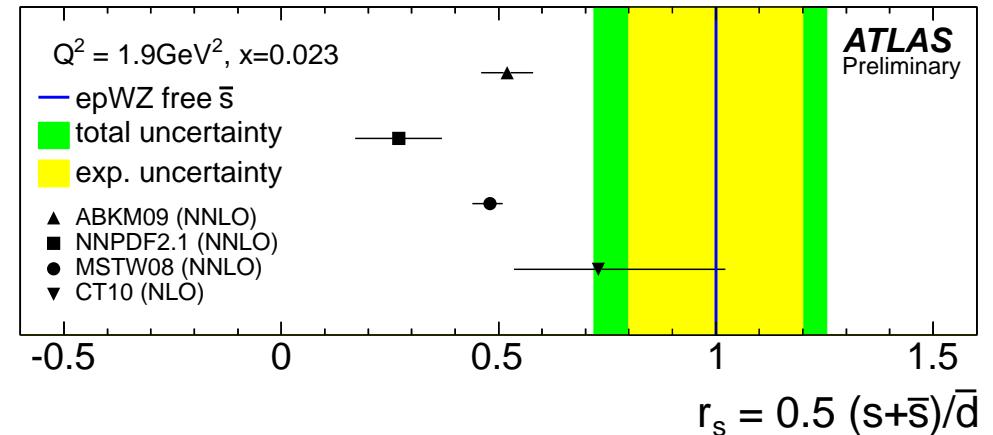


W.J. Stirling: MSTW2008 LO

W, Z data sensitivity to strange sea

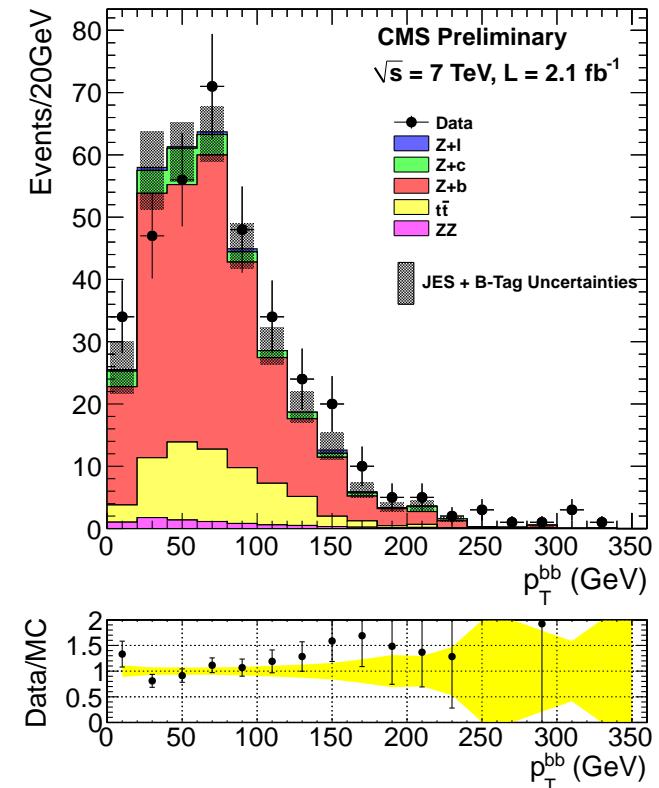
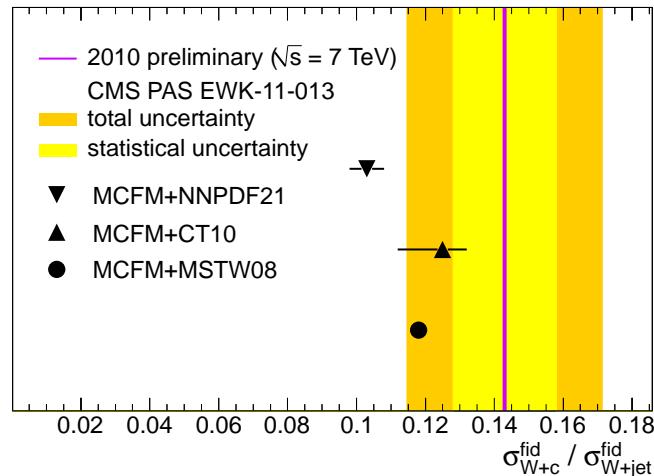
- ATLAS performed NNLO QCD fit to Z, W^+, W^- + HERA ep DIS cross sections: significant tension for Z observed when suppressing strange by 50% at low scale 1.9 GeV^2
- Fit with free strange sea gives no suppression

$$r_s = 1.00 \pm 0.20_{\text{exp}}^{+0.16}_{-0.20 \text{ sys}}$$



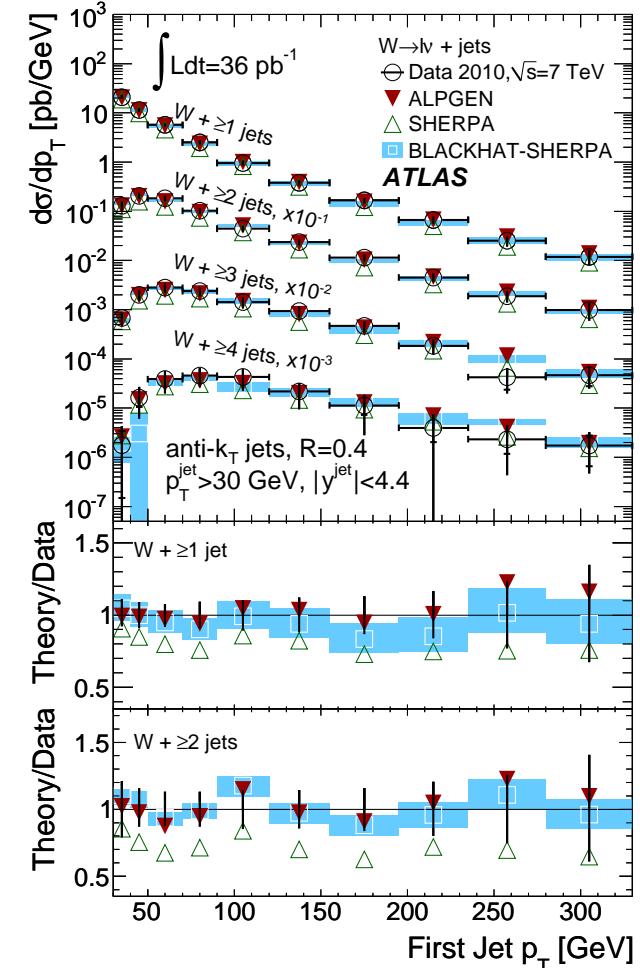
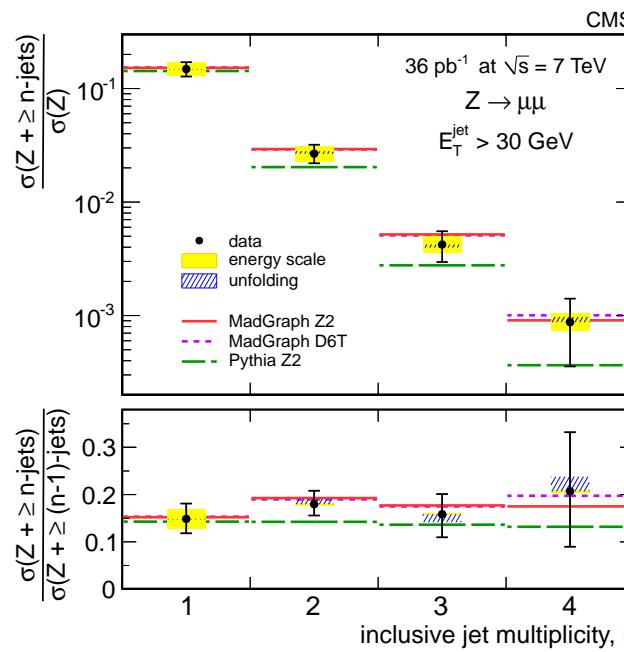
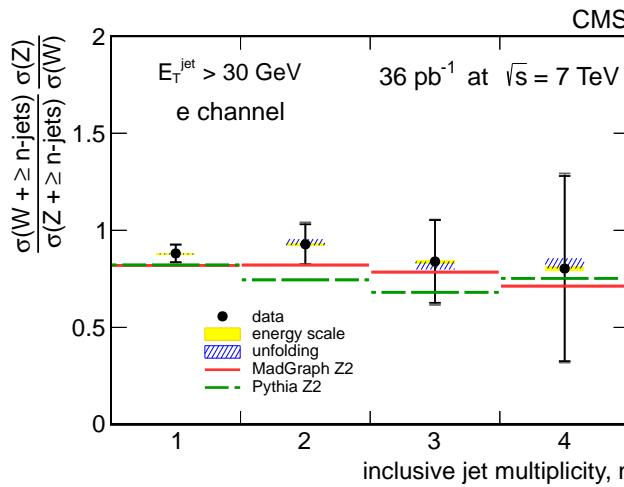
$W + c$ and $Z + b$ production

- Direct access to strange quark content by selecting Cabibbo-favoured processes $\bar{s}g \rightarrow W^+ \bar{c}$ and $sg \rightarrow W^- c$
- First ratio measurements by CMS using $W +$ secondary vertex tagged jets to $\sim 20\%$ precision; $R_c = \sigma(Wc)/\sigma(W + \text{jet})$ indicates large s
- $W + b$ jet (ATLAS) and $Z + b(\bar{b})$ (ATLAS+CMS) were measured
- Latest CMS result: $Z + \geq 1b$ and $Z + 2b$ measured to 9% and 20% \rightarrow YSF talk T.d.P.
- $Z + 2b$ cross section agrees with MadGraph+Pythia expectation



$W, Z + \text{jet production}$

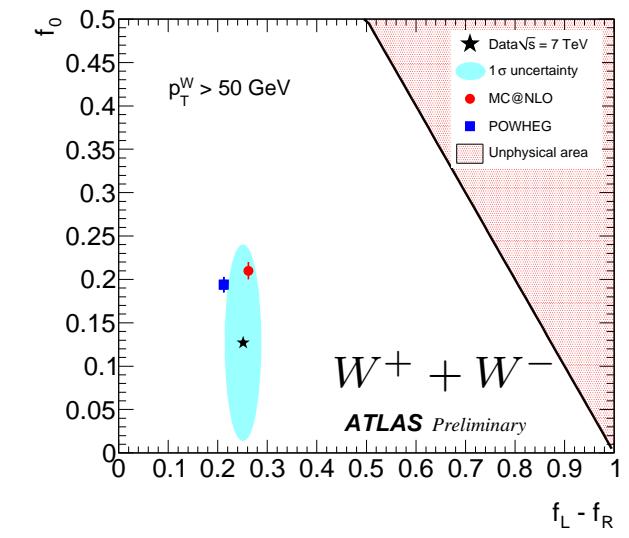
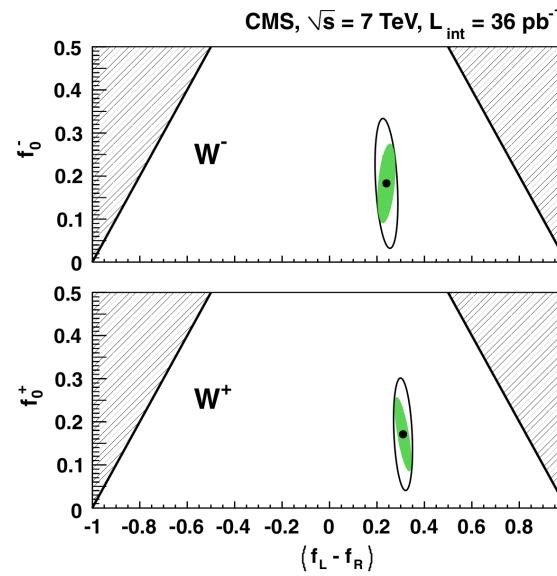
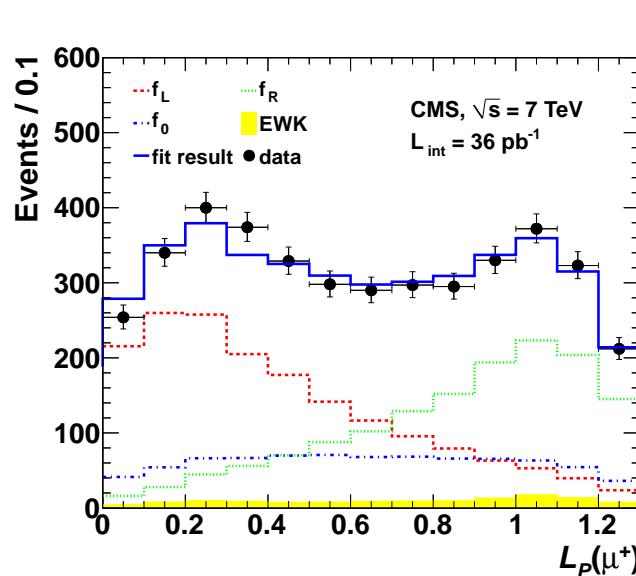
- ATLAS and CMS published rich menu of cross sections and ratios of jets produced in association with W and Z bosons
- Test of tree-level matrix element generators $V + n$ jets with $n \simeq 0 \dots 4$: AlpGen, MadGraph, Sherpa
- NLO QCD calculation by *BlackHat+Sherpa*
- In general good agreement of data with MCs or QCD



arXiv:1111.2690→PRD; arXiv:1201.1276→PRD;
PLB 708 (2012) 221-240; arXiv:1110.3226→JHEP

W polarisation

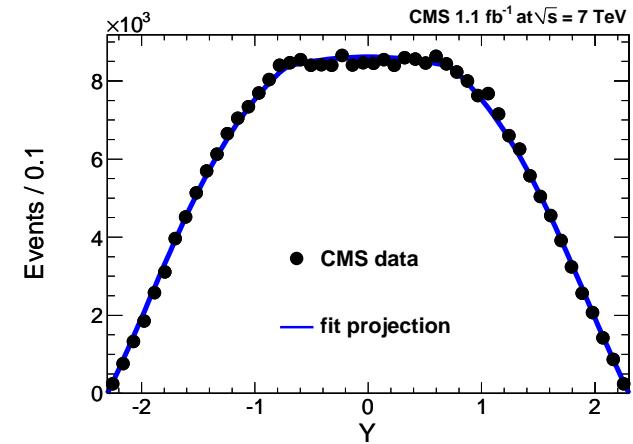
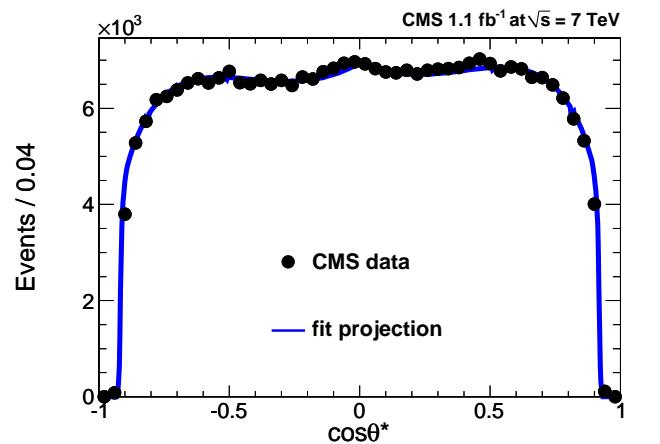
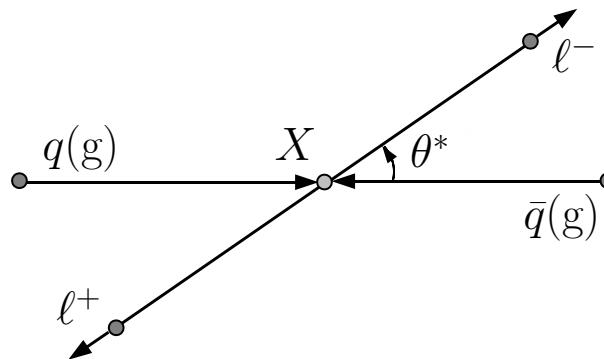
- W bosons can be produced in three polarisation states: f_L, f_R, f_0
- Measured at significant $p_T^W > 35(50)$ GeV by analysing lepton p_T and angular distribution using e.g.: $L_P = \vec{p}_T^\ell \cdot \vec{p}_T^W / |\vec{p}_T^W|^2 \approx \cos\theta$
- Predominantly left-handed W production and non-zero longitudinal component as predicted by NLO QCD
- Important for precision W physics at the LHC



To be submitted to EPJC; PRL 107:021802, 2011

Weak mixing angle $\sin^2 \theta$

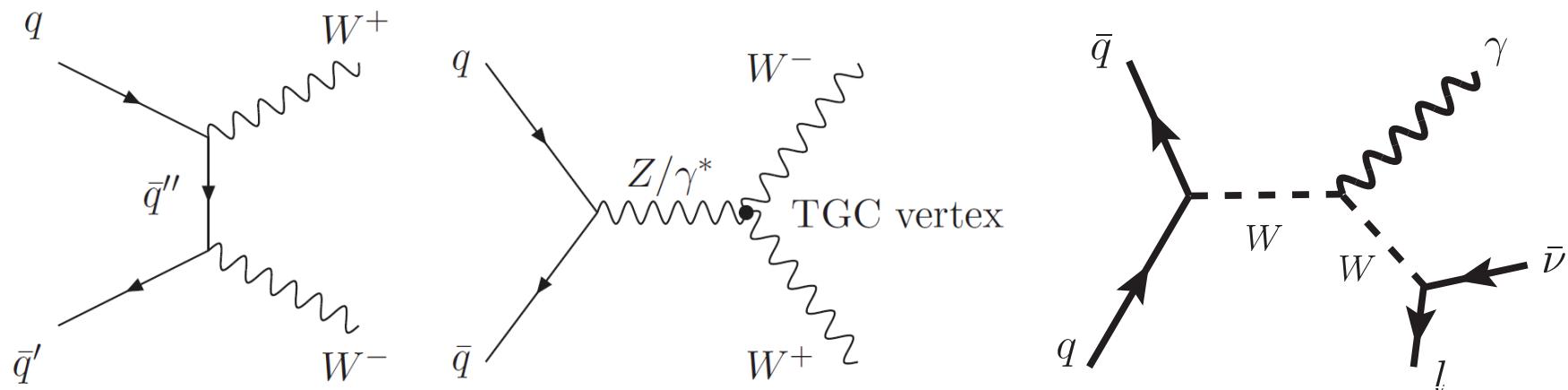
- Fundamental parameter of the SM, world average has 0.1% accuracy, but contains results with few σ tension
- CMS has used large amount of Z/γ^* to measure $\sin^2 \theta_{\text{eff}}$ from the *forward-backward asymmetry* in the $q\bar{q} \rightarrow Z/\gamma^* \rightarrow \mu^-\mu^+$ process
- Quark direction more likely in boost direction: three dimensional fit in decay angle $\cos \theta^*$, mass m and rapidity y to disentangle forward/backward direction on statistical basis
- Result with $\sim 1\%$ precision: $\sin^2 \theta_{\text{eff}} = 0.2287 \pm 0.0020_{\text{stat}} \pm 0.0025_{\text{syst}}$



PRD 84, 112002 (2011)

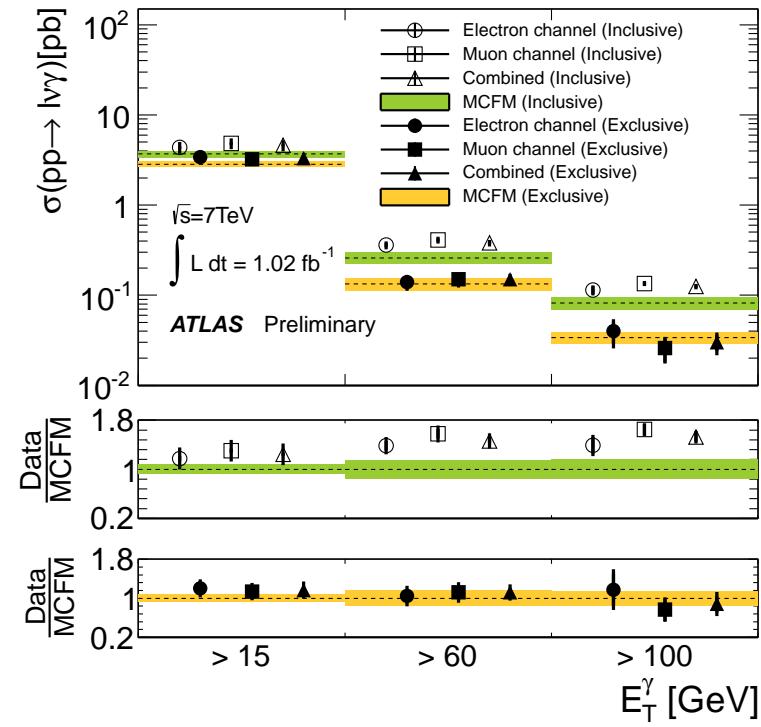
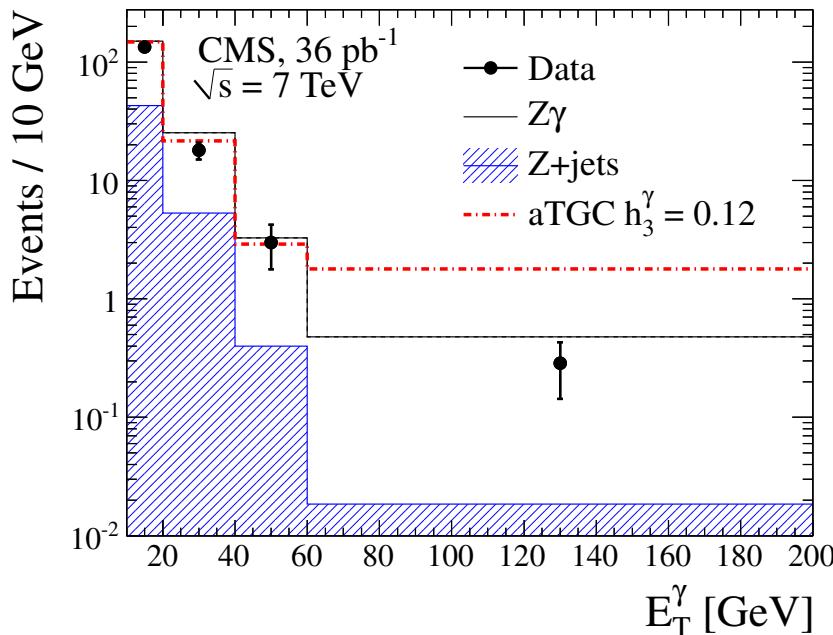
Di-Boson Production

- Main production diagrams for di-bosons are in general t -channel quark exchange and FSR for γ
- In the standard model s -channel contribute with triple gauge coupling (TGC) due to non-Abelian $SU(2)_L \times U(1)_Y$ structure:
 - Allowed for $WW\gamma$ and WWZ vertices
 - Not allowed for “neutral” ZZZ , $ZZ\gamma$ or $Z\gamma\gamma$ vertices
- Select phase space with enhanced TGC contribution, limits on anomalous TGCs (aTGCs); cross sections compared to NLO predictions (both fiducial and total)
- Important irreducible background to some Higgs channels



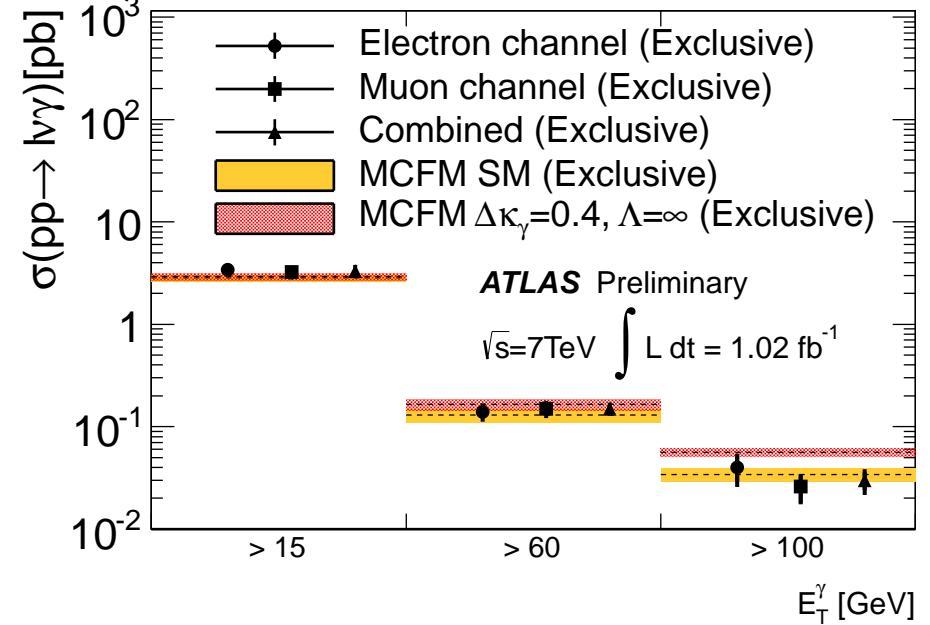
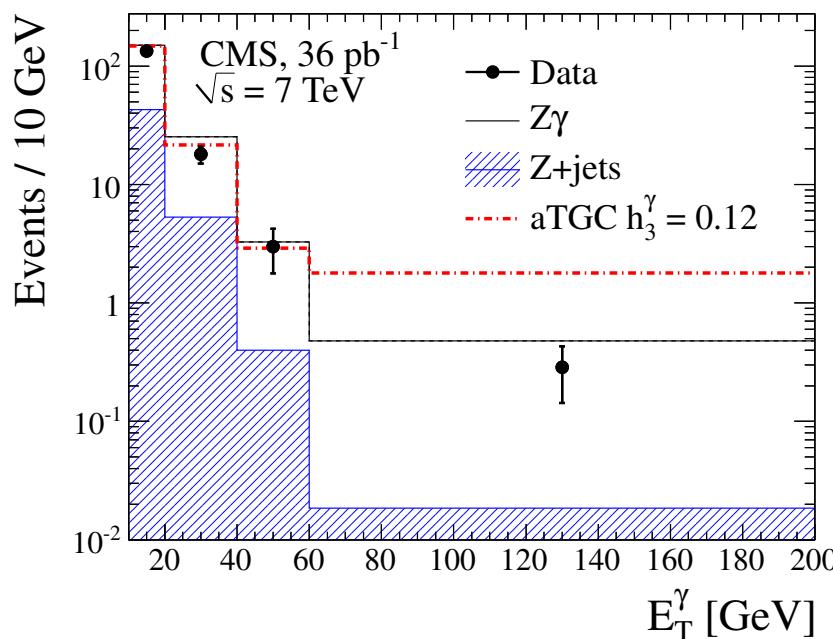
$W^\pm\gamma$ and $Z\gamma$ Production

- Highest cross section di-boson processes: typical Z or W selection, additional isolated photon with $\Delta R(\ell, \gamma) > 0.7$ and $p_T^\gamma > 10..15$ GeV
- Cross sections with $\sim 10..15\%$ uncertainty, mostly good agreement with NLO predictions (especially in *exclusive* selection, jet veto)
- aTGCs on $WW\gamma$ and $ZZ\gamma$, $Z\gamma\gamma$ vertices on similar level as Tevatron and LEP analyses



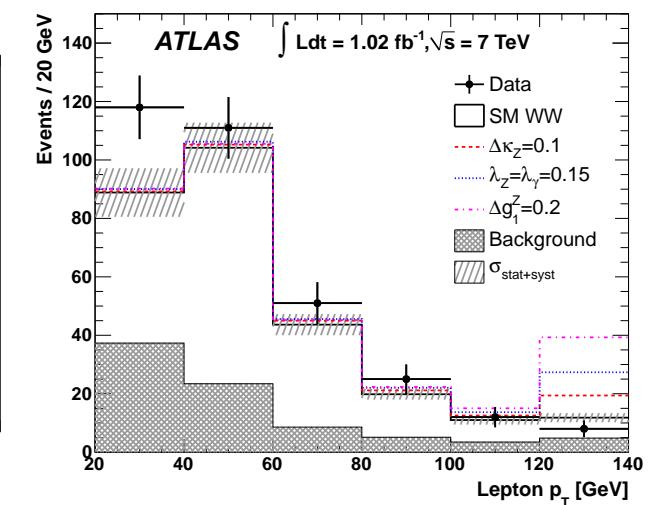
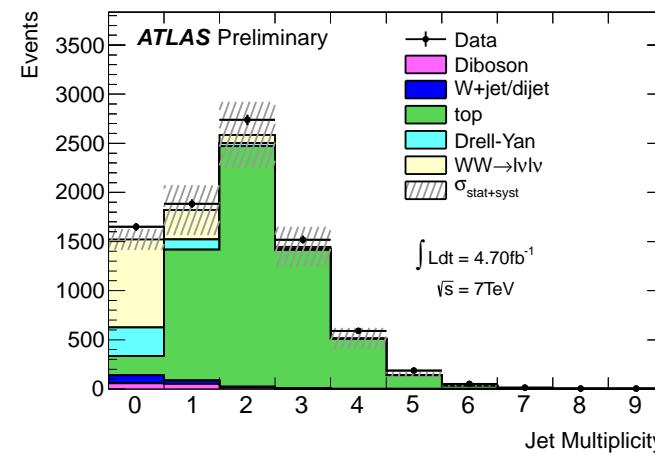
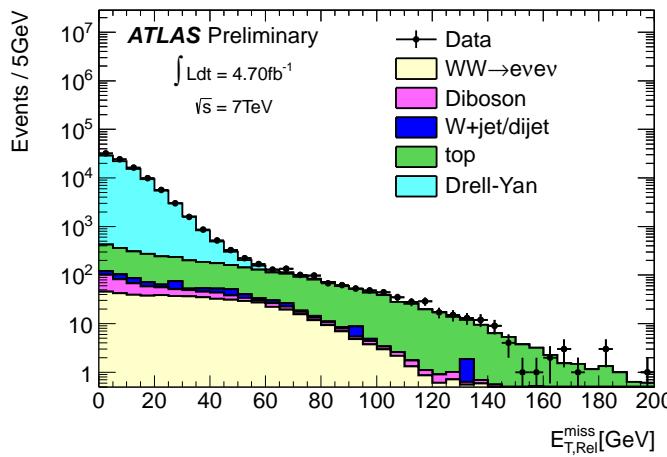
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W^+W^- Production

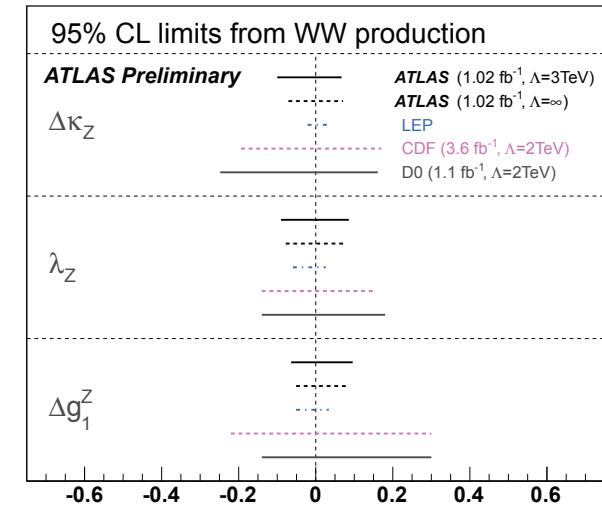
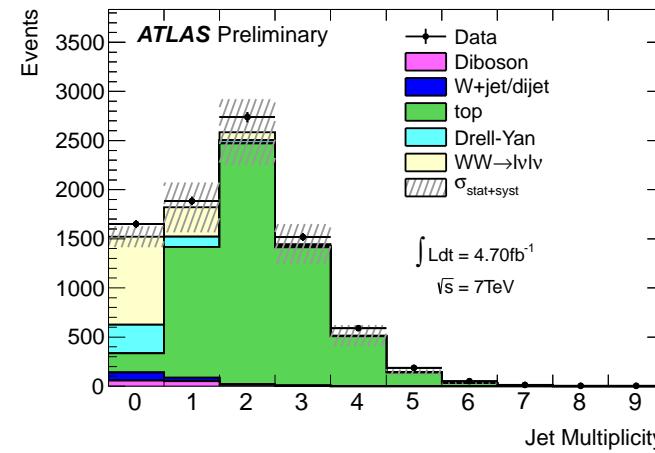
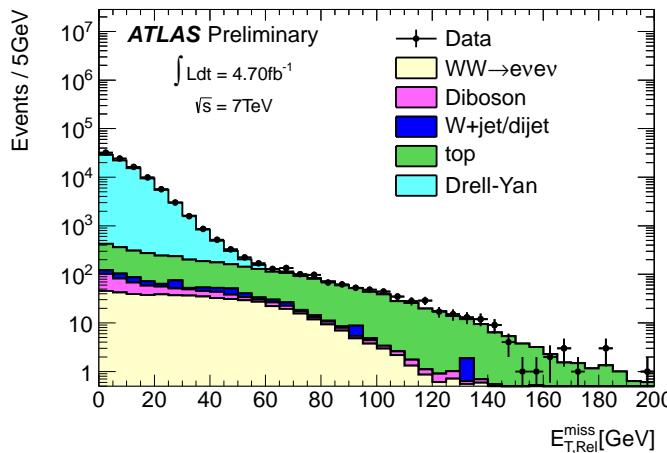
- Measured in leptonic channels $2e2\nu, 2\mu2\nu, e\mu2\nu$
- Large Drell-Yan bkg. (esp. in like-flavour channels): E_T relative to lepton/jets; Z mass window veto; Top background controlled with jet/b-jet/soft muon tag vetos
- Cross section precision $\sim 10..15\%$ (largely systematic): ATLAS and CMS $\sim 1\sigma$ above NLO prediction
- aTGC limits sensitive to high leading lepton p_T : limits in between Tevatron and LEP



ATLAS-STDM-2011-24 → PLB; ATLAS-CONF-2012-025; CMS-PAS-EWK-11-010

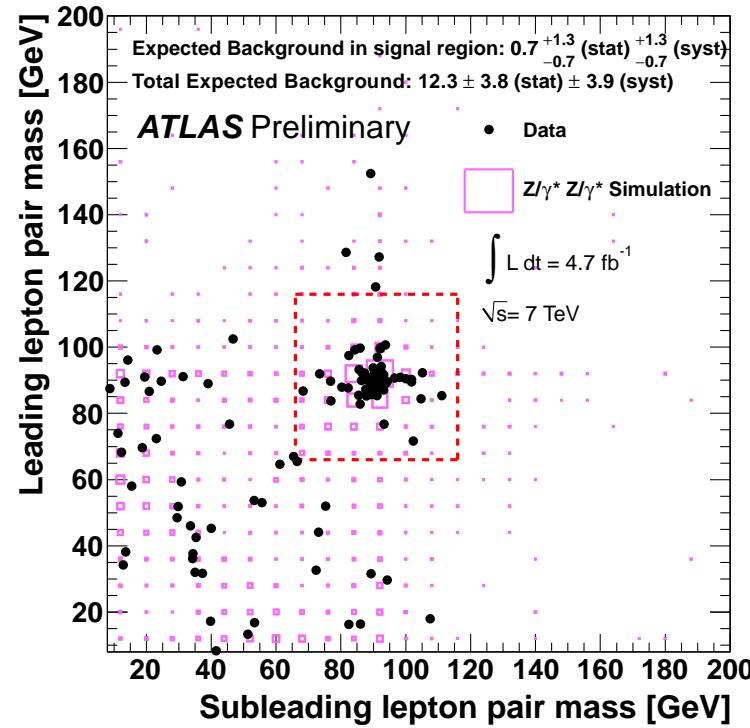
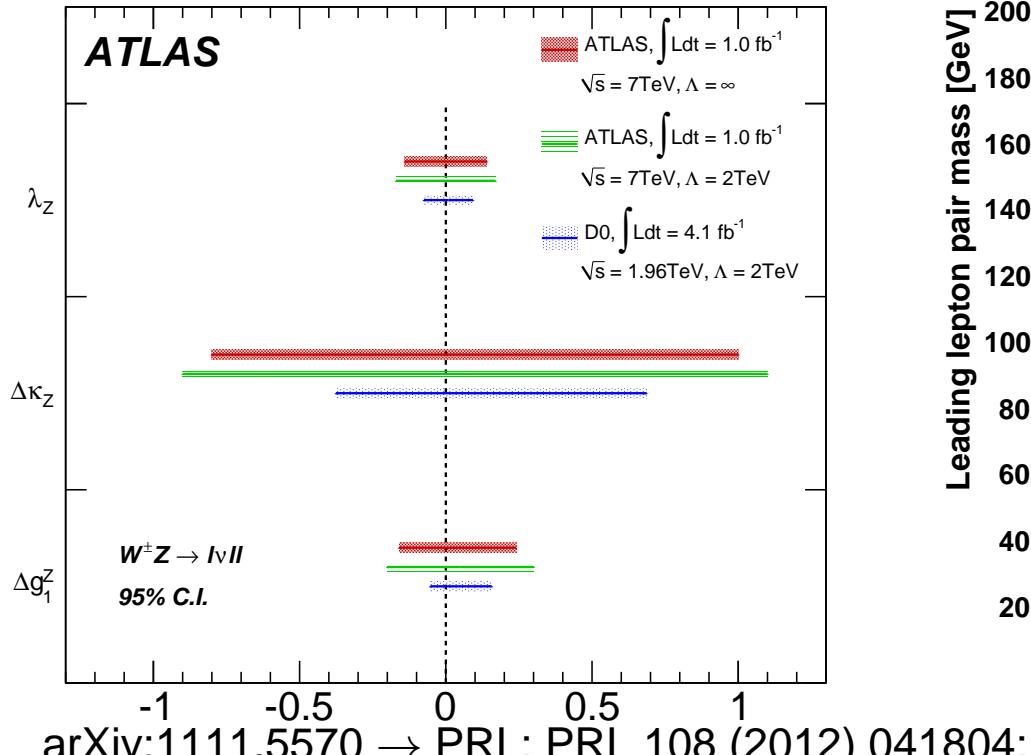
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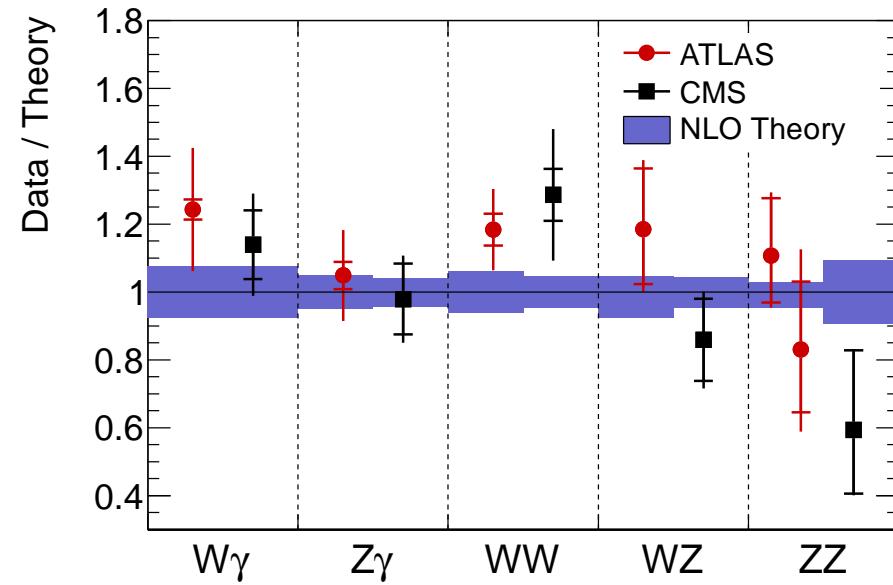
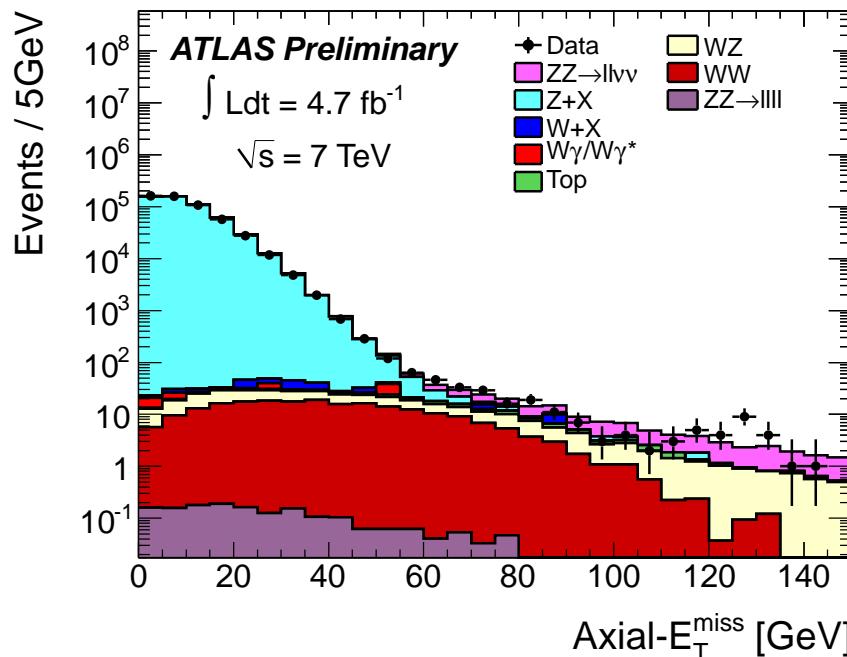
$W^\pm Z$ and ZZ Production

- Main measurements in rare, but “clean” leptonic decays with both bosons resonantly produced: $W^\pm Z \rightarrow \ell\nu\ell'\bar{\nu}'$ and $ZZ \rightarrow \ell\ell\ell'\bar{\nu}'$
- Cross section measurements dominated by $\sim 15\%$ statistical uncertainty; consistent with SM prediction
- Anomalous TGC limits from fit to cross section (ATLAS $W^\pm Z$)



More ZZ Decays and Diboson summary

- CMS considering ZZ final states with $\ell' = \tau$: 1 event in 1.1 fb^{-1}
- ATLAS has measured $ZZ \rightarrow \ell\ell\nu\nu$: higher branching, but a more difficult analysis similar to W^+W^- : strong E_T and jet veto cuts necessary to control backgrounds
- Measurement with $\sim 25\%$ statistical and systematic uncertainty, consistent with SM and $ZZ \rightarrow 4\ell$ channel

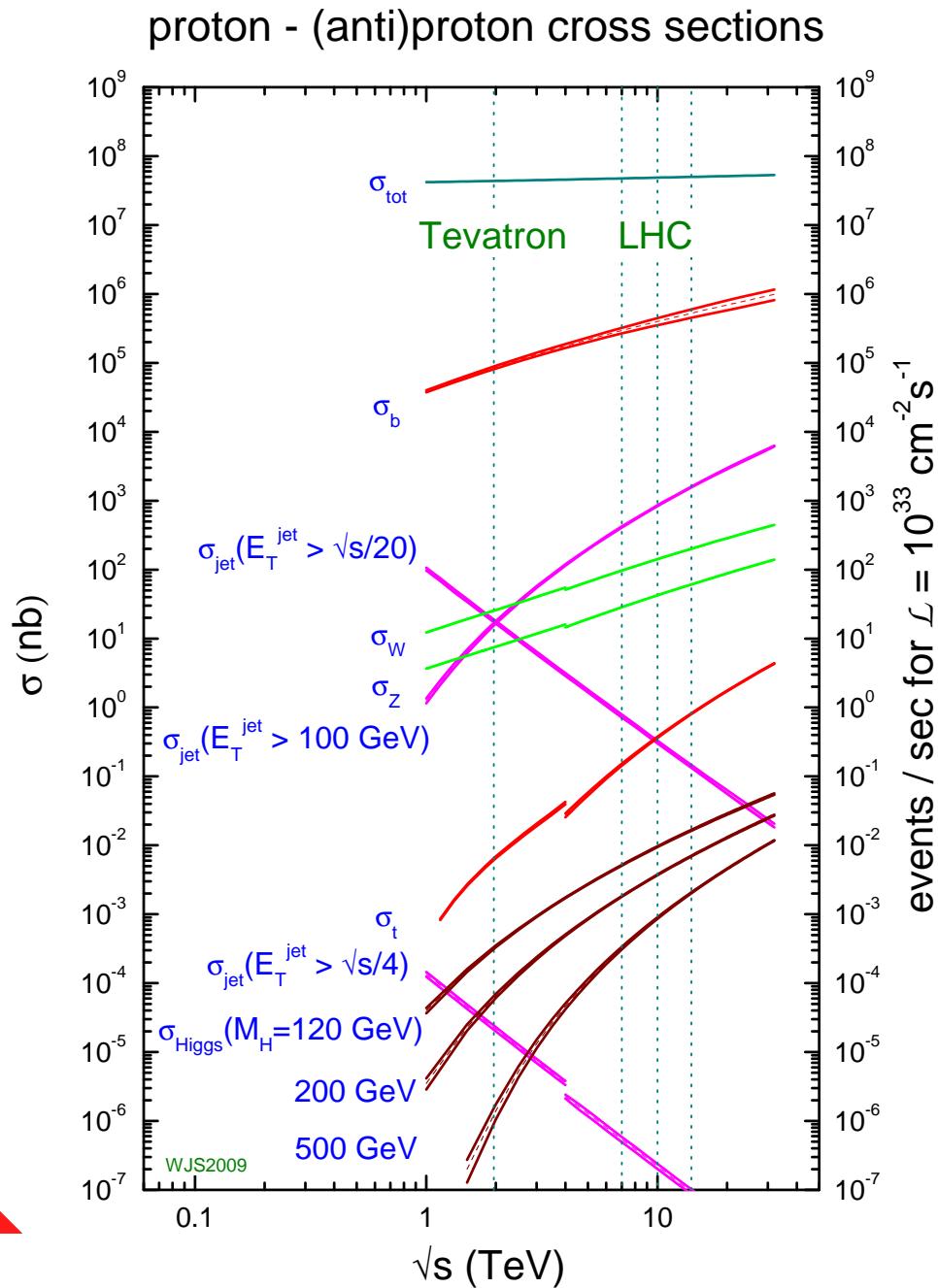


ATLAS-CONF-2012-027; CMS-PAS-EWK-11-010

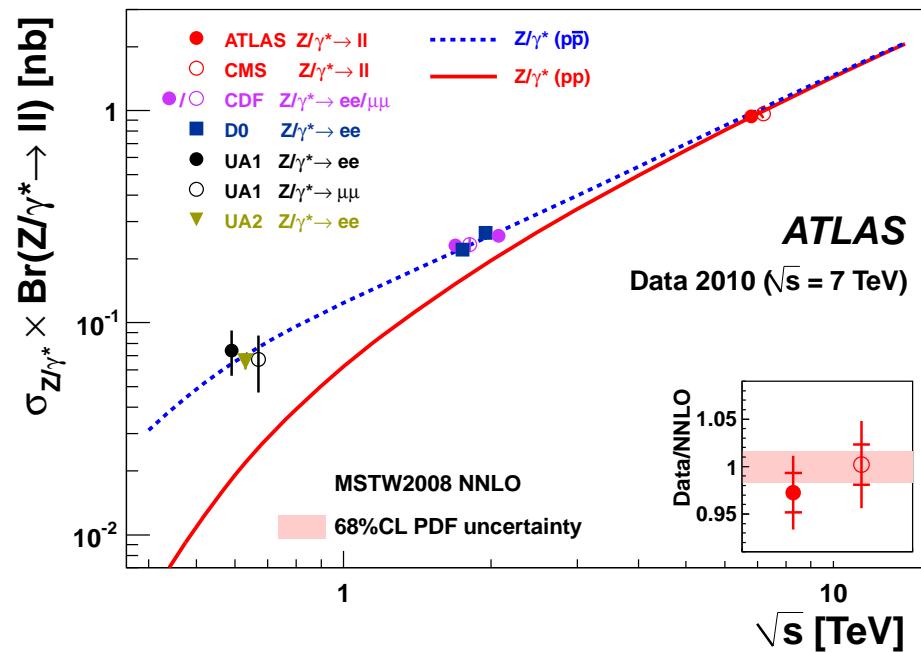
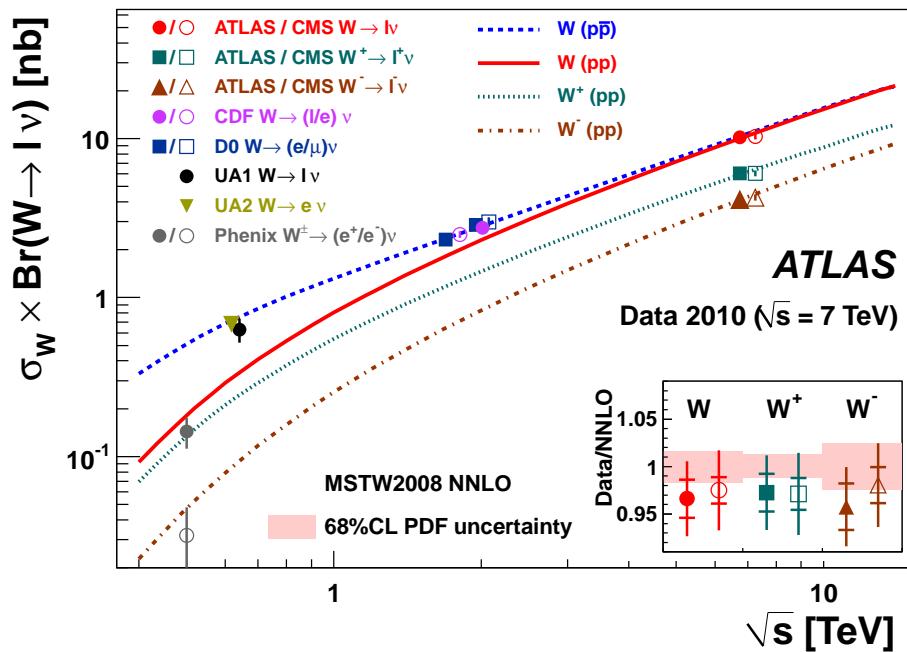
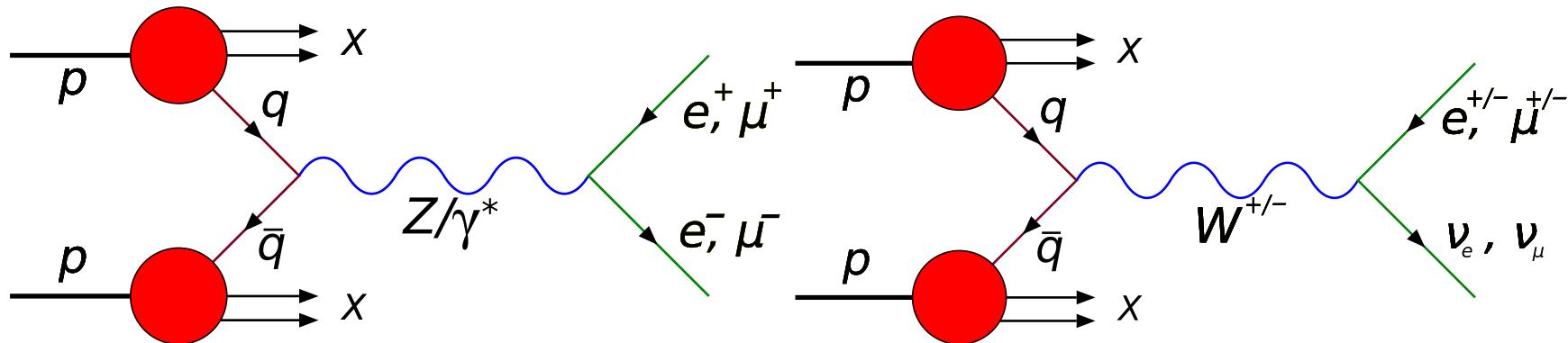
Summary

- Electroweak measurements at ATLAS+CMS entering the precision era after just 2 years of data taking
- High production rate of W and Z bosons enable detailed studies:
 - Precise differential cross sections with impact on our knowledge of proton structure, e.g. strange quark density
 - Production in association with many jets or high boson p_T
- Measurements on fundamental parameters of the EW sector of the standard model:
 - Weak mixing angle $\sin^2 \theta$
 - Di-boson measurements are beyond the “observation phase”, now testing the non-Abelian gauge structure; competitive aTGC limits compared to LEP and Tevatron with $\sim 1 - 5 \text{ fb}^{-1}$
- Competitive measurement of W boson mass still a lot of work, but working on the necessary precision inputs for this

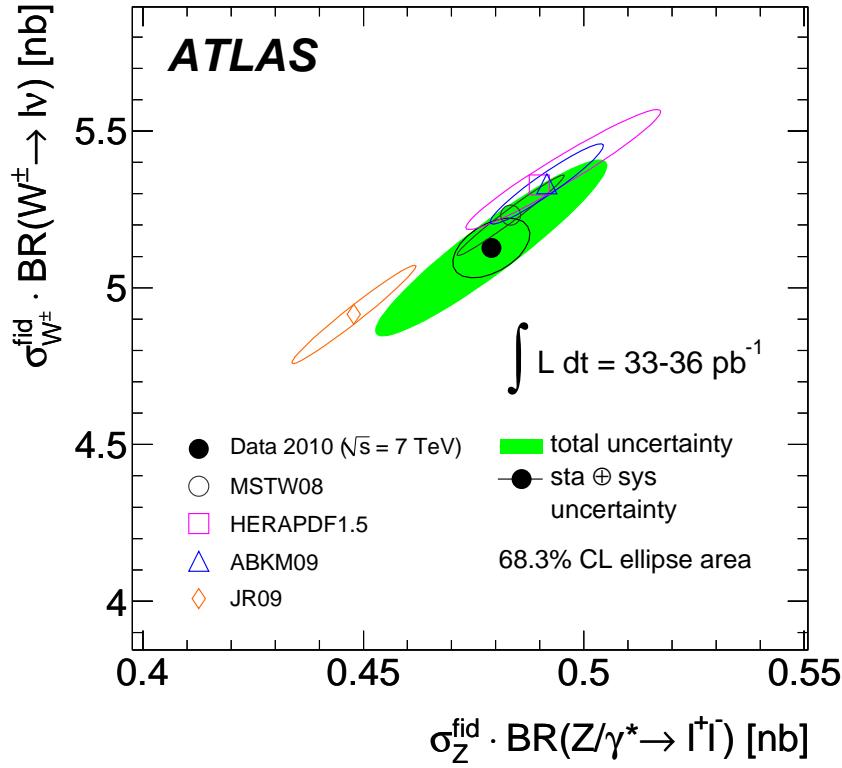
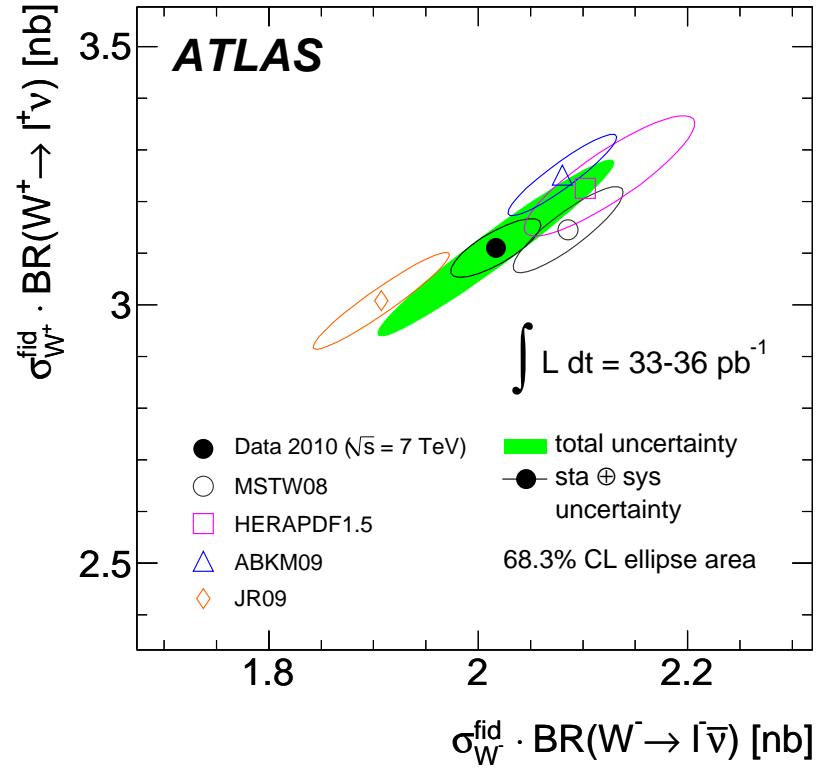
$p\bar{p}/pp$ cross sections



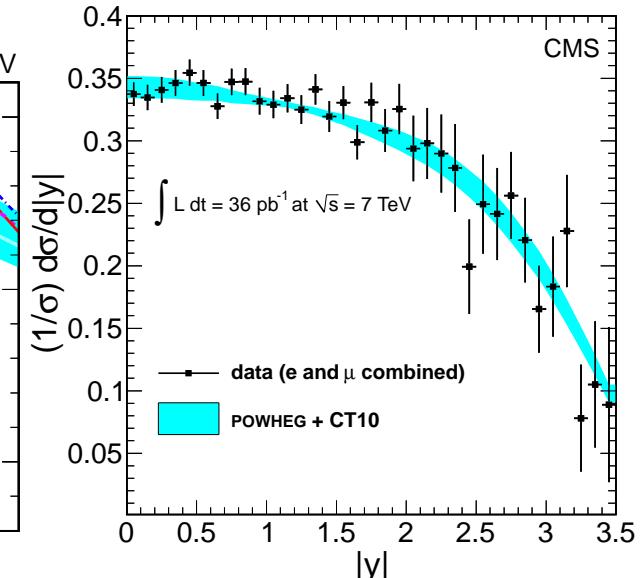
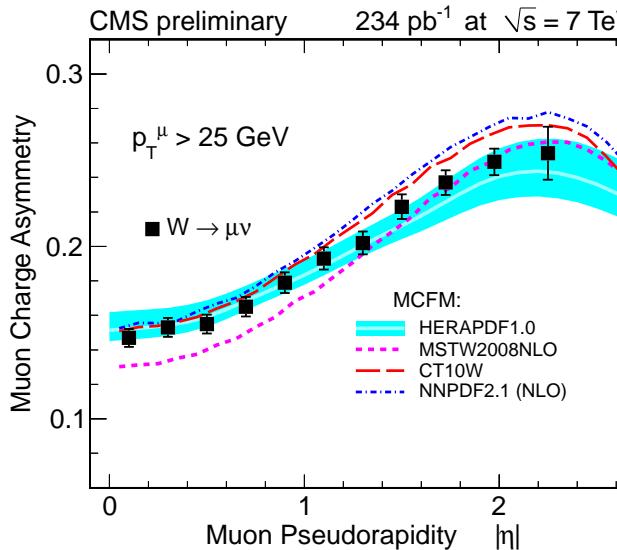
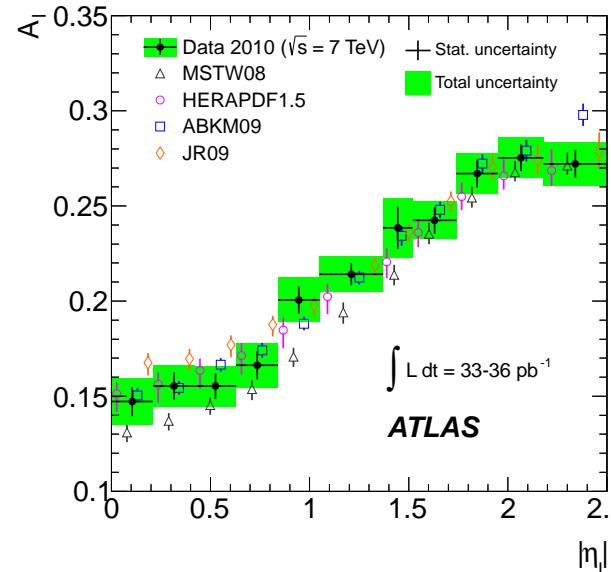
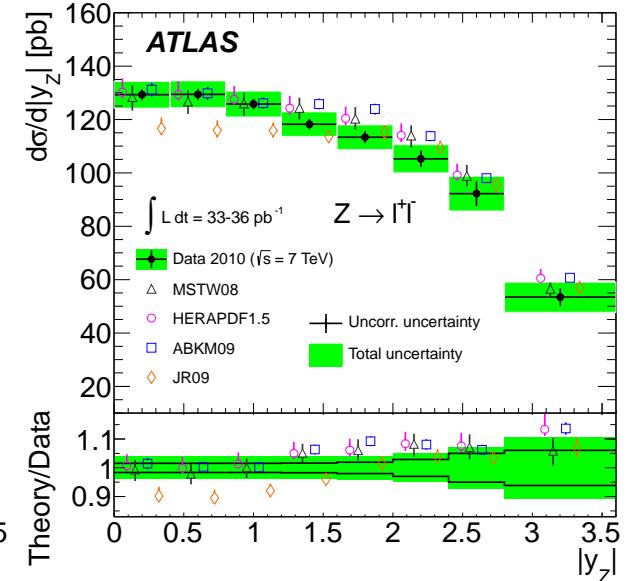
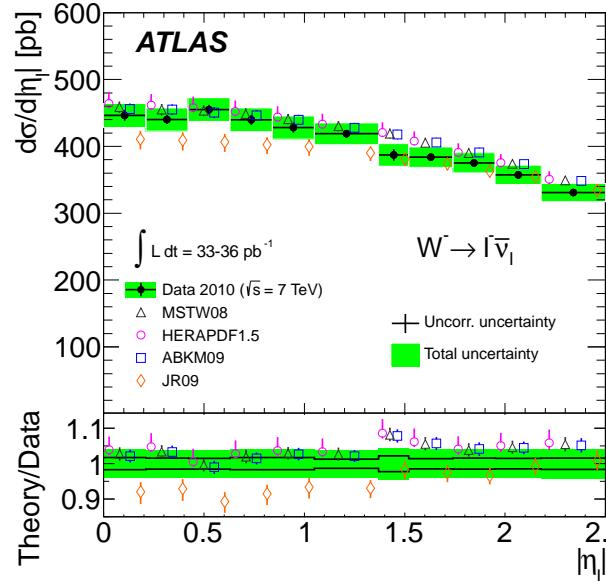
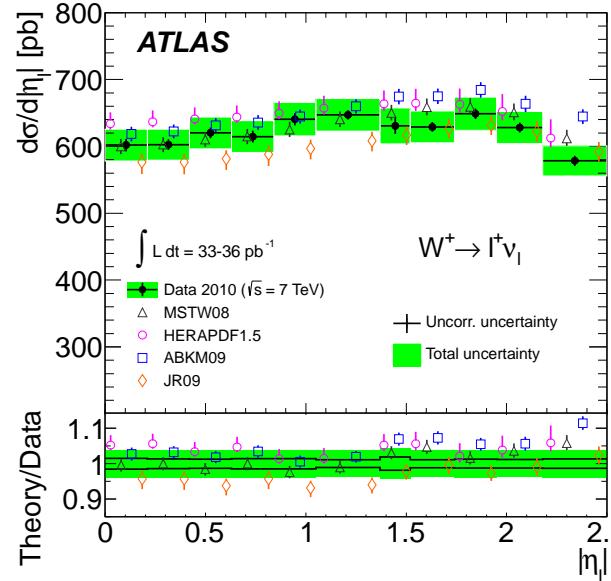
Z, W DY Production



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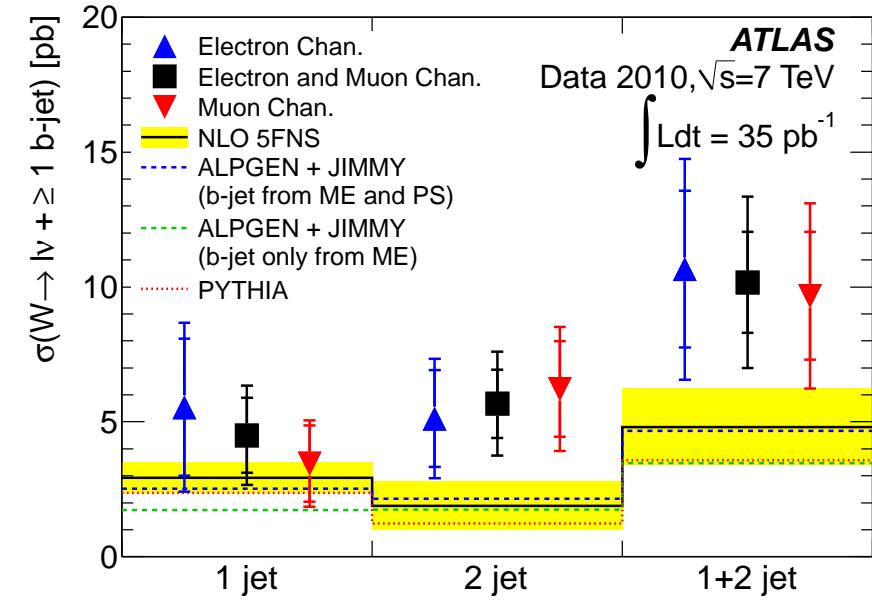
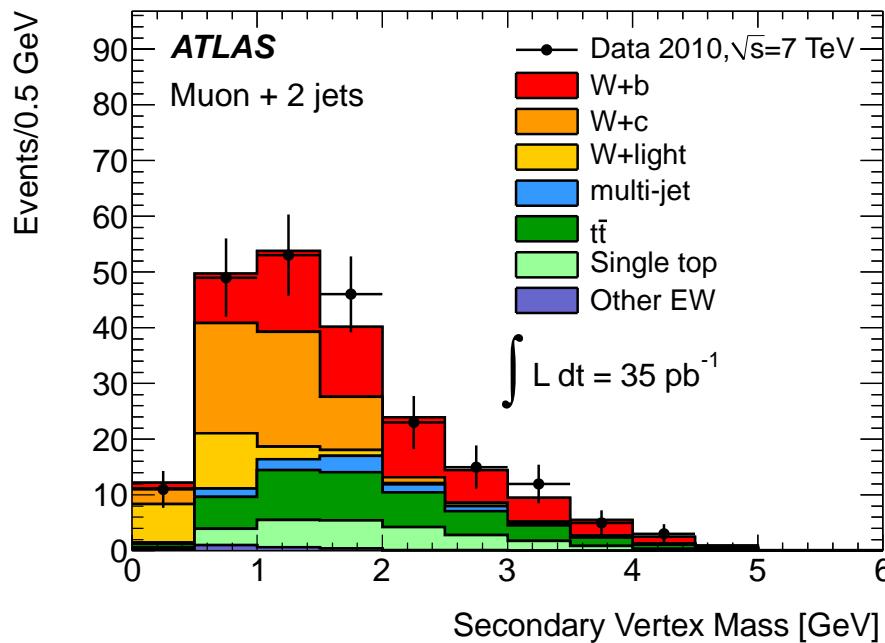


Z, W DY Production



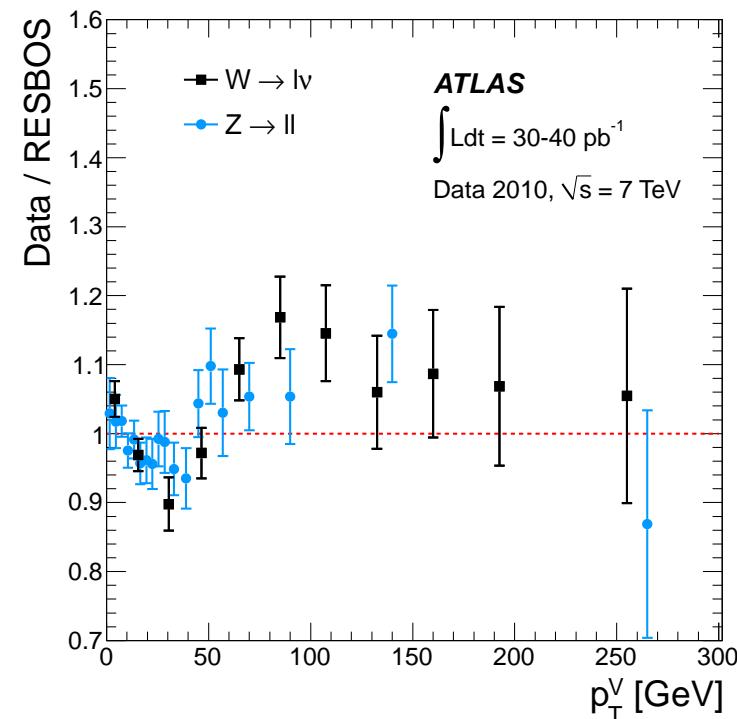
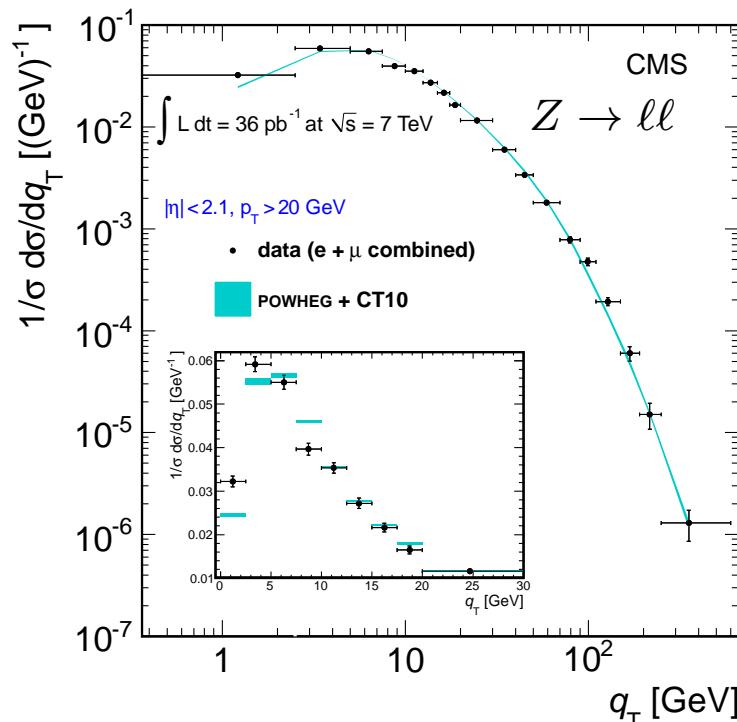
$W, Z + b$ jet production (2010 Results)

- Select W, Z and central jet, applying b tagging: e.g. secondary vertex reconstruction and fit in s. v. mass
- ATLAS $W + b$ cross section measured $\sim 1.5\sigma$ higher than QCD NLO calculation or MC predictions
- $\sigma(Z + b)$, $\sigma(Z + b)/\sigma(Z)$ (ATLAS) and $\sigma(Z + b)/\sigma(Z + \text{jet})$ (CMS) measured to $\sim 25\%$ accuracy, mainly driven by low statistics; in agreement with QCD NLO and MC predictions



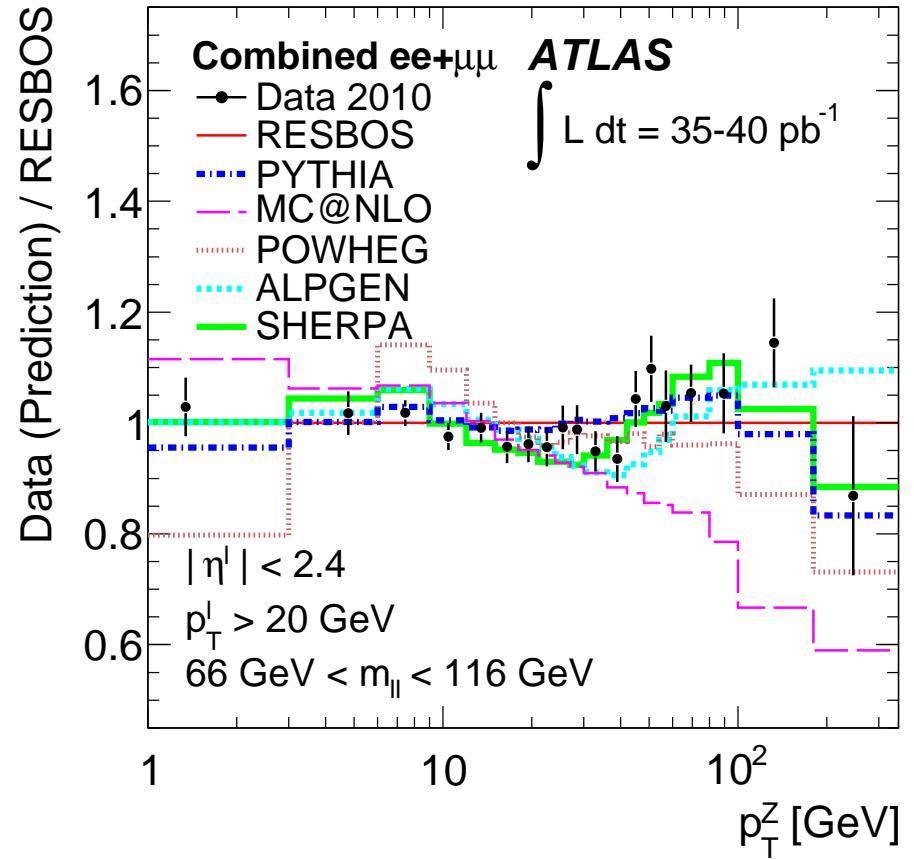
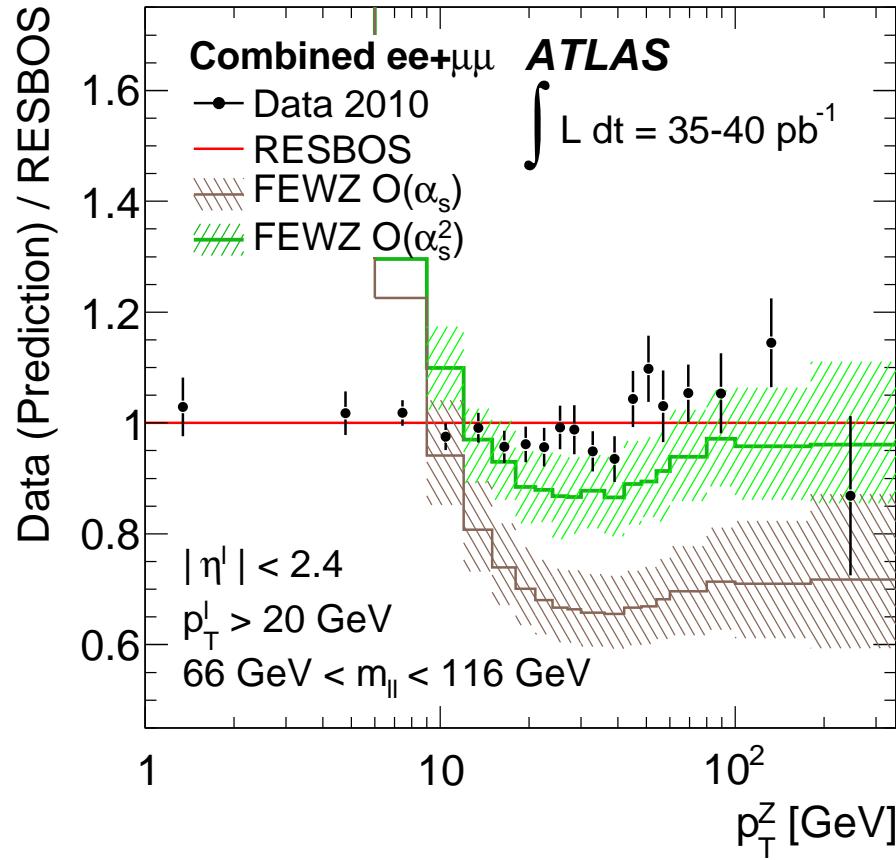
W, Z transverse momentum p_T

- Boson p_T differential cross section measured via di-lepton system for Z (ATLAS+CMS), hadronic recoil for W (ATLAS)
- Small p_T dominated by soft gluon resummation: measurement input to MC tuning and tests of resummed calculations; description varies strongly between available models; vital for W mass measurement
- For large p_T calculable in pQCD: need at least at $O(\alpha_s^2)$

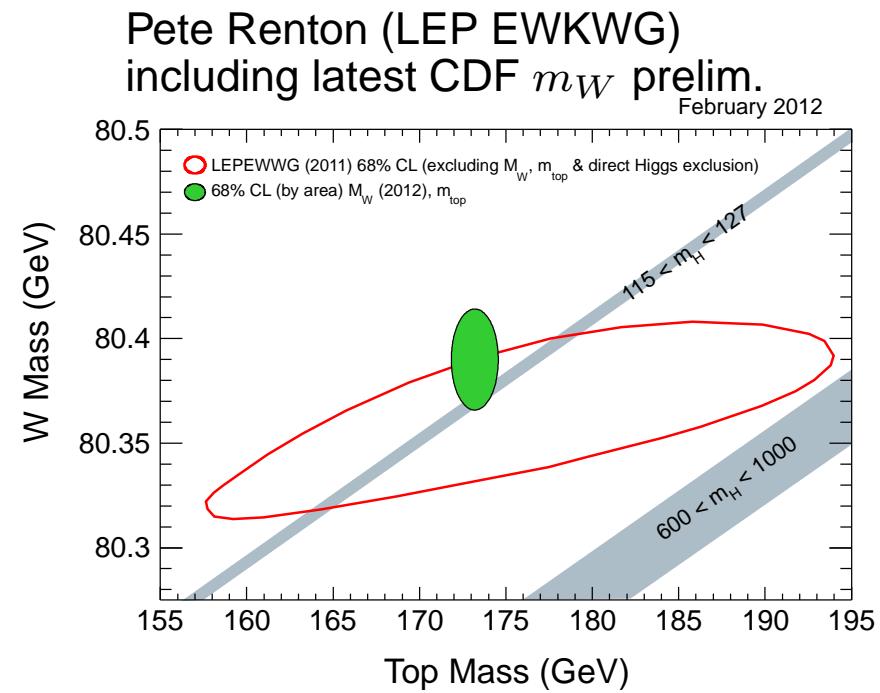
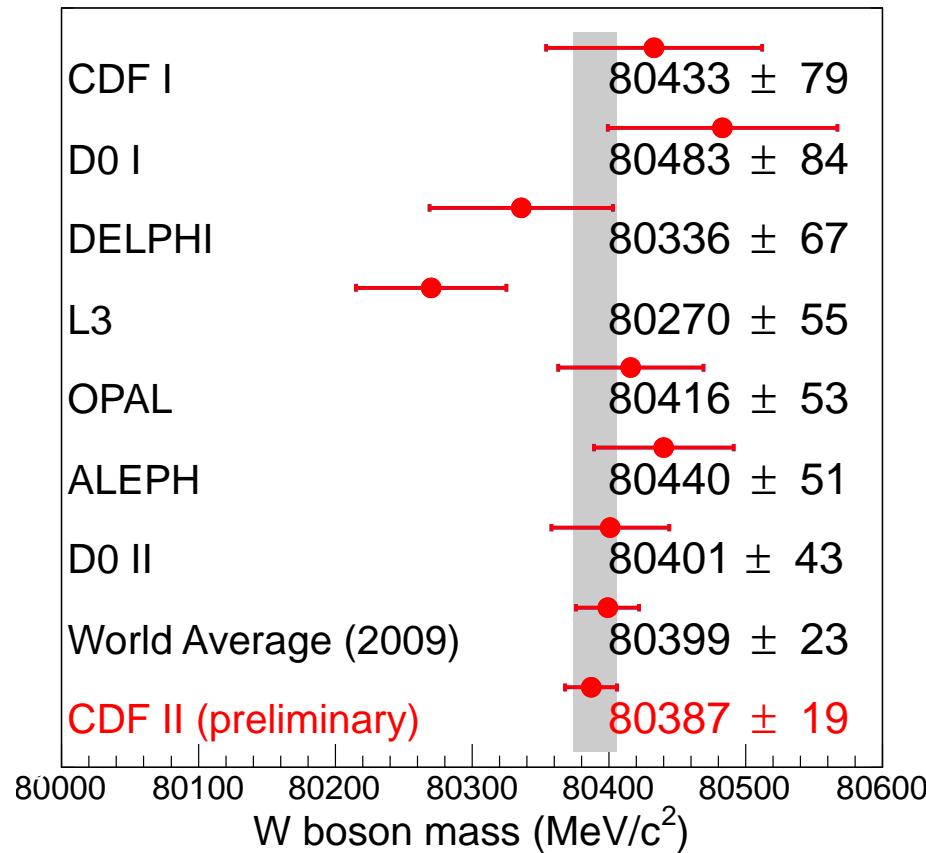


PLB 705 (2011) 415-434; PRD 85 (2012) 012005; arXiv:1110.4973→PRD

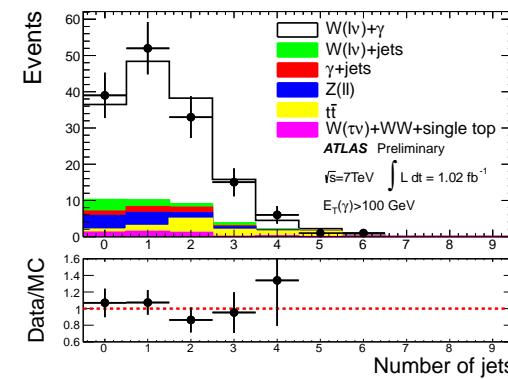
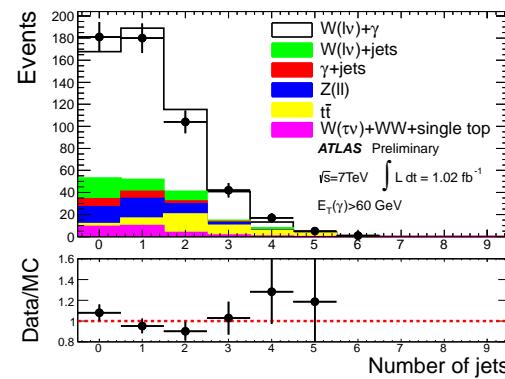
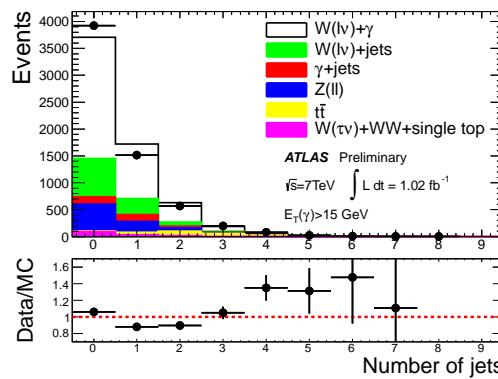
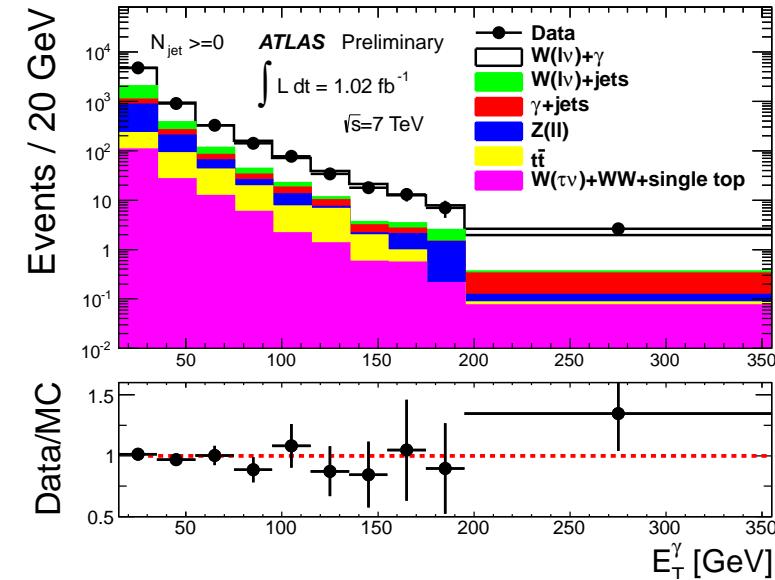
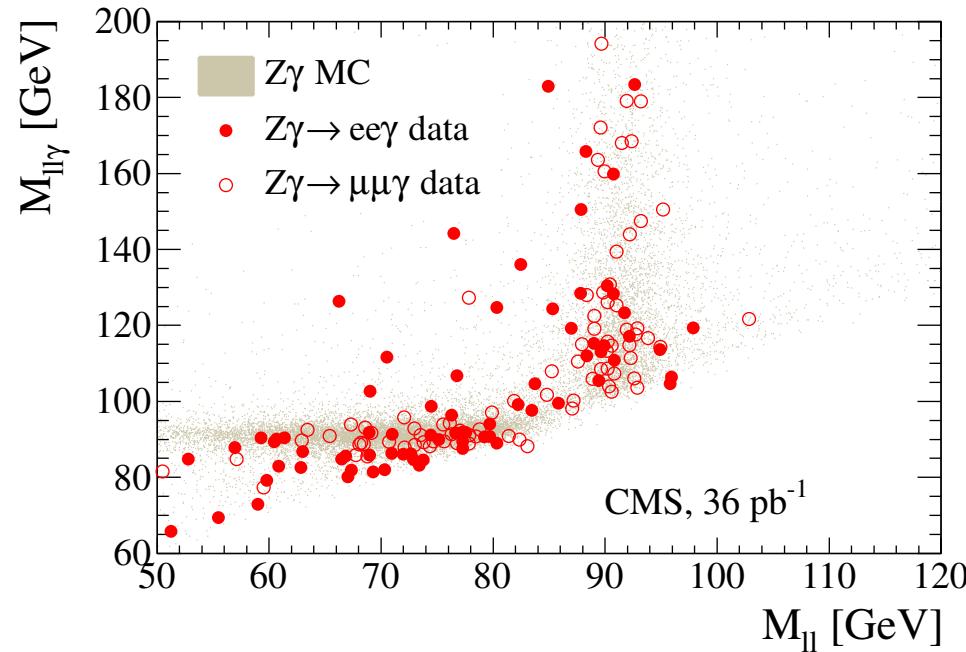
W, Z transverse momentum p_T



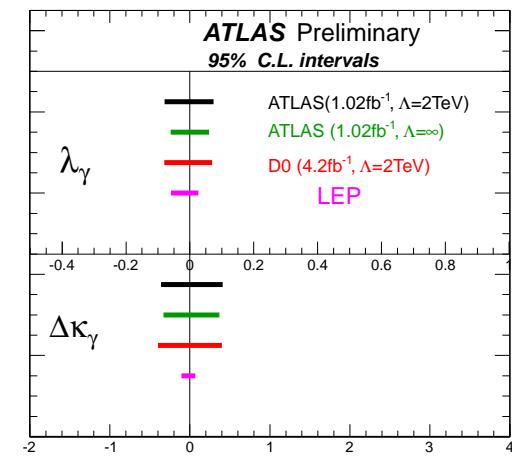
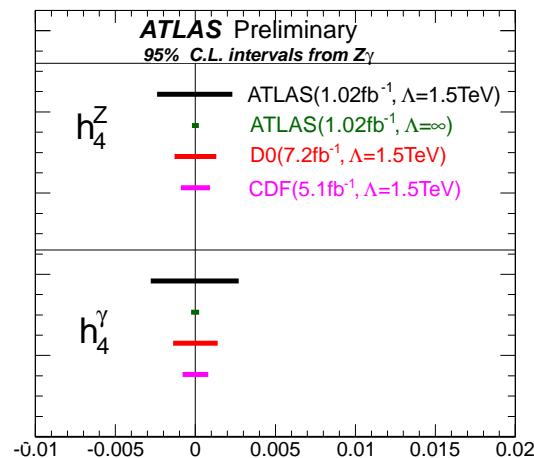
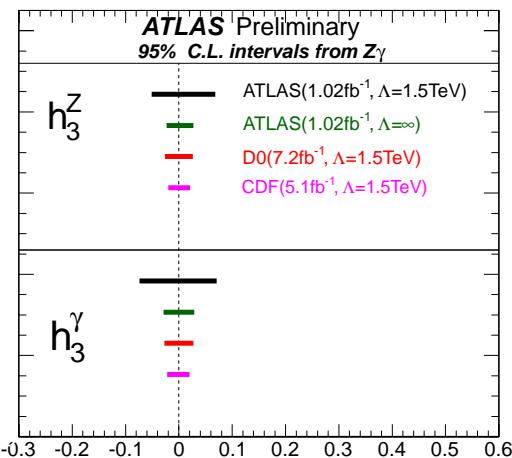
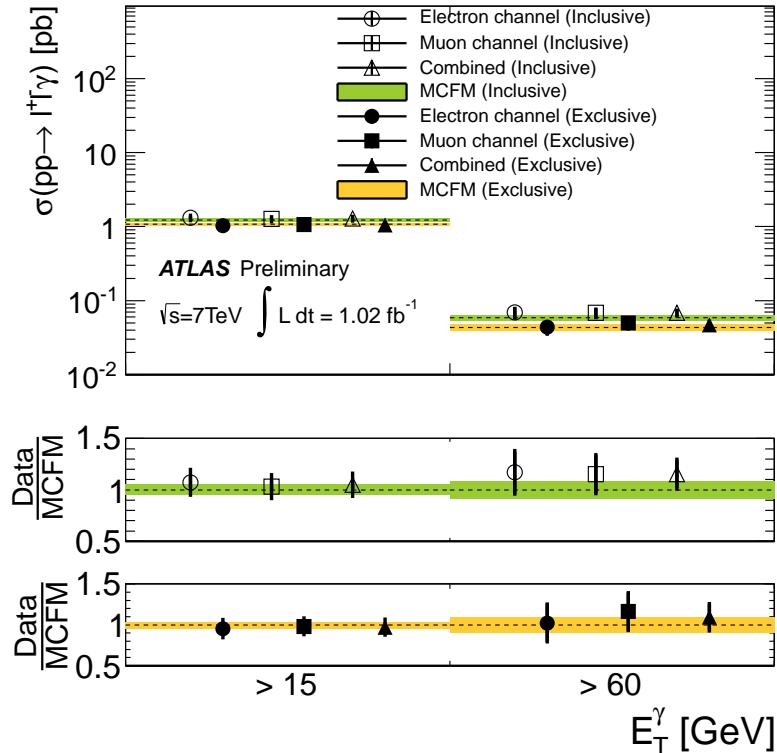
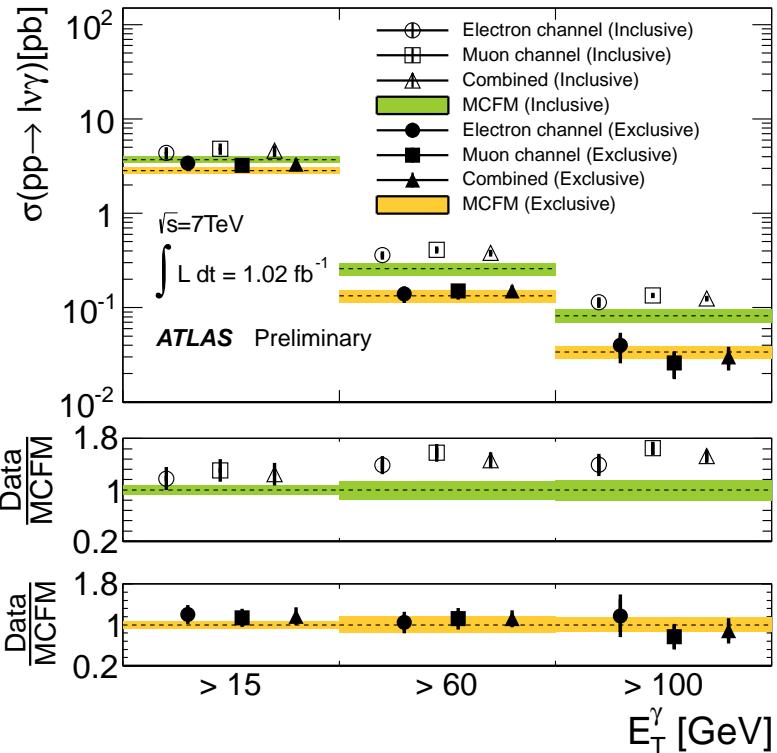
W mass



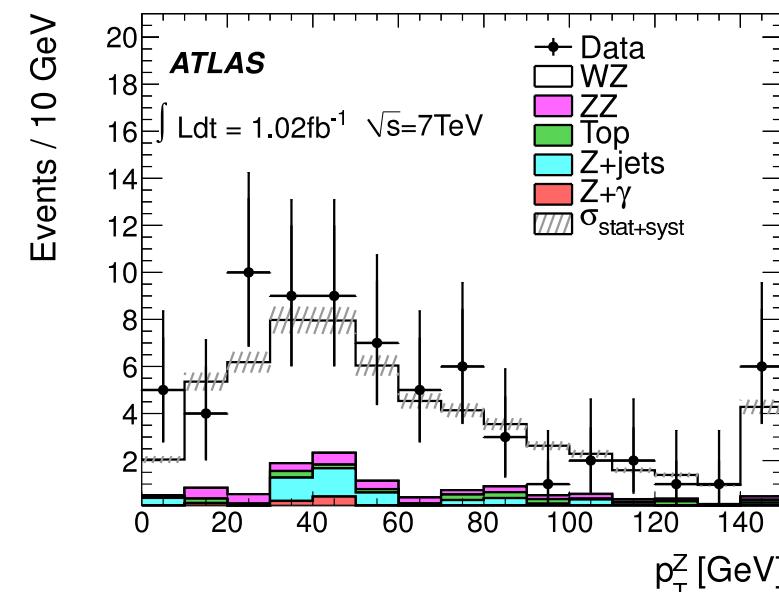
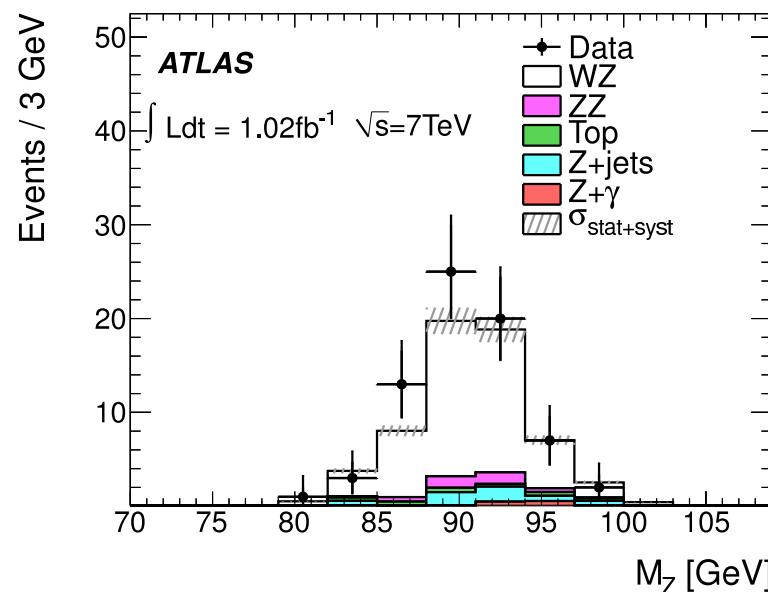
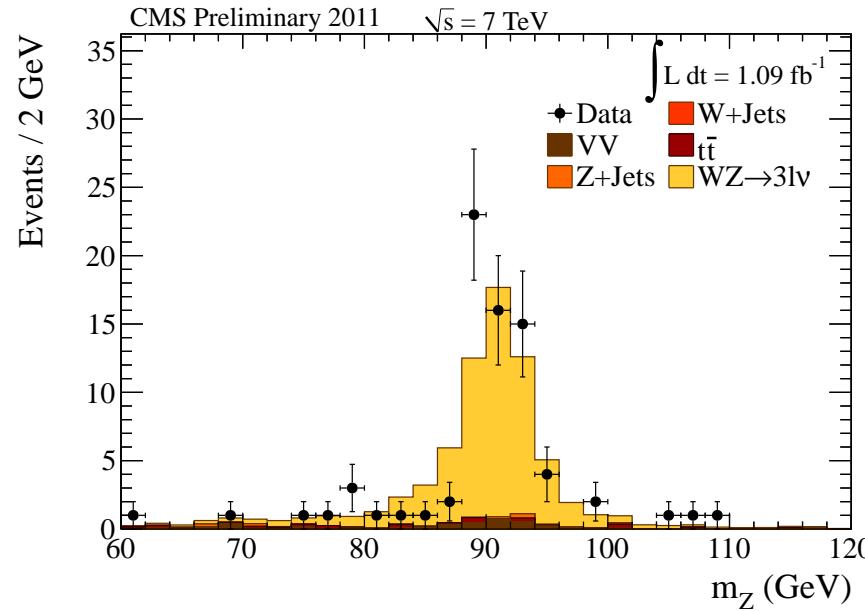
$W\gamma$ and $Z\gamma$

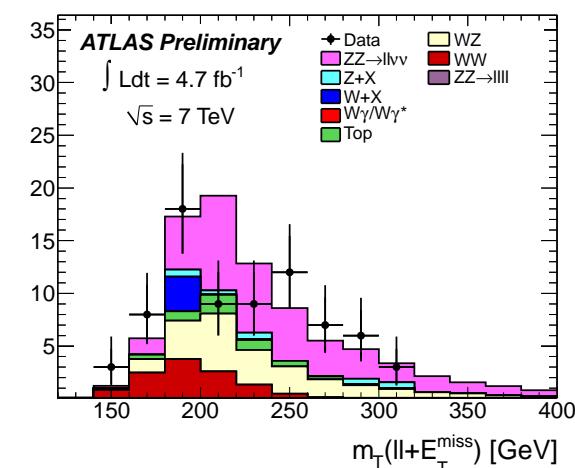
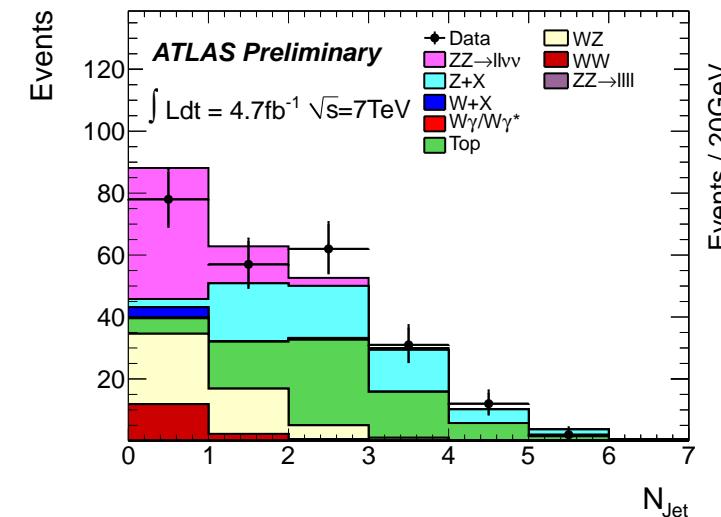
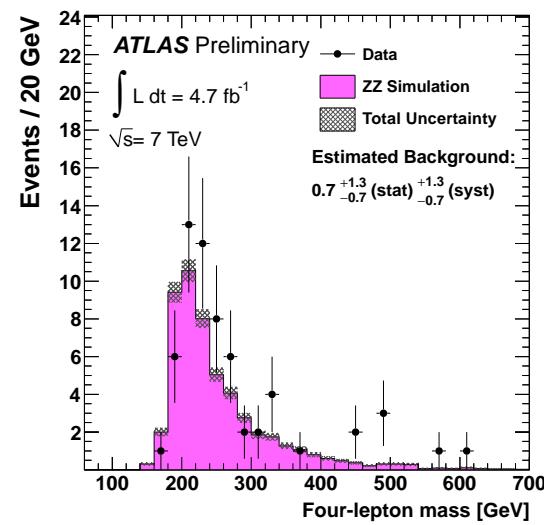
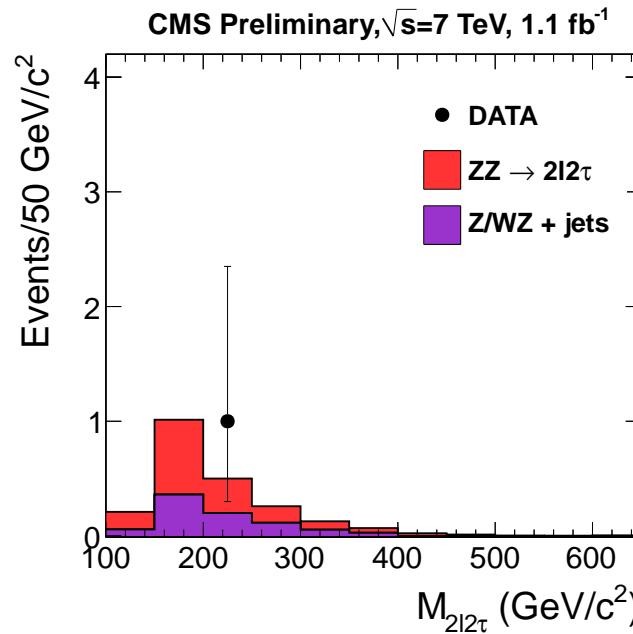
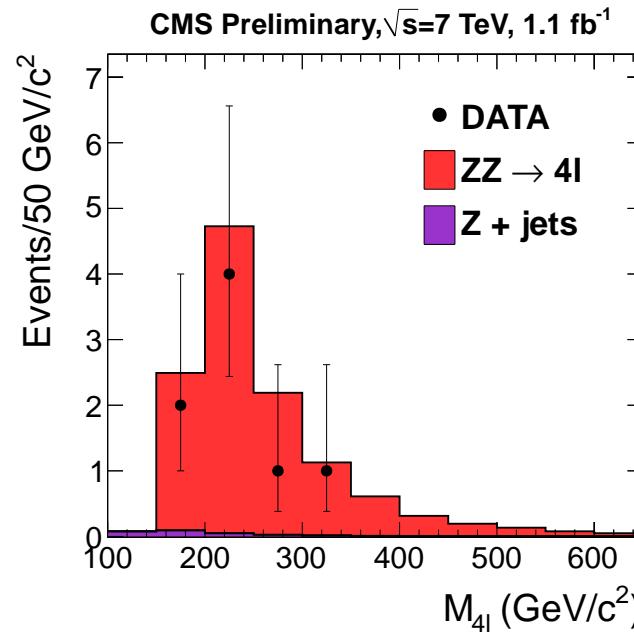


$W\gamma$ and $Z\gamma$



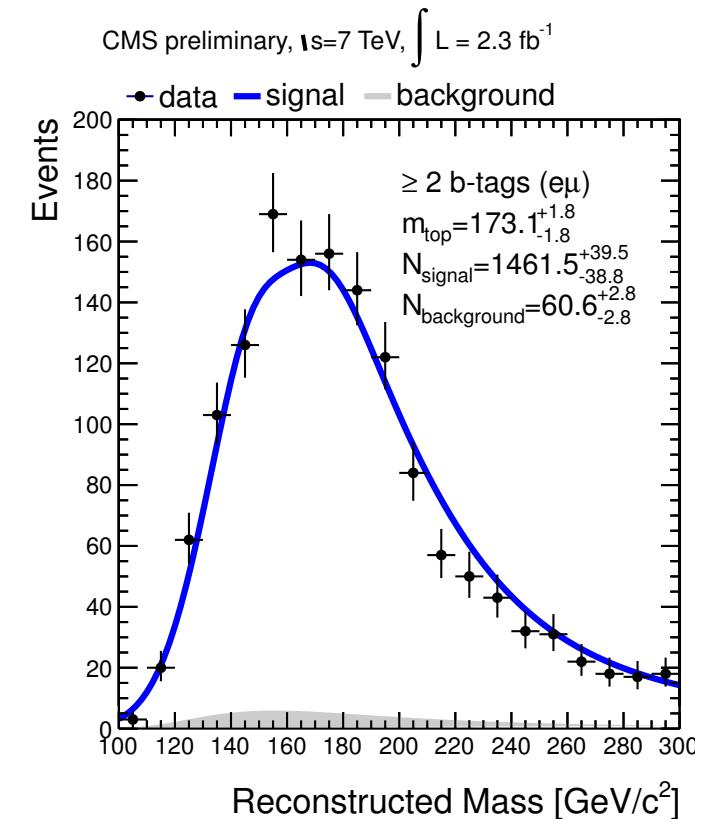
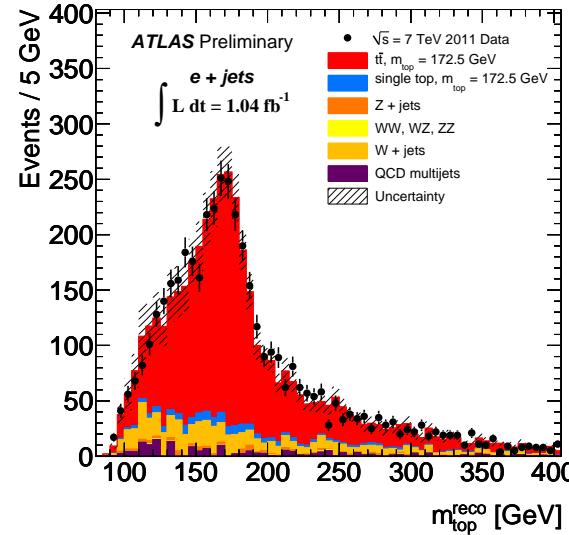
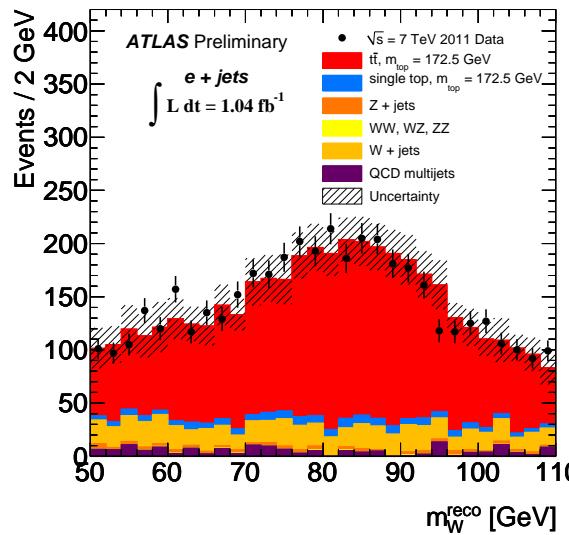
WZ





Top Mass

- Top quark pairs $t\bar{t}$ are abundantly produced at the LHC
→ aim for precise measurement of top quark mass
- Lepton+jet channels*: large statistics, reasonably low backgrounds, full reconstruction: MC templates, 2D fit in m_W and m_{top} to constrain jet energy scale; kinematic fit for CMS
- Di-lepton channels* complementary: cleaner, but underconstrained kinematics, reconstruct using full event information



to be submitted to EPJC; JHEP 07 (2011) 049; CMS PAS TOP-11-015; CMS PAS TOP-11-016

Top Mass

- CMS di-lepton (2.3 fb^{-1}): $m_{\text{top}} = 173.3 \pm 1.2(\text{stat}) \pm 2.6(\text{syst}) \text{ GeV}$
- CMS $\mu+\text{jets}$ (4.7 fb^{-1}): $m_{\text{top}} = 172.6 \pm 0.6(\text{stat + JES}) \pm 1.2(\text{syst}) \text{ GeV}$
- ATLAS $\ell+\text{jets}$ (1 fb^{-1}): $m_{\text{top}} = 174.5 \pm 0.6(\text{stat}) \pm 2.3(\text{syst}) \text{ GeV}$
- Ongoing: m_{top} from $t\bar{t}$ cross section, ATLAS&CMS combination
- Measurements systematics dominated, e.g. b jet energy scale, theory/generator dependence; CMS $\mu+\text{jets}$ w/o non-perturbative syst.

