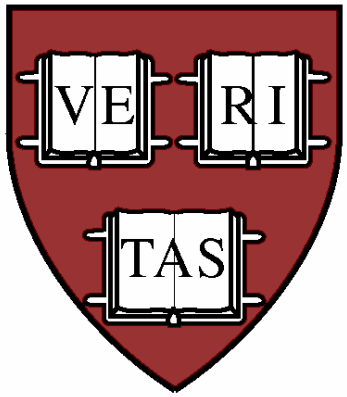


Electroweak Physics at the LHC

A. Belloni

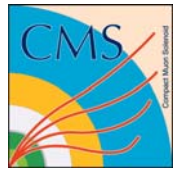
Harvard University

Aspen 2012 – The Hunt for New Particles

February 11th-17th

A Rich Menu of Results

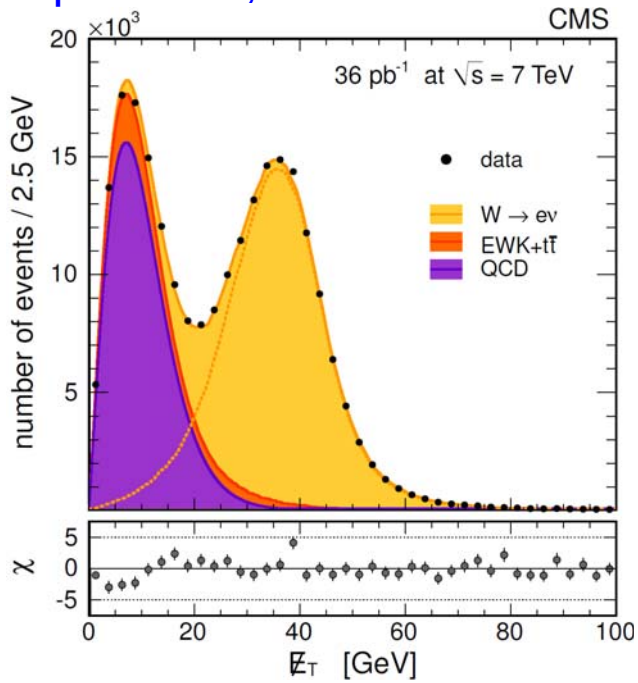
- Electroweak Bosons
  - W and Z total and differential cross sections
  - Lepton charge asymmetry in $W \rightarrow \ell\nu$
  - W polarization
  - Jet production in association with W and Z
- Di-boson final states
  - W/Z+γ, WW, WZ, ZZ production
  - Limits on anomalous Triple-Gauge Couplings



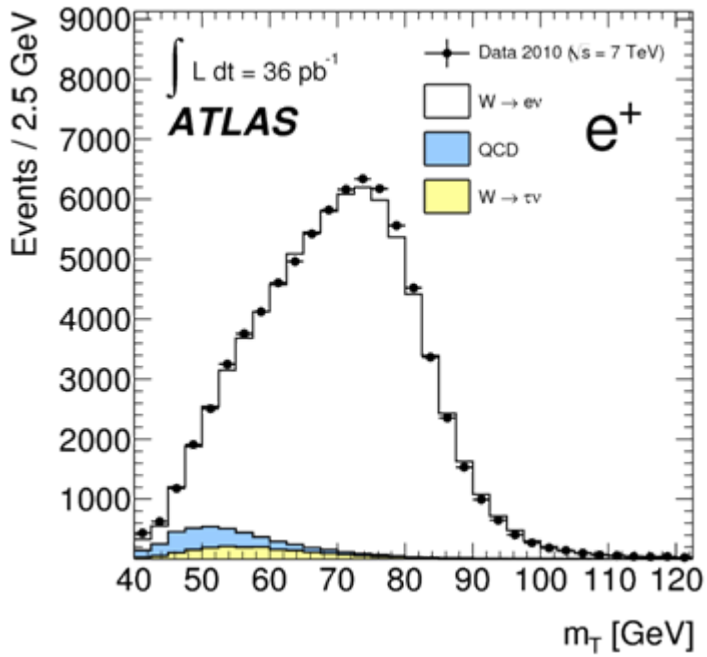
W/Z Physics

W Production Cross Section

- High-p_T lepton + E_T^{miss}
- Backgrounds
  - Z: miss other lepton
  - QCD: jet fakes lepton
    - Estimate with ABCD method or fit of E_T^{miss} in control region
  - Top: real W, but low cross section

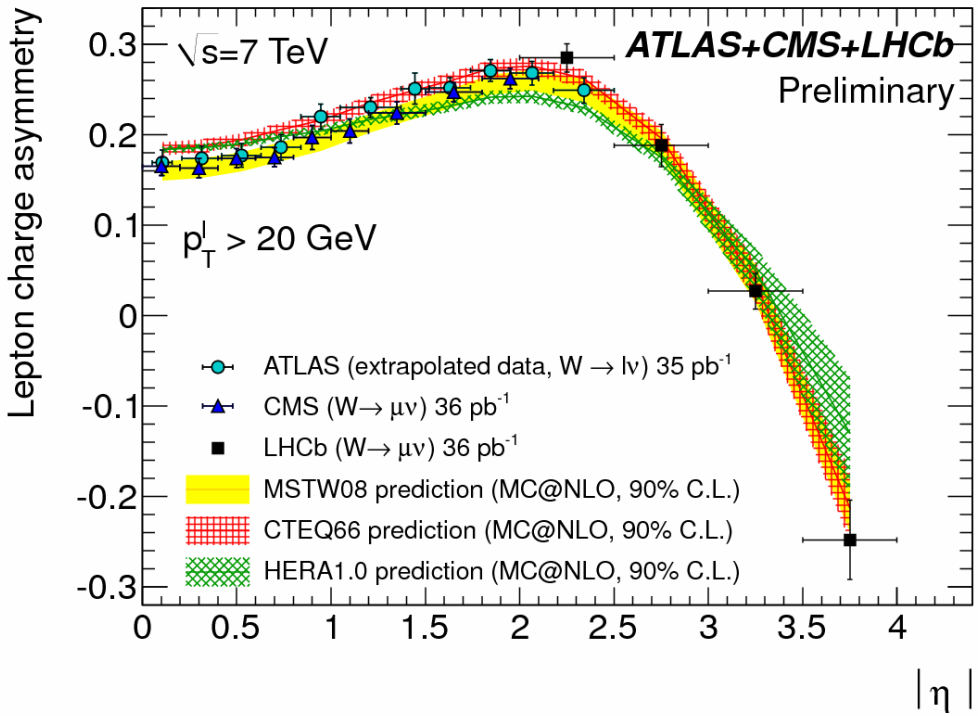


- Different approaches
  - CMS: fit E_T^{miss} distribution
  - ATLAS: cut & count
- Measure total and fiducial cross sections
  - Analysis cuts on lepton to reduce uncertainties from theory



W Charge Asymmetry

- Asymmetric W production provides information about proton structure
  - W produced (mostly) via valence-sea quark interaction
  - |y|-dependency sensitive to differences between *u* and *d* Parton Distribution Functions
  - Difficult to reconstruct W rapidity, use decay lepton pseudorapidity
- Measurement compares well with predictions
  - … however, measurement is *input* to PDF fits



Common phase-space agreed by ATLAS, CMS and LHCb within *LHC Electroweak Working Group*

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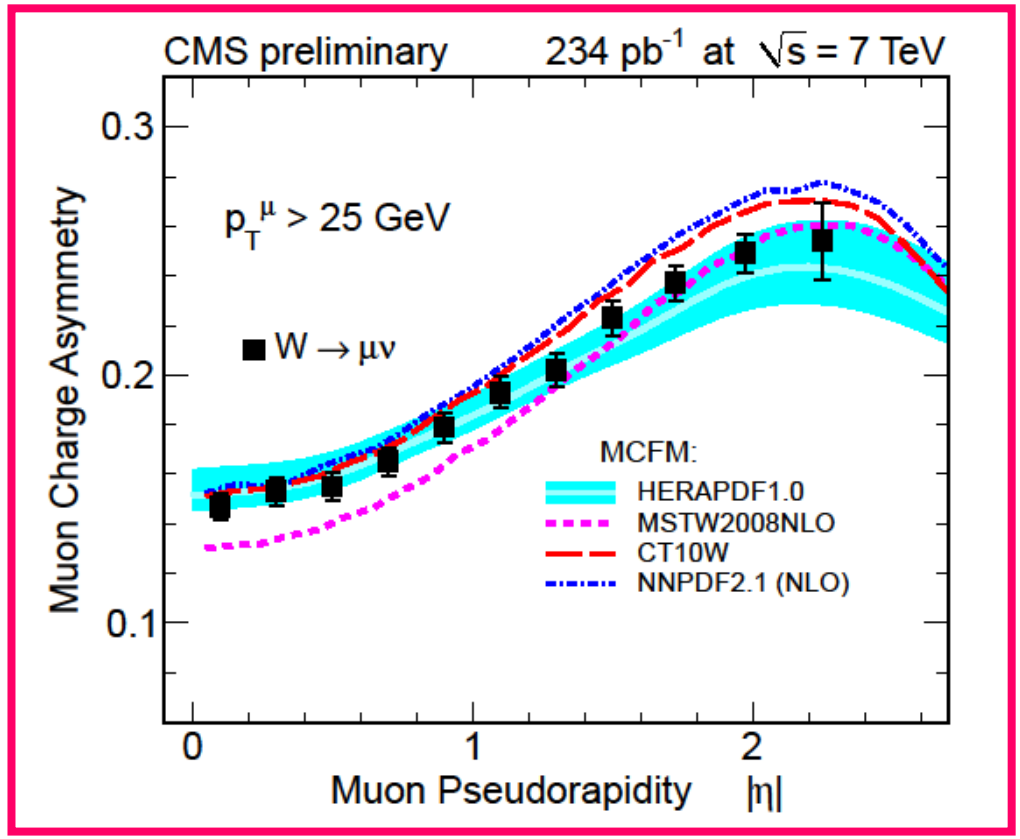
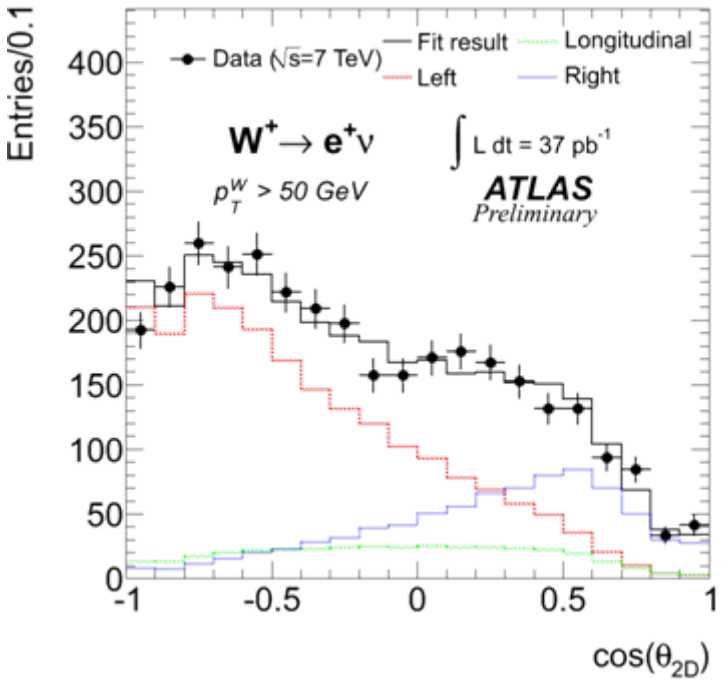


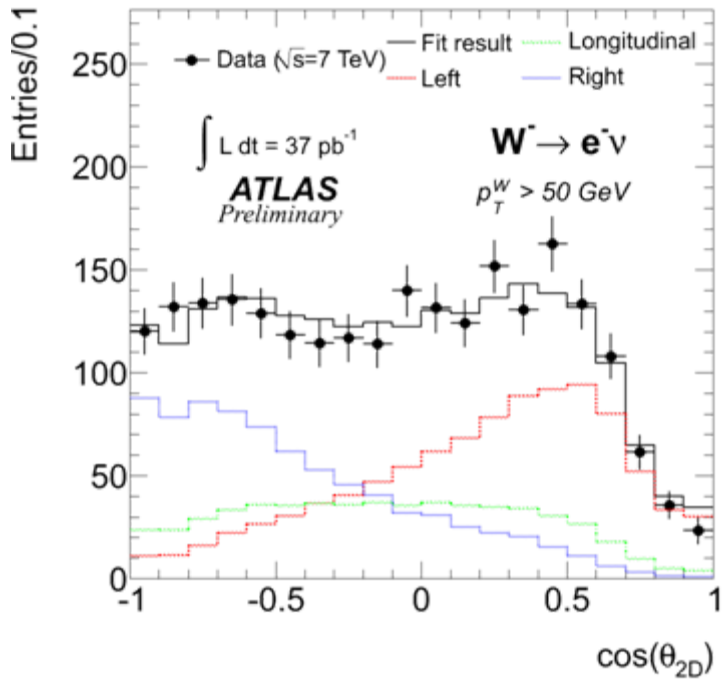
CMS update
234 pb^{-1}, W→μν

W Polarization

- Use high-p_T W
  - Sensitive to gluon content
    - ug→Wd, dg→Wu, ud→Wg
- Analyze angular distribution of decay products
  - Assume ϕ symmetry

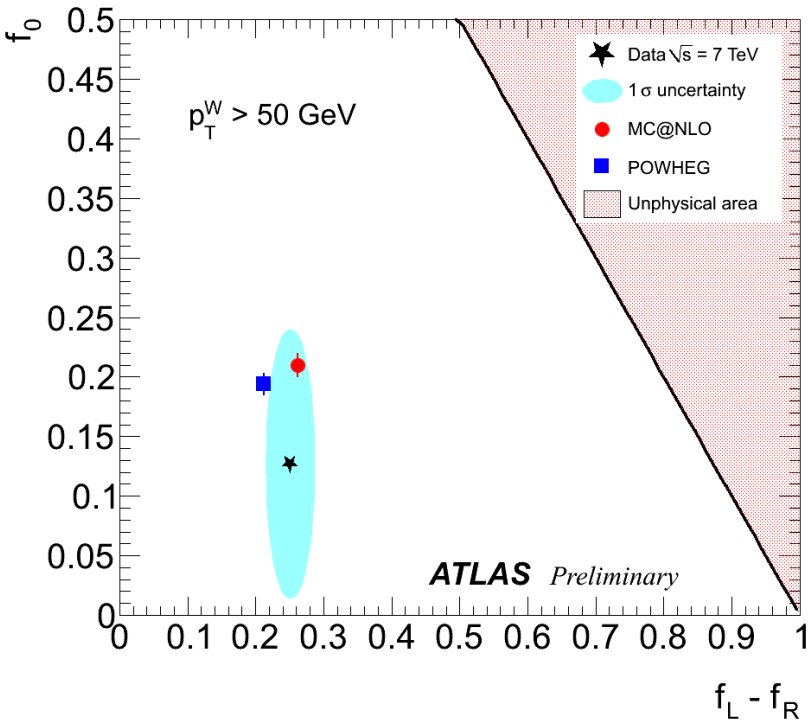
- Replace W decay angle with correlated quantity
  - ATLAS: $\cos\theta_{2D}=p_T^W \cdot p_T^\ell / |p_T^W|*|p_T^\ell|$
  - CMS: $\cos\theta'=p_T^W \cdot p_T^\ell / |p_T^W|^2$
- Fit angular templates

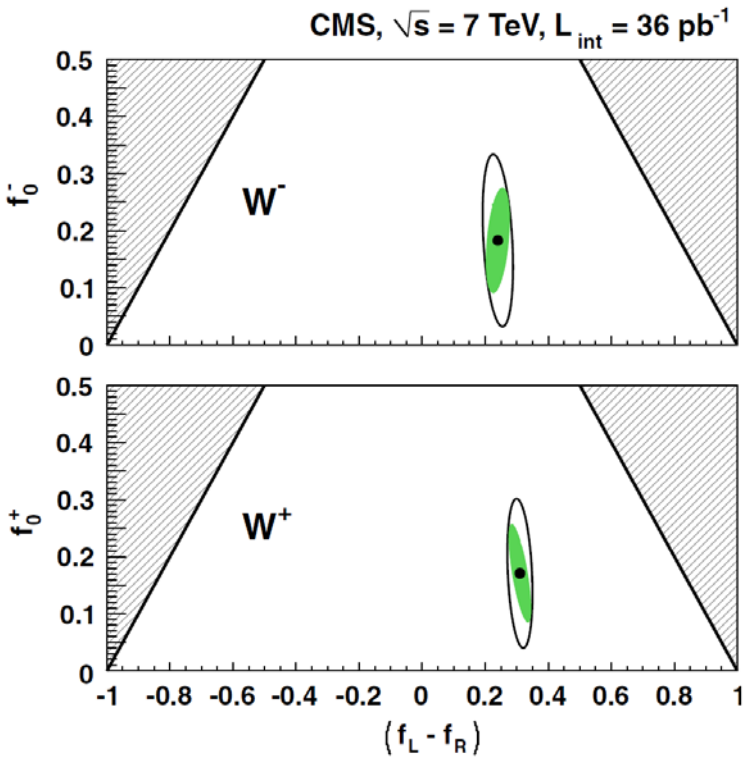




W Polarization – Results

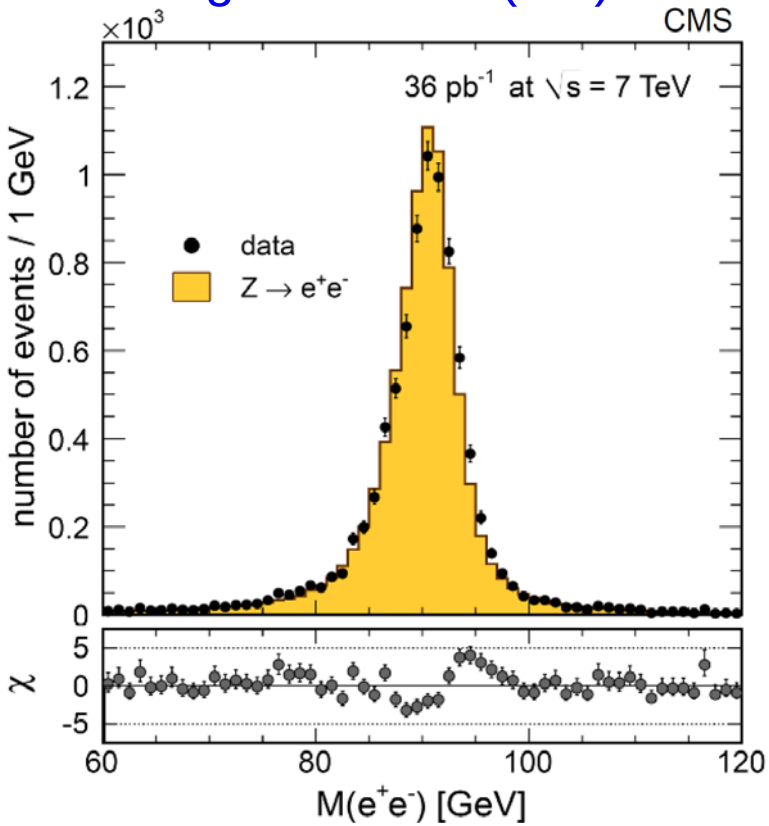
- Measure polarization fractions (longitudinal, left-handed, right-handed)
  - f_0: vanishes for $p_T^W \to 0$ and $p_T^W \to \infty$; predicted maximum for $p_T^W \sim 45$GeV
  - f_L-f_R: at large rapidity, W mostly left-handed (moves in direction of quark)
- Provide information about W production process
  - Test LO and NLO predictions for angular distributions

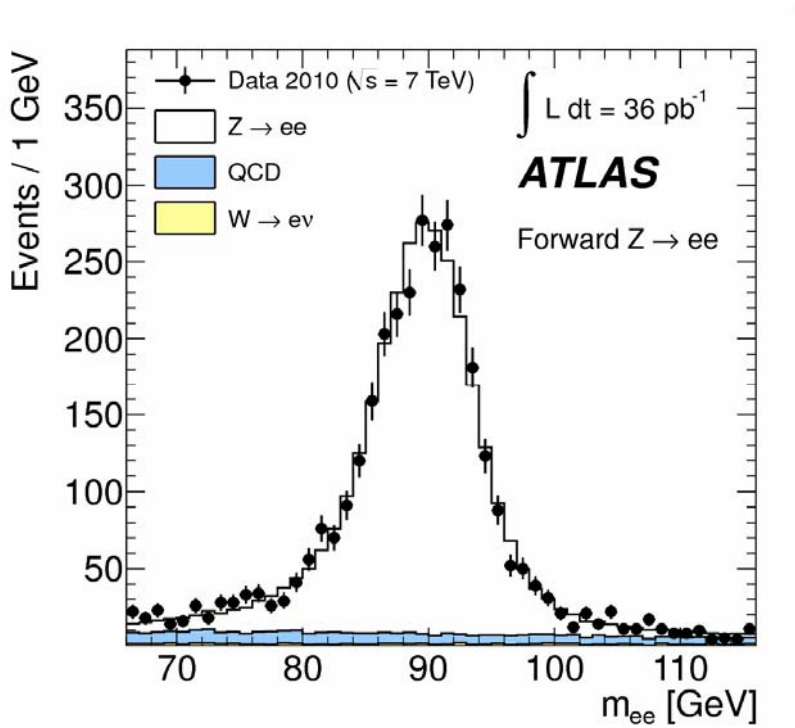




Z Production Cross Section

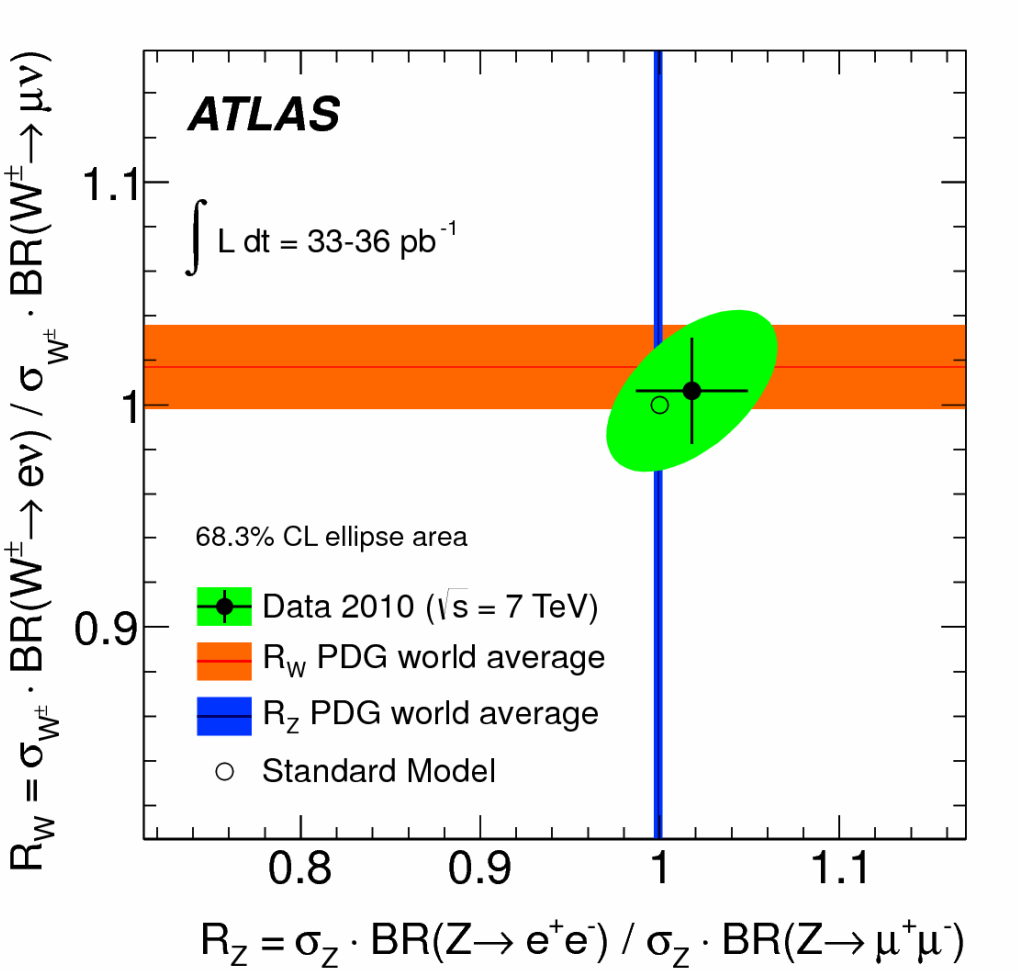
- Standard candle, very clean signature
  - Two high-p_T leptons
  - Backgrounds ~ O(1%)
- Cross-section measurements limited by systematics
  - Uncertainty ~ 2-3%





One electron in 2.5<|η|<4.9

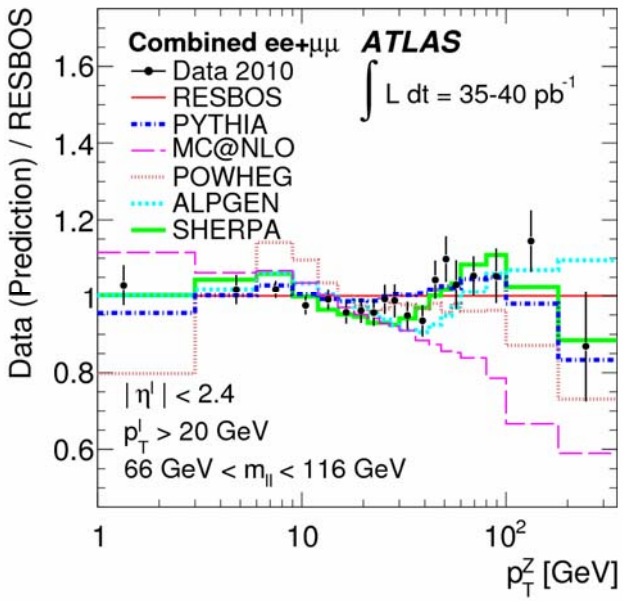
Lepton Universality

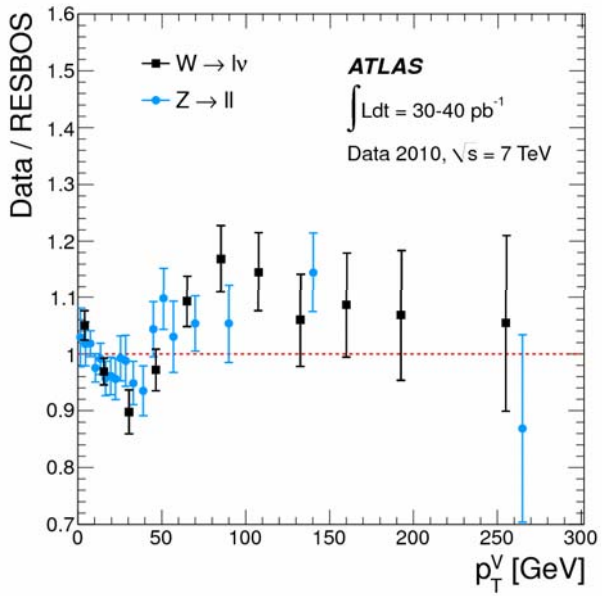


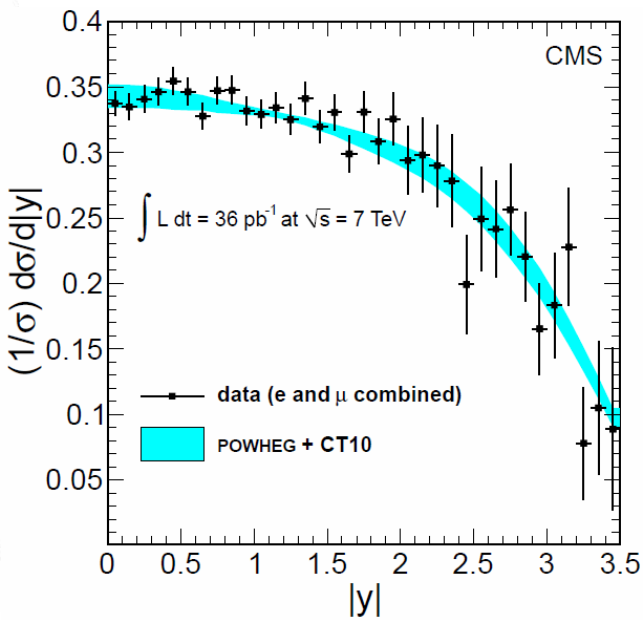
- Highly precise measurements of W and Z cross sections
  - Already comparable with PDG for W case (only 36 pb^{-1}!)

Differential Cross Sections

- Tests of multiple aspects of QCD predictions
  - Low p_T(W/Z): logarithmic resummations
  - High p_T(W/Z): test NNLO perturbative QCD
  - Z vs. y: sensitive to proton structure (esp. |y|>2.5)
- Important ingredients for tuning simulations

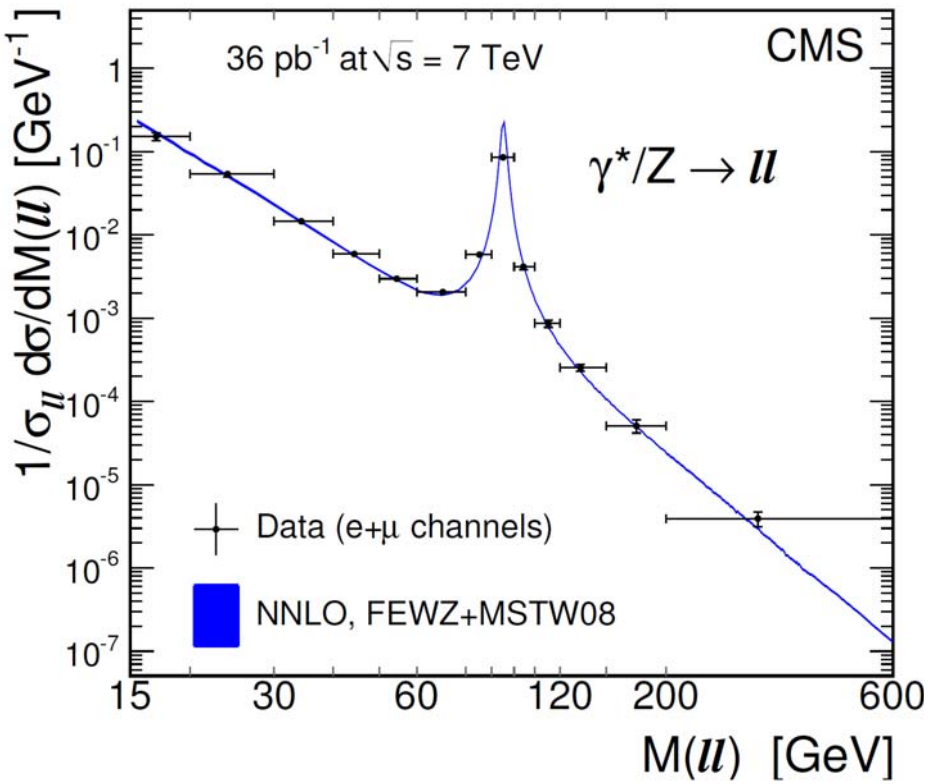






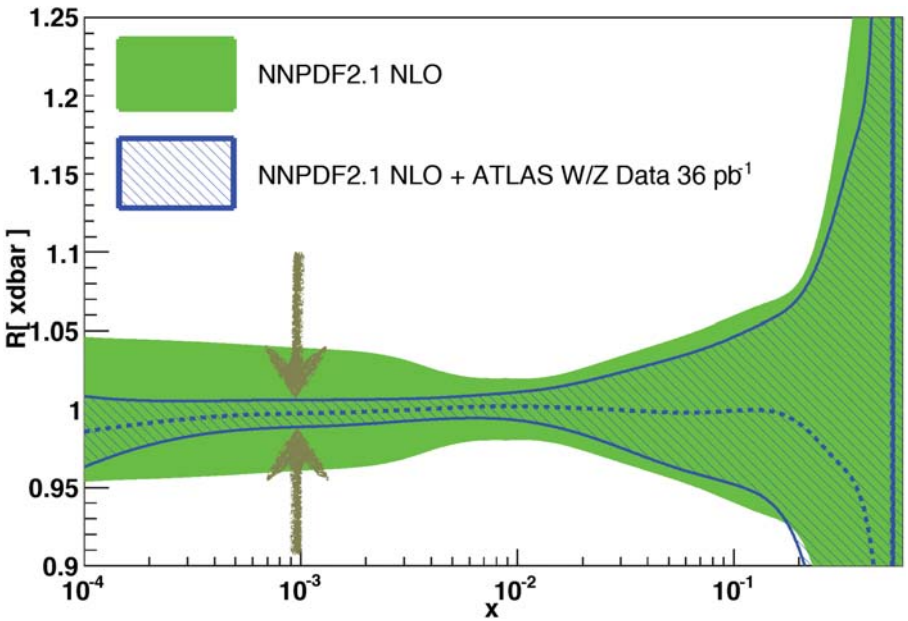
Drell-Yan Cross Section

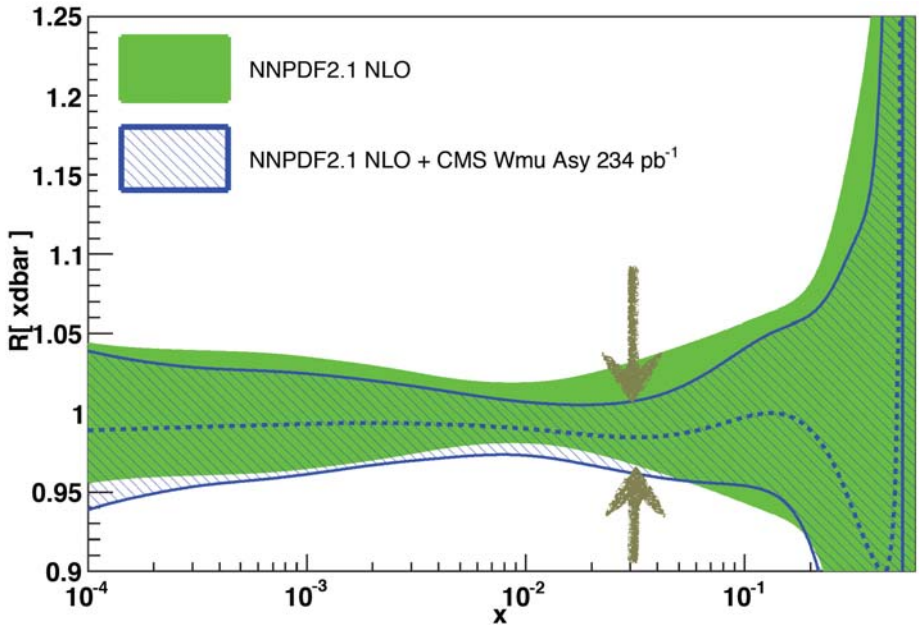
- Predictions available at NNLO
  - Test for QCD
  - Constraints on PDFs
  - Background for new physics searches
- Measured differential $\ell\ell$ cross section normalized w.r.t. Z cross section ($60<m_{\ell\ell}<120$GeV)
  - Also measured fiducial cross section; before and after FSR
  - Good agreement with NNLO prediction

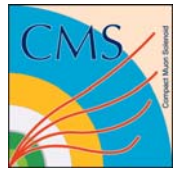


Impact on PDF

- W/Z results included in NNPDF2.2
  - Inclusive, differential cross sections, asymmetry and W/Z+jets results
- Showing impact of W/Z inclusive σ and W asymmetry results
  - Complete set of plots in PDF4LHC talk
    - https://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=145744



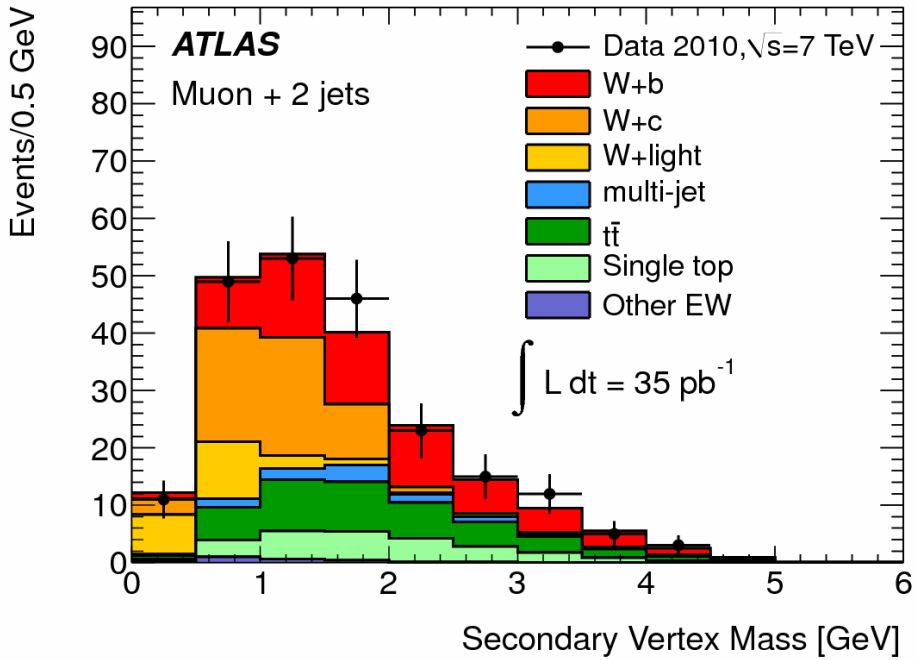


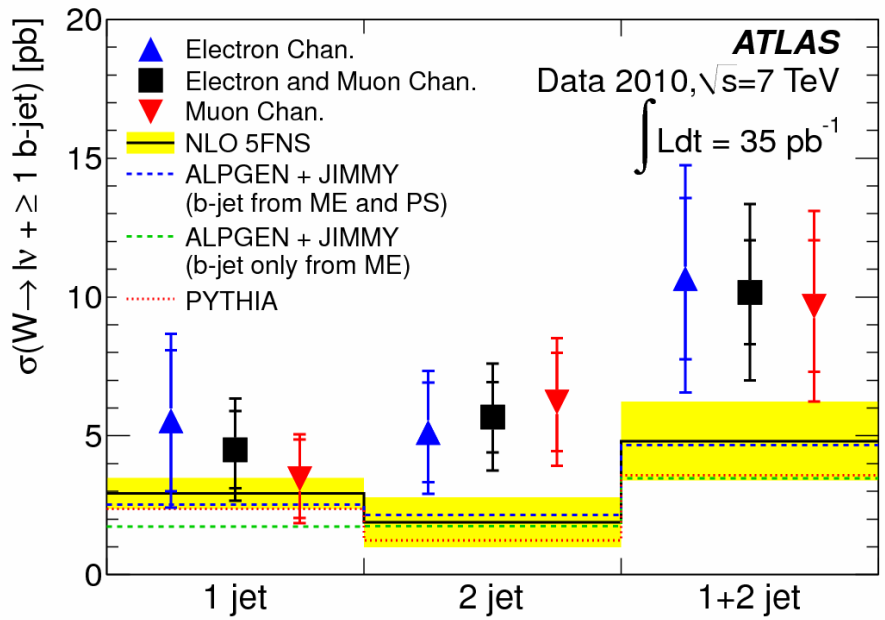


W/Z+jets Analyses

W+b-jet Production

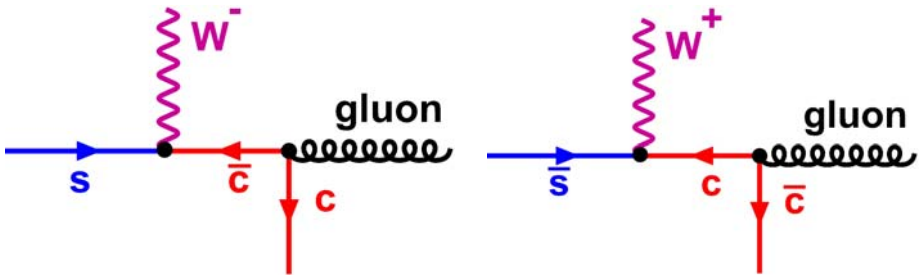
- Test of NLO QCD calculations
  - In 5-Flavor Number Scheme, b quarks in initial state
- Max-Likelihood fit of secondary vertex mass
- First 7TeV measurement of W+1 or 2 b-jets



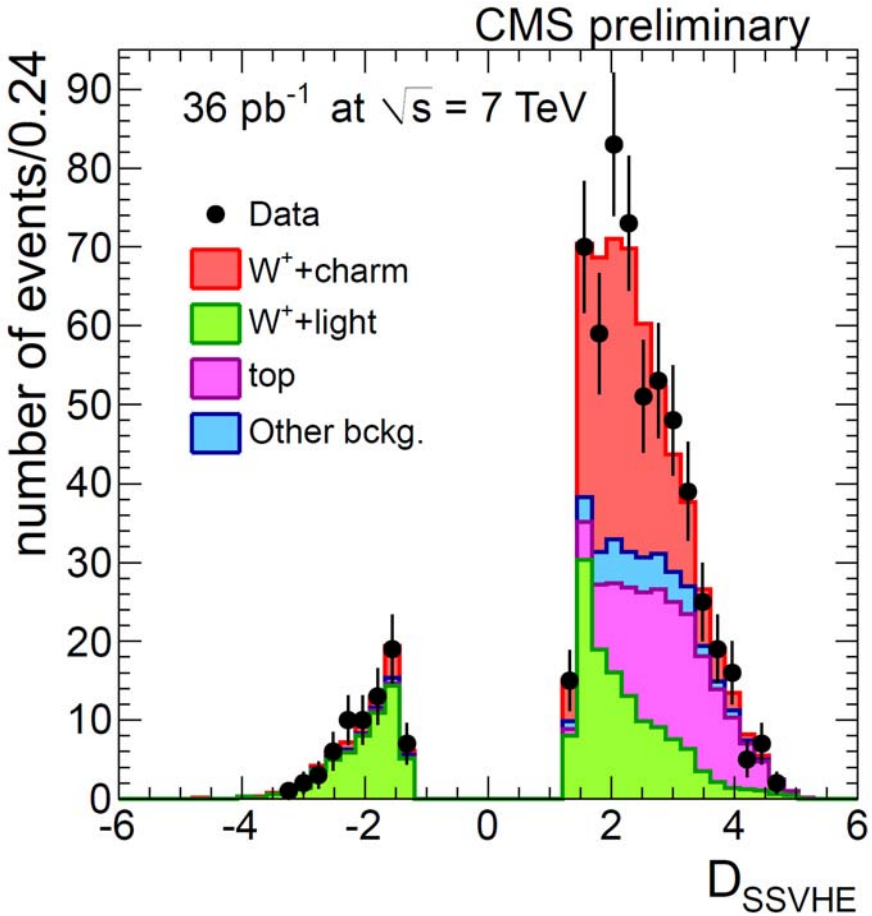


W+c-jet Production

- Measure strangeness content of proton

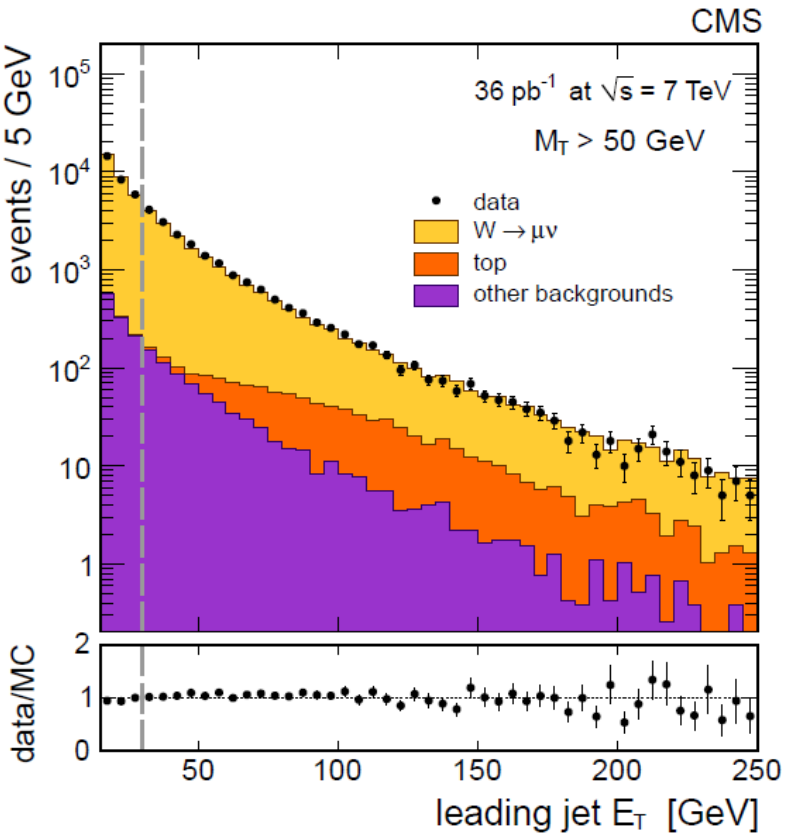


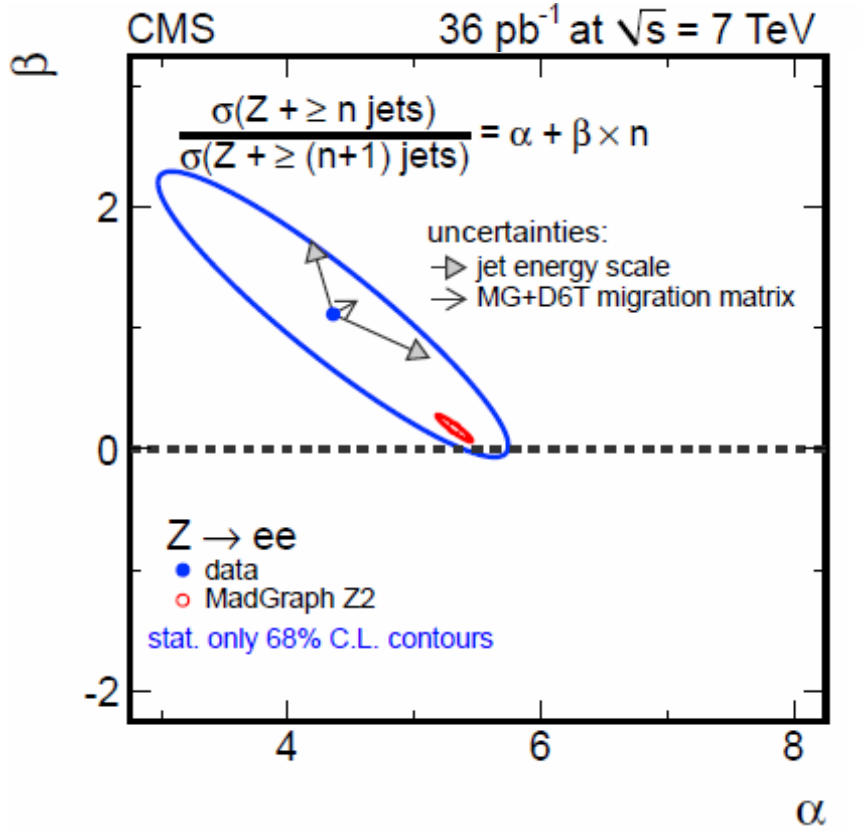
- Separate c-jets with lifetime-based cut
- Observables
  - W^++cbar/W^-+c
  - W+c/W+jet



R-jets Analysis - CMS

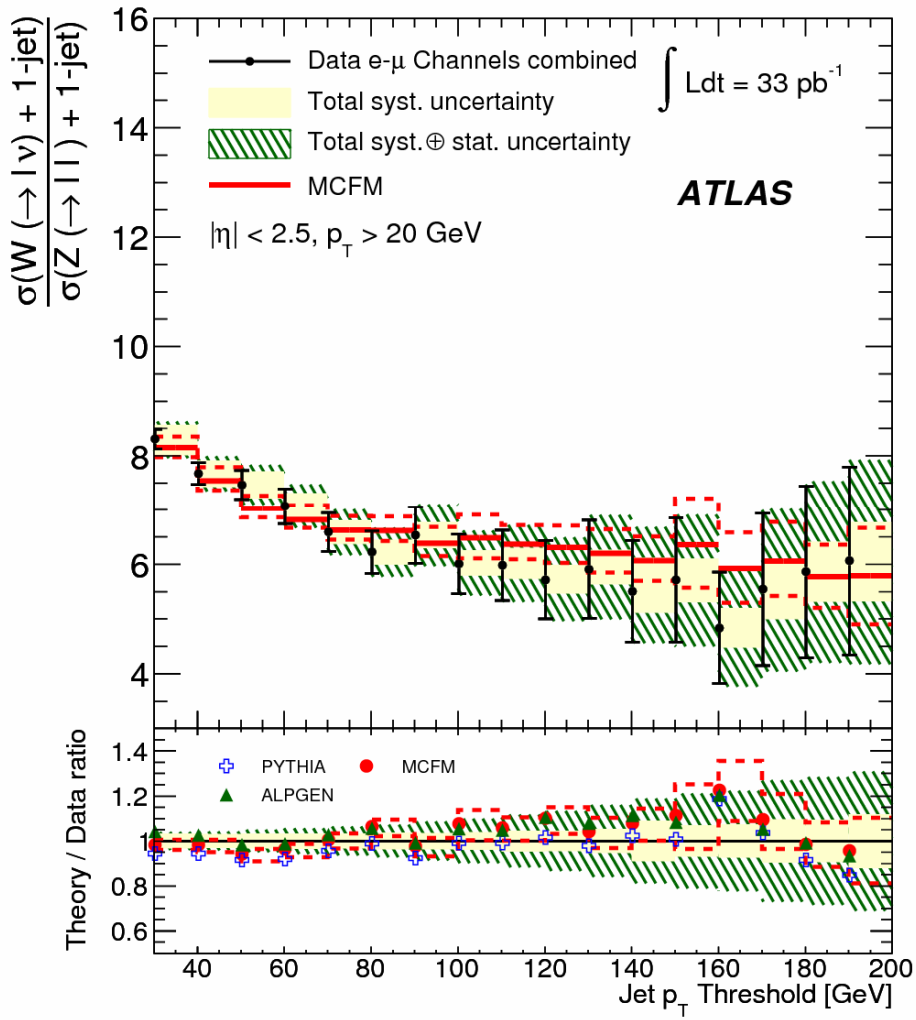
- Count jets with transverse momentum above threshold
- Measure ratio of V+n-jets/V+(n+1)-jets
  - Test Berends-Gele scaling





R-jets Analysis - ATLAS

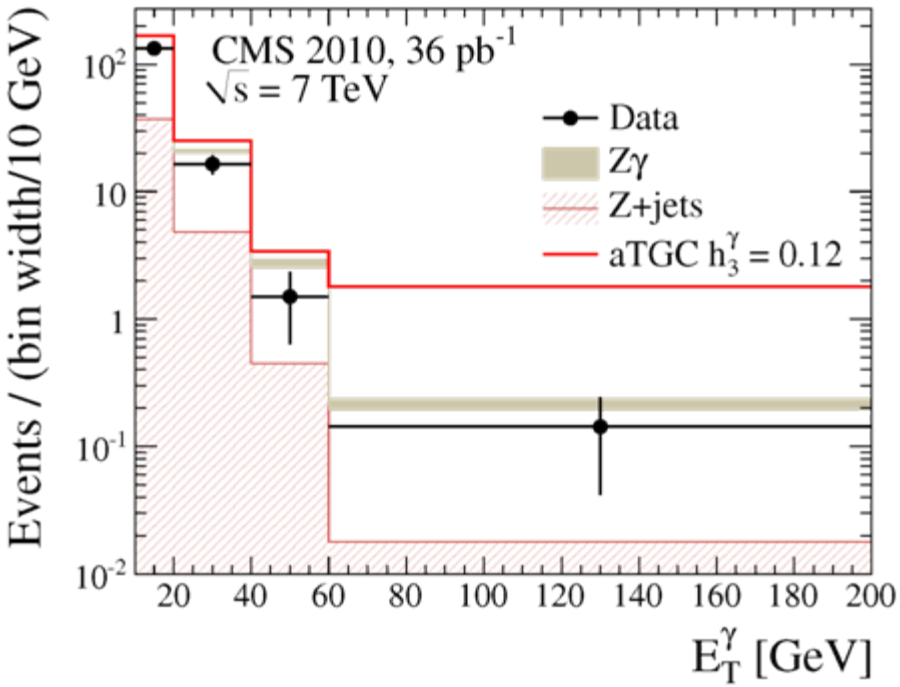
- Measure W+1jet/Z+1jet ratio vs. jet p_T threshold
  - Minimize experimental and theory uncertainties
  - Model-independent sensitivity to new physics coupling to jets and leptons
- Explore transition region of electroweak scale breaking in perturbative jet production
  - In agreement with LO and NLO prediction

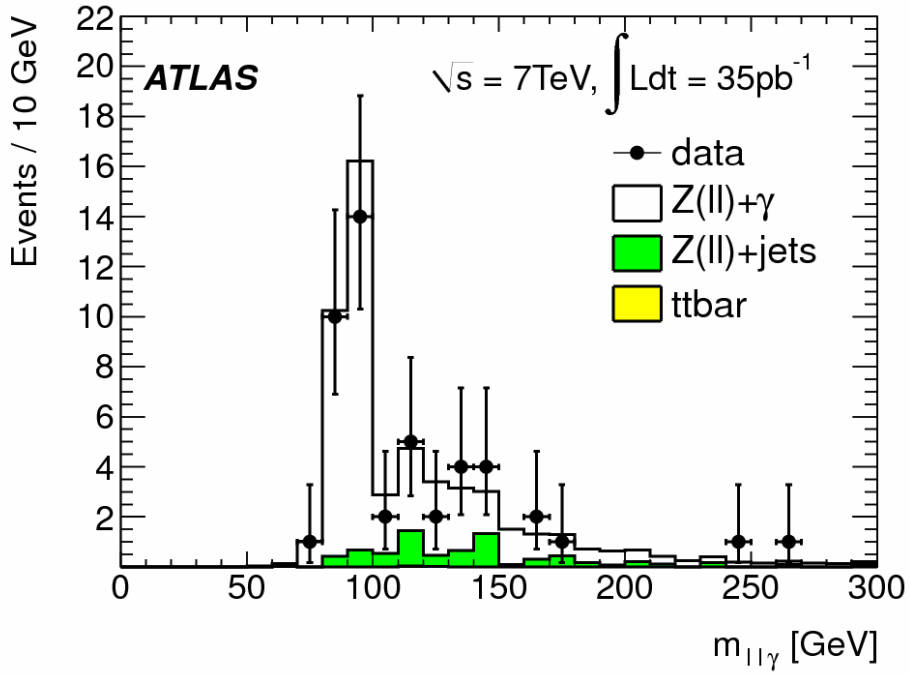


Di-boson Analyses

W/Z+γ Production

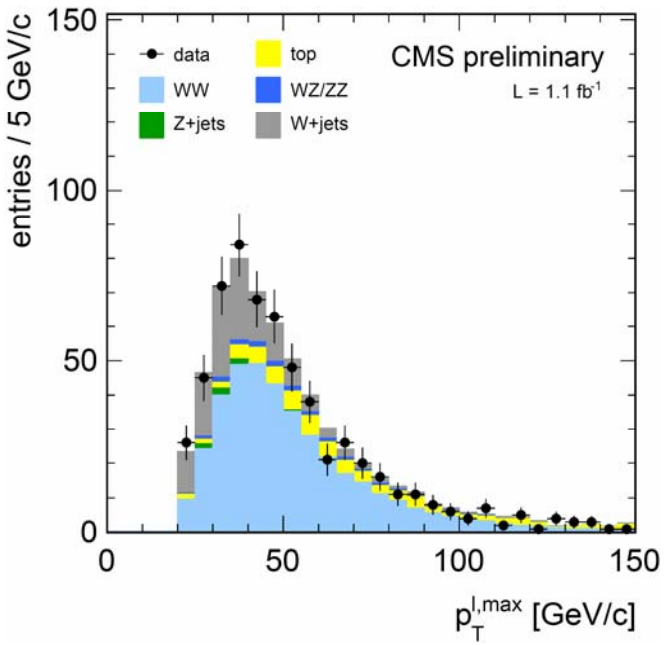
- Highest-σ di-boson process
  - Probe anomalous TGC (ZZγ zero in SM), new physics enhancing production rate
  - Background to searches (e.g. techni-rho, techni-omega, GMSB SUSY)
- High-p_T, isolated lepton, isolated photon
  - Jets fake lepton/photon
- Measure σ^{tot} and σ^{fid}
  - Compare well with NLO, uncertainty ~ 20%

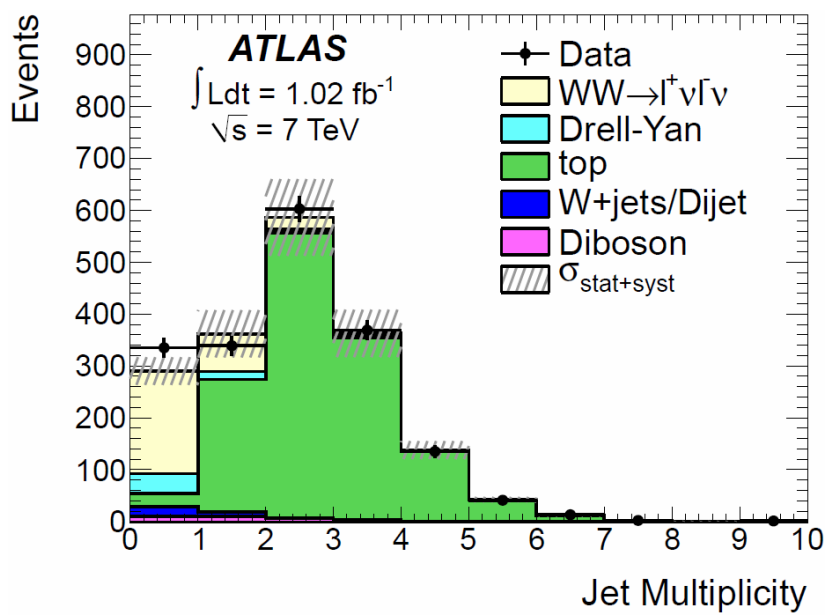




WW Production

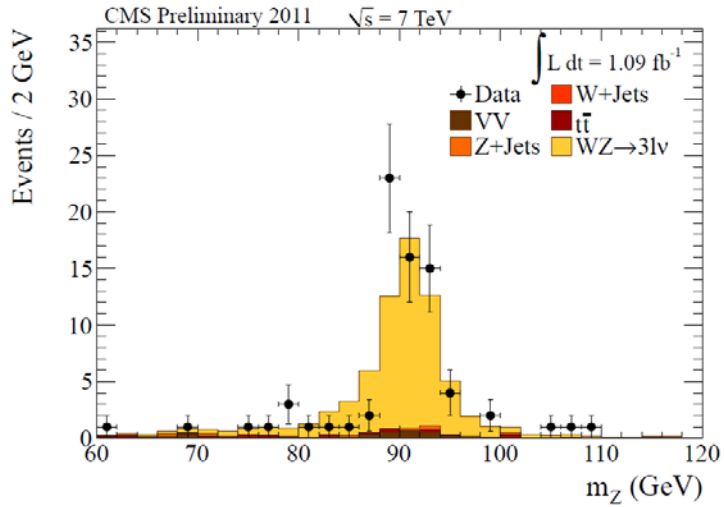
- W^+W^- production via qq (~97%) and gg (~3%)
  - Sensitive to TGC
  - Test of QCD, via gg→WW
  - Irreducible background for H→WW
- Analysis in a nutshell
  - Two high-p_T leptons
  - Missing Transverse Energy
  - m($\ell\ell$) cuts to veto Z+jets
  - Cut on jet multiplicity to remove top

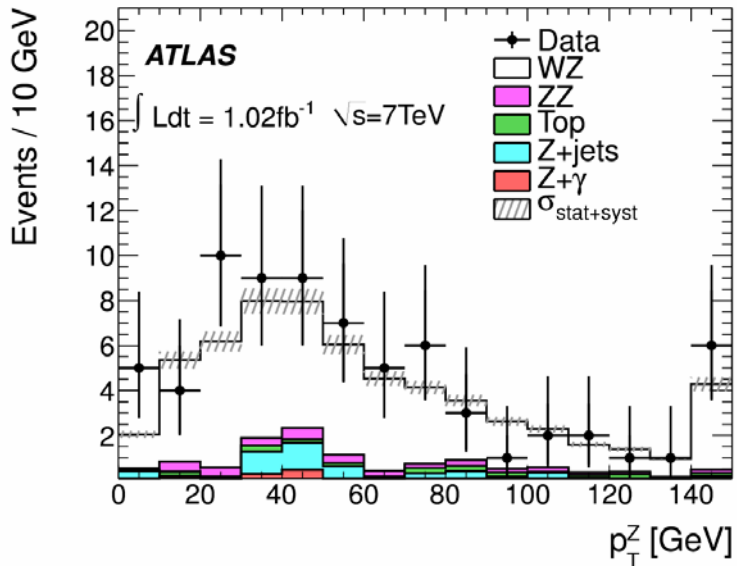




WZ Production

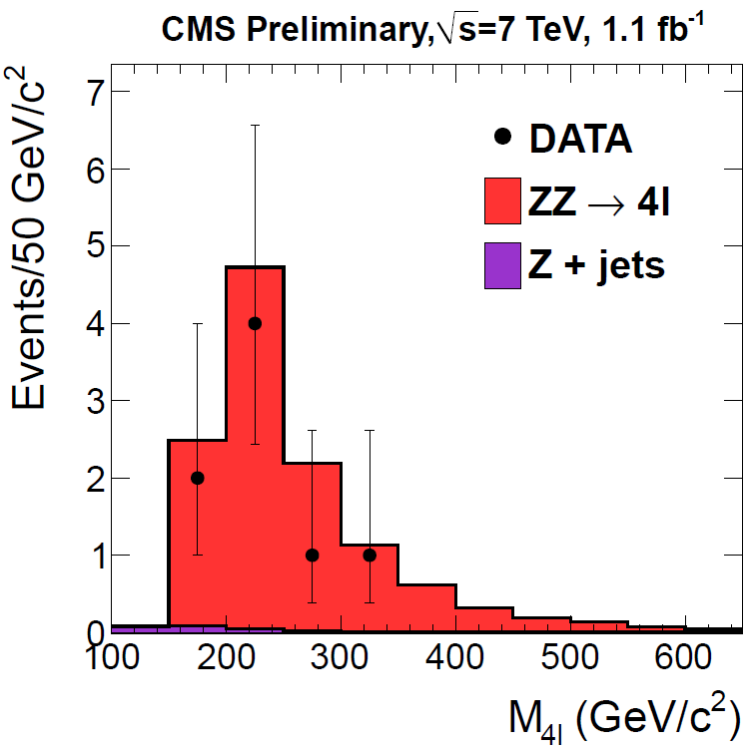
- Sensitive to Technicolor, W', charged Higgs, anomalous TGCs
  - Different sensitivity than WW and W/Z+γ
- Cleaner than WW
  - S:B ~ 5:1
  - Backgrounds: ZZ, top, Z+jets
    - Z mass window, E_T^{miss}, lepton isolation

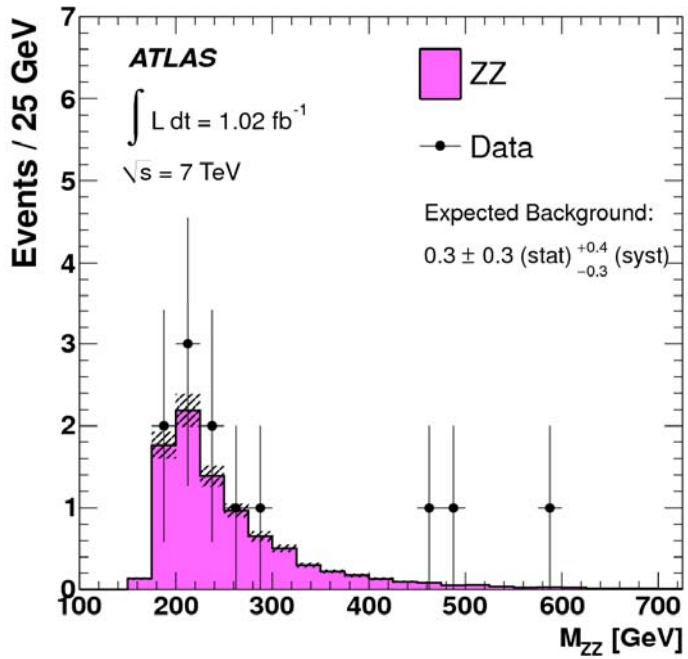




ZZ Production

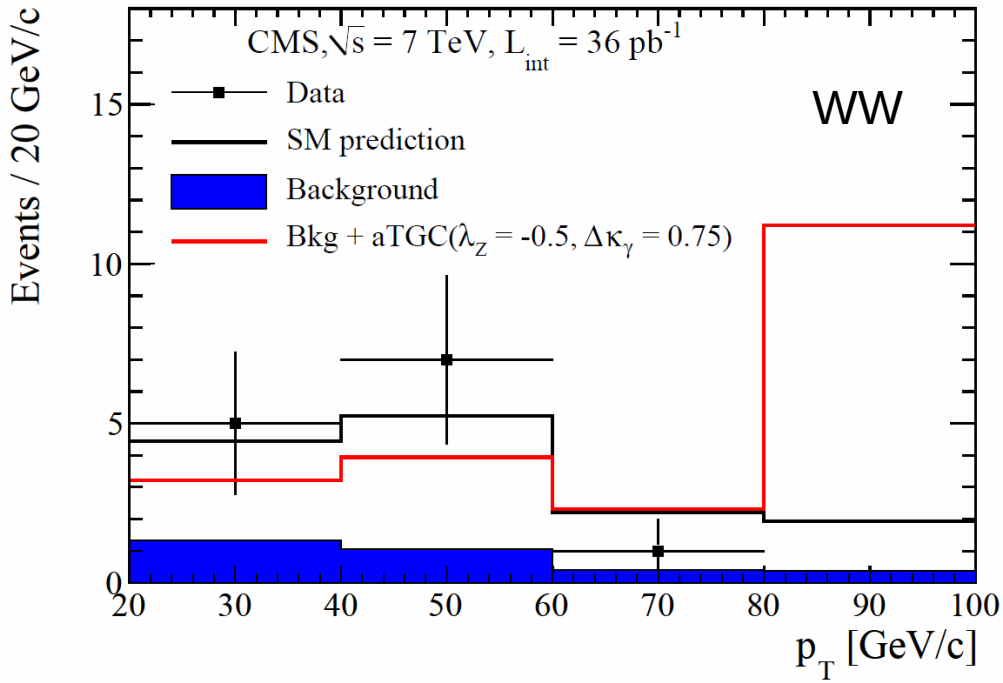
- Four isolated leptons
  - Not much background from SM processes
  - Multiple lepton combinations possible
- Small cross section already accessible
  - Total cross section: few pb
  - 1 fb^{-1} enough to make first, statistically limited, measurement

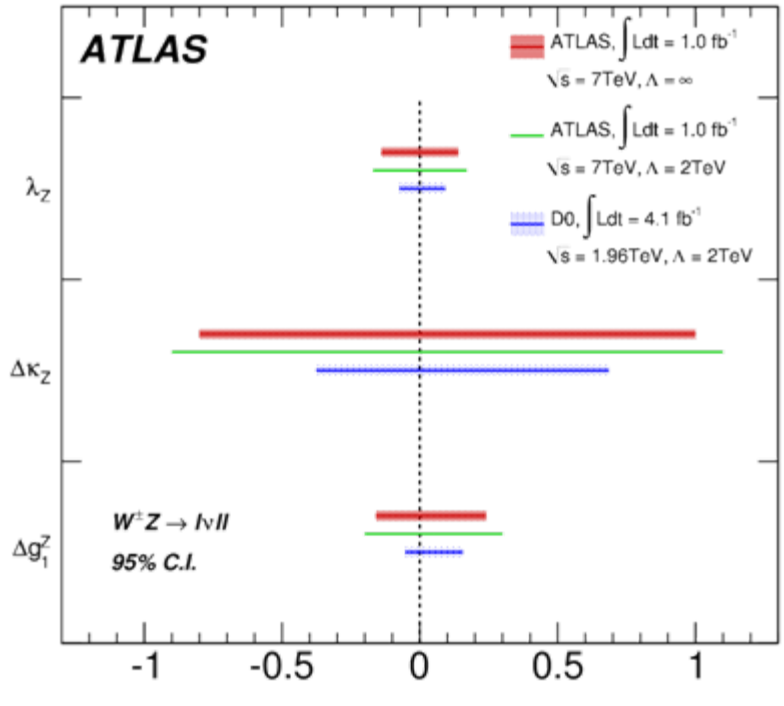




Anomalous TGCs

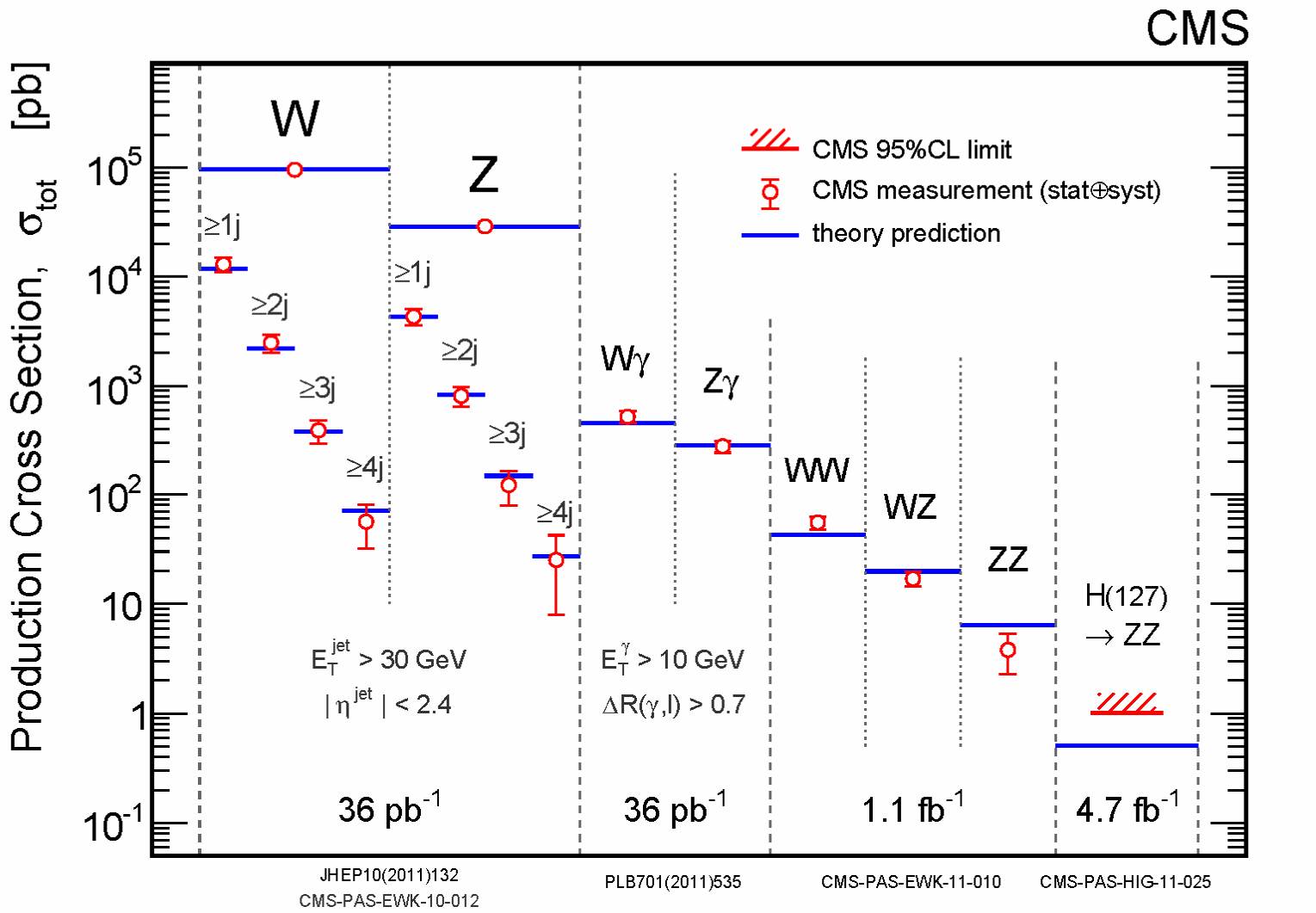
- Allow for modifications of VVV couplings (V=W,Z,γ)
  - Possible modifications modeled by different scenarios (LEP, HISZ, Equal-Coupling)
  - Investigate different cut-off scales
- Quickly competitive with previous measurements
  - High sqrt(s), much larger cross sections



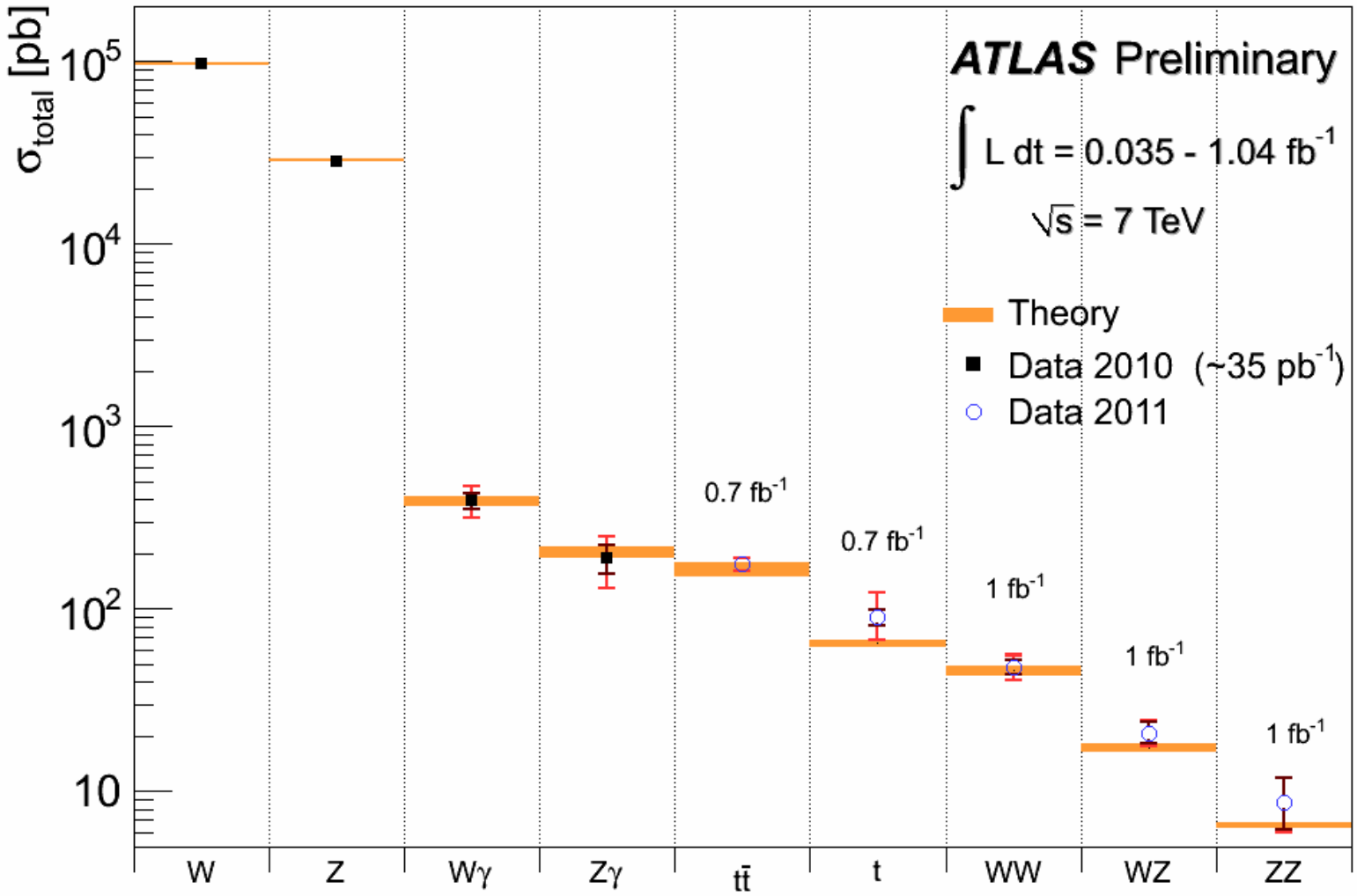


Summary and Conclusions

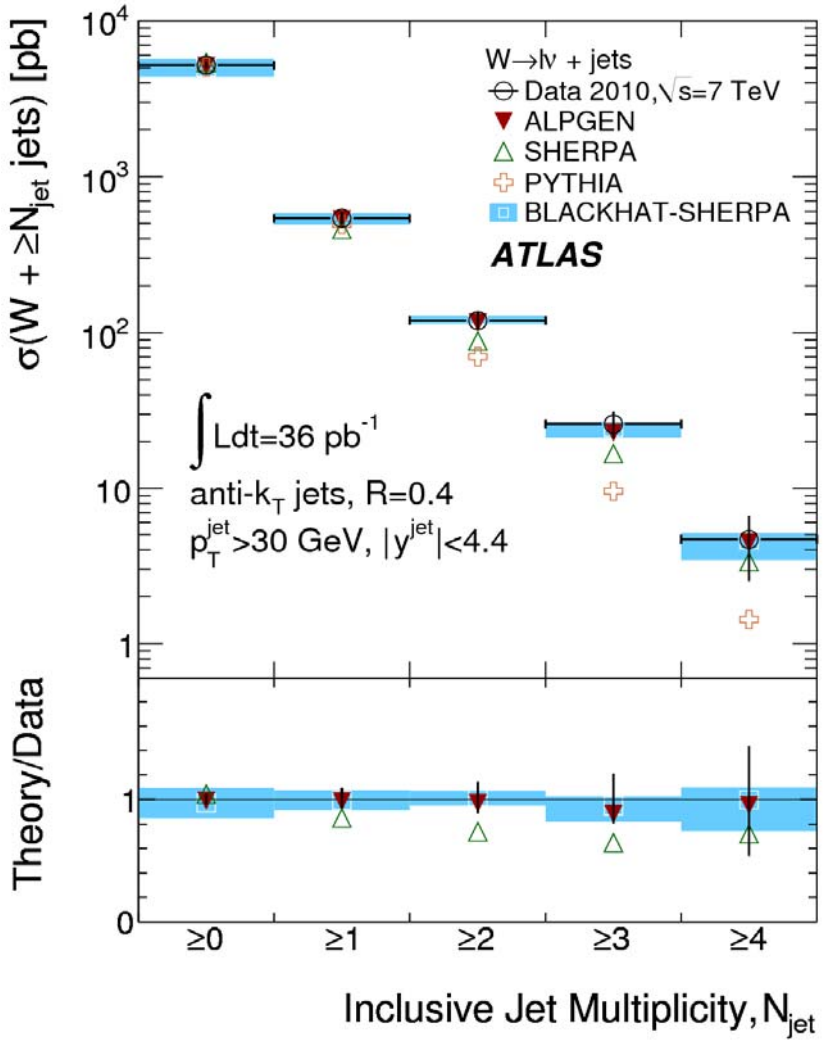
Cross Sections – CMS

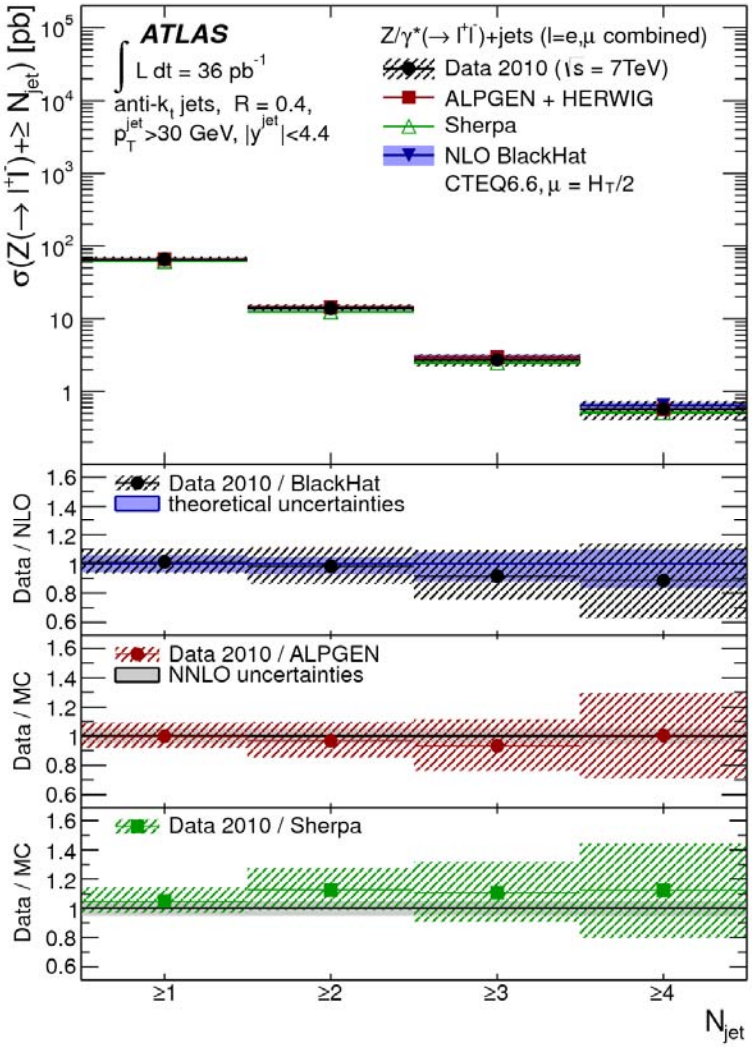


Cross Sections – ATLAS



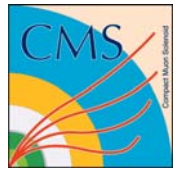
Cross Sections – ATLAS 2





Conclusion

- Cross-section results spanning five orders of magnitude
- Measurements challenging NNLO predictions
  - PDF, QCD at high and low-Q^2
- Covered spectrum of diboson measurements
  - Constraining the Electroweak Lagrangian
  - Tri-boson measurements and QGC limits coming next
- Building fundamental knowledge
  - Extremely important for any search
  - No room for shortcuts
- Ready to catch any new physics



Backup

Documentation – CMS

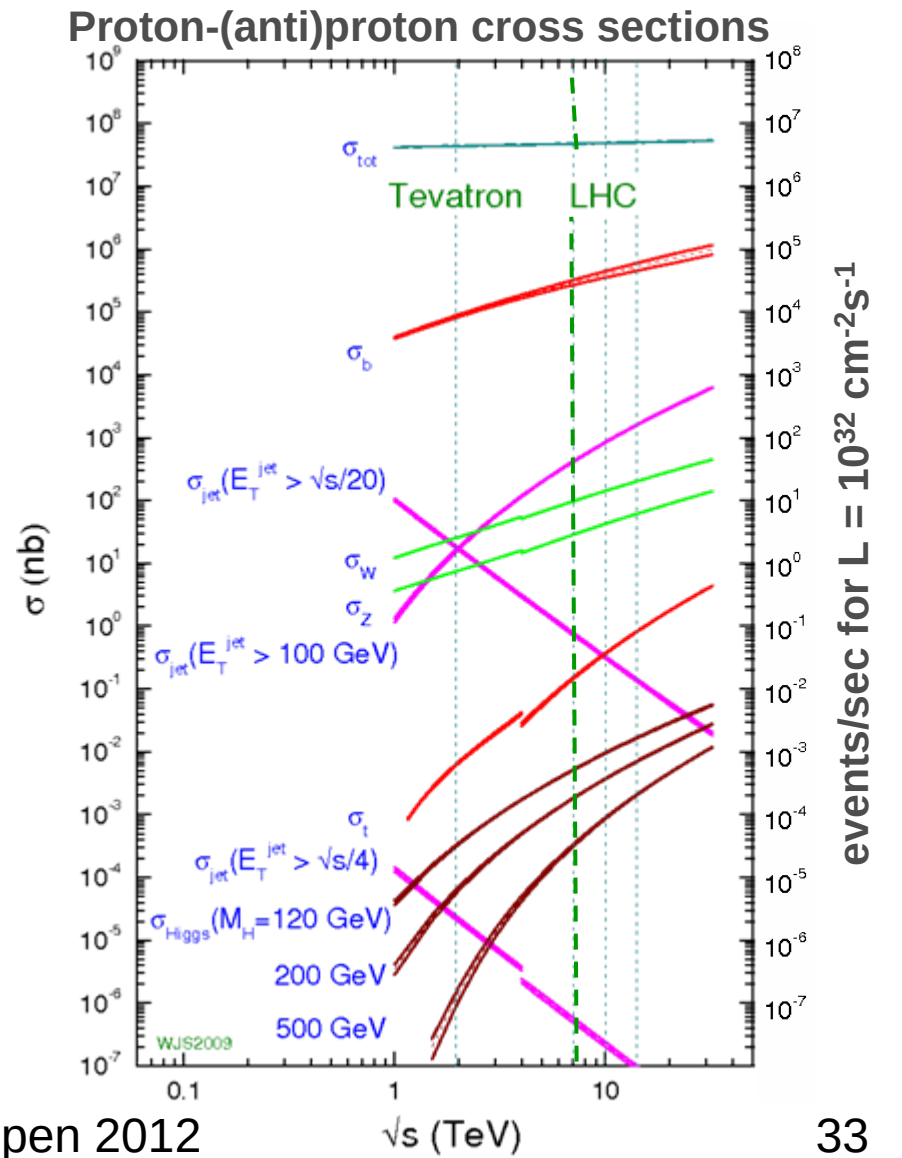
- Measurement of the weak mixing angle with the Drell-Yan process
  - Phys. Rev. D 84, 112002 (2011)
- Measurement of the Drell-Yan Cross Section
  - J. High Energy Phys. 10 (2011) 007
- W and Z Inclusive Cross Sections
  - J. High Energy Phys. 10 (2011) 132
- Z Rapidity and Transverse Momentum Distributions
  - arXiv:1110.4973
- Jet Production Rates in Association with W and Z
  - arXiv:1110.3226
- Measurement of W- γ and Z- γ Production
  - Phys. Lett. B 701 (2011) 535–555
- Update of the Muon Charge Asymmetry
  - CMS-EWK-11-005
- WW, WZ, and ZZ Cross Sections
  - CMS-PAS-EWK-11-010
- W+charm Production
  - CMS-PAS-EWK-11-013
- Polarization of W Bosons with Large Transverse Momenta in W+Jets Events
  - Phys. Rev. Lett. 107 (2011) 021802

Documentation – ATLAS

- Study of jets produced in association with a W boson
- Measurement of the WZ production cross section and limits on anomalous triple gauge couplings
- Measurement of the production cross section for Z/γ* in association with jets
- Measurement of the ZZ production cross section and limits on anomalous neutral triple gauge couplings
- Measurement of the inclusive W+- and Z/γ cross sections in the electron and muon decay channels
- Measurement of the cross section for the production of a W boson in association with b-jets
- Measurement of the cross-section for b-jets produced in association with a Z boson
- Measurement of the Transverse Momentum Distribution of W Bosons
- A measurement of the ratio of the W and Z cross sections with exactly one associated jet
- Measurement of the transverse momentum distribution of Z/γ* bosons
- Measurement of Wγ and Zγ production
- An extrapolation to a larger fiducial volume of the measurement of the W$\rightarrow\ell\nu$ charge asymmetry: Graphical comparison between ATLAS, CMS and LHCb

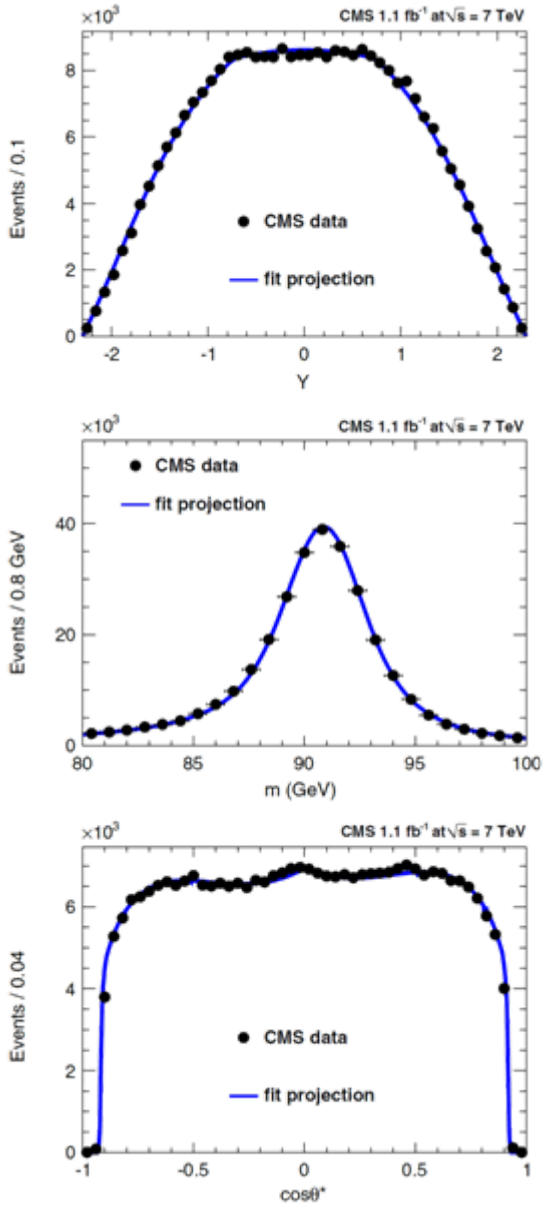
W and Z Production

- Abundantly produced
- Clear signatures
- Probes into proton structure
- Tests of QCD at different energy regimes
- Backgrounds for many searches



Z FB Asymmetry

- Measure forward-backward asymmetry in the lepton-quark polar-angle distribution
  - pp collisions: use Z boost to statistically infer quark direction
- Multivariate analysis
  - Simultaneous fit of polar angle, m($\ell\ell$) and Z rapidity
- Measure $\sin^2\theta_{eff}$ with 1% precision



W+Jets Associated Production

- Comprehensive list of measurements
  - Up to σ(W+$\geq$5-jets)
  - Two jet-p_T thresholds
    - 20GeV and 30GeV
  - Jet multiplicity; 1st, 2nd, 3rd, 4th jet p_T; Δy(l,jet), $\Delta\phi$(jets), Δy(jets), ΔR(jets), y(1st jet), Σ y(l,jet), H_T, m(jets)