XI LISHEP 2013

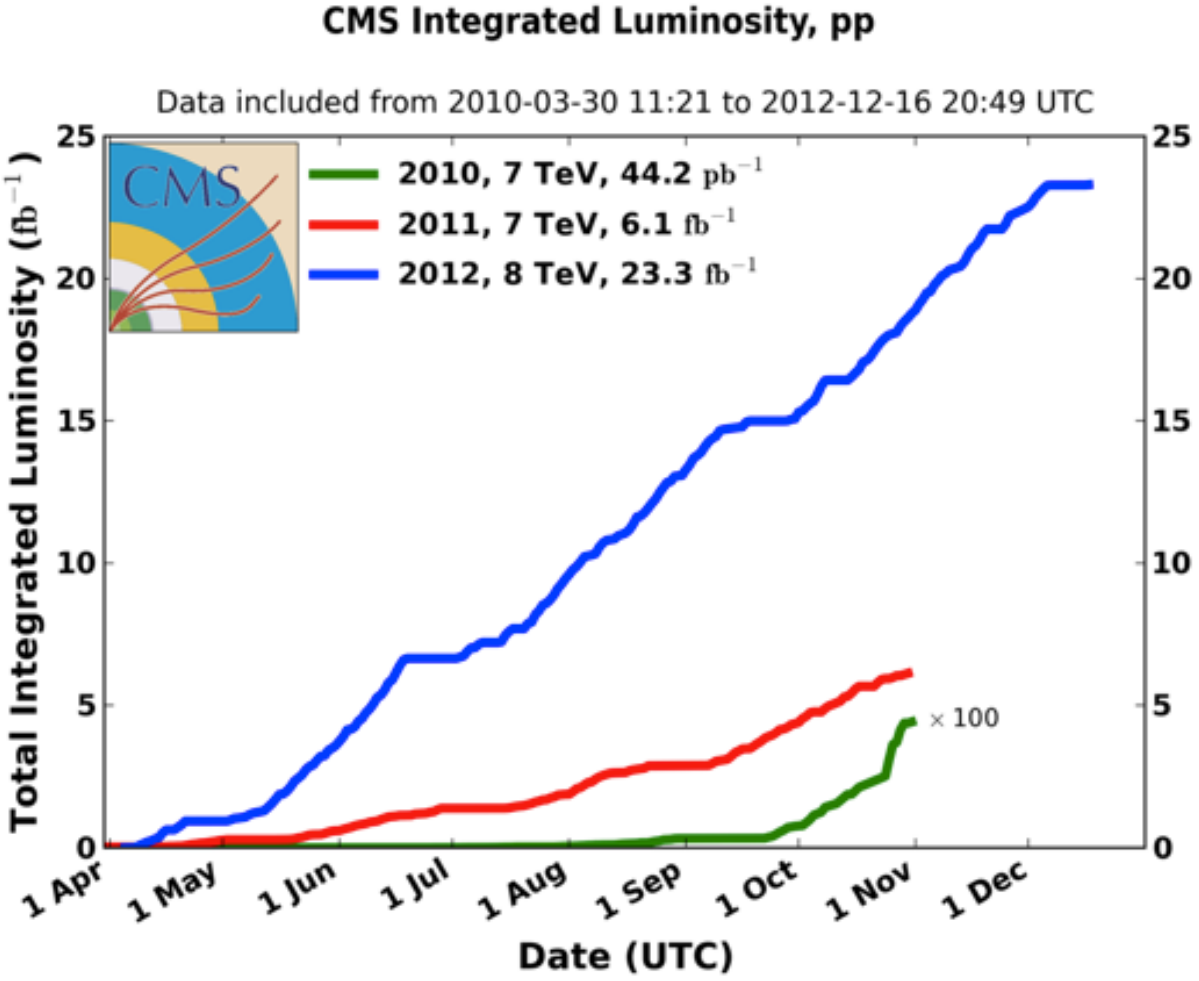
International School on High Energy Physics

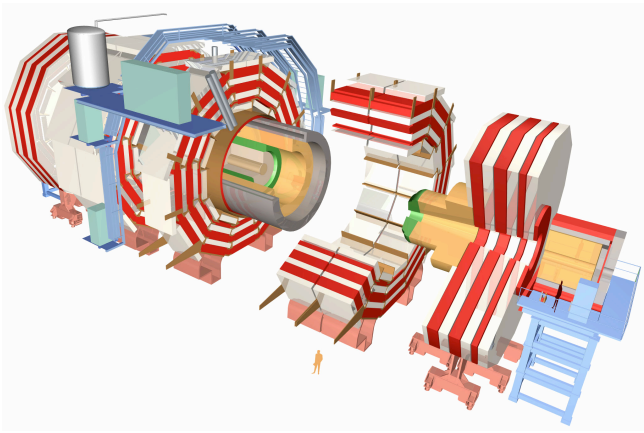
Electroweak Results From CMS

Matt Herndon

University of Wisconsin – Madison

Integrated Luminosity





- Measurements are from 7 TeV and 8 TeV pp collisions
- I concentrate on newer measurements
- All results shown can be found at:

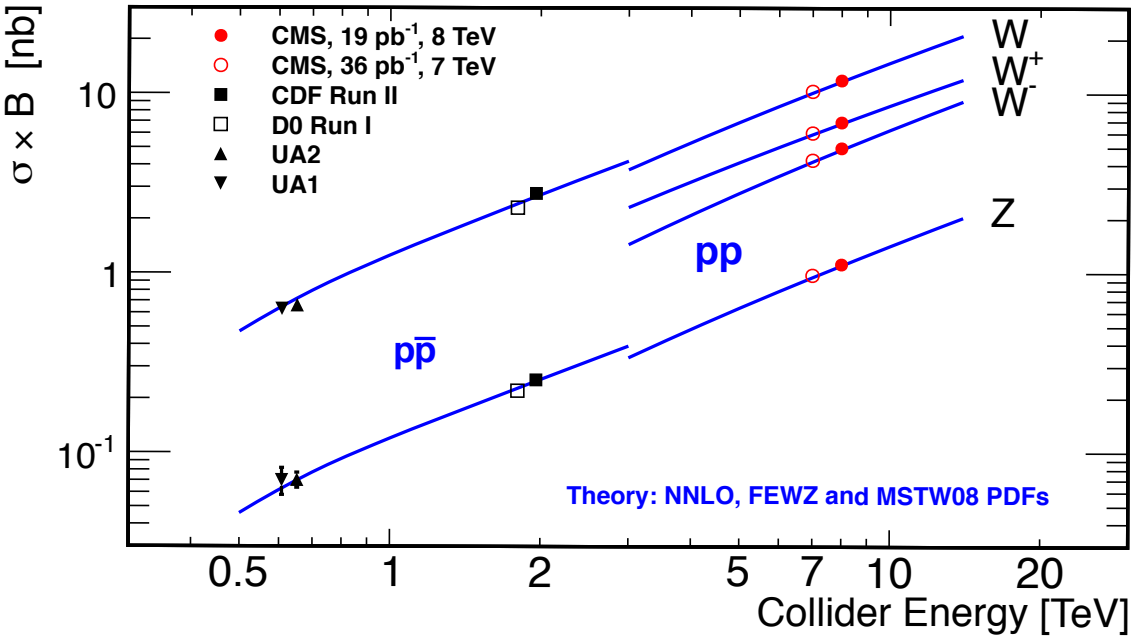
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

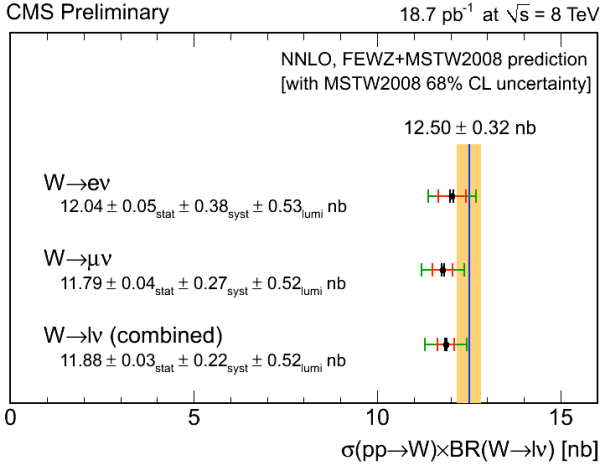
W & Z Precision Measurements

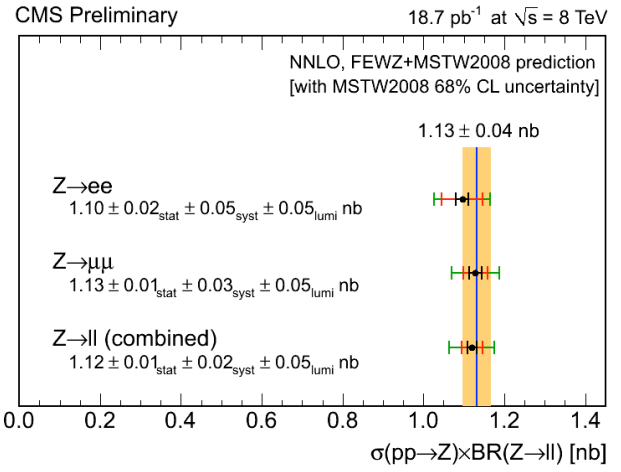
- Combination of several factors have made unprecedented precision measurements possible in a Hadron collider environment.
  - The capabilities and performance of the LHC experiments
  - The development sophisticated experimental techniques to treat collider data
  - The existence of inclusive and differential calculation of cross sections at NLO and NNLO precision
  - The integration of matrix element MCs with parton shower generators in a consistent way at NLO
- These factors allow an exciting program of measurements with sensitivity to fundamental issues.
  - pQCD tests at NLO and NNLO
  - Test of matrix element + parton shower techniques
  - PDF sensitivity
  - Test of Electroweak predictions for asymmetries and polarizations
  - Differential distributions for transverse momentum, rapidity, and jets
  - Associated production of vector boson and heavy flavor jets
  - Vector boson fusion

W & Z Cross Sections

- Measurement of total W and Z cross sections.
  - pQCD test from ratio of 7 TeV to 8 TeV cross sections and W/Z, W^+/W^-
  - PDF sensitivity





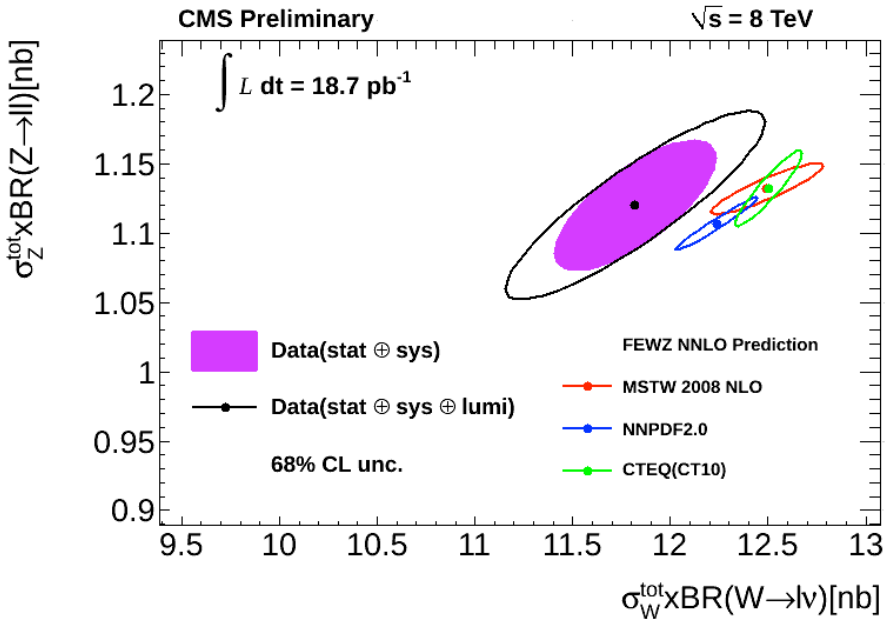


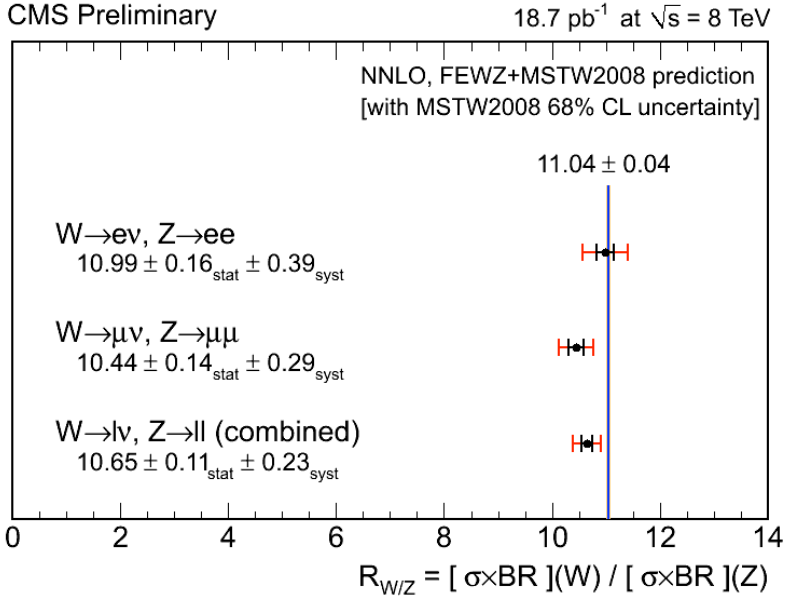
- Comparable experimental and theory uncertainty
- 2-3% systematic and 5% luminosity uncertainty

CMS PAS SMP-12-011

W and Z Cross Sections

- Cancelation of systematic errors in ratio
  - both experimental and theoretical
  - Removes largest experimental uncertainty, luminosity





- W/Z ratio at 8 TeV: ~1.5 sigma difference all PDF sets
  - 2% experimental systematic uncertainty.
  - Milder tension was present in the 7 TeV measurement

CMS PAS SMP-12-011

JHEP 10 (2011) 132

W and Z Cross Sections

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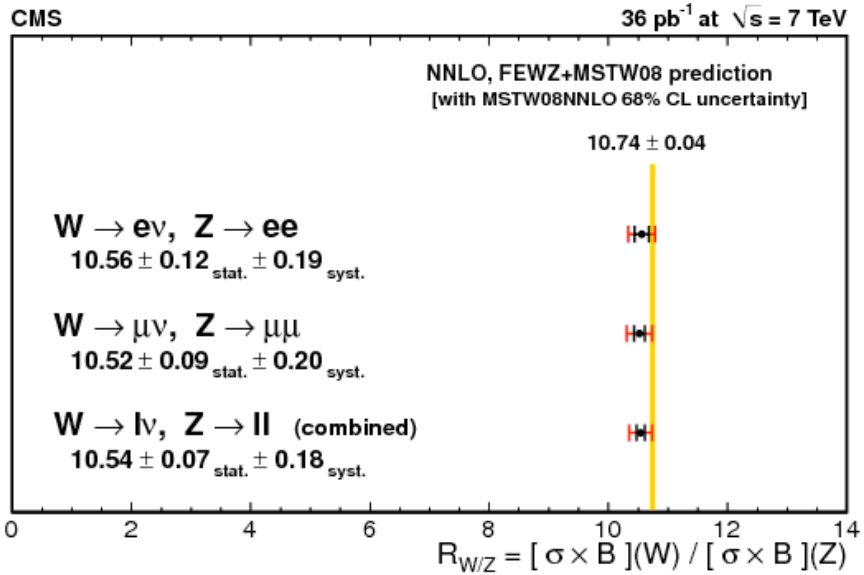

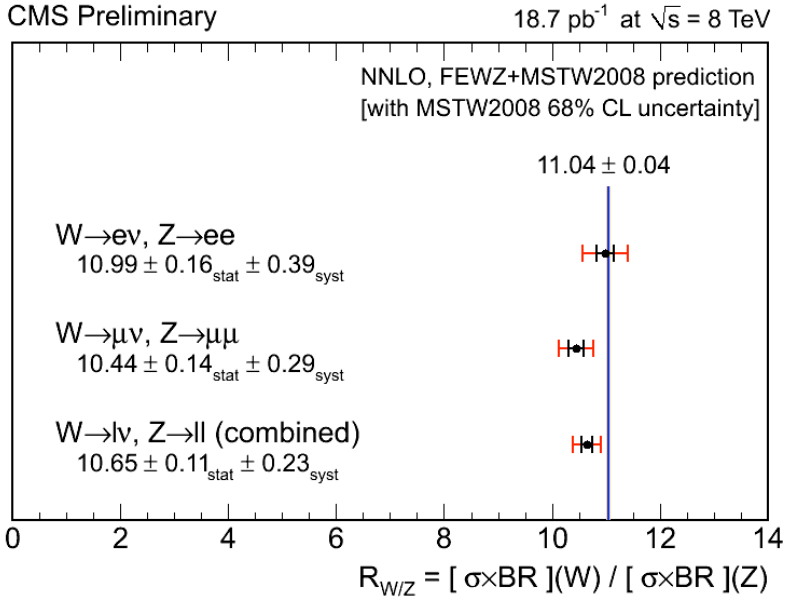

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CMS PAS SMP-12-011

JHEP 10 (2011) 132

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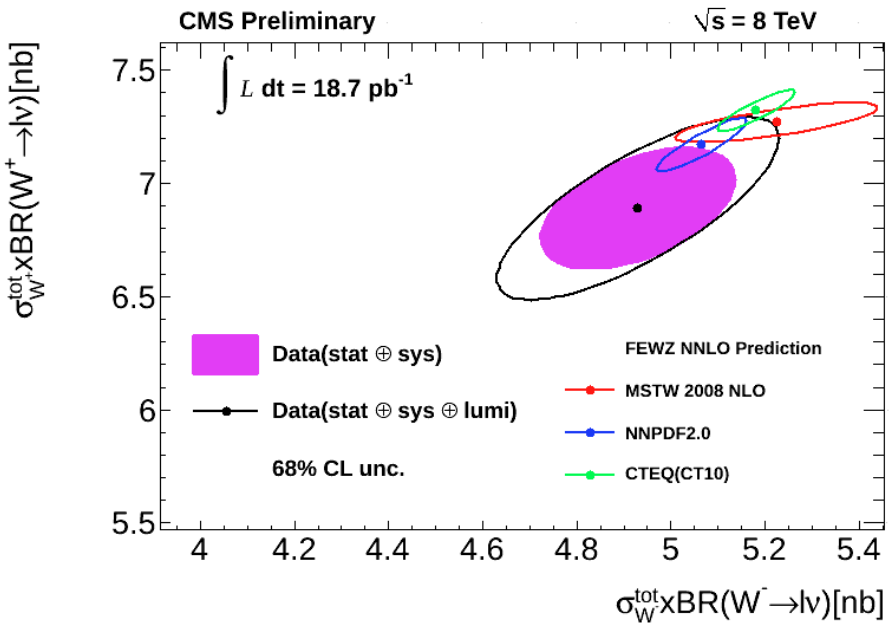
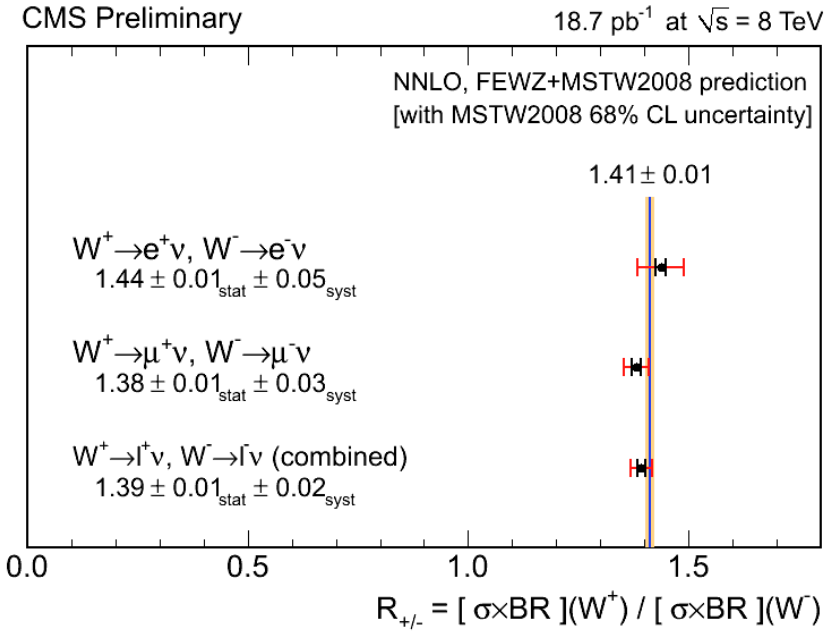


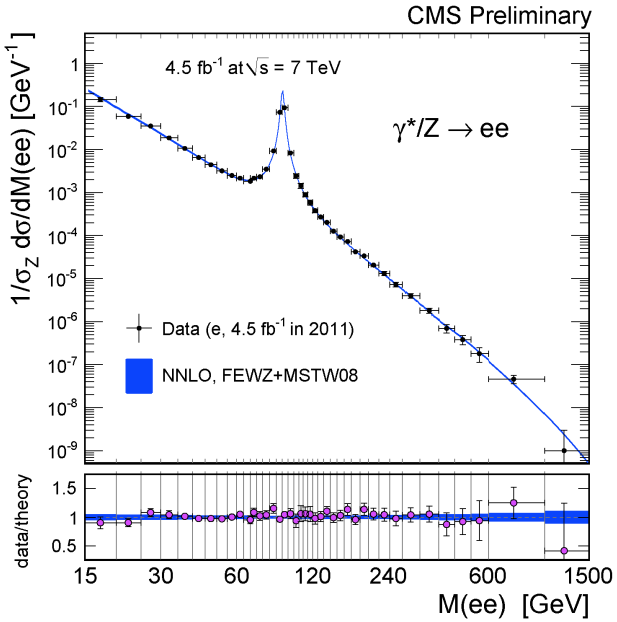


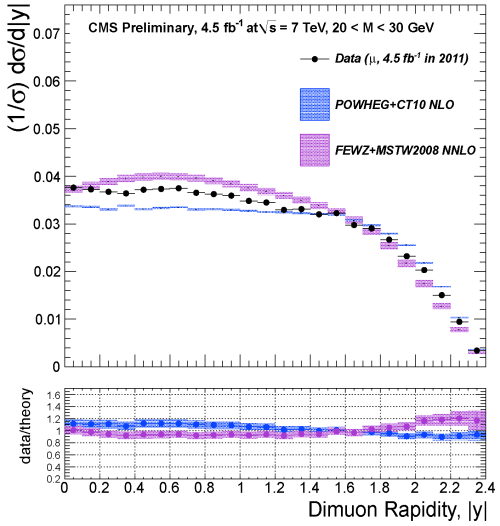
- Expect 2:1 ratio form valence quarks in valance-sea annihilation, diluted by sea-sea
- Agrees with theory predictions
- Tested at 2% level driven by experimental systematic uncertainty.

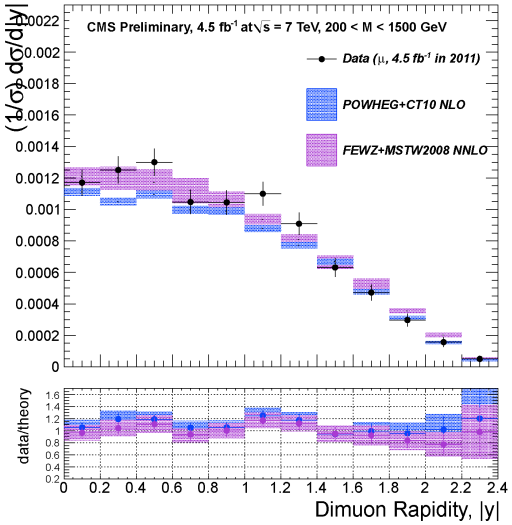
CMS PAS SMP-12-011

Drell-Yan Cross Sections

- Doubly differential in dσ/dM and rapidity in mass bins
  - dσ/dM from 15 to 1500 GeV
  - Rapidity from 0 to 2.4 in 6 mass bins







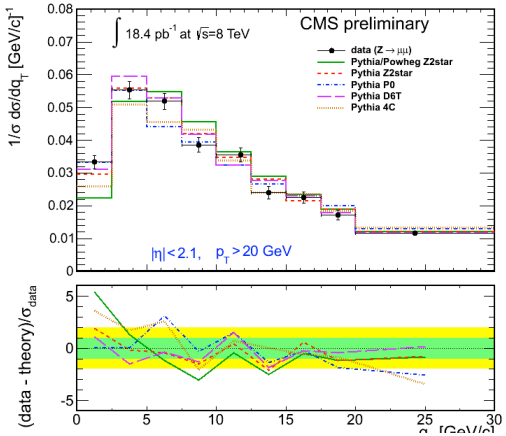
- Comparisons with:
  - FEWZ + MSTW08@NNLO
  - POWHEG + CT10@NLO
- Agreement in dσ/dM
- Expect disagreement in y for low mass bins
- Low mass sensitive to PDF and integration issues.
- Expected to be improved in upcoming papers.

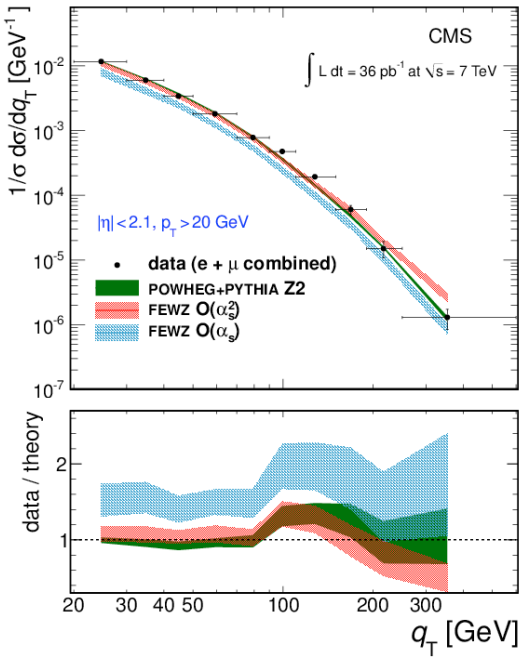
CMS PAS EWK-11-007

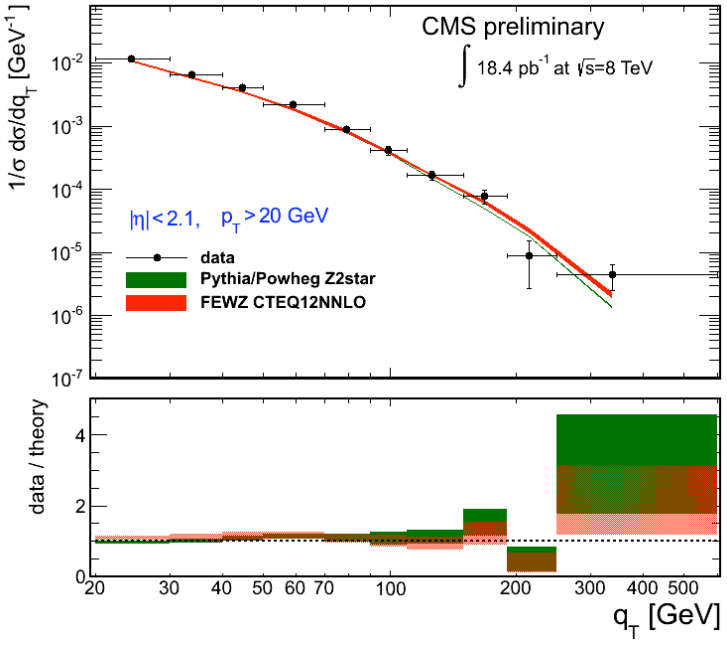
Z p_T at 7 and 8 TeV

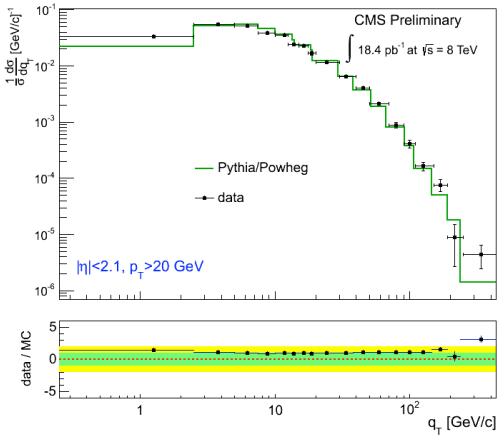
CMS PAS SMP-12-025 Phys. Rev. D 85, 032002 (2012)

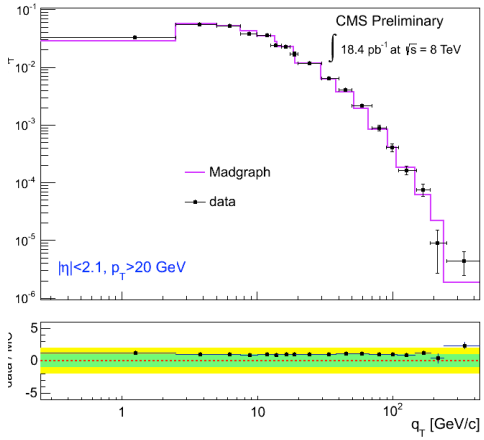
- p_T of Drell Yan (Z) production:
  - 60 < ml l< 120 GeV











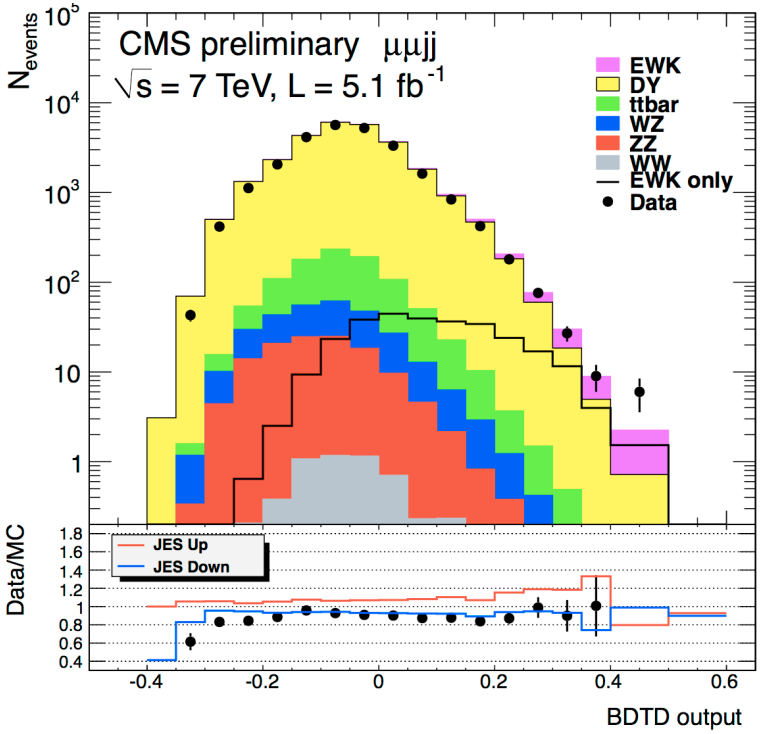
- Agreement with
- Matrix Element + PS generators
  - Madgraph slightly better at high qT – includes multiple hard emission
  - Resbos improves low qT region
- NNLO calculations

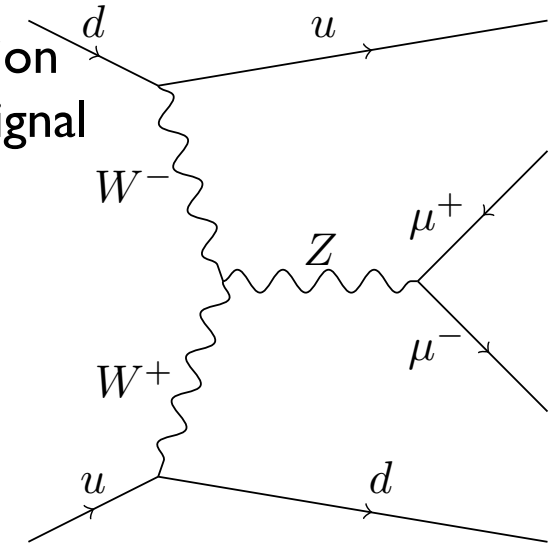
VBF Z Production

- EW VBF production of Z + jets

CMS PAS FSQ-12-019

  - Same topology as VBF Higgs and longitudinal vector boson scattering. Benchmark for EWSB studies
  - Measures WWZ TGC
  - Dominant background from standard DY production
  - Uses multivariate (BDT) discriminant to extract signal

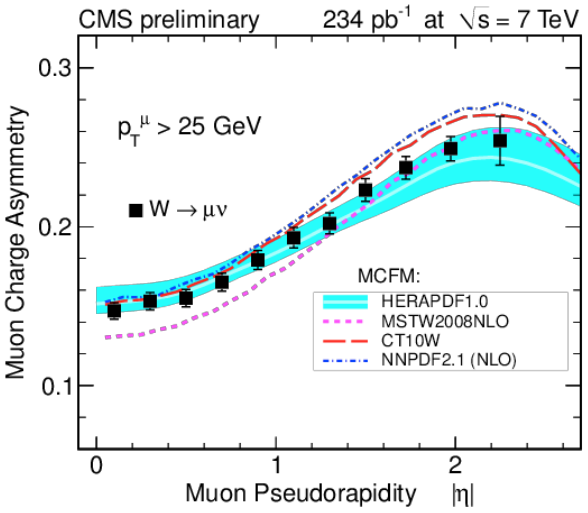


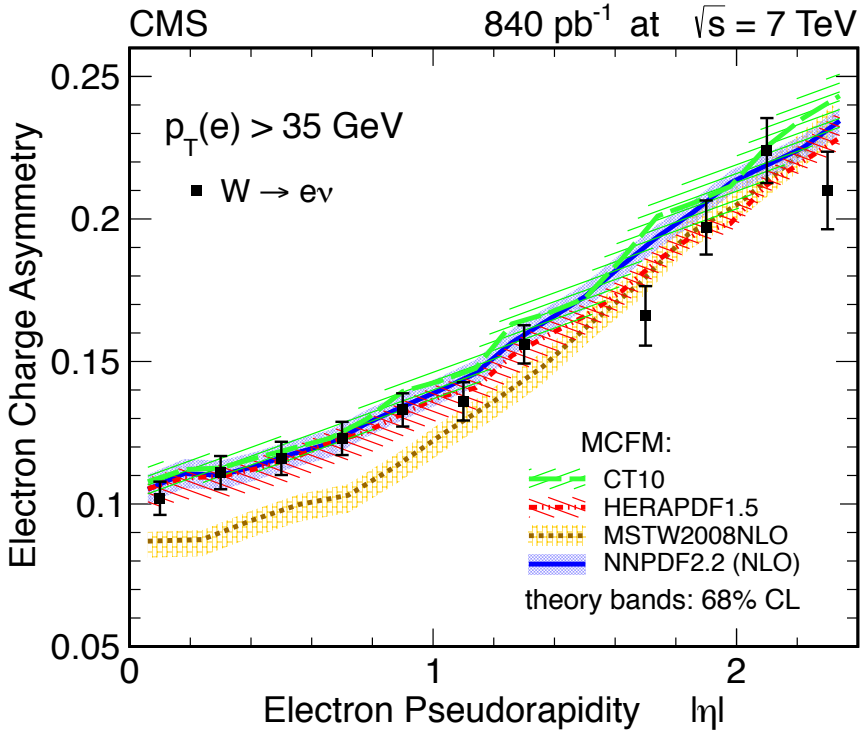


- σ(μμ+ee) = 154 ± 24 (stat.) ± 46 (syst.) ± 27 (th.) ± 3 (lum.)fb
- VBFNLO 166 fb

W Charge Asymmetry

- Study of ratios of kinematic variables between W+ and W- production
  - Cancellation of systematic uncertainties in the ratio maximizing sensitivity to PDF
  - Valance-sea interaction and asymmetry increase at high y
  - Provides significant constraint on the global PDF fit





Phys.Rev.Lett. 109 (2012) 111806

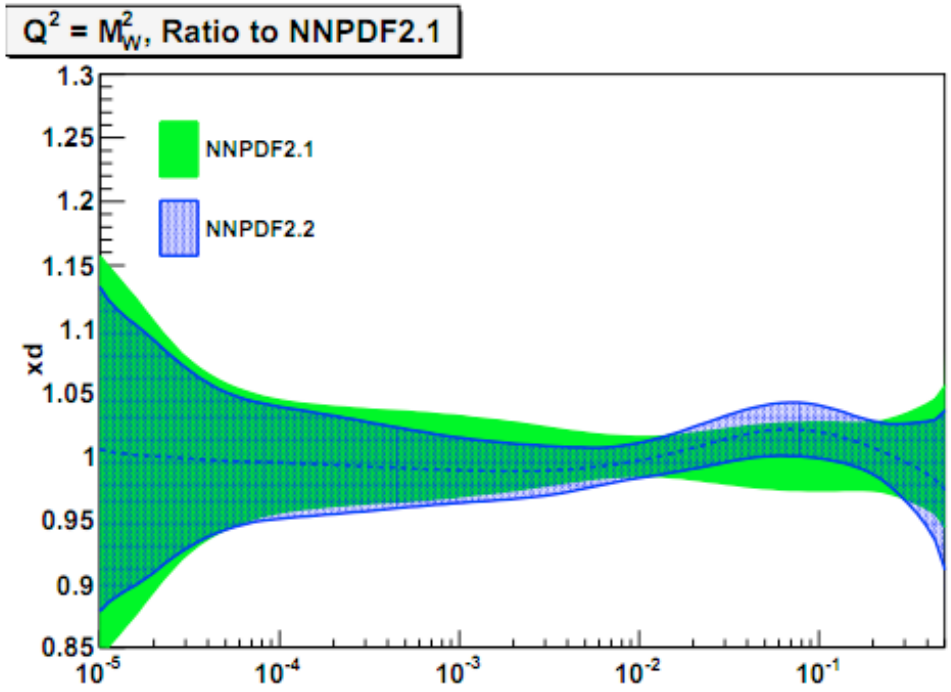
CMS PAS EWK-11-005

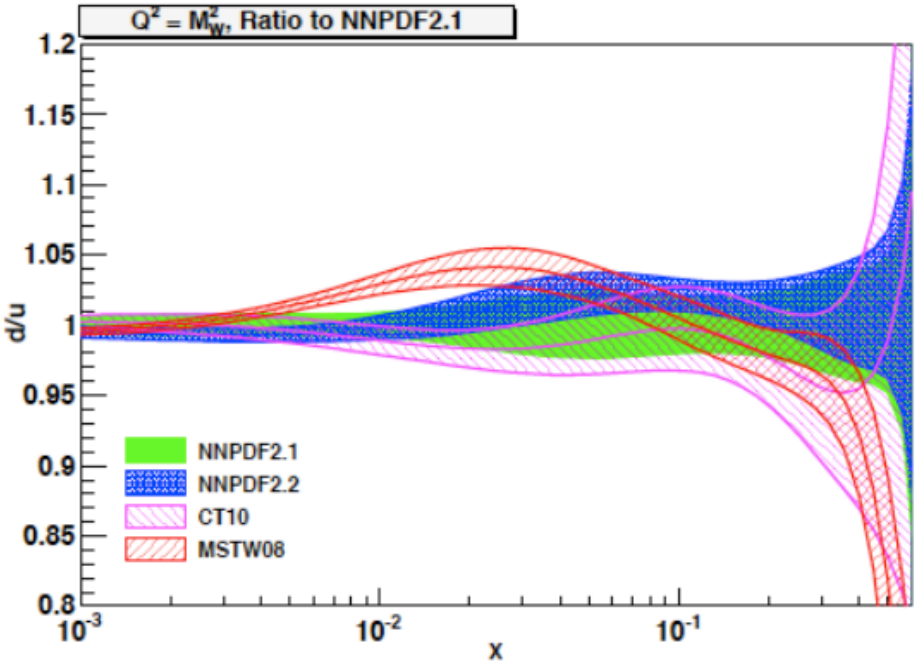
- Good agreement with several PDF sets excluding MSTW in both electrons and muons.
- New MSTW fit introduces new degrees of freedom for valance x distribution improving the agreement

W Charge Asymmetry

- W charge asymmetry results used to constrain PDFs
  - CMS and ATLAS results added in NNPDF2.2 reducing uncertainty.

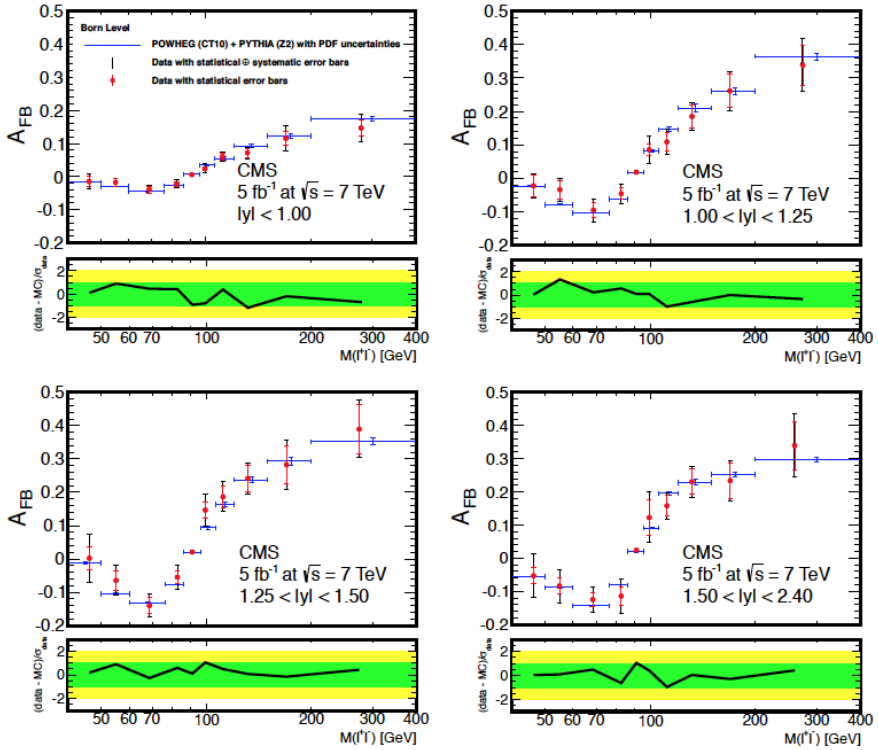
Nucl.Phys. B855 (2012) 608-638
NNPDF Collaboration





Z Forward Backward Asymmetry

- Z forward Backward asymmetry
  - Measured as a function of mass in four rapidity bins
  - Sensitivity to new physics such as new neutral vector bosons which would modify vector coupling of the leptons at high mass



- Also sensitive the weak mixing angle.

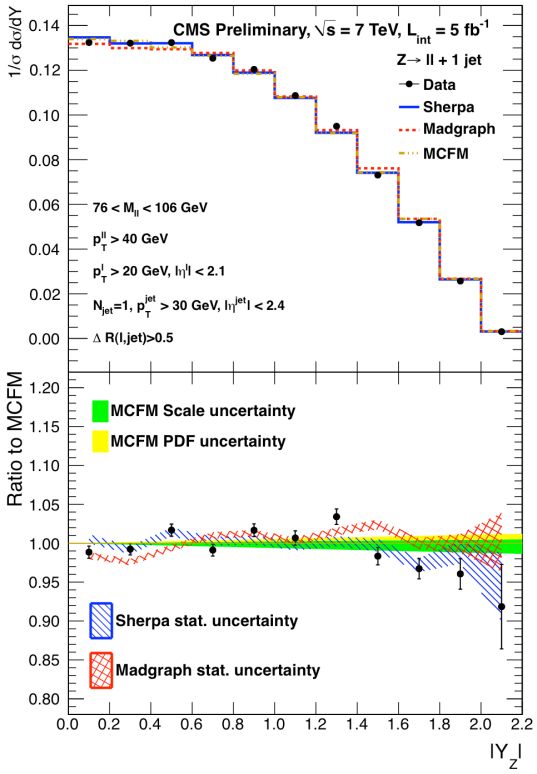
$$\sin^2\theta_{\text{eff}} = 0.2287 \pm 0.0020\,(\text{stat.}) \pm 0.0025\,(\text{syst.}).$$

- Good agreement with theory: POWHEG+CT10

Phys.Lett. B718 (2013) 752-772

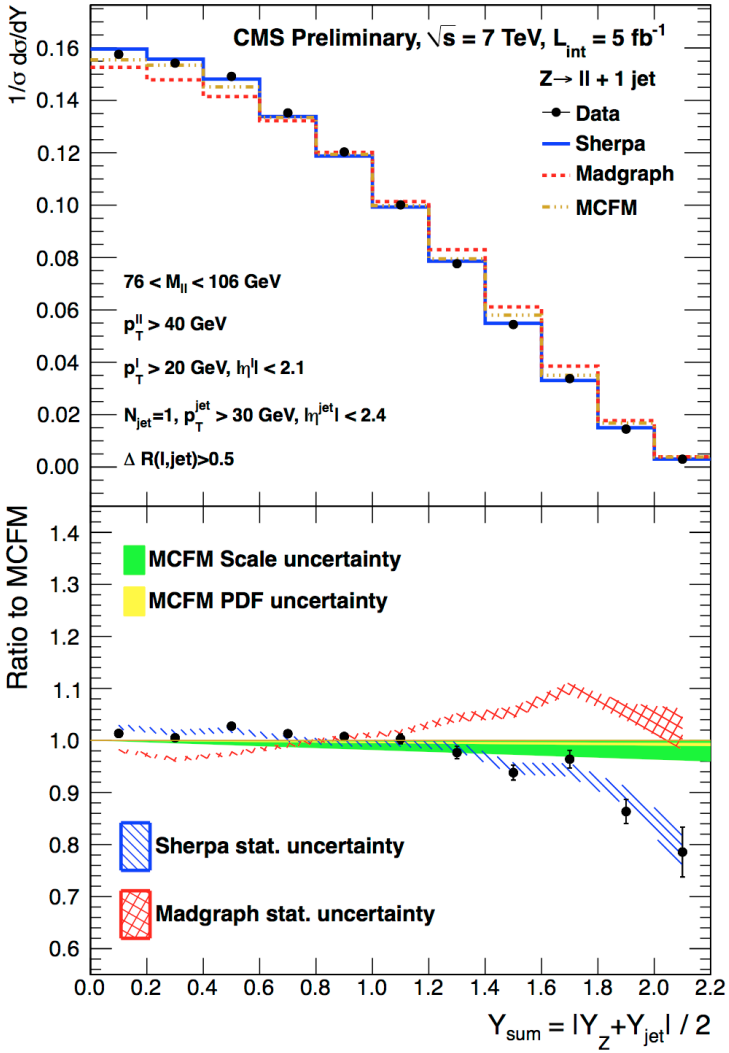
Z + 1j Rapidity

- Z + 1j
  - Test of NLO theory and Matrix Element + parton show MCs



Z and jet rapidity distributions in good agreement. Combined distributions show deviations. Sherpa (employing CKKM matching) shows better agreement

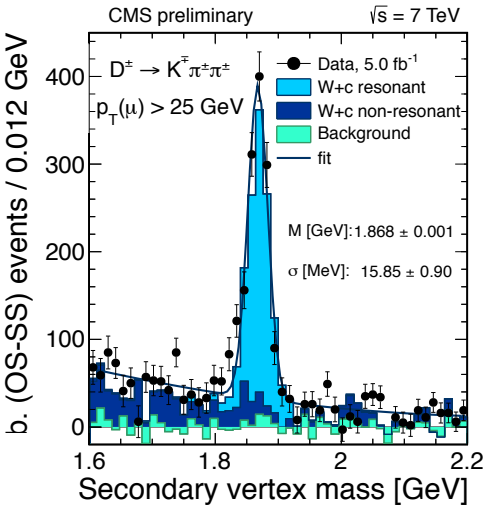
CMS PAS SMP-12-004

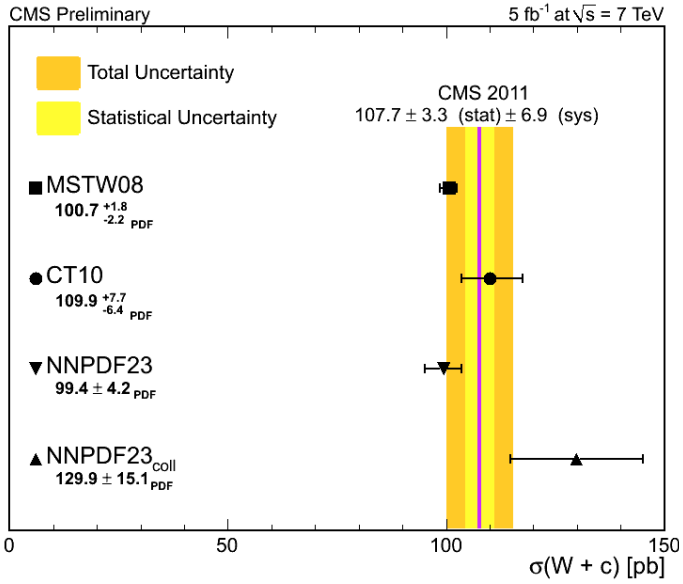


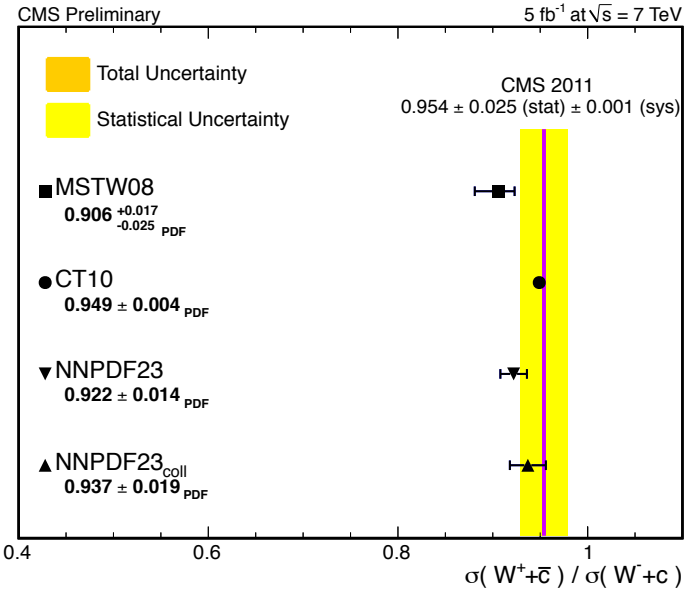
W + c-Jet

- W+c–jet production
  - Sensitive to strange PDF of the proton.
  - W charge the same as initial s quark
  - Strange anti-strange PDF should be ~symmetric
- Analysis uses charm hadron reconstruction to identify charm jets.

CMS PAS SMP-12-002





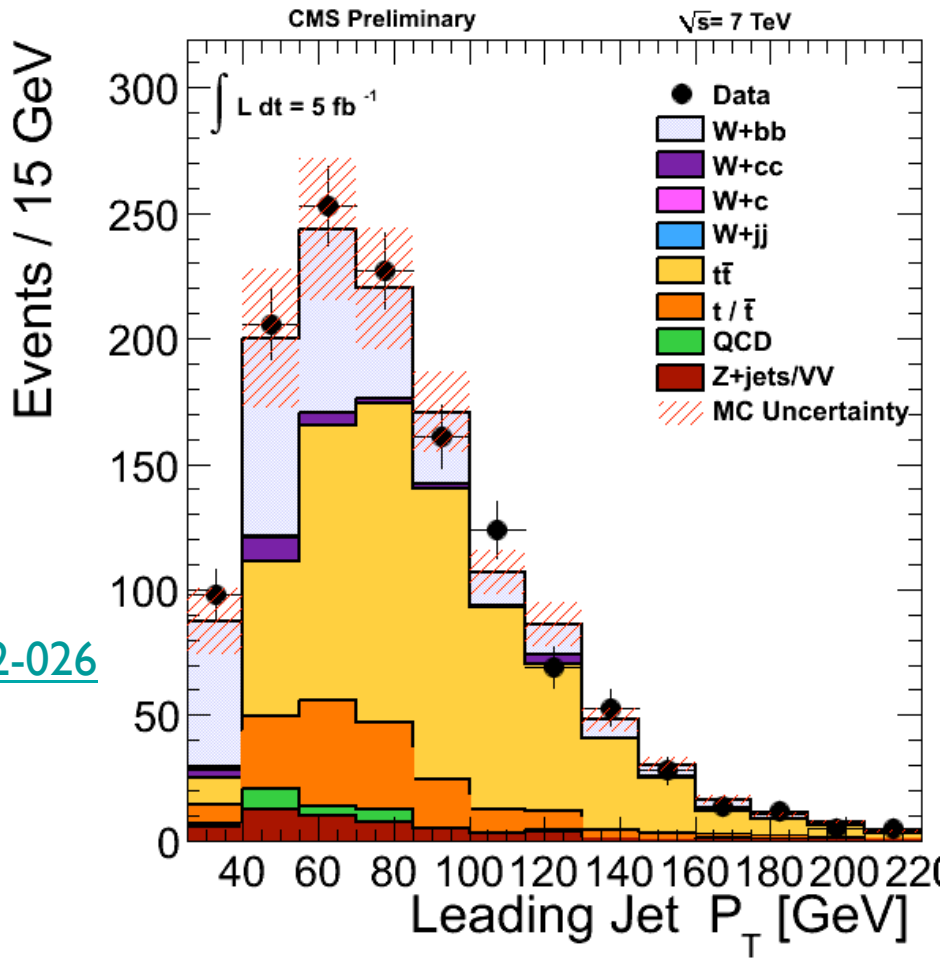


- Fair agreement with PDF fits
- Competitive sensitivity to strange PDF compared to neutrino scattering experiments

W + 2b-Jets

- Production of W +2 central b jets
  - History of disagreement between experiment and data
  - Critical background for searches
- Analysis double tags events to remove W+c and constrains top contribution from high jet multiplicity region. CMS PAS SMP-12-026
- Good agreement with predicted cross section

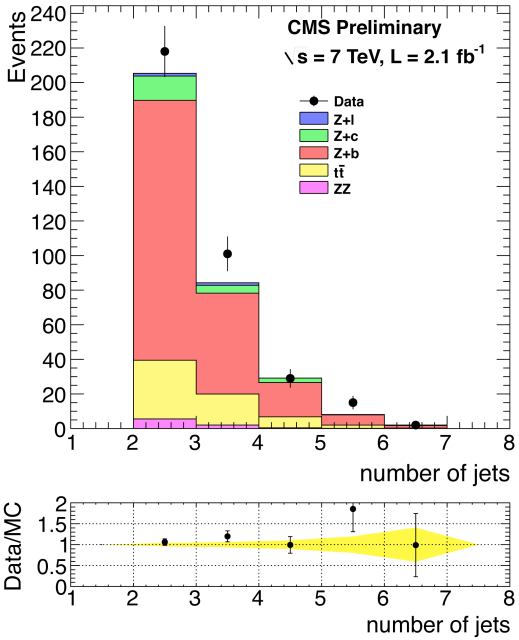
MCFM (MSTW08NNLO) 0.52 ± 0.03 [pb]

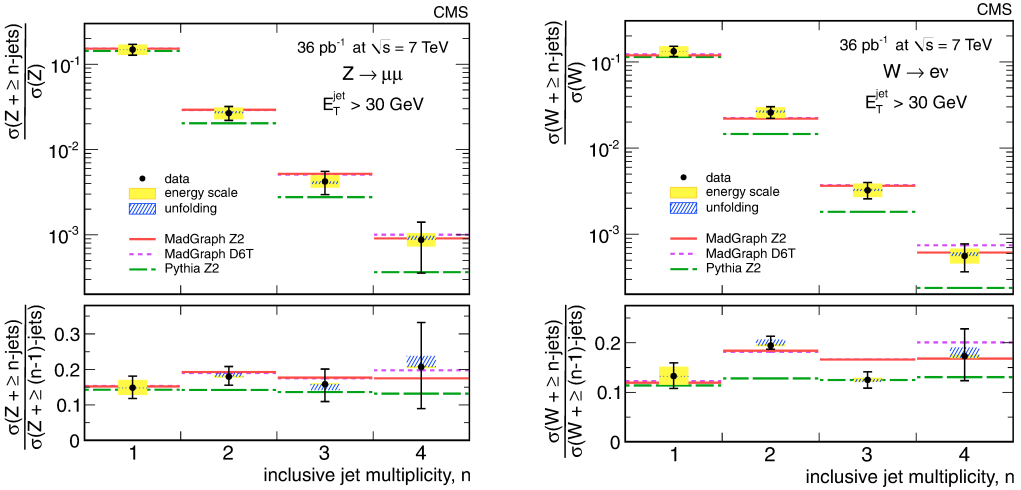


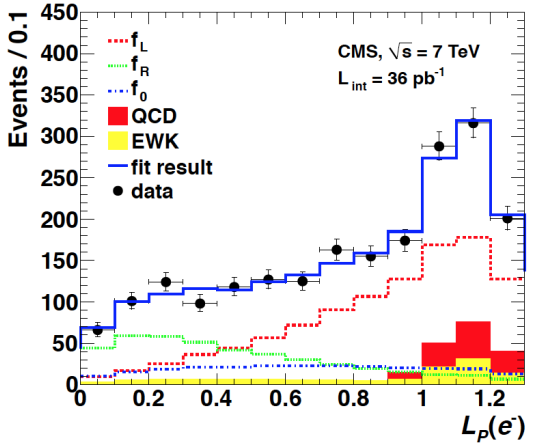
$$\sigma(pp \to W + b\bar{b}, p_T^b > 25\ \text{GeV}, |\eta^b| < 2.4) \times \mathcal{B}(W \to \mu\nu, p_T^\mu > 25\ \text{GeV}, |\eta^\mu| < 2.1) =$$
$$= 0.53 \pm 0.05\,(\text{stat.}) \pm 0.09\,(\text{syst.}) \pm 0.06\,(\text{theo.}) \pm 0.01\,(\text{lum.})\ \text{pb}.$$

Other V (+ jets) Results

- Active program in V (+jets) (not shown here)
  - Z + jets azimuthal correlations
  - Z + b jets cross sections
  - Z + b jets b hadron angular correlations
  - Z differential vs. n jet cross section
  - Z → tautau
  - W differential vs. n jet cross section
  - W polarization at large pT

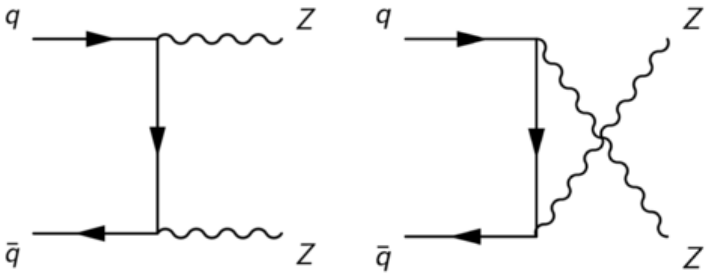


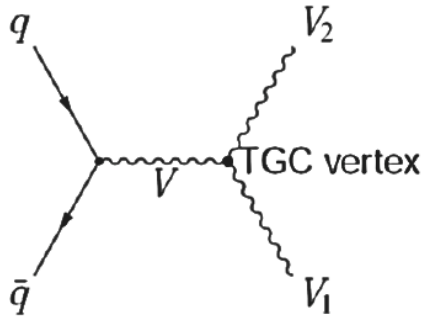


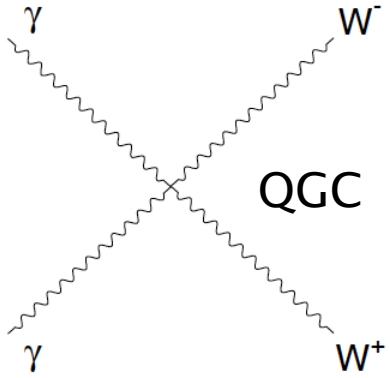


Diboson Production

- Fundamental test of Standard Model
  - Test of gauge structure of the Standard Model
- Probe for new physics
  - Indirect search for tree or loop effects of massive new particles in Anomalous Triple Gauge Couplings (TGC) and Quartic Gauge Couplings (QGC)
  - Search for Resonances





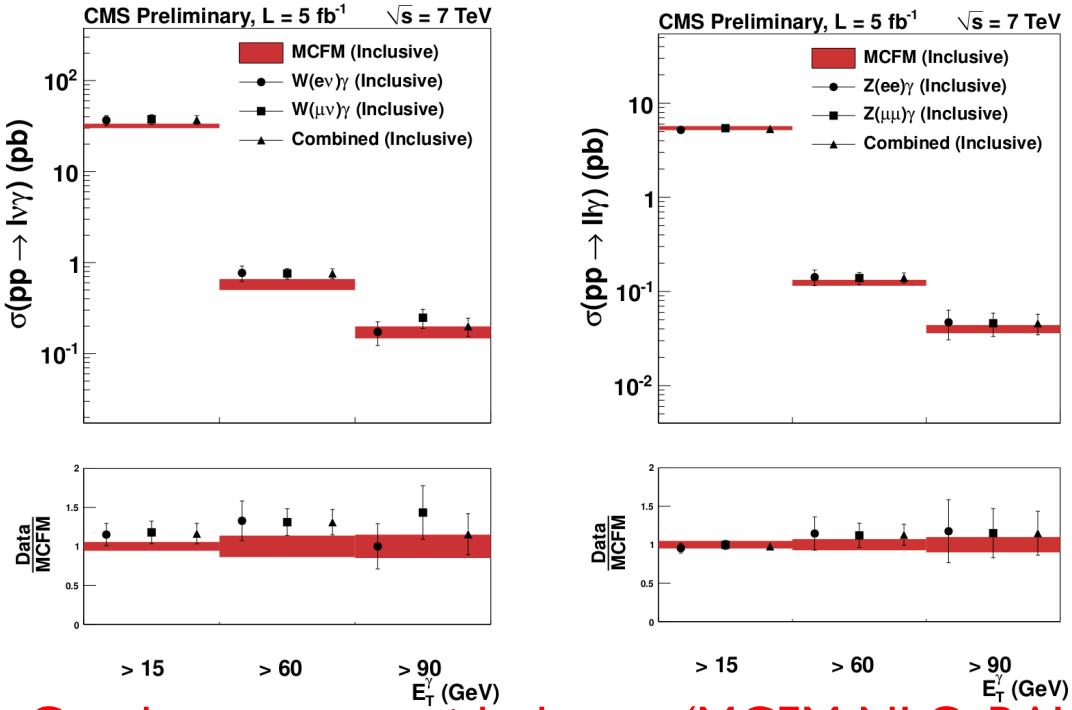


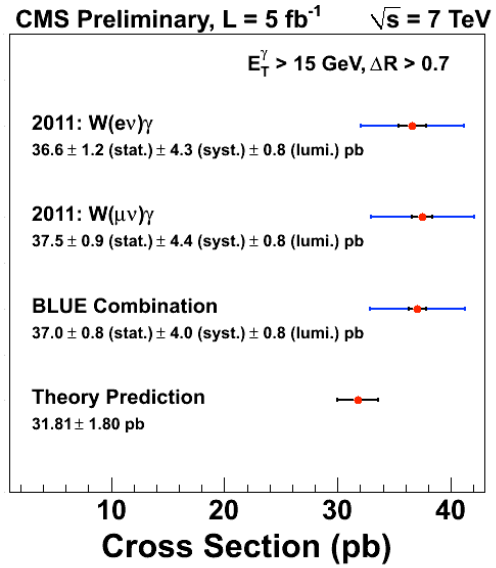
Wγ, Zγ Production

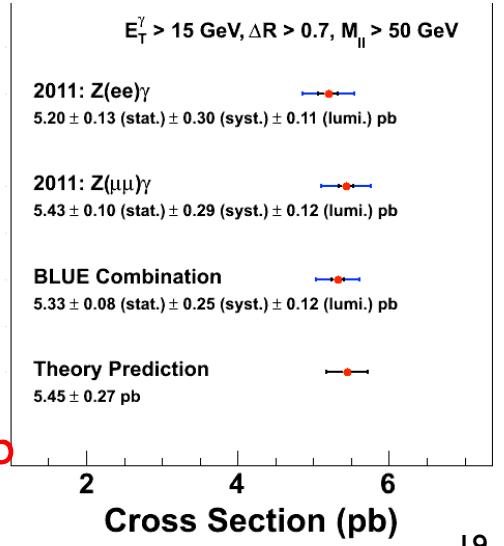
- Wγ→lνγ, Zγ→ llγ νγ
  - Differential with γ in charged lepton modes
  - Minimum γ E_T > 15 GeV
  - Missing E_T and γ with high E_T in Zγ→ νγ

CMS PAS EWK-11-009

CMS PAS SMP-12-020



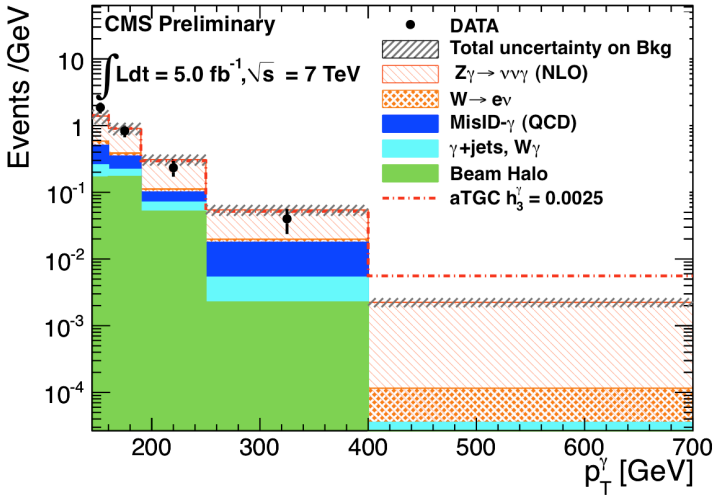


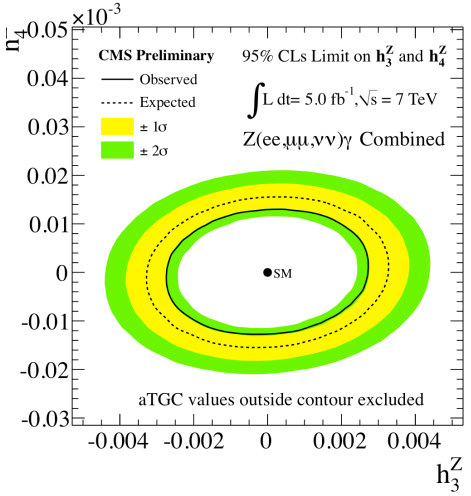


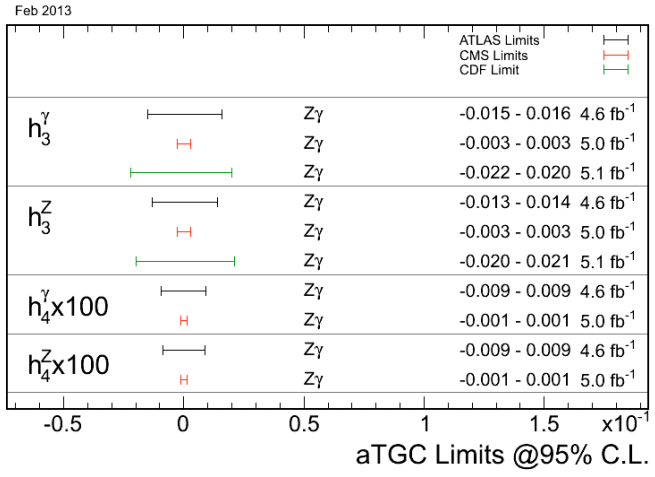
- Good agreement with theory (MCFM NLO, BAUR)
  - σ(Zγ→νγ) = 21.3 ± 4.2 (stat.) ± 4.3 (sys.) ± 0.5 (lum.) fb
  - BAUR: 21.9 ±1.1 fb

Wγ, Zγ aTGC

- aTGC searches
  - Exploit expected high transverse momentum of vector boson if there is aTGC using γ Et distribution
  - Good sensitivity due to higher branching ratios in in Zγ→ νγ
    - Zγ→ νγ dominates sensitivity.







- aTGC limits on ZZγ and Zγγ are worlds best
- Limits on WWγ approaching LEP sensitivity
- $-0.38 < |\Delta\kappa_\gamma| < 0.29$ and $-0.050 < |\lambda_\gamma| < 0.037$

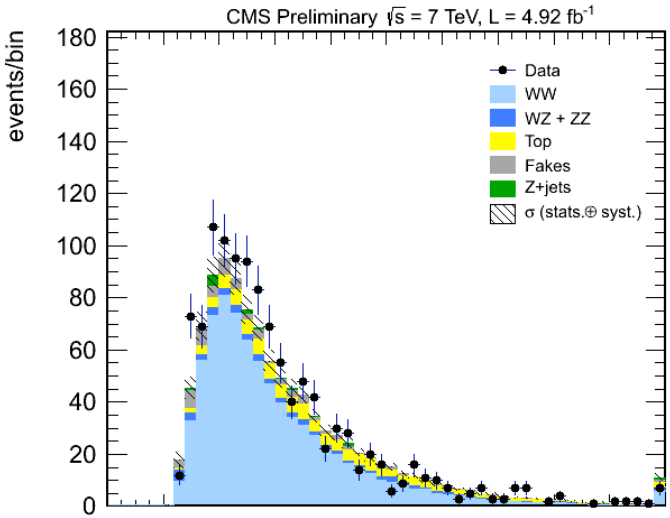
CMS PAS EWK-11-009

CMS PAS SMP-12-020

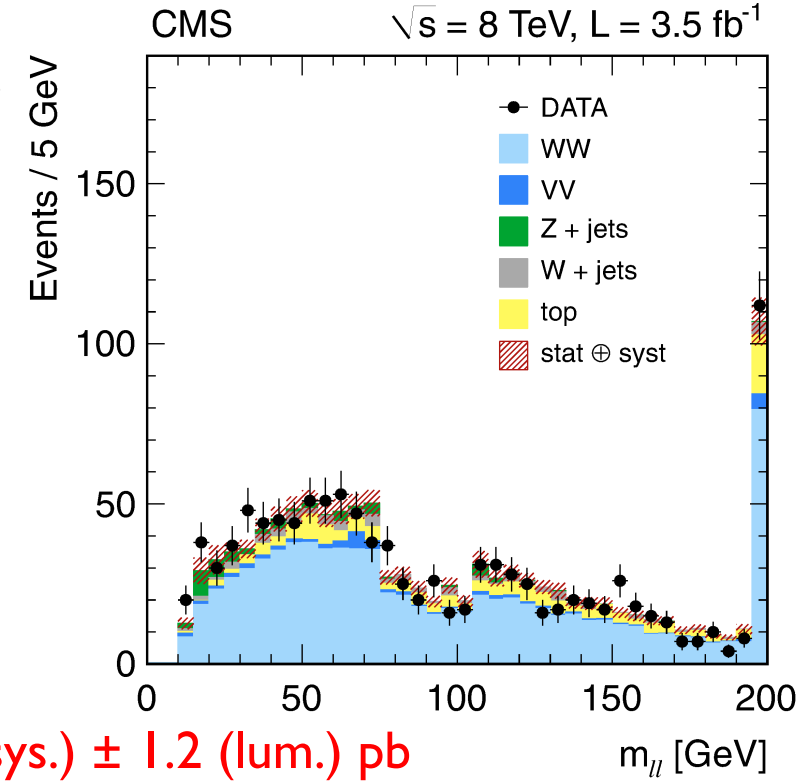
WW Production

- Signal: dileptons (e and μ) and missing E_T
  - Cross sections at 7 and 8 TeV
  - Apply jet veto to reduce top backgrounds

hep-ex/1301.4698
CMS PAS SMP-12-005



jet veto adds systematic uncertainty



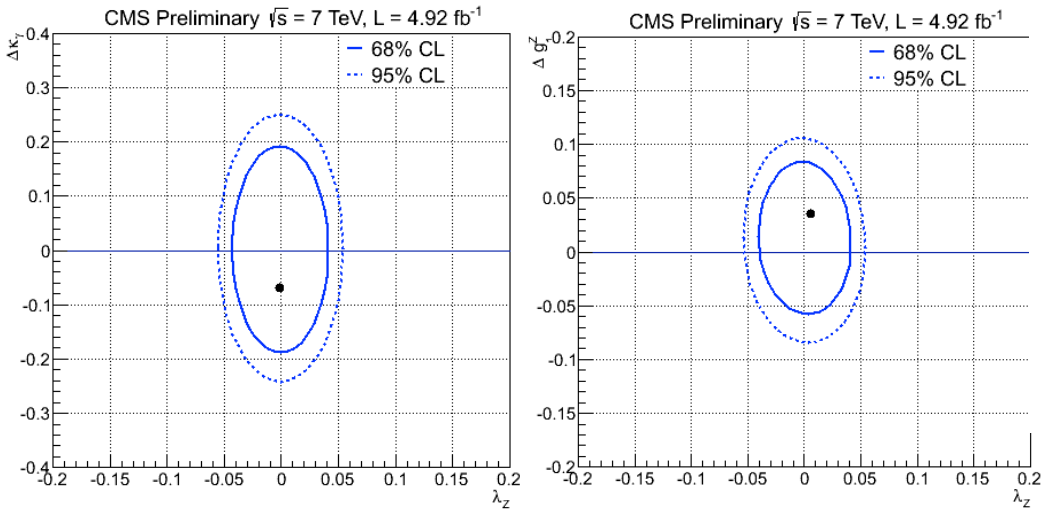
- Cross sections high at 1-1.5σ level
  - σ(WW 7 TeV) = 52.4 ± 2.0 (stat.) ± 4.5 (sys.) ± 1.2 (lum.) pb
  - MCFM NLO : 47.0 ± 2.0 pb
  - σ(WW 8 TeV) = 69.9 ± 2.8 (stat.) ± 5.6 (sys.) ± 3.1 (lum.) pb
  - MCFM NLO : 57.3 + 2.4 – 1.6 pb
- Expect contributions at 5% level from H → WW and other processes

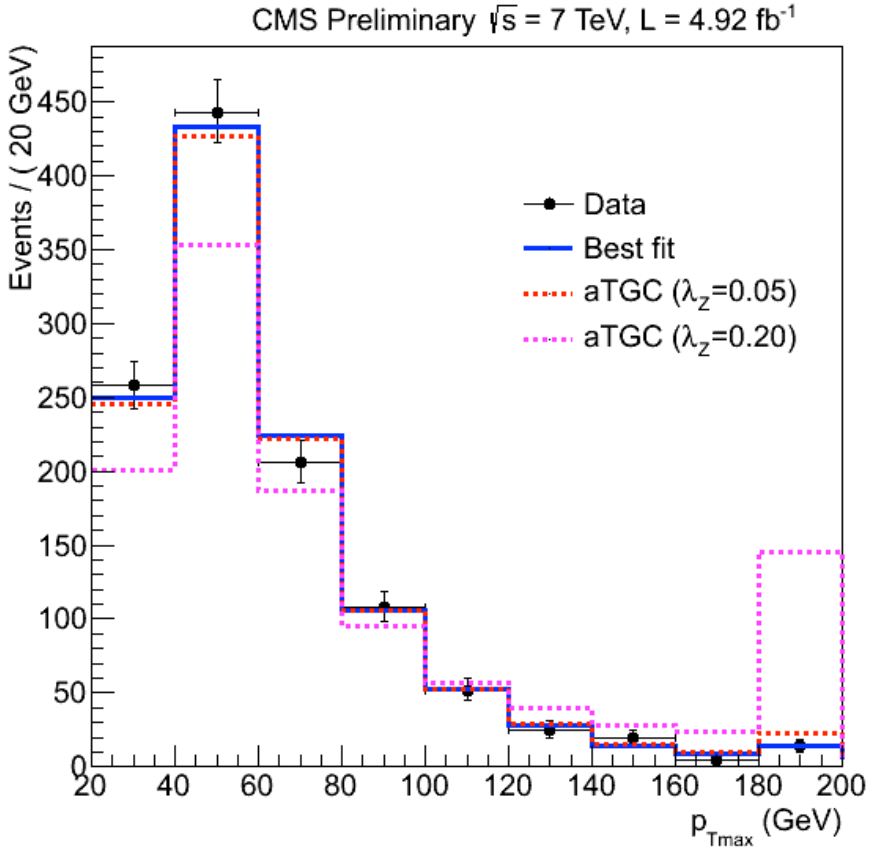
WW aTGC

- aTGC search
  - Exploit expected high transvers momentum of vector boson using leading lepton p_T distribution

CMS PAS SMP-12-005

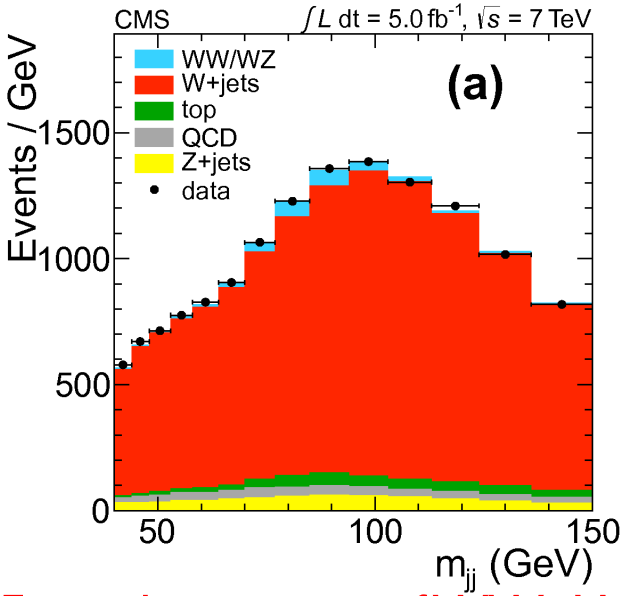
- Limits Limits on WWγ and WWZ approaching LEP sensitivity
- $-0.21 < |\Delta\kappa_\gamma| < 0.22$
- $-0.048 < |\lambda_Z| < 0.048$
- $-0.095 < |g^Z_1| < 0.095$

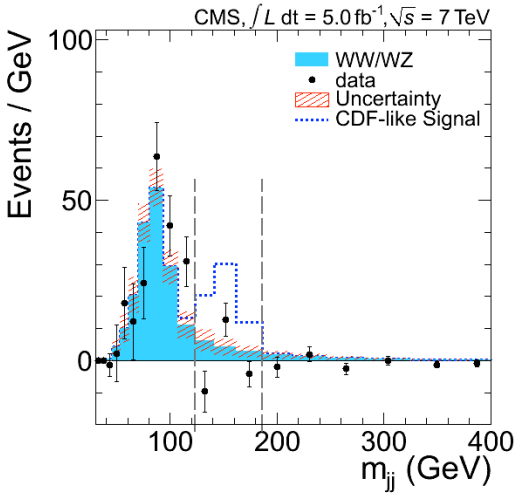


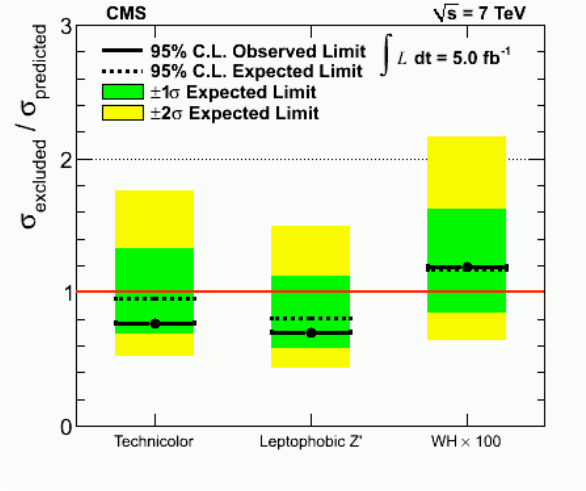


WW+WZ Production

- WW + WZ production in semileptonic decays
  - Signal: leptons (e and μ) and missing E_T and two jets consistent with a W or Z
  - Cross sections at 7 [Eur. Phys. J. C 73 (2013) 2283] [Phys. Rev. Lett. 109 (2012) 251801]
  - Apply jet veto to reduce top backgrounds





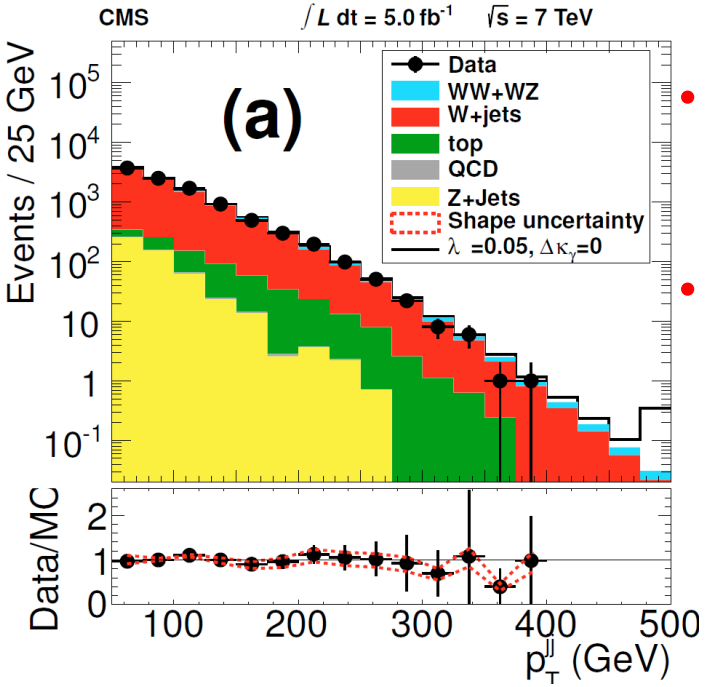


- First observation of WW+WZ: 2700 candidates
- Cross section in agreement with theory
  - σ(WV 7 TeV) = 68.89 ± 8.71 (stat) ± 9.70 (syst) ± 1.52 (lumi) pb
  - MCFM NLO : 65.6 ± 2.2 pb

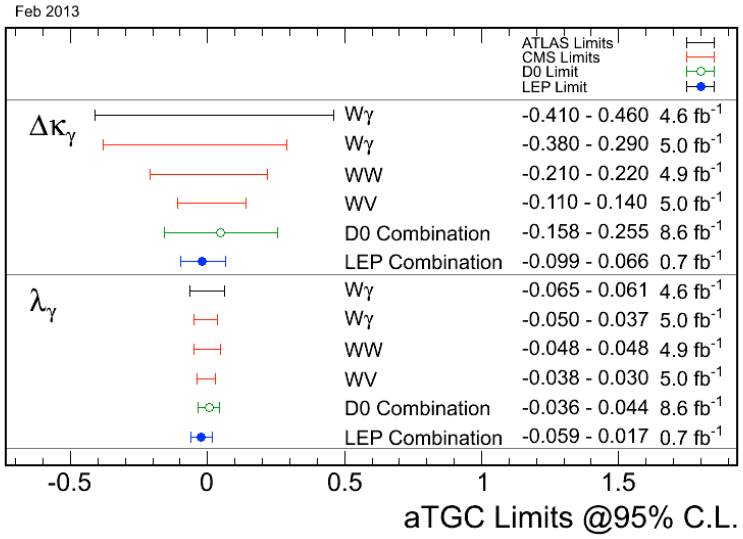
- Also used to search for higher mass resonance produced in associated with a W boson
- No evidence of a resonance and limits placed on several models

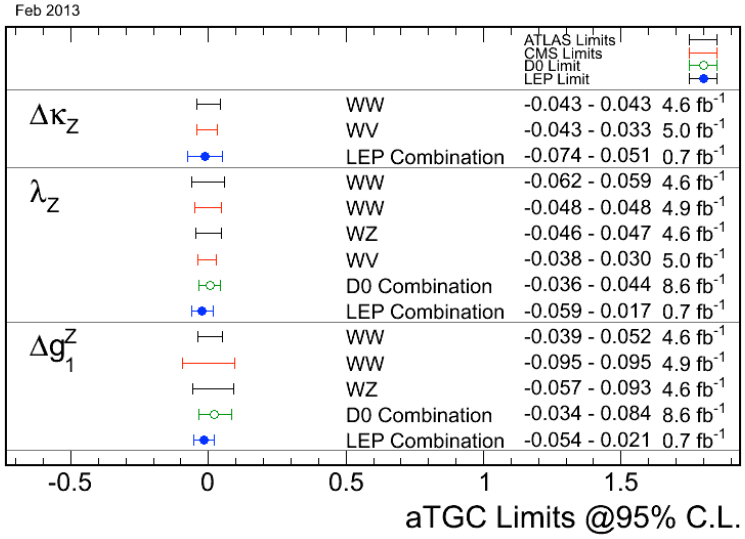
WW+WZ aTGC

- aTGC search [Eur. Phys. J. C 73 (2013) 2283]
  - Exploit expected high transverse momentum of vector boson using hadronically decaying vector boson p_T distribution
  - No sensitivity to gZ1. Set to SM value.



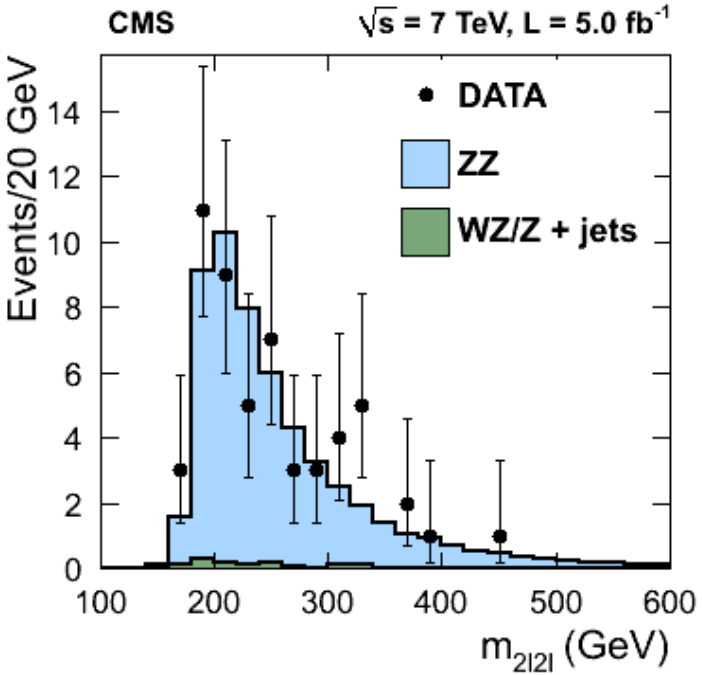
- Limits Limits on WWγ and WWZ
- approaching LEP sensitivity





ZZ Production

- ZZ production in charged leptonic decays (e, μ and tau)
  - Cross sections at 7 and 8 TeV



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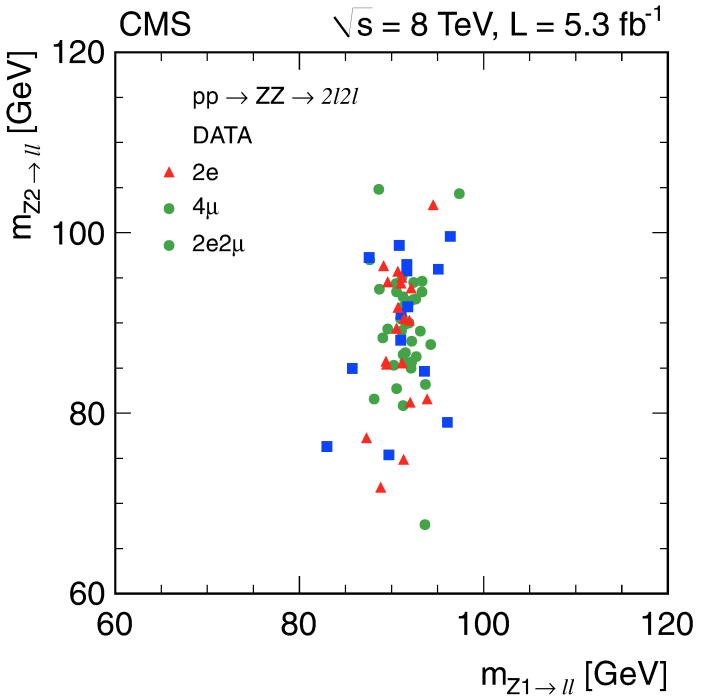


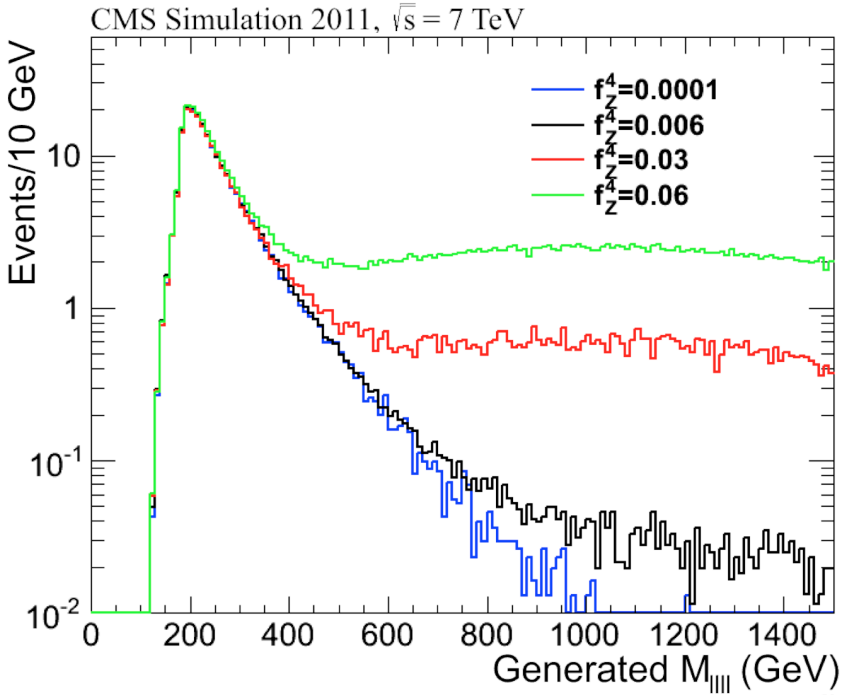
- Cross sections in agreement with theory
  - σ(ZZ 7 TeV) = 6.2 ± 0.8 (stat.) ± 0.4 (sys.) ± 0.1 (lum.) pb
  - MCFM NL) : 6.3 ± 0.4 pb
  - σ(ZZ 8 TeV) = 8.4 ± 1.0 (stat.) ± 0.7 (sys.) ± 0.4 (lum.) pb
  - MCFM NLO : 7.7 ± 0.4 pb

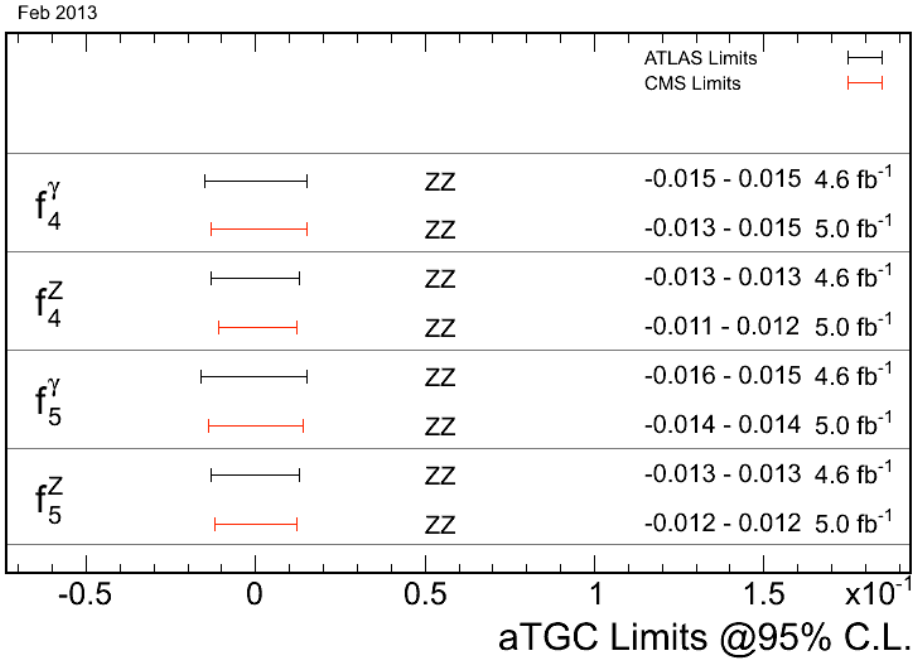
ZZ aTGC

- aTGC search
  - Exploit expected high transvers momentum of vector bosons using the 4l mass.

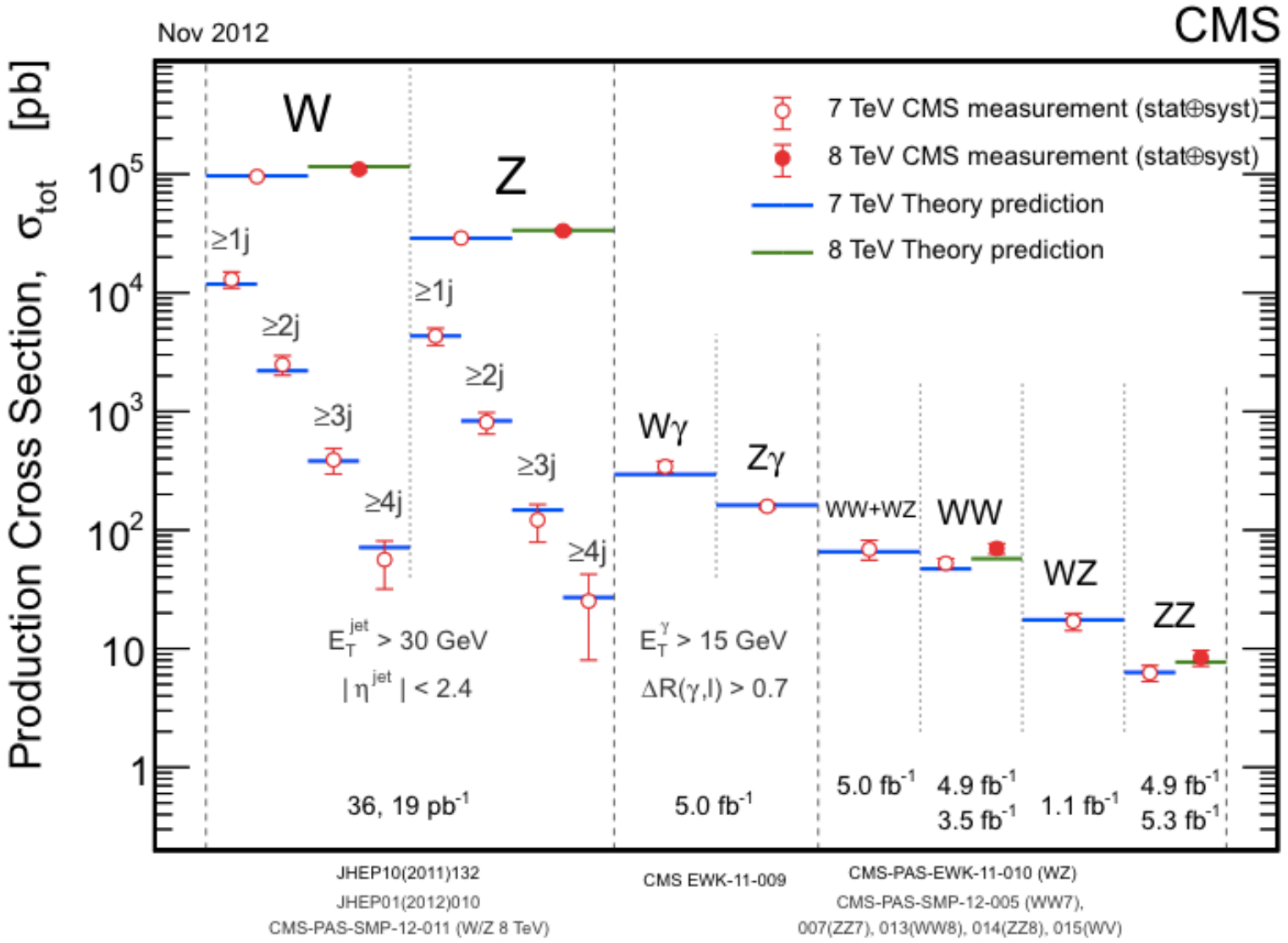
JHEP 12 (2012) 034

- World leading sensitivity to ZZγ and ZZZ



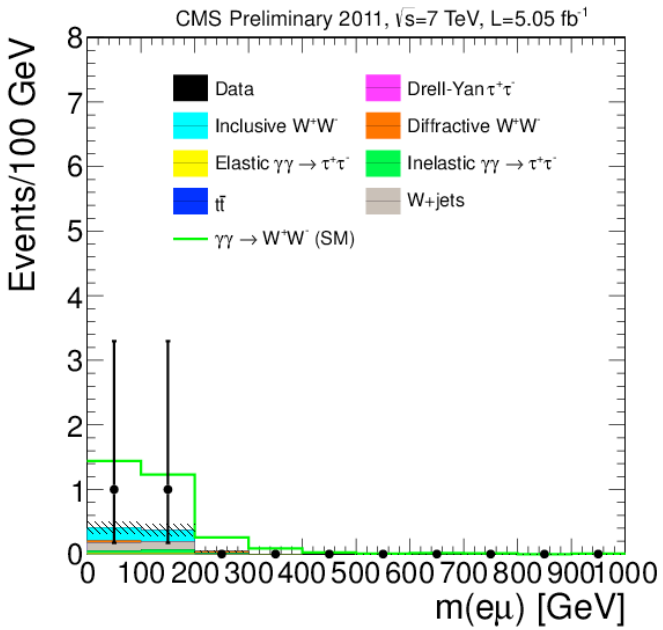


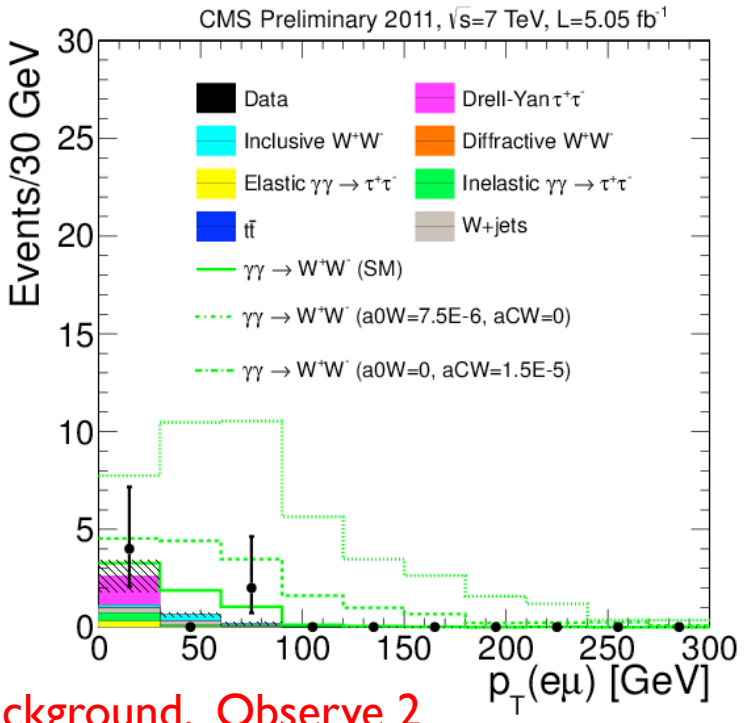
Summary of Cross Sections



Search for γγ → WW and aQGC

- γγ → WW in Central exclusive production [CMS PAS FSQ-12-010]
  - Signal: dileptons (eμ) and missing E_T with central track veto
  - Use pTeμ to search for aQGC.





- Expect 2.2 ± 0.5 signal events, 0.84 ± 0.13 background. Observe 2
- σ(γγ → WW) < 8.4 fb, SM: 3.8 ± 0.9

LEP

$$-2.80 \times 10^{-6} < a_0^W/\Lambda^2 < 2.80 \times 10^{-6}\ \mathrm{GeV}^{-2}$$
$$-1.02 \times 10^{-5} < a_C^W/\Lambda^2 < 1.02 \times 10^{-5}\ \mathrm{GeV}^{-2}$$

$W^+W^-\gamma$	a_0^W	$-0.020\,\mathrm{GeV}^{-2} < a_0^W/\Lambda^2 < 0.020\,\mathrm{GeV}^{-2}$
$W^+W^-\gamma$	a_c^W	$-0.053\,\mathrm{GeV}^{-2} < a_c^W/\Lambda^2 < 0.037\,\mathrm{GeV}^{-2}$

Summary

- Impressive number of EWK results from the CMS
  - Precise tests of the Standard Model at TeV scale
  - Agreement with theory in most cases
  - Starting to set serious constraints on electroweak parameters and PDFs
  - Measurements are challenging NLO and NNLO predictions
- Still much of the LHC data at 8 TeV to be analyzed
  - More results with improved precision and new topics expected soon, stay tuned!