Electroweak results from the CMS experiment

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On behalf of the CMS collaboration

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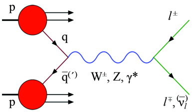
Outline

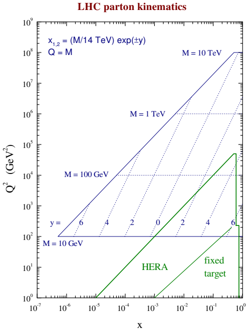
- **W and Z production**
  - W and Z cross-section
  - W, Z decaying to taus
  - Z differential cross-section
  - Drell-Yan cross-section
- **DiBosons production**
  - WW, WZ, ZZ
  - V+gamma
- **EWK bosons in associated production with Jets**
  - V+jets
  - Z+b
  - W+c
- **Asymmetries**
  - Lepton Charge asymmetry
  - Weak mixing angle
  - Forward-Backward asymmetry

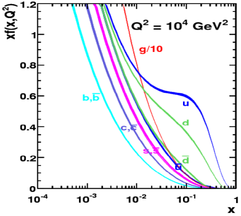
W and Z production at LHC

- W and Z production in pp collisions produced mainly from the scattering of a valence quark with a anti-quark sea
- The involved parton distribution functions (PDF) are low ($10^{-3} < x < 10^{-1}$) and scattering of a sea quark with a sea anti-quark is also important
- W and Z events produce very clean signals and allow to perform precision measurements
  - Large background control samples are available in data and reduce the need to rely on simulation
- Accurate theoretical predictions
  - NLO generators: POWHEG and MC@NLO
  - NNLO cross-sections and differential distributions: FEWZ, RESBOS, DYNNLO
  - Uncertainties in valence and sea PDF limit the accuracy of theoretical predictions
- Differential distributions are sensitive to PDF



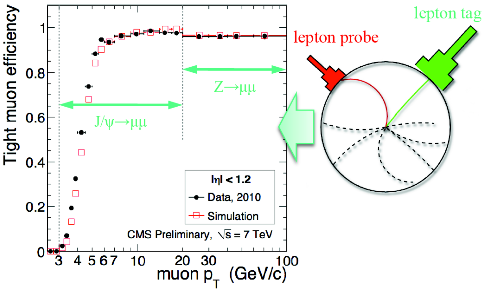
$$Q^2 = m_{W,Z}^2 = x_1 x_2 s$$

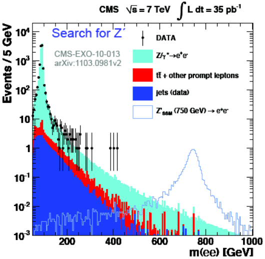


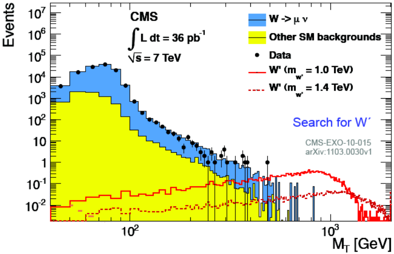


EWK as tool

- W and Z are also tools to understand and calibrate the detector
  - Tag & probe method for efficiency measurements
  - Lepton scale and resolution
- Many searches have EWK processes as a background
  - Understanding EWK processes means keeping background under control







Common selections for EWK measurements

Muons

- consistent measurements in tracker and muon chamber with quality cuts on the global fit
- Isolation requirement (sum of tracks and calorimeter deposits around muon direction), $\Delta R=\sqrt{\Delta\phi^2+\Delta\eta^2}<0.3$, normalized to muon p_T

Electrons

- Cluster shape, track-cluster consistency, isolation

$\not{E}_T$

- Corrections based on hadronic recoil in Z events

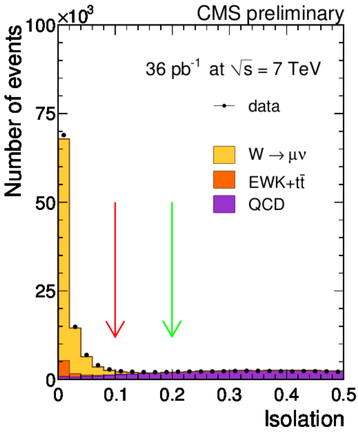
Global Event

- Loose single-lepton trigger
- Isolated leptons with $p_T > 25$ GeV, η within trigger fiducial volume
- 2 leptons in the mass range $60<M(\ell^+,\ell^-)<120$ GeV (Z), $\not{E}_T$ (W)

W/Z signals and backgrounds

Signal extraction

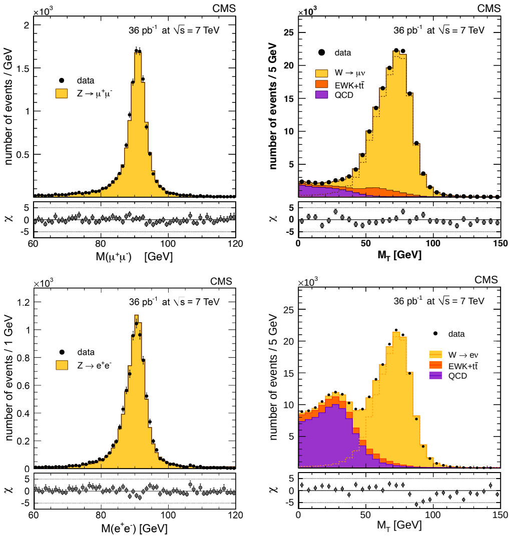
- W fit to $\not{E}_T$ or transverse mass $M_T(\ell, \nu)$
- Z fit to dilepton invariant mass
- Lepton efficiencies from tag&probe as a function of p_T and η
- Momentum scale and resolution from Z$\rightarrow \ell^+\ell^-$ data



Backgrounds

- QCD with real or fake leptons
  - quark/gluon jet mis-identified as a lepton or non-isolated real leptons
  - isolation
  - measured from data (in control regions)
- EWK
  - measured mostly from MC simulation
  - $t\bar{t} \rightarrow$W$b\bar{b}$
  - WW, Wz, ZZ
  - W$\rightarrow \tau\nu$, Z $\rightarrow \tau\tau$ with leptonic τ decays
  - Z with one lepton outside acceptance (background for W)

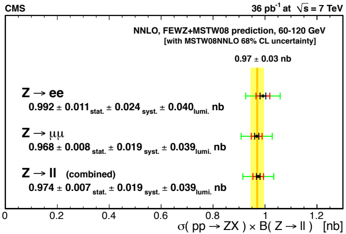
W and Z control plots

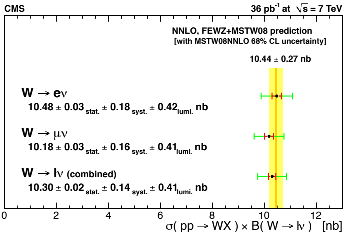


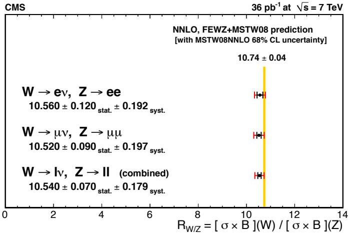
Results:

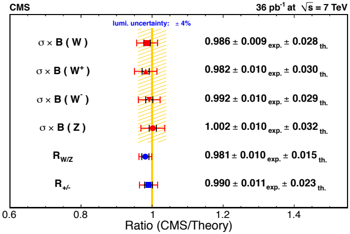
W and Z inclusive cross-sections

Comparison with theoretical predictions (NNLO)



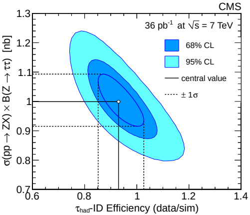


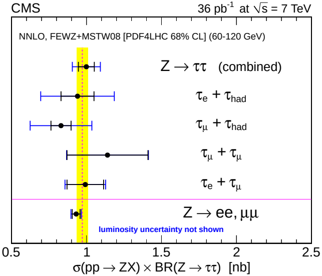


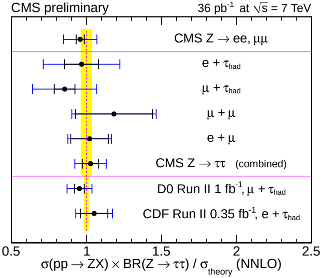


W and Z decaying to taus

- $Z \to \tau^+\tau^-$ important source of high energetic tau leptons in SM
- Measurement of τ identification efficiencies
- Commissioning of τ triggers
- Important background in Searches for BSM Physics
- Particle Flow: combination of tracker and calorimeter measurements
- Main systematics: tau ID=23% from a fit on data

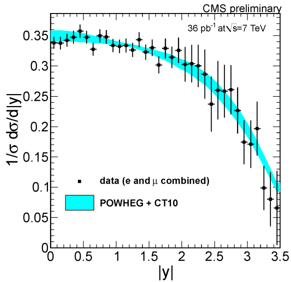






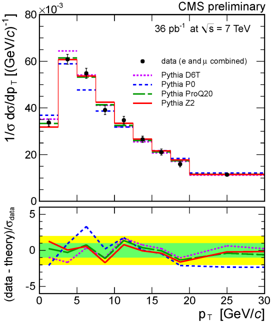
Z differential cross-section

- Large statistics allows to study differential cross sections vs y and p_T
- Comparison to theoretical predictions after an unfolding procedure aimed at correcting for resolution and final-state radiation
- Differential Z cross section as a functions of Z rapidity |y| and as a function of p_T for different Pythia tunes and FEWZ predictions

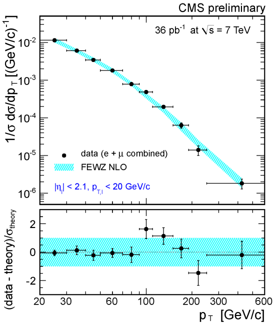


Sensitive to PDF at $x < 10^{-3}$

$x = \frac{m_Z}{\sqrt{s}} e^{\pm y}$



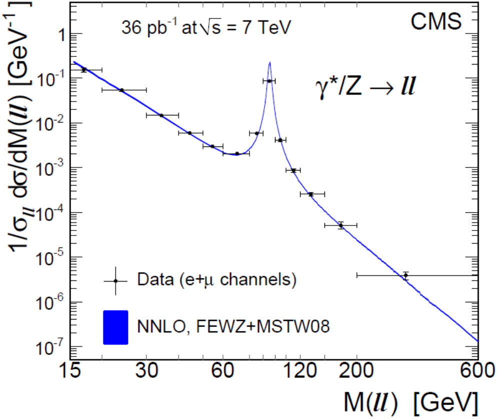
Low-p_T $\rightarrow$ non-perturbative conditions dominate (Pythia)



High-p_T $\rightarrow$ perturbative contributions dominate (FEWZ)

Drell-Yan differential cross section

Drell-Yan invariant mass spectrum normalized to the cross-section in the Z region ($60 < M(\ell, \ell) < 120$ GeV), unfolded, corrected for acceptance, efficiency and FSR effects (not included in FEWZ)



WW production

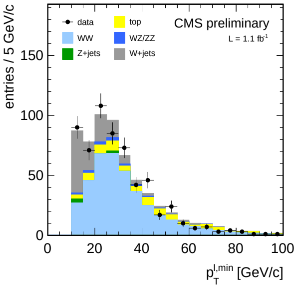
- single-lepton or double-lepton triggers
- two oppositely-charged leptons (p_T >20, p_T>10 GeV)
- projected MET>40 GeV (ee, $\mu\mu$) or 20 GeV (eμ).
- events with any jet of p_T >30 GeV or a third isolated lepton rejected
- DY vetoed with missing E_T and $\ell\ell$ mass far from Z peak
- top quark vetoed using number of jets and soft-muon b-tagging veto

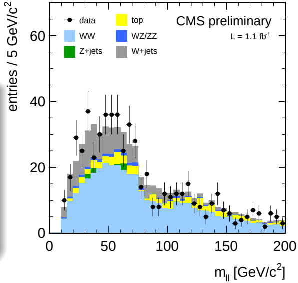
Results

$\sigma(pp \rightarrow$WW+X) = 55.3 $\pm$ 3.3 (stat) $\pm$ 6.9 (syst) $\pm$ 3.3 (lumi) pb

626 events selected in data against a signal+background MC predictions of 568.6 $\pm$ 52.2

SM expectation: 43.0 $\pm$ 2.0 pb at NLO



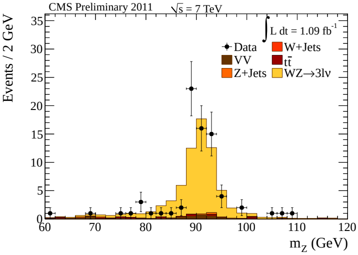


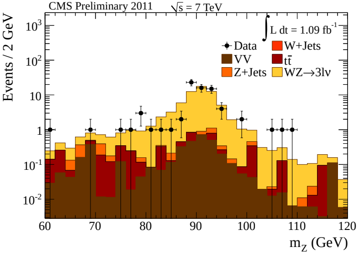
WZ production

- double-electron or double-muon triggers
- Z candidate built from pair of leptons closest to Z mass (60$<$ m(ℓ,ℓ)$<$120 GeV)
- Reject events with a second Z candidate
- Most energetic remaining lepton assigned to the W
- $\not{E}_T$ >30 GeV

Results

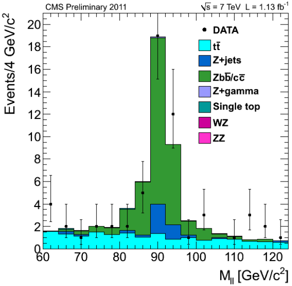
$\sigma(pp \rightarrow$WW+X) = 17.0 $\pm$ 2.4 (stat) $\pm$ 1.1 (syst) $\pm$ 1.0 (lumi) pb
SM expectation of 19.790 $\pm$ 0.088 pb at NLO

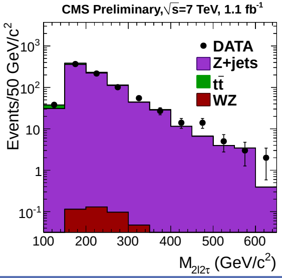




ZZ production

- double-muon or double-electron trigger.
- Z_1 from pair of electrons or muons closest to the Z mass
- Z_2 from most energetic remaining pair of electrons, muons, or taus
- m(Z_2)$>$12 GeV and m(4ℓ)$>$100.
- impact parameter significance IP/σ(IP)$<$ 4 for all 4 leptons (to reject *b* decays)





Results

$\sigma(pp \rightarrow ZZ+X) = 3.8^{+1.5}_{-1.2}$ (stat) $\pm$ 0.2 (syst) $\pm$ 0.2 (lumi) pb

SM expectation of 6.4 $\pm$ 0.6 pb calculated with MCFM

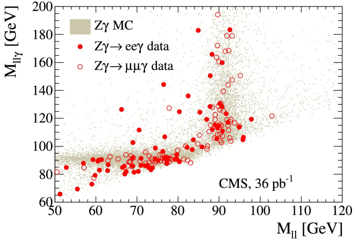
Results limited by statistics

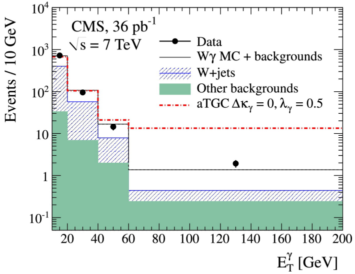
Wγ, Zγ

- Production mechanisms: ISR, FSR
- Probes Triple Gauge Couplings (Z$\gamma\gamma$ and ZZγ $\sim$ 0, only through loops)
- Photon reco: isolated EM calo deposit with correct shape and no track associated and isolation (to remove γ from fragmentation)
- $E_T^\gamma > 10$ GeV, ΔR(ℓ-γ) > 0.7

Results

$\sigma(pp \rightarrow$Wγ+X)xBR(W$\rightarrow \ell\nu$) = 56.3 $\pm$ 5.0 (stat) $\pm$ 5.0 (syst) $\pm$ 2.3 (lumi) pb
$\sigma(pp \rightarrow$Zγ+X)xBR(Z$\rightarrow \ell\ell$) = 9.4 $\pm$ 1.0 (stat) $\pm$ 0.6 (syst) $\pm$ 0.4 (lumi) pb
SM predictions: 49.4 $\pm$ 3.8 pb (Wγ), 9.6 $\pm$ 0.4 pb (Zγ)

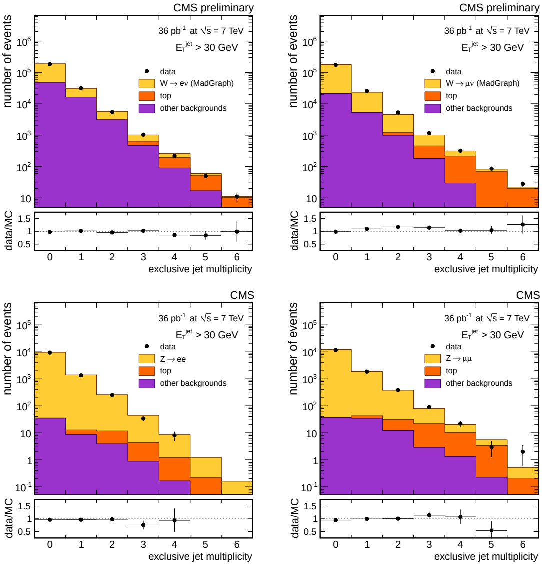




V+jets

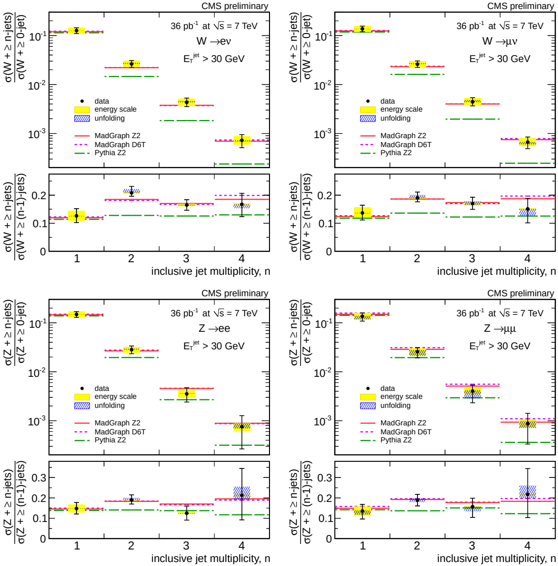
- Importance of Vector+Jets at LHC:
  - test of perturbative QCD calculations
  - background for searches of SM higgs boson, BSM or top quark
  - standard candle for the commissioning of the detector
  - probe of different PDFs through flavor specific final states
- Selection criteria similar to inclusive W/Z cross section analysis
  - jets: anti-k_T algorithm, ΔR=0.5
  - *b* & *c* quarks tagged with Track Counting (TC) and Secondary Vertex (SV) algorithms
- Data unfolded for detector effects
  - comparison to NLO hadron level
- Measurement of ratio of cross section to minimize systematic uncertainties
  - σ(V + n jets) / σ(V)
  - σ(V + n jets) / σ(V + (n-1) jets)
  - σ(W + jets) / σ(Z + jets)
  - systematics dominated by Jet Energy Scale, PileUp removal

V+jets control plots



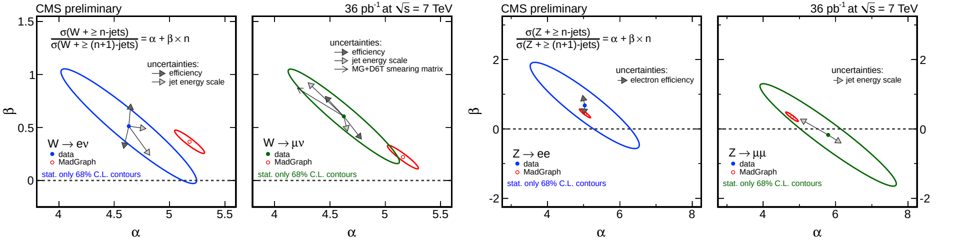
V+jets results

Good agreement with MadGraph for W and Z
At high jet multiplicities Z has large statistical uncertainty compared to W



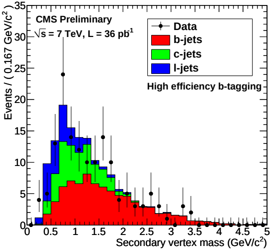
Berends-Gele scaling

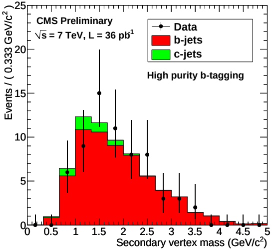
Ratio C(n)= σ(V + $\geq$ n-jets)/σ(V + $\geq$ (n+1)-jets) approximately constant for n$\geq$1.
Fit to the data with the constraint C(n)=α + $\beta\times$n. Result of the fits represented in the (α,β) plane, separately for the electron and muon channels, and compared to the theory prediction from MadGraph interfaced with Pythia/Z2 (ME+PS).



Z + *b*-jets

- Different production mechanisms: b -pairs produced from $q\bar{q}$, gg scattering ("fixed flavour") or quark at partonic level ("variable flavour")
- Selection: two isolated leptons forming a Z, no MET (top-veto), b-tagging (tagger based on lifetime)
- b-tagging purity determined from template fit to the distribution of invariant mass of tracks associated to the secondary vertex
- Measurement of the ratio $\mathcal{R} = \dfrac{\sigma(pp \to Z + b + X)}{\sigma(pp \to Z + j + X)}$
- obtained for p_T(jet)$>$25 GeV and η(jet)$<$2.1.



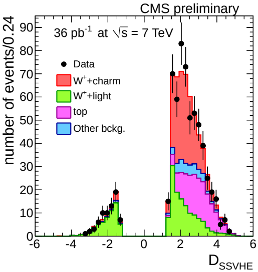


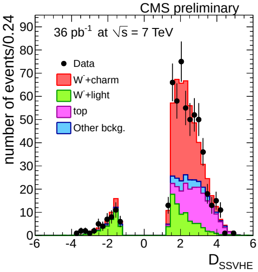
Sample	R(Z→ee) (%), pT(ele) > 25 GeV, η(ele) <2.5	R(Z→μμ) (%), pT(μ) > 20 GeV, η(μ) < 2
Data HE	4.3 +/- 0.6 (stat) +/- 1.1 (syst)	5.1 +/- 0.6 (stat) +/- 1.3 (syst)
Data HP	5.4 +/- 1.0 (stat) +/- 1.2 (syst)	4.6 +/- 0.8 (stat) +/- 1.1 (syst)
MADGRAPH	5.1 +/- 0.2 (stat) +/- 0.2 (syst) +/- 0.6 (theory)	5.3 +/- 0.1 (stat) +/- 0.2 (syst) +/- 0.6 (t
MCFM	4.3 +/- 0.5 (theory)	4.7 +/- 0.5 (theory)

W + *c*-jets

- Rate of W+*c* production sensitive to *s* quark content of the proton
- Dominated by *sg* $\rightarrow W^{-}$ *c* and cc
- W+*b*-jets highly suppressed: *b*-tagging techniques used to identify the *c*-jet
- Measurement of the ratios:

$$\mathcal{R}_{c\pm} = \frac{\sigma(W^{+}\bar{c})}{\sigma(W^{-}c)}, \quad \mathcal{R}_{c} = \frac{\sigma(Wc)}{\sigma(W+jets)}$$





Ratio	MCFM (CT10)	MCFM (MSTW08)	MCFM (NNPDF21)
$R_c^{\pm}$	$0.915^{+0.006}_{-0.006}$	$0.881^{+0.022}_{-0.032}$	0.902 ± 0.008
R_c	$0.125^{+0.013}_{-0.007}$	$0.118^{+0.002}_{-0.002}$	0.103 ± 0.005

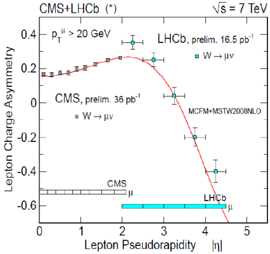
Results

$\mathcal{R}_{c\pm}$ = 0.92 $\pm$ 0.19 (stat.) $\pm$ 0.04 (syst.)
$\mathcal{R}_{c}$ = 0.143 $\pm$ 0.015 (stat.) $\pm$ 0.024 (syst.)

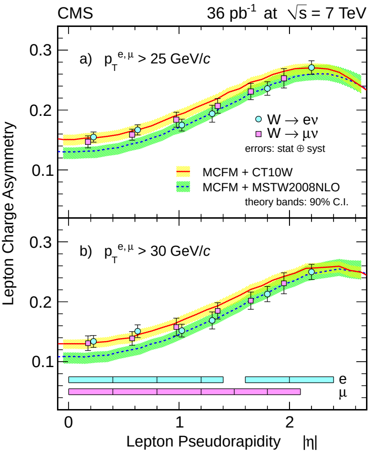
W charge asymmetry

- W^+/W^- ratio as a function of the lepton η
- Different p_T thresholds (25, 30 GeV) to probe different phase space regions
- Charge mis-ID: 0.1(B)-0.4(E)% for e, $<10^{-4}$ for μ
- Sensitive to PDF since several uncertainties cancel in the ratio

$$\mathcal{A}(\eta) = \frac{\frac{d\sigma}{d\eta_\ell}(W^+ \to \ell^+\nu) - \frac{d\sigma}{d\eta_\ell}(W^- \to \ell^-\nu)}{\frac{d\sigma}{d\eta_\ell}(W^+ \to \ell^+\nu) + \frac{d\sigma}{d\eta_\ell}(W^- \to \ell^-\nu)}$$

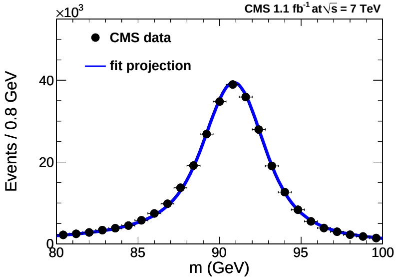


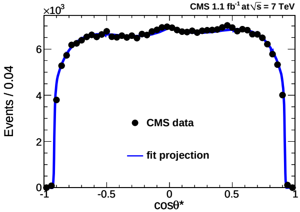
(*) CMS: special p_T cuts and binning used

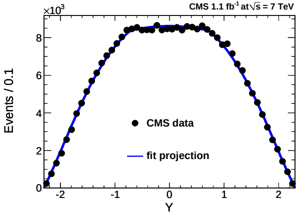


Weak mixing angle

- Vector coupling of fermions related to the weak mixing angle:
  $g_V^f = I_3^f \quad g_A^f = I_3^f - 2q_f \cdot sin^2\theta_W$
- The effective weak mixing angle is extracted from di-muon data using an unbinned extracted maximum-likelihood fit
- Observables of the fit: di-lepton mass, rapidity amd decay angle



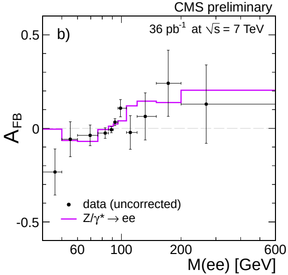




Results

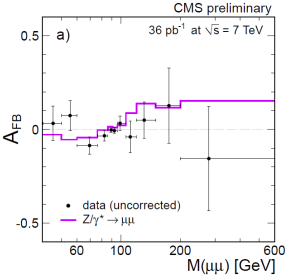
$sin^2\theta_{eff}$ = 0.2287 ± 0.0020 (stat.) ± 0.0025 (syst.)

Forward-Backward Asymmetry

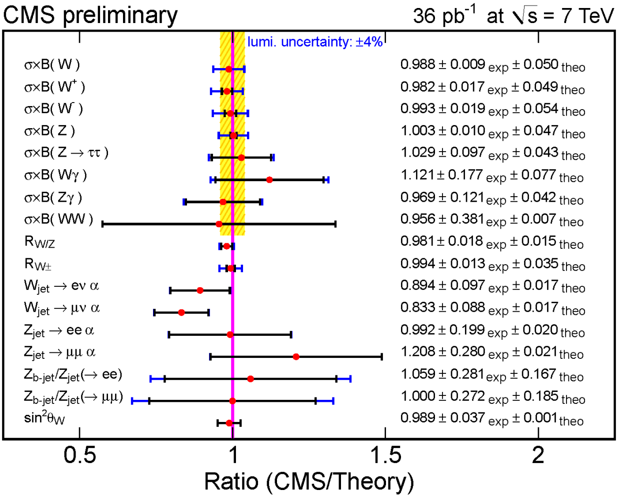


$$A_{FB} = (\sigma_F - \sigma_B)/(\sigma_F + \sigma_B) = (N_F - N_B)/(N_F + N_B)$$

- The Forward-Backward asymmetry A_{FB} is important for:
  - measuring weak mixing angle based on Z to light quark coupling
  - probing the coupling of Z/γ^* to light quarks
  - investigating new possible phenomena/resonances
- Around Z pole, A_{FB} is dominated by interference of vector and axial vector coupling of Z to quarks
- Away from Z-pole, A_{FB} is dominated by Z/γ^* interference (sensitive to new physics)



Summary of CMS EWK results



Conclusions

- CMS produced many EWK measurements with the first 36 pb^{-1} of LHC data 7 TeV, and many results with higher statistics are becoming available!
- **Precision measurements** of inclusive W and Z production cross-section with large statistics
- Detailed studies of **differential cross-sections** and many observables like asymmetries and V+jets
- Detailed studies of **di-bosons** productions
- All measurements in **good agreement** with **theoretical predictions** from the Standard Model

References

CMS PUBLIC EWK RESULTS

(click to open the public twiki page)