W and Z Boson Measurements at CMS at $\sqrt{s}$=7 and 8 TeV

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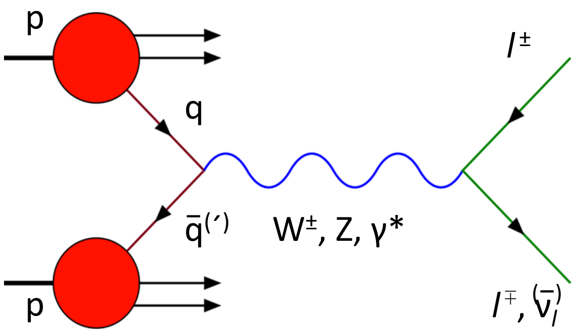
On behalf of the CMS Collaboration

Working Group on Electroweak precision measurements at the LHC, and PDF4LHC
8-10 October 2012 CERN

Electroweak Physics at the LHC



Selected EWK Results from CMS

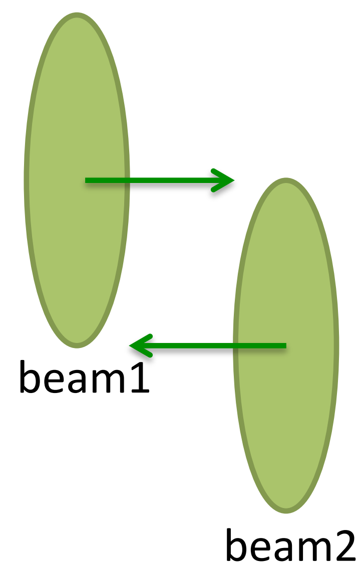
- W/Z Inclusive Cross Sections
- W Charge Asymmetry
- Forward-backward asymmetry of Drell-Yan pairs.

- The production of W and Z bosons decaying into leptons is one of the best understood processes at the colliders.
- Precise measurement of W and Z bosons provide an important test of the standard model.
- Standard candles and backgrounds in searches for new particles
- Some of the EWK measurements are used to constrain PDFs.
- Luminosity measurements.
- High p_T leptons from W's and Z's are used to understand efficiency, resolution, energy scale, and in general understanding the detector.

W and Z Boson Cross-Sections

CMS-PAS-SMP-12-011

- $\sigma_{W,Z}$, $\sigma_{W/Z}$ and $d\sigma_{W,Z}/dX$ measured at √s = 7 TeV by ATLAS and CMS (~36 pb^{-1}).
- Since the √s=7 TeV measurements, L_{inst} increased by ~300x and <pileup> by ~10x.
- At √s=8 TeV, dedicated LHC configuration deployed ← low pileup (~5), unprescaled low p_T triggers, good MET resolution for the W boson cross-section measurement.
  - Reduce inst. lumi. (and pileup) by separating the LHC beams in the transverse plane to reduce the effective overlap.
  - The beam separation was periodically adjusted to compensate the loss of instantaneous luminosity → $\mathcal{L}_{inst}$ kept at ~3-6x10^{32} $cm^{-2}s^{-1}$.
  - 18.8 pb^{-1} collected.



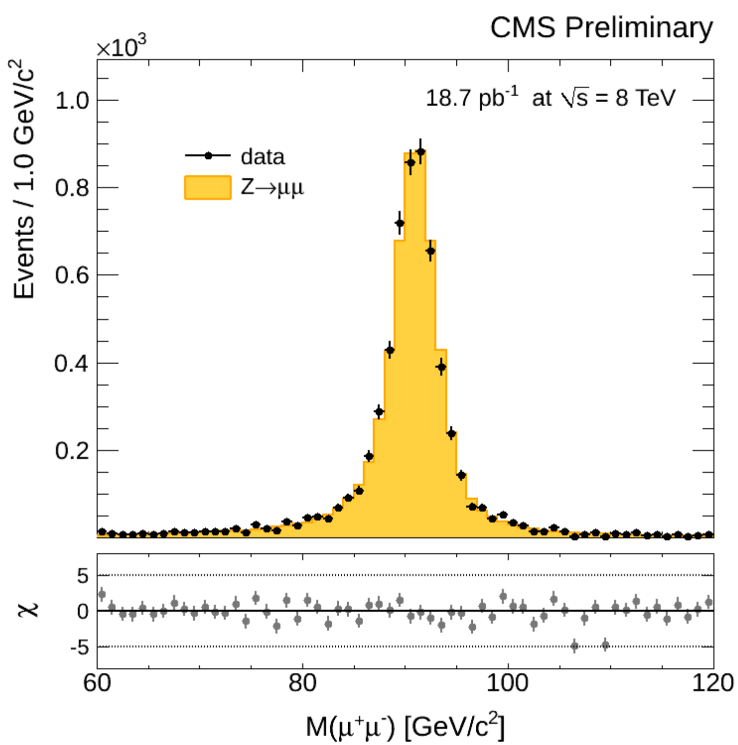
W and Z Boson Cross-Sections: Event Selection

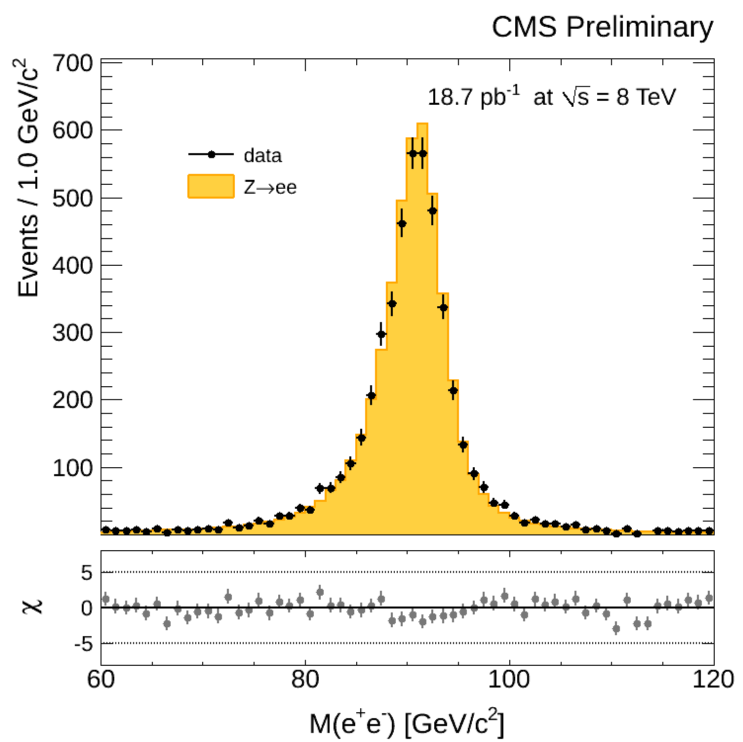
CMS-PAS-SMP-12-011

- Isolated high p_T (> 25 GeV) muons (in $|\eta|<2.1$) and electrons (in $|\eta|<2.5$ excluding the barrel-endcap transition).
- Unprescaled single lepton triggers:
  - muons: 7 GeV (L1), 15 GeV (HLT)
  - electrons: 12 GeV (L1), 22 GeV (HLT)
- Efficiencies determined using tag-and-probe using $Z \rightarrow \ell^+\ell^-$.
- Major backgrounds estimated using data-driven methods.
- W-->lν events with a second lepton is rejected
  - $p_T^{\mu}>10$ GeV, $p_T^{e}>20$ GeV
- Z mass window: 60-120 GeV

Z Boson Cross Section at √s=8 TeV

CMS-PAS-SMP-12-011





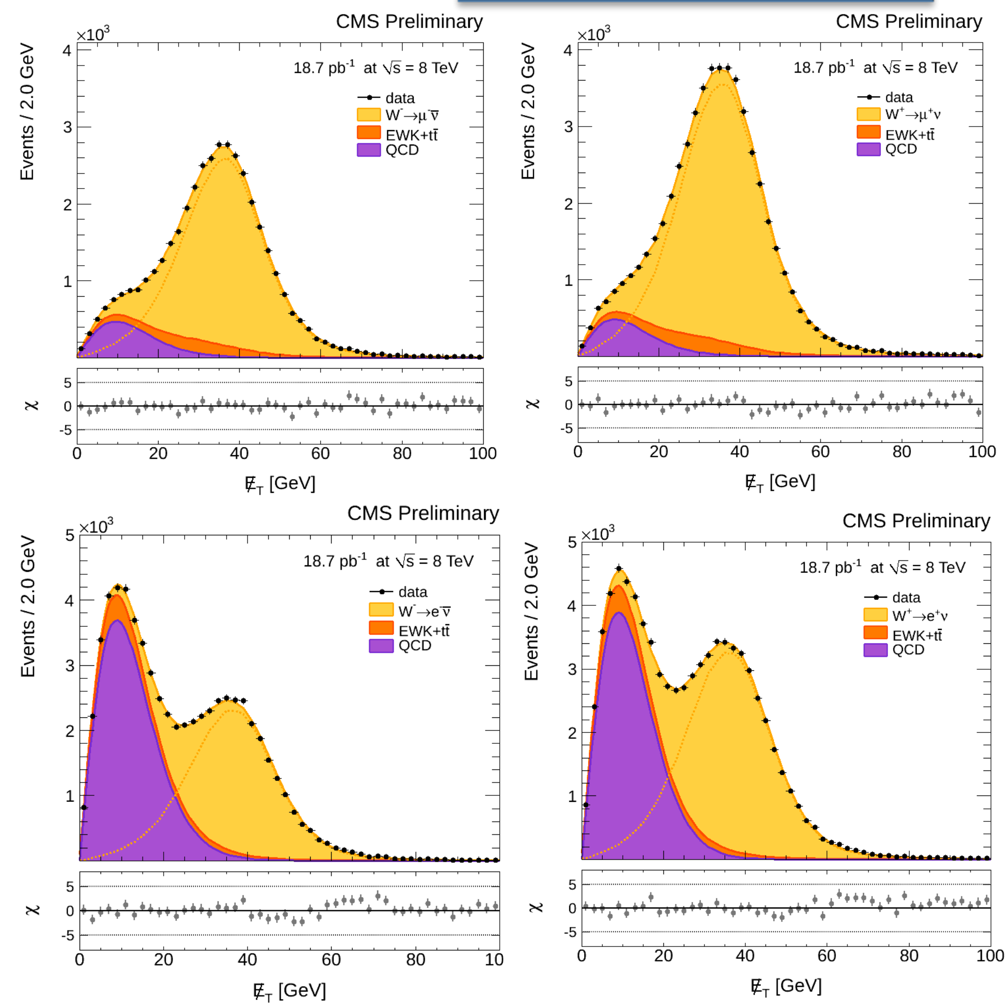
- Z boson yield from cut and count.

σxBR=1.12±0.01(stat)±0.02(sys) ±0.05(lumi) nb

W Boson Cross Section at $\sqrt{s}$=8 TeV

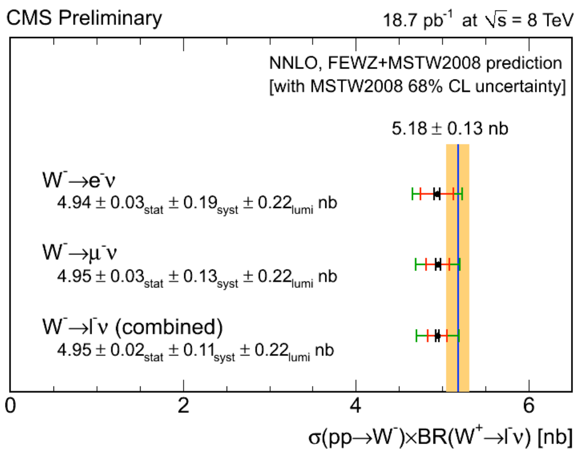
CMS-PAS-SMP-12-011

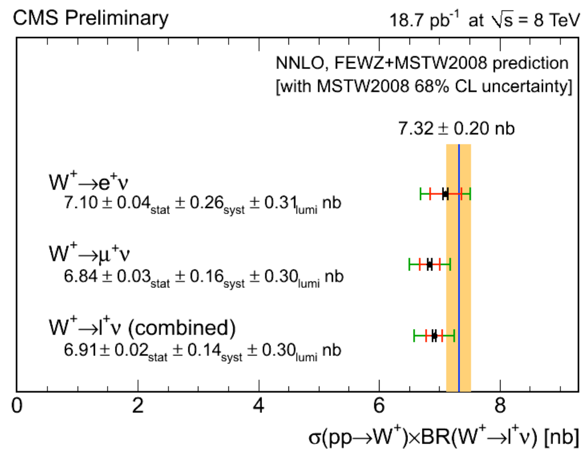
- QCD background shape modeled by a parametric function.
- W signal extracted from binned maximum likelihood fits to the MET distributions with free parameters: signal and QCD background yields and background shape parameters.
- Signal MET shapes from simulation for W^+ and W^- and resolution differences corrected event-by-event vs p_T^W determined from hadronic recoil response and resolution distributions of $Z \rightarrow l^+l^-$ from data.

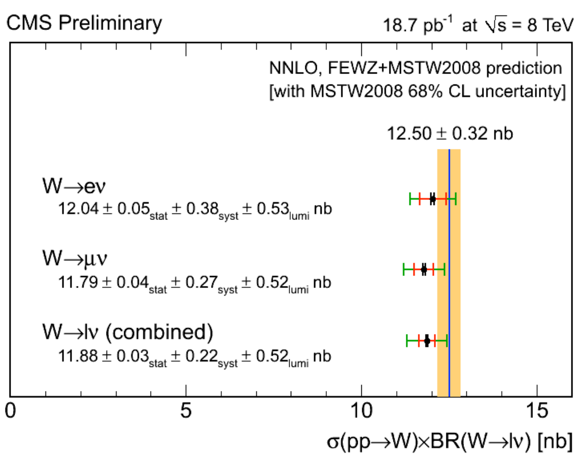


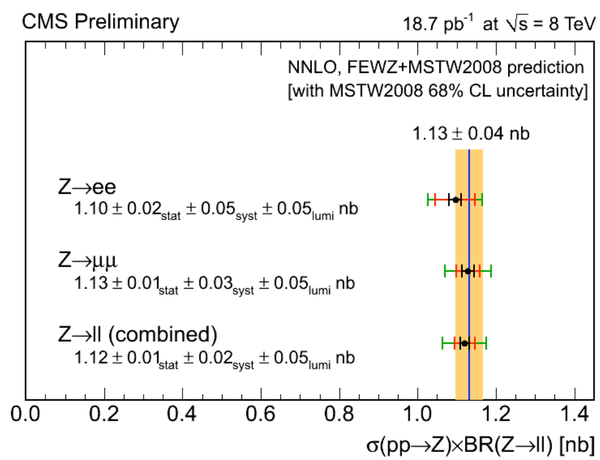
σxBR=11.88±0.03(stat) ±0.22(sys) ±0.52(lumi) nb

Comparison with Theory









CMS-PAS-SMP-12-011

$$\sigma \times BR = \frac{N_s}{A \times \varepsilon \times \int L dt}$$

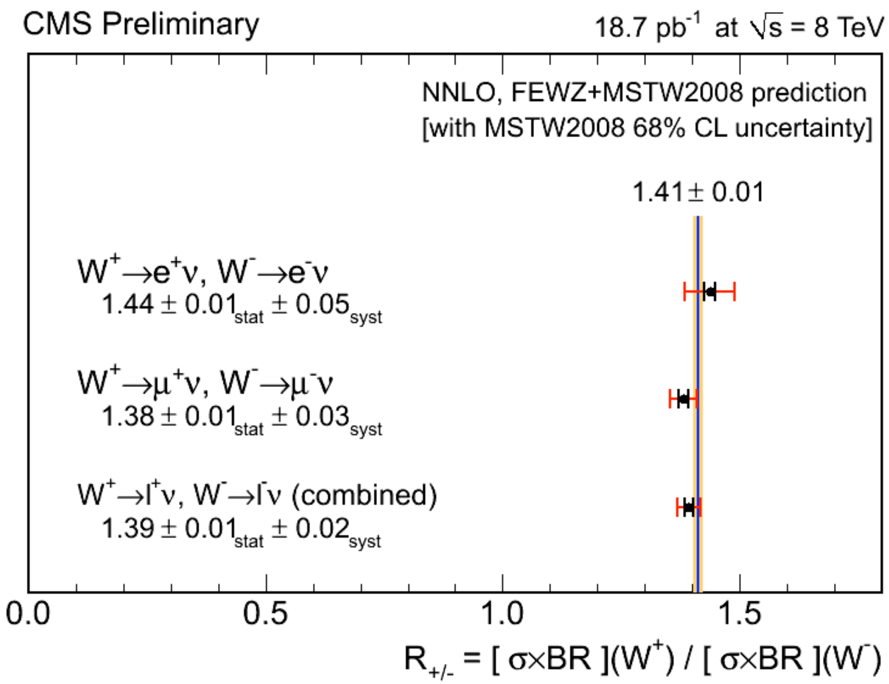
Major Systematics:
Luminosity normalization: 4.4%
Lepton reconstruction (ε): 0.9-3.8%
Backgrounds (N): 0.1-0. 5%
PDFs (A): 1.4-2.7%

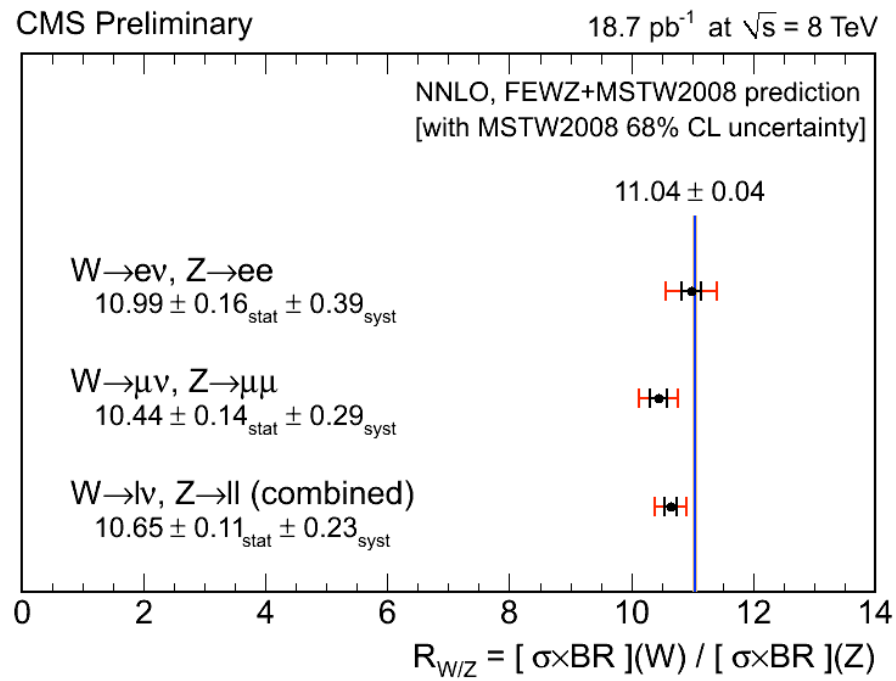
Combination of the lepton channels: Fully correlated theoretical uncertainties for A.
Uncorrelated uncertainties for others.

Measurements are consistent between channels and in good agreement with theory predictions at NNLO.

Comparison with Theory

CMS-PAS-SMP-12-011



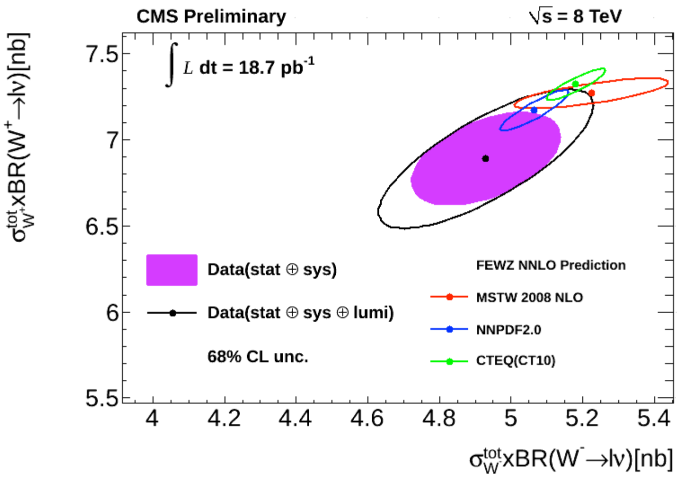


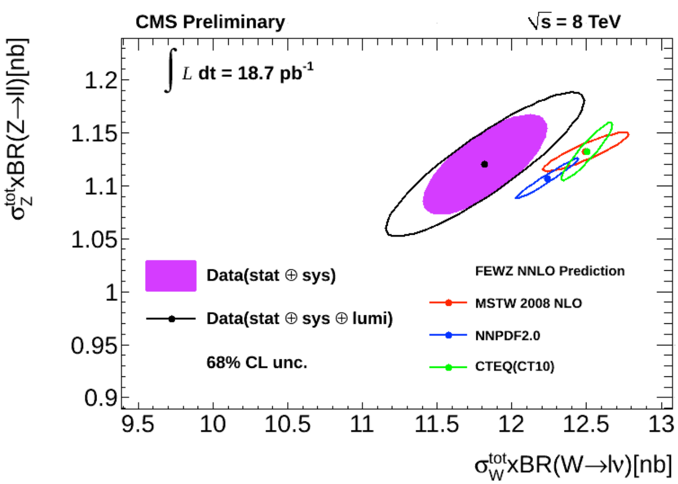
Correlations of lepton efficiencies are taken into account in each channel.

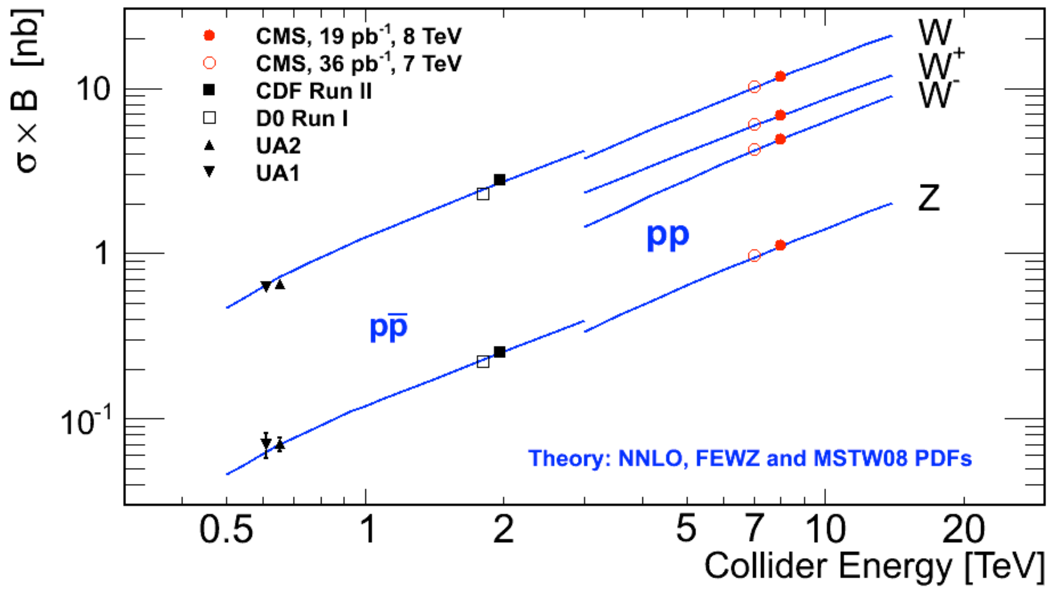
The ratio of cross-sections are in good agreement with theory predictions at NNLO.

Comparison with Theory

CMS-PAS-SMP-12-011







- The increase of the Z and W cross sections with energy is (once again) confirmed.

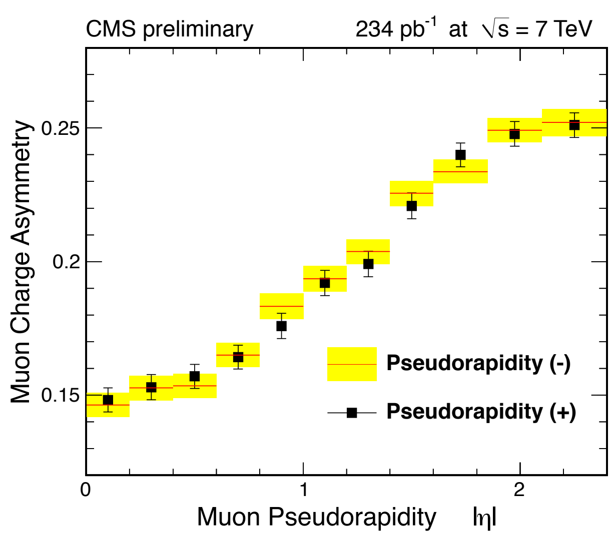
W Lepton Charge Asymmetry

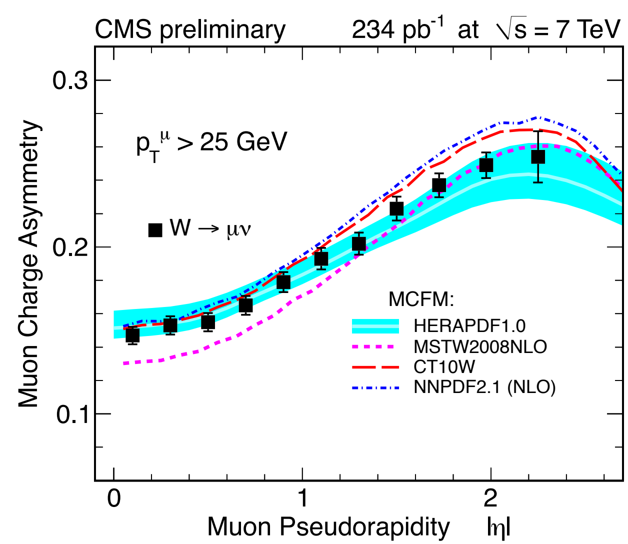
CMS-PAS-EWK-11-005

- Two valence u quarks in the proton, P(uud) --> More W^+(ud~) than W^-(du~) at the LHC.
- A vs y can provide better understanding of u/d ratio and the sea antiquark densities at LHC collision energies.
- Due to MET, boson y is not directly accessible --> measurements as a function of η.
- Highly sensitive to PDFs due to the cancellation of systematic uncertainties.

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) - d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) + d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}$$

→ Charge & η dependent p(μ) scale bias in data corrected for using Z/γ*→μ+μ- events.
→ After corrections flatness of p(μ) scale < 0.3%.

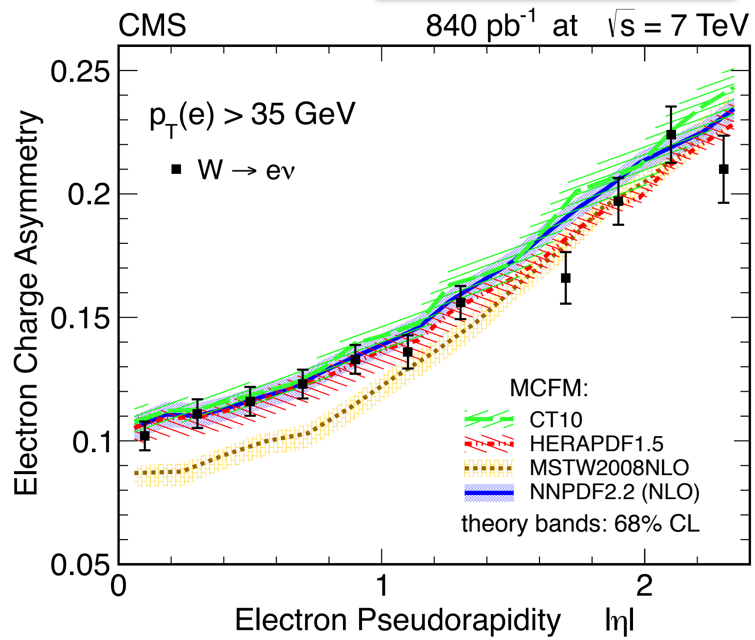




- Not very good agreement with MSTW predictions
- This improved measurement (w.r.t. 36 pb^{-1}) can provide significant constraints to the PDF global fits.

W Electron Charge Asymmetry

arXiv:1206.2598



- Observed asymmetry is corrected for
  - Electron E-scale and resolution (bias)
    - correction to generator level before FSR
    - additional corrections to the simulated electron p_T distributions
  - Relative detection efficiency of positrons and electrons (bias)
  - Electron charge misidentification vs $|\eta|$ (dilution)

p_T threshold increased to 35 GeV to match the updated single electron threshold.

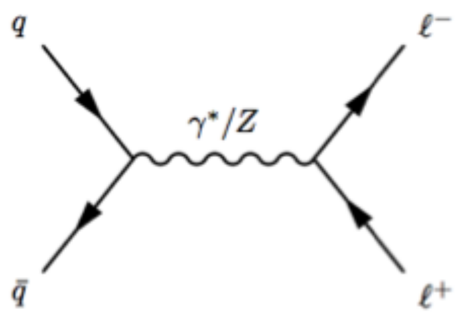
→ **The uncertainty on the measured aymmetry ranges from 0.006 (central) to 0.014 (ECAL endcap).**

→ **The results are in agreement with CTEQ, NNPDF, and HERAPDF predictions, but MSTW predictions are systematically lower.**

  → **See R. Thorne's slides in this workshop that shows very good agreement of CMS data with MSTW with more flexible parametrization and nuclear corrections**

→ **New inputs to the PDF global fits.**

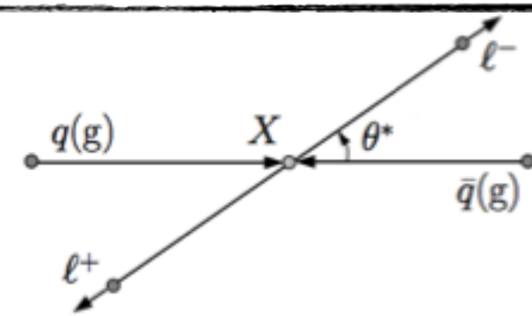
Forward-Backward Asymmetry of the Drell-Yan Pairs



The amplitude has both the vector and axial-vector couplings of EWK bosons to fermions.
Vector coupling: $g_V^f = I_3^f - 2Q_f \sin^2\theta_W$
Axial-Vector coupling: $g_a^f = I_3^f$
→ results in forward-backward asymmetry in the number of Drell-Yan lepton pairs.

M~0 → pure γ* exchange
M~90 GeV → pure Z exchange
Rest → Z/γ* interference

$$\frac{d\sigma}{d(\cos\theta^*)} = A(1+\cos^2\theta^*) + B\cos\theta^*$$



A, B: proportional to the weak isospin and charge of the incoming fermions

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{N_F - N_B}{N_F + N_B} = \frac{3B}{8A}$$

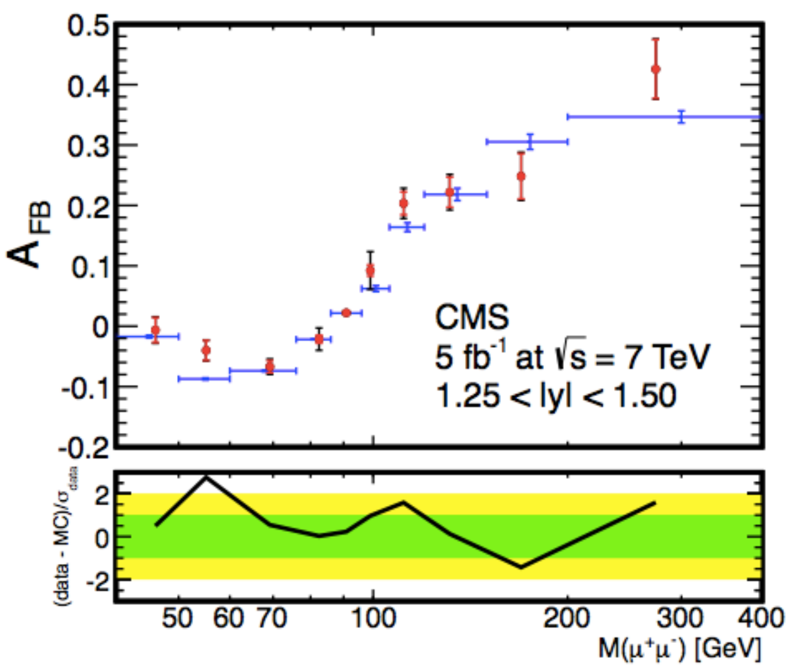
$$A_{FB} = A_{FB}(M, \sin^2\theta_W, q)$$

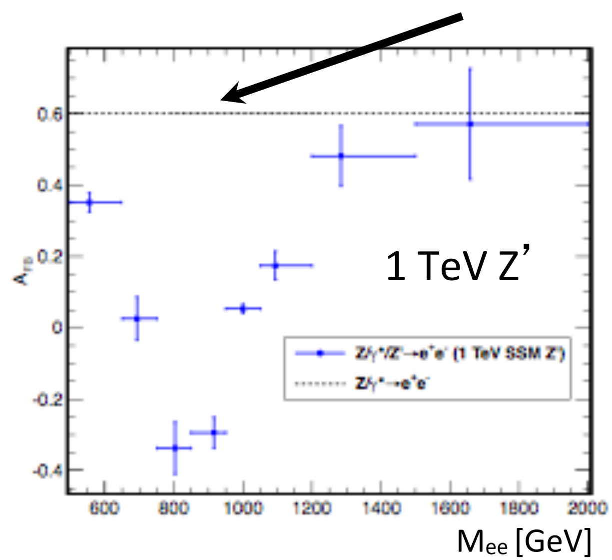
A_{FB} constant at high mass (at the parton level, $A_{FB}^{M > 150\ GeV}$ ~0.6)

Forward-Backward Asymmetry of the Drell-Yan Pairs

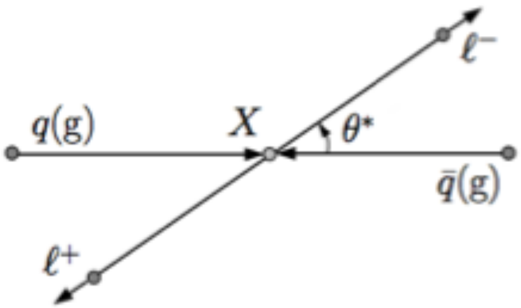
arXiv:1207.3973

- A test of the Standard Model
- Around the Z mass peak, the measurement may be used to extract $\sin^2\theta_W$
  - see the complementary $\sin^2\theta_W$ measurement in CMS using a maximum likelihood fit to the angular distributions around the Z peak (PRD 84, 112002 (2011); also presented in LHC-EWWG April 2011).
- At high dilepton mass, deviations from the SM prediction may indicate the existence of neutral BSM particles. A_{FB} might be better in identifying a broad resonance.





Defining Forward/Backward

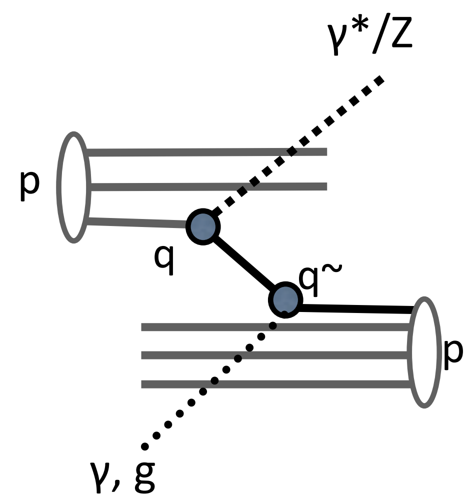


If p_T of the dilepton is zero, θ can be determined unambiguously; θ^*: angle between the lepton and the beam in the dilepton center of mass frame.

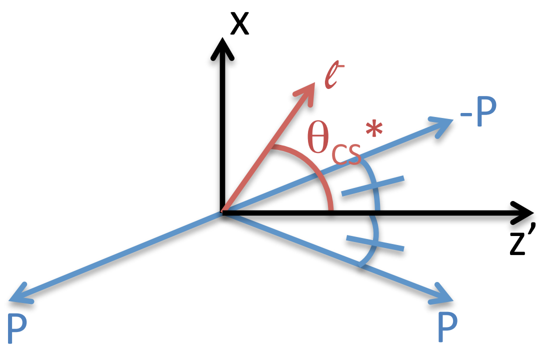
One of the quarks emits a gluon or photon → pT boost to the quark.

The source of the boost is lost once the qq~ annihilates to γ*/Z.

→ θ can't be determined unambiguously since the center of mass of the qq~ system is not well defined.



Defining Forward/Backward: Collins-Soper Frame



Boost into the dilepton rest frame.

p is not collinear with the other p's momentum
→ z' axis: bisector of the two p directions.

Using the Collins-Soper frame reduces the uncertainties due to the unknown and finite transverse momentum of the incoming quarks.

θ_{CS}* is calculated using lab-frame quantities

$$\cos\theta^*_{CS} = \frac{Q_z}{|Q_z|}\frac{2\left(P_1^+P_2^- - P_1^-P_2^+\right)}{|Q|\sqrt{Q^2+Q_T^2}}$$

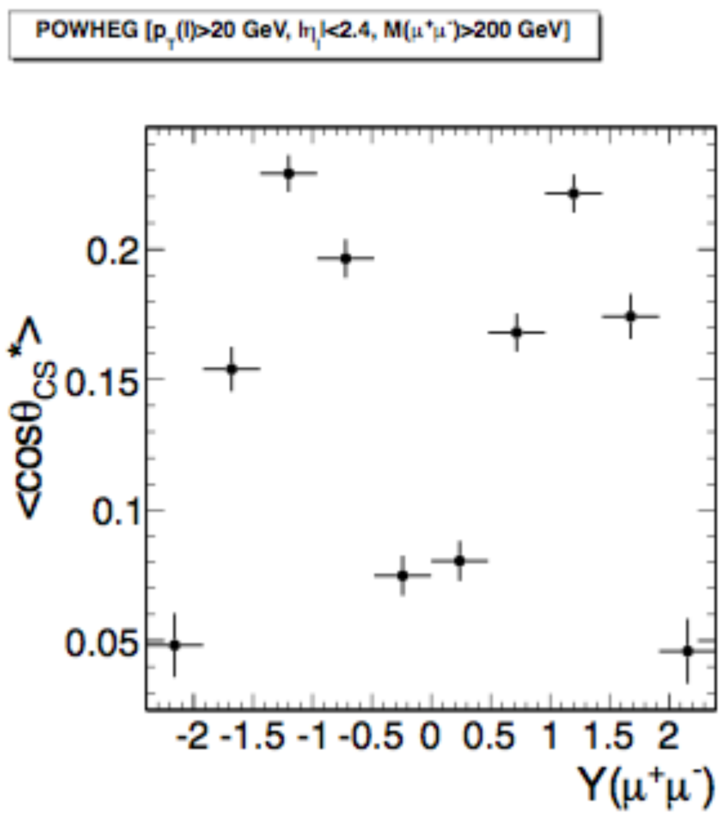
To correct for (partially) the dilution due to the unknown q/q~ directions.
Assume: P_q (valence) > $P_{q\sim}$ (sea) → q along the dilepton boost direction.

Q: four-momentum of the di-lepton system.
P_1(P_2): 4-momenta of the lepton (anti-lepton).

$$P_i^{\pm} = \left(P_i^0 \pm P_i^3\right)/\sqrt{2}$$

The A_{FB} Measurement

- A_{FB} in 4 rapidity and 10 mass bins (the last bin M>200 GeV);
  - Raw measurements are corrected to the Born level (pre-detector and pre-FSR) using an unfolding technique within acceptance.

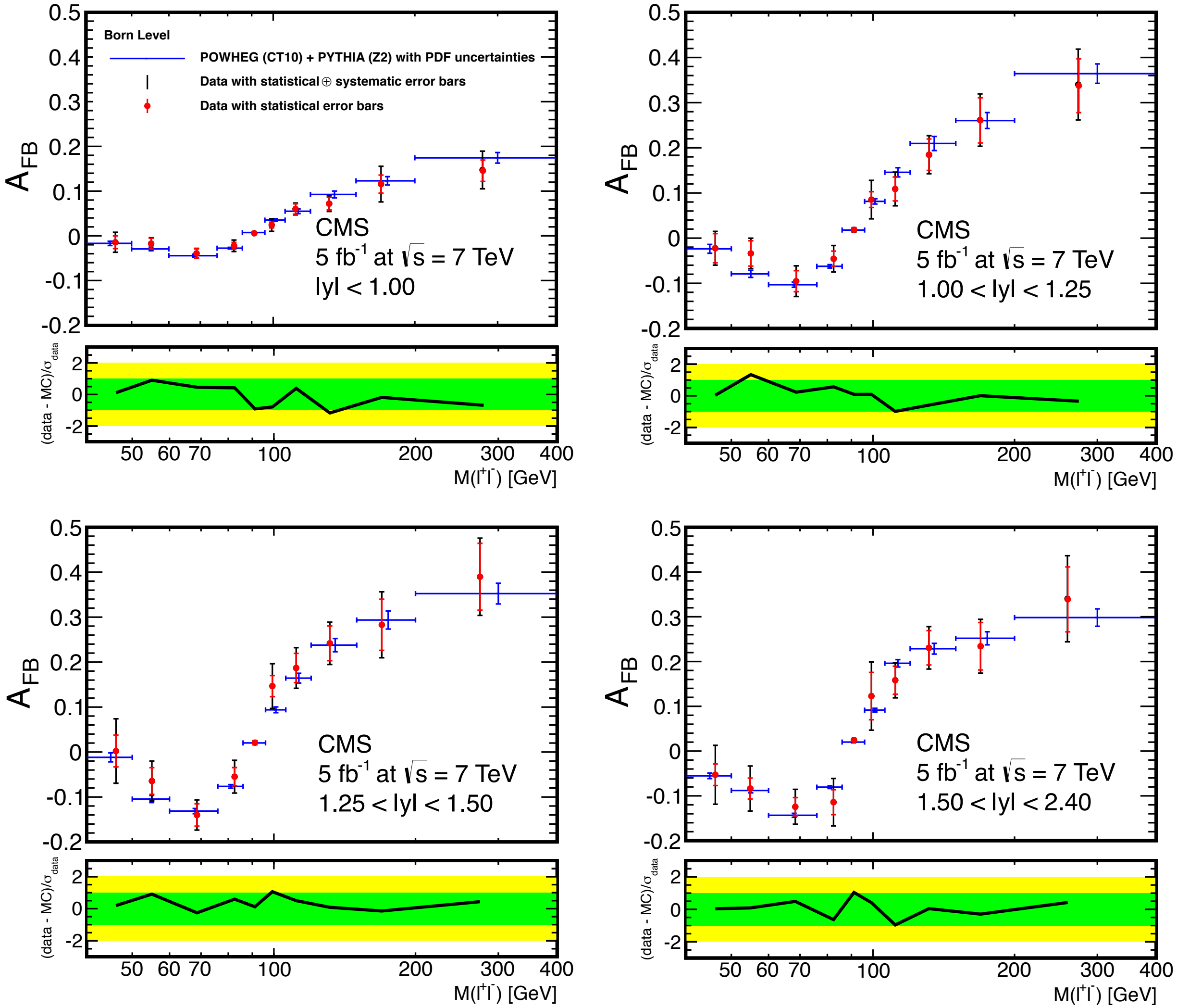


At both levels:
p_T(l)>20 GeV, $|\eta(l)|$<2.4

|Y|=0-1.25 Asymmetry increases (mostly physics effect; dilution due to unknown proton direction decreases with increasing Y).
|Y|>1.25 --> Asymmetry decreases due to Y-acceptance.

The Combined AFB Measurement

arXiv:1207.3973



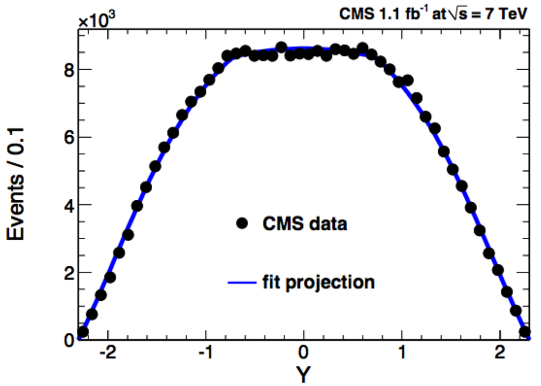
- →Unfolded = Born level (Pythia status=3) within CMS acceptance.
- Individual raw and unfolded measurements in each channel and the unfolded-combined measurements agree well with the SM predictions
  - A_{FB} vs M shows the photon and the Z boson interference
- No new particles

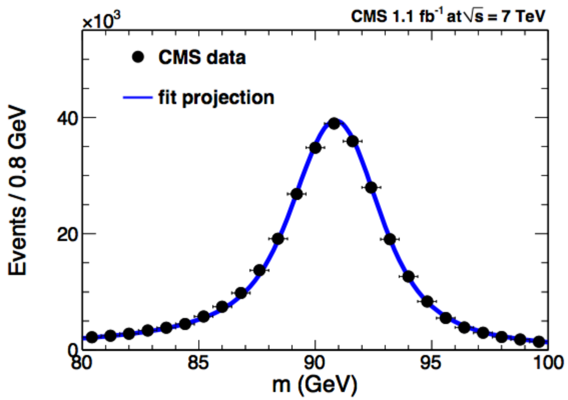
Summary and Conclusions

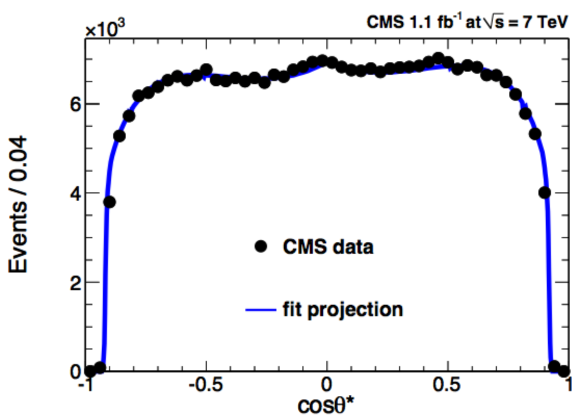
- First W, Z boson cross-section measurements at $\sqrt{8}$ = TeV are presented.
- Updated W charge asymmetry measurements at $\sqrt{s} = 7$ TeV are shown.
  - Good agreement between CTEQ, NNPDF, and HERAPDF sets; and measurements not consistent with the MSTW predictions.
- Forward-backward asymmetry of Drell-Yan pairs measured at $\sqrt{7}$ = TeV are presented as a function of y and M.
  - These are the first measurements of A_{FB} presented in bins of $|y|$, the first in the muon channel and the first combined measurement (in an hadron collider).
- All results are consistent with the standard model predictions within uncertainties.

Back-up

The Weak Mixing Angle







$pp \rightarrow u\tilde{u}, d\tilde{d} \rightarrow Z/\gamma^* \rightarrow \mu^+\mu^-$

Build leading order EWK (analytical) +PDF(CTEQ6) Model.
Correct the fits for NLO effects.

G: Acceptance and efficiency description.
R: Resolution and QED FSR
P_{ideal}: Model from elementary qqbar cross sections and PDF including a dilution factor due to unknown quark direction.

Likelihood fit to the probability density function

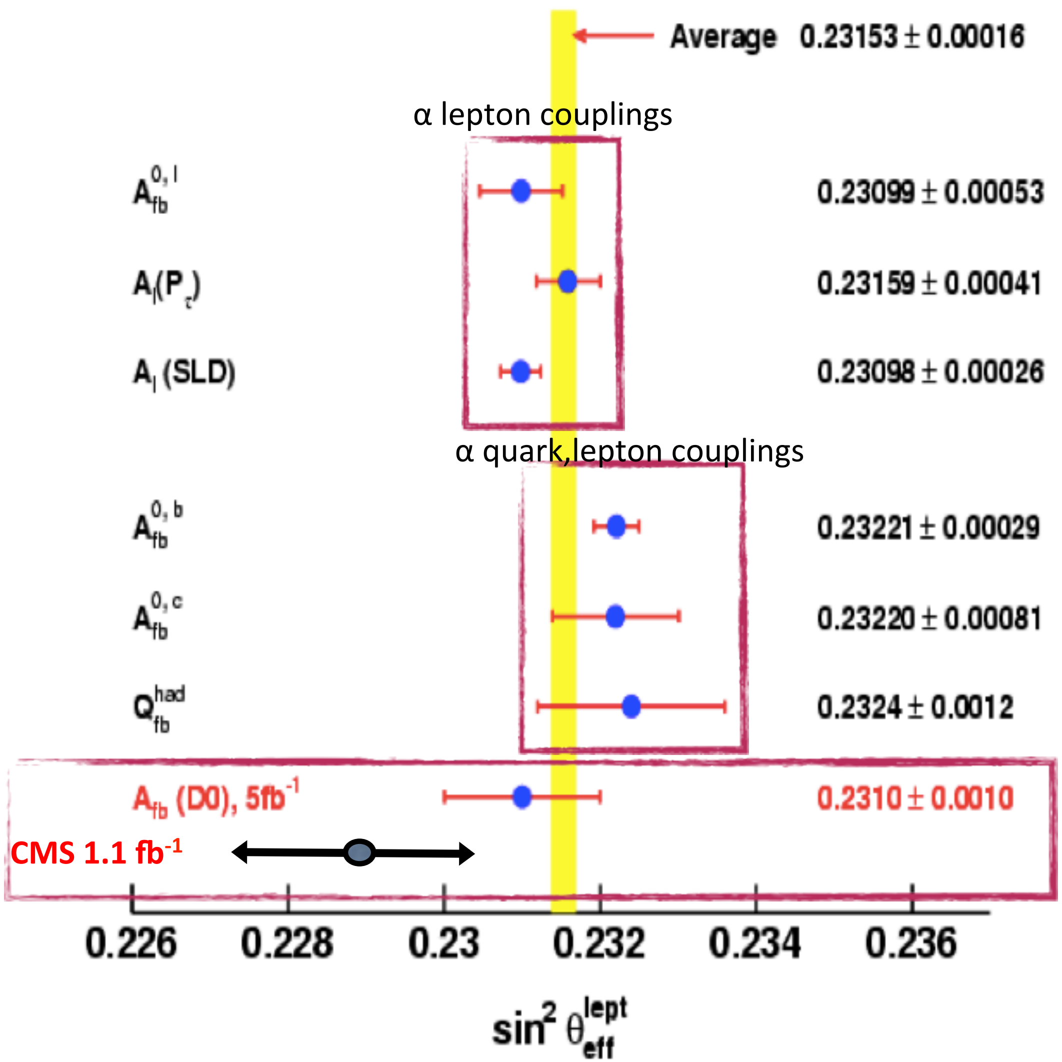
$$\mathcal{P}_{sig}(Y, \hat{s}, \cos\theta^*; \theta_{eff}) = \mathcal{G}(Y, \hat{s}, \cos\theta^*) \times \int_{-\infty}^{+\infty} dx \mathcal{R}(x) \mathcal{P}_{ideal}(Y, \hat{s} - x, \cos\theta^*; \theta_{eff}).$$

M = 80 - 100 GeV.
Allow only θ_W and M to be unconstrained.

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

Phys. Rev. D 84, 112002 (2011)

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



LHC/Tevatron can measure Q_{fb}^{Had} better than LEP with the inverse process of ee→qq~.

Different couplings than LEP/SLC: qq~→Z→μμ

Major systematic uncertainty sources for CMS:

- PDF
- FSR
- LO model(QCD)
- alignment

$W \rightarrow \tau\nu$

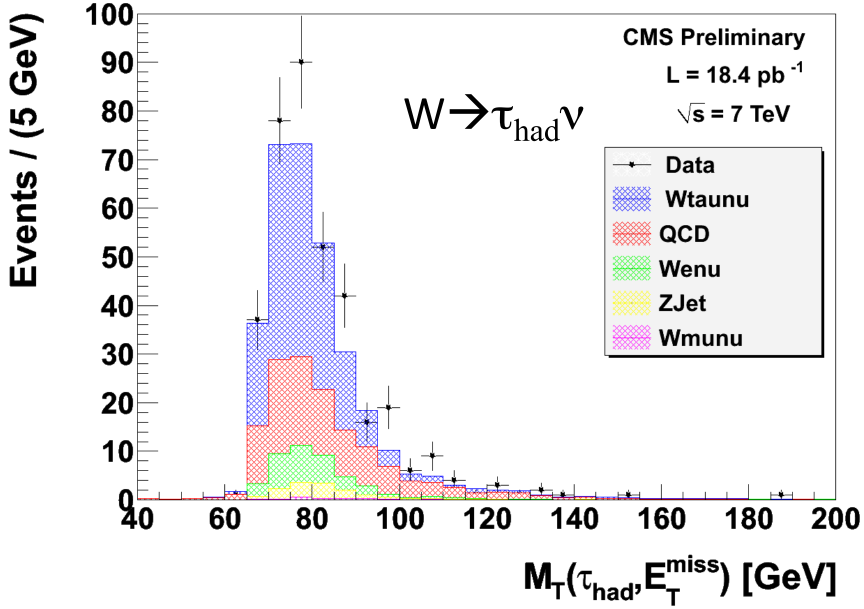
CMS-PAS-EWK-11-002

Important for searches of a light Higgs boson, SUSY or extra dimensions, ..

→ τ_{had}: highly-collimated jet with 1 or 3 charged mesons and 0,1 or 2 neutral pions.
→ **Single τ_{had} and MET trigger.**

QCD multi-jet background is controlled by dividing the phase space defined by MET and $p_T(\tau)/\Sigma p_T$(PF jets) into four regions.

Signal events from simulation: 174±3
EWK backgrounds from simulation: 46±2
QCD events from sideband: 109±6
 # Selected events in data: 372



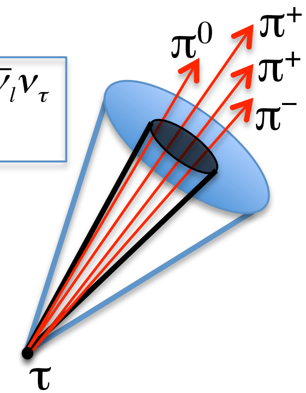
Preliminary analysis provide a statistically significant signal on top of QCD multi-jet and electroweak backgrounds.

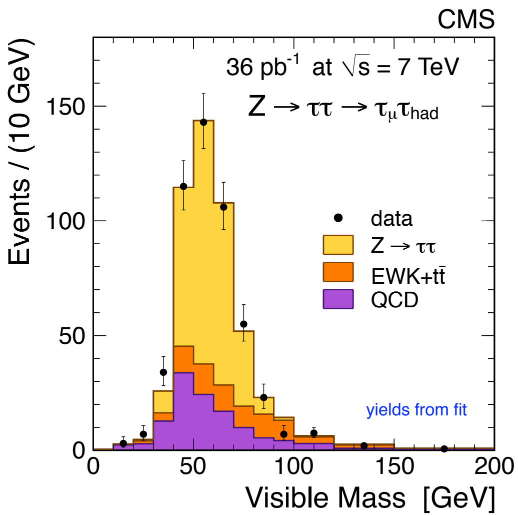
$Z \rightarrow \tau\tau$

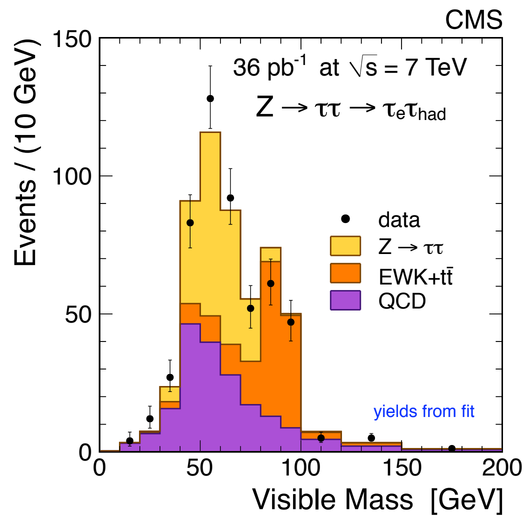
arXiv:1104.1617
CMS-PAS-EWK-10-013

Important for searches of a light Higgs boson, SUSY or extra dimensions, ..

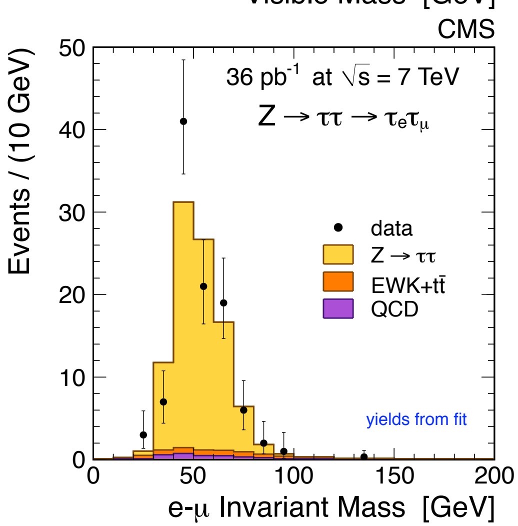
Leptonic final states: $\tau_l \equiv \tau \rightarrow l\bar{\nu}_l\nu_\tau$
Hadronic final states: τ_{had}

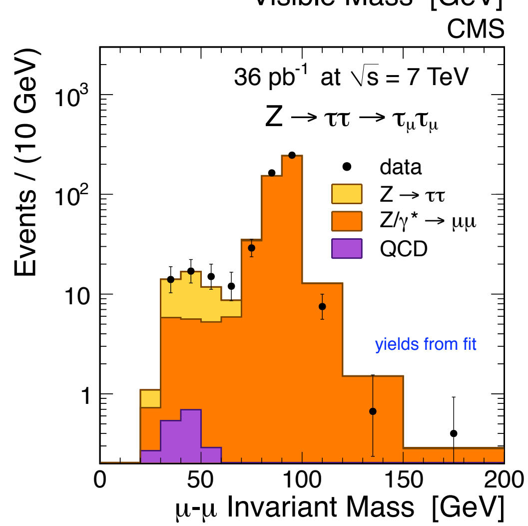






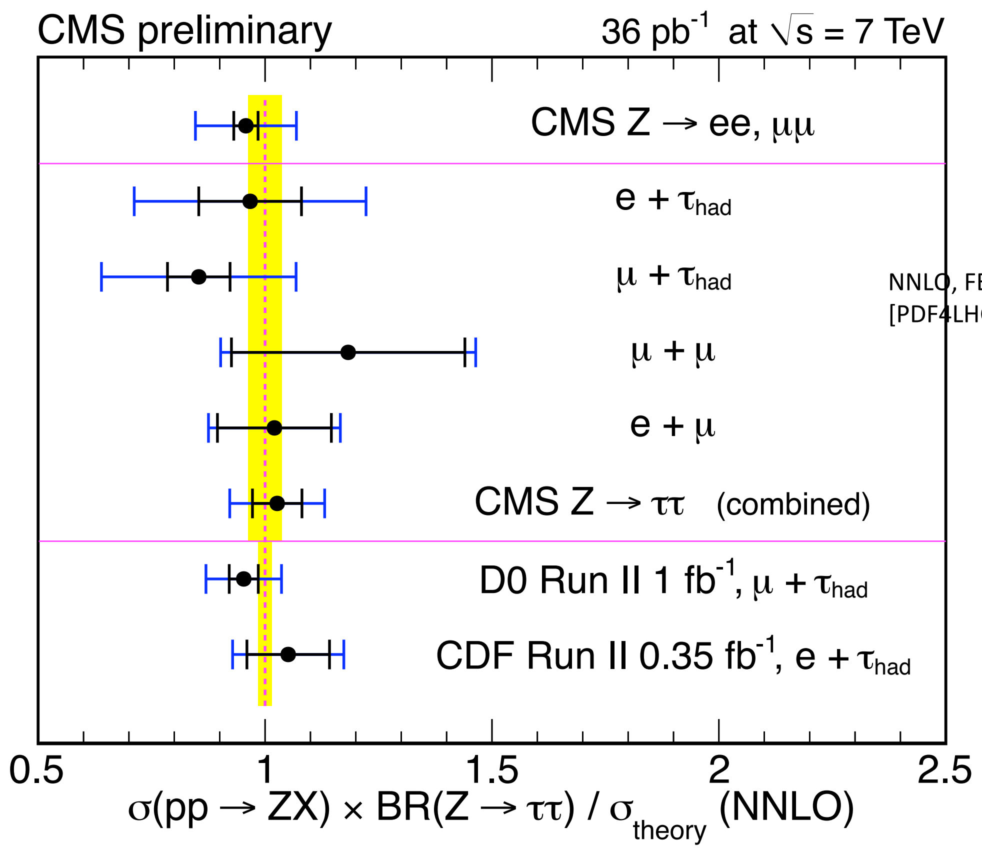
Signal yields from a maximum likelihood fit of the shapes from MC except for QCD, and Z→*ll* backgrounds.





Clear signal in all channels.
A global fit of the lepton+τ_{jet} channels provides a check on the reconstruction efficiency for semi-hadronic τ decays with a precision of ~7%.

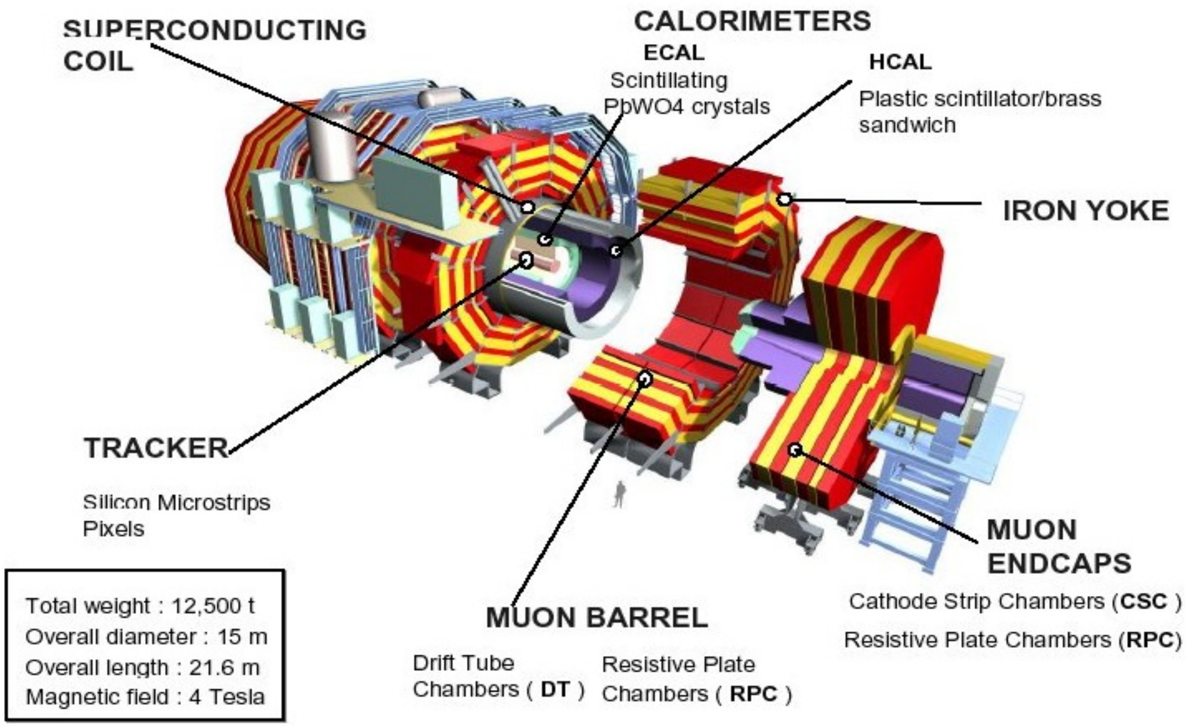
Comparison to Theory and Previous Measurements

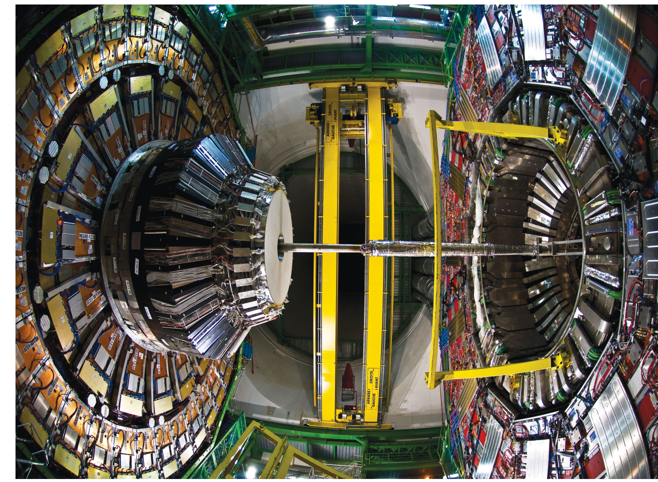


NNLO, FEWZ+MSTW08
[PDF4LHC 68% CL] (60-120 GeV)

Statistical uncertainties smaller than the systematic uncertainties.
σxBR measurements are compatible with each other, with NNLO predictions, Tevatron measurements, and CMS measurements with Z→e^+e^-, $\mu^+\mu^-$ events.

Compact Muon Solenoid(CMS)





Within the solenoid field volume:

ECAL: $PbWO_4$, High resolution, ~70 k crystals
HCAL: Brass and scintillator,
Tracker: 66 M Si pixels and 10 M Si strips
Superconducting Solenoid magnet: 6 m x 13 m, B=3.8 T, E = 1.6 GJ

Embedded within the iron yoke:

Muon System: Drift tubes (DT), Cathode Strip Chambers (CSC), Resistive plate chambers (RPC).

+ Forward Calorimeter: steel absorber, fibers