Electroweak results

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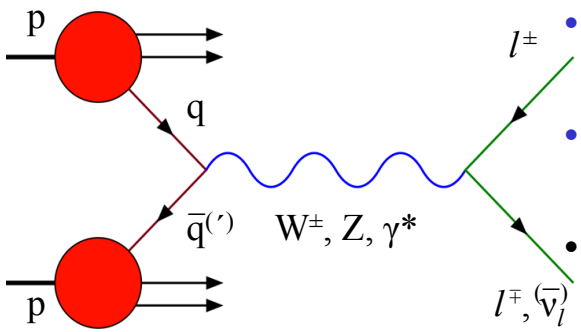
INFN - Napoli

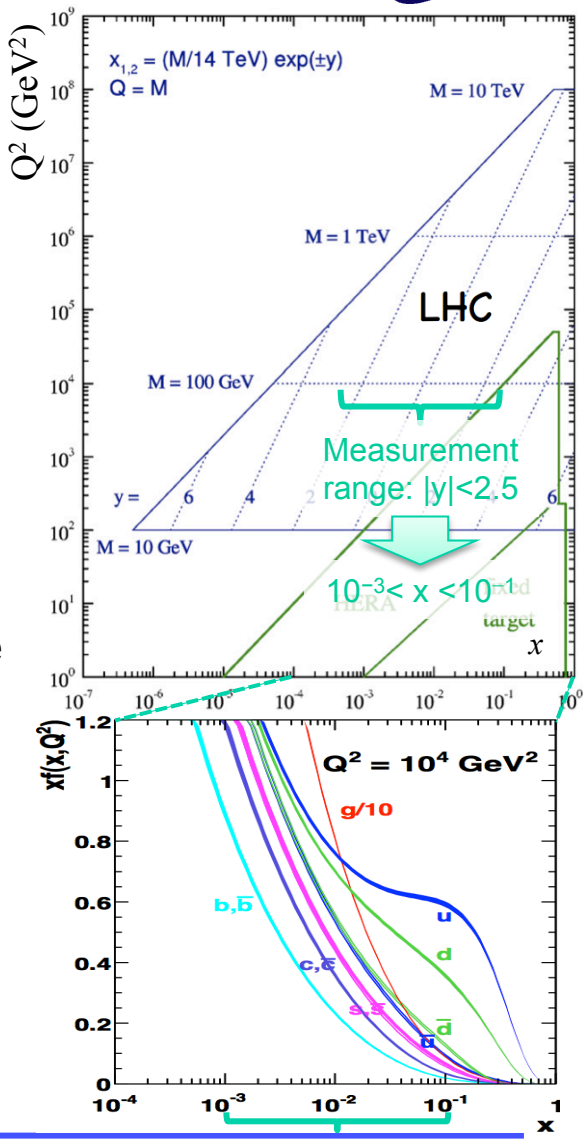
EWK processes at LHC

- W and Z production in pp collisions proceeds mainly form the scattering of a valence quark with a sea anti-quark
- The involved parton fractions are low ($10^{-3} < x < 10^{-1}$) and scattering of a sea quark with a sea anti-quark is also important
- W production is charge asymmetric: $\sigma(W^+)/\sigma(W^-)\sim1.43$ (< 2, as from valence + sea only) in the Standard Model
- 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 simulations



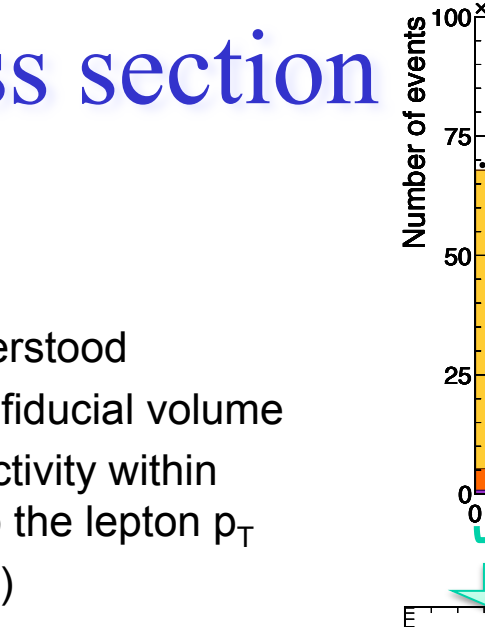
$$Q^2 = m^2_{W,Z} = x_1 x_2 s$$

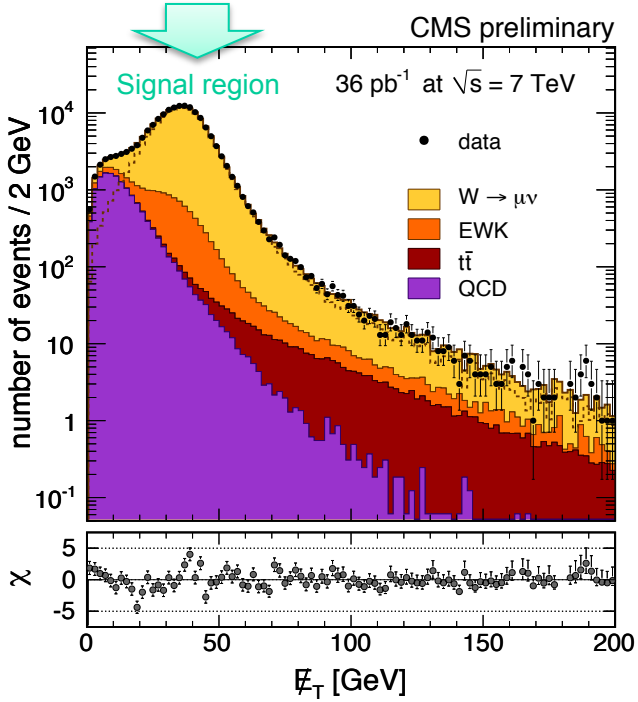
- Accurate theoretical predictions are available
- Differential distributions are sensitive to PDF
- EWK processes are also a tool for detector calibration and backgrounds to searches for Higgs and new physics

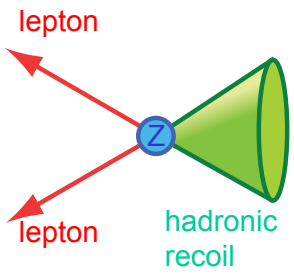


W→*lν* inc. cross section

- W event selection is based on:
  - Loose single-lepton trigger
  - Lepton identification cuts, well understood
  - Lepton p_T>25 GeV, η within trigger fiducial volume
  - Isolation: tracker and calorimeter activity within $\Delta R=\sqrt{(\Delta\varphi^2+\Delta\eta^2)}<0.3$, normalized to the lepton p_T
  - Di-lepton veto (no Drell-Yan events)
- Signal extraction
  - W yield from fit to missing E_T distribution
    - Parameterized shapes or fixed binned templates
  - QCD shape determined from data inverting lepton id / isolation selections
  - Lepton efficiencies from Z tag and probe as a function of p_T and η
  - Missing E_T studied using Z recoil
  - Momentum scale and resolution studied from $Z\to l^+l^-$ data







W^+ and W^- production

- Fit separately positive and negative lepton missing E_T spectra to extract $\sigma(W^+)$ and $\sigma(W^-)$
- Alternatively, fit simultaneously the total yield and ratio to extract $\sigma(W^\pm)$ and $\sigma(W^+)/\sigma(W^-)$
- In the ratio several uncertainties cancel

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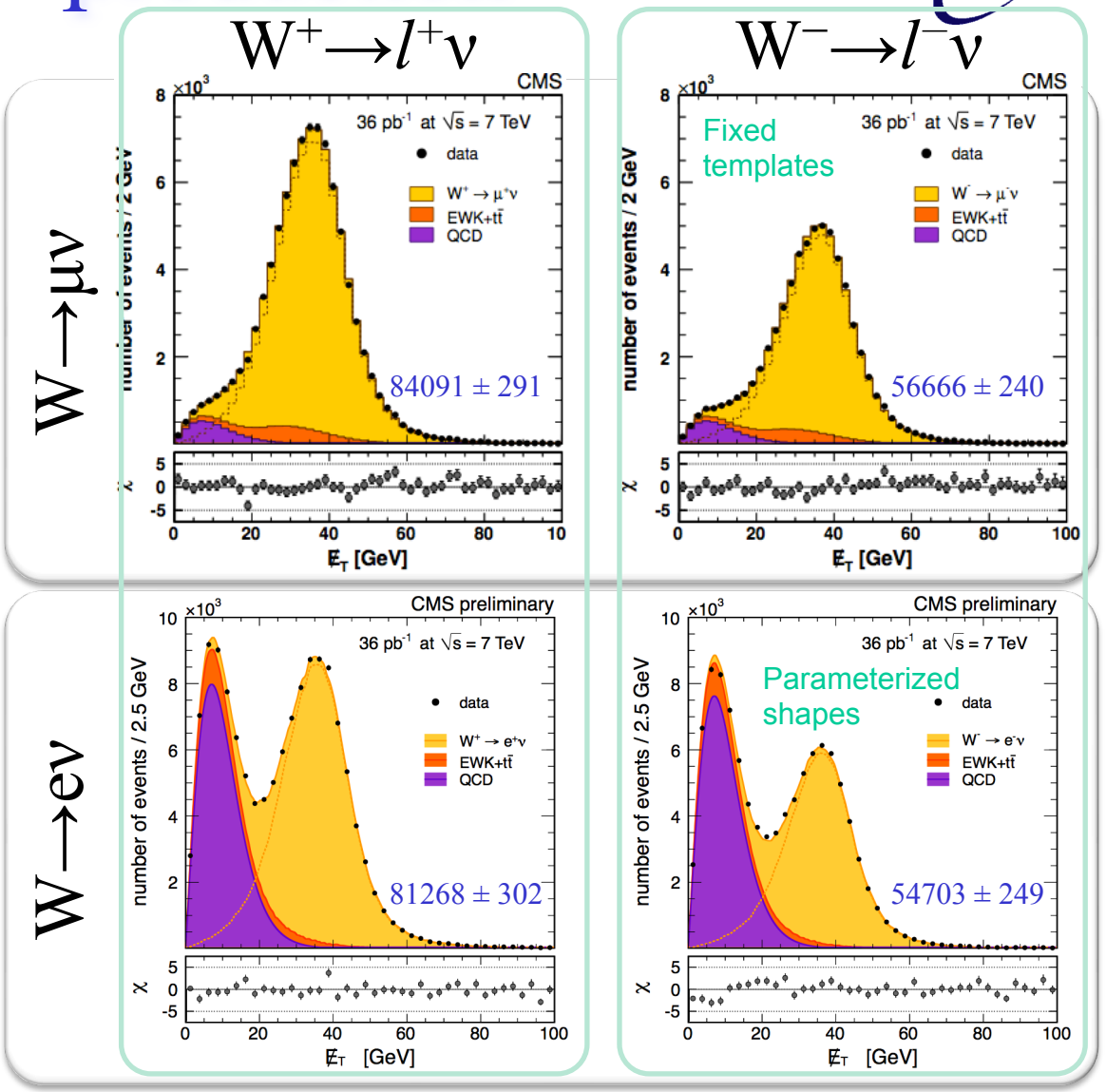
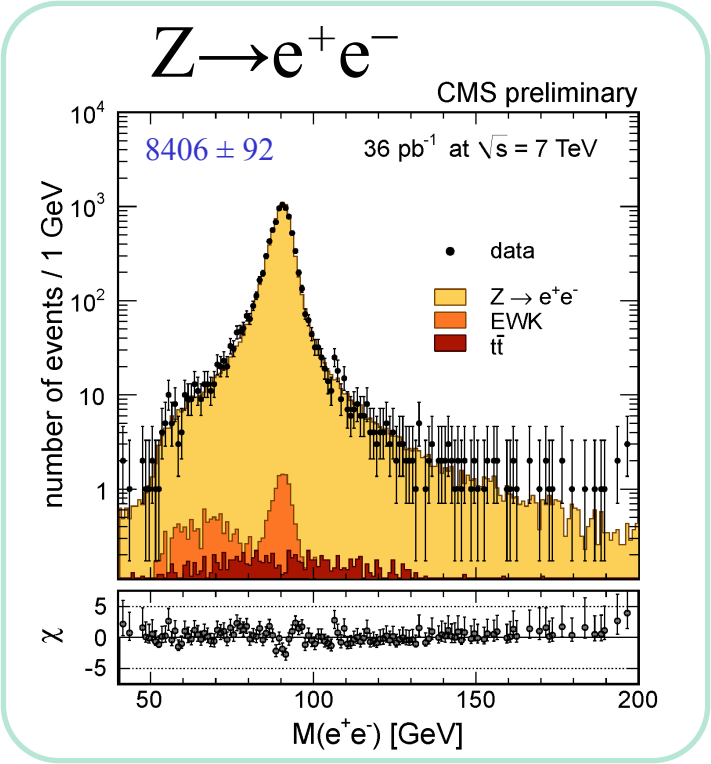
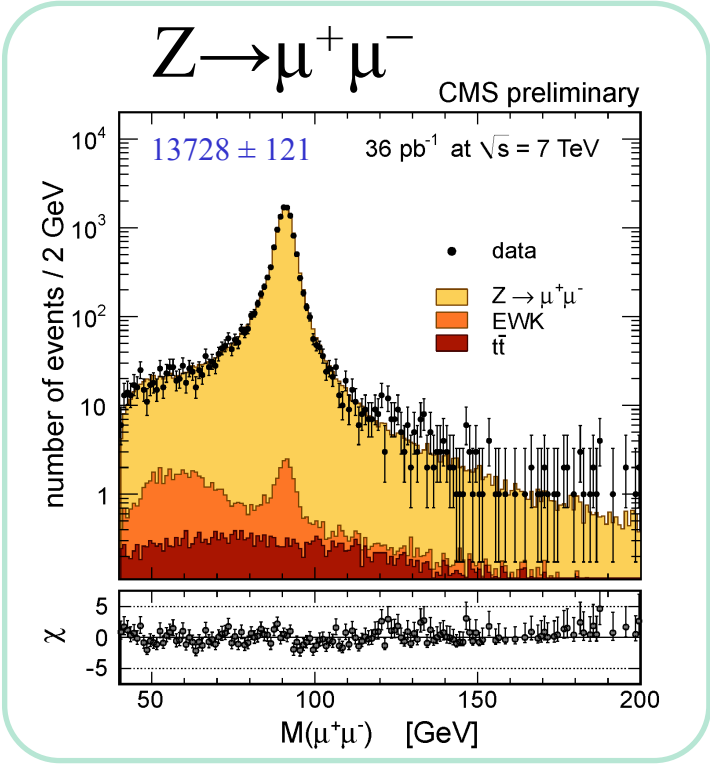


$Z \rightarrow ll$ analysis

- Isolated dilepton pairs with p_T>20 (μ), 25 GeV (e) and η within trigger fiducial region. Mass range: $60 < m_{ll} < 120$ GeV
- Fit simultaneously yield and efficiencies using different dilepton categories (μμ)
- Cut and count analysis using tag & probe efficiencies (ee)





Systematic uncertainties

- Data-driven methods to determine efficiencies, background and signal shapes allow to reduce experimental uncertainties

$$\sigma \times \mathcal{B} = \frac{N}{A \times \varepsilon \times \mathcal{L}}$$

$$\rho = \frac{\varepsilon_{\text{data}}}{\varepsilon_{\text{sim}}}$$

Uncert. propagated from Z T&P to W p_T/η spectrum

Lumi. uncert.: 4%

CMS-DP-2011-002

Source	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	1.3	0.9	1.8	n/a
Trigger prefiring	n/a	0.5	n/a	0.5
Energy/momentum scale & resolution	0.5	0.22	0.12	0.35
$\not{E}_T$ scale & resolution	0.3	0.2	n/a	n/a
Background subtraction / modeling	0.35	0.4	0.14	0.28
Trigger changes throughout 2010	n/a	n/a	n/a	0.1
Total experimental	1.5	1.1	1.8	0.7
PDF uncertainty for acceptance	0.6	0.8	0.9	1.1
Other theoretical uncertainties	0.7	0.8	1.4	1.6
Total theoretical	0.9	1.1	1.6	1.9
Total (excluding luminosity)	1.7	1.6	2.4	2.0

Theory uncertainties affect acceptance determination:

PDF (PDF4LHC: CTEQ, MSTW, NNPDF), Initial-state radiation modeling, higher order effects (RESBOS), EWK corrections, Final-state radiation (HORACE), factorization and renormalization scale (FEWZ)

$Z \rightarrow \tau\tau$

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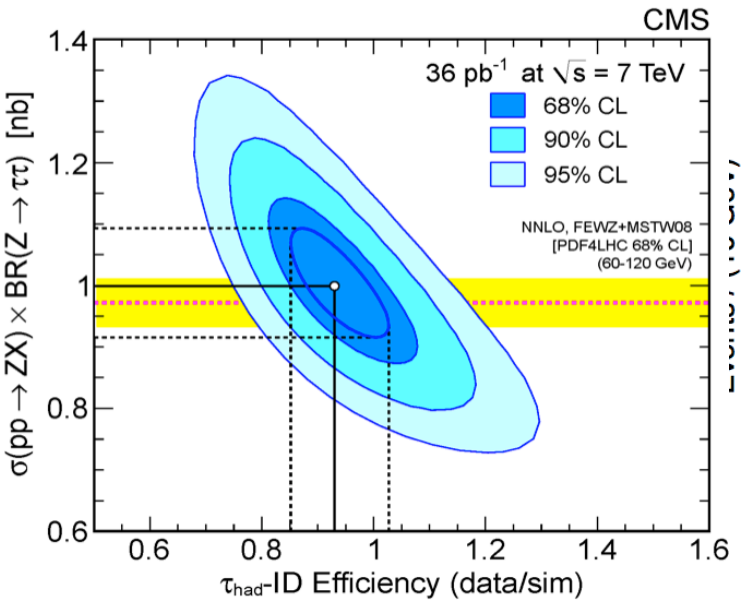
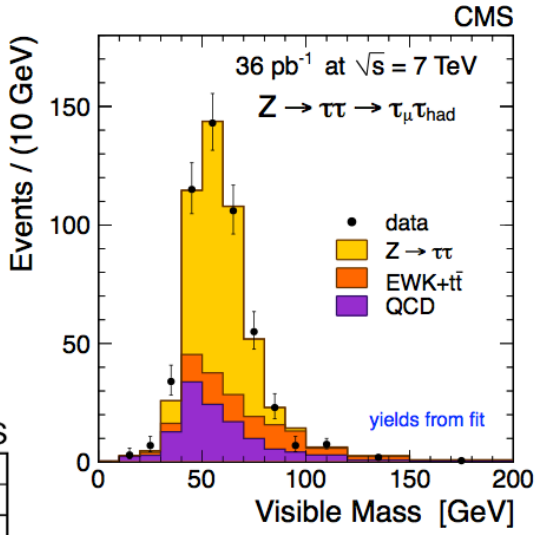
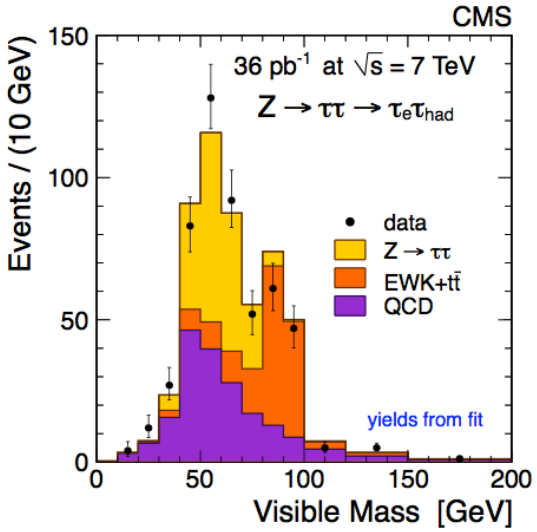
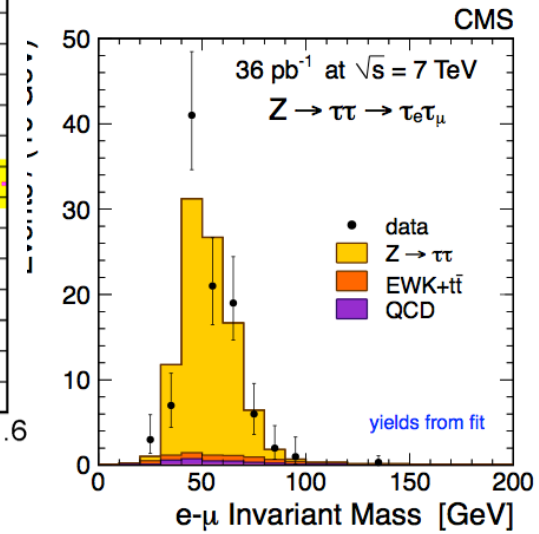
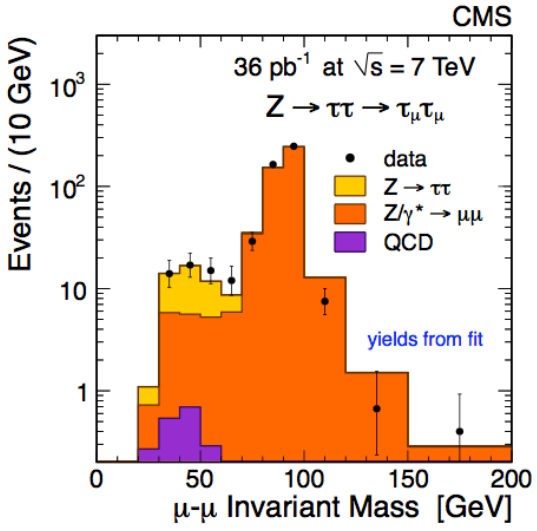
- Benchmark for searches using taus ($H^+ \rightarrow \tau\nu$, $H \rightarrow \tau\tau$, …)
- Particle Flow: combine tracker and calorimeter measurements to determine particle candidates
- Main systematic: tau id, fit from data







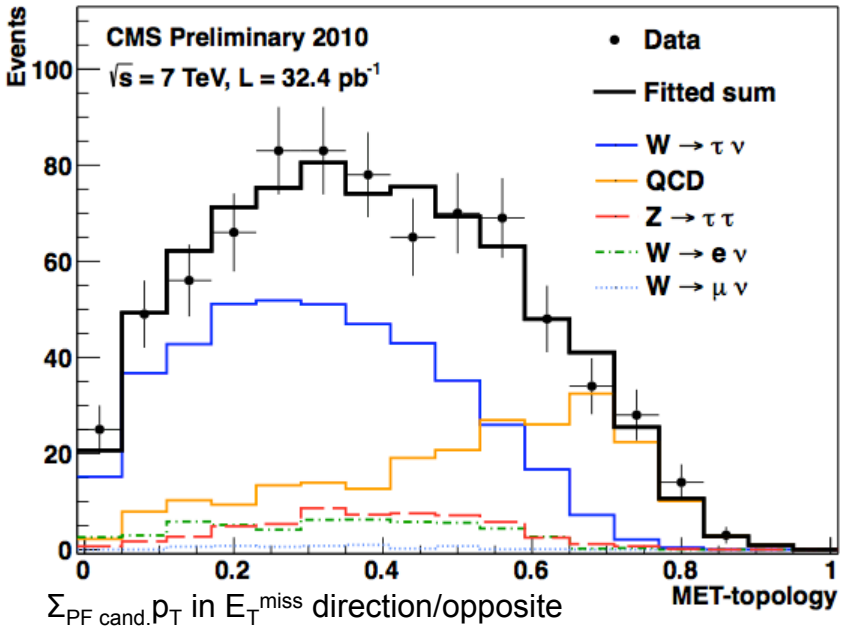




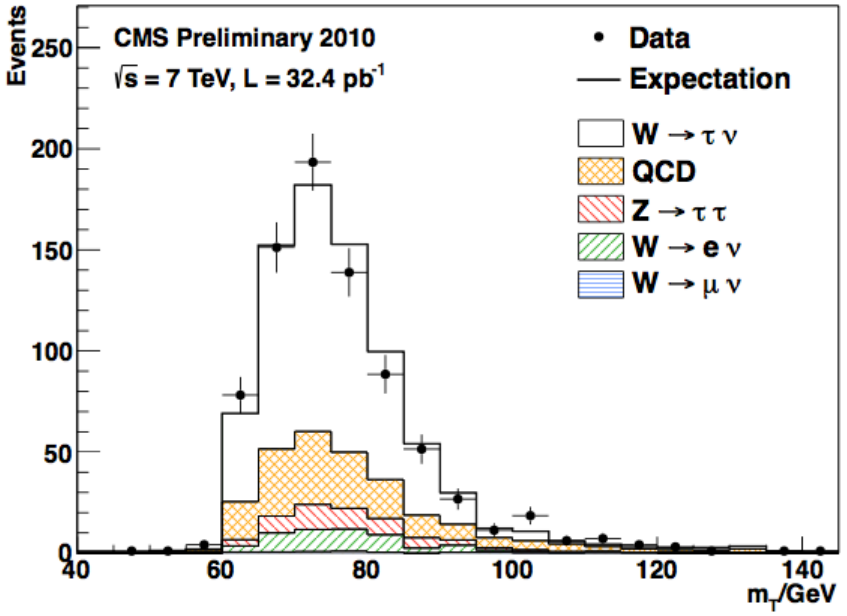
$W \rightarrow \tau\nu$

CMS-PAS-EWK-11-019

- One tau semi-hadronic decay, challenging trigger on tau plus missing E_T:
  - p_T (τ) > 20 GeV, p_T (track)>15 GeV, missing E_T >25 GeV
- 32.4 pb^{-1}, full 2010 data sample



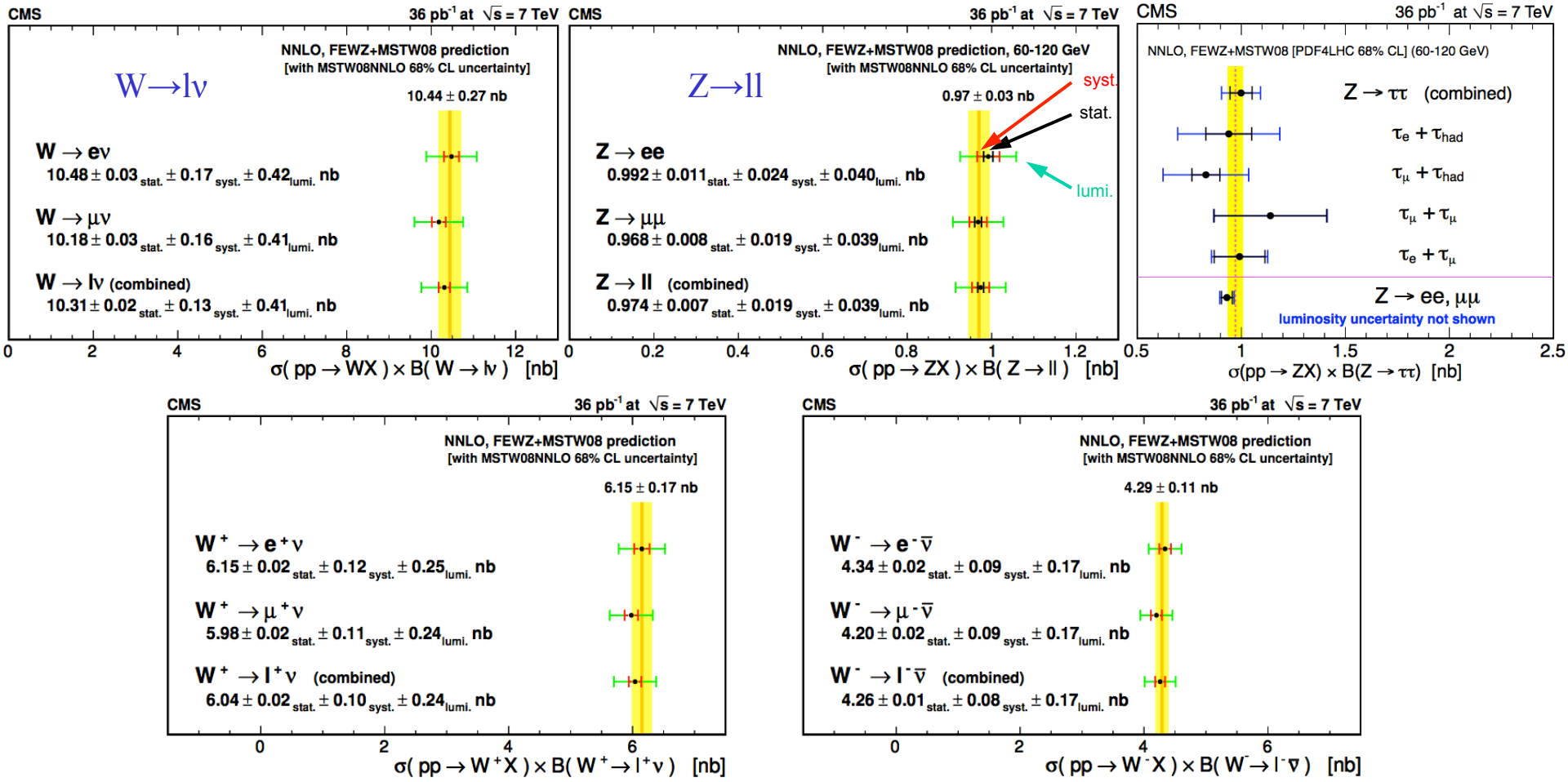
$\Sigma_{PF\ cand.} p_T$ in E_T^{miss} direction/opposite



Channel	$\sigma(pp \rightarrow WX) \times \mathcal{B}$ (nb)	NNLO (nb)
$W \rightarrow \tau\nu$	$8.96 \pm 0.51(\text{stat.})^{+2.31}_{-2.25}(\text{syst.}) \pm 0.36(\text{lumi.})$	10.44 ± 0.52
$W^+ \rightarrow \tau^+\nu$	$5.26 \pm 0.39(\text{stat.})^{+1.36}_{-1.28}(\text{syst.}) \pm 0.21(\text{lumi.})$	6.15 ± 0.29
$W^- \rightarrow \tau^-\nu$	$3.40 \pm 0.33(\text{stat.})^{+0.91}_{-0.93}(\text{syst.}) \pm 0.14(\text{lumi.})$	4.29 ± 0.23

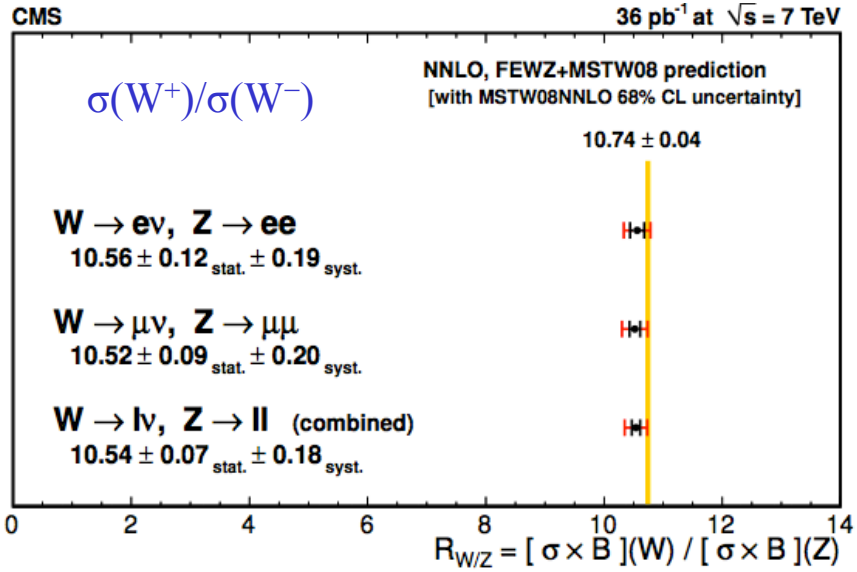
$$R_{+/-} = \frac{\sigma(pp \rightarrow WX) \times \mathcal{B}(W^+ \rightarrow \tau^+\nu)}{\sigma(pp \rightarrow WX) \times \mathcal{B}(W^- \rightarrow \tau^-\nu)} = 1.55 \pm 0.19(\text{stat.})^{+0.11}_{-0.13}(\text{syst.})$$

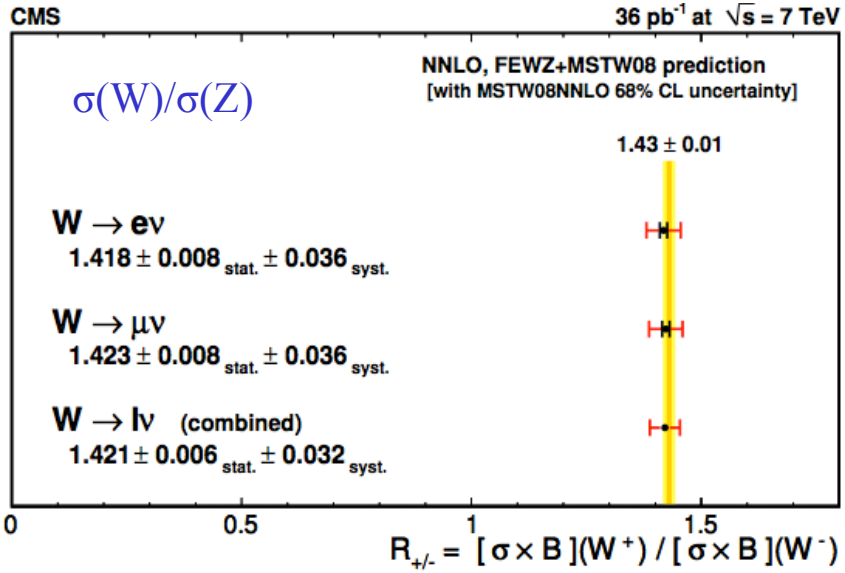
Comparison with theory



- Good agreement with theoretical predictions
- Systematic uncertainty dominates

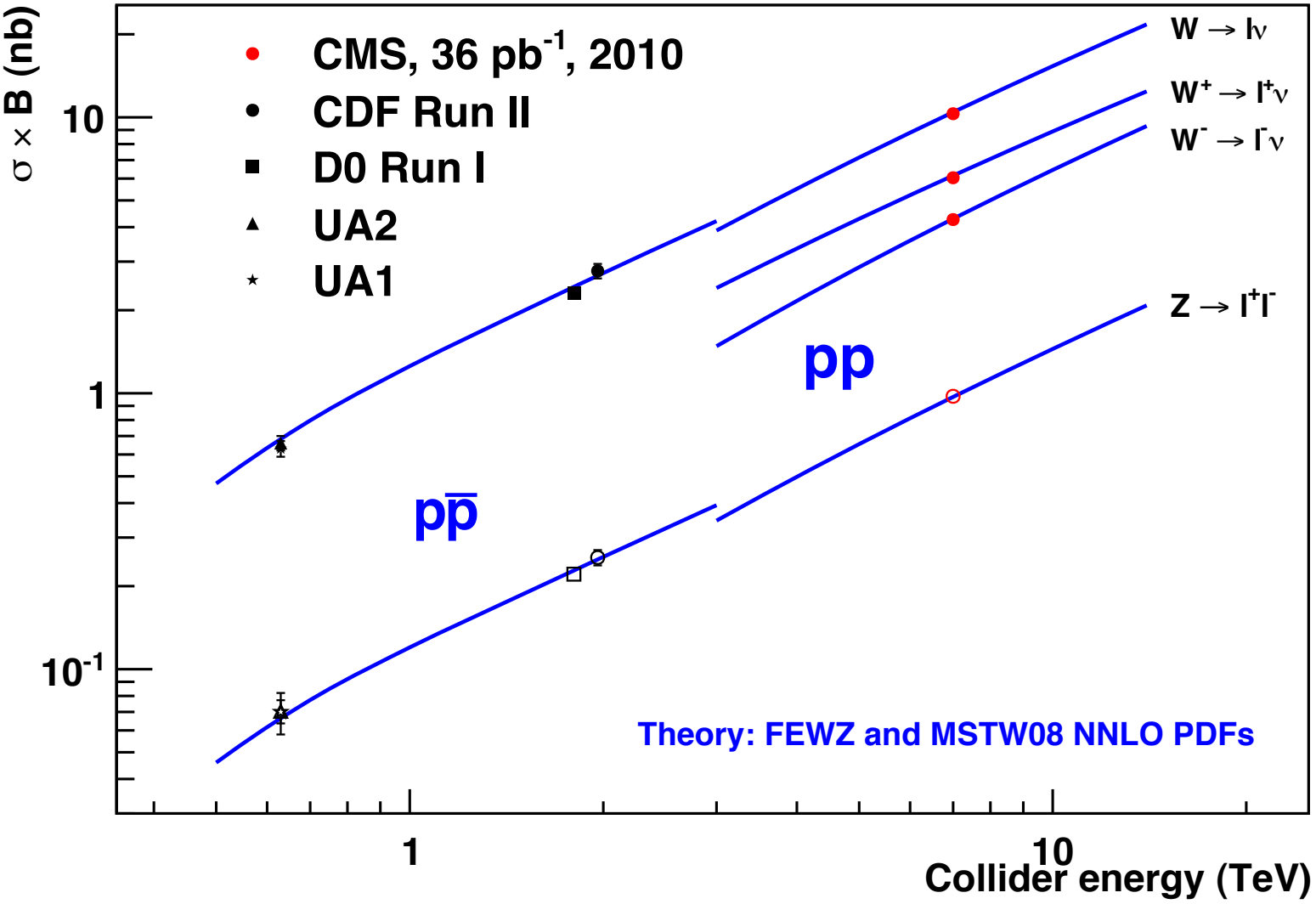
Comparison with theory





- Ratios are not affected by luminosity uncertainty
- W^+/W^- potentially sensitive to PDF, W/Z has precise prediction

Comparison with theory



W charge asymmetry

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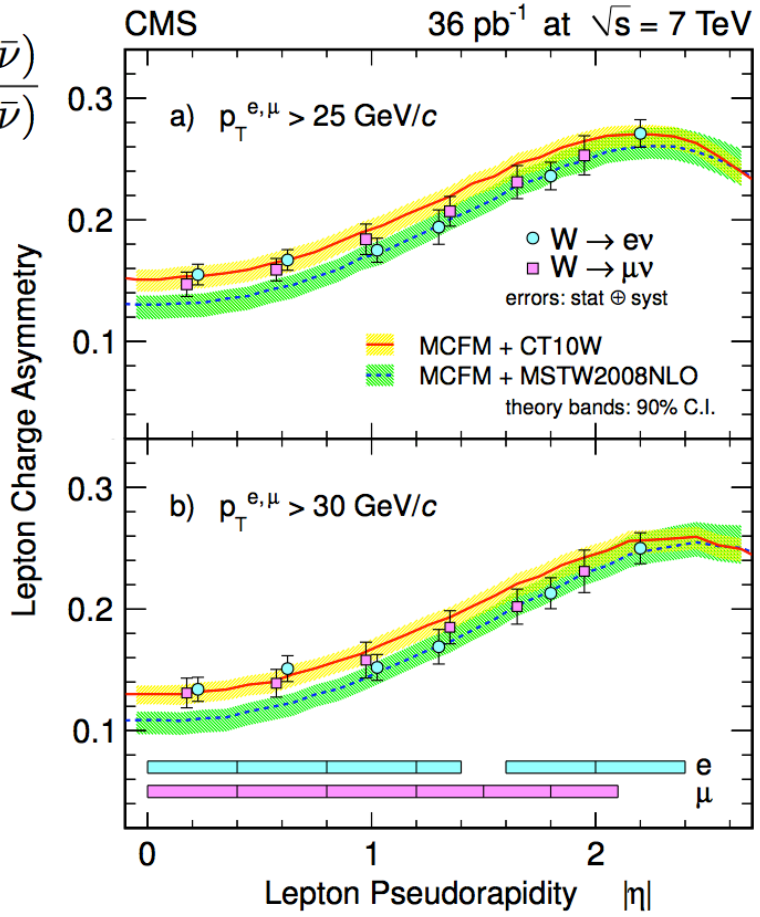
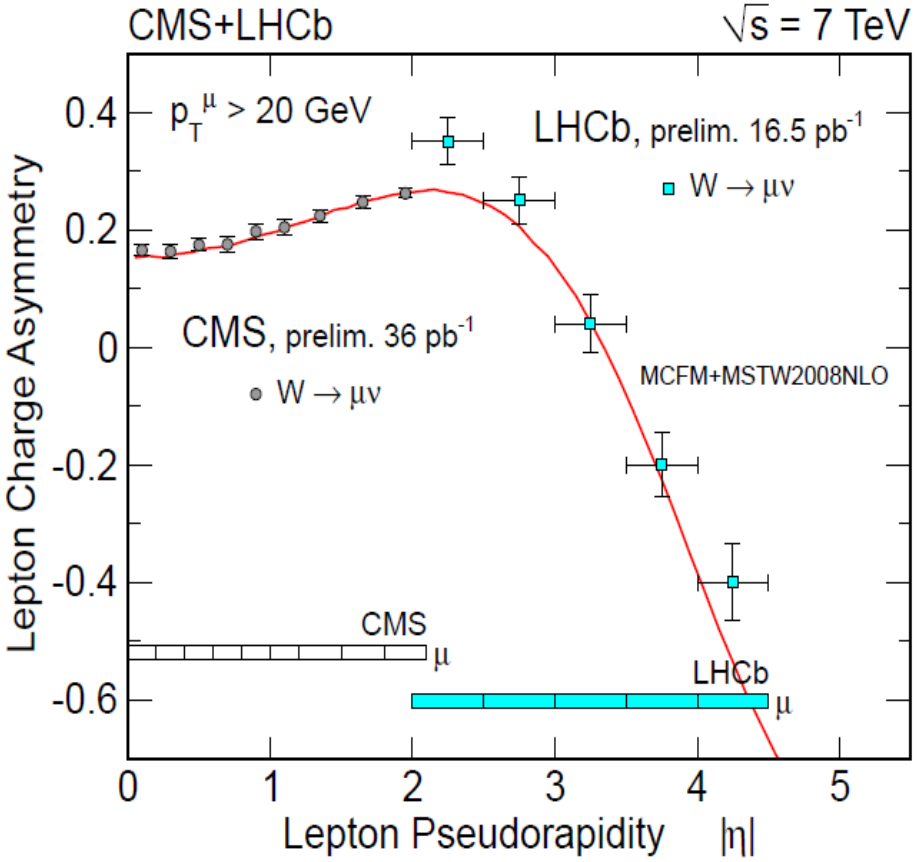
- W^+/W^- ratio measured as a function of the lepton pseudorapidity η
- Sensitive to PDF; several uncertainties cancel in the ratio

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

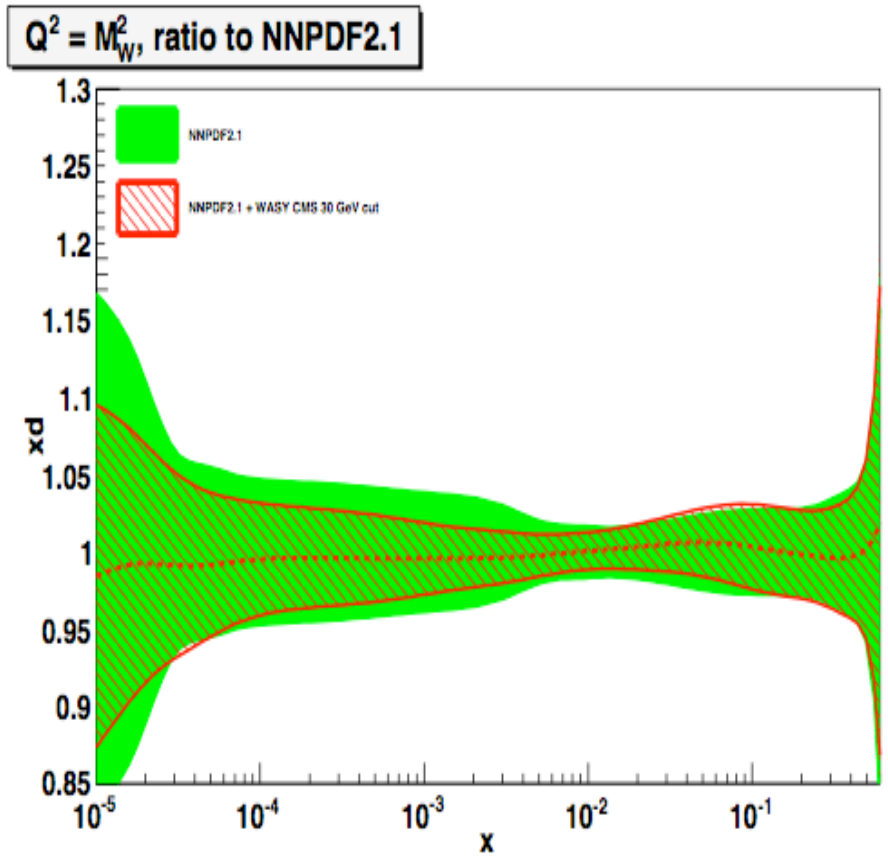
- Similar selection to inclusive cross section analysis
- Two p_T thresholds (25, 30 GeV) to probe different phase space regions
- Charge mis-id: 0.1(barrel)-0.4(endcap)% for electrons, $<10^{-4}$ for muons
- Statistical uncertainty: ~3%
- Systematic uncertainties (~3%), limited by the size of Drell-Yan control samples
  - Separate efficiency estimates for + and − leptons
  - p_T scale and resolution
  - Background and signal modeling



CMS ad LHCb measurements



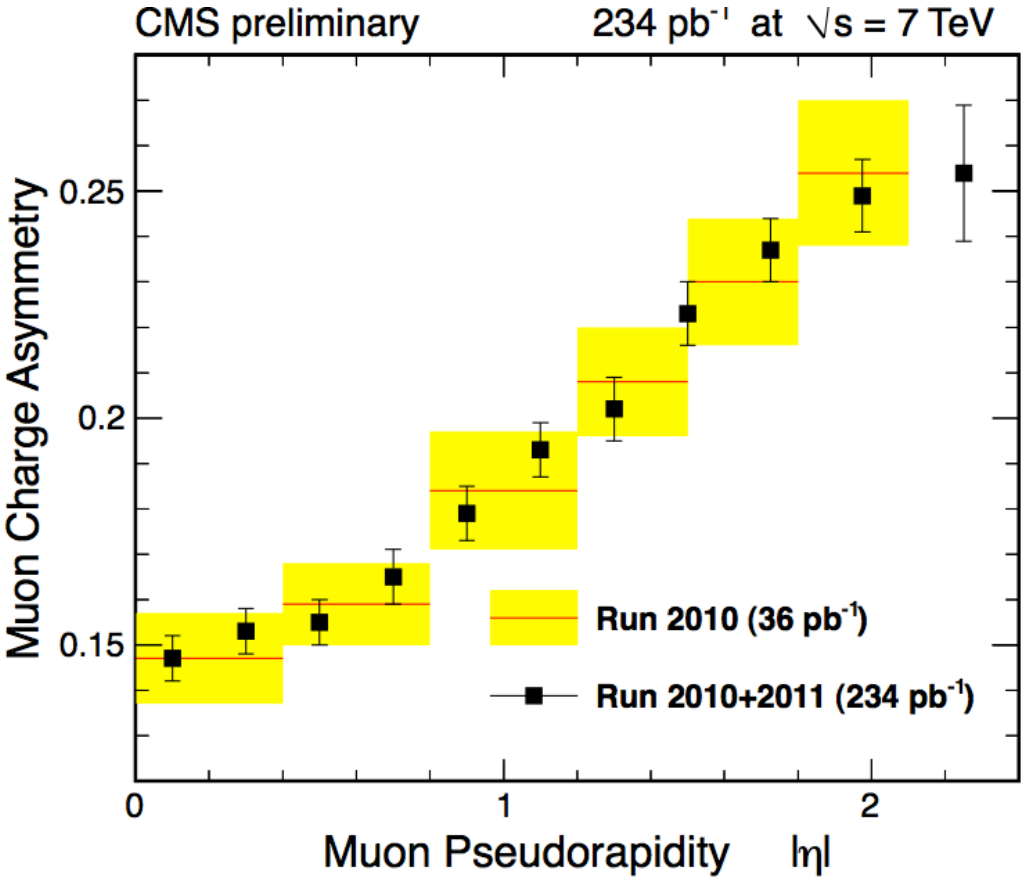
CMS complementary w.r.t. LHCb



CMS results already improve d,u,d,u,s quark PDFs by >40% in the range $10^{-3} < x < 10^{-2}$

Update with 234 pb^{-1} (muons)

- Improved uncertainties with larger statistics and control samples

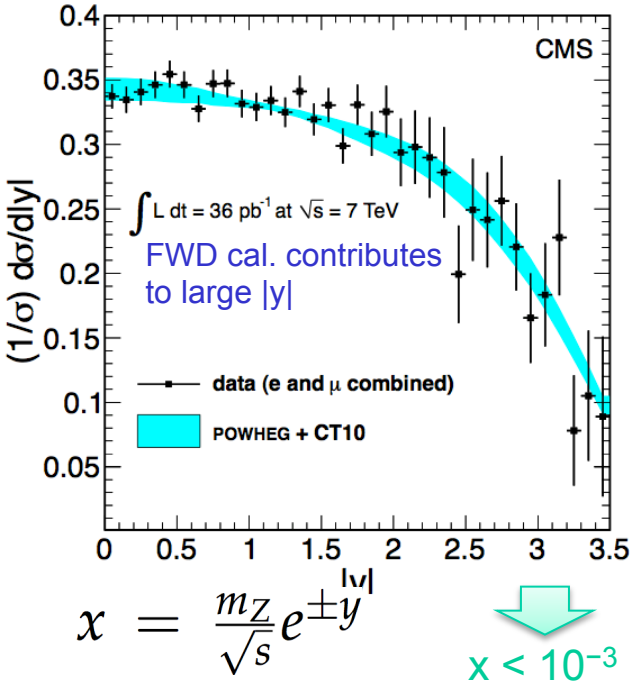


$\lvert\eta\rvert$ bin	$\mathcal{A} \pm \text{stat} \pm \text{sys}$
[0.00, 0.20]	14.7±0.32±0.41
[0.20, 0.40]	15.3±0.33±0.43
[0.40, 0.60]	15.5±0.32±0.44
[0.60, 0.80]	16.5±0.32±0.46
[0.80, 1.00]	17.9±0.34±0.50
[1.00, 1.20]	19.3±0.34±0.54
[1.20, 1.40]	20.2±0.33±0.58
[1.40, 1.60]	22.3±0.34±0.63
[1.60, 1.85]	23.7±0.31±0.64
[1.85, 2.10]	24.9±0.32±0.70
[2.10, 2.40]	25.4±0.35±1.50

CMS PAS EWK-11-005

Z differential cross section

- Large statistics allows to study differential cross sections vs y and p_T
- compared to theory after an unfolding procedure correcting for resolution and final-state radiation

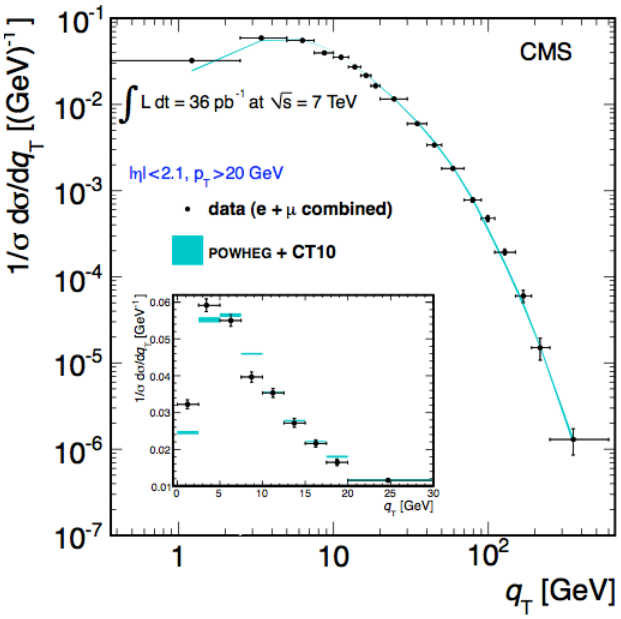


$$x = \frac{m_Z}{\sqrt{s}} e^{\pm y}$$

$x < 10^{-3}$

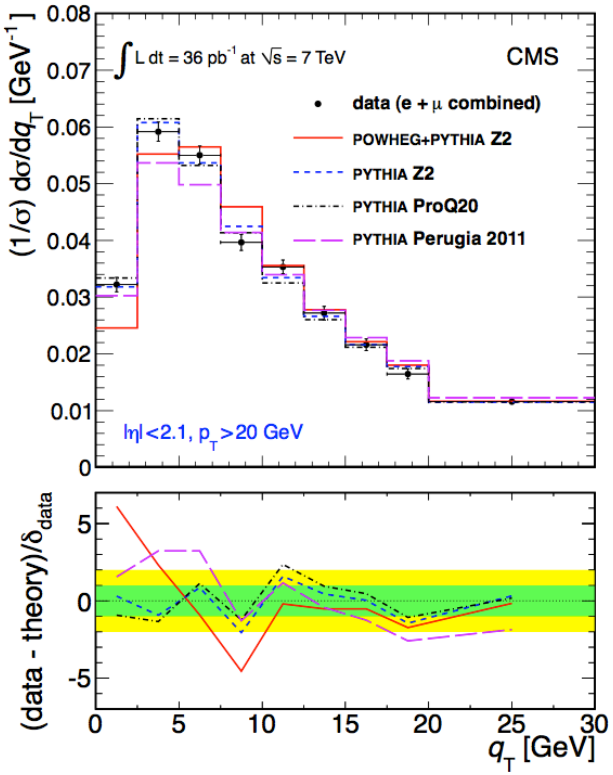
Sensitive to PDF at low x

CMS-PAS-EWK-10-010
arXiv:1110.4973,
sub. to PRD



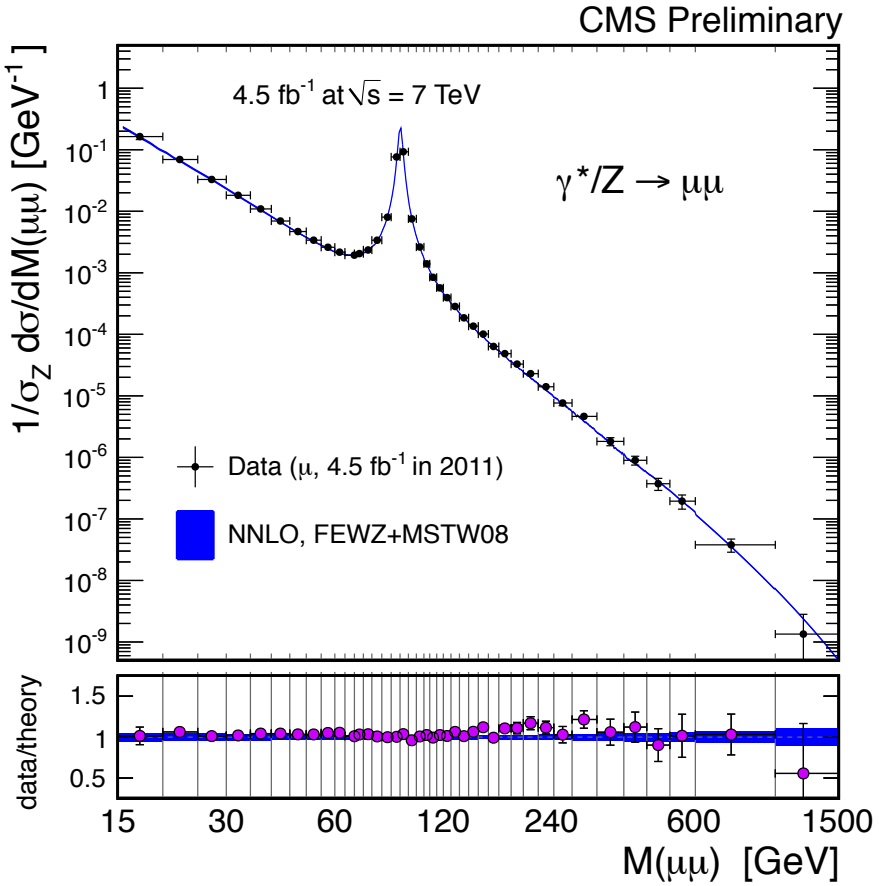
Good agreement with FEWZ prediction (NNLO) at high p_T
Perturbative contributions dominate

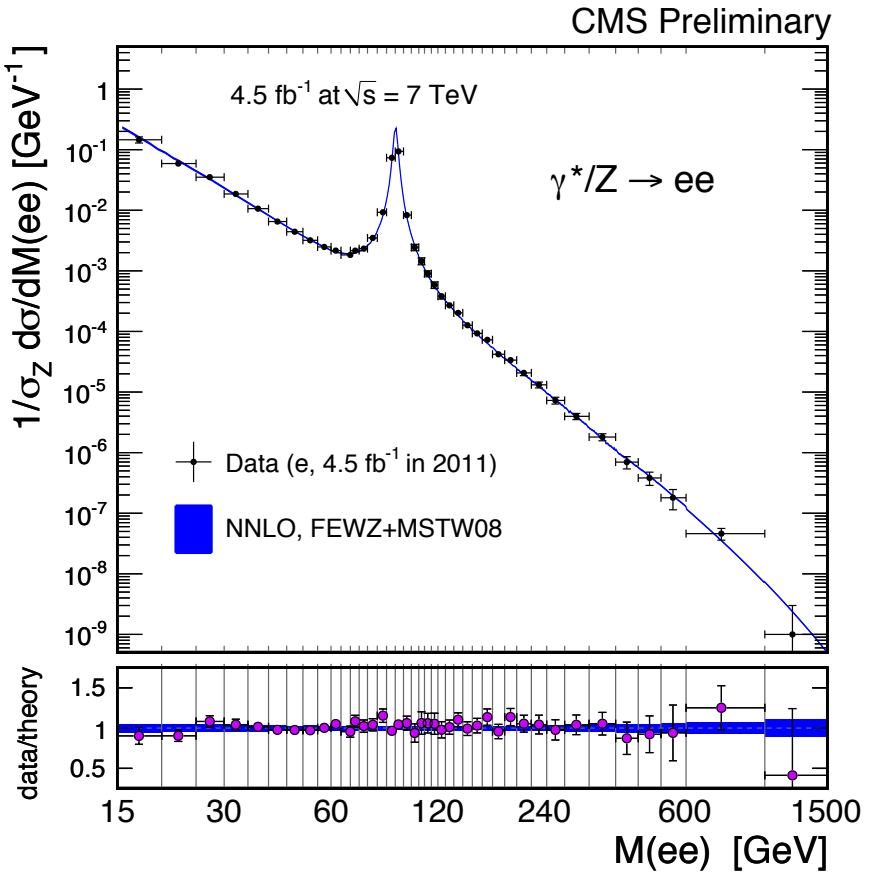
FSR unfolded, not included in FEWZ



Agreement at low p_T requires PYTHIA tuning
Non-perturbative contributions

Drell-Yan spectrum (μμ, ee)

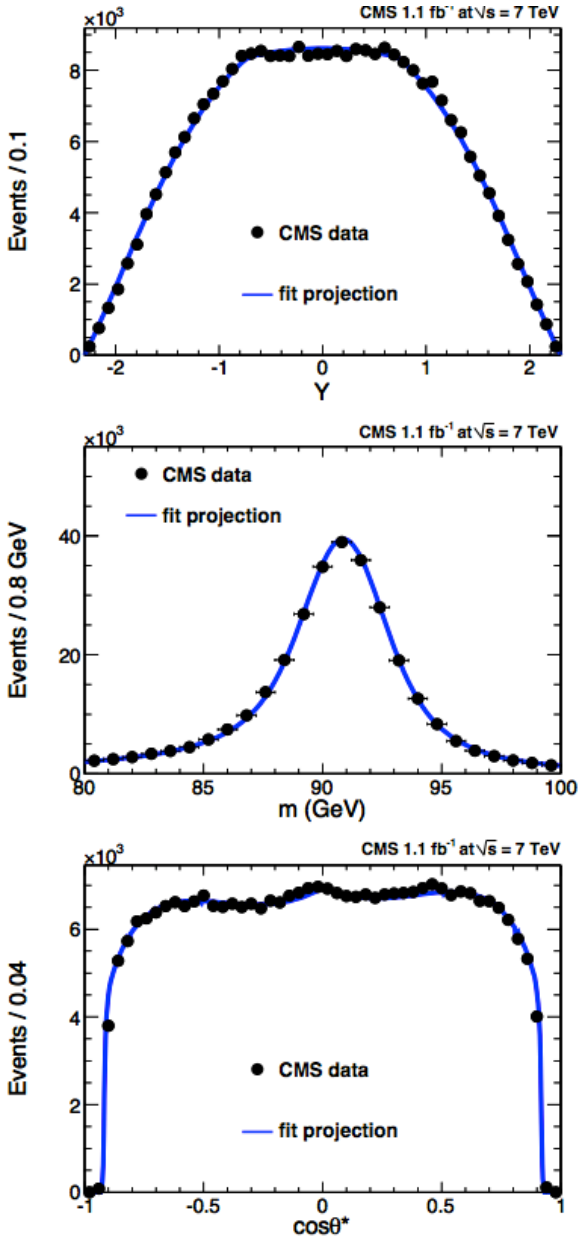




CMS-PAS-EWK-11-007

Unfolded distribution, corrected for acceptance, efficiency and FSR effects (not included in FEWZ)

$\sin^2\theta_W$ (updated with 1.1 fb^{-1})



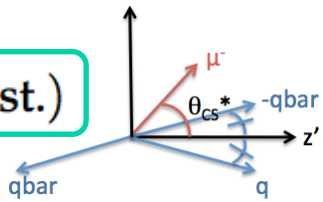
- FB asymmetry allows a measurement of the Weinberg angle
- More precise measurement also using Y and m of the dimuon pair distributions
- Collins-Soper frame adopted[*]

$$\frac{d\sigma}{d\cos\theta} = \frac{3}{8}(1+\cos^2\theta) + A_{FB}\cos\theta$$

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

PRD84(2011)112002

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



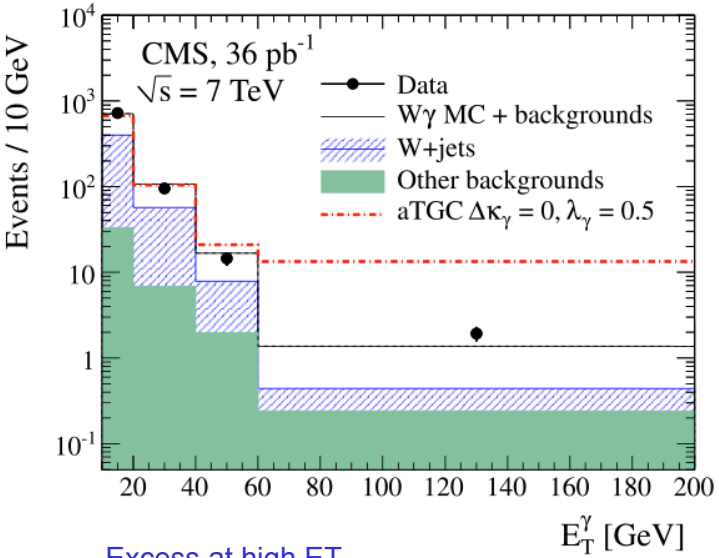
[*] CS frame: Z rest frame in which the z axis bisects p_1, $-p_2$, p_1 and p_2 being the incoming quark and anti-quark momenta

Dibosons

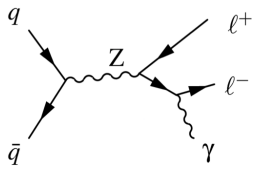
W, Z + γ

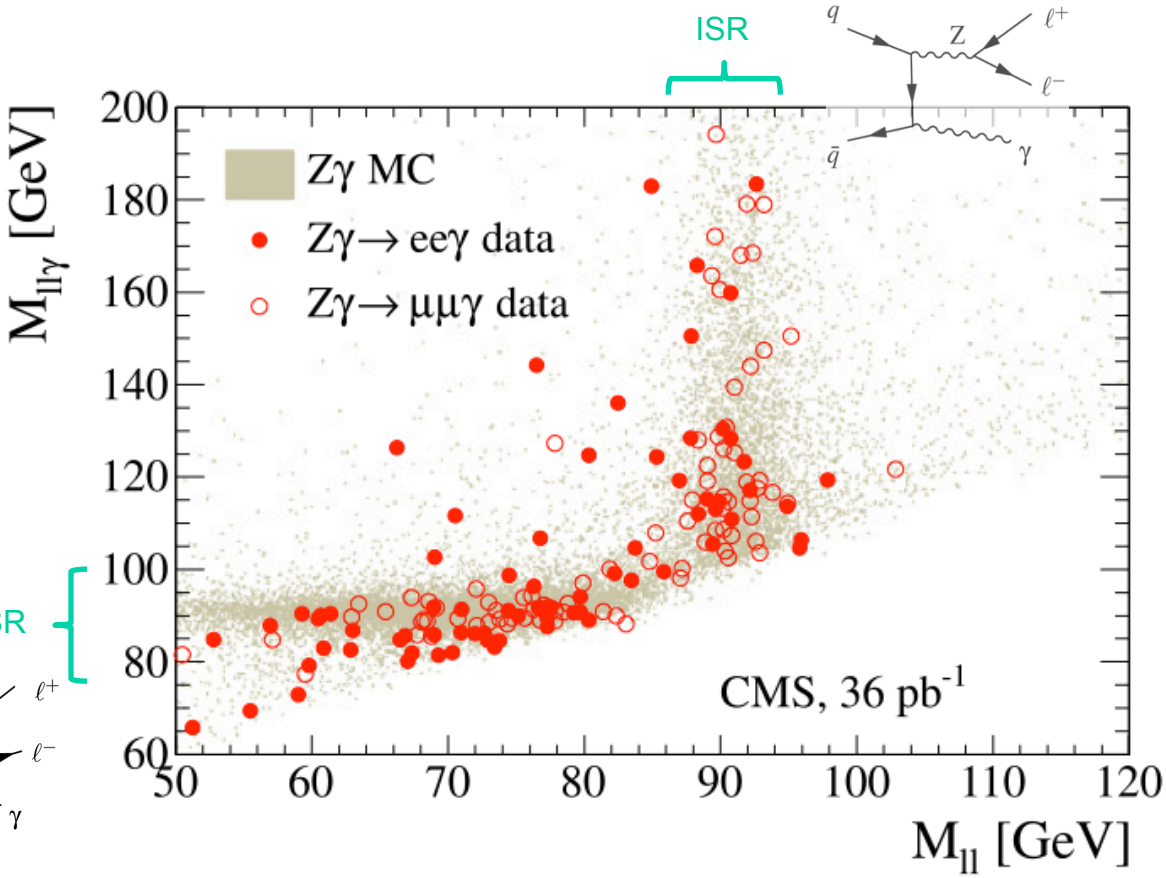
PLB701 (2011) 535

- Final state common to new physics searches, probes triple gauge coupling
- Fake photon estimate is a key task, performed with data-driven methods



Excess at high ET
with anomalous TGC



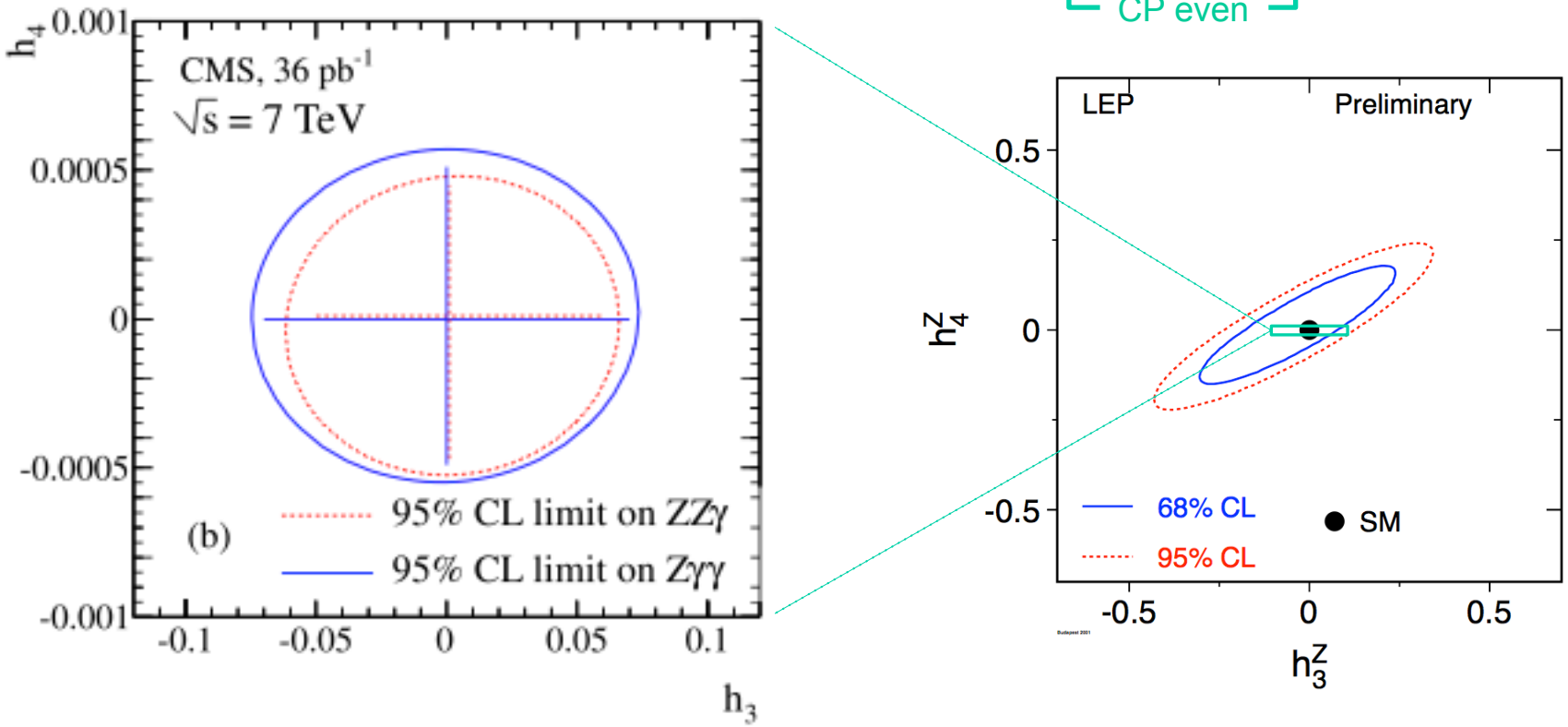


TGC limits

- Competitive with LEP and Tevatron limits

$$\Gamma^{\alpha\beta\mu}_{ZZ\gamma} = \frac{P^2 - q_1^2}{m_Z^2}\left(h_1^Z(q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta}) + \frac{h_2^Z}{m_Z^2}P^\alpha[(P\cdot q_2)g^{\mu\beta} - q_2^\mu P^\beta] + h_3^Z \epsilon^{\mu\alpha\beta\rho} q_{2\rho} + \frac{h_4^Z}{m_Z^2} P^\alpha \epsilon^{\mu\beta\rho\sigma} P_\rho q_{2\sigma}\right)$$

CP even

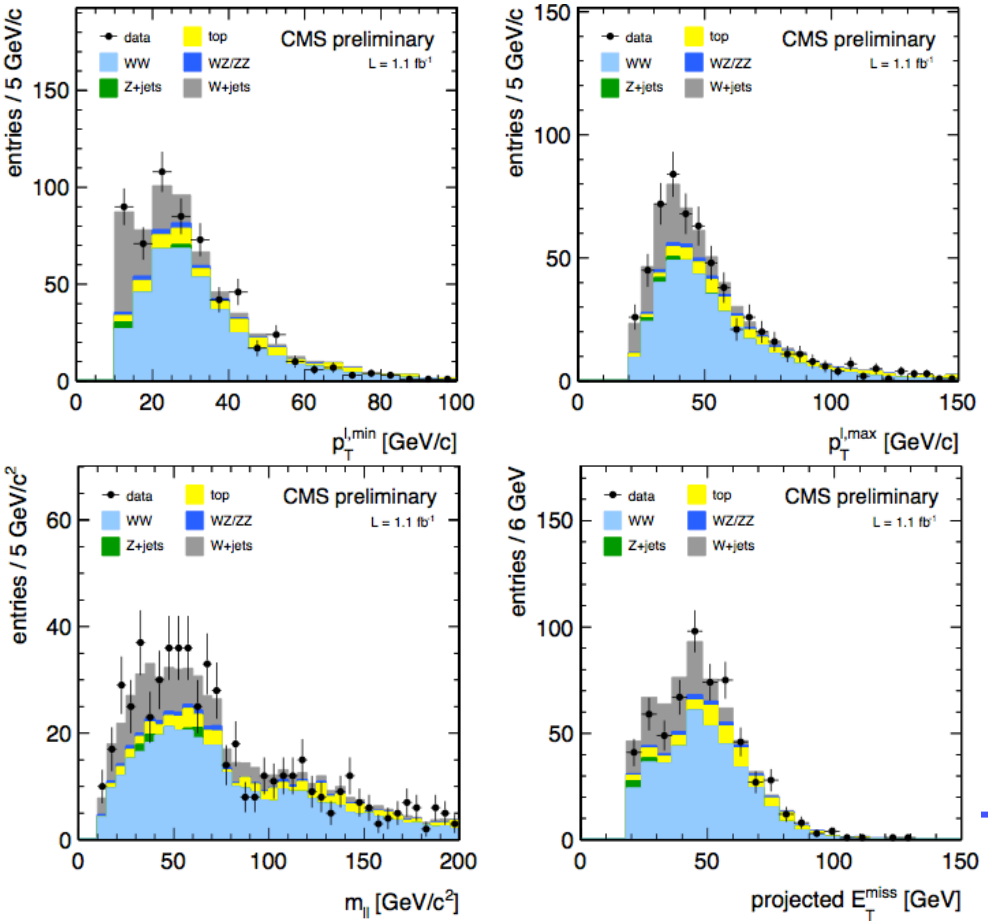


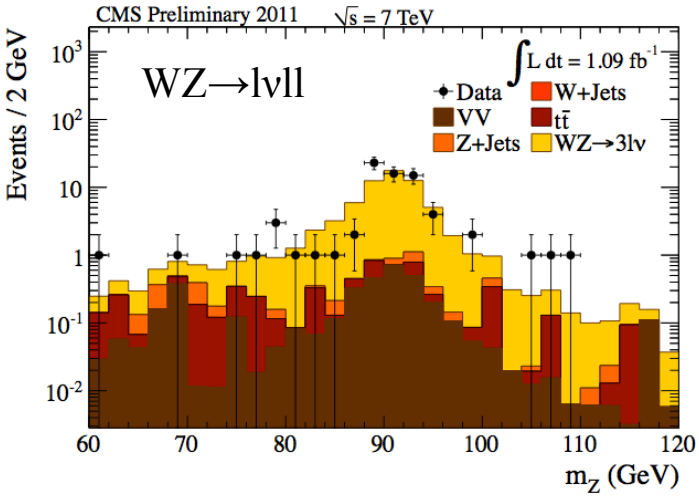
Dibosons: WW, WZ, ZZ

- Important test of the SM non-abelian structure; benchmark for Higgs search
- Measured production cross sections of W^+W^-, WZ, ZZ using leptonic decay modes ($1.1fb^{-1}$)

$$\sigma(pp \to W^+W^- + X) = 55.3 \pm 3.3\ (\text{stat.}) \pm 6.9\ (\text{syst.}) \pm 3.3\ (\text{lumi.})\ \text{pb}.$$
$$\sigma(pp \to WZ + X) = 17.0 \pm 2.4\ (\text{stat.}) \pm 1.1\ (\text{syst.}) \pm 1.0\ (\text{lumi.})\ \text{pb}.$$
$$\sigma(pp \to ZZ + X) = 3.8^{+1.5}_{-1.2}\ (\text{stat.}) \pm 0.2\ (\text{syst.}) \pm 0.2\ (\text{lumi.})\ \text{pb}.$$

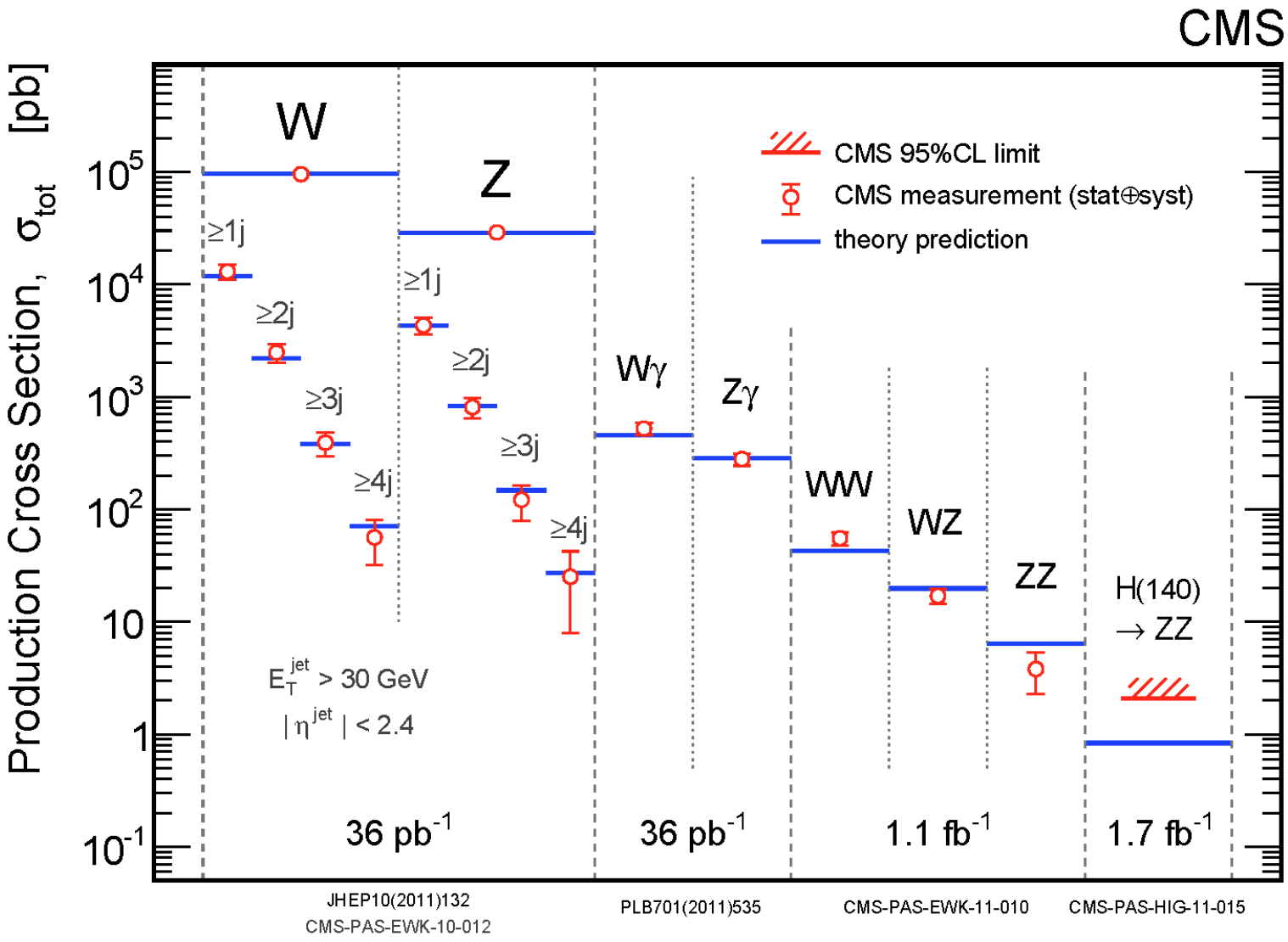
WW→lνlν





CMS PAS EWK-11-010

Summary


CMS
Production Cross Section, σ_{tot} [pb]
10^5
10^4
10^3
10^2
10
1
10^{-1}
W
Z
≥1j
≥2j
≥3j
≥4j
≥1j
≥2j
≥3j
≥4j
Wγ
Zγ
WW
WZ
ZZ
H(140)
→ ZZ
CMS 95%CL limit
CMS measurement (stat⊕syst)
theory prediction
E_T^{jet} > 30 GeV
$|\eta^{jet}| < 2.4$
36 pb^{-1}
36 pb^{-1}
1.1 fb^{-1}
1.7 fb^{-1}
JHEP10(2011)132
CMS-PAS-EWK-10-012
PLB701(2011)535
CMS-PAS-EWK-11-010
CMS-PAS-HIG-11-015

Conclusions

- CMS produced many EWK measurements with the first 36 pb^{-1} of LHC data at 7 TeV
- Several updates are available with 2011 data

- All measurements are so far in agreement with theoretical predictions from the standard model