GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

ElectroWeak Physics at CMS

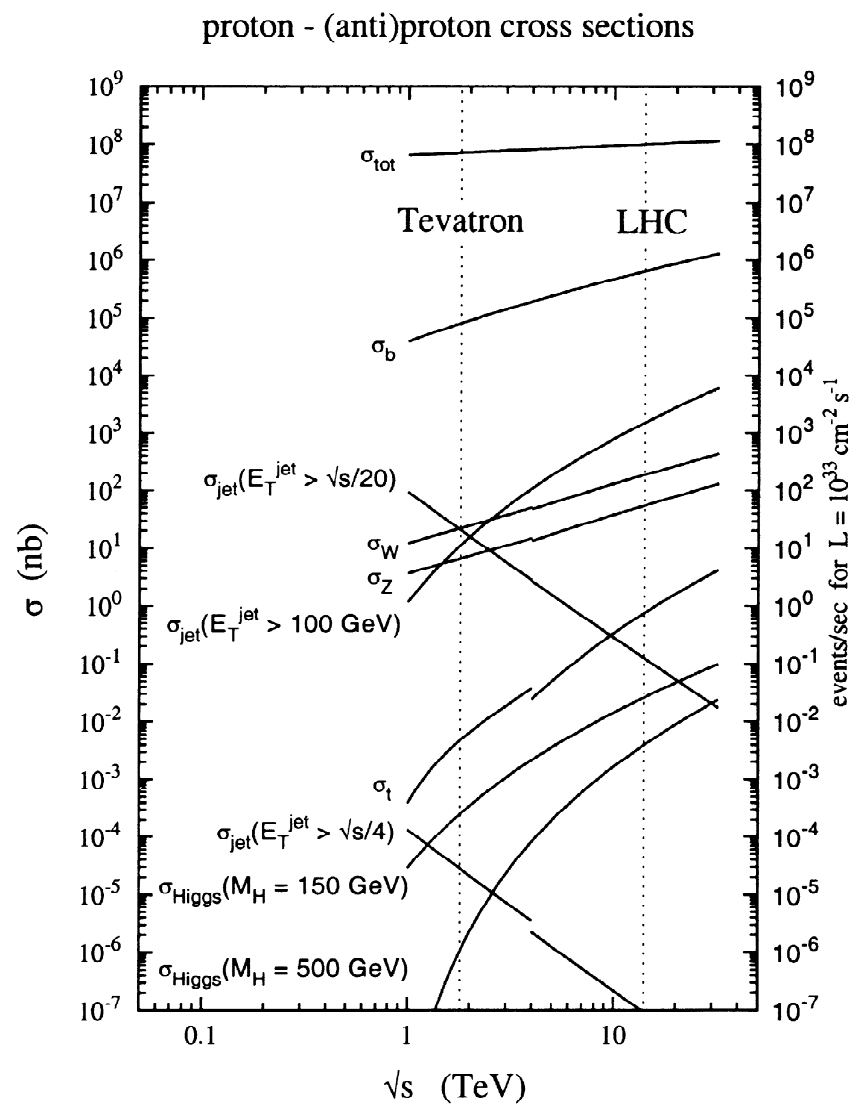
María Cepeda (CIEMAT, Madrid)

Valencia, II CPAN days

ElectroWeak Physics at the LHC

- Studies of **W and Z bosons** in the early phase of the LHC will allow to
  - Measure the first ElectroWeak observables at the LHC
  - Understand the building blocks for future analysis (leptons, met, jets)
  - Test perturbative QCD predictions and PDFs in pp Collisions at the TeV scale
  - Improve our measurements of Luminosity

- W and Z are characterized by their **high production rates** and **clean and simple experimental signatures in their leptonic decay channels** :
  - **W: High pt, isolated lepton + high Missing Transverse Energy (ME_T)**
  - **Z: 2 high pt isolated leptons**

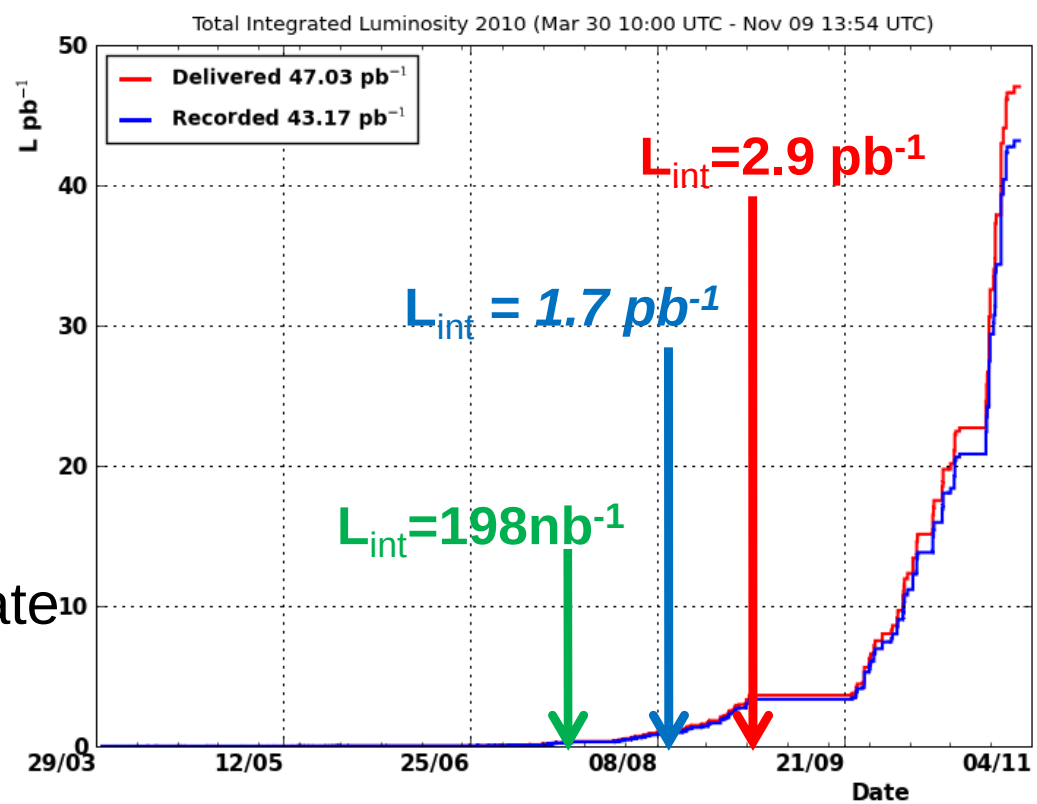


First ElectroWeak measurements in CMS

$W^{\pm} \rightarrow l^{\pm}\nu$ and $Z/\gamma^{*} \rightarrow l^{+}l^{-}$ (l = μ , e)

- L_{int}=198nb^{-1}
  - W and Z cross-sections and ratios
  - W charge assymetry
  - Z Forward Backward asymmetry
  - W+Jets production

- Full cross-section analysis public for L_{int}=2.9 pb^{-1} (to be published soon)
- W/Z distributions with the full 2010 dataset (L_{int}=35 pb^{-1})



$Z \rightarrow \tau^{+}\tau$

- **First distributions with**

L_{int} = *1.7 pb^{-1}*

Dibosons

- First Observation of a ZZ Candidate

$L_{int} = 2.9\ pb^{-1}$

W and Z Cross-Section at 7 TeV (Muons and Electrons)

- Lepton & MET reconstruction
- Z and W Selection
- Systematic Uncertainties
- Results

Muon Reconstruction and Identification

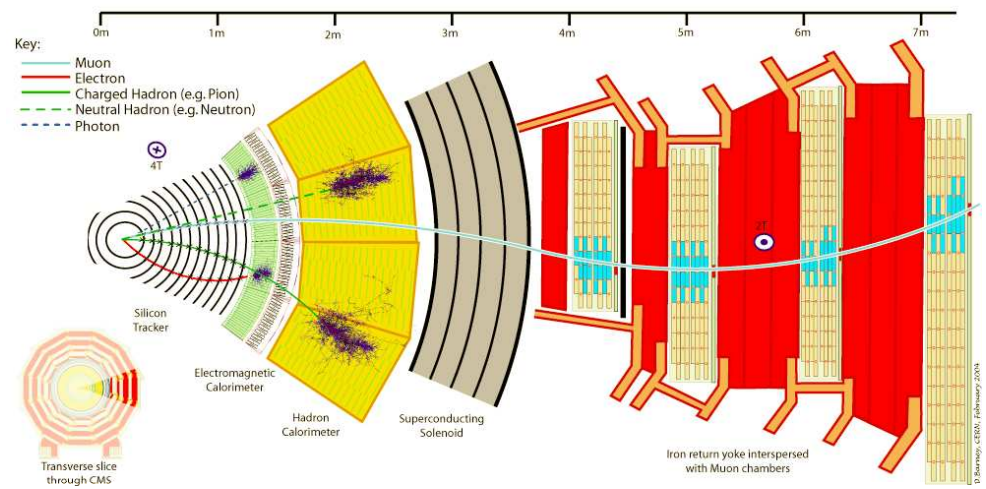
- Events recorded online using Level-1 Muon trigger and High Level Trigger (p_T> 9 GeV, |η|<2.4)

- **Muon Identification**: Consistency between **tracker detector and muon system measurments**:
  - Muon reconstructed by two algorithms (in-out, out-in)
  - Good quality of Global fit (muon+tracker)
- **Precise measurement of momentum** ($\sigma(\Delta p_T/p_T)$<1%) ensured requiring a minimal amount of tracker hits, and at least one in the innermost detector

- Minimal detector activity in tracker and calorimeters around the muon

  Isolation = $(\Sigma p_T\,(tk) + \Sigma E_T\,(had+em))/p_T$< 15%

- **Cosmic contamination** suppressed through requirements on the impact parameter



Muon efficiencies (Reconstruction, ID, trigger , Isolation)
estimated with clean ZMuMu samples (tight selection criteria on one of the legs, probe the efficiency on the other muon)

→ ε_μ **=82.8 ± 1.0 %**

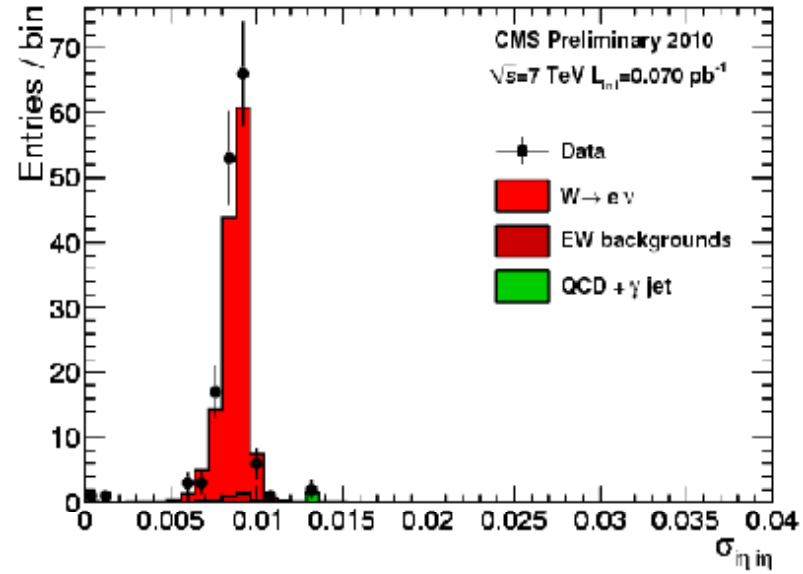
Electron Reconstruction and Identification

- Events required to pass Level-1 and High Level Trigger requirements , with a cluster in the e.m. calorimeter E_T>15 GeV in |η| < 1.4442 or 1.566< |η| <2.5

- **Electron ID** requirements:
  - Clusters of ECAL deposits matched to tracks in the inner detector , taking into account bremsstrahlung
  - Good matching (track, cluster) in η and φ
  - ElectroMagnetic shower shape characteristics (limited leakage in the hadronic calorimeter, narrow width in η)

- Photon conversion rejection (hits in tracker, opening angle with neighbour tracks)

- **Isolation criteria ,** separate requirements on tracker, Ecal and Hcal activity around electron candidates

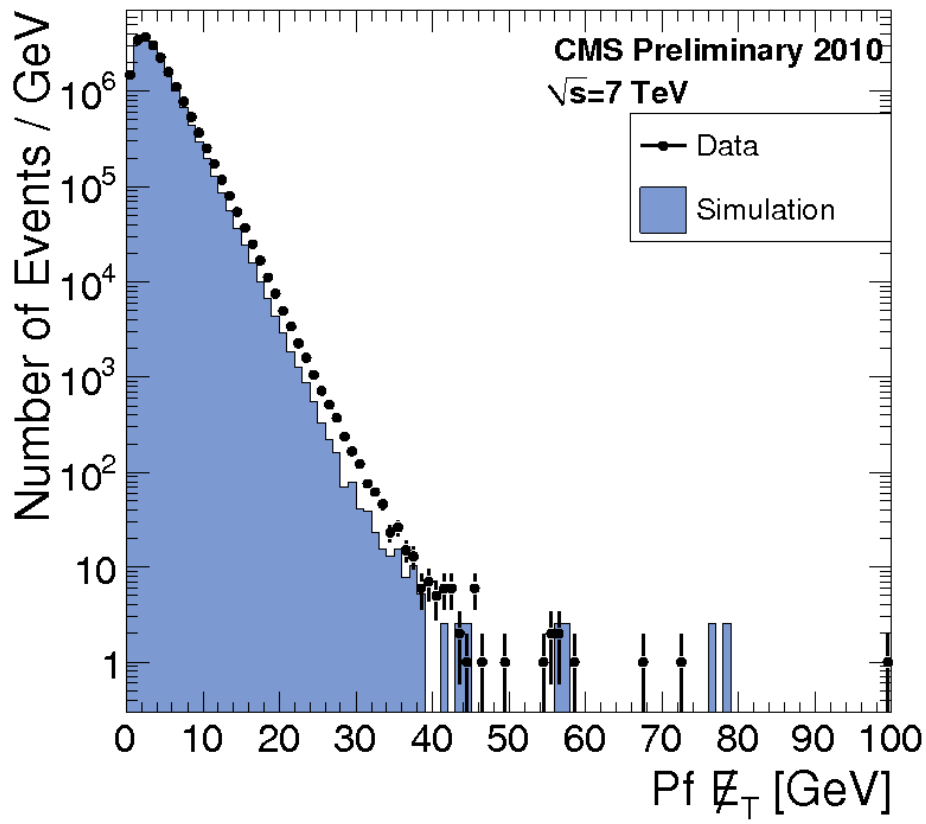


Electron efficiencies
Reconstruction, ID,
Trigger, Isolation efficiency
with clean Zee samples (impossing tight selection criteria on one leg, and probing the efficiency on the other)

→ ε_e =77.1 ± 1.8 % (Barrel)
→ ε_e =66.0 ± 2.0 % (Endcap)

Missing E_T measurement

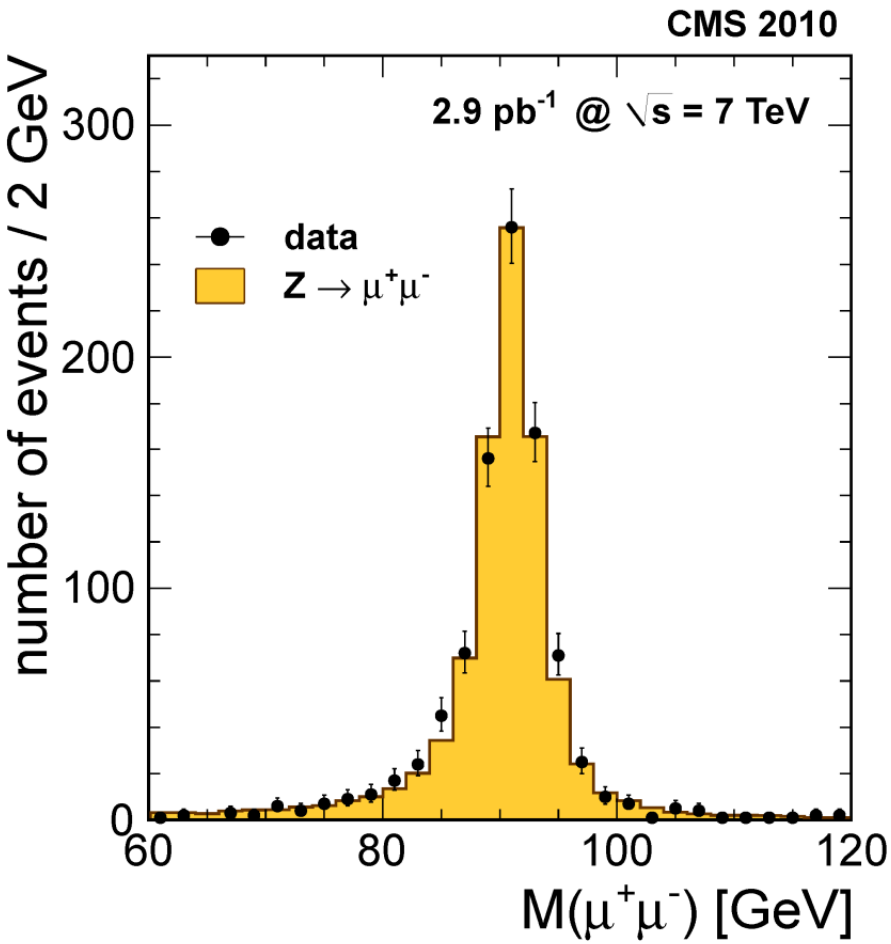
- Essential piece for W → l ν analysis
- Several techniques to compute ME_T:
  - Pure calorimetrical measurement (caloMET)
  - With corrections from tracker, replace tower energy with track pt from tracks matched to hadrons (tcMET)
  - Using particle flow algorithm, using fully reconstructed particles (pfMET)
- Used **pfMET** as baseline for EWK



Minimal effects of Pile-Up (more than one primary vertex in less than 40% of the events, and in these cases there is ~10% broadening of the ME_T distribution

$Z \rightarrow \mu^+\mu^-$ Selection

- 2 muons $p_t > 20$ GeV and $|\eta| < 2.1$
- Opposite charge muons
- Isolation
  $(\Sigma p_T(tk) + \Sigma E_T(had+em))/p_T < 15$

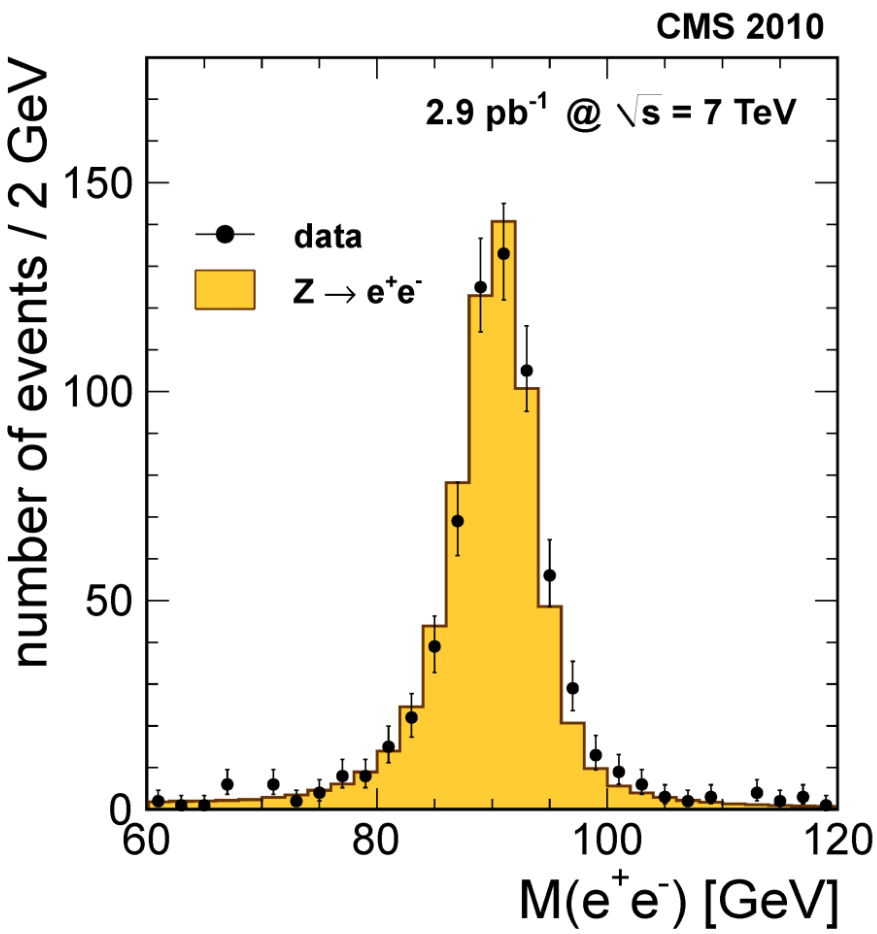


- **N=913 ±30 events** in $M\mu\mu \subset (60,120)$ GeV
- Muon scale effects < 0.4% (no corrections applied)
- Negligible background (estimated from simulation)

$Z \rightarrow e^+e^-$ selection

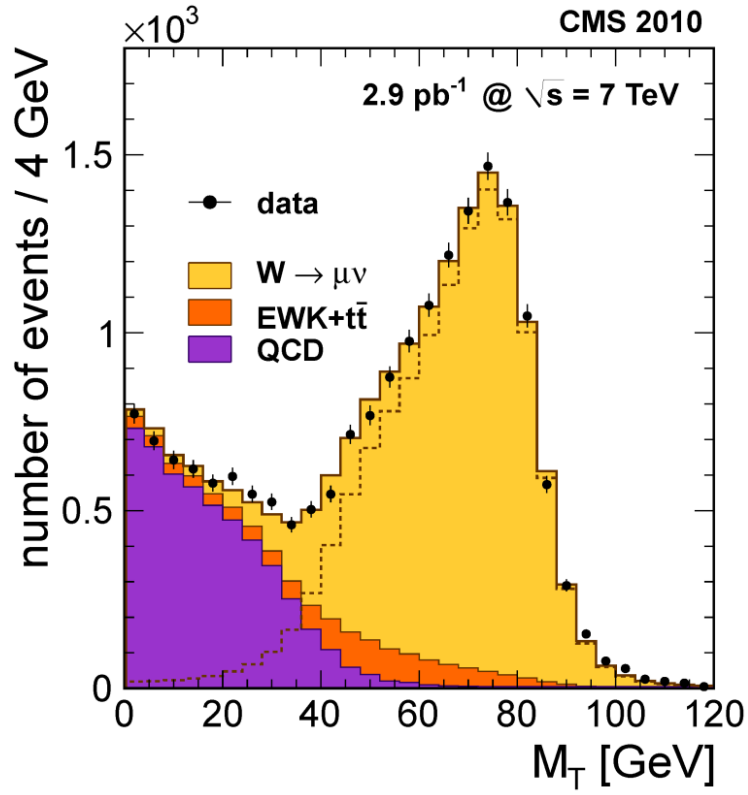
- 2 electrons with E_T>20 GeV
- Isolated (independently on tracker and calorimeters)

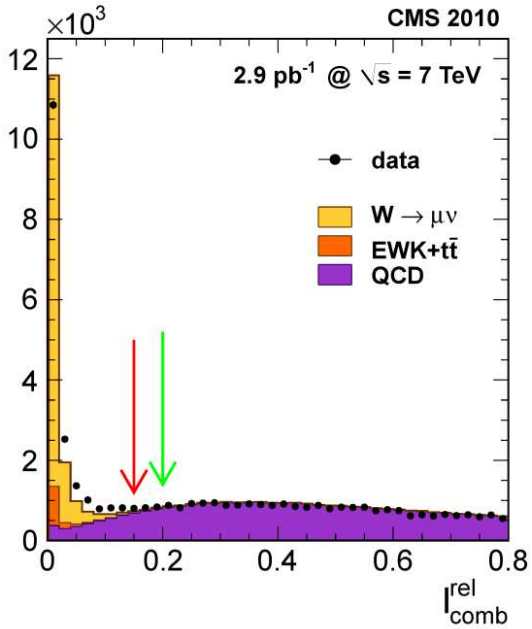
- **N=674±26 candidates in m_{ee} (60,120) GeV**
- Energy scale of leptons correction: 1.5±0.2% (barrel) and 3.3±0.5% (endcap)
- QCD backgrounds modeled from control samples
- EWK backgrounds modeled from simulation



W→μν Selection

- Muon p_t > 20 GeV, $|\eta|$ < 2.1
- Isolation
  $(\Sigma p_T(tk) + \Sigma E_T(had+em))/p_T < 15\%$
- Drell Yan rejection (veto on events with a second muon of p_T>10 GeV)
- Main source of BG: QCD (b hadron decays) .
  Smaller contributions from other EWK processes





$$M_T = \sqrt{2 p_T(\mu) \not{E}_T * (1 - \cos(\Delta\phi_{\mu,\not{E}_T}))}$$

- W Signal yield extracted through a **Binned Likelihood fit to the M_T distribution (Signal + QCD & EWK BGs)**
  - W Signal modeled from MC + corrections from Z recoil studies to model ME_T
  - EWK M_T shapes modeled from MC
  - QCD M_T Shape extracted from data (same selection criteria but not isolated)
- Output: Normalization of QCD and W cross-section

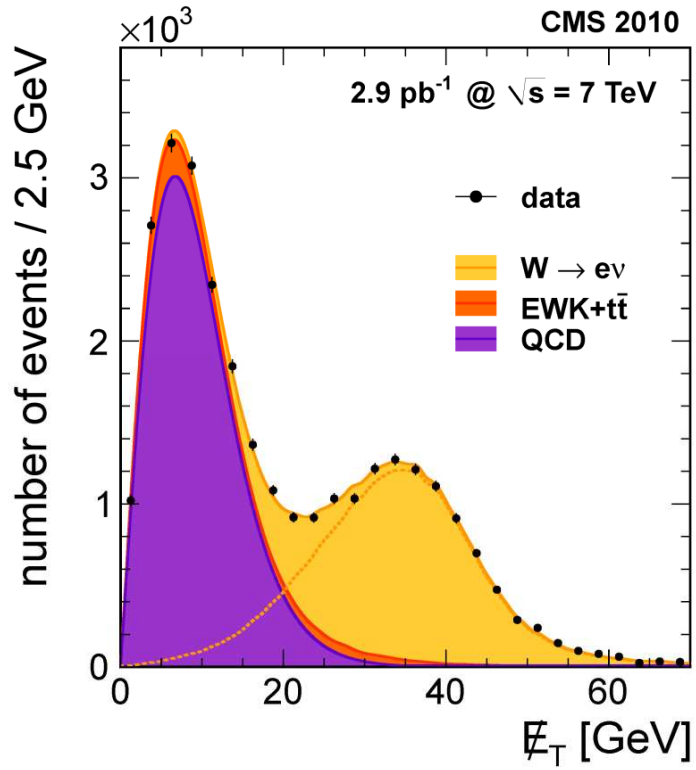
W→eν Selection

- Electron E_T> 20 GeV
- $|\eta|$ < 1.4442 (Barrel), 1.566<$|\eta|$< 2.500 (Endcap)
- Isolation (independent cuts on track, em, had)
- Drell Yan rejection (veto on events with a second electron of E_T>20 GeV)
- BG dominated by QCD (fake electrons). Smaller EWK contributions

Unbinned Likelihood fit to the ME_T distribution

- W Signal from MC + corrections from Z recoil to model ME_T
- Scale corrections as in Zee
- ElectroWeak ME_T shape well modeled from Monte Carlo
- QCD background is parameterized through

$$f(ME_T) = Cx\exp\left(\frac{-x^2}{2(\sigma_0+\sigma_1 x)^2}\right)$$

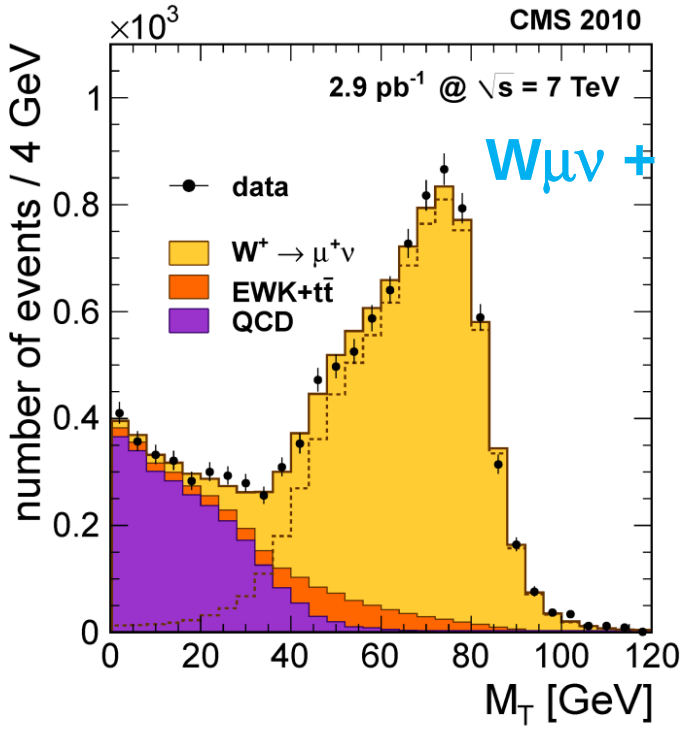


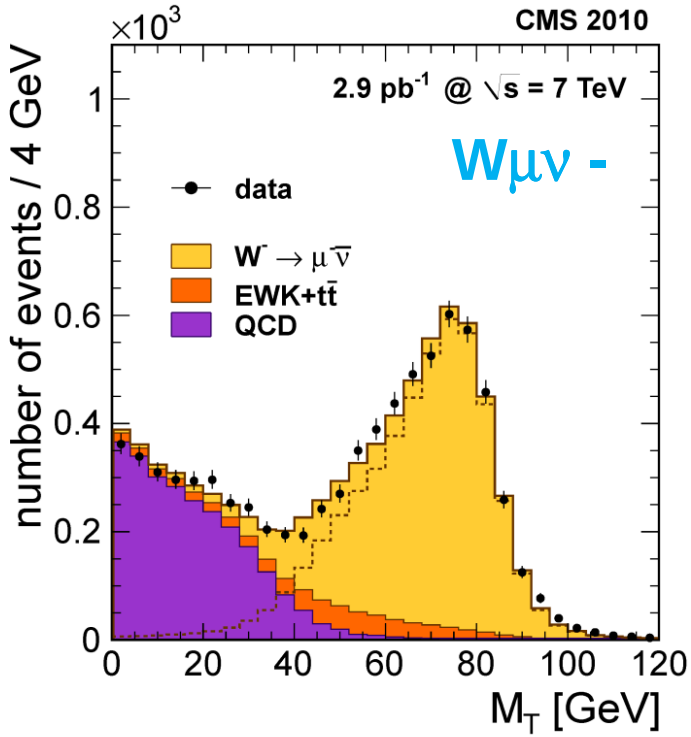
Signal Yields

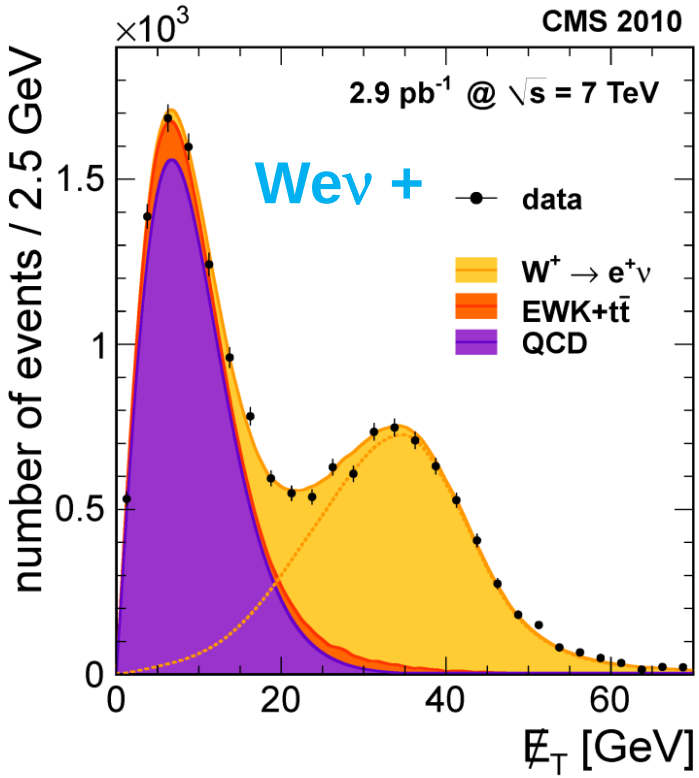
$W^{\pm} \rightarrow \mu^{\pm}\nu$

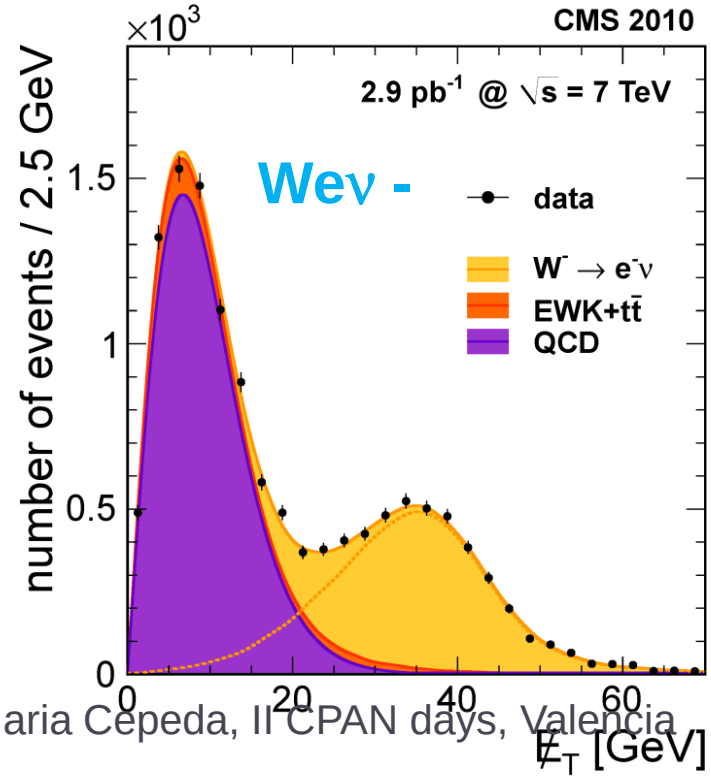
W^{+}=7445 ± 87

W^{-}= 4812 ± 68









$W^{\pm} \rightarrow e^{\pm}\nu$

W^{+}= 7193 ± 89

W^{-}= 4728 ± 73

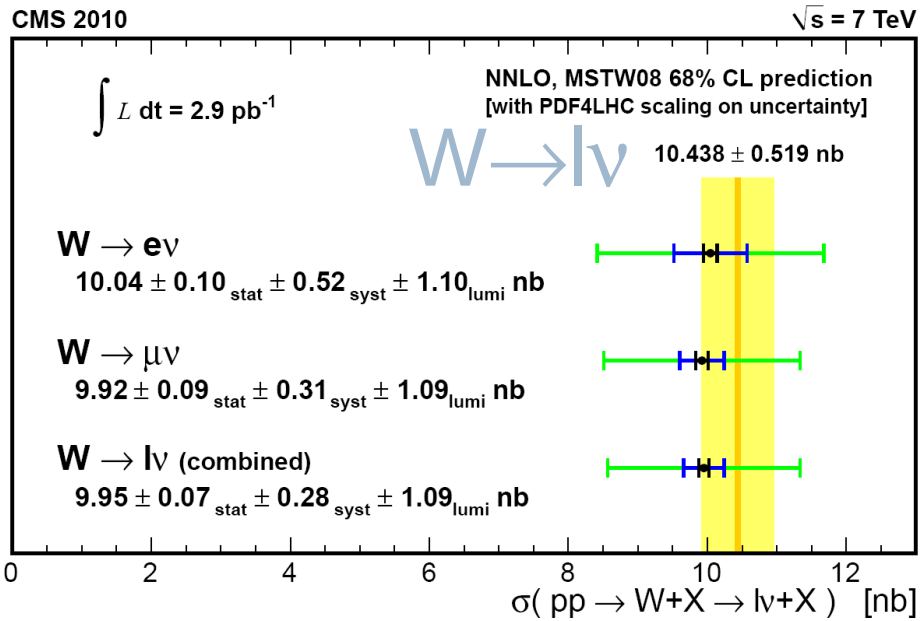
Systematic studies

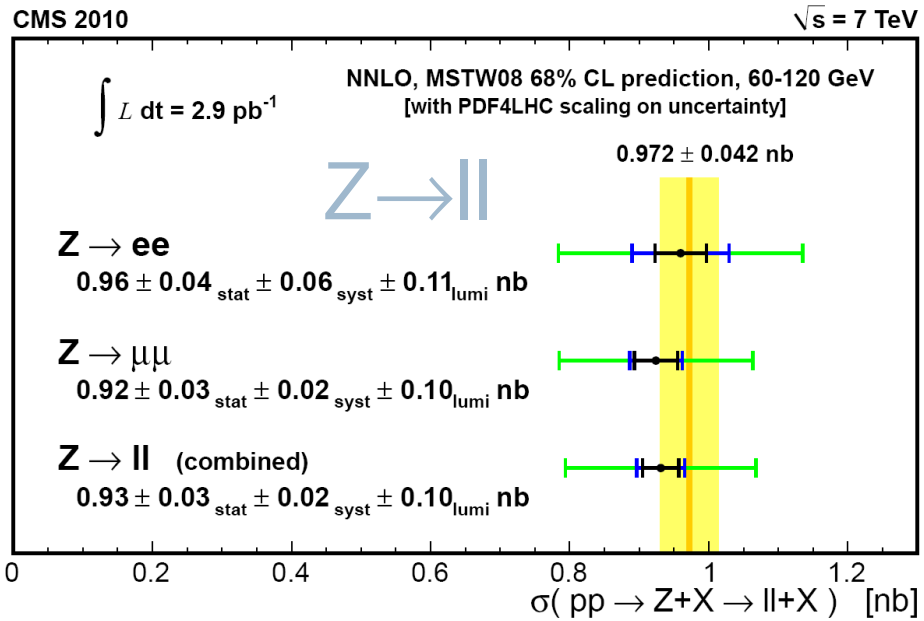
- **Uncertainty on Reconstruction and Lepton ID** from the estatistical errors on the efficiencies
- **Momentum Scale and Resolution** from repeating the fit with modified scales
- **mE_T scale/resolution** repeating the fit comparing with Monte Carlo predictions for the signal shapes
- **QCD W Background** uncertainty from the difference between data modeling and Monte Carlo predictions (conservative)
- **QCD Z Bckg** from " Fake rate" methods, opposite/same sign di-lepton candidates
- **PDF** uncertainties evaluated via CTEQ66, MSTW08NLO, NNPDF2.0 sets
- **Other theoretical** uncertainties (QCD scale, EWK effects, ISR, FSR…)

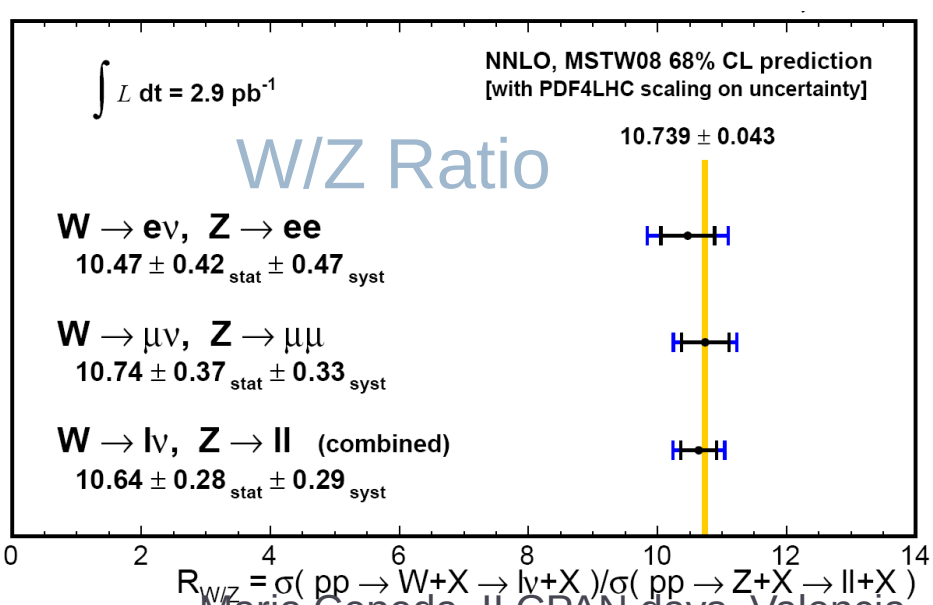
Source	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	3.9	1.5	5.9	0.5
Momentum scale & resolution	2.0	0.3	0.6	0.2
$\not\!\!E_T$ scale & resolution	1.8	0.4	n/a	n/a
Background subtraction	1.3	2.0	0.1	1.0
PDF uncertainty for acceptance	0.8	1.1	1.1	1.2
Other theoretical uncertainties	1.3	1.4	1.3	1.6
Total	5.1	3.1	6.2	2.3

- Dominant uncertainty: **Luminosity** → 11%

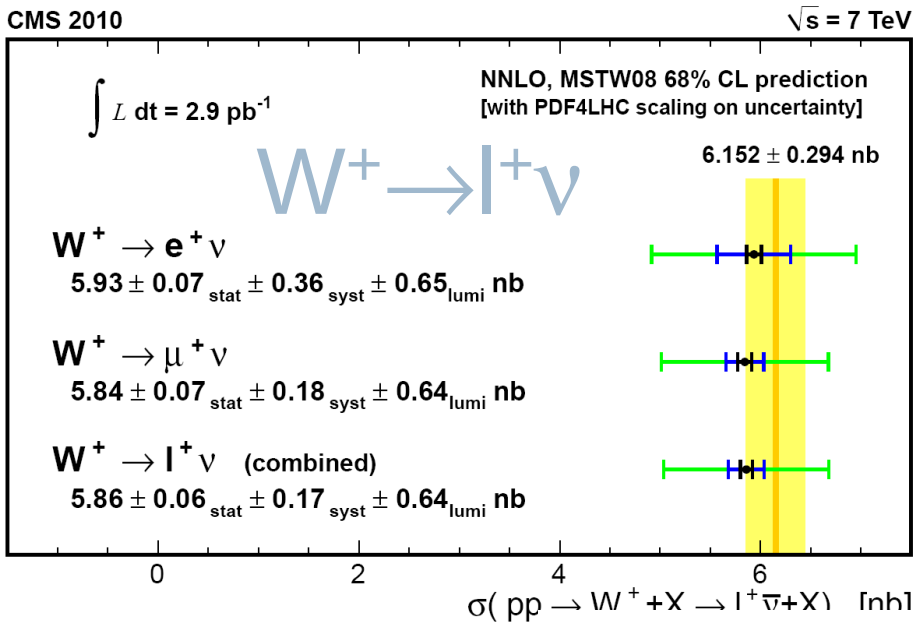
W, Z production cross-sections and Ratio

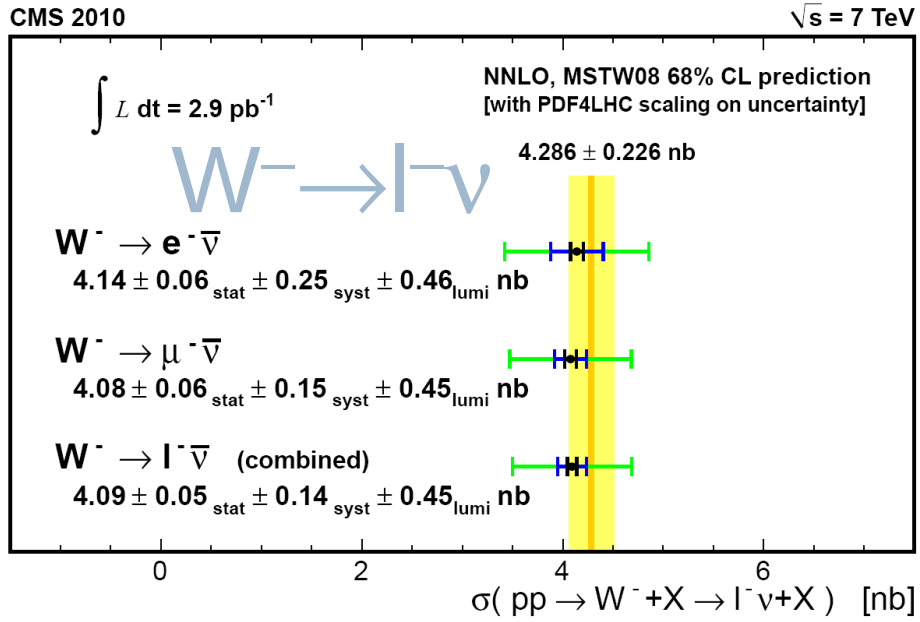


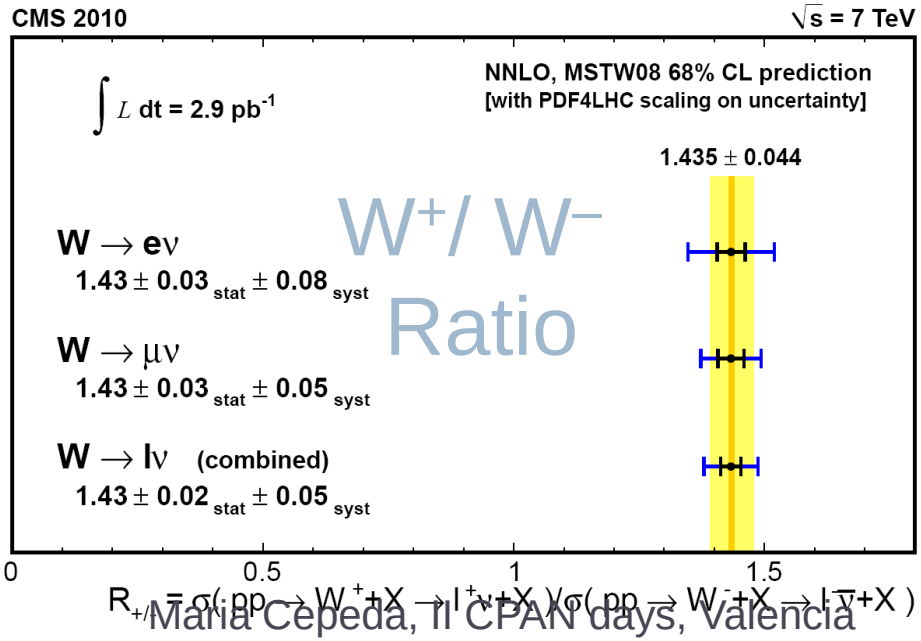




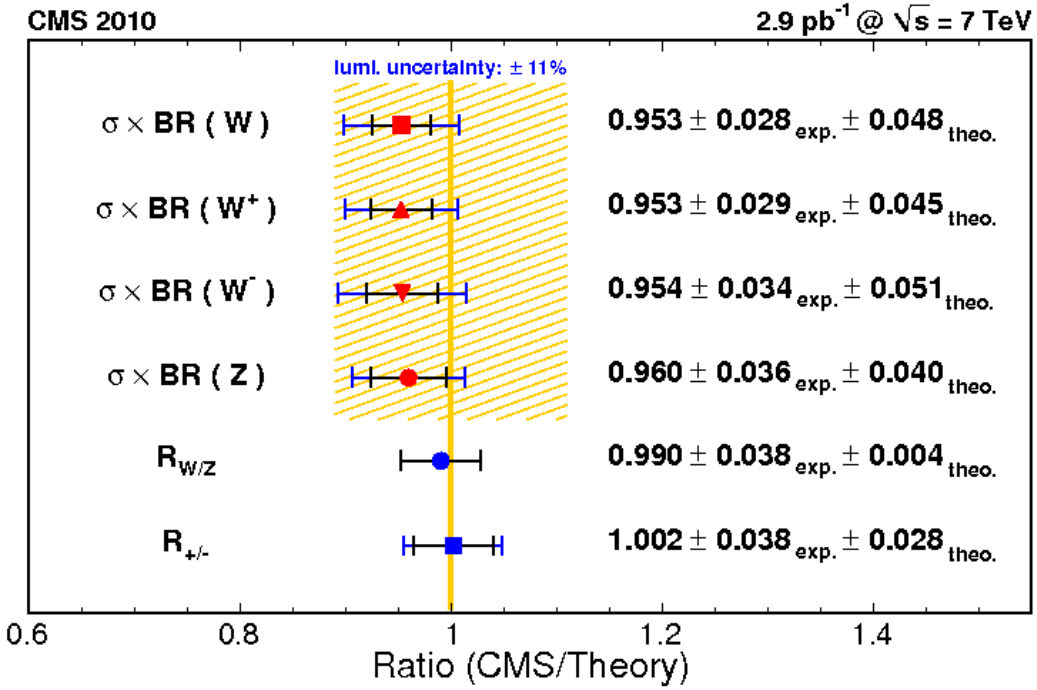
W^+, W^- Cross-Sections and Ratio

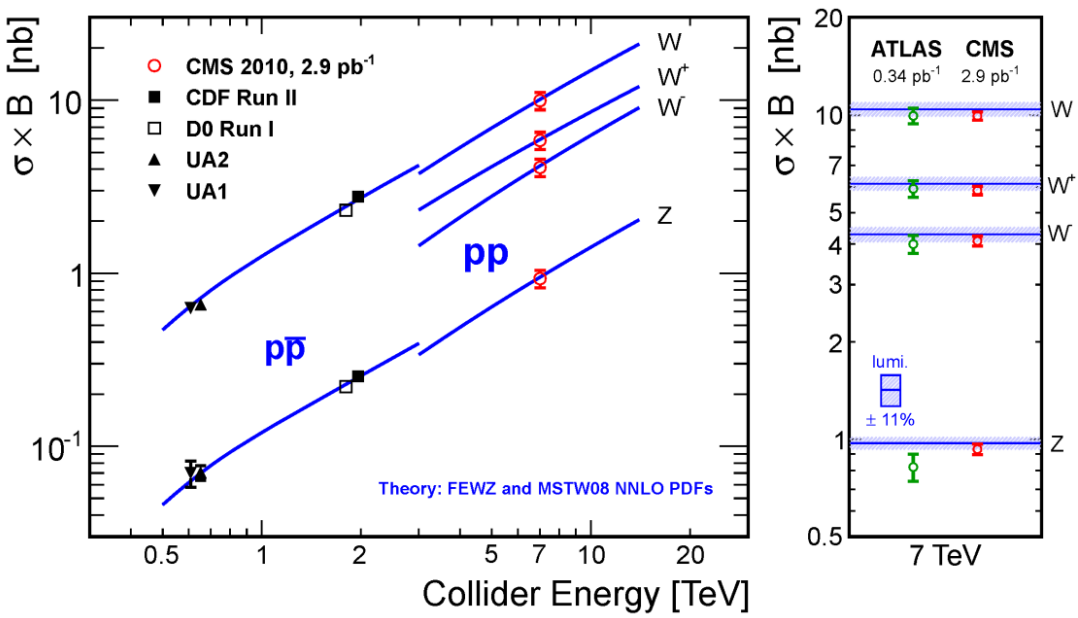






Good agreement with SM predictions

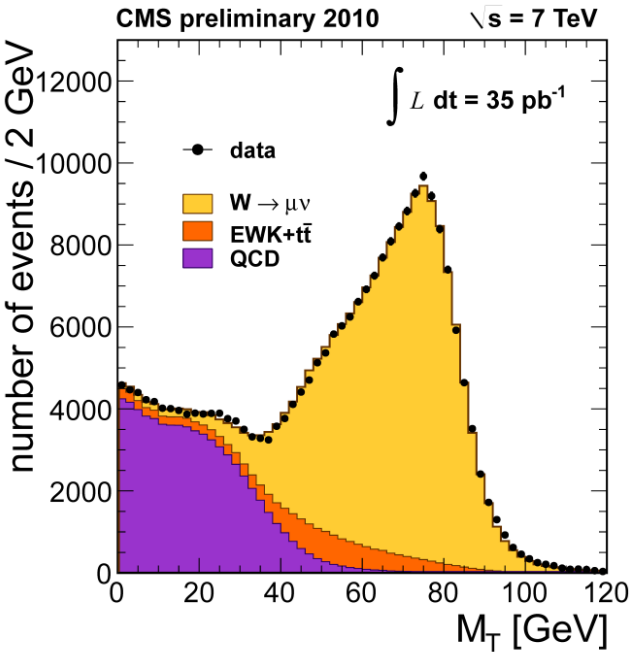


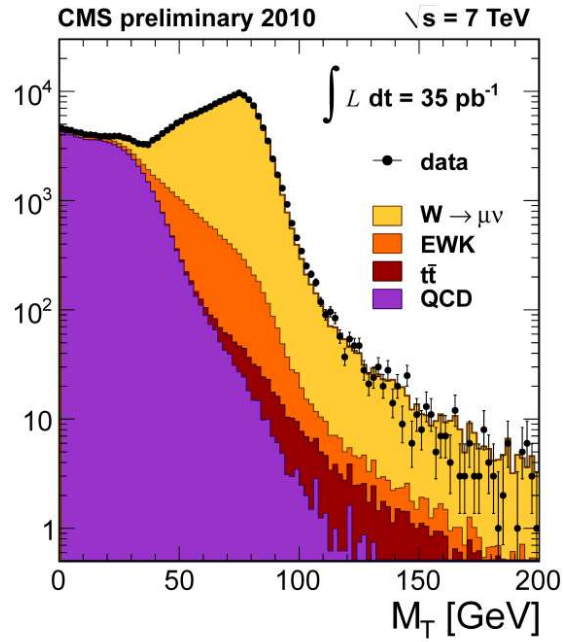


W, Z distributions with the full 2010 dataset

$L_{int} = 35 pb^{-1}$

W Channels



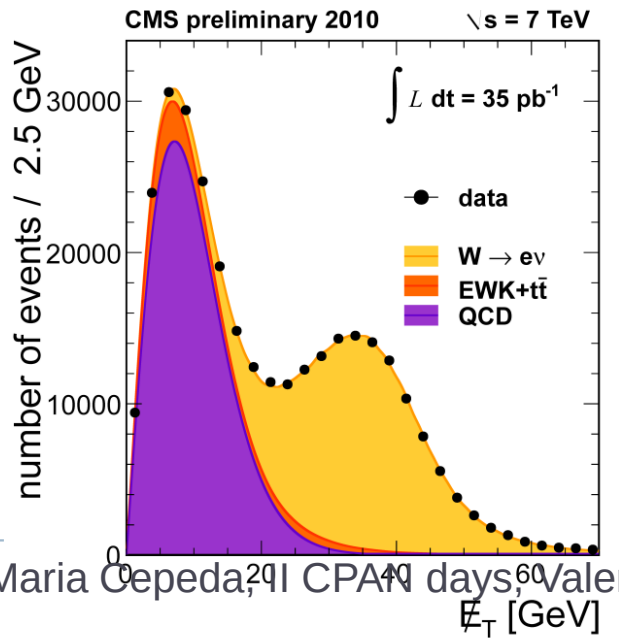


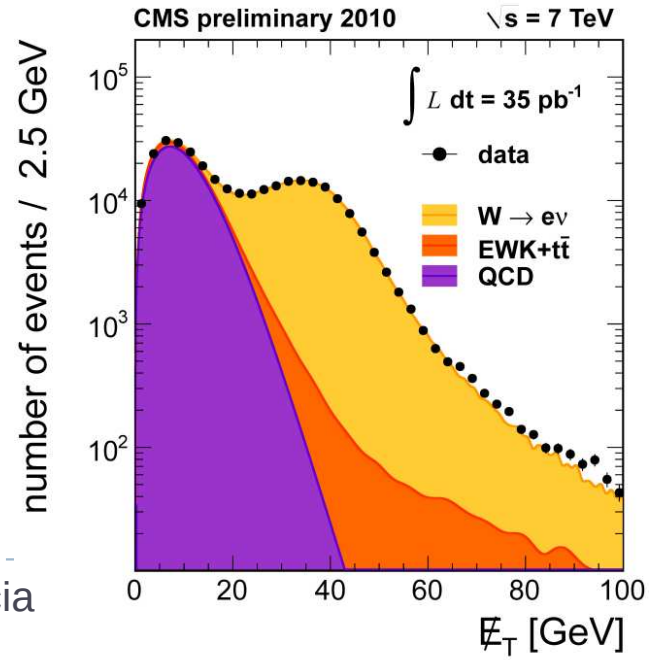
W→μν

W+: 98156 Candidates
W- : 62714 Candidates

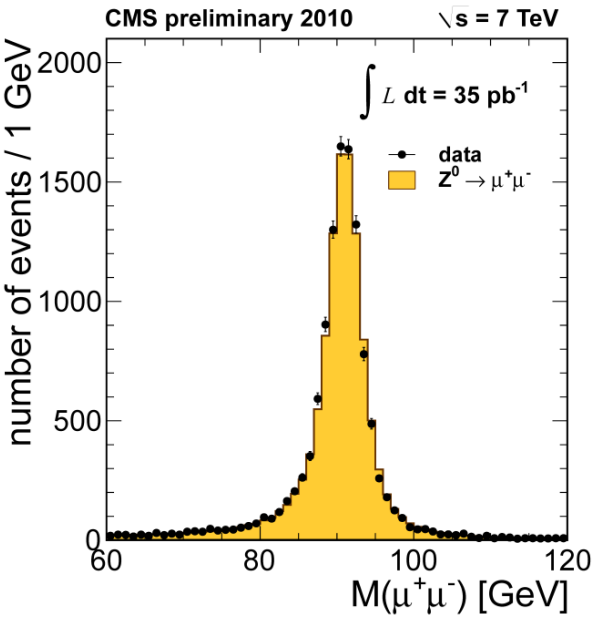
W→eν

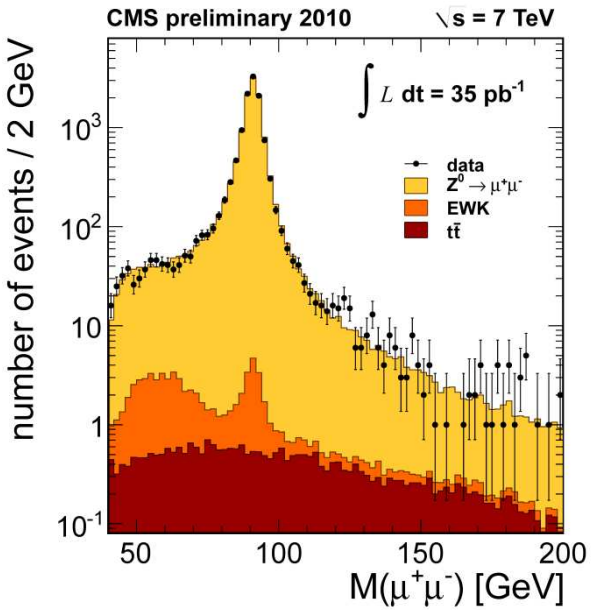
W+: 87884 Candidates
W-: 56912 Candidates





Z Channels



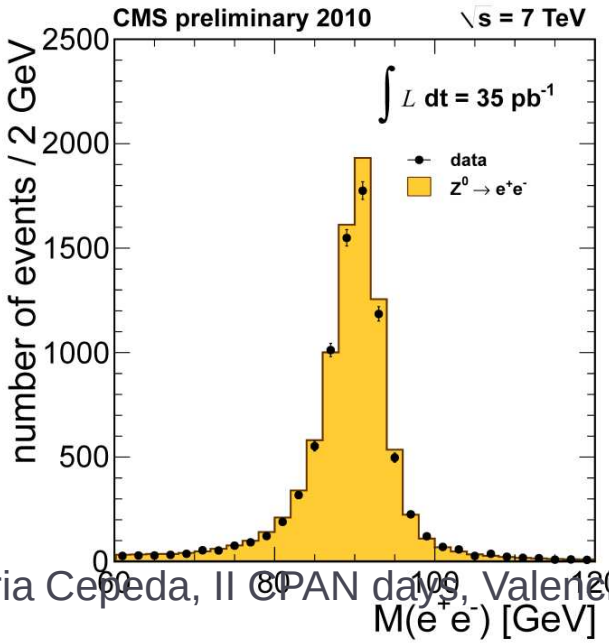


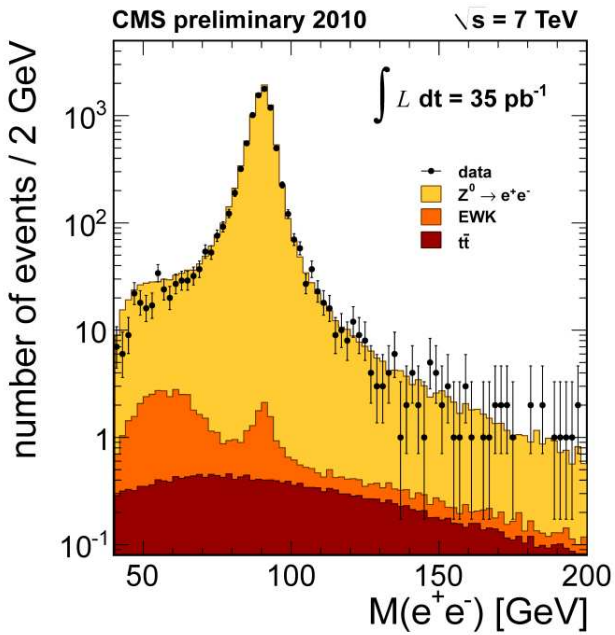
Z→μ⁺μ⁻

11697 Candidates

Z→e⁺e⁻

8253 Candidates



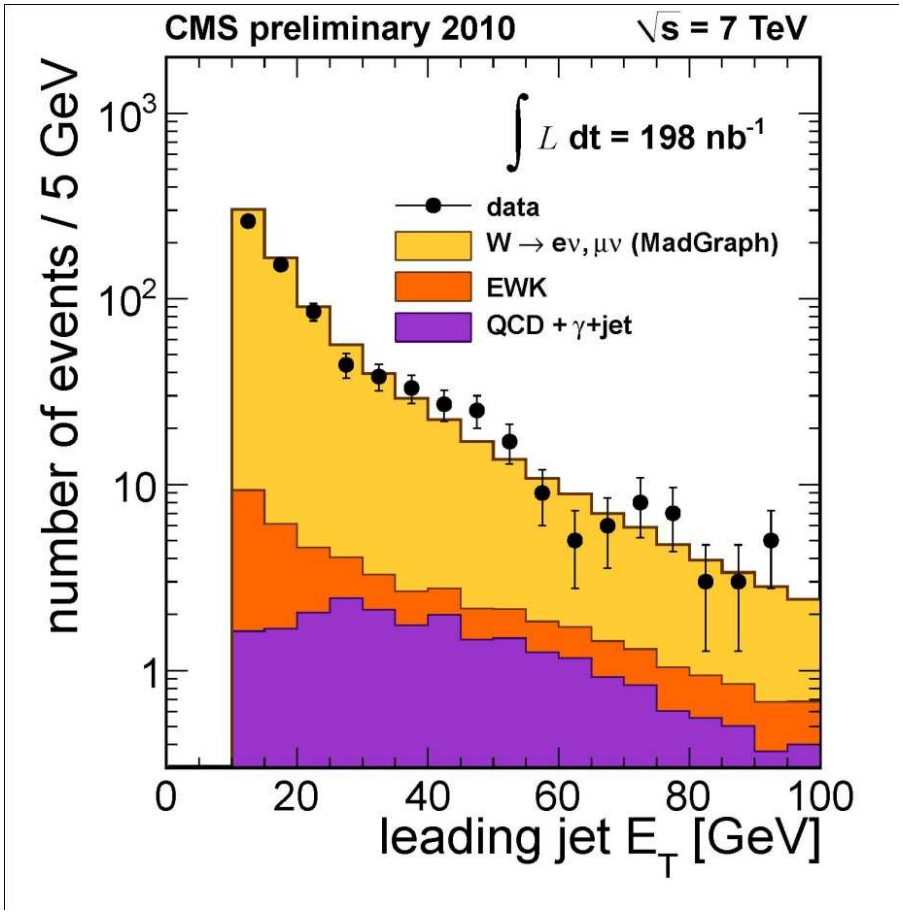


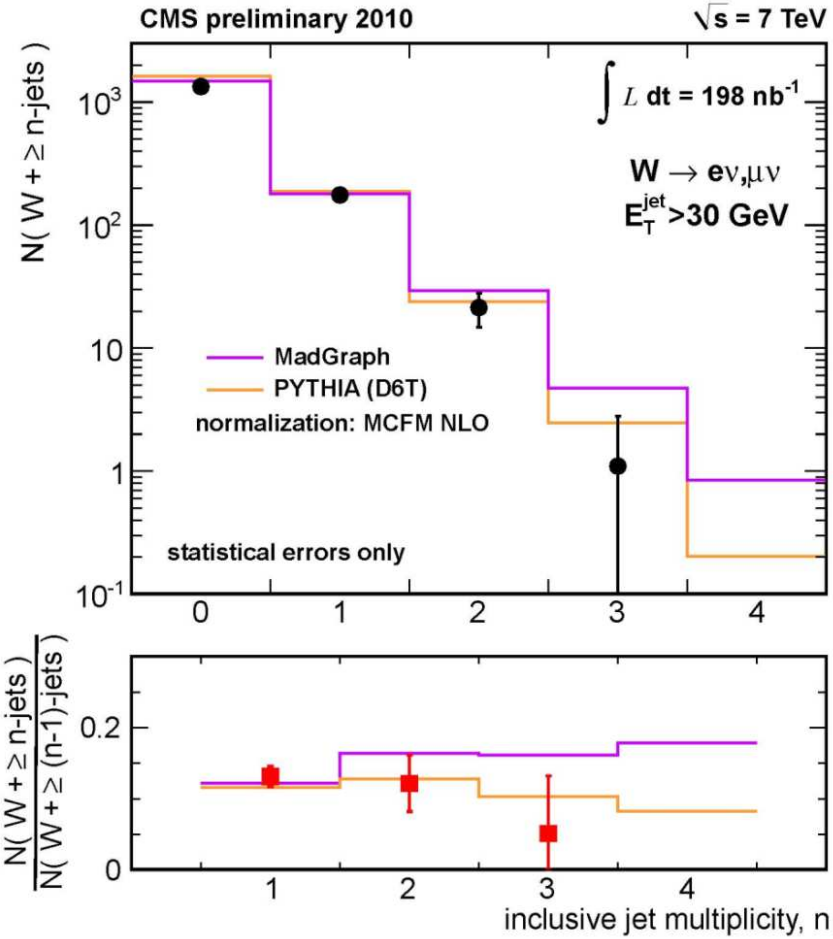
Differential measurements: V+Jets, A_{charge} (W), A_{FB} (Z)

L=198 nb^{-1}

W+Jets Associated Production

- **Jet Reconstruction:**
  - Anti-Kt algorithm (infra-red safe)
  - Particle Flow





- Statistical error only

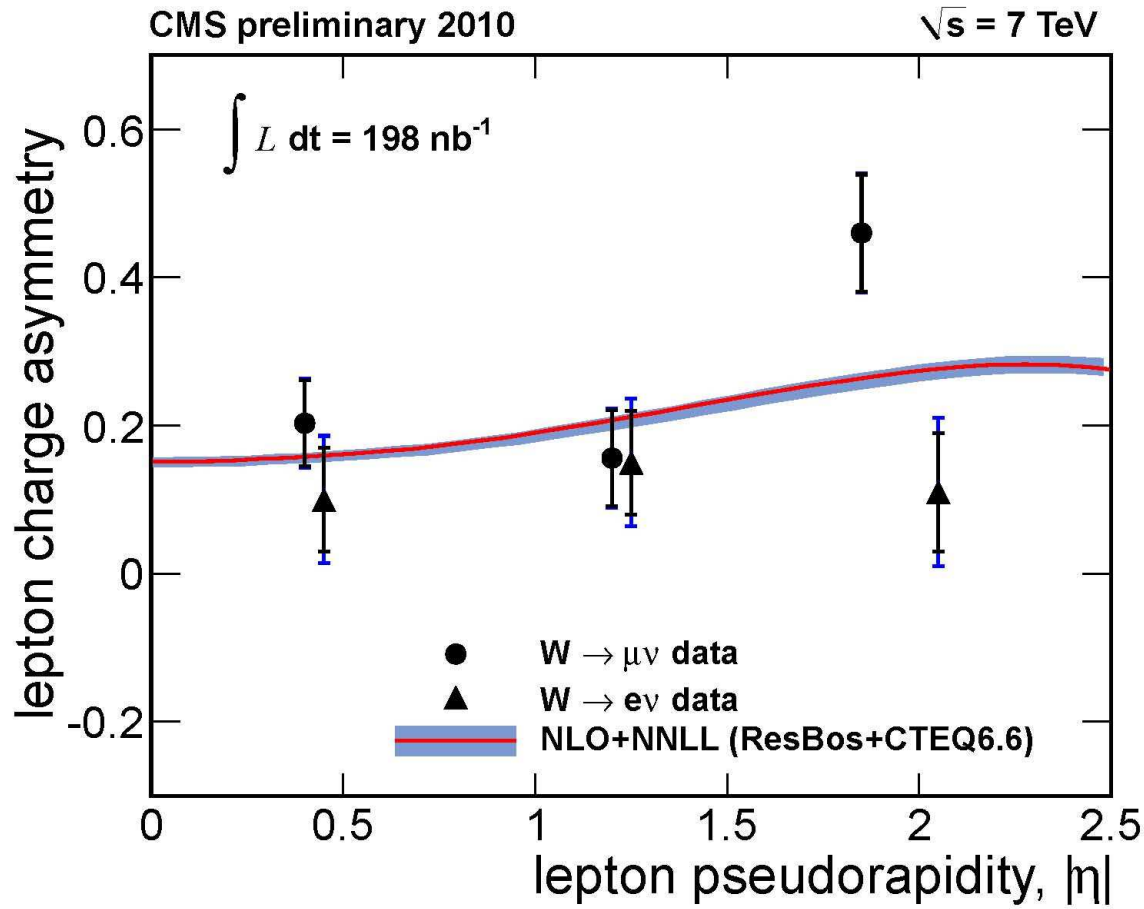
  (Jet energy scale (10-20%))

W Charge Asymmetries

- W charge asymmetry as a function of lepton pseudorapidity will improve our knowledge of Parton Density Functions (PDFs)

$$A(\eta) = \frac{d\sigma^{(+)}/d\eta_\ell - d\sigma^{(-)}/d\eta_\ell}{d\sigma^{(+)}/d\eta_\ell + d\sigma^{(-)}/d\eta_\ell}$$

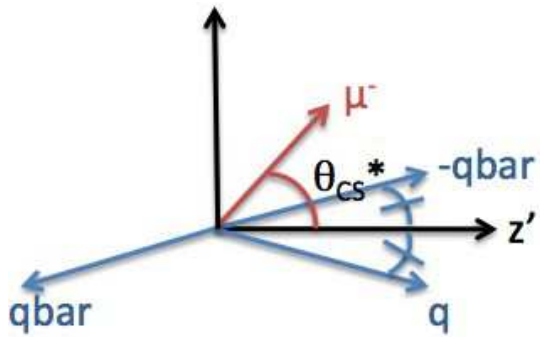
$$A_W \approx \frac{u\bar{d} - \bar{u}d}{u\bar{d} + \bar{u}d} \approx \frac{u_{val} - d_{val}}{u_{val} + d_{val} + 2\bar{q}}$$

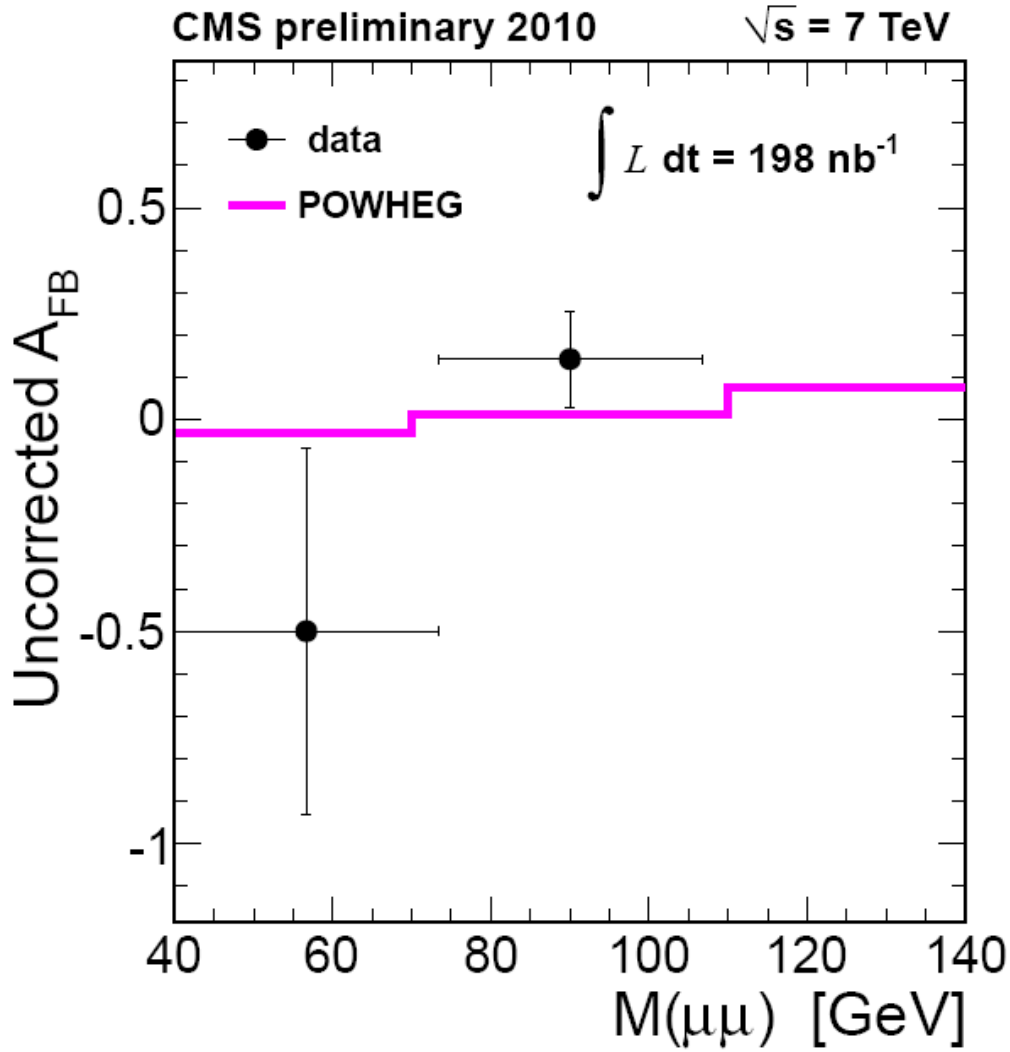


First measurement in 3 pseudorapidity bins

Z Forward-Backward Assymetry

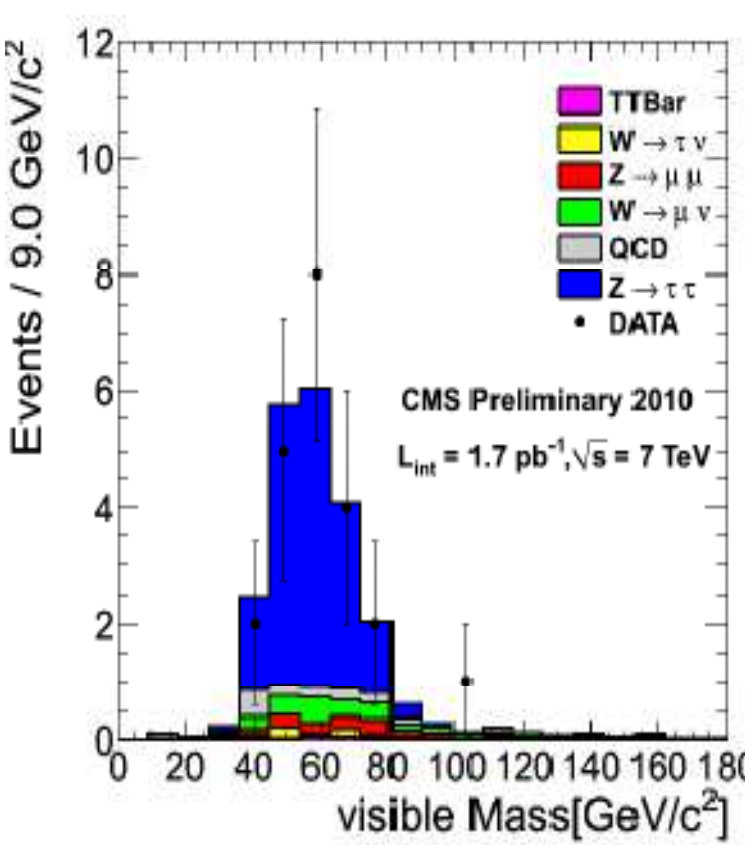
- Di-lepton forward-backward asymmetry depends on the di-lepton invariant mass, being small near the Z mass and sizable around 70 and 110 GeV
- Deviations from SM value may indicate the presence of a new neutral gauge boson

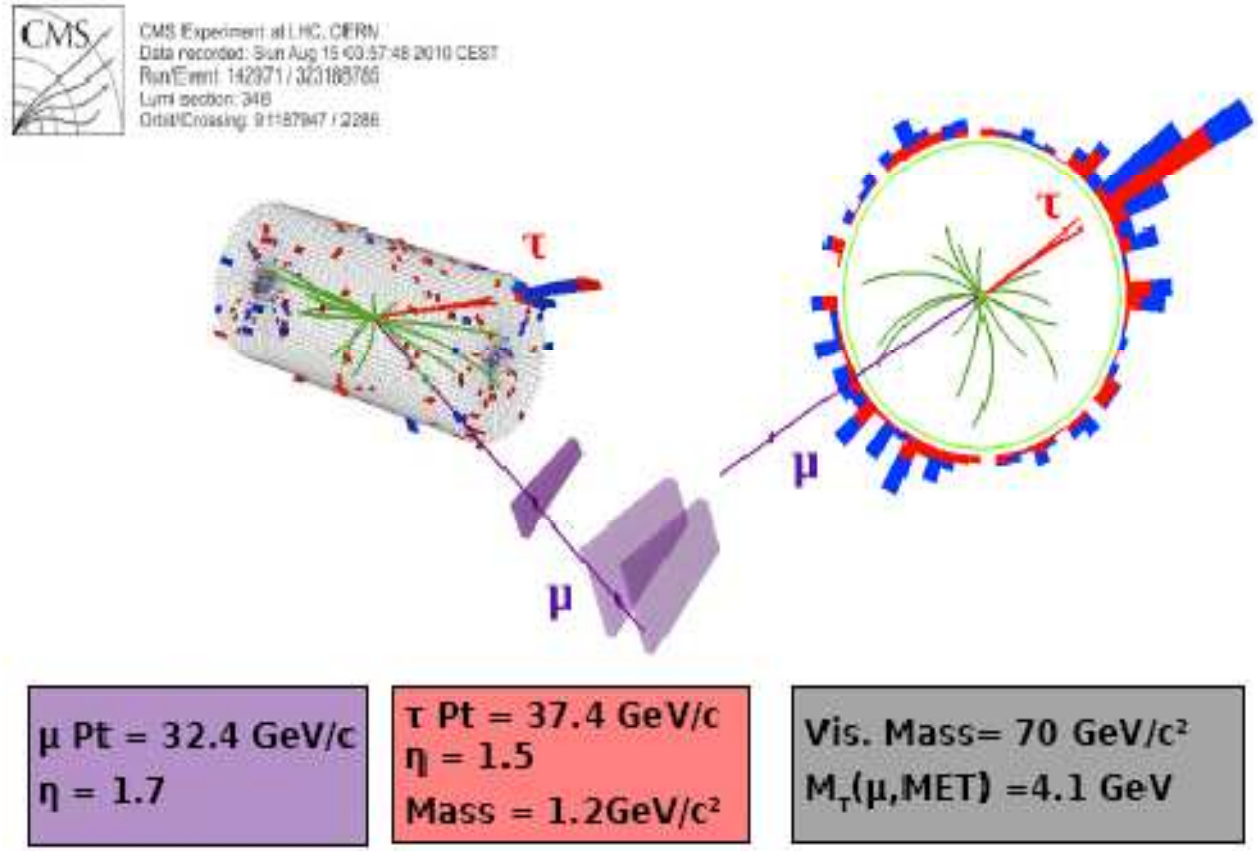




Distribution for $Z \rightarrow \tau\tau$ at $L_{int}=1.7\ pb^{-1}$
First Observation of $ZZ \rightarrow 4\mu$

$Z \rightarrow \tau\,\tau$ with 1.7 pb^{-1}

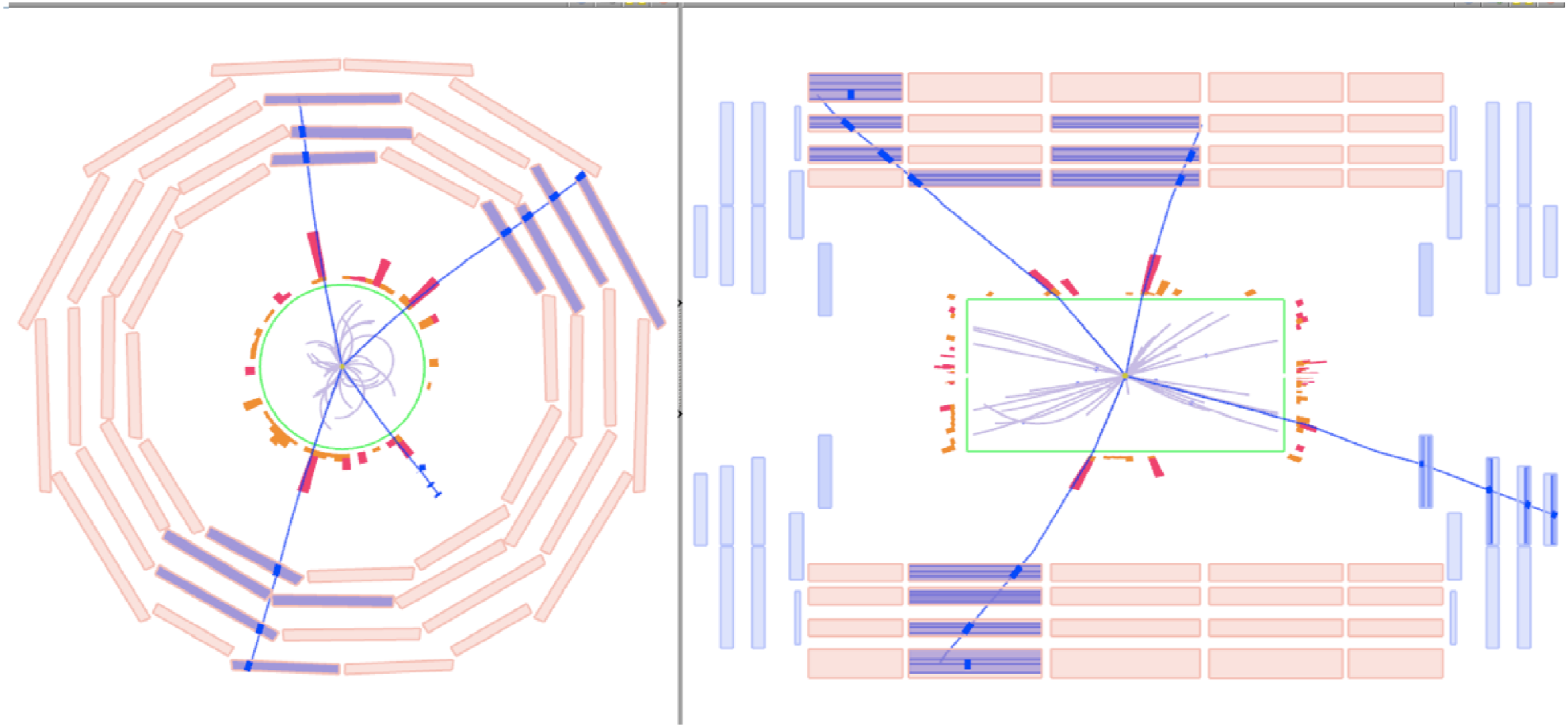




- Reliable reconstruction of taus using the multiplicities and the invariant mass of the hadrons within a narrow cone

- Muon $P_T > 15$ GeV & Tau $P_T > 20$ GeV
- Muon and Tau Isolated

First ZZ→4μ Candidate



Invariant Masses

$\mu_0 + \mu_1$: 92.15 GeV (total(Z) p_T 26.5 GeV, ϕ -3.03),
$\mu_2 + \mu_3$: 92.24 GeV (total(Z) p_T 29.4 GeV, ϕ +.06),
$\mu_0 + \mu_2$: 70.12 GeV (total p_T 27 GeV),
$\mu_3 + \mu_1$: 83.1 GeV (total p_T 26.1 GeV).

Invariant Mass of 4μ: 201 GeV

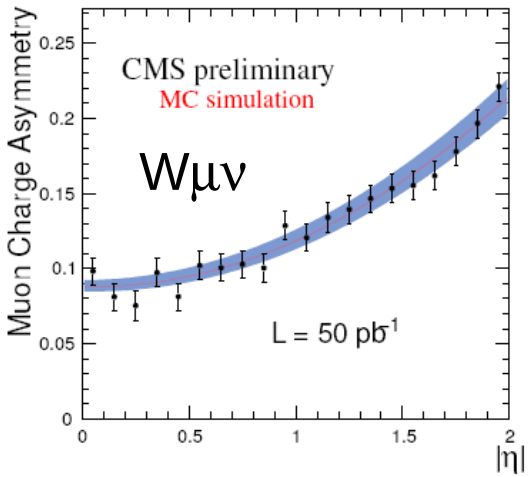
So far…

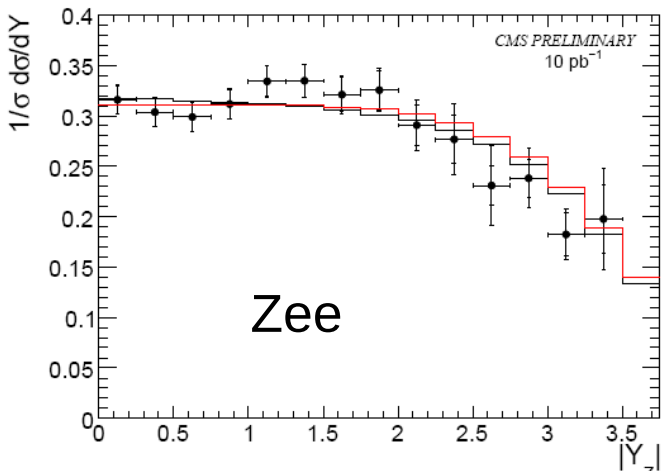
- **First measurements of ElectroWeak physics** in CMS
  - **Full analysis at 2.9 pb^{-1}:**
    - **Inclusive Cross-Sections of W and Z in their leptonic decays (e, mu)**
    - **Ratios of W/Z and W^+/W^- cross sections**
  - **First analysis with 198 nb-1:**
    - **W Charge asymmetry as a function of the lepton pseudo-rapidity**
    - **W+jets Production**

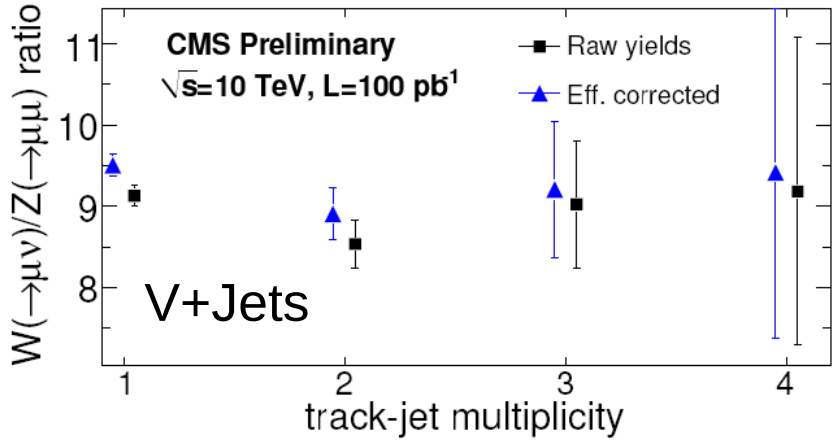
    (full analysis underway)
  - **First distributions of ZTauTau towards a cross-section measurement at 7TeV**
  - **First observation of Dibosons Production at 7 TeV**

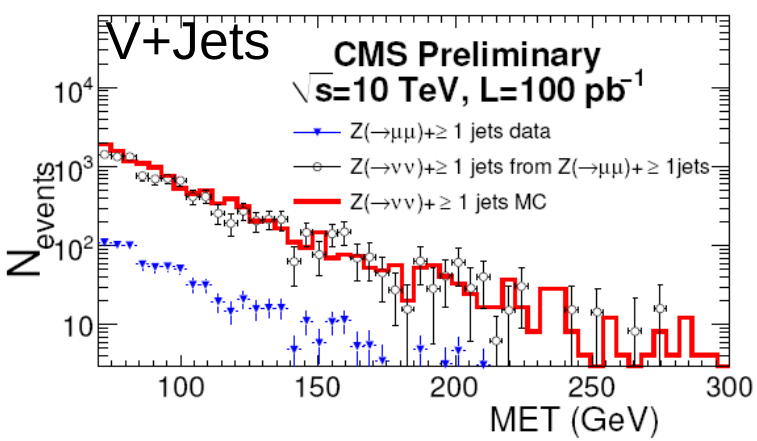
All results in good agreement with SM predictions.

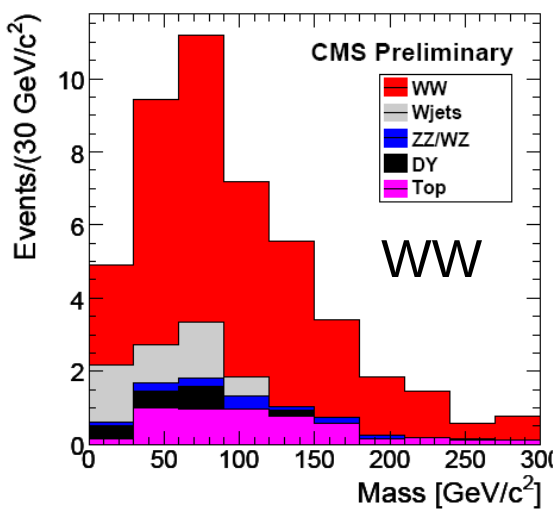
…but this is not all











Examples of EWK MC prospect studies at 10 TeV (2009)

- Analysis of the full 2010 dataset underway
- Many more EWK physics results to be expected from CMS in 2011

References

- ElectroWeak public results:

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

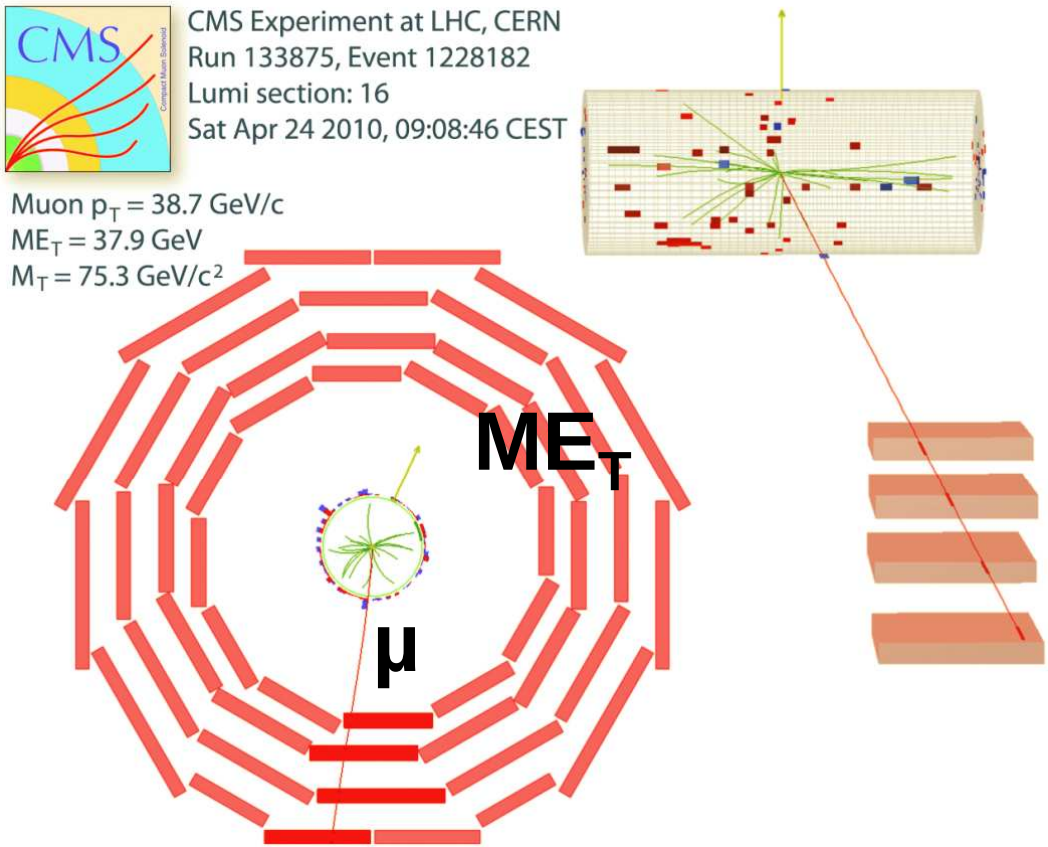
- Conference Reports Summer 2010

CMS-PAS-EWK-10-002 (http://cdsweb.cern.ch/record/1279615?ln=es)

CMS-PAS-PFT-10-004 (http://cdsweb.cern.ch/record/1279358?ln=es)

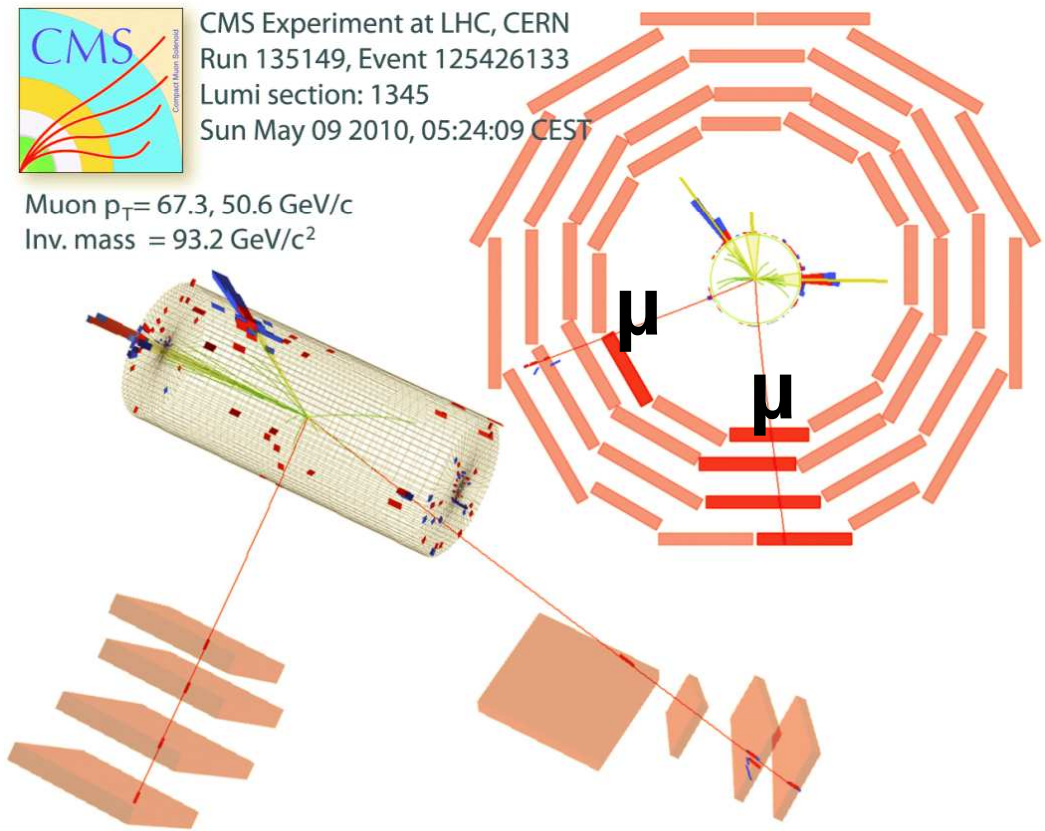
- 2.9pb^{-1} paper ready to be published

$W \rightarrow \mu\nu$ and $Z \rightarrow \mu^+\mu^-$

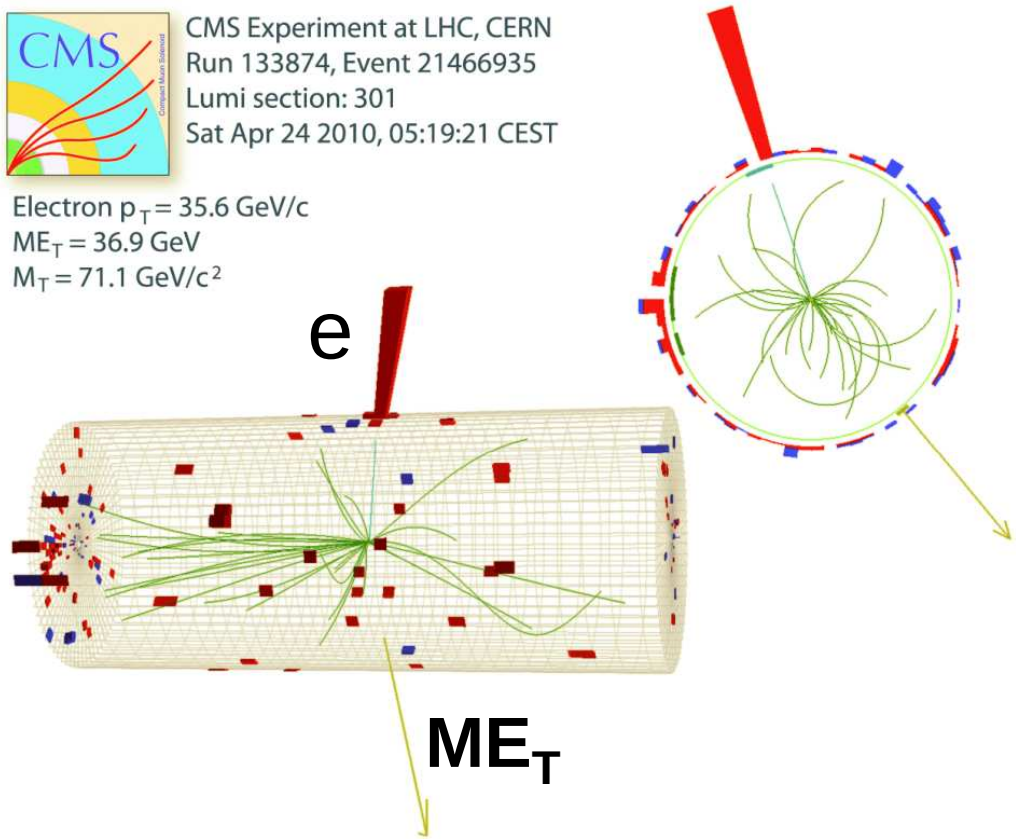


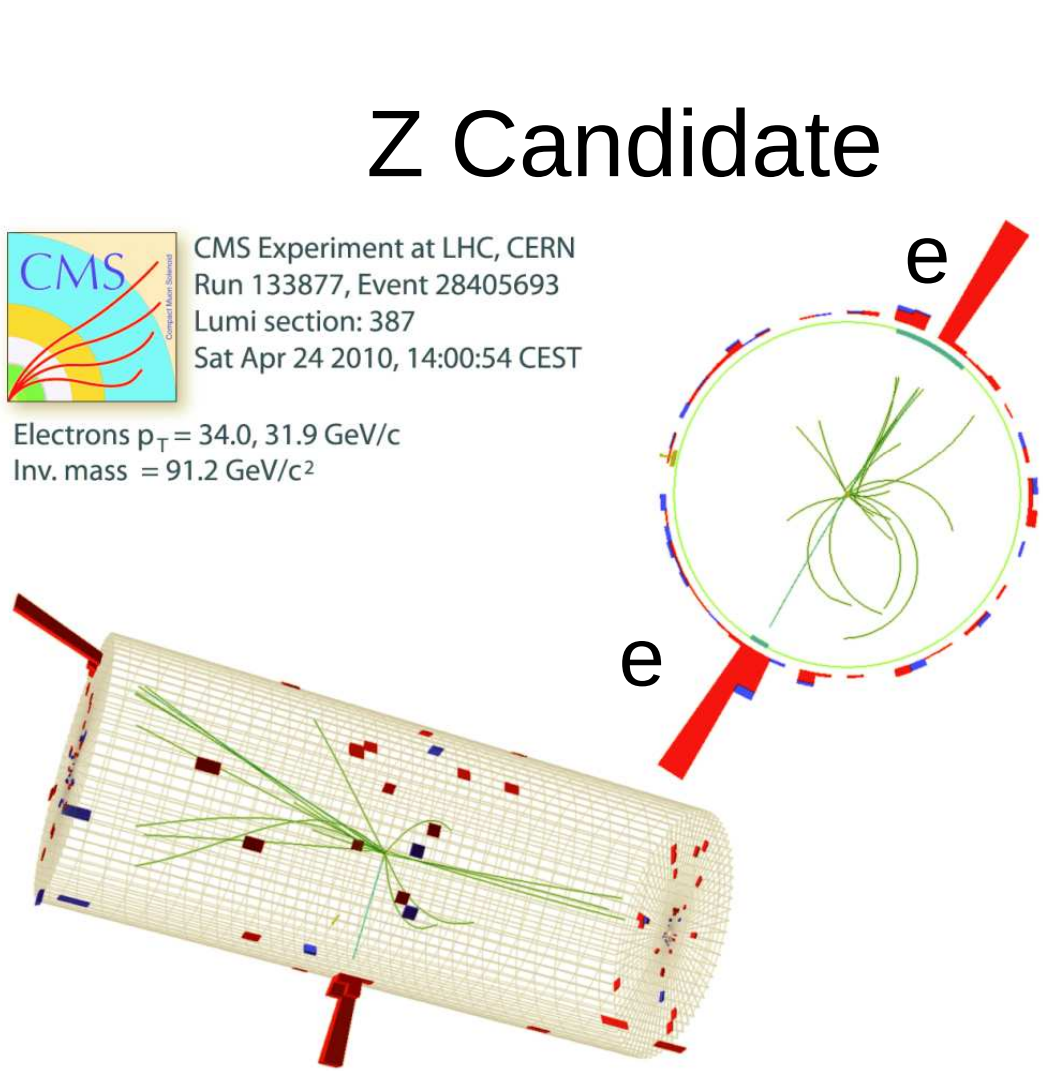
W Candidate

Z Candidate

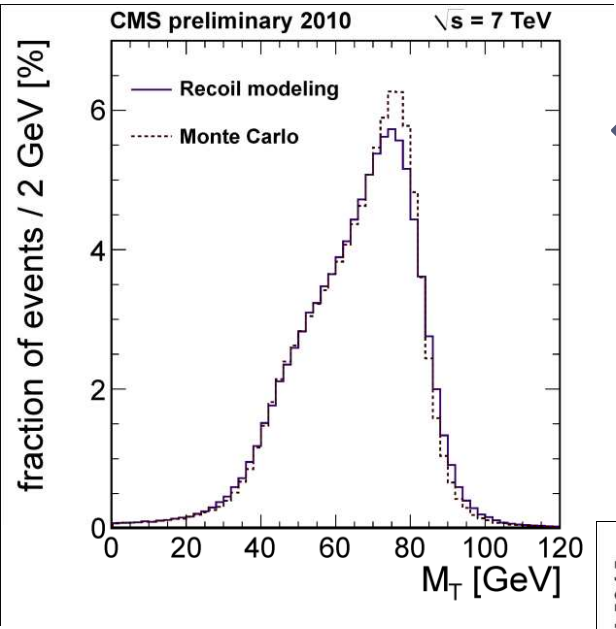


$W \rightarrow e\nu$ and $Z \rightarrow e^+e^-$



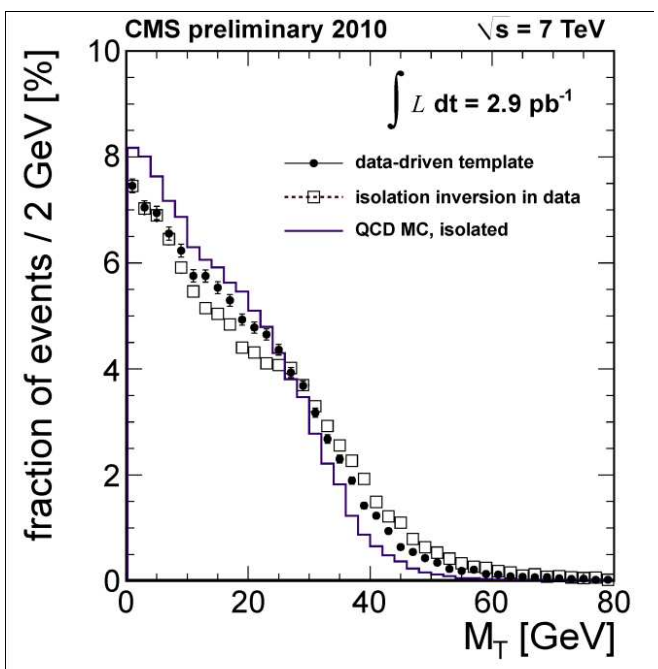


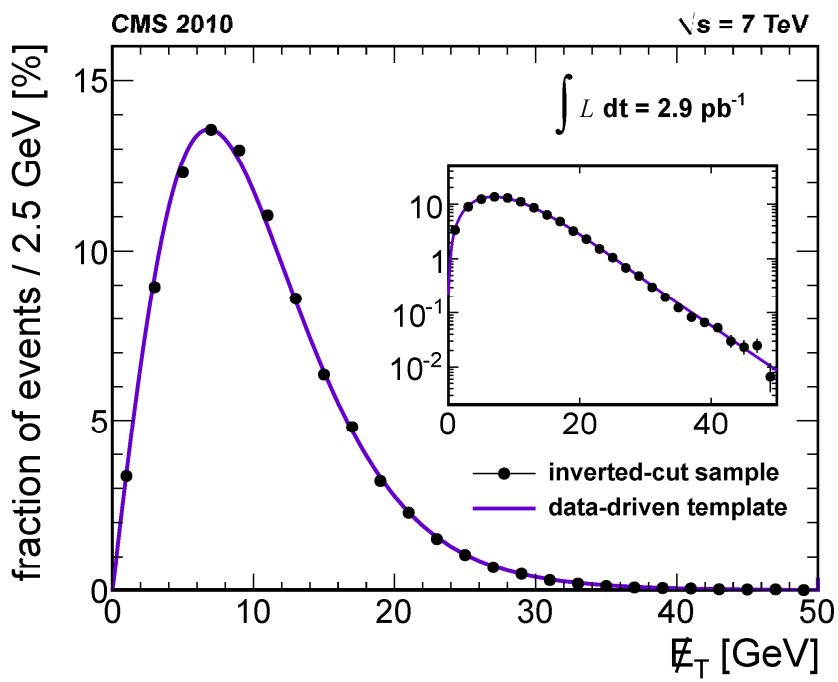
Templates for W Signal Extraction



Signal, from MC and Z recoil

QCD templates

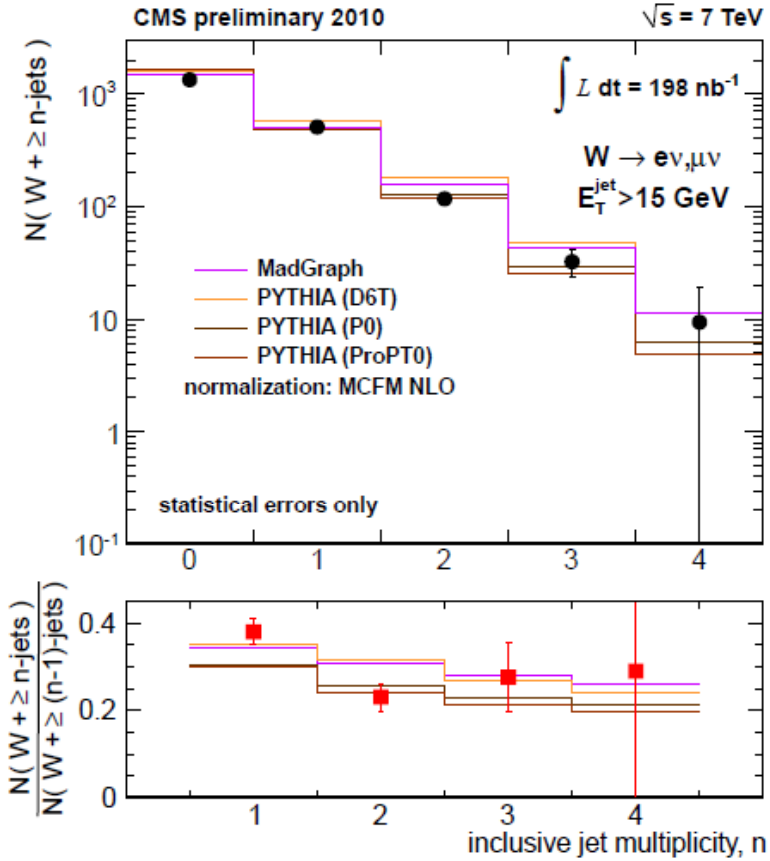




W+Jets Associated Production

- Same lepton selection as the inclusive analysis

- **Jet Selection:**
  - Infra-red safe Anti-Kt Jet reconstruction
  - Two thresholds E_T>15 GeV and E_T>30 GeV
  - Lepton-Jet separation: ΔR<0.5
  - Particle Flow reconstruction
  - Cone radios of ΔR=0.5,
  - |η|<2.5



- M_T used as discriminating variable in both channels

- Main source of systematics error: jet energy scale (10-20%)

W Asymmetry

- More $u\bar{d}$ than $\bar{d}u$ in pp collisions → Charge Asymmetry in W production

$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+ \bar{\nu}_\mu) - \frac{d\sigma}{d\eta}(W^- \to \mu^- \nu_\mu)}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+ \bar{\nu}_\mu) + \frac{d\sigma}{d\eta}(W^- \to \mu^- \nu_\mu)}$$

$$A_W \approx \frac{u\bar{d} - \bar{u}d}{u\bar{d} + \bar{u}d} \approx \frac{u_{val} - d_{val}}{u_{val} + d_{val} + 2\bar{q}}$$

Variation with η → d/u asymmetry & V-A asymmetric decay of W

- Different predictions from PDF sets→ predictions for **valence** distributions at small-x are different
- A_W varies from +10% to +20% (predicted with 1-2% error)
- Precision at 1% or less, sampled in several rapidity bins → constrains PDFs within a same SET (ie CTEQ)