Ciemat

Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas

EWK studies in CMS

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On behalf of the CMS collaboration

III CPAN DAYS, Barcelona

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Outline

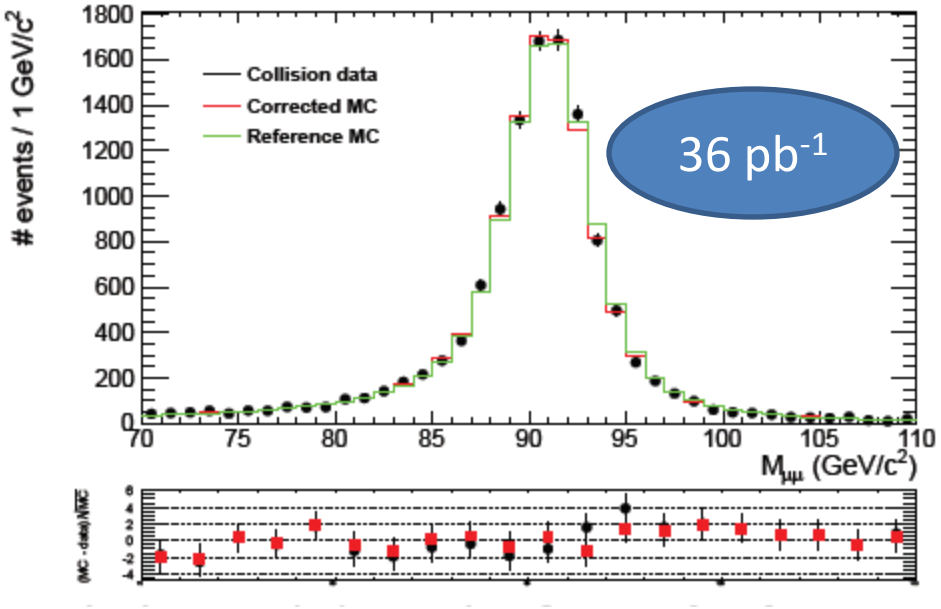
- Introduction
- EWK boson production in CMS
- Precision measurementes with EWK bosons
  - W/Z boson properties
  - W/Z+jets production
  - Dibosons
- Conclusions

Introduction

- EWK studies are important in the early phases of CMS operation since:

1. They are useful to calibrate the detector (trigger, efficiencies, resolutions…)

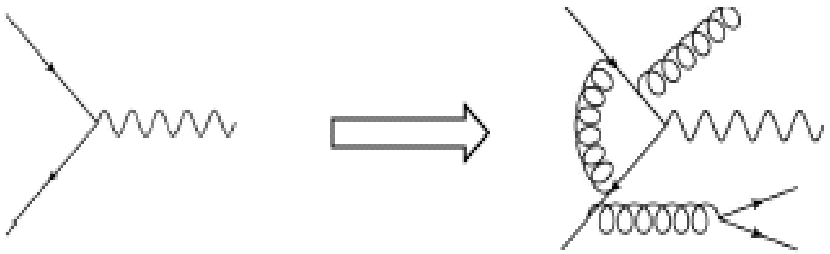
CMS 2010 Data



Experimental Muon Mom resolution estimation used to adequate MC to data

- EWK studies are interesting for physical reasons

1. Measurement of SM parameters
2. Better underst. of QCD processes

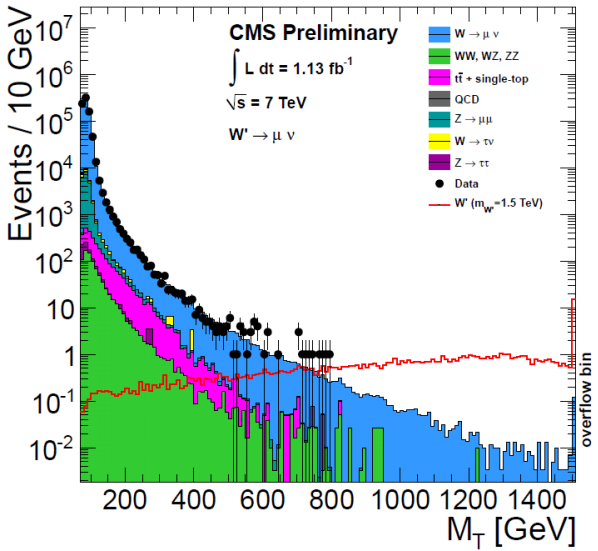


3. Better description of proton composition (PDFs)

Introduction

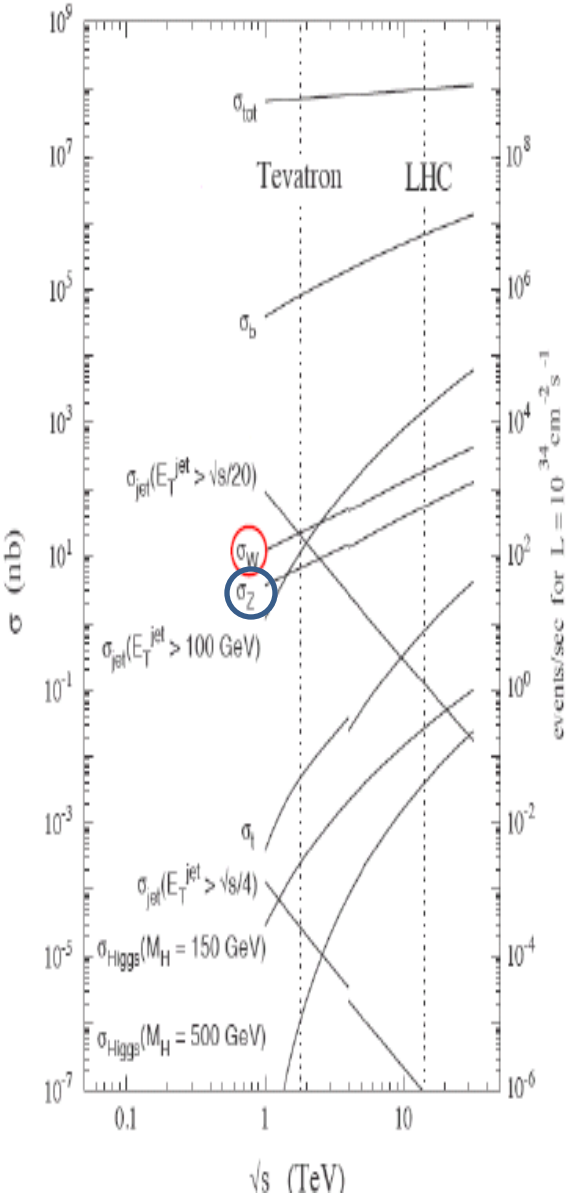
- EWK studies are also important to look for new physics

1. It is background of important searches
2. It can restrict the SM or SM extensions
3. Sensitive to new physics effects



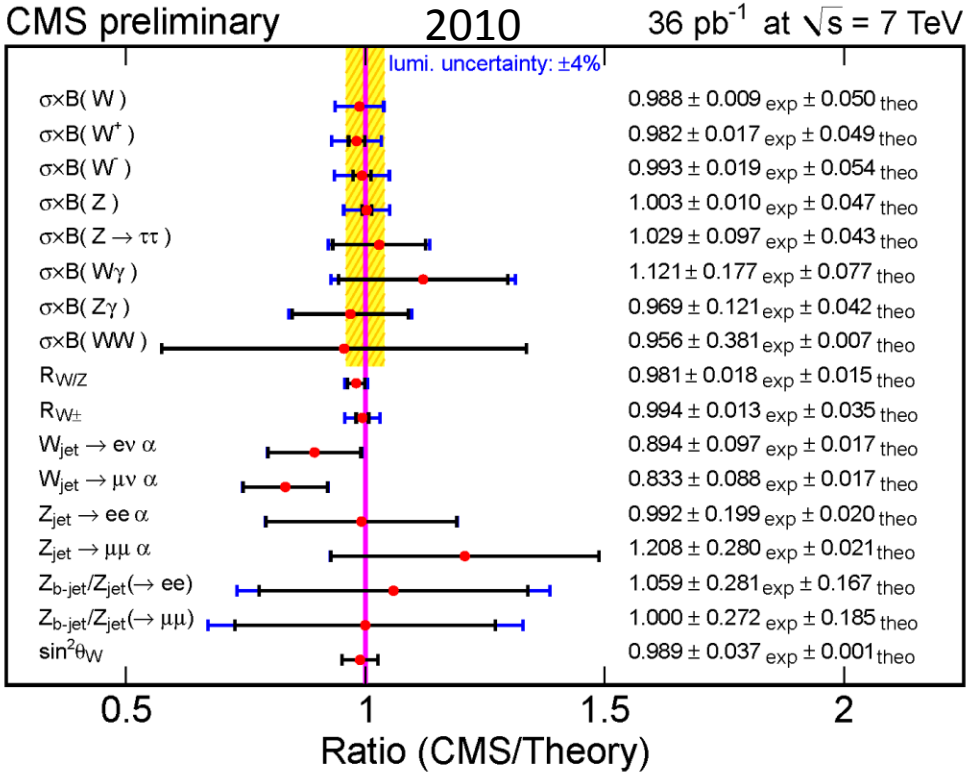
- And…

1. W/Z bosons massively produced in the collisions
2. Leptons are easy and clean to be detected (working with leptonic modes)



Introduction

- EWK results in CMS
  - 13 Conference reports
  - 11 Papers

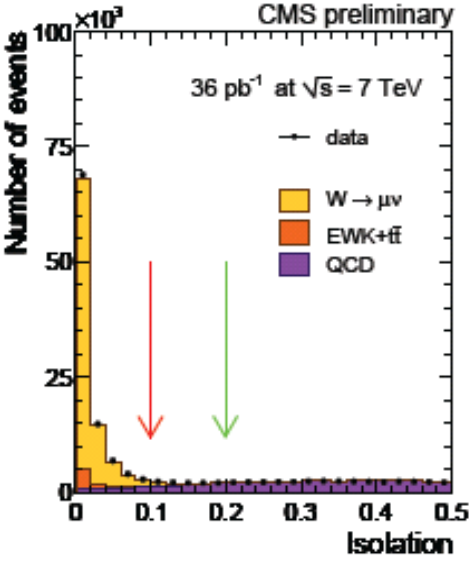


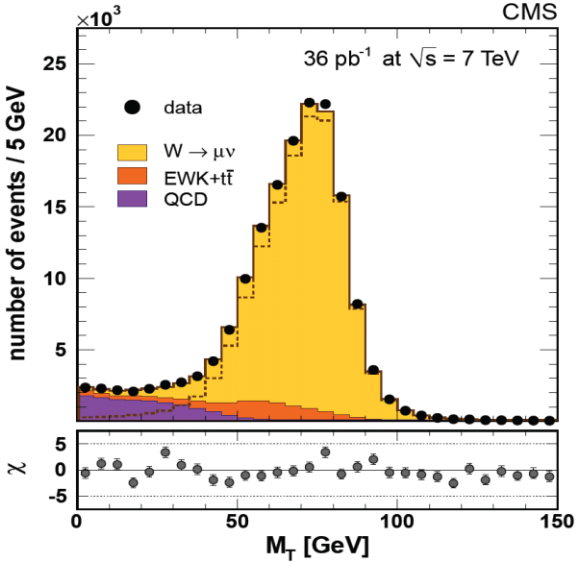
- W/Z cross section measurement (μ,e)
- Z cross section measurement (τ)
- W Charge asymmetry
- W polarization
- Z Differential xsec
- sin θ_W in Z
- W/Z bosons + jets
- W+c
- Z+b
- V+gamma
- WW, WZ and ZZ

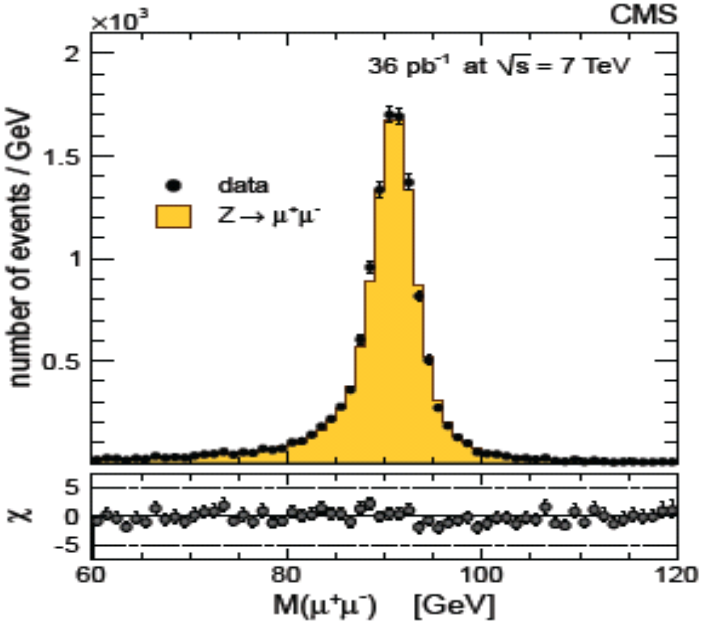
W/Z boson selection

- W→μν selection
  - Pt(mu) > 25 GeV (20 GeV), abs(η)<2.1
  - Muon quality (chi2, number of hits…) and trigger
  - Isolation
  - Zs Veto
  - M_T minimum for a purer sample

$$M_T \equiv \sqrt{2\, p_T^{\mu}\, E_{\mathrm{T}}^{\mathrm{miss}}\, (1-\cos(\phi_{\mu}-\phi_{E_{\mathrm{T}}^{\mathrm{miss}}}))}$$





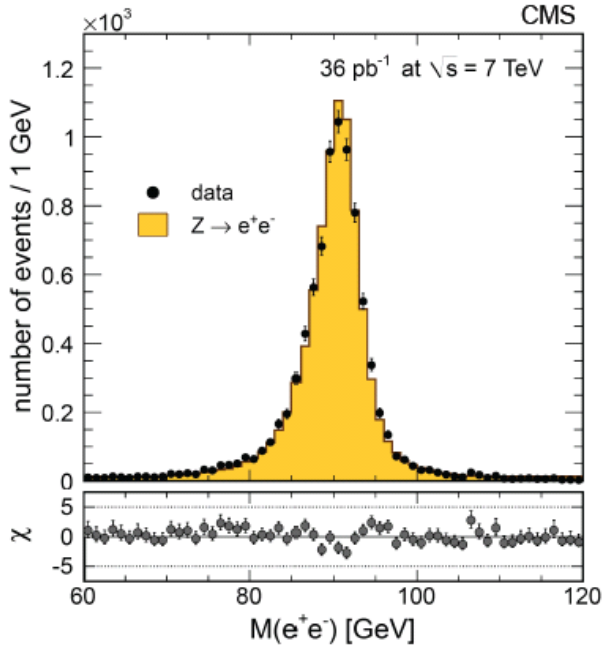


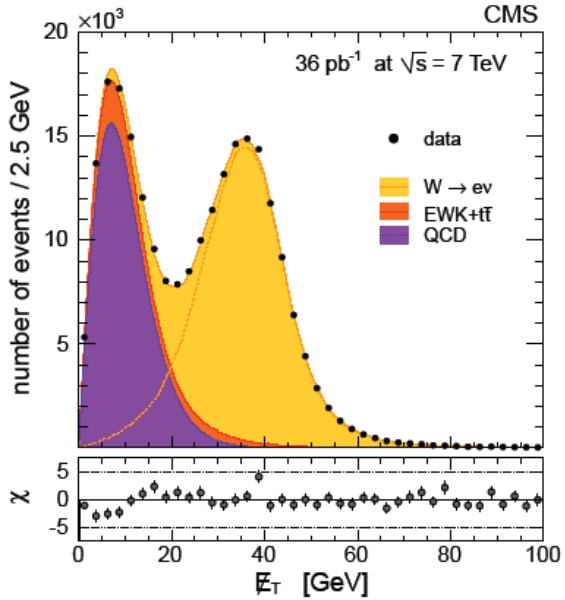
- Z→μμ selection
  - Selection for the second muon may be looser
  - Invariant mass in the mass window [60,120] GeV

W/Z boson selection

- W→eν selection

1. E_T >25 GeV and trigger
2. Cluster-ECAL matching and E_{ECAL} / E_{HCAL} limited
3. Isolated electron
4. Remove conversion of photons
5. Z veto





- Z→ ee selection
  - Second electron requirement may be looser
  - Invariant mass within the window [60,120] GeV

Inclusive measurements

W/Z cross section measurement (μ,e)

CERN-PH-EP-2011-107

Z cross section measurement (τ)

CERN-PH-EP-2011-035

GOALS:

1. Lepton reconstruction and id. test
2. QCD perturbative test
3. PDFs
4. Background for searches

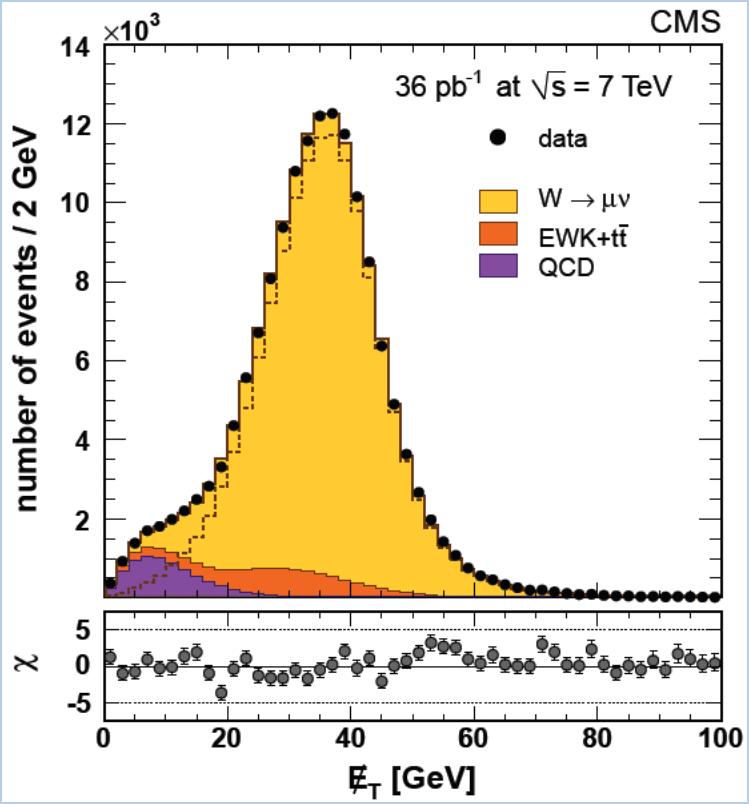
Inclusive measurements

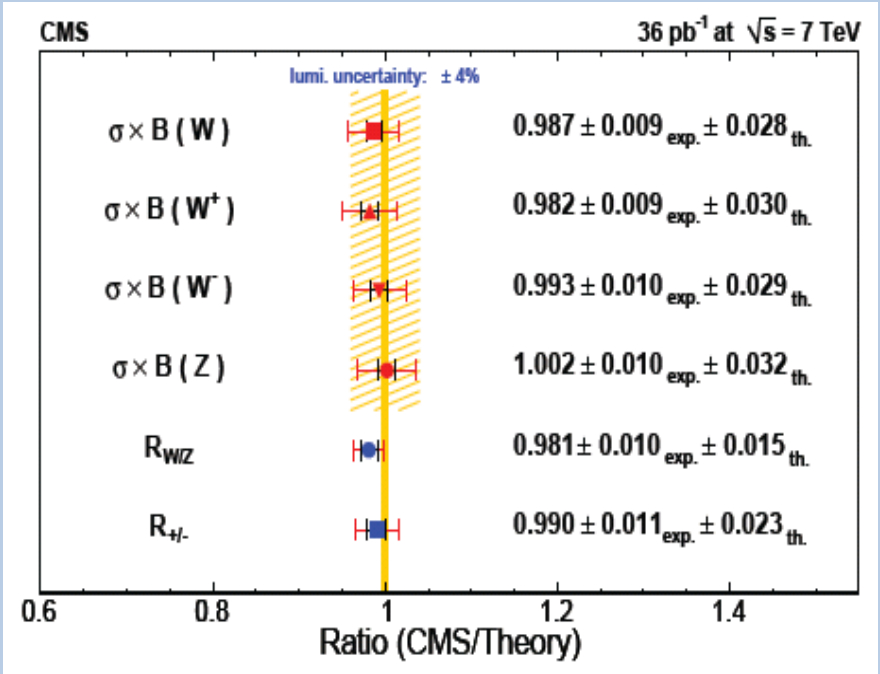
W/Z cross section measurement (μ,e) | Z cross section measurement (τ)

- Results

36 pb^{-1}

1. W cross section fitting on MET (good agreement)
2. Z yield + eff. fitting dilepton inv. mass





Shape and eff from data
Syst. Uncer. Of the order 2%

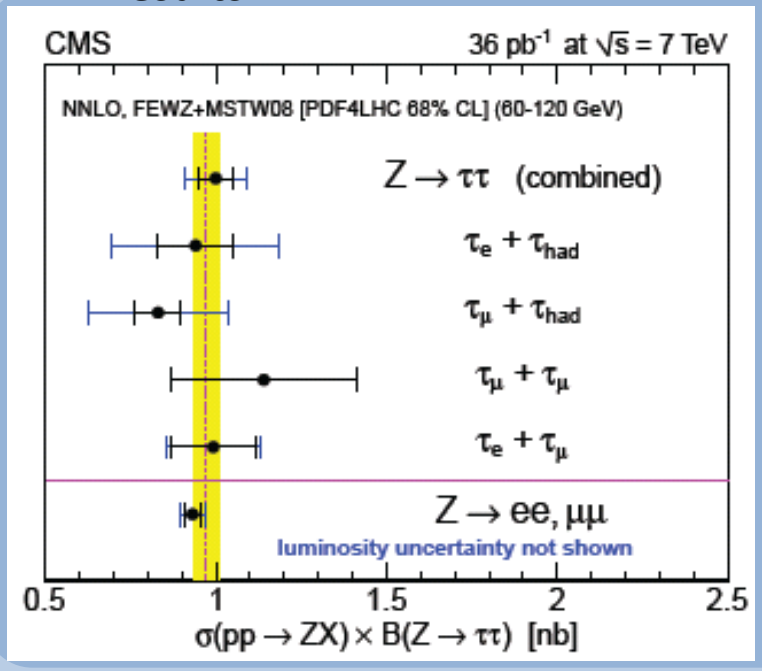
Inclusive measurements

W/Z cross section measurement (μ,e)

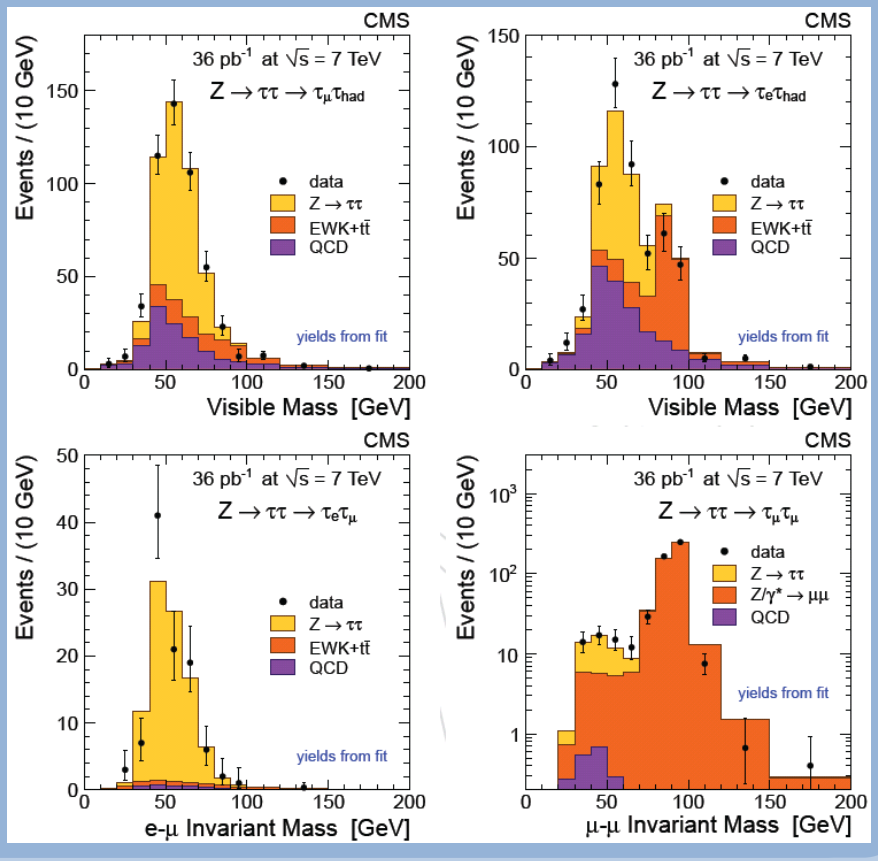
Goals

Foundations for any analysis involving taus (eg. H→ τ τ)

Results



Z cross section measurement (τ)



36 pb^{-1}

Details

- Study of $\tau_\mu\tau_{had}$, $\tau_e\tau_{had}$, $\tau_e\tau_\mu$, $\tau_\mu\tau_\mu$ final states
- τ had: jet collimated wiht low multiplicity
- Fit on the visible mass
- M_T requirement (M_T either smaller than 40 or 50 GeV)

W/Z properties

W Charge asymmetry	W polarization	Z Differential xsec	sin θ_W in Z
CERN-PH-EP-2011-024	CERN-PH-EP-2011-043	CERN-PH-EP-2011-169	CERN-PH-EP-2011-159

GOALS:

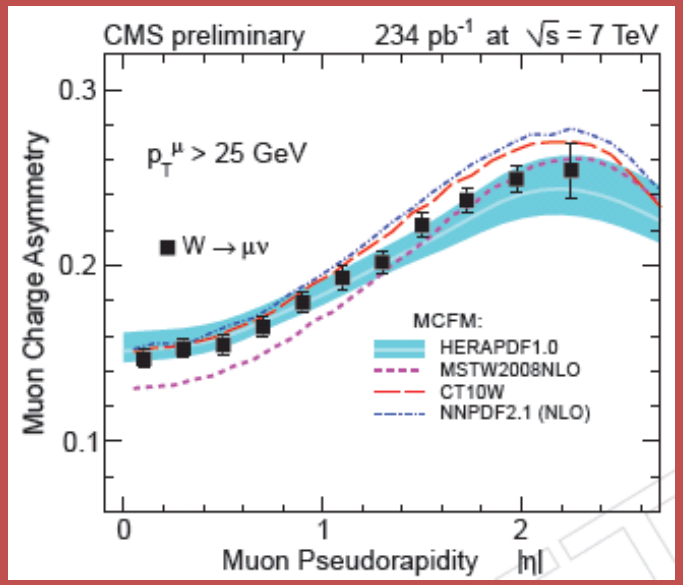
1. Perturb QCD test
2. PDFs
3. Sensitive to new physics

W/Z properties

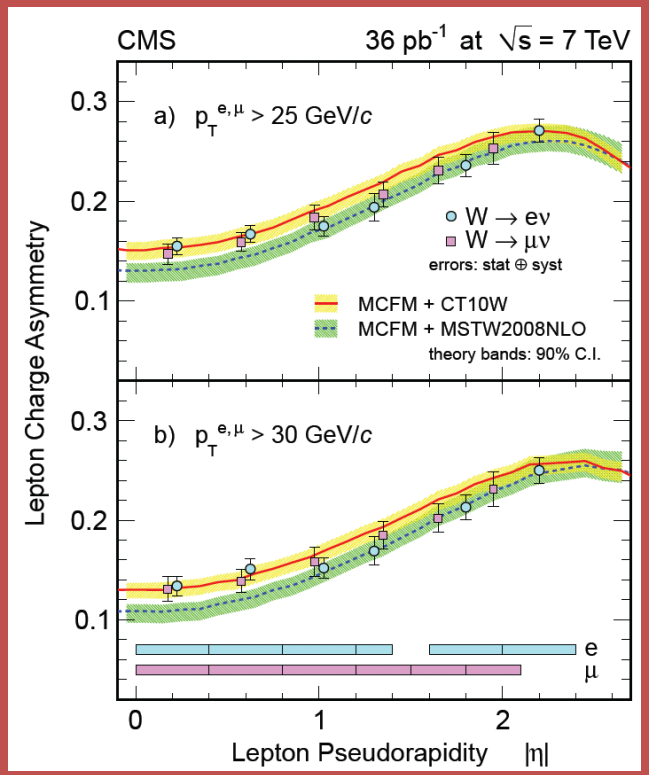
W Charge asymmetry | W polarization | Z Differential xsec | sin θ_W in Z

Goals

u/d ratio and antiquark density in the proton. Check SM prediction



Results



234 pb^{-1}

Definition

we measure the lepton charge asymmetry:

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

W/Z properties

W Charge asymmetry | **W polarization** | Z Differential xsec | sin θ_W in Z

Goals

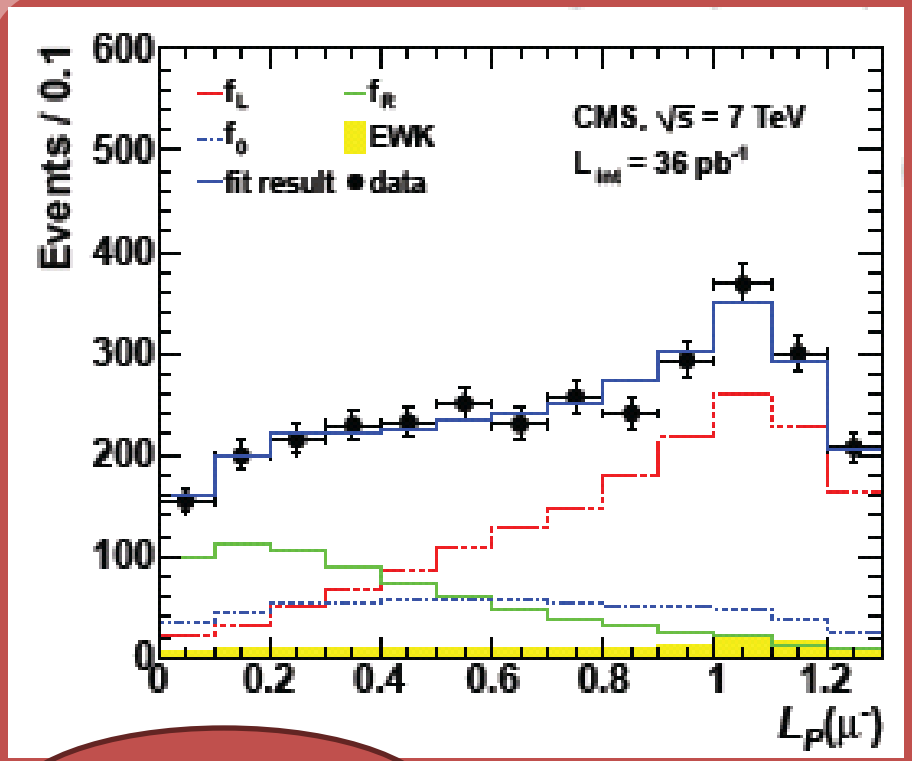
PDFs. Test QCD pertub. Test W boson V-A couplings.

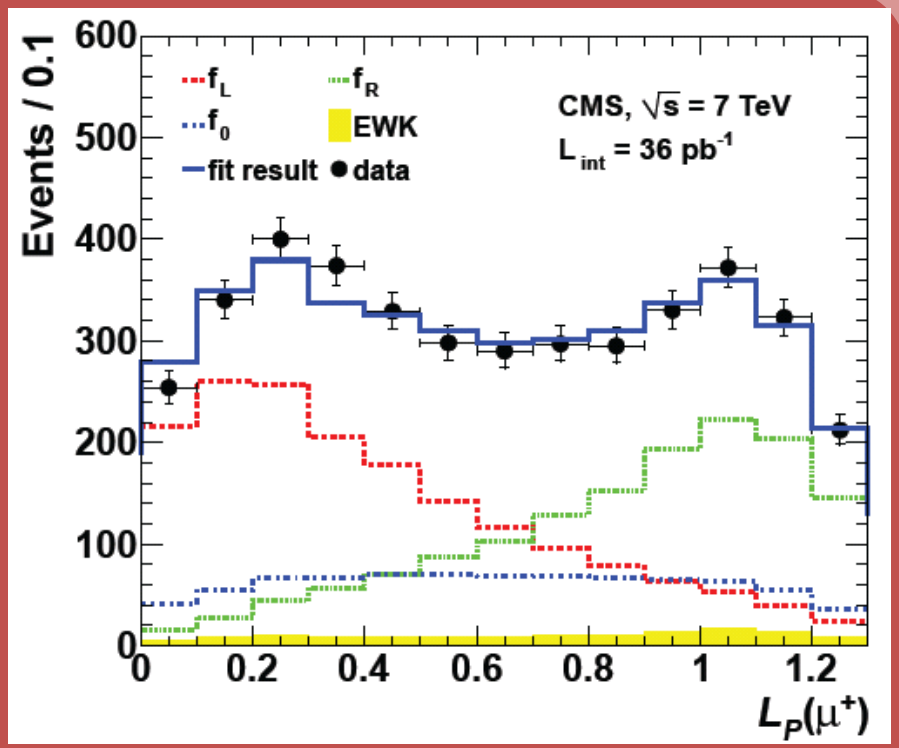
Definition

We measure the polarization through L_P

$$L_P = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

Results





36 pb^{-1}

- Usual requirements plus M_T cut (30 GeV for muons, 50 GeV for electrons)
- pt(W) > 50 GeV (polarization increases with boson pt)
- Cut on number of jets (3 max) with pt>30 GeV and η<5 to reduce ttbar.

W/Z properties

W Charge asymmetry | **W polarization** | Z Differential xsec | sin θ_W in Z

Goals

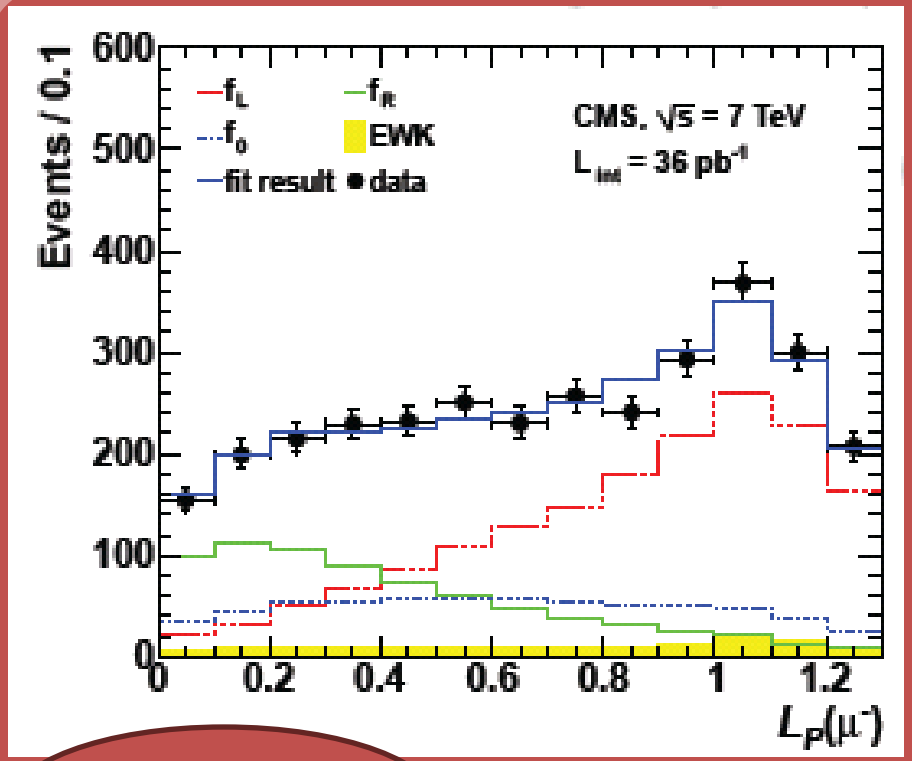
PDFs. Test QCD pertub. Test W boson V-A couplings

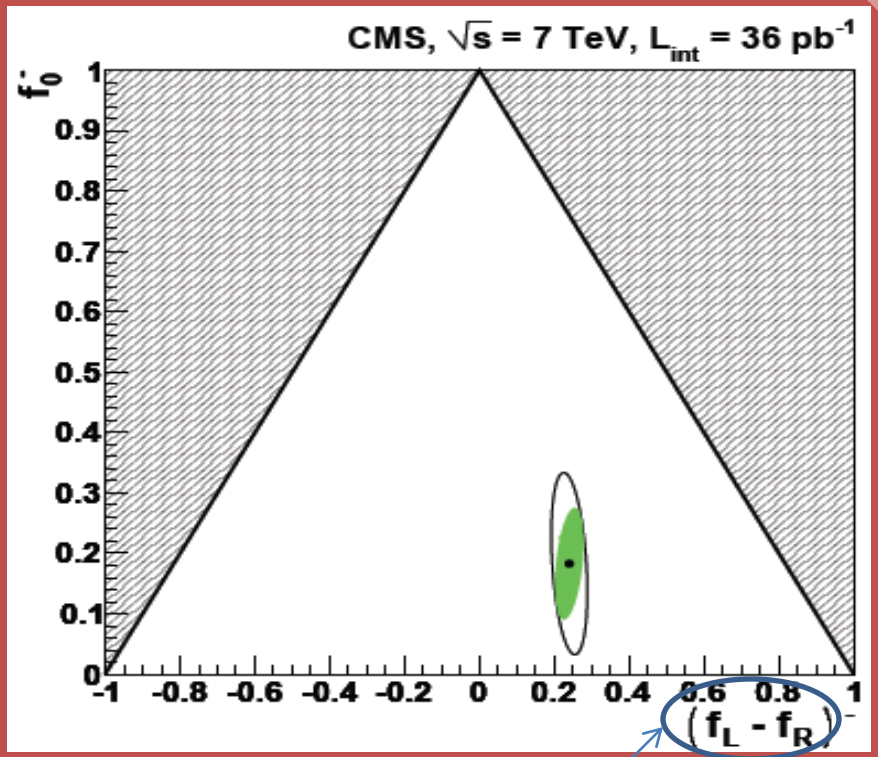
Definition

We measure the polarization through L_P

$$L_P = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

Results





36 pb^{-1}

Left and right polarization fractions

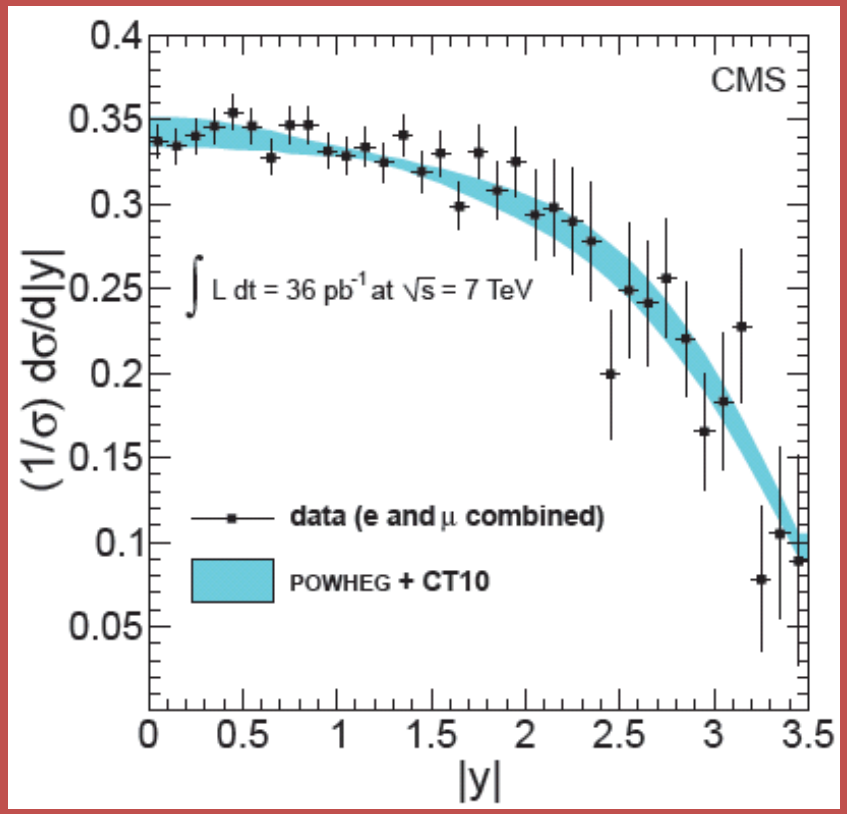
W/Z properties

W Charge asymmetry | W polarization | **Z Differential xsec** | sin θ_W in Z

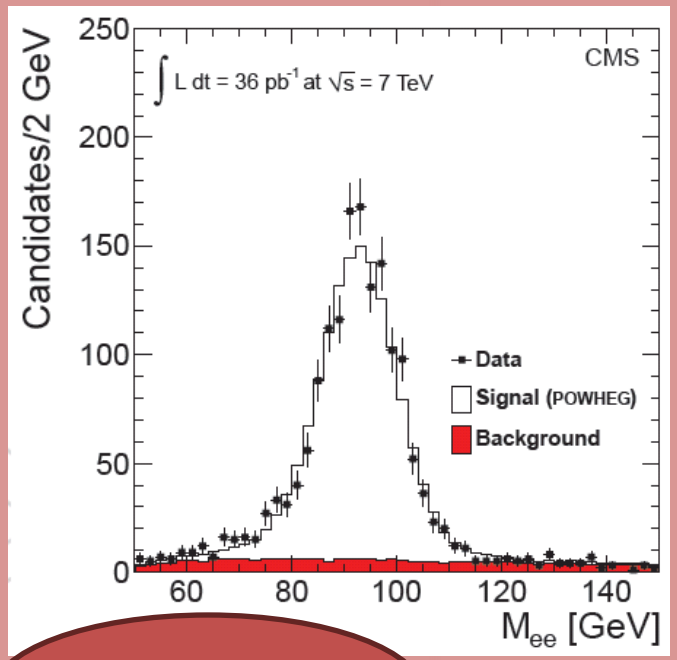
Goals

- Rapidity: sensitive to PDFs , specially high *y* region
- P_T: better unders. of underlying event (low P_T) and NNLO QCD prediction (high P_T)

Results (rapidity)



Cross section studied in a new region in *y*. No tracking used in the forward region (calorimetry)



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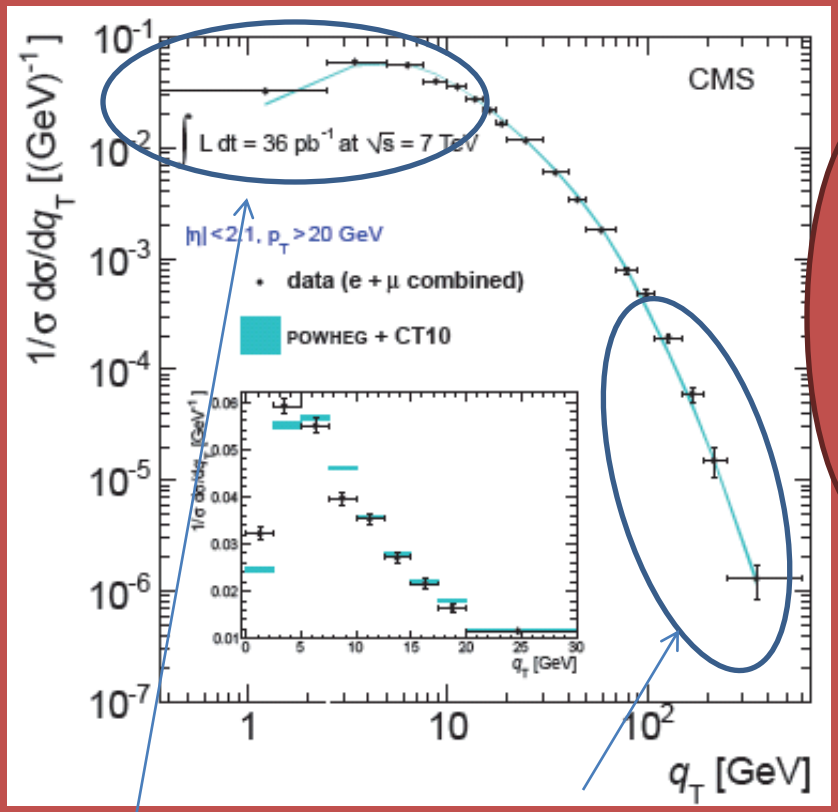
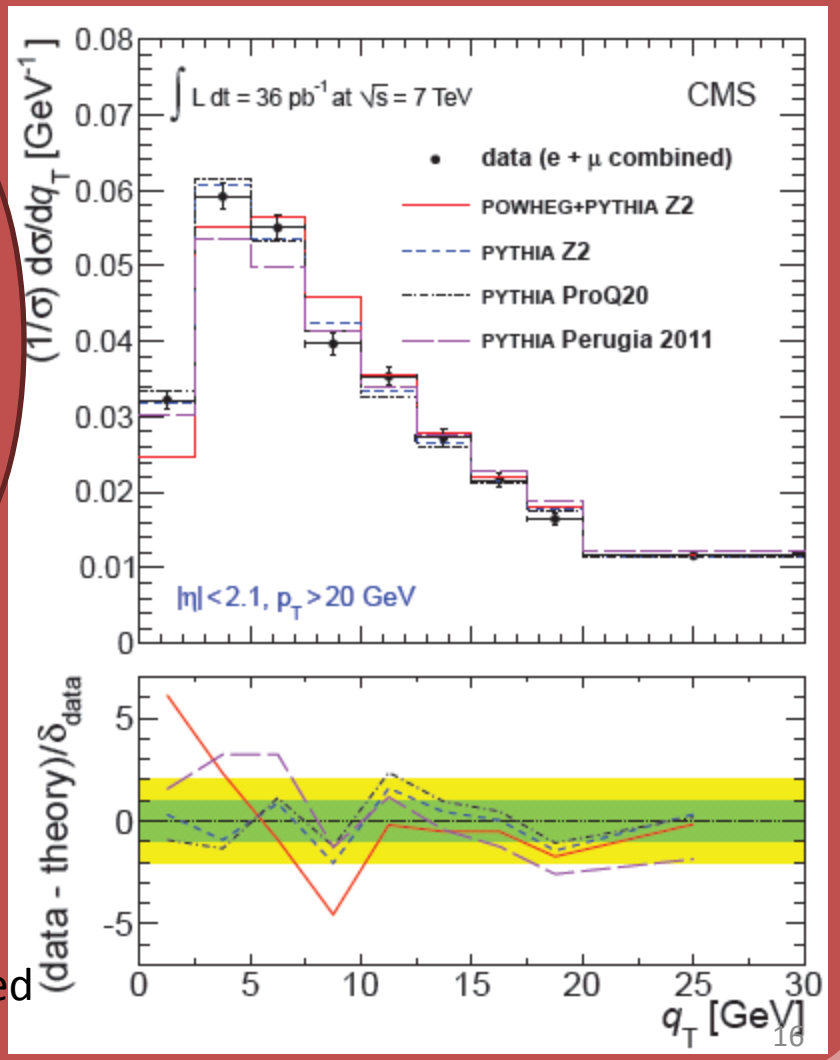
W/Z properties

Results (momentum)



36 pb^{-1}



- Determined by non-perturbative QCD and tuning
- Good agreement with Pythia Z2 tune

- Dominated by perturbative order
- Disagreement observed with Z2 and FEWZ

W/Z properties

W Charge asymmetry | W polarization | Z Differential xsec | **sin θ_W in Z (μ)**

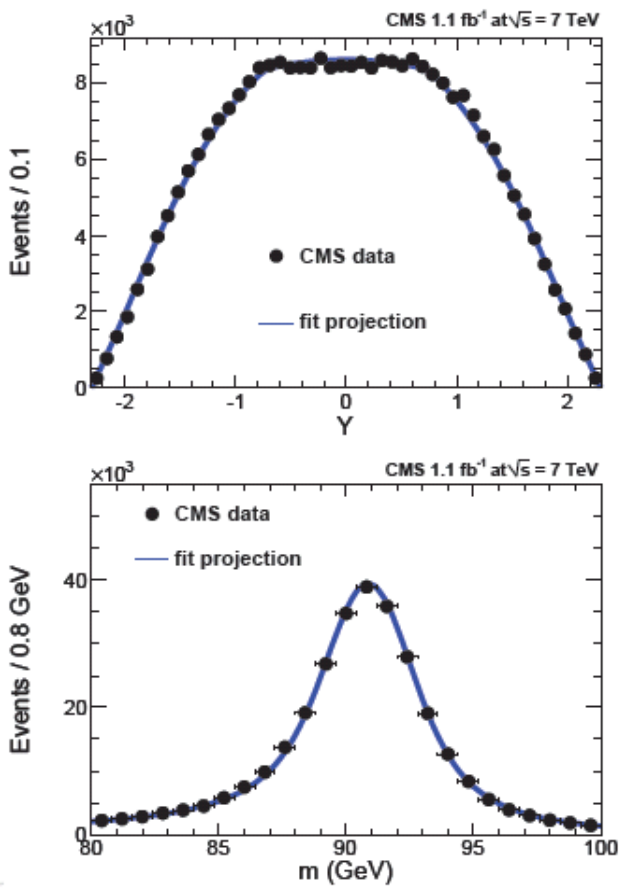
Goals

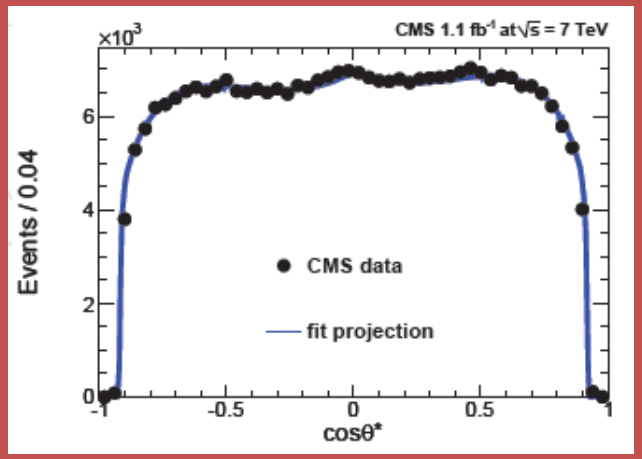
Sin θ_W is the only free parameter to test fermion/boson couplings

Definition

- Multivariate analysis on *y*, inv. mass and Collins-Soper angle
- EWK interactions description is taken from SM, **sin θ_W** is free
- Unbinned maximum likelihood

Results





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

1.1 fb^{-1}

V+jets

W/Z bosons + jets	W+c	Z+b
CERN-PH-EP-2011-125	CMS-EWK-11-013	CMS-EWK-11-012

GOALS:

1. Test QCD perturb.
2. C/B tagging techniques
3. Background of many studies

V+jets

W/Z bosons + jets | W+c | Z+b

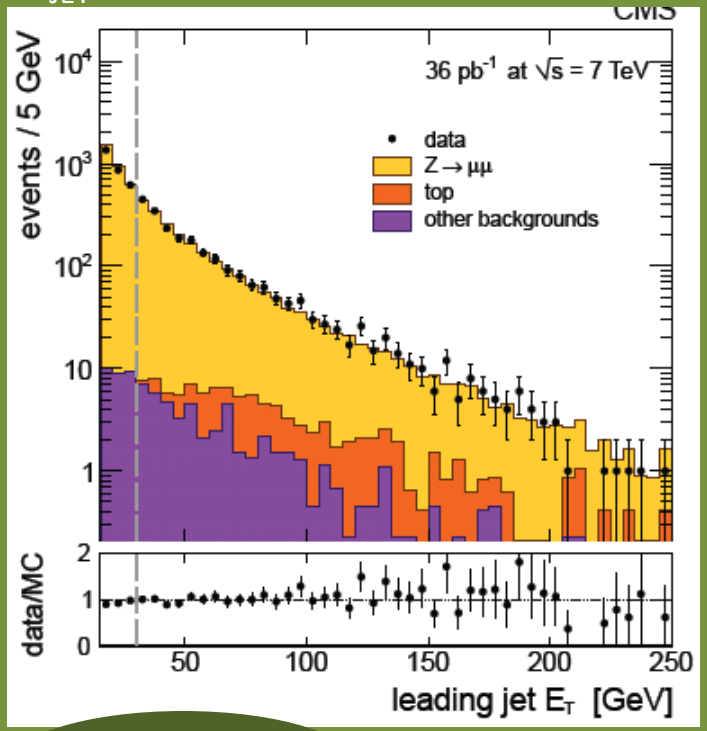
Goals

Test perturb QCD. Background of many studies. Benchmark for top studies (top exclusively decays into W+b).Sensitive to new physics

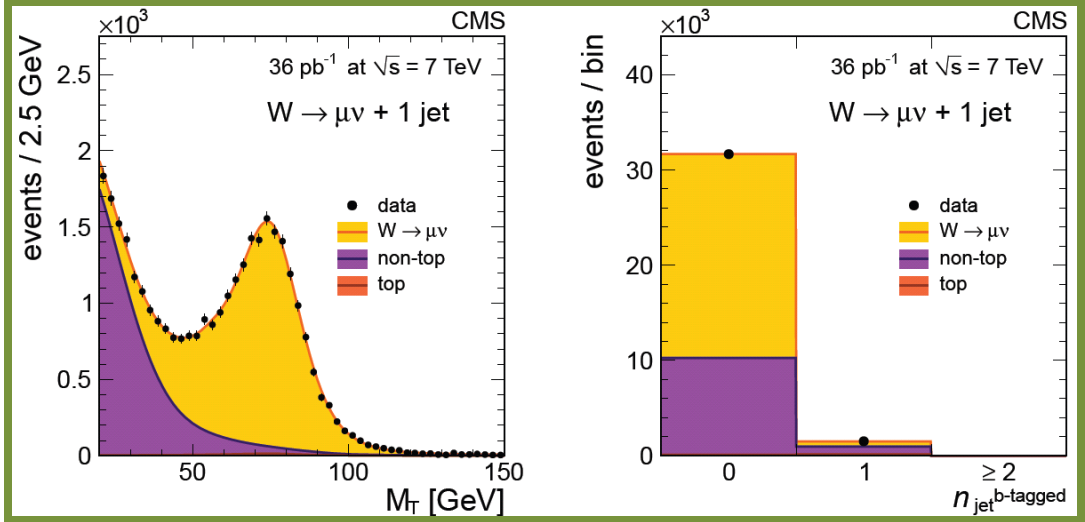
Method

Standard requirements +

E_{JET} > 30 GeV and Min MT = 50GeV



Jet : group of particles defined as jet by PF applying an anti-kt cluster algorithm (R=0.5)



Fit to MT and nbtag (W) and Inv Mass (Z)

36 pb^{-1}

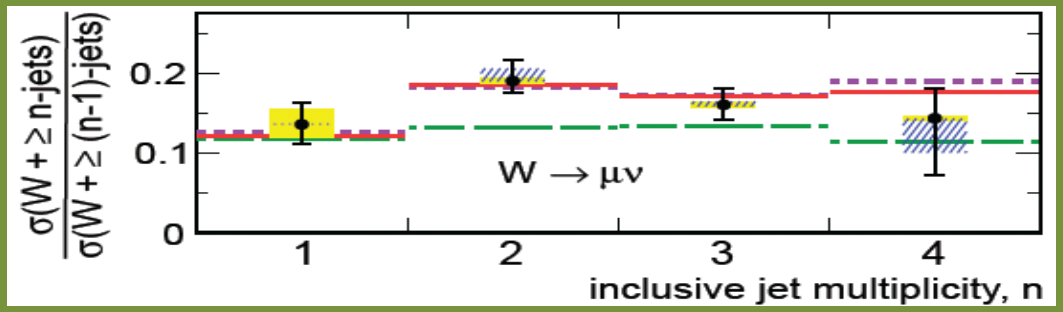
V+jets

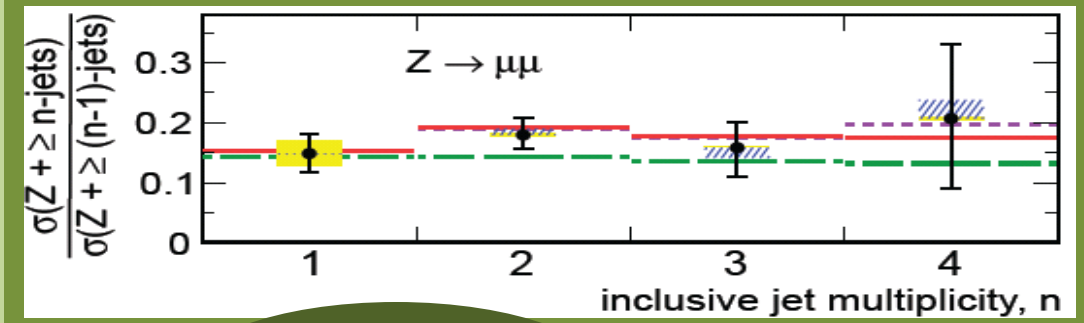
W/Z bosons + jets | W+c | Z+b

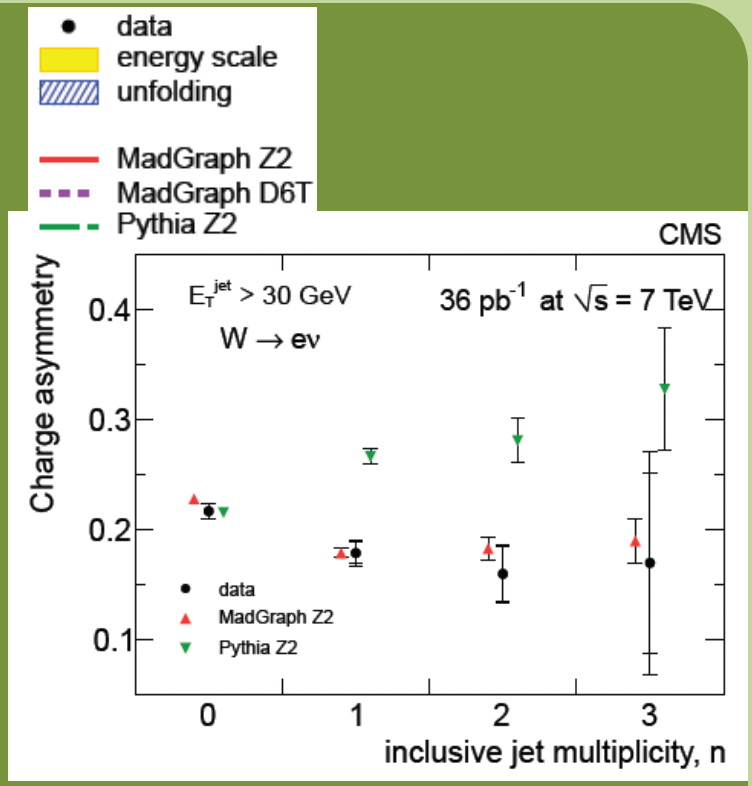
Goals

Test perturb QCD. Background of many studies, top studies.Sensitive to new physics

Results







36 pb^{-1}

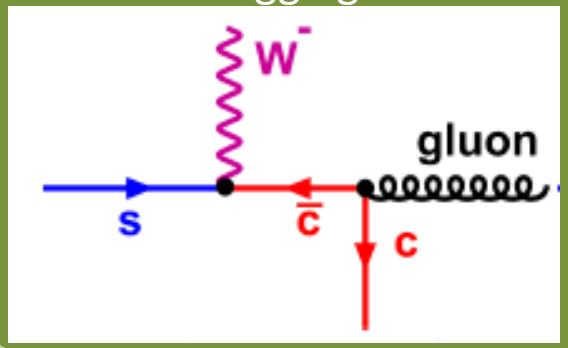
Good agreement with MADGRAPH MC in general

V+jets

W/Z bosons + jets | **W+c** | Z+b

Goals

Direct access to the strange content of the proton. C tagging



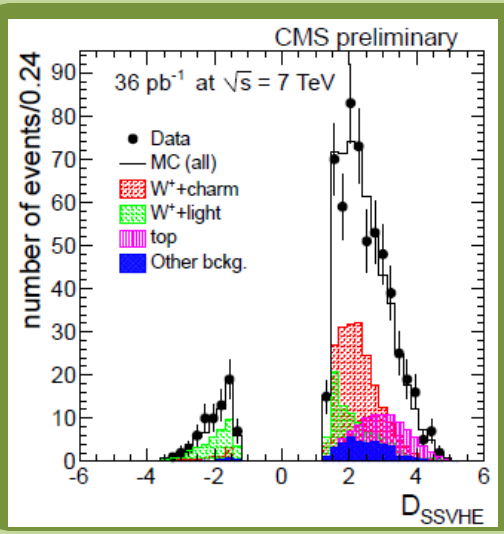
36 pb^{-1}

Method

- Only muon channel
- Standard selection for W + Mt min 50 GeV
- Cut in number of jets to reduce top backg (jet pt > 20 GeV)

$$R_c \equiv \sigma(W+c)/\sigma(W+jets)$$

$$R_c^{\pm} \equiv \sigma(W^+\bar{c})/\sigma(W^-c)$$



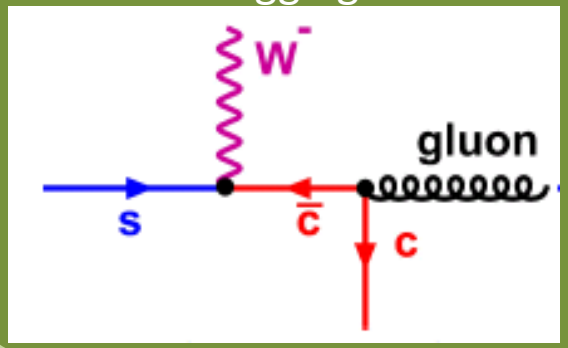
- Binned likelihood fit to 3 components
- SSVHE (Simple Secondary Vertex High Efficiency) b-tagging Discriminator: flight distance significance of the meson/barion
- HE vs HP: High Efficiency implies vertices with at least 2 tracks, High Purity only vertices with 3 tracks

V+jets

W/Z bosons + jets | **W+c** | Z+b

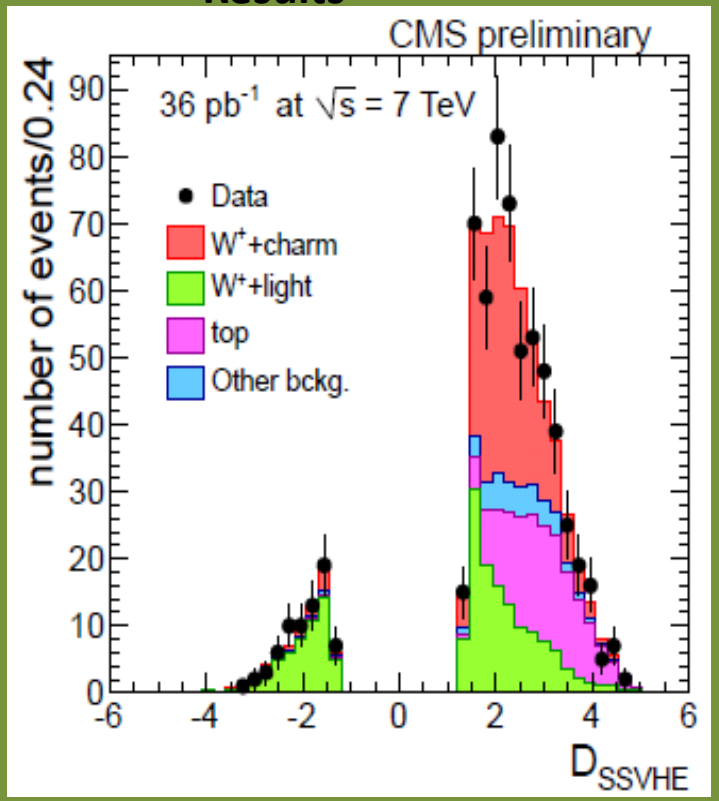
Goals

Direct access to the strange content of the proton. C tagging



36 pb^{-1}

Results



$$R_c^{\pm} = 0.92 \pm 0.19\ (stat.) \pm 0.04\ (syst.)$$

$$R_c = 0.143 \pm 0.015\ (stat.) \pm 0.024\ (syst.)$$

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

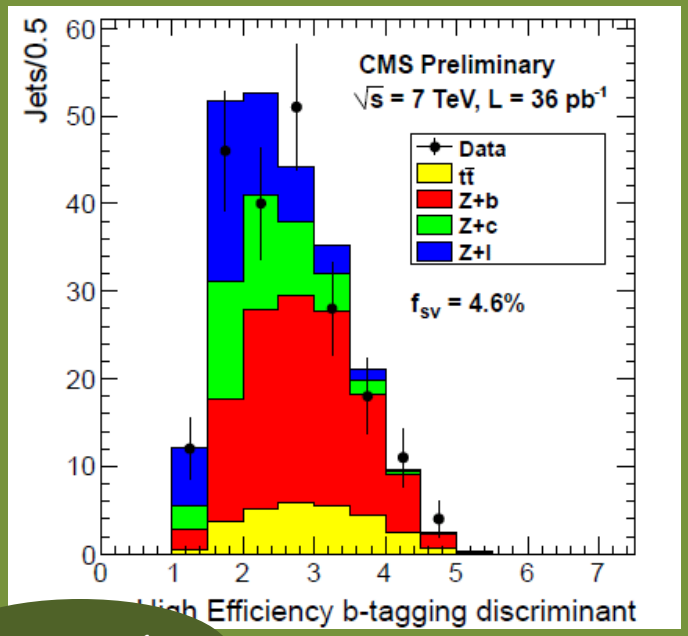
V+jets

W/Z bosons + jets | W+c | **Z+b**

Goals

Background in many searches. Useful for analysis with b quarks

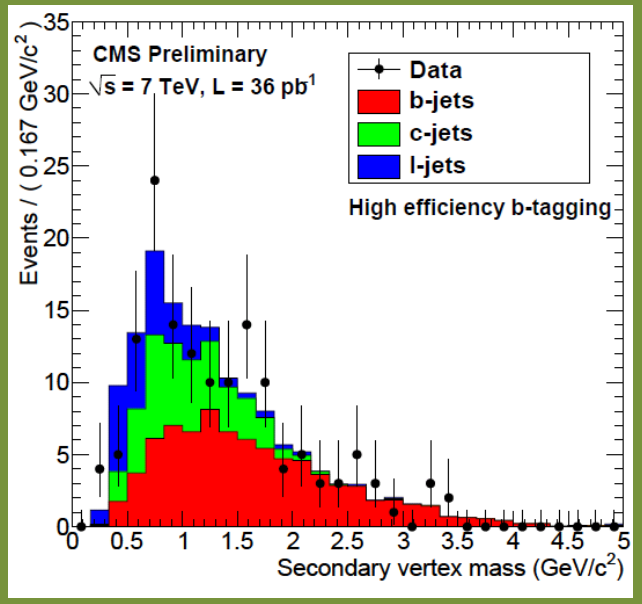
Results



$$\mathcal{R} = \frac{N_{Z+b}^{data}\mathcal{P} - N_{t\bar{t}}^{MC}}{N_{Z+j}^{data}\varepsilon_{MC}}$$

Z decay in e and muons

Jet Pt > 25 GeV
Jet eta < 2.1



36 pb^{-1}

	$\mathcal{R}(Z \to ee)$ (%), $p_T^e > 25$ GeV, $\lvert\eta^e\rvert < 2.5$	$\mathcal{R}(Z \to \mu\mu)$ (%), $p_T^\mu > 20$ GeV, $\lvert\eta^\mu\rvert < 2.1$
Data HE	$4.3 \pm 0.6(stat) \pm 1.1(syst)$	$5.1 \pm 0.6(stat) \pm 1.3(syst)$
Data HP	$5.4 \pm 1.0(stat) \pm 1.2(syst)$	$4.6 \pm 0.8(stat) \pm 1.1(syst)$
MADGRAPH	$5.1 \pm 0.2(stat) \pm 0.2(syst) \pm 0.6(theory)$	$5.3 \pm 0.1(stat) \pm 0.2(syst) \pm 0.6(theory)$
MCFM	$4.3 \pm 0.5(theory)$	$4.7 \pm 0.5(theory)$

Dibosons

V+gamma

CERN-PH-EP-2011-045

WW, WZ and ZZ

CERN-PH-EP-2011-015

GOALS:

1. Study of anomalous triple gauge couplings (new physics)
2. SM test

Dibosons

V+gamma

Goals

SM test. Sensitive to new physics (aTGC)

Selection

Standard selection on V + :

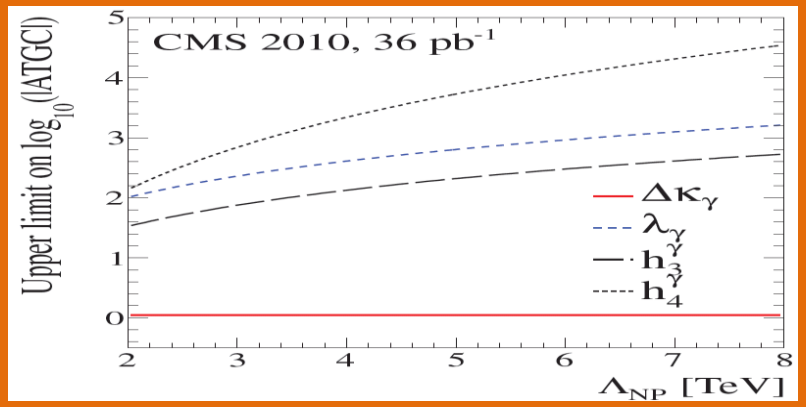
- Only 1 phton with E_T>10 GeV
- Ang. separation lepton-photon >0.7

Dominant bckg W+jets (Z+jets) of 50% (30%)

$$\sigma = \frac{N_{\text{data}} - N_{\text{bkg}}}{A\epsilon\mathcal{L}}$$

Cut-and-count

Anomalous coupling upper limit

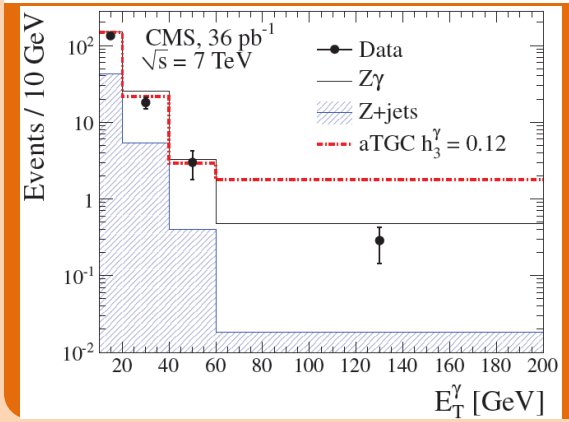


WW, WZ and ZZ

Zγ

Dilepton inv mass > 50 GeV

$\sigma(pp \to Z\gamma + X) \times \mathcal{B}(Z \to \ell\ell) = 9.4 \pm 1.0\,(\text{stat.})$



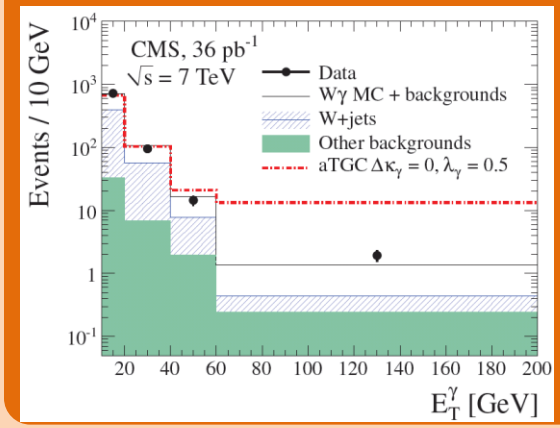
± 0.6 (syst.)

± 0.4 (lumi.) pb

Wγ

MET > 25 GeV

$\sigma(pp \to W\gamma + X) \times \mathcal{B}(W \to \ell\nu) = 56.3 \pm 5.0\,(\text{stat.})$



± 5.0 (syst.)

± 2.3 (lumi.) pb

Dibosons

V+gamma

WW, WZ and ZZ

Goals

Test of SM and sensitive to new physics

WW

3 final states: ee, mumu, emu

Selection requires:
- MET projected > 40 or 20 GeV (DY and tau events)
- No jets (ptjet>30 GeV)
- Top-veto based on soft muon and b-tagging
- Z veto

Result

$\sigma_{W^+W^-} = 55.3 \pm 3.3\,(\text{stat}) \pm 6.9\,(\text{syst}) \pm 3.3\,(\text{lumi})$ pb.

SM 43.0 ± 2.0 pb

36 pb^{-1}

WZ

Four final states: eee, eemu, mumue and mumumu

Selection:
- Z boson reconstructed, + another lepton + MET

75 events reconstructed

SM 19.790 ± 0.088

Result

$\sigma(pp \to WZ + X) = 17.0 \pm 2.4\,(\text{stat.}) \pm 1.1\,(\text{syst.}) \pm 1.0\,(\text{lumi.})$ pb.

ZZ

Final states not only with e/mu but also with taus

Isolation requirement relaxed with respect to standard selection

8 observed events in total

SM 6.4 ± 0.6 pb

Result:

$\sigma(pp \to ZZ + X) = 3.8^{+1.5}_{-1.2}(\text{stat.}) \pm 0.2(\text{sys.}) \pm 0.2(\text{lumi.})$ pb

Cross section measured using Cut-and-count method:

$$\sigma = \frac{N_{sig}}{A \cdot \epsilon \cdot \mathcal{L}}$$

Dibosons

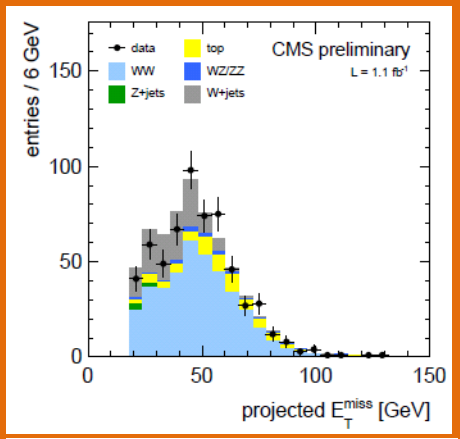
V+gamma

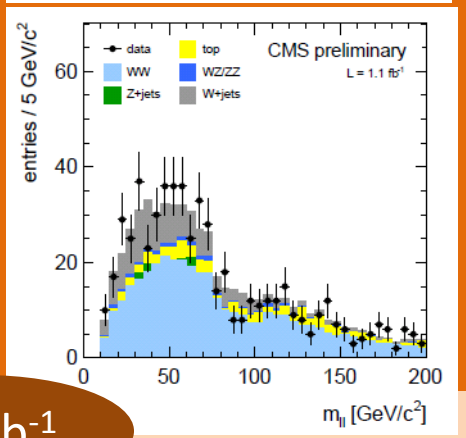
WW, WZ and ZZ

Goals

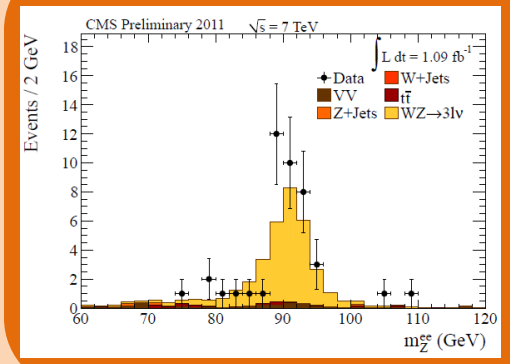
Test of SM and sensitive to new physics

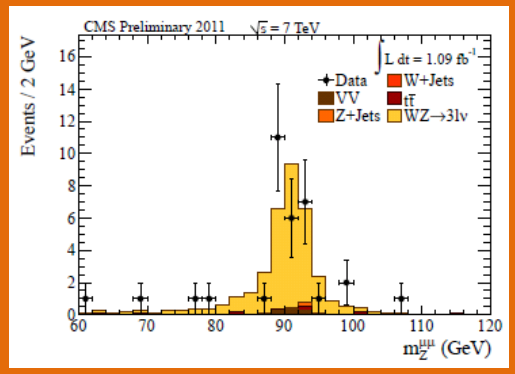
WW



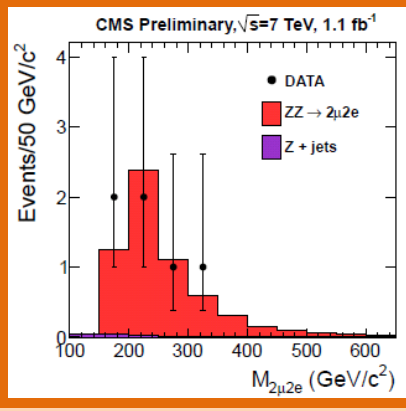


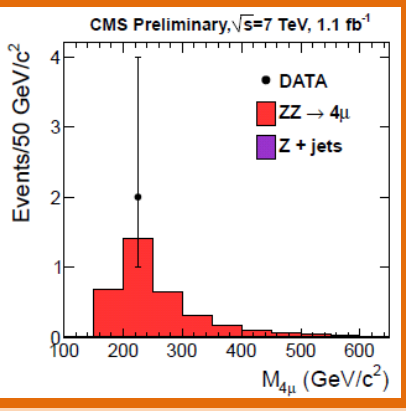
WZ





ZZ





Cross section measured using Cut-and-count method:

$$\sigma = \frac{N_{sig}}{A \cdot \epsilon \cdot \mathcal{L}}$$

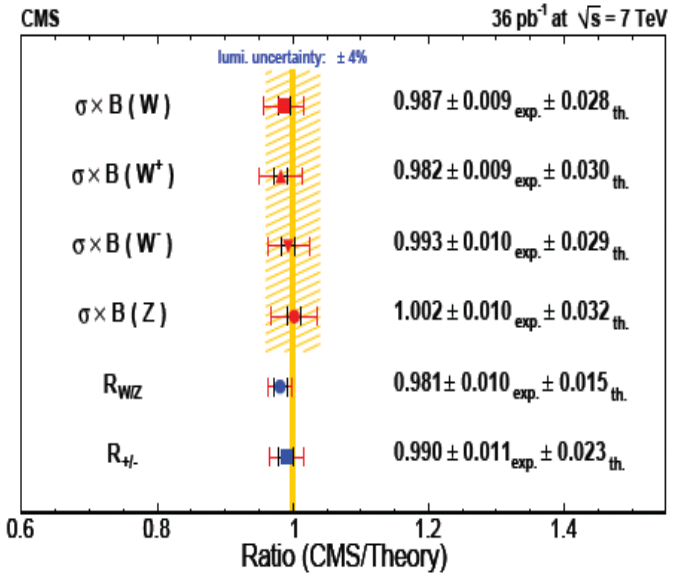
36 pb^{-1}

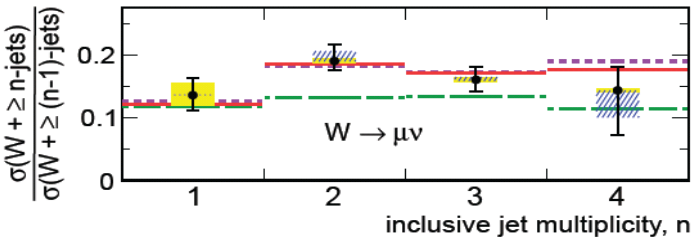
Conclusions (1/2)

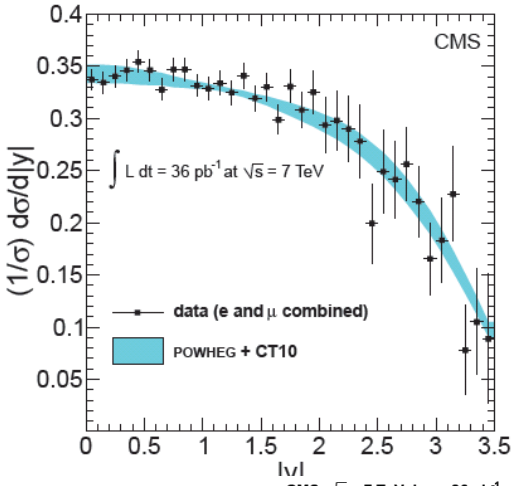
- EWK measurements are very important in CMS for calibration purposes, searches and PDFS
- EWK group in CMS: 11 papers and 13 conference reports published
- Precision measurements with W/Z bosons, interesting results in:
  - W/Z boson properties
  - W/Z + jets production
  - Dibosons

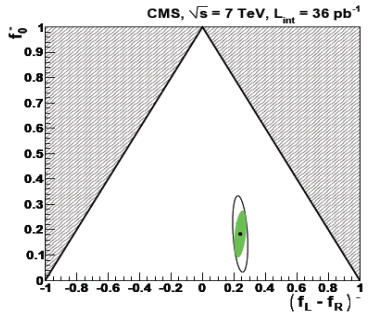
Conclusions (2/2)

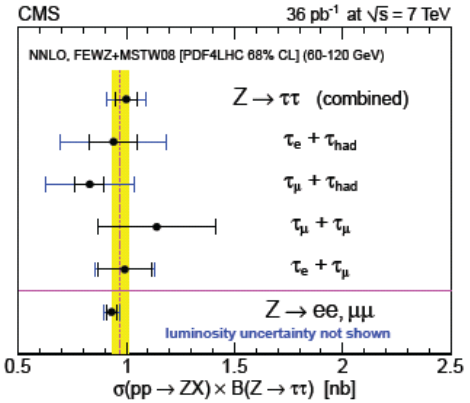
- Results in agreement with SM expectations in a new energy scale

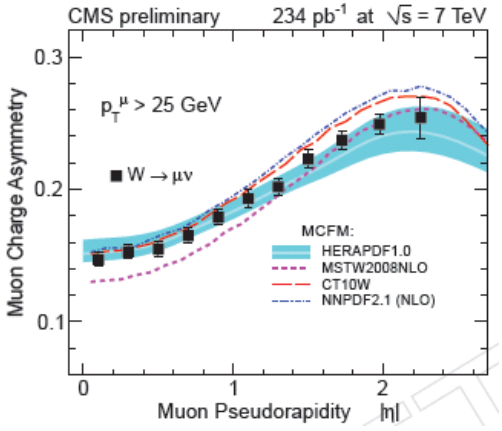












Ciemat

Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas

EWK studies in CMS

Javier Santaolalla (CIEMAT-Madrid)

On behalf of CMS collaboration

III CPAN DAYS, Barcelona

2 Nov 2011