CMS results in Electroweak Physics

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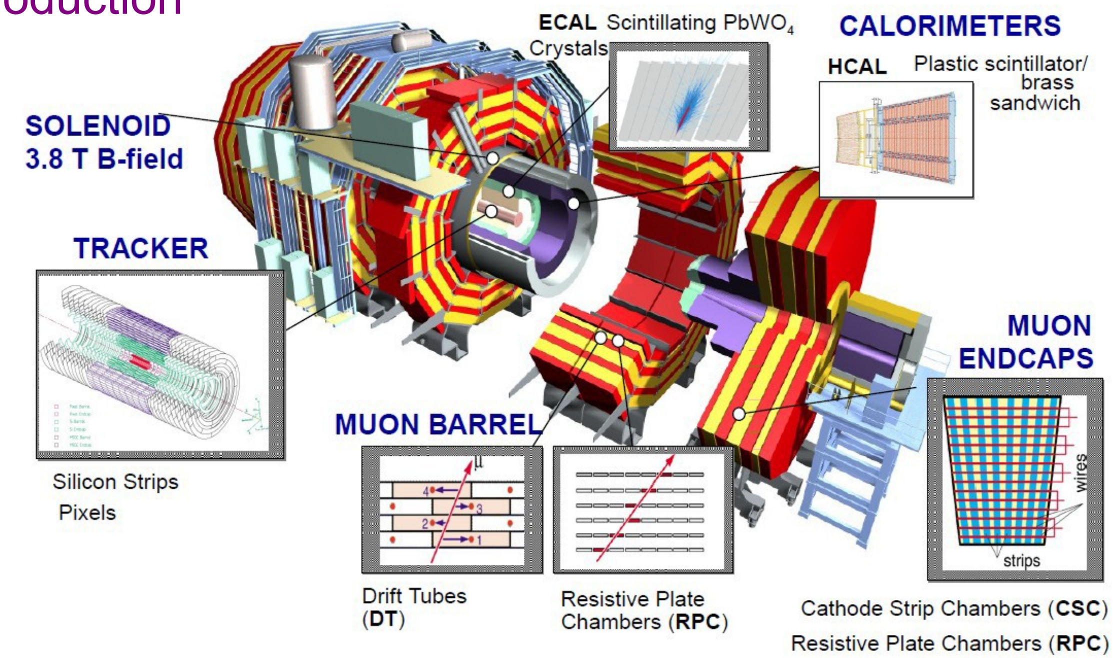
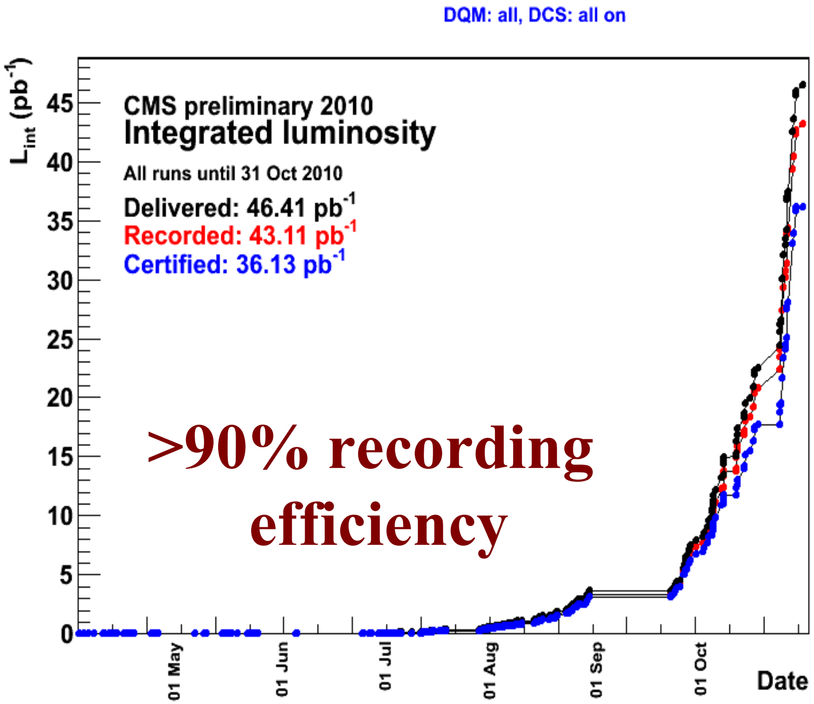
OUTLINE

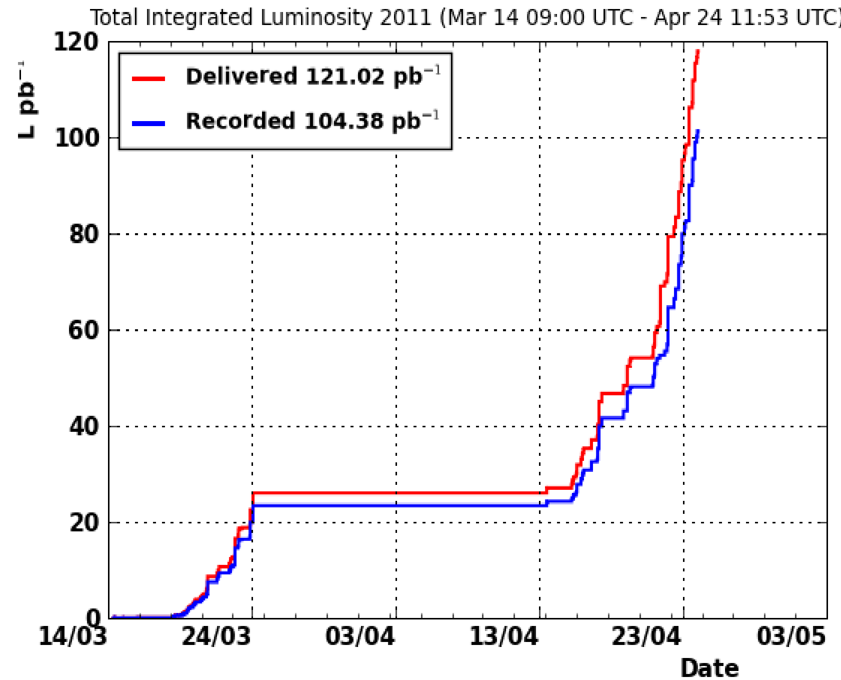
CMS electroweak results reported in this seminar:

- Inclusive W and Z measurements in electron and muon channels
- W lepton charge asymmetry, W polarization
- Drell-Yan differential distributions, measurement of $\overline{\sin^2\bar{\theta}}_W$
- Z and W production in tau channels
- Associated jet production, associated b-jet production
- Diboson production



CMS is taking data ...

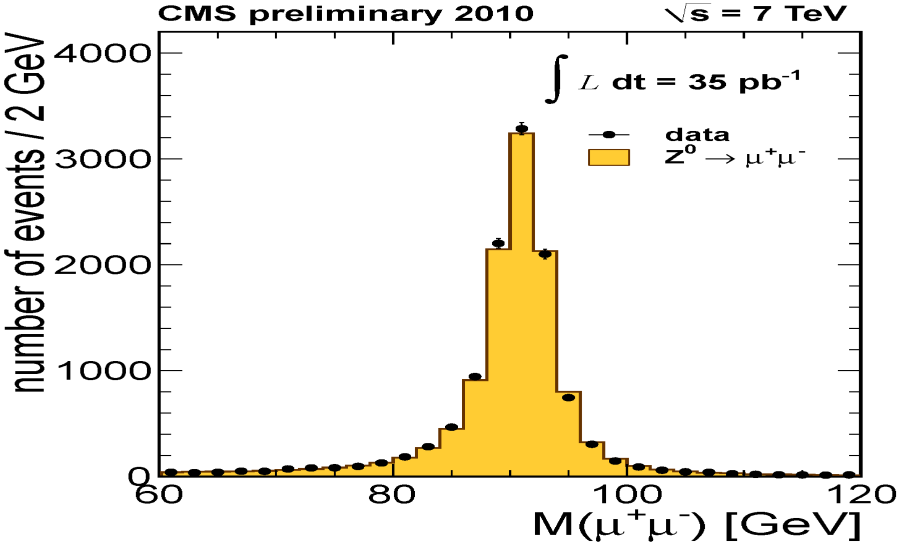


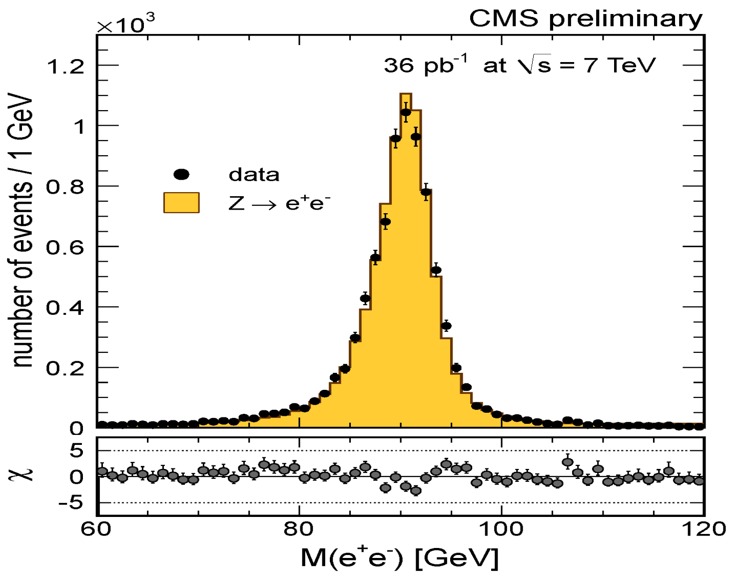


- All studies reported in this talk use 2010 pp collisions data corresponding to an integrated luminosity of ≈ 36 pb^{-1}
- With a >98% operational detector and in essentially 'nominal' conditions: Level-1 trigger rates > 50 kHz, HLT rates > 300 Hz
- Already > 100 pb^{-1} recorded in 2011! More precise measurements (and hopefully discoveries) expected in the next months!

Muons and electrons

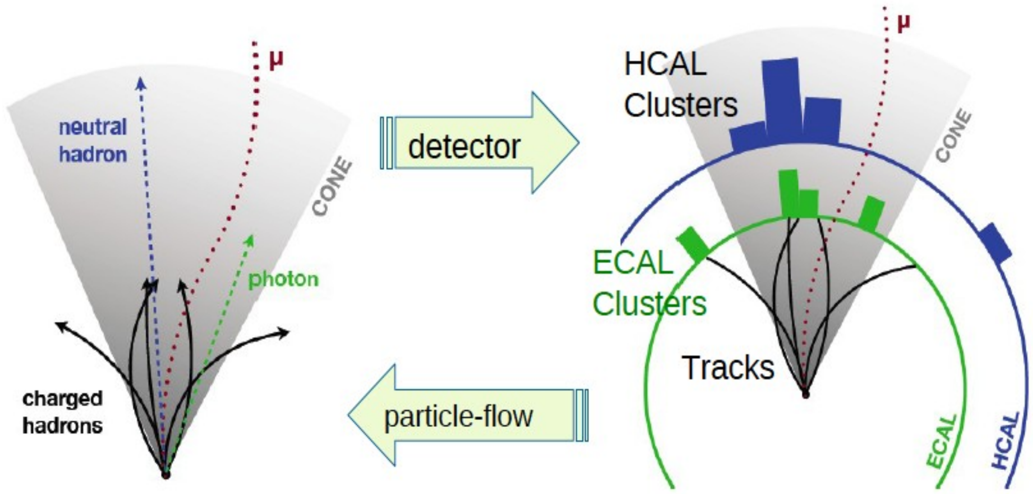
- Muon resolution dominated by inner tracking for p_T<200 GeV. Typical p_T resolution for EWK studies: 1-2%
- Muon chambers: redundant trigger and coverage, muon identification
- Good identification capabilities: muons can be reconstructed both in inner tracker and muon spectrometer

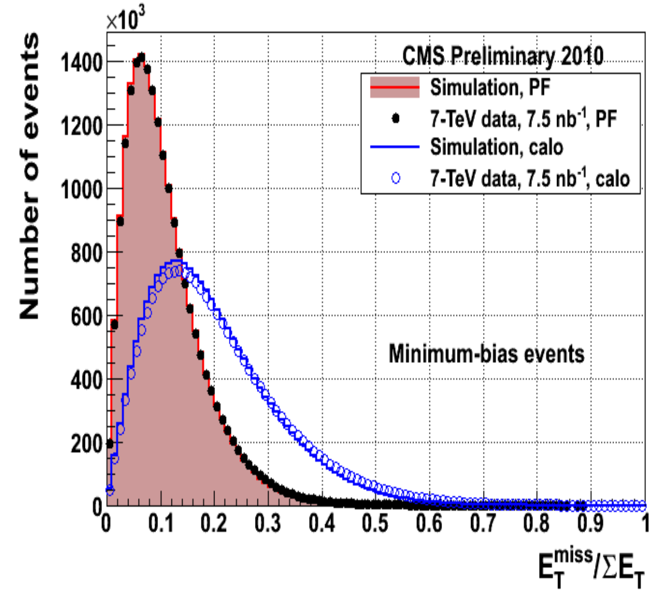




- Excellent energy resolution thanks to the precise $PbWO_4$ crystal calorimeter. Typical E_T resolution for EWK studies: 1%
- Good charge assignment and track matching thanks to fitting techniques that take into account bremsstrahlung emission
- Identification based on shower shape variables, tracking matching and Had./El. ratio (good agreement with the simulations)

Particle-flow techniques in CMS



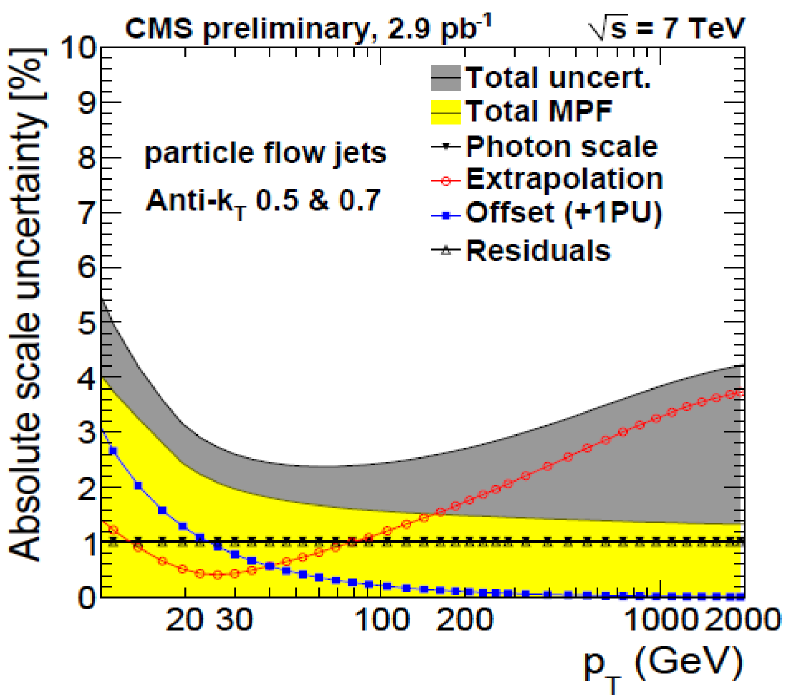


- In CMS, charged particles get well separated due to the huge tracker volume and the high magnetic field (3.8 T)
- CMS has an excellent tracking resolution, able to go to down to very low momenta (~few hundred MeVs)
- CMS has also an excellent electromagnetic calorimeter with good granularity
- In multijet events, only 10% of the energy corresponds to neutral (stable) hadrons

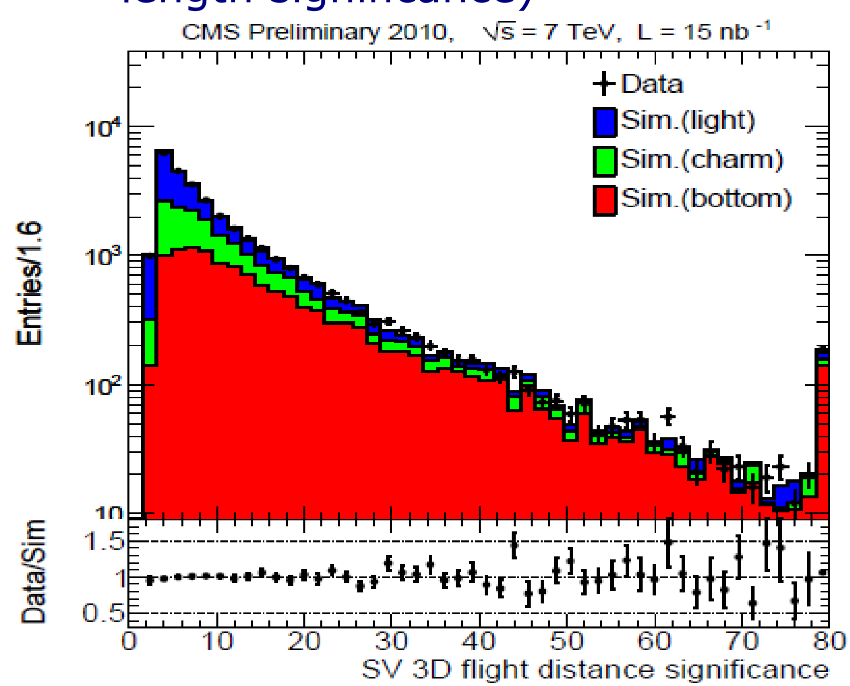
Big improvement in energy resolution and tau identification using particle-flow techniques

Jets and b-tagging

- Most of our EWK jet analyses use particle-flow techniques to define the jet constituents and an anti-kT jet reconstruction algorithm with $\Delta R<0.5$.
- Typical scale uncertainty for EWK measurements < 3%, typical jet resolution 10-15%

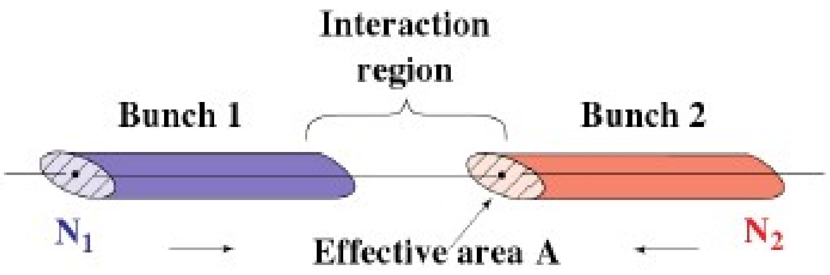


- Good tracker performance and alignment → good b-tagging capabilities
- EWK studies use:
  - a) track counting (above some impact parameter significance threshold)
  - b) secondary vertex tagging (decay length significance)



Luminosity measurement

$$\mathcal{L} = N_1 N_2 f n_b \int \rho_1(x,y)\rho_2(x,y)dxdy$$



$$\mathcal{L} = \frac{N_1 N_2 f n_b}{A_{eff}}$$

$$A_{eff} = 2\pi\sigma_x\sigma_y$$

- Intensities N_1,$N_{2,}$ measured by LHC beam current transformers
- Shape and size of the interaction region, A_{eff}, measured via Van der Meer scans: relative variations or rate as a function of the transverse separation between beams
- Rates measured in CMS using fraction of zero counts of HF and vertexing

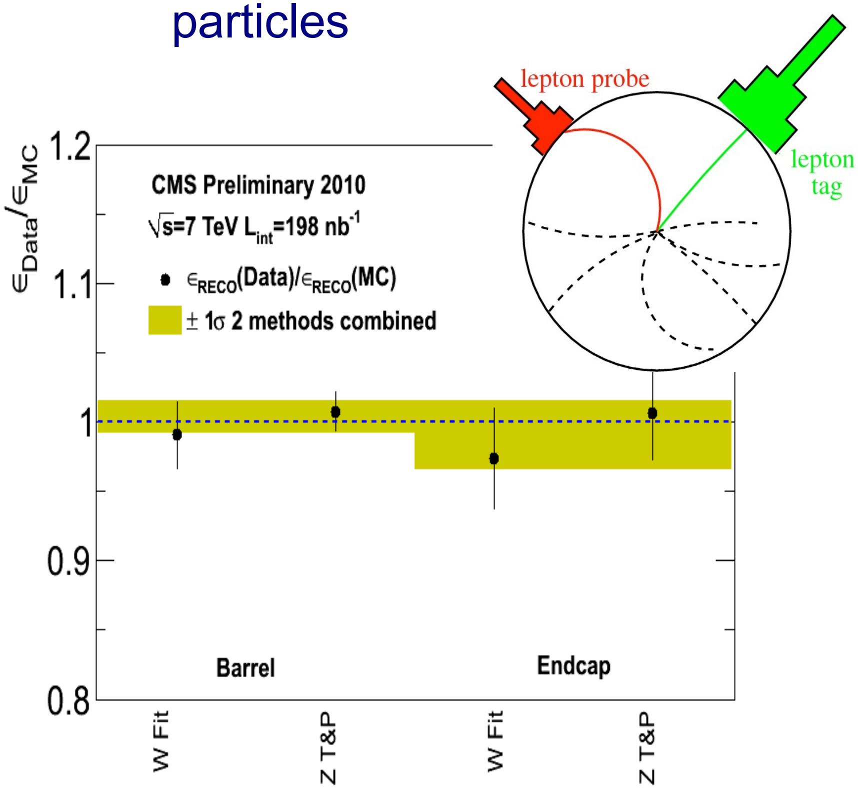
Systematic	Error (%)
Effective Area Determination	2.7
Beam Intensity	2.9
Sample Dependence	0.7
Total	**4.0**

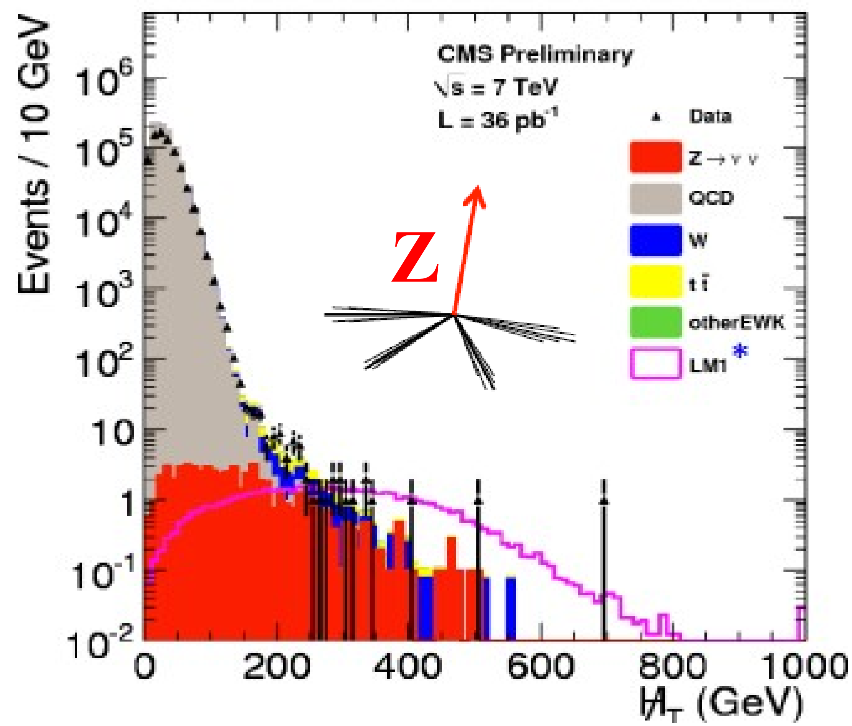
Uncertainty: 4%

Luminosity correction with respect to initial estimates: -0.7%

Why W/Z studies at the LHC?

1) W and Z decays are special final states:
   a) They are used to understand and calibrate our detector response (trigger, identification, resolution, efficiencies)
   b) They are dominant signal and/or background in many searches for new particles

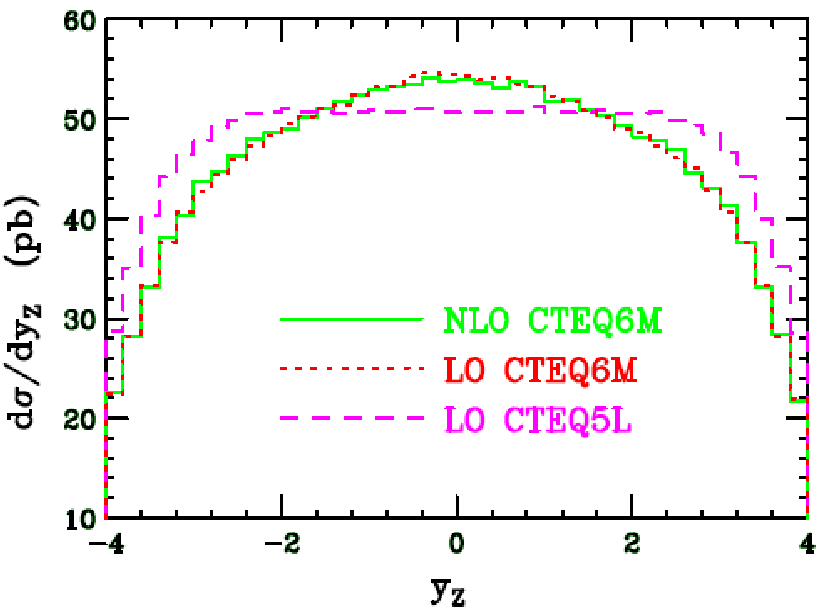


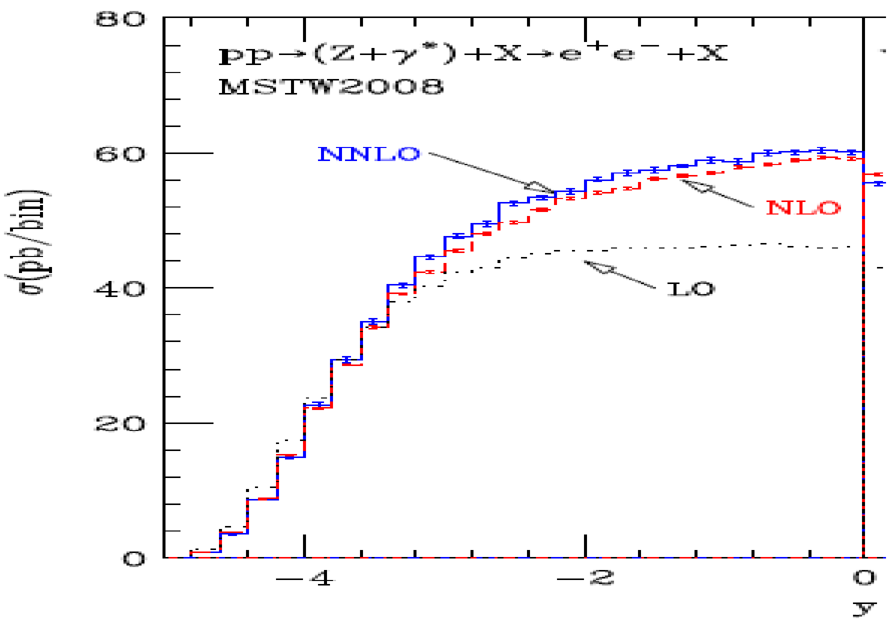


W and Z production at LHC

2) We can really do precision physics studies on W and Z production:

- Experimentally the $W \to l\bar{\nu}$ and $Z \to l\bar{l}$ channels are among the cleanest final states that we can exploit at hadron colliders
- We have now accurate theoretical tools at our disposal: NLO MC generators (MC@NLO, POWHEG, ...). These generators should provide more accurate predictions than LO MCs for these processes (at the few percent level)
- NNLO theoretical predictions for cross section and kinematic studies are also available (FEWZ, DYNNLO, RESBOS)



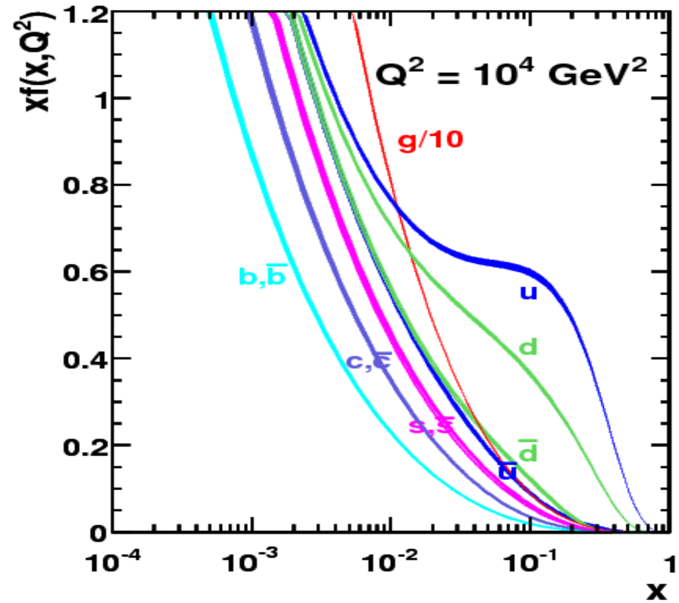


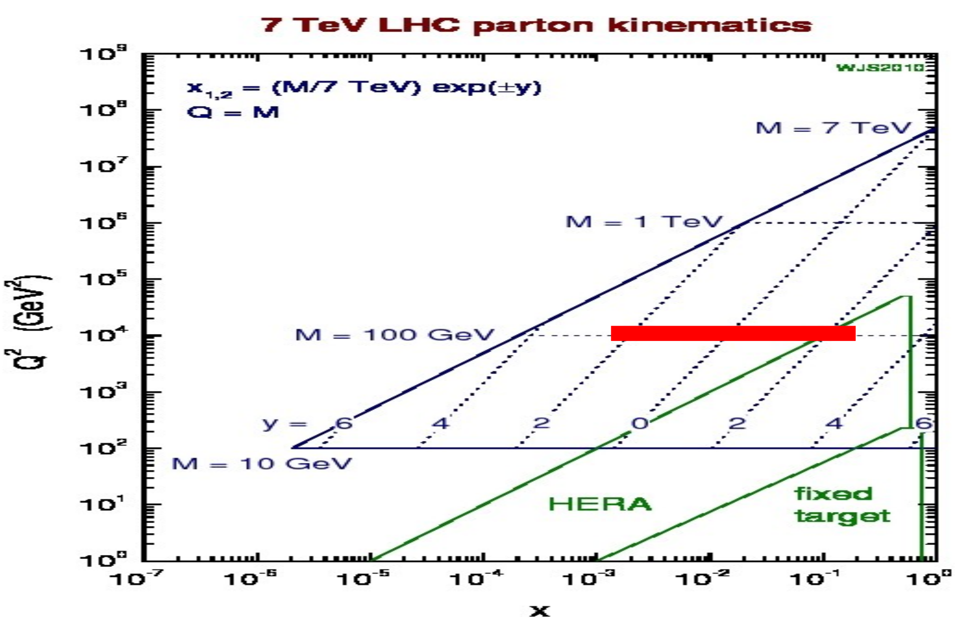
W and Z production at LHC

- W and Z production at LHC proceeds at the hard scattering level and first order via collisions of a valence quark (u,d) and a sea antiquark (Q≈100 GeV):

$$u+\bar{d}(\bar{s})\rightarrow W^{+} \qquad u+\bar{u}\rightarrow Z$$
$$d+\bar{u}(\bar{c})\rightarrow W^{-} \qquad d+\bar{d}\rightarrow Z$$

- But, since parton fractions in this process are typically $10^{-3} < x < 10^{-1}$, sea-sea $q\bar{q}$ contributions are also important





- Cross sections at LHC are a factor of 3 higher than at the Tevatron. We expect: $\sigma(W)*B(W\rightarrow l\nu) \approx 10$ nb, and $\sigma(Z)*B(Z\rightarrow l^+l^-) \approx 1$ nb

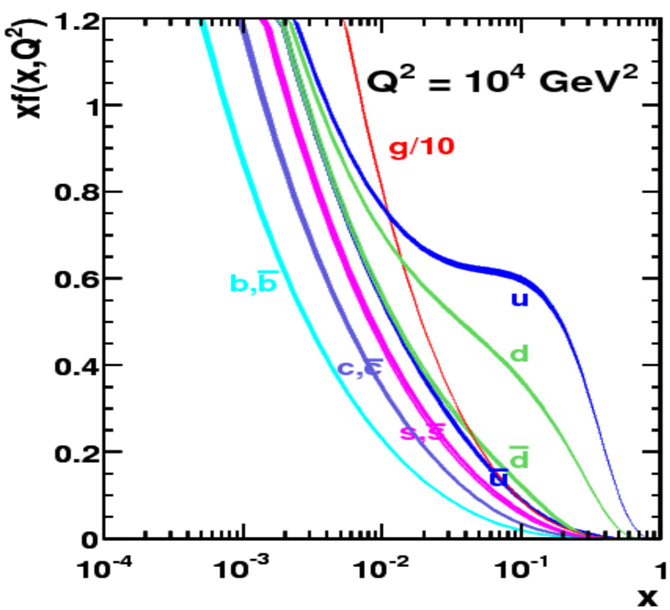
> 10^5 $W\rightarrow l\nu$ events and > 10^4 $Z \rightarrow l^+l^-$ events in 2010 data !!

W and Z production at LHC

- Due to the different valence quark content of the proton, one expects an asymmetry in the production rates of W^+ and W^-:

$$u+\bar{d}(\bar{s})\rightarrow W^+$$
$$d+\bar{u}(\bar{c})\rightarrow W^-$$

  - $N(W^+)/N(W^-) = 2$ counting just valence quarks ($p\equiv uud$)
  - In practice $N(W^+)/N(W^-)$ is closer to 1.5 due to the sizeable contribution from sea-sea quark interactions



- In associated jet production, gluons play a major role:

$$u+g \rightarrow W^+ + q\text{-}jet$$
$$d+g \rightarrow W^- + q\text{-}jet$$

- When associated to specific jet flavors, there is sensitivity to other PDFs too:

$$s+g \rightarrow W^- + c$$
$$b+g \rightarrow Z + b$$

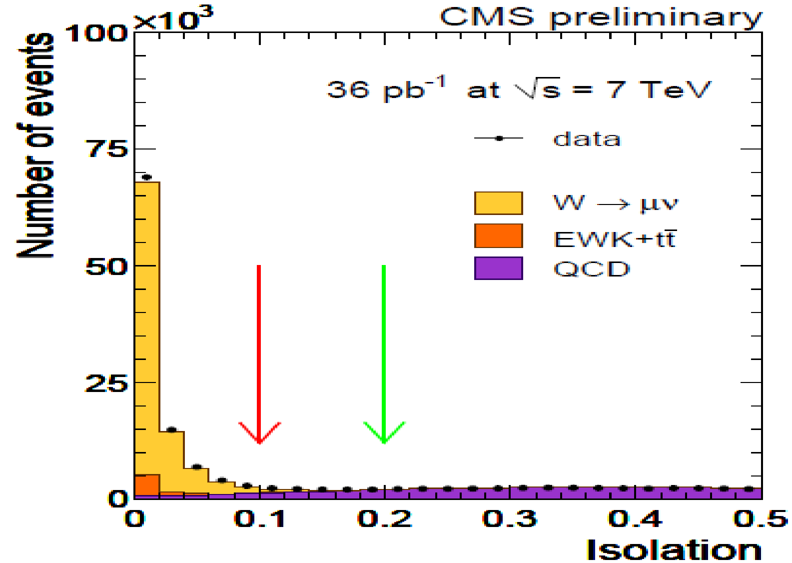
Electroweak processes are ideal for precise measurements and tests of PDFs at the LHC !!

W inclusive production

CMS-PAS-EWK-10-005

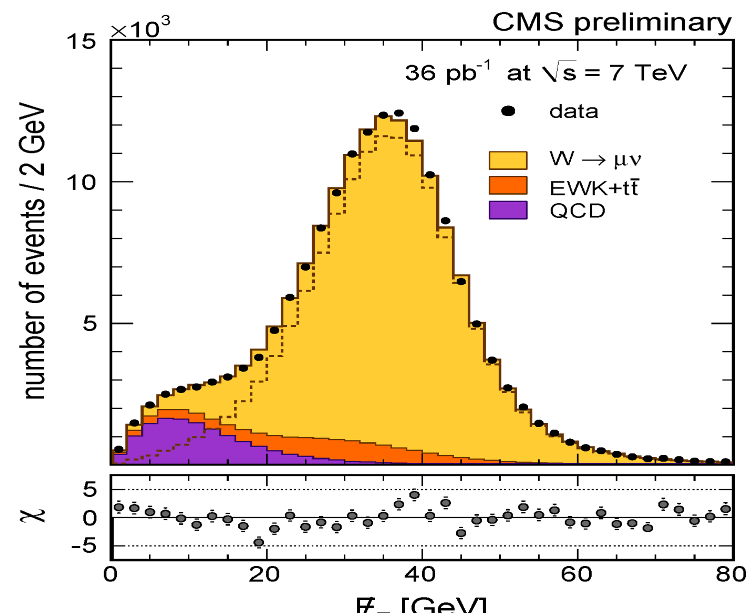
Simple W pre-selection in CMS:

- Loose single-lepton (μ,e) triggers
- Loose/understood identification cuts
- High p_T (>25 GeV) lepton in trigger/detector fiducial volume
- Isolated leptons. Use transverse activity / lepton p_T in a $\Delta R<0.3$ cone
- Dilepton veto



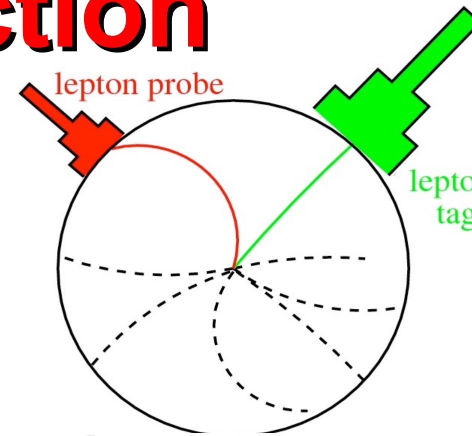
Cross section measurement strategy:

- Fit missing E_T distributions for W^+ and W^- (no cut applied, to avoid biases)
- Efficiencies, resolutions, signal and background shapes studied / extracted from data

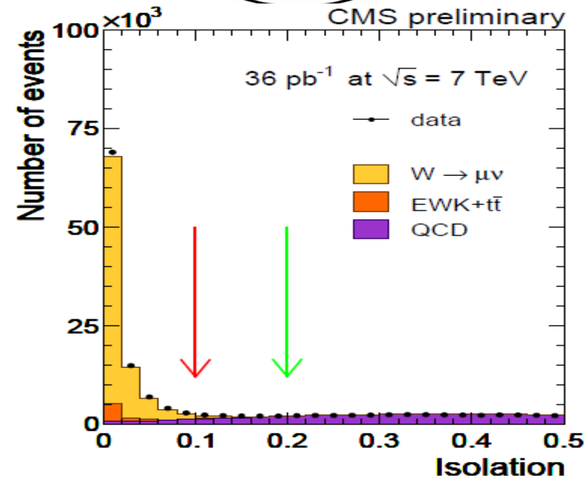


W inclusive production

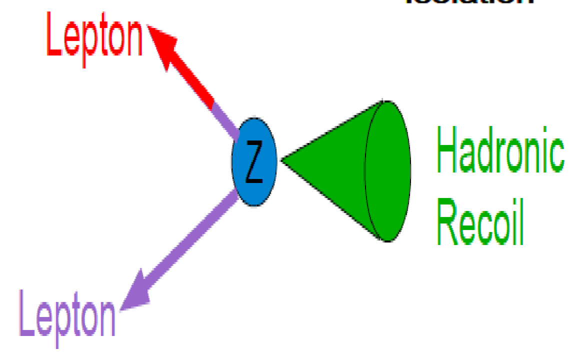
- Efficiencies: tag-and-probe methods with $Z \rightarrow l\bar{l}$ selected events
  - One lepton satisfying tight selection criteria. The second lepton is used to determine TRIGGER, ISOLATION and RECONSTRUCTION/ID efficiencies as a function of p_T and η



- The shape of the remaining QCD background is determined or parametrized from a data sample of non-isolated leptons. The overall QCD normalization is extracted from a fit to the missing E_T distributions

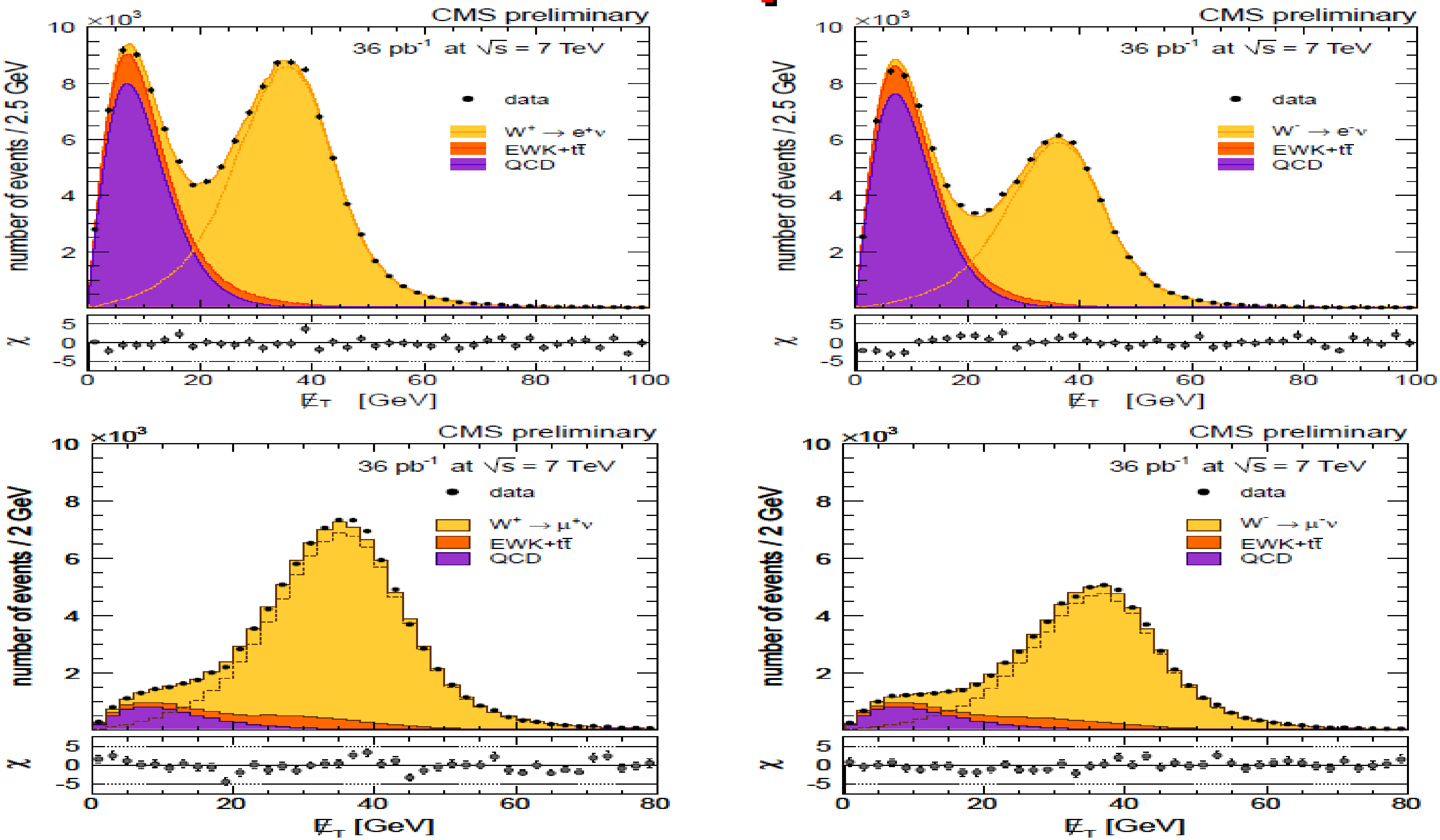


- The signal shape of the missing E_T distribution is extracted from the recoil distribution of $Z \rightarrow l\bar{l}$ events



- $Z \rightarrow l\bar{l}$ events are also used to control momentum and energy resolution discrepancies data-MC

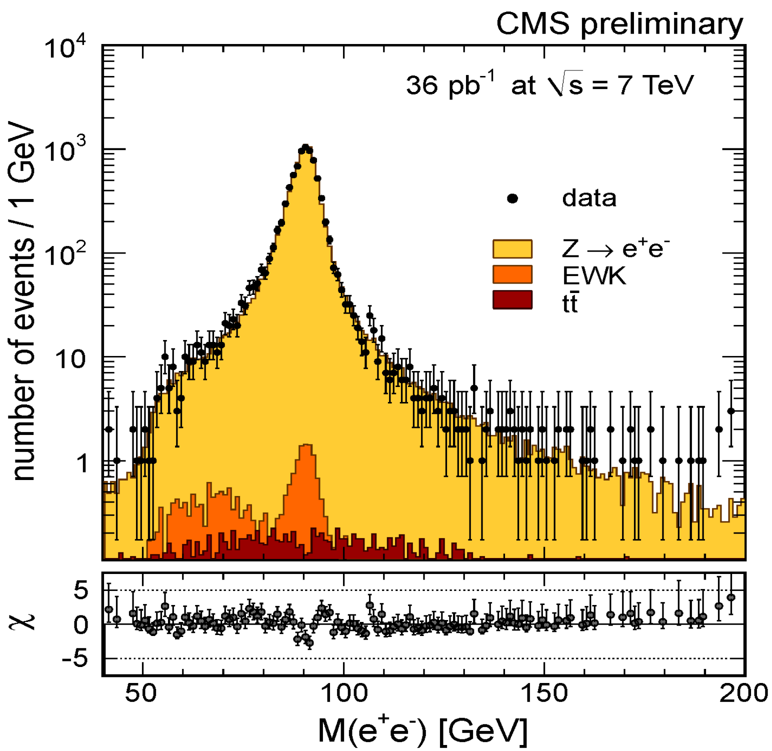
W inclusive production

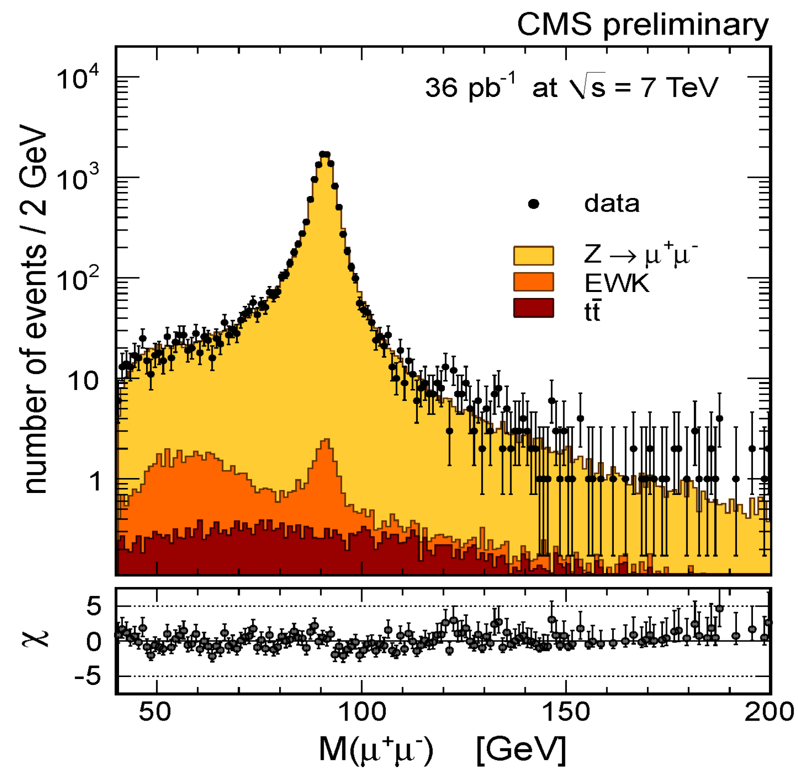


- W^+ and W^- cross sections extracted separately or, equivalently, the total W cross section and the W^+/W^- cross section ratio for each channel

Z production

- We analyze $Z \rightarrow \mu\mu$ and $Z \rightarrow ee$ events by selecting isolated pairs of lepton candidates with high-p_T ($p_T^{lepton} > 20\text{-}25$ GeV) in the fiducial region
  - Cross sections are measured in (and referred to) $60 < M_{ll} < 120$ GeV
- Yield and efficiencies can be determined simultaneously ($\mu\mu$ channel)





Almost a background free analysis (these are logarithmic plots)

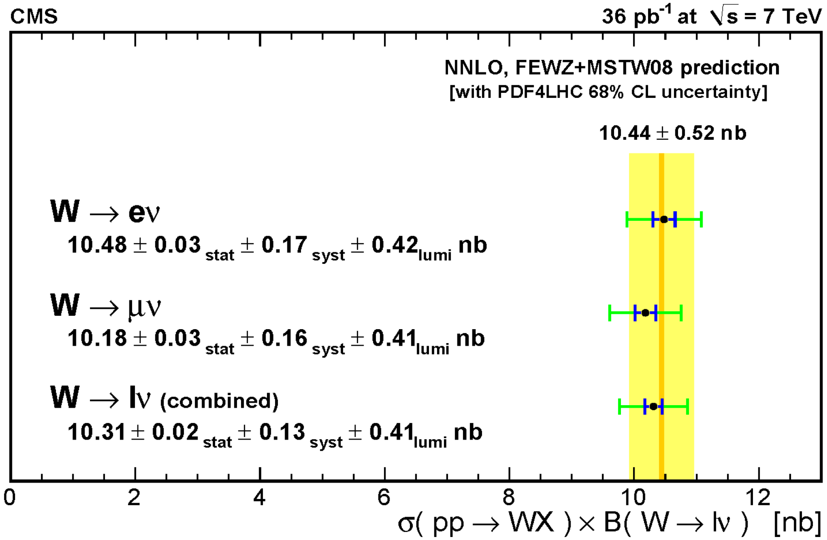
Systematic uncertainties

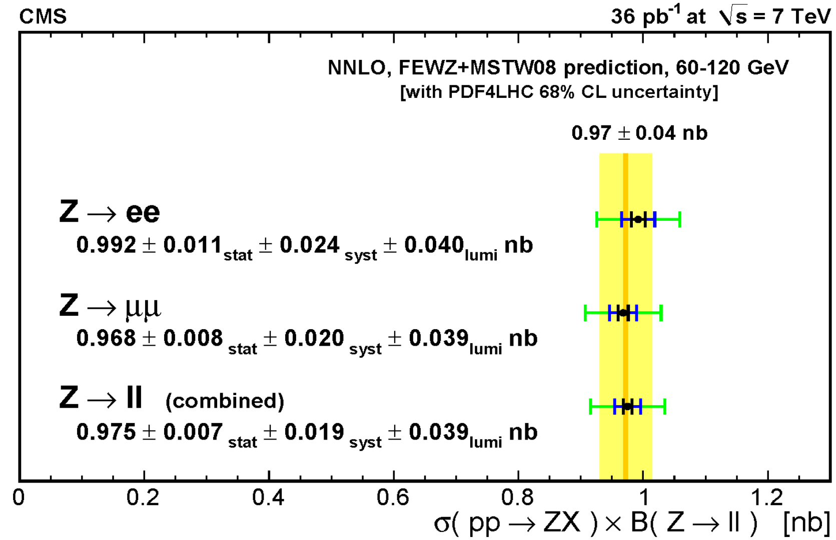
Source	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	1.3	0.9	1.8	n/a
Trigger pre-firing	n/a	0.5	n/a	0.5
Momentum scale & resolution	0.5	0.22	0.12	0.35
$\not\!\!E_T$ scale & resolution	0.3	0.2	n/a	n/a
Background subtraction / modeling	0.35	0.4	0.14	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	0.7	0.9	1.2
Other theoretical uncertainties	0.7	0.8	1.4	1.6
Total theoretical	0.9	1.1	1.7	2.0
Total	1.7	1.6	2.5	2.1

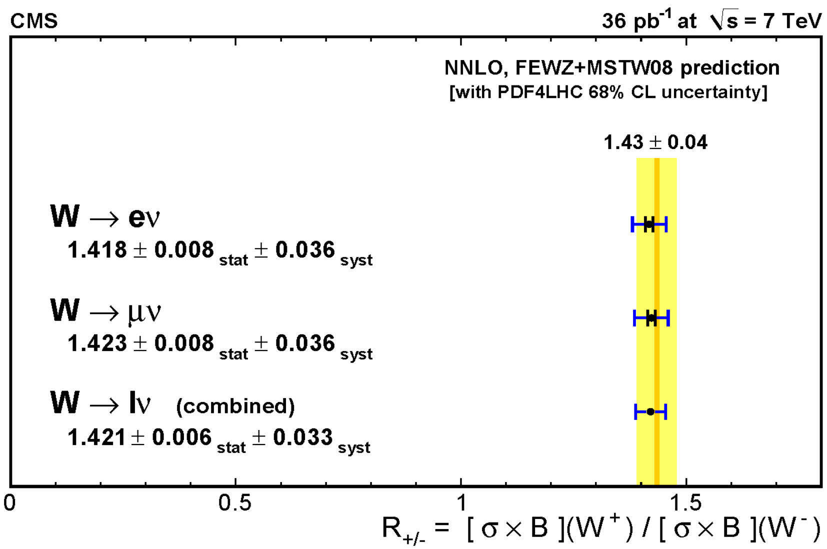
- Experimental uncertainties are significantly reduced thanks to the extensive use of data-driven methods to control efficiencies, backgrounds and signal shapes
- Theoretical and experimental uncertainties have similar sizes:

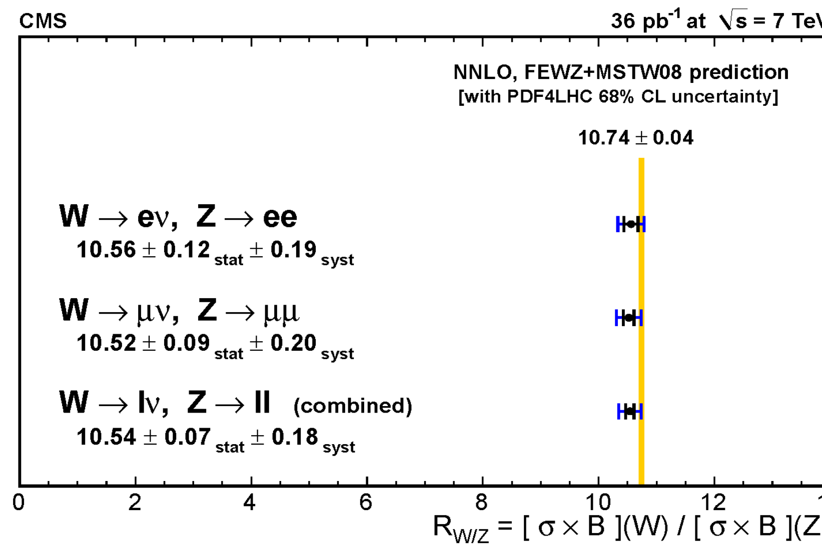
  (theory uncertainties on acceptance include: PDFs (PDF4LHC), ISR/higher order effects(RESBOS), EWK/FSR effects(HORACE), factorization/renormalization scales (FEWZ))

CMS W/Z inclusive results





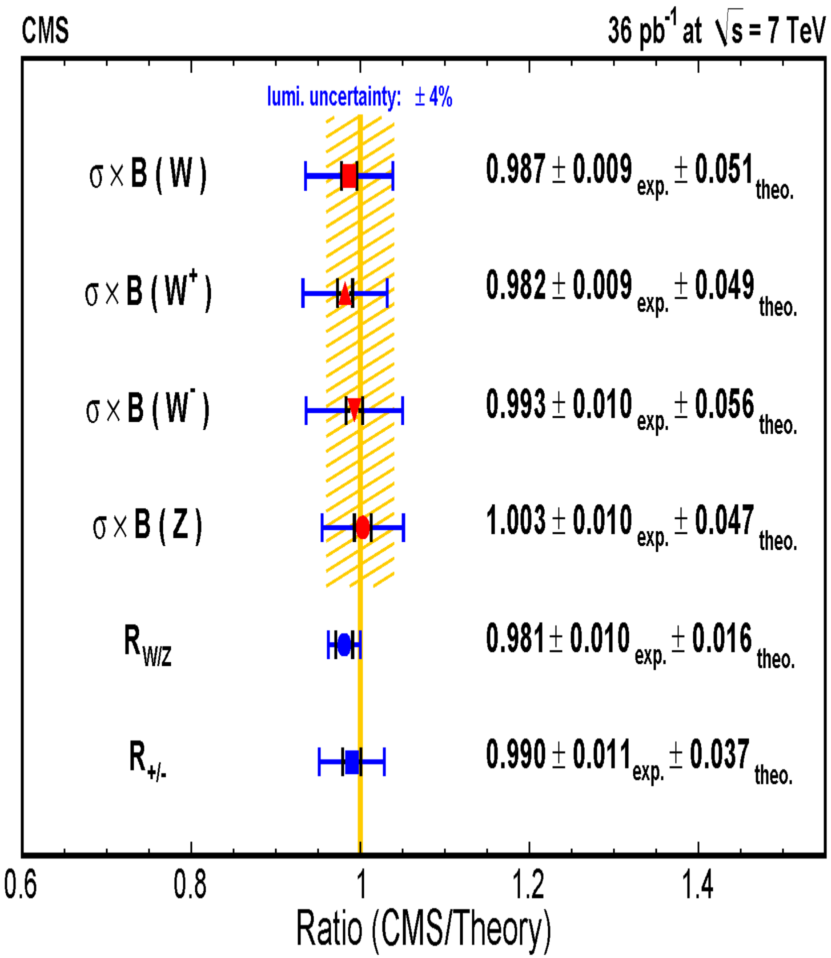


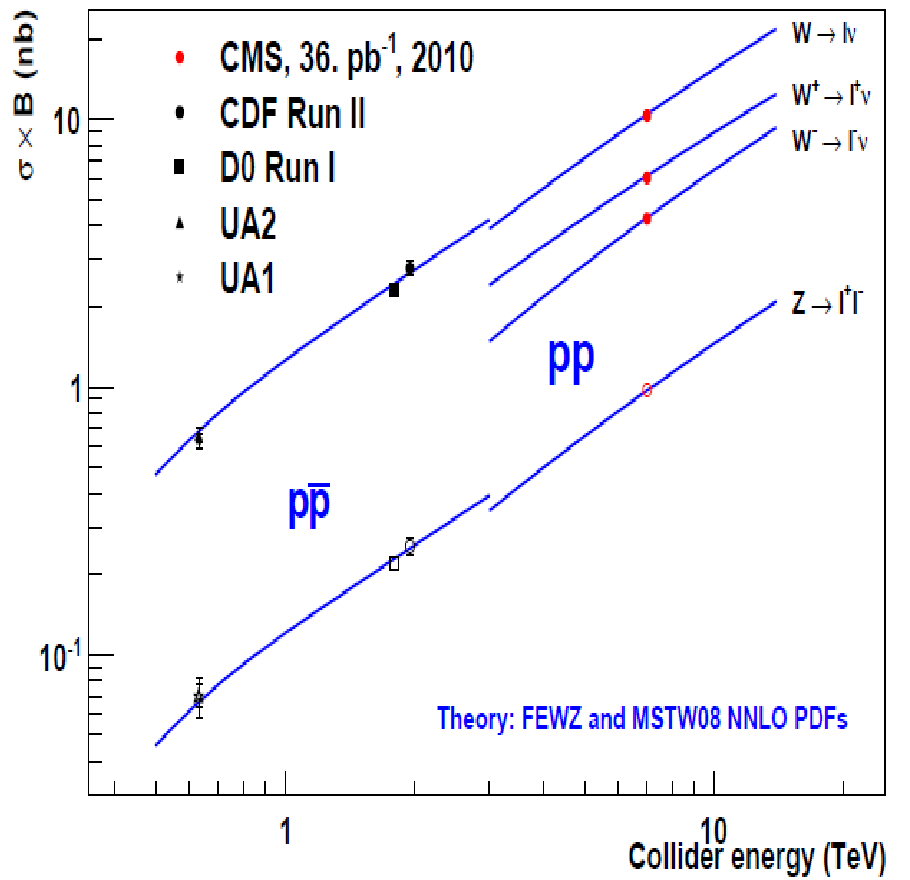


Potential to constrain W+/W- PDF uncertainties

Precise test of W/Z theoretical expectations

CMS W/Z inclusive results





- Good agreement with NNLO theory expectations

W lepton charge asymmetry

arXiv:1103.3470

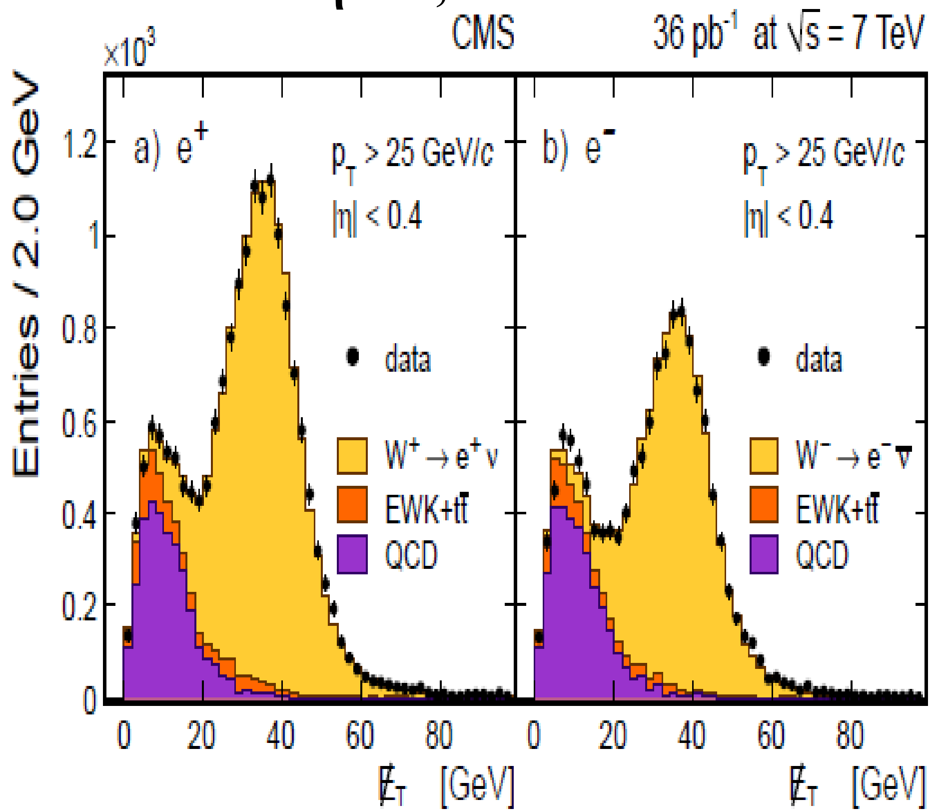
- A first natural extension of the W inclusive studies is the study of the W^+/W^- ratio, R_W, as a function of different kinematic variables.
- Experimentally, a clean way to do this study is to measure the charge asymmetry as a function of the lepton pseudo-rapidity

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

$$\left(A(\eta)\equiv\frac{R_W(\eta)-1}{R_W(\eta)+1}\right)$$

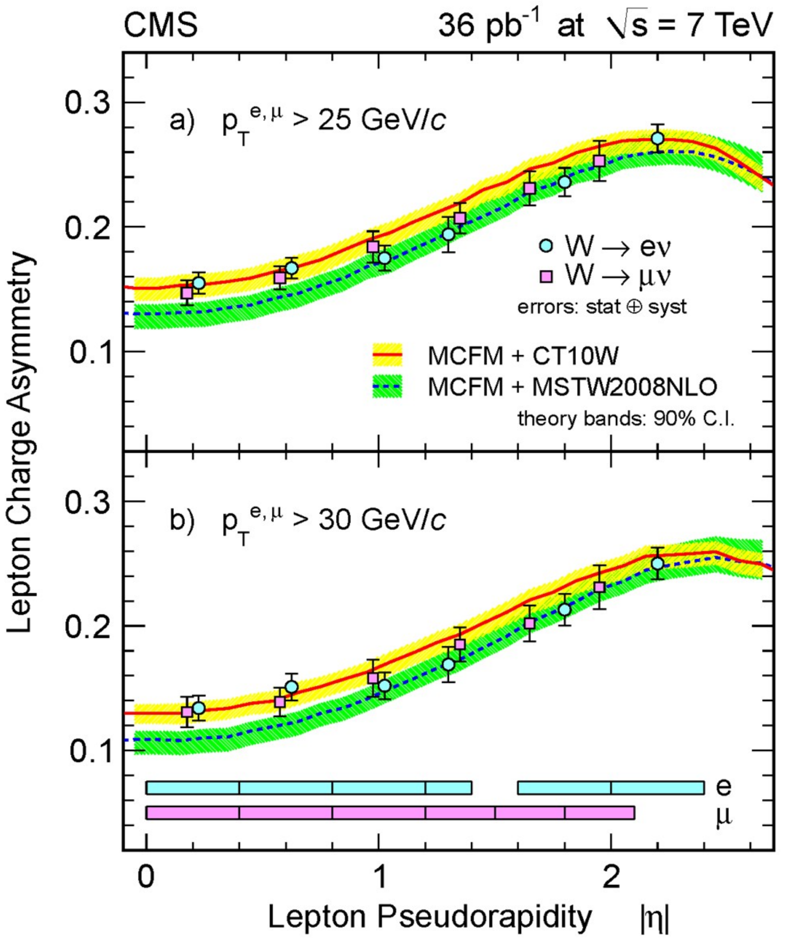
- This measurement is rather sensitive to PDFs because most systematic uncertainties cancel in the ratio
- Selections follow closely the criteria used in inclusive measurements.

First η bin, electron channel



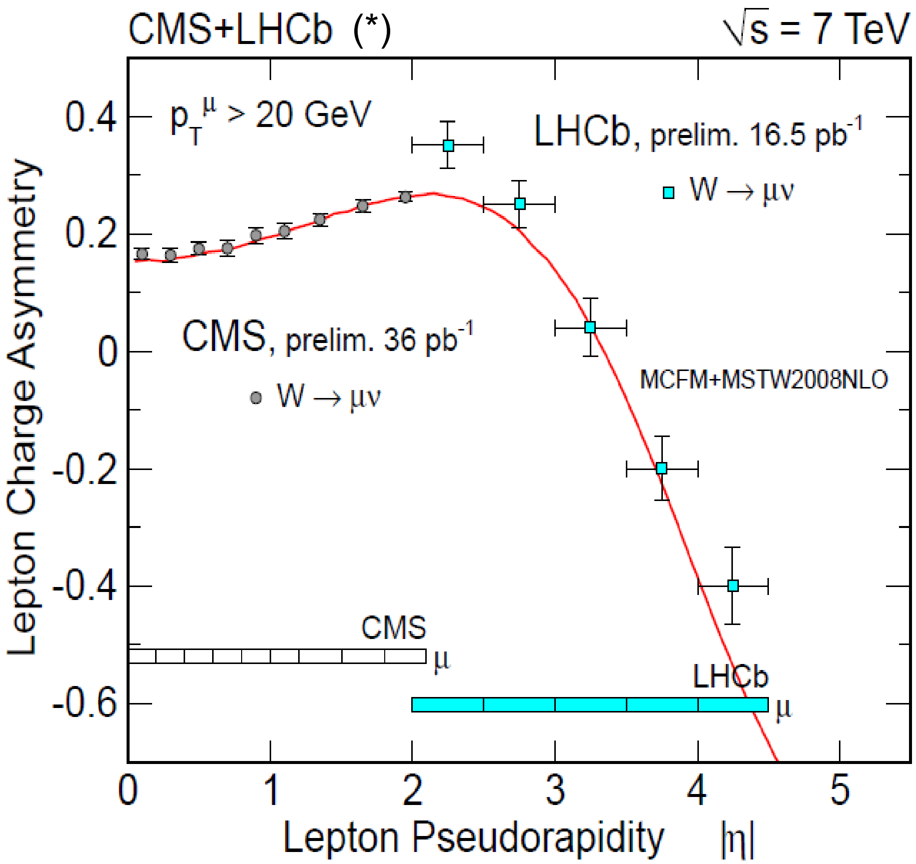
W lepton charge asymmetry

- We divide the electron and muon samples in 6 bins of pseudo-rapidity, according to the acceptances (different for muons and electrons)
- We also apply two different lepton p_T cuts, p_T>25 GeV and p_T>30 GeV, in order to explore more phase space
- Statistical uncertainties: ~ 3% (relative):
- Systematic uncertainties of order 3% (relative):
  - Differences between positive and negative lepton efficiencies (dominant)
  - Charge confusion for electrons
  - Momentum resolution
  - Background subtraction, signal extraction
- Large potential to improve these measurements in the future by at least a actor of 3: systematics is dominated by the limited Drell-Yan statistics used to study lepton efficiencies

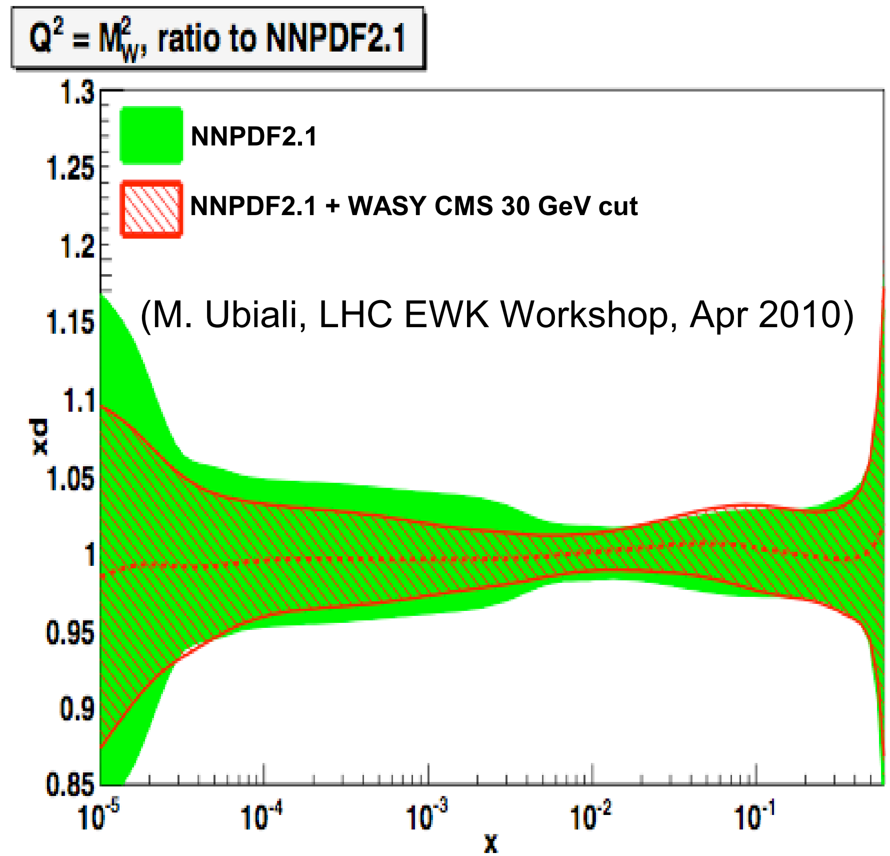


In agreement with CT10 and MSTW08 PDF predictions

W lepton charge asymmetry



(*) CMS: special p_T cuts and binning used



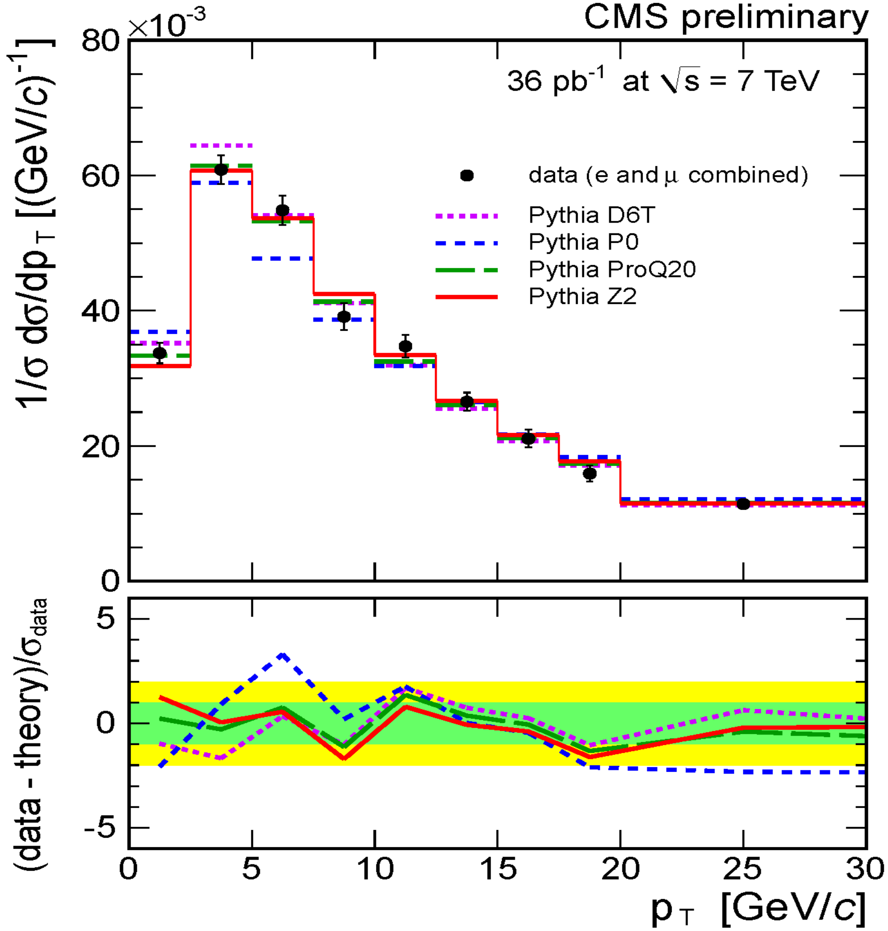
CMS results(*) complementary with other LHC measurements

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

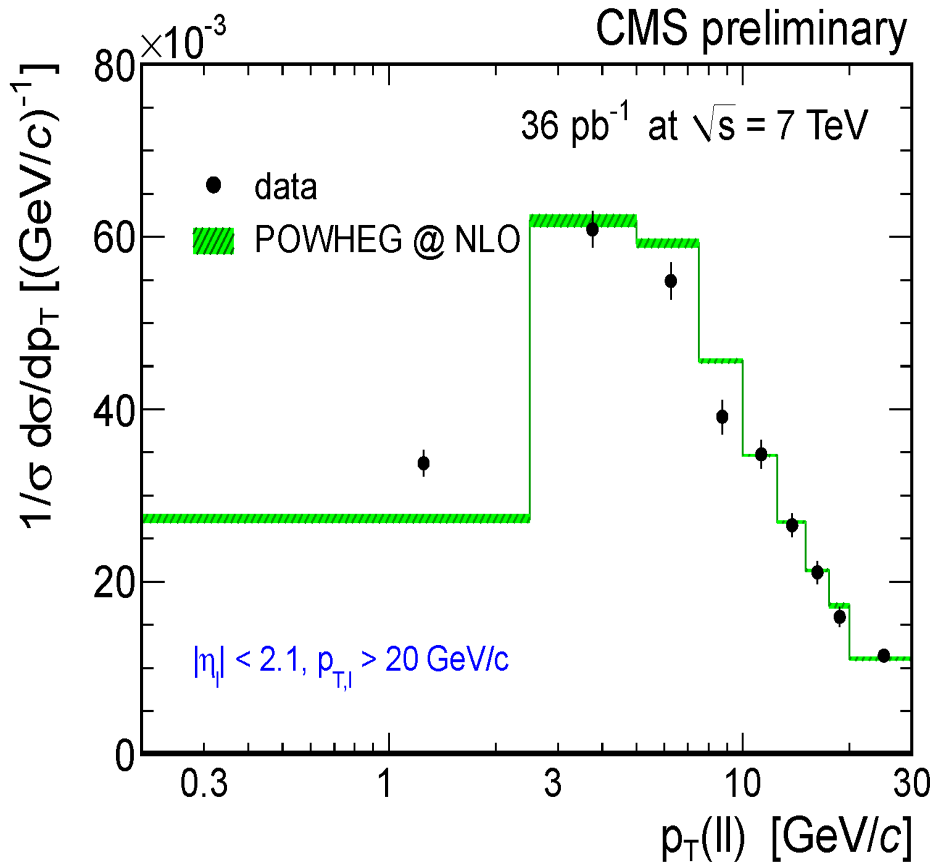
Z differential distributions

CMS-PAS-EWK-10-010

- Drell-Yan events (≈12 000 per lepton channel) are selected following the same criteria as in the inclusive cross section measurement. Mass range: $60 < M_{ll} < 120$ GeV



Z p_T spectrum in agreement with latest PYTHIA tunes



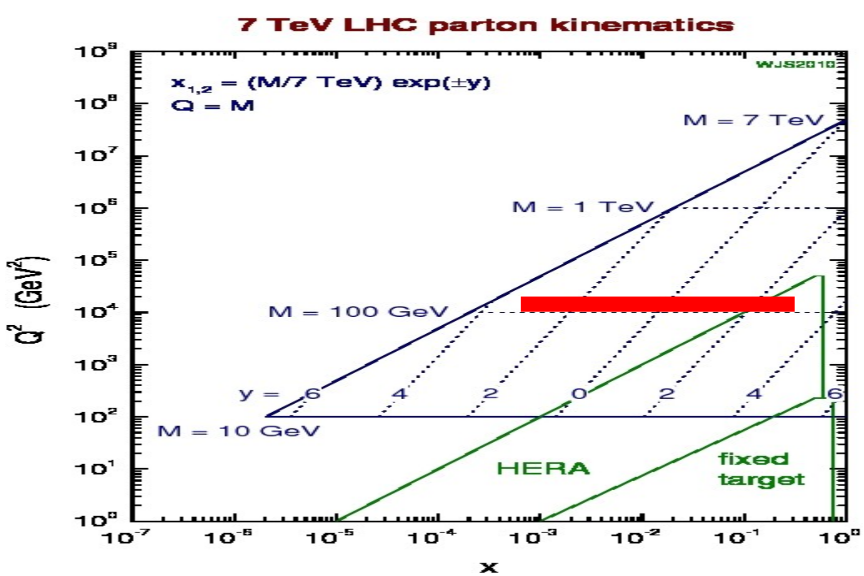
Z p_T spectrum in slight disagreement with current POWHEG simulation (but note that POWHEG uses PYTHIA tune Z2)

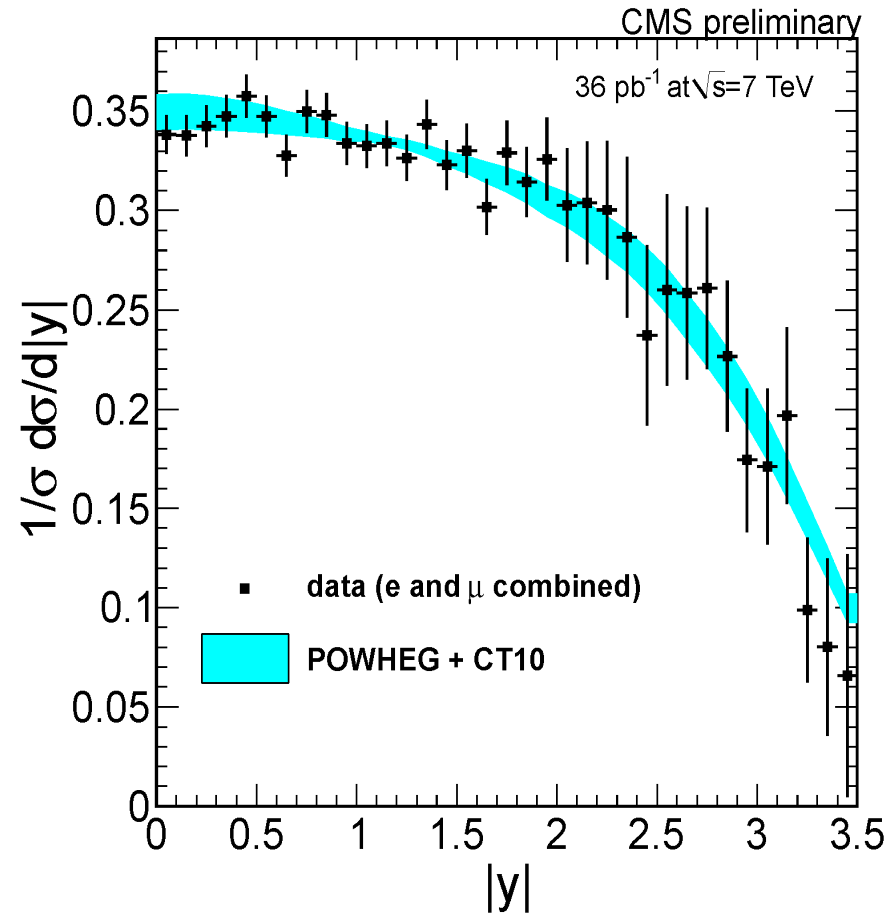
Z rapidity distributions

CMS-PAS-EWK-10-010

- Rapidity distributions have sensitivity to PDFs
- Large rapidities probe the smallest and largest x fractions in the proton

- In CMS we can identiify electrons in the forward hadron calorimeter with decent efficiency up to $|\eta|=5$ to increase the acceptance in rapidity
- We study rapidities up to |y|<3.5, i.e. x fractions below 10^{-3} and above 10^{-2}



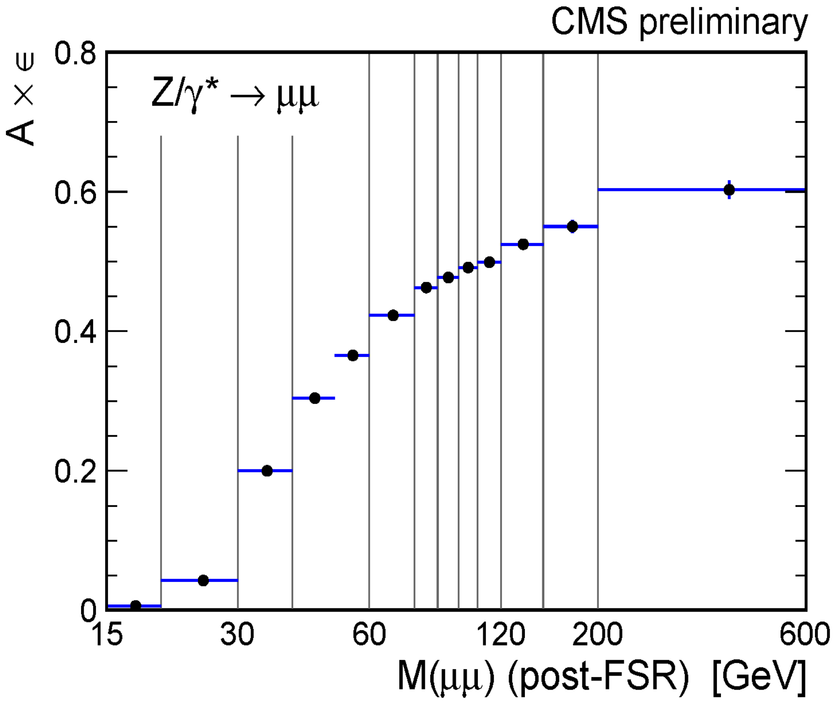


Good agreement with current NLO predictions (POWHEG+CT10)

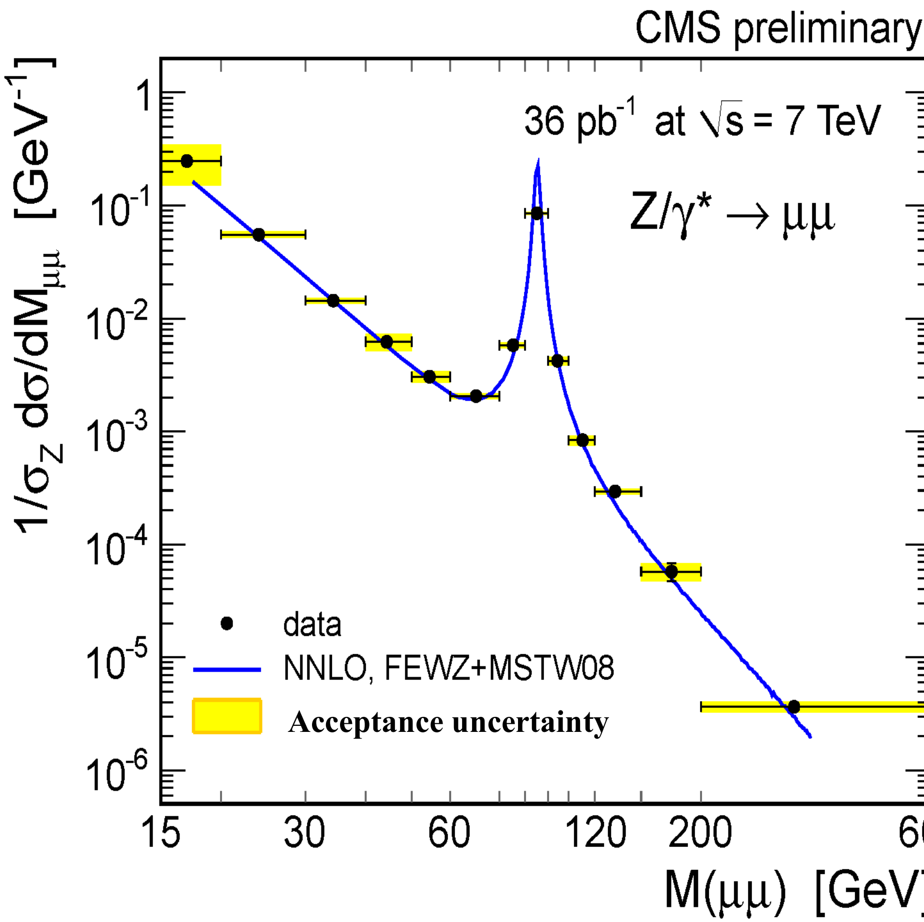
Drell-Yan mass distribution

CMS-PAS-EWK-10-007

- Important benchmark: different PDF dependences compared with Z peak production, background for searches with isolated di-leptons in the final state



- Tighter cuts at low mass to suppress QCD backgrounds



- Unfolded distribution, normalized to Z peak cross section and corrected for QED final-state radiation effects

Good agreement with NNLO predictions within uncertainties

DY forward-backward asymmetry

CMS-PAS-EWK-10-011

- This is a measurement sensitive to the $\overline{\sin^2\theta_w}$ effective parameter in the SM

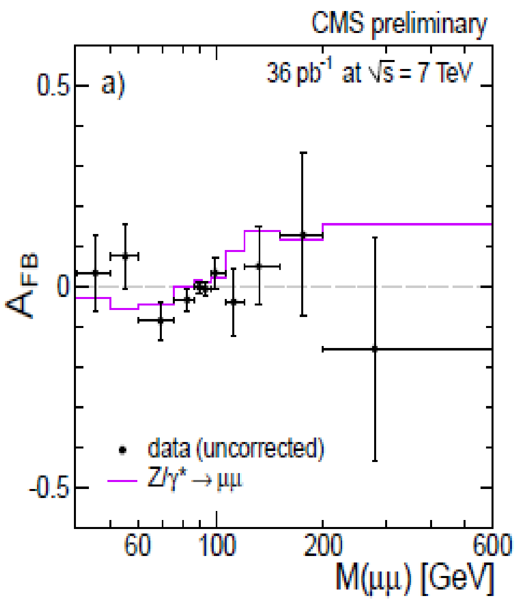
$$\frac{d\rho}{d\cos\theta^*} = \frac{3}{8}\left(1+\cos^2\theta^*\right) + A_{FB}\ \cos\theta^*$$

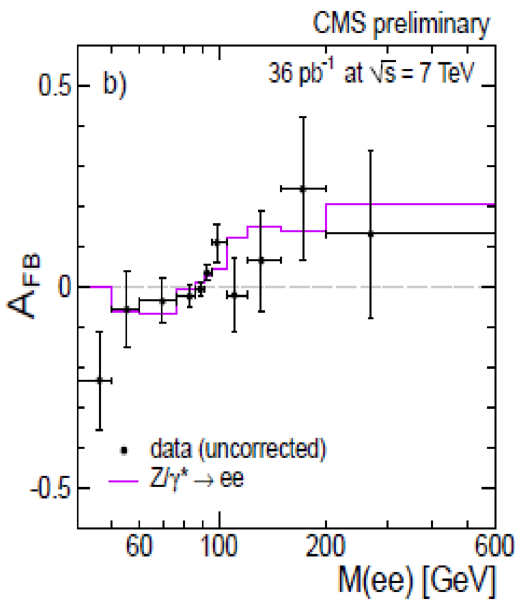
$$\cos\theta^*_{CS} = \frac{2\left(p_z^{l-} E^{l+} - p_z^{l+} E^{l-}\right)}{Q^2\left(Q^2+Q_T^2\right)}$$

θ^* is the quark-lepton angle in the CM frame

A_{FB} depends on the quark type (u,d) and on $\overline{\sin^2\theta_W}$

- cos θ* is approximated by the Collins-Soper angle with respect to the beam direction closer to the dilepton direction (expected to be close to the quark direction in average)





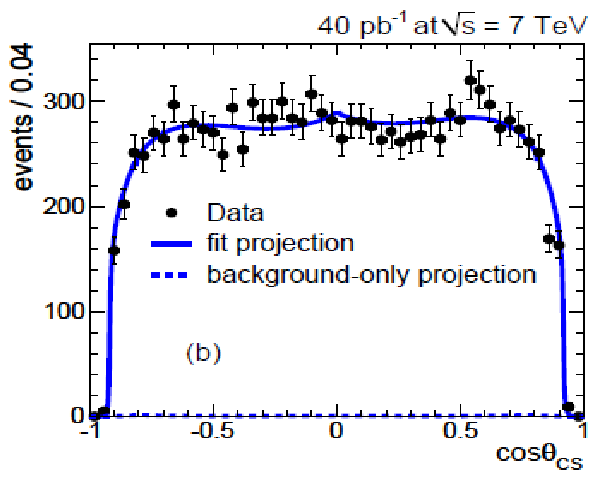
- We expect zero asymmetry at the Z pole ($v_l \approx 0$), negative below and positive above (driven by the axial couplings to the Z)

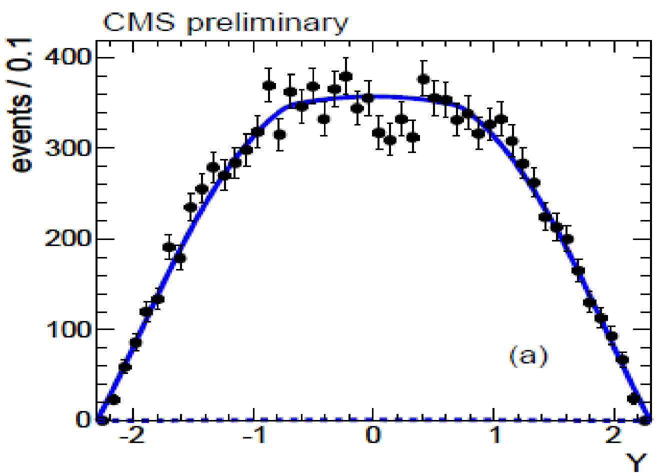
Asymmetry uncorrected for mass resolution or dilution effects.. In agreement with MC predictions (POWHEG+CT10)

A more precise measurement of $\overline{\sin^2\theta}_W$

- Direct measurement: model the $\overline{\sin^2\theta}_w$ dependence at generator level (P_{ideal}) and quantify its effect on the experimental observables in the μμ channel: Collins-Soper angle (θ^*_{CS}), invariant mass ($s^{½} \equiv M(\mu\mu)$) and rapidity (Y) of the dimuon system
- Use convolutions (R) and acceptances (G) in order to parametrize the experimental response:

$$\mathcal{P}_{\text{sig}}(Y, s, \cos\theta^*_{CS}; \sin^2\theta_W) = \mathcal{G}(Y, s, \cos\theta^*_{CS}) \times \int_{-\infty}^{+\infty} dx\, \mathcal{R}(x)\, \mathcal{P}_{\text{ideal}}(Y, s-x, \cos\theta^*_{CS}; \sin^2\theta_W)$$





Phase space limits:
60 < M(μμ)< 120 GeV
P_T*>18 GeV
|η*|<2.3

Avoid biases from hard QCD radiation effects:
$P_T(\mu\mu)$ < 25 GeV

LO model (ISR)	0.0011
PDFs	0.0015
FSR	0.0018
resolution/alignment	0.0022
fit model	0.0010
background	0.0007
total	0.0036

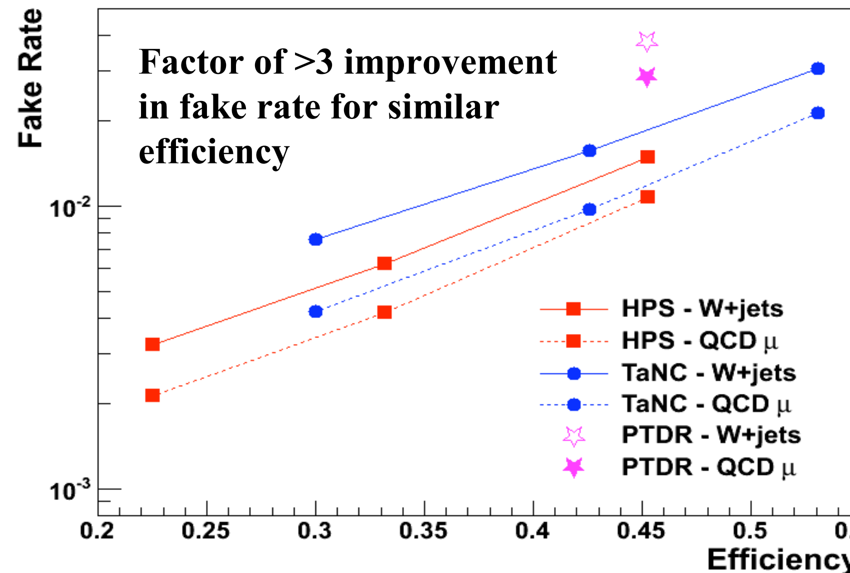
$$\sin^2\theta_{\text{eff}} = 0.2287 \pm 0.0077(\text{stat.}) \pm 0.0036(\text{syst.})$$

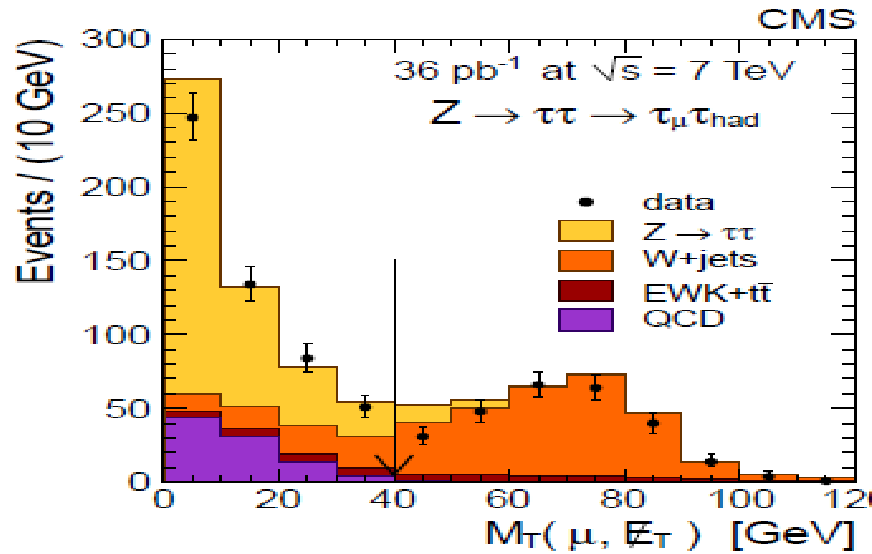
Improved precision with respect to a measurement based on A_{FB} only !

$Z \to \tau\bar{\tau}$ analysis

arXiv:1104.1617

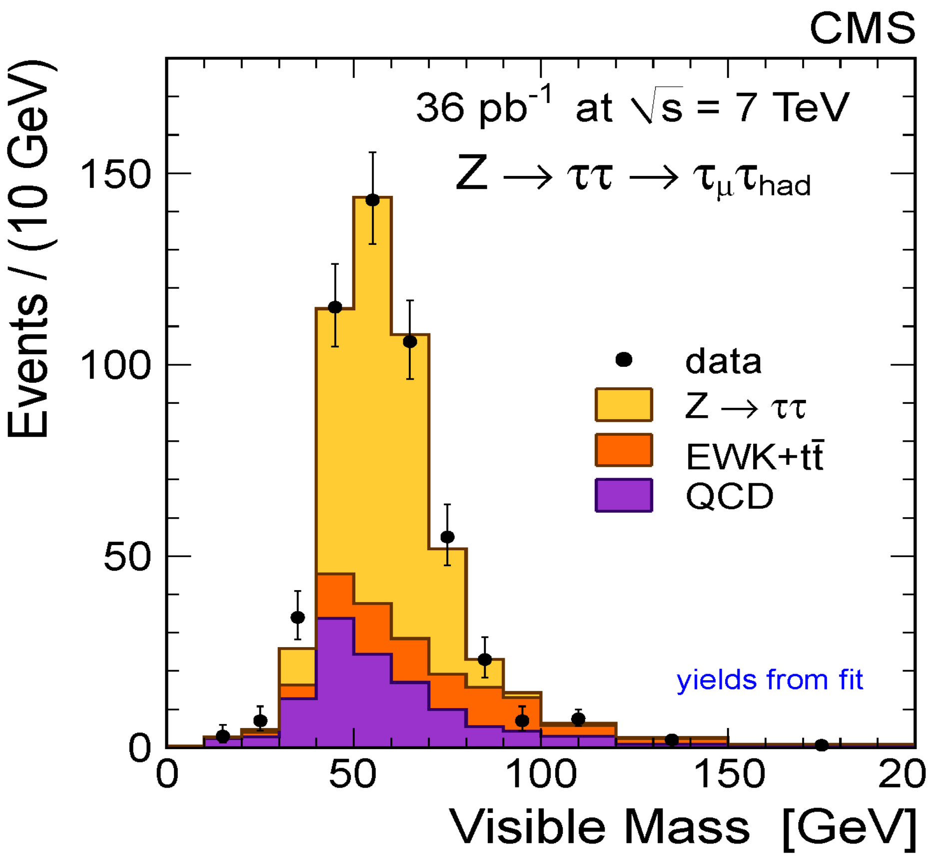
- Important benchmark measurement for new particle searches like MSSM Higgs (with $H \to \tau\bar{\tau}$)
- Big improvements in tau identification in CMS with respect to PTDR expectations. New methods able to improve the identification of exclusive hadronic modes
- Typical selection cuts for tau EWK measurements:
  - p_T(isolated lepton) > 15 GeV
  - p_T(isolated had. tau) > 20 GeV
  - M_T (lepton,MET)< 40-50 GeV
- Special effort to determine most efficiencies and backgrounds using data-driven methods

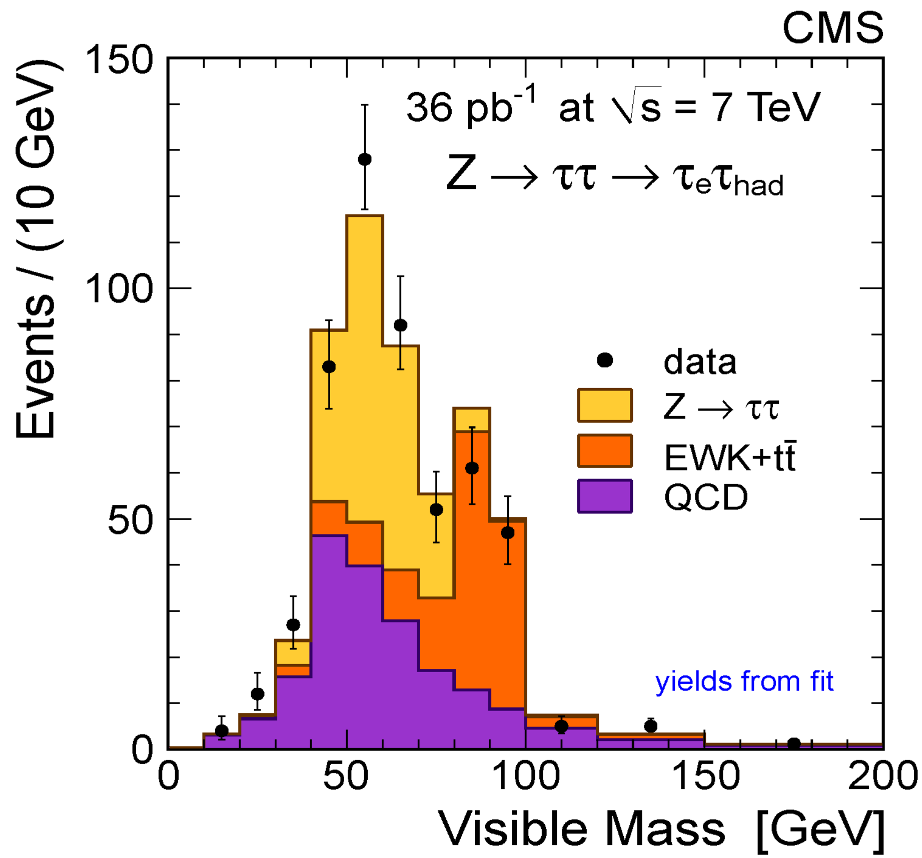




$Z \to \tau\bar{\tau}$ analysis

- Channels with hadronic taus: $Z \to \tau\bar{\tau} \to \mu + \tau_{had}$, $e + \tau_{had}$



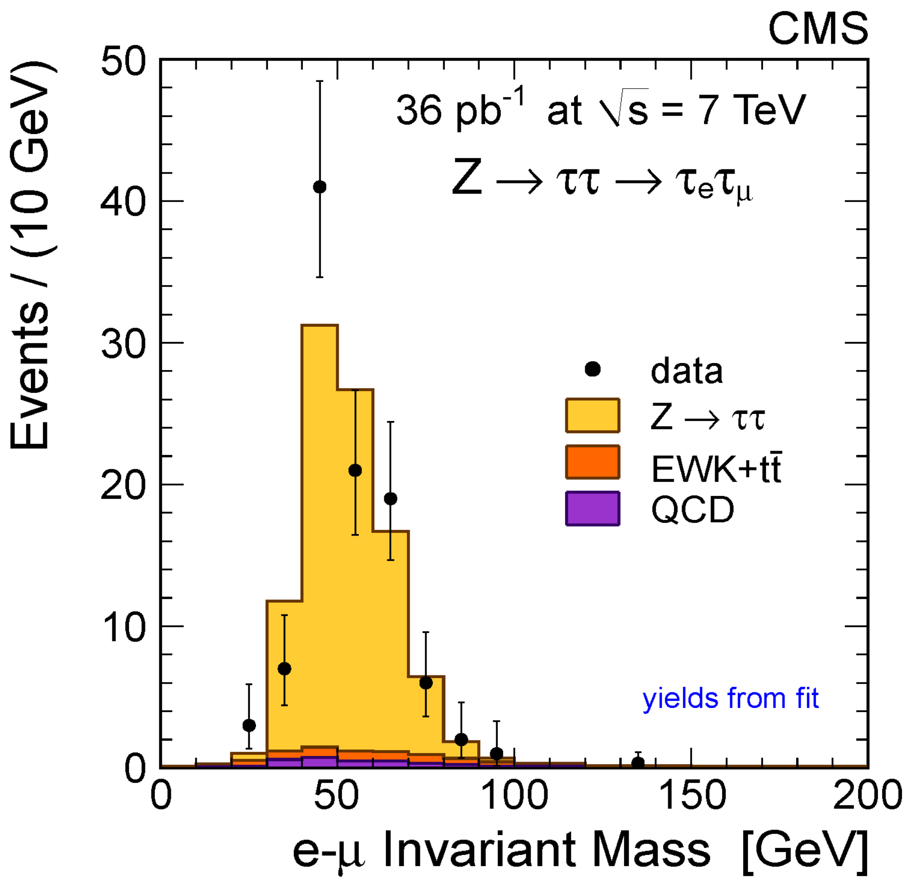


QCD backgrounds with muons ($b \to \mu$, decays in flight, ...)

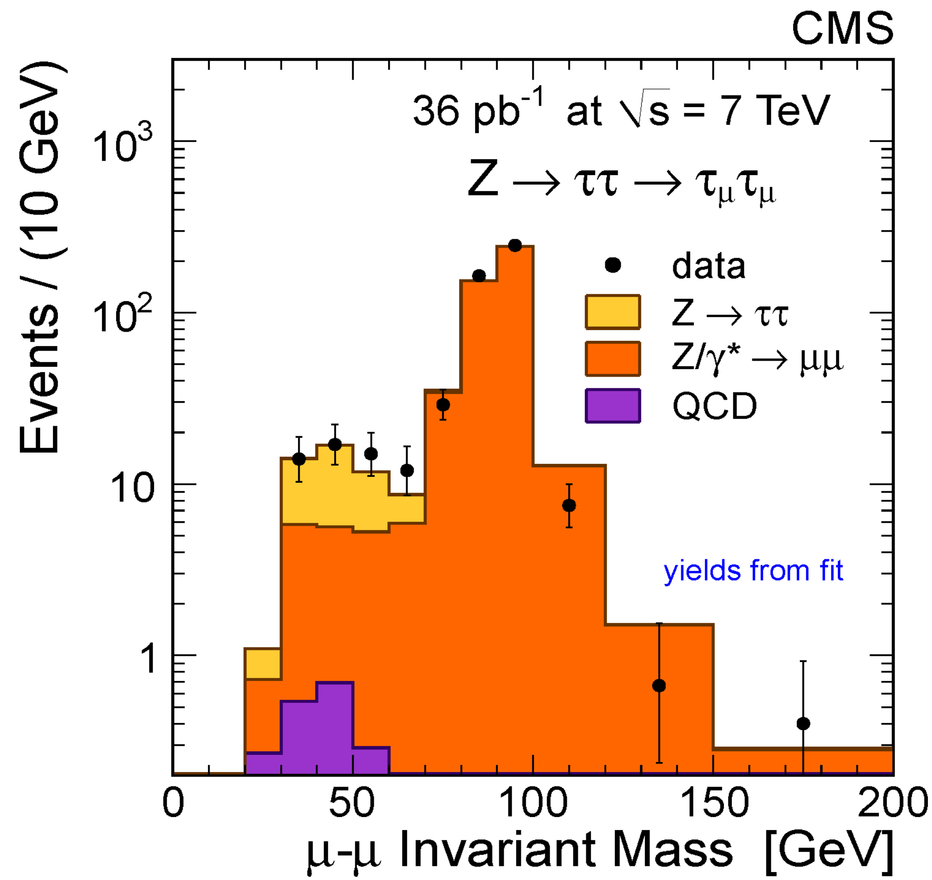
Non-negligible EWK background
QCD contamination (fake electrons)

$Z \to \tau\bar{\tau}$ analysis

- Leptonic channels: $Z \to \tau\bar{\tau} \to \mu\, e$ + neutrinos , $\mu^+\mu^-$ + neutrinos



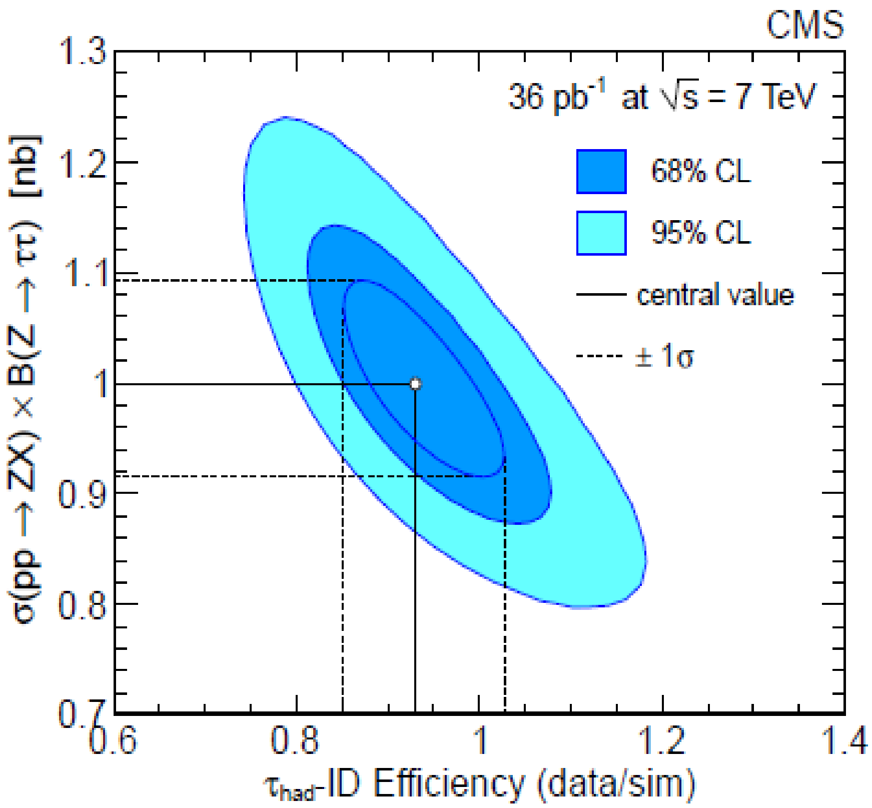
Minimal QCD backgrounds,
no $Z \to ee, \mu\mu$ contributions



Large DY background, reduced via likelihood discrimination

$Z\to\tau\bar{\tau}$ analysis

- Dominant systematics is the tau identification efficiency in hadronic channels (estimated via data-driven methods)
- Simultaneous fit to the cross section and efficiencies in the four channels analyzed in order to improve the final uncertainty:

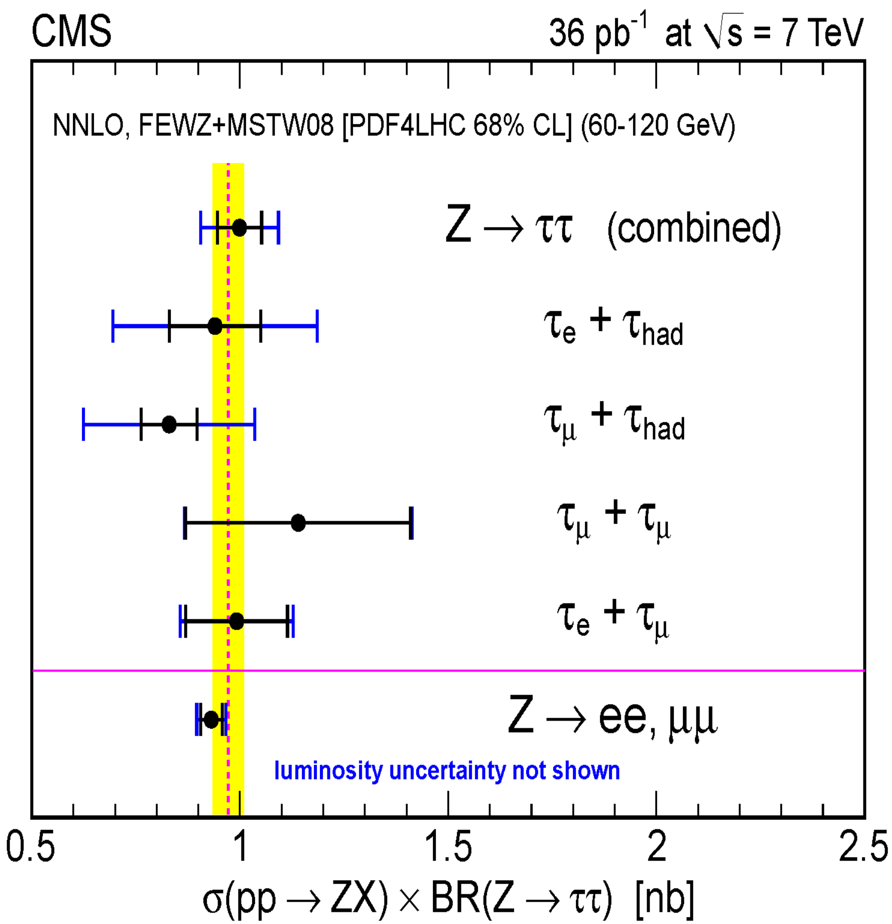


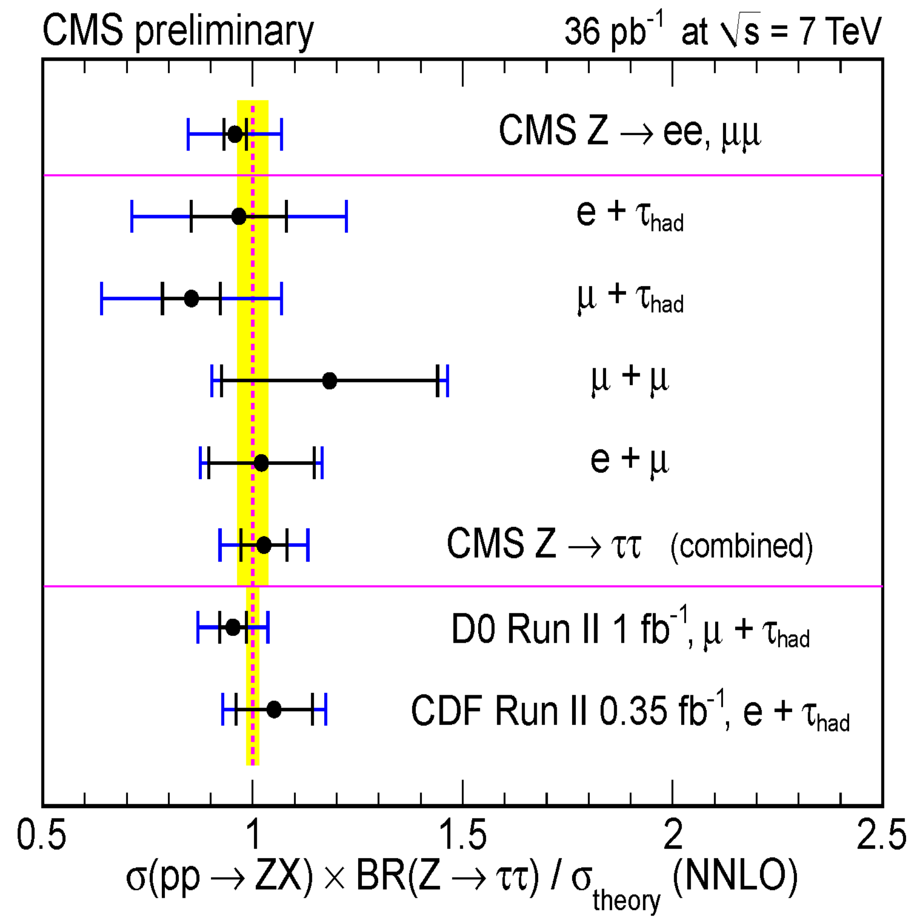
Final state	$\sigma(pp\to ZX)\times\mathcal{B}(Z\to\tau^+\tau^-)$ nb	stat.	syst.	lumi.	τ ID
$\tau_\mu\tau_{had}$	0.83	0.07	0.04	0.03	0.19
$\tau_e\tau_{had}$	0.94	0.11	0.03	0.04	0.22
$\tau_e\tau_\mu$	0.99	0.12	0.06	0.04	
$\tau_\mu\tau_\mu$	1.14	0.27	0.04	0.05	

Combined measurement already dominated by systematic uncertainties!

EWK physics results: Taus

- CMS results: consistent with $Z \rightarrow ee, \mu\mu$ measurements.
- Similar precision as the Tevatron with just 36 pb^{-1} !!

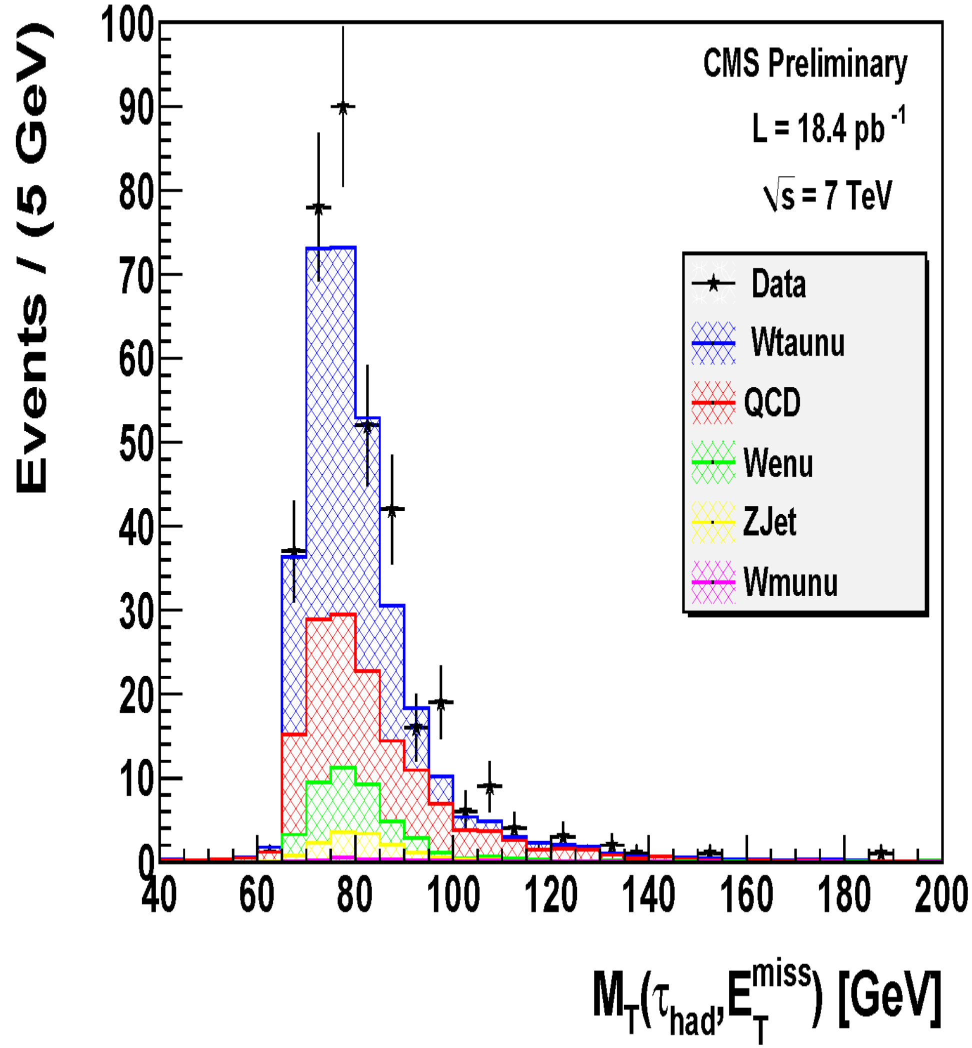




Observation of $W \rightarrow \tau_{had}\nu$

CMS-PAS-EWK-10-011

- Observation of the $W \rightarrow \tau_{had}\ \nu$ channel with 18 pb^{-1} of data:
  - Challenging from the trigger point of view:
    - $p_T(\tau)$>20 GeV
    - p_T(track)>15 GeV (HLT)
    - E_T^{miss}>25 GeV (HLT)
  - Key cuts to reduce QCD background:
    - $R_{HT} \equiv p_T(tau)/p_T(\text{all jets})>0.65$
    - Missing E_T > 35 GeV
  - QCD background is estimated from control regions obtained by inverting the R_{HT} and missing E_T cuts

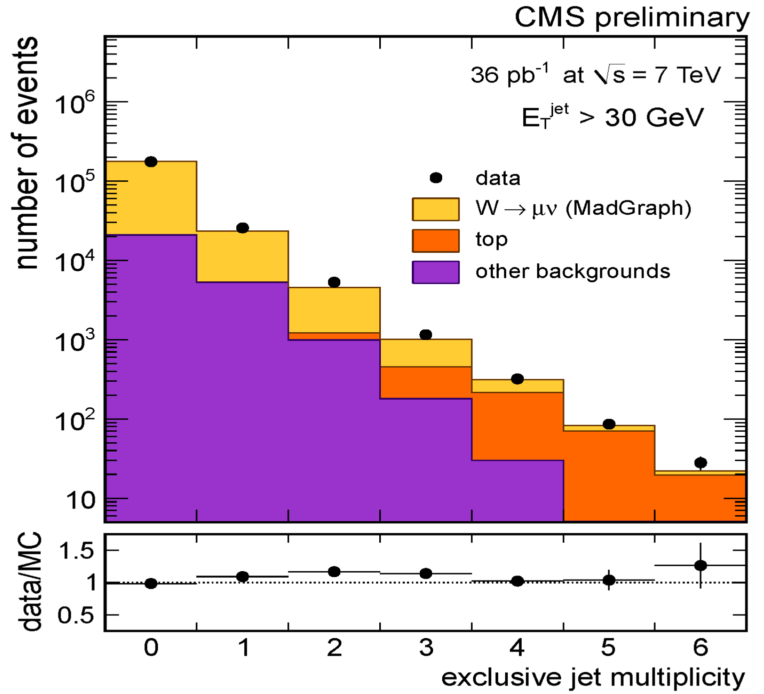


W+jets, Z+jets

CMS-PAS-EWK-10-012

- Key backgrounds in most new physics searches.
- Standard strategy : a) LO matrix element calculations for each jet multiplicity, b) interface with parton shower MCs using specific matching recipes (ALPGEN, MadGraph, SHERPA)
- Despite the difficulty, some NLO analytical calculations have appeared recently

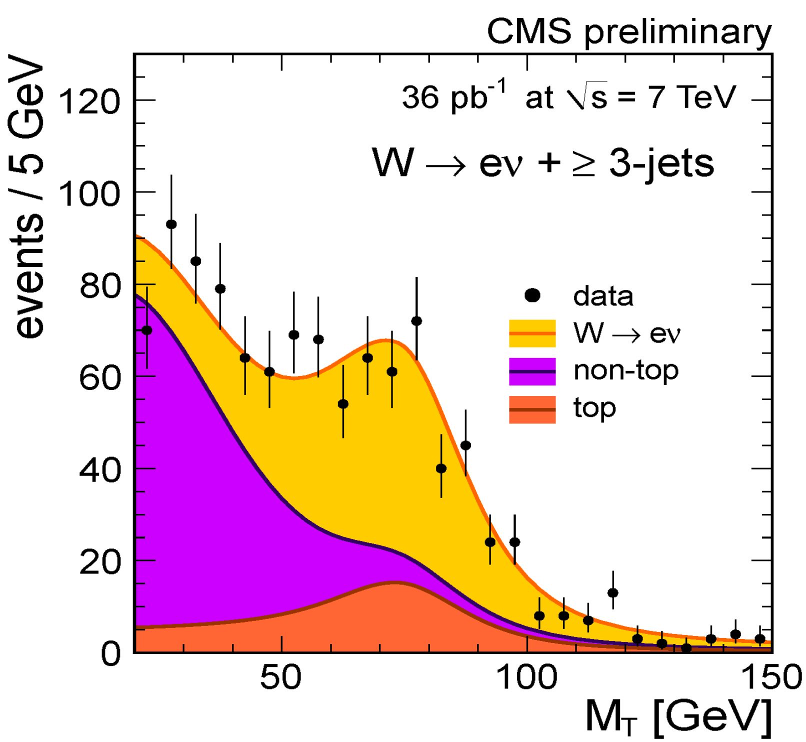
- The selection procedure follows closely what is done for inclusive measurements, adding the requirement of the presence of jets. Signal extraction is more difficult, due to larger backgrounds (QCD and top). Relevant cuts:
  - W: p_T(lepton)> 20 GeV, M_T>20 GeV
  - Z: p_{T1}>20 GeV, p_{T2}>10 GeV
  - Jet p_T > 30 GeV in $|\eta|$<2.4
- Most CMS results are presented in terms of ratios, in order to cancel systematic effects (energy scale, luminosity, selection)

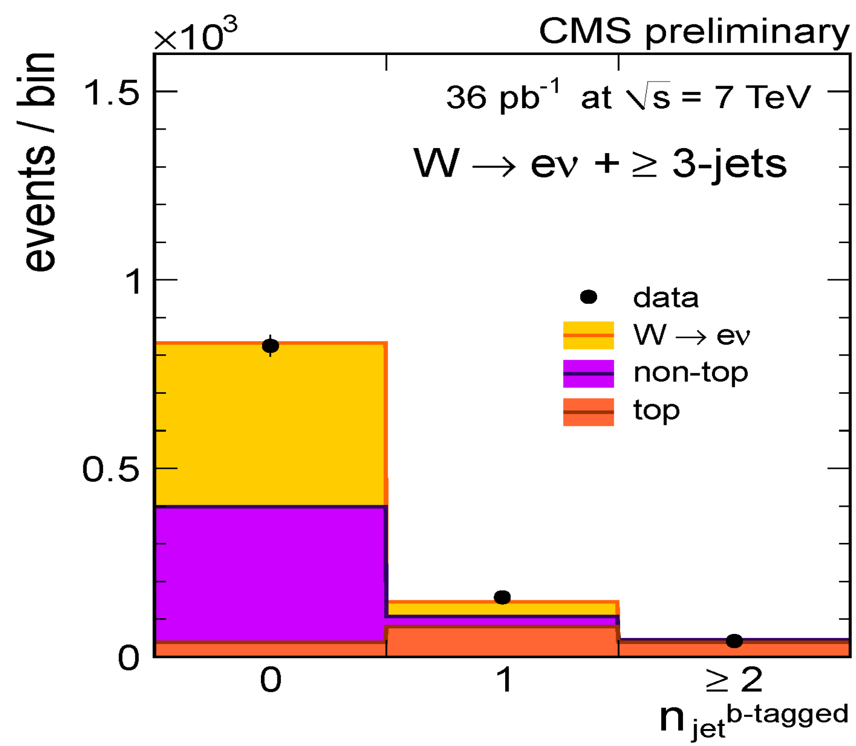


Raw jet distribution for W preselected events

W+jets, Z+jets: signal extraction

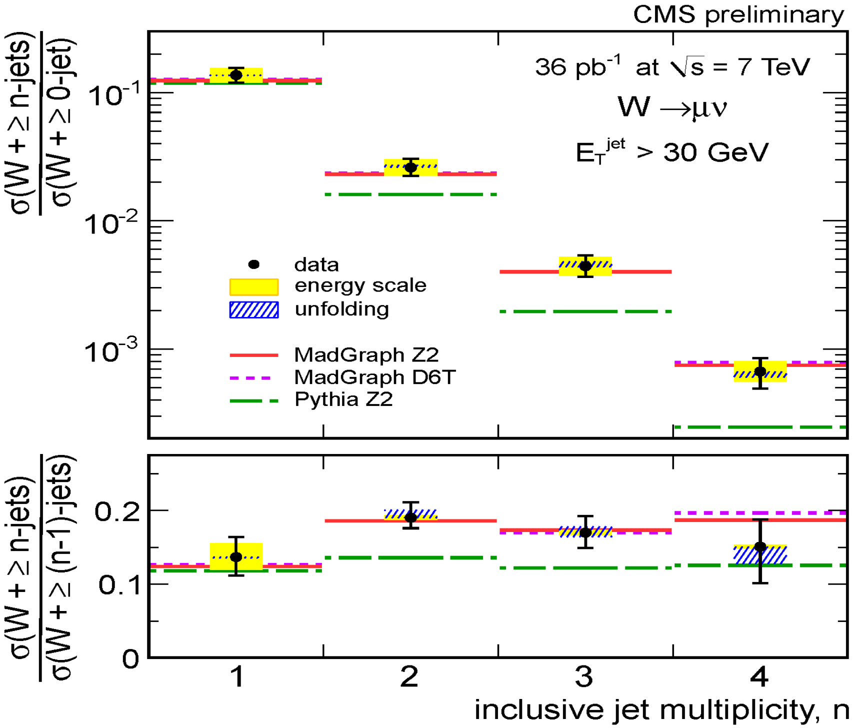
- Done for each jet multiplicity:
  - Z+jet: fit to the di-lepton invariant mass distribution
  - W+jet: fit to the M_T distribution and to the number of b-tagged jets (to extract the top contribution in a data-driven way)
- Relative changes in lepton efficiencies determined with T&P on Z+jet samples

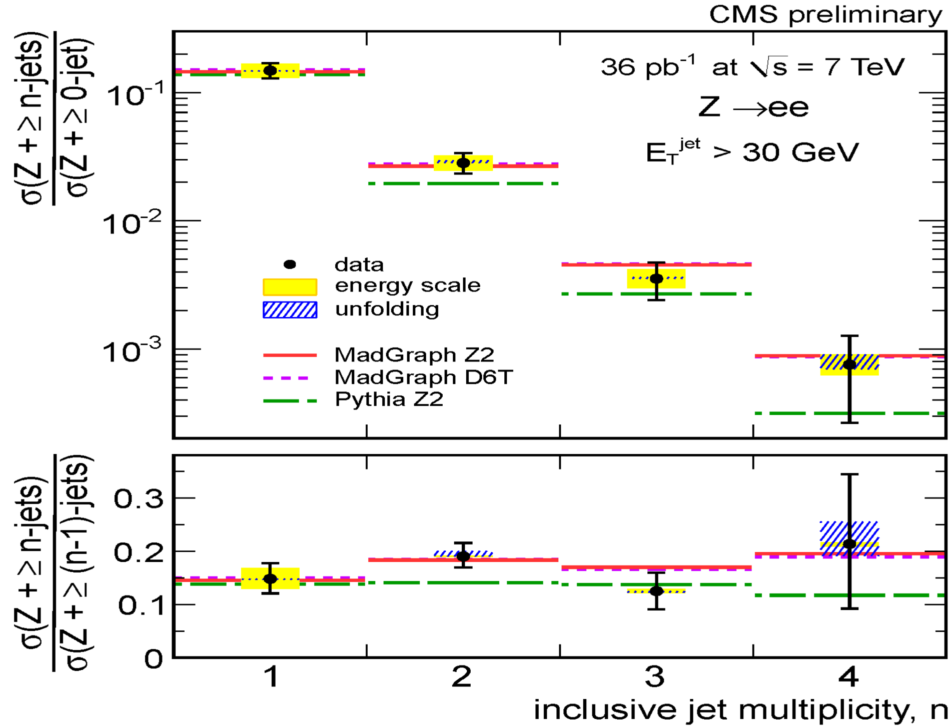




EWK physics results: W+jets, Z+jets

- Dominant systematics: enery scale, unfolding at high jet multiplicity (SVN assuming jet migrations from to MadGraph simulations)





- Results agree with the expectations from MADGRAPH
- PYTHIA does not agree with the data (only expected to describe up to 1 hard jet + soft/collinear radiation (LO+ME reweighting))

W polarization measurement

arXiv:1104.3829

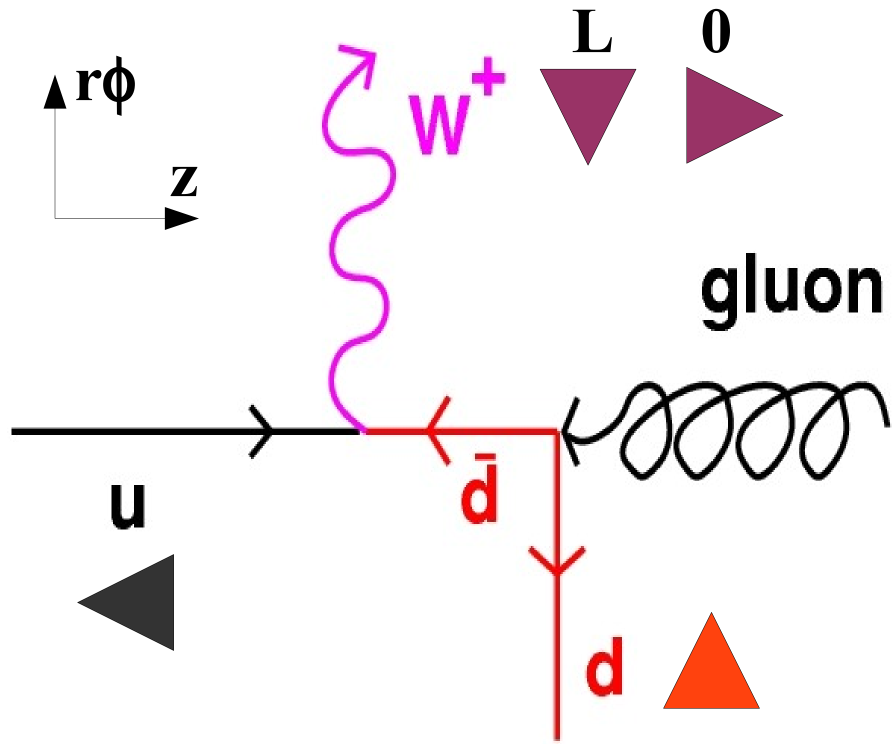
- At the LHC, W bosons exhibit a significant polarization when produced in association with hard jets:

$$u+g \rightarrow W^{+}+\ q\text{-}jet$$
$$d+g \rightarrow W^{-}+\ q\text{-}jet$$

1) "ug" and "dg" initial states are favored with respect to $q\bar{q}$
2) the V-A coupling to the W boson imposes left-handed polarizations to quarks (massless limit)

- The exact value of this polarization depends on the proportion of the "qg", "$\bar{q}$g" and "q$\bar{q}$" contributions

- Understanding this polarization has also implications for new particle searches, where the W polarization may differ significantly (SUSY, for instance)



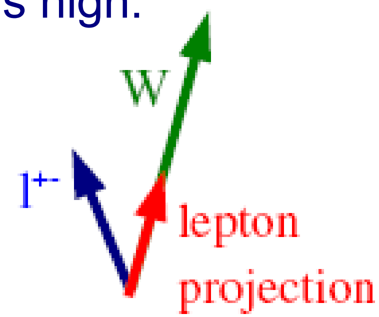
W polarization measurement

- Experimentally, instead of measuring the angular distribution as a function of cosθ* in the helicity center-of-mass frame of the W boson:

$$\frac{d\rho}{d\cos\theta^*} = \frac{3}{8} f_R \left(1+\cos\theta^*\right)^2 + \frac{3}{8} f_L \left(1-\cos\theta^*\right)^2 + \frac{3}{4} f_0 \sin^2\theta^* ; \qquad f_0 + f_L + f_R = 1$$

we use as angular variable a lepton projection in the LAB system / transverse plane, L_P. L_P is closely related with cosθ* when the boson p_T, is high:

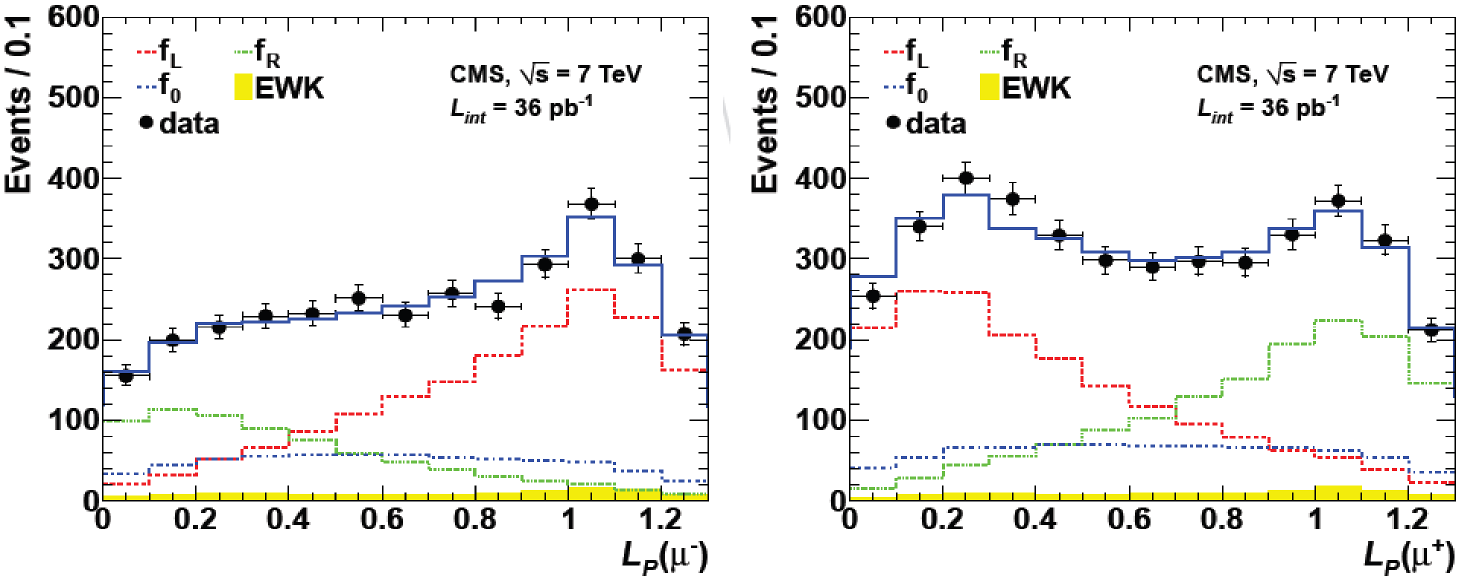
$$L_P = \frac{\vec{p}_T(l)\ \vec{p}_T(W)}{|\vec{p}_T(W)|^2} ; \qquad \lim_{\vec{p}_T(W) \gg M_W,\, p_z(W)} L_P = 1 + \frac{\cos\theta^*}{2}$$

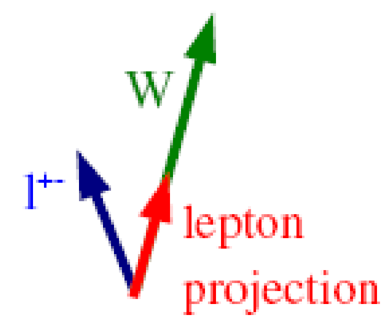


- L_P is built experimentally from the transverse lepton momentum and the transverse missing energy of the event. It does not require full reconstruction of the W (no need to estimate of the longitudinal momentum of the unobserved neutrino).

W polarization measurement

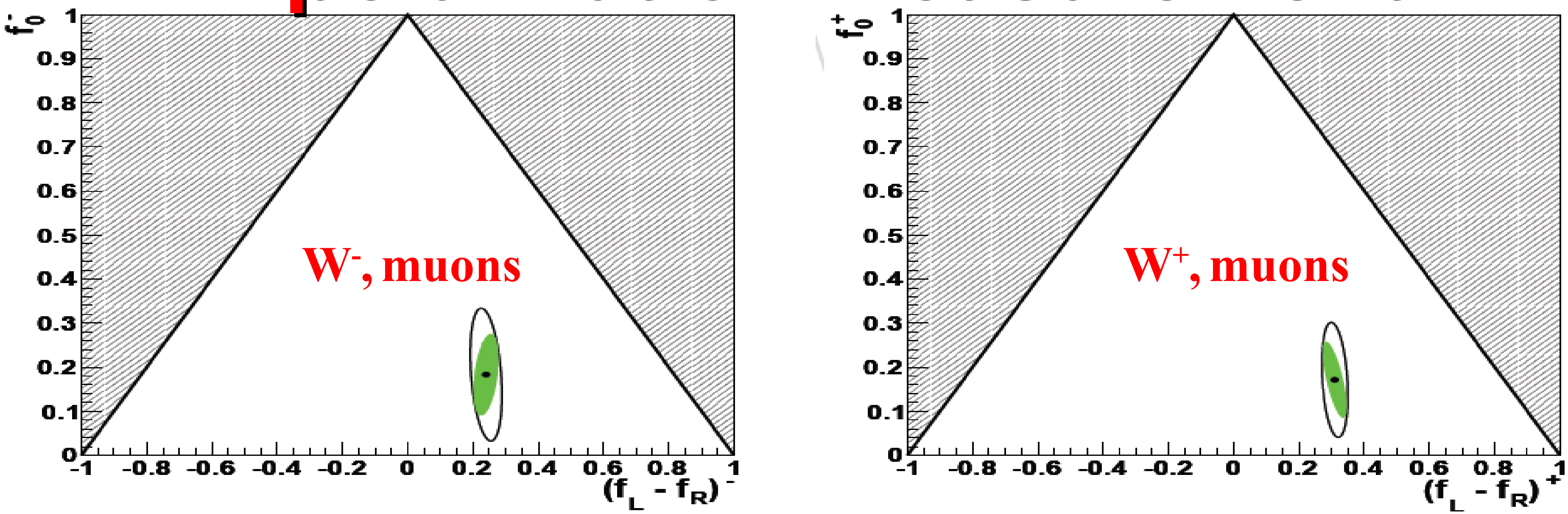
- Again, the analysis follows closely the inclusive selection. In addition:
  - M_T > 50 (30) GeV for the electron (muon) channel (QCD rejection)
  - No more than 3 jets with p_T> 30 GeV ($t\bar{t}$ rejection)
  - $p_T(W)$ > 50 GeV (to enhance the qg component that leads to polarized Ws)





- ≈ 14000 selected events
- EWK backgrounds: ≈ 250 events per channel
- QCD background only relevant in the electron channel (yield is fitted)

W polarization measurement



Uncertainty	$(f_L - f_R)^-$	f_0^-	$(f_L - f_R)^+$	f_0^+
Recoil energy scale	±0.029	±0.123	±0.011	±0.092
Recoil resolution	±0.012	±0.006	±0.012	±0.004
Muon scale	±0.002	±0.007	±0.004	±0.008
Total uncertainty	±0.031	±0.123	±0.017	±0.099

Systematics dominated by recoil uncertainties

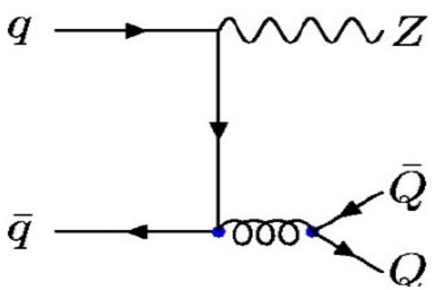
Clear observation of W polarization at the LHC !!

Associated b-jet production

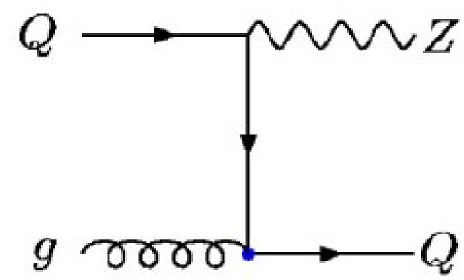
CMS-PAS-EWK-10-015

- pp→Z+b+X in an important background for many particle searches, in particular Higgs (Z+H at low mass, H → ZZ at medium/high mass, ...)

- Two different theory approaches used to deal with this process:



Fixed-flavor scheme (no b-quark at parton level)
Caclulations with massive b quark



Variable-flavor scheme (b-quark at parton level)

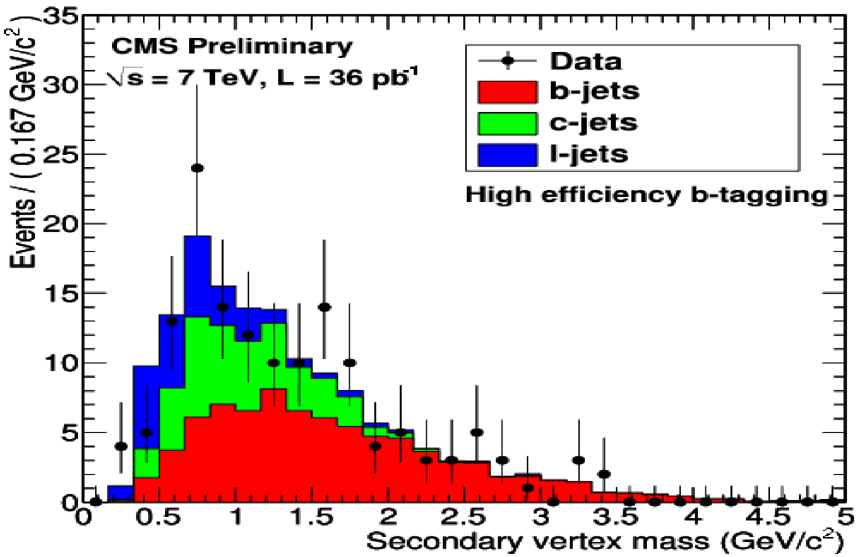
Both are explored in the Z+b CMS analysis using MadGraph+PYTHIA.

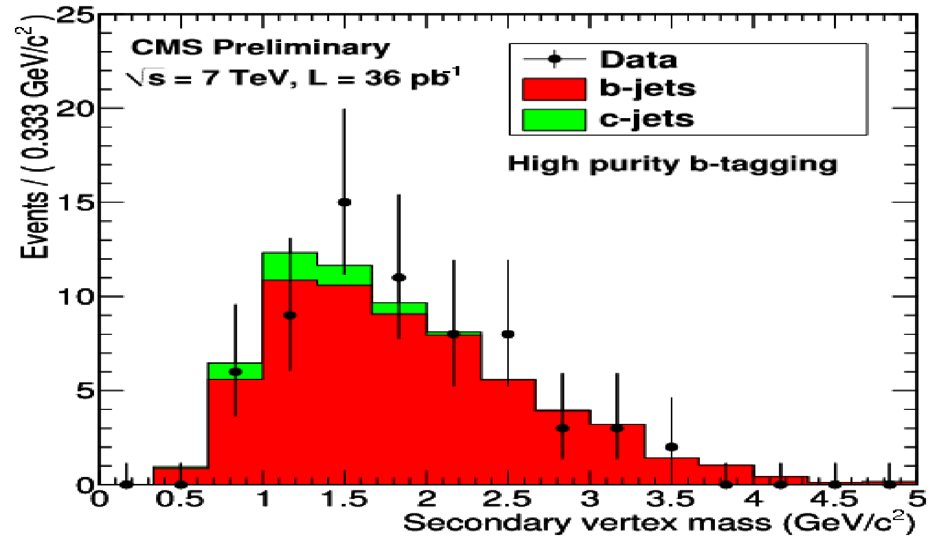
Expected cross section (MCFM, m_{ll}>40 GeV, $|\eta_l|$<2.5, p_{jet}>15 GeV): 26 ± 3 pb

- Basic strategy:
  a) Select clean Z decays into leptons (60 < M_{ll} < 120 GeV), E_T^{miss}<40 GeV against $t\bar{t}$
  b) PF jet with pt>25 GeV. Apply b-tagging on it (secondary vertex with high/low purity)
  c) Measure σ(Z+b) / σ(Z+jet) ratio

Associated b-jet production

- 65 selected events in a 36 pb^{-1} data sample. B-purity determined from template fits to b and non-b components of the secondary vertex mass distribution:





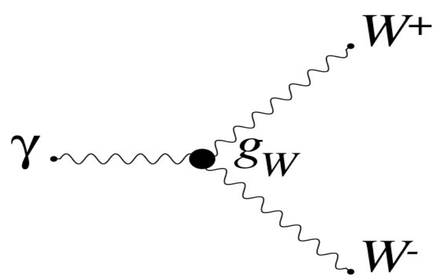
Sample	$\mathcal{R}(Z \to ee)$ (%), $p_T^e > 25$ GeV, $\lvert\eta^e\rvert < 2.5$	$\mathcal{R}(Z \to \mu\mu)$ (%), $p_T^\mu > 20$ GeV, $\lvert\eta^\mu\rvert < 2.1$
Data HE	$4.3 \pm 0.6(stat) \pm 1.1(syst)$	$5.1 \pm 0.6(stat) \pm 1.3(syst)$
Data HP	$5.4 \pm 1.0(stat) \pm 1.2(syst)$	$4.6 \pm 0.8(stat) \pm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

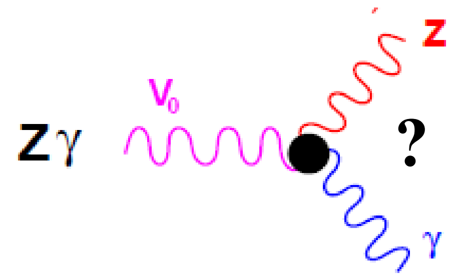
$$\mathcal{R} = \frac{\sigma(pp \to Z+b+X)}{\sigma(pp \to Z+j+X)}$$

Results in agreement with theoretical predictions within experimental and theoretical uncertainties

Vγ production

- Wγ and Zγ production in the SM:
  - Final states appearing in several new physics scenarios (fermiophobic Higgs, SUSY, ...)
  - Allows tests of the triple-gauge coupling structure of the SM and a search for anomalous couplings





Reference phase space:

- $P_T(\gamma)$ > 10 GeV, $\Delta R(l,\gamma)$>0.7
- $M(l\bar{l})$ > 50 GeV (Zγ channel)

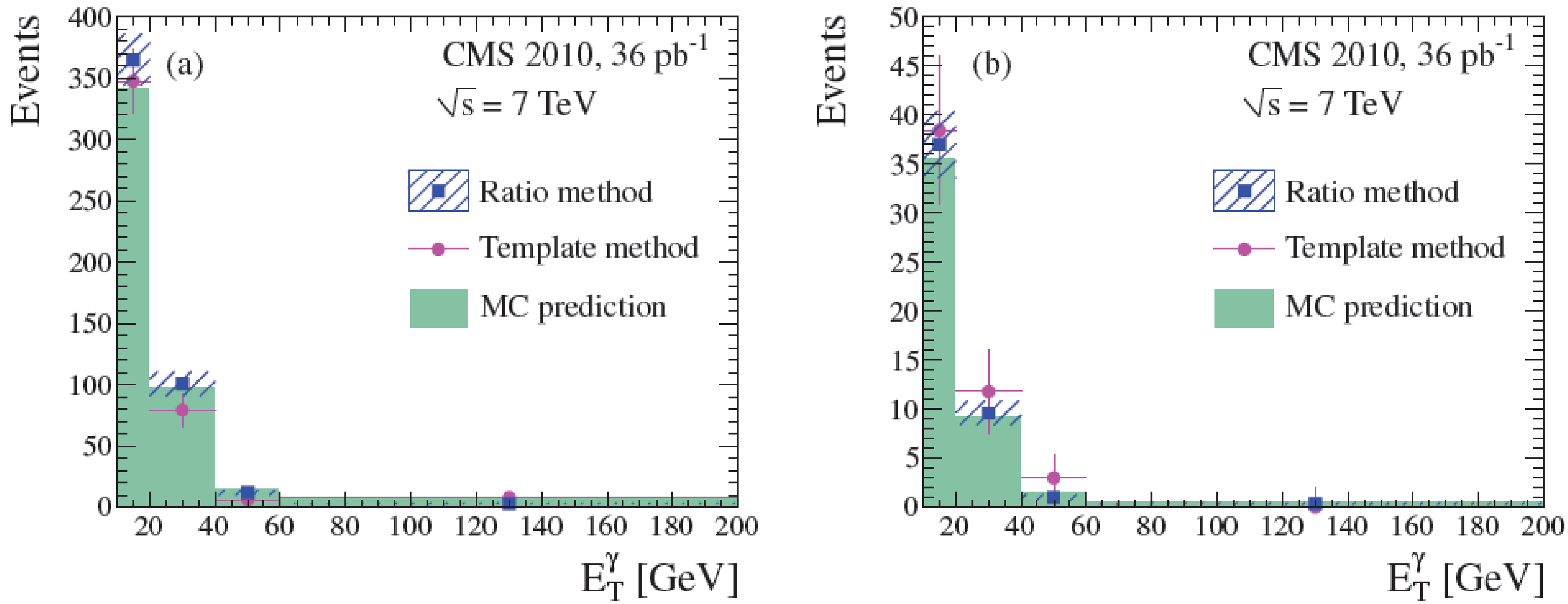
Other experimental cuts:

- Isolated leptons and photons
- $p_T(l)$ > 20 GeV
- E_T^{miss} > 25 GeV (Wγ channel)

- Main difficulty compared with inclusive analyses:
  - Fake-photon backgrounds from W+jets and Z+jets

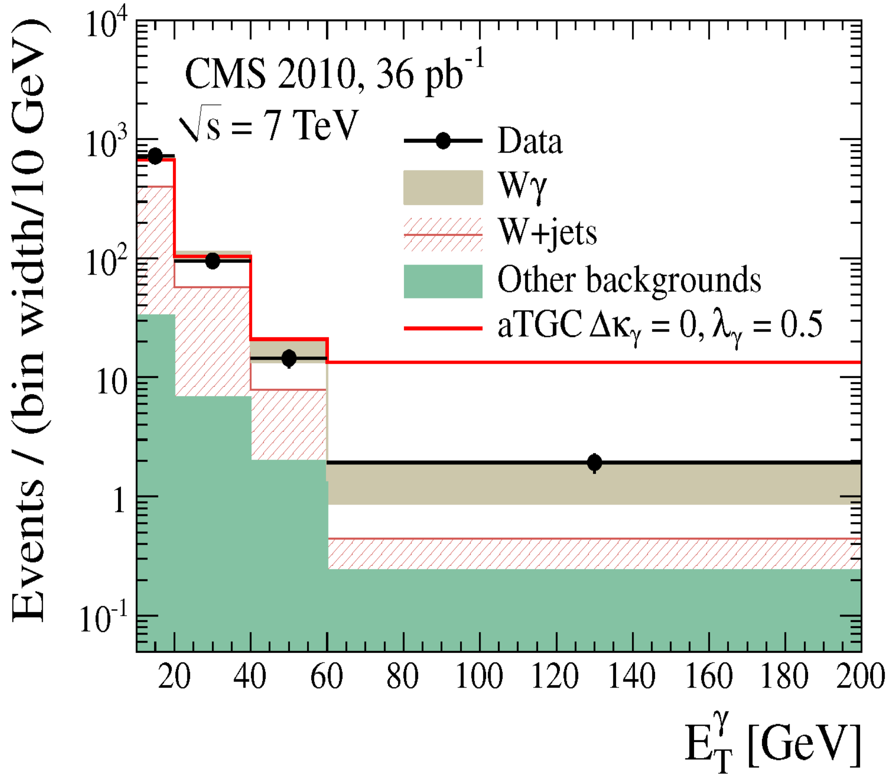
EWK physics results: Vγ production

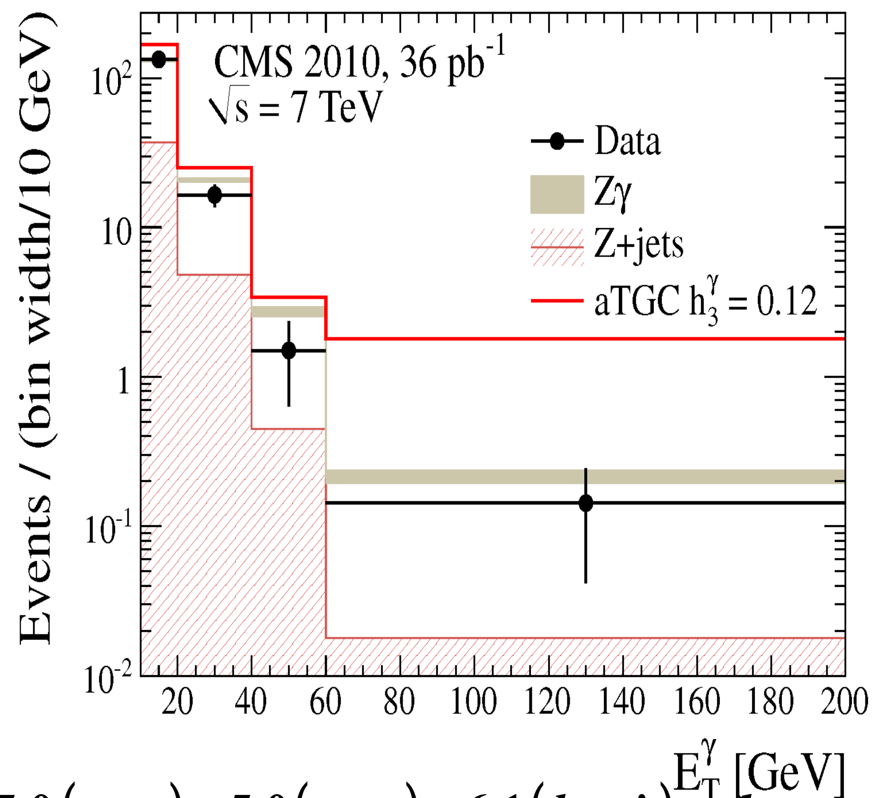
- Strategies to estimate the rate of fake isolated photons:
  - Ratio method: assume the isolation properties of jets in QCD multijet events are the same as in jets from W+jets and Z+jets → take the ratio of isolated/non-isolated photon candidates from QCD events
  - Template method: use the shape of lateral energy deposition as a discriminant between photons and misidentified π^0, η → fit to the two components in data
  - MC estimate



Good agreement between all estimates!

EWK physics results: Vγ production





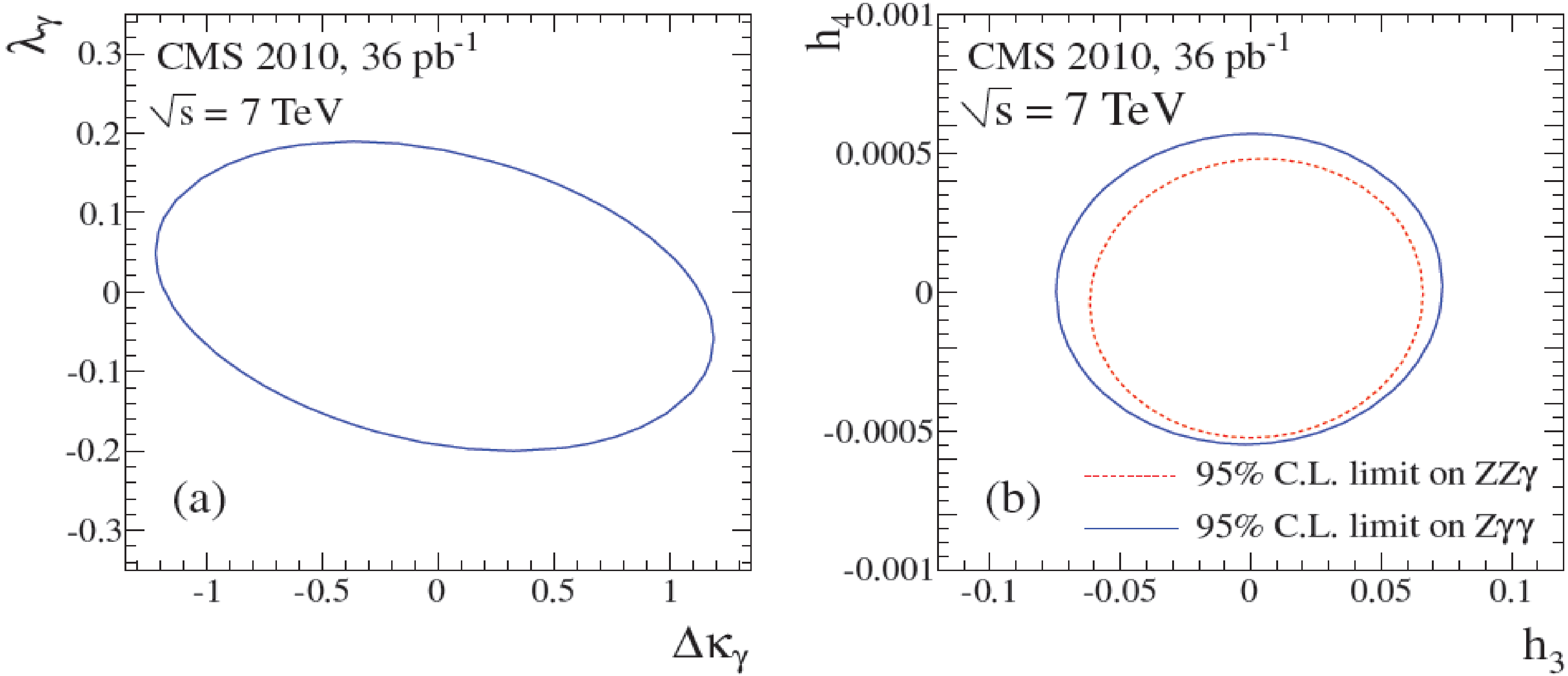
$$\sigma\left(pp \to W\gamma + X\right) B\left(W \to l\nu\right) = 55.9 \pm 5.0\left(stat.\right) \pm 5.0\left(syst.\right) \pm 6.1\left(lumi.\right)\ pb$$

$$\sigma\left(pp \to W\gamma + X\right) B\left(W \to l\nu\right) = 9.3 \pm 1.0\left(stat.\right) \pm 0.6\left(syst.\right) \pm 1.0\left(lumi.\right)\ pb$$

Good agreement with theoretical expectations (49.4±3.8 pb, 9.6±0.4 pb)

Hard part of the photon spectrum used to set limits on anomalous TGCs

EWK physics results: Vγ production



One dimensional 95% C.L. limits on $WW\gamma$, $ZZ\gamma$, and $Z\gamma\gamma$ aTGCs.

$WW\gamma$	$ZZ\gamma$	$Z\gamma\gamma$
$-1.09 < \Delta\kappa_\gamma < 1.03$	$-0.05 < h_3 < 0.06$	$-0.07 < h_3 < 0.07$
$-0.18 < \lambda_\gamma < 0.17$	$-0.0005 < h_4 < 0.0005$	$-0.0005 < h_4 < 0.0006$

Stringent limits on h_4

Sensitivity similar to Tevatron with just 36 pb^{-1}

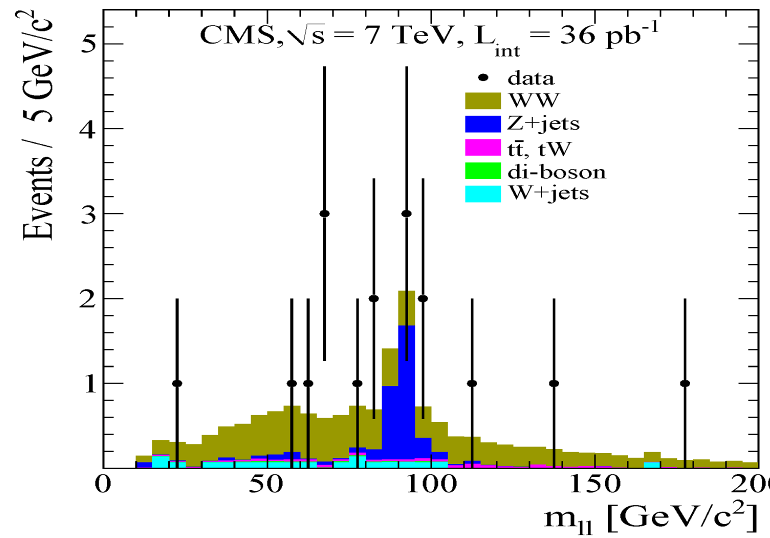
WW production

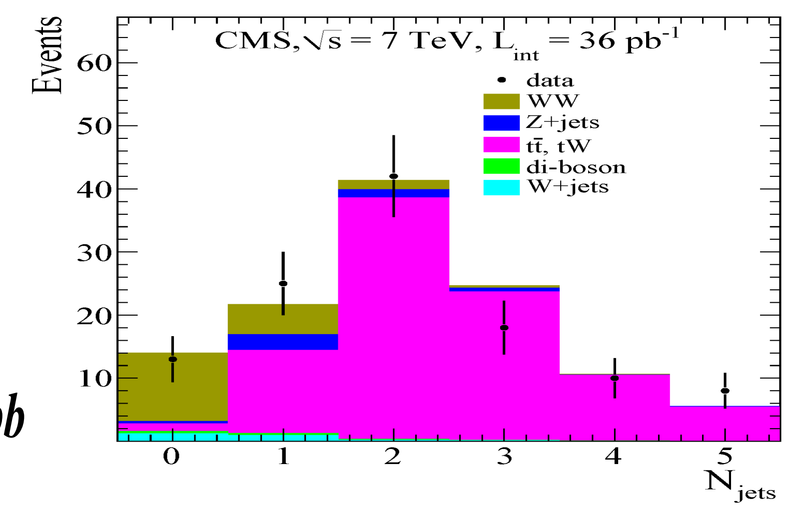
Phys. Lett. B 699 (2011) 25, arXiv:1102.5429

- Challenging analysis, mandatory before performing H → WW searches

Analysis strategy:

- Use W → e,μ decays, $p_T^l > 20$ GeV
- Veto Drell-Yan->ee,μμ (no Z peak, require missing E_T)
- Veto taus (no missing E_T along lepton axes)
- Veto tops, W+jets, WZ, ZZ (no jets, no extra leptons)
- Most backgrounds controlled via data-driven methods (DY, W+jets, top)





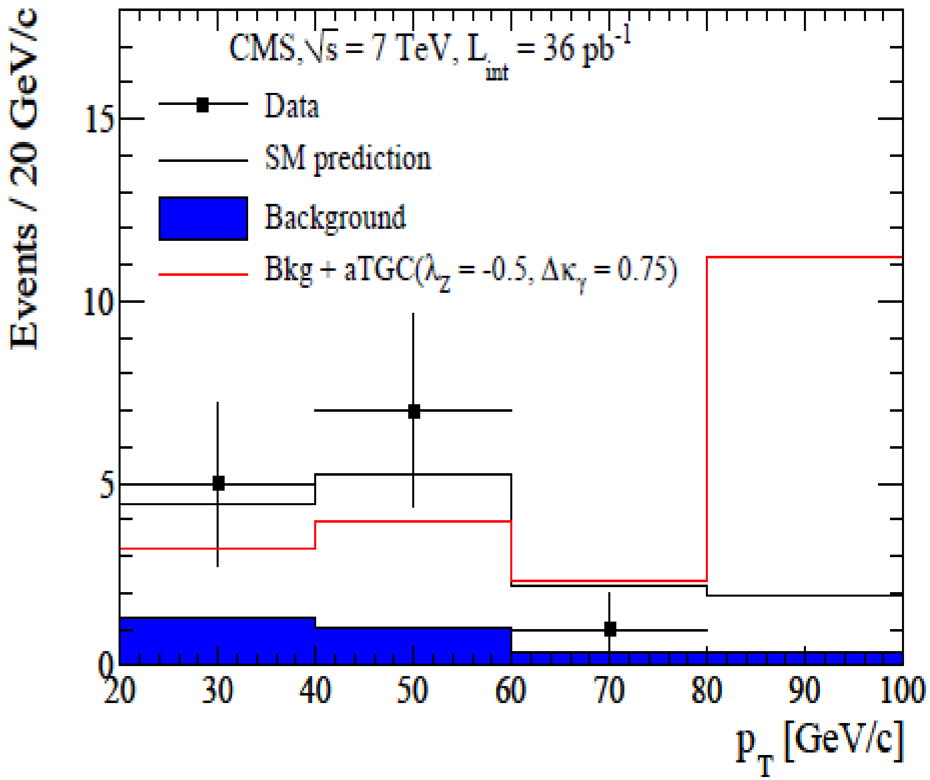
13 events selected in data with an estimated background on 3.3±1.2 events

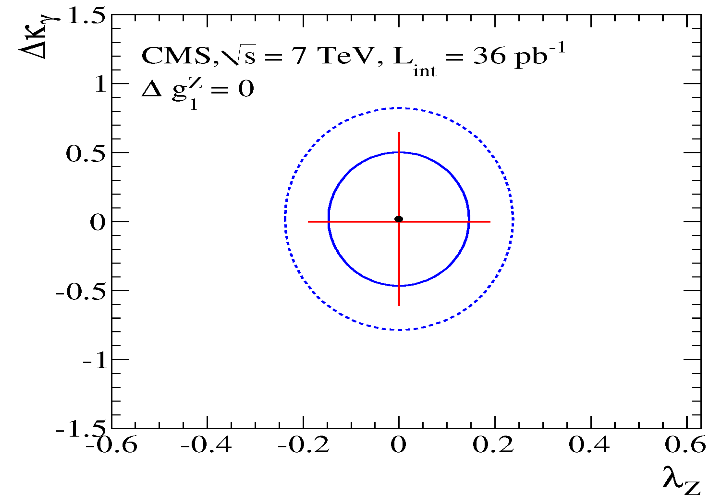
$$\sigma(WW) = 41.1 \pm 15.3(stat) \pm 5.8(syst) \pm 4.5(lumi)\ pb$$

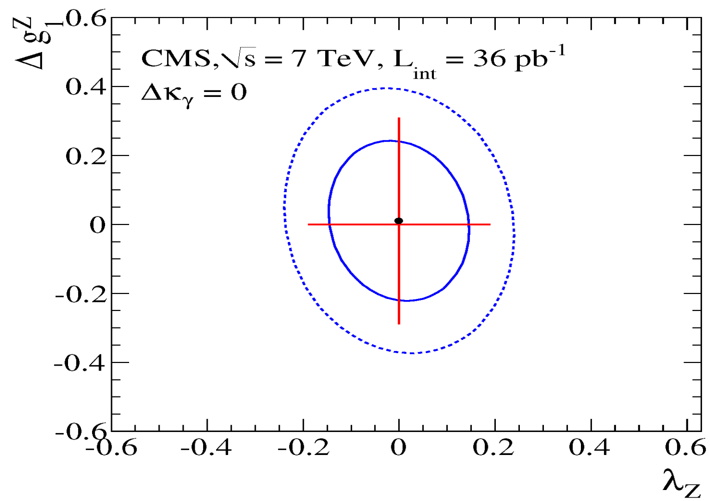
EWK physics results: WW production

- Limits on the anomalous WWγ and WWZ couplings, Δg_1^Z, $\Delta\kappa_\gamma$

Leading lepton p_T used to set aTGC limits



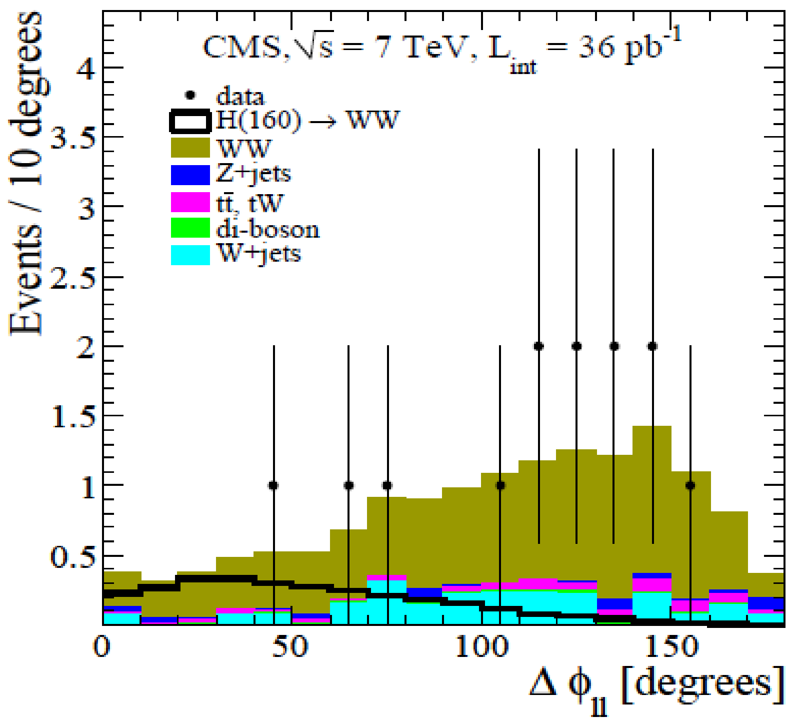


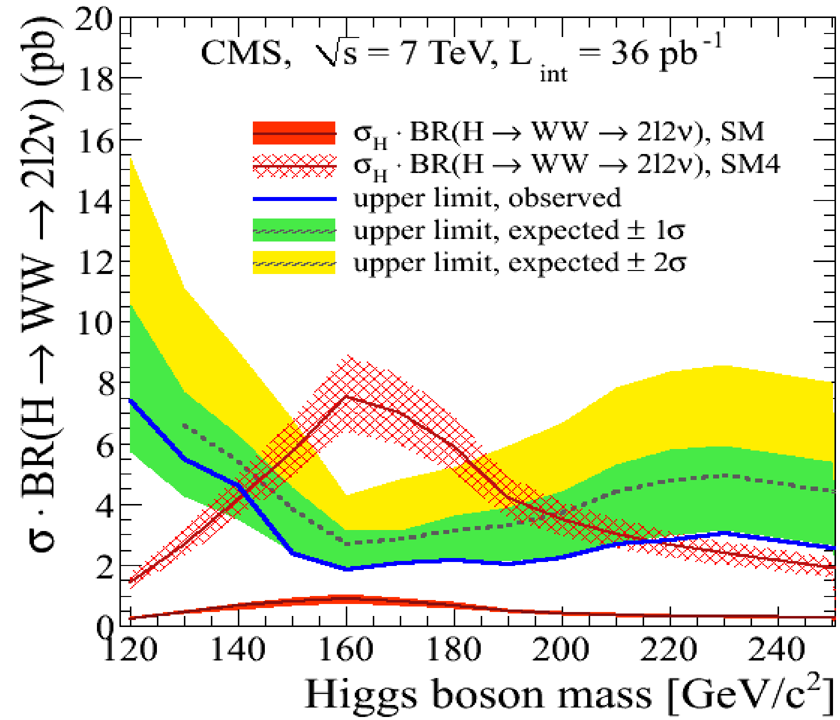


Again, sensitivity similar to Tevatron with just 36 pb^{-1}

EWK physics results: WW production

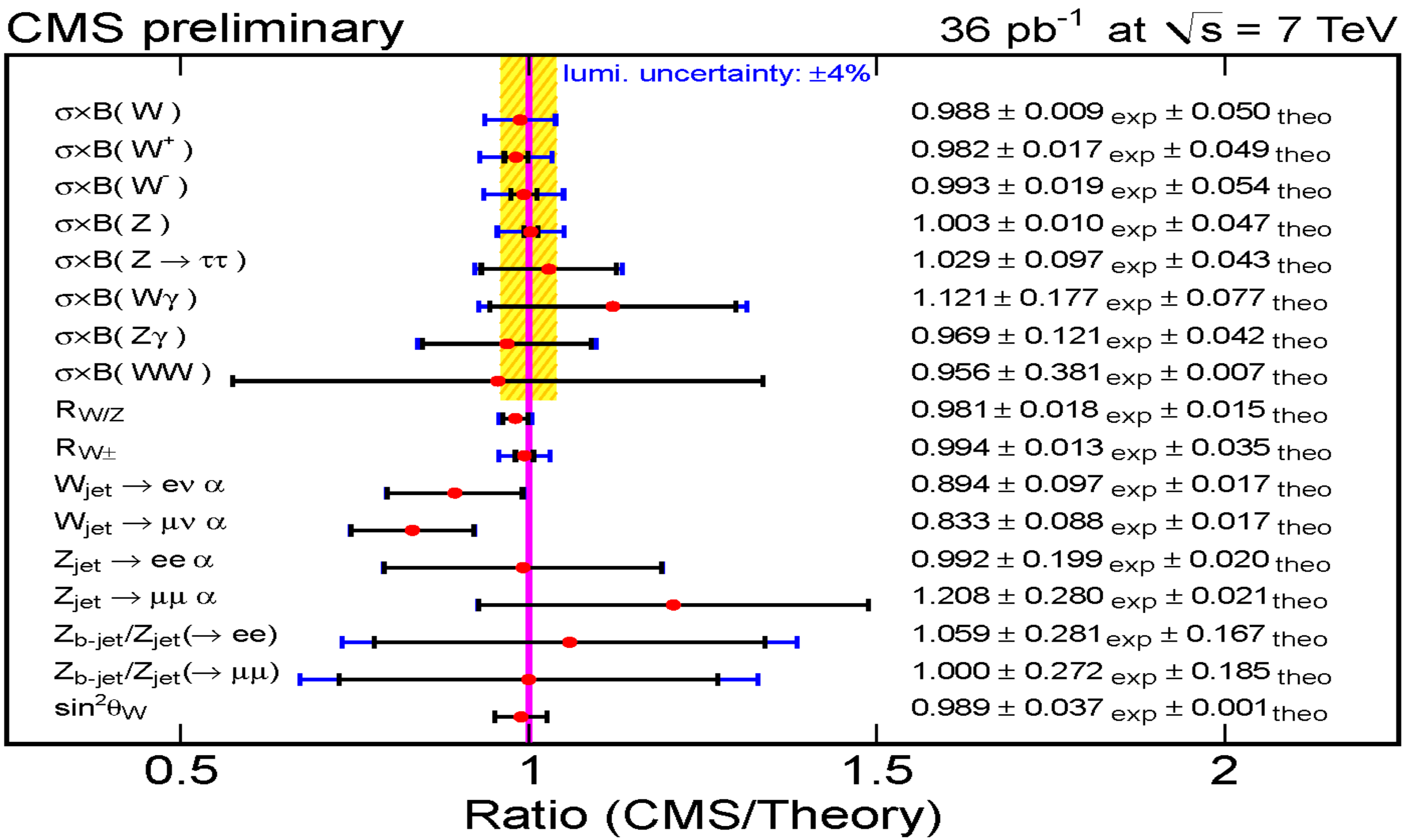
- A simple extension of this analysis has been used to search for the Higgs in the $H \to WW$ decay channel
  - Exploit the different spin correlations existent in the Higgs decay





Enough sensitivity to exclude a Higgs particle in a four-generation SM scheme in the range 144-207 GeV

All CMS EWK measurements



A comprehensive picture of W/Z production properties at the LHC, in agreement with theory expectations

Summary

- With the data from the first LHC run in 2010, CMS has provided a plethora of EWK physics results studying final states containing W and Z boson decays:
  - Precise measurements of inclusive cross sections with boson decays into leptons (electrons, muons and even taus)
  - Detailed studies of differential cross sections in Drell-Yan production (as a function of transverse, rapidity, invariant mass)
  - Precise measurements of different observables (asymmetries, W polarization), including a first measurement of the weak mixing angle
  - Detailed studies of associated jet production (V+jets) and observation of associated b-jet production for the Z case
  - Observation of diboson final states: WW, Wγ, Zγ, and first (competitive) measurements of anomalous triple gauge boson couplings
- All results show good agreement with the SM predictions and with most of the state of the art MC predictions

A successful and necessary step before entering a (hopefully) exciting period of new physics discoveries at the LHC !

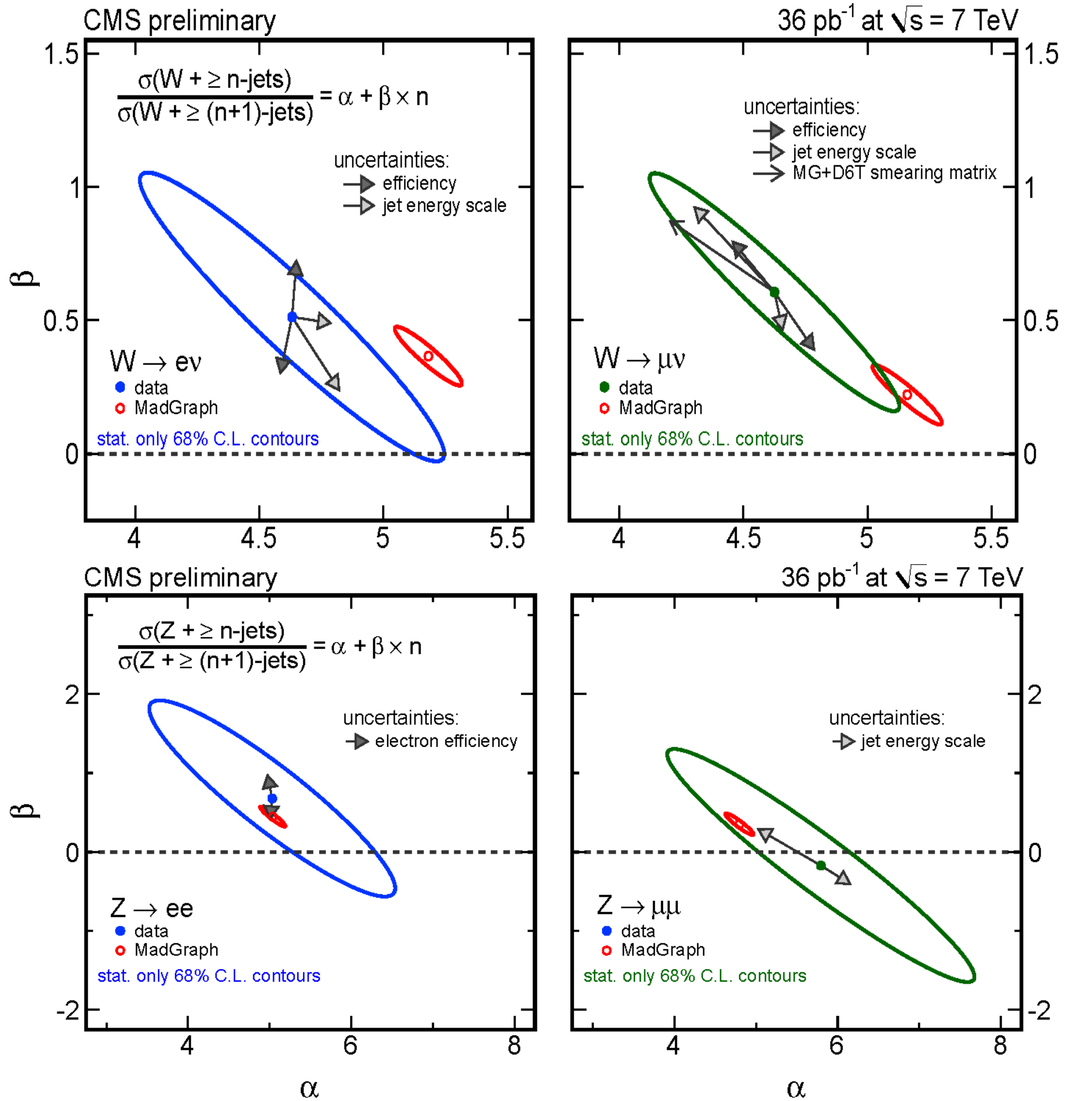
Backup

EWK physics results: W+jets, Z+jets

Test of Berends-Giele scaling:

$$\frac{\sigma(V+\ \geq N_{jet})}{\sigma(V+\ \geq N_{jet}+1)} = \alpha + \beta N_{jet}$$

α, β *constants*, β *small*



- Results in reasonable agreement with MADGRAPH expectations