# Measurement of W/Z Boson Production with Muons in CMS

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GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

# Outline

## Motivation

- W/Z production are the first electroweak processes studied at the LHC.
- Clear signatures with electrons/muons.
  Standard candles for high-pt electron/muon reconstruction and identification.
- Test of perturbative QCD, PDFs.
- Complementary method for estimation of LHC luminosity.
- Important background in several searches.
- In the future: Precision measurements of SM parameters.

**Soon: Publication by CMS EWK Group using $\mathcal{L}_{int} = 2.9\ \text{pb}^{-1}$**

*Measurement of Inclusive W and Z Cross Sections in pp Collisions at $\sqrt{s} = 7$ TeV*

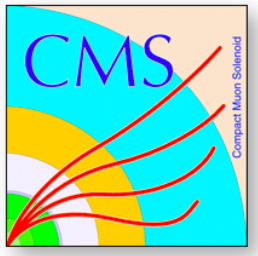
1. Introduction

2. Official CMS Results with $\mathcal{L}_{int} = 2.9$ pb$^{-1}$
   - Measurement of Inclusive W/Z Cross Sections with Muons at $\sqrt{s} = 7$ TeV

3. Work in Progress with $\mathcal{L}_{int} = 32$ pb$^{-1}$
   - Hadronic Recoil Modeling for $W \to \mu\nu$ Signal Shape
   - W Mass Fit

4. Conclusion

# $Z \to \mu\mu$ Event Candidate




CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

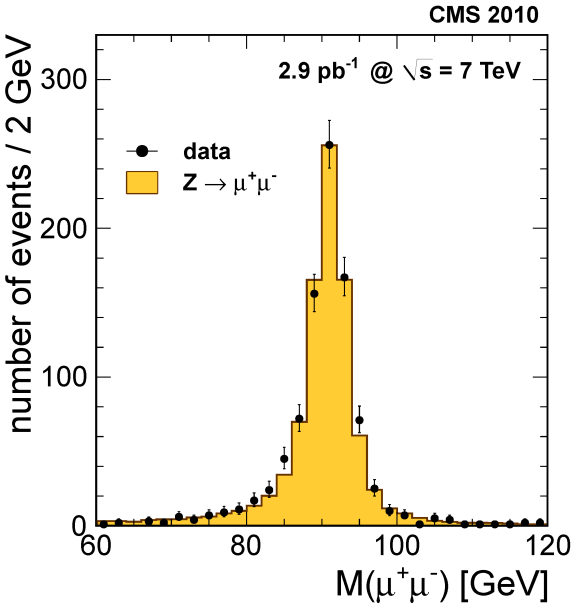
Muon $p_T$= 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/$c^2$

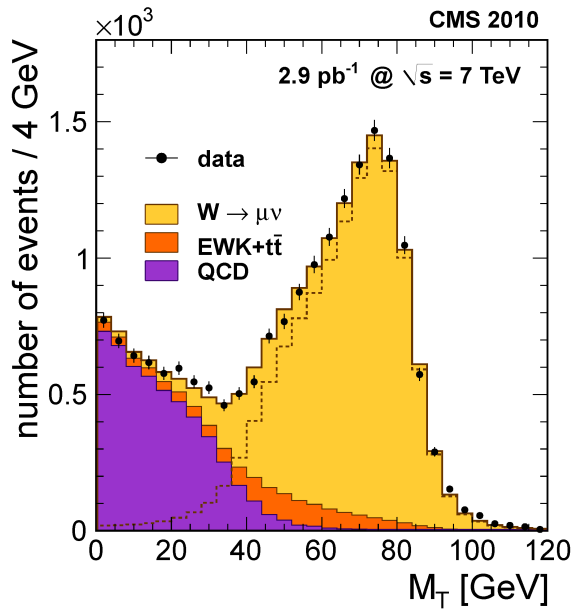
# Selection of Muons in $W/Z$ Analyses

## Selection

- muon trigger, threshold $p_T^\mu > 9$ GeV
- muon with $p_T^\mu > 20$ GeV, $|\eta|^\mu < 2.1$
- muon reconstructed in both tracker and muon system
- muon quality cuts
  - sufficient/good $p_T$ determination at trigger/reconstruction step
  - reject fakes and meson decays in flight
  - reject cosmics
- isolation requirement
  $(\sum_{Tk} p_T + \sum_{ECAL} E_T + \sum_{HCAL} E_T)/p_T^\mu < 0.15$

Conservative set of cuts.



# Ingredients for Cross Section Measurement

**Masterformula for Experimentalists**

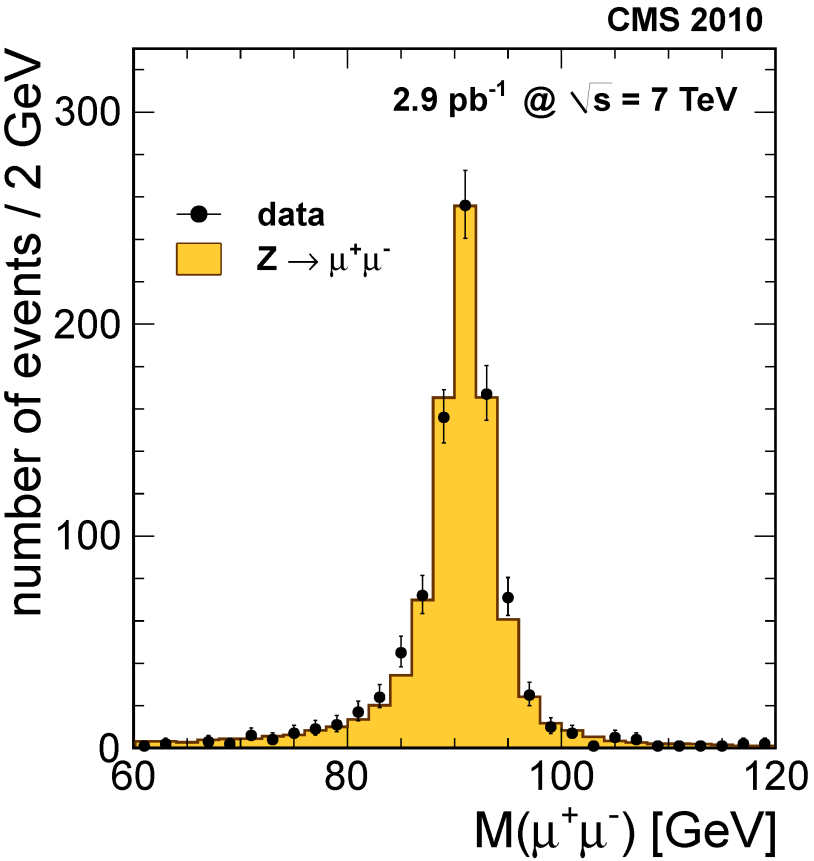
$$\sigma_V \cdot \mathrm{BR}(V \to l_1 l_2) = \frac{(N_{sel} - N_{bg})}{A \ \epsilon \ \mathcal{L}_{int}}$$

- Acceptance $A$ determined from MC simulation.
- Luminosity from Lumi Group, dominant uncertainty $\frac{\sigma_{\mathcal{L}}}{\mathcal{L}} = 11\%$.
- Efficiencies $\epsilon_x$ determined on data: Tag and Probe.
  Simultaneous fit to mutually exclusive $Z$ event categories.
  Z signal yield and efficiencies determined in one fit.
- MC efficiencies corrected with data-driven result:

$$\epsilon_x = \epsilon_x^{MC} \cdot \frac{\epsilon_x^{T\&P}(\mathrm{data})}{\epsilon_x^{T\&P}(\mathrm{MC})}$$

$$\text{Overall correction: } \frac{\epsilon^{T\&P}(\mathrm{data})}{\epsilon^{T\&P}(\mathrm{MC})} = 0.933 \pm 0.012$$

# $Z \to \mu\mu$: Cross Section Result




- Both muons carry opposite charge, 60 GeV $< M_{\mu\mu} <$ 120 GeV.
- 913 events selected in 2.9 pb$^{-1}$.
- Expected background $< 0.5\%$.
- Muon momentum scale well calibrated. Effects on momentum scale $< 0.4\%$.
- Theoretical uncertainties dominate systematics (w/o luminosity).

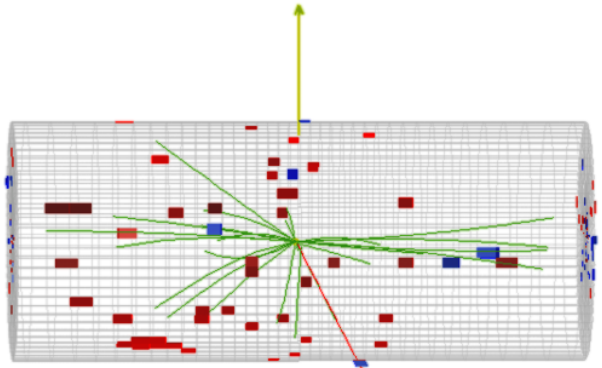
**Cross Section (60 GeV $< M_{\mu\mu} <$ 120 GeV)  FEWZ: $0.97 \pm 0.04$ nb**

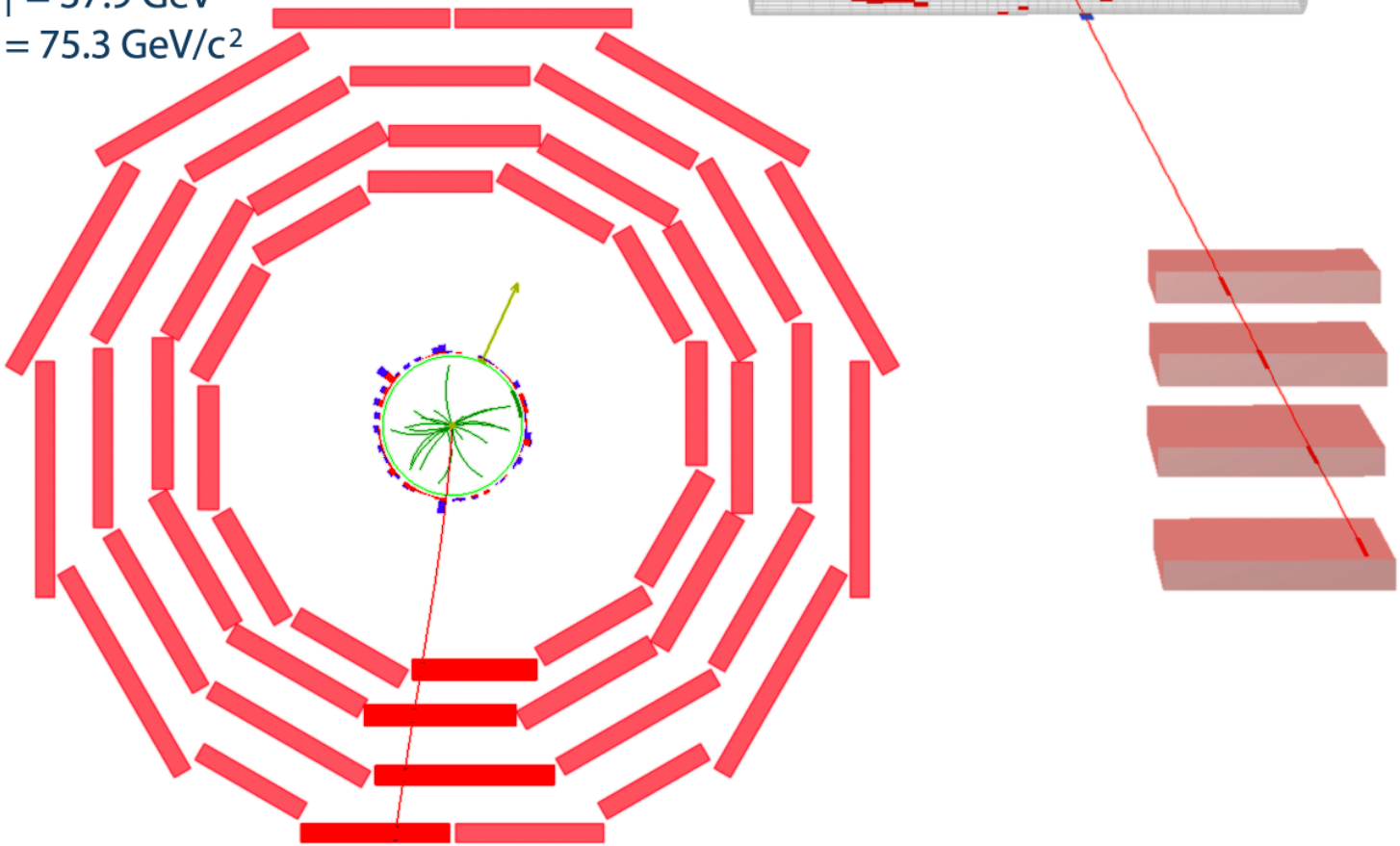
$\sigma_{Z/\gamma^*} \cdot \mathrm{BR}(Z \to \mu\mu) = 0.924 \pm 0.031(\mathrm{stat.}) \pm 0.022(\mathrm{syst.}) \pm 0.102(\mathrm{lumi.})$ nb

# $W \to \mu\nu$ Event Candidate


CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST

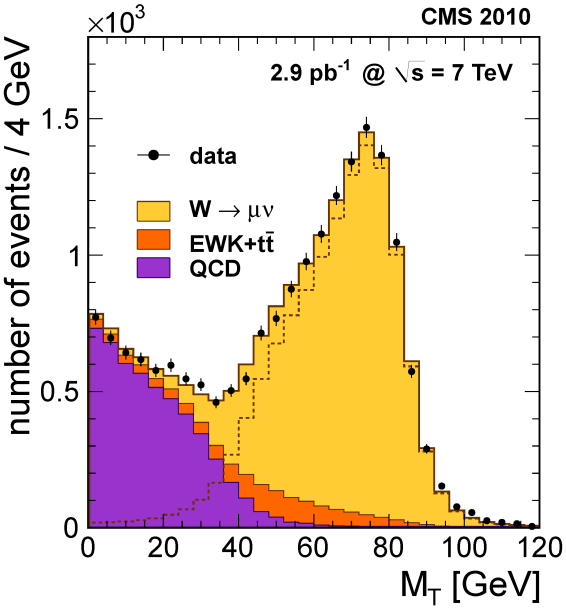
Muon $p_T = 38.7$ GeV/c
$ME_T = 37.9$ GeV
$M_T = 75.3$ GeV/$c^2$

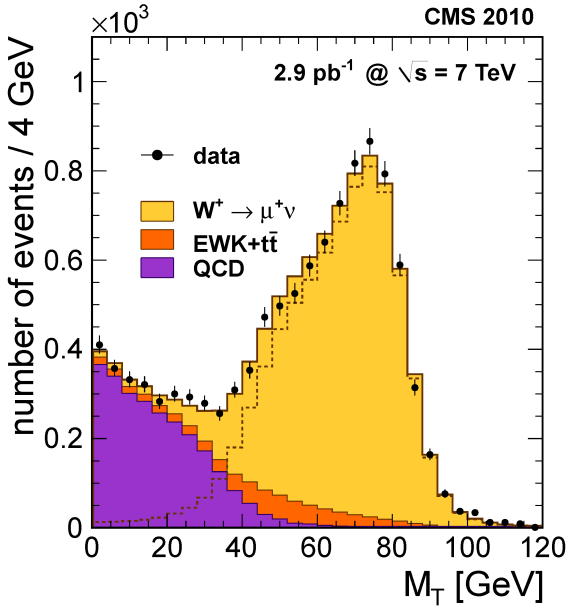


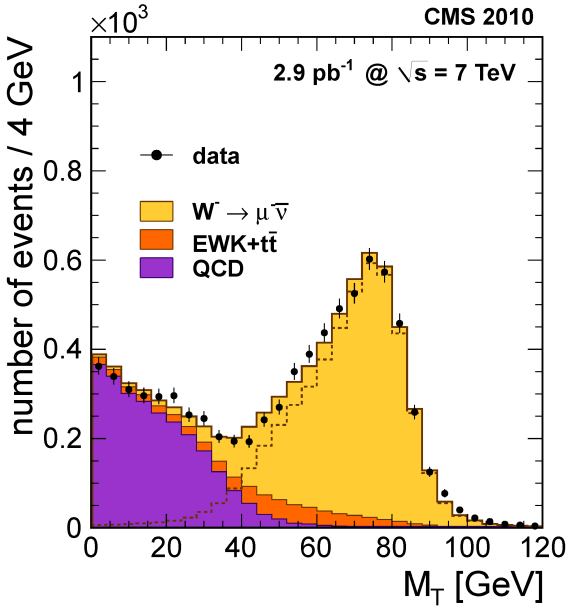


# $W \to \mu\nu$: Cross Section Result

Asymmetric production of $W^+/W^-$: $\frac{\sigma(W^+)}{\sigma(W^-)} = 1.433 \pm 0.026(\text{stat.}) \pm 0.054(\text{syst.})$.




- Cross sections from fits to $M_T$ with an EWK template (MC, corrected), scaling with $N_W$, and the QCD template (data), scaling with $N_{QCD}$.
- Recoil modeling used to improve signal MC shape (see below).

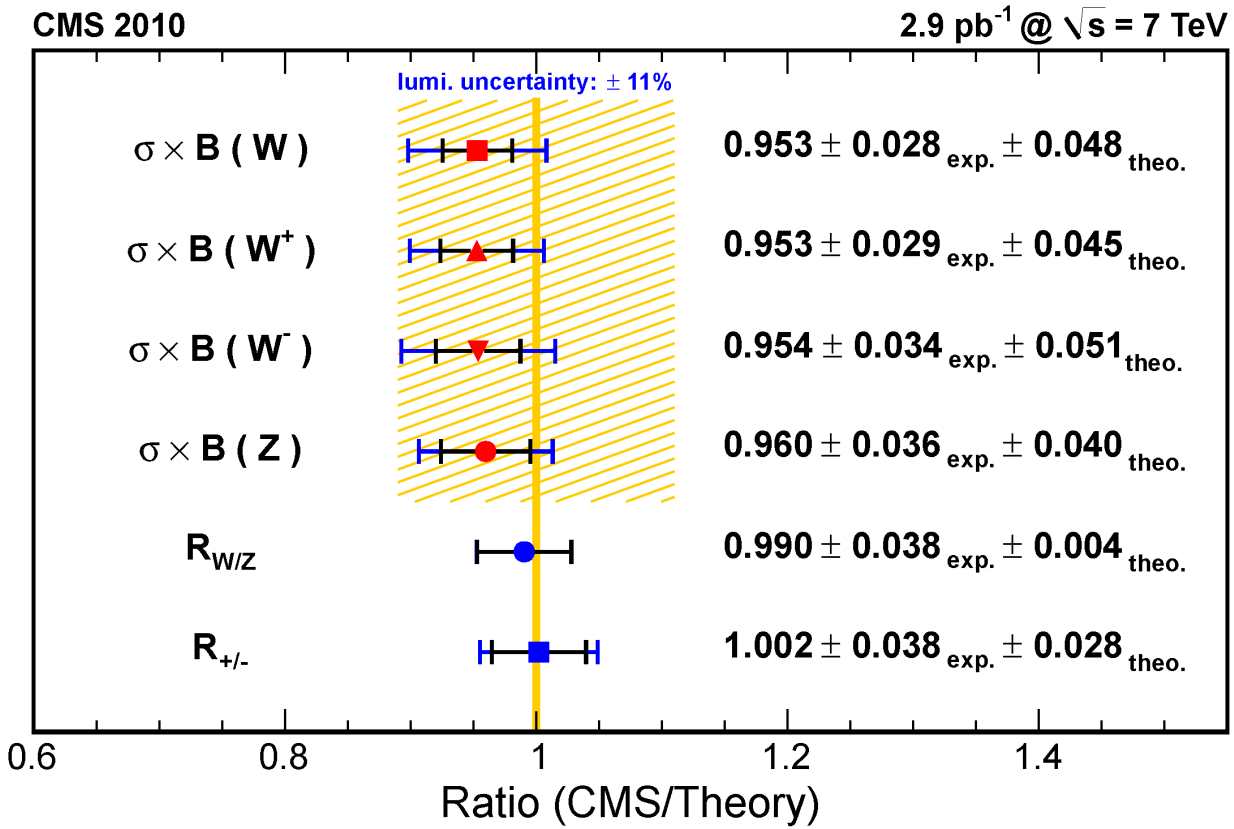
**$W \to \mu\nu$ Cross Section Result** FEWZ: $10.44 \pm 0.52$ nb (FEWZ)

$\sigma_W \cdot \text{BR}(W \to \mu\nu) = 9.922 \pm 0.090(\text{stat.}) \pm 0.307(\text{syst.}) \pm 1.091(\text{lumi.})$ nb

# Overview of Results

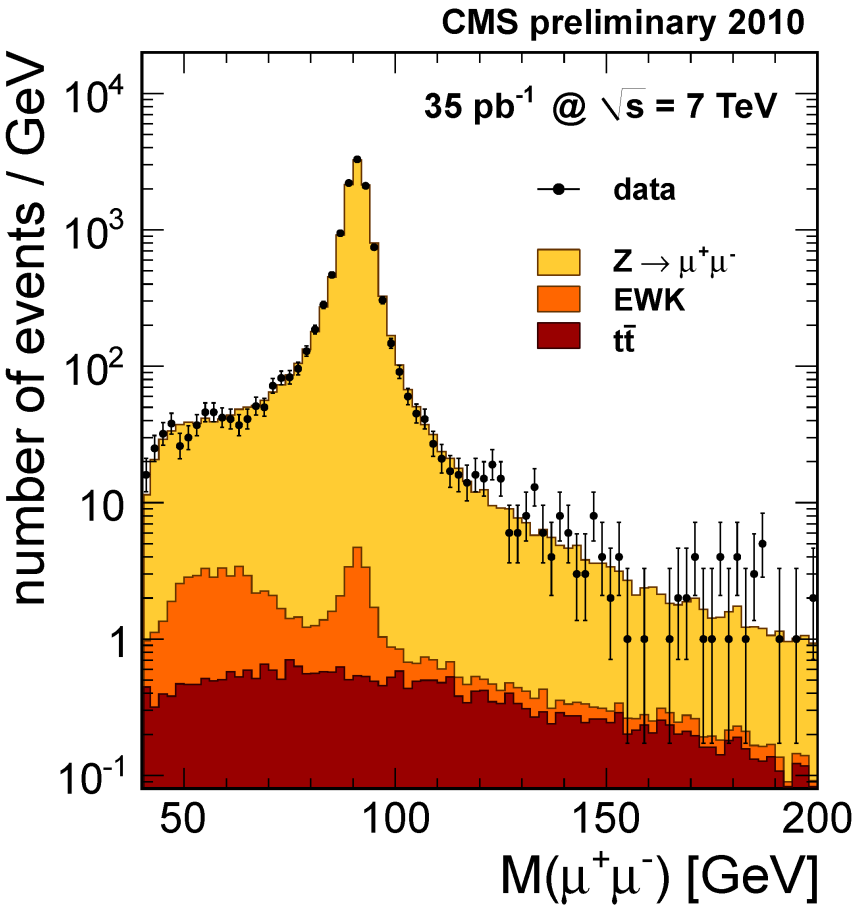
Measurements in electron/muon channels are consistent.

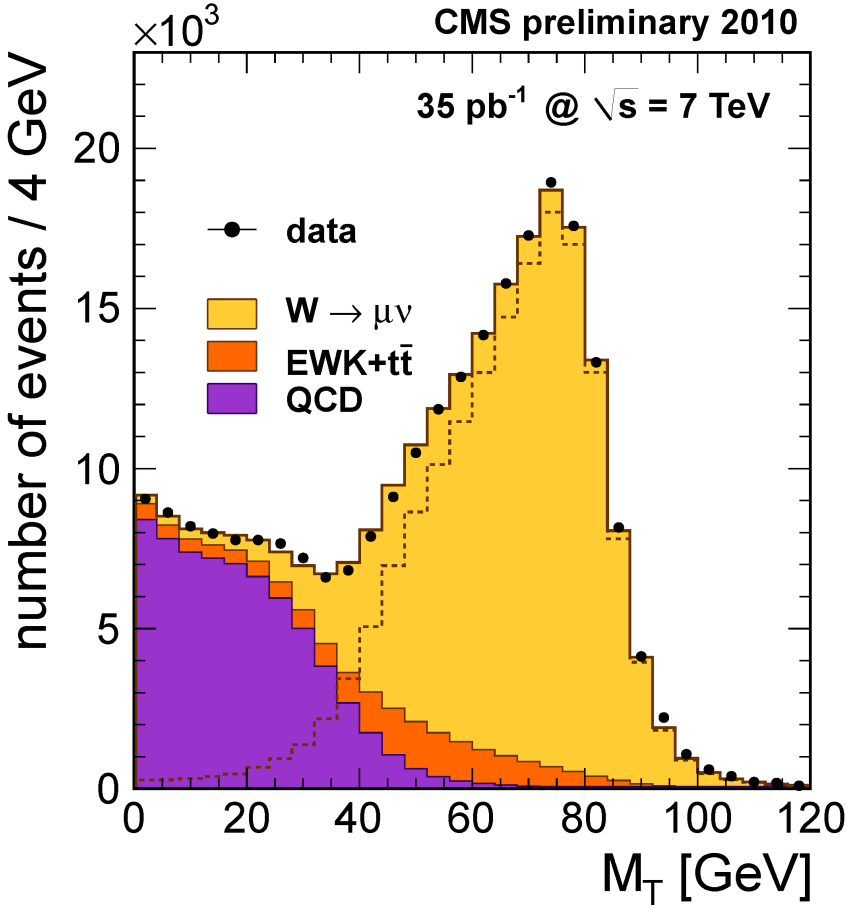
**Electron/muon channels combined:**




Experimental uncertainties on cross sections smaller than theoretical ones.
Systematics start to dominate experimental uncertainty.

# Preliminary Plots with 35 $pb^{-1}$




Still good agreement between the data and data-driven templates/MC.

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# Hadronic Recoil in W/Z Production

## Hadronic Recoil $\vec{U}$

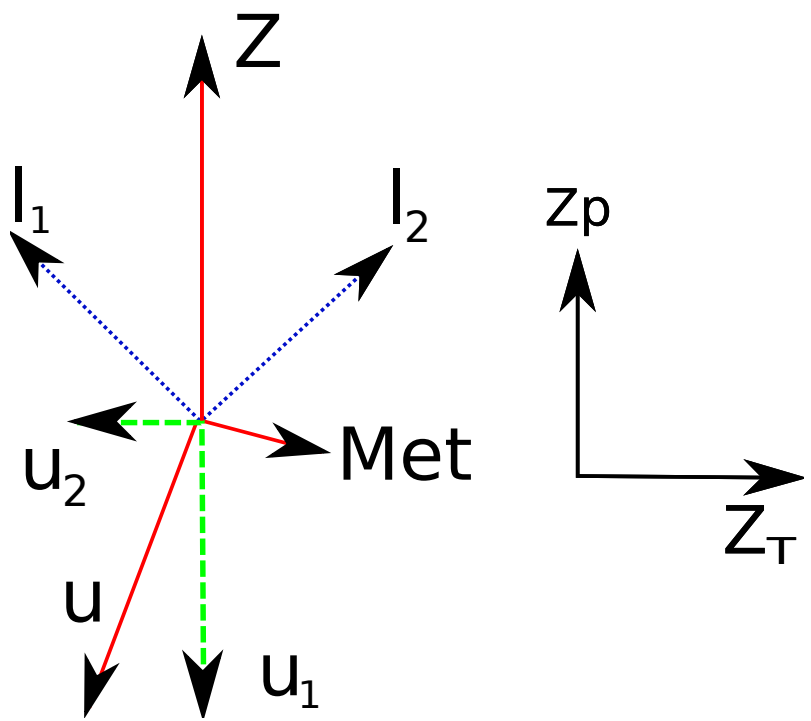
Vector sum of transverse components of had. objects (calorimetry).

Hard interaction: W/Z production
Recoil balances the W/Z $p_T$:
$\vec{p}_T^{\,V} + \vec{U} = -\not{\vec{E}}_T$

Two contributions to had. recoil:

- vector boson related:
  soft radiation (unclustered energy), hard radiation (jets)
- underlying event, pile-up

Reference frame used:



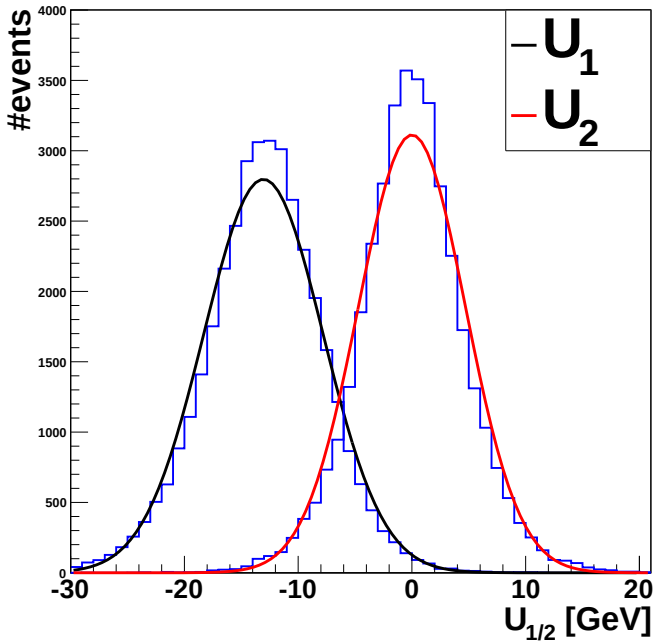

Recoil split into components $u_1$ and $u_2$ parallel and perpendicular to vector boson.

# Hadronic Recoil Model

Model/expectation in small $p_T^{boson}$ range:

$$U_1 = gauss(\langle U_1 \rangle(p_T^{boson}), \sigma_{U_1}(p_T^{boson}))$$
$$U_2 = gauss(0, \sigma_{U_2}(p_T^{boson}))$$

MC: 15 GeV $< p_T^W <$ 16 GeV

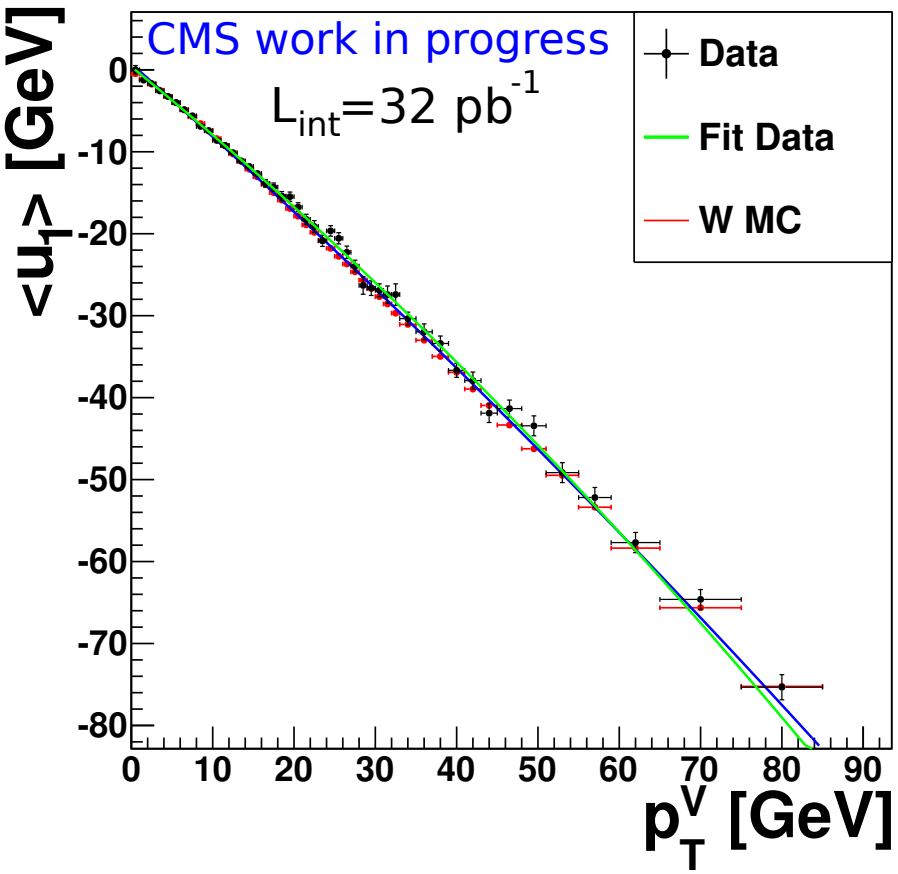


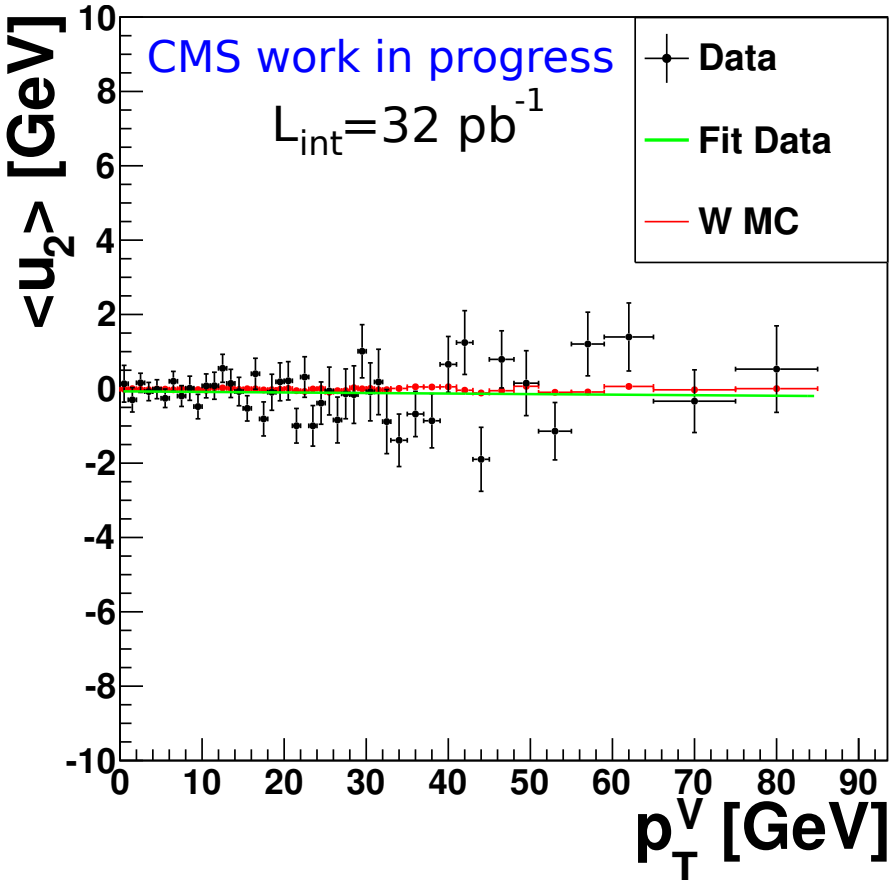

**Workflow:**

- select Z events on data
  - get recoil $\vec{U}$ from leptons, $\not\!\!E_T$
  - get $U_1$ and $U_2$ binned in $p_T^Z$
  - fit gaussian $\rightarrow$ mean, width
- compare model in W and Z MC $\rightarrow$ agreement
- sample recoil from Z(data) into W(MC) $\rightarrow$ corrections to $\not\!\!E_T$

# Recoil Modeling Results (1): Response

Mean $\langle U_1 \rangle$, $\langle U_2 \rangle$ related to calorimetric **response**.

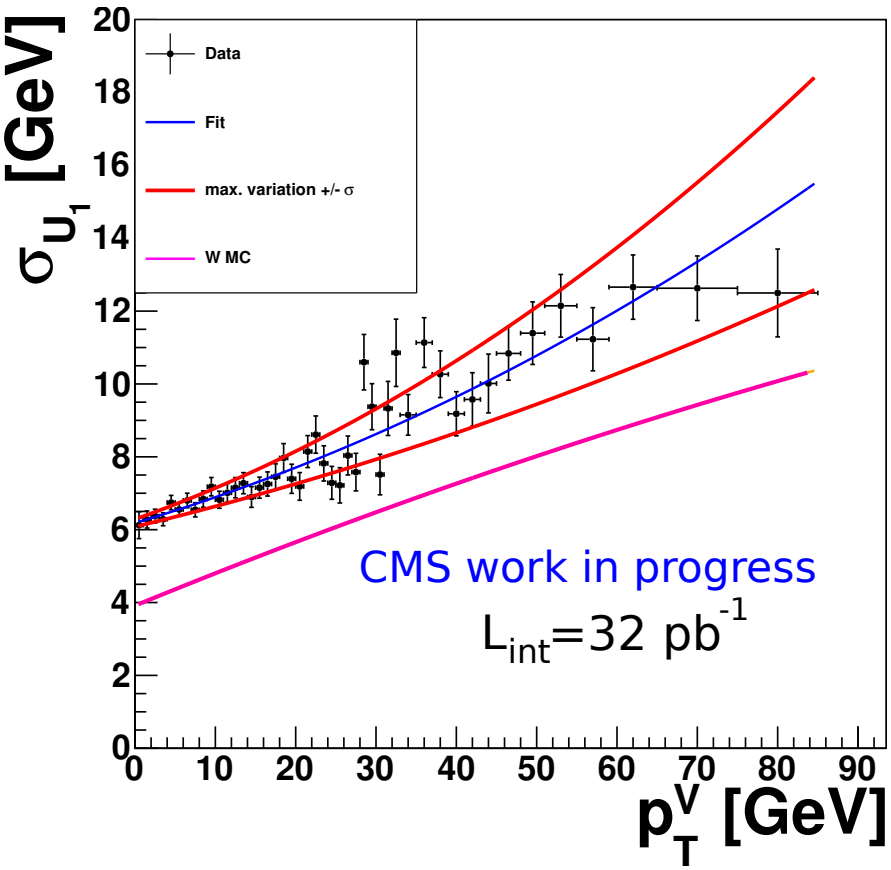


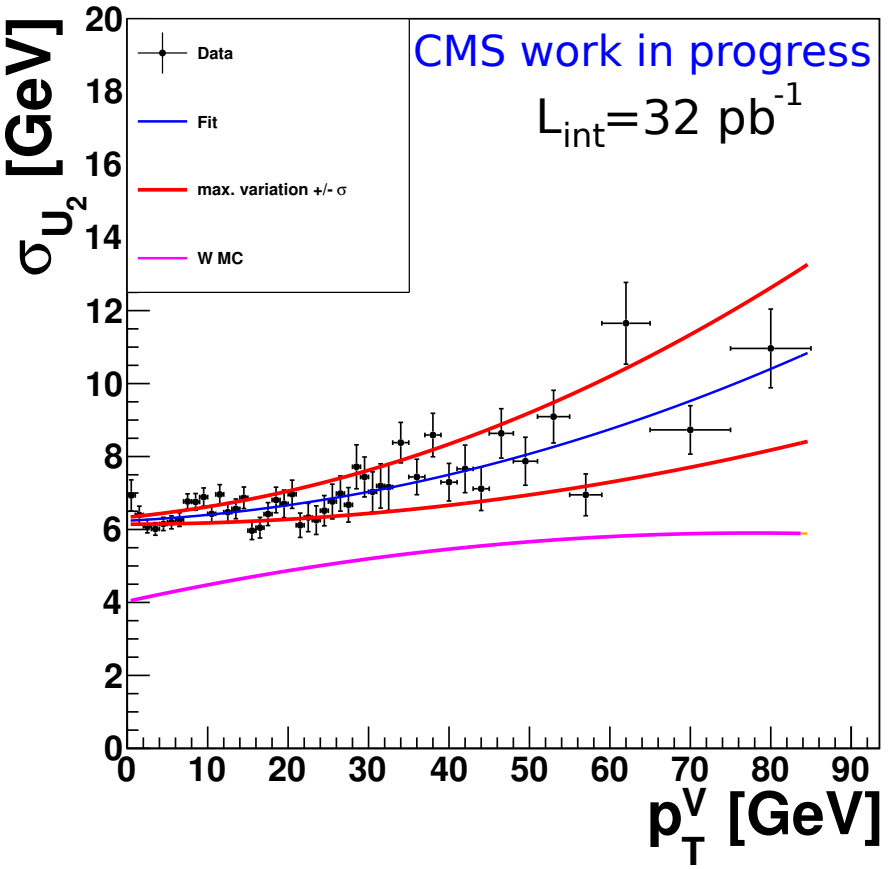




Calorimetric response well modeled. Quadratic fit used to extract $U_1$.
Response perpendicular to vector boson independent of $p_T^V$.

# Recoil Modeling Results (2): Resolution

Width $\sigma_{U_1}$, $\sigma_{U_2}$ related to calorimetric **resolution**.



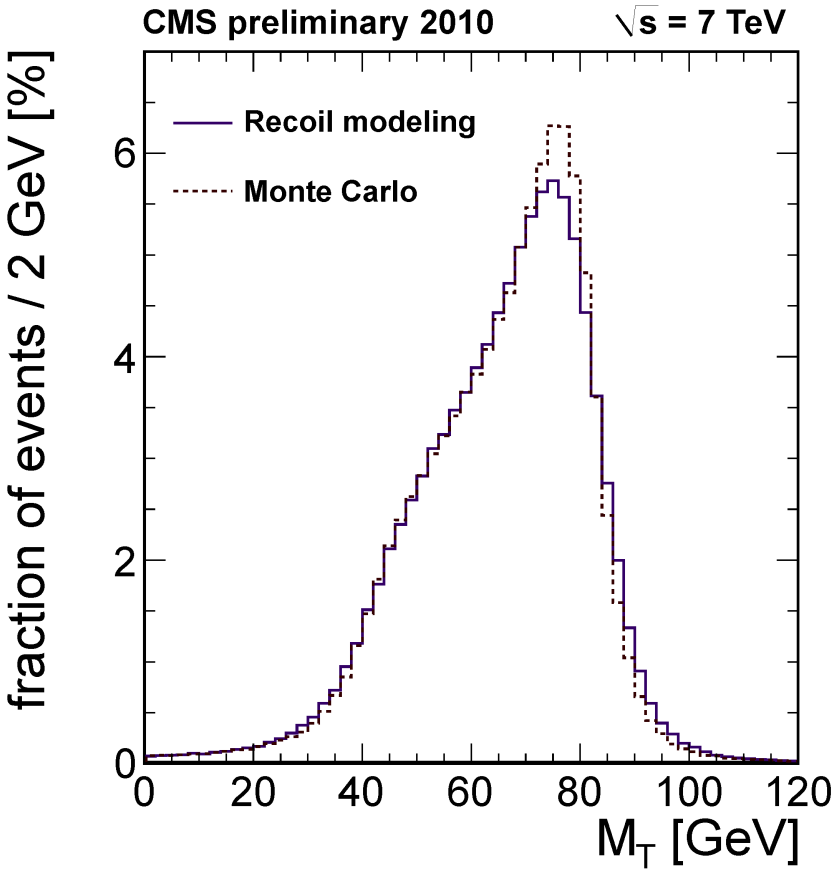



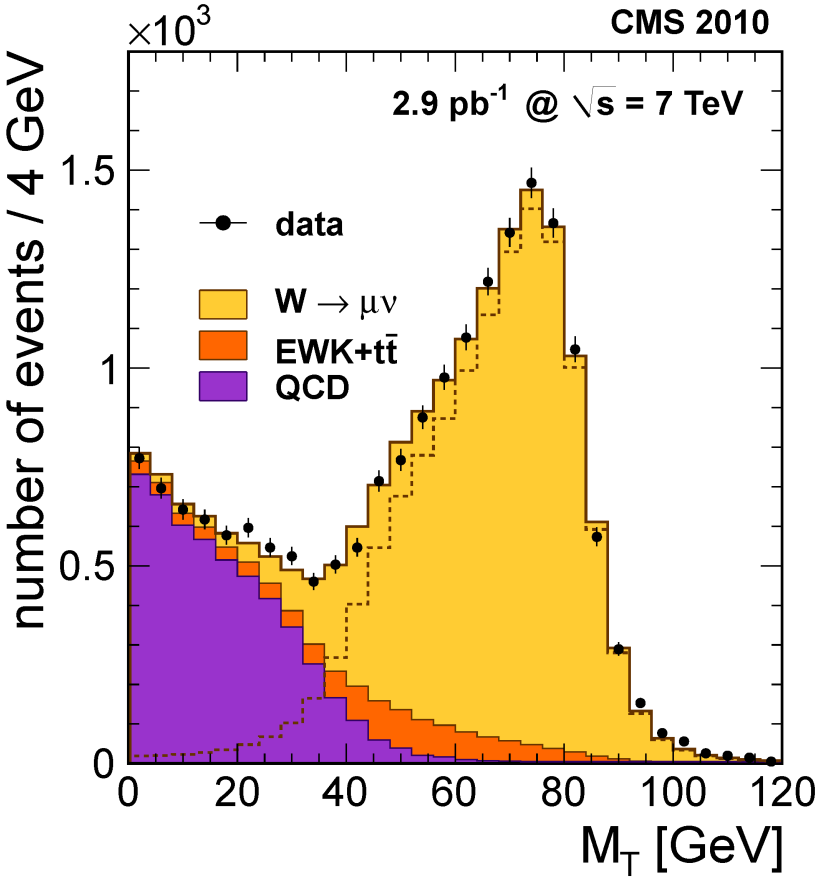

Correction on calorimetric resolution. No pile-up simulated in MC used.

$\sigma_{U_1}$ shows stronger $p_T^V$ dependence than $\sigma_{U_2}$.

# Influence of Recoil Correction

Comparison of W MC before/after recoil correction for $\mathcal{L}_{int} = 2.9\ \mathrm{pb}^{-1}$.



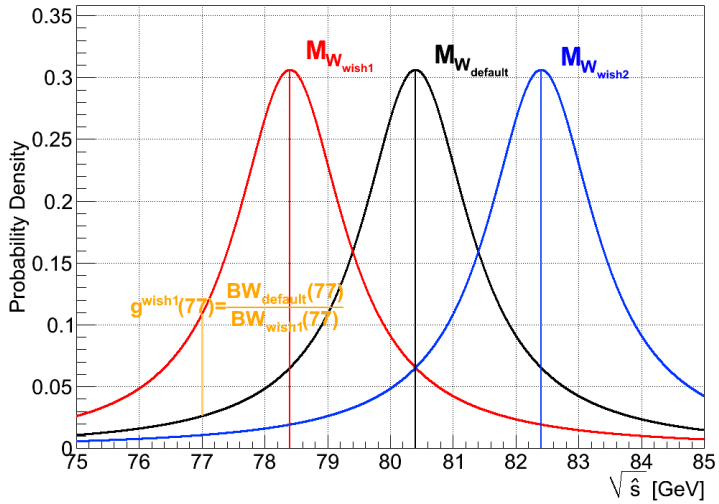

Effect of recoil correction on the W cross section is 0.4%.

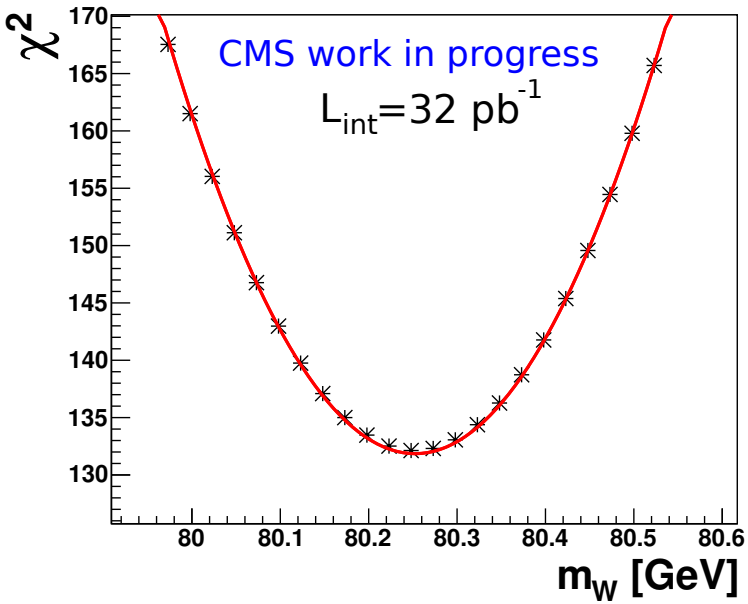
# W Mass Fit - Private Work in Progress

- W MC templates for different $m_W^{wish}$. Generate distributions for new mass $m_W^{wish}$ with event weight g:

$$g = \frac{(m_{inv}^2 - m_{default}^2)^2 - \Gamma_W^2 m_{default}^2}{(m_{inv}^2 - m_{wish}^2)^2 - \Gamma_W^2 m_{wish}^2}$$

- Fit QCD/EWK templates to data. $N_{QCD}$ fixed, $N_{EWK}$ fit parameter. Range: 50 GeV $< M_T <$ 100 GeV.
- Extract $\chi^2$ for each mass $m_W^{wish}$.



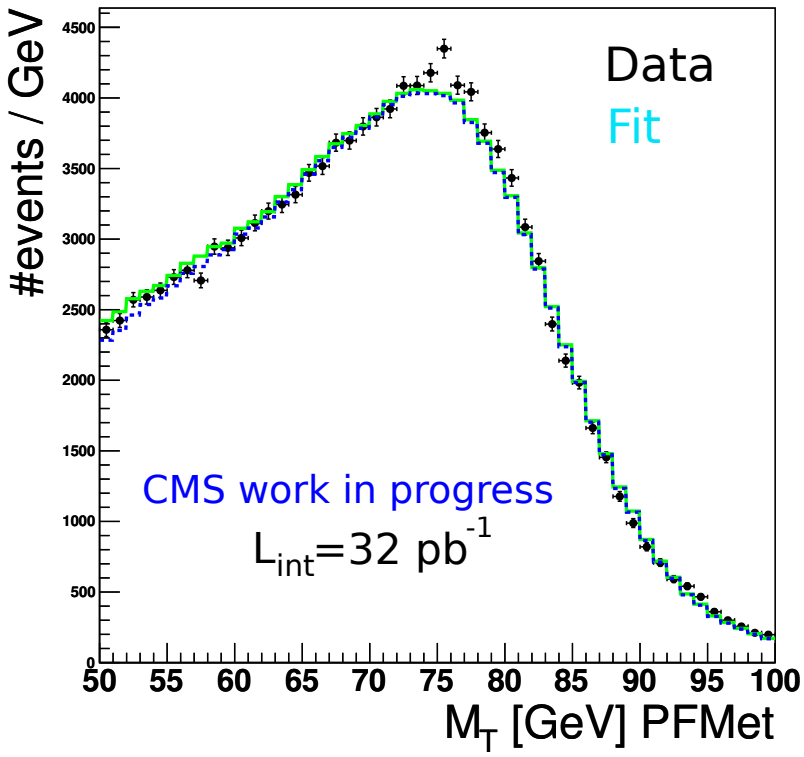

## Fit Result

$m_W^{fit} = 80.25 \pm 0.05$ (stat.) GeV
$\pm 0.19$ (recoil) GeV $\pm$ ...
Not a measurement.

# Influence of Recoil Model on W Mass Fit

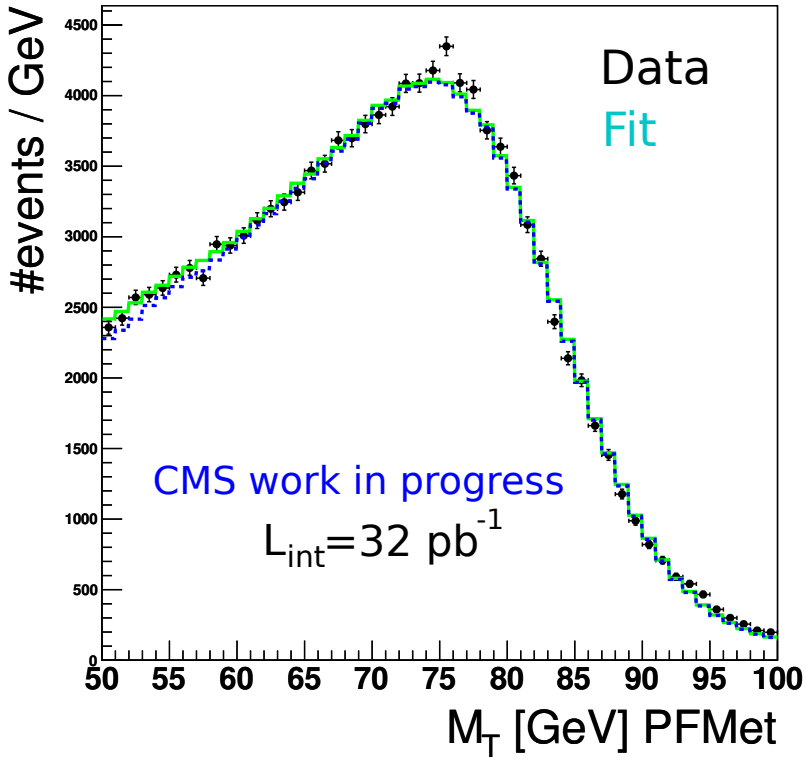
Binned likelihood fit used. Uncorrected W MC template: $m_W^{fit} = 81.07$ GeV.

recoil as shown above




$m_W^{fit} = 80.25$ GeV

recoil resolution varied down $-\sigma$




$m_W^{fit} = 80.42$ GeV

Slightly overestimating the width of had. recoil with current model.

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# Conclusion

## W/Z Cross Section Measurement

- Measured $W/Z$ cross sections (ratios) in good agreement with theory.
- Systematics start to dominate the experimental uncertainty.
- Many systematics are of statistical nature $\rightarrow$ systematics decreasing.
- Plans to normalize the luminosity at the 5% level using $W/Z$ cross sections.

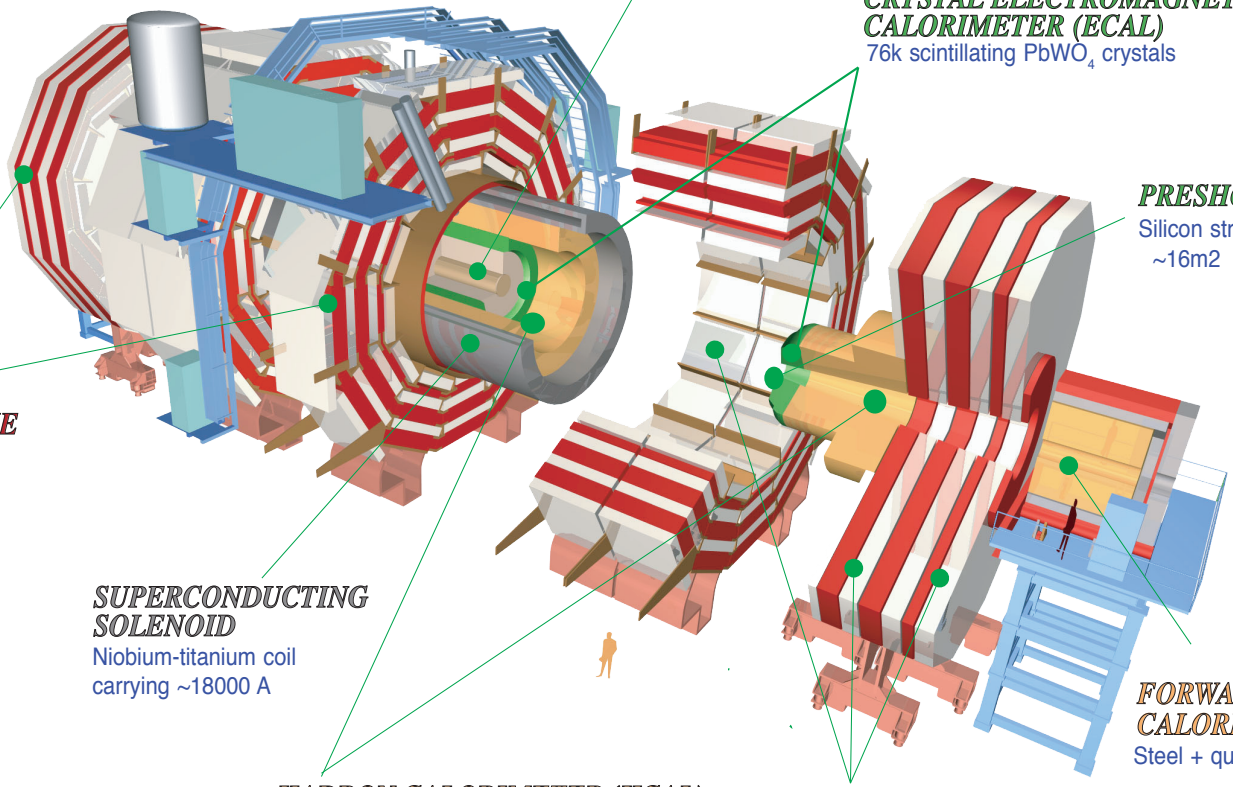
- Agreement between data and simulation illustrates good understanding of the detector, reconstruction and analysis methods after 1 year of running.
- Fit to W mass gives an idea that there is still a long way to go.

Thank you for your attention.

**Backup**

# CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



**SILICON TRACKER**
Pixels (100 x 150 μm²)
~1m² 66M channels
Microstrips (50-100μm)
~210m² 9.6M channels

**CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)**
76k scintillating $PbWO_4$ crystals

**PRESHOWER**
Silicon strips
~16m2 137k channels

**STEEL RETURN YOKE**
~13000 tonnes

**SUPERCONDUCTING SOLENOID**
Niobium-titanium coil
carrying ~18000 A

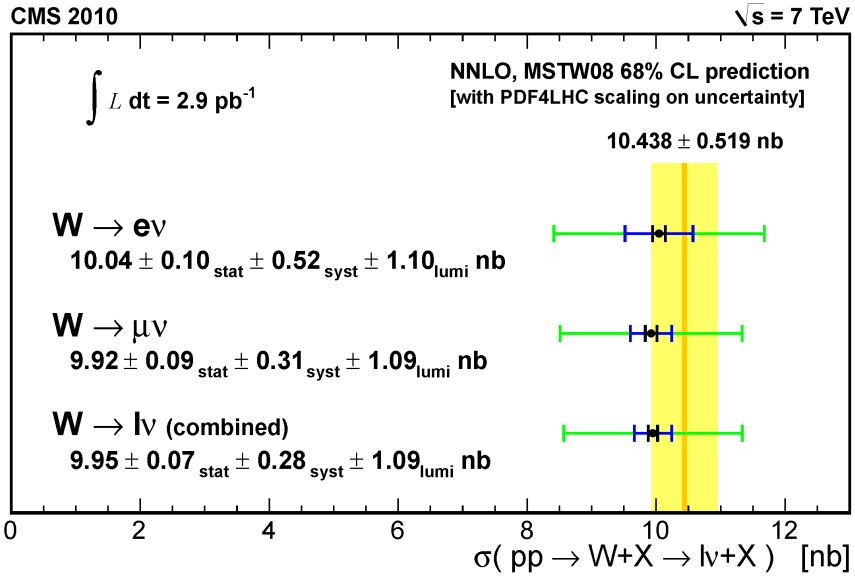
**FORWARD CALORIMETER**
Steel + quartz fibres

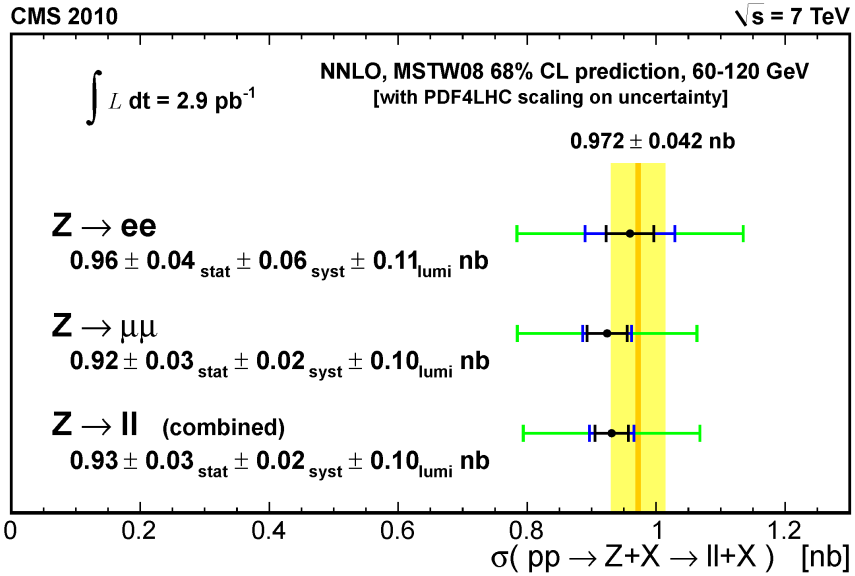
**HADRON CALORIMETER (HCAL)**
Brass + plastic scintillator

**MUON CHAMBERS**
Barrel: 250 Drift Tube & 500 Resistive Plate Chambers
Endcaps: 450 Cathode Strip & 400 Resistive Plate Chambers

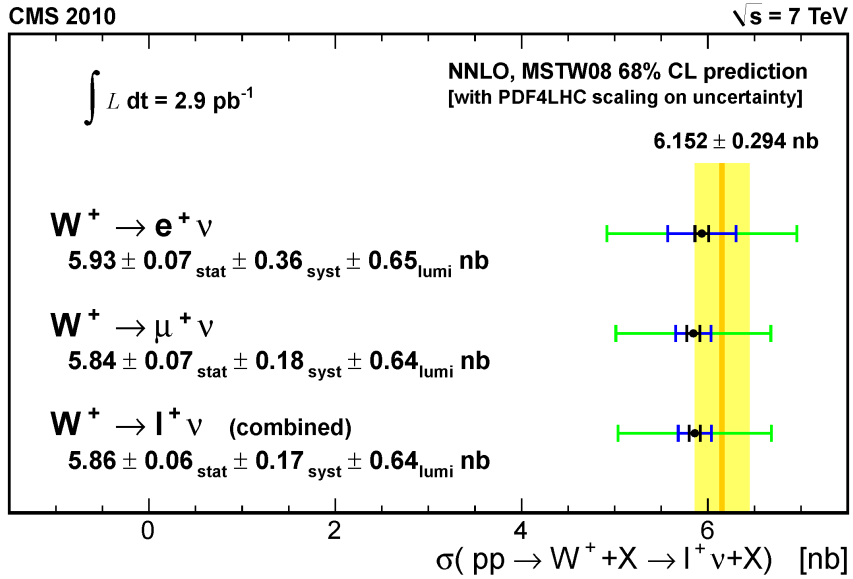
| | |
|---|---|
| **Total weight** | **: 14000 tonnes** |
| **Overall diameter** | **: 15.0 m** |
| **Overall length** | **: 28.7 m** |
| **Magnetic field** | **: 3.8 T** |

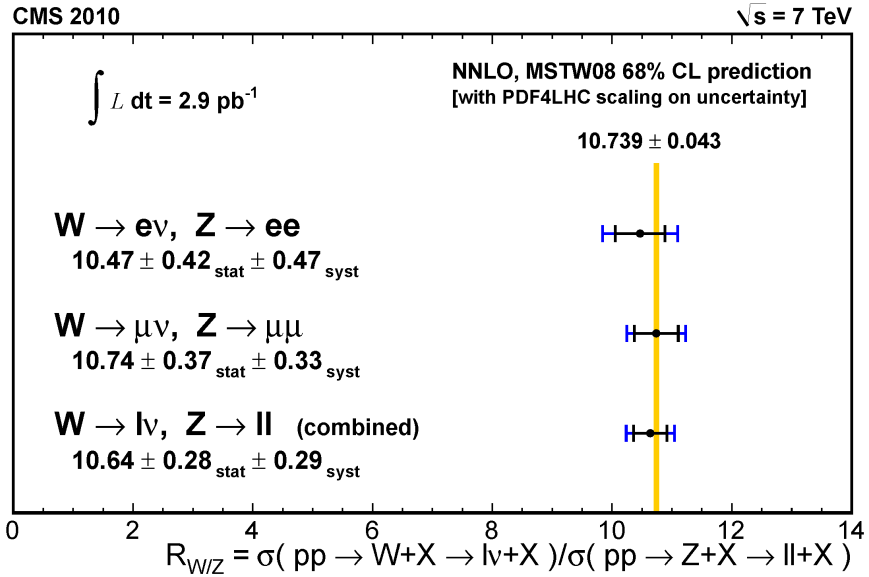
# Results (1): $W/Z$ Cross Sections



# Results (2): $W^+$ Cross Sections, $W/Z$ Ratio



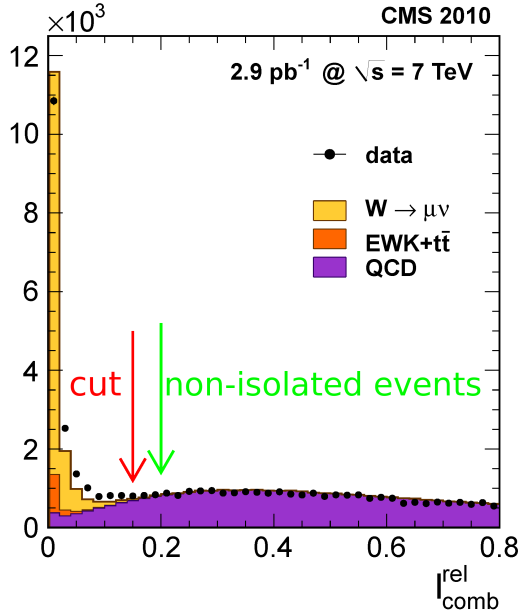



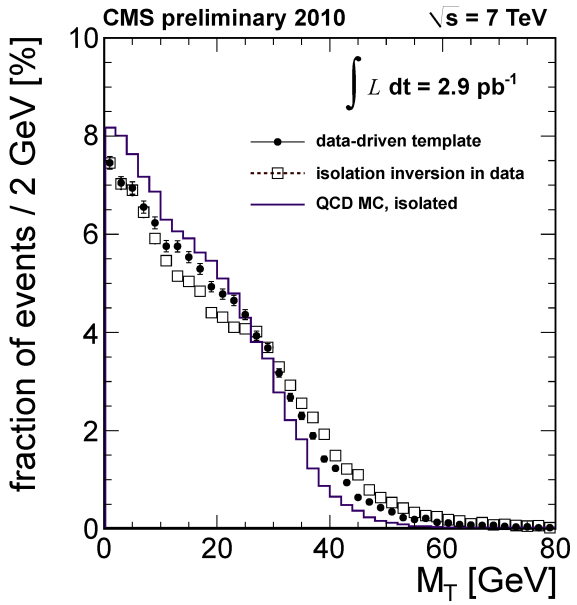
# QCD from Data

W cross-section determination: Fit to $M_T$.

- Multi-jet events dominant background in $W \to \mu\nu$ analysis.
- QCD $M_T$ template for fits extrapolated from the non-isolated region.
- $\not{E}_T$, $p_T^\mu$, isolation $I^{rel}$ in QCD events correlated with $\sum E_T$.
- Correlation $\rho\left(M_T, I^{rel}\right) \approx 0.05$ .
- Templates corrected for correlation.

Template twisted wrt MC.
$\Rightarrow$ 2% effect on cross section,
taken into account as systematic uncertainty.



# Plots with Electrons for $\mathcal{L}_{int} = 35\ \mathrm{pb}^{-1}$