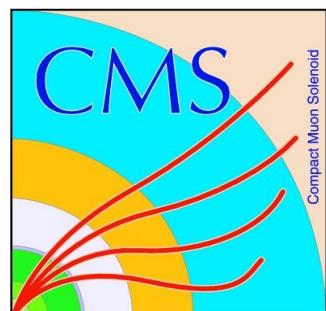
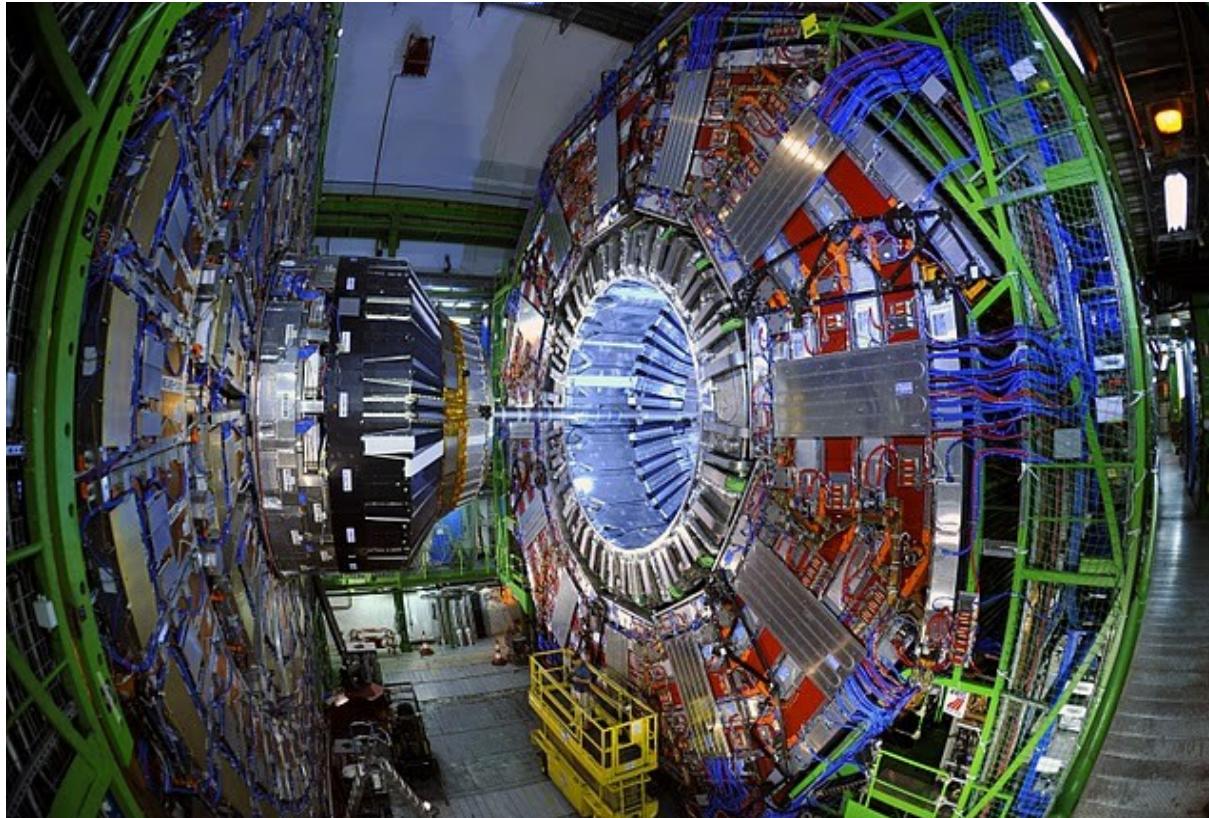


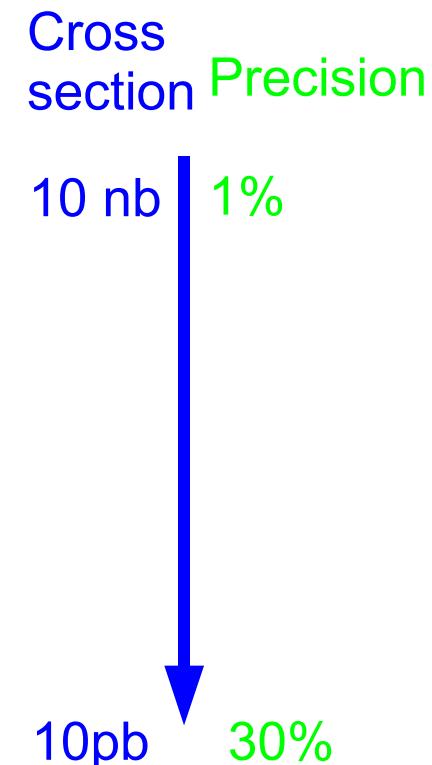
# Standard Model Measurements



Philip Harris (MIT)  
The CMS collaboration  
Rencontres de Moriond/EW



# Overview



- W/Z and di-lepton differential cross sections
- W polarization
- W/Z+Jets cross section
- tt cross section(in 2 channels)
- Mass of the top (in di-lepton channel)
- Single Top cross section

- Additionally

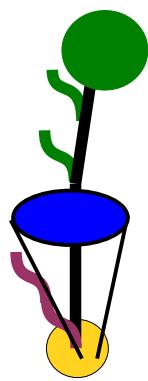
• W charge asymmetry	→ J. Bendavid	• WW Cross section	→ V. Sharma
• Z forward asymmetry	→ N. Tran	• $Z \rightarrow \tau\tau$	→ C. Velken
• W/Z + gamma	→ D. Majumander	• $W \rightarrow \tau\nu$	→ A. Mohammadi
• $M_{tt}$ spectrum+Z' search	→ backup slides		
• Top charge asymmetry	→ backup slides		
• Z+b-jet observation	→ backup slides		

See corresponding talk

# Leptonic Baseline

- Every measurement in this talk requires **isolated high  $p_T$  leptons**

Electron

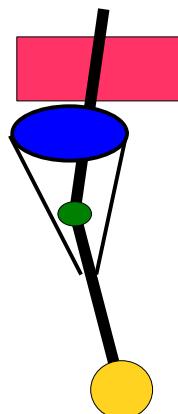


**Select on electron ecal shower shape**

Reject events passing conversion selection

Reject events with non-isolated activity

Muon



**Select well reconstructed muons in muon chamber**

Reject poorly

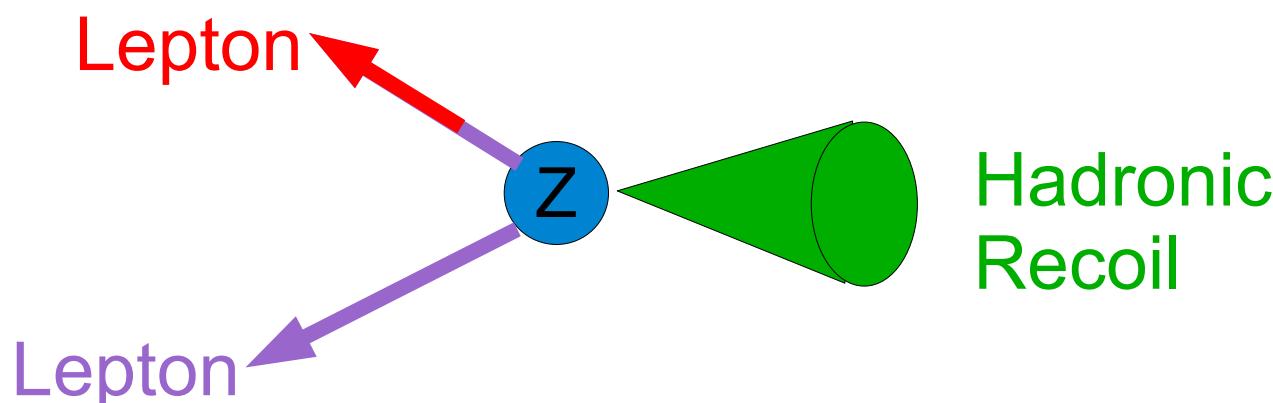
reconstructed tracks

**Select low impact parameter tracks**

- Lepton trigger used in all analyses
  - Single lepton used in all analyses
    - Additionally double electron trigger used in di-lepton top
  - Run on full dataset: triggers w/o prescale used in all analyses

# Calibrating MC

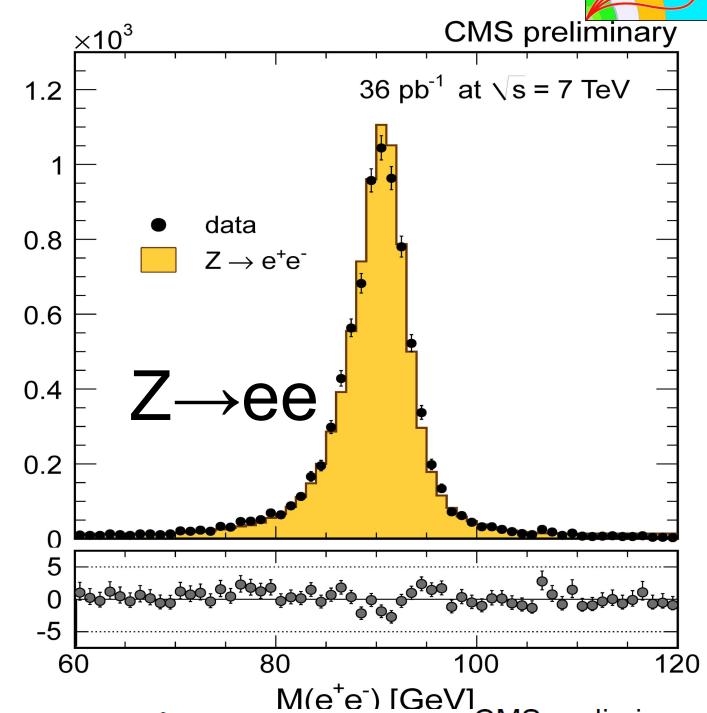
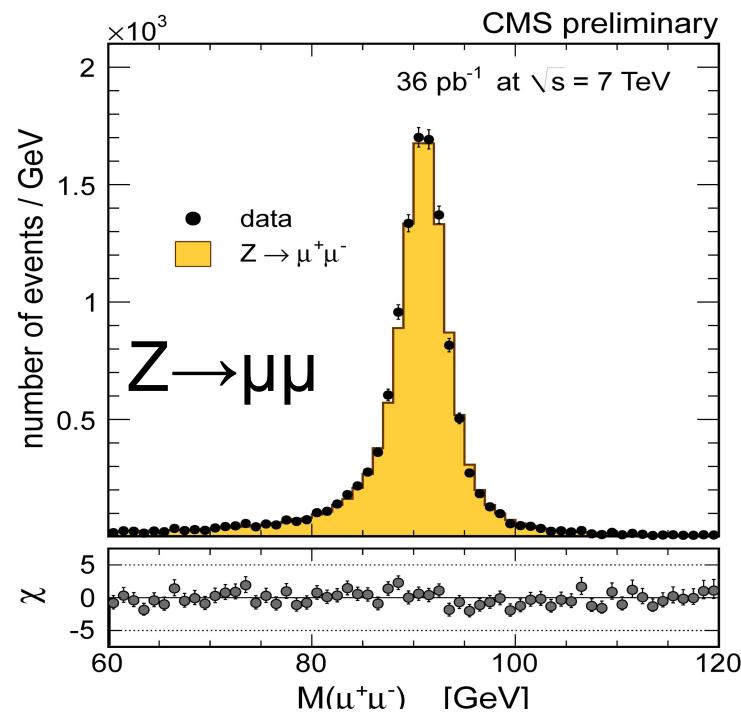
- Z boson used to **calibrate detector simulation**
  - Clean signature make it candle for calibration
- Efficiency : Tag and **Probe** on two leptons
- Lepton energy scale and resolution: Fitting **Z mass**
- Missing Energy: Hadronic recoil from **MET** compared with boson  $p_T$  from leptons



**Correct Monte Carlo lepton efficiency, energy scale and missing  $E_T$  based on Z data**

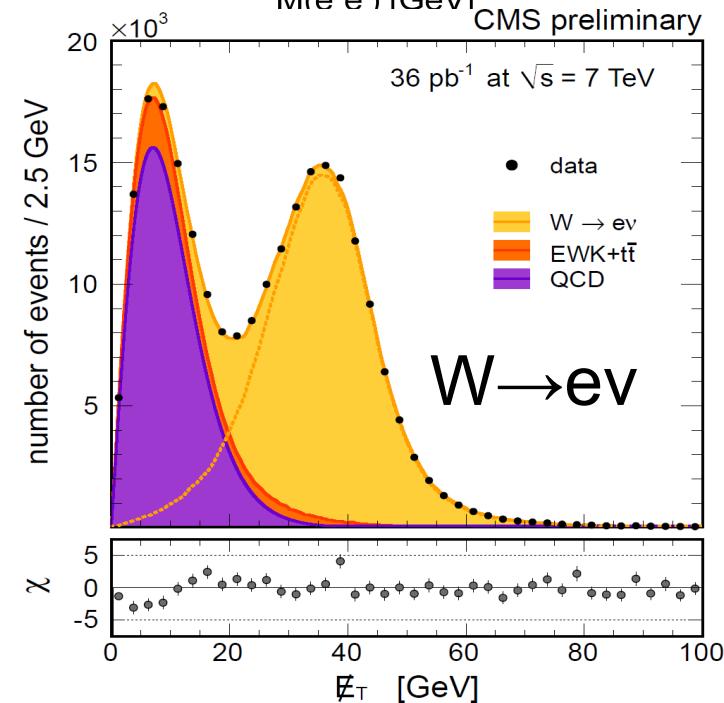
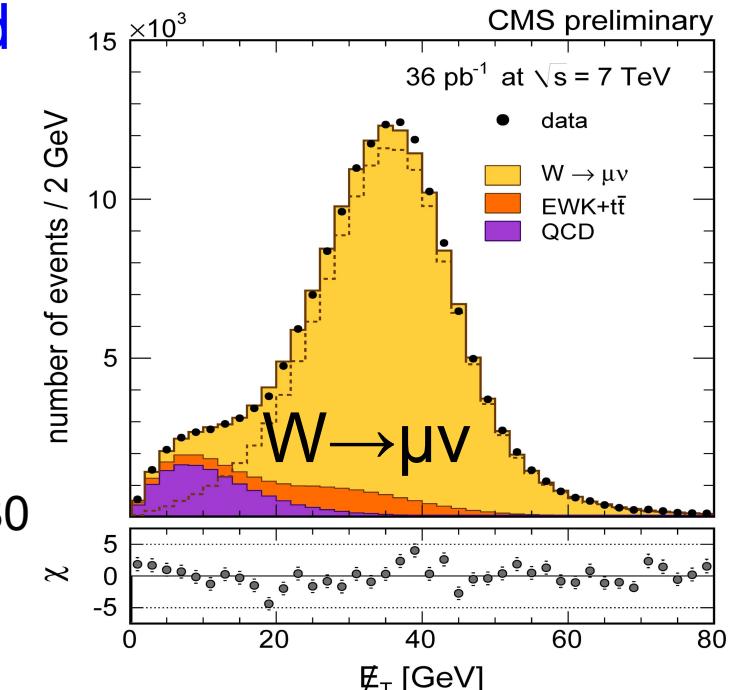
# W and Z cross section

- $Z$  : fit to Mass



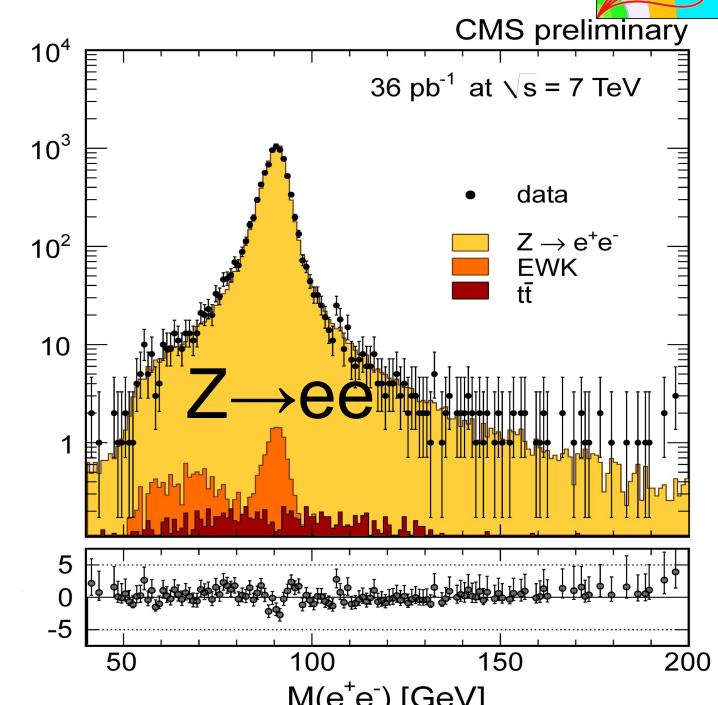
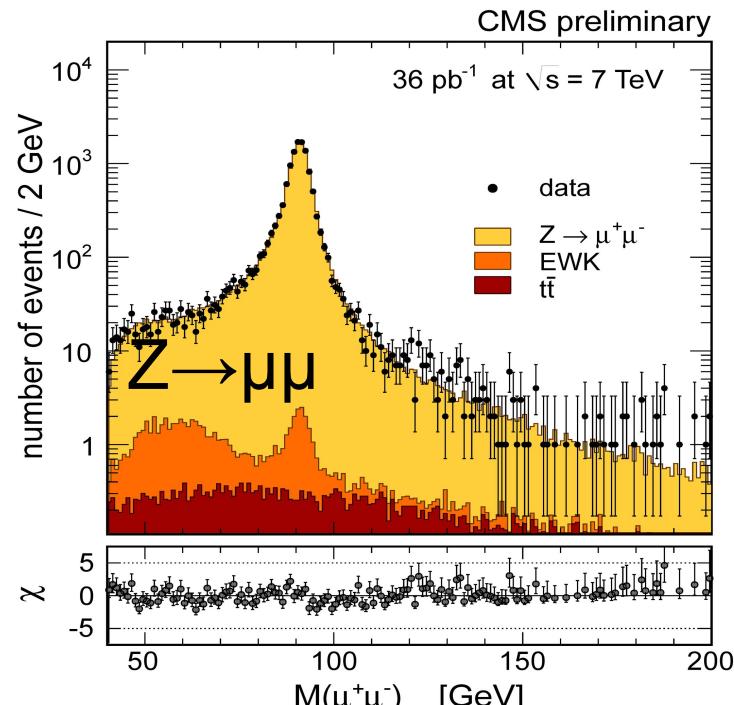
- $W$  : fit in  $MET$

- Data corrected  $MET$
- QCD modeled from data



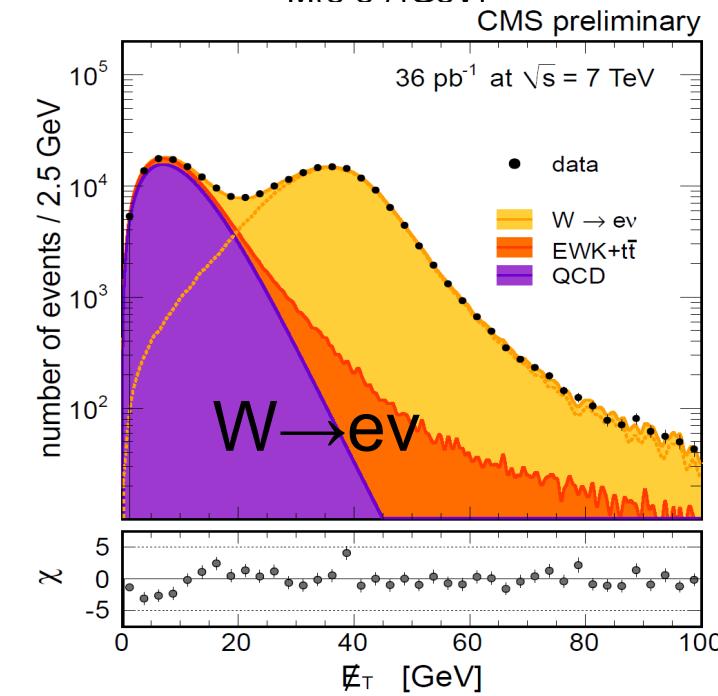
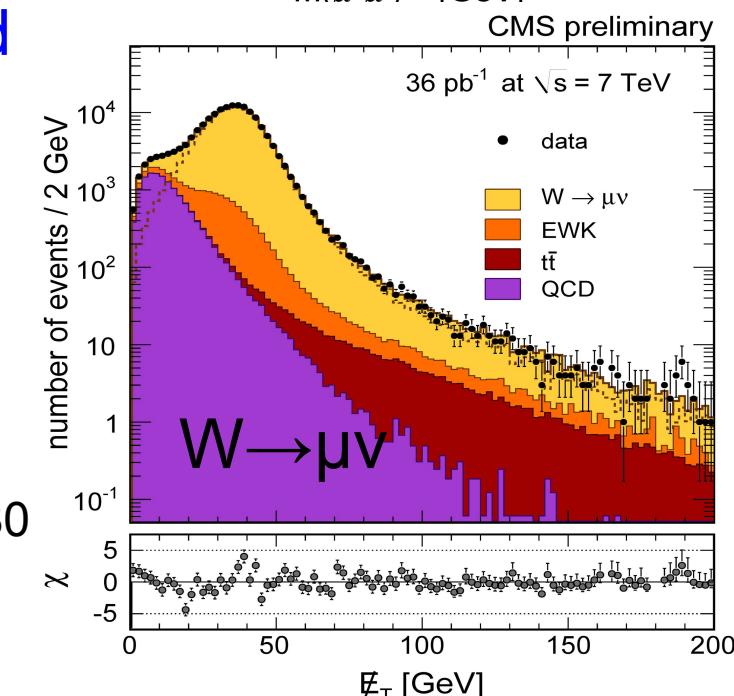
# W and Z cross section

- $Z$  : fit to Mass



- $W$  : fit in  $MET$

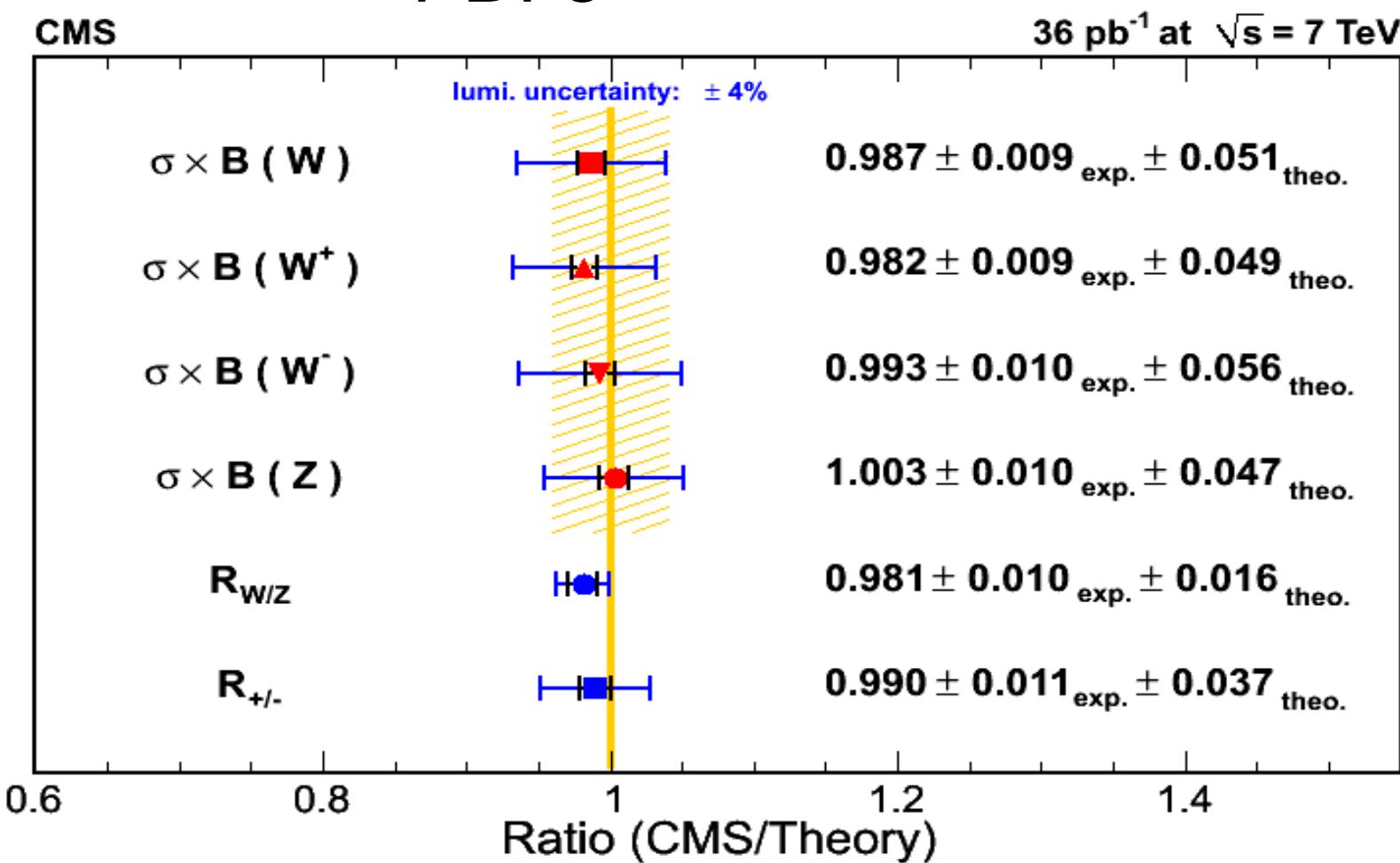
- Data corrected  $MET$
- QCD modeled from data



- 3pb<sup>-1</sup> published:  
[10.1007/JHEP01\(2011\)080](https://doi.org/10.1007/JHEP01(2011)080)

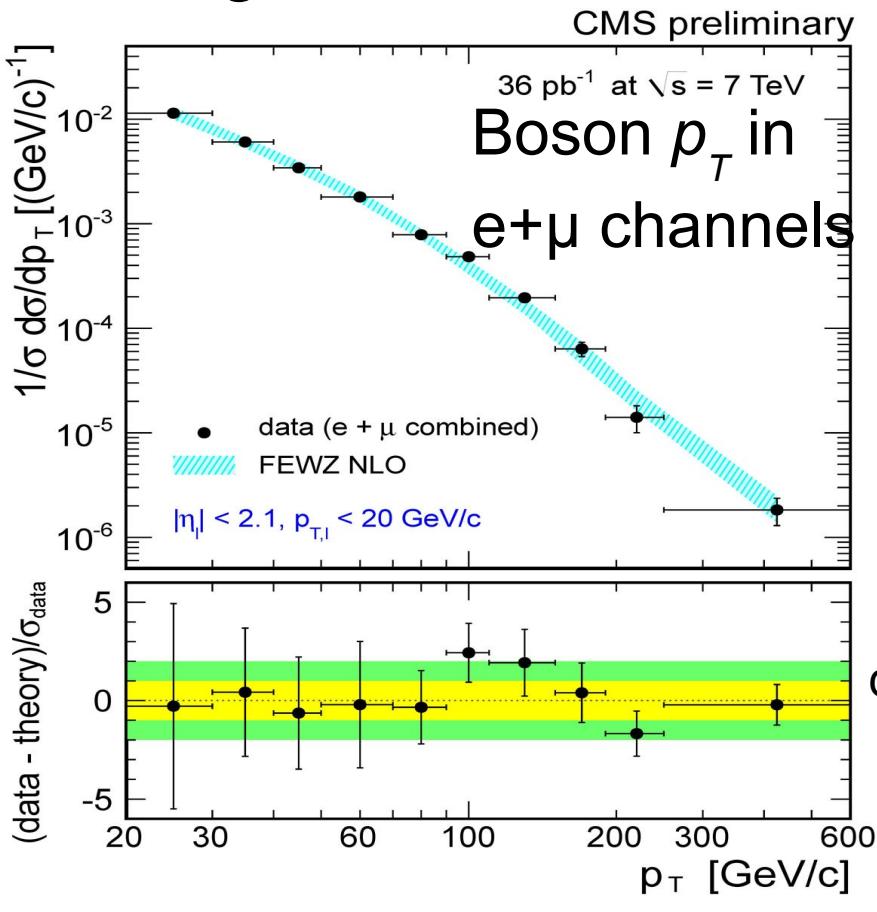
# W and Z results Cont'd

- **Constraining theory**
  - NNLO calculation
  - PDFs

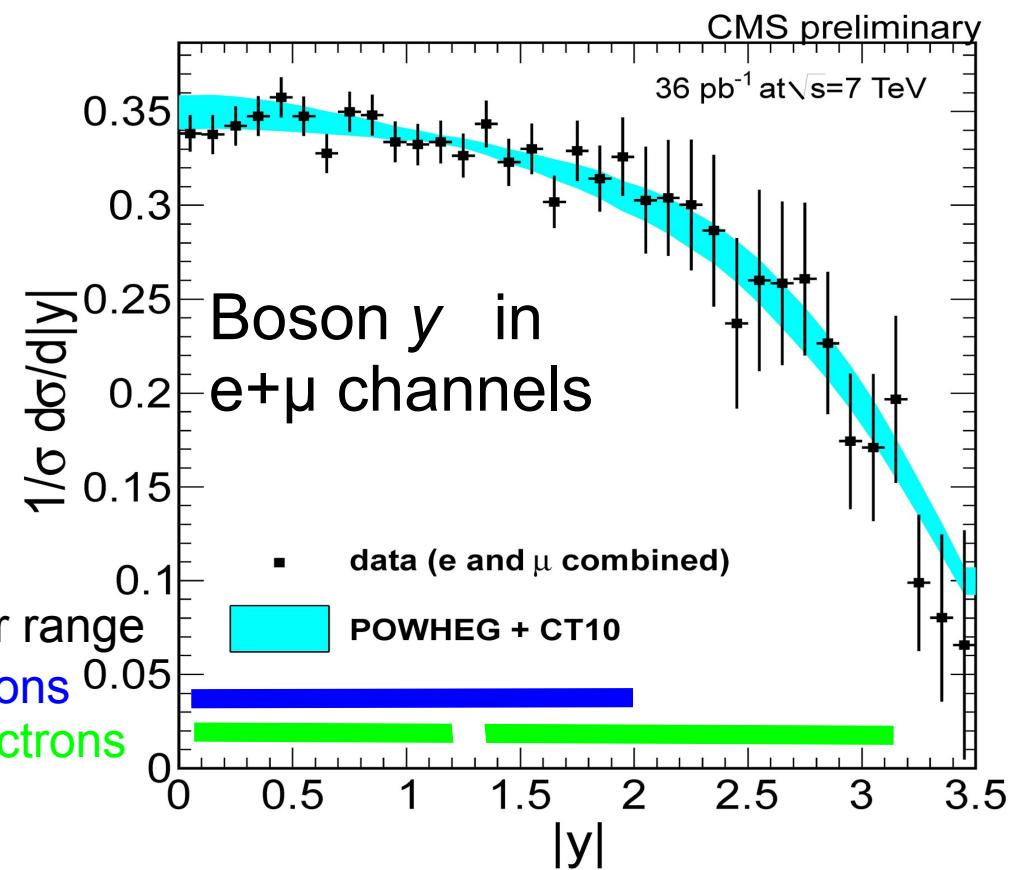


# Z Differential Cross Sections

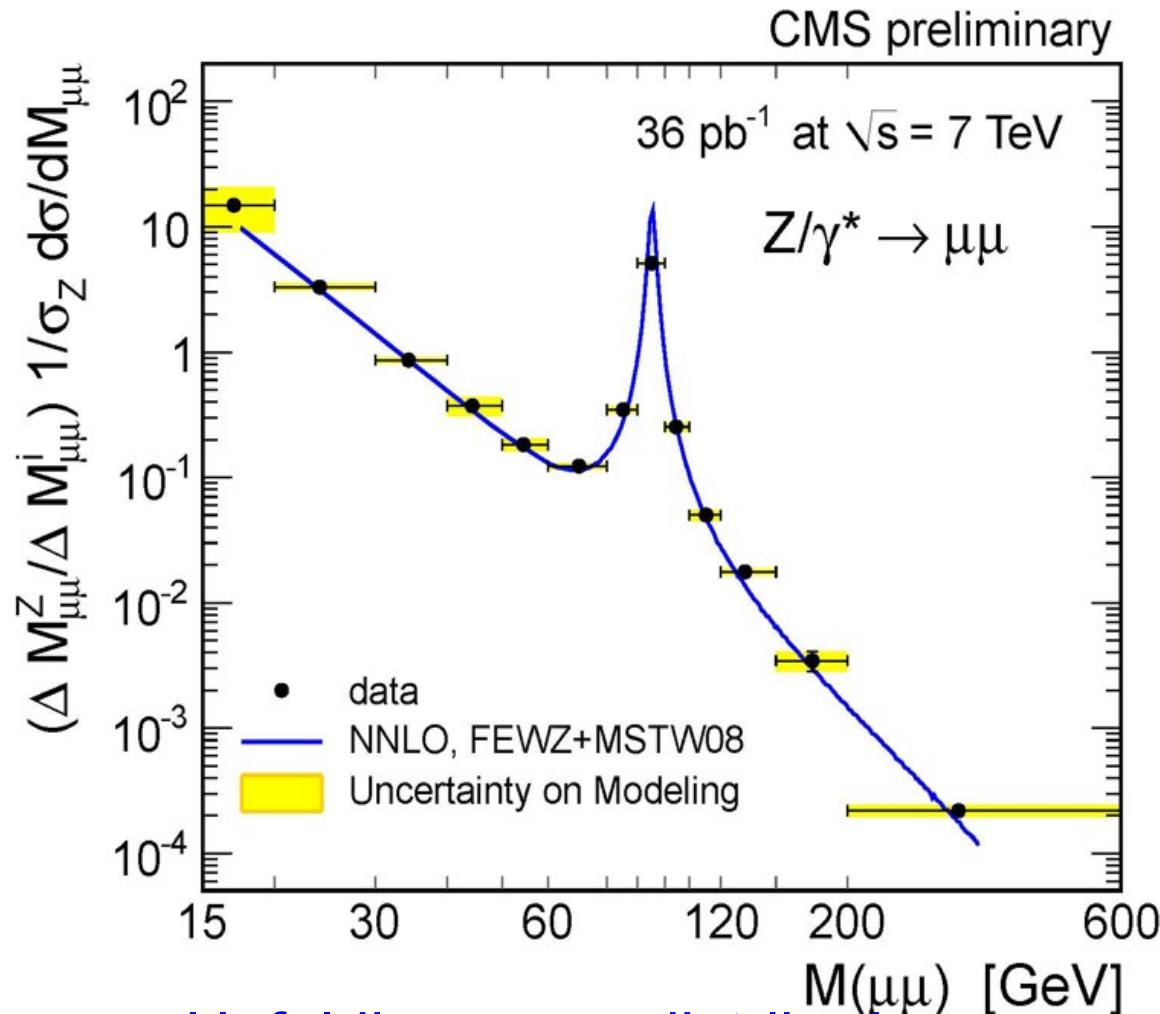
- Yield: events/bin following **background subtraction**
  - Data corrected efficiency + acceptance: **unfold distribution**
    - Unfolding performed with response matrix from MC
- Agreement with NLO at **1 sigma** or **2 sigma** level



detector range  
Muons  
Electrons



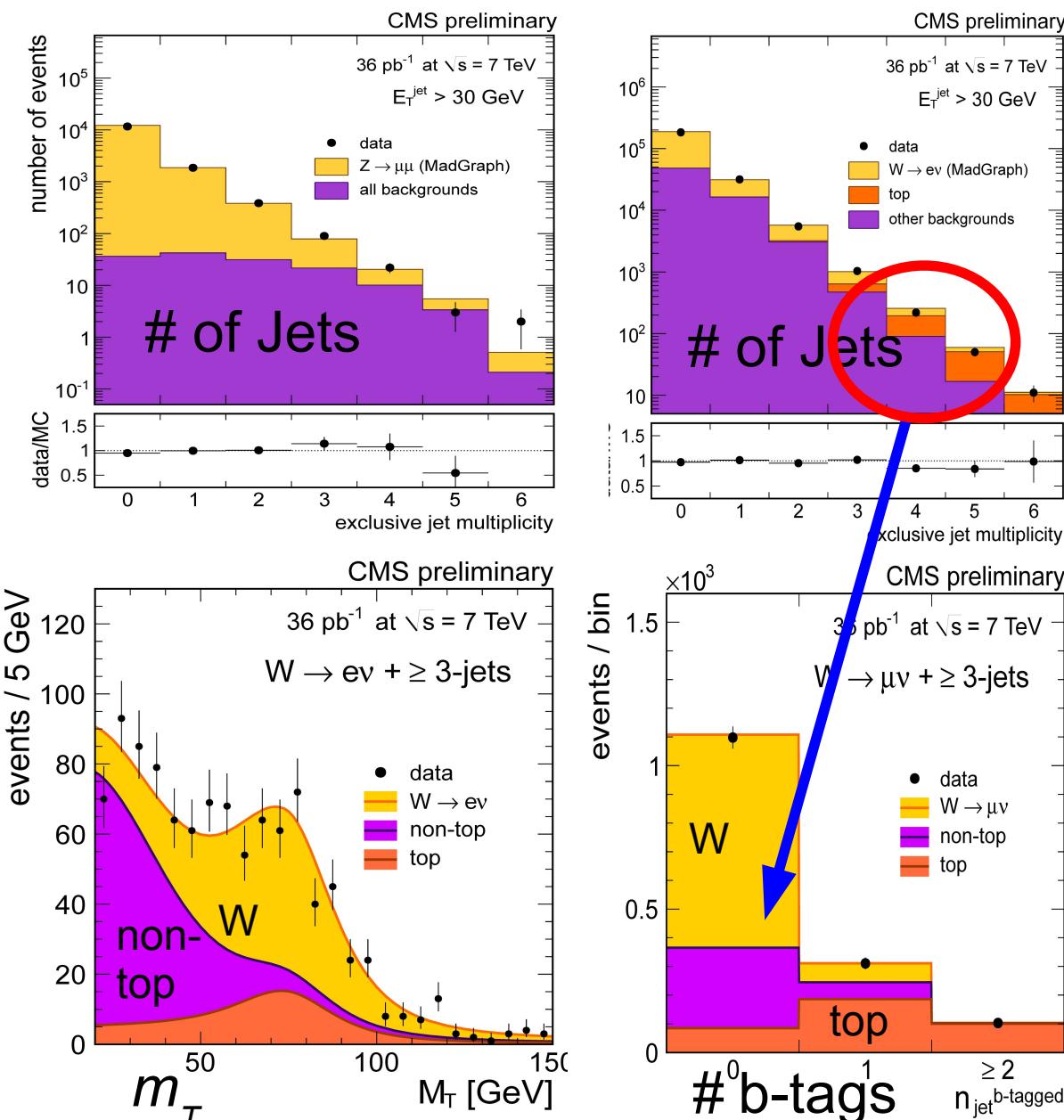
# Drell Yan Cross Section



- **Unfolding mass distribution**
  - Resulting Generator level distribution
  - Unfold w/MC response matrix
- **Agreement with NNLO prediction**

# W and Z + Jets

- Additional selection variable: Jet with  $p_T > 30 \text{ GeV}$

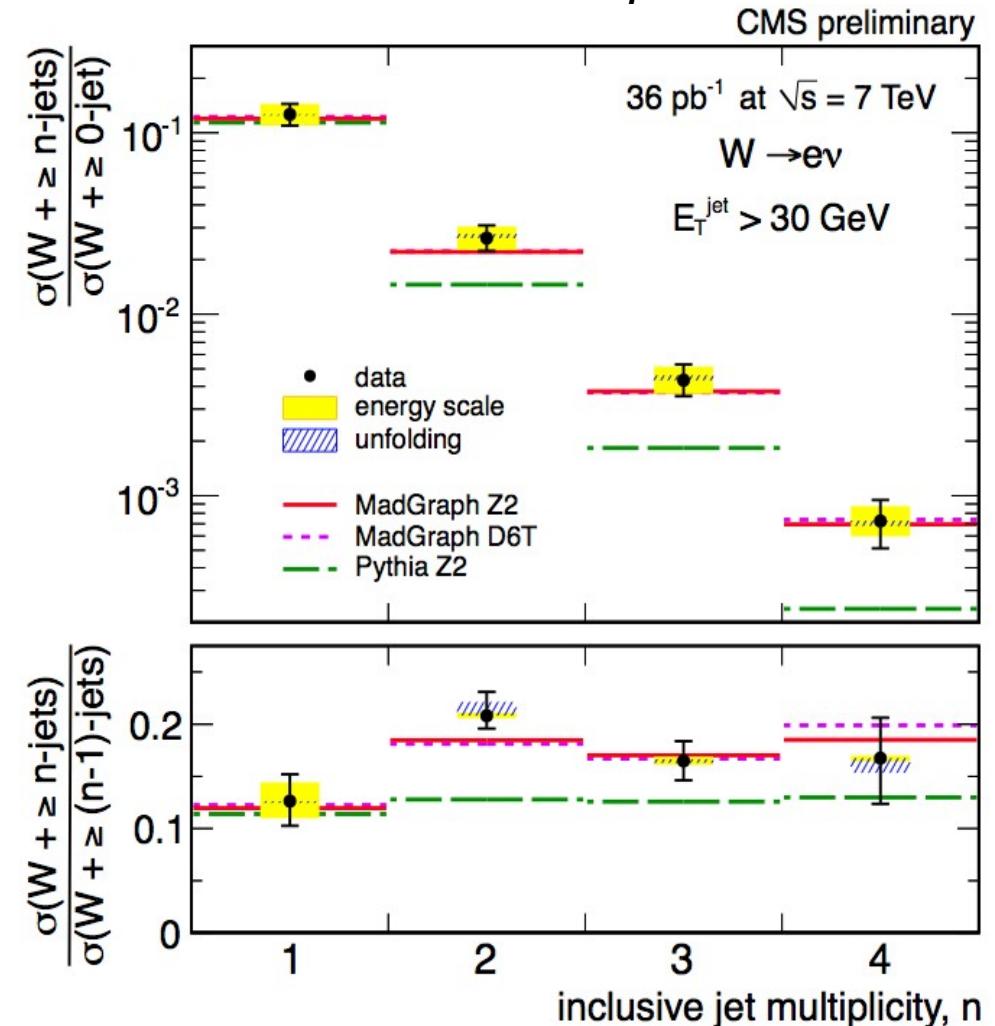
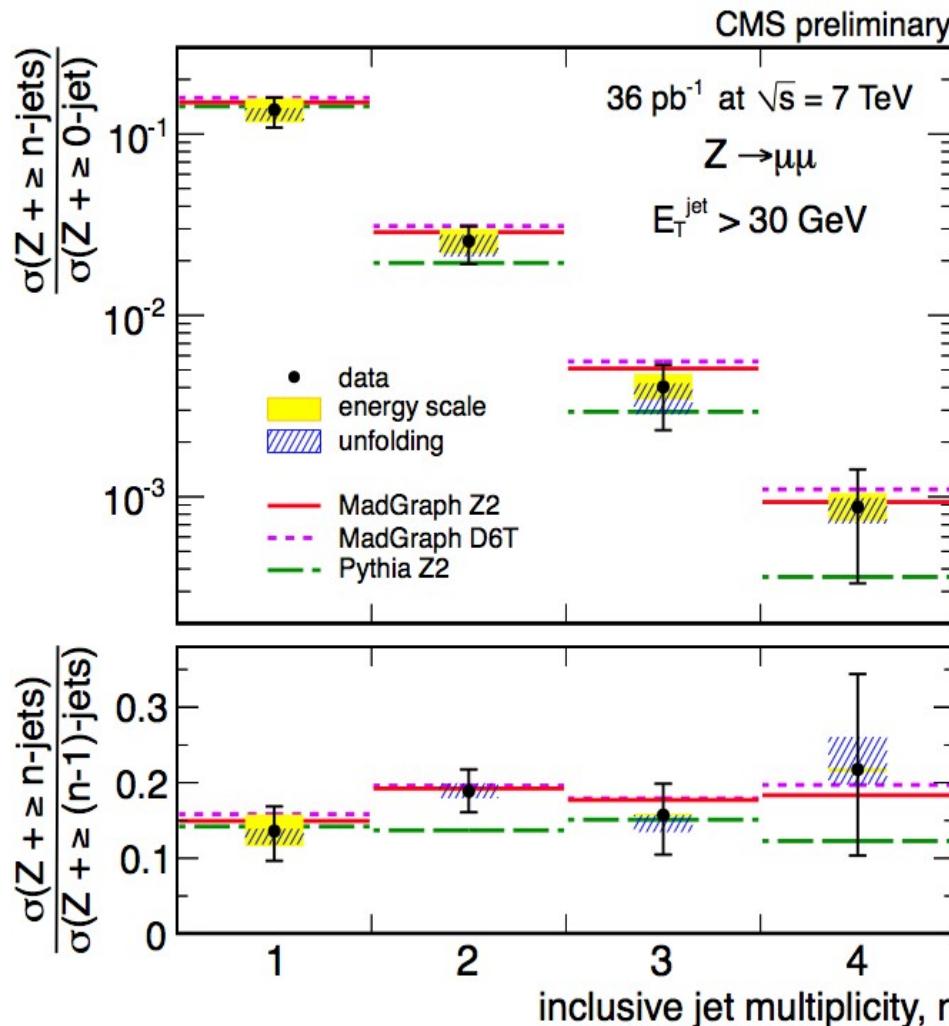


For W in a Jet bin:

- tt large background**
- B-jet tag as discriminant**
- 2D fit  $M_T^W$  vs.  $N_{\text{B-jets}}$**
- Parametric models in  $M_T^W$ 
  - Fitted in control regions
- B-tag eff/purity from data
- Z+jets: similar to Z differential
- Jet multiplicity unfolded

# W and Z + Jets Cont'd

- Additional selection variable: Jet with  $p_T > 30 \text{ GeV}$

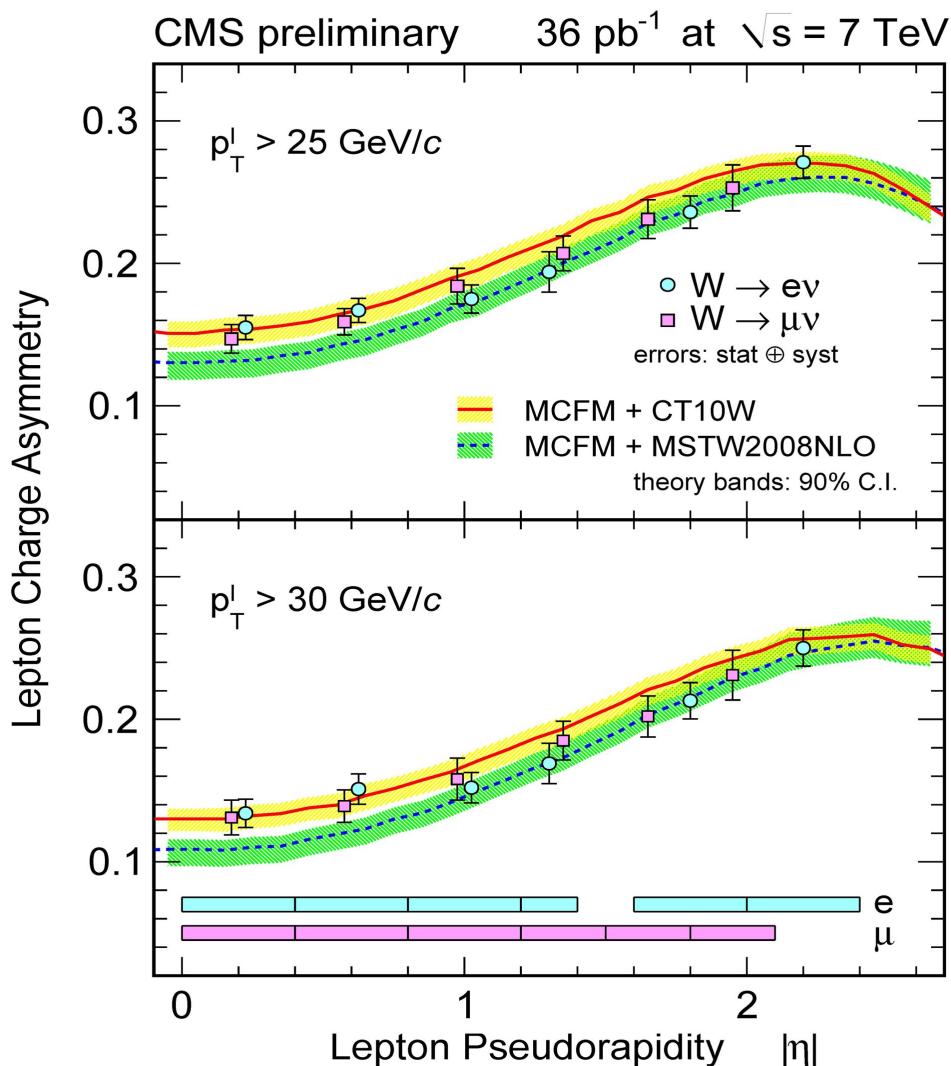


Boson + Jets follow matrix element MC scaling

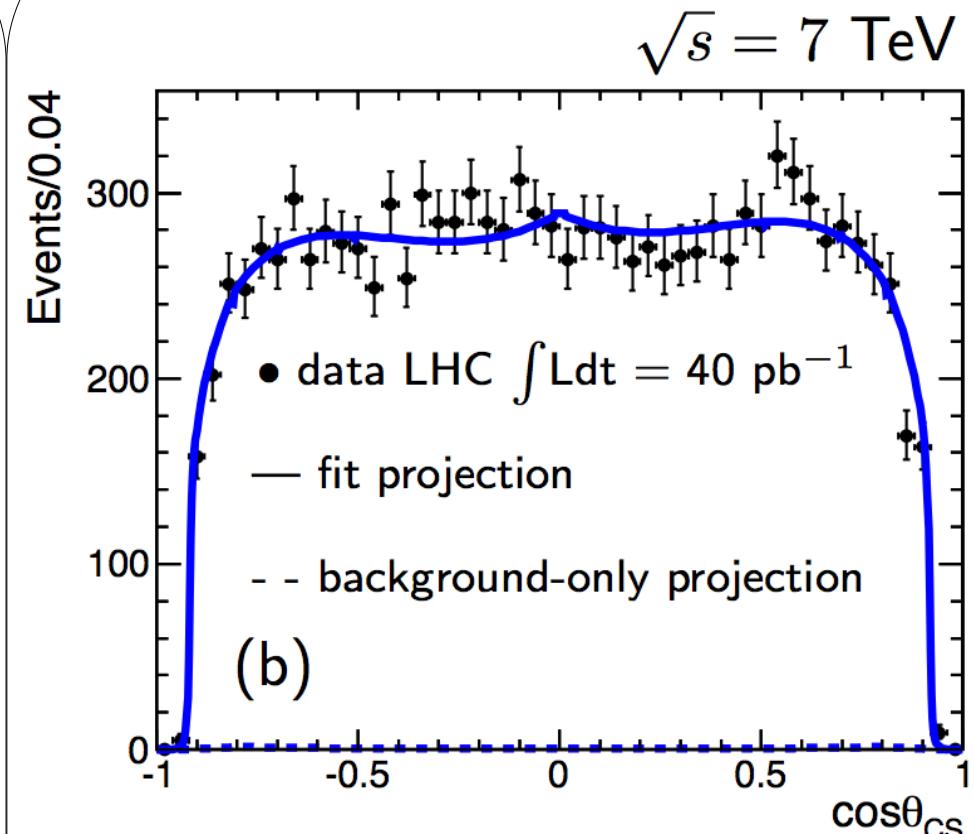
Plots are normalized to the 0 jet bin

# Additional Results

## W charge asymmetry

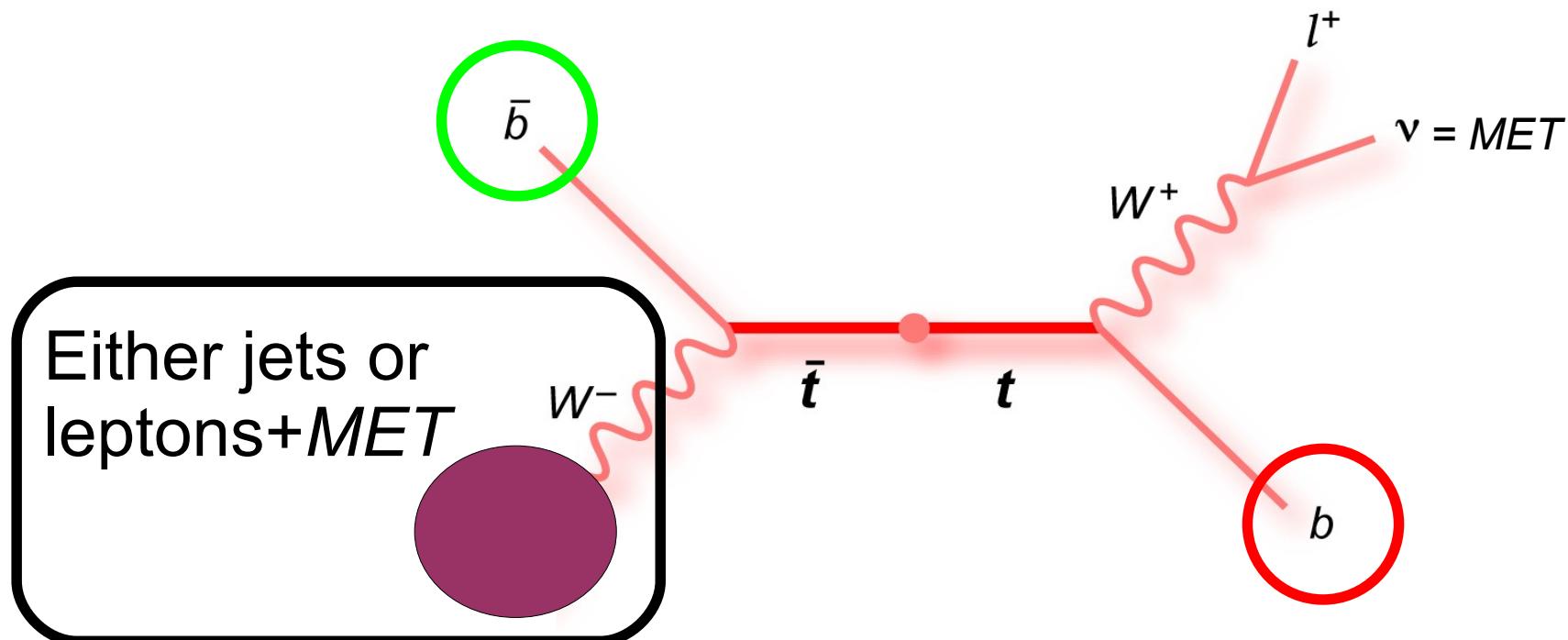


See talk J. Bendavid



Di-lepton  $A_{FB}$   
 New method for  $\sin^2\theta_W$   
 See Talk N. Tran

# Top Decays



**Top is the only raw quark we can study**

**Top is a gateway to new physics**

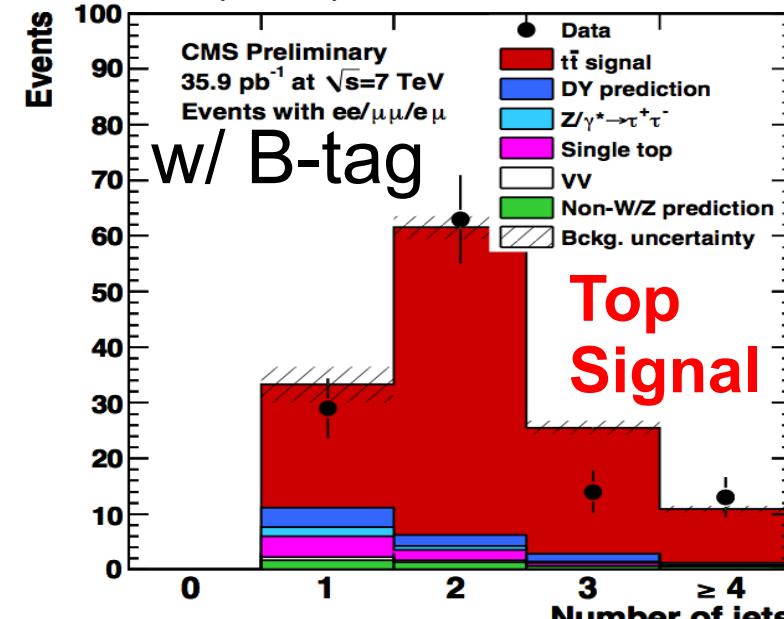
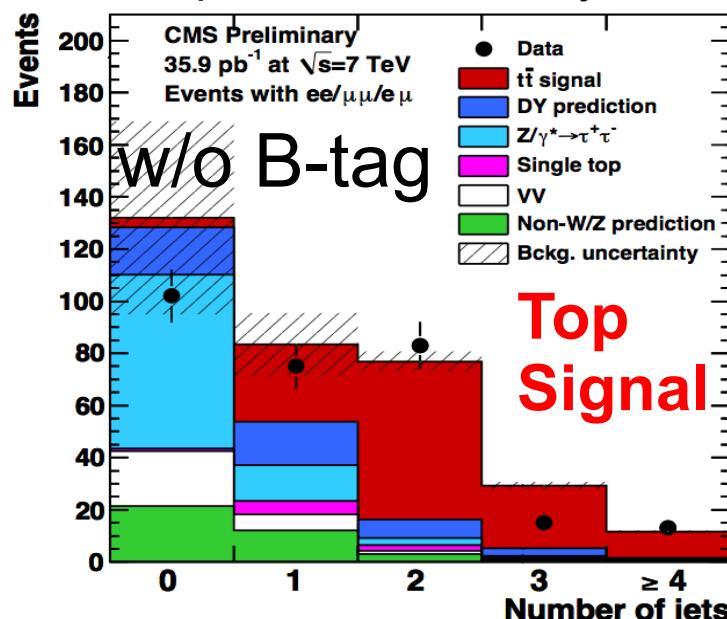
Additional Ingredients in top analyses

- Tag and probe for b-tag efficiency
- Every selection requires at least 2 jets
  - Jet energy uncertainty from QCD studies

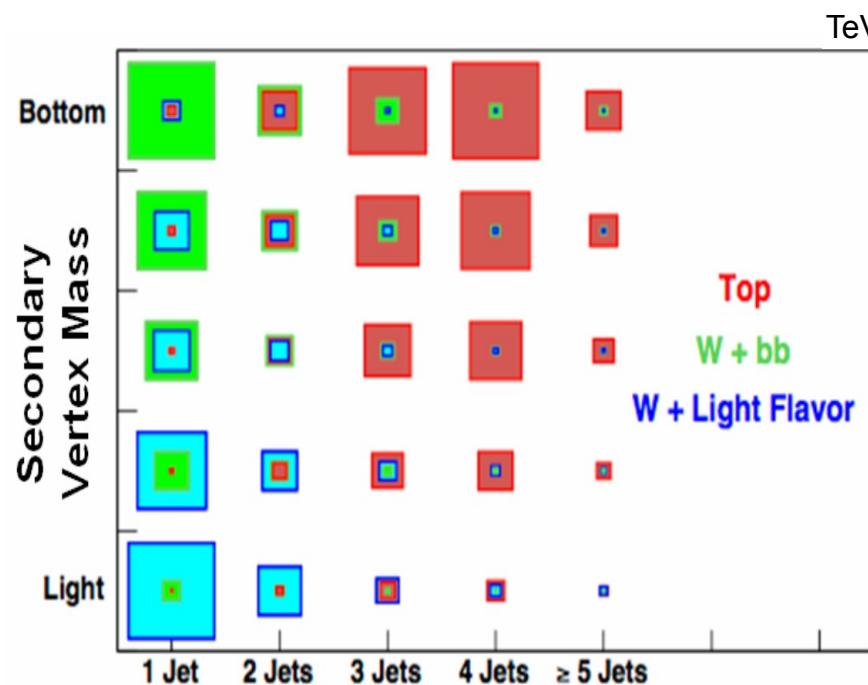
# Top Cross Section

- Cross section measured in 2 channels
  - Single lepton and double lepton + 1 Jet +  $MET$
  - Single lepton: additional + b-tag (and w/o b-tag)
    - Details on without b-tag measurement(see backup)

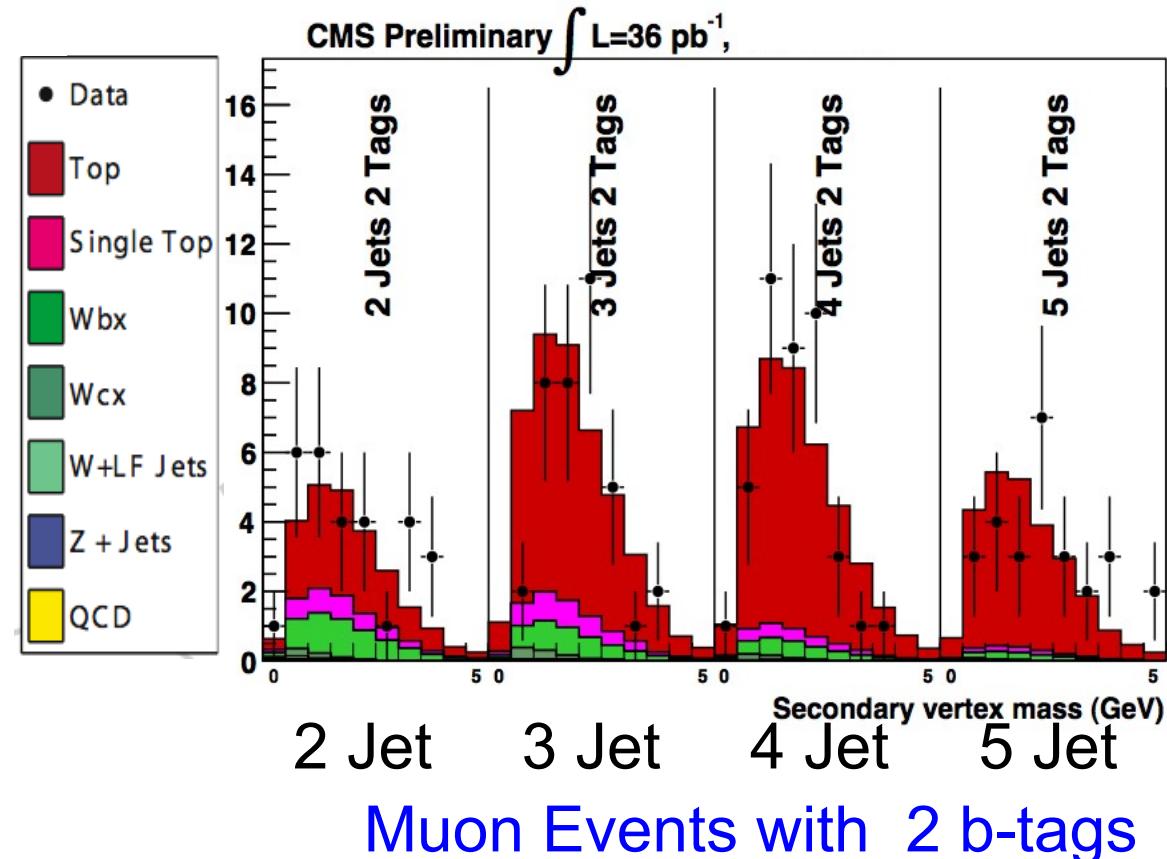
- Double Lepton:  $MET$  cut changing w/ jet multiplicity
  - Count events after background subtraction
  - $3\text{pb}^{-1}$  Published: Physics Letters B695 (2011) 424



# Top Cross Section: Single Lepton

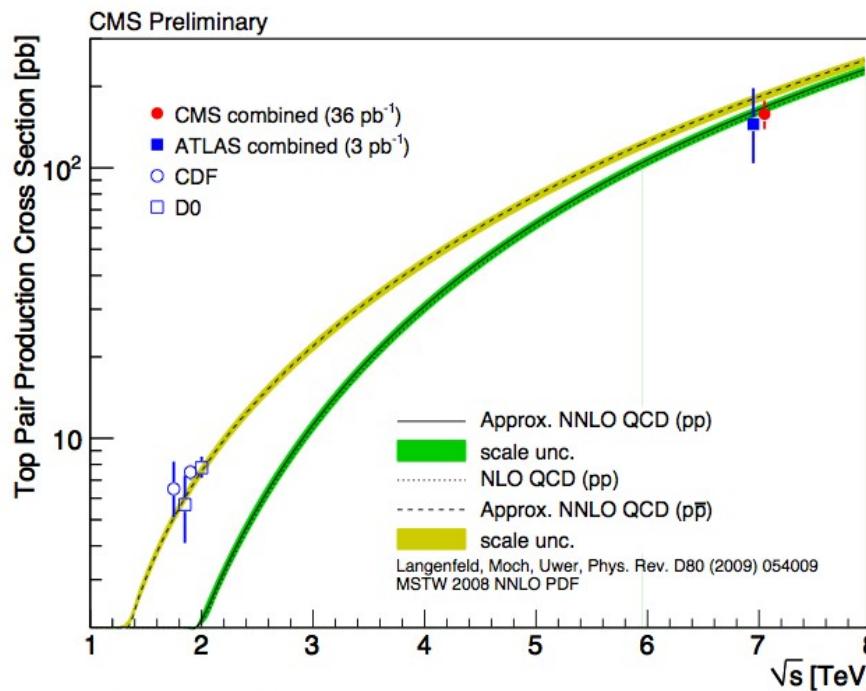


Constraining both Top and  
W+Jets



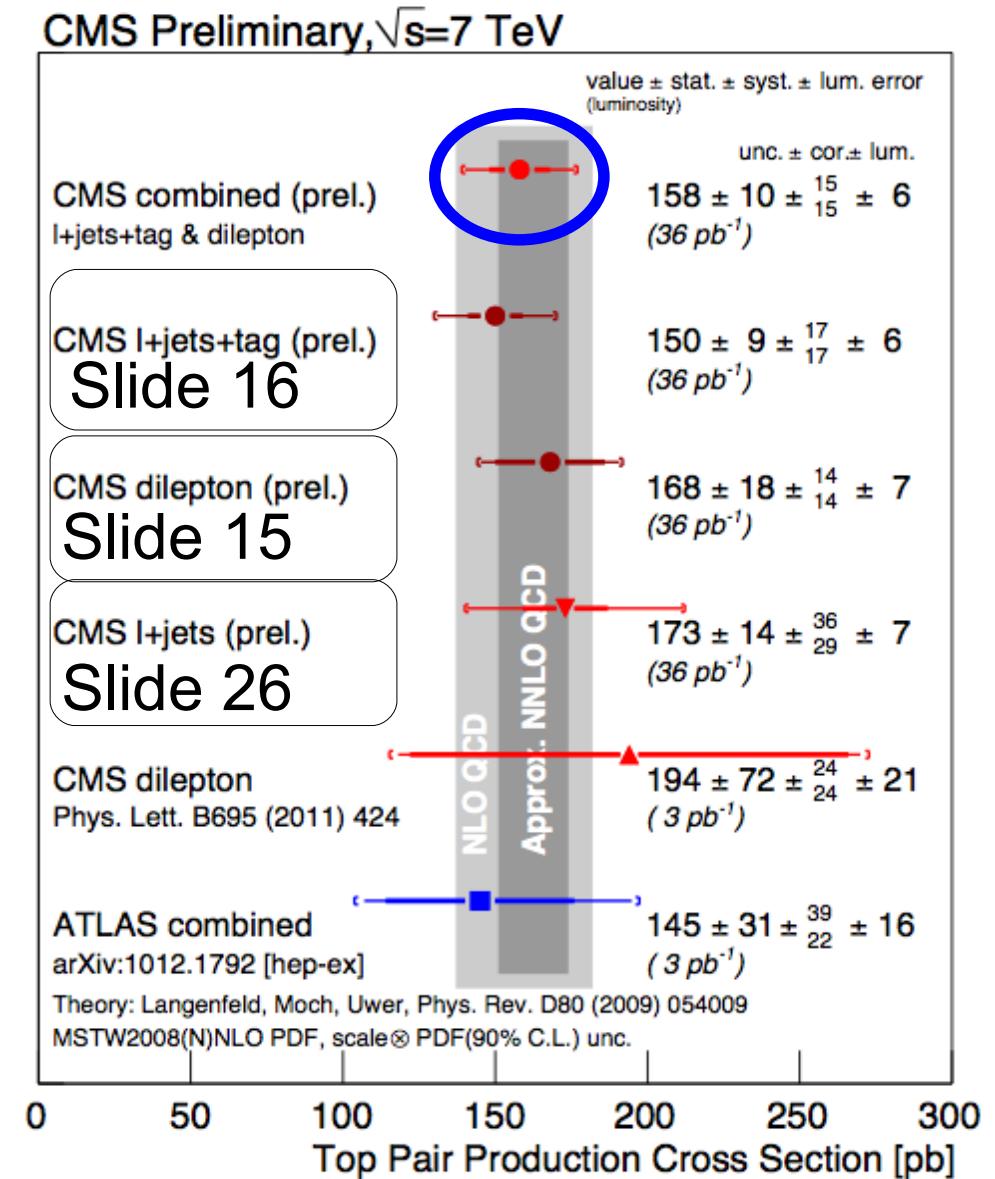
- **Simultaneous** fit for yield in secondary vertex mass
  - Simultaneous for: electrons, muons 1 and 2 b-tag
  - Btag-efficiency and jet energy scale results from fit

# Top Cross Section

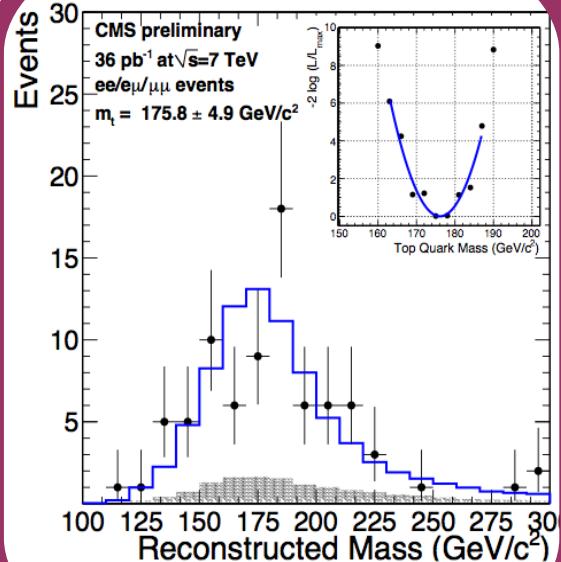
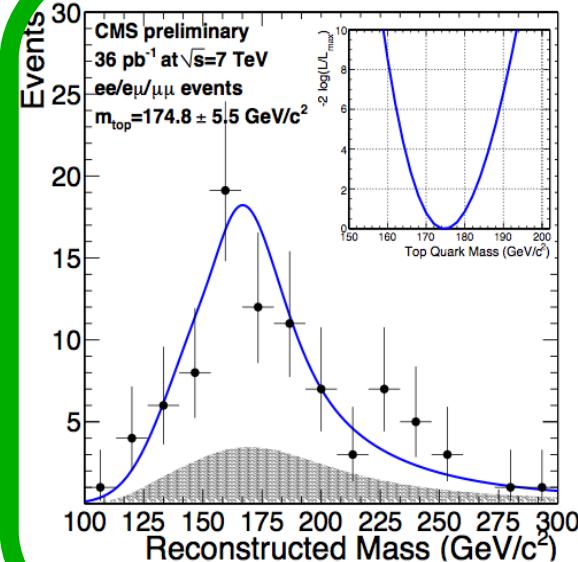


$$\sigma = 158 \pm 10 \pm 15 \pm 6 \text{ pb}^{-1}$$

Starting to test  
higher order  
calculations



# Top Mass Measurement



## Di-Lepton Channel

CMS combined (in GeV/c<sup>2</sup>)  
 $175.5 \pm 4.6$  (stat)  $\pm 4.6$  (sys)

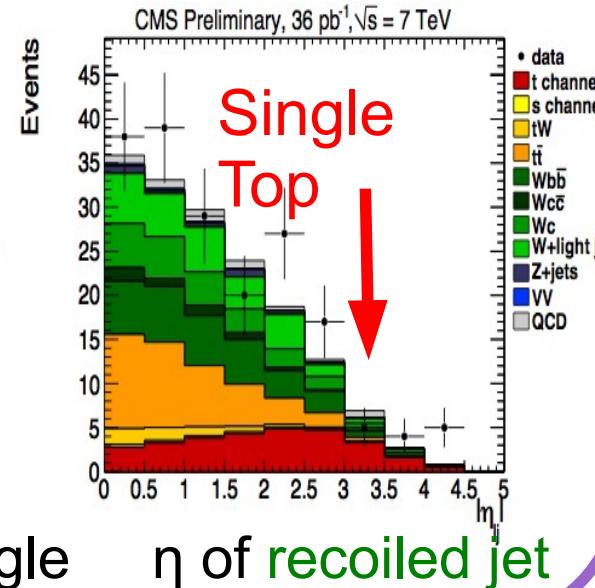
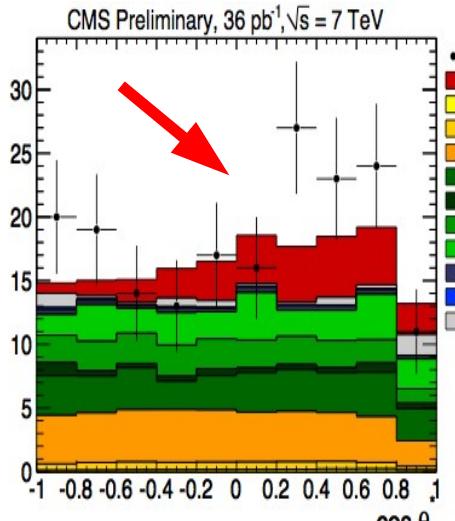
World

$173.1 \pm 1.1$   
di-lepton(D0)  
 $174.7 \pm 3.8$

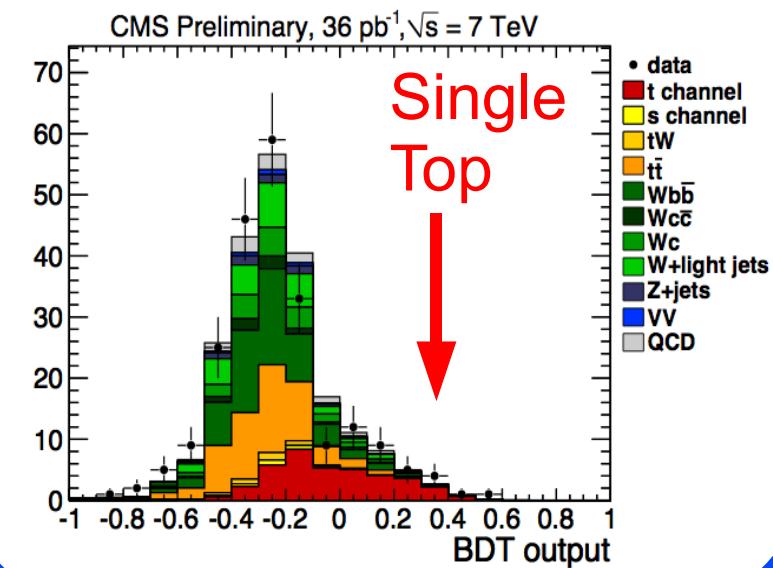
- Method 1: Select most probable mass and fit distribution
  - Given hypotheses on  $p_z^{t\bar{t}}$  and jet energy scale
- Method 2: Scan over top mass assumptions=>choose best
  - For each mass assumption select best combination
    - Given likelihood for lepton energies in top frame

# Single Top Cross Section

## 2 Dimensional fit

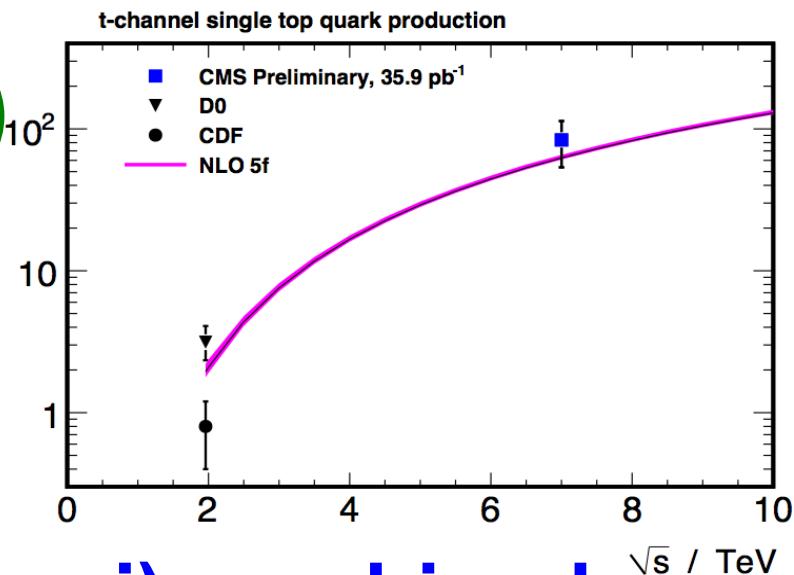
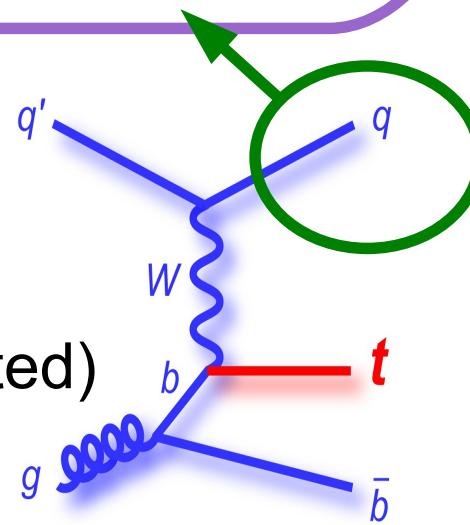


## Fit to Boosted decision tree



lepton-recoiled jet angle       $\eta$  of recoiled jet

- W+2 jet selection
  - Lepton +  $MET$  + 2 jets
  - Require 1 b-tag
- Significance meas(expected)
  - 2D: 3.7(2.1) sigma
  - BDT: 3.5(2.9) sigma



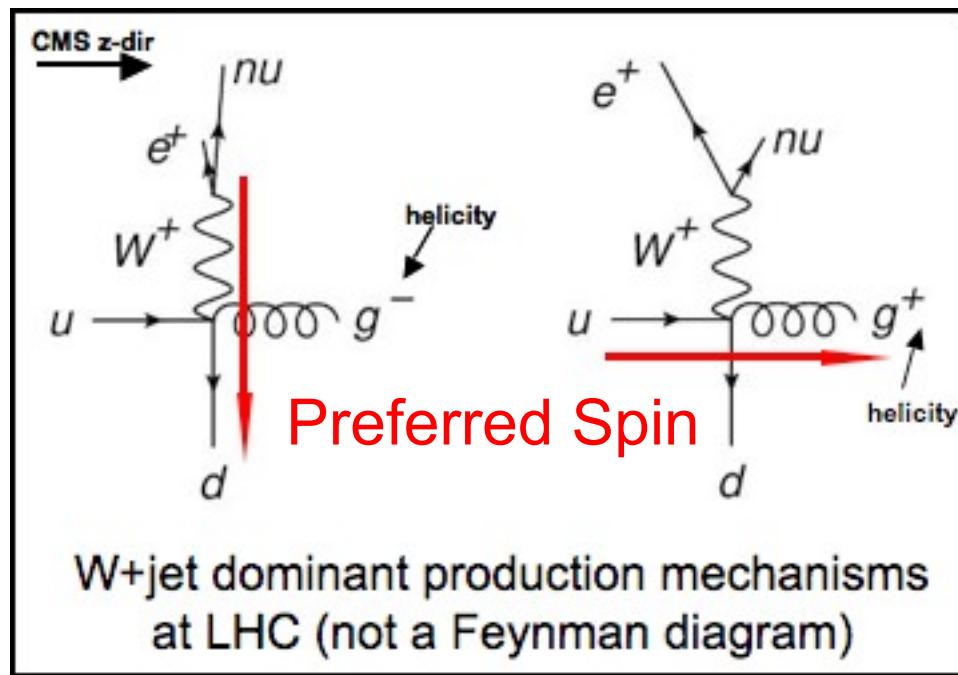
**$83.6 \pm 29.8 (\text{stat+sys}) \pm 3.3 (\text{lumi})$  combined**



# W Polarization Measurement at LHC

# Theoretical Baseline

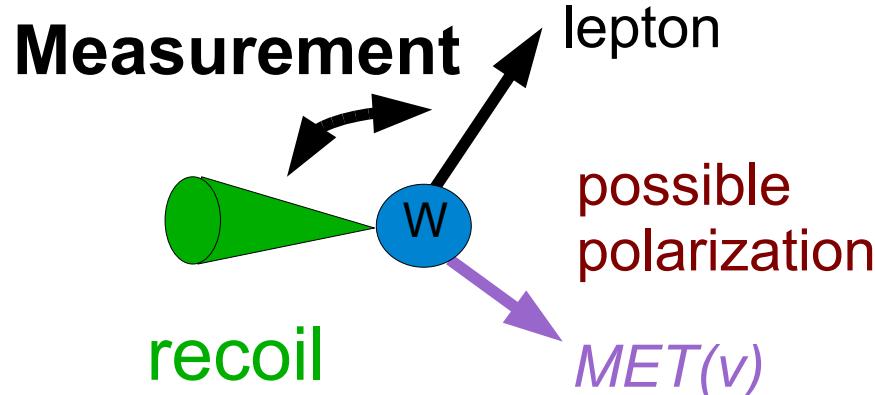
- Production of high  $p_T$  W-bosons ( $p_T > 50$  GeV)
  - 7 TeV+high  $p_T$  dominant production valence quark w/gluon



- **Strong polarization effects in transverse plane**
- SM: Predominant left handedness for + and -
- Unlike tevatron ( $p\bar{p}$ )
  - No CP counterparts
  - Cause for left handedness
  - Robust over jet multiplicity

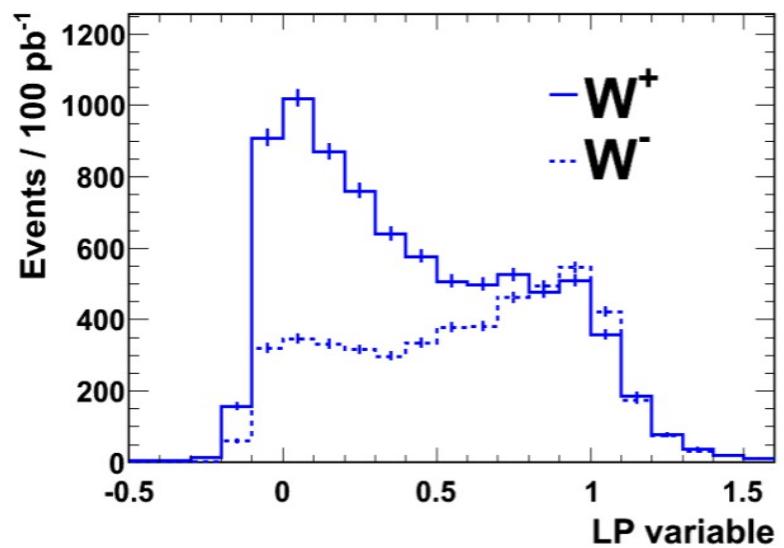
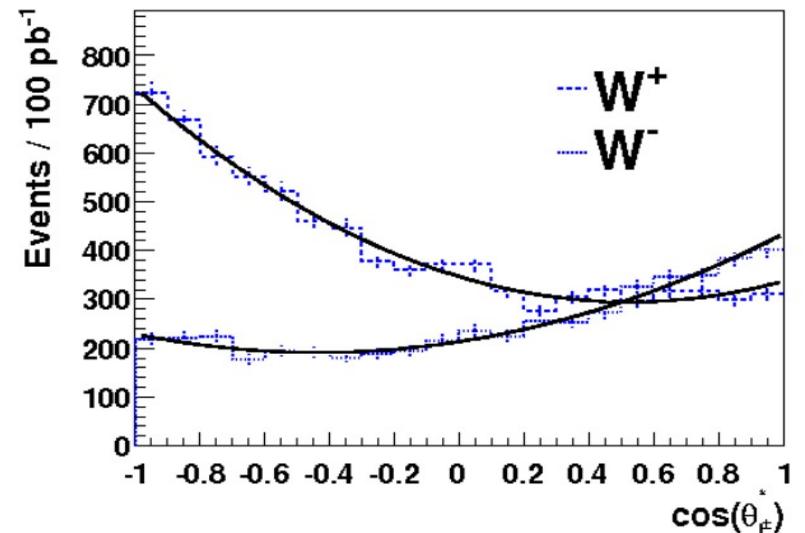
**Expect left right polarization asymmetry in a  $p\bar{p}$  collider**

# LP variable



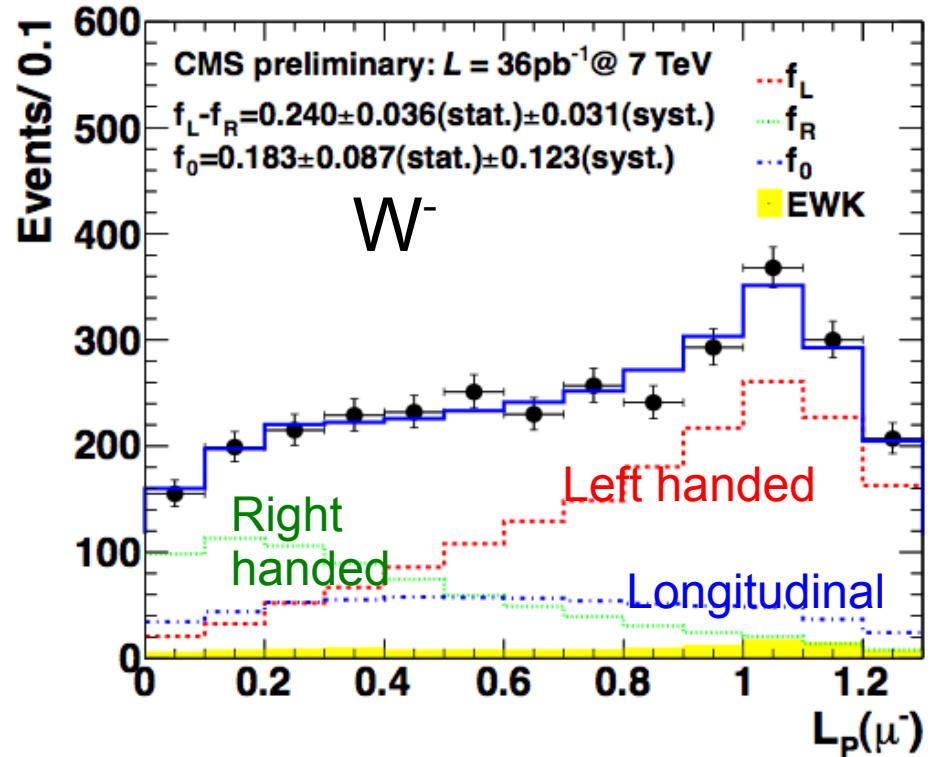
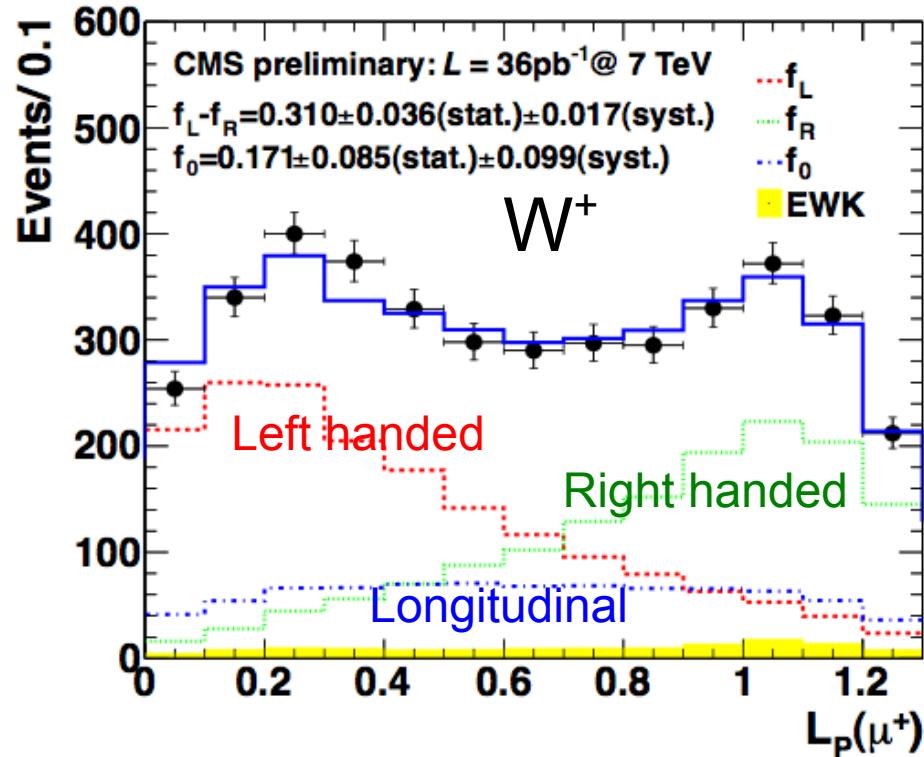
$$LP = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

- Fraction of  $p(W)$  on lepton
  - Determined by  $\cos(\theta^*)$  (Polarization)
- $P_z(W)$  undetermined
  - **Transverse components necessary**
- LP variable
  - Addresses both of these



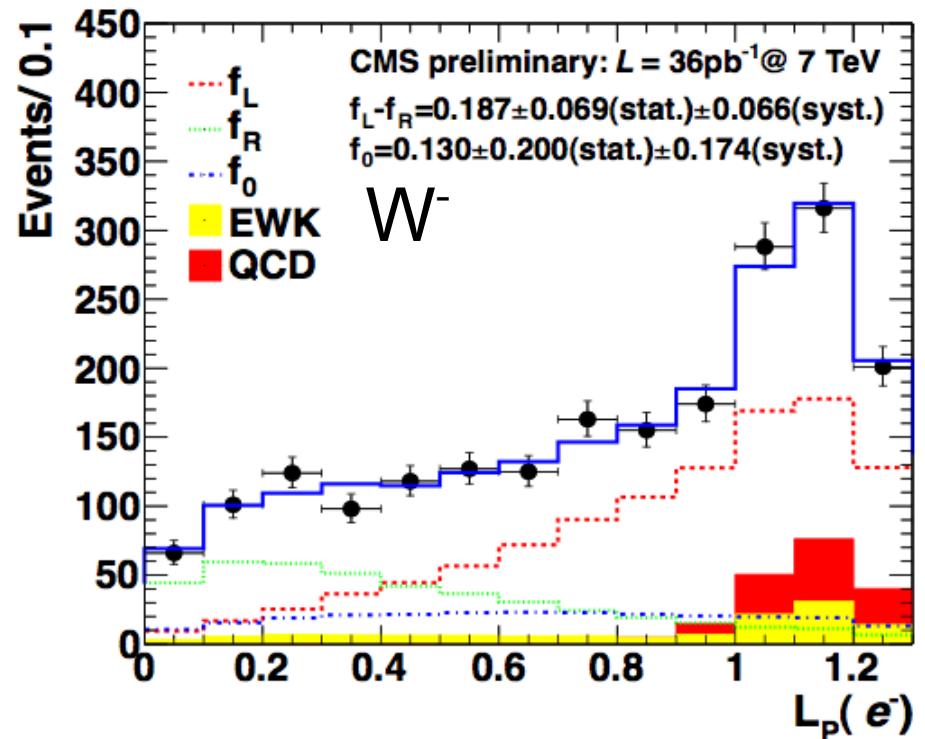
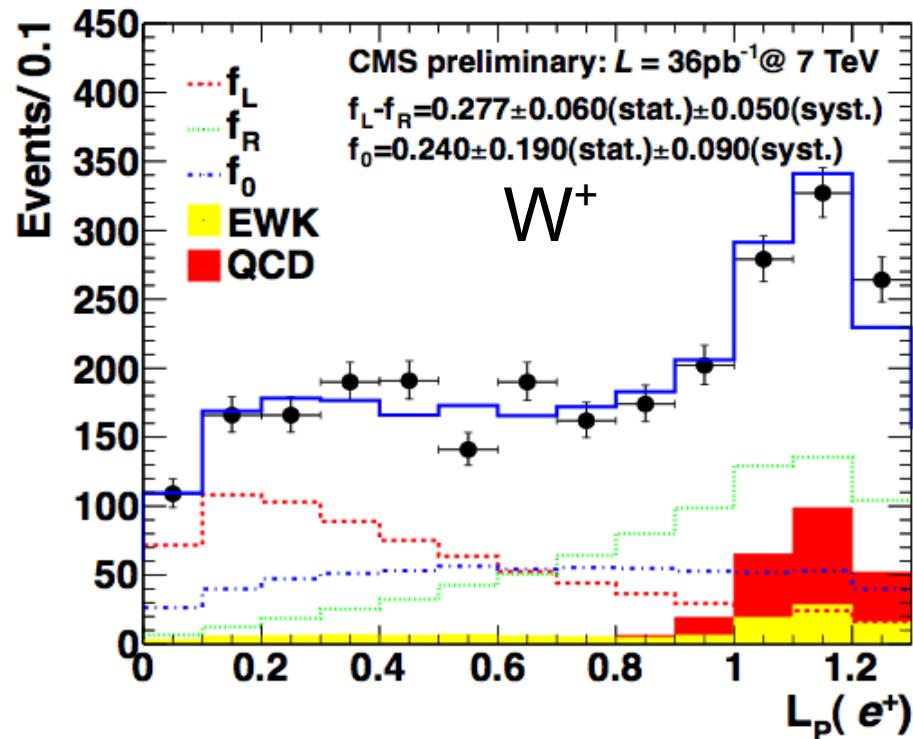
**LP used to determine W  
Polarization**

# Muon Channel Results



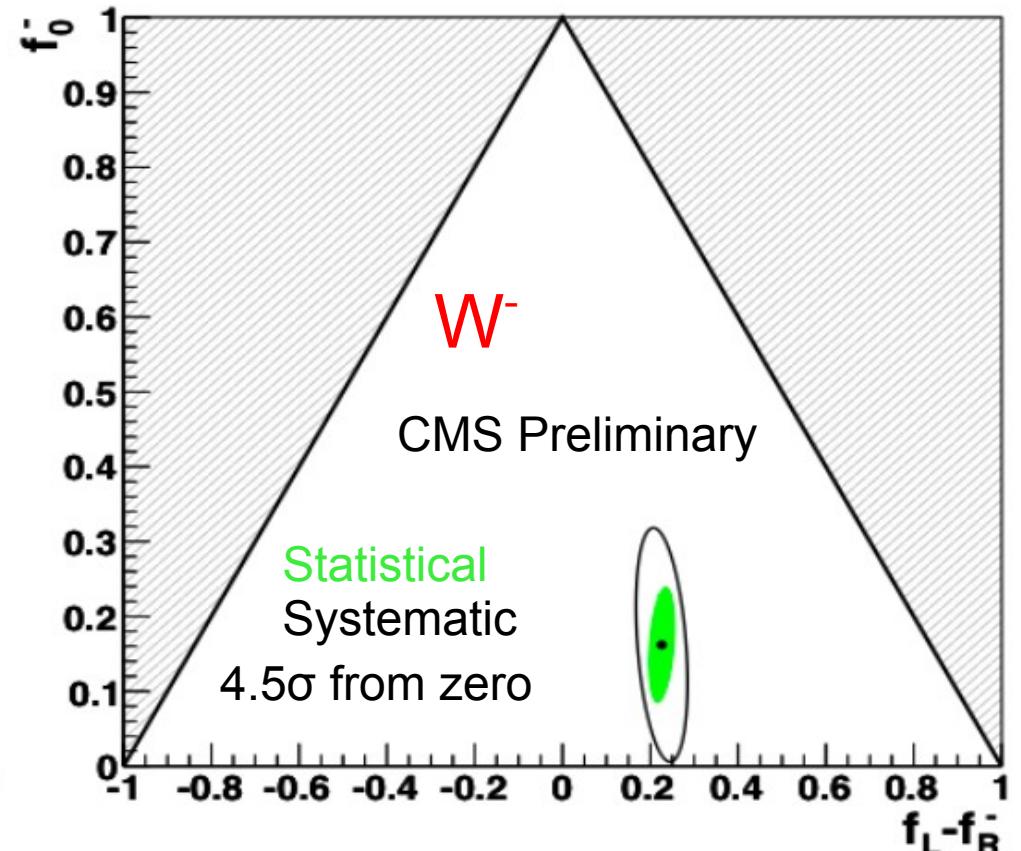
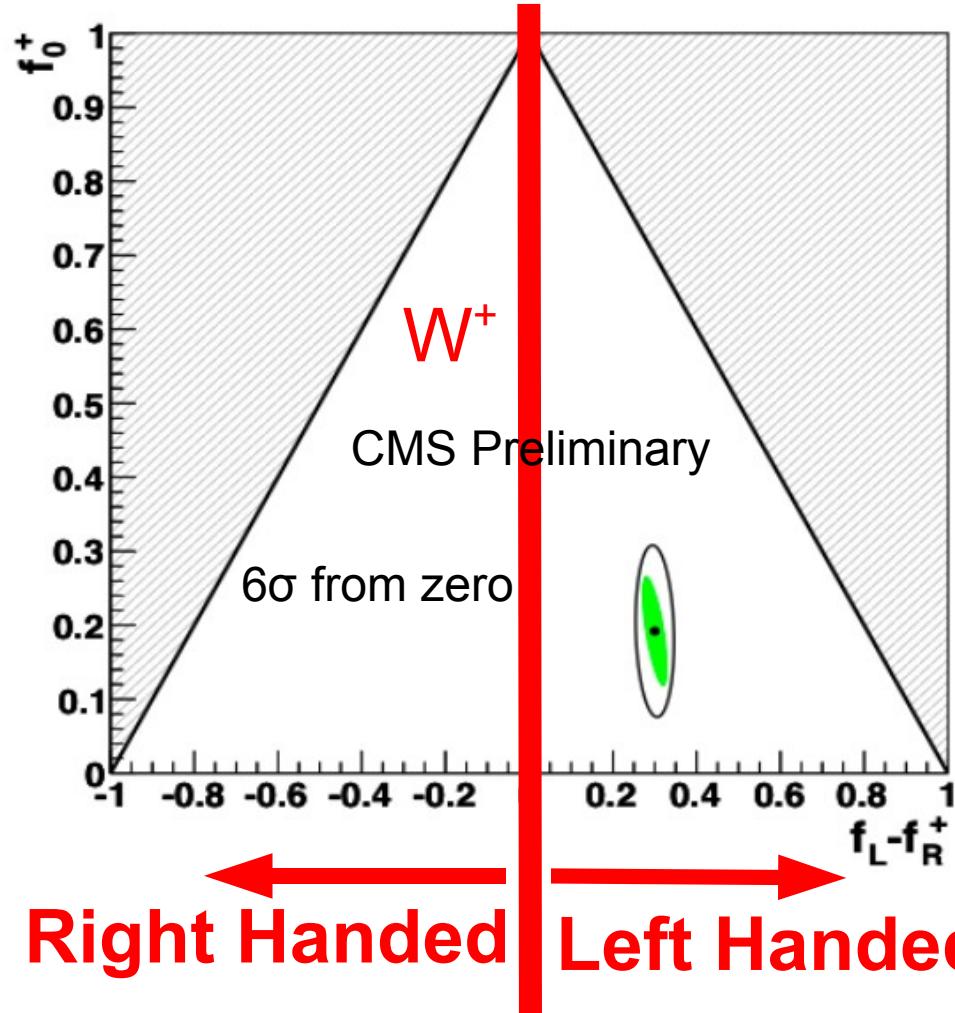
- Fit 3 separate templates(2 Free parameters)
  - $f_0$  longitudinal polarization fraction
  - $f_L - f_R$  left handed – right handed fractions

# Electron Channel Results



- Fit 4 separate templates(3 Free parameters)
  - $f_0$  longitudinal polarization fraction
  - $f_L - f_R$  left handed – right handed fractions
  - **Float QCD fraction**

# Combined Channels



- 68% confidence level contours

# Summary

- Polarization of high  $p_T$  Ws measured
- Predominant left handed polarization for  $W^+$  &  $W^-$

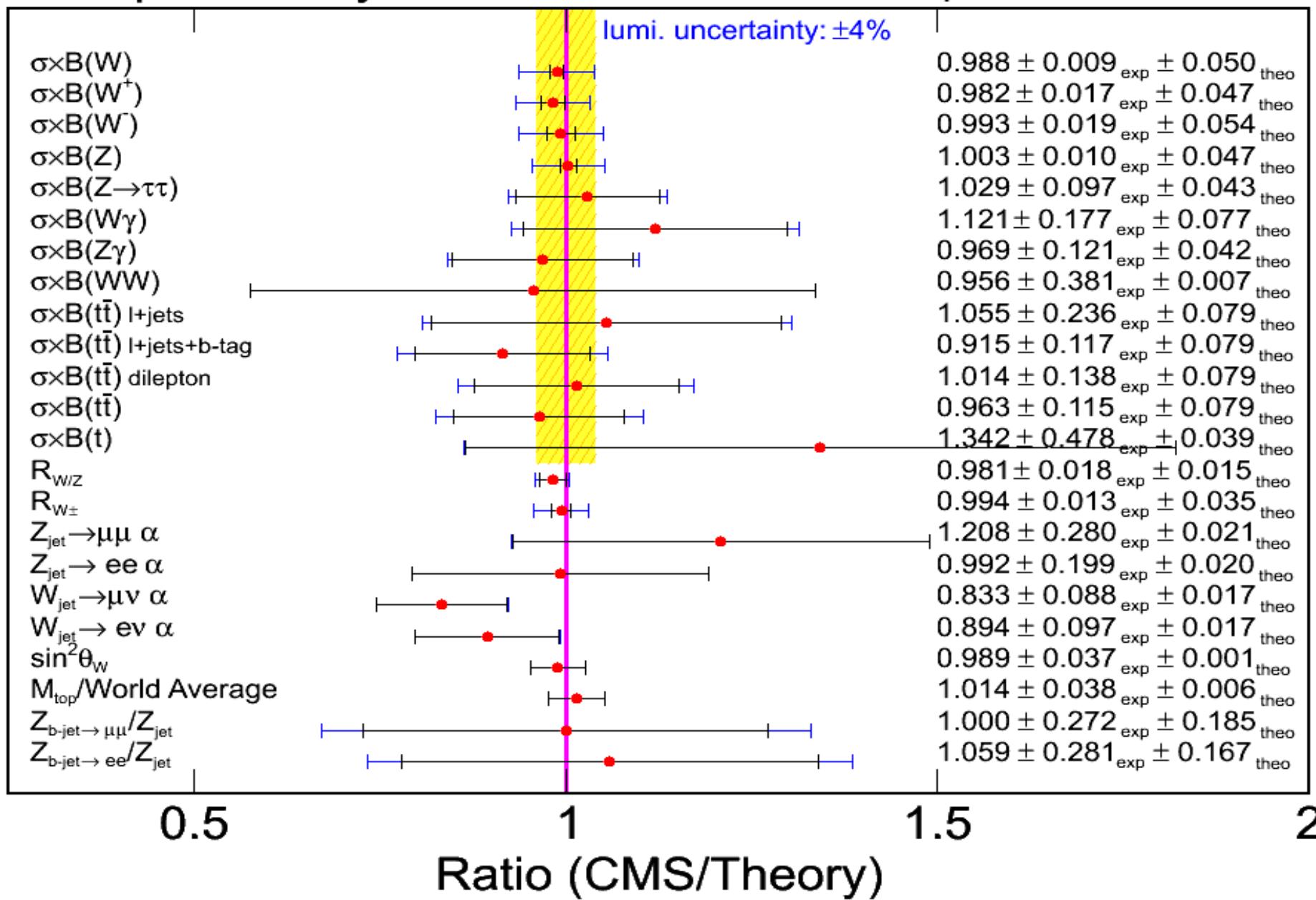
Combined Results	
$(f_L - f_R)^-$	$0.226 \pm 0.031 \text{ (stat)} \pm 0.050 \text{ (syst)}$
$f_0^-$	$0.162 \pm 0.078 \text{ (stat)} \pm 0.136 \text{ (syst)}$
$(f_L - f_R)^+$	$0.300 \pm 0.031 \text{ (stat)} \pm 0.034 \text{ (syst)}$
$f_0^+$	$0.192 \pm 0.075 \text{ (stat)} \pm 0.089 \text{ (syst)}$

# Conclusions

- **A prodigious amount of standard model results**
  - We are starting to put new constraints on:
    - PDF uncertainties
    - Standard Model Couplings
    - NNLO differential calculations
    - Associated Jet production
  - For example, NNPDF already using our results
- **These results are the baseline for next year**
  - Many new studies to come from the upcoming run
  - Many are baseline for beyond standard model physics
    - Already  $Z' \rightarrow tt$  search performed (see backup)
- **Standard model is still in focus**

# Results Summary

CMS preliminary

36 pb<sup>-1</sup> at  $\sqrt{s} = 7$  TeV

# References

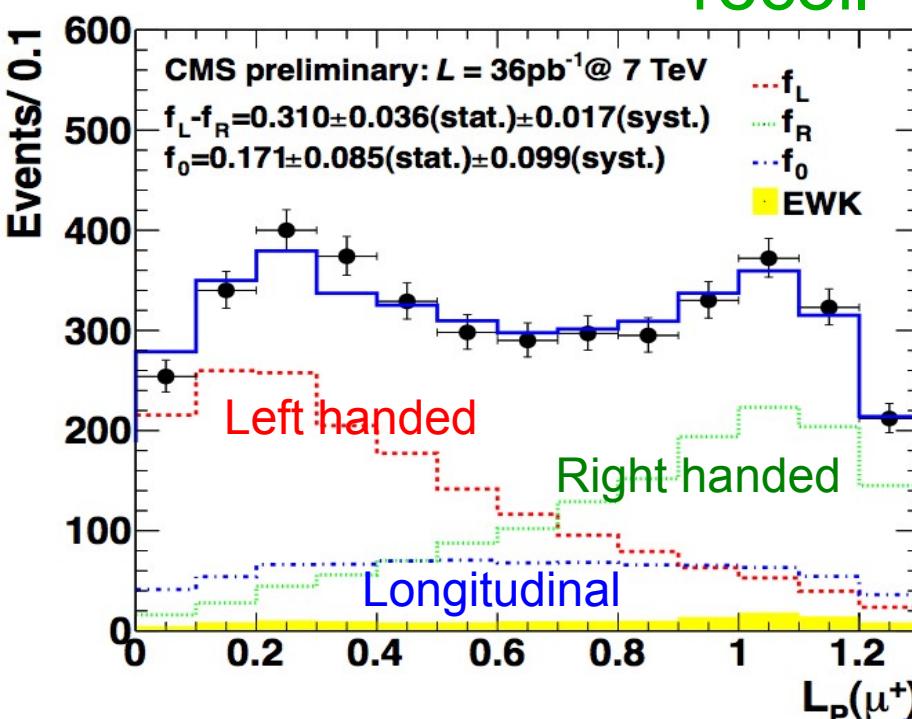
Title	Reference
New Top Results	CMS Top Results
New Electroweak Results	CMS EWK Results
First measurement of the top-quark mass in the dilepton channel in pp collisions at $\sqrt{s}=7\text{TeV}$	CMS-PAS-TOP-10-006
Measurement of the ttbar invariant mass spectrum and a search for new physics at $\sqrt{s}=7\text{TeV}$	CMS-PAS-TOP-10-007
Selection of single top events in pp collisions at $\sqrt{s}=7\text{TeV}$	CMS-PAS-TOP-10-008
Measurement of the charge asymmetry in top quark pair production	CMS-PAS-TOP-10-010
Study of W and Z Boson Production at 7 TeV	CMS-PAS-EWK-10-005
Measurement of the W boson charge asymmetry	CMS-PAS-EWK-10-006
Measurement of the Drell-Yan cross section ( $d\sigma/dM$ )	CMS-PAS-EWK-10-007
Observation of W-gamma and Z-gamma final states	CMS-PAS-EWK-10-008
Observation of WW final state	CMS-PAS-EWK-10-009
Differential Cross Section of Z boson	CMS-PAS-EWK-10-010
Foward-Backward Asymmetry of di-lepton pairs	CMS-PAS-EWK-10-011
Rates of Jets Produced in Association with W and Z Bosons	CMS-PAS-EWK-10-012

# Backup

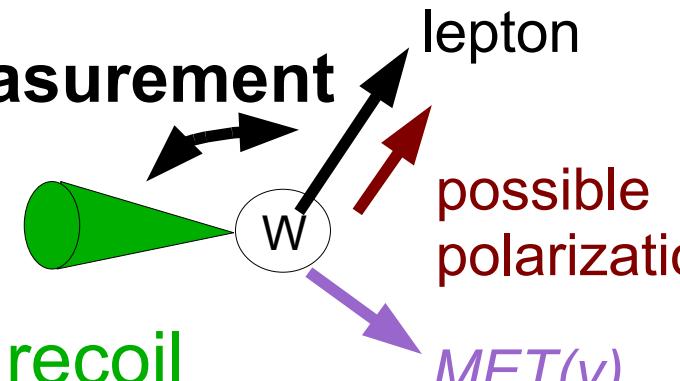
# W Polarization

$W P_T > 50 \text{ GeV}$

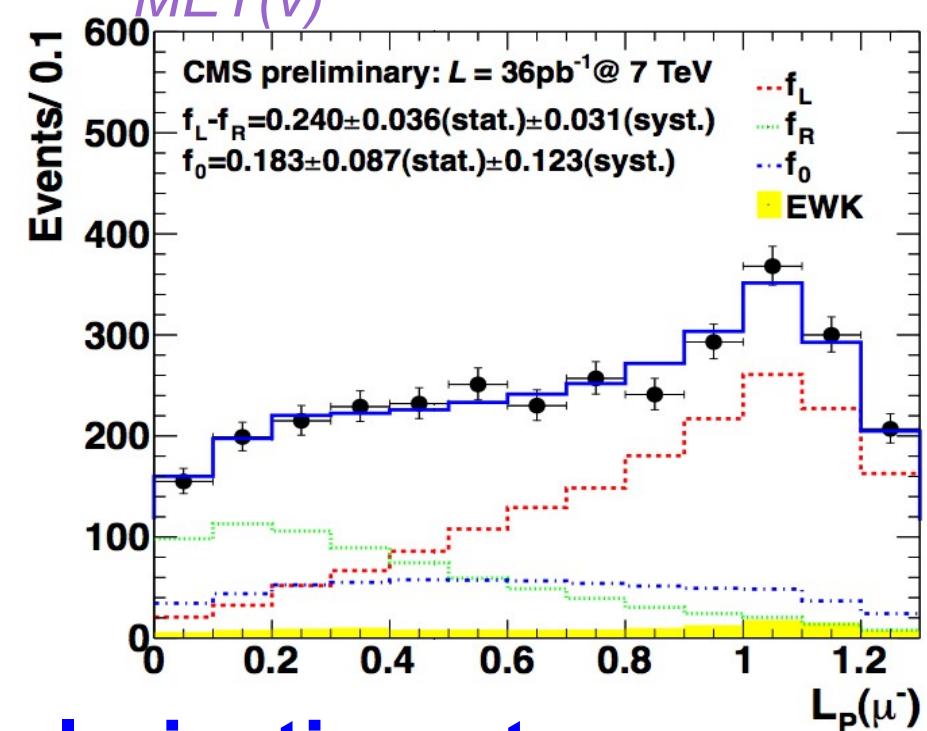
$$\text{LP} = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$



## Measurement



- Fit LP variable
- LP template for each polarization+EWK+QCD(in electrons)



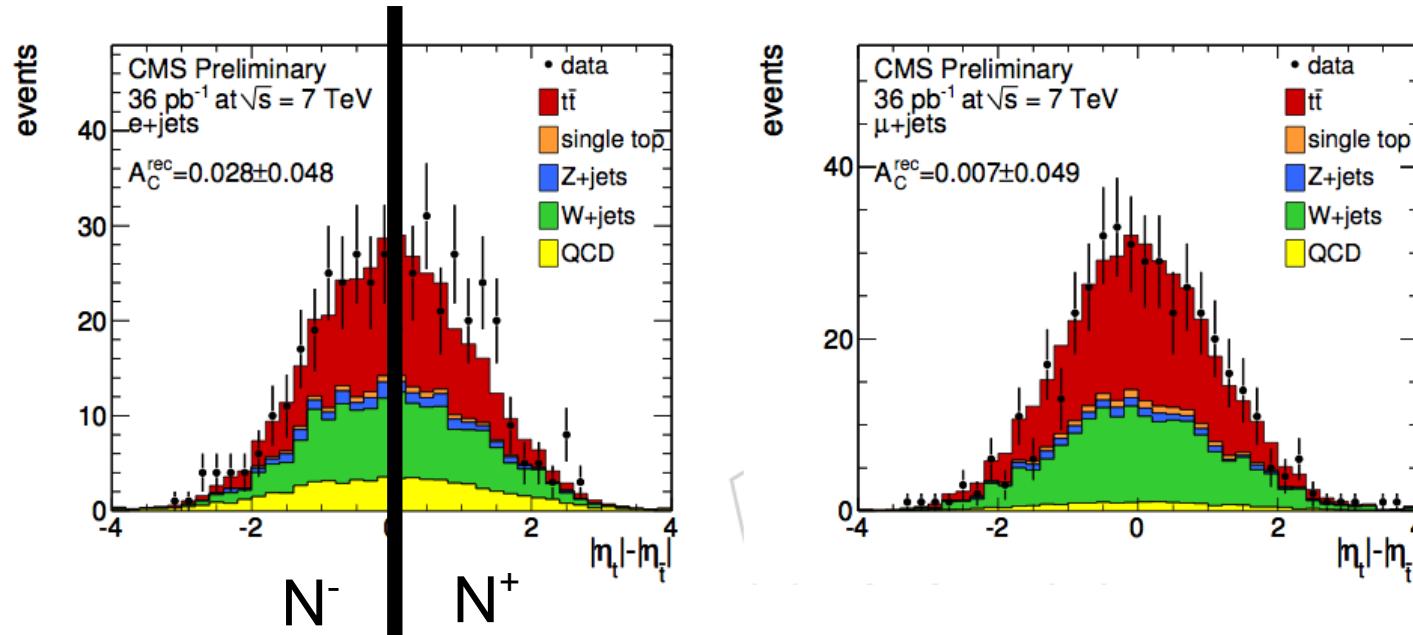
- First measurement of polarization at pp

$$f_0^+ = 0.192 \pm 0.075(\text{stat}) \pm 0.089(\text{sys}) \quad \text{Large theoretical unc.}$$

$$(f_L - f_R)^+ = 0.300 \pm 0.031(\text{stat}) \pm 0.034(\text{sys}) \quad (5\% \text{ sensitivity})$$

# tt Charge Asymmetry

Before  
Unfolding

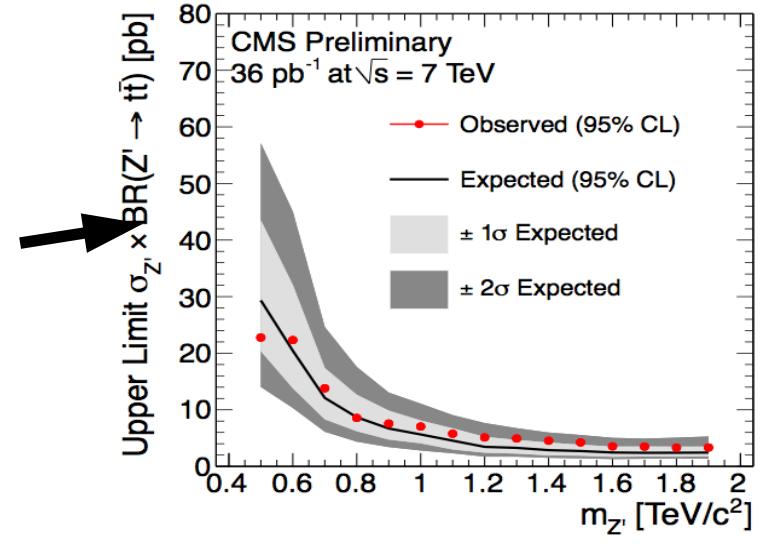
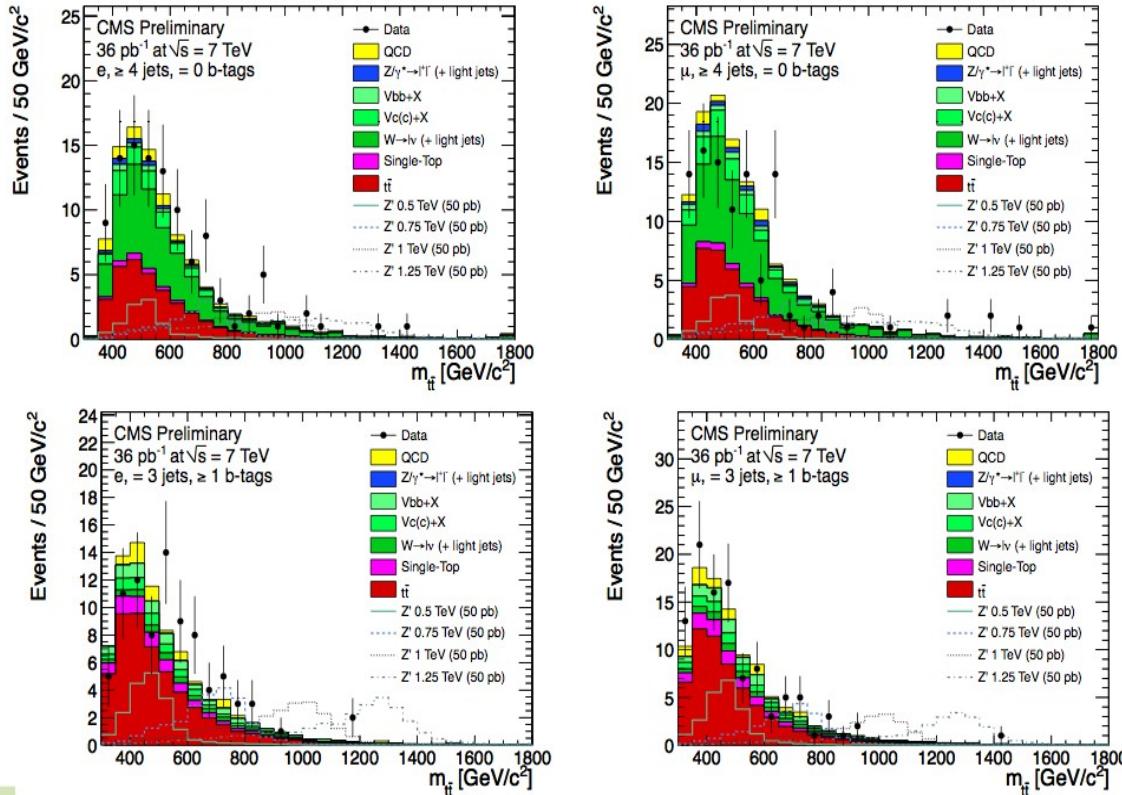


- Top Single lepton + Jet selection
- Asymmetry from  $|\eta_t|$  difference:  $(N^+ - N^-)/(N^+ + N^-)$
- Unfolded result consistent with standard model

$$A_C = 0.060 \pm 0.134(\text{stat.})^{+0.028}_{-0.025}(\text{syst.})$$

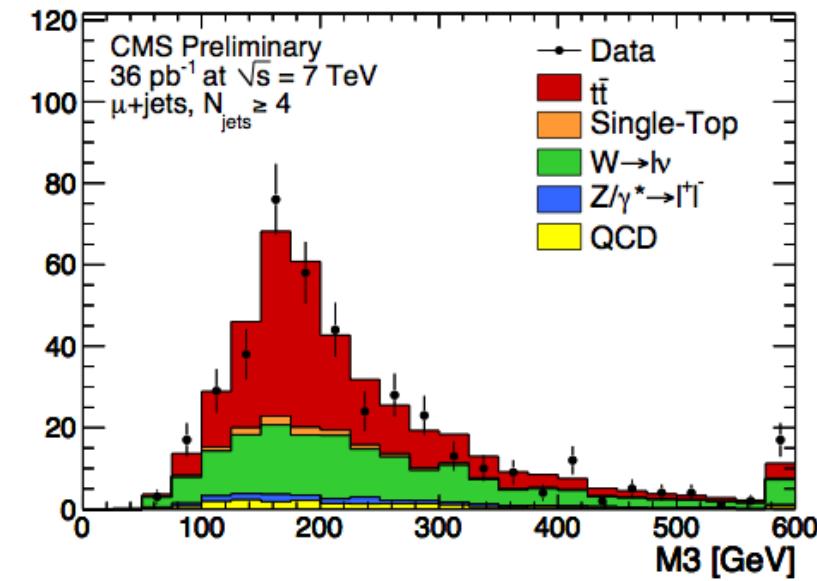
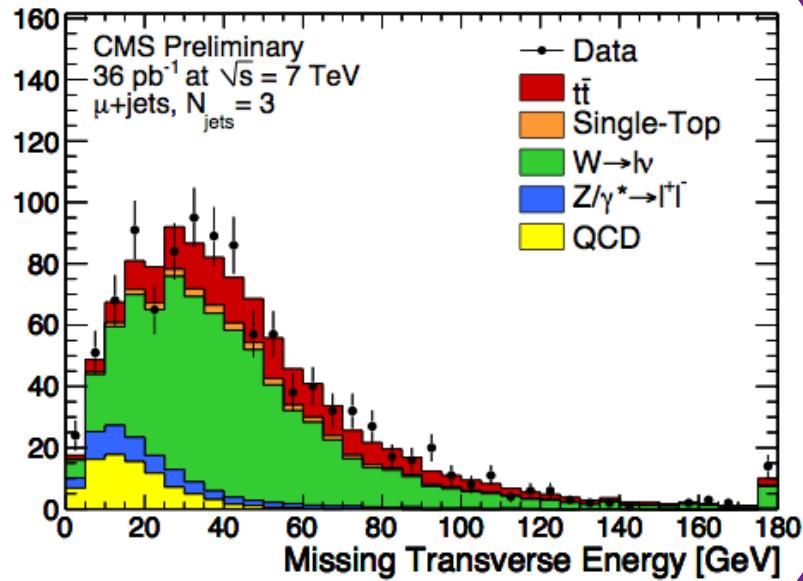
$$A_C^{SM} = 0.011(1)$$

# Measurement of $m_{t\bar{t}}$

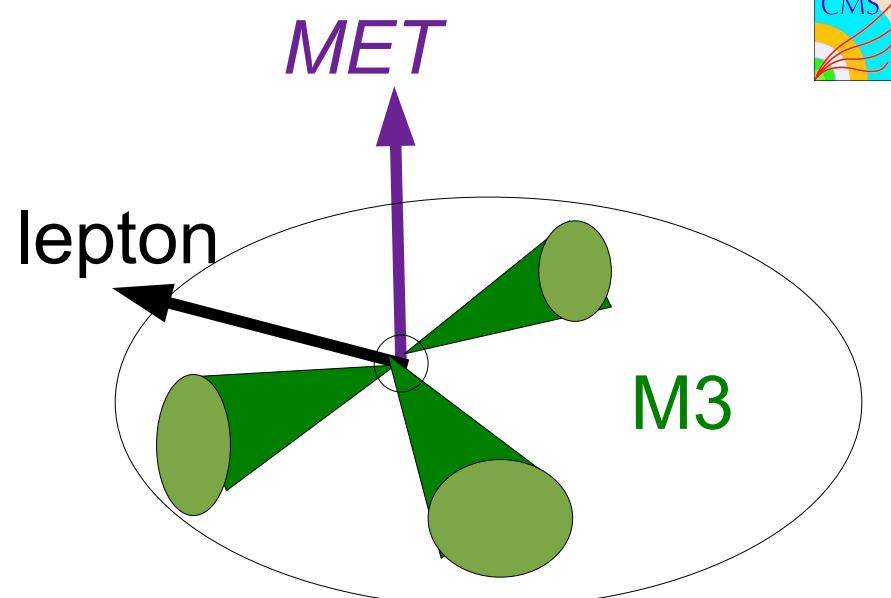


- Measurement of  $m_{t\bar{t}}$  translates to  $Z'$  search
- Limit extrapolated from 4 separate channels
  - Lepton + 4/3 Jets w/ and w/o b-tag
  - Vary results by predicted  $\sigma$  w/unc  $\rightarrow$  extrapolate limit

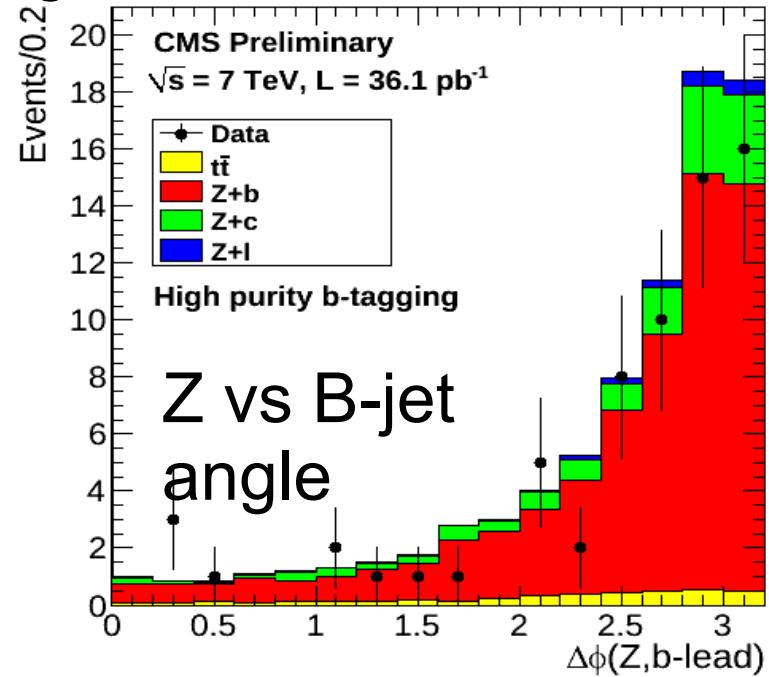
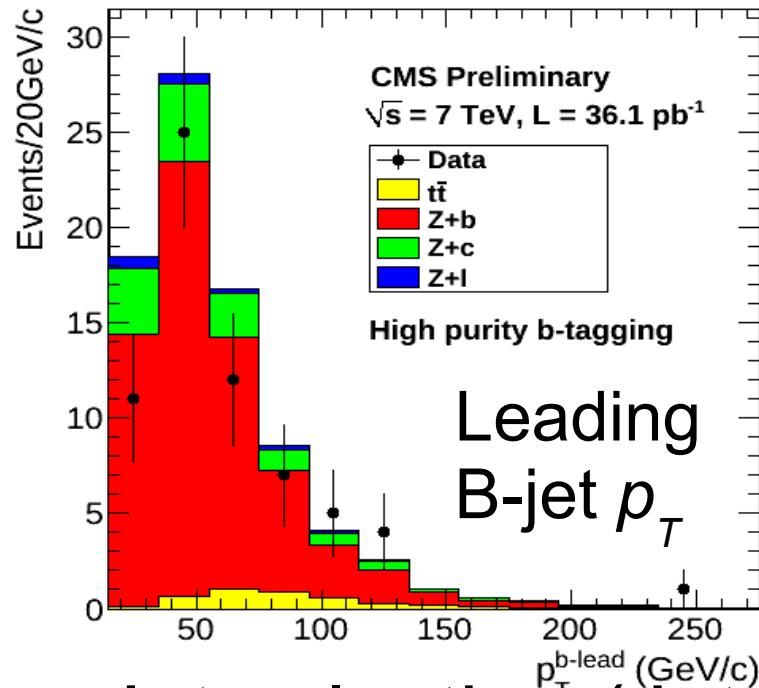
# Top Cross Section: 1 Lepton w/o b-tag



- Lepton + 3 or more jets
- Simultaneous fit in
  - MET
  - M3: Mass 3 jets w/ highest combined  $p_T$
- **Results consistent w/b-tag measurement**



# Z + b jets



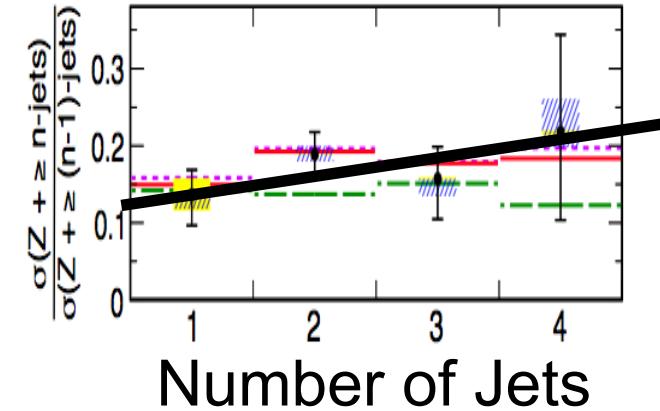
- Z + Jet selection (Jet  $p_T > 25 \text{ GeV}$ )
  - Cut on  $MET < 40 \text{ GeV}$  to eliminate top background
  - Purity/Efficiency from fit to data(2<sup>nd</sup> vertex mass)

## Ratio Z + b / Z + jet

	Electrons	Muons
Data	$0.054 \pm 0.015$	$0.046 \pm 0.014$
MC	$0.043 \pm 0.005$	$0.047 \pm 0.005$

Within kinematic range

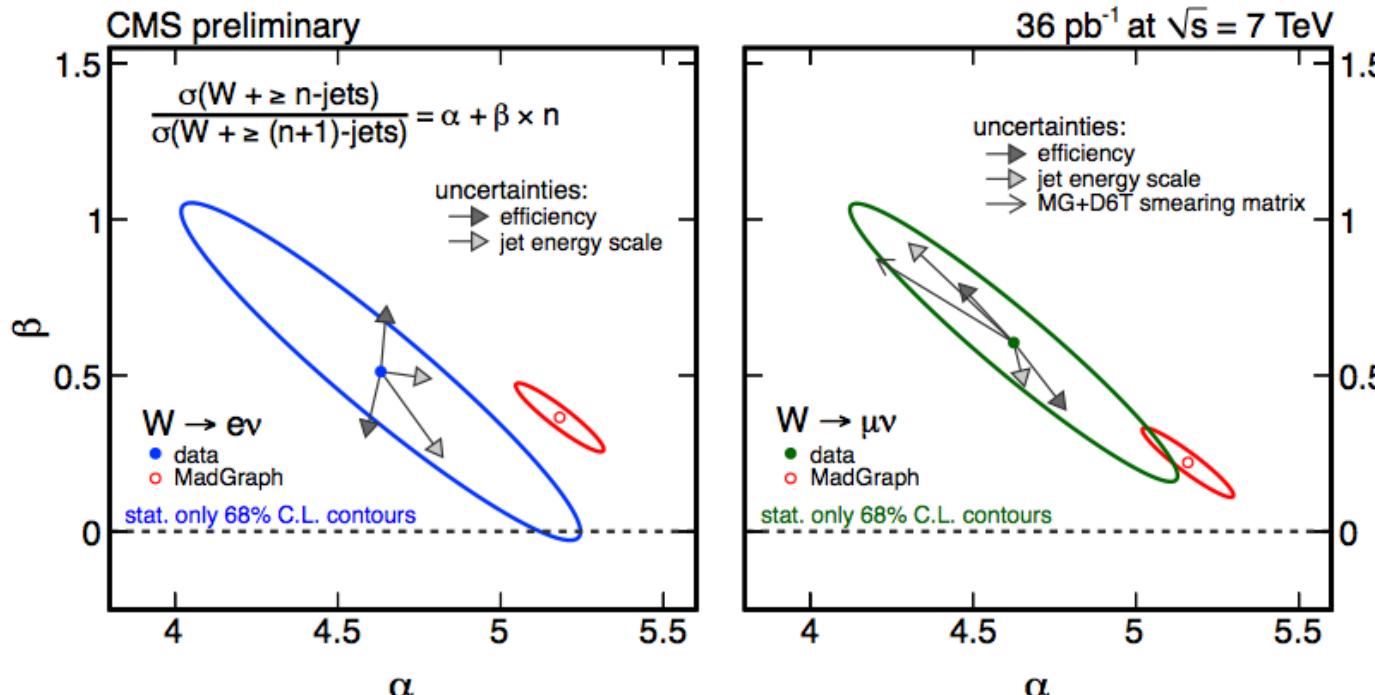
# W/Z+Jets Scaling (Berends-Giele)



$$\frac{\sigma_n}{\sigma_{n+1}} = \alpha + \beta n$$

LO: strong coupling  
 >LO + phase space

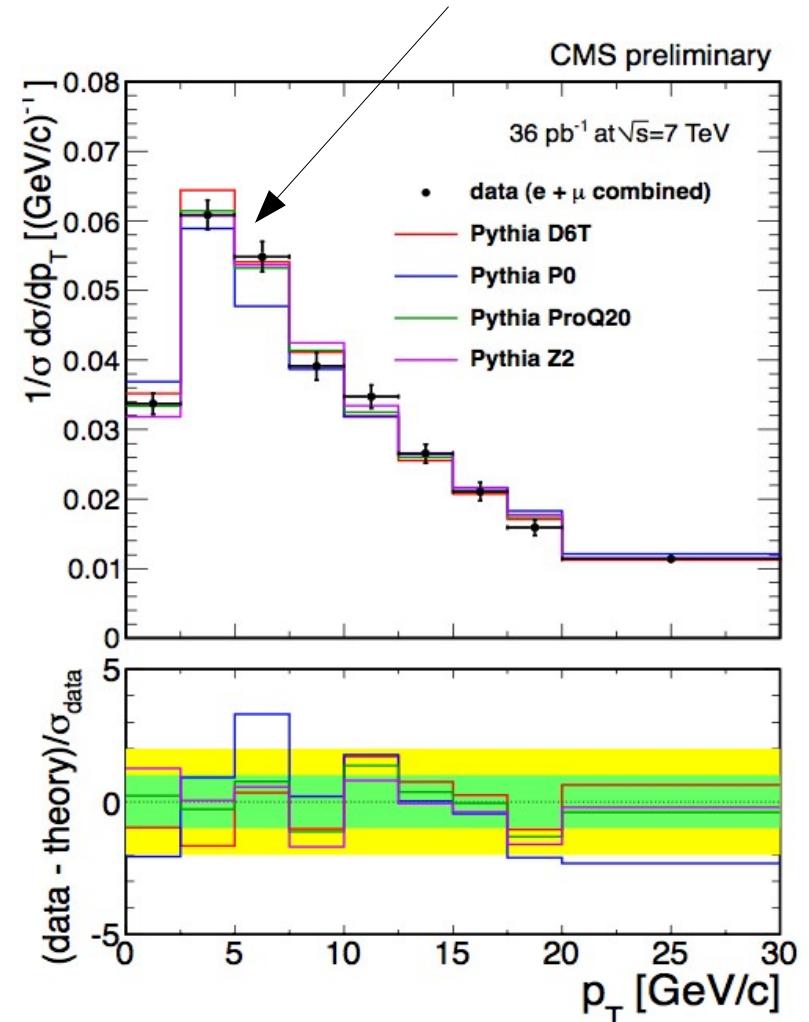
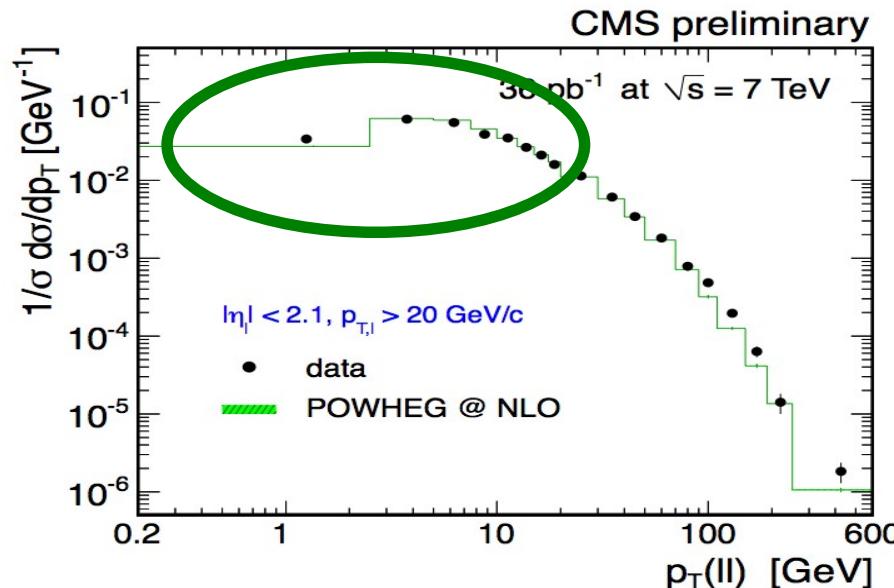
- Fit to number of jets (simultaneous extraction)
  - Sensitive to expected QCD scaling ( $\alpha = \alpha_{\text{strong}}$ )



Lower than MC predicted  
 Still consistent

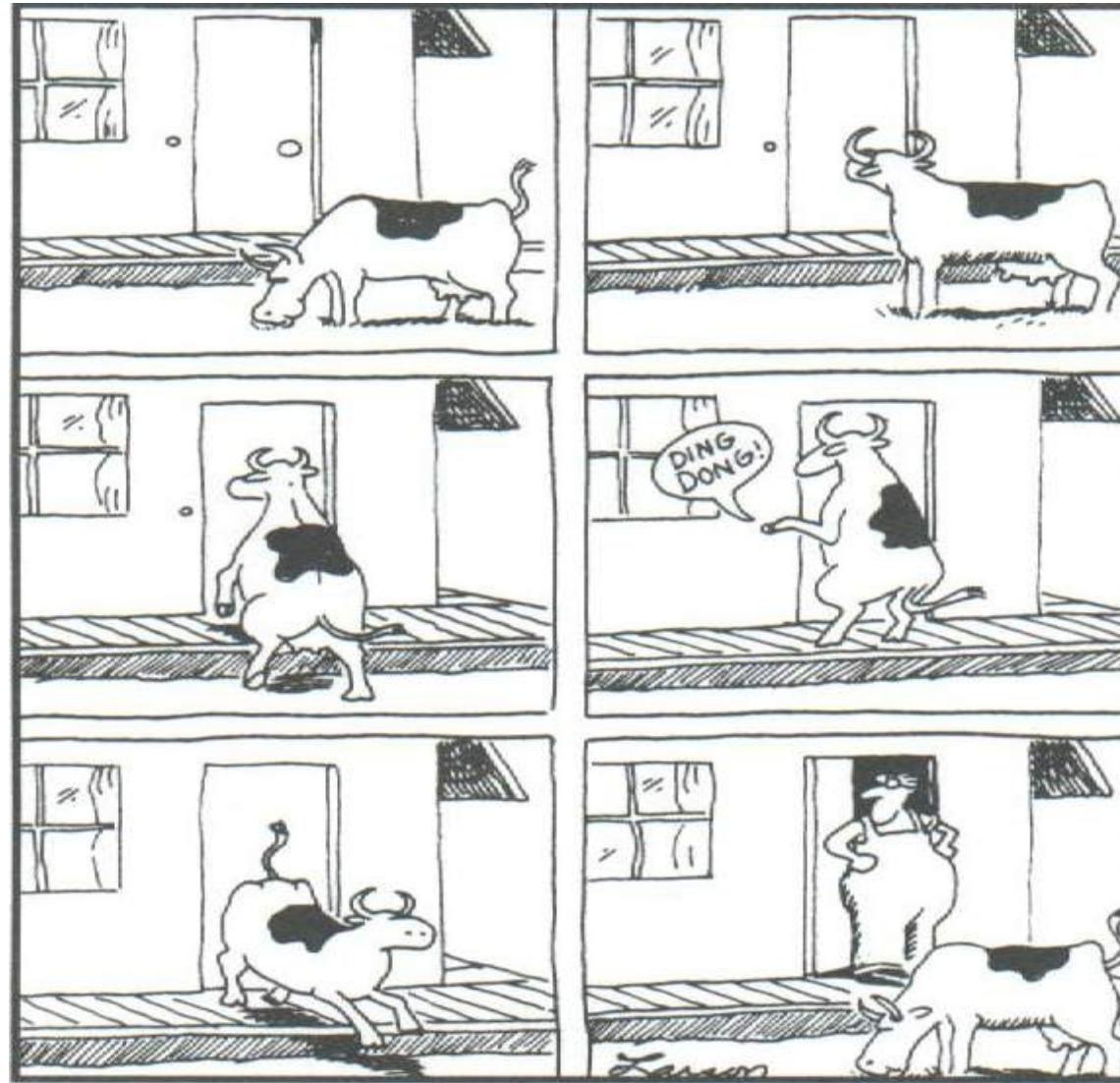
# Low $Z P_T$ Modeling

- At very low  $p_T$  sensitive to non-perturbative effects
  - Modeled empirically (additionally approx w/PS)



Powheg w/D6T tune does not describe data well at low  $p_T$

Various Pythia tunes better



There have been no major surprises in our  
first year of running