

# **Physics of W and Z Bosons at LHC**

Invited mini-review (not an ATLAS/CMS presentation)

APPS, 30.11.2011

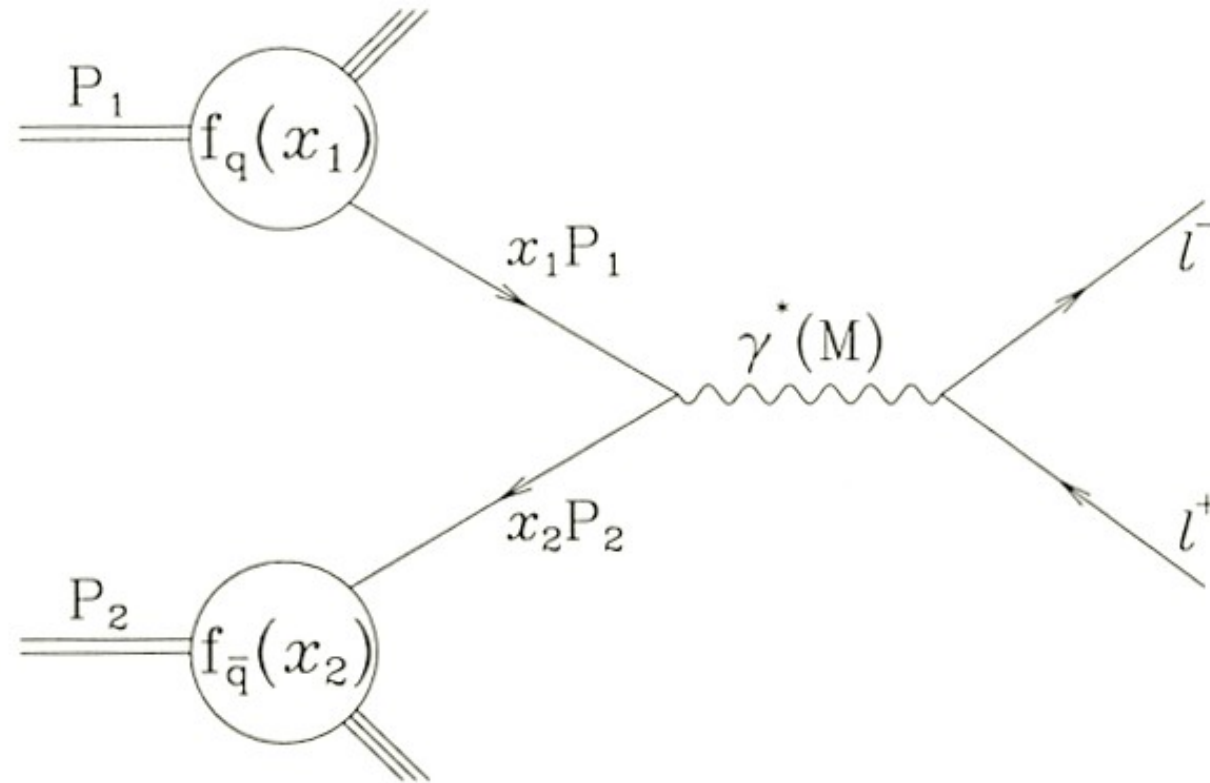
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# Drell-Yan Production

Production of vectorbosons  $\gamma$ ,  $Z$ ,  $W$  in  $pN$ ,  $p\bar{p}$  or  $pp$  collisions with leptons in final state. Quark + Antiquark of  $p$  from universal partondensities  $f_a(x)$ ,  $a=q,\bar{q}$ , from DIS. Factorisation :



Ellis, Stirling, Webber 1996

$$\sigma = \sum_q \int f_q(x_1, Q^2) f_{\bar{q}}(x_2, Q^2) \sigma(q\bar{q} \rightarrow l\bar{l}) dx_1 dx_2$$

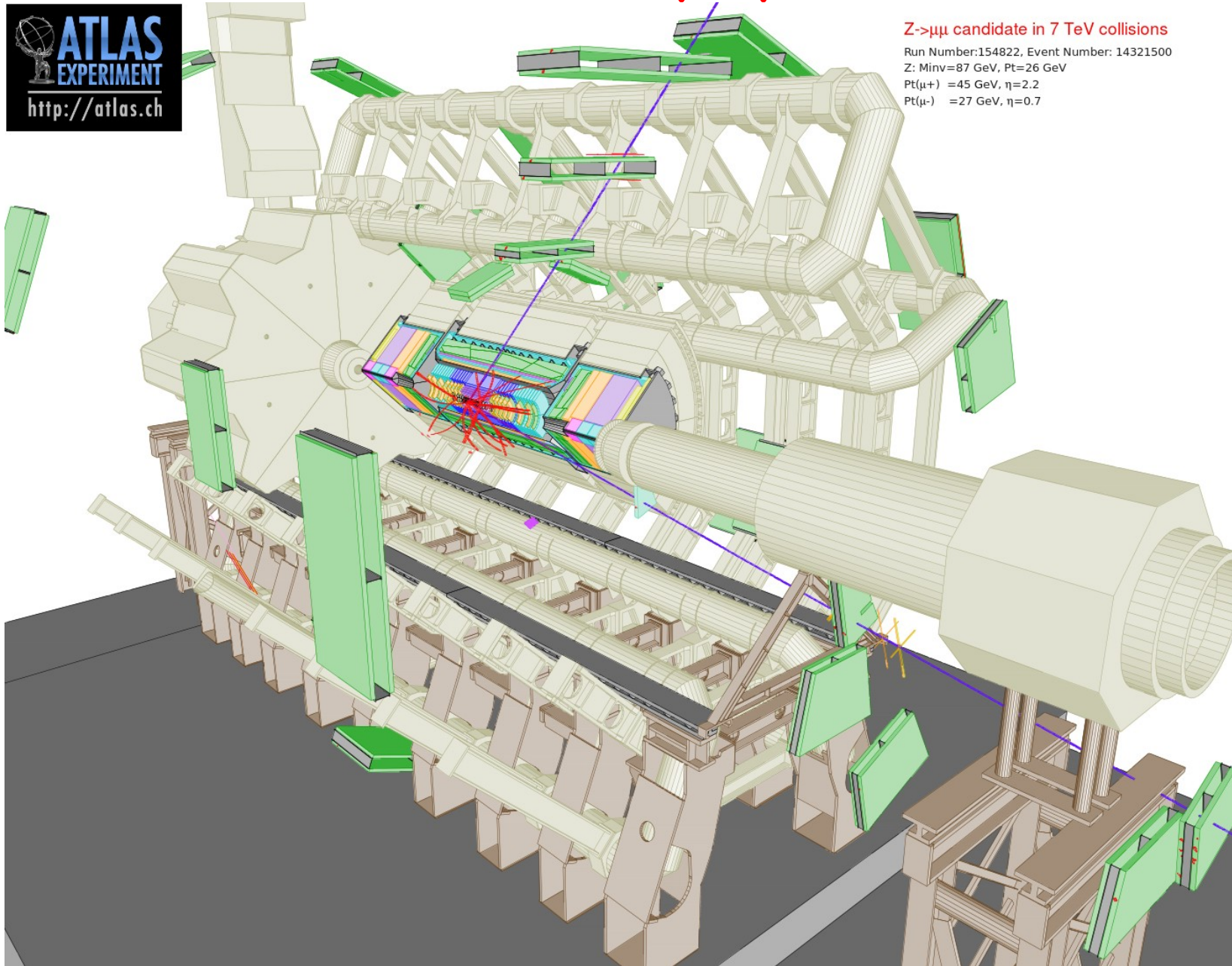
$$\sigma(q\bar{q} \rightarrow l\bar{l}) = 4\pi\alpha^2 e_q^2 / (3s) 1/N$$

$N = \# \text{ colours}$

$$s = (p_1 + p_2)^2 = Q^2 = m_{l\bar{l}}^2$$

$$\mathbf{x}_{1,2} = (s/s_{pp})^{1/2} e^{\pm y_{l\bar{l}}}$$

# ATLAS $Z \rightarrow \mu^+\mu^-$ Event



Z  $\rightarrow \mu\mu$  candidate in 7 TeV collisions

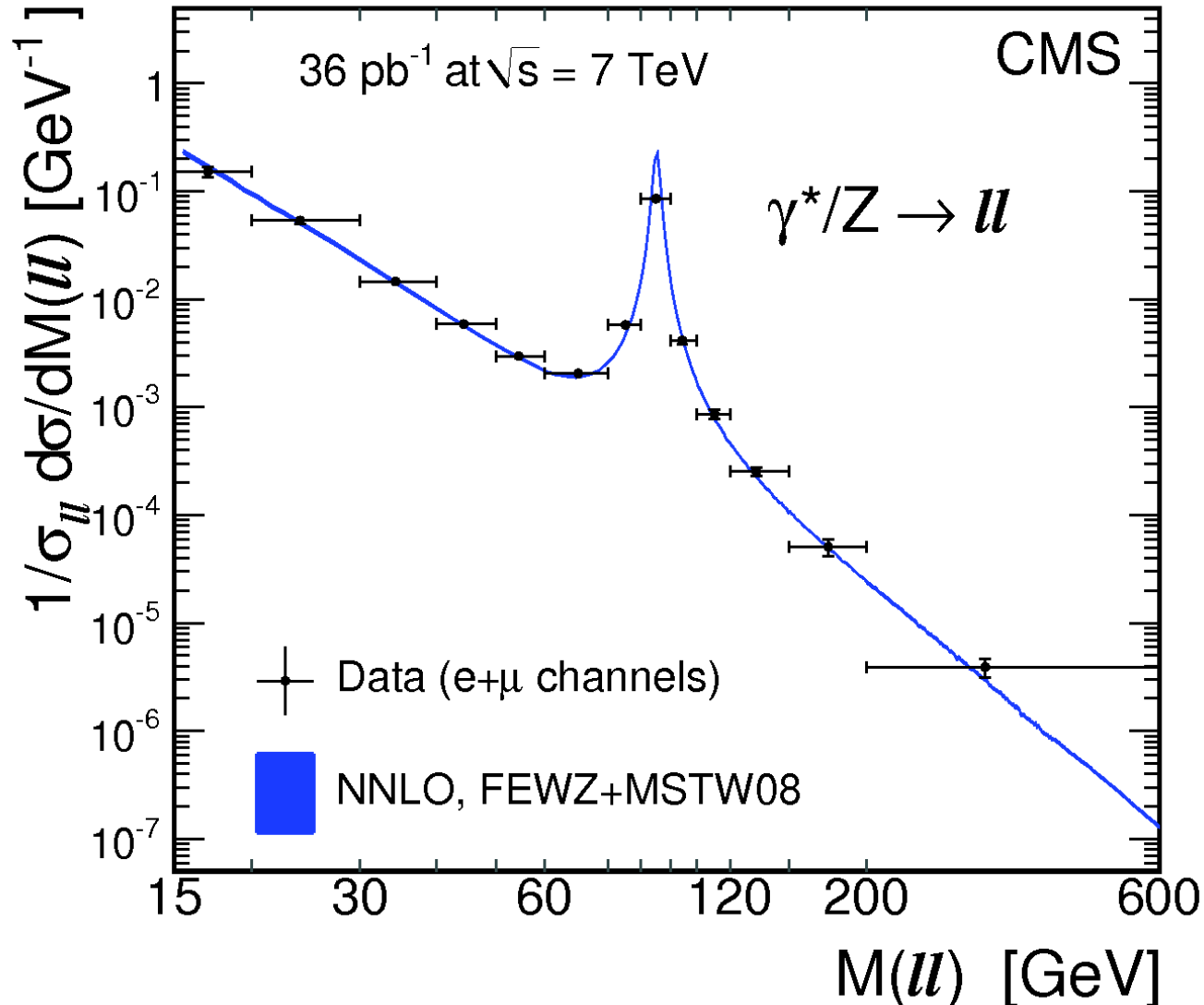
Run Number:154822, Event Number: 14321500

Z: Minv=87 GeV, Pt=26 GeV

Pt( $\mu^+$ ) =45 GeV,  $\eta=2.2$

Pt( $\mu^-$ ) =27 GeV,  $\eta=0.7$

# Drell-Yan spectrum



2010 data, e and  $\mu$  pairs

$0.0003 < x < 0.633$

Norm. to Z peak

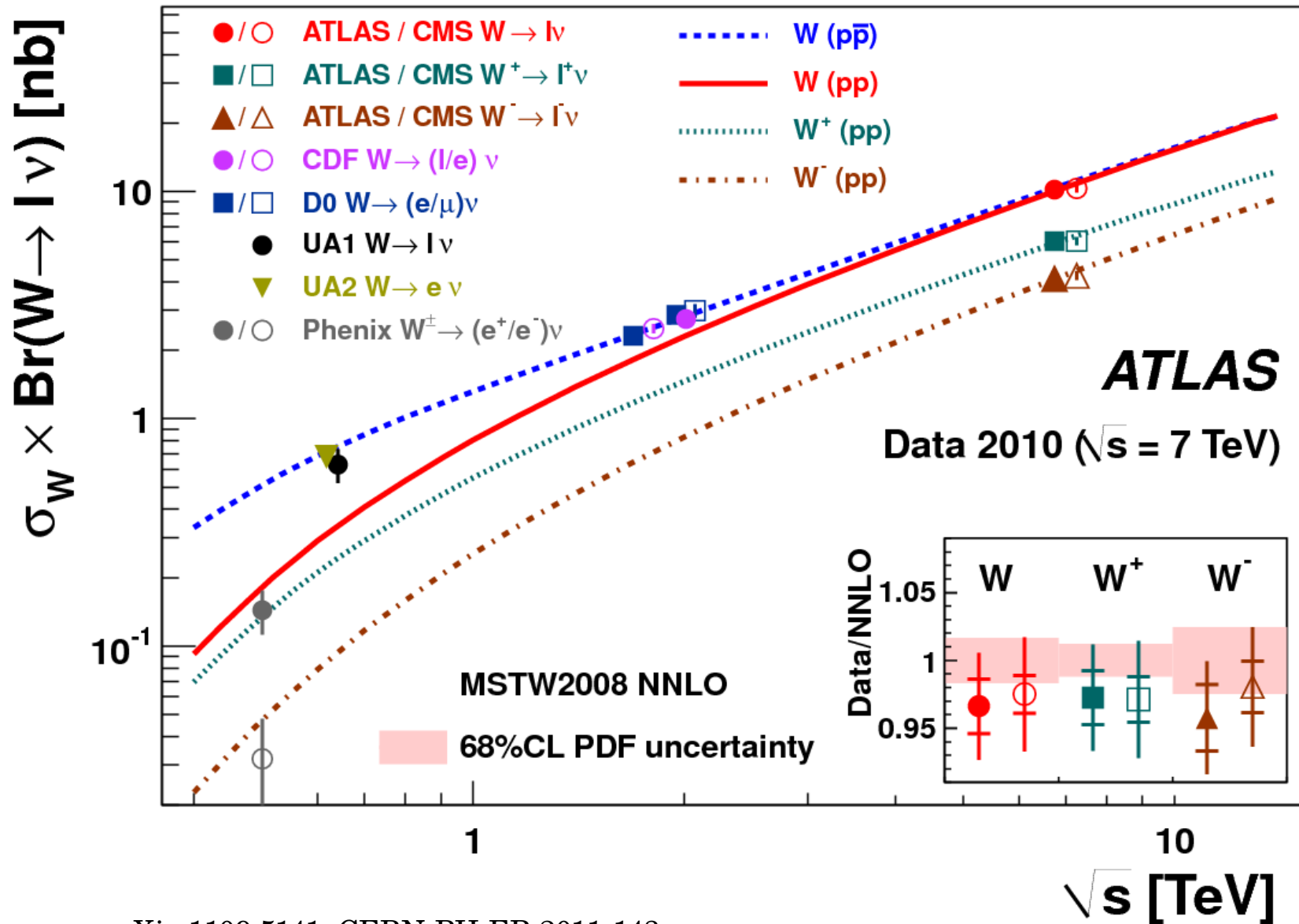
Unfolded using MC response matrix

NNLO with FEWZ or DYNNLO

# Probing pQCD with W/Z

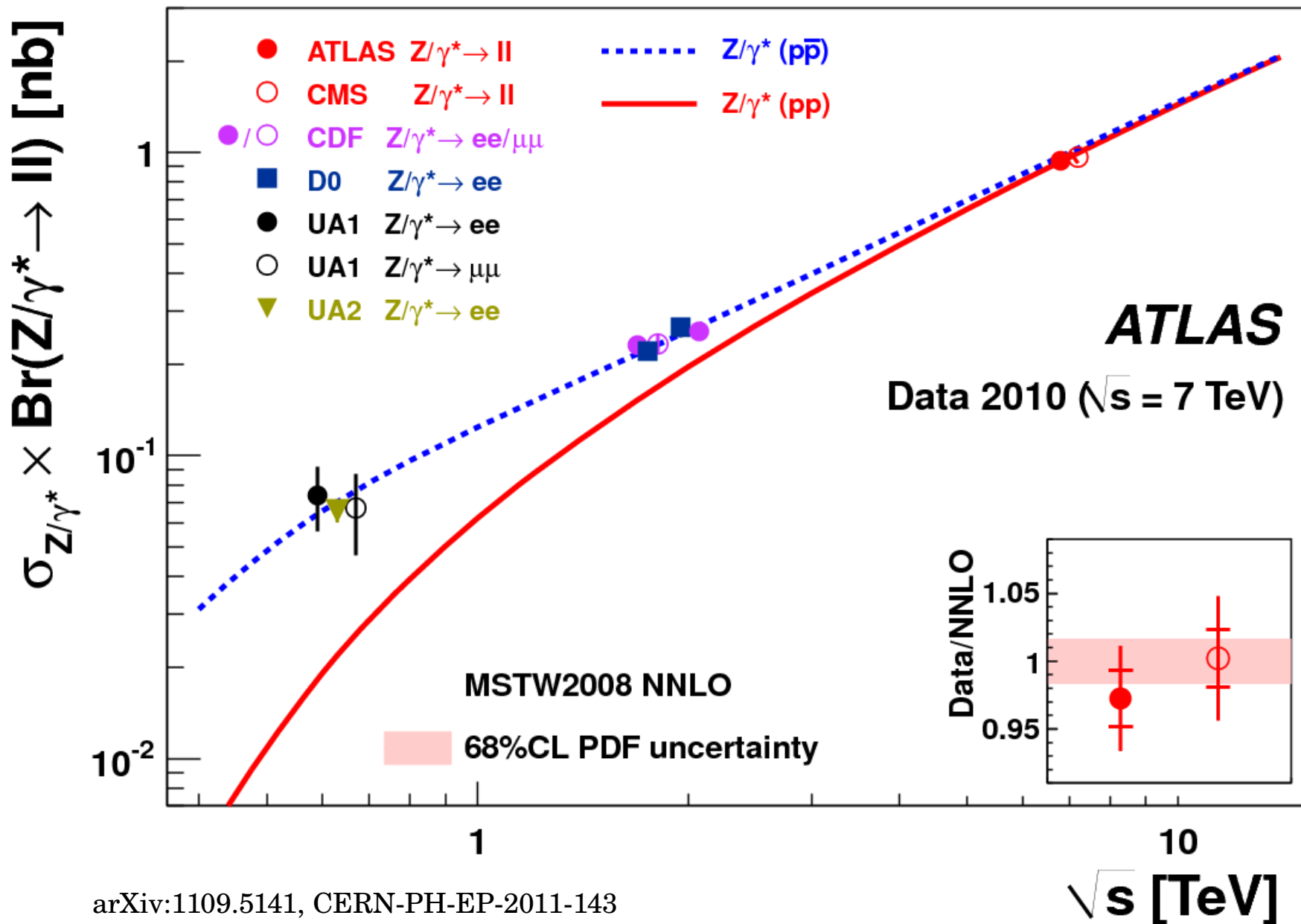
- Total cross sections
- Differential cross sections
- W/Z + jets
- Relation to  $e^+e^-$

# $W^\pm$ total cross sections



arXiv:1109.5141, CERN-PH-EP-2011-143

# Z total cross section



arXiv:1109.5141, CERN-PH-EP-2011-143

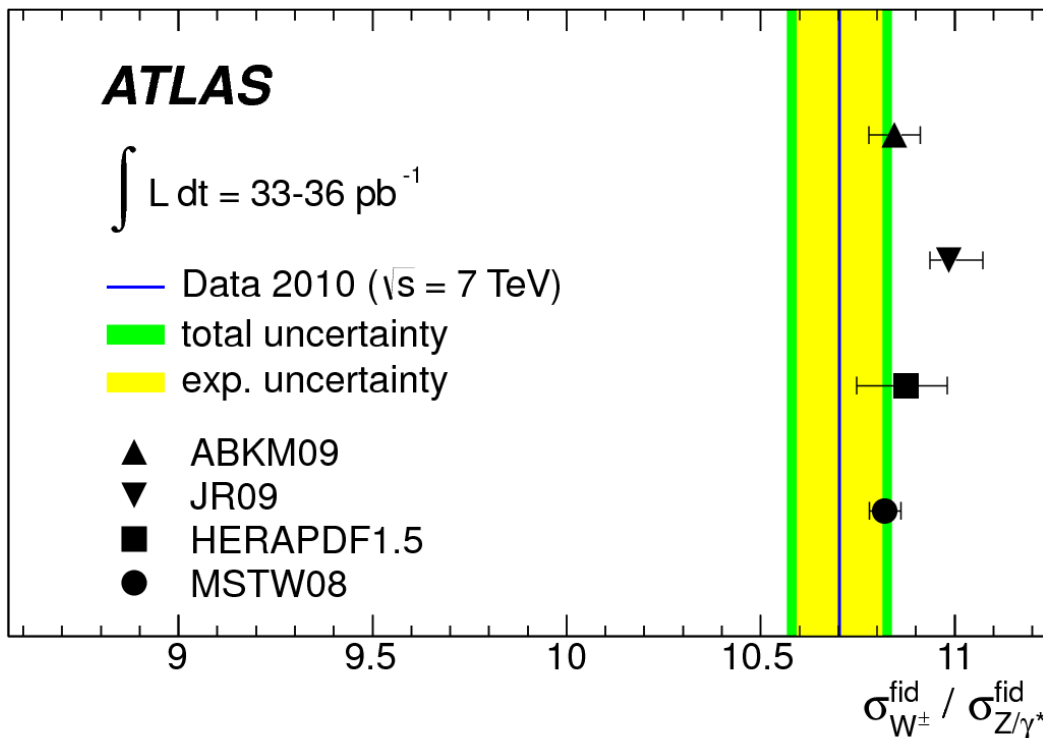


# Cross section ratios

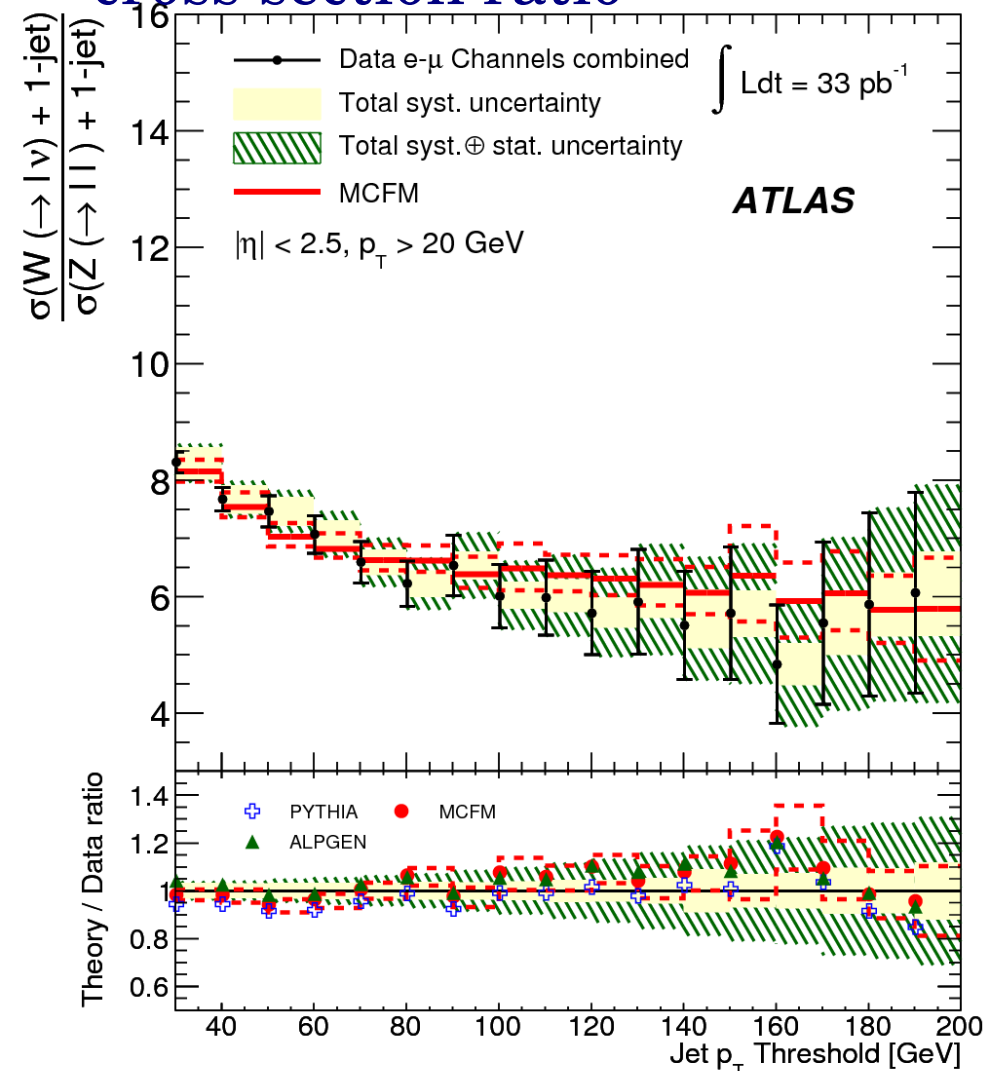
W/Z + 1 jet (anti- $k_t$  (R=0.4))

cross section ratio

W/Z cross section ratio  
Precision measurement  
Constrains PDFs



arXiv:1109.5141, CERN-PH-EP-2011-143

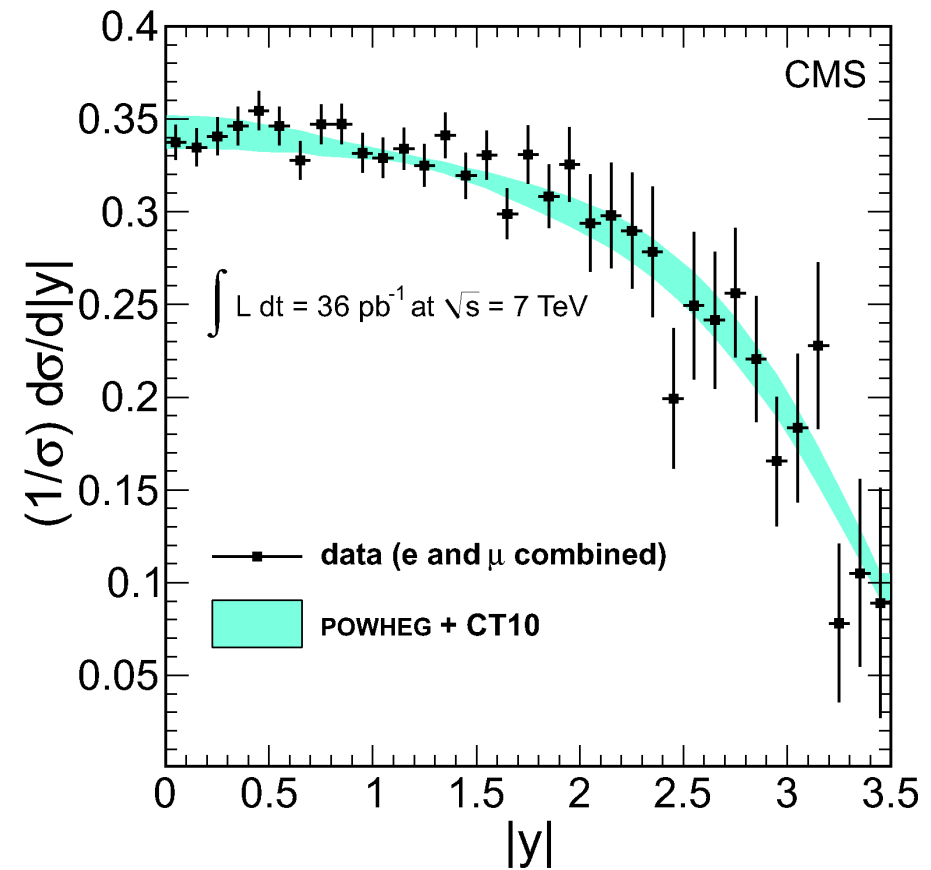
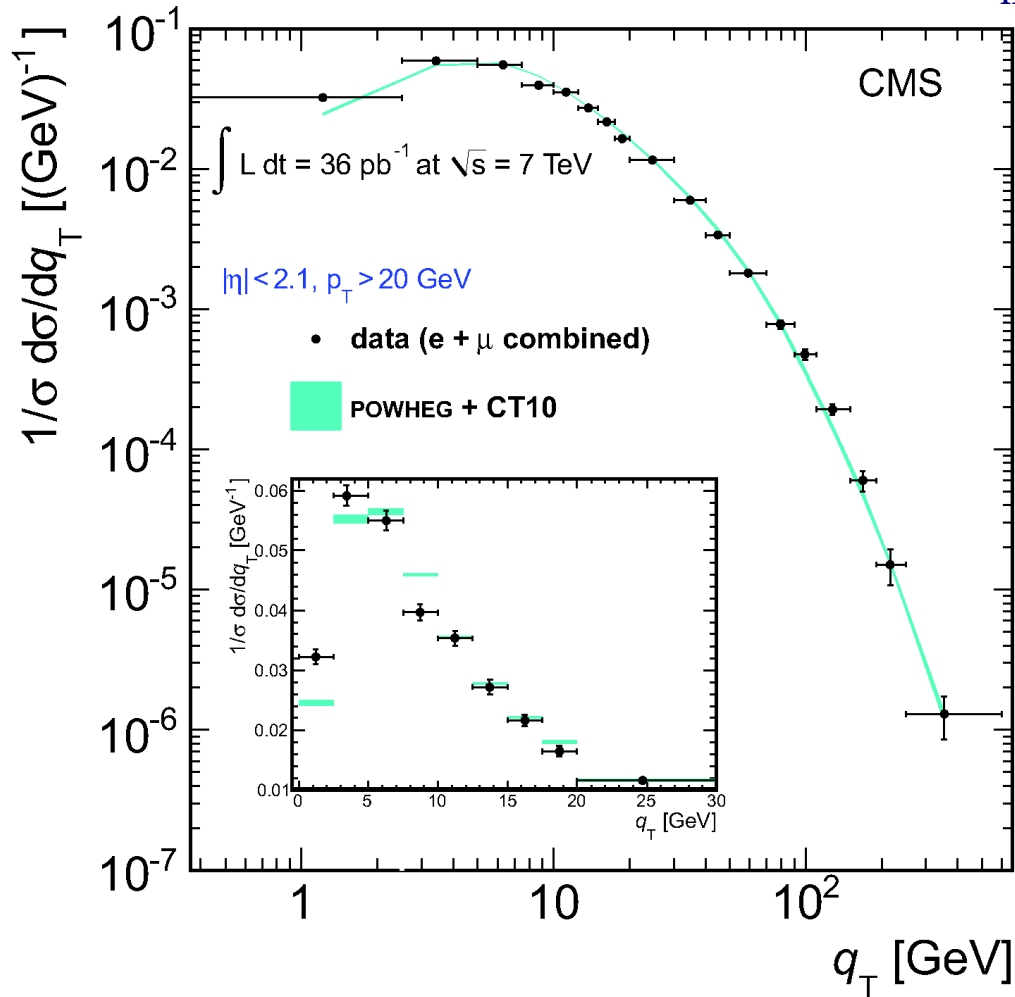


arXiv:1108.4908, CERN-PH-EP-2011-126



# Z differential cross sections

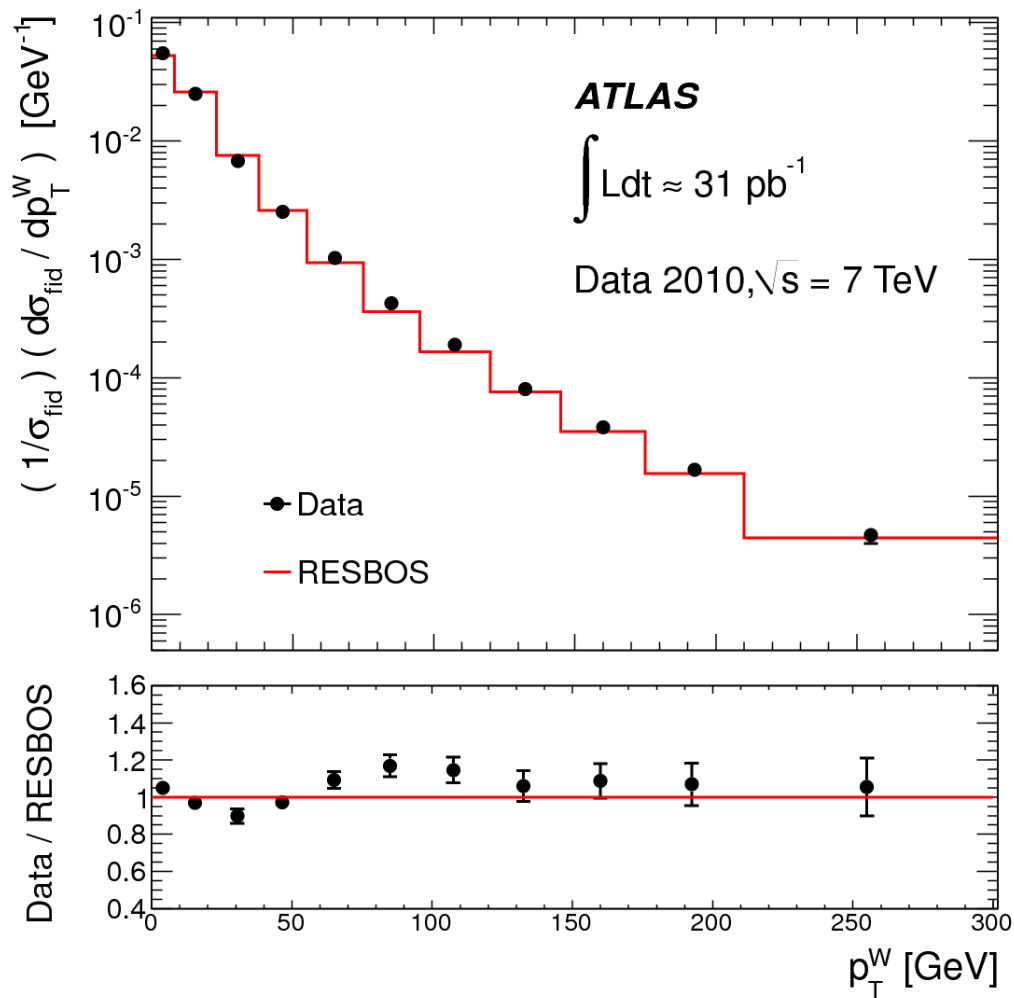
$60 \text{ GeV} < m_{ll} < 120 \text{ GeV}$



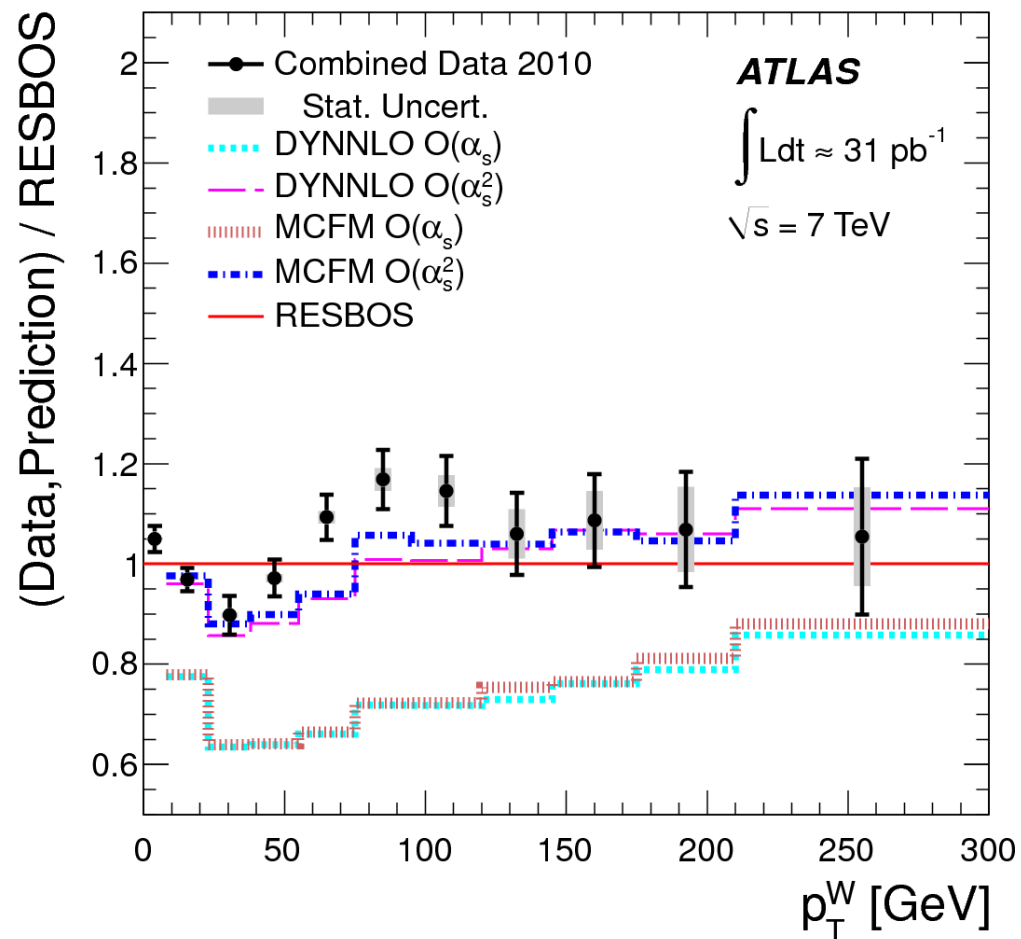
NLO POWHEG reasonable,  
MCs problems at low  $q_t$

arXiv:1110.4973, CERN-PH-EP-2011-169

# W differential cross sections



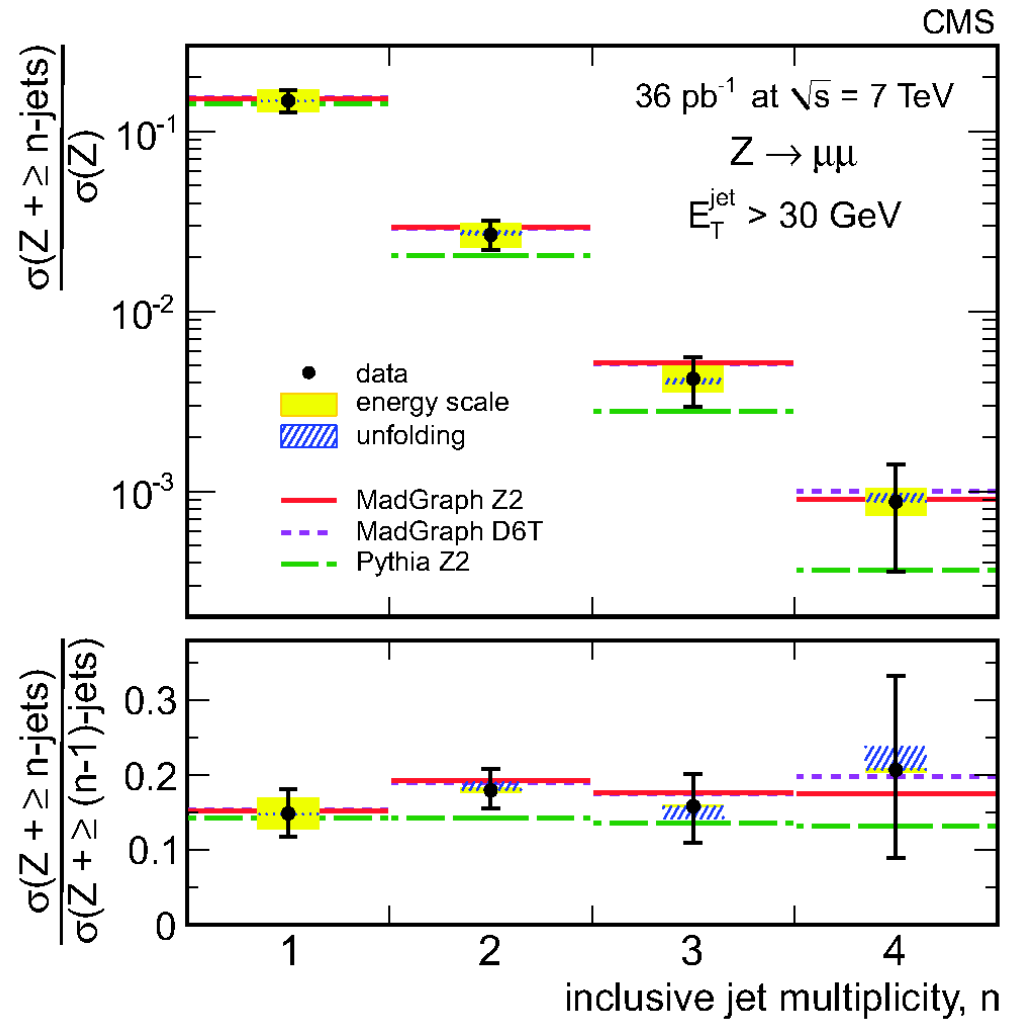
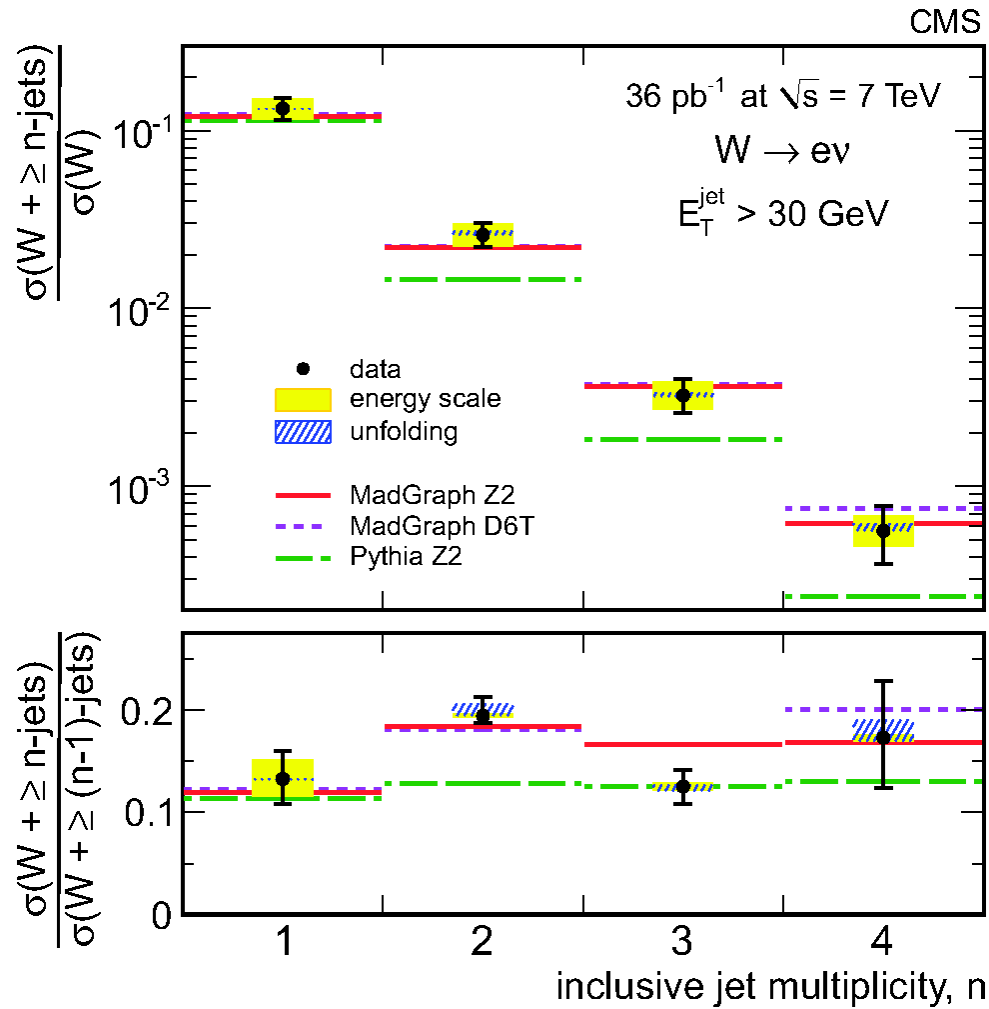
$p_t^1 > 20 \text{ GeV}, E_t^{\text{miss}} > 25 \text{ GeV},$   
 $m_t > 40 \text{ GeV}$



arXiv:1108.6308, CERN-PH-EP-2011-134

# W/Z + jets

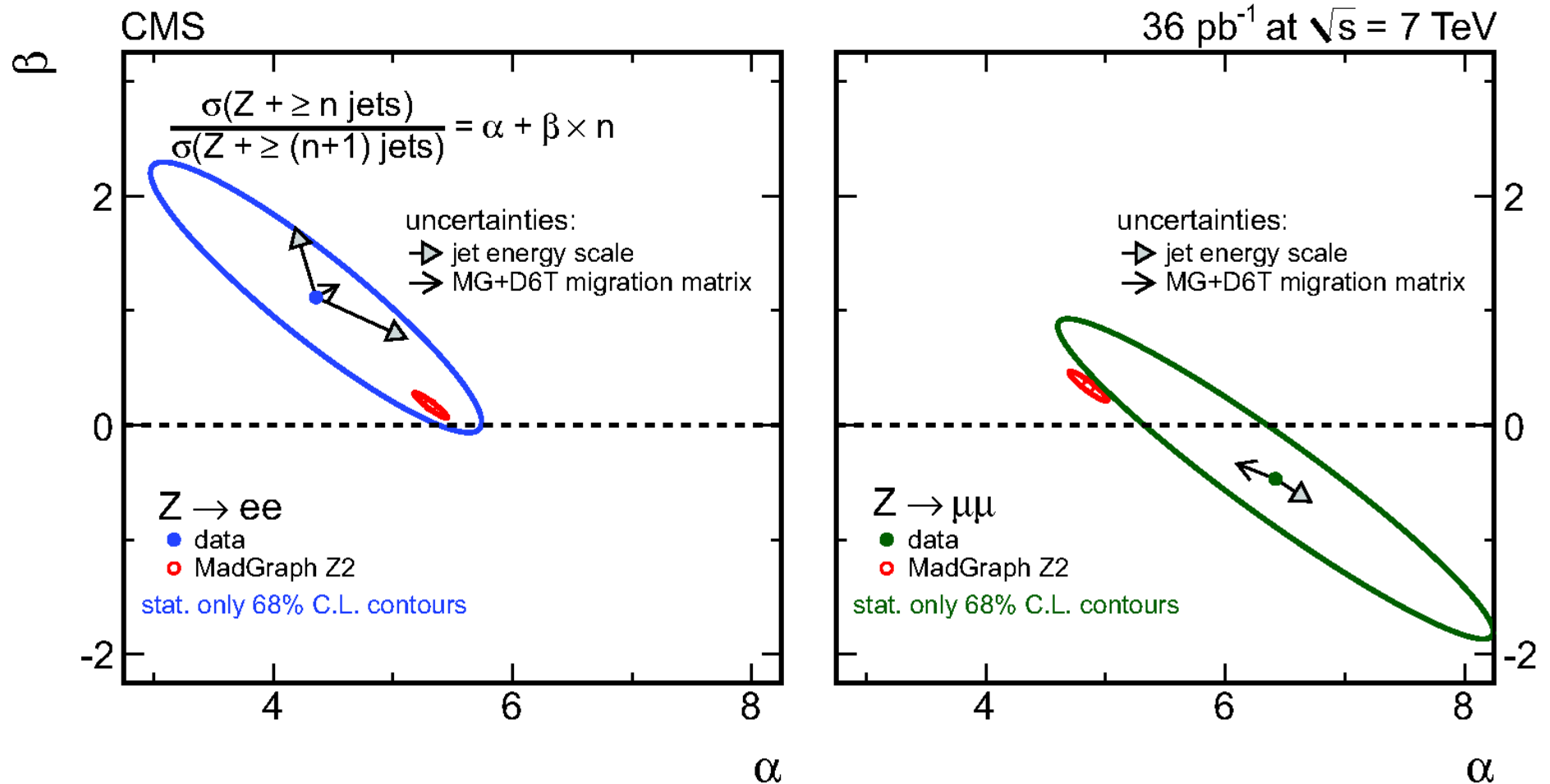
$p_t^1 > 20$  GeV, anti- $k_t$  (R=0.5) jets  $E_T > 30$  GeV



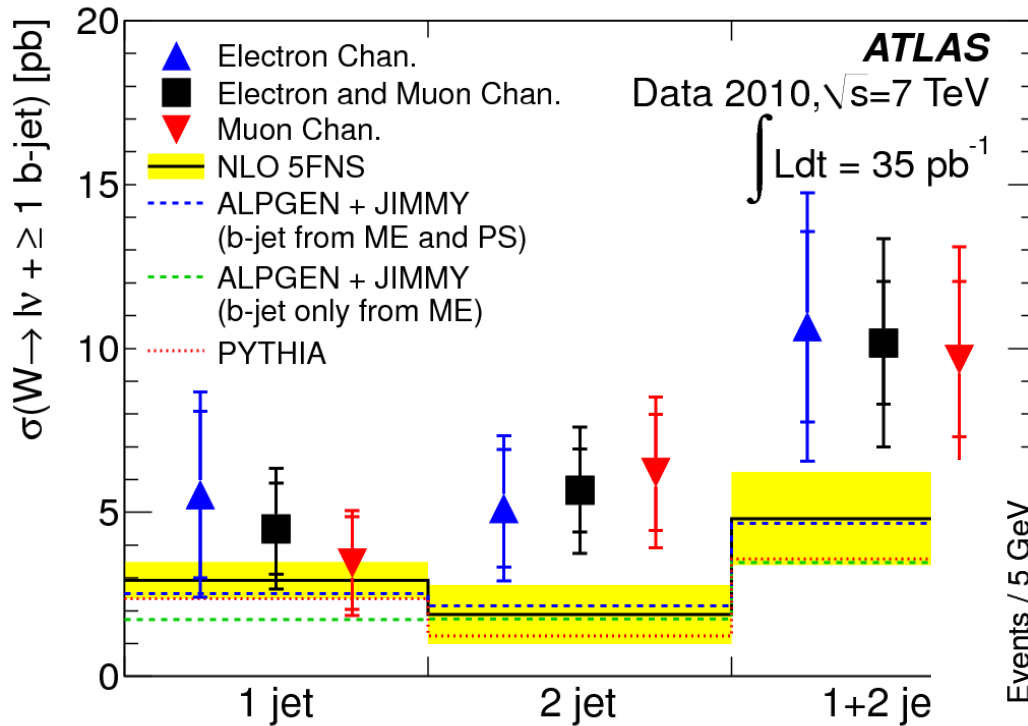
arXiv:1110.3226, CERN-PH-EP-2011-125

# Berends-Gele (Staircase) scaling

Ratios of n and n+1 jet rates in Z events expected to scale



# W/Z + b-jets



Z + b-jet:

$p_t^1 > 20 \text{ GeV}$ , anti- $k_t$  (R=0.4) jet

$E_t > 25 \text{ GeV} + \text{b-tag}$

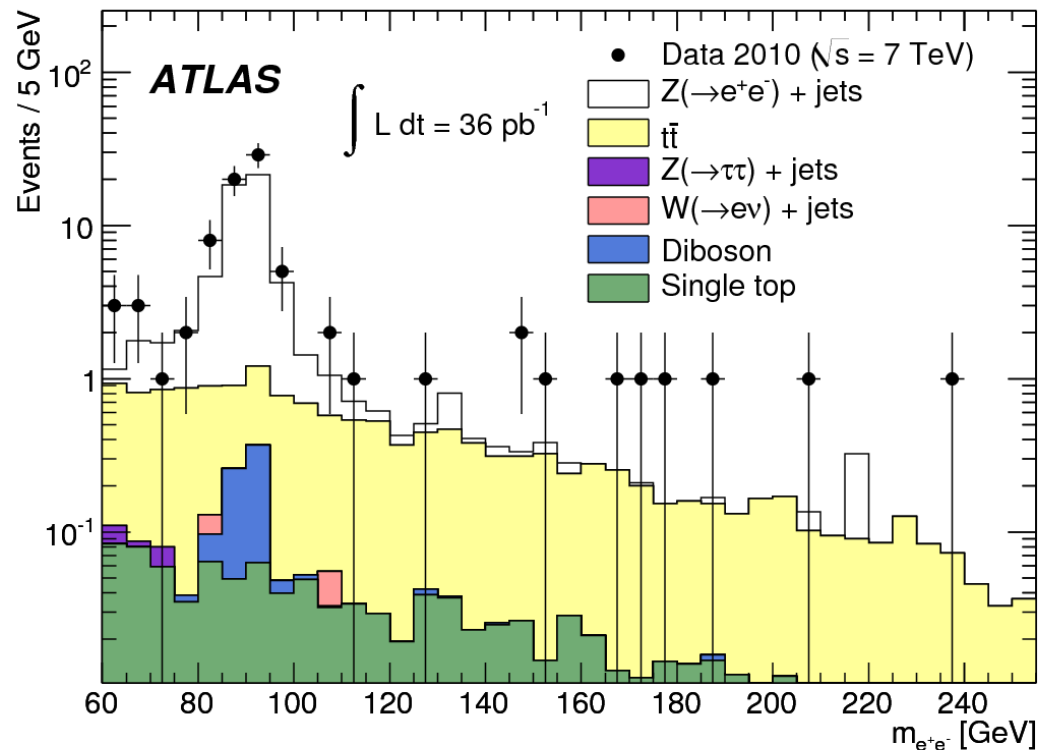
W + b-jet:

as for Z+b-jet, plus

$E_t^{\text{miss}} > 25 \text{ GeV}$ ,  $m_t > 40 \text{ GeV}$

arXiv:1109.1470, CERN-PH-EP-2011-132;

arXiv:1109.1403, CERN-PH-EP-2011-133



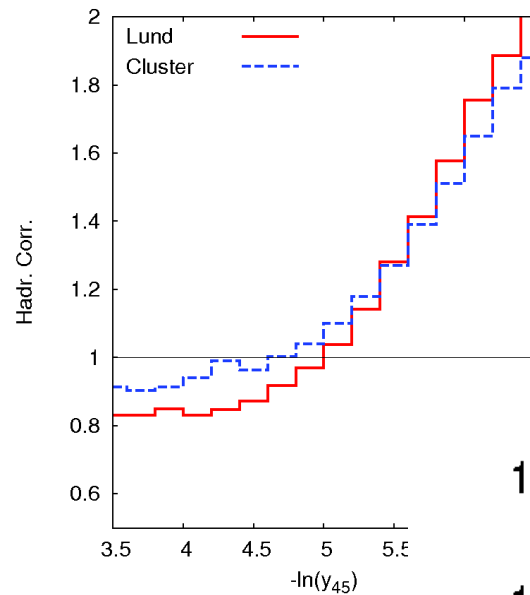
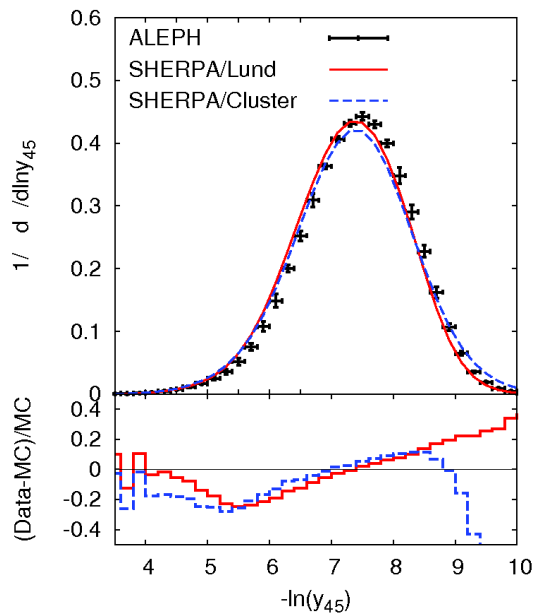
# 5-jet rate in $e^+e^-$ annihilation

Durham ( $k_t$ ) jets

Had. Corrections from LL/LO

MCs problematic  $\rightarrow$  use SHERPA

Extra cross check on theory

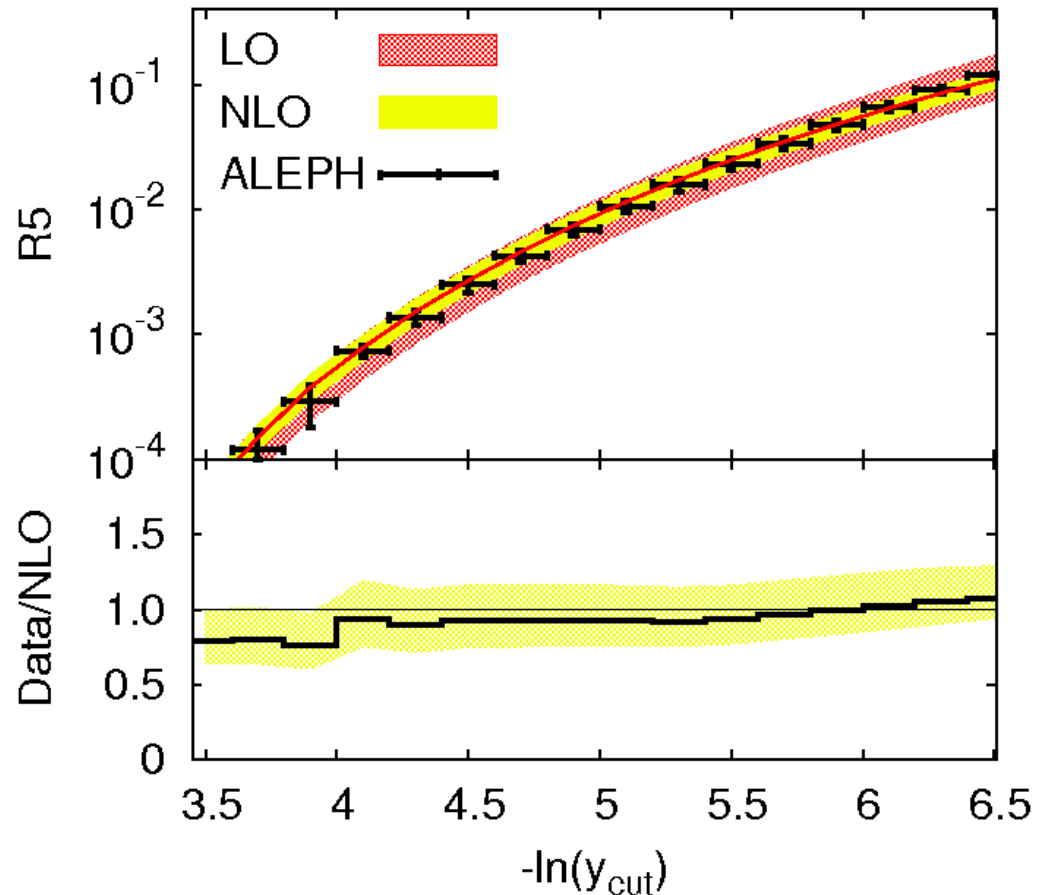


NLO Analysis of LEP 1 and 2

$R_5$  and  $y_{45}$ :

$$1/\sigma d\sigma/dy_{45} = C_{45} \frac{\alpha_S^3}{S} + D_{45} \frac{\alpha_S^4}{S}$$

$$\alpha_S(m_Z) = 0.1156 \pm 0.0038$$



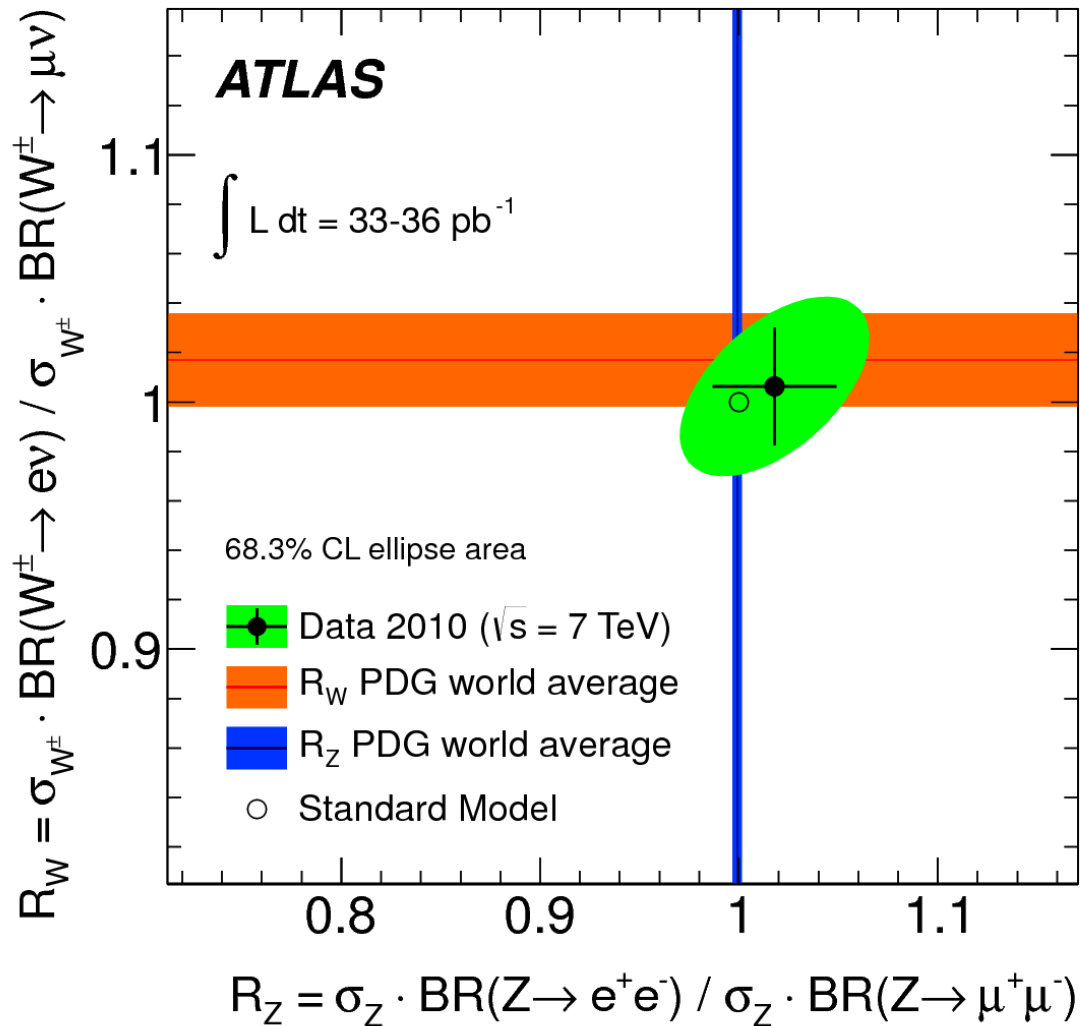
Frederix et al., JHEP 11 (2010) 050

# Electroweak tests

- Lepton universality in W and Z decays
- WW, WZ and ZZ production



# Lepton universality



Lepton universality  
(e and  $\mu$ ) in W and Z  
decays

LEP & Tevatron still  
unbeaten

arXiv:1109.5141, CERN-PH-EP-2011-143

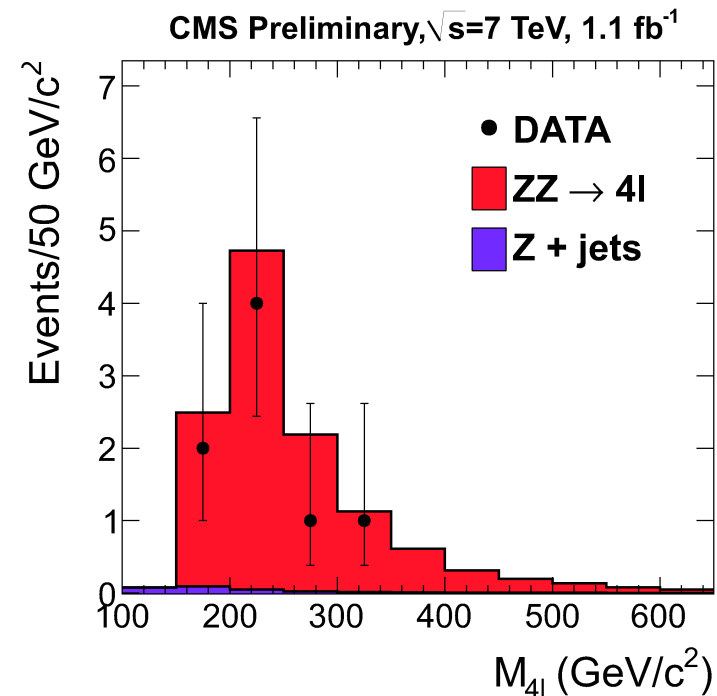
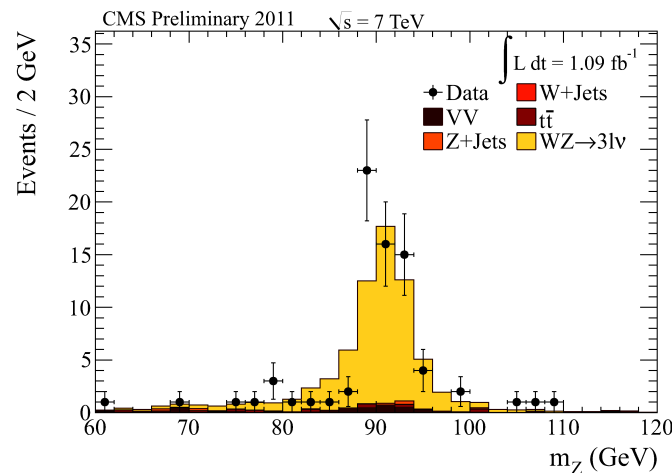
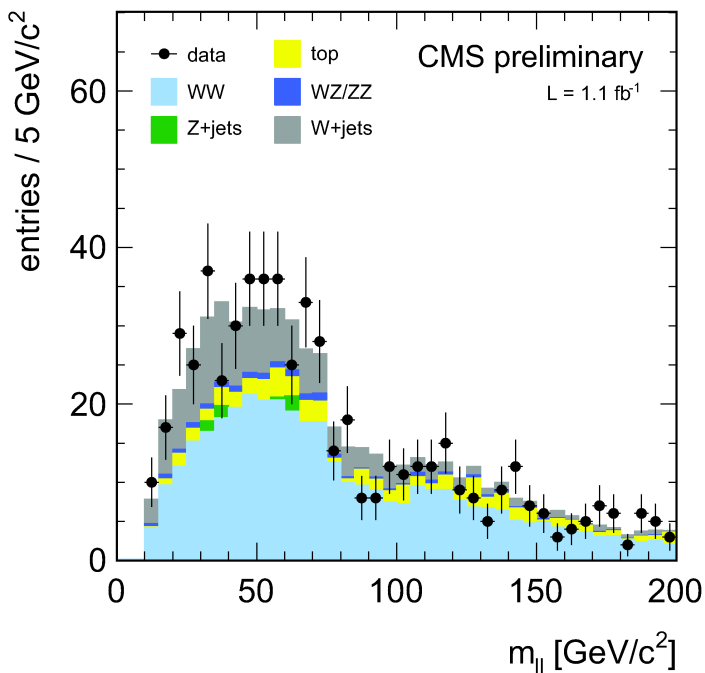
# WW, WZ, ZZ production

Tests of SM, important background to searches,  
limits on SM extensions

WW (ll)

WZ (ll'')

ZZ (ll'')



CMS-PAS-EWK-11-010

# Soft QCD Physics

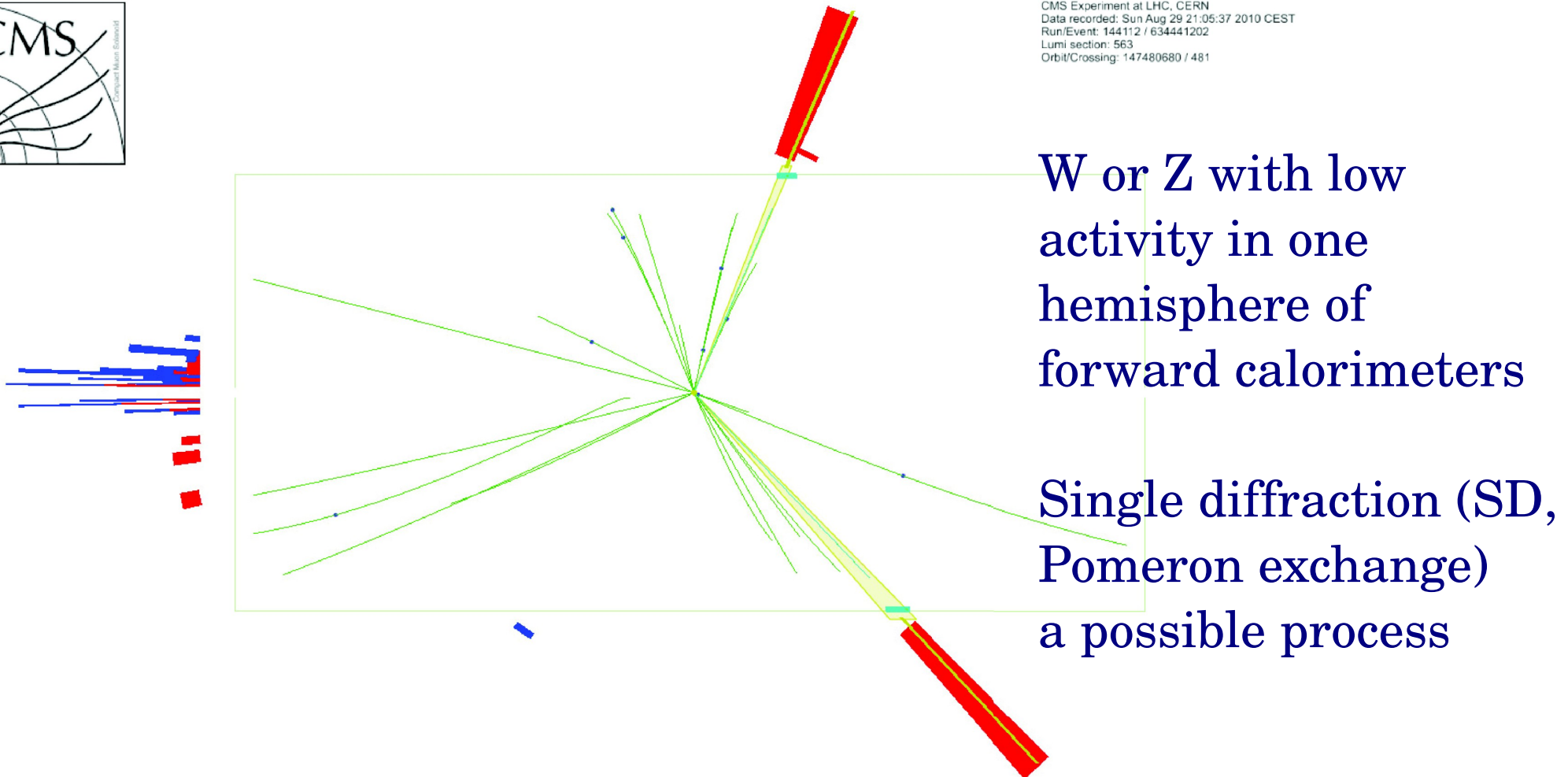
- W/Z events with rapidity gaps
- Associated charm in W events

# Rapidity gaps in W/Z events

Z  $\rightarrow$  e e



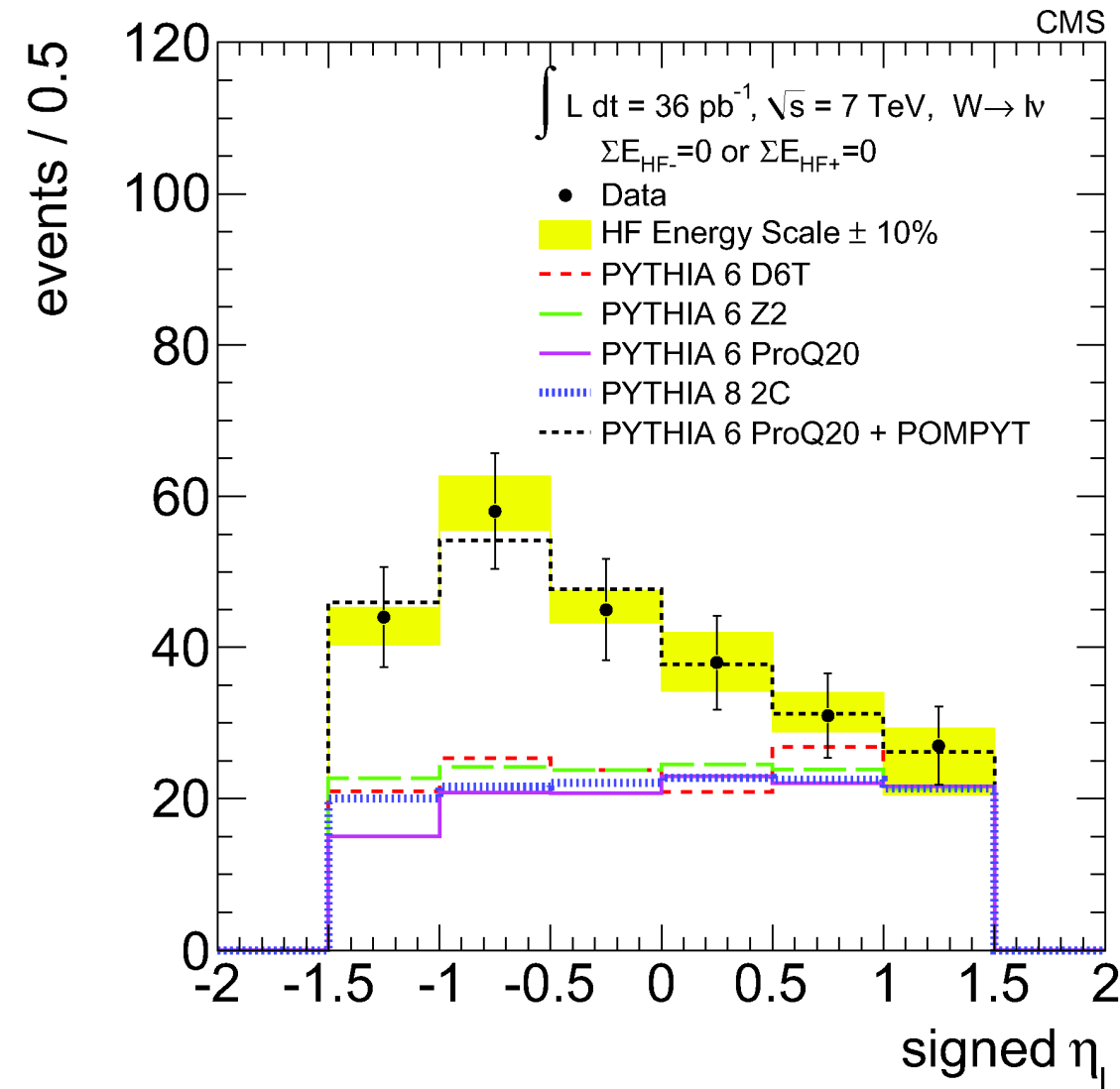
CMS Experiment at LHC, CERN  
Data recorded: Sun Aug 29 21:05:37 2010 CEST  
Run/Event: 144112 / 634441202  
Lumi section: 563  
Orbit/Crossing: 147480680 / 481



W or Z with low activity in one hemisphere of forward calorimeters

Single diffraction (SD, Pomeron exchange) a possible process

# Rapidity gaps in W/Z events



Rapidity sign

+: l and LRG same hemisphere

-: l and LRG opp. hemisphere

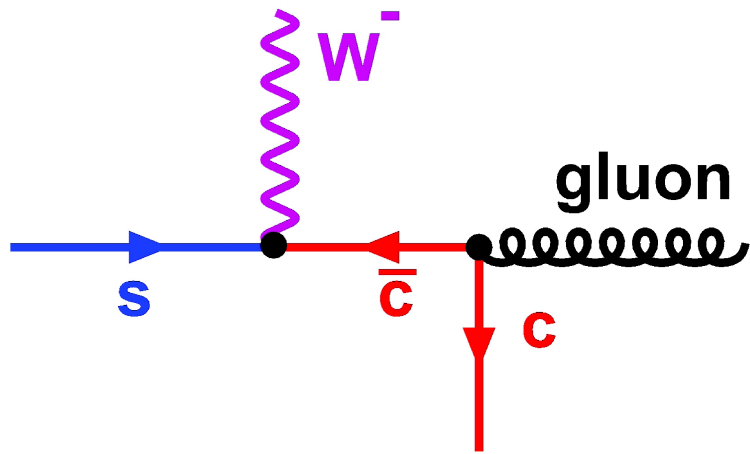
POMPYT: SD simulation

PYTHIA: standard interactions

Clear indication for SD events,  
about  $50 \pm 11\%$

arXiv:1110.0181, CERN-PH-EP-2011-141

# Associated charm in W events



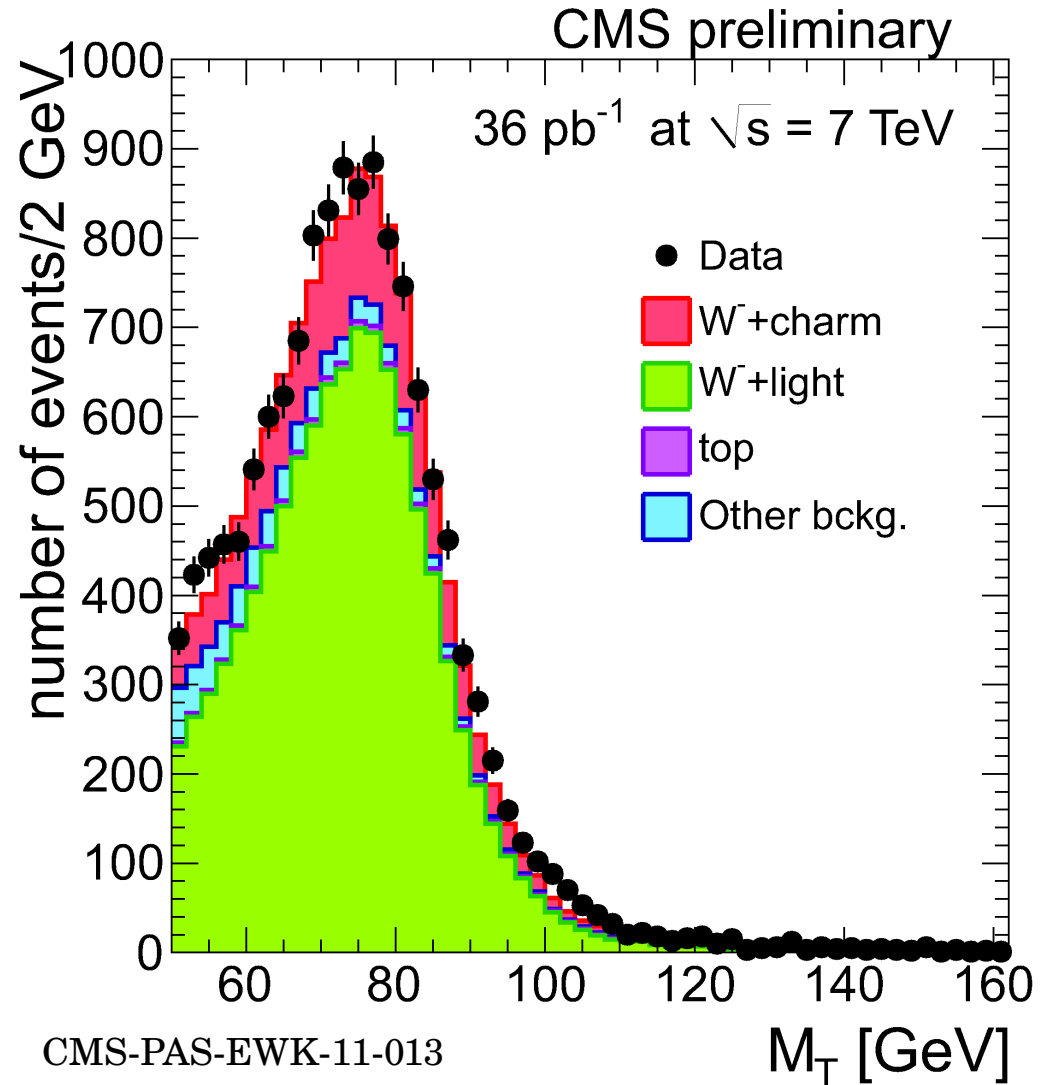
Probes s-quarks pdfs at high momentum transfer

$$p_t^l > 25 \text{ GeV}, |\eta| < 2.1$$

anti-kt(R=0.5) jets, at least one

$$p_t^{\text{jet}} > 20 \text{ GeV}, |\eta| < 2.1$$

Lifetime tagging to enhance c



$$R_c^\pm = 0.92 \pm 0.19 \pm 0.04$$

$$R_c = 0.143 \pm 0.015 \pm 0.024$$

# Summary

- Very rich physics with W and Z at LHC
- Searches not covered
- Mainly probing QCD at EW scale
  - QCD (NLO or NNLO) extremely successful
  - MCs have (known) problems
- EW tests possible
  - LEP+Tevatron still rule
- Studies of soft QCD with W and Z
  - Constrain diffraction models, PDFs, etc