Fermilab

Electroweak measurements from *W*, *Z* and photon final states

Hang Yin

Fermi National Accelerator Laboratory

Physics in Collisions 2013,

Beijing

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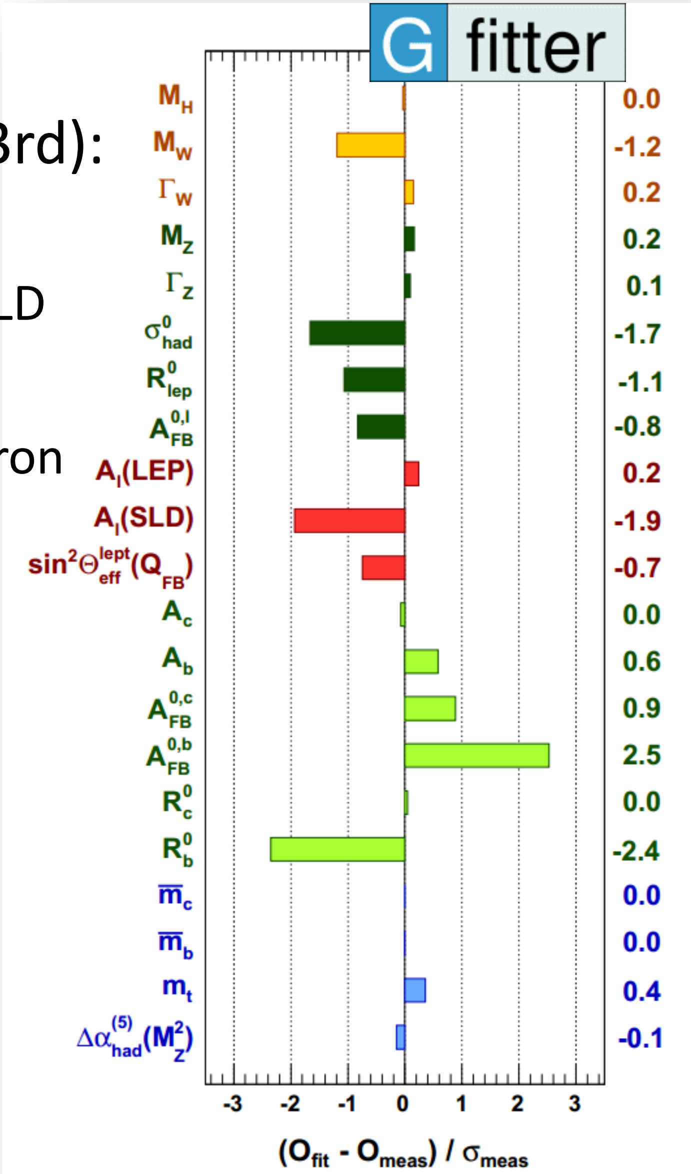
Global electroweak fit

- ✓ Latest version of Gfitter results (May 13rd):
  - ➢ Latest theory calculations
  - ➢ Legacy precision measurement from LEP/SLD
  - ➢ With latest world average *W* boson mass
  - ➢ Direct top mass measurements from Tevatron
  - ➢ Higgs boson mass from LHC
  - ➢ ………
- ✓ Pull values for different observables:
  - ➢ No value exceeds **2.5 σ**
  - ➢ Largest deviation from the FB asymmetry
  - ➢ Good agreement between standard model prediction and data
  - ➢ SLD A_{FB}^{LR} vs. LEP A_{FB}^{b}: **> 3 σ**



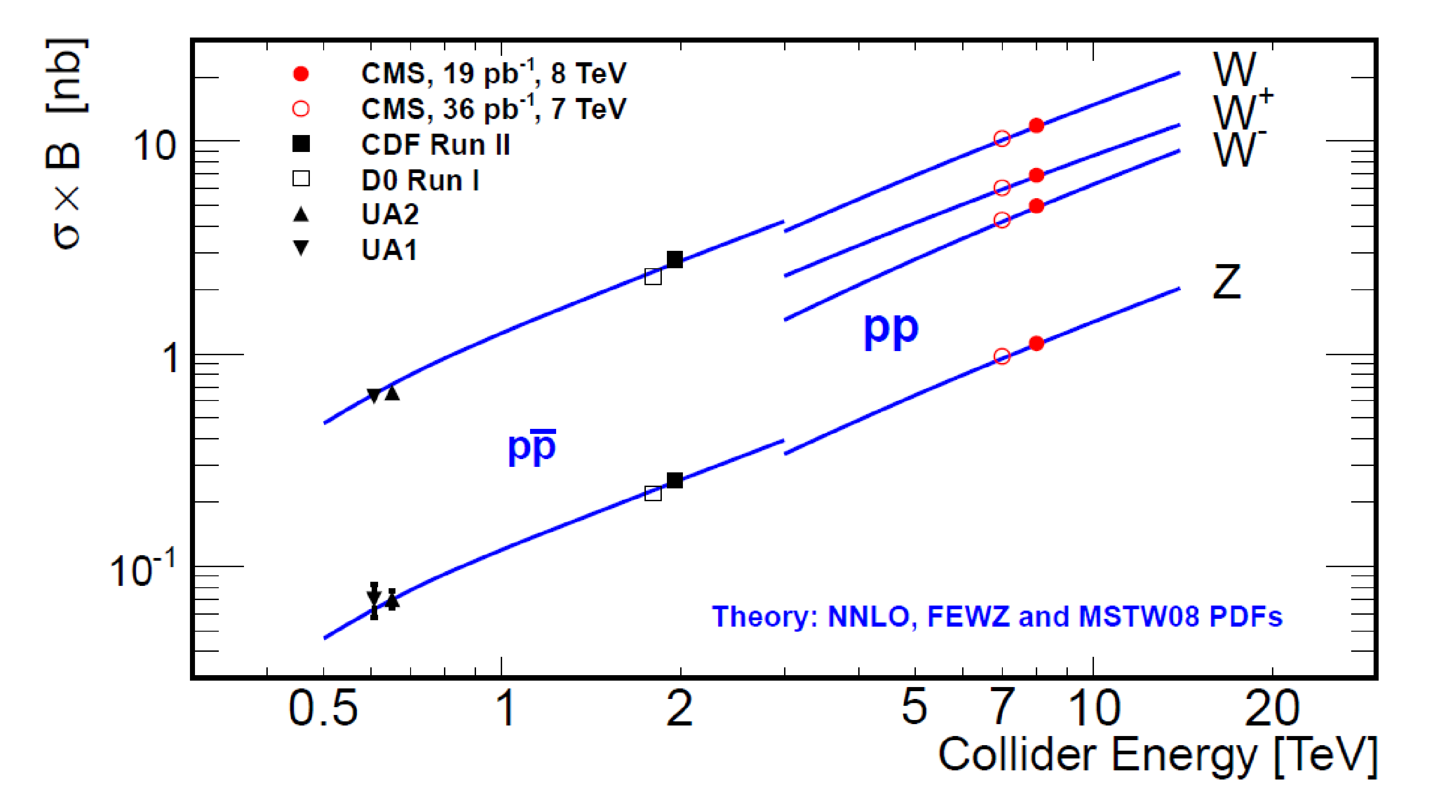
arXiv:1209.2716[hep-ph]

Motivations

- Test standard model (SM)
  - Cross section/ differential cross section: high order theoretic predictions
  - PDFs: constrain PDFs
- Improve precision on parameters
  - *W* boson mass
  - Weak mixing angle (*Z* forward backward asymmetry)

CROSS SECTION MEASUREMENTS

W/Z total Cross sections



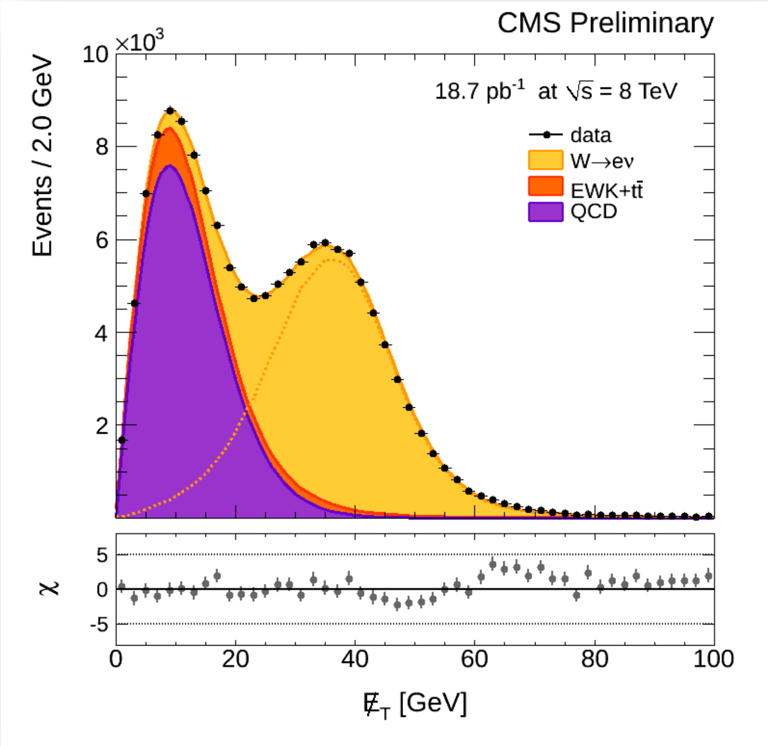
CMS: JHEP 1110 (2011) 132
ATLAS: JHEP 1012 (2010) 060
CMS: CMS-PAS-SMP-12-011

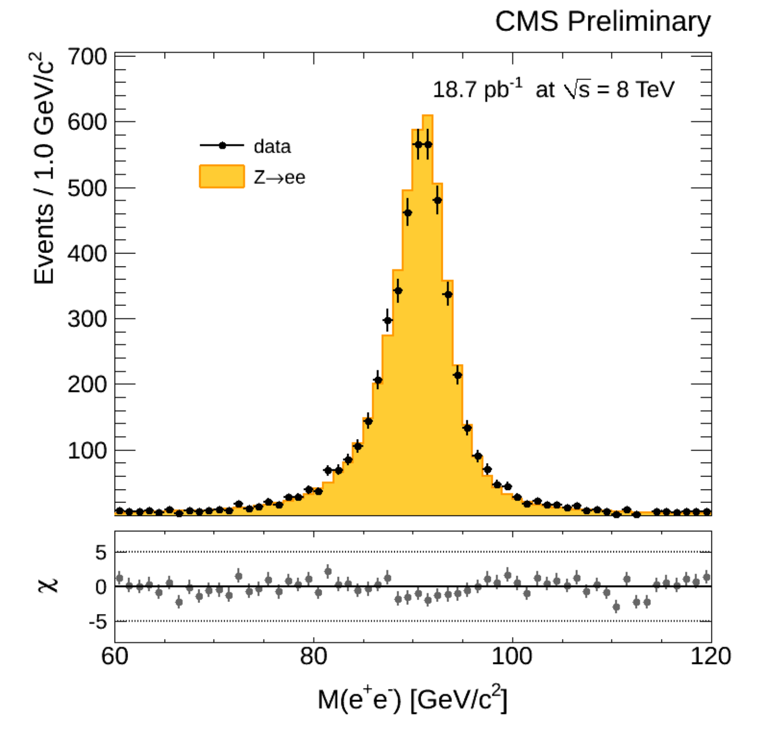
Cross section times branching ratio, compared with NNLO theory predictions.

W and *Z* cross section at 8 TeV

✓ 18 pb^{-1} data (low-pileup) collected at the beginning of 8 TeV run

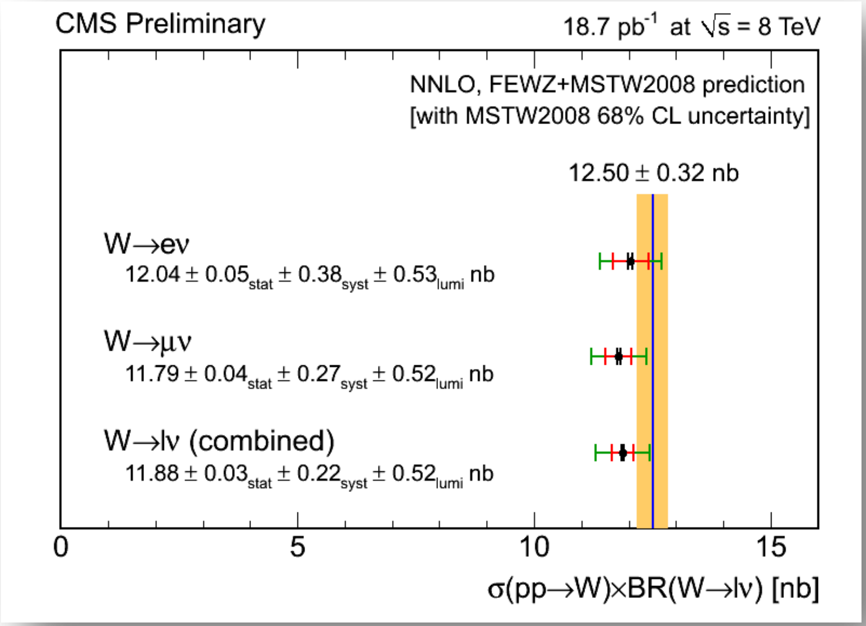
$p_T^{\,e}$> 25 GeV, |η| < 2.5
$p_T^{\,\mu}$> 25 GeV, |η| < 2.1

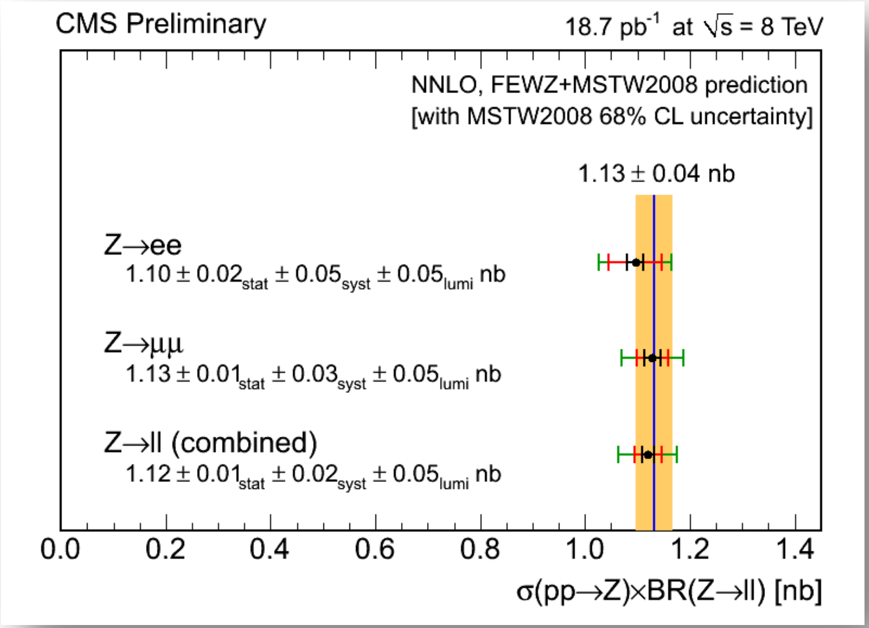




CMS-PAS-SMP-12-011

W and *Z* cross section at 8 TeV



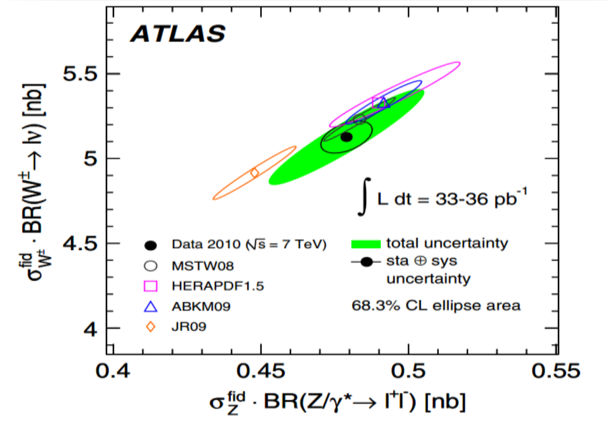


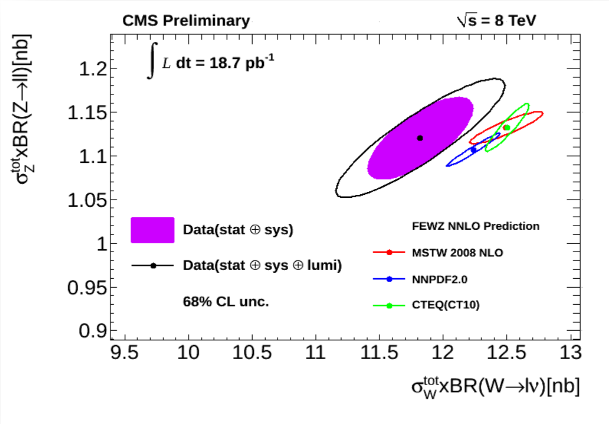
NNLO theoretical predictions: FEWZ + MSTW2008NNLO

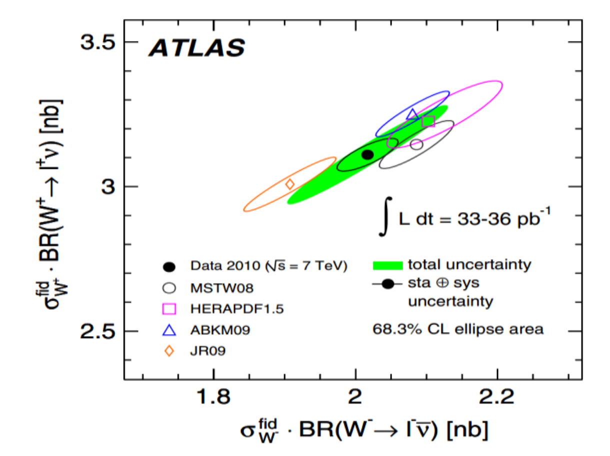
CMS-PAS-SMP-12-011

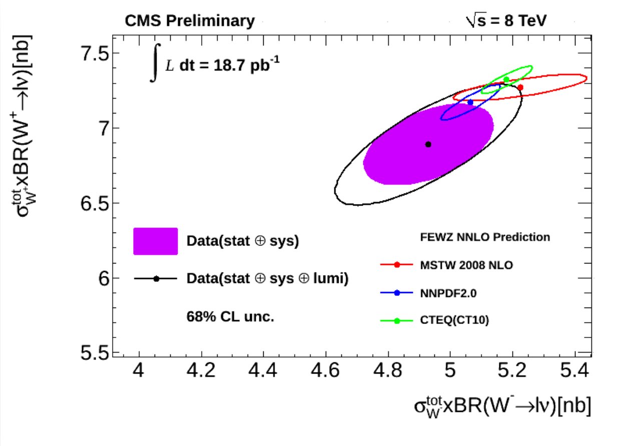
W/Z cross section

- *W* boson versus *Z* boson cross section
- W^+ versus W^- cross section





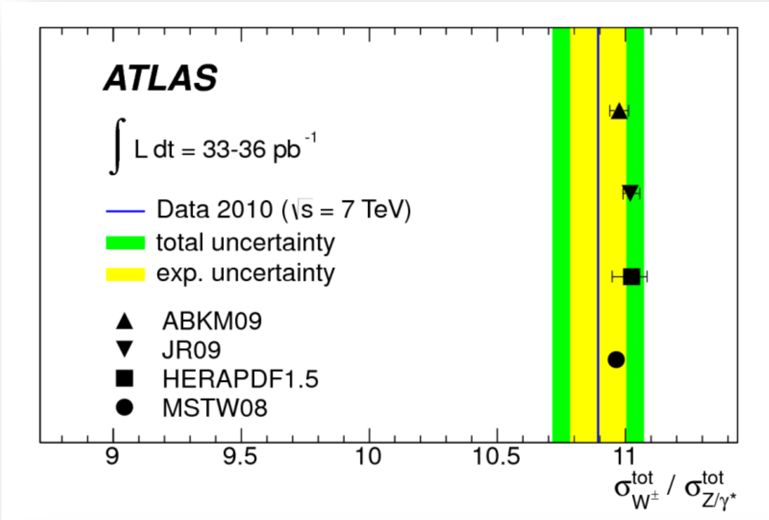


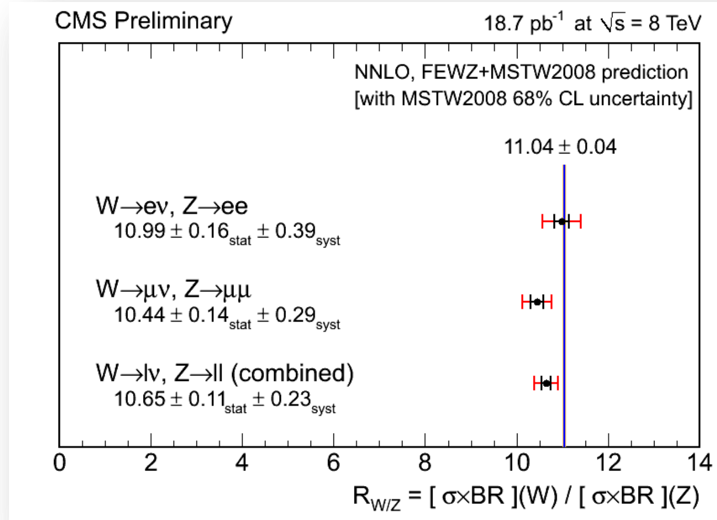


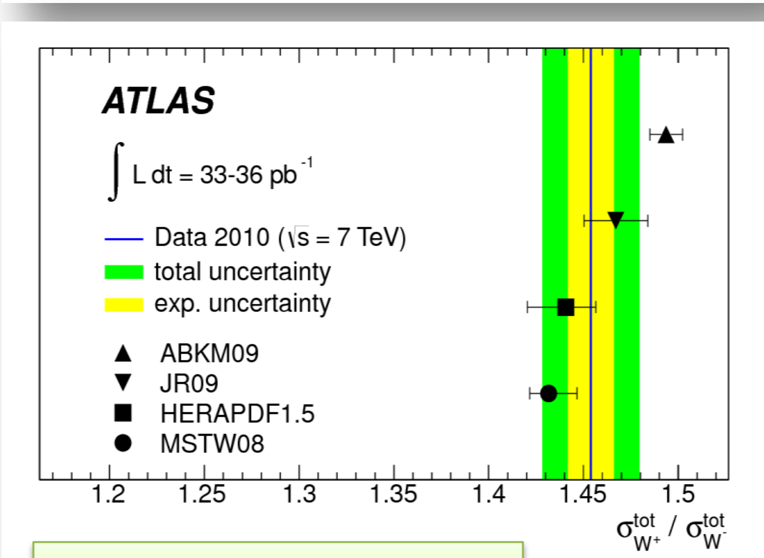
PRD 85, 072004 (2012)

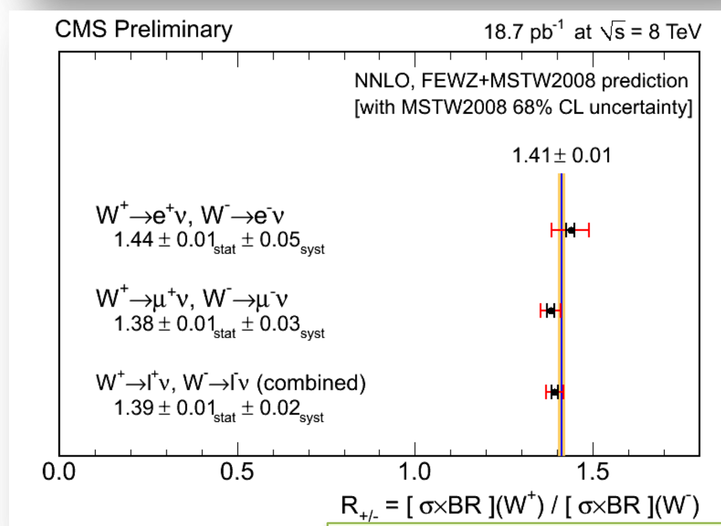
CMS-PAS-SMP-12-011

Cross section ratios *W/Z, W⁺/W⁻*





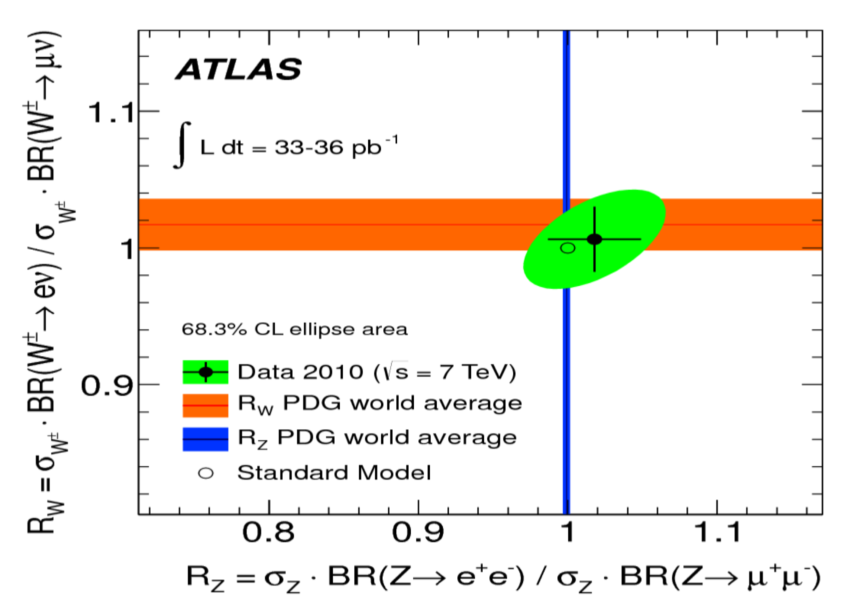




PRD 85, 072004 (2012)

CMS-PAS-SMP-12-011

Lepton universality



World average

R_W=1.017 +/- 0.019

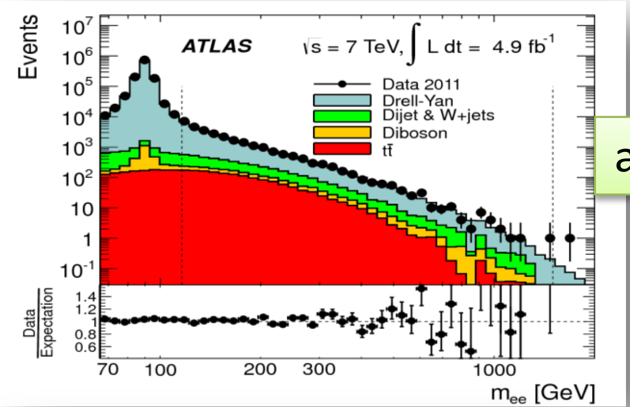
R_Z=0.9991+/-0.0024

$$R_W = \frac{\sigma_W^e}{\sigma_W^\mu} = \frac{\text{Br}(W \to e\nu)}{\text{Br}(W \to \mu\nu)}$$
$$= 1.006 \pm 0.004(\text{sta}) \pm 0.006(\text{unc}) \pm 0.022(\text{cor})$$
$$= 1.006 \pm 0.024.$$

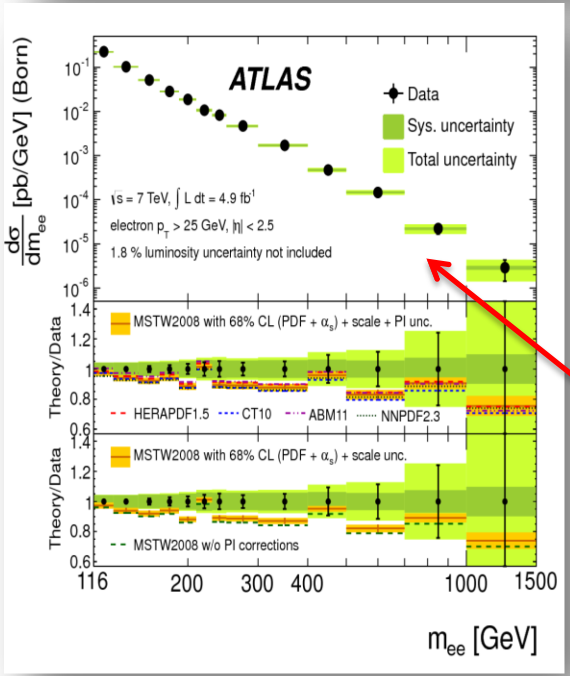
$$R_Z = \frac{\sigma_Z^e}{\sigma_Z^\mu} = \frac{\text{Br}(Z \to ee)}{\text{Br}(Z \to \mu\mu)}$$
$$= 1.018 \pm 0.014(\text{sta}) \pm 0.016(\text{unc}) \pm 0.028(\text{cor})$$
$$= 1.018 \pm 0.031.$$

Differential Drell-Yan (DY) cross section

Electron channel with $p_T > 25$ GeV, and $|\eta| < 2.5$



arXiv:1305.4192

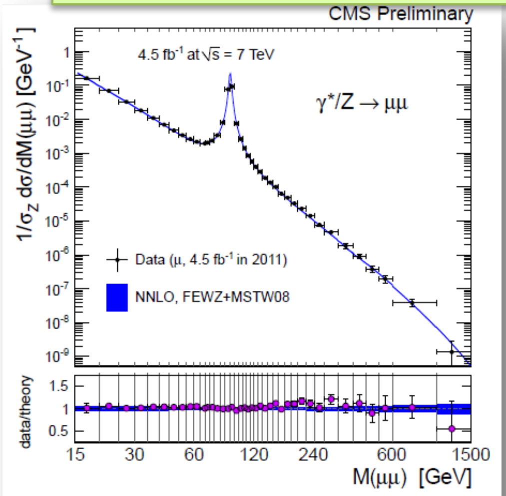


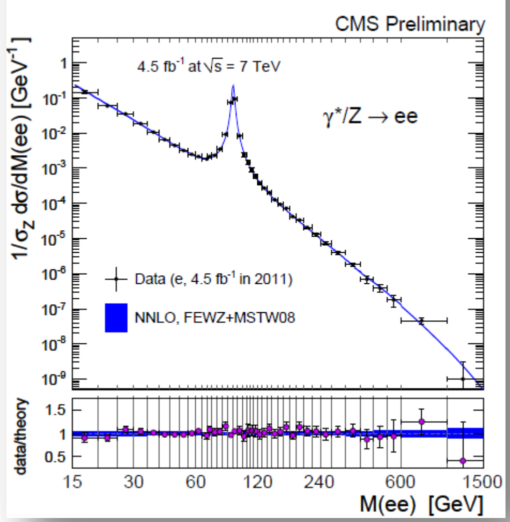
NNLO QCD calculation includes NLO EW correction.

Shown for different NLO PDF sets, photon-induced component is included.

Has potential to constrain PDFs, for anti-quarks at large x

CMS PAS EWK-11-007

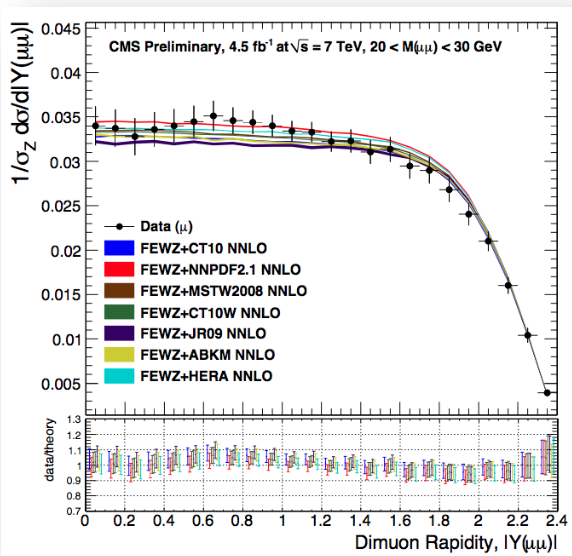




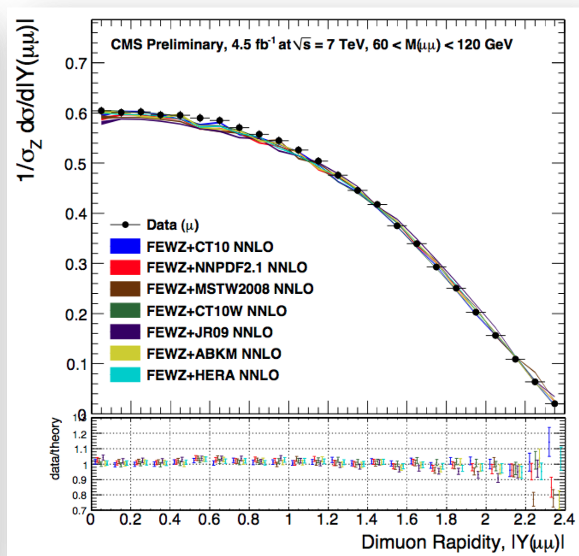
Double differential DY cross section

CMS PAS SMP-13-003

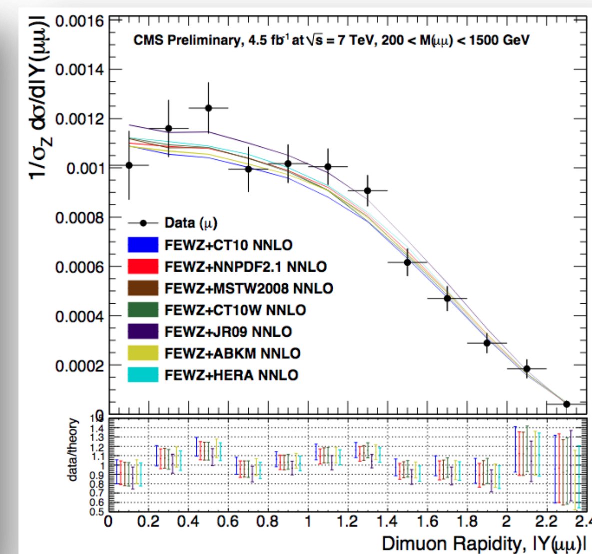
- Mass and rapidity double differential cross section
- Rapidity distribution is sensitive to PDFs
- High order/FSR effects are particularly important at low mass



Low mass region

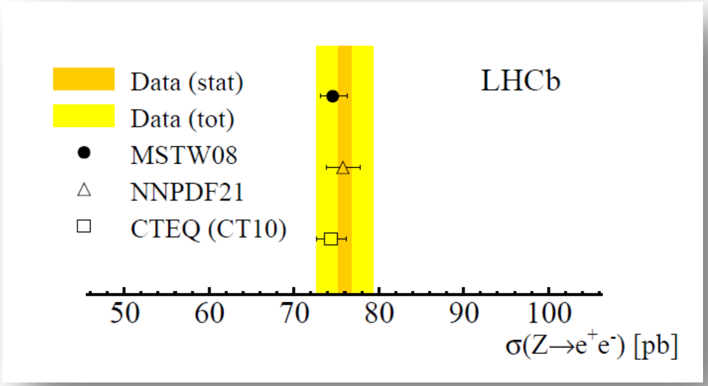


Z peak region

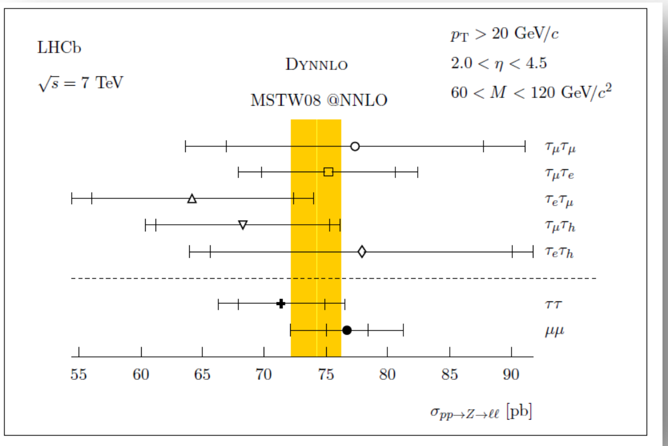


High mass region

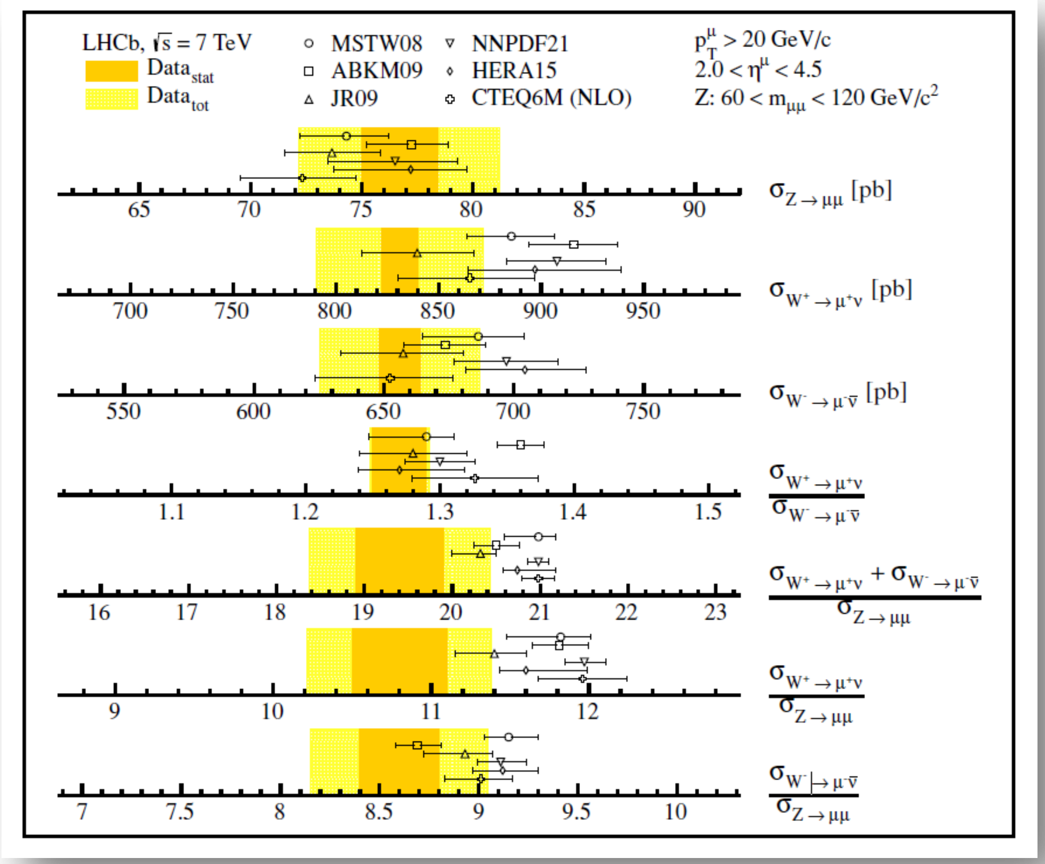
Very forward results from LHCb



J. High Energy Phys. 02 (2013) 106

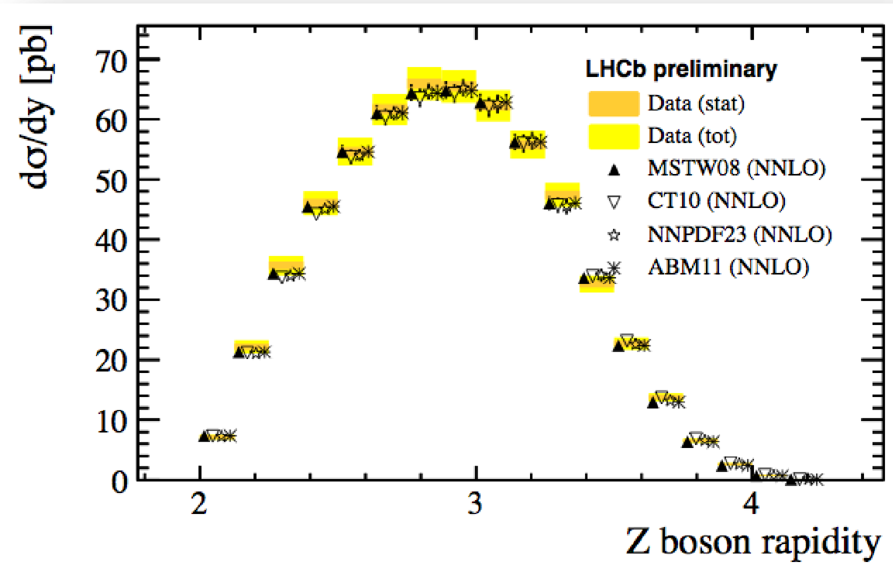


J. High Energy Phys. 01 (2013) 111



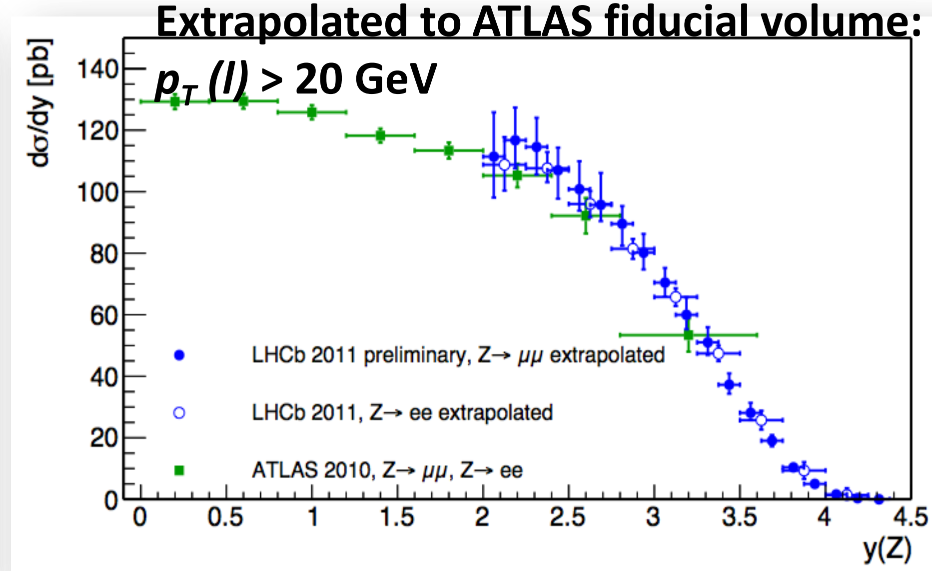
J. High Energy Phys. 06 (2012) 058

Differential cross section from LHCb



Extrapolated to ATLAS fiducial volume:

$p_T(l)$ > 20 GeV



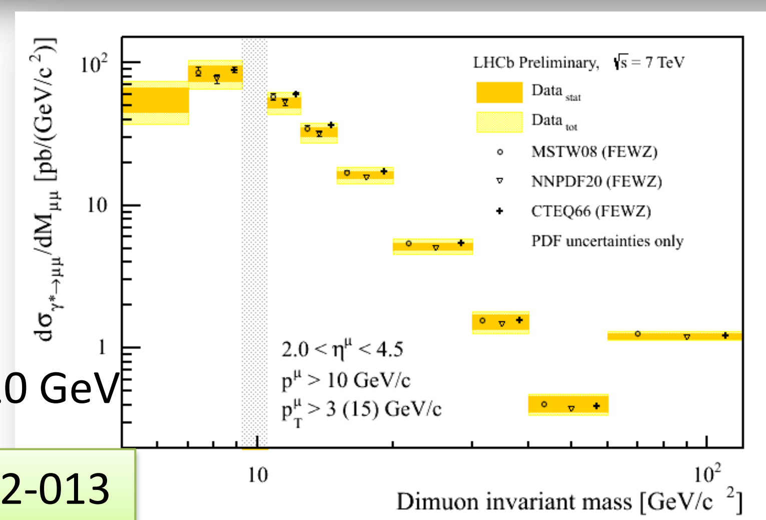
LHCb-CONF-2013-007

p_T^{μ} > 20 GeV,

2.0<η<4.5,

Mass region: 60-120 GeV

Mass region: 5-120 GeV



LHCb-CONF-2012-013

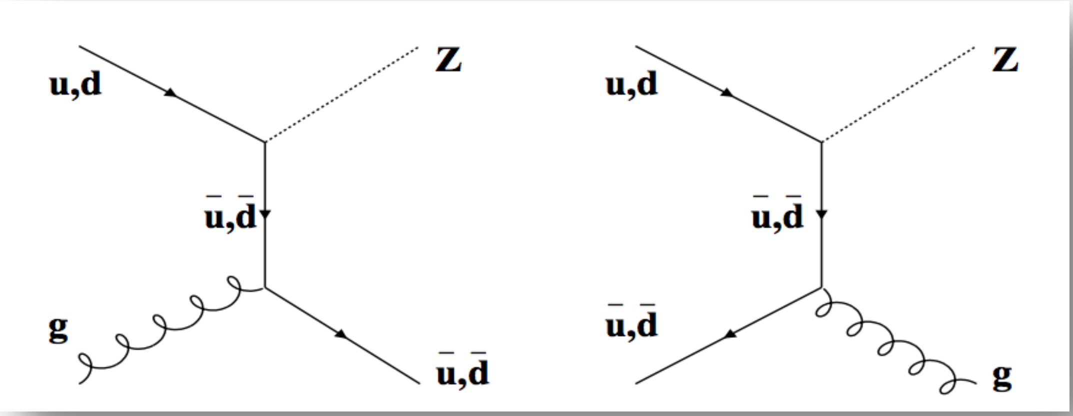
BOSON TRANSVERSE MOMENTUM

Z p_T measurement

✓ Motivation:

- Test the vector boson production formalism
- Reduce theory uncertainty of the precision W mass measurement
- Reduce uncertainties on searches with backgrounds from high p_T boson

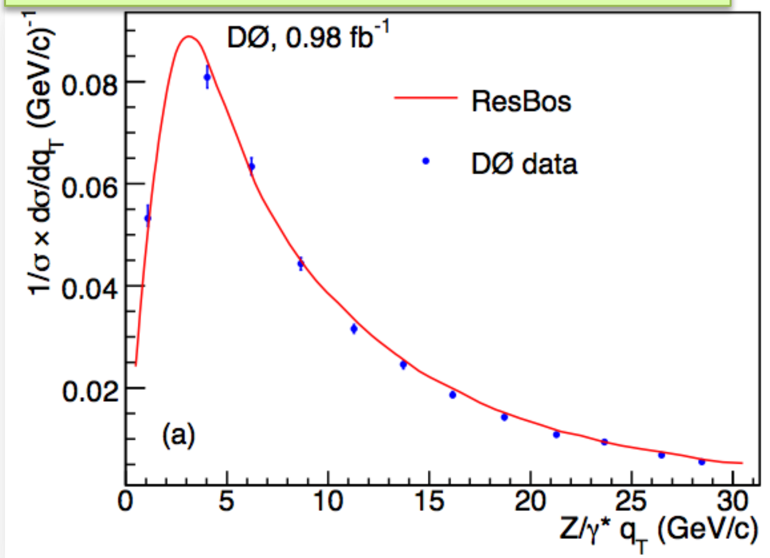
✓ Z boson p_T: Comes from initial QCD radiation



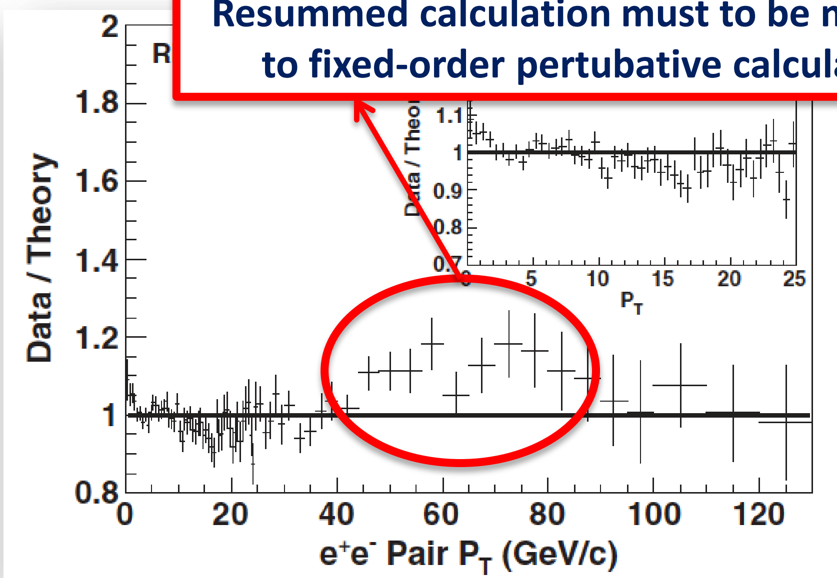
Tevatron results

- ✓ Low p_T region: dominated by soft and collinear gluon emission, limitation of standard perturbative calculation
  - ➢ Use QCD resummation methods
- ✓ High p_T region: dominated by single parton emission
  - ➢ Use Fixed-order perturbative calculations

Phys. Rev. Lett. 100, 102002 (2008)



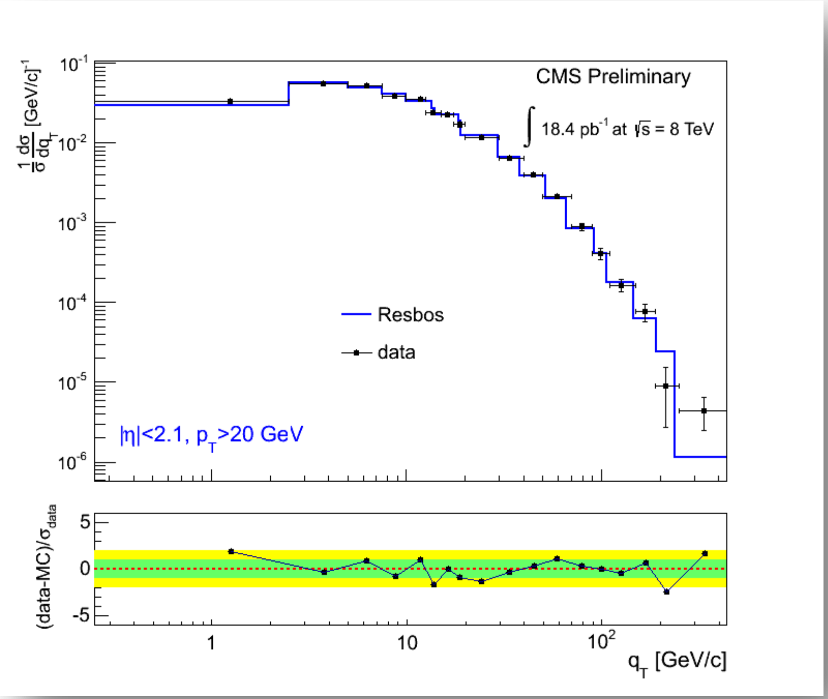
Resummed calculation must to be matched to fixed-order pertubative calculation

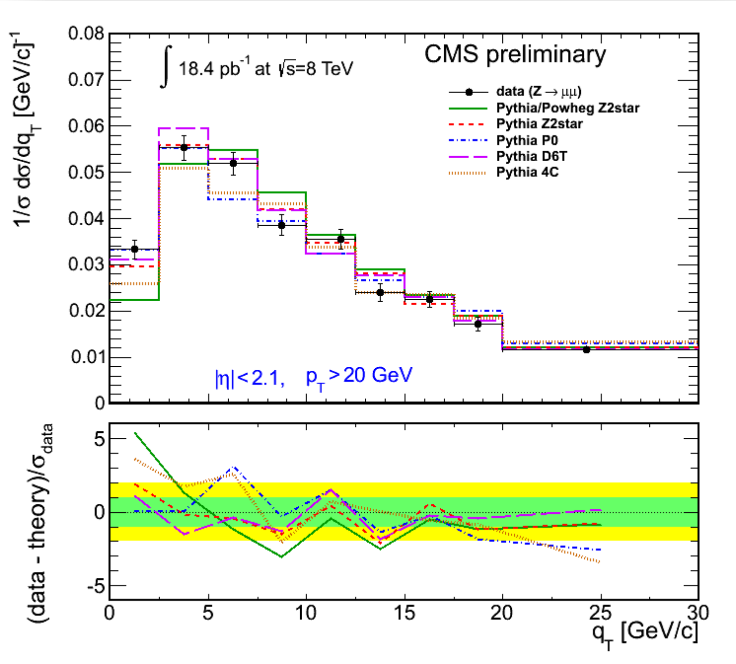


Due to the poor resolution on $p_T(Z)$, the measurements are limited by systematic uncertainties.

Phy. Rev. D 86, 052010 (2012)

LHC results





Low pileup run 18.4 pb^{-1}

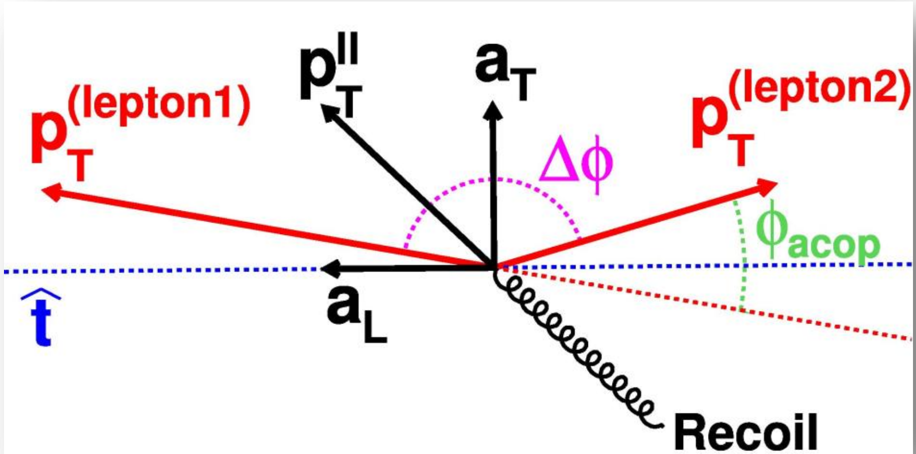
Dimuon channel: p_T > 20 GeV, |η| < 2.1, 60-120 GeV

$Z\ p_T$ up to 600 GeV

RESBOS describes the whole spectrum well

CMS-PAS-SMP-12-025

A Novel technique



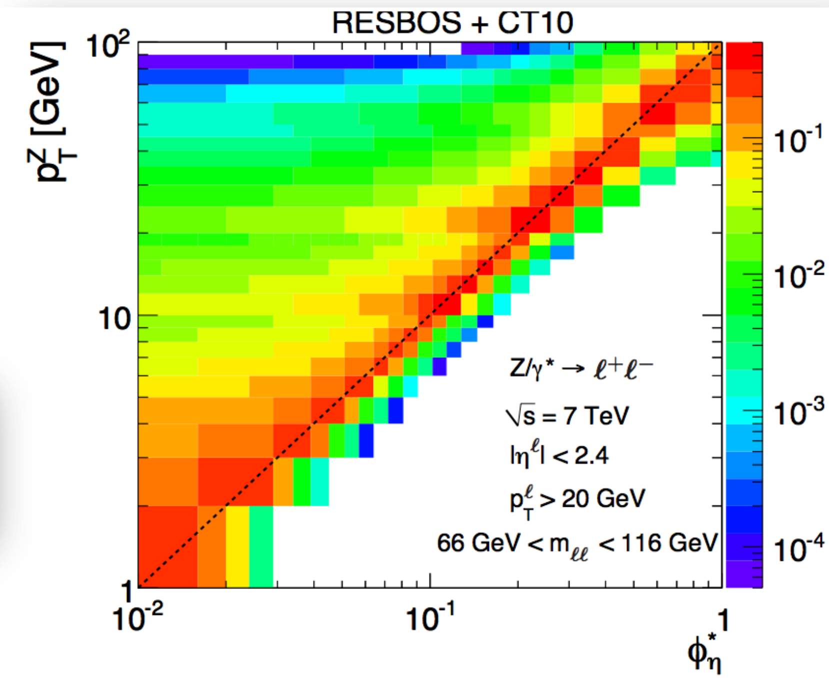
ϕ_η variable correlated with p_T^Z/M_{ll}

ϕ_η is less sensitive to detector resolution effects

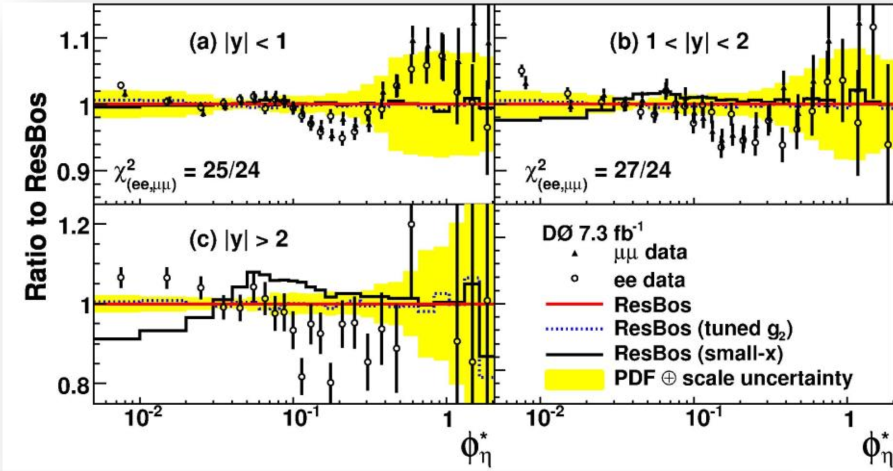
M. Vesterinen and T.R. Wyatt, NIM A602, 432.
A. Banfi et al. EPJ C 71, 1600.

$$\phi^* \equiv tan(\phi_{acop}/2) \cdot sin(\theta^*_\eta)$$

$$\cos(\theta^*_\eta) = \tanh\left[\left(\eta^- - \eta^+\right)/2\right]$$

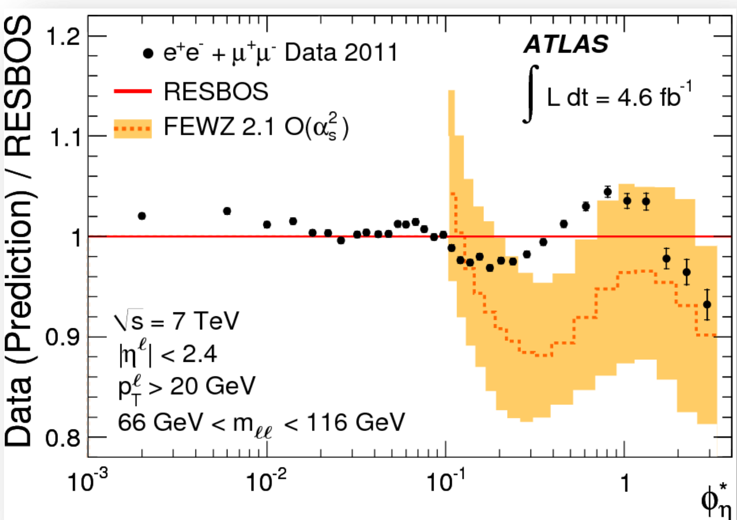


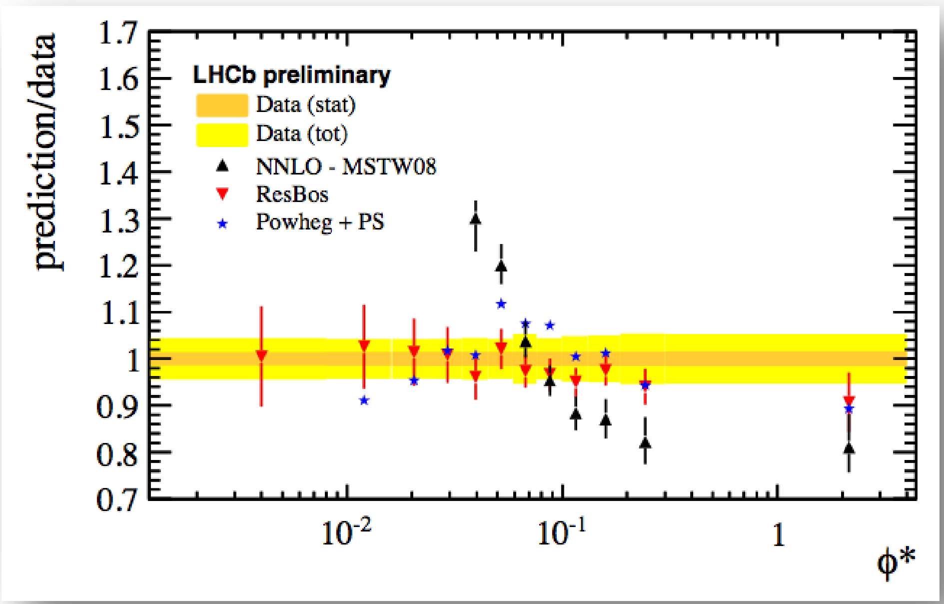
Φ* results



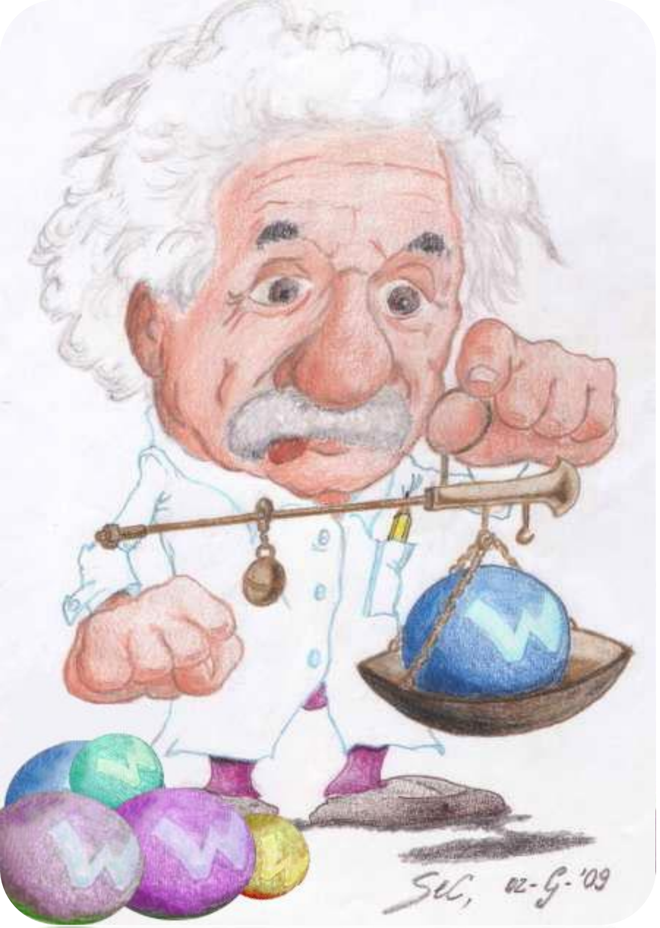
D0: Phys. Rev. Lett. **106**, 122001 (2011)

LHCb: J. High Energy Phys. 02 (2013) 106





Atlas: Phys. Lett. B 720, 32



PROPERTIES MEASUREMENTS

W boson mass: motivation

- ✓ *W* mass is a key parameter in the Standard Model (SM):
  - SM does not predict the value of the *W* mass, but it predicts this relation between the *W* mass and other experimental observables

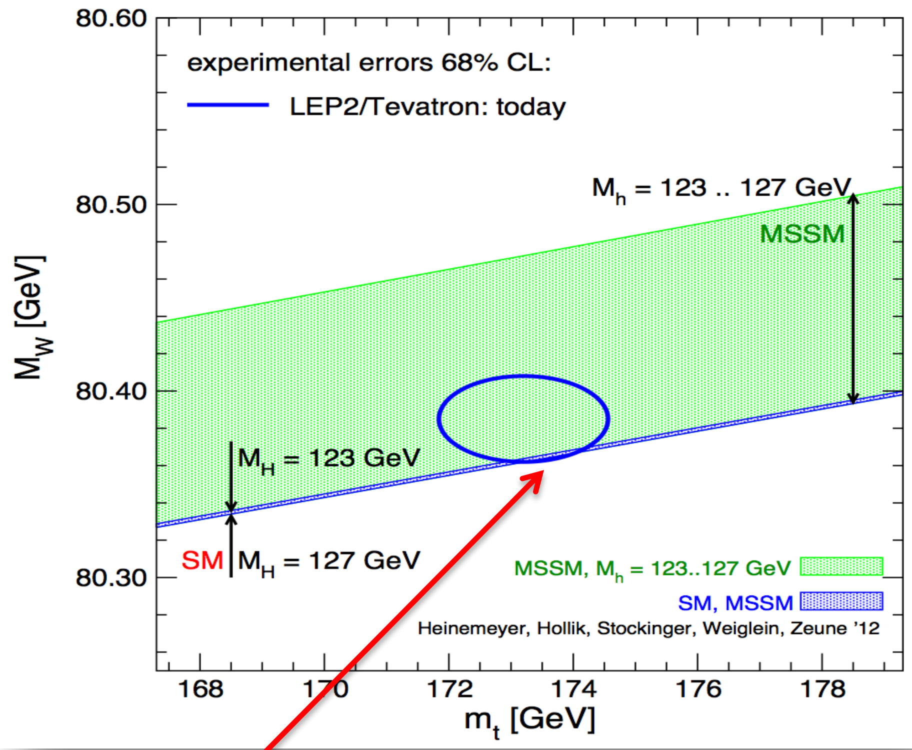
$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}} \frac{1}{\sin\theta_W \sqrt{1-\Delta r}}$$

  - Radiative corrections (Δr) depend on M_t as ~ M_t^2 and on M_H as ~*log* M_H. They include diagrams like these:

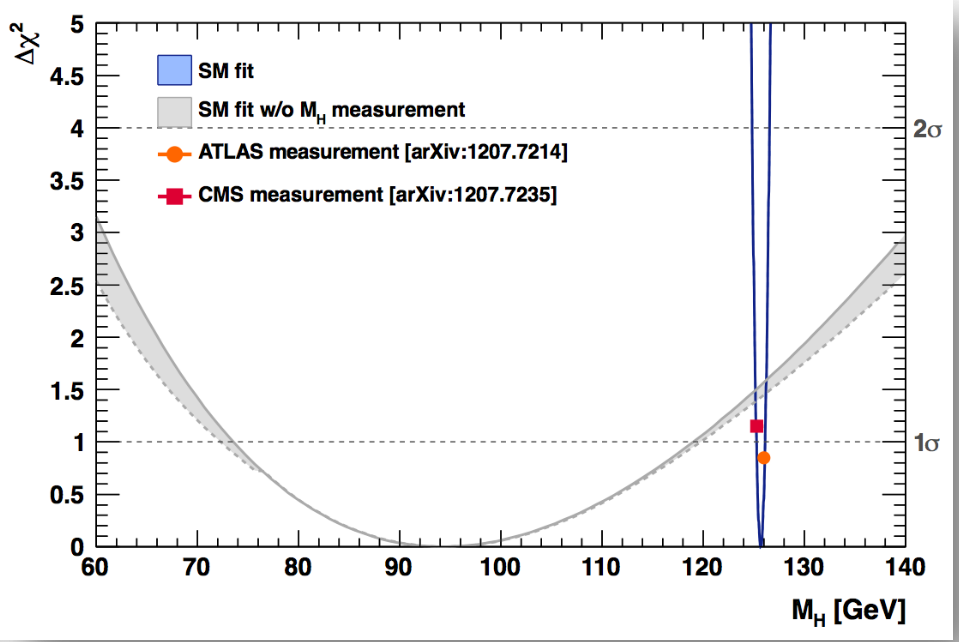
Precision measurements of M_W and M_t constrain SM Higgs mass.

- ✓ *W* mass can help to determine if the observed boson is consistent with SM Higgs or not

W boson mass



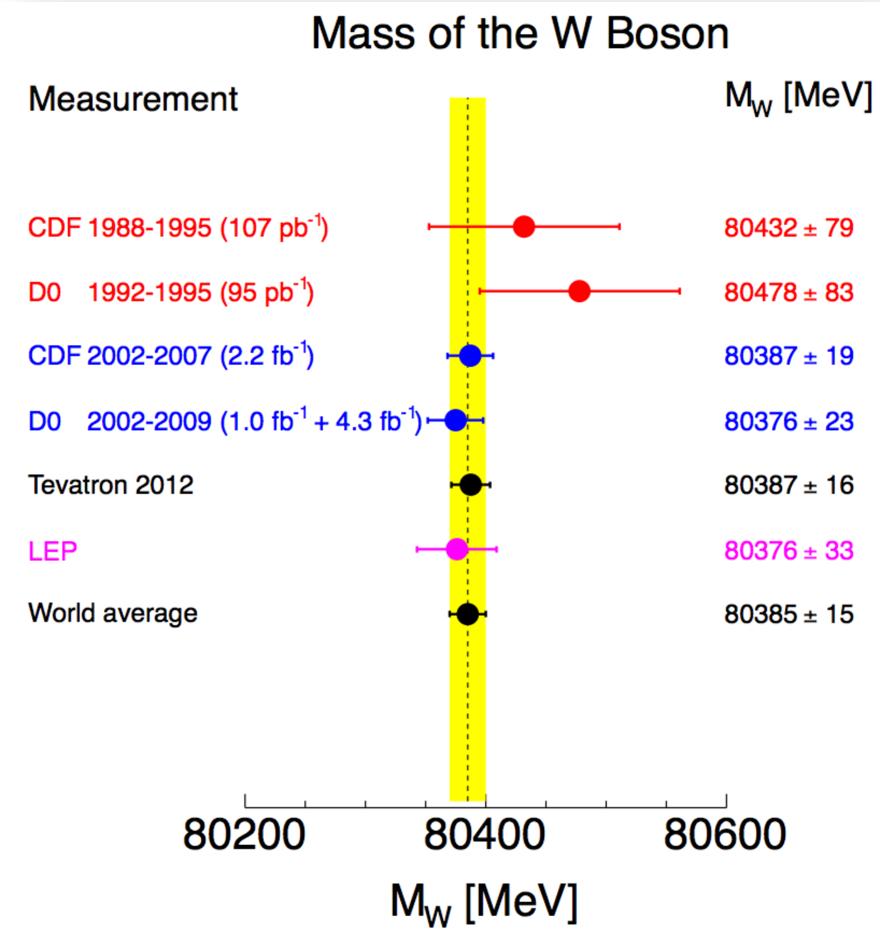
The mass of the new boson discovered by ATLAS+CMS is inside this blue band.



Comparison between indirect constraints on the SM Higgs boson and direct measurements of mass of boson discovered by ATLAS and CMS.

Consistent at the 1.3σ level.

W boson mass



arXiv:1307.7627 [hep-ex]
Accepted by Phys. Rev. D

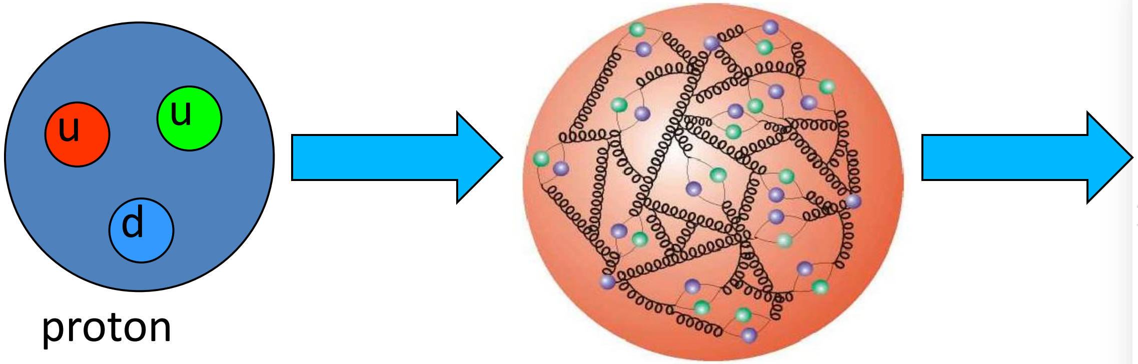
Future:

D0: with full data set, include forward region to reduce PDF uncertainty
➔15 MeV

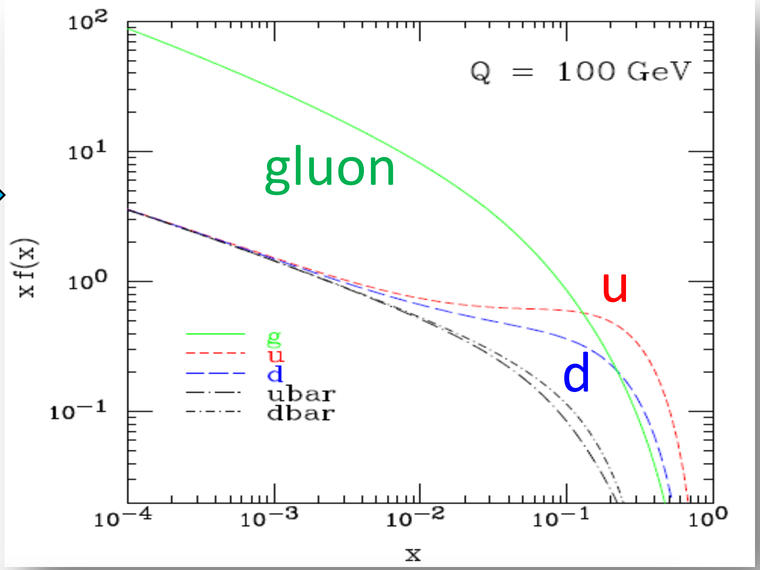
CDF: with full data set
➔10 MeV (include improvement in PDFs)

LHC:
➔10 MeV to 5 MeV, ultimately
Boson P_T measurement, rapidity, W charge asymmetry

W boson asymmetry

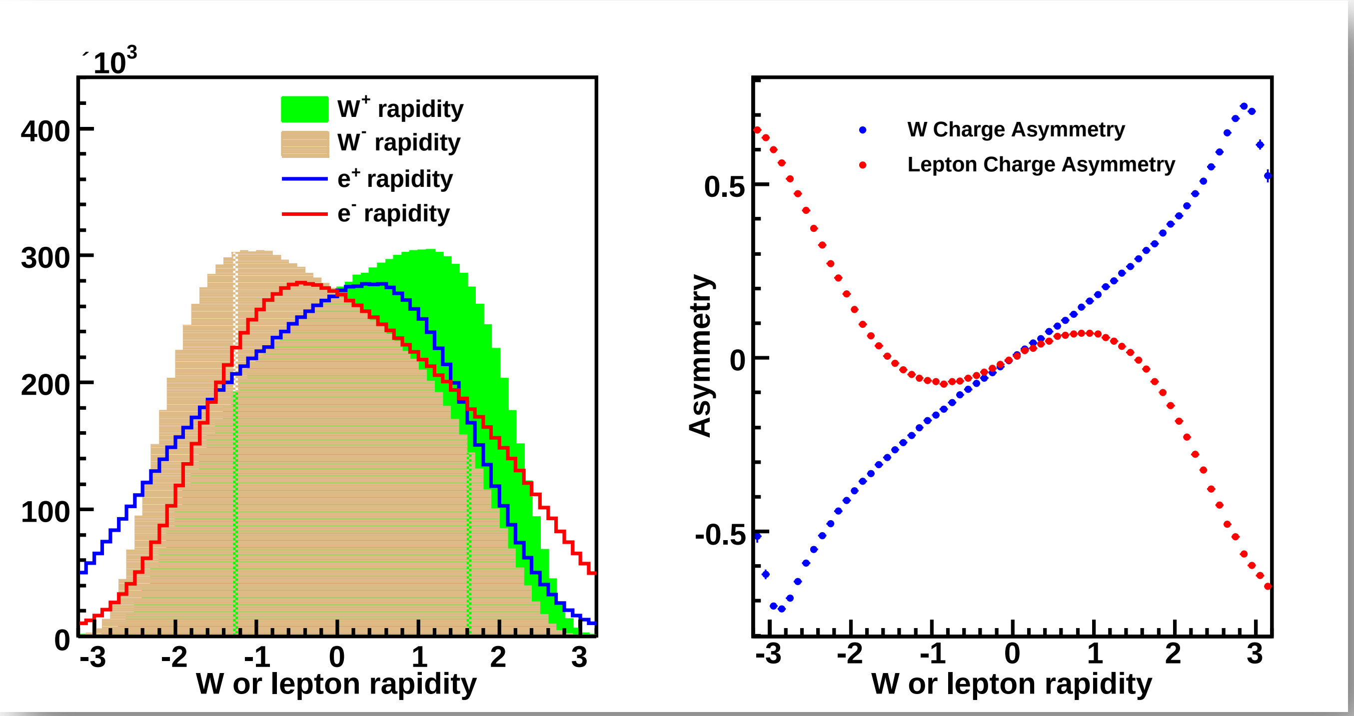


proton



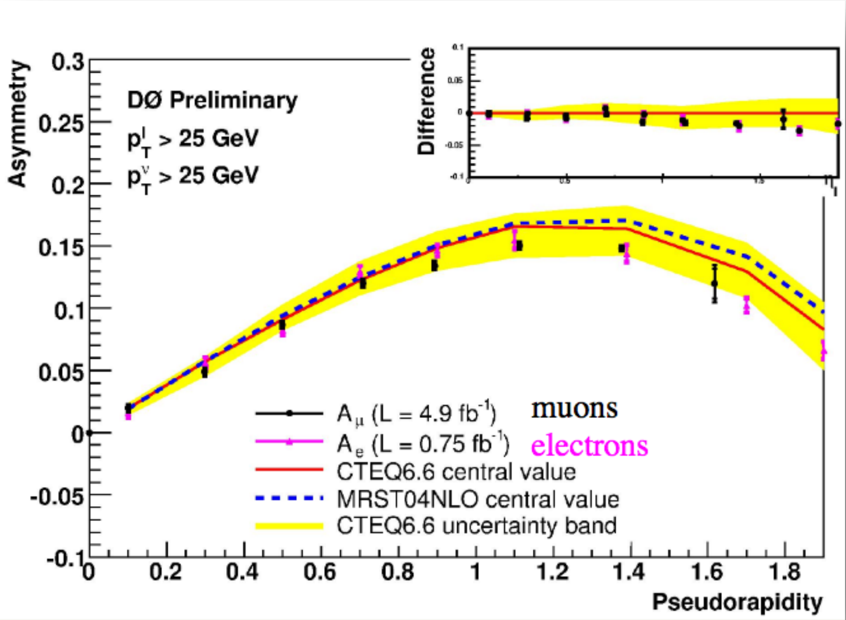
Lepton asymmetry vs. *W* asymmetry

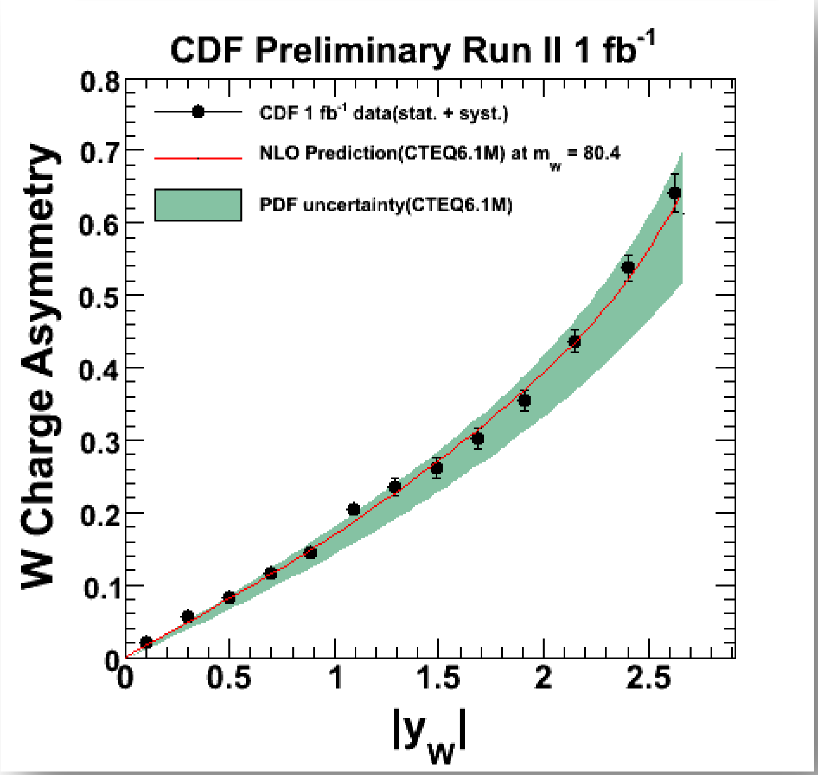
- ✓ *W* charge asymmetry is sensitive to Patron Distribution Functions (PDFs)
  - ➢ Tevatron is ppbar collider: *u* quark tends to carry higher momentum than *d* quark
  - ➢ LHC is pp collider: proton has two valence *u* quarks and one valence *d* quark. More W^+ than W^-
- ✓ Lepton asymmetry comes from a convolution of *W* asymmetry and the *W* *V-A* decay: A(y) ⊗ (V-A)



Tevatron results

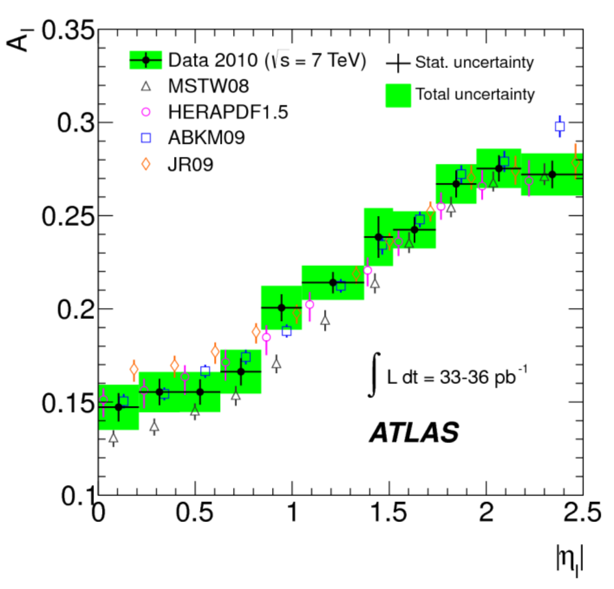
Phy. Rev. Lett. 102, 181801 (2009)



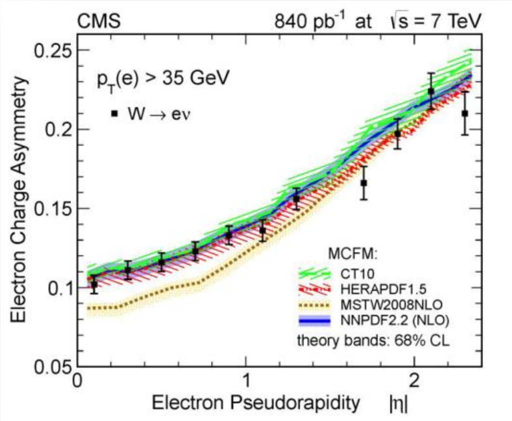


More results with full data set (10 fb^{-1}) will coming out soon!

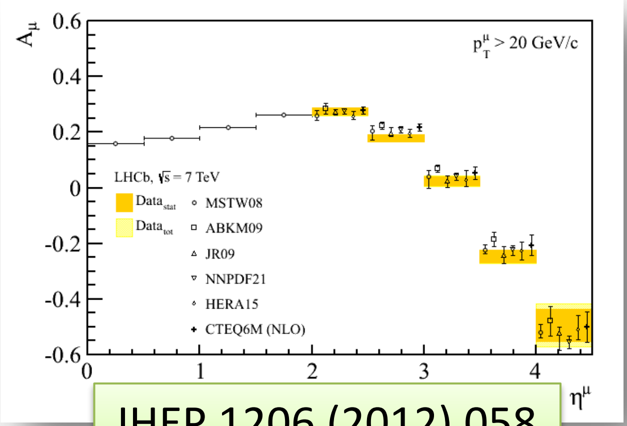
LHC results



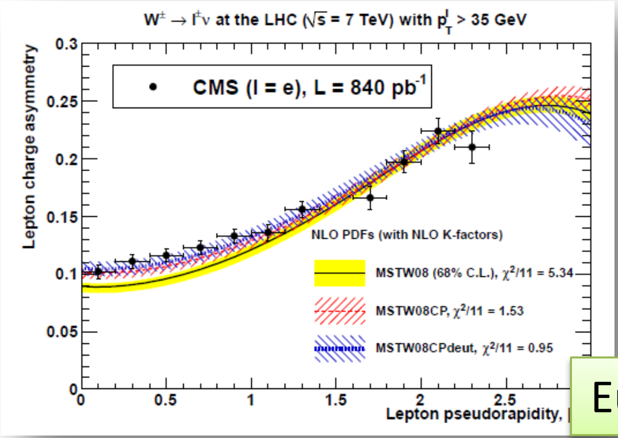
Phys. Rev. D 85 (2012) 072004



Phys. Rev. Lett. 109 (2012) 111806



JHEP 1206 (2012) 058

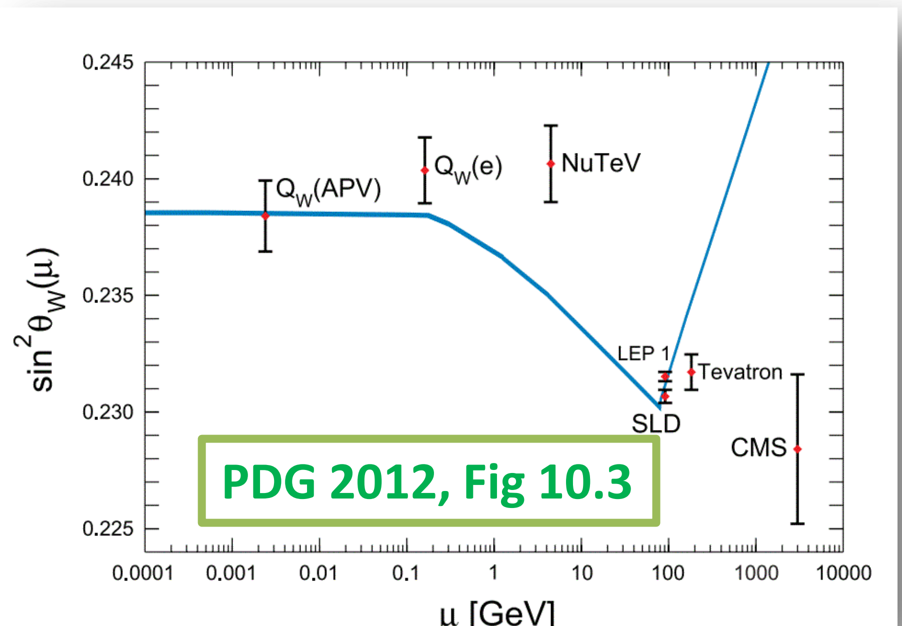


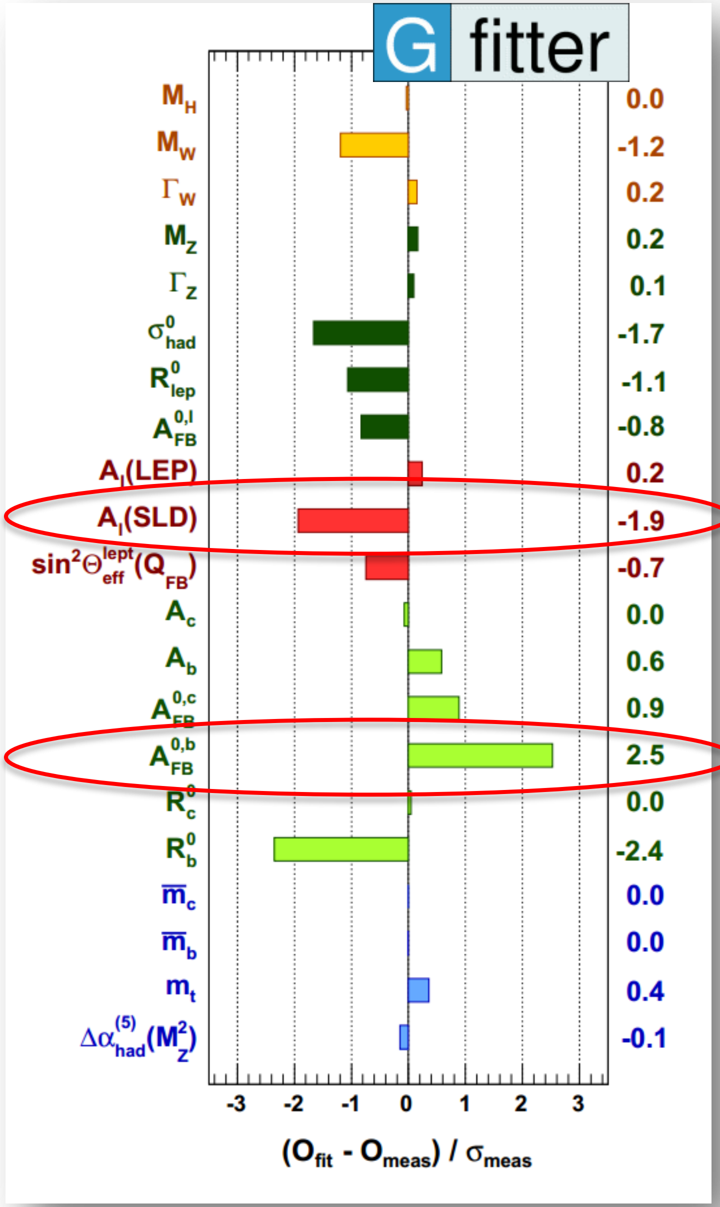
Eur. Phys. J.C (2013) 73: 2318

Weak mixing angle

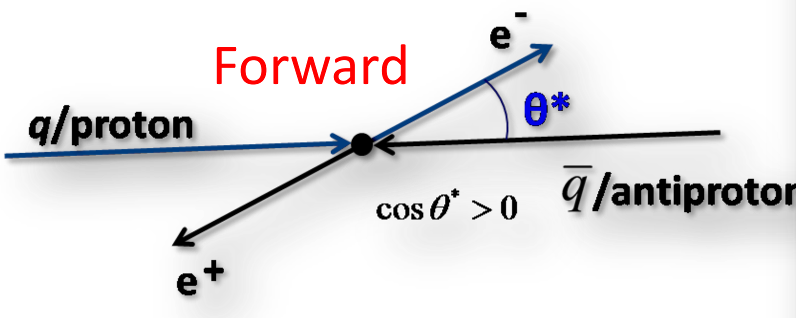
✓ Fundamental parameter in the electroweak theory

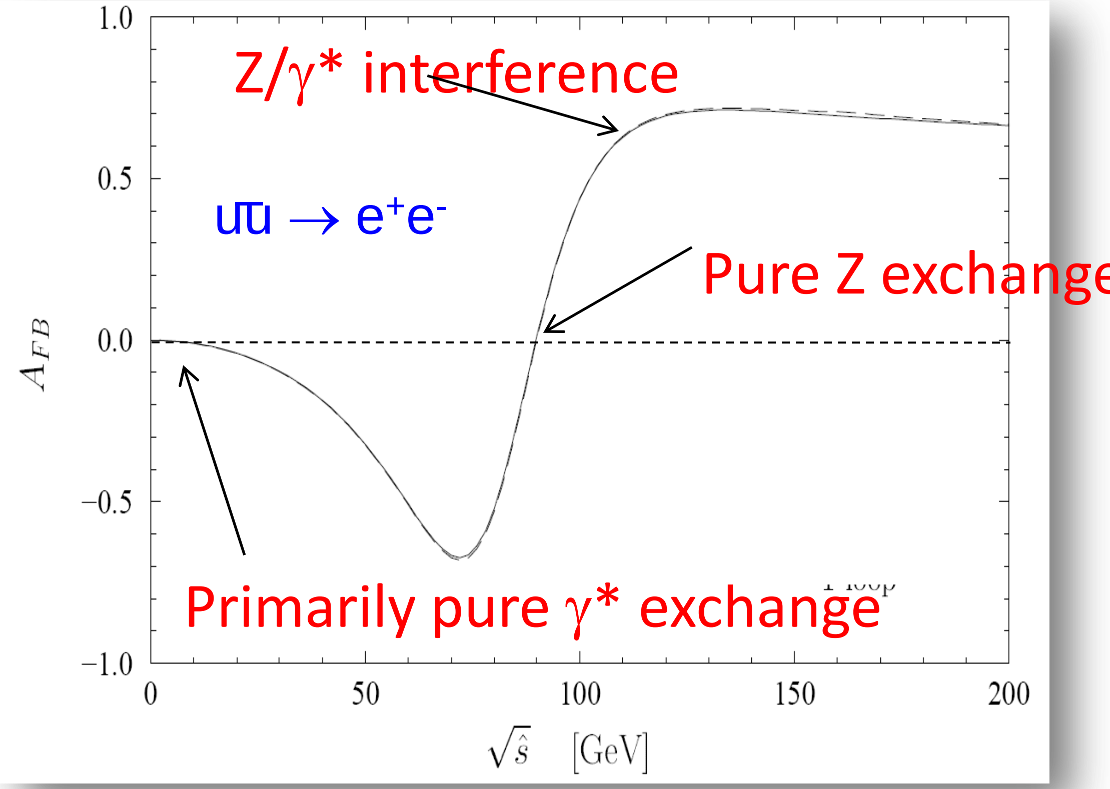
✓ LEP A_{FB}^{b} and SLD A_{FB}^{LR} : off by 3σ in opposite direction





Forward-backward asymmetry





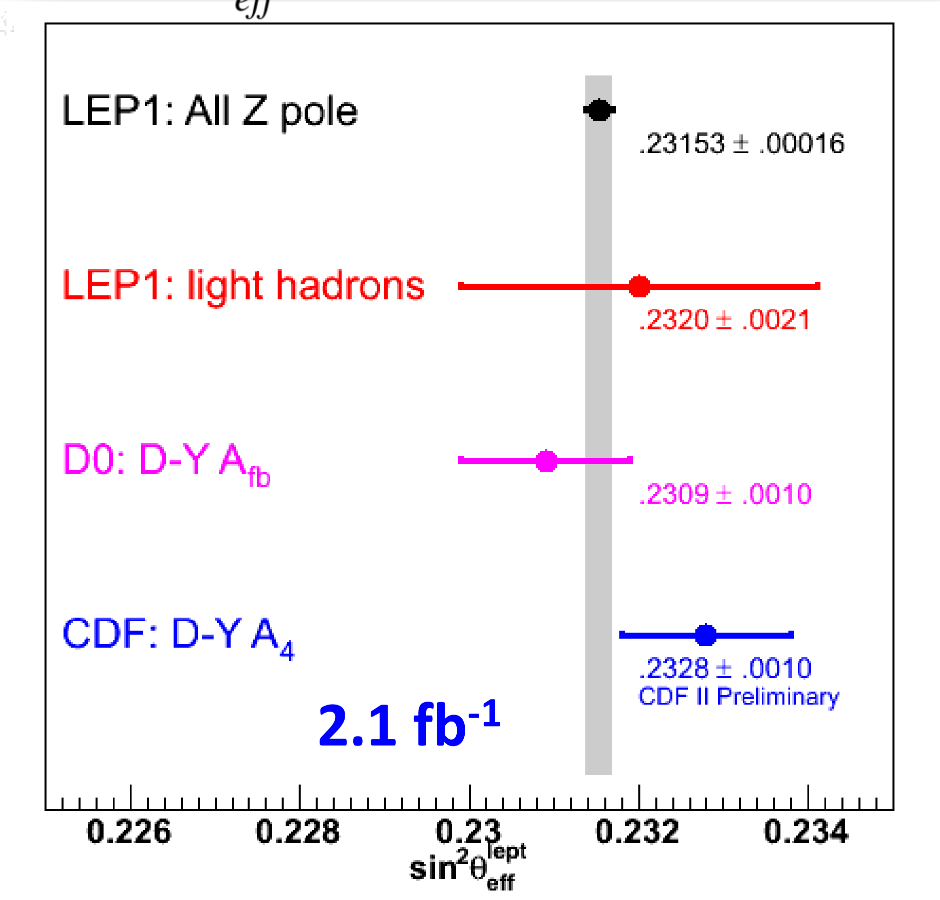
- Forward-backward asymmetry : $A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$

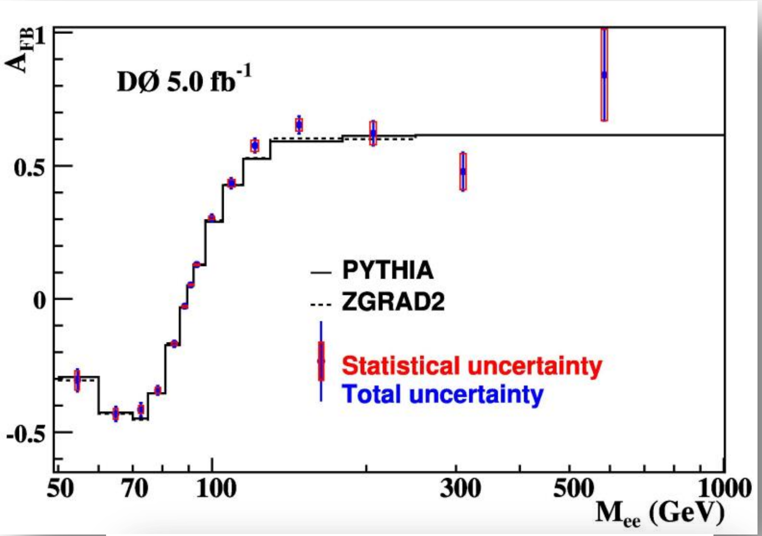
$$\sigma_F = \int_0^{+1} \frac{d\sigma}{d\cos\theta^*} d\cos\theta^*, \qquad \sigma_B = \int_{-1}^{0} \frac{d\sigma}{d\cos\theta^*} d\cos\theta^*$$

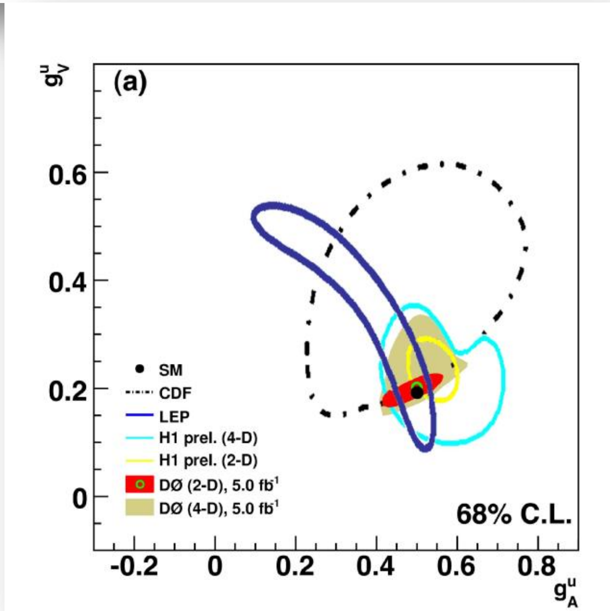
Tevatron results

Using A_4 to measure $\sin^2\Theta_W$

$$\sin^2\theta_{eff}^{lept} = 0.2328 \pm 0.0010$$

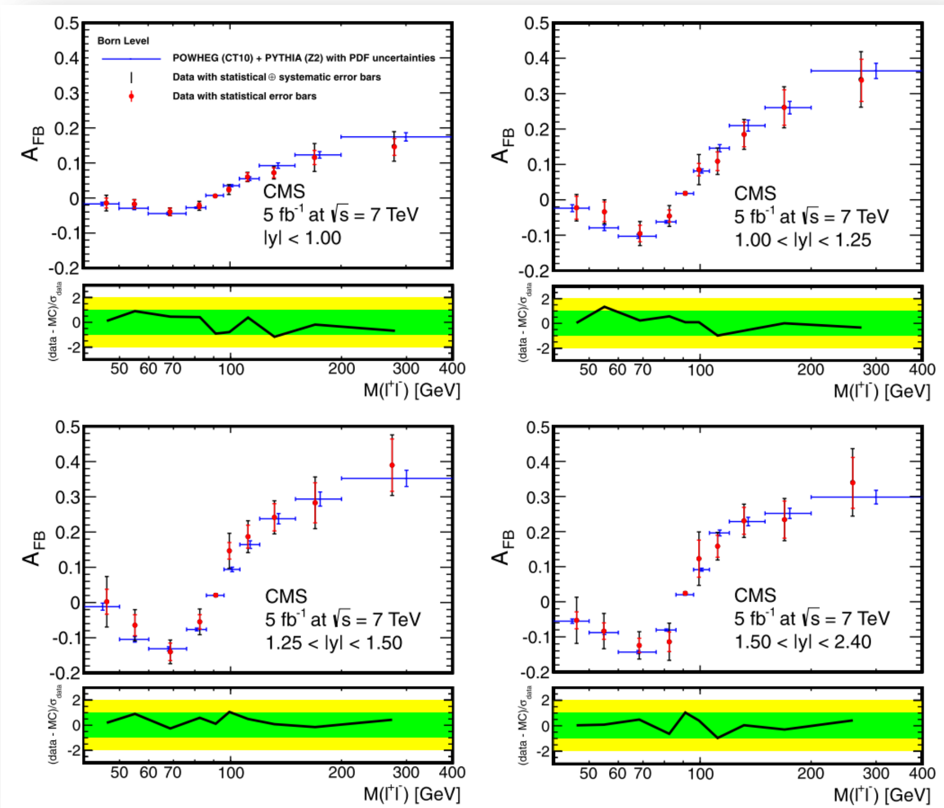




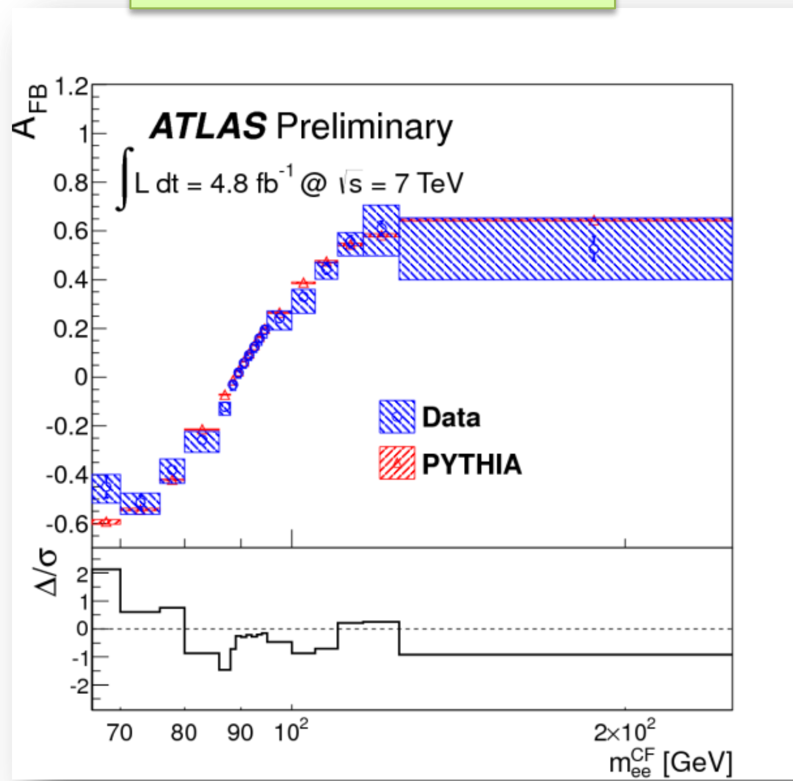


LHC results

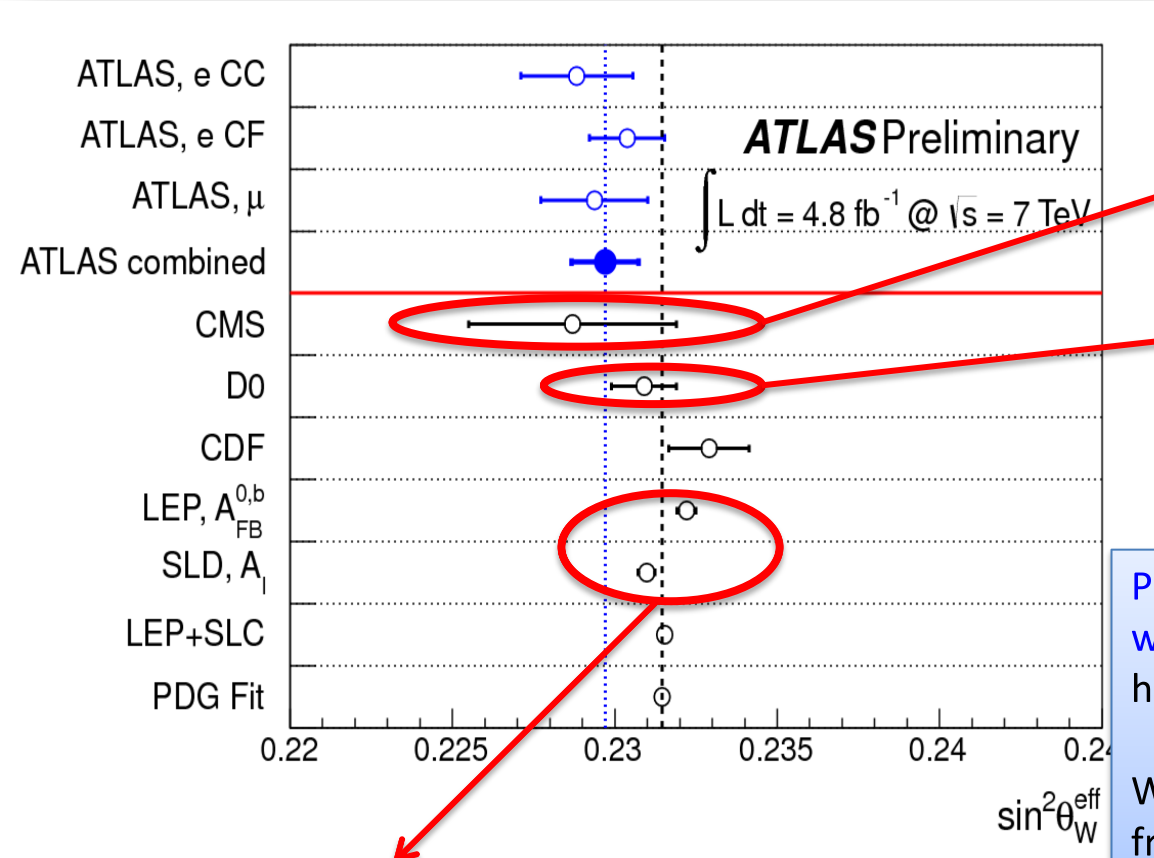
Phys. Lett. B 718 (2013) 752



ATLAS-CONF-2013-043



Summary of weak mixing angle



First measurement at LHC (CMS)
Phys. Rev. D 84 112002 (2011)

D0 5 fb^{-1}, with 90% C.L. PDF uncertainty.

> 3 sigma deviation

PDF uncertainty will be the key element for weak mixing angle measurements at hadron colliders.

With more data and new PDF set, precision from hadron collider may be comparable to that from LEP.

Summary

- ✓ Precision measurements on single *W* and *Z* bosons provide stringent tests of the SM
  - ➢ Good consistency between SM and data
  - ➢ Provide more information for PDF fitting
  - ➢ High order corrections (NLO, NNLO), pQCD
  - ➢ Precision measurements on the SM input parameters (*W* boson mass, weak mixing angle)

- ✓ More precision electroweak results with larger data-set from both *LHC* and *Tevatron* coming soon

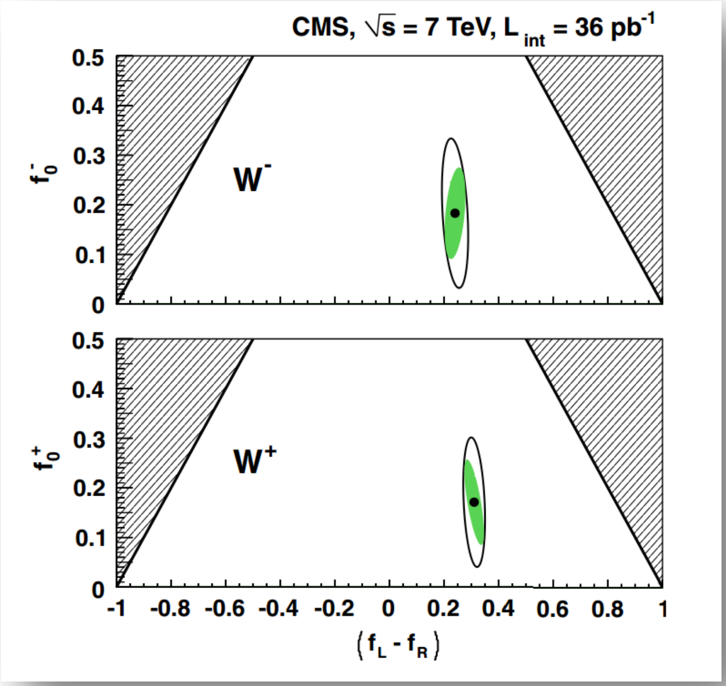

W BOSON
W-, W+
W- side
W+ side
2-SIDED
LIGHT
HEAVY
The W BOSON is a messenger particle which communicates the weak force. Unlike the photon and gluon bosons, it has a mass. Like the Z boson, it is one of the most short-lived particles known, with a mere 10-25 second lifetime. It can be negatively charged (W-) or positively charged (W+). Luckily you can have both, as the toy is double-sided.
Wool felt with gravel fill for maximum mass.
$16.49 PLUS SHIPPING
W BOSON
The PARTICLE ZOO


Z boson

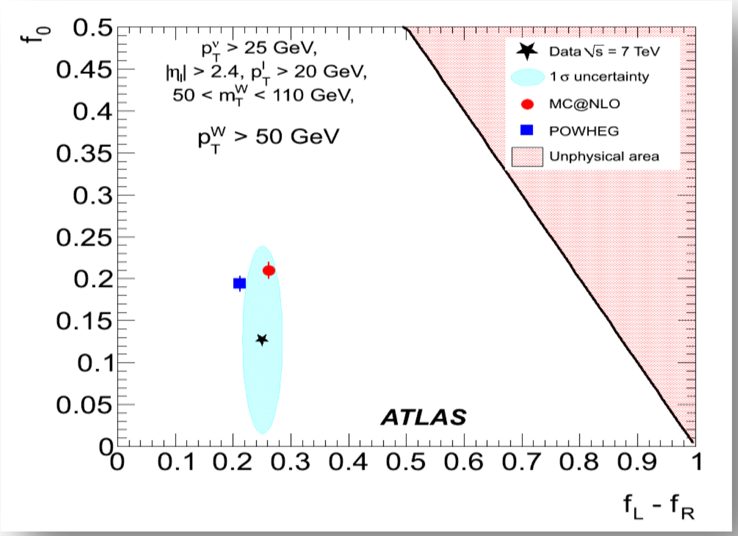
BACKUP

W polarization

✓ The left-handed, right-handed and longitudinal polarization fractions are measured using both electron and muon channels



Phys. Rev. Lett. 107 (2011) 021802



Eur. Phys. J. C 72 (2012) 2001

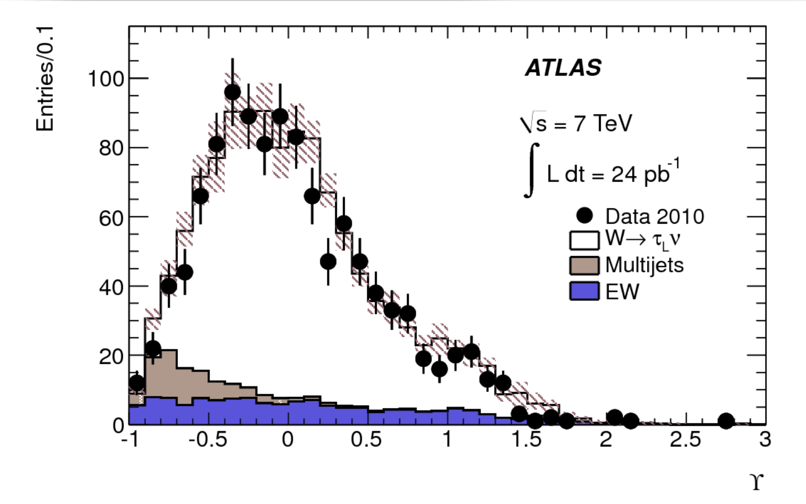
τ polarization

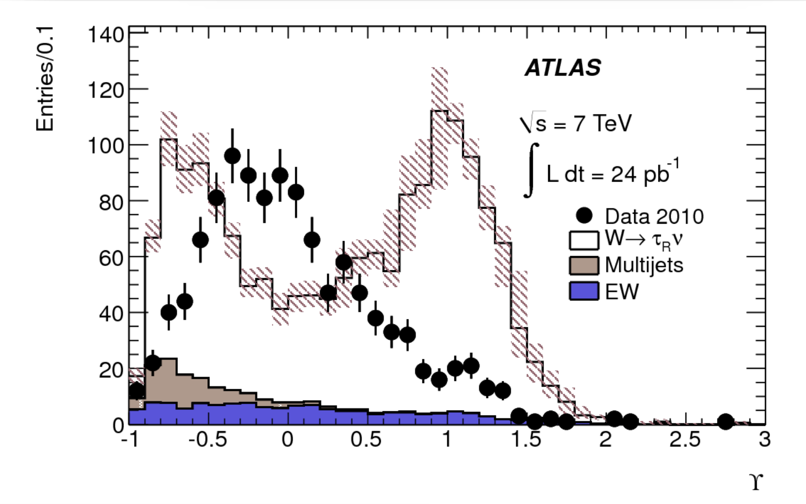
- ✓ Using W→ τν
- ✓ W^- coupled to left-handed τ
- ✓ W^+ coupled to right-handed τ

Eur. Phys. J. C 72 (2012) 2062

$$P_\tau = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

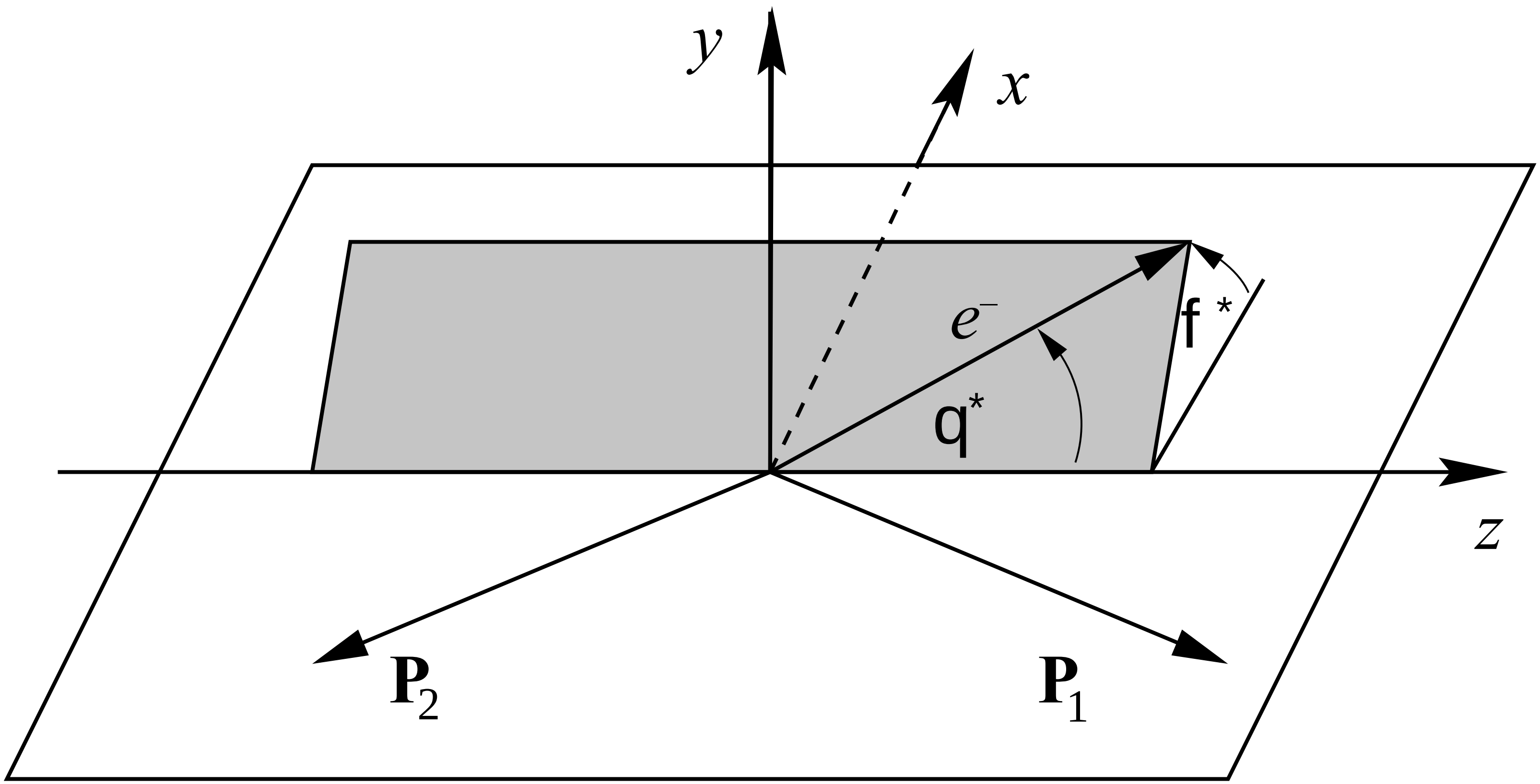
$$\frac{E_T^{\pi^-} - E_T^{\pi^0}}{p_T} \approx 2\frac{p_T^{trk}}{p_T} - 1 = \Upsilon.$$



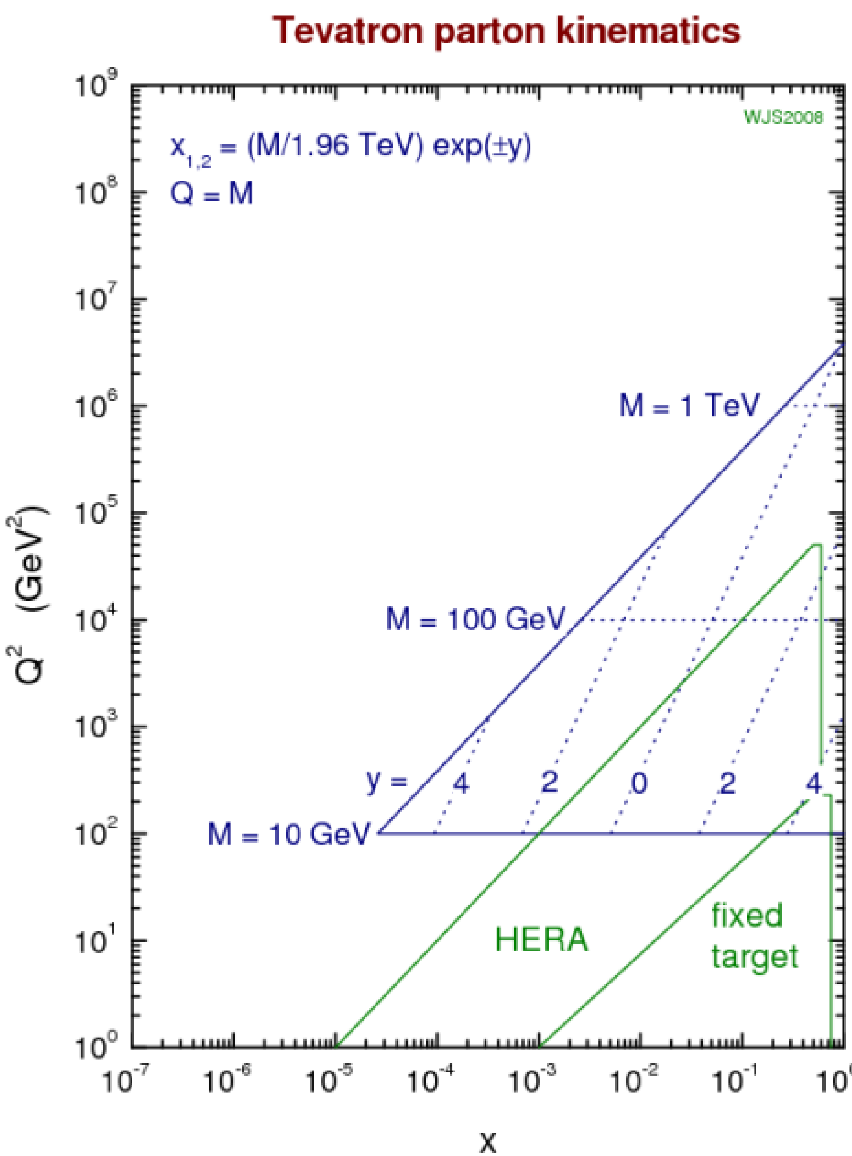


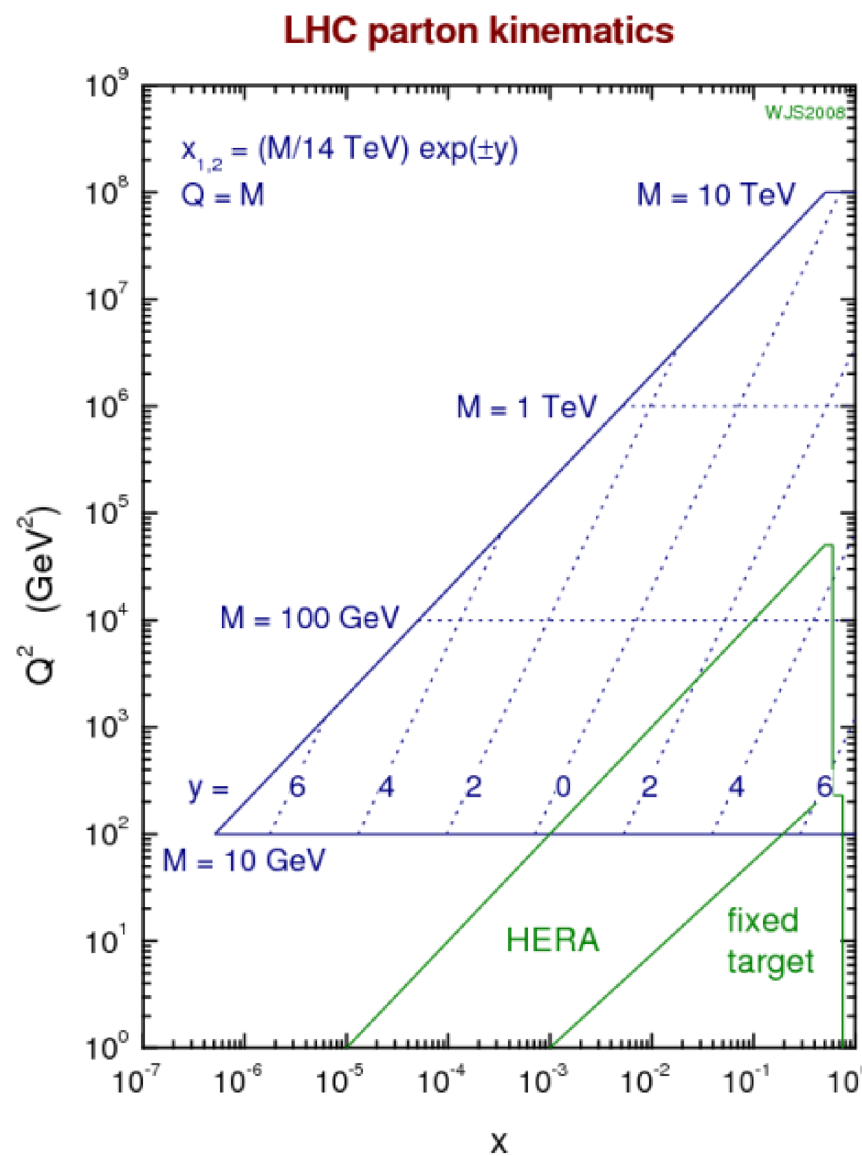
$$P_\tau = -1.06 \pm 0.04\,(stat)\,^{+0.05}_{-0.07}\,(syst).$$

Collins-Soper frame

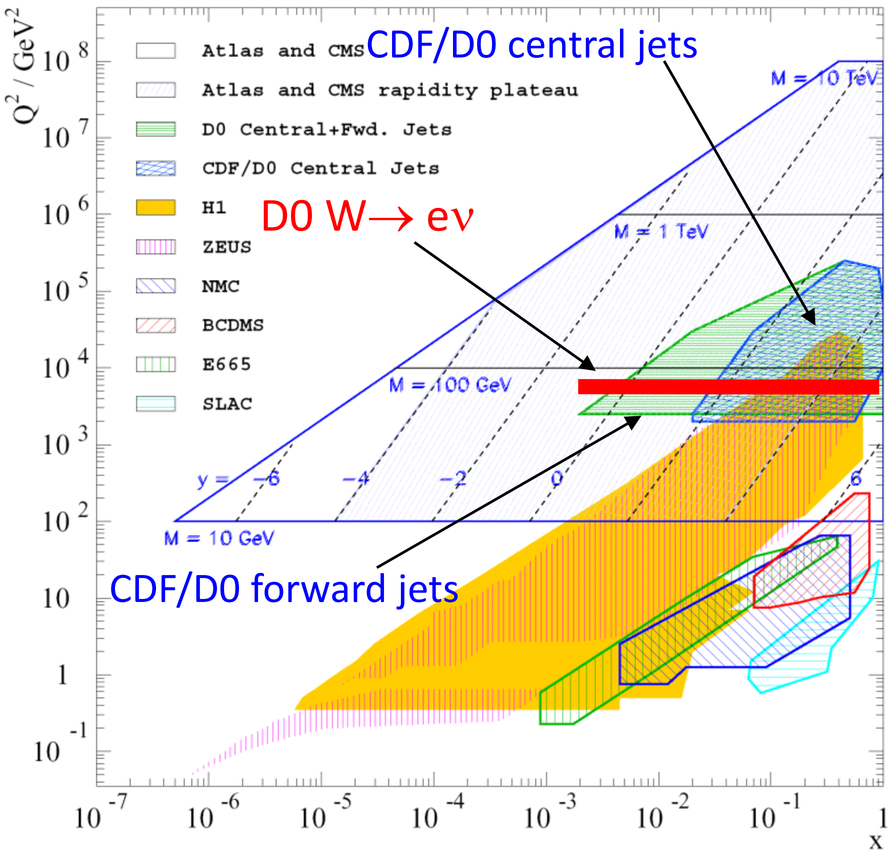


Tevatron compared with LHC





X-Q^2 reach



x = momentum fraction of parton

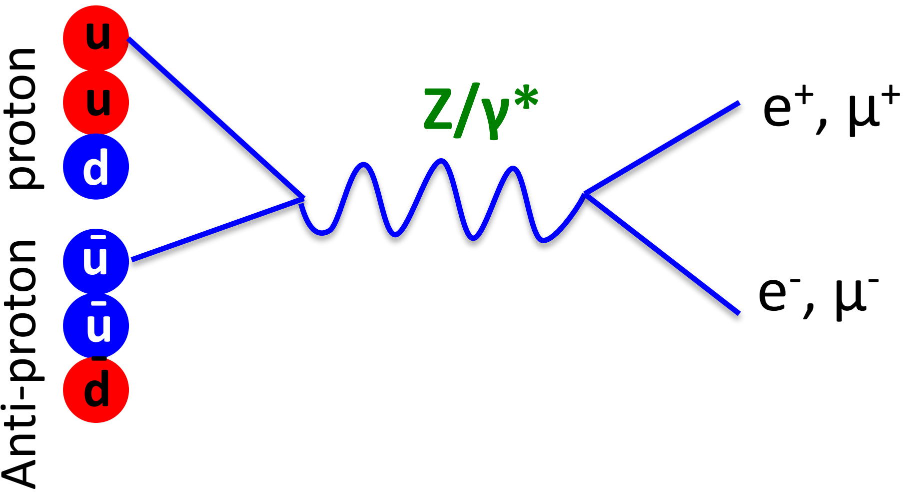
Q^2 = square of momentum transfer

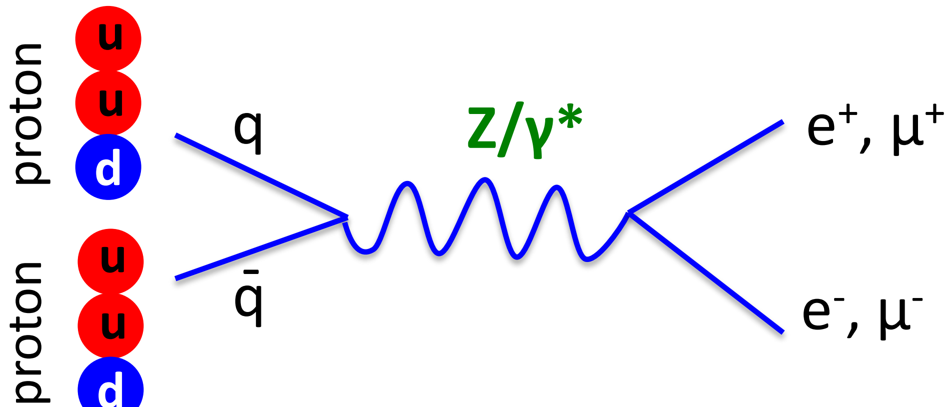
- **W asymmetry measurement:**

$$Q^2 \approx M_W^2, \qquad x = \frac{M_W}{\sqrt{s}} e^{\pm y_W}$$

- This measurement:
  $|y_W| < 3.2 \Rightarrow 0.002 < x < 1.0$
- Previous measurements:
  $|y_W| < 2.5 \Rightarrow 0.003 < x < 0.5$
- Complementary to central and forward jet measurements at D0 and CDF
- CTEQ and MRST groups
- Well constrained PDFs are essential for many measurements and searches at hadron colliders
  - ✓ Expect Tevatron Run II ΔW_M <15 MeV, currently 11 MeV due to PDFs

Tevatron vs. LHC





With known incoming quark direction.

In the forward region, the valence quark has higher momentum.