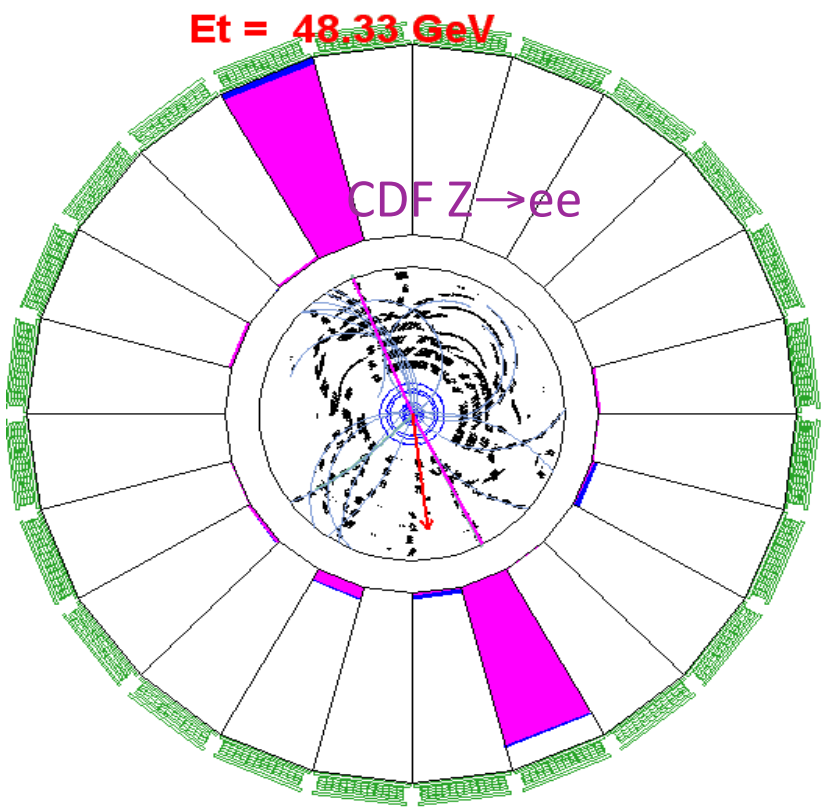
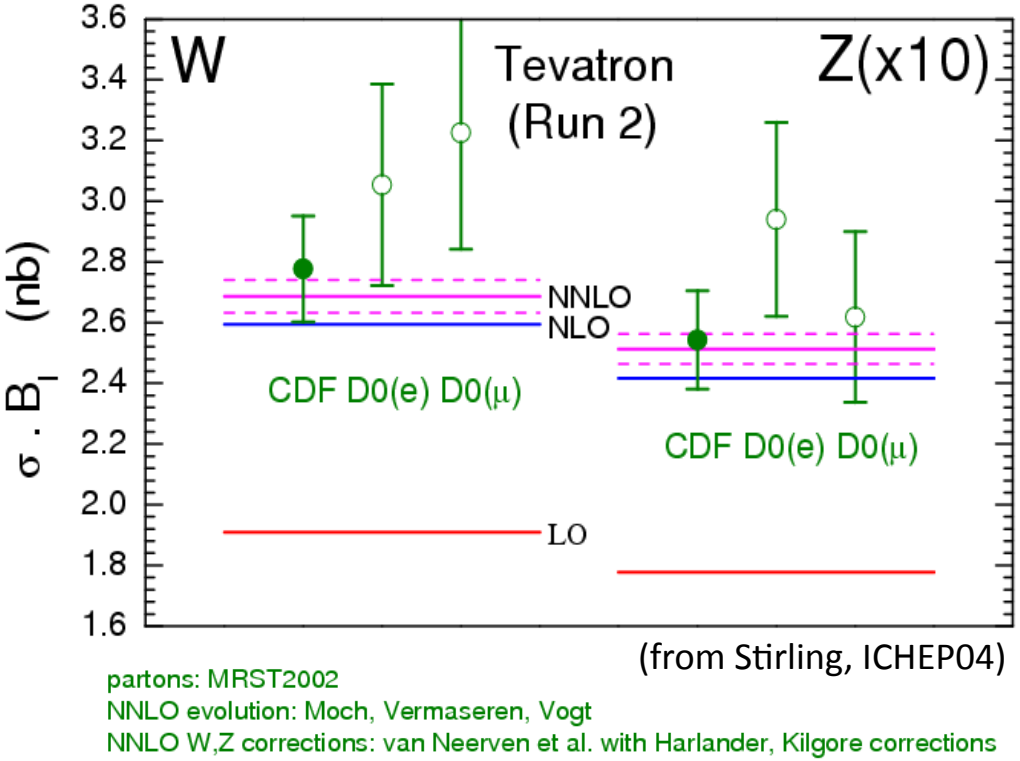
Electroweak Physics at the Tevatron

(excluding dibosons)

Aidan Robson, University of Glasgow
for the CDF and D0 Collaborations

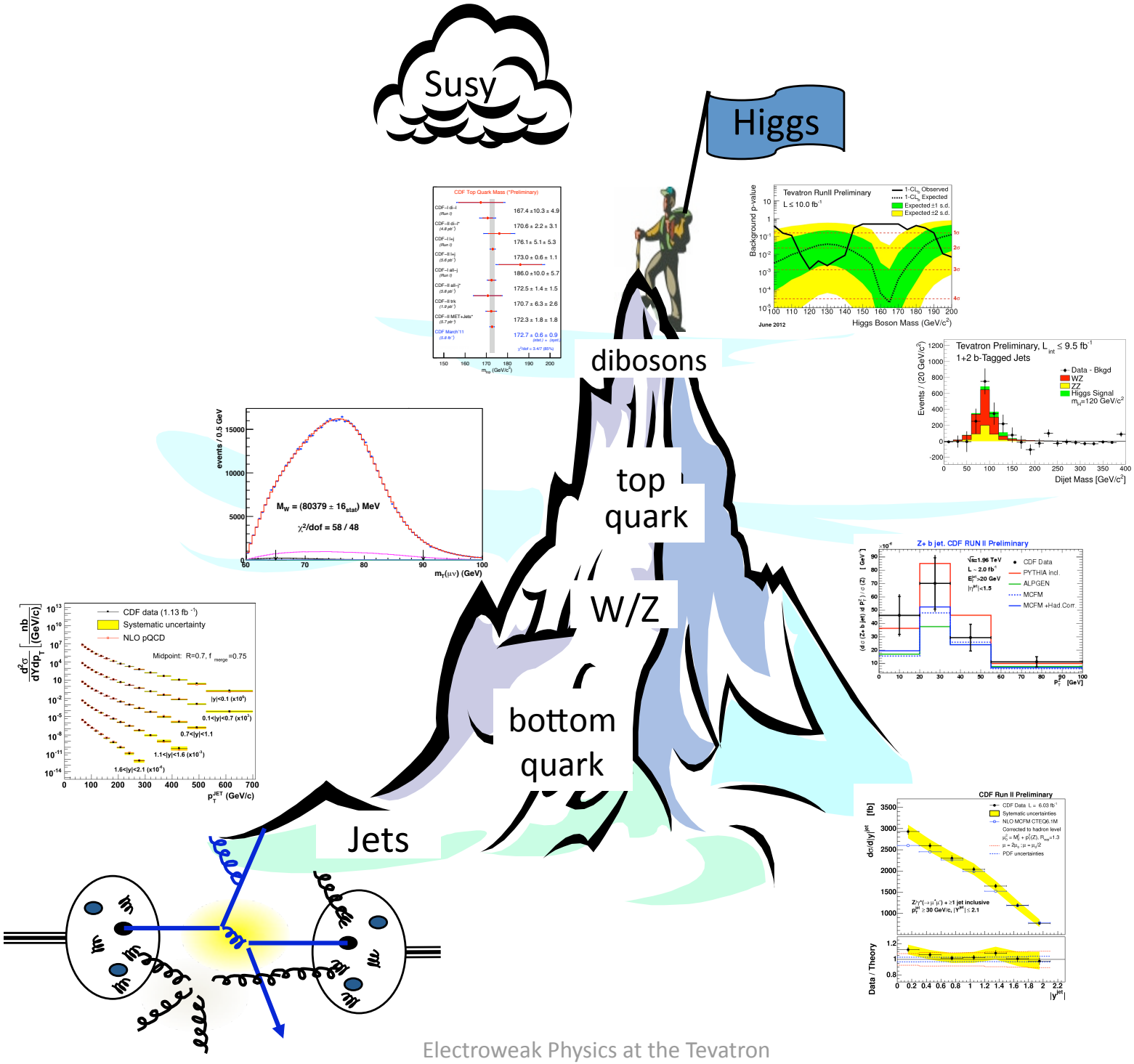
SM@LHC, 9 April 2013





(from Stirling, ICHEP04)

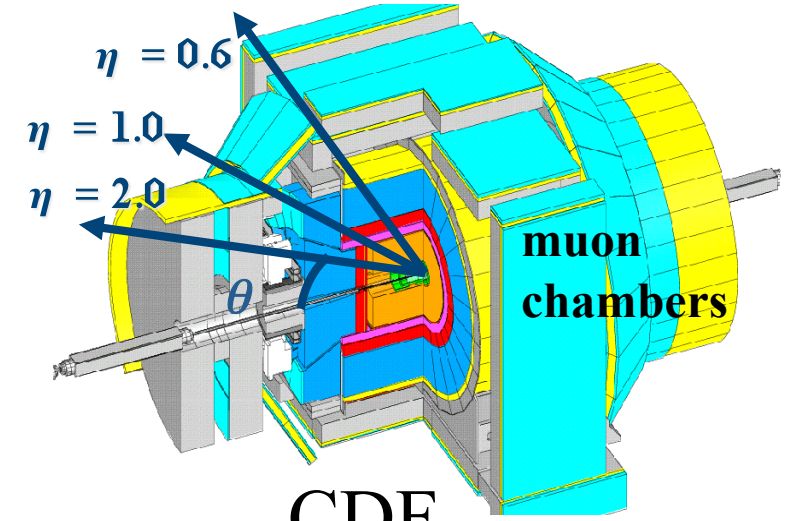
2004, using < 100 pb^{-1}


Susy
Higgs
dibosons
top quark
W/Z
bottom quark
Jets
CDF Top Quark Mass (*Preliminary)
Tevatron RunII Preliminary
Higgs Boson Mass (GeV/c²)
Tevatron Preliminary
1+2 b-Tagged Jets
Dijet Mass [GeV/c²]
M_W = (80379 ± 16_stat) MeV
χ²/dof = 58 / 48
Z+ b jet. CDF RUN II Preliminary
CDF data (1.13 fb⁻¹)
Systematic uncertainty
NLO pQCD
CDF Run II Preliminary
Data / Theory

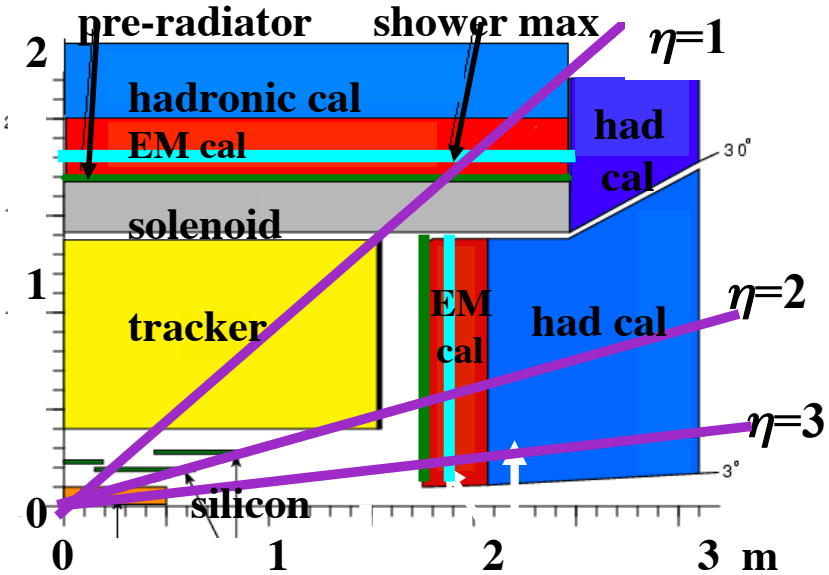
- Motivation
- High-statistics precision measurements
  - $p_T(Z)$ x4
  - Drell-Yan angular distributions
  - m_W
- Outlook

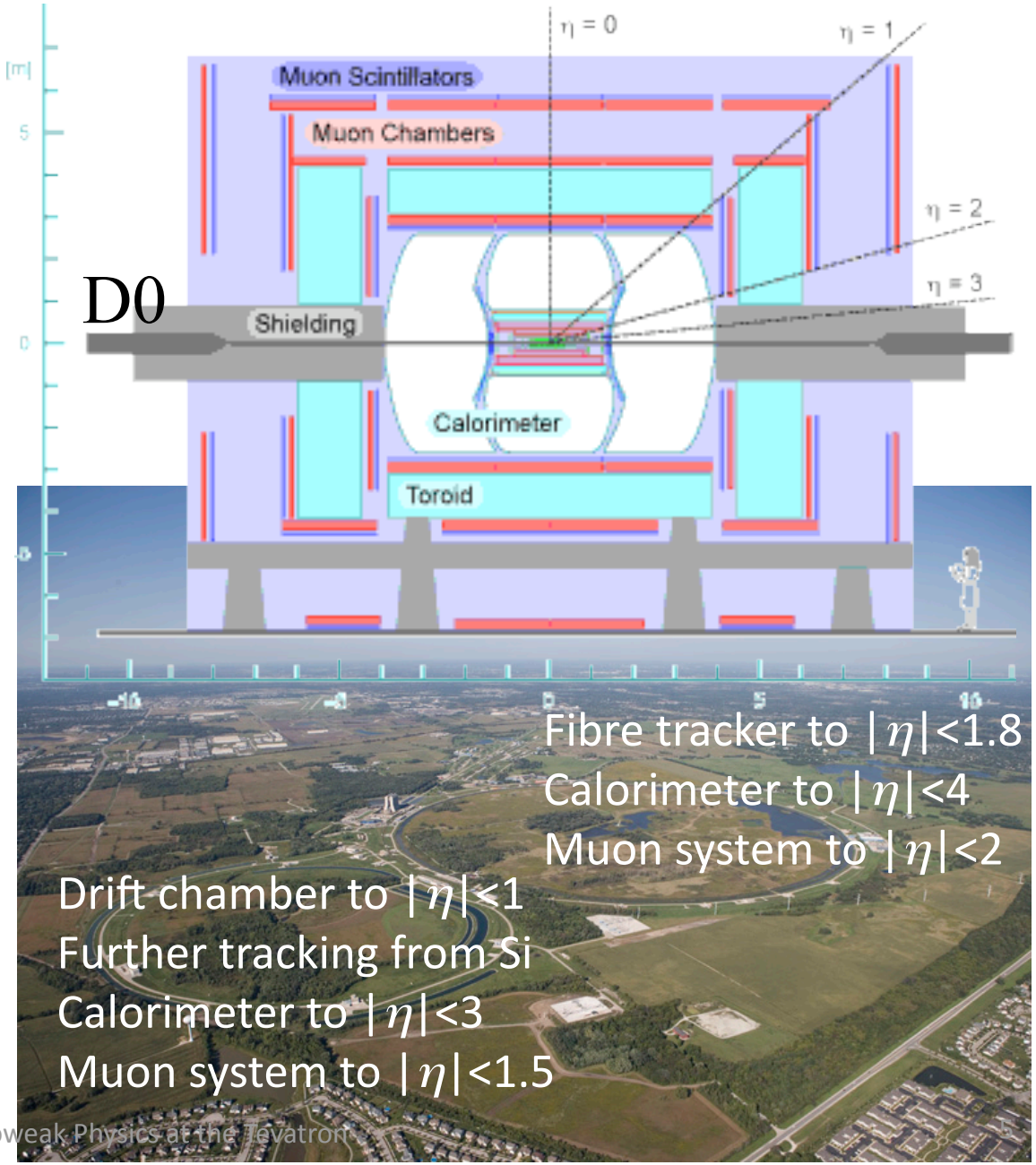
(Diboson physics in later talk from Masahiro Morii)

Tevatron



CDF





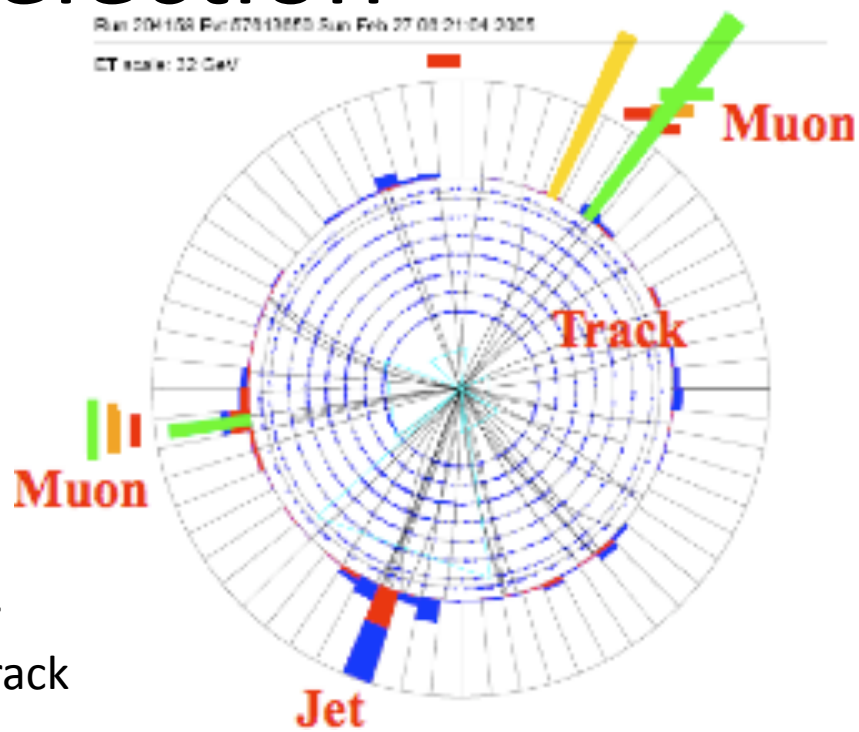
W and Z selection

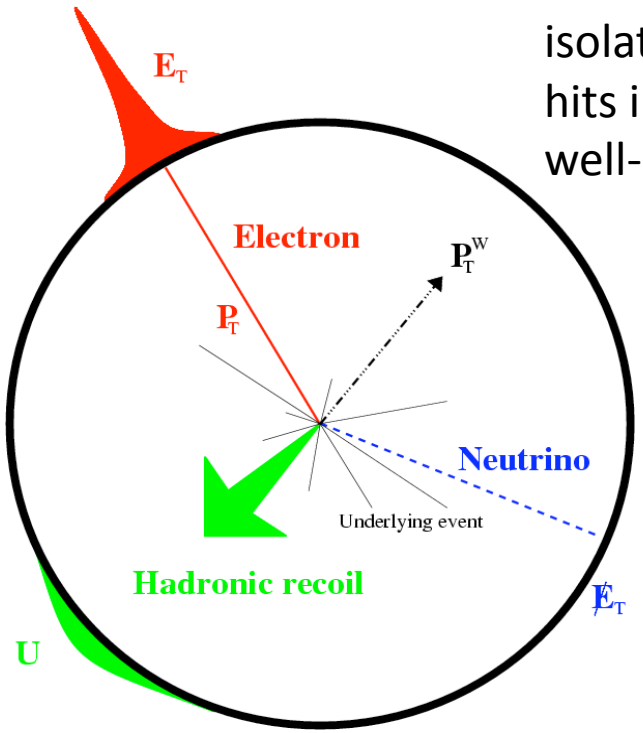
Electrons:

good EM shower shape
small hadronic energy
isolated in calorimeter
well-matching good track
(except far forward)

Muons:

MIP in calorimeter
isolated
hits in muon chamber
well-matching good track



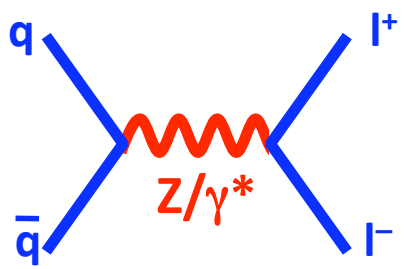


Z selection:

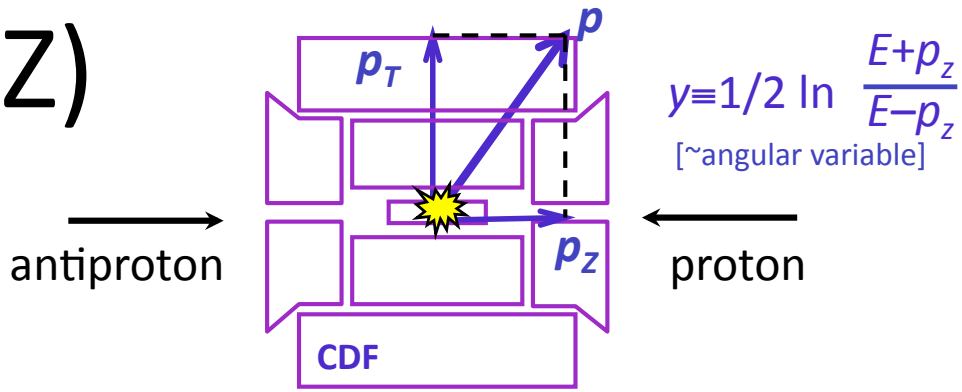
2 oppositely-charged electrons or muons
invariant mass consistent with m_Z

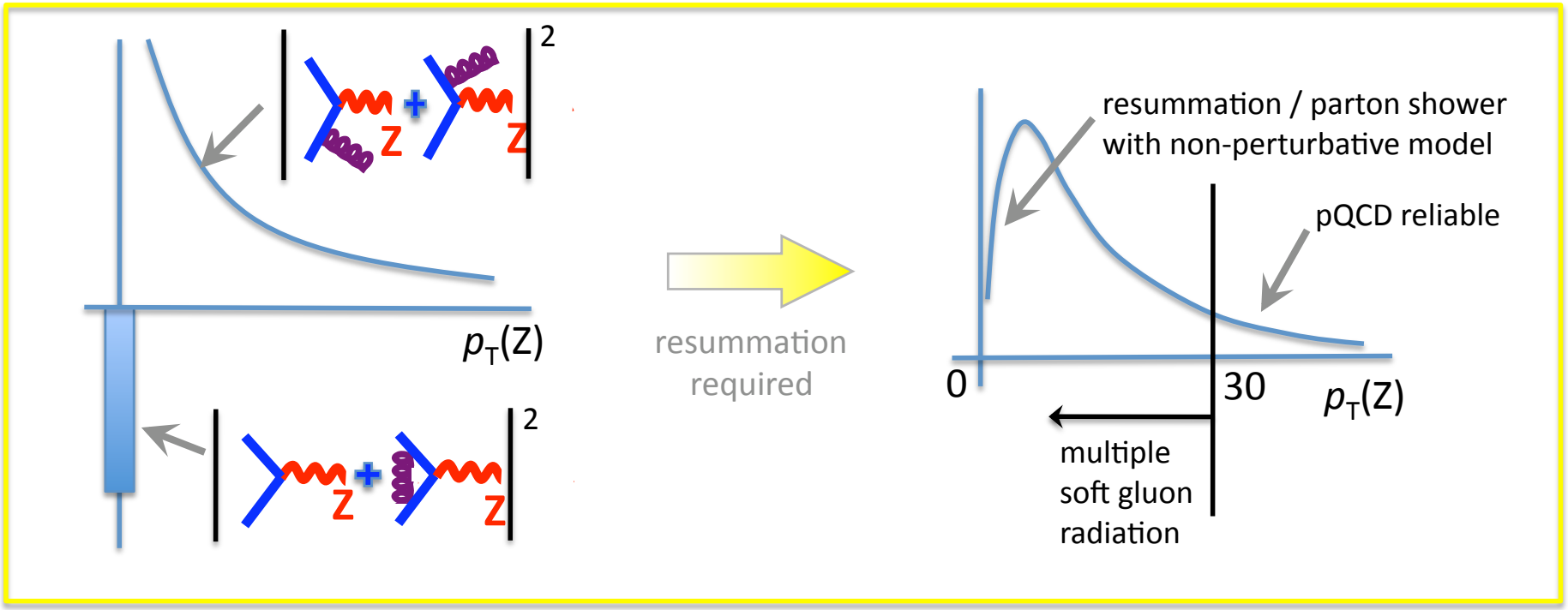
W selection:

exactly one electron or muon
energy imbalance in reconstructed event, associated with neutrino

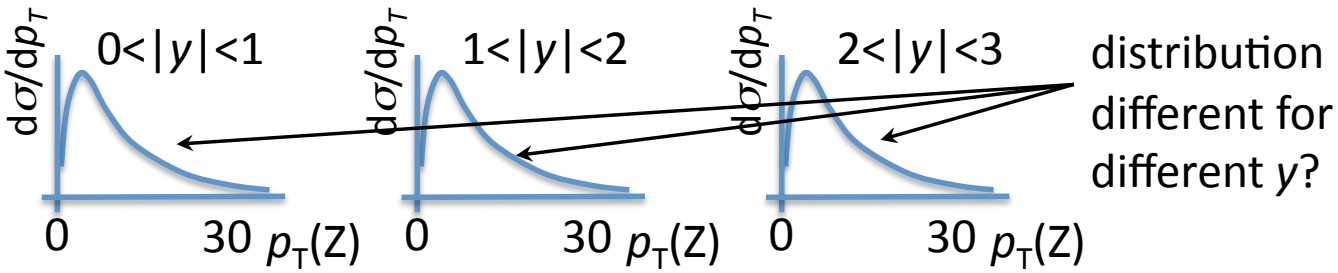


$p_T(Z)$



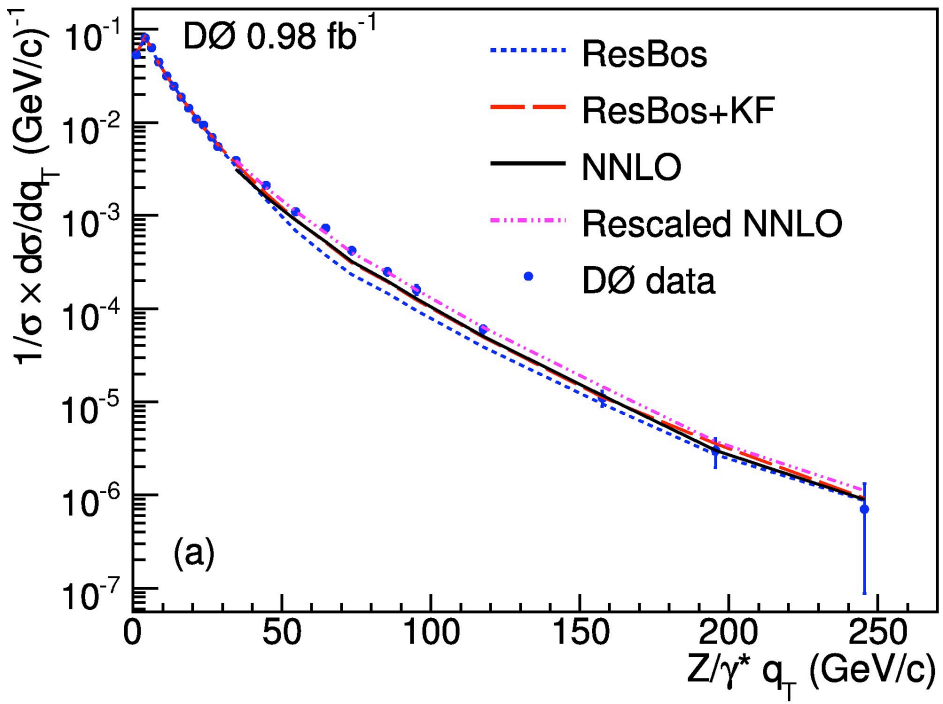


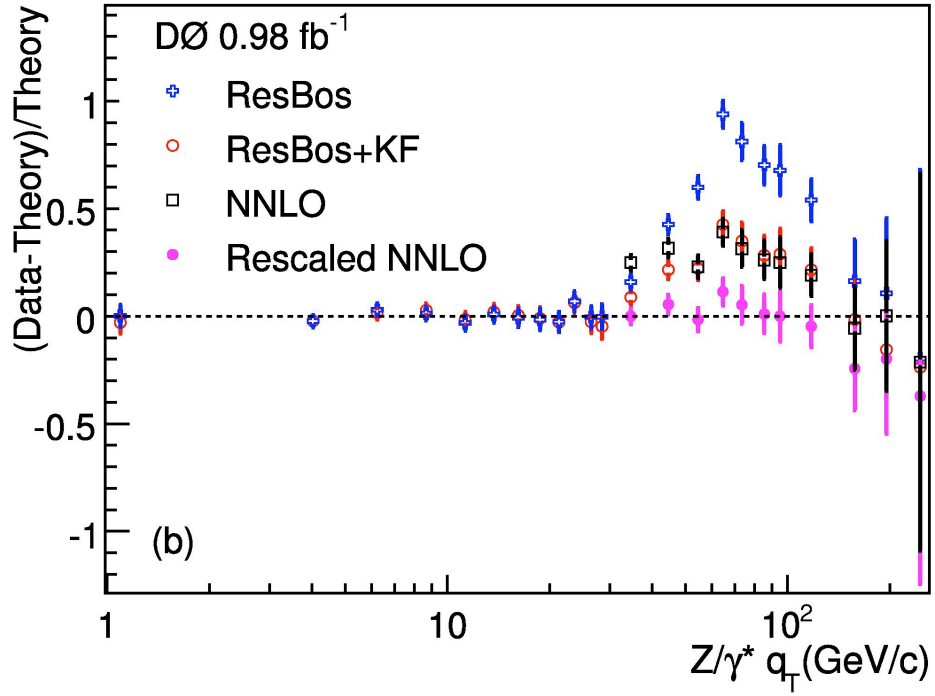
event generator tuning



Earlier $p_T(Z)$

Electron channel:





PRL **100** (2008) 102002

Compare 4 models:

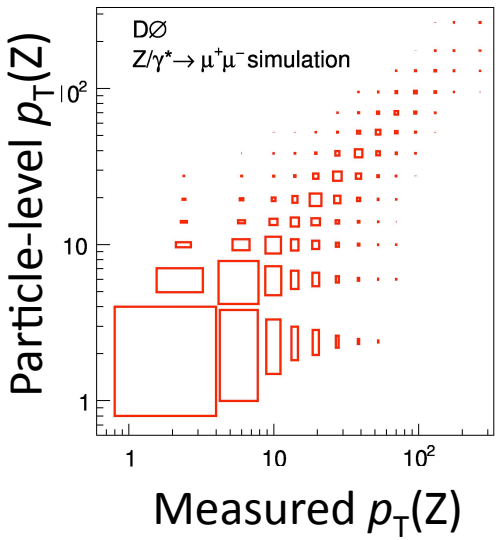
- Resbos with default parameters
- Resbos with additional NLO–NNLO K-factor
- NNLO (Melnikov and Petriello)
- NNLO rescaled to data at 30GeV/*c*

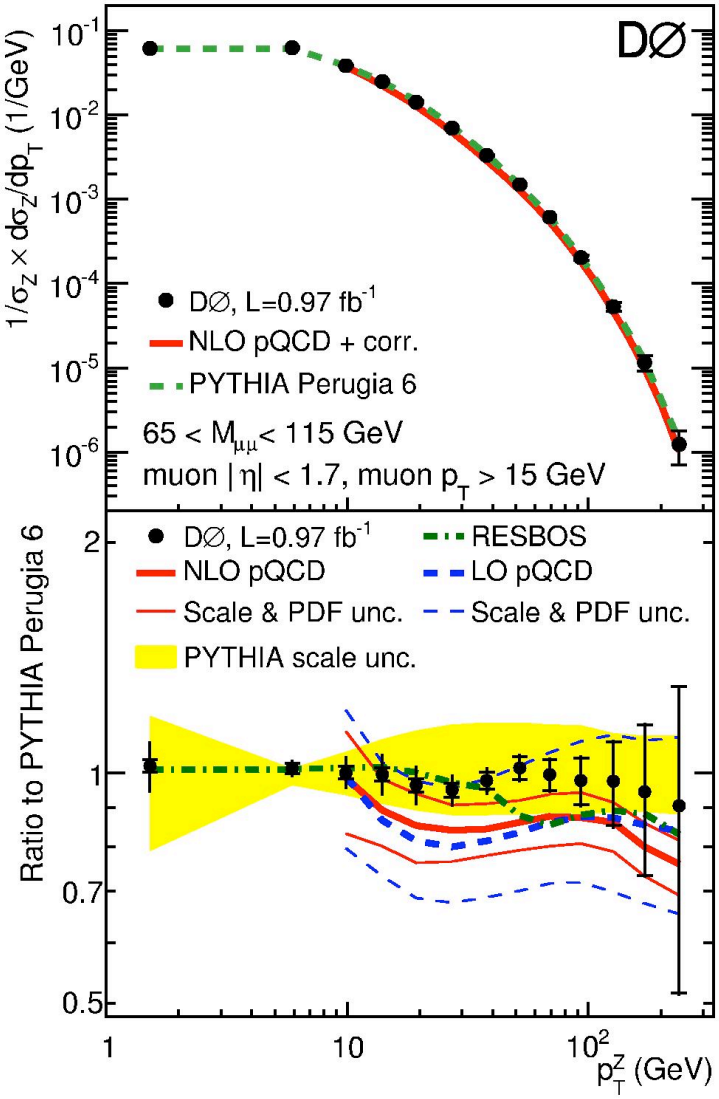
RESBOS event generator implements NLO QCD and CSS resummation

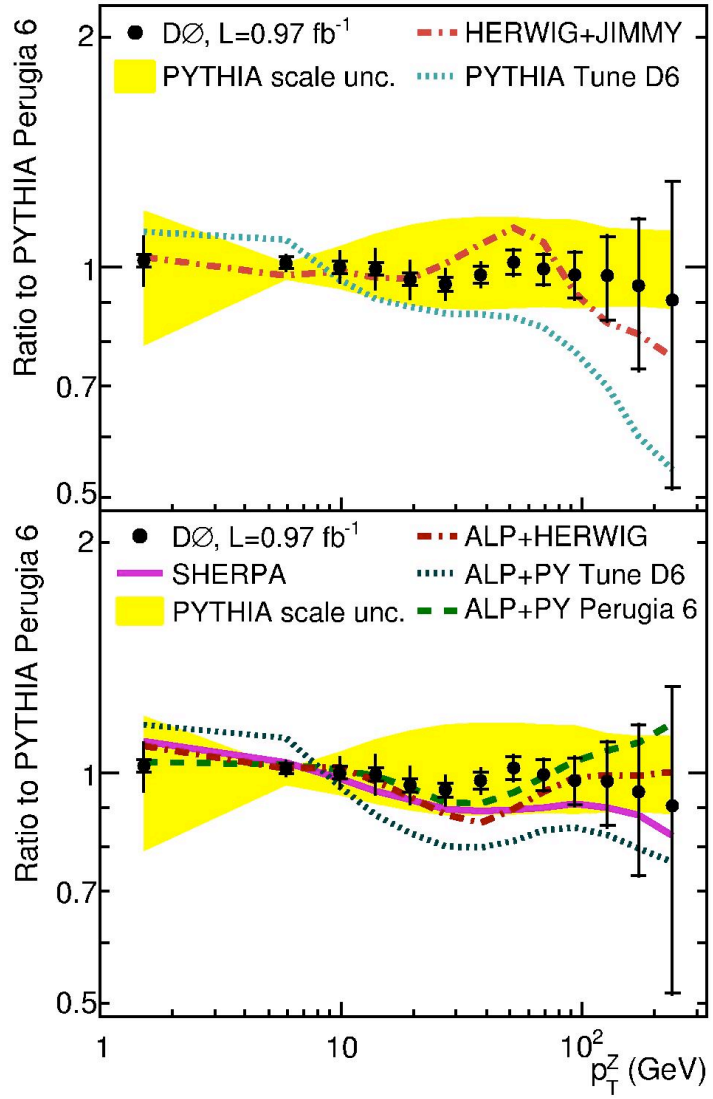
$p_T(Z)$

Further measurement in muon channel

Presented at the level of particles entering the detector to avoid model-dependent corrections

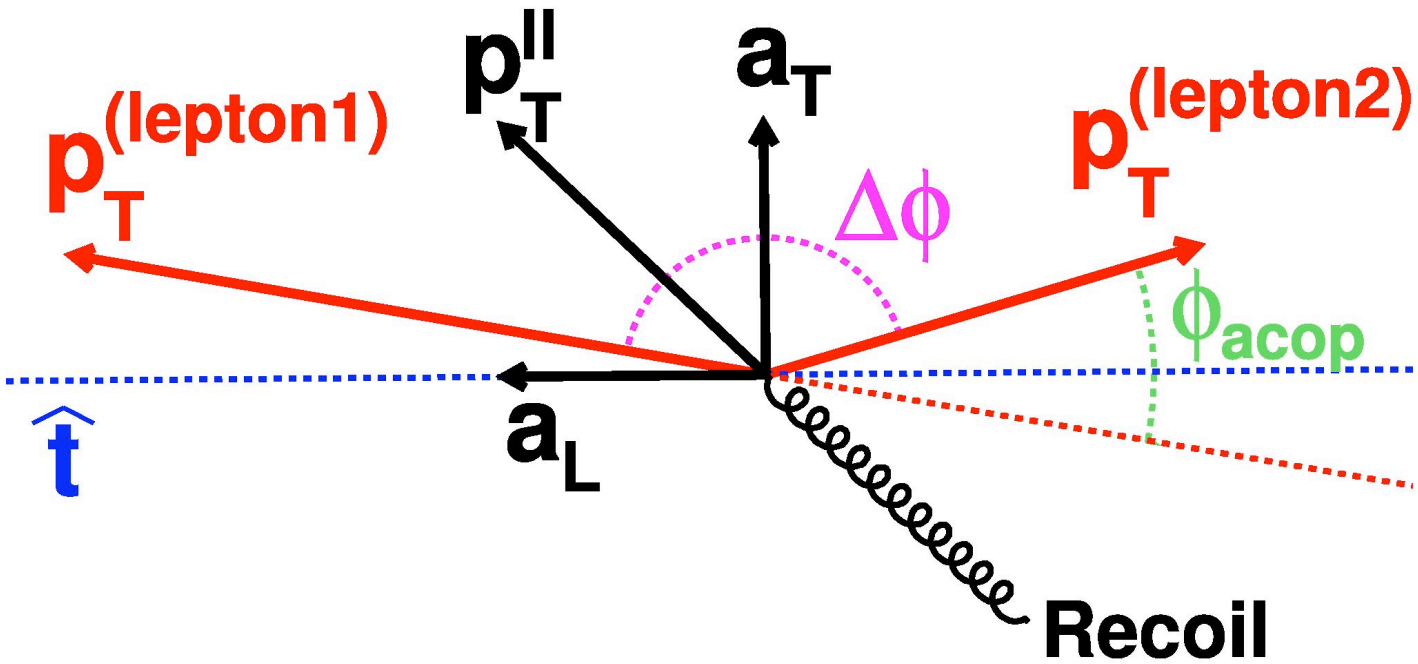






Phys. Lett. B **693** (2010) 522

ϕ^*_η

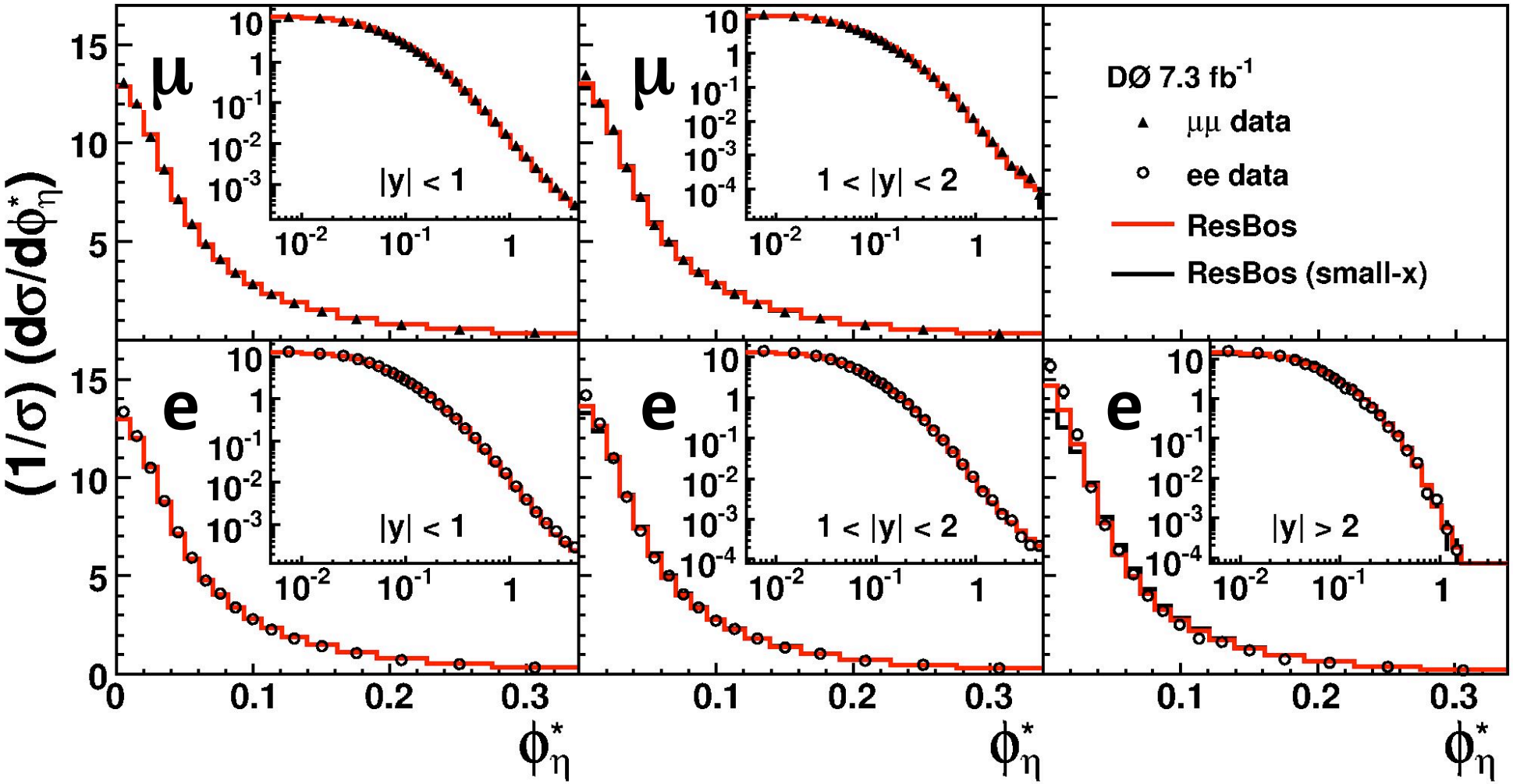


a_T : component of p_T(ll) transverse to dilepton thrust axis.
Less susceptible than p_T(ll) to detector effects

Best variable: $\phi^*_\eta = \tan(\phi_{acop}/2)\sin(\theta^*_\eta)$ – highly correlated with a_T/m_{ll}

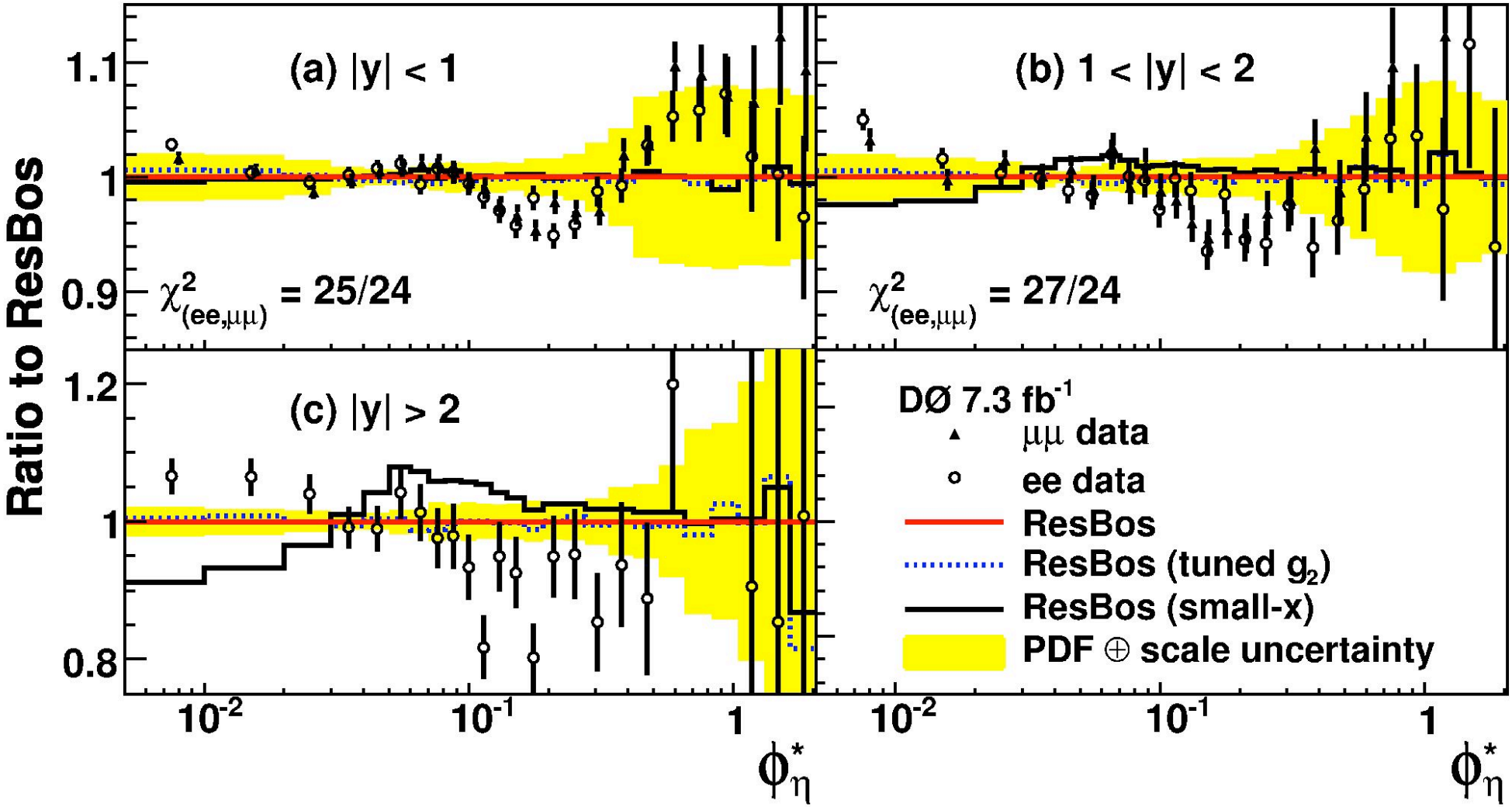
(θ^*_η measures scattering angle of leptons wrt beam, in rest frame of dilepton system)

ϕ^*_η



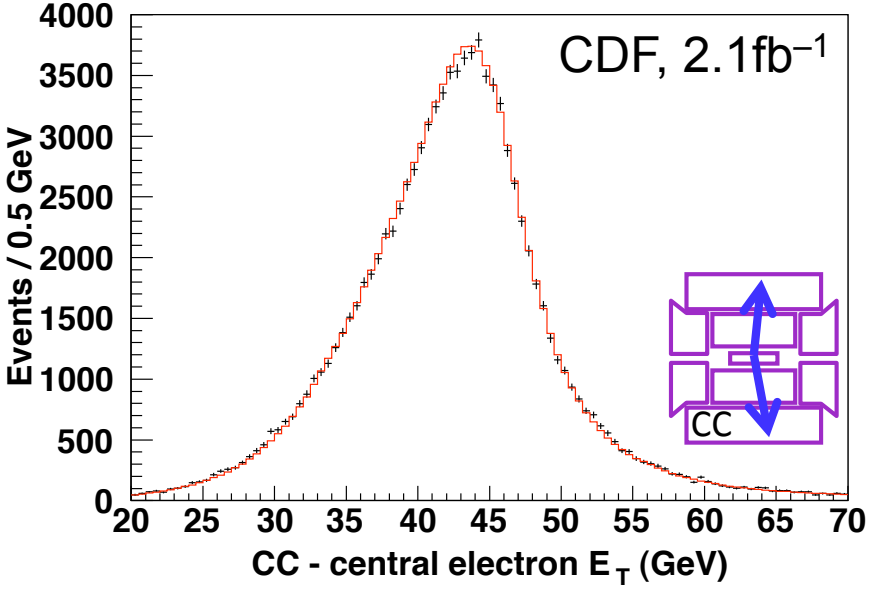
PRL **106** (2011) 122001

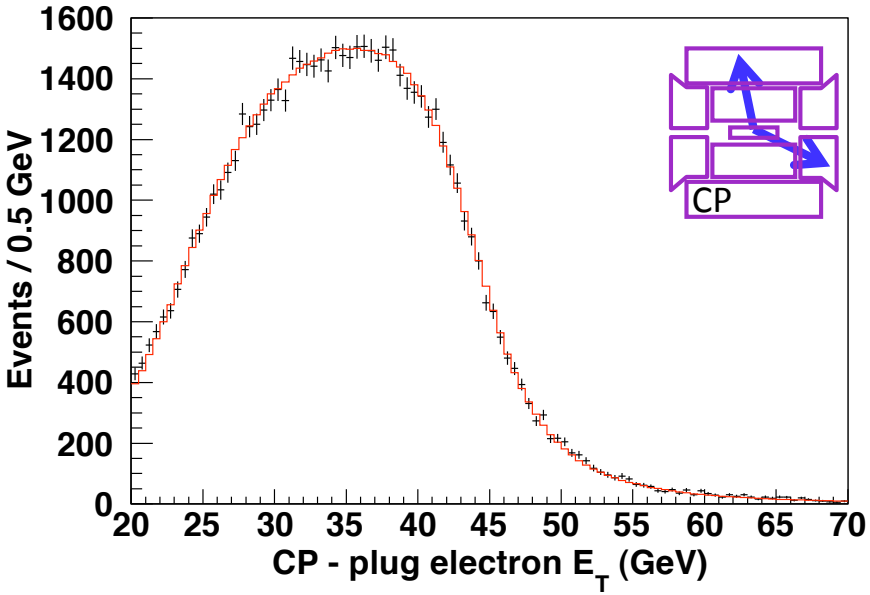
ϕ^*_η

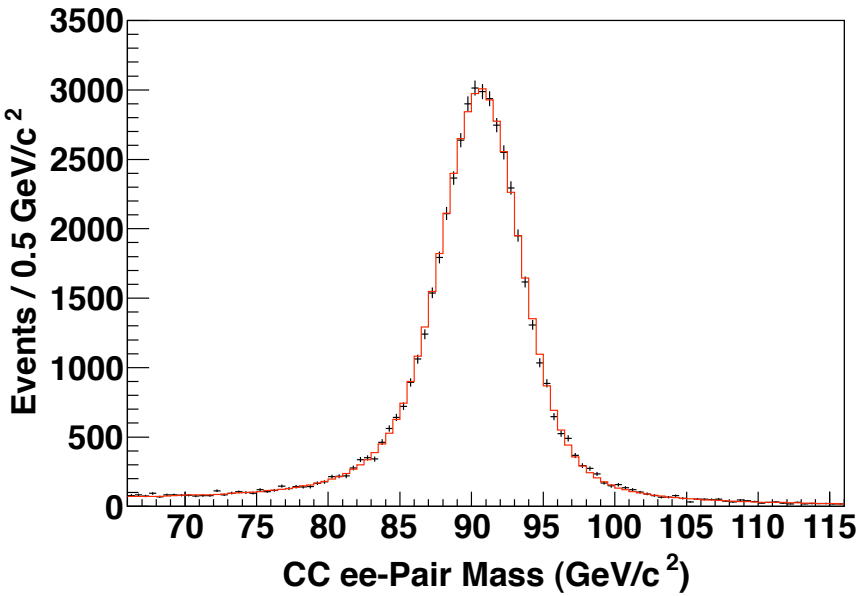


PRL **106** (2011) 122001

Drell-Yan at CDF





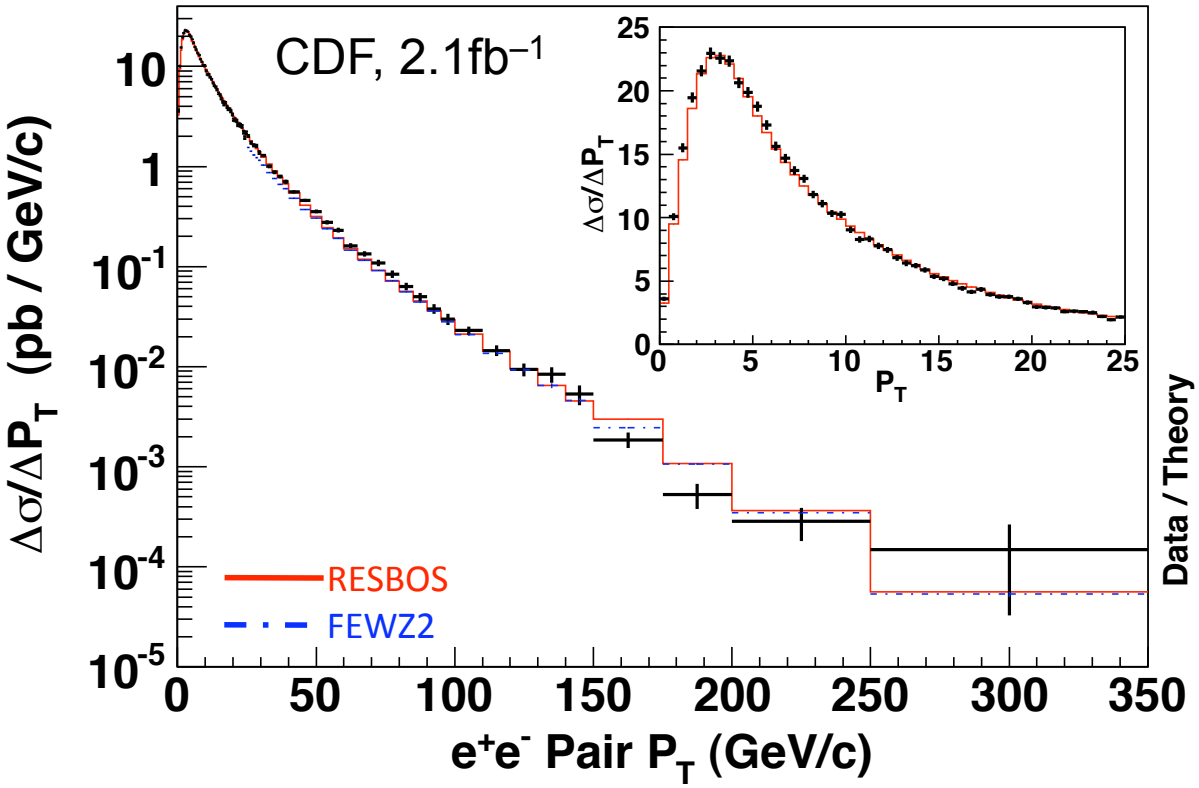


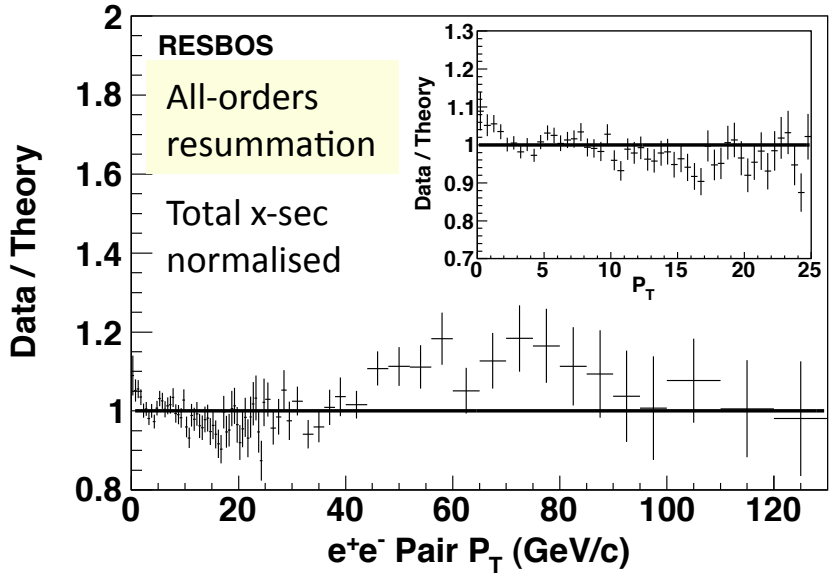
Careful tuning of the simulation and differential corrections
→ set of precise measurements

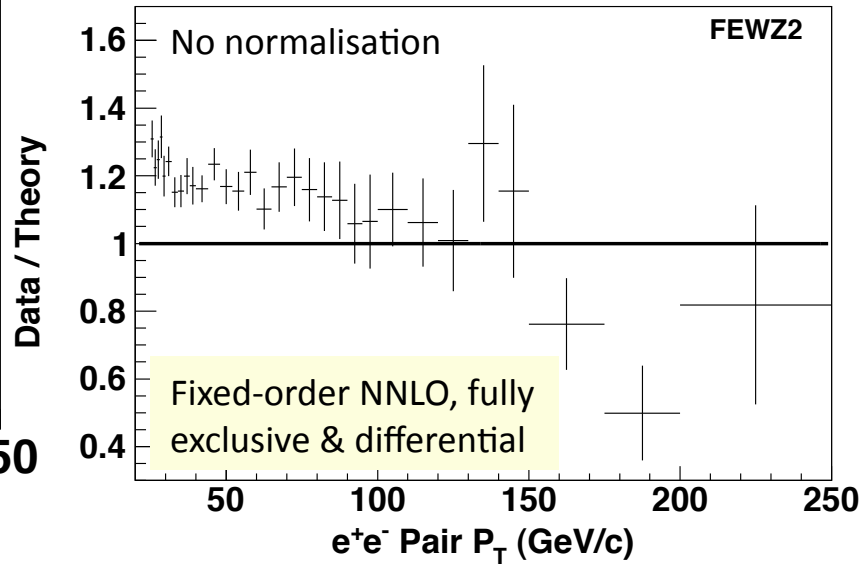
PRD **86** (2012) 052010

$p_T(Z)$

Detector acceptance and resolution unfolded to include all boson rapidities



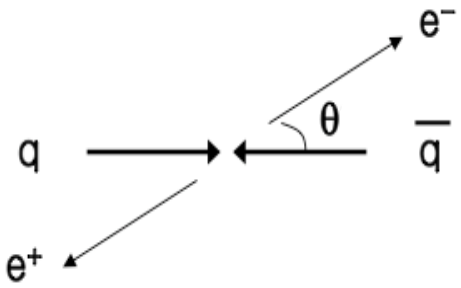




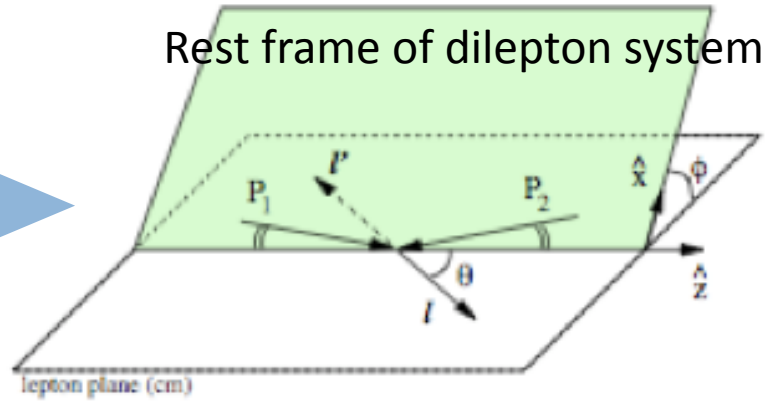
PRD **86** (2012) 052010

Drell-Yan angular coefficients

$q\bar{q} \to Z/\gamma* \to \ell^+\ell^-$



Rest frame of dilepton system



$$\frac{d\sigma}{dP_T^2 dy d\cos\theta d\phi} \propto (1+\cos^2\theta)$$ → *LO term*

$$+ \frac{1}{2}A_0(1-3\cos^2\theta)$$ → *$\cos^2\theta$: higher order term*

$$+ A_1 \sin 2\theta \cos\phi + \frac{1}{2}A_2 \sin^2\theta \cos 2\phi + A_3 \sin\theta\cos\phi$$ → *(θ, ϕ) terms*

$$+ A_4 \cos\theta$$ → *LO term : determine A_{fb}*

$$+ A_5 \sin^2\theta \sin 2\phi + A_6 \sin 2\theta \sin\phi + A_7 \sin\theta \sin\phi$$ → *very small terms*

Integrate over all ϕ ,

$$\frac{d\sigma}{d\cos\theta} \propto (1+\cos^2\theta) + \frac{1}{2}A_0(1-3\cos^2\theta) + A_4\cos\theta$$

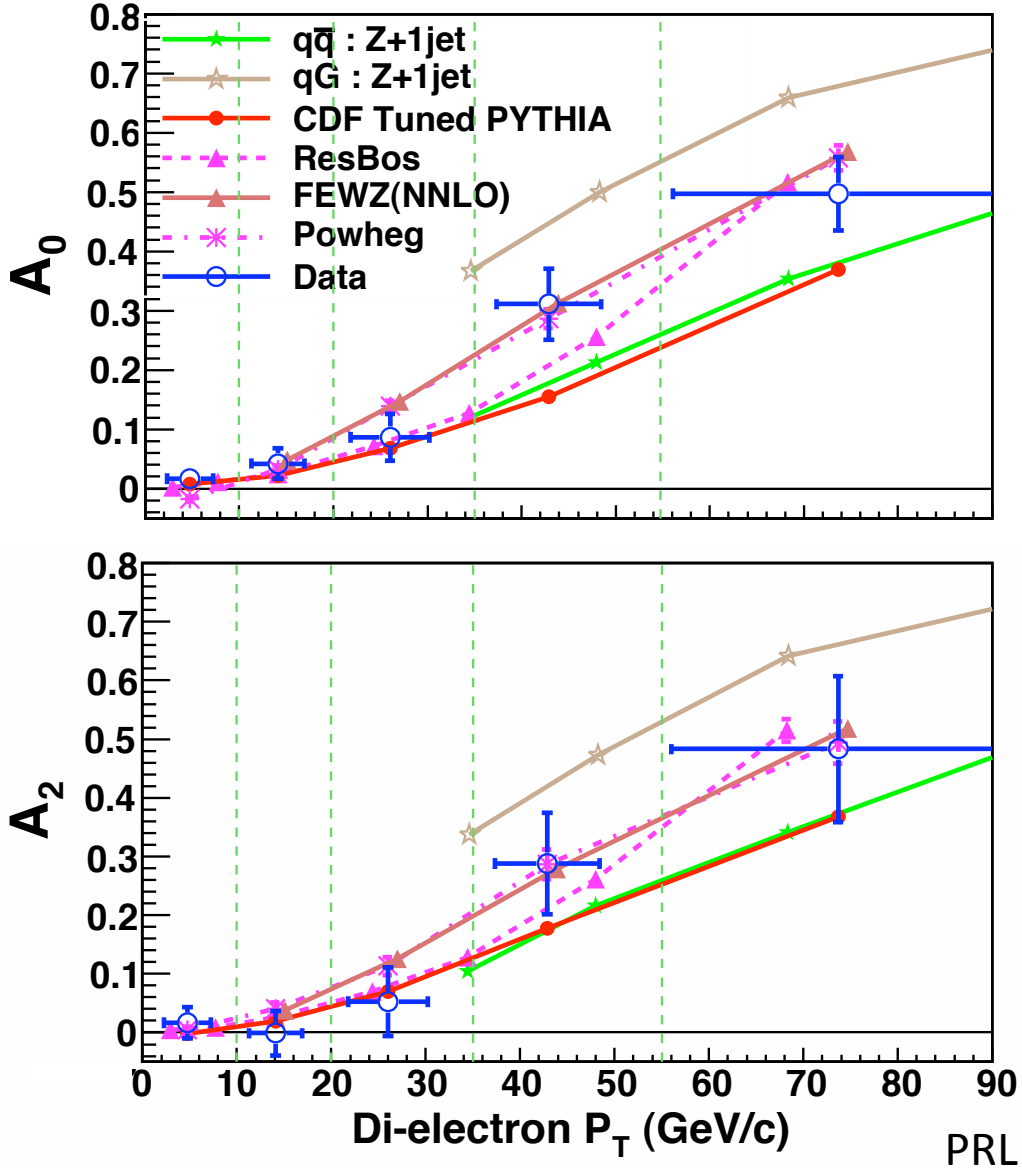
measure as function of p_T

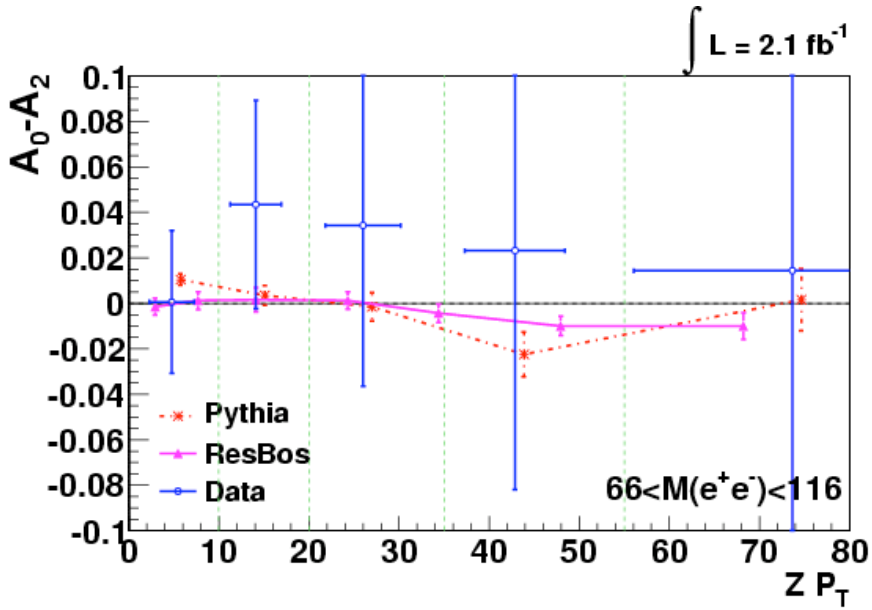
Integrate over all $\cos\theta$,

$$\frac{d\sigma}{d\phi} \propto 1 + \frac{3\pi A_3}{16}\cos\phi + \frac{A_2}{4}\cos 2\phi + \frac{3\pi A_7}{16}\sin\phi + \frac{A_5}{4}\sin 2\phi$$

$\frac{3\pi A_7}{16}\sin\phi \to 0$, $\frac{A_5}{4}\sin 2\phi \to 0$

Drell-Yan angular coefficients

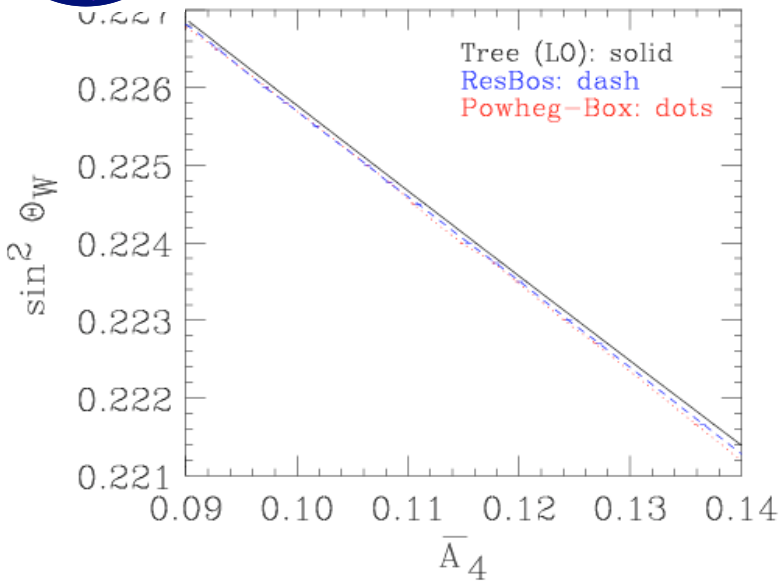




A_2=A_0 at leading order
'Lam-Tung' relation
True only for spin-1 gluons,
strongly broken for scalar gluons

PRL **106** (2011) 241801

$\sin^2\theta_W$

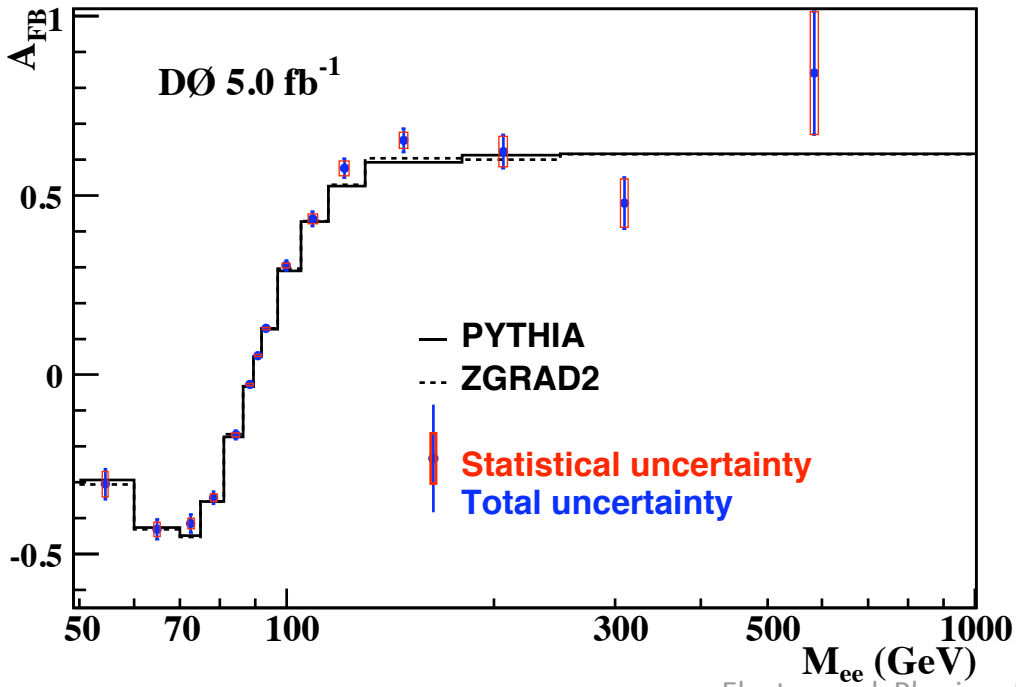


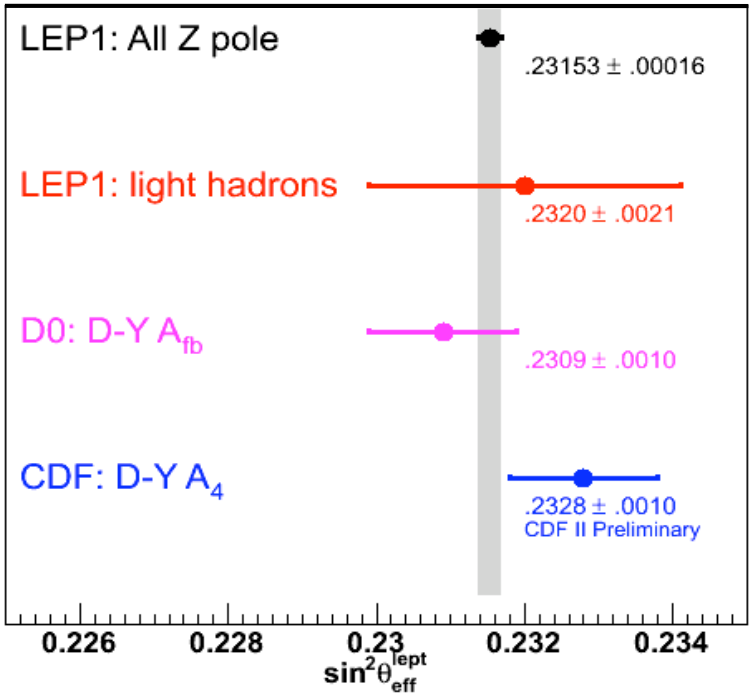
A_4 sensitive to Weinberg angle

A_4 using 2.1 fb^{-1} data = 0.110 ± 0.008

Translated to $\sin^2\theta_W$:
$\sin^2\theta_W = 0.2328 \pm 0.0010$

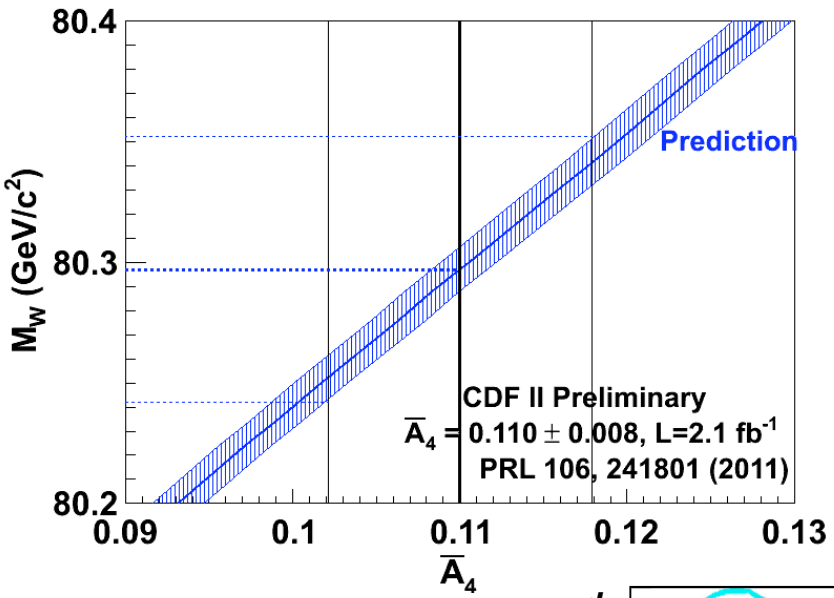
CDF Run II Preliminary

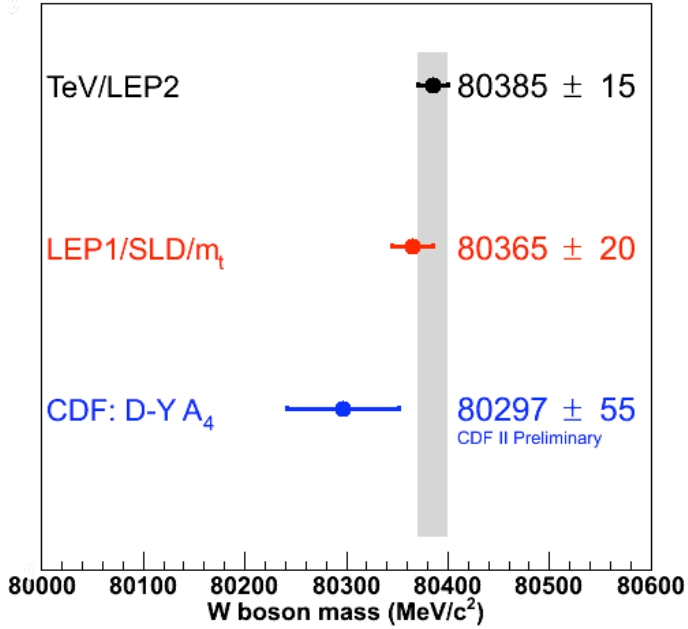


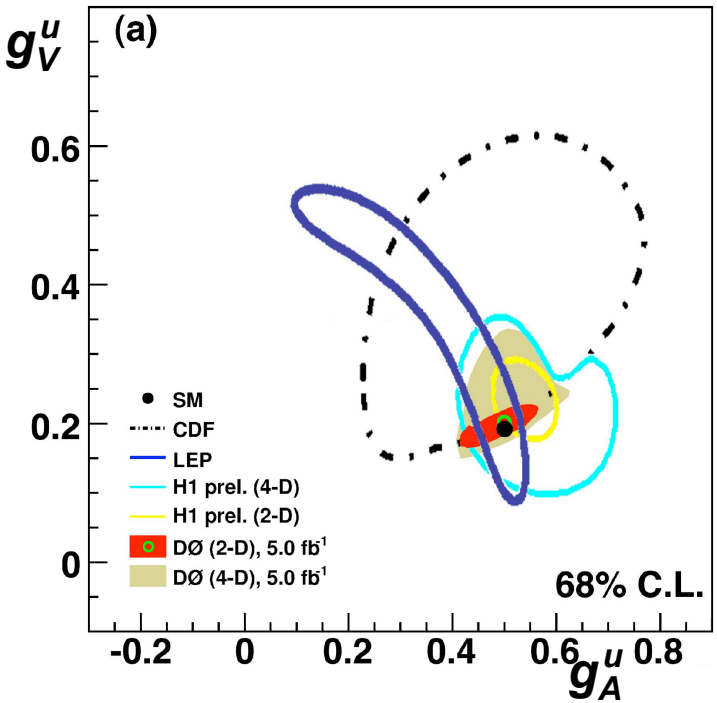


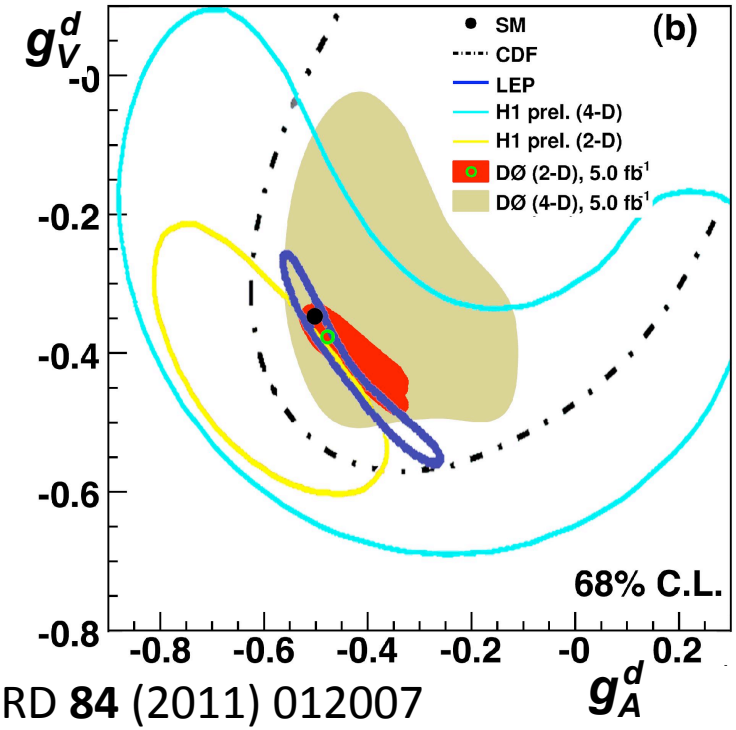
m_W & couplings

$\sin^2\theta_W$ from Z boson A_{FB} → best determination of light-quark couplings



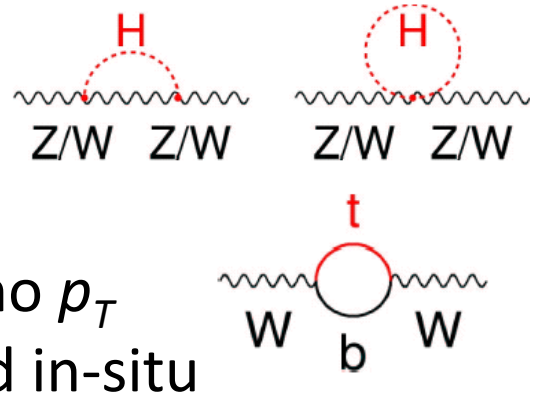






PRD **84** (2011) 012007

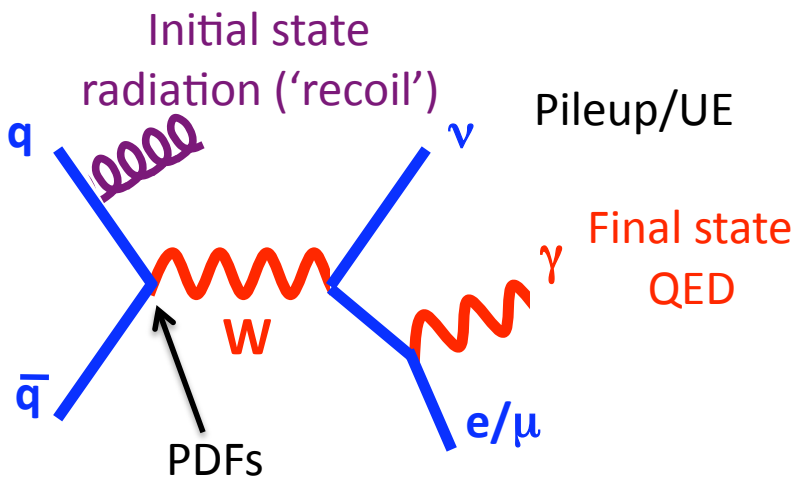
m_W

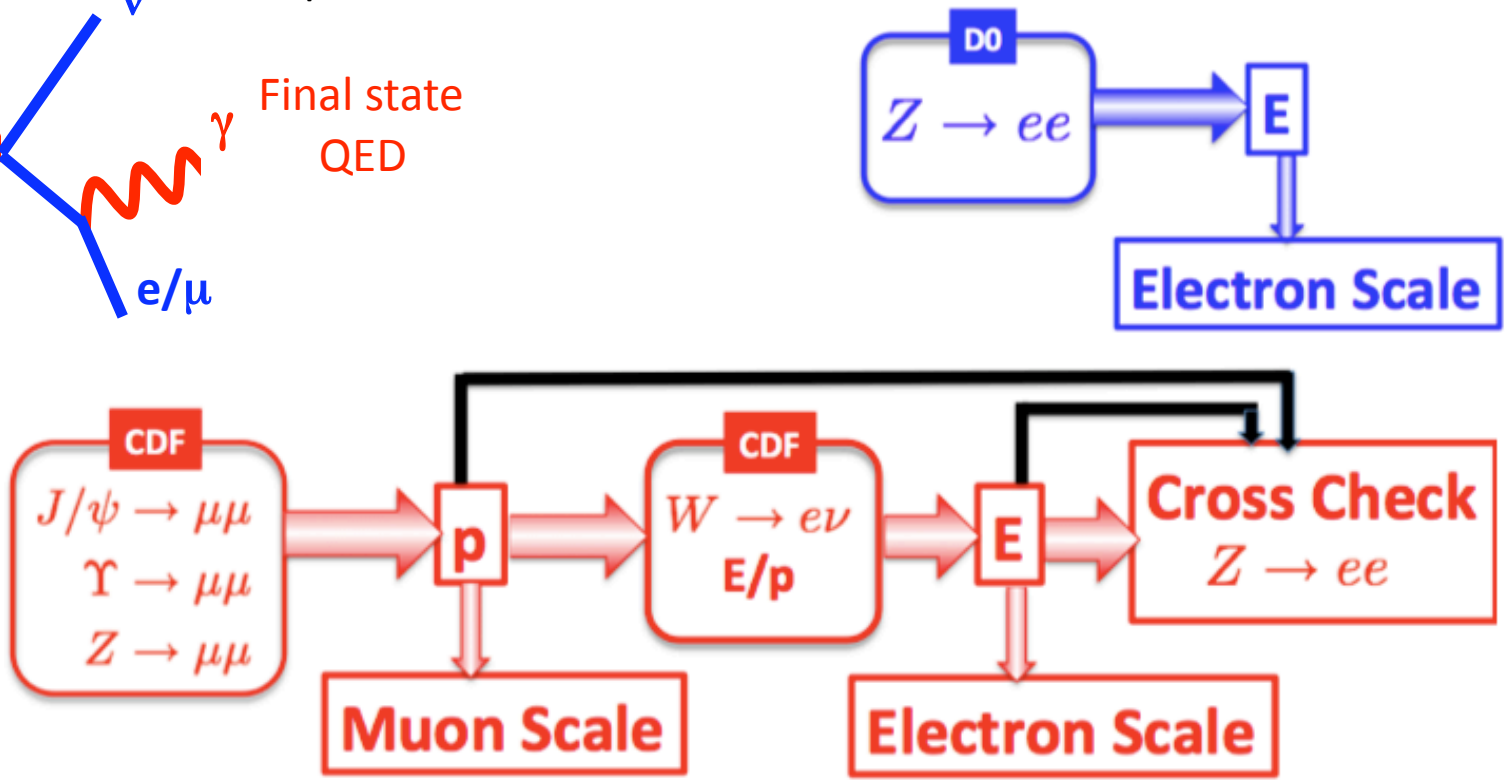


W mass determined from template fits to:

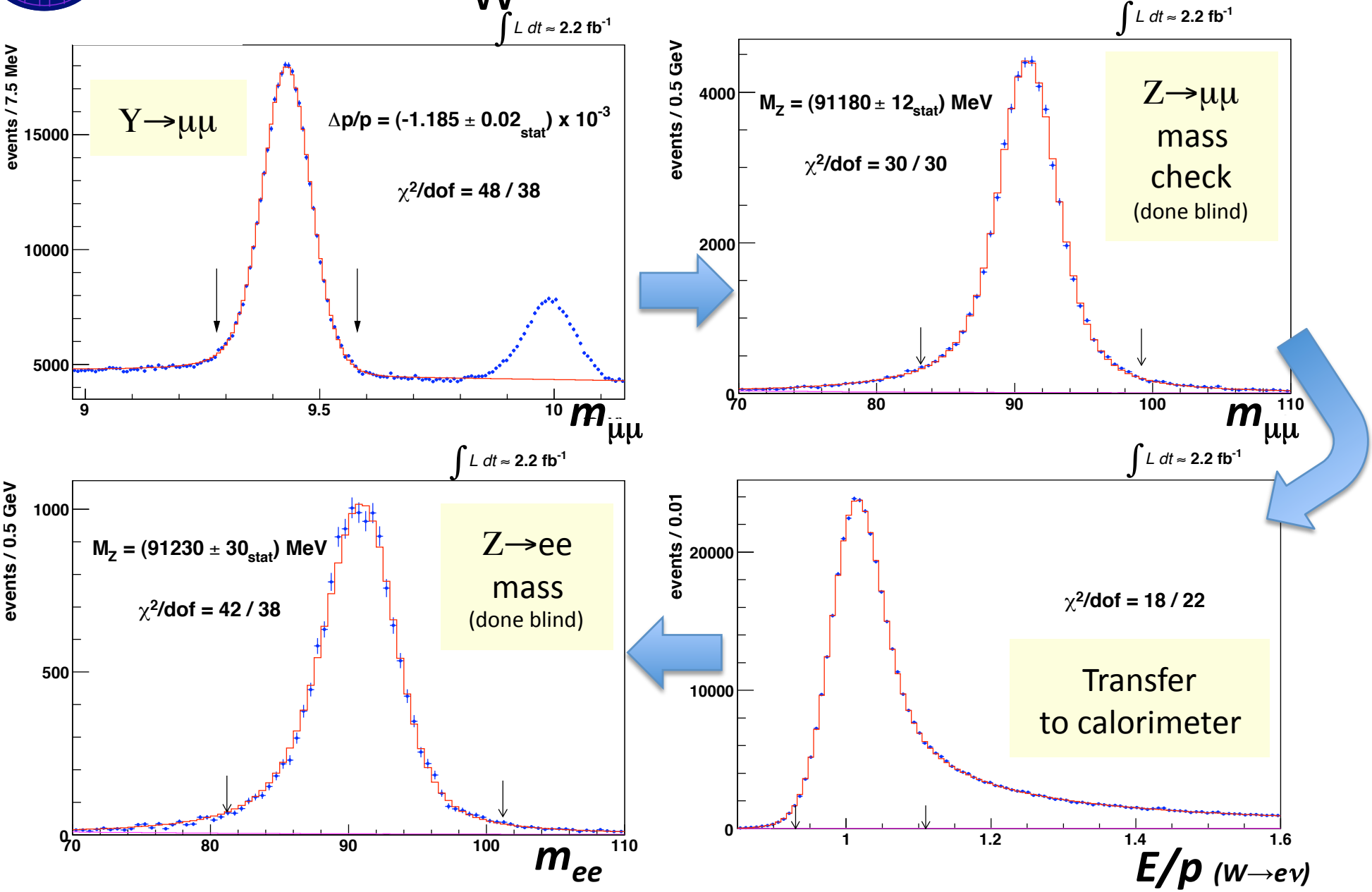
charged-lepton p_T, boson m_T, and neutrino p_T

Lepton and recoil measurements calibrated in-situ



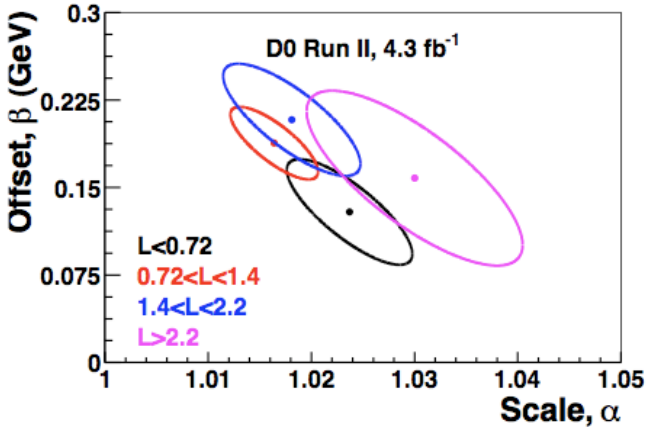


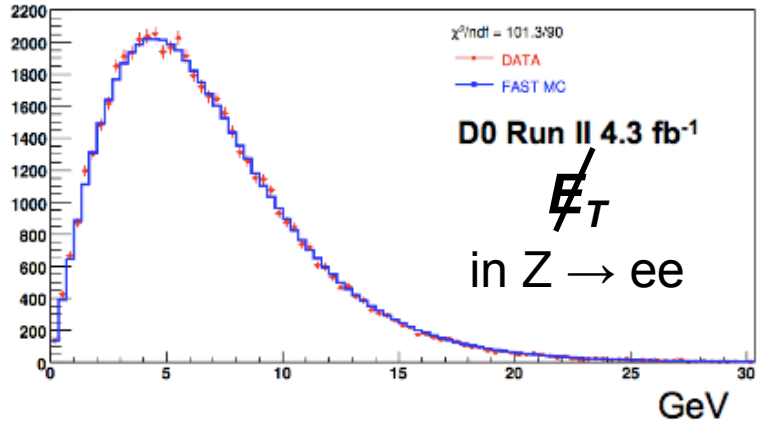
m_W : calibration



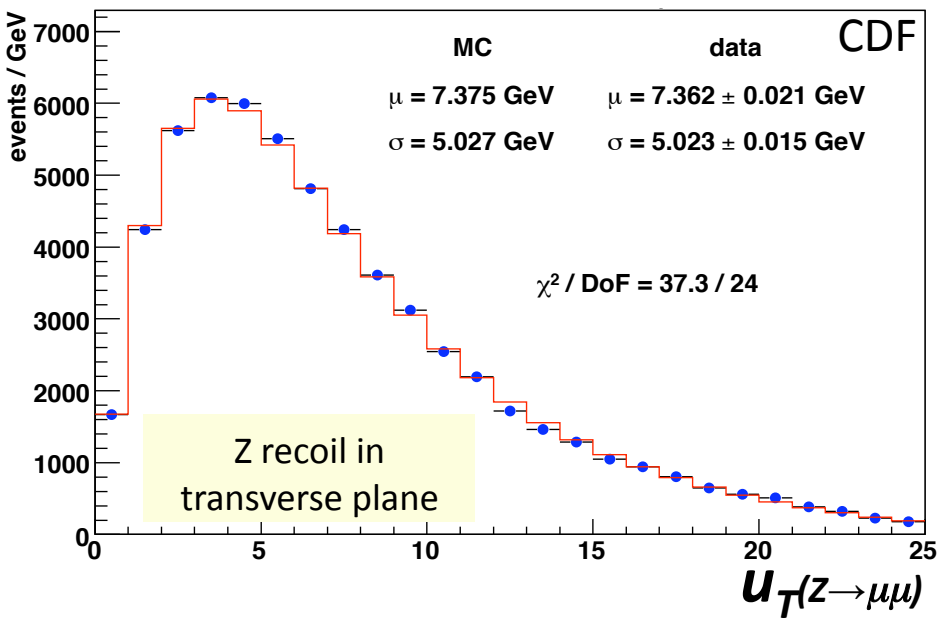
m_W : calibration

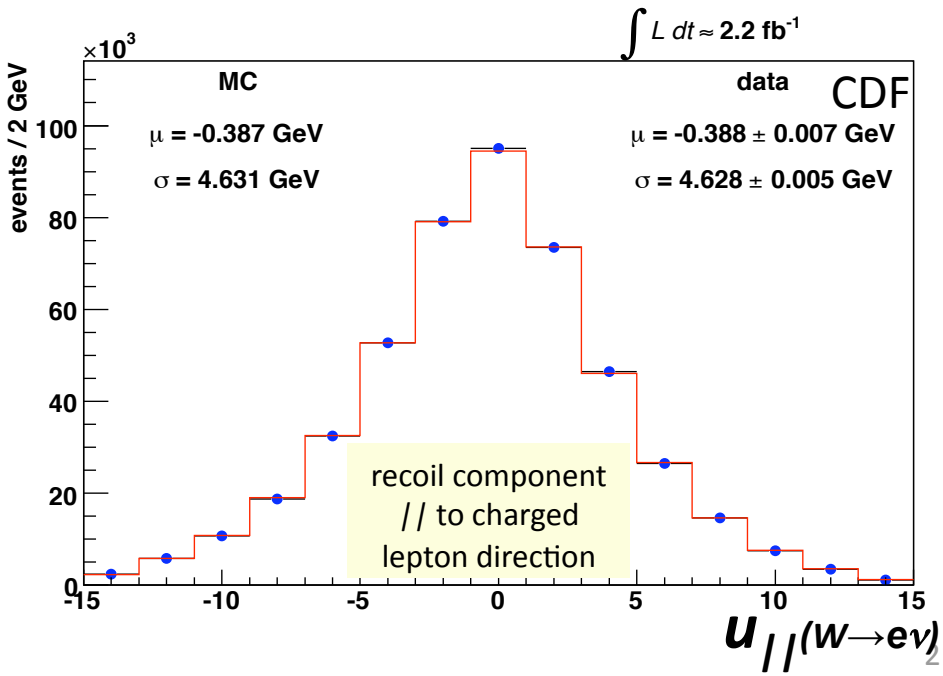
D0: Improvements to previous parameterised detector model



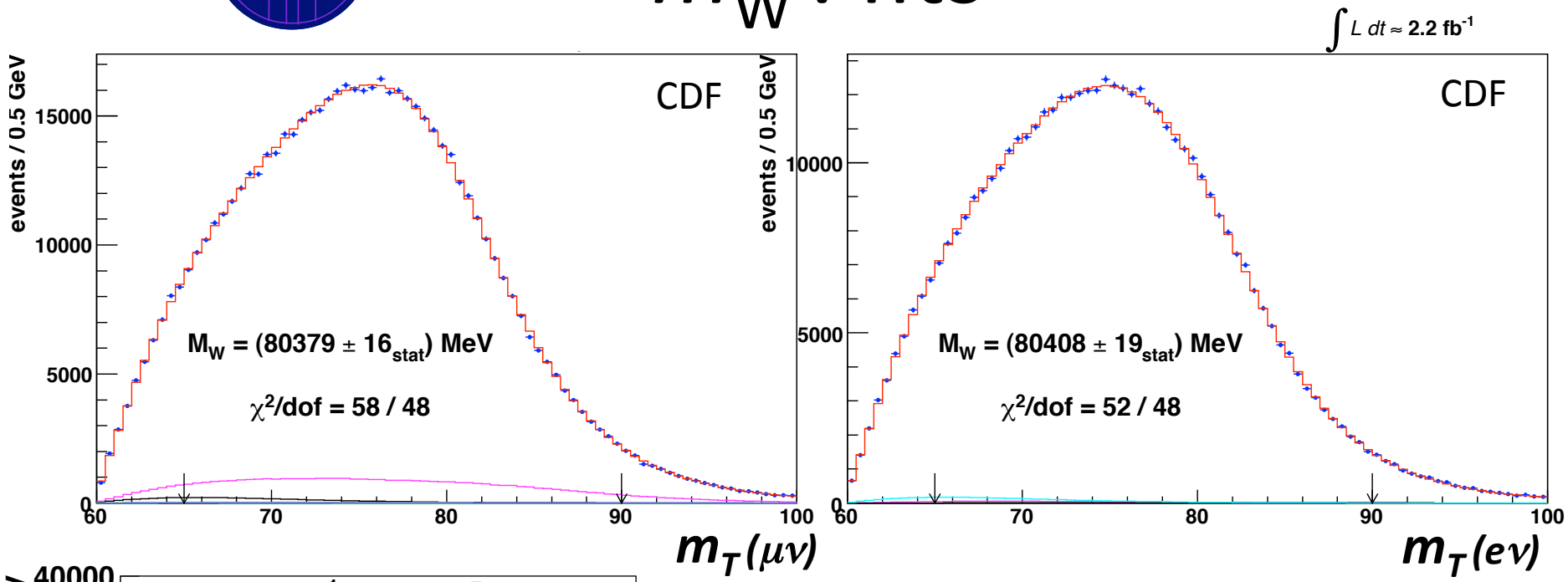


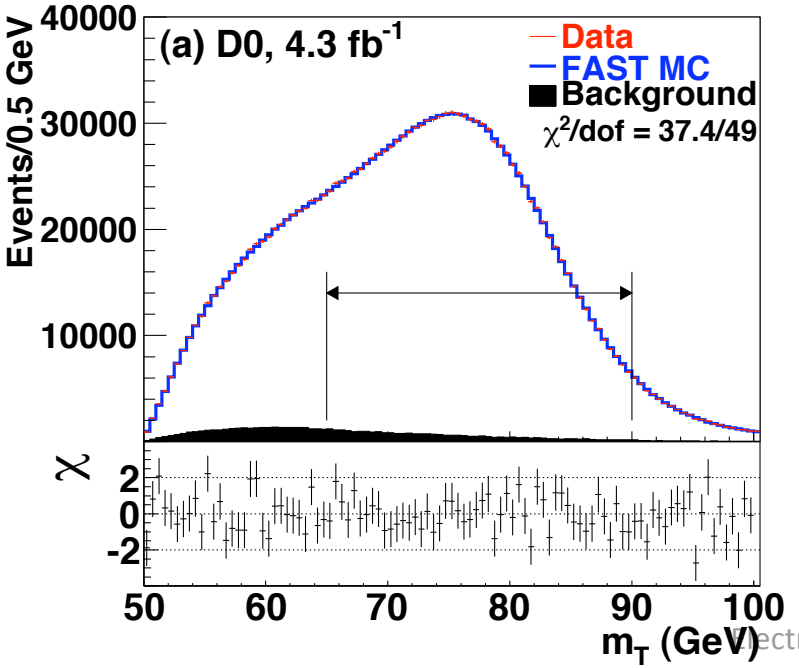
remove/correct non-linear effects, then: $R_{EM}(E_{true}) = \alpha \cdot (E_{true} - \bar{E}_{true}) + \beta + \bar{E}_{true}$





m_W : fits





CDF: $m_W = 80387 \pm 12$ (stat) ± 15 (sys) MeV

D0: $m_W = 80367 \pm 13$ (stat) ± 22 (sys) MeV

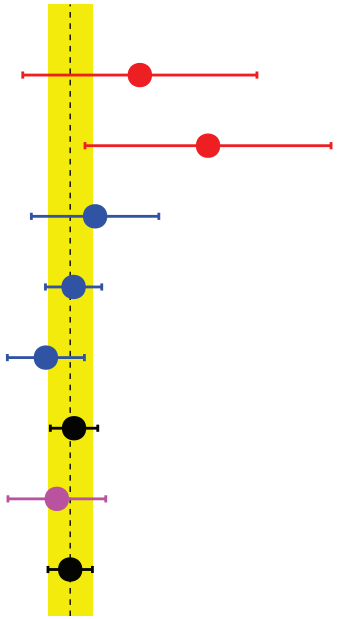
PRL **108** (2012) 151803 and 151804

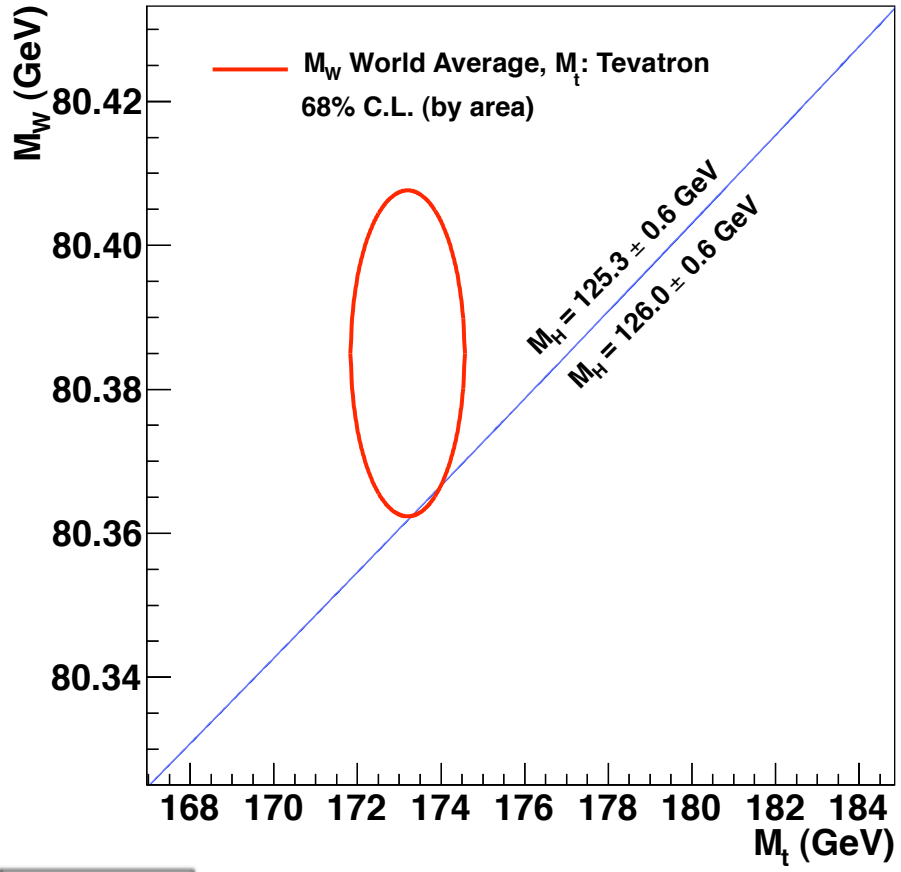
Combined Run 2:

$m_W = 80375 \pm 11$ (stat) ± 20 (sys) MeV

m_W

Measurement	M_W [MeV]
CDF-0/I	80432 ± 79
DØ-I	80478 ± 83
DØ-II (1.0 fb^{-1})	80402 ± 43
CDF-II (2.2 fb^{-1})	80387 ± 19
DØ-II (4.3 fb^{-1})	80369 ± 26
Tevatron Run-0/I/II	80387 ± 16
LEP-2	80376 ± 33
World Average	80385 ± 15





Uncertainty	D0	CDF
Lepton energy scale/resn/modelling	17	7
Hadronic recoil energy scale and resolution	5	6
Backgrounds	2	3
Parton distributions	11	10
QED radiation	7	4
$p_T(W)$ model	2	5
Total systematic uncertainty	22	15
W-boson statistics	13	12
Total uncertainty	26 MeV	19 MeV

→ ~ statistical: 10 MeV

→ ~ theory: 12 MeV

Outlook

- Completing strong electroweak physics programme

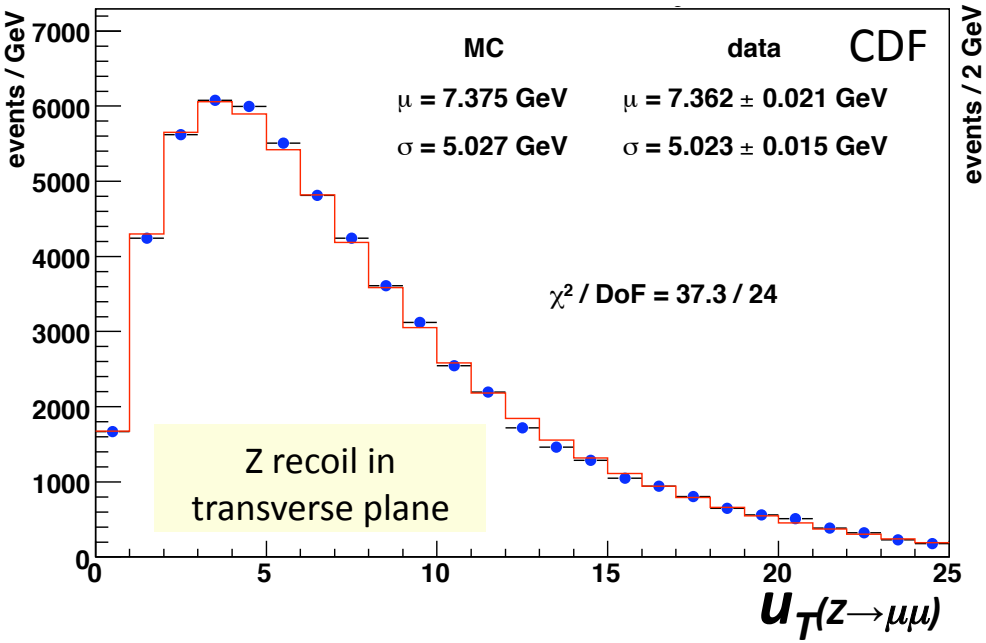
- Focusing on high-statistics Tevatron legacy measurements
  - $p_T(Z)$ for refining Drell-Yan phenomenology
  - $\sin^2\theta_W$ determinations
  - vector and axial couplings of Z to light quarks
  - Drell-Yan angular coefficients
  - m_W

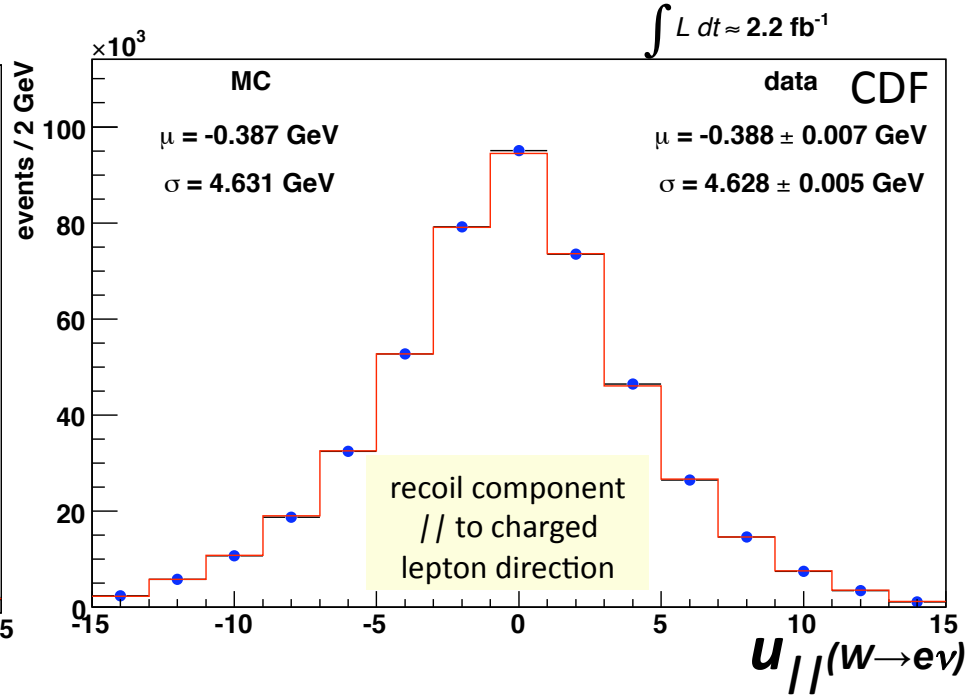
(and diboson physics; see talk from Masahiro Morii)

http://www-cdf.fnal.gov/physics/ewk/
http://www-d0.fnal.gov/d0_publications/

Backup

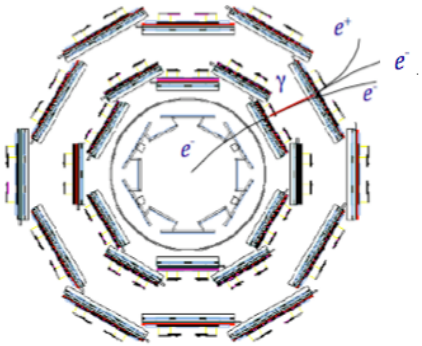
m_W : recoil


events / GeV
MC
data
CDF
μ = 7.375 GeV
σ = 5.027 GeV
μ = 7.362 ± 0.021 GeV
σ = 5.023 ± 0.015 GeV
χ² / DoF = 37.3 / 24
Z recoil in transverse plane
u_T(Z→μμ)

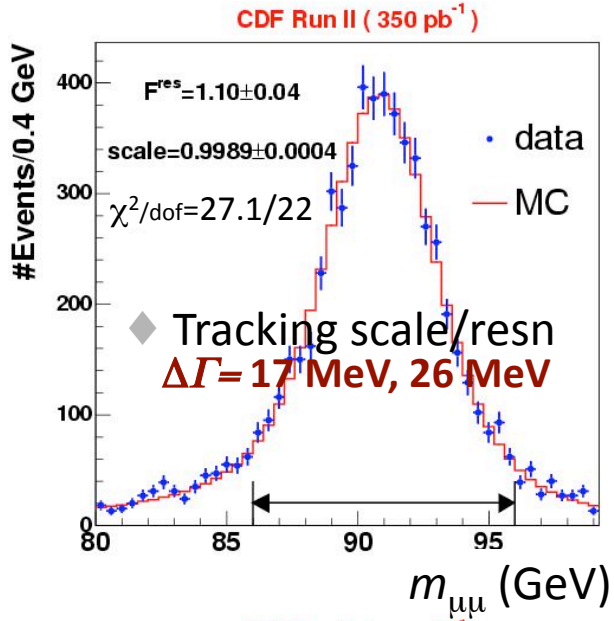

∫ L dt ≈ 2.2 fb⁻¹
×10³
events / 2 GeV
MC
data
CDF
μ = -0.387 GeV
σ = 4.631 GeV
μ = -0.388 ± 0.007 GeV
σ = 4.628 ± 0.005 GeV
recoil component // to charged lepton direction
u_//(W→eν)

W width

- Generator:
  LO MC
  matched with Resbos (QCD ISR)
  and Berends/Kleiss (QED FSR)

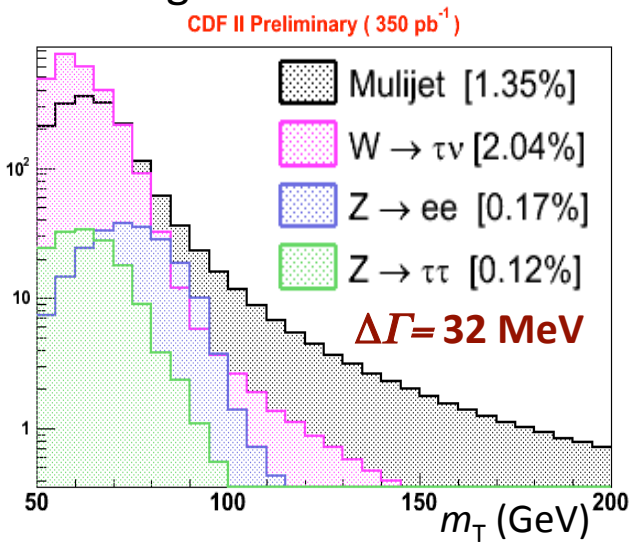


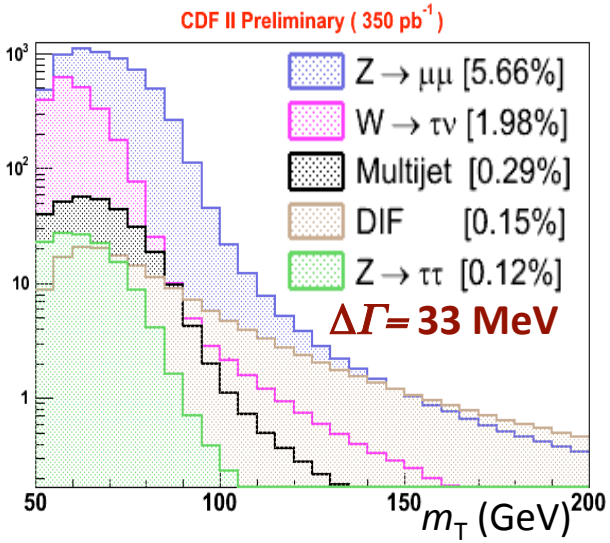
- Fast simulation for templates:
  electron conversions + showering
  muon energy loss
  parametric model of recoil energy
  (QCD, underlying event + brem)
  $\Delta\Gamma$= 54 MeV (ele), 49 MeV (mu)

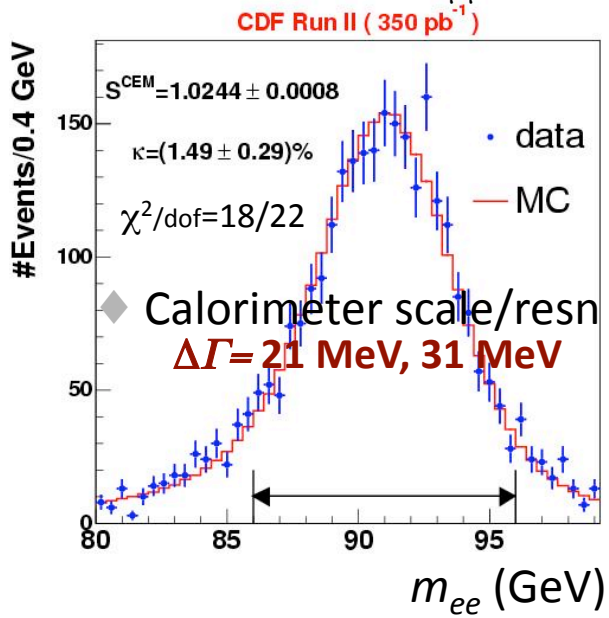


- Tracking scale/resn
  $\Delta\Gamma$= 17 MeV, 26 MeV

- Backgrounds

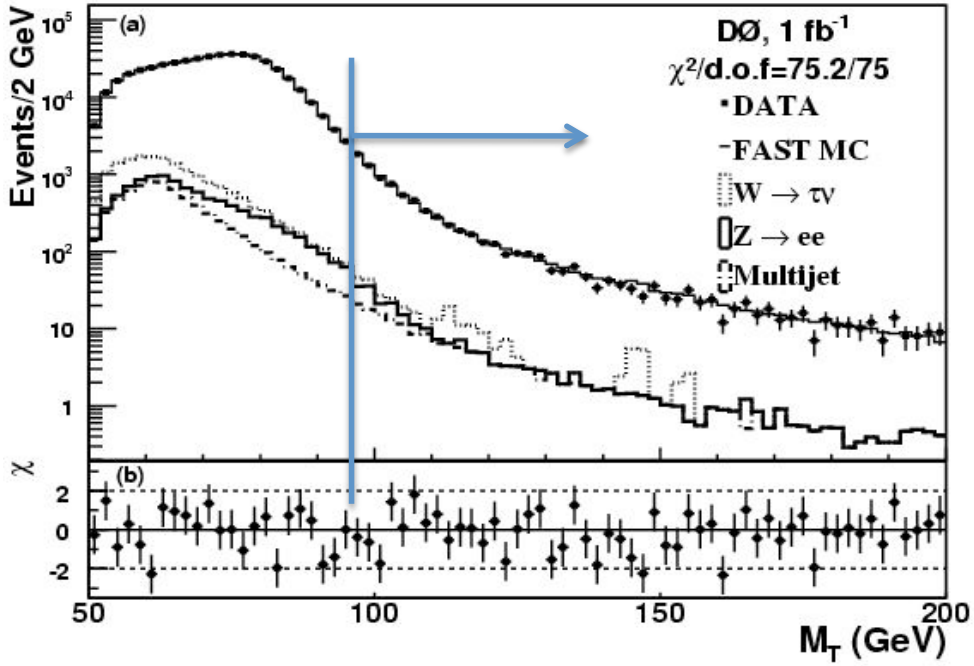


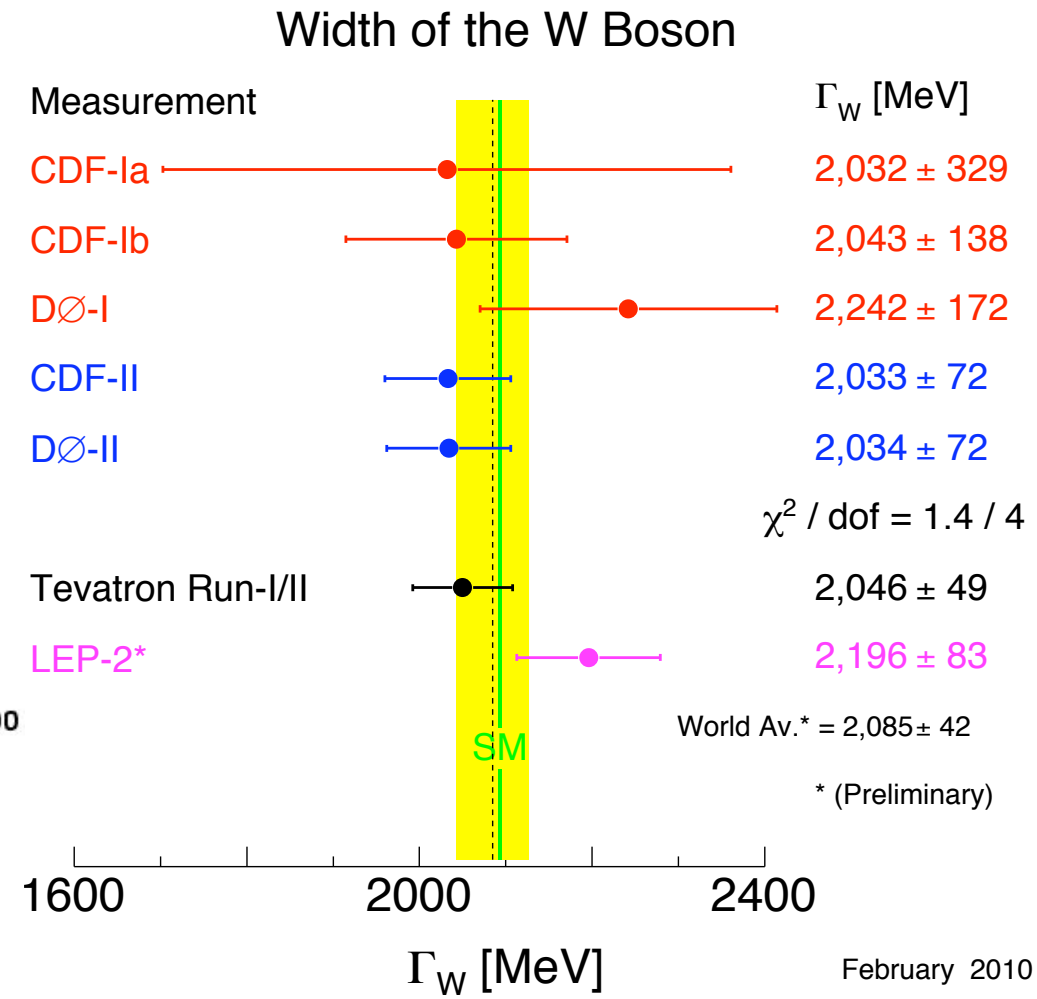




- Calorimeter scale/resn
  $\Delta\Gamma$= 21 MeV, 31 MeV

Γ_W



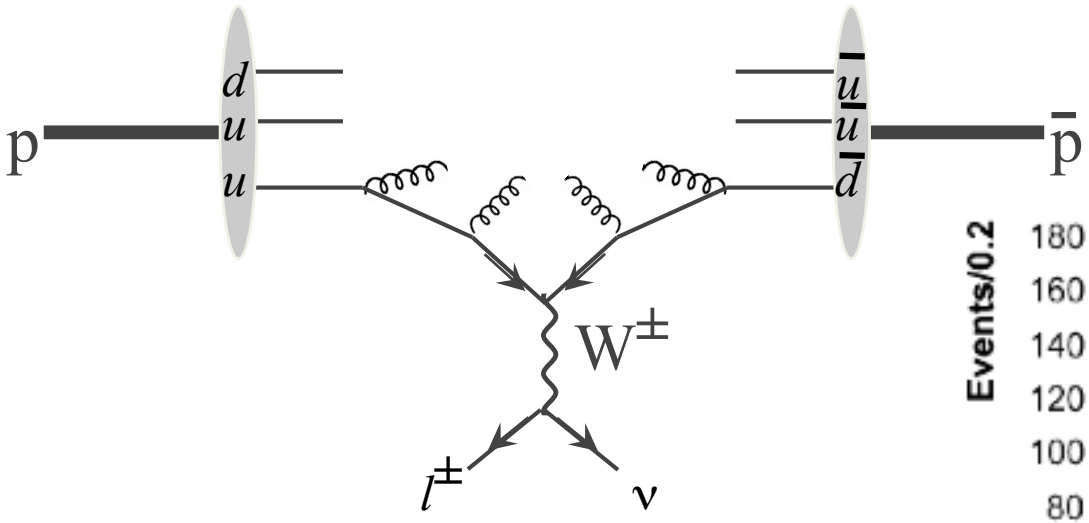


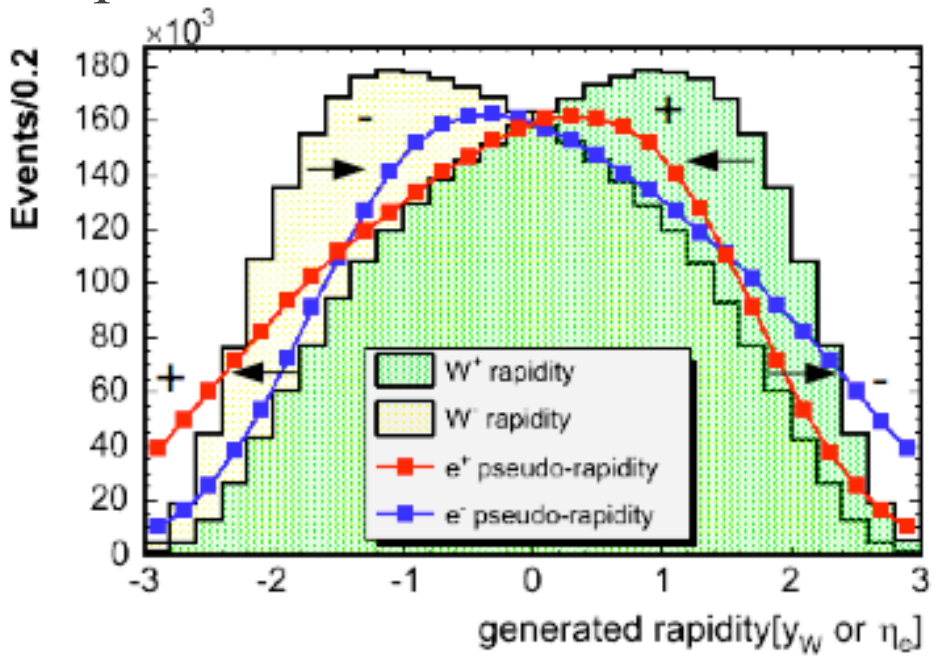
Γ_W predicted in Standard Model:

Γ_W^{SM} = 2091±2 MeV (PDG)

Tev error improves from 62 to 49 MeV

W charge asymmetry



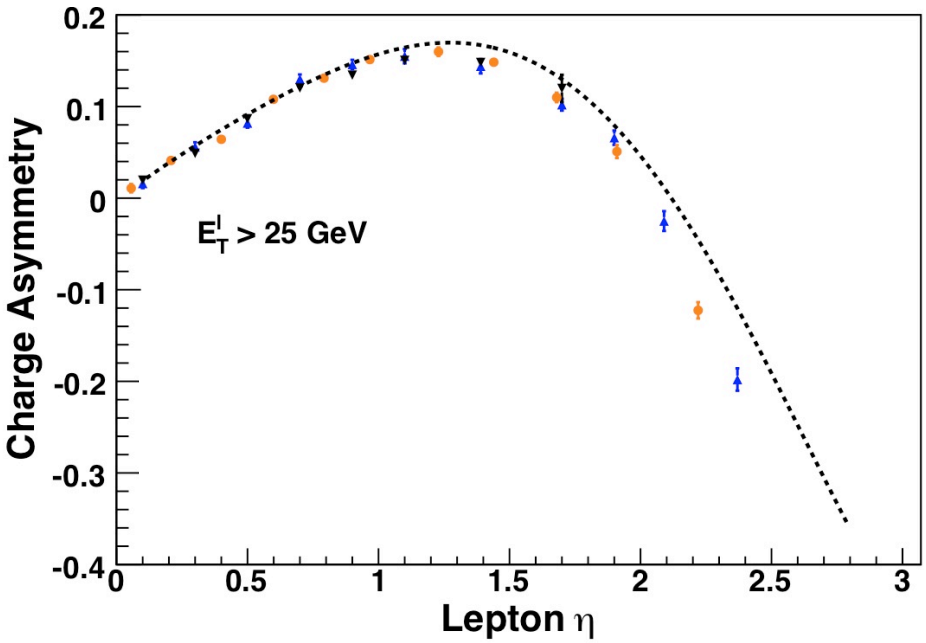


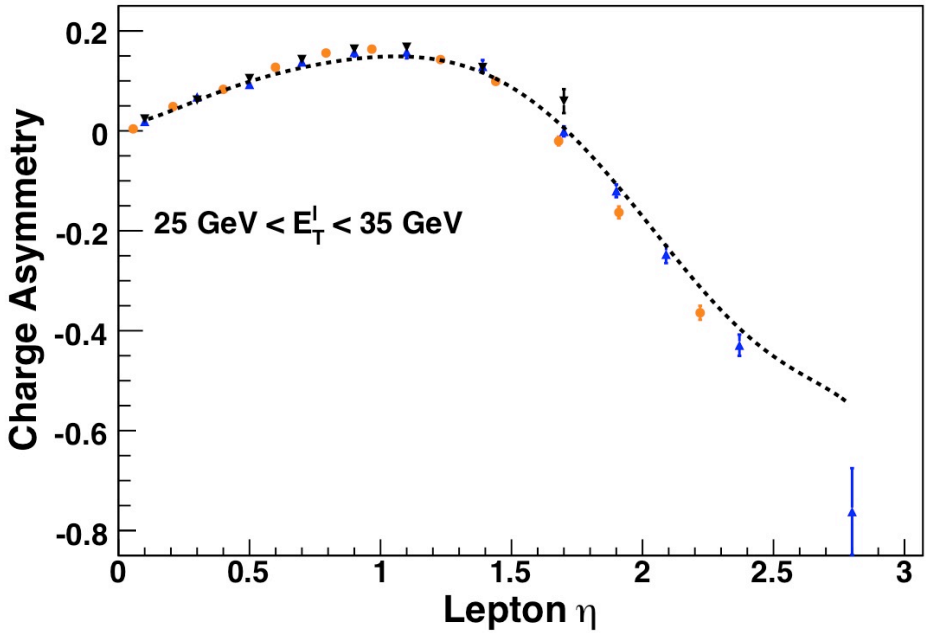
$$A_W(y) \equiv \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

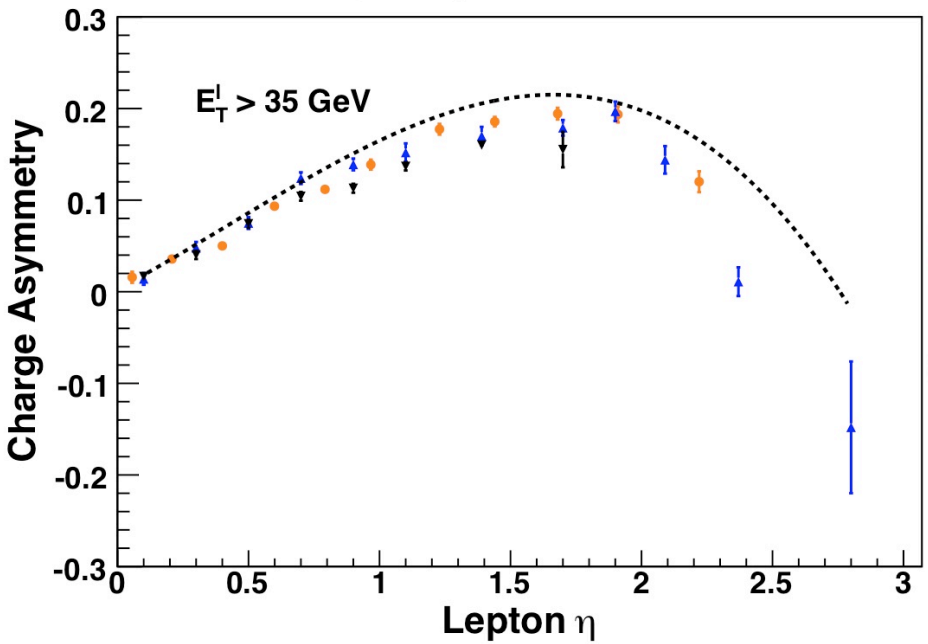
$$A_\ell(\eta) \equiv \frac{d\sigma(\ell^+)/d\eta - d\sigma(\ell^-)/d\eta}{d\sigma(\ell^+)/d\eta + d\sigma(\ell^-)/d\eta} = A(y_W) \otimes (V-A) \sim \frac{d(x)}{u(x)}$$

Run 1 measurement resulted in d quark increased by 30% at Q^2=(20GeV)^2

W charge asymmetry







- CDF Run II Preliminary 1 fb^{-1} data (e) (no systematic uncertainties)
- DØ 0.75 fb^{-1} data (e)
- DØ Run II Preliminary 5 fb^{-1} data (μ)
- RESBOS with CTEQ6.6