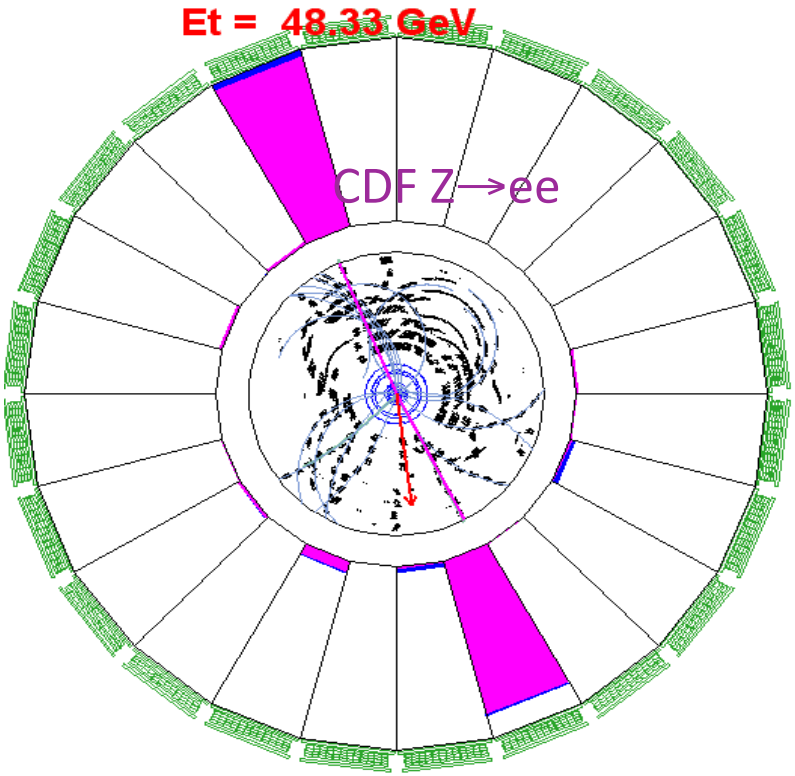
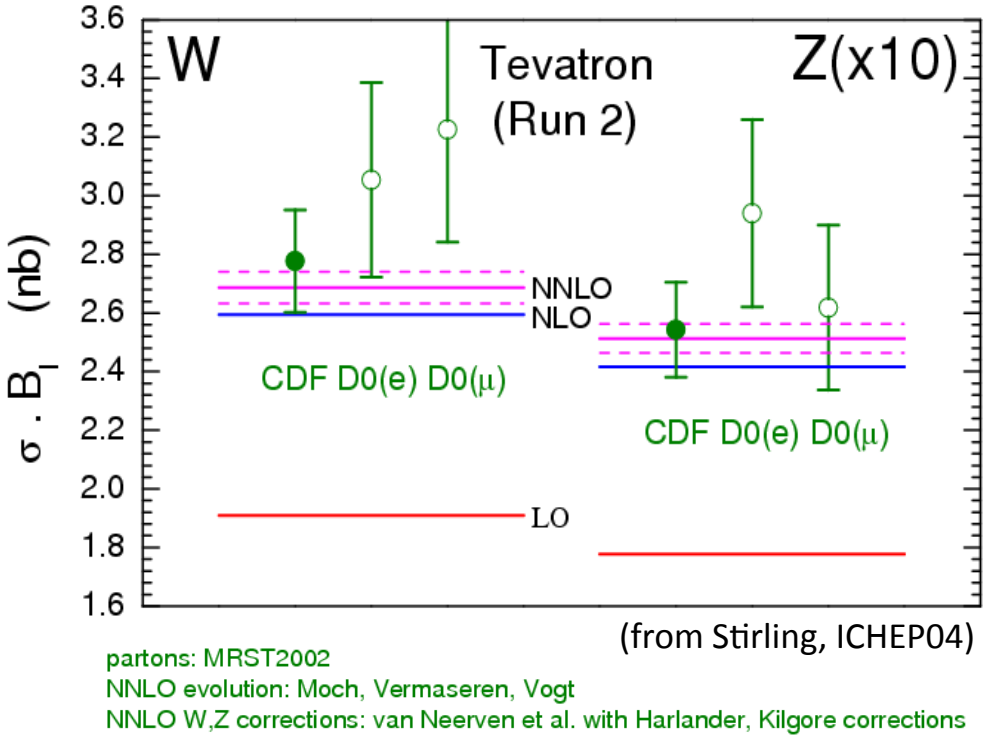
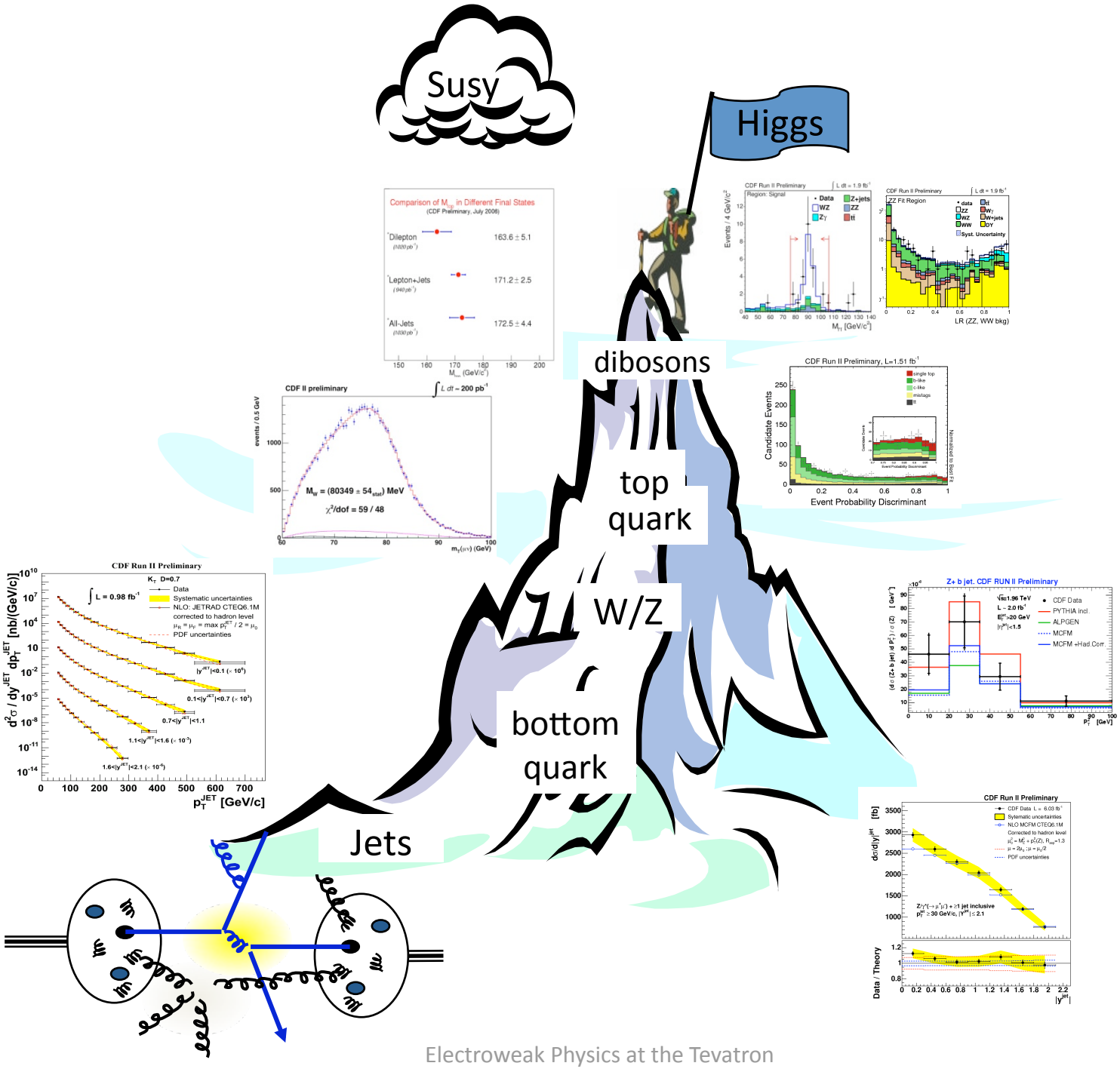
Electroweak Physics at the Tevatron

Aidan Robson
University of Glasgow
for the CDF and D0 Collaborations
Aspen, 13 February 2011



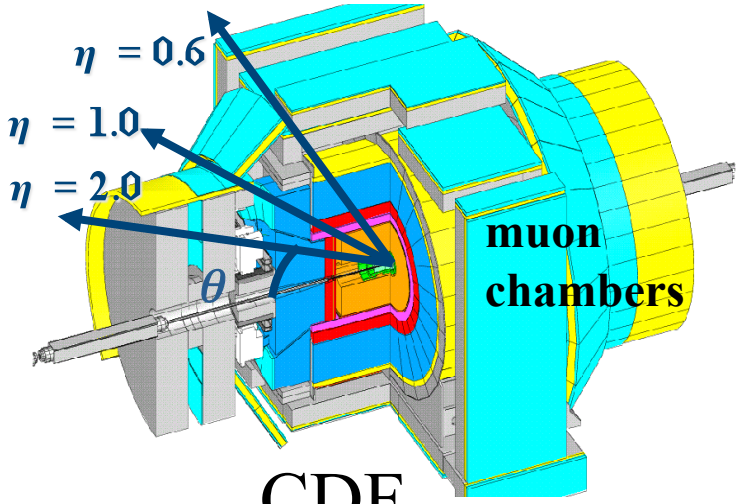


2004, using < 100 pb^{-1}

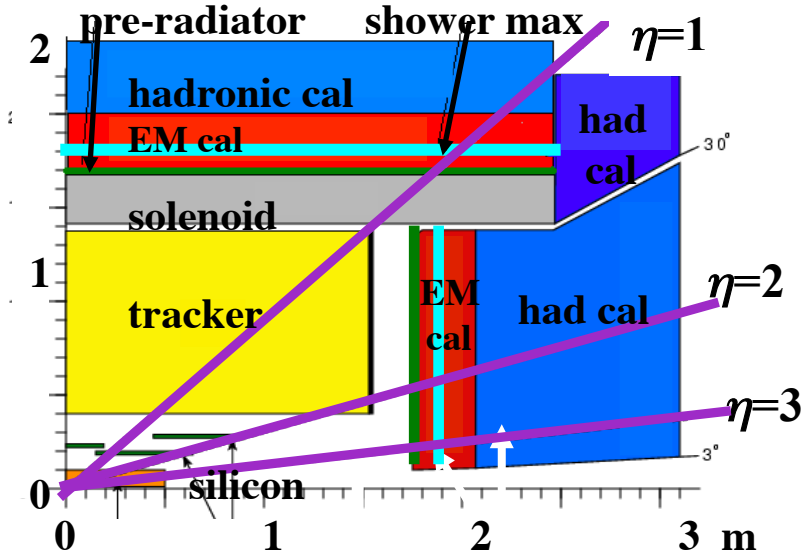

Susy
Higgs
dibosons
top quark
W/Z
bottom quark
Jets
Comparison of M_{top} in Different Final States
(CDF Preliminary, July 2008)
Dilepton
Lepton+Jets
All-Jets
163.6 ± 5.1
171.2 ± 2.5
172.5 ± 4.4
M_{top} (GeV/c^2)
CDF II preliminary
$\int L\,dt \sim 200\ pb^{-1}$
$M_W = (80349 \pm 54_{stat})$ MeV
χ^2/dof = 59 / 48
$m_T(\mu\nu)$ (GeV)
CDF Run II Preliminary
Region: Signal
Data
WZ
Zγ
Z+jets
ZZ
tt̄
M_{ll} [GeV/c^2]
CDF Run II Preliminary
ZZ Fit Region
Syst. Uncertainty
LR (ZZ, WW bkg)
CDF Run II Preliminary, L=1.51 fb^{-1}
Candidate Events
Event Probability Discriminant
CDF Run II Preliminary
K_T D=0.7
$\int L = 0.98\ fb^{-1}$
Data
Systematic uncertainties
NLO: JETRAD CTEQ6.1M
corrected to hadron level
PDF uncertainties
$d^2\sigma / dy^{JET} dp_T^{JET}$ [nb/(GeV/c)]
p_T^{JET} [GeV/c]
Z+ b jet, CDF RUN II Preliminary
CDF Data
PYTHIA Incl.
ALPGEN
MCFM
MCFM +Had.Corr.
CDF Run II Preliminary
CDF Data
Systematic uncertainties
NLO MCFM CTEQ6.1M
Corrected to hadron level
PDF uncertainties
Data / Theory

- Motivation
- High-statistics precision measurements
  - p_T(Z) x3
  - Γ(W)
- Diboson physics
  - Zγ
  - WZ
  - ZZ
  - WW/WZ -> lνjj
- Outlook

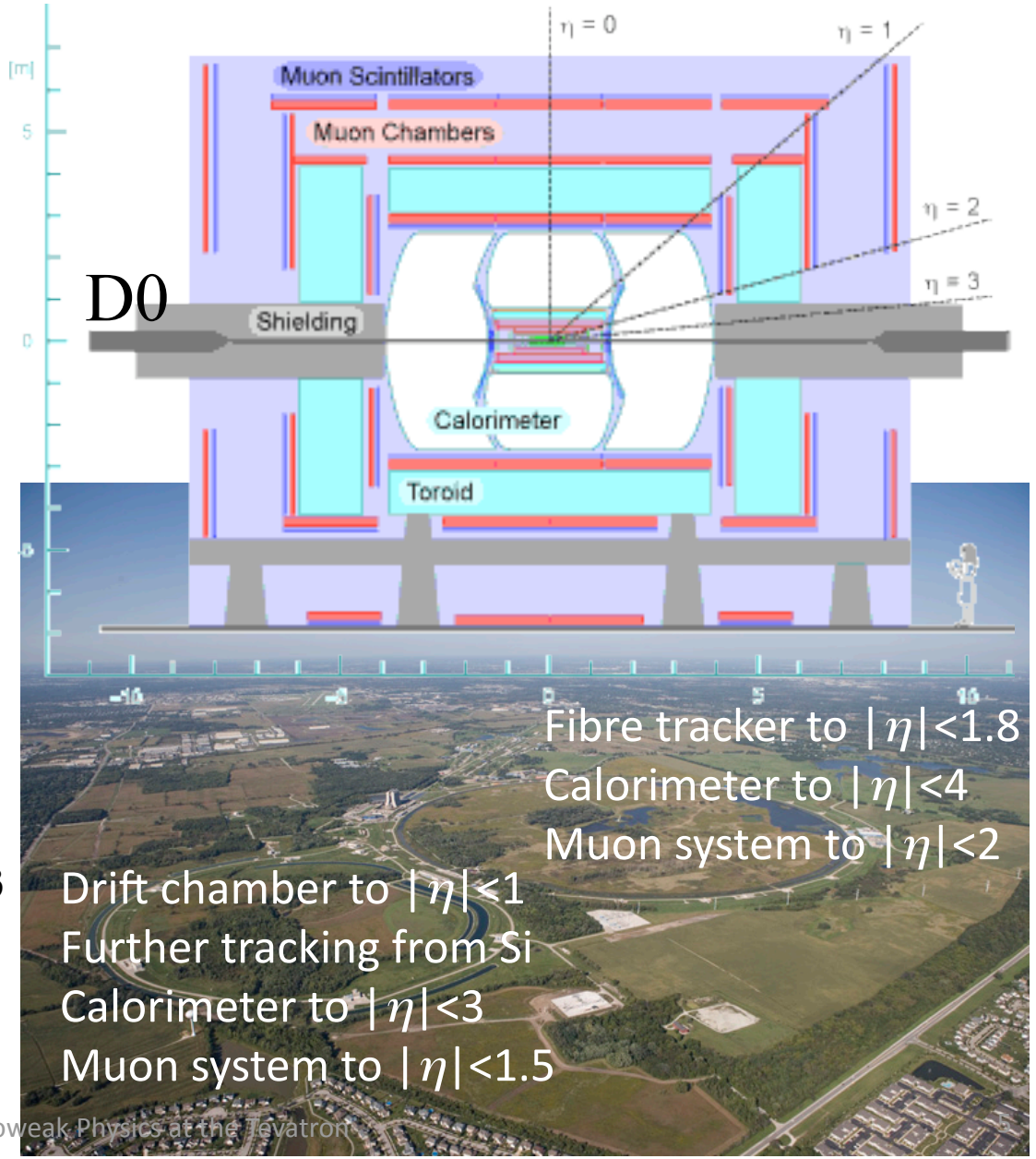
Tevatron



CDF



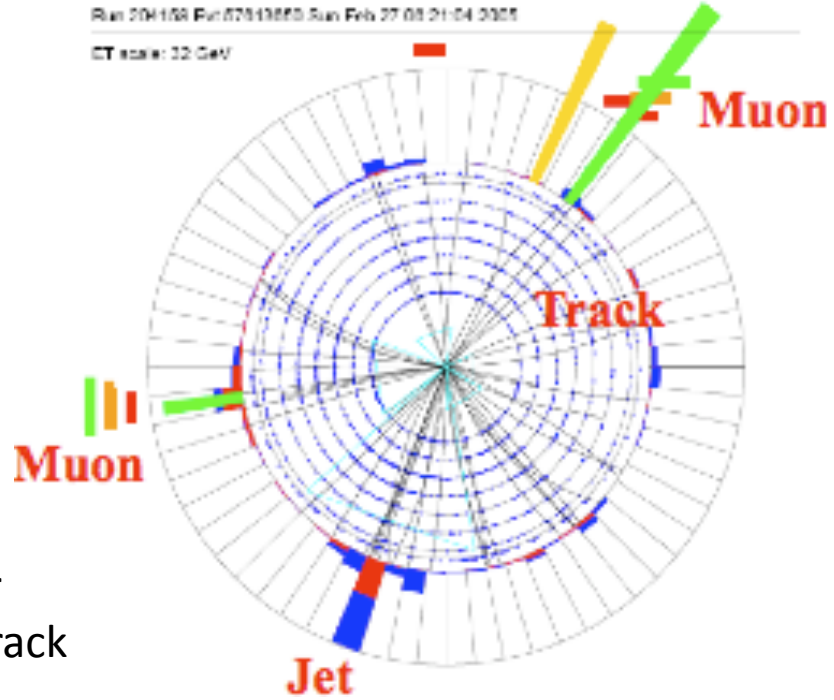
D0



W and Z selection

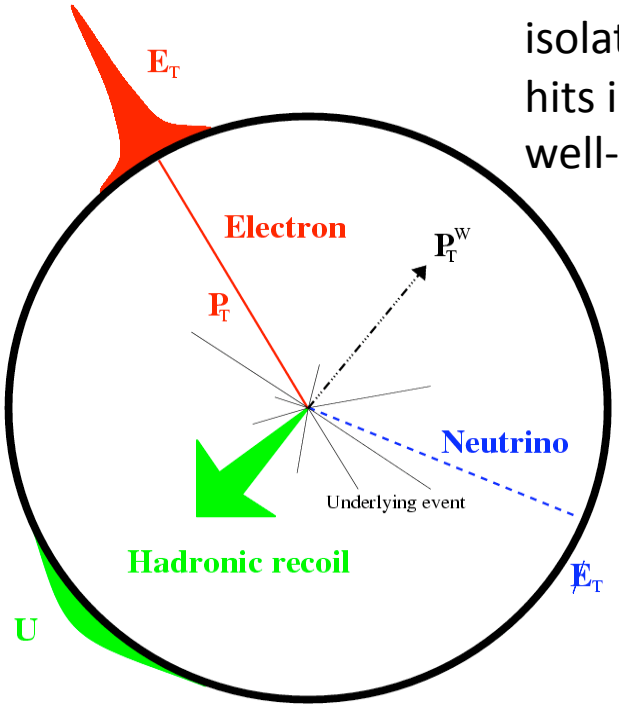
Electrons:

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

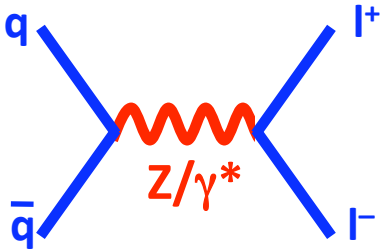


Z selection:

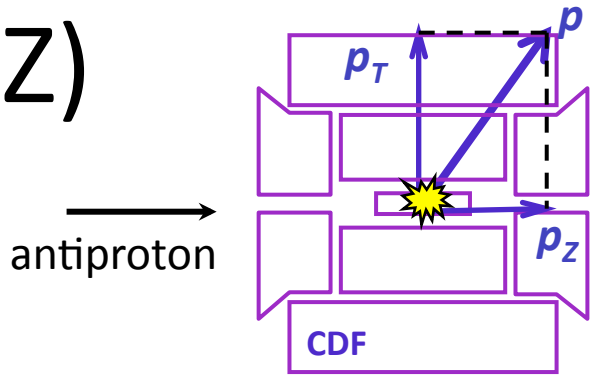
2 oppositely-charged electrons or muons
invariant mass consistent with m_Z

W selection:

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



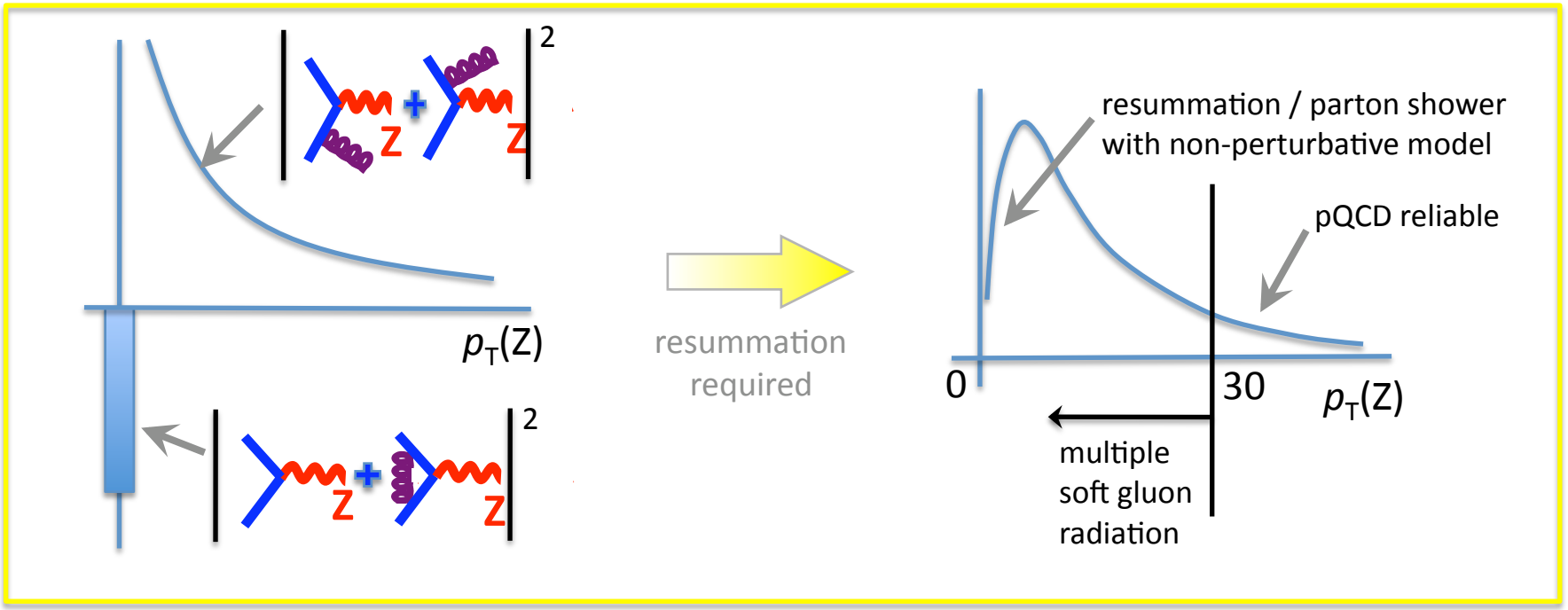
$p_T(Z)$



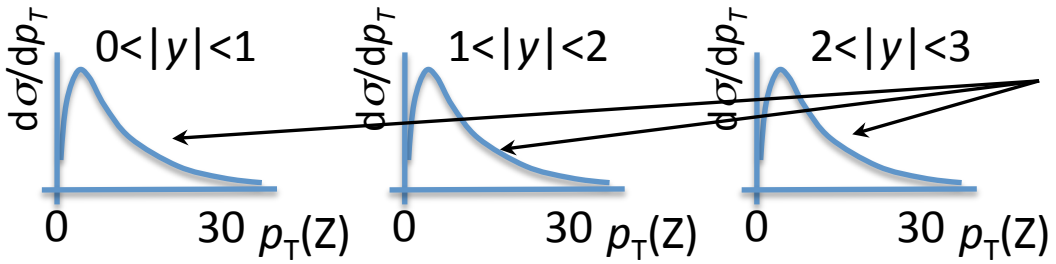
$y \equiv 1/2 \ln \frac{E+p_z}{E-p_z}$

[~angular variable]

antiproton → ← proton

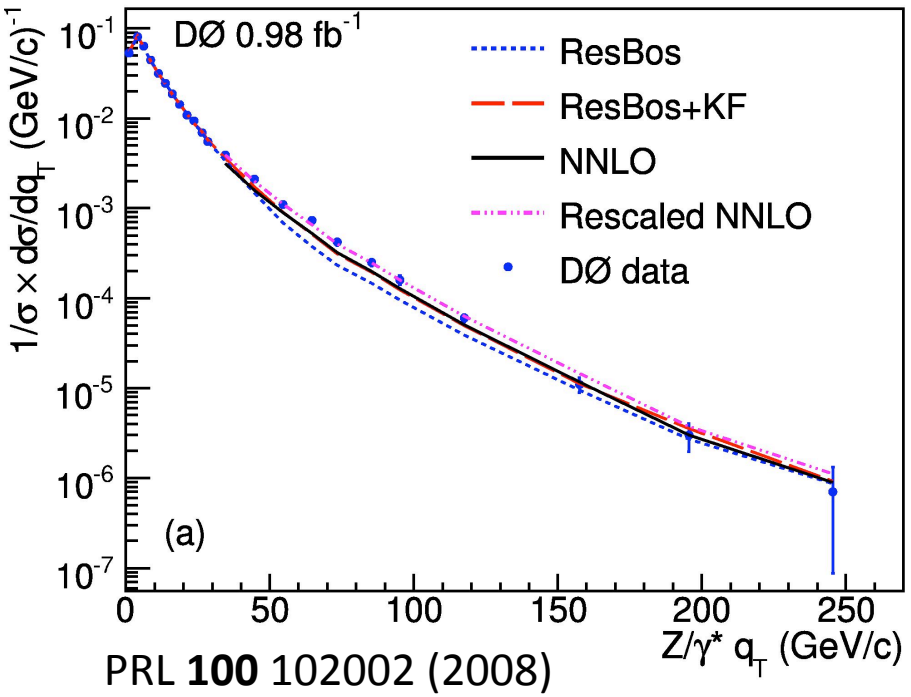


event generator tuning

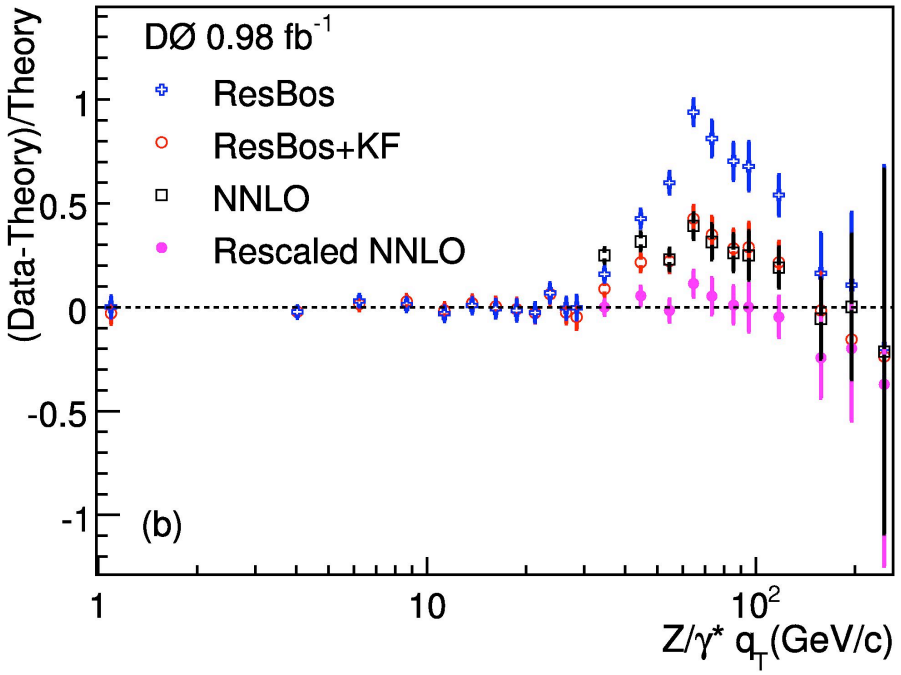


Earlier p_T(Z)

Electron channel:



PRL **100** 102002 (2008)



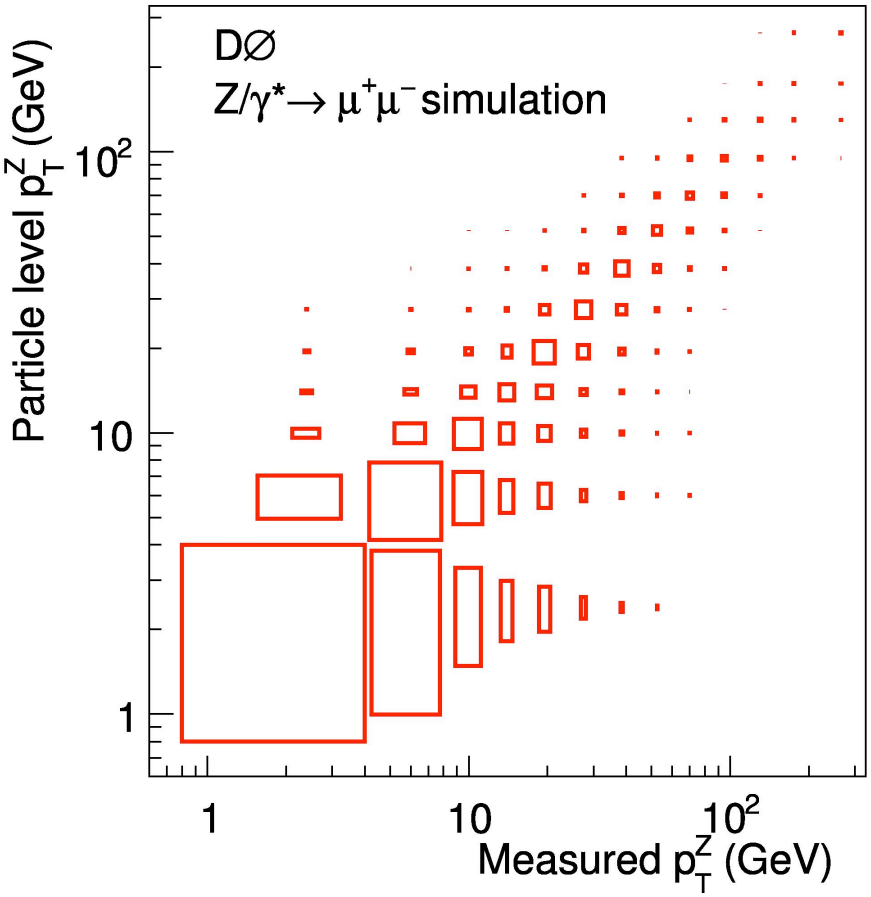
Compare 4 models:

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

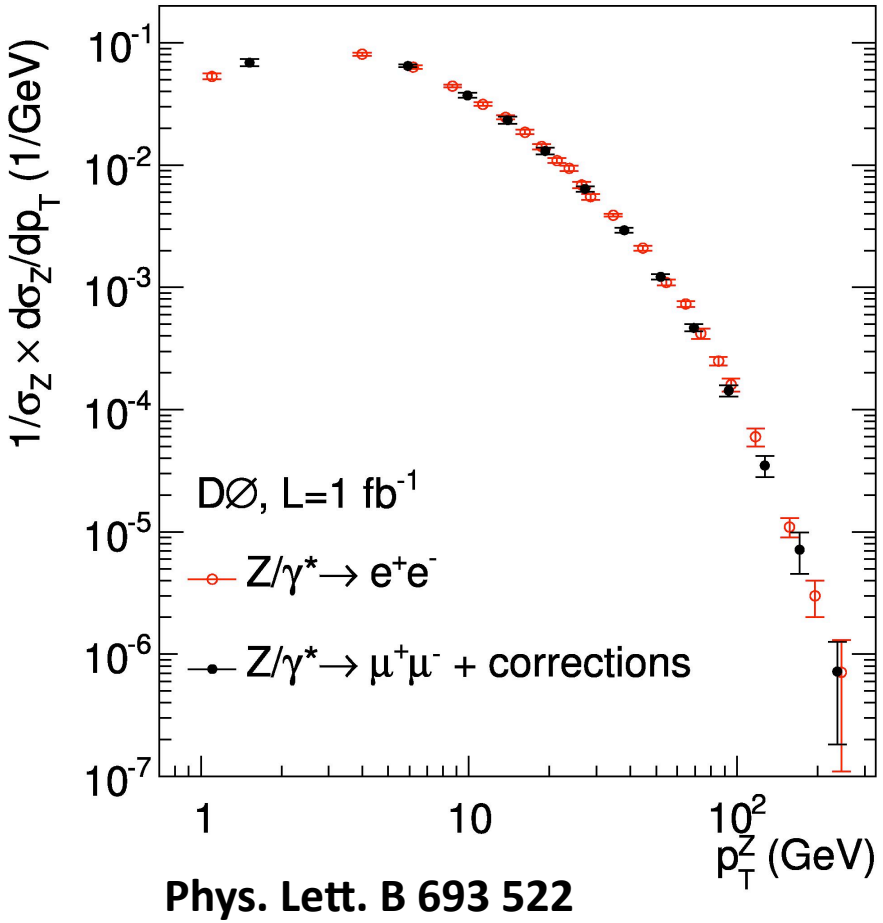
RESBOS event generator implements NLO QCD and CSS resummation

$p_T(Z)$

New measurement in muon channel
Presented at the level of particles entering the detector to avoid model-dependent corrections



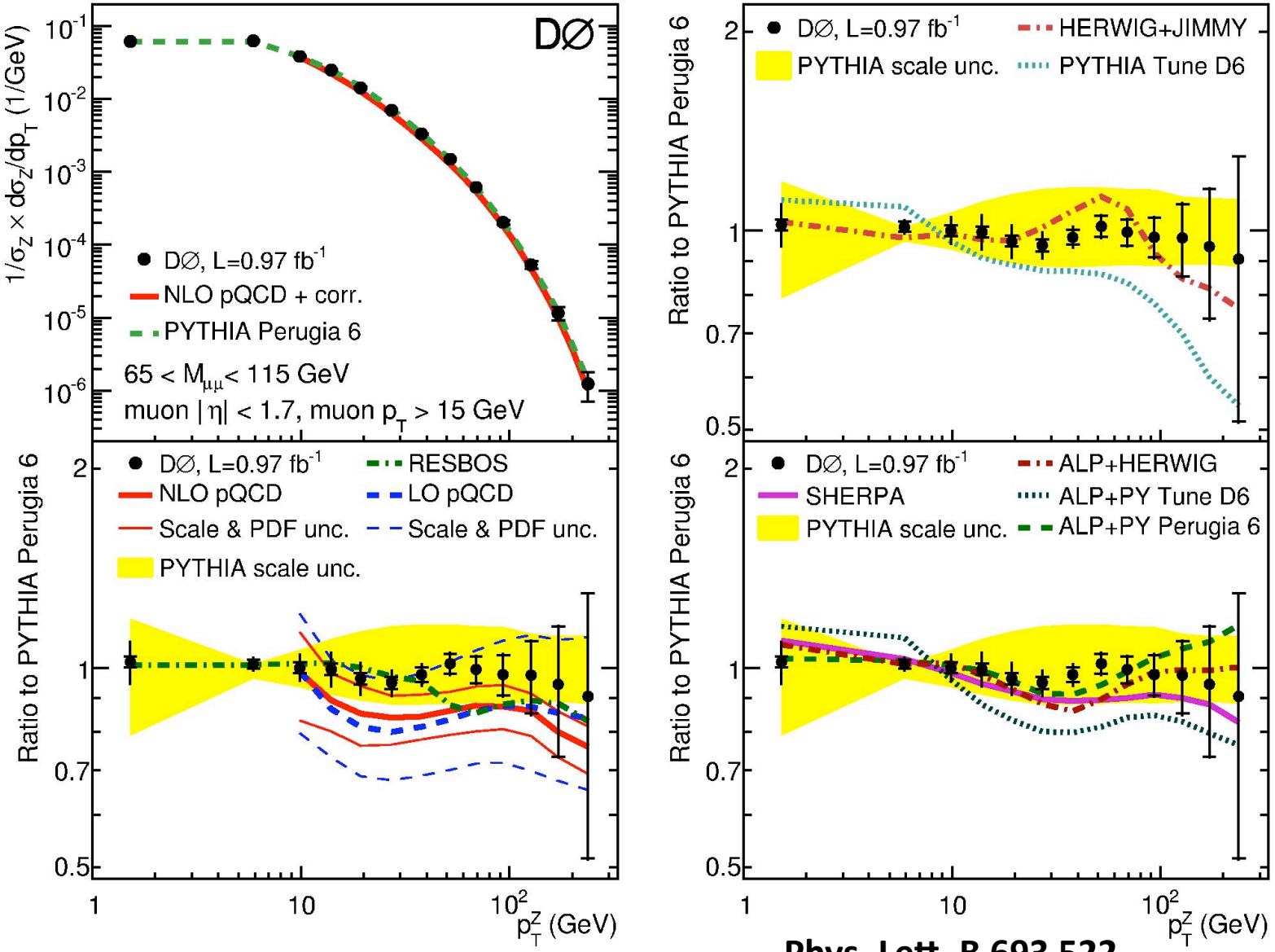
However for comparison with previous measurement, correct to 4π and for mass window:



Phys. Lett. B 693 522

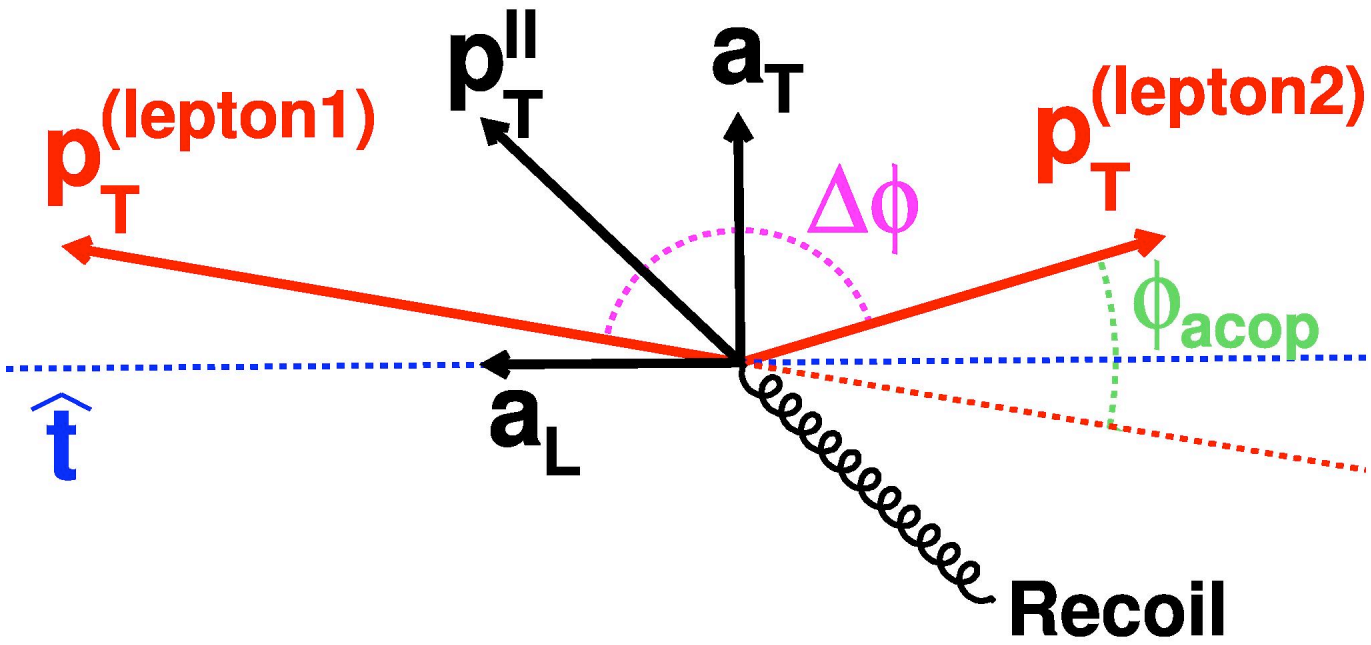
$p_T(Z)$

At particle level:



Phys. Lett. B 693 522

ϕ^*_η

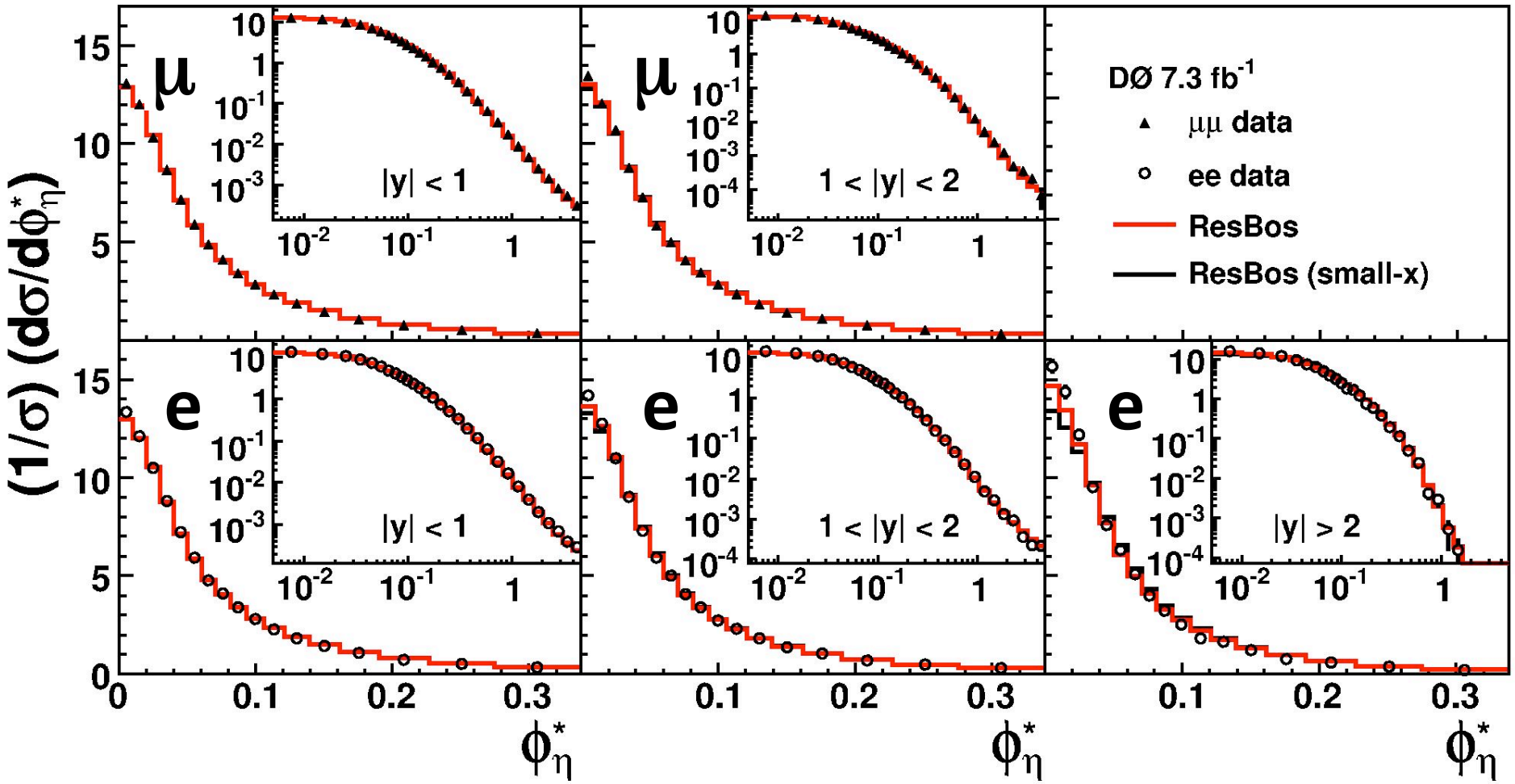


a_T : component of p_T(ll) transverse to dilepton thrust axis.
Less susceptible than p_T(ll) to detector effects

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

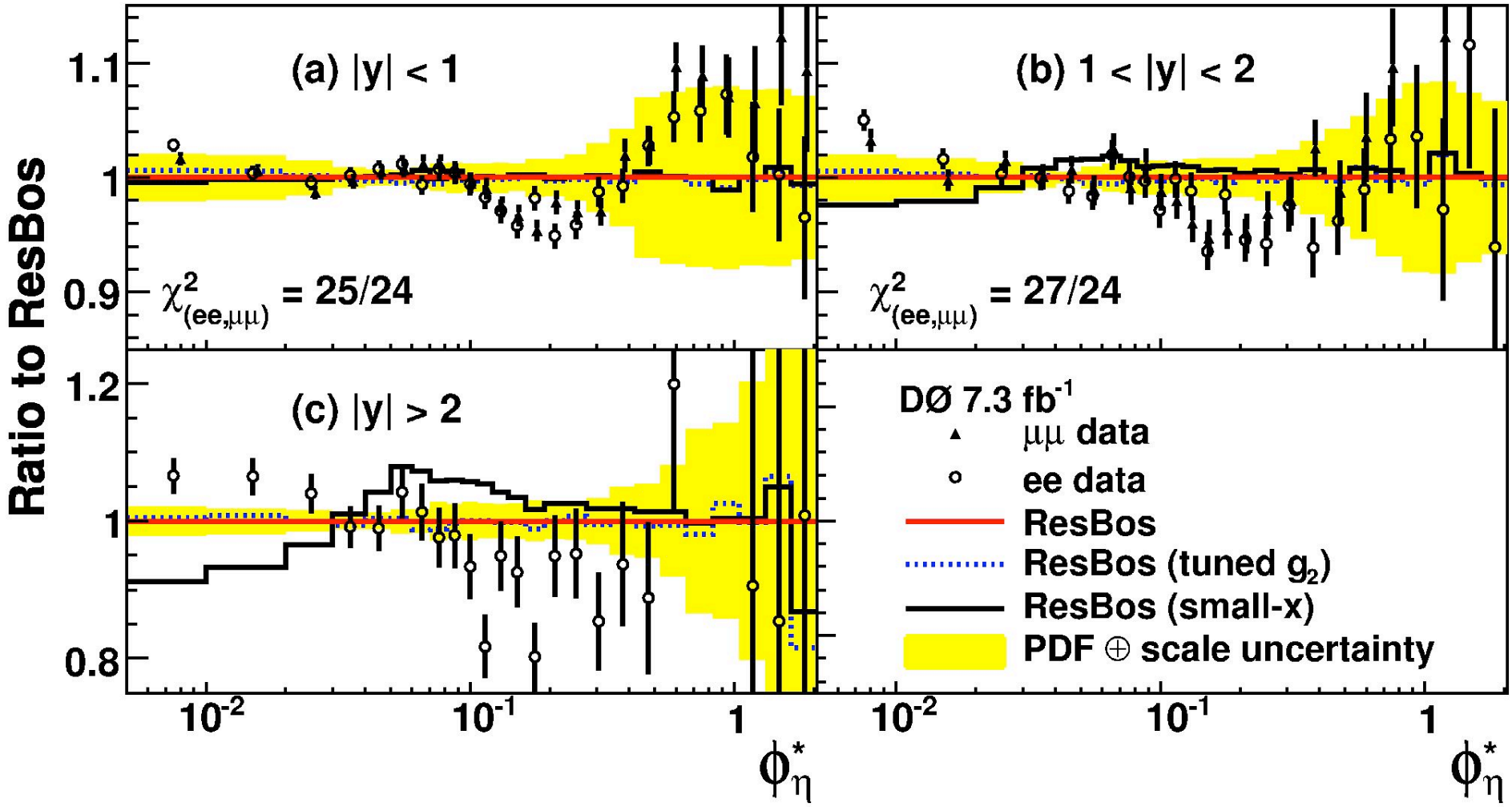
(θ^*_η measures scattering angle of leptons wrt beam, in rest frame of dilepton system)

ϕ^*_η



arXiv:1010.0262

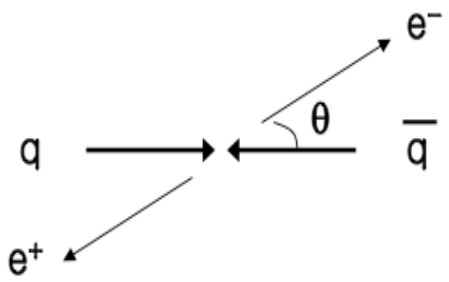
ϕ^*_η

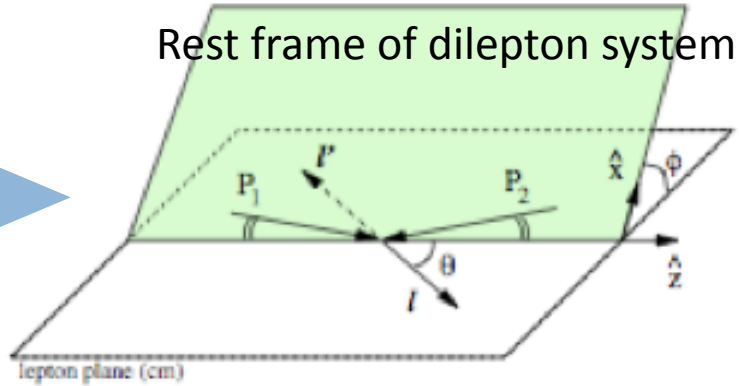


arXiv:1010.0262

Drell-Yan angular coefficients

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





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

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

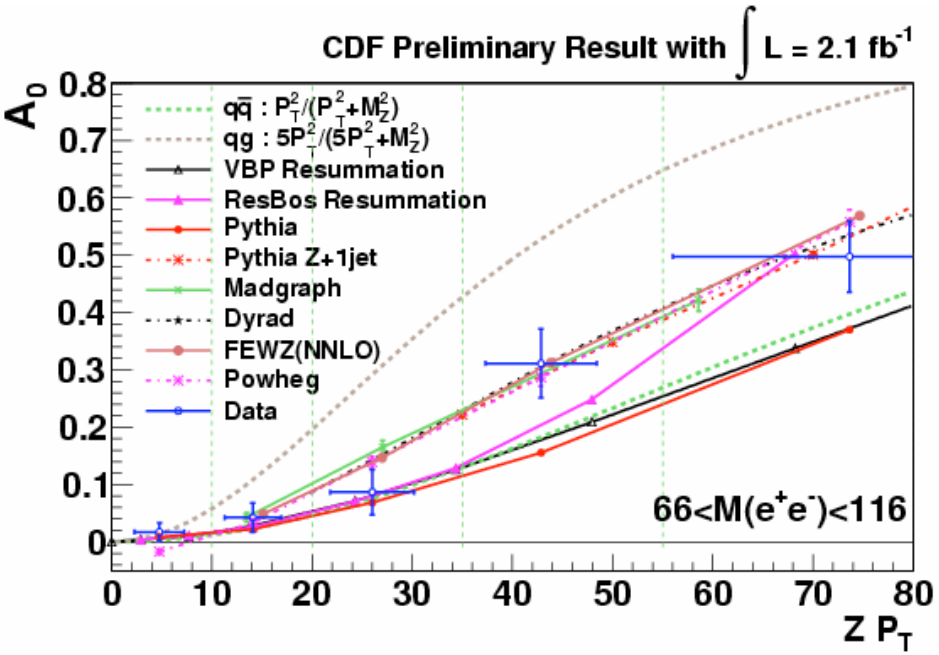
measure as function of p_T

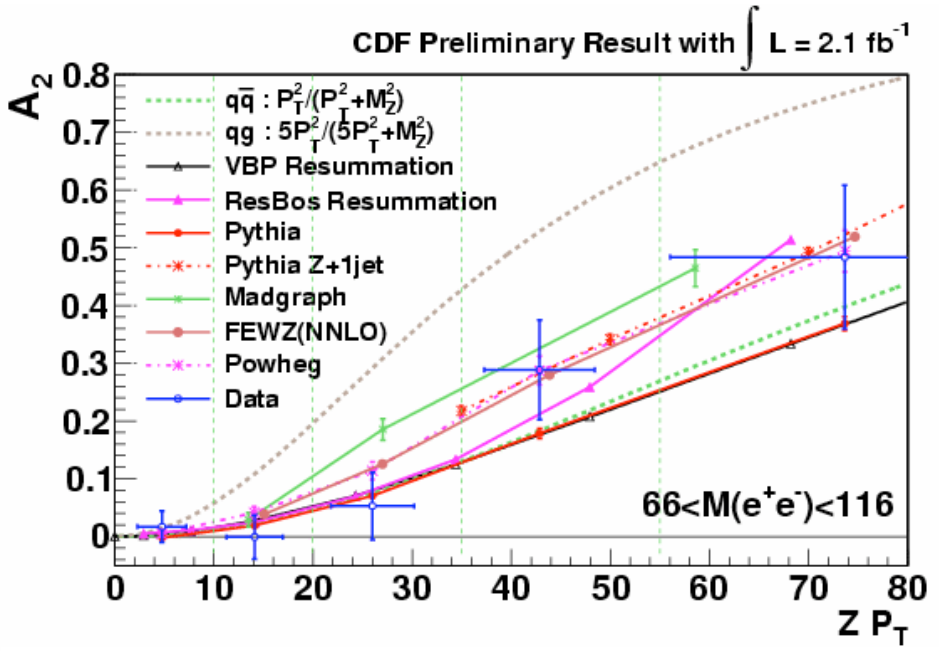
Integrate over all cosθ ,

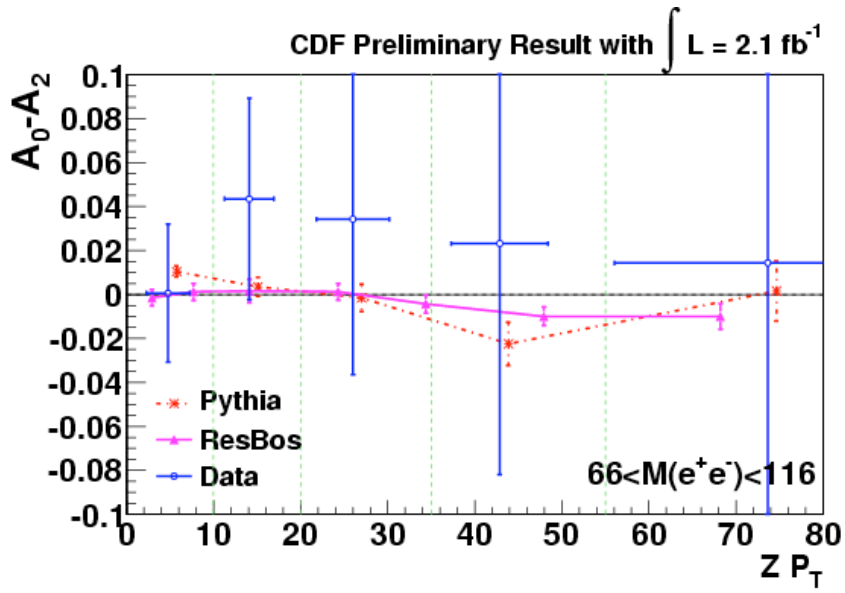
$$\frac{\mathbf{d}\sigma}{\mathbf{d}\phi} \propto 1 + \frac{3\pi A_3}{16}\cos\phi + \frac{A_2}{4}\cos 2\phi + \frac{3\pi A_7}{16}\sin\phi + \frac{A_5}{4}\sin 2\phi$$

(the last two terms: =0)

Drell-Yan angular coefficients

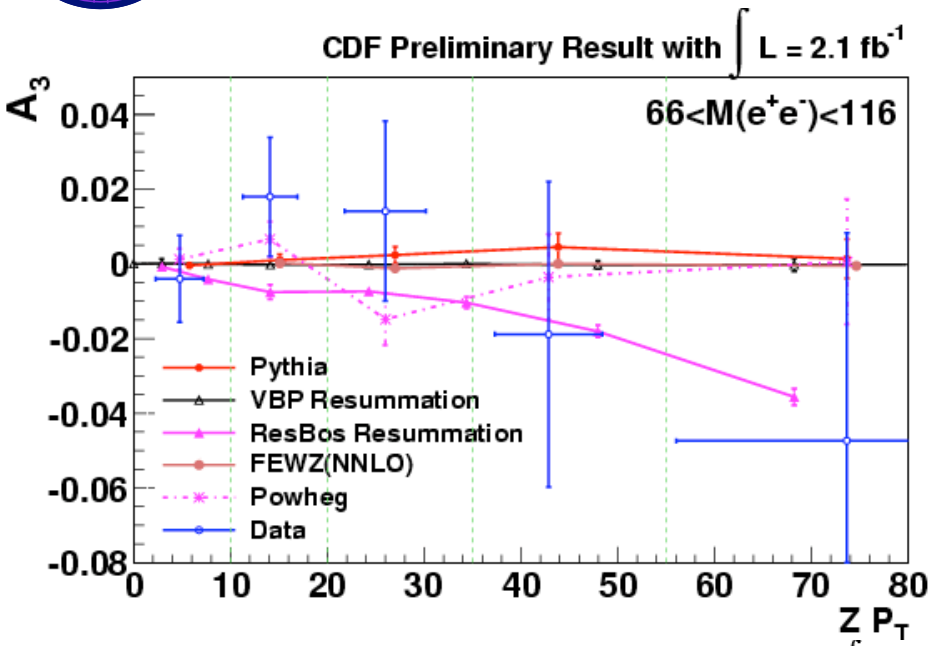


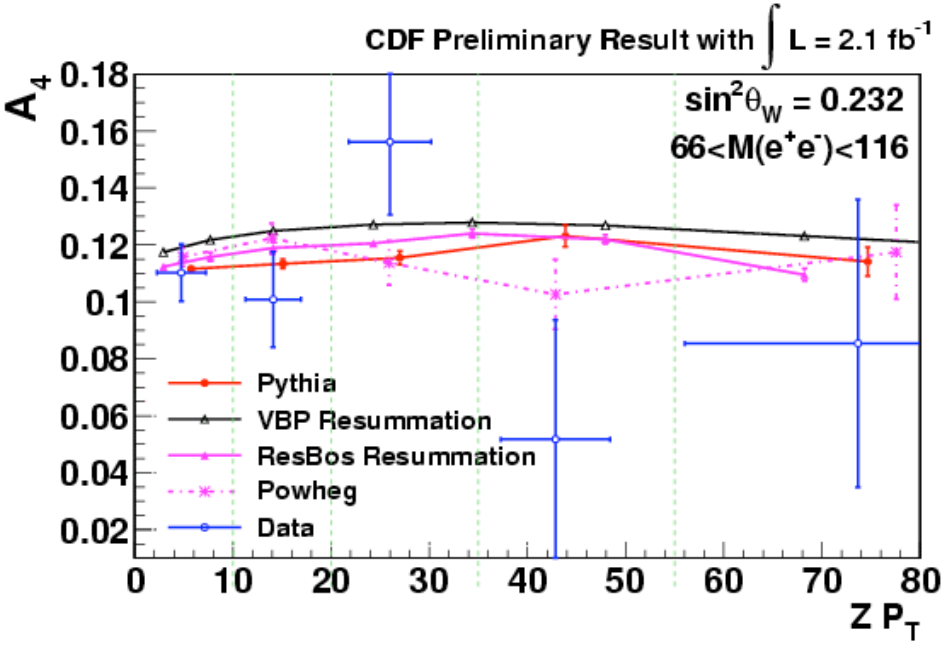


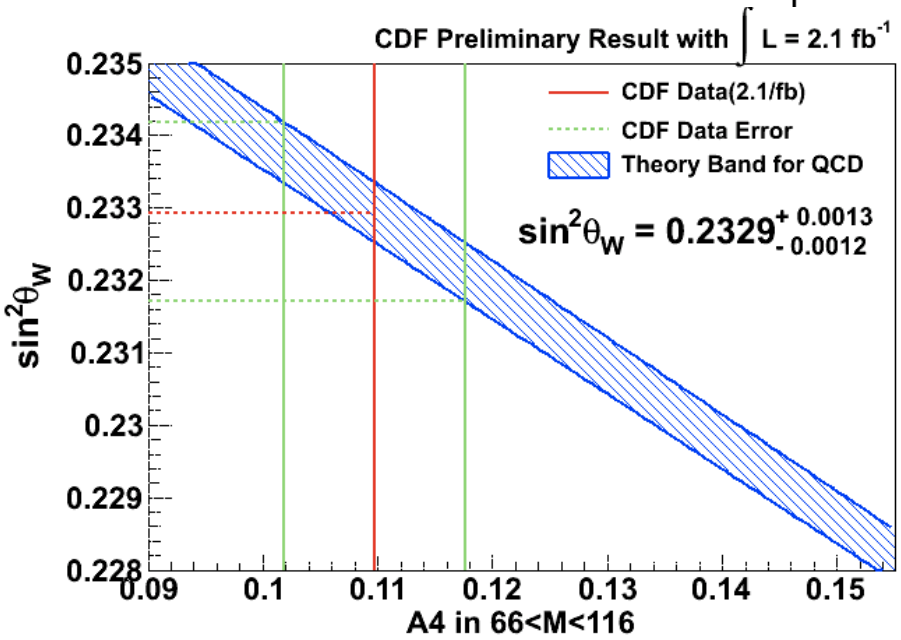


A2=A0 at LO
'Lam-Tung' relation
True only for spin-1 gluons,
strongly broken for scalar gluons

Drell-Yan angular coefficients







A4 sensitive to Weinberg angle

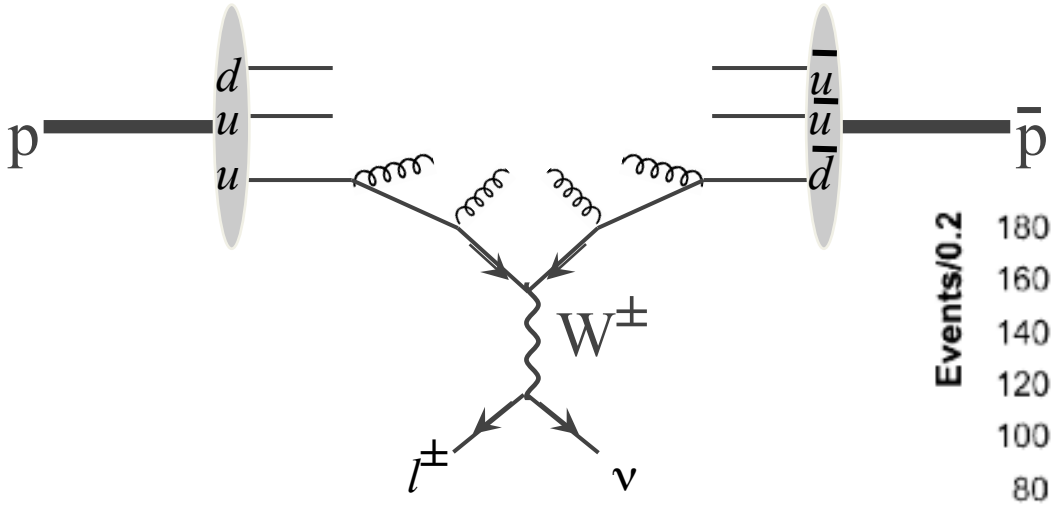
A4 using 2.1 fb^{-1} data = 0.1098 ± 0.0079

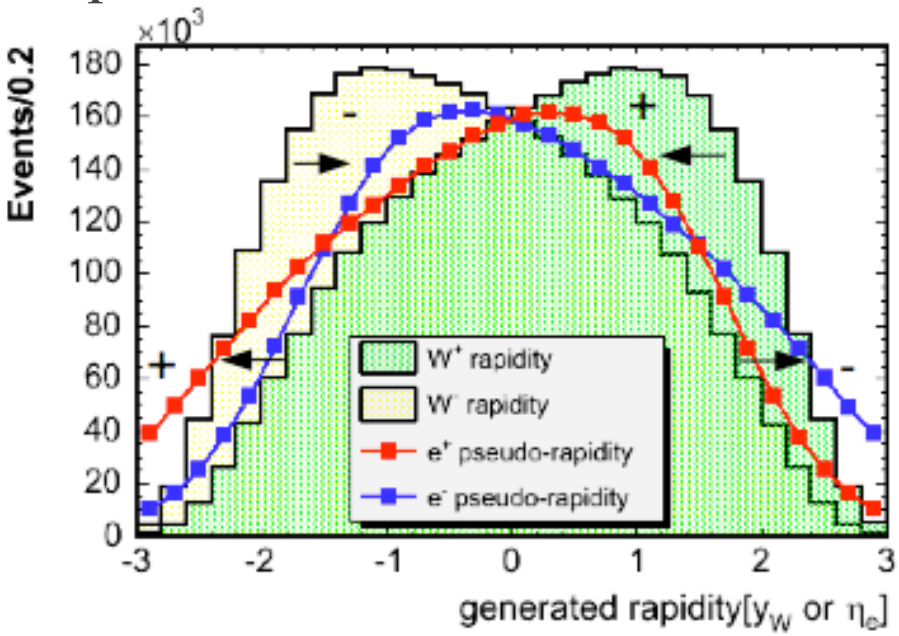
Translated to $\sin^2\vartheta_W$ in FEWZ :
$\sin^2\vartheta_W = 0.2331 \pm 0.0008$

Translated $\sin^2\vartheta_W$ in POWHEG :
$\sin^2\vartheta_W = 0.2328 \pm 0.0008$

CDF Run II Preliminary

W charge asymmetry



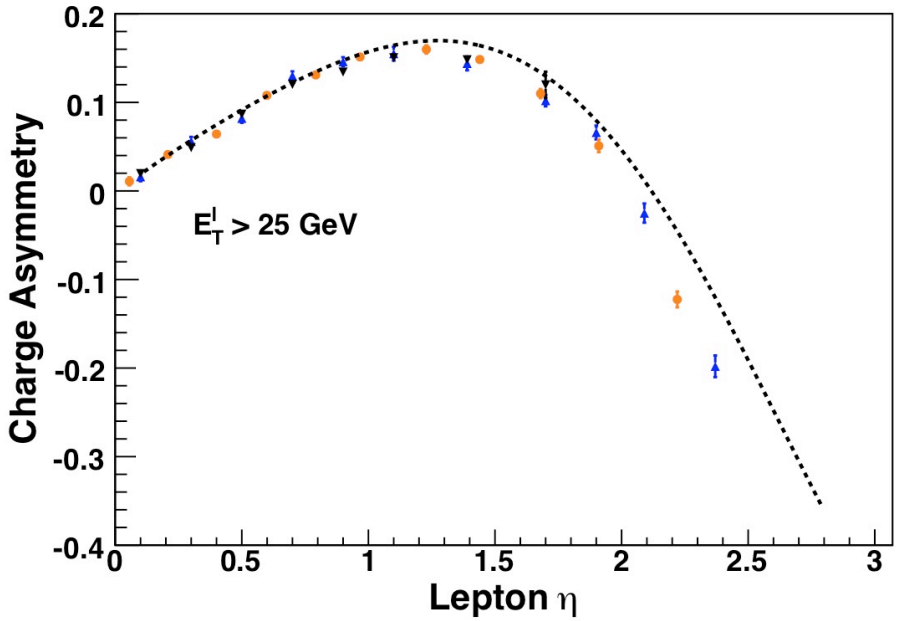


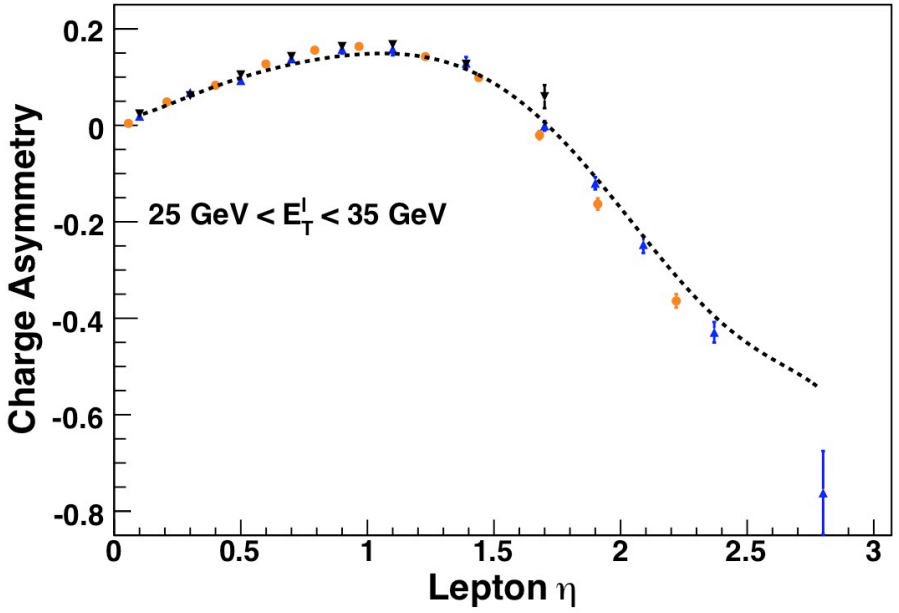
$$A_W(y) \equiv \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

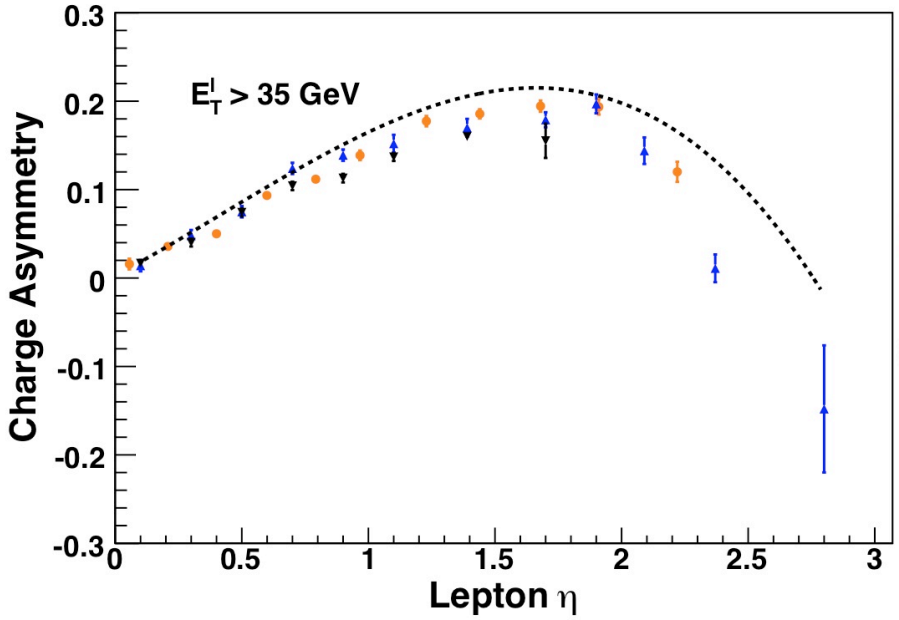
$$A_\ell(\eta) \equiv \frac{d\sigma(\ell^+)/d\eta - d\sigma(\ell^-)/d\eta}{d\sigma(\ell^+)/d\eta + d\sigma(\ell^-)/d\eta} = A(y_W) \otimes (V\text{–}A) \sim \frac{d(x)}{u(x)}$$

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

W charge asymmetry

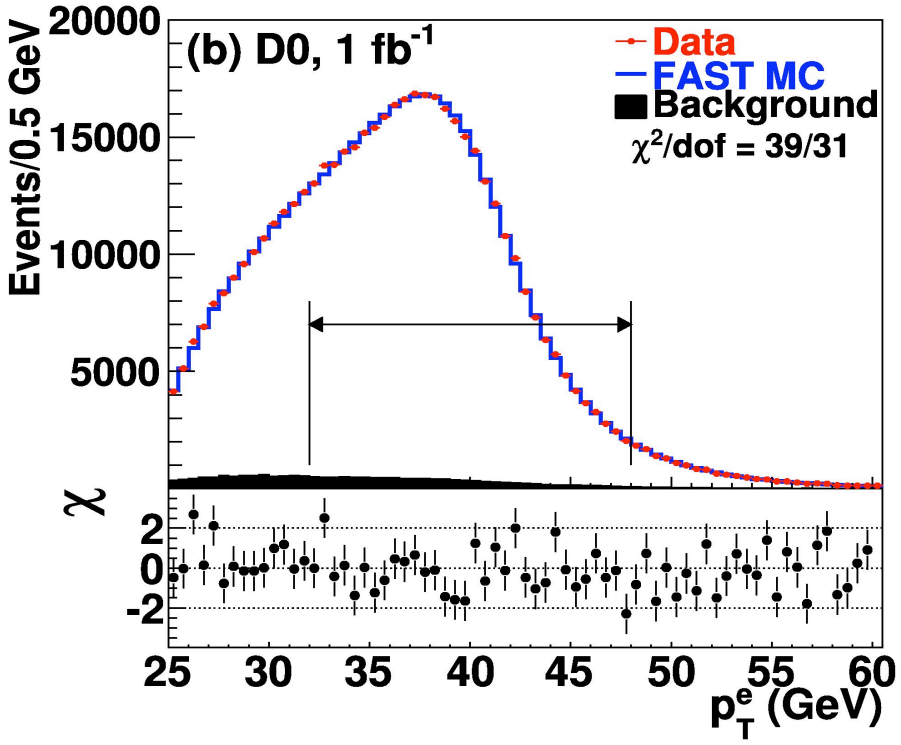


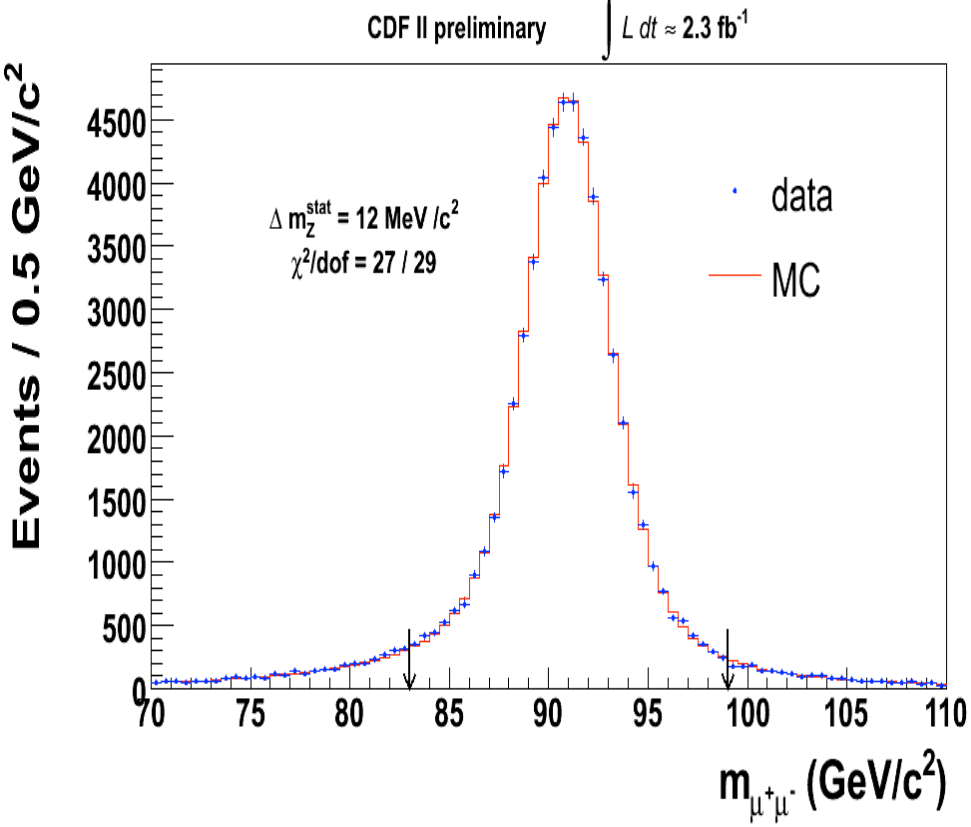




- CDF Run II Preliminary 1 fb^{-1} data (e) (no systematic uncertainties)
- DØ 0.75 fb^{-1} data (e)
- DØ Run II Preliminary 5 fb^{-1} data (μ)
- RESBOS with CTEQ6.6

m_W





m_W:

D0: $m_W = 80402 \pm 43$ MeV/c^2

CDF: $m_W = 80413 \pm 48$ MeV/c^2

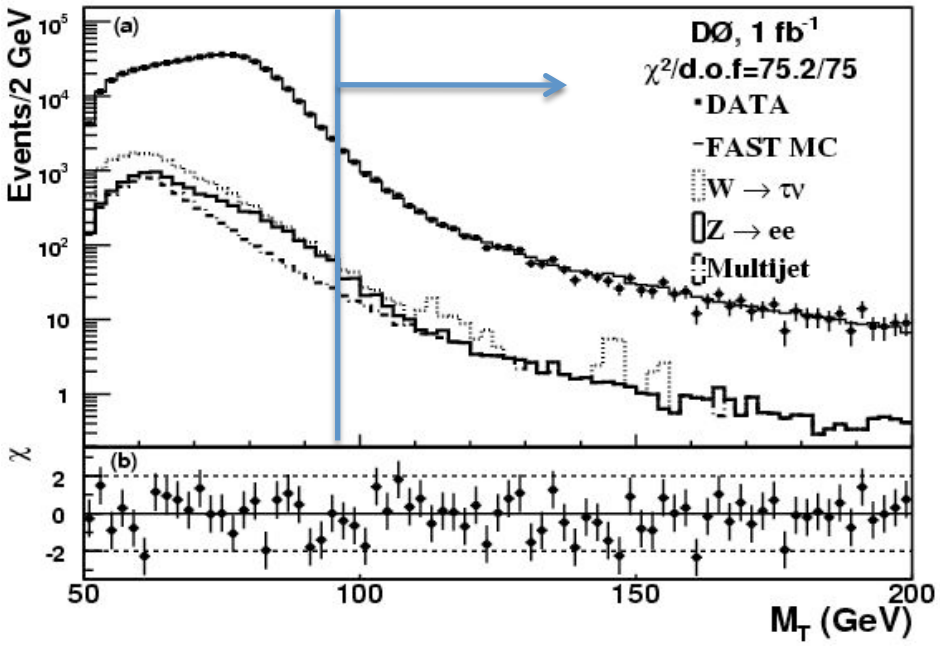
Tev: $m_W = 80420 \pm 31$ MeV/c^2 (includes Run 1)

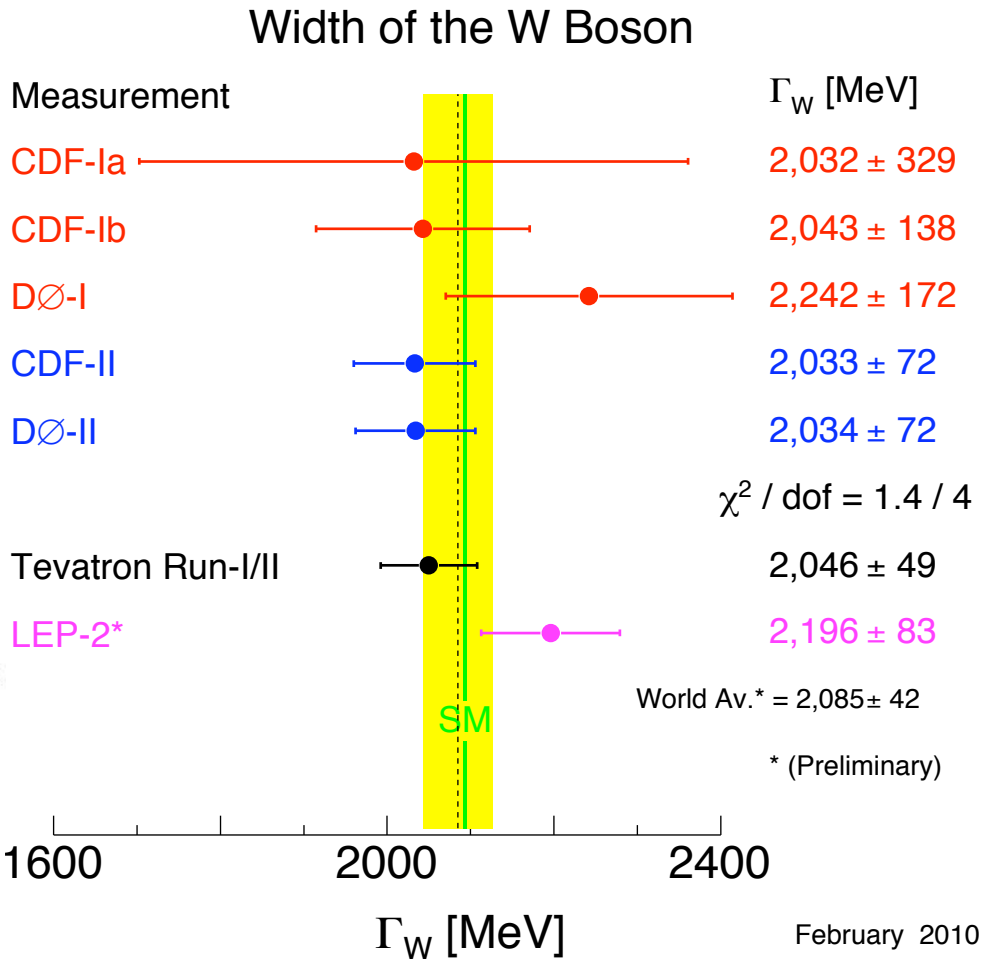
LEP: $m_W = 80376 \pm 33$ MeV/c^2

Heading to CDF 25MeV/c^2 measurement

CDF	Δm_Z (stat)
published (200/pb)	43 MeV
expected (2.3/fb)	13 MeV

Γ_W

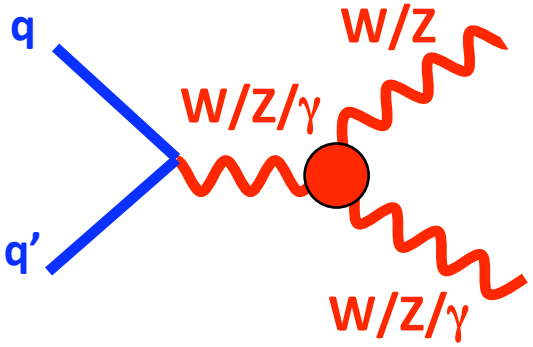


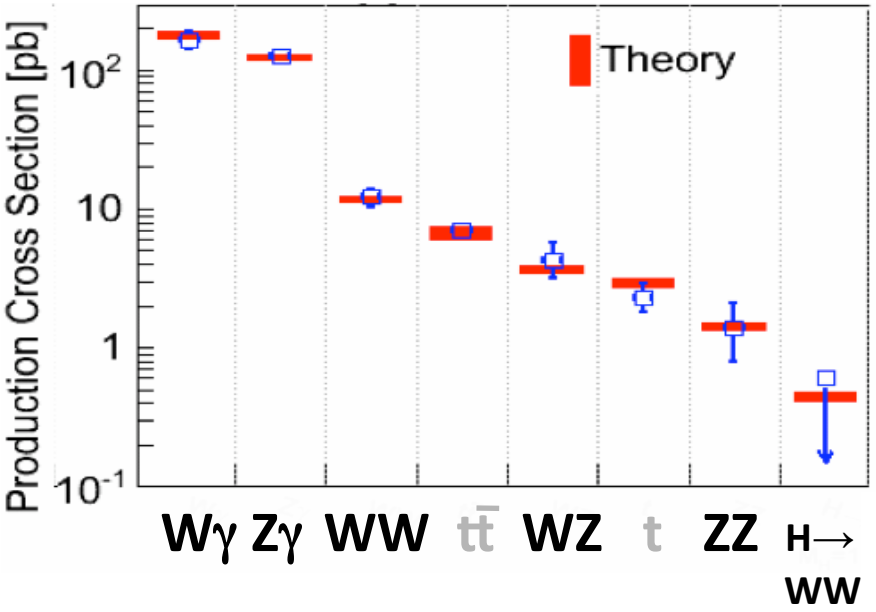


Γ_W predicted in Standard Model:
Γ_W^{SM} = 2091±2 MeV (PDG)

Tev error improves from 62 to 49 MeV

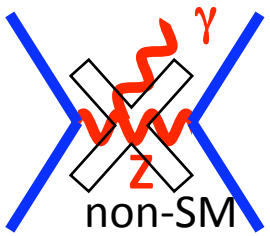
Dibosons

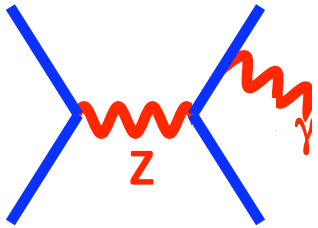

q
q'
W/Z
W/Z/γ
W/Z/γ

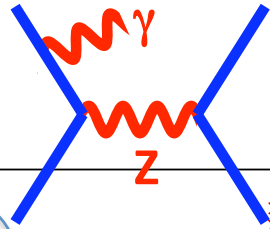

Production Cross Section [pb]
10²
10
1
10⁻¹
Theory
Wγ
Zγ
WW
tt̄
WZ
t
ZZ
H→ WW

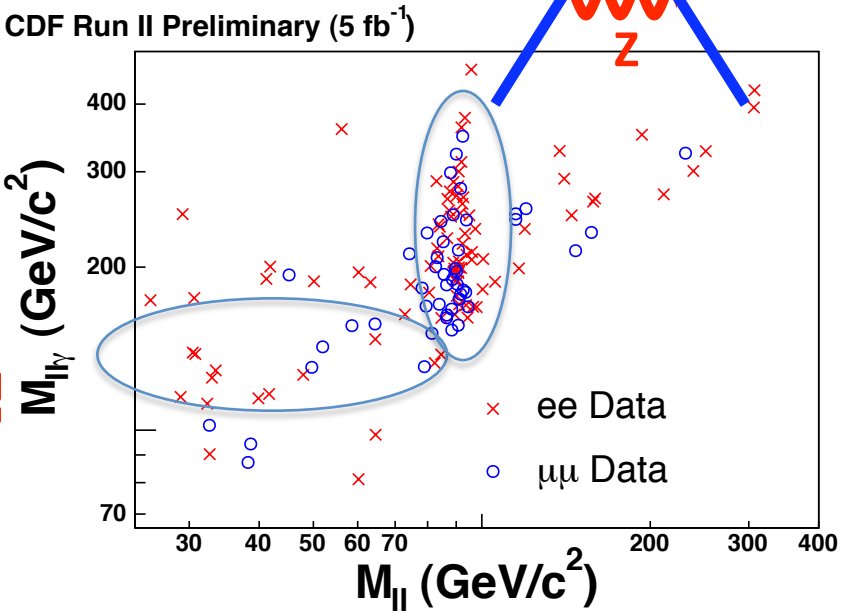
Zγ

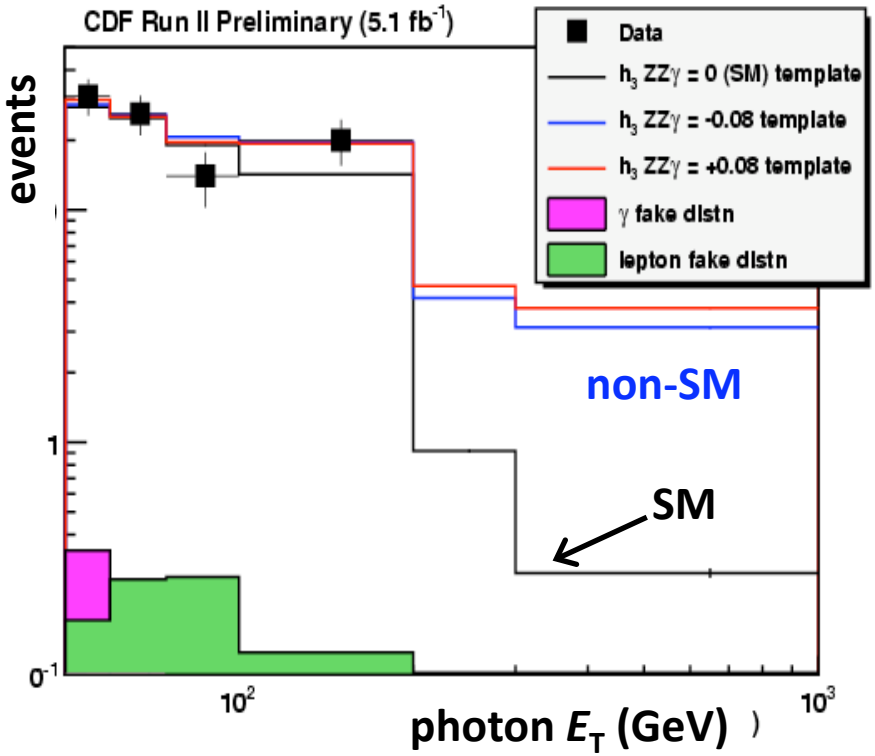
Using (Z→ll)+γ
and (Z→νν)+γ

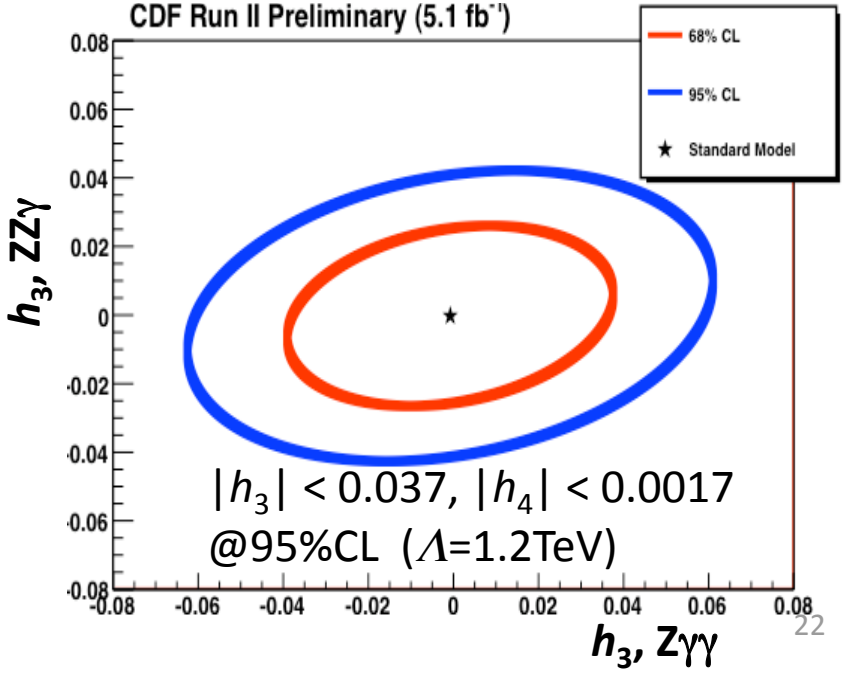




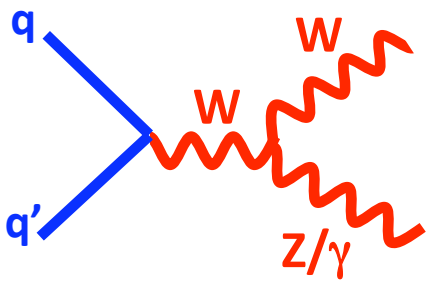


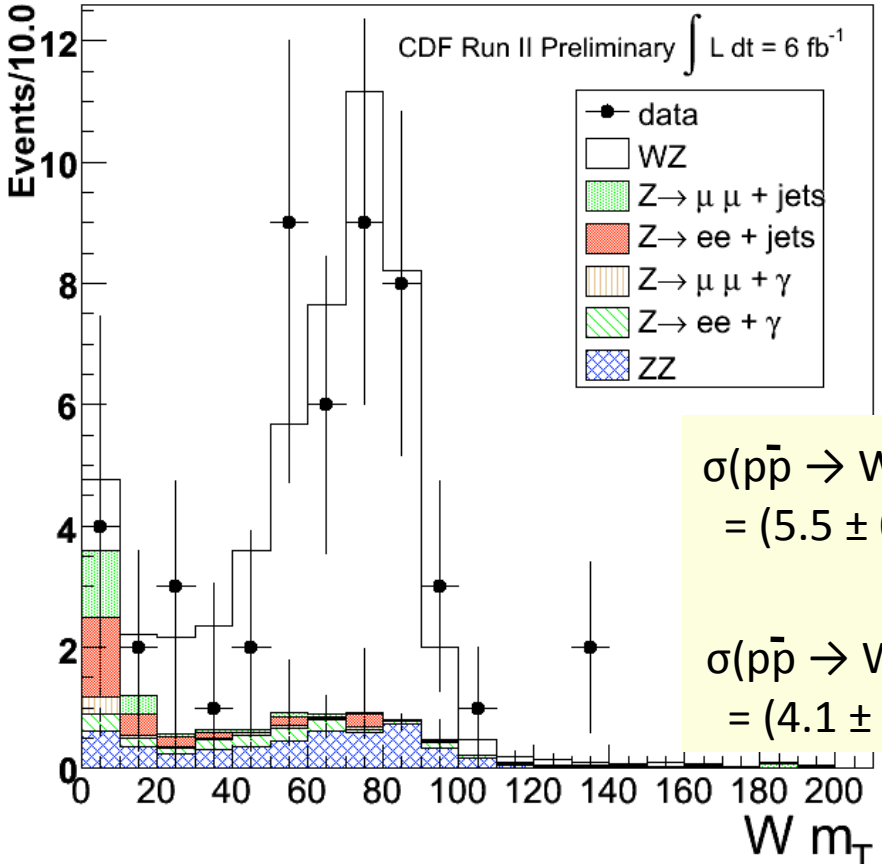






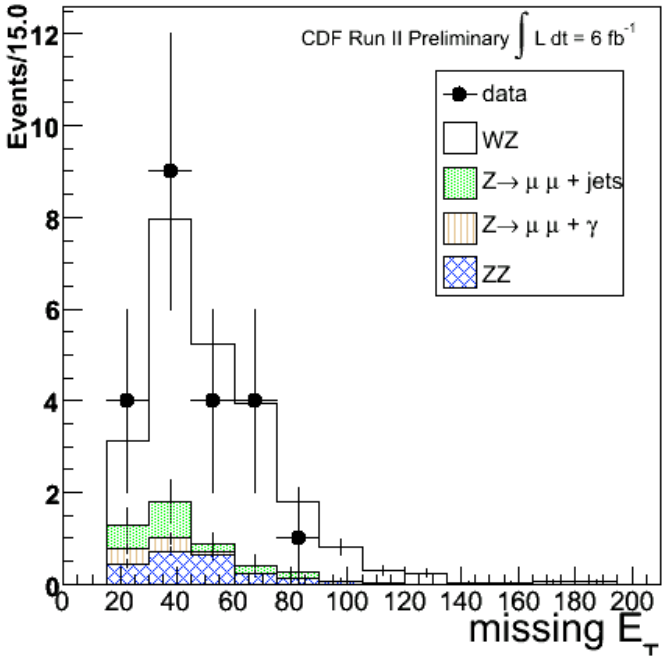
WZ

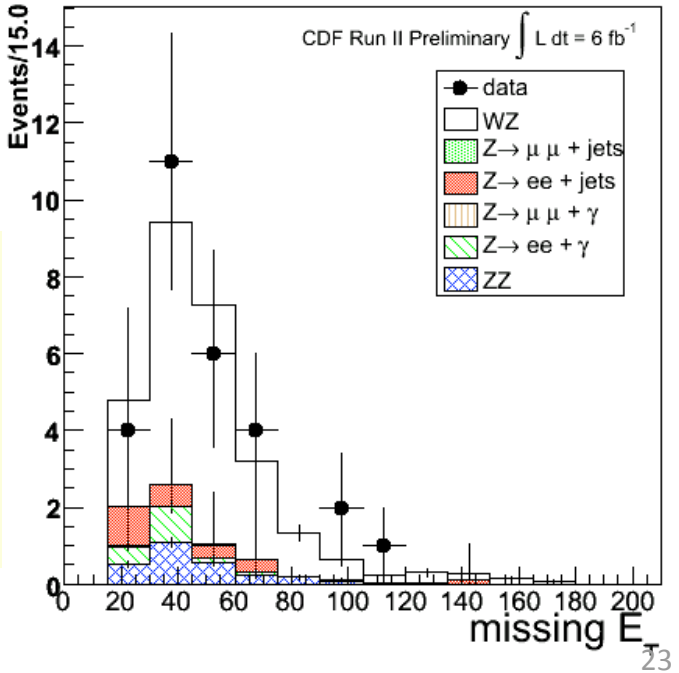




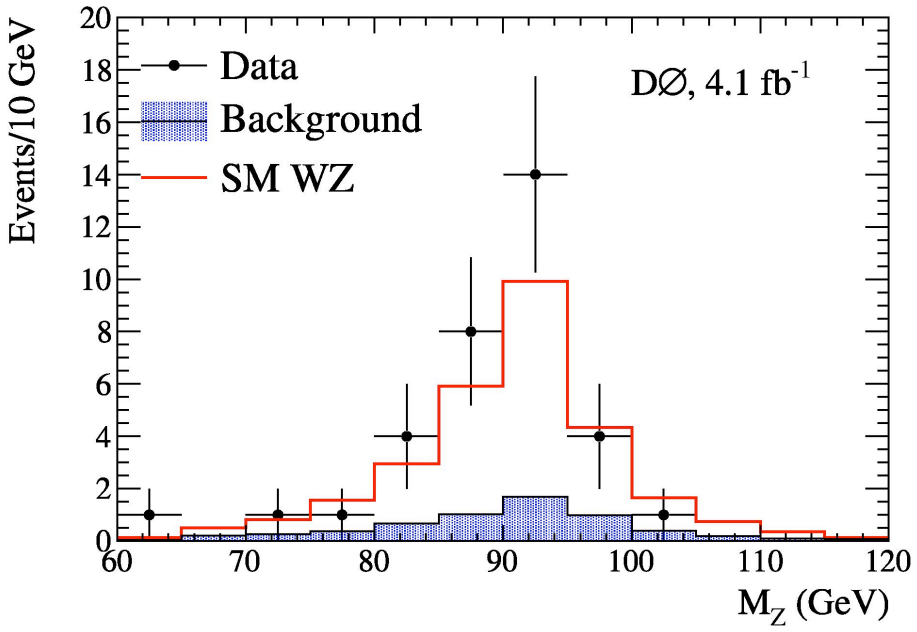
$\sigma(p\bar{p} \rightarrow WZ) / \sigma(p\bar{p} \rightarrow Z)$
$= (5.5 \pm 0.9) \times 10^{-4}$

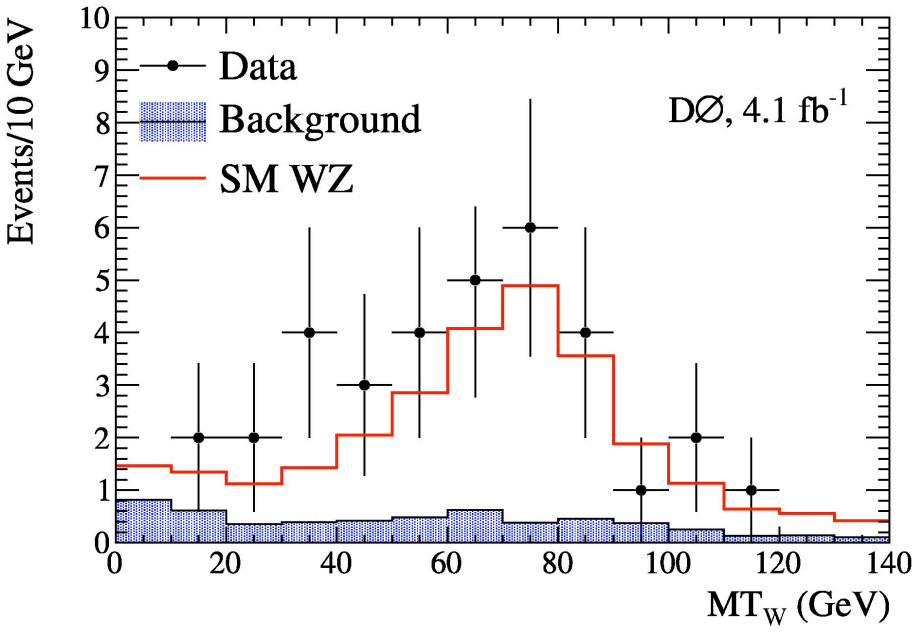
$\sigma(p\bar{p} \rightarrow WZ)$
$= (4.1 \pm 0.7)$ pb

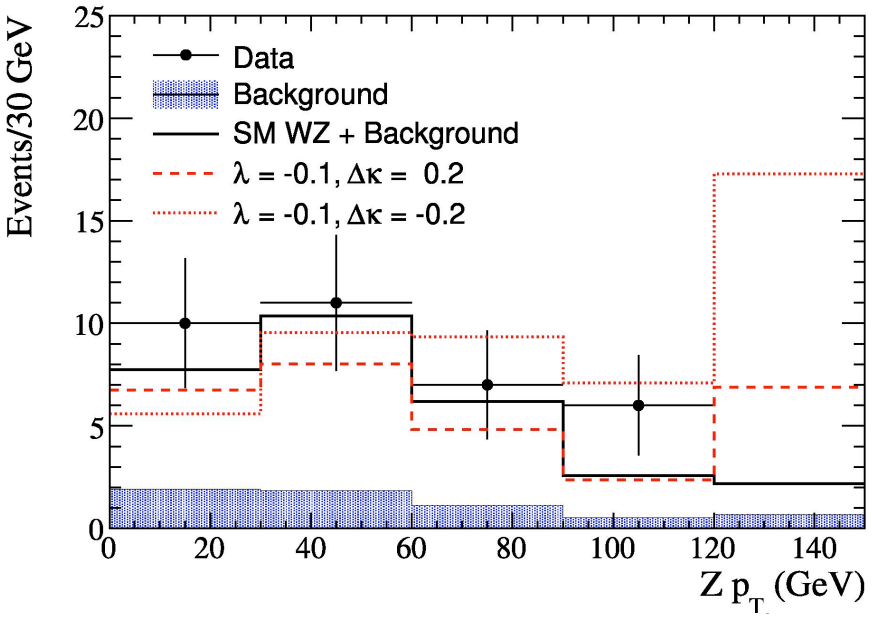




WZ







$\sigma(p\bar{p} \rightarrow WZ) = 3.89\ ^{+1.07}_{-0.90}$ pb

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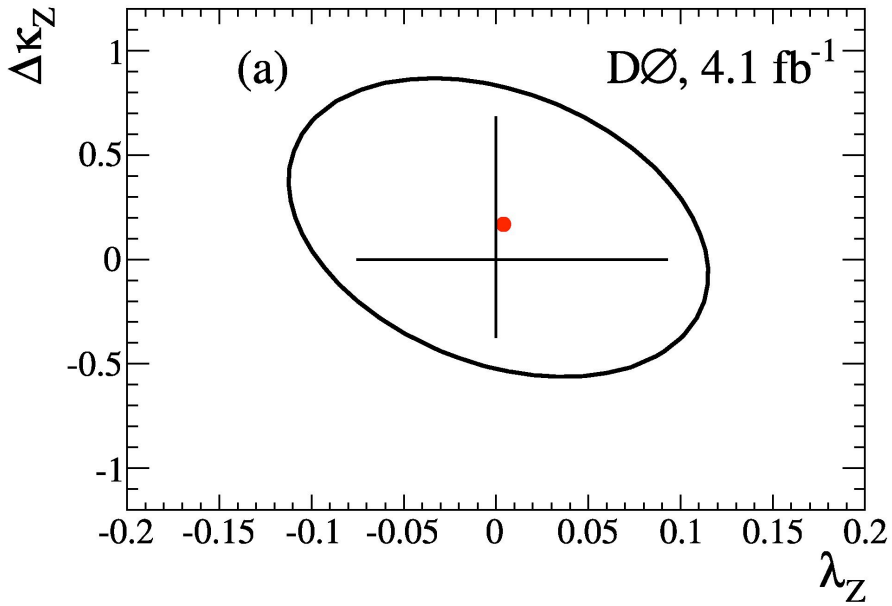
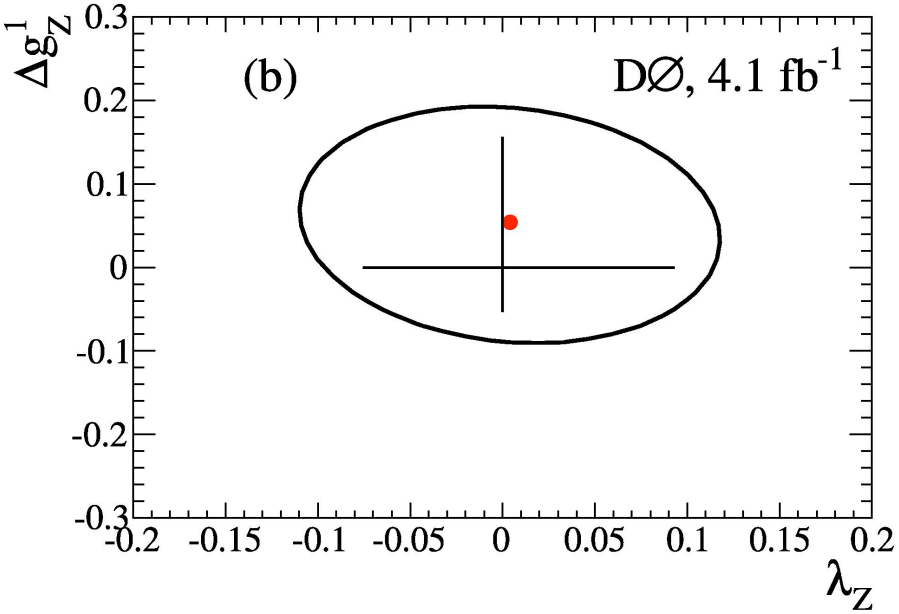
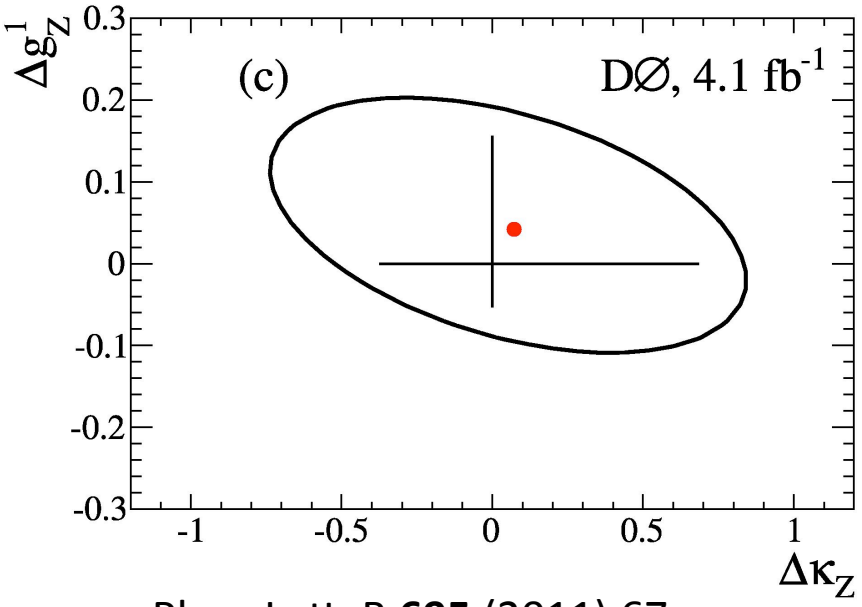
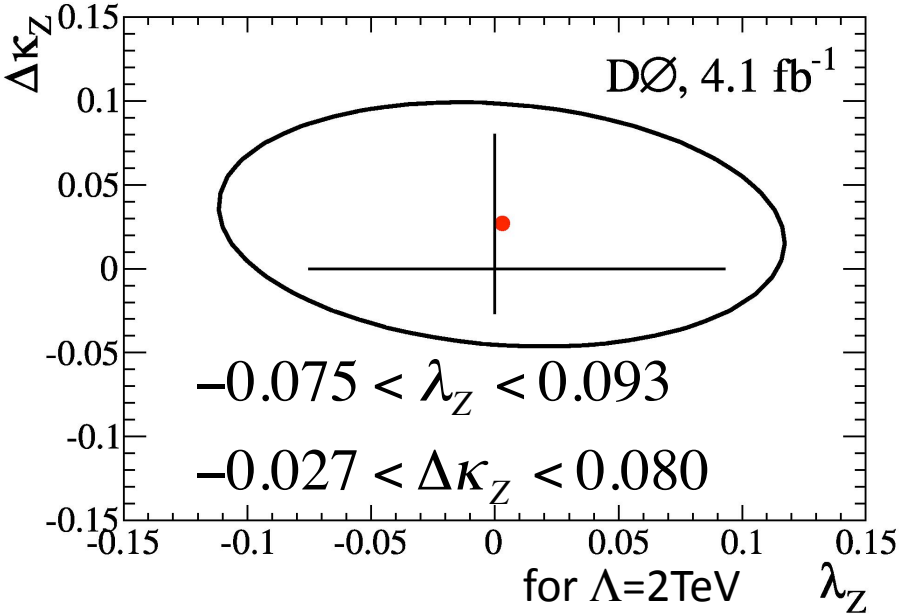
WZ









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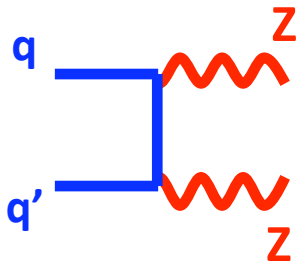
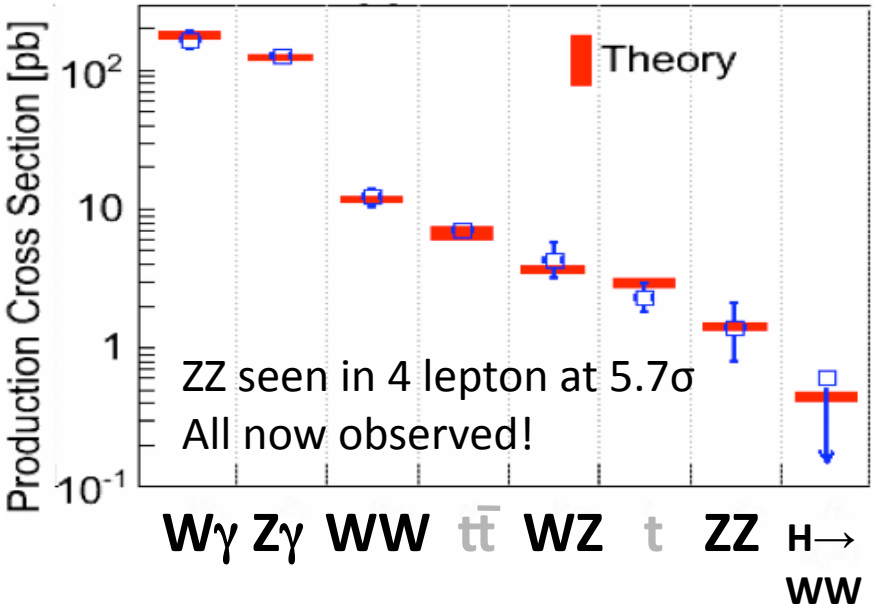
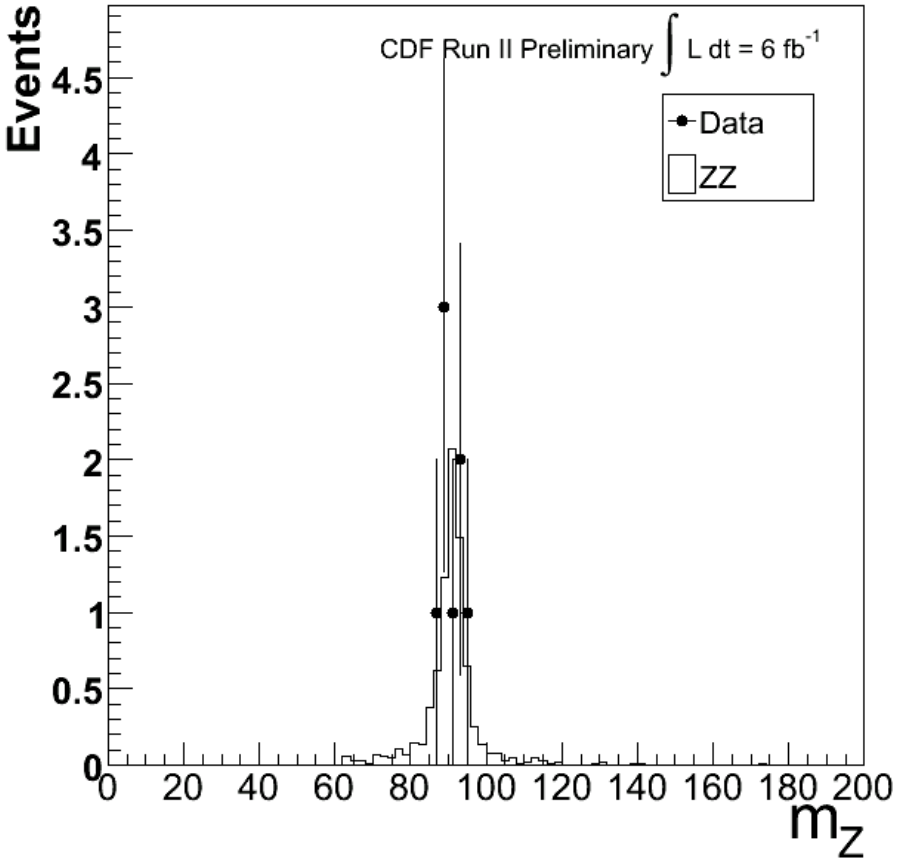
ZZ→4l



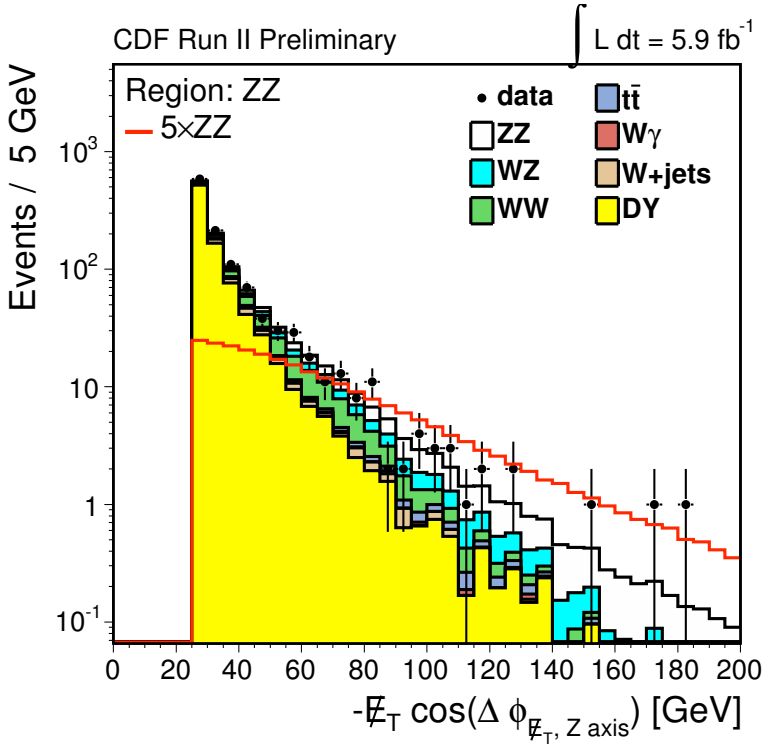


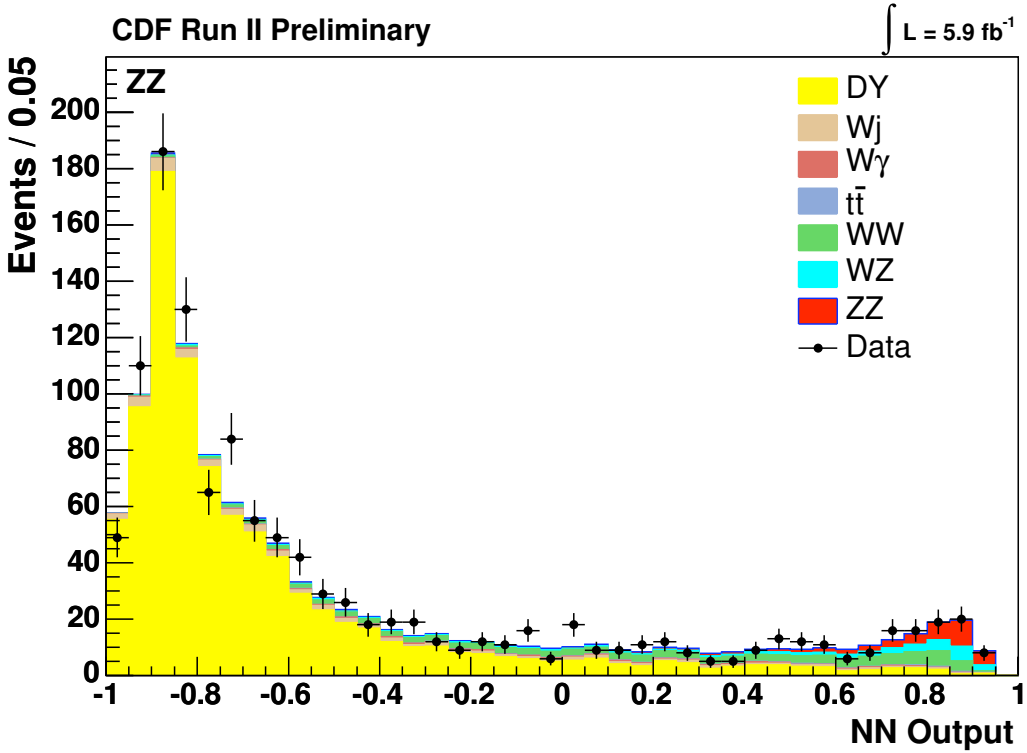


$\sigma(p\bar{p} \rightarrow ZZ) / \sigma(p\bar{p} \rightarrow Z)$
$= (2.3^{+1.5}_{-0.9}\,(stat) \pm 0.3\,(syst)) \times 10^{-4}$

$\sigma(p\bar{p} \rightarrow ZZ)$
$= (1.7\,^{+1.2}_{-0.7}\,(stat)$
$\pm 0.2\,(syst))\ pb$

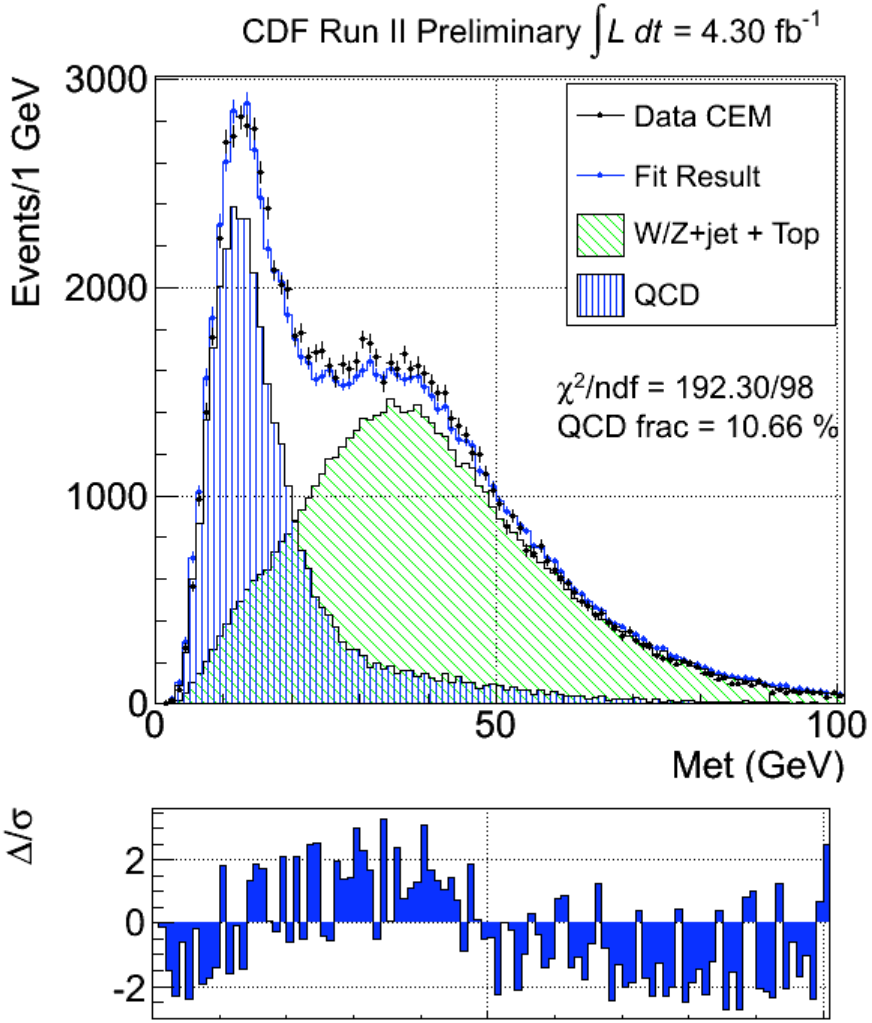
ZZ→llνν



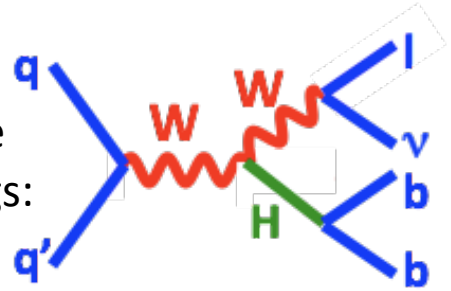


$$\sigma(p\bar{p} \to ZZ) = 1.45^{+0.45}_{-0.42}(stat.)^{+0.41}_{-0.30}(syst.)\ \text{pb}$$

WW/WZ → lνjj

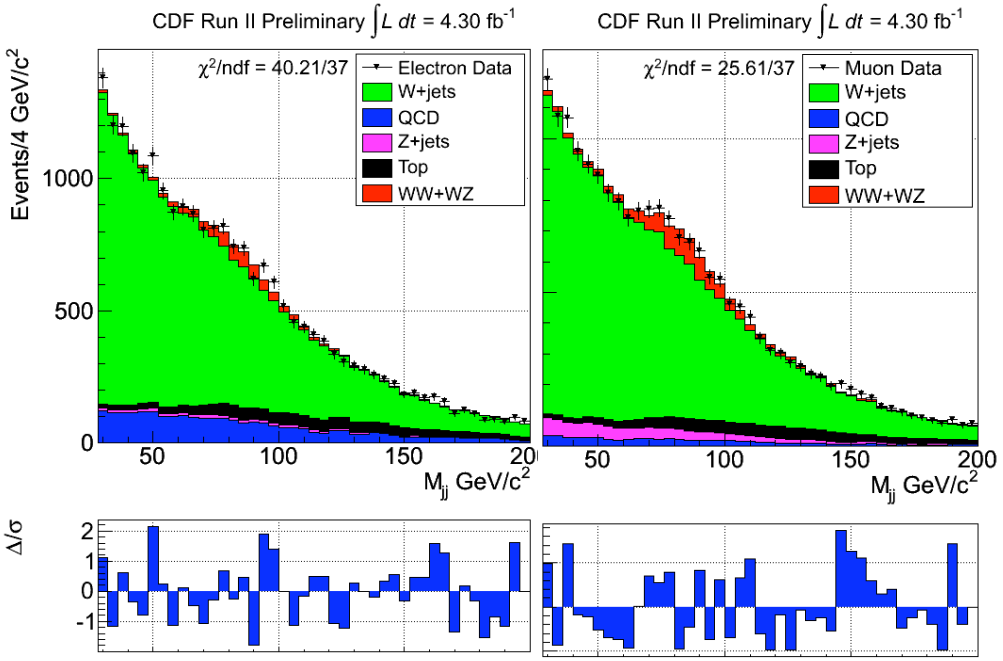


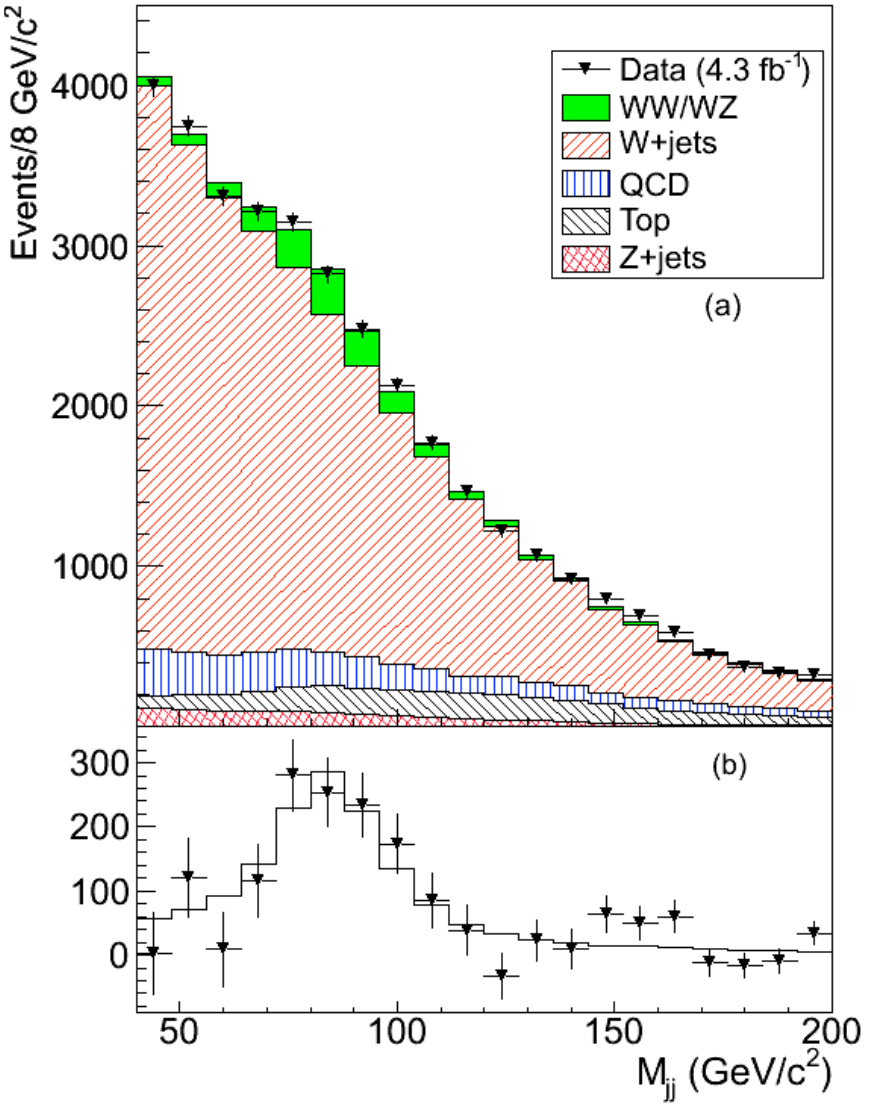
Similar final state to low-mass Higgs:



Sample	Electrons	Muons
MC W +jets	18010 ± 531	16673 ± 482
MC Z+jets	353 ± 42	966 ± 115
diboson	750 ± 68	651 ± 59
top	1324 ± 134	1149± 115
QCD (from data)	2314 ± 462	639 ± 159
Total MC + QCD	22751	20078
data	22204 ± 149	19738 ± 141

WW/WZ → lνjj

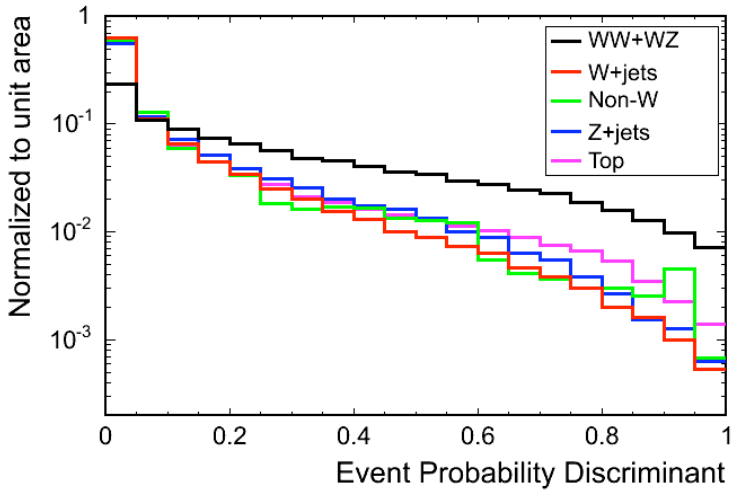




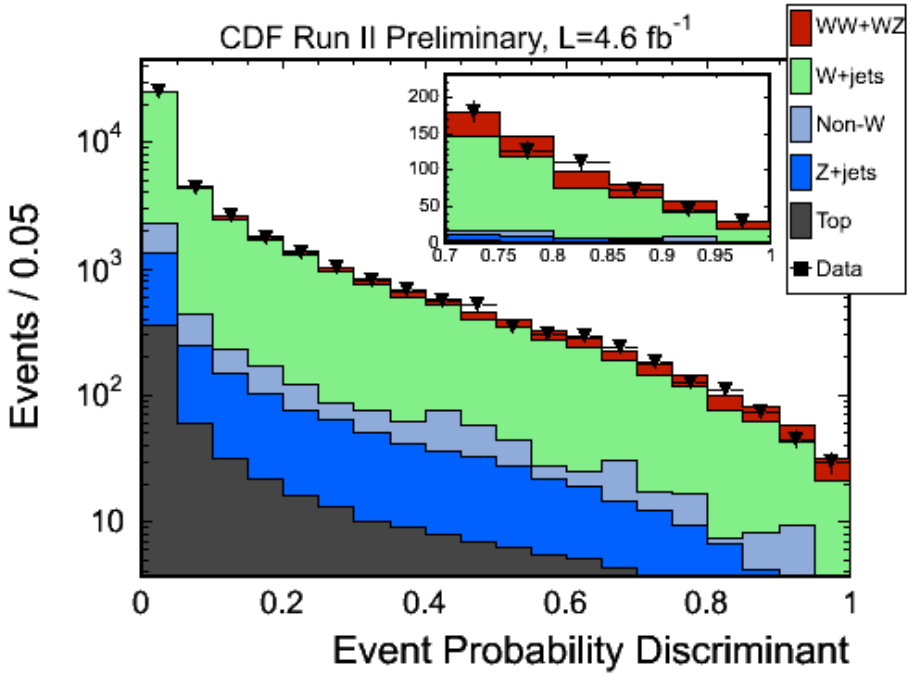
σ(WW+WZ)
= (18.1 ± 3.3(stat) ± 2.5(sys))pb

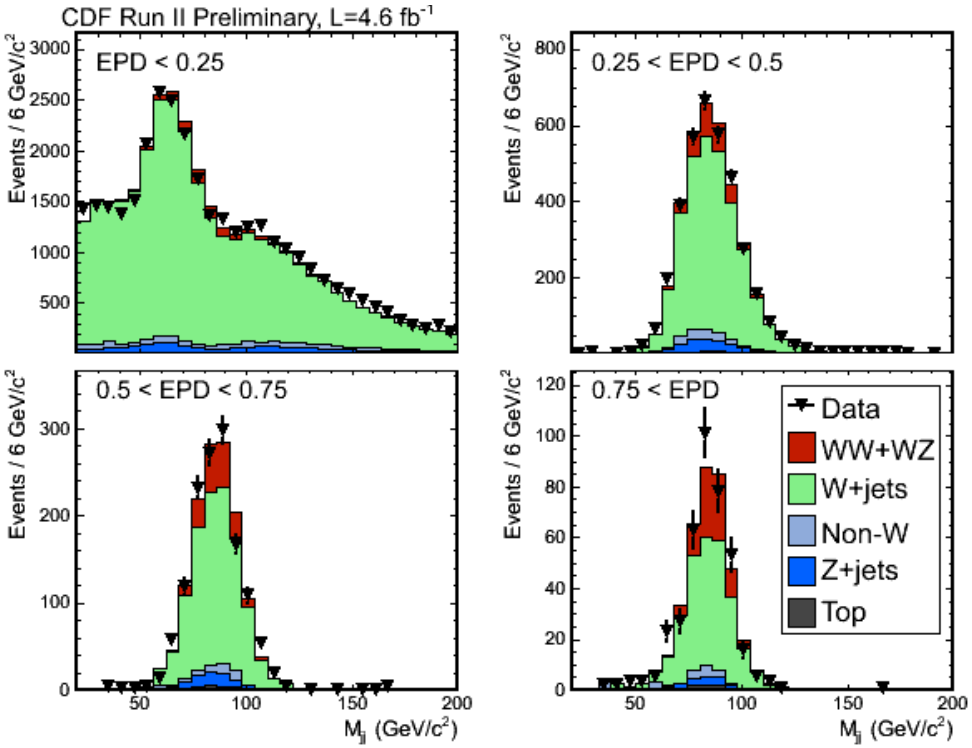
5.2σ significance

WW/WZ → lνjj



Use matrix element techniques



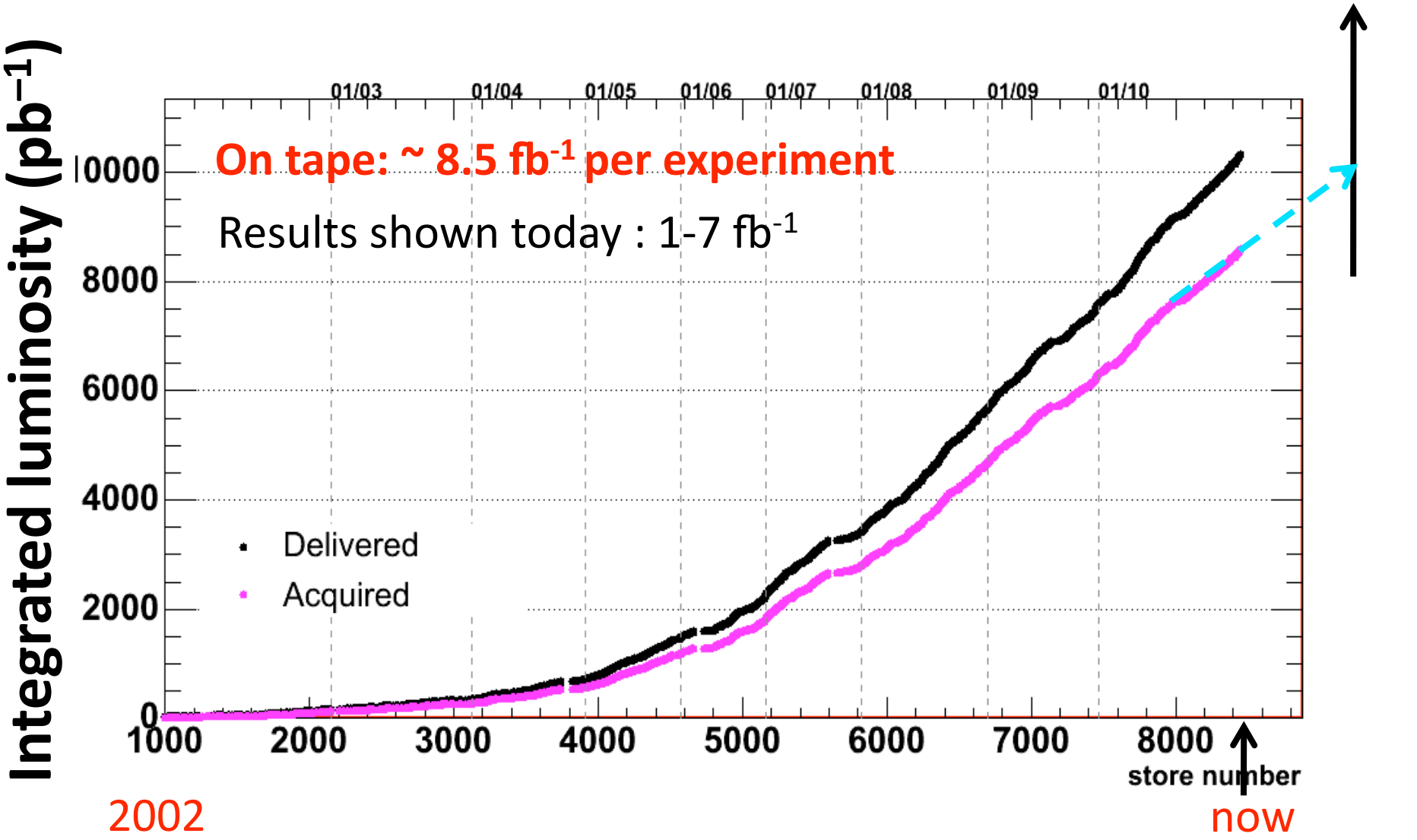


$\sigma(WW+WZ) = (16.5\ ^{+3.3}_{-3.0})$ pb

5.4σ significance

Tevatron outlook

End : Sep 2011(?)



Outlook

- Completing strong electroweak physics programme

- Focusing on high-statistics Tevatron legacy measurements and diboson physics underpinning symmetry-breaking searches