Electroweak Measurements at CDF

A. Sidoti
For the CDF Collaboration

LPNHE- Universite Paris VI "Pierre et Marie Curie"
(Paris, France)

IN2P3
Institut National de Physique Nucléaire et de Physique des Particules

Université Pierre & Marie Curie

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Research Training Networks

Lake Louise Winter Institute
(Canada)
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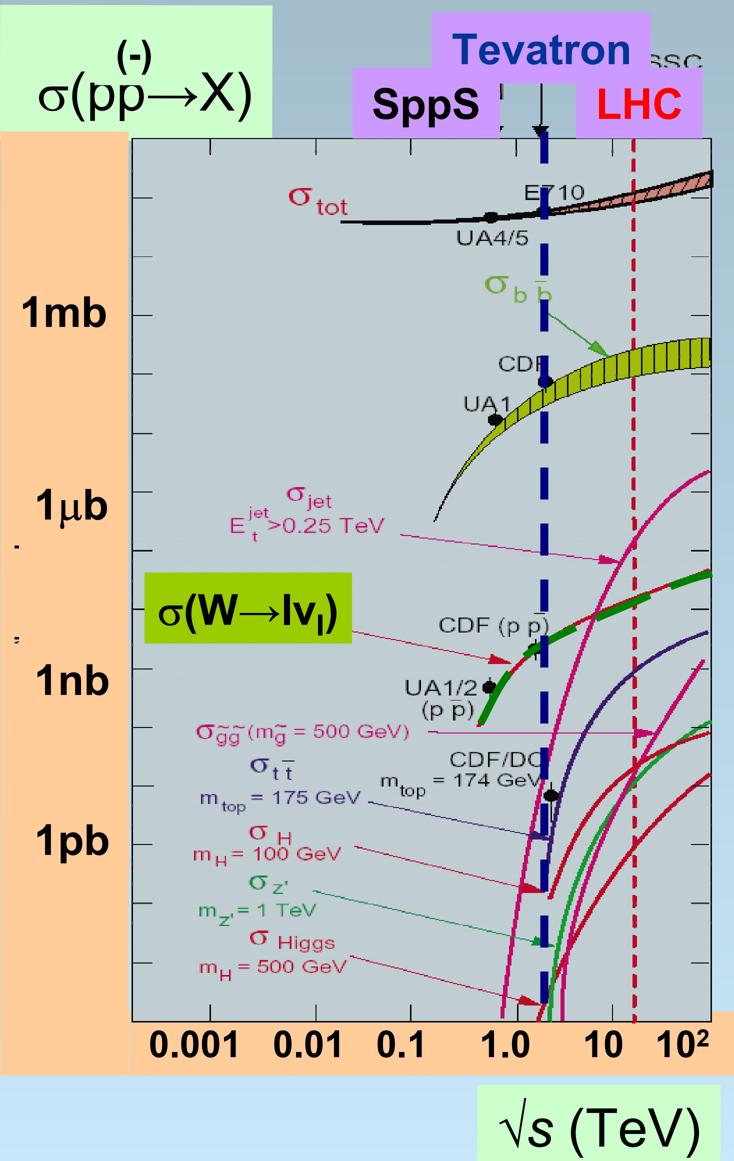
Why Electroweak Measurements?

- Precise Electroweak predictions
- Challenge for Electroweak physics measurement
    - Constrains the Standard Model

      OR
- Appearance of Physics Beyond SM
- Also crucial as input for LHC physics program:
    - Input to Parton Distribution Functions
    - Some Tevatron signals will be LHC background
- After LEP era stepping into Tevatron era:

  N(Z)@Tevatron > N(W)@LEP

Production Processes at Tevatron



Rate @L=10^{32}cm^{-2}s^{-1}

	σ(pb)	(Hz)	Evts/Week
bb	~10^8	~10^4	6.10^9
W→eν_e	~2700	~0.3	~2.10^5
Z→ee	~250	~0.03	~2.10^4
Wγ→eνγ	~20	~0.02	~10^3
WW	~10	~10^{-3}	600
Zγ→eνγ	~4	~4.10^{-4}	240
t t	~6	~6.10^{-4}	360

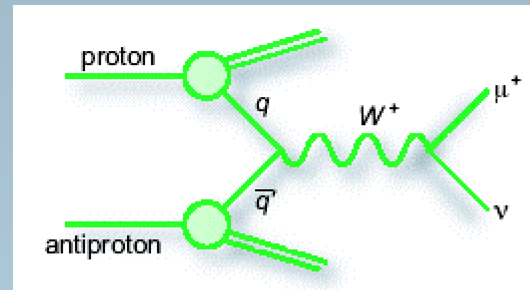
Yield ~10^4 Ws , ~10^3 Zs

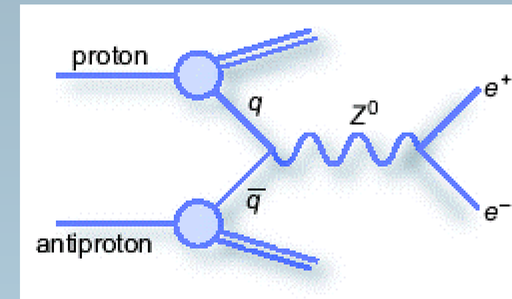
Outline:

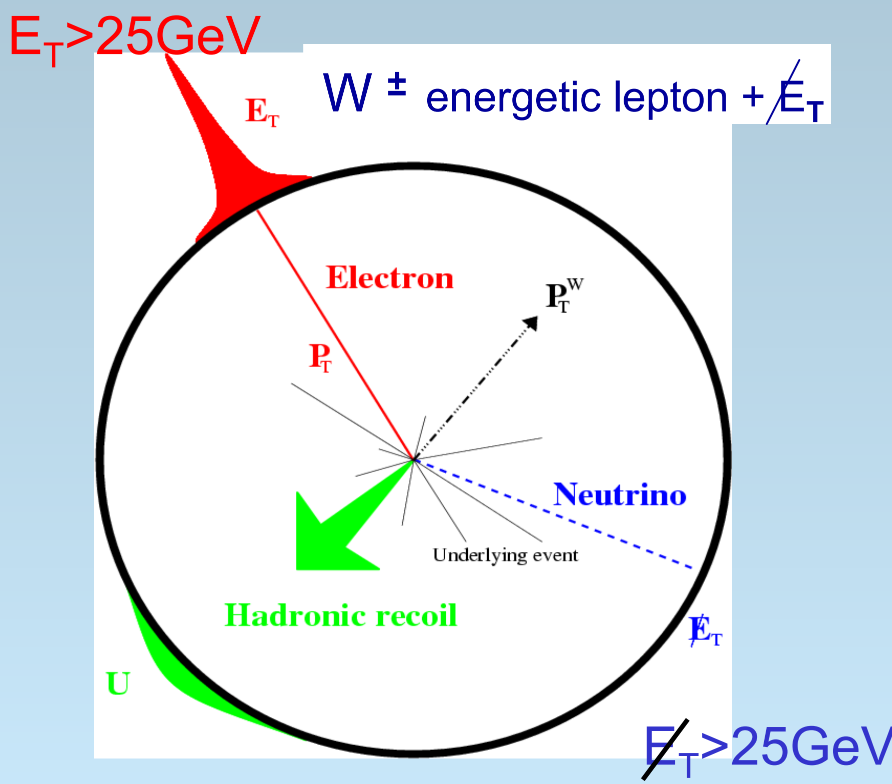
- W and Z cross sections
- Asymmetries (W and Z)
- Diboson production
- W mass measurement

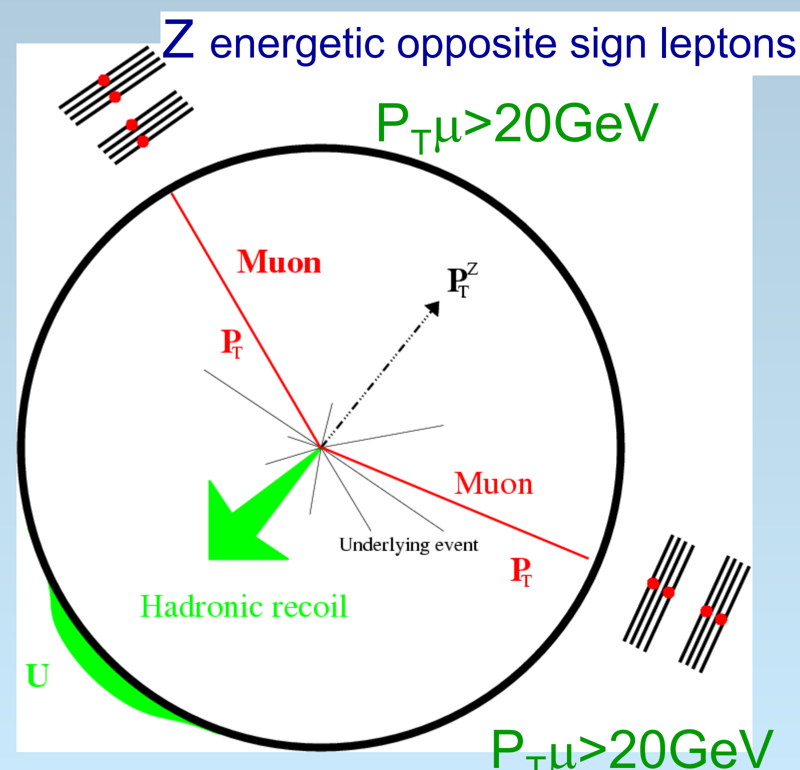
W/Z Gauge Bosons and Event Topology

At hadron colliders
Use clean leptonic decays

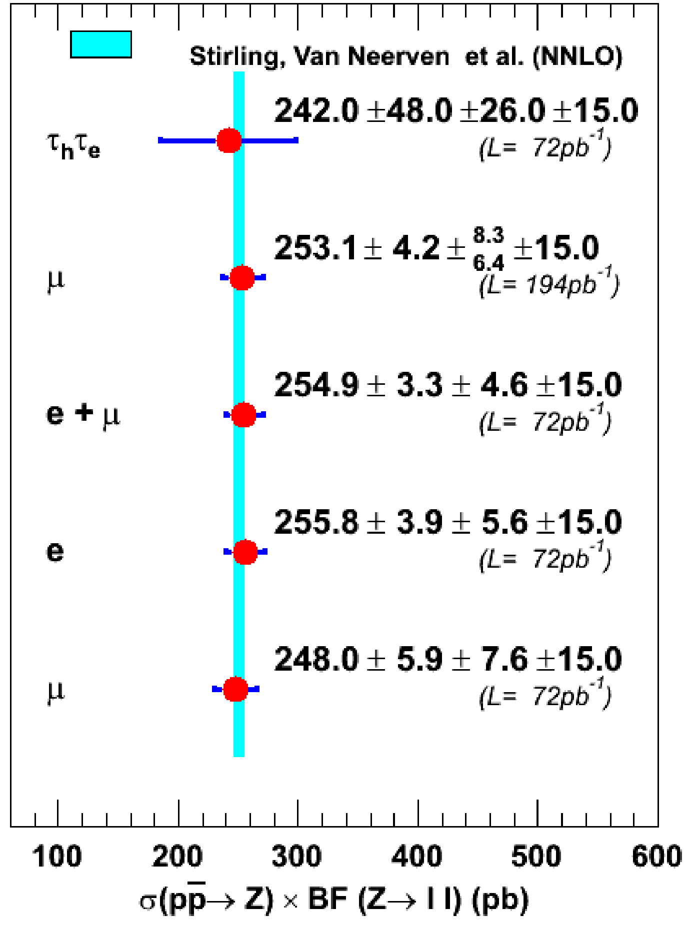


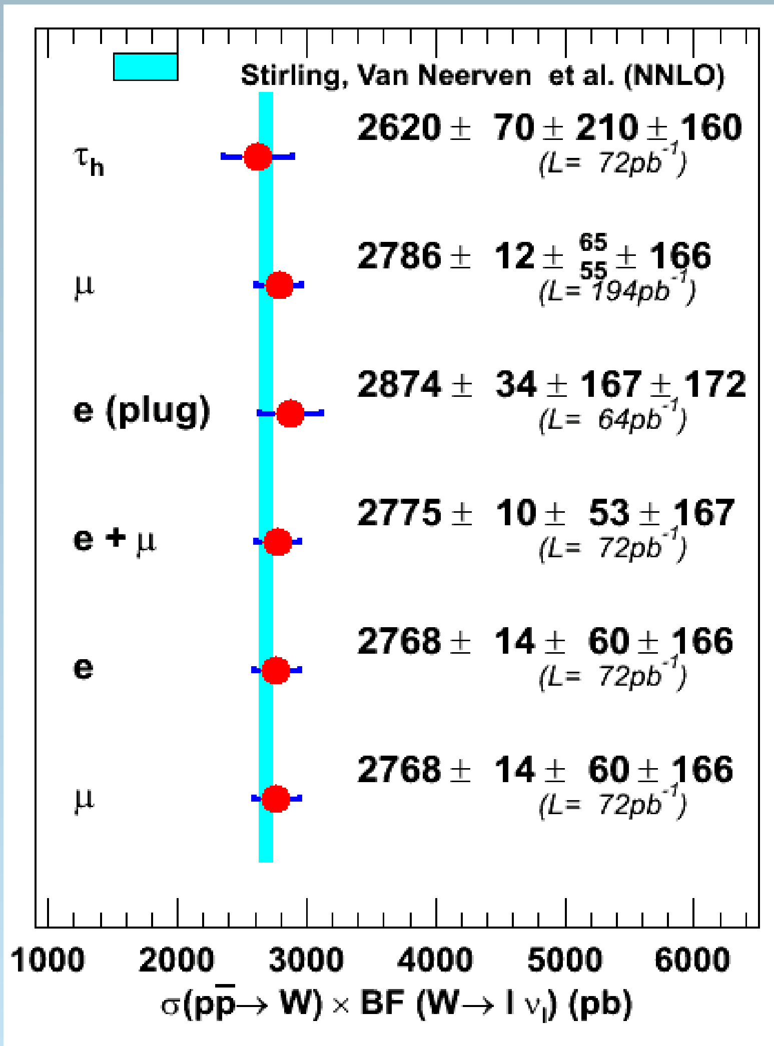






Inclusive W/Z Cross Sections





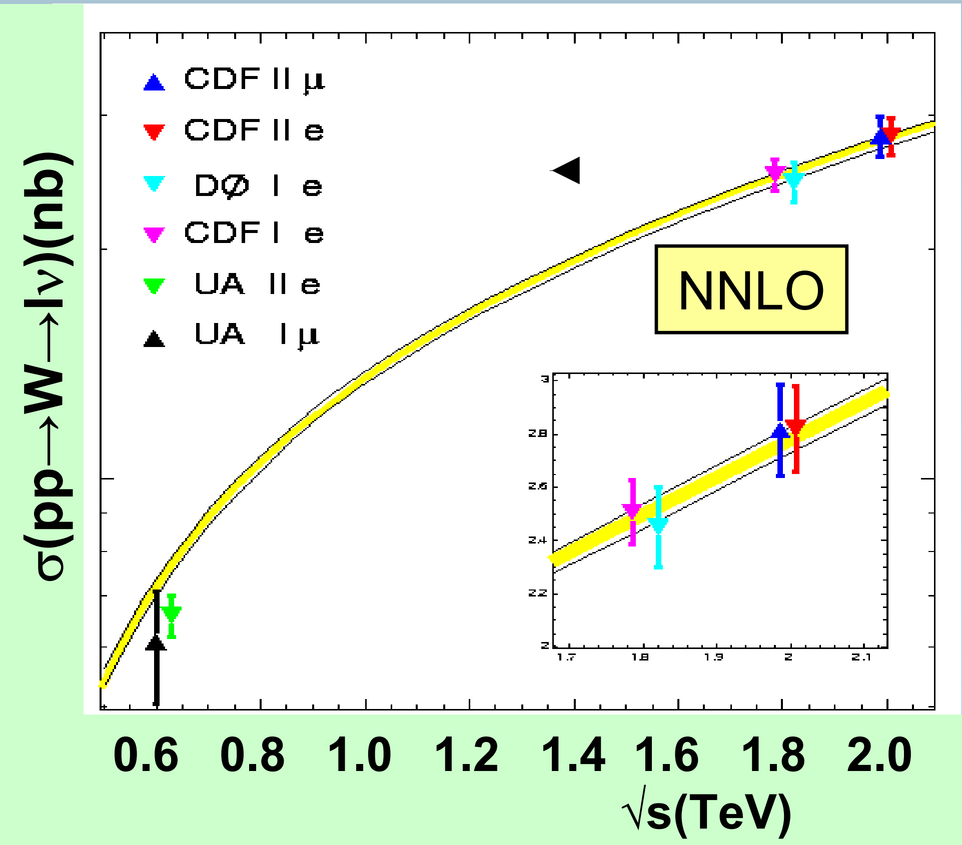
$\sigma(pp \to Z) x BF(Z \to ll)_{Th,NNLO} = 251.3 \pm 5.0$pb

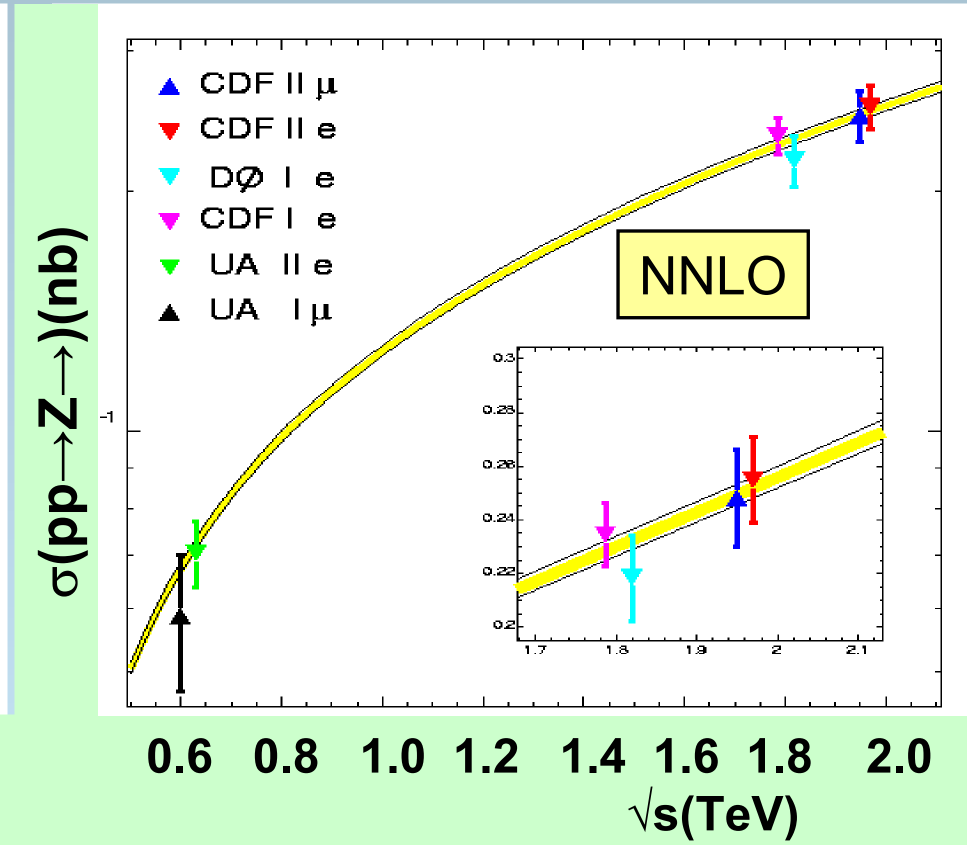
Good agreement with NNLO

- Systematics limited measurement
- Uncertainties: Luminosity (6%)
  PDFs(2%)

$\sigma(pp \to W) x BF(W \to l\nu)_{Th,NNLO} = 2687 \pm 54$pb

20 Years of W and Z at hadronic colliders





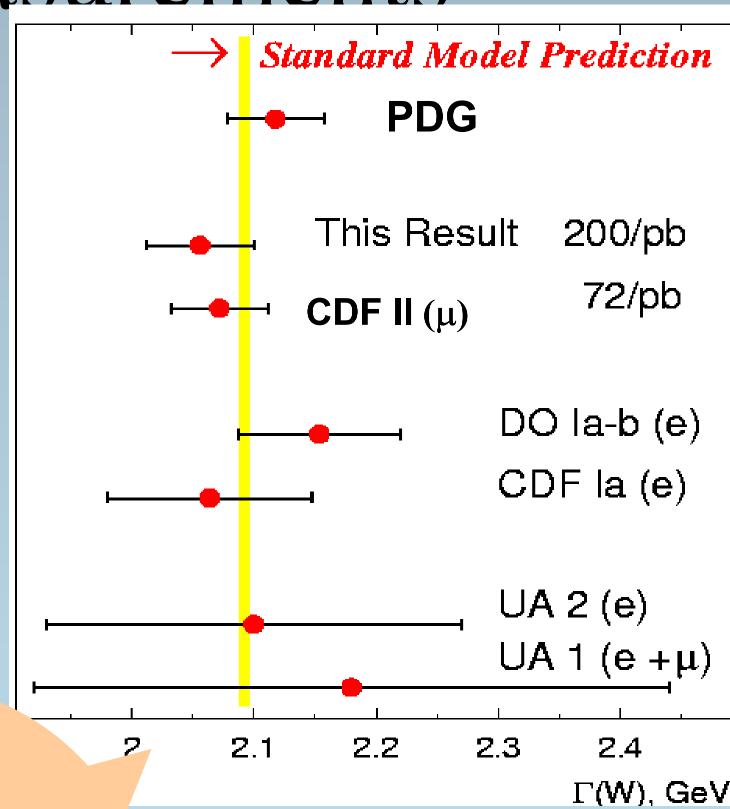
Indirect W Width Measurements

Checking internal consistency of SM with direct $\Gamma(W)$ measurement

R: cross section measurement ratio:

$$R = \frac{\sigma . BF(W \to l\nu_l)}{\sigma . BF(Z \to l^+ l^-)}$$

Many systematic uncertainties cancel out(Luminosity)



$$R = \frac{\sigma(pp \to W)}{\sigma(pp \to Z)} \frac{\Gamma(Z)}{\Gamma(Z \to ll)} \frac{\Gamma(W \to l\nu_l)}{\Gamma(W)}$$

Indirect W Width measurement

Channel	$\Gamma(W)$(MeV)	$\int Ldt(pb^{-1})$
e+μ	2079±41	72
μ	2056±44	194
PDG	2118±41	
SM Pred.	2092.1±2.5	

Z Asymmetry

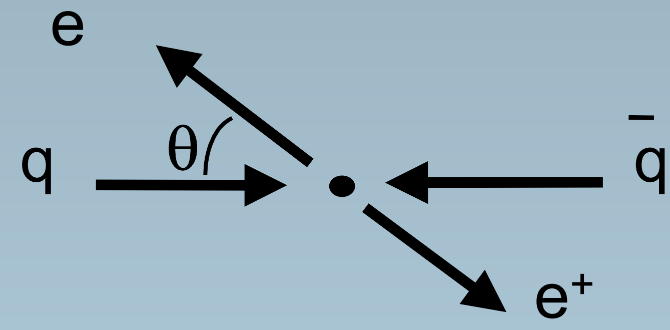
A_{FB} arises from Axial and Vector couplings

Z and γ interference term

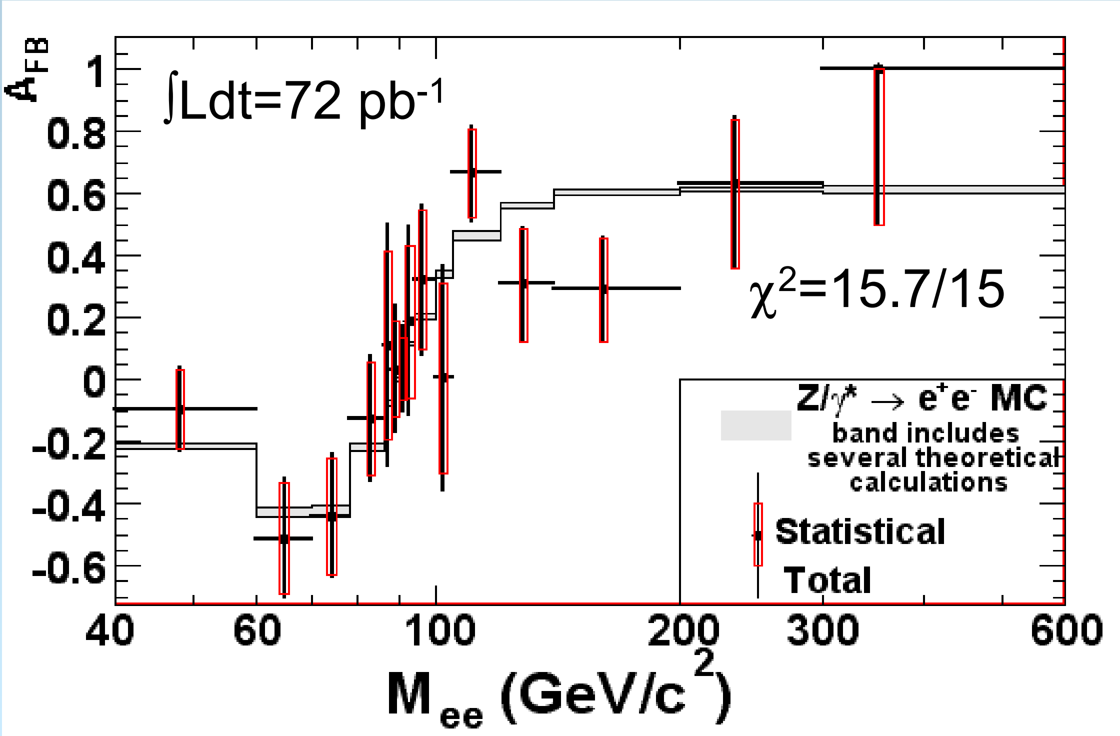
$$\frac{d\sigma}{d\cos\theta} = A(1+\cos^2\theta) + B\cos\theta$$

$$A_{FB} = \frac{d\sigma(\cos\theta>0) - d\sigma(\cos\theta<0)}{d\sigma(\cos\theta>0) + d\sigma(\cos\theta<0)}$$

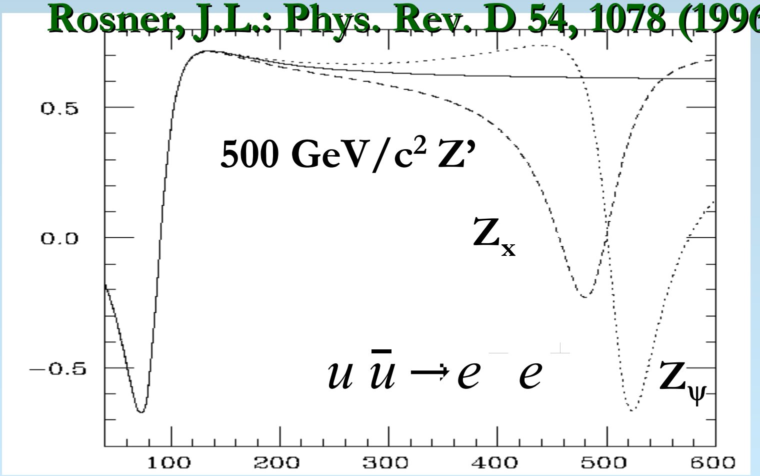
$$A_{FB} = \frac{3B}{8A}$$



- Measurement limited by statistics
- Complementary to LEP measurement far from the Z pole
- Sensitivity to heavy neutral bosons (Z')
- Extract quark, electron couplings and $\sin^2\theta_W^{Eff}$



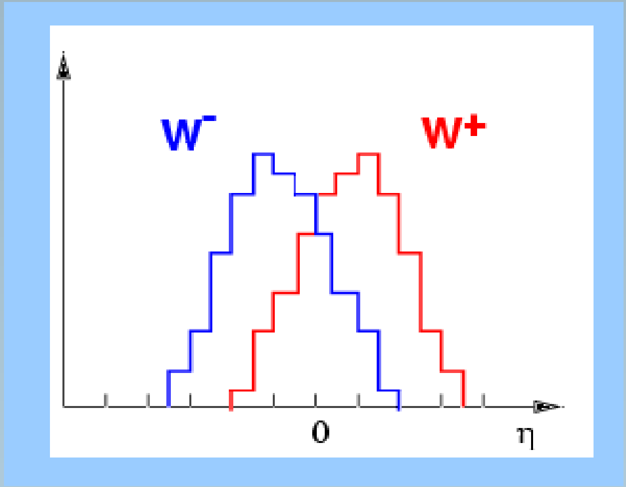
Rosner, J.L.: Phys. Rev. D 54, 1078 (1996



W Asymmetry

Sensitivity to PDF distributions(u/d ratio):
u carries more momentum than d

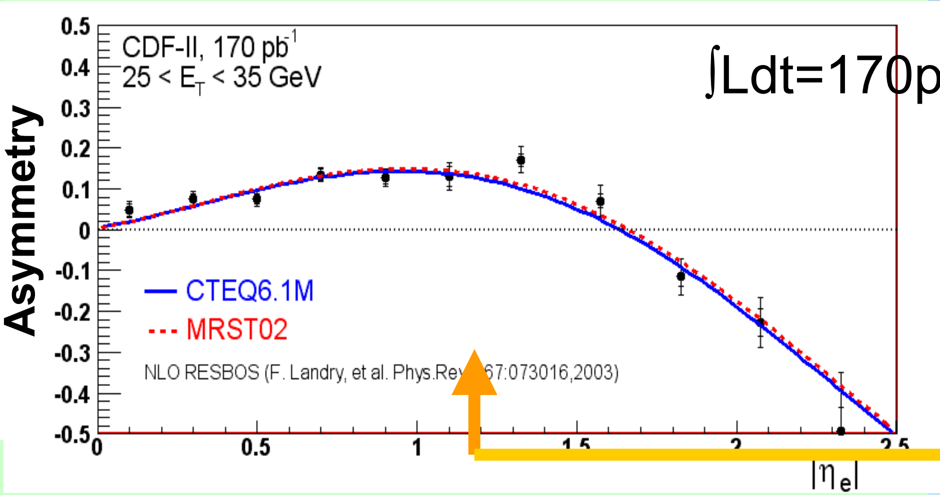
$$A(y_W) = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

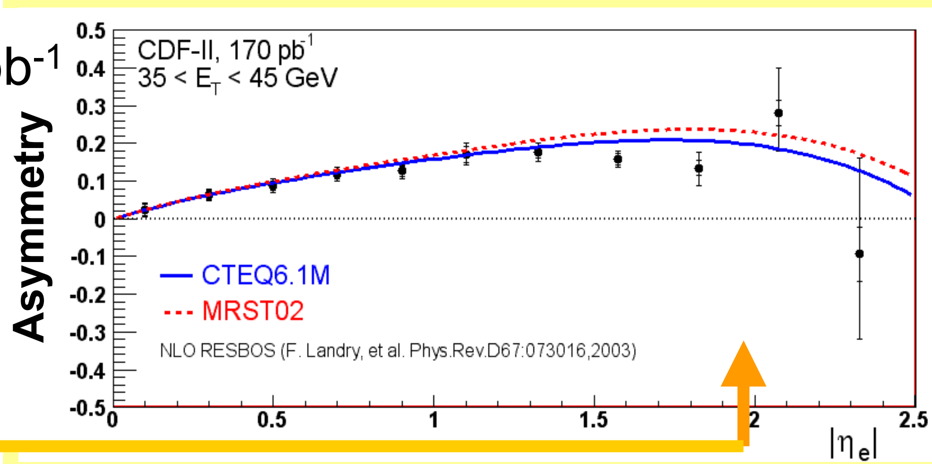


Observable quantity is lepton rapidity:
Convolution of W asymmetry and V-A interactions
Charge ID at high |η| is crucial: Use of calorimeter seeded tracks

$$A(\eta_l) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta}$$

$\int Ldt = 170 pb^{-1}$



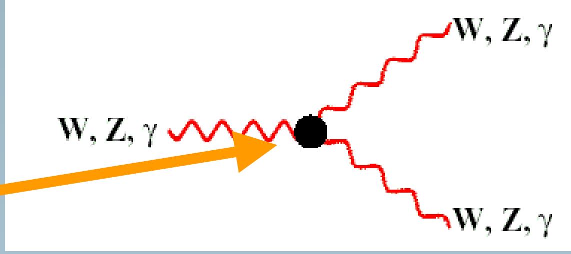


Lower E_T: decay asymmetry enhanced

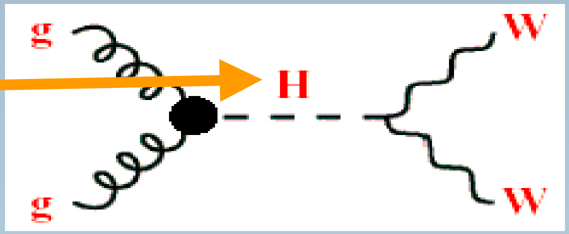
Larger E_T: electron direction closer to W direction.

Production asymmetry enhanced.

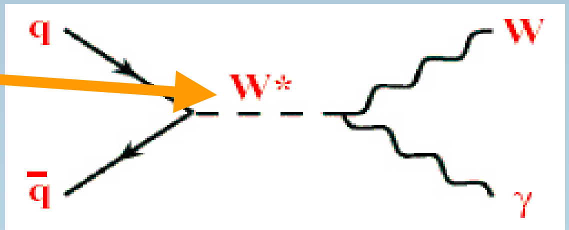
DiBoson Production



- Test Gauge Boson Self Interactions



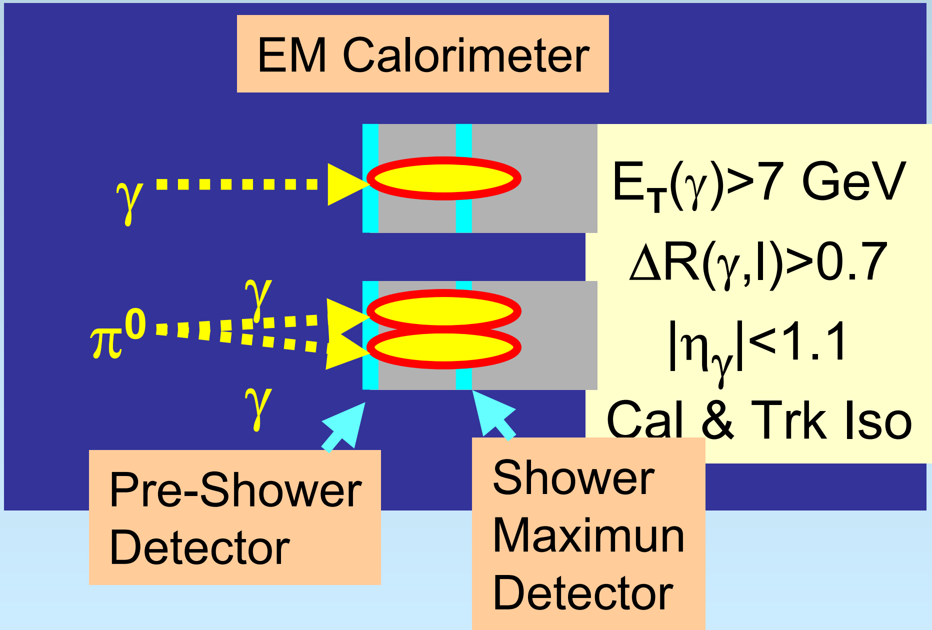
- SM Higgs searches



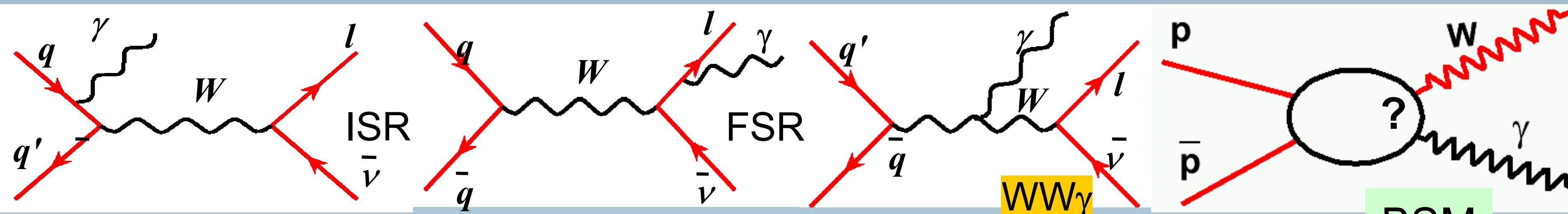
- Resonance searches: Look for excess in kinematical distributions: $E_T(\gamma)$, 3body mass, lepton P_T

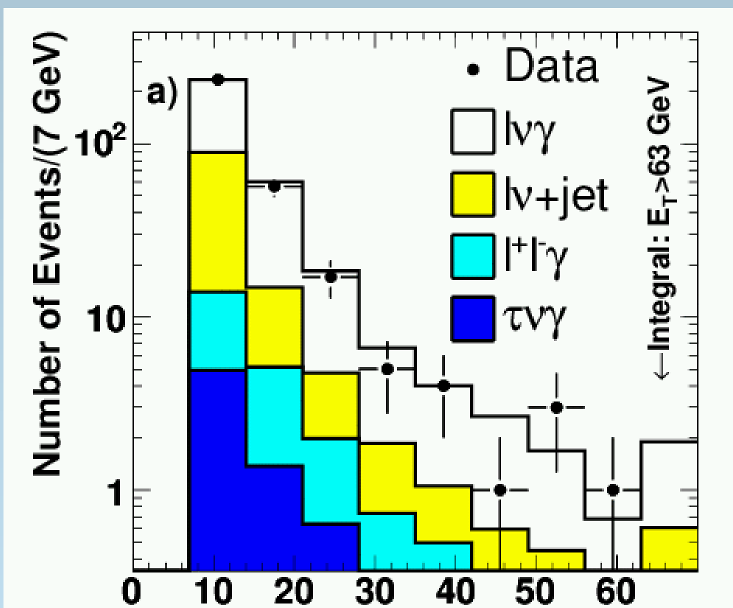
Complementarity with LEP experiments:
Probing at higher $\sqrt{s}$
W-γ final state

For Wγ/Zγ Photon Id is crucial:
Main backgrounds:
$\pi^0 \rightarrow \gamma\gamma$, jets faking photon

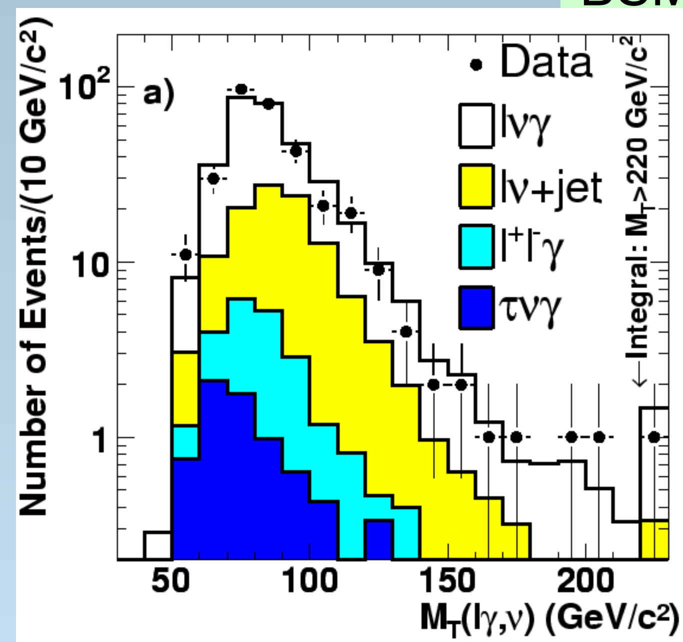


Wγ Production





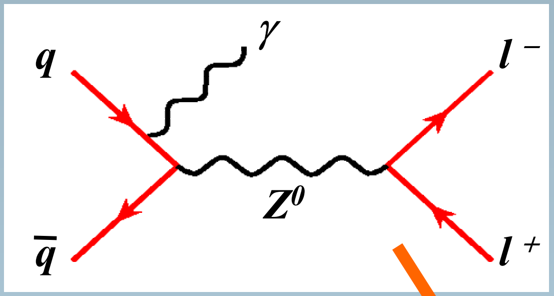
$E_T(\gamma)$ Distribution



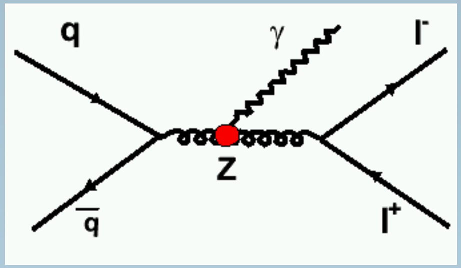
Events(e+μ)	Back(%)	$\sigma \bullet B(W\gamma \rightarrow l\nu\gamma)$ (pb)	$\sigma \times B_{Th}$(pb)
195+128	35(e),33(μ)	$18.1 \pm 1.6_{stat} \pm 2.4_{sys} \pm 1.2_{lum}$	19.3±1.4

CDF Run II $\int Ldt \approx 200$ pb^{-1} Baur, Han, Ohnemus(1993,1998)

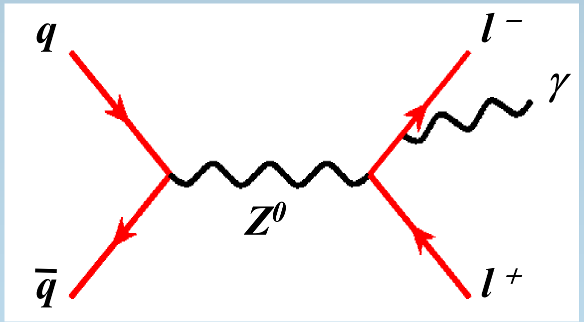
Zγ Production



CDF Run II

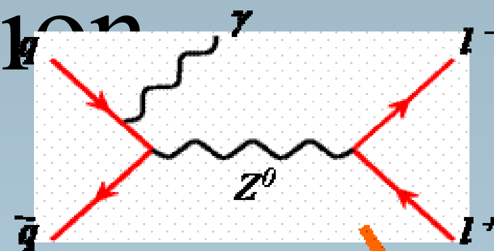


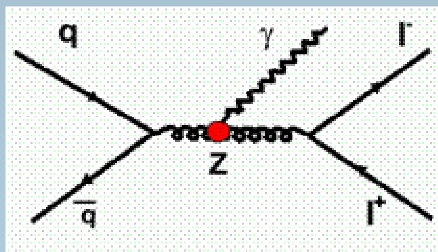
Non SM process!



Events(e+μ)	Back(%)	σ(Zγ)•B(Z→ll) (pb)	σ x $B_{(Th)}$(pb)
36+35	7.8e,5.8μ	$4.6 \pm 0.5_{stat+sys} \pm 0.3_{lum}$	4.5±0.3

Z-γ Production





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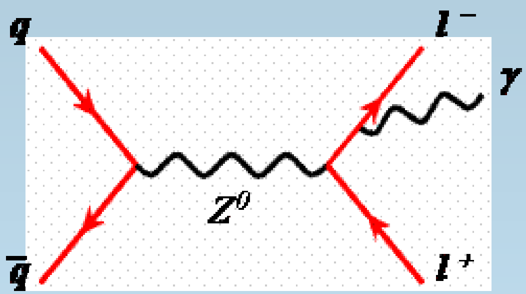
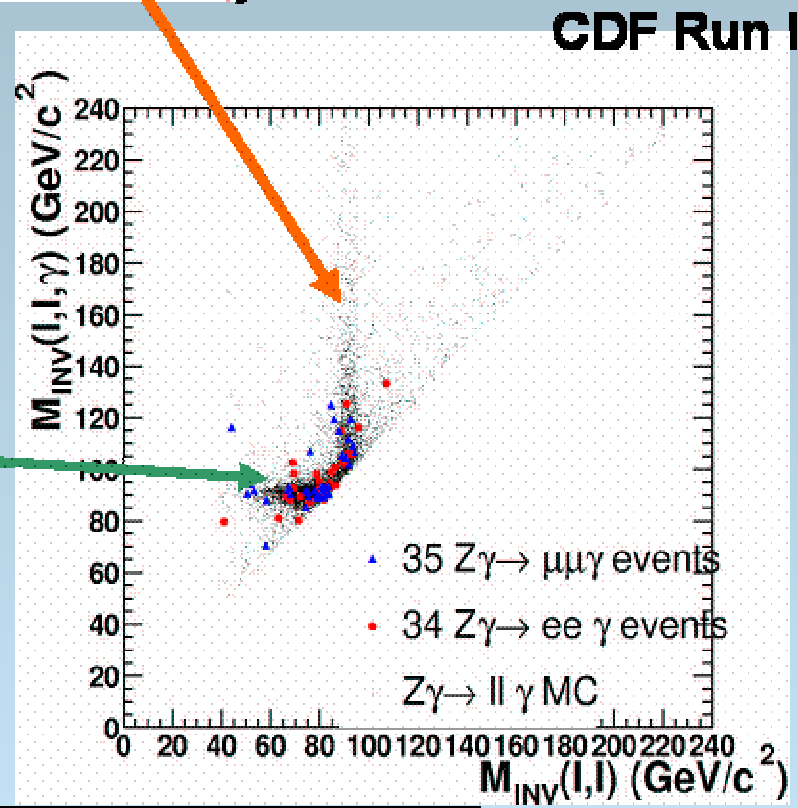
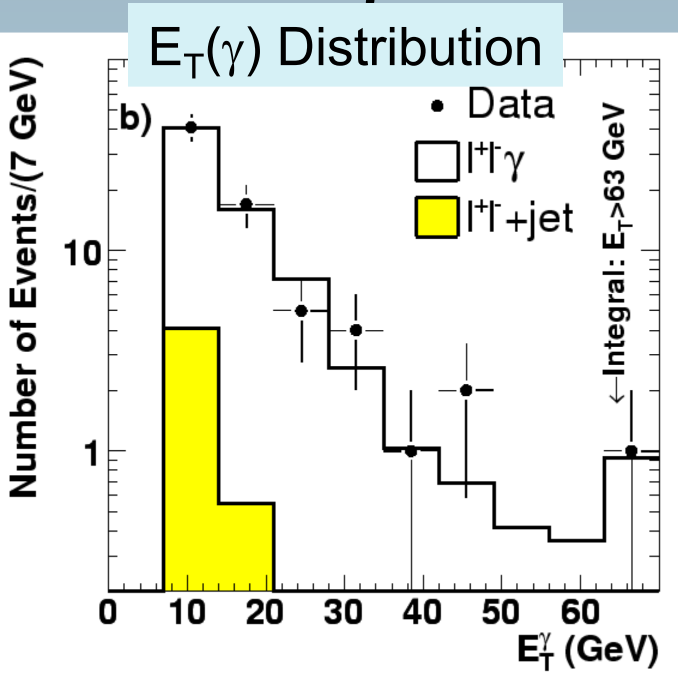
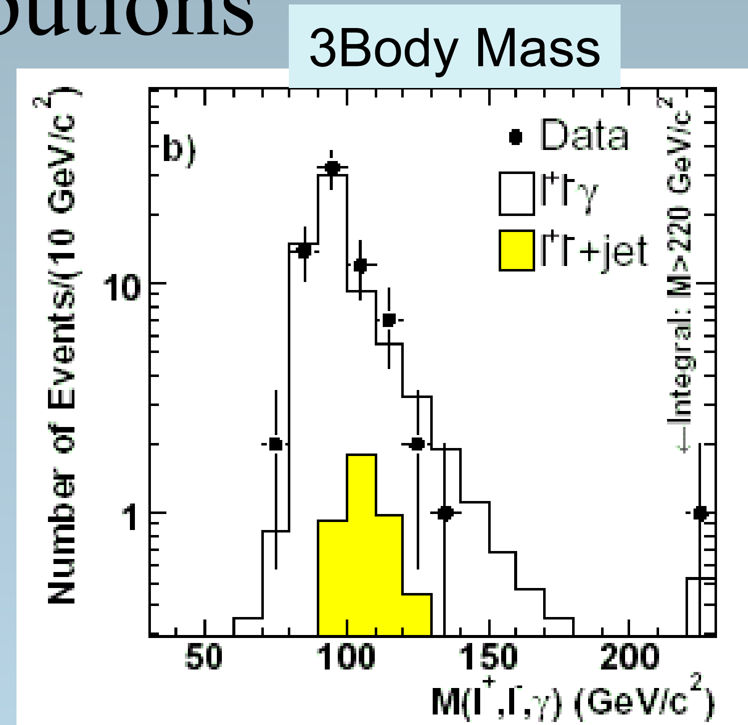


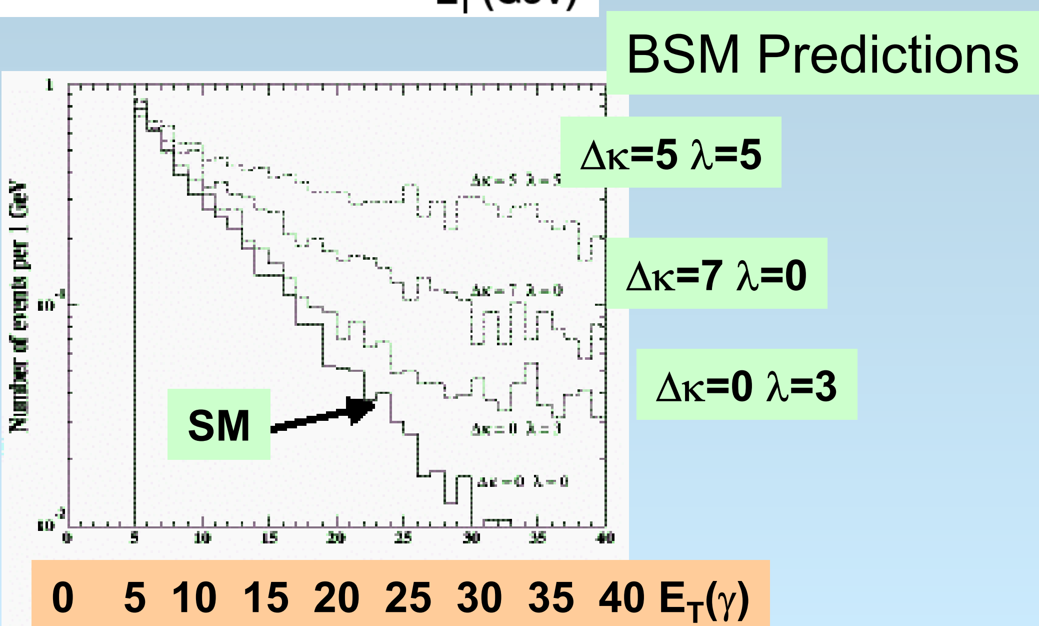


Events(e+μ)	Back(%)	$\sigma(Z\gamma)\cdot B(Z\rightarrow ll)$ (pb)	$\sigma \times B_{(Th)}$(pb)
36+35	7.8e,5.8μ	$4.6\pm0.5_{stat+sys}\pm0.3_{lum}$	4.5 ± 0.3

Zγ Kinematical Distributions

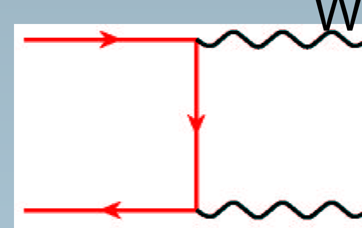






No significant excess with respect to SM expectations

WW production



W

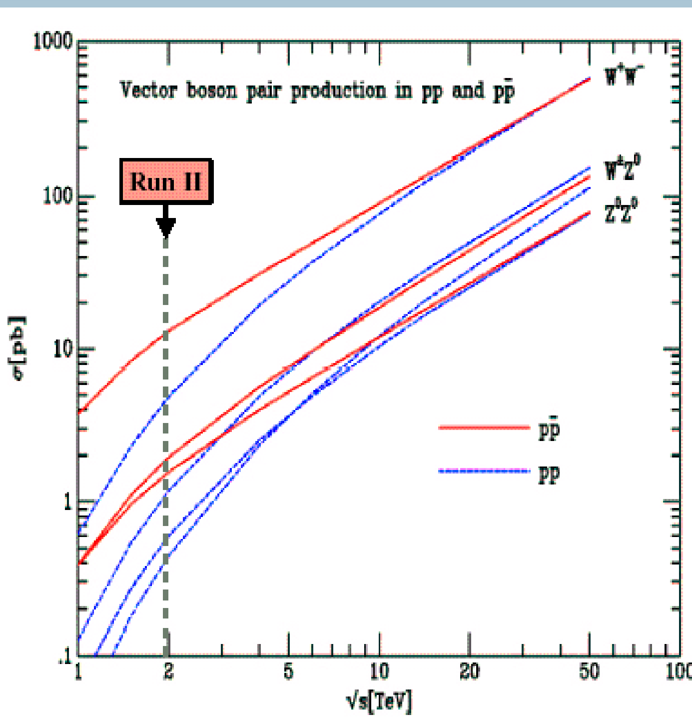
Z,γ*

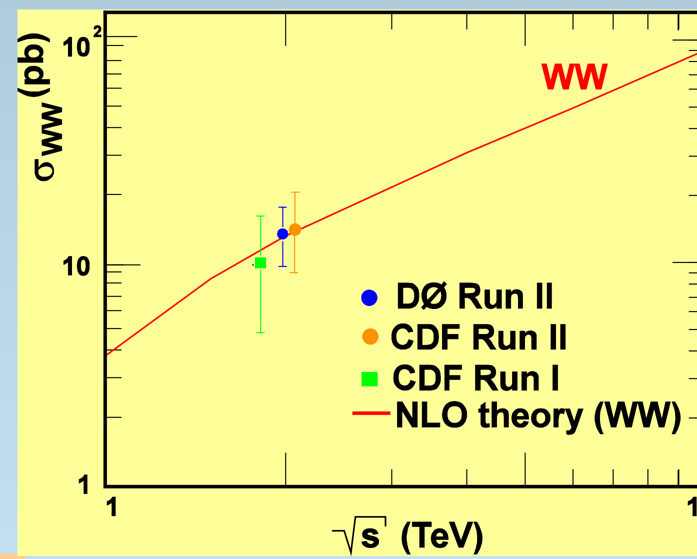
W

- Interesting Signal
- Background in SM Higgs searches
- Probe for new physics

H

Z',G





17 candidate events

Estimated Bkg **$5.0^{+2.2}_{-0.8}$**

$\int L dt = 184\ pb^{-1}$

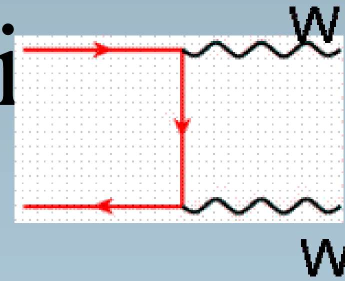
$\sigma(WW) = 14.6\ ^{+5.8}_{-5.1}\ (stat)\ ^{+1.8}_{-3.0}\ (syst) \pm 0.9 (lum)\ pb$

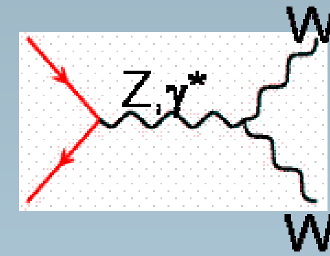
$\sigma(pp \rightarrow WW)_{NLO} = 11.3 \pm 1.3 pb$

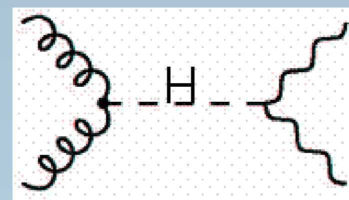
Looking for WW→(qq') ($l\nu_l$) final states

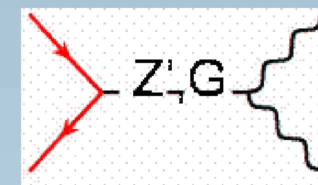
WW Producti

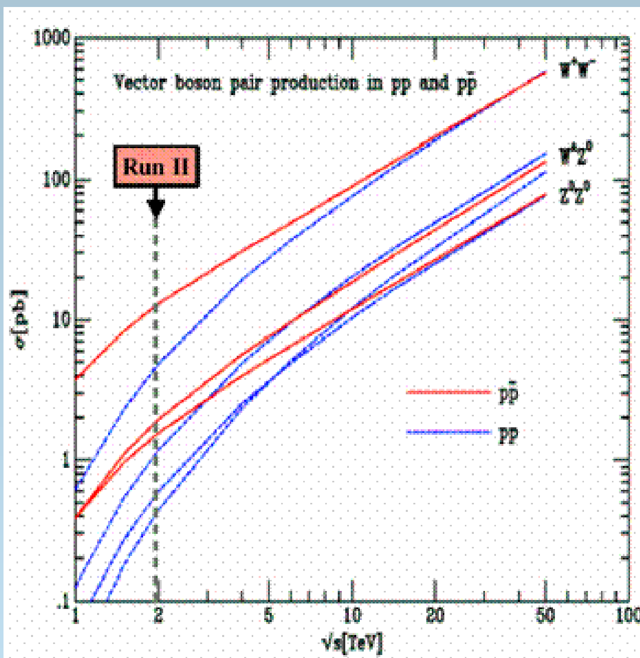
- Interesting Signal
- Background in SM Higgs searches
- Probe for new physics

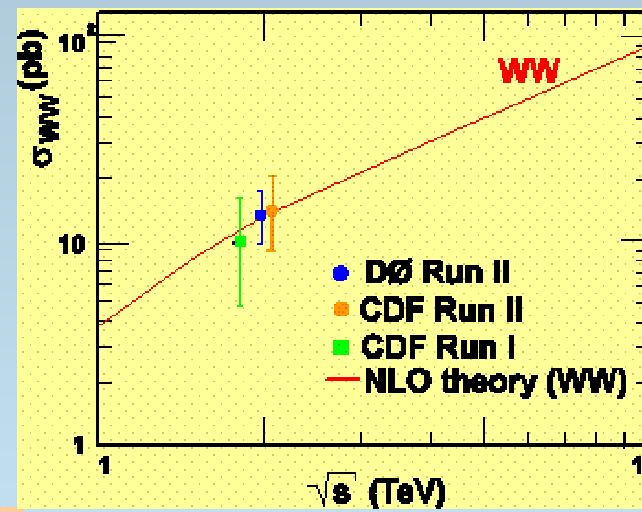












17 candidate events
Estimated Bkg $\mathbf{5.0}^{+2.2}_{-0.8}$

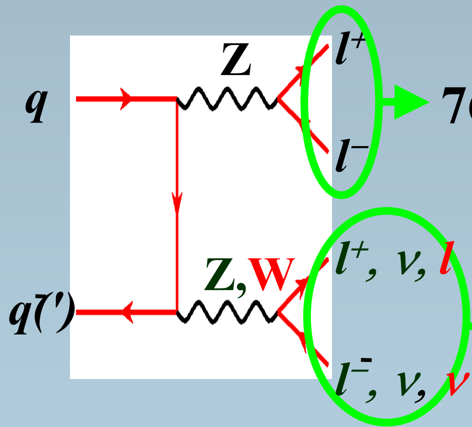
$\int L dt = 184\ pb^{-1}$

$\sigma(WW) = 14.6\ ^{+5.8}_{-5.1}\ (stat)\ ^{+1.8}_{-3.0}\ (syst) \pm 0.9 (lum)\ pb$

$\sigma(p\bar{p} \rightarrow WW)_{NLO} = 11.3 \pm 1.3 pb$

Looking for $WW \rightarrow (qq')\ (l\nu_l)$ final states

WZ and ZZ Searches



$76 < M(l^+l^-) < 106$ GeV

Entangled Processes

$l^+ l^-$: $76 < M(l^+l^-) < 106$ GeV

νν : large $\not{E}_T$-significance

l ν : lepton + $\not{E}_T > 20$ GeV

$\int L dt = 194 pb^{-1}$

$\sigma(pp \rightarrow ZZ/ZW+X)_{NLO} = 5.0 \pm 0.4\ pb^{-1}$

	4 Lep	3 Lep	2 Lep	Comb.
WZ/ZZ	0.06±0.01	0.91±0.07	1.34±0.21	2.31±0.29
Bkg	0.01±0.02	0.07±0.06	0.94±0.22	1.02±0.24
Bkg+Sig	0.07±0.02	0.98±0.09	2.28±0.35	3.33±0.42
Data	0	0	3	3

Extracted a limit for cross section

Measurement possible with available collected statistics

$\sigma(pp \rightarrow ZZ/ZW+X)_{CDF} < 15.2$ pb @95% C.L.

W Boson Mass

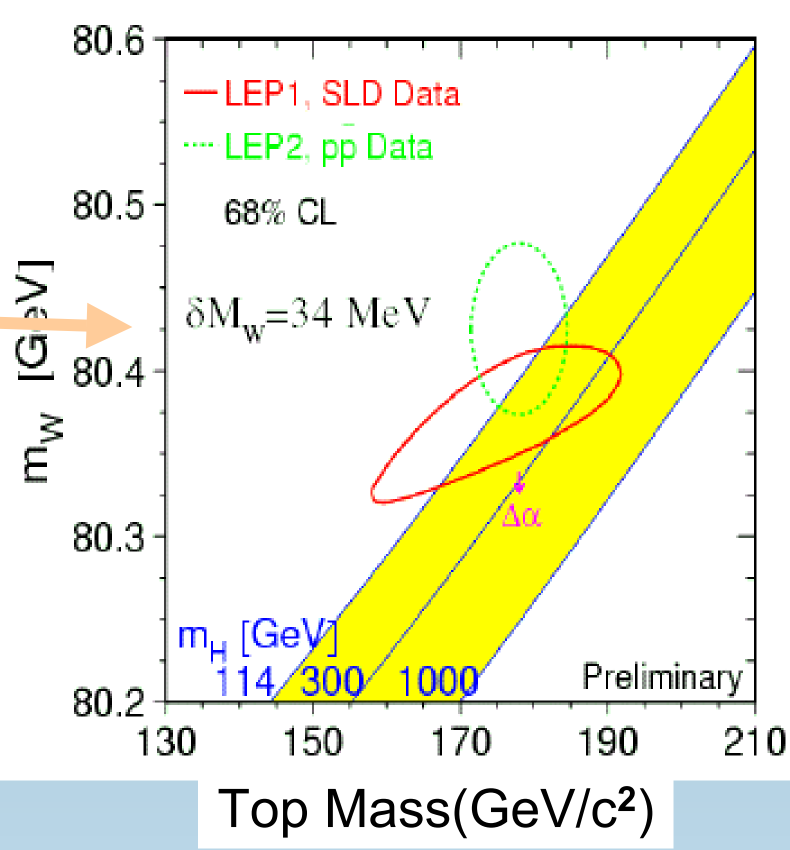
Bound to SM Higgs Mass

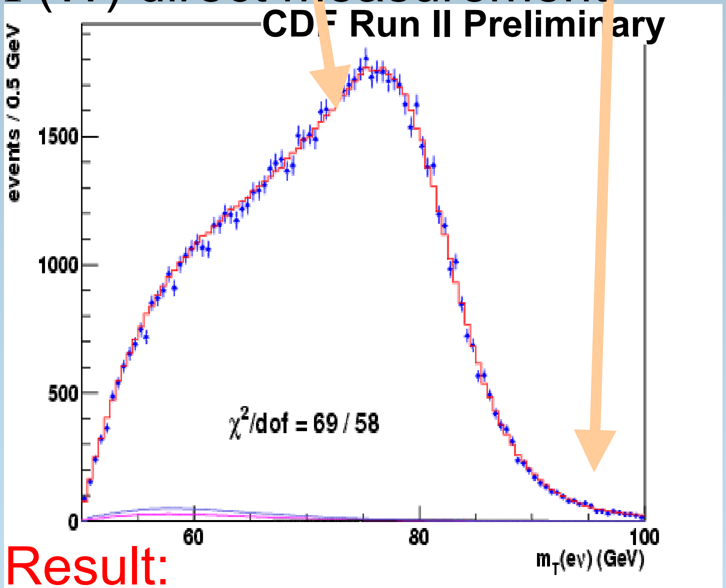
Indirect searches of physics BSM

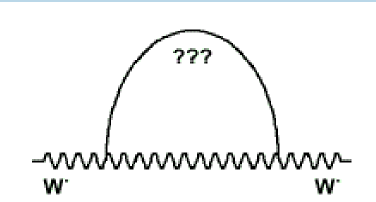
Need accuracy better than 10^{-3}

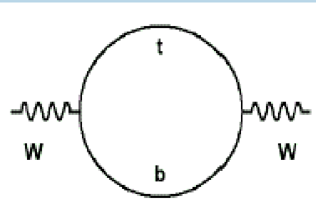
Fit of transverse mass distribution

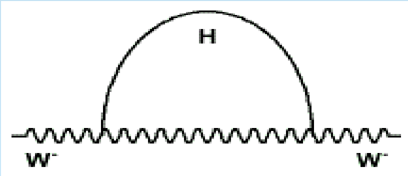
$\Gamma(W)$ direct measurement











Result:

With L=200pb^{-1} ΔM_W=76 MeV/c^2 (e+μ) combined

→Already better than RunI CDF

With 2fb^{-1} expect Δ(Mw)~30MeV/c^2

Will use next PDFs fits with CDF W charge asymmetry measurement

Perspectives and Working Areas

Electroweak physics program at CDF goes well

- Inclusive cross section, widths, BF in all leptonic channels.
  - Working on Differential Cross Sections
- Z asymmetries
  - Quark gauge bosons couplings
- W asymmetries
  - Shall be included in 2005 PDFs
  - W Rapidity reconstruction
- Diboson production cross section (increase statistics)
  - Extracting Triple Gauge Coupling
  - Looking for hadronic final states $WW \rightarrow (qq')(l\nu_l)$
- W Boson Mass Measurement: unveiling the central value
  - Direct $\Gamma(W)$ measurement

O fortunati, quorum iam moenia surgunt!

Verg., Aen., I 437

Electroweak RunII Publications

hep-ex/0406078: “Inclusive W and Z Cross Section”

hep-ex/0501023: “W Charge Asymmetry”

hep-ex/0411059: “Z Forward Backward Asymmetry”

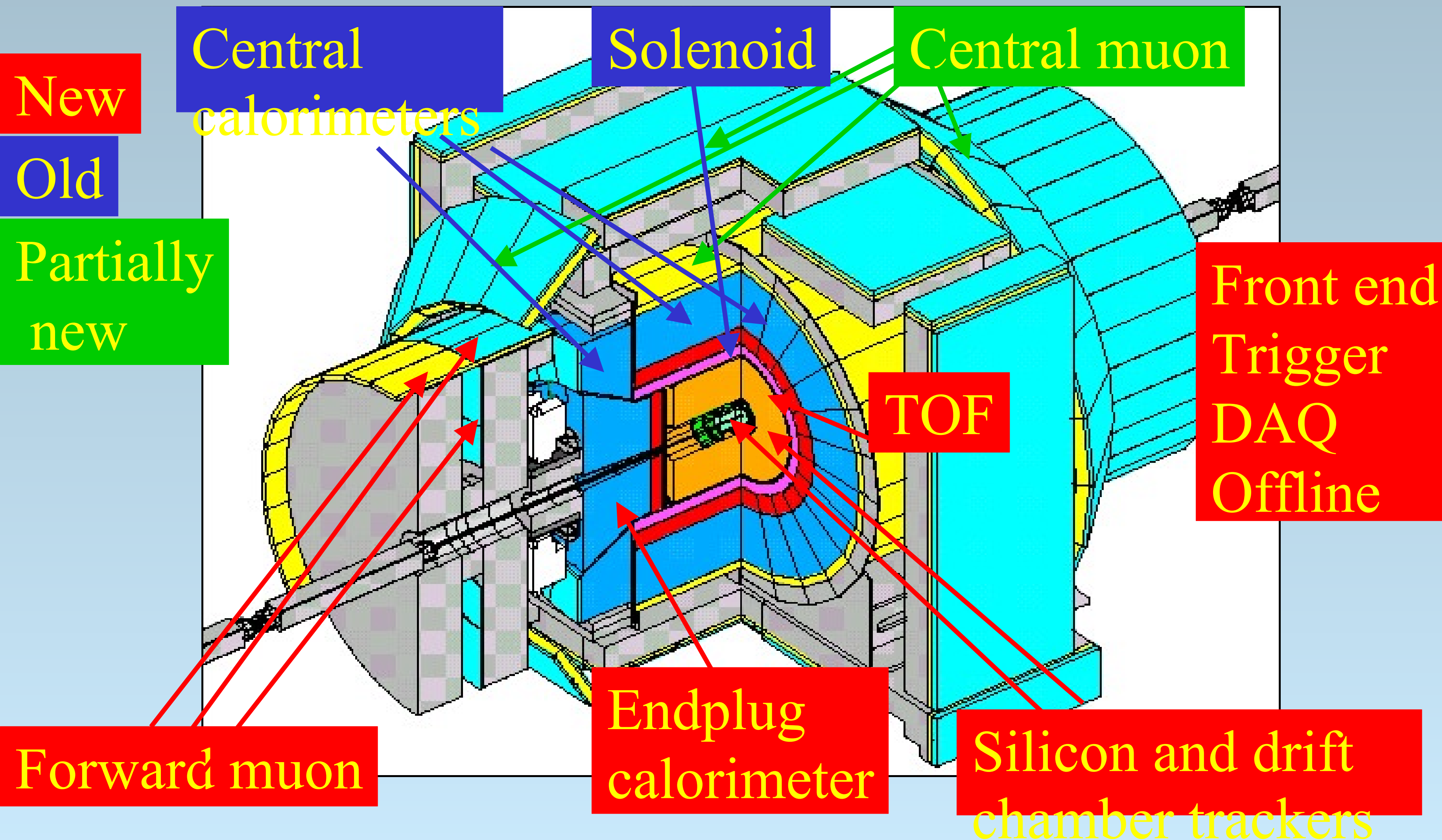
hep-ex/0410008: “W gamma, Z gamma production”

hep-ex/0501050: ”WW Production”

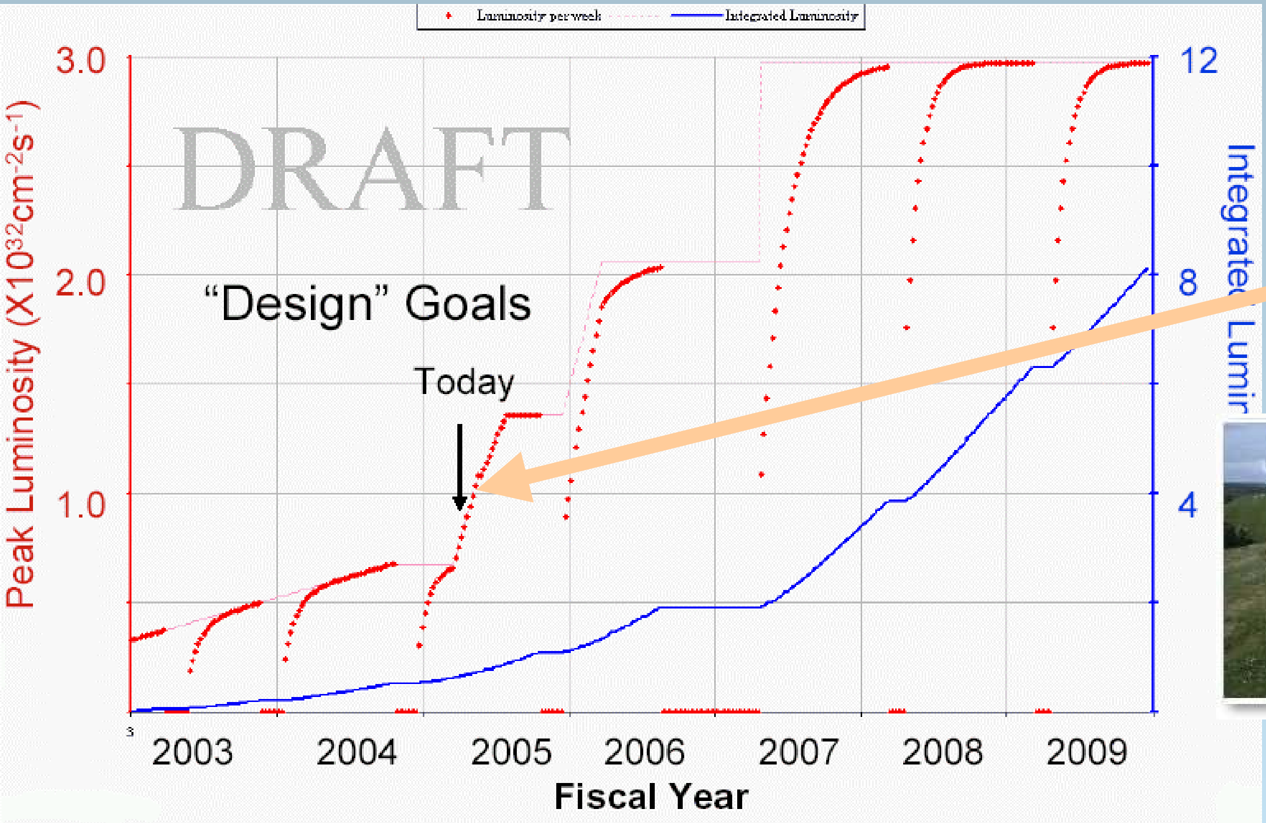
hep-ex/0501021: “WZ/ZZ Searches”

Backup Slides

The Run II CDF Detector



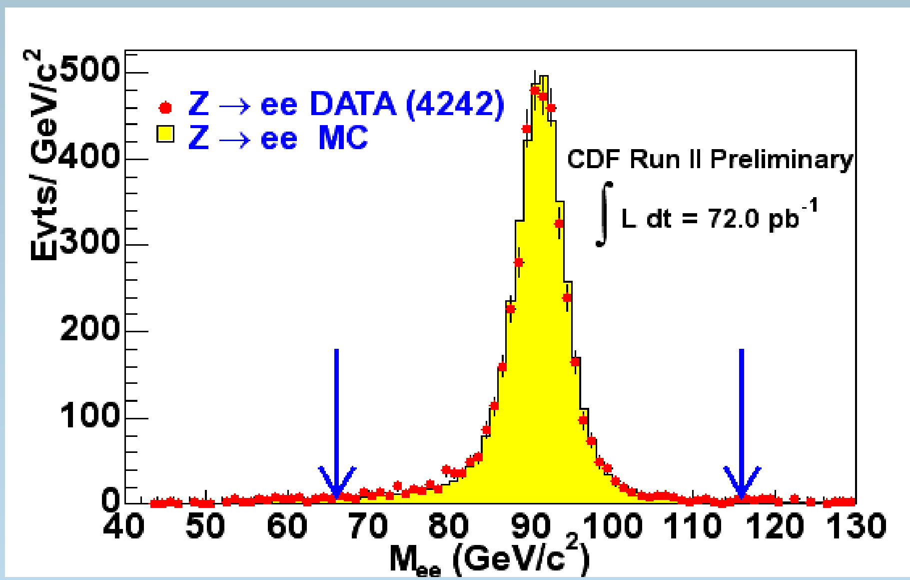
Tevatron Performances and Perspectives



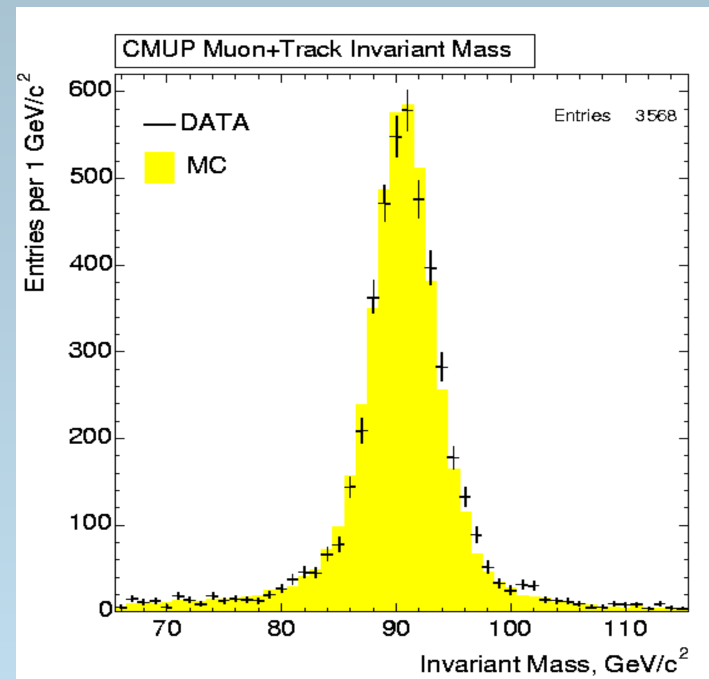
Breaking the wall of 10^{32}

Z Boson Cross Sections(e,μ)

Electron Channel
Electron |η|<2.8
E_T>25 GeV



Muon Channel
$P_T\mu$>20 GeV/c

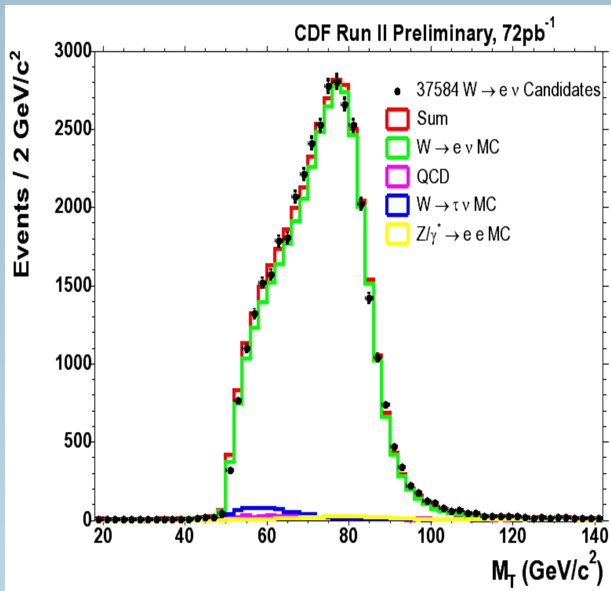


- Clean Signature
- Two High E_T Isolated lepton
- Opposite Charge
- High σ & S/B

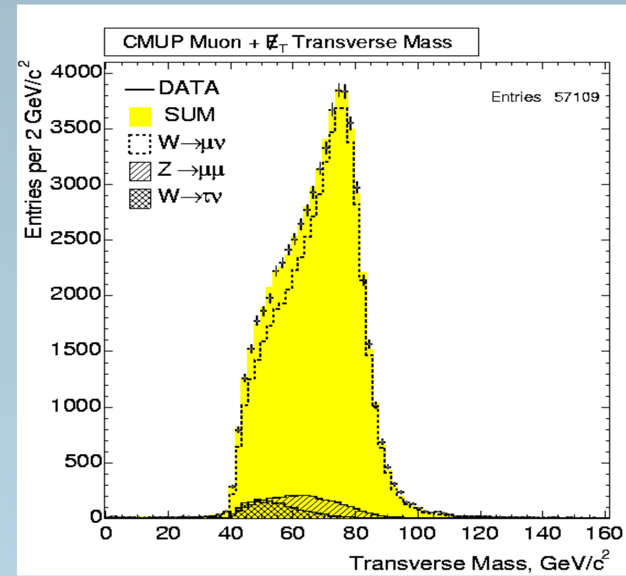
	Events	Back.	σ•B(Z-->ll) (pb)	Lum
e	1830	0.6%	$267\pm6_{stat}\pm15_{sys}\pm16_{lum}$	72.0
μ	3568	0.4%	$253\pm4.2_{stat}{}^{+8.3}_{-6.4}{}_{sys}\pm15.2_{lum}$	193.5

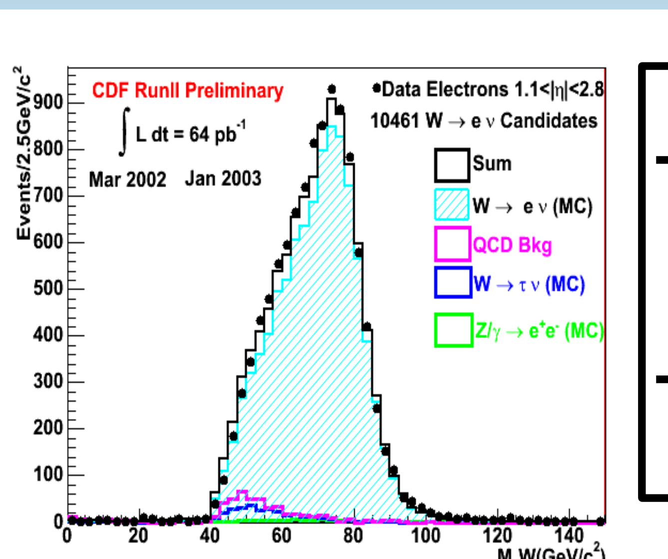
W Boson Production

Electron Channel



Muon Channel





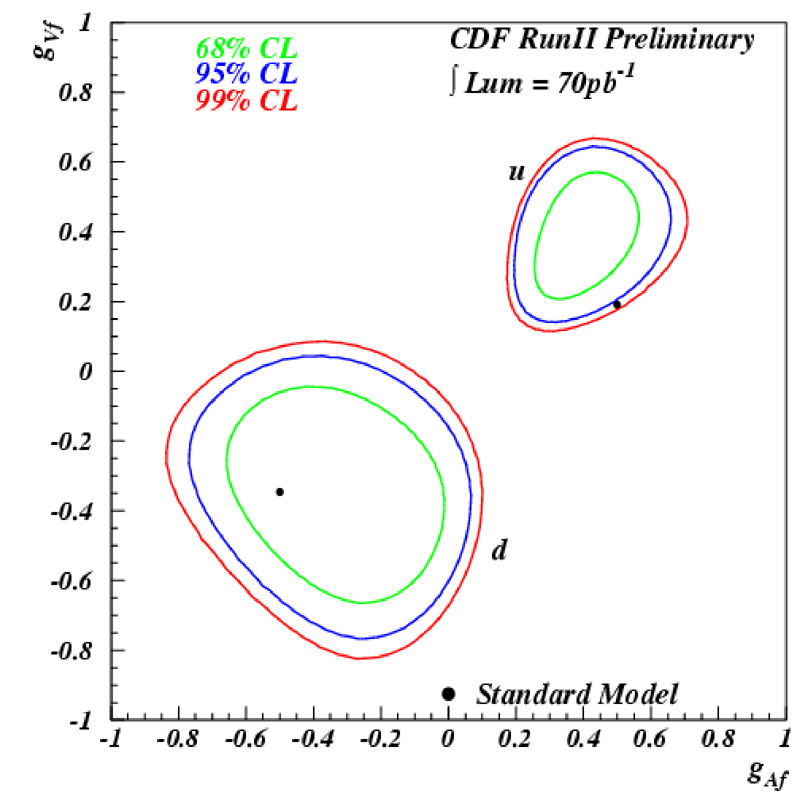
	Region	Events	Bkg		$\sigma \bullet B(W \to e\nu)$ (pb)
e	$\lvert\eta\rvert<1.0$	37584	4.4	72	$2786 \pm 16_{stat} \pm 64_{sys} \pm 166_{lum}$
	$1.1<\lvert\eta\rvert<2.8$	10464	8.7	64	$2874 \pm 34_{stat} \pm 167_{sys} \pm 172_{lum}$
μ	$\lvert\eta\rvert<1.0$	57109	9.5	194	$2786 \pm 12_{stat}{}^{+65}_{-55 sys} \pm 172_{lum}$

Couplings Results

χ^2=10.40/11

Quark Couplings:

	CDF Run II	2 fb^{-1} Uncert.	Experimental values (PDG)	SM Prediction
u_L	0.41 ± 0.14	± 0.028	0.330 ± 0.016	0.3459 ± 0.0002
u_r	0.02 ± 0.15	± 0.024	-0.176 ± 0.008	-0.1550 ± 0.0001
d_L	-0.12 ± 0.39	± 0.057	-0.439 ± 0.011	-0.4291 ± 0.0002
d_r	-0.02 ± 0.22	± 0.088	-0.023 ± 0.058	0.0776 ± 0.0001



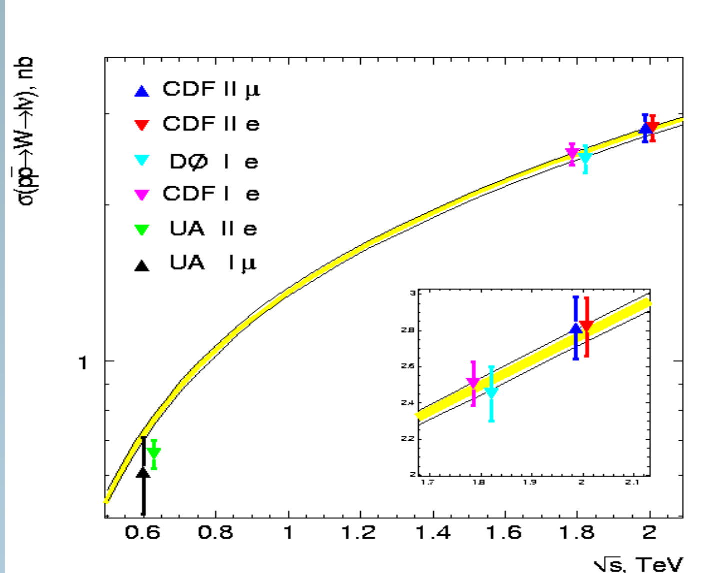
$\sin^2\theta_W^{Eff}=0.2238\pm0.0040_{(stat)}\pm0.0030_{(syst)}$

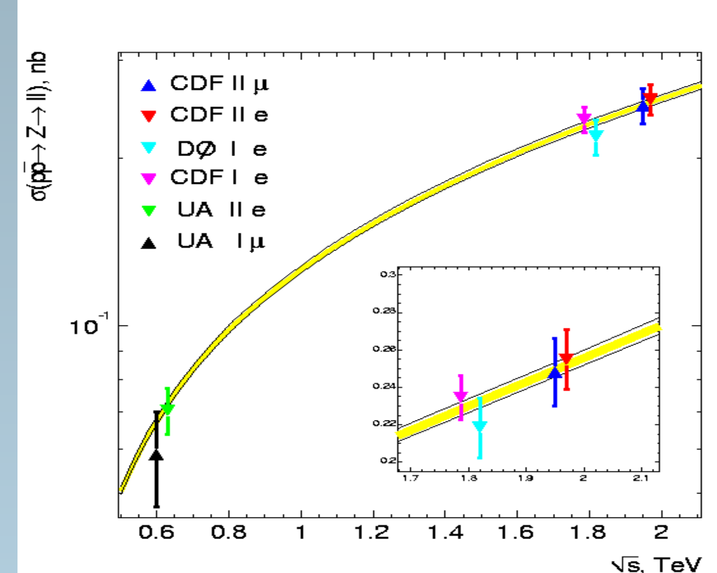
χ^2=12.50/14

Electron Couplings:

χ^2=13.14/13

	CDF Run II	SLD+LEP	SM prediction
e_V	-0.058 ± 0.017	-0.03816 ± 0.00047	-0.03816 ± 0.00047
e_A	-0.53 ± 0.14	-0.50111 ± 0.00035	-0.5064 ± 0.0001



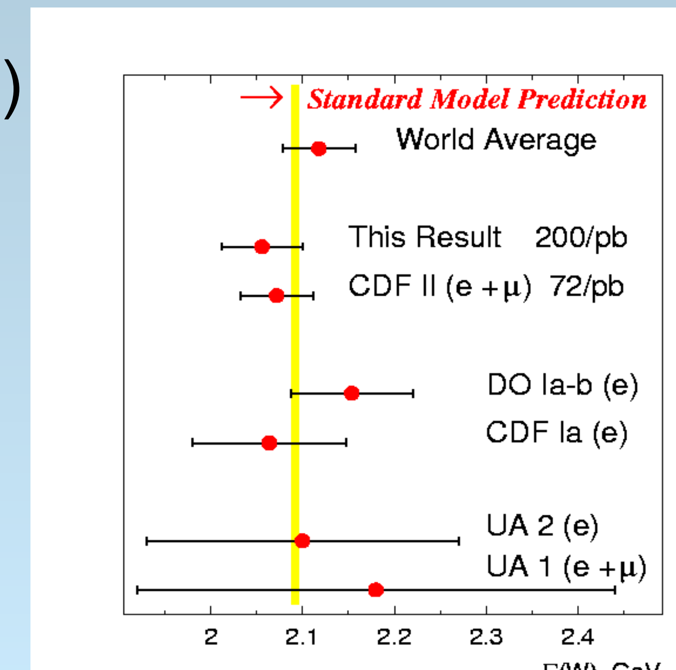


20+ years of W and Z bosons at hadron colliders

From R to Γ(W)

$$R = \frac{\sigma . BF(W\text{->}l\nu_l)}{\sigma . BF(Z\text{->}ll)}$$

$$\frac{\sigma(pp\text{->}W)}{\sigma(pp\text{->}Z)} \; \frac{\Gamma(Z)}{\Gamma(Z\text{->}ll)} \; \frac{\Gamma(W\text{->}l\nu_l)}{\Gamma(W)}$$



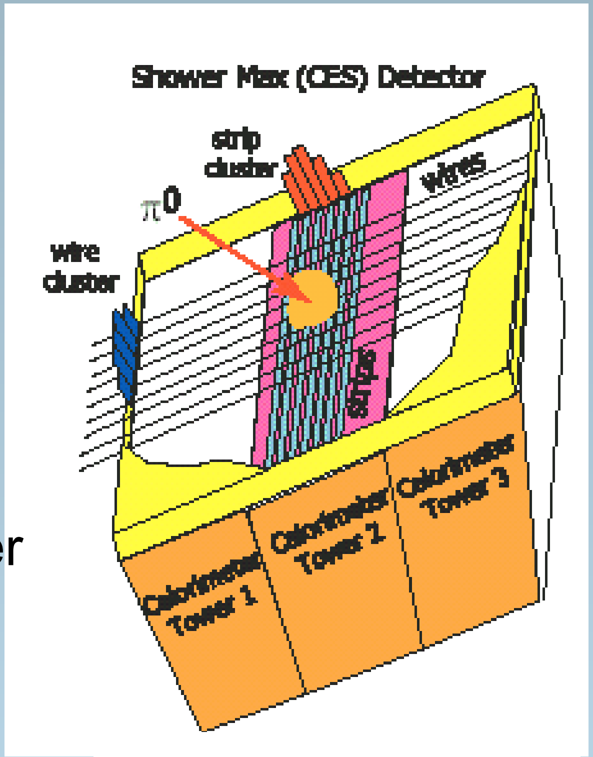
Indirect W Width measurement

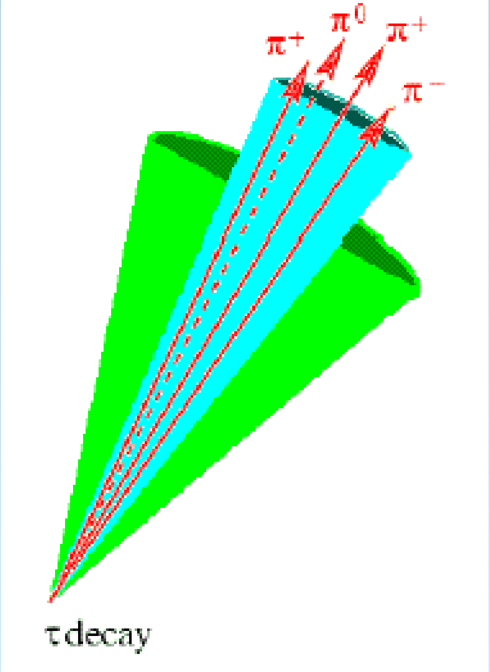
Tau

Taus are difficult at hadronic colliders
$\tau \rightarrow$hadrons (τ_h) look like jets
Need to combine:
Tracking ($|\eta|<1$)
Calorimetric Clusters $\Delta\eta$x $\Delta\phi$ (0.1 x 15°)
π^o reconstruction (showermax inside EM Calorimeter resol. ~few mm)

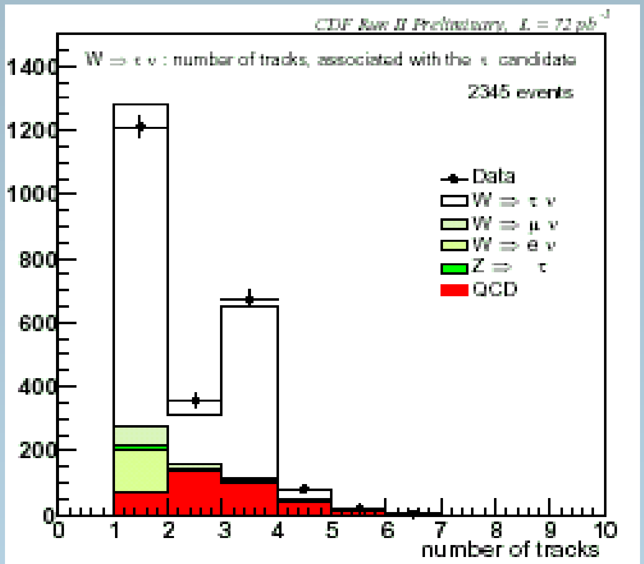
Reconstruction Efficiency:
~70% @15 GeV
~85% @25 GeV
~95% @40 GeV

It is possibile to trigger on taus:
Lepton + Track trigger (lepton + isolated track). Final states:$\tau_h+\tau_{(e,\mu)}$+X,τ_h+(e,μ)+X

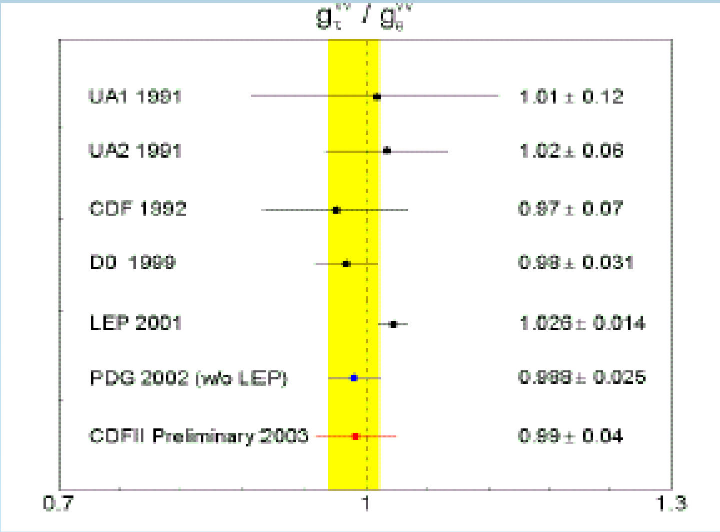


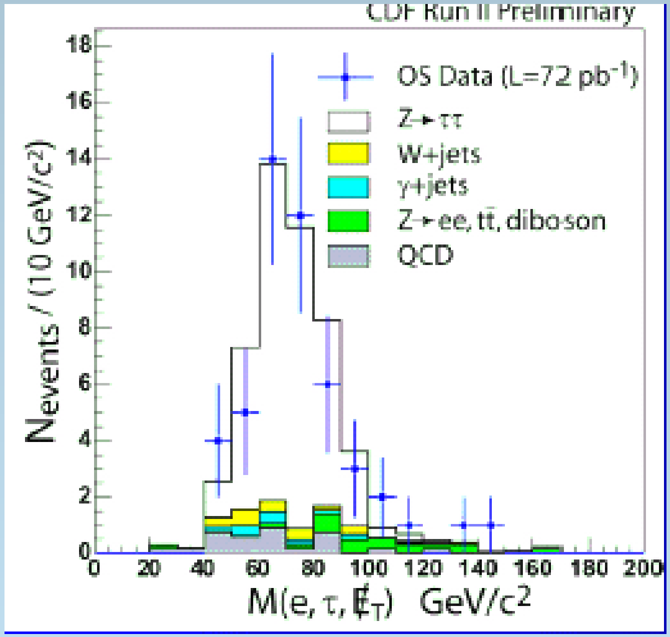


Tau Physics Measurement



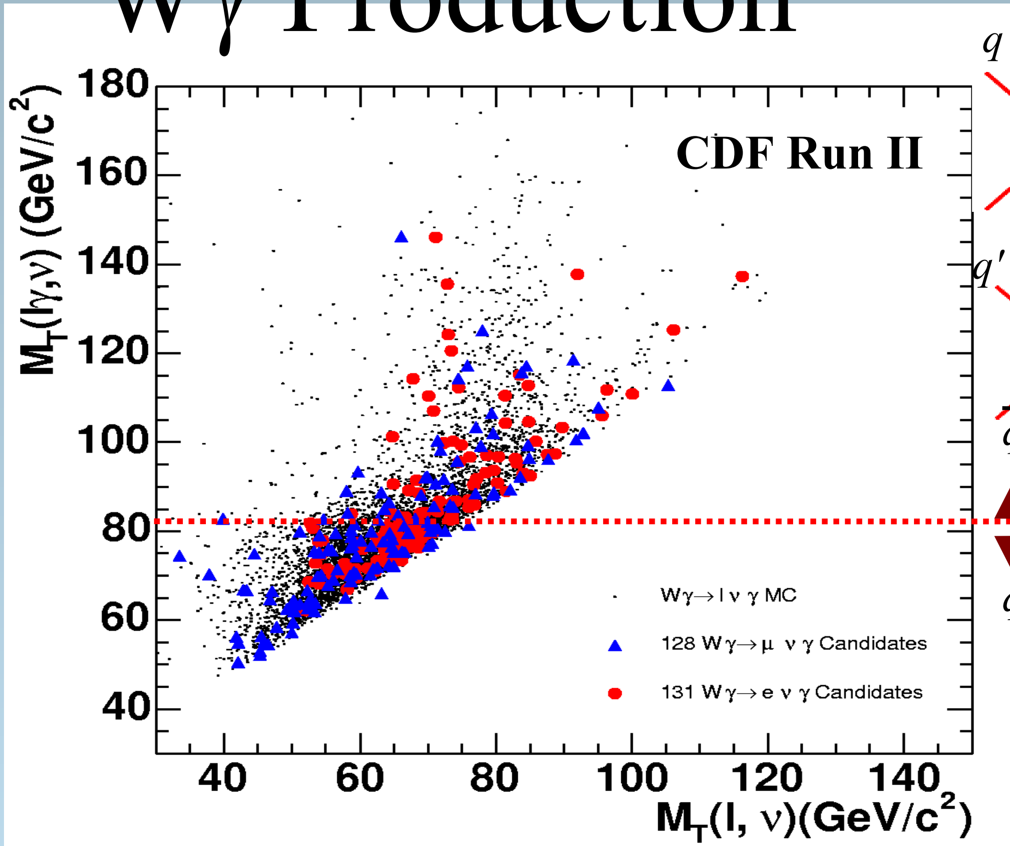
Track Multiplicity: 1 and 3 prongs

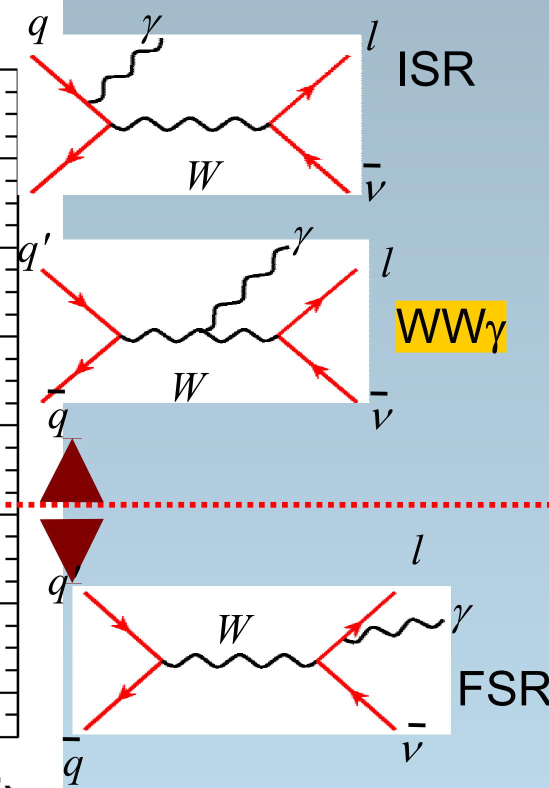




Z->teth

Wγ Production



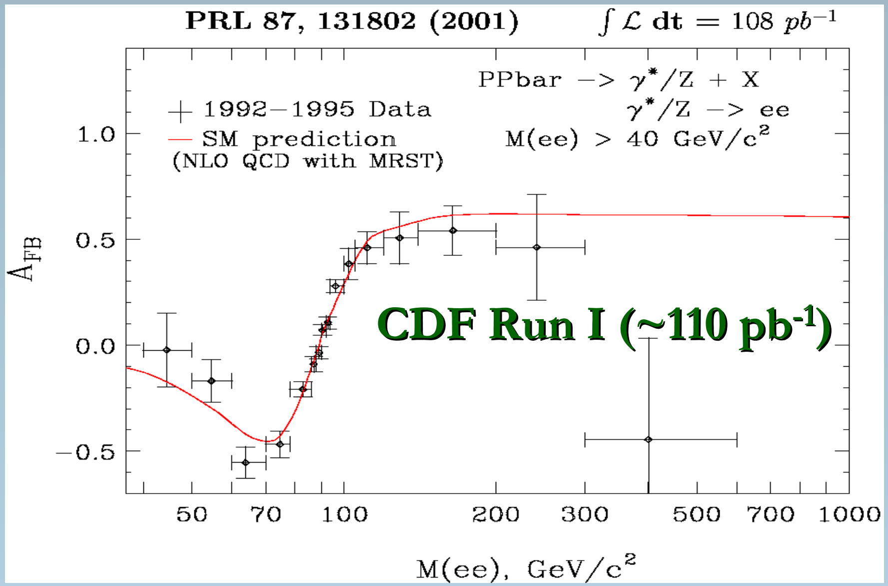


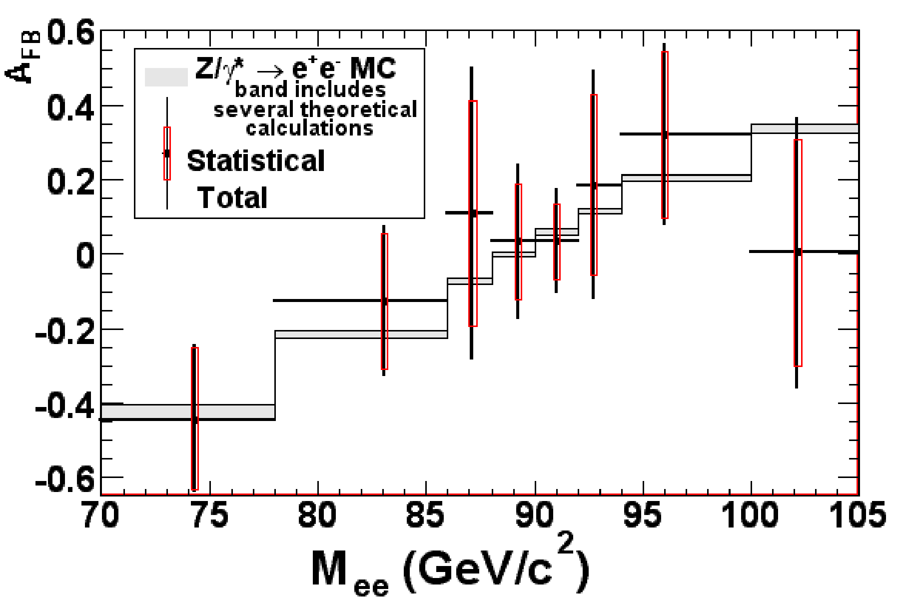
$\int L dt \approx 200\ pb^{-1}$

Events(e+μ)	Back(%)	σ•B(Wγ→lνγ) (pb)	σ x B_{Th}(pb)
195+128	35(e),33(μ)	$18.1 \pm 1.6_{stat} \pm 2.4_{sys} \pm 1.2_{lum}$	19.3±1.4

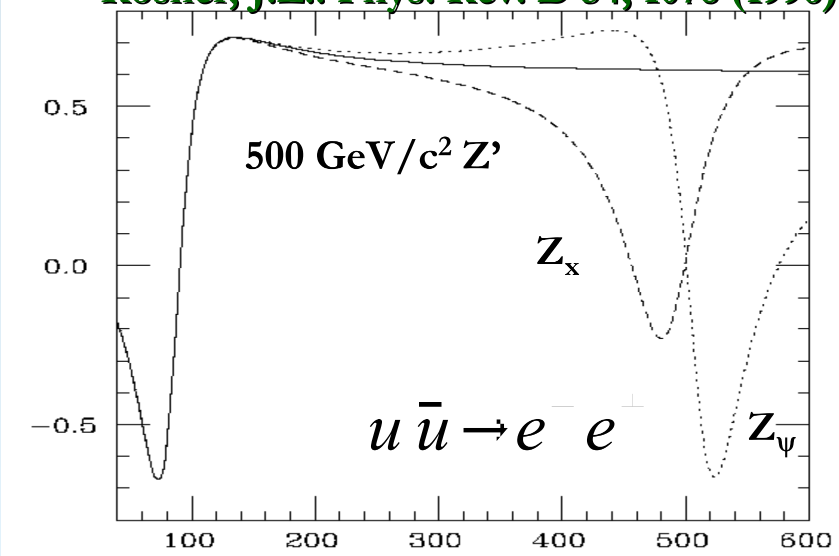
Baur, Han Ohnemus(1993,1998)

Z Asymmetry



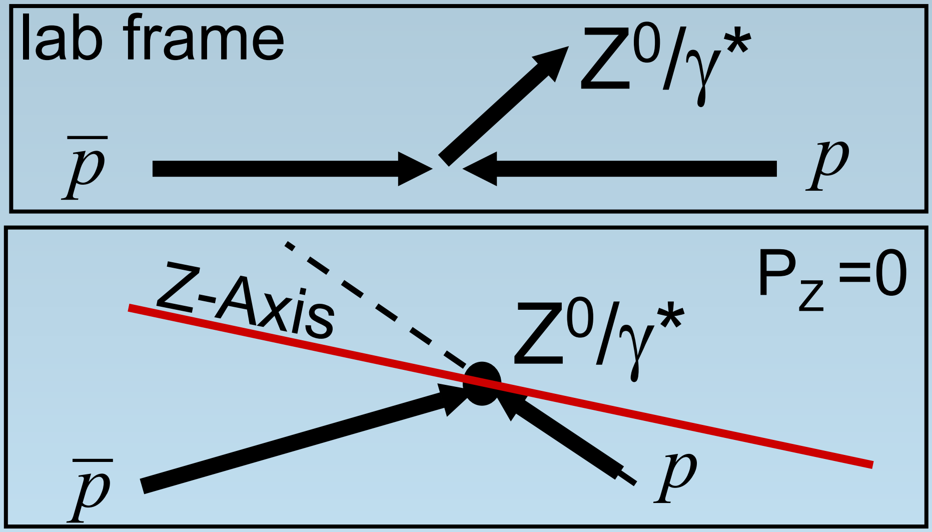


Rosner, J.L.: Phys. Rev. D 54, 1078 (1996)



Calculating A_{FB}

- $\cos\theta^*$ in Collin-Soper frame
  - **Minimize ambiguity in the incoming quark Pt**



- $\cos\theta^* > 0 \equiv$ Forward
- $\cos\theta^* < 0 \equiv$ Backward

- Calculating A_{FB}:

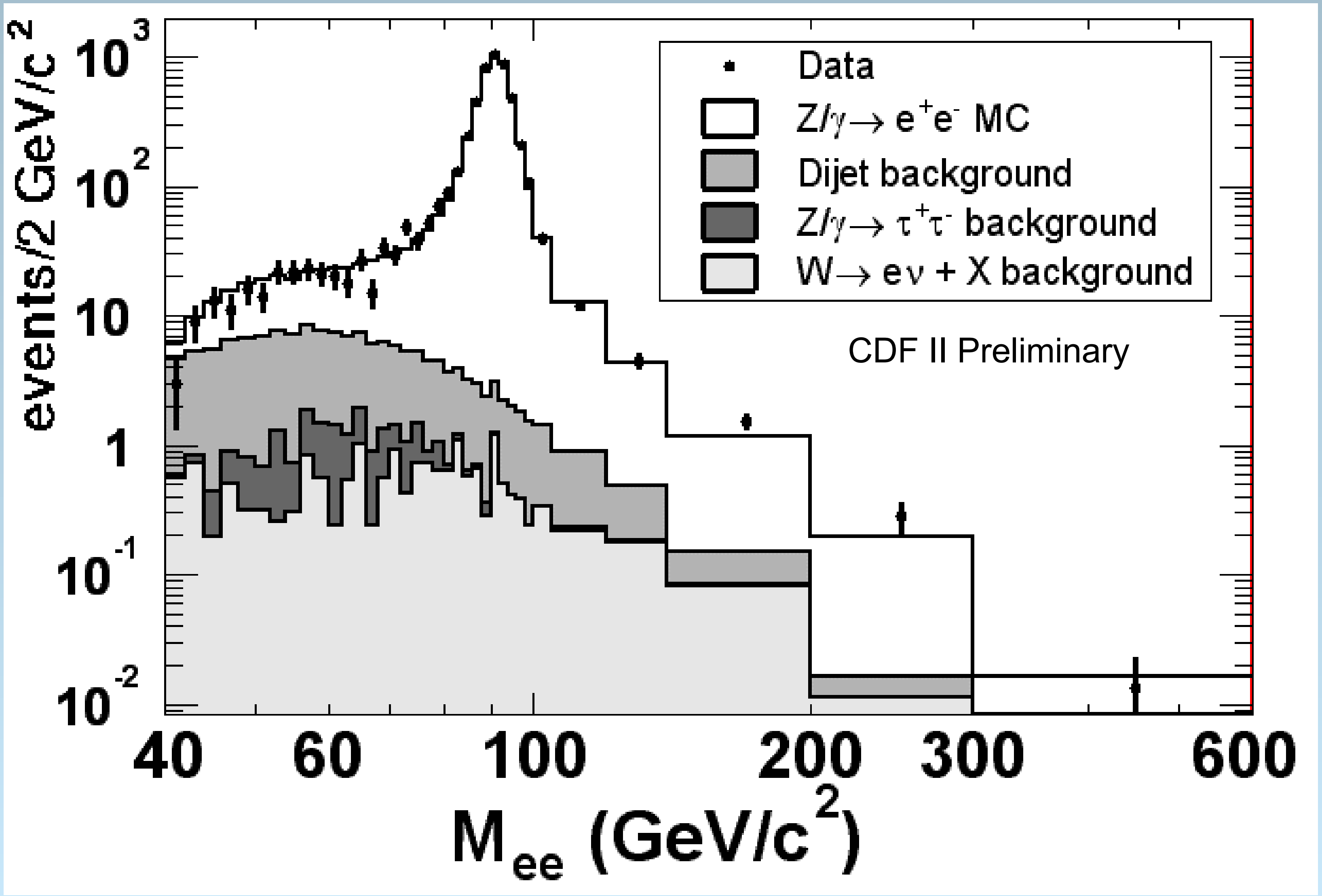
$$A_{FB} = \frac{d\sigma(\cos\theta^* > 0) - d\sigma(\cos\theta^* < 0)}{d\sigma(\cos\theta^* > 0) + d\sigma(\cos\theta^* < 0)}$$

$$A_{FB} = \frac{\dfrac{N^+ - N^+_{Bkgrnd}}{a^+} - \dfrac{N^- - N^-_{Bkgrnd}}{a^-}}{\dfrac{N^+ - N^+_{Bkgrnd}}{a^+} + \dfrac{N^- - N^-_{Bkgrnd}}{a^-}}$$

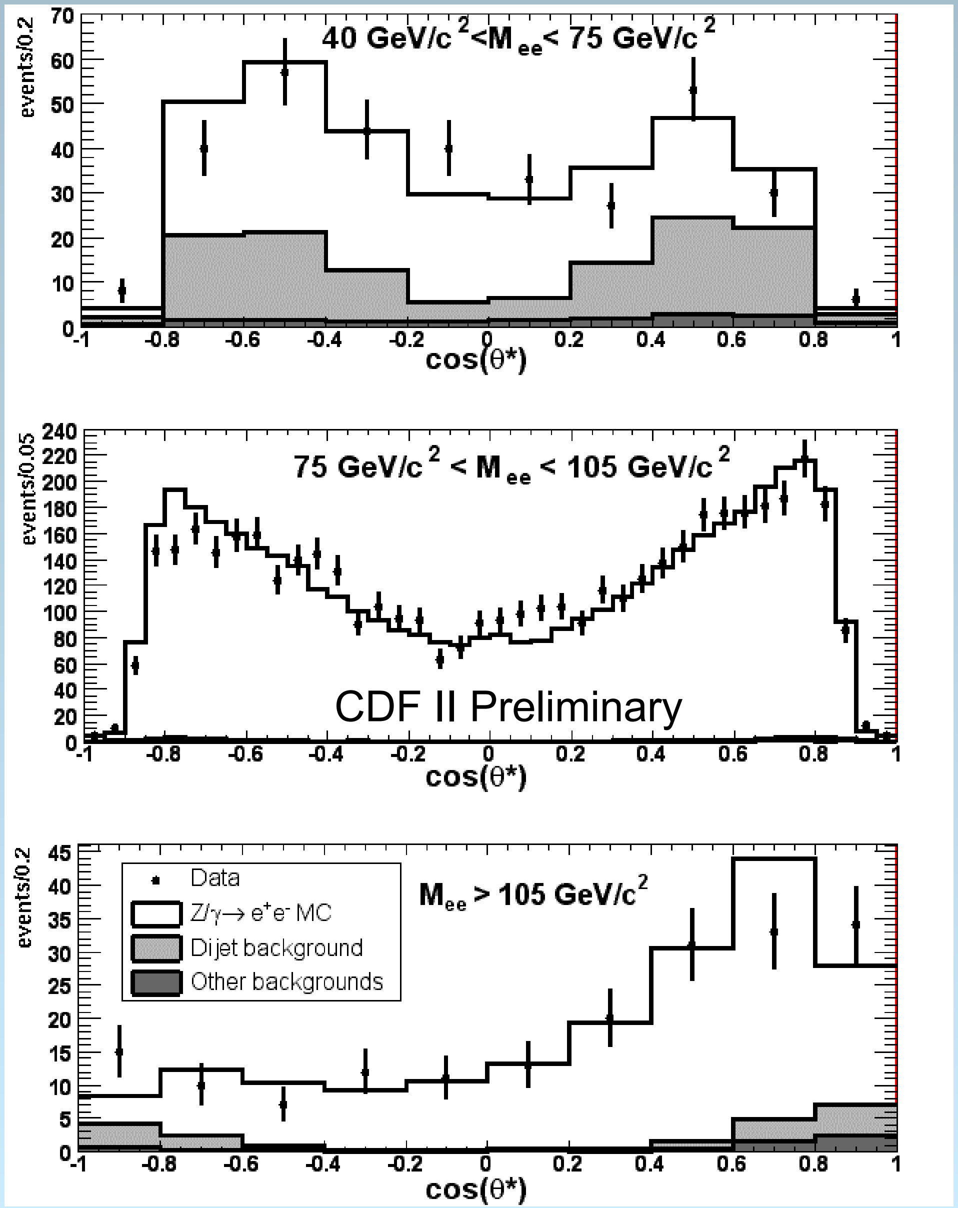
a : Forward/Backward Acceptance & Efficiency

$N^{\pm}$: Forward/Backward Candidates

Data-MC Comparisons



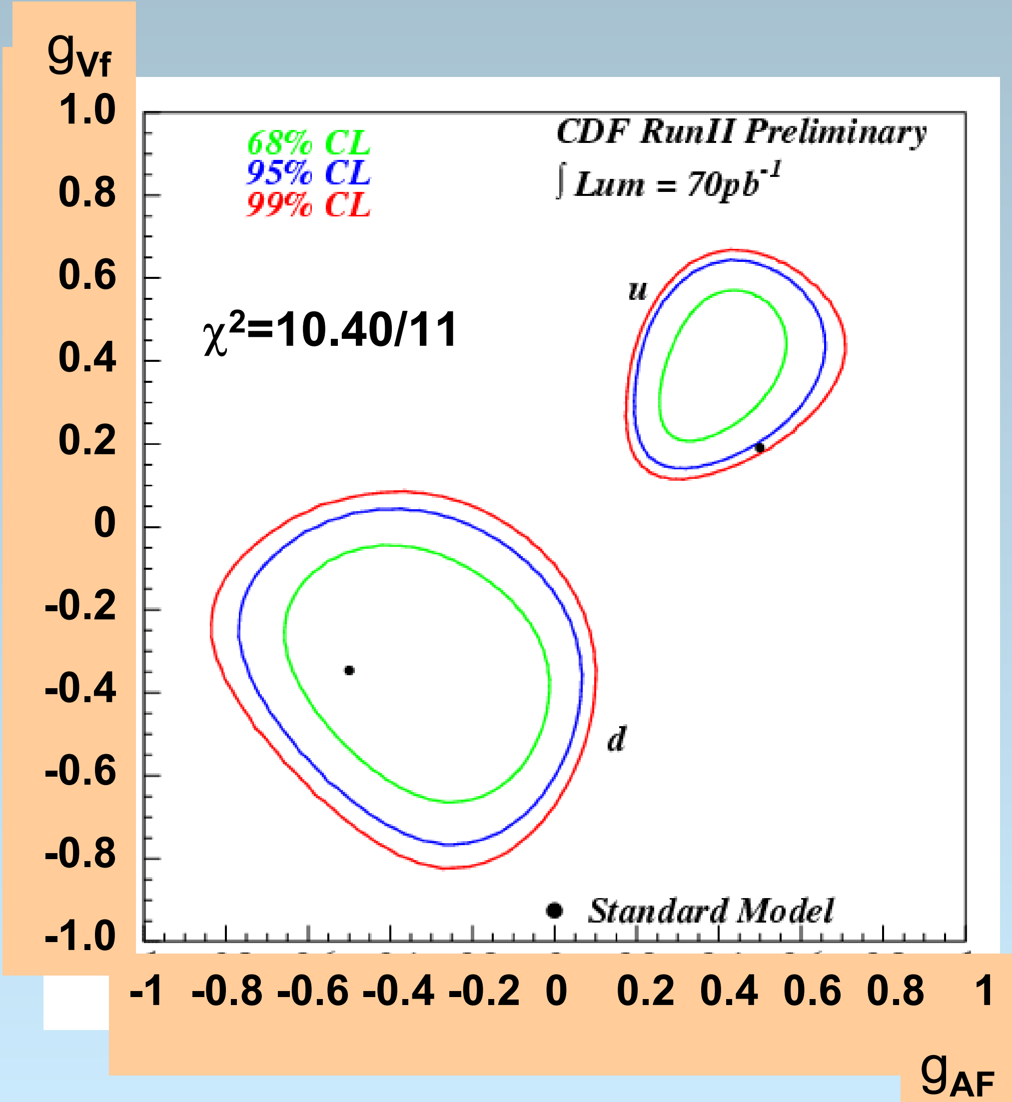
Data-MC: Cos(θ*)



40 GeV/c²<Mee< 75 GeV/c²
events/0.2
cos(θ*)
75 GeV/c² < Mee < 105 GeV/c²
events/0.05
CDF II Preliminary
cos(θ*)
Data
Z/γ→ e⁺e⁻ MC
Dijet background
Other backgrounds
Mee > 105 GeV/c²
events/0.2
cos(θ*)

Couplings Results

Quark Couplings:



Electron Couplings:

χ^2=13.14/13

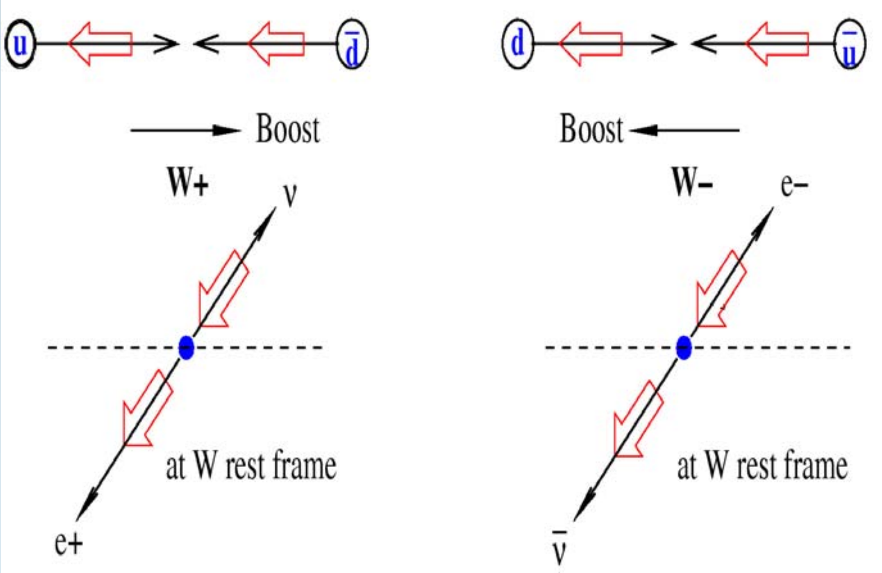
	CDF Run II	SLD+LEP	SM prediction
e_V	-0.058 ± 0.017	-0.03816 ± 0.00047	-0.03816 ± 0.00047
e_A	-0.53 ± 0.14	-0.50111 ± 0.00035	-0.5064 ± 0.0001

$\sin^2\Theta_W^{Eff}$ Measurement:

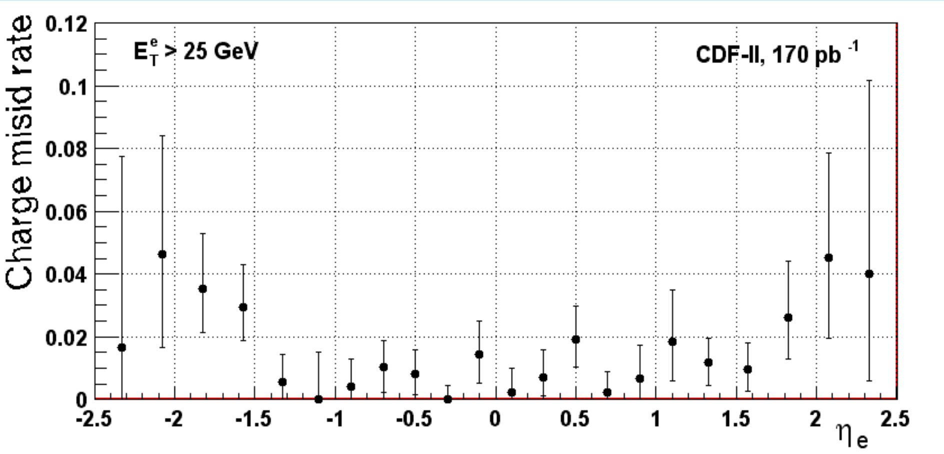
$\sin^2\theta_W^{Eff}$=0.2238±0.0040$_{(stat)}$±0.0030$_{(syst)}$

χ^2=12.50/14

W Asymmetry



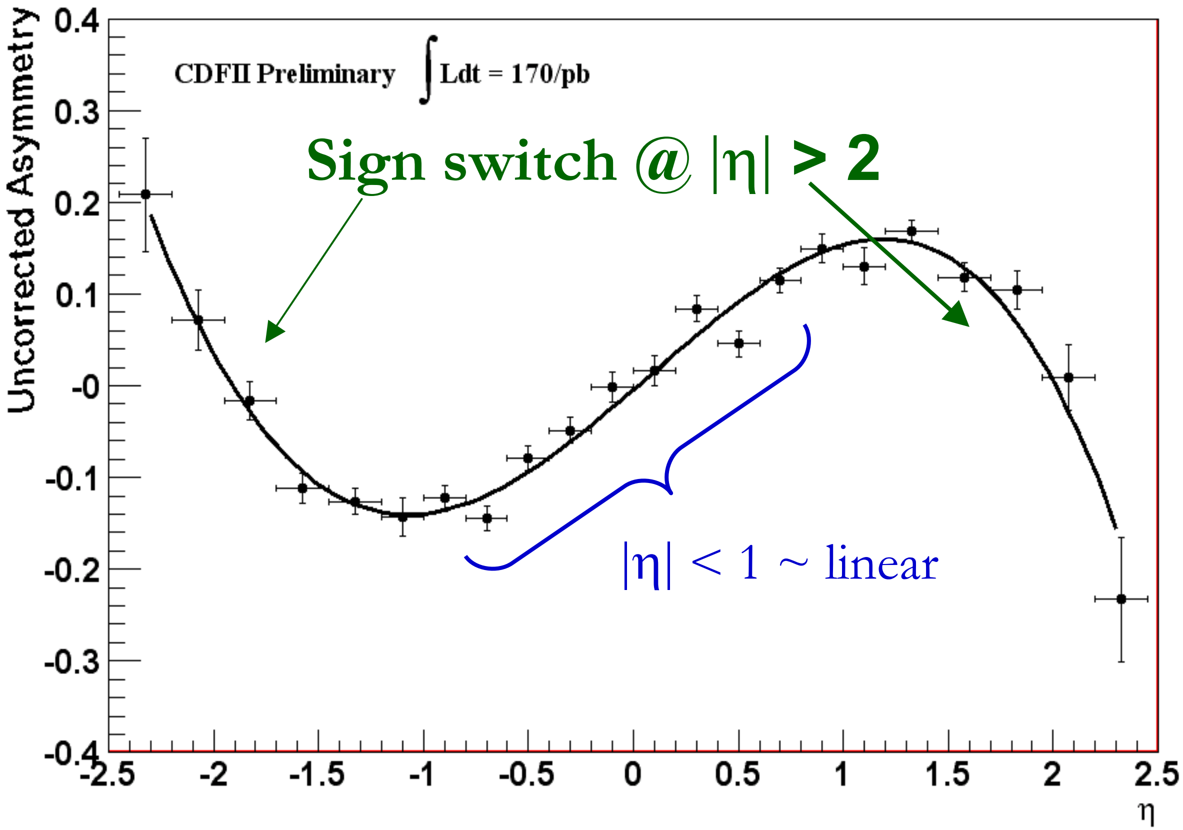
Anastasiou, Dixon, Melnikov, Petriello, Phys Rev D 69, 094008 (2004)



Charge ID is crucial at high rapidity

Raw Asymmetry

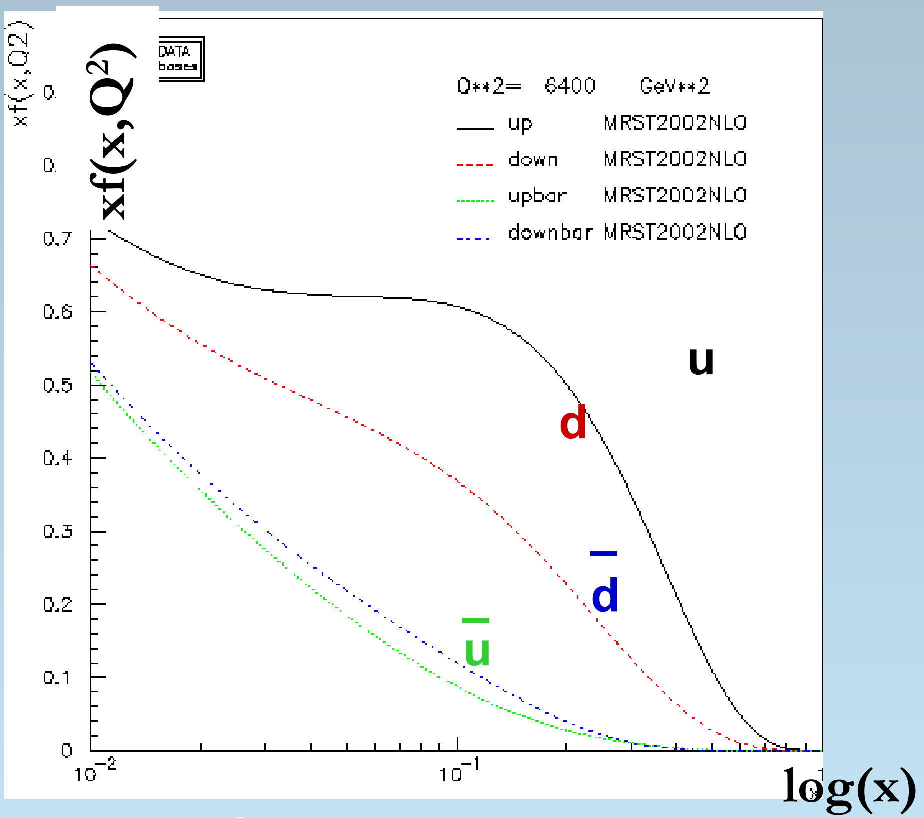
Shape is convolution of $\mathcal{A}(y_W)$ and V-A



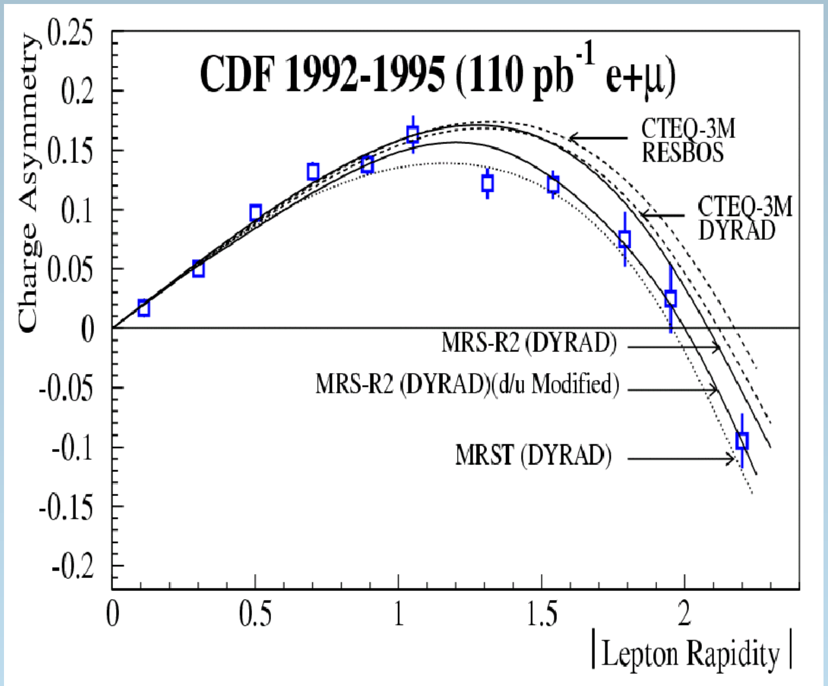
Curve is just to guide the eye.

- Corrections to extract true asymmetry:
  - Charge misidentification rate.
  - Background subtraction.
    - Both bias the asymmetry low → dilution.
    - Measured in each η bin.
    - Uncertainties in corrections go directly in $\mathcal{A}$.

W Asymmetry



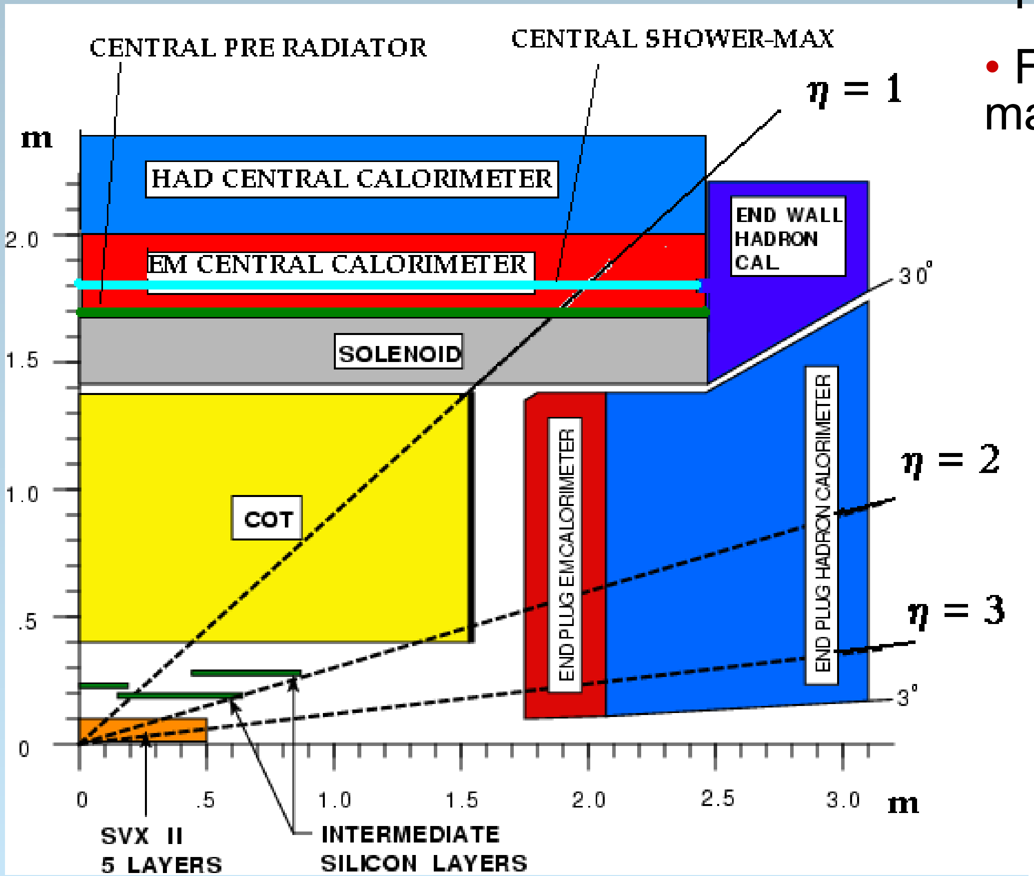
[http://durpdg.dur.ac.uk/hepdata/pdf3.html]



Run I Result

Phoenix (Calorimeter-Seeded) Tracking

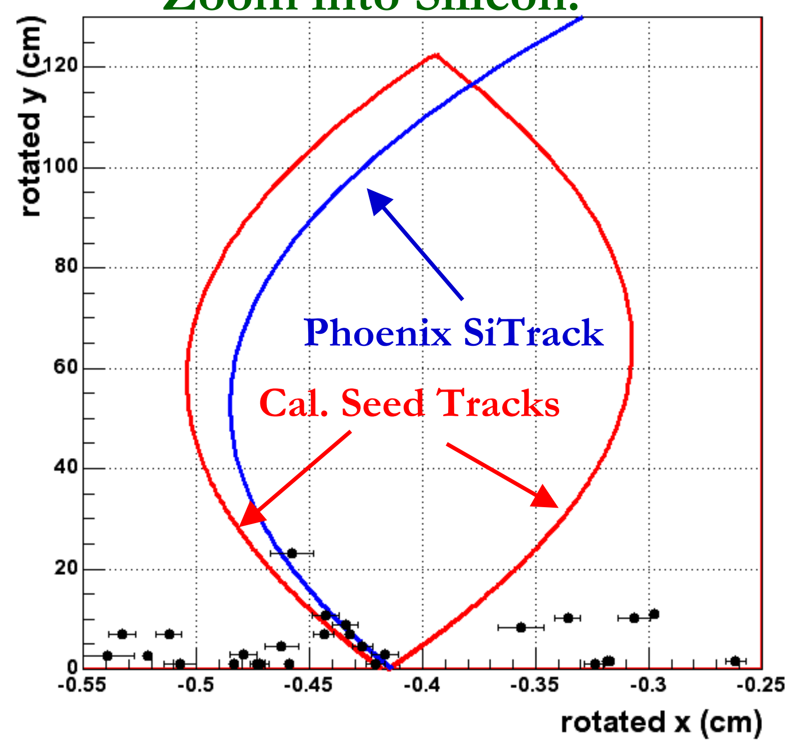
Use both central and <u>forward</u> electrons! |η| < 2.8



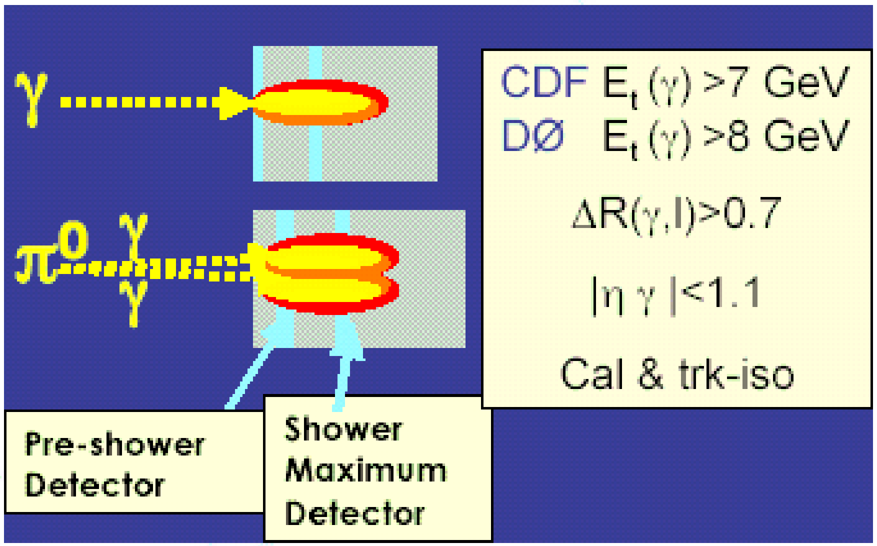
Two points and a curvature define a helix:

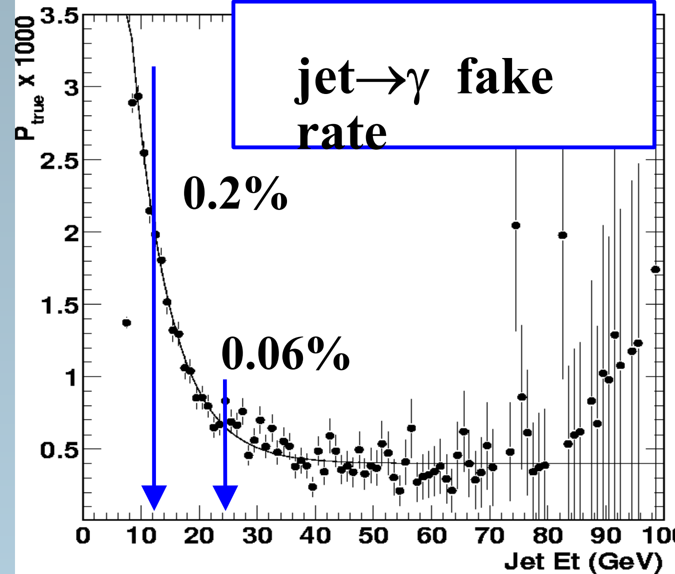
- Primary collision vertex position.
- Fitted position of calorimeter shower maximum.

Zoom into Silicon:

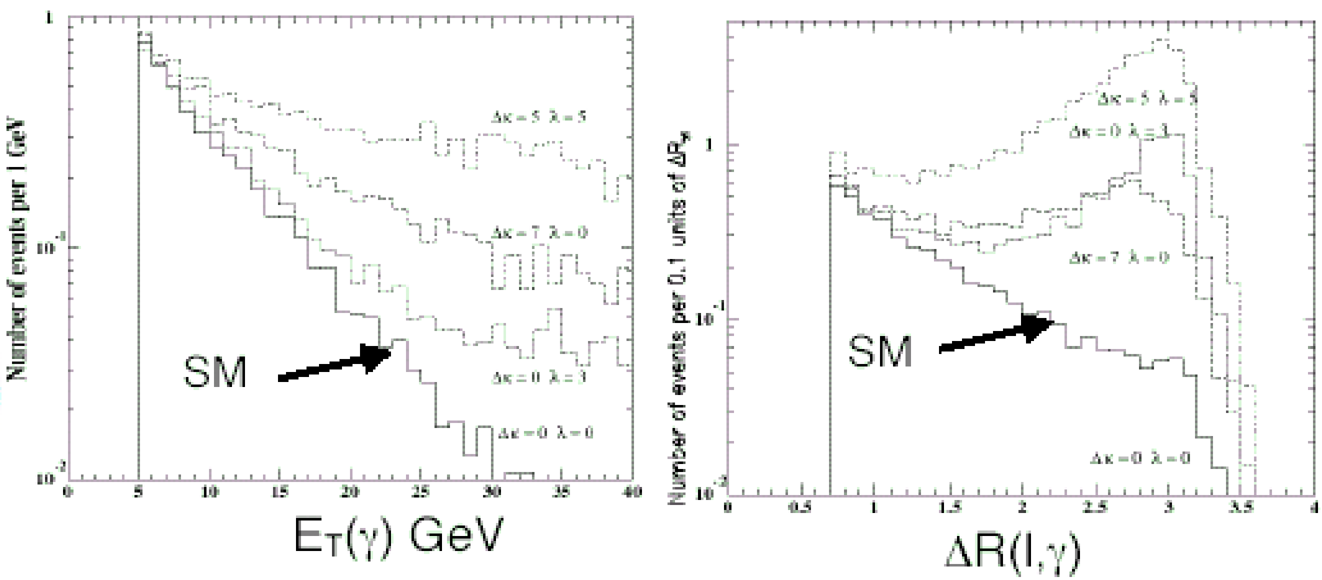


Wg production





cluster transverse mass $M_T^2(l\gamma, \not{E}_T) = [(M_{l\gamma}^2 + |\vec{p_T}(l)+\vec{p_T}(\gamma)|^2)^{1/2} + \not{E}_T]^2 - |\vec{p_T}(l)+\vec{p_T}(\gamma)+\vec{\not{E}}_T|^2$



$W\gamma$

LO MC

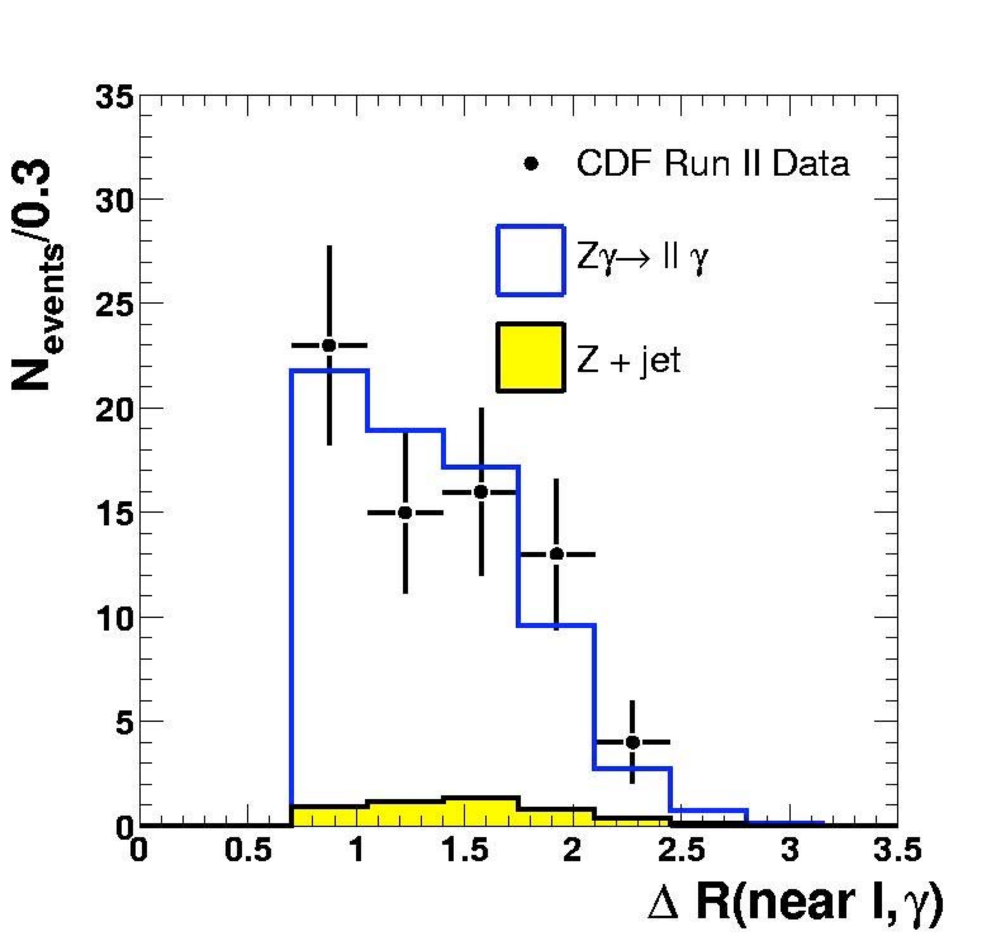
Inteference between ISR and TGZ gives radiation zero (RAZ)

RAZ

$Q(\eta_\gamma - \eta_l)$

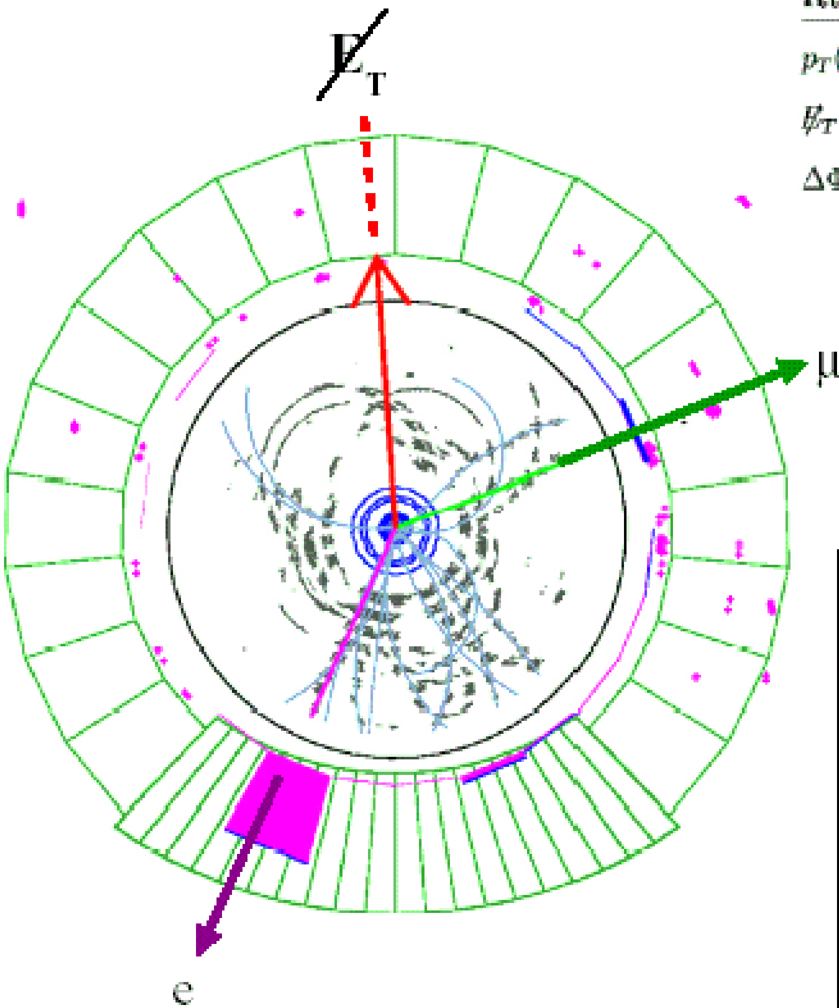
$\Delta R(\gamma - l)$

Z-γ



$N_{events}/0.3$
35
30
25
20
15
10
5
0
CDF Run II Data
$Z\gamma \rightarrow ll\ \gamma$
Z + jet
0
0.5
1
1.5
2
2.5
3
3.5
Δ R(near l,γ)

WW->eν+μν$_\mu$



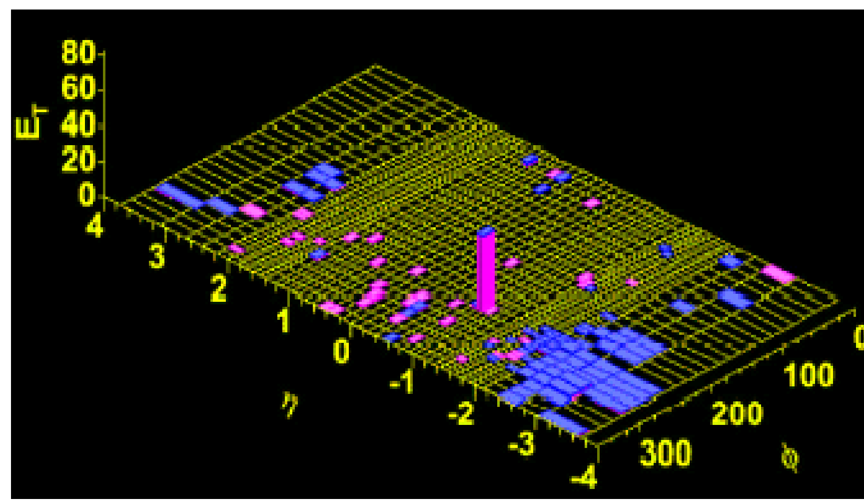
Run 155364 Event 3494901 : $WW \to e^+\nu_e\mu^-\bar{\nu}_\mu$ Candidate

$p_T(e) = 42.0$ GeV/c; $p_T(\mu) = 20.0$ GeV/c; $M_{e\mu} = 81.5$ GeV

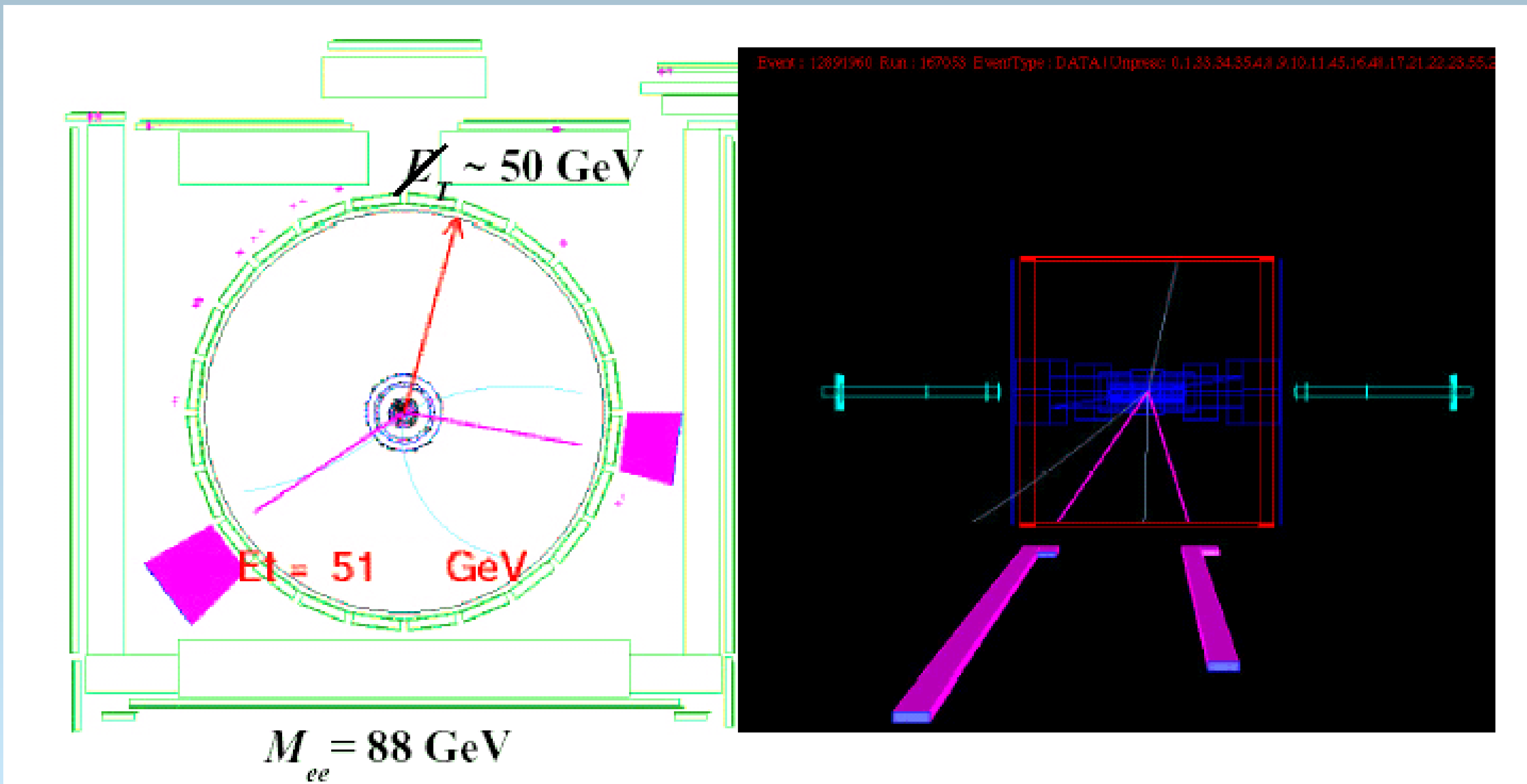
$\not{E}_T = 64.8$ GeV; $\Phi(\not{E}_T) = 1.6$

$\Delta\Phi(\not{E}_T$, lepton$) = 1.3$; $\Delta\Phi(e,\mu) = 2.4$; Opening-Angle(e,μ)=2.6

- eμ channel has little Standard Model background
- Signal/Background = 4



WW->$e\nu+\mu\nu_\mu$ or ZZ->ee $\nu\nu$?



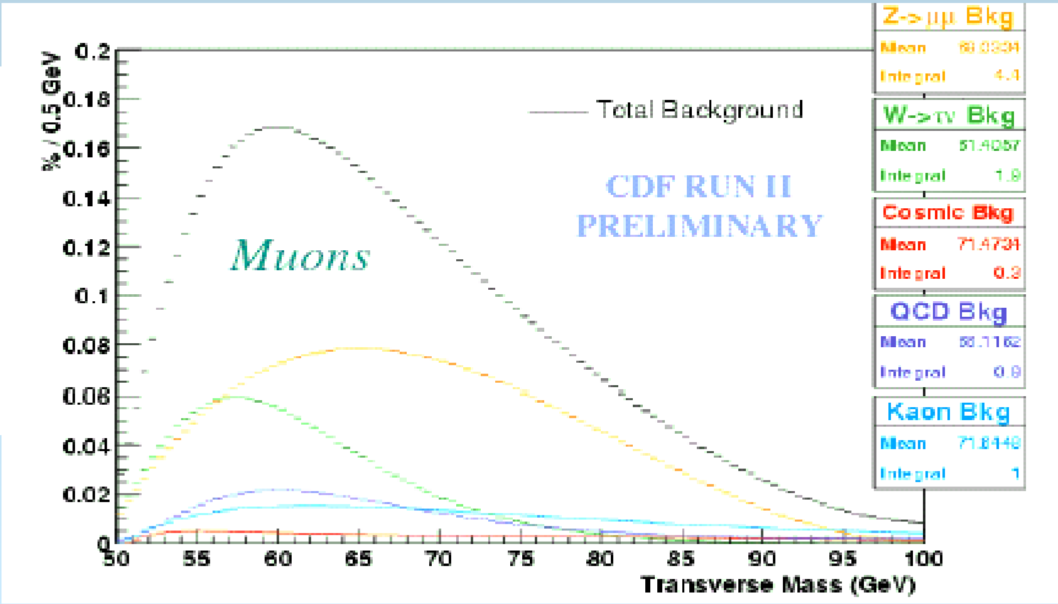
W Boson Mass background

Muons

Background	%
Hadronic Jets	0.9 ± 0.5
Kaons	1.0 ± 1.0
Cosmic Rays	0.3 ± 0.1
$Z \rightarrow \mu\mu$	4.4 ± 0.2
$W \rightarrow \tau\nu$	1.9 ± 0.1

Electrons

Background	%
Hadronic Jets	1.1 ± 0.4
$Z \rightarrow ee$	0.27 ± 0.03
$W \rightarrow \tau\nu$	1.9 ± 0.1

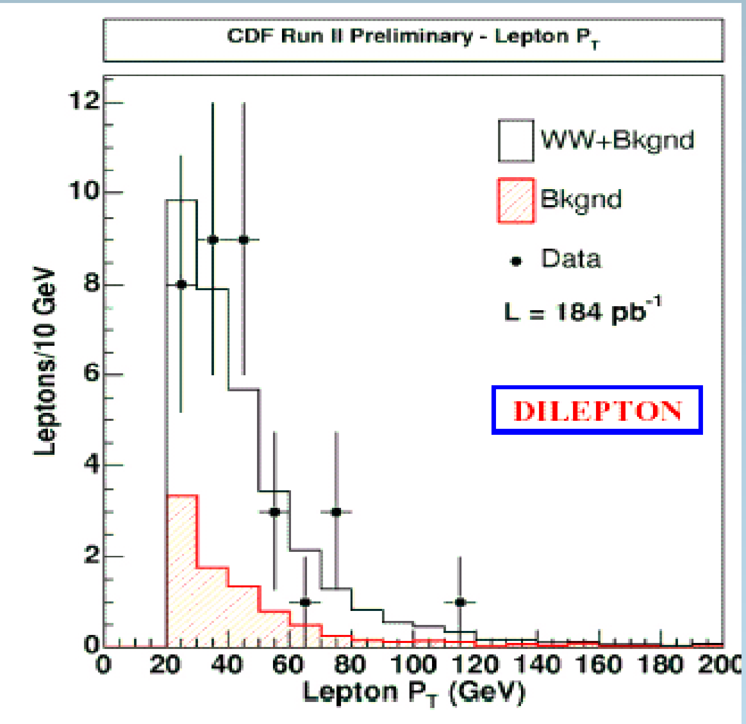


W Boson Mass

Systematic	Electrons (Run 1b)	Muons (Run 1b)
Lepton Energy Scale and Resolution	70 (80)	30 (87)
Recoil Scale and Resolution	50 (37)	50 (35)
Backgrounds	20 (5)	20 (25)
Statistics	45 (65)	50 (100)
Production and Decay Model	30 (30)	30 (30)
Total	105 (110)	85 (140)

CD
PRE

WW production: Kinematical Distributions



Lepton P_T

Dilepton Invariant Mass

No significant excess so far