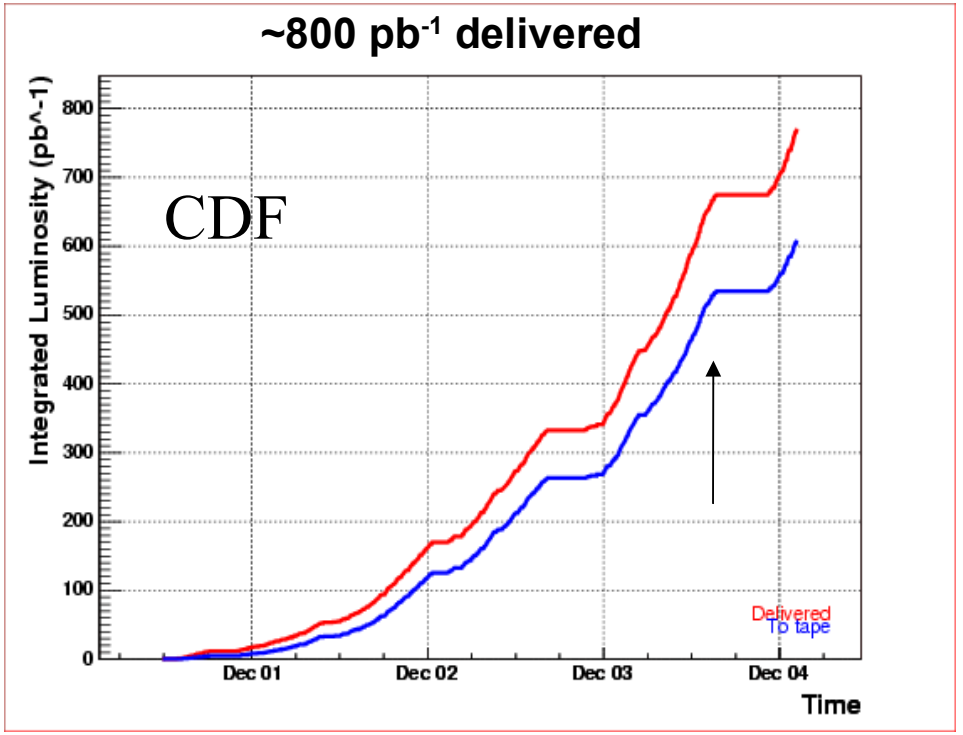
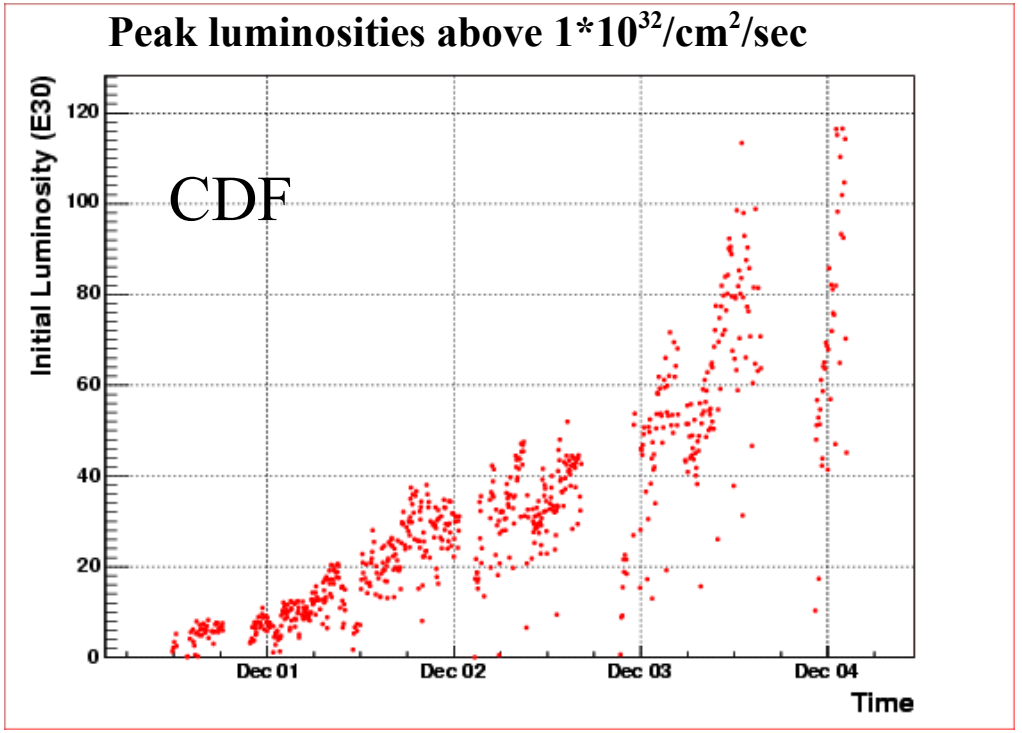
EWK physics at the Tevatron

P.Murat(FNAL) for the CDF and DO collaborations

- physics of the gauge bosons - W, Z, photons
  - single boson production: couplings to the fermions
  - diboson production: self- or triple gauge couplings
- Tevatron vs LEP:
  - LEP: Z pole, WW and ZZ production
  - Tevatron: more W's, WZ pairs, large sqrt(s) and Pt
- precision measurements
  - Properties of the W's: mass, width, branching ratios
  - W's vs Z's - consistency of SM
  - Probe QCD and internal structure of the proton
- Signature-based searches

Tevatron today





- Tevatron as a vector boson factory: *)
  - ~30,000 W->e events/week
  - ~2500 Z->ee events/week
  - 120 WW, 40 WZ events/week

*) for L ~ 10 pb-1/week

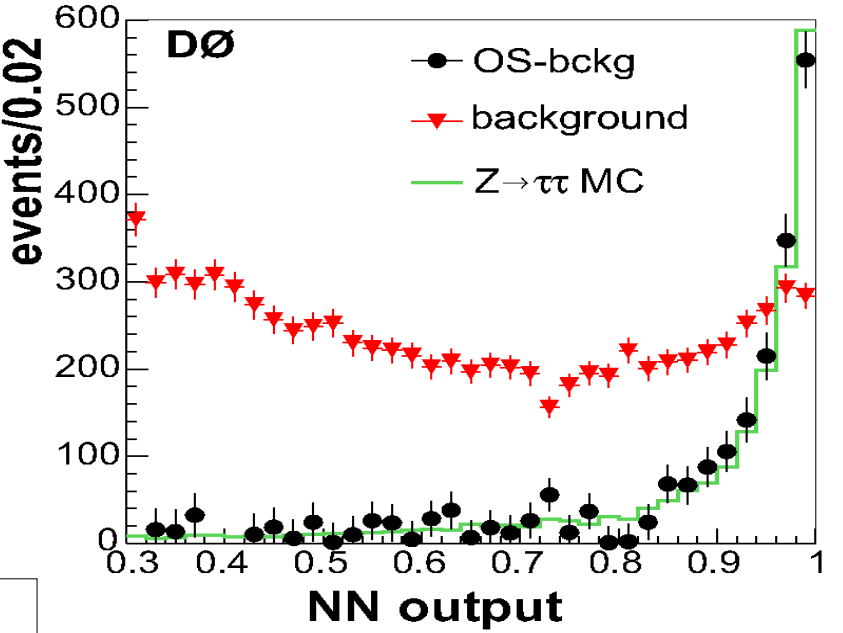
EWK results'2004

- Single boson production
  - Z->tau tau
  - W charge asymmetry
- Diboson physics
  - W gamma and Z gamma cross sections
  - W gamma/Z gamma: limits on anomalous couplings
  - WW production
  - WZ/ZZ results
  - WZ: limits on anomalous couplings
- Properties of the W-boson: mass (status) and width

$p\bar{p}$->Z->tau tau cross section

- Taus very important
  - H->tautau, SUSY at large tan(β)
- Z->tautau - establishes the baseline
  - Learn if accuracy better than 10%

$$p\,\bar{p} \rightarrow Z \rightarrow \tau(\mu\,\nu\,\bar{\nu})\,\tau(e/hadrons\,\nu)$$



DO measurement:

- Single muon trigger, neural network-based τ ID
- $P_t(\mu) > 12$ GeV, $E_T(\tau) > 10(5)$ GeV
- ~2000 events, S/B ~ 1
- Z->tautau signal: 914+/-24 events

$$\sigma(p\,\bar{p} \rightarrow ZZ) \times BR(Z \rightarrow \tau\,\tau) = (252 \pm 16_{STAT} \pm 19_{SYST} \pm 17_{LUM})\ pb$$

[m($\tau\tau$)>60 GeV/c^2]

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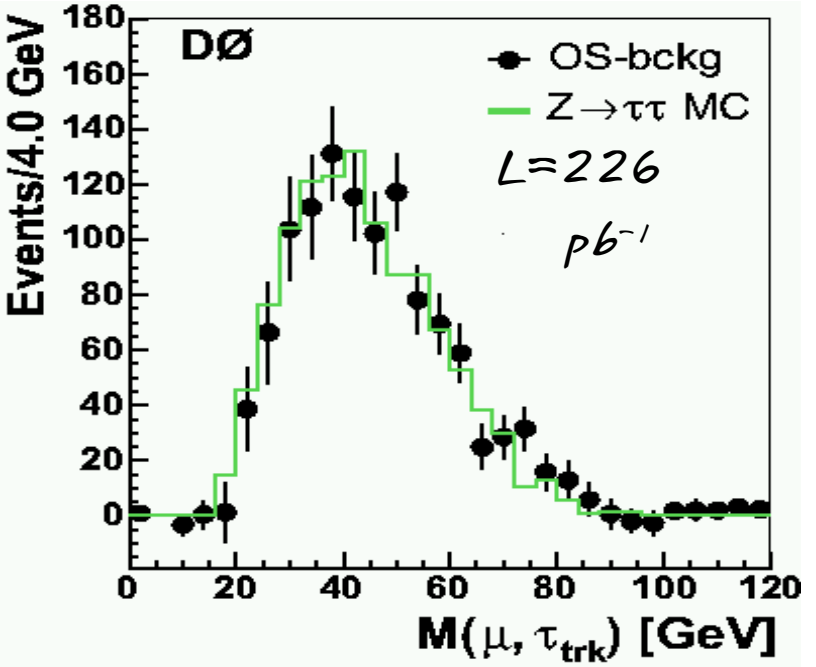
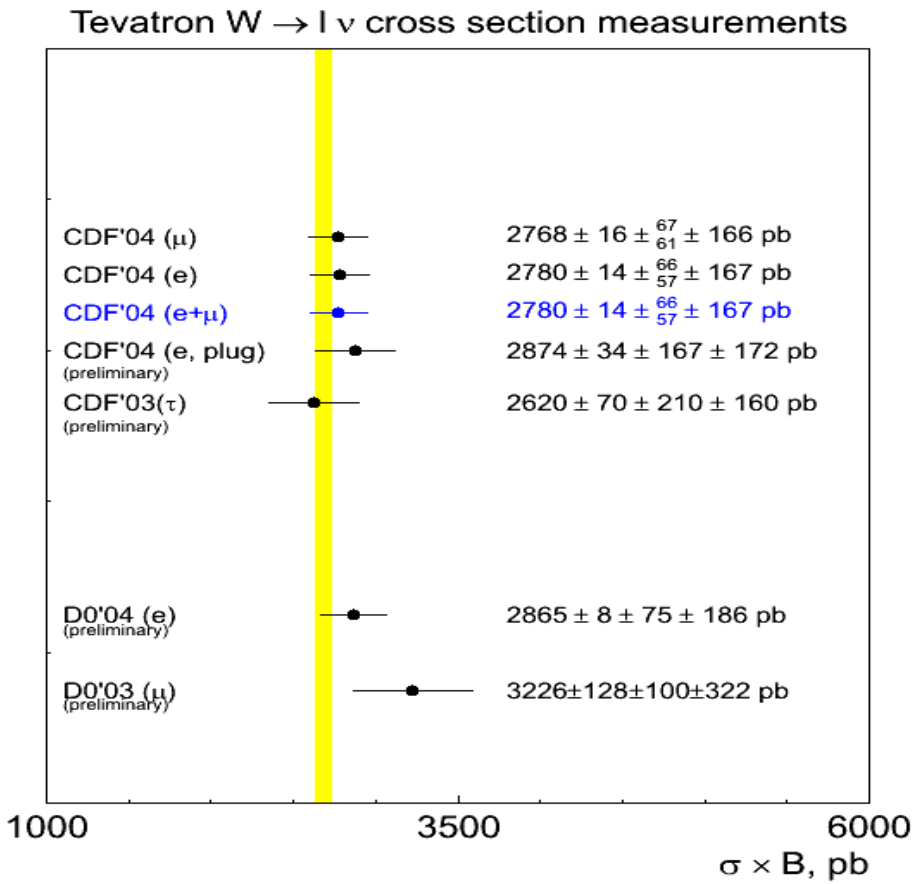
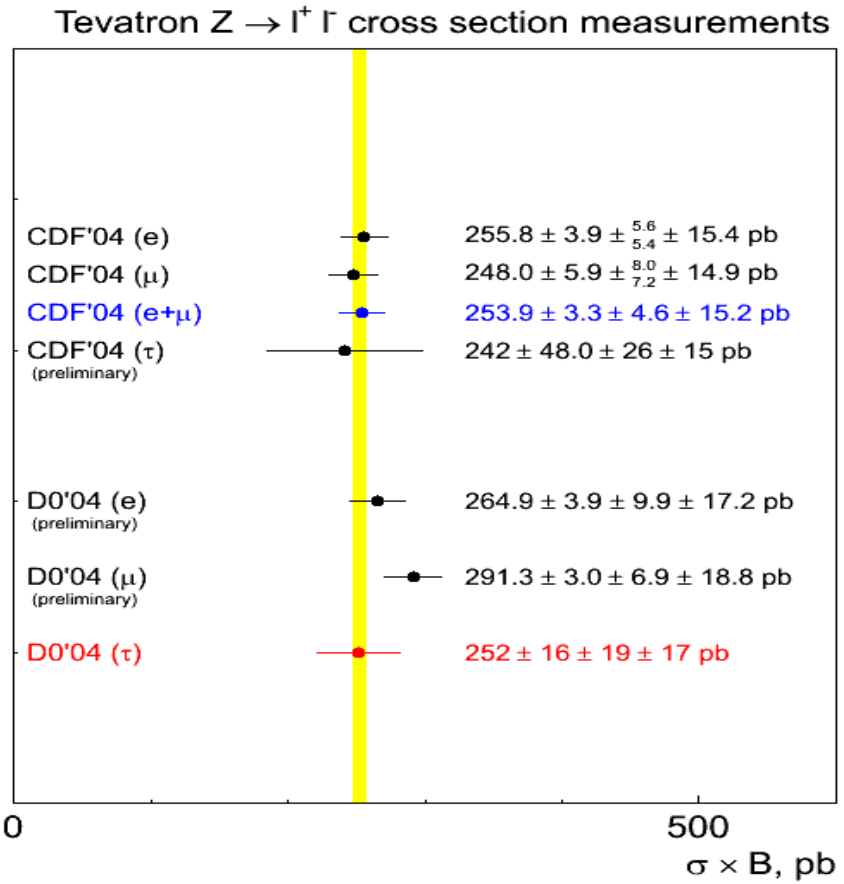


Inclusive $p\bar{p}$->W/Z cross sections





- Good agreement with the NNLO calculations
- Accuracy limited by the systematic effects, dominant sources:
  - luminosity measurements (~6%) , correlated
  - PDF uncertainties (~2%)

W charge asymmetry

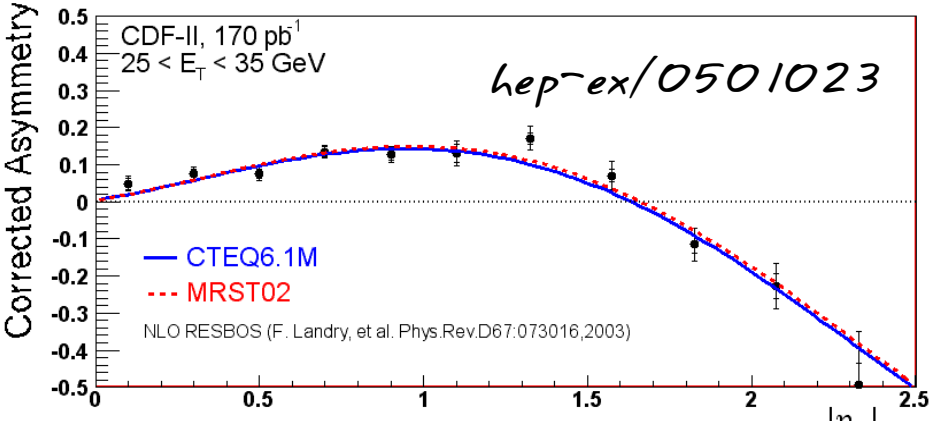
- Use W's to probe the proton structure (quark/gluon momentum distributions)

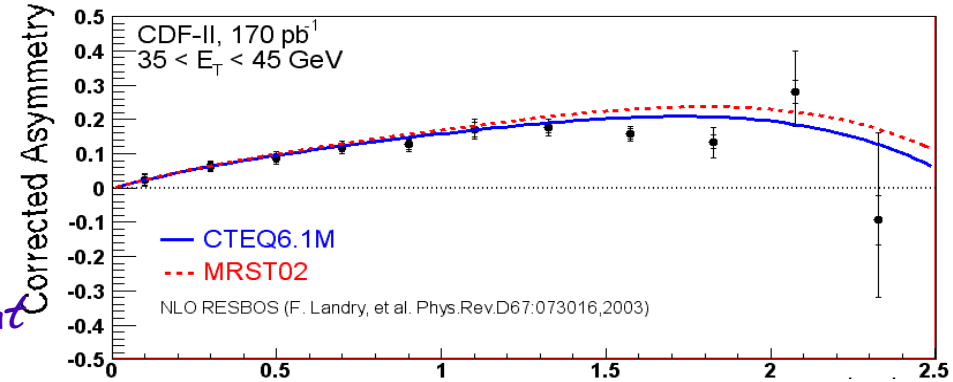
$$A(y) = \frac{d\sigma(W^{+\cdot})/dy - d\sigma(W^{-\cdot})/dy}{d\sigma(W^{+\cdot})/dy + d\sigma(W^{-\cdot})/dy}$$

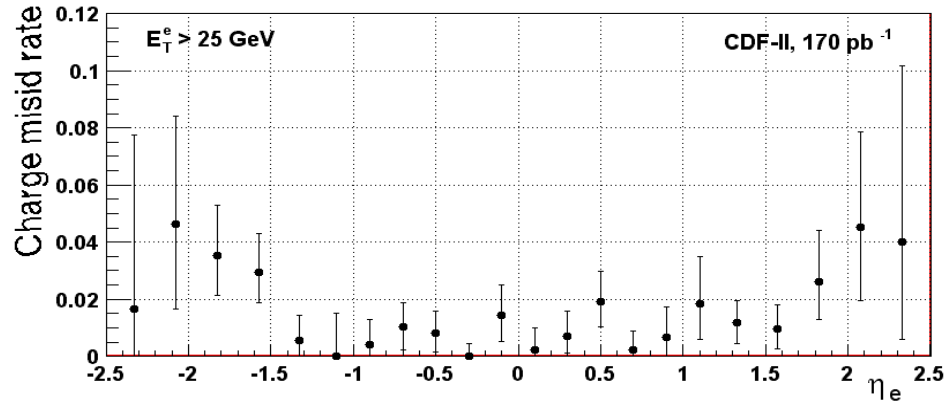
- A(y) is sensitive to U(x)/D(x)
- Measure lepton charge asymmetry

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

- deconvolute it to extract information about the parton momentum distributions
- CDF: W->ev cross section up to $|\eta_e| = 2.5$
- Lepton asymmetry: W asymmetry*(V-A)
- Key: lepton charge misID ~4% at $|\eta| \sim 2$



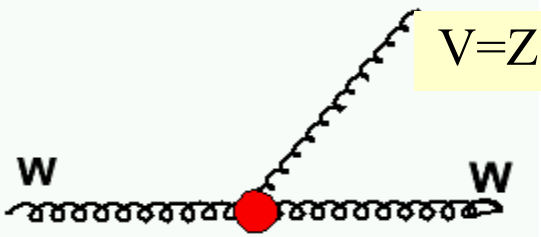




Results available for PDF'2005 fits

Diboson physics: probing gauge sector

- SU(2)xU(1) breaks in the gauge sector W,Z,γ, Higgs!
- Probing interactions between the gauge bosons - important test of the SM



$$L_{eff}^{WWV} = i g_{WWV} \cdot \left(g_1^V \cdot \left(W^{+}_{\mu\nu} W^{-\mu} - W^{+\mu} W^{-}_{\mu\nu} \right) V^{\nu} + k_V W^{+}_{\mu} W^{-}_{\nu} V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W^{+\nu}_{\mu} W^{-\rho}_{\nu} V^{\mu}_{\rho} \right)$$

SM: $g^Z_1 = g^\gamma_1 = k_Z = k_\gamma = 1 \qquad \lambda_Z = \lambda_\gamma = 0$

Phys.Rev.D48(5)2182 (HISZ)

λ_γ and κ_γ are related to magnetic and quadrupole moment of the W:

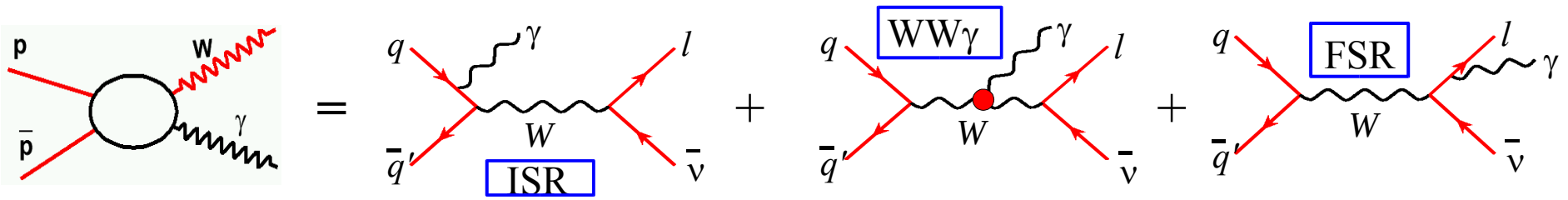
$$\mu_W = e(1+\kappa_\gamma+\lambda_\gamma)/2m_W$$
$$q_W = -e(\kappa_\gamma-\lambda_\gamma)/m_W^2$$

- Charged couplings (WWZ/γ): 5 parameters [$g_Z, \kappa_Z, K_\gamma, \lambda_Z, \lambda_\gamma$]
- neutral couplings (ZZγ, Zγγ): 8 parameters [h_i^Z, h_i^γ, i=1,4]
- Stringent limits from LEP
- Tevatron: higher √s, higher Pt's => competitive with ~ few fb^{-1}

Experimental Language

- W/Z selections are based on selection of high-Pt leptons
  - $Z \rightarrow ll$, $W \rightarrow l$
- high-Pt lepton
  - N(definitions) = 2 experiments * several analyses * 2 lepton flavors
- "High-Pt lepton"
  - Electron or muon with $Pt > 25\ (20, 15)$ GeV/c
  - "Isolated" : E_T in cone R=0.4 less than 0.1 E_T(lepton)
  - "Central" : $|\eta| < 1\ (1.1)$
- Neutrinos result in mis-balance of transverse energy,
  - "large missing E_T: $\not{E}_T > 25\ (20)$ GeV

$p\bar{p}->W\gamma$



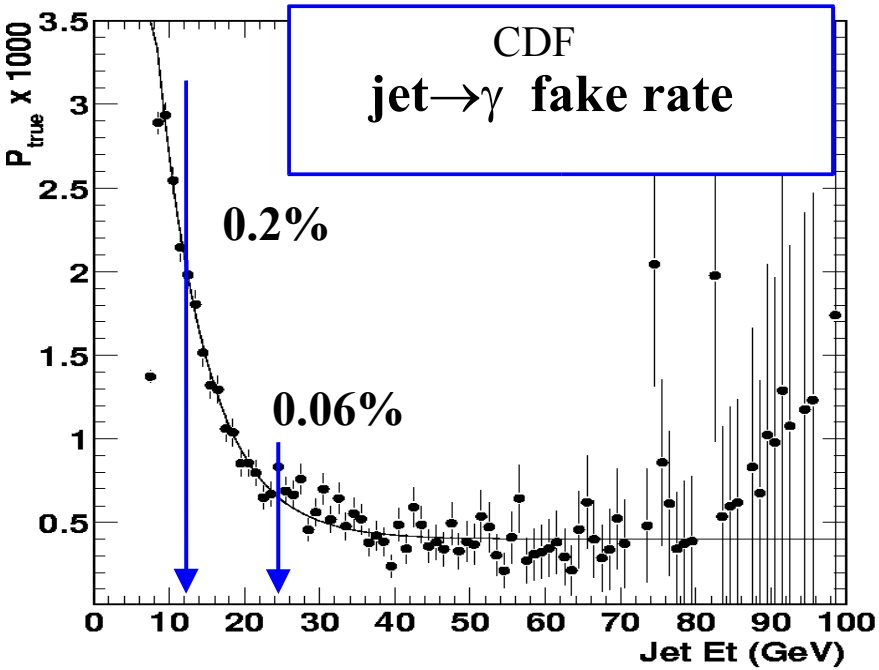
Probe trilinear WWγ couplings

W selection

- Isolated high-Pt lepton
- Large missing $\not{E}_T$

Photon identification critical:

- $|\eta| < 1.1$, $R(\gamma l) > 0.7$



	σ(pp̄->Wγ) , pb	SM expectation, pb	E_T , GeV
CDF	$18.1 \pm 1.6_{STAT} \pm 2.4_{SYST} \pm 1.2_{LUM}$	19.3 ± 1.4	7
D0	$14.8 \pm 1.6_{STAT} \pm 1.0_{SYST} \pm 1.0_{LUM}$	16.0 ± 0.4	8

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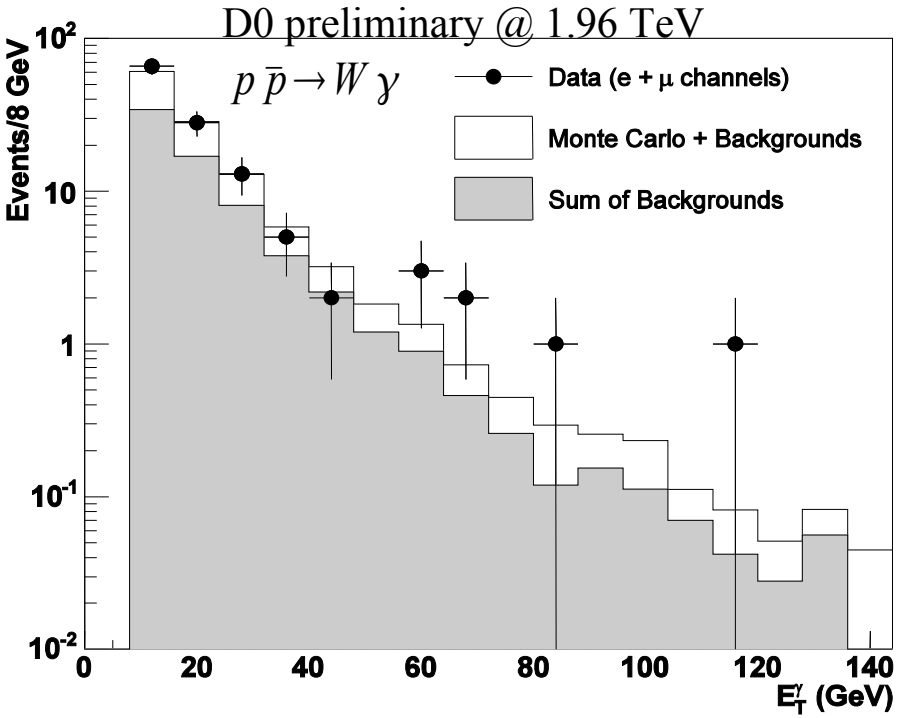
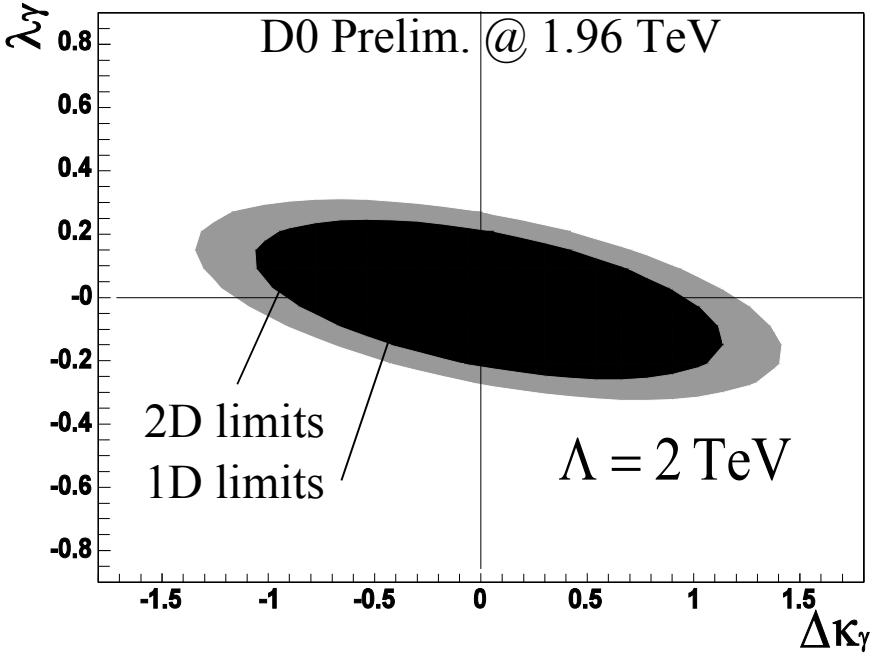
*both experiments quote cross section integrated over the acceptance

WWγ couplings (2005)





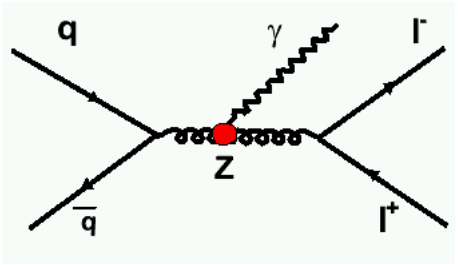
1D limits @ 95% CL:

	Tevatron Run I	Tevatron Run II (D0)	LEP combined
$\Delta\kappa_\gamma$	-0.93, 0.94	-0.93, 0.97	-0.105, 0.069
λ_γ	-0.31, 0.29	**-0.22, 0.22**	-0.059, 0.026

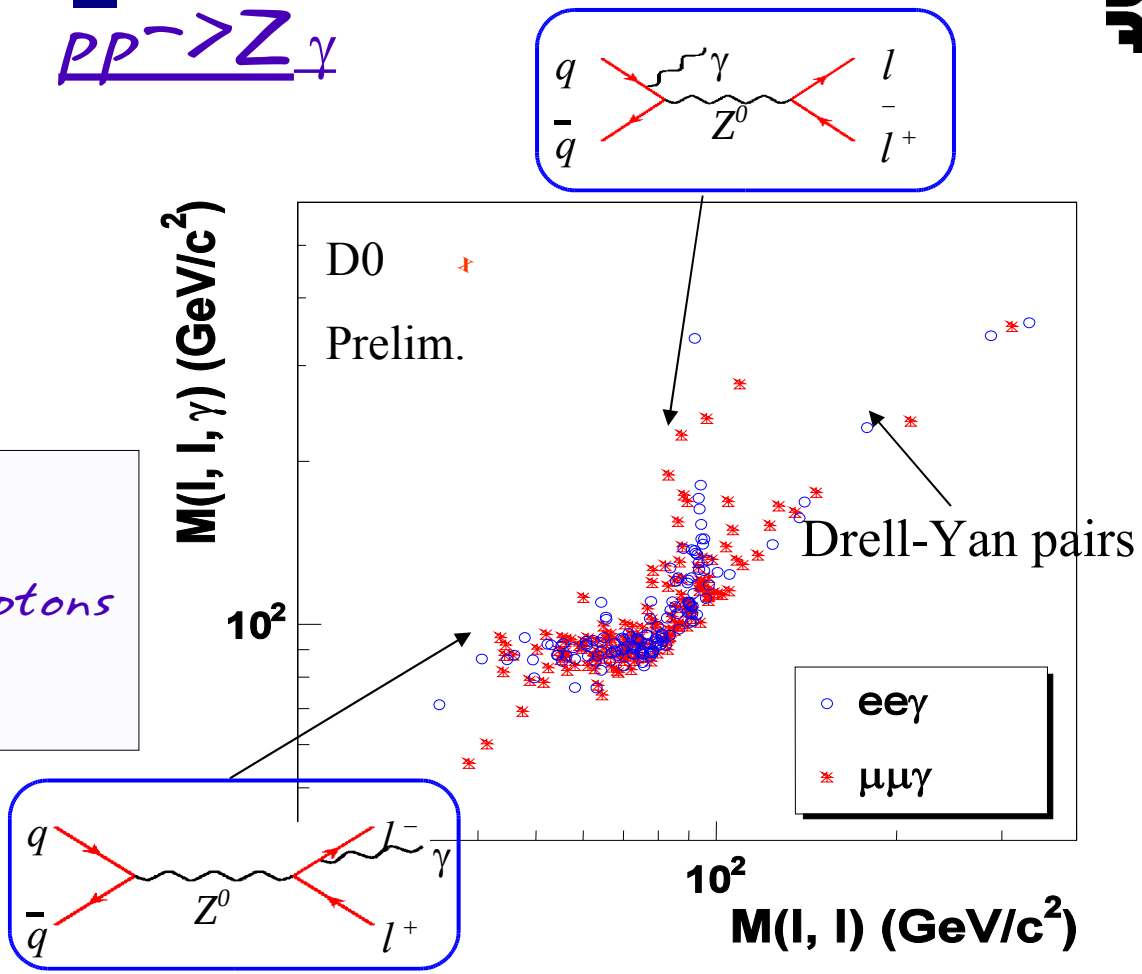
=2 TeV

Tevatron Run I limit for λ_γ already improved!

$p\bar{p}->Z\gamma$



$= 0$?



Event selection:

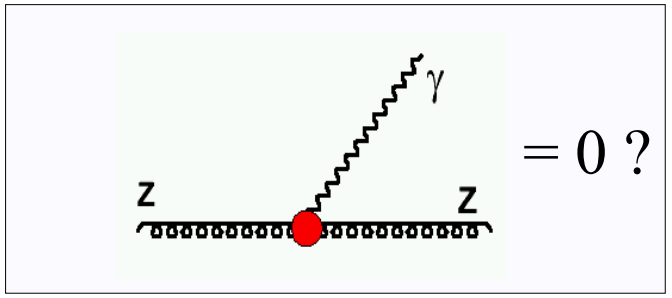
- Z-boson: 2 high-Pt isolated leptons
- central photon, $\Delta R(\gamma l) > 0.7$

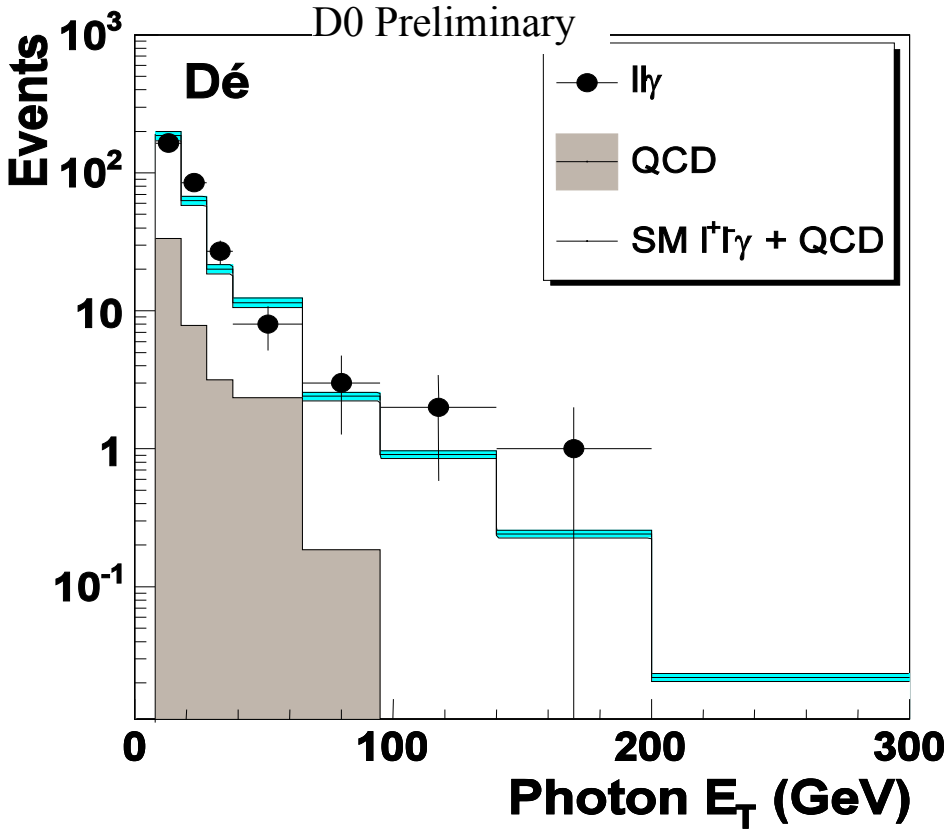
	$\sigma(p\bar{p}->Z\gamma)$, pb	SM expectation, pb	E_T, GeV
CDF, ~200 pb^{-1}	$4.6 \pm 0.5_{STAT+SYST} \pm 0.3_{LUM}$	4.5 ± 0.3	7
D0, ~300 pb-1	$4.2 \pm 0.4_{STAT+SYST} \pm 0.3_{LUM}$	3.9 ± 0.2	8

hep-ex/041000

*both experiments quote cross section integral within the acceptance

neutral tri-boson couplings (2005)





LEP	Tevatron (D0)
$-0.056 < h_{10}^{\gamma} < 0.055$	
$-0.045 < h_{20}^{\gamma} < 0.025$	
$-0.049 < h_{30}^{\gamma} < 0.008$	$-0.22 < h_{30}^{\gamma} < 0.22$
$-0.002 < h_{40}^{\lambda} < 0.034$	$-0.019 < h_{40}^{\gamma} < 0.019$
$-0.13 < h_{10}^{Z} < 0.13$	
$-0.078 < h_{20}^{Z} < 0.071$	
$-0.20 < h_{30}^{Z} < 0.07$	$-0.21 < h_{30}^{Z} < 0.21$
$-0.05 < h_{40}^{Z} < 0.12$	$-0.019 < h_{40}^{Z} < 0.019$

1D, 95% CL

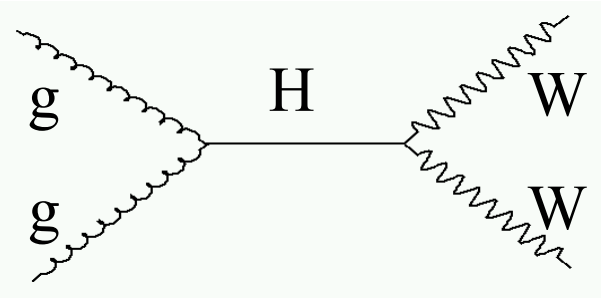
Tevatron already has better limits on h_4 than LEP

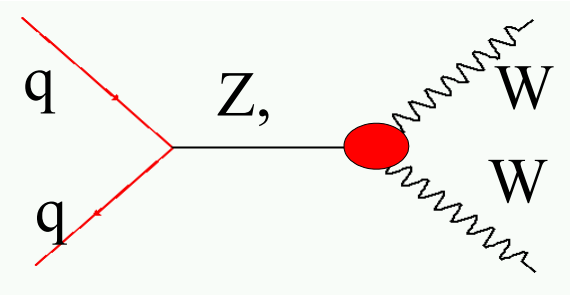
WW: interesting signal, important background

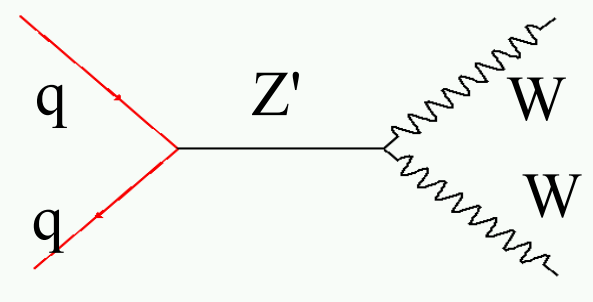
- Very important for the Higgs searches:

$$gg \rightarrow H \rightarrow WW$$

- Self-interaction of the heavy bosons (WWZ)
- Search for new heavy boson states

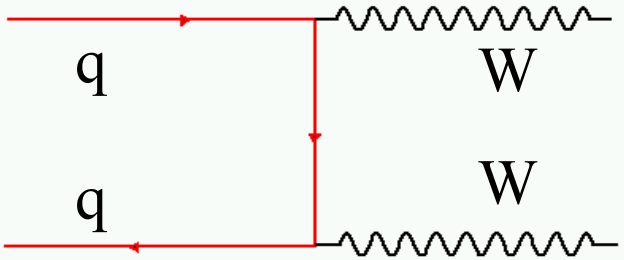






- Large statistics of WW events at LEP2 (~10K/expt)
- Run 1: only one measurement with limited sensitivity (CDF):

$$\sigma(p\bar{p} \rightarrow WW) = (10.2^{+6.1}_{-5.2} \pm 1.6)\, pb$$



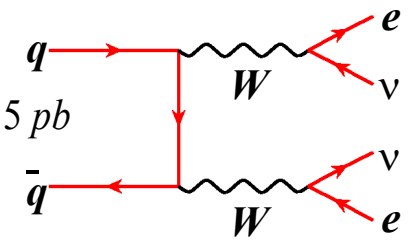
$p\bar{p}$->WW: event selection

- First goal for Run II:
  - establish the signal
- Prediction for the cross section:

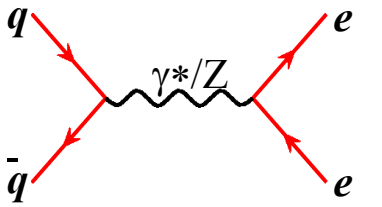
$$\sigma(p\bar{p}\to WW)_{NLO} = (12.4\pm0.8)\,pb \quad at\ 1.96\ TeV$$

- CDF and DO used dilepton channel
  - BR~5%, best sensitivity (S/B)
- Selection:
  - 2 isolated leptons, large E_T (2ν)
- Background sources
  - Remove Drell-Yan pairs
  - Control rate of fake leptons
  - Veto extra jets

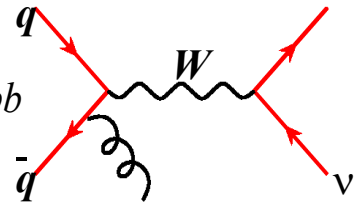
$\sigma(p\bar{p}\to WW\to e\nu e\nu) \sim 0.15\,pb$



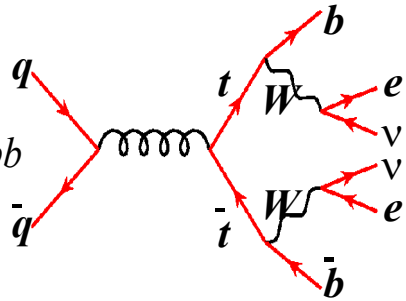
$\sigma(p\bar{p}\to Z/\gamma*\to ee) \sim 250\,pb$



$\sigma(p\bar{p}\to(W\to e\nu)+jets) \sim 500\,pb$



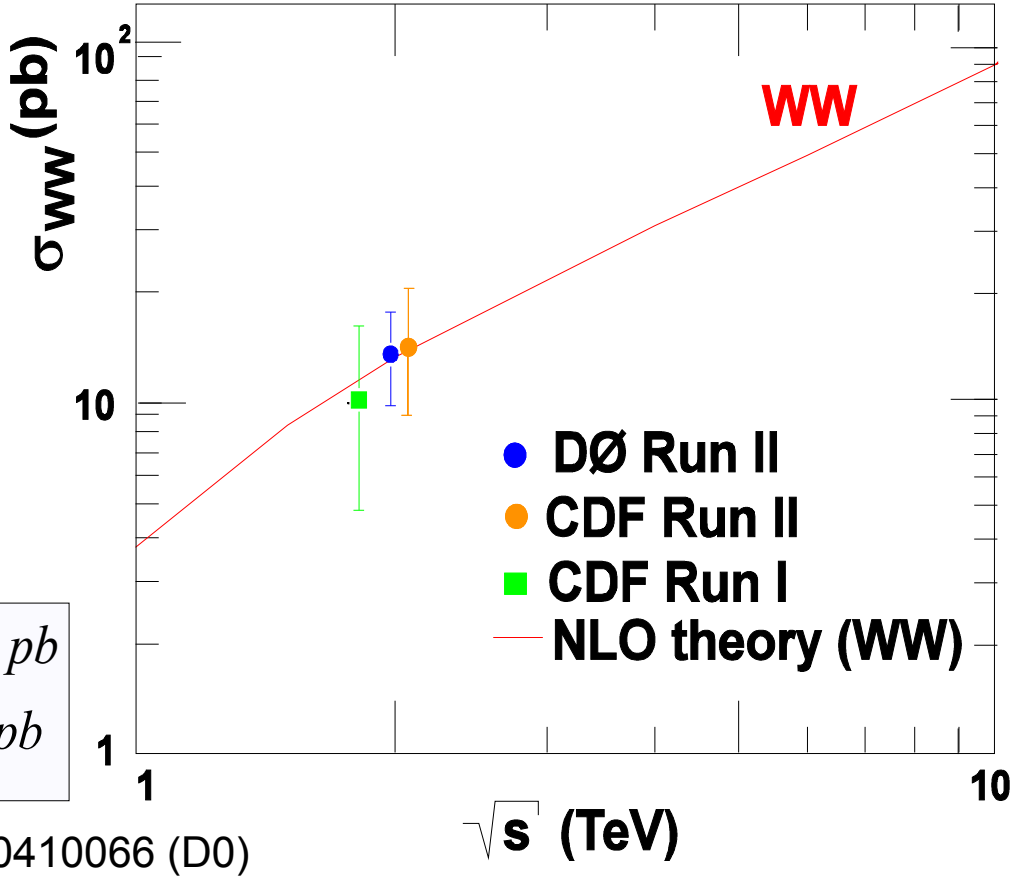
$\sigma(p\bar{p}\to t\bar{t}\to e\nu e\nu b\bar{b}) \sim 0.1\,pb$



WW: the Run II measurements

	CDF	D0
Luminosity	200pb-1	224-252pb-1
WW signal	11.3+/-1.3	16.6+/-0.1
Background	4.8+/-0.7	8.1+/-0.5
Expected total	16.1+/-1.6	24.7+/-0.5
Observed	17	25

$$\sigma(p\bar{p}\to WW)_{CDF} = 14.6^{+5.8}_{-5.1}(stat)^{+1.8}_{-3.0}(syst)\pm 0.9(lum)\ pb$$
$$\sigma(p\bar{p}\to WW)_{D0} = 13.8^{+4.3}_{-3.8}(stat)^{+1.2}_{-0.9}(sys)\pm 0.9(lum)\ pb$$



Run II WW signal established

hep-ex/0410066 (D0)
hep-ex/0501050 (CDF)

Studies of the mode most sensitive to self-interactions of the W's

$$p\bar{p}\to W(l\nu)W(qq)$$

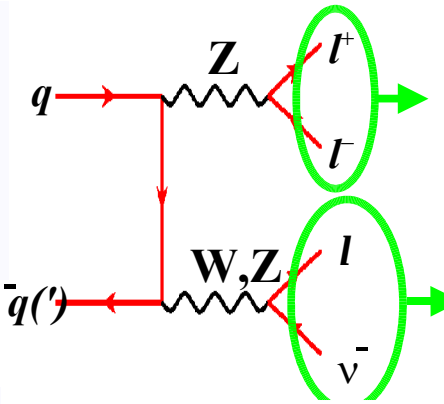
are in progress

WZ: the selections

- Study of WZ and ZZ production at the Tevatron -steps towards Higgs searches
- final state unique for hadron machines

$$\sigma(p\bar{p} \to ZW + X)_{\mathrm{NLO}} \sim 4\,\mathrm{pb}$$

- $p\bar{p} \to WZ$: final states with 3 leptons have no irreducible SM backgrounds
- Z selection: 2 isolated leptons, M(ll) consistent with M_Z .
- W selection: isolated lepton + $\not{E}_T$
- $\Delta R(ll) > 0.2$

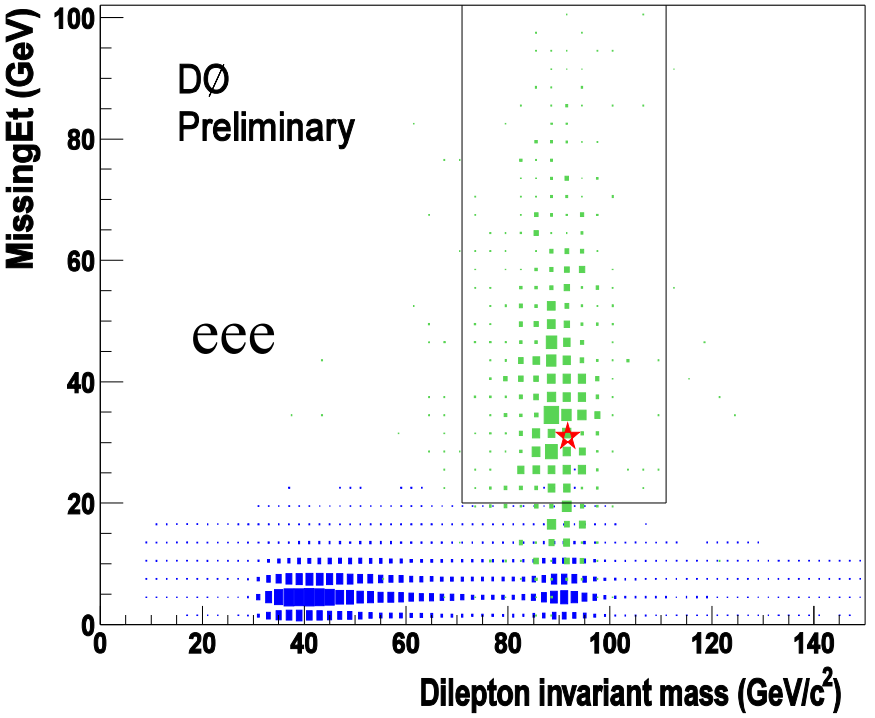


71 GeV< M(e^+e^-) < 111 GeV

50 GeV< M($\mu^+\mu^-$) < 130 GeV

lepton Pt >15 GeV

missing Et > 20 GeV



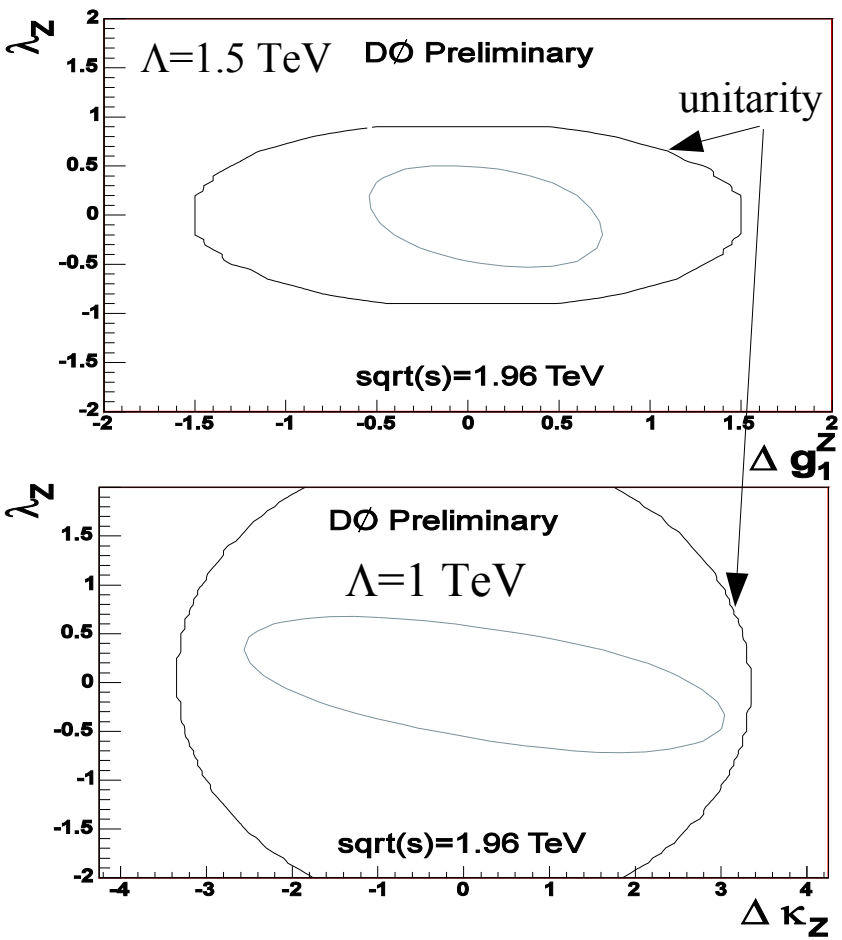
D0(285-320 pb^{-1})	$L_1 l_2 l_3 E_T$
WZ	2.04+/-0.13
Background	0.71+/-0.08
Expected total	2.75+/-0.15
Observed	3 (1eee ,2 μμμ)

WZ : the results

	The 95% CL upper limits:	3 events -> cross section estimate
DO:	$\sigma(p\bar{p}\to ZW+X) < 13.3\ pb$	$\sigma(p\bar{p}\to ZW+X) = 4.5^{+3.8}_{-2.6}\ pb$
CDF: hep-ex/0501021	$\sigma(p\bar{p}\to ZZ/ZW+X) < 15.2\ pb$	

1D limits [DØ Preliminary, 95% CL]

$\Lambda = 1.0$ TeV	$\Lambda = 1.5$ GeV
$-0.53 < \lambda_Z < 0.56$	$-0.48 < \lambda_Z < 0.48$
$-0.57 < \Delta g_1^Z < 0.76$	$-0.49 < \Delta g_1^Z < 0.66$
$-2.0 < \Delta\kappa_Z < 2.4$	-

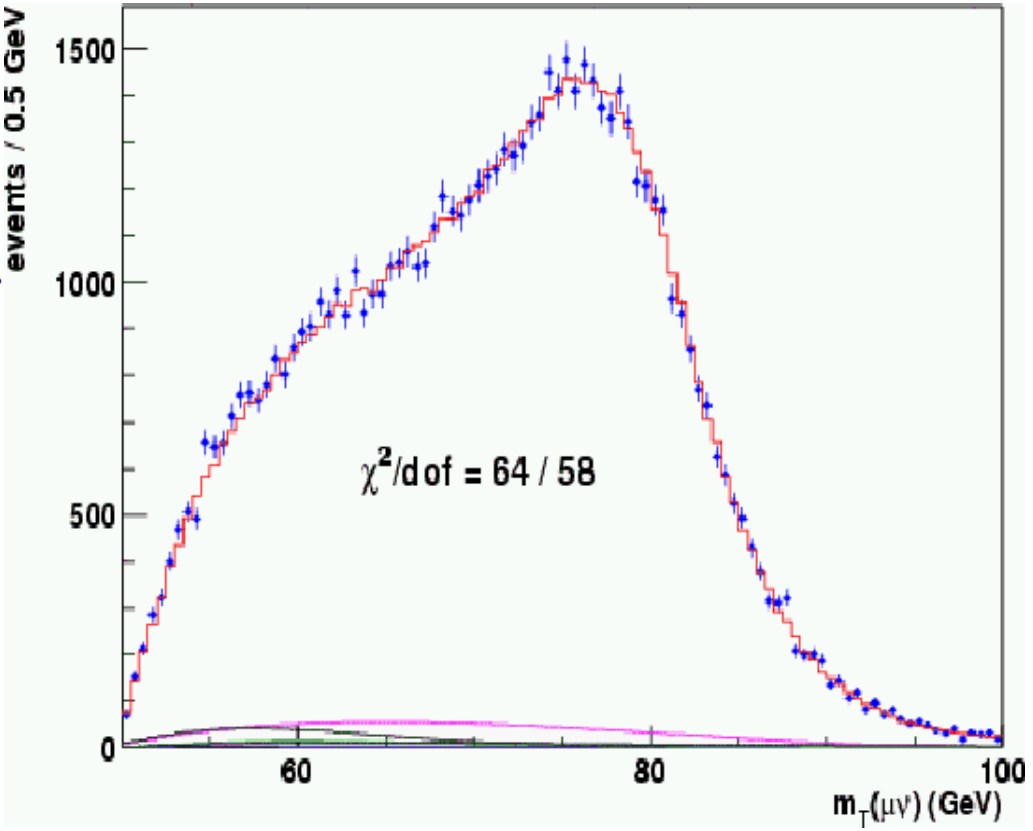


- Best limits on WWZ couplings in WZ final states
- The first and the best 2D limits in κ_z vs λ_z using WZ
- Best limits available on Δg_1^Z, $\Delta\kappa_z$ and λ_z from direct, model-independent measurements.

The DO Run II 1D limits are x3 better than Run I limits.

W mass measurement: work in progress

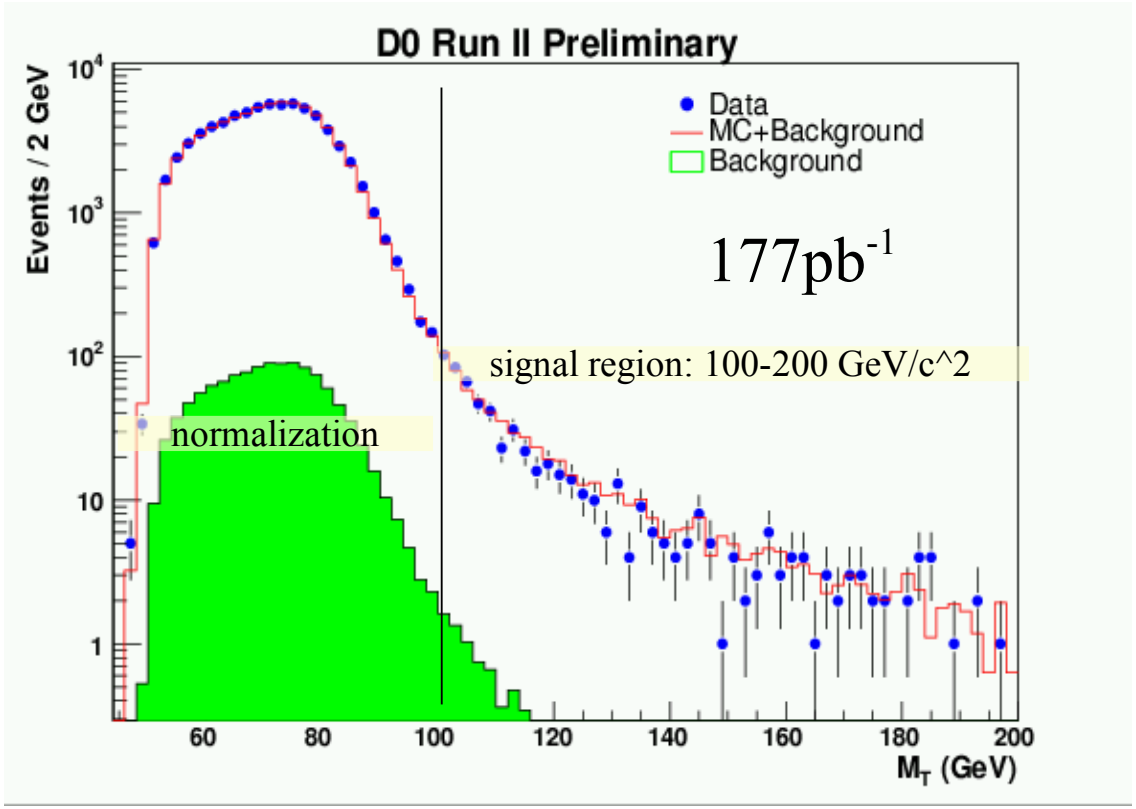
- Need accuracy better than 10^{-3}
- fit $M_T(W)$ - the most accurate
- Theoretical / phenomenological inputs:
  - QED radiation
  - QCD : W Pt spectrum, PDF's
  - uncertainties on W mass ~ 30 MeV

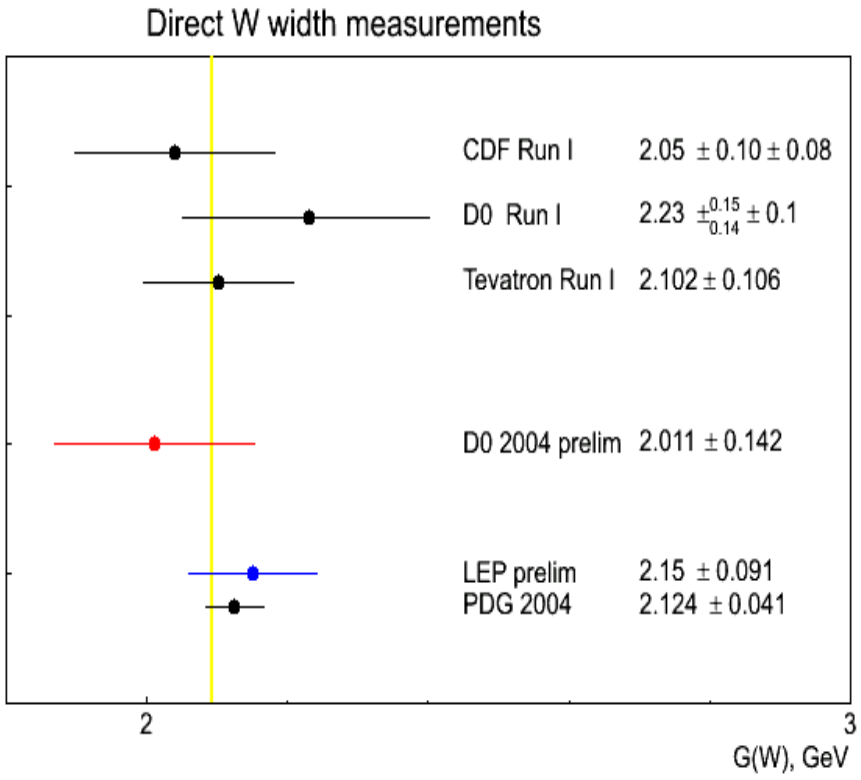


- ICHEP'2004 (CDF):

  $200pb^{-1}$: $\sigma(M_W)$ ($e^+\mu$ combined) = 76 MeV
  - $2fb^{-1}$: other sources ~ 30MeV
  - $L > 1fb^{-1}$: theoretical uncertainties [if not improved] will become important

W width: direct measurement

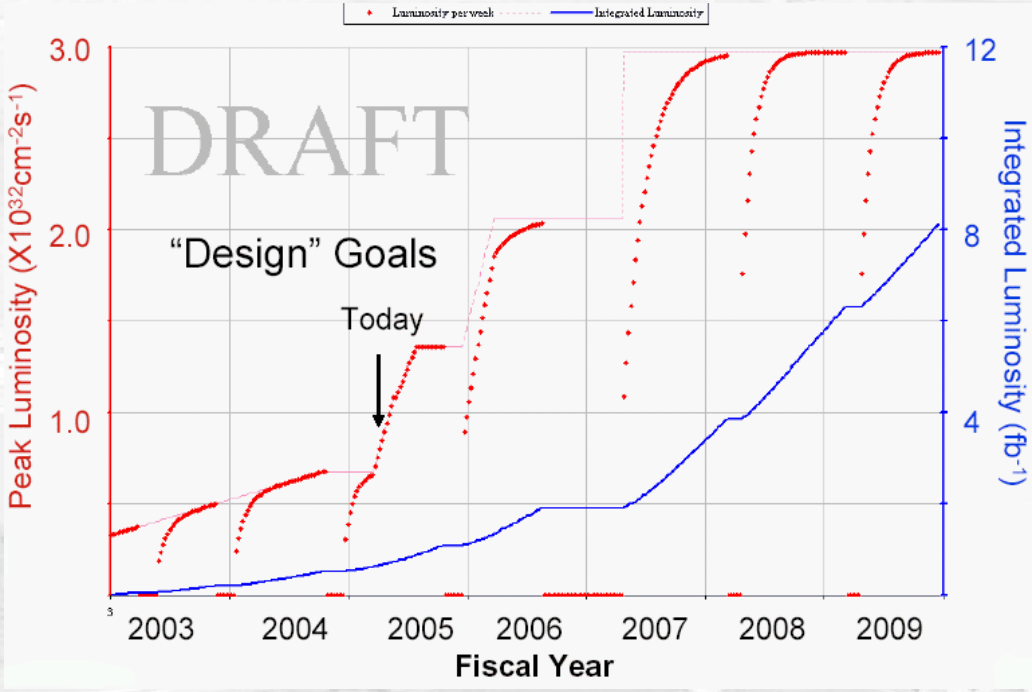




- Determine W width using the tail of M_T(lν) distribution
- Event counting experiment:
  - 75K W->eν candidates total
  - 625 events $100 < M_T < 200$ GeV/c^2
- Result already competitive, a lot of room for improvement

Summary and outlook

- Many new results on diboson production - important steps towards the Higgs searches
- measurement of pp-bar->Z->tau tau - a milestone in collider physics with tau's
- First Run II measurement of the W width
- Looking forward to high precision EWK measurements
  - W mas s, width, branching ratios
  - Precision diboson measurements
  - differential W/Z cross sections - there are interesting predictions to test
- PDF'2005 fits with new W charge asymmetry data included



Tevatron experiments just starting to explore potential of Run II data