Electroweak Physics from the Tevatron

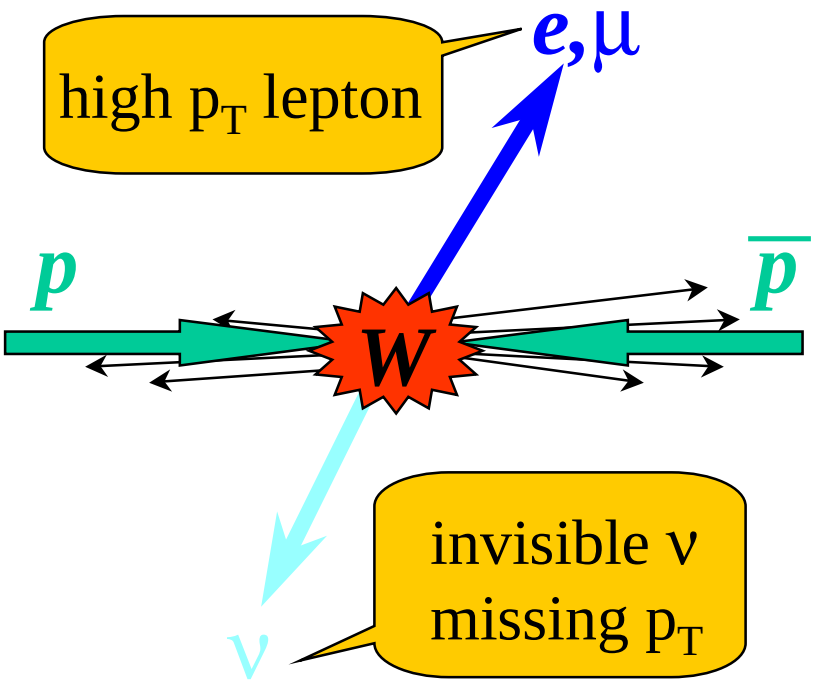
Ulrich Heintz

Fermilab

- W and Z production and decay
  - W boson width
  - lepton universality
- trilinear gauge couplings
- W boson mass
- top quark mass
- constraints on the Higgs sector

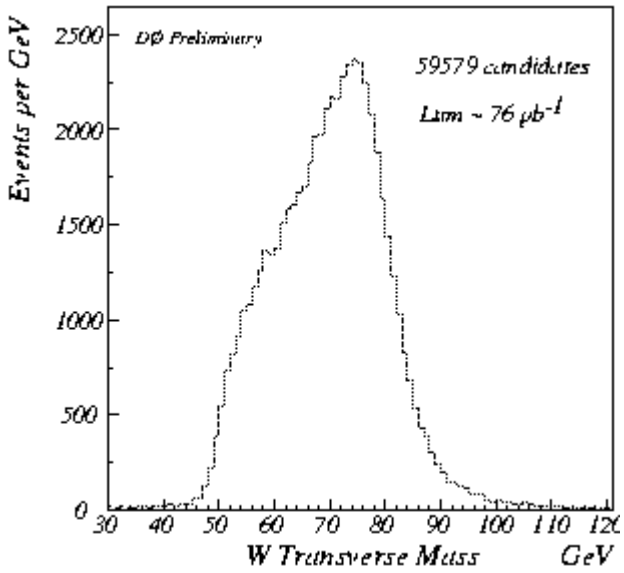
W and Z production and decay

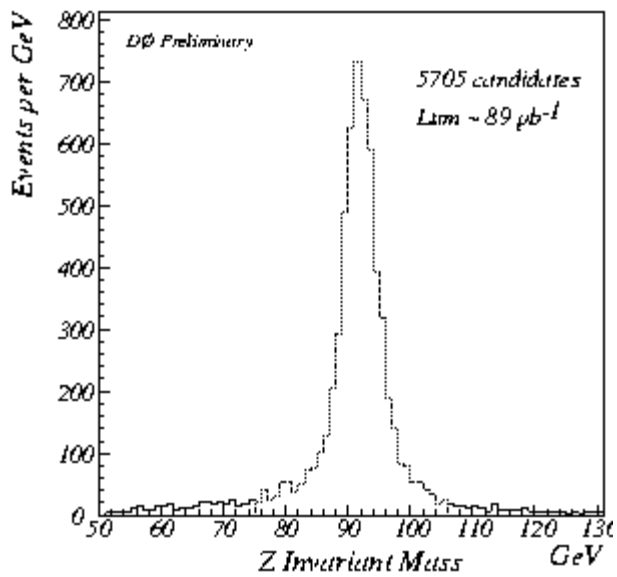
- Fermilab Tevatron
  - pp collisions at 1.8 TeV
  - luminosity up to 2 ☆ $10^{31} cm^{-2} s^{-1}$
  - delivered 125 pb^{-1} in 1992-1996
  - two experiments: D0 and CDF



- tag by their leptonic decays
- dominant source of high p_T leptons

W and Z production and decay





- transverse mass
- invariant mass

$$m_T = \sqrt{2 p_T^l p_T^\nu (1 - \cos \Delta\phi)}$$

	$W \to e\nu$	$Z \to ee$	$W \to \mu\nu$	$Z \to \mu\mu$
	DØ (Run Ia) PRL 75, 1456 (1995)			
events	10338	775	1665	77
σB (nb)	2.36±0.15	0.218±0.016	2.09±0.25	0.18±0.03
	DØ (Run Ib) preliminary			
events	59579	5702	4472	173
σB (nb)	2.38±0.22	0.235±0.021	2.32±0.25	0.20±0.03
	CDF (Run Ia) PRL 76, 3070 (1996)			
events	13796	1312		
σB (nb)	2.49±0.12	0.231±0.012		

W boson width

- indirect measurement

  (luminosity uncertainty cancels)

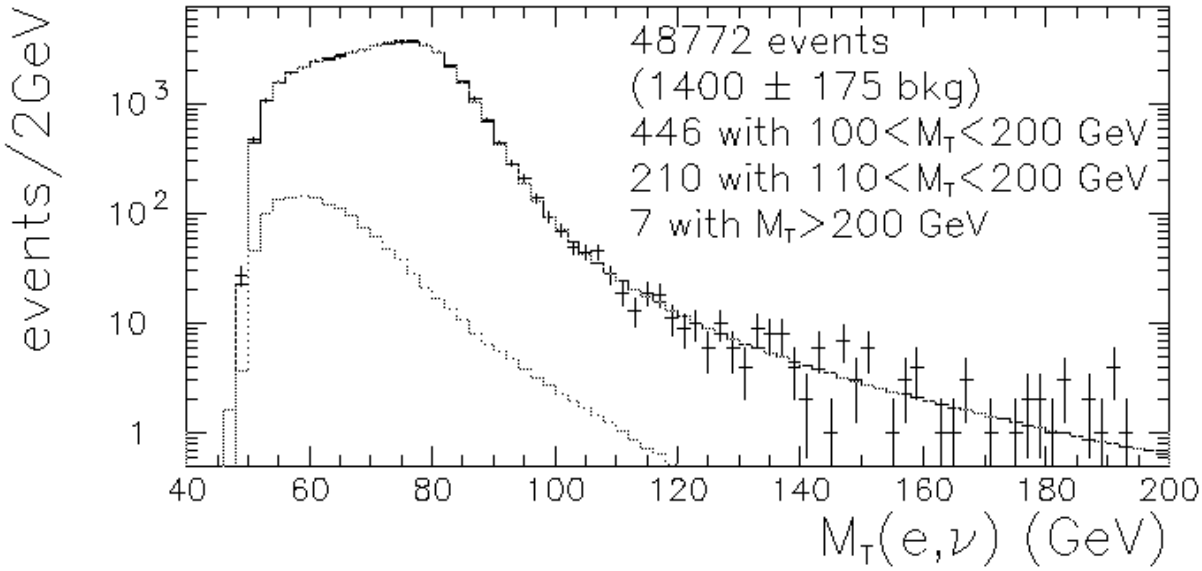
$$R = \frac{\sigma_W B(W \to l\nu)}{\sigma_Z B(Z \to ll)}$$

$$= \frac{\sigma_W}{\sigma_Z} \frac{\Gamma(W \to l\nu)}{\Gamma(Z \to ll)} \frac{\Gamma_Z}{\Gamma_W}$$

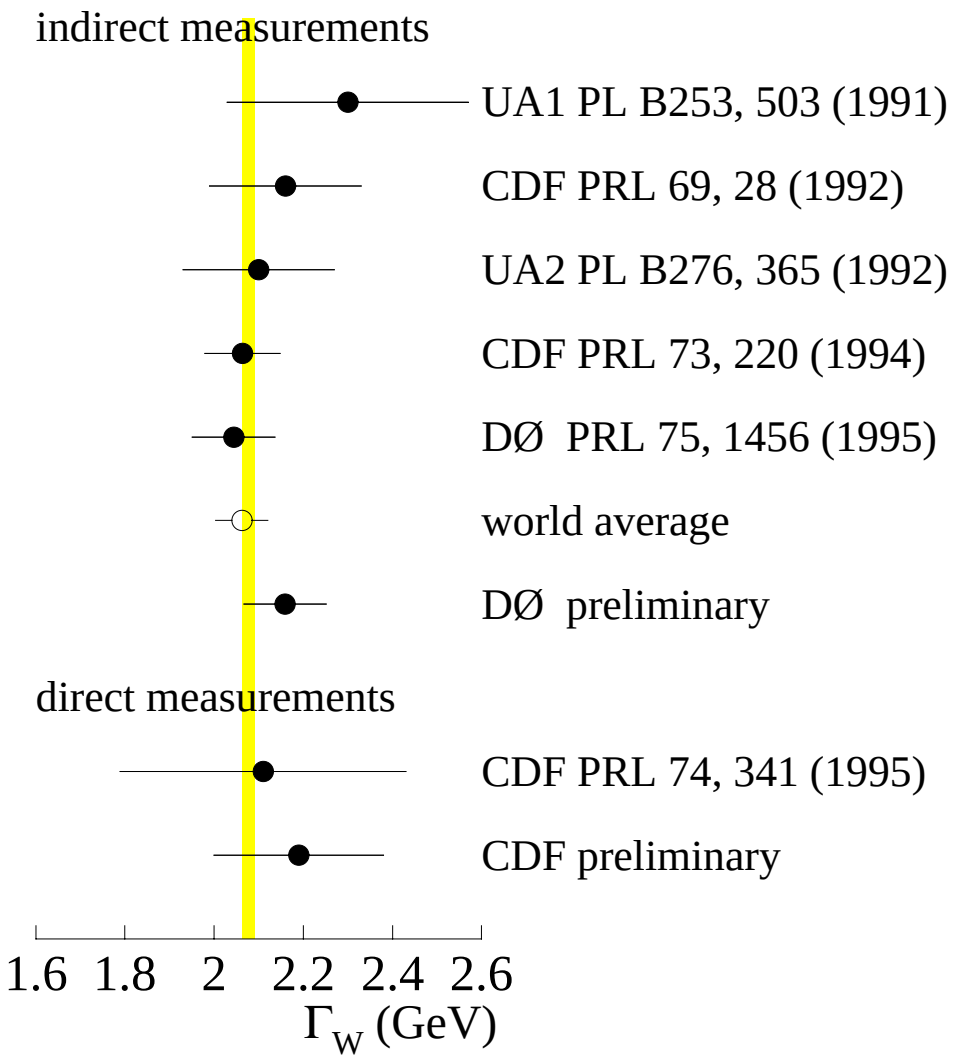
solve

- direct measurement

CDF preliminary



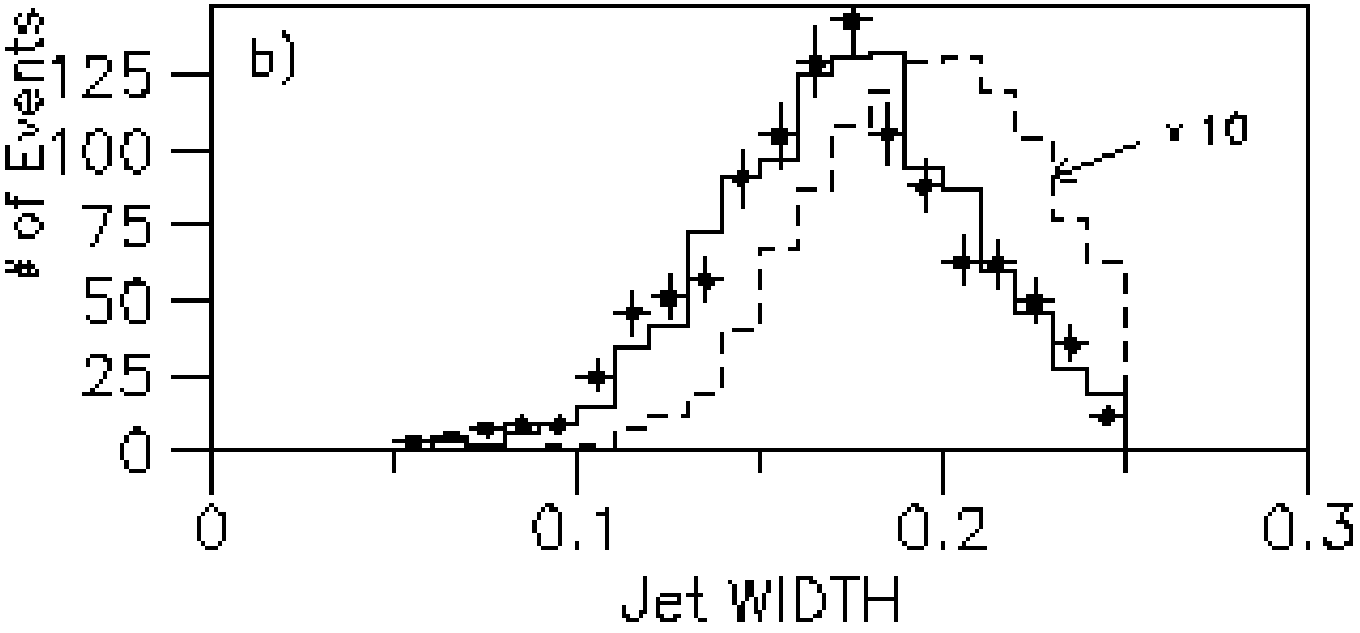
W boson width



- world average Γ_W=2.062±0.059 GeV
- Standard Model Γ_W=2.077±0.014 GeV
  - ⇨ rate for unknown decays <109 MeV @ 95% CL

lepton universality

- measure $\sigma_W B(W \rightarrow \tau\nu)$
  - use hadronic τ decay
  - select isolated narrow jets
  - 1202 events (222 background)

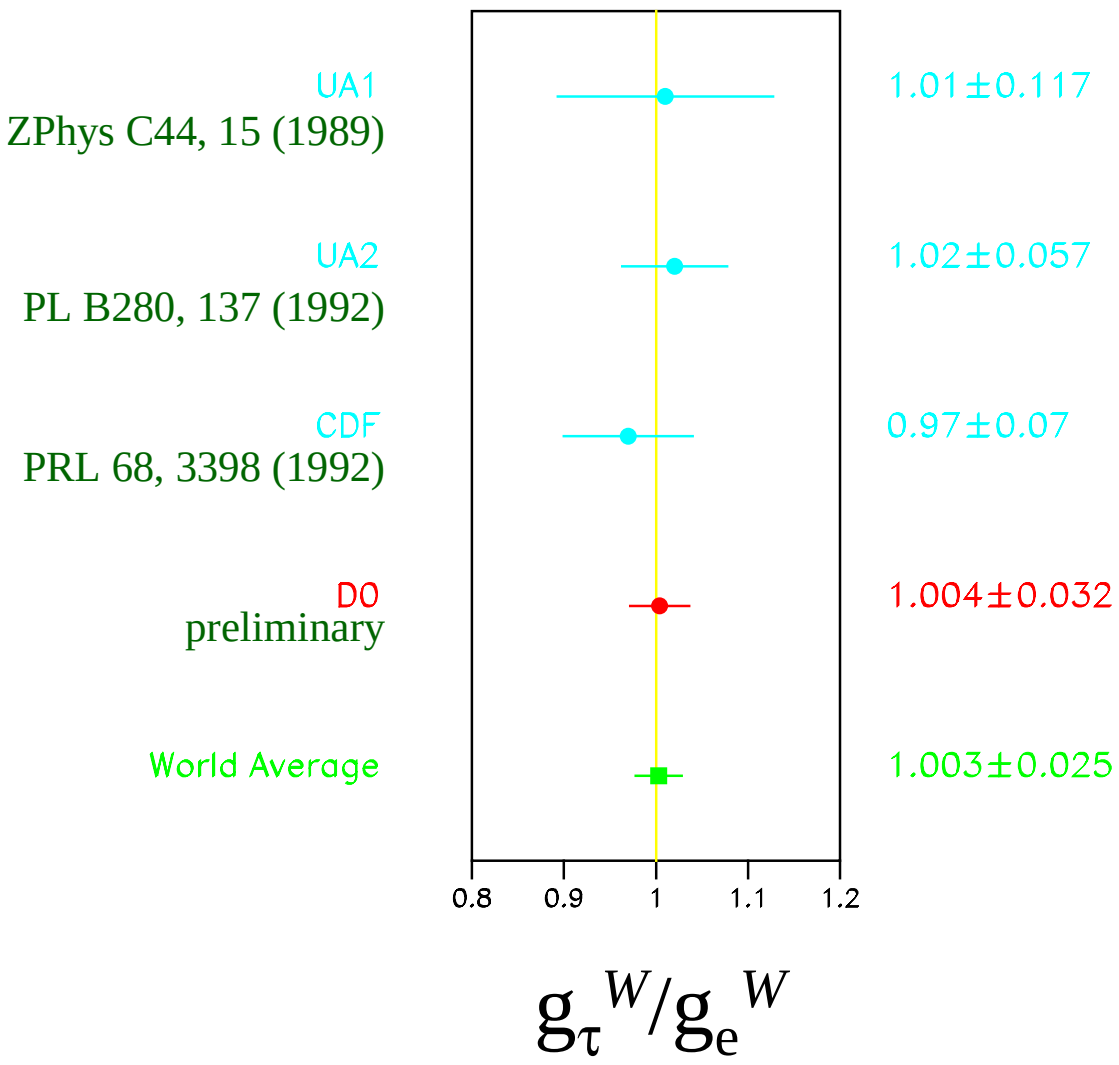


$\sigma B = 2.38 \pm 0.14$ nb

lepton universality

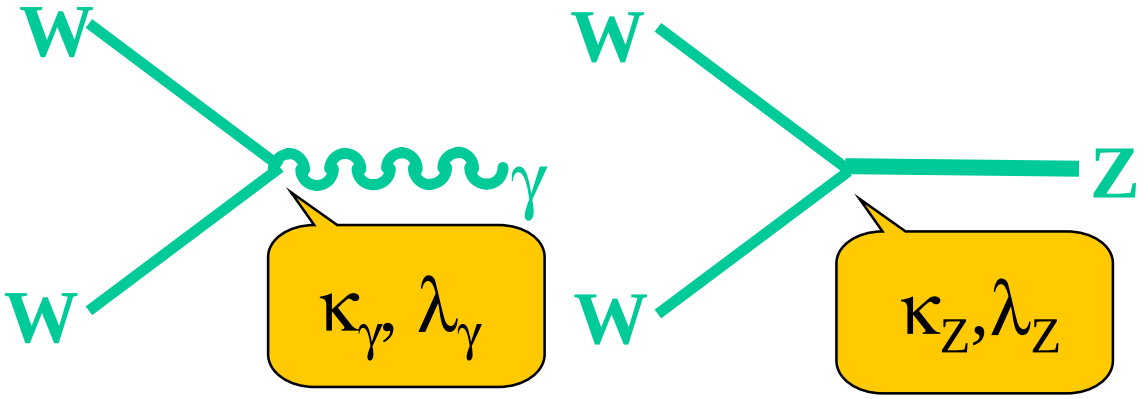
$g_\tau^W/g_e^W = 1.004 \pm 0.032$

(5.5% luminosity uncertainty cancels)



trilinear gauge couplings

- ewk interactions are non-abelean

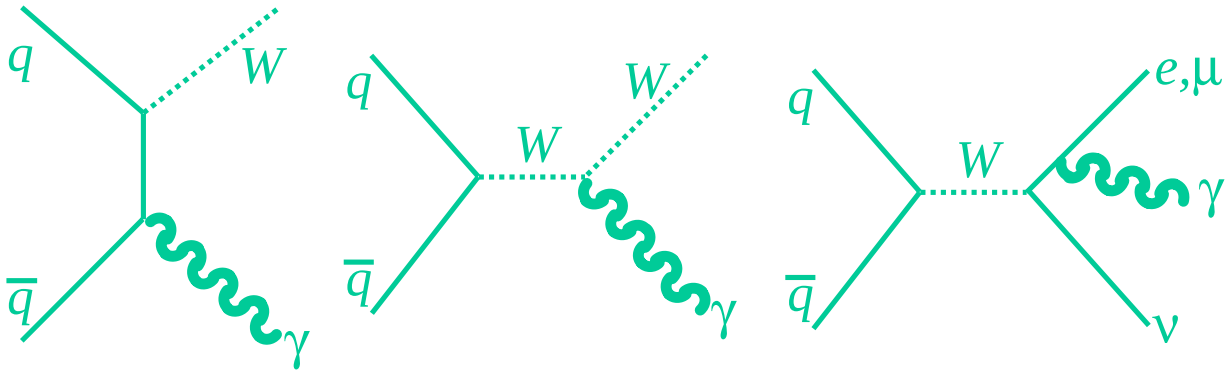


- CP conserving amplitudes
- unitarity→SM values for E→∞

  $\kappa_\gamma=\kappa_Z=1, \quad \lambda_\gamma=\lambda_Z=0$
- form factor $\propto \dfrac{1}{\left(1+\dfrac{\hat{s}}{\Lambda^2}\right)^n}$
- study Wγ, WW, WZ production

trilinear gauge couplings

- $W\gamma$ production



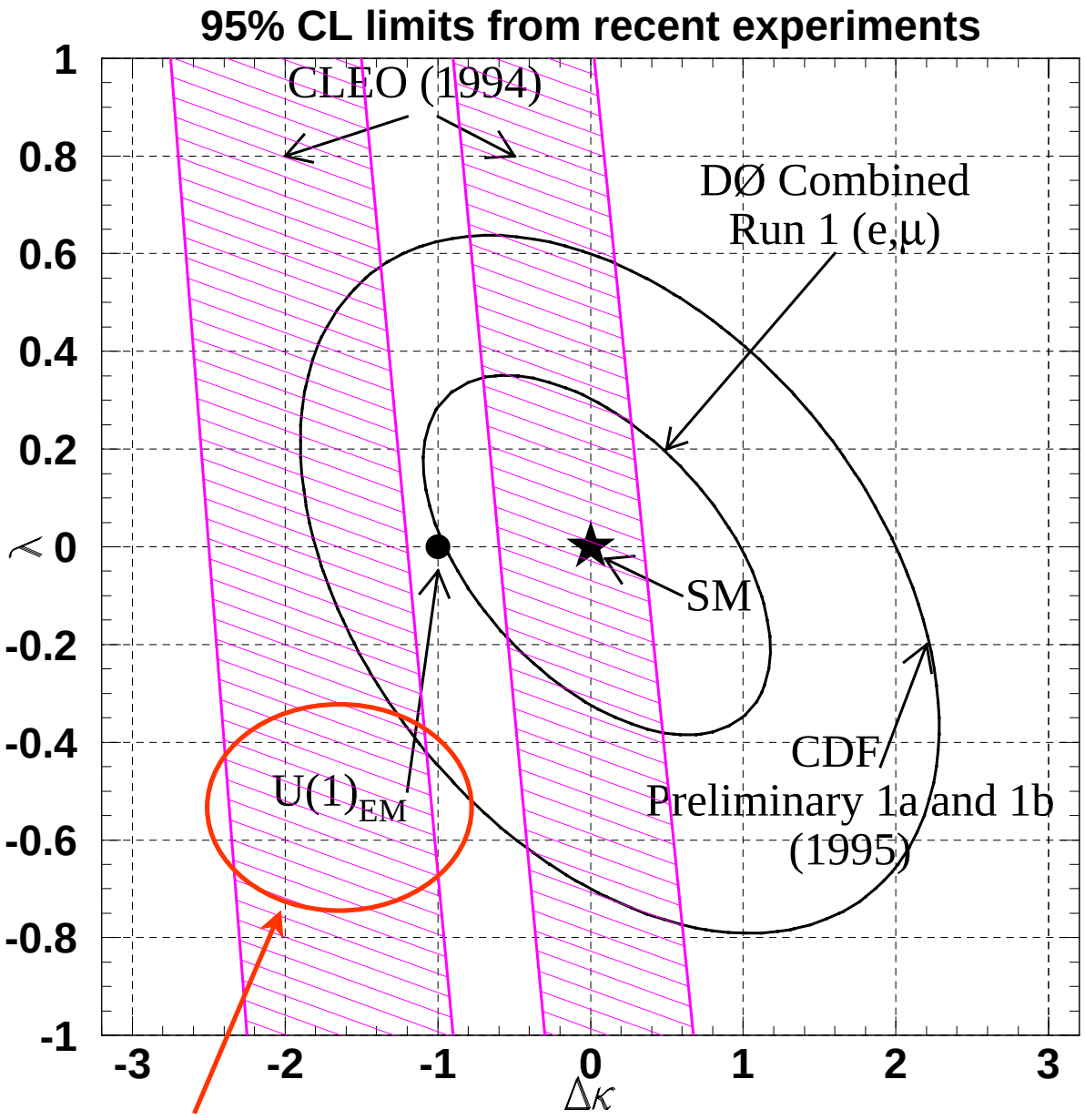
	Lum	E_γ	events (bkg)	cross section (pb) data	SM
D0	93 pb^{-1}	>10 GeV	127 (43)	11.3±2.2	12.5±1.0
	1A: PRL 75, 1034 (1995) 1B: PRL 78, 3634 (1997)				
CDF	67 pb^{-1}	>7 GeV	109 (26)	20.7±3.0	18.6±2.9
	1A: PRL 74, 1936 (1995) 1B: preliminary				

- fit γ p_T spectrum to theory prediction
  Baur+Zeppenfeld, Nucl Phys B308, 127 (1998)
- 95% CL limits (Λ=1.5 TeV):

D0	$-0.93<\kappa-1<0.94$	$-0.31<\lambda<0.29$
CDF	$-1.8<\kappa-1<2.0$	$-0.7<\lambda<0.6$

trilinear gauge couplings

- Wγ production

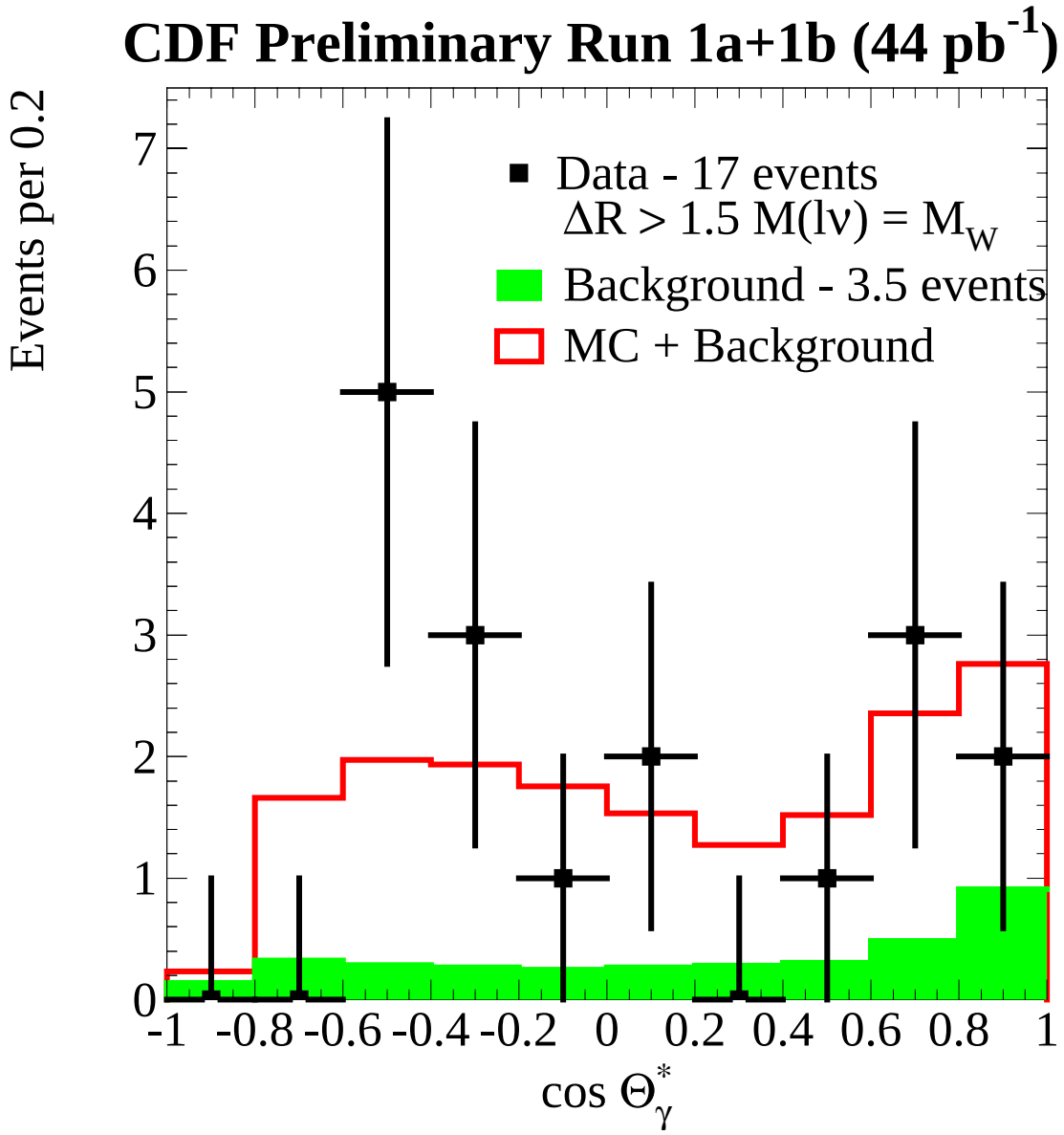


ruled out
at 96% CL

CLEO: PRL 74, 2885 (1995)

trilinear gauge couplings

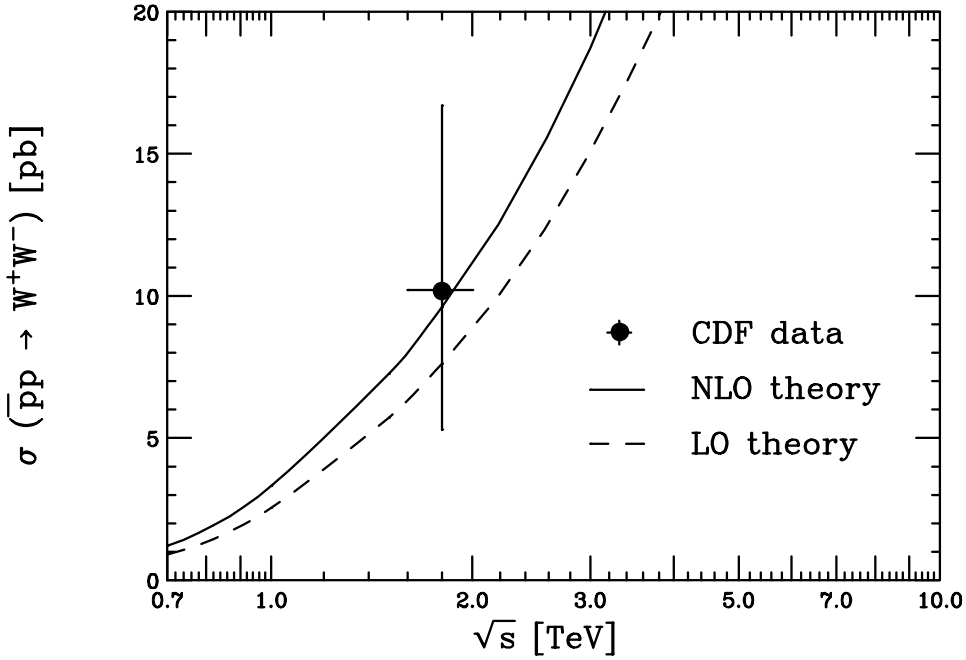
- radiation zero
  - $q\bar{q} \rightarrow W\gamma$ vanishes for $\cos\theta^*=1/3$



trilinear gauge couplings

- WW → dileptons

	Lum	events (bkg)	cross section (pb)
D0	97 pb^{-1}	5 (3.3)	
	1A: PRL 75, 1023 (1995) 1B: preliminary		
CDF	108 pb^{-1}	5 (1.2)	10.2+6.5–5.3
	PRL 78, 4536 (1997)		
SM			9.5

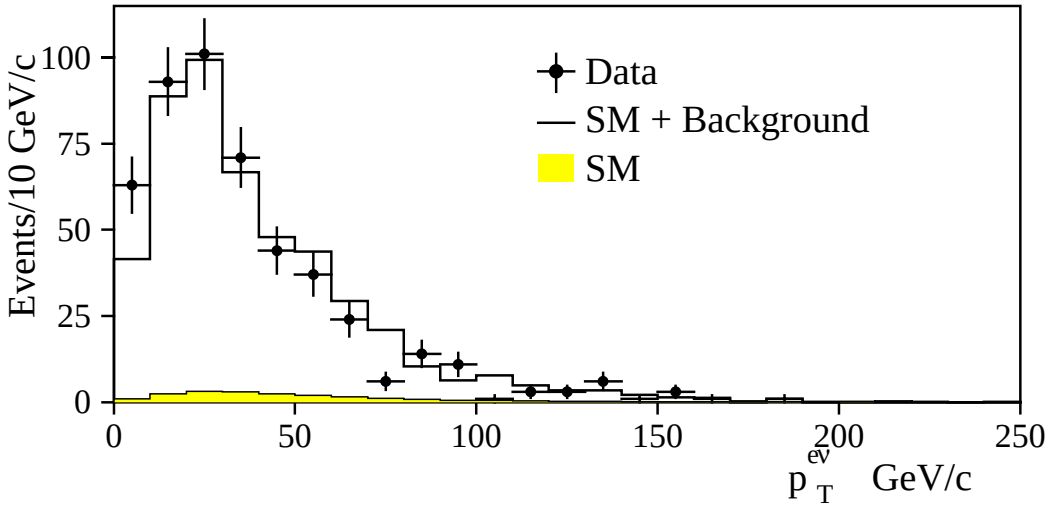


- 95% CL limits (Λ=1.5 TeV):

D0 $-0.62<\kappa-1<0.77$ $-0.52<\lambda<0.56$

trilinear gauge couplings

- *WW/WZ→lν jj,lljj*
  - CDF (110 pb^{-1})
  - no events with $p_T(jj)$>200 GeV, $m(jj) \neq m_W, m_Z$
  - 1A: PRL 75, 1017 (1995) , 1B: preliminary
  - D0 (96 pb^{-1})
  - 483 (463) *eνjj* events, SM predicts 21
  - 1A: PRL 77, 3303 (1996) 1B: PRL 79, 1441 (1997)



- 95% CL limits (Λ=2 TeV):

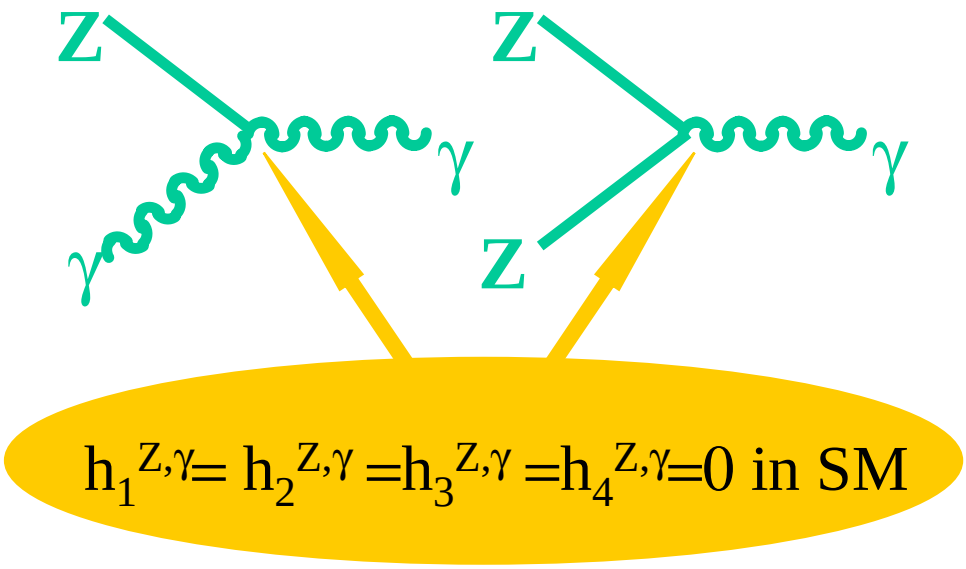
D0	$-0.43<\kappa-1<0.59$	$-0.33<\lambda<0.36$
CDF	$-0.49<\kappa-1<0.54$	$-0.35<\lambda<0.32$

- Combined *WWγ/WWZ* limits:

D0	$-0.33<\kappa-1<0.45$	$-0.20<\lambda<0.20$

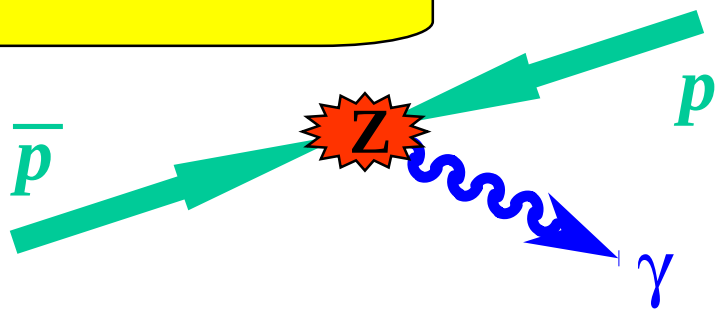
trilinear gauge couplings

- $ZZ\gamma$ and $Z\gamma\gamma$ couplings



- $Z\gamma$ production
  - $ee\gamma$, $\mu\mu\gamma$, $\nu\nu\gamma$ final states

no final state radiation



trilinear gauge couplings

- $Z\gamma$ production

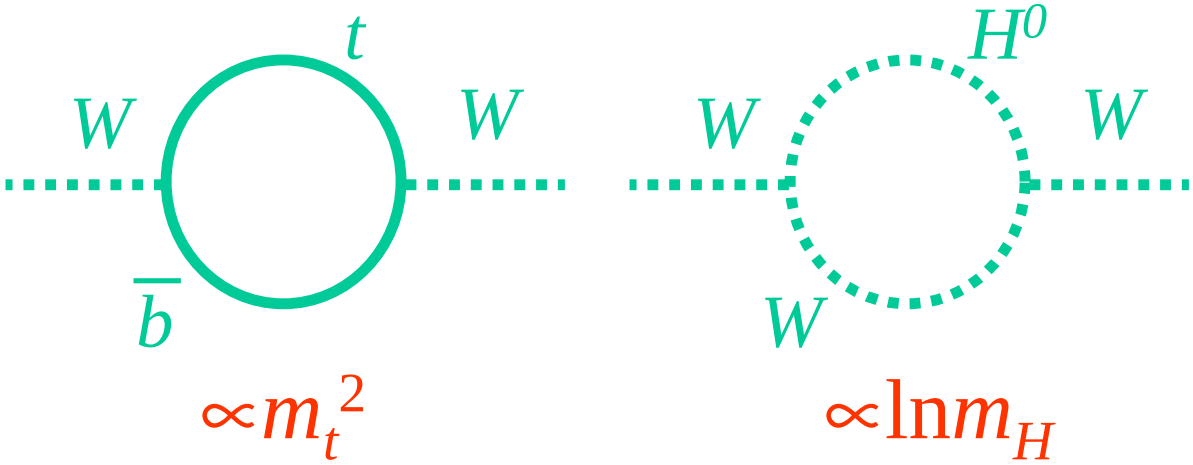
	Lum	events	95% CL limits		Λ (TeV)
D0 ($ll\gamma$)	14 pb^{-1}	6 (0.5)	$\lvert h_3^Z\rvert<1.9$	$\lvert h_4^Z\rvert<0.50$	0.5
E_γ>10 GeV	89 pb^{-1}	29 (5.4)	$\lvert h_3^Z\rvert<1.3$	$\lvert h_4^Z\rvert<0.26$	0.5
	1A: PRL 75, 1028 (1995) 1B: Fermi-Pub 97/363-E				
D0 ($\nu\nu\gamma$)	14 pb^{-1}	4 (5.8)	$\lvert h_3^Z\rvert<0.87$	$\lvert h_4^Z\rvert<0.21$	0.5
E_γ>40 GeV	1A: PRL 78, 3640 (1997)				
D0 combined			$\lvert h_3^Z\rvert<0.36$	$\lvert h_4^Z\rvert<0.05$	0.75
CDF	67 pb^{-1}	31 (1.4)	$\lvert h_3^Z\rvert<1.60$	$\lvert h_4^Z\rvert<0.40$	0.5
E_γ>7 GeV	1A: PRL 74, 1941 (1995) 1B: preliminary				

- fit γ p_T spectrum to theory prediction

  Baur+Berger, PRD 41, 1476 (1990)

W boson mass

- m_Z, G_μ, α determine m_W at tree level
- radiative corrections



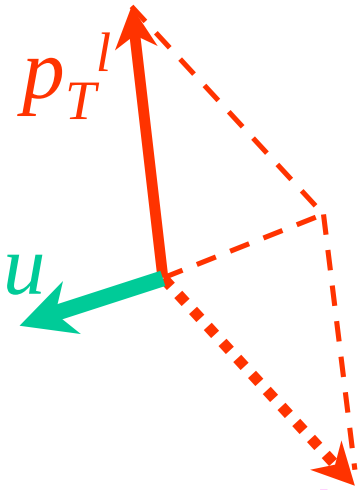
☞electroweak radiative corrections

☞test the Standard Model

☞constrain the Higgs mass

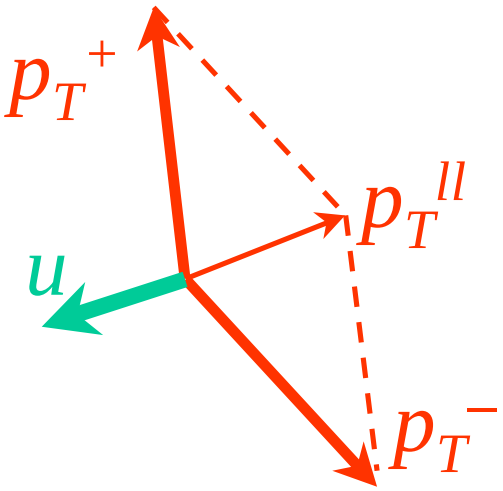
W boson mass

- $W \rightarrow e\nu$



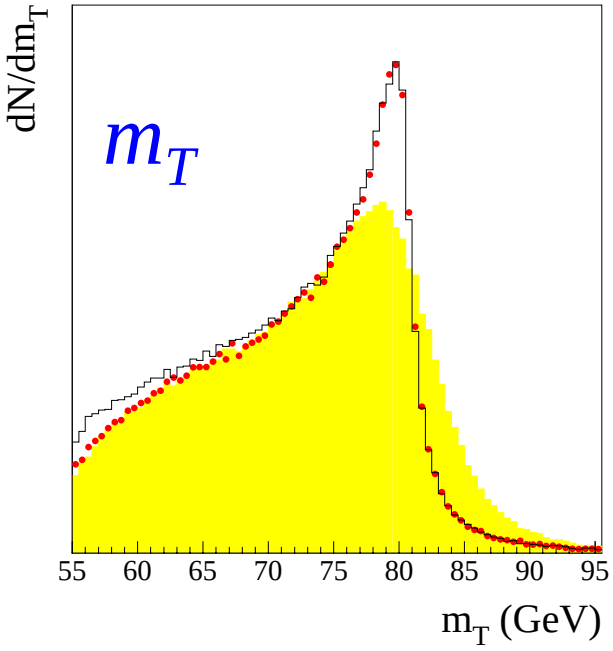
- measure p_T^l, u
- $p_T^\nu = -p_T^l - u$
- p_z^ν unknown

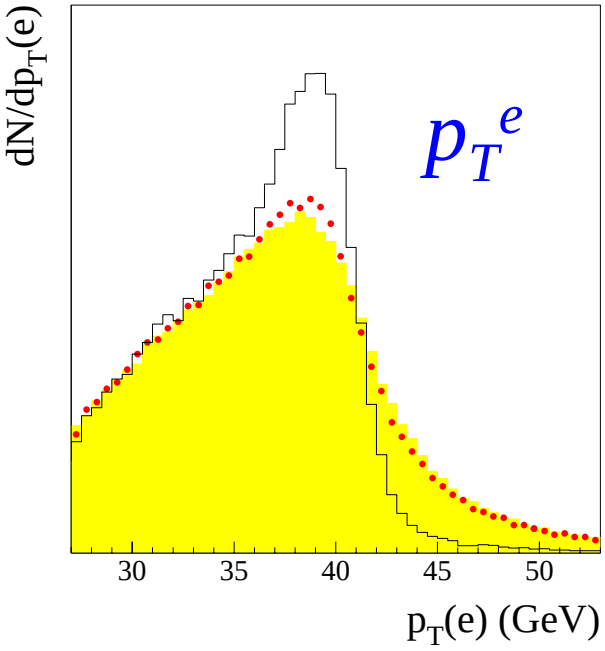
- $Z \rightarrow ee$



- reconstruct completely

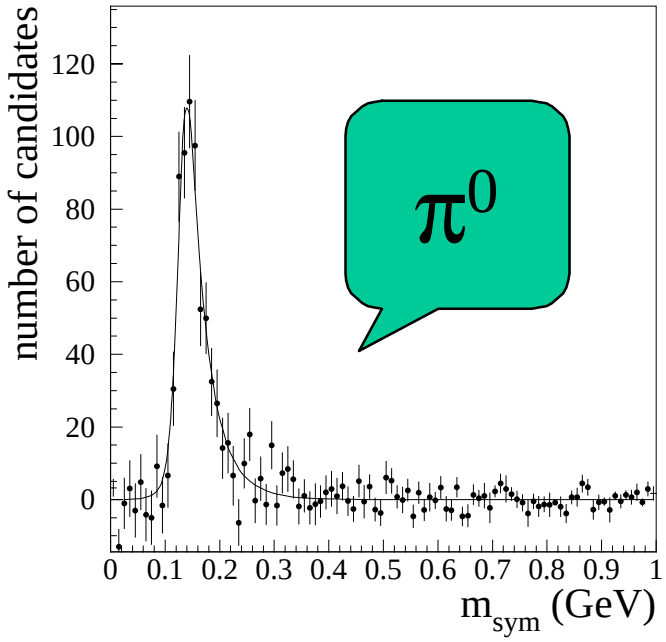
⇨ calibration

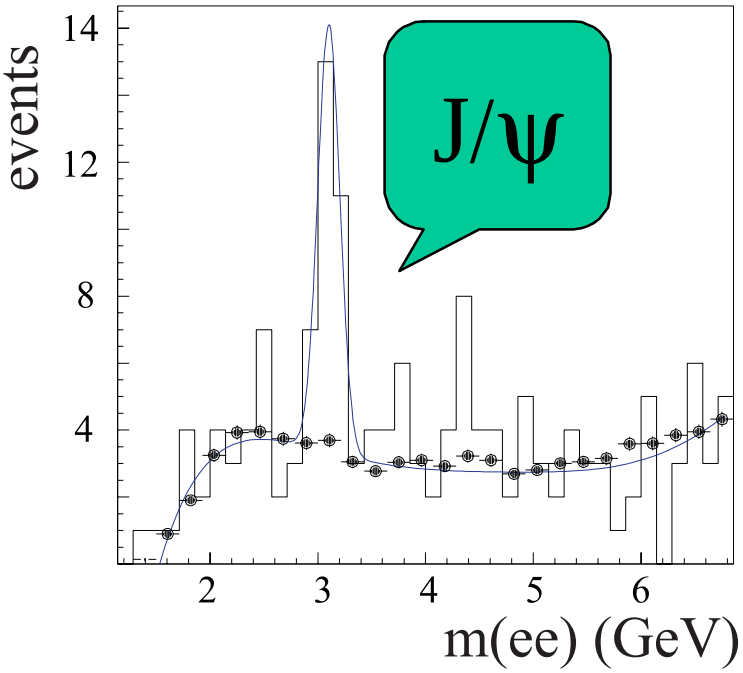


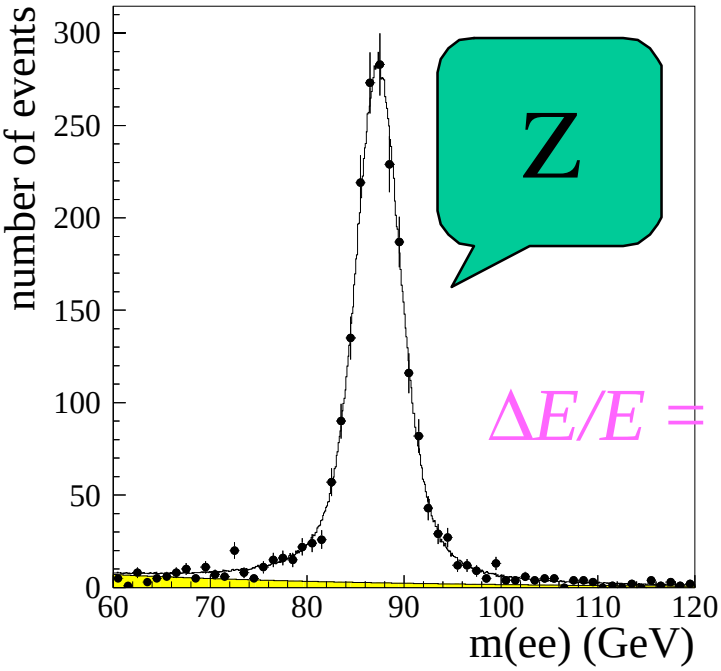


W boson mass

- Electron energy scale calibration (D0)



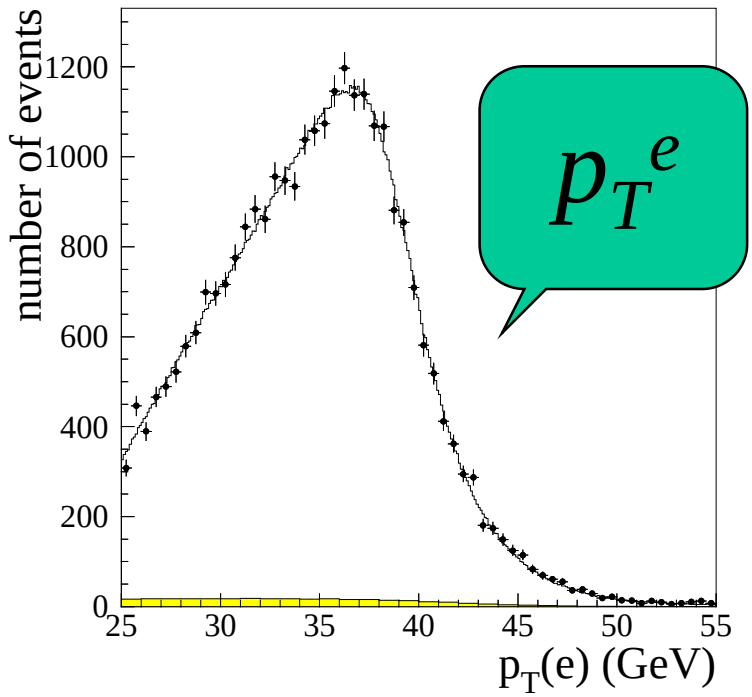




$\Delta E/E = 0.08\%$

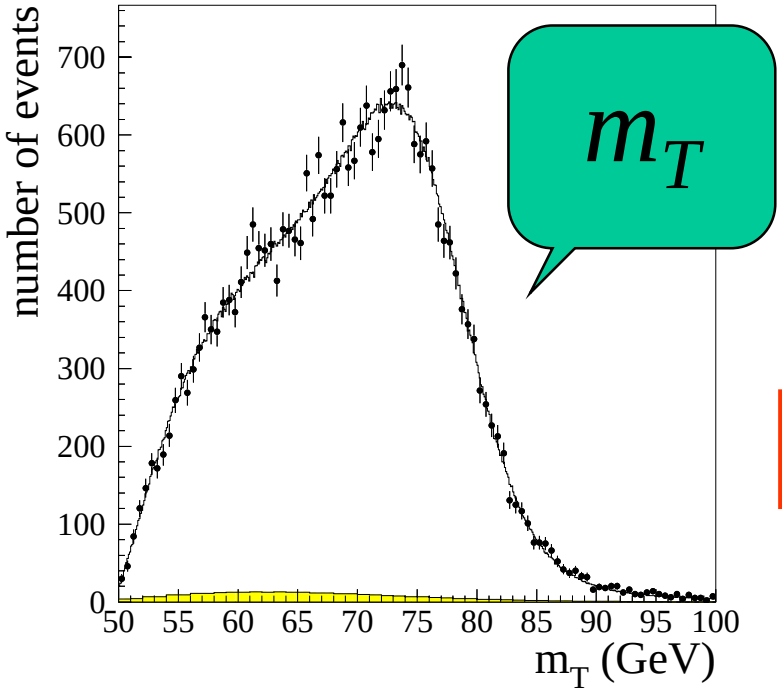
W boson mass

- W mass measurement by D0



80.48±0.14 GeV

Run 1B uncertainties	
statistical	95 MeV
detector	60 MeV
backgrnd	10 MeV
theory	30 MeV
total	120 MeV



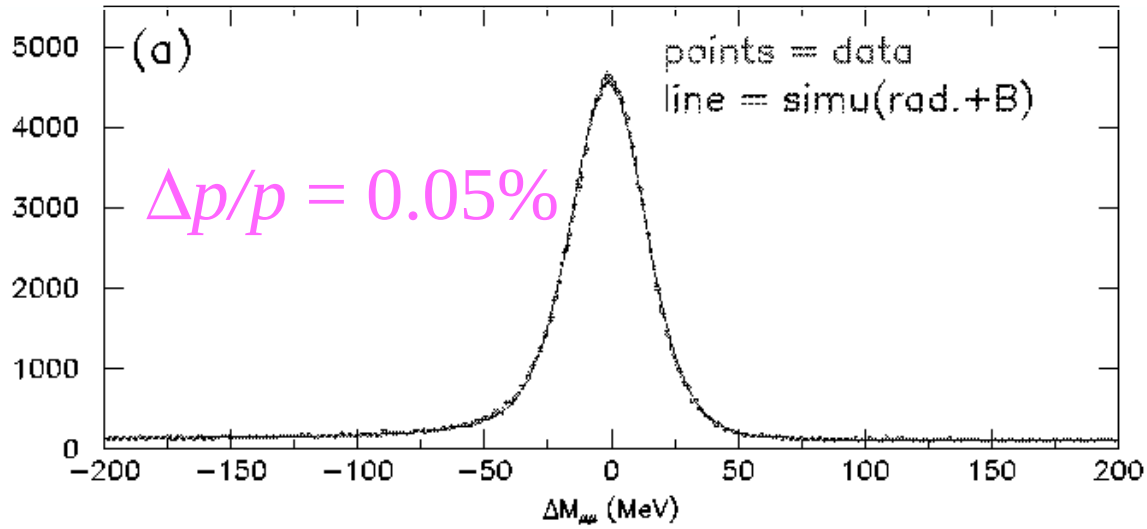
Run 1A+1B combined:

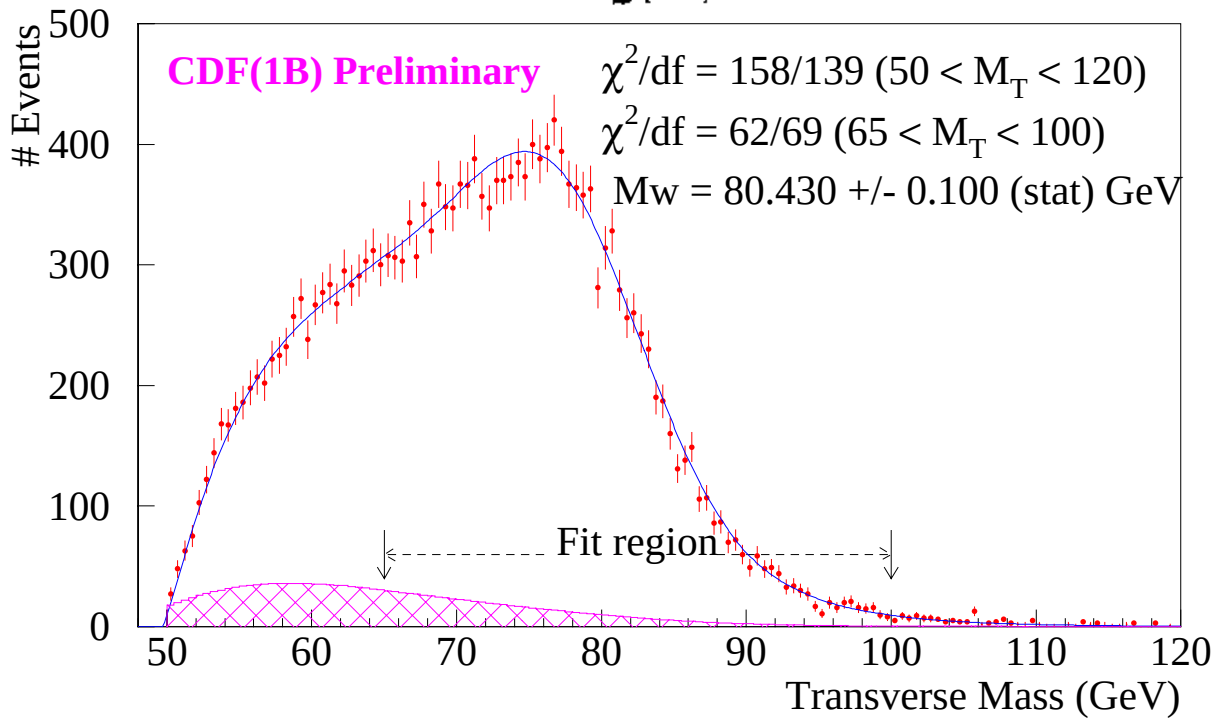
80.43±0.11 GeV

(Fermi-Pub/97/422-E)

W boson mass

- muon momentum calibration (CDF)

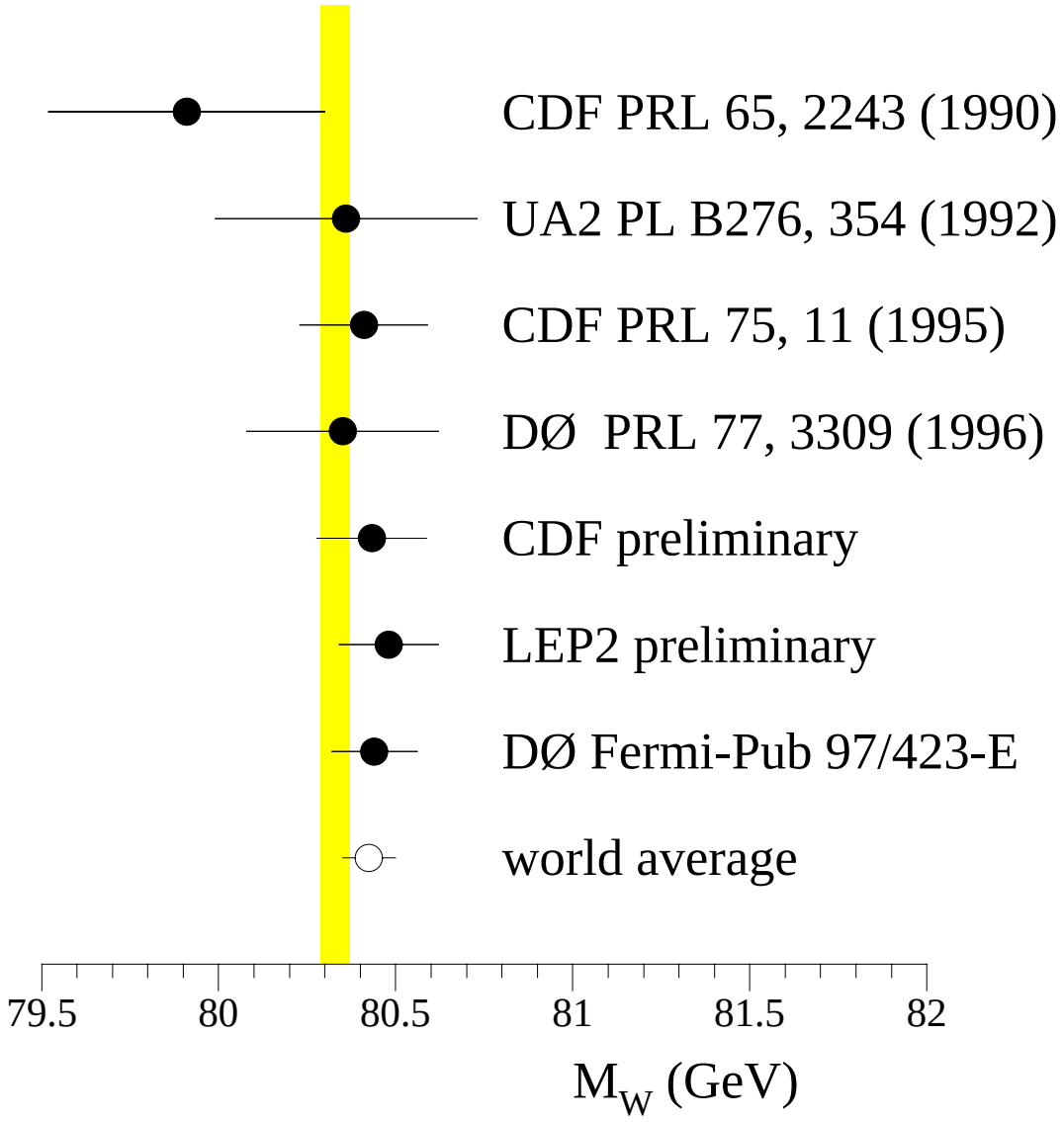




- W mass measurement by CDF

80.38±0.12 GeV

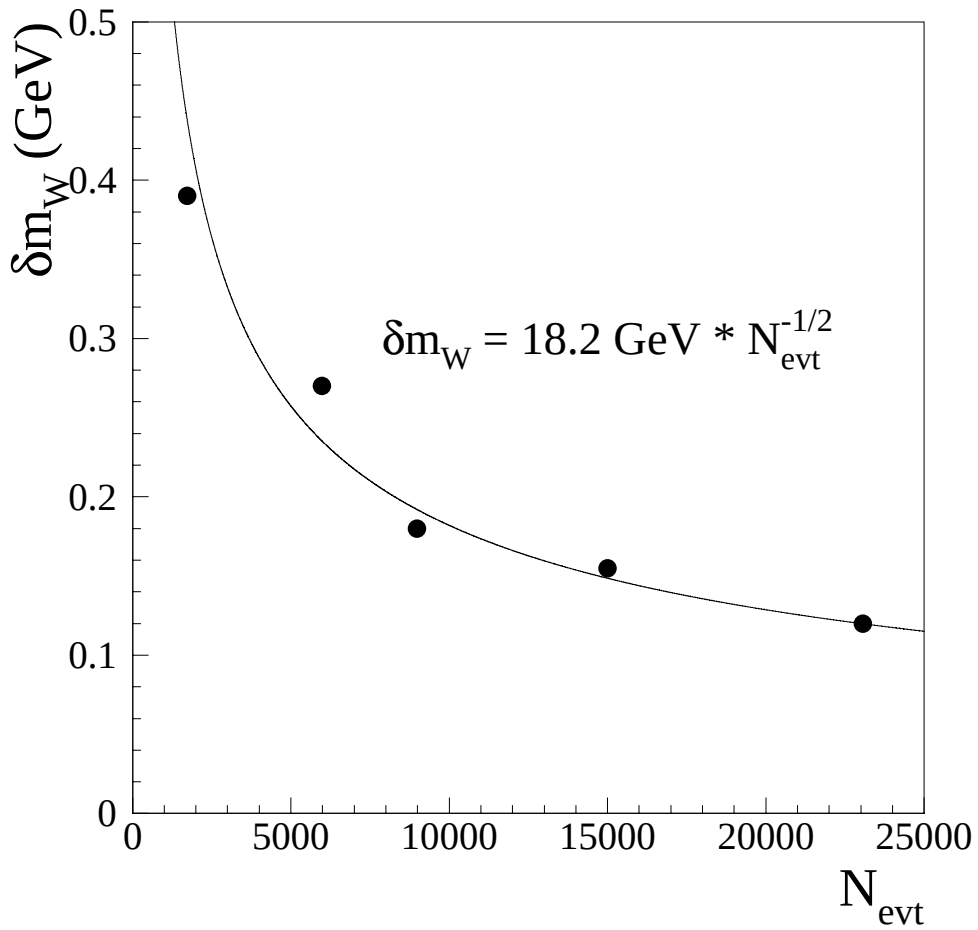
W boson mass



- world average: 80.43±0.07 GeV
- fit to ewk data: 80.33±0.04 GeV

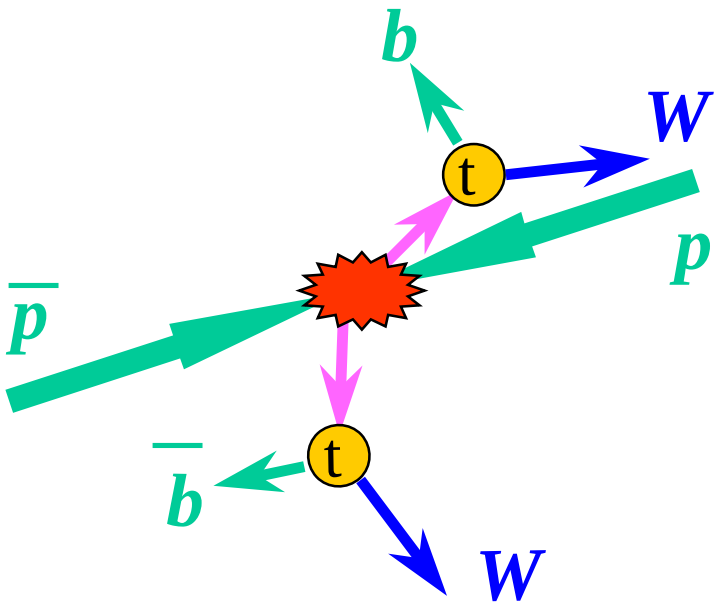
(CERN-PPE/97-154)

W boson mass



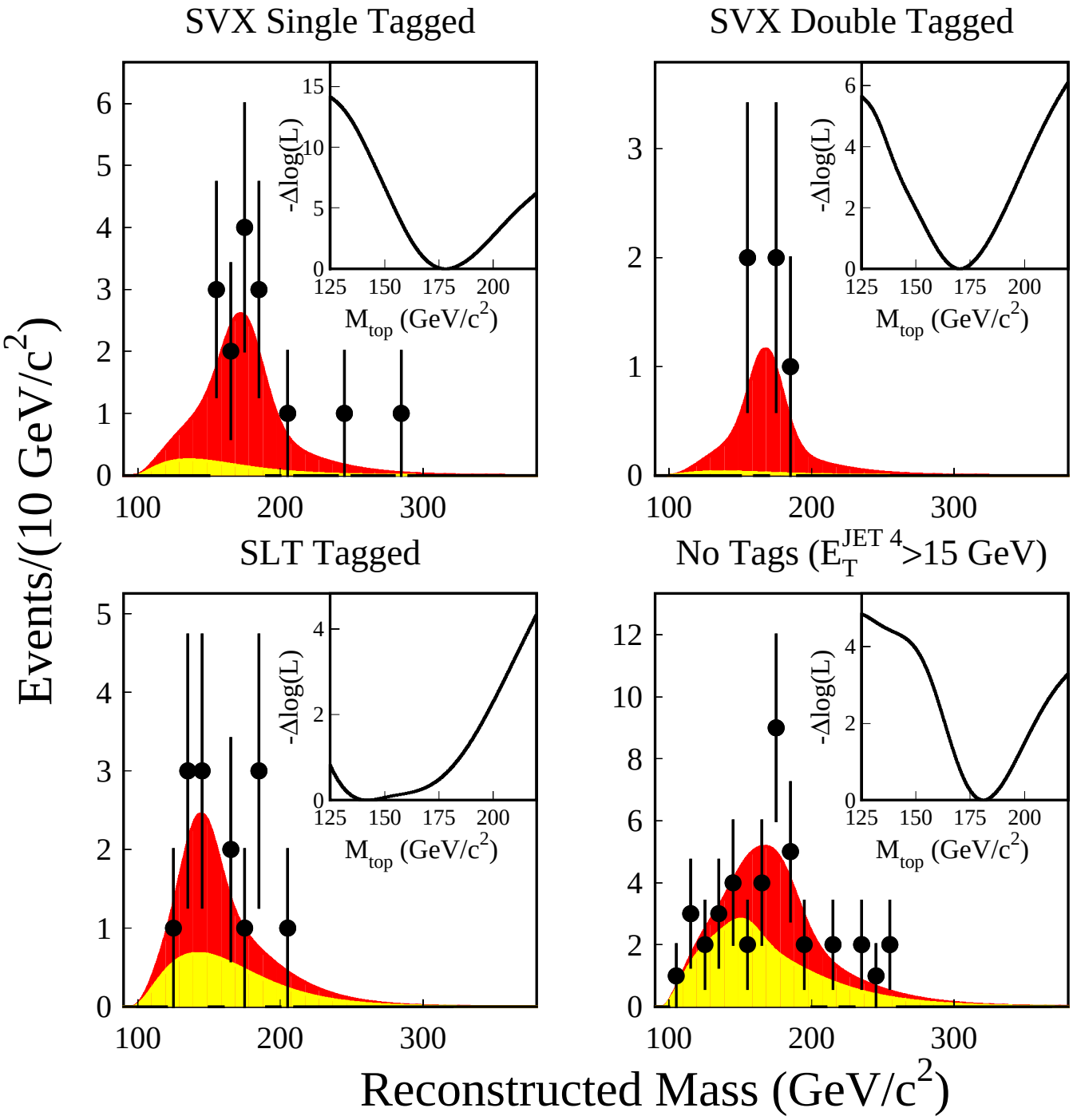
$\Rightarrow$expect $\delta m_W \approx 40$ MeV in Run II

top quark mass

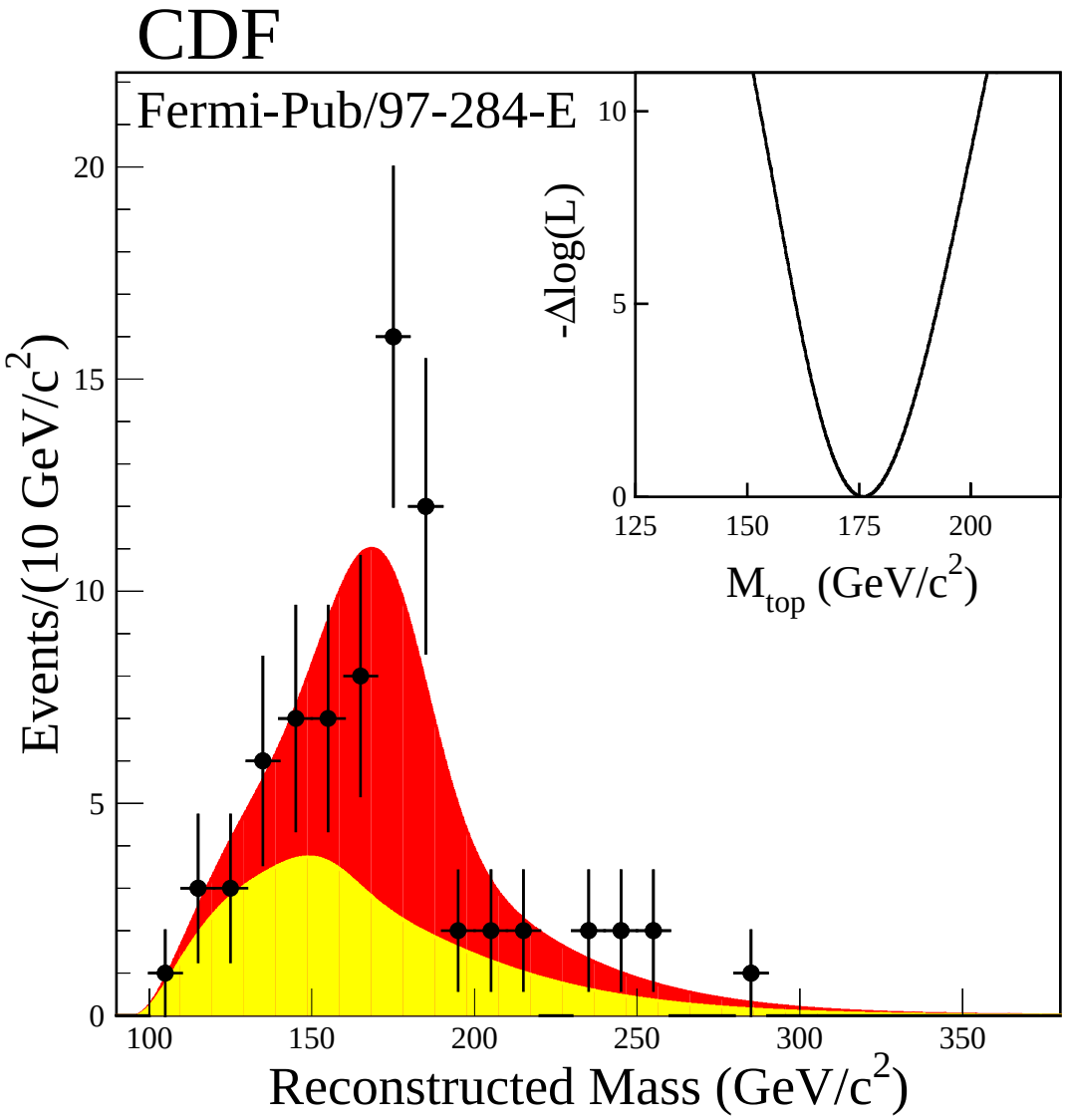


- lepton+jets channel: $tt \rightarrow l\nu b\ qqb$
  - 1 unknown (p_z^{ν})
  - 3 constraints
    - $m(l\nu) = m(qq) = m_W$
    - $m(l\nu b) = m(qqb)$
  - 2-constraint kinematic fit
  - up to 24-fold ambiguity
  - ⇨need to compare to MC shapes to measure top mass

top quark mass



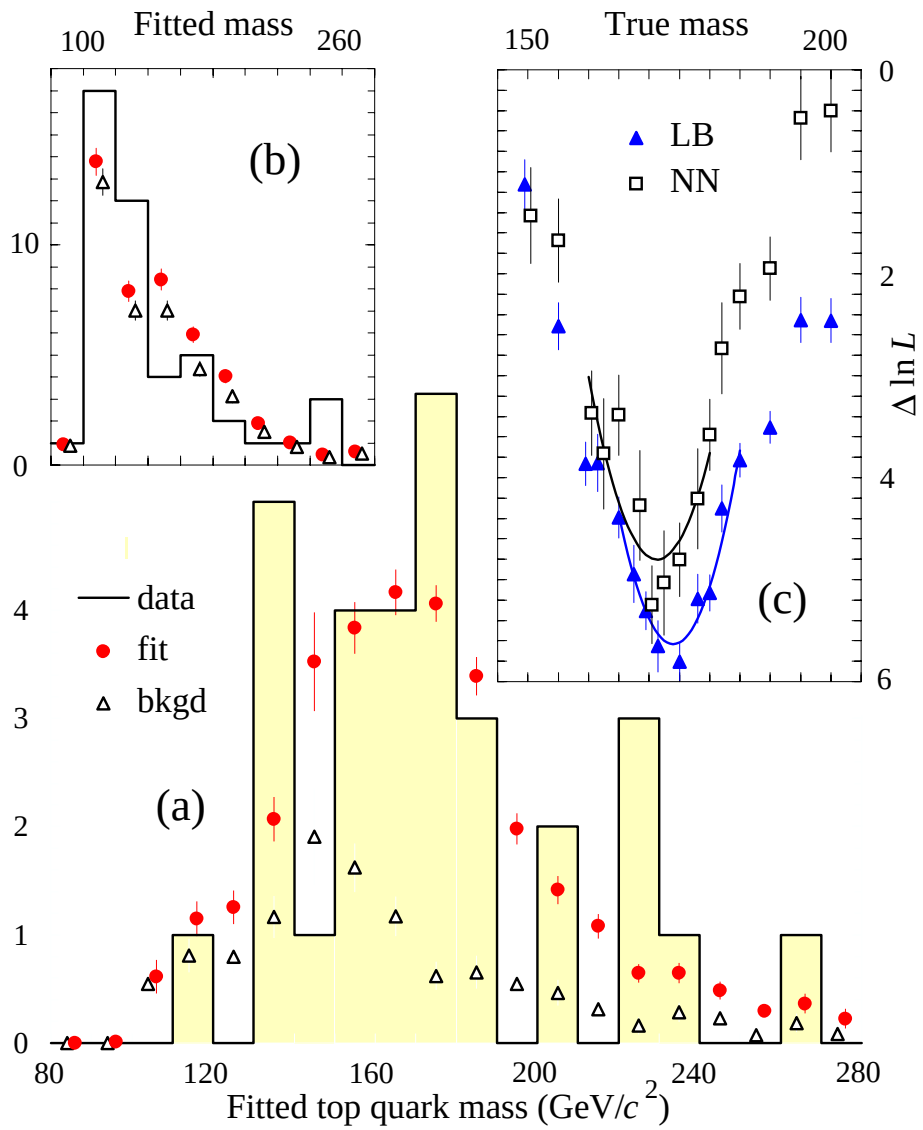
top quark mass



- m_t = 175.9±4.8±4.9 GeV

largest systematics	
jet energy	4.4 GeV
gluon radiation	1.8 GeV
background	1.3 GeV

top quark mass



- m_t = 173.3±5.6±5.5 GeV

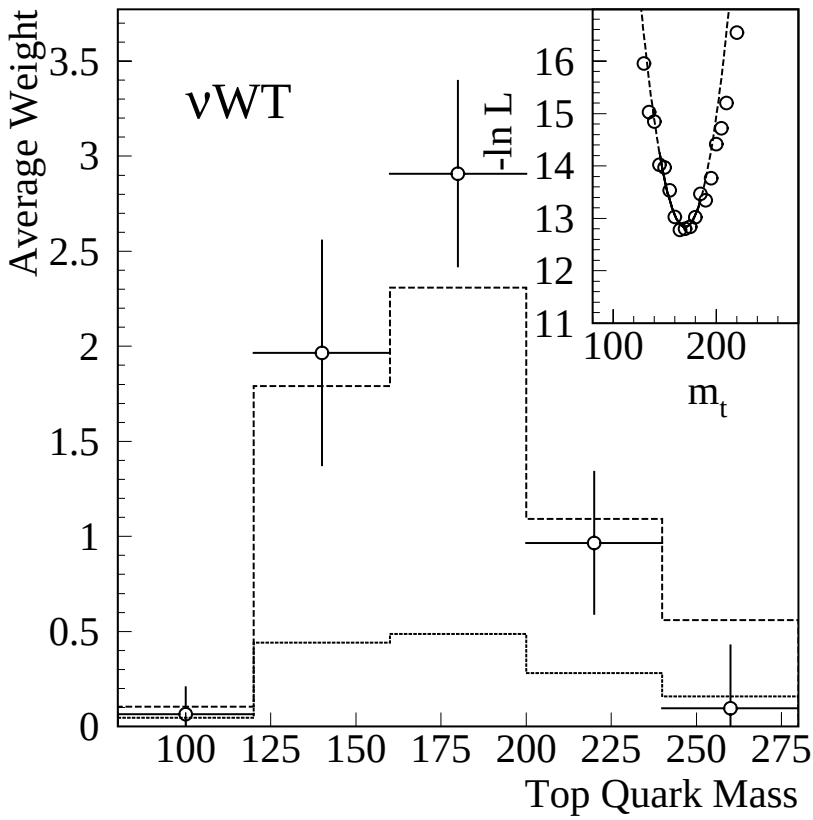
largest systematics	
jet energy	4.0 GeV
MC generator	3.1 GeV
noise/pile-up	1.3 GeV

PRL 79, 1197 (1997)

top quark mass

- dilepton channel: $tt \rightarrow l\nu b\ l\nu b$
  - 4 unknowns (only Σp_T^{ν} is known)
  - 3 constraints
    - $m(l\nu) = m(qq) = m_W$
    - $m(l\nu b) = m(qqb)$
  - underconstrained
  - ⇨perform a dynamical likelihood analysis (D0)
  - ⇨use kinematic variables (CDF)
- all jets channel: $tt \rightarrow qqb\ qqb$
  - large background
  - no unknowns
  - 3-constrained kinematic fit

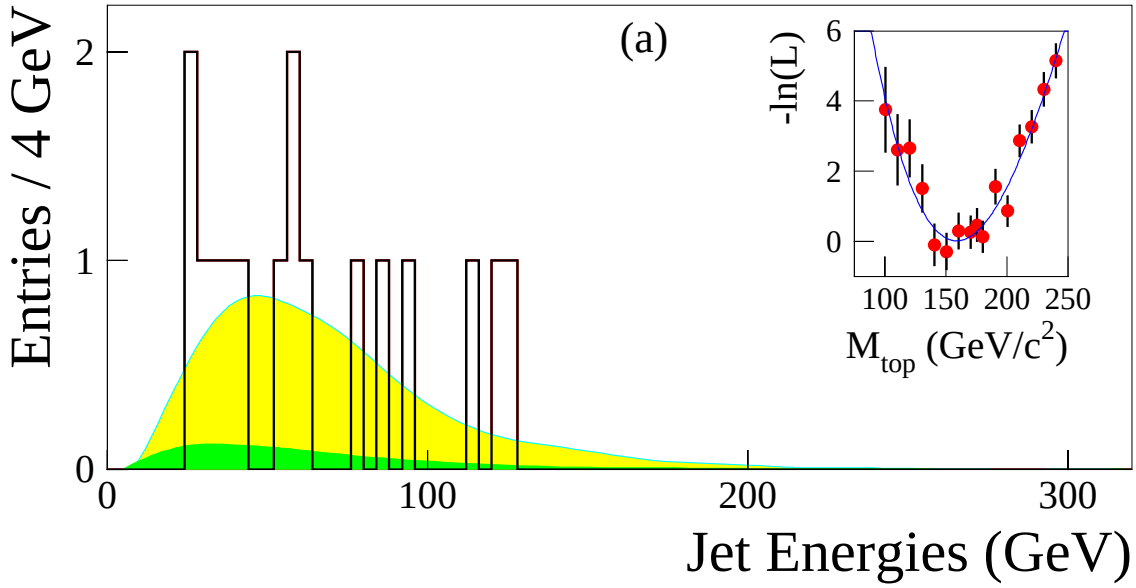
top quark mass

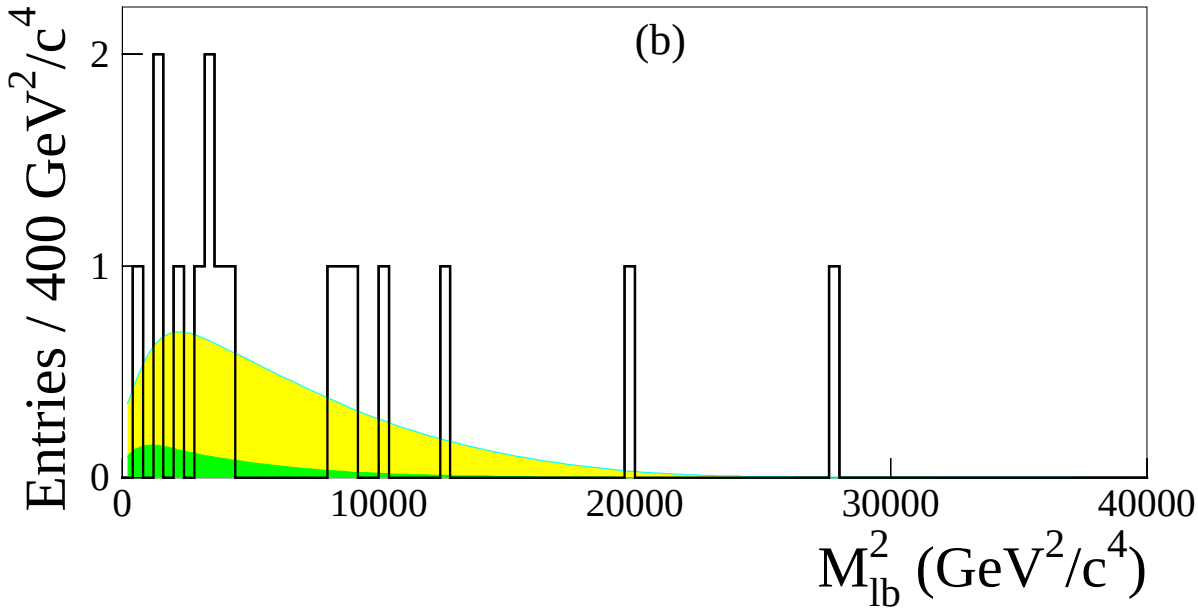


- m_t = 168.4±12.3±3.6 GeV
  (Fermi-Pub/97-172-E)
- combined m_t measurement by D0

$\boxed{172.1 \pm 7.1 \text{ GeV}}$

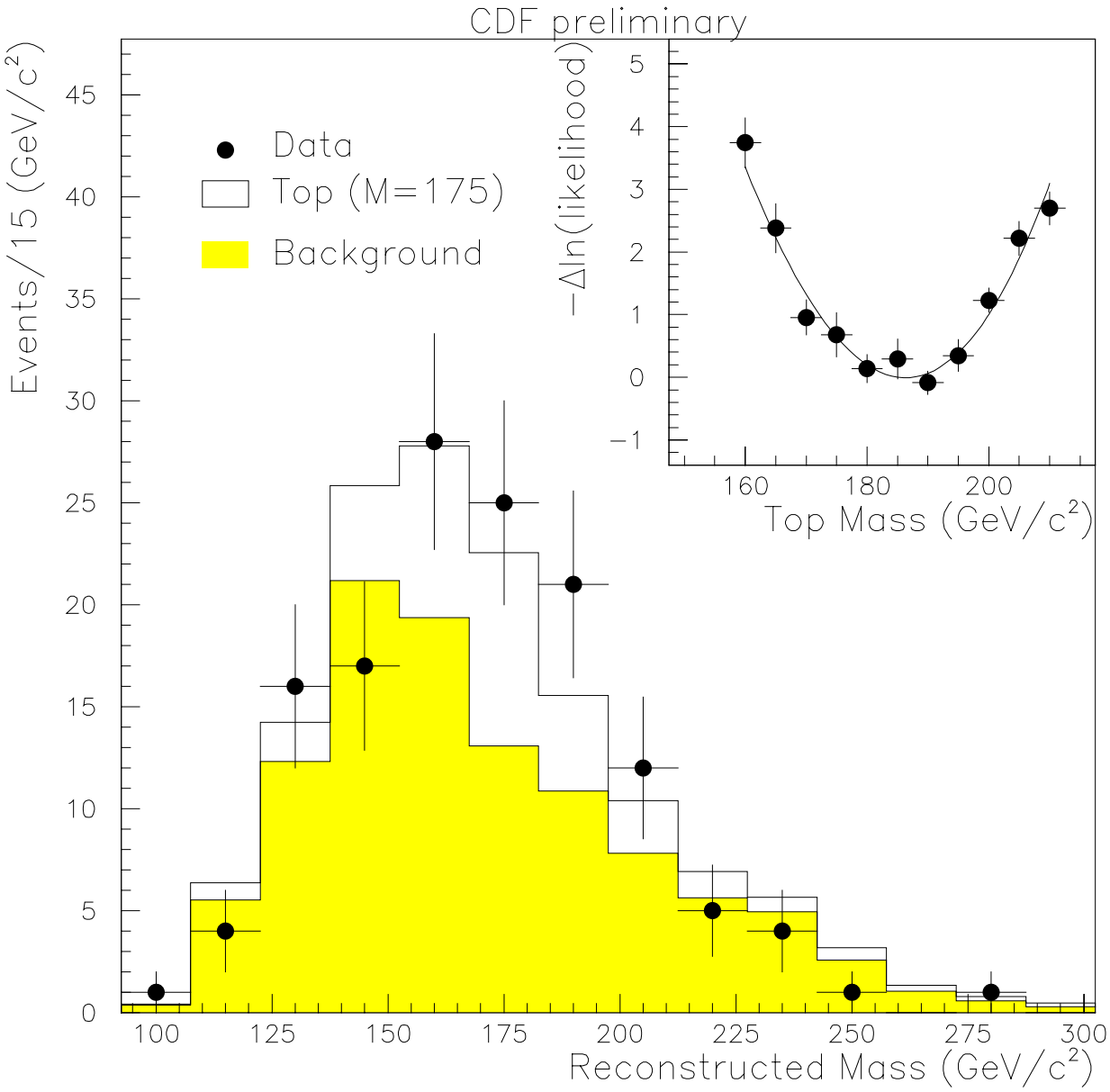
top quark mass





m_t = 161±17±10 GeV

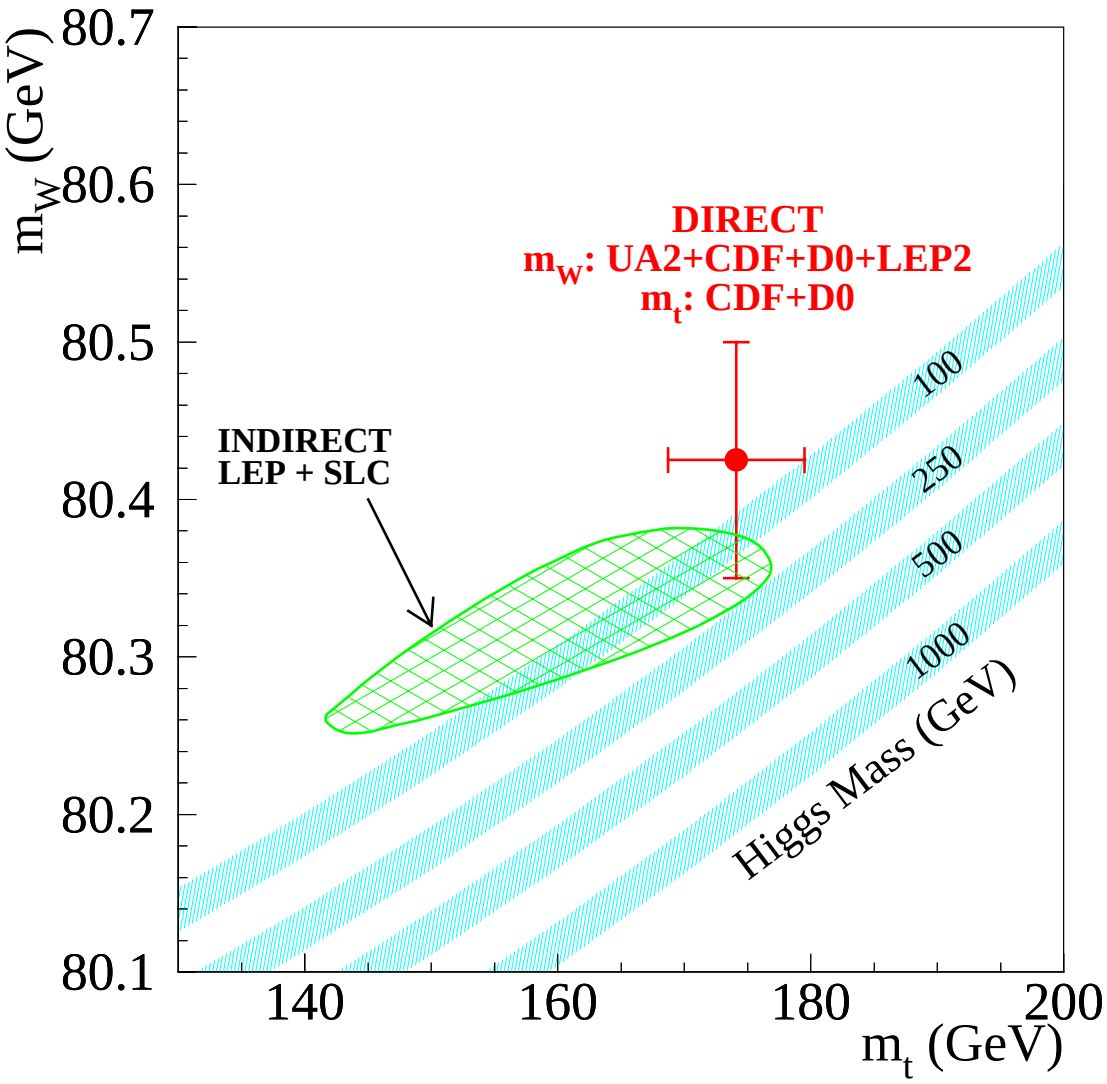
top quark mass



m_t = 186±10±12 GeV

(Fermi-Pub/97-075-E)

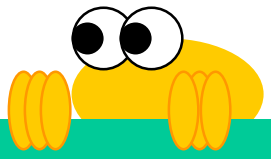
constraints on the Higgs sector



- world average m_t = 174.1±5.4 GeV (inofficial)
- SM predictions for m_W
  - Degrassi *etal*, CERN-TH/97-197
  - Degrassi, Gambino, Sirlin, PL B394, 188 (1997)

summary and outlook

- Tevatron Run I ⇒ Success
  - discovery of top quark
  - measure top mass to 3%
  - measure W mass to < 100 MeV
  - demonstrate electroweak self - couplings of gauge bosons



coming soon:

Run II