Precision EWK Measurements at Hadron Machines

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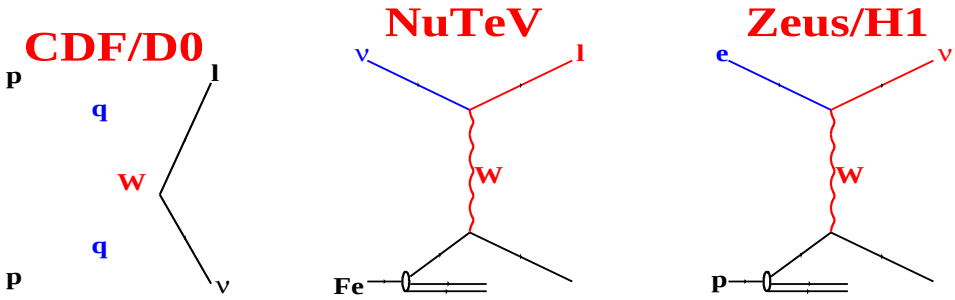
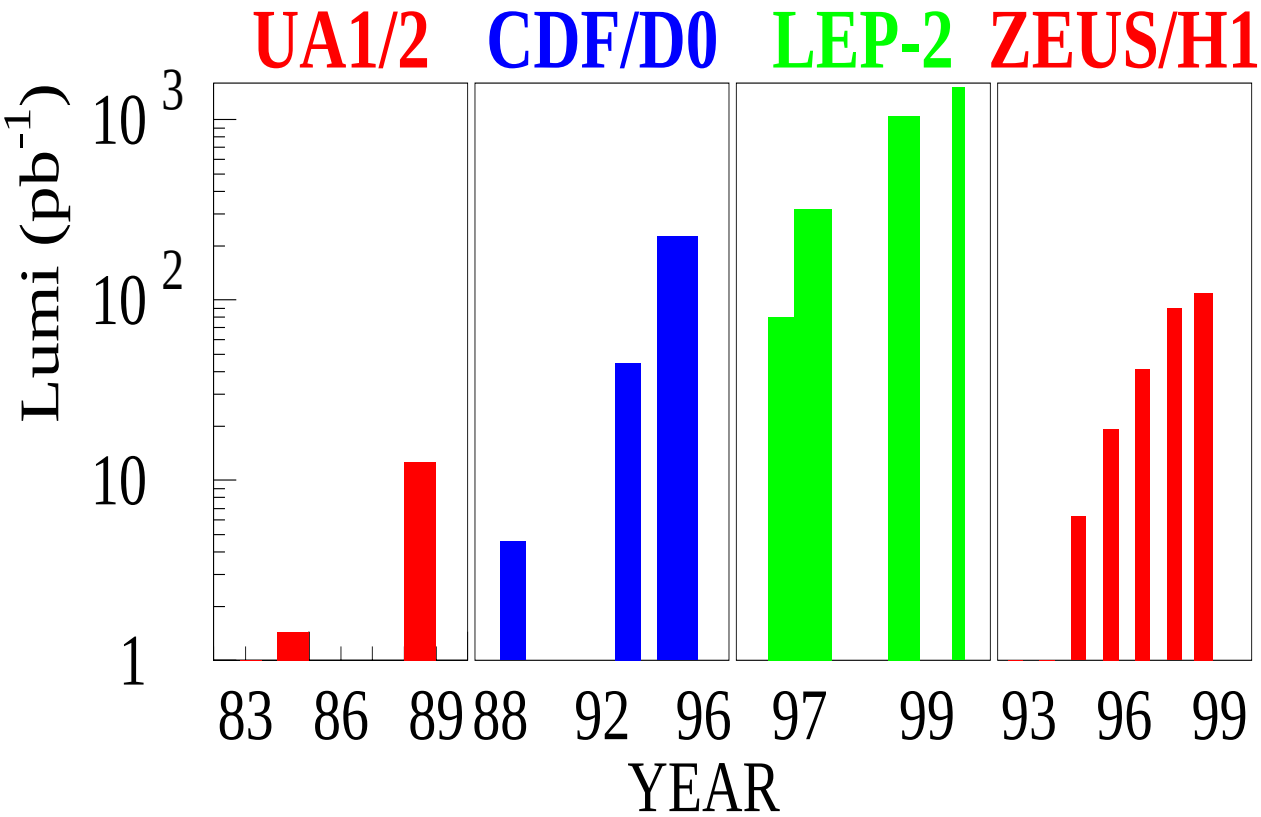
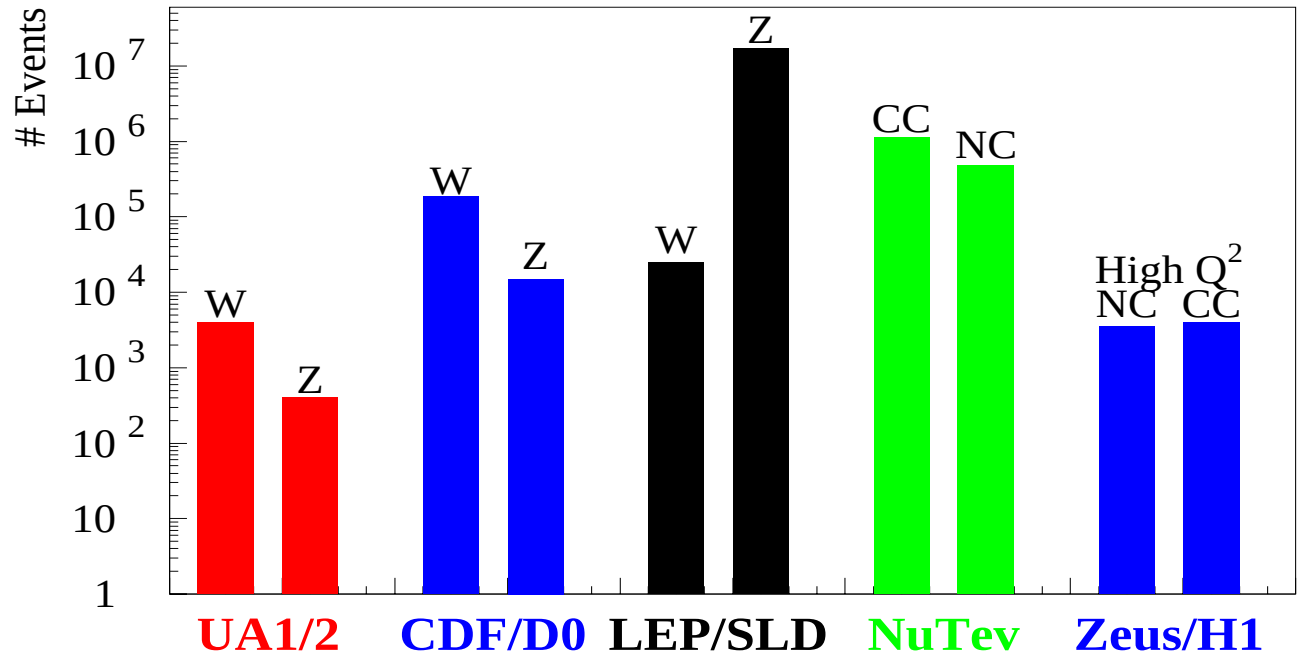


* Mw, Mt results from CDF/D0
* sin $^2\theta_w$ from NuTev
* EWK tests in space-like domain ZEUS/H1

- **CDF/DØ : $p\bar{p}$ @ $\sqrt{S}$ = 1800 GeV**
- **NuTeV : $< E_\nu >$ = 125 GeV on Fe target.**
- **HERA : $e^{\pm}p$ @ $\sqrt{S}$ = 300, 320 GeV**

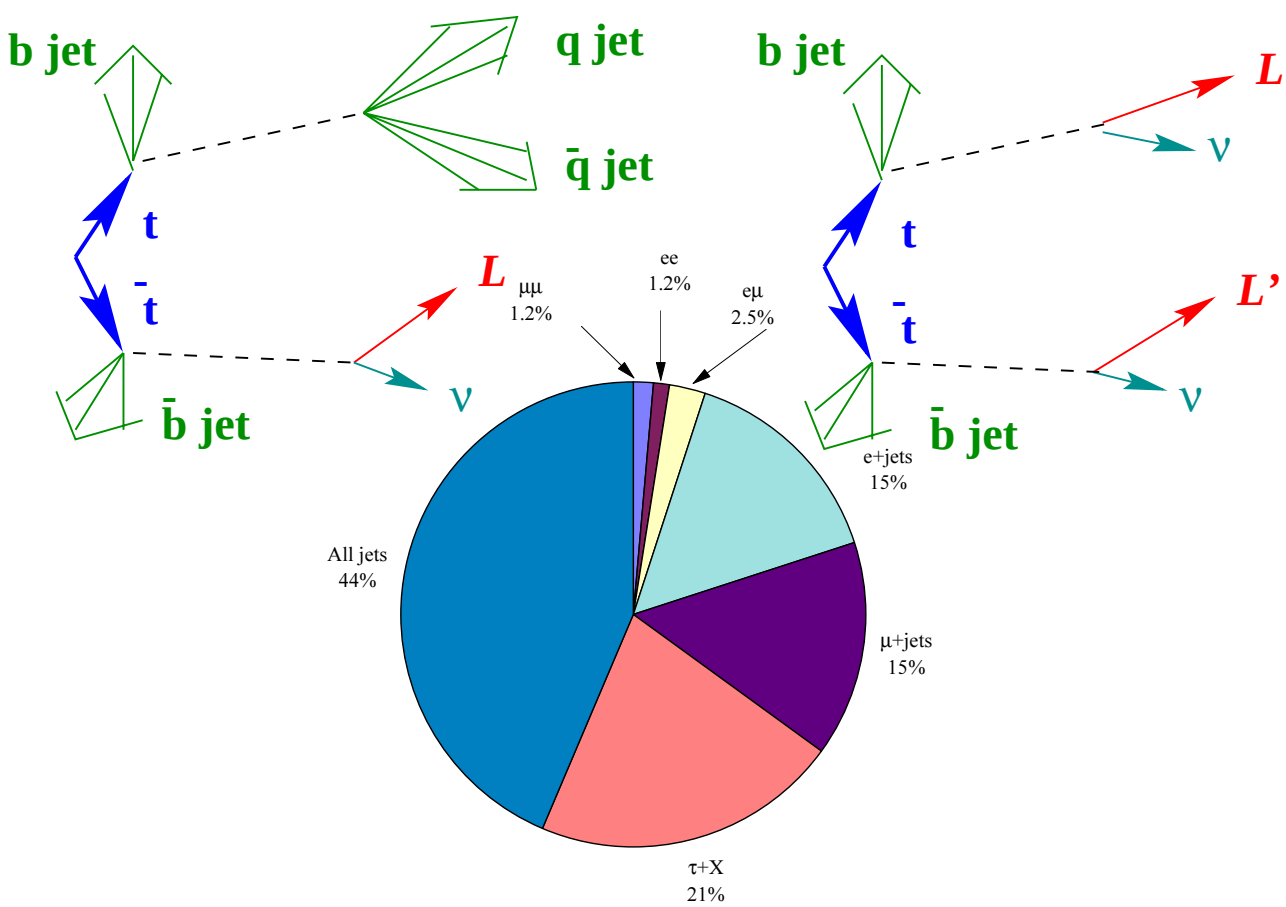




Tevatron Top Mass Measurement

- **Most incisive EWK measurement at Tevatron.**
- **Predicted M_T has large uncertainty from Higgs RC.**
  $\rightarrow \Delta M_T < 10$ GeV – information on Higgs mass.
- **Post 1995 discovery much progress in reducing mass error from ~ 10 GeV $\rightarrow \sim 5$ GeV**
- **In last year**
  - *CDF/DØ : new results from di-lepton channel*
  - *CDF : re-evaluated errors in all-hadronic channel*
  - *These measurement incorporated into final values*
  - *Final Tevatron average : accounting for correlations*

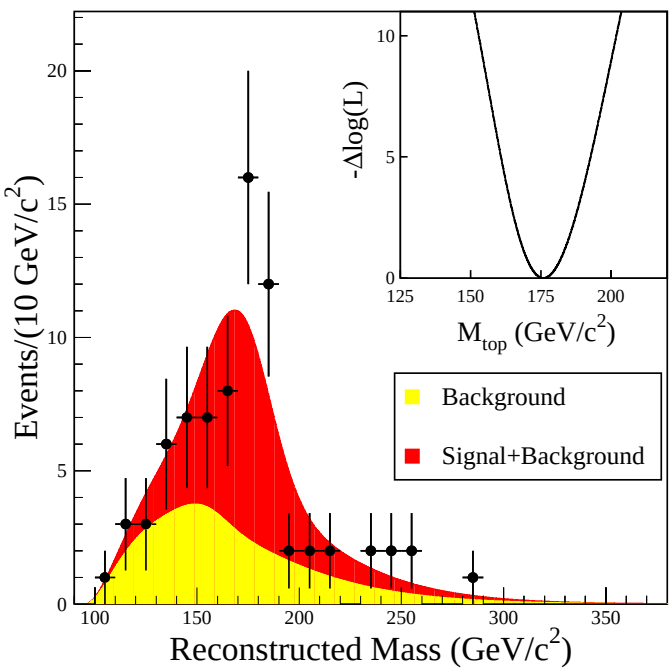
lepton+jets **dilepton**

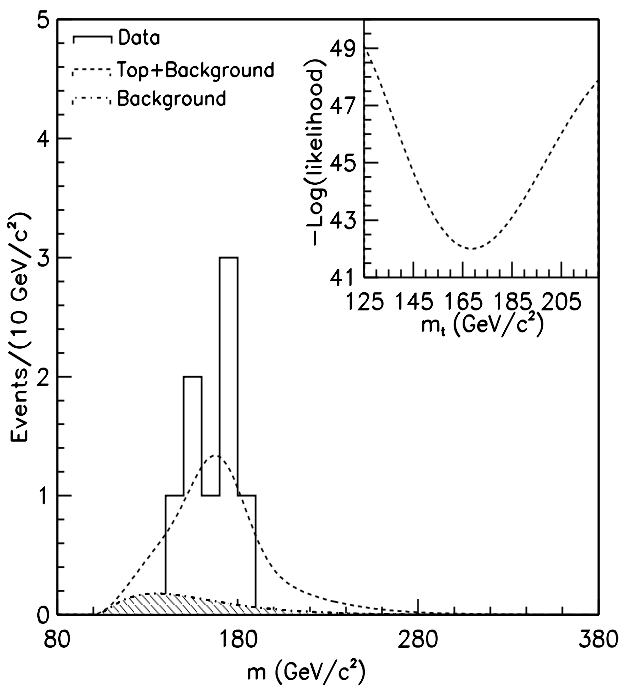


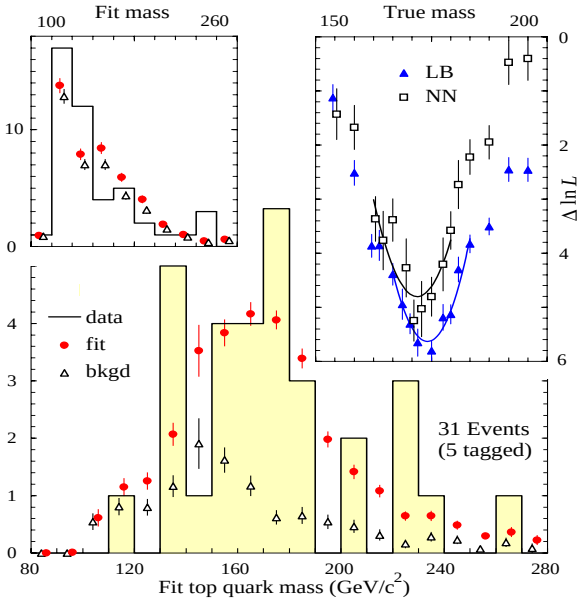
Tevatron Top Mass Measurement

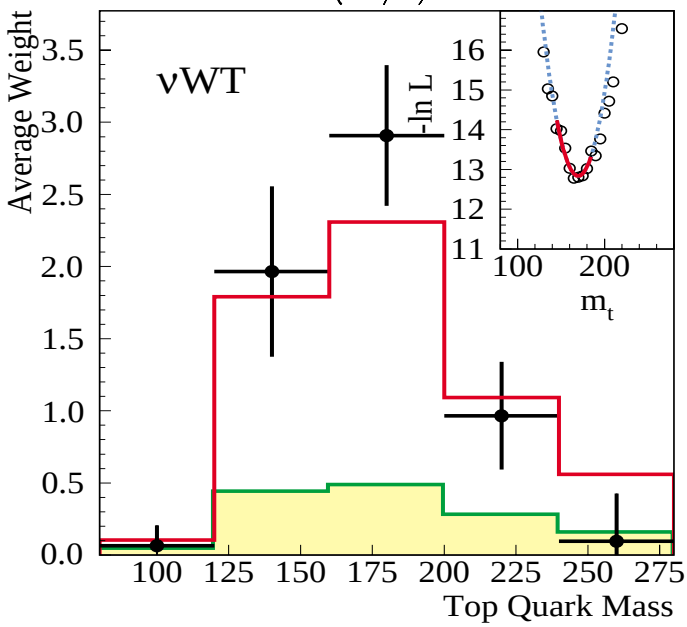
Channel	Pros	Cons	S/N (CDF)
Di Lepton	Low Background Resolutions known	Small Statistics Under Constrained	4
All Hadronic	Large Sample	Large Backgrounds	0.3
Lepton + jets	Reasonable Stats Reasonable Bgrds		2.5

In total : CDF + DØ ~ 150 signal events.









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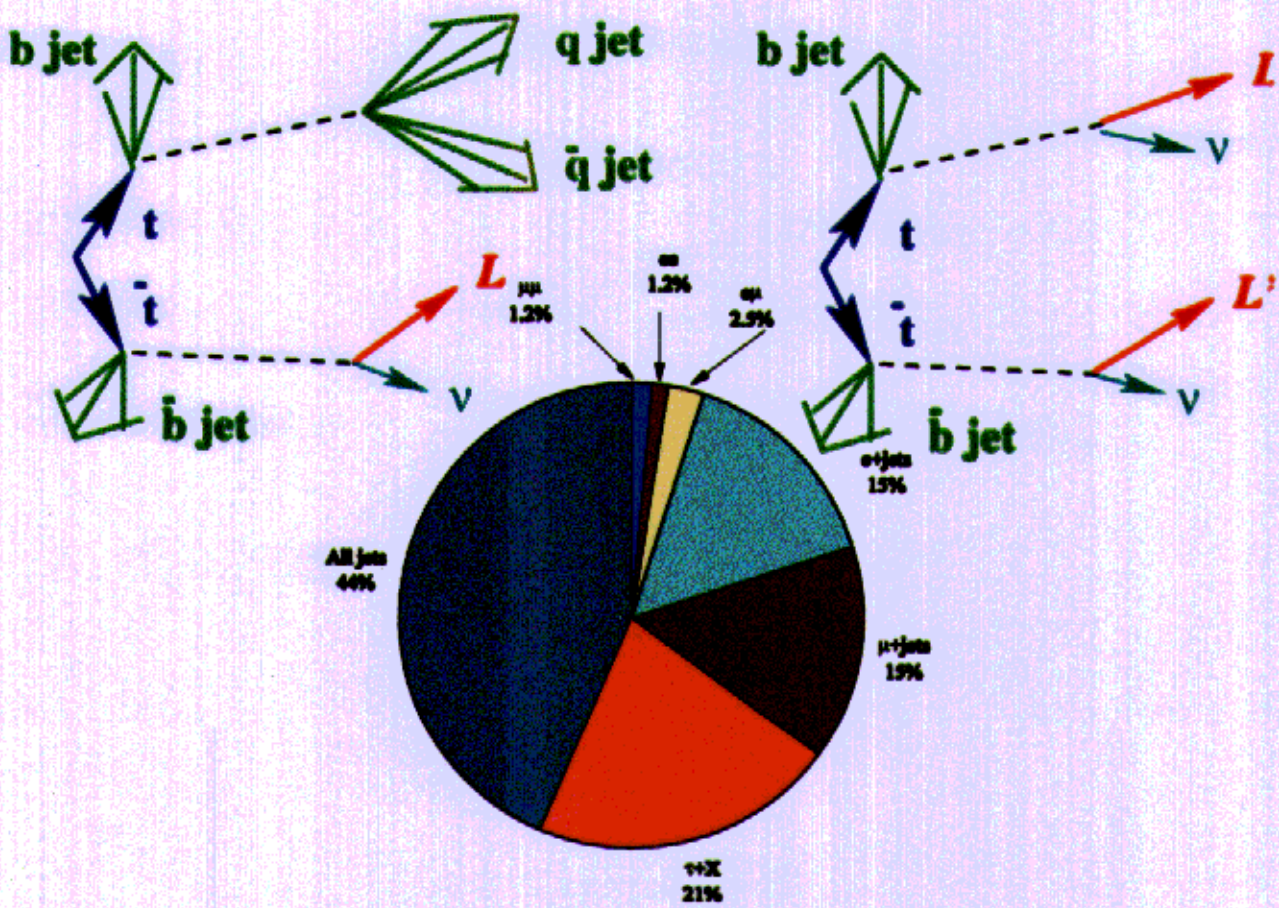
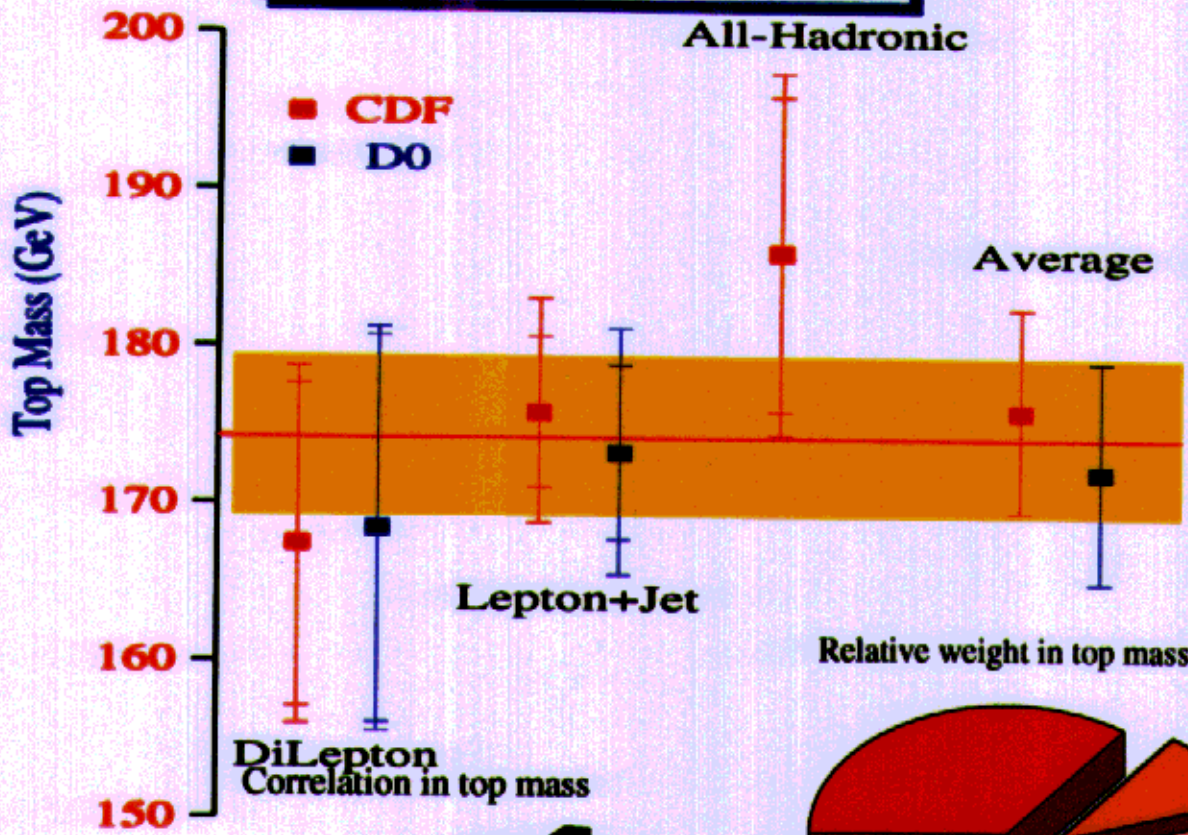
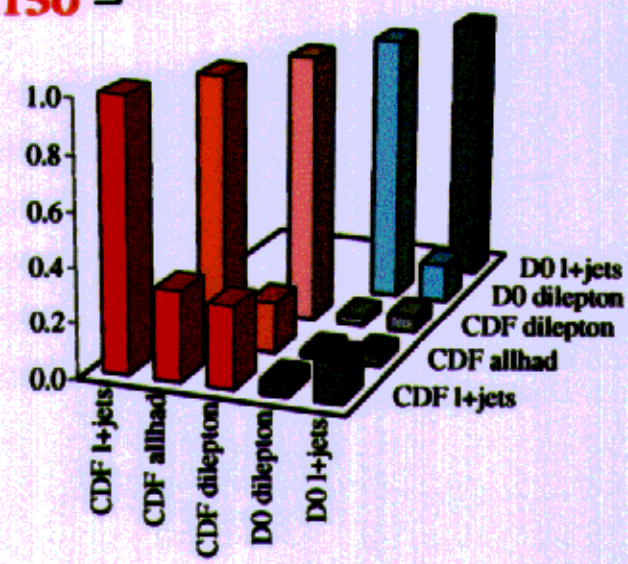
lepton+jets **dilepton**



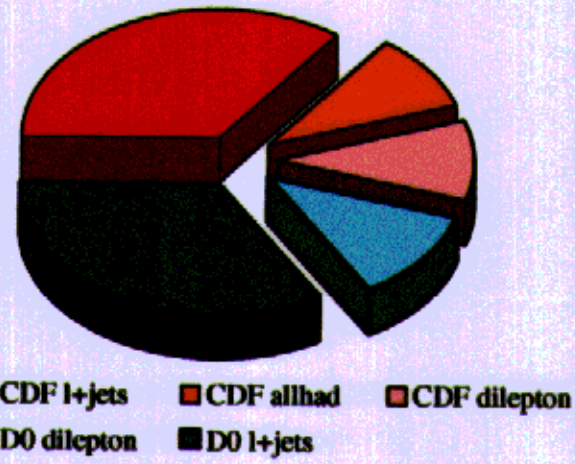
Tevatron Top Mass Average



Correlation in top mass



Relative weight in top mass average



Mt = 174.3 ± 3.2 (stat.) ± 4.0 (sys.) GeV

Best measured quark mass : $\Delta M_t/M_t < 3\%$

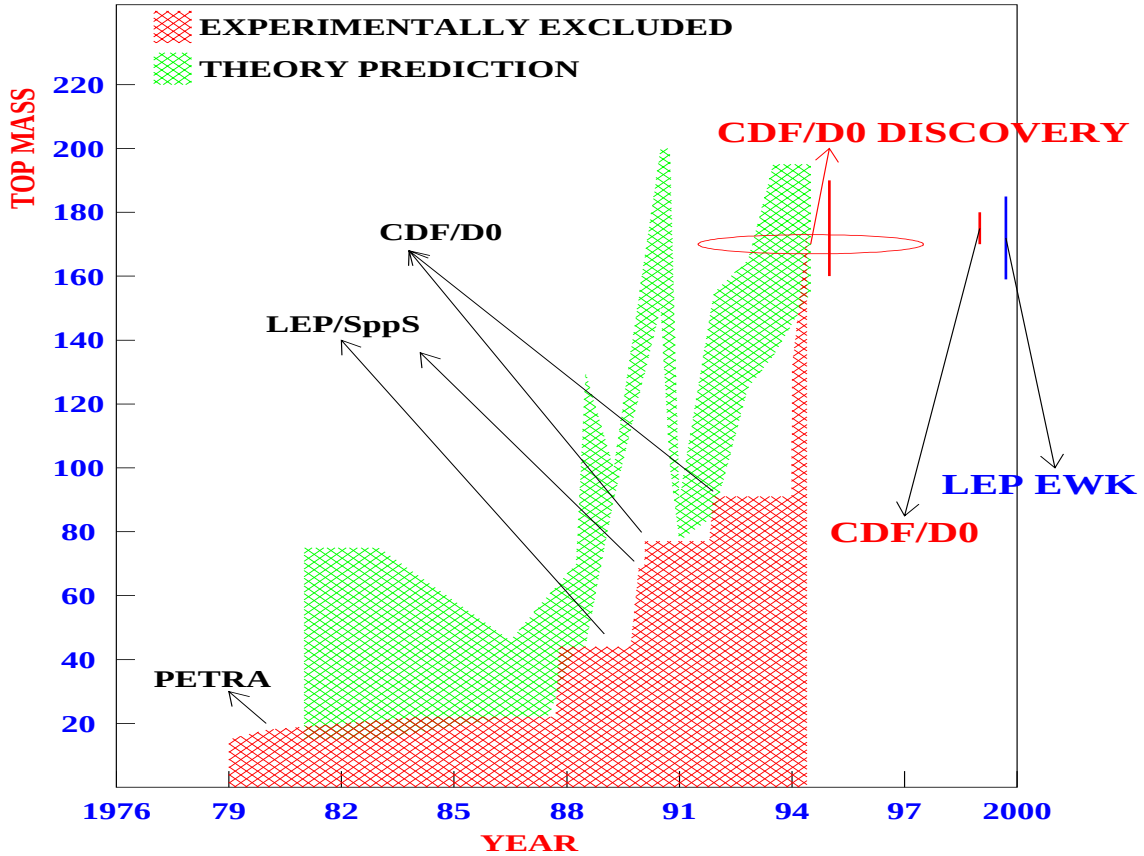
Systematic Error dominated by uncertainties in :

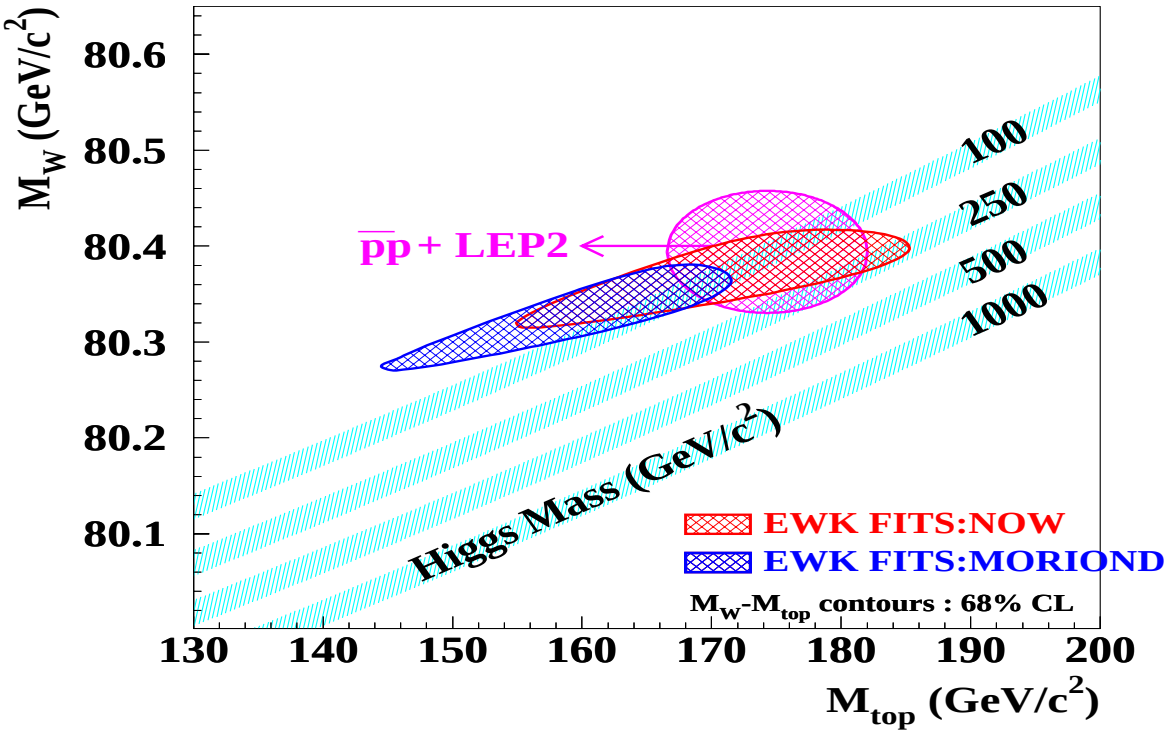
- **Jet Energy Scale**
- **MC effects : QCD radiation**

Comparison with SM

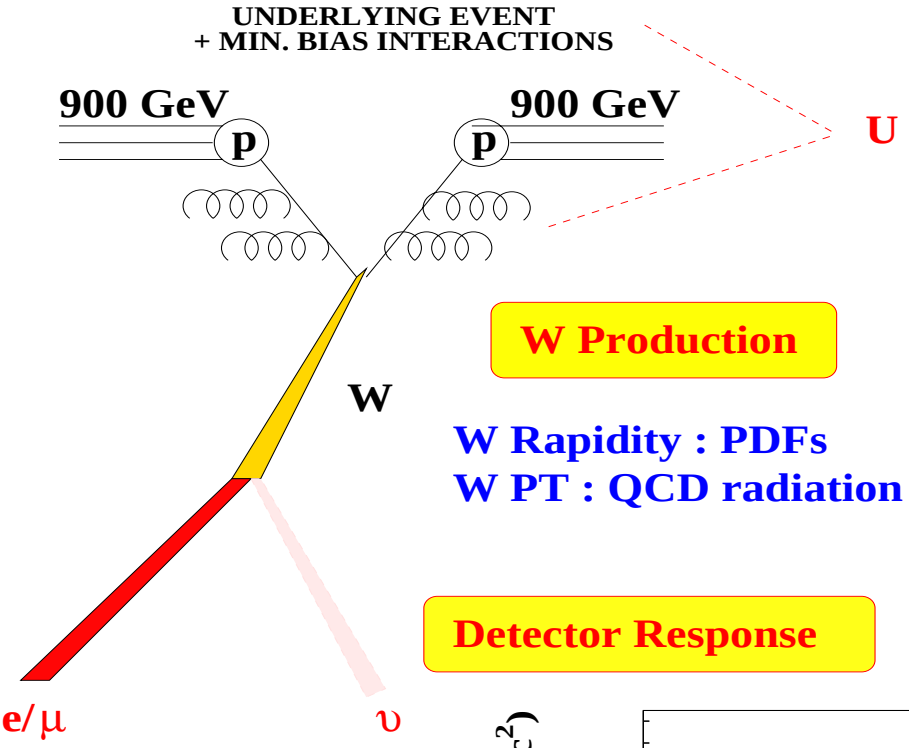
From LEP-1 + LEP-II Mw EWK : MT = 172^{+14}_{-11} GeV

From CDF/DØ Top sample : MT = 174.3± 5.1 GeV





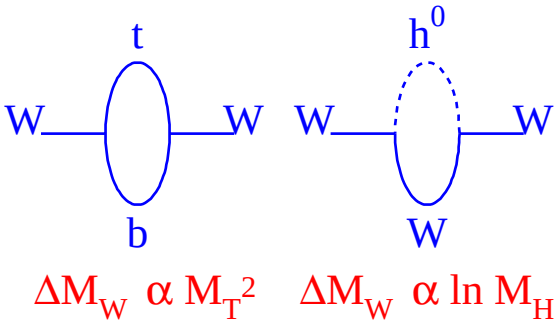
Tevatron W Mass



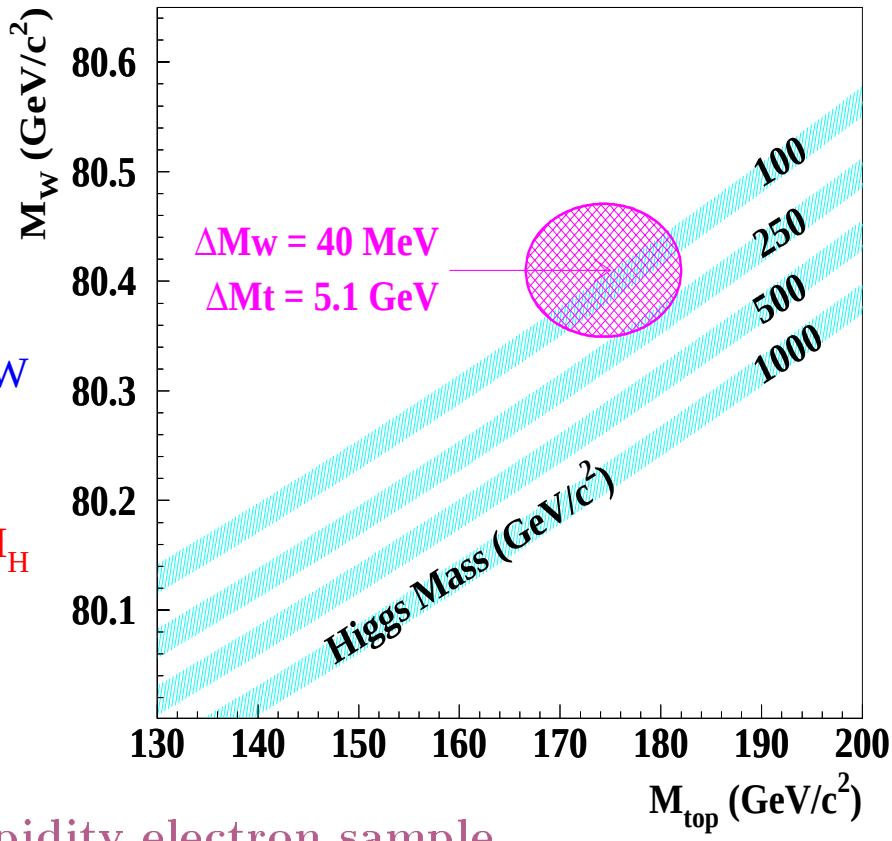
W Production

W Rapidity : PDFs
W PT : QCD radiation

Detector Response



$\Delta M_W \propto M_T^2$ $\Delta M_W \propto \ln M_H$

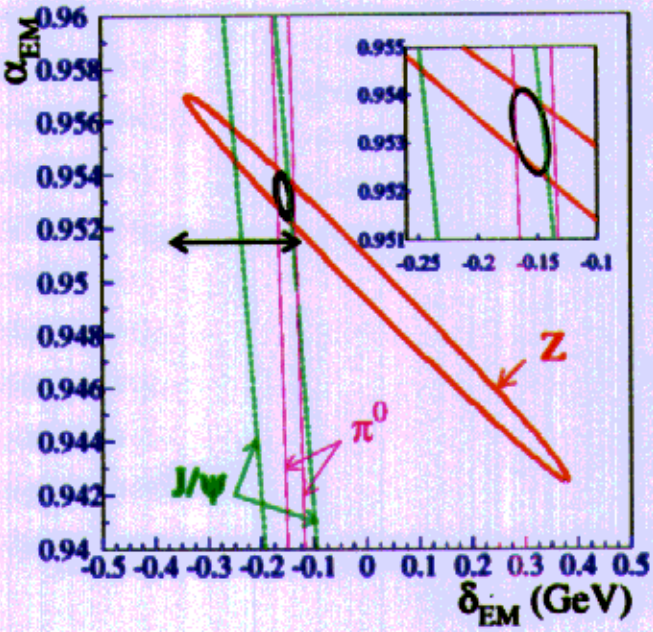


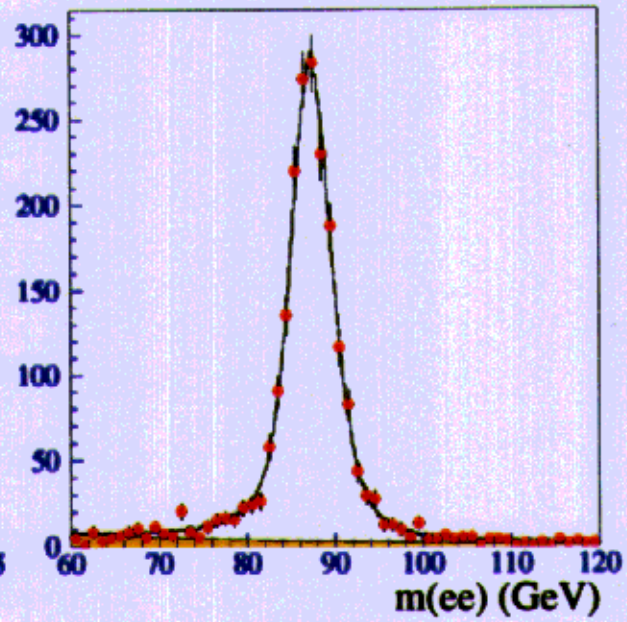
In last year :

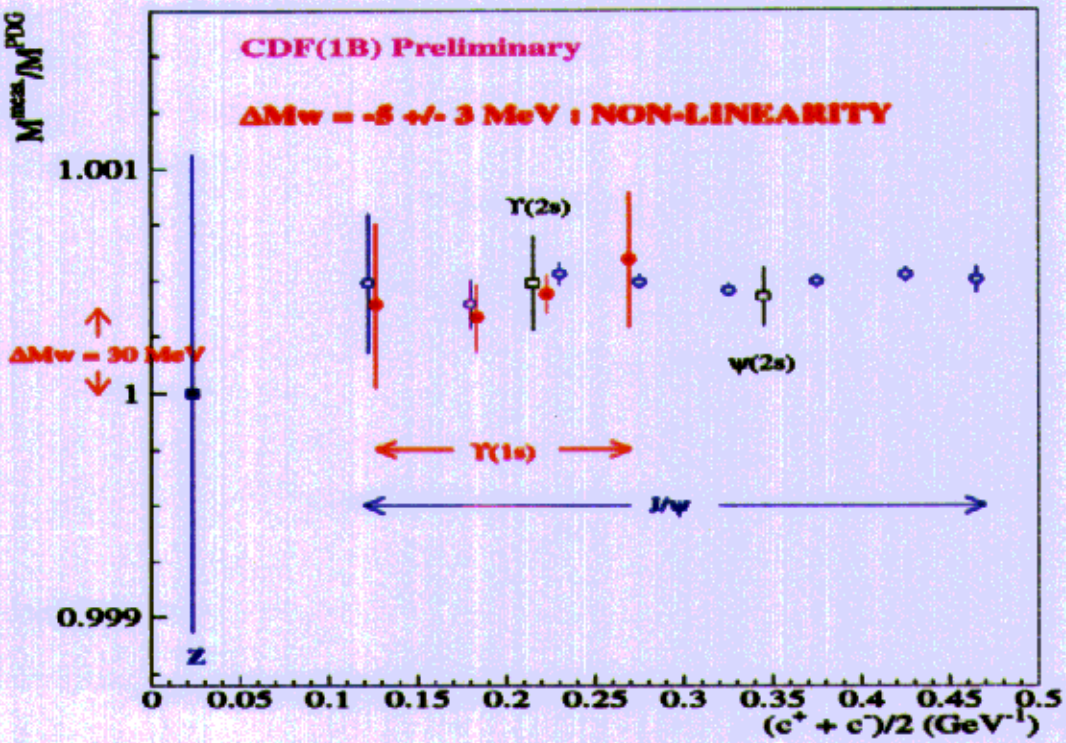
- DØ added high rapidity electron sample
- CDF added run-1B electron data and improved model for QCD radiation

Tevatron W Mass

- **Z sample is central to W mass analysis**
  - Calibrate lepton p_T scale + resolution
  - Model QCD radiation + detector response



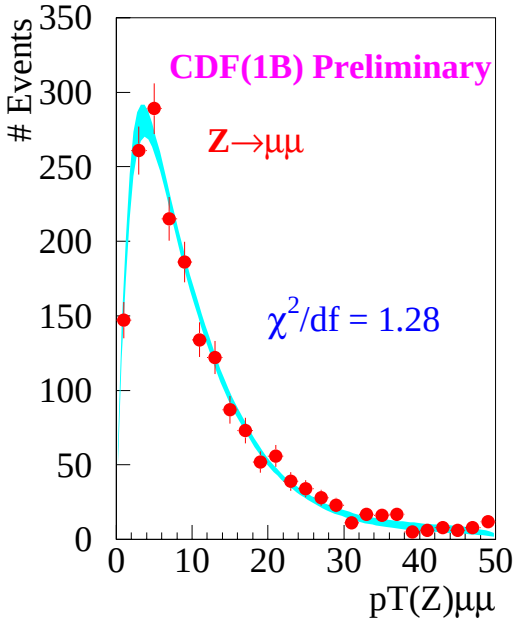


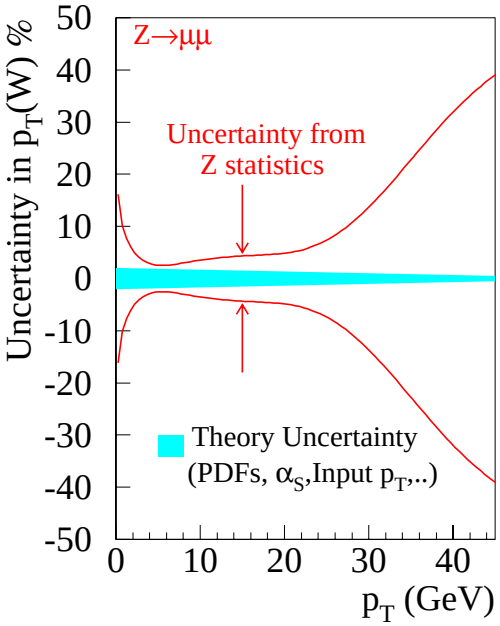


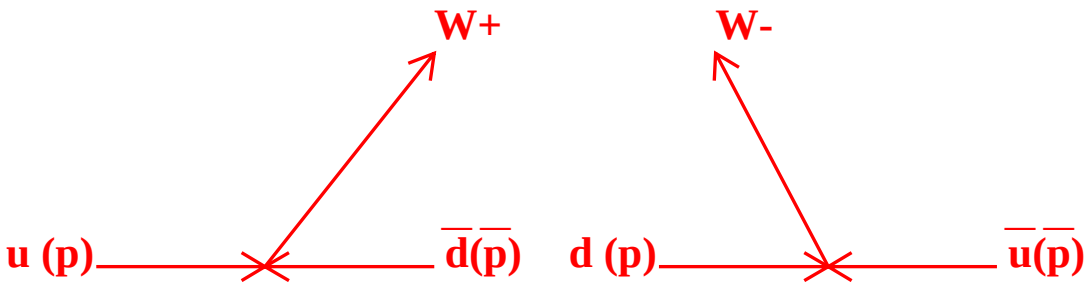
$\Delta M_W/M_W \sim 0.08\%$ from Z statistics.

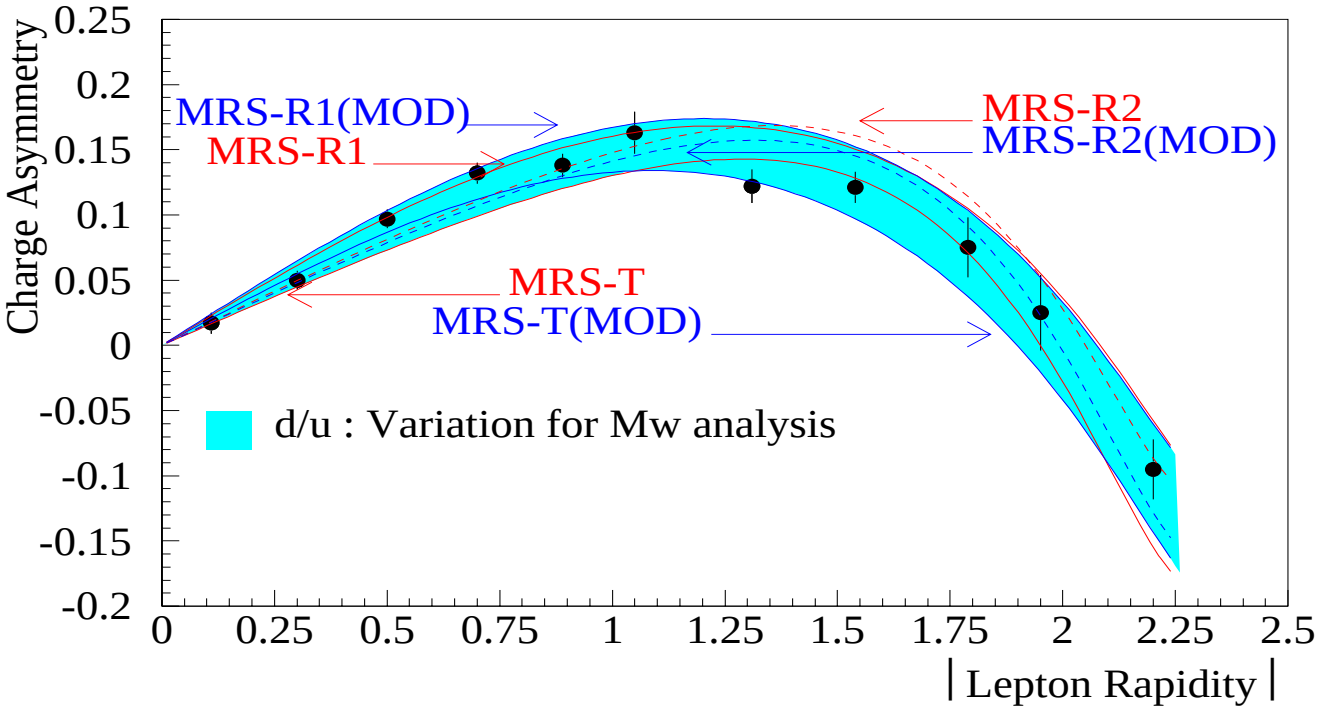
Tevatron W Mass

- **Model W rapidity and p_T by fits to data.**





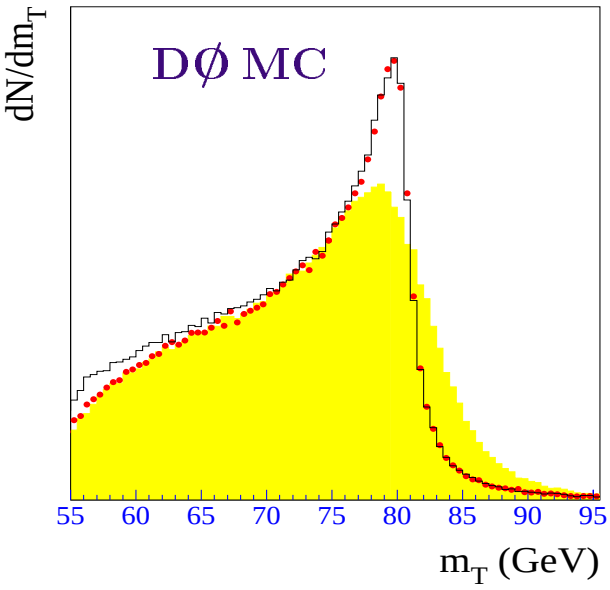


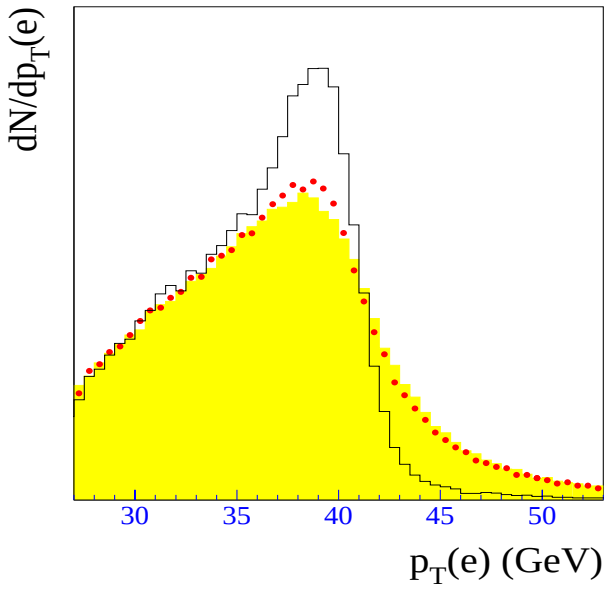


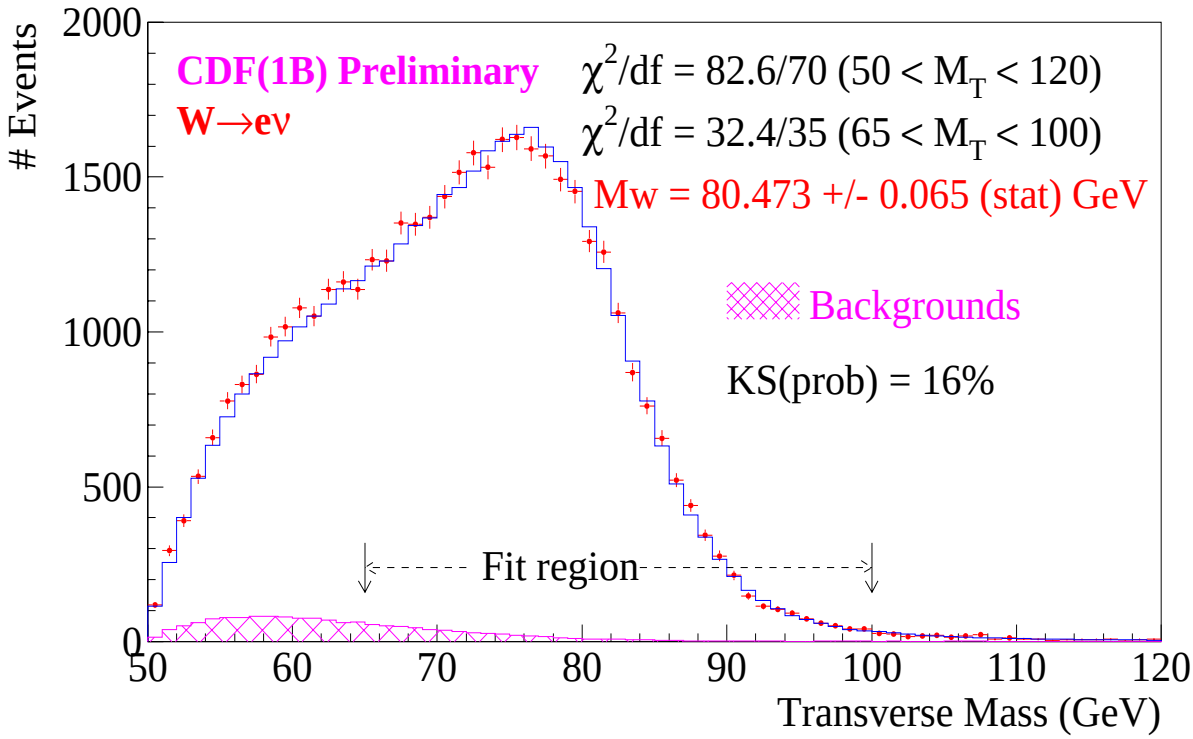
Tevatron W Mass

- **Measure from transverse mass distribution**
- **Cross check systematics using p_T lepton**

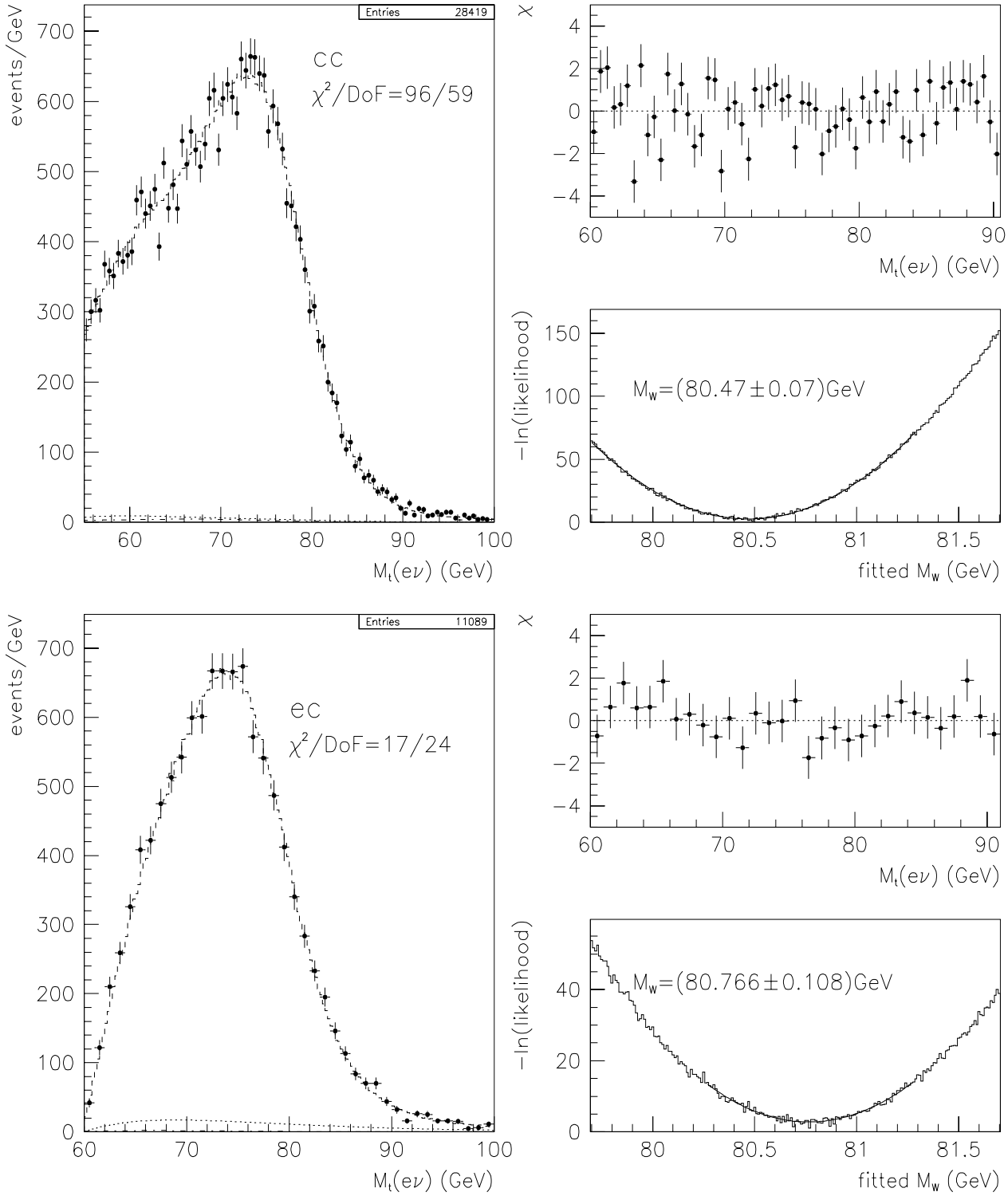
$$M_T = \sqrt{2p_T^{lep}p_T^{\nu}(1-\cos\phi_{lep\nu})}$$: best domino at present $\mathcal{L}$







Tevatron W Mass : DØ



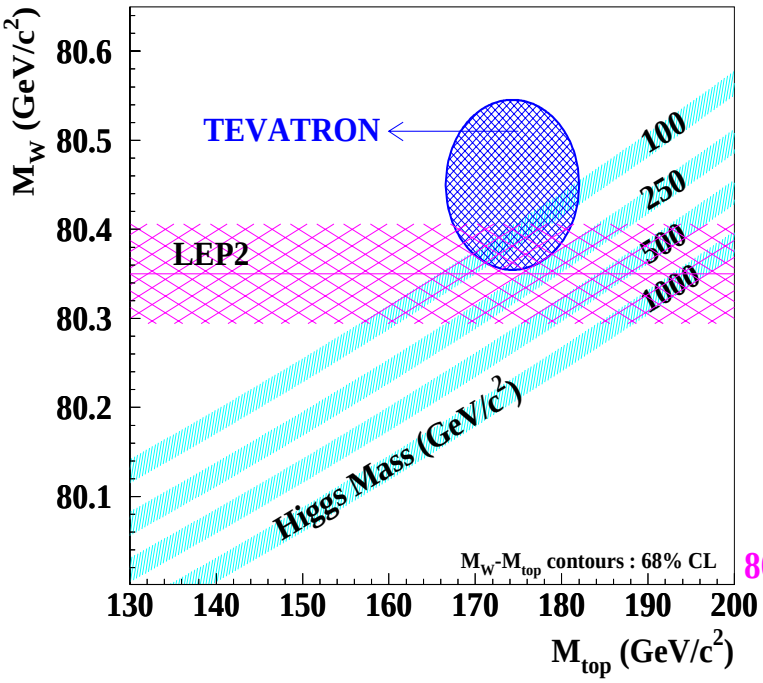
Tevatron Mw uncertainties

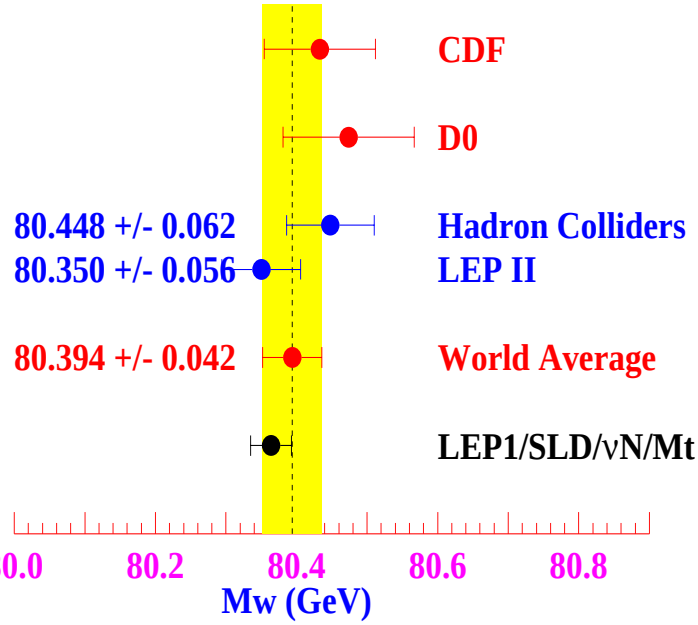
Dominated by statistics of Z sample.

Z sample – sets E,p scales + resolution
– W p_T & model for $\not{E}_T$

Error Source	DØ(C)	DØ(EC)	CDF(e)	CDF(μ)
Stat	70	105	65	100
Scale + Resolution [Zs]	70	185	80	90
W pT + $\not{E}_T$ Model [Zs]	35	50	40	40
Other Exp.	40	60	5	30
Theory (PDFs, QED)	30	40	25	20

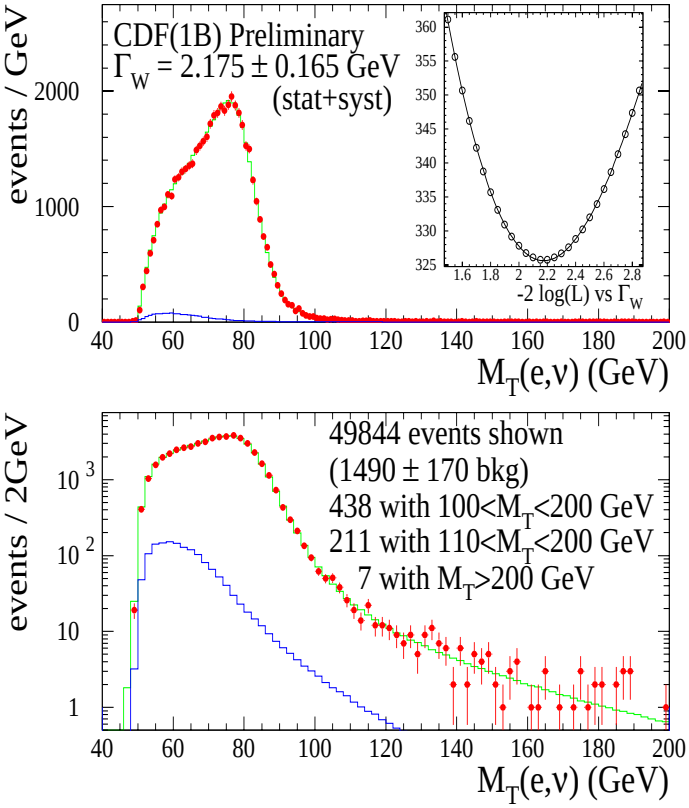
Mw (Tevatron) = 80.450 ± 0.063 GeV

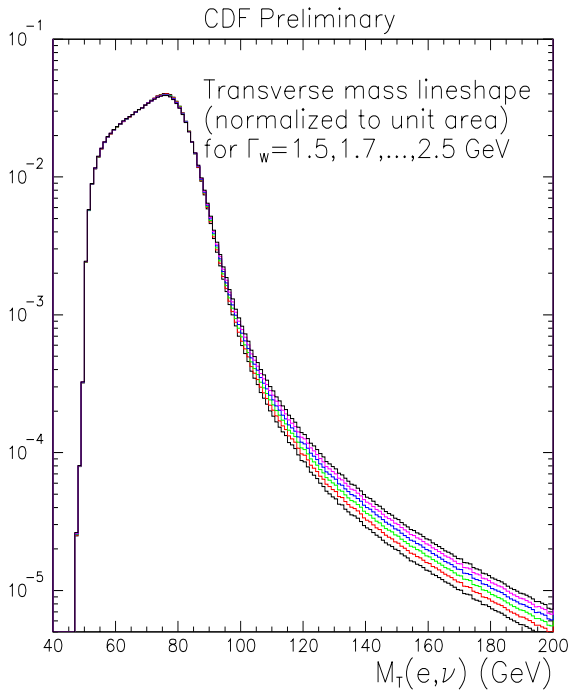


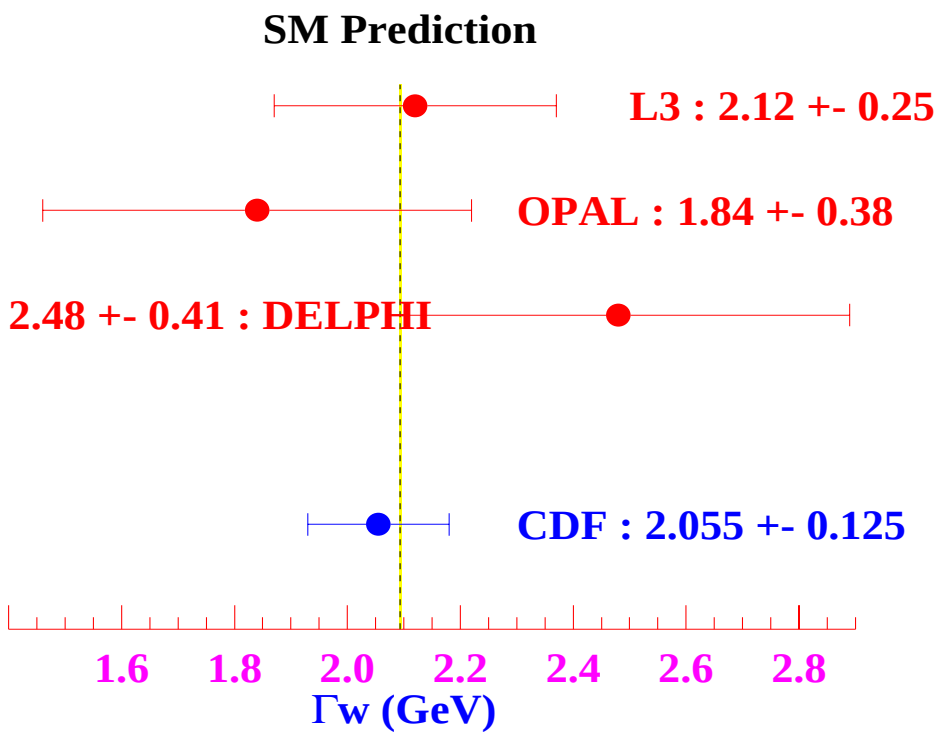


Other Tevatron EWK measurements

- **Most precise determinations of Γ_W from tail of transverse mass distribution**



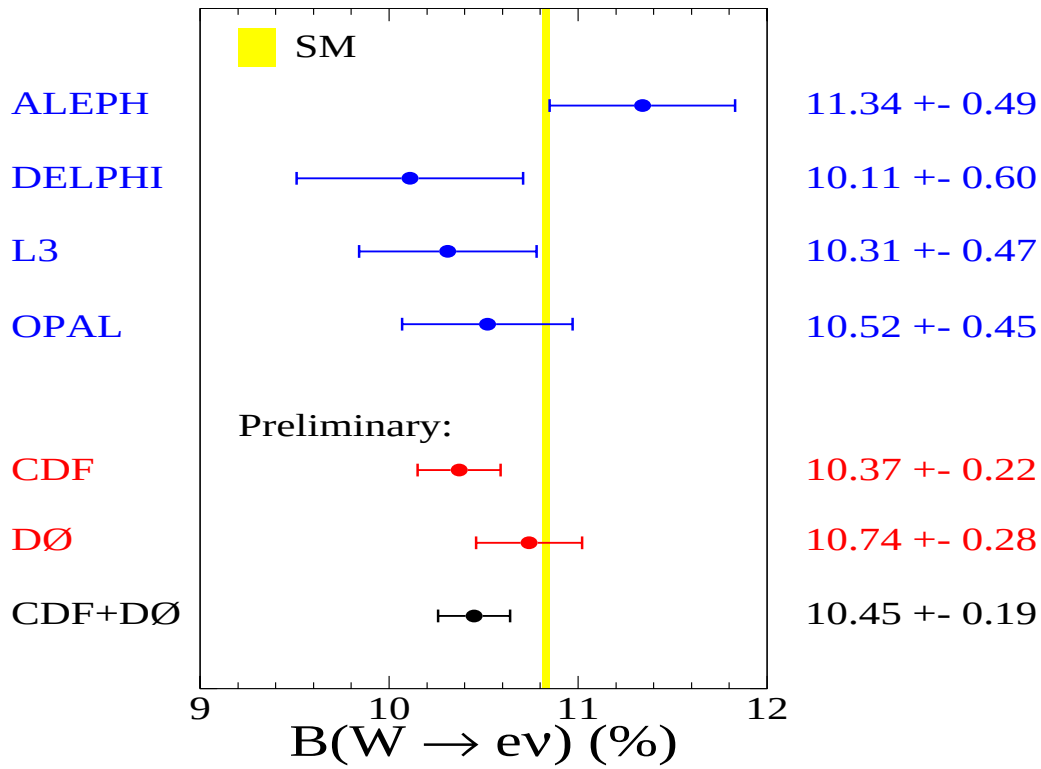




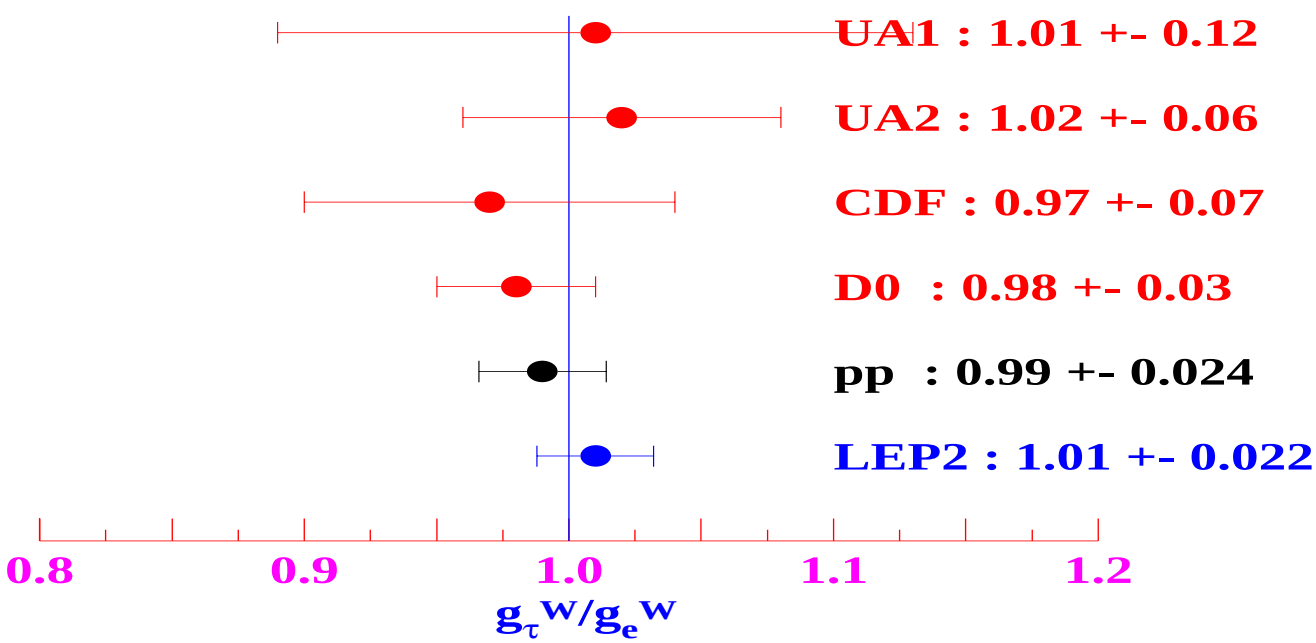
Tevatron : Branching Ratios

At Tevatron measure : $R = \frac{\sigma_W \cdot Br(W \to e\nu)}{\sigma_Z \cdot Br(Z \to ee)}$

$\rightarrow \frac{\Gamma(W \to e\nu)}{\Gamma(W)} = \frac{\sigma_W}{\sigma_Z} \cdot \frac{\Gamma(Z \to ee)}{\Gamma(Z)} \cdot \frac{1}{R}$; $\frac{\sigma_W}{\sigma_Z}$:from QCD, $\frac{\Gamma(Z \to ee)}{\Gamma(Z)}$ from LEP1

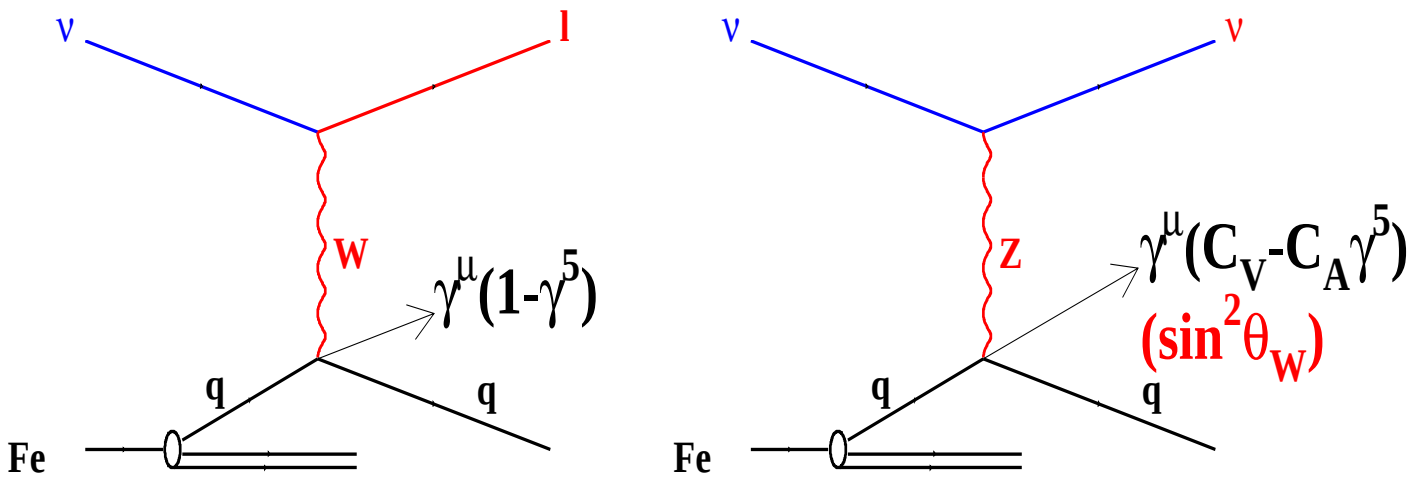


Large sample of W events also permit : g_τ^W / g_e^W



NuTeV $\sin^2\theta_w$ Measurement

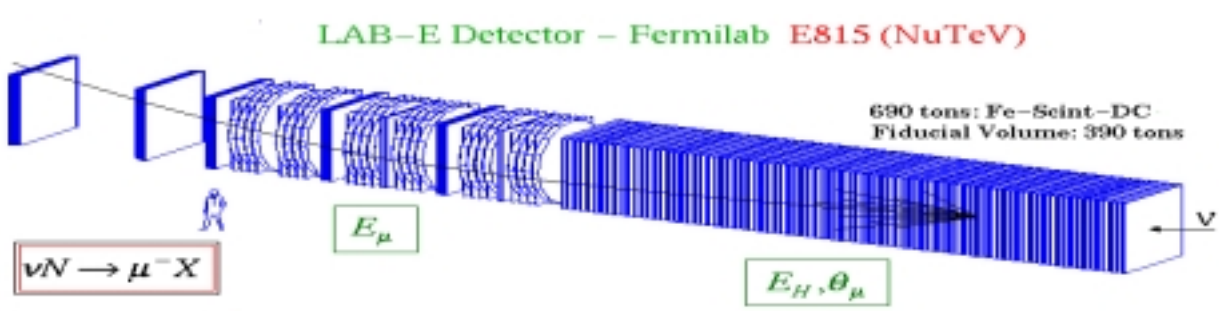
- From NC and CC cross sections in νN scattering.



Paschos-Wolfenestein relation :

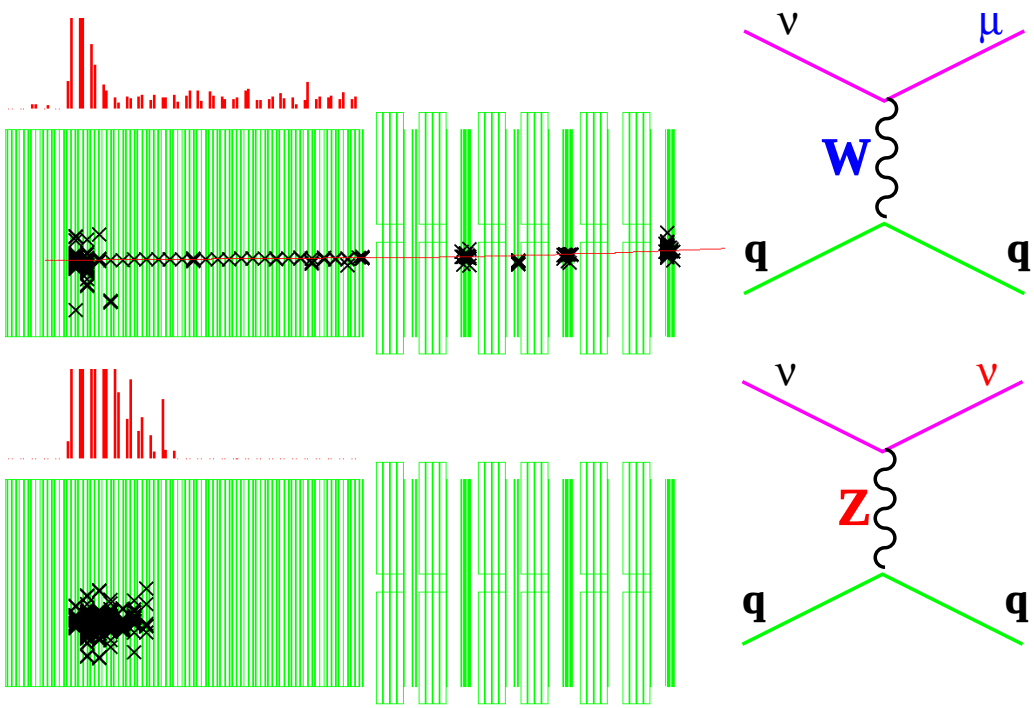
$$R^- = \frac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}} = \frac{1}{2} - \sin^2\theta_w$$

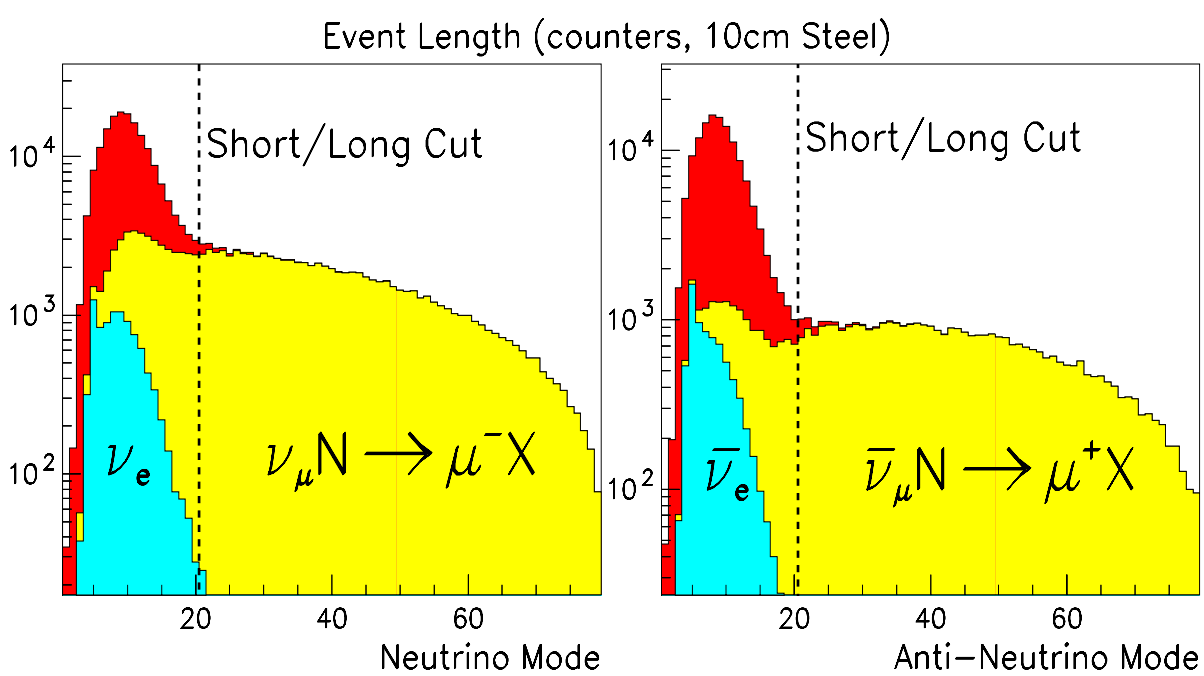
- Reduced systematic : sea quark contributions $\sim$ cancel
- Requires separate ν nd $\bar{\nu}$ beams (SSQT system)



NuTeV $\sin^2\theta_w$ Measurement

- **NC,CC events discriminated by "event-length"**
- **ν_e contamination small**





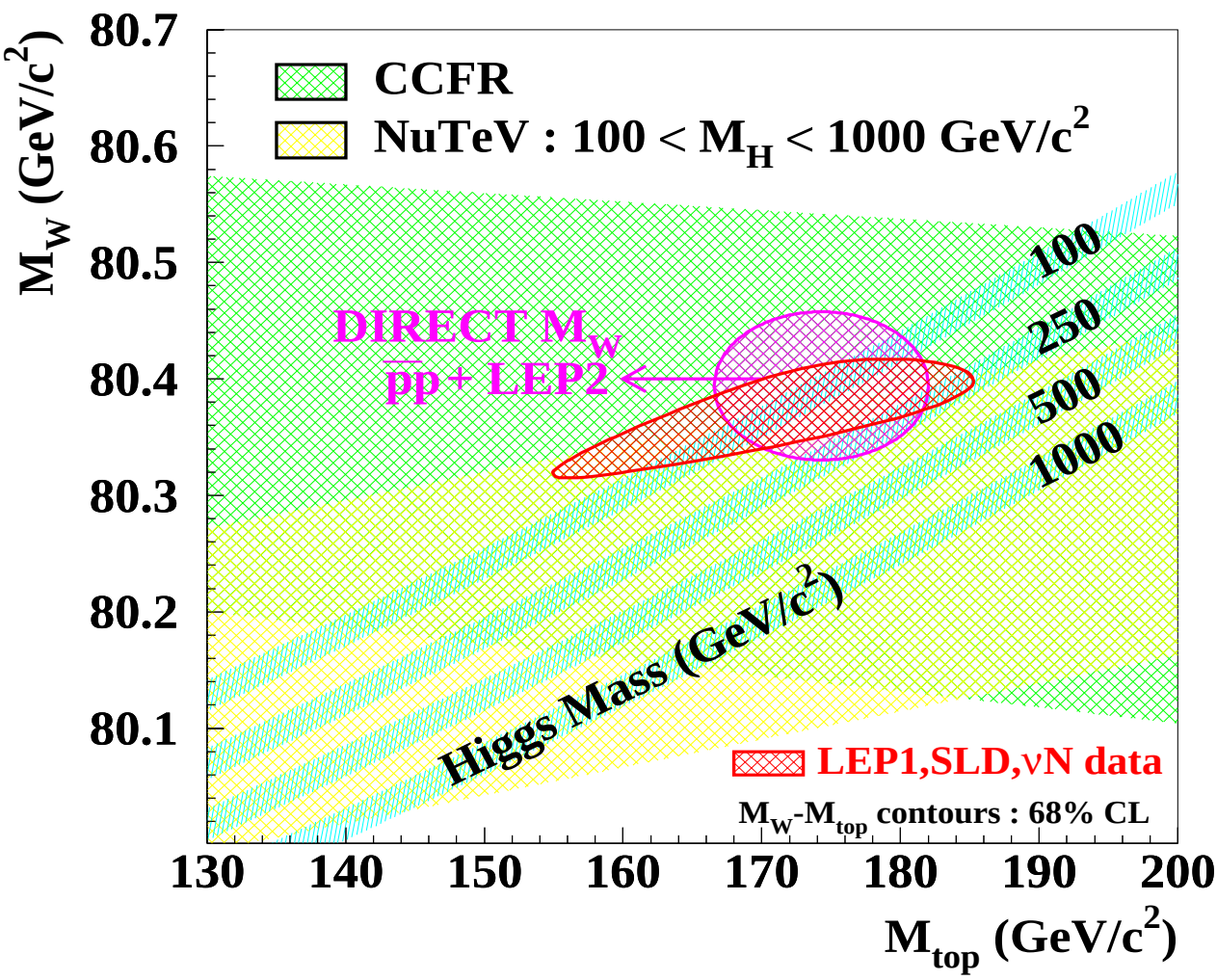
NuTeV $\sin^2\theta_w$ Measurement

Beam	Short	Long	R
ν ($< 0.1\%$ $\bar{\nu}$)	386k	919k	0.4198 ± 0.0008(stat)
$\bar{\nu}$ ($< 0.2\%$ ν)	89k	210k	0.4215 ± 0.0017 (stat)

$\sin^2\theta_W$ (on-shell) $= 0.2253 \pm 0.0021$

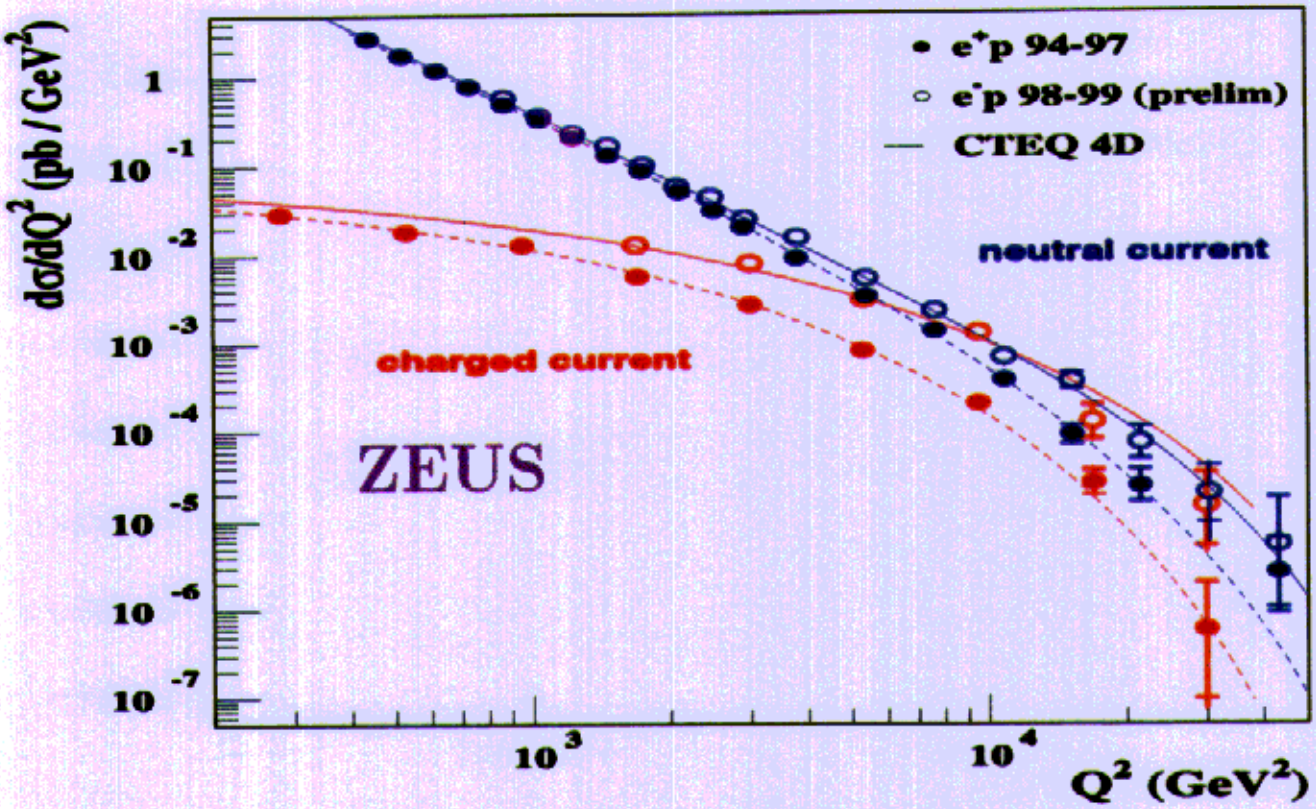
Mw $= 80.26 \pm 0.10$ (stat) ± 0.05 (syst) GeV

- Error is statistics dominated

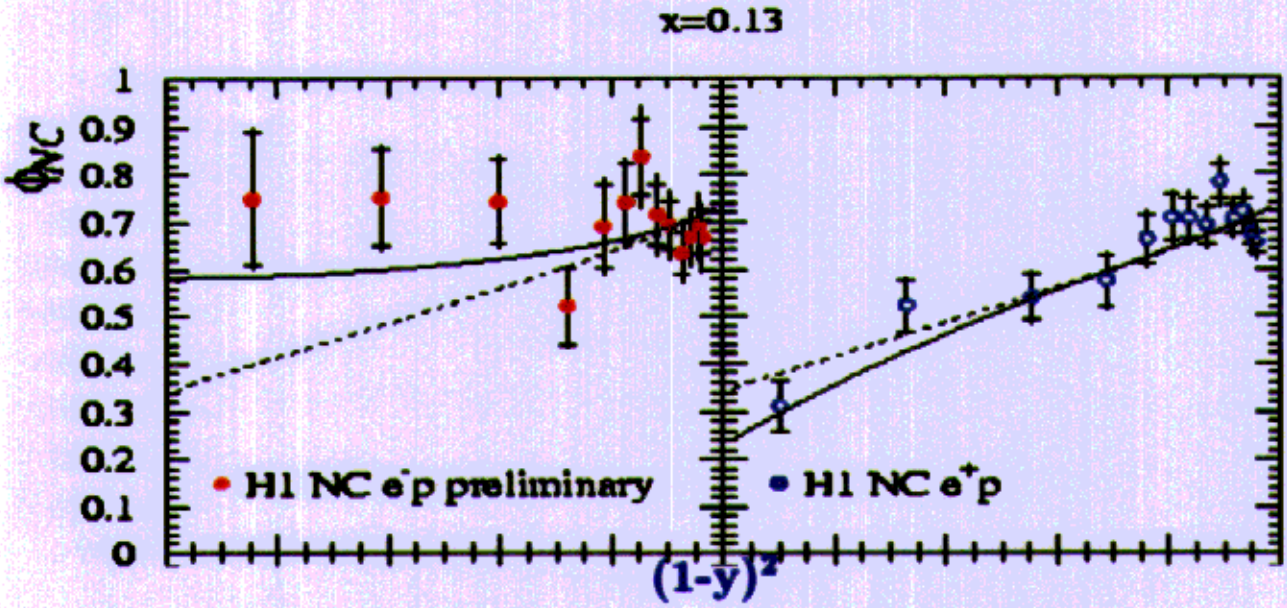


HERA EWK Measurements

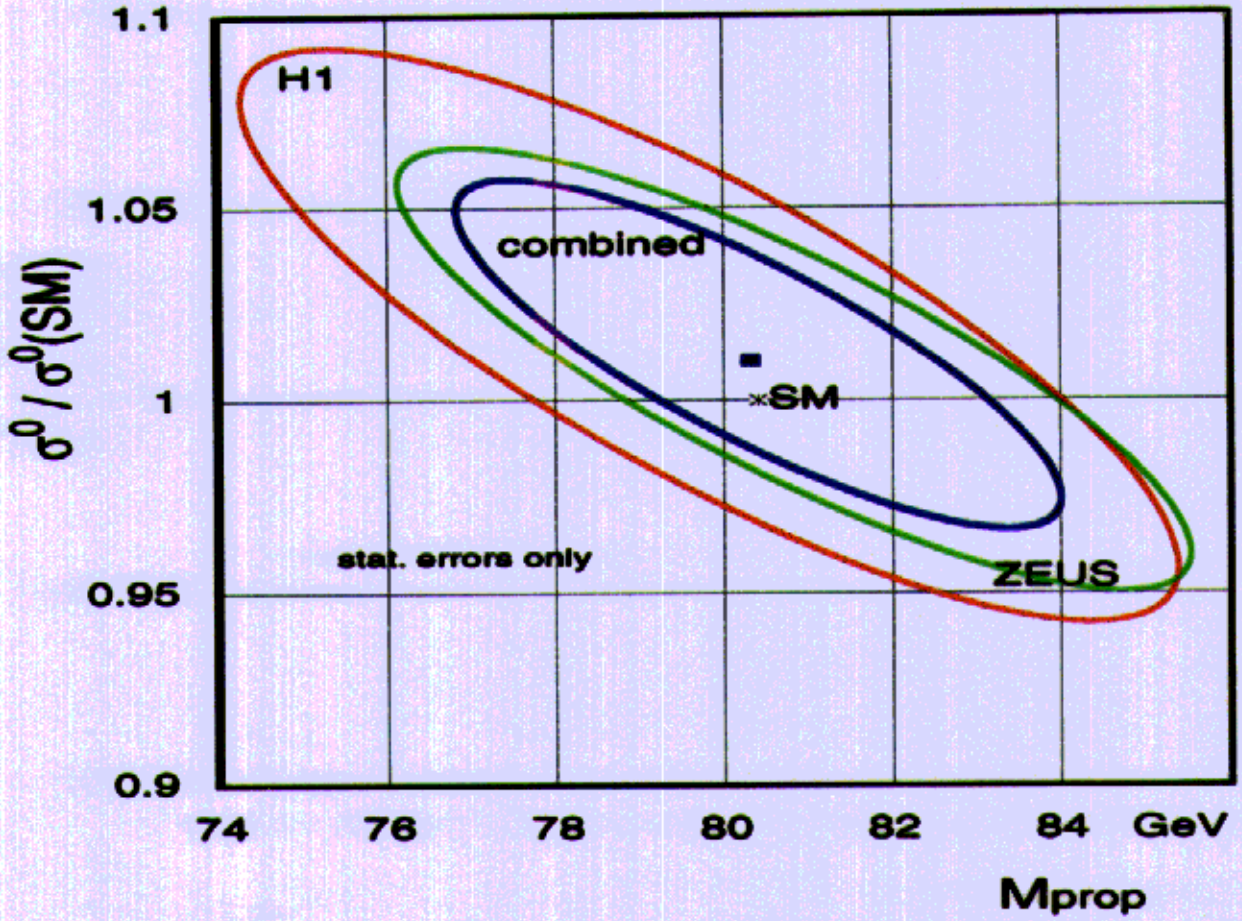
- **Probing EWK sector at 10^{-3} fm in space-like interactions**
- **No anomalous Q^2 behaviour to high Q^2**



- helicity structure : γ–Z interference.



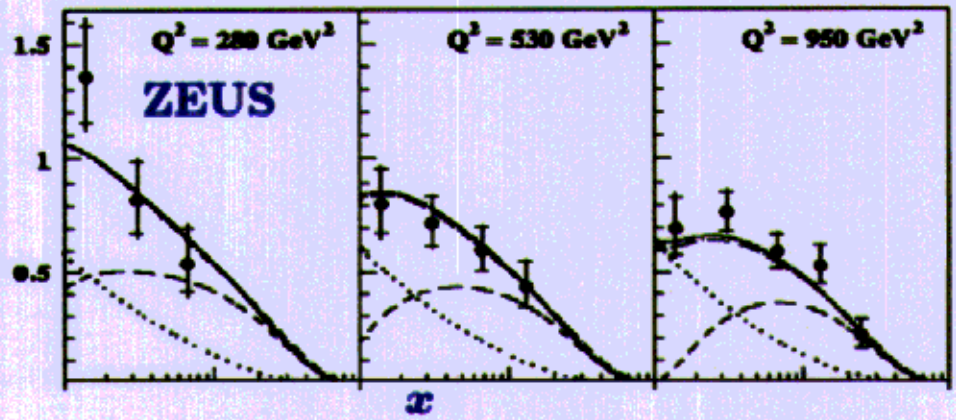
- # Direct Ws small : observe 11 expect ~ 8.
- CC propagator dependence : $\frac{d\sigma}{dQ^2} = \sigma^0 \left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 \phi_W$



M_{Prop} = 80.9 ± 3.3 (stat) ± 1.7 (syst.) ± 3.7 (pdf) : H1

$80.9^{+2.7}_{-2.6}$ (stat) ± 2.0 (syst.) $^{+3.3}_{-3.0}$ (pdf) : ZEUS

Using SM relation between $G_F + M_W$: $\Delta M_w \sim 400$ MeV



Outlook

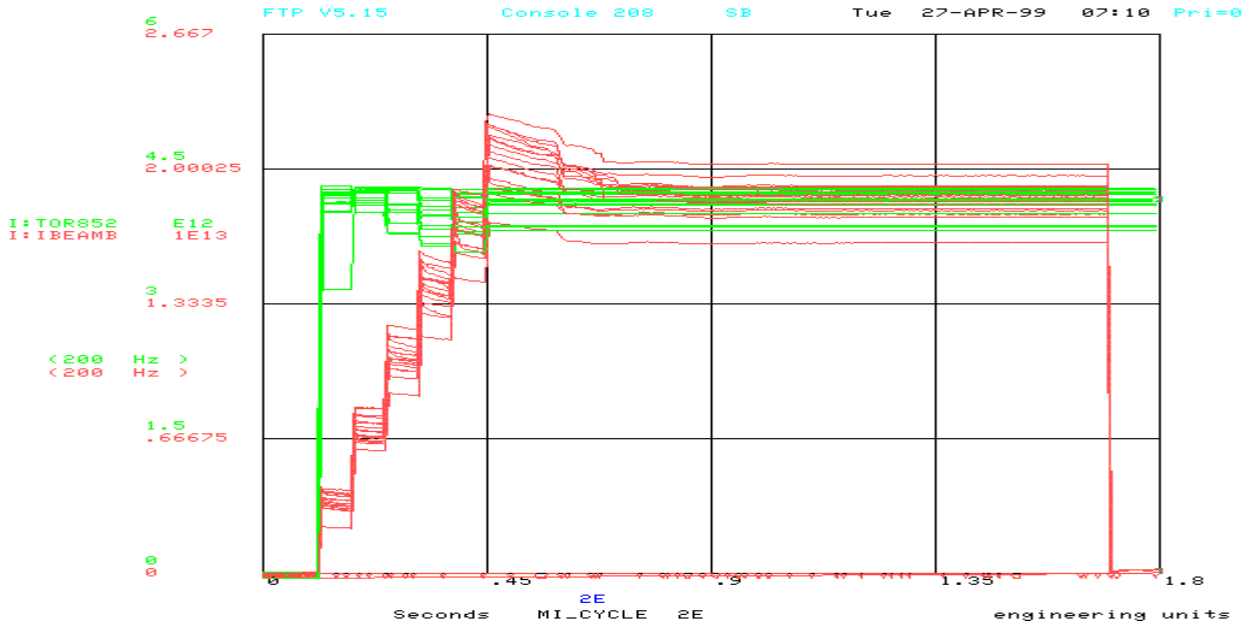
- **All EWK results are presently dominated by statistical uncertainties : either directly or in the control samples.**

- **NuTev no futher runs planned : final $\Delta M_{\mathrm{W}} \sim 90$ MeV**

- **HERA + Tevatron expect large increase in data sample**

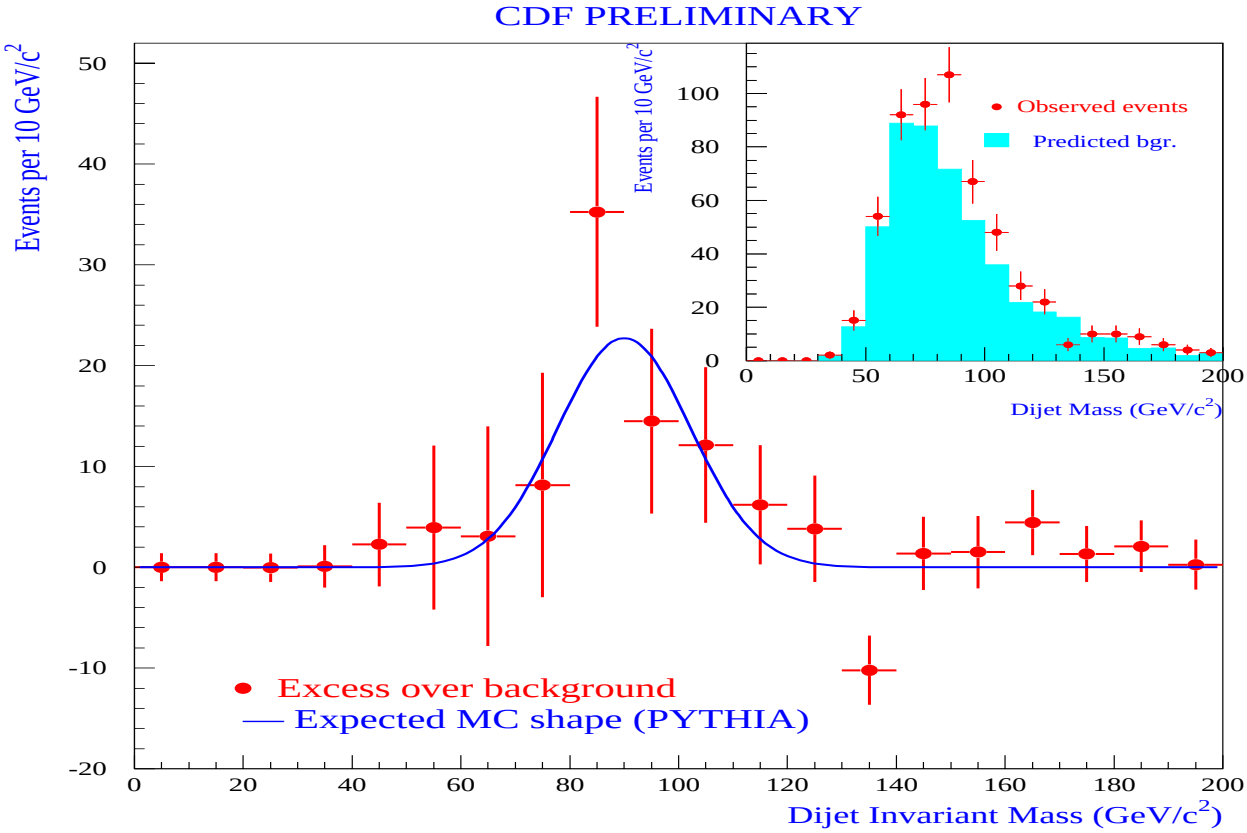
- **HERA :**
  - **Luminosity upgrade : 150 pb^{-1}/year/exp.**
  - **Polarised e$^-$ and e$^+$**
  - **Detector upgrades e.g Si detector.**
  - **$\Delta M_{\mathrm{W}} < 100$ MeV**

- **Tevatron :**
  - **Lumi upgrade : > 2000 pb^{-1}/exp @ $\sqrt{S} = 2.0$ TeV**
  - **Significant detector/DAQ upgrades.**



Outlook

- $M_T + M_W$ measurements will become systematics limited.
- W mass : statistical error $\sim$ 10 MeV per exp.
  - Many of systematics e.g. energy scale, W pT scale with Z statistics
  - But e.g. QED uncertainties, PDFs do not.
- Expect $\Delta M_W \sim$ 20–40 MeV from Tevatron
- W width : $\Delta\Gamma_W \sim$ 20-40 MeV
- Top Mass
  - Statistical error $\sim$ 1 GeV per experiment.
  - Systematics of QCD radiation and b-jet energy scale will dominate
  - Conservative estimate : $\Delta M_T \sim$ 2–3 GeV per exp.



Conclusions

- EWK results from hadron colliders complement those from e^+e^-
- Higher cross sections and $\sqrt{S}$ allow greater precision in some measurements and some unique measurements e.g. top quark mass.
- Results in beautiful agreement with SM in a range of processes : qq, eq, νq over a large range of Q^2 virtualities.
- Future is bright pre-LHC, expect significant results from Tevatron + HERA.