M_W - 1A and 1B Event Sample

$W \to e\nu$

- ⋆ e in central calorimeter (CC): $|\eta| < 1.2$(1.0 for 1B)
- ⋆ electron: $p_T^e > 25$ GeV
- ⋆ neutrino: $\not{E}_T > 25$ GeV
- ⋆ W transverse momentum: $P_T^W < 30$ GeV
- ⋆ transverse mass (1A) $50 < M_T^W < 110$ GeV

$Z \to ee$

- ⋆ e's in CC: $|\eta| < 1.2$(1.0 for 1B)
- ⋆ 2 isolated electrons: $p_T(e) > 25$ GeV
- ⋆ invariant mass (1A) $70 < M_Z < 110$ GeV

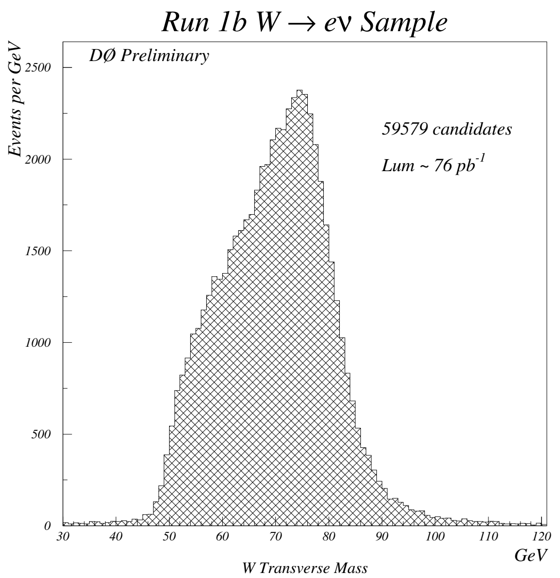
$W \to e\nu$

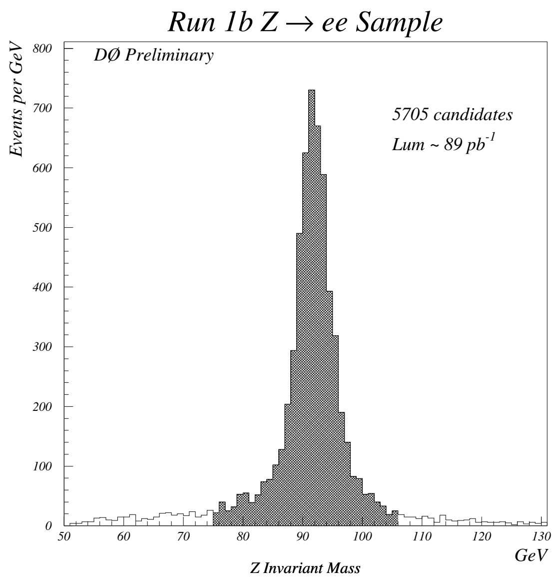
Topology	1A	1B
Central Calorimeter (CC)	7234	32856
End Calorimeters (EC)	3519	24670

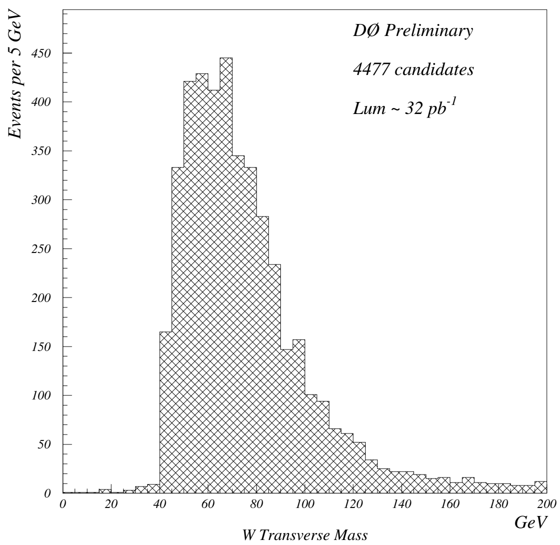
$Z \to ee$

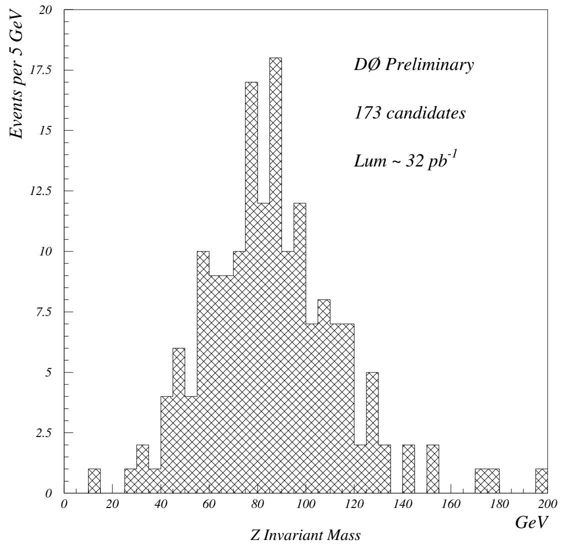
Topology	1A	1B
CC-CC	366	1562
CC-EC	281	1548
EC-EC	87	646

W and Z Spectra - Run 1B









Electron Identification - DØ

Offline Selection - Electron Quality Cuts:

- fraction of energy in EM calorimeter $> 90\%$
- longitudinal and transverse shower shape requirements:
  H-matrix $\chi^2 < 100$
- isolation requirement:

$$\frac{E_{tot}(R = 0.4) - E_{EM}(R = 0.2)}{E_{EM}(R = 0.2)} < 0.15$$

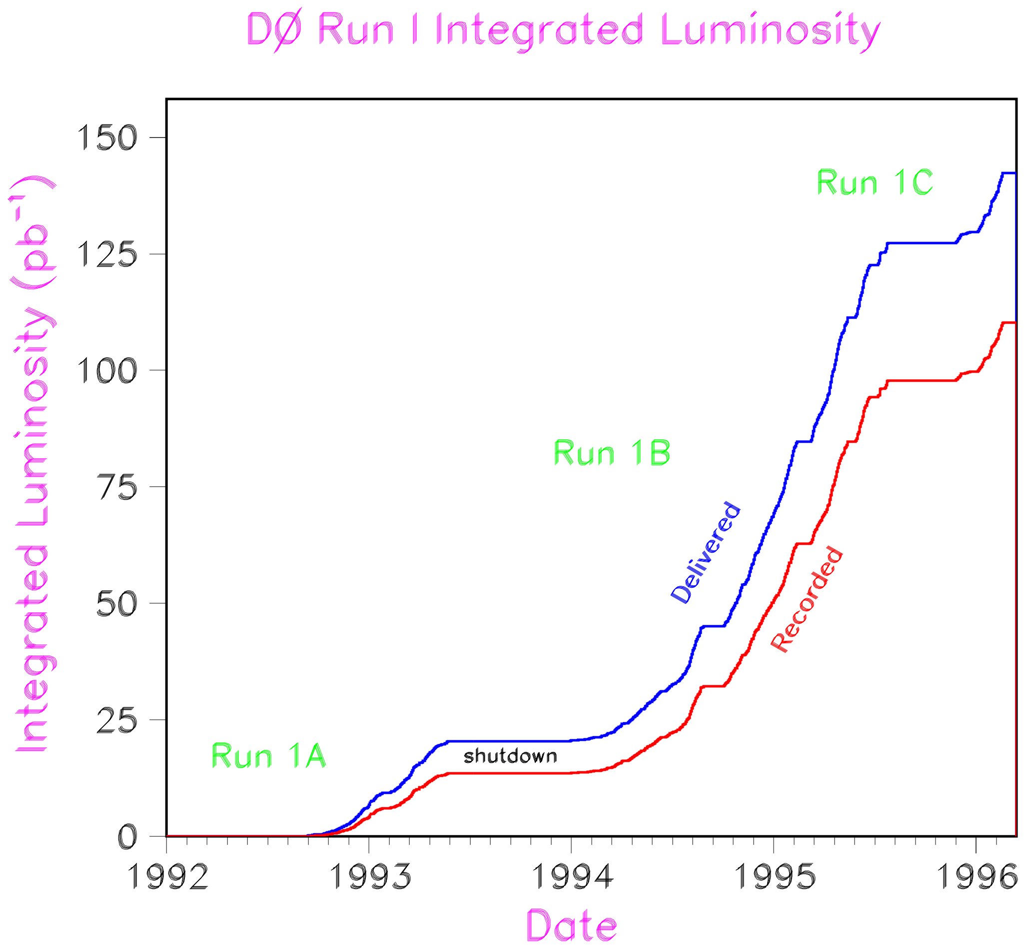
- fiducial requirement: $\phi > 10\%$ from module edge
- match between track in central detector and calorimeter

$$\sigma_{trk} < 10$$

  where

$$\sigma_{trk} = \sqrt{\left(\frac{R\Delta\phi}{\sigma(R\Delta\phi)}\right)^2 + \left(\frac{\Delta z}{\sigma(z)}\right)^2}$$

- event requirement: no jets with fraction of energy in CH > 0.4


DØ Run I Integrated Luminosity
Integrated Luminosity (pb⁻¹)
150
125
100
75
50
25
0
1992
1993
1994
1995
1996
Date
Run 1A
shutdown
Run 1B
Run 1C
Delivered
Recorded

DØ Top Mass History

March 1995 $m_{top} = 199^{+19}_{-21}(stat) \pm 22(syst.)$

- 17 events, background $= 3.8 \pm 0.6$
- PRL 74, 2632(1995)

Feb 1996 major changes: doubled luminosity, particle ID, jet energy scale

$m_{top} = 170 \pm 15(stat) \pm 10(syst.)$

July 1996 major changes: multivariate discriminate

$m_{top} = 169 \pm 8(stat) \pm 8(syst.)$

- world avg $= 175 \pm 6$

Feb 1997 major changes: full data set, jet energy scale, fully-optimized analysis

$m_{top} = 173.3 \pm 5.6(stat) \pm 6.2(syst.)$

- world avg $= 175.6 \pm 5.5$
- submitted to PRL
- hep-ex/9703008 & Fnal-pub-97/059-E

DØ Top Mass Analysis Method

- use events with 4 or more jets (corrected to parton level)
  - 90 events, 7 with b tag
- fit to find m_{fit} and χ^2 (constrained fit)
  - use permutation with smallest χ^2
  - require $\chi^2 < 10 \rightarrow 77$ events, 5 with b tag
- compute signal probability, $\mathcal{D}$ (discriminant)
  - $\mathcal{D}$ from 0 to 1 (background to signal-like)
  - 4 variables in discriminant with small correlation to m_{fit}:

    $x_1 = \not{E}_T$

    $x_2 =$ aplanarity

    $x_3 = H_{T2}$ - centrality of event

    $x_4 =$ measure of extent to which jets are clustered together
- do 2D fit in $(\mathcal{D}, m_{fit})$ to signal and background models to determine likelihood $\mathcal{L}$
  - signal model: Herwig (5.7) for $t\bar{t}$
  - background models: Vecbos (3.0) for $W + jet$, Data for fake lepton bkgnd
  - LowBias method: 2 bins in $\mathcal{D}$ (signal-rich and bkgnd-rich) passes if has μtag, fails if $\mathcal{D} < .43$ or $H_{T2} < 90$ GeV
    20 bins in m_{fit}
  - Neural Net method: 20 bins in $\mathcal{D}$
    20 bins in m_{fit}
- quadratic fit in $(-ln\ \mathcal{L})$ to extract m_{top}

  LB fit: $m_{top} = 174.0 \pm 5.6(stat)$

  NN fit: $m_{top} = 171.3 \pm 6.0(stat)$

Top Mass Analysis
Event Selection

- $E_T^l > 20$ GeV, $|\eta_e| < 2.0$, $|\eta_\mu| < 2.0$
- $\not{E}_T > 20$ GeV
- $\not{E}_{T\ cal} > 25(20)$ GeV for $e(\mu)+$ jets
- ≥ 4 jets with $E_T > 15$ GeV and $|\eta_{jet}| < 2.0$
- $E_T^L \equiv (E_T^l + \not{E}_T) > 60$ GeV and $|\eta_W| < 2.0$

OR

- $b-$tag muon:
  $p_T^\mu > 4$ GeV, within $\sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.5$ of a jet

90 events selected, 7 with $b-$tag

- constrained fit $\longrightarrow m_{fit}$
- require $\chi^2_{fit} < 10$

final: 77 events selected, 5 with $b-$tag

Top Quark Mass Results

Fits to data		---LB fit---		---NN fit---	
Quantity fit		value	σ(stat)	value	σ(stat)
m_t (GeV/c^2)		174.0	$\pm$ 5.6	171.3	$\pm$ 6.0
n_s		23.8	$^{+8.3}_{-7.8}$	28.8	$^{+8.4}_{-9.1}$
n_b		53.2	$^{+10.7}_{-9.3}$	48.2	$^{+11.4}_{-8.7}$
Systematic error on $\boldsymbol{m_t}$		energy scale	$\pm$ 4.0		
		generator	$\pm$ 4.1		
		other	$\pm$ 2.2		
Resulting $\boldsymbol{m_t}$ (GeV/c^2)		**173.3 $\pm$ 5.6 (stat) $\pm$ 6.2 (syst)**			

Fits to MC	type	----input----			----output----		
(top + background)	of fit	m_t	$\langle n_s \rangle$	$\langle n_b \rangle$	$\langle \sigma_m \rangle$	$\langle m_t \rangle$	δm
full ensemble	LB	175	24	53	9.9	175.0	8.7
"	NN	172	29	48	8.5	171.6	8.0

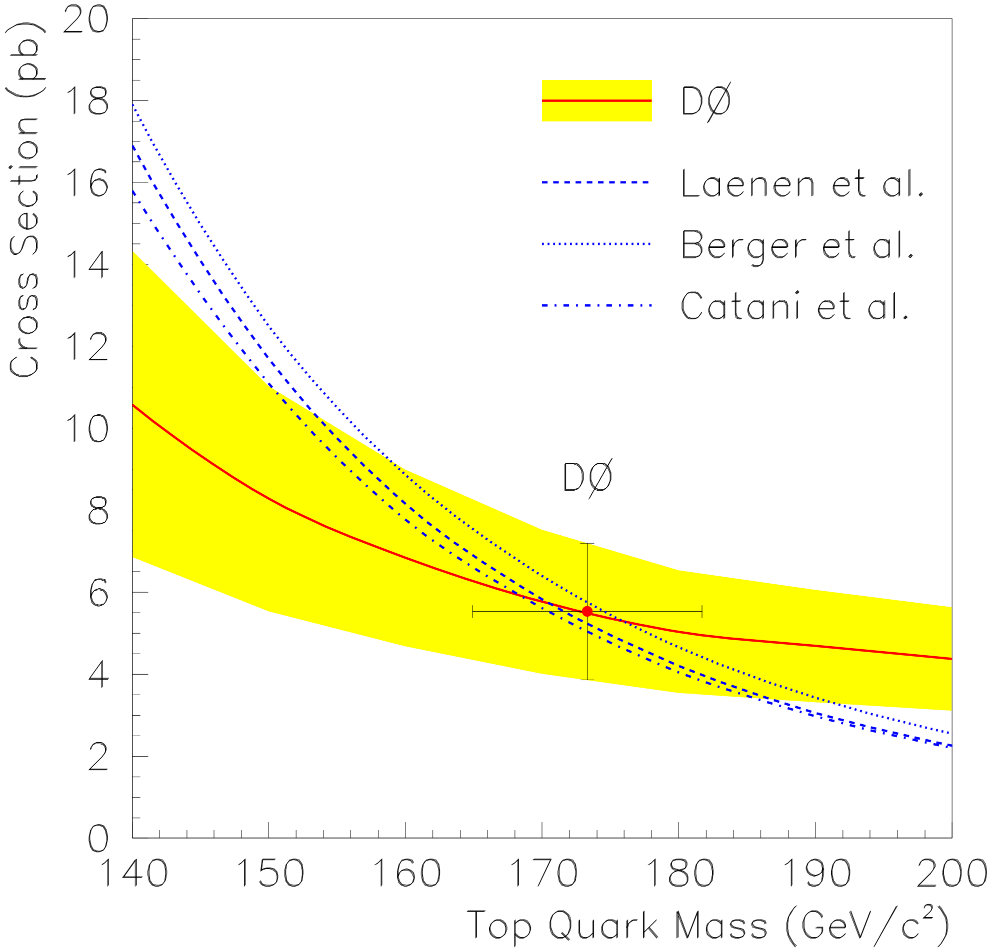
Top Mass - Systematic Errors

- **Jet Energy Scale → 4.0 GeV**
- **Generator (Isajet/Herwig) → 3.3 GeV**
- **Generator (VECBOS) → 2.6 GeV**
- **Multiple Interactions → 1.2 GeV**
- **MC statistics → 0.8 GeV**
- **LB/NN difference → 1.4 GeV**
- **Likelihood Fit → 1.0 GeV**
- **TOTAL → 6.2 GeV**

Top Mass - Jet Energy Corrections

- **Apply standard DØ corrections**
- **Correct to parton level (from $t\bar{t}$ MC)**
- η**-dependent corrections**
  - from study of E_T balance in $\gamma + jets$ in data & MC
- **examine scale difference between data and MC as function of $E_T(\gamma)$**
  $\Rightarrow$ **gives energy scale uncertainty** $\pm(2.5\% \times E_T + 0.5)$ **GeV**

Top Quark Results



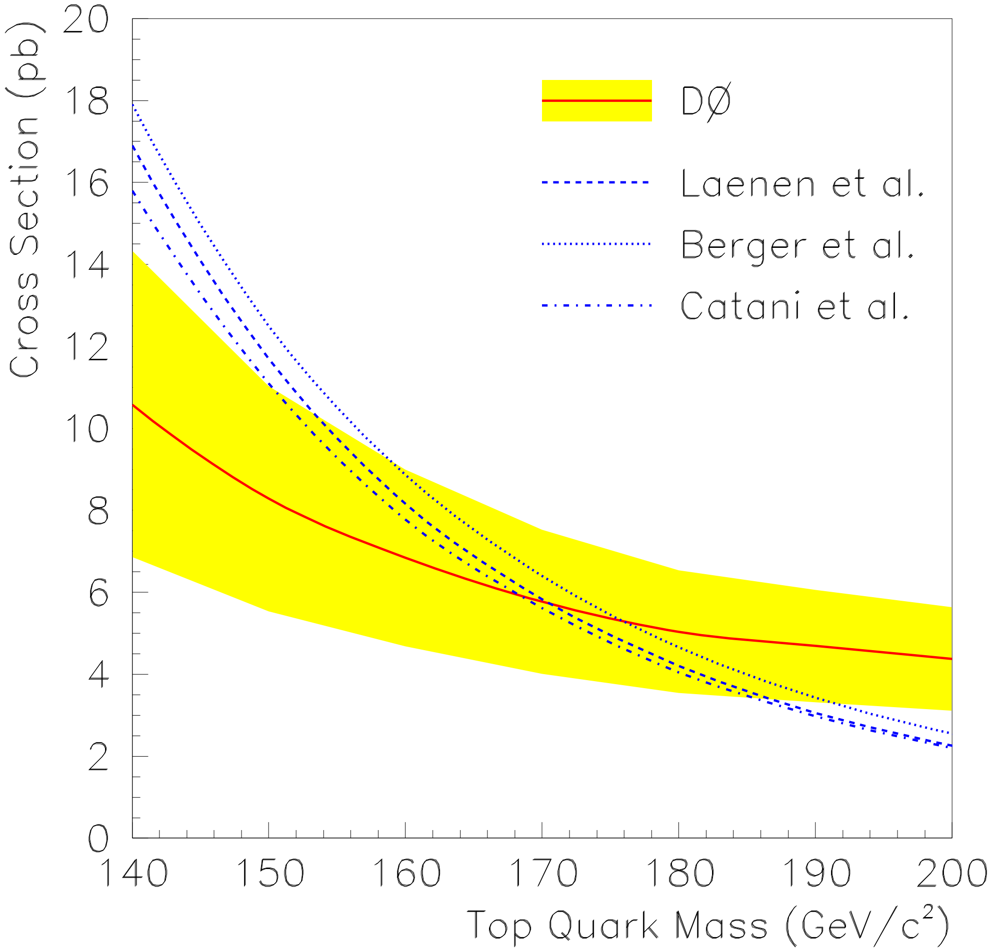
$$m_{top} = 173.3 \pm 5.6(stat) \pm 6.2(syst)\ \textbf{GeV}$$

$$\sigma_{t\bar{t}} = 5.53 \pm 1.67\ \textbf{pb}$$

New World Average:

$$m_{top} = 175.6 \pm 5.5\ \textbf{GeV}$$

Top Quark Results



$m_{top} = 173.3 \pm 5.6(stat) \pm 6.2(syst)$ **GeV**

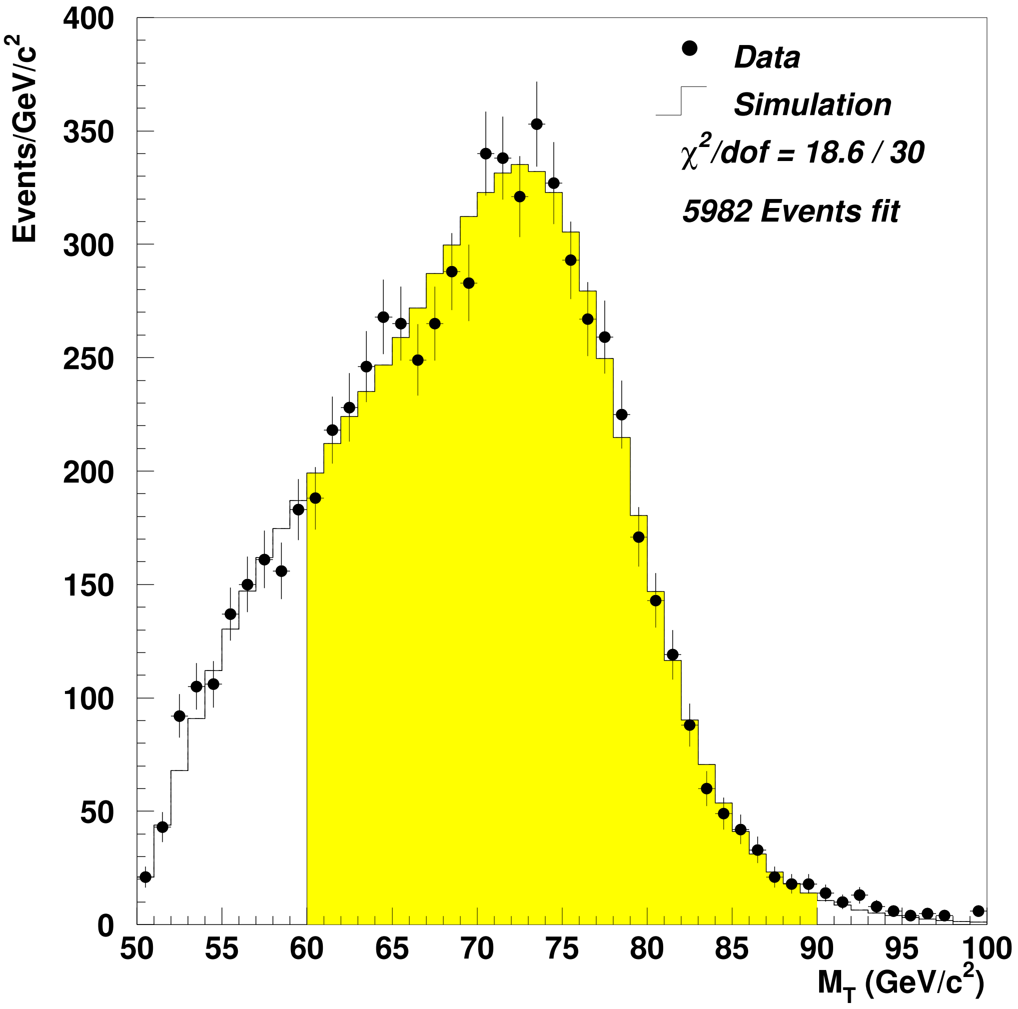
$\sigma_{t\bar{t}} = 5.53 \pm 1.67$ **pb**

New World Average:

$m_{top} = 175.6 \pm 5.5$ **GeV**

DØ Run 1A:
M_W - from Fit to Transverse Mass Spectrum

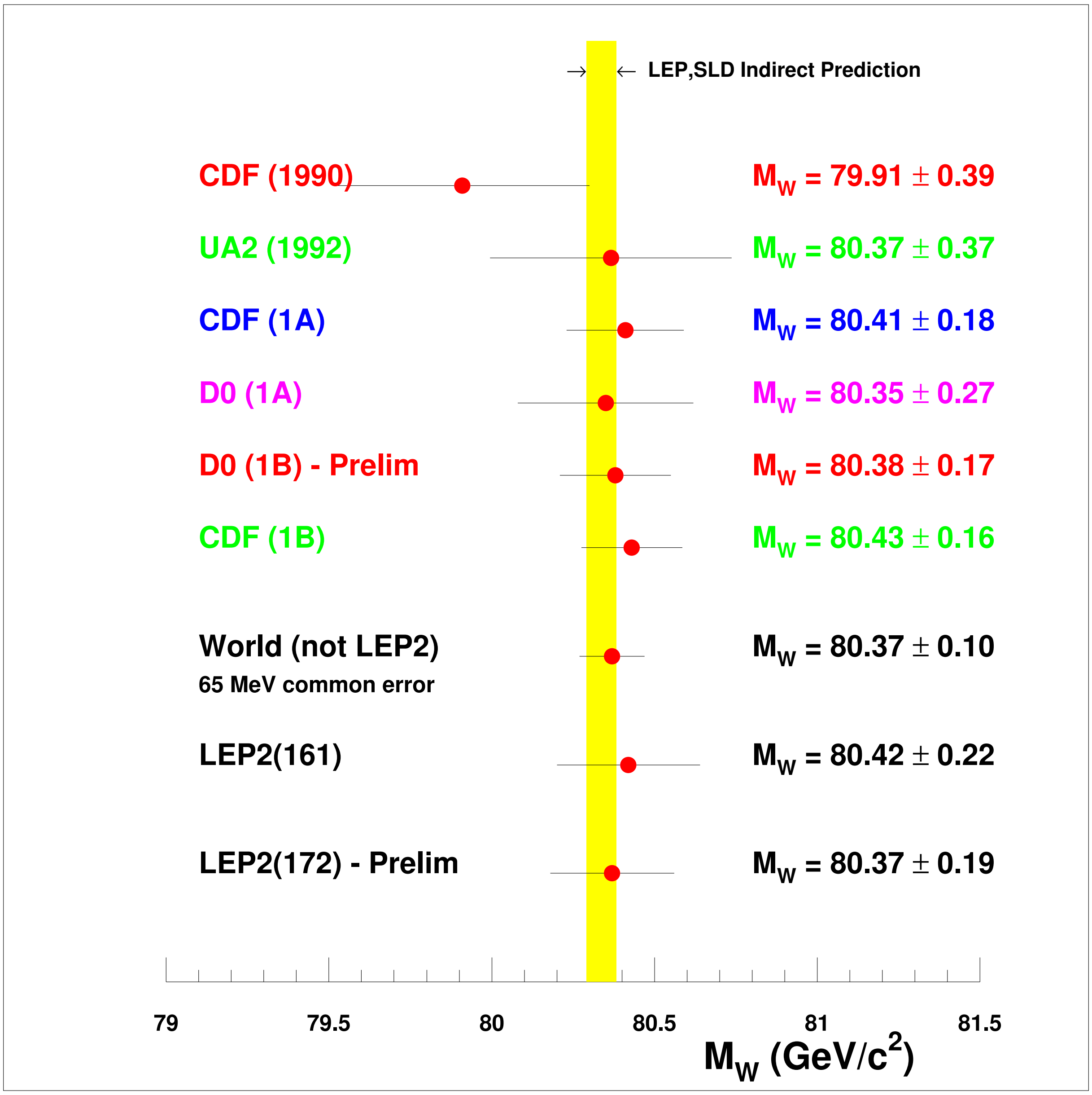
(fitting window 60 - 90 GeV)



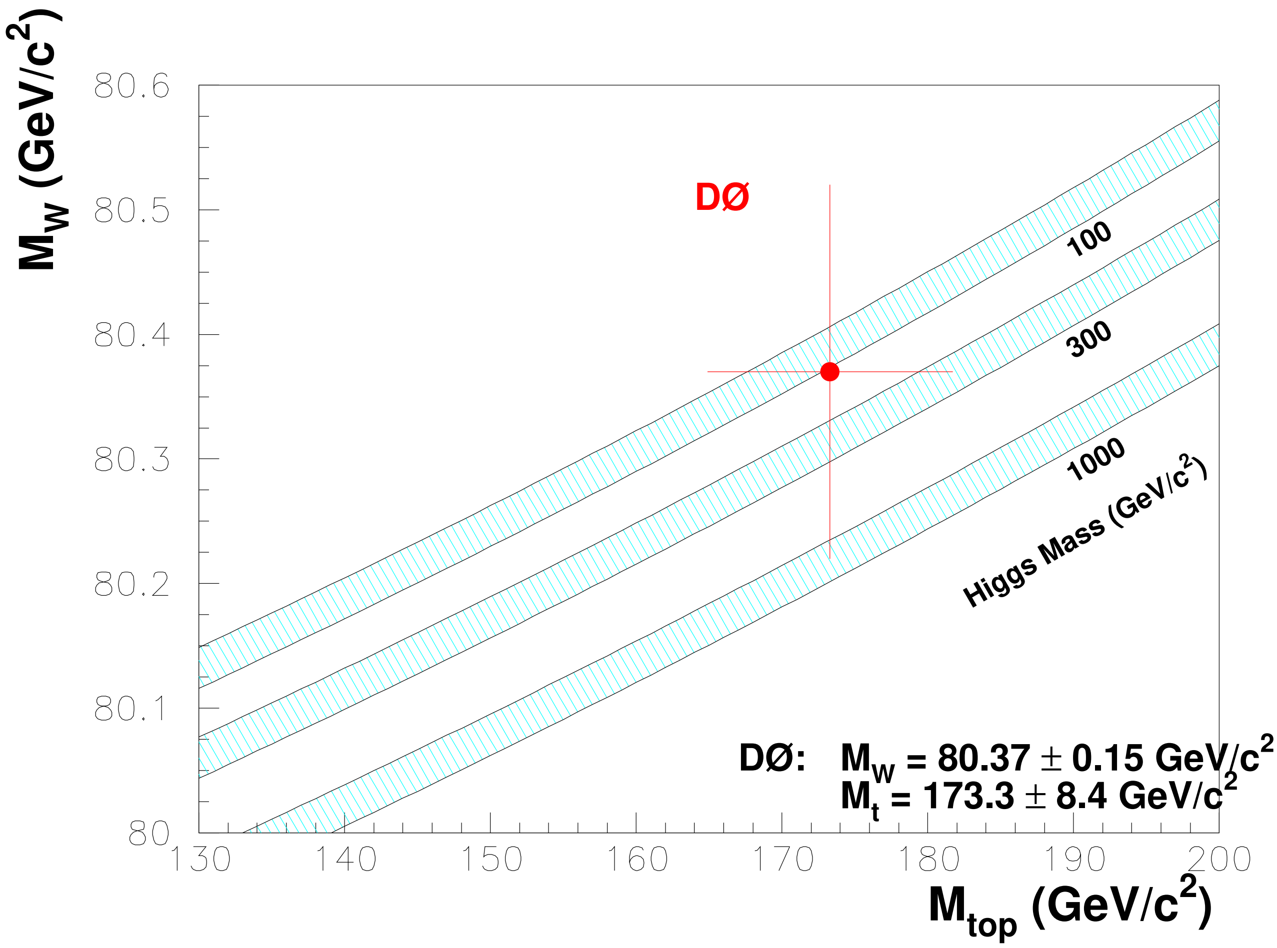
M_W(Run 1A) $= 80.350 \pm 0.140(stat.) \pm 0.160(scale) \pm 0.165(syst.)$ GeV/c^2

PRL 77, 3309 (1996), PRD in progress.

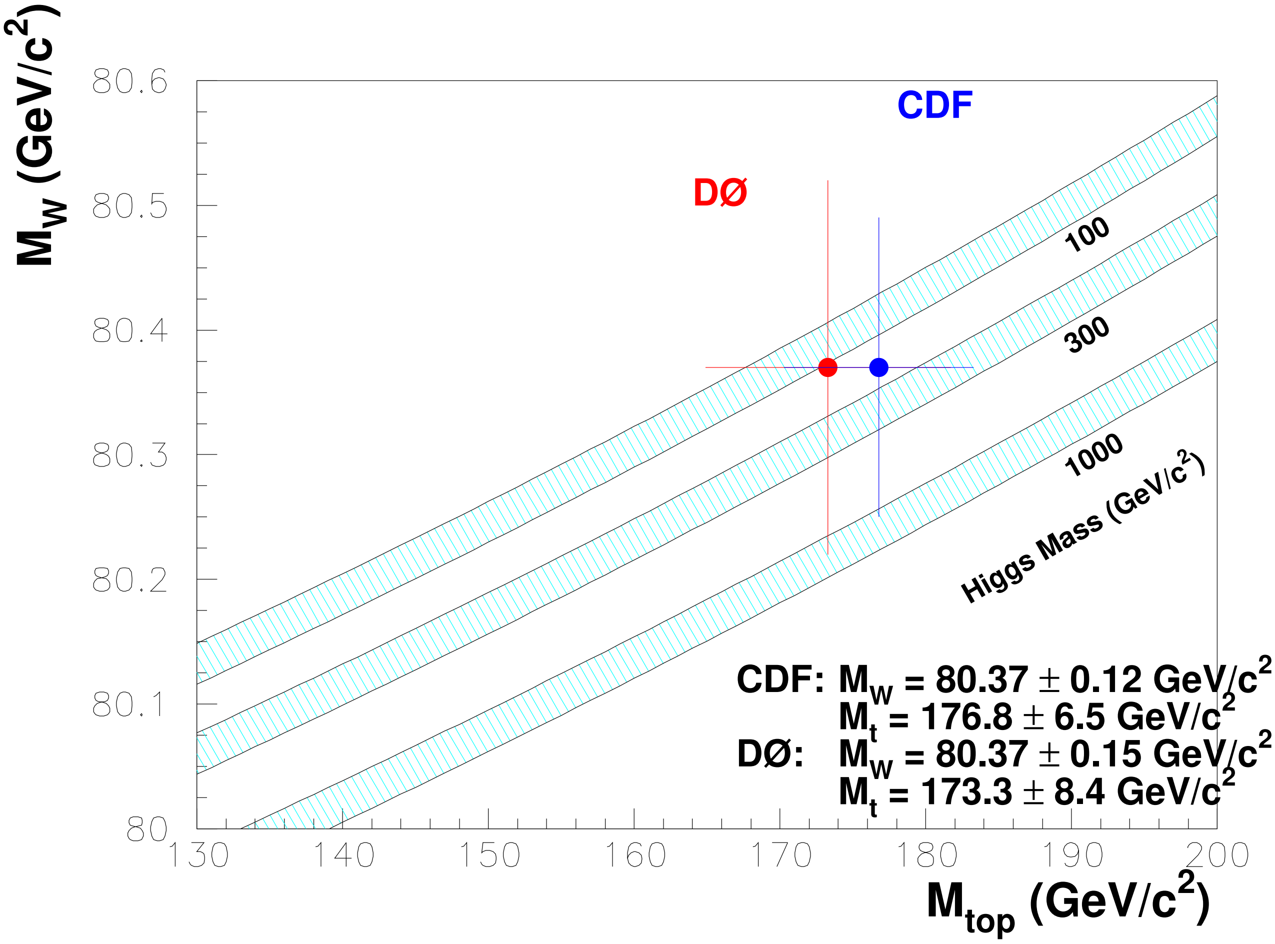
Current Results of M_W - March 97



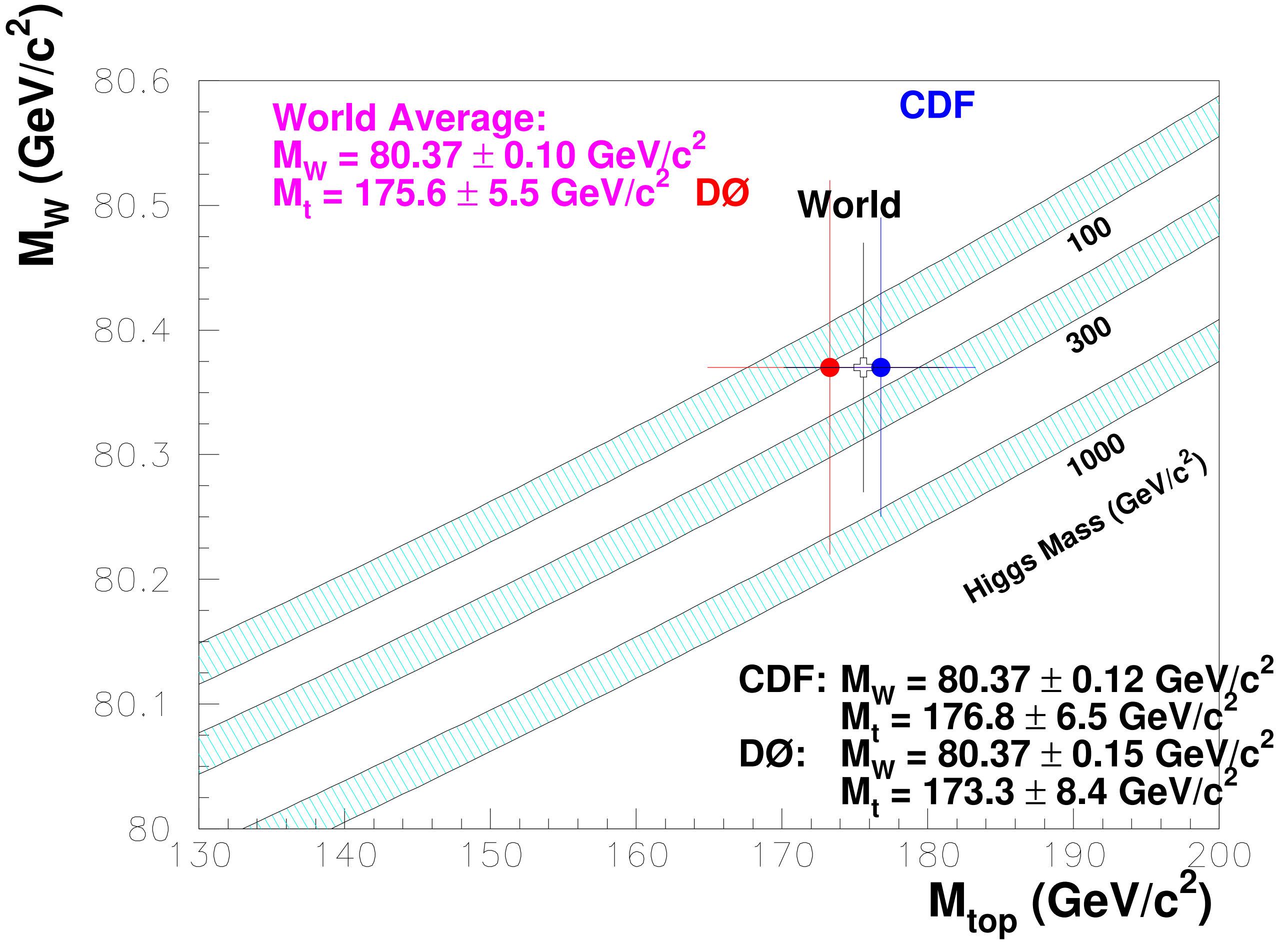
Constraints on Higgs Mass



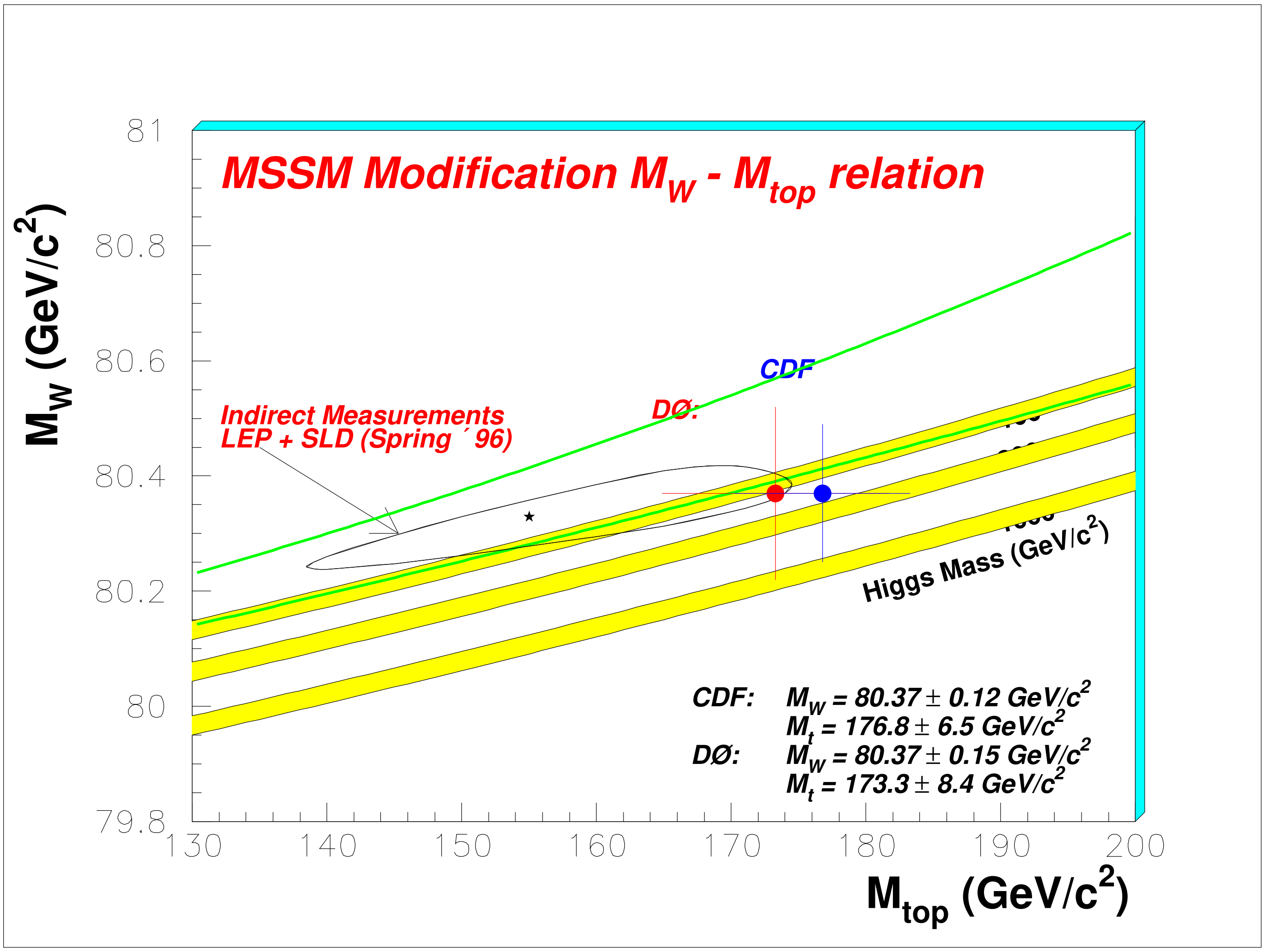
Constraints on Higgs Mass



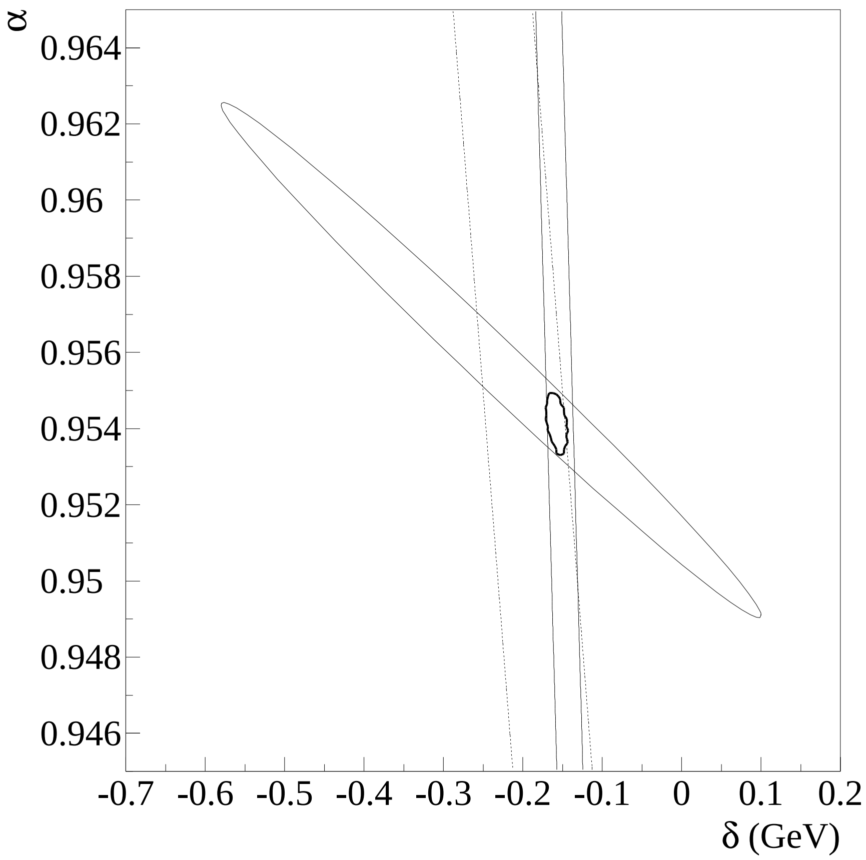
Constraints on Higgs Mass



Constraints on Higgs Mass



DØ Run 1B M_W
EM Energy Scale



$$E_{meas} = \alpha E_{true} + \delta$$

$\alpha = 0.95372 \pm 0.00091$ $\qquad$ $\delta = -0.16\ ^{+0.03}_{-0.21}$ GeV

Error due to EM scale: $\sigma(M_W) = 80\ \mathrm{MeV/c^2}$

DØ M_W Run 1B
EM Energy Scale

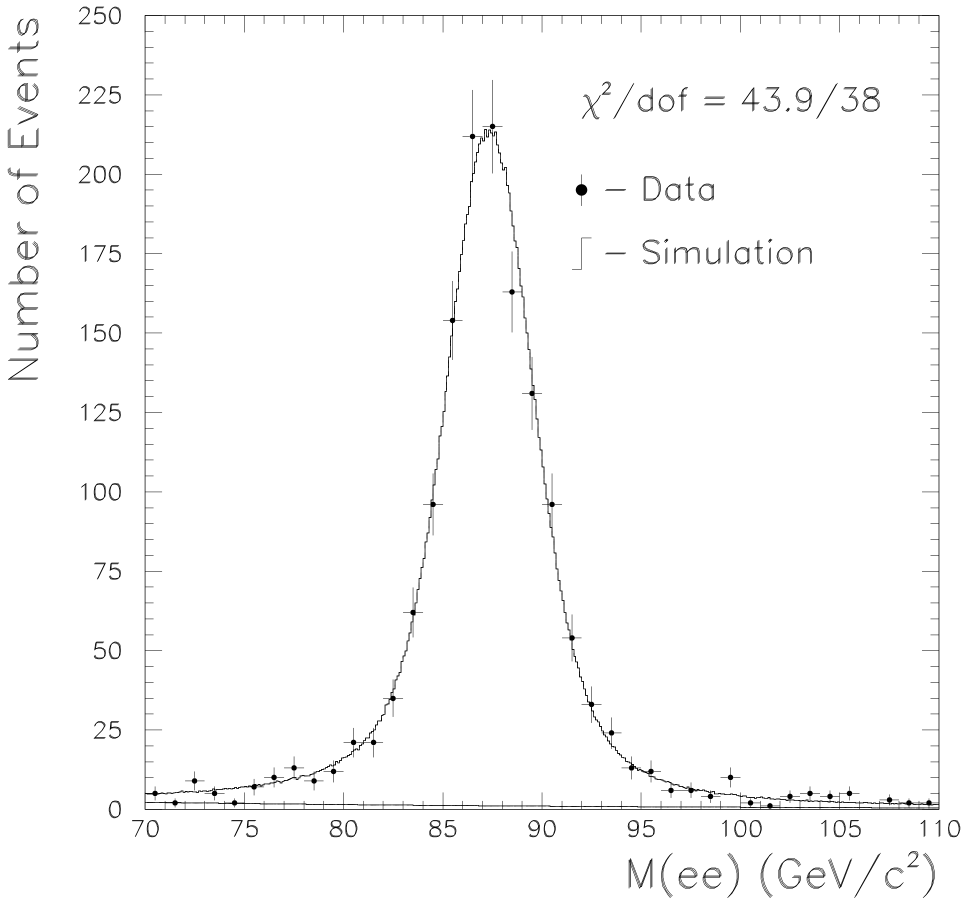


Figure 1: Distribution of invariant mass of the 2 electrons from Z decays

DØ Run 1A: M_W - EM energy scale

→ **Determine EM energy scale using J/ψ, π^0, and Z event samples**

→ **EM energy response:**

$$E^{meas} = \alpha E^{true} + \delta$$

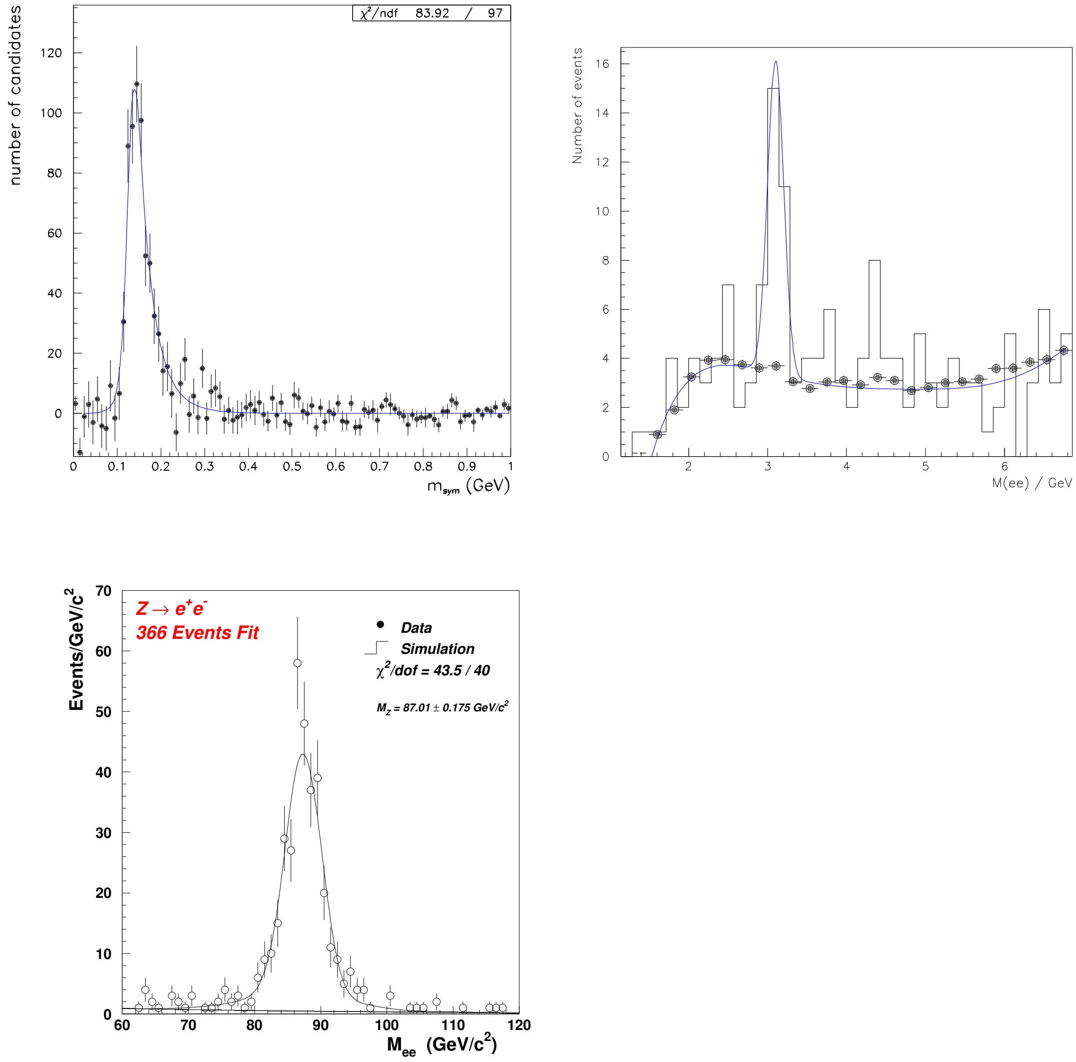


Figure 2: Distributions in mass of $\pi^0, J/\psi$ and Z events

DØ Run 1A: M_W - EM energy scale

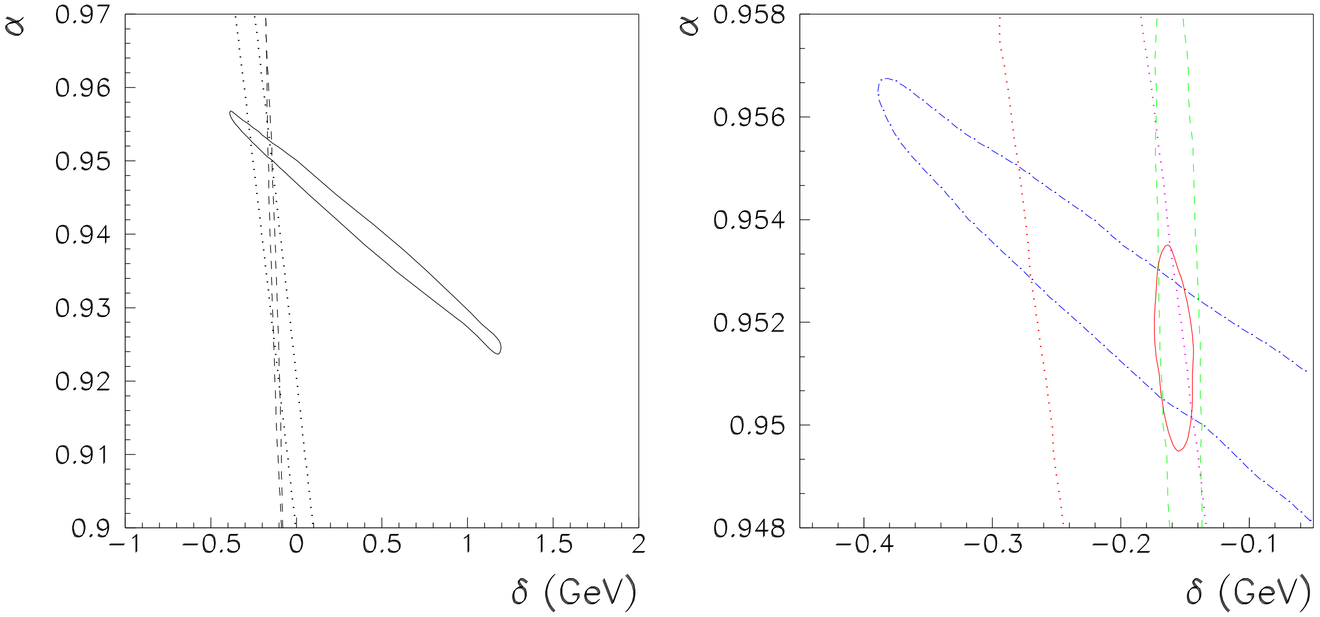


Figure 3: Values of scale (α) and offset (δ) of EM energy scale mapped out by the J/ψ (dotted), π^0 (dashed) and Z (line) events. The overlap region of all 3 data samples constrains the values of α and δ.

$$\alpha = 0.9514 \pm 0.0018 \qquad \delta = -0.158 \pm 0.015 \,{}^{+.030}_{-.210}\ \text{GeV}$$

error on M_W due to EM scale: $\sigma(M_W) = 160$ MeV

$\star$ **error dominated by Z statistics**

Di-Boson Production
$\rightarrow$ Study of Anomalous Couplings

The most general effective Lagrangian, invariant under $U(1)_{EM}$, for the $WW\gamma, WWZ$ interactions contains 4 coupling parameters:

CP-conserving parameters: related to magnetic dipole (μ_W) and electric quadrupole (Q^e_W) moments of the W.

κ, λ **with**

$\mu_W = \frac{e}{2M_W}(1+\kappa+\lambda)$ **and** $Q^e_W = \frac{-e}{M_W^2}(\kappa-\lambda)$

CP-violating parameters: related to electric dipole (d_W) and magnetic quadrupole (Q^m_W) moments of the W.

$\tilde{\kappa}$, $\tilde{\lambda}$ **with**

$d_W = \frac{e}{2M_W}(\tilde{\kappa}+\tilde{\lambda})$ **and** $Q^m_W = \frac{-e}{M_W^2}(\tilde{\kappa}-\tilde{\lambda})$

A $WW\gamma, WWZ$ interaction Lagrangian with constant, anomalous couplings violates unitarity at high energies, and therefore the coupling parameters must be modified to include form factors:

$$\Delta\kappa \rightarrow \frac{\Delta\kappa}{(1+\frac{s}{\Lambda^2})^2}$$

Di-Boson Production
$\rightarrow$ Study of Anomalous Couplings

The most general $ZZ\gamma(Z\gamma\gamma)$ vertex is described by 4 coupling parameters:

CP-conserving parameters: related to electric dipole and magnetic quadrupole moments of the vertex.
h_3, h_4

CP-violating parameters: related to magnetic dipole and electric quadrupole moments of the vertex.
h_1, h_2

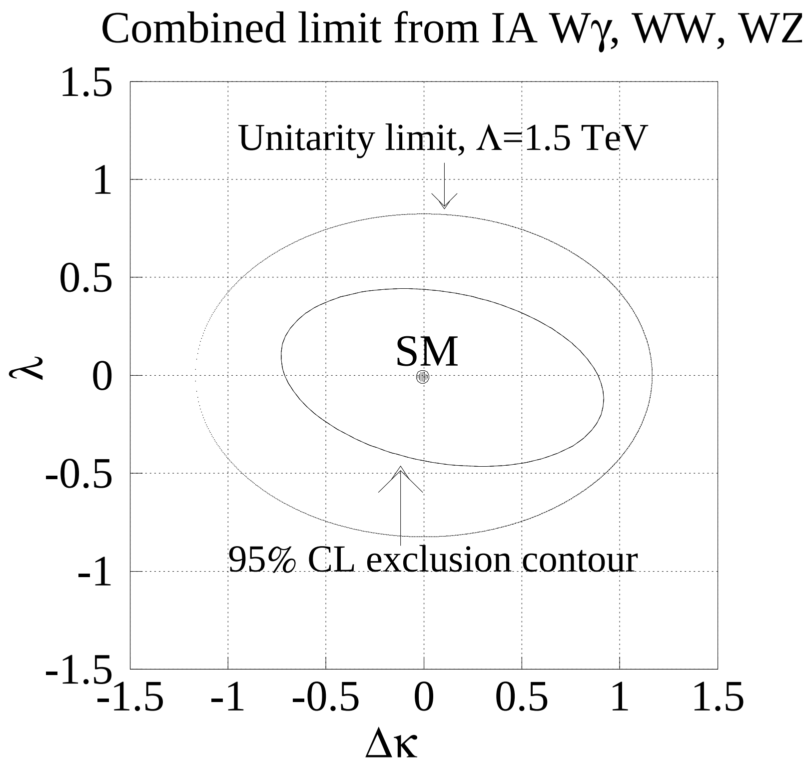
Nonzero (*i.e. anomalous*) values of the couplings result in increase in production of $Z\gamma$ and change in kinematic distributions
Unitary restricts the couplings to their vanishing SM limits at high energies and the couplings are therefore modified by form factors:

$$h_i = \frac{h_{i0}}{(1 + \frac{s}{\Lambda^2})^n}$$

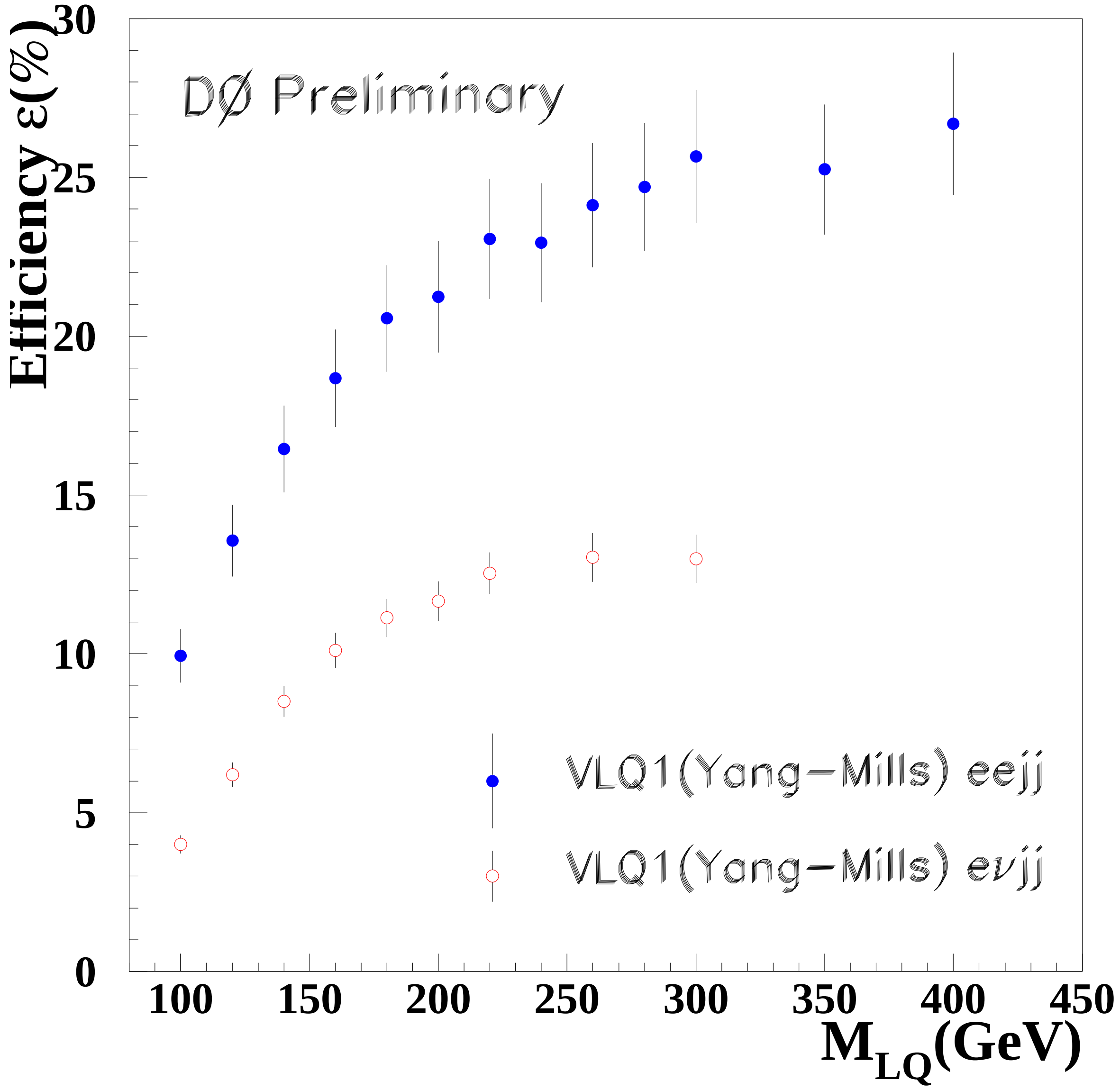
with $n = 3$ for $h_{1,3}$ and $n = 4$ for $h_{2,4}$

Combined Results from $W\gamma$, WW and WZ Production - Run 1A

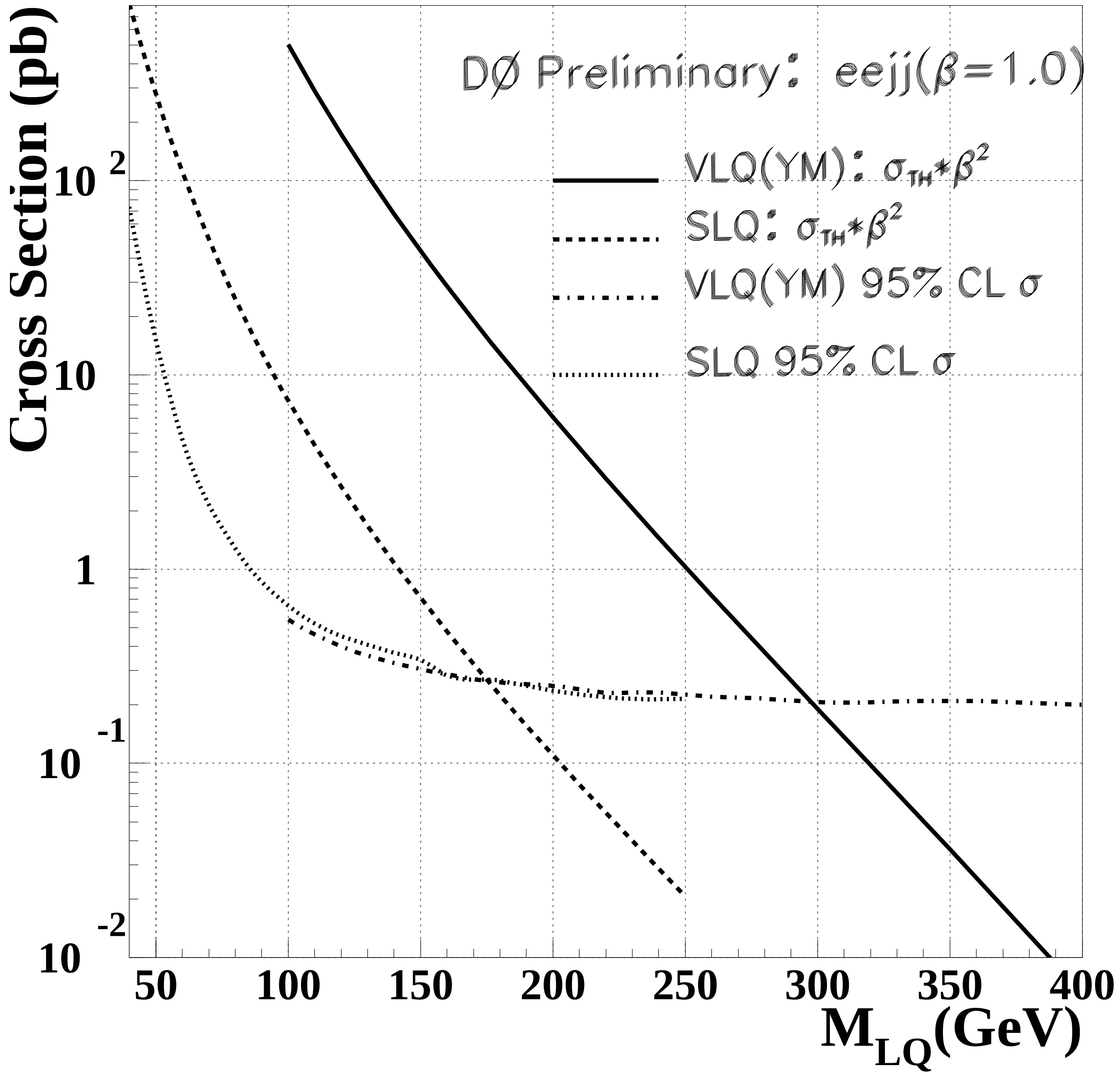
	$a < \kappa - 1 < b$ a,b	$a < \lambda < b$ a,b
$W\gamma \to e\nu\gamma, \mu\nu\gamma$	$-1.6, 1.8$	$-0.6, 0.6$
$WW \to ee, e\mu, \mu\mu$	$-2.6, 2.8$	$-2.1, 2.1$
$WW/WZ \to e\nu jj$	$-0.9, 1.1$	$-0.6, 0.7$
Combined Result (PRELIMINARY)	$-0.71, 0.89$	$-0.44, 0.44$



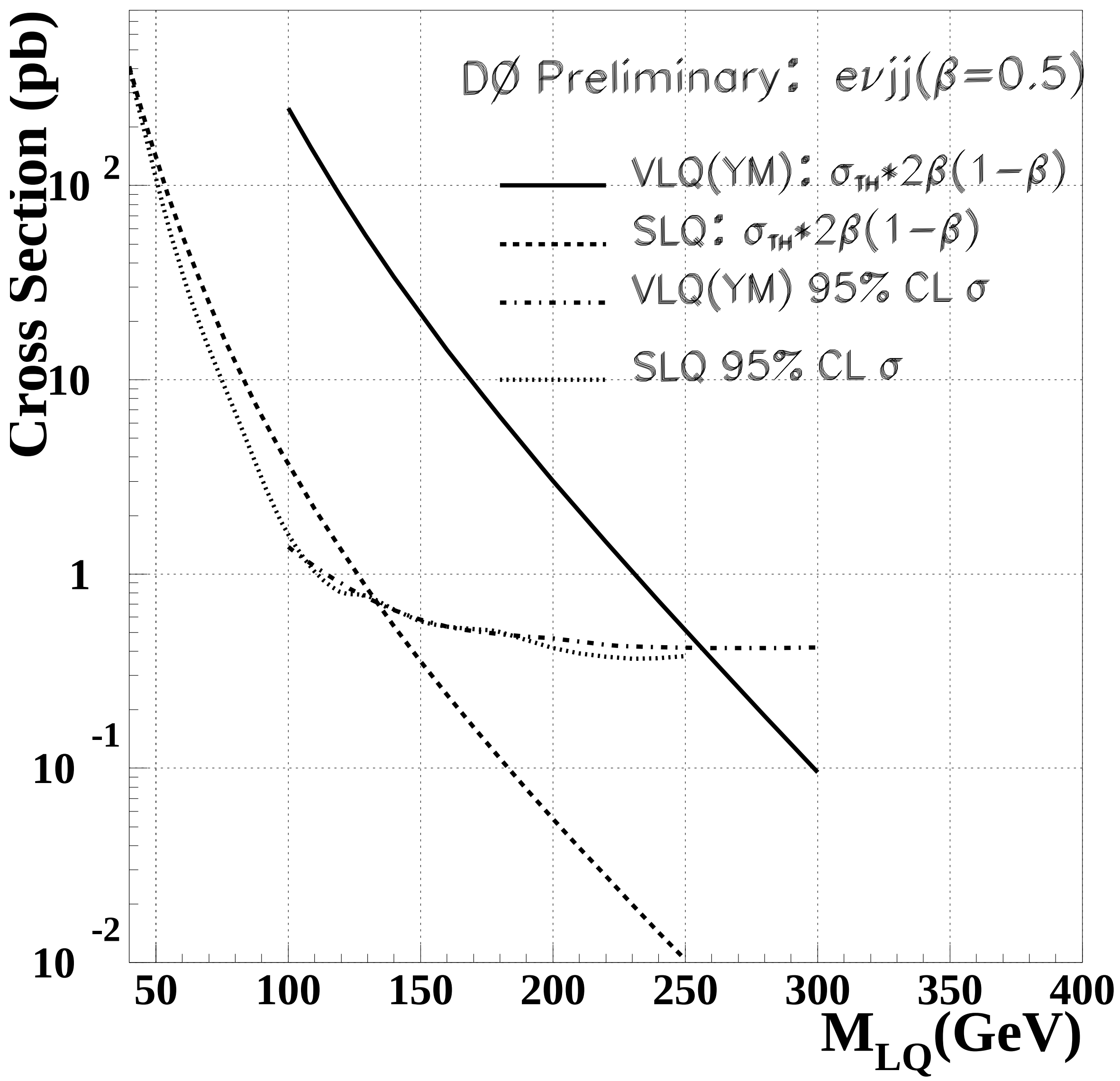
Leptoquarks - First Generation



Leptoquarks - First Generation



Leptoquarks - First Generation



DØ Second Generation Leptoquarks

$\beta = 1.0 (\mu\mu jj$ channel)

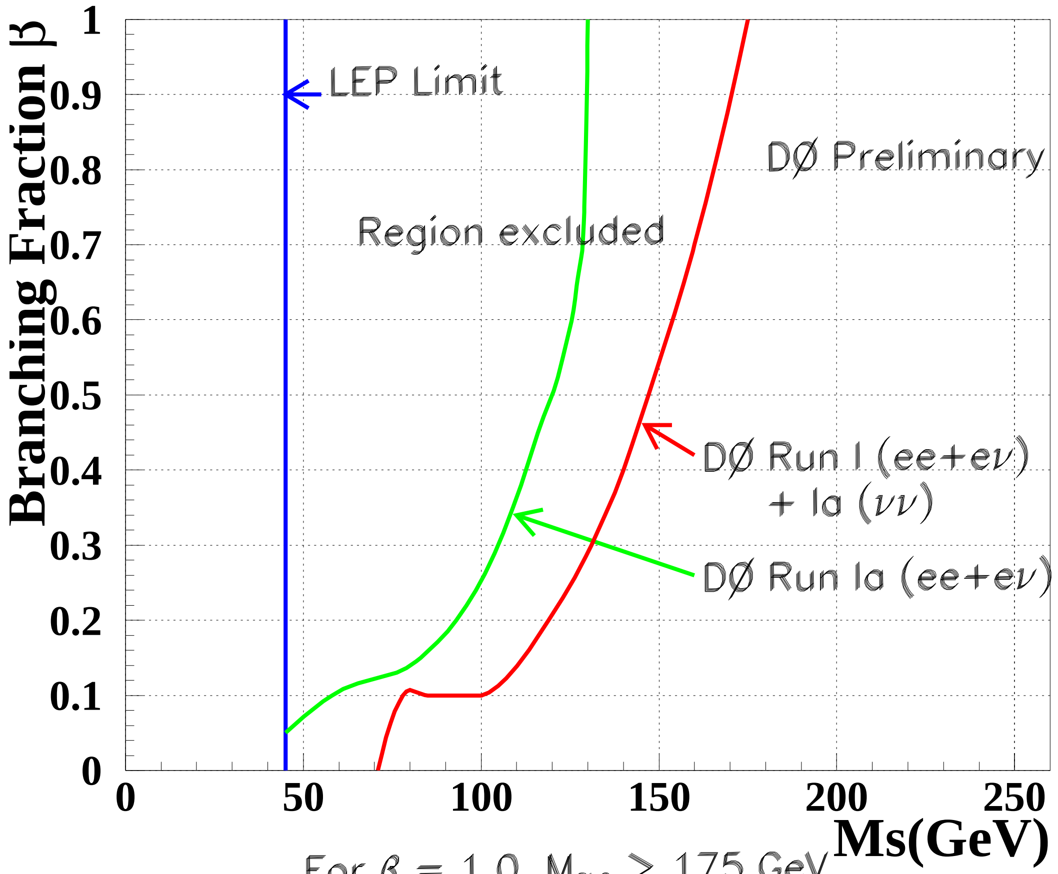
Data sample is the 1994-1996 Tevatron run - 94.4 pb^{-1}.

Event Selection:

- Trigger : Require a MU_JET_xxxx trigger.
- 2 CF Muons : $p_T > 15$ GeV/c with loose muon ID and isolation $\Delta R\ (\mu, jet) > 0.5$ required.
- 2 Jets : $E_T > 20$ GeV , use 0.5 cone jet algorithm, $|\eta| < 2.5$
- $\Delta\phi(\vec{p}_T^{\mu_1}, \vec{p}_T^{\mu_2}) < 165° for |\eta(\vec{p}_T^{\mu_1}) + \eta(\vec{p}_T^{\mu_2})| < 0.3$
- $M_{\mu\mu} > 10$ GeV/c^2
- $H_T(jets) > 100$ GeV ($\sum |E_T^j|$ of ALL jets $E_T^j > 15$ GeV)
- $\mathcal{P}(\chi^2) < 0.01$
- Max ϕ Gap $< \pi$

Zero events survive in the data.

Leptoquarks - First Generation
Scalar LeptoQuark Limits



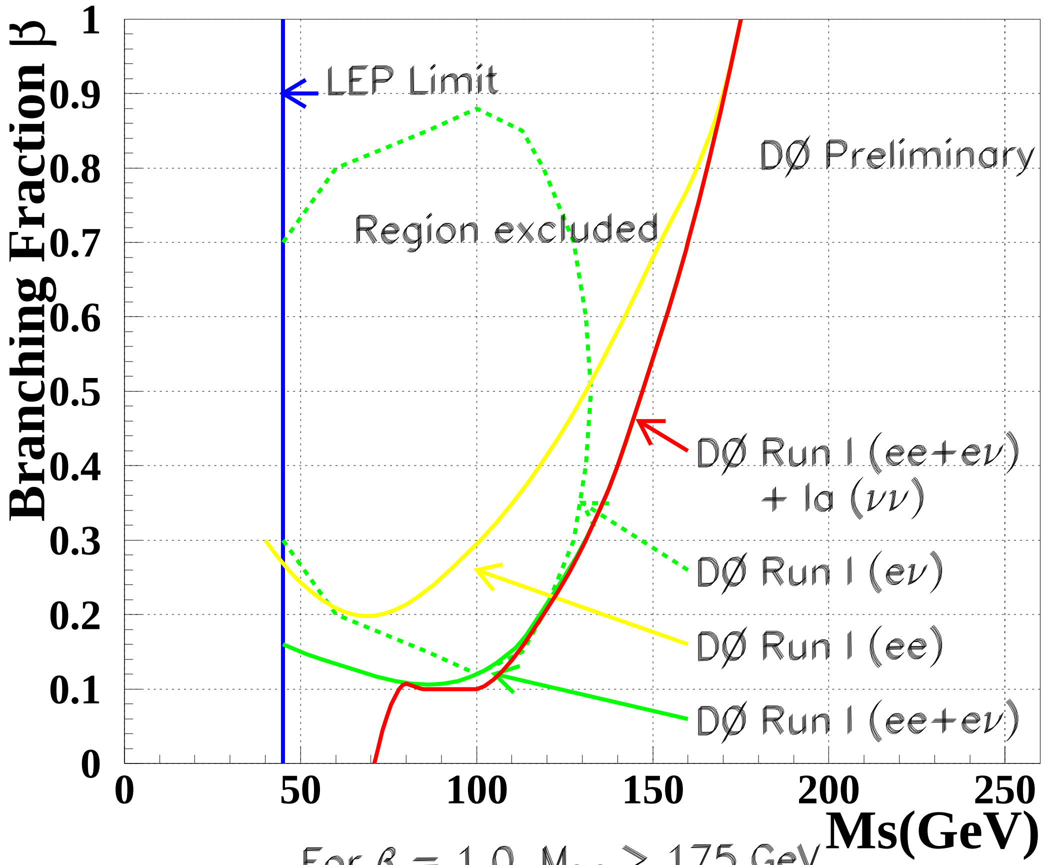
For $\beta = 1.0$, $M_{SLQ} > 175$ GeV

For $\beta = 0.5$, $M_{SLQ} > 147$ GeV

For $\beta = 0.0$, $M_{SLQ} > 71$ GeV

Leptoquarks - First Generation

Scalar LeptoQuark Limits

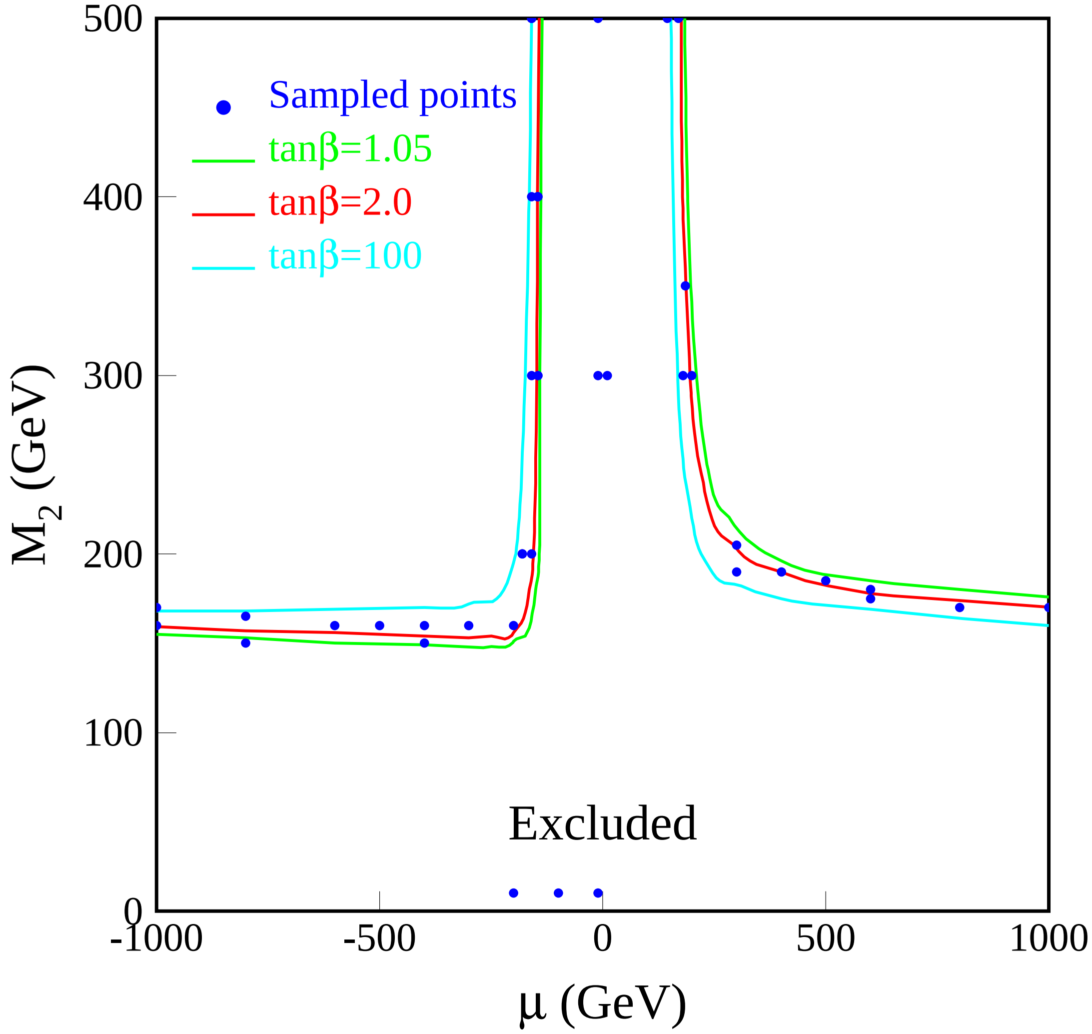


For β = 1.0, M_{SLQ} > 175 GeV

For β = 0.5, M_{SLQ} > 147 GeV

For β = 0.0, M_{SLQ} > 71 GeV

SUSY with γ's



INCLUSIVE JET CROSS SECTION

Motivation

PARTON–PARTON hard scattering events $\Rightarrow$ JET PRODUCTION

$$\frac{d^2\sigma}{dE_T d\eta} \equiv \frac{N}{L\,\Delta E_T\,\Delta\eta} \;\; vs. \;\; E_T \qquad |\eta| < 0.5$$

N: **# of jets,** L: **integrated luminosity,** ΔE_T: E_T **bin size,** $\Delta\eta$: η **bin size**

- **Precise measurement of the inclusive jet cross section**
- **Test of (NLO) QCD predictions**
- **Test different PDF**
- **Search for new physics**

Jet Energy Scale

Essential correction for the inclusive jet analysis

Re–evaluated during 1996 using full Ia and Ib data set

We correct the measured energy back to the PARTICLE LEVEL

$$E_{jet} = \frac{(E_{meas} - O)}{[(1 - S)R_{had}]}$$

- **O: offset due to noise, pileup and underlying event**

  Und.Evt is 0.8 and noise, pileup and extra interactions $1.2 - 3.2$ GeV for a 0.7 cone

- **S: Showering losses. Energy showered outside (inside) the cone in the calorimeter by particles emitted inside (outside) the cone**

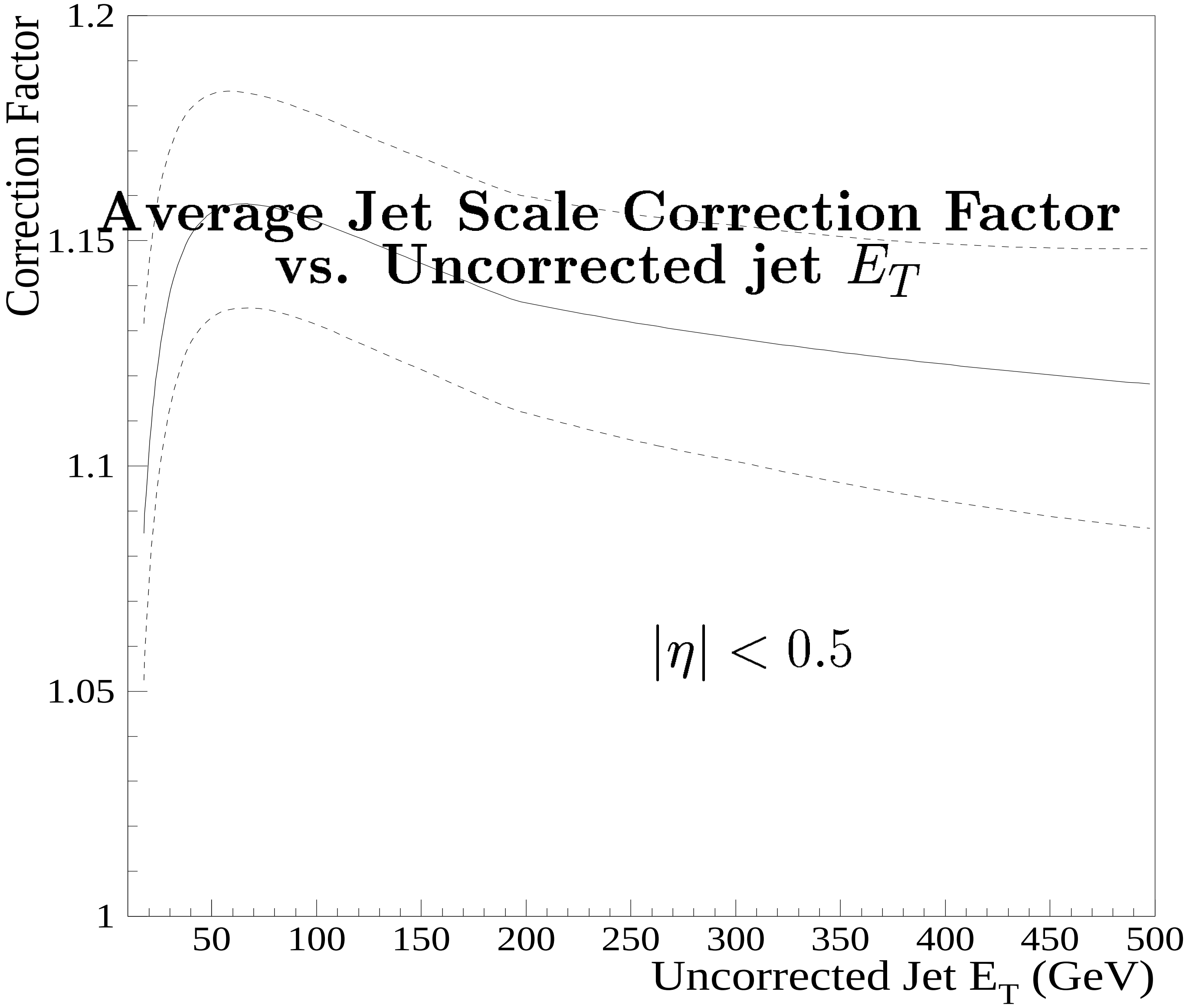
  Negligible for 0.7 cone

- R_{had}: **hadronic response. MPF method with γ–jet events. Scale of photons determined from Z mass (LEP) and Z $\rightarrow e^+e^-$ (DØ).**

$R_{had} = 1 + MPF$ **with** $MPF = \frac{\vec{\not{E}}_T \cdot \hat{n}_\gamma}{E_{T\gamma}}$

$E' = E_{T\gamma}\, cosh(\eta_{jet}) \Rightarrow E_{jet}$

Average Jet Scale Correction Factor vs. Uncorrected jet E_T



Average Correction Factor is $\approx 16\%$ **for** $E_T = 70$ **GeV**

(18.5% **in 1996**)

12.5% **for** $E_T = 400$ **GeV**

(13.5% **in 1996**)

Uncertainty is $\approx 2\%$ **for** $E_T = 70$ **GeV**

(3% **in 1996**)

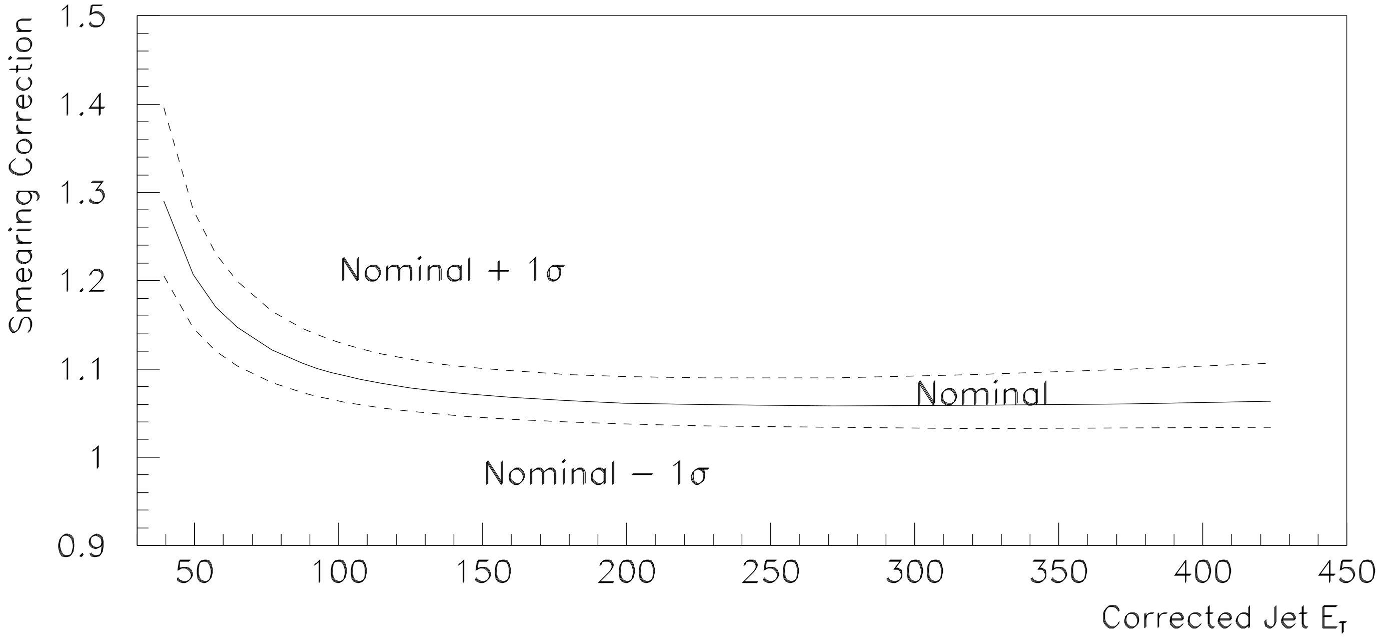
2.6% **for** $E_T = 400$ **GeV**

(5% **in 1996**)

Jet Resolution and unsmearing

Jet E_T Resolution is 17% at 30 GeV and 4% at high E_T in $\eta < 0.5$

Ansatz function, convoluted with σ_{E_T}, is fit to the cross section $\Rightarrow$ unsmearing correction



At 40 GeV, unsmearing corr $\approx 1.29 + -0.10$
At 60 GeV, $\approx 1.16 + -0.07$
At 200 GeV, $\approx 1.06 + -0.03$
At 420 GeV, $\approx 1.08 + -0.04$

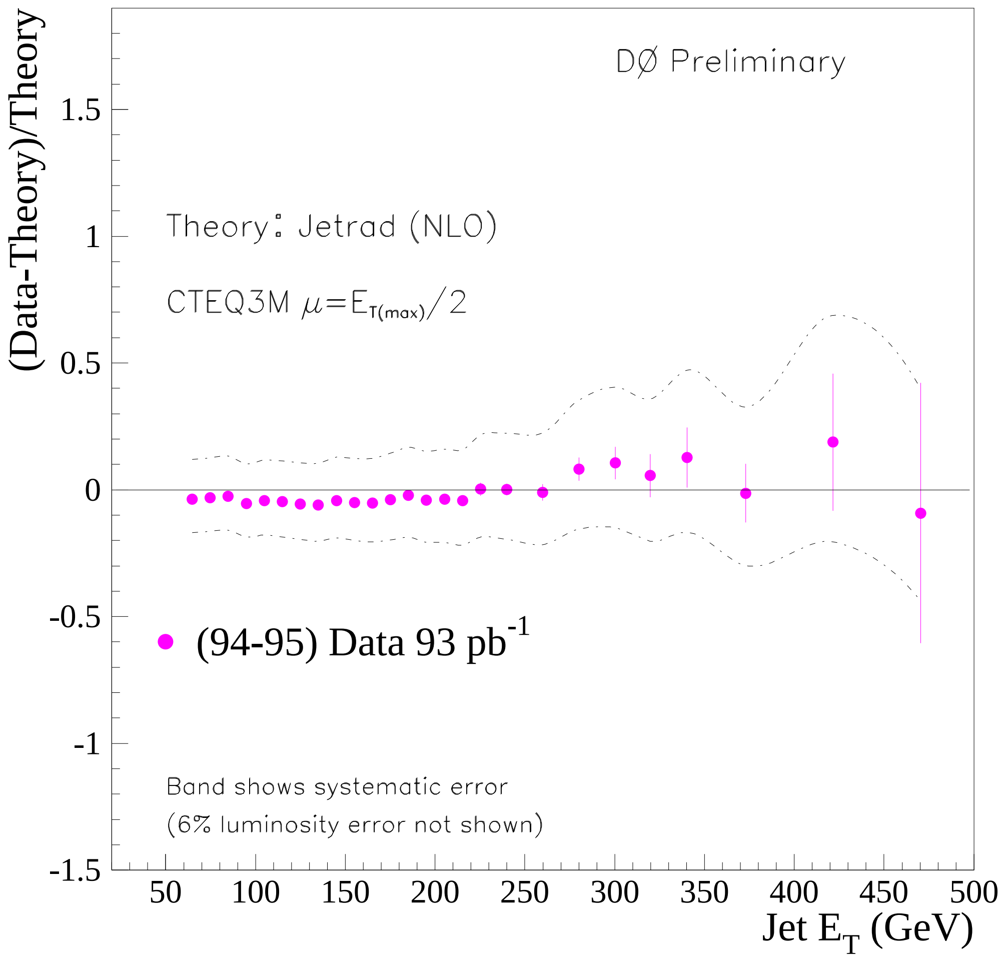
Compared to the J.E.S. correction, the unsmearing correction is SMALL and contributes a SMALL ERROR to the jet cross section

Theory

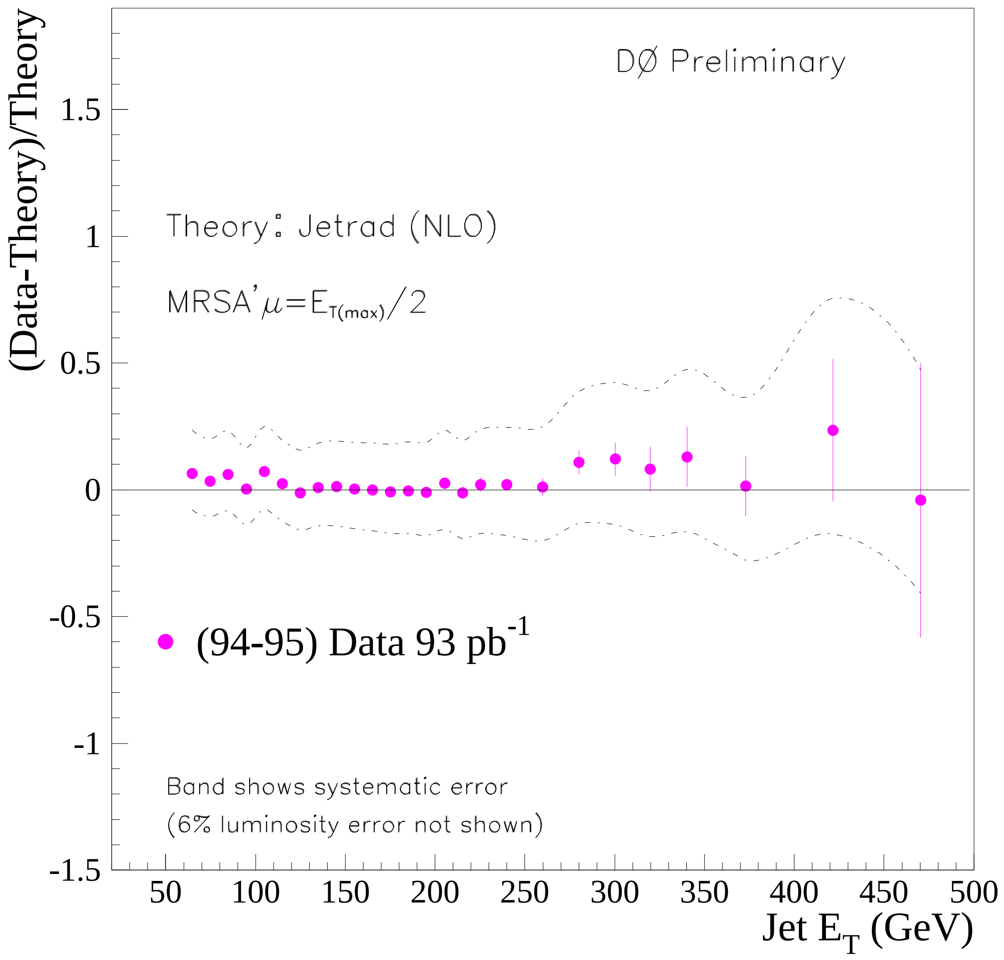
We use JETRAD , by Giele et al. to calculate a (NLO) QCD prediction of the inclusive jet cross section
Choices:

- **Renormalization scale** ($\approx 10\%$)
- **PDF's** (20% **with** E_T **dependence)**
- **Clustering algorithms** (5% **with** E_T **dependence)**

Inclusive Jet Cross Section



Inclusive Jet Cross Section



DIJET ANGULAR DISTRIBUTIONS

Motivation

$\frac{1}{N}\frac{dN}{d\chi}$ $vs.$ χ **for different M_{jj} mass bins**

$$M_{jj}^2 = 2E_{T1}E_{T2}\left(cosh(\eta_1 - \eta_2) - cos(\varphi_1 - \varphi_2)\right)$$

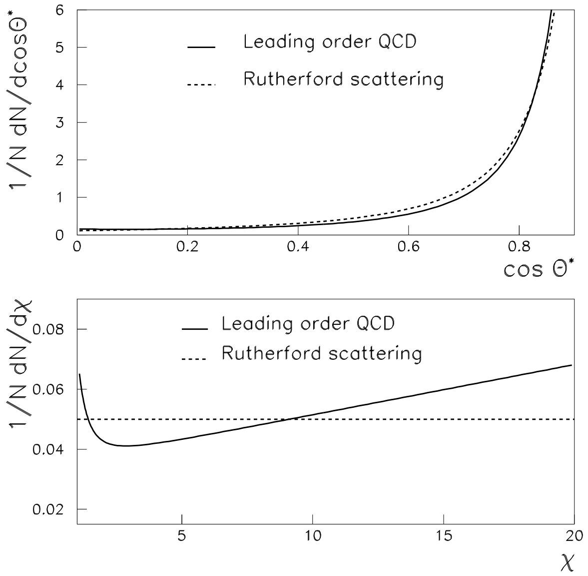
Other useful variables:

$\eta^* = \frac{1}{2}(\eta_1 - \eta_2) \Leftarrow \eta$ **of the CM system**

$\eta_{boost} = \frac{1}{2}(\eta_1 + \eta_2) \Leftarrow$ **Lab frame to CM frame**

$\chi = e^{2|\eta|^*} = \frac{1+cos(\theta^*)}{1-cos(\theta^*)}$

χ flattens out the angular distribution and facilitates comparison with theory

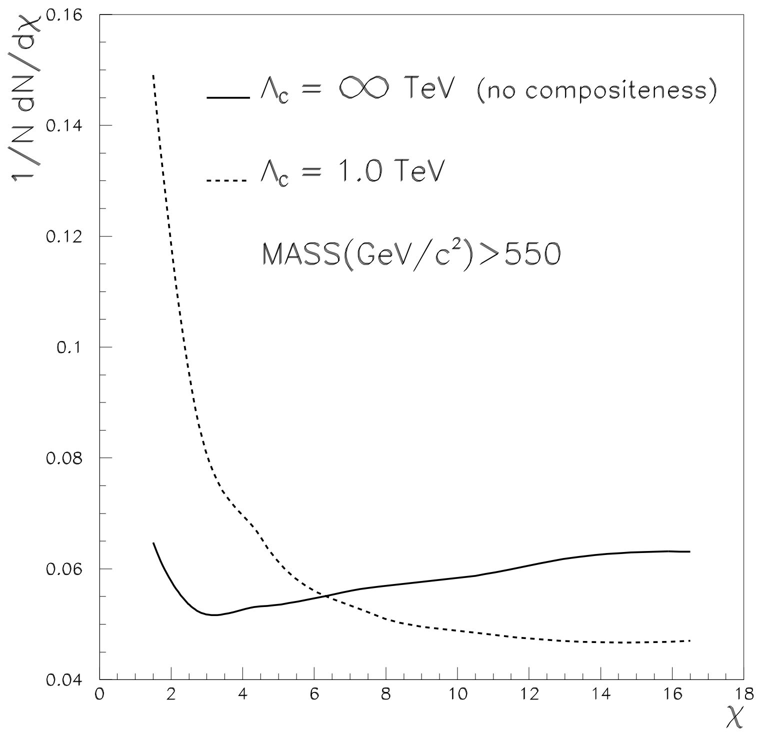


Direct test of QCD, since $dN/d\chi$ is insensitive to parton distribution functions

- **Shape of the angular distributions unaffected by boost of the system**

- **gg $\rightarrow$ gg, gq $\rightarrow$ gq, qq $\rightarrow$ qq produce similar angular distribution**

$dN/d\chi$ is sensitive to contact interactions introduced by compositeness models



Sample Selection

- **Fixed cone algorithm with a 0.7 cone size**
- **Events with two or more jets are selected**
- **Same jet triggers and cuts used in the inclusive jet analysis**

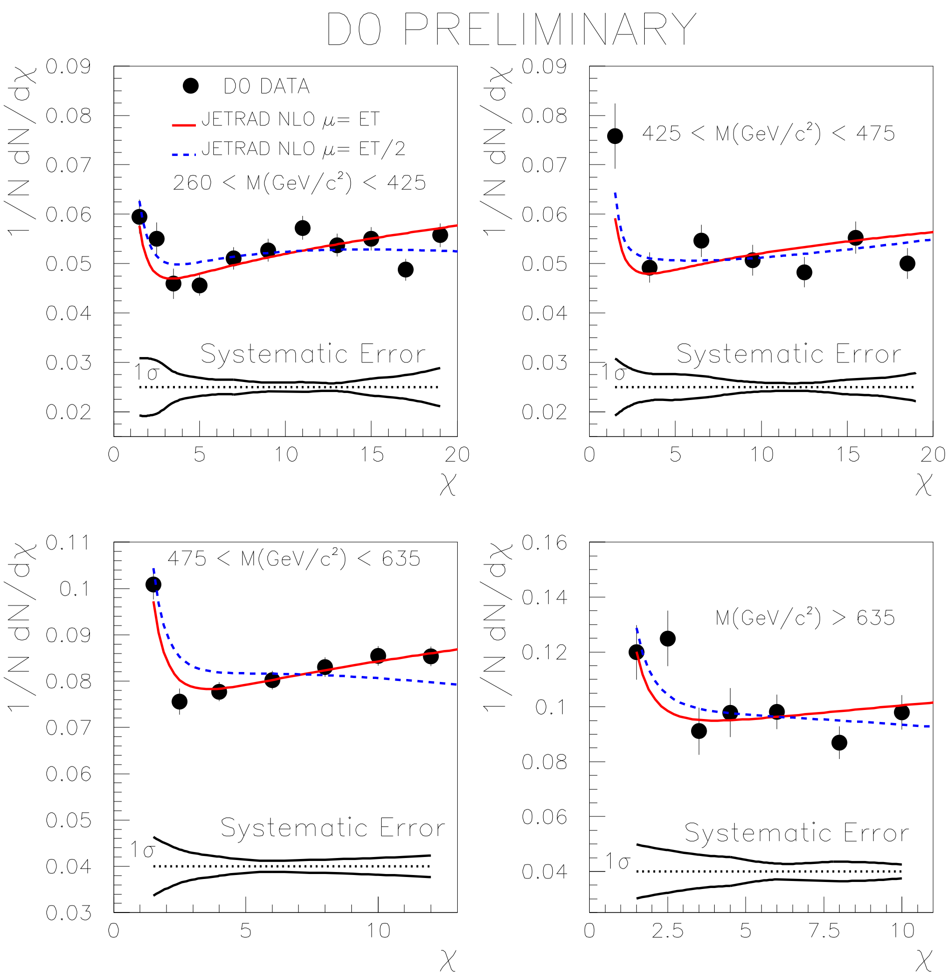
Large rapidity range: $|\eta| < 3$ and χ up to 20

Systematic Errors

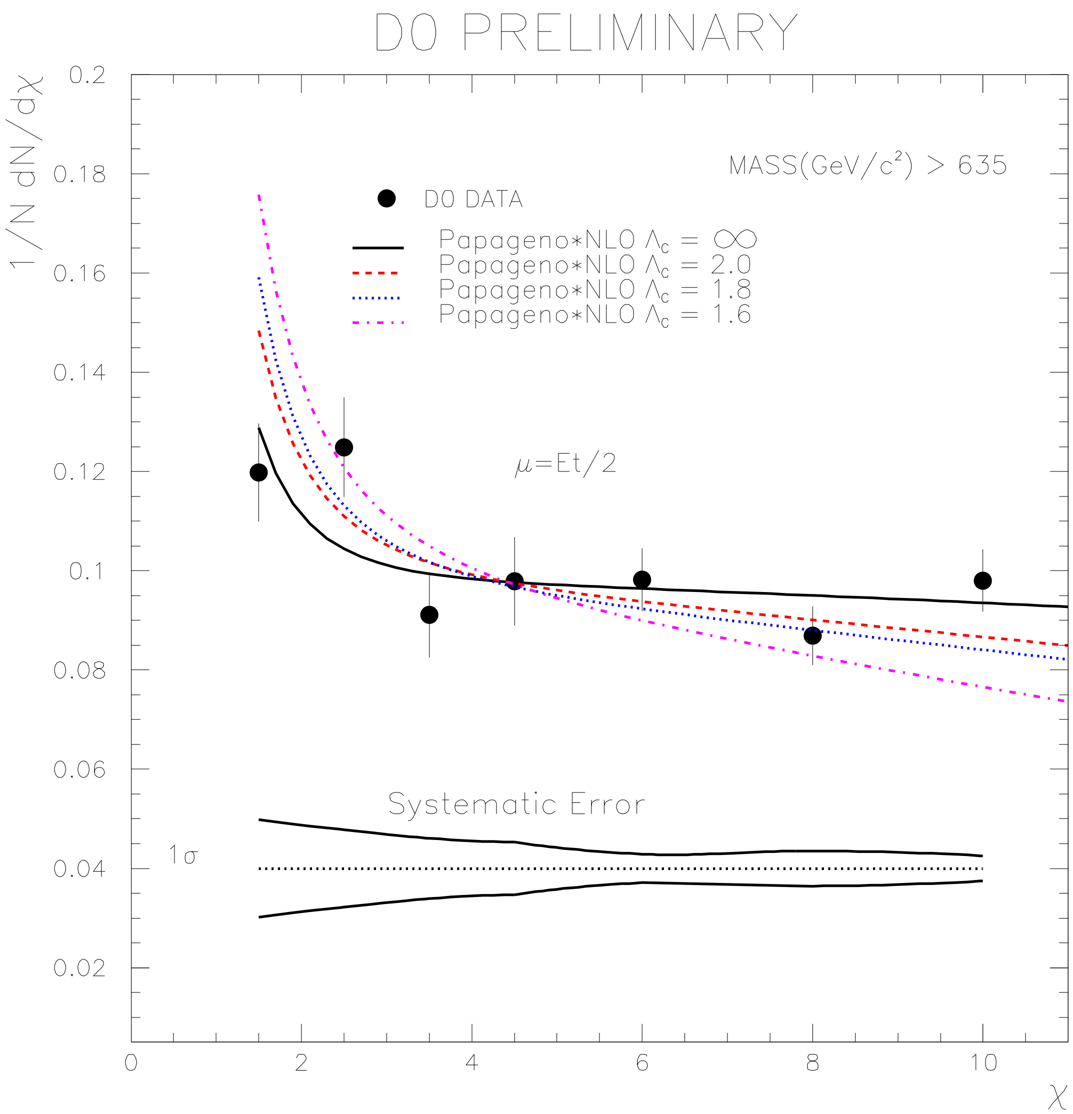
- **Quality cuts and efficiency corrections**
- **Misvertexing in multiple $p\overline{p}$ interactions**
- **Biases in η like splitting–merging and other algorithm effects**
- **η dependence of the jet energy scale correction**
- **Jet energy resolution**

Each source contribute an average $1 - 2\%$ on the angular distribution

Dijet Angular Distributions
(μ scale comparison)



Dijet Angular Distributions



Limit on Quark Compositeness

- **We define:**

$$R_\chi = \frac{\#\, of\ events\ \chi < 4}{\#\, of\ events\ \chi > 4}$$

R_χ vs M_{jj} removes correlations and reduces the curve to a single number.

- **Apply the BAYESIAN method to compare the measured R_χ vs M_{jj} with theory.**

μ	**Prior Dist.**	**Limit on Λ_c**
$E_T/2$	$1/\Lambda^2$	2.2
E_T	$1/\Lambda^2$	2.
$2E_T$	$1/\Lambda^2$	1.9
$E_T/2$	$1/\Lambda$	2.4
$E_T/2$	$1/\Lambda^4$	2.0