Recent Results in Electroweak, Exotic & Top Physics from CDF

Fermilab Wine & Cheese Seminar
March 21, 2003

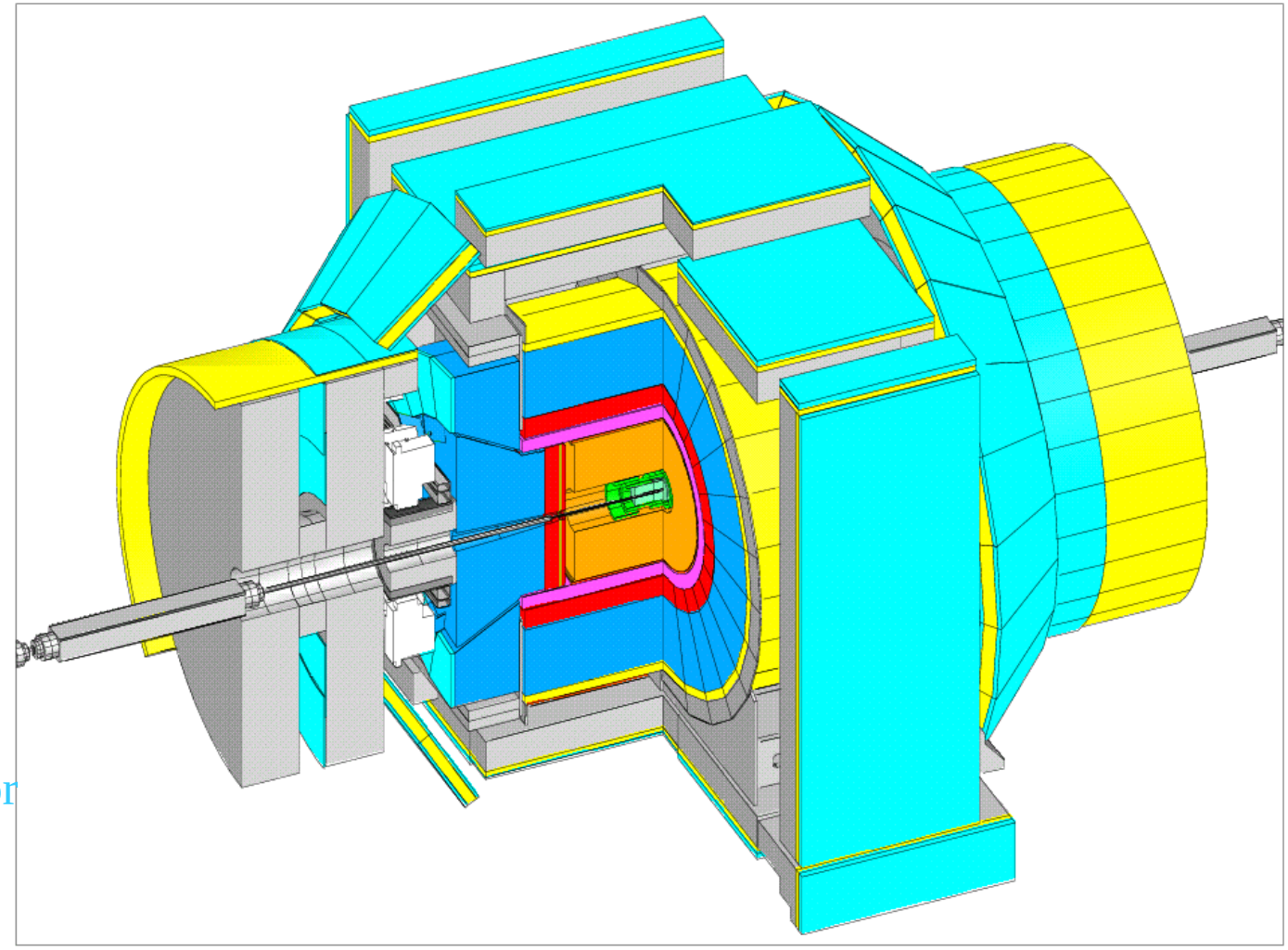
Eva Halkiadakis
University of Rochester
For the CDF Collaboration

Outline

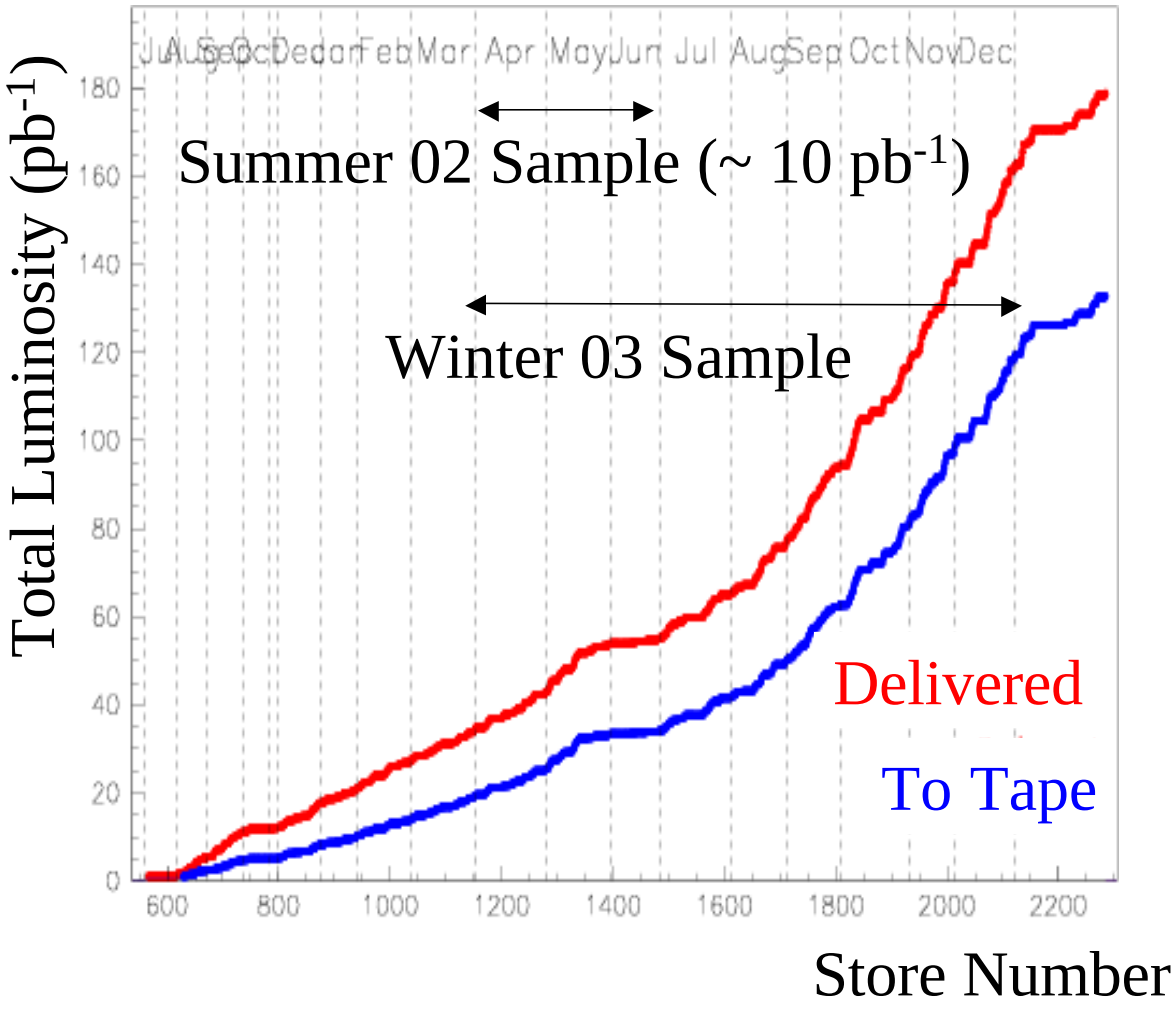
- **Electroweak Analyses** (*Reestablish baseline measurements*)
  - W/Z production cross sections
  - R= $\sigma(W \rightarrow l\nu)/\sigma(Z^0 \rightarrow l^+l^-)$ (e,μ)
    - extract $\Gamma(W)$
  - $\sigma(W \rightarrow \tau\nu)/\sigma(W \rightarrow e\nu)$
    - extract g_τ/g_e
  - Forward-Backward Asymmetry with $Z^0 \rightarrow e^+e^-$
  - Diboson: WW production
- *Exotic* **Physics**
  - Searches for new particles in DY spectrum
    - Z'
    - Randall-Sundrum Graviton
  - Search for new physics involving photons
  - Searches for resonances in the dijet spectrum
  - Search for 1st generation Leptoquarks in dielectrons + jets
  - Searches for CHArged Massive ParticleS
  - Search for doubly charged Higgs
- **Top Physics**
  - $t\bar{t}$ production cross sections
    - Dileptons
    - Lepton + jets
  - Top mass
- **Summary**

The CDF-II Detector

- Silicon Tracking Detectors
- Central Drift Chambers
- Solenoid Coil
- EM Calorimeter
- Hadronic Calorimeter
- Muon Drift Chambers
- Muon Scintillator Counters
- Steel Shielding



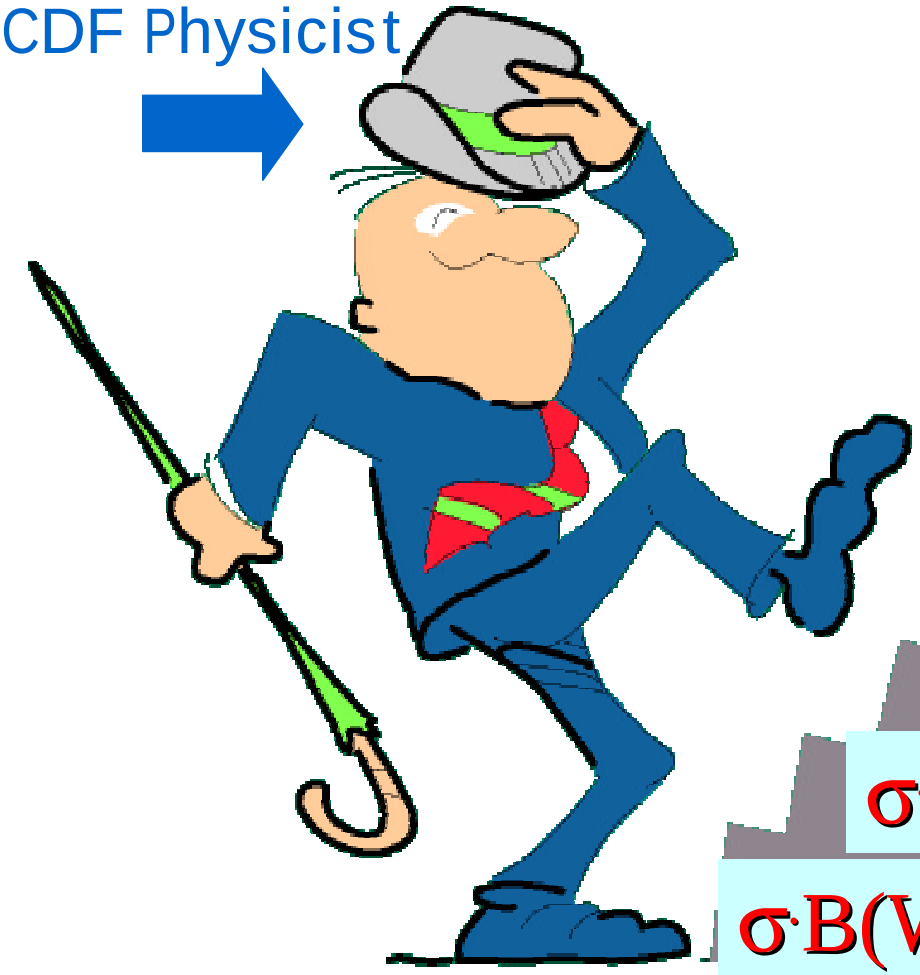
CDF Data



- ~ 130 pb^{-1} on tape
- Stable data-taking since June shutdown
- > 90% of silicon integrated
- ~ 5-7 pb^{-1}/wk @ > 90% efficiency

Analyses for today:
53 - 91 pb^{-1}
(March 02 – January 03)

Electroweak Physics Program



M_W

Boson Kinematics

Dibosons

W charge asymmetry

A_{FB}

$\sigma \cdot B(Z^0 \rightarrow l^+ l^-)$

$\sigma \cdot B(W \rightarrow l\nu)$

G(W)

W/Z Production Cross Sections

- ***W's and Z's are our standard candles – we better get them right!***
- ***Re-establishing baseline measurements gives us confidence.***
- ***Measuring the W cross section is useful check of our luminosity.***
- ***Z's also provide us with useful information about our detector (e.g., EM energy scale and resolution from electrons, p_T scale from muons).***

The measurement of a cross section is Primarily a "counting experiment"

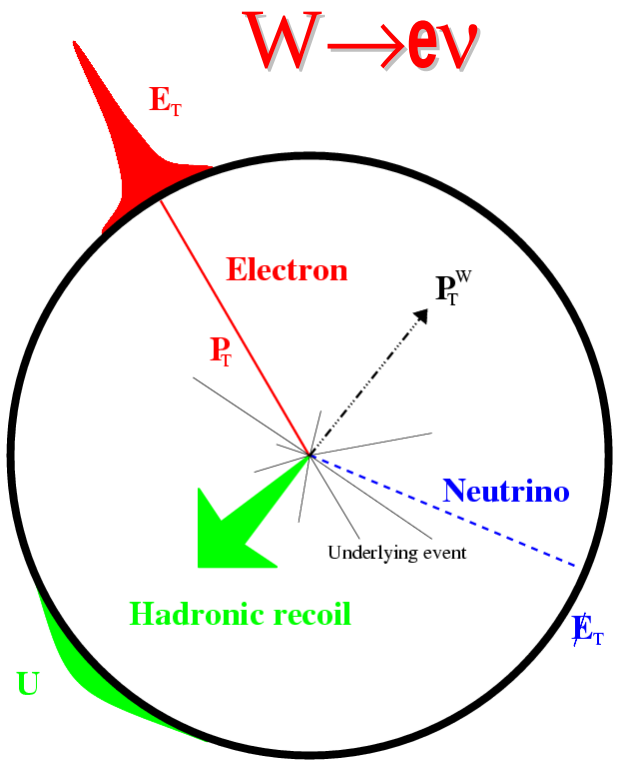
$$s \cdot B = \frac{N_{obs} - N_{bkg}}{A \cdot \int L}$$

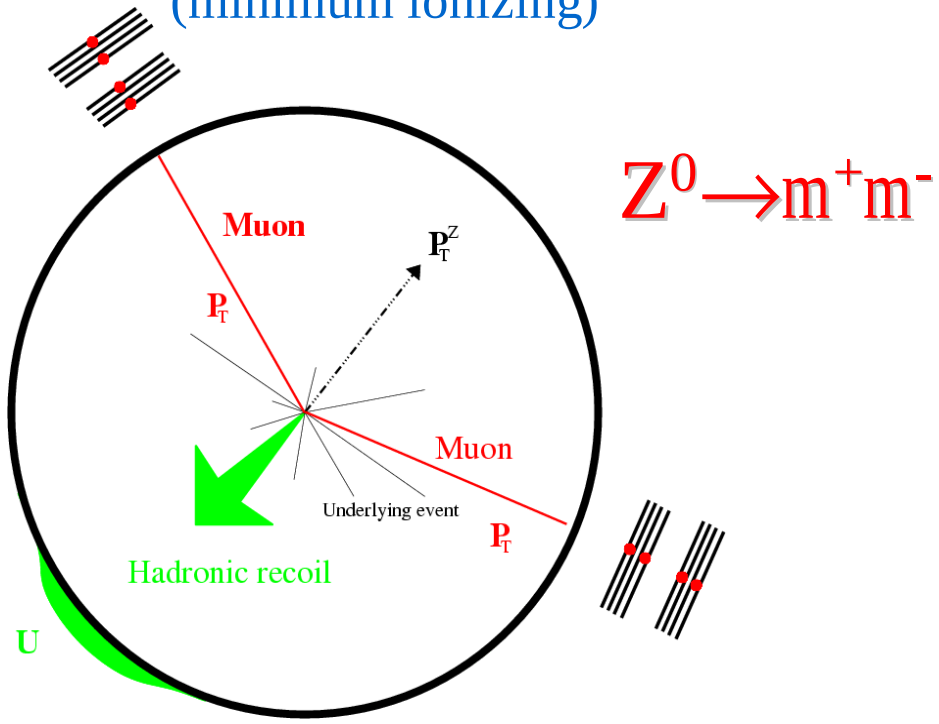
$\sigma_{inelastic}$ = 60.7 ± 2.4 mb (CDF+E811)

Selecting W's & Z's

- W Event selection
  - One isolated high p_T central e, μ or τ
  - Large $\not{E}_T$
- Z Event selection
  - Two isolated high p_T e's

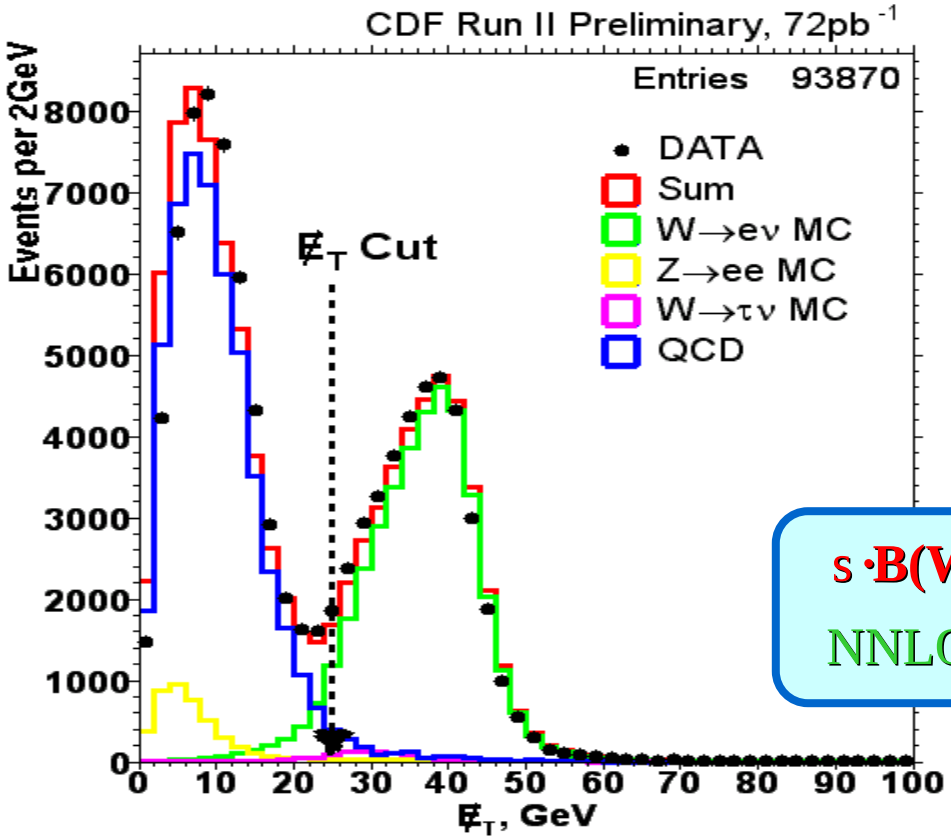
  OR
  - One isolated high p_T central μ
  - A second isolated high p_T track (minimum ionizing)

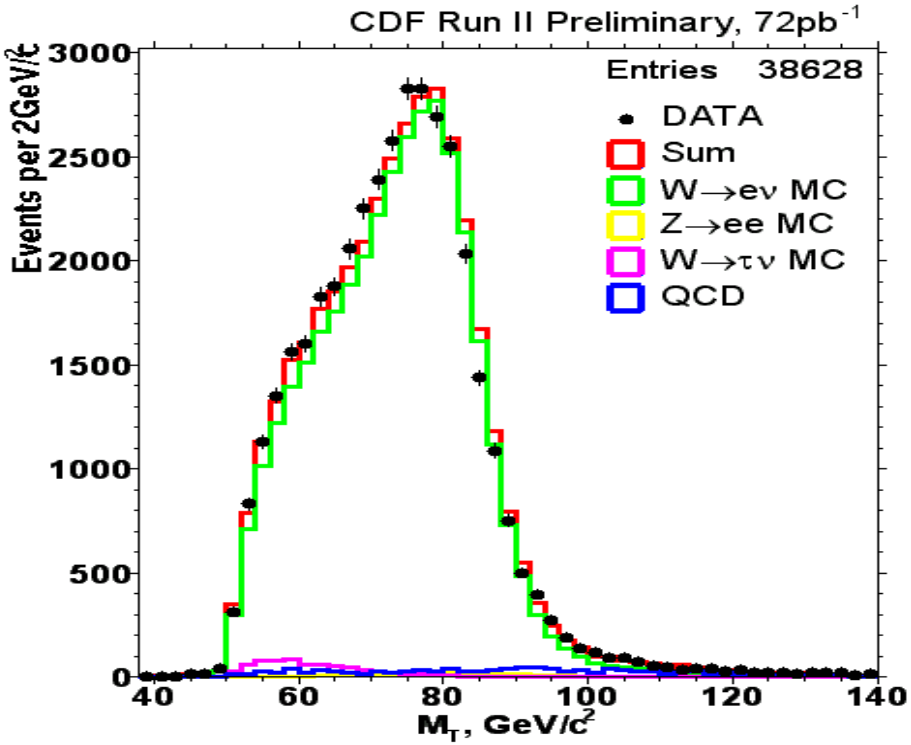




$\sigma \cdot B(W \rightarrow e\nu_e)$

- Candidates: 38625 in ~ 72 pb^{-1}
- Backgrounds ~ 6 % (dominated by QCD)





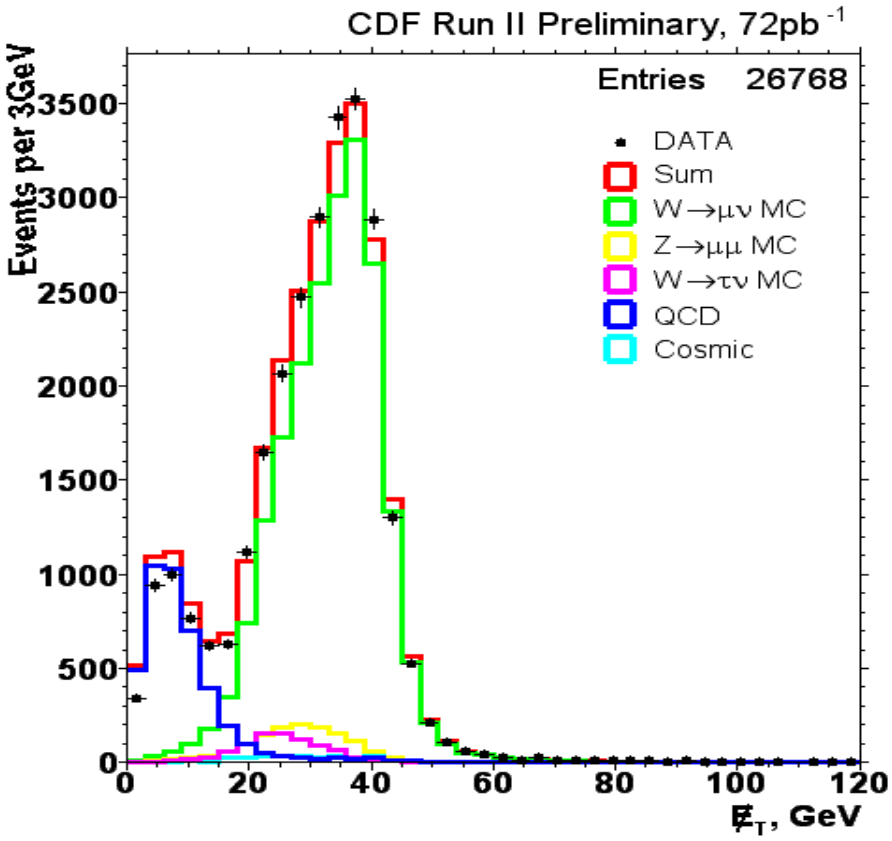
$\sigma \cdot B(W \rightarrow e\nu) = 2.64 \pm 0.01_{stat} \pm 0.09_{sys} \pm 0.16_{lum}$ nb

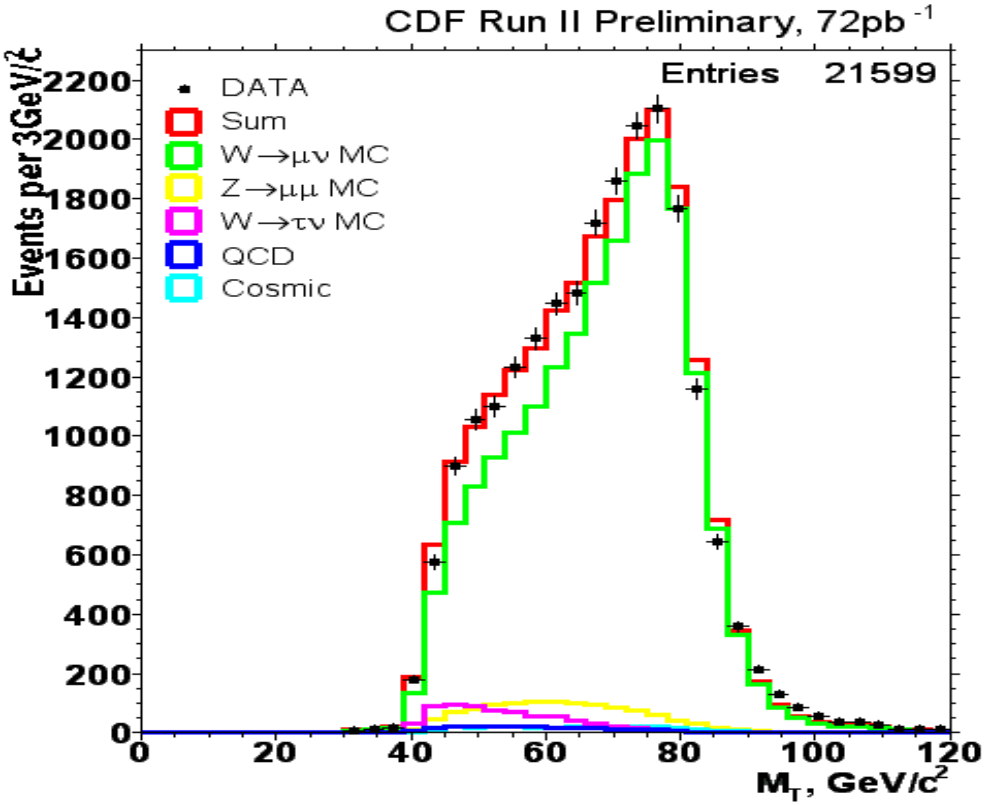
NNLO @ $\sqrt{s}$=1.96 TeV‡: 2.69 ± 0.10 nb

‡ Nucl. Phys. B359,343 (1991)
Phys.Rev. Lett. 88,201801 (2002)

$\sigma \cdot B(W \rightarrow \mu \nu_\mu)$

- Candidates: 21599 in ~ 72 pb^{-1}
- Backgrounds ~ 11 % (dominated by $Z \rightarrow \mu\mu$)





$s \cdot B(W \to mn) =$

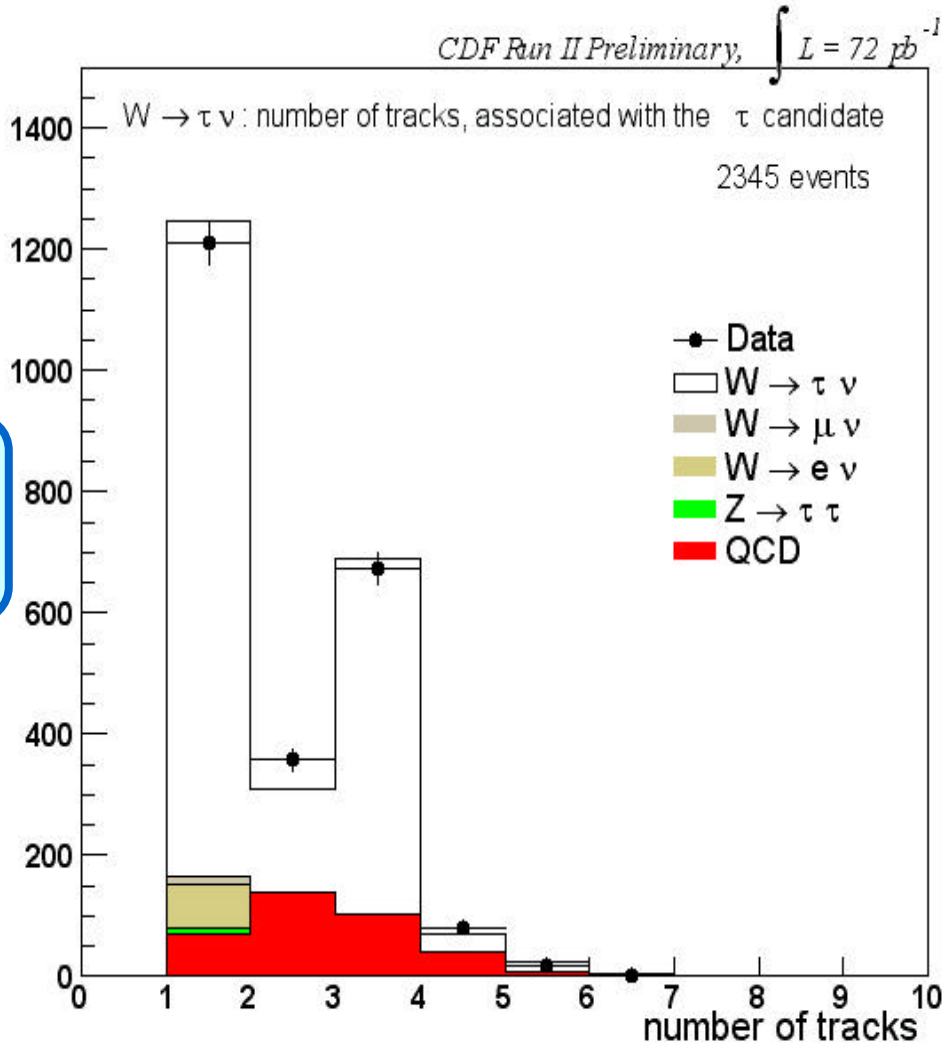
$2.64 \pm 0.02_{stat} \pm 0.12_{sys} \pm 0.16_{lum}$ nb

$\sigma \cdot B(W \to \tau \nu_\tau)$

- Candidates: 2345 in ~ 72 pb^{-1}
- Backgrounds ~ 26 % (dominated by QCD)

$$s \cdot B(W \to t n) = 2.62 \pm 0.07_{stat} \pm 0.21_{sys} \pm 0.16_{lum}\ nb$$

(See Feb. 21 seminar by Pasha Murat.)

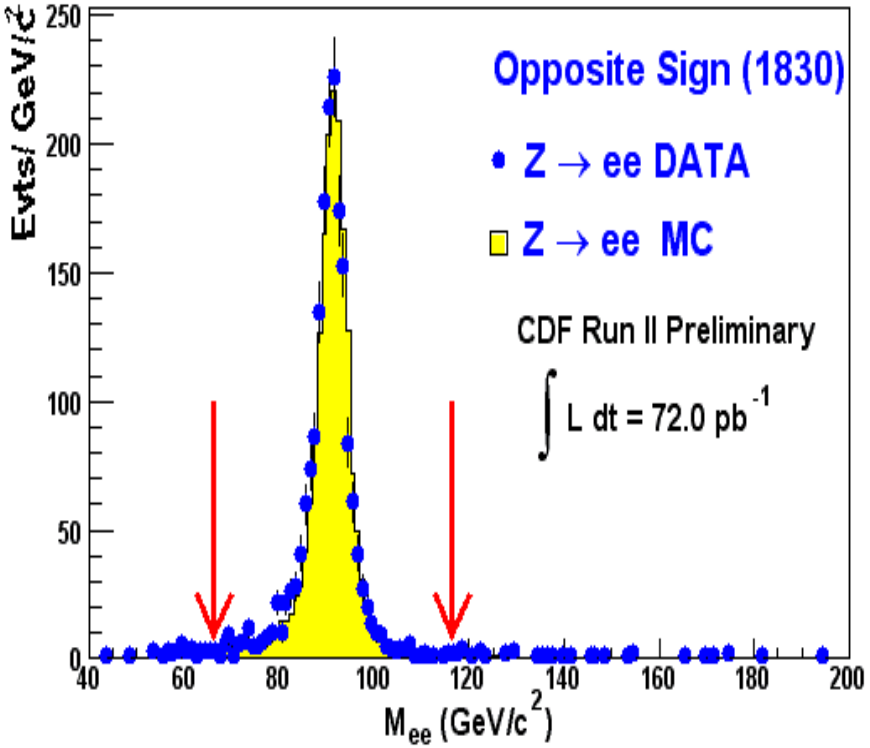


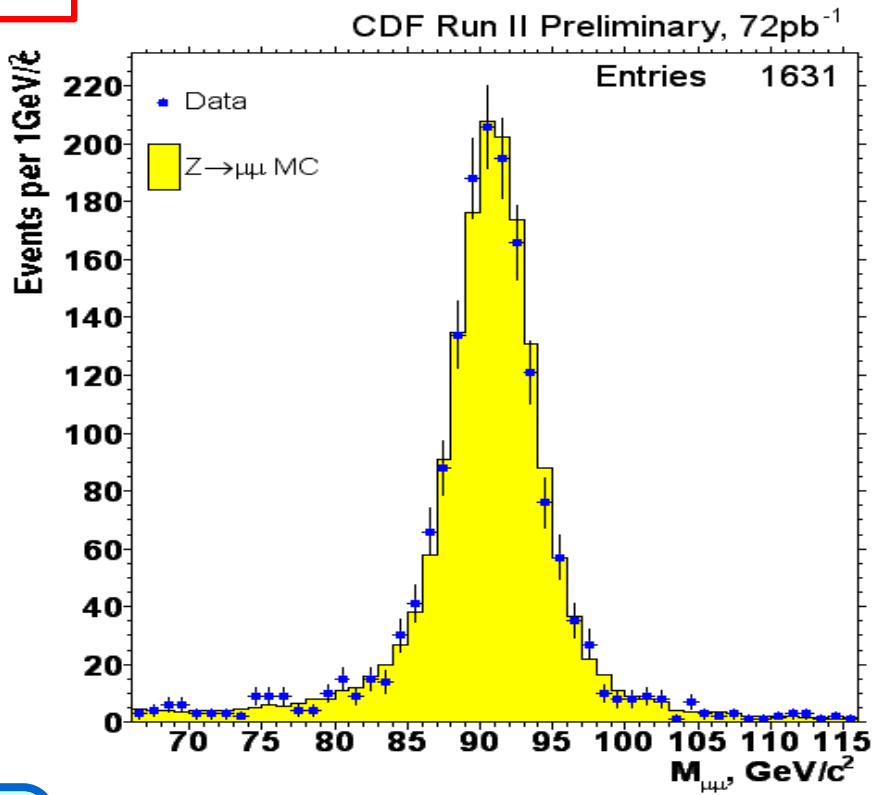
$\sigma \cdot B(Z^0 \rightarrow l^+ l^-)$

- Candidates: 1830 in ~ 72 pb^{-1}
- Backgrounds ~ 0.6 %

VERY CLEAN

- Candidates: 1631 in ~ 72 pb^{-1}
- Backgrounds: ~ 0.9 %





$\sigma \cdot B(Z^0 \rightarrow ee) = 267 \pm 6_{stat} \pm 15_{sys} \pm 16_{lum}$ pb

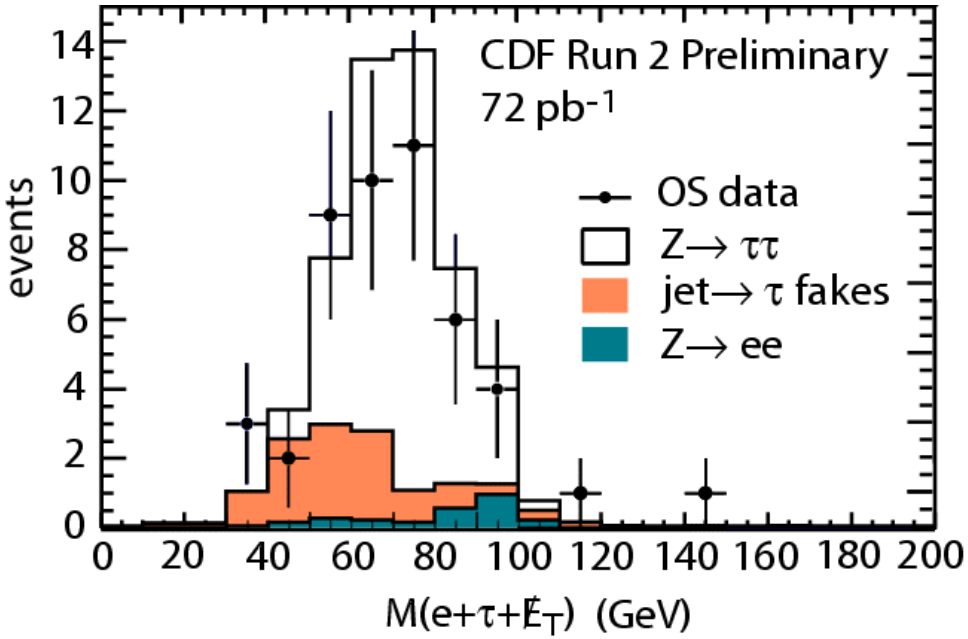
$\sigma \cdot B(Z^0 \rightarrow \mu\mu) = 246 \pm 6_{stat} \pm 12_{sys} \pm 15_{lum}$ pb

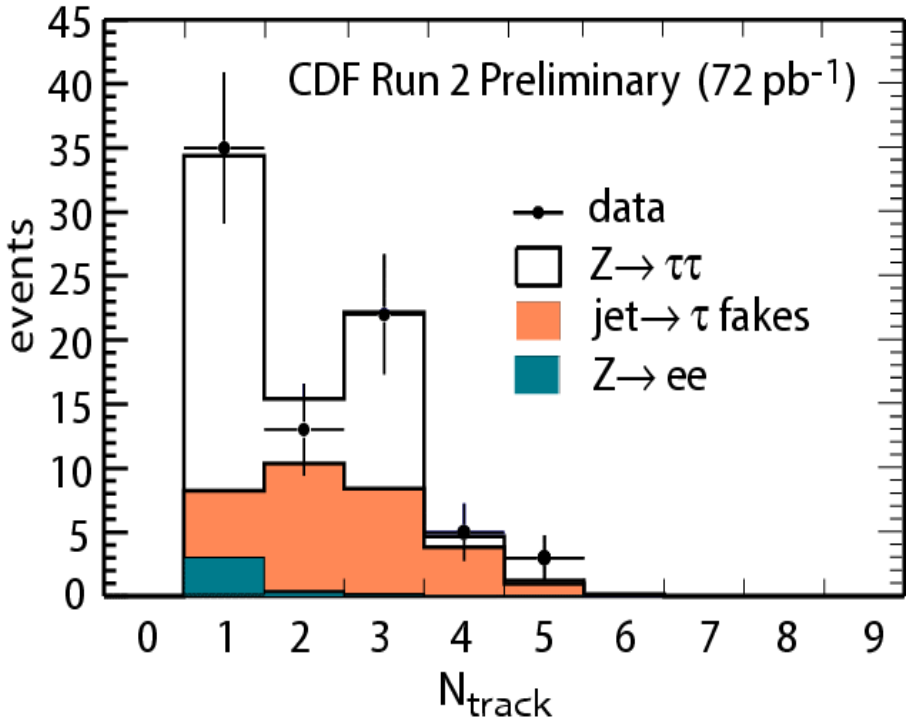
NNLO @ $\sqrt{s}$=1.96 TeV‡: 252 ± 9 pb

‡ Nucl. Phys. B359,343 (1991)
Phys.Rev. Lett. 88,201801 (2002)

$Z^0 \rightarrow \tau_e \tau_h$

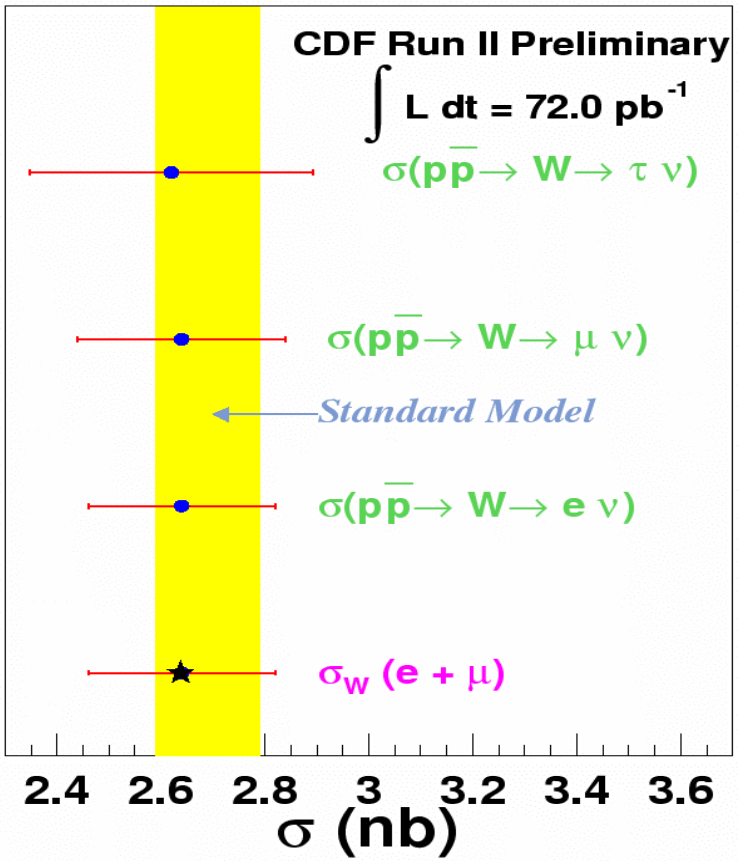
- We have a clear $Z^0 \rightarrow \tau_e \tau_h$ signal.
- Further study of backgrounds is underway.
- Our goal is to have a preliminary cross section measurement by summer.

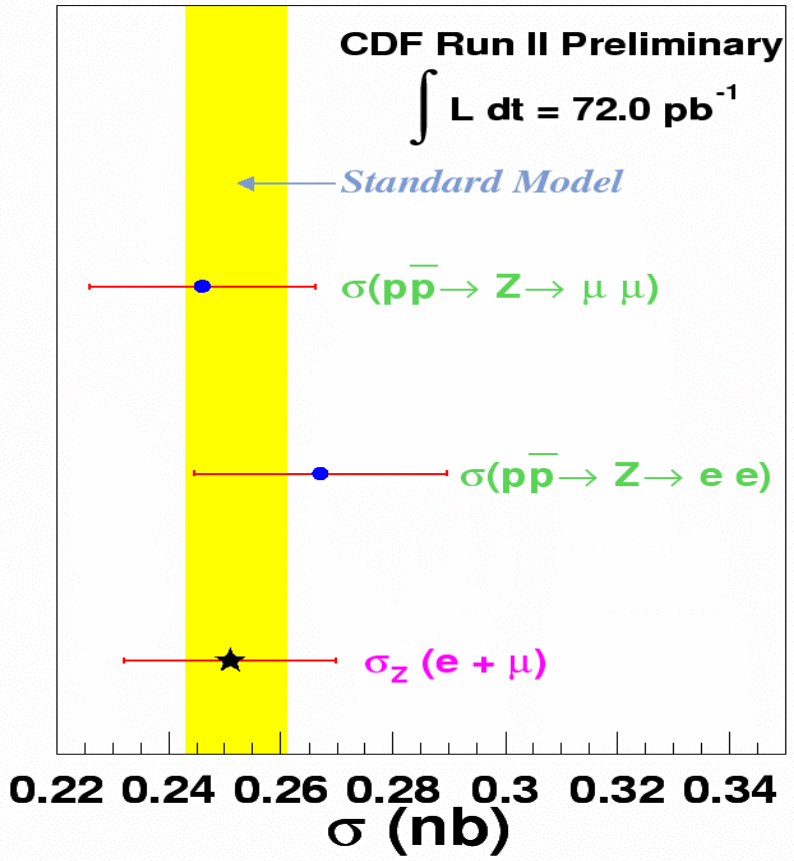




Not only interesting as an EWK measurement, it is important for Higgs and SUSYsearches.

Summary of W & Z Cross Sections



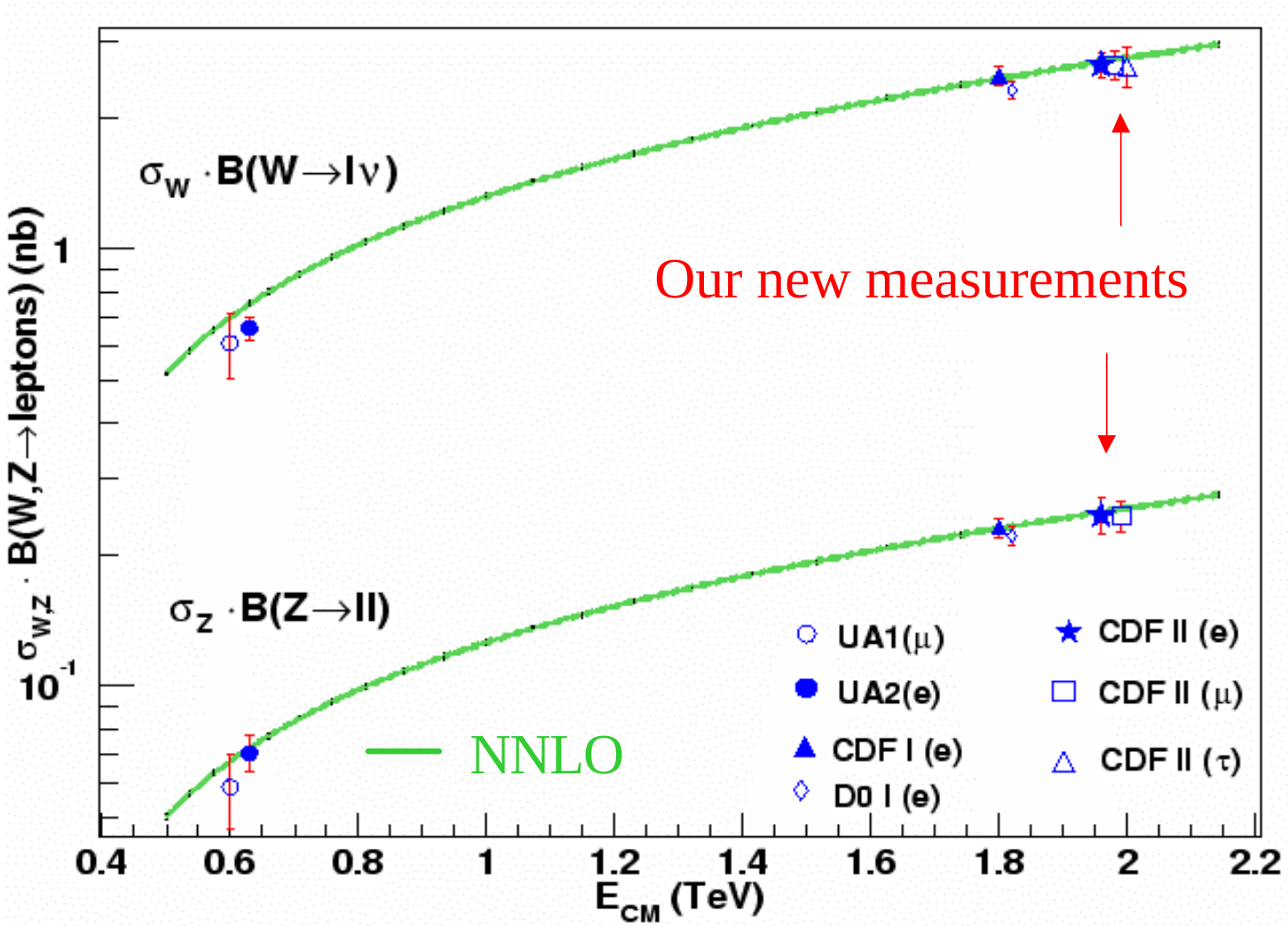


Combined e and μ values:

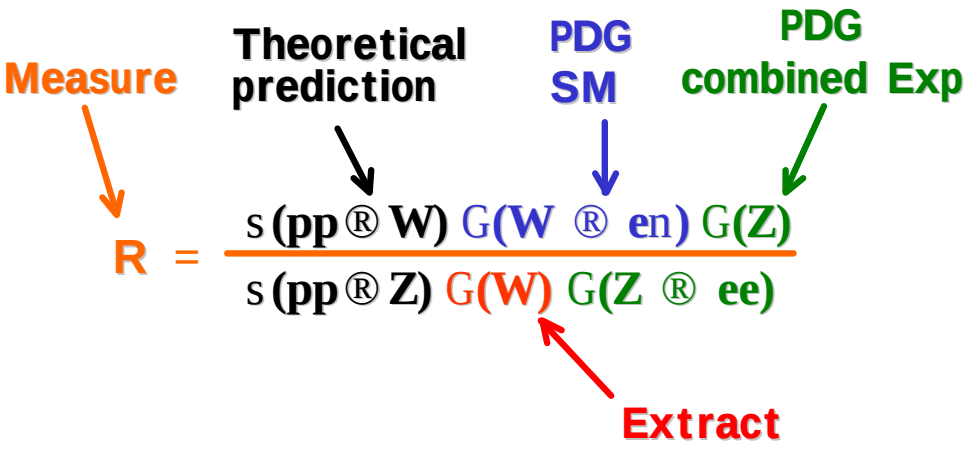
$$s \cdot B(W \to l\nu) = 2.640 \pm 0.012_{stat} \pm 0.093_{sys} \pm 0.158_{lum}\ nb$$

$$s \cdot B(Z^0 \to ll) = 251.5 \pm 4.3_{stat} \pm 10.6_{sys} \pm 15.1_{lum}\ pb$$

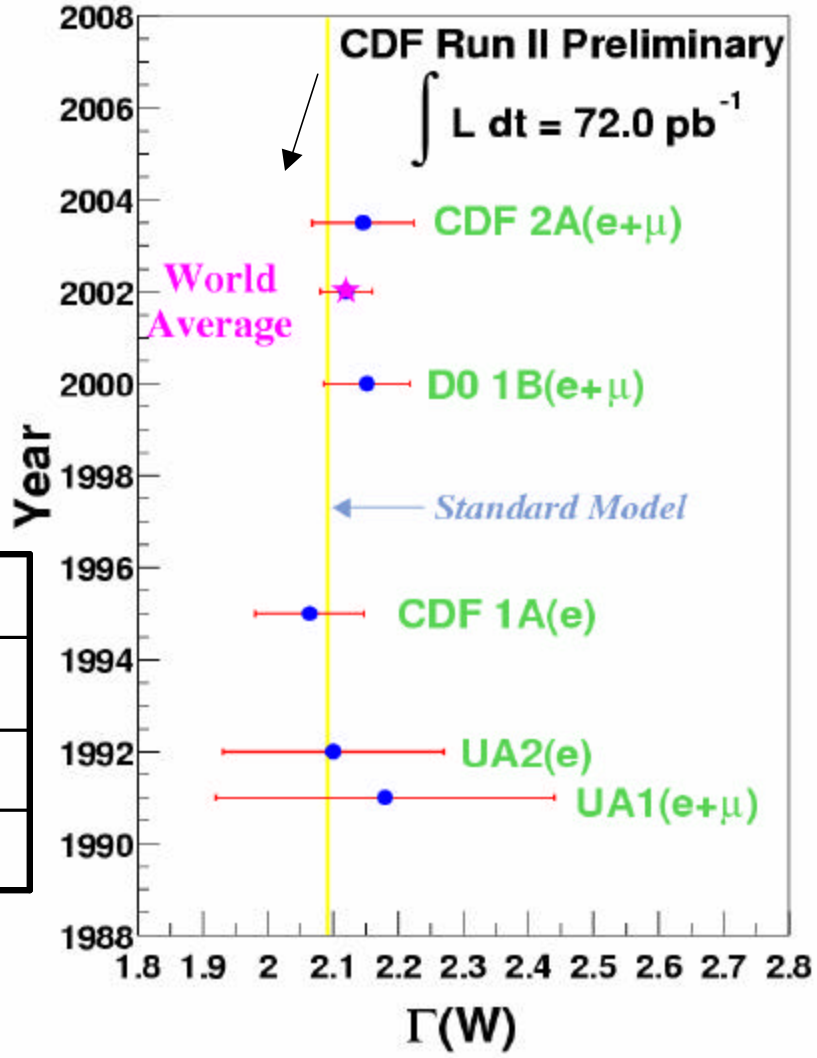
W & Cross Sections vs. E_{CM}



Γ(W)


Measure
Theoretical prediction
PDG SM
PDG combined Exp
R = s(pp® W) G(W ® en) G(Z) / s(pp® Z) G(W) G(Z ® ee)
Extract

	R		G	
e	±	±	±	±
m	±	±	±	±
e+m	±	±	±	±

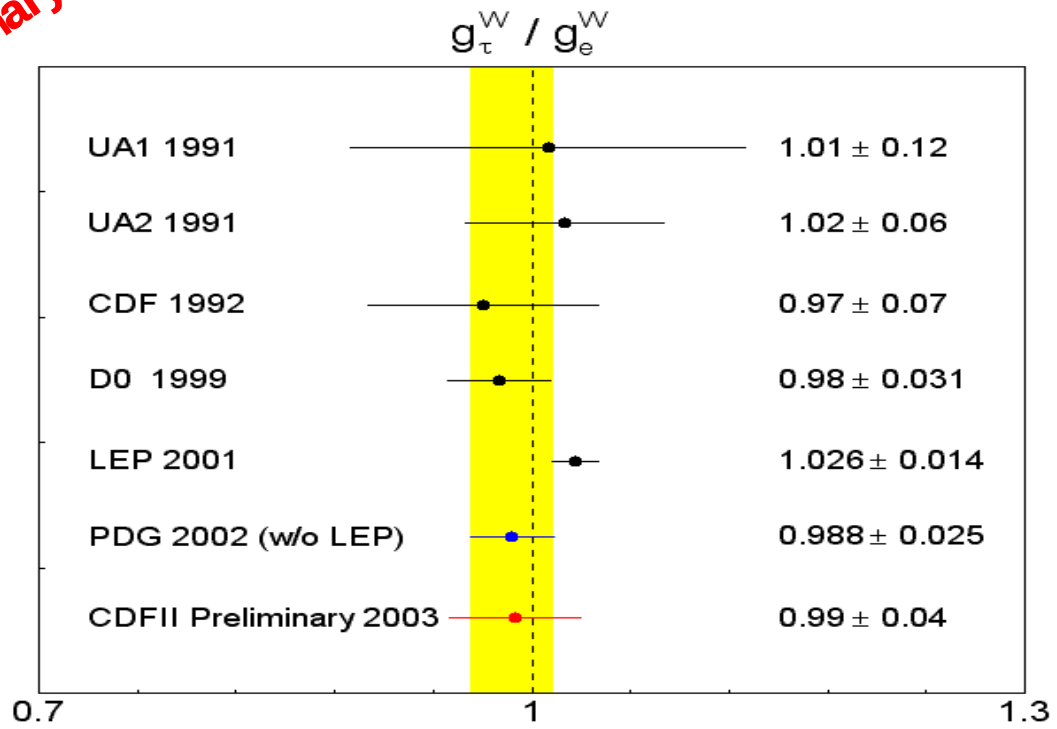

CDF Run II Preliminary
∫ L dt = 72.0 pb-1
CDF 2A(e+μ)
World Average
D0 1B(e+μ)
Standard Model
CDF 1A(e)
UA2(e)
UA1(e+μ)
Year
2008
2006
2004
2002
2000
1998
1996
1994
1992
1990
1988
1.8 1.9 2 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8
Γ(W)

Lepton Universality

Check of Lepton Universality in W decays: measurement of ratio of branching ratios and ratio of electroweak couplings:

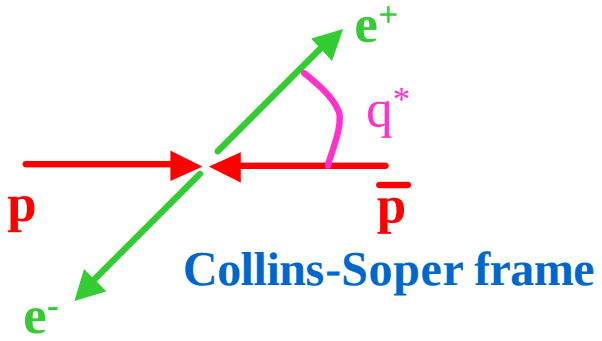
$$\frac{\mathcal{B}(W \to \tau\nu)}{\mathcal{B}(W \to e\nu)} = \left(\frac{g_\tau^W}{g_e^W}\right)^2 \Leftrightarrow \frac{g_\tau^W}{g_e^W}$$

CDF Run II Preliminary



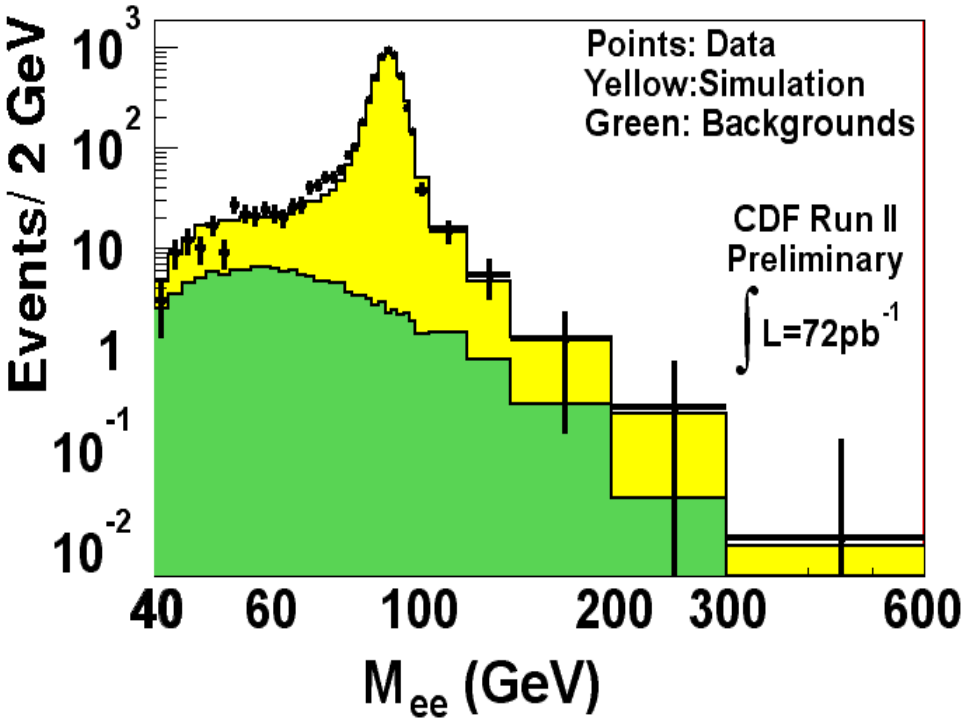
A_{FB} with $Z^0 \rightarrow e^+e^-$

- **Forward-Backward asymmetry A_{FB}:** $A_{FB} = \frac{N_F - N_B}{N_F + N_B}$
  - Direct probe V,A ⇨ Extract $\sin^2\theta_W$
  - Constrains the properties of any hypothetical heavy neutral gauge boson not in SM (e.g. Z') (would be seen as a drop in as A_{FB} at high M_{ee})



Collins-Soper frame

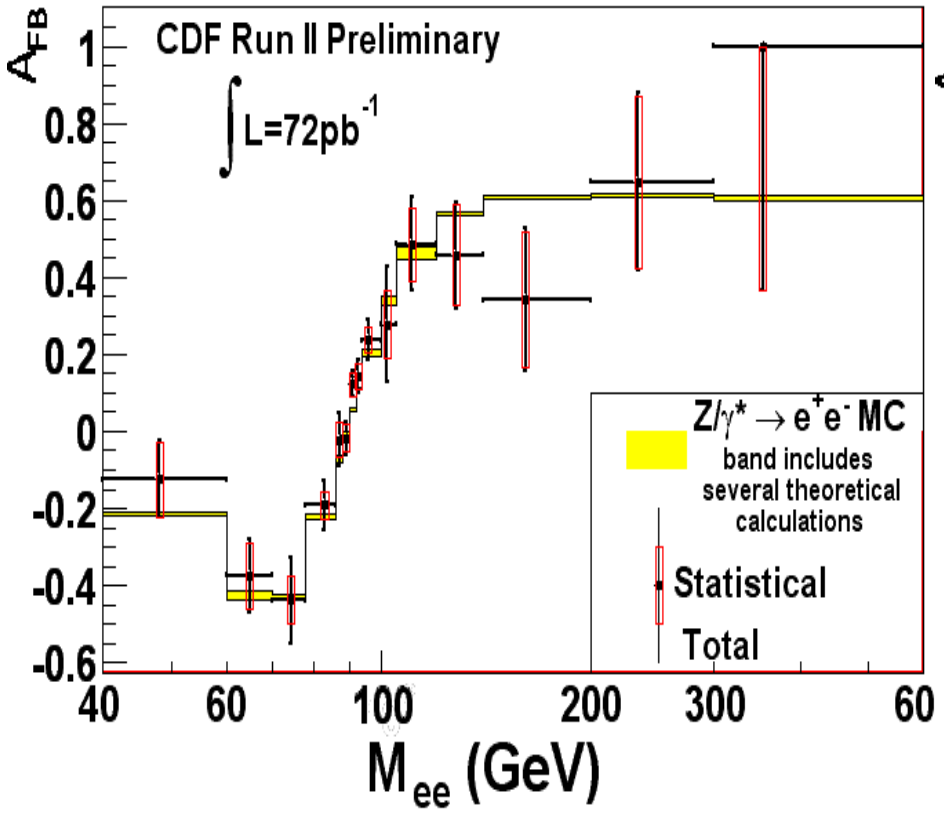
- **Event selection**
  - Two isolated high p_T e (one central, other central or plug)
  - 40 GeV/c^2 < M_{ee} < 600 GeV/c^2
- **Candidates:**
  - 5438 in ~ 72 pb^{-1}
- **Backgrounds:** ~ 3 % (dominated by QCD)

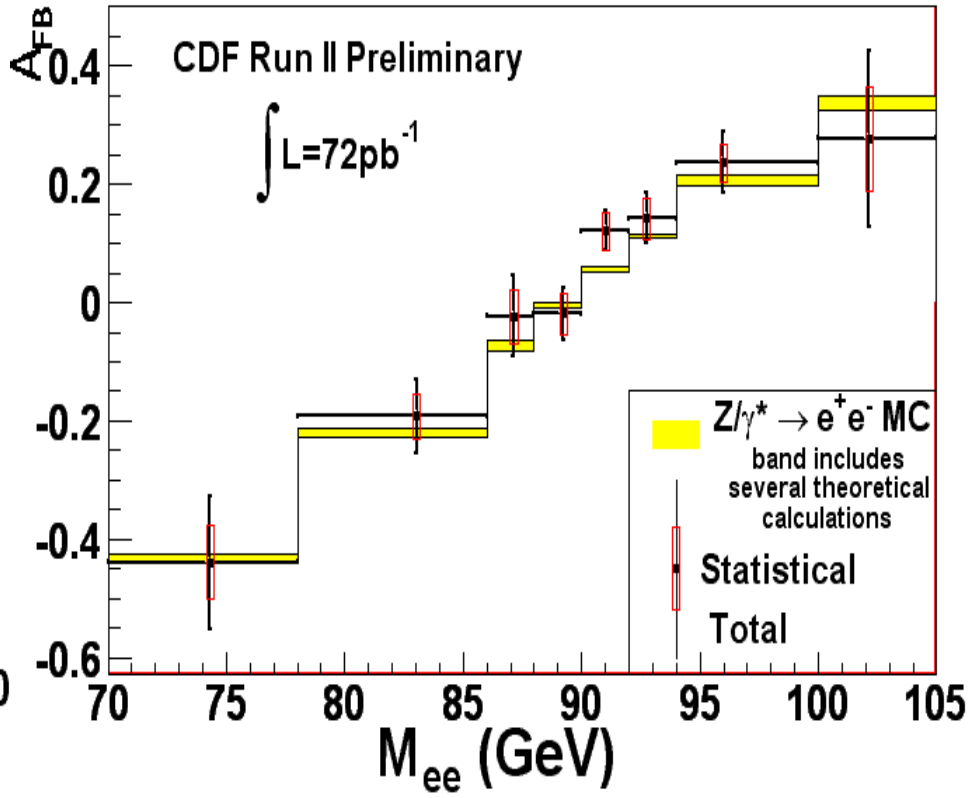


A_{FB} with $Z^0 \rightarrow e^+e^-$

A_{FB} (corrected)

Z Pole Region

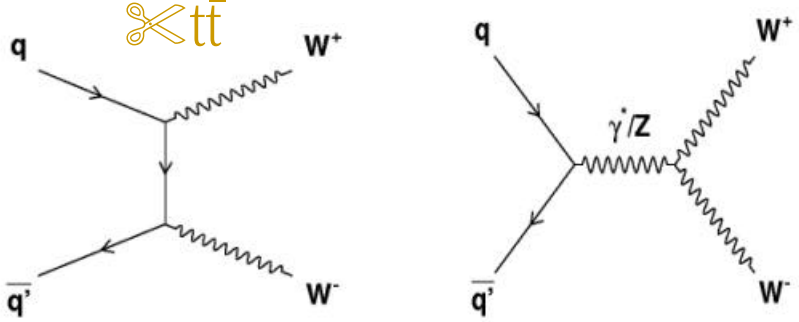


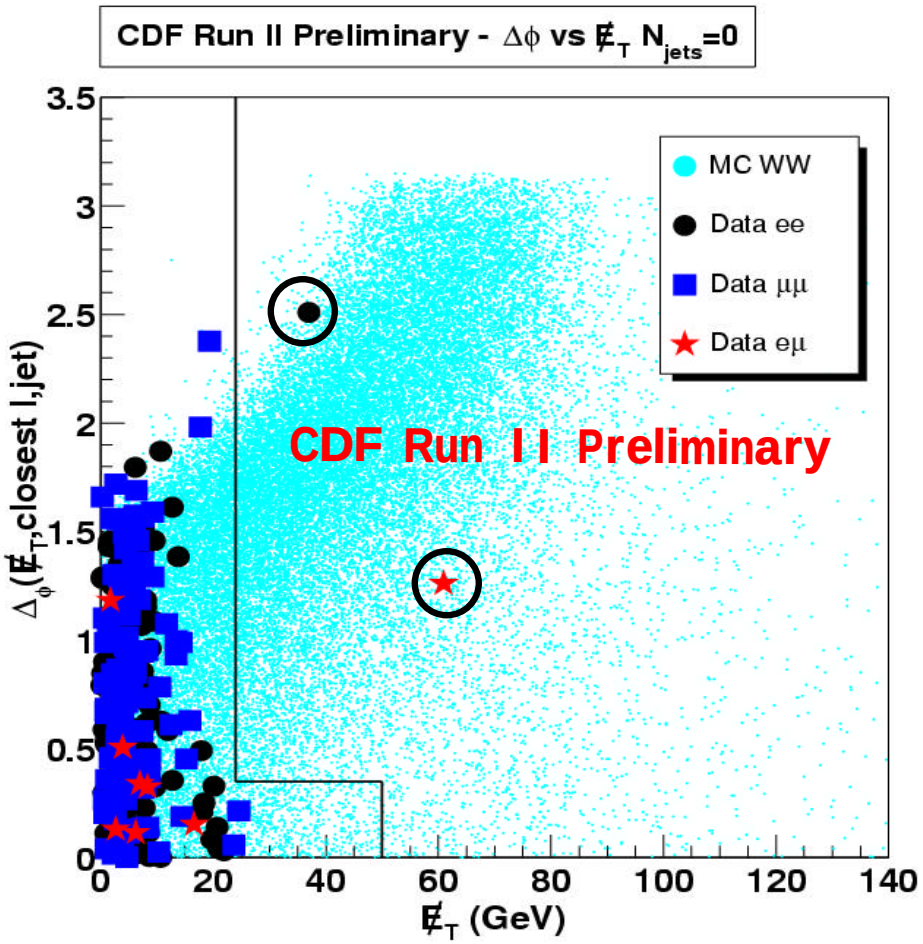


Results are consistent with predictions.

Diboson: WW→llνν

- Event selection
  - Two isolated high p_T e or μ with opposite charge
    - ✂ Fakes
  - $\not\!\!E_T$>25 GeV
  - $\Delta\phi(\not\!\!E_T, l/j)>20^0$ or $\not\!\!E_T$>50 GeV
    - ✂DrellYan,Z→ττ
  - Z veto
  - Jet veto
    - ✂$t\bar{t}$





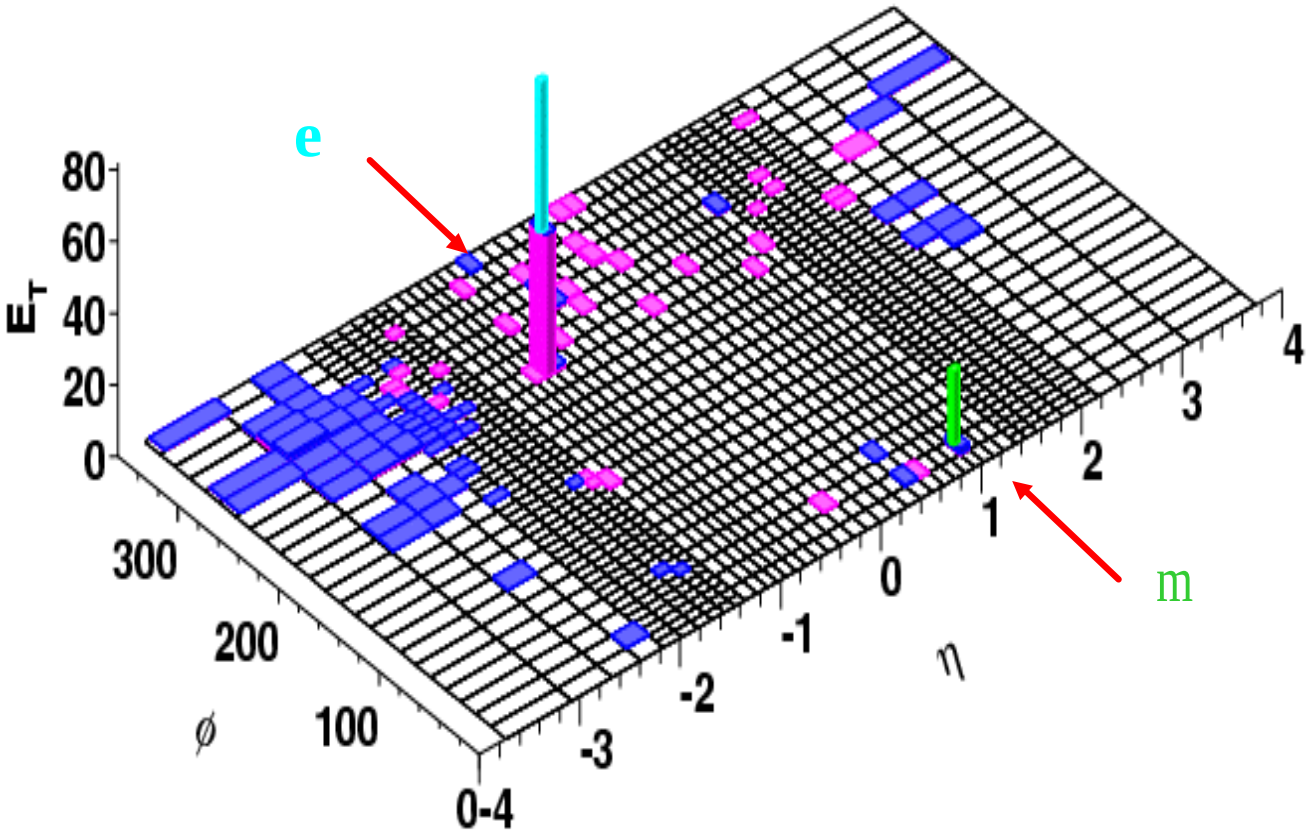
2 Candidates in ~ 72 pb^{-1}

WW→llνν Candidate Event

CDF Run II Preliminary

WW candidate:
Dec 14 2002 run:
155364 event:
3494901
e μ event

$E_T(e)$=41.8 GeV
$P_T(m)$=20.5 GeV/c^2
$\not{E}_T$=60.2 GeV



Diboson: WW→llνν

In ~ 72 pb^{-1}: **CDF Run II Preliminary**

		mm	m	
	±	±	±	±
→ νν	±	±	±	±

(Backgrounds: QCD, Drell Yan, WZ, $t\bar{t}$)

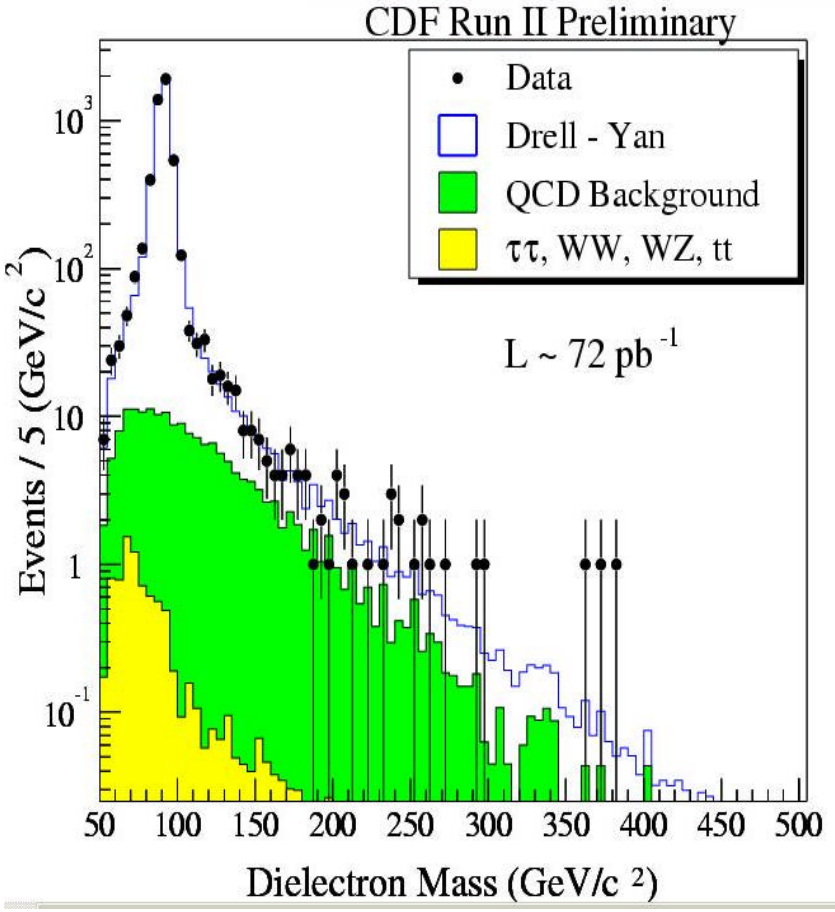
Cross section to come with more statistics …

Wg results also coming soon …

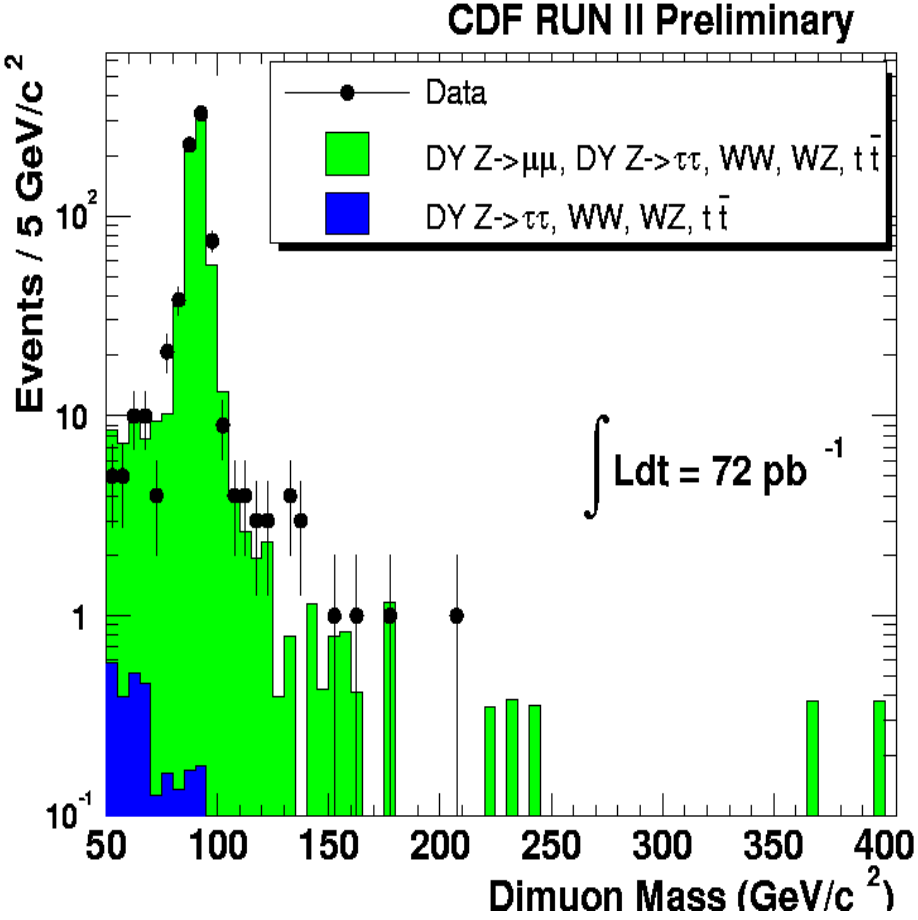
Exotic Physics Program

Search for New Resonances in High Mass Dileptons

Dielectron Invariant Mass



Dimuon Invariant Mass

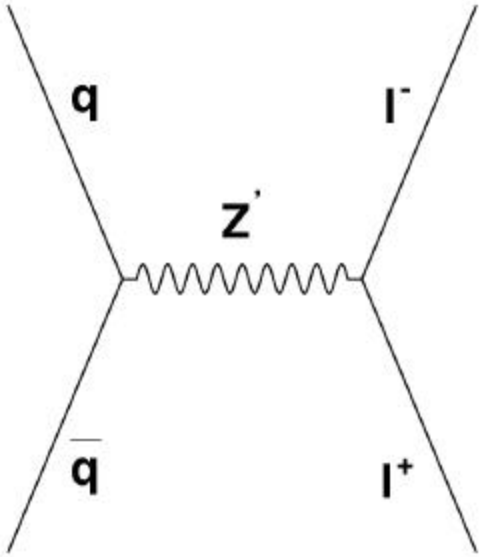


Data consistent with SM background. No excess observed.

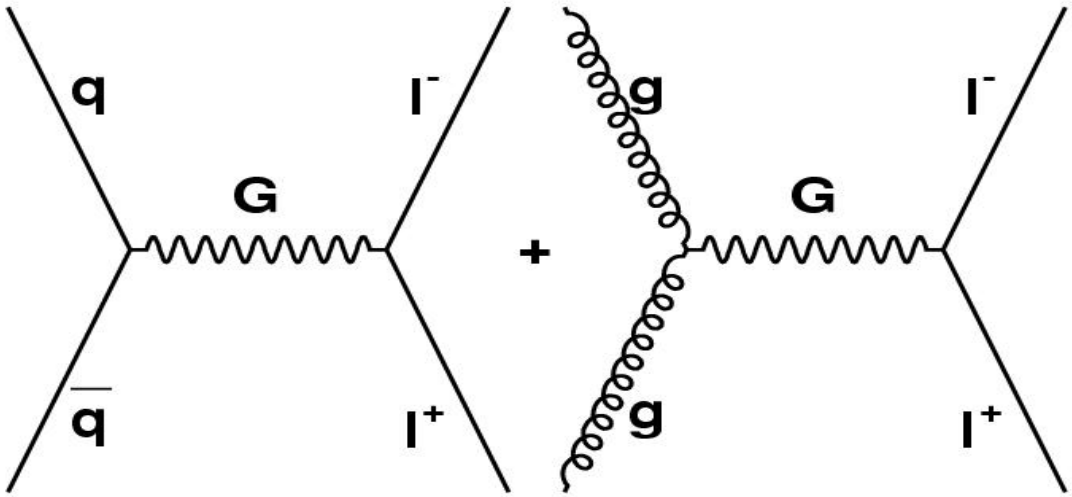
Search for New Resonances in High Mass Dileptons

High Mass Dileptons allow searches for new particle production.

- **Neutral Gauge Boson Z'**
  - SM Coupling assumed

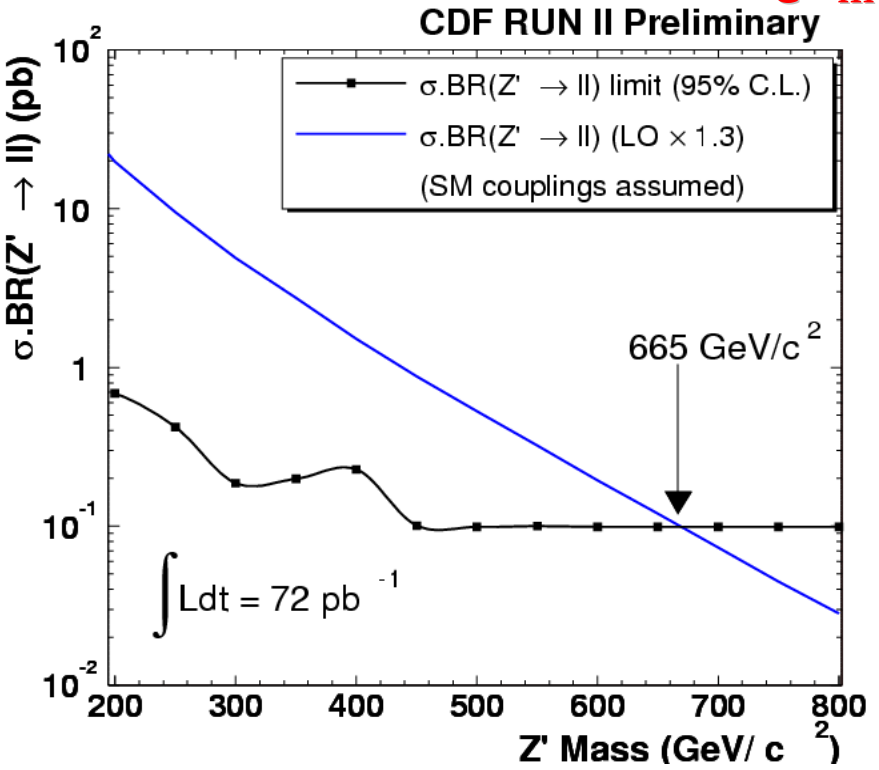


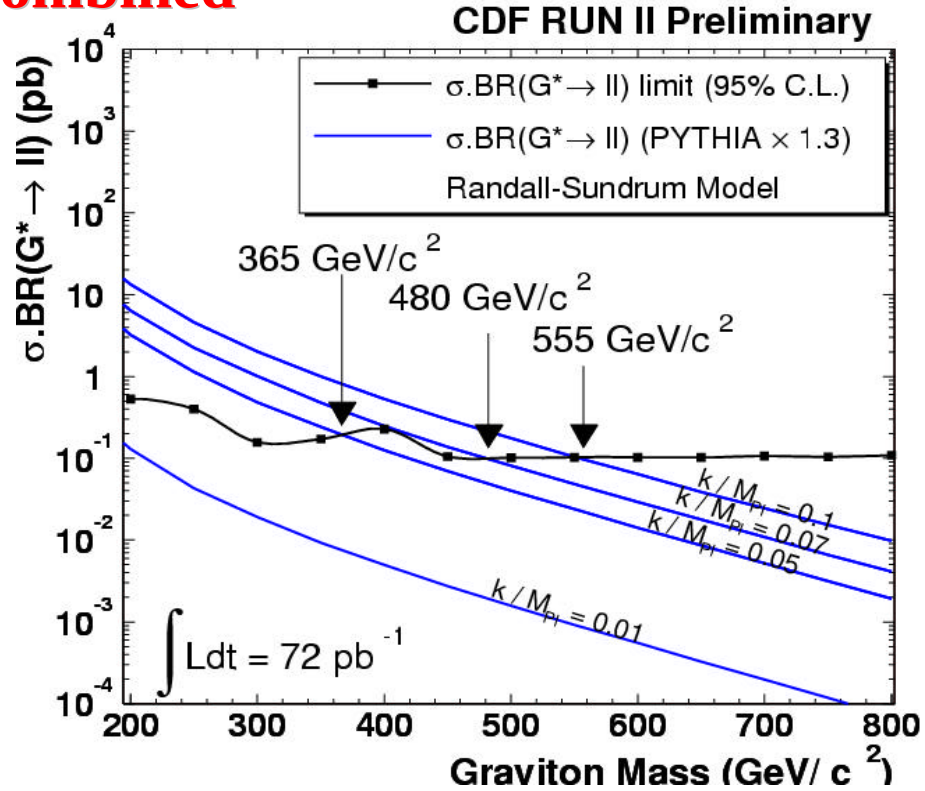
- **Randall-Sundrum Graviton**
  - Excited Graviton in 5 dimensions
  - Free parameters:
    - Mass M_G
    - Coupling $\mathbf{k}/M_{PL}$



Limits: New Neutral Gauge Boson Z' and R-S Graviton

e+m combined





Z' search history

($e^+ e^-$ mode):

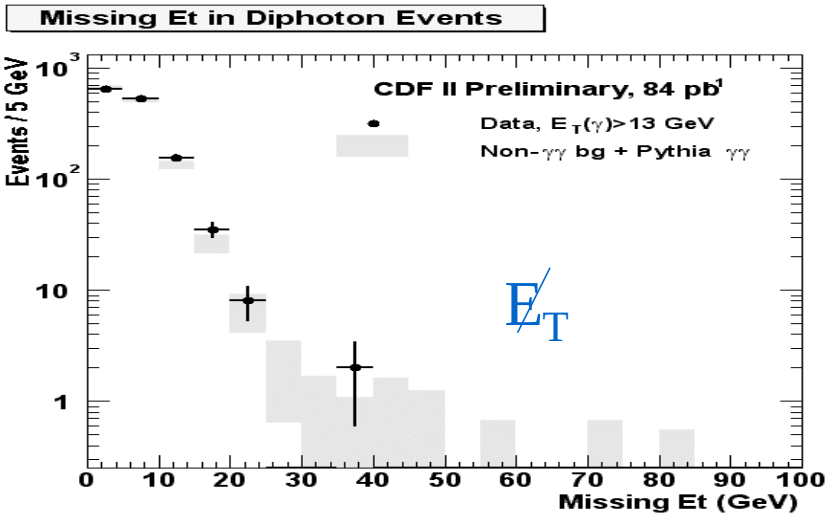
Run	Lum.(pb^{-1})	Mass Limit (95% CL)(GeV/c^2)
Run1a (1.8TeV)	19.7	505
Run1b (1.8TeV)	90	640
Run2(1.96TeV)	**72**	**650**

New Physics Searches in the Diphoton Sample

- **Event selection (84 pb^{-1}):**
  - 2 central photons E_T > 13 GeV
  - cosmic rays and beam halo rejection
  - Observed 1365 events

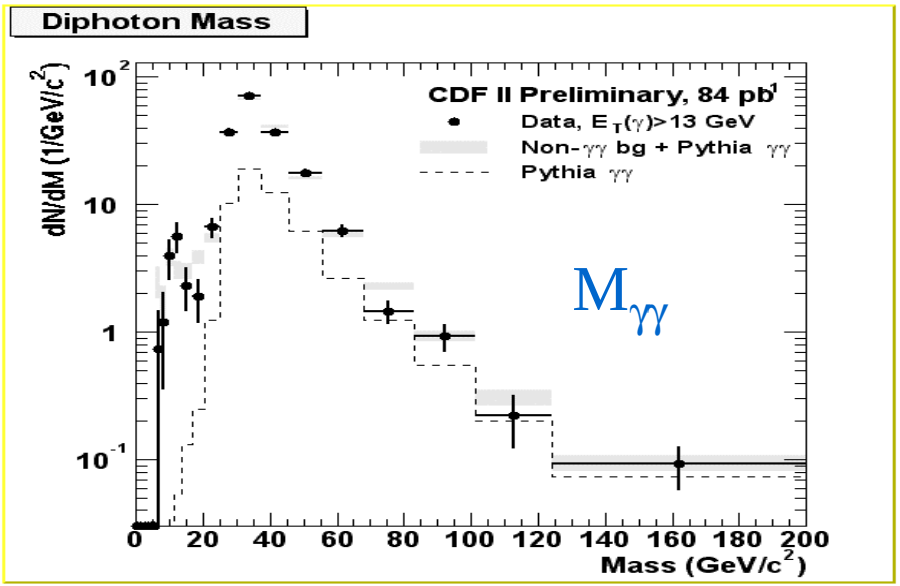
  (95 events with E_T > 25 GeV)

Good agreement between data and expectation.



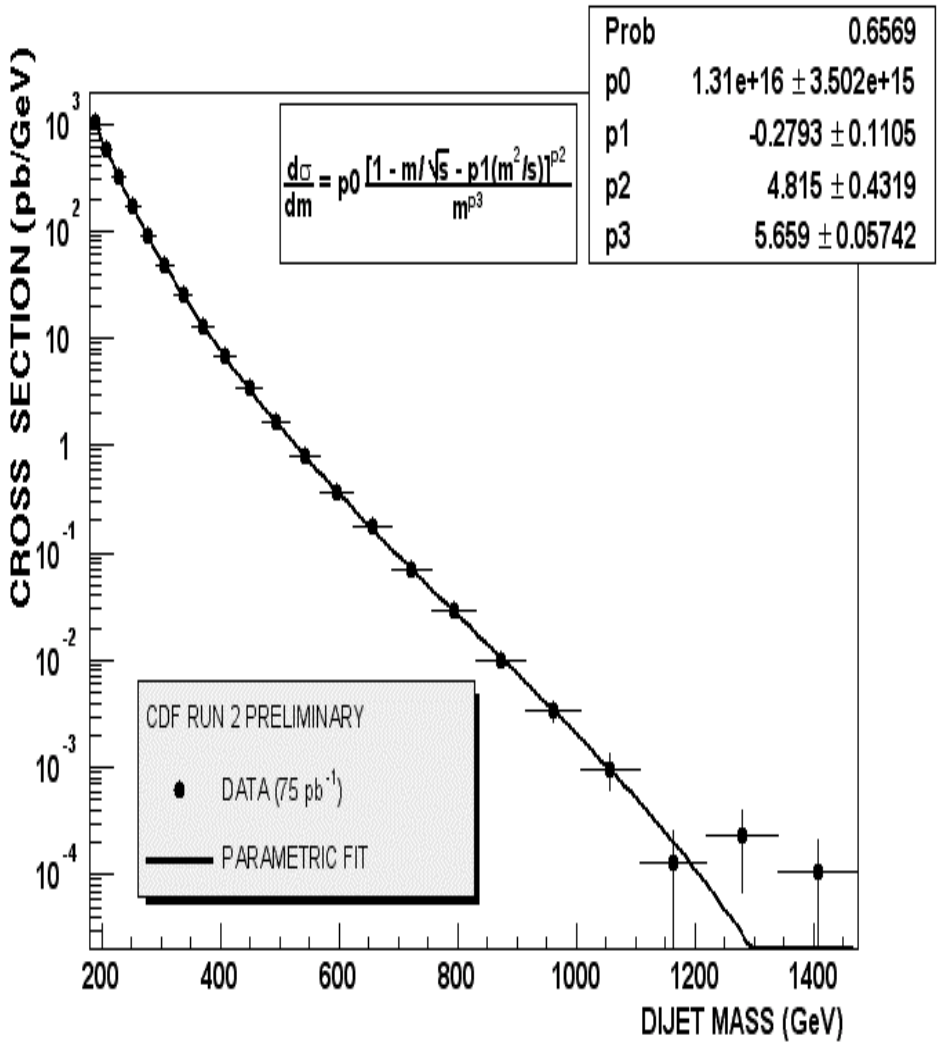
Diphoton + Lepton Events

	Obs.	Exp. $E_T^\gamma > 13$ GeV	Exp. $E_T^\gamma > 25$ GeV
$e\gamma\gamma$	0	$0.27 \pm 0.10 \pm 0.14$	$0.04 \pm 0.03 \pm 0.02$
$\mu\gamma\gamma$	0	$0.04 \pm 0.007 \pm 0.02$	$0.007 \pm 0.005 \pm 0.004$



Search for Mass Resonances in Dijets

- Inclusive jet samples
- 2 highest E_T jets selected
- Fit of the mass spectrum with a simple background parameterization and search for bumps comparable with the mass resolution.



No significant evidence for a new particle signal in ~ 75 pb^{-1}.

Calibration still in progress.

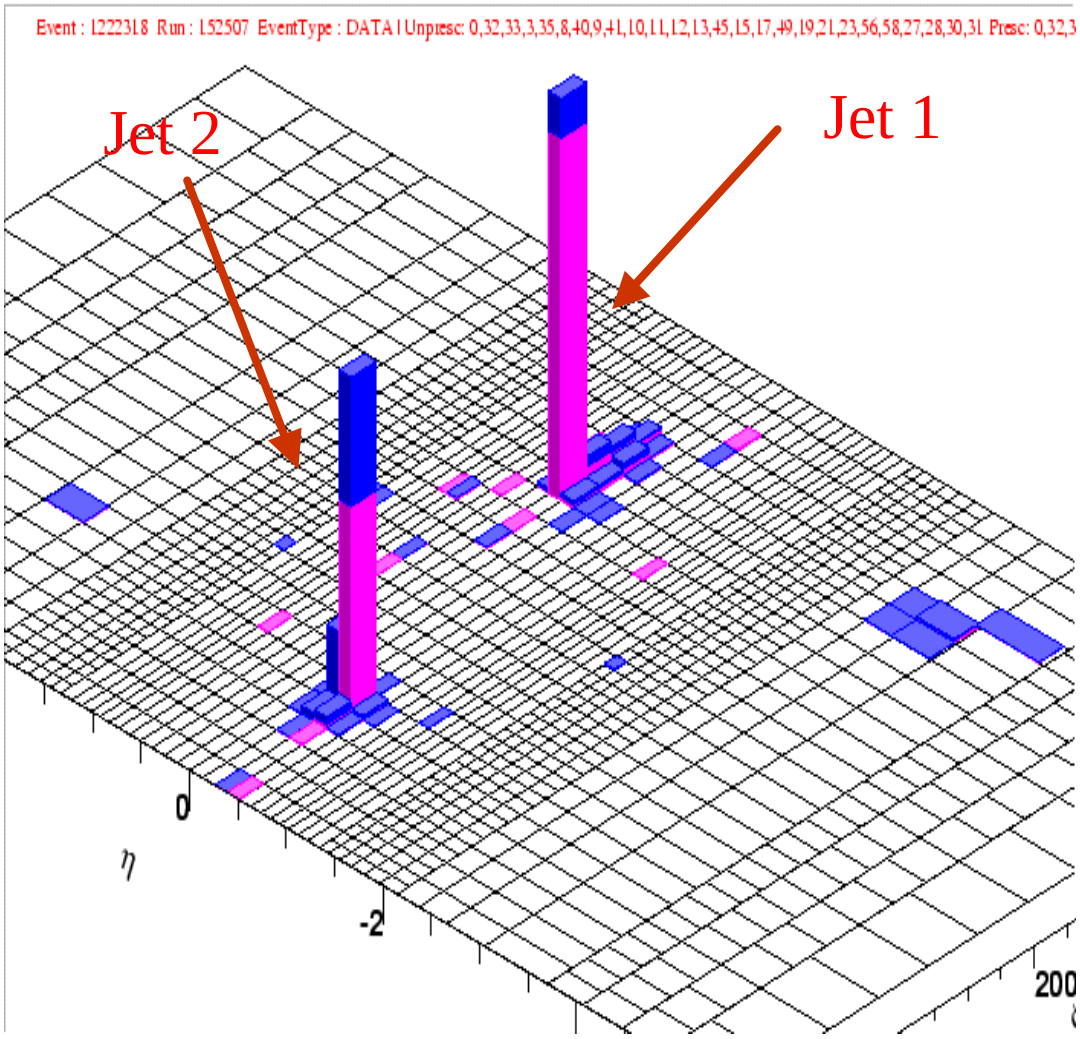
Highest Mass Dijet Event

CDF Run II Preliminary

dijet event:
Oct 4 2002 Run:152507 event: 1222318
Dijet Mass = 1364 GeV/c^2
cos θ* = 0.30
z vertex = -25 cm

J2 E_T = 633 GeV
J2 η = -0.19

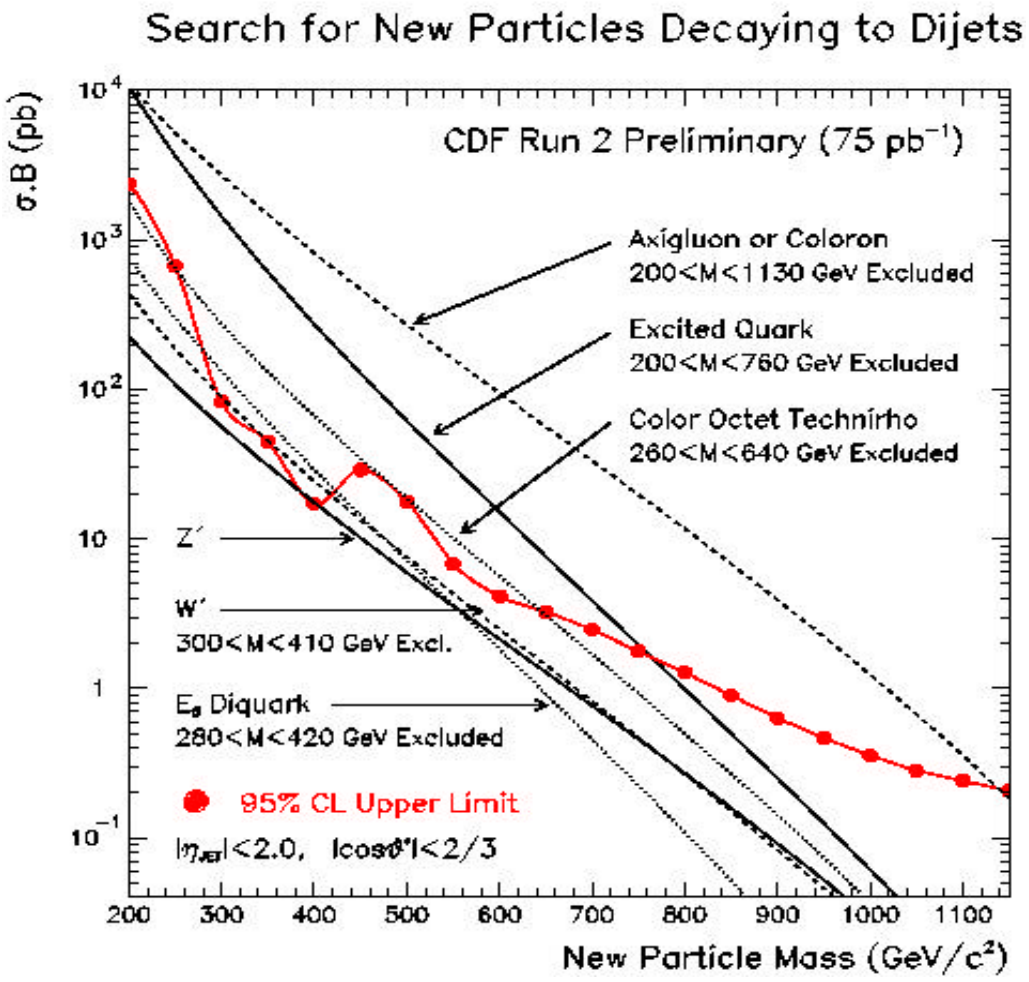
J1 E_T = 666 GeV
J1 η = 0.43



Search for Mass Resonances in Dijets

Excluded

- **Axigluons or flavor universal colorons:**
  - **$200 < m < 1130$ GeV/c^2**
- **Excited quarks:**
  - **$200 < m <$ and 760 GeV/c^2**
- **Color octet techni-r's:**
  - **$260 < m < 640$ GeV/c^2**
- **E6 diquarks:**
  - **$280 < m < 420$ GeV/c^2**
- **W' :**
  - **$300 < m < 410$ GeV/c^2**

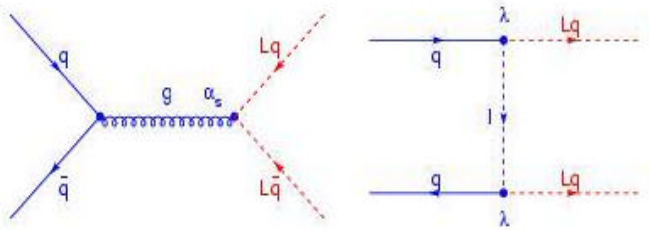


Results improved with respect to CDF Run I

Search for First Generation scalar LQ

Production

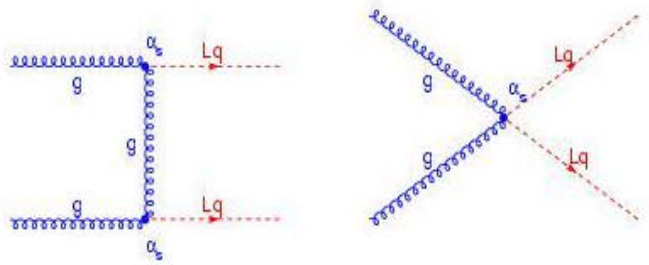
- qg → LQ + LQbar
- gg → LQ + LQbar
- qqbar → LQ + LQbar



Decay

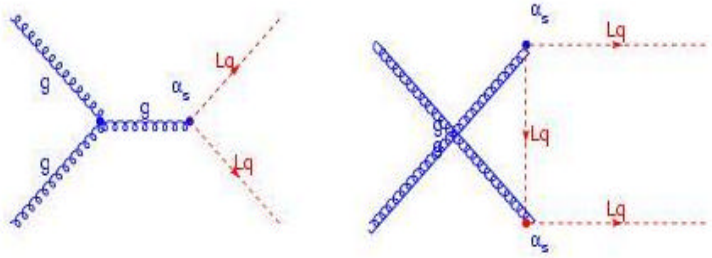
- LQLQ → l^+l^-qq,
- LQLQ → $l^\pm\nu qq$,
- LQLQ → $\nu\nu qq$

We search for di-electrons + jets.



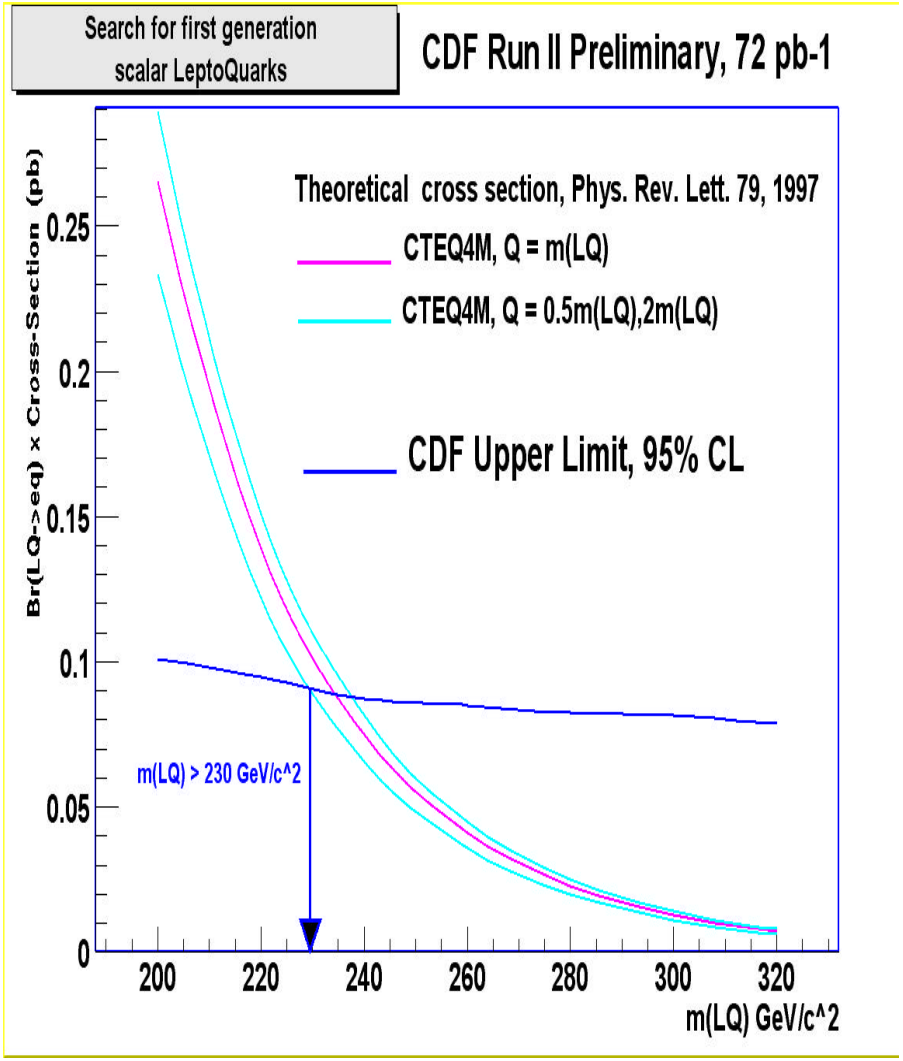
Experimental signature

- 2 high pt isolated leptons + jets
- one isolated lepton + MET + jets
- MET + jets



Search for First Generation scalar LQ

- **Event Selection:**
  - 2 central electrons with E_T > 25 GeV
  - 2 jets with E_T(j1) > 30 and E_T(j1) > 15 GeV
  - Z veto
  - Cuts on *sum* of jet and electron E_T's to reject SM backgrounds
- **Expected Bkg:** 3.4 ± 3.2 events (DY+2jet events, tt)



0 events observed in 72 pb-1.
M(LQ) > 230 GeV/c^2 @ 95% CL
(Run I 220 GeV/c^2)

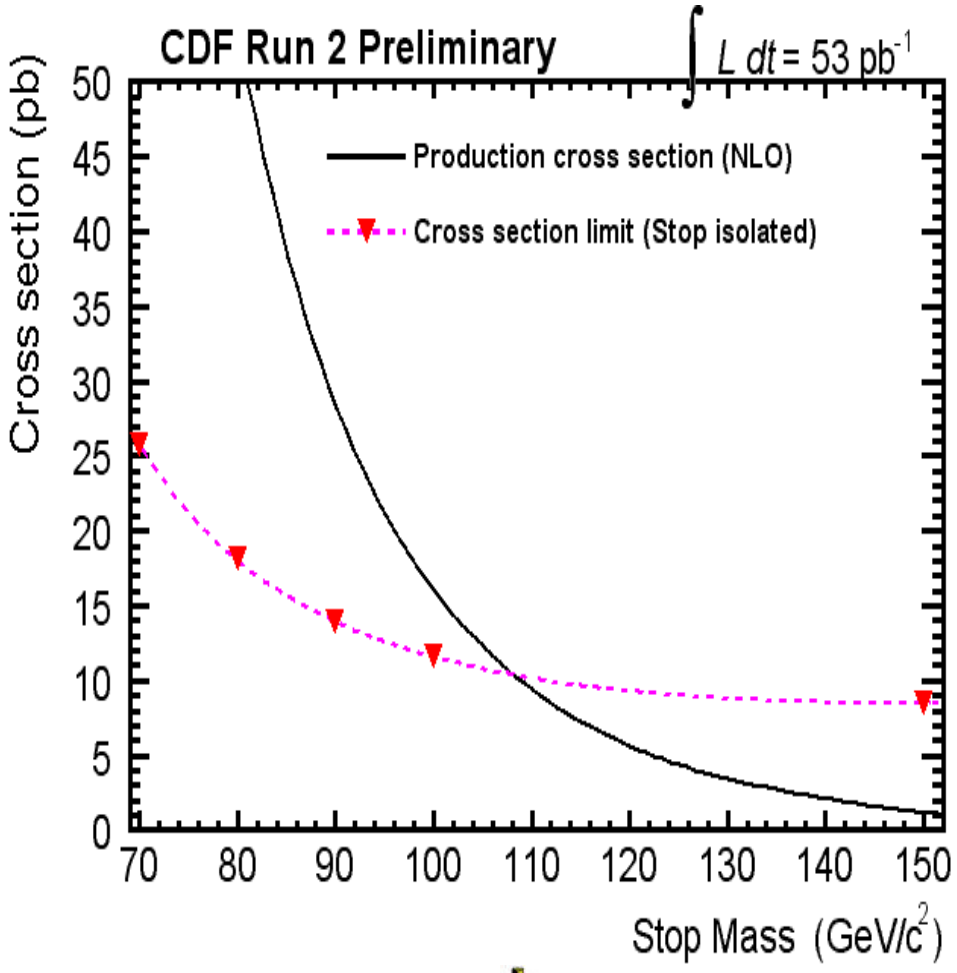
CHArged Massive ParticleS

- Long lived particles escaping the CDF detector
- Isolated, slow moving
- Use our TOF detector

7 events observed.
Background prediction:
2.9 +/- 0.7 (stat) +/- 3.1 (sys)

stop:
- NLSP in GMSB
- strongly interacting

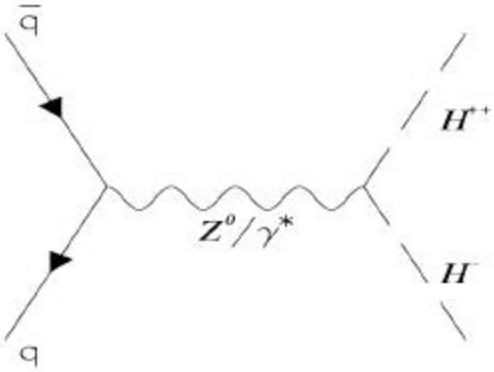
M(stop) > 107 GeV
at 95% CL. (isolated stop)

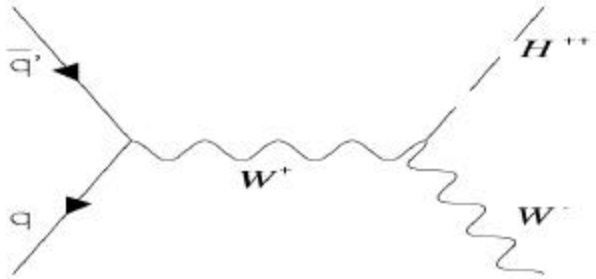


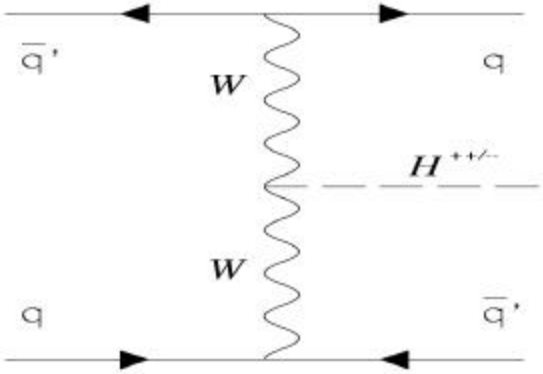
(See Feb. 28 seminar by Rick Snider.)

Search for Doubly Charged Higgs

- **No H^{++} in SM. Arises in extensions of SM.**
- **At the TeVatron H^{++} can be pair-produced (Z exchange) or singly produced (WW fusion).**
- **signature: *same sign leptons***
- **Backgrounds are low**
- **Easy to extend our knowledge of Higgs early.**





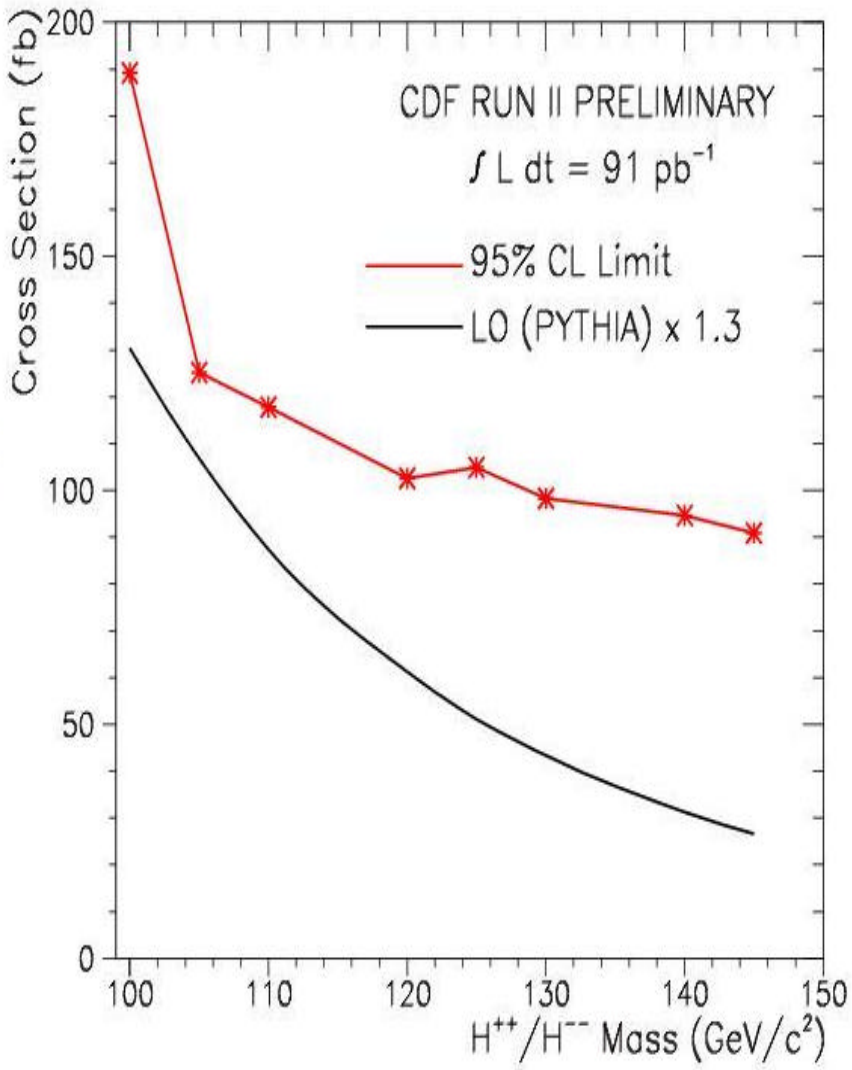


LEP limit up to 100 GeV/c^2 (prompt and long lived)

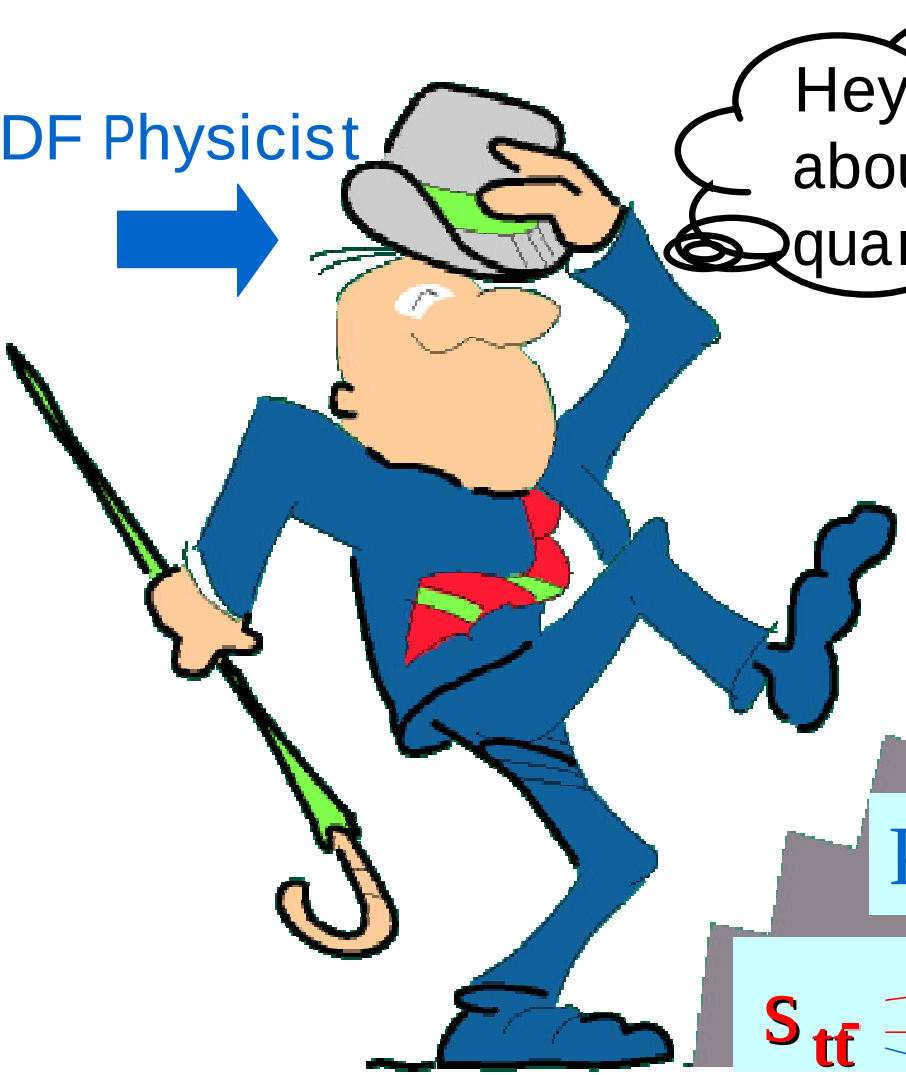
Search for Doubly Charged Higgs

- Same-sign dielectron mass distribution is used to search for doubly charged Higgs of a given mass
  - search region defined as of ± 10% of Higgs mass
  - signal region above the Z mass (>100 GeV)
  - low mass region as control region (< 80 GeV)
- Very low background ($0.6\ ^{+0.5}_{-0.1}$ events)
  - W/Z + misidentified jet
  - WZ production
  - opposite signed mis-measured electron

0 events observed in 91 pb^{-1}



Top Physics Program



M_{Top}

Single Top

Rare Decays

W Helicity

Production Kinematics

$S_{t\bar{t}}$ → **dileptons**

→ **lepton+jets**

→ All-hadronic

$t\bar{t}$ Decay Modes

BR(t ® Wb) @ 100 % ® 3 main experimental signatures

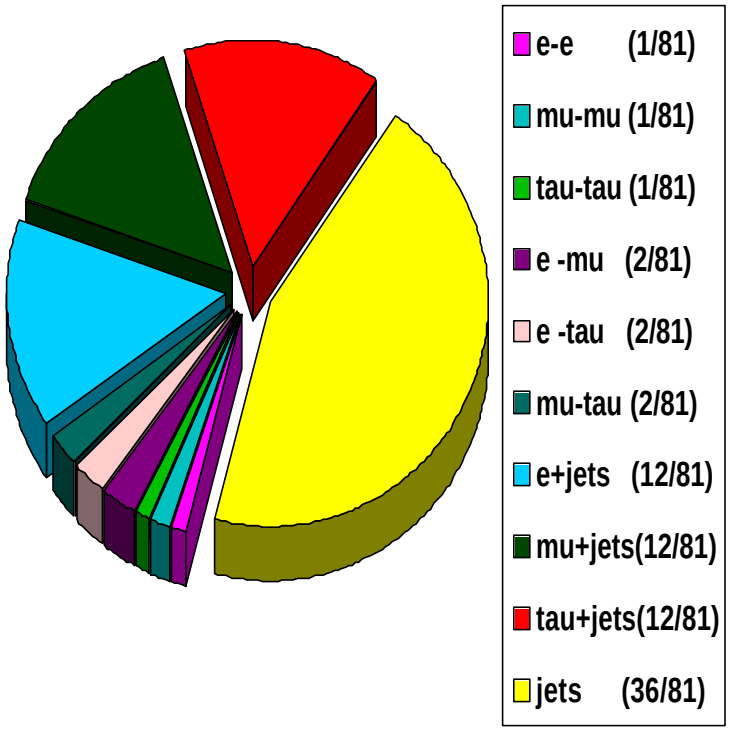
- Dilepton (2 high-P_T leptons, 2 b jets, large E_T) : BR = 1 / 9

  BR(ee,μμ,eμ) = 5%

- Lepton + Jets (1 high-P_T lepton, 4 jets (2 b's), large E_T): BR = 4 / 9

  BR(e, μ + jets) = 30%

- All-hadronic (6 jets) : BR = 4 / 9



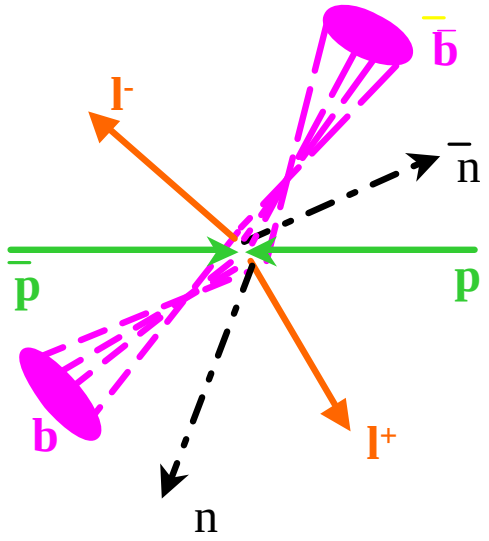
$$s_{t\bar{t}}(\sqrt{s}=1.96\,\text{TeV}) \approx 1.30 \times s_{t\bar{t}}(\sqrt{s}=1.8\,\text{TeV})$$

Top Dilepton Channel: $t\bar{t} \rightarrow l\nu l\nu bb$

- Event selection
  (similar to Run I)
  - Two ***isolated*** high p_T e or μ with opposite charge
    ✂ Fakes,Wbb
  - $\Delta\phi(\not{E}_T, l/j) > 20^0$, or $\not{E}_T > 50$ GeV
    ✂DrellYan,$Z \rightarrow \tau\tau$
  - Z, cosmic, conversion vetos
  - $\not{E}_T > 25$ GeV
  - Jets $E_T > 10$ GeV & $|\eta| < 2.0$
  - use ≥2 jets for $\sigma_{t\bar{t}}$
    ✂WW/WZ
  - ***Total E_T in the event, H_T >200 GeV***
    ✂WW/WZ,$Z \rightarrow \tau\tau$

Disadvantages low yield

Advantages high S/B~ 8



5 Candidates in ~ 72 pb^{-1}

b tagging will come with more statistics.

$\sigma_{t\bar{t}}$ Dilepton Channel: $t\bar{t} \rightarrow l\nu l\nu bb$

Run II Top Dilepton Summary Table:

_____	__	mm	_m	ll
	±	±	±	±
	±	±	±	±

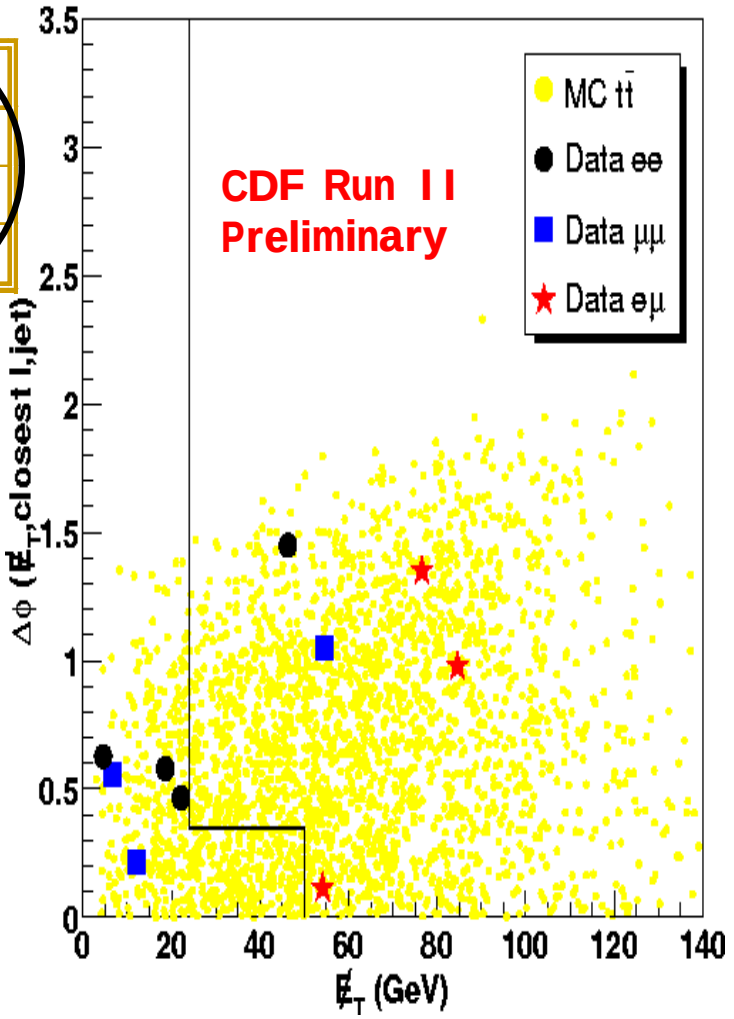
$s_{t\bar{t}}$ = 13.2 ± 5.9$_{stat}$ ± 1.5$_{sys}$ ± 0.8$_{lum}$ pb

NLO @ Ös=1.96 TeV for

M_{top} = 175 GeV‡: 6.70$^{+0.71}_{-0.88}$ pb

‡ hep-ph/0303085(ML Mangano et al)

$\Delta\phi$ vs. $\not{E}_T$ N $_{jets} \geq 2$

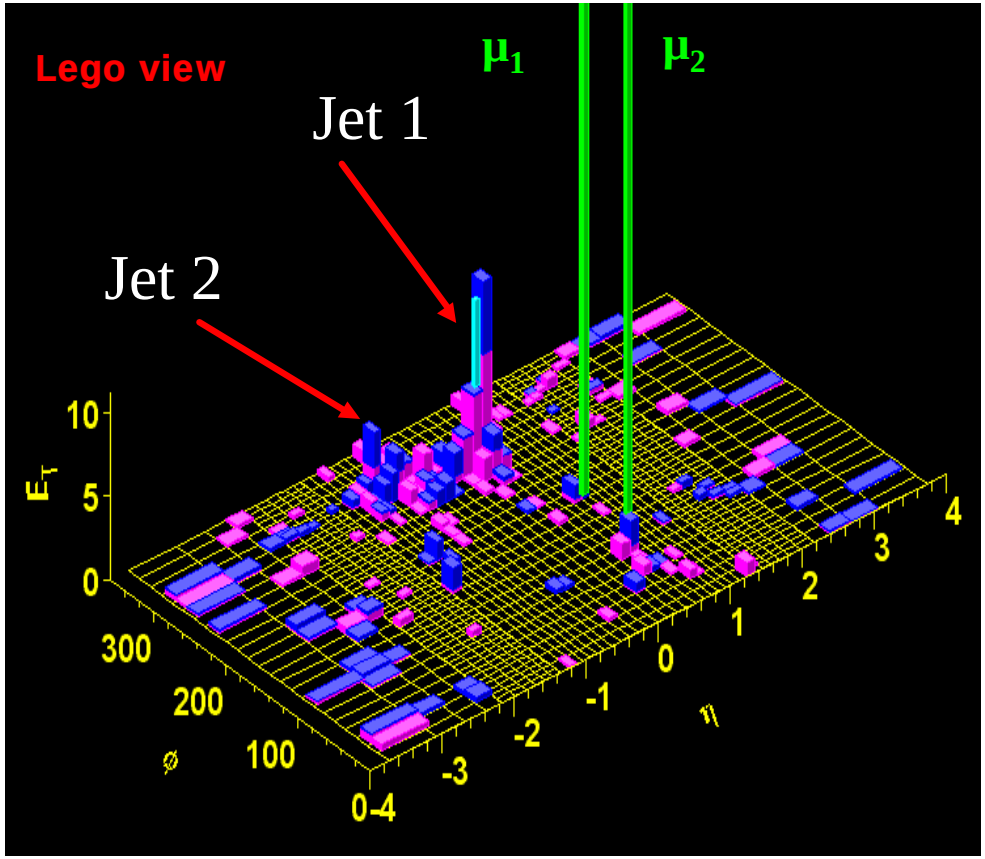


Top Dilepton Candidate Event

tt dilepton candidate:
Nov 26 2002 run: 154654 event: 7344016
$\mu^+\mu^-$ (CMUP-CMX) + 2 jets

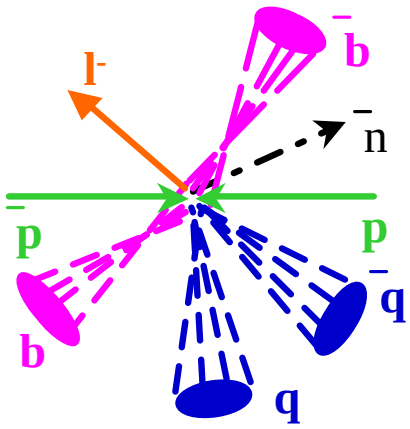
$p_T(m_1) = 57$ GeV/c^2
$p_T(m_2) = 53$ GeV/c^2
$M_{mm} = 69$ GeV/c

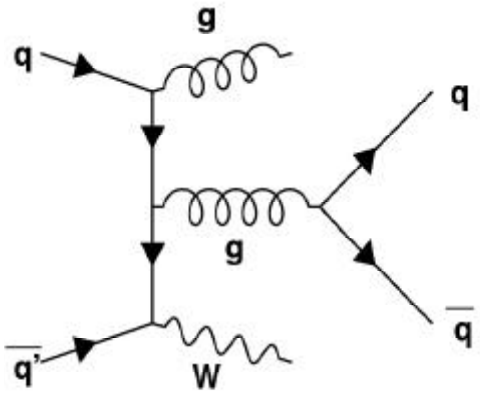
$E_T^j = 32{,}15$ GeV
$\not{E}_T = 54$ GeV
$H_T = 212$ GeV



Lepton + Jets Channel: $t\bar{t} \rightarrow l\nu qqbb$

- Event selection (same as Run I)
  - Exactly one isolated high p_T e or μ
  - $\not\!\!E_T$>20 GeV
  - Jets E_T>15 GeV & $|\eta|$<2.0
  - Z, cosmic, conversion vetos
  - use ≥3 jets for $\sigma_{t\bar{t}}$
  - ≥ 1 b-tag jet





Advantages:

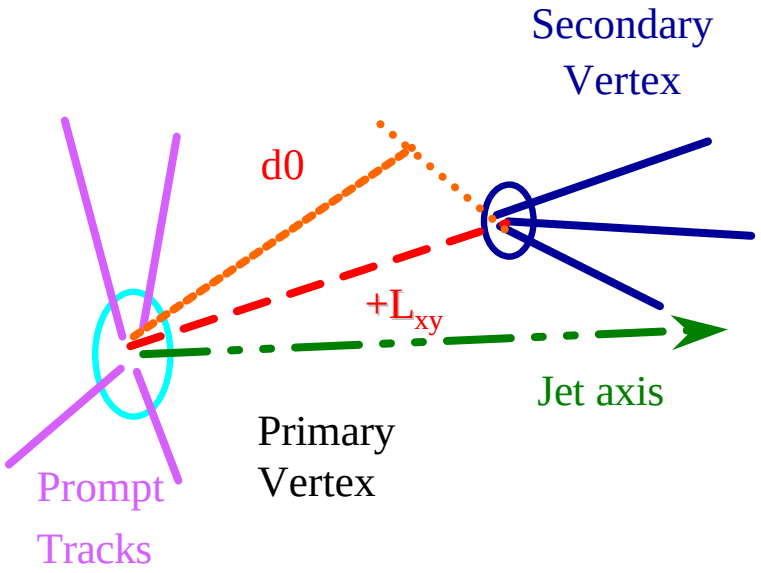
- Lower S/B≈1:6 for W+≥ 3 jets
  - b-tagging improve S/B≈3:1
- Higher statistics
- Essential for M_{top}(2 b-tags jets)

- Backgrounds
  - Wbb, Wcc, Wc (*measured from data and MC*)
  - Mistags from light quarks and gluon jets (*measured from data*)
  - Non W background (fake lepton) (*measured from data*)
  - Diboson, Drell-Yan, single top (small) (*measured from MC*)

Secondary Vertex Tagging (SECVTX)

- Signature of a b decay is a displaced vertex:
  - Long lifetime of b/c hadrons ($c\tau \sim 450\ \mu m$)
  - B hadrons travel L_{xy}~3mm before decay with large charged track multiplicity.
- Algorithm:
  - Look for displaced vertices: all combination of at least 2 tracks
  - Jet is tagged as b-jet if $L_{xy}/\sigma_{xy} > 3$ (typical σ_{xy}~150μm)

Efficiency of b-tagging a tt event:
(Measured in tt MC)
ε(event tag) =
$45 \pm 1 \pm 5$ %

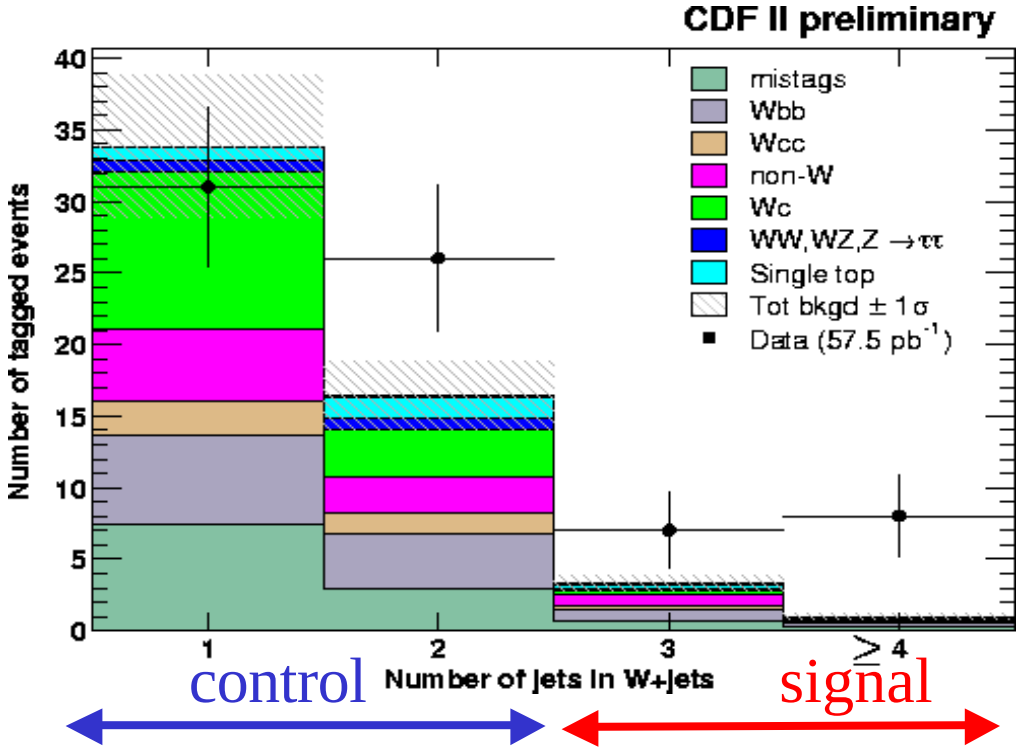


Lepton + Jets Backgrounds

Jet Multiplicity in b-tagged W+jets events

CDF Run II Preliminary

15 Candidates in ~ 57.5 pb^{-1}

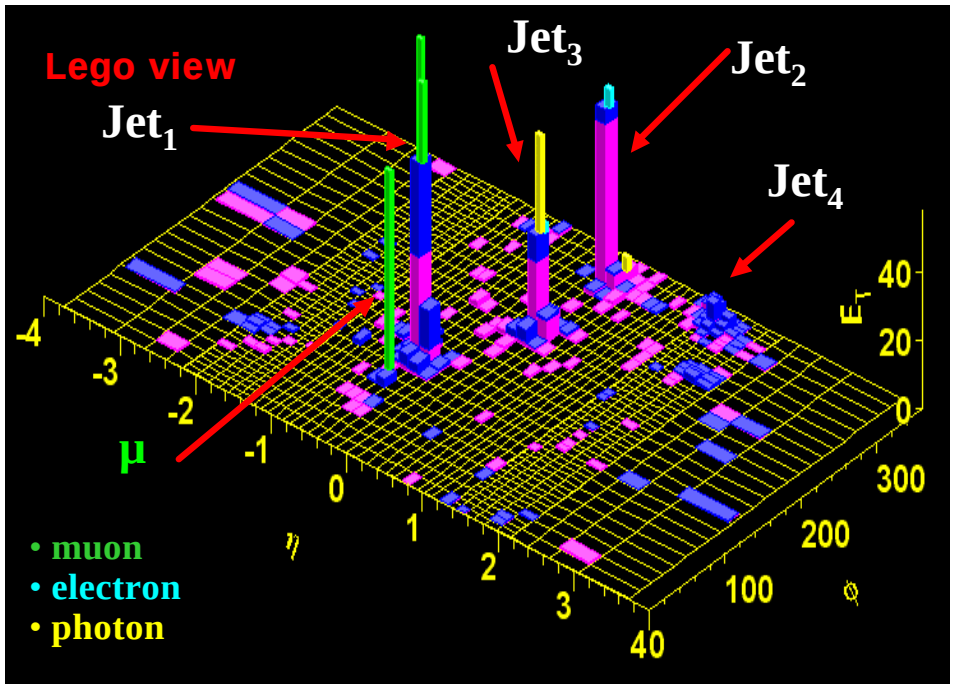


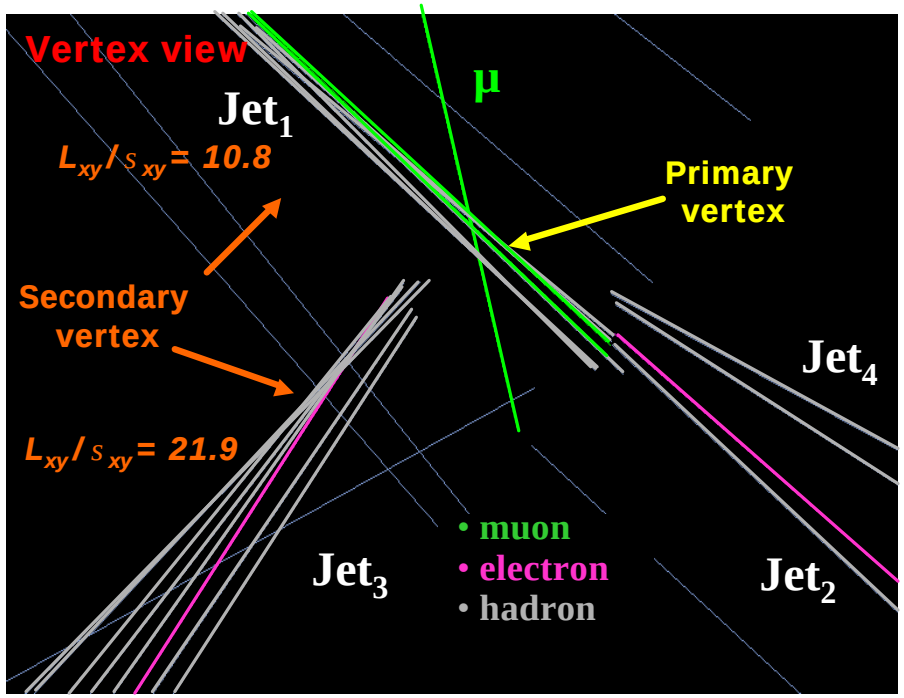
				3
	±	±	±	±
–	±	±	±	±

Lepton + Jets Candidate Event

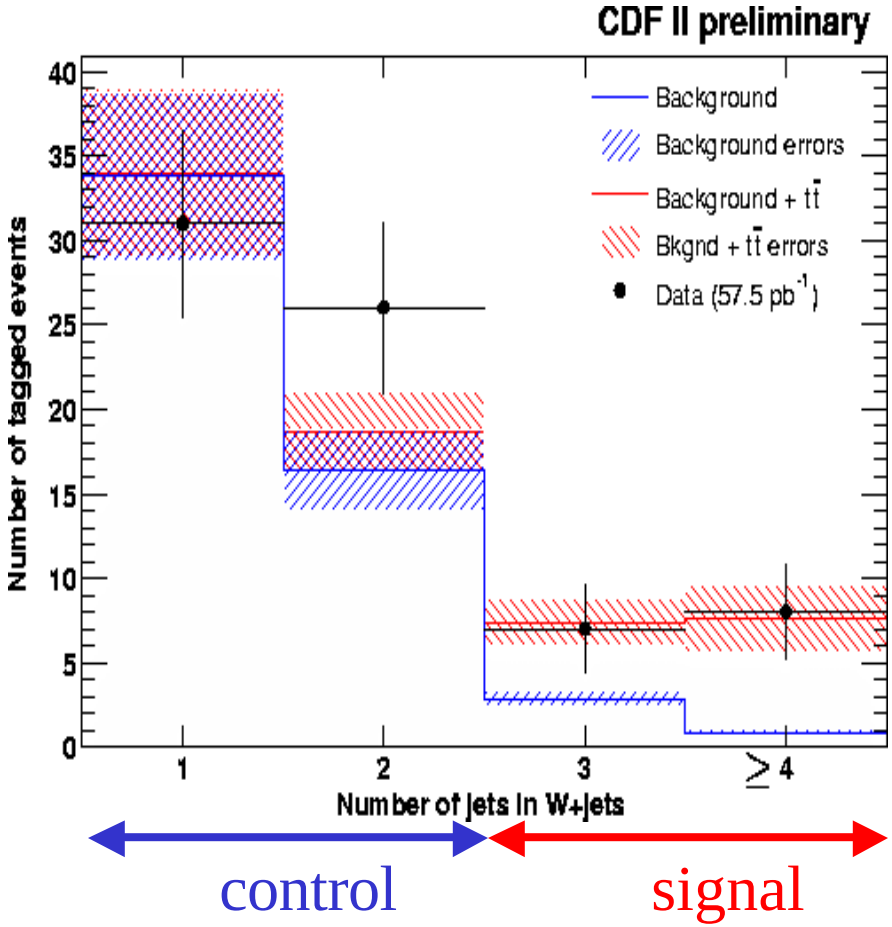
tt l + jet candidate:
Nov 02 2002 run: 153693 event: 799494
μ (CMUP) + 4 jets

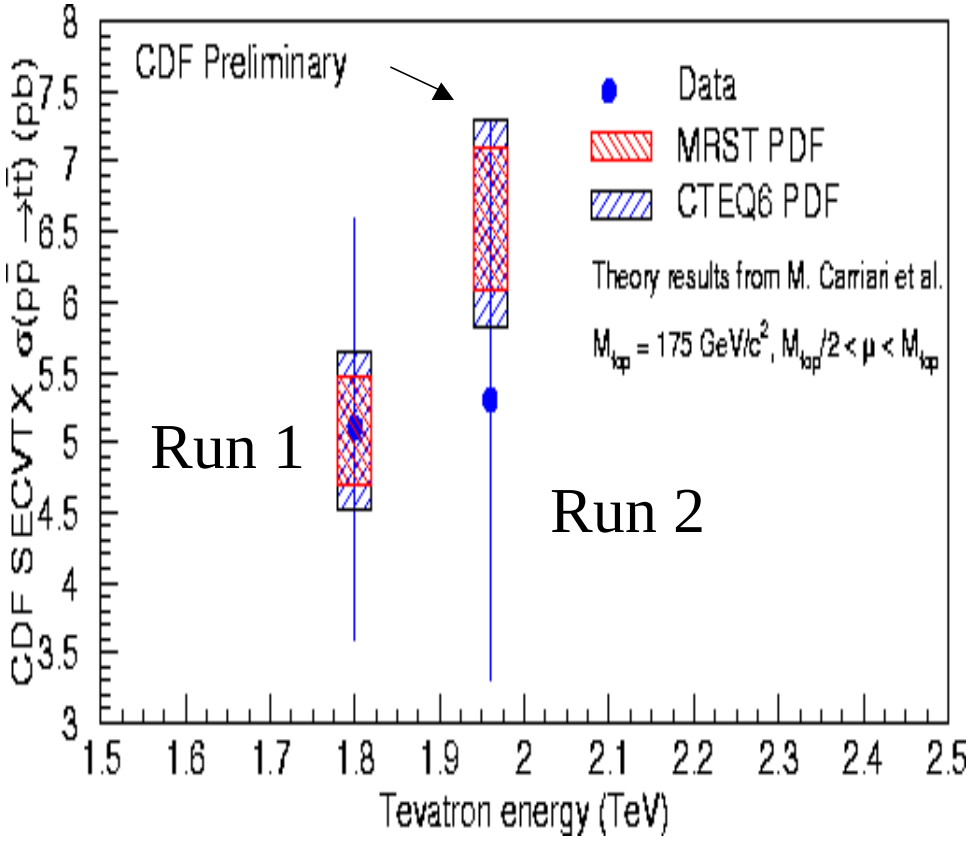
$p_T(m) = 54.4$ GeV/c^2
$E_T^j = 96.7, 65{,}8, 54.8, 33.8$ GeV
$\not\!\!E_T = 40.8$ GeV





$\sigma_{t\bar{t}}$ - Lepton + Jets Channel

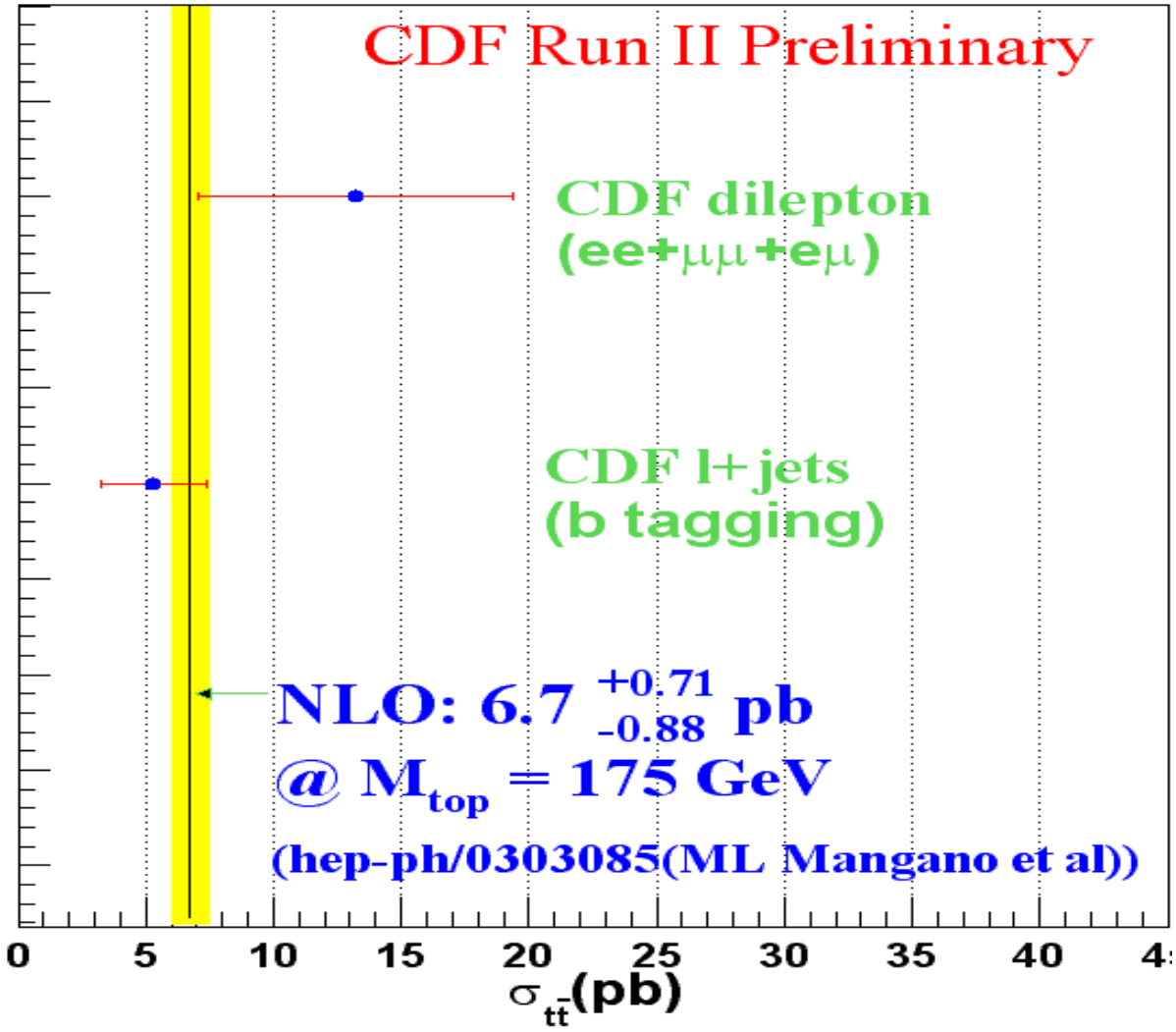




CDF Run II Preliminary

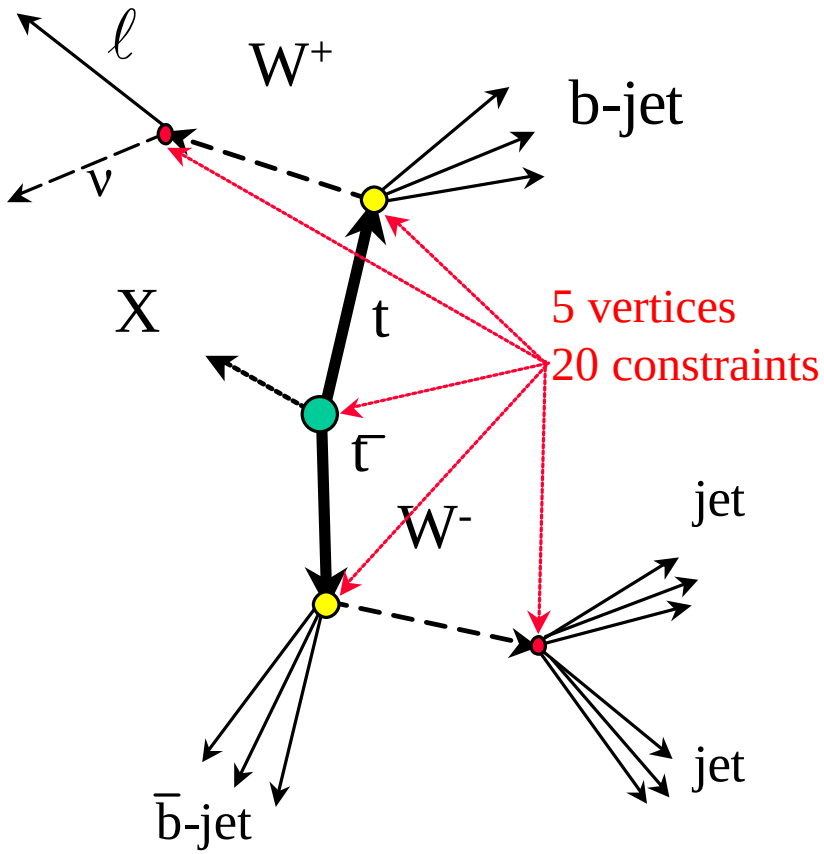
$$s_{tt} = 5.3 \pm 1.9_{stat} \pm 0.8_{sys} \pm 0.3_{lum}\ pb$$

Summary of $\sigma_{t\bar{t}}$ Measurements



Top Mass: Lepton + jets

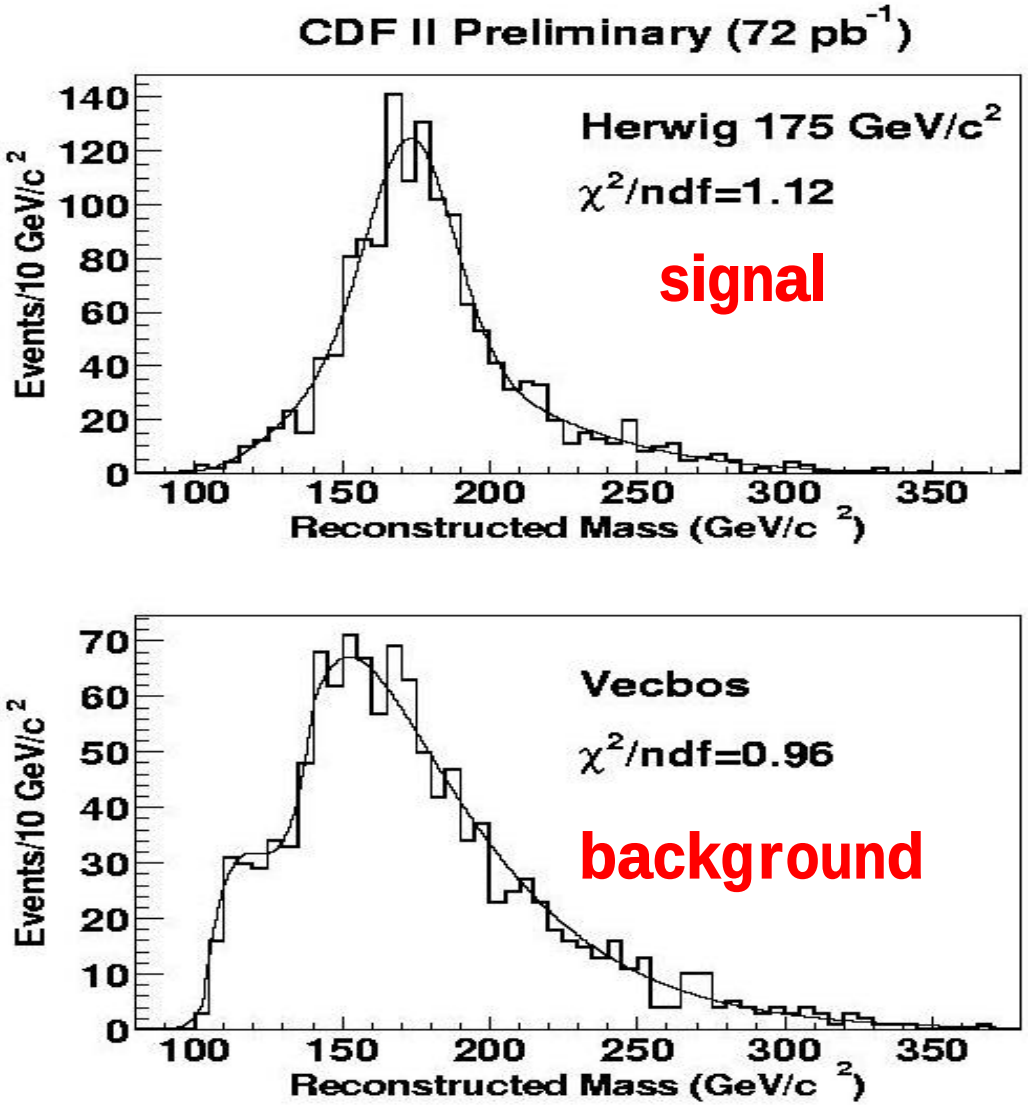
- **Event Selection:**
  - Select lepton + 4 jet events, similar to σ_{tt}-measurement, except no requirement on silicon.
- **Method**
  - 24 combinations
    - 12 correspond to the jet-parton match
    - every combination has two solutions for p_z^{ν}
  - Impose $M_t=M_t$, $M(j,j)=M(l,\nu)=M_W$,
    - PDG: M_W, Γ_W, Γ_t
  - 2-C fit applied, lower χ^2 is chosen for top mass



Top Mass

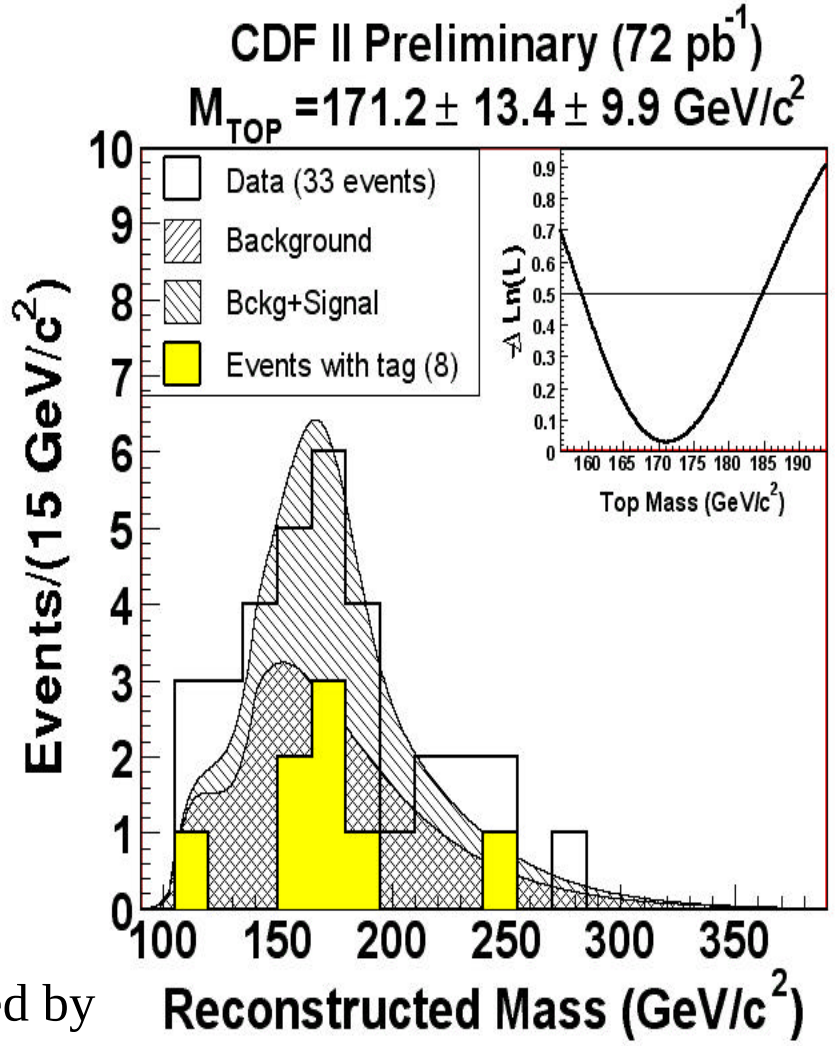
Reconstructed top masses from data are compared to *parameterized* templates of top and background Monte Carlo.

Extract top quark mass using maximum Likelihood.



Top Mass

- Use a continuous likelihood method to extract top mass and statistical uncertainty
- M_{top} is the minimum of the log-likelihood distribution
- σ_{top} corresponds to a change of 0.5 units in the log-likelihood



M_{top} =

$171.2 \pm 13.4_{stat} \pm 9.9_{sys}$ GeV/c^2

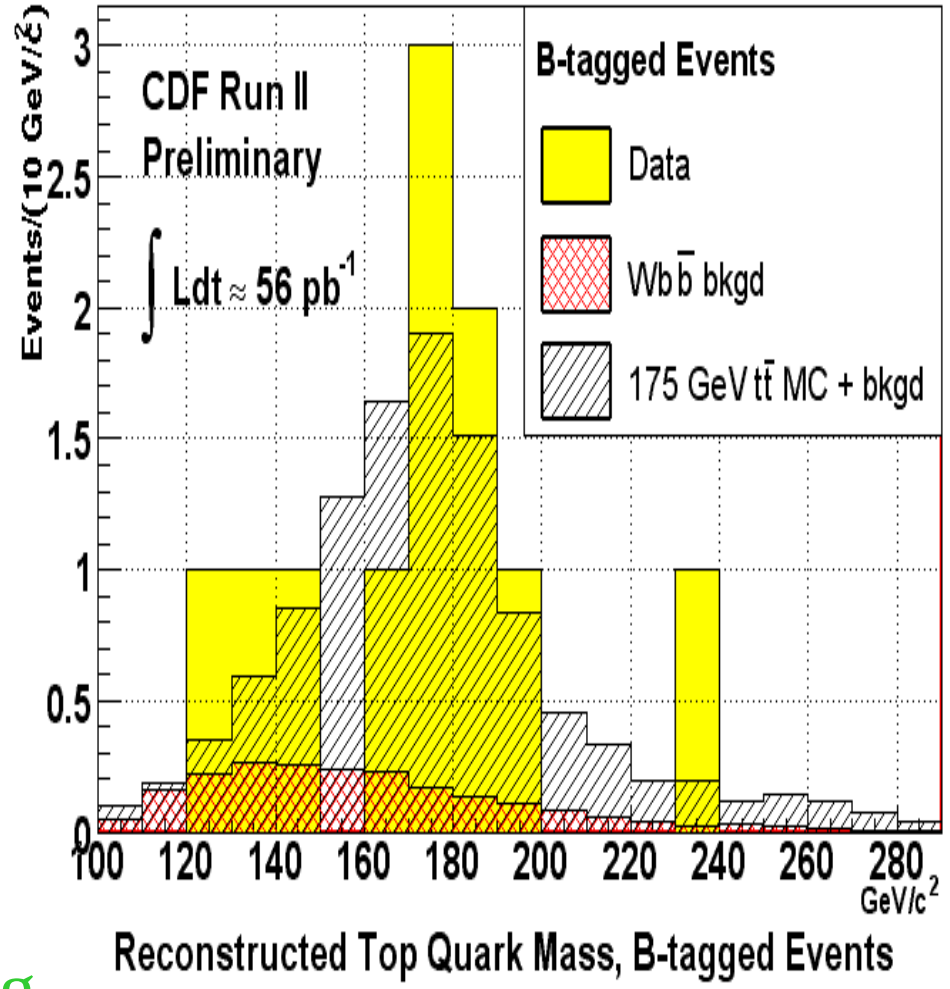
CDF Run 1 combined:

$M_{top} = 176.1 \pm 6.5$ GeV/c^2

Currently dominated by Jet energy measurement.

What about using b-tagging?

- **Event Selection:**
  - Select lepton + 4 jet events, similar to $\sigma_{t\bar{t}}$ measurement. Require *at least* one b-tagged jet.



B-tagging:

- Improves mass resolution
- Lower backgrounds

M_{top} with b-tagging is coming….

SUMMARY

- **Run 2a is well underway!**
- **We have reestablished some basic physics measurements and we have many new interesting physics results:**
  - ➔ **W/Z Cross Sections: our *standard candles***
  - ➔ **Searches for new particles: we have established our sensitivity**
  - ➔ **$t\bar{t}$ Cross Section and Top mass: the top quark is back**
- **With larger samples (~200 pb^{-1} by summer?) we will be able to extend our Run I searches for extensions to the standard model.**