Recent Results in Electroweak, *Exotic* & Top Physics from CDF

Rutgers University
HEX Seminar
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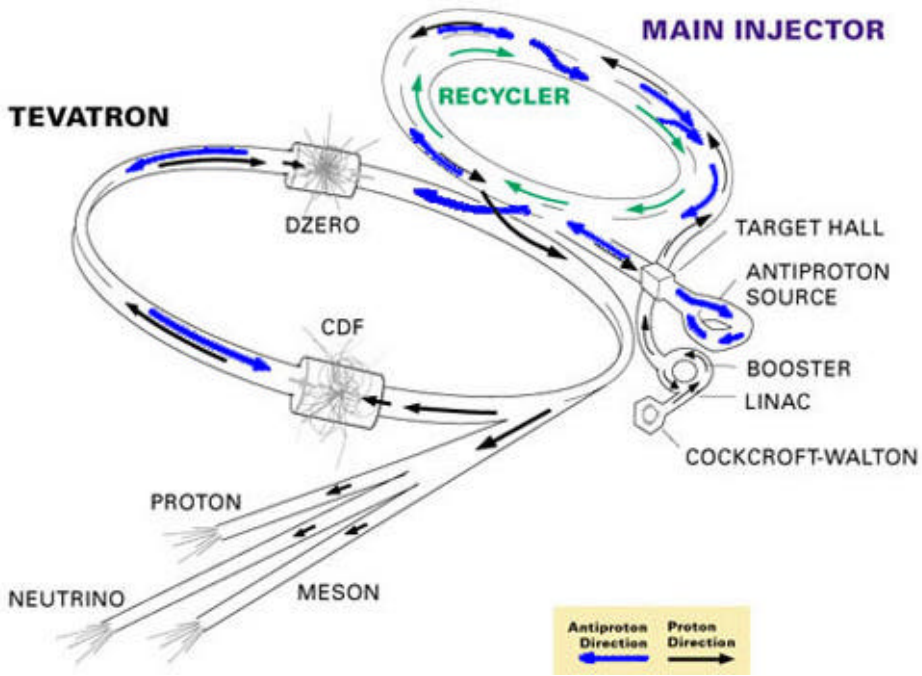
Outline

- **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 $Z^0 \rightarrow e^+e^-$
- ***Exotic* Physics**
  - Searches for new particles in DY spectrum
    - Z'
    - Randall-Sundrum Graviton
  - Searches for resonances in the dijet spectrum
  - Search for 1st generation Leptoquarks in dielectrons + jets
  - Search for doubly charged Higgs
- **Top Physics**
  - $t\bar{t}$ production cross sections
    - Dileptons
    - Lepton + jets
  - Top mass
- **Summary**

Fermilab Tevatron



Operated with proton on anti-proton bunches at CM energy of 1.96 TeV.

The CDF-II Detector

What did CDF Keep ?

- **Solenoid**
- **Central calorimeter**
- **Parts of the muon system**

Most of the detector is NEW

- **Tracking**
  - **Silicon Tracker (L00, SVX, ISL)**
  - **Central Outer Tracker**
  - **Time of Flight**
- **Endplug Calorimeter**
- **Muon systems**
- **Front End Electronics**
- **Trigger/DAQ (pipelined)**
- **Online and Offline software**

Silicon Tracking Detectors

Central Drift Chambers

Solenoid Coil

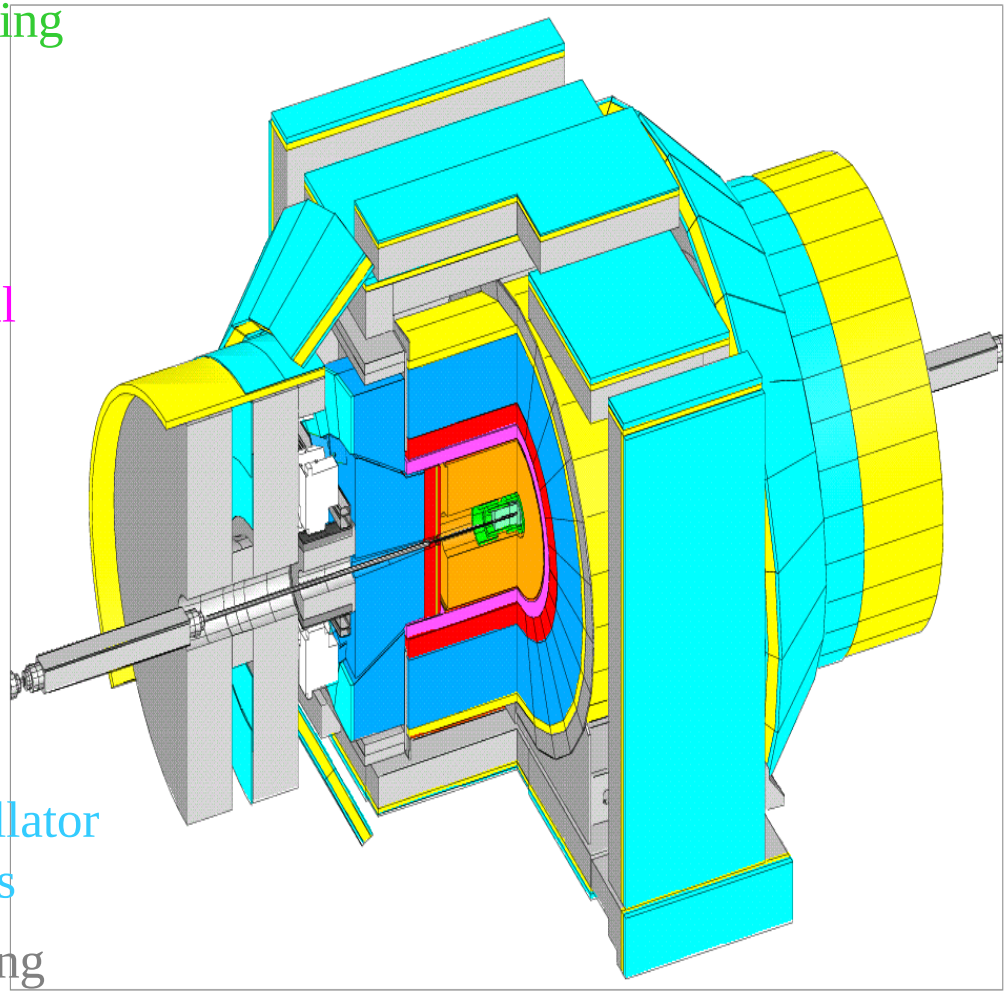
EM Calorimeter

Hadronic Calorimeter

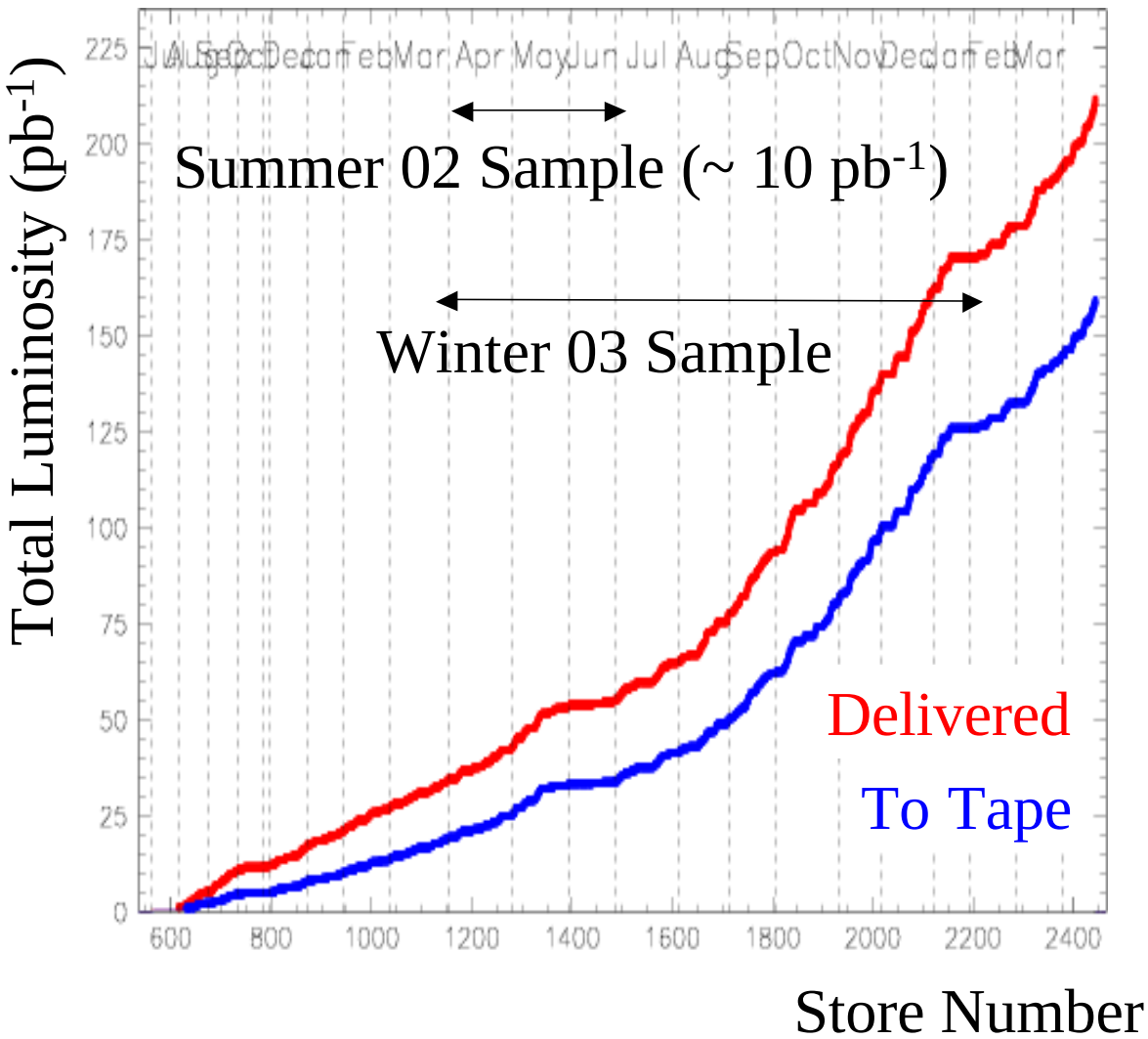
Muon Drift Chambers

Muon Scintillator Counters

Steel Shielding



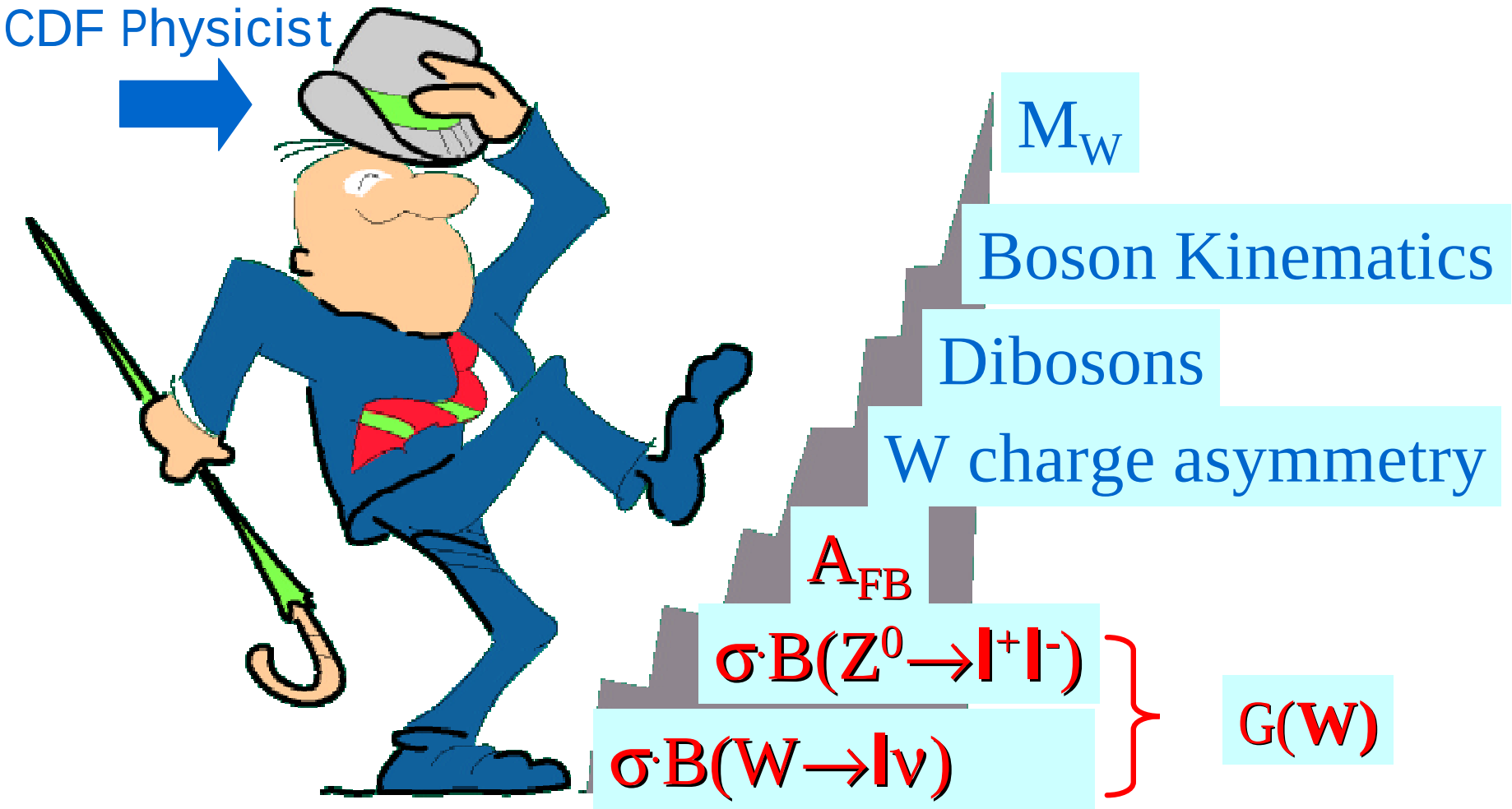
CDF Data



- > 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



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. (Let's walk before we run.)***
- ***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).***
- ***Signatures of other particle searches (e.g. top quark) include these bosons.***

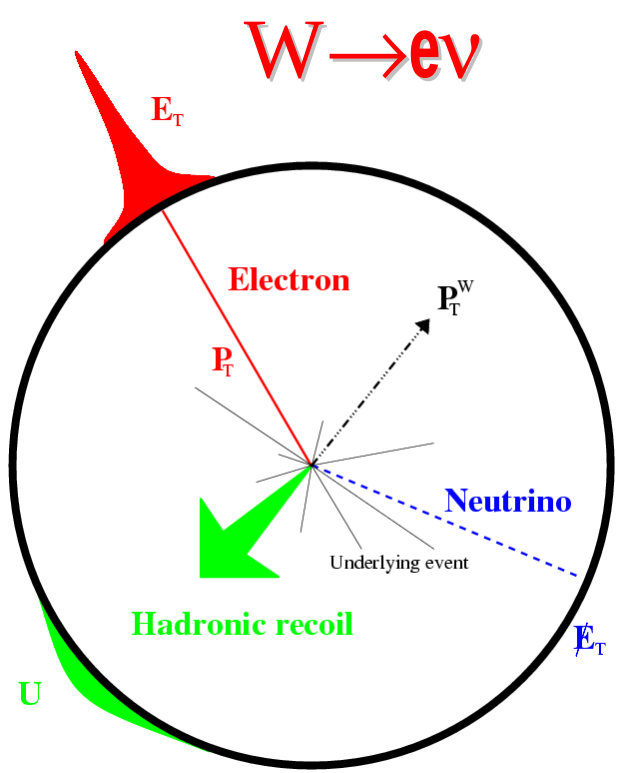
The measurement of a cross section is primarily a "counting experiment" →

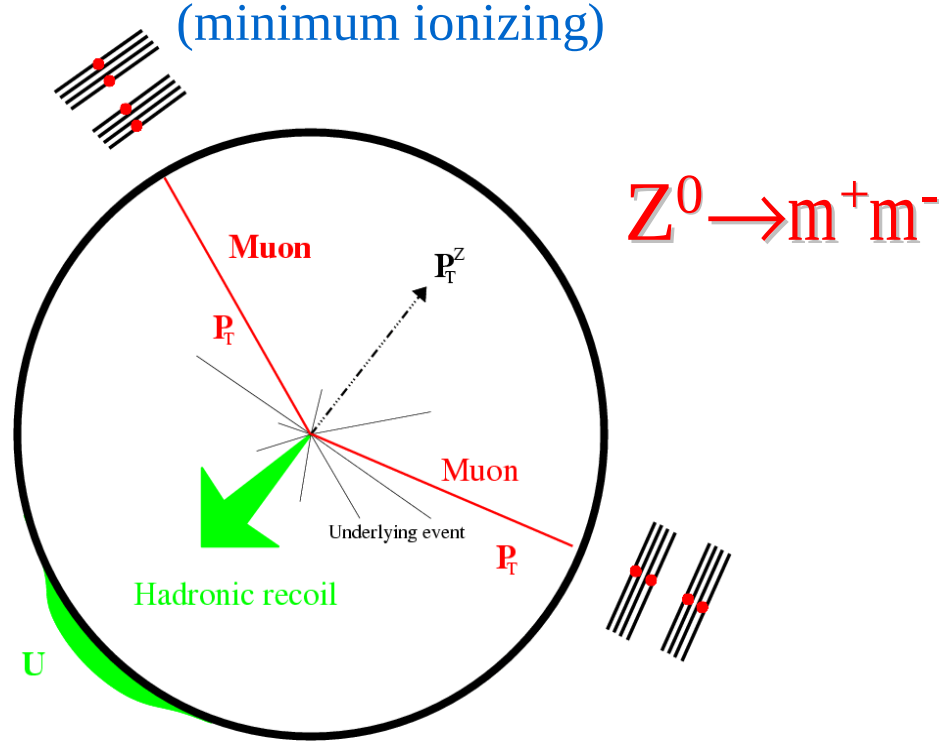
$$s \cdot B = \frac{N_{obs} - N_{bkg}}{A \cdot \int L}$$

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

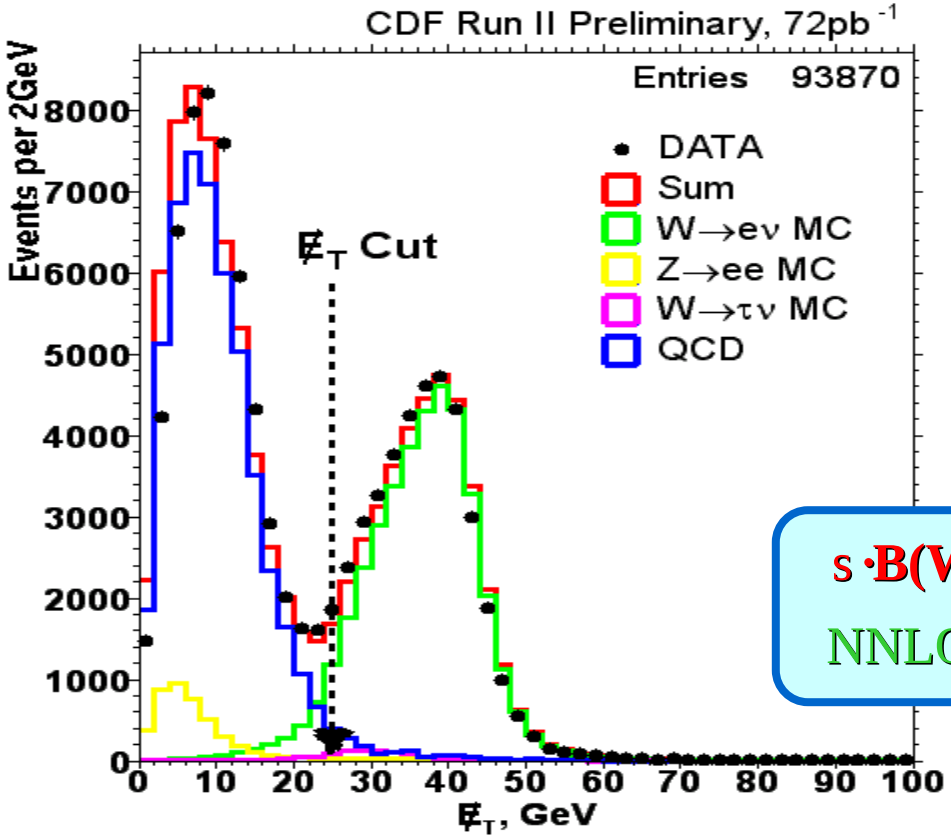
    OR
  - One isolated high p_T central μ
  - A second isolated high p_T track (minimum ionizing)

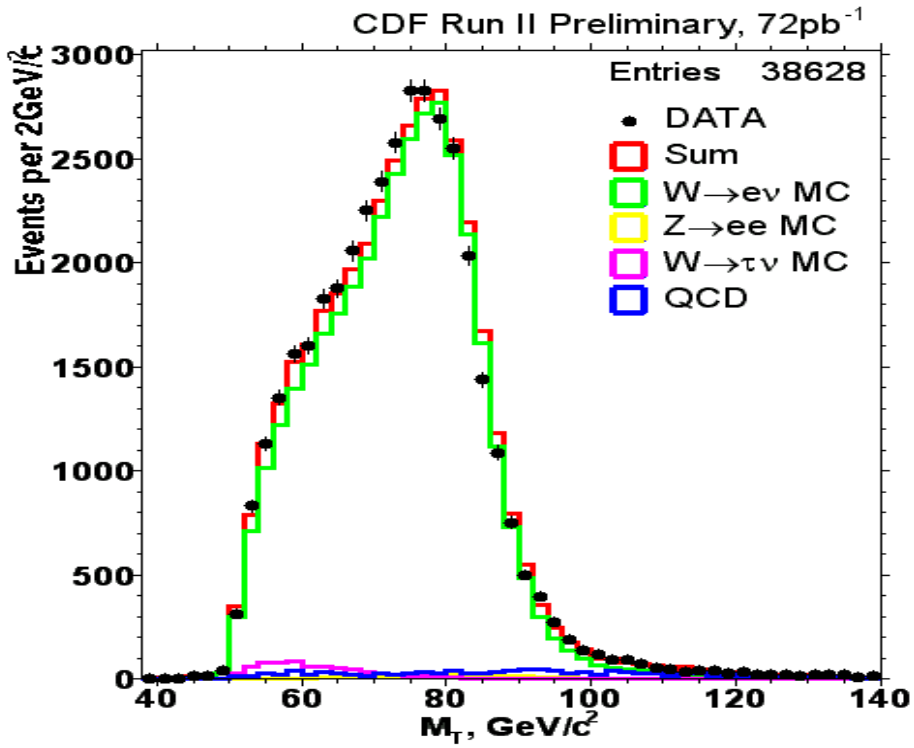




$\sigma \cdot B(W \rightarrow e\nu_e)$

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





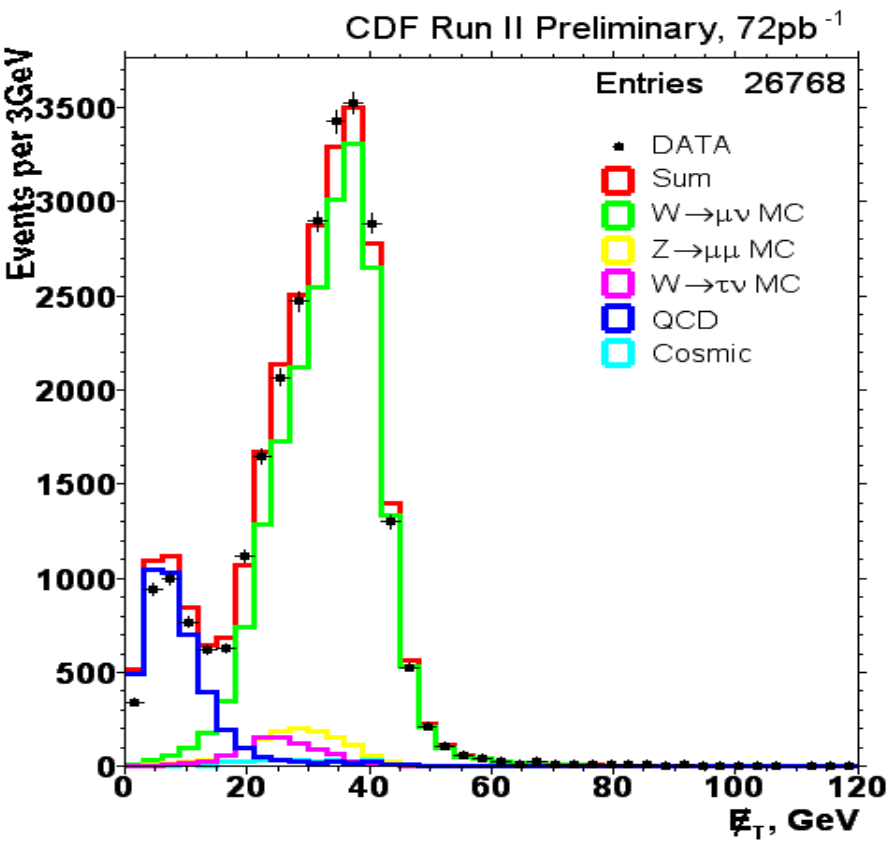
$s \cdot B(W \rightarrow en) = 2.64 \pm 0.01_{stat} \pm 0.09_{sys} \pm 0.16_{lum}$ nb

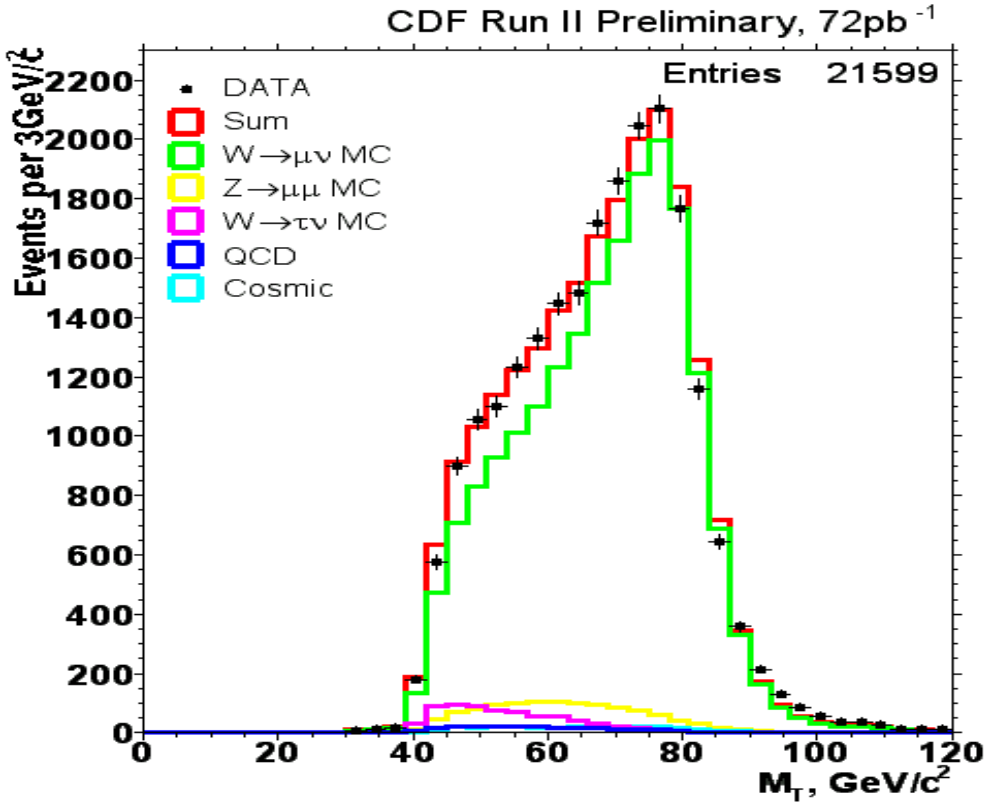
NNLO @ $\sqrt{s}$=1.96 TeV‡: 2.69 ± 0.10 nb

‡ 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 $Z \rightarrow \mu\mu$)





$\sigma \cdot B(W \rightarrow \mu\nu) =$

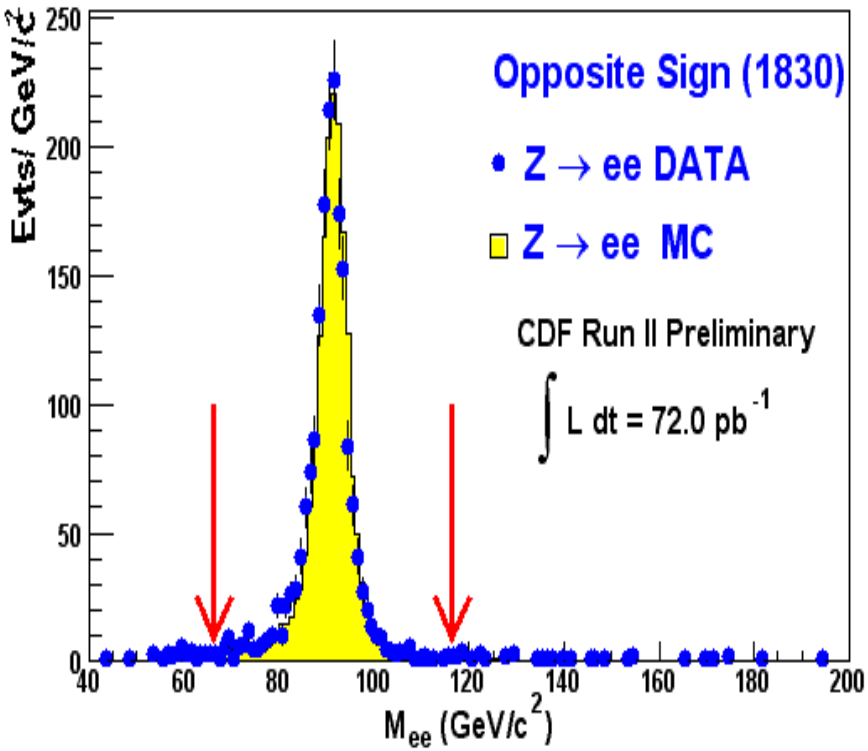
$2.64 \pm 0.02_{stat} \pm 0.12_{sys} \pm 0.16_{lum}$ nb

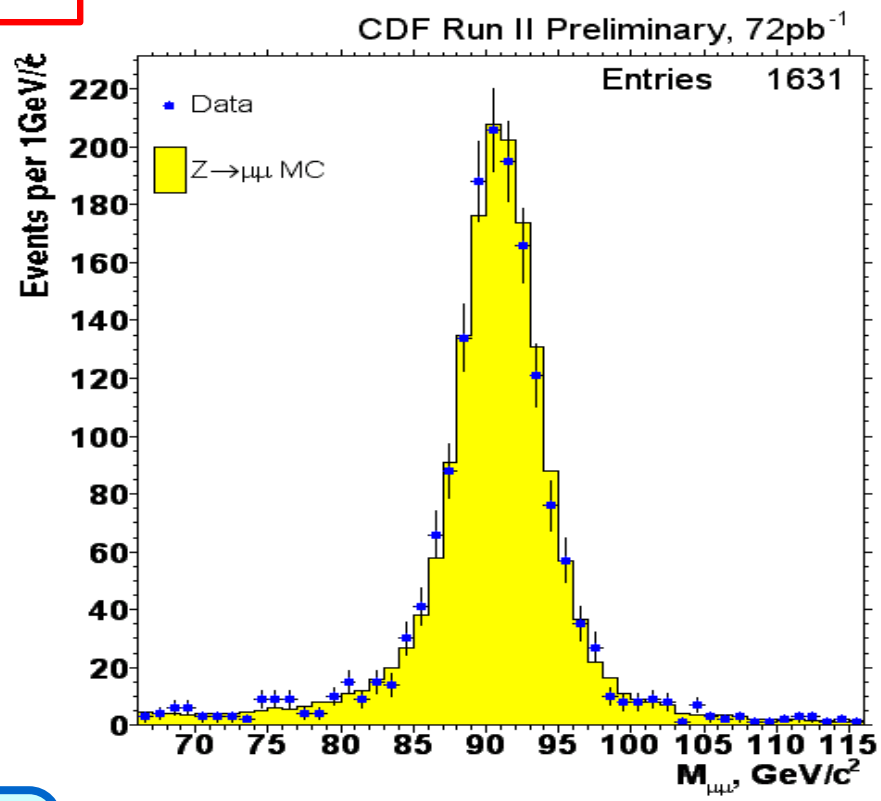
$\sigma \cdot B(Z^0 \rightarrow l^+ l^-)$

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

VERY CLEAN

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





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

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

NNLO @ Ös=1.96 TeV‡: 252 ± 9 pb

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

Total Width of W Boson Γ(W)

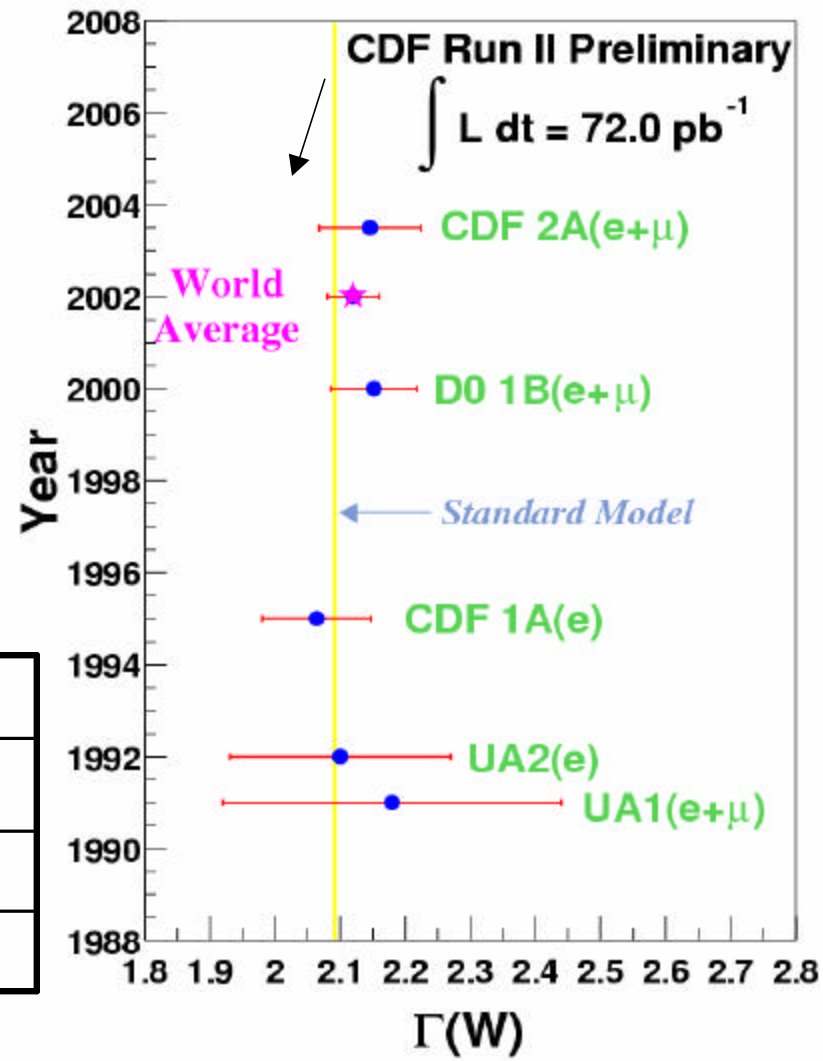
A measurement of the ratio
of the W / Z cross sections gives:

Measure — Theoretical prediction — PDG SM — PDG combined Exp

$$R = \frac{s(pp \to W)\, G(W \to en)\, G(Z)}{s(pp \to Z)\, G(W)\, G(Z \to ee)}$$

Extract

	R	G
e	± ±	± ±
m	± ±	± ±
e+m	± ±	± ±



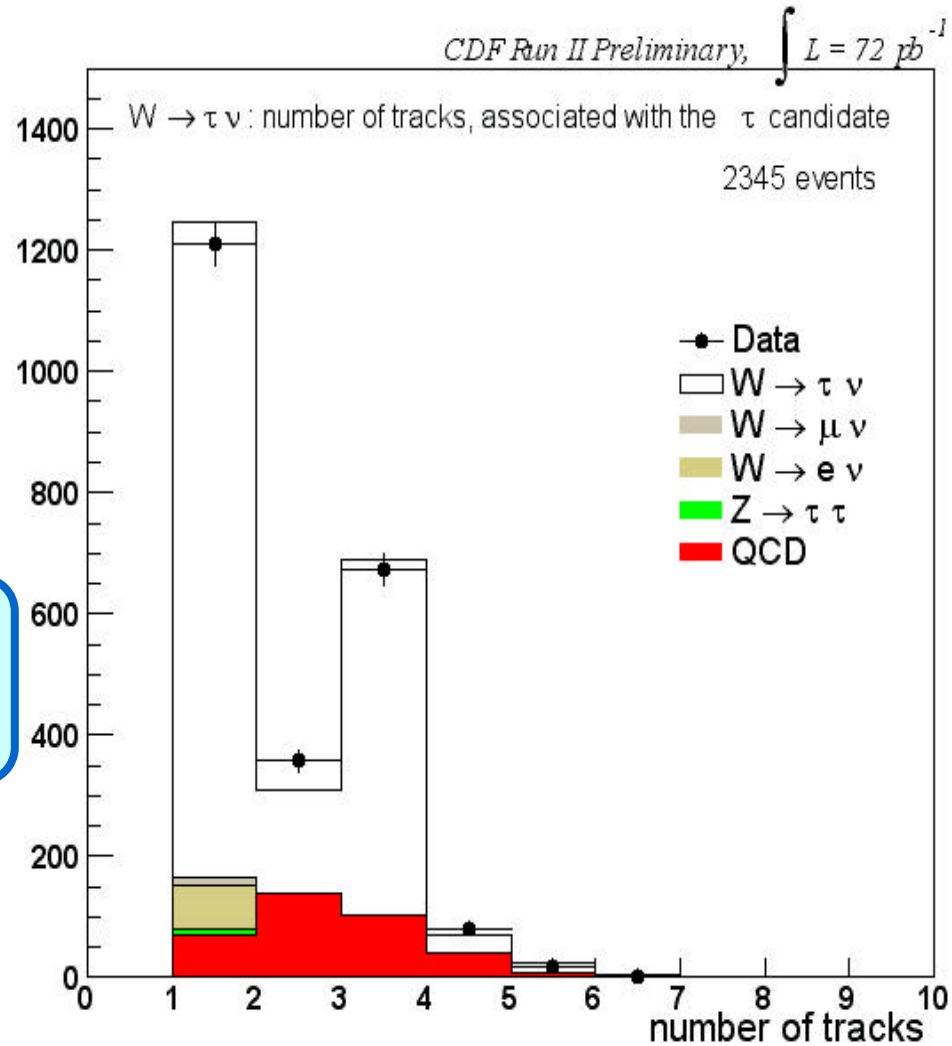
$\sigma \cdot B(W \rightarrow \tau \nu_\tau)$

We can also do τ identification!

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

s ·B(W ® tn) =

$2.62 \pm 0.07_{stat} \pm 0.21_{sys} \pm 0.16_{lum}$ nb

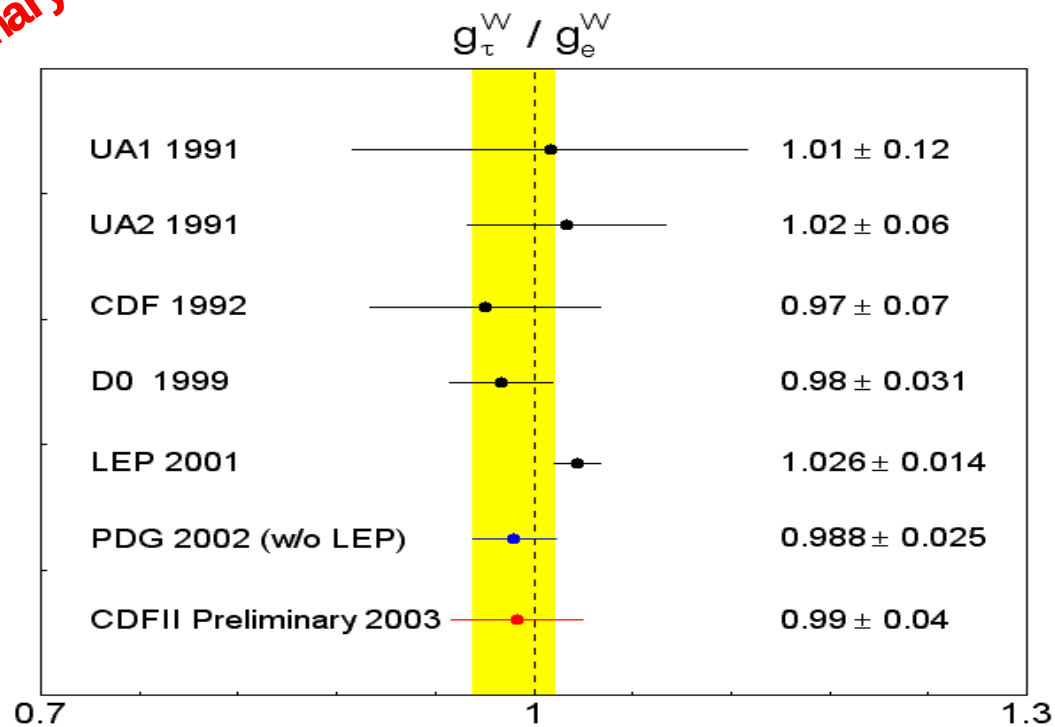


Lepton Universality

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

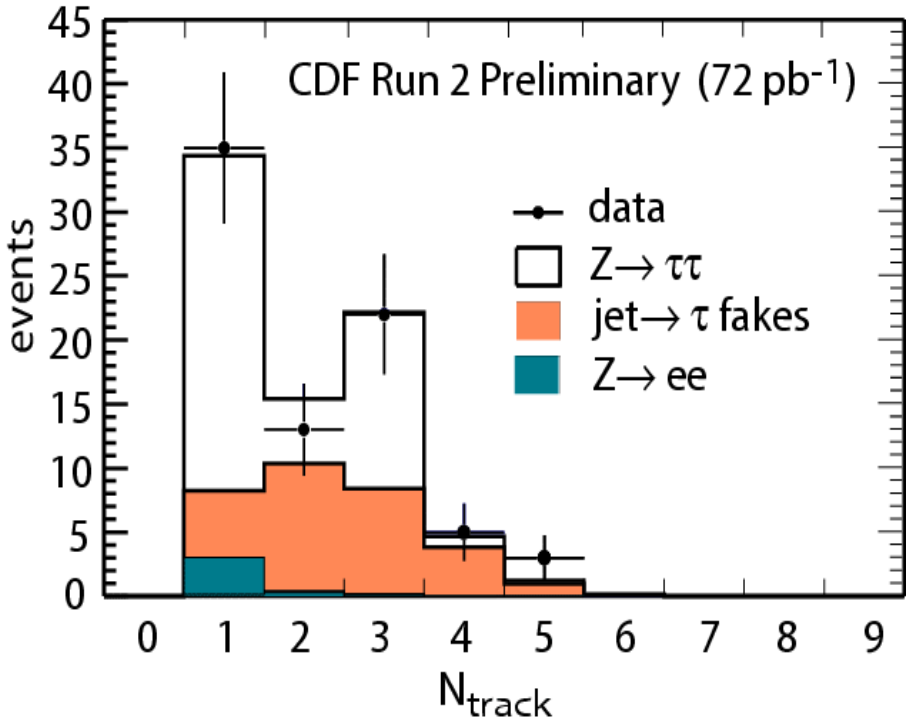
$$\frac{® \; tn}{® \; n} = \quad \pm \quad \pm \quad \Rightarrow \quad \frac{t}{} \quad \pm \quad \pm$$

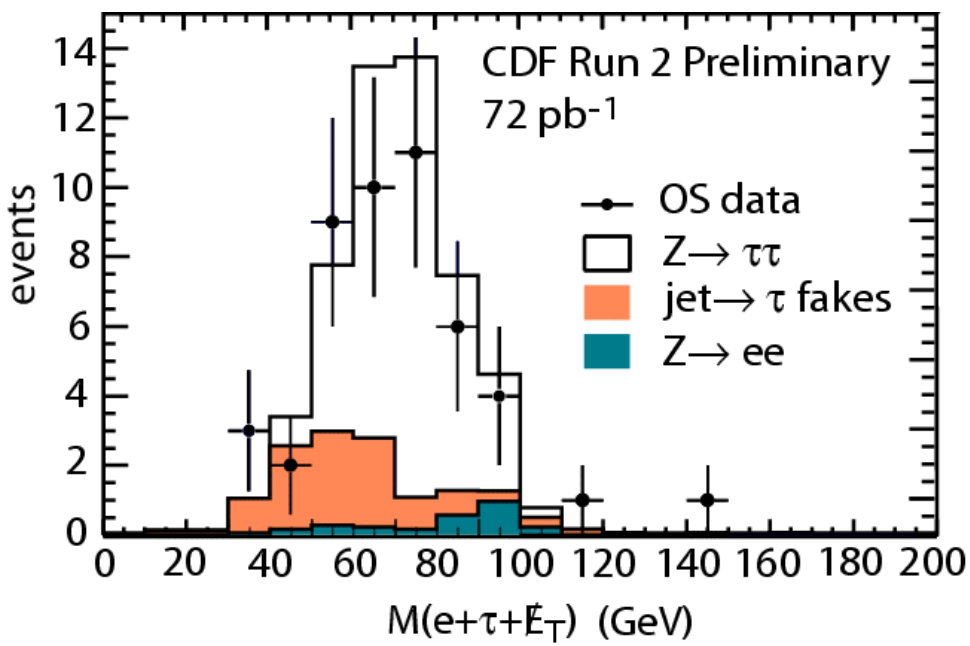
CDF Run II Preliminary



$Z^0 \rightarrow \tau_e \tau_h$

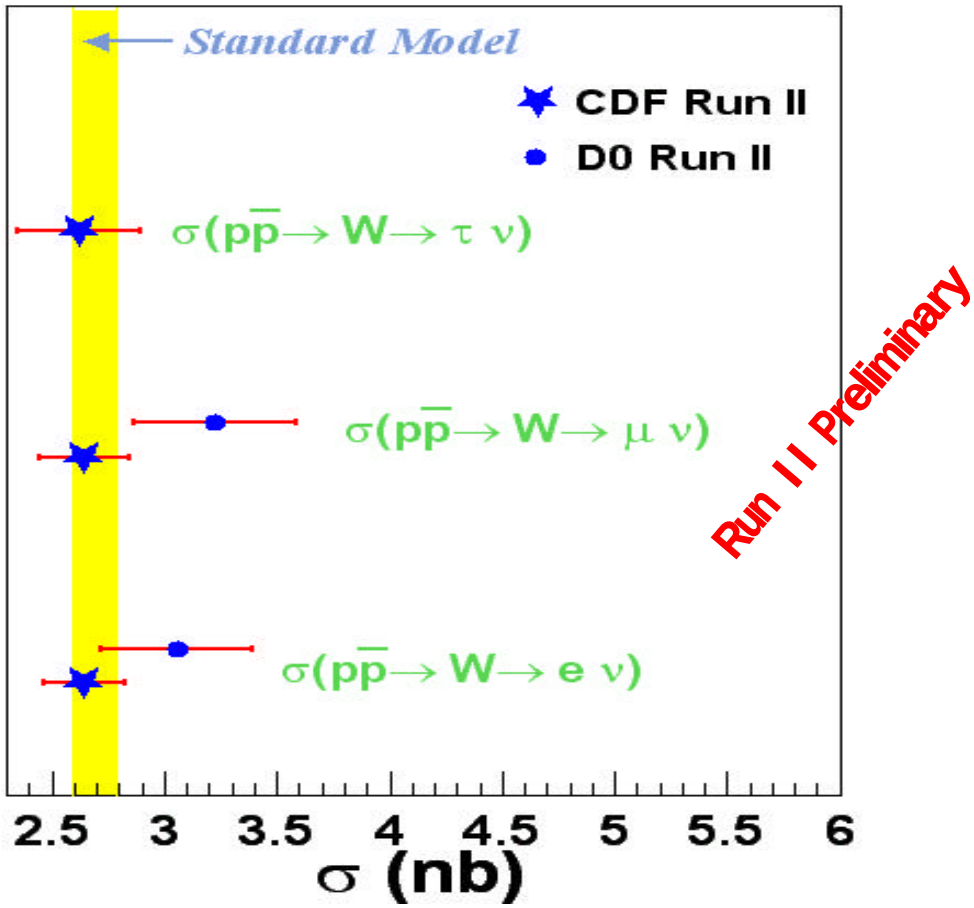
- We have a clear $Z^0 \rightarrow \tau_e \tau_h$ signal.
- Further study of backgrounds is underway.
- Our goal is to have a preliminary cross section measurement by summer.



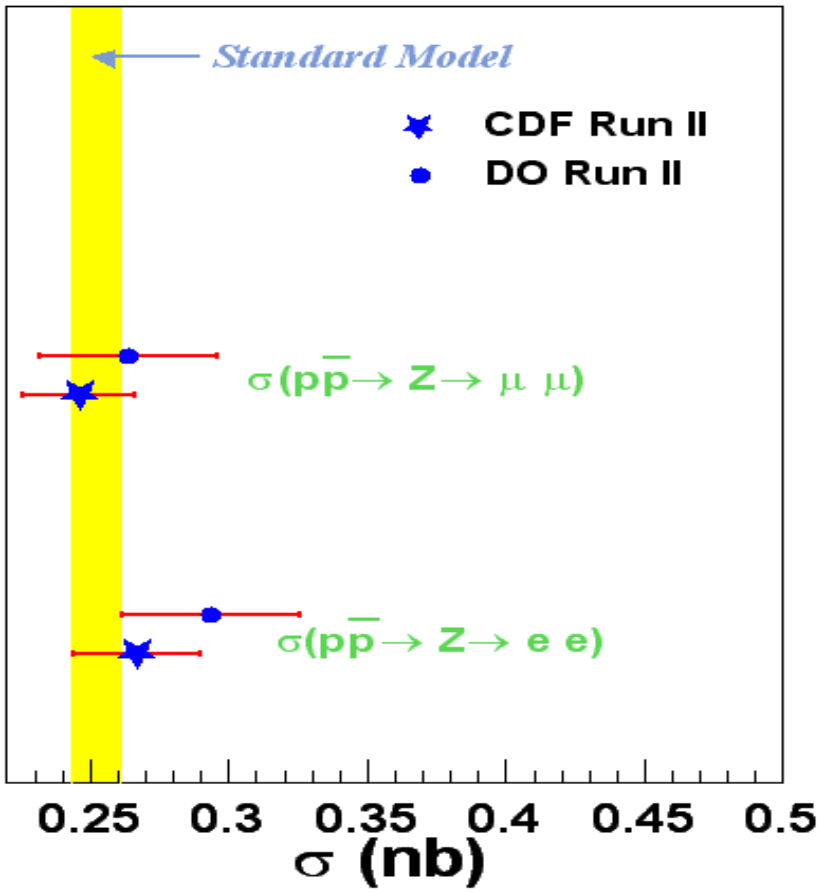


Not only interesting as an EWK measurement, it is important for Higgs and SUSY searches.

Summary of W & Z Cross Sections



Run I I Preliminary

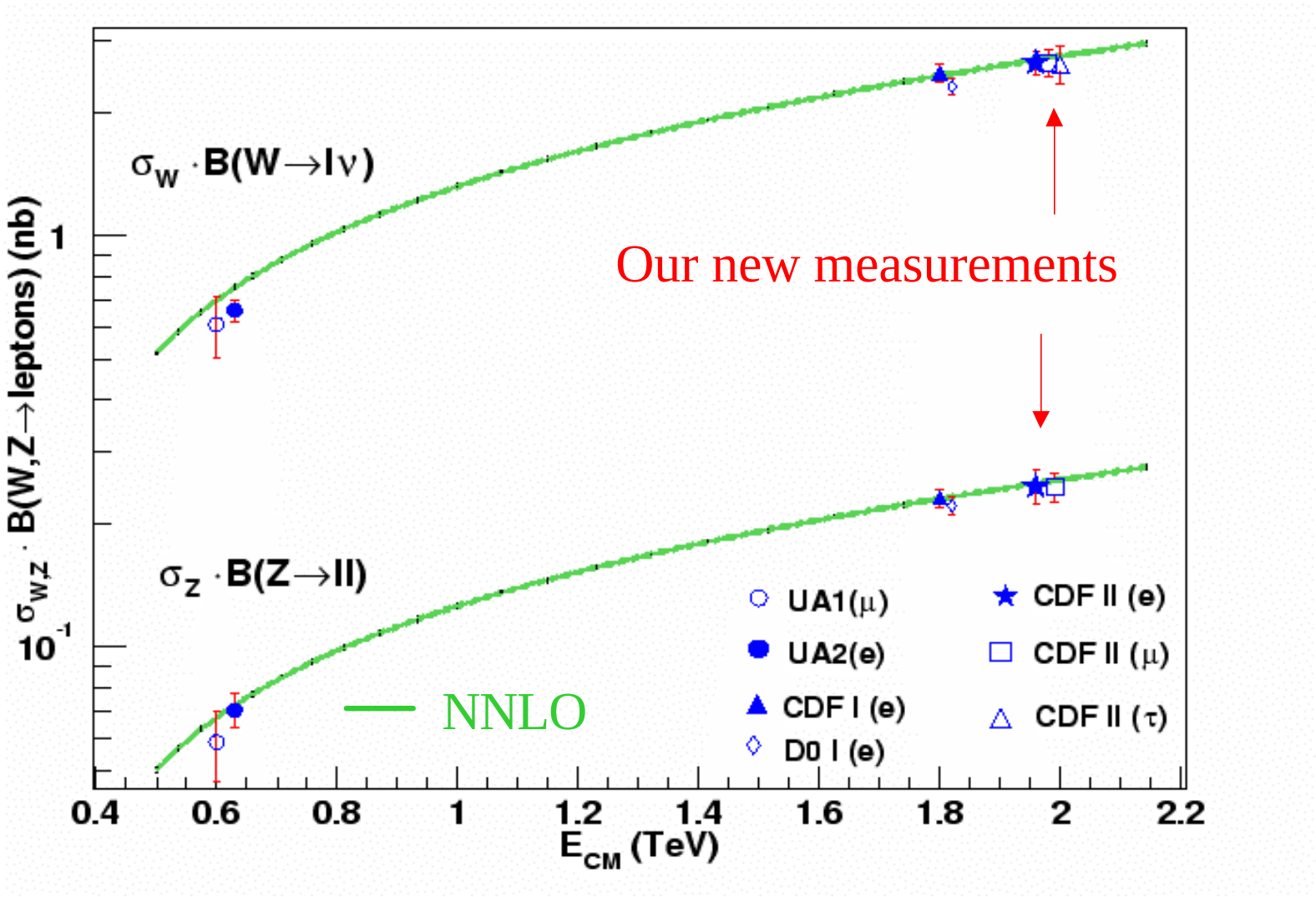


CDF combined e and μ values:

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

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

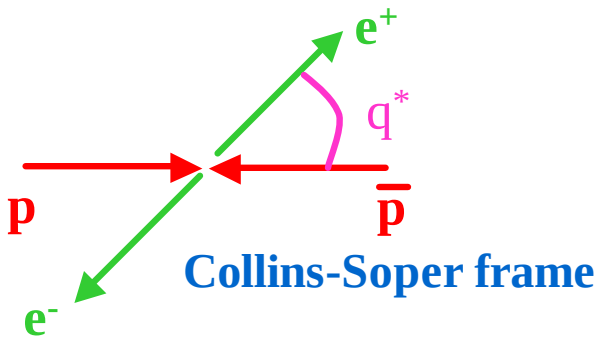
W & Cross Sections vs. E_{CM}



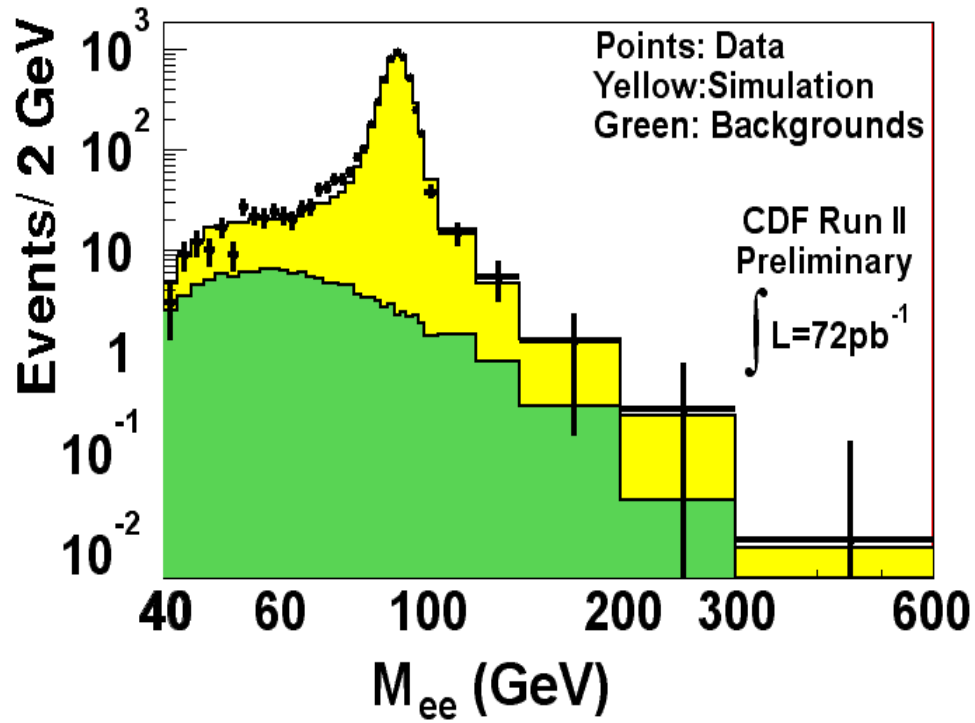
A_{FB} with $Z^0 \rightarrow e^+e^-$

- **Forward-Backward asymmetry A_{FB}:**
  - 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})

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

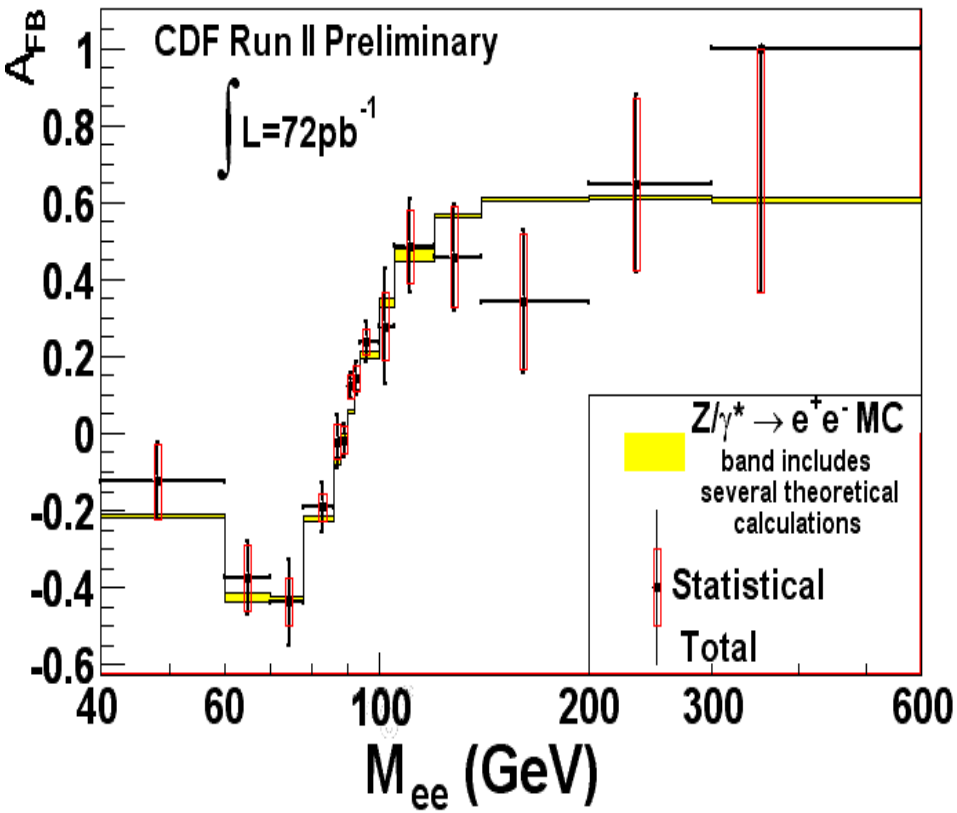


- **Event selection**
  - Two isolated high p_T e (one central, other central or plug)
  - 40 GeV/c^2 < M_{ee} < 600 GeV/c^2
- **Candidates:**
  - 5438 in ~ 72 pb^{-1}
- **Backgrounds:** ~ 3 % (dominated by QCD)

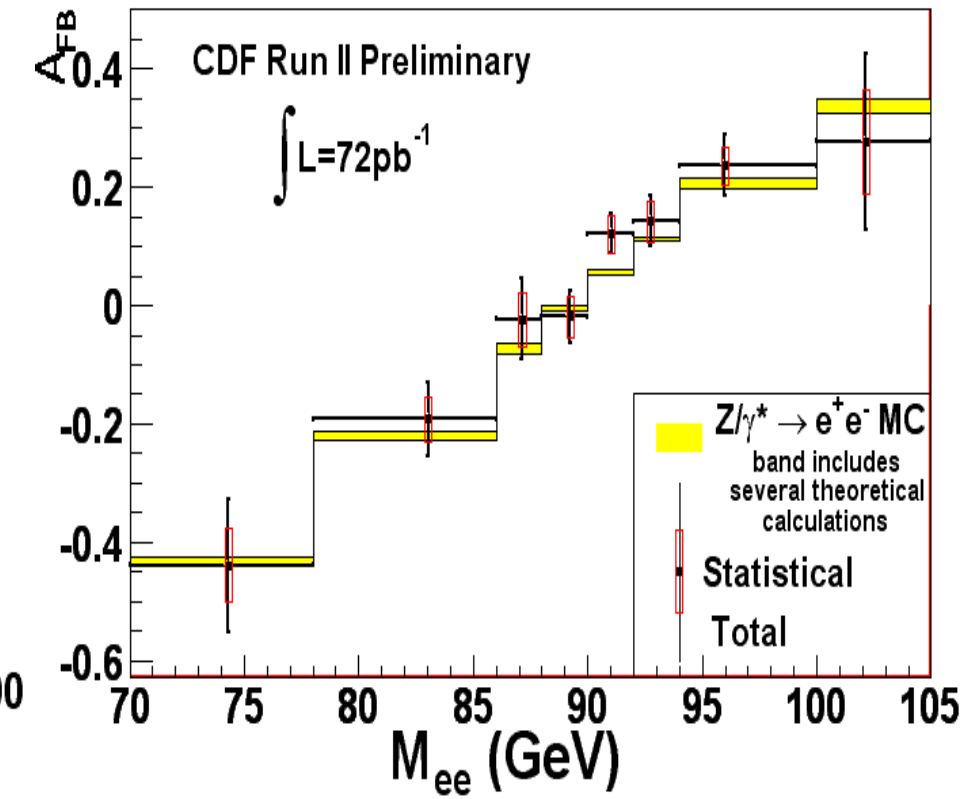


A_{FB} with $Z^0 \rightarrow e^+e^-$

A_{FB} (corrected)



Z Pole Region



Results are consistent with predictions.

Exotic Physics Program

CDF Physicist

Higgs → H^{++}

SUSY

New Excited Fermions

New Gauge Bosons

Signature Based Searches

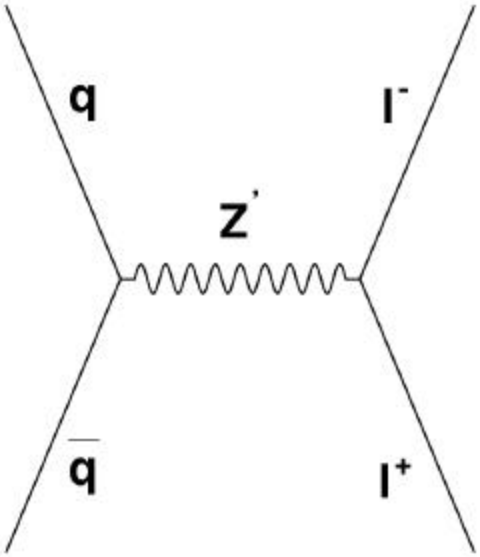
New Particles & Dimensions

Searches for new resonances

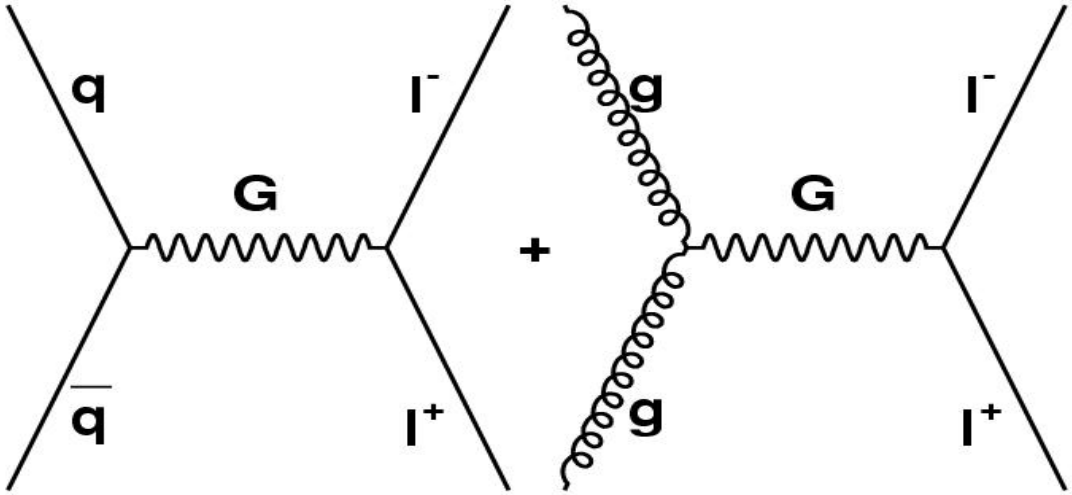
Search for New Resonances in High Mass Dileptons

High Mass Dileptons allow searches for new particle production.

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

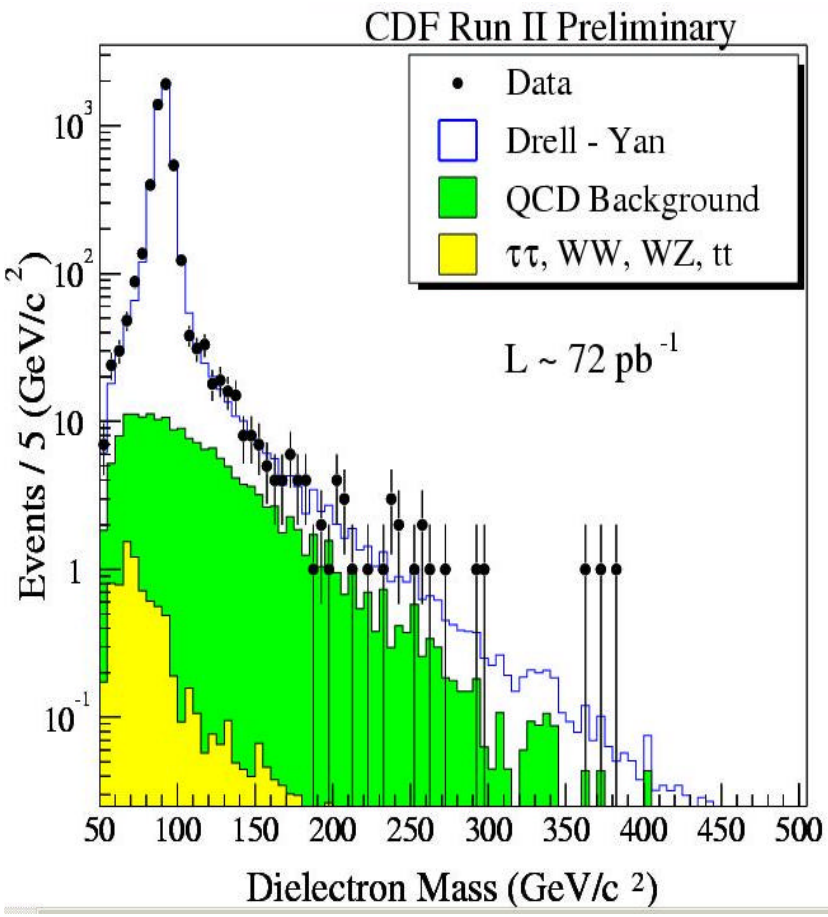


- **Randall-Sundrum Graviton**
  - Excited Graviton in 5 dimensions
  - Free parameters:
    - Mass M_G
    - Coupling k/M_{PL}

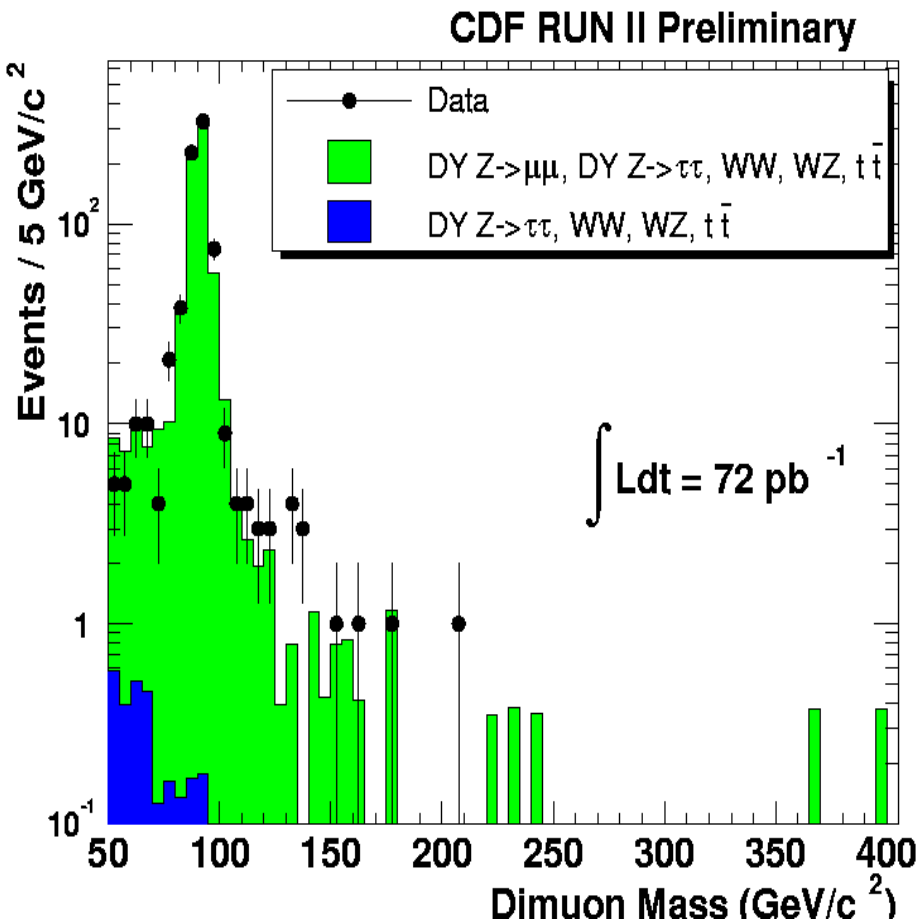


Search for New Resonances in High Mass Dileptons

Dielectron Invariant Mass



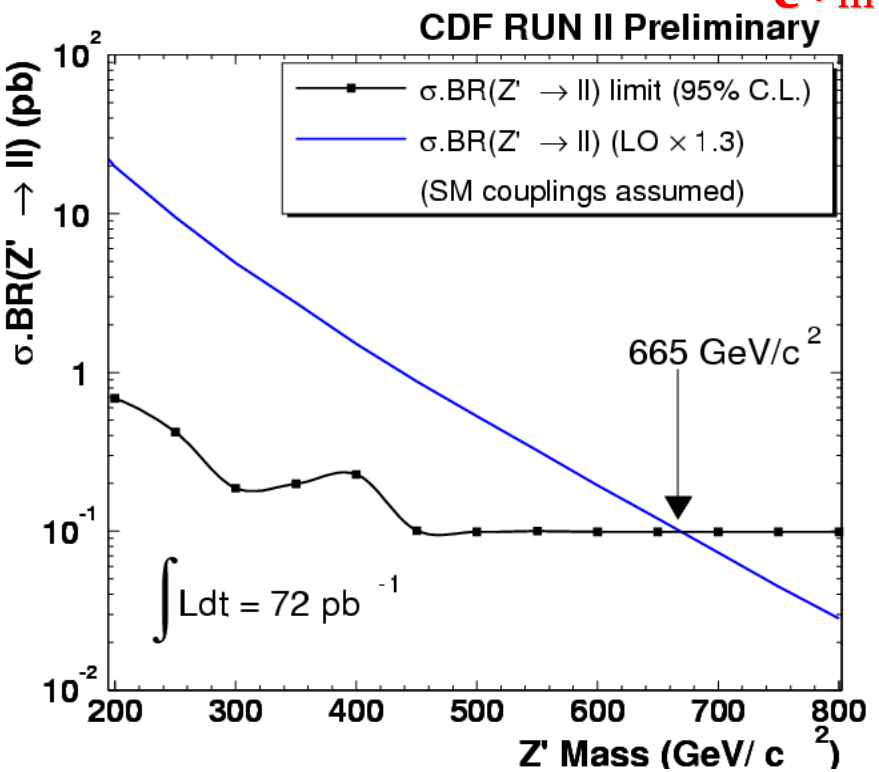
Dimuon Invariant Mass

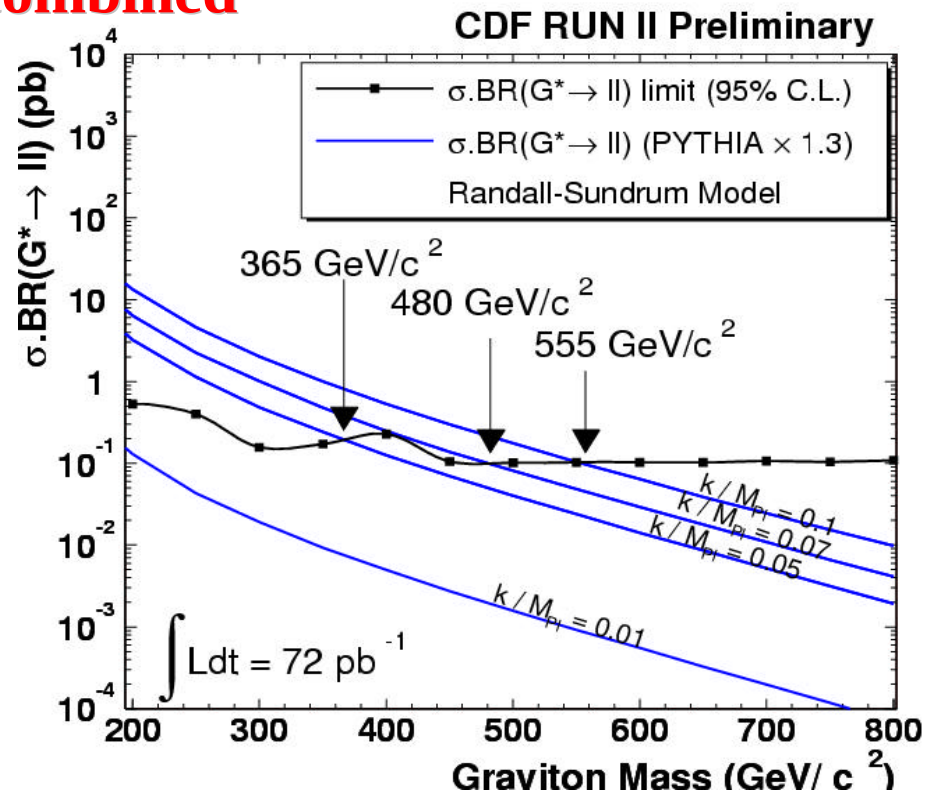


Data consistent with SM background. No excess observed.

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

e+m combined





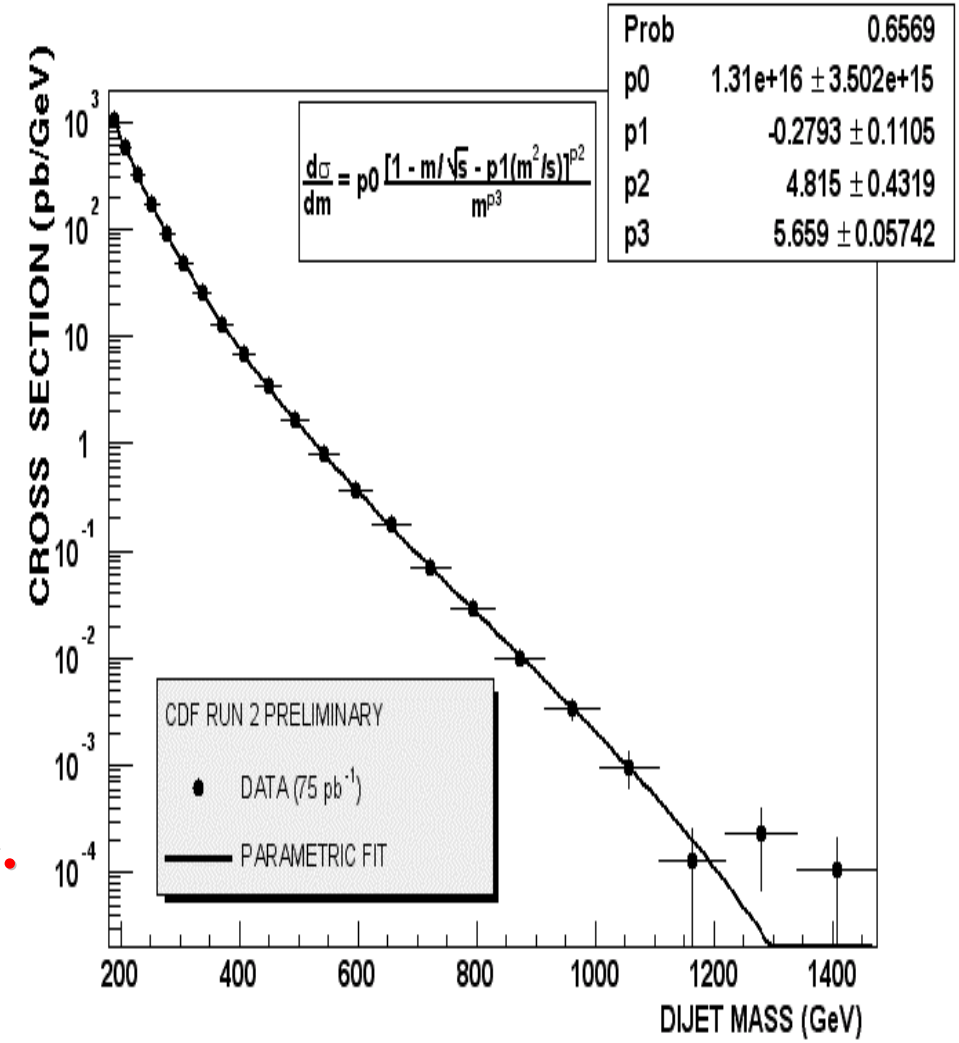
Z' search history ($e^+ e^-$ mode):

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**

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.

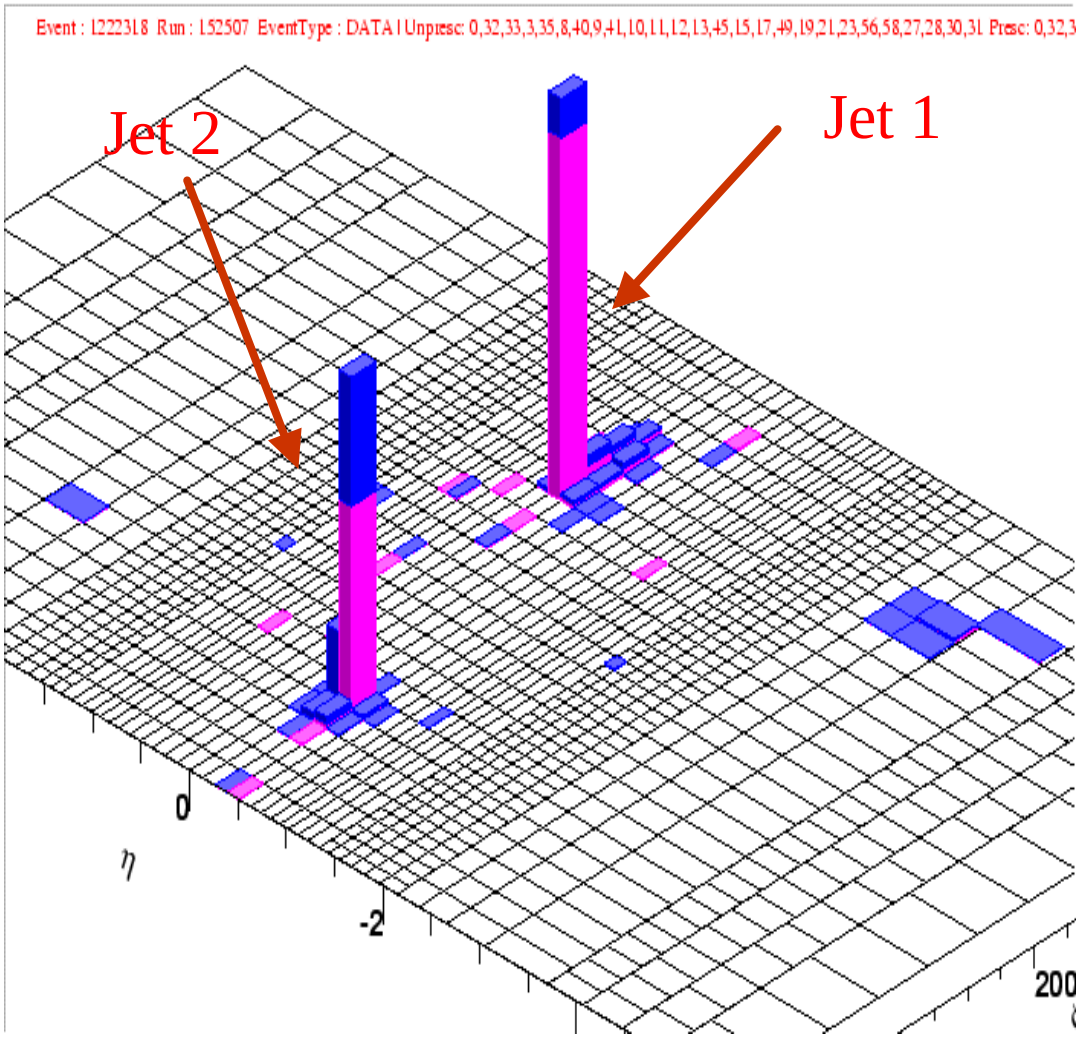
Highest Mass Dijet Event

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

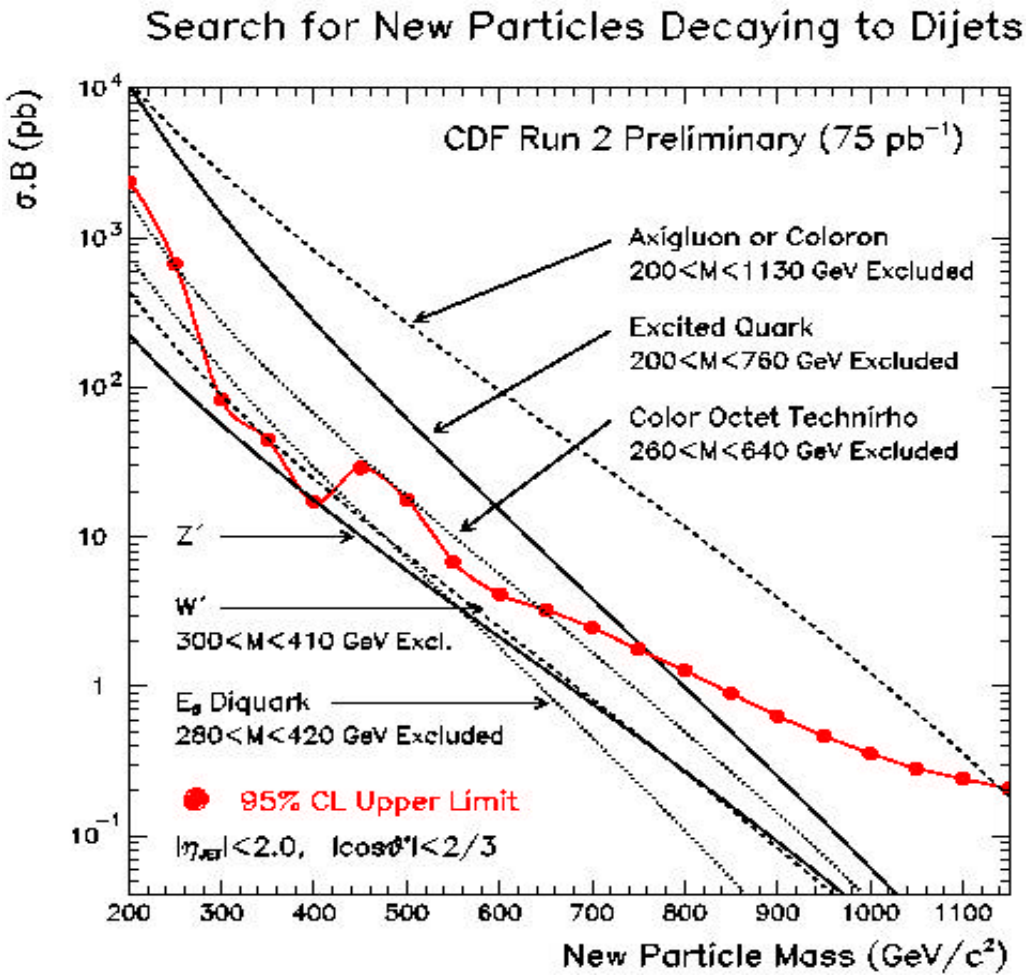
J1 E_T = 666 GeV
J1 η = 0.43



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**

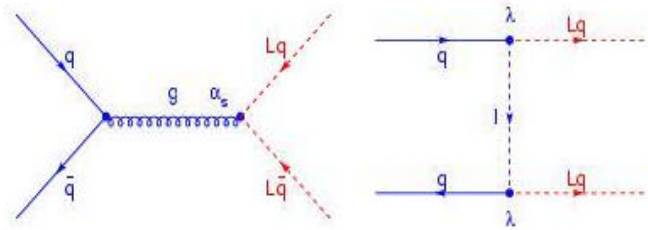


Results improved with respect to CDF Run I

Search for First Generation scalar LQ

➢ Production

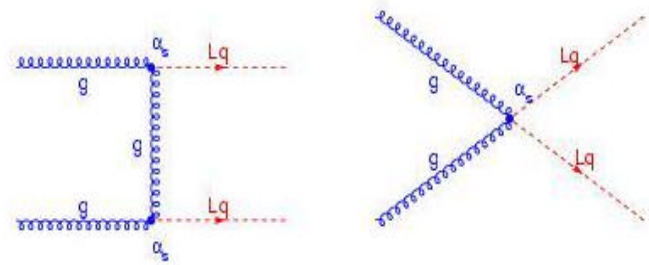
- qg → LQ + LQbar
- gg → LQ + LQbar
- qqbar → LQ + LQbar



➢ Decay

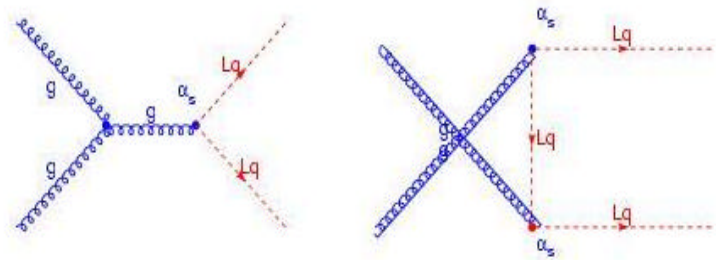
- LQLQ → l^+l^-qq,
- LQLQ → $l^\pm\nu$qq,
- LQLQ → ννqq

We search for di-electrons + jets.



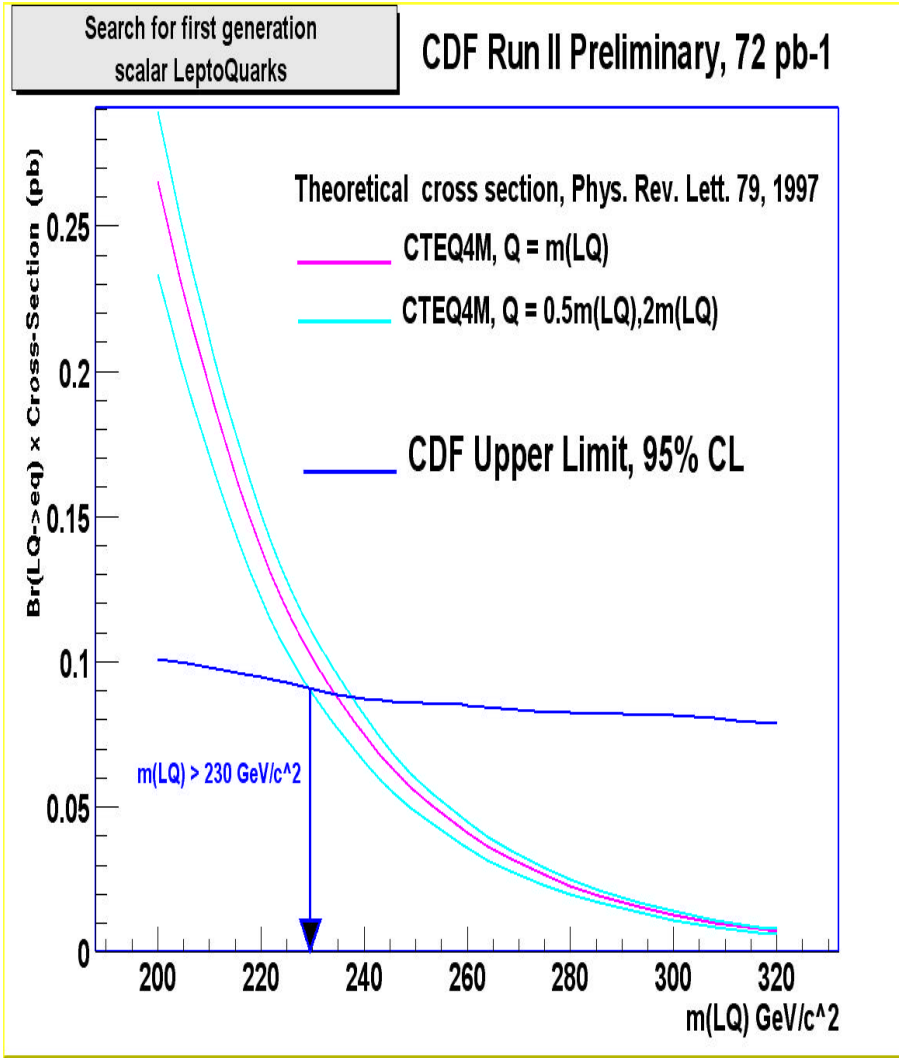
➢ Experimental signature

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



Search for First Generation scalar LQ

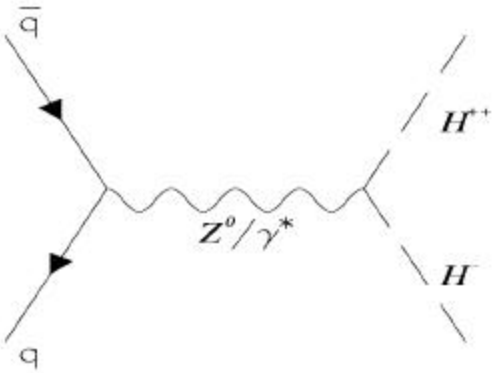
- **Event Selection:**
  - 2 central electrons with $E_T > 25$ GeV
  - 2 jets with $E_T(j1) > 30$ and $E_T(j1) > 15$ GeV
  - Z veto
  - Cuts on *sum* of jet and electron E_T's to reject SM backgrounds
- **Expected Bkg:** 3.4 ± 3.2 events (DY+2jet events, tt)

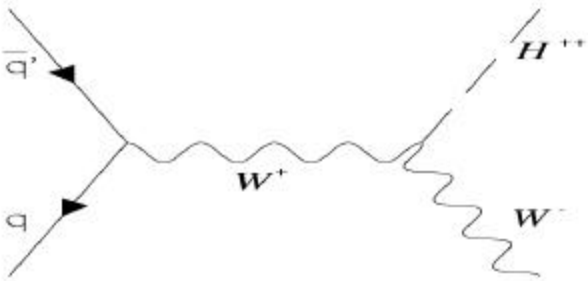


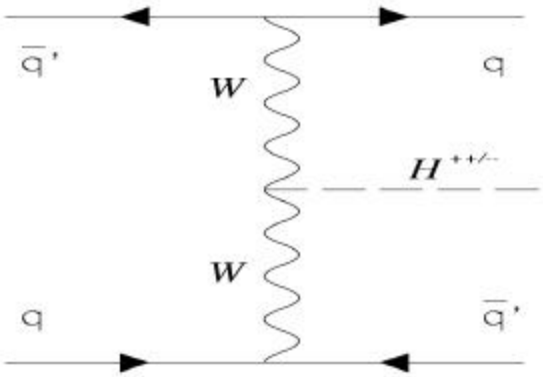
0 events observed in 72 pb-1.
M(LQ) > 230 GeV/c^2 @ 95% CL
(Run I 220 GeV/c^2)

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.**





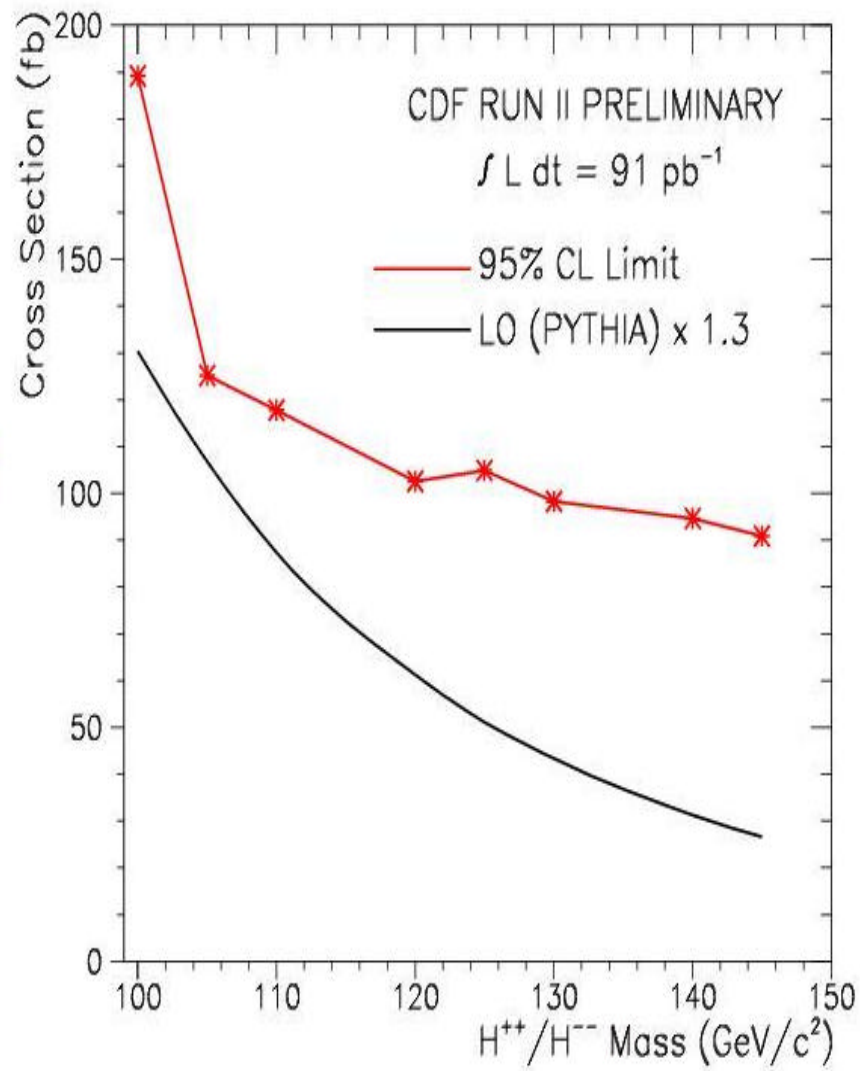


LEP limit up to 100 GeV/c^2 (prompt and long lived)

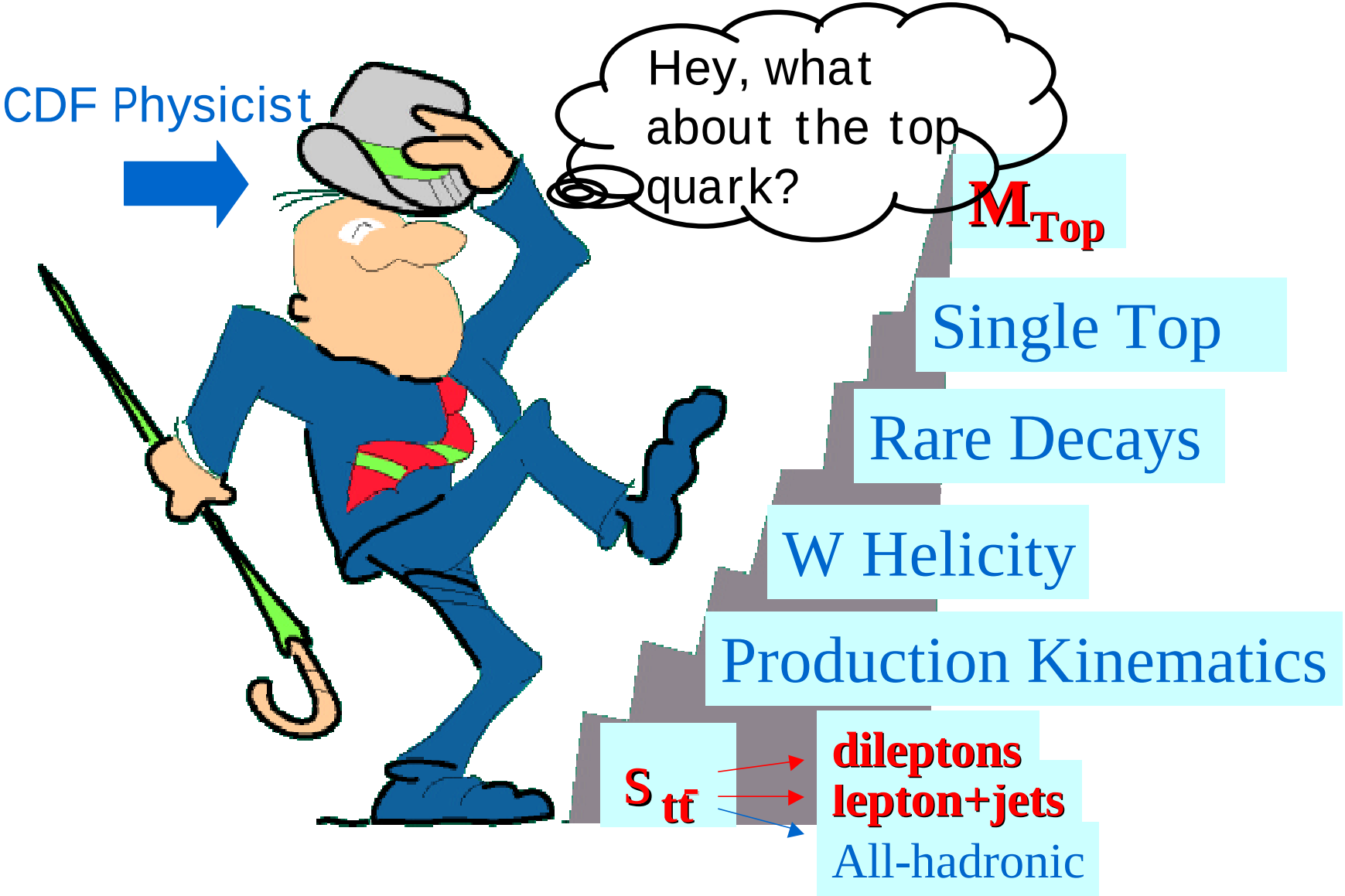
Search for Doubly Charged Higgs

- 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



$t\bar{t}$ Decay Modes

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

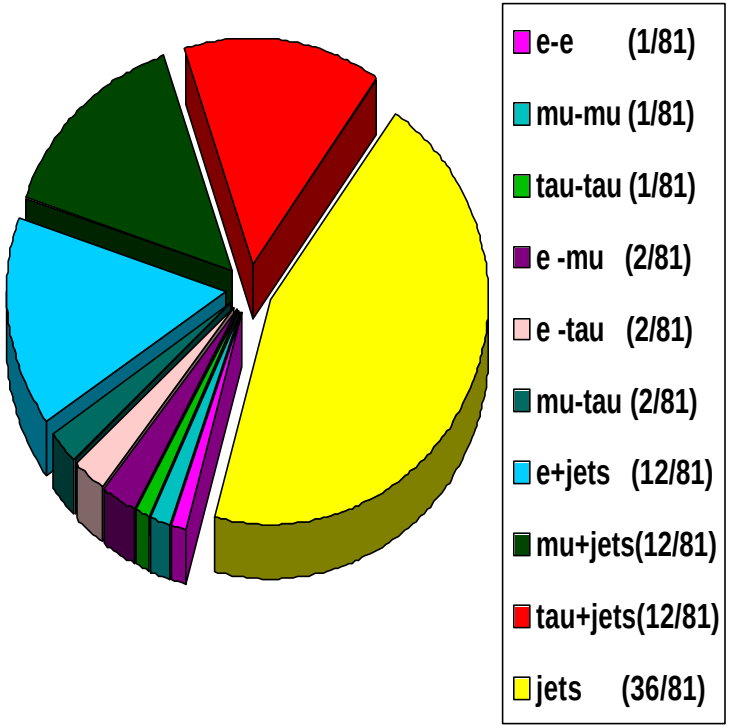
- Dilepton (2 high-P_T leptons, 2 b jets, large $\not{E}_T$) : BR = 1 / 9

  BR(ee,μμ,eμ) = 5%

- Lepton + Jets (1 high-P_T lepton, 4 jets (2 b's), large $\not{E}_T$): BR = 4 / 9

  BR(e, μ + jets) = 30%

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



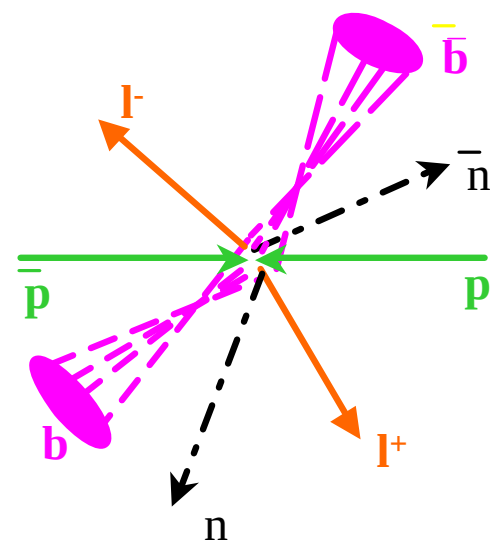
$$s_{t\bar{t}}(\sqrt{s} = 1.96\,\text{TeV}) \approx 1.30 \times s_{t\bar{t}}(\sqrt{s} = 1.8\,\text{TeV})$$

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 $E_T > 50$ 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
	±	±	±	±
	±	±	±	±

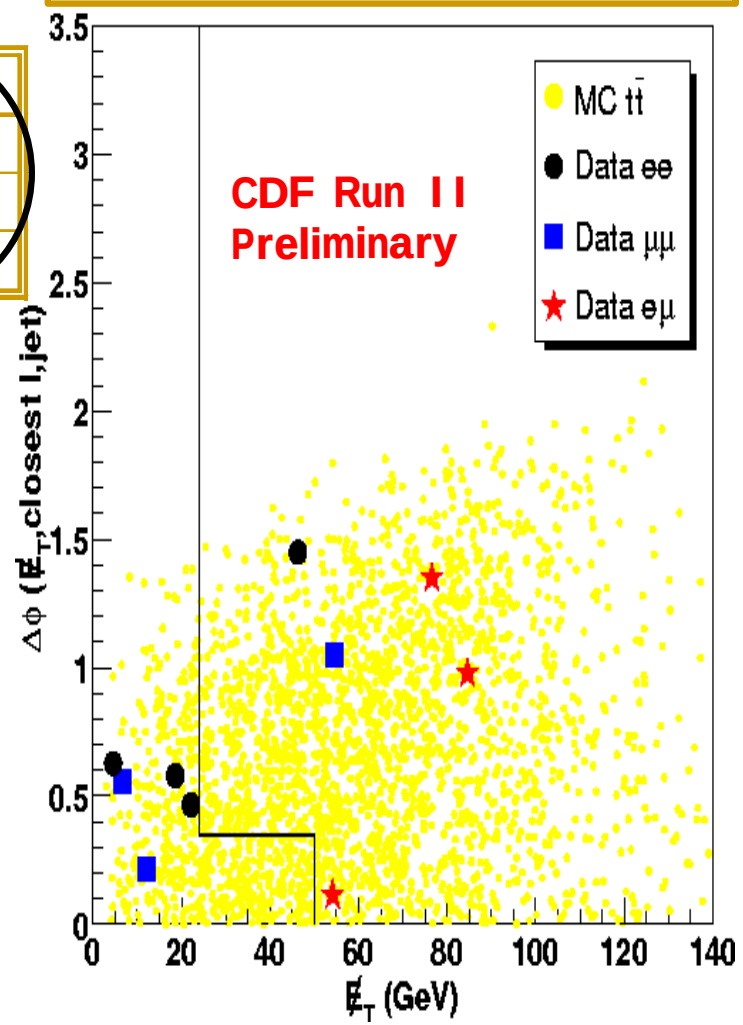
$s_{t\bar{t}} = 13.2 \pm 5.9_{stat} \pm 1.5_{sys} \pm 0.8_{lum}$ pb

NLO @ Ös=1.96 TeV for

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

‡ hep-ph/0303085(ML Mangano et al)

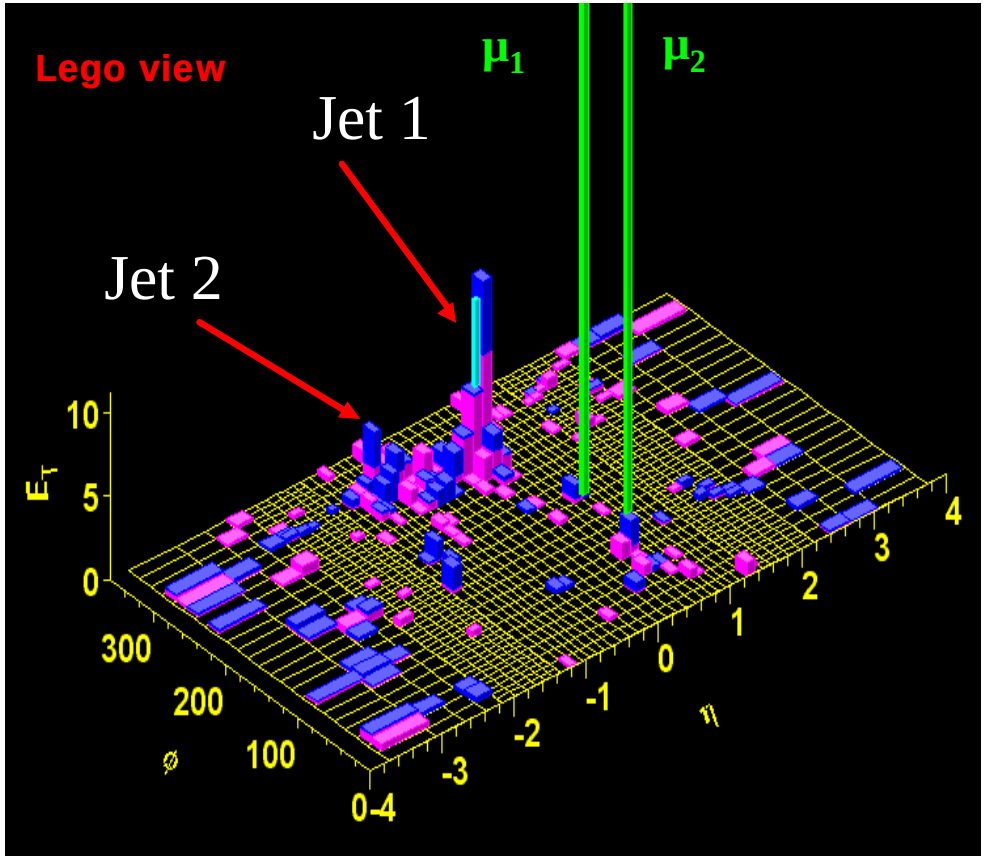
$\Delta\phi$ vs. $\not{E}_T$ $N_{jets} \geq 2$



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	E_T^j = 32,15 GeV
$p_T(m_2)$ = 53 GeV/c^2	$\not{E}_T$=54 GeV
M_{mm} = 69 GeV/c	H_T=212 GeV



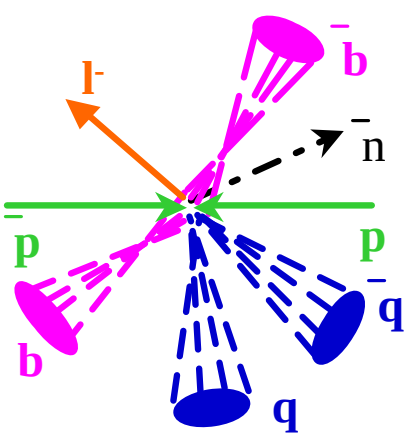
Lepton + Jets Channel: $t\bar{t} \rightarrow l\nu qqbb$

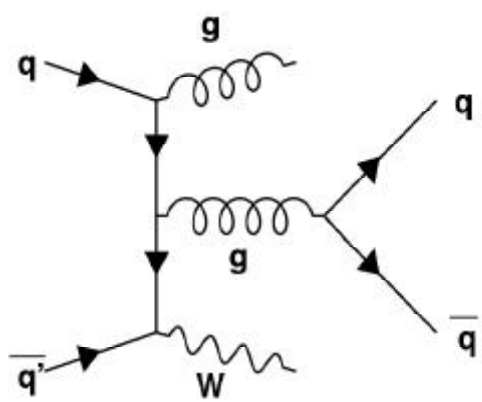
- Event selection (same as Run I)
  - Exactly one isolated high p_T e or μ
  - $\not{E}_T$>20 GeV
  - Jets E_T>15 GeV & $|\eta|$<2.0
  - Z, cosmic, conversion vetos
  - use ≥3 jets for $\sigma_{t\bar{t}}$
  - ≥ 1 b-tag jet

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
  - Mistags from light quarks and gluon jets
  - Non W background (fake lepton)
  - Diboson, Drell-Yan, single top (small)



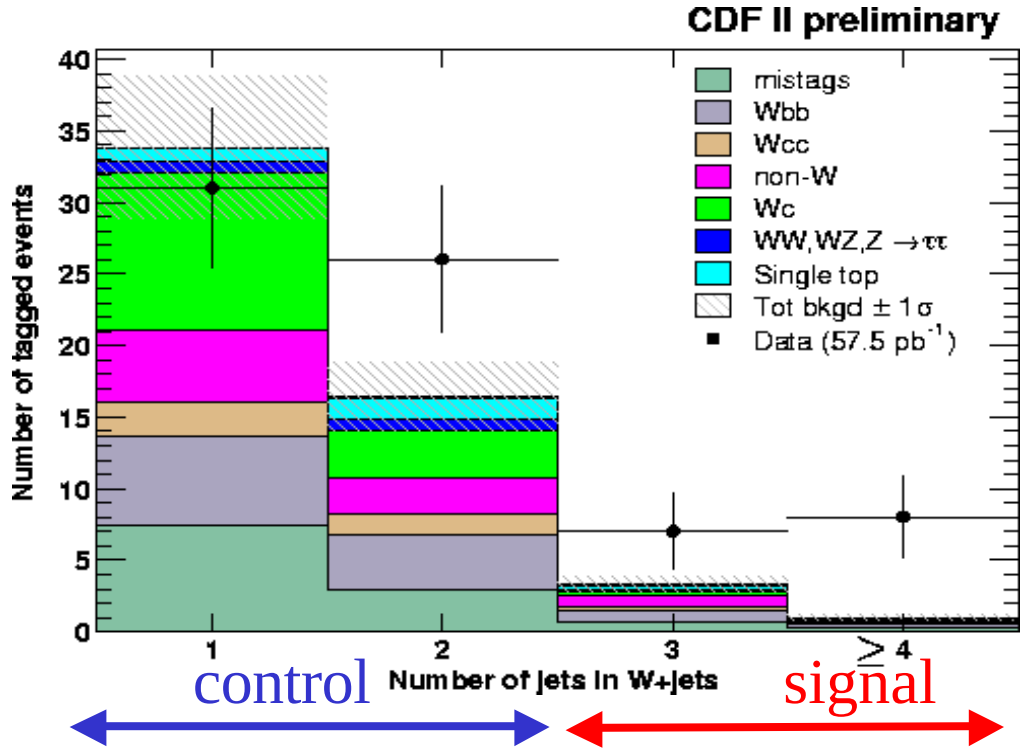


Lepton + Jets Backgrounds

Jet Multiplicity in b-tagged W+jets events

CDF Run II Preliminary

15 Candidates in ~ 57.5 pb^{-1}

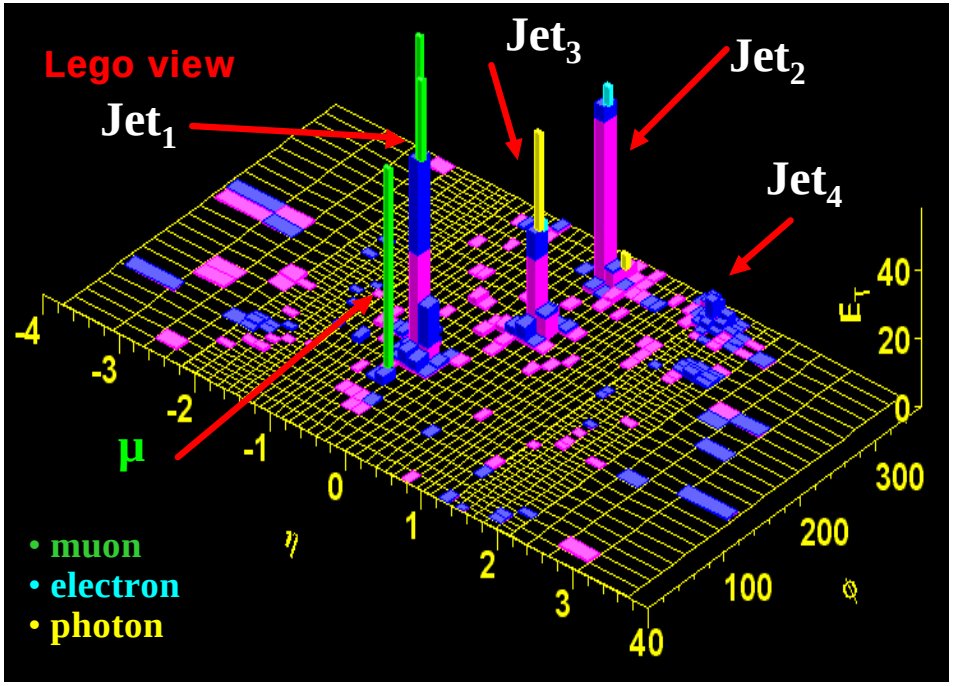


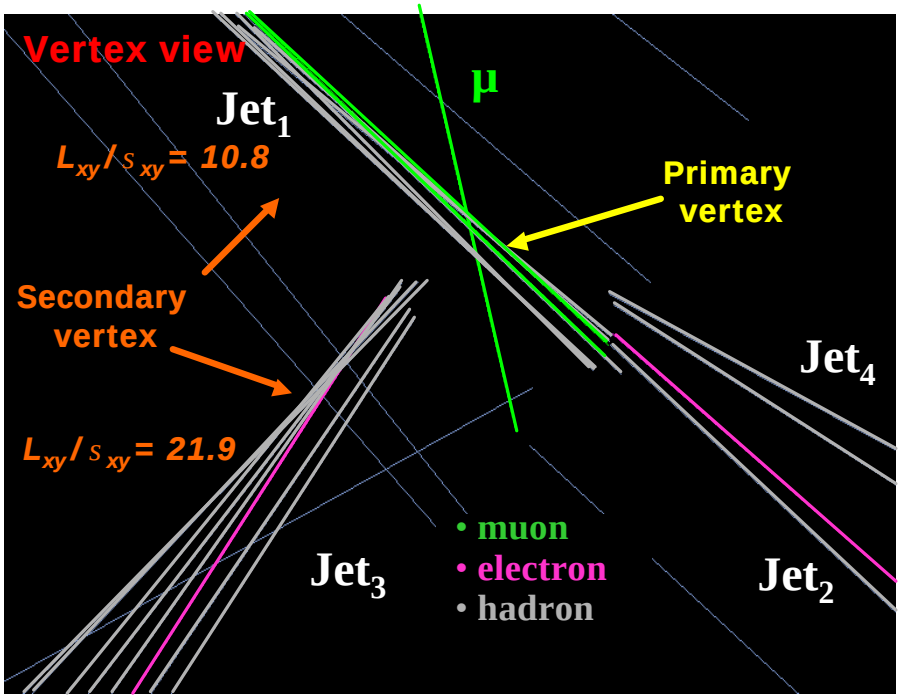
				3
	±	±	±	±
	±	±	±	±

Lepton + Jets Candidate Event

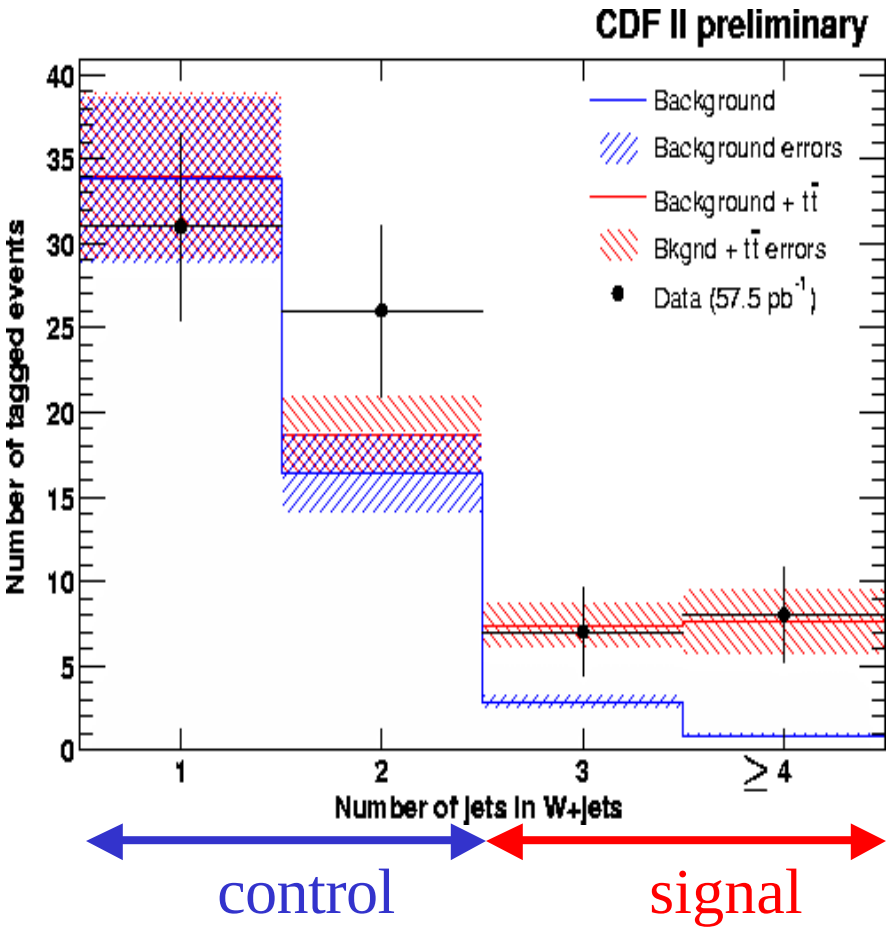
$t\bar{t}$ l + jet candidate:
Nov 02 2002 run: 153693 event: 799494
μ (CMUP) + 4 jets

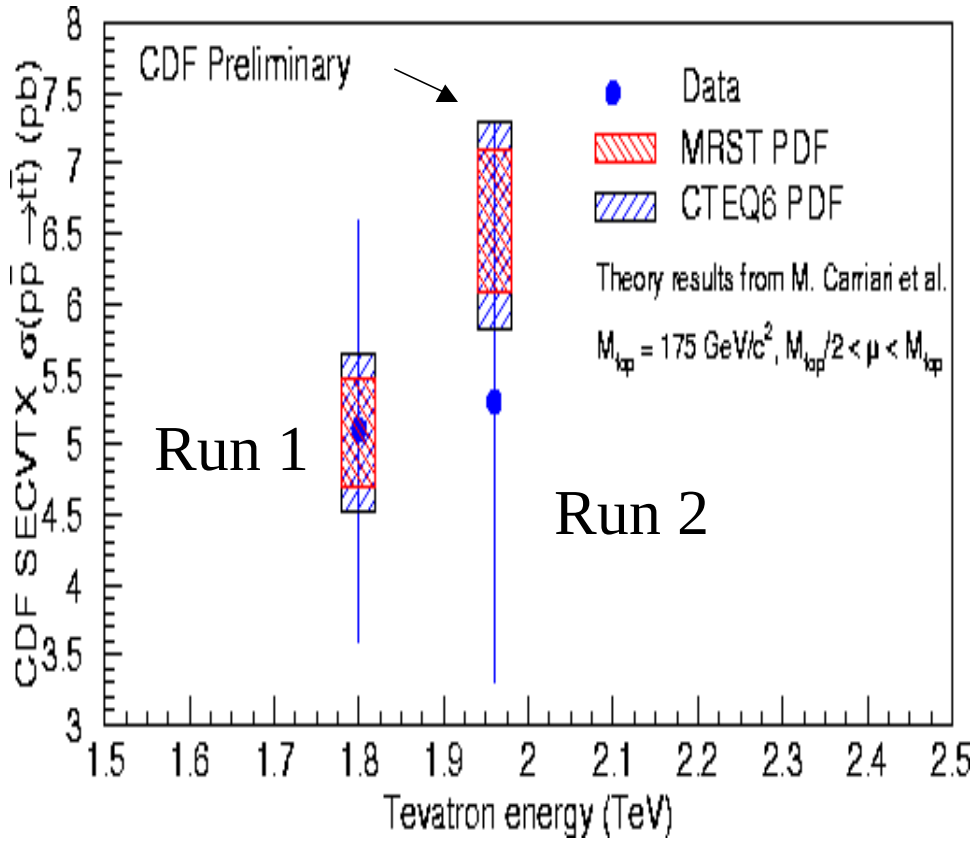
$p_T(m)$ = 54.4 GeV/c^2
E_T^j = 96.7, 65,8, 54.8, 33.8 GeV
$\not{E}_T$= 40.8 GeV





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

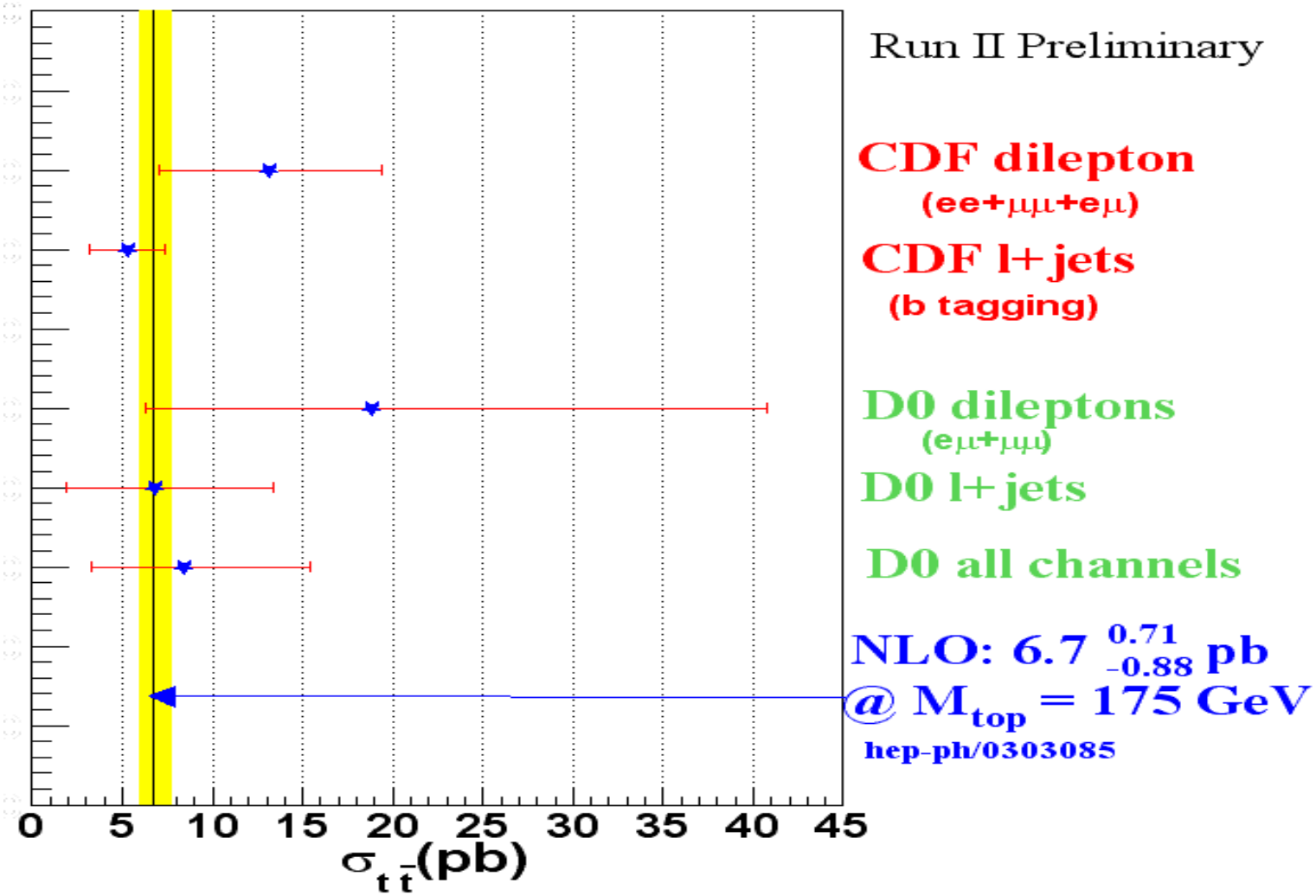




CDF Run II Preliminary

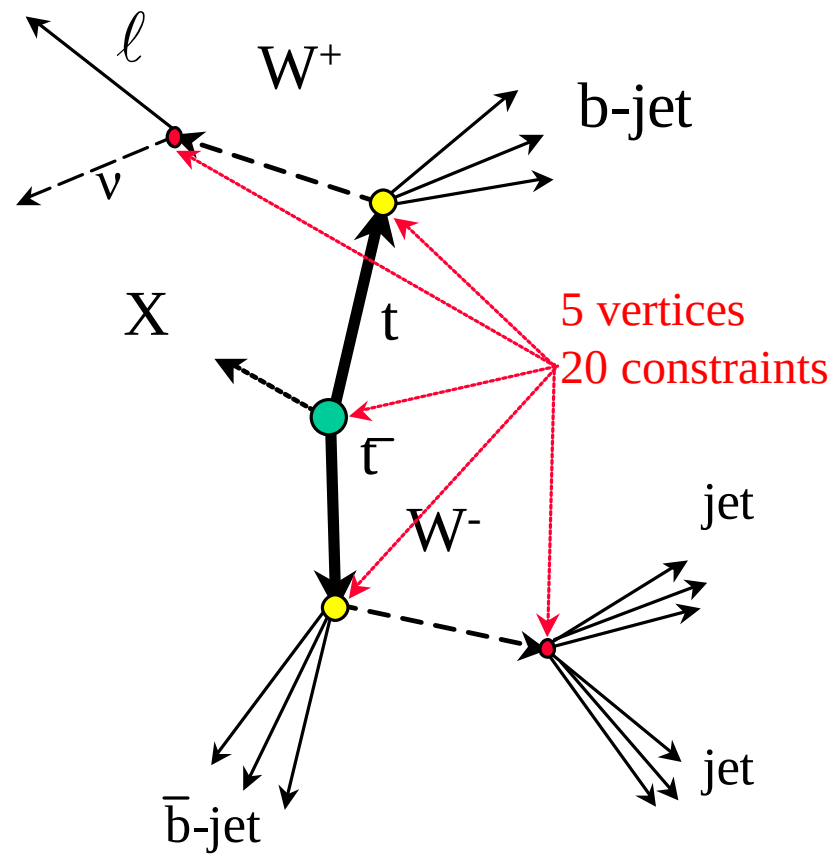
$$s_{t\bar{t}} = 5.3 \pm 1.9_{stat} \pm 0.8_{sys} \pm 0.3_{lum}\ pb$$

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



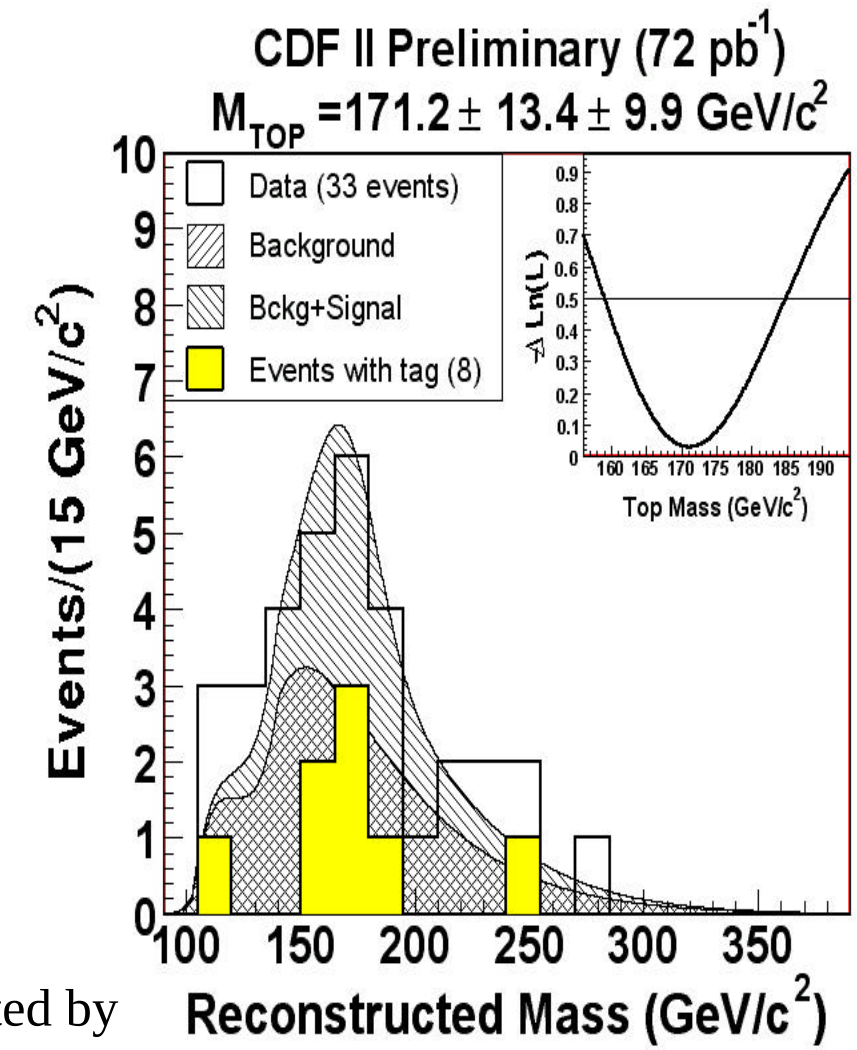
Top Mass: Lepton + jets

- **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

- 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

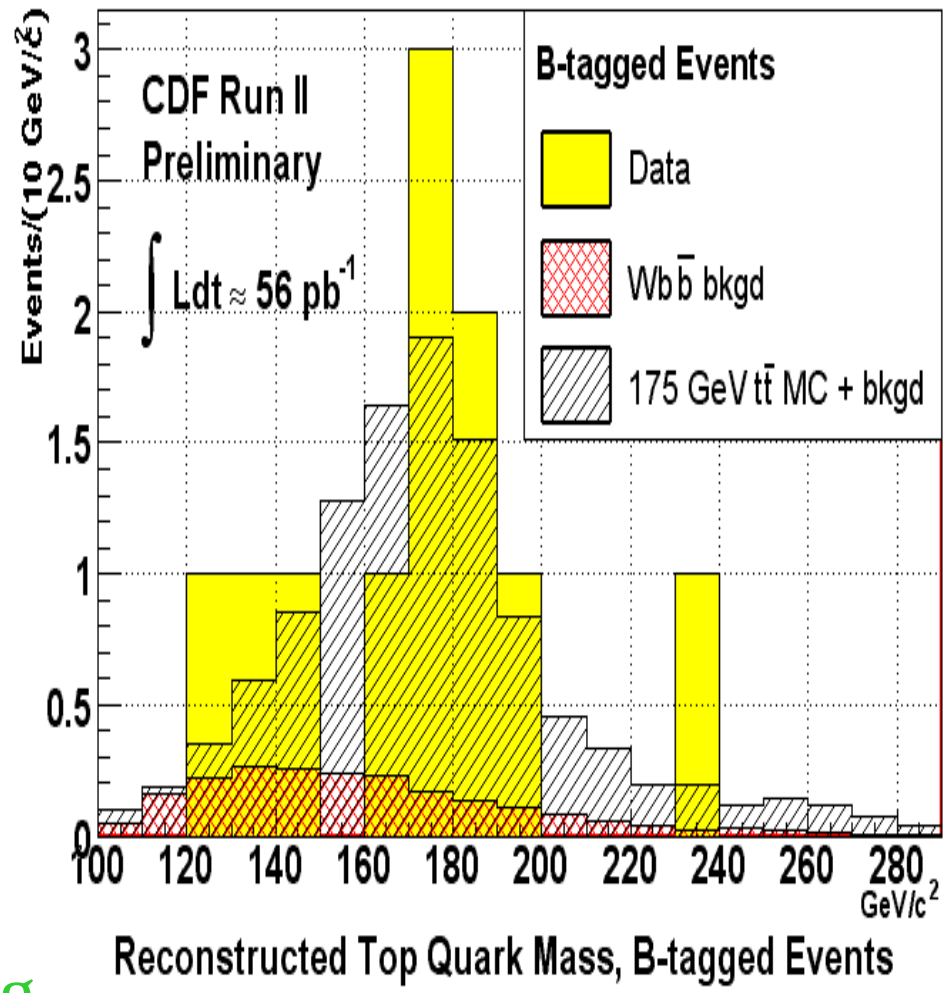
CDF Run 1 combined:

$M_{top} = 176.1 \pm 6.5$ 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 (goal: ~200 pb^{-1} by summer) we will be able to extend our Run I searches for extensions to the standard model.**