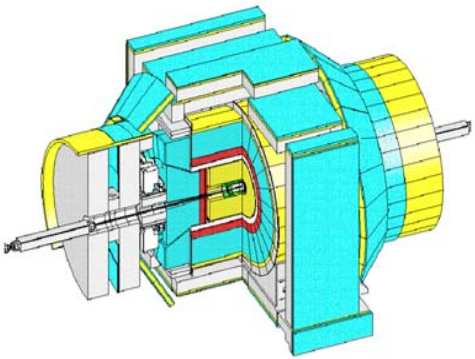
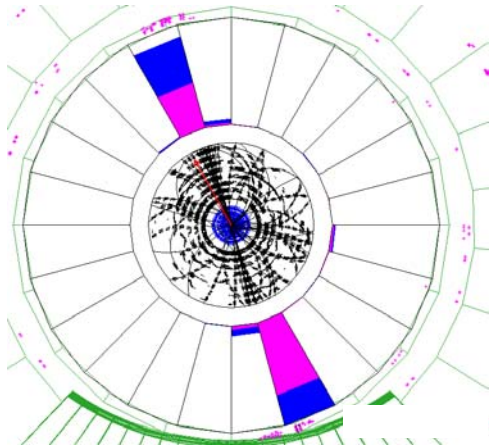
Status of CDF Physics

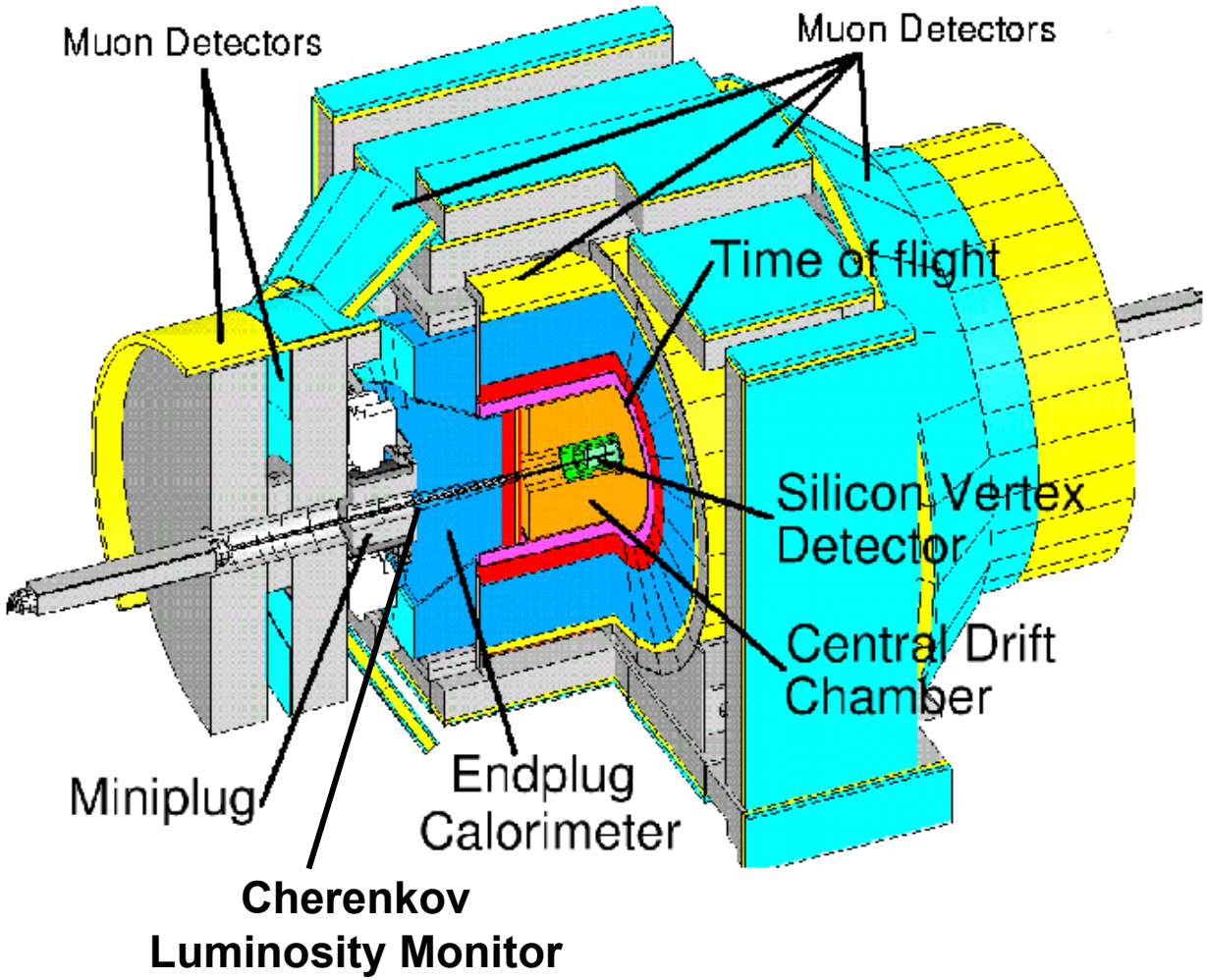




Fermilab PAC
March 28, 2003
Tony Liss
University of Illinois

Detector and Offline Operations

The CDF Detector showing Run 2a Upgrades



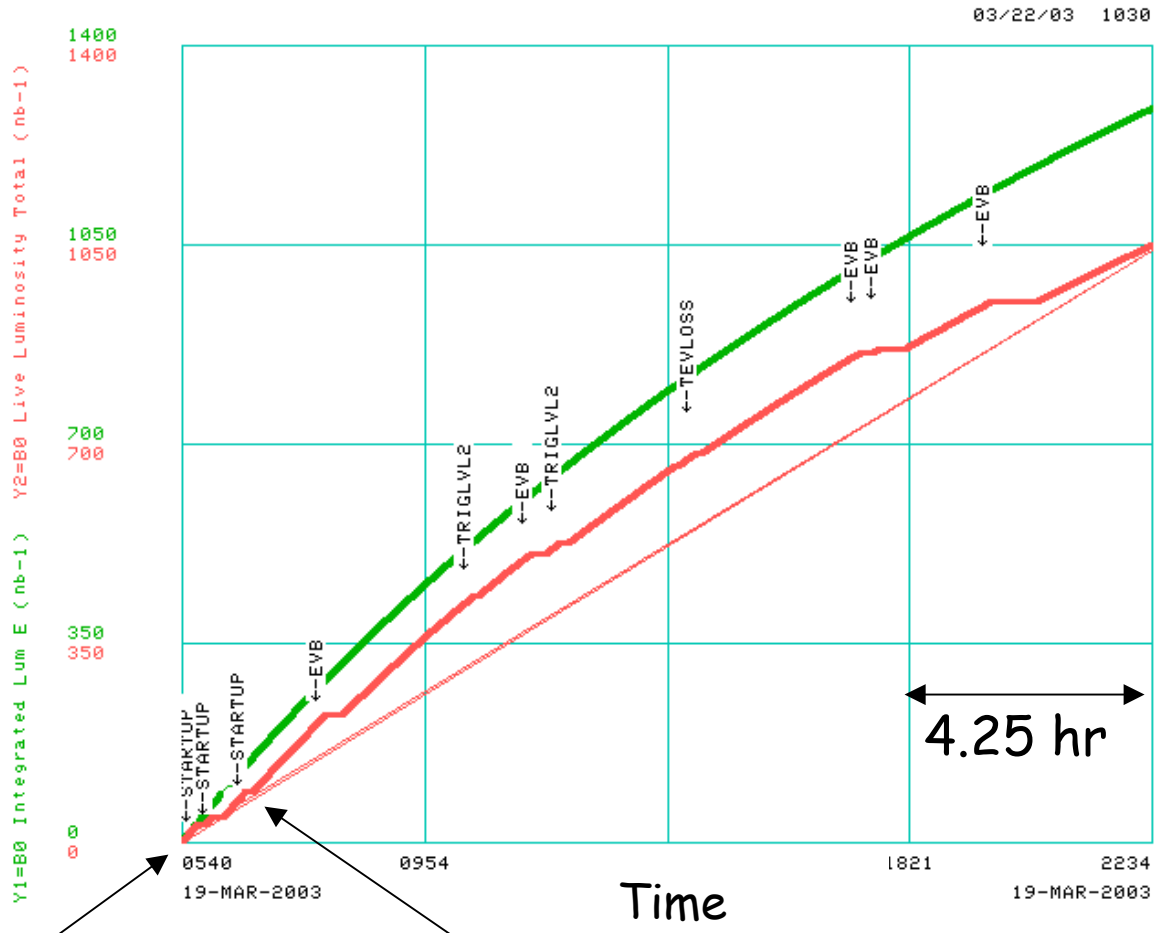
New

L1, L2, L3 Triggers

DAQ System

Monitoring

A Typical Store (Really)
(19-Mar-2003)



delivered
1.29 pb^{-1}

recorded
1.05 pb^{-1}

ε=81.4%

17 hr store

Init. Lum=3.5E31

Si Integrated after 1 hr
(beam losses)

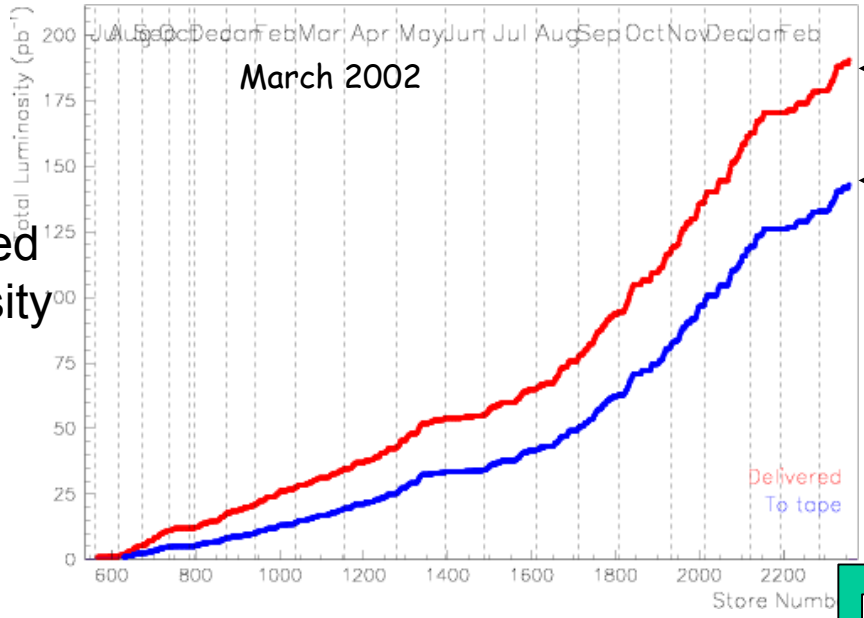
Final Lum=1.4E31

~ commissioning

physics

March 2003

Integrated Luminosity pb^{-1}

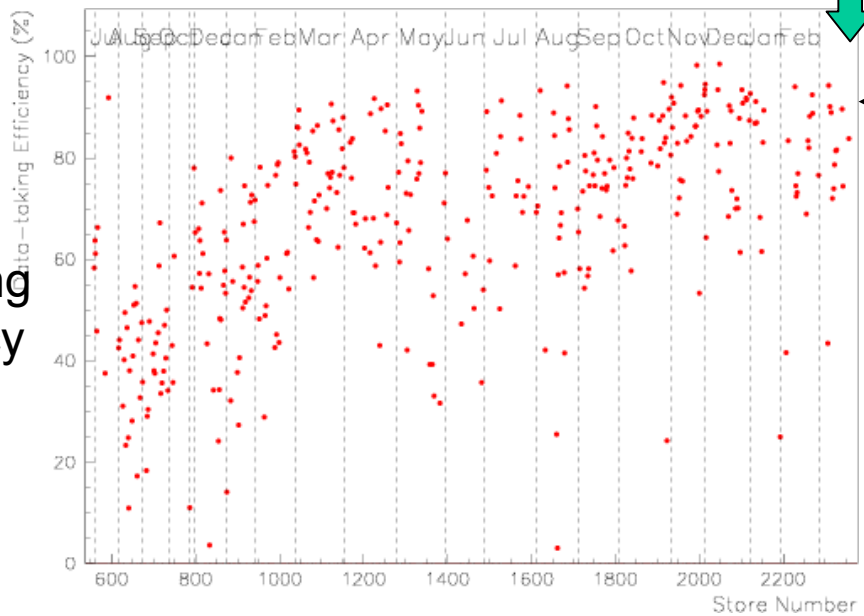


~190 pb^{-1} delivered

~140 pb^{-1} recorded (including early data used for commissioning)

March 2003

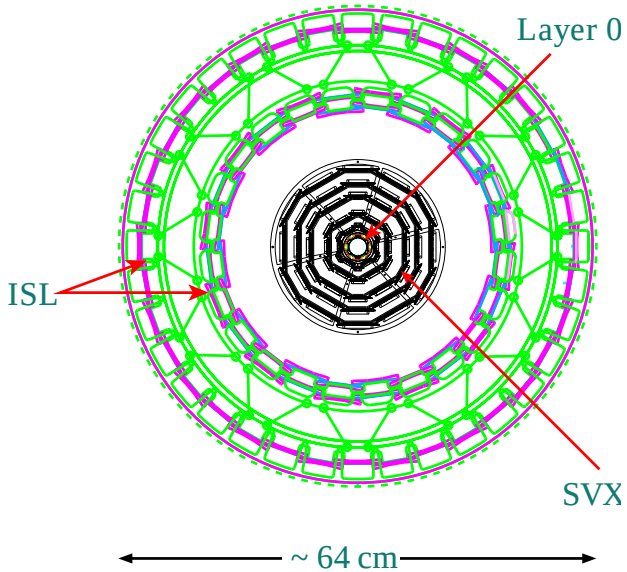
Data Recording Efficiency



90% efficiency

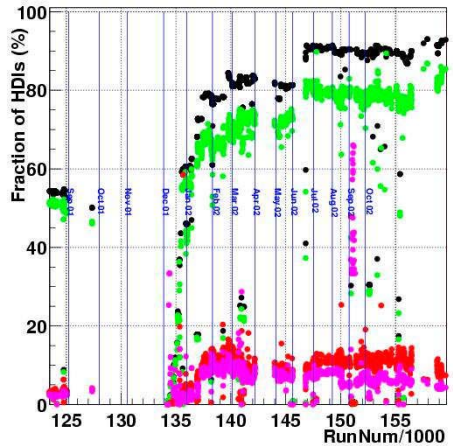
Silicon Trackers

Stable data taking since June shutdown
>90 % of the Silicon is integrated



Sub-detector	Running %	S/N rΦ (z)
L00	97.0 %	S/N 10:1
SVXII	92.5 %	S/N 14:1(12:1)
ISL	89.0 %	S/N 12/1(12:1)

- 12 KHz L1 accept limit removed. Cautiously stepping up. Up to 16 KHz so far.
- Now working on minimizing:
  - **inefficiency at the beginning of each store**
  - **Error rate**
- Upcoming Challenges
  - **Higher trigger rates**
  - **A good maintenance plan for stable operations in the years to come**

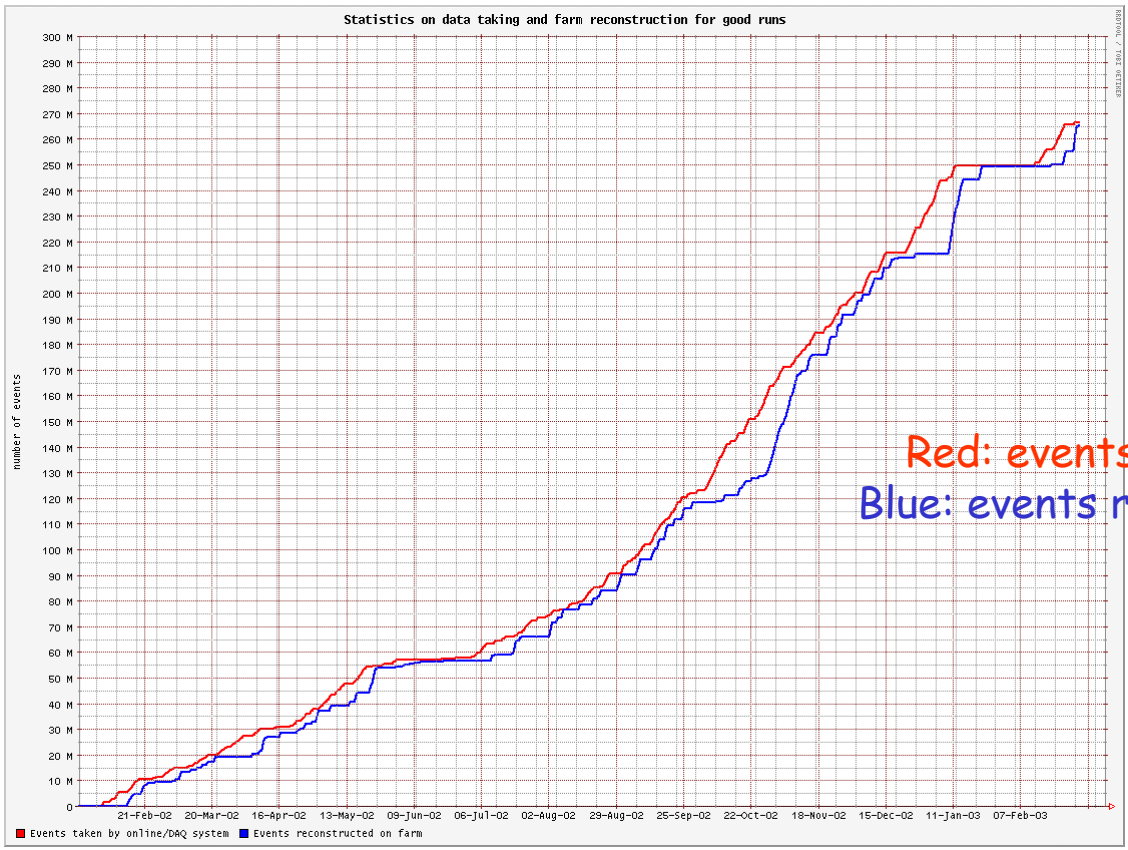


Offline data processing

- Physics analysis for Winter Conferences
  - All physics quality data up to January 2003 shutdown reprocessed

300 million →

200 million →



Red: events from DAQ
Blue: events reconstructed

Events processed by offline reconstruction

Feb. 2002 ↑

↑ Feb. 2003

Run 2 Physics Analyses

There's Too Much To Show in 20 min. So:

- Results I Will Show Are In A Box & In This Color

- Results Included In Your Slides But Not Shown Are in Blue (and not in a box) .

Integrated Luminosity for Physics

- Total data recorded to tape (~140 pb^{-1}) includes that taken early in Run 2 when detector was not fully commissioned.

- Data acquired over past year ~ 100 pb^{-1}

- As of end of January 2003 $\int Ldt$ for physics:
  - Jet measurements 85 pb^{-1}
  - High Et electrons, muons 72 pb^{-1}
  - Top lepton plus jets with B tags 56 pb^{-1}

- The silicon detectors are integrated into physics data taking 98% of the time for clean stores (since ~ October 2002).

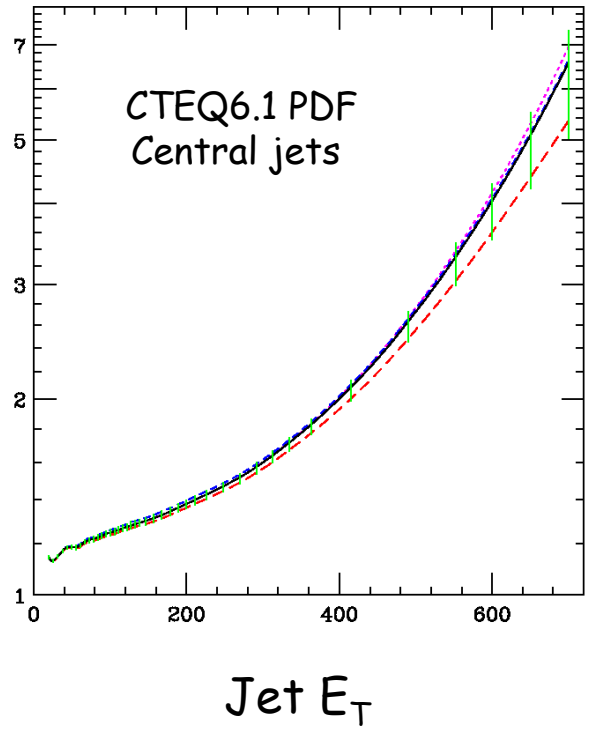
- Now working on improving recorded data -> physics data efficiency

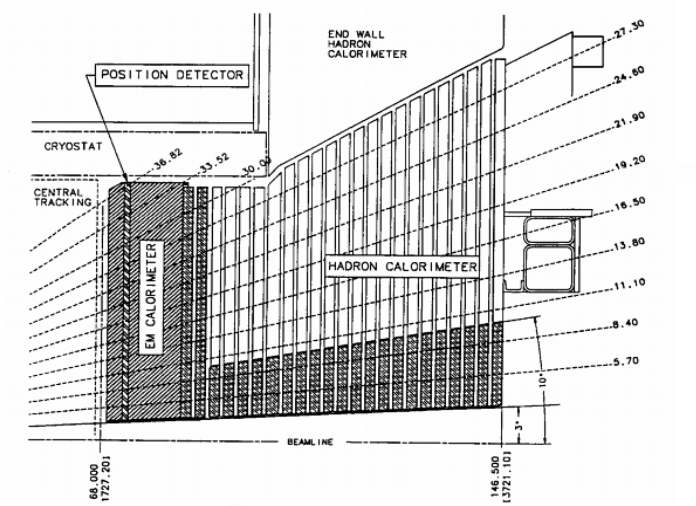
QCD Physics

- High E_t probes with inclusive jets
- Di-jet Cross Section
- Jet structure
- Diffractive Structure Function

Inclusive high Et jets

Run II/Run I
Inclusive jet
Cross section





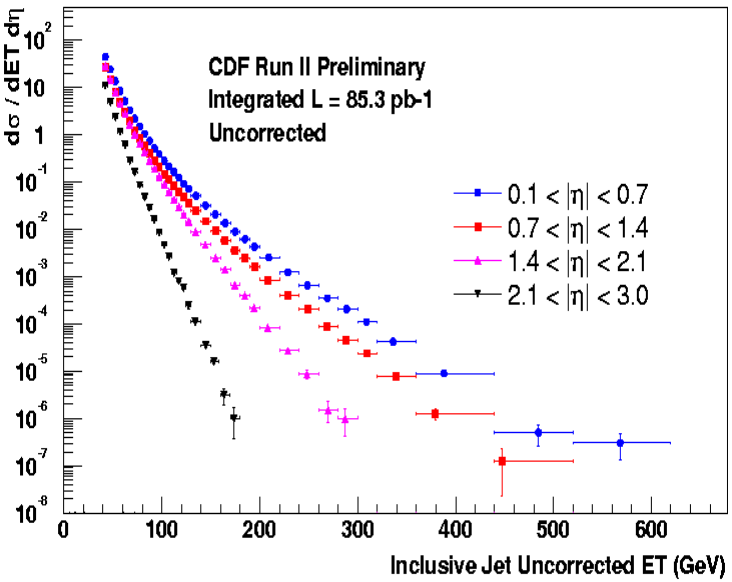
Increased cm energy
1.80 ➔ 1.96 TeV

New CDF plug calorimeter
extends eta coverage to ~ 3

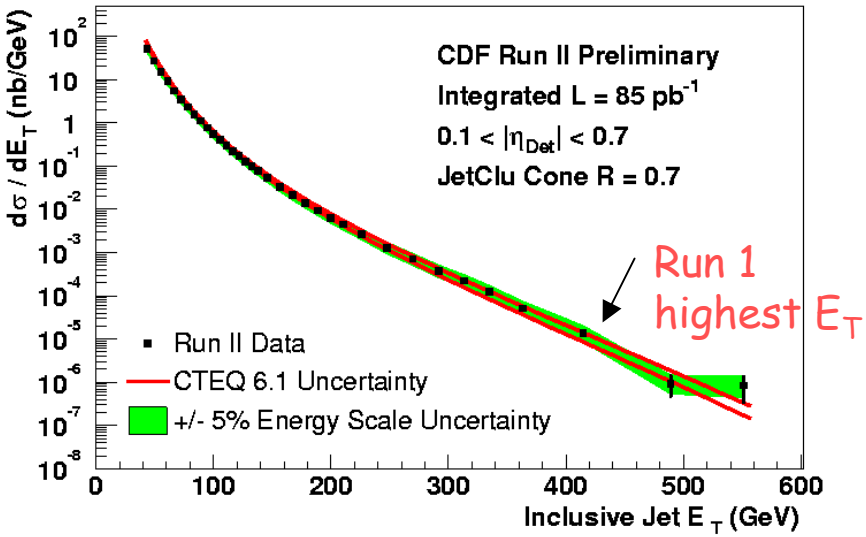
Inclusive high Et jets

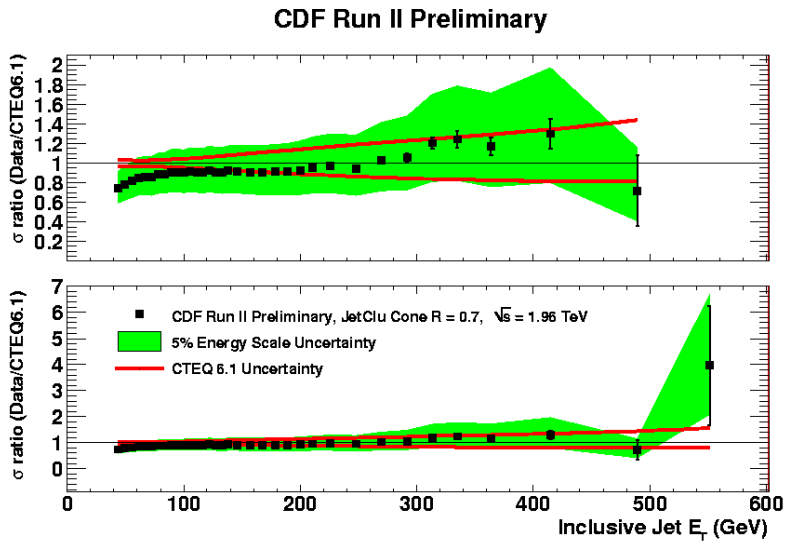
Corrected Et spectra compared to NLO (EKS) predictions With CTEQ6.1 PDF's

Inclusive jet E_T in η bins

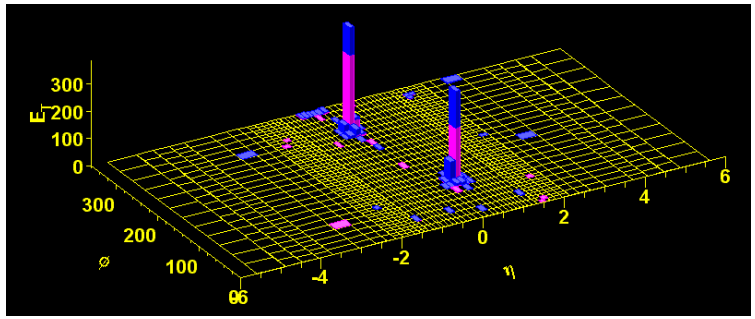


CDF Run II Preliminary

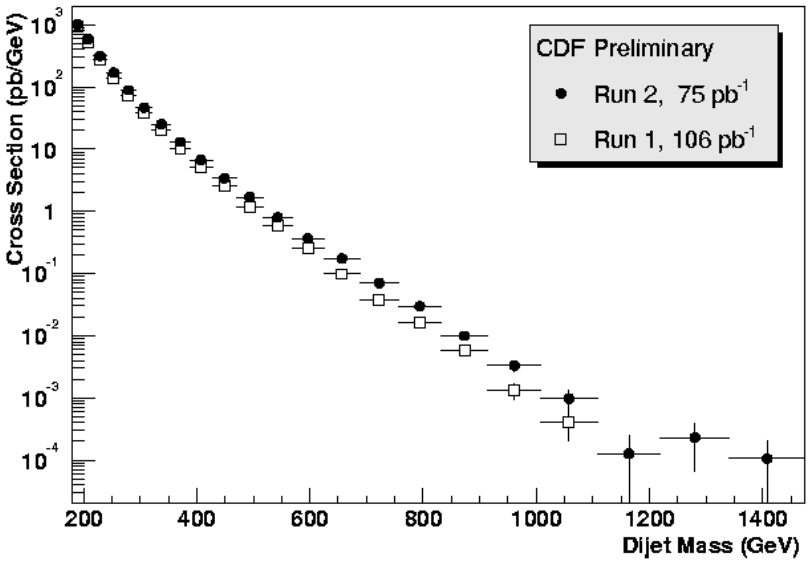


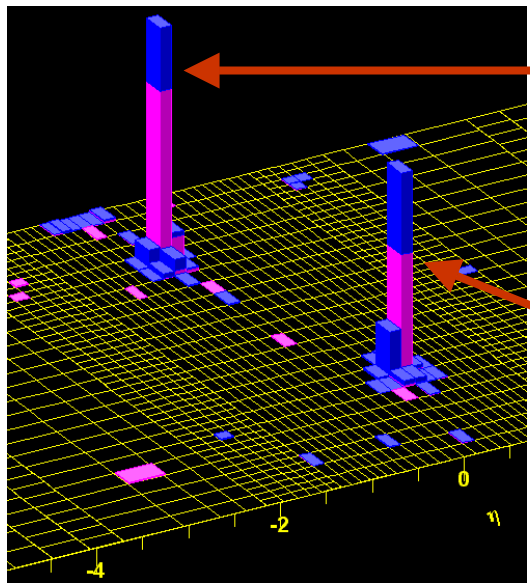


Di-jet studies



Dijet Mass = 1146 GeV!

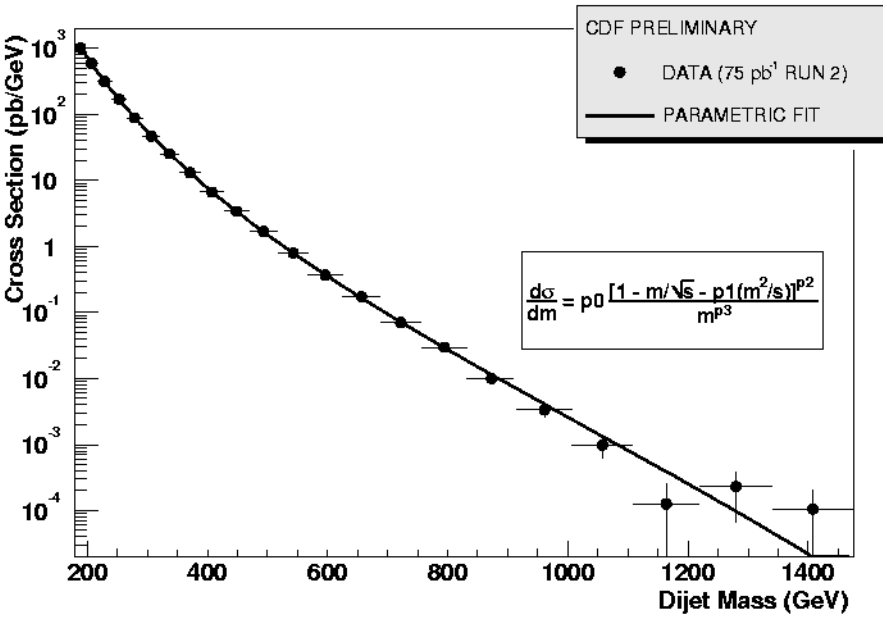


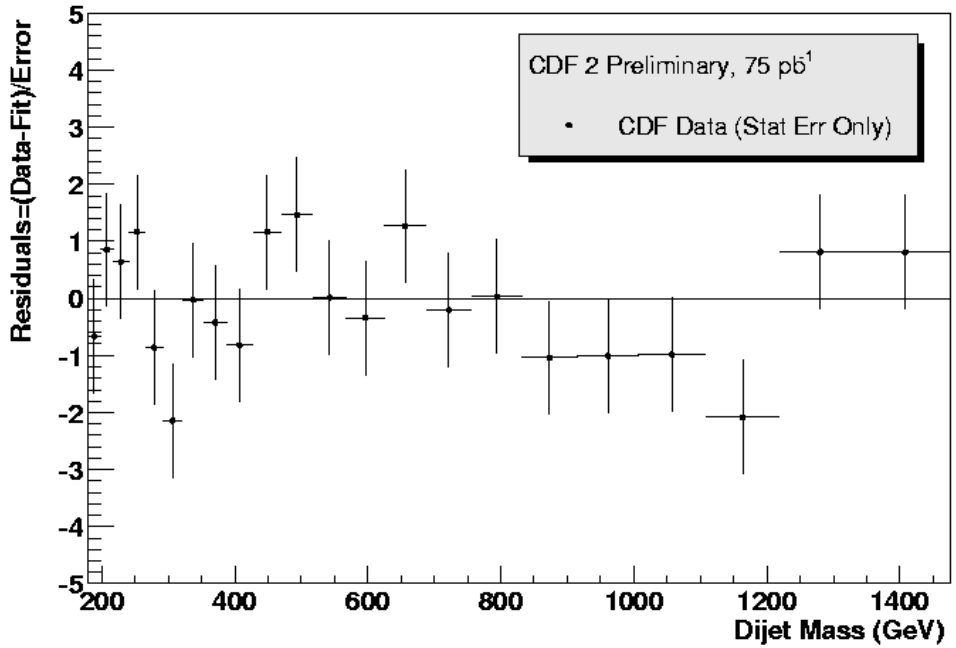


E_T = 528 GeV
η = -0.55

E_T = 538 GeV
η = 0.20

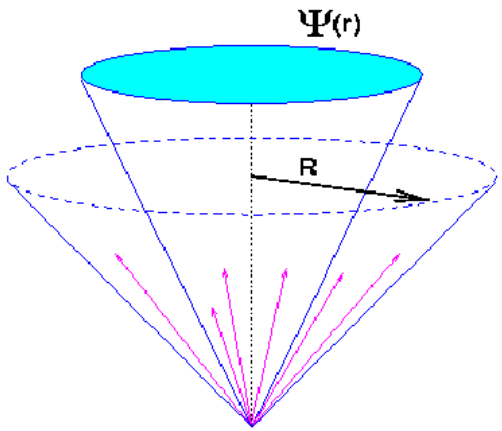
Di-jet Cross Section





CDF Run II Preliminary

Jet Structure and Underlying Event



Measure E_T with
calorimeter towers
and
tracking chambers

$$\Psi(r) = \frac{1}{N_{\text{jets}}} \Sigma_{\text{jets}} \frac{E_T(0,r)}{E_T^{\text{jet}}(0,R)}$$

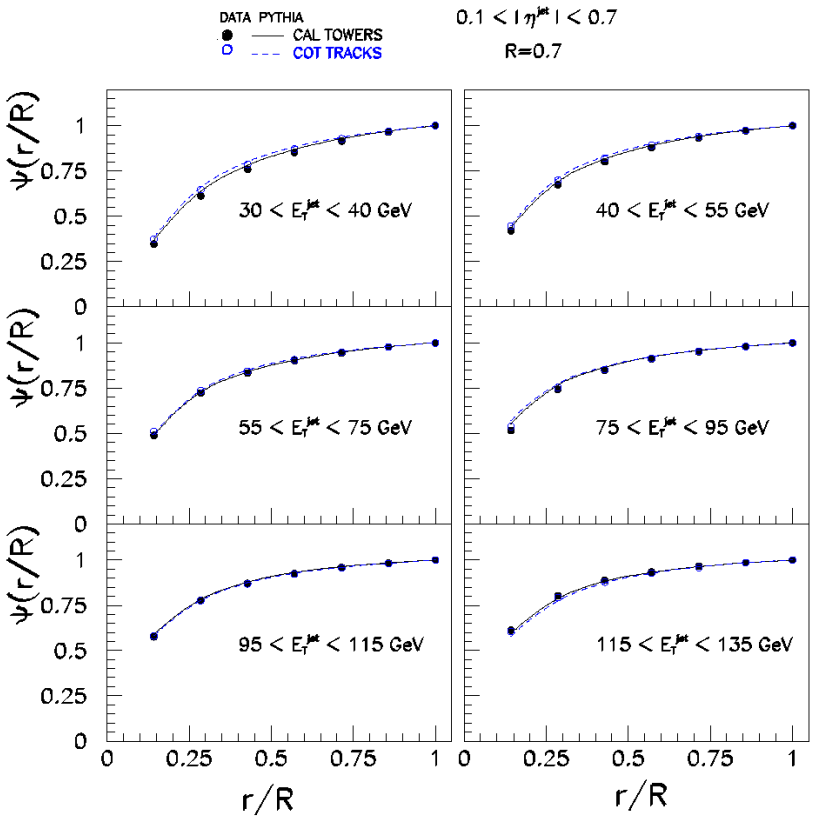
$$\Psi(r = R) = 1$$

Study Ψ(r) and jet energy flow

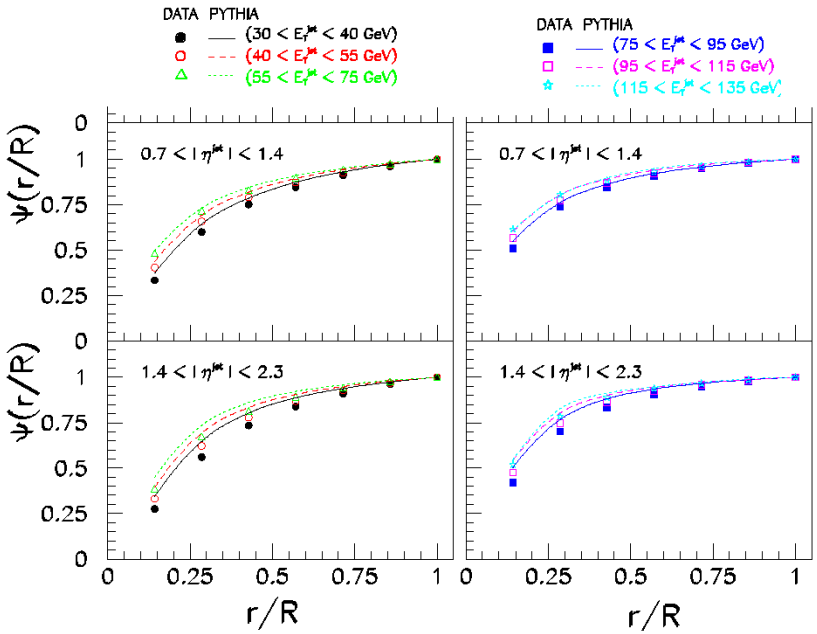
Compare to PYTHIA(6.203) 2->2 processes
plus CDF detector simulation

Jet structure

Central Jets
Good agreement with PYTHIA
and detector simulation

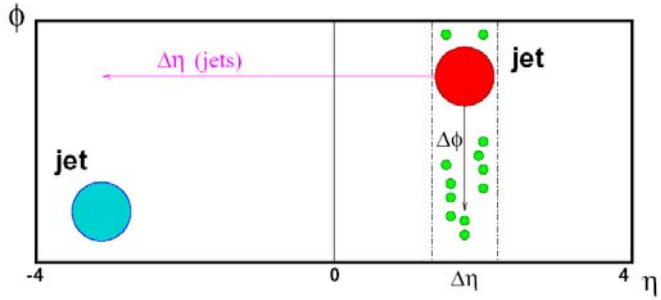


Forward Jets
New plug calorimeter
Needs some simulation tuning.



CDF Run II Preliminary

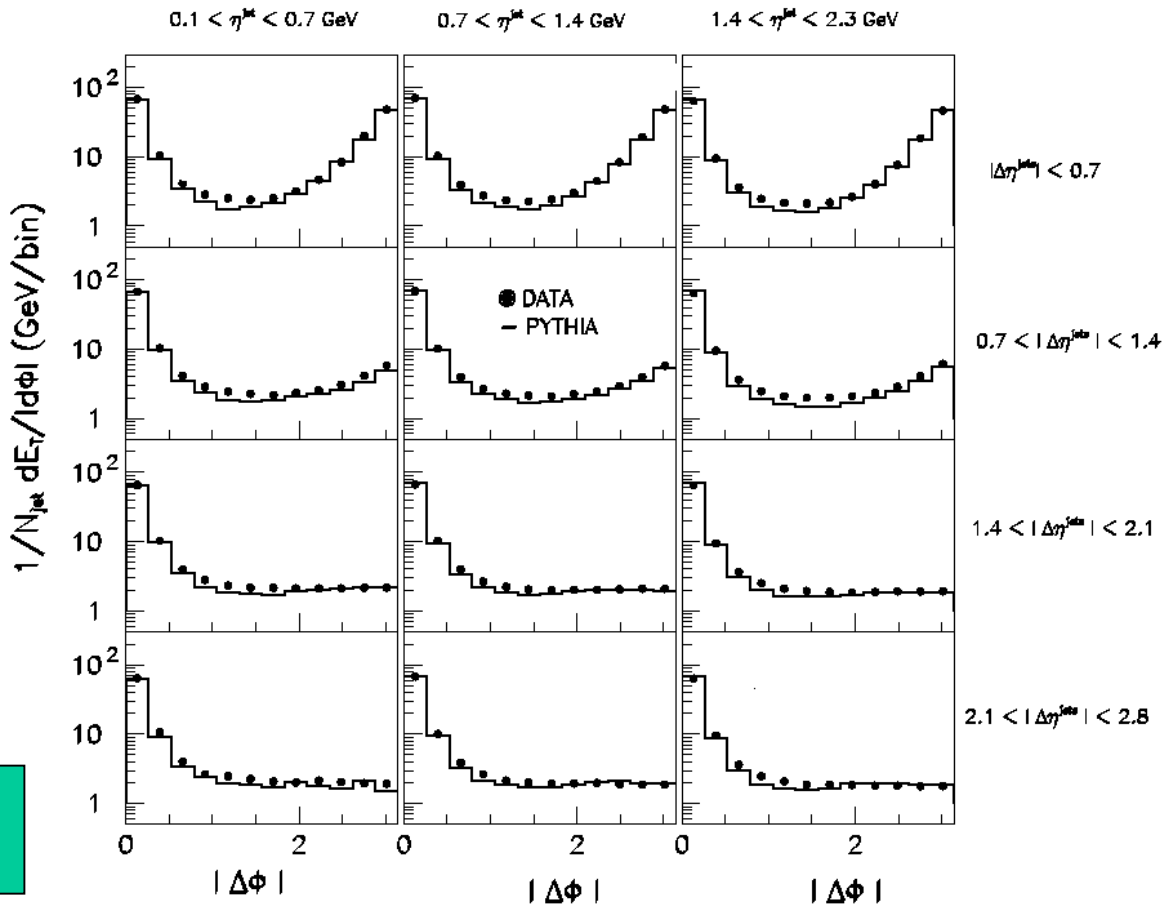
Jet energy flow and underlying event structure



Increasing probe jet η

Increasing jet Δη separation

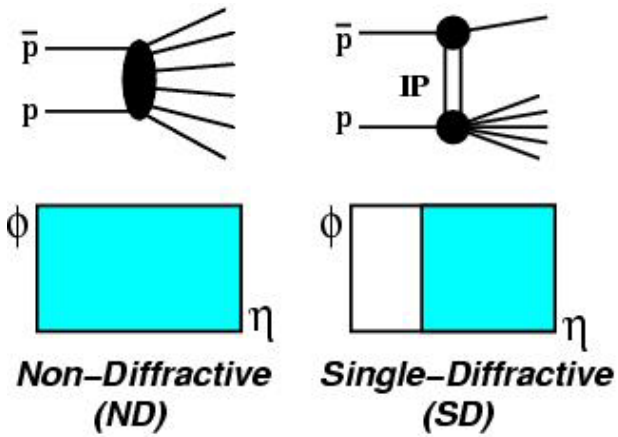
Jet Energy Flow

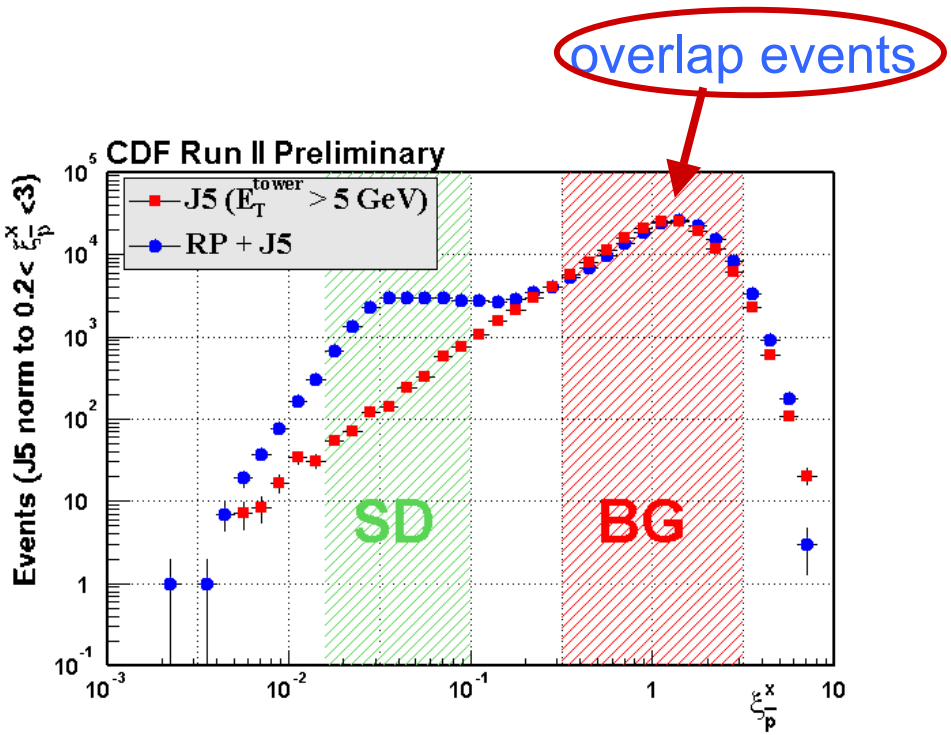


CDF Run II Preliminary

Diffractive Dijets

- First results w/ miniplug
- Compare diffractive events to ND
- Measure diffractive structure function from $R_{SD/ND}$ vs x_{Bj}





Measure x ($\bar{p}$ momentum loss fraction) from calorimeter information

$$\xi = \frac{\sum E_T e^{-\eta}}{\sqrt{s}}$$

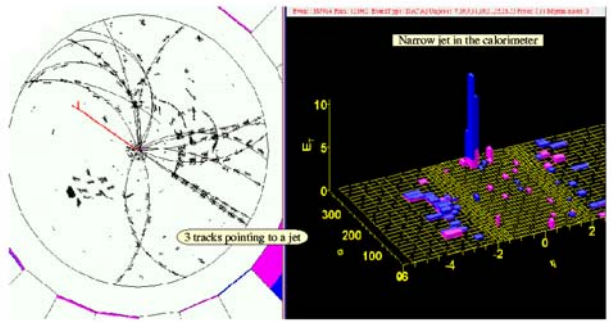
Electroweak Physics

- W and Z boson production
- $e^+ e^-$ forward-backward asymmetry
- Di-boson production

W and Z boson inclusive production

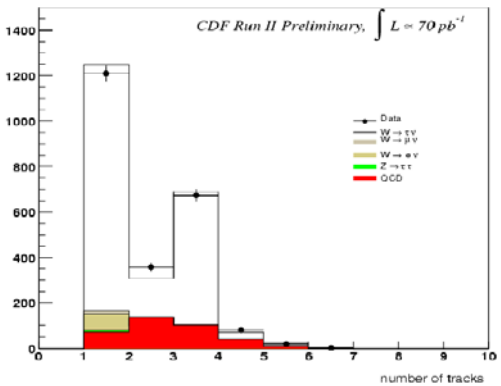
- Clean signals of inclusive W and Z bosons are the first step in CDF's precision electroweak physics program

- Measurements based upon 72 pb^{-1} of data :
  - W -> e ν, μ ν and τ ν
  - Z -> e e , μ μ *and* $\tau\tau$



- The W -> τ ν channel allows clean study of tau lepton identification

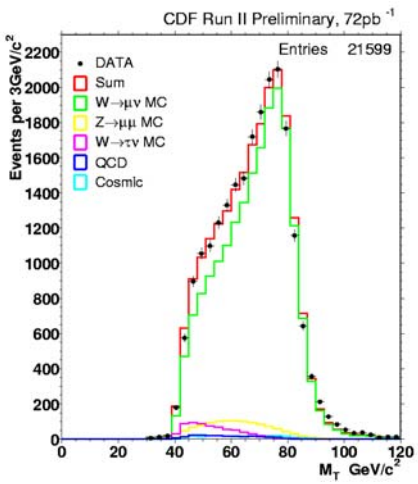
Charged particle multiplicity from W -> τ ν candidates



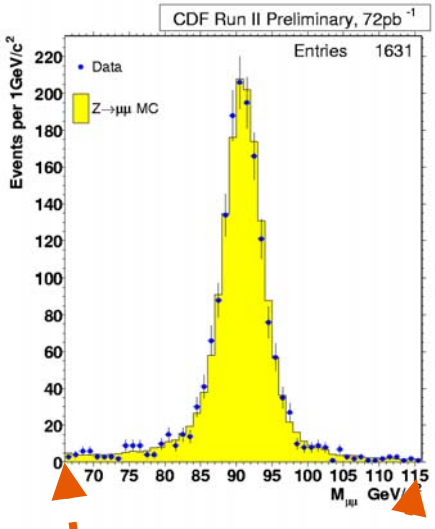
Compare $\sigma(W)*BR(W\to\tau\,\nu)$ to $\sigma(W)*BR(W\to e\,\nu)$

$g_\tau / g_e = 0.99 \pm 0.04$

W -> μ ν

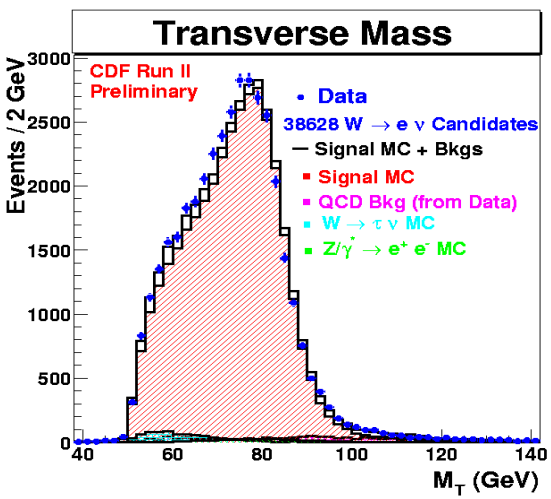


Z -> μ μ

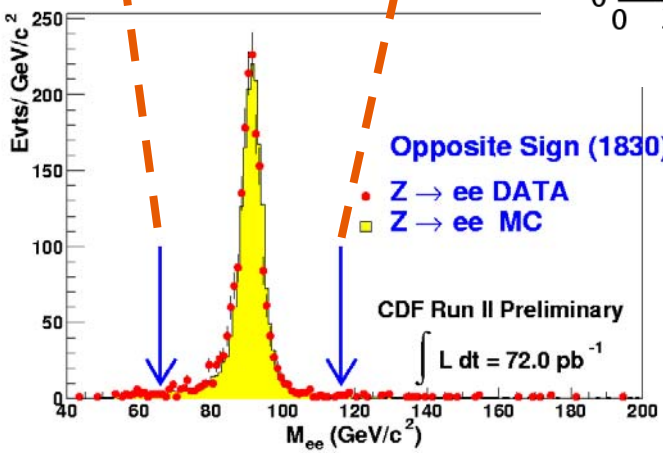


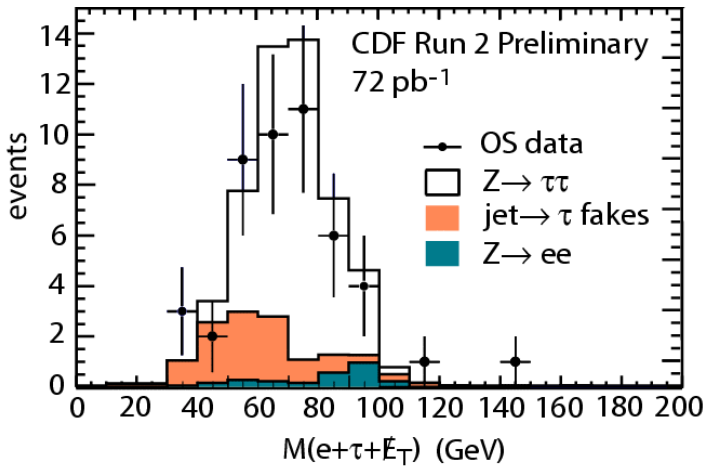
- Backgrounds low
- Detector simulation reproduces data

W -> e ν



Z -> e e





Z→ττ!

W, Z production and Γ(W)

σ_W* BR(W→eν) = $2.64 \pm 0.01_{stat} \pm 0.09_{syst} \pm 0.16_{lum}$ nb
σ_W* BR(W→μν) = $2.64 \pm 0.02_{stat} \pm 0.12_{syst} \pm 0.16_{lum}$ nb
σ_W* BR(W→τ ν) = $2.62 \pm 0.07_{stat} \pm 0.21_{syst} \pm 0.16_{lum}$ nb

NNLO Prediction
2.69 nb

σ_Z* BR(Z→ee) = $267 \pm 6_{stat} \pm 15_{syst} \pm 0.16_{lum}$ pb
σ_Z* BR(Z→μμ) = $246 \pm 6_{stat} \pm 12_{syst} \pm 0.15_{lum}$ pb
σ_Z* BR(Z→ττ) = in progress

NNLO Prediction
252 pb

Measure R(e) = σ(W)*BR(W->e ν)/ σ(Z)*BR(Z->e e) and R(μ)

$$\Gamma(W) = \frac{\sigma(p\bar{p} \to W)}{\sigma(p\bar{p} \to Z)} \frac{\Gamma(W \to e\nu)}{\Gamma(Z \to ee)} \frac{\Gamma(Z)}{R}$$

Γ(W) = 2.29 ± 0.12 GeV from R(e)
Γ(W) = 2.11 ± 0.09 GeV from R(μ)

PDG value
2.12 ± 0.04 GeV

e+ e- forward-backward asymmetry

Sensitive to new neutral gauge bosons

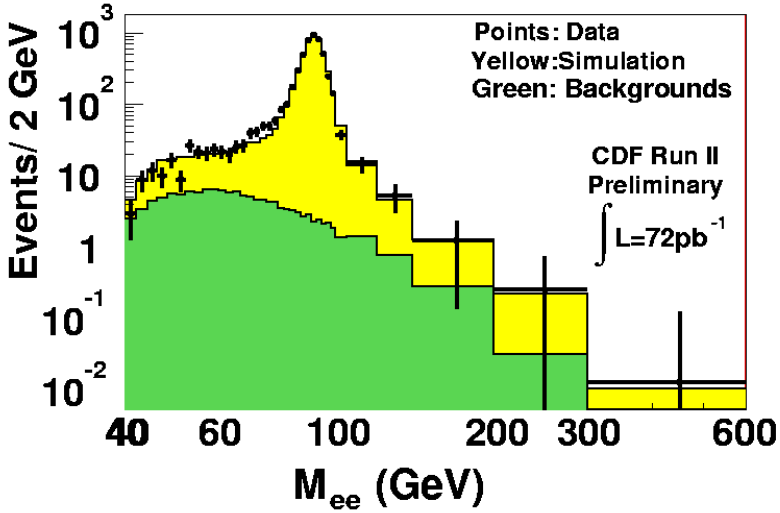
$$\frac{d\sigma(\bar{q}q \to Z/\gamma \to \ell^+\ell^-)}{d\cos\theta} = A(1+\cos^2\theta) + B\cos\theta$$

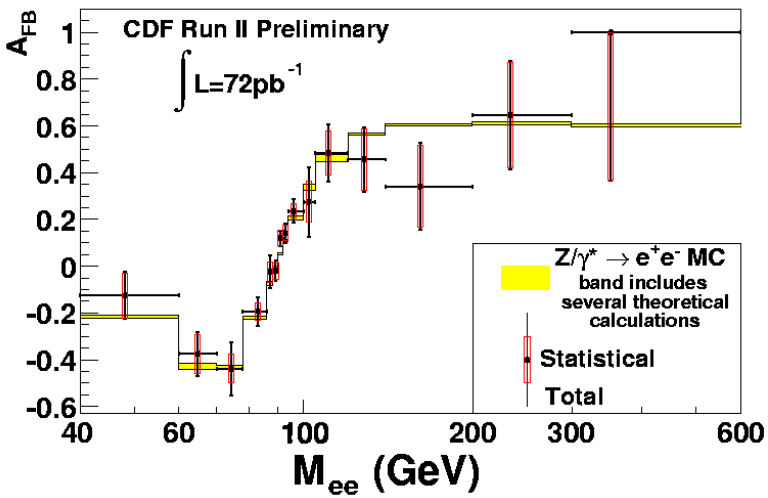
$$A_{FB} = \frac{N_F - N_B}{N_F + N_B} = \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma(\cos\theta > 0) + \sigma(\cos\theta < 0)}$$

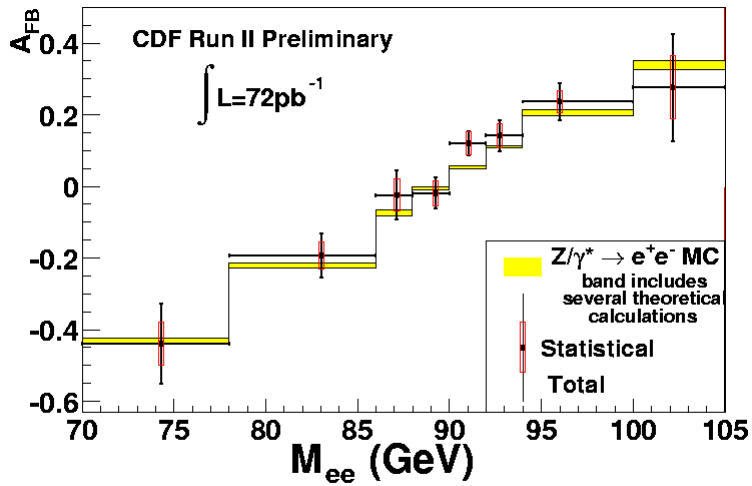
Measure θ in Collin-Soper reference frame

Data: $e^{\pm}$ with Et > 20 GeV, $|\eta| < 3.0$

Theory: SM via Pythia with CTEQ5L

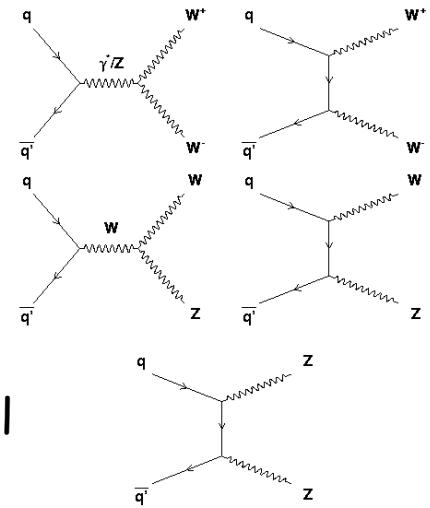






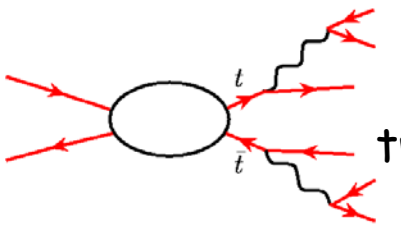
Di-boson production (WW)

- Measurements of di-boson production provide tests of the SM and are necessary parts of the program for Higgs boson searches
  - e.g. $p\bar{p} \rightarrow W Z + X$ and $p\bar{p} \rightarrow W H + X$
    - ✓ similar decay channels Z , H -> $b\bar{b}$
    - ✓ similar radiation X from color singlet $p\bar{p}$ production
  - WW , ZW , WH, ZH also have similar detector demands



- Current data allows the first look at WW production
  Done in conjunction with top studies in di-lepton channel

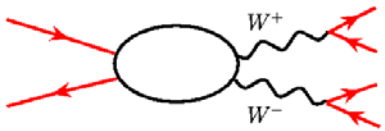
top pairs



W W plus
two hard B jets

$\sigma(t\bar{t}) \sim 7$ pb

W pairs



W W plus
soft gluon jets

$\sigma(W^+ W^-) \sim 13$ pb

WW production

- Search based on di-lepton channel with ee+μμ+eμ ➡ σ ~ 0.05*13 pb
- Selection cuts the same as for top di-lepton study
- Central, isolated e, μ Et > 20 GeV missing Et > 25 GeV
- Rejection of top background: no jets with Et > 10 GeV within | η | < 2.0

	e e	μ μ	e μ
relative acceptance	0.19	0.25	0.56
signal/background	2.6	1.8	2.9

	CDF Run II Preliminary			
Source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
Drell-Yan e^+e^-	0.15 ± 0.08	0	0	0.15 ± 0.08
Drell-Yan $\mu^+\mu^-$	0	0.33 ± 0.15	0.15 ± 0.08	0.49 ± 0.17
Drell-Yan $\tau^+\tau^-$	0.010 ± 0.004	0.012 ± 0.005	0.033 ± 0.012	0.056 ± 0.014
WZ	0.010 ± 0.001	0.017 ± 0.002	0.029 ± 0.003	0.056 ± 0.003
Fake	0.034 ± 0.034	$0 + 0.011$	0.31 ± 0.29	0.343 ± 0.293
$t\bar{t}$	0.0038 ± 0.0025	0.0033 ± 0.0021	0.015 ± 0.006	0.022 ± 0.007
Total Background	0.21 ± 0.09	0.37 ± 0.15	0.54 ± 0.30	1.12 ± 0.35
$WW \rightarrow$ dileptons	0.54 ± 0.12	0.65 ± 0.14	1.55 ± 0.34	2.74 ± 0.59
Run 2 Data	1	0	1	2

Data: 2 events
SM+backg. = 3.9 ± 0.7

Di-boson production ($W\gamma$)

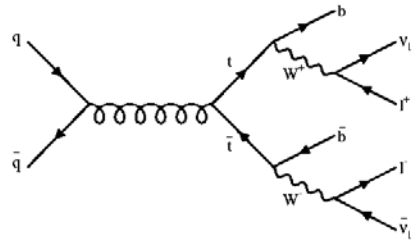
- Just blessed yesterday

Top Physics

- top pair production using ee+μμ+eμ
- top pair production using e, μ + jets
- first look at top mass in Run 2

Dileptons

$$t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow \ell^+\ell^-\nu\bar{\nu}\,jj$$



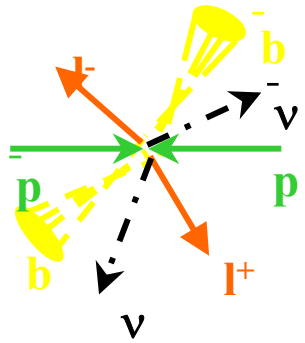
- Measurement based on channels with ee+μμ+eμ
- Kinematic selection cuts:
  - e and μ central and isolated with E_T > 20 GeV
  - At least 2 jets with $\not\!\!E_T$ > 10 GeV within |η| < 2.0
  - Missing Et > 25 GeV
  - H_T (scalar sum of E_T , leptons, jets) > 200 GeV
  - plus various background rejection cuts (Z veto, jets and leptons away from $\not\!\!E_T$ …)

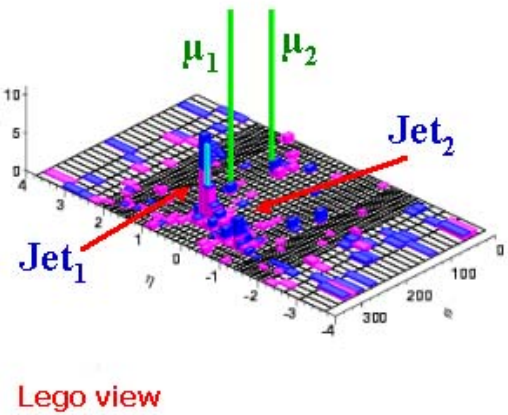
σ(tt) acceptance = (0.52+0.05)%
Signal/background ~ 8

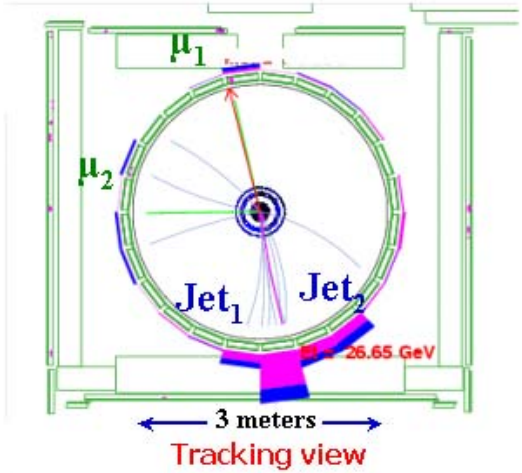
Source	Events per 72 pb^{-1} after all cuts			
	ee	$\mu\mu$	$e\mu$	$\ell\ell$
WW/WZ	0.019 ± 0.012	0.022 ± 0.014	0.050 ± 0.025	0.091 ± 0.046
Drell-Yan	0.05 ± 0.05	0.05 ± 0.05	–	0.10 ± 0.07
$Z \rightarrow \tau\tau$	0.014 ± 0.008	0.021 ± 0.013	0.030 ± 0.018	0.065 ± 0.040
Fake	0.02 ± 0.02	0	0.02 ± 0.02	0.04 ± 0.03
Total Background, B	0.103 ± 0.056	0.093 ± 0.054	0.100 ± 0.037	0.30 ± 0.12
$t\bar{t} \rightarrow$ *dileptons*	0.47 ± 0.05	0.59 ± 0.07	1.44 ± 0.16	2.5 ± 0.3
Total SM expectation	0.57 ± 0.08	0.68 ± 0.09	1.5 ± 0.2	2.8 ± 0.3
Run 2 data, N	**1**	**1**	**3**	**5**

Data: 5 events
Total bkg ~ 0.3 events
SM tt +backg. = 2.8 ± 0.3

Top → dileptons

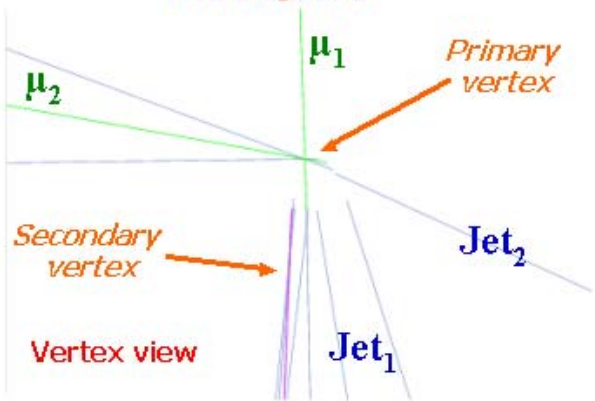






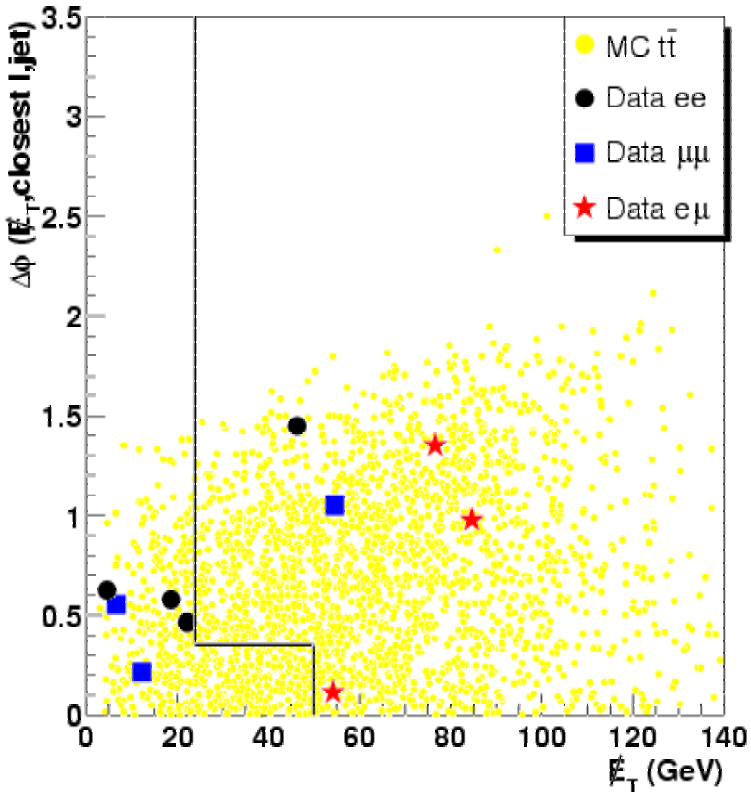
Run 154654, Event=7344016 [top $\mu\mu$ candidate]

- $P_t(\mu) = 57$ GeV [CMX]
- $P_t(\mu) = 53$ GeV [CMUP]
- $E_t(jet) = 32, 15$ GeV (2jets)
- $MET = 54$ GeV
- $M_{\mu\mu} = 69$ GeV
- $H_t = 212$ GeV



Di-muon top candidate with a B jet tag

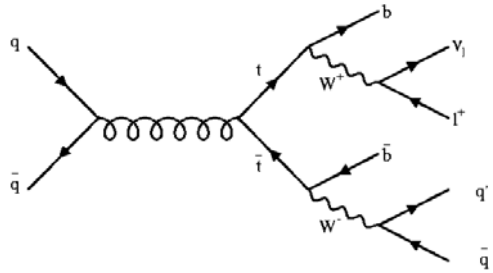
$t\bar{t} \rightarrow$ Dilepton candidates



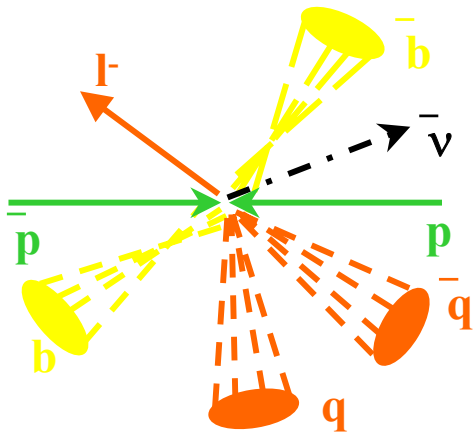
$$\sigma\left(t\bar{t}\right) = 13.2 \pm 5.9_{stat} \pm 1.5_{sys} \quad pb$$

lepton plus jets

$$t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow \ell\nu jjjj$$

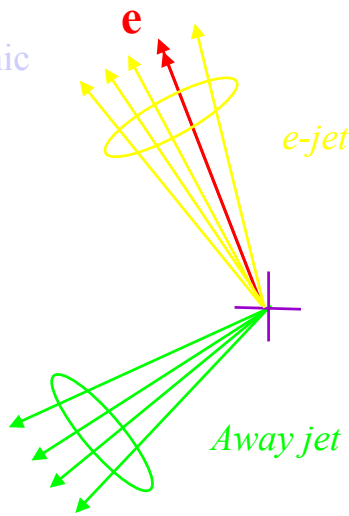


- Measurement based on e and μ plus jets channels
- Select W->e ν and μ ν using standard cuts
  - e and μ central and isolated with E_T > 20 GeV
  - Missing Et > 20 GeV
- Select jets with E_T > 15 GeV within |η| < 2.0
  - Use silicon SVXII detector to tag the jets with b decays
- Backgrounds determined from data and SM Monte Carlo simulations
  - Fake W's
  - W bb, W cc and fake tags
  - W c
  - WW WZ
  - Z-> τ τ
  - Z bb Z cc
  - Single top



b-tagging efficiency with SVX detector

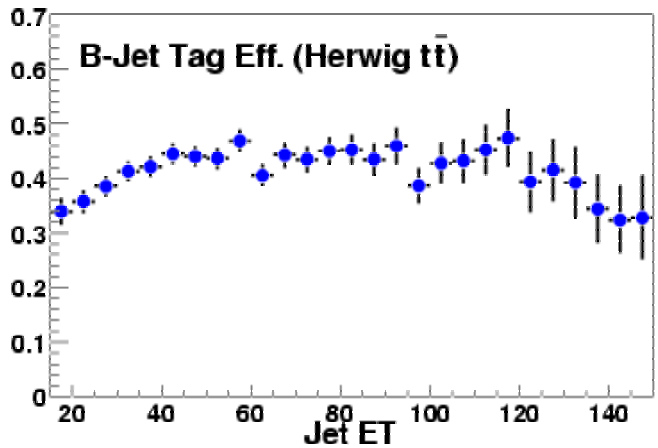
- Jet b-tagging efficiency
  - $\varepsilon_B = r/F_B$
    - Tagging rate: $r = (N_+ - N_-)/N_{tot}$
    - F_B: Fraction of e-jets containing heavy flavor
  - Done with few different methods:
    - results all consistent with each other
- Measured in data & $b\bar{b}$ MC
  - Scale Factor



ε (Data)	ε (MC)	Scale Factor
0.20±0.01	0.22±0.01	0.89±0.07

Apply SF to $t\bar{t}$ MC

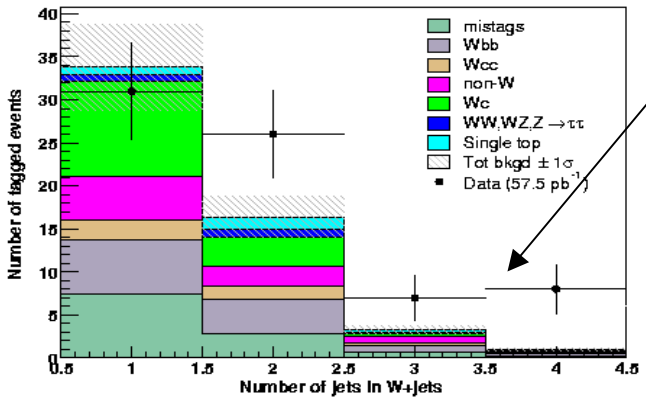
ε(event tag) = 45 ± 1 ± 5 %



top→lepton plus jets

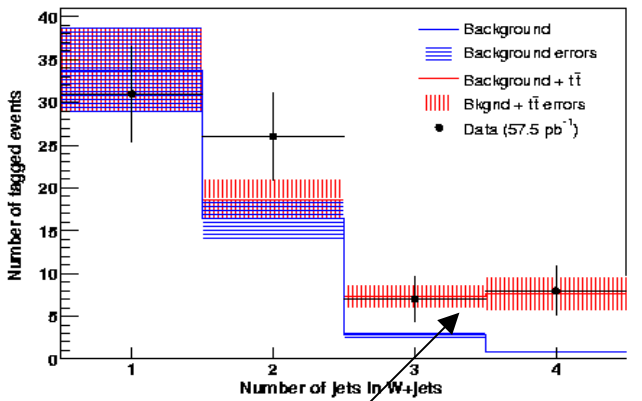
W events with b-tagged jets from 57.5 pb^{-1} of data

Use excess events in ≥ 3 jets bins to measure the top cross section

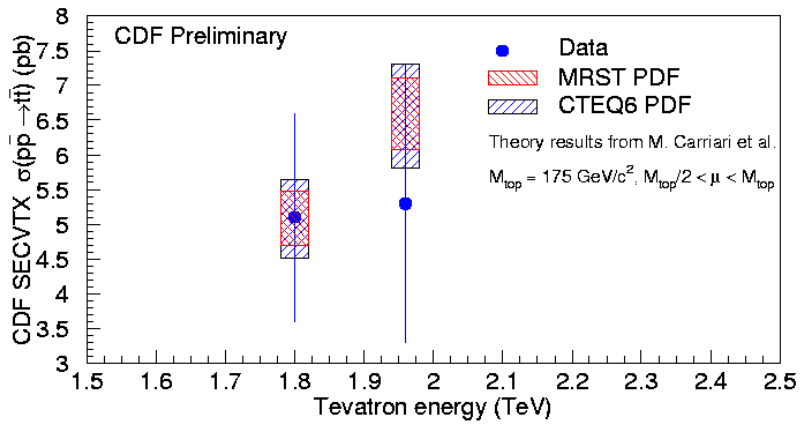


Data = 15 events
Background =3.8 ± 0.5

$$\sigma\left(t\bar{t}\right) = 5.3 \pm 1.9_{stat} \pm 0.8_{sys}\ pb$$



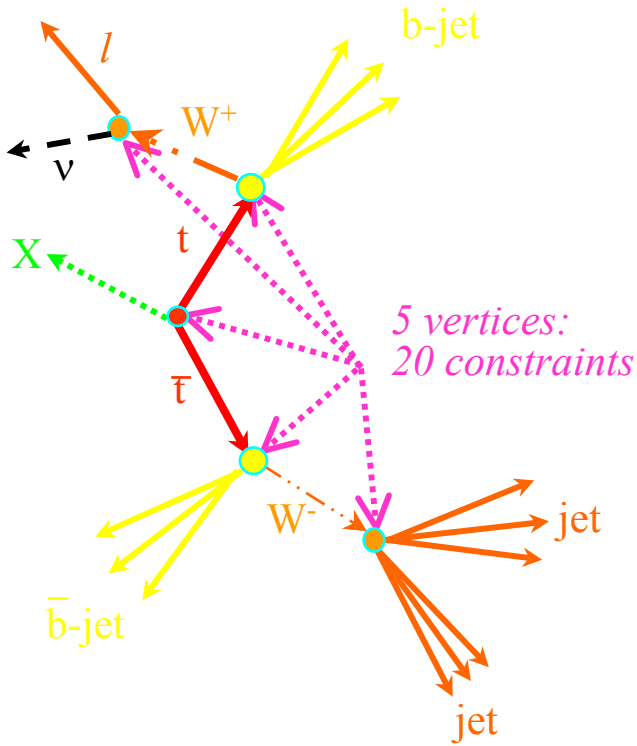
top contribution included



First Look at top mass in Run 2

First pass done without use of b-tag information

- Sample: e/μ + > 3 jets
  - 24 combinations
    - 12 correspond to the jet-parton match
    - every combination has two solutions for p_z^{ν}
  - with 1 b-tagged jet goes down to 12
  - with 2 b-tagged jets to 4
  - 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



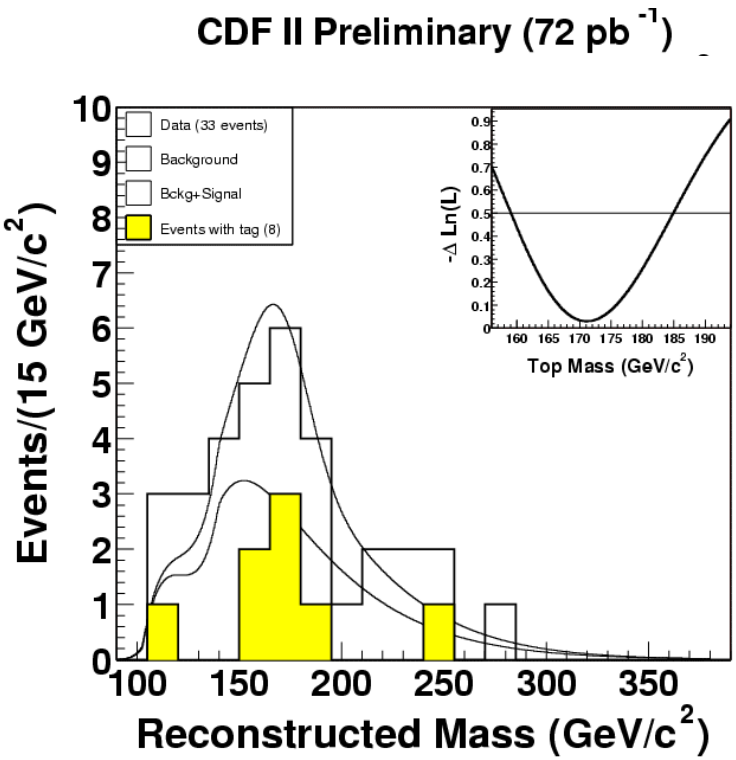
- Model the shape of the reconstructed top mass distribution and the background

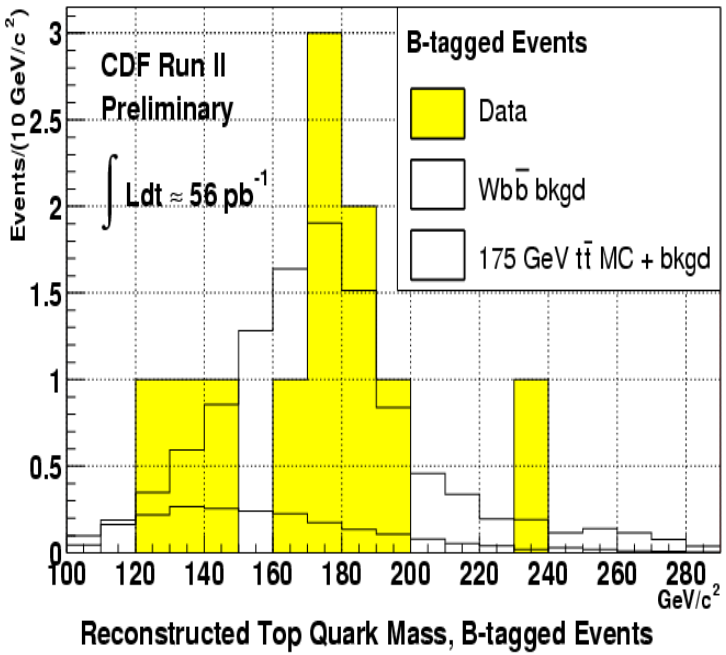
- Extract top quark mass using maximum likelihood

Top Mass from e/μ + jets channel

33 events without b-tagging required
≥ 4 jets with Et > 15 GeV
13 $t\bar{t}$ events plus 20 background events

11 events with a b-tag
3 jets Et > 15, 4th jet Et > 8 GeV)
9 $t\bar{t}$ events plus 2 background events





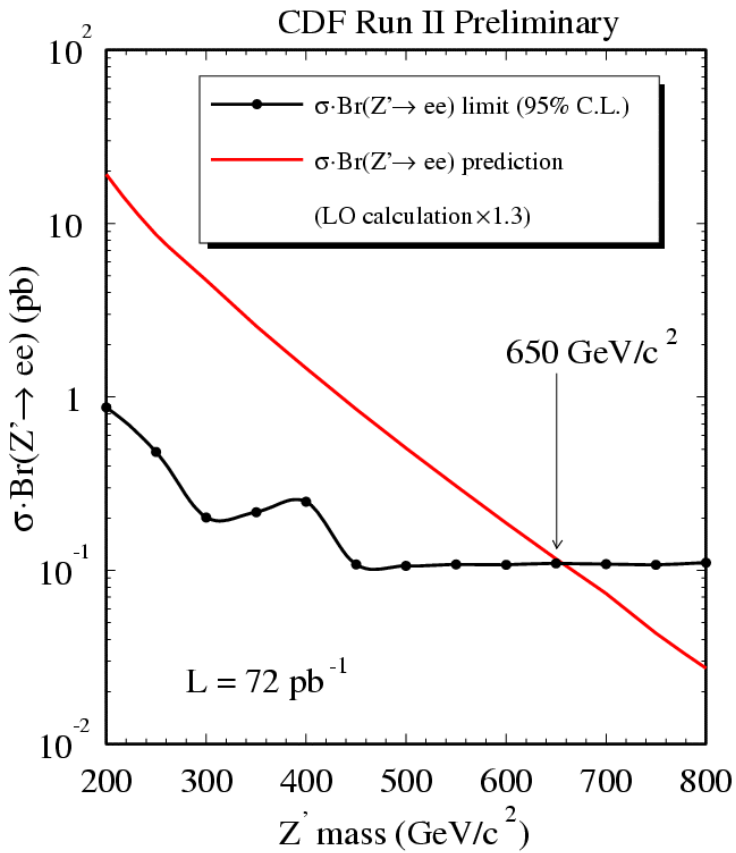
$M_{top} = 171.2^{+14.4}_{-12.5\ stat} \pm 9.9_{sys}$ GeV/c^2

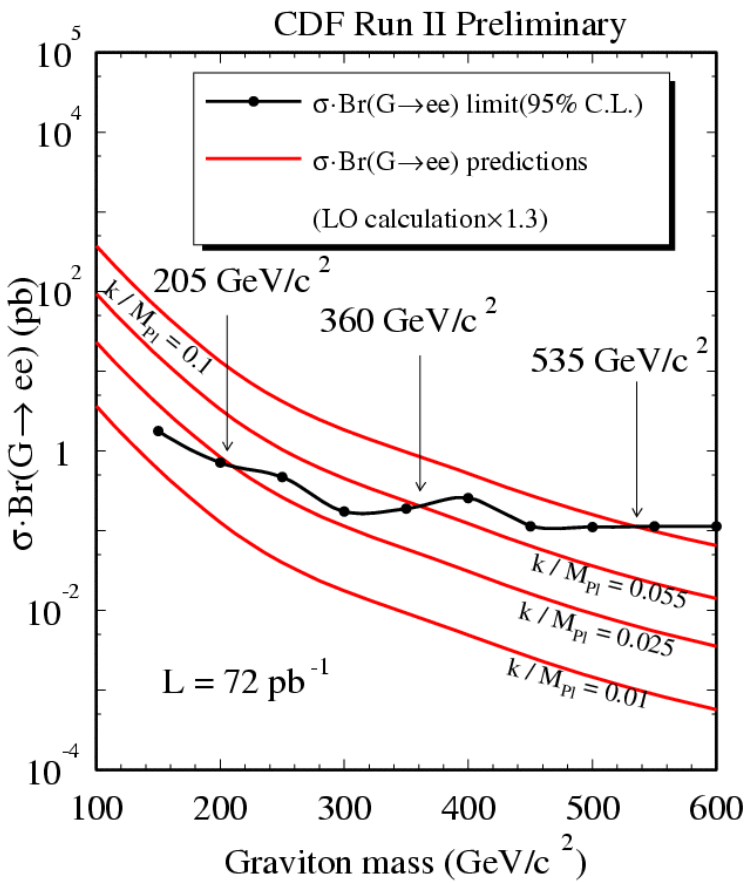
Without using B-tag info

New Phenomena Searches

- Z' and Randall Sundrum gravitons
- New Particle Searches with Dijets
- Charged massive particles
- Leptoquarks
- Doubly charged Higgs bosons

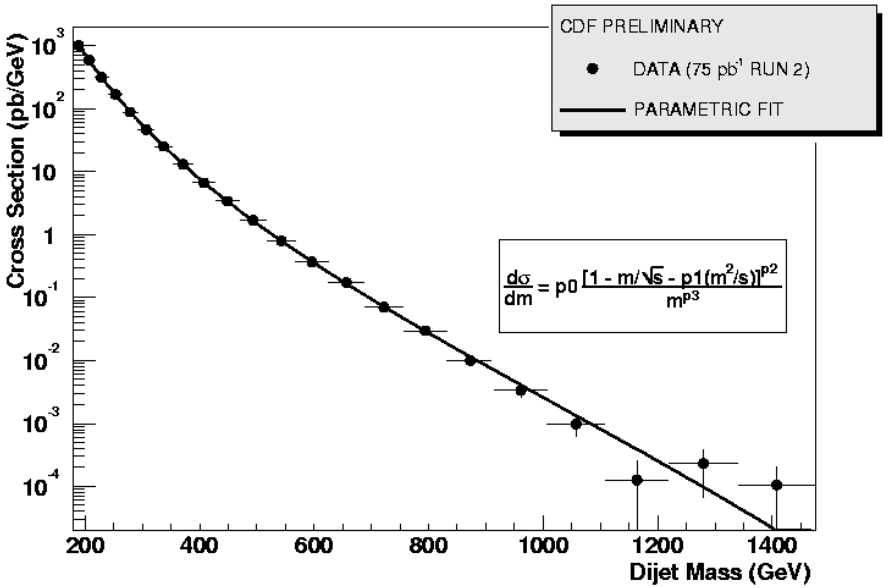
Z' and RS-Graviton Search

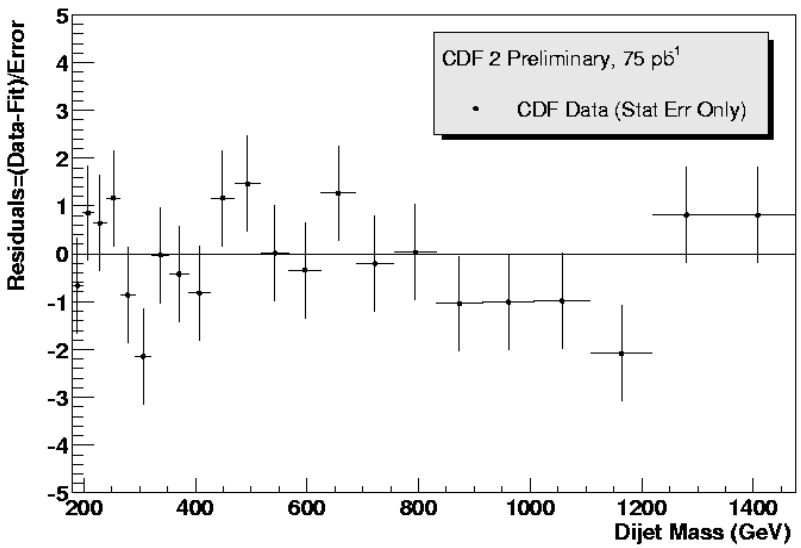


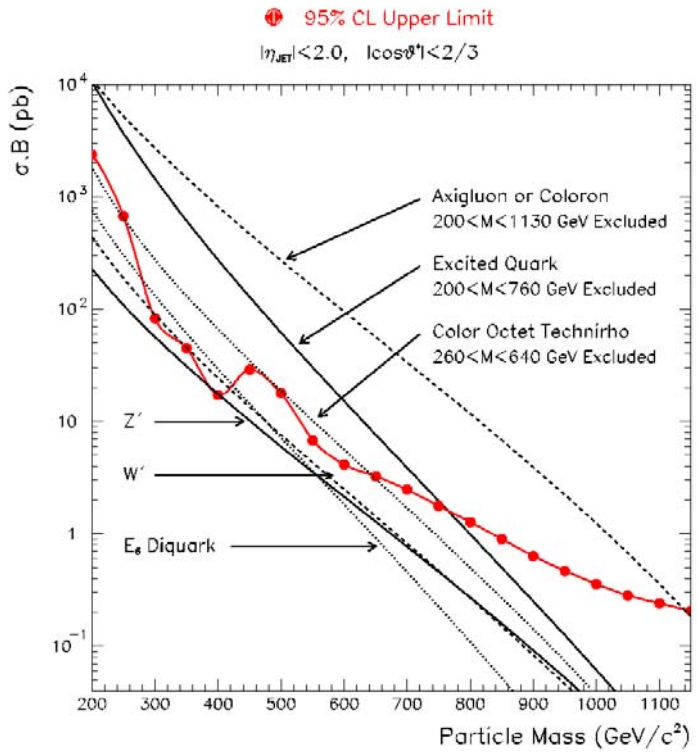


Run II 650 GeV/c² Run I 640 GeV/c²

Particle Searches with Di-jets



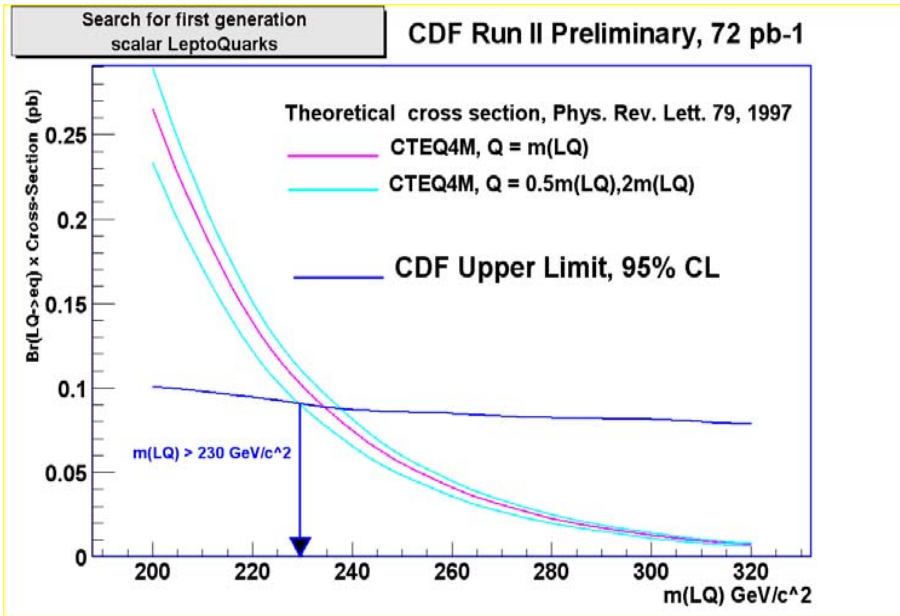




CDF Run II Preliminary

Lepto-quarks and Doubly Charged Higgs

Scalar LQ LQ ->
e e jet jet

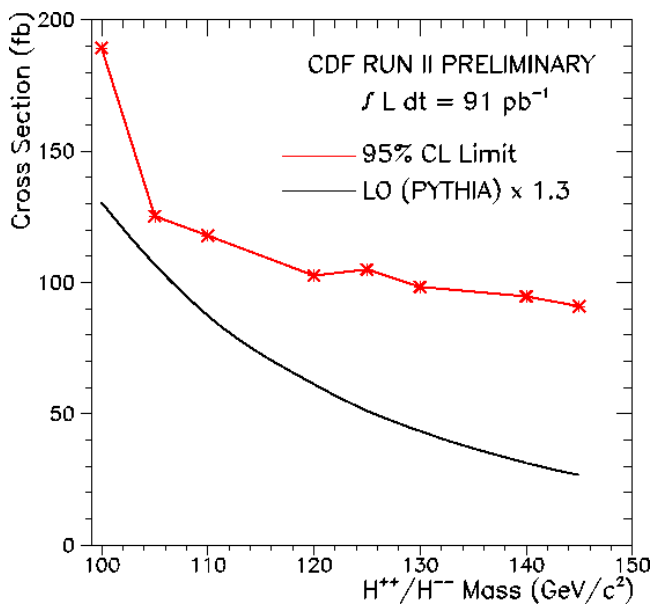


M(LQ) > 230 GeV/c^2 @ 95% CL

Run I > 220 GeV/c^2

0 events observed

$H^{++} \rightarrow e^+ e^+$

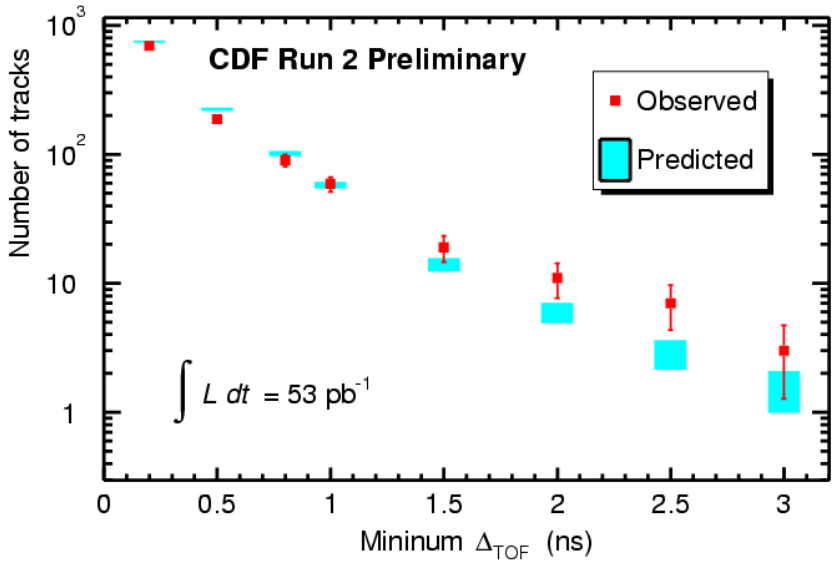


Same sign di-electrons

0 events observed

Background Z, dijet, W/Z+jet

CHArged Massive Particle Search

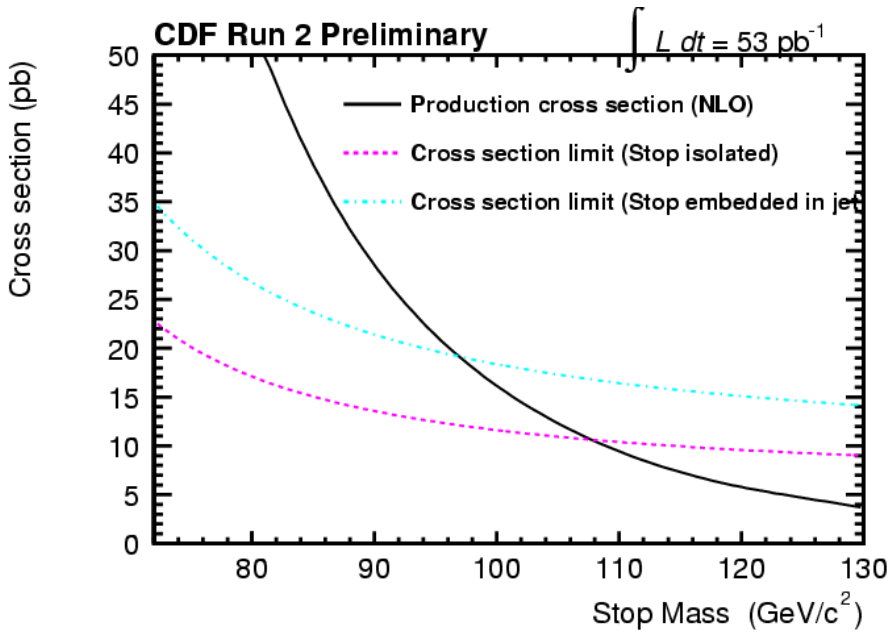


Long lived particles escape CDF

Isolated, slow moving, hi pt, muon-like

Use TOF and look for TOF-t_0

To set limits use stable stop model



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

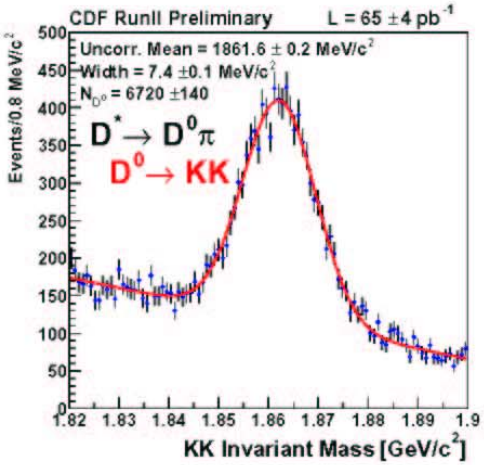
M(non-isolated stop)>96 GeV at 95% CL

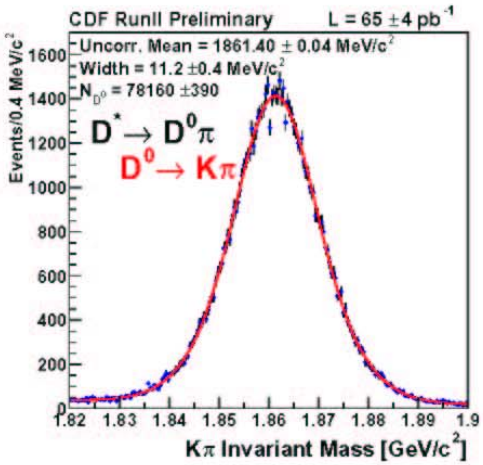
Heavy Flavor Physics

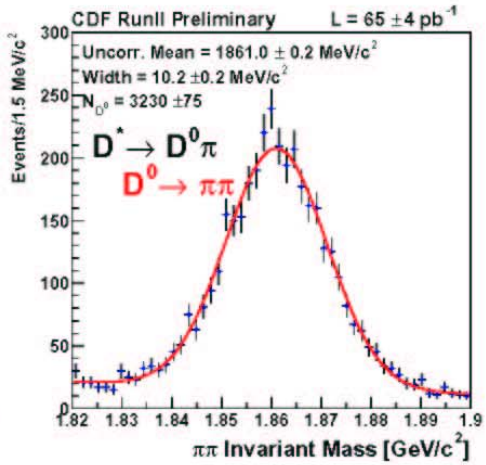
Silicon Vertex Trigger (SVT)!

- Charm
  - Branching Fractions
  - Rare Decays
  - D_s-D^+ mass difference (First Run 2 paper!)
  - Cross Section
- Bottom
  - Lifetimes
  - Exclusive Decays (masses, BFs,…)

Charm Physics

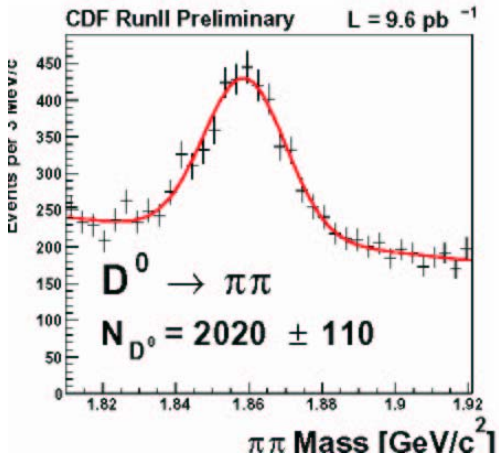




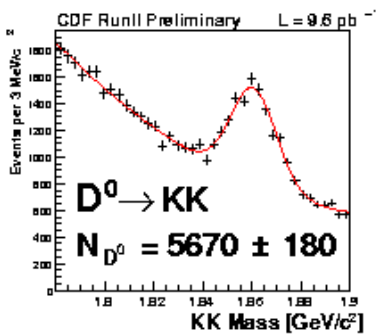


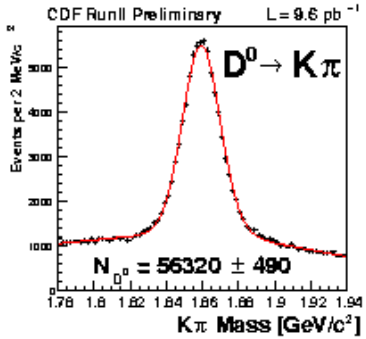
Datasets for

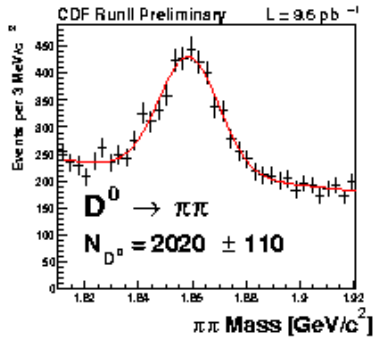
- Branching fractions
- Cross section
- Mixing
- CP



Cabibbo suppressed D^0 decays







☛ correct for relative trigger and reconstruction efficiency:

$$\frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K^-\pi^+)} = (11.17 \pm 0.48 \pm 0.98)\%$$

$$\frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = (3.37 \pm 0.20 \pm 0.16)\%$$

☛ comparable to 2002 PDG:

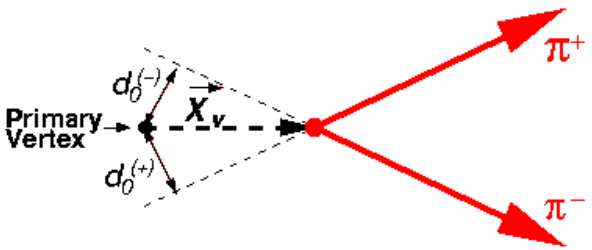
(used only 9.6 pb^{-1})

$$\frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K^-\pi^+)} = (10.40 \pm 0.33 \pm 0.27)\%$$

$$\frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = (3.51 \pm 0.16 \pm 0.17)\%$$

Search for FCNC decay $D^0 \to \mu^+ \mu^-$

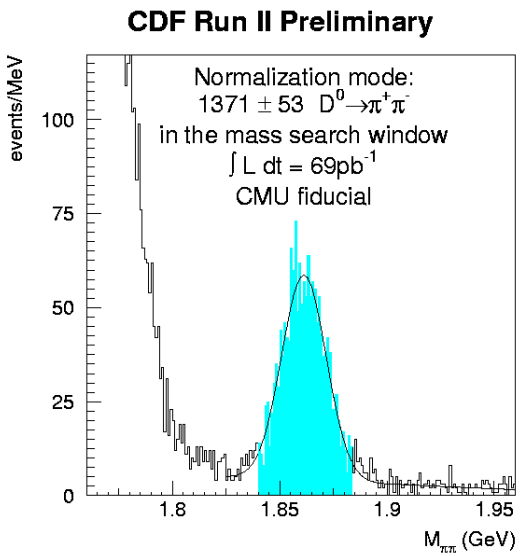
Select events using the SVT two-track-trigger



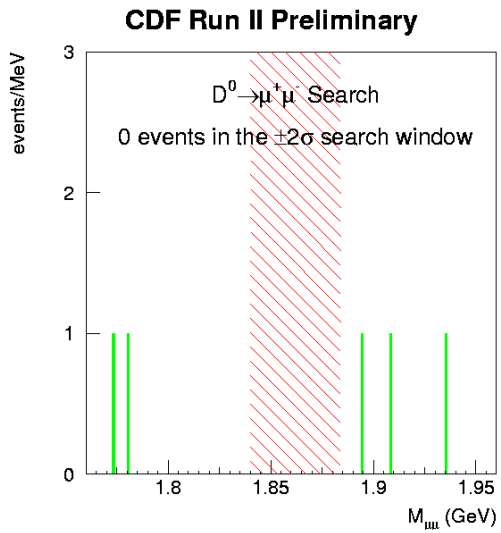
$P_t > 2$ GeV/c

$120\ \mu < |d_0| < 1$ mm

Normalization
$D^o \to \pi^+ \pi^-$



Blind search for
$D^o \to \mu^+ \mu^-$



SM prediction
$BR(D^o \to \mu^+ \mu^-) \sim 10^{-13}$
$\Rightarrow$ clean territory for new physics search

$BR(D^o \to \mu^+ \mu^-) < 3.1 \times 10^{-6}$ 95% CL
(factor of 2 below previous best limit)

First CDF Run II Publication Submitted

CDF/PHYS/BOTTOM/CDFR/6207
March 2, 2003 - Version 4.2 - Draft

Measurement of the Mass Difference $m(D_s^+) - m(D^+)$ at CDF II

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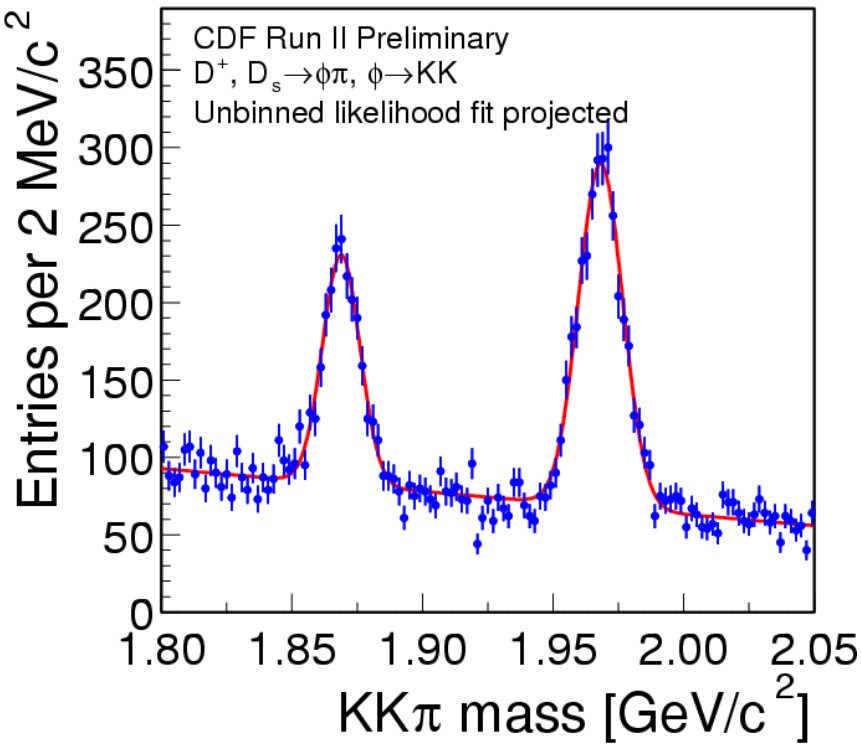
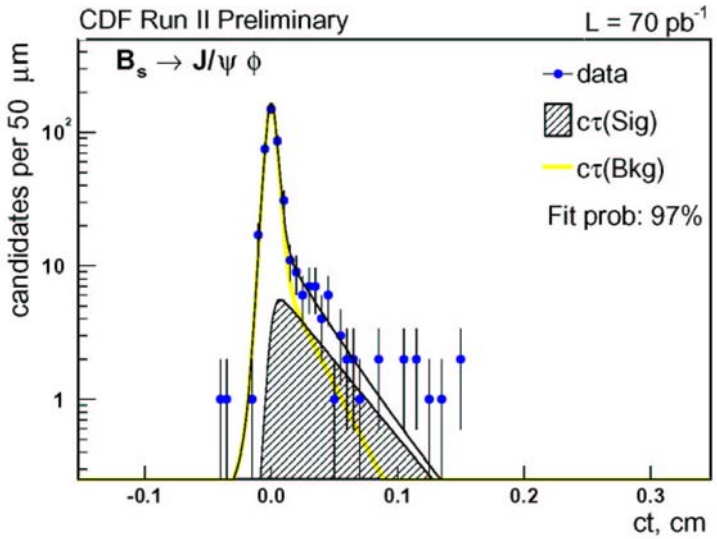
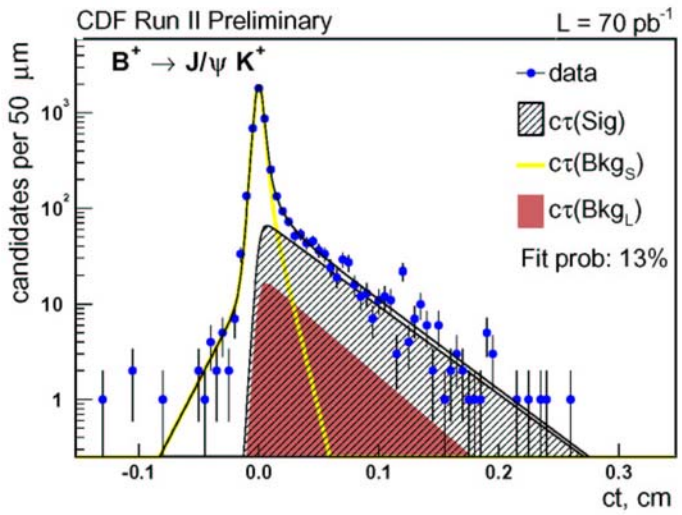
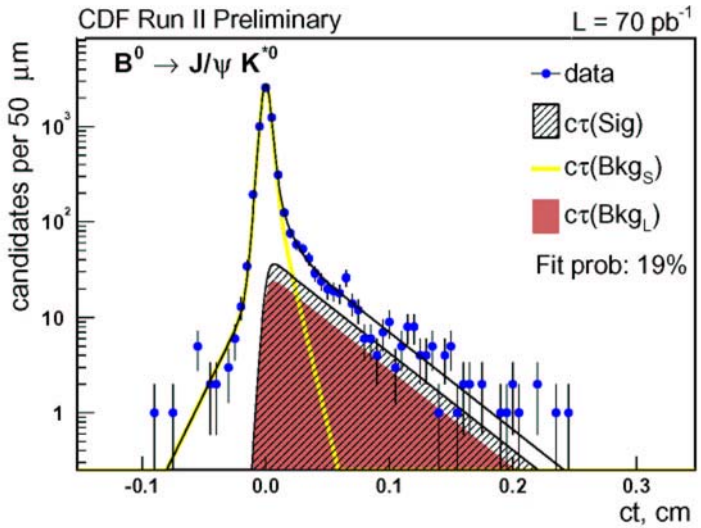


$M(D_s\text{-}D^+) = 99.28 \pm 0.43(stat) \pm 0.27(syst)$

B Lifetimes







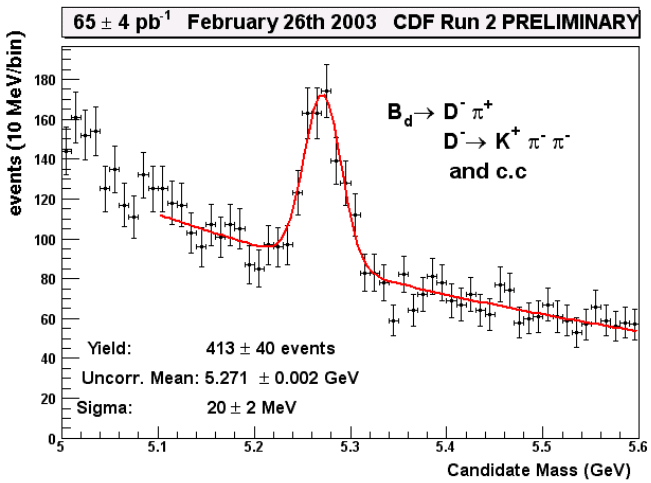
$\tau_{Bs} = 1.26 \pm 0.20_{stat} \pm 0.02_{sys}$ ps

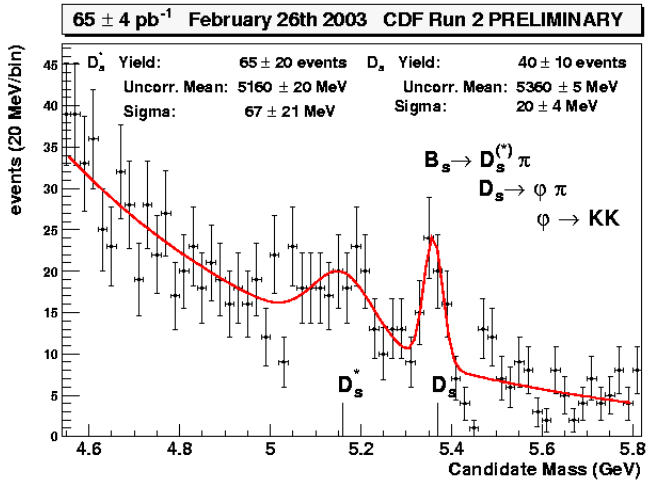
$\tau_{B+} = 1.57 \pm 0.07_{stat} \pm 0.02_{sys}$ ps

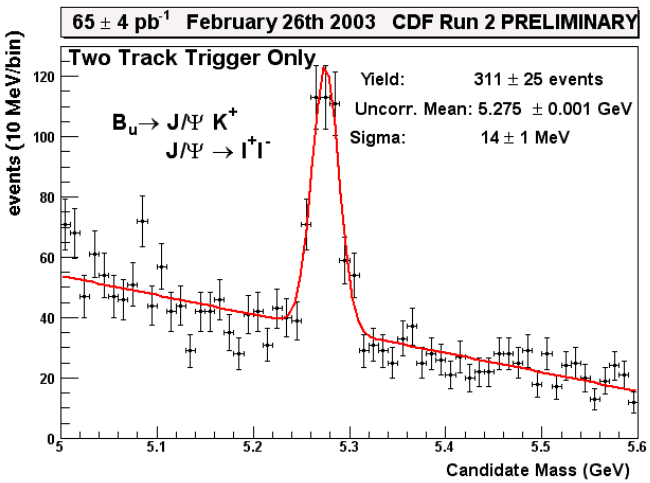
$\tau_{B0} = 1.42 \pm 0.09_{stat} \pm 0.02_{sys}$ ps

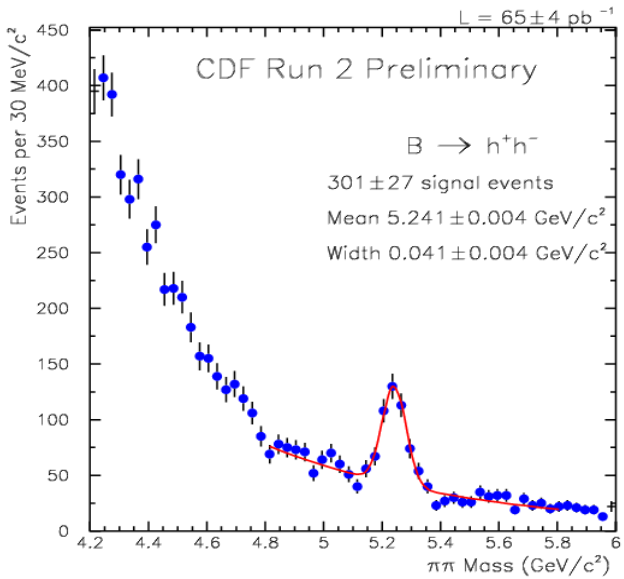
Systematics from alignment and knowledge of resolution function

Exclusive B meson decays





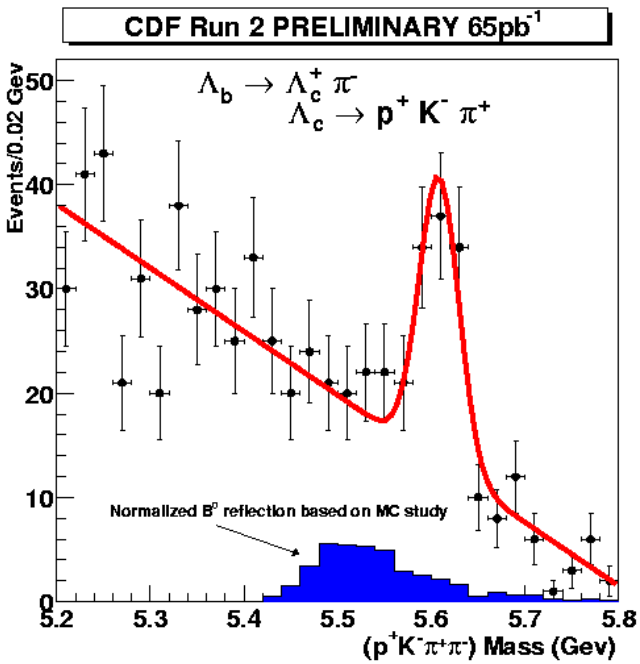


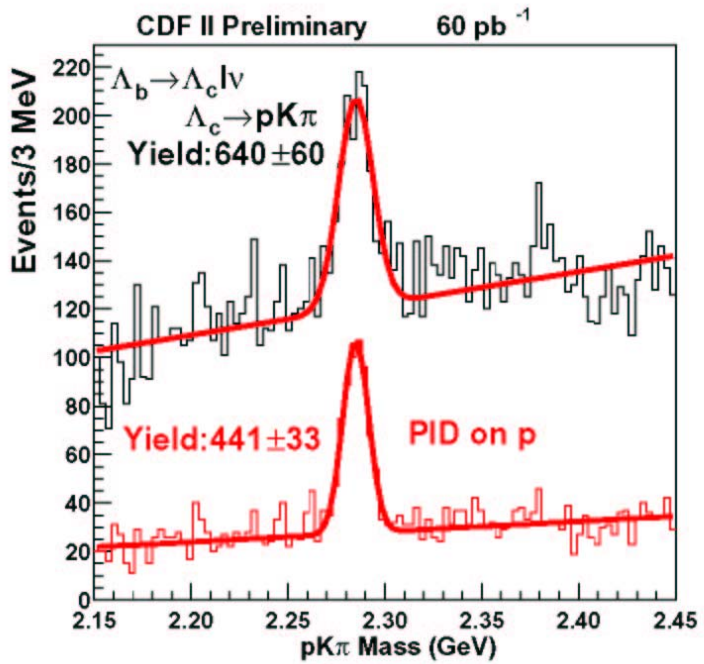


B baryon decays

$\Lambda_b \rightarrow \Lambda_c \pi^-$

$\Lambda_b \rightarrow \Lambda_c l \nu$





Short-term B physics Program

- Goals for 100-200 pb^{-1} (Lepton-Photon 2003)
  - High statistics charm physics: mixing, rare decays, search for CPV
  - B_d mixing, tagging studies and dilutions
  - B_s and Λ_b life times, masses and BR's
  - B open charm relative BR's
  - B_s -> $D_s\pi$ reconstruction, and estimate of B_s reach
  - Heavy flavor production cross sections
- Goals for several hundred pb^{-1}
  - First B_s mixing limit/measurement
  - CPV in Bd→J/Ψ K_s and Bs→J/Ψ ϕ
  - B_s and B baryon studies
  - Fully reconstructed B_c
  - B -> h h with particle ID and first look at CP asymmetry
  - Search for rare and forbidden B and C decays (e.g. B_s -> $\mu\,\mu$)

Summary

Summary

- The CDF detector is working very well
  - Lots of physics results coming out
- Early Run II measurements on track for publication
  - D_s – D^+ mass difference approved by collaboration
  - e+ e- forward-backward asymmetry under godparent review
  - W and Z cross sections, W width in advanced analysis stage
  - Basic jets shape, energy flow measurements ready soon
  - Worlds-best charm BR limits
- Many QCD and Electroweak measurements in progress
  - inclusive jets, di-jets
  - di-bosons: W W, W γ, Z γ
  - W properties from electron, muon and tau decays
- Top pair production at $\sqrt{s} = 1.96\ TeV$
  - Cross sections from dilepton and lepton +jets channels
  - First top mass measurement in Run II
  - Other top analyses in progress

Summary (2)

- Heavy flavor physics
  - Establishing a new charm physics program
  - Extensive B physics program
- New phenomena searches
  - Limits approaching or exceeding Run 1 sensitivity
  - Following up Run I anomalies

- Winter Conferences 2003
  - Presented results demonstrating the broad potential of the CDFII physics program.
- Summer Conferences 2003 (Lepton-Photon, etc.)
  - Look for many measurements that will supercede Run I results