



CDF Research Program

Ray Culbertson
FNAL

◆ Detector and Operations

◆ Physics Highlights

◆ Preparing for the Future

CDF Collaboration

North America

- ◆ 34 institutions,
- ◆ FNAL, ANL and LBNL

Europe

- ◆ 19 institutions

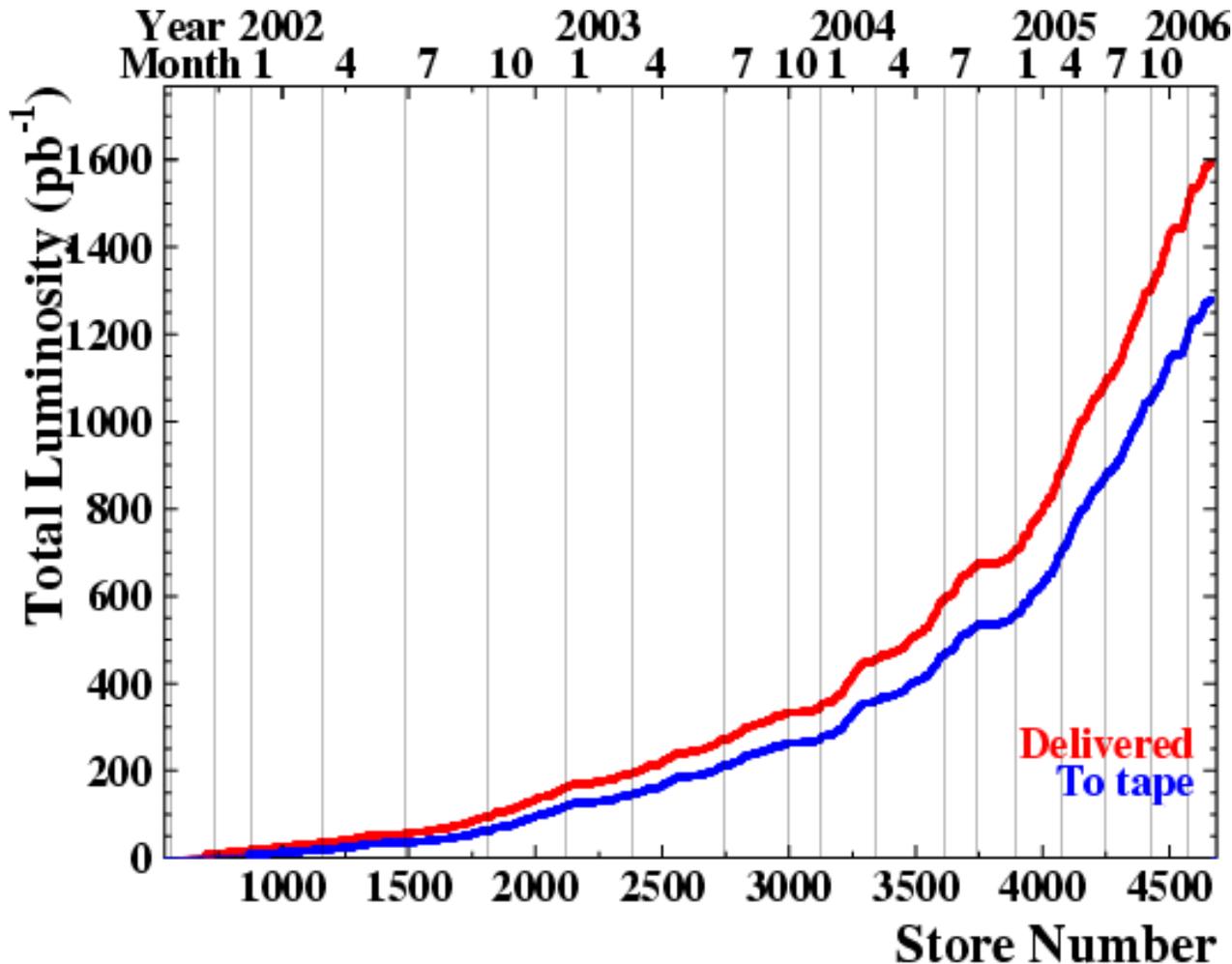
Asia

- ◆ 8 institutions

As the CDF Collaboration

- ◆ 12 Countries
- ◆ 61 institutions
- ◆ 620 authors

CDF Dataset

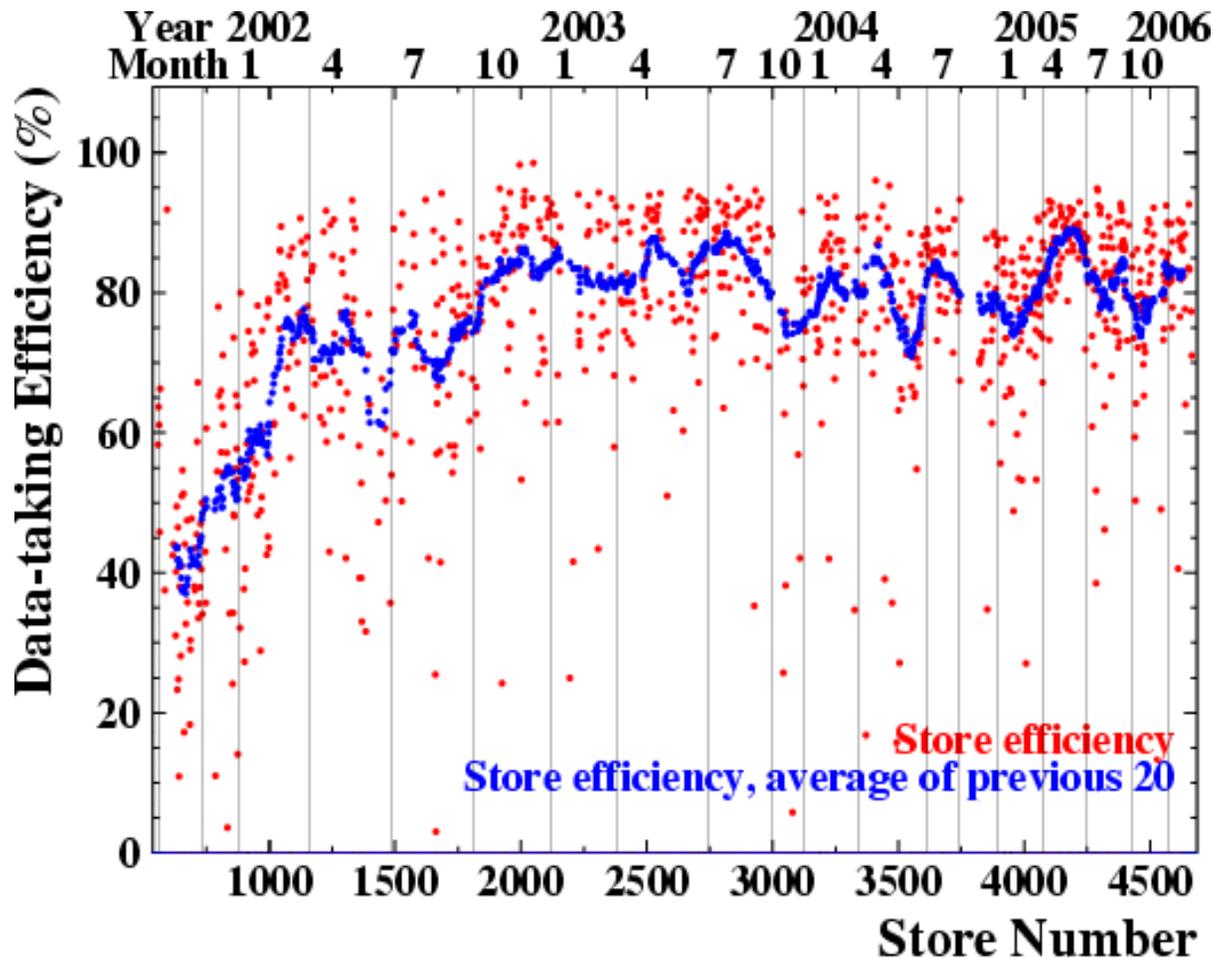


Data to this shutdown:

- ◆ $\sim 1.6 \text{ fb}^{-1}$ delivered
- ◆ $\sim 1.3 \text{ fb}^{-1}$ on tape
- ◆ the full dataset is reconstructed and available in common ntuples now

dataset has doubled each of the last 3 years

Data-taking Efficiency



Efficiency ~85% total

- ◆ 5% Trigger deadtime
- ◆ 5% beam conditions
- ◆ 5% other

Predominately stable running for years

Detector Upgrades

- ◆ Timing for EM calorimeter towers - *fully operational*
- ◆ Central preshower - *fully operational*
- ◆ Level 2 trigger - *fully operational*
- ◆ Central Tracker TDC's - *fully operational*
- ◆ Silicon Trigger - *fully operational*
- ◆ Event Builder - *fully operational*
- ◆ Level 3 computing upgrade - *fully operational*
- ◆ 3-D tracking in trigger - *hardware complete, commissioning*
- ◆ Higher-bandwidth Data Logger - *in progress*

Final configuration is essentially in place

CDF Computing

Data Processing- Reconstruction

- ◆ First pass for beamlines and calibration ntuples: ~few days
- ◆ 8 weeks for calibration and final production - will be even faster
- ◆ Can process 25M events per day (we take 8M max per day)
- ◆ Common ntuples now produced on the farms
- ◆ In the next year, will be merged with Analysis farms
- ◆ Final reconstruction software version almost finished

Data Processing - Analysis

- ◆ 8.2 THz available
 - 5.8 on-site (30% from non-FNAL funds)
 - 2.4 off-site (mostly for Monte Carlo)
- ◆ Scratch (ntuple) space: changing disk servers to persistent dCache

Reconstruction in good shape

Offline resources should be adequate

FNAL Group on CDF

- ◆ 64 FNAL authors
 - 42 from Particle Physics Division
 - 10 from Computing division
 - 7 from Technical Division
 - 5 from Accelerator Division
- ◆ This includes ~10 post-docs
- ◆ Many FNAL personnel contribute mostly technical expertise
- ◆ Many FNAL personnel have non-CDF obligations
- ◆ About 35 FTE on CDF (including all departments)
- ◆ About 30/65 contribute to CDF analysis

continued success in attracting great post-docs

FNAL Group on CDF - Budget

	FY 2005 (M\$)	FY 2006 (M\$)
SWF	2.4	3.0
M&S	0.15	0.25
Total	2.6	3.2

- ◆ SWF = direct costs for PPD scientists on CDF
- ◆ M&S = travel, office support, desktops
- ◆ FY06 bump due to merging CDF ops dept with CDF
- ◆ Expect CDF budget approximately constant after FY 2006

FNAL Group Leadership

Over the past 2 years, these authors have...

- ◆ held 13 leadership positions in analysis
- ◆ held ~30 leadership positions in online and offline operations

Including:

- current Operations Head (P. Lukens)
- incoming Operations Head (P. Wilson)
- incoming CDF Physics Coordinator (D. Glenzinski)
- CDF Spokesperson (R. Roser)

FNAL Operations Responsibilities

Line Responsibility- Operations

- ◆ CDF Safety - *no injuries since 10/2003*
- ◆ Flammable gases, cryogenics, solenoid, etc.
- ◆ All training related to collision hall access

Line Responsibility - Computing

- ◆ Long term data storage
- ◆ Offline software and re-processing

CDF MOU Responsibility for:

- ◆ Central Outer Tracker Chamber
- ◆ Silicon Vertex Detector
- ◆ Data Acquisition
- ◆ Level 2 Trigger

Physics Highlights

FNAL RA's

Physics

- ◆ Fermi group loosely organized in 4 analysis groups
- ◆ Incoming RA's have options for projects waiting for them
- ◆ All have mentors, and report regularly to FNAL physics meeting

Recent RA Track record

- AP Colijn (Faculty U. Amsterdam)
- M. Martinez (Faculty U. Barcelona)
- M. Bishai (BNL - hired with tenure)
- T. Nelson (SLAC - hired with tenure)
- R. Erbacher (Faculty UC Davis) *recent OJI recipient!*
- P. Merkel (Res. Sci. Purdue U.)
- J. Thom (Faculty Cornell)

Fermilab RA's do physics and succeed

CDF Physics Publications

Physics Publications

- ◆ 2003 : 3
- ◆ 2004 : 4
- ◆ 2005 : 36
- ◆ 2006 : 4 so far,
(on track for 30-40)

Plus:

- ◆ 9 accepted
- ◆ 18 submitted
- ◆ 16 drafts under review

*Fermilab group has
been very active,
counted as authors on
~30% of these papers.*

And 31 NIM papers...

CDF Physics Bests and Firsts

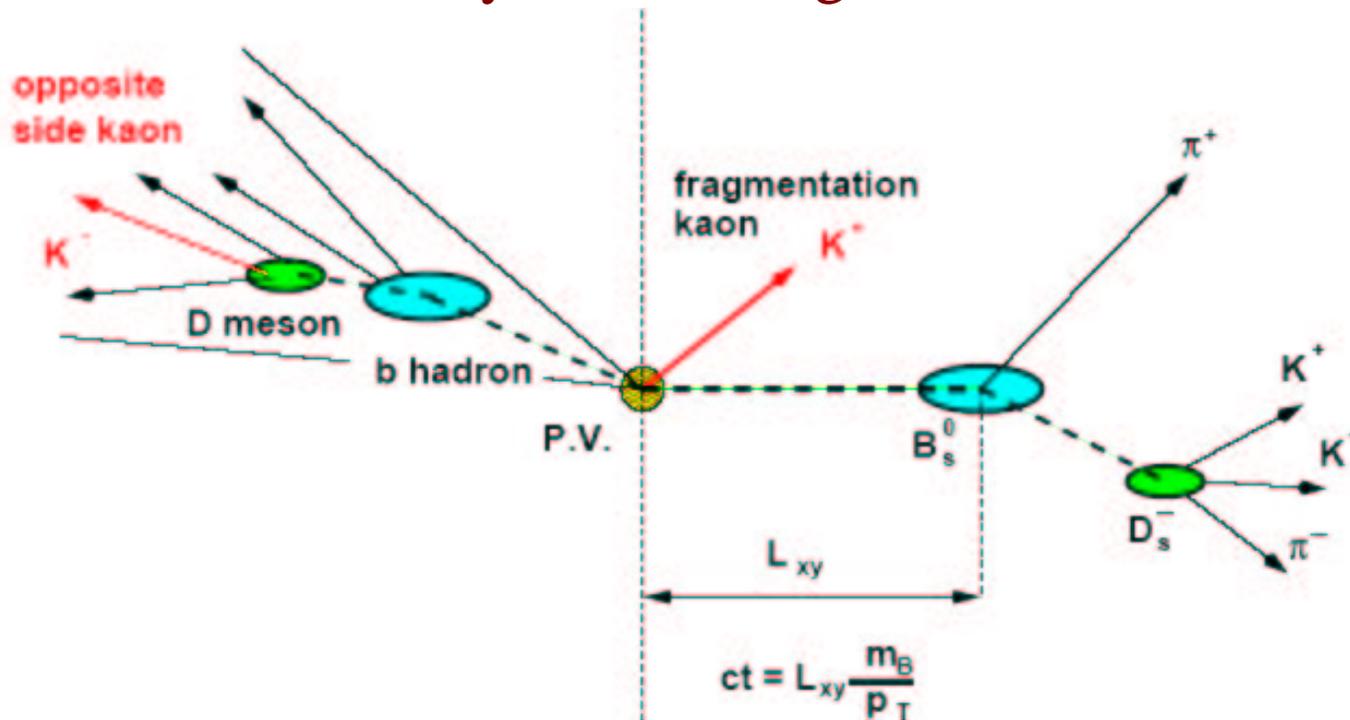
A partial list of things CDF has done first or best

- ◆ Best top mass
- ◆ Best top cross section
- ◆ Best limits on single top
- ◆ Best limits on $t \rightarrow H^+$
- ◆ Best B_s mixing measurement
- ◆ First $B_c \rightarrow J/\Psi\pi$
- ◆ Best B_c lifetime
- ◆ Best B cross section
- ◆ First lifetime for $X(3872)$
- ◆ Best $p\bar{p} \rightarrow D$ cross section
- ◆ Best limits on some Z'
- ◆ Best direct limit on W'
- ◆ Best Leptoquark $\rightarrow \tau$ limits
- ◆ Best limits on squark and gluino
- ◆ First Z' search in di- τ channel
- ◆ Best $W\gamma$ and $Z\gamma$ cross sections
- ◆ Best WW cross section
- ◆ Best W width and asymmetry
- ◆ Highest-Et b-jet cross section
- ◆ First obs. of exclusive e^+e^- and $\gamma\gamma$

Overall, 72 best's and first's so far!!

Measurement of Bs Oscillations

- ◆ $B_s \leftrightarrow \bar{B}_s$
- ◆ crucial test of unitarity CKM triangle closure



- ◆ infer production flavor from opposite and same-sign tags
- ◆ measure proper time of decay
- ◆ determine decay flavor from decay products

Bs Oscillations - Sample

Hadronic Sample

- ◆ From SVT Trigger:

$$B_s \rightarrow D_s \pi, D_s 3\pi$$

$$D_s \rightarrow \phi \pi, K^* K, 3\pi$$

- ◆ Most important for high frequency

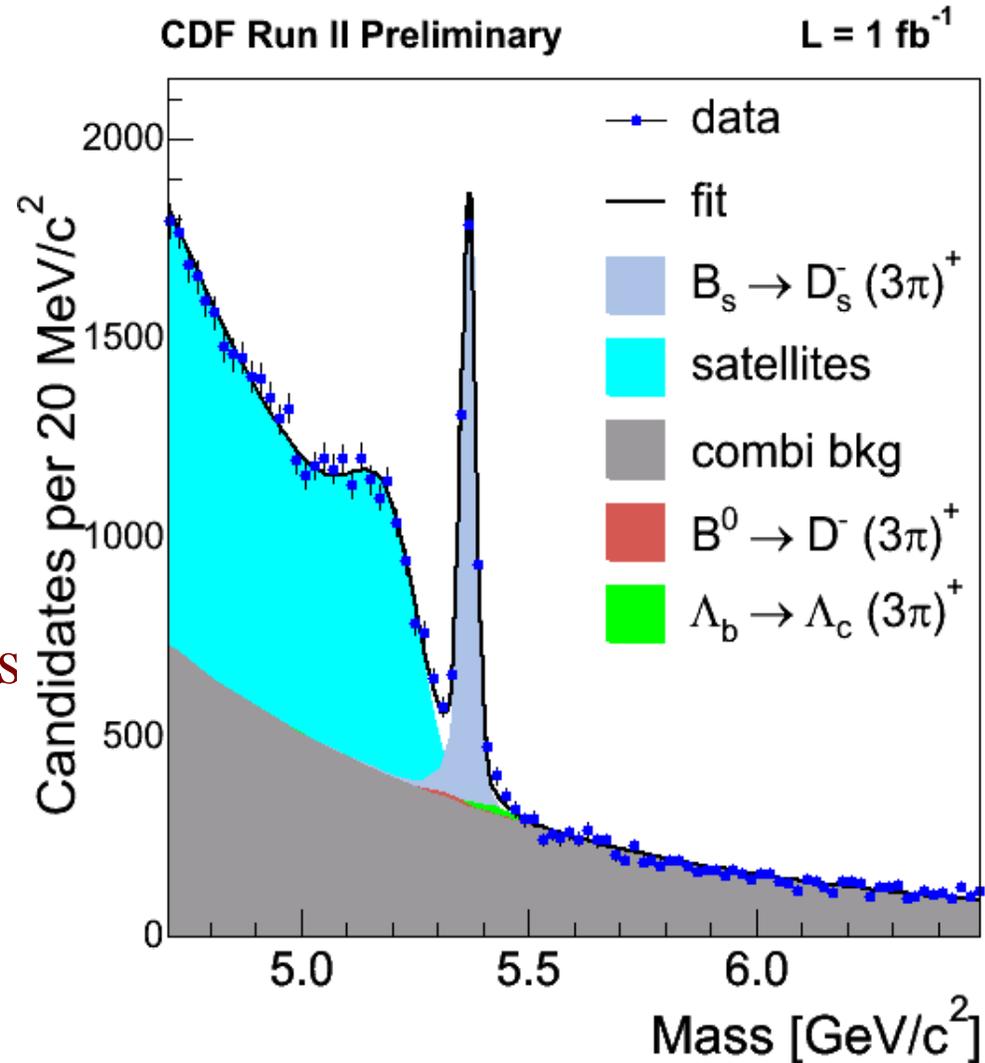
Semileptonic Sample

- ◆ From lepton+SVT triggers

$$B_s \rightarrow D_s \mu \nu, D_s e \nu$$

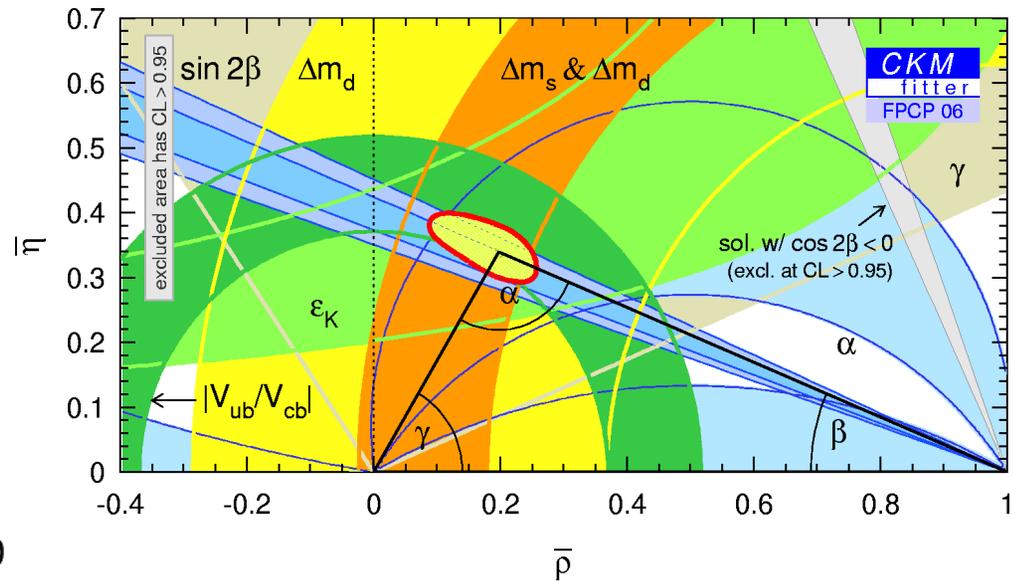
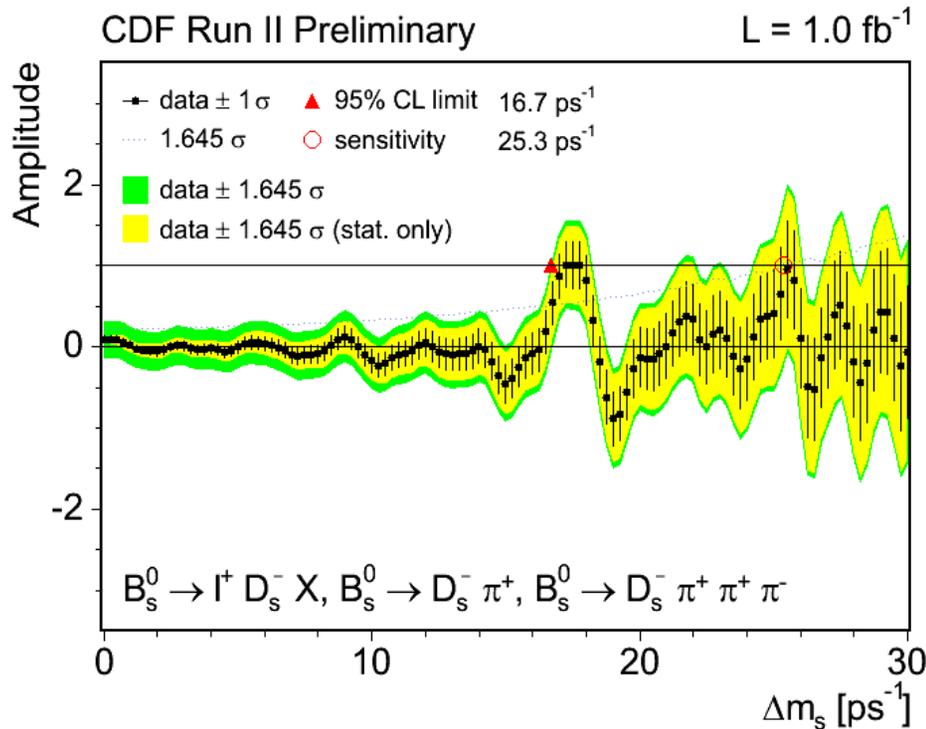
$$D_s \rightarrow \phi \pi, K^* K, 3\pi$$

- ◆ Correct for neutrino p_T
- ◆ Higher stats, lower proper time resolution



Bs Oscillations - Results

- ◆ Scan each frequency, fit for amplitude
- ◆ Probability of a fluctuation: 0.5%

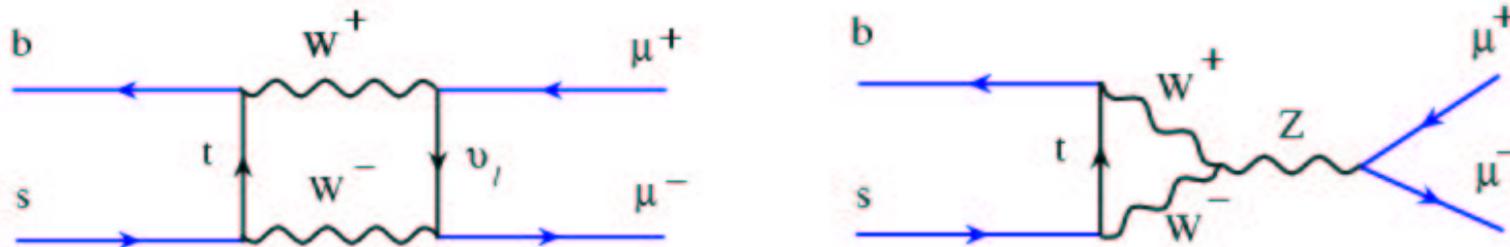


$$\Delta M_S = 17.33^{+0.42}_{-0.21} \text{ (stat)} \pm 0.07 \text{ (sys)}$$

$$|V_{td}|/|V_{ts}| = 0.208^{+0.001}_{-0.003} \text{ (stat and sys)}^{+0.008}_{-0.006} \text{ (theory)}$$

Search for $B_{s,d} \rightarrow \mu^+ \mu^-$ (C. Lin, D. Glenzinski, *et al.*)

- ◆ In the Standard model, FCNC $B \rightarrow \mu\mu$ is heavily suppressed



- ◆ Branching ratio = $3.9 \pm 0.9 \times 10^{-9}$ in the SM
- ◆ And will be enhanced if there is new physics:



Search for $B_{s,d} \rightarrow \mu^+ \mu^-$

(C. Lin, D. Glenzinski, *et al.*)

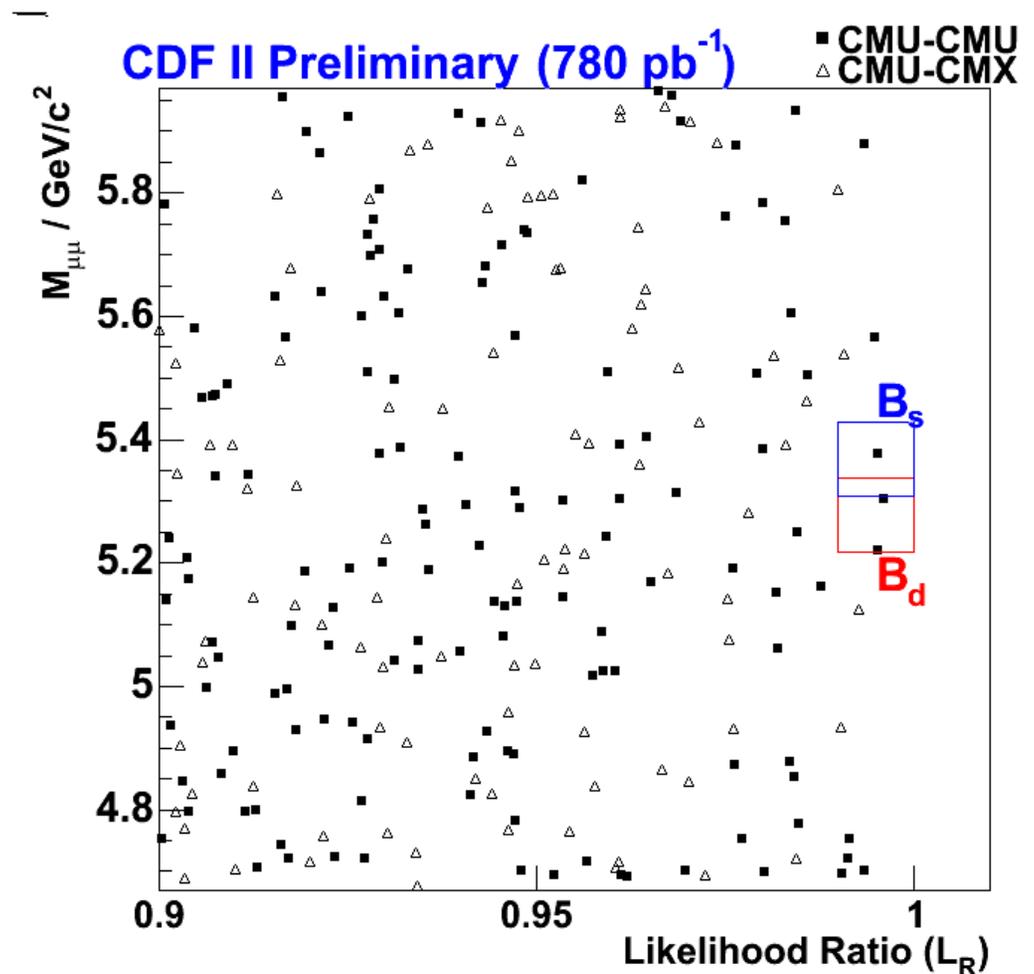
Results

◆ Consistent with background from combinatorics and $B \rightarrow hh$

Limits

- ◆ $BR(B_d \rightarrow \mu\mu) < 1.0 \times 10^{-7}$
- ◆ $BR(B_s \rightarrow \mu\mu) < 3.0 \times 10^{-8}$
- ◆ Some SO10 models excluded, MSSM high- $\tan\beta$ parameter space limited

World's best limit



- ◆ Likelihood formed from lifetime, pointback, isolation

$B_s \rightarrow \Psi(2s)\phi$

(T. Liu, *et al.*)

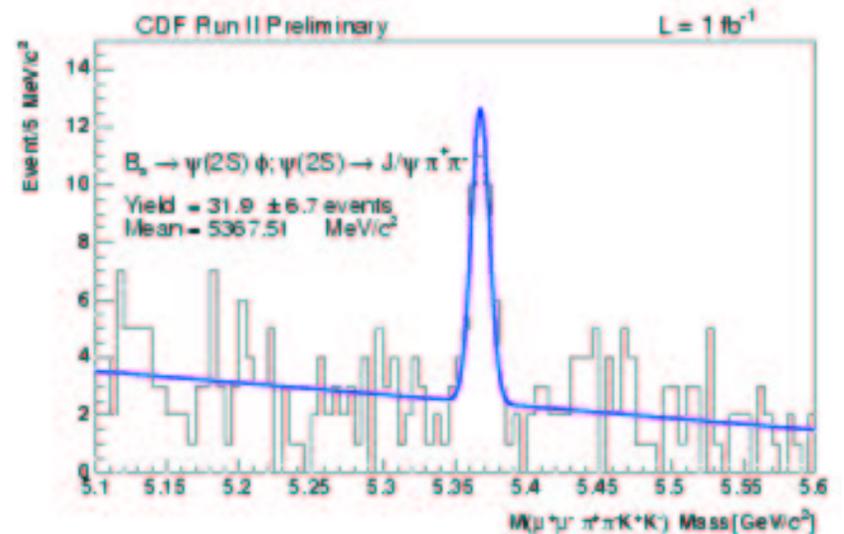
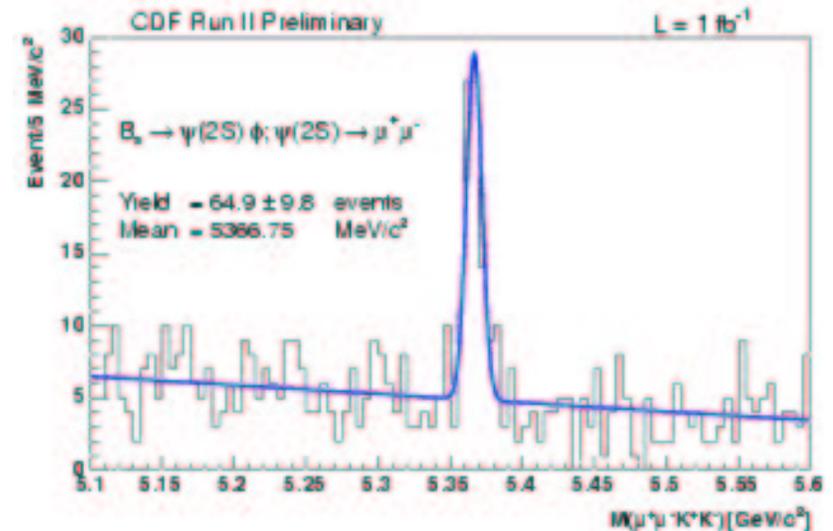
Sample

- ◆ $\Psi(2s) \rightarrow \mu\mu$
- ◆ $\Psi(2s) \rightarrow J/\Psi\pi\pi$
- ◆ Require high-pt,
displaced vertex

BR

- ◆ $B_s \rightarrow \Psi(2s)\phi / B_s \rightarrow J/\Psi\phi = 0.52 \pm 0.13_{\text{stat}} \pm 0.06_{\text{BR}} \pm 0.04_{\text{sys}}$
- ◆ Similar to other $\Psi(2s) / J/\Psi$

World's first observation



B_c Mass

(W. Wester, P. Lukens, S. Tkaczyk)

Sample

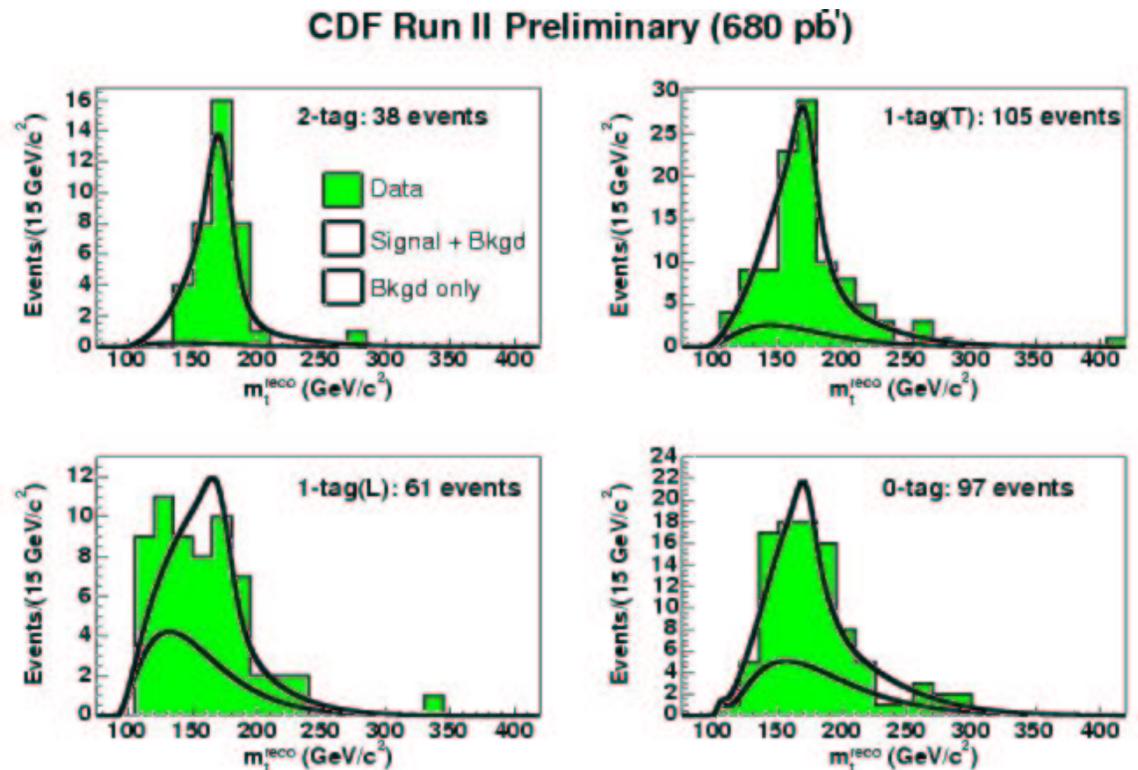
- ◆ J/Ψπ mode
- ◆ 38.9 signal over
26.1 background, > 6σ
- ◆ Mass:
6275.2 ±4.3 ±2.3 MeV
- ◆ Reasonable agreement with
recent lattice calculations

World's best measurement

Top Quark Mass

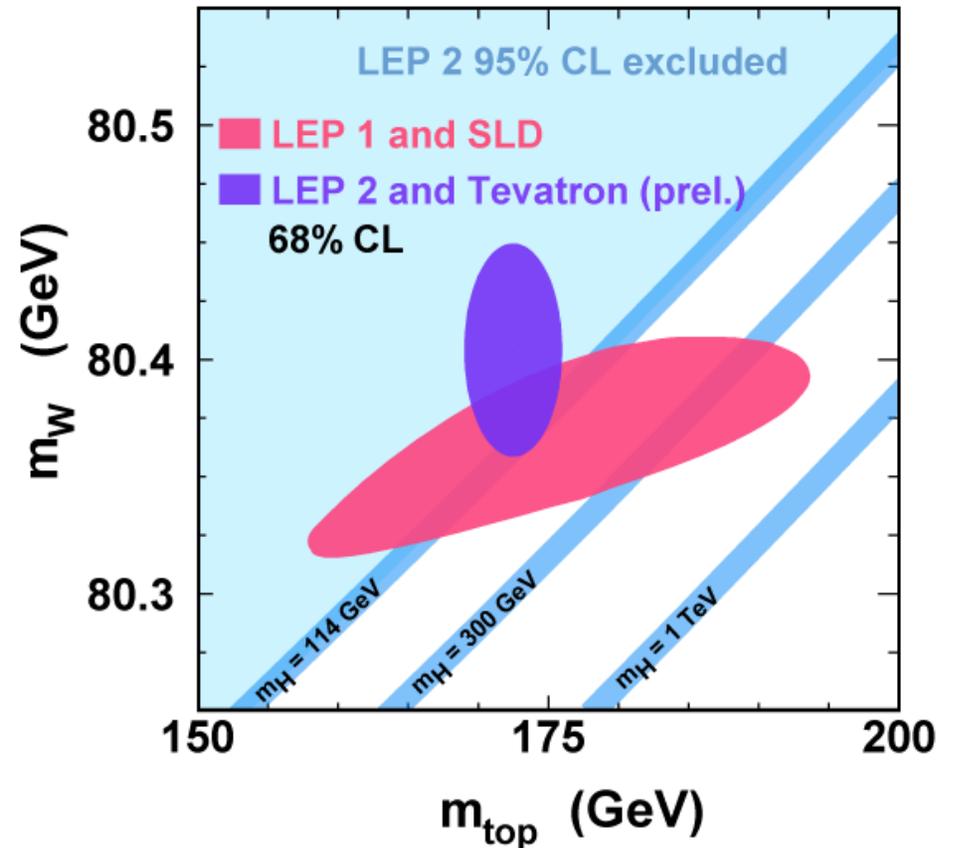
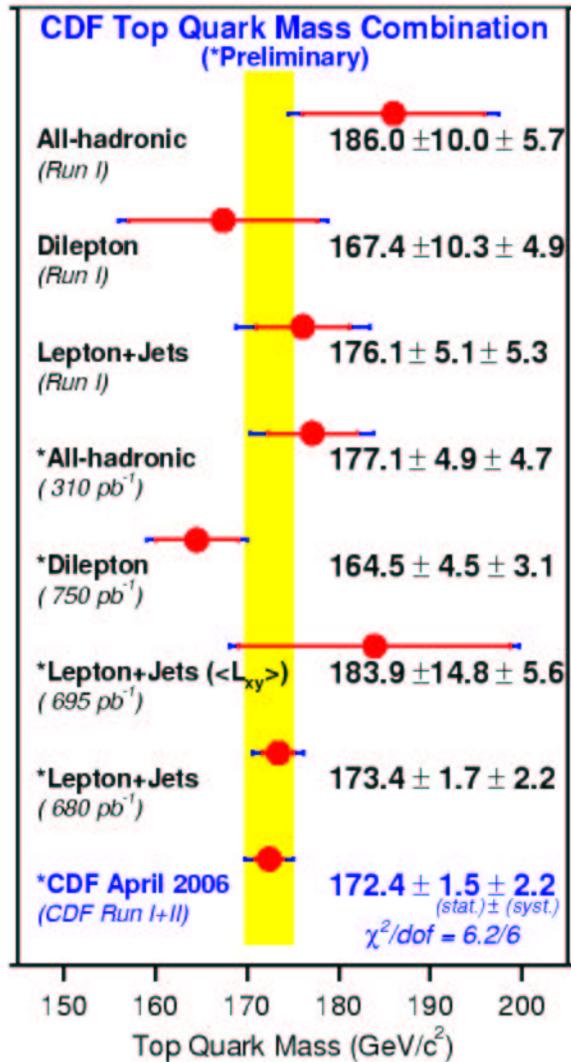
(D. Ambrose, G. Chlachidze,
A. Beretvas D. Glenzinski, G. Velez, *et al.*)

- ◆ $t\bar{t} \rightarrow WbWb$,
each $W \rightarrow jj$ or lv
- ◆ Best measurement from
lepton plus jets
- ◆ Leading systematic is
jet energy scale, which is
now set by the $W \rightarrow jj$
peak in the top events!



- ◆ Break down data by sub-samples,
different signal/noise

Top Quark Mass

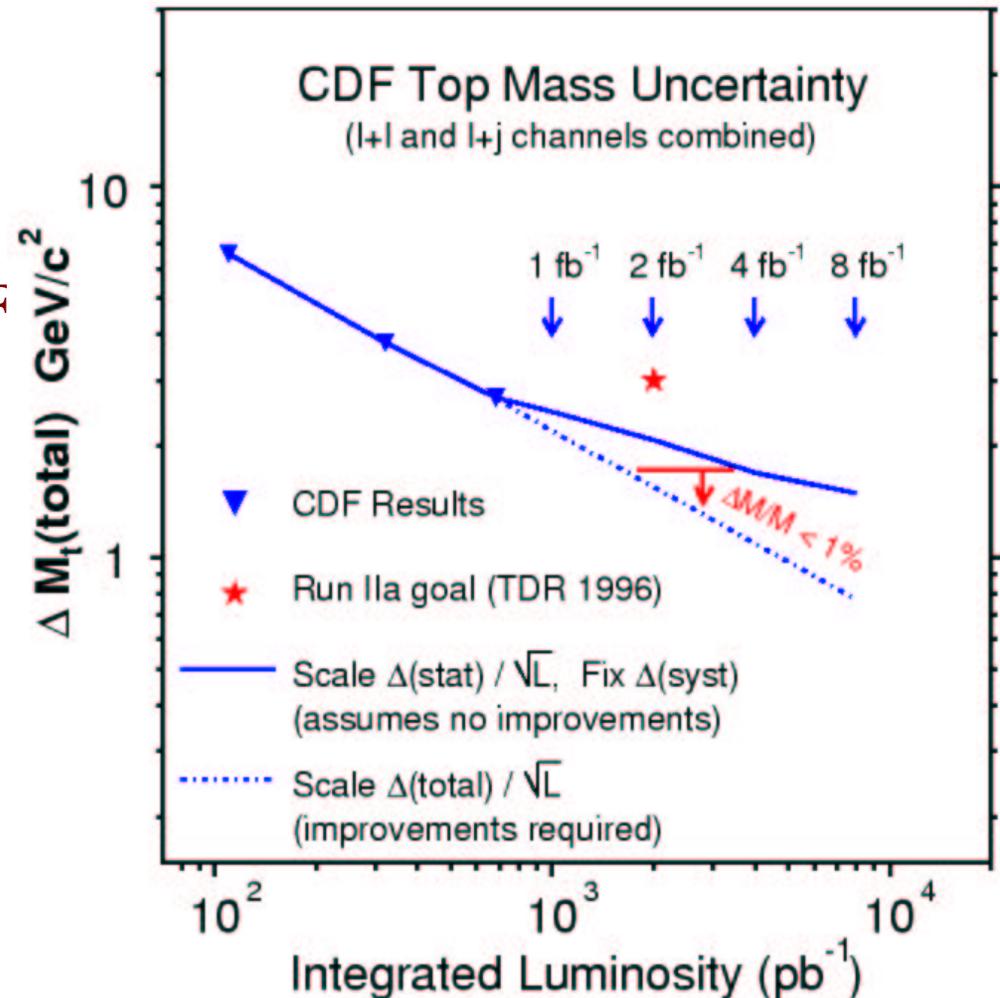


- ◆ Higgs constraint implies lighter-where we are more sensitive!

World's best measurements

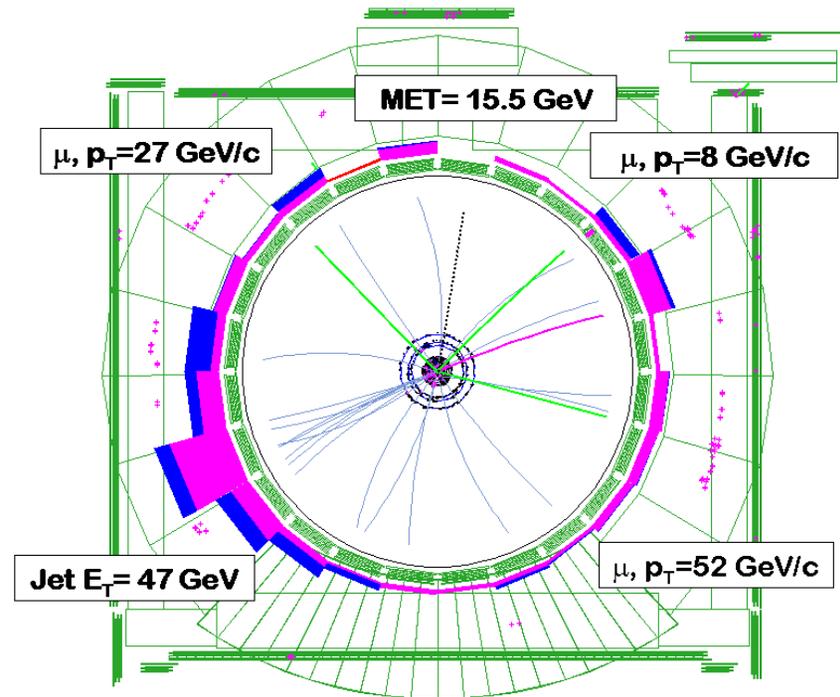
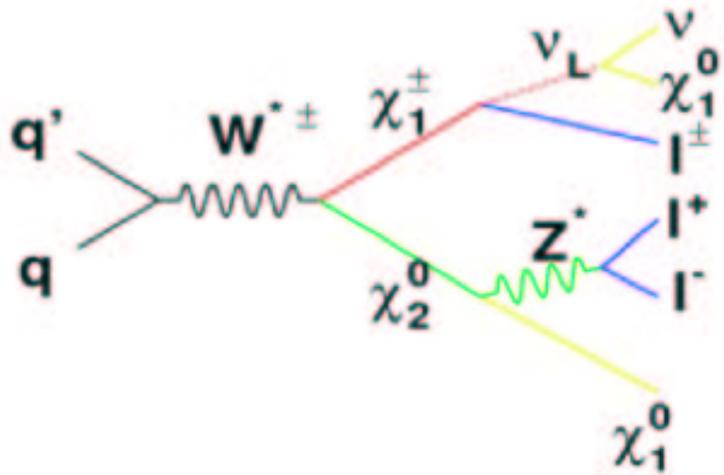
Top Quark Mass - Future

- ◆ Expect to end up with CDF $\sigma = 1.5 \text{ GeV}$ ($\sim 1\%$) by the end of Run II



Already exceeded pre-Run II projections!

Search for SUSY Trileptons



- ◆ Final state is 3 leptons and missing E_t
- ◆ This is $\mu+2$ leptons, also search
 - 2 like-sign leptons
 - ee +track (tau)

Process	$\mu\mu$ Channel	μ +CEM e Channel	μ + <i>Plug</i> - e Channel
DY+ γ	0.22 ± 0.11	0.10 ± 0.04	0.04 ± 0.04
WW-WZ γ^* -W γ	0.20 ± 0.02	0.19 ± 0.02	0.25 ± 0.03
$t\bar{t}$	0.014 ± 0.006	0.009 ± 0.005	0.007 ± 0.004
DY+fake leptons	0.20 ± 0.10	0.11 ± 0.55	0.06 ± 0.03
Total background	$0.64 \pm 0.11 \pm 0.14$	$0.42 \pm 0.05 \pm 0.08$	$0.36 \pm 0.05 \pm 0.07$
SUSY signal	$1.6 \pm 0.1 \pm 0.2$	$0.83 \pm 0.06 \pm 0.10$	$0.20 \pm 0.02 \pm 0.02$

Search for LED

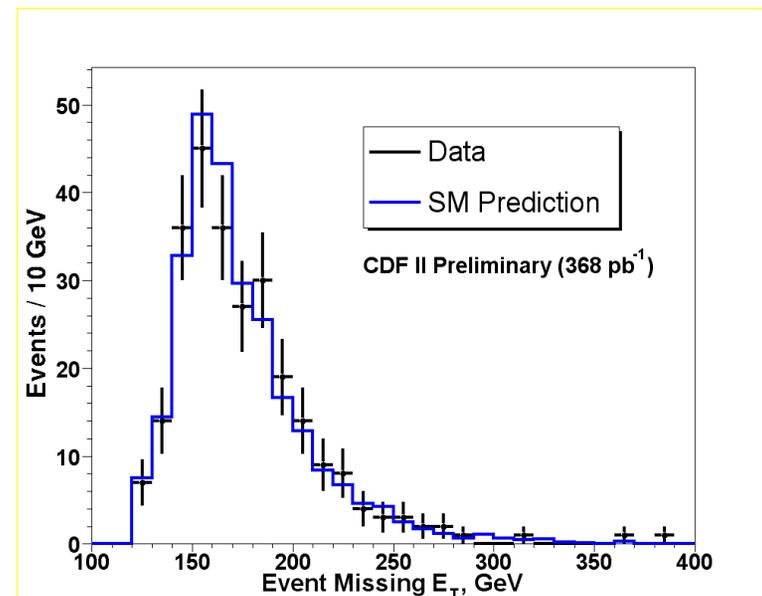
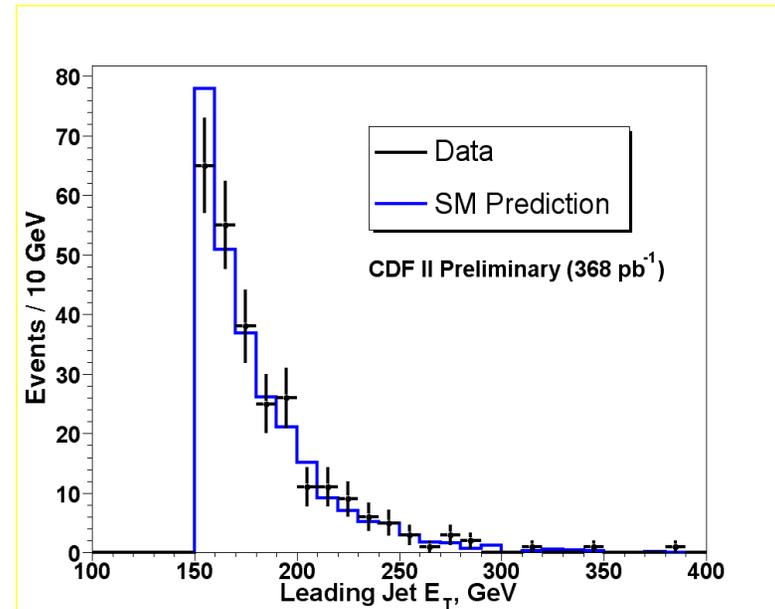
(K. Burkett, E. James, A. Yagil, *et al.*)

Large Extra Dimensions

- ◆ ADD Model: produce graviton + one jet
- ◆ graviton escapes into another dimension (MET)

Analysis

- ◆ cleanup of mismeasurements and cosmic ray interactions is important
- ◆ Remove $W \rightarrow lv$
- ◆ Require :
 - one jet, $E_T > 150 \text{ GeV}$
 - no other jets
 - $\text{MET} > 120 \text{ GeV}$

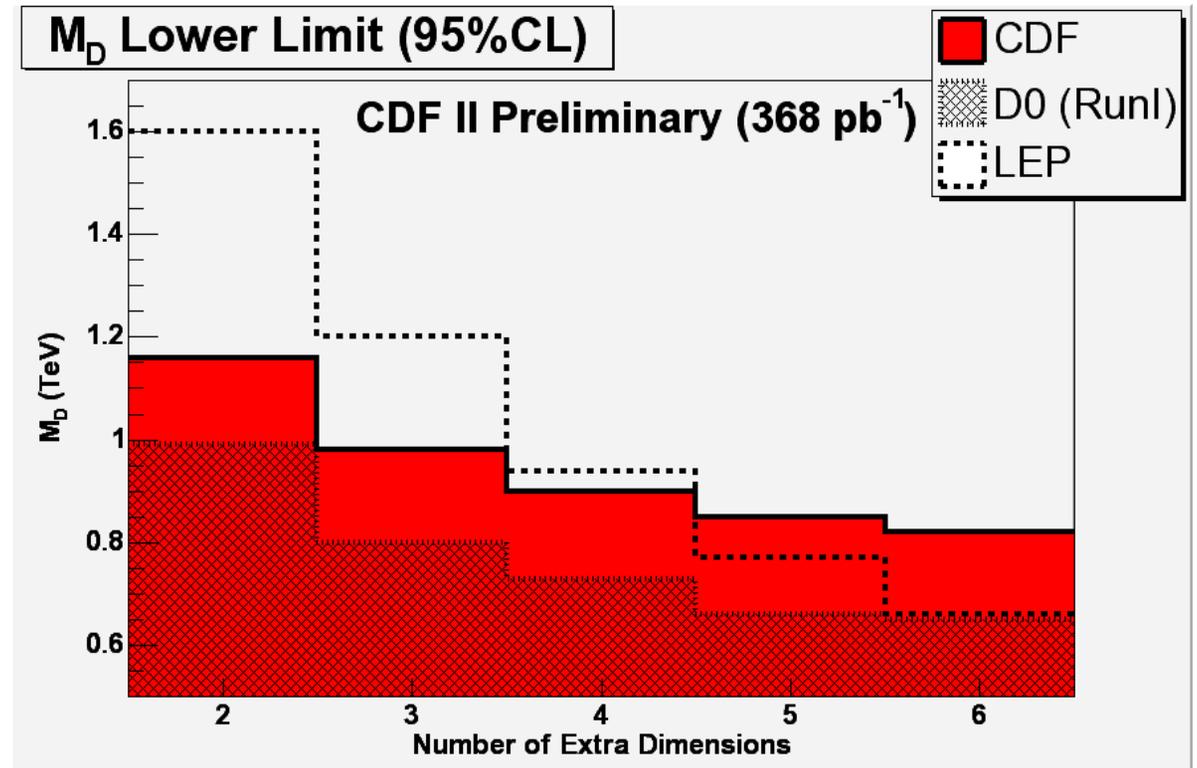


Search for LED

(K. Burkett, E. James, A. Yagil, *et al.*)

Limits

- ◆ K-factor = 1.3
- ◆ Limits depend on the number of large extra dimensions
- ◆ Effective Planck mass scale > 0.83 to 1.16 TeV



Comparison to LEP and D0

Search for $\gamma\gamma+X$

Signature-based

- ◆ No model examined (though several models can appear in this final state)
- ◆ Spend time on data!

Base Sample

- ◆ 2 central photons
- ◆ $E_T > 13$ GeV

X = third photon

- ◆ 1 fb^{-1}
- ◆ Backgrounds:

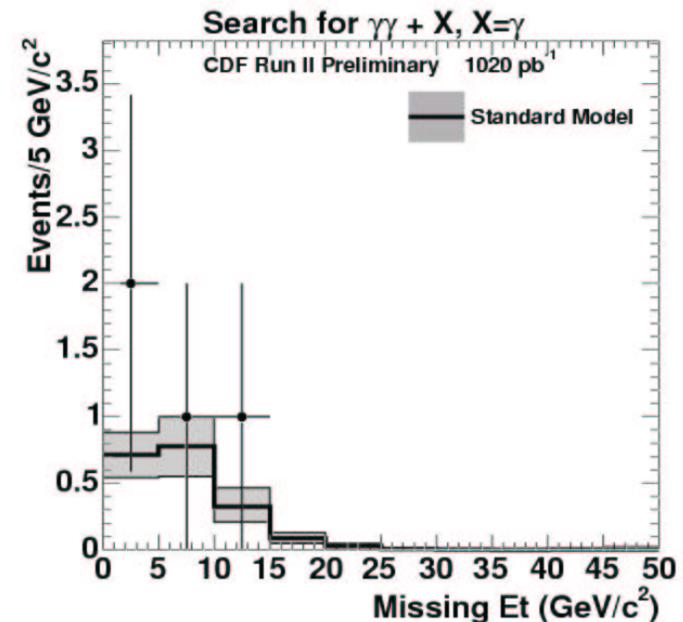
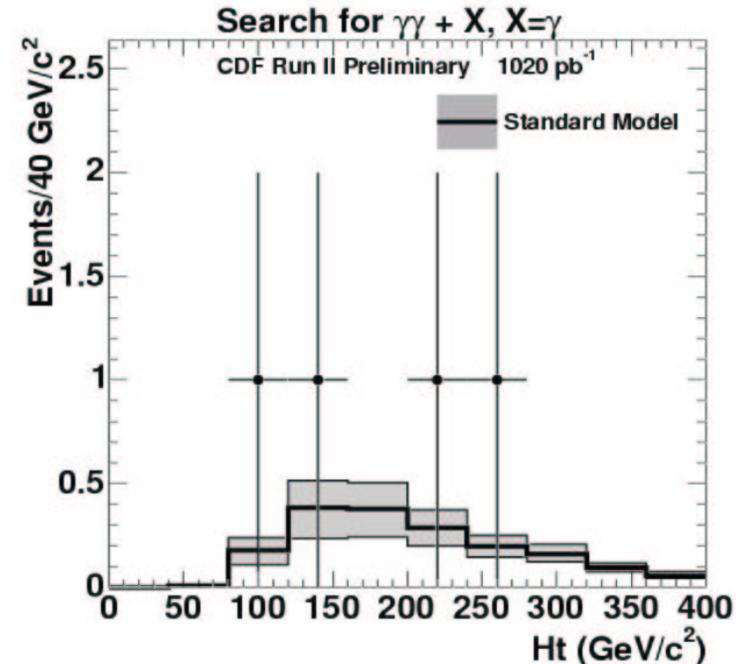
fake γ 1.2 ± 0.6

triphoton 0.7 ± 0.1

total 1.9 ± 0.6

Observed: 4

(E. Yu, S. Pronko, RLC)



Search for $\gamma\gamma+X$

(E. Yu, S. Pronko, RLC)

$X = e$ or μ

◆ Require standard high-pt lepton

Electron

W,Z $\gamma\gamma$ 0.65 ± 0.5

fakes 3.8 ± 0.8

total 4.5 ± 0.8

Observed: 2

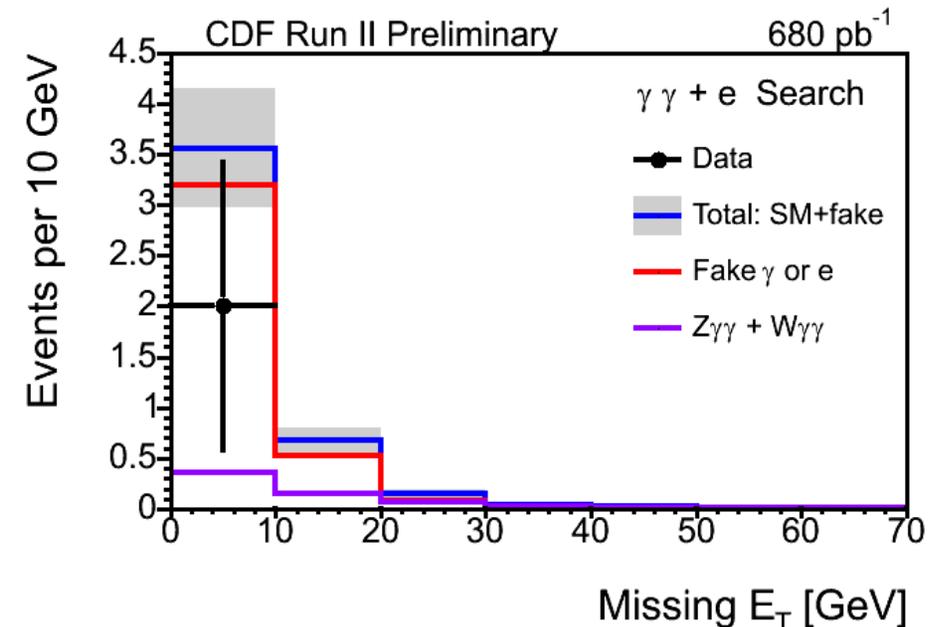
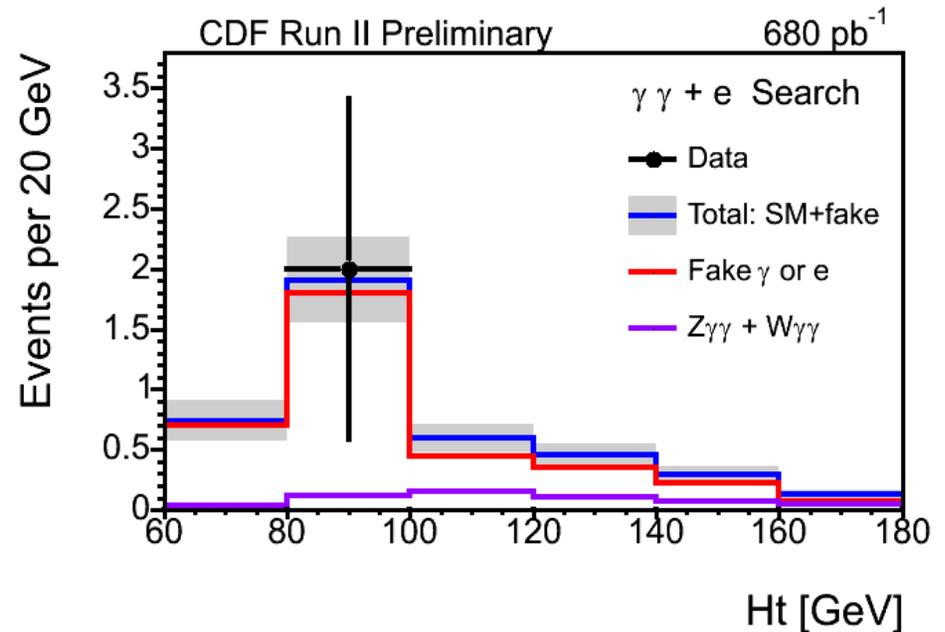
Muon

W,Z $\gamma\gamma$ 0.3 ± 0.03

fakes 0.1 ± 0.1

total 0.47 ± 0.12

Observed: 0

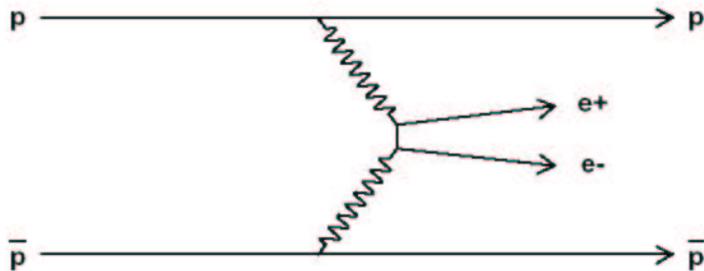


Exclusive e^+e^- Production

(M. Albrow, *et al.*)

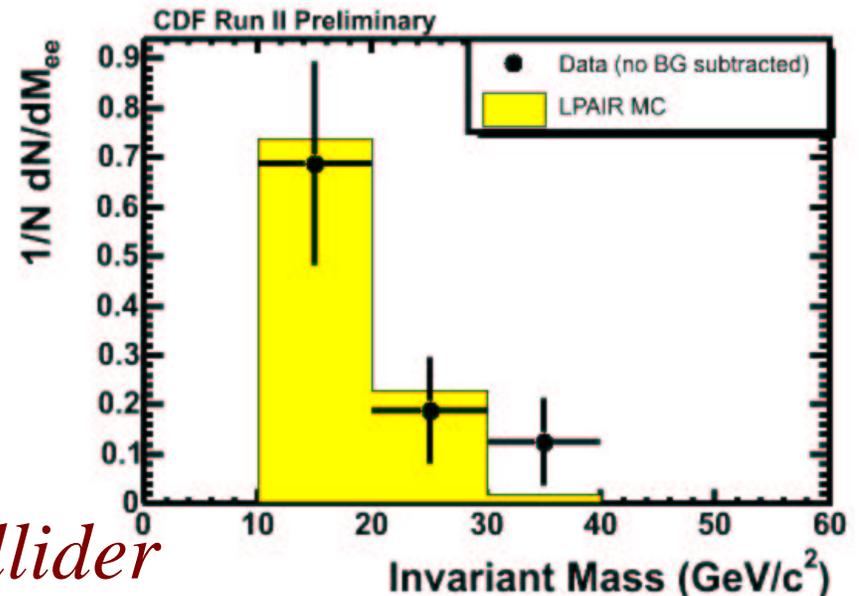
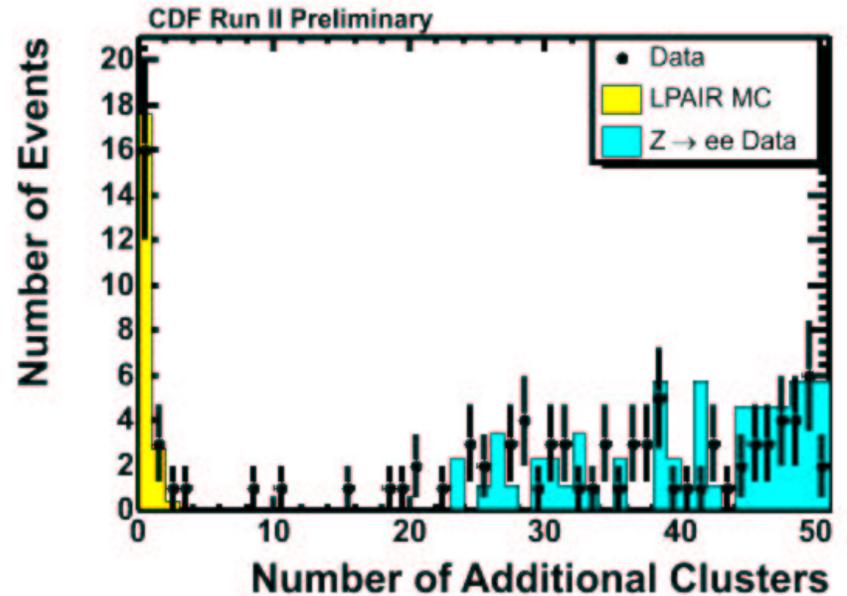
Process

◆ QED: proton acts like a charge with EM form factor:



- ◆ Determine exclusivity by the lack of energy in cal and hits in forward counters
- ◆ find 16 events, 2.1 bg
- ◆ Results in good agreement:
 σ meas $1.6 \pm 0.5 \pm 0.3$ pb
LPAIR MC 1.711 pb

first observation at hadron collider

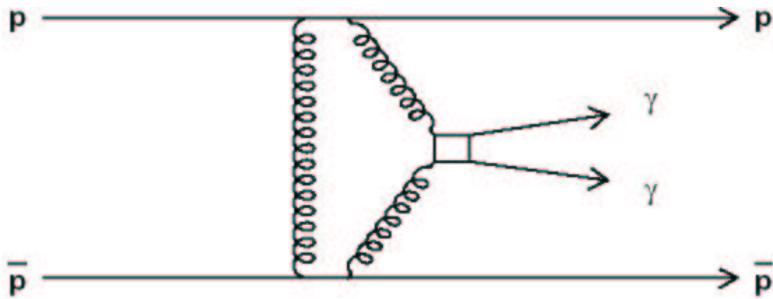


Exclusive $\gamma\gamma$ Production

(M. Albrow, *et al.*)

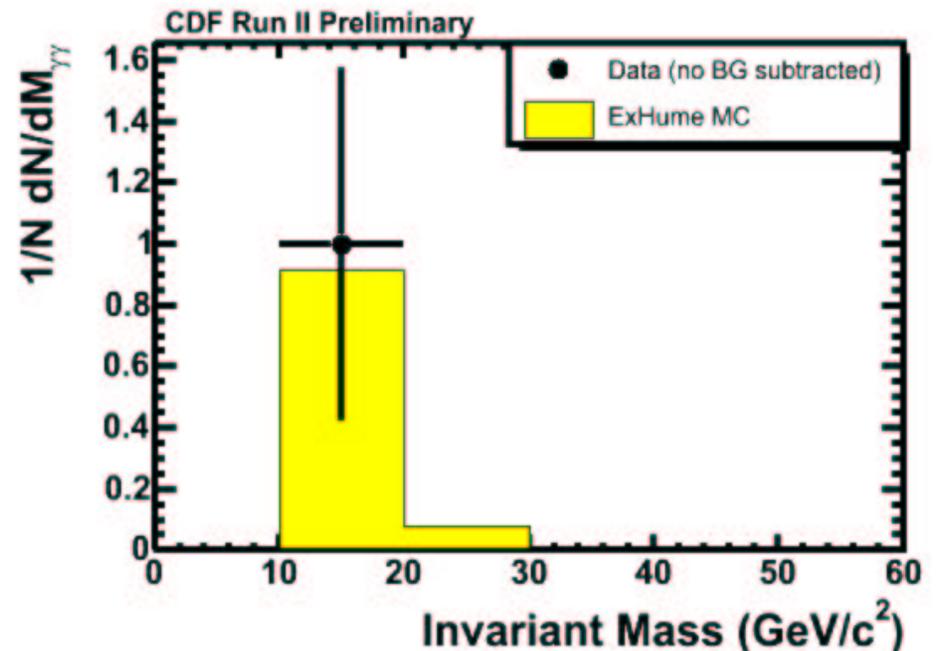
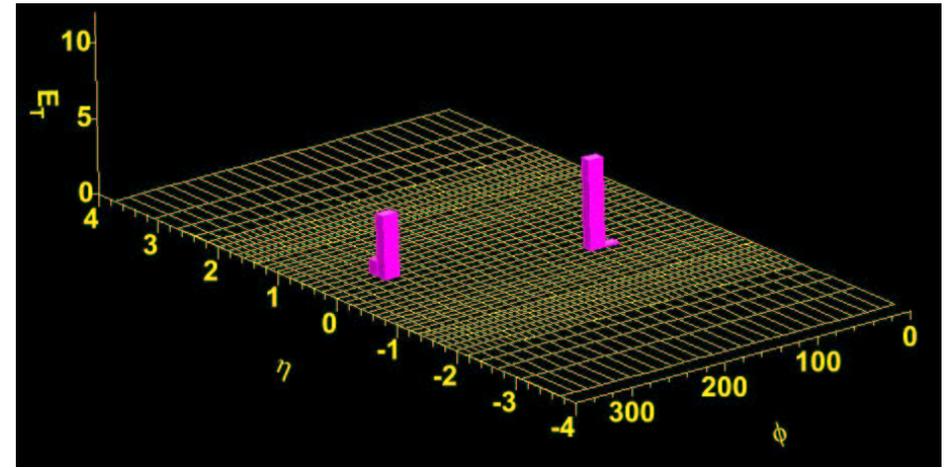
Sample

- ◆ QCD process:



- ◆ Techniques the same as e^+e^-
- ◆ 3 events, ~ 0 bg expected
- ◆ Cross Section:
 σ meas $0.14 \pm 0.14 \pm 0.03$ pb
ExHuME 0.04 - 0.20 pb
- ◆ This process helps predict diffractive Higgs production

first evidence at hadron collider

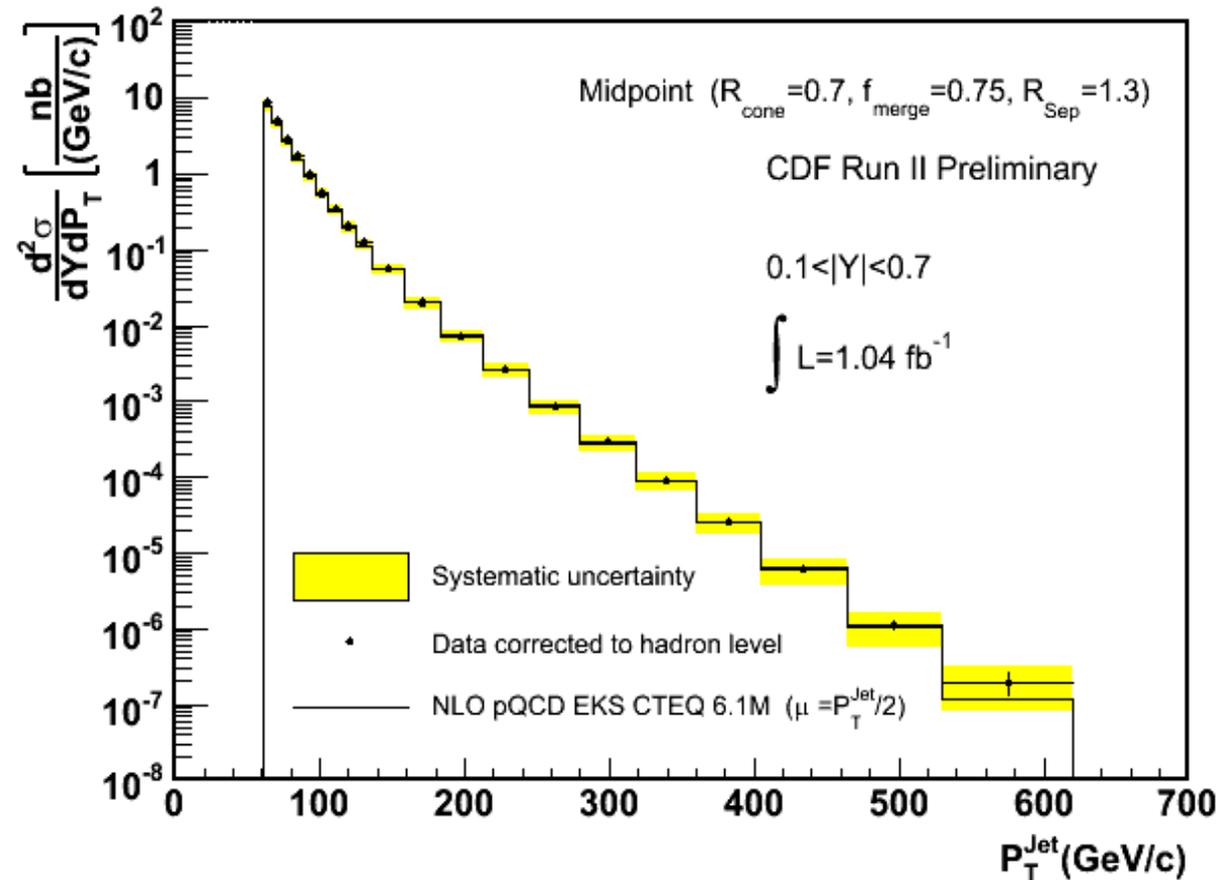


Jets Cross Section

(F. Chlebana *et al.*)

Sample

- ◆ 1 fb-1
- ◆ Central: $\eta < 0.7$ only
- ◆ Corrected for UE and hadronization
- ◆ Largest uncertainties from jet energy scale
- ◆ covers 8+ orders of magnitude!



Jet Cross Section

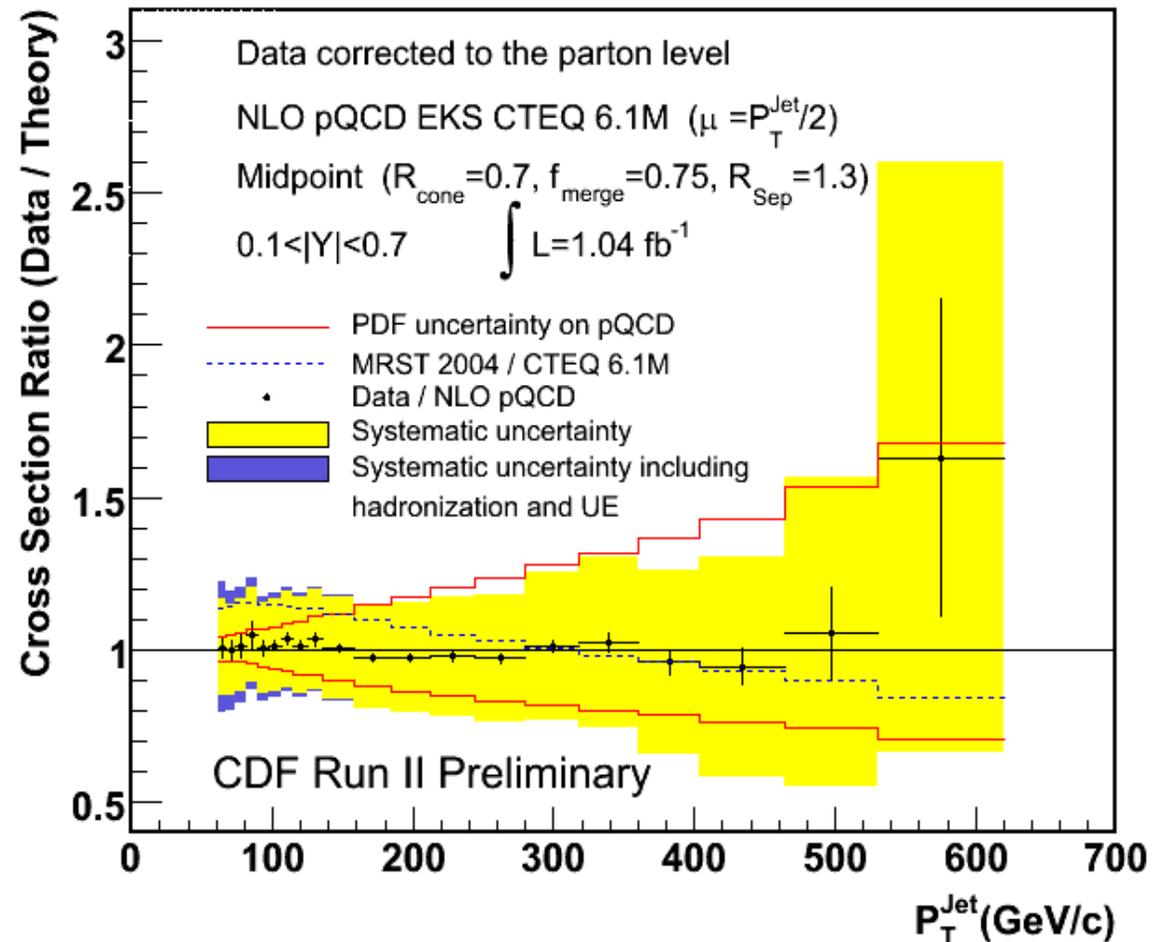
(F. Chlebana *et al.*)

Comparison

- ◆ Unfold to parton level
- ◆ Compare to NLO pQCD (EKS program)
- ◆ $\mu = P_T(\text{jet})/2$
- ◆ CTEQ6.1M PDF

Conclude

- ◆ Excellent agreement
- ◆ Strong test of pQCD
- ◆ Sensitive to α_s running
- ◆ Sensitive to new physics



Fermilab Group - Ongoing Physics

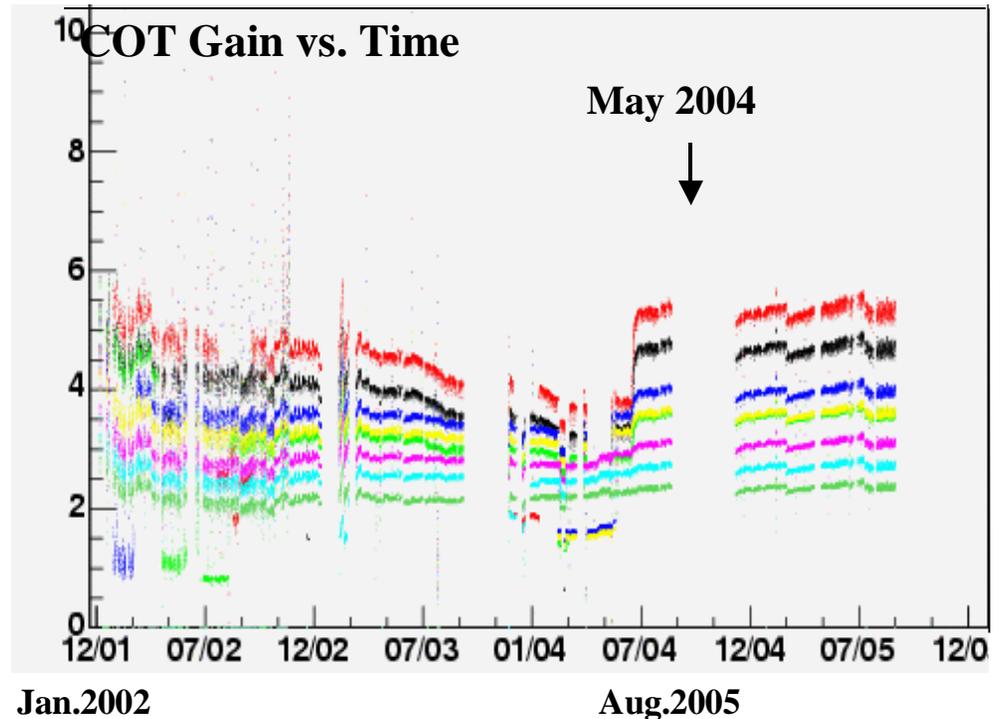
The Fermilab CDF physicists are also performing these world-class investigations, and others...

- ◆ Improved top mass (M. Datta)
- ◆ W helicity in top decays (A. Hocker, S. Golossanov)
- ◆ Top spin correlations (R. Eusebi)
- ◆ Bs Oscillations (K. Anikeev)
- ◆ Double Charm Correlation (B. Reisert)
- ◆ $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in $J/\Psi\gamma$ (P. Lukens)
- ◆ Bc Lifetime (T. Miao)
- ◆ Search for high-PT dimuons (SUSY) (J. Nachtman)
- ◆ Search for dimuon mass peak (Z') (J. Nachtman)
- ◆ Long-lived Massive Particles (R. Snider)

**We are ready for
several years of
high-luminosity
running...**

Long-term Success: COT

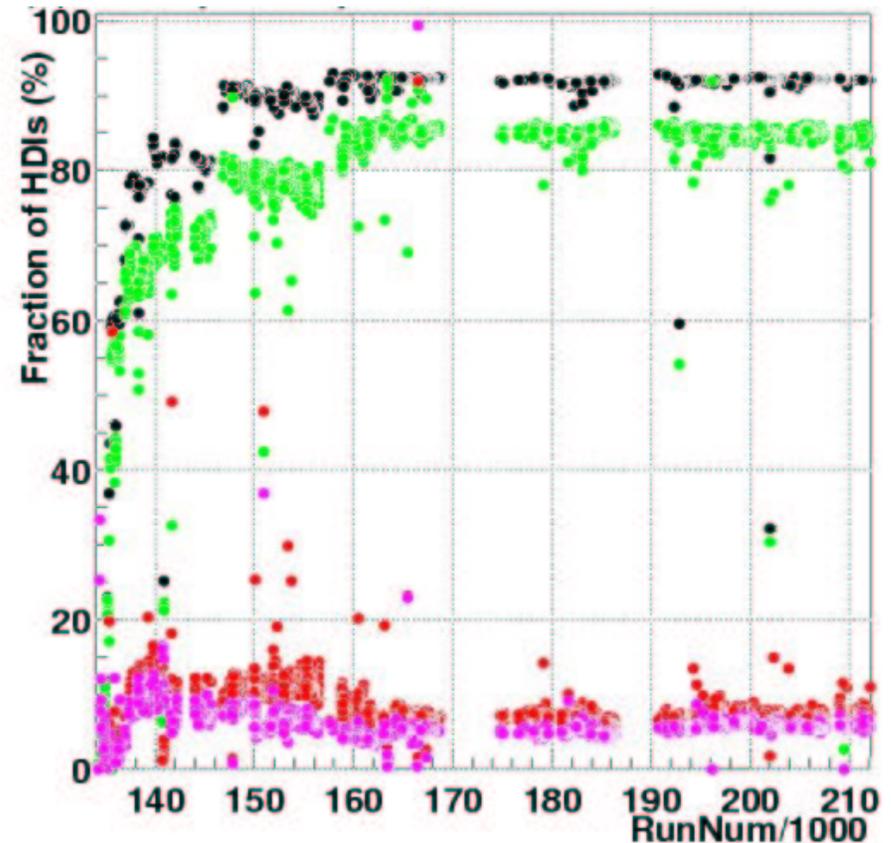
- ◆ The Central Outer Tracker is critical to virtually all physics
- ◆ In Spring 2004 - aging clearly observed, due to hydrocarbons
- ◆ Adding O₂ to the Ar-Ethane gas fixed it
- ◆ gain vs run is now very stable



No further problems, OK for $8fb^{-1}$

Long-term Success: SVX

- ◆ Usable fraction is 90% and stable
- ◆ Silicon trigger still 96% coverage
- ◆ Steps to mitigate radiation damage are being implemented
- ◆ Layer 0 approaching inversion



Stable operations

*Some degradation due to radiation, as predicted,
but all layers should keep working until 8fb^{-1}*

Long-term Success: Reconstruction

More crossings

- ◆ Need to plan for 3×10^{32} at start of store
 - that's 10 interactions per crossing
 - *but it decays quickly, 5 more typical*

Algorithm Performance

- ◆ Dedicated studies for tracking, lepton ID, B-tagging, MET resolution, jet corrections
- ◆ Use MC
 - overlay minbias events to simulate $L = 3E32$
- ◆ Use data
 - use bins of N Vertices as level arm to project
 - check with data/MC comparison

*CDF preparations are well underway,
and we expect no show-stoppers*

Long-term Success - Triggering

Stay on top of it

- ◆ High-Lumi Trigger Task Force formed in 2005
- ◆ Subject of ongoing intensive work

Trigger Table

- ◆ High-PT occupies 50% of bandwidth at $3E32$
 - remainder is calibration and backup triggers
- ◆ B-physics dynamically enabled $\sim 1.5E32$

Size of the Collaboration

- ◆ In 2004, HEPAP commissioned a survey to evaluate HEP resources *vs* the proposed physics program
- ◆ Results showed a significant gap between the demand for physicists and their availability
- ◆ Fermilab established a collider experiment task force to perform a bottoms up analysis of the resources available to each experiment and the requirements to operate (detector, computing and physics).
- ◆ Conclusions
 - CDF has the manpower needed through 2007
 - CDF may require small incremental help in 08-09
 - Working with the lab to address these potential shortfalls

Conclusions

- ◆ Detector is running well
- ◆ CDF is publishing physics results at a tremendous pace
- ◆ The collaboration is strong and dedicated
- ◆ Fermilab physicists continue to take on leading roles in all aspects of the experiment
- ◆ We are prepared to run for several more years at record luminosities