Status of CDF
And
Recent Physics Highlights

Annual Program Review
Sept 24 – 27, 2007

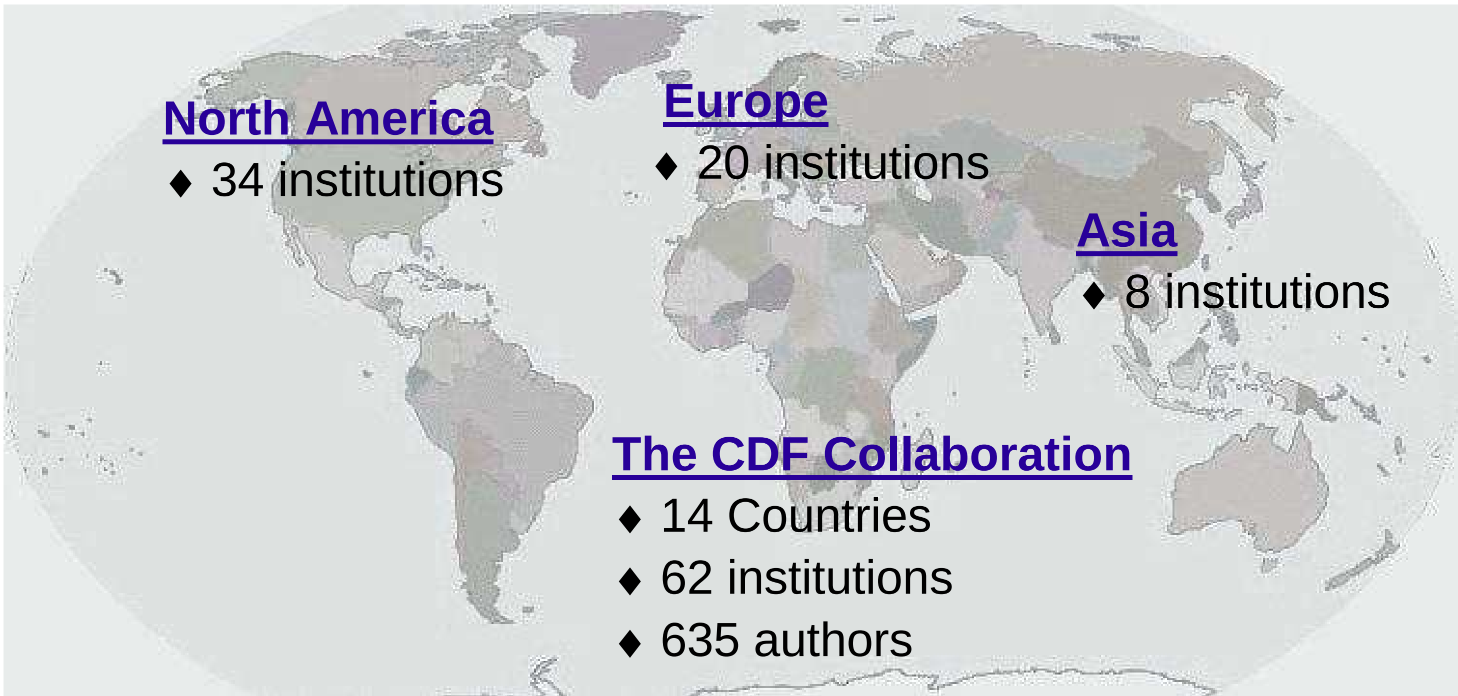
Frank Chlebana, Fermilab

Outline

- Detector Performance and Operations
  - CDF detector status
  - Trigger and DAQ improvements
- Some Recent Physics Highlights
  - B_s mixing
  - Single Top production
  - B_c mass and observation of Ξ_b
  - Inclusive jet cross section
  - Evidence for single Top production
  - The M_w - M_{top} - M_{Higgs} relationship
  - Searches for FCNC
  - Searching for the Higgs

Will emphasize FNAL contributions but also discuss CDF in general

The CDF Collaboration



North America
- 34 institutions

Europe
- 20 institutions

Asia
- 8 institutions

The CDF Collaboration
- 14 Countries
- 62 institutions
- 635 authors

FNAL Scientists and RAs

73 Fermilab CDF Authors

50 from Particle Physics Division
10 from Computing Division
5 from Technical Division
7 from Accelerator Division

Includes ~12 Research Associates

Fermilab RAs do very well at finding permanent positions in the field

In the last year three members left
- *1 faculty position*
- *2 staff at other labs*

- Fermilab personal have many leading roles in operations, detector upgrades/improvements, physics analysis, and management

  Spokesperson, Physics Coordinator, Head of offline and online Operations, Physics Conveners

- Many FNAL personal contribute technical expertise
- Many FNAL personal have non-CDF obligations
- About 25 FTE on CDF

Fermilab CDF Program Budget

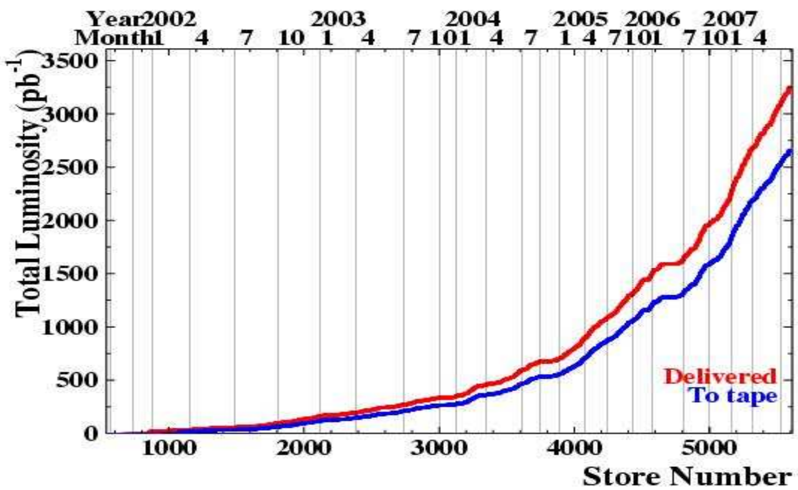
	FY 2007 (M$)	FY 2008 (M$)	FY 2009 (M$)
SWF	5.2	6.4	6.7
M&S	0.24	0.23	0.25
Total	5.4	6.7	7.0

SWF : *Salaries for PPD scientists on CDF*

M&S (Material and Services) : *Travel, office support, desktop computing*

Support maintained at current levels through the end of running

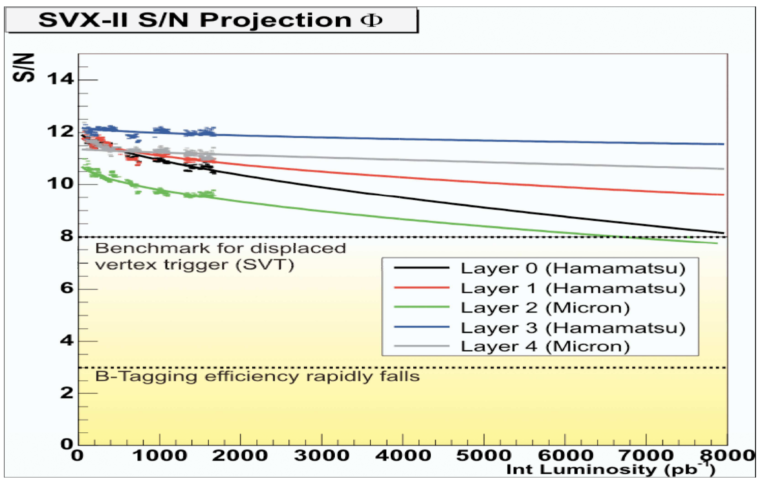
Detector Performance



Collected over 2.5 fb^{-1} of data with high (>85%) efficiency

- 5% Trigger deadtime
- 5% Beam conditions
- 5% Other

Tevatron projected to deliver 5.8 – 6.8 fb^{-1} by 2009 2x more data!



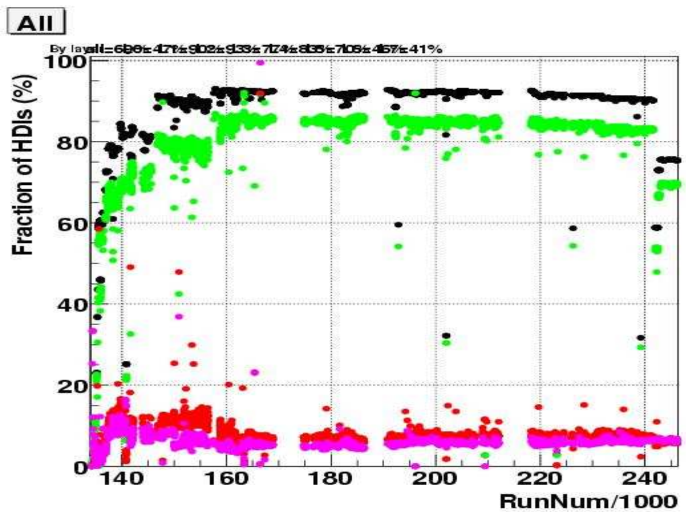
As expected we observe some radiation damage to the Si

All layers expected to remain operational beyond 8 fb^{-1}

COT aging that was previously reported is no longer a problem!

All detectors operating well and expected to remain functional beyond 8 fb^{-1}

Detector Performance



Holes in the cooling tubes prevented us from cooling the electronics for half of the outer Si layers and half of the innermost Si layers

Pitting observed around Al welded joints

Most likely resulted from acidic coolant

Cooling lines have been inspected and repaired

→ *Pressure tests indicate we are now able to operate Si electronics*

→ *Additional monitoring and testing established as part of operations*

Image from boroscope showing epoxy being applied using a custom built tool

Bandwidth Improvements

Anticipating higher initial luminosities

→ *higher trigger rates and events with larger occupancy*

Event Builder: Increased rate into the Level 3 trigger   400 → 1000 Hz

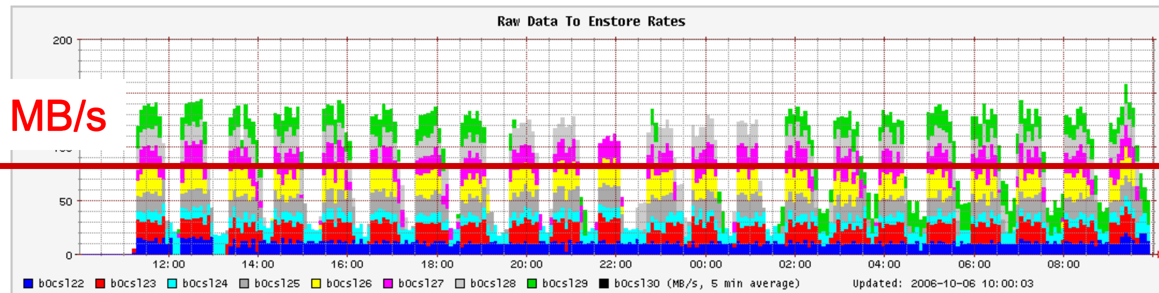
Data Logger

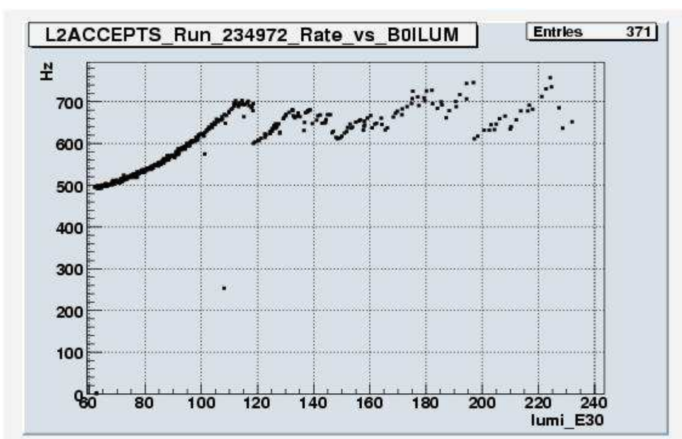
(F.Chlebana, R.Snider)

Increased logging rate

24 → 100 MB/s

80 MB/s





Dynamically adjust trigger prescales during the run to fill available bandwidth *(J.Lewis, B.Badgett)*

→ Maintain priority triggers throughout the store

→ Enable secondary triggers as bandwidth becomes available

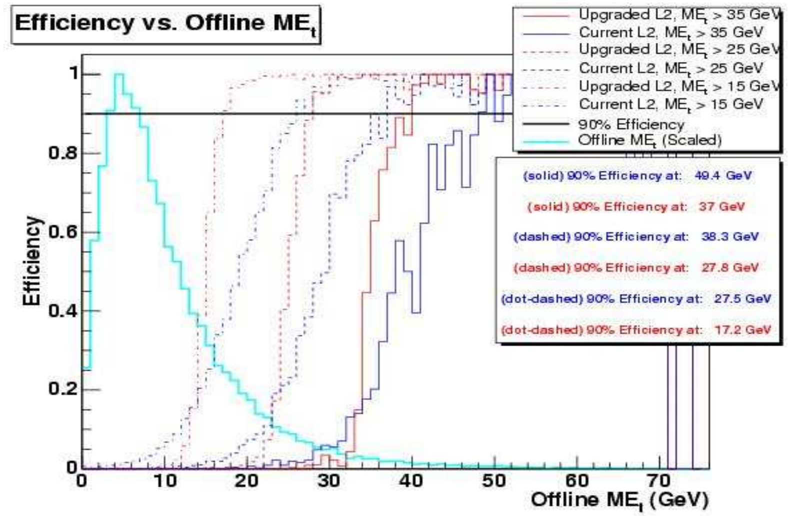
Trigger Enhancements

Level 2 Trigger

(T. Liu, C.J.Lin, B.Reisert, K.Anikeev, P.Wilson)

→ *Reduced decision time*

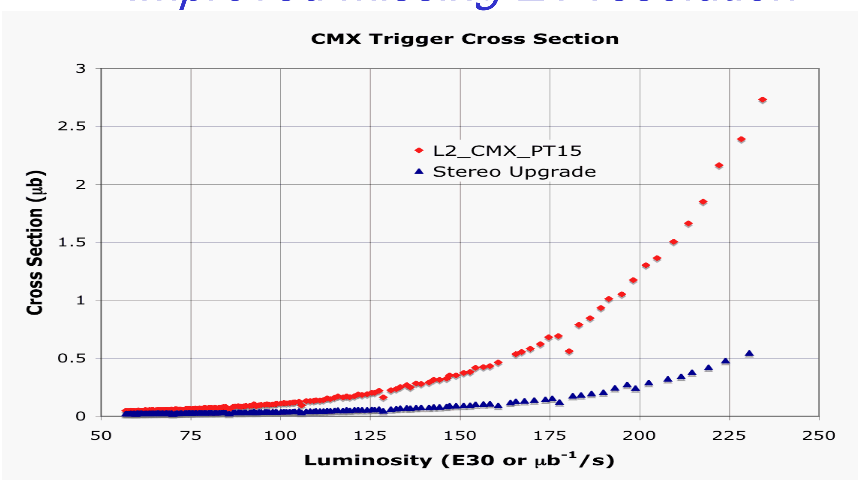
→ *Improved reliability*



Level 2 Calorimeter Clusterin

(V.Rusu, P.Wilson)

→ *Improved missing ET resolution*



High PT muons (CMX)

(E.James)

Adding COT stereo layer information to Level 1 tracking

Fake rate reduced by 4 – 5x with only a 2% loss in efficiency

Trigger enhancements help maintain efficiency as luminosity increases

Human Resources

Do we have enough people to continue running? Yes!

	CY2007	CY2009
Total for Operations	124	102
Resources available	392	236
FTE for physics	268	134
Post Docs	101	53
Students	147	77

~ 30% more FTE in CY2007 than was estimated in CY2005

- More stable running conditions
- Automated error recover

- Reduced the number of people on shift (4 → 3)

(P.Wilson, M.Convery, E.Schmidt, S.Hahn)

Continue efficient operations with fewer people

- Established Remote Data Monitoring shift from Italy and Japan

(K.Maeshima, E.Schmidt)

Easier for Asian and European members to fulfill operating obligations

Physics Highlights

CDF Results for 2007

Bottom Physics

F	Observation of $B_c \to J/\Psi\pi$ and Precision Mass Determination	2.2 fb^{-1}
F	Observation of the Ξ_b	1.9 fb^{-1}
	Measurement of $\Delta\Gamma_s/\Gamma_s$ and ϕ_s using $B_c \to J/\Psi\phi$	1.9 fb^{-1}
F	Search for FCNC $B_{s(d)} \to \mu^+\mu^-$ Decays	1.9 fb^{-1}
	Orbitally Excited B mesons (B^{**})	1.7 fb^{-1}
	Observation of $B_s \to D_s K$	1.2 fb^{-1}
	Evidence for $D_0 - \bar{D}_0$ Mixing	1 fb^{-1}

Electroweak Physics

	Measurement of the WZ Production Cross Section	1.9 fb^{-1}
	Anomalous Coupling Limits from WZ events	1.9 fb^{-1}
	Evidence for ZZ Production	1.5 fb^{-1}
	Measurement of $d\sigma(Z/\gamma* \to e^+e^-)/dy$	1.1 fb^{-1}
	Measurement of the W-Charge Asymmetry	1 fb^{-1}
F	Direct Measurement of the Z-Boson Invisible Width	1 fb^{-1}

Exotic Physics

F	Search for Anomalous Production of $\gamma\gamma\tau$	2 fb^{-1}
	Search for Direct Production of Squarks and Gluinos	1.4 fb^{-1}
	Search for Heavy Quarks in Dileptons+X	1.2 fb^{-1}
F	Global Search for New Physics at High-p_T	1 fb^{-1}
F	Search for Large Extra Dimensions using MET+1 Jet Events	1 fb^{-1}
	Search for high mass resonance decaying to e^+e^-	1 fb^{-1}

Higgs Physics

Search for $H \to W^+W^-$ Events	1.9 fb^{-1}
Search for $WH \to l\nu b\bar{b}$ Events	1.7 fb^{-1}
Search for $ZH \to l\nu b\bar{b}$ Events	1.7 fb^{-1}
Search for hbb in Events with at least 3 B-tags	1 fb^{-1}
Updated CDF SM Higgs Combination	1-2 fb^{-1}
Updated CDF+D0 SM Higgs Combination	1-2 fb^{-1}

CDF Results for 2007

QCD Results

	Inclusive Z+Jets Cross Section	1.7 fb^{-1}
	Measurement of the Inclusive Z+bjet Cross Section	1.5 fb^{-1}
F	Inclusive Jet Cross Section using MidPoint Algorithm	1 fb^{-1}
	Measurement of $b\bar{b}$ Differential Cross Sections	0.26 fb^{-1}

Top Physics

F	Evidence for Single-Top Production using ME Discriminant	1.5 fb^{-1}
	Search for Single-Top Production using Likelihood Discriminant	1.5 fb^{-1}
F	Measurement of Mt in Lepton plus Jets events using KDE	1.7 fb^{-1}
	Measurement of Mt in Dilepton events using ME	1.9 fb^{-1}
F	Measurement of Mt in Dilepton events using KDE	1.9 fb^{-1}
	Measurement of Mt using lepton-p_T	1.9 fb^{-1}
	First Measurement of W+c Cross Section	1.8 fb^{-1}
	Measurement of W-Helicity Fractions in $t\bar{t}$ decays using an Unfolding Method	1.7 fb^{-1}
F	Measurement of W-Helicity Fractions in $t\bar{t}$ decays using a Template Method	1.7 fb^{-1}
	Measurement of AFB in $t\bar{t}$ events	1.7 fb^{-1}
F	Measurement of the Charge of the top-quark	1.5 fb^{-1}
	Measurement of top-quark Width and Lifetime	1 fb^{-1}
F	Meas. of Mt in Dilepton events using Templates and $t\bar{t}$ P_z with Cross Sect. Constr.	1.2 fb^{-1}
F	Measurement of Mt in Dilepton events using Templates and $t\bar{t}$ P_z	1.2 fb^{-1}
	$t\bar{t}$ Cross Section using lepton plus jets events with a Btag	1.1 fb^{-1}
	$t\bar{t}$ Cross Section using ee, $\mu\mu$, $e\mu$ Dilepton events	1.2 fb^{-1}
F	$t\bar{t}$ Cross Section using e/μ plus track events	1.1 fb^{-1}
F	$t\bar{t}$ Cross Section using e/μ plus track plus Btag events	1.1 fb^{-1}
	Measurement of the fraction of $gg \to t\bar{t}$ events using low p_T tracks	1 fb^{-1}
F	Measurement of the fraction of $gg \to t\bar{t}$ events using NN Discriminant	1 fb^{-1}
	Search for the FCNC Decays $t \to Zq$	1.1 fb^{-1}
	Search for $W' \to tb$ Events	1 fb^{-1}

New Results in 2007

51 new results presented at conferences this last year

19 (37%) of those new results had an FNAL person involved

FNAL fraction of the CDF Collaboration is 11% (73/635)

Over the last year

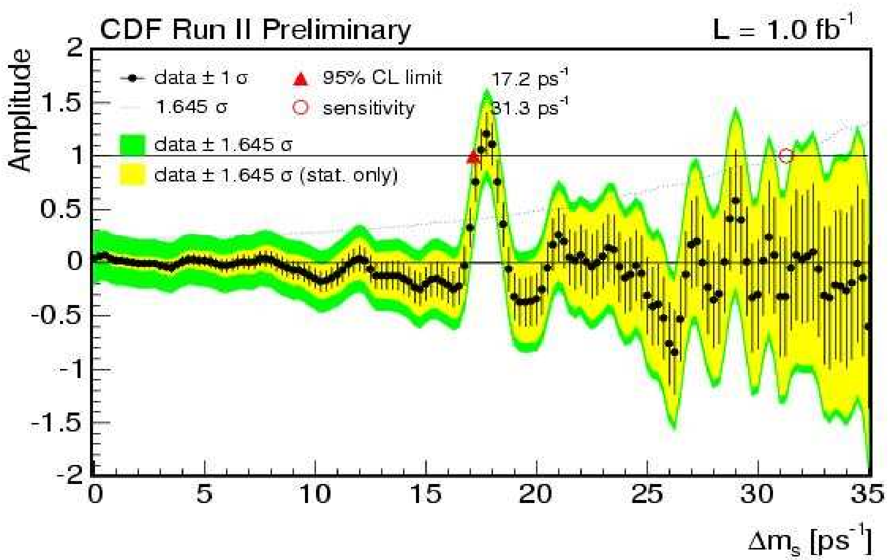
- 28 papers published
- 17 papers submitted and being reviewed
- ~ 44 papers under internal review
- ~ 40 PhDs granted

CDF Publications

- ~ 137 Run II published papers

FNAL personnel play a major role in the success of CDF

Observation of B_s Mixing by CDF



Improvements in the analysis technique allowed us to go from a 3σ evidence to a >5σ observation *using the same data set!*

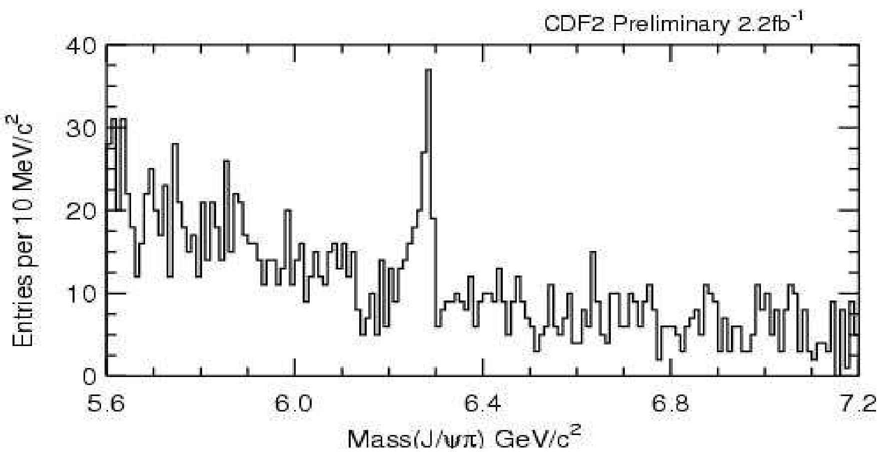
$$\Delta m_s = 17.77 \pm 0.10(stat) \pm 0.07(sys)$$

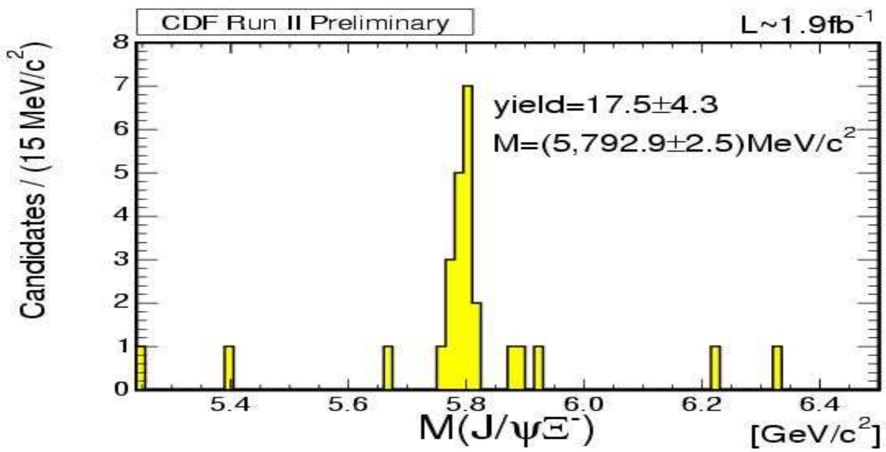
$$\frac{|Vtd|}{|Vts|} = 0.2060 \pm 0.0007(exp)^{+0.0081}_{-0.0060}(th)$$

- Increased Bs signal yield (Hadronic channel) *(K.Anikeev, T.Miao)*
  - → *Neural Net to improve candidate selection with reduced background*
  - → *Able to add additional decay modes*
- Improved flavor (b or $\bar{b}$) identification of B_s at production

Improvements resulted in an effective increase of 2.5x in the data sample

Observation of New Particles





Measurement of the B_c mass
(P.Lukens, W.Wester, S.Tkaczyk)

B_c not produced at B factories

Best in the world mass measurement

$m(B_c) = 6274.1 \pm 3.2\ (stat) \pm 2.6\ (sys)\ MeV/c^2$

Observation of Ξ_b at CDF
(P.Lukens, D.Litvintsev)

$m(\Xi_b^-) = 5792.9 \pm 2.5\ (stat) \pm 1.7\ (sys)\ MeV/c^2$

Statistical significance of signal >7σ

Both measurements need as many J/Ψ candidates as we can get
Data collected on triggers that are *dynamically prescaled*

Inclusive Jet Cross Section

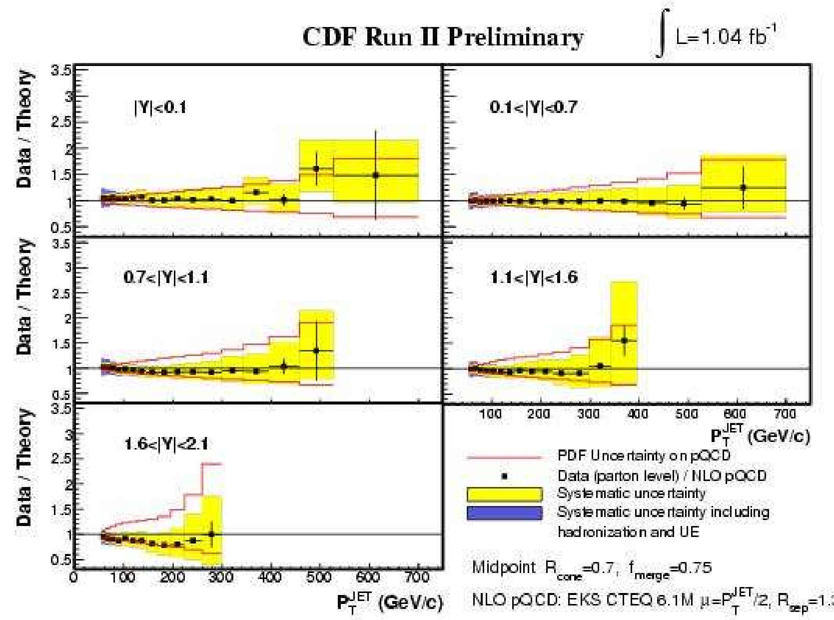
(C.Group, F.Chlebana)

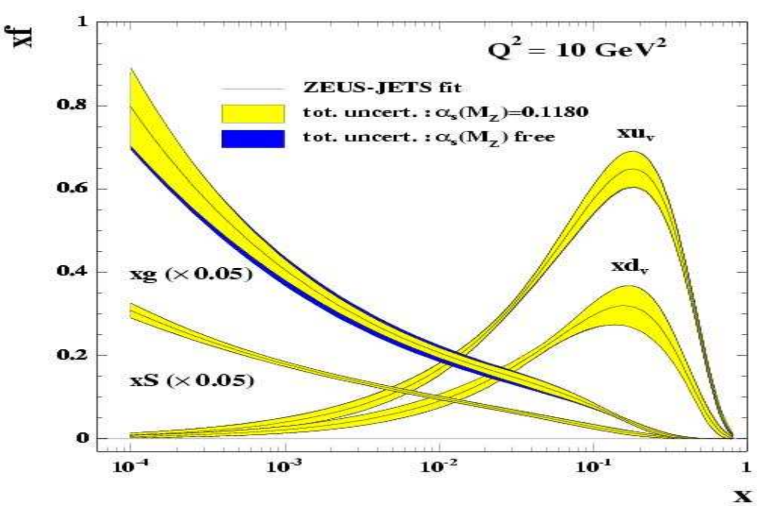
Search for new physics

Probing distances of ~ 10^{-17} cm

Need to measure jets in the forward region to separate old physics from new

Used as input to produce more precise Parton Density Functions





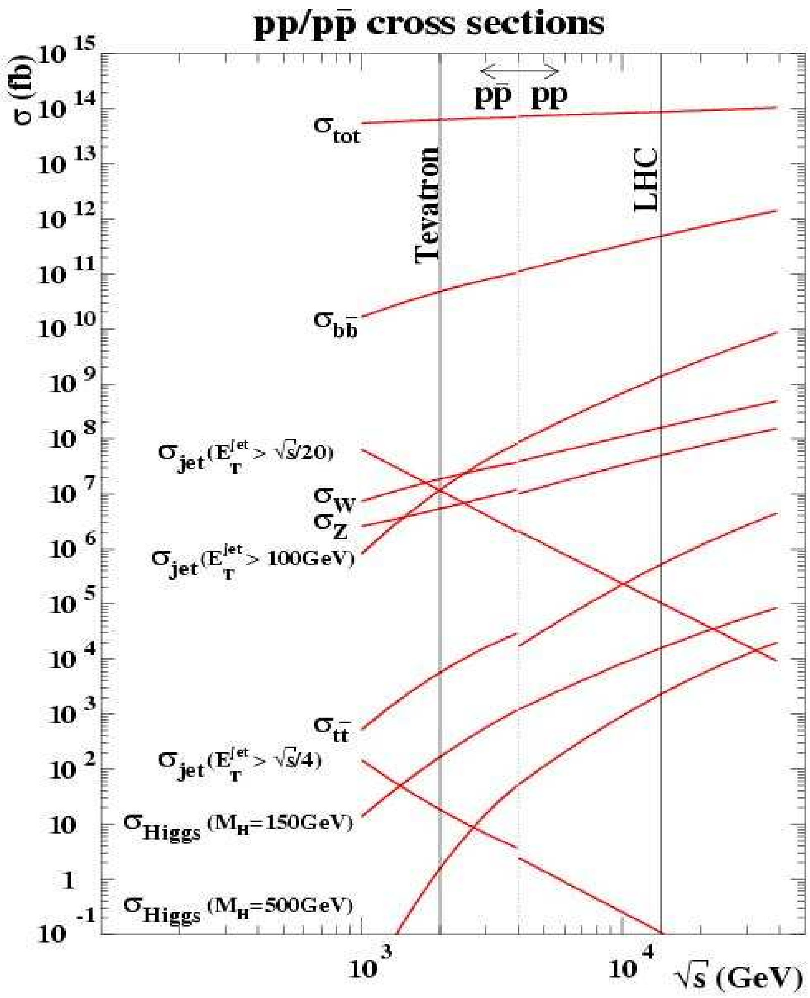
Particle structure is parameterized by PDFs

Cross sections can be calculated once you know the probability of probing the parton

→ Used in theory calculations

→ Used in essentially all measurements

Understanding the Backgrounds



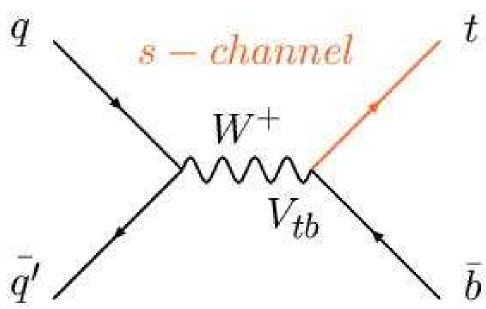
New Physics has small cross sections and is swamped by standard physics backgrounds

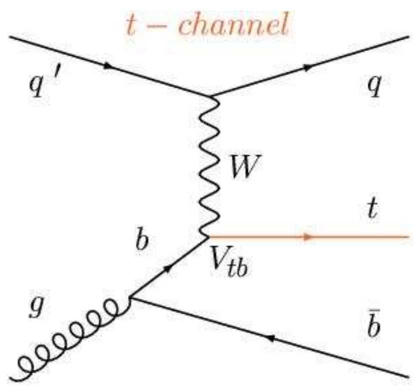
Standard physics processes have relatively large uncertainties

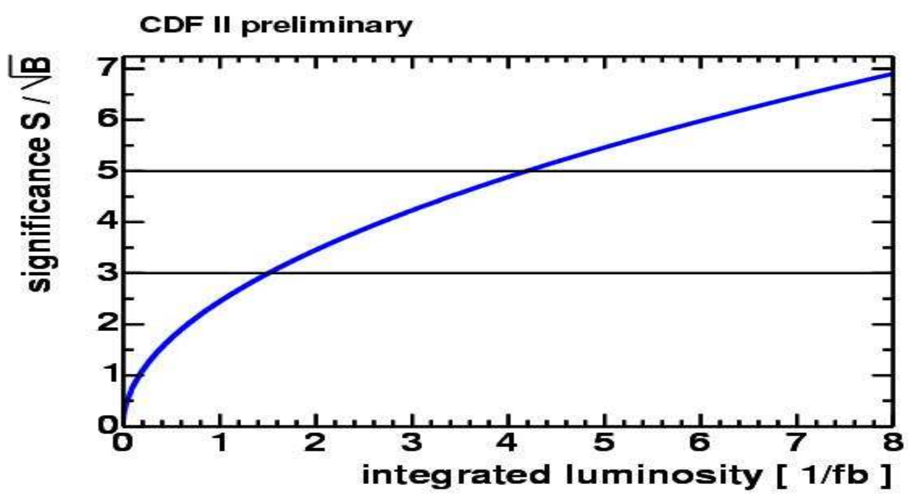
→ Need to have an accurate prediction for backgrounds in order to claim a discovery

"Todays physics is tomorrows Background"

Single Top Production







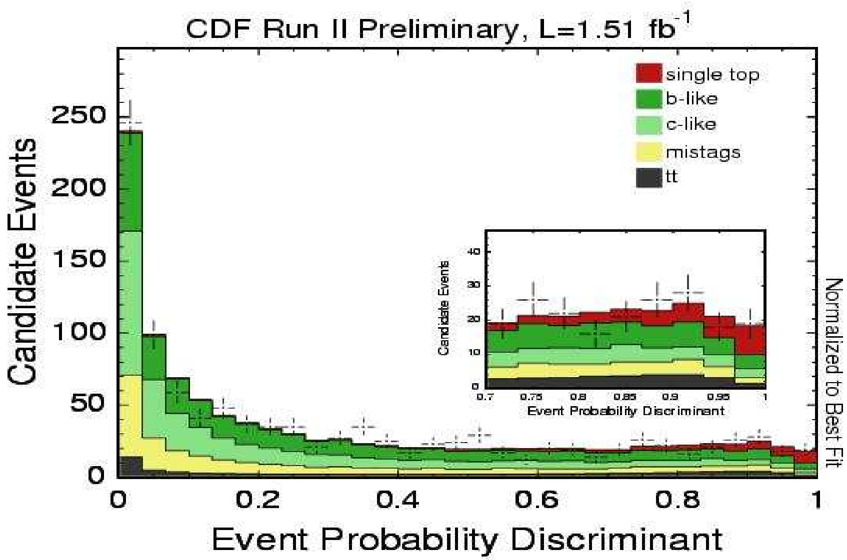
- Tests the SM, search for new Physics
- Important to fully understand top Production (probes V_{tb})
- Important for Higgs searches

With 4 fb^{-1} we expect enough events for a 5σ discovery

Will need more data to further study single top production to see if the properties agree with Standard Model predictions

Evidence for Single Top Production

(F.Canelli)



- Matrix element method evaluates an event probability for the signal and background hypotheses
- Combine probabilities with a neural network *b*-tagger to obtain a single discriminant
- Fit template distributions to extract signal

Measured:

$$\sigma_{\mathrm{singletop}} = 3.0^{+1.2}_{-1.1} \text{ pb}$$

$$\sigma_{\mathrm{s-channel}} = 1.1^{+1.0}_{-0.8} \text{ pb}$$

$$\sigma_{\mathrm{t-channel}} = 1.9^{+1.0}_{-0.9} \text{ pb}$$

$$|V_{tb}| = 1.02 \pm 0.18(\mathrm{exp}) \pm 0.07(\mathrm{th})$$

Expected significance: 3.0 σ

Observed significance: 3.1 σ

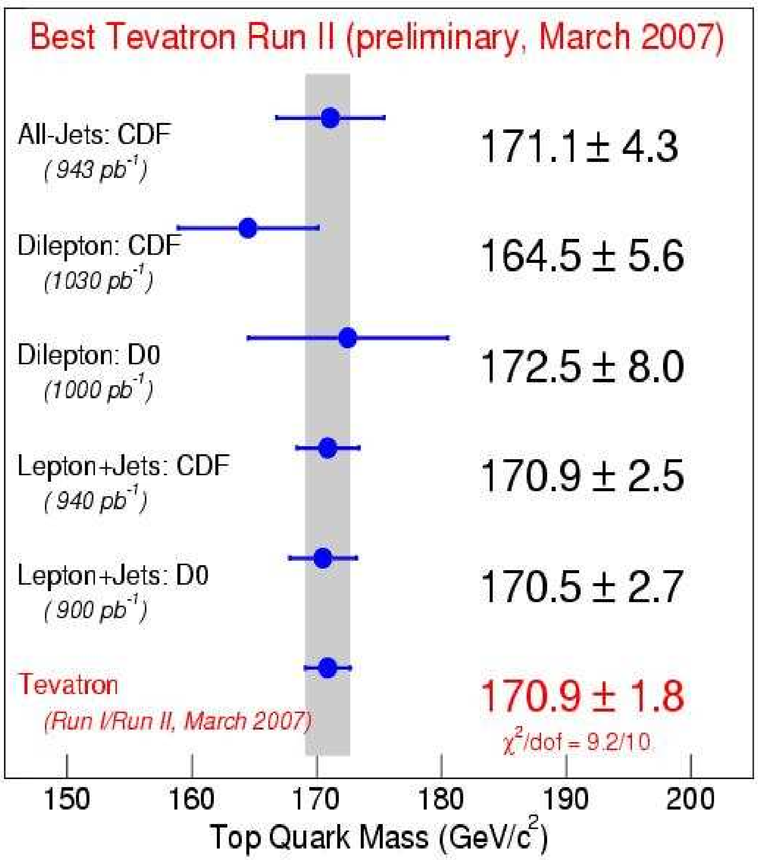
SM Predictions:

$$\sigma_{\mathrm{s-channel}} = 0.88 \pm 0.14 \text{ pb}$$

$$\sigma_{\mathrm{t-channel}} = 1.98 \pm 0.30 \text{ pb}$$

Top Mass

The FNAL group has a strong presence in the Top group and is involved in the measurement of the top mass, cross section and other properties

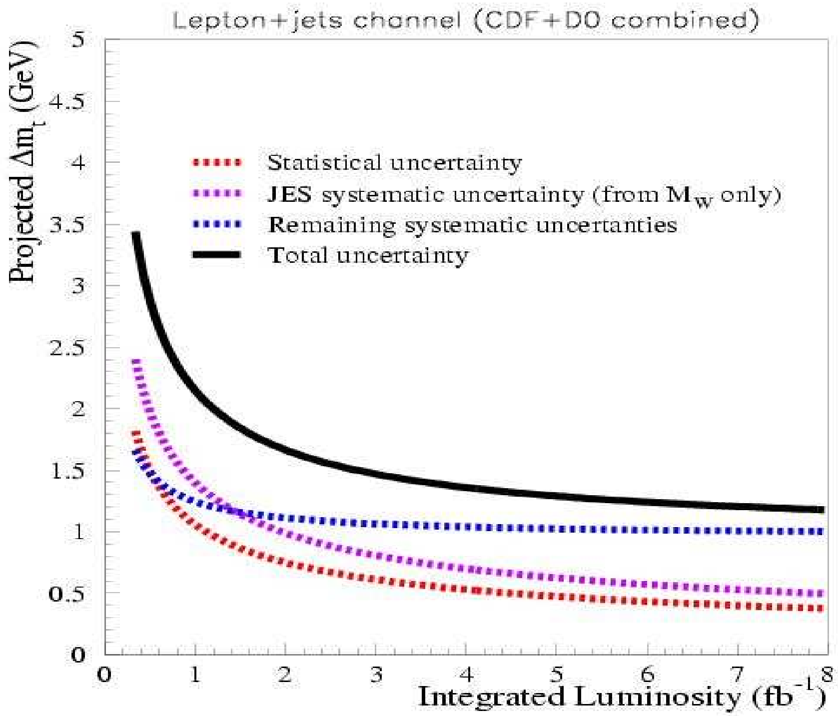


Measurement of the top quark mass using the Matrix Element Analysis Technique in the lepton+jets channel with 940 pb^{-1}

Best published single measurement in the world

(F.Canelli)

Top Mass Prospects: $\delta m_t \sim 1.2 – 1.4$ GeV



4 fb^{-1}: $\delta m_t = 1.4$ GeV
8 fb^{-1}: $\delta m_t = 1.2$ GeV

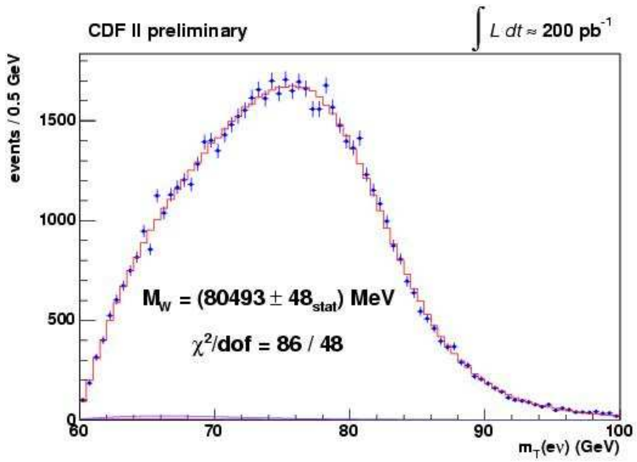
Competitive to the uncertainly on the top mass at the LHC

Projected at the LHC 1.5 GeV (hep-ph/0412214)

Perhaps as good as 1.0 GeV (hep-ex/0403021)

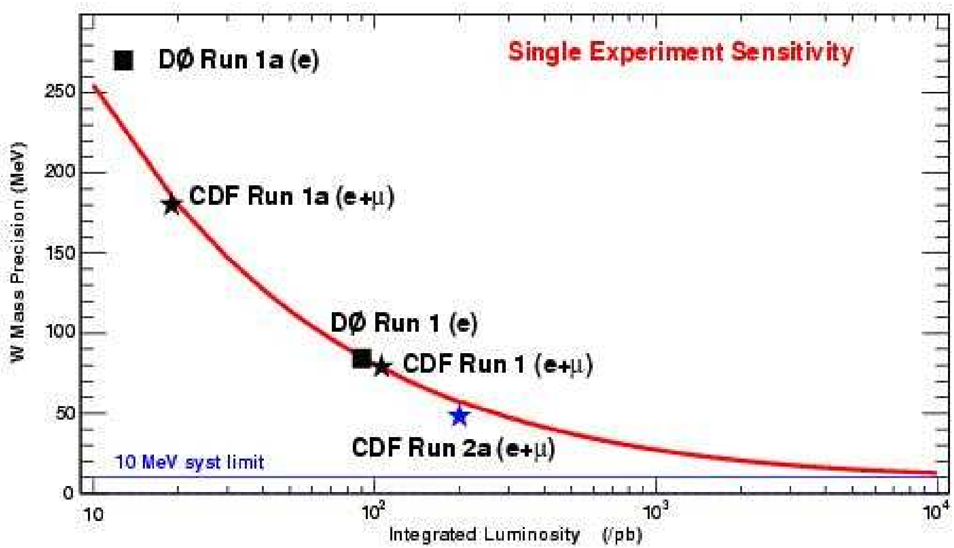
Expect to take several years to commission and fully understand the new LHC detectors

W Mass Prospects: $\delta m_W \sim 10 - 20$ MeV



CDF has produced the world's most precise single *W* mass measurement

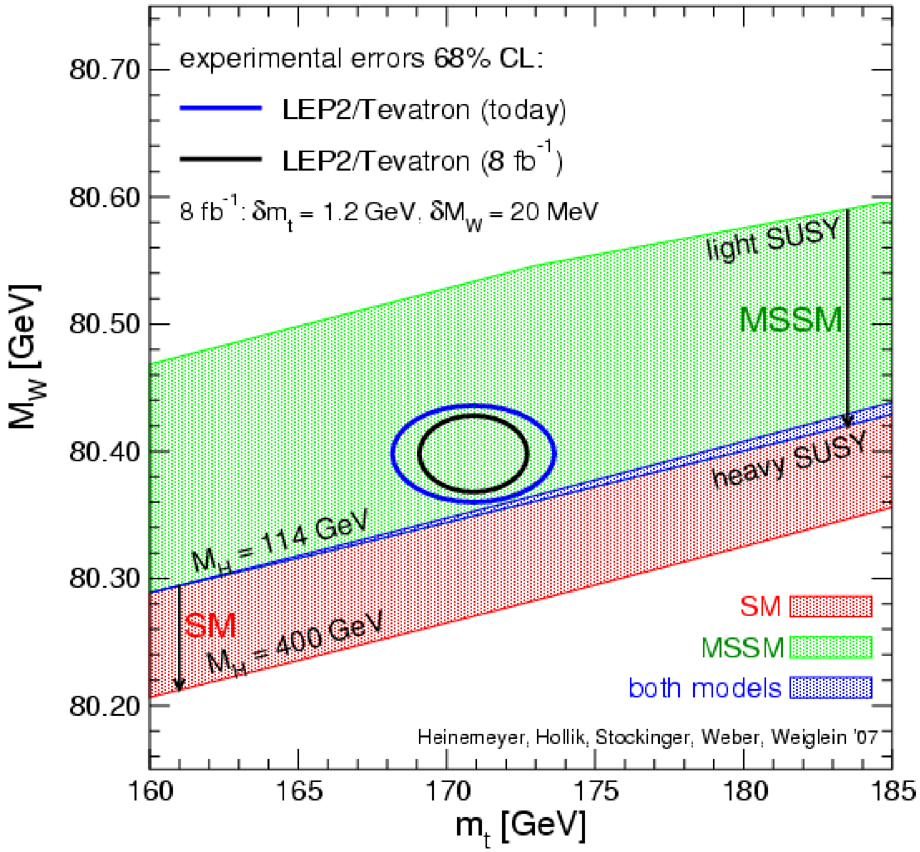
Using only 200 pb^{-1} *of data!*



LHC expectations are

$\delta m_W \sim 10 - 20$ MeV

W – Top – Higgs Mass Relationship



World combined mass

M_W = 80.398 ± 0.025 GeV
M_{top} = 170.9 ± 1.8 GeV

Direct searches at LEP

M_{Higgs} > 114 GeV 98% CL

Indirect measurements favor a low mass Higgs

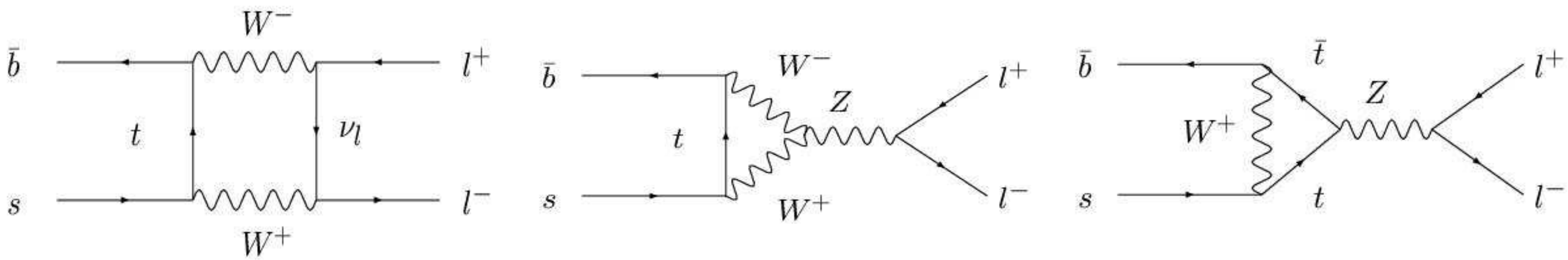
M_{Higgs} < 144 GeV 95% CL

68% CL elipse now outside of the SM Higgs region

With 8 fb^{-1} of data, the Tevatron can provide a comparable measurement of both the Top and W mass to what is expected at the LHC

Search for FCNC

(C.J.Lin, D.Glenzinski)



Flavor Changing Neutral Current decays are highly suppressed in the SM

$Br(B_s \rightarrow \mu^+\mu^-) \sim 10^{-9}$ Proportional to the CKM matrix element $|V_{ts}|^2$

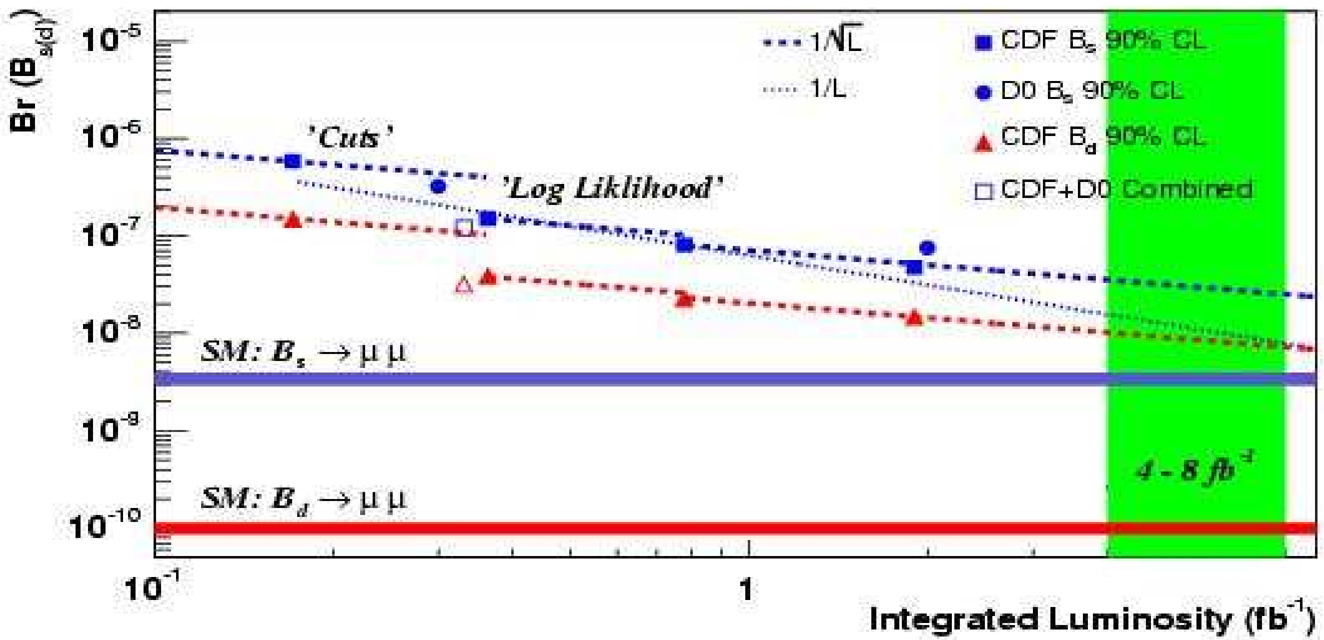
$Br(B_d \rightarrow \mu^+\mu^-) \sim 10^{-10}$ Further suppressed by $|V_{td}/V_{ts}|^2$

New Physics contributions can significantly enhance the branching fractions observation at the Tevatron would be a signature of new physics

A great deal of interest from the astrophysics community…

Potential signature for Dark Matter Candidates

Summary of Limits on $B_{s(d)} \rightarrow \mu^+\mu^-$

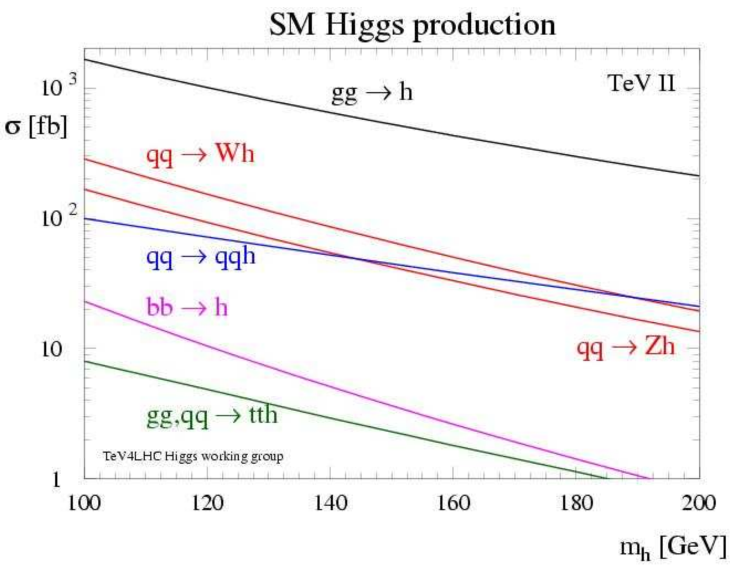


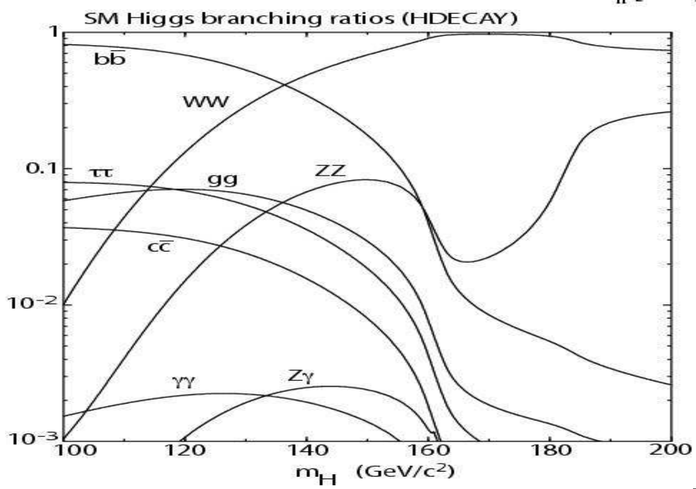
Improvements over first measurements resulted from a better separation of signal from background ("cuts" → "log likelihood")

Worlds best limit from CDF based on 2 fb^{-1}

$Br(B_s \rightarrow \mu^+\mu^-) < 4.7\ (5.8) \times 10^{-8}$ 90% (95%) CL

Searching for the Higgs





Direct searches at LEP:
M_{Higgs} > 114 GeV 95% CL

Indirect measurements suggest:
M_{Higgs} < 144 GeV 95% CL

Tevatron Reach < 180 GeV

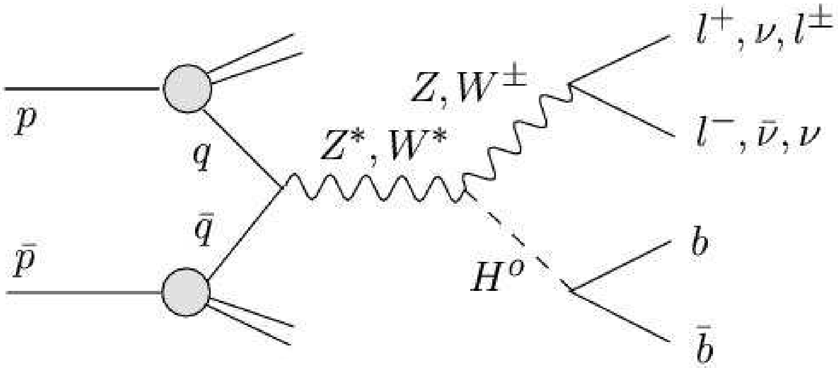
Dominant decay chain
$gg \rightarrow H \rightarrow b\bar{b}$

σ_{bb} is huge!

Need to look for channels that are easy to separate from the background

Higgs Search Channels – *Low Mass*

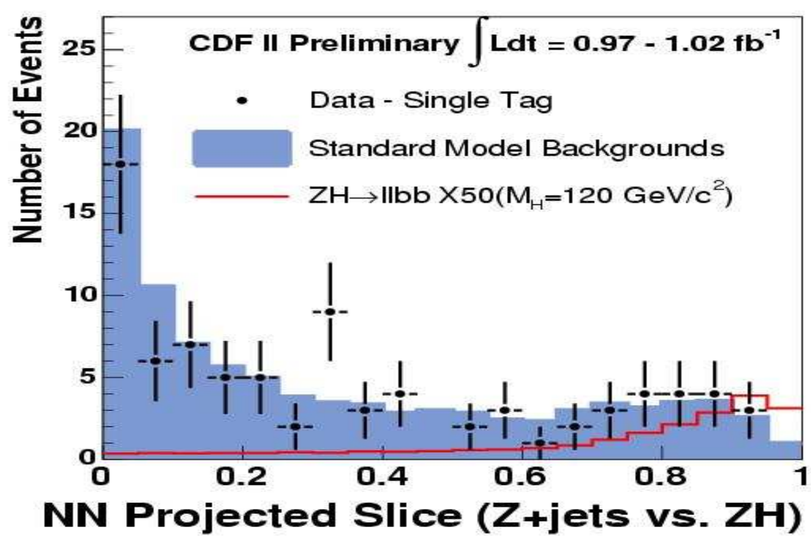
Main search channels from associative production with a *Z* or *W*



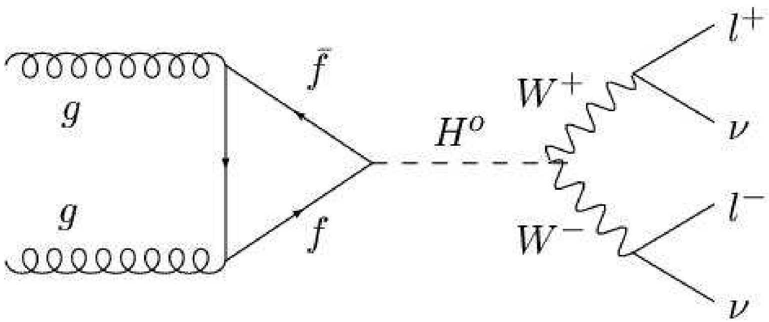
$$ZH \rightarrow l^{+}l^{-}b\bar{b}$$
$$ZH \rightarrow \nu\bar{\nu}b\bar{b}$$
$$W^{\pm}H \rightarrow l^{\pm}\nu b\bar{b}$$

Requires:

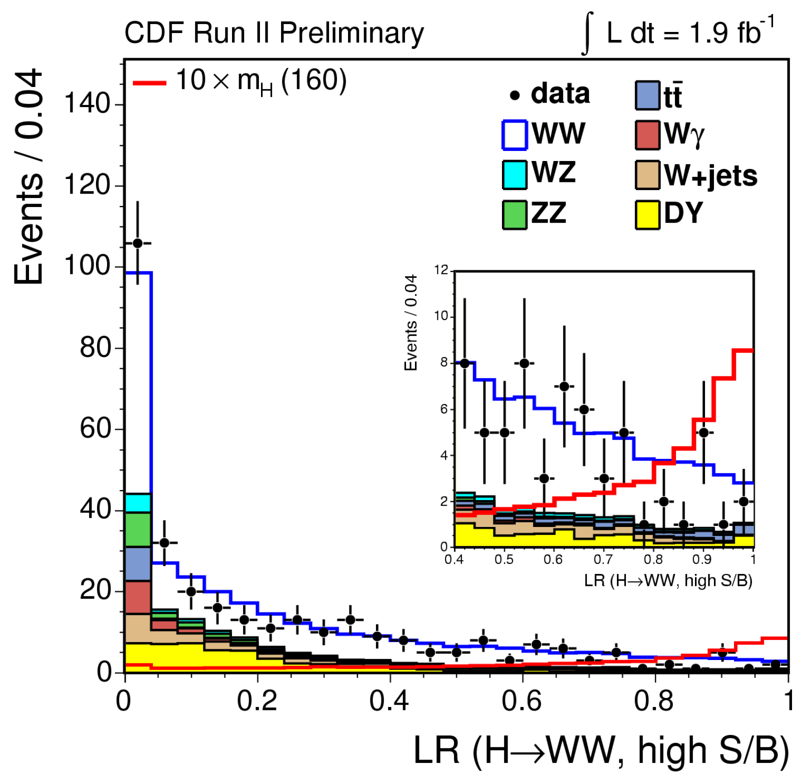
- ➢*Excellent b tagging*
- ➢*Optimal $b\bar{b}$ mass resolution*
- ➢*Good Missing E_T resolution*
- ➢*Lepton tagging*
- ➢*Understanding of backgrounds*
- ➢*Good signal/background separation*



Higgs Search Channels – *High Mass*



gg → *H* → *WW* → *l l* νν

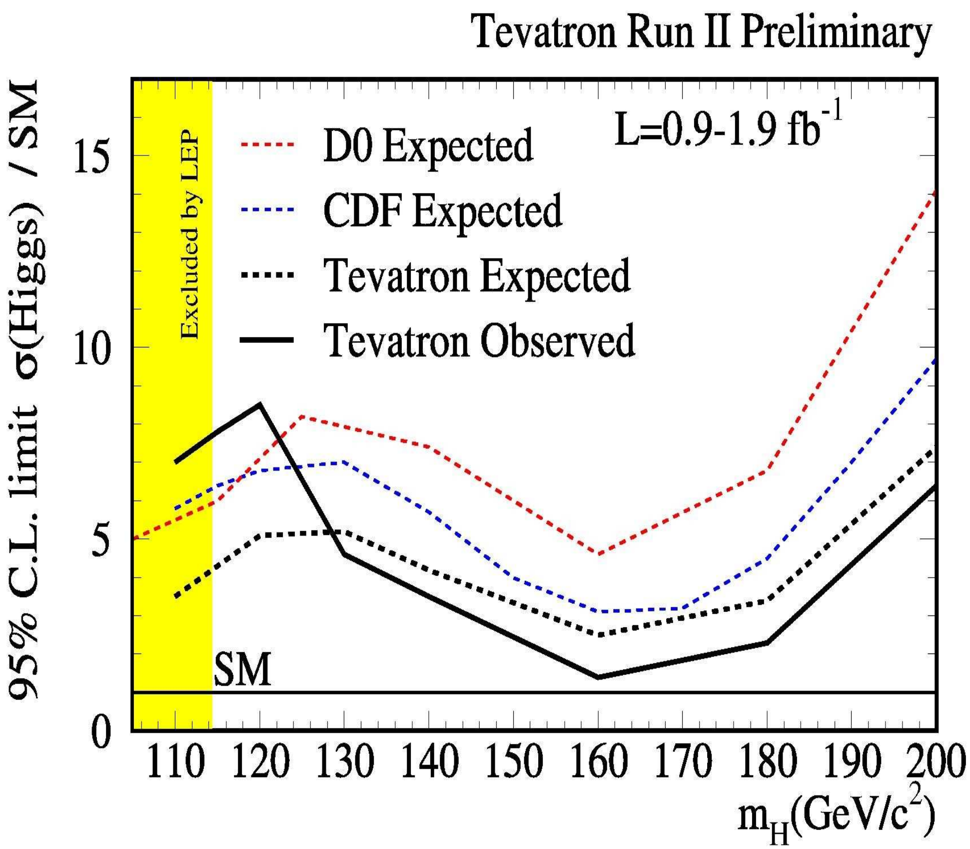


Select events with two high p_T leptons (*ee*, *e*μ, μμ)

Initial analysis used simple cuts to separate signal from background

Newer analyses are greatly improved by using more sophisticated techniques to separate signal from background

Progress on Higgs Limits



Need to combine results from many channels and from both CDF and DØ to maximize sensitivity

Improvements arising mainly from the use of sophisticated techniques to separate signal from background

Matrix Element, Neural Net, Boosted Decision Trees…

Combined results for lepton photon 2007 do not include newer DØ results

The Fermilab group is becoming more involved in Higgs searches

Leveraging past experience
→ *Triggering, Jet reconstruction, Single Top, Muons…*

Conclusion

- The Data Acquisition and Trigger system has been improved to handle the expected higher trigger rates and larger data volumes

- Personnel is available to continue operations and analysis of the data

- The Tevatron has a broad and active physics program

- Improvement are driven by both "doubling statistics and halving systematics"

- What we learn at the Tevatron is directly applicable to the LHC

The Fermilab Group plays a vital role in the ongoing success of CDF