



Tevatron Era - Status and Future Prospects

Outline

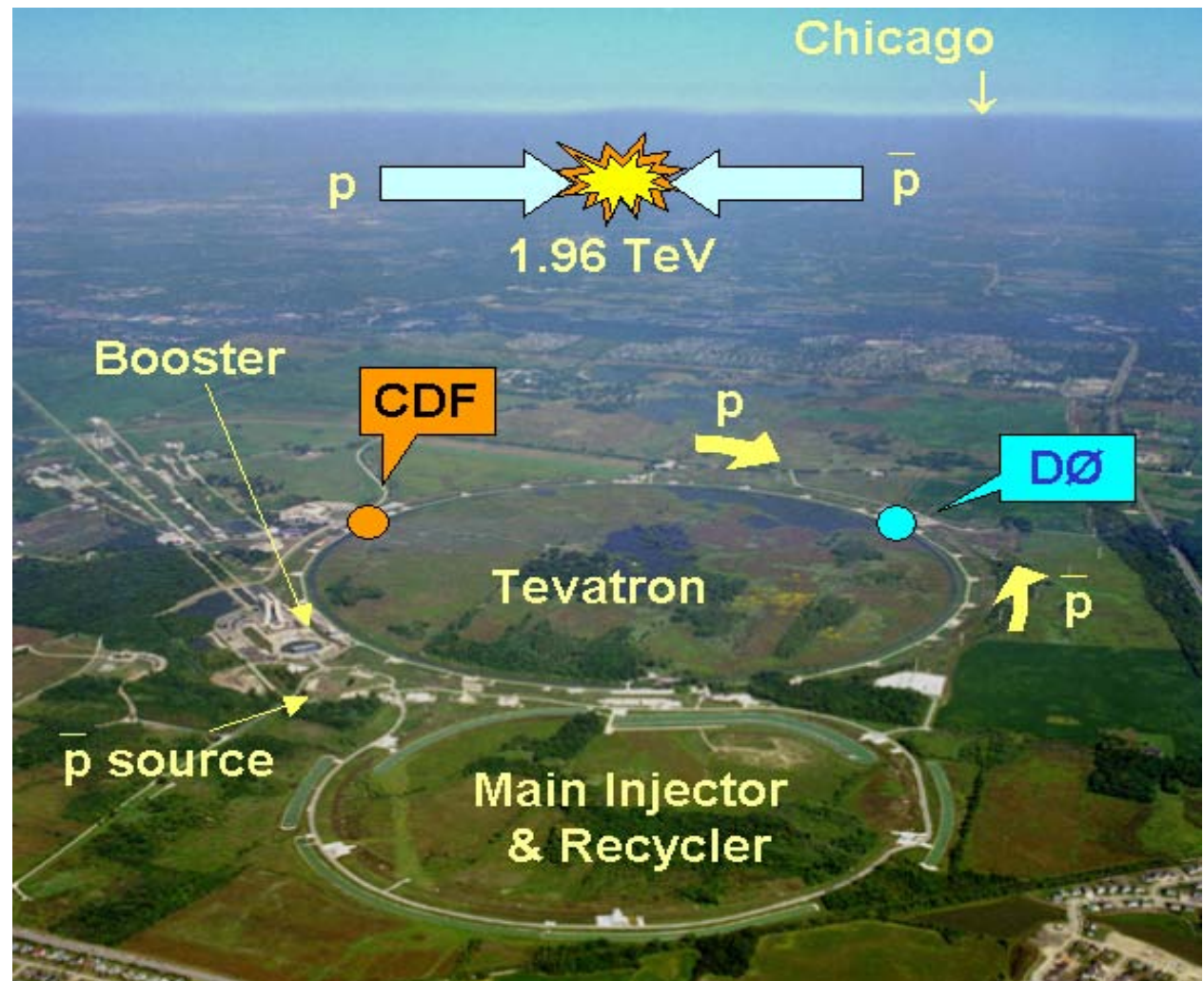
Program goals

Detector and data

Highlights of the recent results

Future experimental program

Summary



La Thuile Round Table Discussion

March 3, 2010

Dmitri Denisov, Fermilab

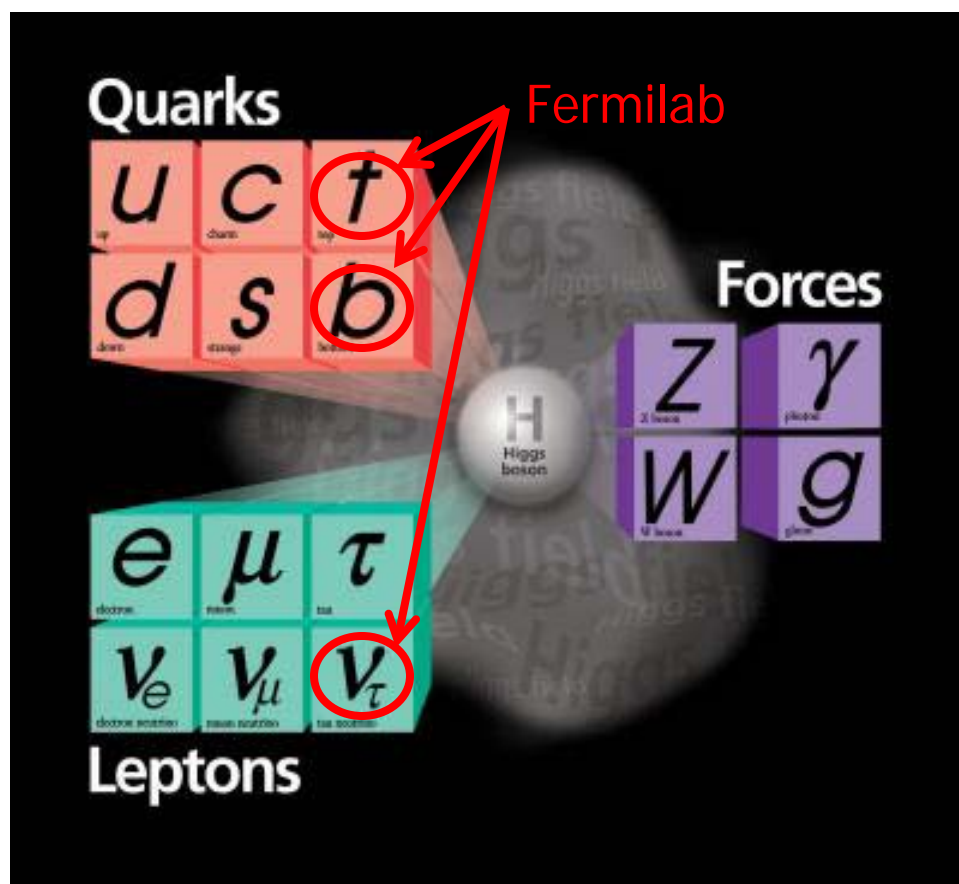
Tevatron Physics Goals

Precision tests of the Standard Model

- Weak bosons, top quark, QCD, B-physics...

Search for particles and forces beyond those known

- Higgs, supersymmetry, extra dimensions....



Addressing Fundamental Questions Facing Science

Origin of the mass?

Quark sub-structure?

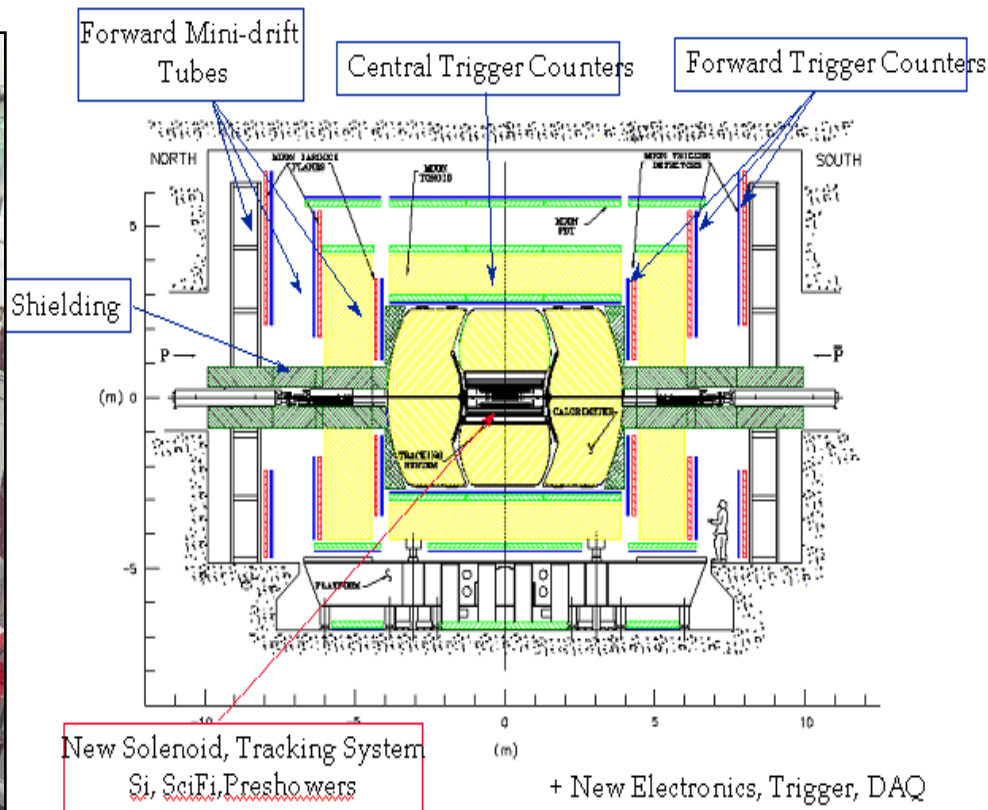
Matter-antimatter asymmetry?

What is cosmic dark matter?

SUSY?

What is space-time structure?

Extra dimensions?...



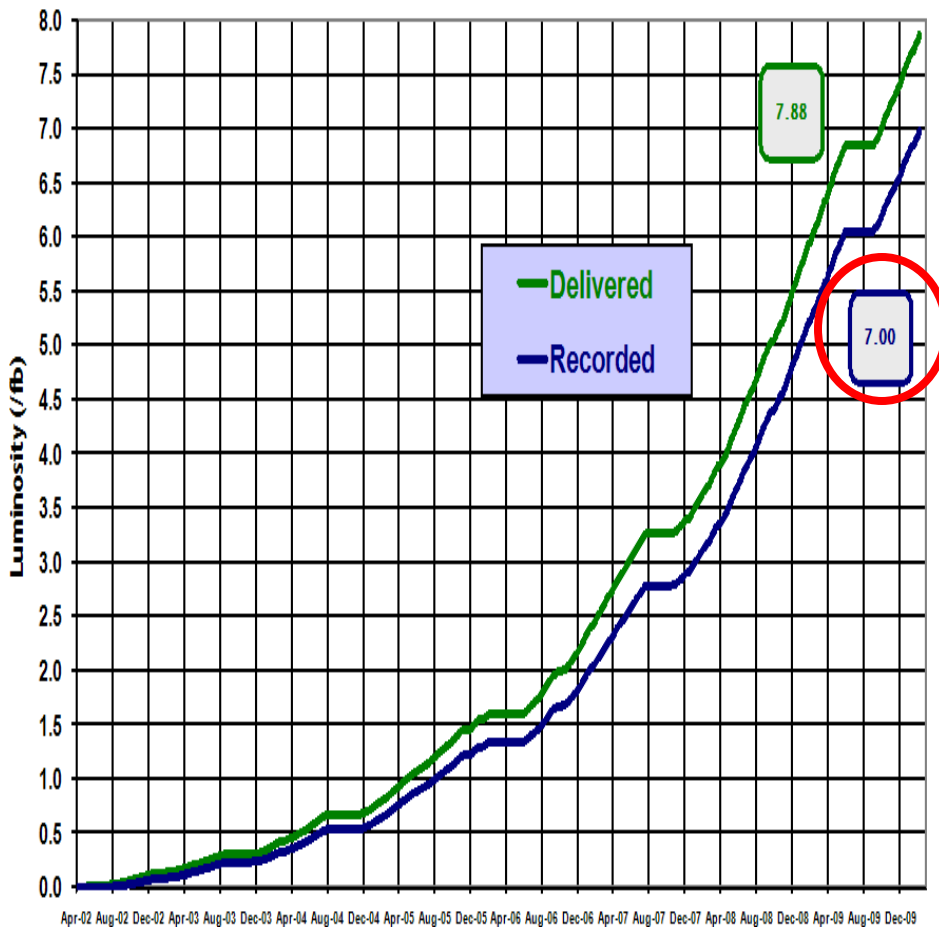
Silicon Detector
2 T solenoid and central fiber tracker
Large coverage muon system

**Driven by physics goals detectors are becoming "similar":
silicon, central magnetic field, hermetic calorimetry and muon systems**



Run II Integrated Luminosity

19 April 2002 - 23 February 2010



2002

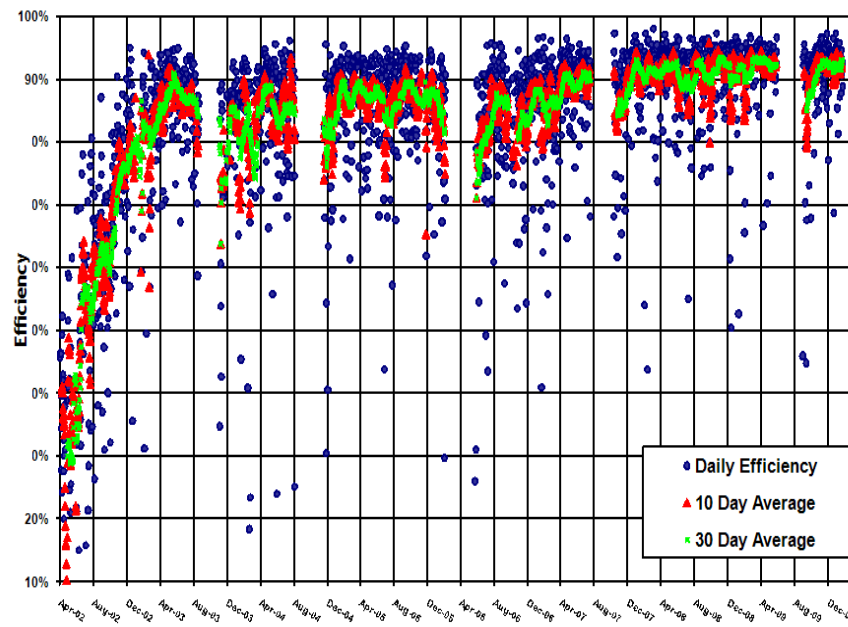
February 2010

- Smoothly recording physics data
 - Typical week is above 50 pb^{-1}
 - 7 fb^{-1} recorded!
- 90% data taking efficiency



Daily Data Taking Efficiency

19 April 2002 - 7 February 2010

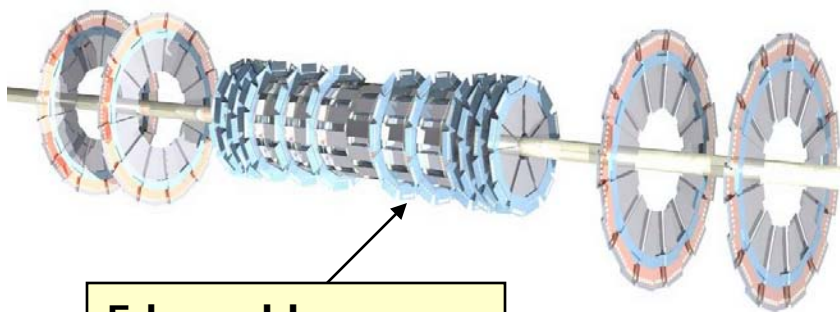


2002

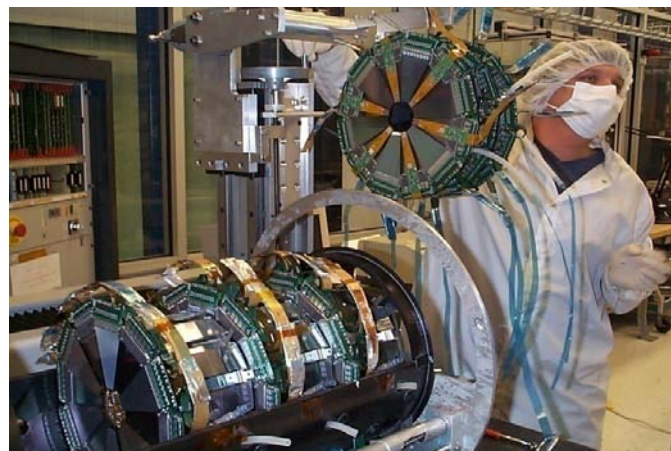
February 2010



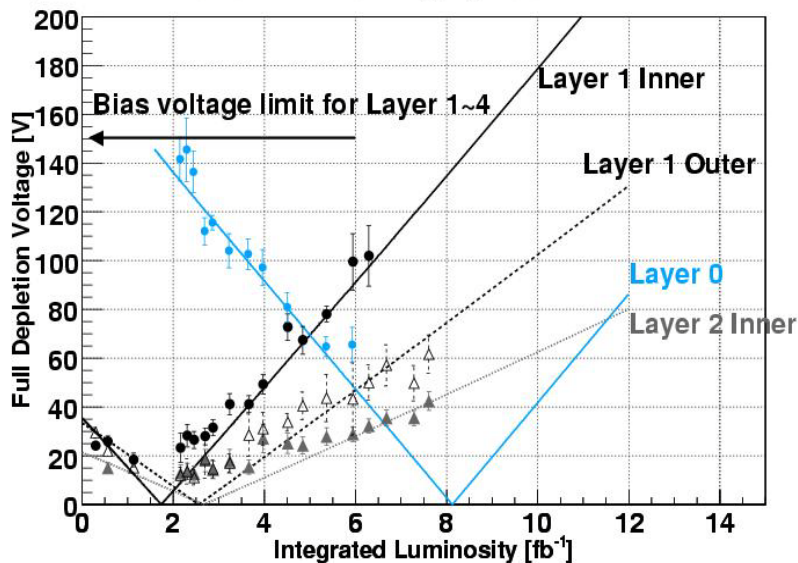
Silicon Vertex Tracker



5 barrel layers
800k channels
~ 10 μm precision



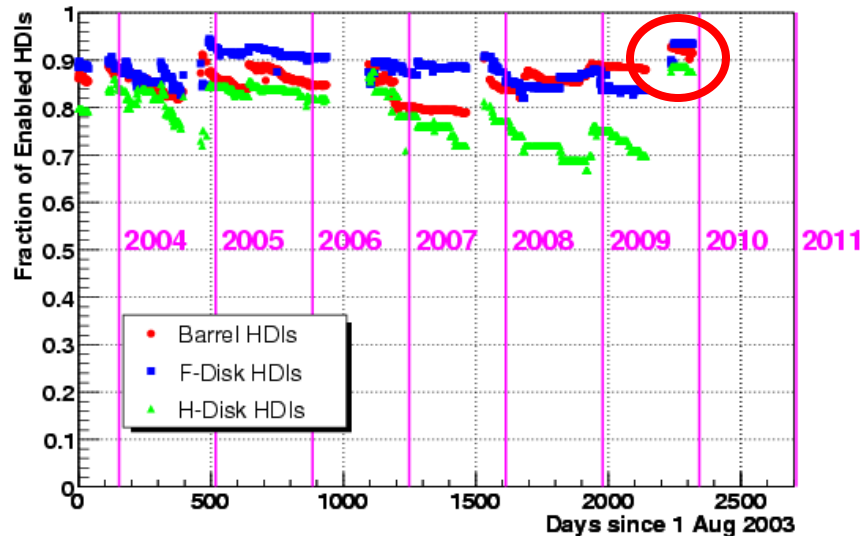
Ø Silicon Detector Radiation Aging Status as of Jan. 2010



Radiation dose \rightarrow no issues for running up to 12 fb^{-1} of delivered luminosity

Detector is working well
Stable number of operating sensors

Enabled HDIs versus time (December 6, 2009)





The DØ Collaboration



DØ today is international Collaboration of 500 physicists from 19 nations



1984



2001



2008



AZ U. of Arizona
CA U. of California, Riverside
FL Florida State U.
IL Fermilab
U. of Illinois, Chicago
Northern Illinois U.
Northwestern U.
IN Indiana U.
U. of Notre Dame
Purdue U. Calumet
IA Iowa State U.
KS U. of Kansas
Kansas State U.
LA Louisiana Tech U.
MD U. of Maryland
MA Boston U.
Northeastern U.
MI U. of Michigan
Michigan State U.
MS U. of Mississippi
NE U. of Nebraska
NJ Princeton U.
Rutgers U.
NY Brookhaven Nat. Lab.
Columbia U.
SUNY, Buffalo
SUNY, Stony Brook
U. of Rochester
OK Langston U.
U. of Oklahoma
Oklahoma State U.
RI Brown U.
TX Southern Methodist U.
U. of Texas at Arlington
Rice U.
VA U. of Virginia
WA U. of Washington



U. de Buenos Aires



LAFEX, CBPF, Rio de Janeiro
State U. do Rio de Janeiro
U. Federal do ABC, São Paulo
State U. Paulista, São Paulo



Simon Fraser U.
York U.



U. of Science and Technology
of China, Hefei



U. de los Andes, Bogotá



Charles U., Prague
Czech Tech. U., Prague
Academy of Sciences, Prague



U. San Francisco de Quito



LPC, Clermont-Ferrand
ISN, IN2P3, Grenoble
CPPM, IN2P3, Marseille
LAL, IN2P3, Orsay
LPHNE, IN2P3, Paris
DAPHNIA/SPP, CEA, Saclay
IRIS, Strasbourg
IPN, IN2P3, Villeurbanne



RWTH Aachen
Bonn U.
Freiburg U.
Göttingen U.
Mainz U.
LMU München
Wuppertal U.



Punjab U. Chandigarh
Delhi U. Delhi
Tata Institute, Mumbai

The DØ Collaboration



University College, Dublin



KDI, Korea U., Seoul
Sungkyunkwan U., Suwan



CINVESTAV, Mexico City



FOM-NIKHEF, Amsterdam
U. of Amsterdam / NIKHEF
U. of Nijmegen / NIKHEF



JINR, Dubna
ITEP, Moscow
Moscow State U.
IHEP, Protvino
PNPI, St. Petersburg



Stockholm U.
Uppsala U.



National U. of Kiev

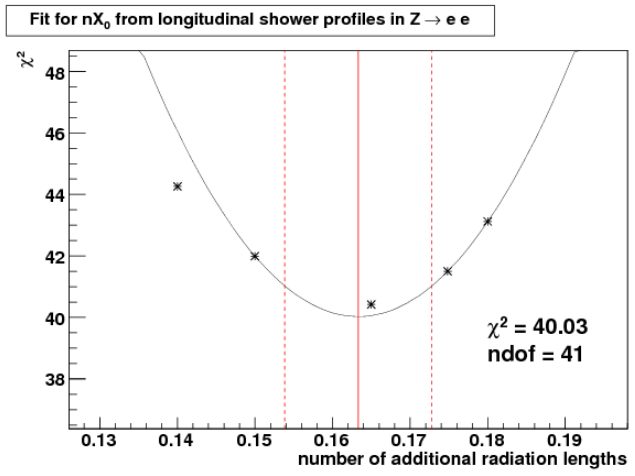
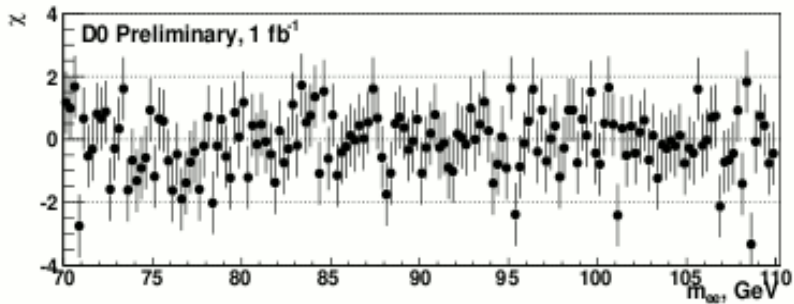
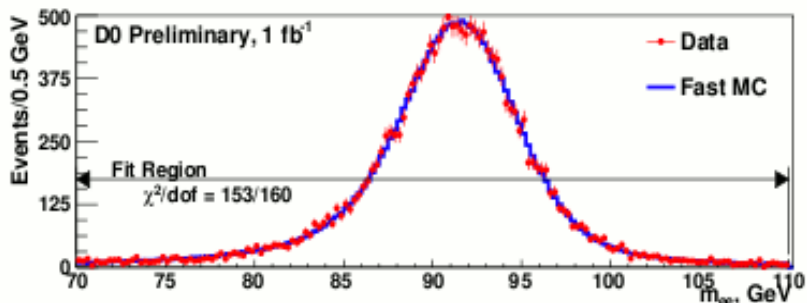
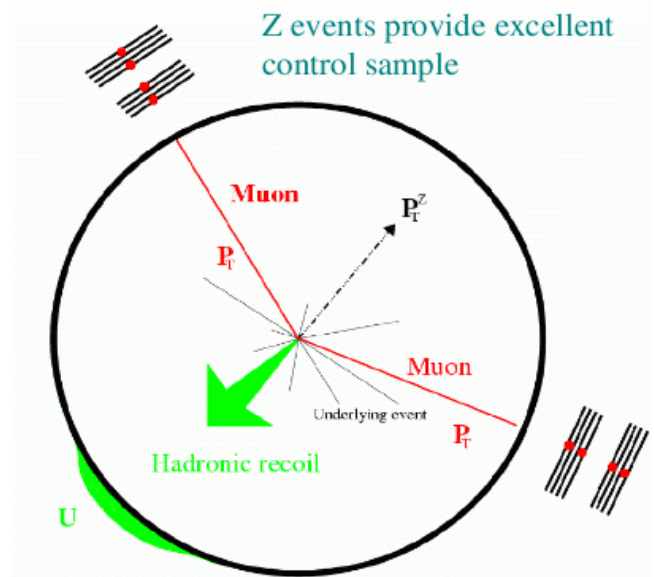


Imperial College London
Lancaster U.
U. of Manchester

- Excellent example of productive international cooperation
 - 50/50 mix of US and non-US groups
- ~50% of the collaboration are students and postdocs

Algorithms – “Test Beam at Collider”

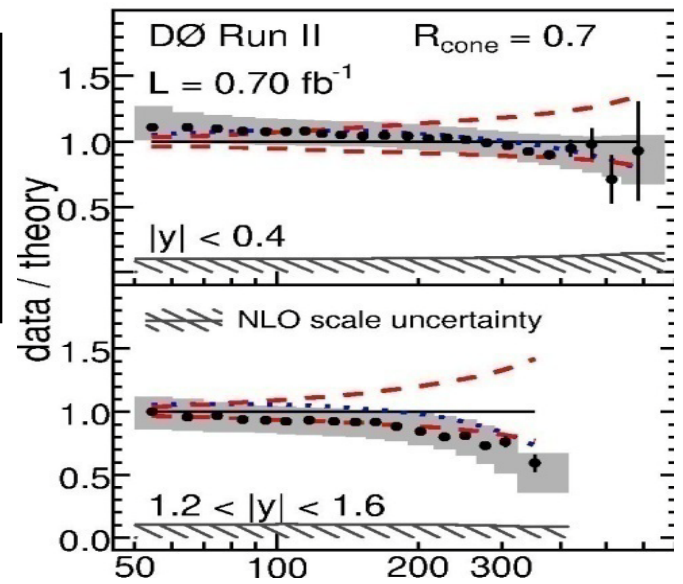
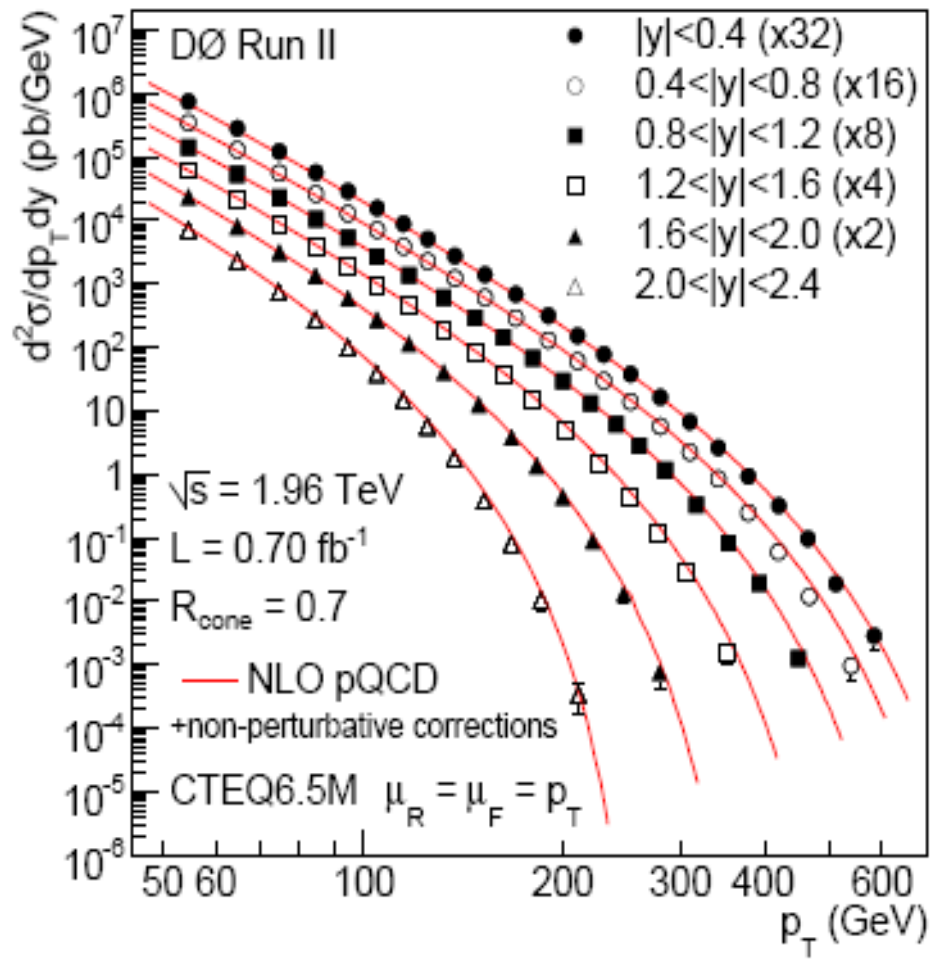
- Major efforts have been devoted at DØ to develop methods of particle identification
 - Electrons, muons, jets, charged particles, missing energy
- Large luminosity provides accurate “in situ” calibrations of the detector
 - “Standard candles”



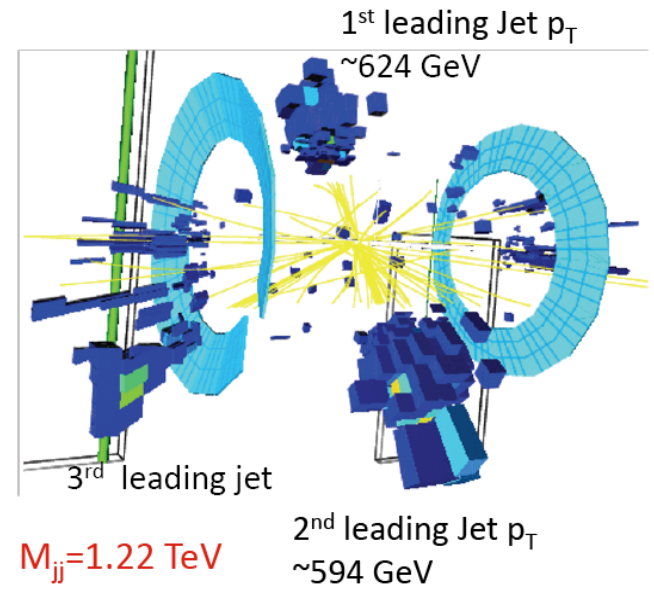
Calorimeter calibration to ~0.05% accuracy and measurement of the material in the detector within 0.01X₀

QCD Studies

- Use parton scattering to study proton structure
 - Rutherford style experiments at 10^{-16} cm
- Jet cross sections, di-jet mass studies, angular distributions in η and ϕ



1 TeV energy deposition!



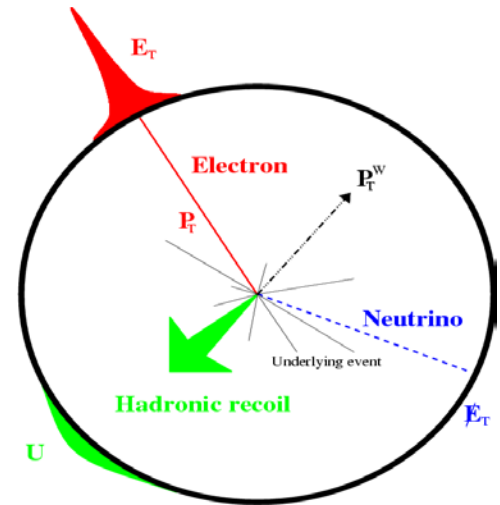
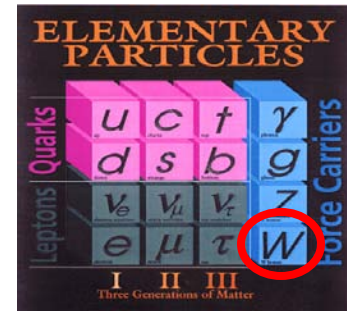
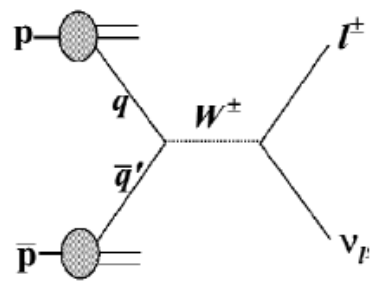
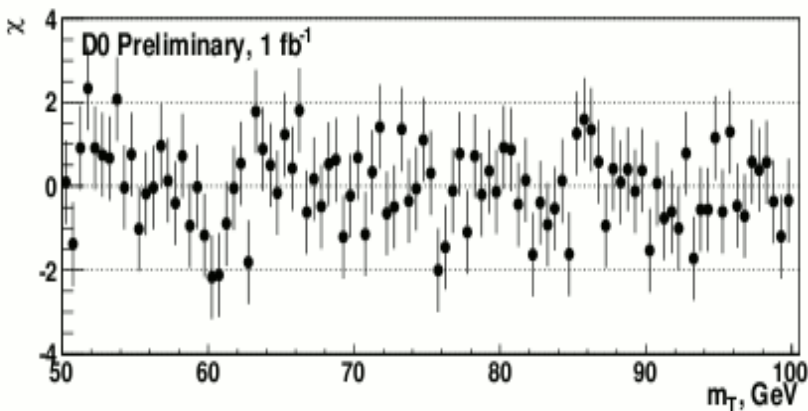
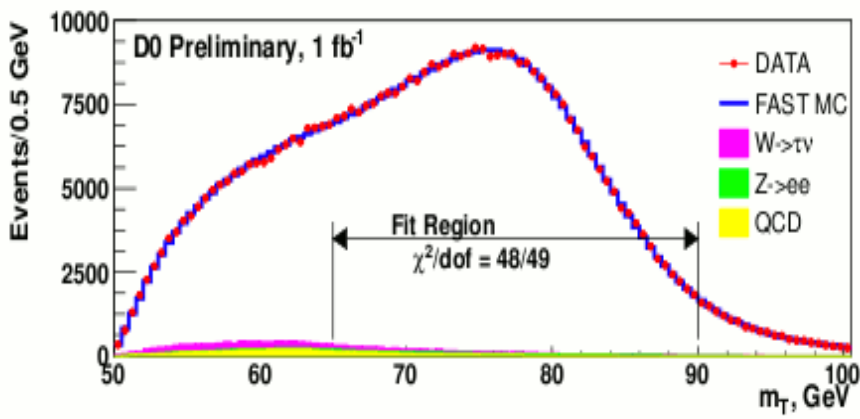


Electroweak Physics



Indirectly constrain new physics through precision measurements of parameters
Measure single and multi-boson production, W mass, W production asymmetry,...

World's most precise W mass measurement



World average is now
80.399 ± 0.023 GeV (0.025%)
Provides strict Higgs mass constraints

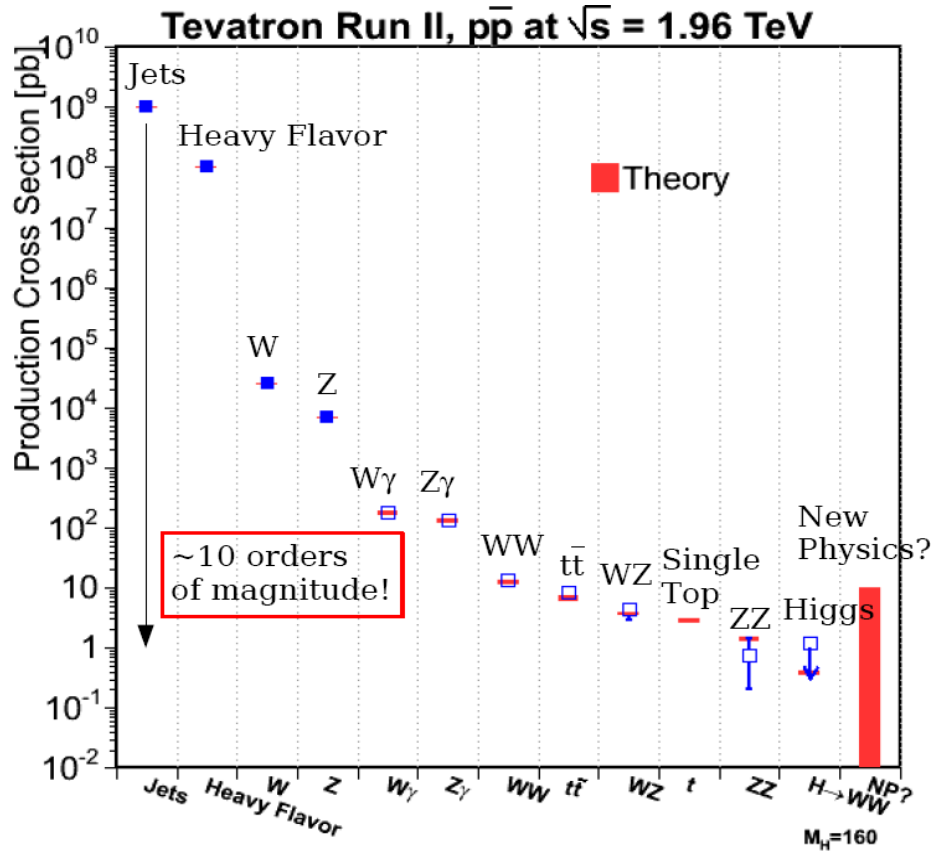
$M_W = 80.401 \pm 0.021(\text{stat}) \pm 0.038(\text{syst}) \text{ GeV}$



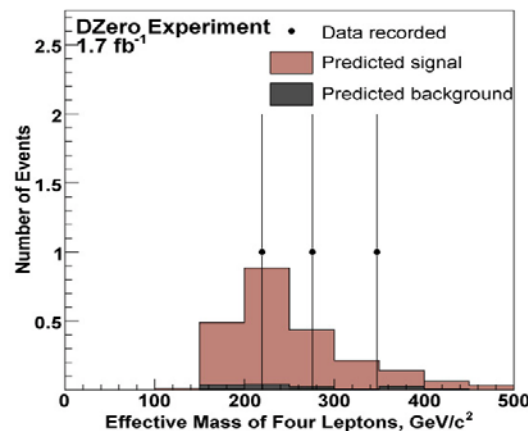
Studies of di-boson Production



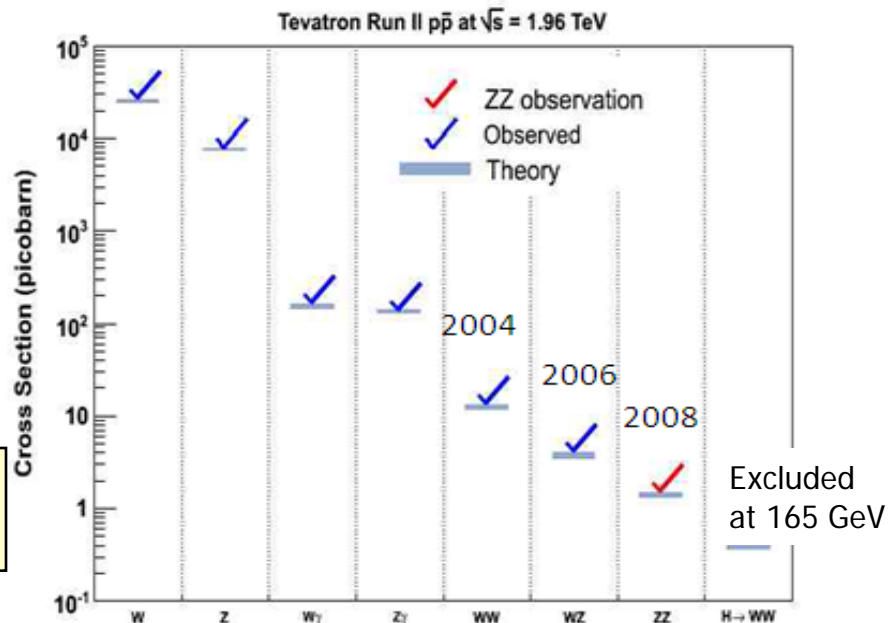
Detect very rare processes, search for anomalous vector boson couplings and develop experimental methods for Higgs hunting



Discovery of ZZ production



ZZ cross section of $1.6 \pm 0.1 \text{ pb}$ is similar to anticipated Higgs cross section

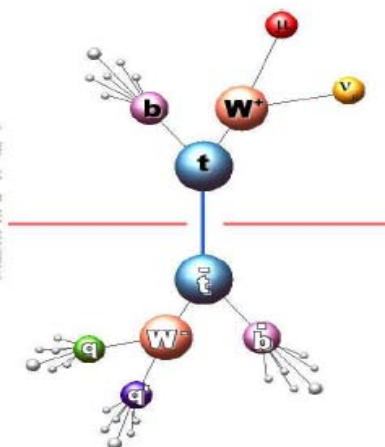




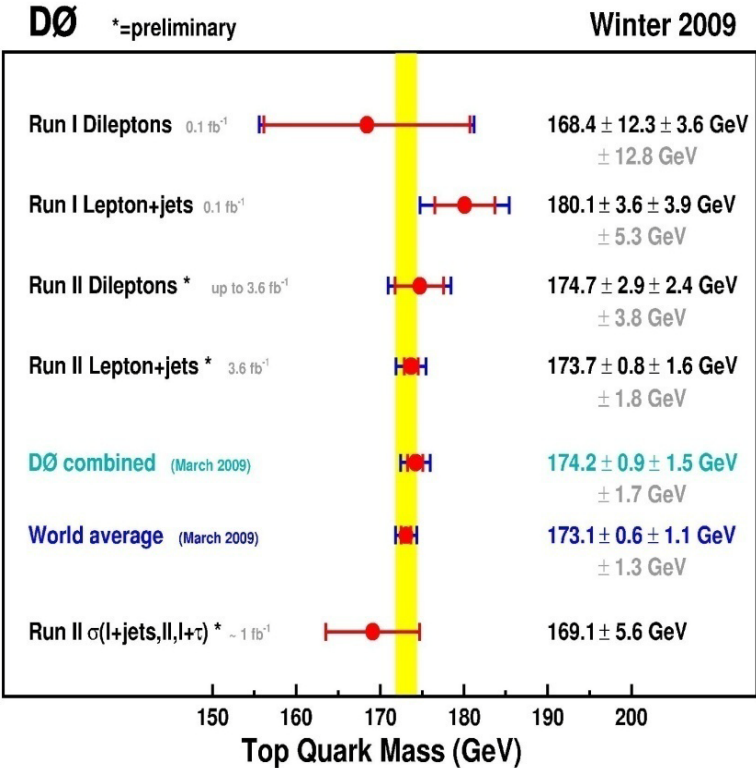
Top Quark Mass Measurement



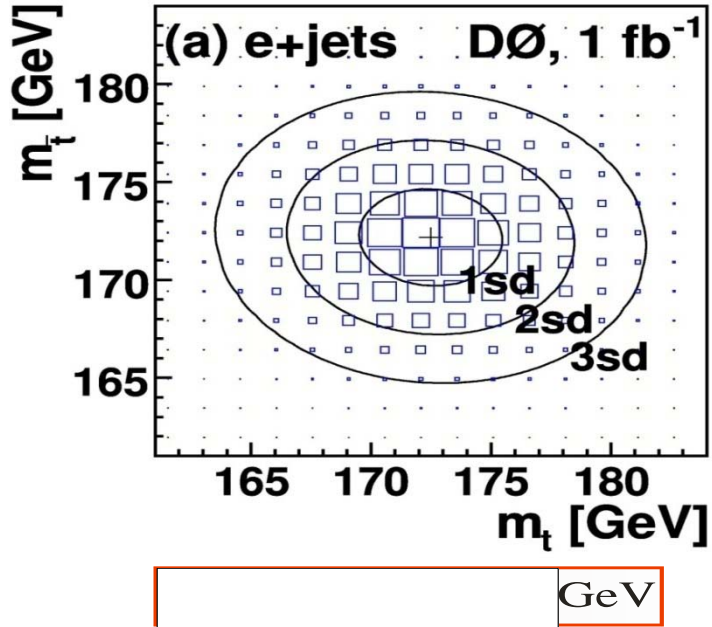
Top mass is fundamental parameter of the Standard Model measured in many different decay channels



First measurement of quark-anti quark mass difference: CPT test in quark sector



DØ and CDF combined top mass
 $m_t = 173.1 \pm 1.2 \text{ GeV}$
0.7% accuracy
Best (of any) quark mass measurement!





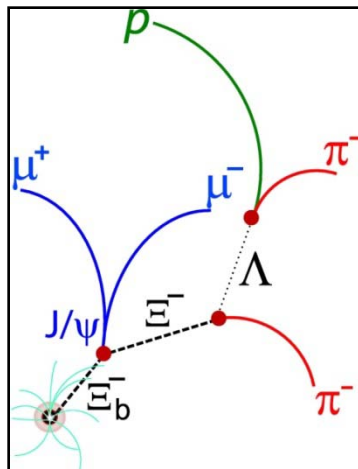
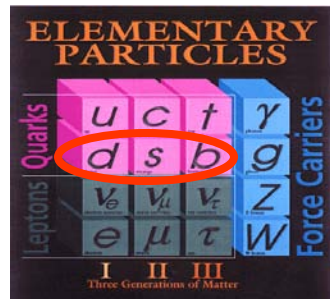
b Quark Studies

High b quark cross section: $\sim 10^{-3} \sigma_{\text{tot}}$

$\sim 10^4$ b's per second produced

All b containing species are produced

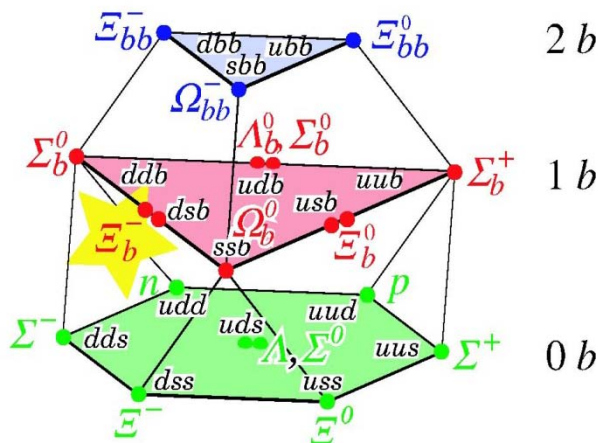
$B^\pm, B^0, B_s, B_c, \Lambda_b \dots$



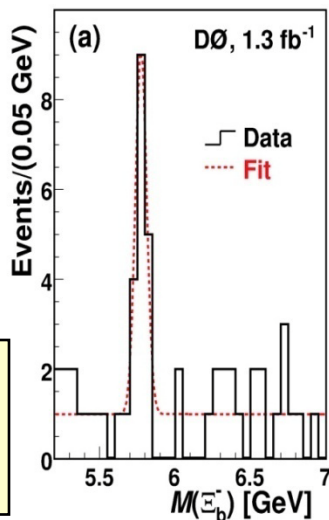
2 b

1 b

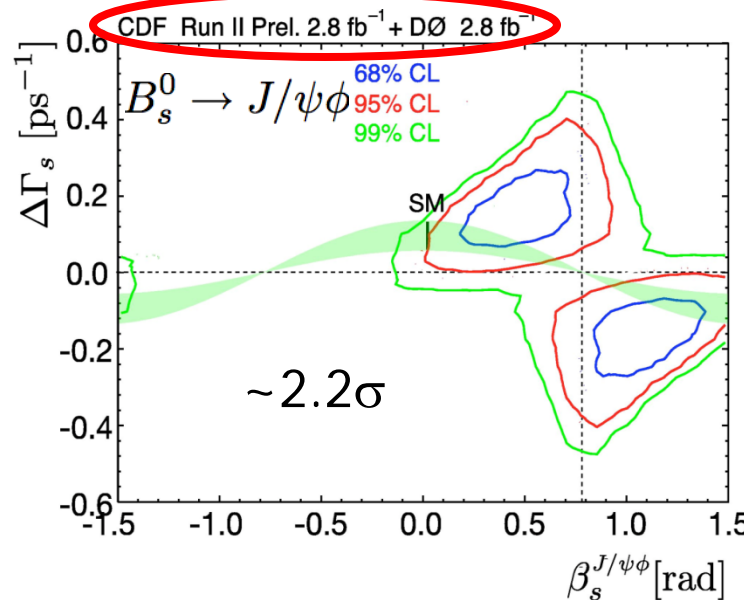
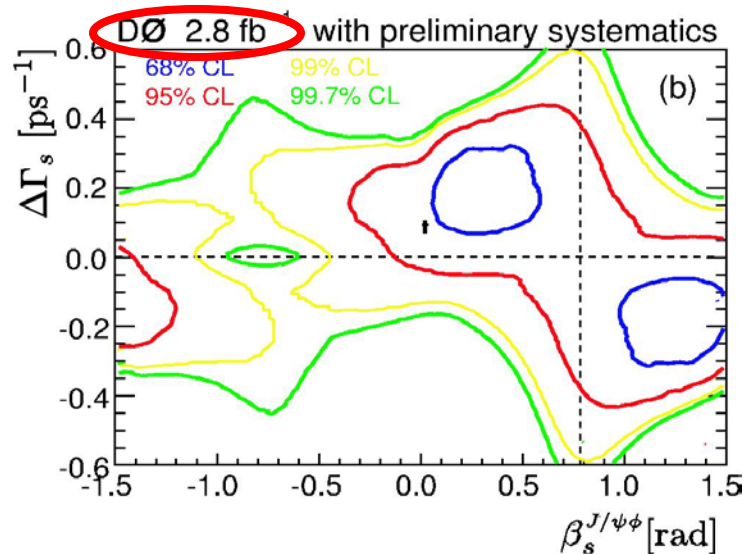
0 b



First particle with quarks from all three generations observed!

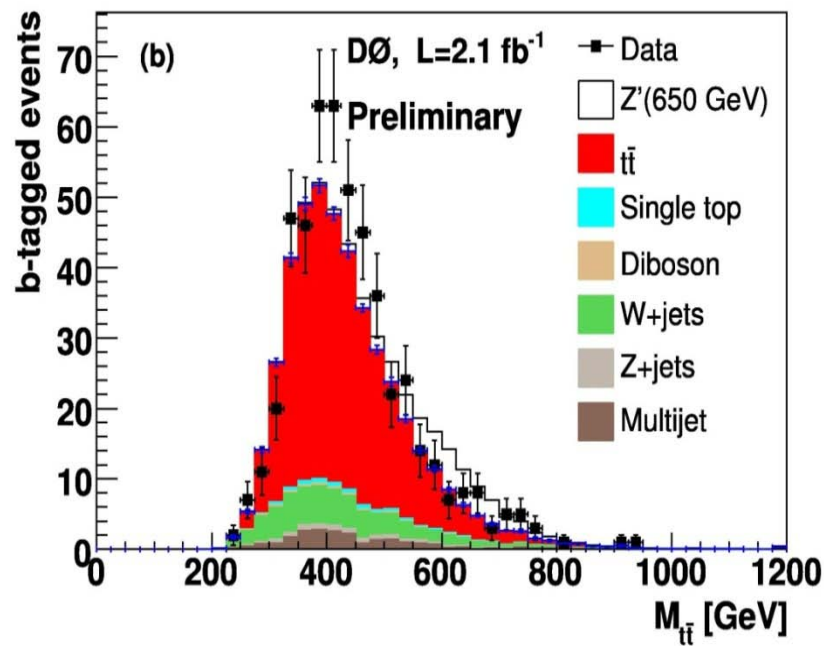
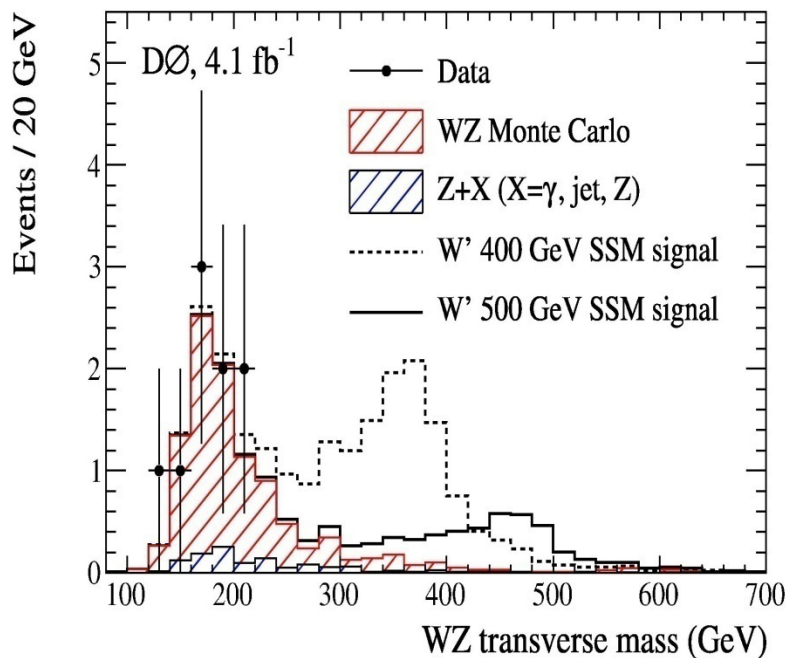
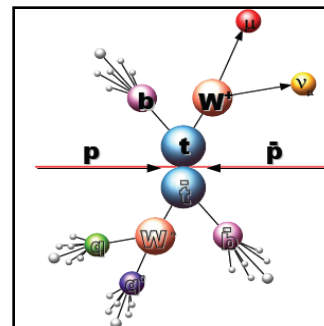
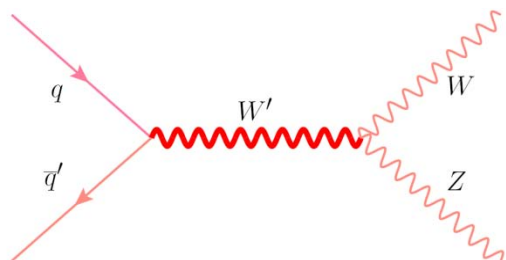


Hint of physics beyond Standard Model in $B_s^0 \rightarrow J/\psi\phi$ decay?



Search for New Phenomena

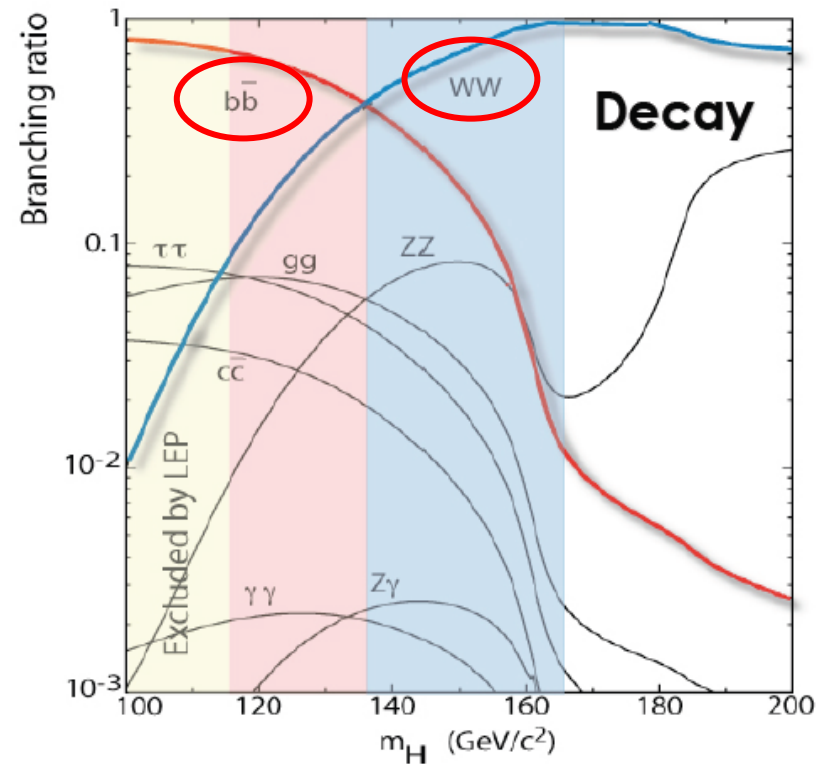
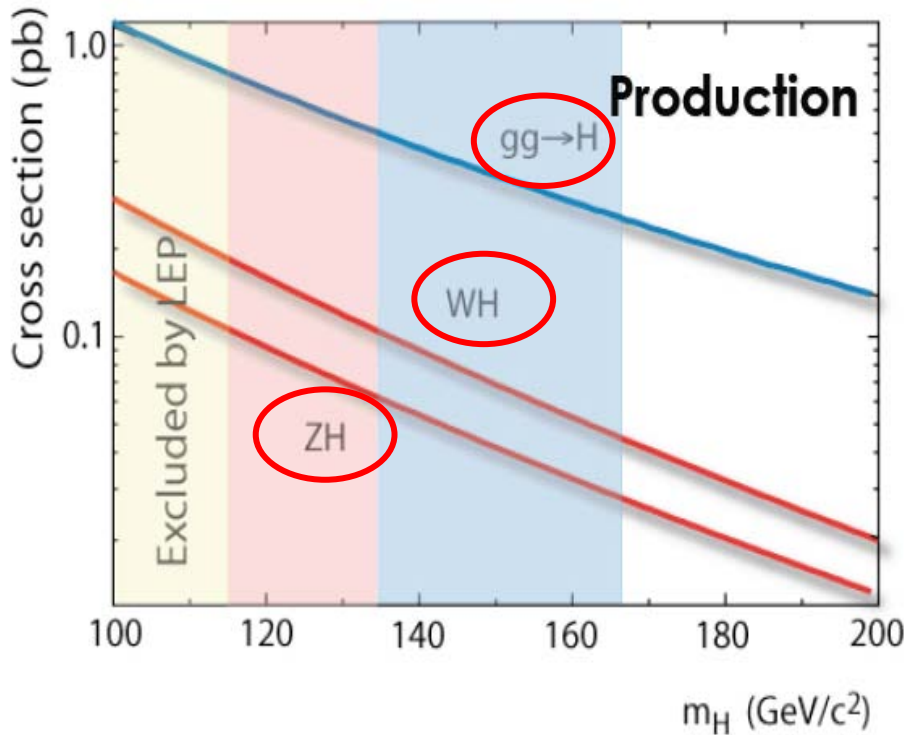
Recipe: search for irregularities in effective mass spectra or other kinematic parameters to find events not described by the Standard Model



In many searches reaching masses of $\sim 1\text{TeV}$ – $\frac{1}{2}$ of the Tevatron center of mass!



Higgs Production and Decays at the Tevatron



Production cross sections

- in the 1 pb range for $gg \rightarrow H$
- in the 0.1 pb range for associated vector boson production

Decays

- bb for $M_H < 130$ GeV
- WW for $M_H > 130$ GeV

Search strategy:

- $M_H < 130$ GeV associated production and Higgs to bb decay
- $M_H > 130$ GeV $gg \rightarrow H$ production with decay to WW

At 115 GeV ~5 inclusive Higgs bosons would be produced at Tevatron per day
Separation from large backgrounds is the major challenge



Combining Two Experiments - exclusion!



Tevatron Run II Preliminary, $L=2.0-5.4 \text{ fb}^{-1}$

95% CL Limit/SM

10

1

LEP Exclusion

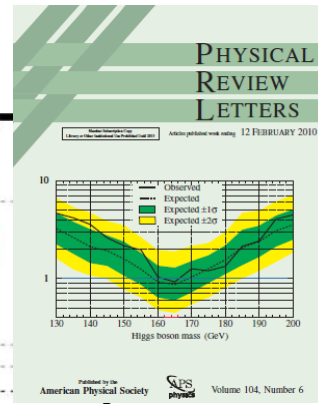
Tevatron Exclusion

- Expected
- Observed
- ±1σ Expected
- ±2σ Expected

SM=1

November 6, 2009

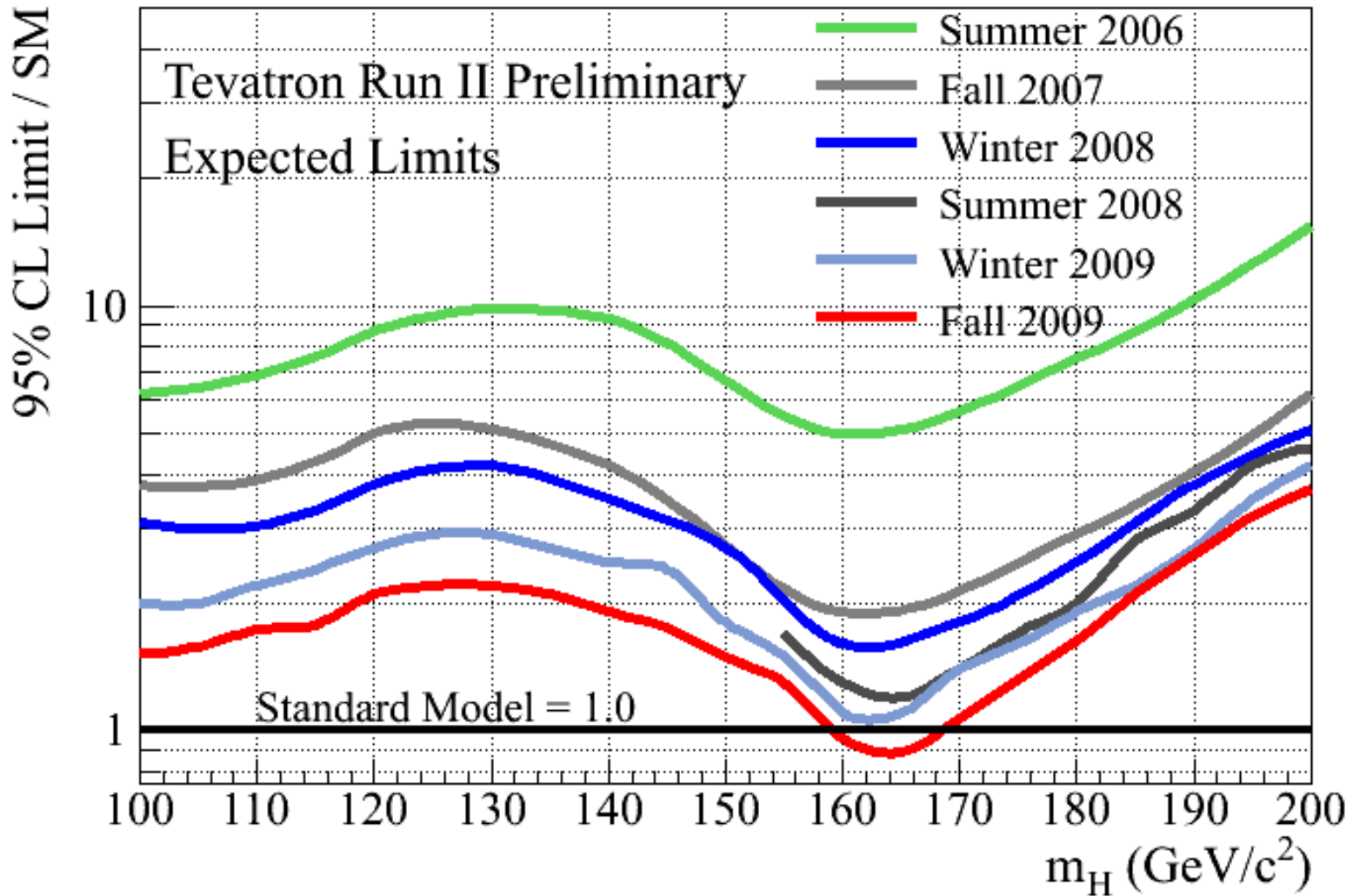
100 110 120 130 140 150 160 170 180 190 200
 $m_H(\text{GeV}/c^2)$



Tevatron is sensitive to Higgs boson and already excluded masses around 165 GeV



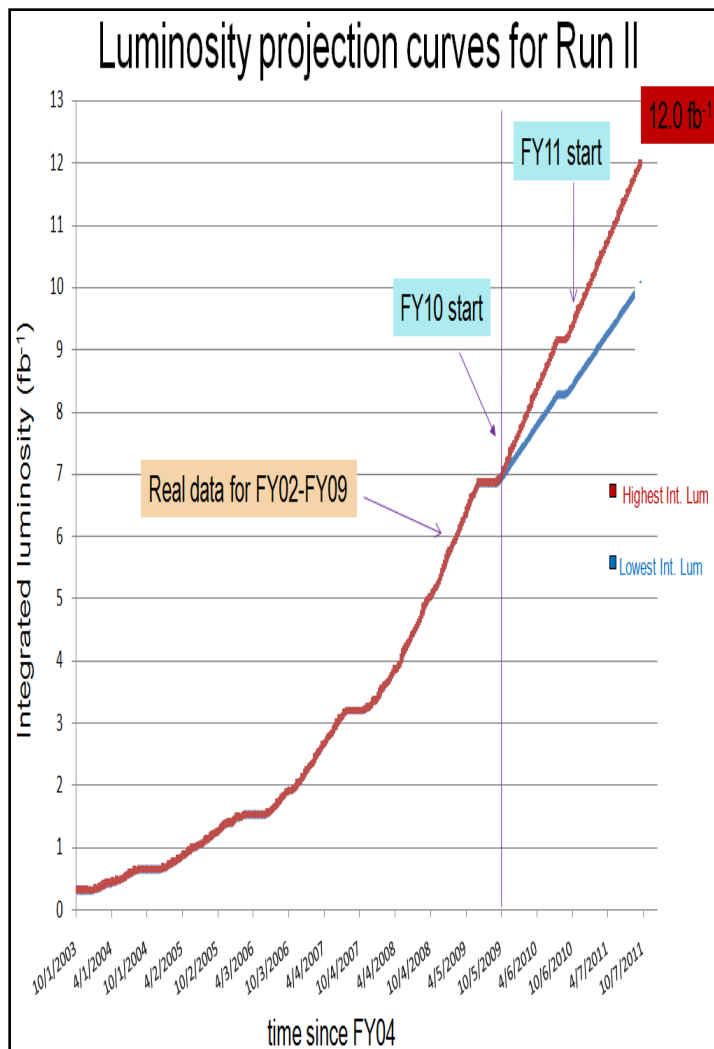
Progress with Higgs limits at the Tevatron



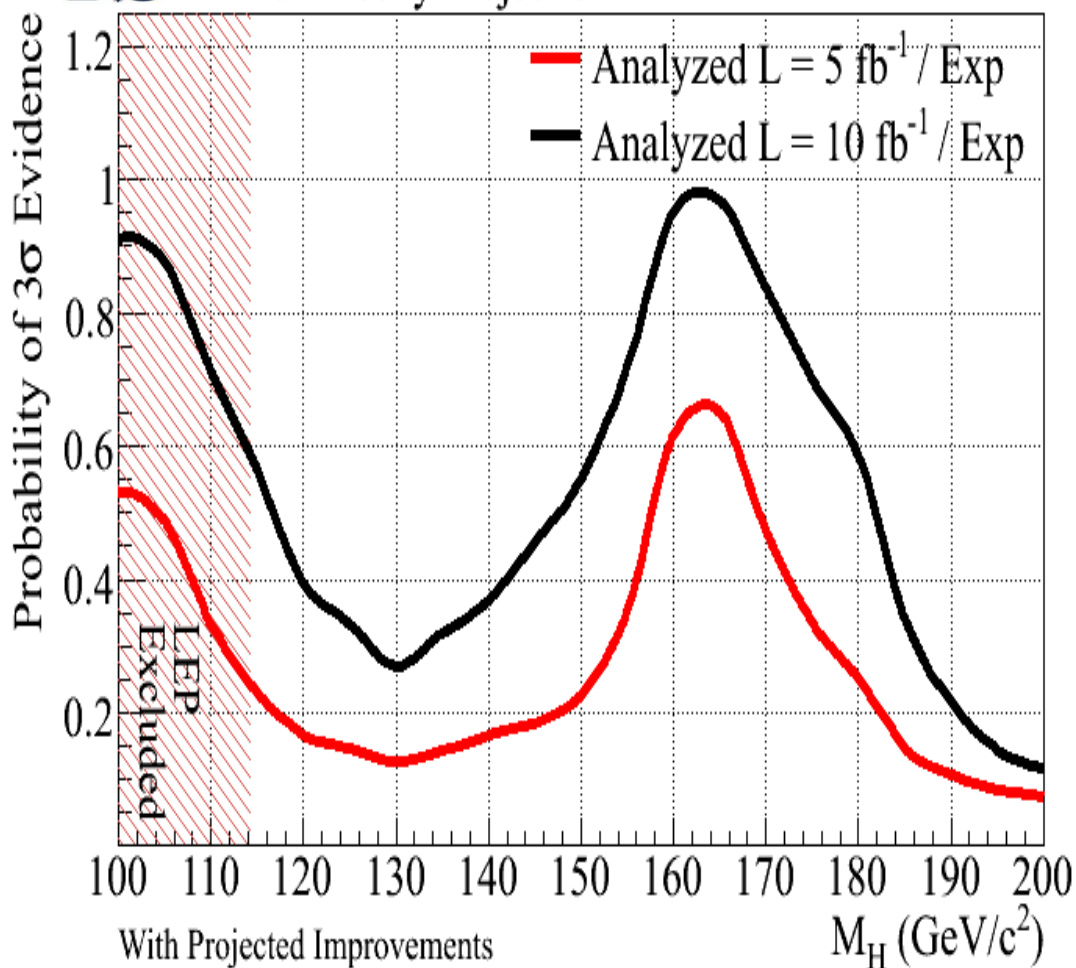
Steady progress with increase in data set and analysis experience
Factor of 1.8 from prediction at Higgs mass of 115 GeV



Tevatron Standard Model Higgs Projections

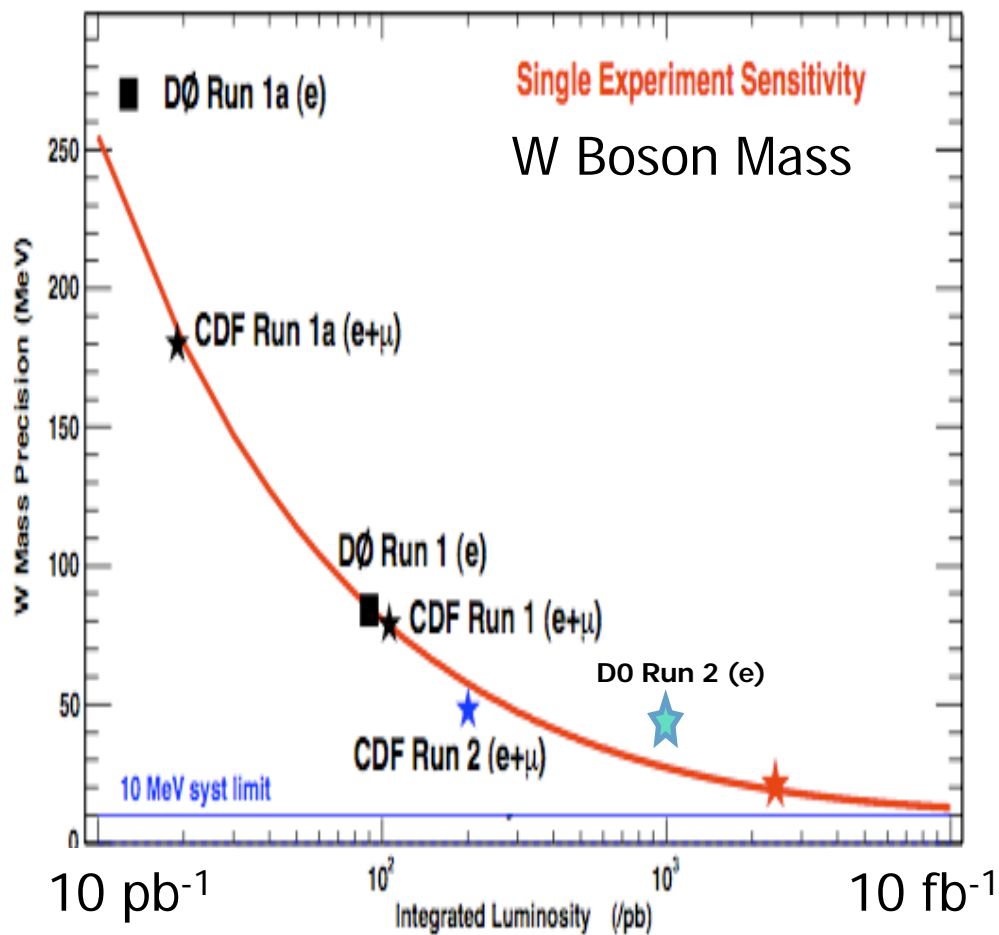


$\times 2$ Luminosity Projection



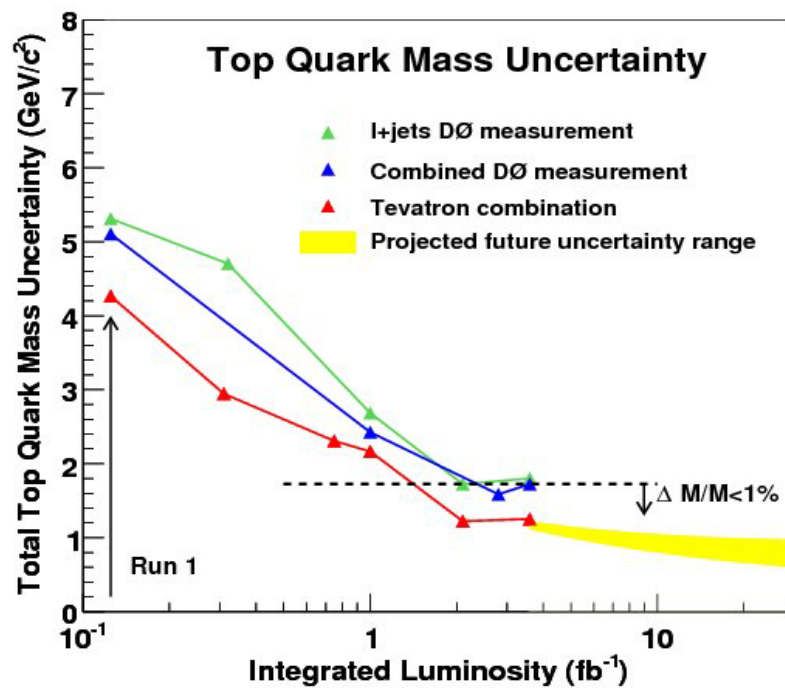
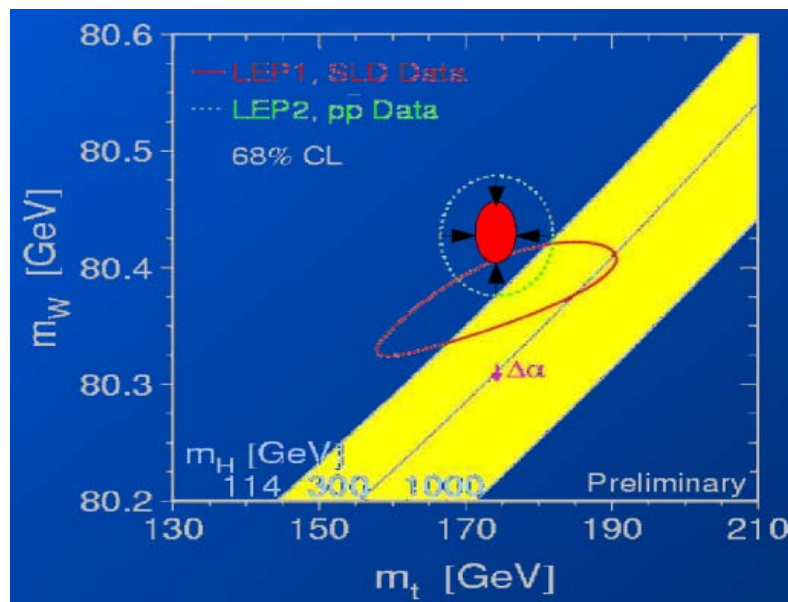
With 10 fb^{-1} available for analysis by the end of 2011 it will be possible to either exclude at 95% over entire allowed mass range or... see hints of the Higgs boson!

Tevatron Projections



**15 MeV error on W boson mass and no changes in the mean value:
Higgs exclusion with $M_H < 117$ GeV**

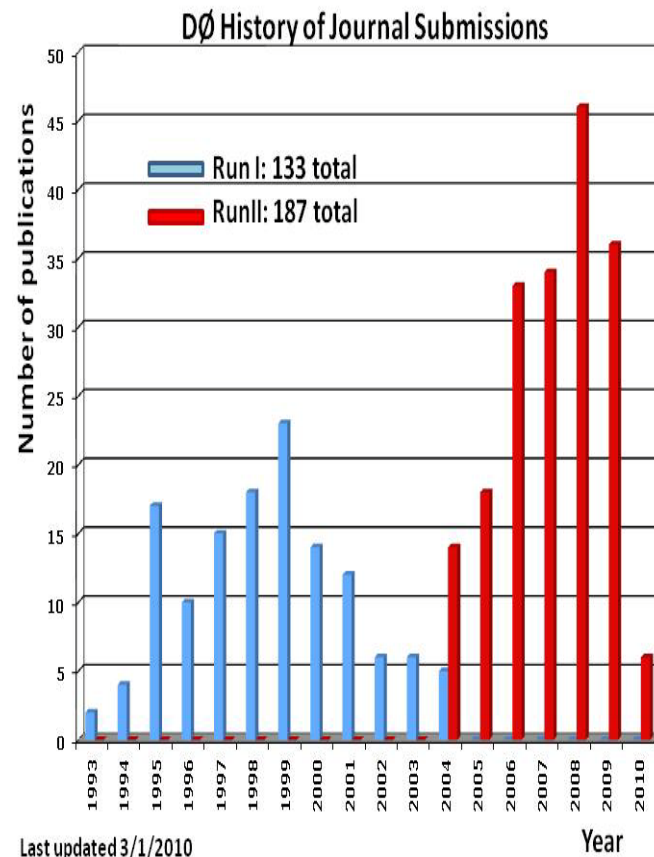
Many other exciting studies progressing



Summary: 2010-2011

Congratulations to our CERN colleagues with LHC startup and first impressive results!

- Tevatron run in 2011 is confirmed
 - Expect 10 fb^{-1} on tapes for analysis, well understood detectors
 - 100+ studies in progress
- Excellent chance to nail down "2 sigma" discrepancies
- Legacy measurements in progress
 - High precision, unique for ppbar
- Higgs search is in progress
 - $\sim 165 \text{ GeV}$ excluded, getting sensitive at low mass



Natural opportunity for both Tevatron and LHC to produce excellent results over next two years!

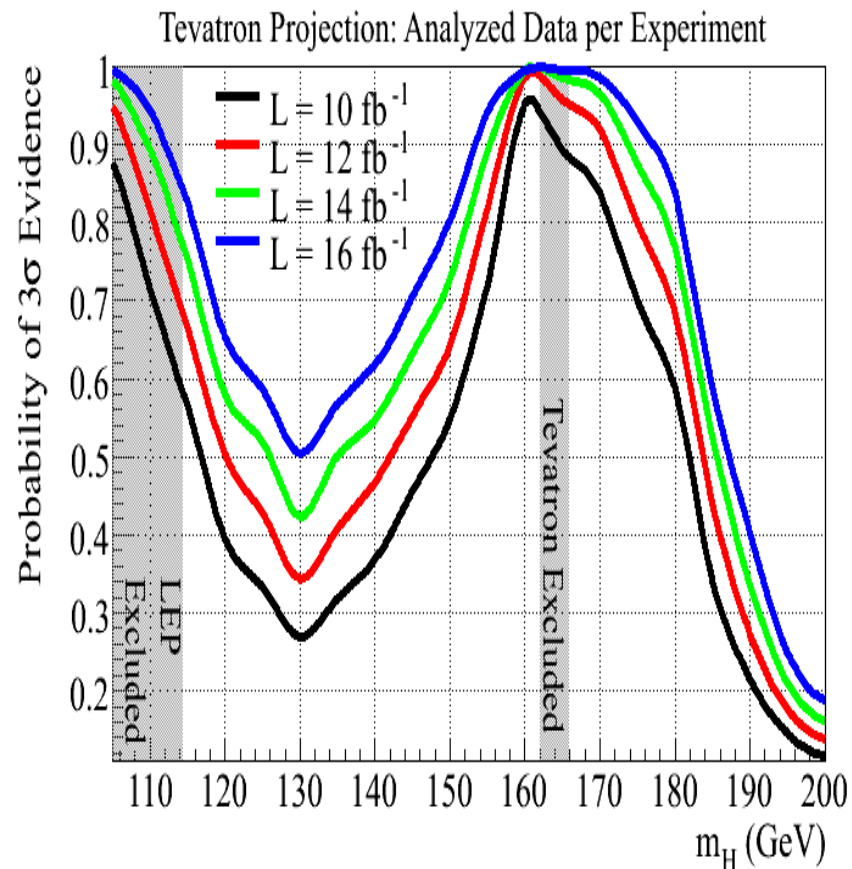


Looking Beyond 2011



- Many topics have to be considered
 - Physics potential
 - Low mass Higgs sensitivity is steadily increasing
 - Detectors longevity
 - Collaborations strength
 - LHC progress
 - Fermilab's long term plans

- Discussing different options
 - Continue integrating luminosity?
 - Have Tevatron and detectors upgrades?
- Started efforts to study all of the above



It is a bad plan which admits of no modification

Publius Syrus, 100 BC, Italy



Back up

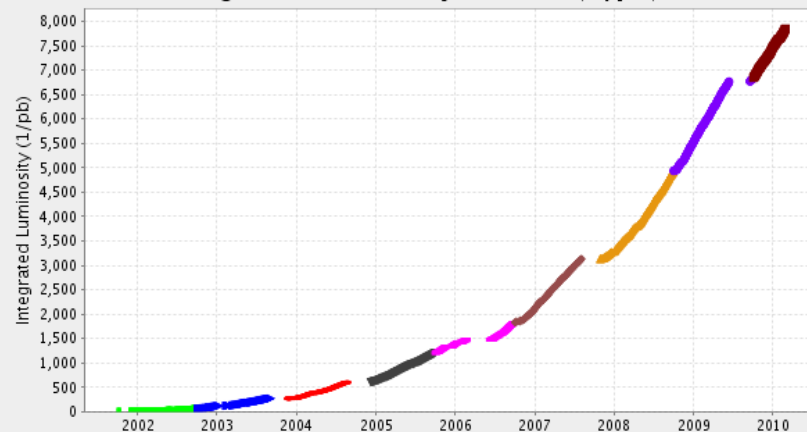


Fermilab Accelerator Complex Status



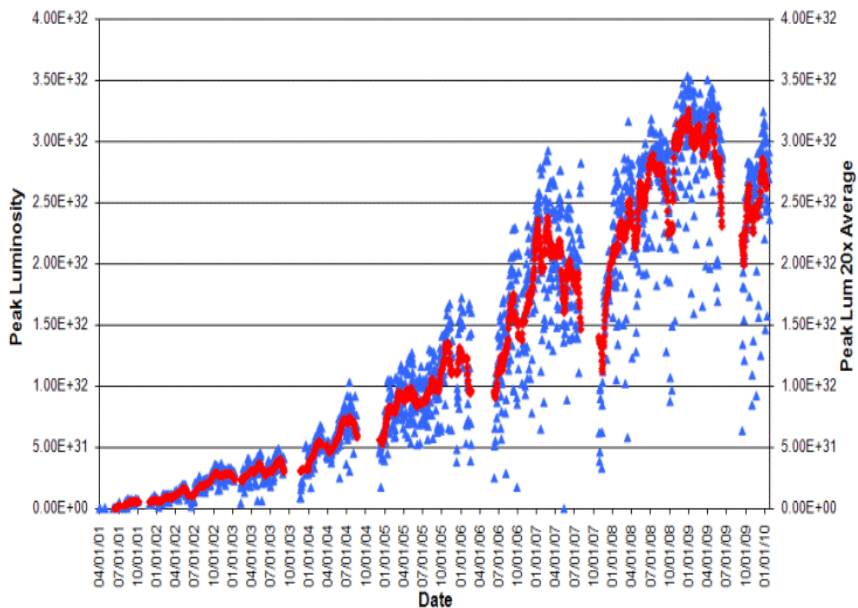
- **Tevatron complex**
 - Smooth operation
 - Over 50 pb⁻¹ per week delivered
- 7.8 fb⁻¹ delivered total and going
- Plan is to deliver 12 fb⁻¹ by the end of 2011

Integrated Luminosity 7850.59 (1/pb)



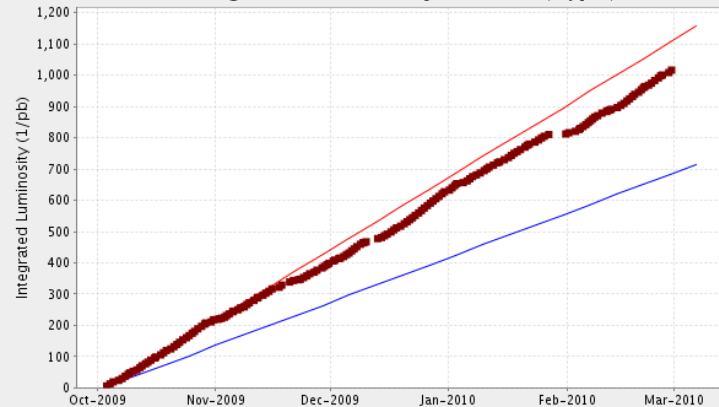
- Fiscal Year 10
- Fiscal Year 09
- ▲ Fiscal Year 08
- ◆ Fiscal Year 07
- ◆ Fiscal Year 06
- ▼ Fiscal Year 05
- ◆ Fiscal Year 04
- ▶ Fiscal Year 03
- Fiscal Year 02

Collider Run II Peak Luminosity



- ▲ Peak Luminosity
- ◆ Peak Lum 20x Average

FY10 Integrated Luminosity 1016.07 (1/pb)

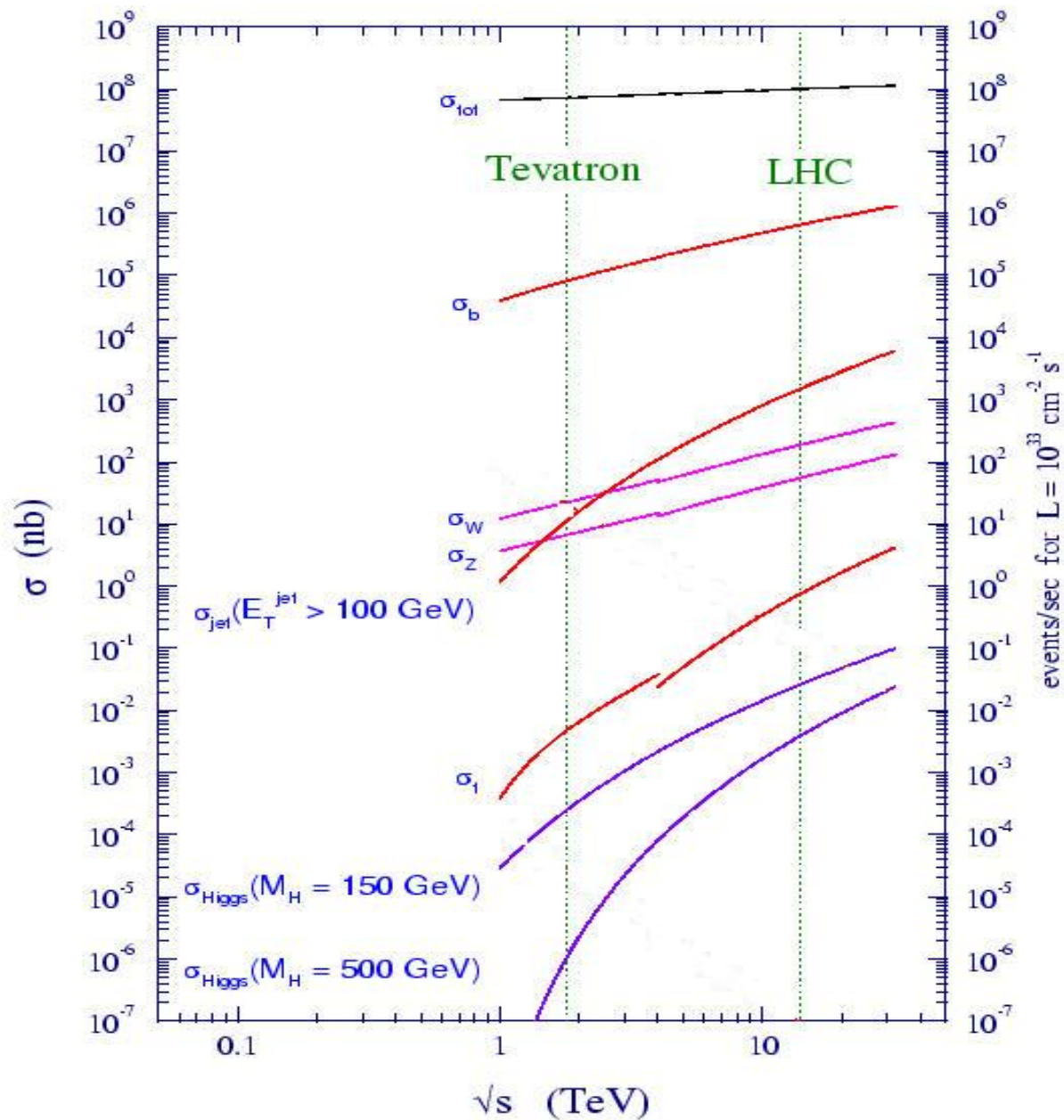


- Fiscal Year 10 Integrated Luminosity
- Highest
- Lowest

Fermilab's accelerator team is devoted to continue accelerator improvements and reliable operation

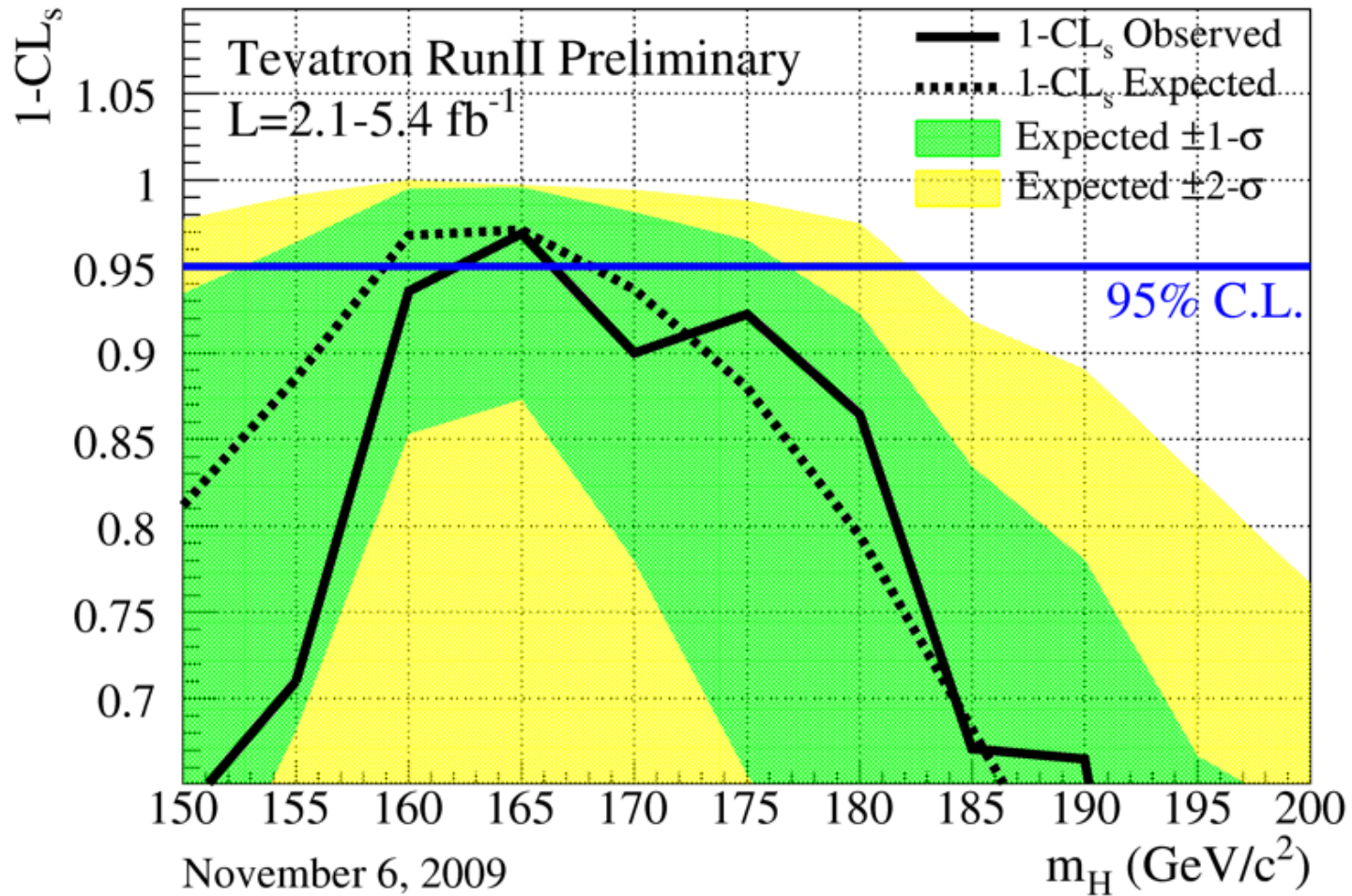


proton - (anti)proton cross sections



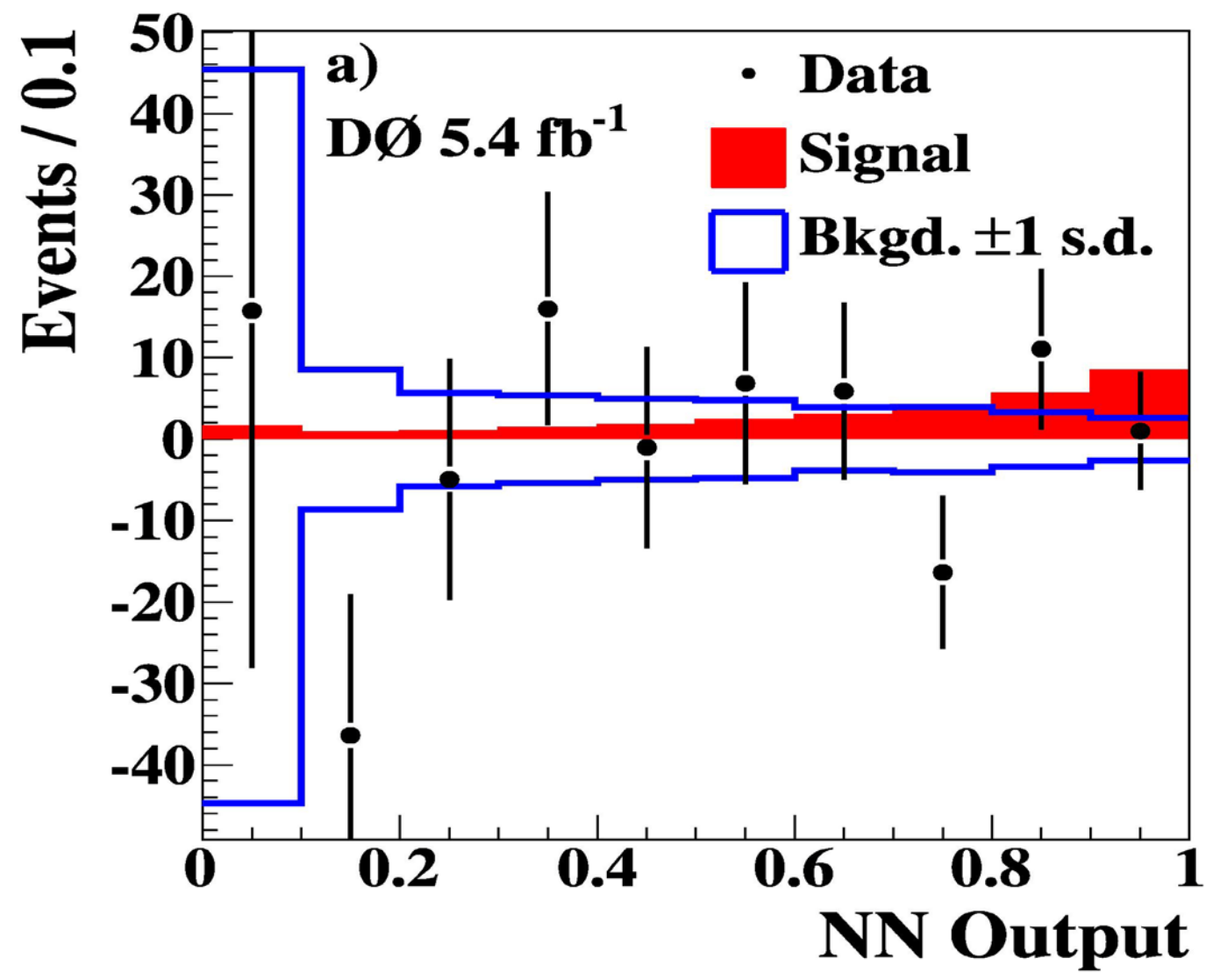


Confidence Level Combined Plot



Higgs excluded in the range 163-166 GeV at 95% confidence level

H \rightarrow WW

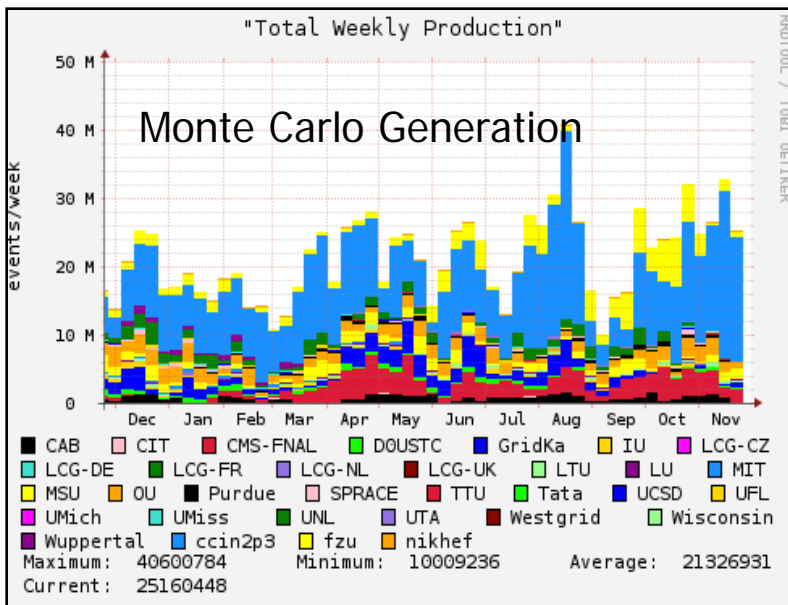
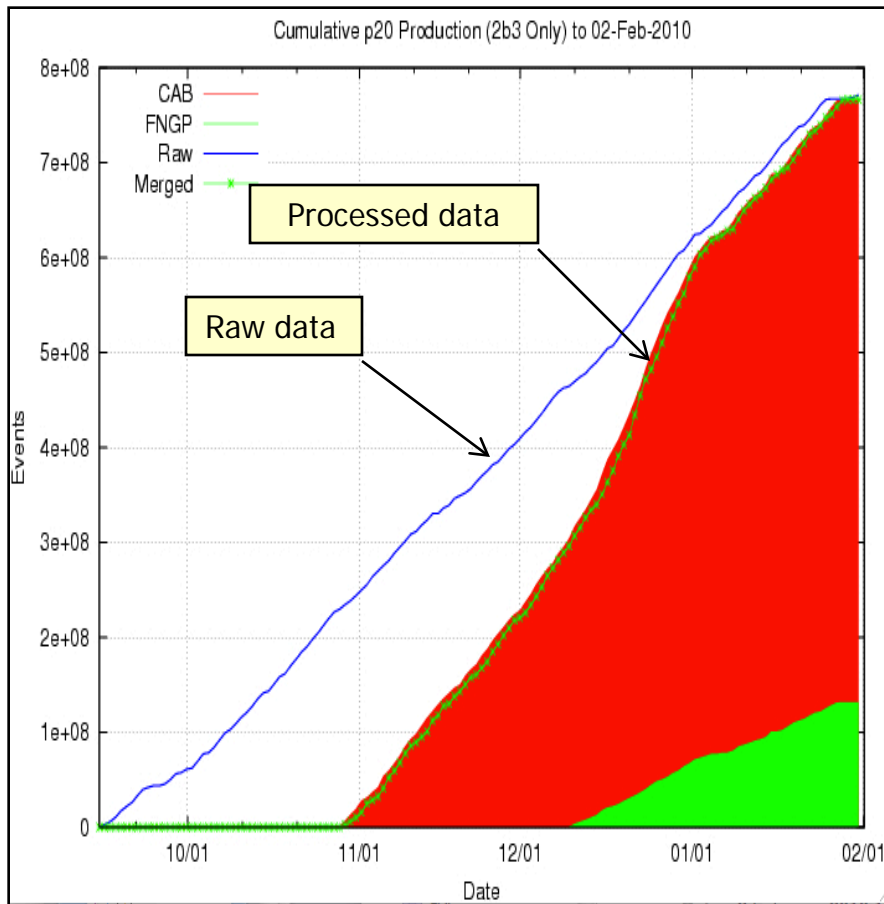




Computing



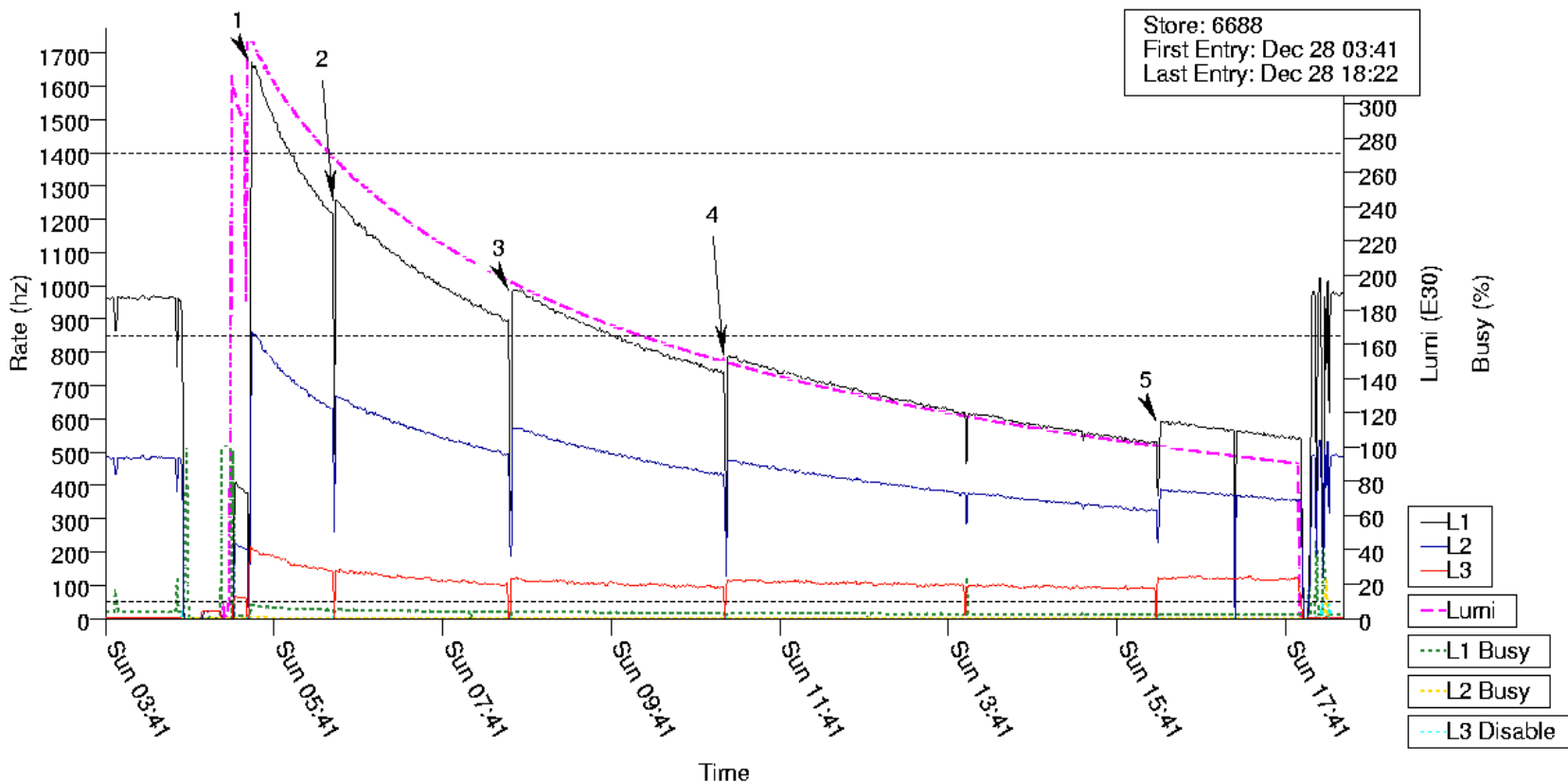
- Recording ~2 billion events per year
 - All processed within weeks after collection
 - Efforts are devoted to improvements in alignment, calibrations and reconstruction algorithms
- Extensive use of computing farms at Fermilab



- Monte Carlo generation, including Geant simulation of the detector, provides large samples of signal and background events
 - Dedicated computing centers
 - Extensive use of available Grid resources

Triggering at DØ

With interaction rate of ~ 10 MHz the experiment is recording ~ 100 Hz to tape.
 Even at highest luminosities high P_t physics program triggers remain unprescaled!

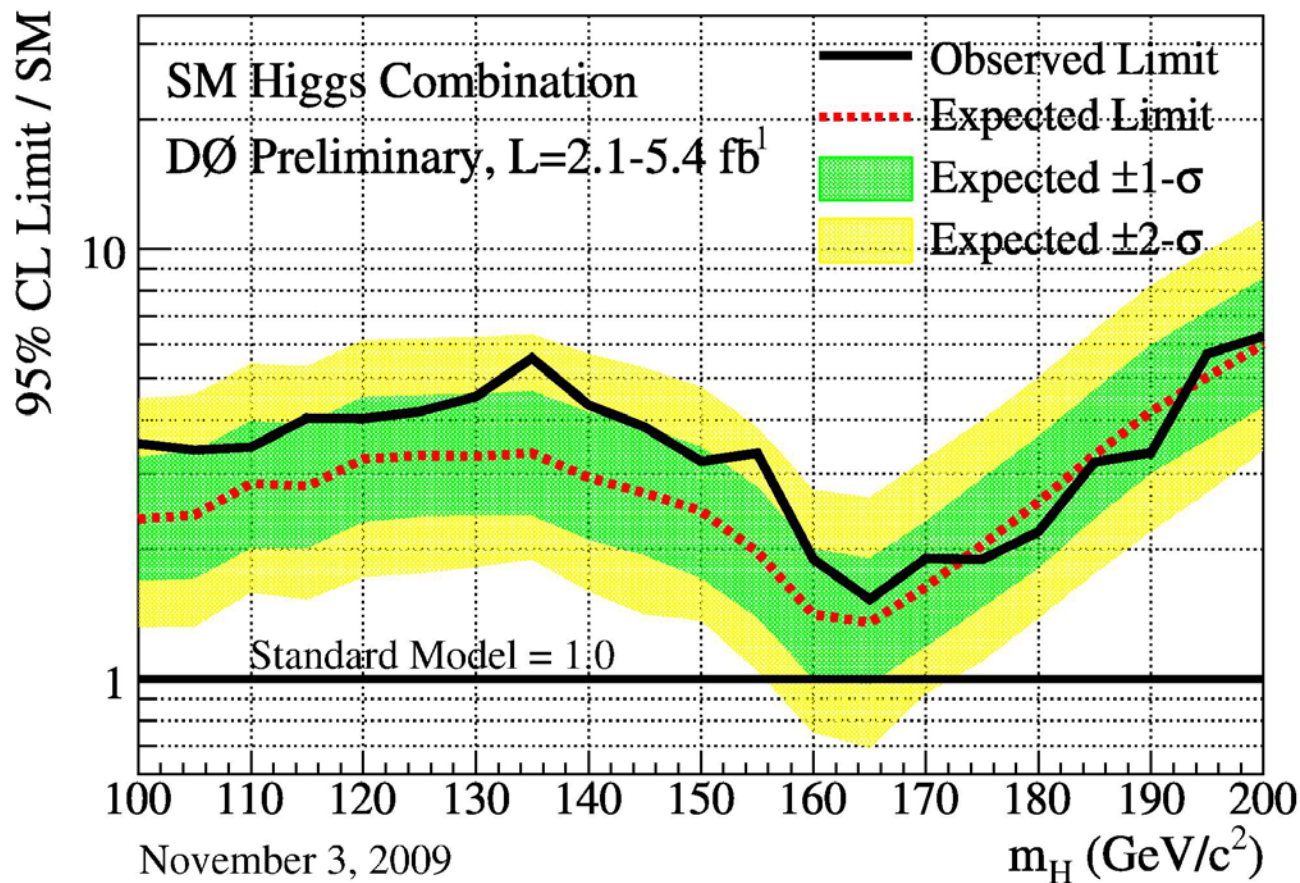


~ 12 hours store with starting luminosity of $3.5 \cdot 10^{32} \text{ cm}^{-2}\text{sec}^{-1}$, next store to follow within about an hour



Setting Limits on Standard Model Higgs

Limits on Higgs cross section set in each individual search channel and normalized to Standard Model Higgs cross section at a given mass



When line equal to 1.0 is crossed – Higgs is excluded at that mass



Tevatron Higgs Exclusion Potential

