Standard Model Physics at the Tevatron

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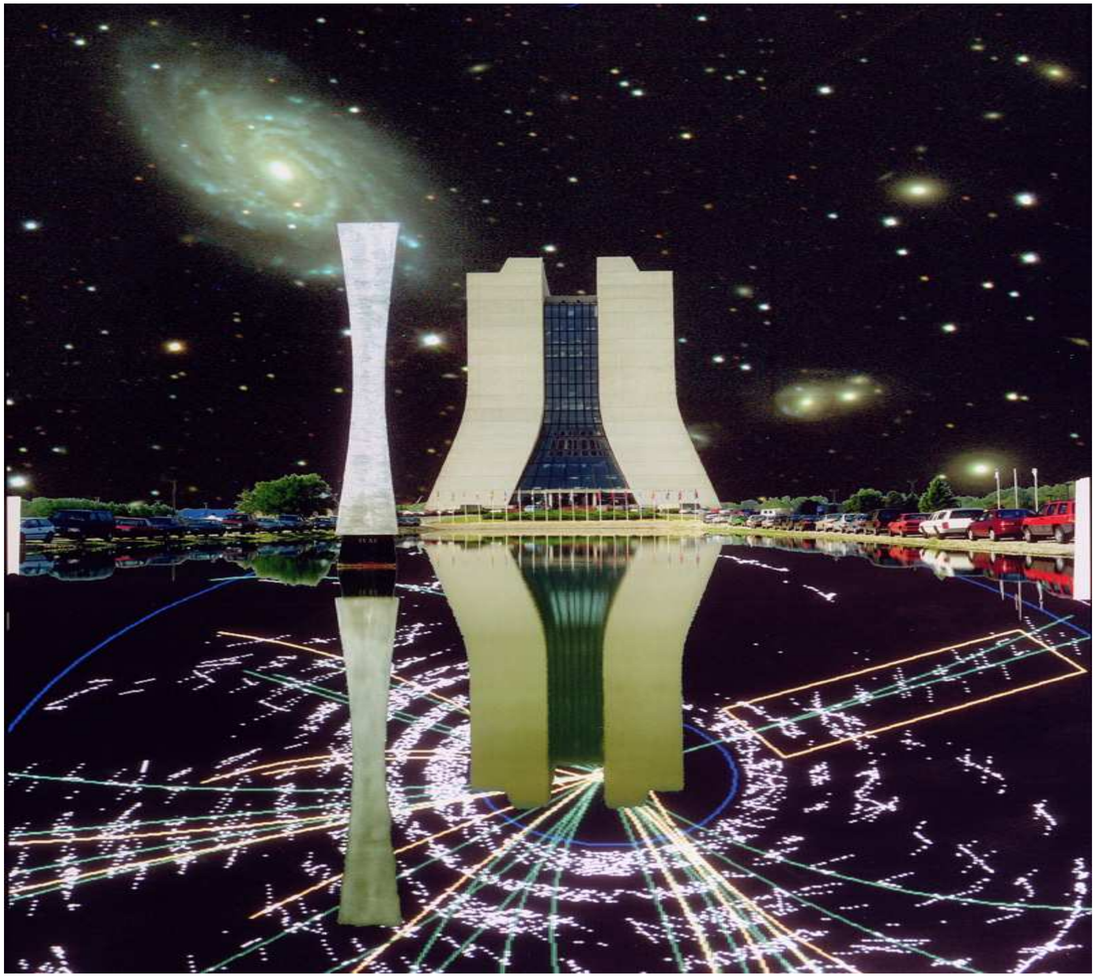
(for the CDF and D0 Collaborations)



Pheno 2009 Symposium
Madison, 11 May 2009

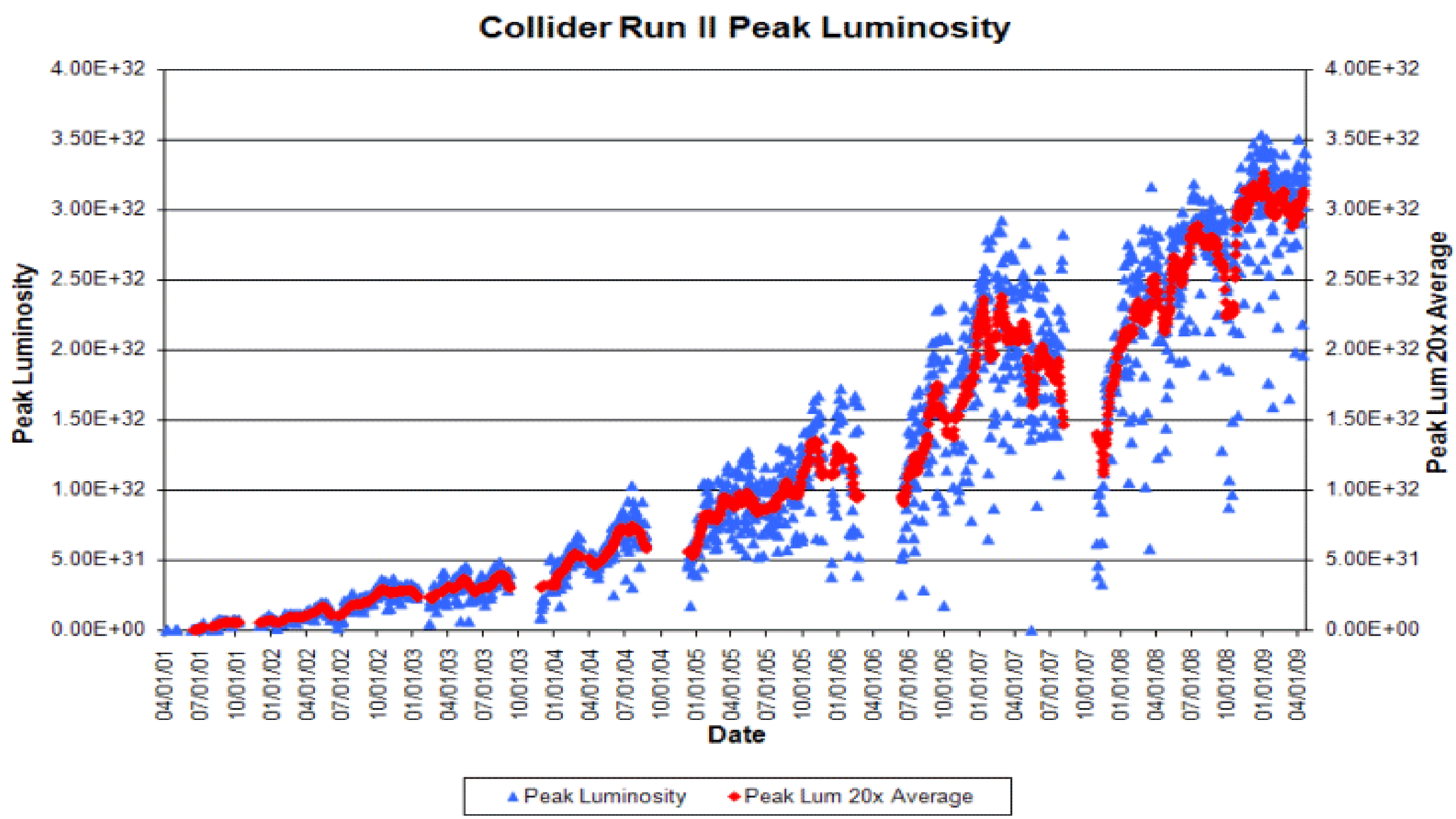
Introduction

- Very rich Tevatron program: probes physics at the highest Q^2
  - Direct searches for new physics
  - Top physics
  - High E_T jets, leptons and photons
- ...to intermediate Q^2
  - Precision electroweak physics
- ...to low Q^2
  - B and charm physics
- Selected topics discussed today span the range of
  - Statistical and systematic contributions to precision
  - Importance of tracking, calorimetry and particle identification
  - Connections to LHC physics

Tevatron at Fermilab

Tevatron is routinely exceeding nominal Run II instantaneous luminosity target of $2x10^{32}$ /cm^2/s

Recently achieved $3.5x10^{32}$ /cm^2/s

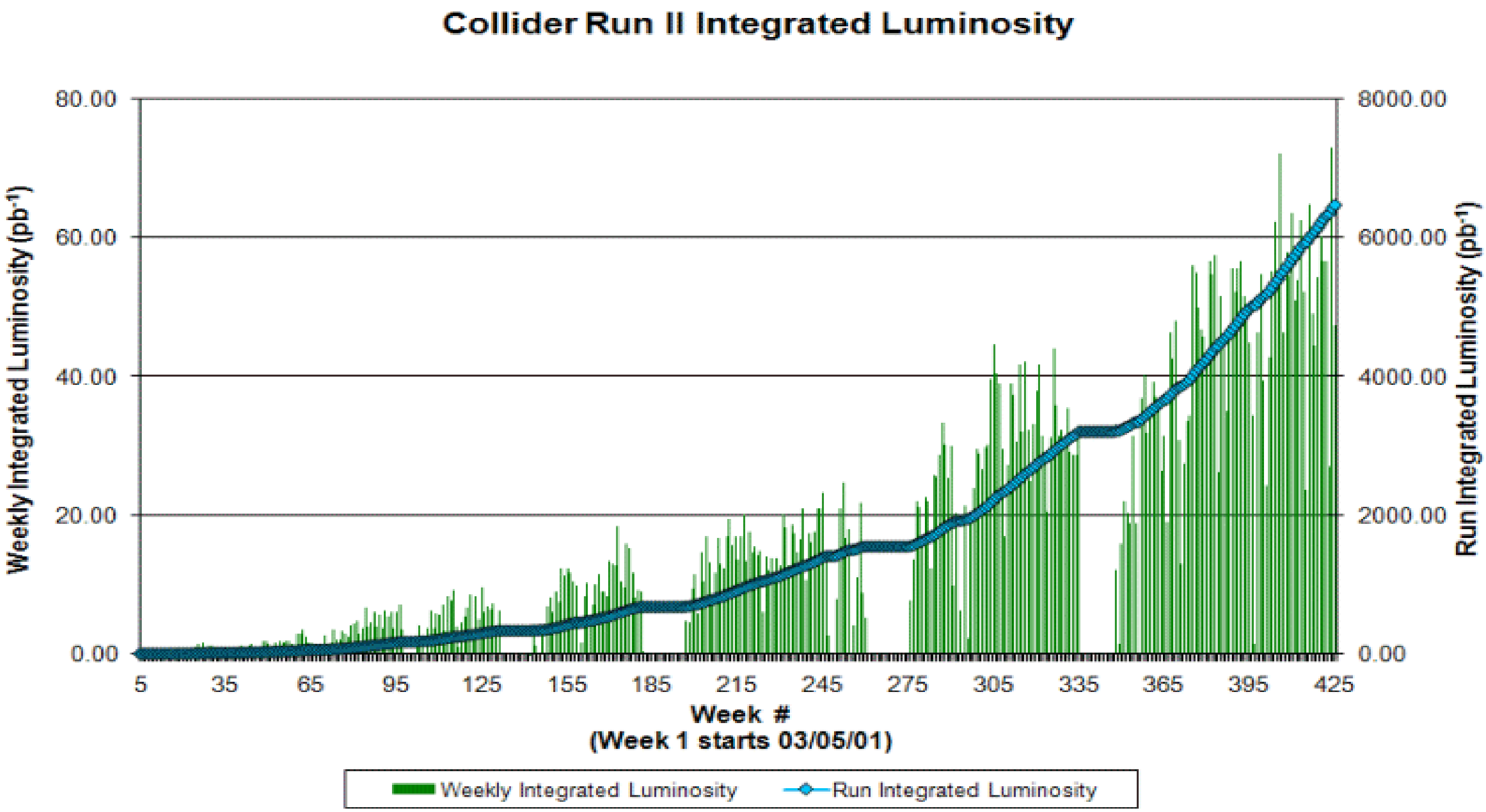


Tevatron at Fermilab

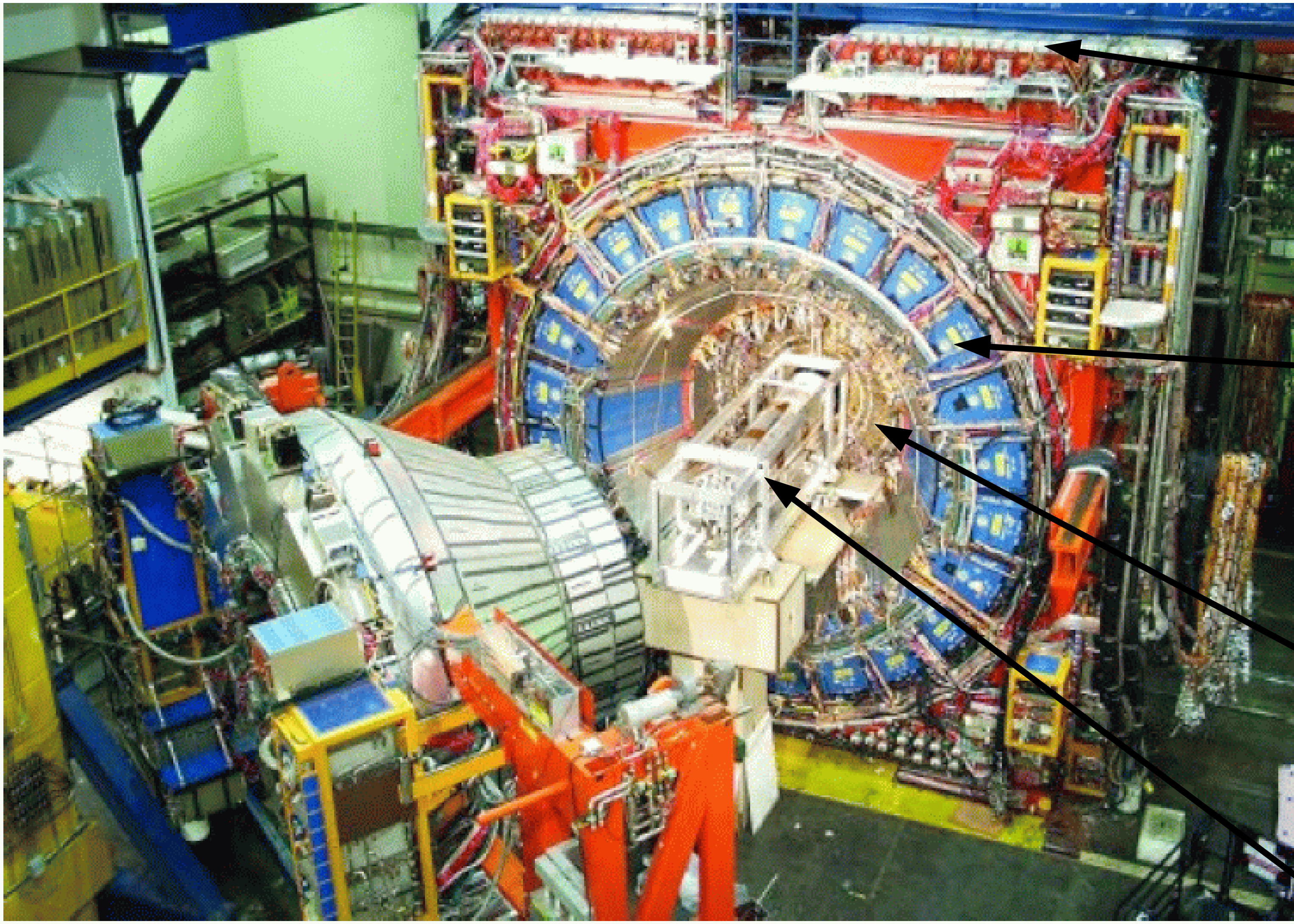
Tevatron has delivered >6 fb^{-1} of integrated luminosity

On track to deliver 9 fb^{-1} by 2010

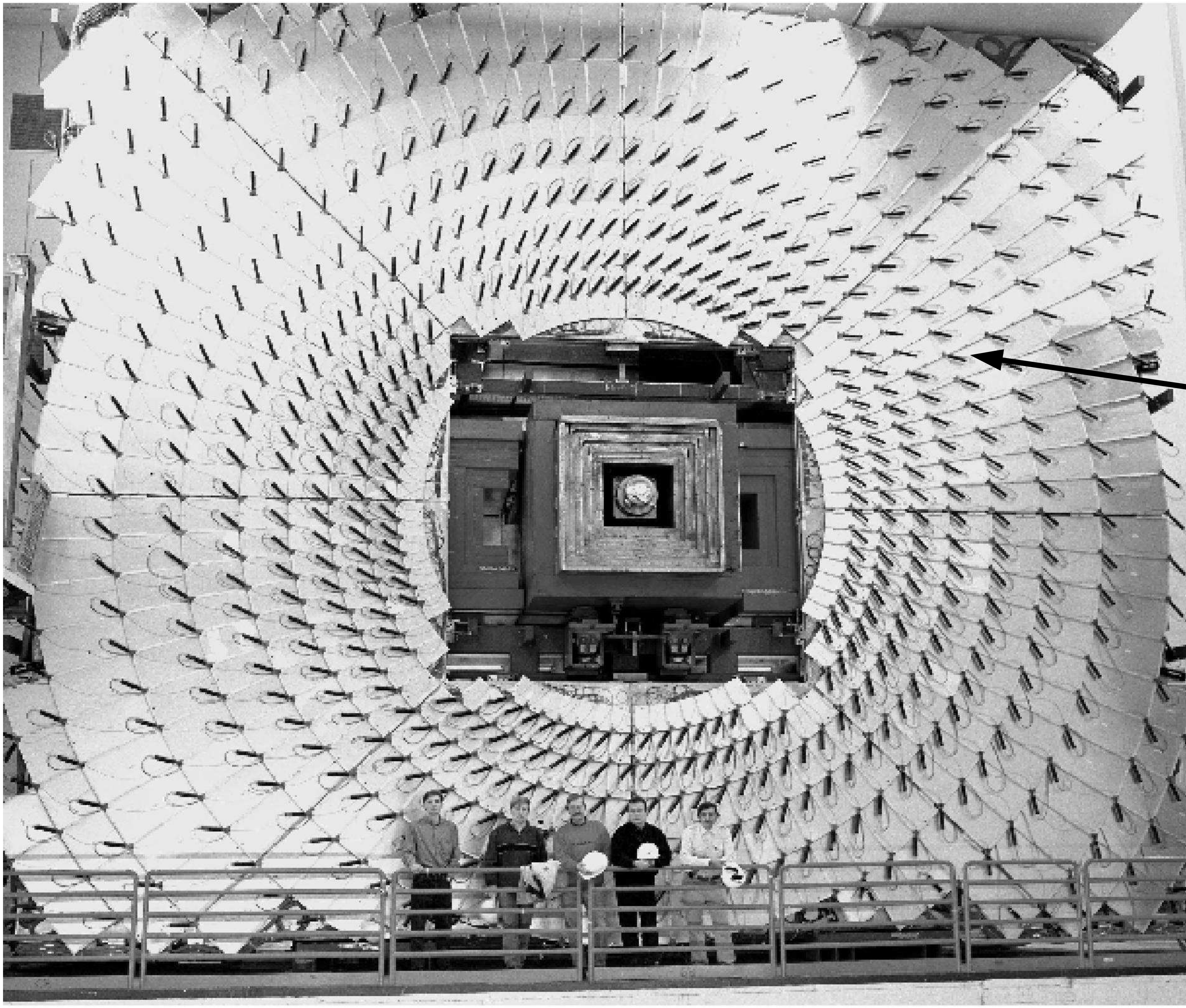
decision on running in 2011 pending



Collider Detector at Fermilab (CDF)



D0 Detector

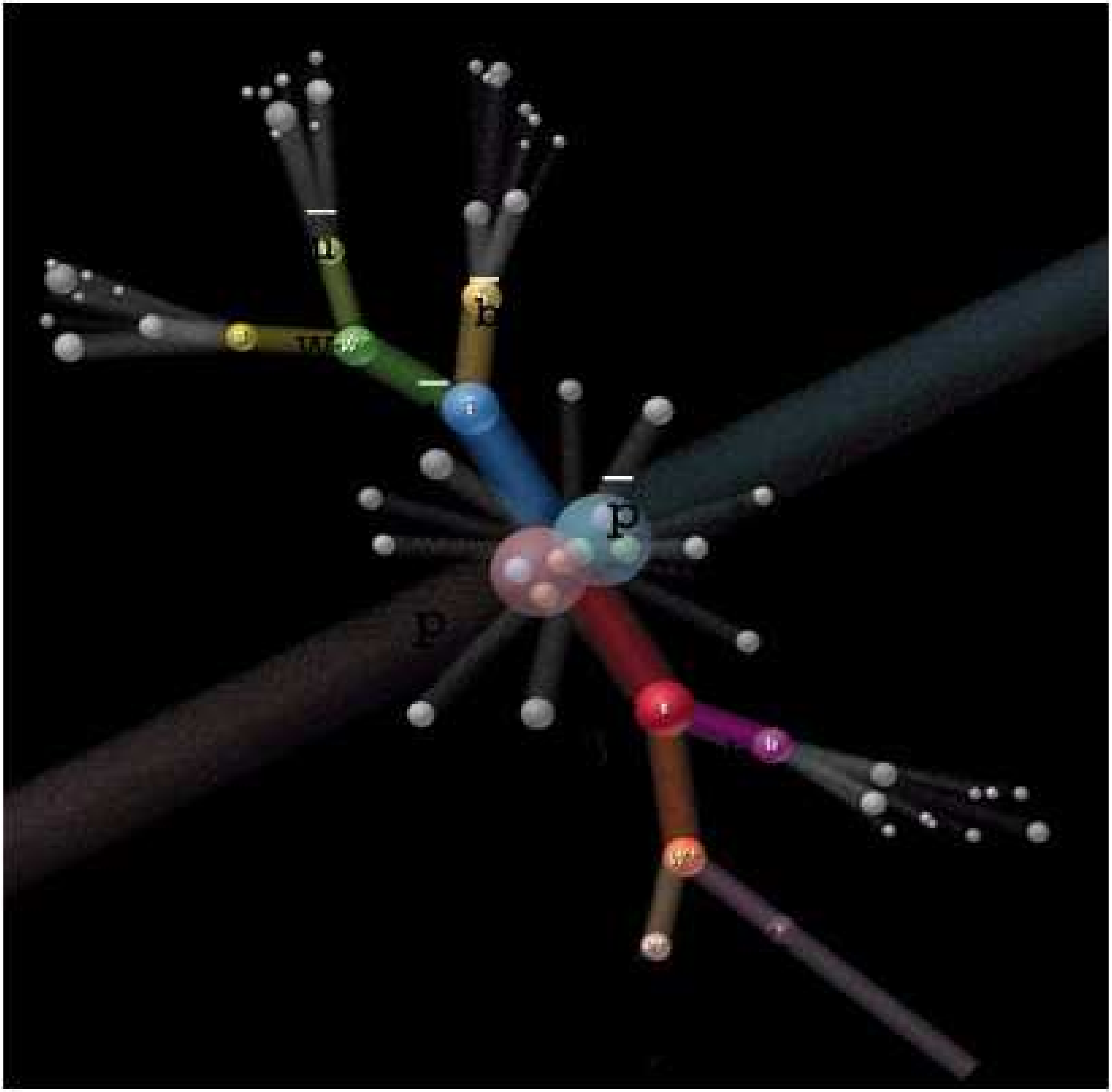


Forward
muon
detectors

Outline

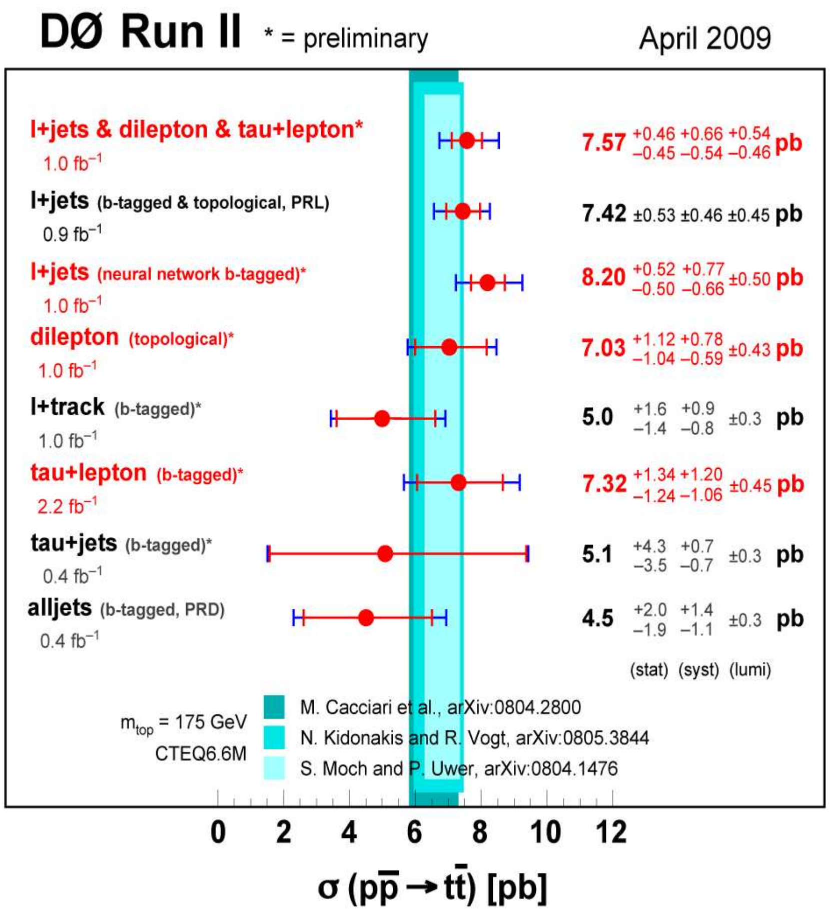
- Top quark physics
  - Cross sections in lepton+jets and dilepton channels
  - Top quark mass
  - Discovery of single top quark production
- Electroweak physics
  - W boson mass
- SM Higgs search
- Other direct searches, QCD and B physics
  - See the following talks

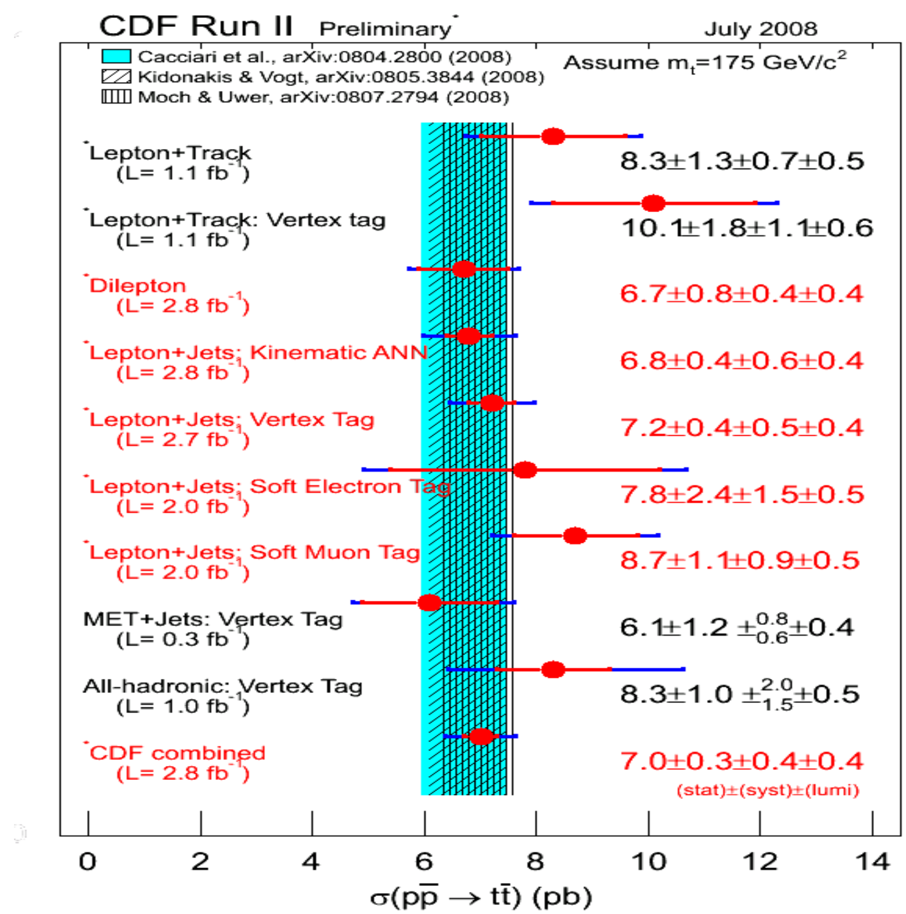
Top Quark Production at the Tevatron



Top Signals

- Is it the standard model top quark? Or does its large mass give it access to new physics? Probing the *tWb* electroweak vertex in top decays:
- Probes:
  - Event topology, Comparing cross sections in different decay modes





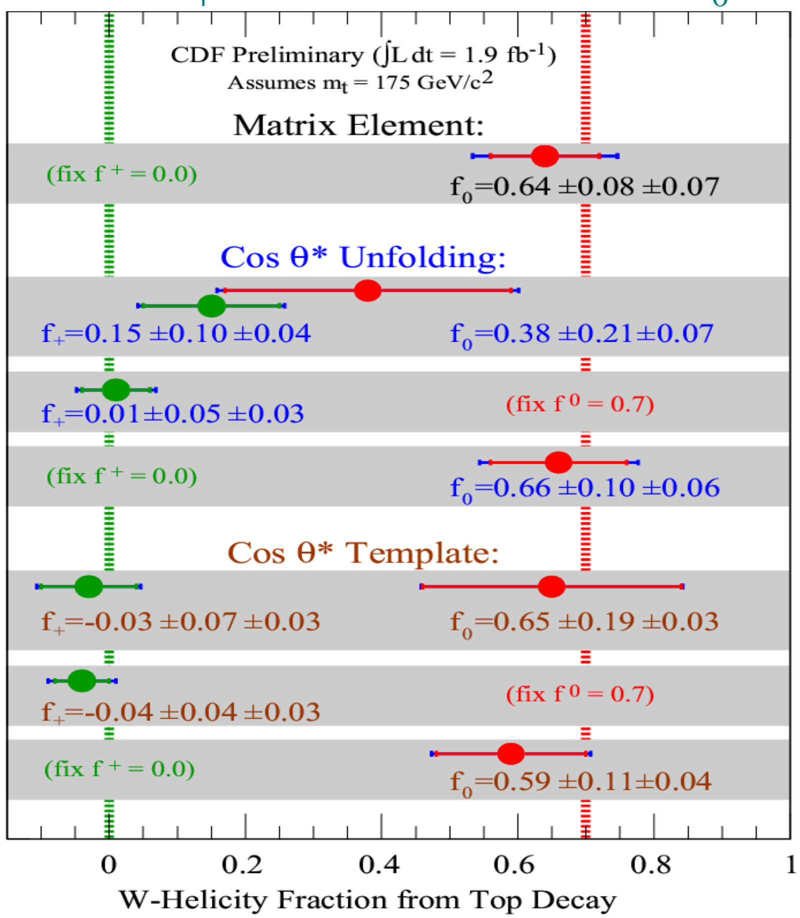
Top Signals

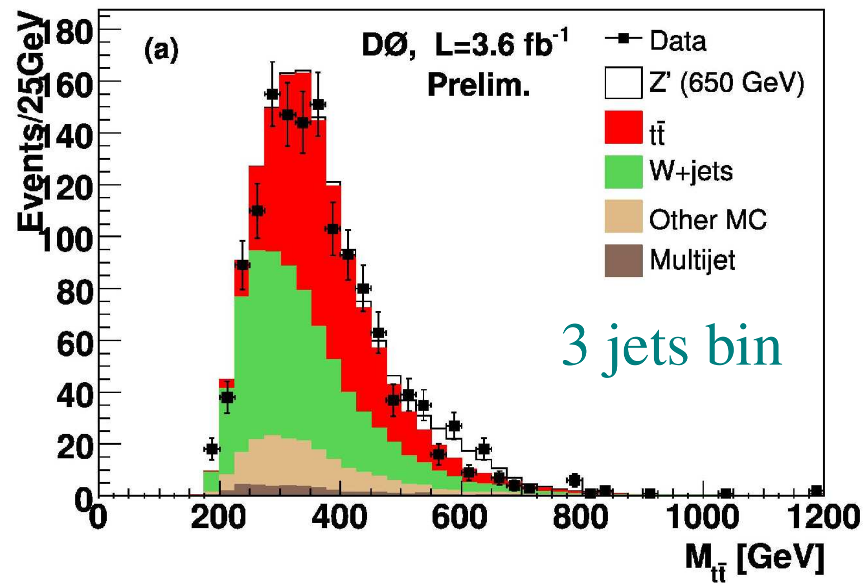
- Probes:
  - Heavy resonances decaying to top quark pairs
  - Spin structure: W helicity in top decays

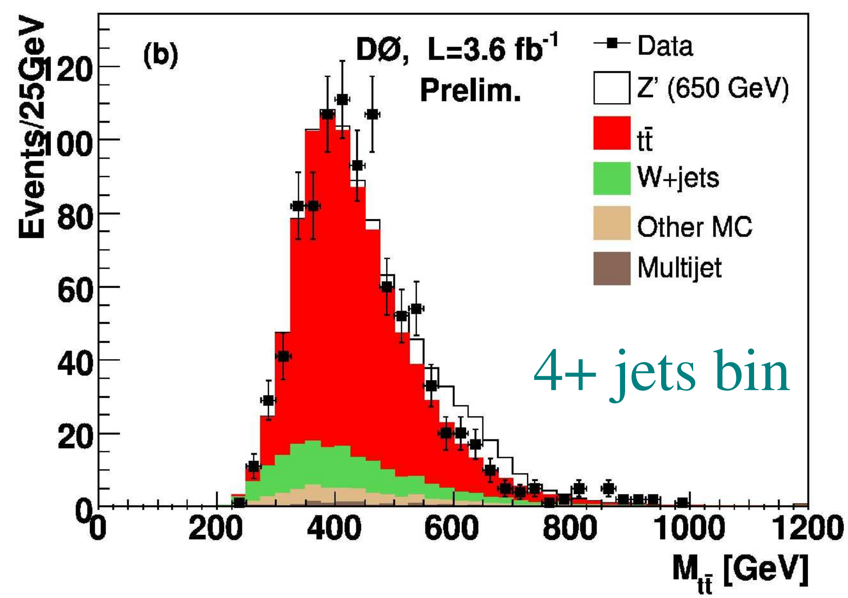
Lepton + jets channel

Right-handed W fraction f_+

Longitudinal W fraction f_0

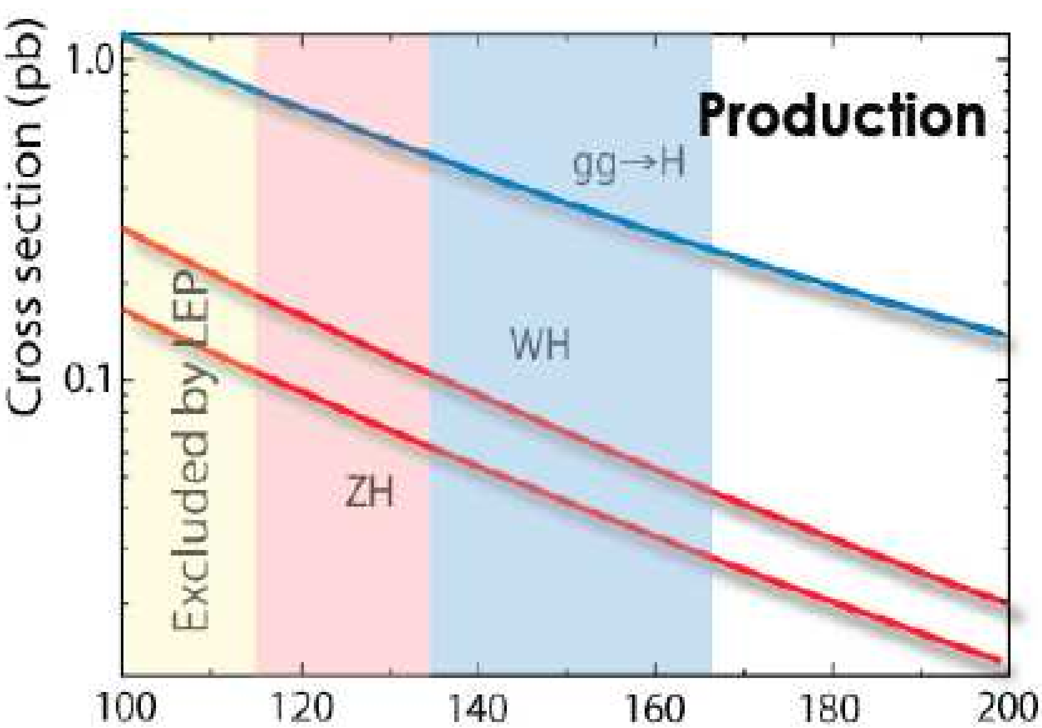


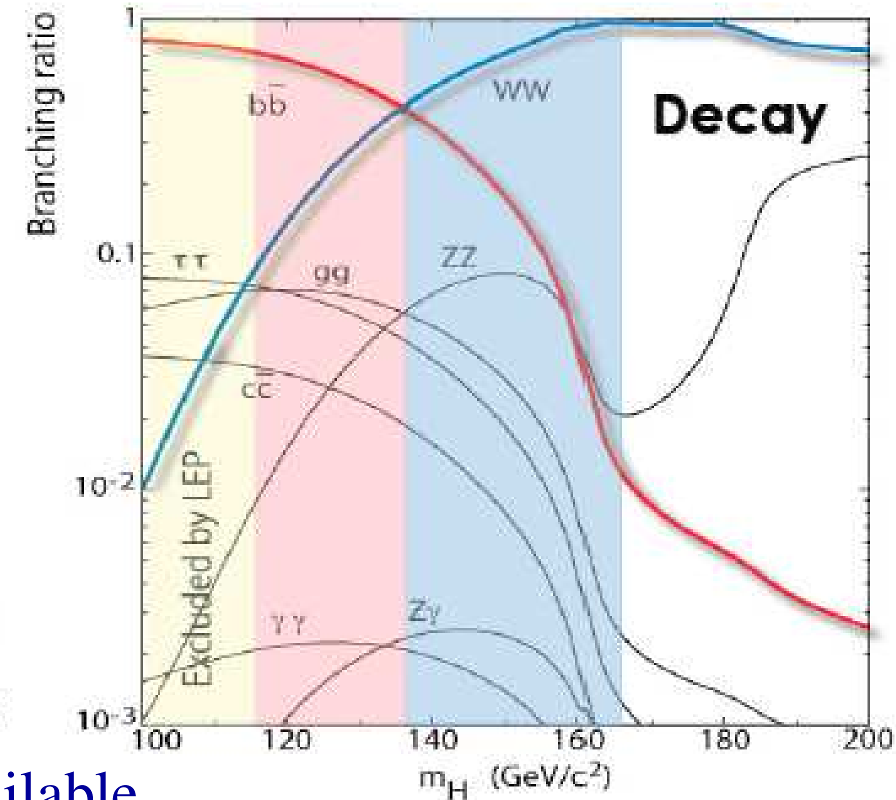




Standard Model Higgs Boson Production and Decay

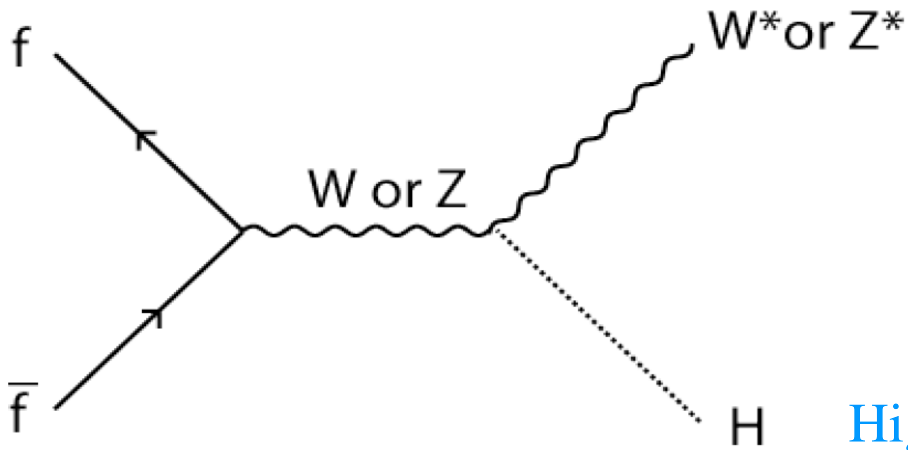
Higgs Boson Production and Decay





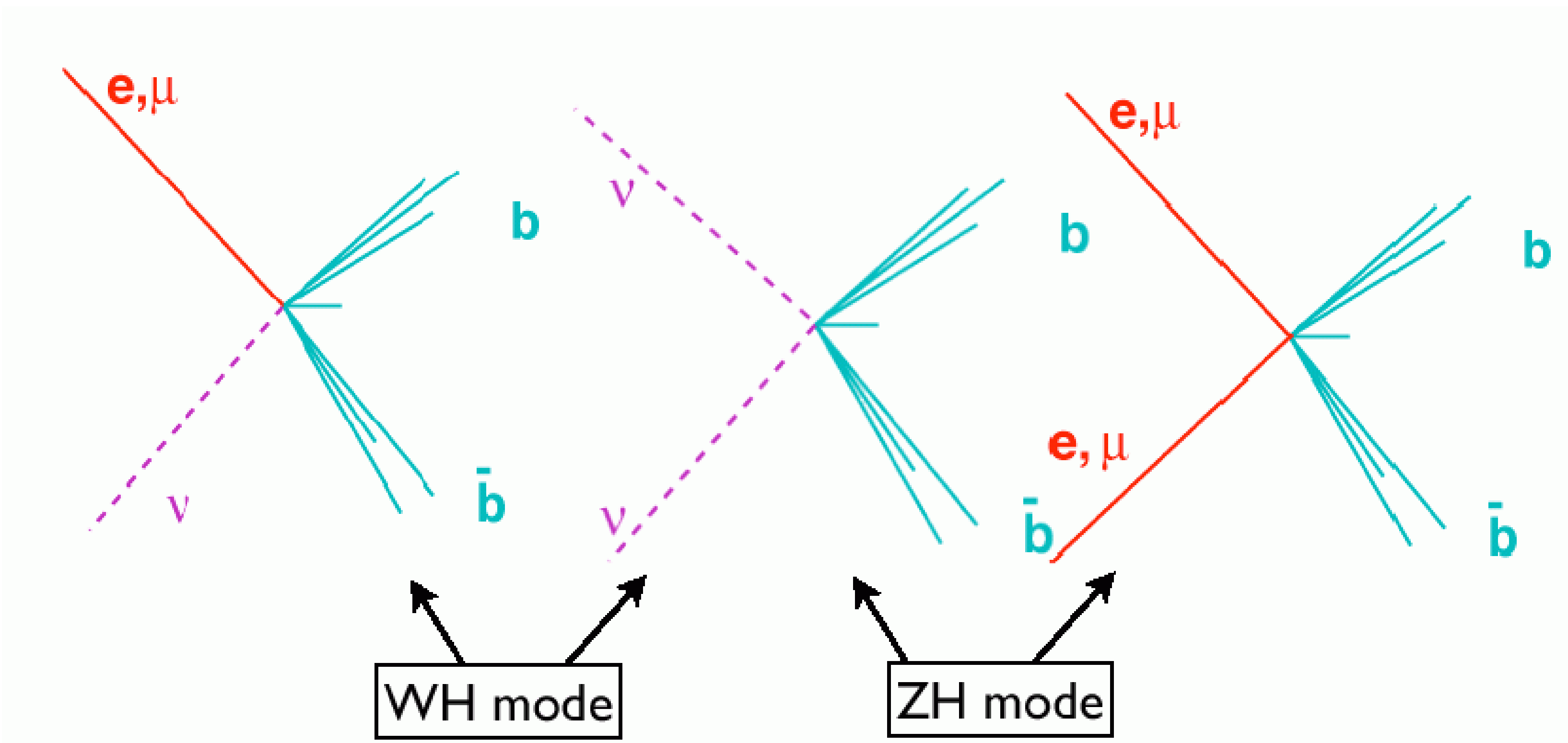
- High mass: H→WW→lνlν decay available
  - Take advantage of large gg→H production cross section
- Low Mass: H→bb, QCD bb background overwhelming
  - Use associated production with W or Z for background discrimination
  - WH→lνbb, ZH→ννbb (MET+bb), ZH→llbb
- Also: Vector Boson Fusion Production,VH→qqbb, H→ττ (with 2 jets), H→γγ, WH->WWW, ttH

Light Higgs Boson Production and Decay



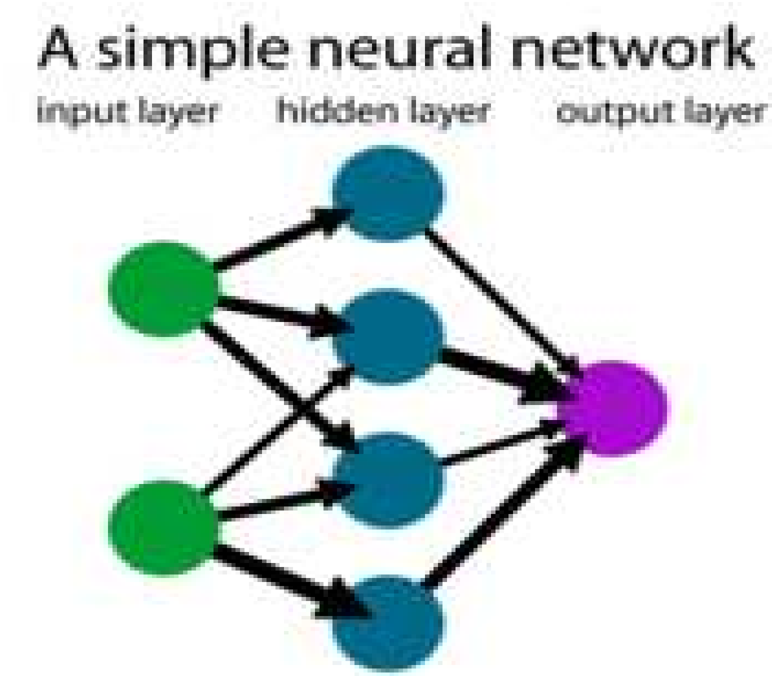
W, Z decay to electrons, muons, τ, and/or neutrinos

Higgs boson decays to bottom quarks

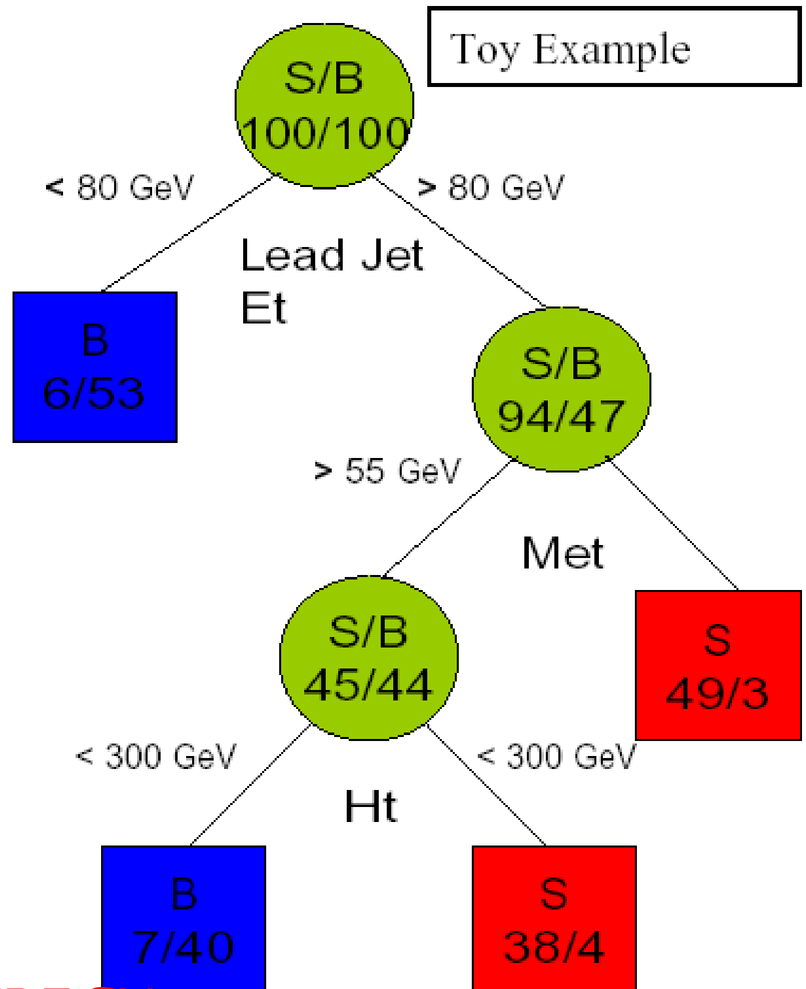


Multivariate Techniques for Signal/Background Discrimination

- Likelihood discriminants: Often using Standard Model Matrix Elements to compute differential probability distributions for kinematics
- Artificial Neural Networks: construct non-linear function of kinematics
- Decision trees: event classification using sequential cuts

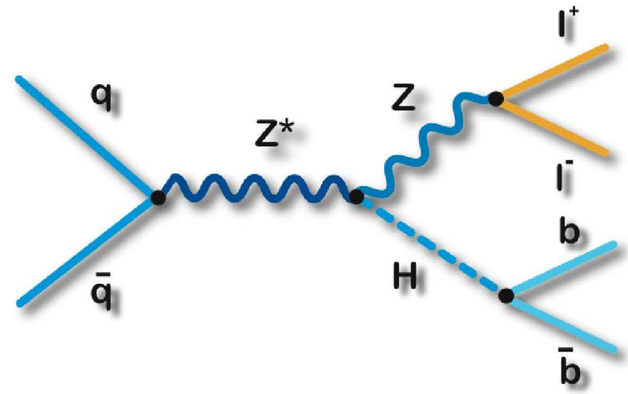


Decision Tree

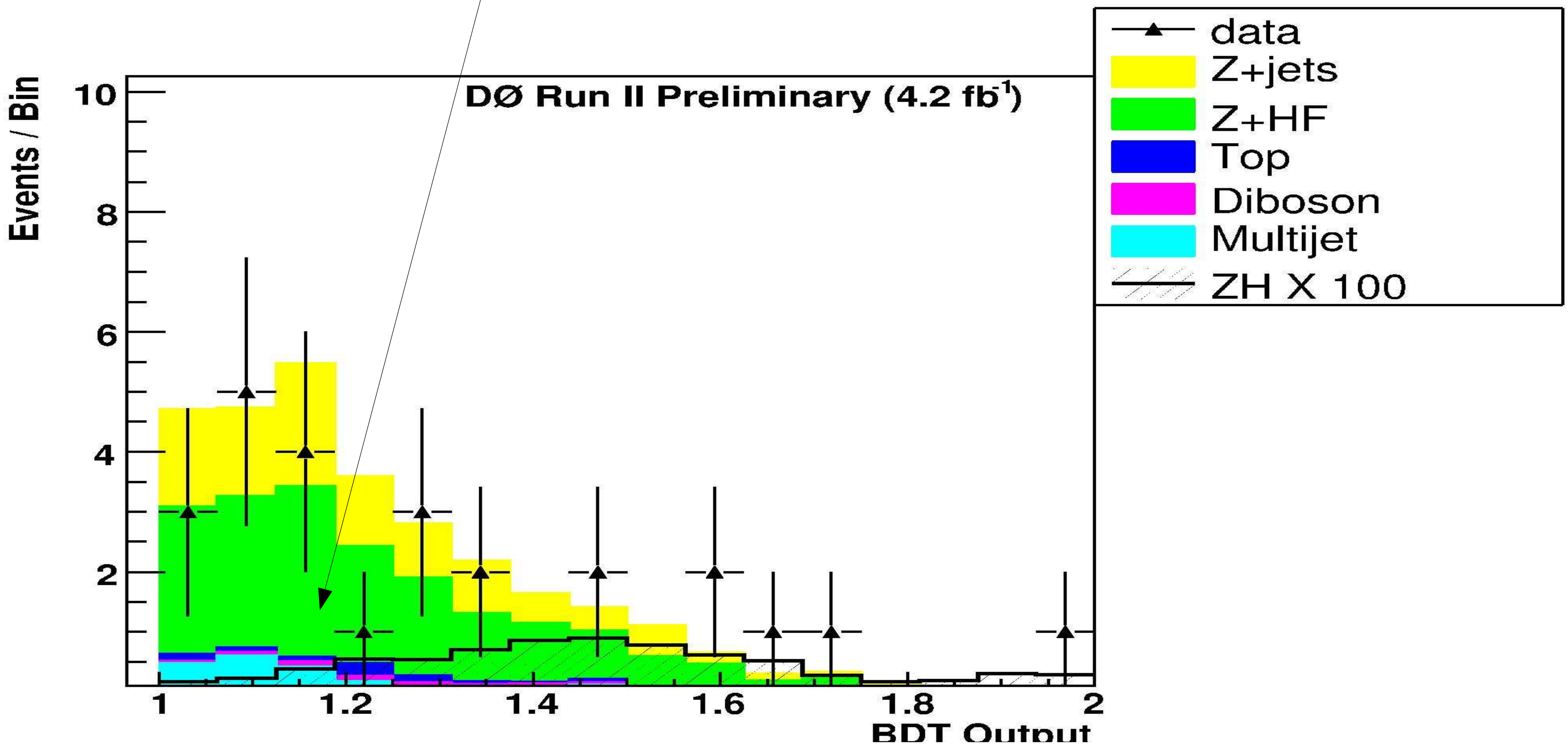


CDF SV tagger

SM Higgs: ZH→llbb

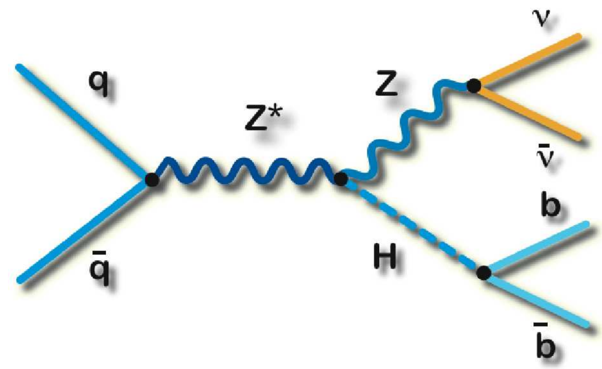


Z + 2 jets background dominant



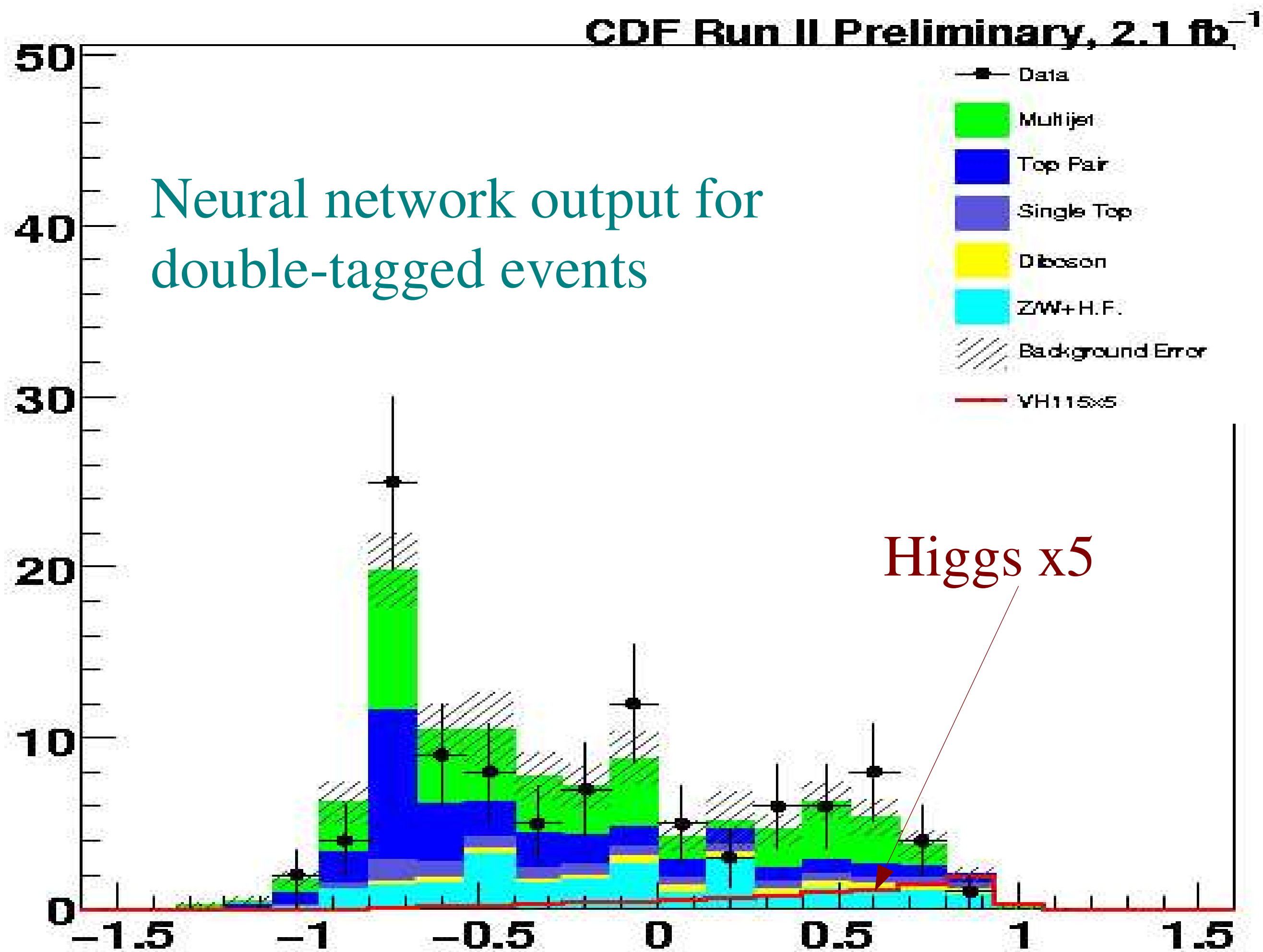
backgrounds ← Boosted Decision Tree Output → ZH

SM Higgs: VH→ννbb

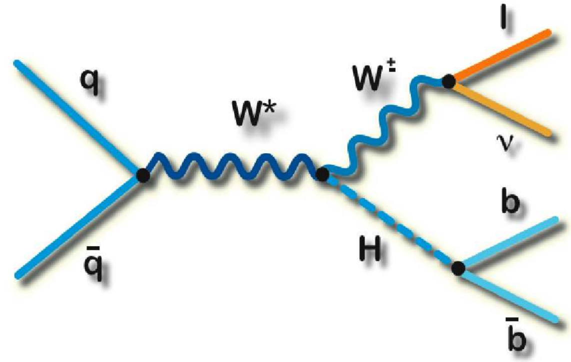


W (-> lν) + Higgs with lepton undetected also included in signal

large branching ratio and acceptance for vector boson



SM Higgs: WH→lνbb



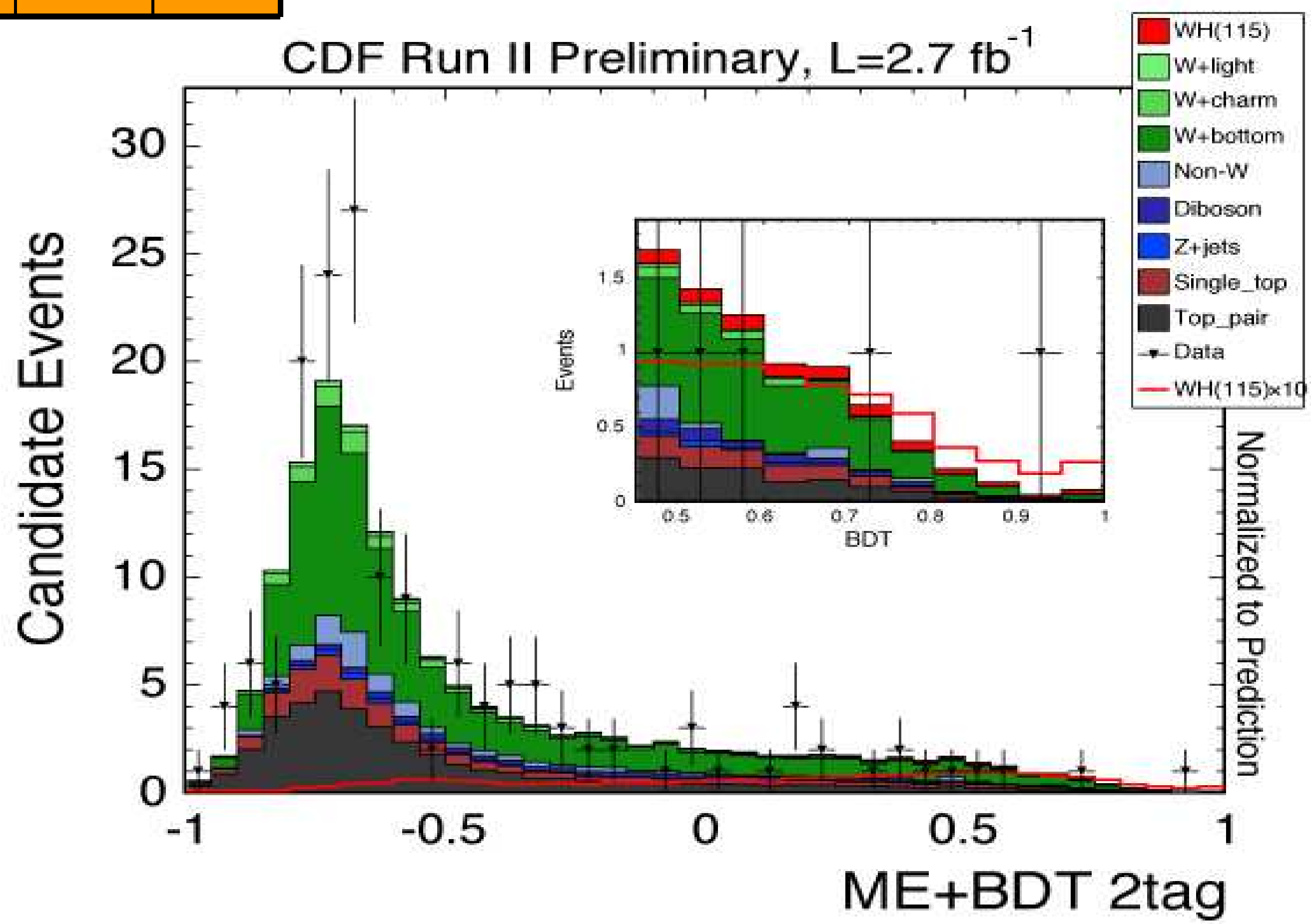
Results at mH = 115GeV: 95%CL Limits/SM

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.7	8.3	5.8	5.0
CDF ME+BDT	2.7	7.8	5.6	5.7
DØ NN	1.7	7.5	8.5	9.3

Key issue: shape of W+bb background

obtained from simulation, with normalization from data control regions

most sensitive channel for low-mass Higgs at Tevatron



Heavy Higgs Boson Production and Decay

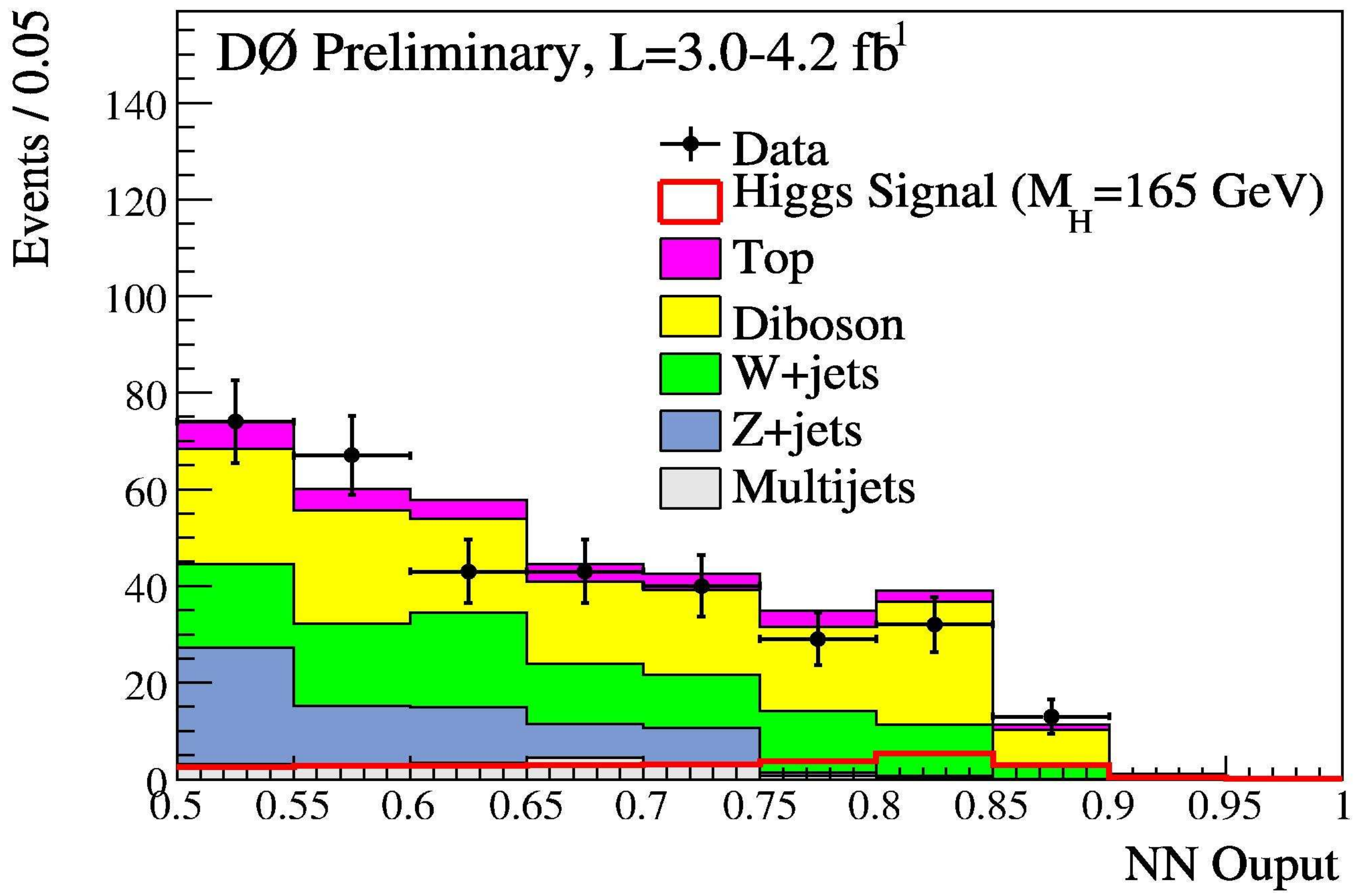
Results at mH = 160 GeV : 95%CL Limits/SM

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF ME+NN	3.6	20.0	1.47	1.37
DØ NN	3.0-4.2	18.6	1.8	1.7

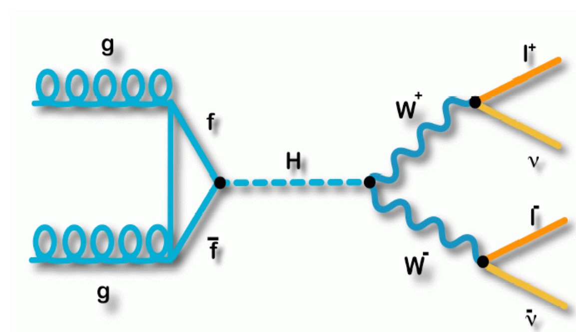
Dileptons + missing E_T :

Most sensitive channel at the Tevatron

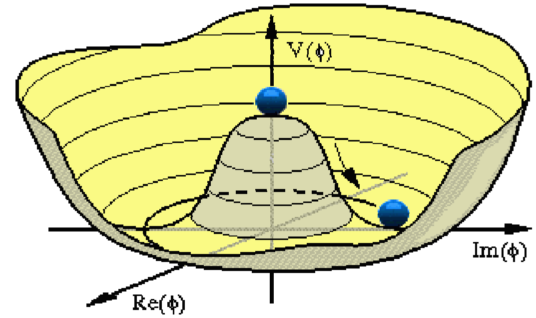
Key issue: maximizing lepton acceptance



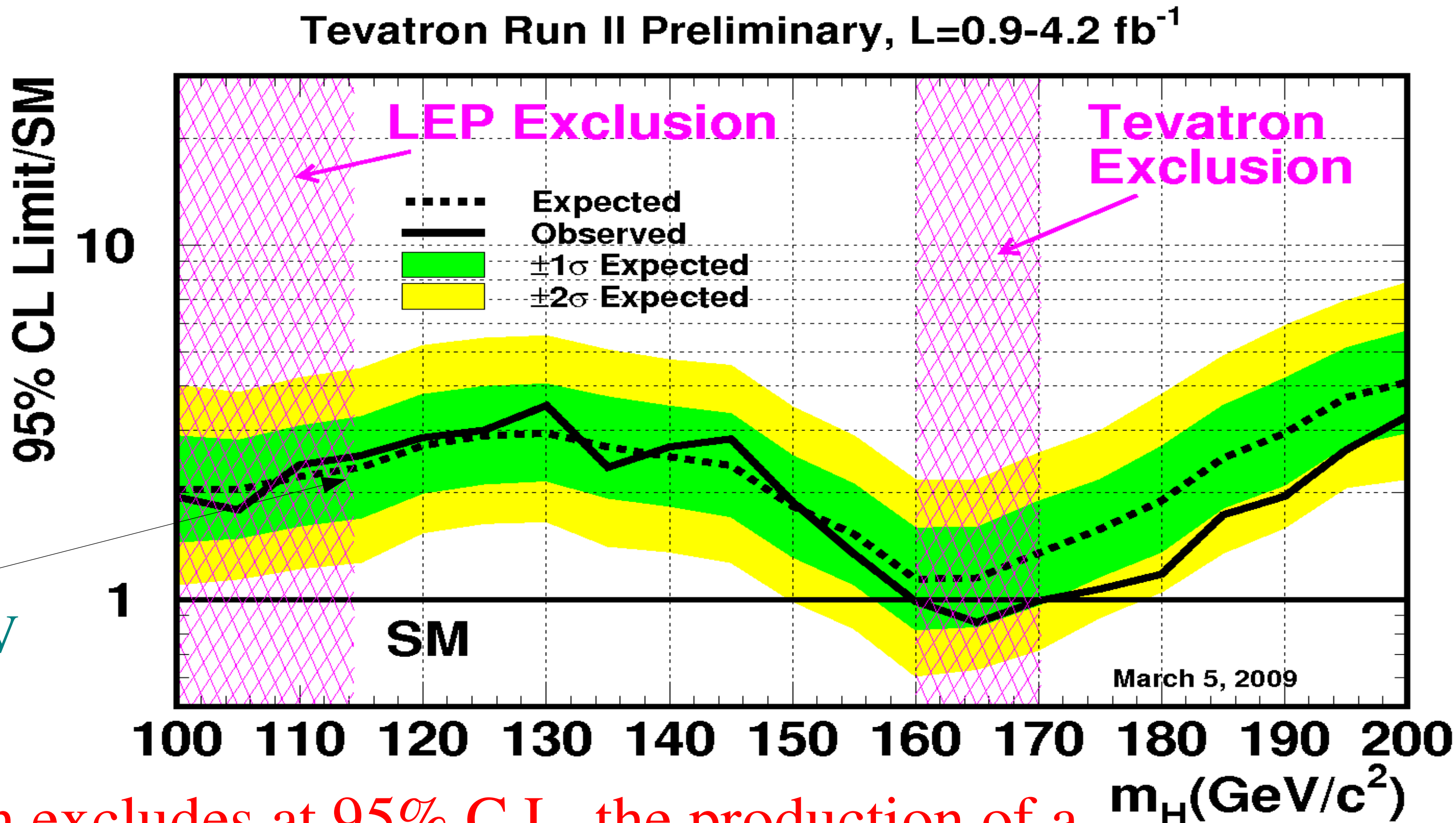
Includes H → WWW*



SM Higgs Boson Production Limits



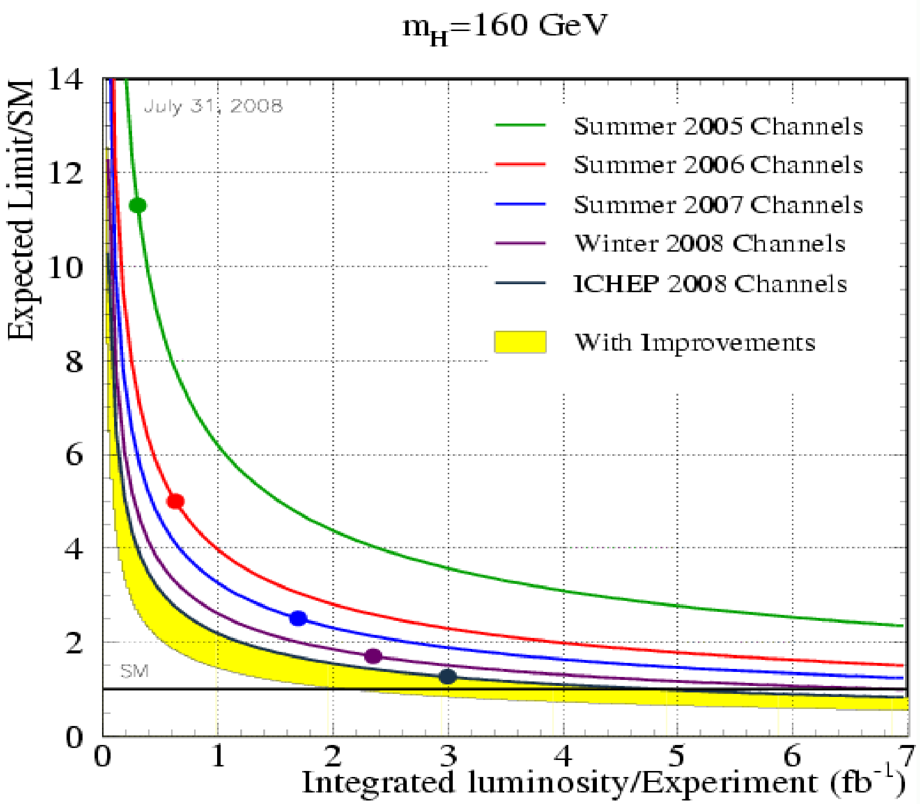
Comparison of Higgs boson production cross section upper limit to the theoretical expectation

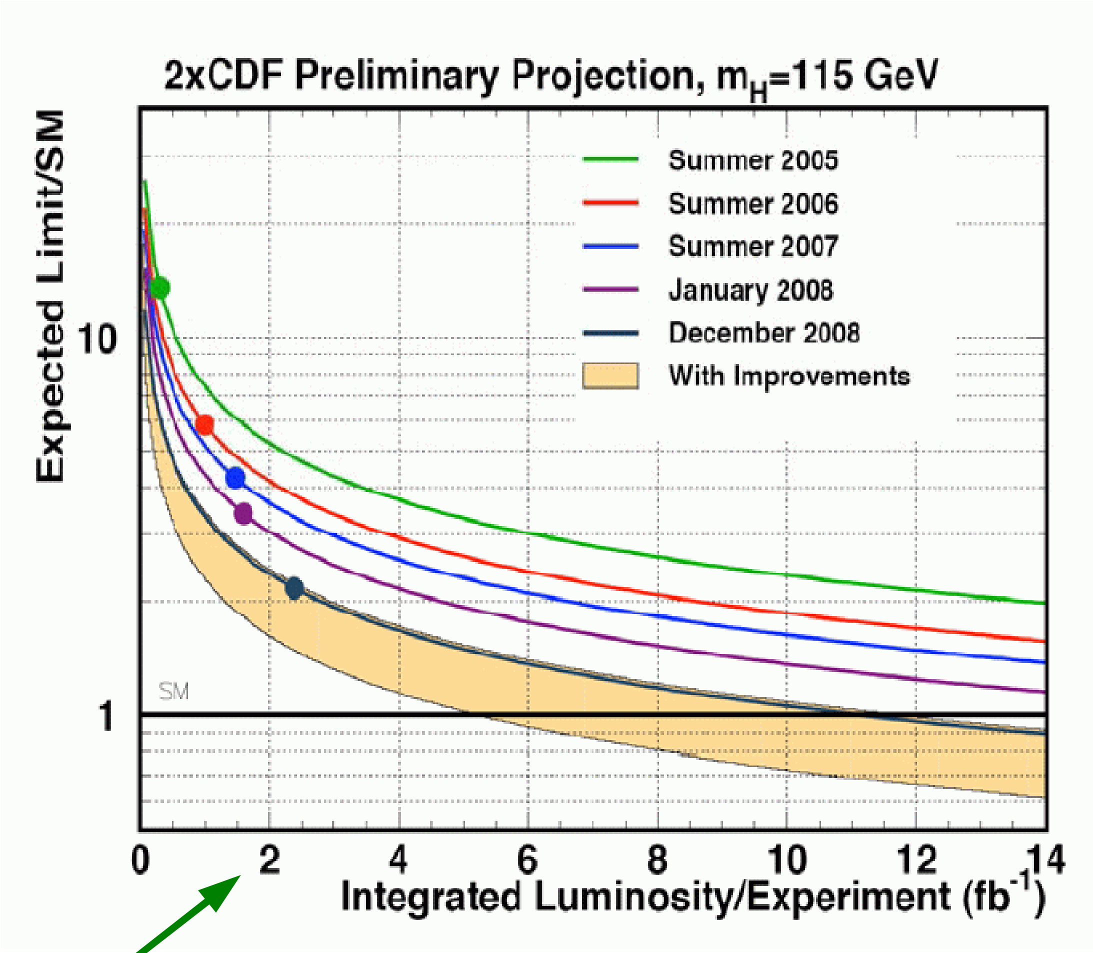


2.4 @ 115 GeV

Tevatron excludes at 95% C.L. the production of a SM Higgs boson in mass range 160-170 GeV

Tevatron Higgs Search Projections





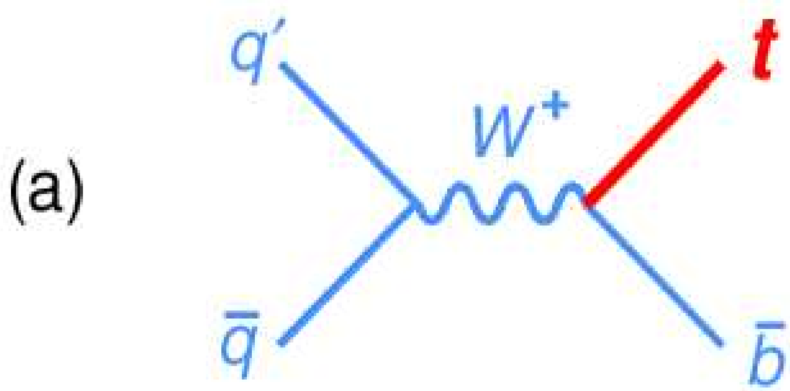
- Improvements for low-mass Higgs in progress
  - Dijet mass resolution, increased lepton acceptance and b-tagging efficiency

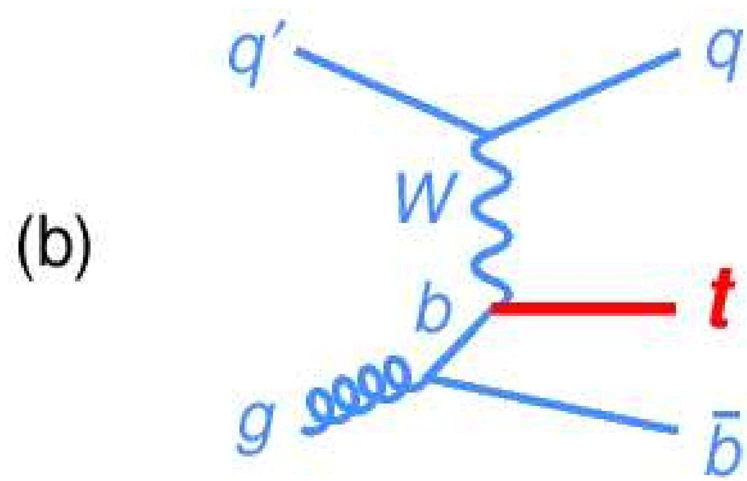
Single Top Production

Milestone in Standard Model Observations towards the Higgs

Single Top Production

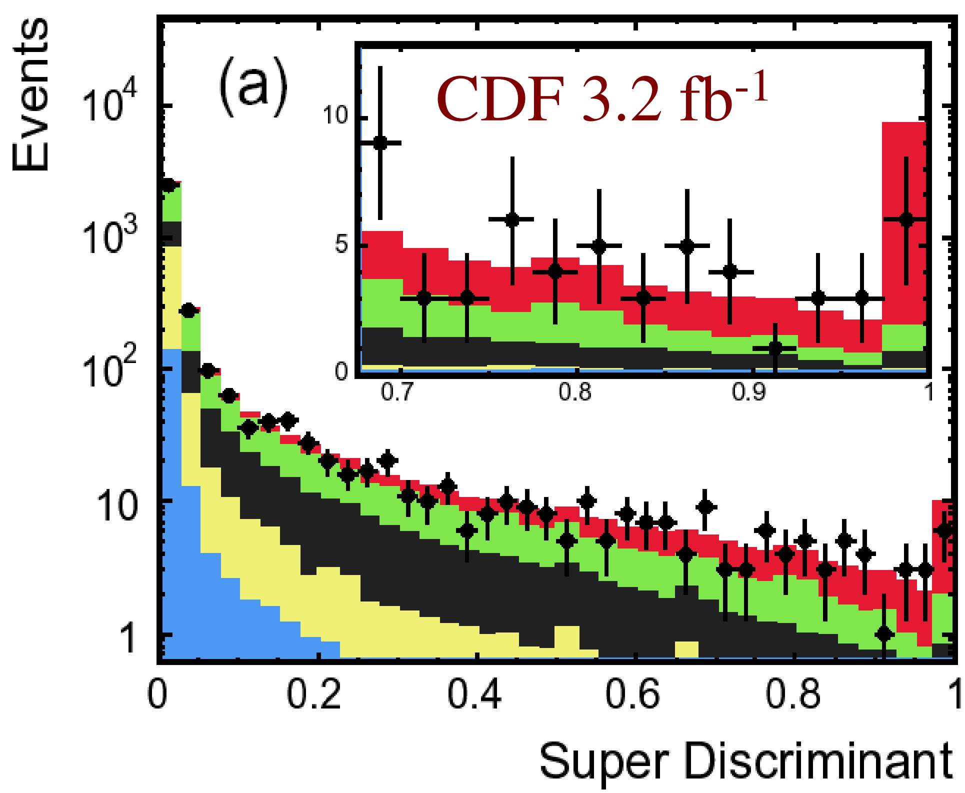
- Top quark discovered in 1995 at the Tevatron using the pair production mode
- Important measurement of the *t*-*b* coupling
- Similar final state as WH -> *lv* + *bb* search
  - Therefore also a key milestone in the Higgs search

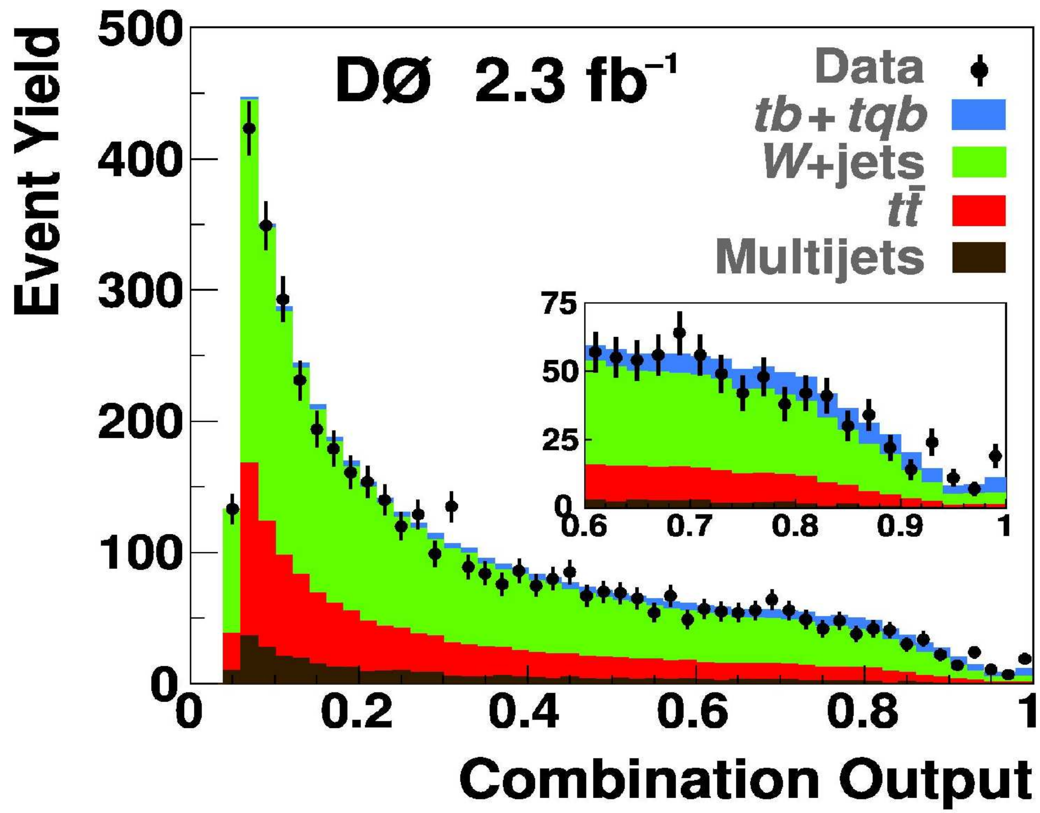




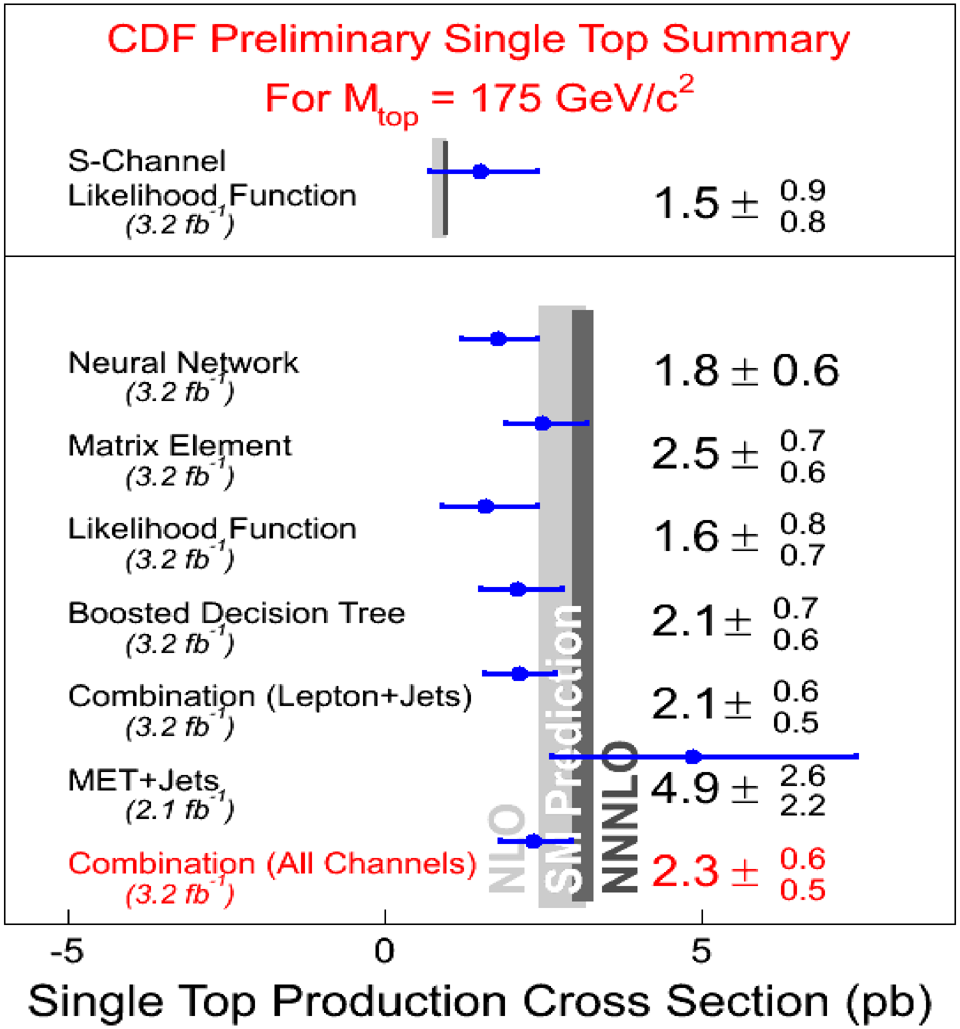
Single Top Production – Multivariate Techniques

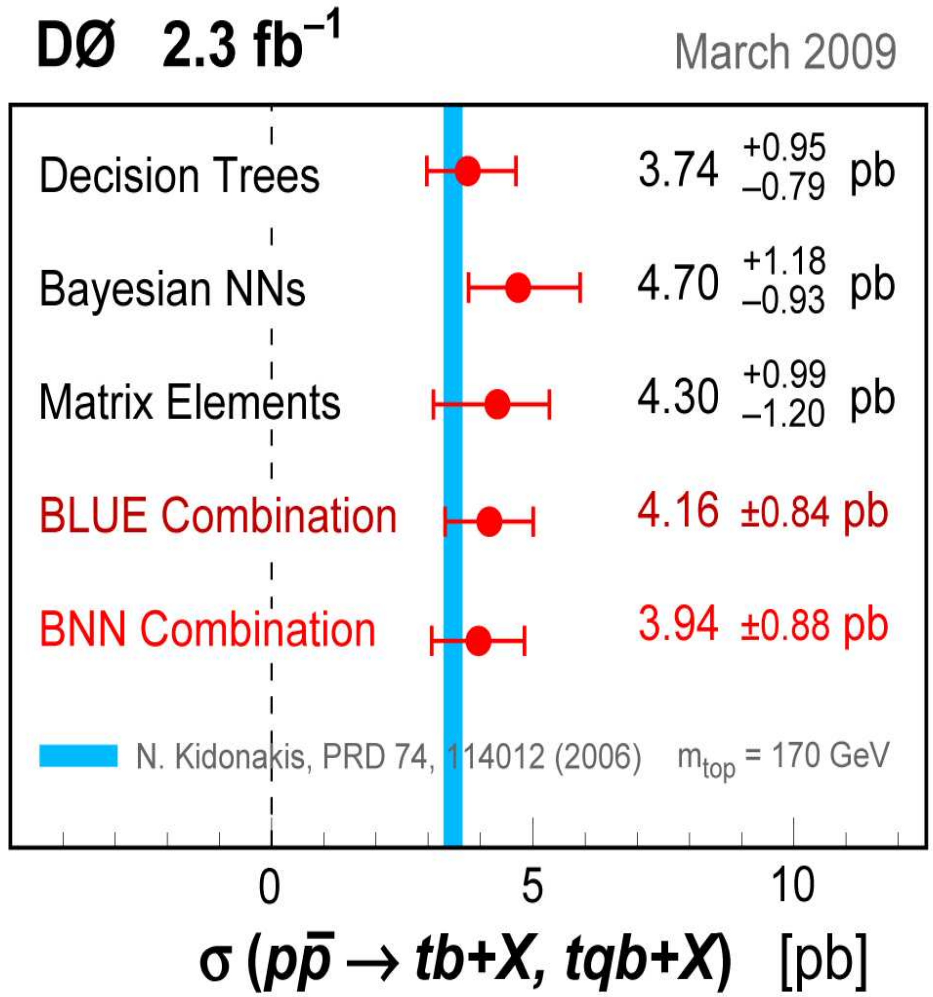
- Small Signal/Background: ½ of top pair production cross section
- Fewer particles in the final state that top pair production
- Full power of diverse techniques employed:
  - Likelihoods based on SM matrix element probabilities
  - Neural networks
  - Decision trees





Observation of Single Top Production – Cross Sections





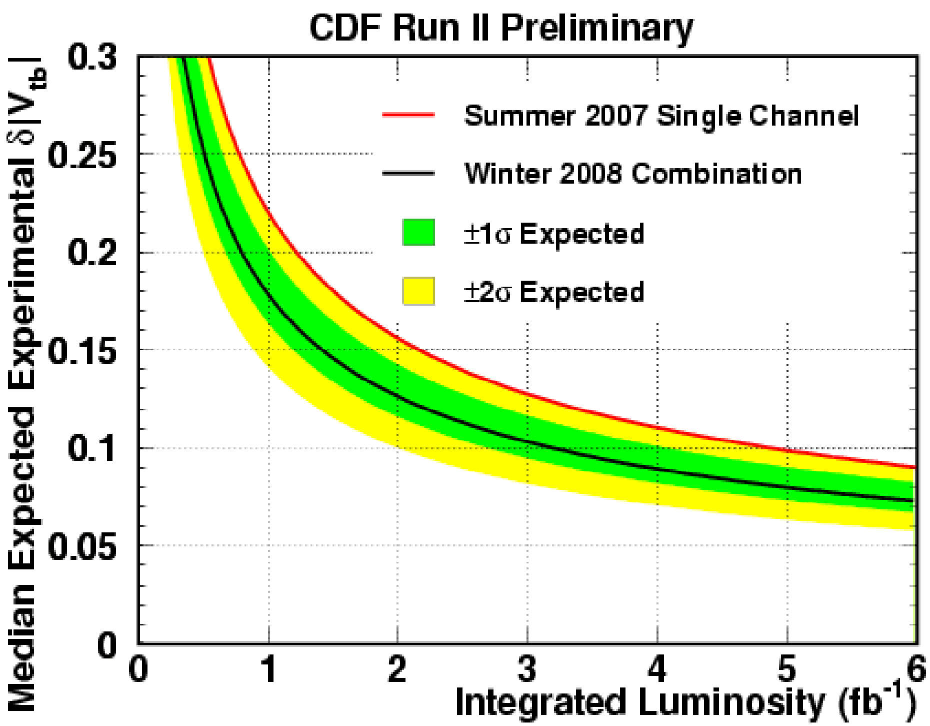
CDF and D0 papers submitted for publication

significance of signal: CDF 5.0 σ (5.9 σ) observed (expected)

D0 5.0 σ (4.5 σ) observed (expected)

Single Top Production & $|V_{tb}|$

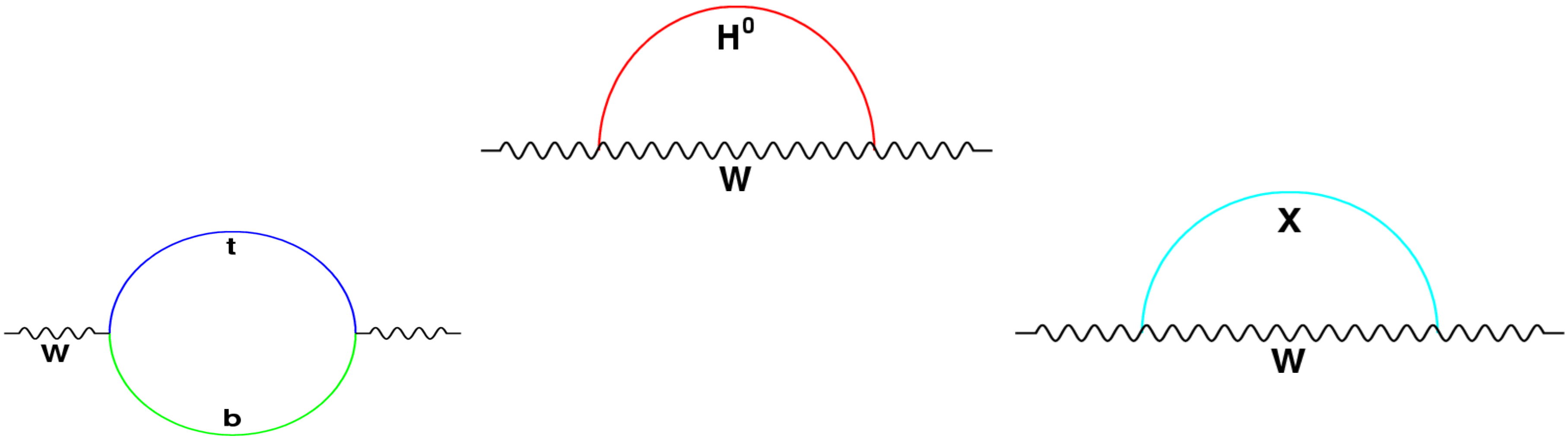
- CKM matrix element V_{tb}
  - CDF: $V_{tb} = 0.91 \pm 0.11$ (stat+syst) $\pm$ 0.07 (theory)
    - $1 > V_{tb} > 0.71$ (95% CL)
  - D0: $V_{tb} = 1.07 \pm 0.12$
    - $1 > V_{tb} > 0.78$ (95% CL)
- No assumption on CKM unitarity or number of quark families



Precision Standard Model Measurements Constraining the Higgs and New Physics

Precision Measurements of W boson and top quark masses

- Radiative corrections due to heavy quark and Higgs loops and exotica

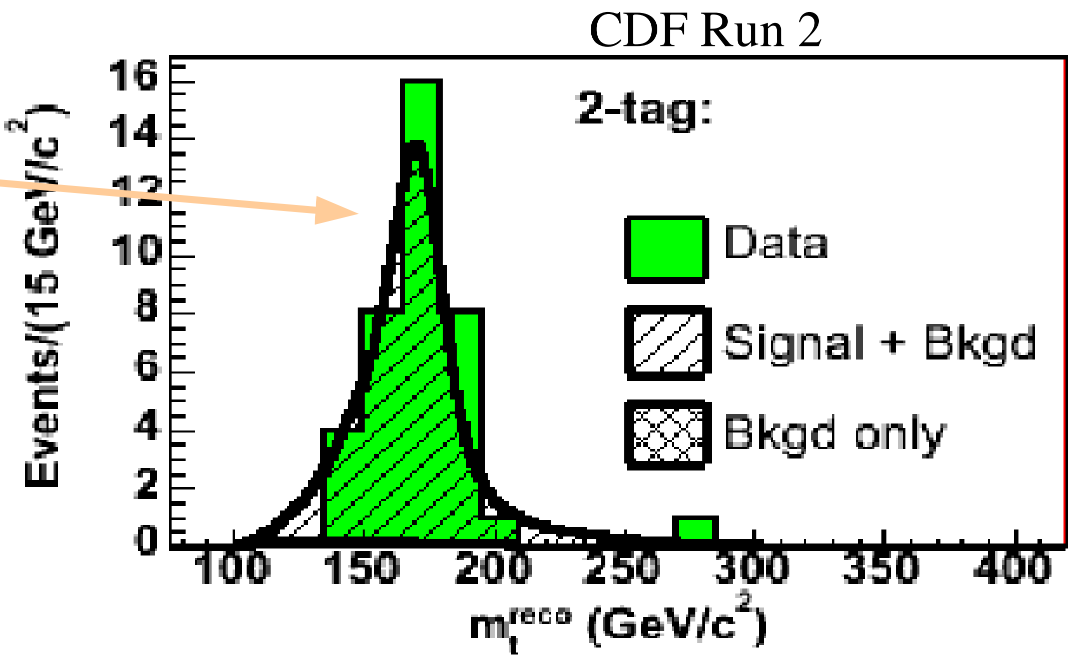


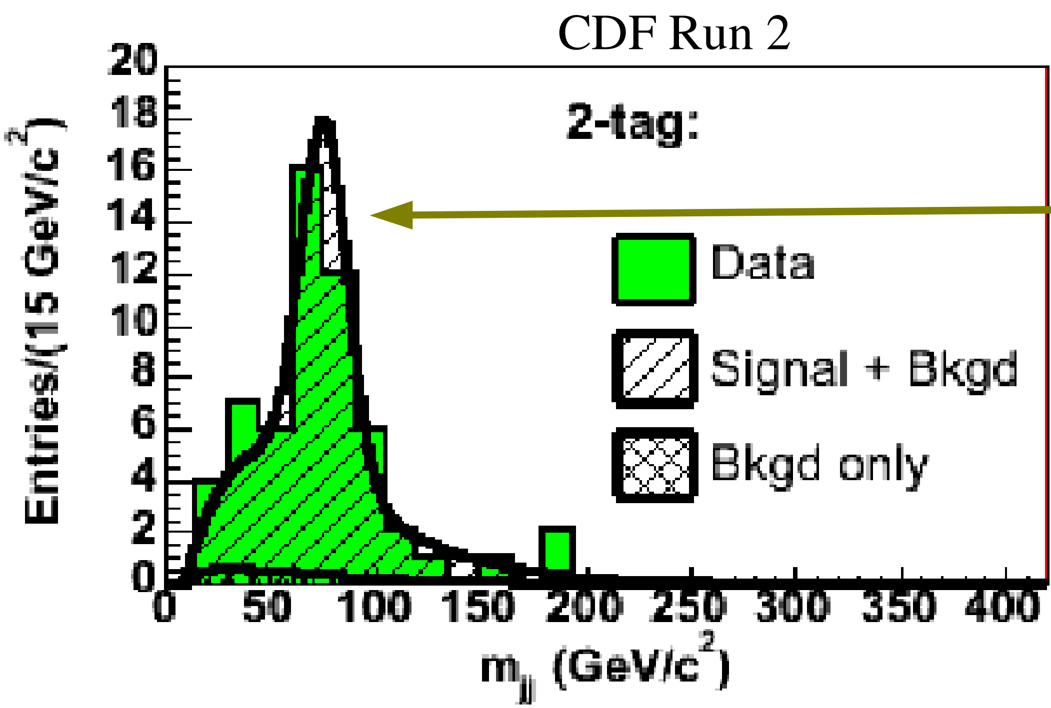
- Top quark mass and W boson mass constrain the mass of the Higgs boson, and possibly new particles beyond the standard model

Top Quark Mass Measurement

Progress on M_{top} at the Tevatron

Reconstructed top mass in 680 pb^{-1} of CDF data, fit with simulated lineshape

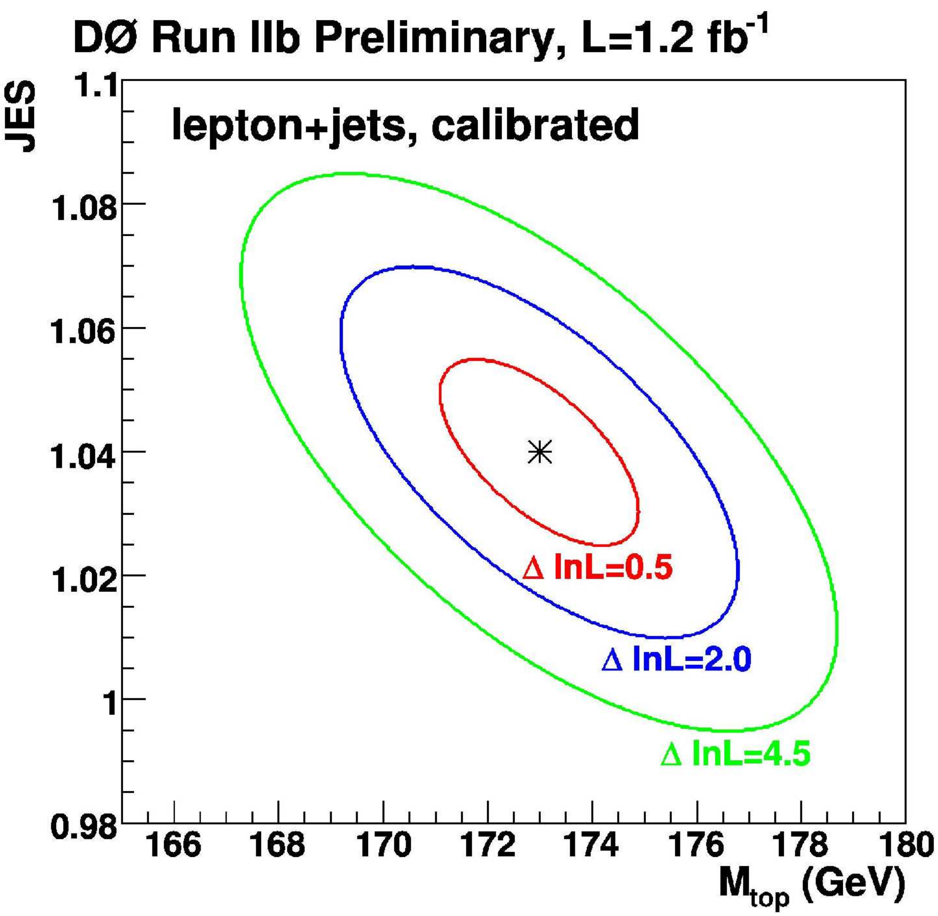




Improved top mass precision due to in-situ calibration of jet energy using W->jj decays in the same events

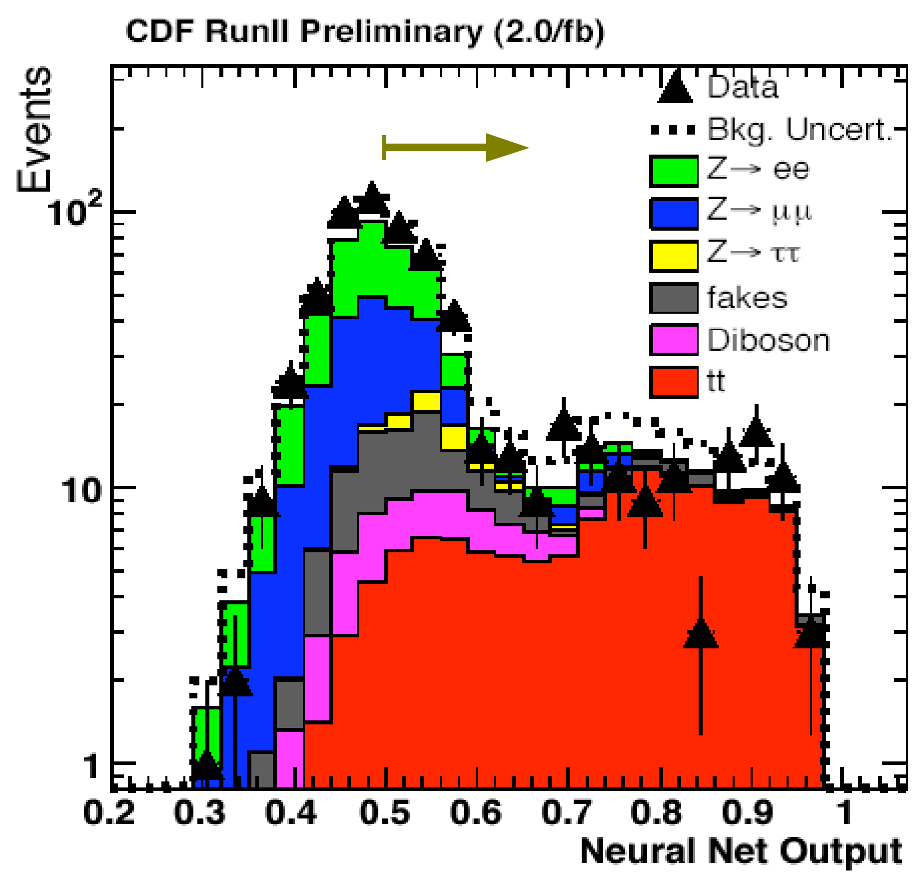
Progress on M_{top} at the Tevatron

2D fit for W->jj mass (to obtain jet energy scale JES) and top quark mass

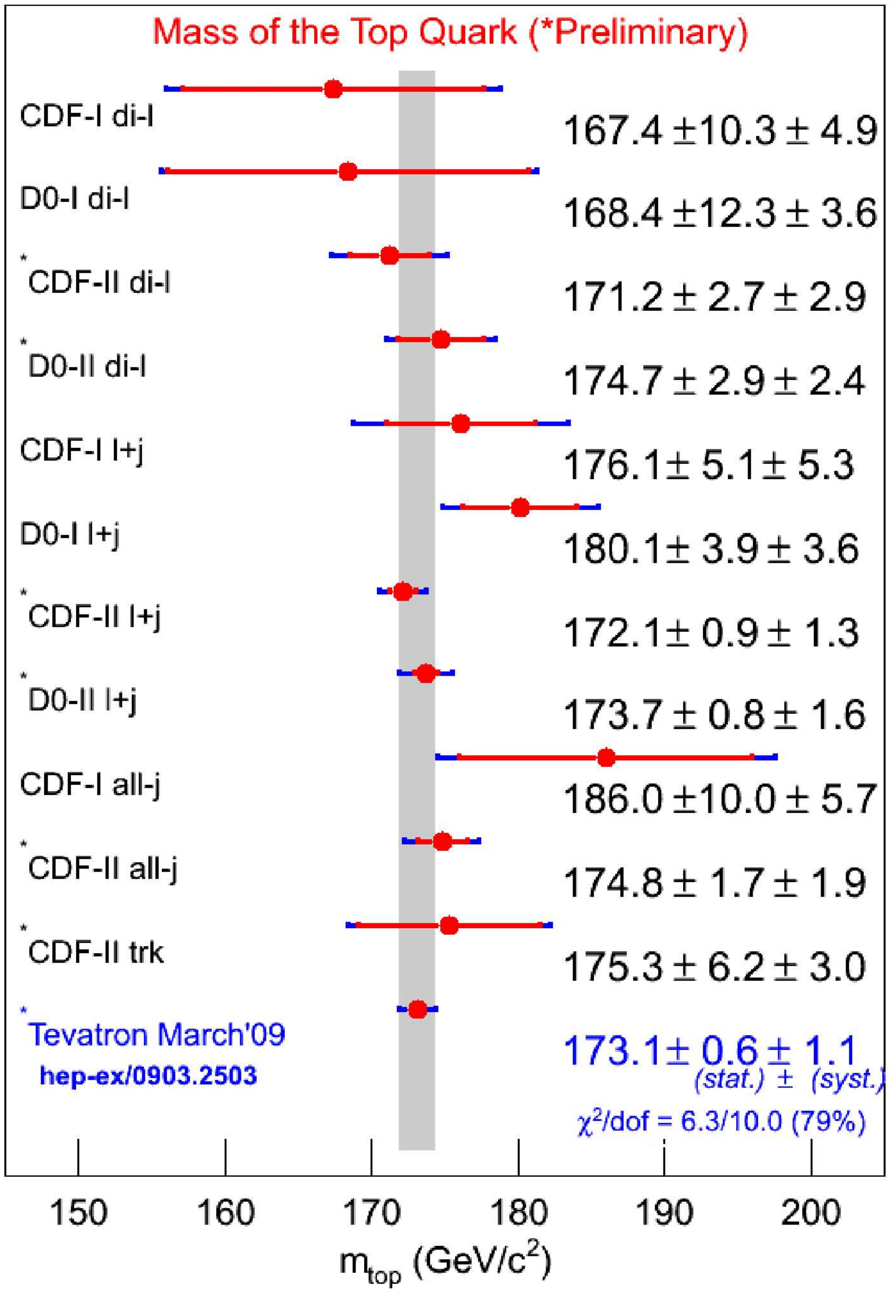


Neural Network for optimized event selection

Matrix-element-based likelihood fitting in dilepton channel



Progress on M_{top} at the Tevatron



	Tevatron Combined
Result	173.12
iJES	0.48
aJES	0.33
bJES	0.23
cJES	0.19
dJES	0.30
rJES	0.13
lepPt	0.11
Signal	0.30
MC	0.49
UN/MI	0.03
BG	0.26
Fit	0.16
CR	0.41
MHI	0.07
Syst.	1.07
Stat.	0.65
Total	1.25

Jet energy scale

Signal model

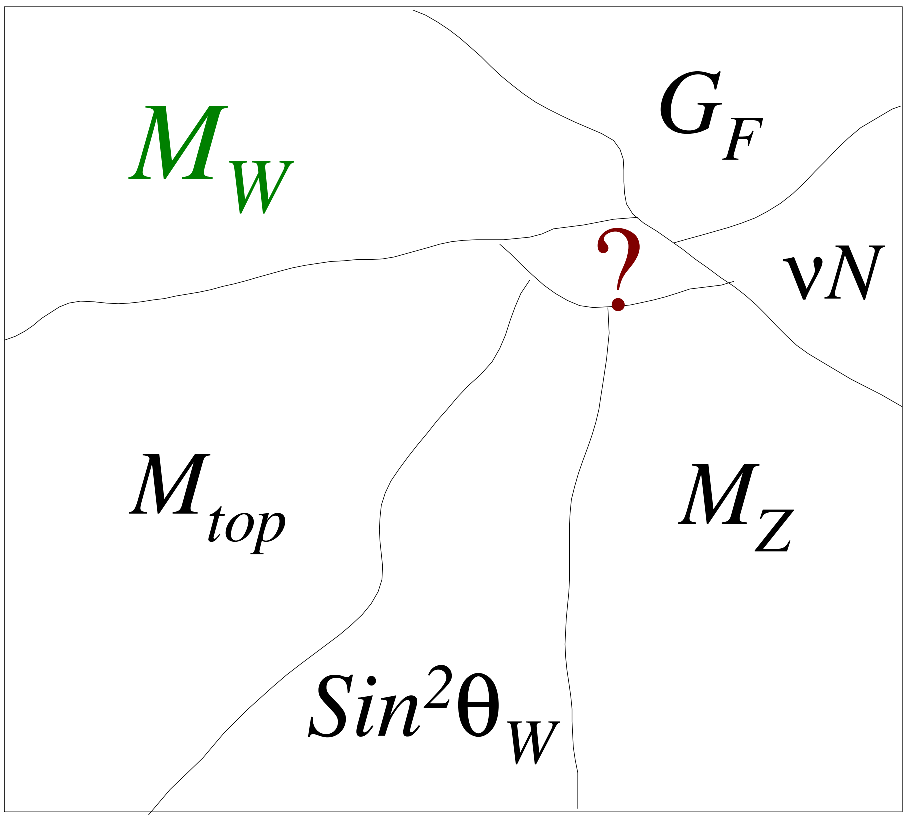
Color reconnection

δM_{top} < 1 GeV may be possible

W Boson Mass Measurement

Motivation for M_W measurement

- SM Higgs fit: $M_H = 83^{+30}_{-23}$ GeV (http://gfitter.desy.de)
- LEPII direct searches: $M_H > 114.4$ GeV @ 95% CL (PLB 565, 61)



In addition to the Higgs, is there another missing piece in this puzzle?

(A_{FB}^b *vs* A_{LR}: 3.2σ)

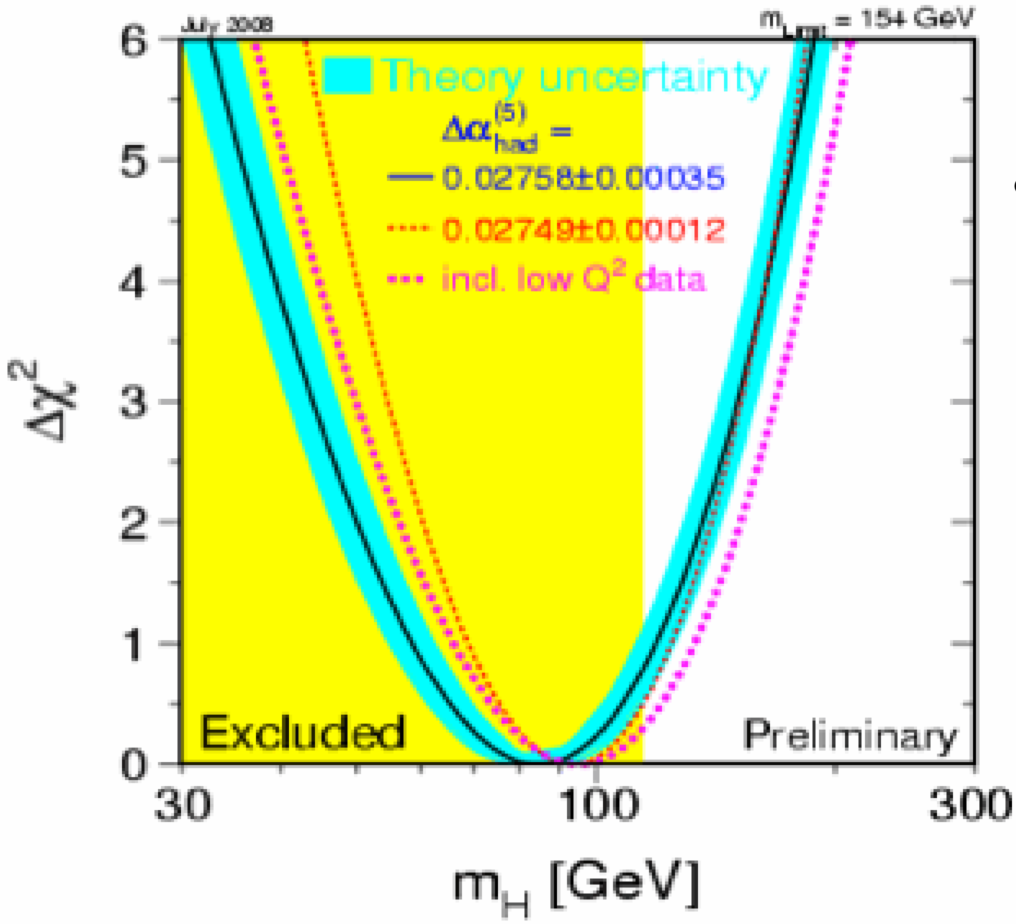
Must continue improving precision of M_W, M_{top} ...

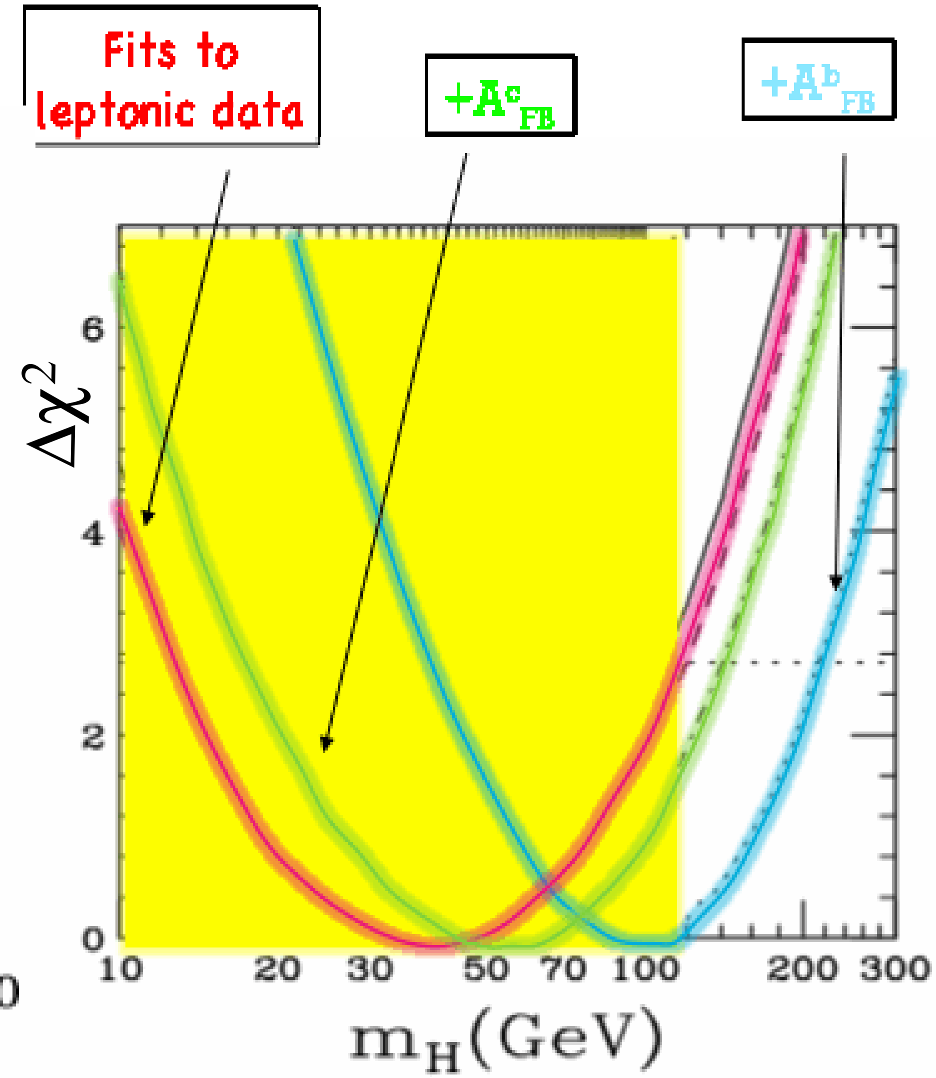
other precision measurements constrain Higgs, equivalent to $\delta M_W \sim 20$ MeV

Motivate direct measurement of M_W at the 20 MeV level

Standard Model Higgs Constraint

M_W and leptonic measurements of $\sin^2\theta$ prefer low SM Higgs mass, hadronic (heavy flavor) measurements of $\sin^2\theta$ prefer higher SM Higgs mass (A^b_{FB} prefers ~ 500 GeV Higgs)



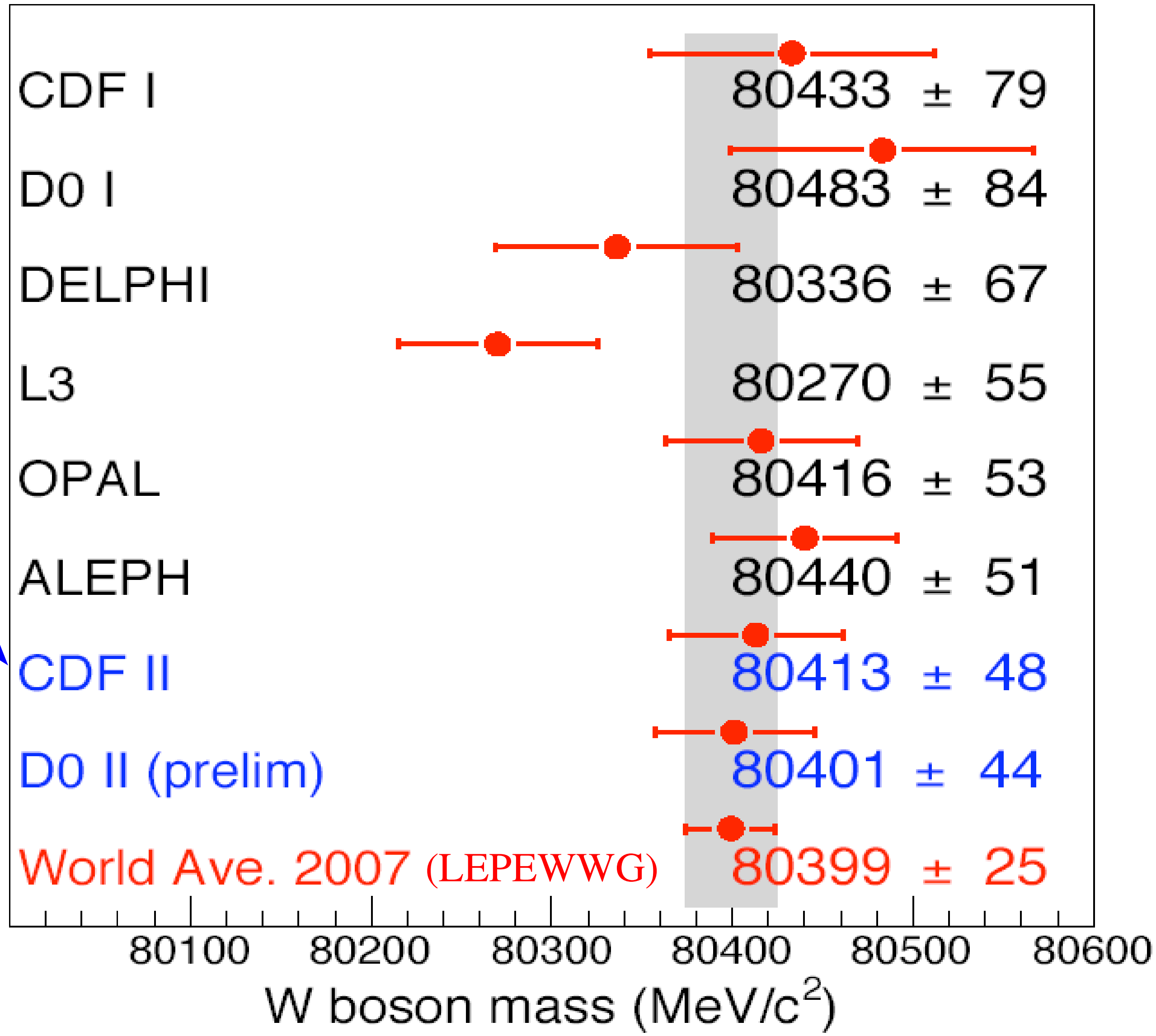


M. Chanowitz, PRL 97 (2001) 231802

W Boson Mass Measurements

New preliminary result from D0: $M_W = 80401 \pm 23(\text{stat}) \pm 37(\text{syst})$

PRL 99:151801, 2007
PRD 77:112001, 2008

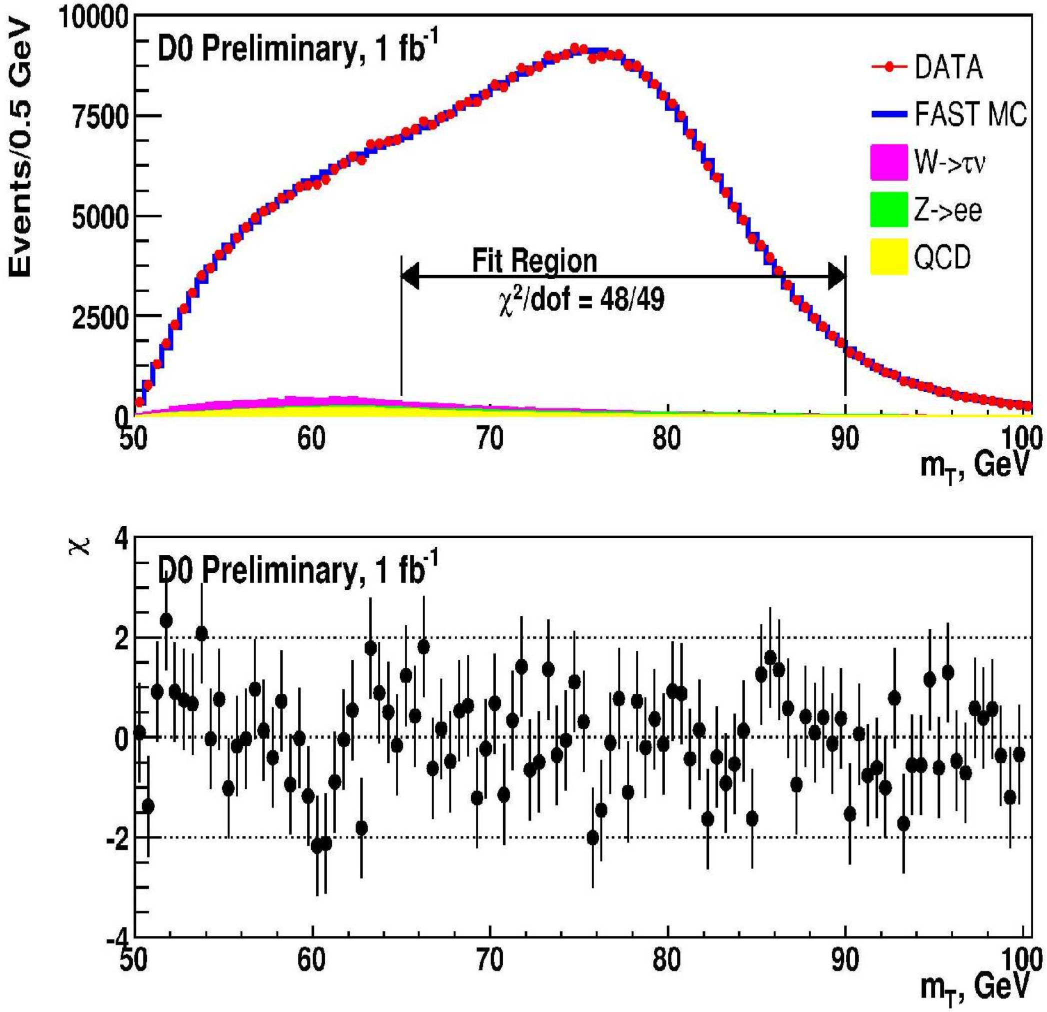


Gfitter yields new world average

$M_W = 80399 \pm 23$ MeV

(http://gfitter.desy.de)

New Measurement of the W Boson Mass by D0



uncertainties

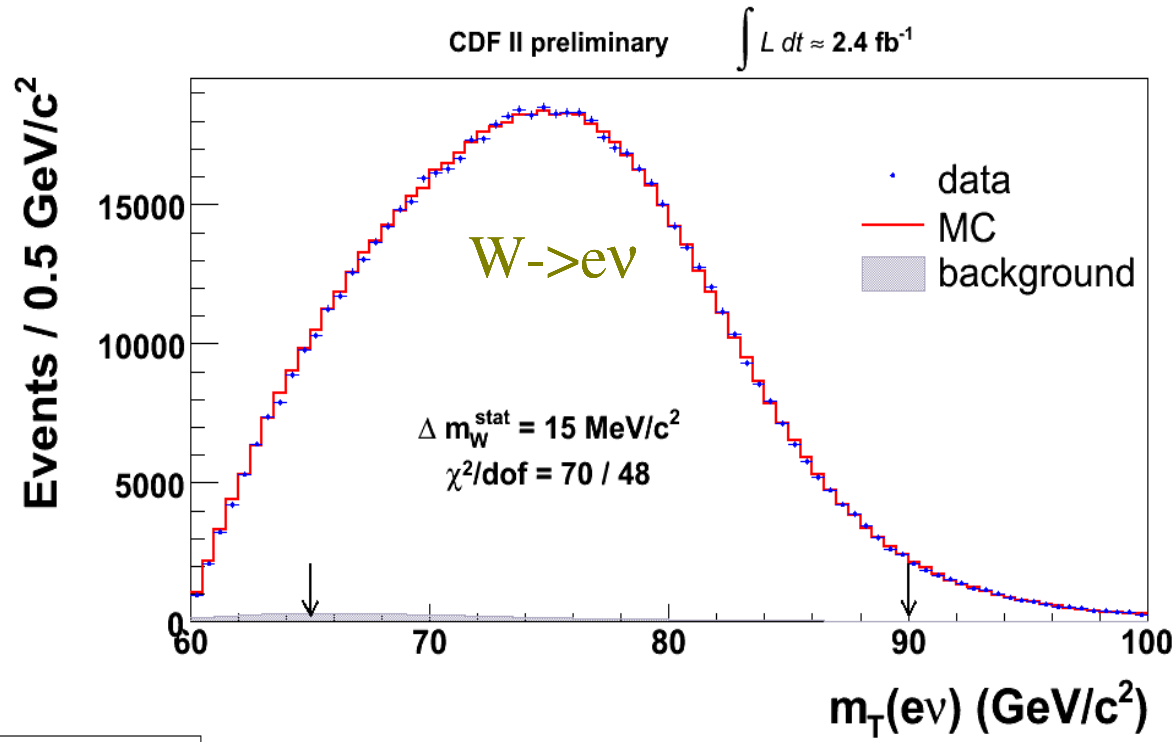
Source	$\sigma(m_W)$ MeV m_T
Experimental	
Electron Energy Scale	34
Electron Energy Resolution Model	2
Electron Energy Nonlinearity	4
W and Z Electron energy loss differences	4
Recoil Model	6
Electron Efficiencies	5
Backgrounds	2
Experimental Total	35
W production and decay model	
PDF	9
QED	7
Boson p_T	2
W model Total	12
Total	37

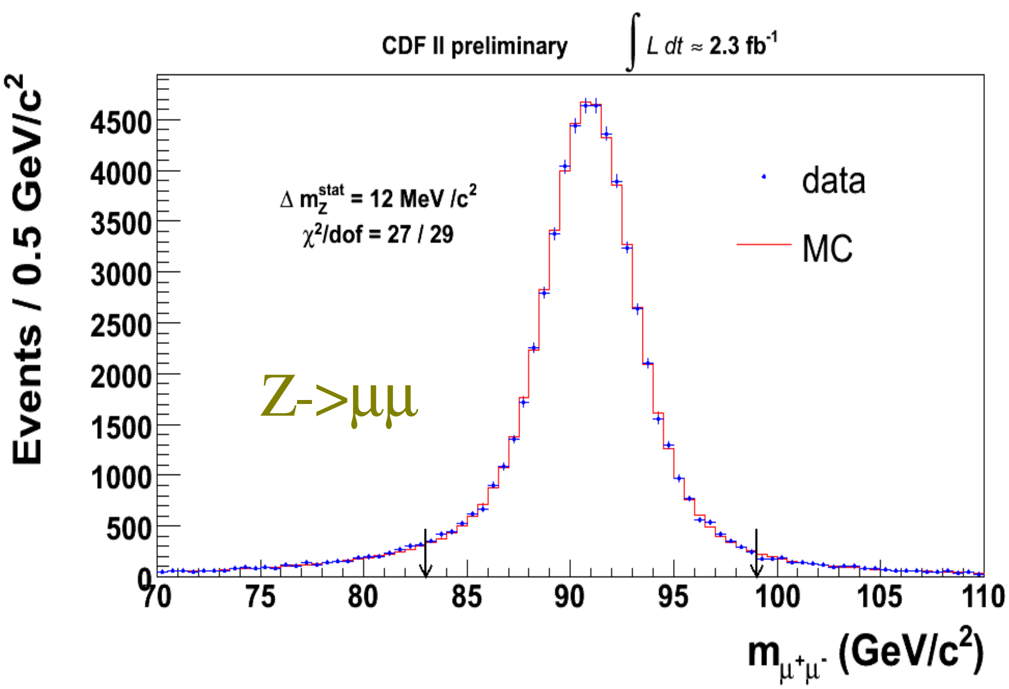
Best single measurement of M_W!

Consistent results from lepton and neutrino p_T fits

Preliminary Studies of 2.4 fb^{-1} Data at CDF

CDF has started the analysis of 2.4 fb^{-1} of data, with the goal of measuring M_W with precision ~ 25 MeV





statistical errors on W and Z boson mass fits and calibrations are scaling with statistics

Summary

- CDF and D0 experiments at Fermilab Tevatron in pursuit of direct observation of standard model Higgs in the 115-200 GeV range
  - SM Higgs excluded for masses between 160-170 GeV @ 95% CL
- Production of single top quarks observed at the Tevatron
- Top quark mass $M_{top} = 173.1 \pm 0.6_{stat} \pm 1.1_{syst}$ GeV = 173.1 ± 1.3 GeV
- Preliminary W mass measurement from D0 is the most precise single measurement:
  - $M_W = 80401 \pm 23_{stat} \pm 37_{syst}$ MeV
    $= 80401 \pm 44$ MeV
- SM Higgs fit (gfitter.desy.de) excluding direct searches yields $m_H < 155$ GeV @ 95% CL (direct search limit is 2.5*SM @ 115 GeV)
- Tevatron pushing towards $\delta M_W < 25$ MeV and $\delta M_{top} < 1$ GeV