Overview of the Tevatron Physics Program

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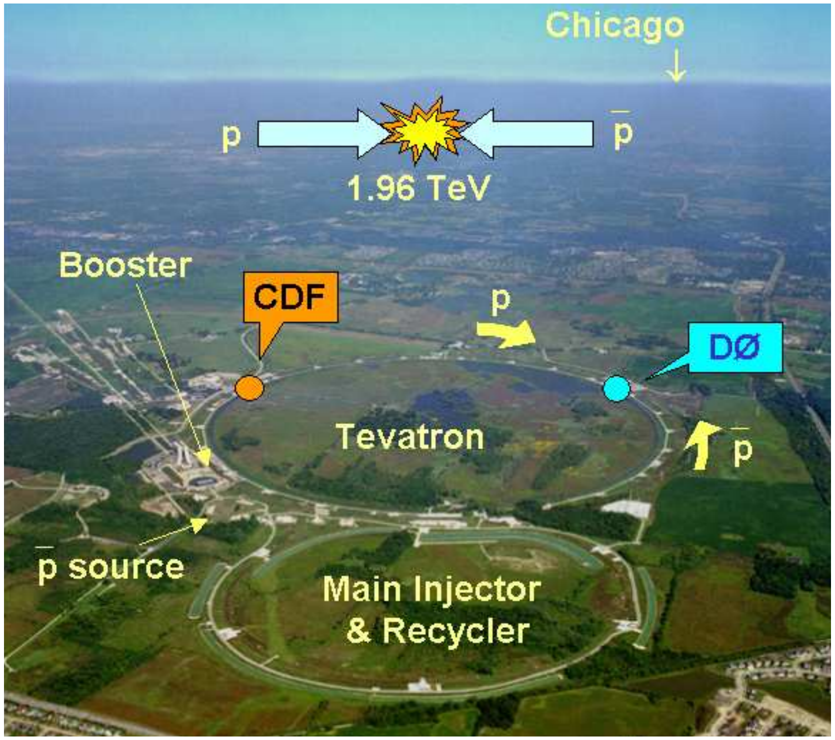
(for the CDF and D0 Collaborations)



TEV4LHC Workshop
Fermilab, 16 September 2004

Introduction

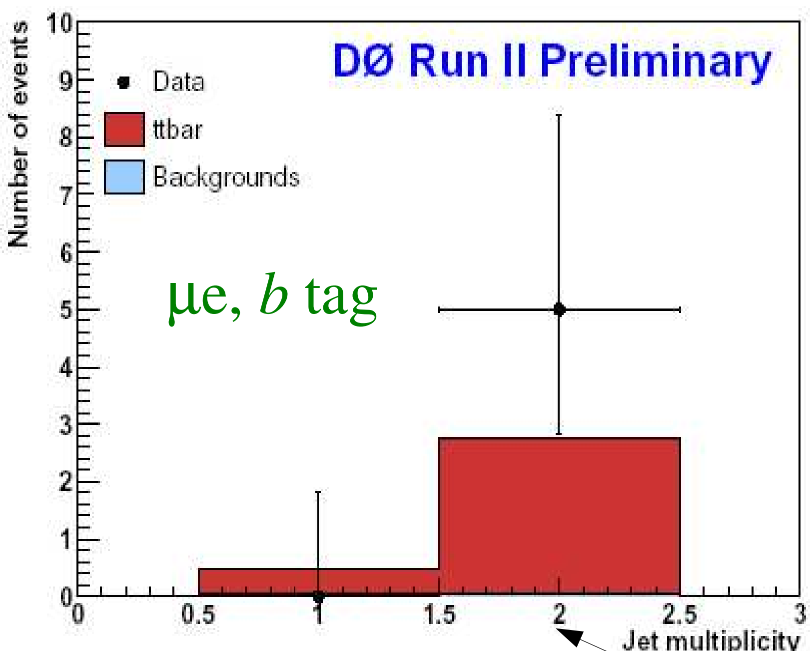
- Very rich Tevatron program: probes physics at the highest Q^2
  - Direct searches
  - Top physics
  - High E_T jets
- ...to intermediate Q^2
  - Precision electroweak physics
- ...to low Q^2
  - B and charm physics
- Selected topics discussed today span the range of
  - Statistical and systematic contributions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

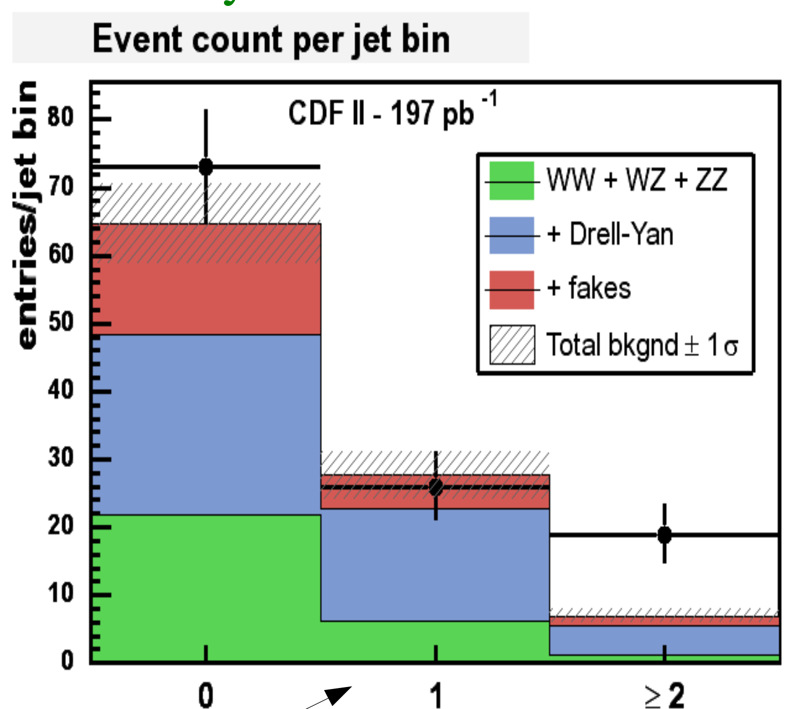
Outline

- Top quark physics
  - Cross sections in lepton+jets and dilepton channels
  - Top quark mass
- Electroweak physics
  - W boson mass
  - Pair production of gauge bosons
  - High mass Drell-Yan forward-backward asymmetry
- QCD physics
  - Jet and photon cross sections
- SM Higgs search
- Other direct searches
  - NonSM Higgs
  - SUSY and exotica
- B physics
  - B mixing
  - Rare decays

Top Signals

- Is it the standard model top quark? Or does its large mass give it access to new physics?
- Probes:
  - Spin structure: W helicity in top decays
  - Event topology
  - Comparing cross sections in different decay modes

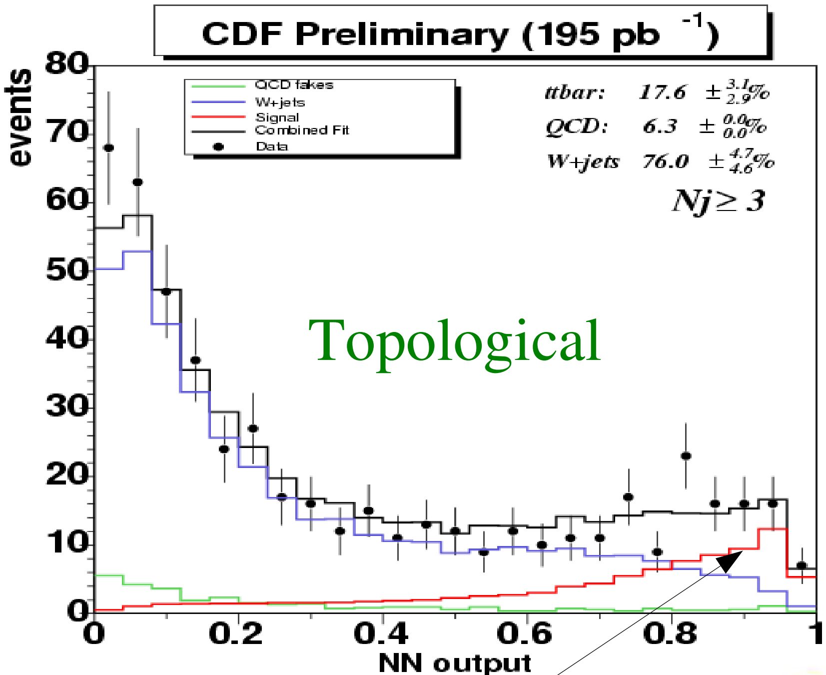




Dilepton channels

Top Cross Sections, lepton + jets channels

- Explore many different strategies: leave no stone unturned

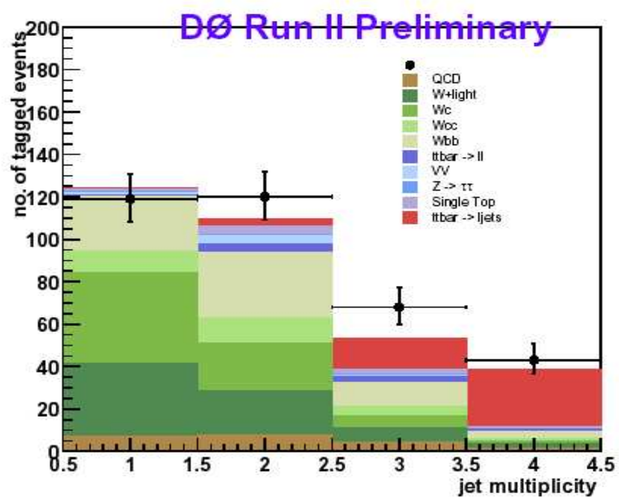


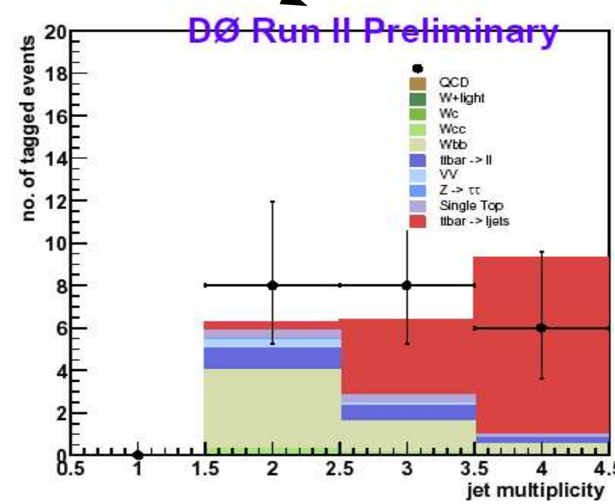
Topological

Important to understand the shapes of the W + *n* jet backgrounds: jet multiplicity and kinematics for large *n*, and *b* quark content, especially @LHC energy.

Single and double *b* tag

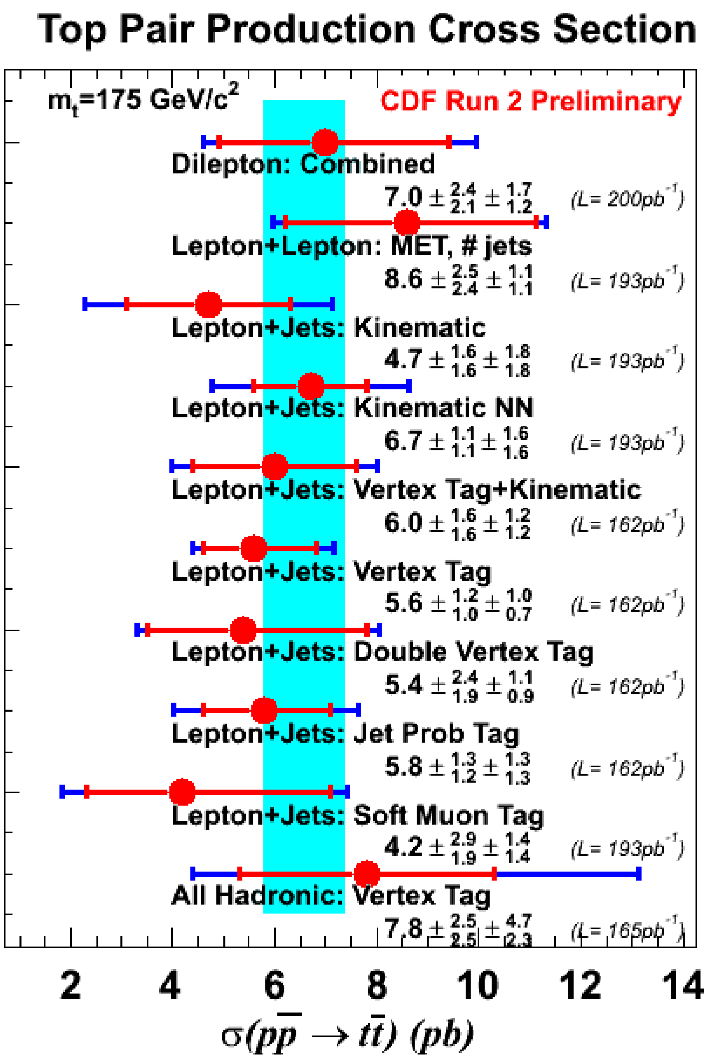
Top signal

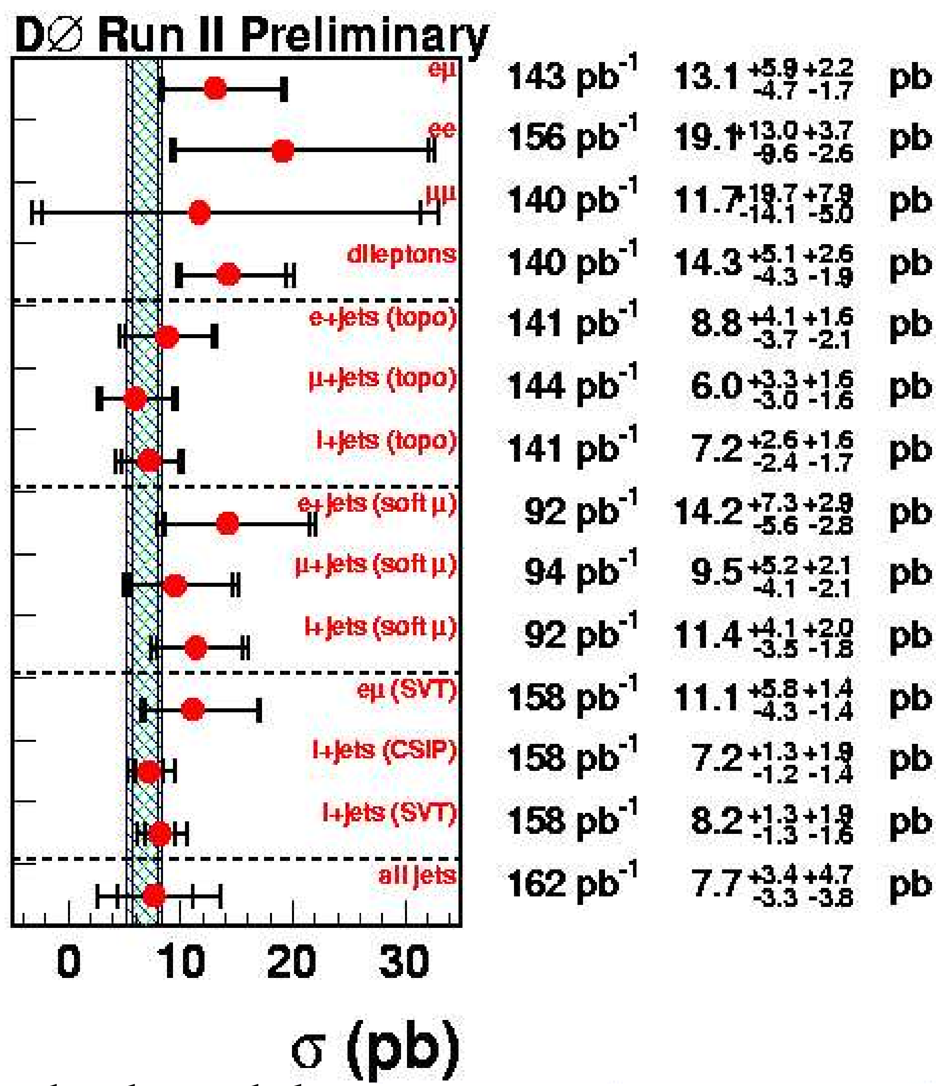




Top Cross Sections Summary

Probing the *tWb* electroweak vertex in top decays:

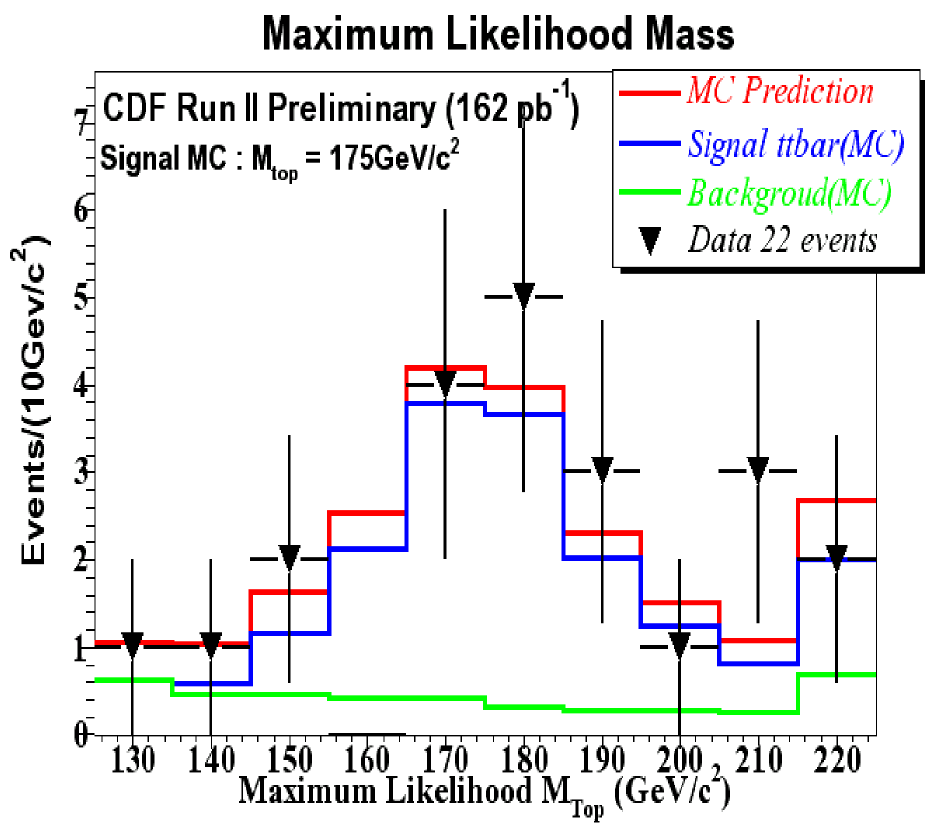


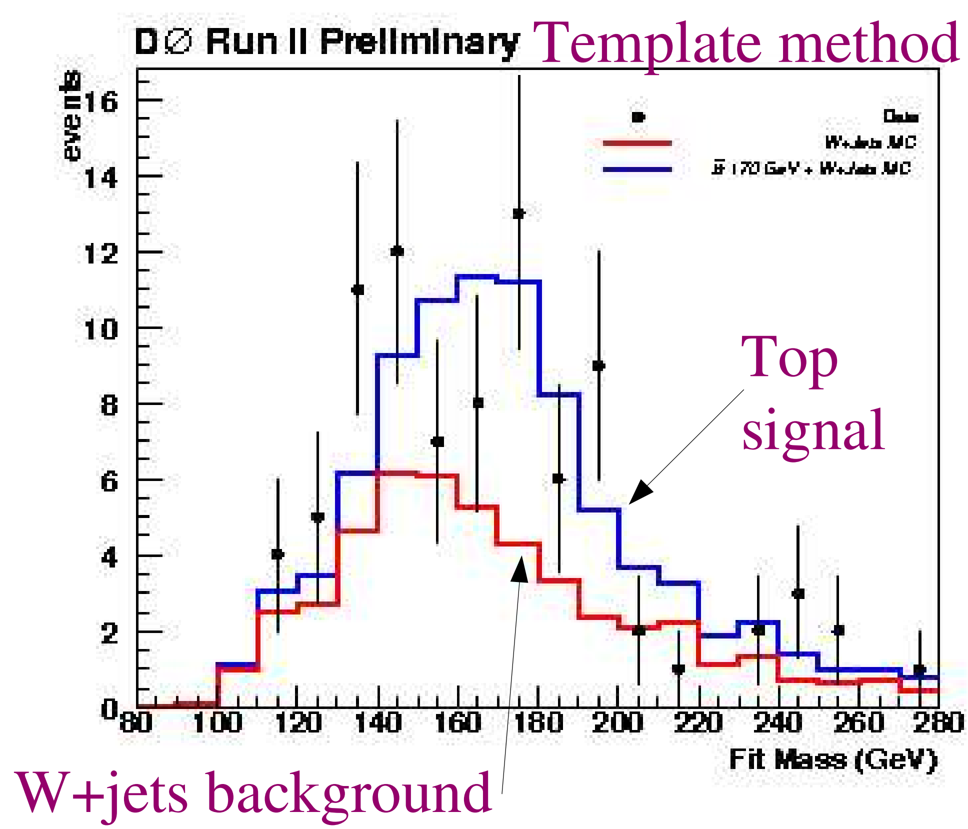


Statistics-limited, consistent with standard model

Top Quark Mass

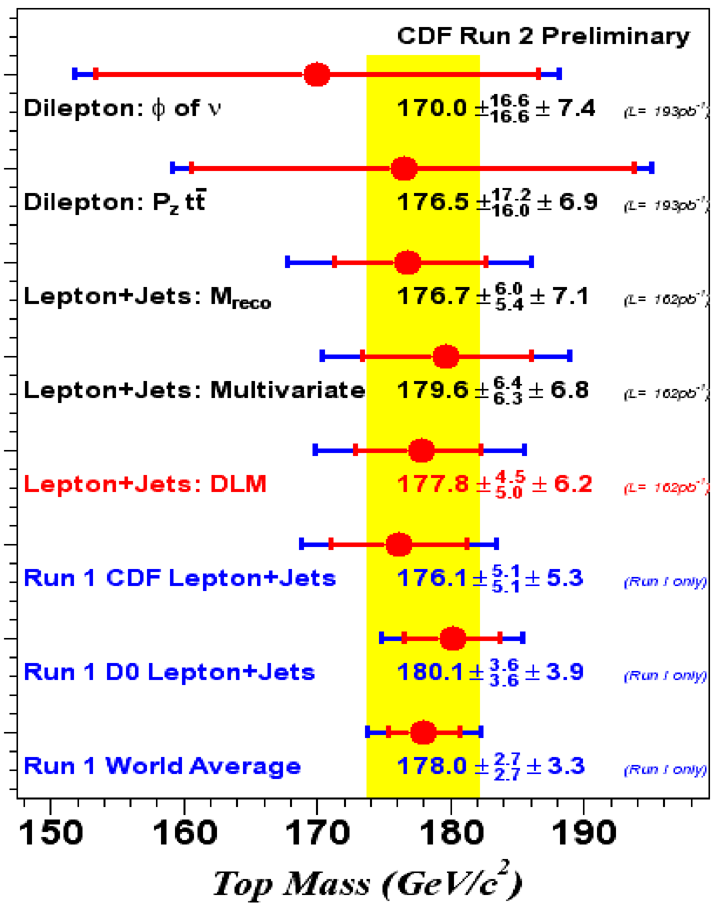
- Important standard model parameter, ingredient of indirect Higgs constraint
- Complicated event topology => many fitting techniques, with different sensitivities to modelling
  - Histogram & template-fitting method
  - "per-event" mass extraction method





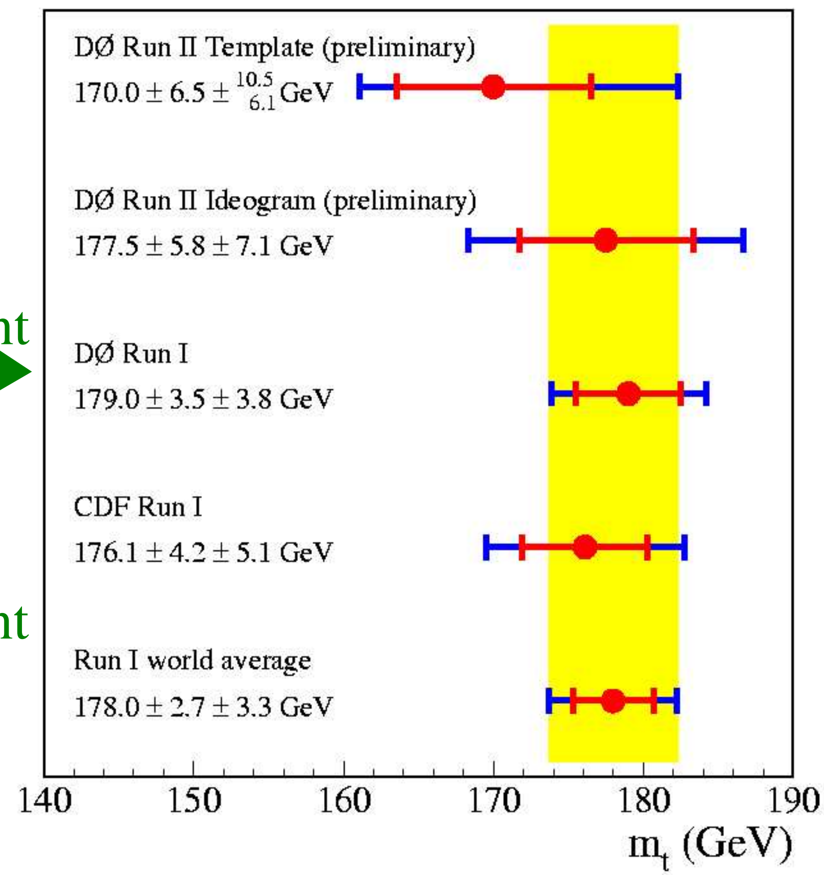
Top Quark Mass Summary

- Run 2 measurements catching up in precision to latest Run 1 result (M_t = 178.0 ± 4.3 GeV)



Best Run 2 measurement

Best measurement



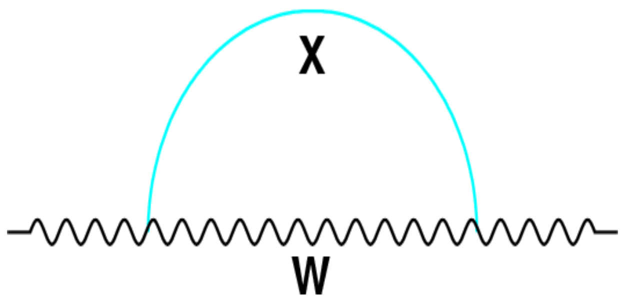
Systematics: jet energy scale (experimental) and gluon radiation (theoretical) need continous improvements to match statistics

Electroweak Physics

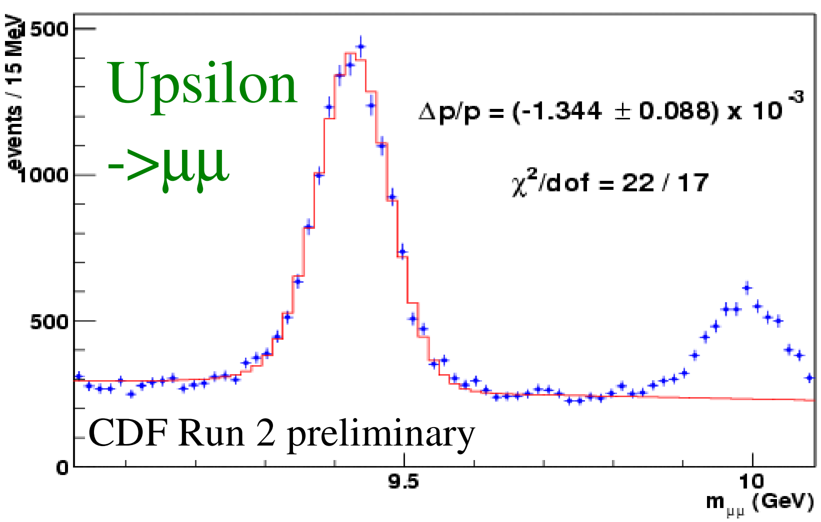
- Direct measurement of W boson mass and width
- W and Z boson cross section measurements
  - Extract BR(W->lν) from W/Z ratio, lepton universality
  - Establish baseline of detector performance
  - Luminosity measurement technique
- W and Z asymmetries
- Pair production of gauge bosons
  - Fundamental prediction of electroweak gauge theory
  - Establish baseline for multiple lepton-photon-jet-missing E_T final states, relevant for
    - Top physics (WW->dileptons, lν+jets)
    - Higgs search (WZ->lν + bb)
    - Searches (e*, μ*, leptoquarks, SUSY...)

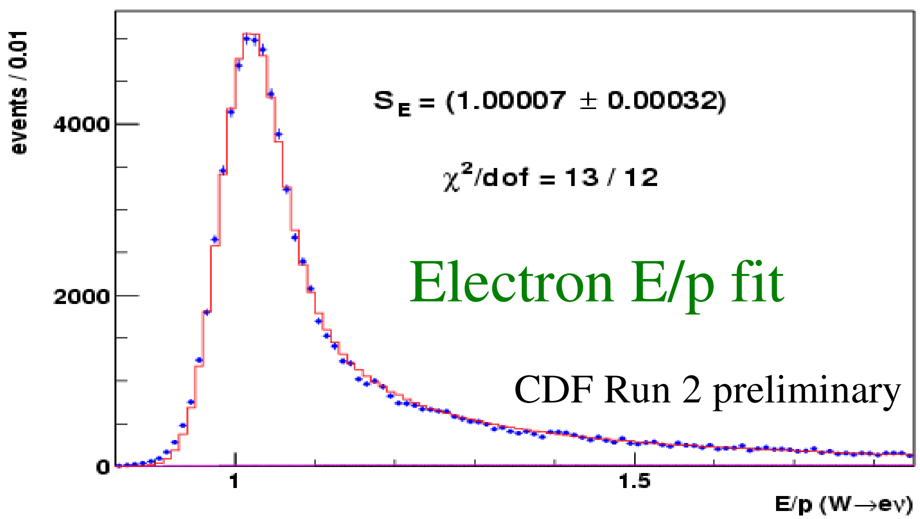
W boson mass

- Radiative corrections to W mass probe a wide range of new physics: SM Higgs, non-SM Higgs, SUSY...anything that couples to the W boson

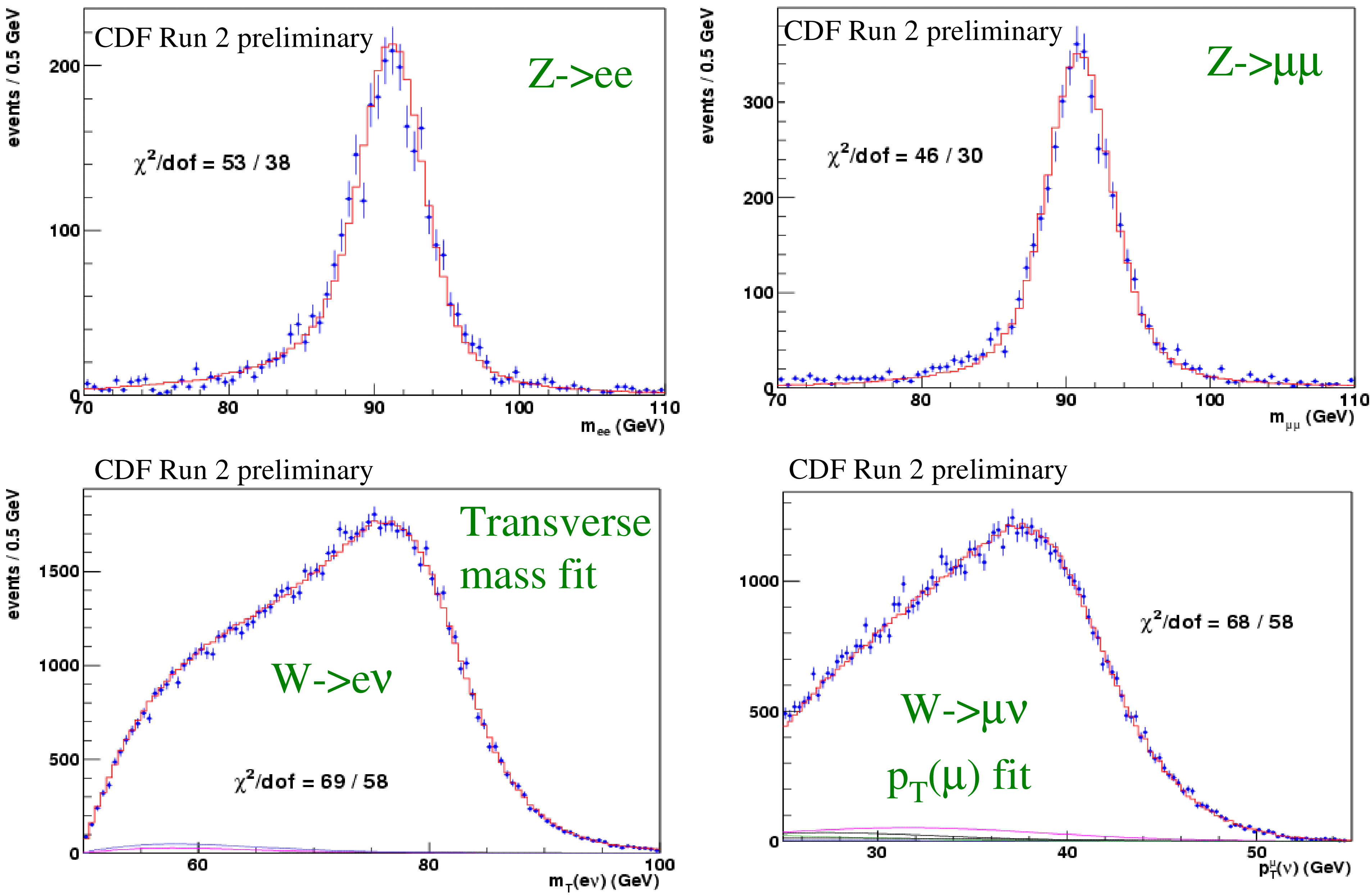


- Energy / momentum calibration is THE KEY aspect of this measurement
  - Other systematics: QED corrections, parton distribution functions, $p_T(W)$ model continue to reduce with improved calculations, tools and judicious use of collider data





W and Z boson mass fits



W boson mass

CDF Run 2
preliminary

Systematic	Electrons (Run 1)	Muons (Run 1)
Lepton Energy Scale and Resolution	70 (80)	30 (87)
Recoil Scale and Resolution	50 (37)	50 (35)
Backgrounds	20 (5)	20 (25)
Statistics	45 (65)	50 (100)
Production and Decay Model	30 (30)	30 (30)
Total	105 (110)	85 (140)

First experience with complete Run 2 analysis of 200/pb

Combined Run 2 uncertainty of 76 MeV already better than Run 1 from CDF (79 MeV) or D0 (84 MeV)

Mass value internally blinded with random offset until cross-checks completed

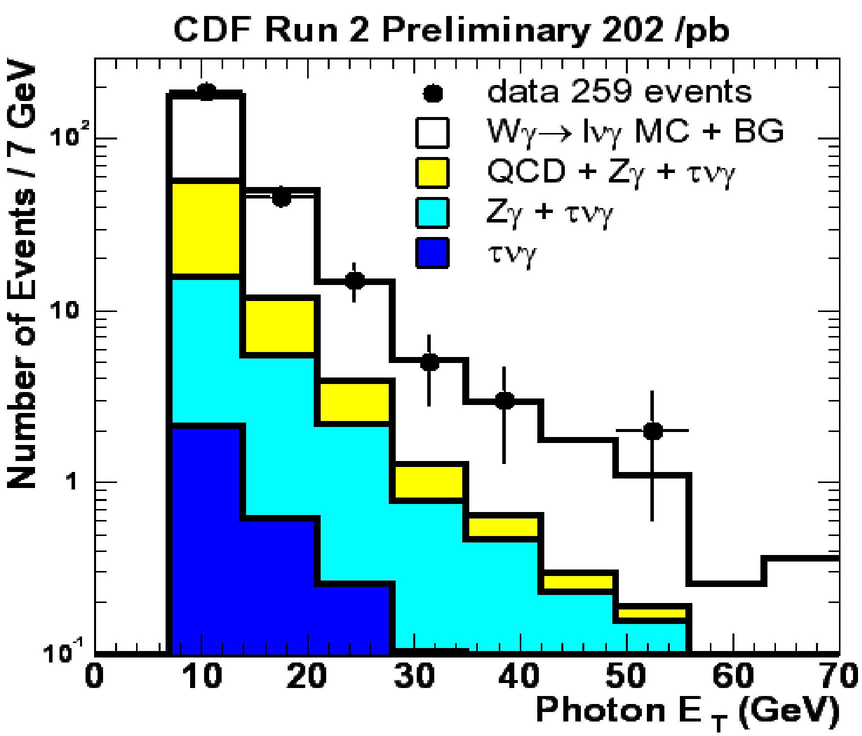
400/pb on tape: precision of best single measurement (ALEPH, 58 MeV) and combined LEP (42 MeV) within reach

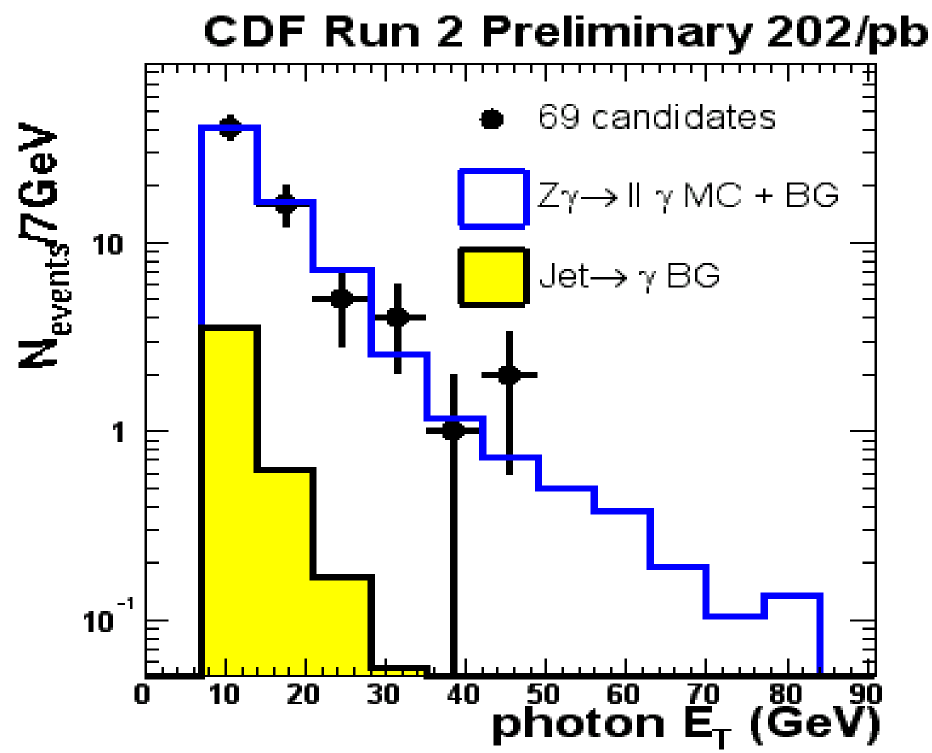
Wγ / Zγ

Good agreement with SM in rate and kinematics, giving confidence in photon techniques

D0: σ (Zγ -> *l l* γ) = 3.86 ± 0.46(stat & sys) ± 0.25(lum) pb (SM: 4.3 pb)

CDF: σ (Zγ -> *l l* γ) = 5.3 ± 0.6(stat) ± 0.3(sys) ± 0.3(lum) pb (SM: 5.4 ± 0.3 pb)





D0: σ (Wγ -> *l* ν γ) = 19.3 ± 6.7(stat & sys) ± 1.2(lum) pb (SM: 16.4 ± 0.4 pb)

CDF: σ (Wγ -> *l* ν γ) = 19.7 ± 1.7(stat) ± 2.0(sys) ± 1.1(lum) pb (SM: 19.3 ± 1.4 pb)

WW->dileptons

D0: $\sigma(WW) = 13.8^{+4.3}_{-3.8}(stat)^{+1.0}_{-0.8}(sys) \pm 0.9(lum)$ pb

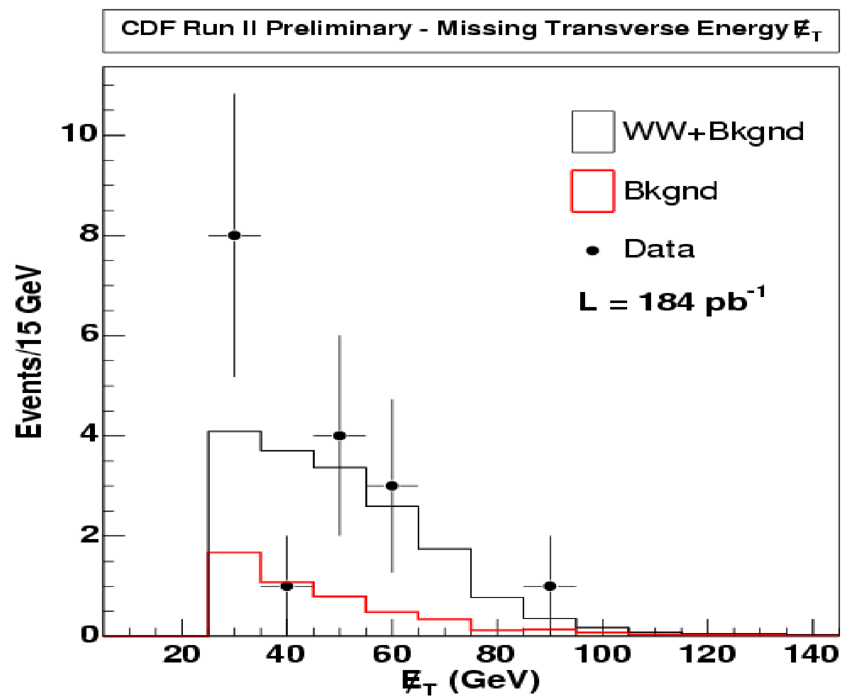
CDF Tight cuts: $\sigma(WW) = 14.3^{+5.6}_{-4.9}(stat) \pm 1.6(sys) \pm 0.9(lum)$ pb

CDF Loose cuts: $\sigma(WW) = 19.4 \pm 5.1(stat) \pm 3.5(sys) \pm 1.2(lum)$ pb

SM prediction 12.5 ± 0.8 pb

Agreement with SM in
rate and kinematics, tight and loose
selection cuts

Checks top and H->WW background



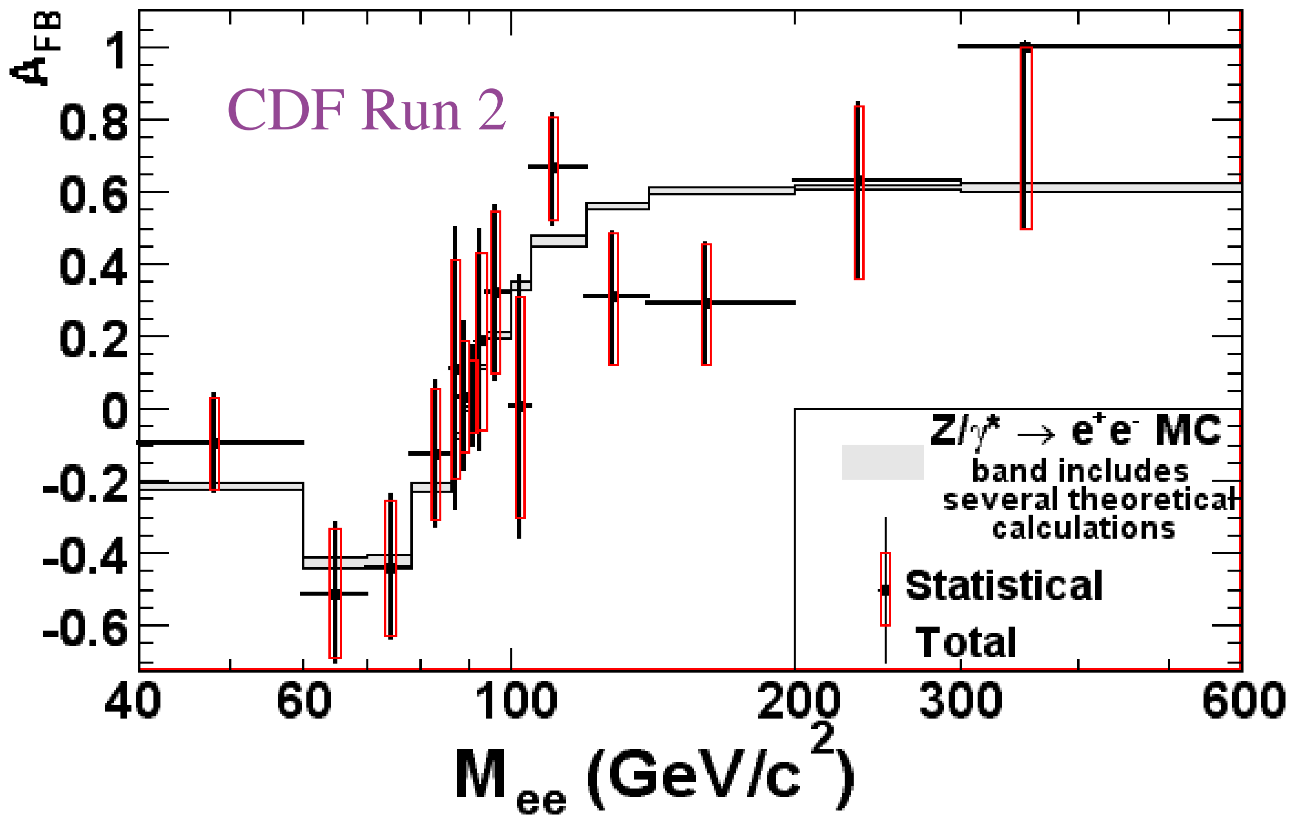
Drell-Yan Forward-Backward Asymmetry

- Probes new physics at high-mass through interference with SM (linear in coupling strength of new physics α_{new})
  - Complementary to cross section based search (quadratic in α_{new})

- Consistent with SM

- statistics-limited

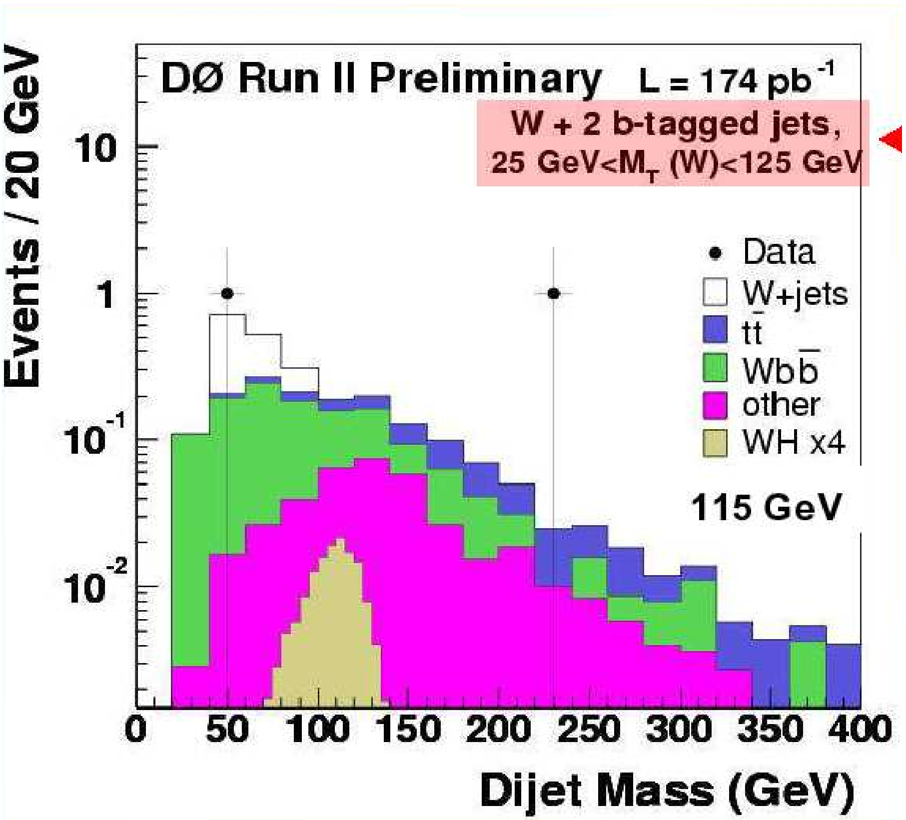
- Important to maintain charge-discrimination at high momentum



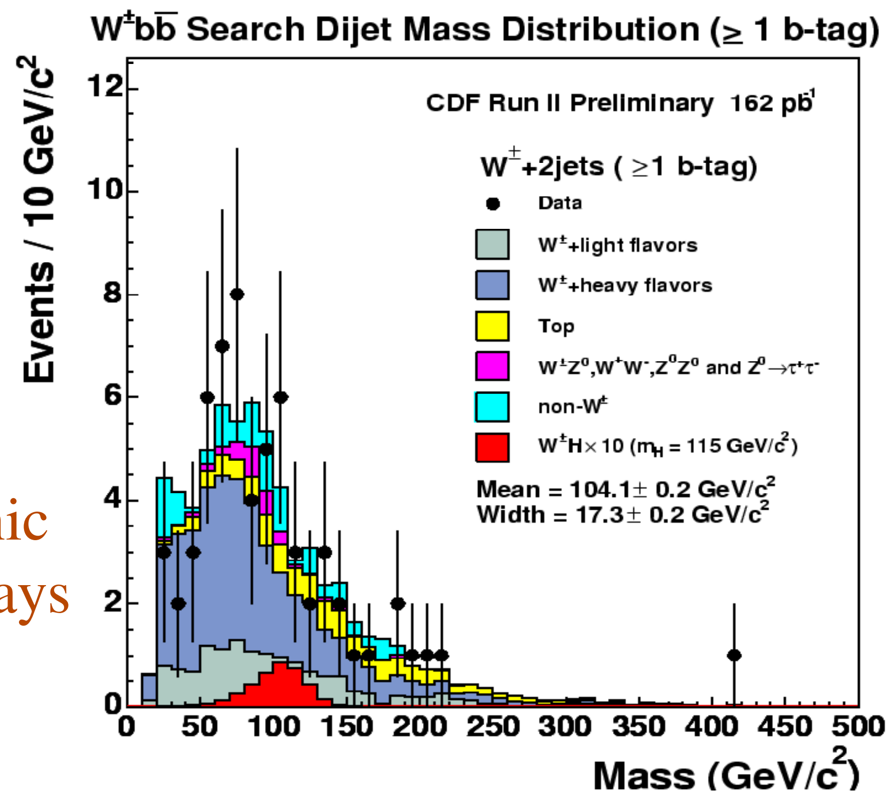
Higgs and Other Searches

SM Higgs Search

- Associated production: W,Z + H (->bb) for M_H < 130 GeV
- H->WW for M_H > 130 GeV



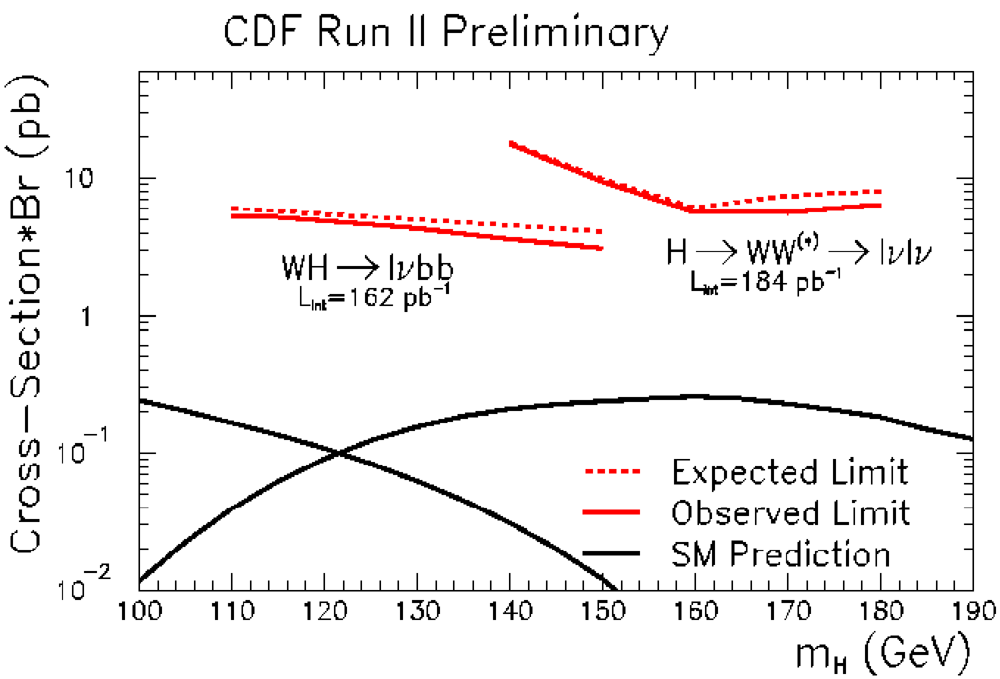
Leptonic W decays used



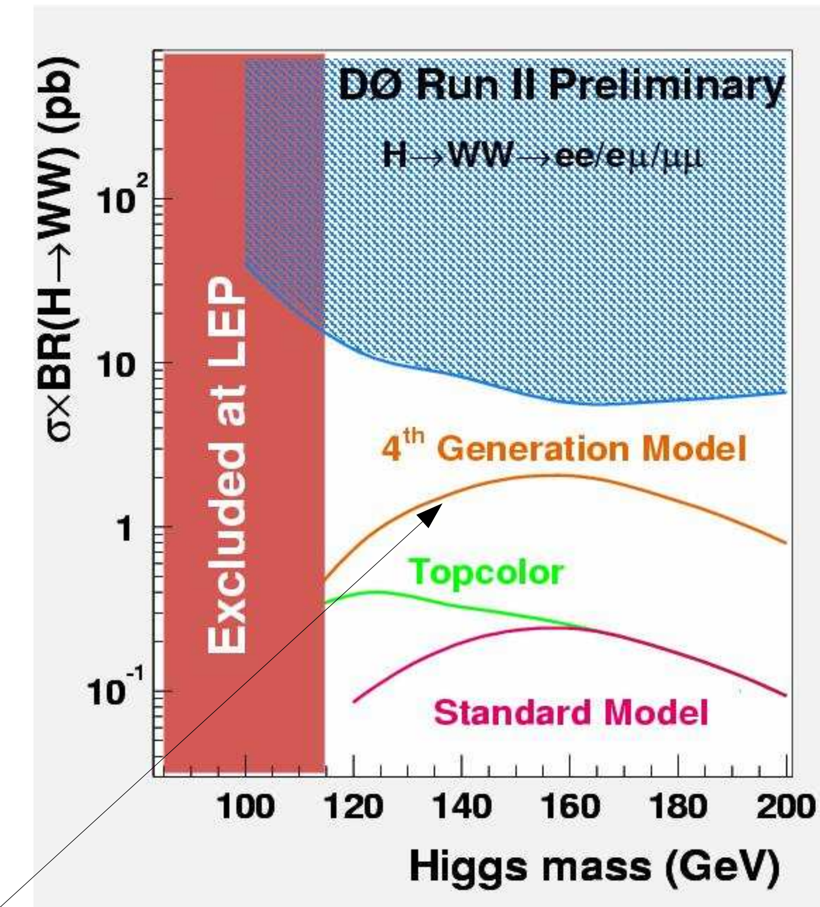
Improvements from: better *b* tagging, using topological (spin 0) information, more channels (Z), mass resolution (Z->*bb* sample very important)

SM Higgs Search

Exploit angular (spin 0) information for H->WW mode



Limits already exceeding Run 1 results

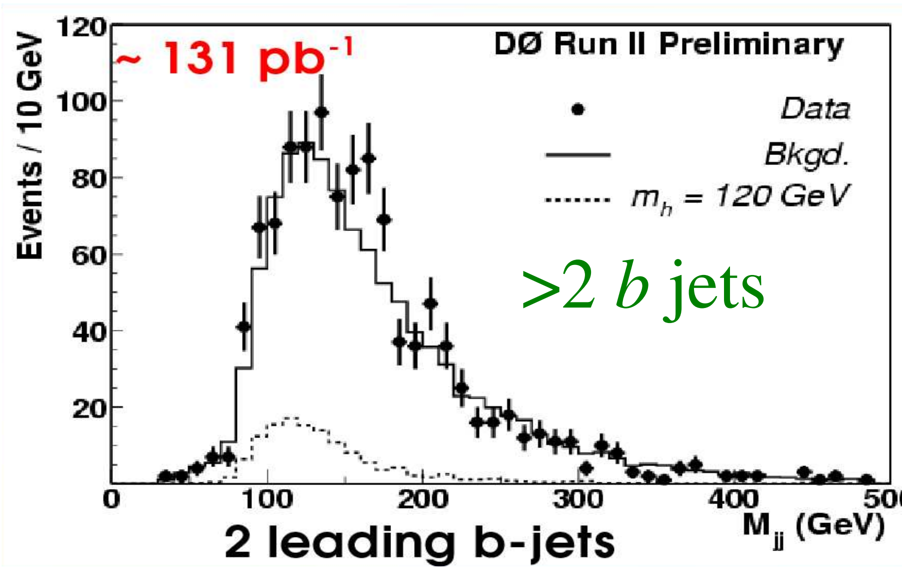


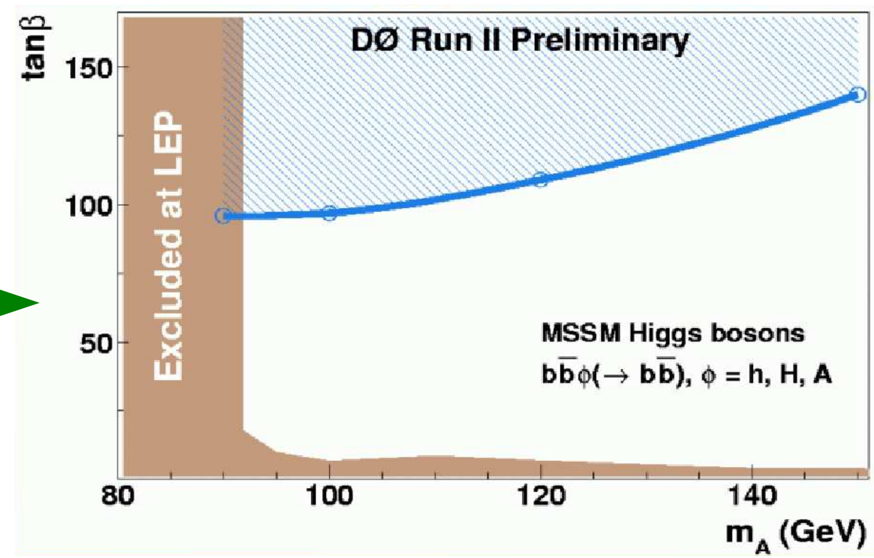
Sensitivity beyond LEP exclusion starts at ~2/fb

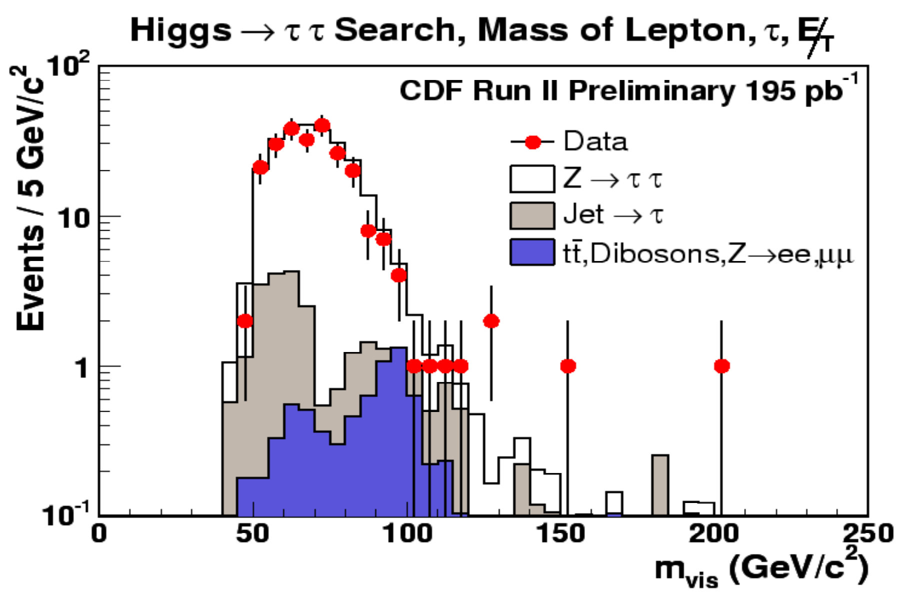
...but interesting sensitivity to other new physics sooner

MSSM Higgs Search

Enhanced cross sections, heavy flavors (b, τ) preferred @ high tanβ

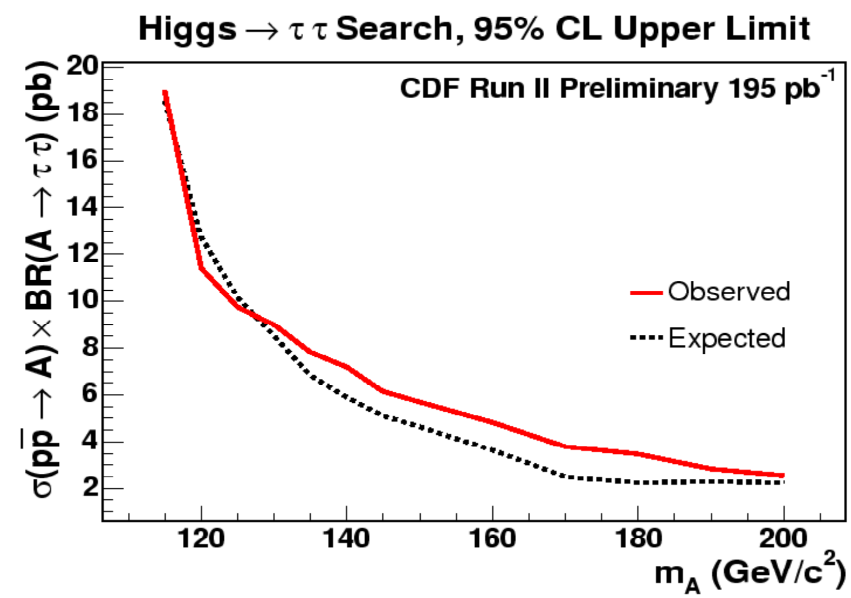






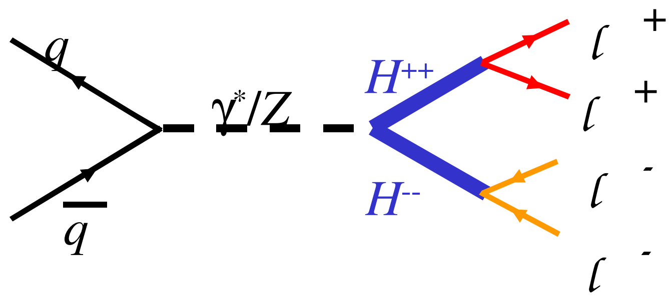
$\tau_l\tau_h$

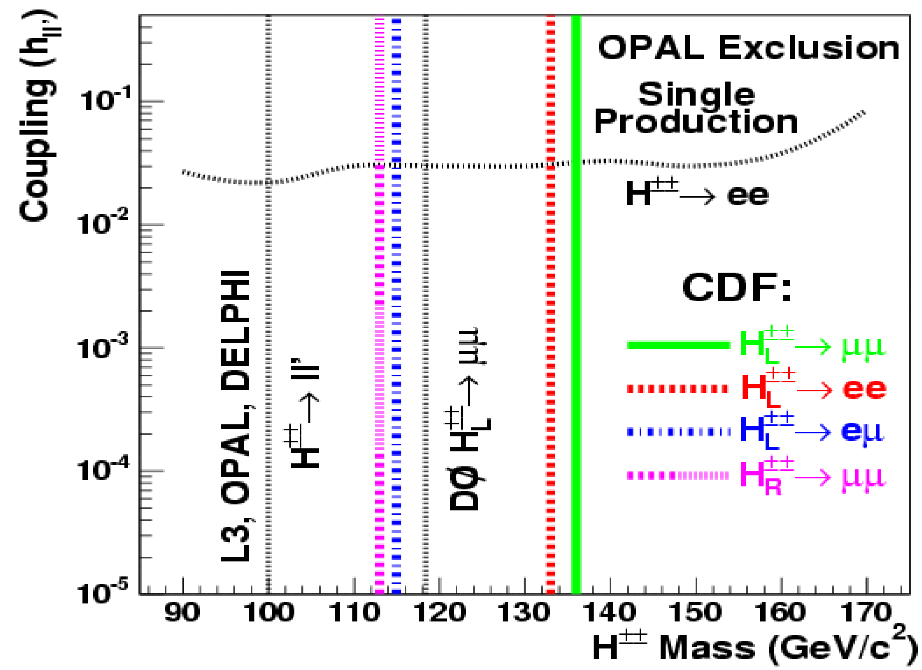
mode



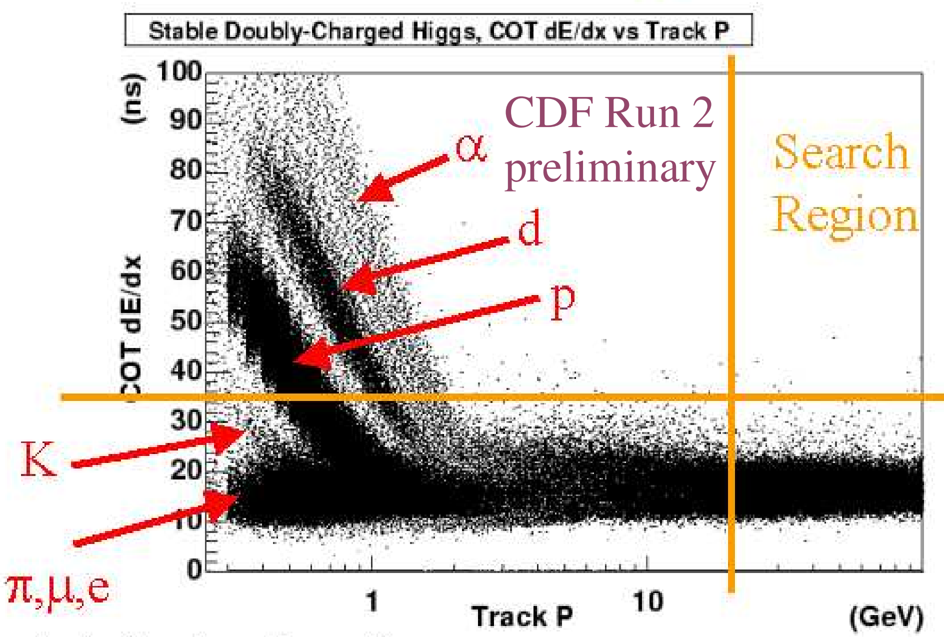
Doubly-Charged Higgs Search

Predicted by Left-Right Symmetric Model (motivated by neutrino mass) & light in SUSY-LR





Surpass LEP limits for $h_{ll} < 0.02$



Possibly long-lived due to limited decay modes => highly ionizing

Background $< 10^{-5}$ due to drift chamber dE/dx

CDF: $m(H^{\pm\pm}) > 134$ GeV @95%CL

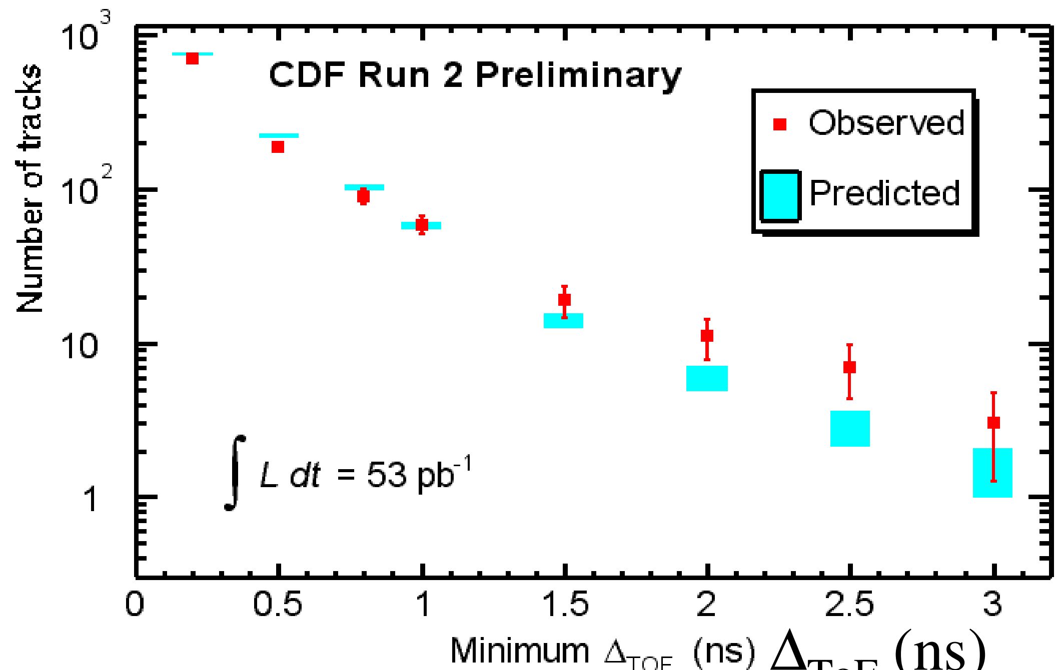
(LEP limit ~ 98 GeV)

SUSY Searches

Stop quark

use new Run 2 capability:

Time-of-Flight detector



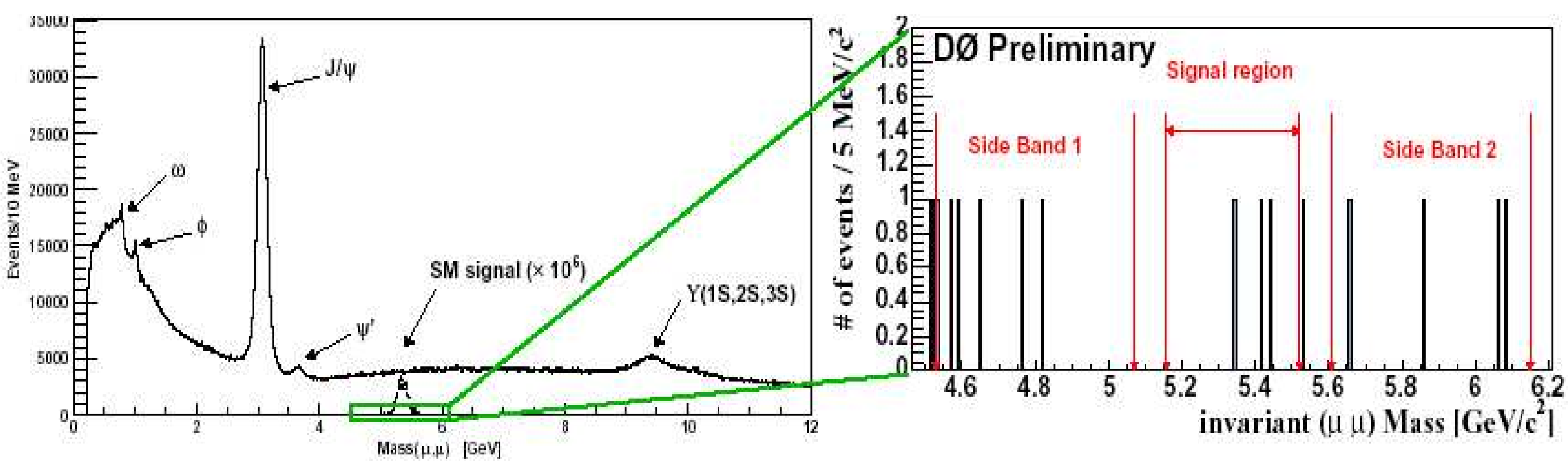
Δ_{ToF} (ns)

M(stop) > 97–107 GeV @95%CL

(LEP limit 95 GeV)

improvements in event time and ToF reconstruction in progress, will suppress backgrounds

Indirect Search: B_s -> μμ   BR proportional to $\tan^6\beta$



SUSY Searches

Stop quark

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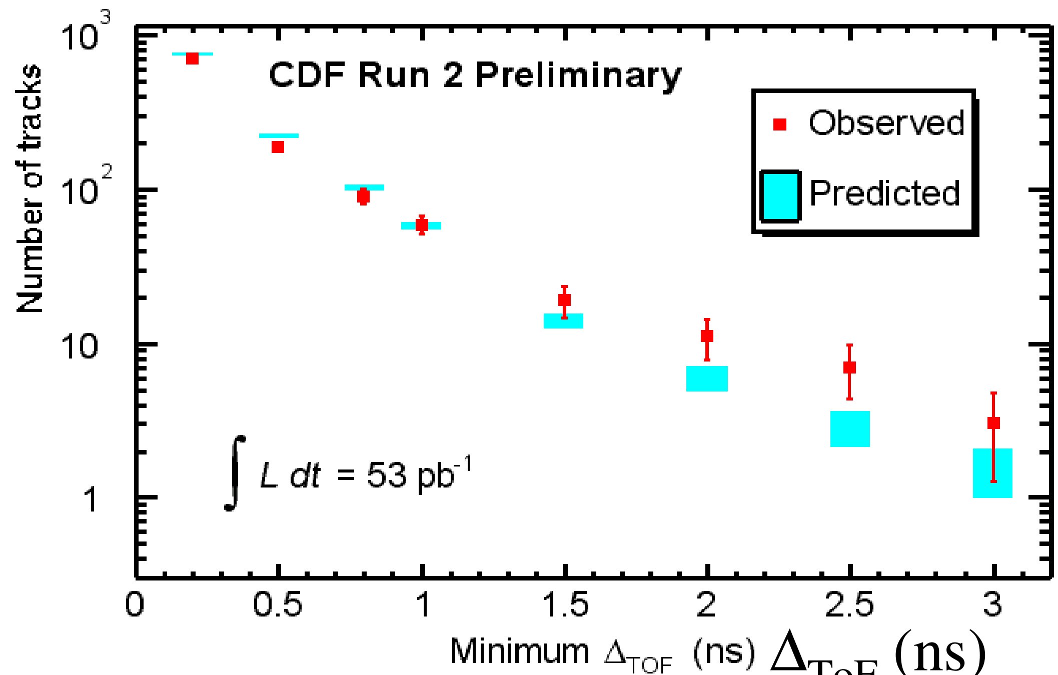


Δ_{ToF} (ns)

M(stop) > 97–107 GeV @95%CL
(LEP limit 95 GeV)

improvements in event time and ToF reconstruction in progress, will suppress backgrounds

Indirect Search: $B_s \to \mu\mu$ BR proportional to $\tan^6\beta$

Sensitive to $\tan\beta \sim 40$ for BR ~ 10^{-7}

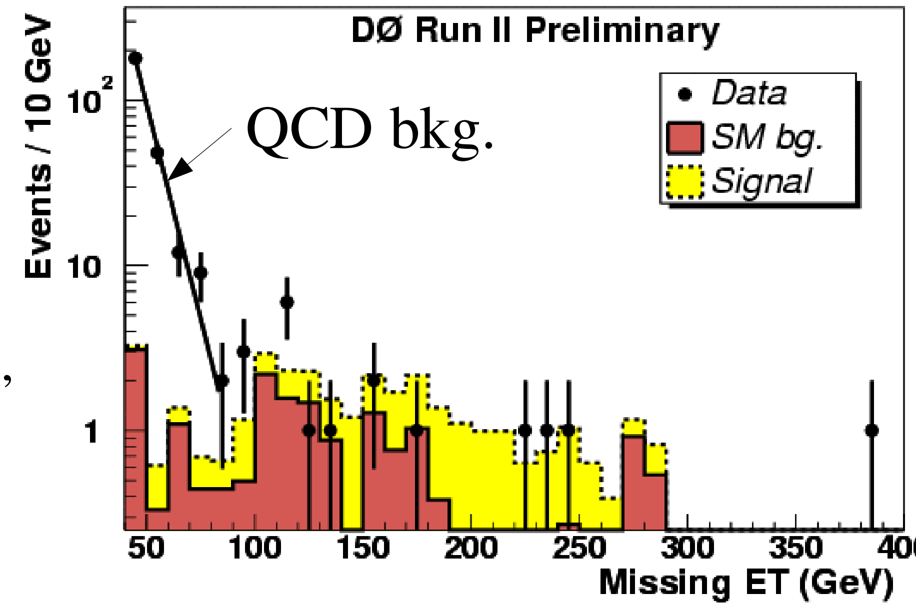
World's best limit from D0,
CDF & D0 combined limit: BR ($B_s \to \mu\mu$) < 2.7×10^{-7} @90%CL

Start to limit $\tan\beta$ as more data analysed

SUSY Searches

Squark-gluino search

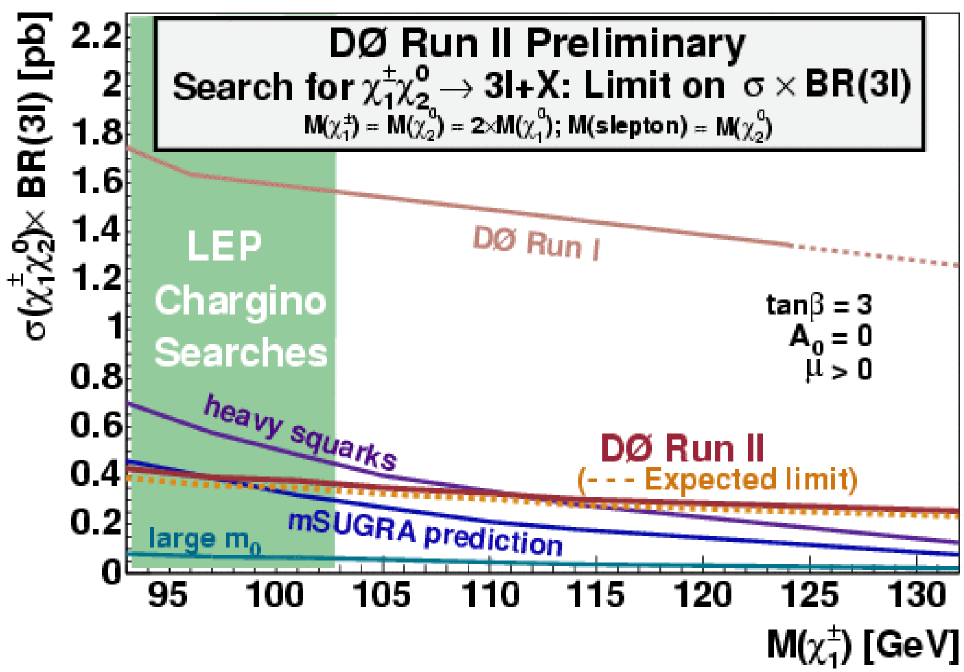
signature: 2 jets + missing E_T →



For mSugra @ $m_0 = 25$ GeV, tanβ=3, A_0 =0, m<0,

exclude m(squark/gluino)< 292/333 GeV

improves Run 1 limits



Chargino-neutralino search

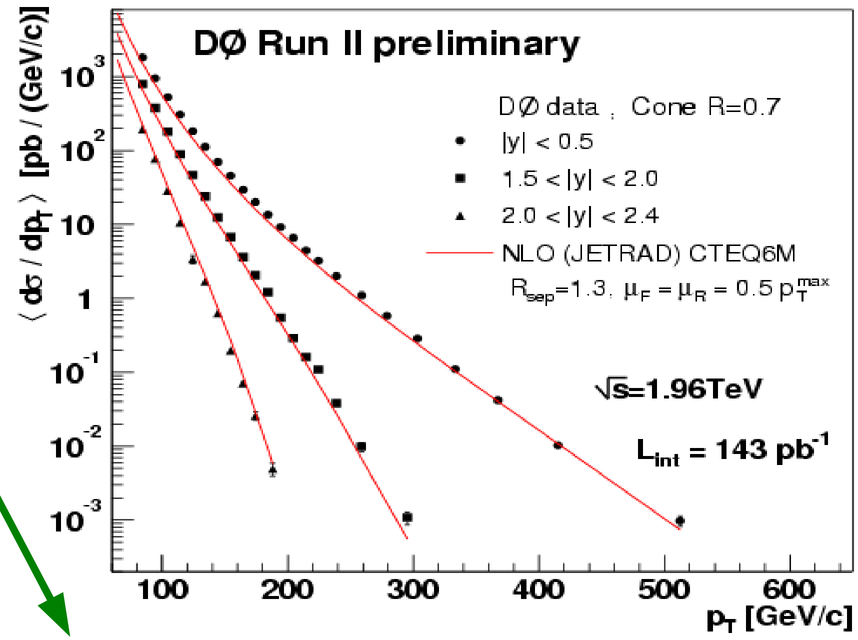
using trileptons

One of the golden discovery modes at Tevatron and LHC

Analysis of data already on tape will extend sensitivity beyond LEP

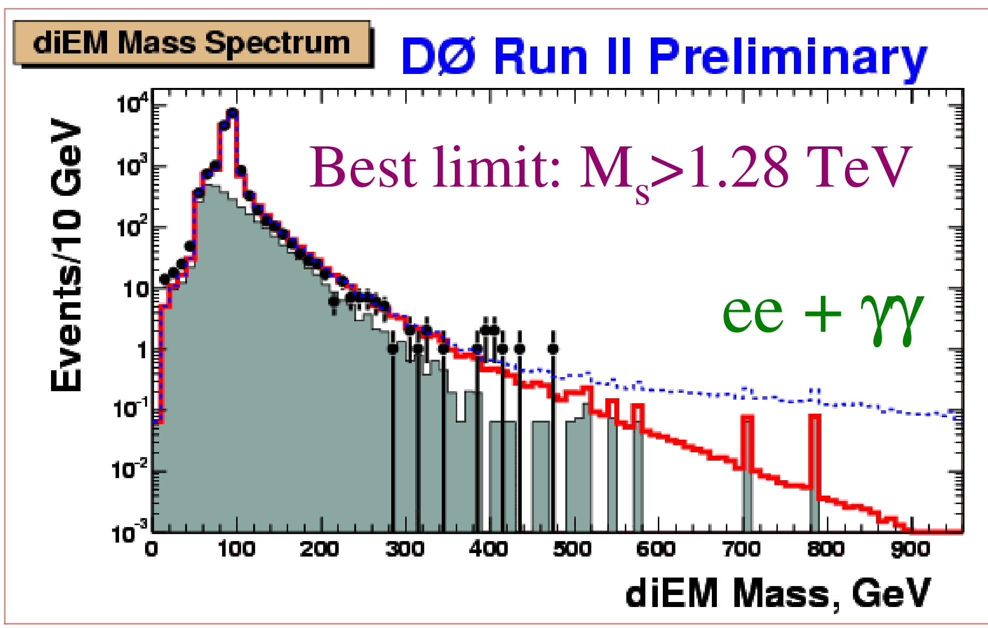
Very-High P_T Physics

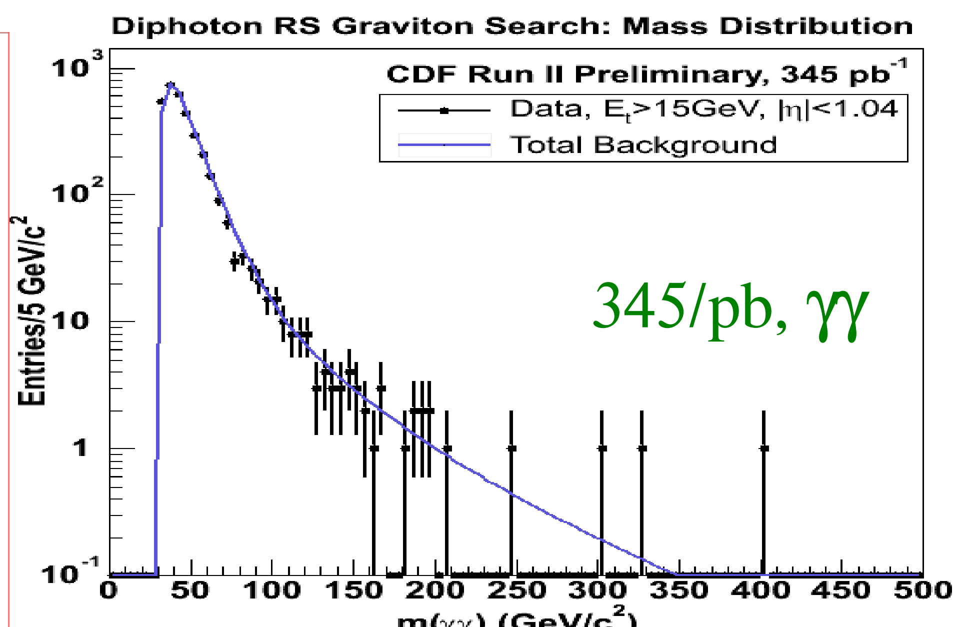
Jet spectra
probing high-x gluons and compositeness



Good dilepton, diphoton mass resolution for Z', large extra dimensions searches

New best limits on RS gravitons and LED (D0) and Z' (D0:ee, CDF:μμ,ττ)





B Physics

B_s Mixing Sensitivity

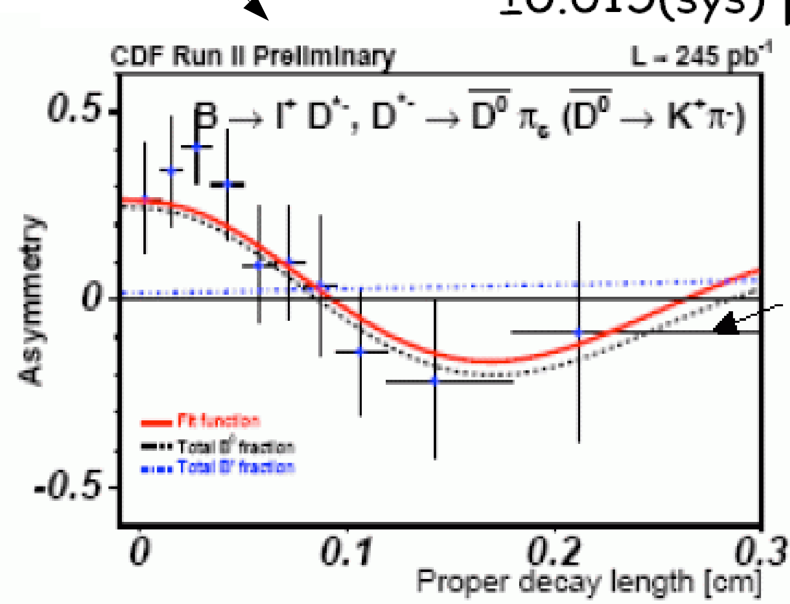
B_d mixing => prepare machinery for B_s mixing analysis

Flavor tagging at production: maximize effective efficiency εD^2

eg. CDF combined tagger: $\varepsilon D^2 = 1.82 \pm 0.114$ %

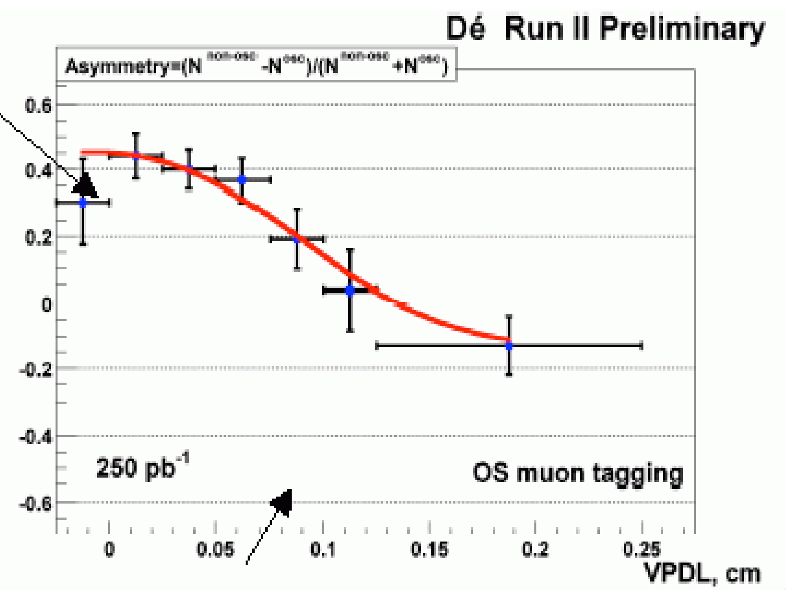
Maximize $c\tau$ resolution σ_τ

$\Delta m = 0.536 \pm 0.037(stat) \pm 0.009(s.c) \pm 0.015(sys)\ ps^{-1}$



Soft μ tagger

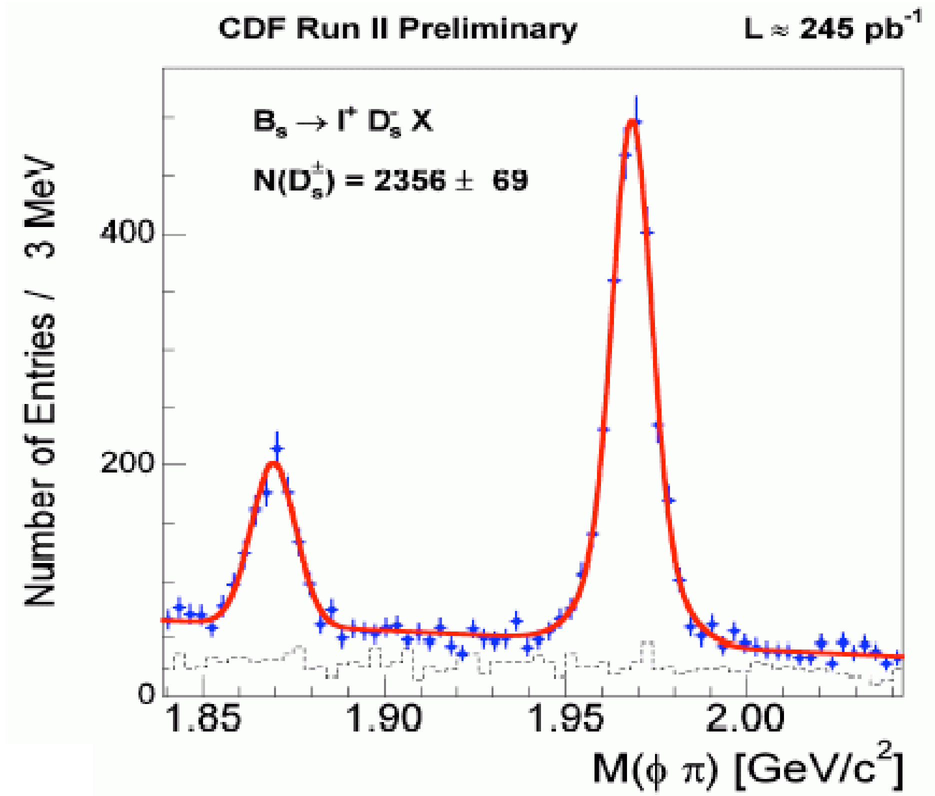
Opposite Side taggers

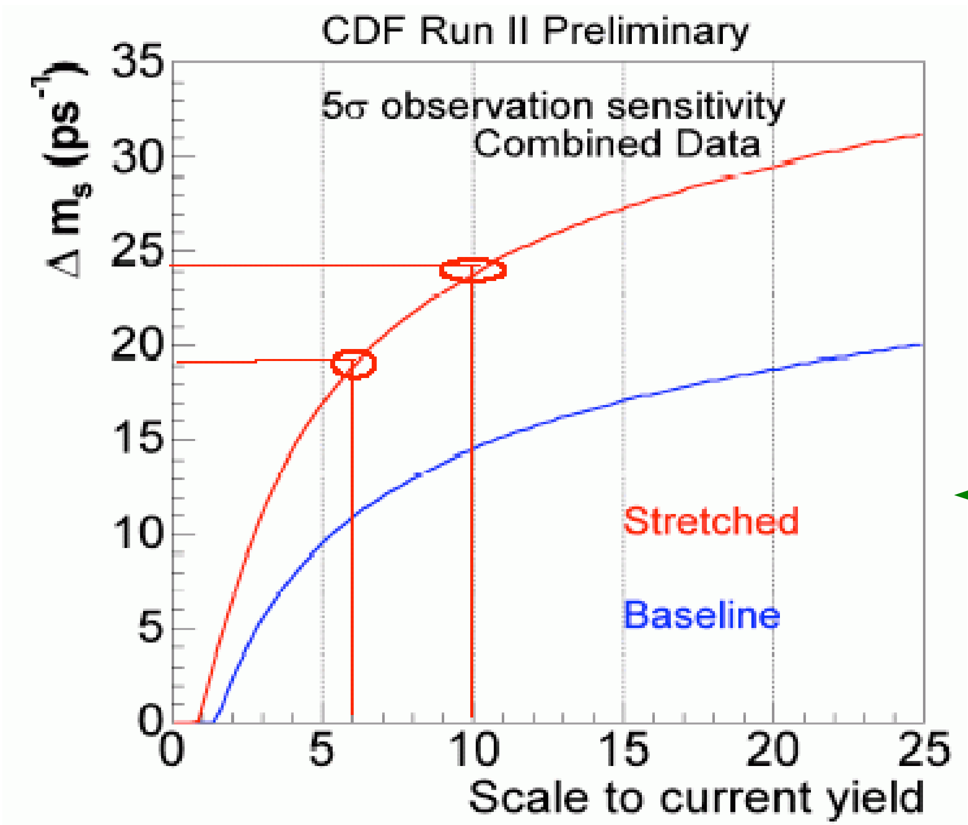


$\Delta m = 0.506 \pm 0.055(stat) \pm 0.049(sys)\ ps^{-1}$

B_s Mixing Sensitivity

Predictions based on observed B_s signals





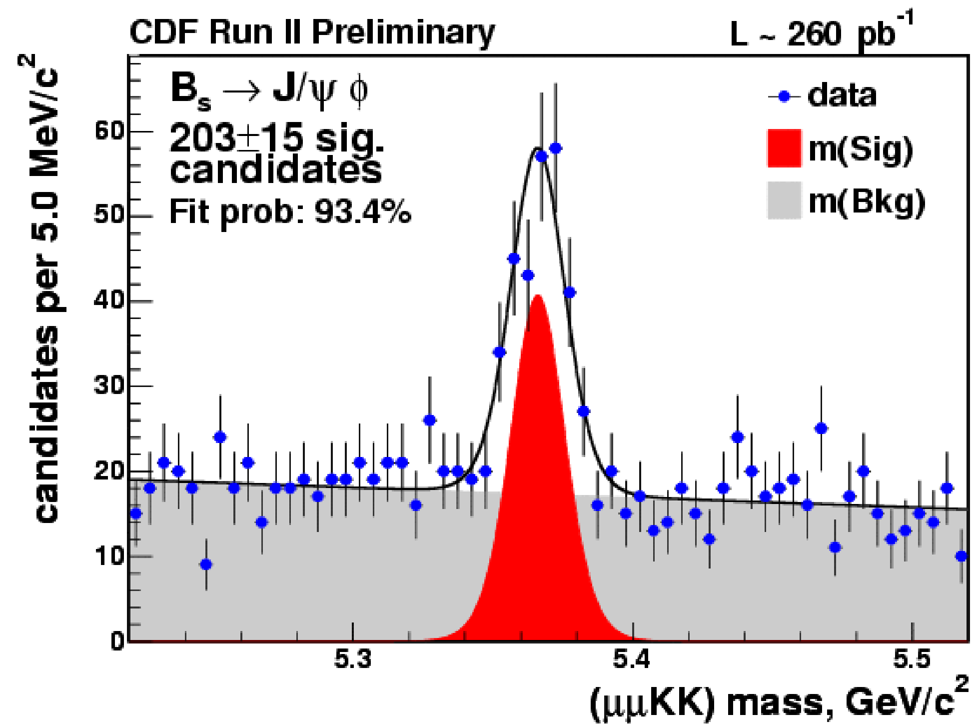
CDF Baseline:
$\varepsilon D^2 = 1.6\%$
σ_t = 67 fs

CDF Stretched:
$\varepsilon D^2 = 2.6\%$
σ_t = 47 fs

eg. 5σ discovery Δm_s = 19/ps with 1.5/fb

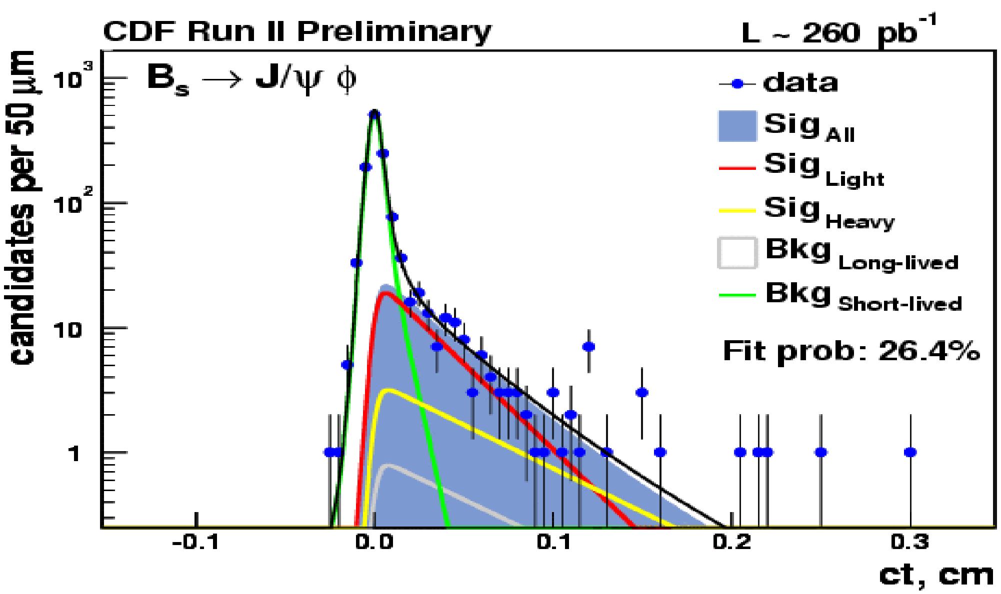
$\Delta\Gamma/\Gamma$ in B_s system

Motivation: lifetime difference between B_s eigenstates could be sizable, interesting to measure



CDF:

$\Delta\Gamma/\Gamma = 0.65^{+0.25}_{-0.33}\text{(stat)} \pm 0.01\text{(sys)}$



SM expectation:

$\Delta\Gamma/\Delta m_s = (3.7^{+0.8}_{-1.5}) \times 10^{-3}$

Implies $\Delta m_s = 125^{+69}_{-55}$

Summary

- Run 2 is firmly established, with >3 x Run 1 data recorded
- Many new results, often already world's best
- Anticipate ~2 fb^{-1} by 2007
  - 2M leptonic W's and 200k leptonic Z's
- ...and 4-8 fb^{-1} by 2009
- Continue to build on success, expect much more physics!
- Invaluable experience for LHC