Review of Tevatron Results

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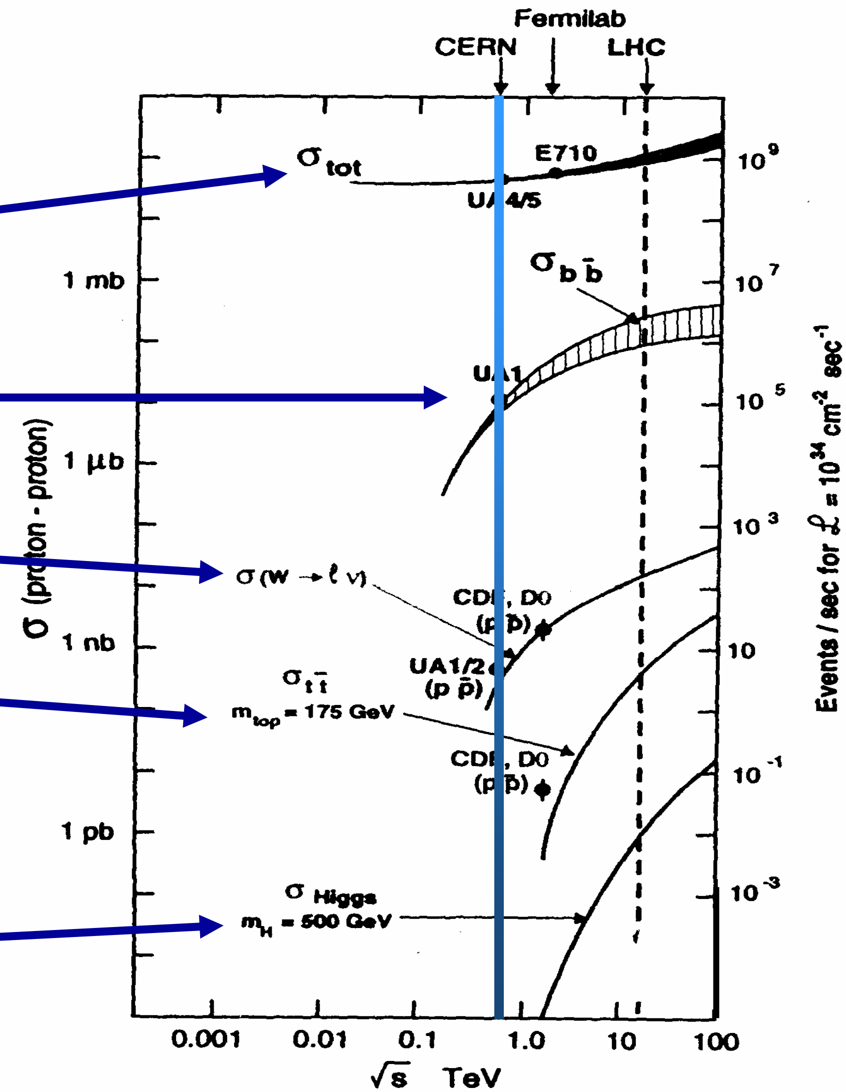
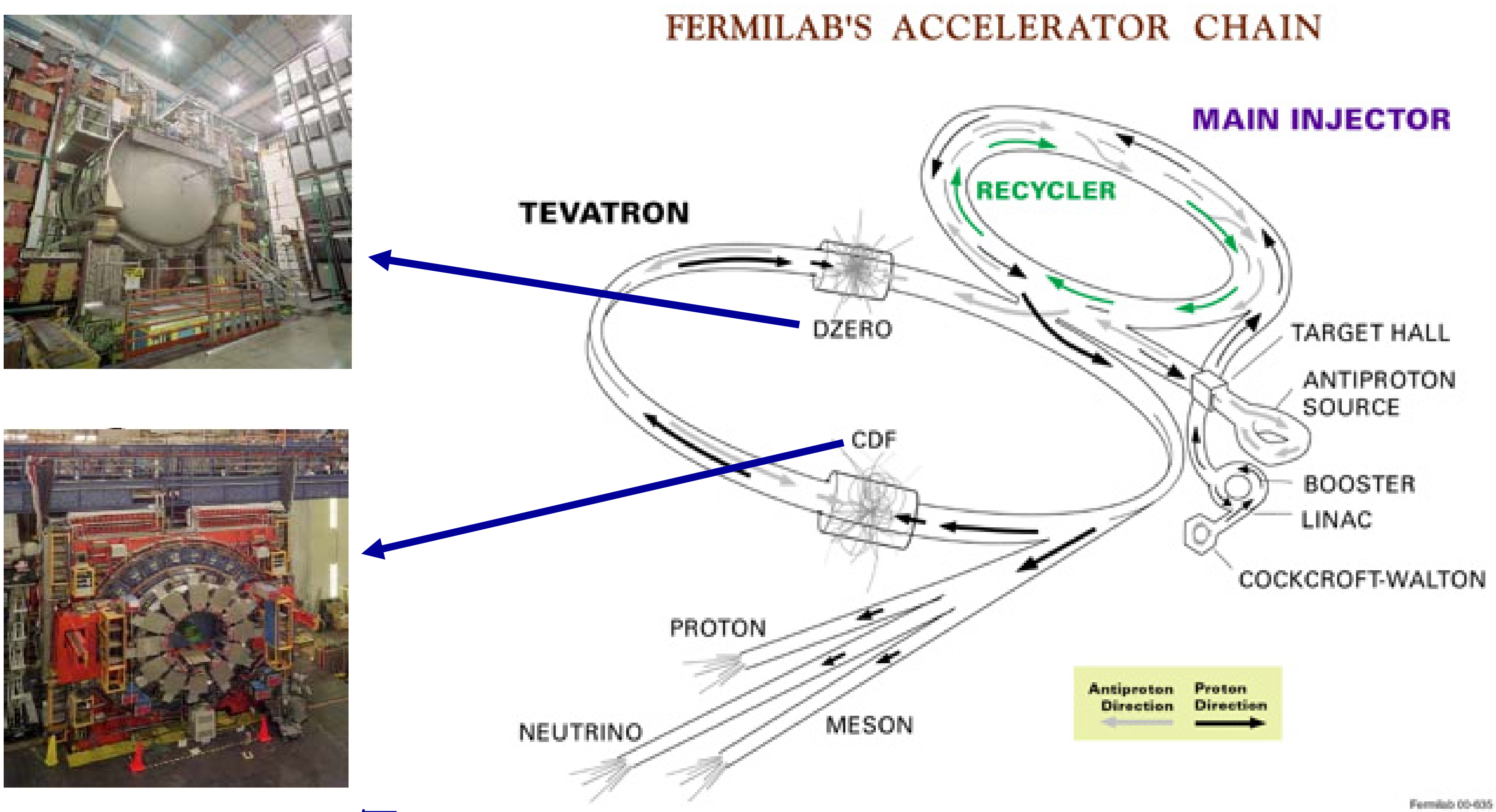
Overview

- Tevatron
- Detectors
- QCD Measurements
- B&Charm Physics
- Electroweak Results
- Top Quark Physics
- Direct Searches

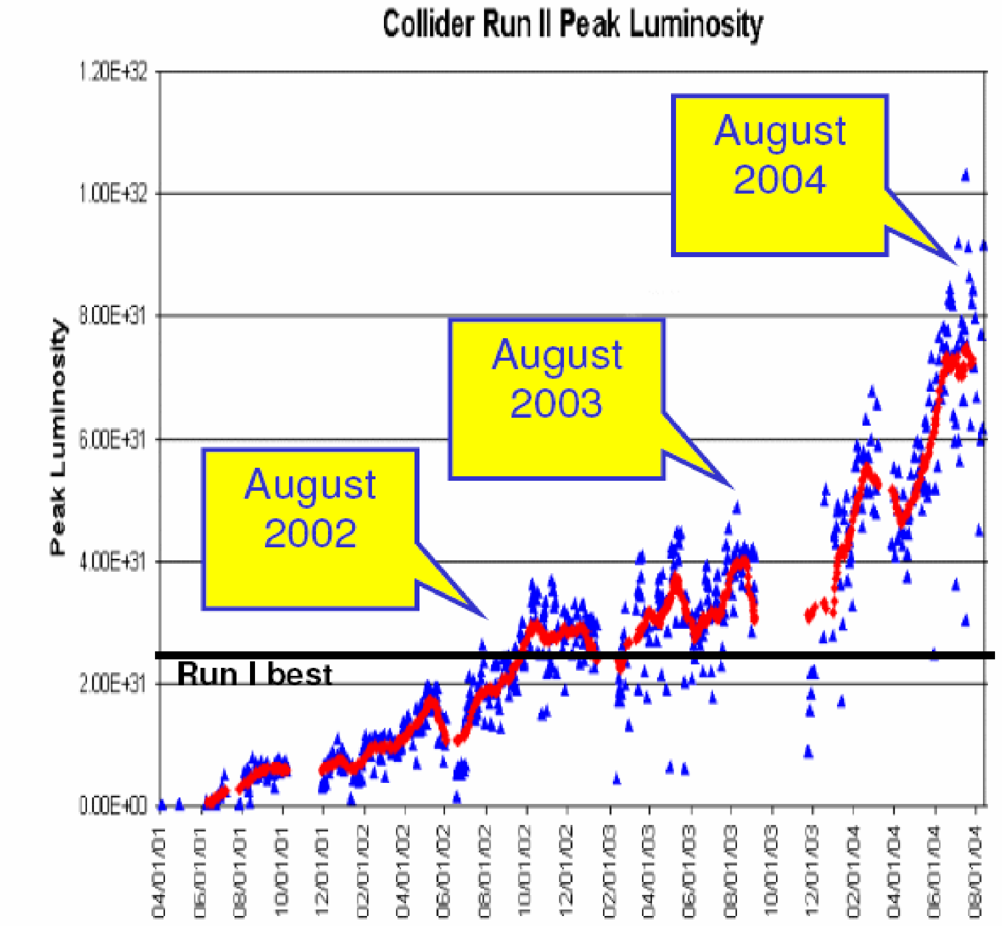


The Tevatron Collider



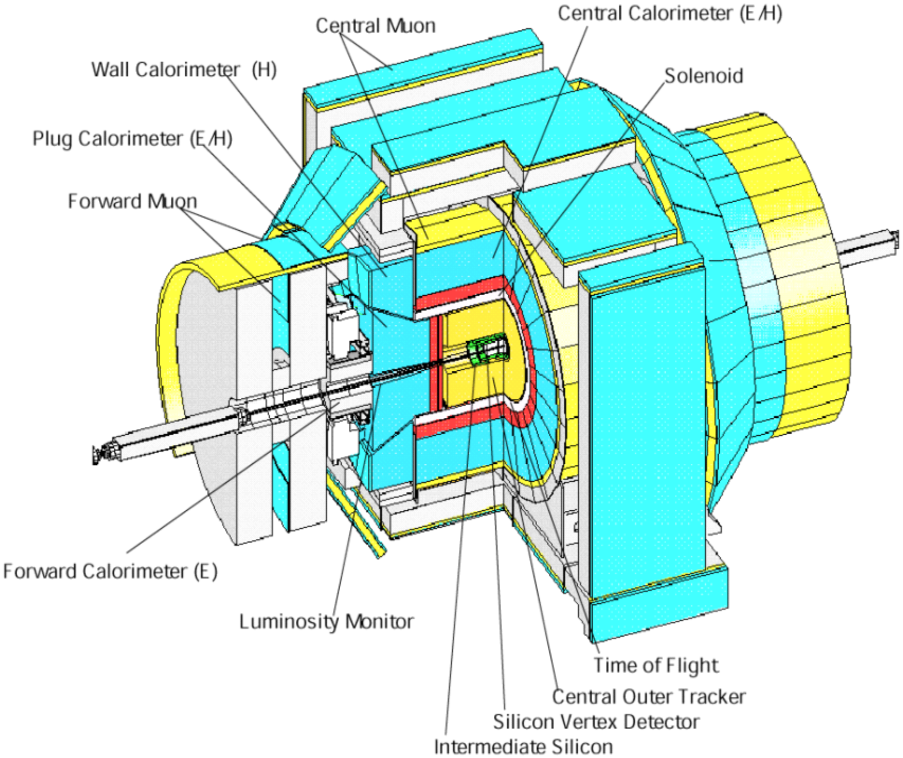
- $p\bar{p}$ collider, $\sqrt{s}$ = 1.96 TeV, collisions every 396 ns
- major upgrades: main injector, recycler
- two multi-purpose detectors: CDF & D0

Tevatron Performance

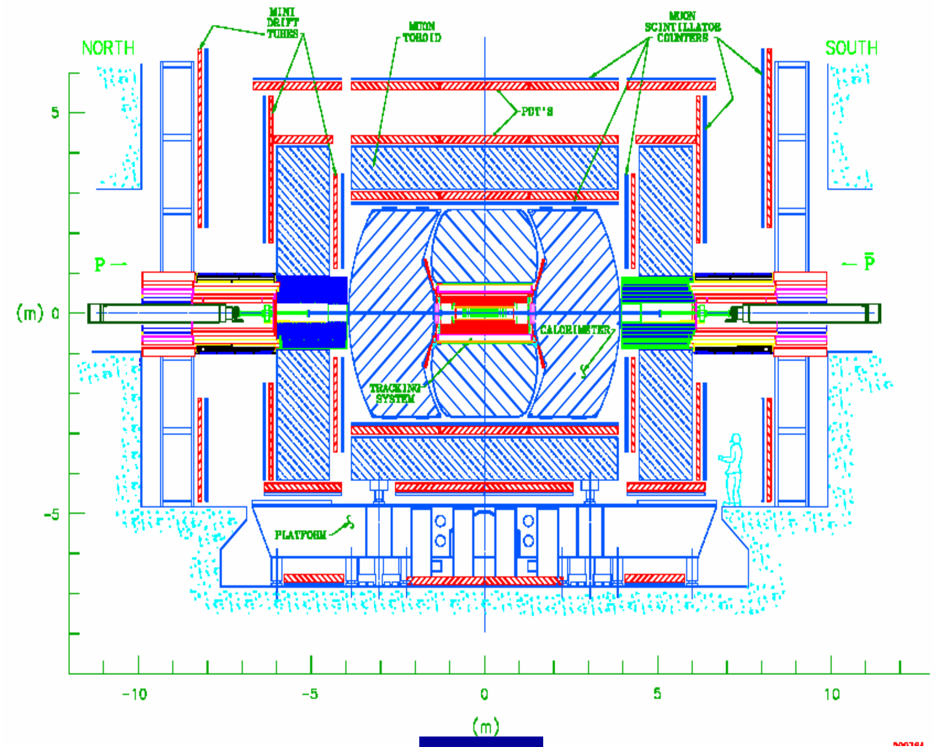


- $\bar{p}$ recycler is now working
- Peak luminosity
  - ×2 increase since 2003
  - reached $\mathcal{L}$=$10^{32}cm^{-2}s^{-1}$
- Future Plans:
  - run until 2009
  - deliver 4-9 fb^{-1}

Tevatron Detectors



CDF



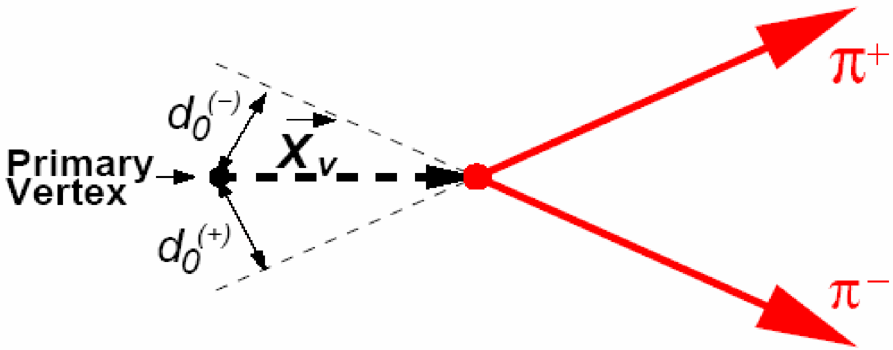
D0

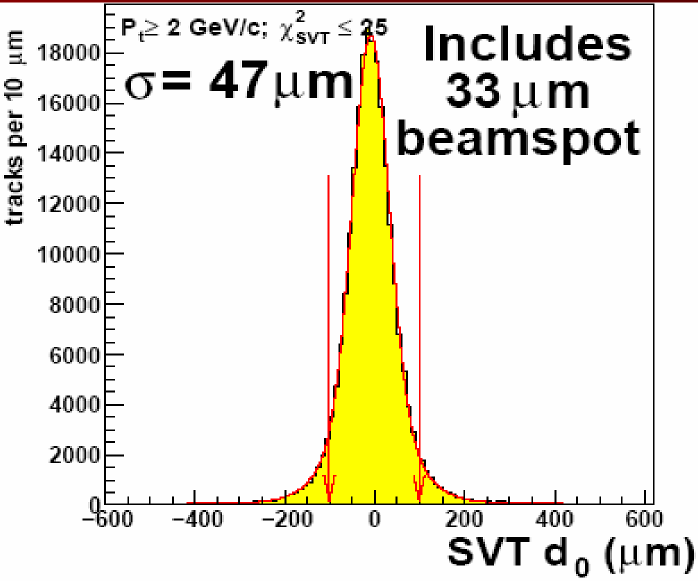
- excellent p resolution
- more silicon layers (7 vs 4)
- L1 trigger accept ~20 kHz
- displaced track trigger (SVT)

- excellent coverage for μ and SI systems ($|\eta| < \sim 2$ vs. ~ 3)
- excellent calorimeter

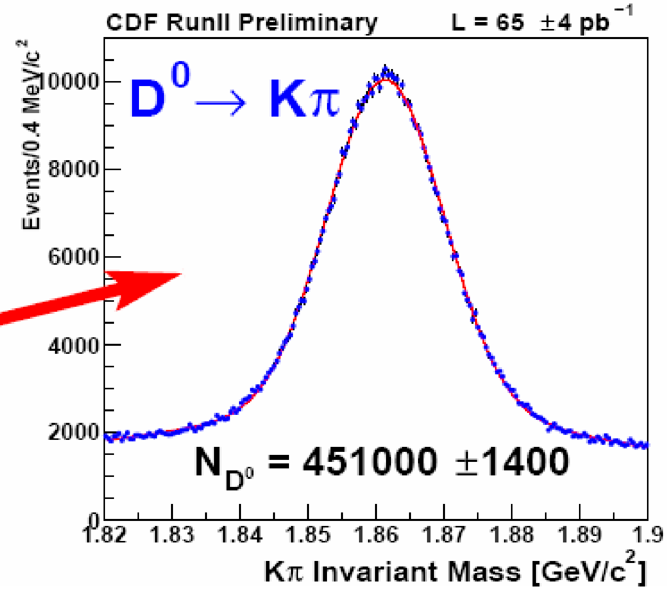
Triggering on Displaced Tracks

- trigger $B \to \pi\pi, B_s \to D_s\pi$
- challenge: read out SVX and track at 10's of kHz $\to$ SVT

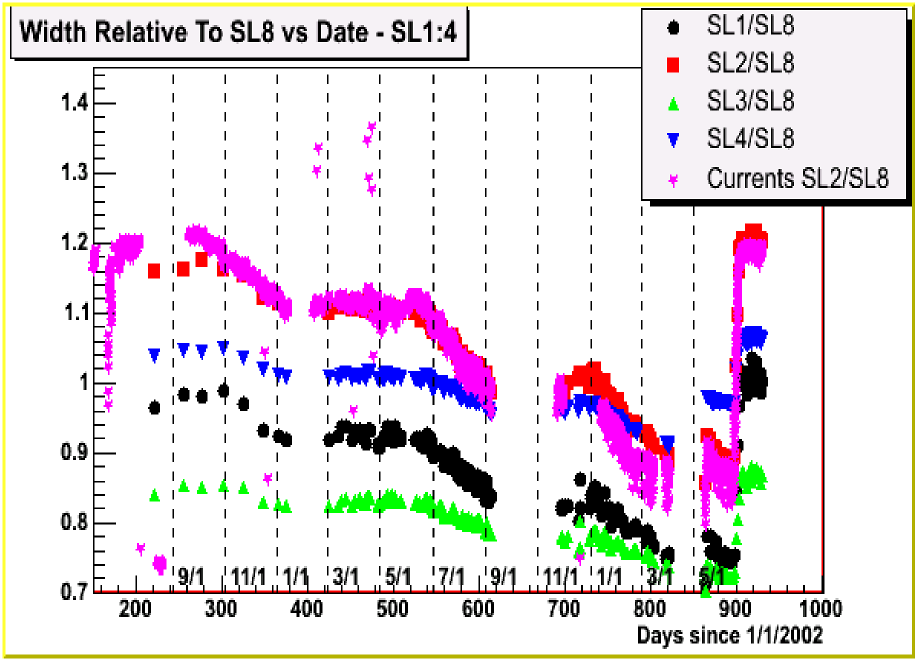


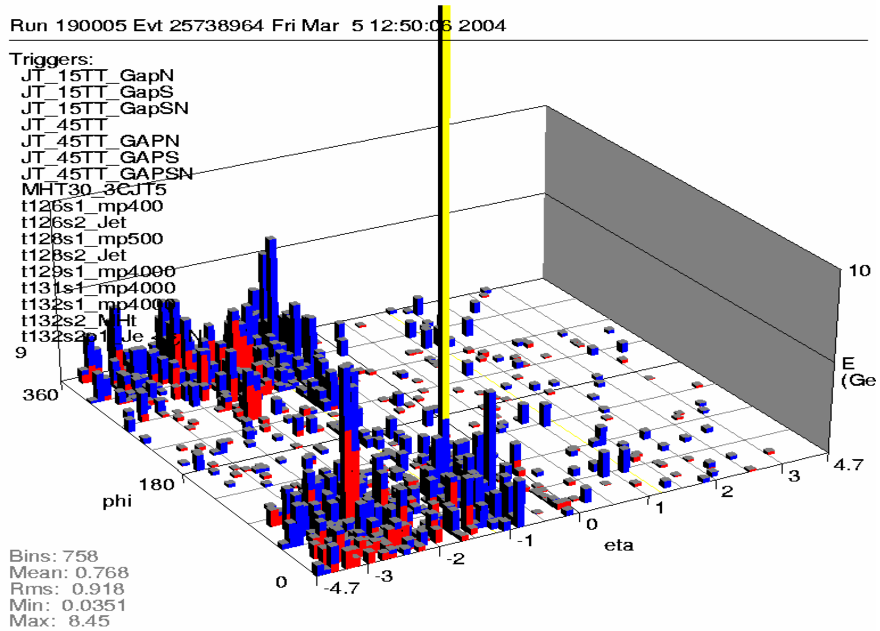


- trigger on 2 displaced tracks
  ($p_T > 2$ GeV/c, 120 μm $< |d_0| <$ 1 mm)
- huge charm samples gathered
- with small int. luminosity, competitive charm analyses



Detector Operations



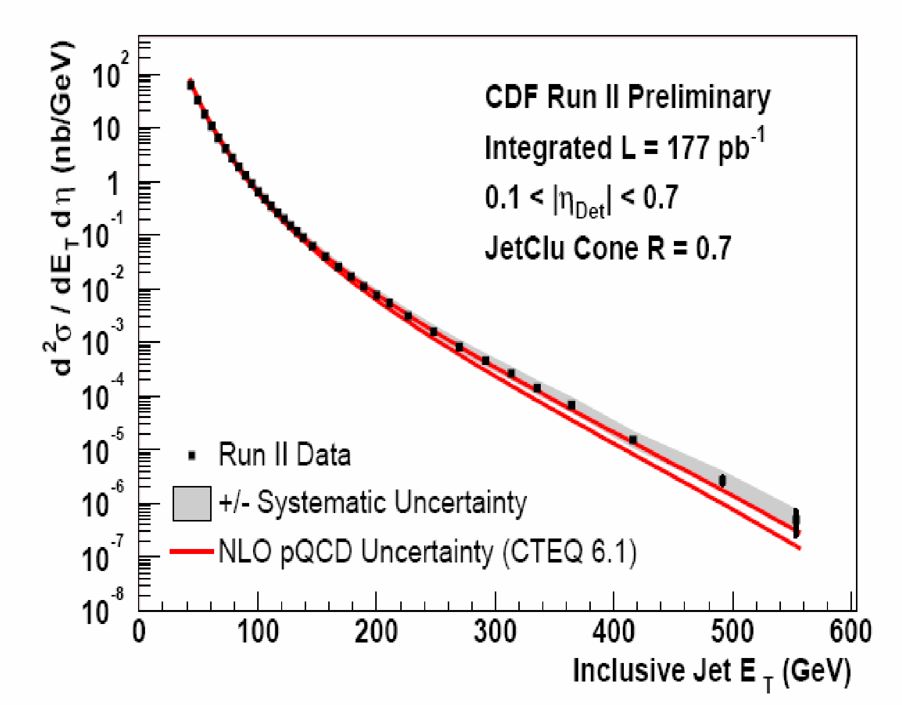


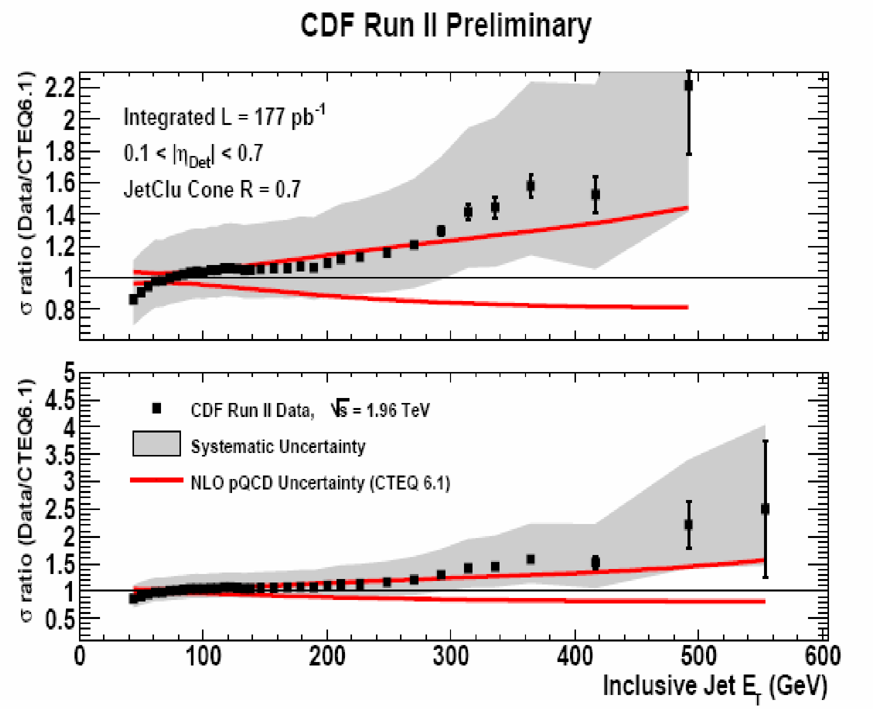
CDF COT gain problems fixed by adding oxygen

D0 calorimeter problems traced to grounding problem

QCD Physics

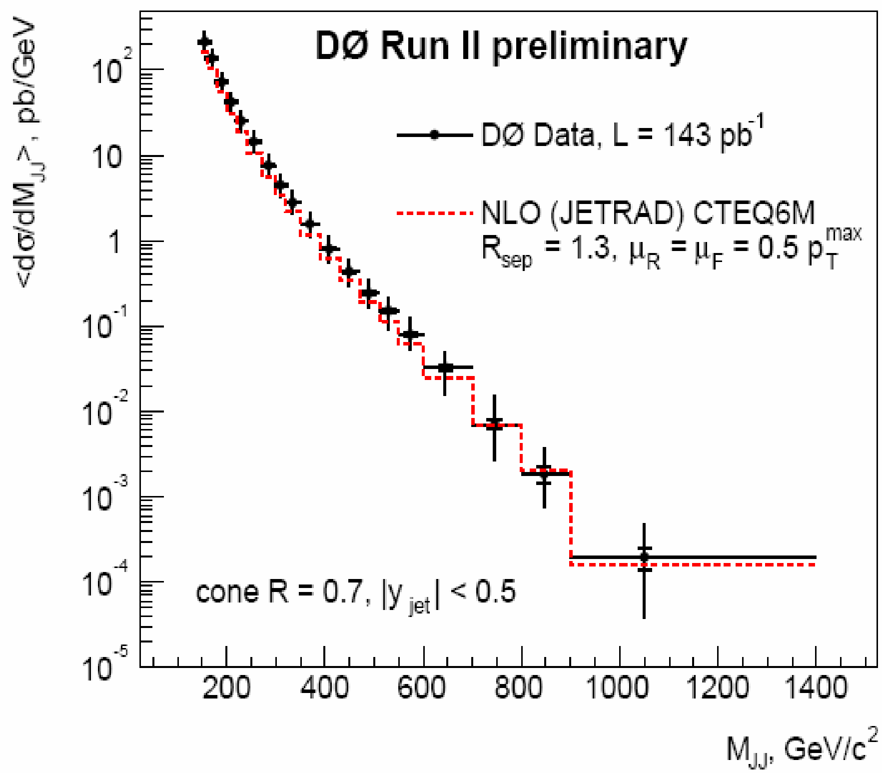
Inclusive Jet Cross Section

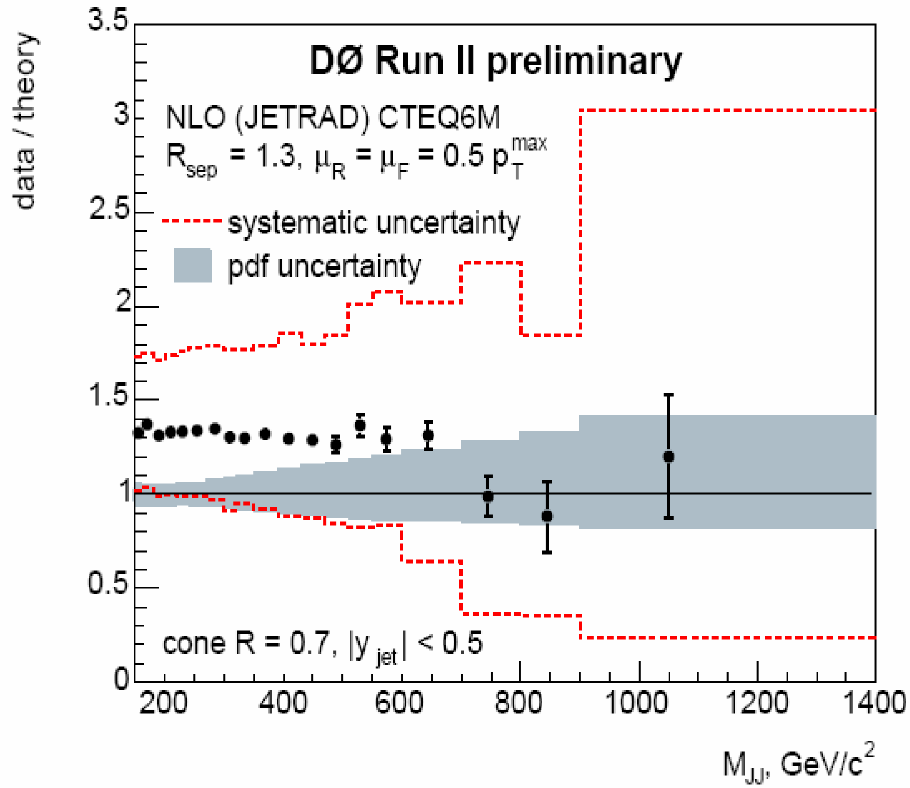




- test perturbative QCD over 9 orders of magnitude
- measurement extended to higher E_T by ~ 200 GeV
- systematic unc. dominated by jet energy scale (~3%) will improve (~ 1% in Run I)

Dijet Cross Section

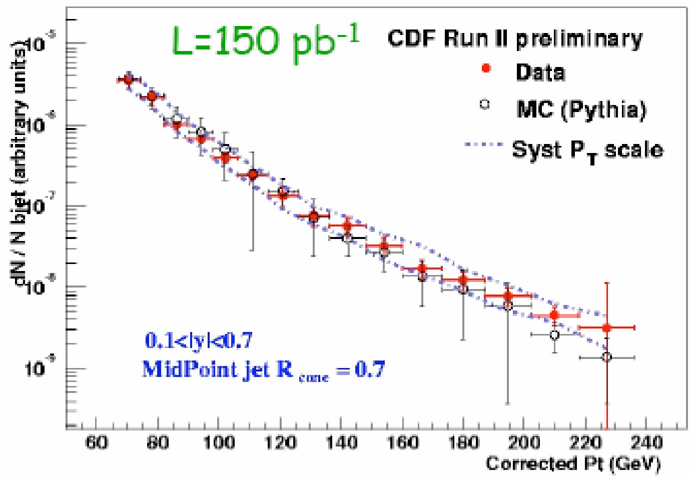




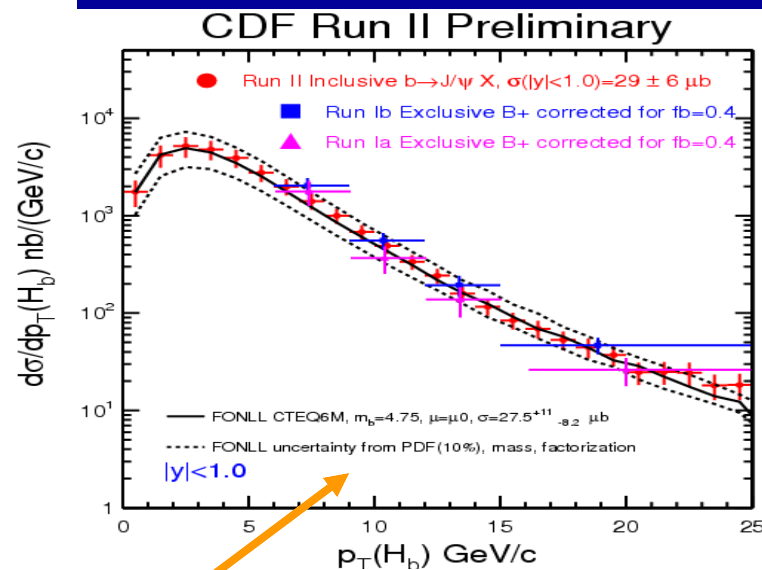
- dijet mass has greater sensitivity to new phenomena
- agreement with theory within experimental error
- same source of dominant systematic

Heavy Flavor Production

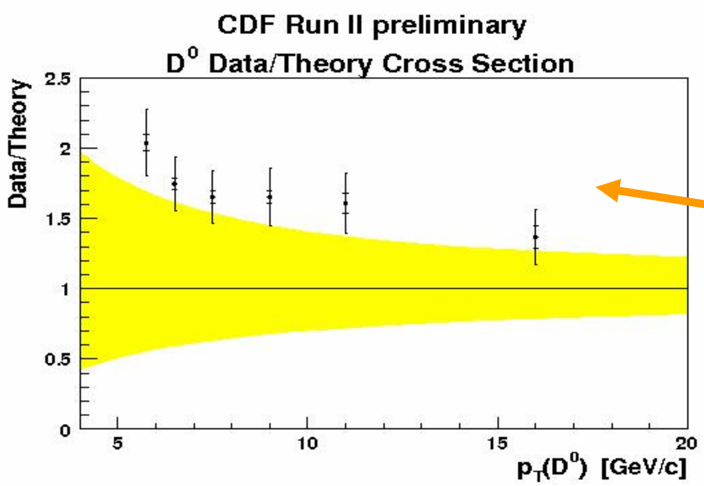
jets (R_{cone} = 0.7) + Sec. Vtx.



inclusive J/ψ + lifetime



$\sigma(H_b, |y|<1.0) = 29 \pm 6\ \mu b$



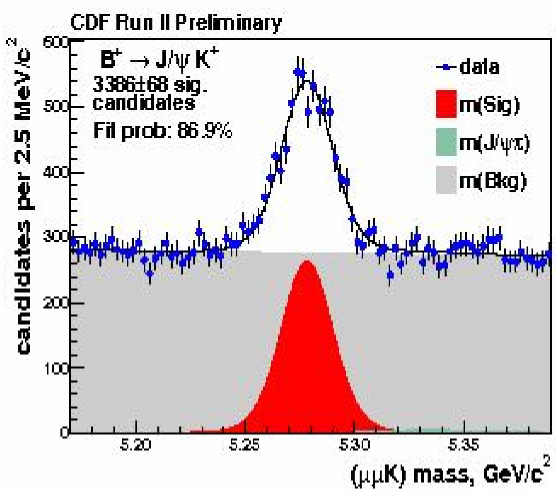
$D^0 \rightarrow K\pi$ in SVT trigger

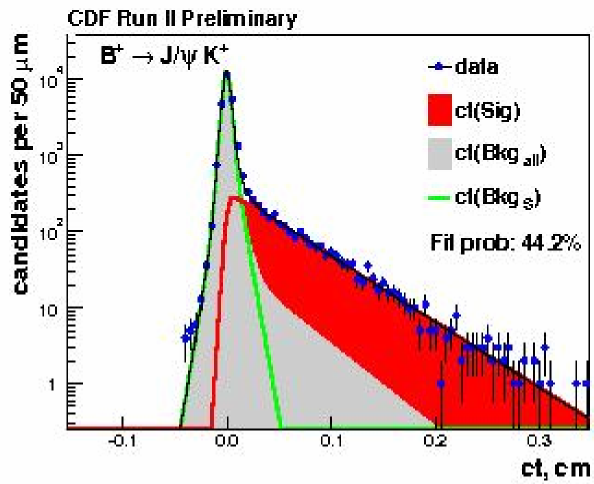
$\sigma(D^0 X, |y|<1.0, p_T > 5.5\ GeV/c)= 13.3 \pm 0.2(stat) \pm 1.5(syst)\ \mu b$

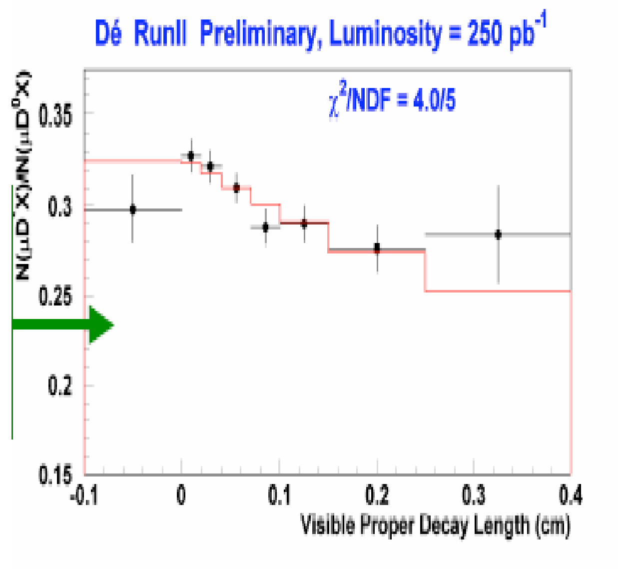
Physics with Bottom and Charm Mesons

- large signal cross sectios – triggers are crucial
- large samples – precision measurements
  - lifetimes, masses, BR's, CP, mixing
- B_s, Λ_b, B_c currently exclusive to Tevatron!

B Meson Lifetimes





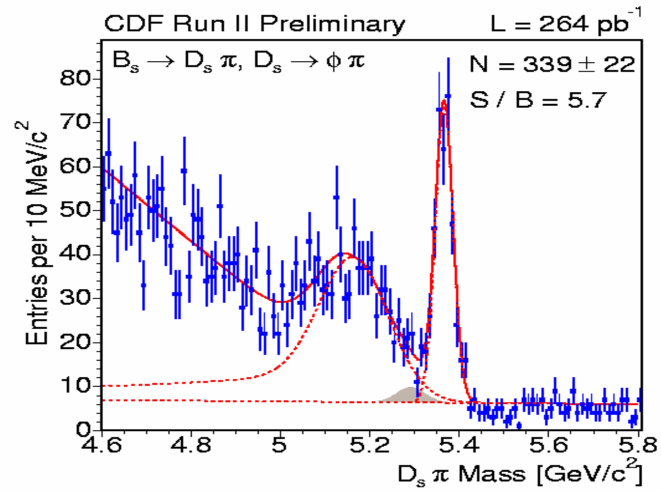


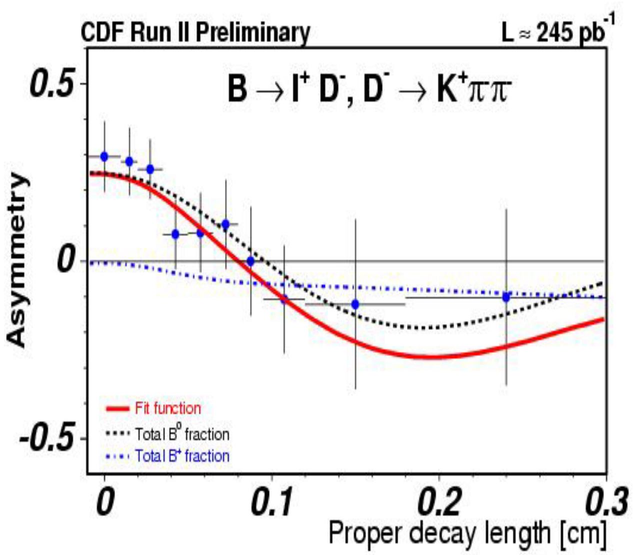
- lifetime ratios predicted by HQET
- average $p_T(B)$ ~ 10 GeV/c
- results competitive with best single measurements
- systematics at ~1% level

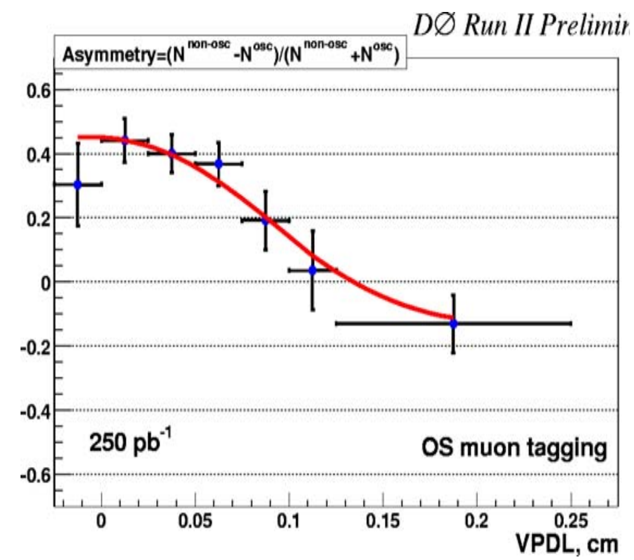
D0	$\tau(B^+)/\tau(B^0) = 1.093 \pm 0.021 \pm 0.022$
	$\tau(B^0) = 1.397 \pm^{0.107}_{0.098} \pm 0.031$ ps
	$\tau(\Lambda_b) = 1.221 \pm^{0.217}_{0.179} \pm 0.043$ ps
CDF	$\tau(B^+) = 1.662 \pm 0.033 \pm 0.008$ ps
	$\tau(B^0) = 1.539 \pm 0.051 \pm 0.008$ ps
	$\tau(B_s) = 1.369 \pm 0.100 \pm^{0.008}_{0.010}$ ps

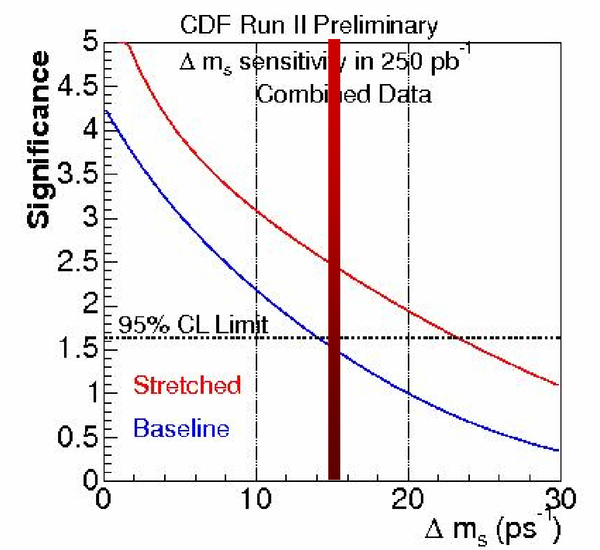
B_s Mixing Sensitivity

- ~ 25 times faster than B0 mixing → ct resolution matters!
- analysis samples:
  - semi-leptonic (D_s+e,μ): $\sigma(p_B)$~15%
  - fully hadronic ($D_s\pi$,3π): $\sigma(p_B)$~0.1%
    crucial for high ms
- effective tagging power εD^2 ~ 2%
- with data in hand, 95% CL sens: 15 ps^{-1}



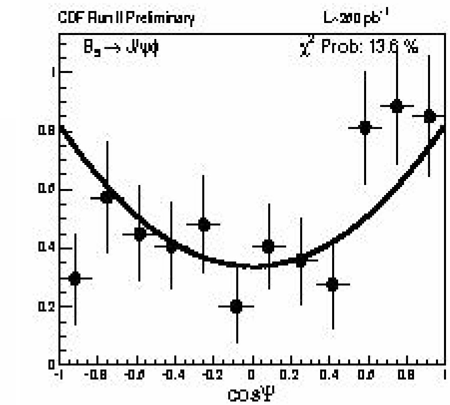


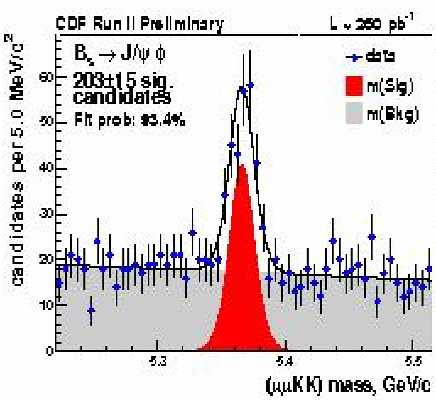


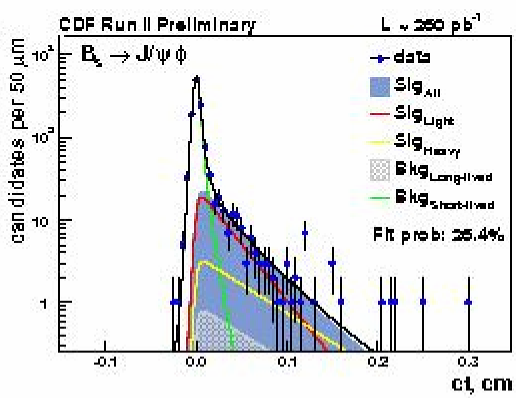


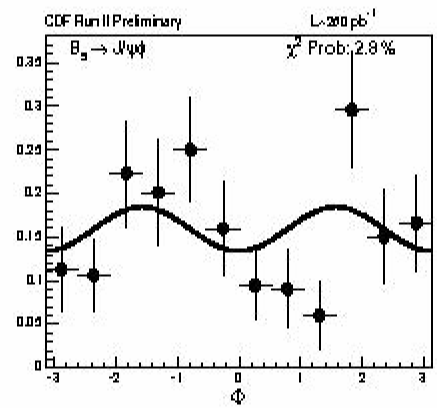
Width Difference in $B_s \to J/\psi\phi$

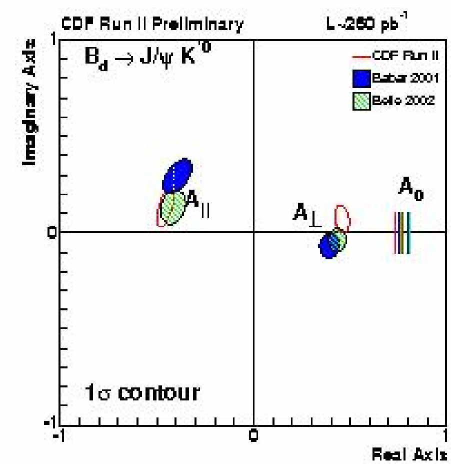
- another way to probe B_s eigenstates: $\Delta\Gamma_s/\Delta m_s = 3.7^{+0.8}_{-1.5}\times10^{-3}$
- angular information separates heavy from light component
- fit heavy and light lifetimes separately
- $B^0 \to J/\psi\ K^{*0}$ agrees with B factories





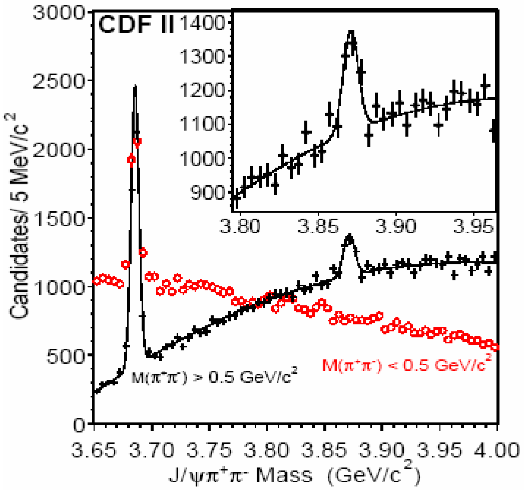


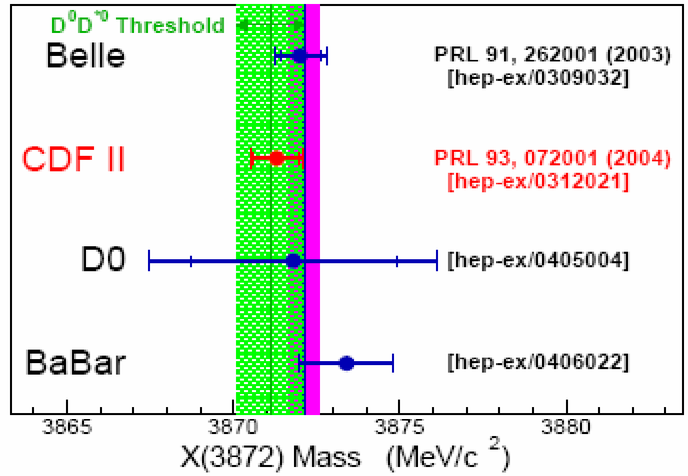


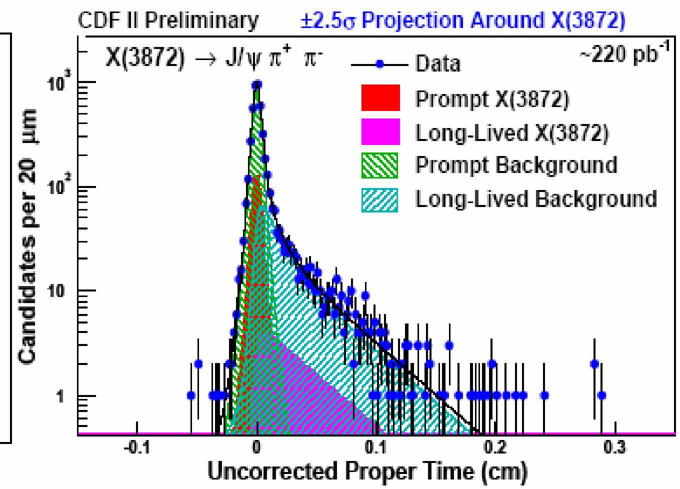


- prediction: $\Delta\Gamma_s/\Gamma_s = 0.12$
- CDF measured: $\Delta\Gamma_s/\Gamma_s = 0.71^{+0.24}_{-0.28}\pm0.01$
- implies $\Delta m_s = 129^{+69}_{-55}\ ps^{-1}$
- $p(\Delta\Gamma/\Gamma=0) < 1/718$, $p(\Delta\Gamma/\Gamma=0.12) < 1/204$
- D0 result coming soon

The X(3872)

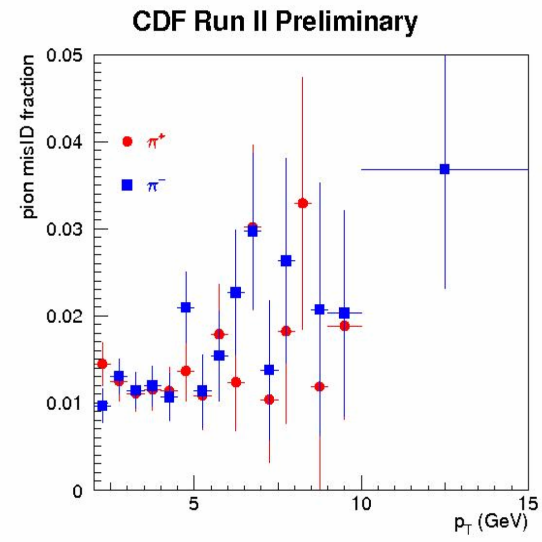


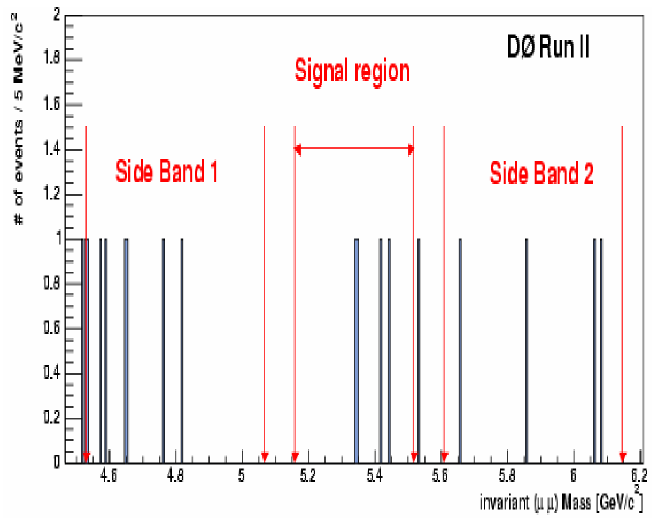


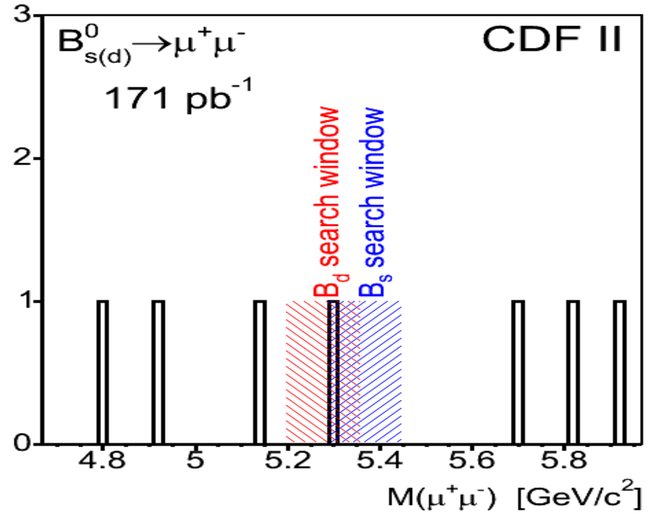


- August 2003: Belle announces the X(3872) discovery
- Tevatron confirms within one month
- prompt fraction same as $\Psi(2S) \rightarrow J/\psi\ \pi^+\pi^-$
- analysis of $\pi^+\pi^-$ invariant mass spectrum in progress
  - possibly $J/\psi\ \rho$?

Rare Decays: B_s, B^0, $D^0 \to \mu\mu$

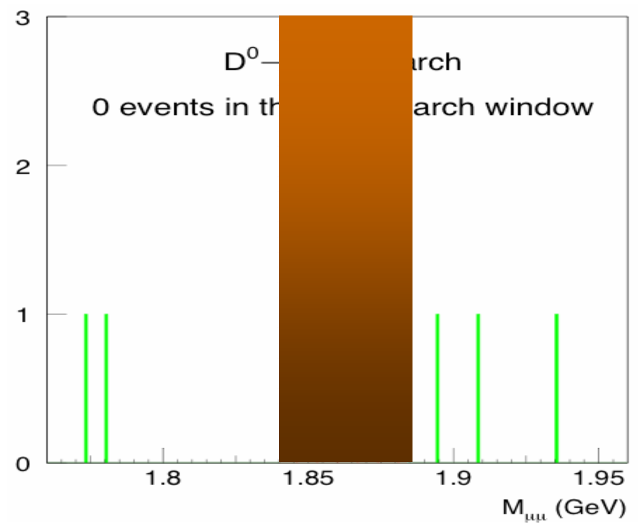






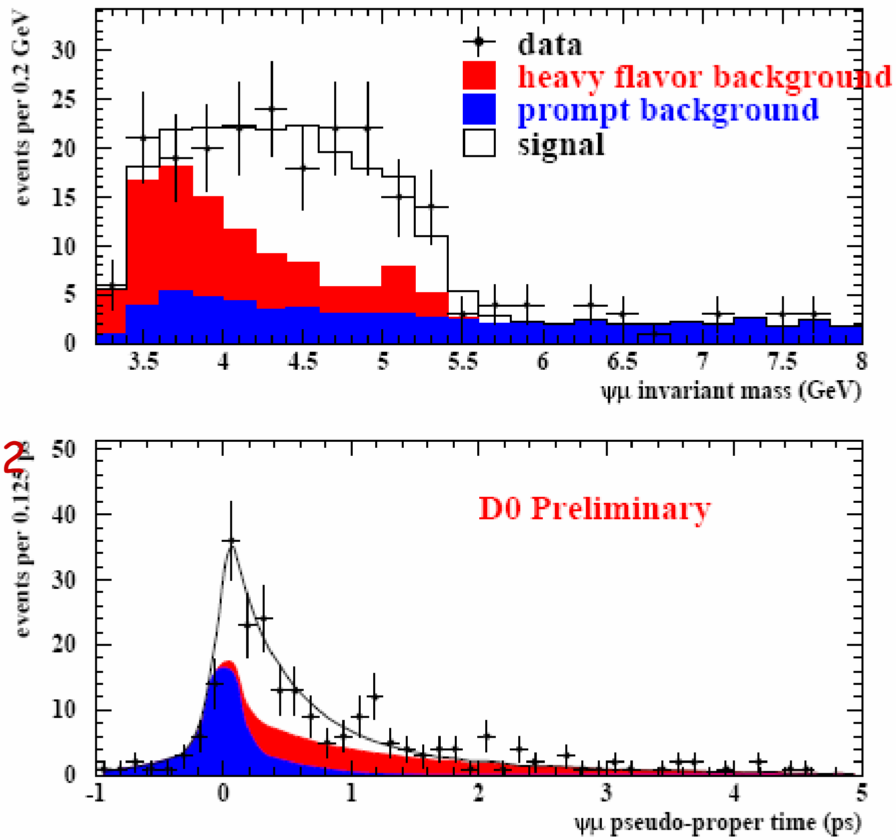
muons are hard to fake (fake rate ~1%)

	Decay	95% CL	SM Exp
D0	$B_s \to \mu\mu$	5.8×10^{-7}	~10^{-9}
CDF	$B_s \to \mu\mu$	7.5×10^{-7}	
	$B^0 \to \mu\mu$	1.91×10^{-7}	
	$D^0 \to \mu\mu$	3.3×10^{-6}	~10^{-13}



(Re)Discovery of the B_c

- search for $B_c \to J/\psi\, \mu\nu$ decays
- D0 (210 pb^{-1}) combined fit to mass and lifetime:



- Event count:
  - 231 total candidates
  - 95±12±11 signal
- Mass:
  - $m=5.95\pm0.14\pm0.34$ GeV/c^2
- Lifetime:
  - $\tau=0.448^{+0.123}_{-0.096}\pm0.121$ ps

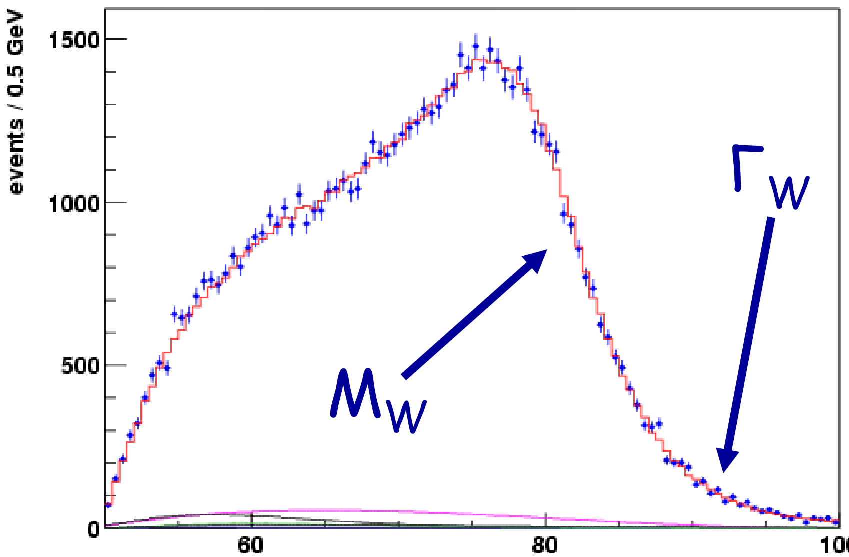
- first B_c search with > 5σ signal significance

Physics with Vector Bosons

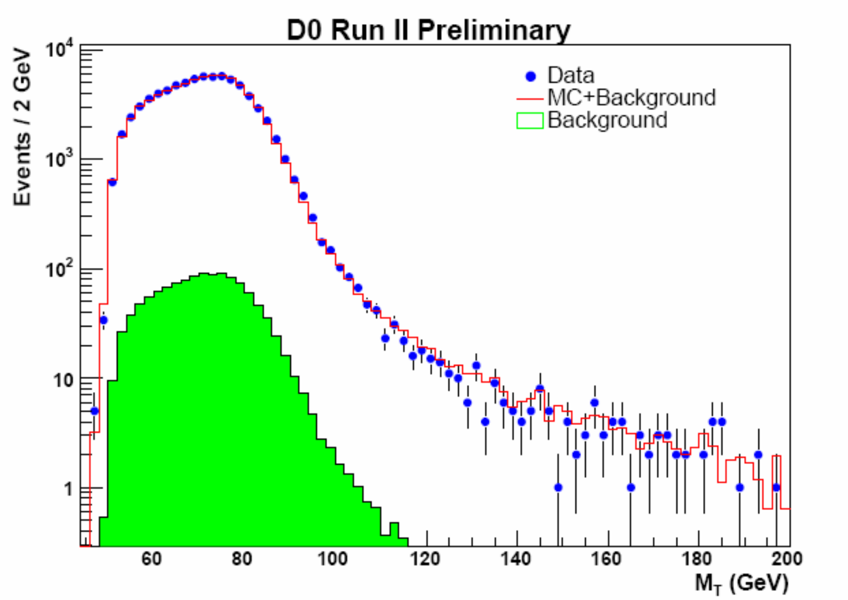
- W mass and width
- cross section measurements test SM predictions
- WW production important background for Higgs

W Mass Measurement

- reconstruct W→lν transverse mass: $M_T = \sqrt{2E_T^{\ell}E_T^{\nu}(1-\cos\phi_{\ell\nu})}$
- fit distribution to extract mass and width
- statistical uncertainty ~ 35 MeV/c^2
- Systematic uncertainty:
  - dominated by lepton E scale, work in progress
- D0 width measurement: 2.011±0.093±0.107 GeV/c^2 (177 pb^{-1})

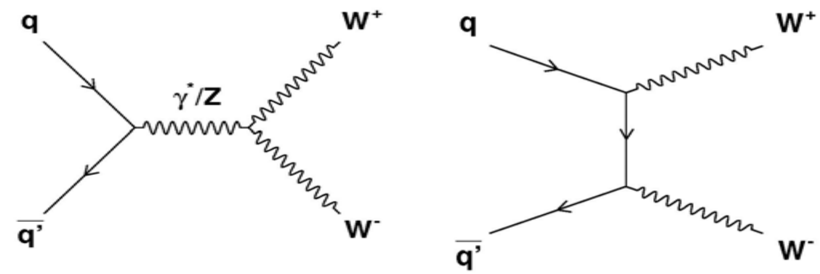


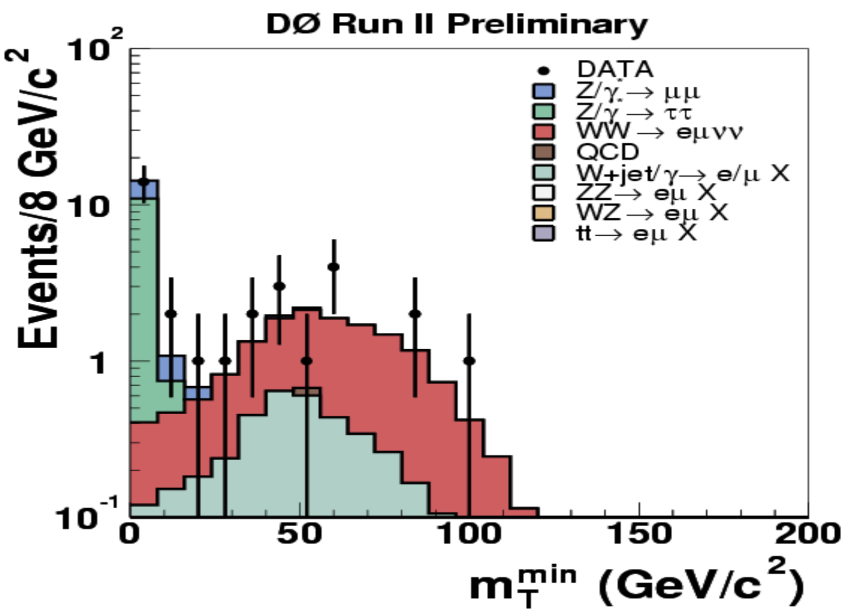
I.K. Furic, Review of Tevatron Results, LHC Days in Split 2004

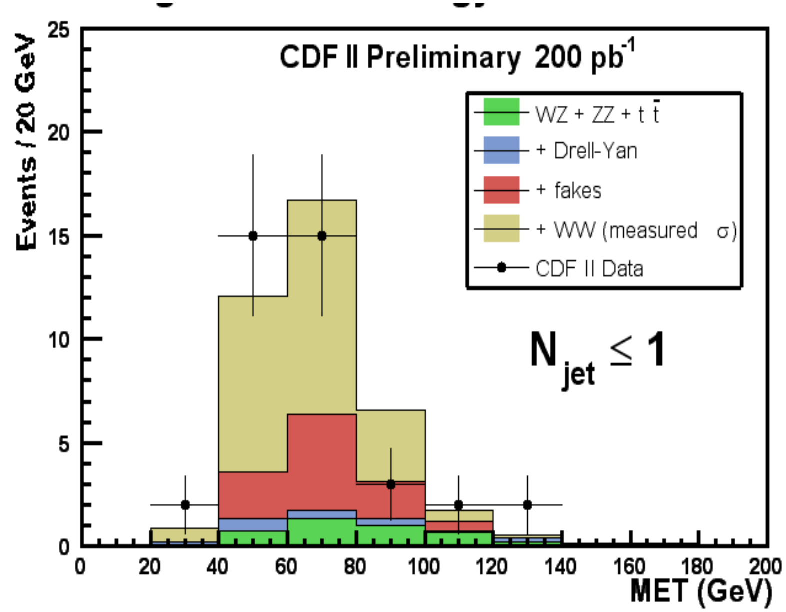


WW, WZ, ZZ Production

- WW (SM 12.5 ± 0.8 pb)
  - Trilinear Gauge Coupling
  - hard to beat LEP (40k WW)
  - Important backgrounds to Higgs search!

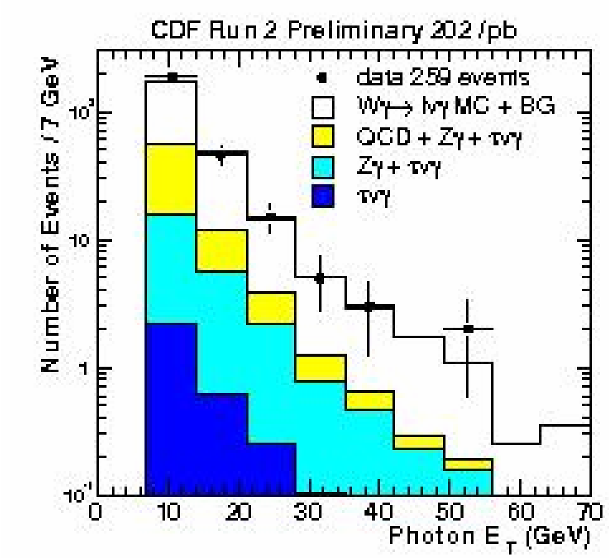


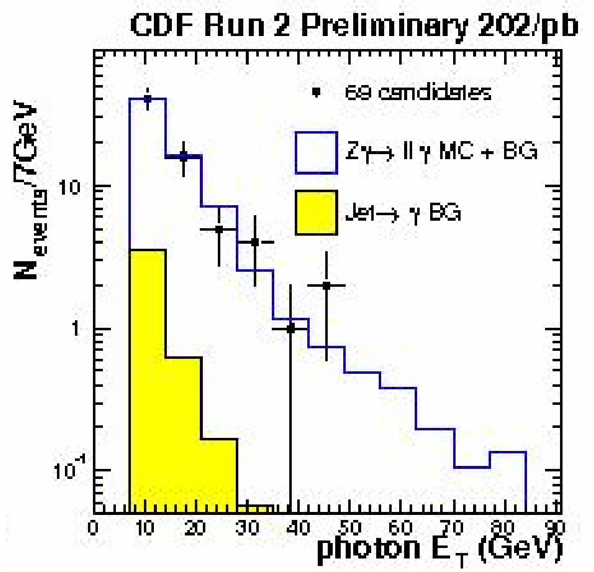


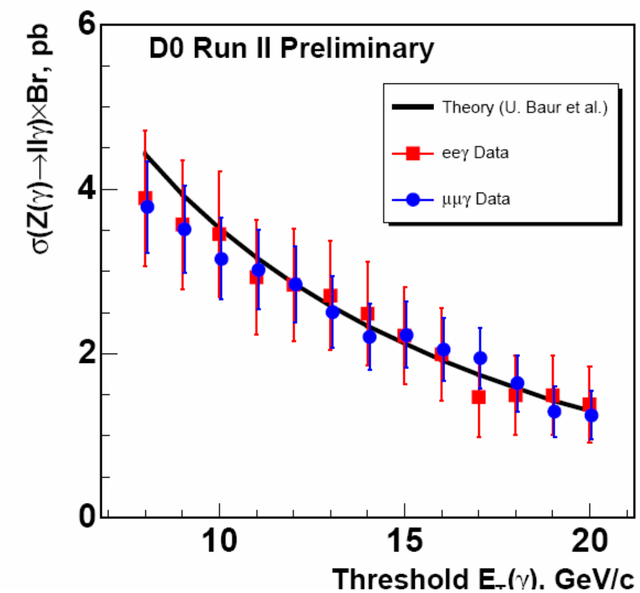


CDF	$\sigma(WW) = 14.3 \pm^{5.6}_{4.9} \pm^{1.8}_{1.8}\, pb$	$\sigma(WZ) < 13.9\, pb$ @ 95% C.L.
D0	$\sigma(WW) = 13.8 \pm^{4.3}_{3.8} \pm^{1.3}_{1.2}\, pb$	$\sigma(WZ) < 15.1 pb$ @ 95% C.L.

Wγ, Zγ Production







- $\Delta R(l\gamma) > 0.7$
- CDF $E_T(\gamma) > 7$ GeV
- D0 $E_T(\gamma) > 8$ GeV
- results consistent with SM predictions

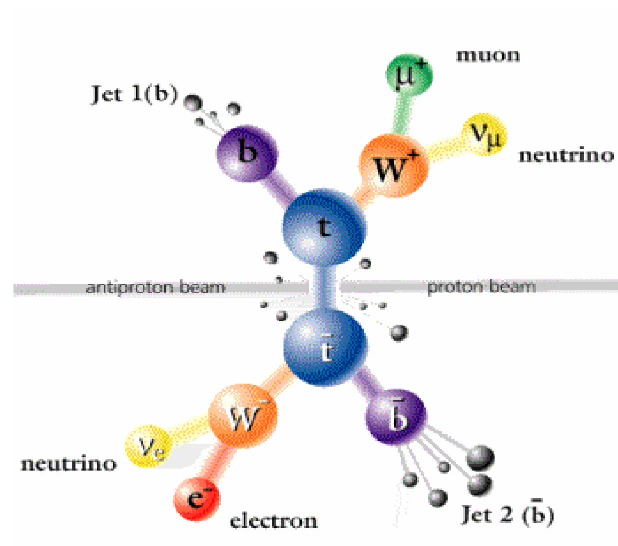
Measurement	Result [pb]	SM [pb]
CDF σ(Wγ)	19.7±2.8	19.3±1.4
D0 σ(Wγ)	19.3±6.7	16.4±0.4
CDF σ(Zγ)	5.3±0.7	5.4±0.4
D0 σ(Zγ)	3.86±0.46	4.3

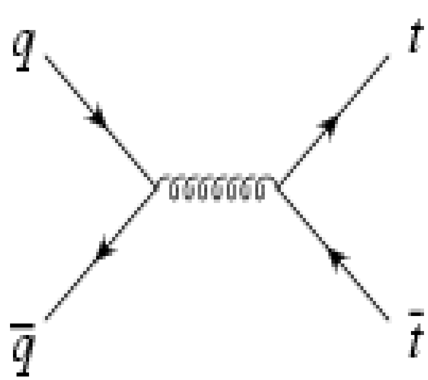
Physics with Top Quarks

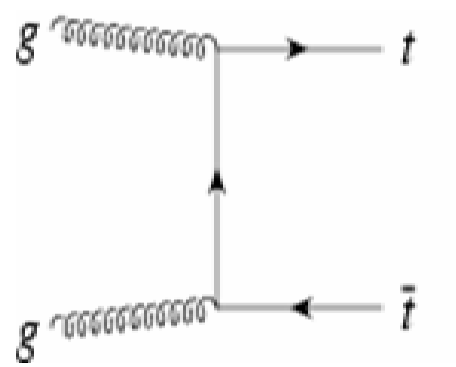
- top quark discovered in Run I
- Run II: precision measurements of top properties
- bare quark (decays too fast to hadronize)
- very massive: m ~ 175 GeV/c^2

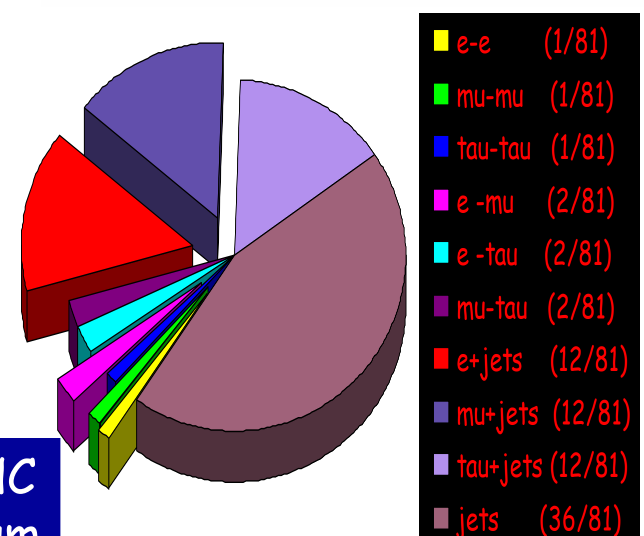
The top quark

- Precision measurements of top properties:
  - top production cross section
  - top mass
  - top spin: W helicity in top decays
  - cross sections in different final states
- Top pair production via strong interaction







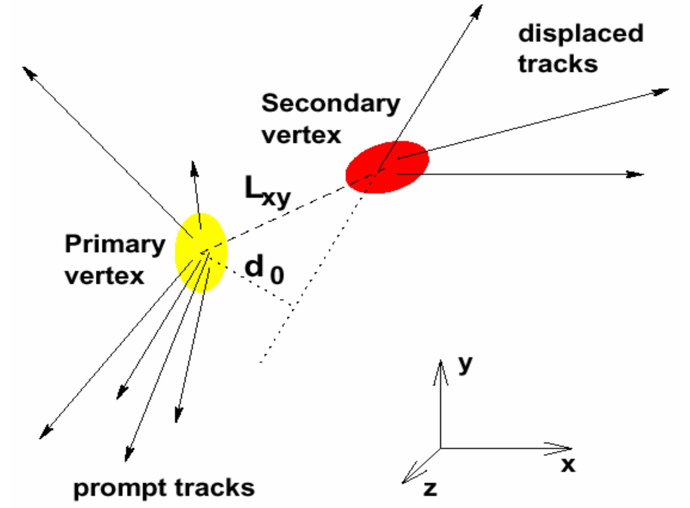


85% qq, 15% gg at Tevatron,
~1 event/hour at recent lum

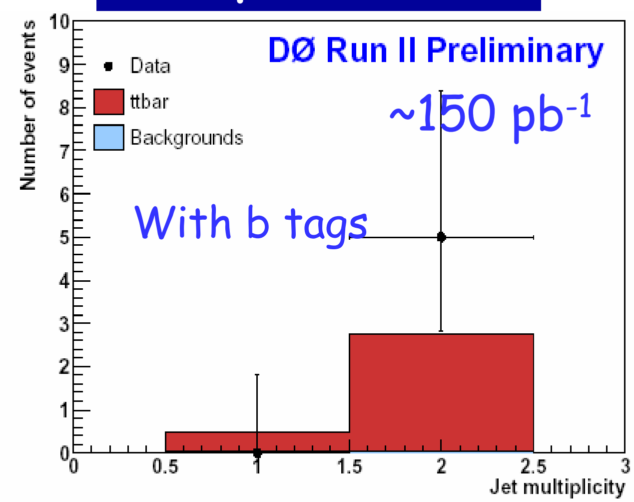
10% qq, 90% gg at LHC
~1 event/sec at low lum

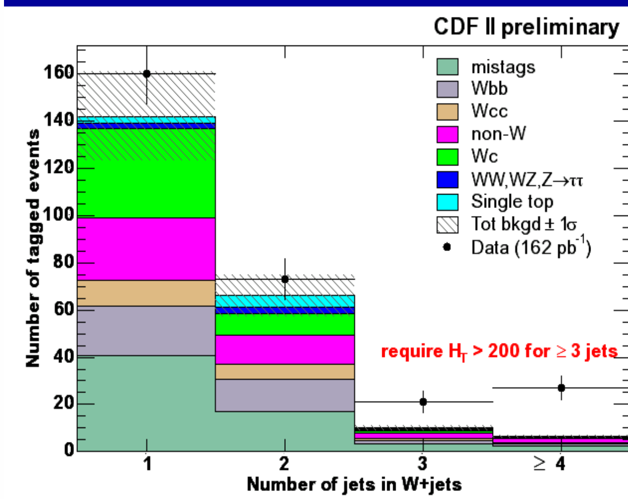
Top quark final states

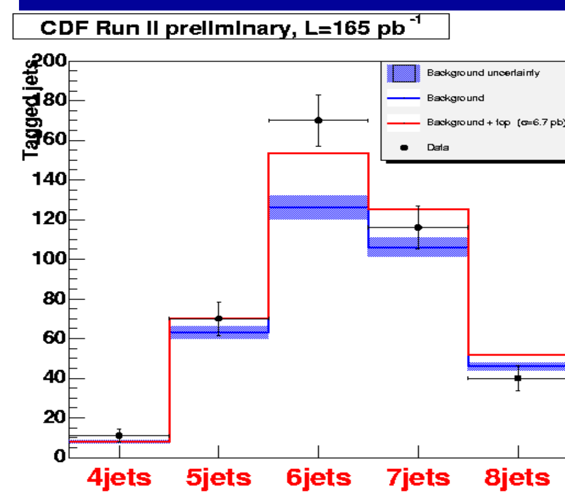
- signal has ≥ 2 jets in final state
- tag b jets using:
  - displaced vertex (~ 3 mm)
  - soft lepton from b decay
- understand shapes of W/Z+n jet backgrounds (multiplicity, kinematics)



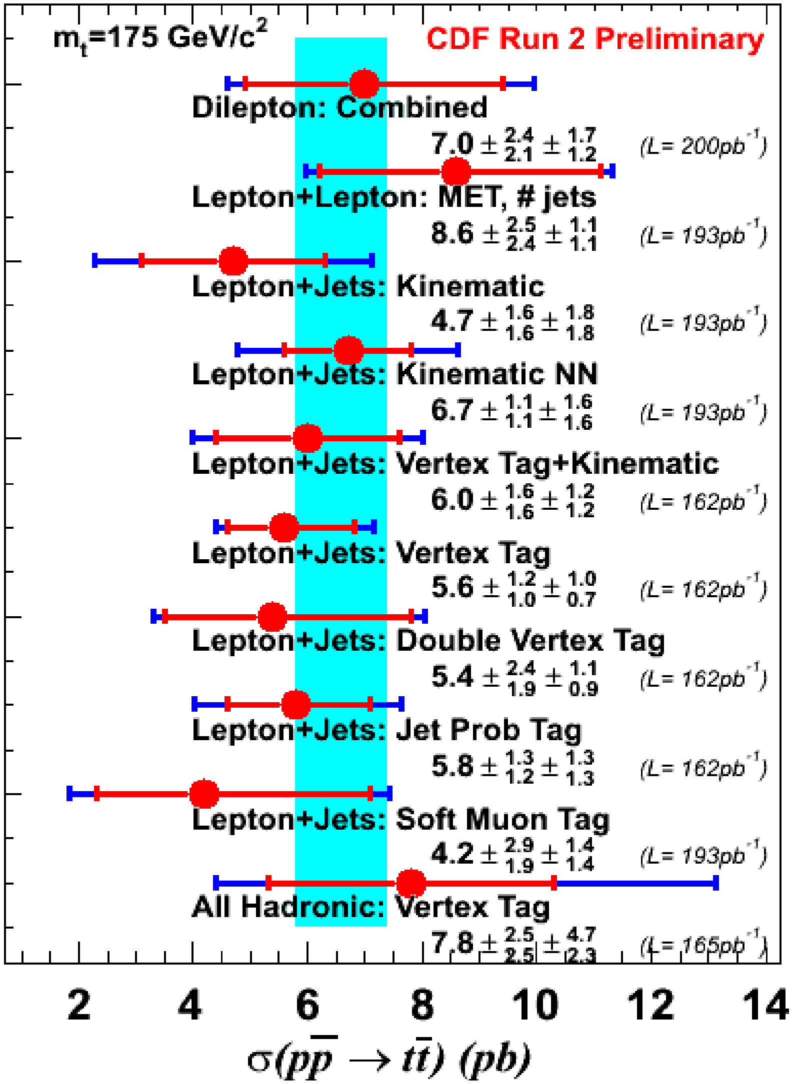
Dilepton (5%)	Lepton + Jets (35%)	All-Hadronic (40%)



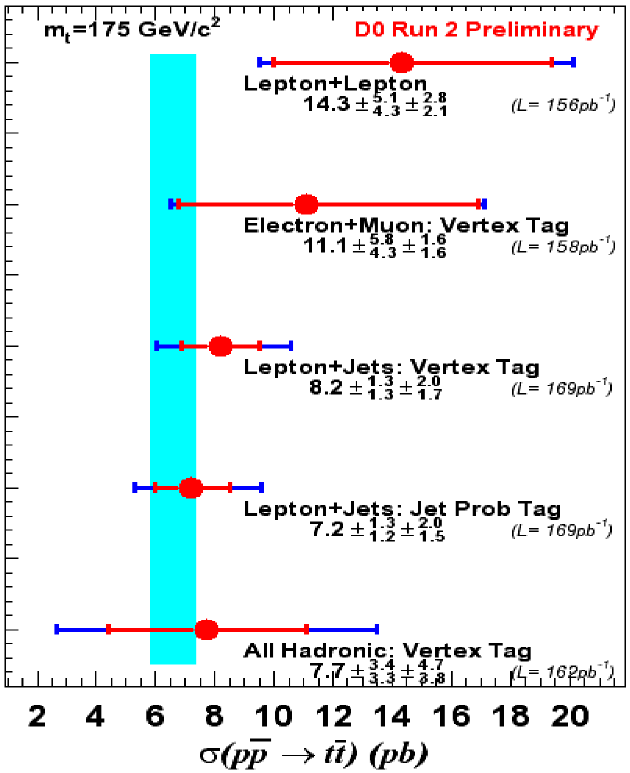




Top pair cross sections



- many different measurements
- ~20% precision - statistics limited

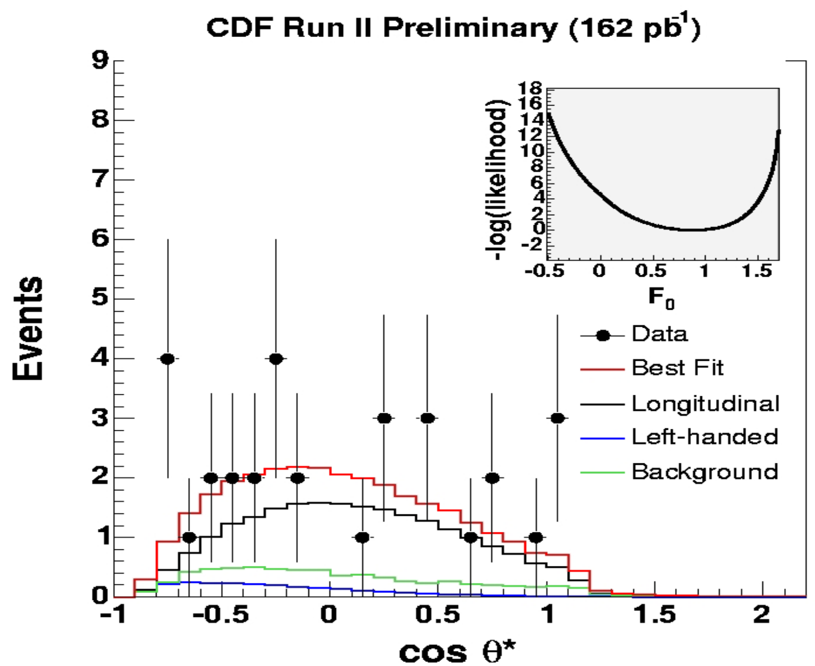


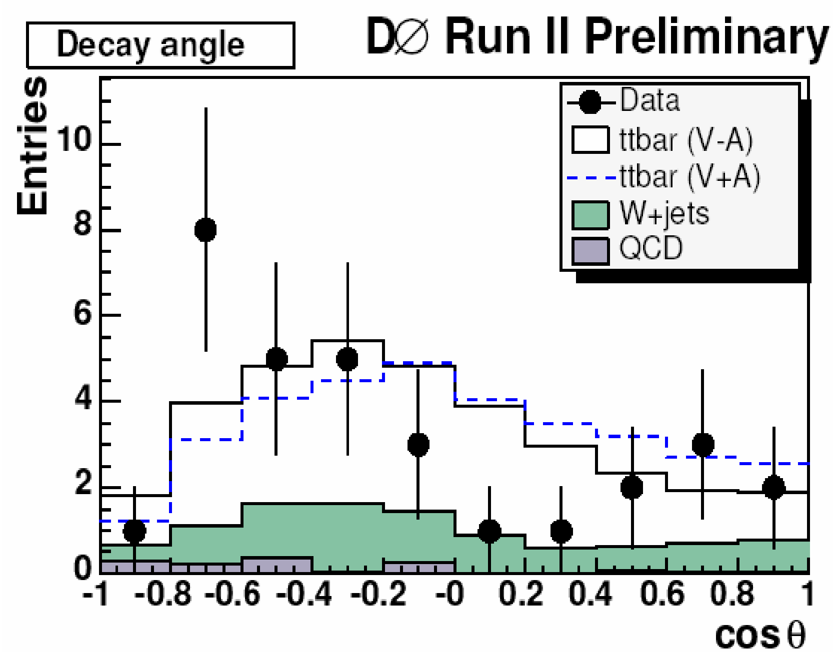
W helicity in t→Wb decays

SM is V-A theory: predicts W's from top decays are
F_0 = 70% longitudinal, F_- = 30% left-handed

- assume F_+=0.0 (ie no V+A)
- measure $F_0=0.89^{+0.30}_{-0.34}\pm0.17$
  $F_0 > 0.25$ at 95% C.L.

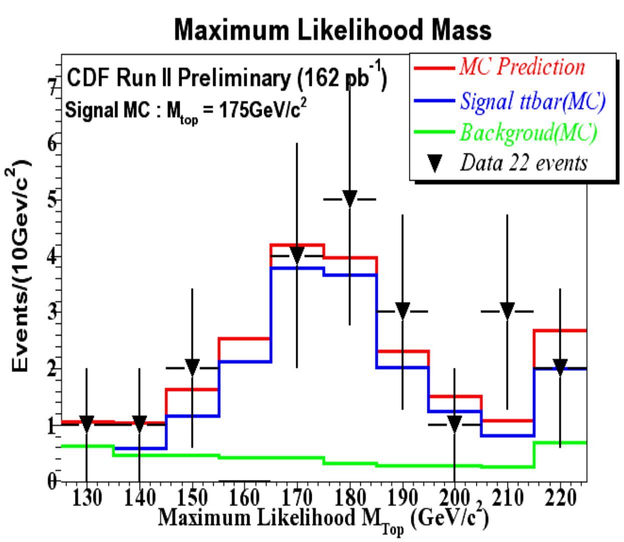
- assume F_0=70%
- limit on V+A fraction
  $F_+ < 0.269$ at 90% C.L.

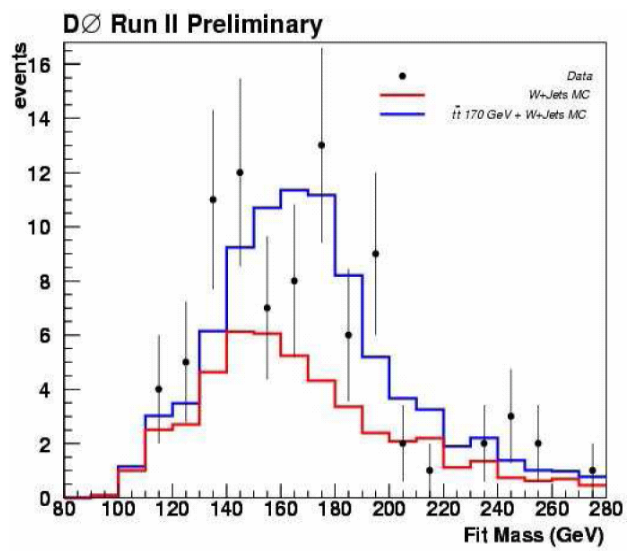


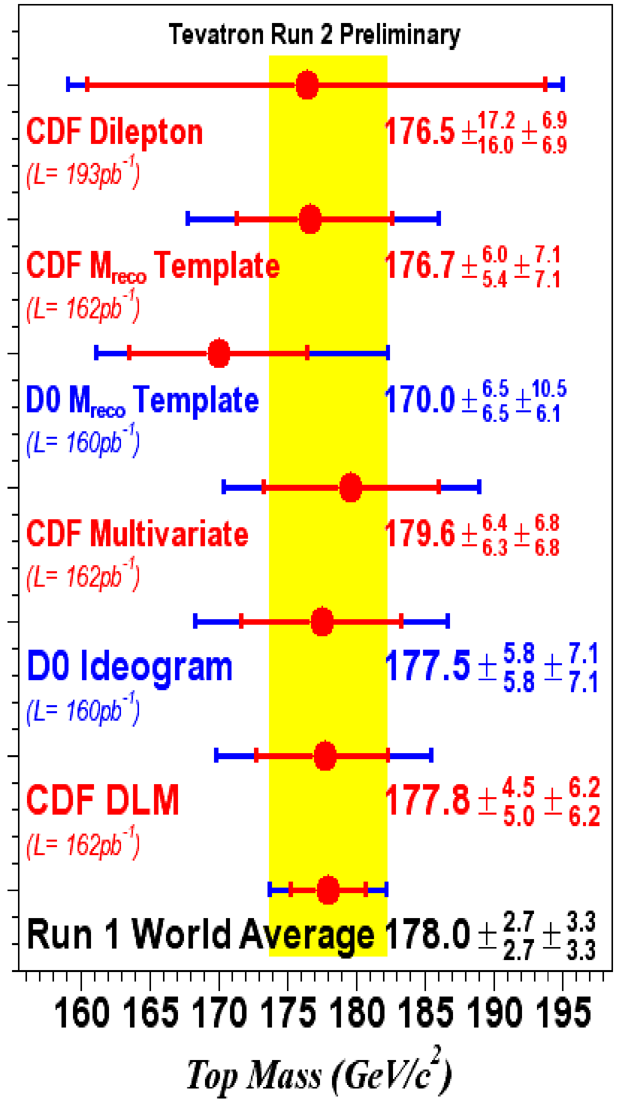


Measuring the top quark mass

- important SM parameter
- indirect Higgs mass constraint
- complicated event topology
- many fitting techniques with different sensitivities
- goal - $\delta m_{top} \sim 2\text{-}3\ GeV/c^2$

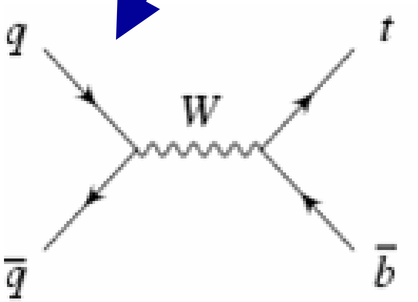


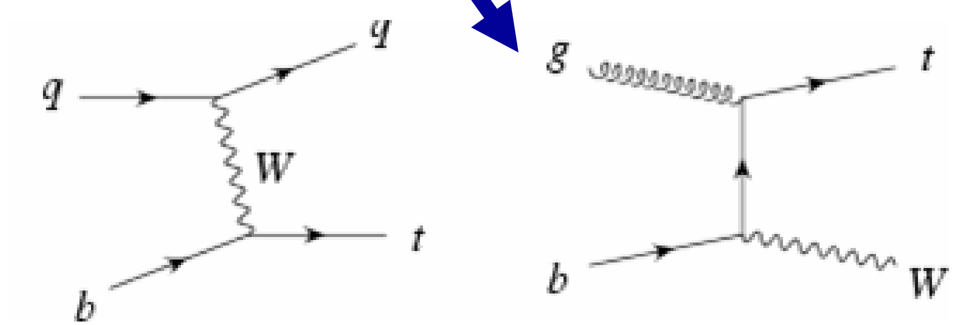




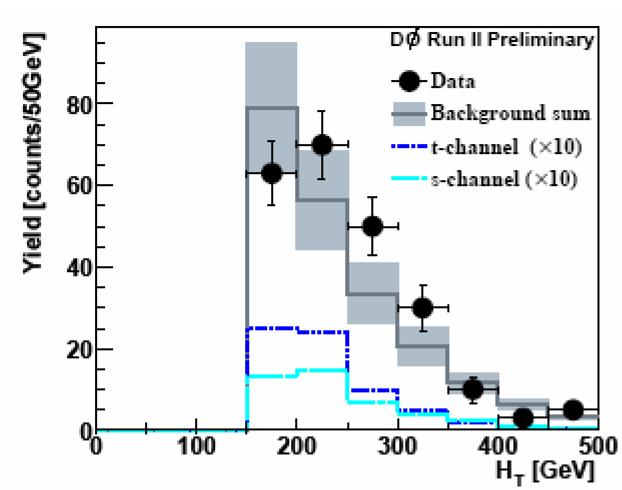
Single top production

- Probe EW coupling, direct determination of V_{tb}
- Sensitive to new physics
  - s-channel: new charged gauge boson
  - t-channel: anomalous couplings, FCNC





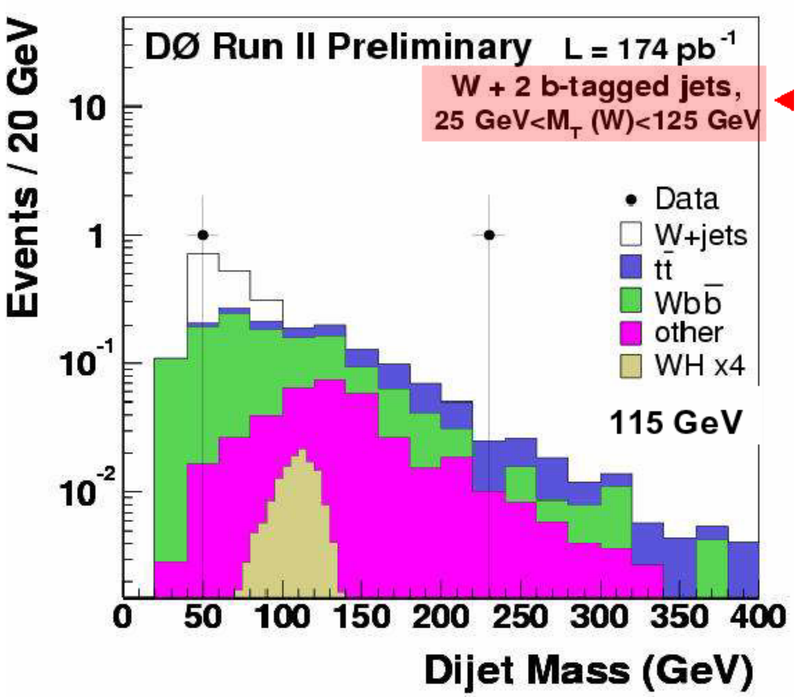
Channel	CDF, 95% C.L.	D0, 95% C.L
s-channel	< 13.6 pb	< 19 pb
t-channel	< 10.1 pb	< 25 pb
Combined	< 17.8 pb	< 23 pb

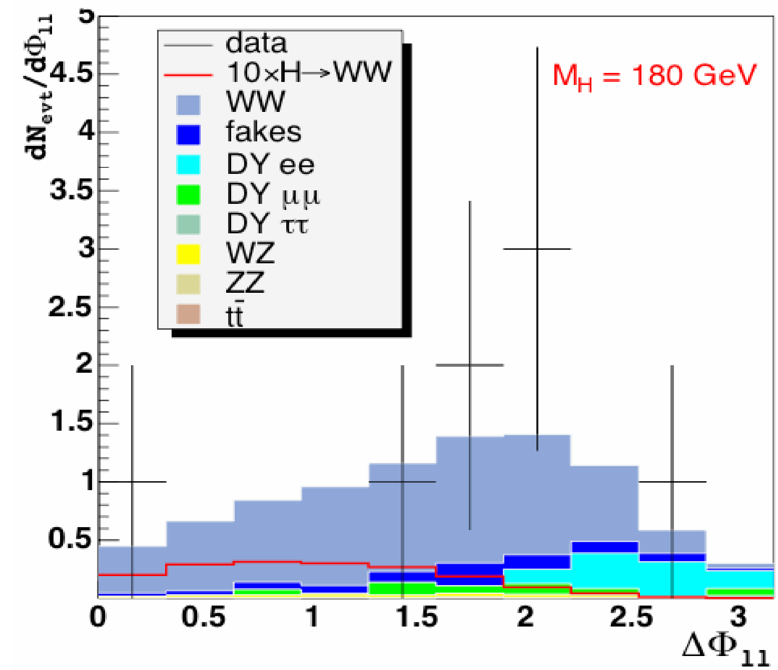


Higgs, SUSY and Other Searches

Standard Model Higgs Search

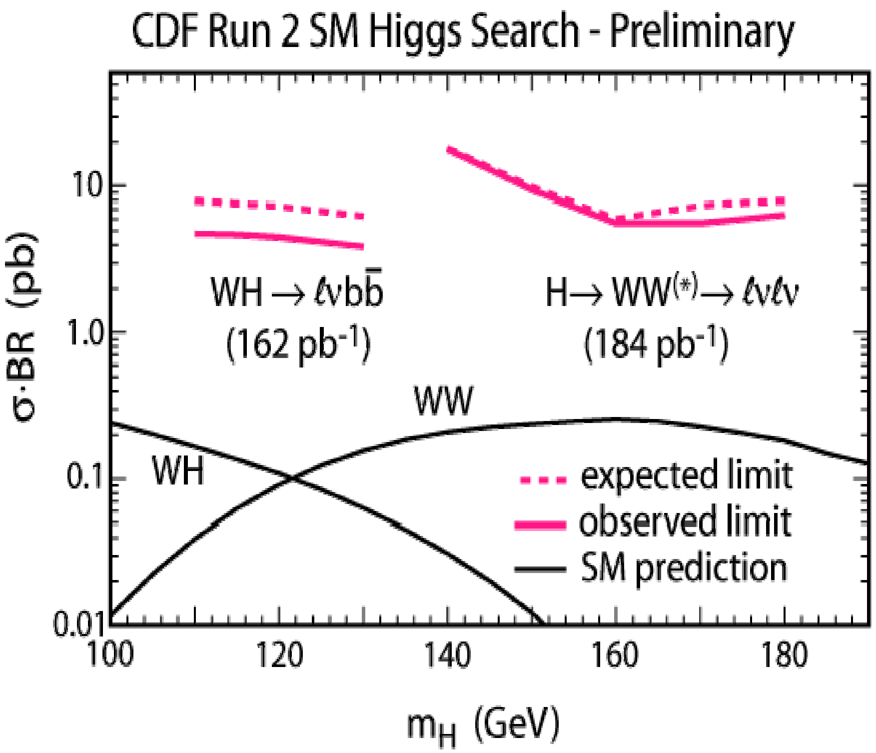
- m(H) < 130 GeV/c^2: Associated production: W,Z + H (→bb)
- m(H) > 130 GeV/c^2: H → WW

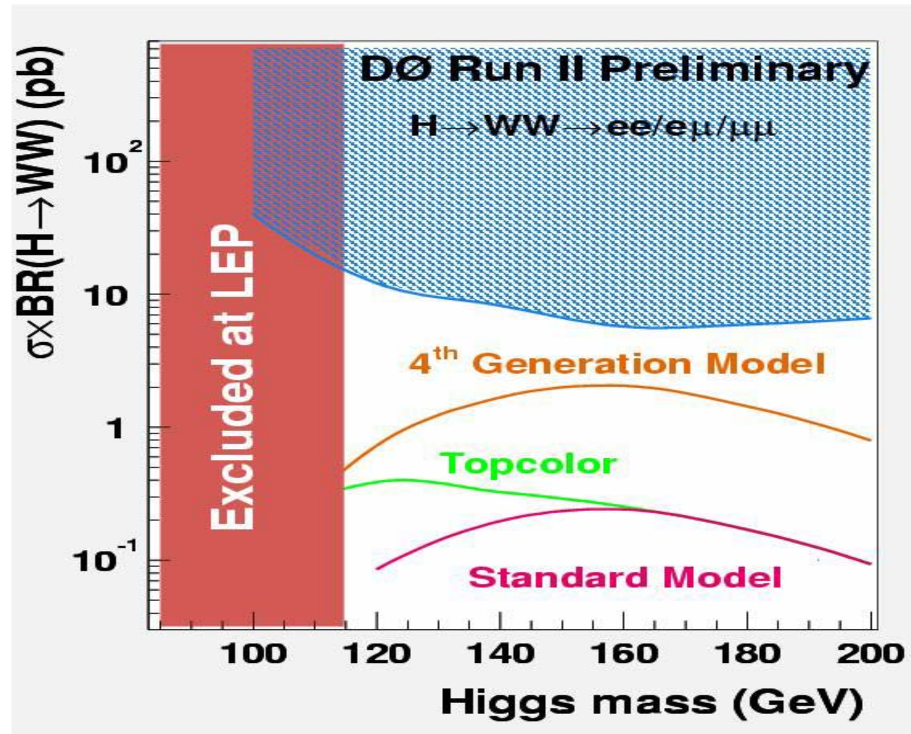




Improvements from
better b tagging, topological (spin 0) information,
more channels (ZH), mass resolution (Z→bb sample)

Standard Model Higgs Limits

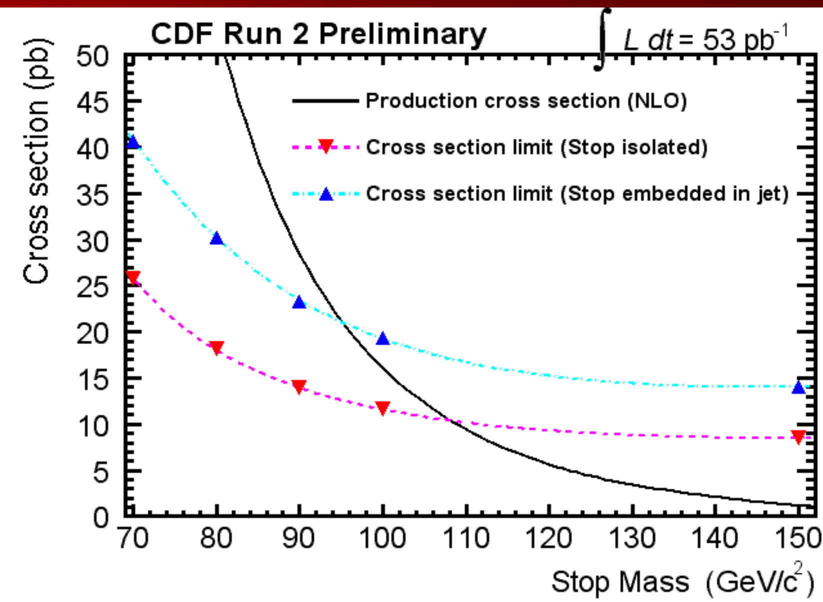




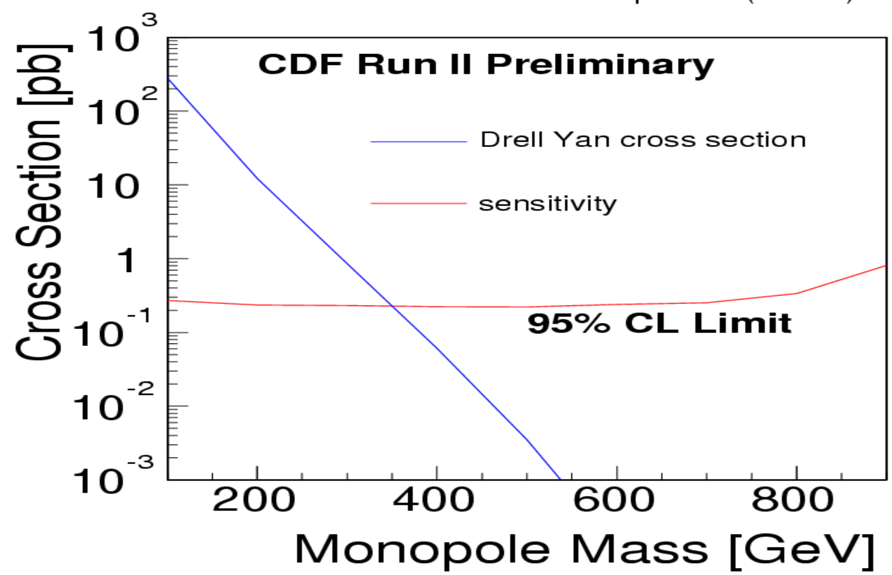
- SM: Limits already exceeding Run I results
- Sensitivity beyond LEP exclusion starts at ~2 fb^{-1}.
- New Physics: Interesting sensitivity to other new physics sooner?

Massive, long-lived objects

- Stop quark
  - Use new Run II Time oF Flight capability (v << c)
  - ToF resolution ~110 ps
  - Mstop > 97 - 107 GeV @ 95% CL using 53 pb-1 (LEP limit 95 GeV)



- Magnetic monopoles
  - highly ionizing (500 mips)
  - straight track in r-ϕ
  - curved in r-z plane
  - dedicated ToF-based trigger
  - dE/dX in drift chamber
  - m(monopole) > 350 GeV/c^2 at 95% C.L. using 25 pb^{-1}

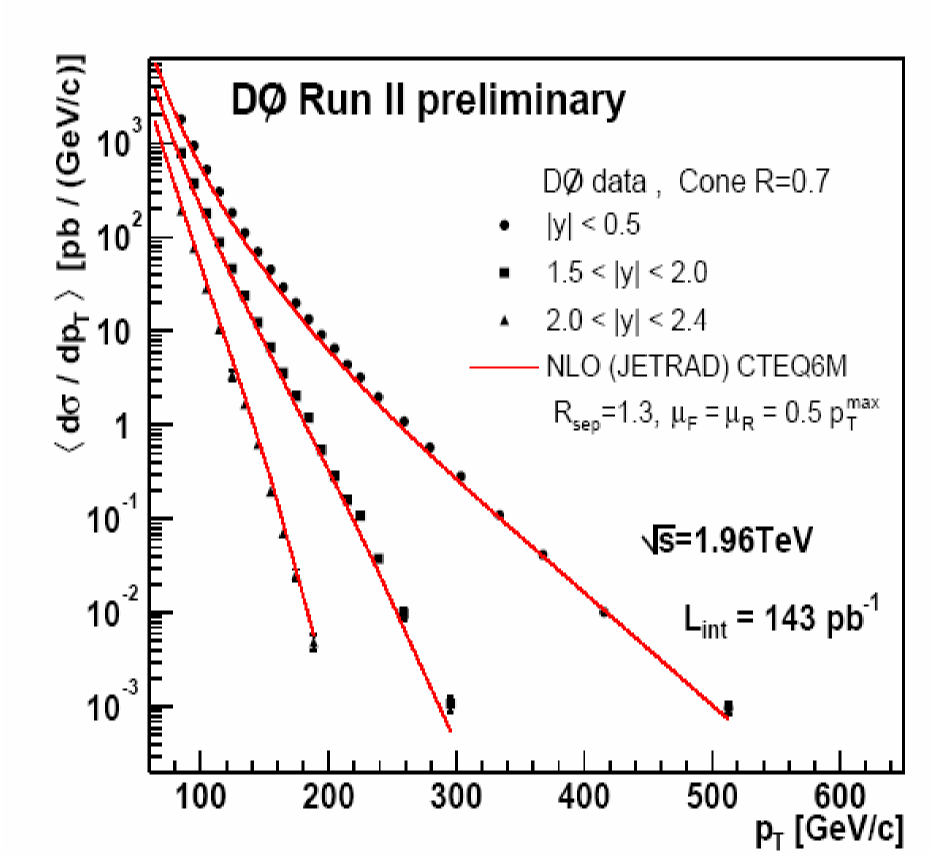


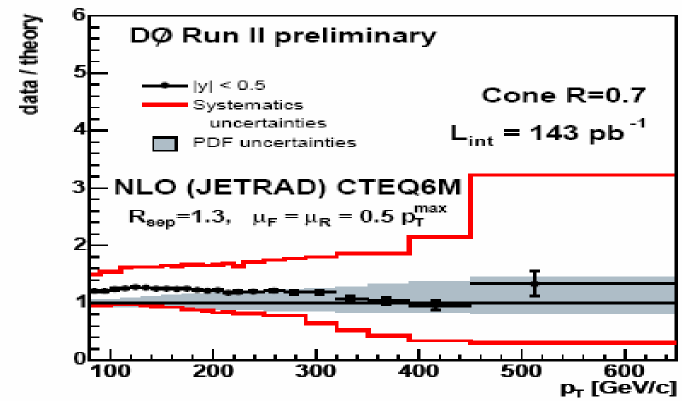
Conclusions

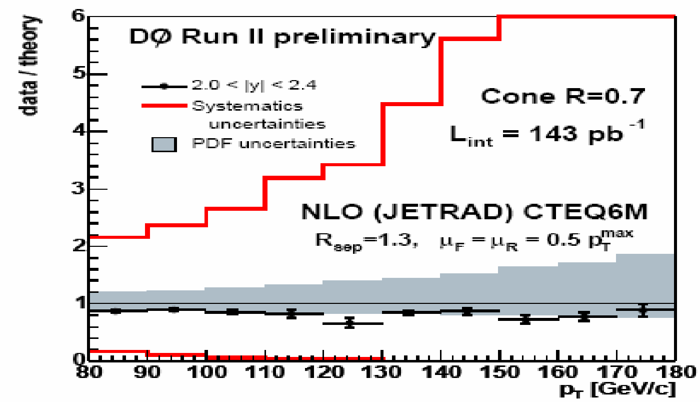
- Tevatron luminosity ramped up, $10^{32}cm^{-2}s^{-1}$ reached
- Detectors
  - Both CDF and D0 detectors are performing well.
  - Triggers & DAQ - still improving
- Data analysis
  - currently analyzing ~400 pb^{-1} per experiment
  - producing good physics results
  - understanding detectors and backgrounds
  - developing and optimizing physics algorithms
  - much better measurements will come soon.
- Discoveries
  - For the Tevatron to progress significantly beyond LEP new physics limits, we need 2-5 fb per experiment.

Backup Slides

Inclusive Jet Cross Section vs y





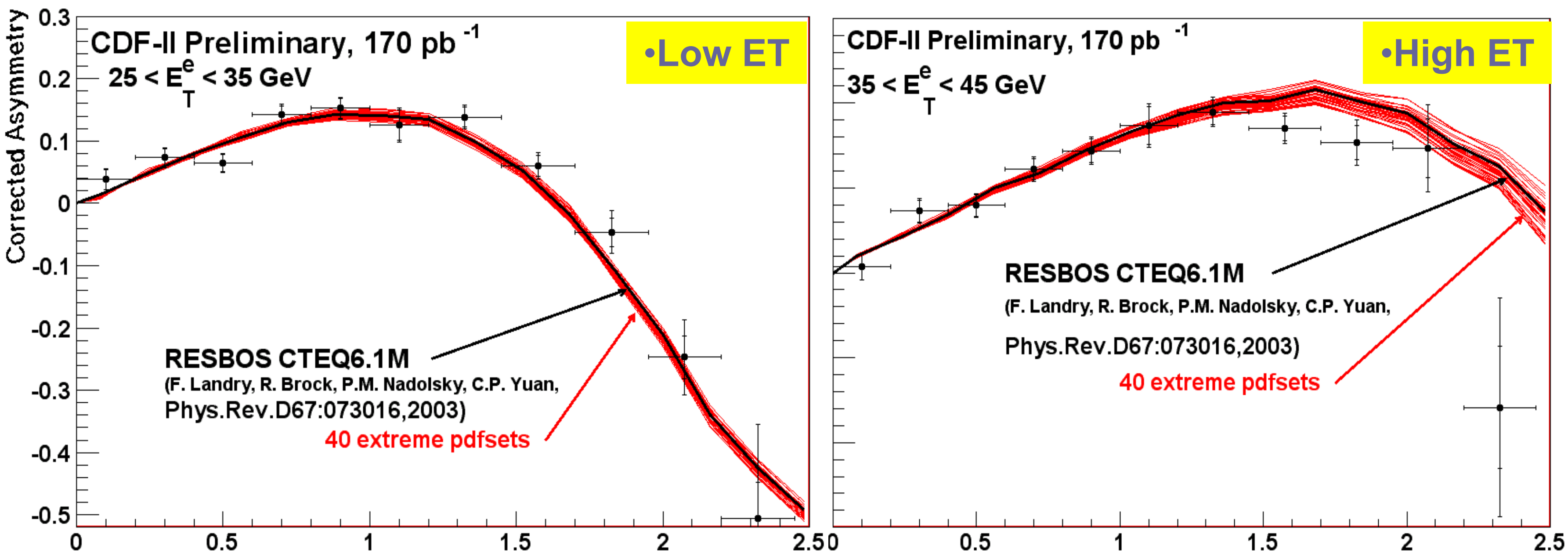


- y-dependent σ constrains gluon at medium to high x
- dominant systematic again jet energy scale

W Charge Asymmetry

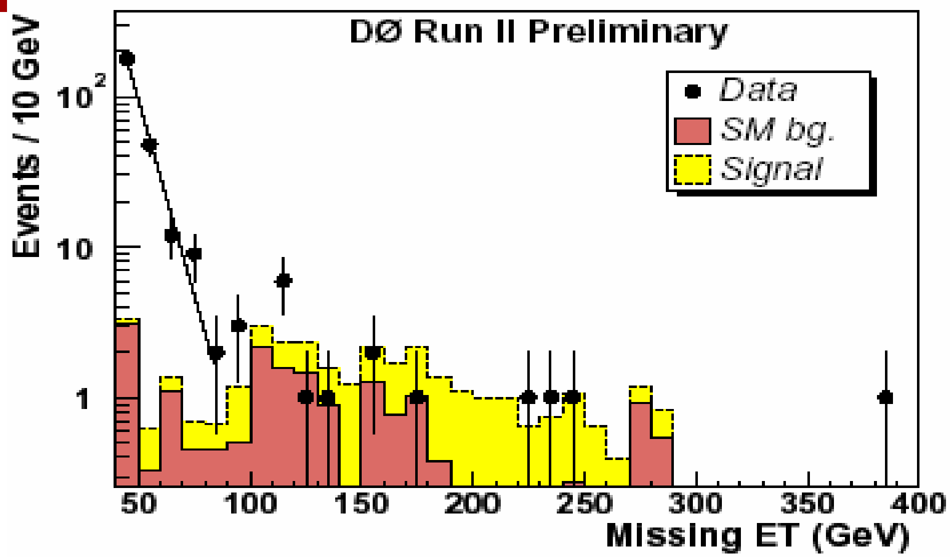
- On average, pu > pd in proton: W+ (W-) boosted along proton (anti-proton) beam direction
- Asymmetry between N(W+) and N(W-) versus η or Asymmetry between N(e+) and N(e-) versus η
- Sensitive to u/d quark momentum ratio at large x
- Constrain PDFs at large x

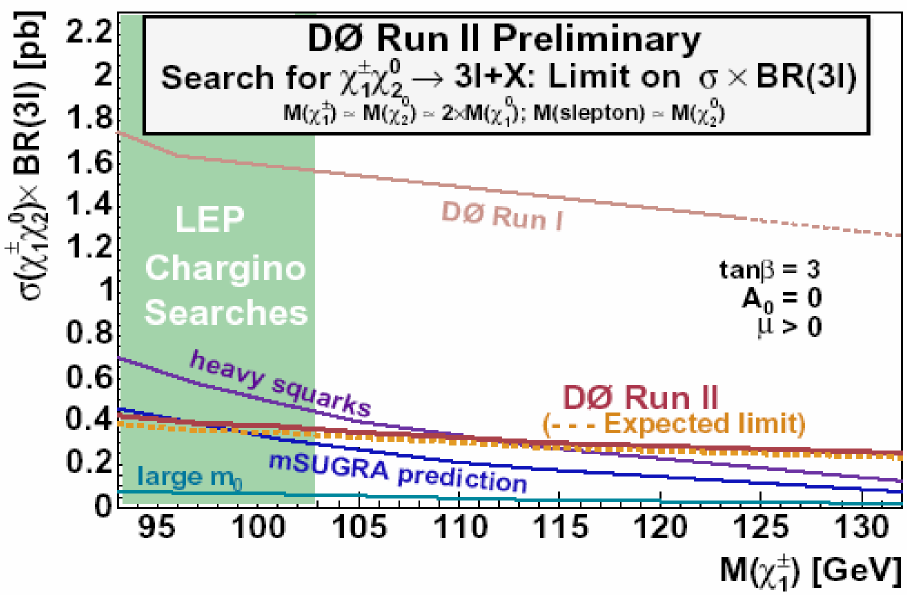
$$\frac{\frac{d\sigma(e^+)}{d\eta} - \frac{d\sigma(e^-)}{d\eta}}{\frac{d\sigma(e^+)}{d\eta} + \frac{d\sigma(e^-)}{d\eta}}$$



SUSY Searches

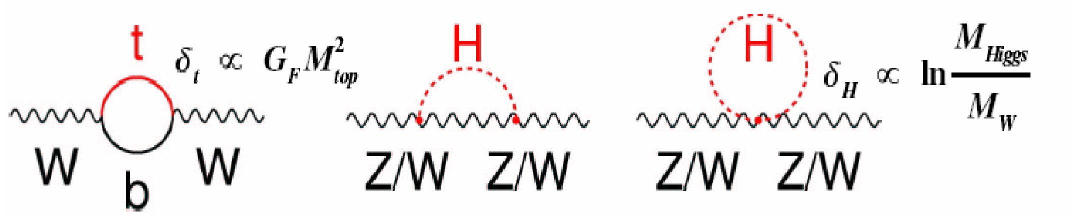
- Squark-gluino search
  - 2 jets +missing E_T
  - For MSUGRA @ m_0=25GeV, tanb=3, A_0=0, m<0, exclude m(squark/gluino) < 292/333 GeV
  - Improves Run I limits
- Chargino-neutralino search
  - Using trileptons
  - One of the golden discovery modes at Tevatron and LHC
  - Analysis of data already on tape will extend sensitivity beyond LEP2



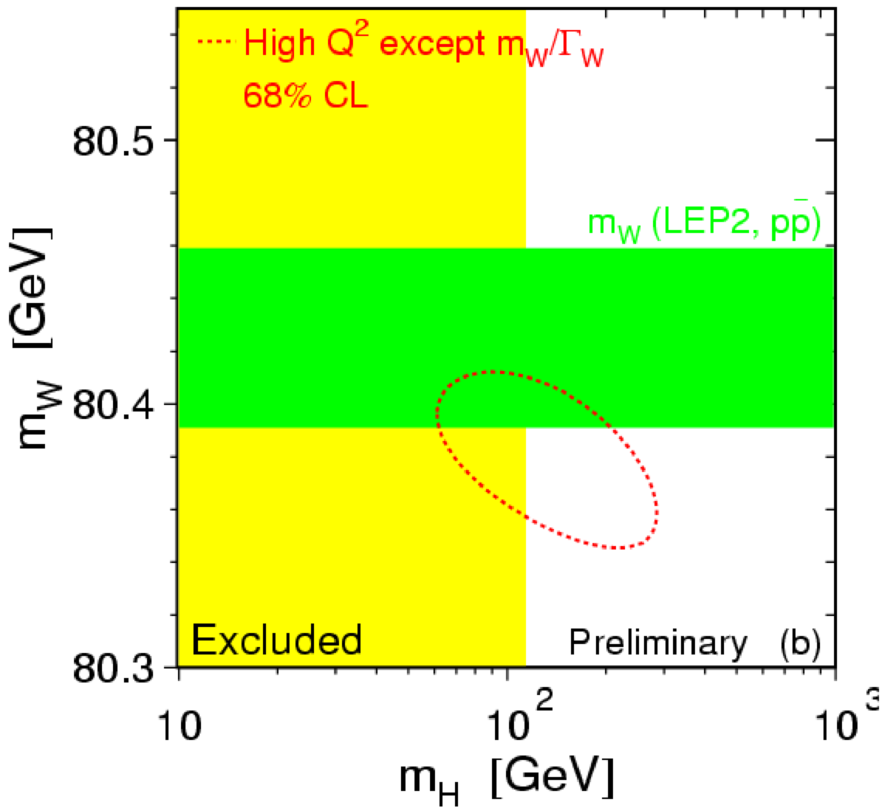


SM Prediction of W mass

Radiative corrections make W mass sensitive to top and Higgs mass



A. Freitas et al
hep-ph/0311148



$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r)$$

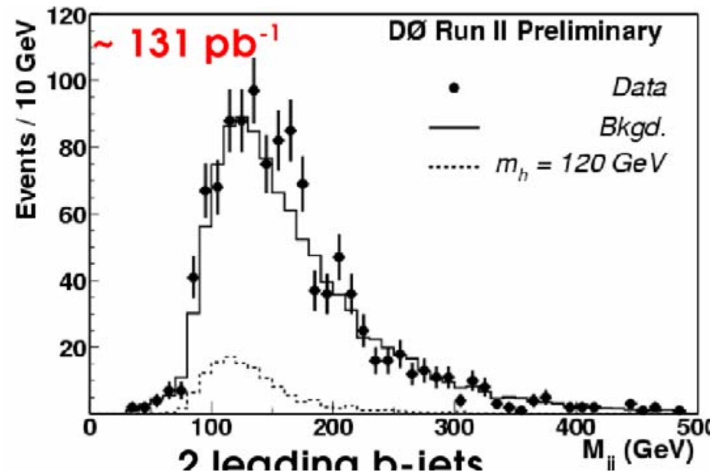
SM prediction for W mass dominated by error on top mass

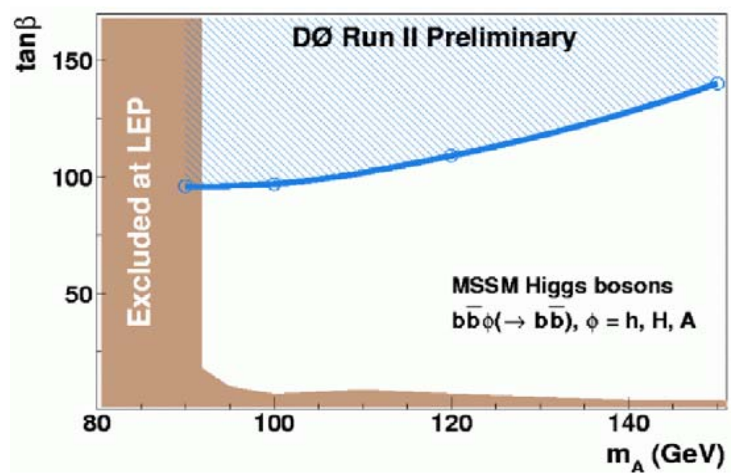
	Experiment ΔM_{top}(GeV)	Prediction ΔM_W (MeV)
Now	4.3	26
TeV	2.5	15
LHC	1.3	8
LC	0.1	-

MSSM Higgs Search

at high tanβ: enhanced x-sections, heavy flavor (b, τ) preferred

bbbb:



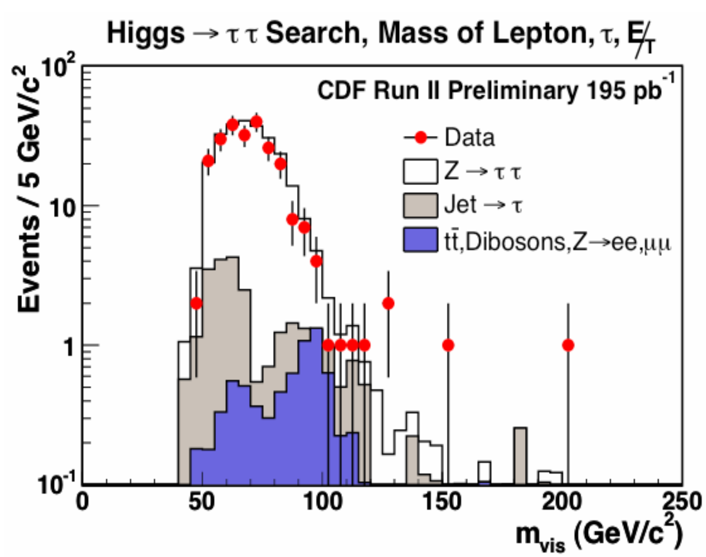


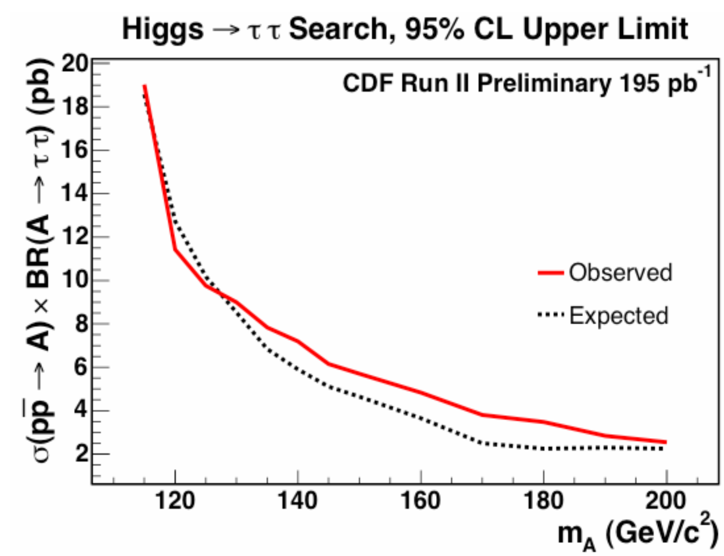
ττ:

gg□A

bb□A

bbA





Unexpected top quark decays?

- assuming three-generation CKM matrix unitarity, $|V_{tb}|$~1

$$R = BR(t \to Wb)/BR(t \to Wq) \sim 1.0$$

- measure b quark content of top decay products

$$BR(t \to Wb)/BR(t \to Wq) > 0.6 \text{ at } 95\% \text{ C.L. (CDF)}$$

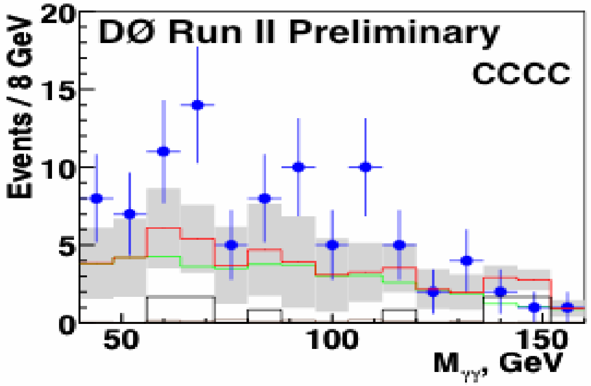
- does top decay into something besides SM $t \to Wb$?

  $t \to Xb$, where $X \to qq$ (100%)?
  $t \to Yb$, where $Y \to l\nu$ (100%)?

- estimate limits using ratio of top cross sections $\sigma(ll)/\sigma(lj)$

CDF: $Br(t \to Xb) < 0.46$ at 95% C.L.
$Br(t \to Yb) < 0.47$ at 95%C.L.

Higgs → γγ (non-SM Light Higgs)



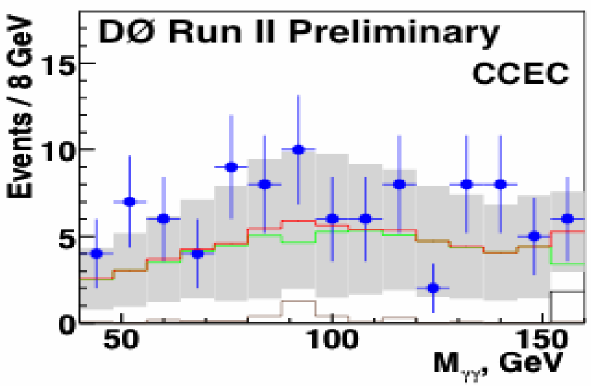
data = 93.0

bkgd = 52.4 +- 28.0

QCD = 42.7 +- 28.0

DY = 1.4 +- 1.3

γγ = 8.3 +- 0.6



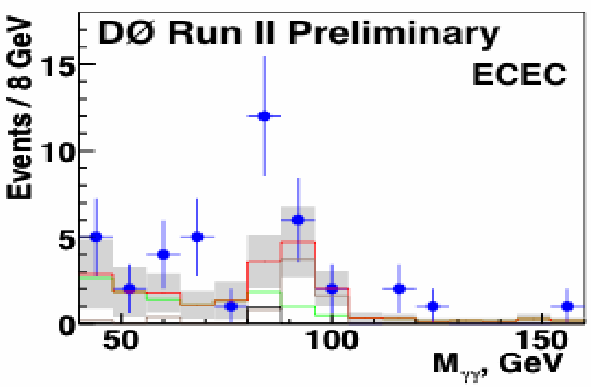
data = 97.0

bkgd = 68.8 +- 45.8

QCD = 64.0 +- 45.7

DY = 3.0 +- 3.0

γγ = 1.8 +- 0.1



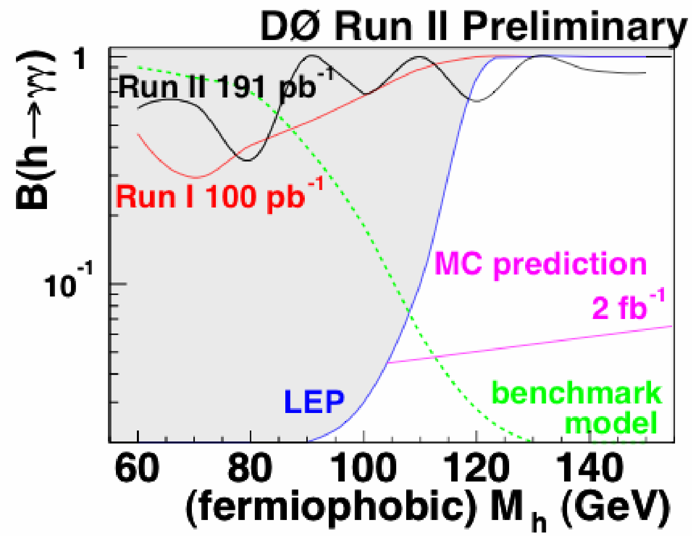
data = 41.0

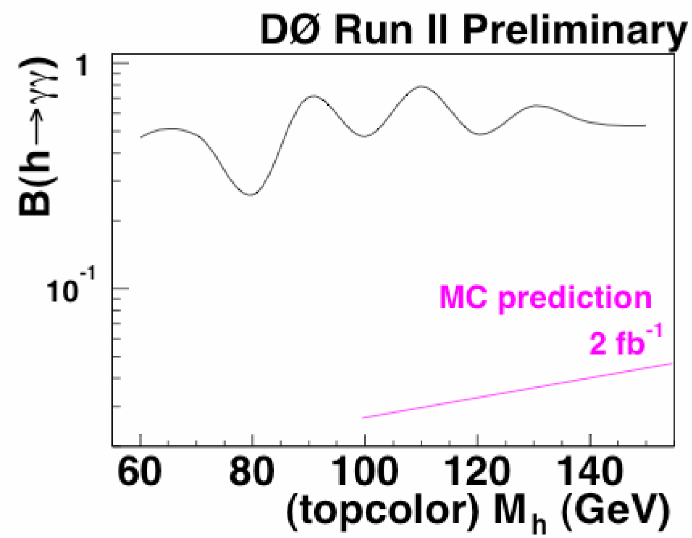
bkgd = 20.8 +- 10.4

QCD = 13.1 +- 10.0

DY = 6.7 +- 3.0

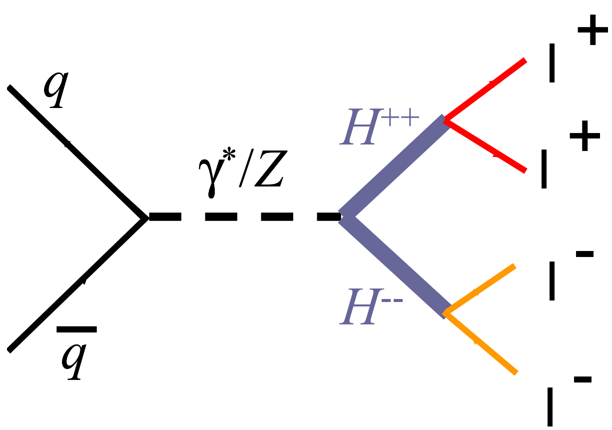
γγ = 1.0 +- 0.1

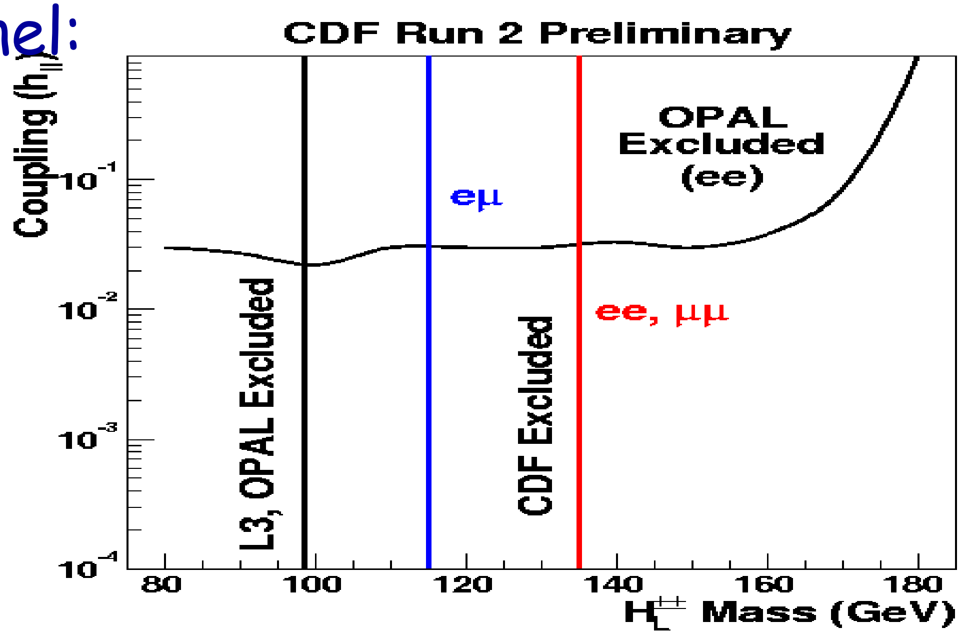




Doubly Charged Higgs Search

- Predicted by Left-Right Symmetric Model
- (motivated by neutrino mass), light in SUSY-LR
  - search in dilepton channel:





- Surpass LEP limits for coupling to leptons < 0.02
  - Possibly long-lived due to limited decay modes
- Highly ionizing
- M(H±±) > 134 GeV/c^2 at 95% CL (LEP limit ~ 98 GeV/c^2)