Physics Results from Tevatron Run II

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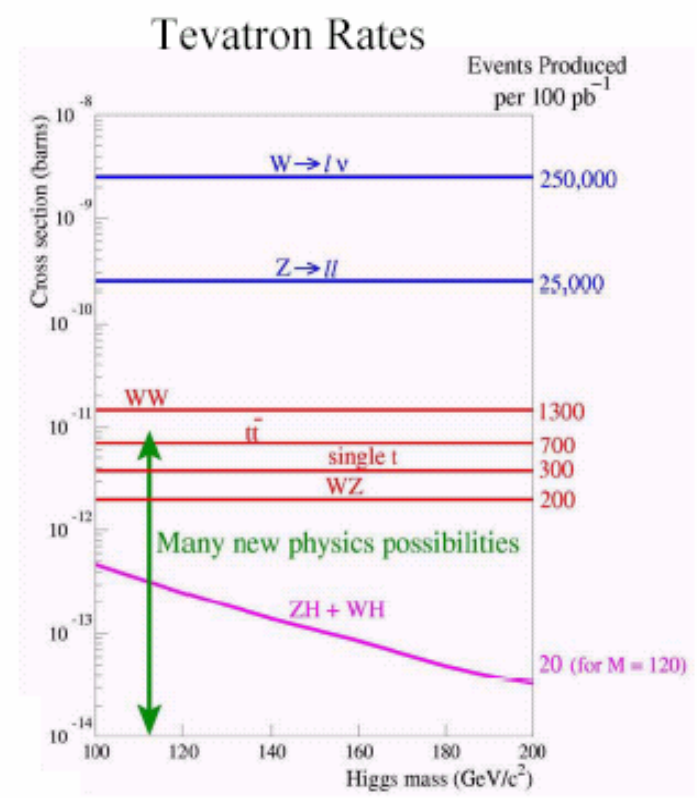
(for the D0 and CDF Collaborations)

Lattice 2004

Fermilab, June 26, 2004

Tevatron Run II rich physics program



M. Kruse, 2004 FNAL User's Mrg

- **EW physics : W, Z's have large cross sections → high statistics; precision measurements**
  - W, Z masses, width, σ, W helicity
  - Gauge boson pair production
- **Top σ, mass, properties, single top**
- **Higgs searches**
- **Precision QCD measurements**
- **Diffractive phenomena**
- **New physics searches : SUSY, Extra Dimensions etc**
- **B and Charm physics**
  - 10^{10} b-quarks produced per 100 pb^{-1}

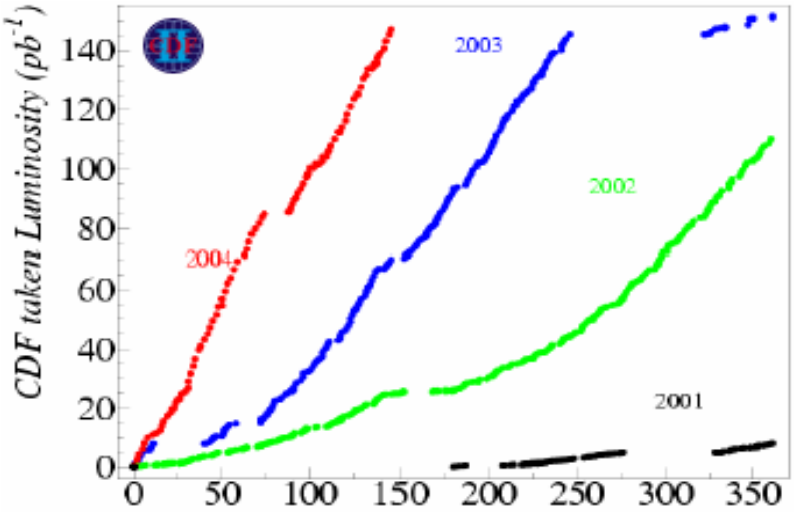
Contents

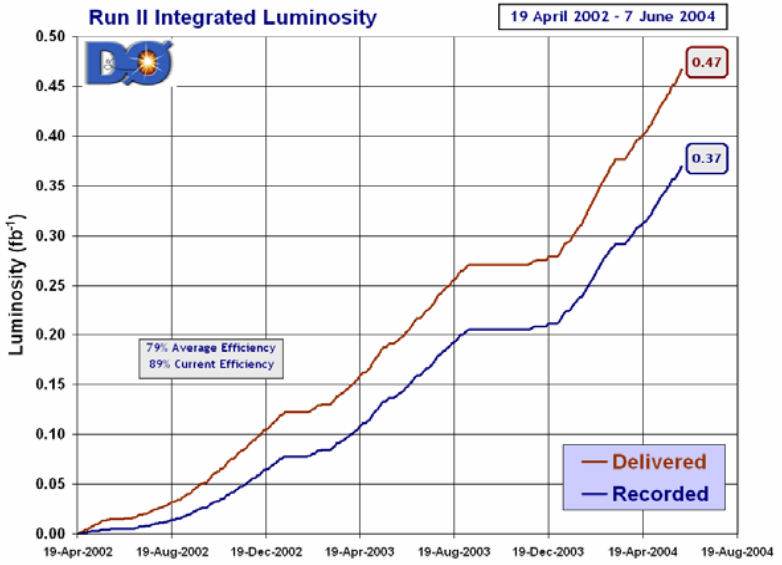
- Top quark mass & implications for SM Higgs
- SM Higgs limits
- Production cross sections
- New states (X(3872), pentaquarks)
- B physics results

  - spectroscopy
  - lifetimes
  - towards B_s mixing
  - rare decays ($B_{s,d} \rightarrow \mu\mu$ limits)

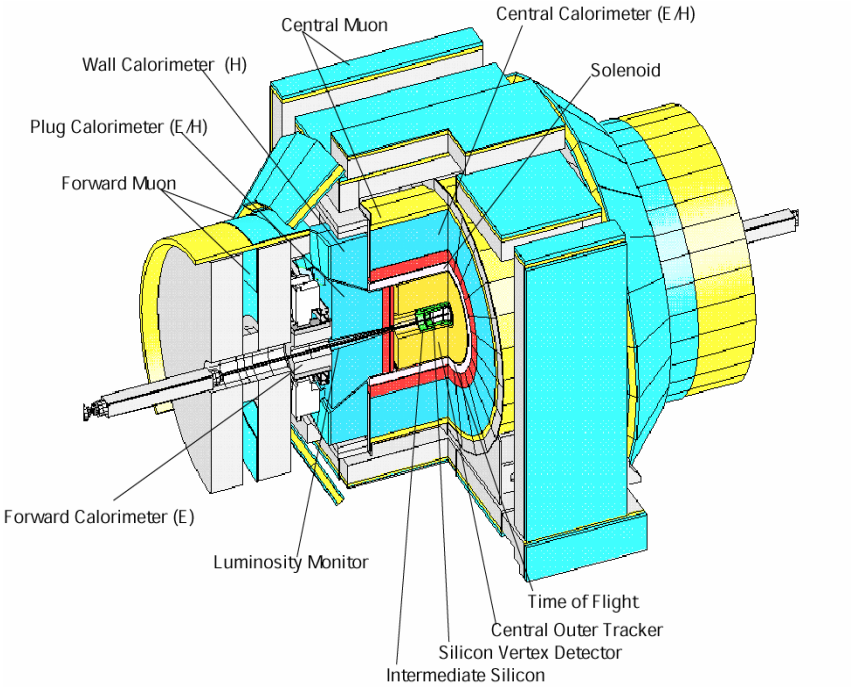
Tevatron Performance

- **Tevatron has been working well in 2004**
- Record initial luminosity =
  = 7.8 x 10^{31} cm^{-2} sec^{-1}
- Recent data taking rate:
  ~10 pb^{-1} / week
- **~ 0.4 fb^{-1}** on tape per experiment
- ~ 100–270 pb^{-1} used for analysis
- CDF & D0 performing well
- Data taking efficiency ~80–90%





Detectors

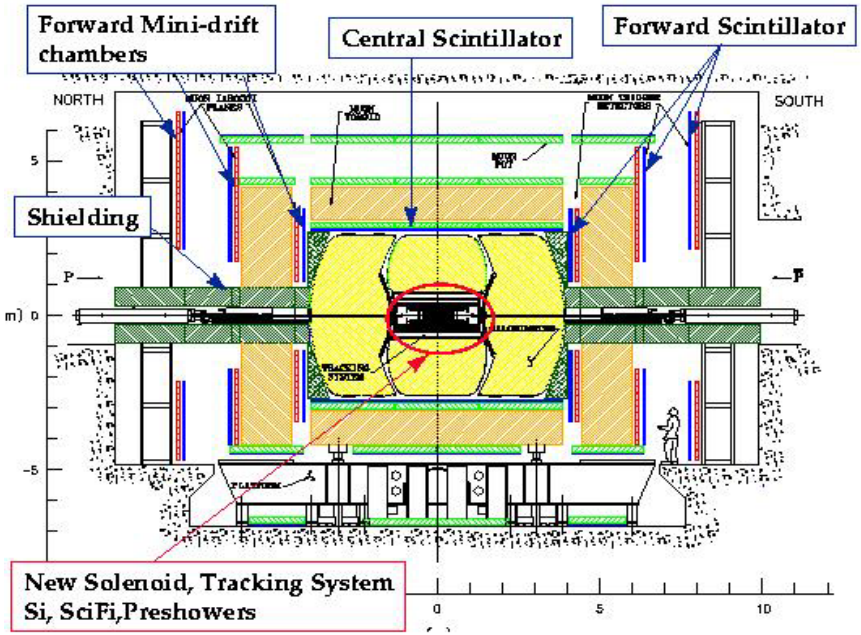


CDF

L1 Fast Track Trigger
L2 trigger on impact parameter
$\sigma(p_T)/p_T = 0.002p_T$
Particle ID (TOF and dE/dx)

DØ

Muon ID; $|\eta| < 2$
Tracking acceptance $|\eta| < 2\text{-}3$
L2 IP trigger being commissioned



Both detectors

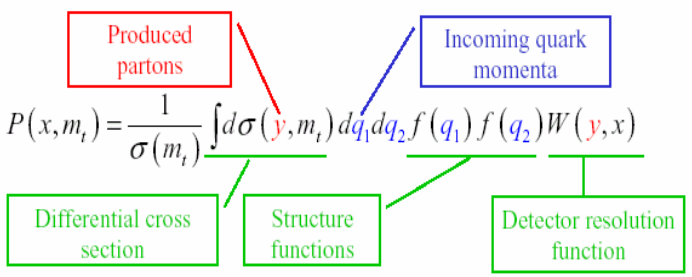
Silicon microvertex tracker
Axial solenoid
Central tracking
High rate trigger/DAQ
Calorimeters and muons

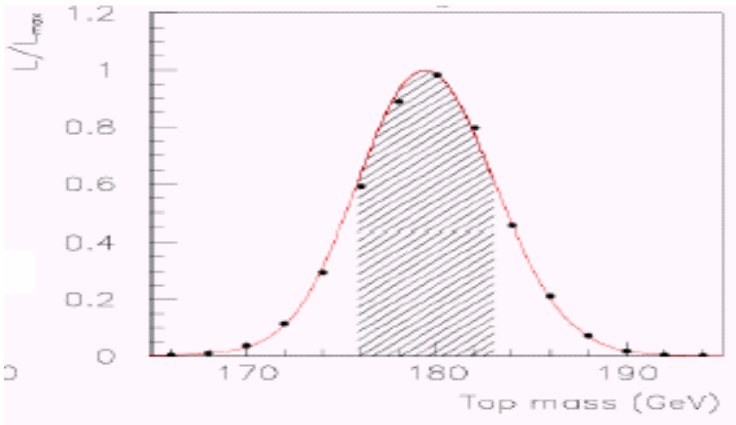
Top Quark Mass Measurements

D0: New analysis of Run I Data

Nature 429, 638 (2004)

- Rather than a kinematic fit, the probability for a top (or background) event to give rise to observed jets, leptons and MET is computed
- Also define background probability for each event
- M_t measured by maximizing Poisson likelihood for entire event sample
- Advantages
  - all jet permutations contribute
  - additional kinematic information used
  - event-by-event resolutions considered
  - non-Gaussian detector response accounted for
- Compromises
  - only leading-order tt cross section is used
    → only events with exactly four jets can be used
  - gluon fusion diagrams neglected
  - only background process computed is W + jets





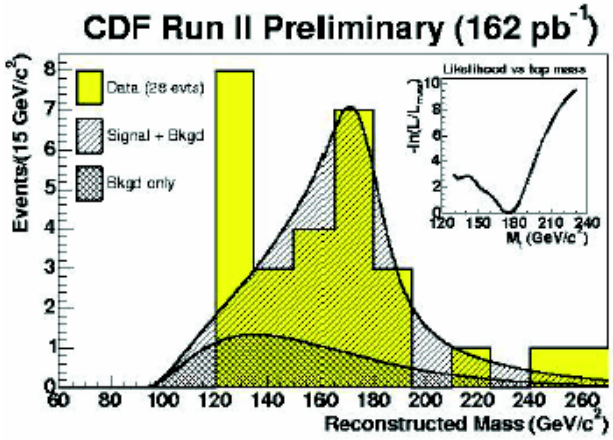
22 events including 10 background

M_t = 180.1 ± 3.6 (*stat*) ± 4.0 (*syst*) GeV

Top Quark Mass Measurements

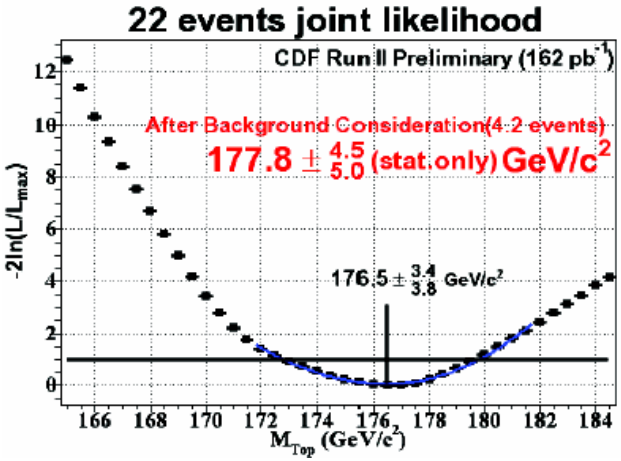
CDF: Analyses of Run II data

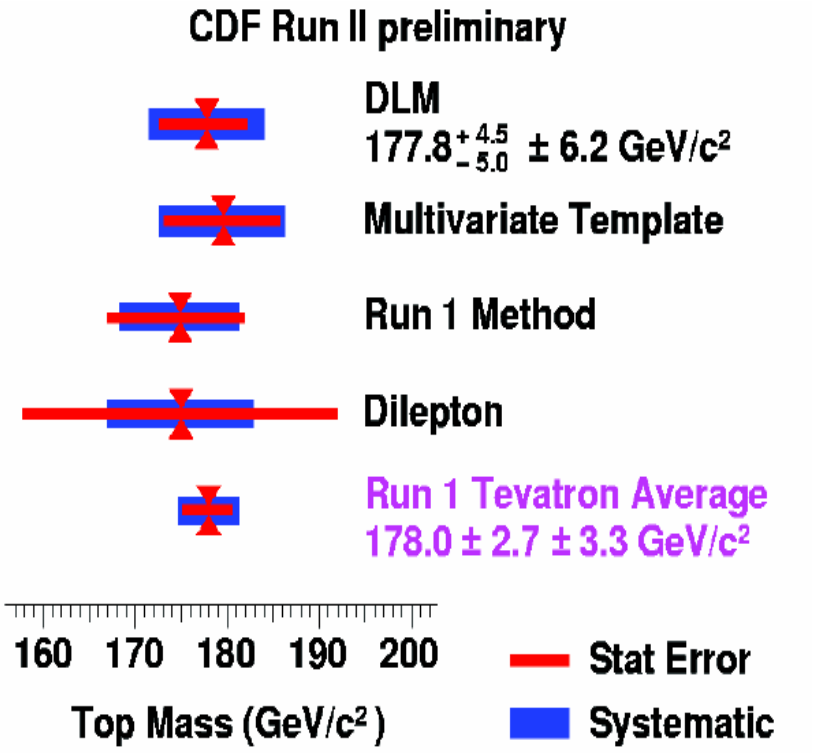
(1) Analysis a la Run I



(2) Dynamic Likelihood Method

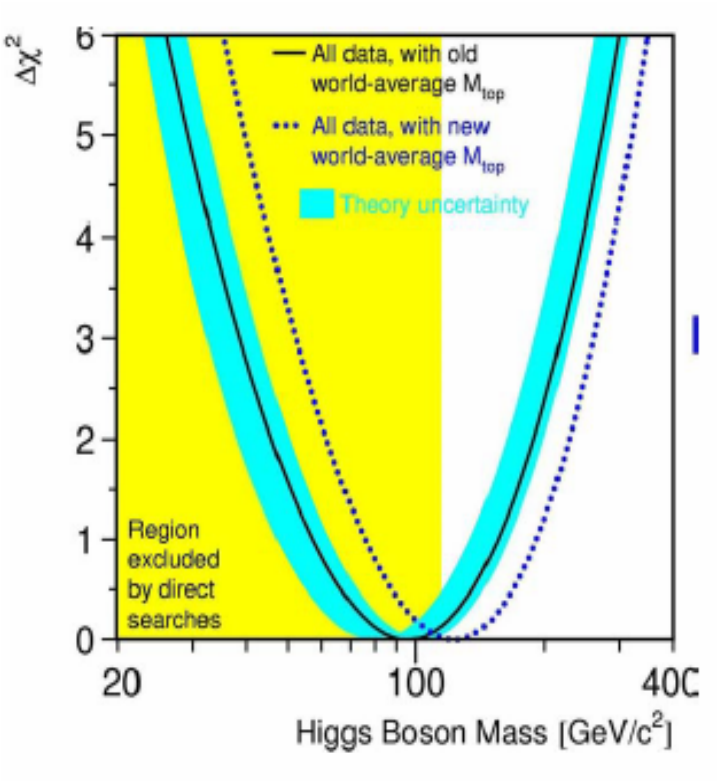
Similar to new D0 analysis





D0 Run II M_t results → soon

New M_t Implication for SM Higgs Mass



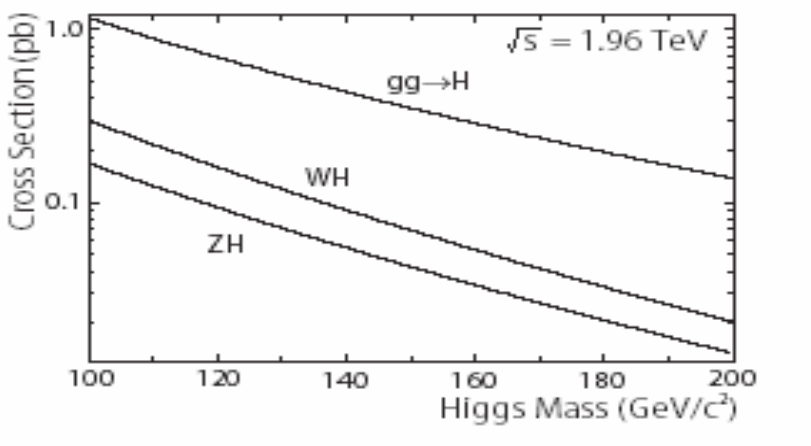
- **Old:**
  - $M_t = 174 \pm 5.1$ GeV
  - $M_H = 96^{+60}_{-38}$ GeV
  - $M_H < 219$ GeV (95% cl)
- **New:**
  - $M_t = 178 \pm 4.3$ GeV
  - $M_H = 117^{+67}_{-45}$ GeV
  - $M_H < 251$ GeV (95% cl)

Prospects with 2 fb^{-1} :

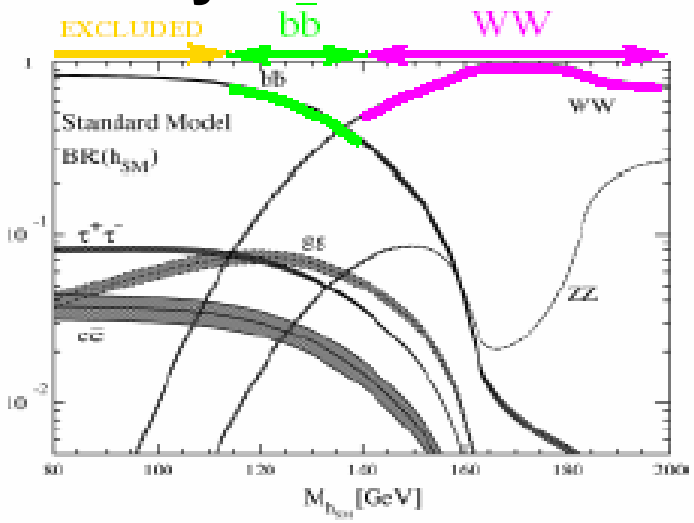
- $\delta M_W = 40$ MeV per channel & exper (current WA = 34 MeV)
- $\delta M_t = 2$ GeV (current WA = 4.3 GeV)
- $\delta M_H / M_H \approx 35$ %

SM Higgs Overview

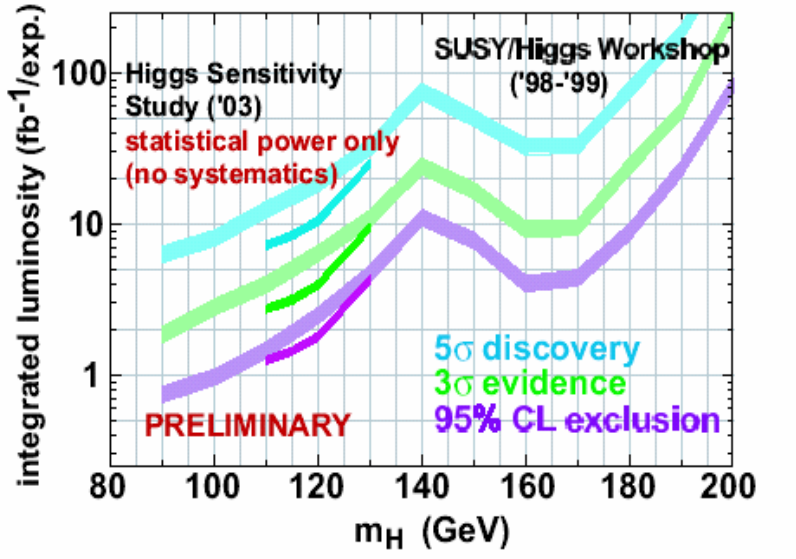
Production



Decay



Sensitivity

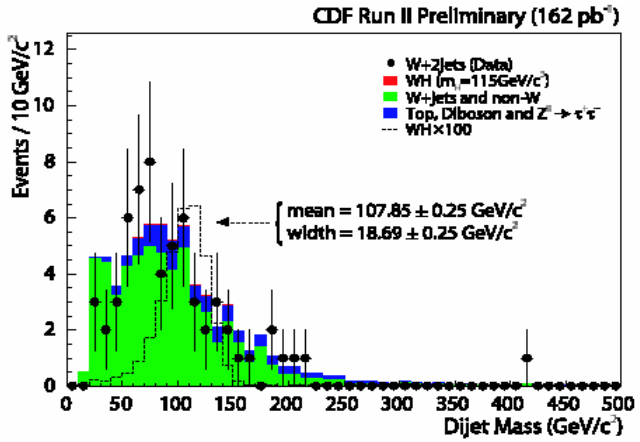


- for low mass Higgs use associated production
- for M_H > 140 GeV use WW*

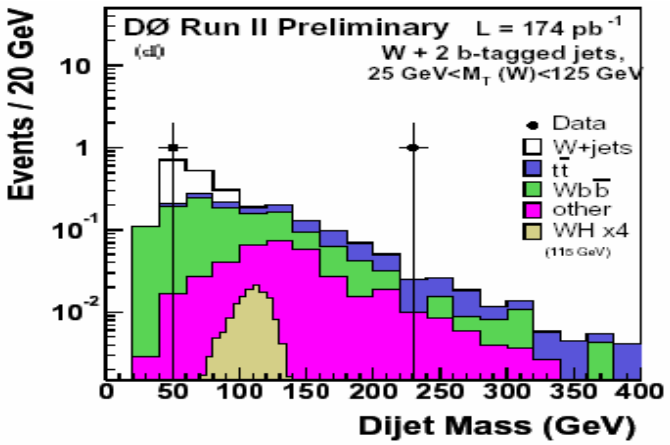
SM Higgs Searches

$H \rightarrow b\bar{b}$ data

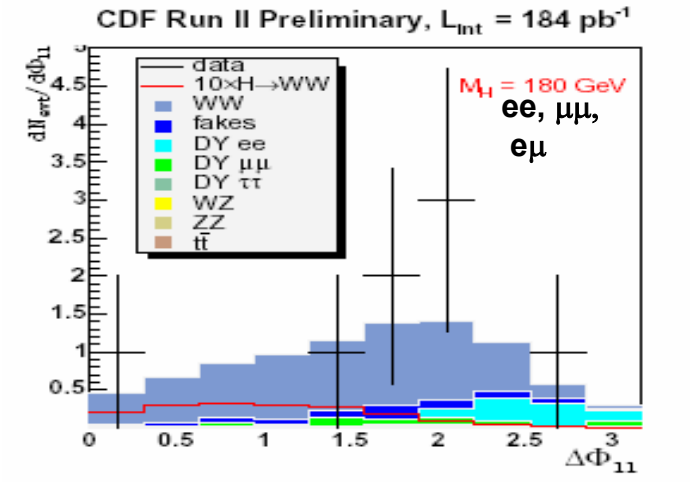
$W \rightarrow l\nu$ + ≥ 2j (≥ 1 b tag)

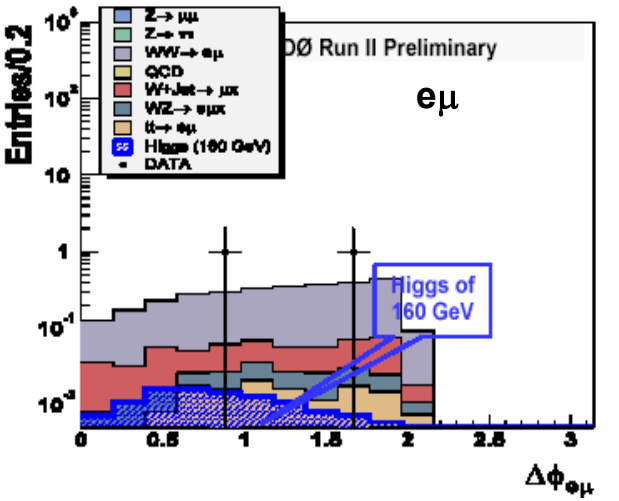


$W \rightarrow e\nu$ + 2j (2 b tag)

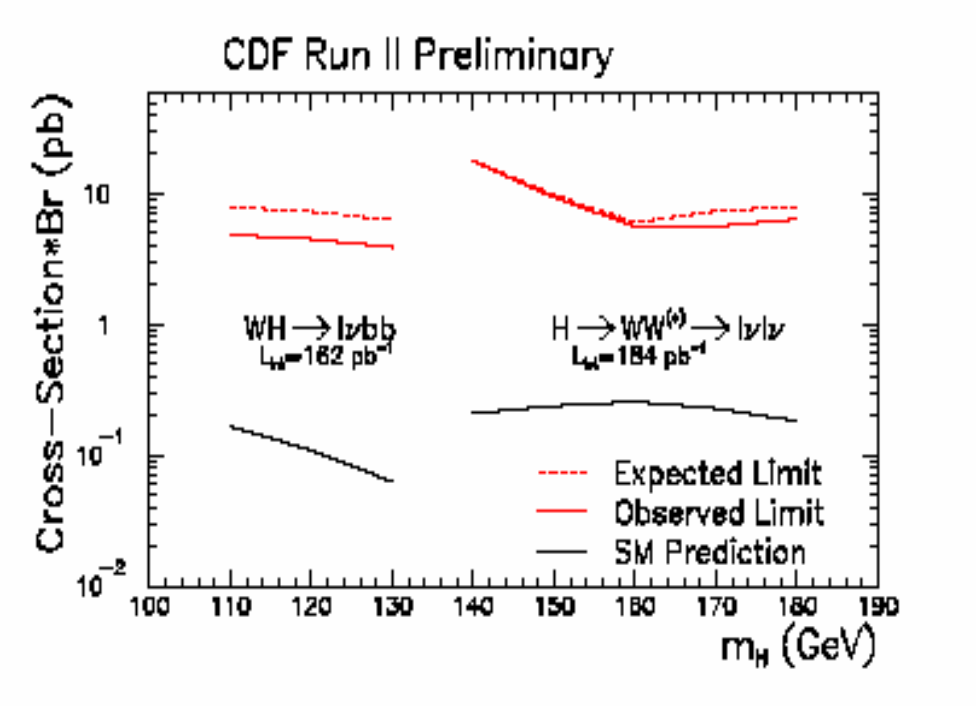


$H \rightarrow WW^{(*)} \rightarrow l^+l^- \nu\nu$



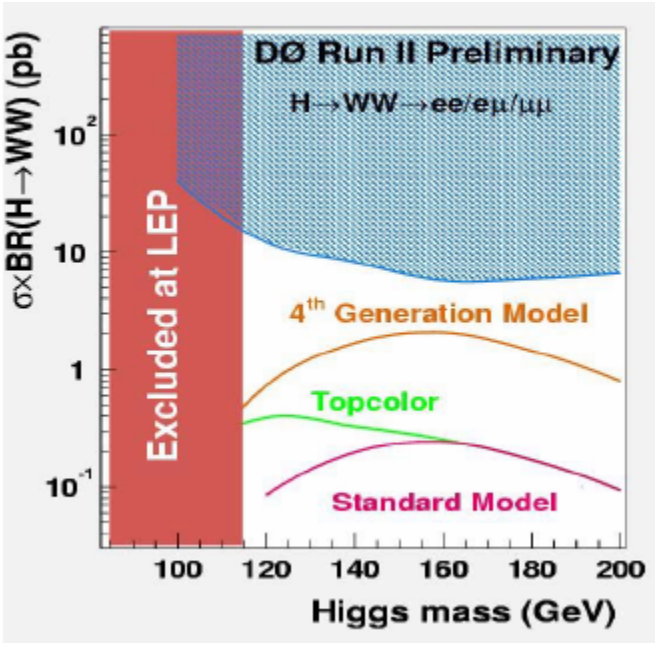


SM Higgs Search Results

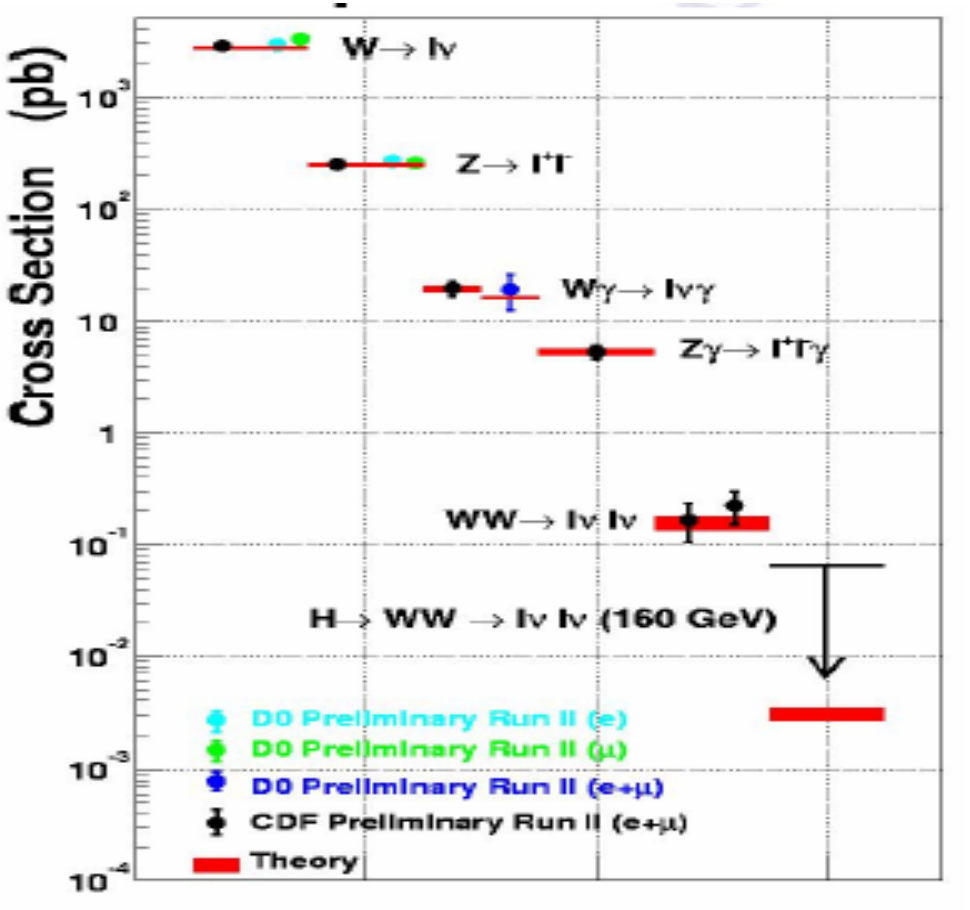


– $\sigma(p\bar{p} \rightarrow WH) \cdot BR(H \rightarrow b\bar{b})$
< 12.4 pb @ 95% C.L.
for M_H = 115 GeV

– $\sigma(p\bar{p} \rightarrow H) \cdot BR(H \rightarrow WW^*)$



Summary of cross section measurements

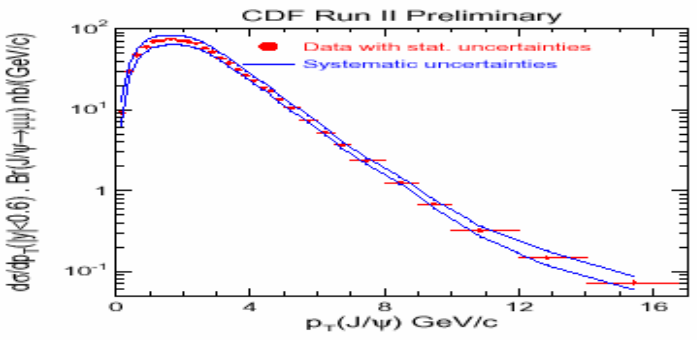


Inclusive J/ψ, H_b & top cross sections

J/ψ inclusive cross section:

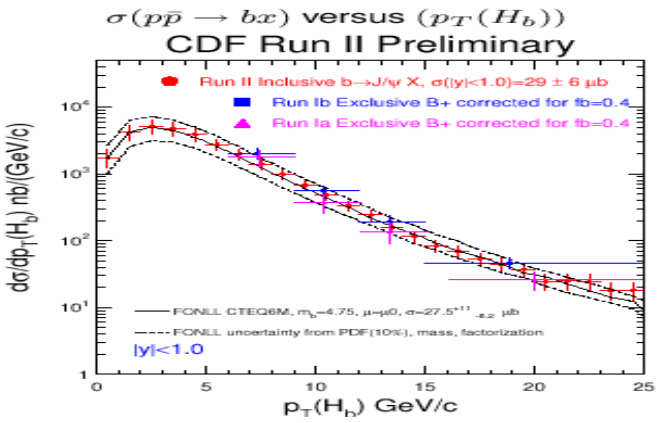
- J/ψ acceptance down to $p_T = 0$

σ (|y(J/ψ)|<0.6) = $4.08 \pm 0.02^{+0.60}_{-0.48}$ μb



b quark production cross-section:

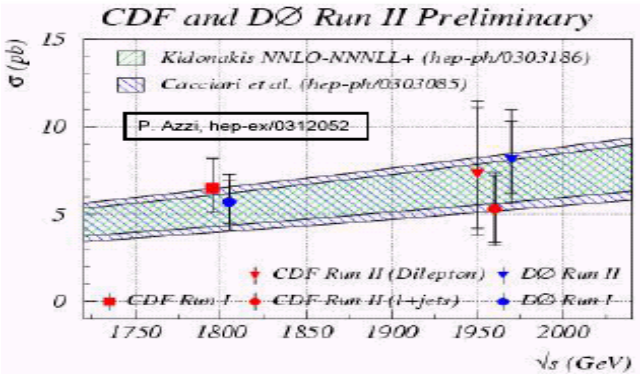
- **Run I cross-section:** ~3x old NLO QCD
- **Theoretical advances:**
  Next-to-Leading-log resummations, non perturbative fragmentation function from LEP, new parton distr. functions
- **Run II preliminary result →**



$$\sigma(p\bar{p} \to bX)|_{|y|<1.0} = (29.4 \pm 0.6(stat) \pm 6.2(sys))\ \mu b$$

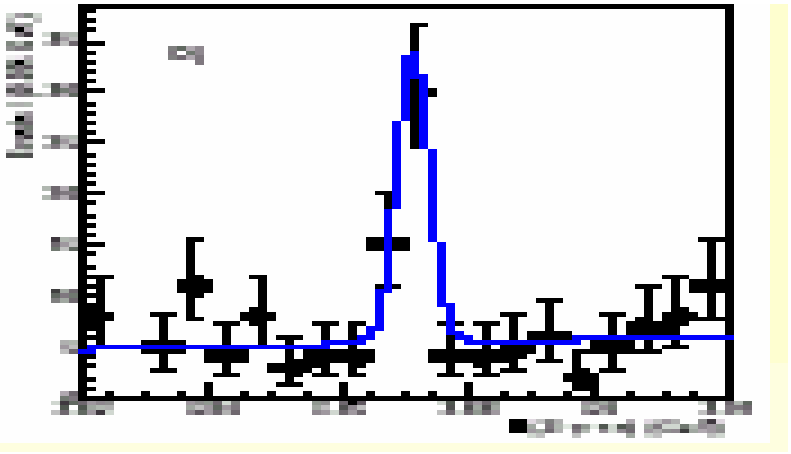
FONLL $\sigma(p\bar{p} \to bX)|_{|y|<1.0} = (27.5^{+11}_{-8.2})\ \mu b$

top pair production cross section:

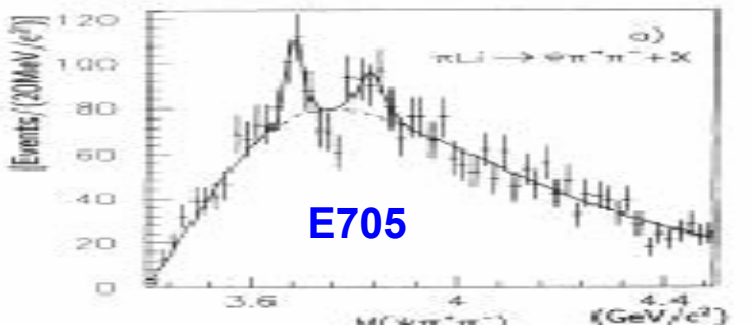


X(3872) → J/ψ $\pi^+\pi^-$

- **Announced by BELLE in 2003** →

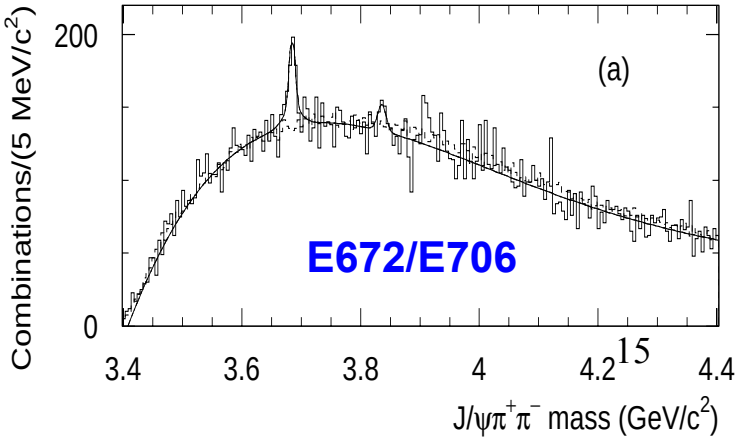


- **Local interest**
  - 1994: E705 (fixed target at FNAL) in π Li → J/ψ $\pi^+\pi^-$ + anything observed 58 ± 21 excess events at 3.838 ± 0.013 GeV

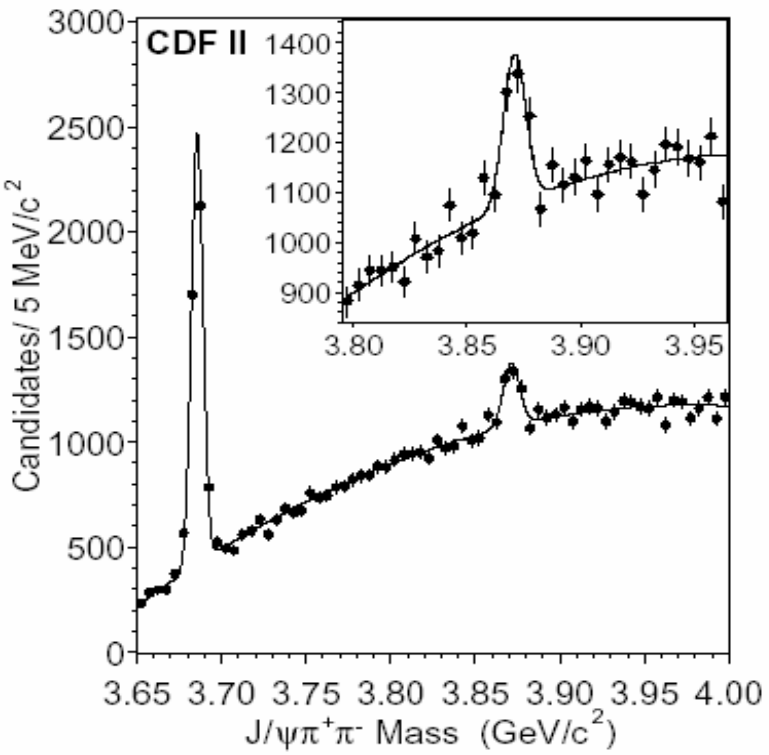


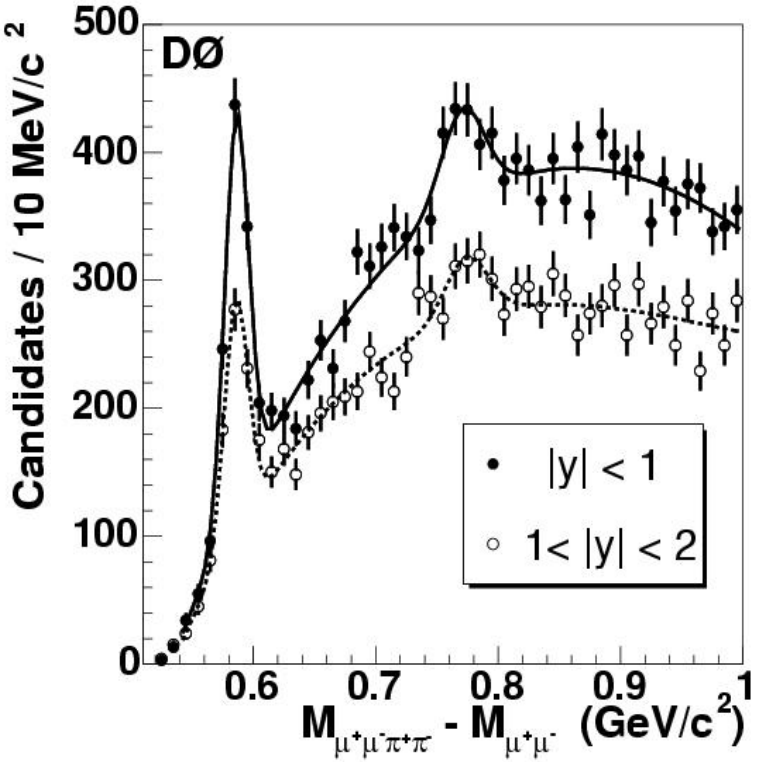
possible interpretations
$^1P_1(1^{+-})$, $^3D_2(2^{--})$, $^1F_3(3^{+-})$ $c\bar{c}$ or $c\bar{c}q\bar{q}$

- 1995: E672/E706 52 ± 30 events



X(3872) confirmed by CDF & D0



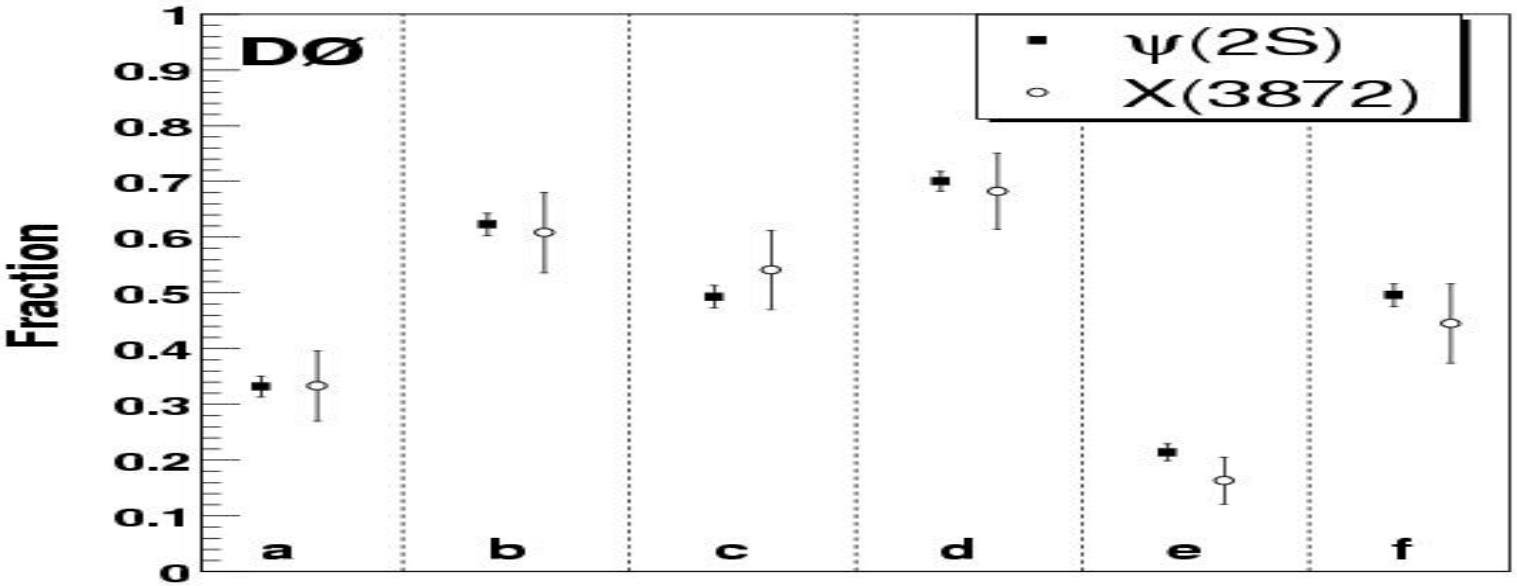


Exp	Lumi [pb^{-1}]	range	Mass [MeV]	M res	Signal	Signif
CDF	220	$\|y\| < 1$	$3871.3 \pm 0.7 \pm 0.3$	4.9	730 ± 90	$\approx 12\sigma$
DØ	230	$\|y\| < 2$	$3871.8 \pm 3.1 \pm 3.0$	17	522 ± 100	$\approx 5\sigma$

Belle: $M_X = 3872.0 \pm 0.6 \pm 0.5$ MeV

X(3872) – $\psi(2S)$ comparison

- Is the ***X*** charmonium, D – D* molecule, ccg hybrid, … ?
- No significant differences between $\psi(2S)$ and ***X*** have been observed yet
- From isolation and decay length comparisons, the production of **X** appears to have the same mixture of prompt and long-lived fractions as the $\psi(2S)$



a	b	c	d	e	f
p_T (J/ψππ) > 15 GeV	|y| <1	Cos(θ_π) < 0.4	Decay Length < 0.01cm	Isolation = 1	Cos(θ_μ) < 0.4

Pentaquarks at Tevatron ?

Five quark state: 4 quarks + 1 anti-quark

flavour (anti-quark) ≠ flavour(quarks)

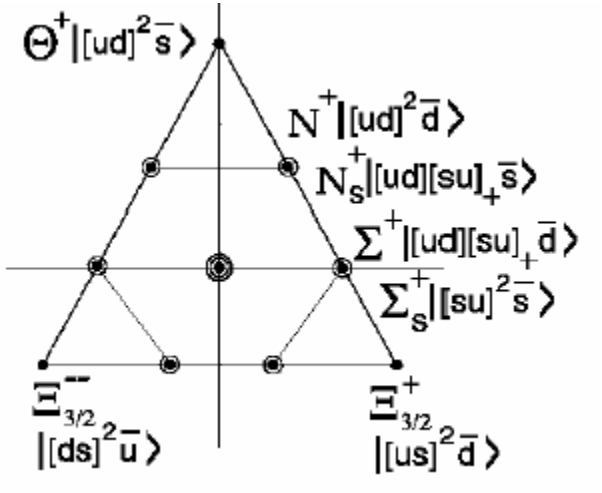
Predicted by Diakonov, Petrov, Polyakov (1997)

States observed so far:

$\Theta^+ : |u\,u\,d\,d\,\bar{s}\rangle$

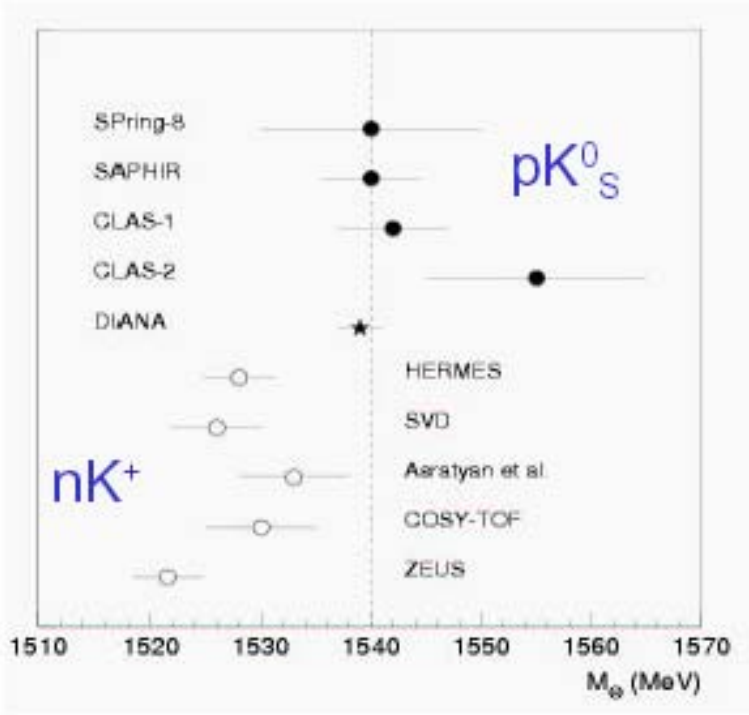
$\Xi^{--} : |s\,s\,d\,d\,\bar{u}\rangle \qquad \Xi^0 : |\bar{s}\,\bar{s}\,\bar{d}\,d\,\bar{u}\rangle$

$\Theta_c^0 : |u\,u\,d\,d\,\bar{c}\rangle$



Θ^+: Summary of evidence:

10 pos., several neg. reports, mass consitency?

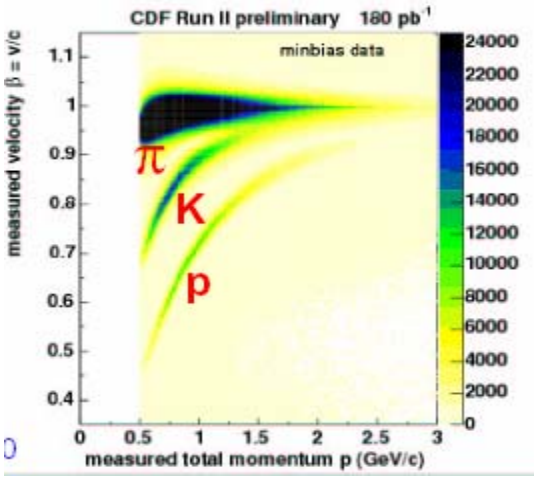


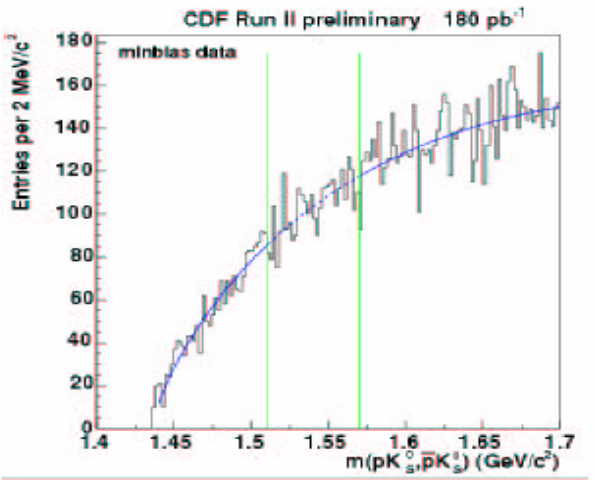
Search for $\Theta^+ \rightarrow pK^0_s \rightarrow p\,\pi^+\,\pi^-$

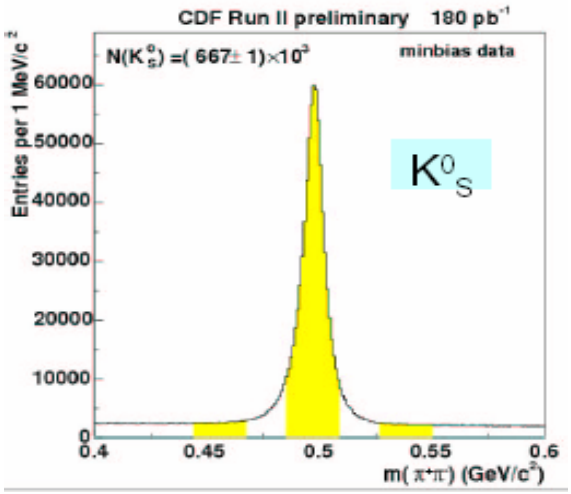
Two energy ranges:
- minbias, jet20

Protons identified with ToF

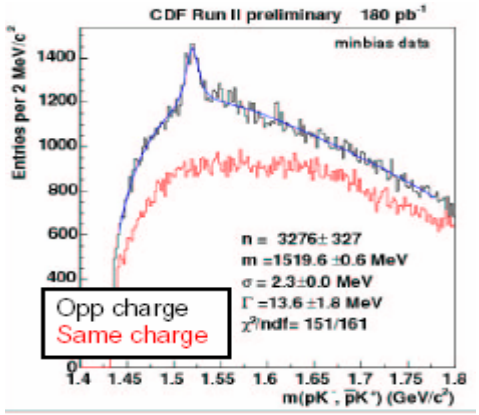
Reference states reconstructed

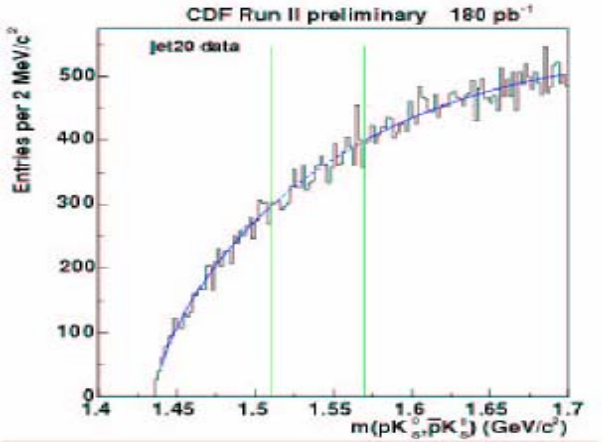






Λ (1520) $\rightarrow$ p K$^-$

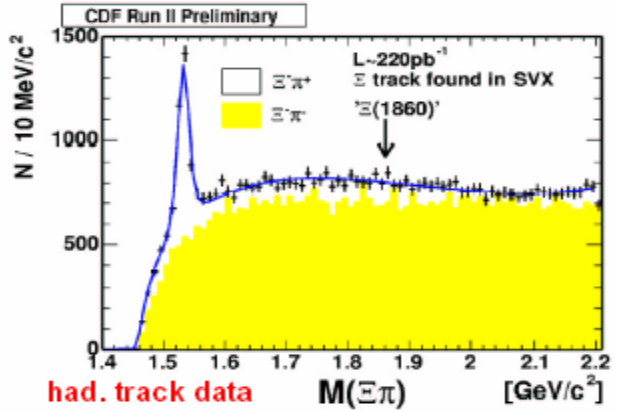


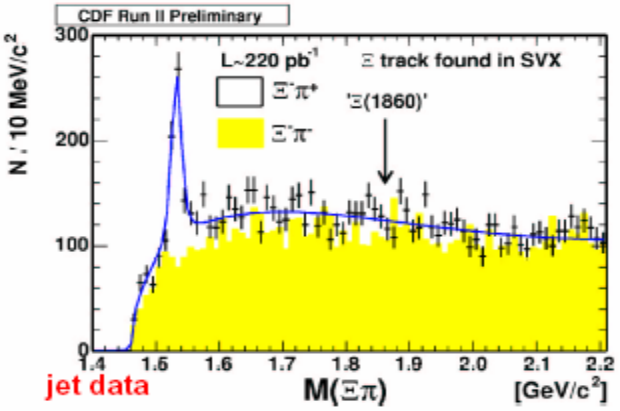


No evidence for narrow resonance

Search for Ξ(1860) & Charmed Pentaquarks

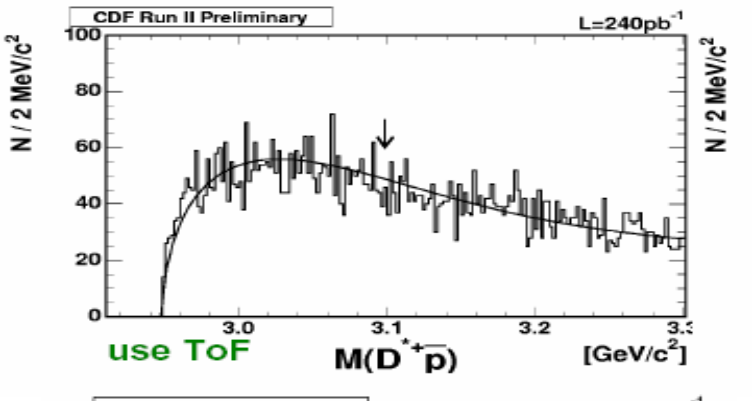
Special tracking for long lived Hyperons in the SVX detector

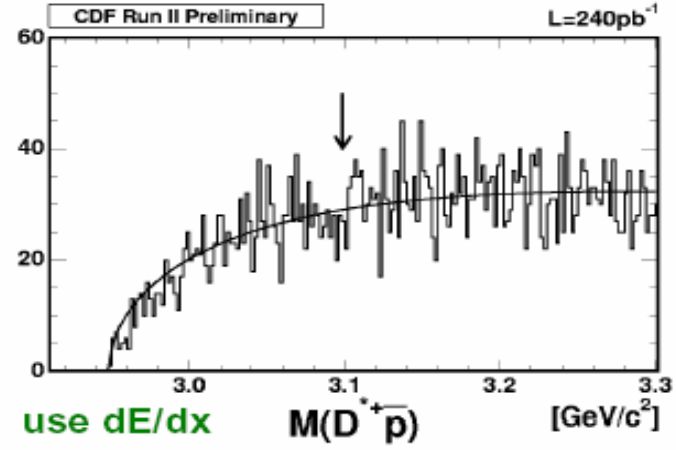




- No evidence for narrow signal found in 2 data samples (had. track & jets)

Protons identified with ToF (p<2.75 GeV) And dE/dx (p>2.75 GeV, ~2s separation





- No evidence of charmed pentaquark seen
- Combined upper limit: < 29 events (90% C.L.)

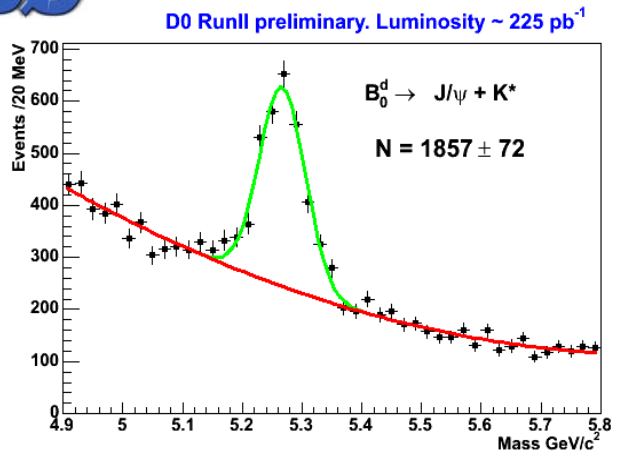
Pentaquarks at Tevatron - Summary

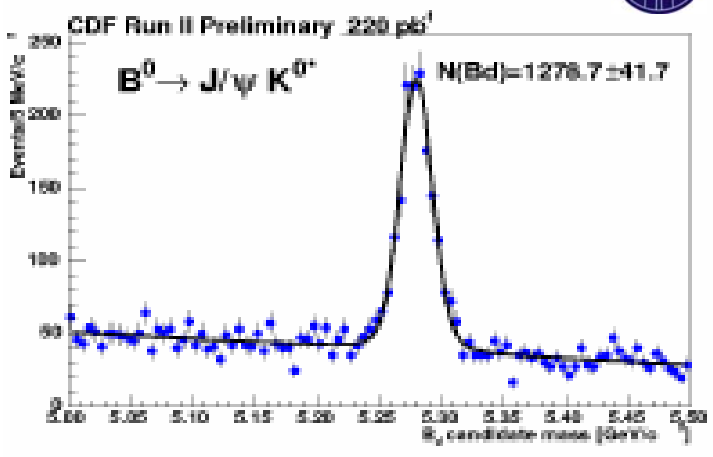
- With: high statistics
  excellent mass resolution
  good particle ID
  strong conventional signals

CDF finds **no pentaquark states with u, s, c antiquarks**

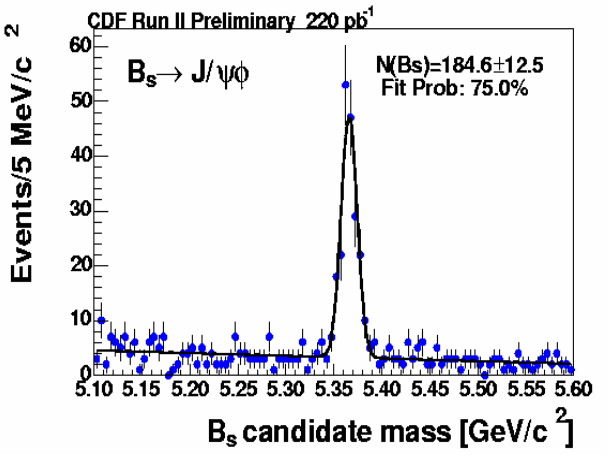
- Beauty pentaquark ? Θ^+_b analog of Θ^+_s ?
  $|uuddb\rangle$ $|uudds\rangle$?
  $\Theta^+_b \rightarrow pB^0$ $\Theta^+_s \rightarrow pK^0_s$?

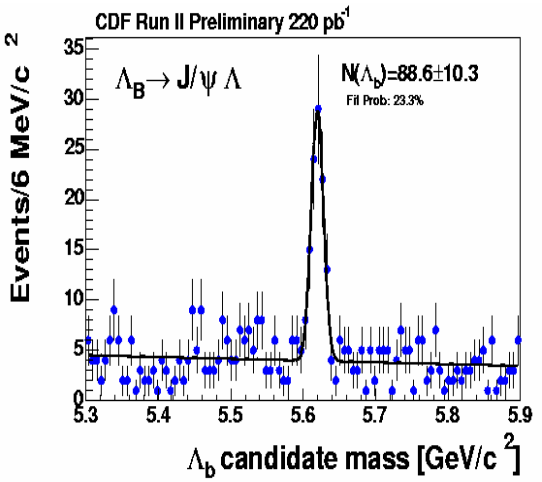
$B^0 \rightarrow J/\psi\, K^*$, $K^* \rightarrow K\pi$ signals :

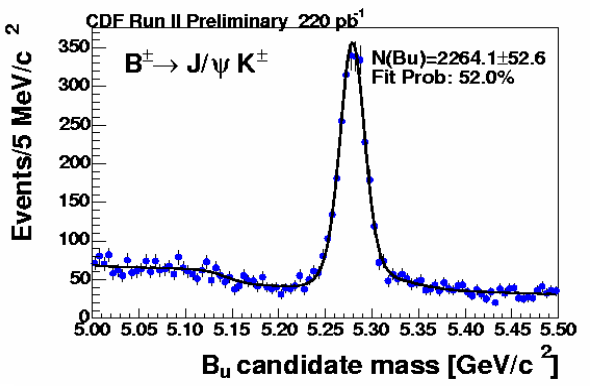


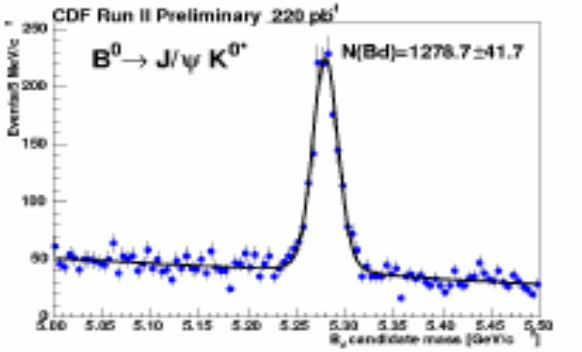


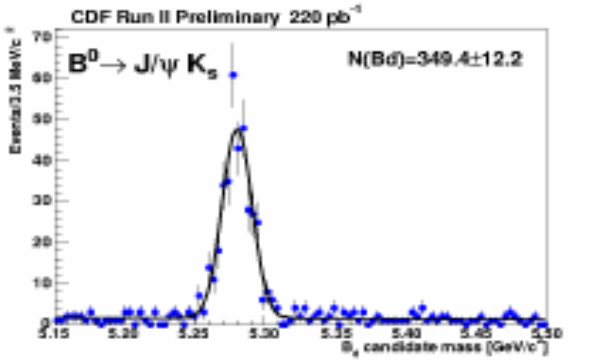
New B hadron mass measurements











Mass measurements from exclusive B→J/ψ X channels:

	mass, MeV/c² CDF -preliminary	mass, MeV/c² PDG
B^+	5279.10 ± 0.41 ± 0.34	5279.0 ± 0.5
B^0	5279.57 ± 0.53 ± 0.30	5279.4 ± 0.5
B_s	5366.01 ± 0.73 ± 0.30	5369.6 ± 2.4
Λ_b	5619.7 ± 1.2 ± 1.2	5624 ± 9

$m(B_s)$ & $m(\Lambda_b)$ – the world best measurement

Observation of B_d^{**}

- **bq Spectroscopy:** Lowest states:
  - **B ($J^P = 0^-$)** – stable particle;
  - **B^* ($J^P = 1^-$)** – decays to **$B\gamma$** (100%);
  - **2** narrow states **B_1^* (1^+)** & **B_2^* (2^+)** – decay through D-wave;
  - **2** wide states **B_0^{*w} (0^+)** & **B_1^{*w} (1^+)** – decay through S-wave too wide to be observed;
- **B** & **B^*** are well established;
- **B_1^*** & **B_2^*** (also called **B^{**}**) are not known

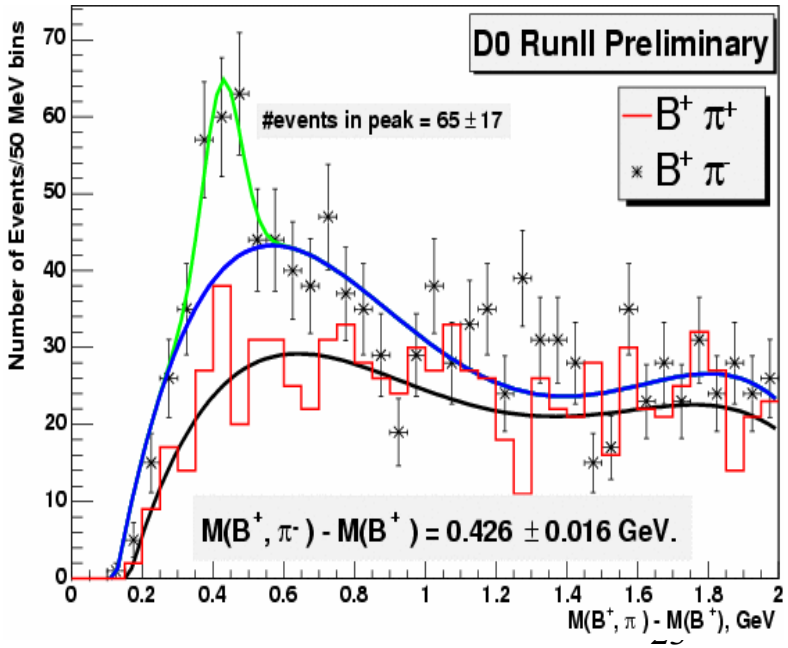
B_d^{**} is seen (with ~115 pb^{-1})

→ **ICHEP 04**

B_1 & B_2 separated

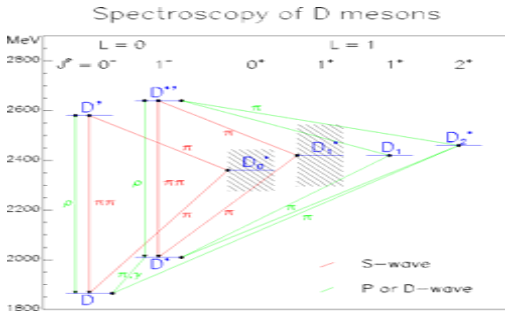
> 600 events

mass measurement

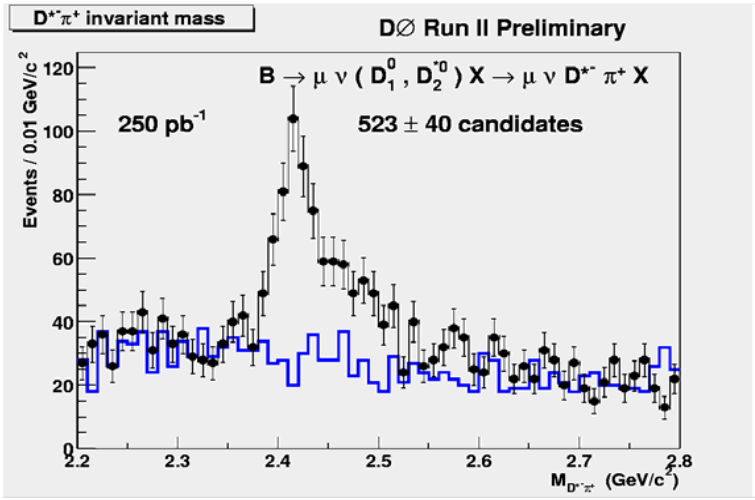


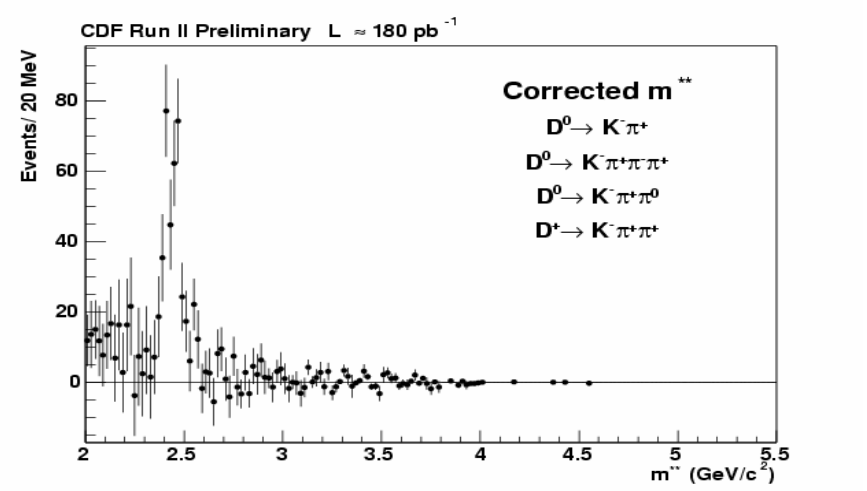
$B \rightarrow X_c \mu \nu$; $X_c = D^+/D^0/D^*/D^{**}$

- **Observed excess of events in right-sign combinations $D^*\pi$ interpreted as a merged $D_1^0(2420)$ & $D_2^0(2460)$ signal**
- **Work in progress:** extract separate **amplitudes**, & **relative phase**



Measurement of **mass moments** provides constraints on the OPE parameters and improves determination of V_{cb}





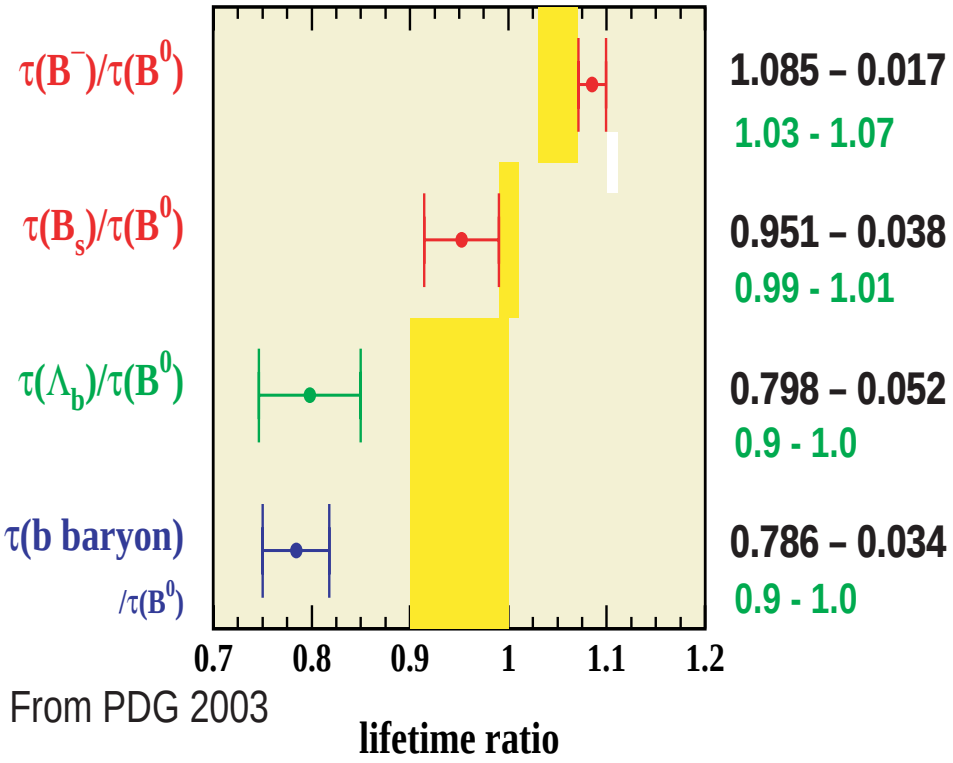
$Br(B \rightarrow \{D_1^0, D_2^{*0}\} \mu \nu X) \times Br(\{D_1^0, D_2^{*0}\} \rightarrow D^{*+} \pi^-) =$

$(0.280 \pm 0.021 \pm 0.088)\ \%$

Hadronic mass moments measured and OPE parameters extracted

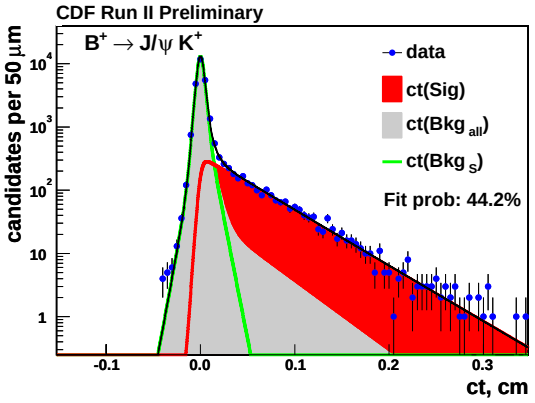
B Hadron Lifetimes:
Expectations and Existing Data

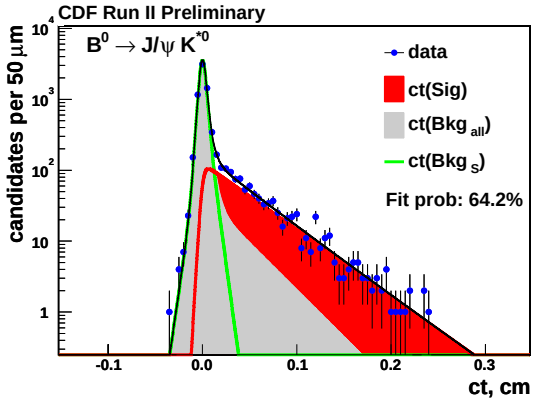
- **Heavy Quark Expansion Theory** predicts lifetime ratios in **rough** agreement with data
- Experimental and theoretical uncertainties are comparable
- Tevatron the best source of B_s and Λ_b
- **Goal → measure the ratios accurately**

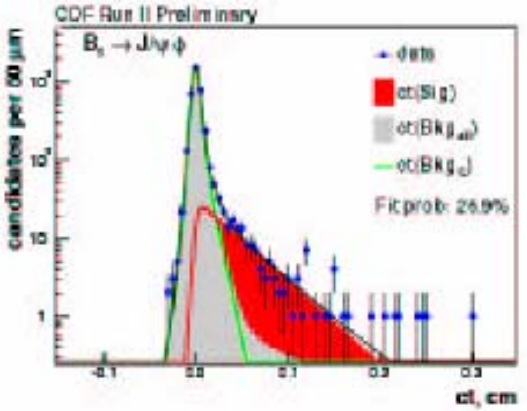


From PDG 2003

Exclusive B Lifetimes; CDF results







B meson	N(B)	τ (B), ps	PDG'03, ps	Single best measur., ps
B^+	~3390	**$1.662 \pm 0.033 \pm 0.008$**	**1.671 ± 0.018**	$1.695 \pm 0.026 \pm 0.015$
B^0	~1160	**$1.539 \pm 0.051 \pm 0.008$**	**1.537 ± 0.015**	$1.529 \pm 0.012 \pm 0.029$
B_s	~260	**$1.369 \pm 0.100\ ^{+0.008}_{-0.010}$**	**1.461 ± 0.057**	$1.36 \pm 0.09\ ^{+0.06}_{-0.05}$

Lifetime Ratios (most systematic uncertainties 100 % correlated)

$\tau(B^+) / \tau(B^0) = 1.080 \pm 0.042$ (*tot.*)

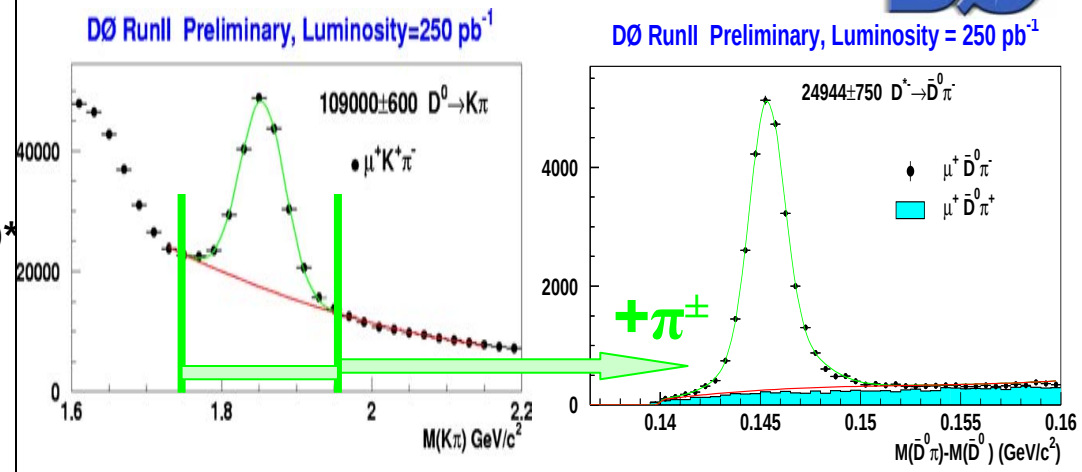
$\tau(B_s) / \tau(B^0) = 0.890 \pm 0.072$ (*tot.*)

D0 Results with comparable accuracy are expected for ICHEP 04

$\tau(B^+)/\tau(B^0_d)$ from Semileptonic Decays

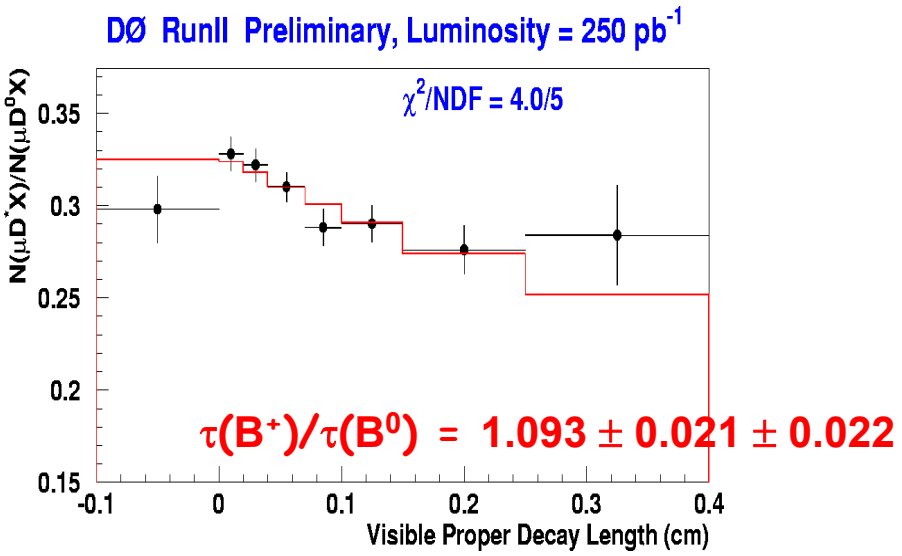
Novel experimental method

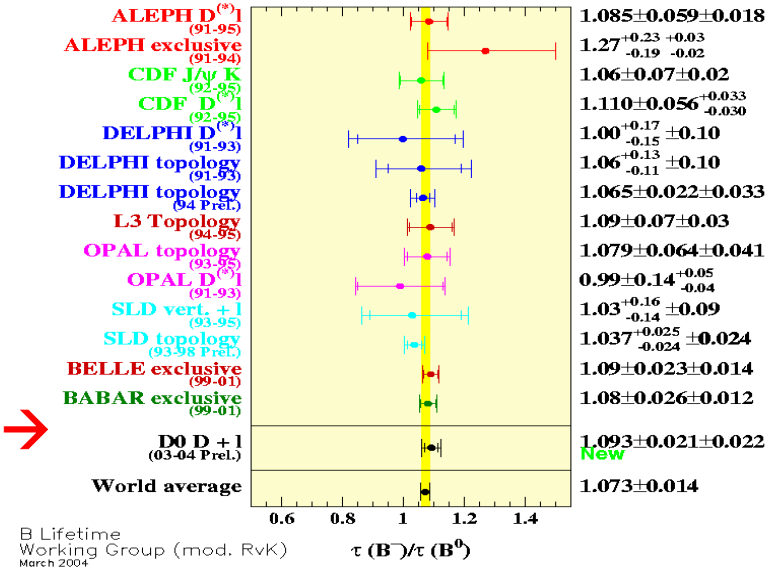
- Measure ratios directly
- Data sample $B \rightarrow \mu\nu D^0 X$
- Use slow π□s to check if D^0 from D^*
- Calculate ratios of $N(\mu D^*) / N(\mu D^0)$ in several bins of **Visible Proper Decay Length =** $= L_T \cdot M_B / P_T(\mu D^0)$
- account for **D** feeddown** using **PDG BRs** and **MC**



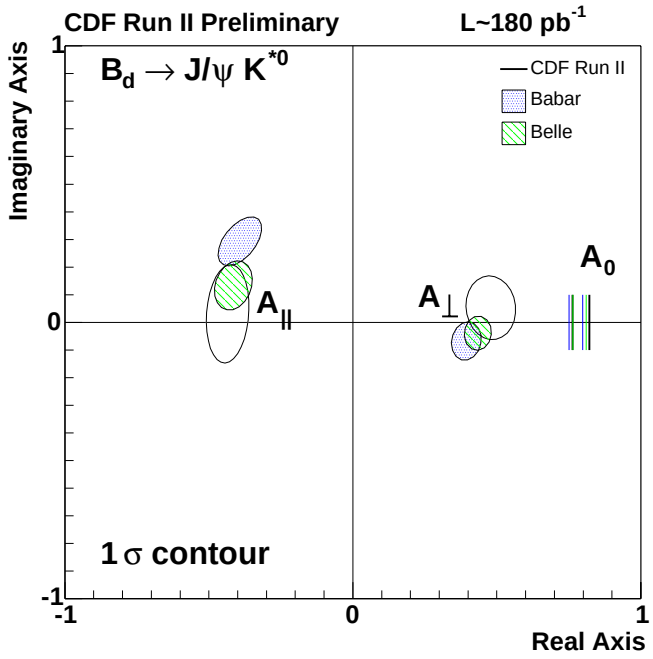
Dominated (82%) by B^+ decays If no slow π to form D*

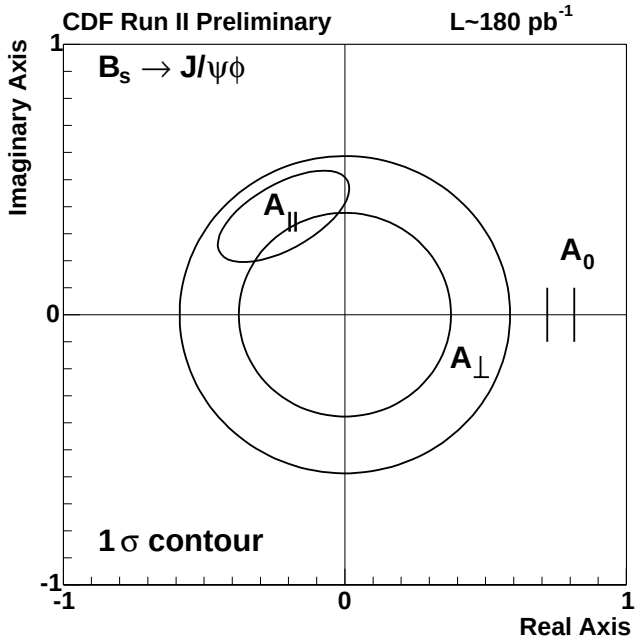
Dominated (86%) by B^0 decays





B → J/ψV Amplitudes





- dominant longitudinal polarization $\Gamma_L/\Gamma = |A_0|^2$
- non-zero parity-odd fraction $\Gamma_\perp/\Gamma = |A_\perp|^2$, (P-wave, CP= -1 for B_s)

- $\Delta\Gamma_s/\Gamma_s$ from $B_s \rightarrow J/\psi\phi$ via **3-D** fits (mass, ct, transversity Θ_T) from **both** experiments expected soon --anticipated precision of $\delta\Delta\Gamma_s/\Gamma_s \approx$ **5% at 2 fb^{-1}**

Summary - lifetimes

- **Current Status:**

	CDF	D0	World average
B^+	1.662 ± 0.033 ± 0.008 ps	1.65 ± 0.08 ± 0.12 ps (2003)	1.671 ± 0.018 ps
B^0_d	1.539 ± 0.051 ± 0.008 ps	1.51 ± 0.18 ± 0.20 ps (2003) → ICHEP	1.537 ± 0.015 ps
B^0_s	1.369 ± 0.100±0.008- 0.01 ps	1.19 ± 0.18 ± 0.14 ps (2003) → ICHEP	1.461 ± 0.057 ps
Λ_b	1.25 ± 0.26 ± 0.10 ps (2003)	→ ICHEP 04	1.233 ± 0.077 ps
$\tau(B_\Lambda)/\tau(B^0)$	0.91 ± 0.20 (tot) (2003)	→ ICHEP 04	0.798 ± 0.052
$\tau(B^+)/\tau(B^0)$	1.08 ± 0.042 (tot.)	1.093 ± 0.021 ± 0.022	1.085 ± 0.017
$\tau(B_s)/\tau(B^0)$	0.890 ± 0.072 (tot.)	→ ICHEP 04	0.951 ± 0.038

- **Results competitive with B-factories, expect 1% ratio precision (2 fb^{-1})**
- **Measurement of polarization amplitudes of $B_d \rightarrow J/\psi K^*$ & $B^0_s \rightarrow J/\psi\phi$**
- **Measurement of $\Delta\Gamma_s/\Gamma_s$ → in progress , expect 5% precision (2 fb^{-1})**

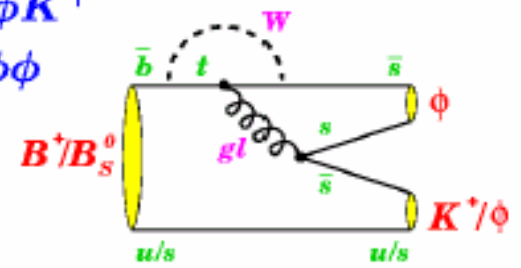
Charmless B Decays

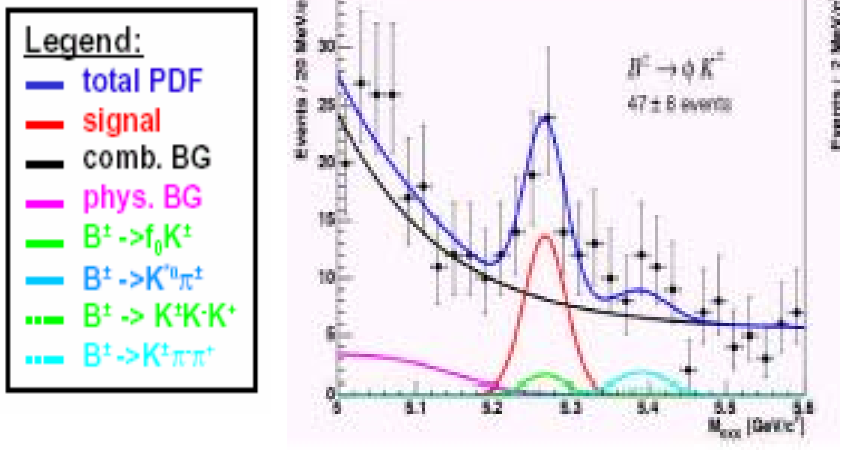
Search for charmless B decays from gluonic penguin decays

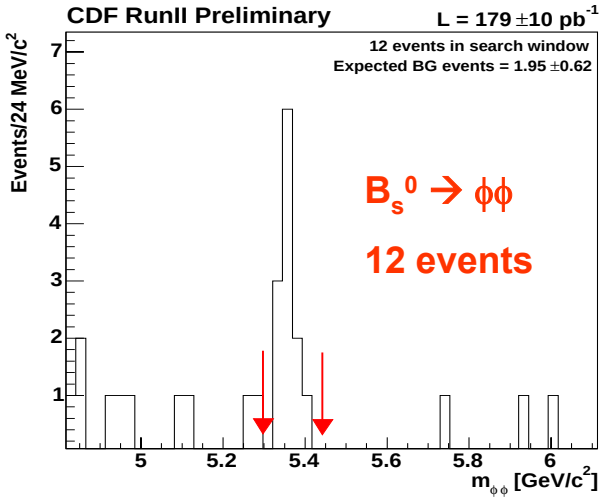
using displaced track trigger (~ 180 pb^{-1})

$B^+ \to \phi K^+$

$B_s^0 \to \phi\phi$







BR = (7.2± 1.3 ± 0.7) ·10^{-6}

HFAG average = (9.0 ± 0.6) · 10^{-6}

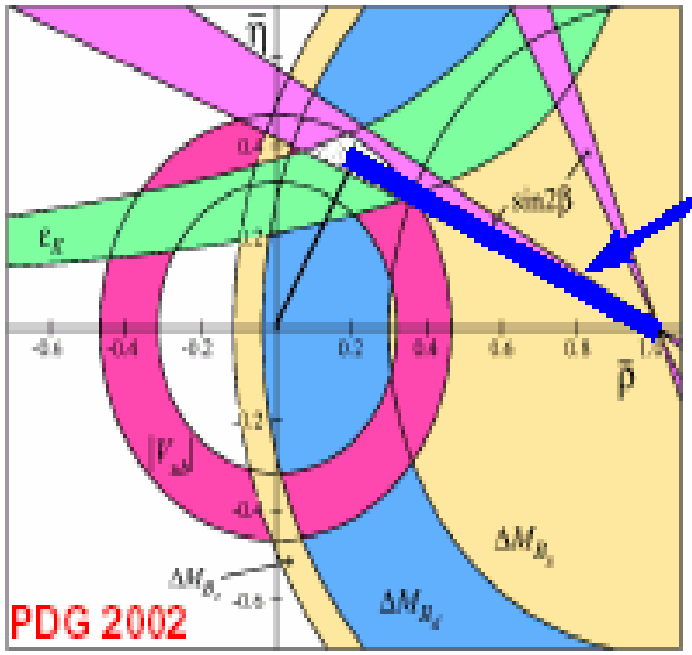
A_{CP} = 0.07 ± 0.17 ± 0.06

4.8 σ, first evidence for $B_s^0 \to \phi\phi$

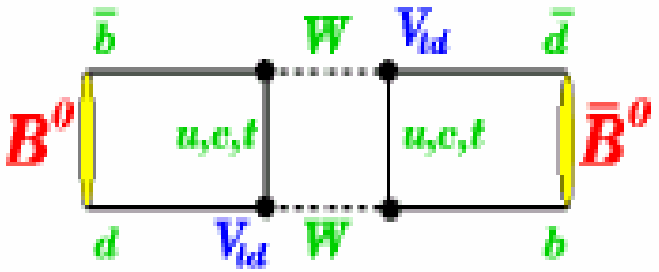
BR = (1.4 ± 0.6 ± 0.2± 0.5) · 10^{-5}

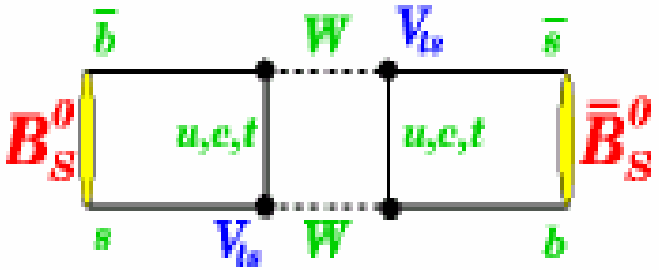
SM→ 3.7 10^{-5}

$B_{d,s}$ oscillations



$$\frac{|V_{td}|}{|V_{ts}|}$$



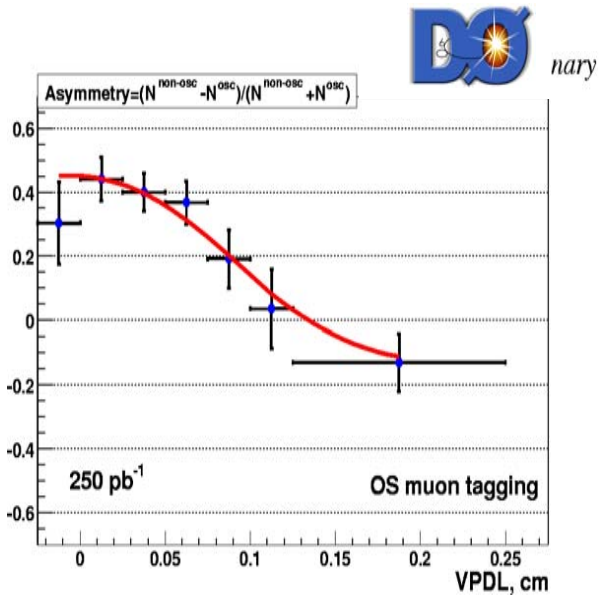


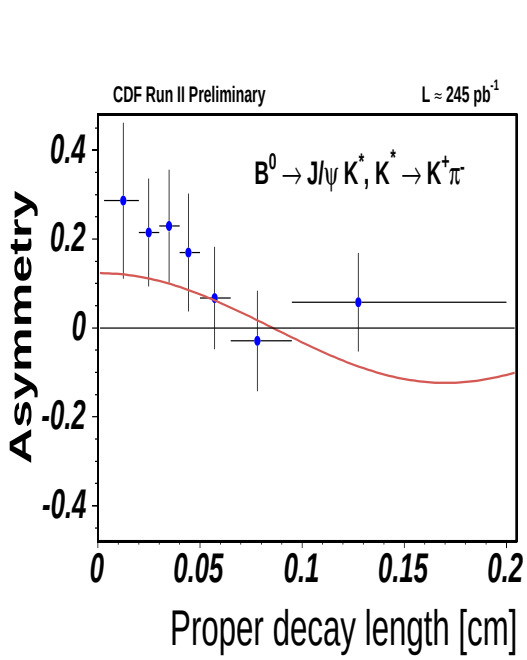
The aim is to measure:

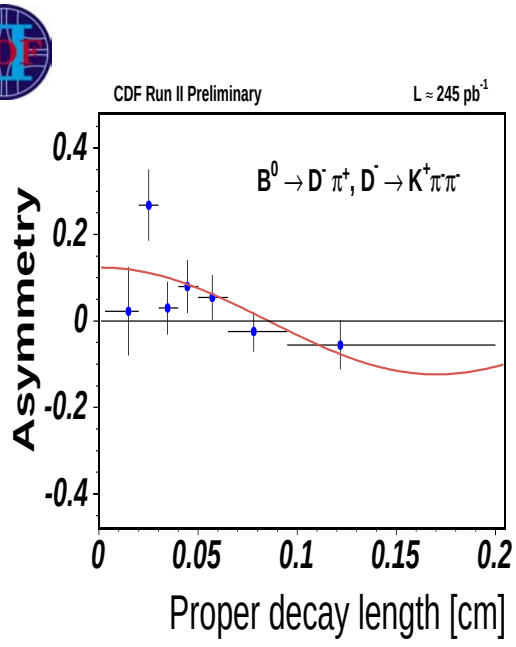
$$\frac{\Delta m_S}{\Delta m_d} = \frac{m_{B_S^0}}{m_{B^0}} \frac{f_{B_S^0}^2 B_{B_S^0}}{f_{B^0}^2 B_{B^0}} \frac{|V_{ts}|^2}{|V_{td}|^2}$$

ξ^2 from Lattice

Run II B^0_d / $\overline{B}^0_d$ Mixing Results:







Δm_d = **0.506 ± 0.055 ± 0.049 ps^{-1}** ← μ ν D* X ; Opposite Side μ (D0)

Δm_d = **0.55 ± 0.10 ± 0.01 ps^{-1}** ← J/ψ K*^{0} & D$^-\pi^+$; Same Side π (CDF)

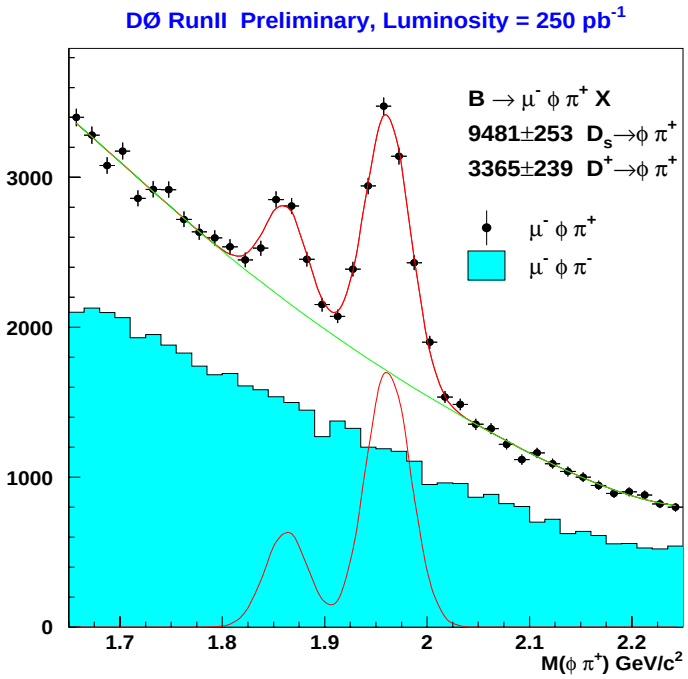
Δm_d = **0.495 ± 0.026 ± 0.025 ps^{-1}** ← all methods CDF Run I

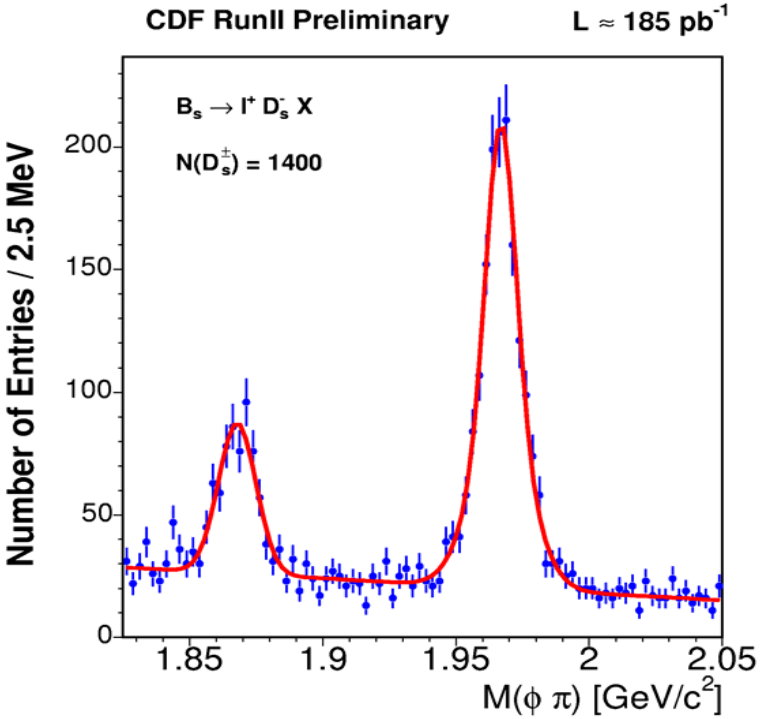
Δm_d = **0.502 ± 0.007** ← world average

Many improvements to the Run II results underway: all tagging methods, channels, reduced systematics etc

Semileptonic $B_s \rightarrow \mu \nu D_s X$ samples

$D_s \rightarrow \phi\pi$; $\phi \rightarrow K^+K^-$; μ`s charge opposite to D_s





Work in progress on: B_s/B_d lifetime ratio; B_s mixing , using also $D_s \rightarrow K^*K$

D0 perspective: if $\Delta m_s = 15$ ps $^{-1}$ measurement may be possible with **0.5 fb^{-1}**

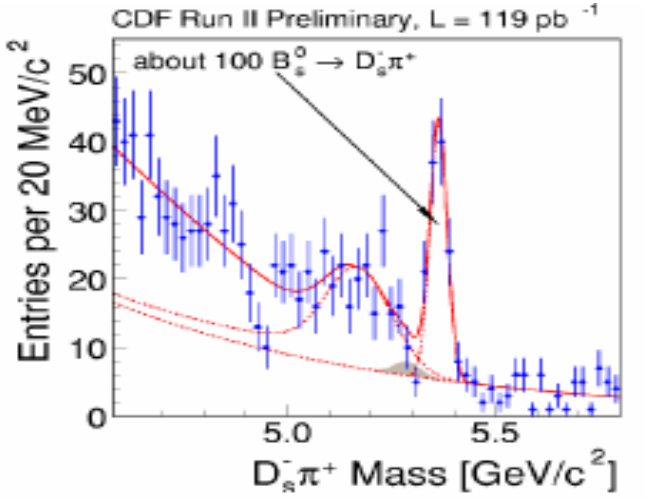
Semileptonic $c\tau$ measurement will improve constraint on $\Delta\Gamma_s$

B_s Oscillations – prospects

CDF perspective ← from M. Paulini

Current status: fully rec. $B_s \rightarrow D_s \pi$

Signal = 1600 events / fb^{-1}
S/B = 2/1
εD^2 = 4% (SLT+SST+JQT)
σ_t = 67 fs

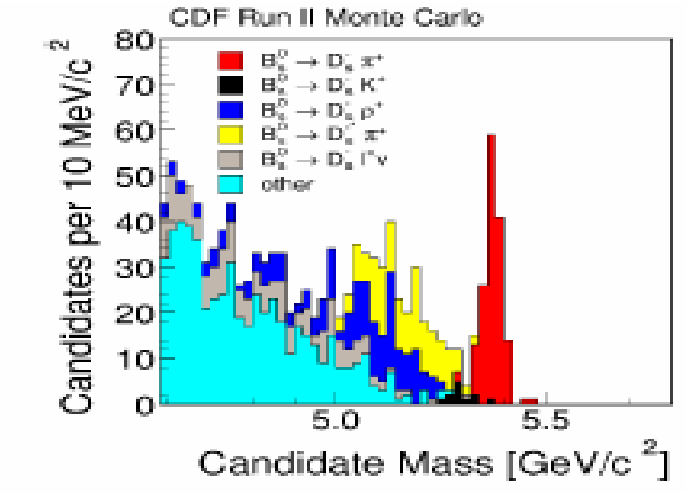


Prospects (near term):

2σ if **Δm_s = 15 ps $^{-1}$** with **0.5 fb^{-1}**

(assuming no improvements)

CDF will reach the current indirect limit & cover the **SM** favored range



Prospects (long term):

(assuming conservative improvements)

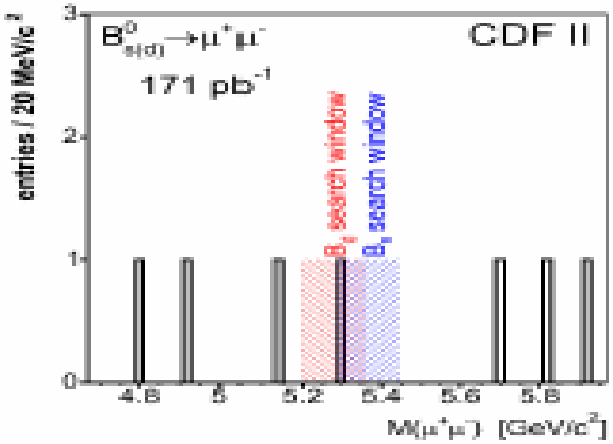
5σ if **Δm_s = 18 ps $^{-1}$** with **1.8 fb^{-1}**

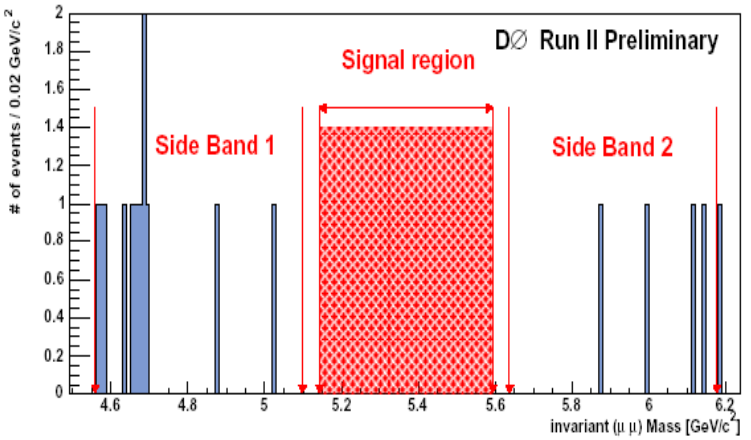
5σ if **Δm_s = 24 ps $^{-1}$** with **3.2 fb^{-1}**

Rare decays – $B_{d,s} \to \mu^+\mu^-$

BR($B_s \to \mu+\mu-$) ~ 10^{-9} suppressed in SM

SUSY up to two orders of magnitude enhancement





Limits at 90% C.L.

BR($B_s \to \mu^+ \mu^-$) < 5.8•10^{-7}

BR($B_d \to \mu^+ \mu^-$) < 1.5•10^{-7}

Expected improvements:

↑ Acceptance & ↓ bkgs

Blind analysis, expected limits at 95% C.L.

BR($B_s \to \mu^+ \mu^-$) <1.0 •10^{-6} (Moriond 04)

Improved for ICHEP 04, box to be opened at 400 pb^{-1}

BR($B_d \to \mu^+ \mu^-$) < 1.6 (2.0) •10^{-7} ← Belle (BaBar) at LP03

Work in progress on $B^0_d \to \mu\mu K^{(*)}$

Summary

- New **top quark mass**, updated predictions for **SM** M_H
- First Tevatron direct **SM Higgs** production limits ~ x 25 above **SM** prediction
- **X(3872)** confirmed by CDF & D0
- **Pentaquarks** not seen by CDF
- **B physics program** competitive and complementary to B factories
  - best B_s, Λ_b mass measurements
  - observation of: B**, narrow D** states in semileptonic B decays, $B_s \rightarrow \phi\phi$, best limits on $B_{d,s} \rightarrow \mu^+\mu^-$
  - work towards B_s oscillations
- very rich program in EW, QCD, charm, new phenomena etc , not covered in this talk