b(c) physics at the Tevatron collider

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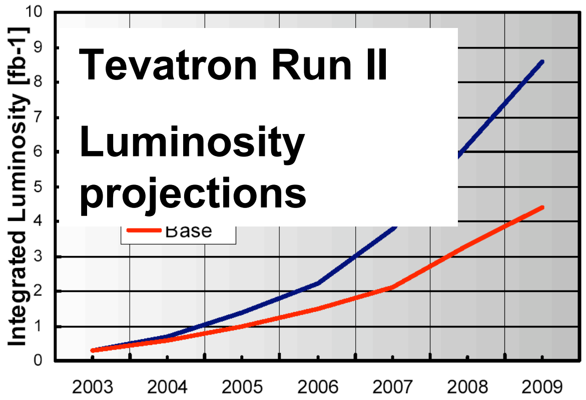
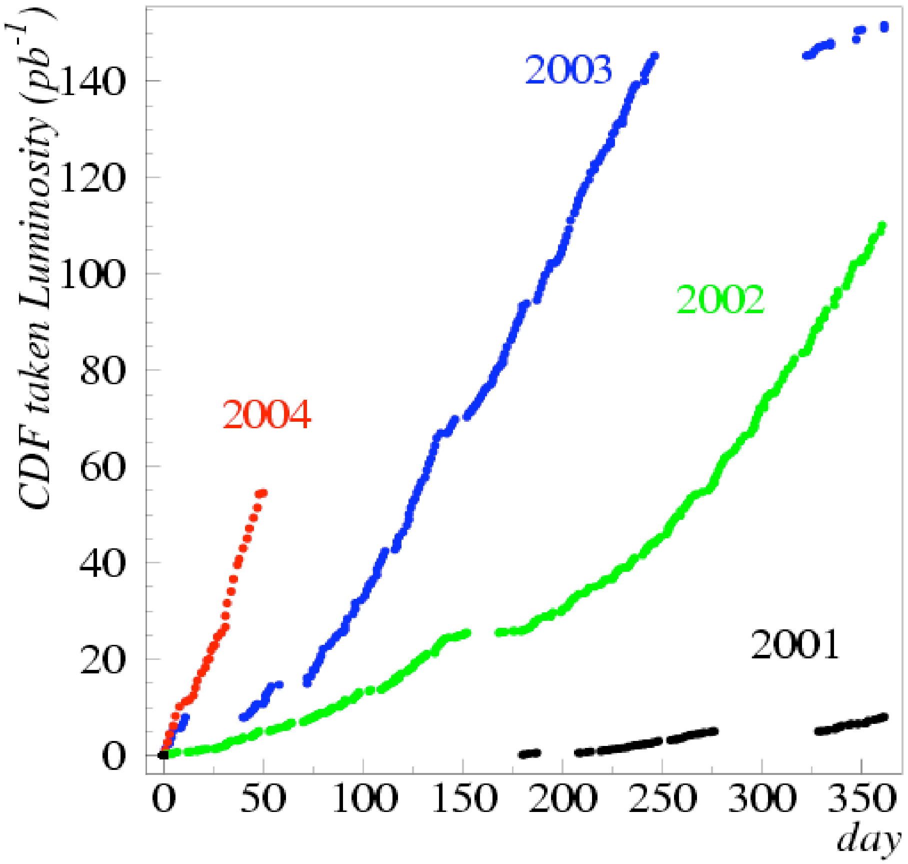
Tevatron performance

- Tevatron working ***very well*** this year
- Record Initial luminosity = 7.2 X 10^{31} sec^{-1} cm^{-2}
  DESIGN (no recycler): 8 X 10^{31} sec^{-1} cm^{-2}

•RECYCLER had a first successful test

- CDF/D0 DAQ efficiency ~85-90%





~300 pb^{-1} on tape
~100-200 pb^{-1} used for analysis so far
…now integrating data at the rate of ~300pb^{-1}/year. Plan is 4 to 8.5 fb^{-1}
Large production a strong point of B program @TeV

The CDF & D0 Detectors in Run-II

New: Time of Flight (TOF): some hadron ID

New: Silicon (SVT) online Si tracker: Select high IP tracks from b and c @ trigger level (First time at a hadron collider !)

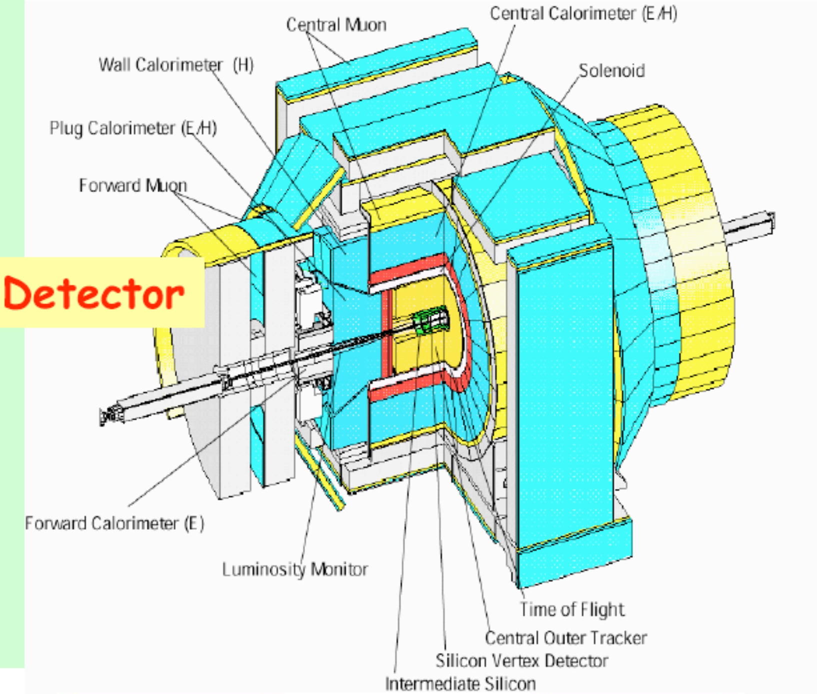
Improvements over Run-I

-Silicon Detector : 3-D tracking, 5 layers: B vertex, track IP resolution,

-Faster Drift Chamber : Momentum measurement

-Greater muon coverage : Select b, c → μ

CDF Detector



New : 2T Super conducting Magnet

New: Silicon tracker (vertex, track IP resolution)

New: Fiber tracker : Momentum

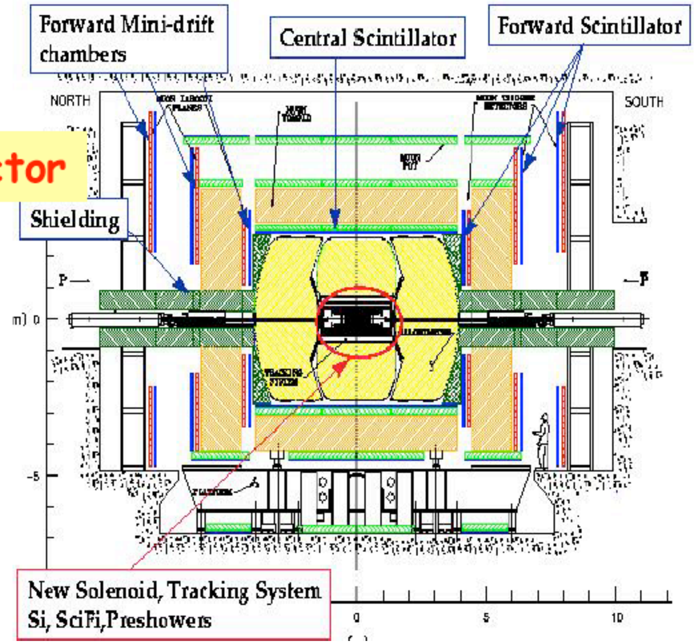
New: Si Track Trigger (displaced vertices) (Coming soon)

Improvements over Run-I

-Calorimetry and faster readout

-Upgraded muon system.

D0 Detector

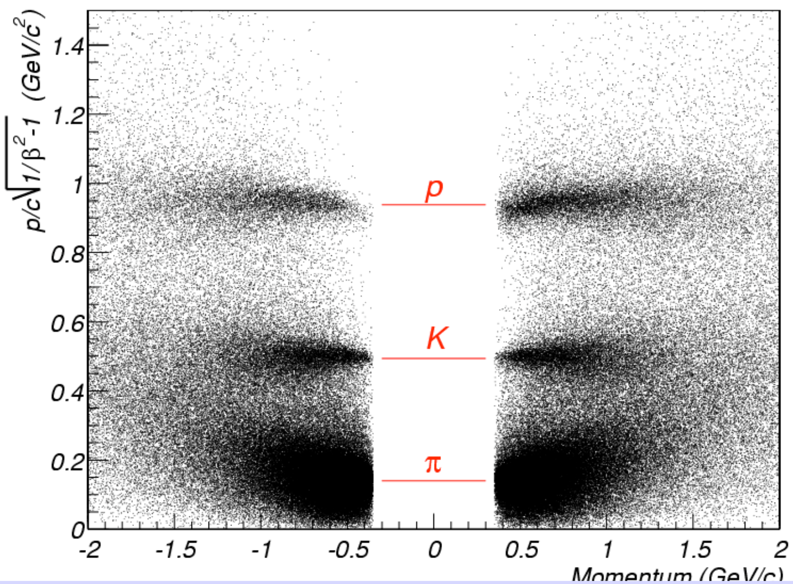


D0 has a magnetic field, and is able to pursue a competitive B-physics program as well !

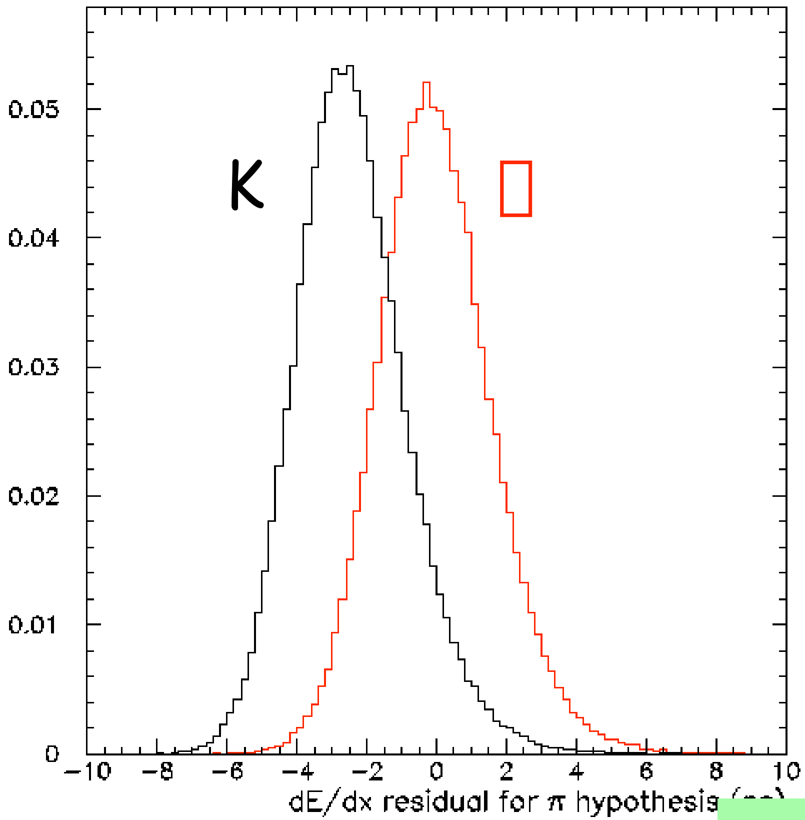
CDF tracking/PID performance

- I.P. resolution: 13μm + 40μm/p_T(GeV)
- Recent trouble with drift chamber:
  (www-cdf.fnal.gov/upgrades/cot/aging_committee.html)

CDF Time-of-Flight : Tevatron store 860 - 12/23/2001



TOF : >1□ K/π separation up to p=2 GeV



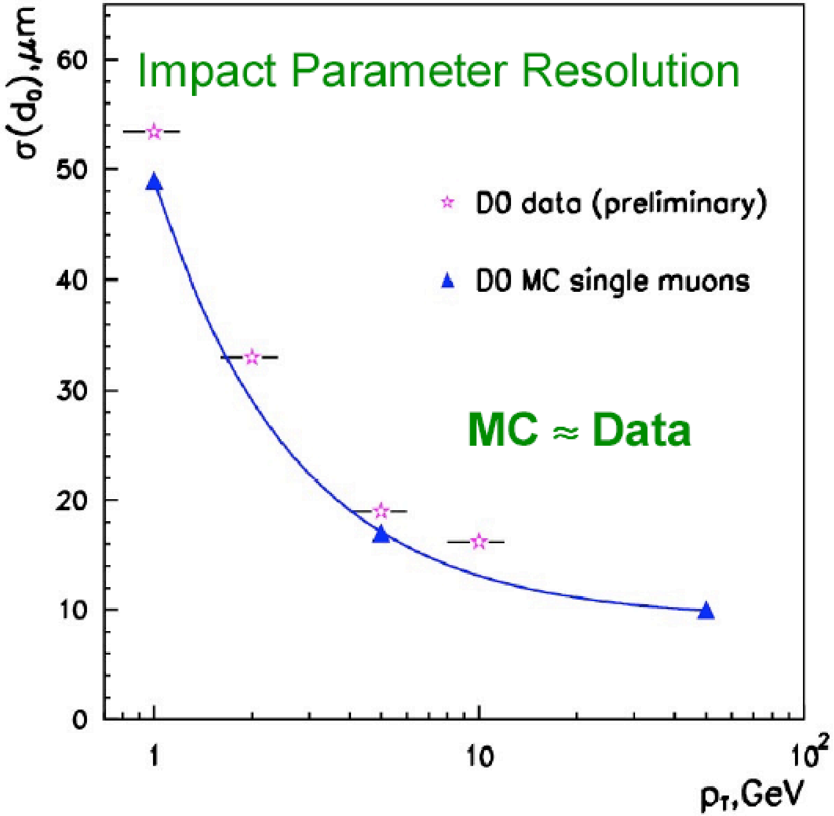
dE/dx in central drift chamber

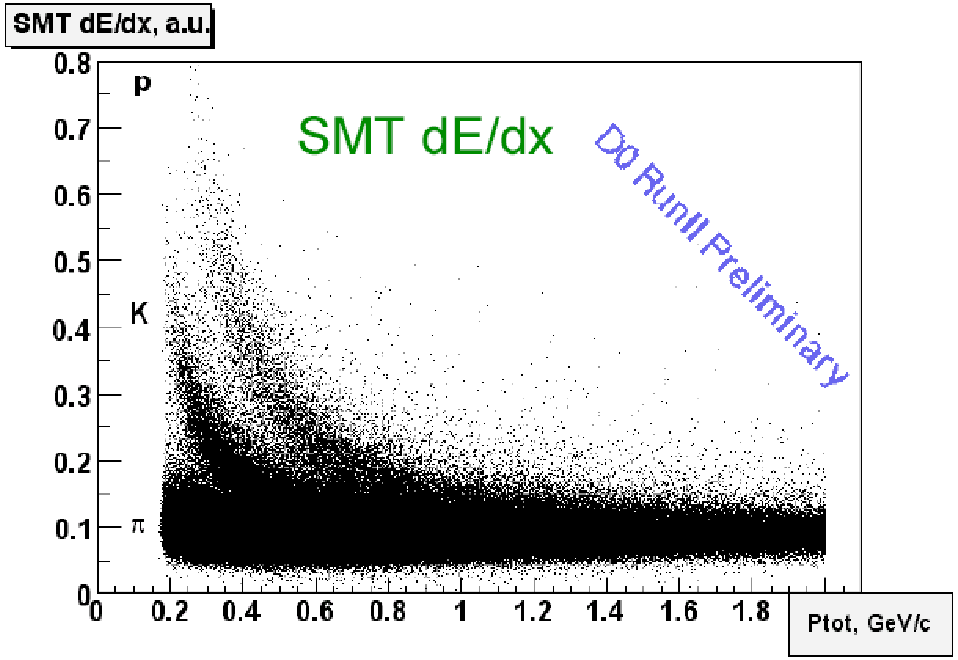
K/π separation 1.4 □ (Pt>2GeV)

(≡60% of perfect separation)

Development: dEdx in Silicon Vertex for low-pt tracks

D0 performance





K/π separation for P_{tot}< 400 MeV
p/π separation for P_{tot}<700 MeV

NOT yet used for PID

σ(DCA) ≈ 53 μm @ P_T = 1 GeV
and ≈15 μm @ higher P_T

Triggering *bs*′ (and *cs*′) @Tevatron

conventional | ***new approach***

Di-lepton

CDF and DØ

B ⟶ charmonium
Rare B ⟶ $\mu\mu$

Two muons with:

p_T> 1.5 GeV $|\eta|$< 1

p_T> 2.5-4.5 GeV $|\eta|$<2

Single-muon

DØ only

Semileptonic decays

one muon with:

p_T > 2 - 4 GeV $|\eta|$ <2

electron or μ and displaced track

CDF only

Semileptonic decays

Electron (μ) with:

p_T> 4 (1.5) GeV $|\eta|$< 1

and one track with:

p_T > 2.0 GeV IP > 120 μm

Two displaced tracks

CDF only

n-body hadronic B

Two tracks with:

p_T > 2.0 GeV

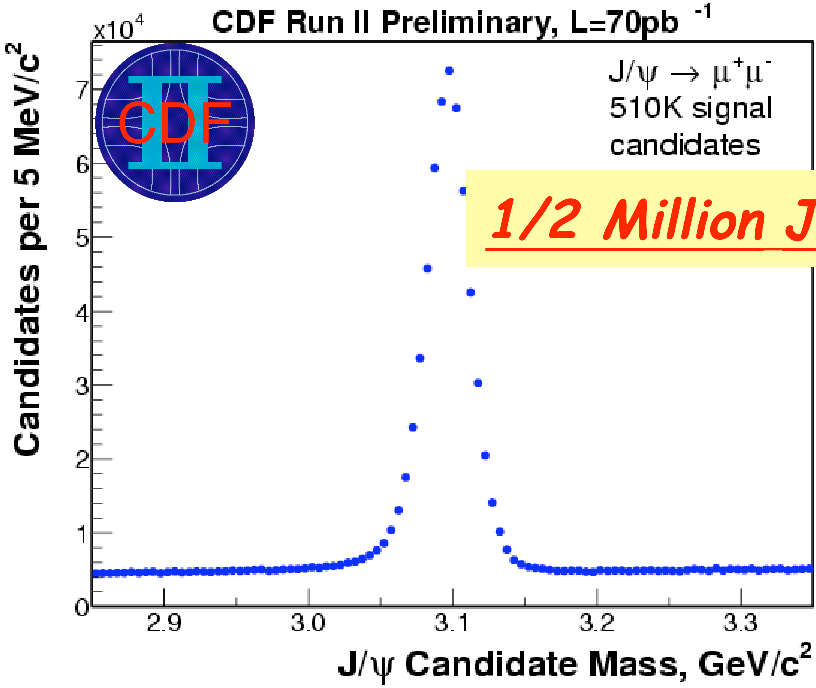
Σp_T > 5.5 GeV

IP > 120 (100) μm

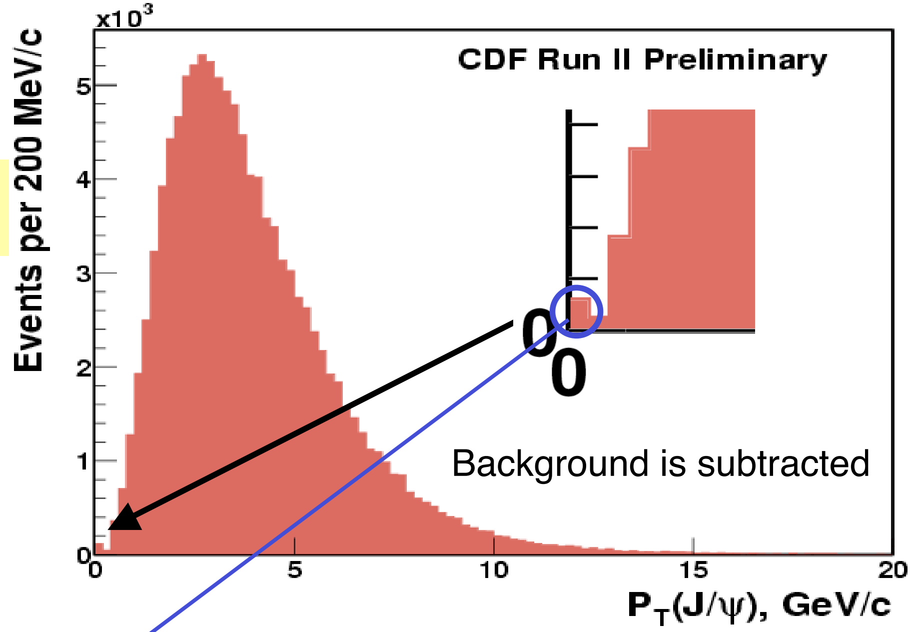
Both experiment have a 3-level trigger, and B takes a good fraction of resources.

Trigger selection determines the physics.

J/ψ → μμ (“conventional way” to B)

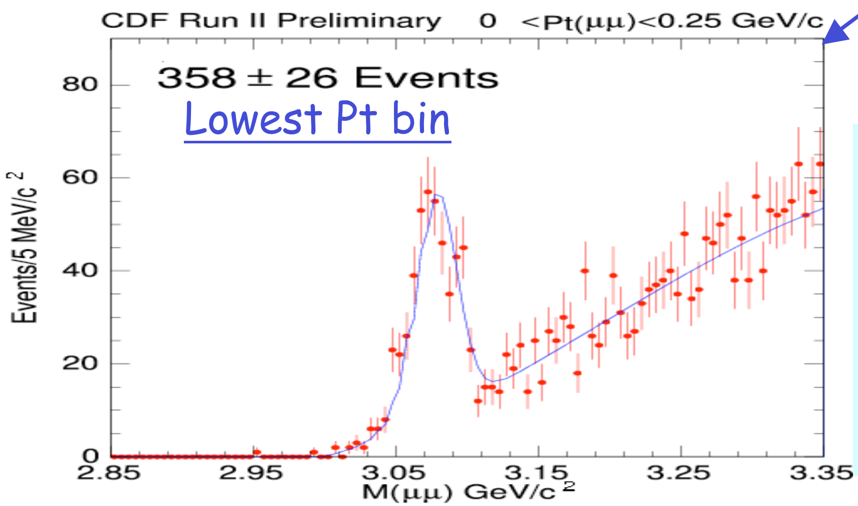


1/2 Million J/ψ



L1 tracking → pt(μ)≥1.5 GeV/c → trigger on J/ψ at rest

Yield ~2.5×RunI

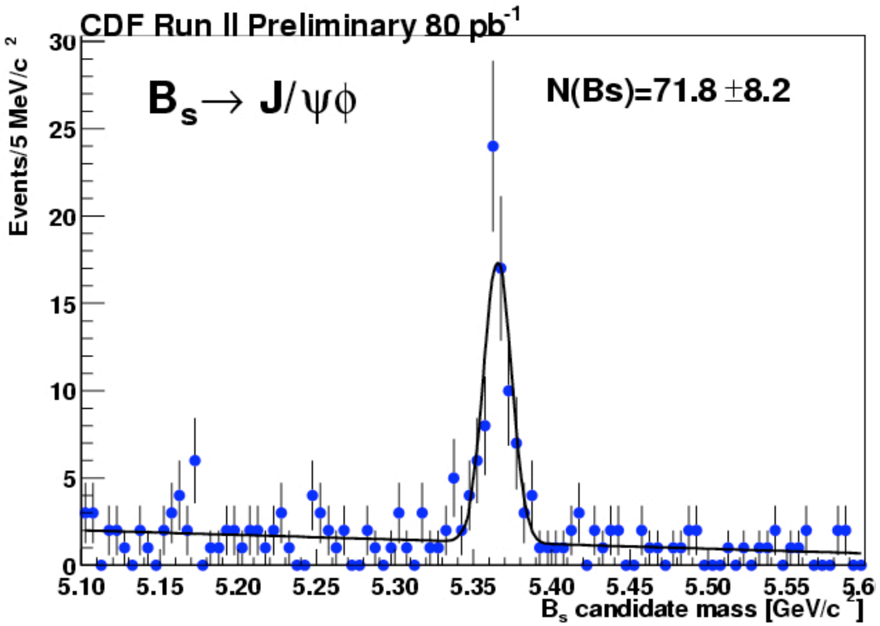


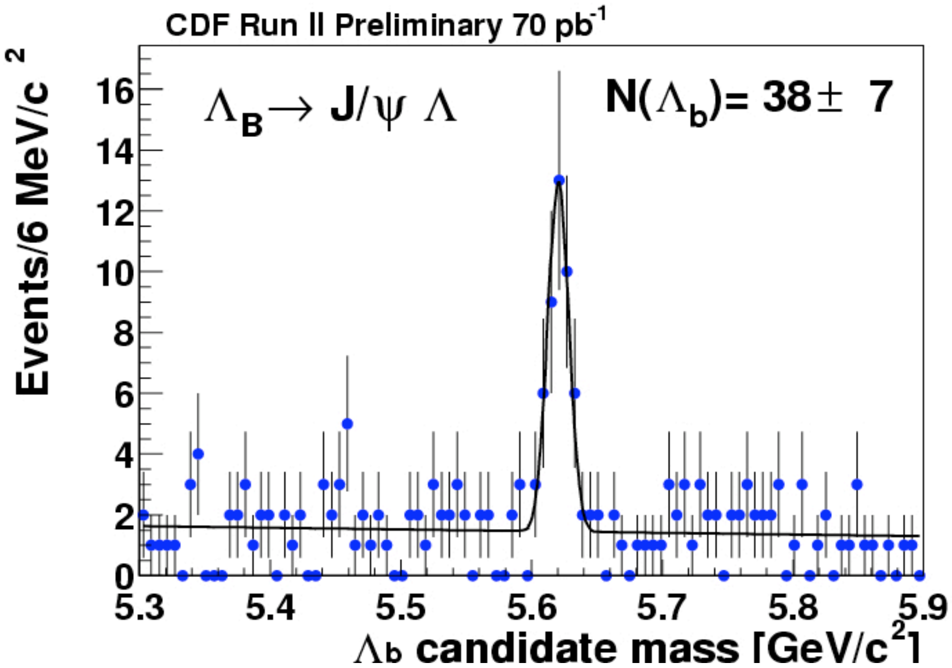
Cross section measured down to $p_T = 0$
(*first at hadron collider*)

$\sigma(p\bar{p} \to J/\psi;\ p_T>0;\ |\eta|<0.6) =$

$240 \pm 1(stat) \pm 35/28(syst)$ nb

B hadron masses measurements





Competitive measurements for B_d and B^+:

$M(B_d) = 5280.30 \pm 0.92 \pm 0.96$ MeV/c^2

$M(B^+) = 5279.32 \pm 0.68 \pm 0.94$ MeV/c^2

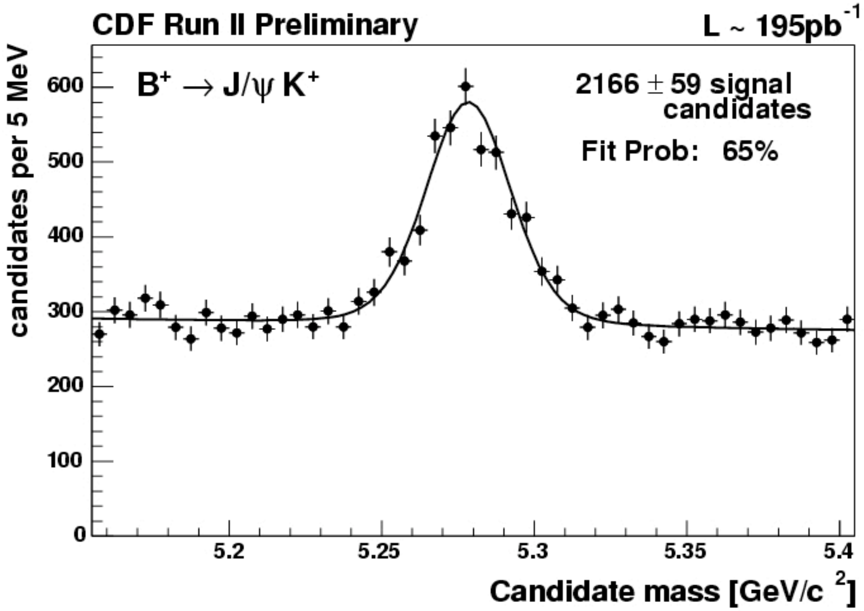
World's best measurements for B_s and Λ_b:

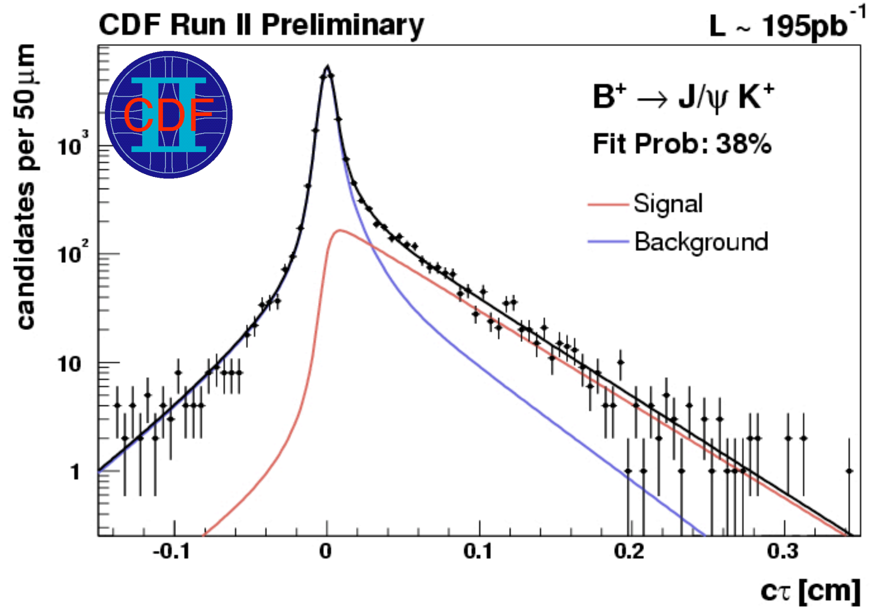
$M(B_s) = 5365.50 \pm 1.29 \pm 0.94$ MeV/c^2

$M(\Lambda_b) = 5620.4 \pm 1.6 \pm 1.2$ MeV/c^2

All use J/psi mass as reference

Exclusive Bu,Bd lifetimes





$B^+ \to J/\psi K^+$	2160 events	Unbinned simultaneous fit of
$B^+ \to J/\psi K^{*+}$ ($K^{*+} \to Ks\, \pi$)	200 events	M_B: extract signal fraction
$B^0 \to J/\psi K^{*0}$ ($K^{*0} \to K\, \pi$)	950 events	ct: extract the lifetime
$B^0 \to J/\psi Ks$	600 events	

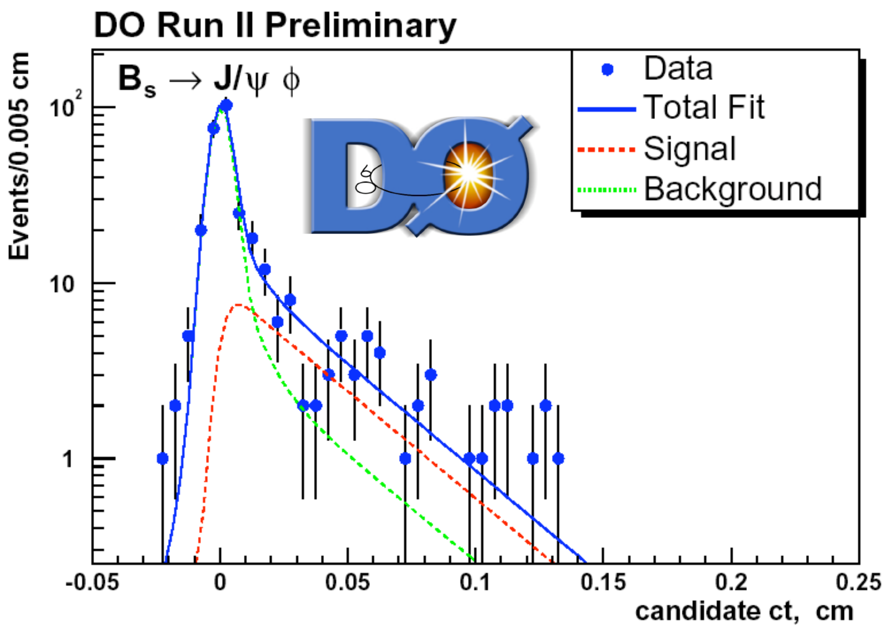
$\tau(B^+) = 1.66 \pm 0.04(stat) \pm 0.02(sys)$ ps

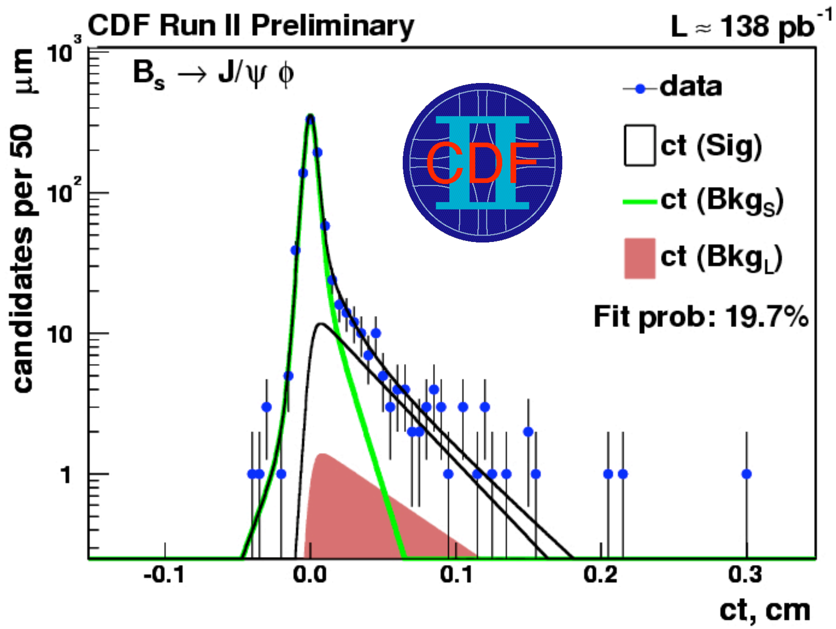
$\tau(B^0) = 1.49 \pm 0.05(stat) \pm 0.03(sys)$ ps

$\tau(B^+)/\tau(B^0) = 1.119 \pm 0.046(stat) \pm 0.014(sys)$

Largest systematic error from background model

Exclusive $B_s \to J/\psi\ \phi$ lifetime
(Unique to Tevatron)





$\tau(Bs)$ = 1.19 +0.19 -0.16(stat) ± 0.14(sys) ps

$\tau(Bs)$ = 1.33 ± 0.14(stat) ± 0.02(sys) ps

$\tau(Bs)/\tau(B^0)$ = 0.88 ± 0.11(stat)

With more statistics:

Angular analysis measures $\Delta\Gamma_s = B_s^H - B_s^L$

Large CP asymmetry (measures phase of V_{ts})

is a signal of new physics (requires $\Delta m_s t$)

B Lifetime summary

- Accurate measurements from Tevatron, still statistics-dominated

- Theory errors are still smaller than experiment

HQET:

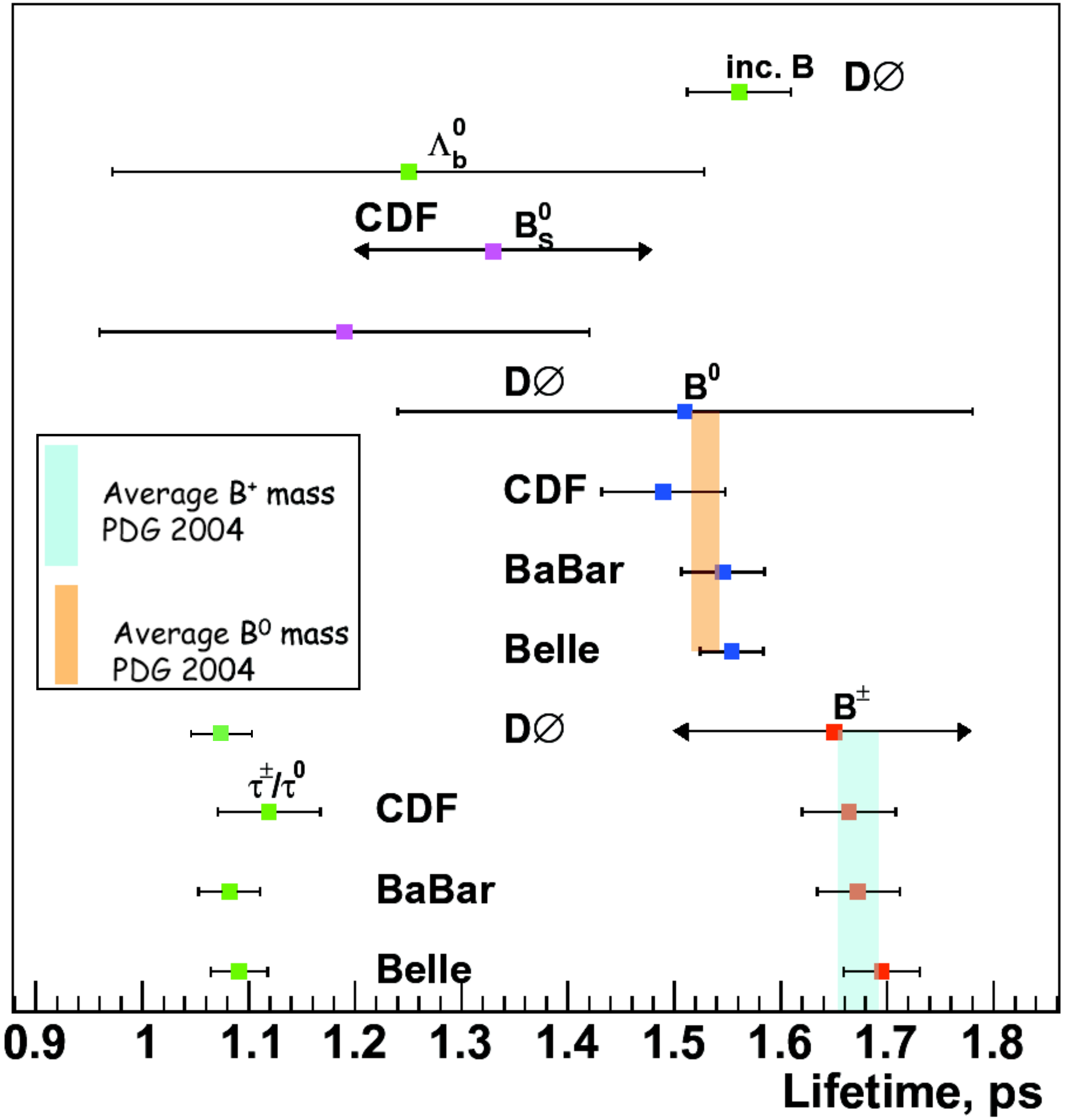
□(B^+)/□(B^0) = 1.067 ± 0.027

□(B_s)/□(B^0) = 0.998 ± 0.015

□(□$_b$)/□(B^0) = 0.90 ± 0.05

- More B hadrons coming:

B_c , □$_b$



B_s Lifetime Difference: $\Delta\Gamma_s$

- $\Delta\Gamma_s/\Delta M_s$ in SM does not depend on CKM parameters
  - $\Delta\Gamma_s$ determines ΔM_s up to QCD uncertainties (~20%)
  - Large ΔM_s (hard to measure) → Large $\Delta\Gamma_s$ (easy to measure) → complementarity
- Several methods available at Tevatron RunII:

- Theory: $\frac{\Delta\Gamma_s}{\Gamma_s} = 7\% \pm 4\%$
- Exp: $\frac{\Delta\Gamma_s}{\Gamma_s} < 0.31,\ 95\%\ \mathrm{CL}$
- $\frac{\Delta\Gamma_s}{\Delta m_s} = \frac{\pi}{2}\frac{m_b^2}{m_W^2}\left|\frac{V_{cb}V_{cs}}{V_{ts}V_{tb}}\right|^2 \times \mathrm{QCD}$

$B_s \to J/\psi\phi$:

Angular analysis to separate CP even/odd components

~ 10,000 events in 6.5 fb^{-1}

$\sigma(\Delta\Gamma/\Gamma) \approx 0.01 \div 0.03$

Hadronic modes (being evaluated):

$B_s \to K^+K^-$

No angular analysis needed

~ 10,000 eventi in 6.5 fb^{-1}

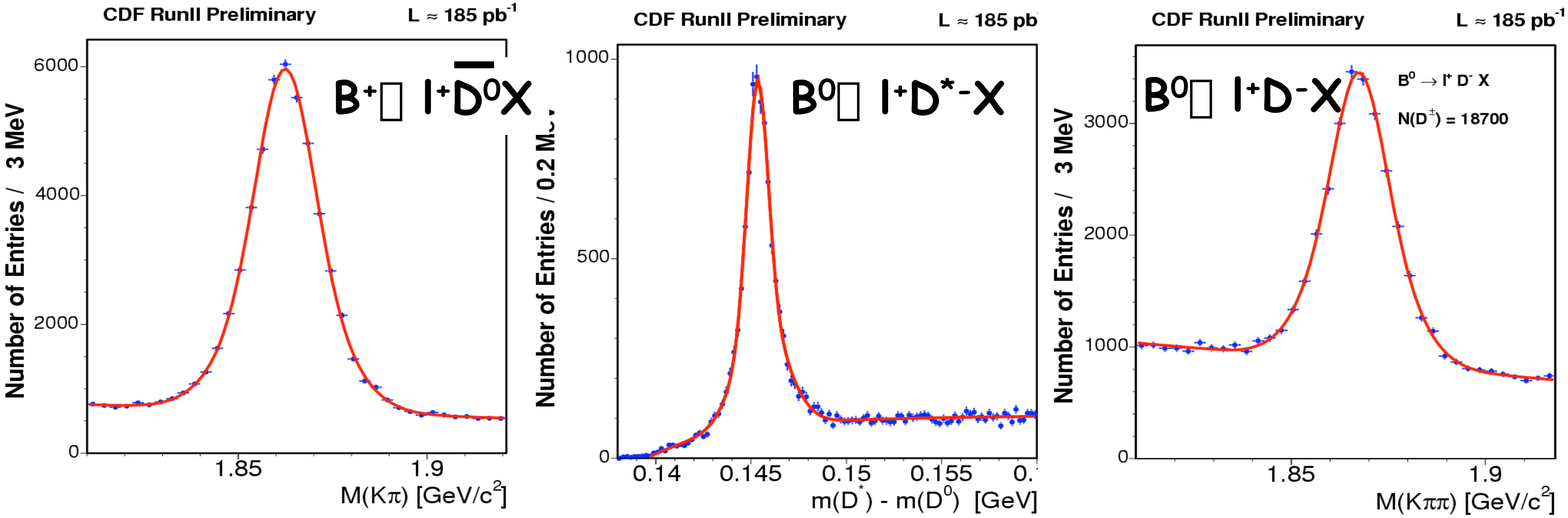
(see Bhh below)

$B_s \to D_s\pi / D_sD_s$:

Fit 2 exponential to known mixture of states (ex. $B_s \to D_s\pi$, $B_s \to D_sl\nu$)

Compare with CP eigenstate (ex. $B_s \to D_sD_s$)

B^+/B^0 from lepton+displaced track



High statistics semileptonic B samples

Excellent calibration samples for B^+/B^0 lifetime, tagging and B^0 mixing

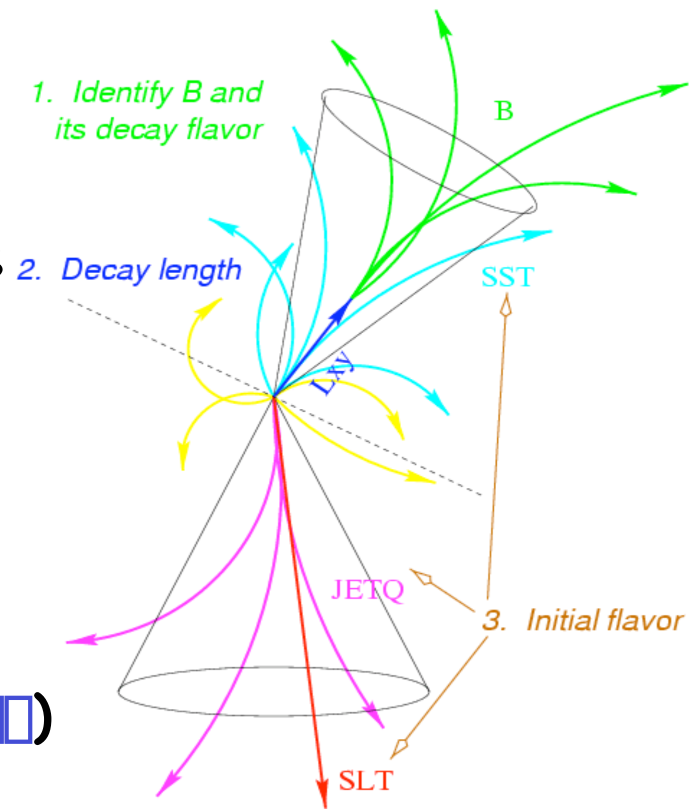
$B \to lD^0X$ ($D^0 \to K\pi$): ~41,800 events

$B \to lD^{*+}X$ ($D^{*+} \to D^0\pi$): ~8,400 events

$B \to lD^+X$ ($D^+ \to K\pi\pi$): ~18,700 events

CDF runII yields significantly larger: lower lepton pt threshold possible thanks to i.p trigger

B Flavor Tagging



OST (opposite side tagging):

B's produced in pairs → tag flavor of opposite B

JETQ: sign of the weighted average charge of opposite B-Jet

SLT: identify the soft lepton from semileptonic decay of opposite B

SST (same side tagging):

B^0 (B^0) is likely to be accompanied by a π^+ (π^-)

Search for the track with minimum P_T^{REL}

Kaon taggers (new in CDF):

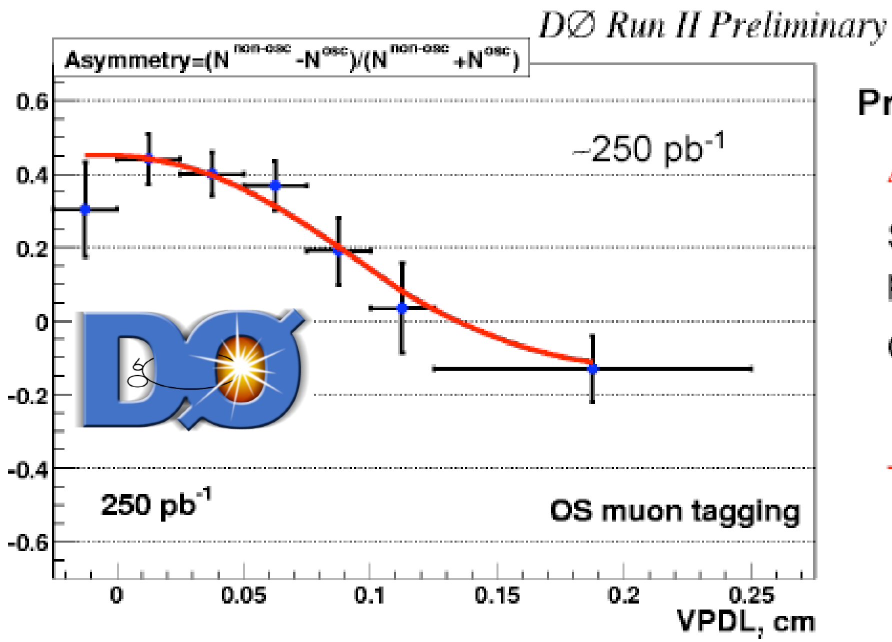
OST (K from b→ c→ s transition)

SST (K from fragmentation)

- Evaluation in progress, but not expecting more than 5-10%
- Learning process in runII no faster than runI...

ϵD^2 [%]	CDF	DØ
Soft muon	0.7 ± 0.1	1.0 ± 0.2
Soft electron	in progress	in progress
Jet charge	in progress	3.3 ± 1.7
Same side	1.9 ± 0.9	5.5 ± 2.0
Opp. side kaon	in progress	N/A
Same side kaon	in progress	N/A

Bd oscillations



Preliminary results:

Δm_d = 0.506 ± 0.055 (stat) ± 0.049 (syst) ps^{-1}

Syst. dominated by uncertainty on μ+D*- yield per VPDL bin.

Consistent with world average:
0.502 ± 0.007 ps^{-1}

Tagging efficiency:

$$\varepsilon = \frac{N_R + N_W}{N_R + N_W + N_{notag}} = 4.76 \pm 0.19\,\%$$

Tagging purity:

$$\kappa = \frac{N_R}{N_R + N_W} = 73.0 \pm 2.1\,\%$$

Work in progress:

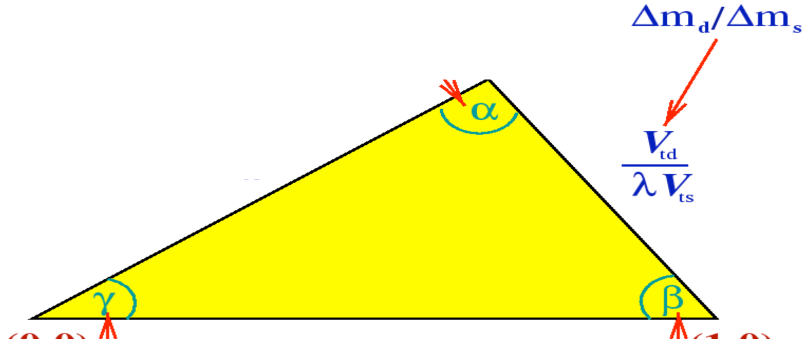
- also use electron tags
- other tagging methods:
  jet charge,
  same side tagging.

Significance of B^0_s mixing measurement

$$A_{mix}(t) = \frac{N_{mix}(t) - N_{unmix}(t)}{N_{mix}(t) + N_{unmix}(t)} = -D * cos(\Delta m_s t)$$

$$\text{SIG} \approx \sqrt{N \epsilon D^2} e^{-(x_s \sigma_{c\tau}/\tau)^2/2} \sqrt{\frac{S}{S+B}}$$

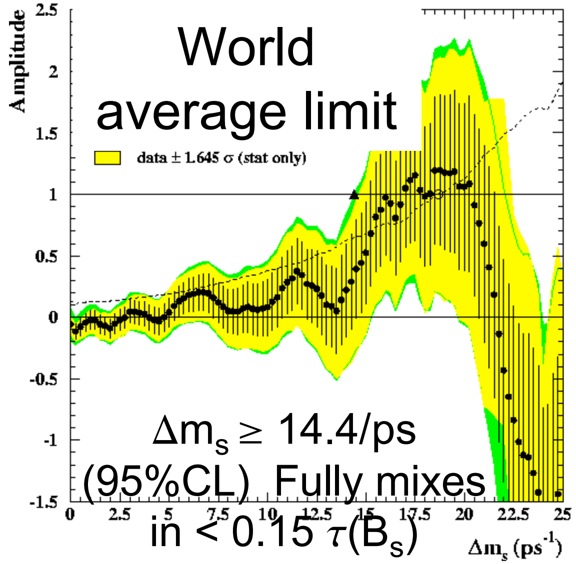
Units of sigma



$$c\tau = \frac{L_{xy}}{\beta_T \gamma} = \frac{L_{xy} m(B)}{p_T(B)}$$

vertexing and momentum resolution

$$\sigma_{c\tau} = \left(\frac{\sigma_{L_{xy}} \cdot m(B)}{p_T(B)}\right) \oplus \left(\frac{\sigma_{p_T}}{p_T(B)}\right) \cdot c\tau$$

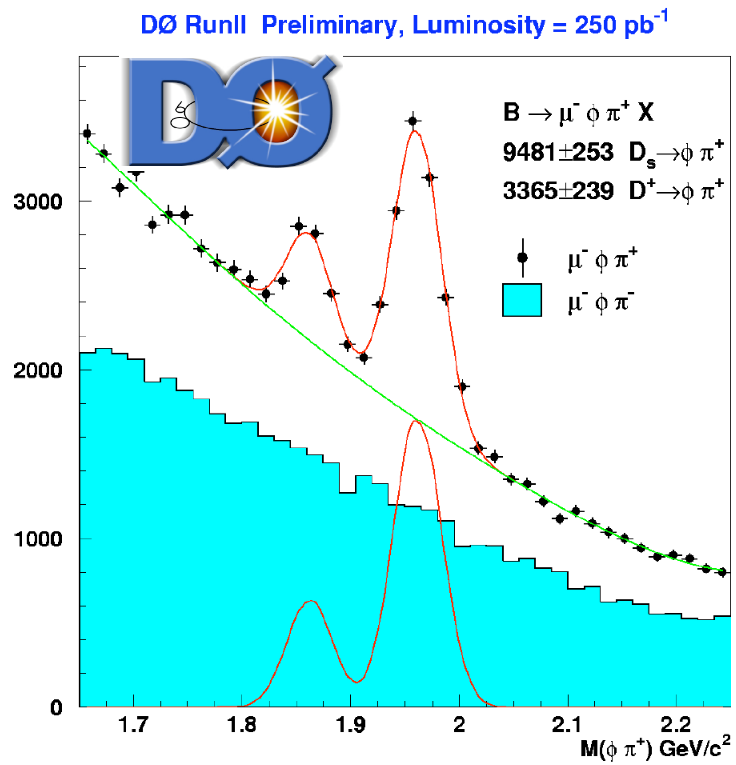


	• $\sigma_{c\tau}$ [fs]
•Hadr.	•67 (50 exp. with LØØ)
•l+X	•110 - 150

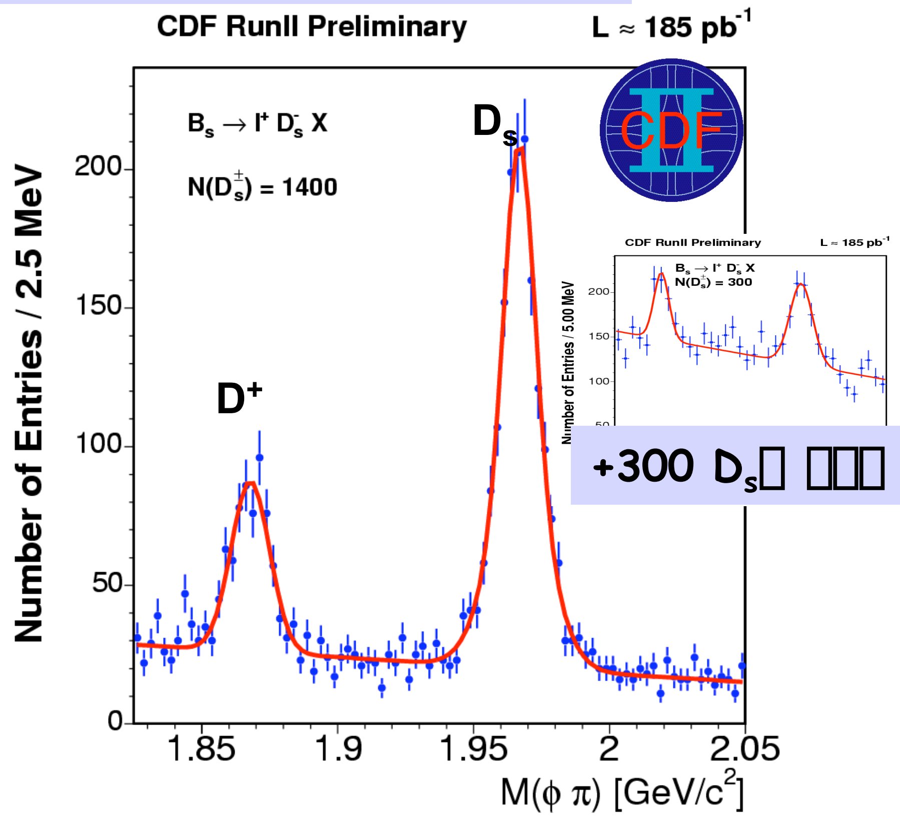
Towards B^0_s mixing - semileptonic side

$B^0_s \longrightarrow D^-_s\, l^+\nu + X \longrightarrow [\phi\pi^-]\, l^+\nu \longrightarrow [[K^+K^-]\, \pi^-]\, l^+\nu$ and

D0: expect 1.5□ sensitivity to 15/ps in 0.5 fb-1
Exponential in resolution limits ultimate reach of this mode



Yield ~ 31 pb just muons

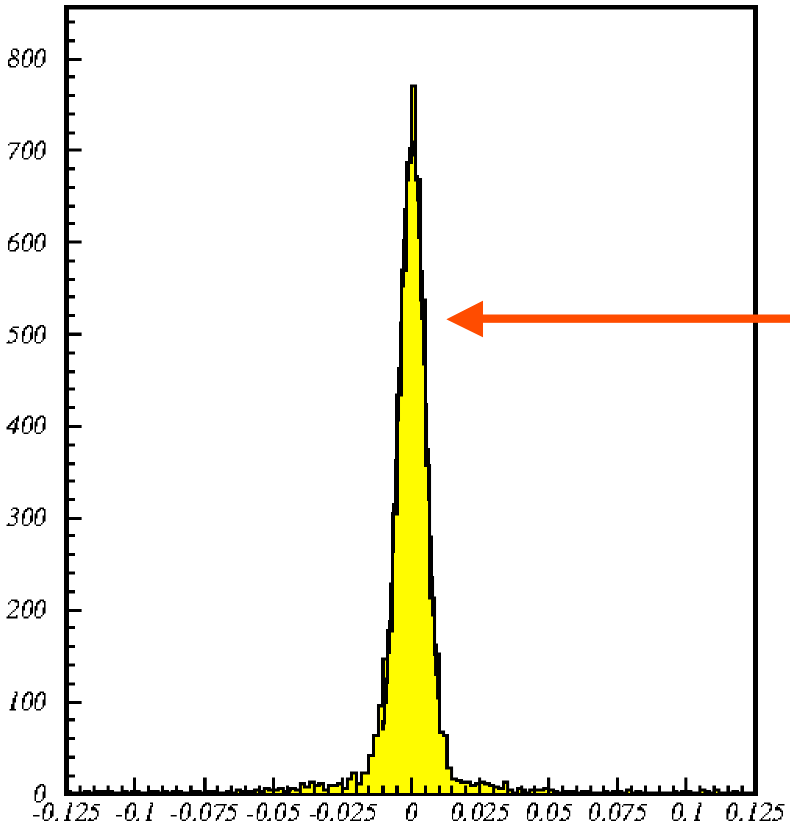


Yield ~ 7.6 pb μ & electrons

Hadronic modes

Online IP from SVT: Unique to CDF hadronic B trigger

Impact parameter distribution



This distribution is the convolution of the actual transverse size of the beam spot with the impact parameter resolution of the SVT
Available at trigger Level 2 (20μs latency)

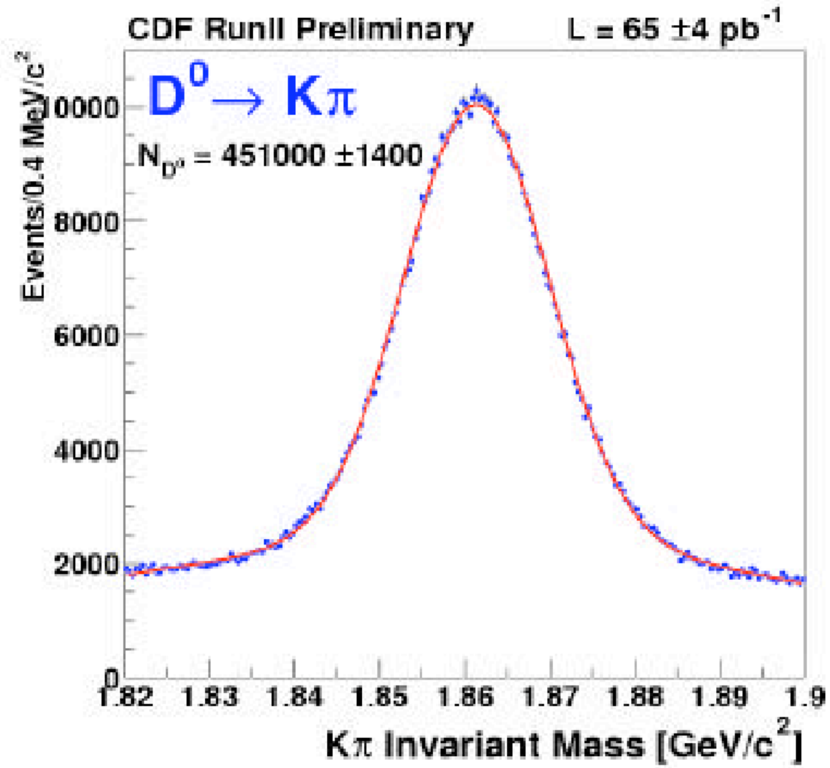
sigma ~ 48 um ~ 42 um ⊕ 23 um

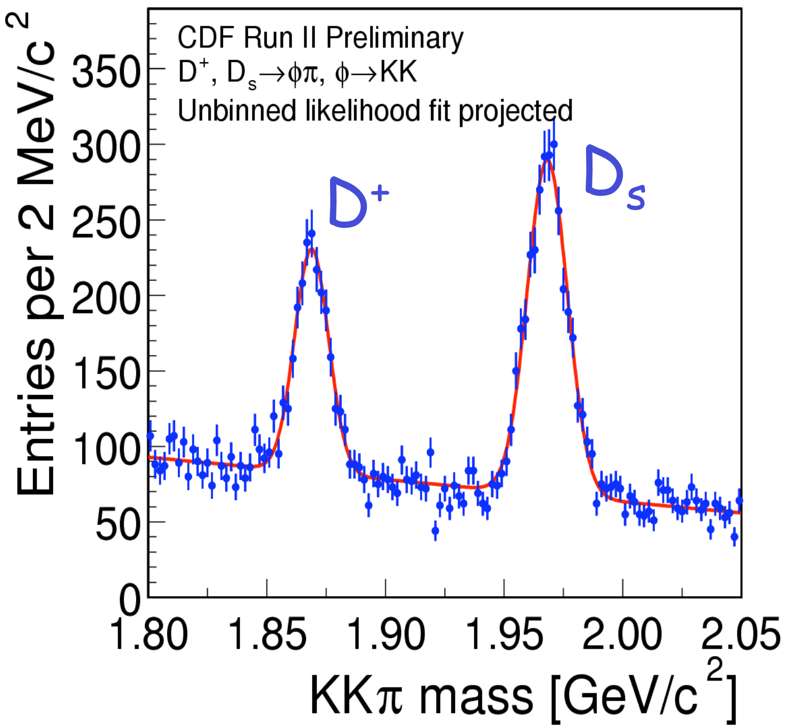
SVT resolution — beam spot size

Compare to offline ~ 46 um

	beam	SVT	Total
sigma	23	42	48
rms	23	51	56

Huge Charm samples from impact parameter trigger

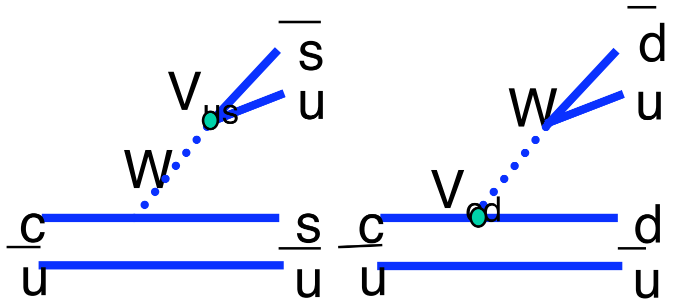


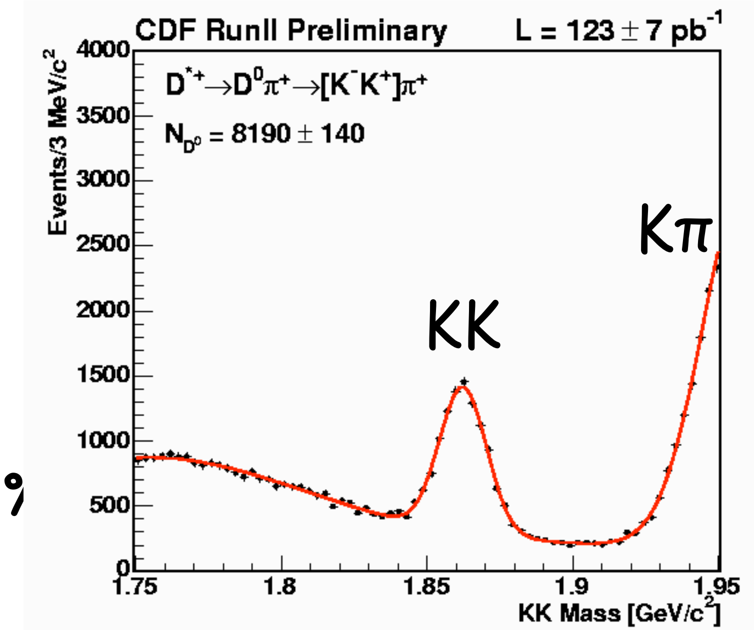


Access to fully hadronic B DX signals

- D^0 as trigger monitor/control sample
- D^0 is "**the hadronic J/psi**"
- CDF to produce precision charm measurements

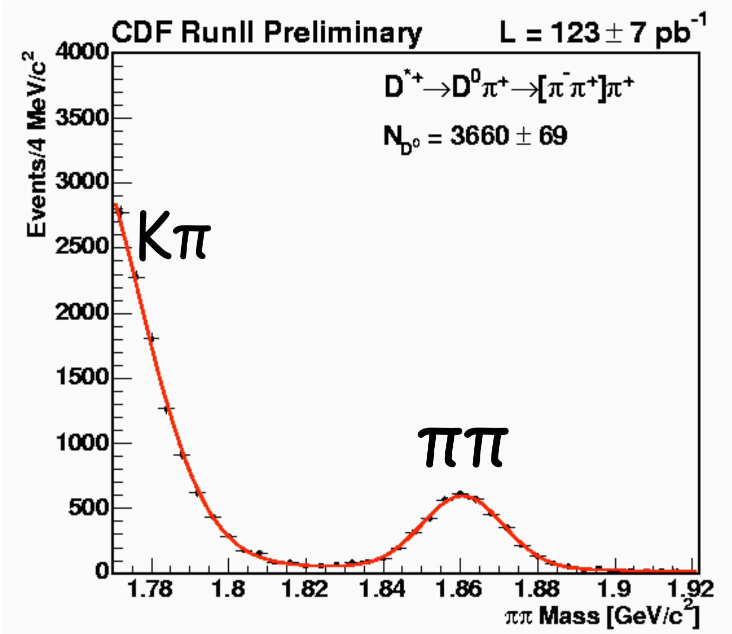
Cabibbo-suppressed decays of D^0





$\Gamma(D^0 \to KK)/\ \Gamma(D^0 \to K\pi)=9.96\pm0.11\pm0.12\%$
$\Gamma(D^0 \to \pi\pi)/\ \Gamma(D^0 \to K\pi)=3.608\pm0.054\pm0.012\%$

compare with FOCUS (2003)
$\Gamma(D^0 \to KK)/\Gamma(D^0 \to K\pi) = 9.93\pm0.14\pm0.14\%$
$\Gamma(D^0 \to \pi\pi)/\Gamma(D^0 \to K\pi) = 3.53\pm0.12\pm0.06\%$



CP asymmetry: tagging the soft π with D* decays.

$A(D^0 \to KK) = 2.0 \pm 1.2 \pm 0.6\ \%$

$A(D^0 \to \pi\pi) = 1.0 \pm 1.2 \pm 0.6\ \%$

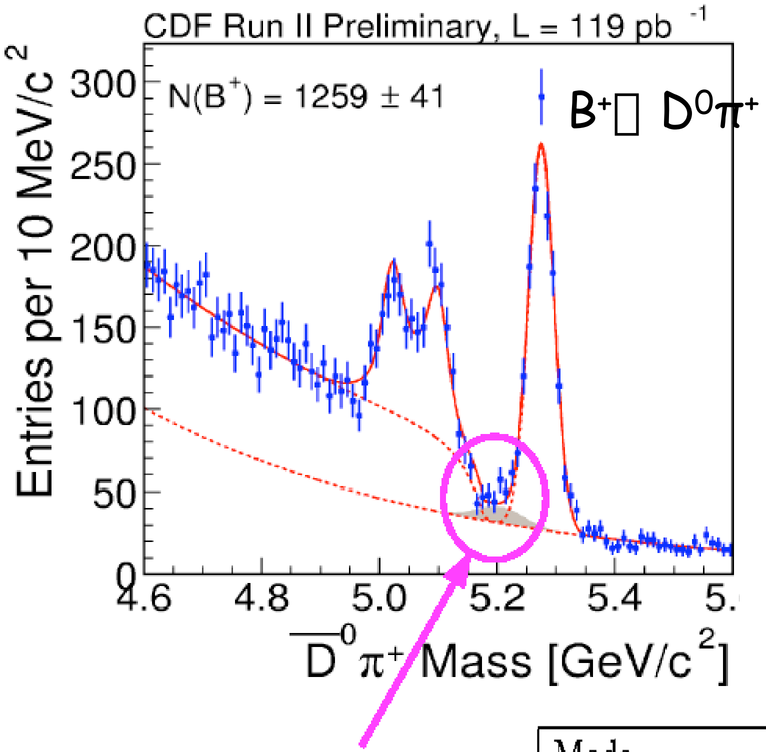
World-class Charm samples in CDF runII

	2 fb^{-1}	6.5 fb^{-1}
$D^0 \rightarrow K\pi$	24M*	78M*
$D^0 \rightarrow K\pi\pi\pi$	4M*	13M*
$D^0 \rightarrow KK$	2.5M*	8.5M*
$D^0 \rightarrow \pi\pi$	0.7M*	2.3M*
$D^{\pm} \rightarrow K\pi\pi$	18M	58M
$D^{+}s \rightarrow KK\pi$	1M	6.5M
$\Lambda_c \rightarrow p\pi K$	18K	59K

* ≈1/3 with D* tag

- CP asymmetries at 0.1% level
- D mixing

Dπ and DK exclusive modes



8% D0 K

Mode	Yield in 2 fb^{-1}	Yield in 3.5 fb−1
$B^{\pm} \to \overline{D}^0\pi, \overline{D}^0 \to K\pi$	48,000	84,000
$B^{\pm} \to \overline{D}^0K, \overline{D}^0 \to K\pi$	3990	6980
$B^{\pm} \to \overline{D}^0K, (\overline{D}^0 \to KK + \overline{D}^0 \to \pi\pi)$	520	910
$B_s \to D_s\pi, D_s \to \phi\pi$	3200	5600
$B_s \to D_sK, D_s \to \phi\pi$	256	448

Self-tagging mode for angle
(Atwood-Dunietz-Soni method
based on DCS decays)
300pb-1 CDF ~ 80fb-1 BaBar

Good yields at the Tevatron - DK-Dπ separation study has been performed - perspectives for a good measurement of gamma

Hadronic B_s for mixing at high xs

"Golden channel": B^0_s □ D^-_s □$^+$□ [□□ $^-$] □$^+$ □ [[K^+K^-]□$^-$] □$^+$

Best proper time resolution, can resolve fast oscillations.

S/B ~ 2

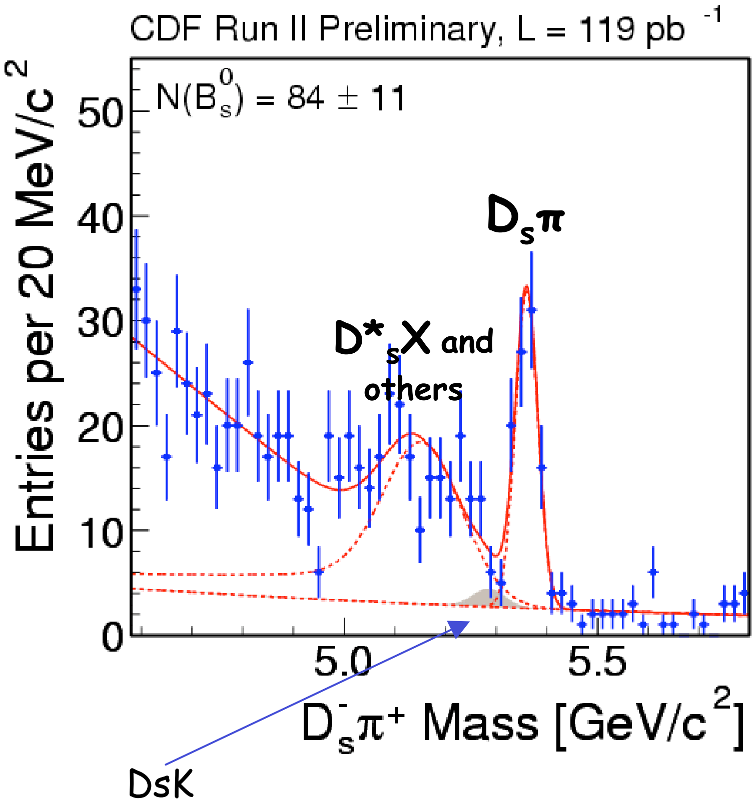
Yield/Lum=0.7 pb

Currently working on B_s□ D_s3□

and D_s□ K^*K/K_sK/3□ □ signals seen

Need 2pb and □D^2 = 5% for 5□ sensitivity up to 24ps^{-1} in 3.2 fb^{-1}

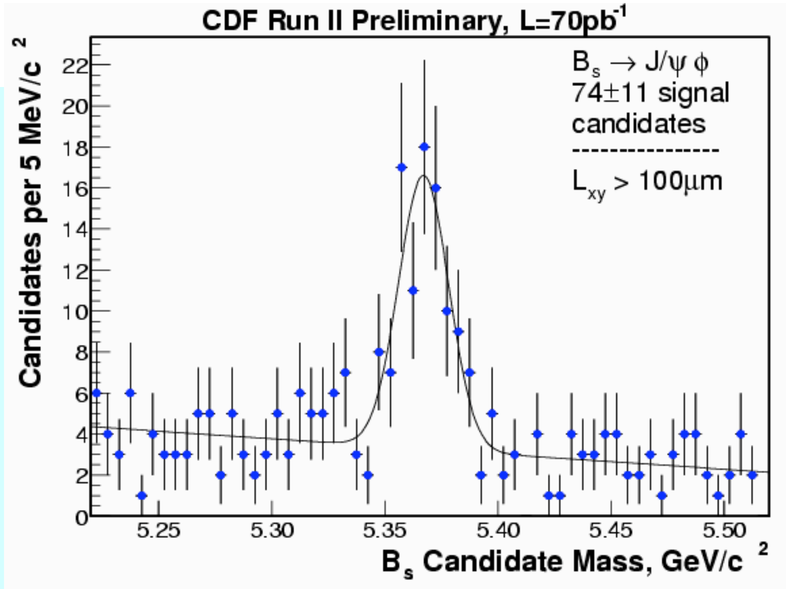
After xs measured, can measure asymmetry in DsK mode -> angle gamma



BR measurement:

$$\frac{f_s \cdot BR(B_s^0 \rightarrow D_s^- \pi^+)}{f_d \cdot BR(B_d^0 \rightarrow D^- \pi^+)} = 0.35 \pm 0.05(stat) \pm 0.04(syst) \pm 0.09(BR)$$

CP asymmetry in $B^0_s \rightarrow J/\psi\ \phi$



After xs measurement:

CP asymmetry in $J/\psi\ \phi$ measures weak phase of V_{ts} (angle $\phi_s = 2\beta_s$)

Also plan to look at $B_s \rightarrow J/\psi\ \eta^{(\prime)}$

Expected to be small: $\sin(2\beta_s) \approx O(\lambda^2) \approx 0.03$

Complicated analysis: requires x_s and angular analysis to disentangle CP even/odd final states

CDF reach: $\sigma(\sin(2\beta_s)) \approx 0.1$ with $2fb^{-1}$ (≈ 0.06 with $8fb^{-1}$)

If asymmetry observed with $2fb^{-1}$ $\Rightarrow$ signal for NEW Physics

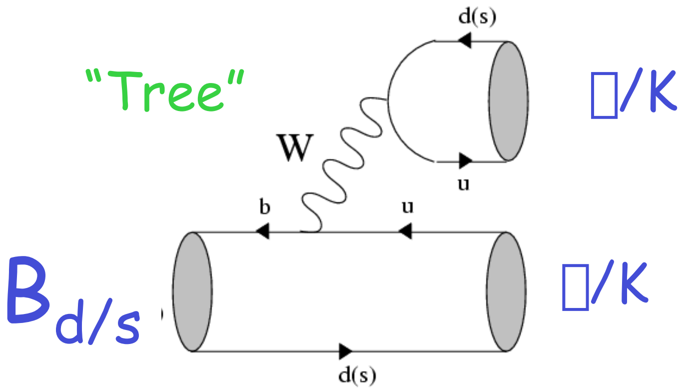
CHARMLESS

Hadronic modes

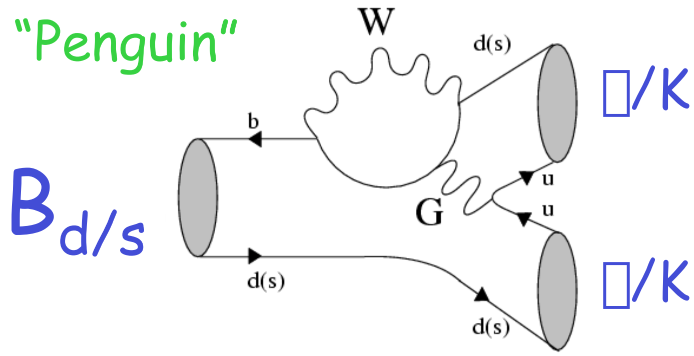
$B \to h^+h^-$ decays at the Tevatron

$B_d \to \pi\pi$, $B_d \to K\pi$, $B_s \to K\pi$, $B_s \to KK$

"Tree"



"Penguin"



direct CP (crossed out) — CP (crossed out) from mixing alone

→ $B_d \to \pi^+\pi^-$ $\quad A_{CP}(t) = A_{CP}^{dir}\cos(\Delta m_d t) + A_{CP}^{mix}\sin(\Delta m_d t)$

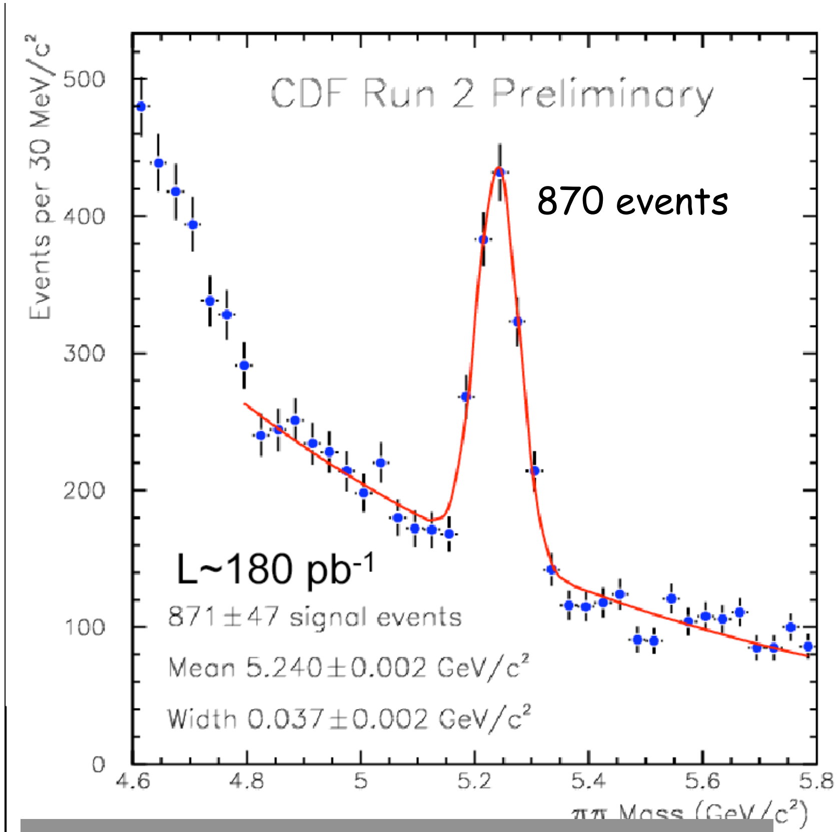
→ $B_d \to K\pi$ $\quad A_{CP}^{dir} = (N_+ - N_-)/(N_+ + N_-)$

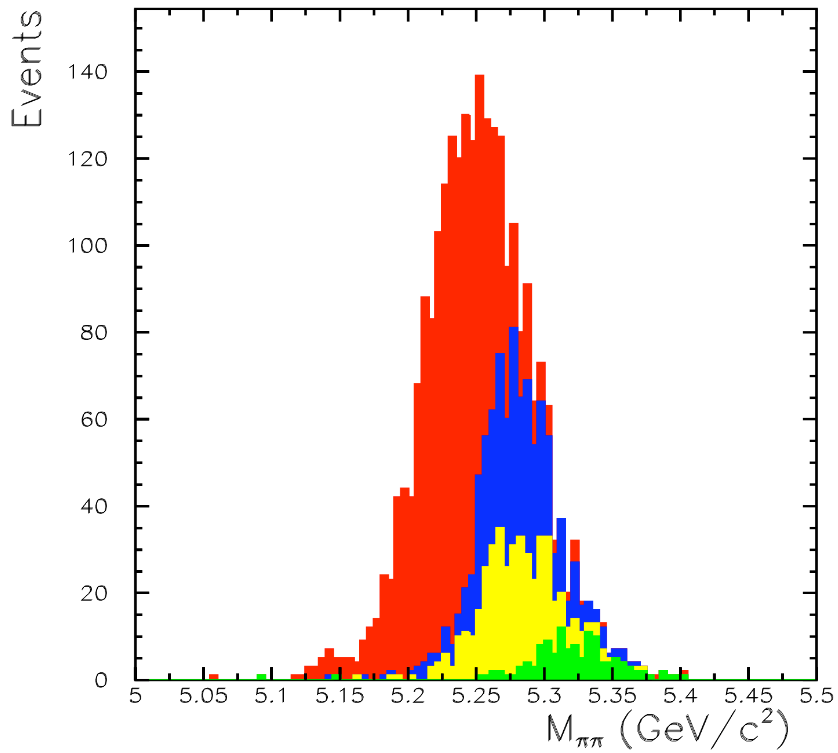
→ $B_s \to K\pi$ $\quad A_{CP}^{dir} = (N_+ - N_-)/(N_+ + N_-)$

→ $B_s \to K^+K^-$ $\quad A_{CP}(t) = A_{CP}^{dir}\cos(\Delta m_s t) + A_{CP}^{mix}\sin(\Delta m_s t)$

Bs channels never observed

Reconstruction of Charmless 2-body





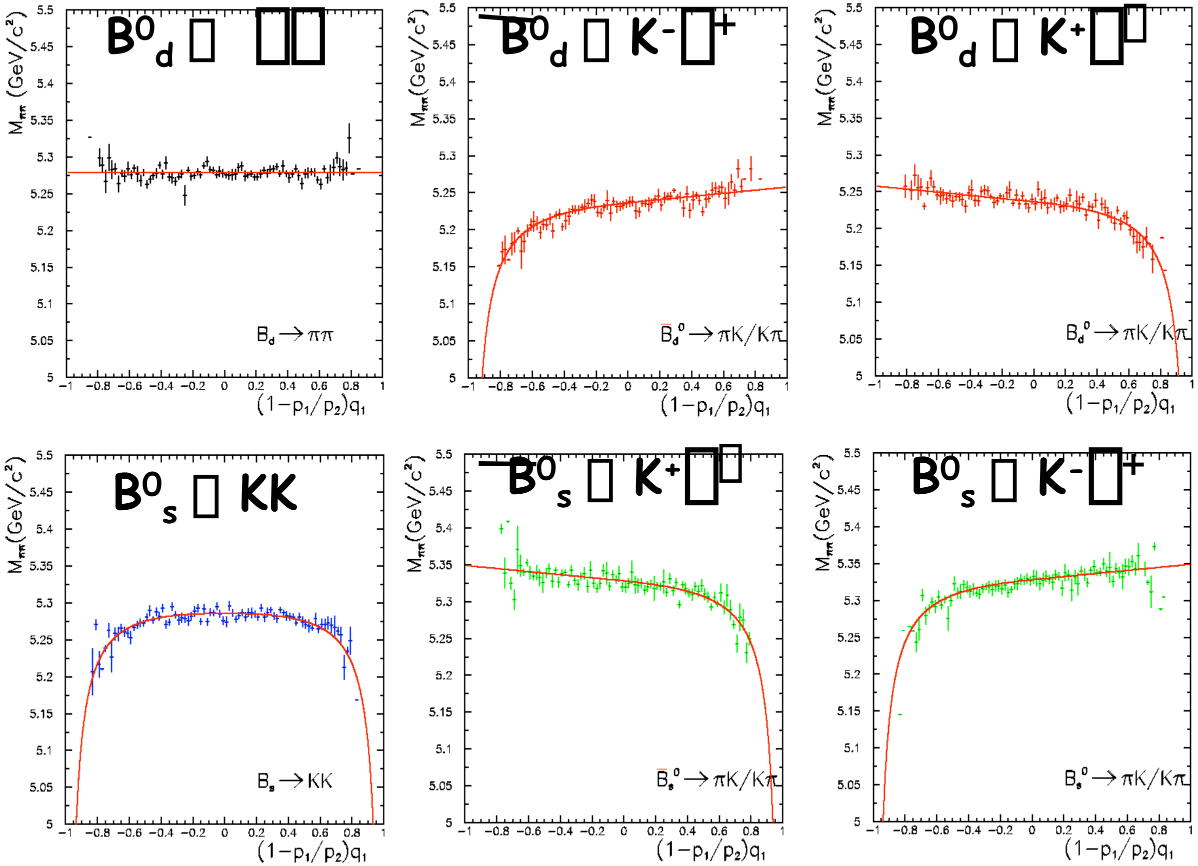
- $\min(|d_{01}|,|d_{02}|)$ □ 150 □m
- $L_{xy}(B^0) \geq 300$ □m
- $|d_{B0}|$ □ 80 □m , $d_{01} \cdot d_{02} < 0$
- $I(B^0) > 0.5$ (ISOLATION)

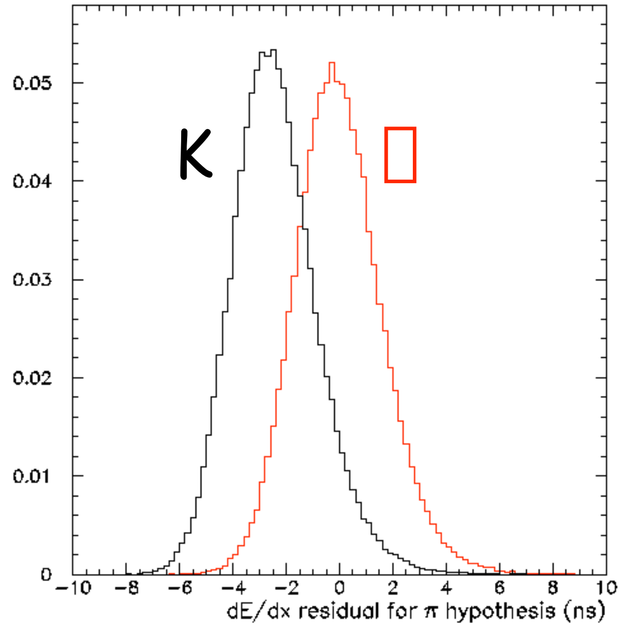
$$I(B^0) = \frac{Pt(B)}{Pt(B) + \square_{cone} Pt_i}$$

Isolation crucial cut to reduce background

Separation of $B^0 \to h^+h^-$ contributions

Use $M_{\pi\pi}$ vs $(1-p_1/p_2)\cdot q_1$





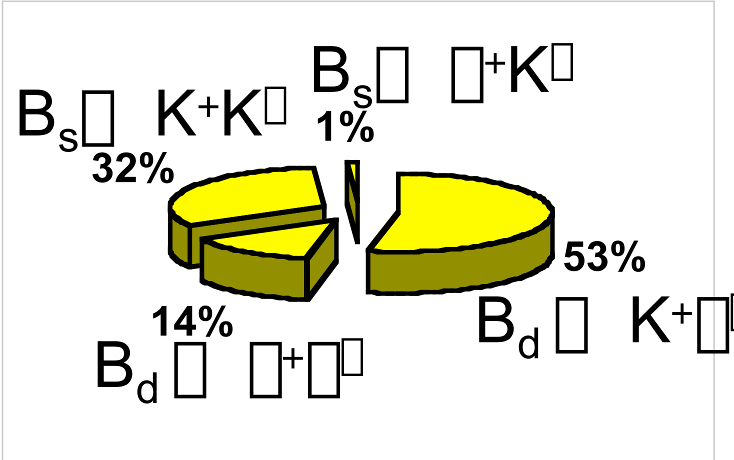
Use dE/dx calibrated on D* (K/π separation 1.4σ)

Overall separation power

σ(CDF) = σ(ideal)/0.6

σ(Babar) = σ(ideal)/0.8 (hep-ex/0207055)

B → $h^+h'^-$ results (LP03, 65 pb^{-1})



BR(Bd → ππ)/BR(Bd → Kπ) = 0.26 ± 0.11(stat) ± 0.06(syst)

Direct ACP(Bd → Kπ) = 0.02 ± 0.15(stat) ± 0.02(syst)

Consistent with B-factories results **(0.25±0.06)**

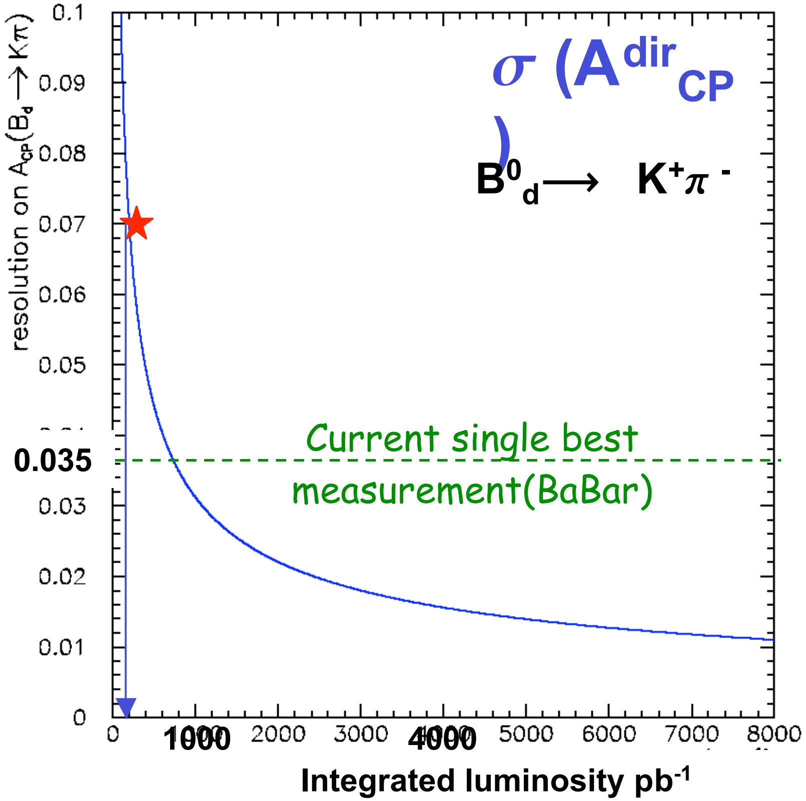
fs·BR(Bs → KK)/fd·BR(Bd → Kπ) = 0.74±0.20(stat)±0.22(syst)

First evidence of Bs → K+K- ***(CDF's largest fully reconstructed Bs sample!)***

Update on 185pb-1 coming out soon
x4 statistics and smaller syst (mainly dEdx)

Resolutions with current 180pb-1 sample

CDF Run II Preliminary



- Acp(Kπ) to 7%
- BR(BsKK) to 15%
- Yields: 130pb-1 CDF = 80fb-1 Babar

Risoluzioni attese	180pb-1	65pb-1
Bdpipi	± 0.024	± 0.05
BdKpi+barBdKpi	± 0.028	± 0.05
BsKpi+barBsKpi	± 0.024	± 0.05
BsKK	± 0.026	± 0.06
ACP	± 0.071	± 0.14
BsKK/(BdKpi+barBdKpi)	± 0.053	± 0.13
Bdpipi/(BdKpi+barBdKpi)	± 0.046	± 0.10

BaBar ($81 fb^{-1}$) 88M eventi/$B\overline{B}$			
Canale	eventi	B.R.(10^{-6})	$\mathcal{A}^{dir}_{CP}(K^+\pi^-)$
$B_d \to \pi\pi$	$157 \pm 19 \pm 7$	$4.6 \pm 0.6 \pm 0.2$	
$B_d \to K\pi$	$589 \pm 30 \pm 17$	$17.9 \pm 0.9 \pm 0.7$	$-0.102 \pm 0.050 \pm 0.016$
$B_d \to KK$	$1 \pm 8 (< 16)$	< 6.0	< 1.9

Bd→□□=144 ± 23

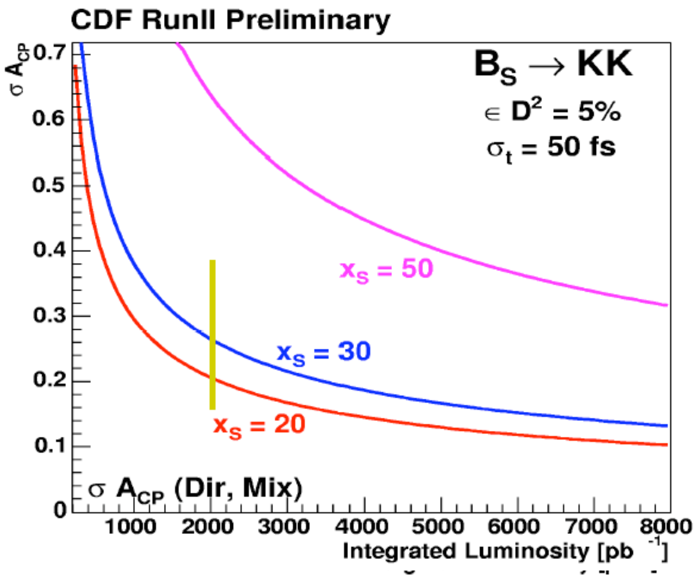
Bd→K□=576 ± 27

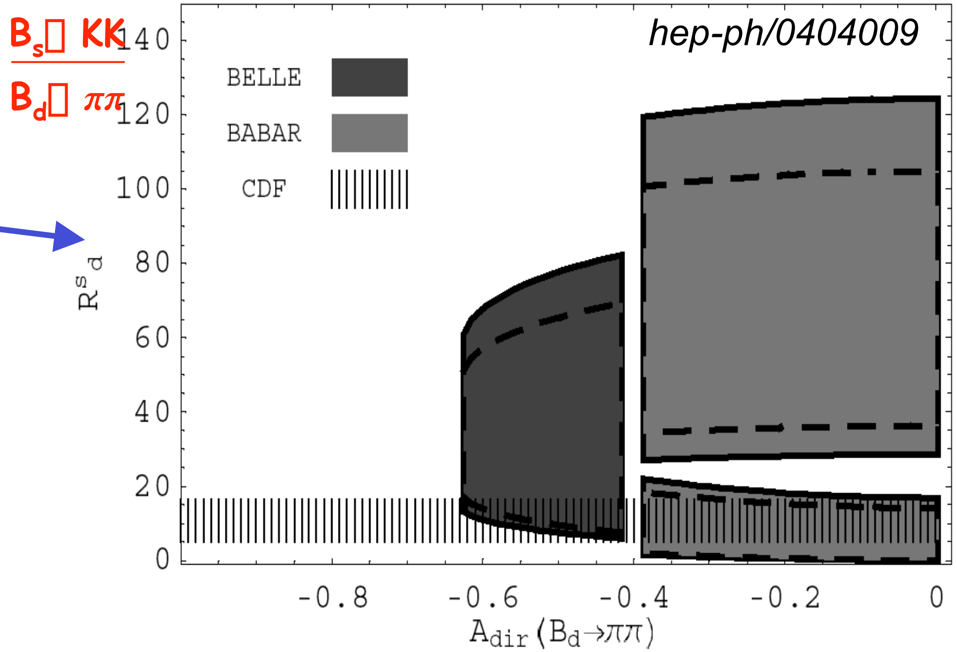
$B \to h^+h'^-$ future measurements

Mode	Yield 2 fb^{-1}	Yield 3.5 fb^{-1}
$B_d \to K\pi$	6700	11,725
$B_d \to \pi\pi$	1770	3097
$B_s \to KK$	4040	7070
$B_s \to K\pi$	1070	1870

- $B_s \to K\pi$ BR/Acp measurement
- Limits on $B_s \to \pi\pi$, $B_d \to KK$
- Lifetime in $B_s \to KK$: $\Delta\Gamma_s$
- ACP in $B_d \to \pi\pi$, $B_s \to KK$

Bs+Bd BRs' alone provide, via U-spin simmetry, informations of γ *(R. Fleischer hep-ph/0306270)* and checks of CKM model *(Matias&London, hep-ph/0404009)*





Longer time-scale: time dependent ACP in BsKK measure γ independently of penguin pollution *(Fleischer and Matias: PRD669 (2002) 054009)*

BR and A_{CP} in Charmless Bd,Bs

- QCD Factorization now provides predictions for PP, PV and VV 2-body charmless BR and ACP. Fits to experimental data allow extracting angle □ and other interesting parameters.
  - D.Du, hep/ph/0311135
  - N. deGroot et al., hep-ph/0305263
  - Benecke and Neubert, Nucl.Phys. B651,225(2003)
  - D.Du et al, hep-ph/0211154 (Bs->PP, PV)
  - Y.Yang et al, hep-ph/0309136 (Bs->VV)

- Lots of unseen channels, accessible to Tevatron experiments

All-charged modes only

	Decay	BR(10^{-6})
b→d	$K^{*0}\rho^0$	1.95
b→s	$K^{*+}K^{*-}$	2.10
	$\rho^0\phi$	1.67
Pure penguin	$K^{*0}K^{*0}$	3.72
	$K^{*0}\phi$	0.2
	$\phi\phi$	36.8

B^+ □ □K^+ □ $[K^+K^-]K^+$

$$\frac{BR(B^{\pm} \to \phi K^{\pm})}{BR(B^{\pm} \to J/\psi K^{\pm})} = [6.8 \pm 2.1(stat) \pm 0.7(syst)] \cdot 10^{-3}$$

Next:

Measure direct A_{CP}

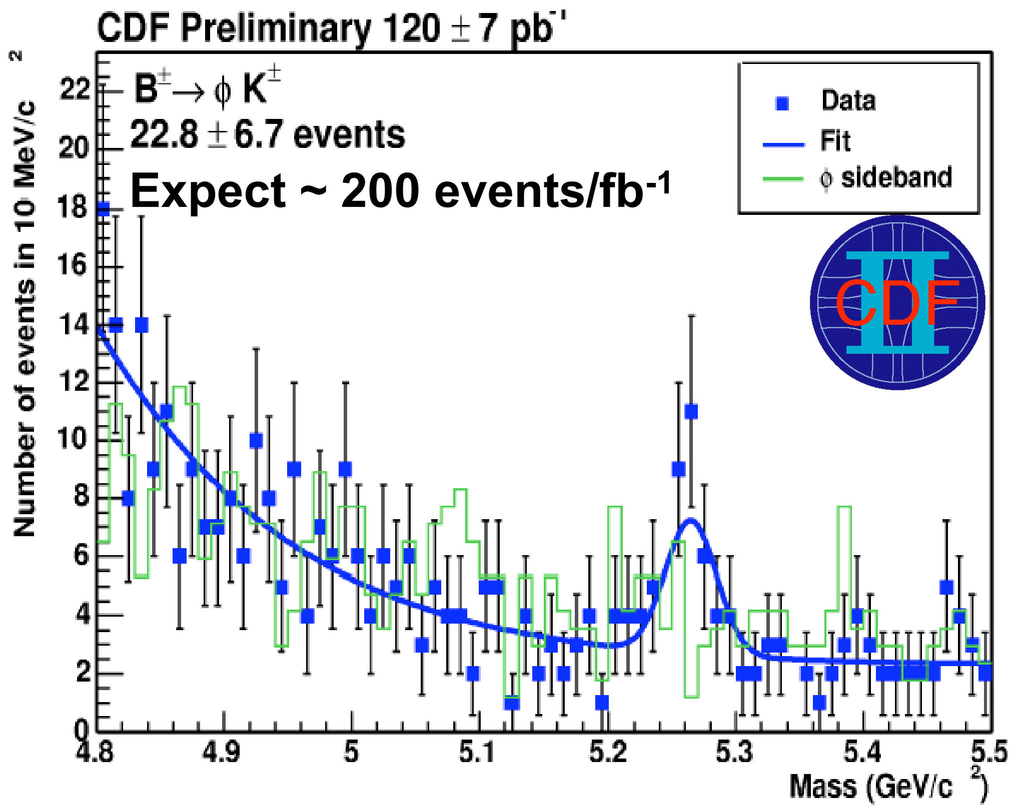
B^0_d □ □ K^* and c.c.

B^0_d □ □ K^0_s and c.c.

..and A_{CP} in baryons (SM expects ~10% CPV)

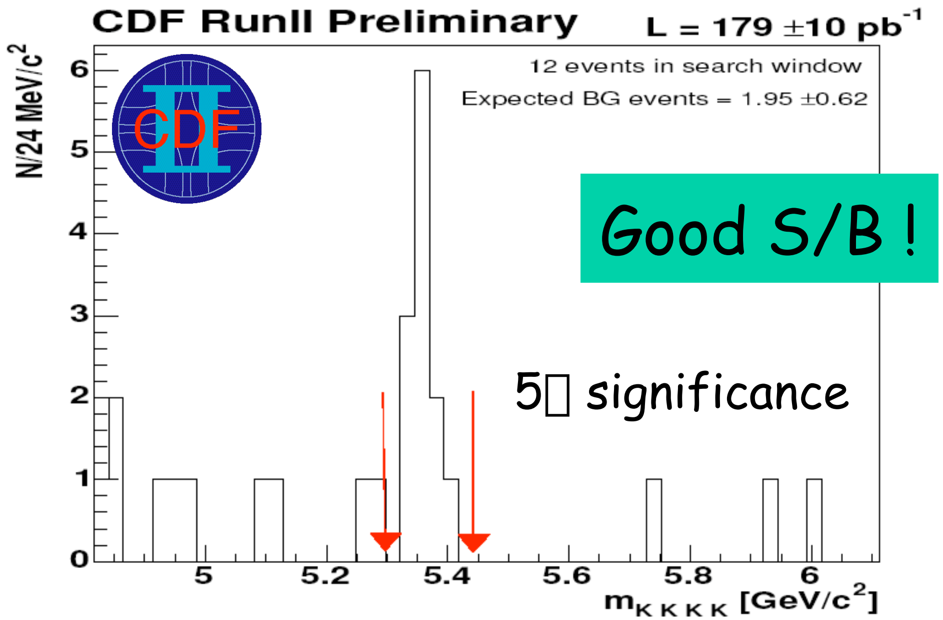
□$_b$ □ □□ and c.c.

□$_b$ □ pK^-/p□$^-$ and c.c.



NEW: Observation of $B_s \to \phi\phi$

B->ss$\bar{s}$ process, like Bd → φKs, Bd → φK*



$$BR^{B_s \to \phi\phi} = (1.4 \pm 0.6(stat.) \pm 0.2(syst.) \pm 0.5(BRs)) \cdot 10^{-5}$$ (Expected 3.68 10^{-5})

Blind analysis, optimized according to hep-physics/0308063
With more statistics, can get larger yields by looser cuts
FUTURE: Angular analysis

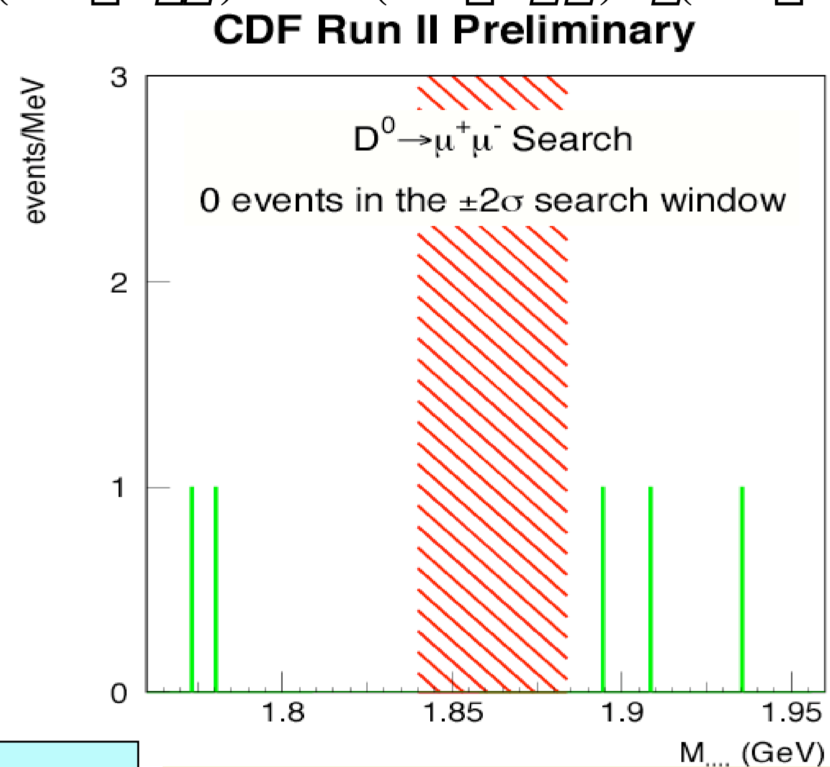
FCNC

Flavor Changing Neutral Currents in $D^0 \to \mu^+\mu^-$

FROM the *HADRONIC* TRIGGER, not the MUON TRIGGER !!

- Look for FCNC in the decay $D^0 \to \mu^+\mu^-$.
- SM prediction ~10^{-13}.
- R̸ SUSY effects can raise to ~10^{-6}.
- Normalize to $D^0 \to \pi\pi$ cancels out various normalizations and reduce acceptance effects.
- Blind analysis. Optimize cuts on ππ sample.
- *Push current limit downward by ~2.*

$$\frac{BR(D^0 \to \mu\mu)}{BR(D^0 \to \pi\pi)} = \frac{N_{CL}(D^0 \to \mu\mu)}{N(D^0 \to \pi\pi)} \frac{\varepsilon(D^0 \to \pi\pi)}{\varepsilon(D^0 \to \mu\mu)}$$



$BR(D^0 \to \mu\mu) \leq 2.4 \times 10^{-6}$ at 90% CL

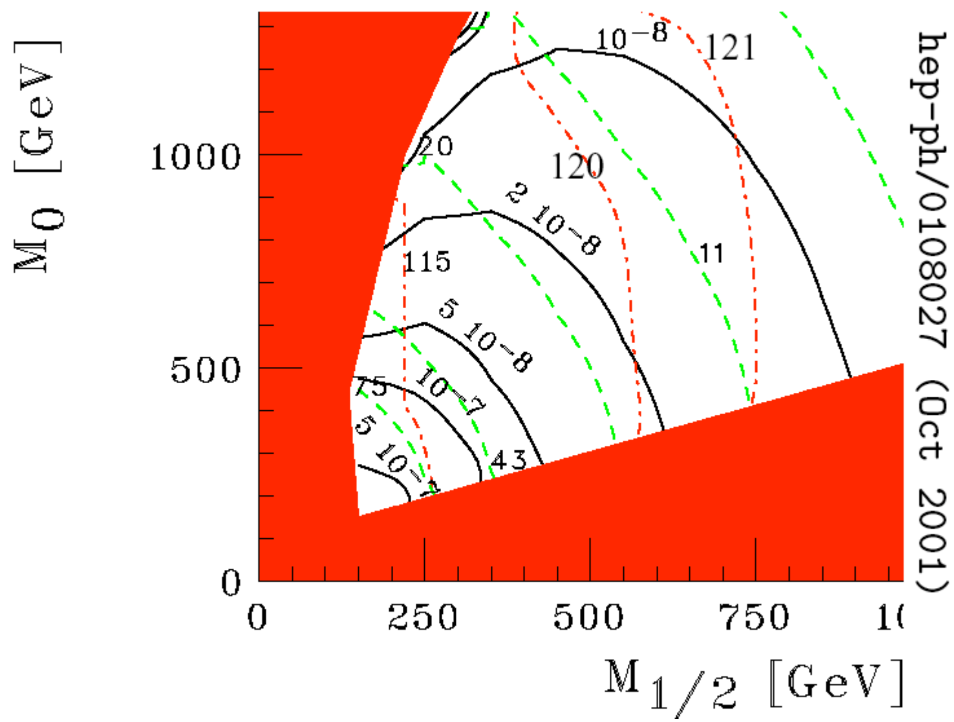
(PDG 90%CL: < 4.1×10^{-6})

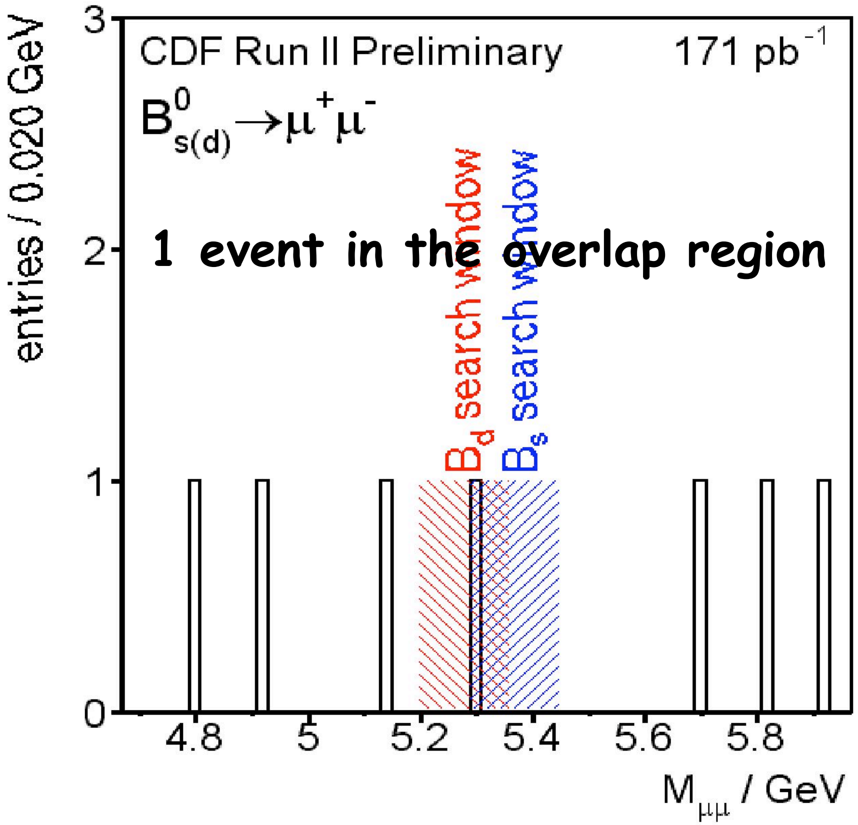
Rare decays expected in runII: ~100 $D^\pm \to \pi^\pm\mu\mu$

Rare decays: $B_{d(s)} \to \mu^+\mu^-$

Standard Model predicts $BR(B_s \to \mu^+\mu^-) = (3.8 \pm 1.0) \times 10^{-9}$

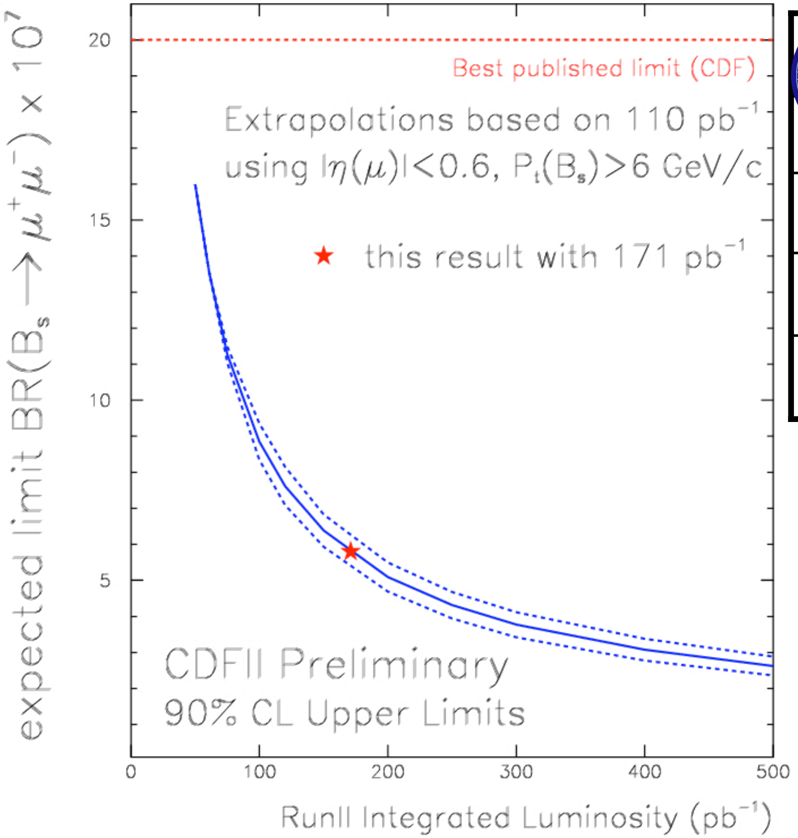
Several SM extensions predict an enhancement by 1 to 3 orders of magnitude, no excess already constrains several SUSY models





"Blind" analysis: cuts were optimized before looking at the signal mass region

Rare decays: $B_{d(s)} \to \mu^+\mu^-$



	$B_s \to \mu^+\mu^-$	$B_d \to \mu^+\mu^-$
Background	1.05±0.30	1.07±0.31
Data	1	1
BR limit @95% C.L.	7.5×10^{-7}	1.9×10^{-7}
BR limit @90% C.L.	5.8×10^{-7}	1.5×10^{-7}

Best world result for B_s
(improves CDF Run I)

Slightly better results than
Belle and BaBar for Bd

1.6×10^{-7} | 2.0×10^{-7}

Measured/Expected
BR limits vs. luminosity

DØ expects similar sensitivity

Conclusions

- B physics at Tevatron is kicking in: machine is starting to give yields
- Good results already on FCNC, Charm physics, charmless modes.
- A plethora of new Bs measurements coming.
- Bs mixing on the radar screen, will require statistics and patient tuning of flavor tagging
- Expect from Tevatron a significant contribution to CKM understanding