B Physics Expectations for Tevatron Experiments

Stephanie Menzemer

Massachusetts Insitute of Technology

for the CDF, D0 and BTeV Collaborations

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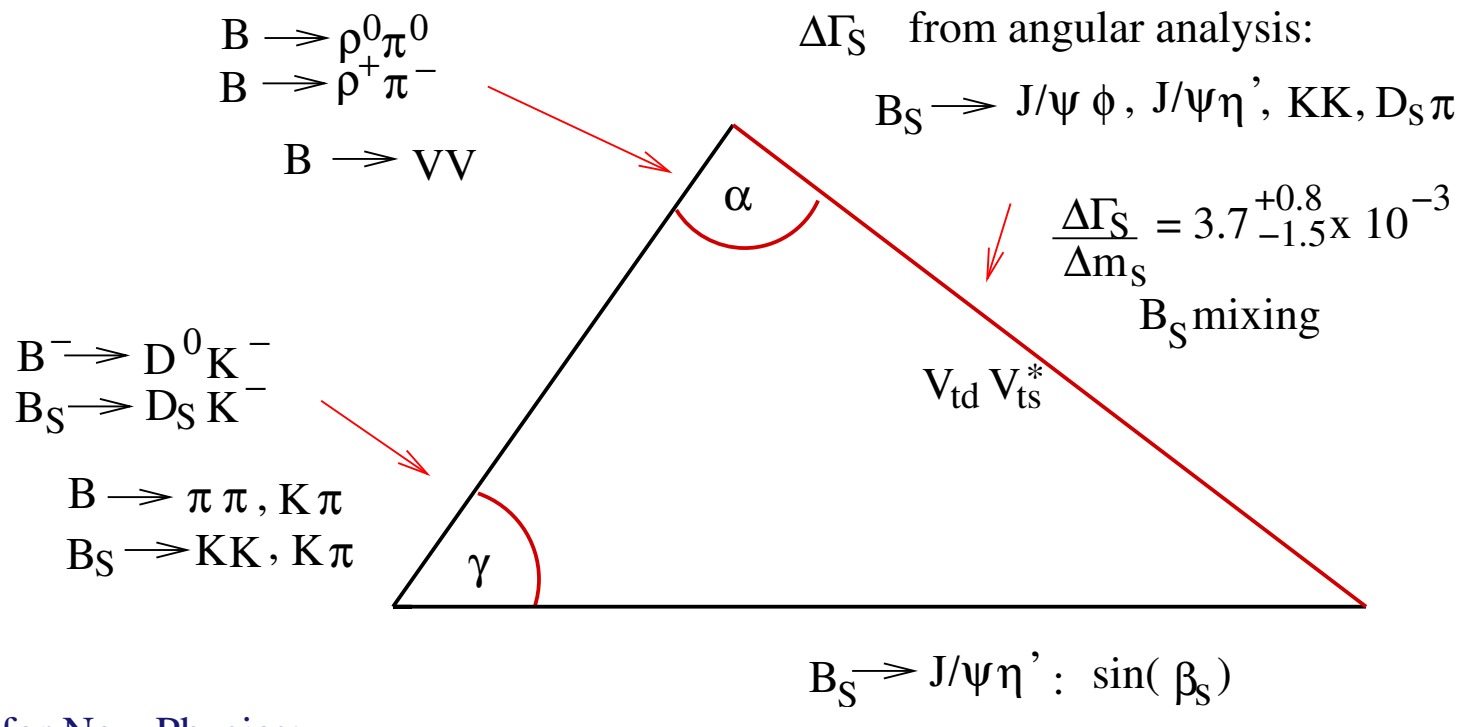
Physics Potential

- Tevatron has a huge procution rate and is uniquely able to study heavy states produced : B_s, B_c, Λ_b, Ξ_b, B^{**}, B_s^{**} and other excited states
- Constraining the CKM matrix



- Search for New Physics:
  - Search for Rare Decays: e.g. $B \to \mu\mu$
  - Indirect search: contribution from new particles in loops (BTeV sensitive to TeV mass scale)
  - Especially interessting: hints from B-Factories for new contributions in $b \to s\bar{s}s$ transition

Tevatron B-Physics program is complementary to the one from B-Factories!

Outline

- Most of our current analysis are limited by statistics
- Projections are hard to make for higher luminosities ...
  (more signal but as well higher S/N, different trigger strategies ...)
- mainly concentrate in this talk on existing measurements and point out their potential

- Present and near future: CDF and D0
  - CP Violation and Mixing
  - Search for FCNC - Rare Decays
  - Test of Heavy Quark Expansion:

    Masses & Lifetimes, Hadronic Moments
- A little bit further ahead
  - Physics plans for BTeV

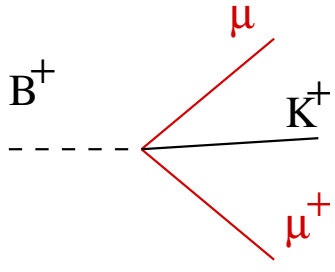
Triggering B Decays

$\sigma_{b\bar{b}}/\sigma_{tot} \approx 10^{-3}$, pick one B decay out of 10^3 QCD events

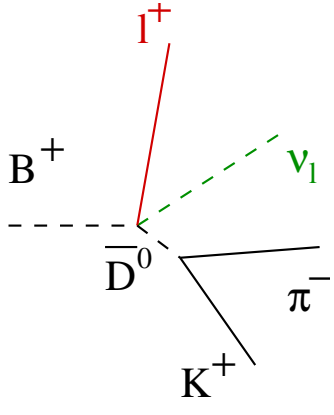
Trigger signatures: lepton (e, μ) and displaced tracks

Generally 3 trigger types for different types of B decays:

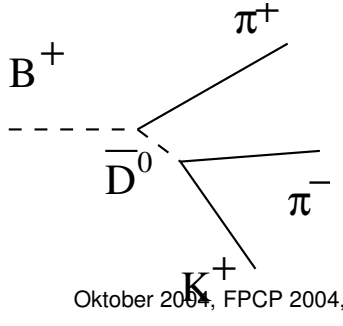
- B decays to J/ψ
  + muon provides easy trigger
  - small branching fraction



- Semi-leptonic B decays
  + large branching rations → large yields
  - missing neutrino



- Fully hadronic B decays
  + ≈ 80% of branching fraction
  - requires silicon track trigger

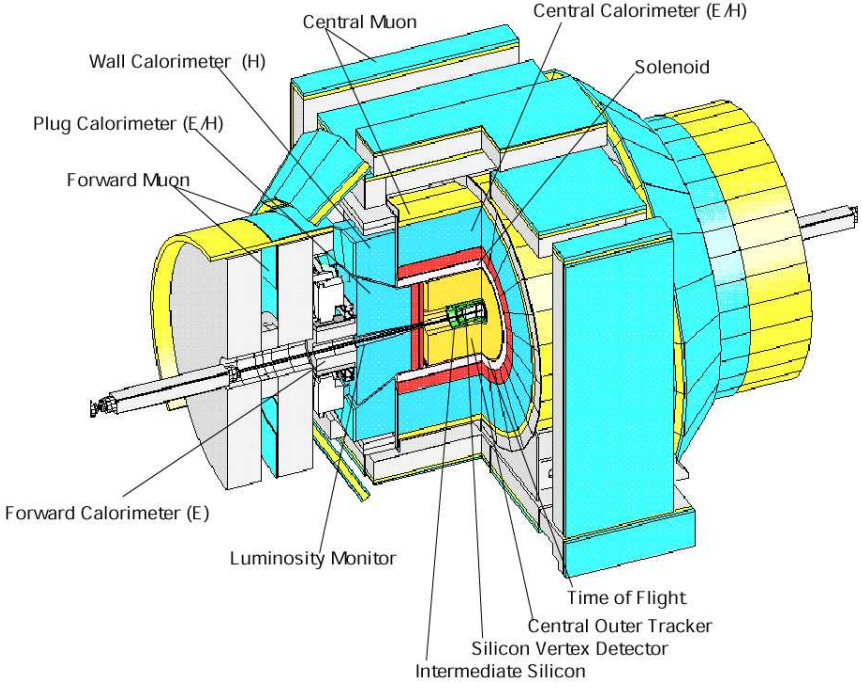


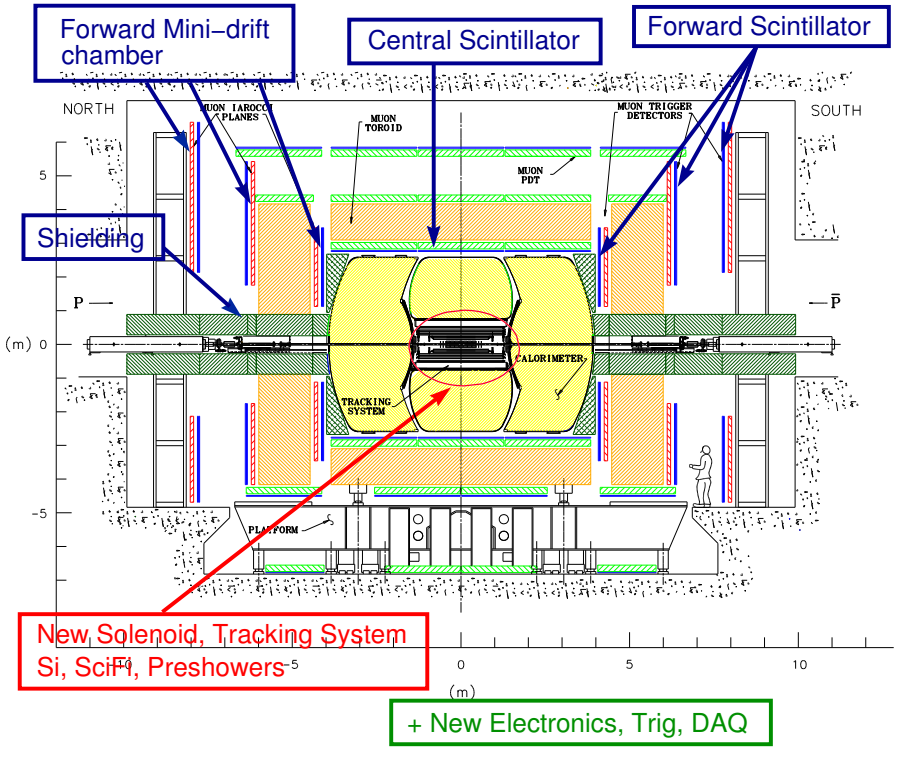
CDF versus D0 Detector

CDF

- Displaced track trigger
- PID: TOF and dE/dx
- Better mass resolution

Strong in fully hadronic modes





D0

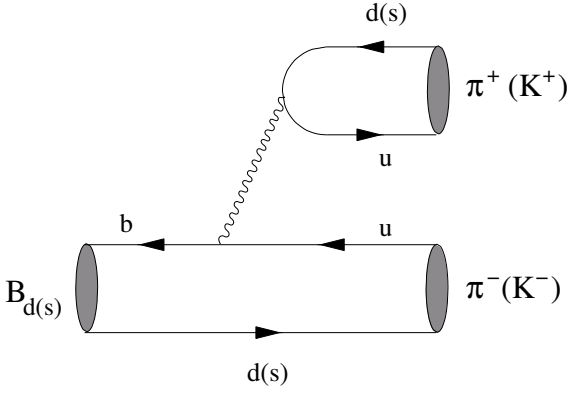
- Large muon coverage
- Better forward tracking

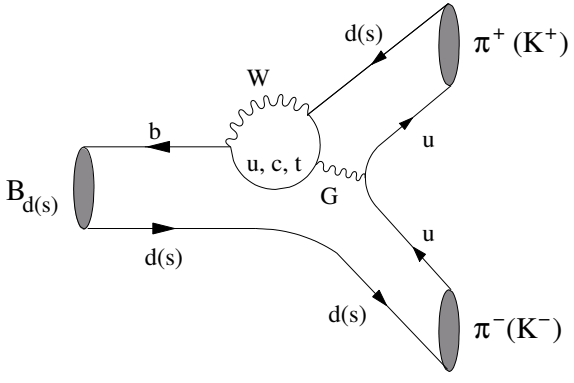
Strong in J/ψ modes

Strong in semileptonic modes

CP Violation in $B \to hh$

Tree (T) amplitupde larger than penguin (P) in $B_d \to \pi\pi$, vice-versa in $B_s \to KK$





- BR and A_{CP} for charmless 2 body B decays are predicted but variety of unknown amplitudes require reconstruction of a lot of modes
- Exploit U-Spin symmetry, 4 unknowns in time dependent asymmetry

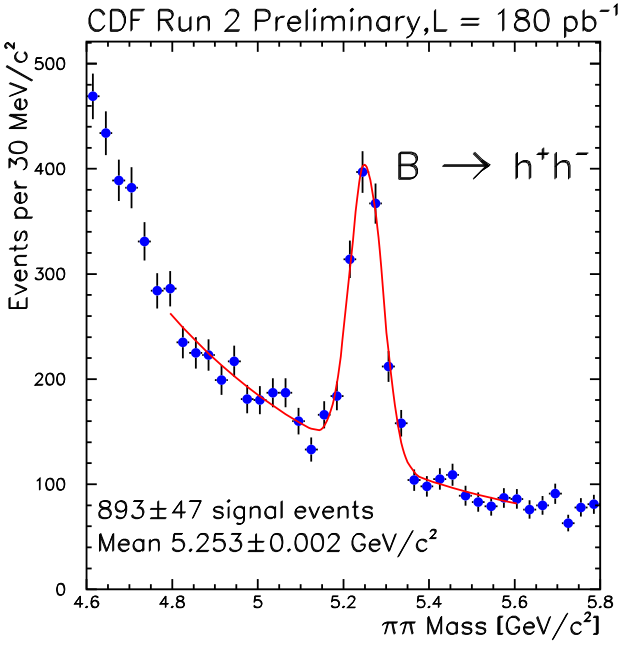
  d : ratio P/T hadronic matrix elements, θ : phase of d, γ, β: weak phases
- Hadronic uncertainties cancel up to small U-Spin breaking effects
- Fleischer (2 fb^{-1}): $\sigma(\gamma) = \pm 10^\circ(\text{stat}) \pm 3^\circ$ (SU(3) breaking)
- BR measurements, CP violation in $B_s \to KK$, $\Delta\Gamma_s$ from $B_s \to KK$ (compare $B_s \to J/\psi\phi$), ...

$B \to hh$ (CDF)

- Trigger on track pairs with large impact parameter
- Track cuts: $P_{T_{1/2}}$, $|D_{1/2}|$, $(P_{T_1} + P_{T_2})$
- B candidate cuts: L_{xy}, $|D_B|$, pointing constraint to primary vertex, Isolation cut:

$$I(B) = \frac{P_T(B)}{P_T(B) + \sum_{cone} P_{T_i}}$$

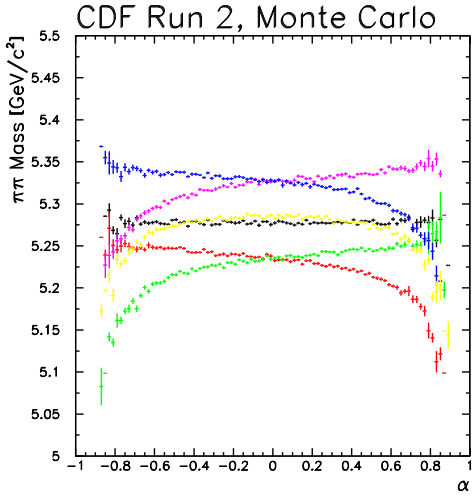
Signal: 893 ± 47, S/B>2



- The 4 major expected modes overlap to form a single bump
- Approach: use mass + kinematics + track PID in an unbinned Maximum Likelihood fit → extract the fraction of each component

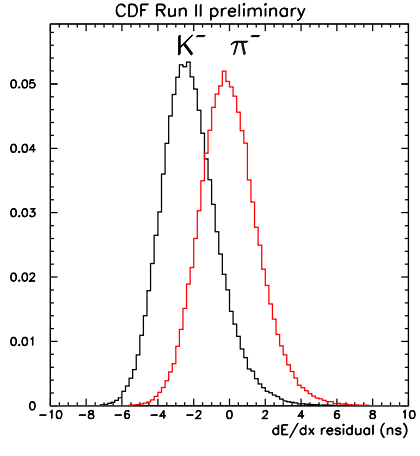
$B \to hh$: Separation of Modes (CDF)

Mass ($\pi\pi$ hypothesis) versus signed momentum inbalance $\alpha = (1 - \frac{p_1}{p_2}) * q_1$

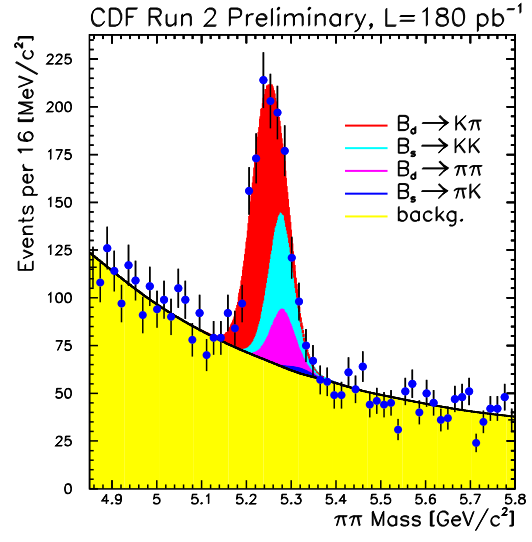


- $\bar{B}_s \to K\pi$
- $B_s \to K\pi$
- $\bar{B} \to K\pi$
- $B \to K\pi$
- $B_s \to KK$
- $B \to \pi\pi$

Kaon/Pion separation from dE/dx: 1.4σ ($p_T \geq 2$ GeV/c) calibration via $D^* \to \pi D^0 \to \pi h^+ h^-$



Fit Result



Decay	# events
$B \to K^+\pi^-$	509
$B \to \pi^+\pi^-$	134
$B_s \to K^+K^-$	232
$B_s \to K^-\pi^+$	–

$B \to hh$: Results (CDF)

B_d sector

- $\frac{BR(B_d \to \pi^+\pi^-)}{BR(B_d \to K^+\pi^-)} = 0.24 \pm 0.06 \pm 0.04$
  Ratio of B_d BR consistent with other experiments
- $A_{CP}(B_d \to K^+\pi^-) = -0.04 \pm 0.08 \pm 0.01$
  expect to reduce σ by factor 2 with available data
  $A_{CP} = -0.133 \pm 0.03 \pm 0.009$ (Babar), $A_{CP} = -0.088 \pm 0.03 \pm 0.013$ (Belle)
  A_{CP} results compatible with Babar/Belle

B_s sector

- $BR(B_s \to K^+K^-) = 0.50 \pm 0.08 \pm 0.07 * BR(B_d \to K\pi) * (f_s/f_d)$
- $BR(B_s \to K^+\pi^-) < 0.11 * BR(B_d \to K\pi) * (f_s/f_d)$

Limits on rare B_d, B_s modes *

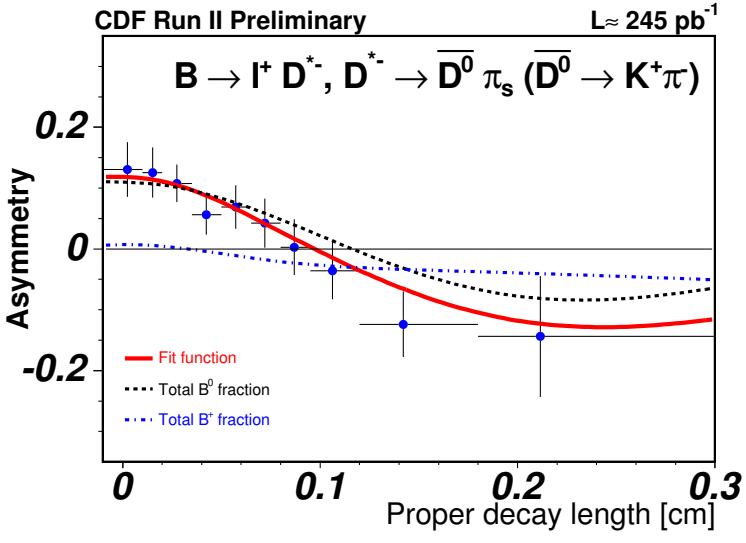
- $BR(B_d \to K^+K^-) = 0.17 * BR(B_d \to K\pi)$
- $BR(B_s \to \pi^+\pi^-) < 0.10 * BR(B_s \to KK)$

* Those limits might improved with a targeted analysis

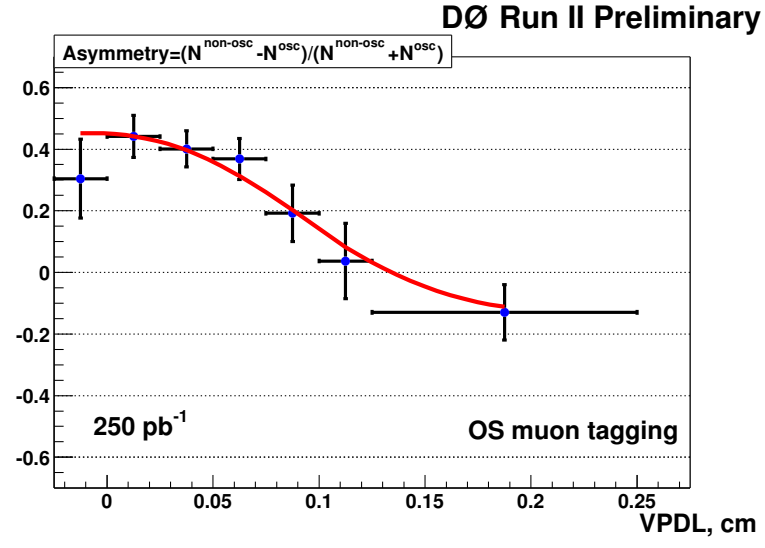
CDF has data from $2 \times$ more luminosity, with improved tracking and PID

Proof of Principle: B_d Mixing

CDF: Soft Muon Tagger



D0: Soft Muon Tagger



Combined taggers CDF:

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

$$\epsilon D^2 = 1.820 \pm 0.114\%$$

* sample composition

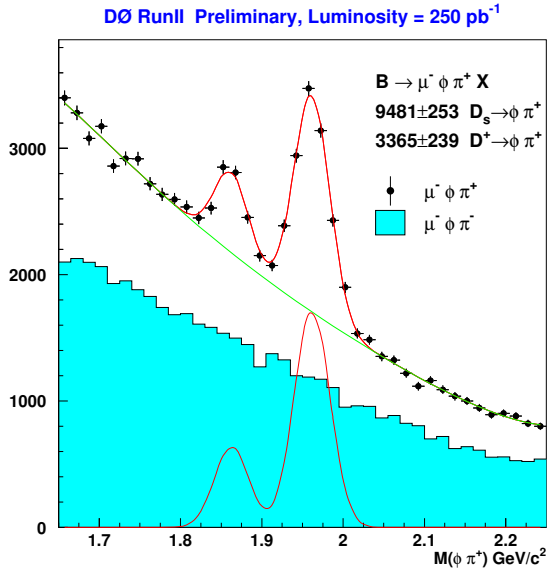
Combined taggers D0:

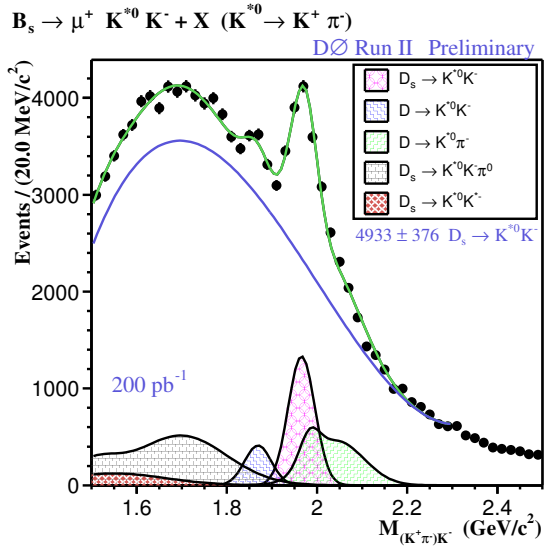
$$\Delta m_d = 0.456 \pm 0.034(\text{stat}) \pm 0.025(\text{syst})$$

$\epsilon D^2(\%)$	CDF	D0
SST	$1.04 \pm 0.35 \pm 0.06$	1.00 ± 0.36
Soft μ	$0.70 \pm 0.042^{+0.051}_{-0.027}$	2.54 ± 0.18
Soft e	0.35 ± 0.05	-
Jet-Q	0.715 ± 0.027	~ 1

B_s Mixing Sensitivity

D0: $B_s \to \mu D X$





CDF available modes:

- hadronic modes:
  - $B_s \to D_s \pi (D_s \to \phi\pi)$
  - $B_s \to D_s 3\pi (D_s \to \phi\pi)$
  - $B_s \to D_s \pi (D_s \to K^* K)$
  - $B_s \to D_s \pi (D_s \to 3\pi)$
- semileptonic mode:
  - $B_s \to l\nu D_s X (D_s \to \phi\pi)$

CDF baseline:

$\epsilon D^2 = 1.6\%$

$\sigma_t = 67$ fs

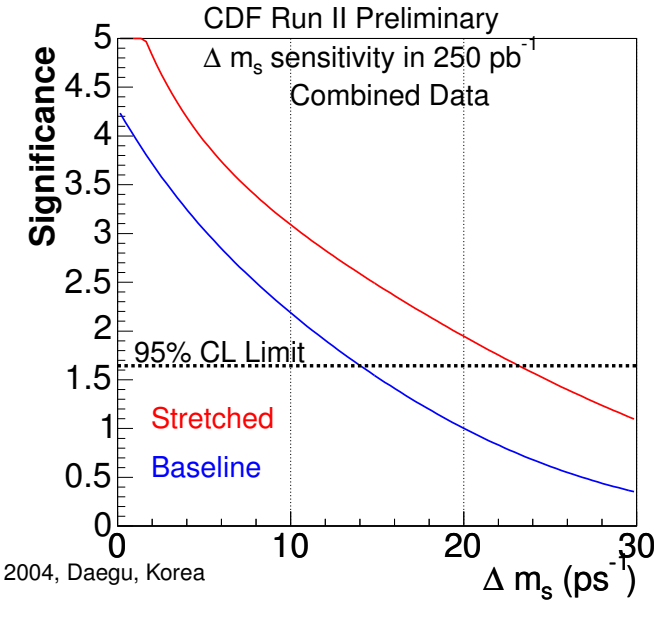
$\Delta m_s = 14$ ps^{-1}

CDF stretch:

$\epsilon D^2 = 2.6\%$

$\sigma_t = 47$ fs

$\Delta m_s = 23$ ps^{-1}



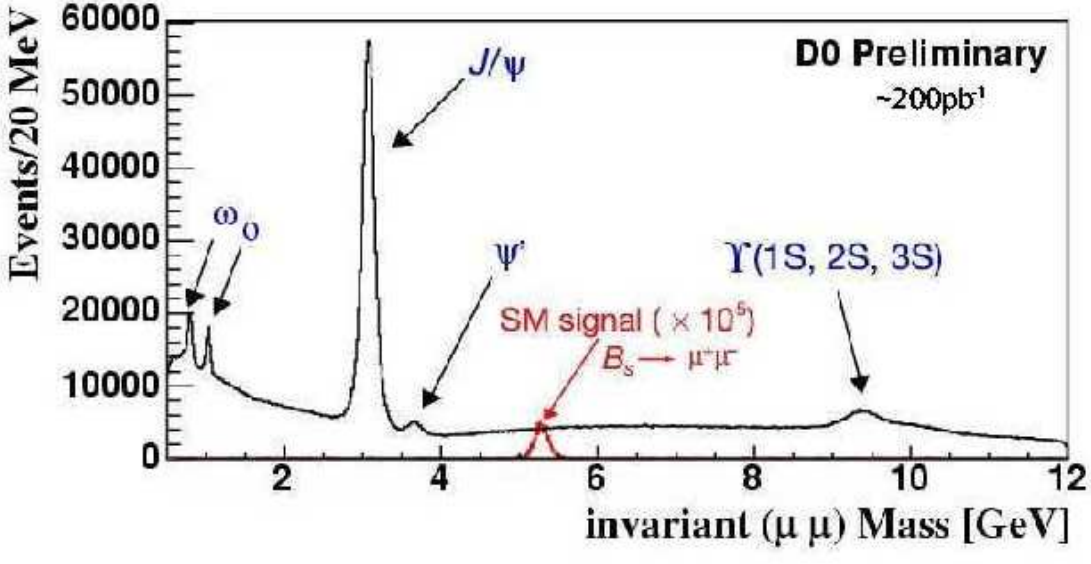
For more on B_s mixing see talks from

A. Nomerotski & S. Menzemer

Rare Decays: $B_{s(d)} \rightarrow \mu\mu$

- FCNC don't exist on tree level, suppressed on penguin level
- Theory prediction SM: $BR(B_{s(d)} \rightarrow \mu\mu) = 3.5 \times 10^{-9}(1.0 \times 10^{-10})$

  G. Buchalla, A.Buras, Nucl. Phys. B398,285
- But New Physics possibilities !

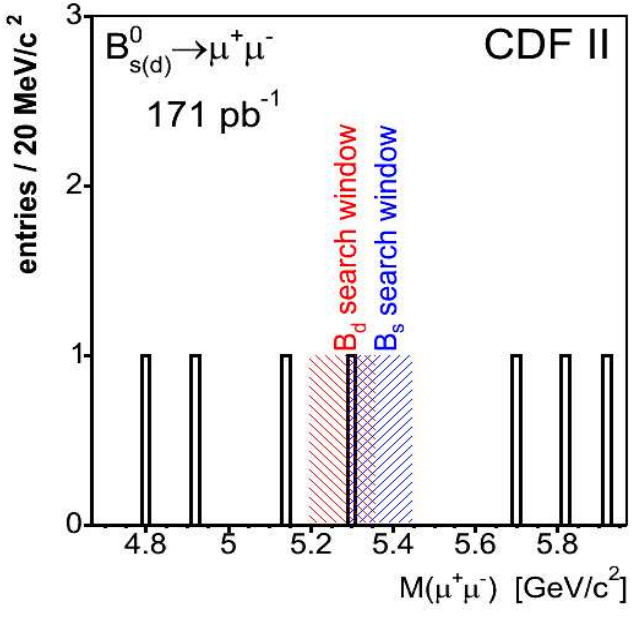


Key issue of the analysis at hadron colliders is to find discriminating variables to reject huge background!

CDF: $B_{s(d)} \to \mu\mu$

CDF perform blind analysis

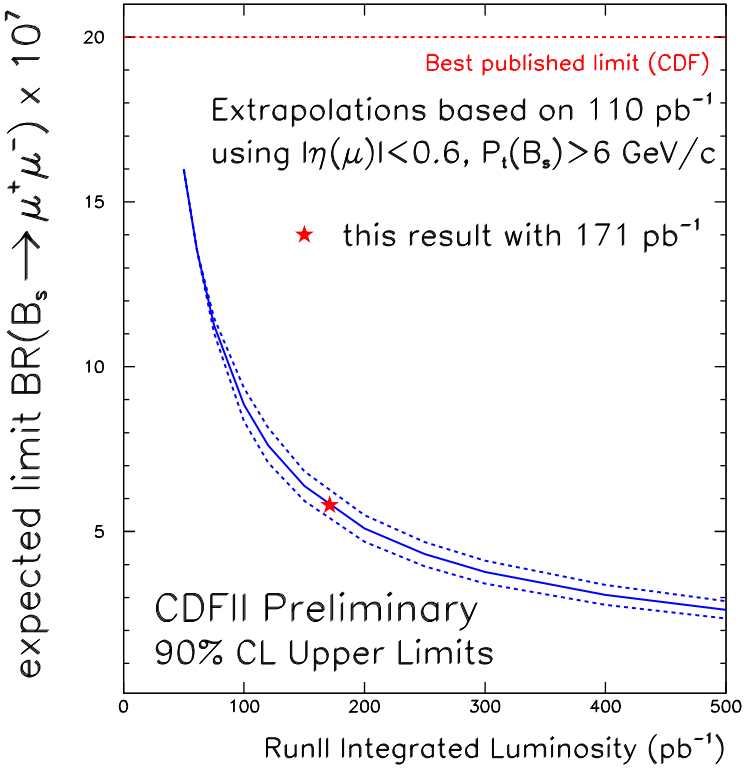
- Expected background
  $B_s(d) : 1.05 \pm 0.30 \; (1.07 \pm 0.31)$
- Observe 1 common event in 3σ $B_{s(d)}$ mass window



$BR(B_s \to \mu\mu) < 5.8 \times 10^{-7} @ 90\% CL$

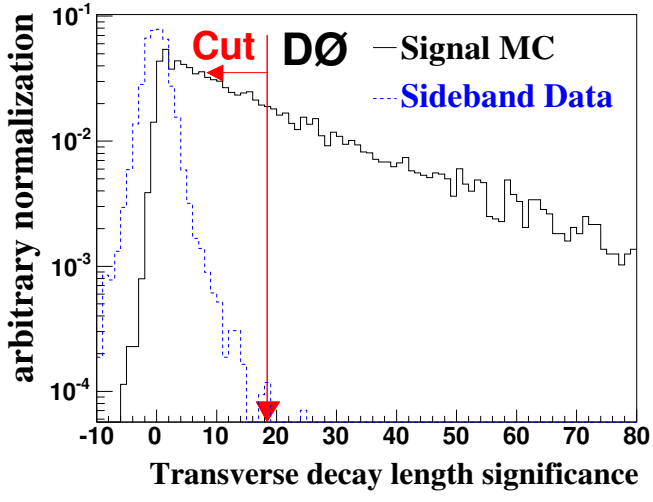
$BR(B_d \to \mu\mu) < 1.5 \times 10^{-7} @ 90\% CL$

BaBar B_d result: 8.3×10^{-8}



not sensitive to SM, but limit many models

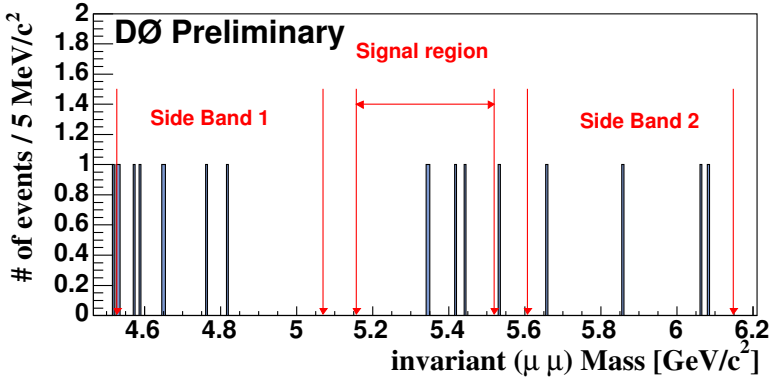
D0: $B_s \to \mu\mu$



Results

- Expected background B_s : 3.7 ± 1.1
- Observe 4 events in 2σ B_s mass window

- L_{xy} significance: $L_{xy}/\delta L_{xy} > 18.47$
- $\Delta\Phi$: $|\phi_B - \phi_{vtx}| < 0.203$ rad
- Isolation cut: I(B) > 0.56
- Mass $M_{\mu\mu}$: 2σ window (σ = 90 MeV/c^2)
- Use random grid search for optimization
- Use $B^+ \to J/\psi K^+$ for relative normalization



$$BR(B_s \to \mu\mu) < 3.8 \times 10^{-7} @ 90\% CL$$

D0 result: world best limit

Testing HQET

Goal: Test the HQE predicted B lifetime hierarchy:

$$\tau_{B_c} \ll \tau_{\Xi b0} \sim \tau_{\Lambda_b} < \tau_{B_d} \sim \tau_{B_s} < \tau_{B^-} < \tau_{\Xi b^-}$$

- Fully reconstructed B from Di-Muon trigger (e.g. $B_s \to J/\psi\phi$) or Two Track Trigger ($B_s \to KK$)
- Find vertex, 2D-distance L_{xy}, invariant mass: M_B, 2D momentum: p_T^B $\to$ proper time: $c\tau = L_{xy} * M_B/p_T^B$
- Fit mass distribution only or simultaneously mass and lifetime

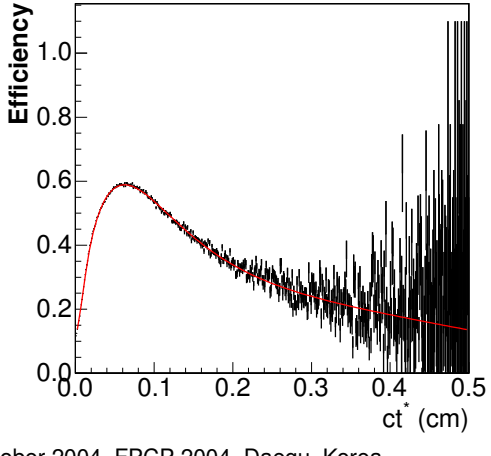
- Partially reconstructed $(B \to \mu D^- X)$ from lepton (+ SVT (CDF)) trigger
- Incomplete reconstruction:

  $c\tau = L_{xy}(\mu D) * M_B * \kappa/p_T^{\mu D}$; κ from MC

+ high statistic

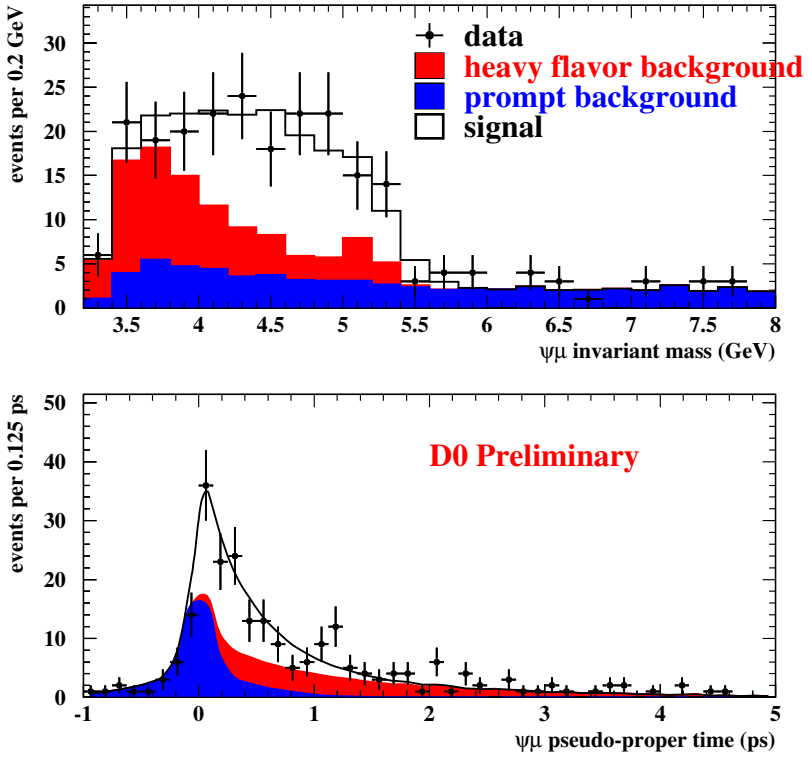
- complex sample composition

- SVT trigger have **biased** $c\tau$



Observation of B_c (D0)

B_c Meson in $J/\psi\mu X$ final state



Combined mass and lifetime fit

Fit Result:

- 95 ± 11.8 signal events
- 66.0 prompt bgr. events
- 69.5 bgr. events from heavy flavour

$$m(B_c) = 5.95^{+0.14}_{-0.13} \pm 0.34 \text{ GeV/c}^2$$
$$\tau(B_c) = 0.448^{+0.123}_{-0.096} \pm 0.121 \text{ ps}$$

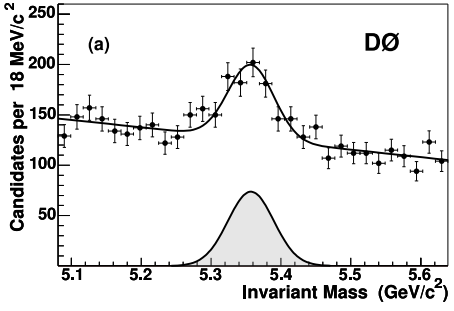
For the first time more than 5σ significance in access of B_c signal!

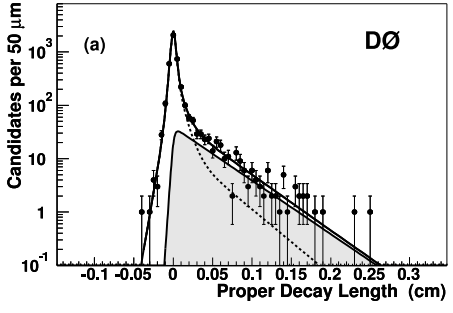
More on heavy Bs in A. Nomerotski's talk

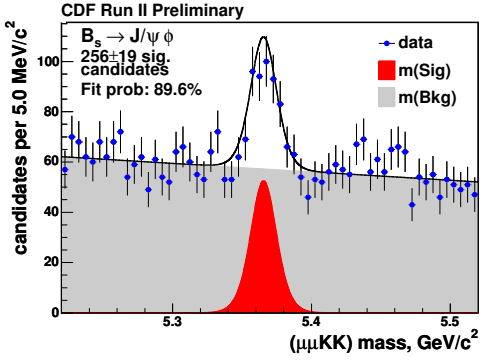
$B_s \to J/\psi\phi$ Lifetime and Mass

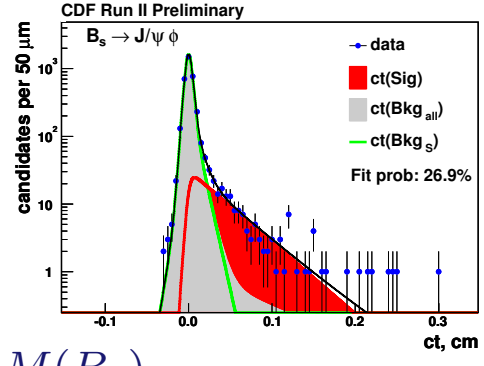
D0

(337 events)









CDF

$M(B_s)$

$M(B_s) = 5360 \pm 5$ MeV/c^2

$= 5366.01 \pm 0.73$ (stat)± 0.033 (sys)MeV/c^2

$\tau_s/\tau_d = 0.980^{+0.075}_{-0.070}$(stat)$\pm 0.003$ (syst)

$\tau_s/\tau_d = 0.890 \pm 0.072$ (tot)

Ratio respect to $B_d \to J/\psi K^{*0}$

Other masses & lifetime results:

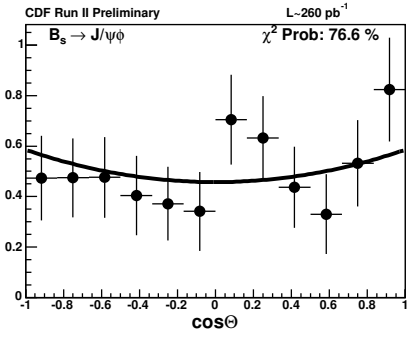
$\tau(\Lambda_B) = 1.25 \pm 0.26 \pm 0.10$ ps, $M(\Lambda_b) = 5619.7 \pm 1.3 \pm 1.2$MeV/c^2 (CDF)

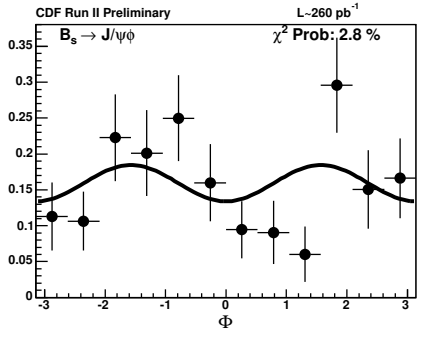
$\tau(\Lambda_B) = 1.221^{+0.217}_{-0.179} \pm 0.043$ ps, (D0)

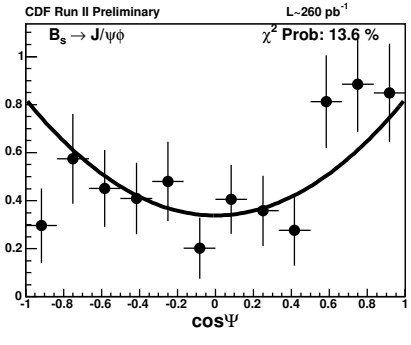
B^+, B^0, B_s and Λ_B mass measurements are world best!

Polarisation Amplitudes (CDF)

- $B_s \to J/\psi\phi$: Pseudoscalar $\to$ Vector - Vector
- Decay amplitude decomposed into 3 linear polarization states
  - $|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$
  - A_0 : S+D wave $\to$ P even
  - $A_\parallel$: S+D wave $\to$ P even
  - $A_\perp$: P wave $\to$ P odd
- If CP violation neglected
  - $B_{s,L} \approx$ CP even
  - $B_{s,H} \approx$ CP odd

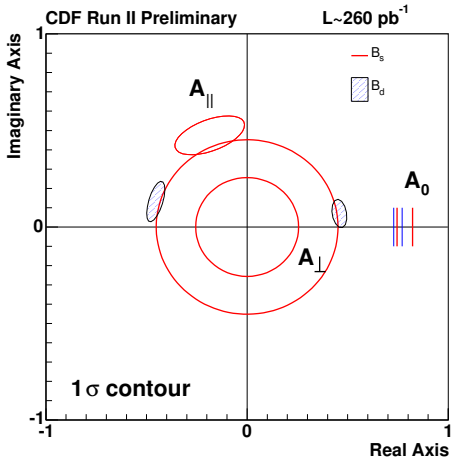


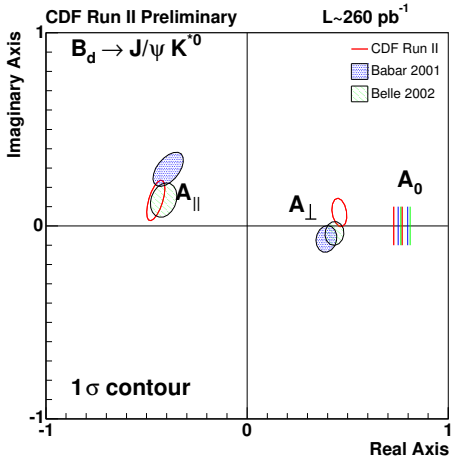




  - Angular distributions are different
- Together with lifetime measurement, angular analysis can separate both states and determine $\Delta\Gamma_s \to$ independent cross check for Δm_s

$B_s \to J/\psi\phi$: $\Delta\Gamma_s$(CDF)





Analysis as well performed for

$$B_d \to J/\psi K^{*0}$$

$$A_{\|} = (0.510 \pm 0.082 \pm 0.013)e^{(1.94\pm0.36\pm0.03)i}$$

$$|A_\perp| = 0.354\pm0.098\pm0.003$$

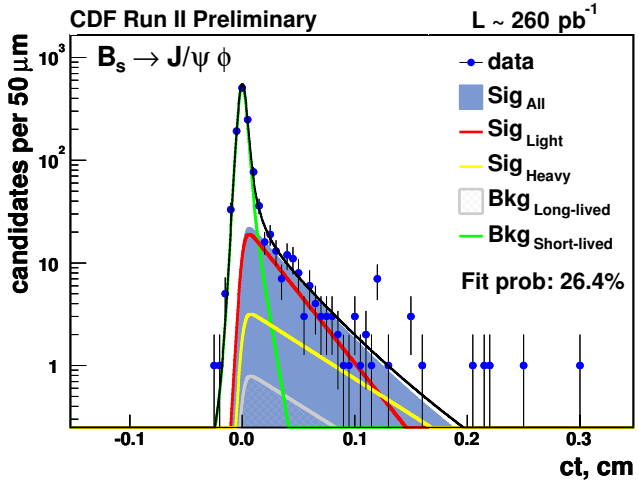
$$A_0 = 0.784 \pm 0.039 \pm 0.007$$

$$\tau_L = 1.05^{0.16}_{0.13} \pm 0.02 \text{ ps}$$

$$\tau_H = 2.07^{+0.58}_{-0.40} \pm 0.03 \text{ ps}$$

$$\Delta\Gamma/\Gamma = 0.65^{+0.25}_{-0.33} \pm 0.01$$

$$\Delta\Gamma = 0.47^{+0.19}_{-0.24} \pm 0.01 \text{ ps}^{-1}$$



- B_d amplitudes compare well with Babar/Belle
- With $\approx$ 200 signal events CDF finds a large value for the lifetime difference, $\approx 3\ \sigma$ away from $\Delta\Gamma_s = 0$

D0 result ready soon!

Charmless $B \to VV$

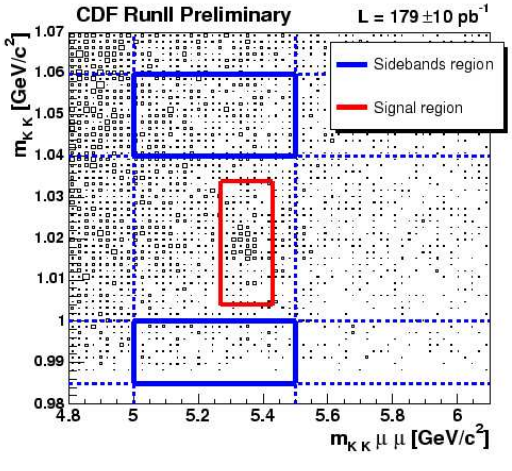
Motivation

- much smaller branching rations than $b \to c\bar{c}s$
- test predictions from QCD factorization
- α & γ measurement from comparison of angular distributions of various $B \to VV$ decays
- Study $b \to s\bar{s}s$ transition in B_s modes; verify hints from B-Factories for effects in $B_d \to \phi K_s$ and in $B \to \phi K^*$.

$B_s \to \phi\phi$ (CDF):

- Blind analysis
- For normalization topological similar decay: $B_s \to J/\psi\phi$

  no uncertainty due to B_s/B_d cross section
- $B_d \to J/\psi K^{*0}$ for acceptance corrections and cut optimization



sideband and signal region in $M_\phi - M_{B_s}$ plane

Evidence for $B_s \to \phi\phi$ (CDF)

$$BR(B_s \to \phi\phi) = \frac{N(\phi\phi)}{N^{corr}(J/\psi\phi)} \frac{\epsilon(J/\psi\phi)}{\epsilon(\phi\phi)} \frac{BR(B_s \to J/\psi\phi) BR(J/\psi \to \mu\mu)}{BR(\phi \to KK)}$$

ϵ total acceptance from detailed simulation

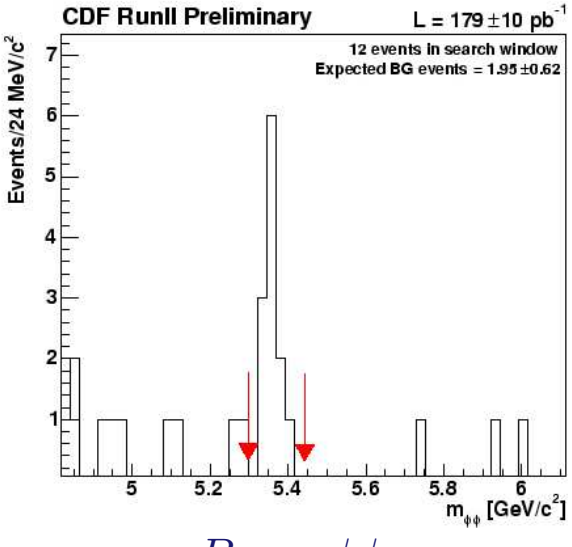
N number of events (N^{corr} includes muon trigger and reconstruction efficiency)

BR taken from PDG

$$BR(B_s \to \phi\phi) = (1.4 \pm 0.6(\text{stat}) \pm 0.2(\text{syst}) \pm 0.5(BR)) \times 10^{-5}$$

QCD factorization: BR = 3.68×10^{-5}

$4.7\ \sigma$



$B_s \to \phi\phi$ mass

Measure soon polarization amplitudes (signal very clean) !

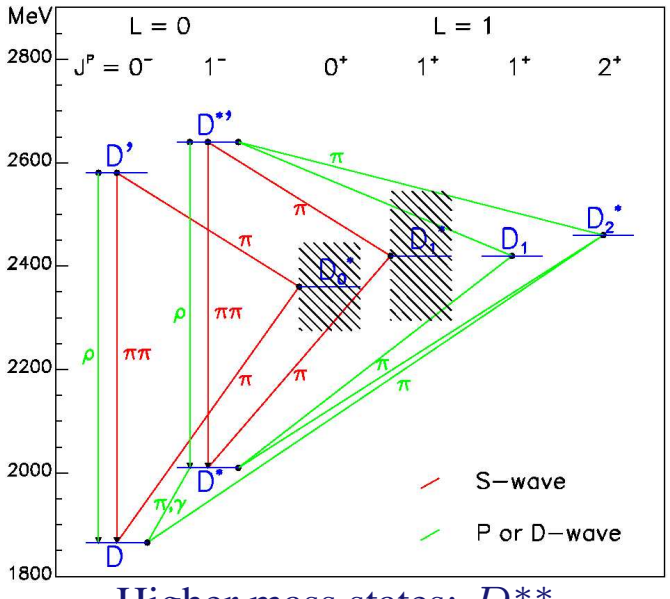
Hadronic Moments

- V_{cb} is mostly determined by Γ_{sl}

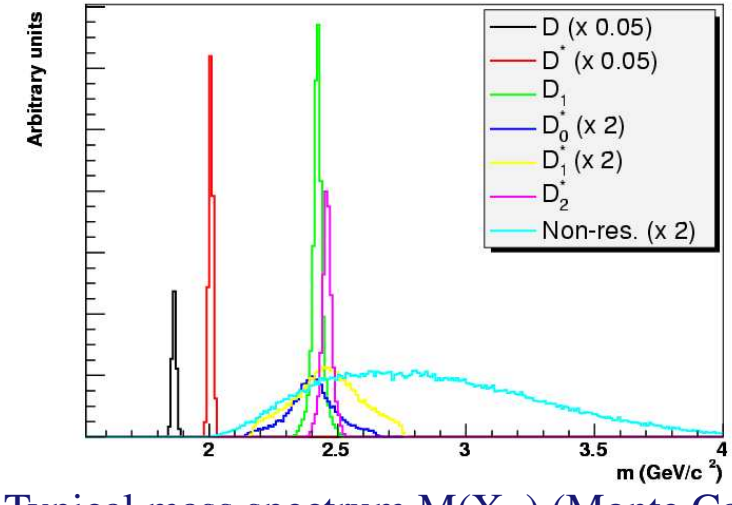
$$\Gamma_{sl}(B \to X_c l\nu)) = \frac{BR(b \to X_c l\nu)}{\tau_b} = |V_{cb}|^2 \times F_{theory}$$

- Uncertainties on V_{cb} dominated by theoretical errors.
- Γ_{sl}, V_{cb} are related within OPE in HQET in expansions in $1/m_b$ with unknown coefficients
- Measure hadronic moments to nail down those parameters
- Measure first and second moment of $M(X_c)$ distribution $(B \to X_c l\nu)$

X_c = { D^0, D^{*0} from PDG , D^{**0} }



Higher mass states: D^{**}



Typical mass spectrum M(X_c) (Monte Carlo)

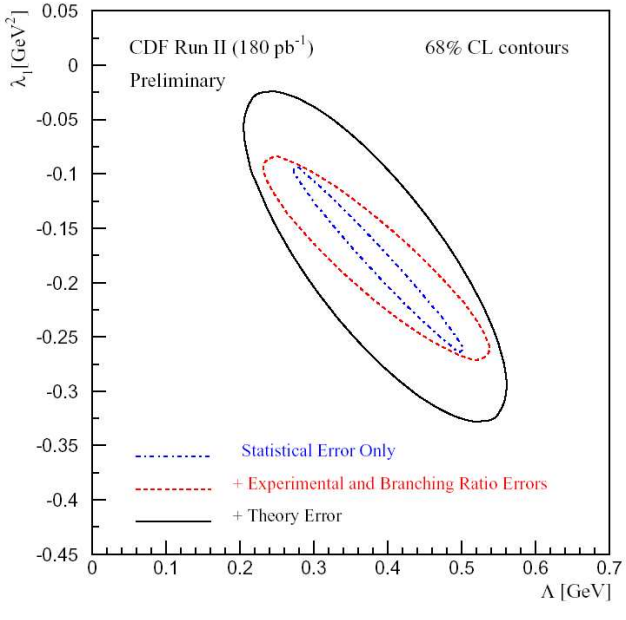
Hadronic Moments (CDF)

measurement:

$$
\begin{aligned}
m_1 \equiv \left\langle m_{D^{**}}^2 \right\rangle &= (5.83 \pm 0.16_{\text{stat}} \pm 0.08_{\text{exp}})\ \text{GeV}^2 \\
m_2 \equiv \left\langle \left(m_{D^{**}}^2 - \left\langle m_{D^{**}}^2 \right\rangle \right)^2 \right\rangle &= (1.30 \pm 0.69_{\text{stat}} \pm 0.20_{\text{exp}})\ \text{GeV}^4 \\
\rho_{m_1,m_2} &= 0.48
\end{aligned}
$$

derived quantities:

$$
\begin{aligned}
M_1 \equiv \langle s_H \rangle - m_D^2 &= (0.459 \pm 0.037_{\text{stat}} \pm 0.019_{\text{exp}} \pm 0.062_{\text{BR}})\ \text{GeV}^2 \\
M_2 \equiv \left\langle \left(s_H - \langle s_H \rangle \right)^2 \right\rangle &= (1.04 \pm 0.25_{\text{stat}} \pm 0.07_{\text{exp}} \pm 0.10_{\text{BR}})\ \text{GeV}^4 \\
\rho_{M_1,M_2} &= 0.62
\end{aligned}
$$



λ_1, Λ of OPE (pole mass scheme)

- First measurement of hadronic moments in semileptonic B decays at $p\bar{p}$
- Good agreement with HQET and previous determination.
- Increased statistics and improved tracking will lead to substantially more precise results in the near future

BTeV: Detection in Forward Region

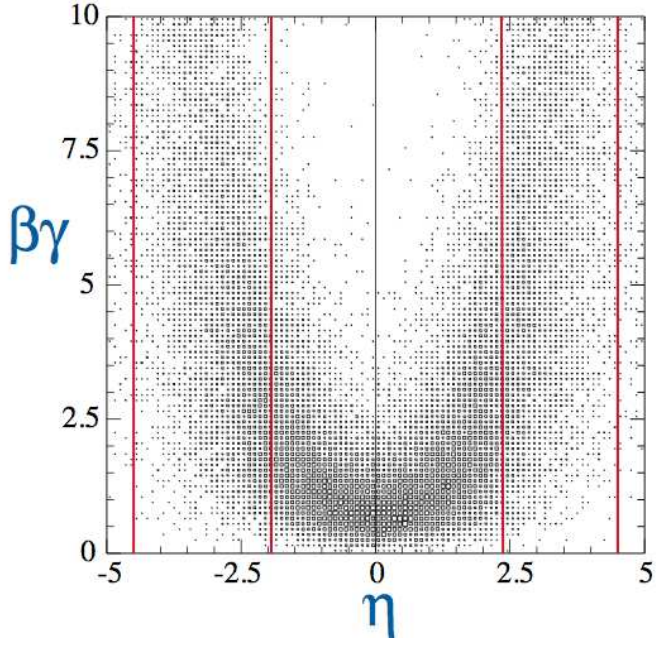
The high momentum b's are at large η

$\rightarrow$ larger decay length in lab frame

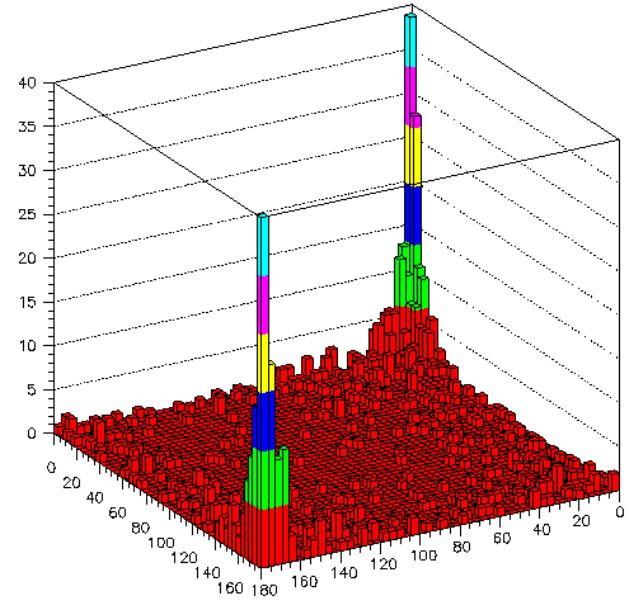
$\rightarrow$ less multiple scattering

$$p\bar{p} \rightarrow b\bar{b} + X$$

b production peaks at large angles with large $b\bar{b}$ correlation (opposite side tagging)

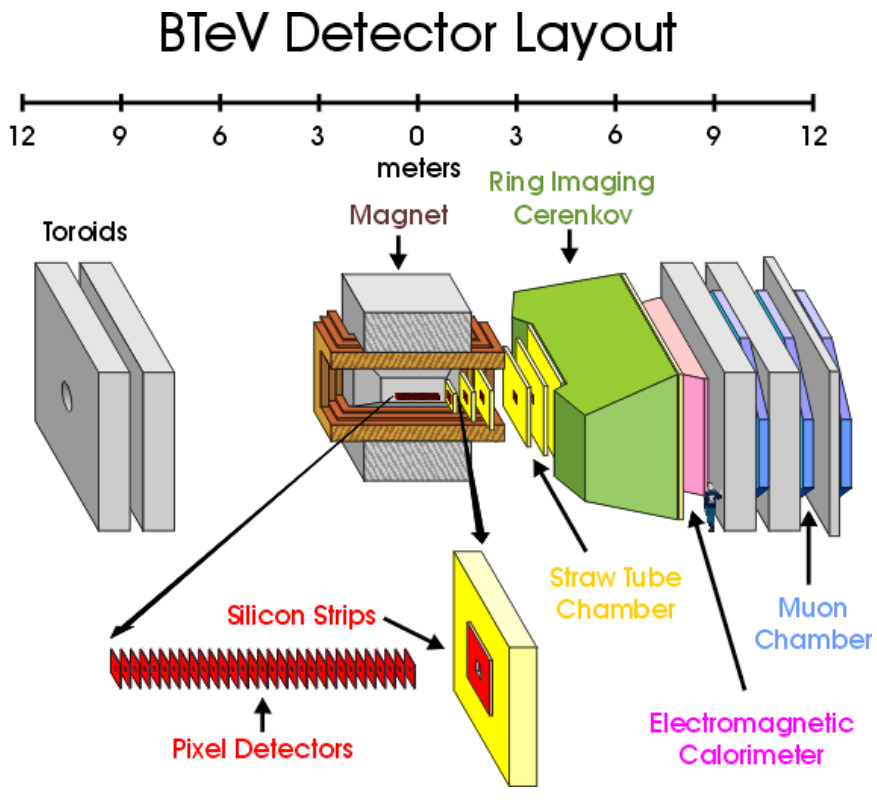


$$\eta = -ln\tan(\frac{\theta}{2})$$



BTeV detects in the forward region ($1.9 < |\eta| < 4.5$)

BTeV: Detector



- Start construction 2005
- Start data taking 2009

- high resolution pixel detector: 5-10μm, used for L1 vertex triggering
- $PbW0_4$ EM calorimeter for neutral particles, excellent spatial and energy resolution

  each cristal: $28 \times 28\text{mm}^2 \times 22\text{cm}$, stochastic term = 1.8%

- RICH for PID

BTEV: Physics Reach

potential CKM physics reach with 2 fb^{-}1 of data

Decay	BR ($\times 10^{-6}$)	# of Events	S/B	Parameter	Error or Value
$B \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7,500	7	$\gamma - 2\chi$	8°
$B \to J/\psi(l^+l^-)K_S$	445	168,000	10	$\sin(2\beta)$	0.017
$B_s \to D_s\pi^-$	3000	59,000	3	x_s	75
$B^- \to D^0(K^+\pi^-)K^-$	0.17	170	1		
$B^- \to D^0(K^+K^-)K^-$	1.1	1,000	>10	γ	13°
$B^- \to K_s\pi^-$	12.1	4,600	1		$<4^\circ$ +
$B^0 \to K^+\pi^-$	18.8	62,100	20	γ	theory errors
$B^0 \to \rho^+\pi^-$	28	5,400	4.1		
$B^0 \to \rho^0\pi^0$	5	780	0.3	α	$\approx 4^\circ$
$B_s \to J/\psi(l^+l^-)\eta$	330	2,800	15		
$B_s \to J/\psi(l^+l^-)\eta'$	670	9,800	30	$\sin(2\chi)$	0.024

BTeV is not just doing SM but is sensitive to New Physics as well!

Using b and c decays mediated by loop diagrams BTeV is sensitive to mass scales of up to TeV.

Summary

CDF/D0:

- Results from $\sim 250pb^{-1}$ of data:
  - Precision mass and lifetime measurements
    (as well test of vertexing/tracking for future measurements)
  - Search for CPV in the neutral B system
  - First limits on rare BRs
- Future plans - $2fb^{-1}$ of data:
  - Achieve better than 1% accuracy on uncertainty on lifetime ratios
  - Measure B_s mixing parameter x_s, expect to measure $\delta(\Delta\Gamma_s) \sim 5\%$
  - Measure CKM angle γ
  - Improve limits on rare decays

BTeV

- Detector is specialized on B-Physics needs, start data taking 2009
- Large range of B-Physics analysis due to high statistic and cabability to reconstruct neutrals
- Precision measurements of SM and beyond feasible

Future Tevatron program will be mostly complementary to the B-factories