Study of $B_s \to D_s^{+(*)} D_s^{-(*)}$ and $B_s \to \phi\phi$ Decays at CDF II

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Some of the Challenging Questions in B_s Physics

- New Physics (NP) in B_s mixing?
  - Measurement of the CP violating phase $\phi_s = 2\beta_s$ based on an angular- and time-dependent analysis of $B_s \to J/\psi\phi$ (J. Morlock's talk)
- $\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H$ sizable as predicted in standard model (SM)?
  - Constrain $\Delta\Gamma_s^{CP}/\Gamma_s$ by measuring the branching fractions of $B_s \to D_s^{+(*)} D_s^{-(*)}$ (this talk)
- NP in $b \to s$ penguin transitions and/or B_s mixing?
  - Measure Branching fraction of $B_s \to \phi\phi$ (this talk)
  - Polarization measurement in $B_s \to \phi\phi$ (near future)
  - Test of new physics contributions to the vanishing weak phase $\phi_s(B_s \to \phi\phi)$ (future)

Introduction

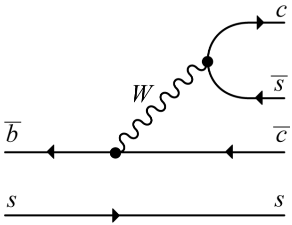
$B_s \to D_s^{+(*)} D_s^{-(*)}$ Analysis

$B_s \to \phi\phi$ Analysis

Conclusion and Outlook

Backup

Motivation



- SM: Decay governed by tree level $b \to c\bar{c}s$ transition
- Sizable $\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H$ predicted in SM
- Assuming Γ_{12} receives its dominant contribution from $b \to c\bar{c}s$ transitions:
  $\Rightarrow \Delta\Gamma_s = \Delta\Gamma_s^{CP} \cos\phi_s$
- Assuming that the preferred final state of $b\bar{s} \to c\bar{c}s\bar{s}$ is $D_s^{+(*)} D_s^{-(*)}$ and that this has a defined, predominantly even CP content:
  $\Rightarrow 2\mathcal{B}[B_s \to D_s^{+(*)} D_s^{-(*)}] \cong \Delta\Gamma_s^{CP}/\Gamma_s$[1]

[1] I. Dunietz, R. Fleischer, U. Nierste, *In Pursuit of New Physics with B_s Decays*, arxiv:hep-ph/0012219 (2001)

Existing Measurements

- DØ (2.8 fb^{-1})[2]: Evidence for $B_s \to D_s^{+(*)}(\phi\pi) D_s^{-(*)}(\phi\mu\nu)$ using semi-leptonic, semi-inclusive reconstruction
  - About 27 signal events
  - $\mathcal{B}[B_s \to D_s^{+(*)} D_s^{-(*)}] = 0.035 \pm 0.010(stat) \pm 0.011(syst)$
  - $\Rightarrow \Delta\Gamma_{CP}/\Gamma = 0.072 \pm 0.021(stat) \pm 0.022(syst)$
- CDF (355 pb^{-1})[3]: Observation of $B_s \to D_s^+(\phi\pi) D_s^-(\phi\pi; K^{0*}K^-; 3\pi)$, exclusive hadronic reconstruction
  - About 24 signal events
  - $\mathcal{B}[B_s \to D_s^+ D_s^-] = 0.0094^{+0.0044}_{-0.0042}$
  - $\Rightarrow \Delta\Gamma_{CP}/\Gamma > 0.012$ at 95% C.L.

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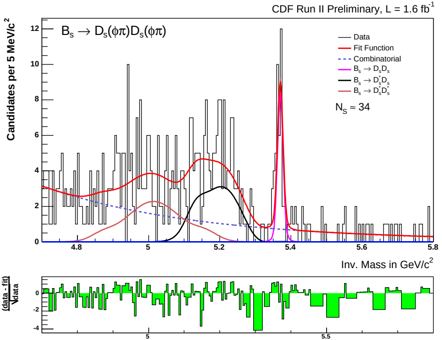
[2] DØ Collaboration, *Evidence for the Decay $B_s \to D_s^{+(*)} D_s^{-(*)}$ and a Measurement of $\Delta\Gamma_s^{CP}/\Gamma$*, PRL 102, 091801 (2009)

[3] CDF Collaboration, *First Observation of the Decay $B_s \to D_s^+ D_s^-$ and Measurement of its Branching Ratio*, PRL 100, 021803 (2008)

Ongoing Analysis

- Currently repeating branching fraction measurement on up to 4 fb^{-1} using same hadronic decay modes
- Makes additionally use of PID and neural networks for optimized candidate selection



- In addition to $\mathcal{B}[B_s \to D_s^+ D_s^-]$ we will be able to also measure $\mathcal{B}[B_s \to D_s^{+(*)} D_s^{-(*)}]$ separately
- Given sufficient statistics, lifetime measurements might offer additional insights on $\Delta\Gamma_s$

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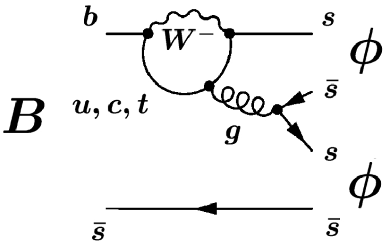
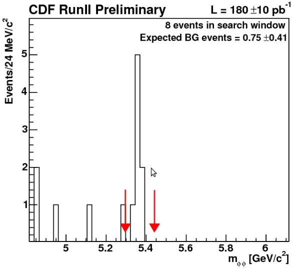
- Self-conjugate $B_s \to VV$ decay



- Dominant decay process in SM: $b \to s\bar{s}s$ penguin transition

- Provides opportunity for several interesting checks:
  - Test of SM branching fraction expectation
  - Potential probe of CP-violating phases in penguin decay and/or mixing by $\Delta\Gamma_s$ measurement
  - Check polarization predictions, compare to decays like $B^0 \to \phi K^*$

First Evidence for $B_s \to \phi\phi$[5]



- Data sample of 180 pb^{-1}
- 8 signal events seen

- $\mathcal{B}[B_s \to \phi\phi] = [1.4 \pm 0.6(stat) \pm 0.6(syst)] \cdot 10^{-5}$
- Theoretical estimation[4]:
  $\mathcal{B}[B_s \to \phi\phi] = [2.18^{+0.11+3.04}_{-0.11-1.7}] \cdot 10^{-5}$

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[4] Beneke at al., *Branching fractions, polarization and asymmetry in $B \to VV$ decays* (2006)

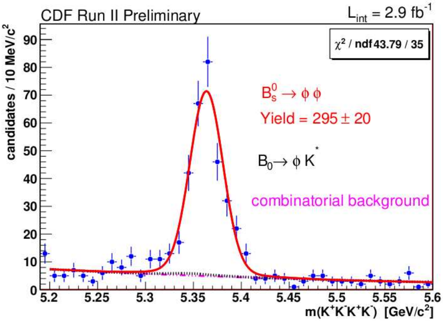
[5] CDF Collaboration, *Evidence for $B_s \to \phi\phi$ decay and Measurements of Branching Ratio and A_{CP} for $B_+ \to \phi K^+$*, PRL 95, 031801 (2005)

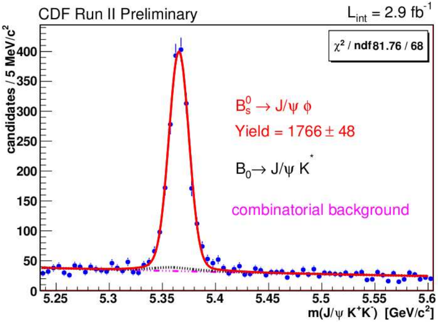
$B_s \to \phi\phi$ Reconstruction and Selection

- Due to similar decay topology and to suppress systematics, branching fraction measured in ratio to $\mathcal{B}[B_s \to J/\psi\phi]$
- Decays reconstructed in $\phi \to K^+K^-$ and $J/\psi \to \mu\mu$ using Two Track Trigger data sample corresponding to 2.9 fb^{-1}
- For $J/\psi \to \mu\mu$ positive identification of at least 1 muon is required to obtain best compromise between signal to background ratio and suppression of $J/\psi \to ee$
- Cut based optimization procedure geared towards maximizing $S = N_S/\sqrt{N_S + N_B}$
- Uses kinematic variables like L_{xy}, χ^2_{xy}, p_T, $d0$
- Still room for improvements by using PID

Signal Yields

- Binned maximum likelihood fit using signal shape and physics background shapes from MC, empirical exponential function for combinatoric background





Branching Fraction Result

$$\frac{\mathcal{B}[B_s \to \phi\phi]}{\mathcal{B}[B_s \to J/\psi\phi]} = \frac{N_{\phi\phi}}{N_{J/\psi\phi}} \cdot \frac{\epsilon_{rec}^{J/\psi\phi}}{\epsilon_{tot}^{\phi\phi}} \cdot \frac{\mathcal{B}[J/\psi \to \mu\mu]}{\mathcal{B}[\phi \to KK]} \cdot \epsilon_{tot}^{\mu}$$

- $\epsilon_{rec}^{J/\psi\phi}/\epsilon_{tot}^{\phi\phi} = 0.939 \pm 0.030$: ratio of combined trigger and selection efficiencies determined on MC
- $\epsilon^{\mu} = \epsilon_{tot}^{\mu} = 0.8695 \pm 0.0044$: muon identification efficiency evaluated on $J/\psi \to \mu\mu$ data
- Relative branching fraction:

$$\frac{\mathcal{B}[B_s \to \phi\phi]}{\mathcal{B}[B_s \to J/\psi\phi]} = [1.78 \pm 0.14(stat) \pm 0.20(syst)] \cdot 10^{-2}$$

- Absolute branching fraction:

$$\mathcal{B}[B_s \to \phi\phi] = [2.40 \pm 0.21(stat) \pm 0.27(syst) \pm 0.82(BR)] \cdot 10^{-5}$$

Conclusion and Outlook

- This talk presented two interesting ongoing analyses of B_s decays at CDF
- Analysis of $B_s \rightarrow D_s^{+(*)} D_s^{-(*)}$ under way, intermediate results promising
- Measurement of $\mathcal{B}[B_s \rightarrow \phi\phi]$ yields a reduction of factor 3 in statistical uncertainty
- $\mathcal{B}[B_s \rightarrow \phi\phi]$ analysis represents valuable preparative step towards polarization measurement
- Tevatron will certainly run up to October 2010
  - Several additional fb^{-1} will be available to CDF in the near future
  - Additional enhancements in the measurements are to be expected

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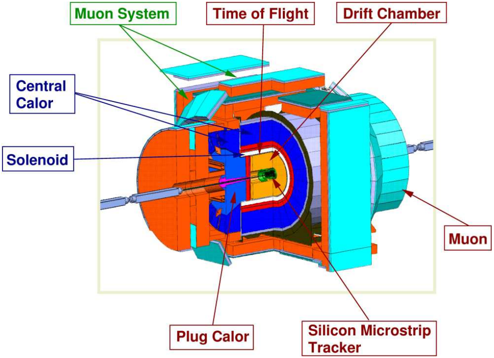
The Collider Detector at Fermilab (CDF)

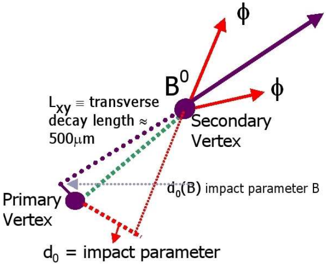
- Multi-purpose detector at the $p\bar{p}$ collider *Tevatron* ($\sqrt{s} = 1.96$ TeV)



- Cylindrical and forward-backward symmetrical setup of detector components
- Charged particle tracking system with high resolution
  - Silicon microstrip detector system (L00, SVXII, ISL)
  - Drift chamber (COT)
  - Muon chambers

The Two Track Trigger (TTT)

- Three-level online trigger logic for identification of hadronic decays from heavy flavour particles
- Combines and processes information from the tracking system
- Selects two displaced charged tracks, requiring:
  - Transverse momentum $p_T > 2$ GeV/c
  - Impact parameter 0.12 mm $\leq d_0 \leq 1$ mm
  - Opening angle $2^\circ \leq \Delta\phi \leq 90^\circ$
  - Decay length $L_{xy} > 200\ \mu$m



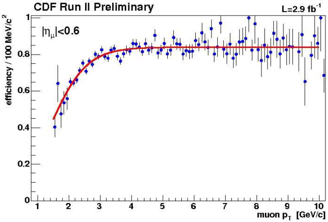
- Adjusting of data taking to different luminosity scenarios by applying prescale factors to different TTT subpaths

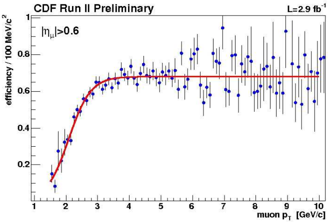
Combined Trigger and Selection Efficiencies

- Evaluated using Monte Carlo, in principle: $\epsilon = N_{MC}^{rec}/N_{MC}^{gen}$
- However, some effects have to be accounted for:
  - Datasets consist of an admixture of three different trigger subpaths
  - Prescale factors for different TTT subpaths not identical in data and MC
  - $p_T^{B_s}$ spectrum not the same in data and MC
- Therefore:
  - Based on data/MC comparison in $B_s \to J/\psi\phi$ MCs are reweighted
  - ϵ_i, $i = 1, 2, 3$, are calculated separately and summed up using adjusted prescale factors
- This gives an effective efficiency ratio: $\epsilon_{rec}^{J/\psi\phi}/\epsilon_{tot}^{\phi\phi} = 0.939 \pm 0.030(stat)$

Muon Efficiency in $B_s \to J/\psi\phi$

- Evaluated separately on data itself (signal region) since MC not fully reliable for simulation of muon detectors
- ϵ^{μ}_{tot} calculated as a function of p^{μ}_{T} in two pseudo-rapidity regions and assuming efficiencies for first and second muon being uncorrelated





- Per event efficiency for reconstructing at least 1 muon: $\epsilon^{\mu}_{tot} = 0.8695 \pm 0.0044(stat)$

Systematics

- Considered systematic uncertainty on...
  - number of signal events due to fit mass range and signal parameterization
  - background subtraction
  - muon efficiency
  - ratio of trigger and selection efficiencies due to effects not considered in MC simulation
  - branching fraction of the normalization channel $B_s \to J/\psi\phi$
- Gives a total relative uncertainty of 11% (systematics) and 34% (BR)