CP-conserving and CP-violating properties in semileptonic B_s decays with DØ

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on behalf of the DØ collaboration

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Outline

- Introduction to CP violation in B_s^0 decays

- Flavour tagging

- Search for CP-violation in $B_s^0 \longrightarrow D_s^- \mu^+ \nu X$ decays

- Evidence for $B_s^0 \longrightarrow D_s^{(*)} D_s^{(*)}$ decay and measurement of $\Delta\Gamma_s^{CP}/\Gamma_s$

Motivation

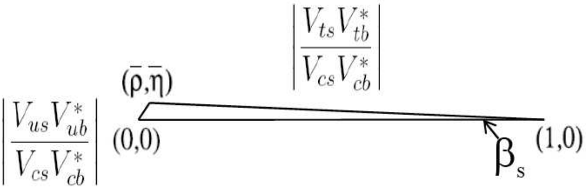
Why measuring B_s^0 decay properties?

- B mesons live for a relatively long time ($c\tau_B \sim 0.5$ mm)
- $\frac{\Delta\Gamma_s}{\bar{\Gamma}_{B_s}} \simeq 1 \sim 10\%$
- Measuring CP asymmetries in B^0 decays will shed further light on $|V_{td}|$, $|V_{ts}|$
- Complementary to B factories (sensitive to A_{B^0})

- SM predicts relatively small CPV effects
- Measurement of large CPV contributions in B_s^0 decays can provide indirect evidence for physics beyond the SM

B meson mixing

Unitarity triangle in B_S system



Area $\propto$ level of CP violation

- SM CP violation phase β_s^{SM} is predicted to be small[1]:

$$\phi_s^{\mathrm{SM}} = -2\beta_s^{\mathrm{SM}} = -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) \simeq 0.04 \pm 0.01 \text{ rad}$$

- Flavour-specific asymmetry $a_{fs}^s = \frac{\Gamma_{\overline{B_s^0}(t)\to f} - \Gamma_{B_s^0(t)\to \bar{f}}}{\Gamma_{\overline{B_s^0}(t)\to f} + \Gamma_{B_s^0(t)\to \bar{f}}} = \frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s$

[1] A. Lenz and U. Nierste, JHEP **0706**, 072 (2007), arXiv:hep-ph/0612167

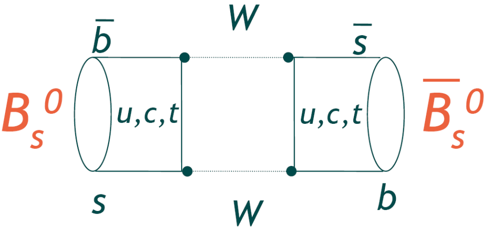
CP violation in $B_s^0 - \bar{B}_s^0$ mixing

Schrödinger equation:

$$i\frac{d}{dt}\begin{pmatrix}|B_s^0>\\|\bar{B}_s^0>\end{pmatrix} = \begin{pmatrix} M - i\frac{\Gamma}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{12}^* - i\frac{\Gamma_{12}^*}{2} & M - i\frac{\Gamma}{2}\end{pmatrix}\cdot\begin{pmatrix}|B_s^0>\\|\bar{B}_s^0>\end{pmatrix}$$

In SM: Γ_{12} from long distance contributions; M_{12} dominated by top quark box diagram

Matter ⟷ Antimatter



Mass eigenstates:

$|B_L>= p|B_s^0> +q|\bar{B}_s^0>$ $\approx$ CP even

$|B_H>= p|B_s^0> -q|\bar{B}_s^0>$ $\approx$ CP odd

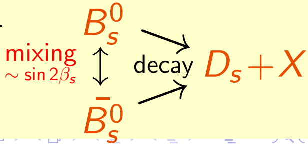
CPV: $|p/q| \neq 1$, or interference

between direct/mixed decays

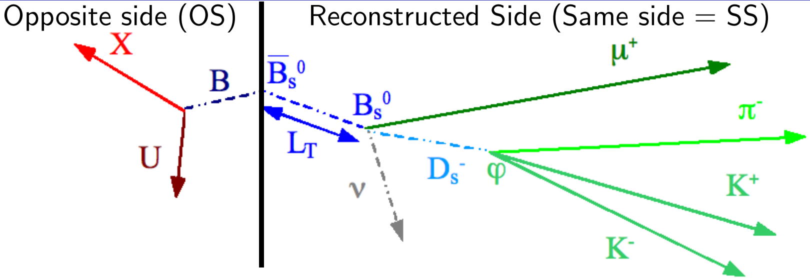
Charge asymmetry ($B \to \mu + X$):

$$A = \frac{N^{--} - N^{++}}{N^{--} + N^{++}} = \frac{1 - \left|\frac{p}{q}\right|^4}{1 + \left|\frac{p}{q}\right|^4}$$

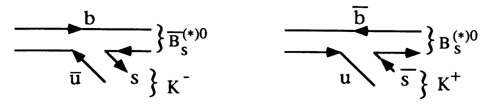
Interference:



B meson flavour tagging



- Reconstruct B_s decay on one side, flavour at decay time is given by charges of decay products, measure momentum and (transverse) decay length L_T (to determine proper lifetime)
- Tag flavour at production using either opposite side b-hadron (most b's are pair-produced), or *same side* hadron from fragmentation



- DØ combined tagging power (SS + OS): $\mathcal{P} = \epsilon\mathcal{D}^2 = 4.7\%$

DØ B_s^0 decay analyses

- Search for CP-violation in $B_s^0 \longrightarrow D_s^- \mu^+ \nu X$ decays

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- Evidence for $B_s^0 \longrightarrow D_s^{(*)} D_s^{(*)}$ decay and measurement of $\Delta\Gamma_s^{CP}/\Gamma_s$

Search for CP-violation in $B_s \to D_s^- \mu^+ \nu X$ decays

DØ Collab., Submitted PRL, Fermilab-Pub-09-140-E | $\mathcal{L} = 5.0 \text{ fb}^{-1}$

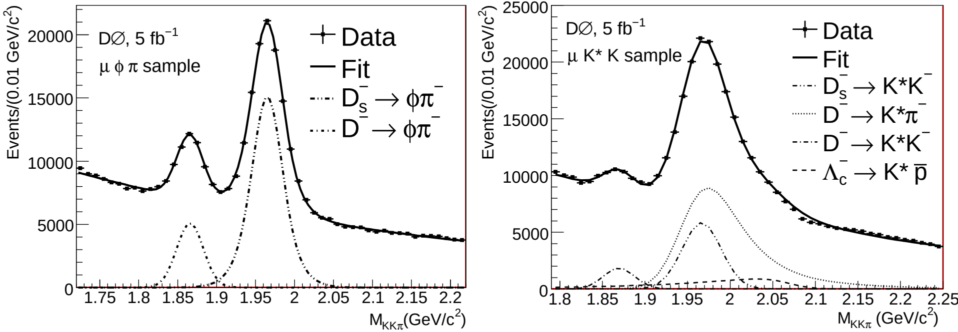
- CP violation phase ϕ_s has been measured by DØ and CDF with some deviation from SM
- Flavour-specific asymmetry $a_{fs}^s = \frac{\Gamma_{\overline{B_s^0}(t)\to f} - \Gamma_{B_s^0(t)\to \overline{f}}}{\Gamma_{\overline{B_s^0}(t)\to f} + \Gamma_{B_s^0(t)\to \overline{f}}} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s$ is complementary
- Former DØ dimuon a_{fs}^s analysis depends heavily on B_d^0 asymmetry results from B factories.
- In contrast to $B_s^0 \to J/\psi\phi$ CPV measurements no angular analysis

- ► No explicit trigger requirement (most events single muon triggered)
- ► Two reconstructed $B_s^0 \to \mu^+ D_s^- X$ final states:
  a): $D_s^- \to \phi\pi^-$ (with $\phi \to K^+K^-$) and
  b): $D_s^- \to K^{0*}K^-$ (with $K^{0*} \to K^+\pi^-$)

Search for CP-violation in $B_s \to D_s \mu \nu X$ decays

- Reconstructing inv. masses: $m(K^+K^-), m(K^+\pi^-)$
- Initial state flavour from OST
- Final state flavour from $B \to \mu^+ X$ muon charge
- likelihood ratio method (μD_s isolation, vertex χ^2, track transverse momenta)

$K^+K^-\pi^-$ invariant mass distributions



Search for CP-violation in $B_s \to D_s \mu \nu X$ decays

- Asymmetry a^s_{fs} contributes to mixed B^0_s decays:

$$\Gamma_{B^0{}_s(t)\to\bar{f}} = N_f |\bar{A}_{\bar{f}}|^2 (1-a^s_{fs}) e^{-(\Gamma_s t)} \cdot \frac{\cosh(\Delta\Gamma_s t/2)-\cos(\Delta m_s t)}{2}$$

- a^s_{fs} as well as B^0_d semileptonic asymmetry a^d_{fs} (and $a^{\text{bkg.}}_{fs}$) determined from unbinned likelihood fit to

$$\mathcal{L} = \prod_{j=1}^{N} \sum_i \left(f_i \cdot P_i^{VPDL} \cdot P_i^{\sigma VPDL} \cdot P_i^{y_{\text{sel}}} \cdot P_i^{M(K^+K^-\pi^-)} \cdot P_i^{d_{\text{tag}}} \right), \quad i \in \{s, d, \text{bkg.}\}$$

- PDF's P_i take into account detector asymmetries:

$$A_\mu = (1+qA_q)(1+\gamma A_{\text{det}})(1+q\beta\gamma A_{\text{ro}})(1+q\gamma A_{fb})(1+\beta\gamma A_{\beta\gamma})(1+q\beta A_{q\beta})$$

with muon charge $q = \pm 1$, pseudorapidity of $D_s\mu$ system $\eta \gtrless 0$ ($\gamma = \pm 1$) and toroid polarity $\beta = \pm 1$

- A_q = muon reconstruction asymmetry measured using $J/\psi \to \mu^+\mu^-$
- A_{det} = North south asymmetry of detector
- A_{ro} = Range out asymmetry (charged track magnet polarity acceptance)
- A_{fb} = forward backward asymmetry (more muons go into proton direction)
- $A_{\beta\gamma}$ = After magnet polarity flip remaining detector forward backward asymmetry
- $A_{q\beta}$ = Detector asymmetry between north and south bending tracks

Search for CP-violation in $B_s \to D_s \mu\nu X$ decays

- Separate fit for $\mu^+\phi\pi^-$ and $\mu^+K^{0*}K^-$ samples
- B_s^0 oscillation frequency fixed at $\Delta m_s = 17.77$ ps^{-1}
- B_s^0 decay width difference fixed at $\Delta\Gamma_s = 0.10$ ps

Asymmetries with statistical uncertainties

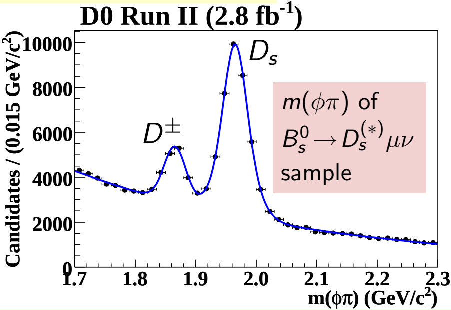
	$\mu^+\phi\pi^-$	$\mu^+K^{0*}K^-$	Combined
$a_{fs}^s \times 10^3$	-7.0 ± 9.9	20.3 ± 24.9	-1.7 ± 9.1
$a_{fs}^d \times 10^3$	-21.4 ± 36.3	50.1 ± 19.5	40.5 ± 16.5
$a_{fs}^{bkg.} \times 10^3$	-2.2 ± 10.6	-0.1 ± 13.5	-3.1 ± 8.3
$A_{fb} \times 10^3$	-1.8 ± 1.5	-2.0 ± 1.5	-1.9 ± 1.1
$A_{det} \times 10^3$	3.2 ± 1.5	3.1 ± 1.5	3.1 ± 1.1
$A_{ro} \times 10^3$	-36.7 ± 1.5	-30.2 ± 1.5	-33.3 ± 1.1
$A_{\beta\gamma} \times 10^3$	1.1 ± 1.5	0.2 ± 1.5	0.6 ± 1.1
$A_{q\beta} \times 10^3$	4.3 ± 1.5	2.0 ± 1.5	3.1 ± 1.1

- **Asymmetry in semileptonic B_s^0 decays**: $\mathbf{a_{fs}^s = \left(-1.7 \pm 9.1(stat)^{+1.2}_{-2.3}(syst)\right) \times 10^{-3}}$
- Factor 2 improvement over previous direct measurement (DØ PRL **98**, 151801 (2007))
- Consistent with a_{fs}^s from di-muon analysis and more precise (DØ PRD **76** 057101 (2007))
- Consistent with world average values of $\Delta\Gamma_s$, Δm_s and ϕ_s
- Expected to be combined with di-muon result (DØ PRD **74**, 092001 (2006))

$B_s \to D_s^{(*)} D_s^{(*)}$ decay and $\Delta\Gamma_s^{CP}/\Gamma_s$

DØ Collab., Phys. Rev. Lett. **102**, 091801 (2009) $\mathcal{L} = 2.8\ \text{fb}^{-1}$

- μ of semileptonic D_S decay has to satisfy inclusive single muon triggers
- Consider $B_s^0 \to D_s^{(*)} D_s^{(*)}$ decays: γ's and π^0's from D_s^* decays are not identified
- one $D_s \to \phi\pi$ (with $\phi \to K^+K^-$) and other $D_s \to \phi\mu\nu$ ($\phi \to K^+K^-$)
- Branching fraction extracted by normalising $B_s^0 \to D_s^{(*)} D_s^{(*)}$ to $B_s^0 \to D_s^{(*)}\mu\nu$ decay.



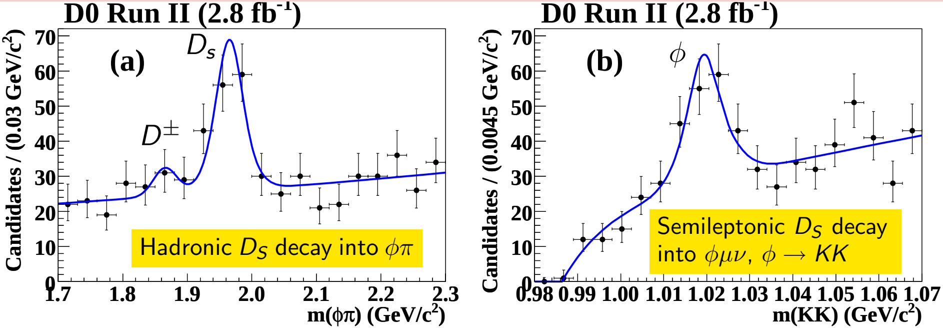
- $\Delta\Gamma_s = \Gamma_L - \Gamma_H$
- $\Delta\Gamma_s^{CP} = \Gamma_s^{\text{even}} - \Gamma_s^{\text{odd}}$
- Possible new physics: $\Delta\Gamma_s = \Delta\Gamma_s^{CP} \cos\phi_s$
- $B_s^0 \to D_s^{(*)\pm} D_s^{(*)\pm}$ contribute largest to $\Delta\Gamma_s$
- Shifman-Voloshin limit ($m_b - 2m_c \to 0$, $N_c \to \infty$): $\Delta\Gamma_s^{CP}$ saturated by $\Gamma(B_s^0 \to D_s^{(*)} D_s^{(*)})$
- $2\mathcal{B}(B_s \to D_s D_s) \simeq \Delta\Gamma_s^{CP}\left(\frac{\frac{1}{1-2\chi_f}+\cos\phi_s}{2\Gamma_L} + \frac{\frac{1}{1-2\chi_f}-\cos\phi_s}{2\Gamma_H}\right)$ with fraction χ_f of CP-odd component

  $\Gamma_s^{\text{odd}}/\Gamma_s^{\text{even}} = \chi_f/(1-\chi_f) \Rightarrow \Delta\Gamma_s^{CP}$ can be measured without lifetime fit

$B_s \to D_s^{(*)} D_s^{(*)}$ decay and $\Delta\Gamma_s^{CP}/\Gamma_s$

- Fit to 2-dim. distribution $m(\phi\pi)$ of hadr. D_s cand. vs. $m(KK)$ of semileptonic D_s cand.
- 4 components: • Correlated $D_s D_s$ signal,
  • (2×) uncorrelated D_s signal with D_s background,
  • correlated $D_s D_s$ background ($p\bar{p} \to c\bar{c}$, $B_s^0 \to D_s^{(*)}\phi\mu\nu$, $B_s^0 \to D_s^{(*)} D_s^{(*)} KX$)
- Signal template extracted from $B_s^0 \to D_s^{(*)}\mu\nu$ sample

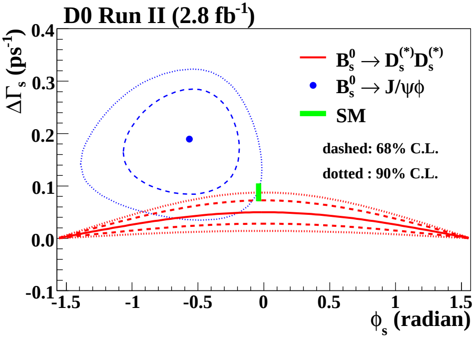
- Projections of 2-dim ML fit $\{m(\phi\pi)$ vs. $m(KK)\}$
- 26.6 ± 8.4 signal events (3.2σ significance above background)



$B_s \longrightarrow D_s^{(*)} D_s^{(*)}$ decay and $\Delta\Gamma_s^{CP}/\Gamma_s$

- Measured $\mathcal{B}(B_s^0 \to D_s^{(*)} D_s^{(*)}) = 0.035 \pm 0.010(\text{stat}) \pm 0.008(\text{exp syst}) \pm 0.007(\text{ext})$
- Consider heavy quark hypothesis (PLB 316, 567(1993)) along with SV limit
  $\Rightarrow$ No CP-odd component in decay, i.e. $\chi_f = 0$ with theo. uncertainty $\sim 5\%$
- Within SM mass eigenstates coincide with CP eigenstates

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} \simeq \frac{2\mathcal{B}(B_s^0 \to D_s^{(*)} D_s^{(*)})}{1-\mathcal{B}(B_s^0 \to D_s^{(*)} D_s^{(*)})} = 0.072 \pm 0.021(\text{stat}) \pm 0.022(\text{syst})$$



- Result consistent with SM prediction and current world average value
- Need to
  - disentangle CP structure of final state
  - control theoretical errors

  $\Rightarrow$ Powerful constraint on B_s^0 mixing and CP violation

Summary

- Tevatron and DØ are performing well (CDF too)

- Search for CP-violation in $B_s^0 \to D_s^- \mu^+ \nu X$ decays performed:

  Measured $\boxed{a_{fs}^s = \left(-1.7 \pm 9.1(\text{stat})^{+1.2}_{-2.3}(\text{syst})\right) \times 10^{-3}}$

- Evidence for $B_s^0 \to D_s^{(*)} D_s^{(*)}$ decay (3.2σ):

$$\boxed{\mathcal{B}(B_s^0 \to D_s^{(*)} D_s^{(*)}) = 0.035 \pm 0.010(\text{stat}) \pm 0.008(\text{exp. syst}) \pm 0.007(\text{ext})}$$

$$\Rightarrow \boxed{\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} \simeq \frac{2\mathcal{B}(B_s^0 \to D_s^{(*)} D_s^{(*)})}{1 - \mathcal{B}(B_s^0 \to D_s^{(*)} D_s^{(*)})} = 0.072 \pm 0.021(\text{stat}) \pm 0.022(\text{syst})}$$

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