Time-Integrated Charge Asymmetries at DØ

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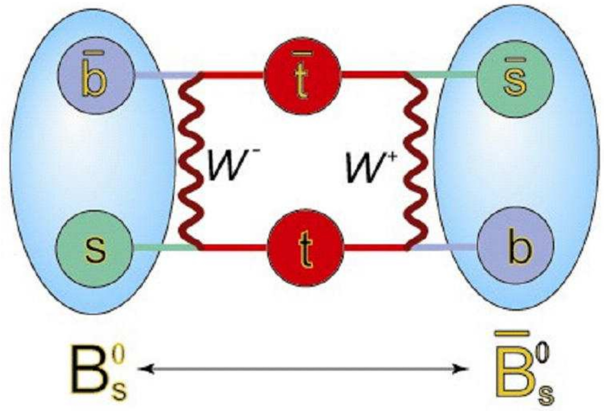
(D0 Collaboration)

- Introduction
- Dimuon Charge Asymmetry
- $B_s \to D_s \mu\nu$ Charge Asymmetry
- Combined Charge Asymmetry
- Summary

Introduction

- Mass eigenstates are different from flavor eigenstates.
  - $|B_{H,L}\rangle = p|B_s^0\rangle \mp q|\bar{B}_s^0\rangle$
- B_s mixing occurs through $|\Delta B| = 2$ transitions.
- Three possible mechanisms for CP violation.
  - Mixing, decay and interference.



$$\lambda = \frac{|p|}{|q|} \frac{|A_{\bar{f}}|}{|A_f|} e^{-i\phi}$$

CP Violating phase: ϕ_s

- Oscillations can be described by three physical quantities.
  - $|M_{12}|$ and $|\Gamma_{12}|$: elements of complex mass matrix.
  - $\phi_s = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$: CP violating phase.
- Can relate to mass and width differences.

$$\Delta m_s = M_H - M_L = 2|M_{12}|$$
$$\Delta\Gamma_s = \Gamma_L - \Gamma_H = 2|\Gamma_{12}|\cos\phi_s$$

- In the Standard Model ϕ_s is small in SM ($\sim 0.3^\circ$).
  - GIM suppression and $|V_{us}|^2$.
  - Mass eigenstates are nearly CP eigenstates.
- New Physics can lead to enhancement of ϕ_s.
  - Small value of ϕ_s in SM simplifies search for New Physics.

DØ Charge Asymmetry Measurements

- Charge asymmetry is sensitive to CP violation in mixing.

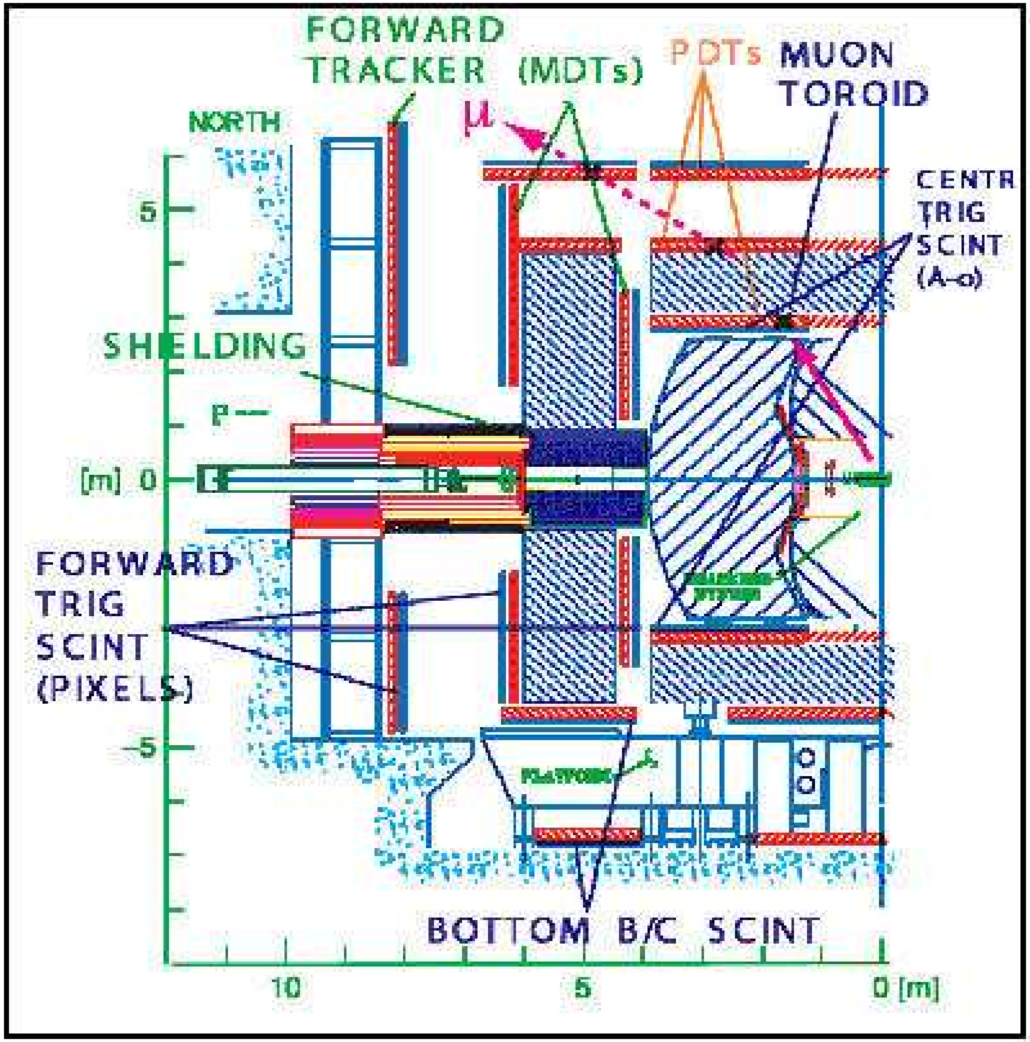
$$A_{SL} = \frac{N(\bar{B}\to l^+X) - N(B\to l^-X)}{N(\bar{B}\to l^+X) + N(B\to l^-X)}$$

$$A_{SL} = \frac{1-|q/p|^4}{1+|q/p|^4} = \frac{\Delta\Gamma}{\Delta m}\tan\phi$$

- Dimuon charge asymmetry.
  - $A_{SL} = \frac{N(b\bar{b}\to\mu^+\mu^+X) - N(b\bar{b}\to\mu^-\mu^-X)}{N(b\bar{b}\to\mu^+\mu^+X) - N(b\bar{b}\to\mu^-\mu^-X)}$
  - Systematics more easily handled relative to $B \to l + X$.
- Charge asymmetry in $B_s \to D_s\mu\nu$.
  - Untagged sample.
  - $A_{SL}^{untagged} = \frac{N(B_s\to D_s\mu^+) - N(B_s\to D_s\mu^-)}{N(B_s\to D_s\mu^+) + N(B_s\to D_s\mu^-)} = \frac{1}{2}\frac{x_s^2}{1+x_s^2}A_{SL}^s$
  - $x_s \gg 1 \to A_{SL}^{untagged} \simeq \frac{1}{2}A_{SL}^s$

D0 Detector

- Good muon coverage.
- Very low punch through.
- Strong suppression of cosmic ray background.
- Two separate spectrometers.
  - Toroid and solenoid polarities can be reversed independently.



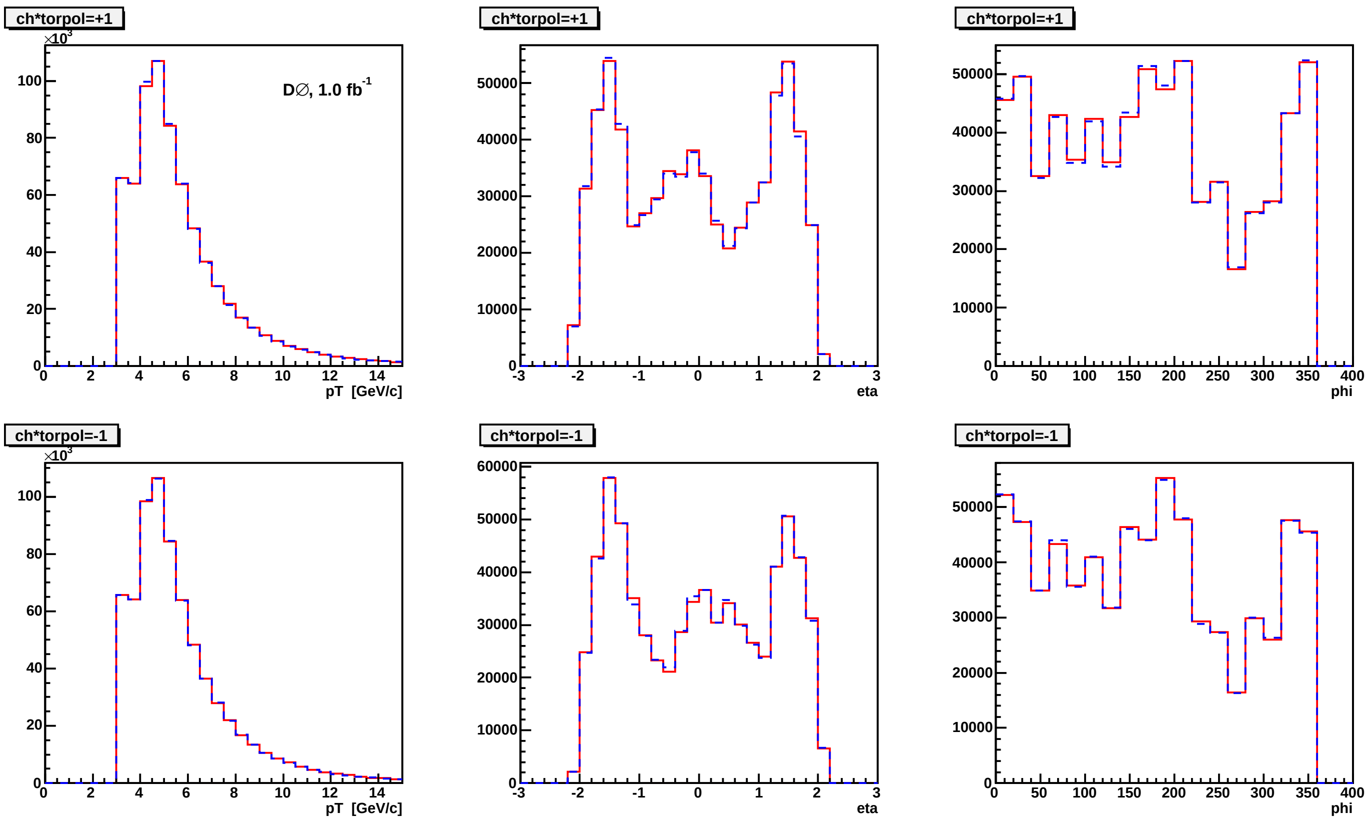
Like-sign Dimuon Charge Asymmetry

- Measure charge asymmetry in direct decays of $B\bar{B}^0$ pairs.

$$A_{SL} = \frac{N(b\bar{b}\to\mu^+\mu^+X) - N(b\bar{b}\to\mu^-\mu^-X)}{N(b\bar{b}\to\mu^+\mu^+X) - N(b\bar{b}\to\mu^-\mu^-X)}$$

- Clean channel.
  - Relatively few processes contribute to same-sign samples.
  - To first order no charge asymmetry in background processes.

Magnet Polarities



- Polarities reversed approximately weekly.
  - To first order detector charge asymmetries cancel.
  - Two histograms with same charge$\times$polarity (p_T, η, ϕ).

Measurement Technique

- Divided into eight subsamples.
  - $n_q^{\beta\gamma}$
  - Toroid polarity (β), muon charge (q), sign of pseudorapidity (γ).

$$A + A_{fb}A_{ns} = \frac{(n_+^{++}+n_+^{+-}-n_-^{++}-n_-^{+-})+e(n_+^{-+}+n_+^{--}-n_-^{-+}-n_-^{--})}{(n_+^{++}+n_+^{+-}+n_-^{++}+n_-^{+-})+e(n_+^{-+}+n_+^{--}+n_-^{-+}+n_-^{--})}$$

  - A_{fb}: Tendency of $\mu^{\pm}$ to go in $p^{\pm}$ direction.
  - A_{ns}: North/South detector asymmetry.
  - e: Ratio of events with opposite toroid polarities.
  - $A_{fb}A_{ns}$ is compatible with zero.
    - Used to estimate systematic error.

Data Sample

- 1 fb^{-1} data taken during RunII.
- Sources of background.

Background	Cut
Cosmic Rays	Timing requirement
$K^{\pm}$ and $\pi^{\pm}$ decays	$p_T > 3.0$ GeV/c
Punch through	Muons must traverse toroid
Wrong sign, $W^{\pm}$, Z decay	$p_T < 15.0$ GeV/c

- Approximately 3×10^6 dimuon events.

Raw Charge Asymmetry

Sample	Relative Polarities	
	Opposite	Same
N^{++}	177,950	156,183
N^{--}	176,939	156,148
N^{+-}	1,175,547	1,209,605

- Raw charge asymmetry.

$$A = -0.0013 \pm 0.0012 \pm 0.0008$$

- $A_{SL} = f_b \times A$
  - f_b: fraction of μ from B decays.

Sources of Systematic Error

Source of Error	ΔA
$K^{\pm}$ Decay + prompt μ	0.00068
Sample Normalization	0.00018
Misreconstructed charge	0.00015
Detector	0.00015
Cosmic Rays	0.00010
Punch through	0.00001
Total	0.00074

- Largest source of systematics from $K^{\pm}$ decays.
  - Difference in inelastic interaction length for K^{+} vs. K^{-}.
  - Presence of $S = -1$ baryons (Λ, Σ, Y^{*}).
  - Correction: -0.0028 ± 0.0007.

Dimuon Charge Asymmetry

$$A_{SL} = (-0.0044 \pm 0.0040 \pm 0.0028)$$

- Most precise measurement of A_{SL}.
  - Submitted to PRD.
- B Factory results.
  - $A^d_{SL} = (-1.1 \pm 7.9 \pm 7.0) \times 10^{-3}$ (Belle)
  - $A^d_{SL} = (+1.6 \pm 5.4 \pm 3.8) \times 10^{-3}$ (BaBar)

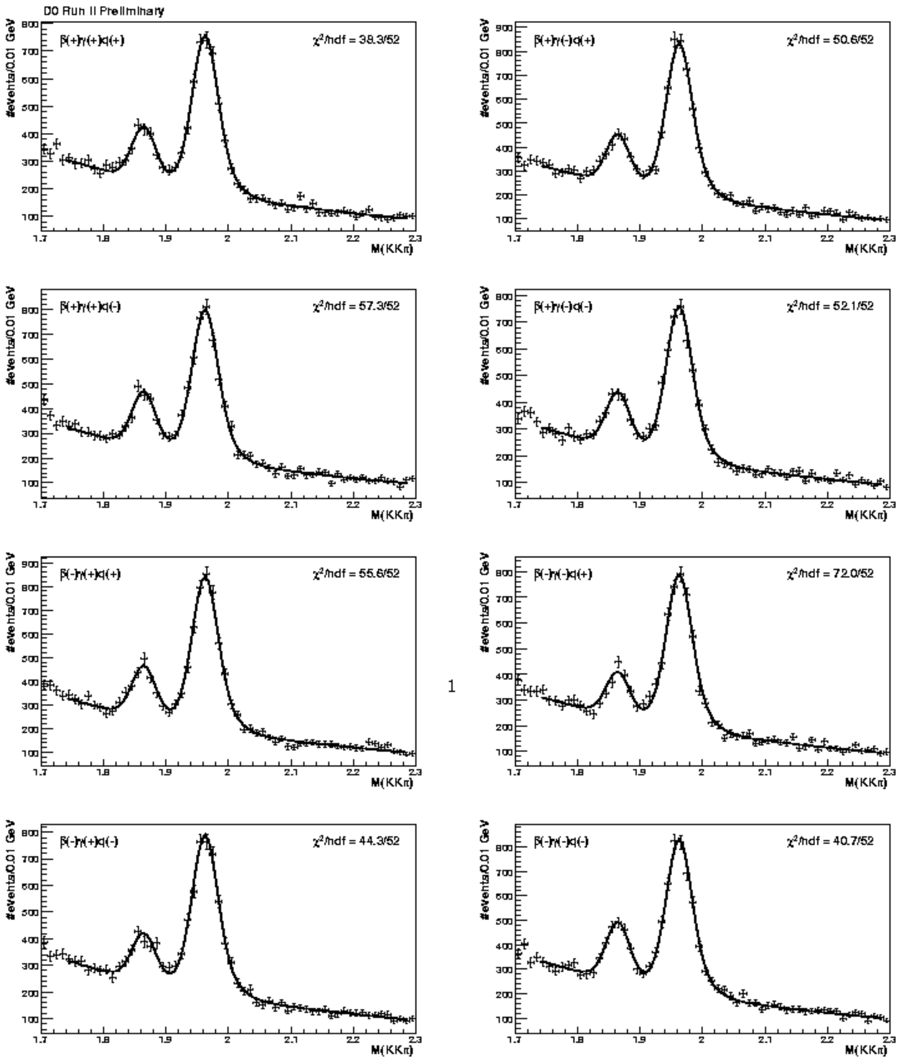
Dimuon Charge Asymmetry

- A_{SL} contains contributions from B_d and B_s.
- We can use the B factory results to extract A^s_{SL}
  - A_{SL}(DØ) $= A^d_{SL} + \frac{f_s Z_s}{f_d Z_d} A^s_{SL}$.
  - $Z_q = \frac{1}{1-y_q^2} - \frac{1}{1+x_q^2}$.
  - f_q: BF($b \rightarrow B_q$).
- $A^d_{SL} = +0.0011 \pm 0.0055$ (B factories)
- DØ value for A^s_{SL}

$$A^s_{SL} = -0.0076 \pm 0.0102$$

Charge Asymmetry in $B_s \rightarrow D_s \mu X$

- $B_s \rightarrow D_s \mu \nu$
  - $D_s \rightarrow \phi \pi$
- Collected approximately 27K D_s decays.
  - D^+ and D_s^+ candidates.
  - Divided into same eight subsamples as in dimuon analysis.
    - Toroid polarity (β), muon charge (q), sign of η (γ).



Systematic Errors

Source	ΔA
Mass fitting	0.0027
Sample composition	0.0022
$\pi^{\pm}$ interactions	0.0004
Contribution from A^d_{SL}	0.0002
Total	0.0035

- Magnet reversal helps cancel detector asymmetries.
- Sample composition: vary signal contribution by 1σ.
- Mass fitting: vary bkg slope and width by 1σ.

B_s charge asymmetry

- First direct measurement of A^s_{SL}.

$$A^s_{SL} = 0.0245 \pm 0.0193 \pm 0.0035$$

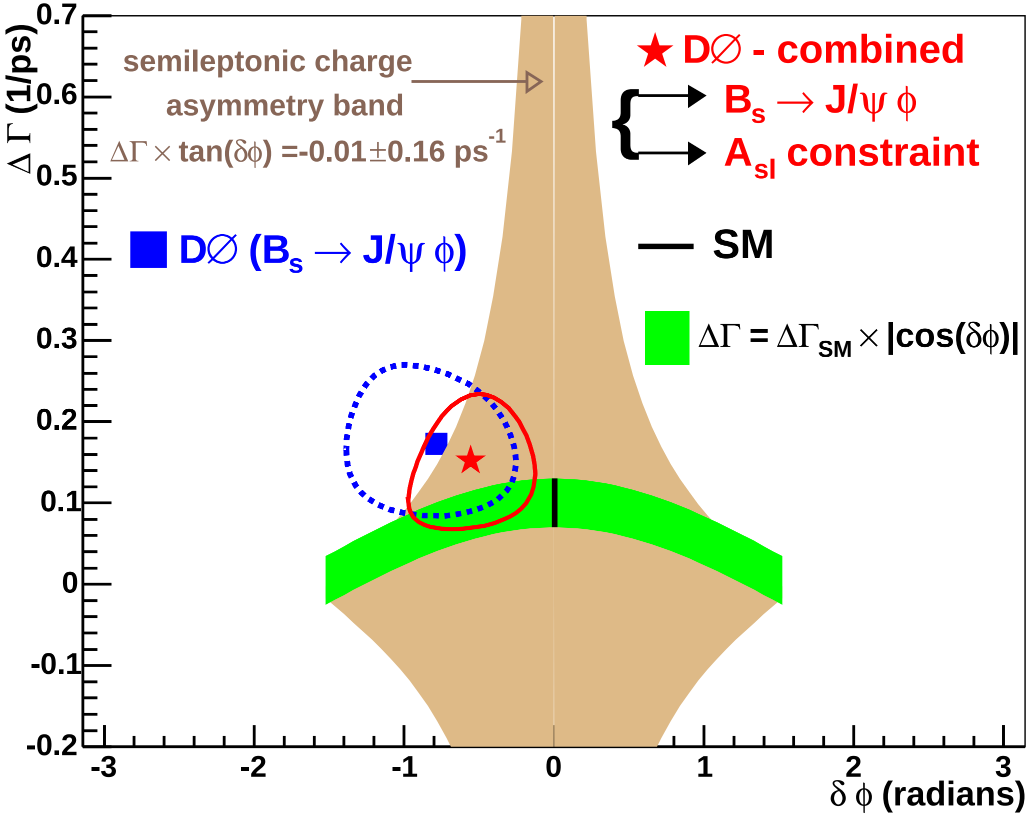
- Combine with result from dimuon asymmetry.

$$A^s_{SL} = -0.0007 \pm 0.0090$$

Combined DØResults

- Combined charge asymmetry result.
  - $A^s_{SL} = -0.0007 \pm 0.0090.$
  - $A^s_{SL} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s.$
- DØ result on $B_s \rightarrow J/\psi\phi$
  - $\Delta\Gamma_s = 0.17 \pm 0.09 \pm 0.03$ ps^{-1}.
  - $\phi_s = -0.79 \pm 0.56 \pm 0.01.$
  - See A. Chandra talk.
- Combined DØ Result

$\Delta\Gamma_s = 0.15^{+0.09}_{-0.08}$ ps^{-1}
$\phi_s = -0.56^{+0.44}_{-0.41}$



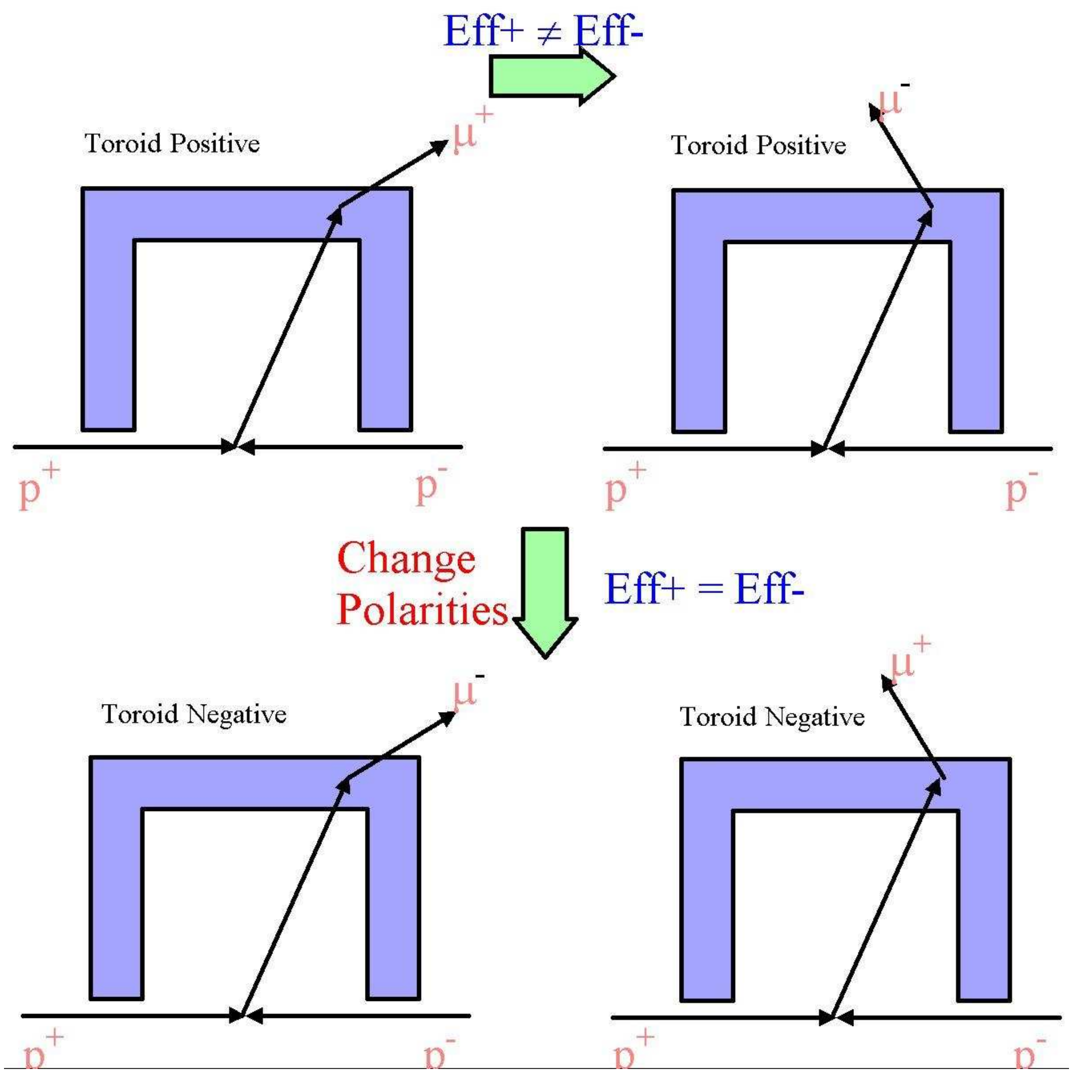
Conclusions

- DØ has made precise charge asymmetry measurements.
  - $A_{SL} = -0.0044 \pm 0.0040 \pm 0.0028$ (Dimuon)
  - $A_{SL}^{s} = 0.0245 \pm 0.0193 \pm 0.0035$ (Semileptonic B_s)
- New measurements place first constraints on the CP violating phase: ϕ_s.
  - $\phi_s = -0.56^{+0.44}_{-0.41}$
- Results on CP phase consistent with Standard Model.

Backup Slides

Magnet Polarities

- Polarities reversed approximately weekly.
- Nearly equal luminosities for all four combinations.
  - To first order detector charge asymmetries cancel.
  - Without cancellation, dimuon charge asymmetry ~ 0.006 for a given toroid-solenoid setting.



Sample Composition

- Signal
  - $\bar{b} \to \mu^+$, $b \to \bar{b} \to \mu^+$
- Sequential decays
  - $\bar{b} \to \mu^+$, $b \to c \to \mu^+$
- Asymmetries due to baryon asymmetry.
  - $\bar{b} \to \bar{c}\mu^+$, $\bar{c} \to K \to \mu^+$.
- Cross Check (Average B mixing probability)
  - $\chi_{meas} = 0.136 \pm 0.001 \pm 0.024$
  - $\chi_{PDG} = 0.1281 \pm 0.0076$