# Charmless and Double-Charm B Decays at SLD

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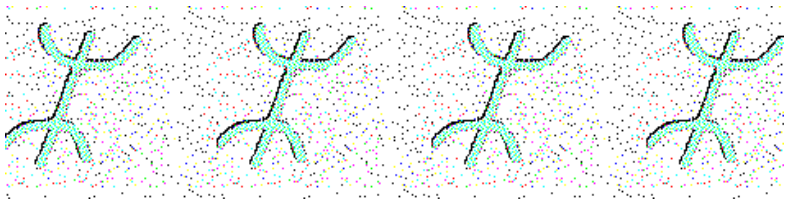
**Representing the SLD Collaboration**



- Measurement of $\mathcal{B}(B \to D\bar{D}X)$
- Search for exclusive charmless $B^{\pm}$ decays

**ICHEP 98**
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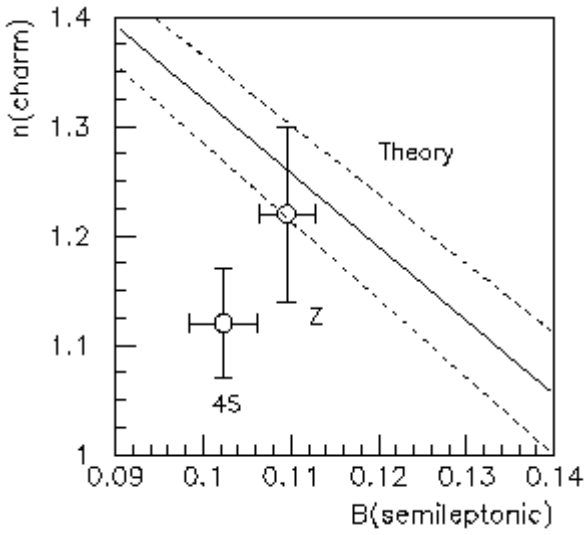
# Motivation

**$B$ decay puzzle:**

$B$ semileptonic Branching Ratio ($B_{SL}$) and Charm Yield in $B$ decays ($n_C$) appear to be too low

J. Richman, ICHEP-96




$$B_{SL} = \frac{\Gamma_{SL}}{\Gamma_{SL} + \Gamma_{Had}}$$

$$\Gamma_{Had} = \Gamma(b \to c\bar{u}d) + \Gamma(b \to c\bar{c}s) + \Gamma(b \to sg) + \Gamma(b \to u)$$

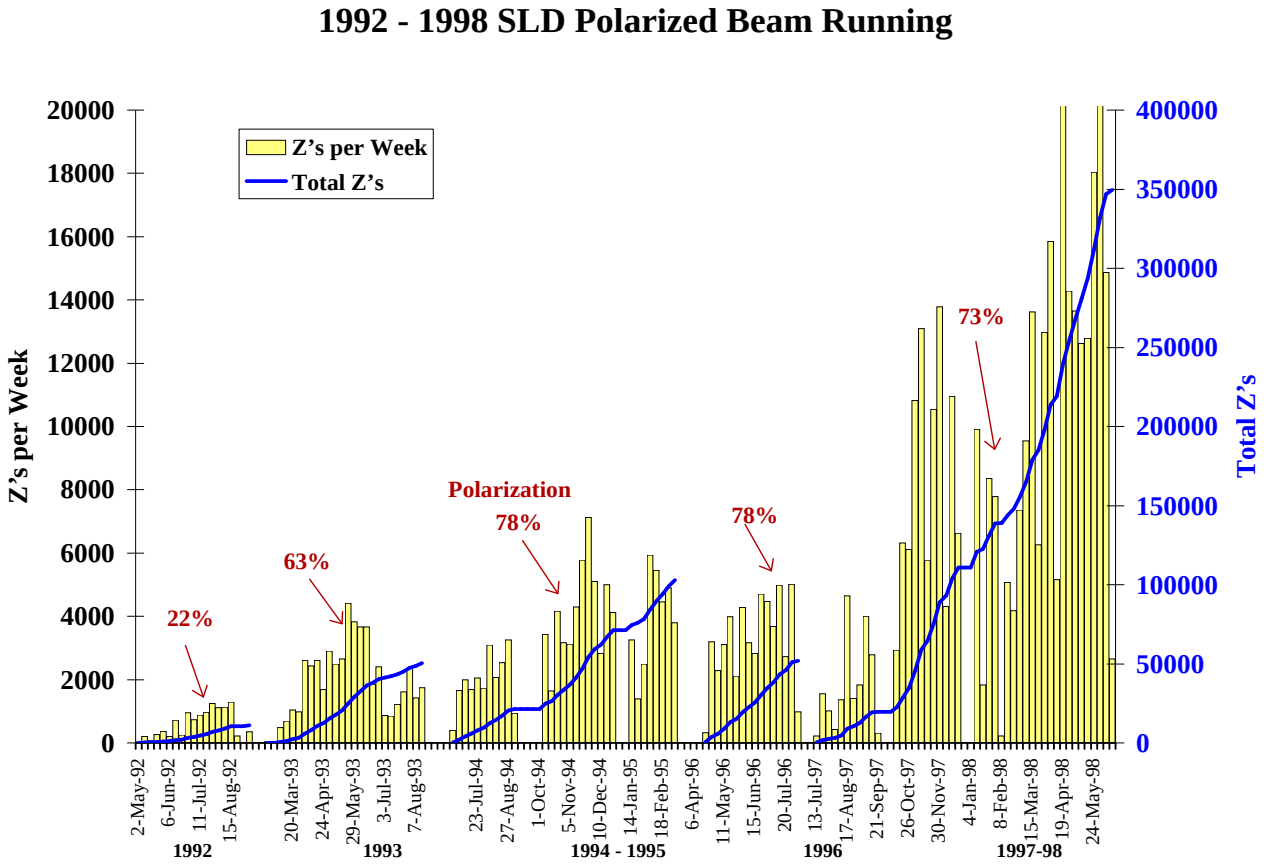
$$n_C = 1 + n_{CC} - n_{NOC}$$

- ⋆ Larger $\Gamma(b \to c\bar{c}s)$ $\Longrightarrow$ smaller $B_{SL}$
- ⋆ Larger $n_{CC}$ $\Longrightarrow$ larger $n_C$
- ⋆ Large $\Gamma(b \to sg)$ or $\Gamma(b \to u)$ (New Physics) $\Longrightarrow$ smaller $B_{SL}$

e.g., A. Kagan and J. Rathsman → $\mathcal{B}(b \to sg) \sim 10\%$
See talk by A. Litke in parallel session 7

# Data Sample

| | | | $b \to c\bar{c}s$ | $b \to u$ |
|---|---|---|---|---|
| 1993 – 95 | $150k$ $Z$'s | VXD2 | | Yes |
| 1996 – 98 | $250k$ $Z$'s | VXD3 | Yes | Yes |
| Spring 98 | $150k$ $Z$'s | | | Yes |




# SLD Detector

- **Precise 3D CCD pixel vertex detector**

  Topological vertexing

  $B$ mass tag $\Longrightarrow$ $\epsilon = 50\%$, $\pi = 98\%$

  $B$ decay length resolution $\sim 100$ $\mu$m

- **Electron beam polarization**

  Very good $b - \bar{b}$ separation

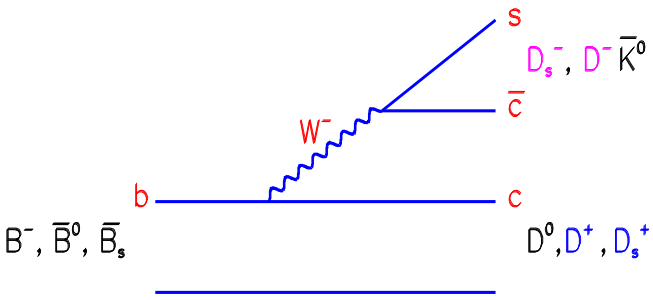
- **Čerenkov Ring Imaging Detector**

  Good particle (Kaon) identification

# Measurement of $\mathcal{B}(B \to D\bar{D}X)$

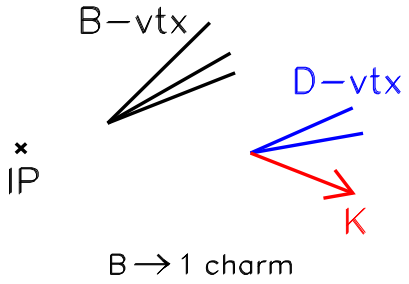
Quark transition $b \to c\bar{c}s$

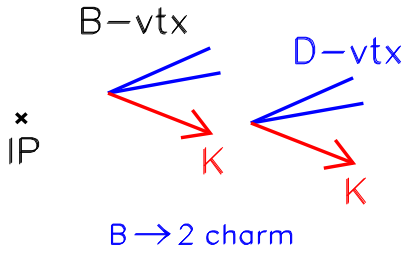
| | | |
|---|---|---|
| CLEO: | $\mathcal{B}(B \to D\bar{D}X)$ | $= (18 \pm 4)\%$ |
| ALEPH: | | $= (25 \pm 4 \pm 4)\%$ |
| DELPHI: | | $= (17 \pm 4)\%$ |




## At SLD:

- Select $B$ decays with 2 separated vertices
- Require 1-vertex probability $< 5.0\%$
- Fit for $f_{D\bar{D}}$ in Data using pure $B \to$ 1-charm and $B \to$ 2-charm Monte Carlo samples
- Two techniques are utilized




## 1. KAON COUNTING TECHNIQUE:

Count number of (charged) Kaons in $B$ and $D$ vertex

Expect more $K^{\pm}$'s in $D$ vertex for $B \to$ 1-charm

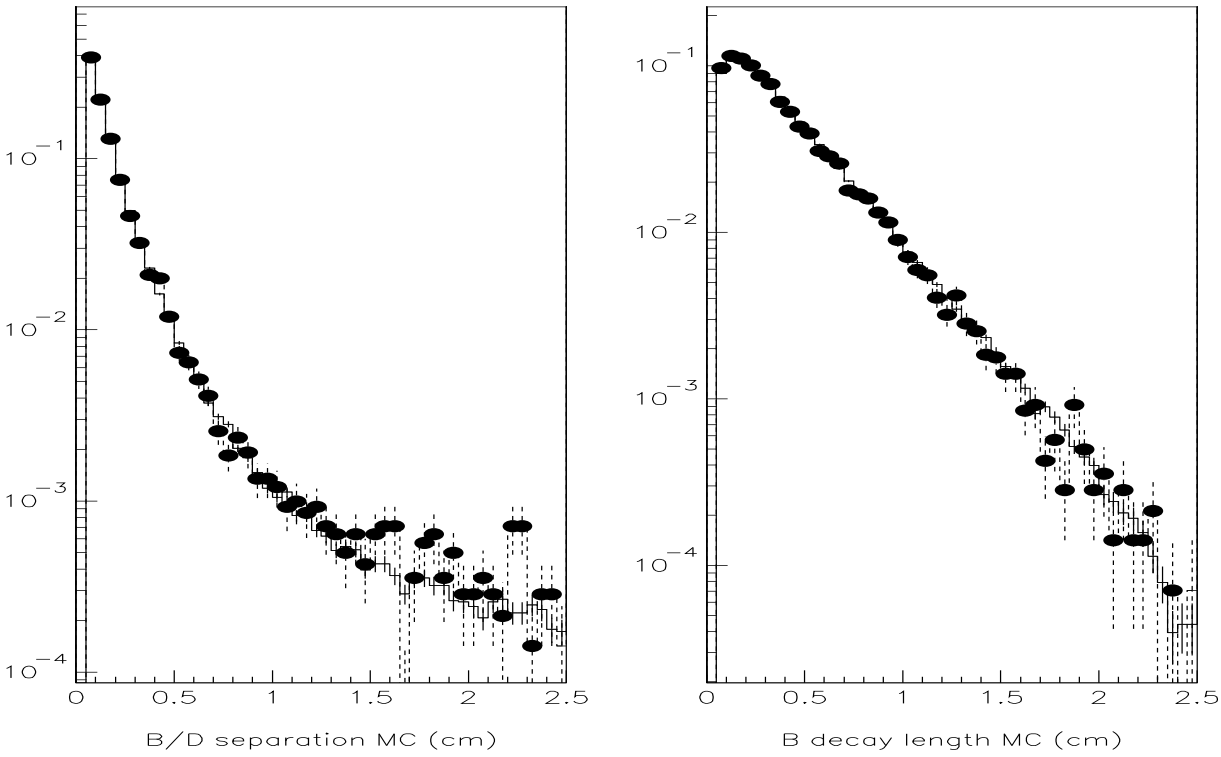
Unlike $B \to$ 2-charm, where $B$ vertex can actually be a $D$

## 2. $D$ CHARGE TECHNIQUE:

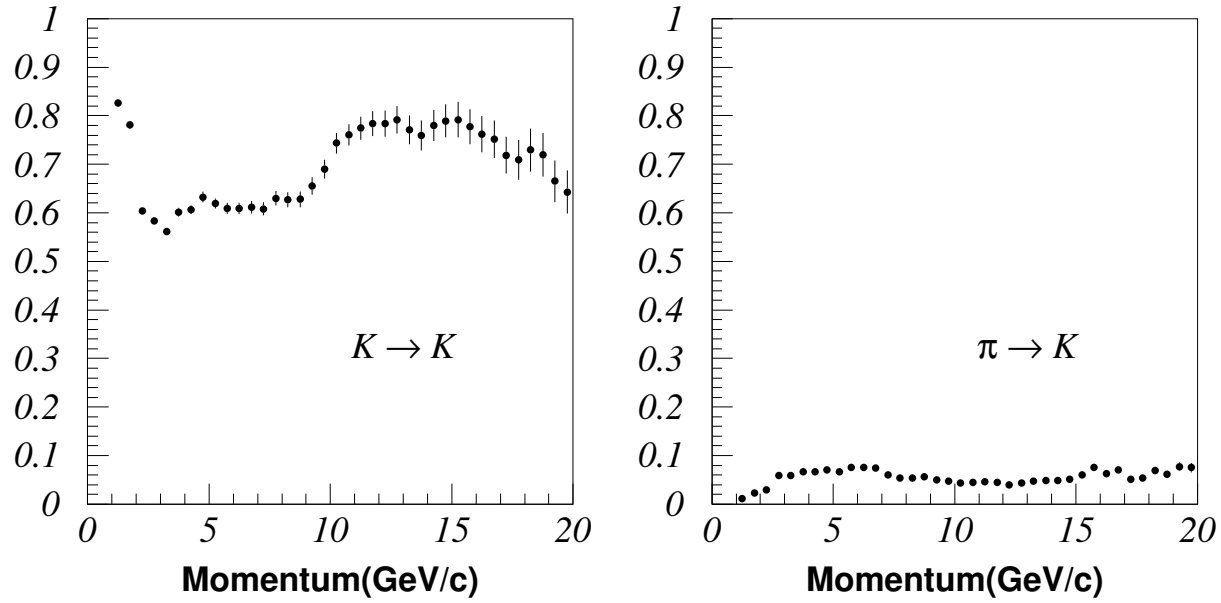
Compare charge of $D$ vertex to flavor of $B$

For $B \to$ 2-charm, $D$ vertex can have "wrong-sign" charge

# $D$ and $B$ Decay Length




# Kaon ID Efficiency



# $K^{\pm}$ Counting Analysis

| | $N_{K^-,B}$ | $N_{K^+,B}$ | $N_{K^-,D}$ | $N_{K^+,D}$ | $N_{K,B}/N_{K,D}$ |
|---|---|---|---|---|---|
| Data | 758 | 559 | 1168 | 746 | $0.688 \pm 0.025$ |
| M.C. $D\bar{D}$ | 3115 | 2339 | 2380 | 1880 | $1.280 \pm 0.026$ |
| M.C. "Not-$D\bar{D}$" | 5386 | 3974 | 11489 | 6549 | $0.519 \pm 0.007$ |

$$\Longrightarrow \quad \boxed{f_{D\bar{D}} = (18.8 \pm 2.5)\%}$$

- Measured $f_{D\bar{D}}$ corrected for difference in efficiency for $B \to$ 1-charm and $B \to$ 2-charm: $\epsilon_{D\bar{D}}/\epsilon_D = 1.34 \pm 0.03$

- Track misassignment rate (between $B$ and $D$ vertex) calibrated using leptons

- CROSS CHECKS:

  $K^{\pm}$ Asymmetry in $D$ Vertex
  $f_{D\bar{D}} = (29 \pm 11)\%$

  Subsamples
  $Q_V = 0$: $f_{D\bar{D}} = (20.9 \pm 4.2)\%$
  $Q_V = \pm 1$: $f_{D\bar{D}} = (17.0 \pm 3.1)\%$

# Systematic Errors

| Detector Systematics | $\sigma_{\text{stat}}$ (abs.) |
|---|---|
| Tracking Efficiency | $\pm 0.3\%$ |
| Tracking Resolution | $\pm 0.7\%$ |
| $K^{\pm}$ Id. Efficiency | $< 0.1\%$ |
| $\pi^{\pm}$ Fake Rate | $\pm 0.7\%$ |
| Track Misassignment | $\pm 4.2\%$ |

| Physics Systematics | |
|---|---|
| $udsc$ Background | $\pm 0.4\%$ |
| $B$ Multiplicity | $\pm 1.5\%$ |
| $B_s$ Fraction | $\pm 1.1\%$ |
| $\Lambda_b$ Fraction | $\pm 0.7\%$ |
| $\mathcal{B}(B_{u,d} \to D^0 X)$ | $\pm 0.2\%$ |
| $\mathcal{B}(B_{u,d} \to D^+ X)$ | $\pm 0.2\%$ |
| $\mathcal{B}(B_{u,d} \to D_s^+ X)$ | $\pm 0.4\%$ |
| $B \to D\bar{D}$ Model | $\pm 1.5\%$ |
| Charm Multiplicity | $\pm 3.2\%$ |
| TOTAL | $\pm 5.9\%$ |

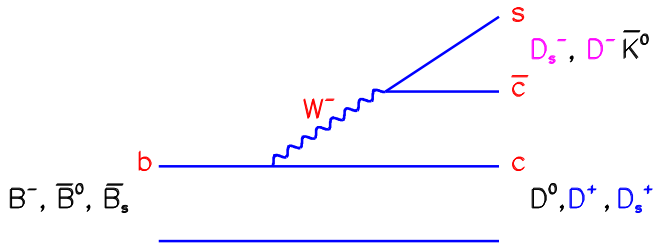
# RESULT

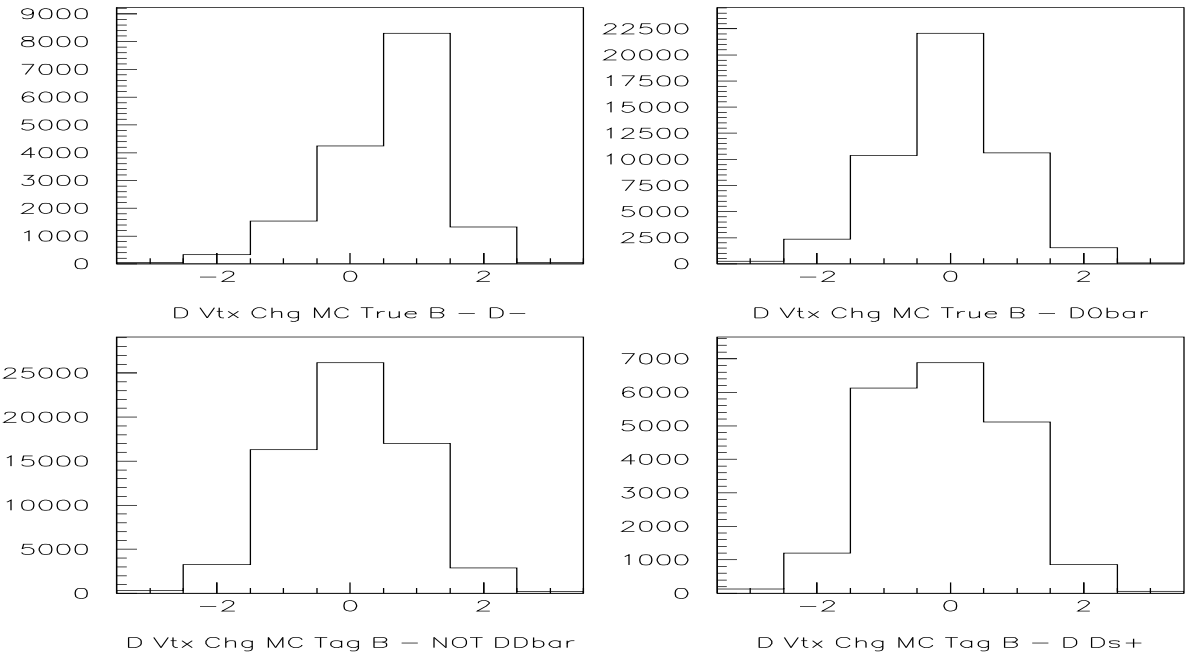
$$\mathcal{B}(B \to D\bar{D}X) = (18.8 \pm 2.5 \pm 5.9)\%$$

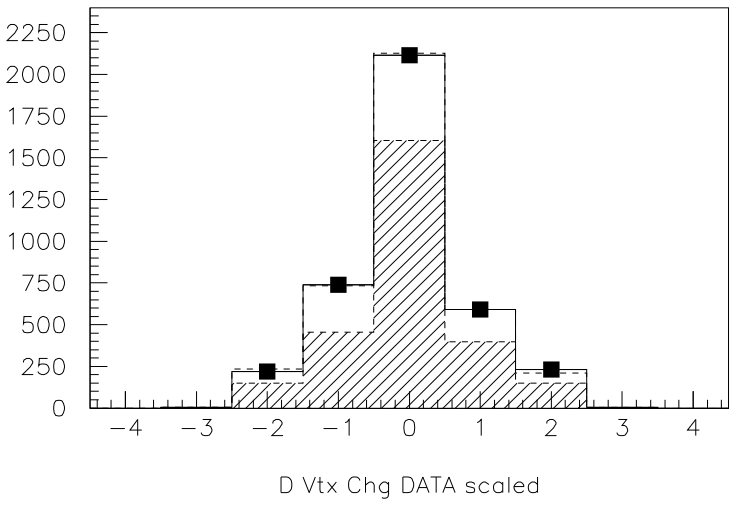
(SLD Preliminary)

# $D$ Charge Analysis

- Tag flavor of $B$ using Polarization and Jet Charge
- For $b$-type $B$ Meson:
  $D$ Charge $= +$, if $B \to$ 1-charm
  $D$ Charge $= +$ or $-$, if $B \to$ 2-charm
- Fit $D$ Charge distribution in Data to Monte Carlo shapes for 1-charm and 2-charm, and extract $f_{D\bar{D}}$




- $\chi^2$ Fit $\Longrightarrow$
  $f_{D\bar{D}} = (19.5 \pm 4.5)\%$
- Consistent with $K^{\pm}$ counting analysis

# Search for Charmless $B^+$ Decays

- Exclusive (3-prong) hadronic channels
  $B^+ \to \rho^0 \ \pi^+(K^+)$, $\rho^0 \ \to \pi^+\pi^-$
  and $B^+ \to K^{*0}\pi^+(K^+)$, $K^{*0} \to K^+\pi^-$
- Decays due to tree-level $b \to u$ and one-loop penguin $b \to d(s)$ transitions
- Current experimental limits $\sim \times 5$ larger than theoretical predictions

| | Theory | CLEO | DELPHI | ALEPH |
|---|---|---|---|---|
| | BR $\times 10^{-5}$ | 90% C.L. $\times 10^{-5}$ | | |
| $B^+ \to \rho^0\pi^+$ | 0.4 – 1.4 | $< 5.8$ | $< 16$ | $< 3.2$ |
| $B^+ \to \rho^0 K^+$ | 0.01 – 0.06 | $< 1.4$ | $< 12$ | |
| $B^+ \to K^{*0}\pi^+$ | 0.6 – 0.9 | $< 3.9$ | $< 39$ | |

DELPHI $\longrightarrow$ $\mathcal{B}(B \to \rho(K^*)\pi) = (1.7^{+1.2}_{-0.8} \pm 0.2) \times 10^{-4}$

| | Number of $\#B^+$'s | Effic. (%) | $B \to \rho\pi$ Obs | Bkg | $B \to \rho K$ Obs | Bkg | $B \to K^*\pi$ Obs | Bkg |
|---|---|---|---|---|---|---|---|---|
| CLEO | 2.64 $M$ | $\approx 6.0$ | 8 | 3.0 | 1 | 4.8 | 3 | 1.3 |
| DELPHI | 0.5 $M$ | $\approx 6.0$ | 1 | 0.09 | 0 | 0.17 | 2 | 0.06 |

- At SLD:
  Expect relatively high efficiency, due to very good tracking and vertexing efficiency and resolution (VXD3)
- Extrapolating from DELPHI B.R. measurement, we should expect $\sim 6$ decays in our $550k$ $Z^0$ Data sample ($\sim 100k$ $B^+$'s)

# Analysis

- **Final-State Selection**

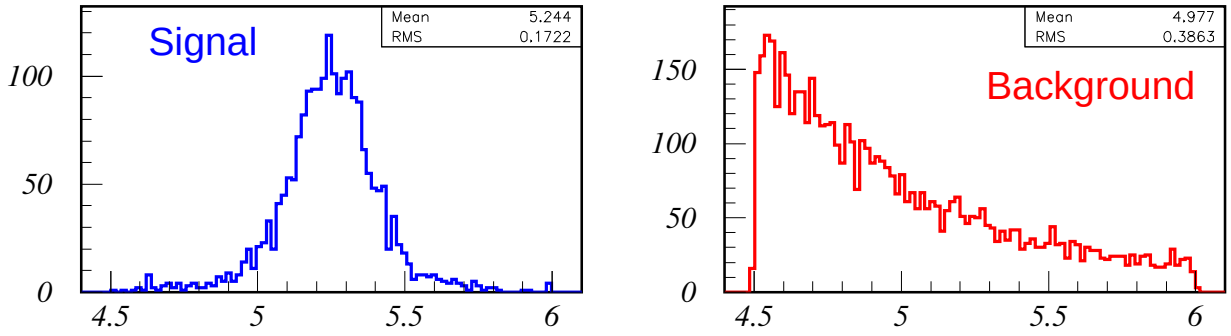
  Three-prong vertex with Charge $= \pm 1$

  Decay kinematics requirements

  $B$ mass and energy, $\rho^0$ mass, $K^{*0}$ mass, C.M. helicity angle, ...

  Track quality requirements

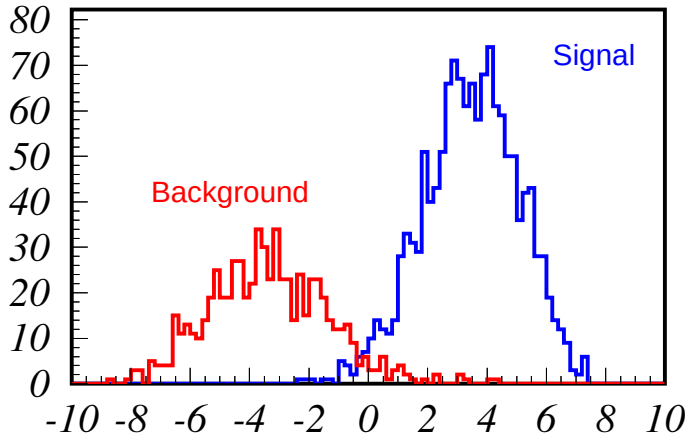
*Vertex Mass*




- **Fischer Discriminant Function**

  constructed using 8 kinematic variables, each with a parametrization for signal and background

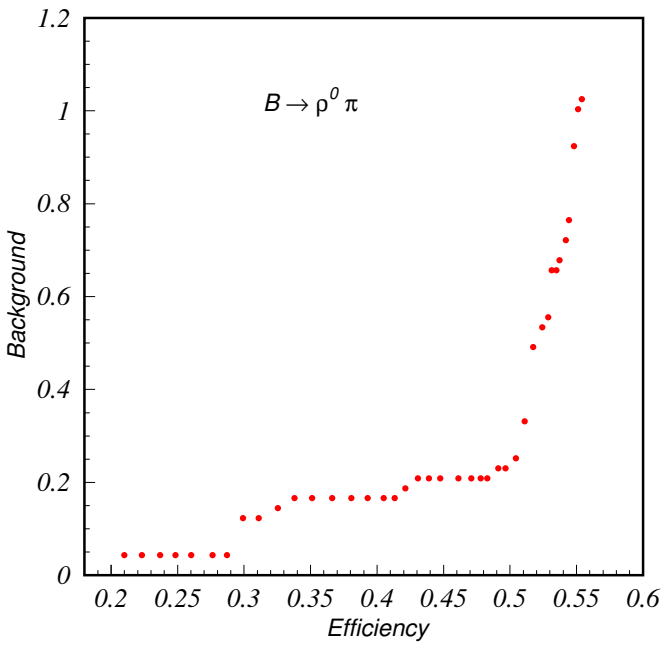
*Fischer Discriminant*

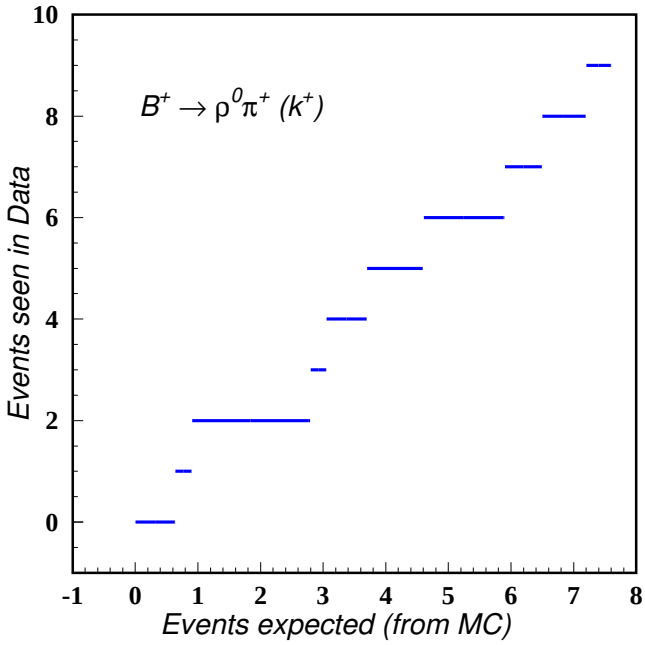


# Analysis (continued)

- **Optimal Analysis Point**

  found by minimizing upper limit vs. efficiency (Poisson statistics)




- **No decays observed in Data**

| | Efficiency | Decays Observed | Estimated Background |
|---|---|---|---|
| $\rho^0\pi^+$ | 0.50 | 0 | 0.61 |
| $\rho^0 K^+$ | 0.45 | 0 | 0.61 |
| $K^{*0}\pi^+$ | 0.52 | 0 | 0.37 |
| $K^{*0}K^+$ | 0.46 | 0 | 0.37 |

- **CROSS CHECK:**

  With looser selection cuts, number of observed decays in Data tracks very well expected background from the Monte Carlo

# Systematic Errors

Variation in Efficiency (%)

| | $\rho^0\pi^+$ | $\rho^0 K^+$ | $K^{*0}\pi^+$ | $K^{*0}K^+$ |
|---|---|---|---|---|
| Mass Resolution | -0.3 | -0.9 | -0.4 | +0.1 |
| Tracking Efficiency | -0.6 | -0.5 | -0.4 | -0.2 |
| Vertex Resolution | -2.5 | -1.7 | -1.0 | -0.9 |
| $b$ Fragmentation | $\pm$0.4 | $\pm$0.0 | $\pm$0.3 | $\pm$0.4 |
| TOTAL | 3.8 | 3.1 | 2.1 | 1.4 |

# RESULTS

1993 – 98 SLD Data $\longrightarrow$ 583,867 Hadronic $Z^0$'s (101,937 $B^{\pm}$'s)

Uncertainty in $N_{B^{\pm}} = 1.1\%$

No decays seen in Data $\Longrightarrow$ 90% CL limit $< 2.3$ Decays

90% C.L. Upper Limit (BR $\times 10^{-5}$), including systematic errors

| | CLEO | DELPHI | SLD Preliminary |
|---|---|---|---|
| $B^+ \to \rho^0\pi^+$ | 5.8 | 16 | 8.2 |
| $B^+ \to \rho^0 K^+$ | 1.4 | 12 | 9.2 |
| $B^+ \to K^{*0}\pi^+$ | 3.9 | 39 | 7.9 |
| $B^+ \to K^{*0}K^+$ | | | 9.0 |

# SUMMARY

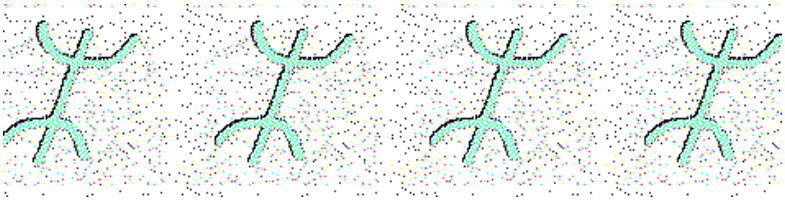
- $B \rightarrow$ Double-Charm branching ratio measurement

$$\mathcal{B}(B \rightarrow D\bar{D}X) = (18.8 \pm 2.5 \pm 5.9)\%$$

(SLD Preliminary)

$K^{\pm}$ Counting and $D$ Charge Techniques will be combined

Will work on reducing systematic error

- Competitive upper limits on Exclusive Charmless $B^{\pm}$ Decays

- Other $B$ Decay analyses are currently underway at SLD
  e.g., $b$ semileptonic branching ratio