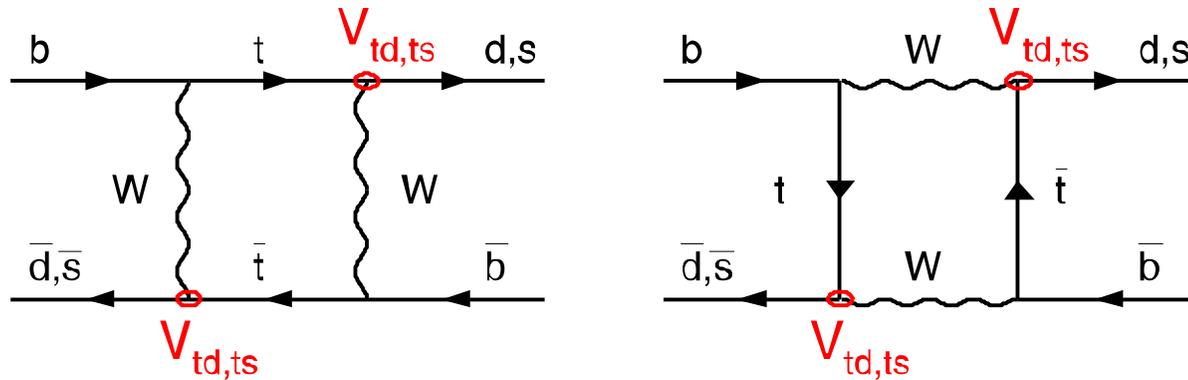


B Mixing at SLD



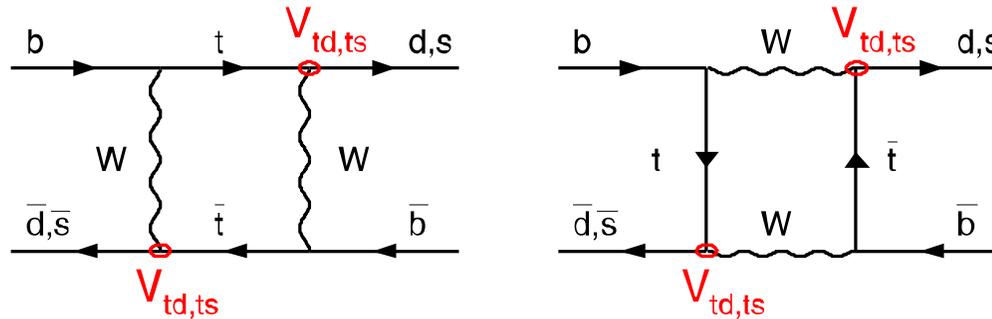
Julia Thom
SLAC

EPS HEP2001

Budapest

July 12-18, 2001

B⁰ – B⁰ System



Oscillation frequency :

$$\Delta m = m_H - m_L$$

Mixing Probability:

$$P(B^0 \rightarrow \bar{B}^0) = \frac{1}{2} \Gamma e^{-\frac{\Gamma t}{2}} (1 + \cos \Delta m t)$$

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_{B_d} m_t^2 F\left(\frac{m_t^2}{m_W^2}\right) B_{B_d} f_{B_d}^2 \eta_{QCD} |V_{tb}^* V_{td}|^2 = 0.487 \pm 0.014 \text{ ps}^{-1}$$

Extraction of V_{td} from Δm_d : ~20% uncertain mostly due to $\sqrt{B_{B_d} f_{B_d}}$

most precise determination of V_{td} → measure $\Delta m_s / \Delta m_d$

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_s}}{m_{B_d}} (1.16 \pm 0.05)^2 \left| \frac{V_{ts}}{V_{td}} \right|^2$$

S.Aoki BCP4

Impact on CKM parameters

Measurements of Δm : Significant constraints on (ρ, η)

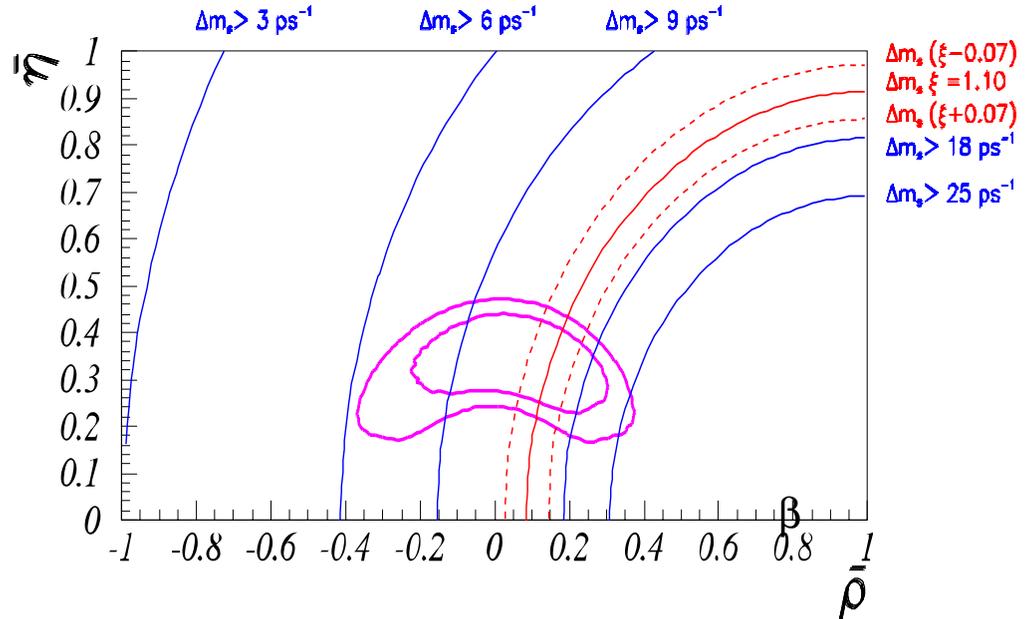
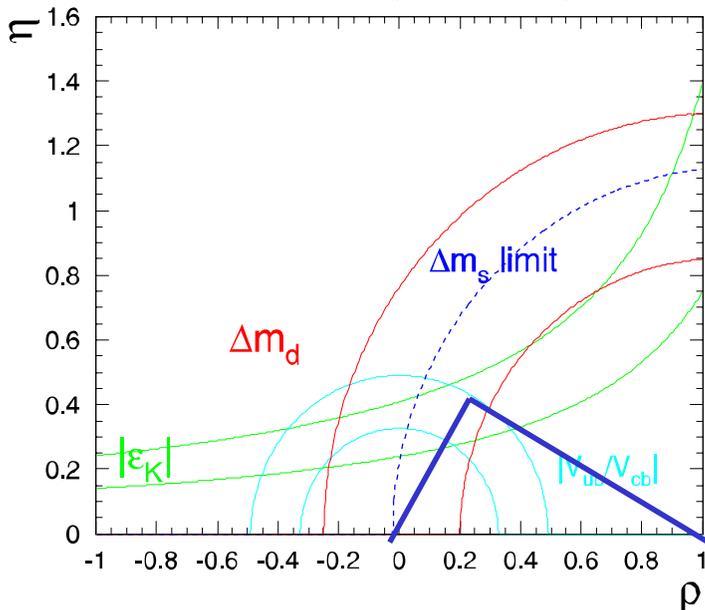
$$\Delta m_s \propto |V_{ts}|^2 = A^2 \lambda^4 \quad \Rightarrow \quad \frac{\Delta m_s}{\Delta m_d} \approx \frac{1}{\lambda^2} \approx 20$$

$$\Delta m_d \propto |V_{td}|^2 = A^2 \lambda^6 \left[(1 - \bar{\rho})^2 + \bar{\eta}^2 \right]$$

\rightarrow fast B_s oscillations

$$\frac{V_{td}}{V_{ts}} \propto \frac{\Delta m_d}{\Delta m_s}$$

Lower limit on $\Delta m_s \Rightarrow$ upper limit on $|V_{td}|$

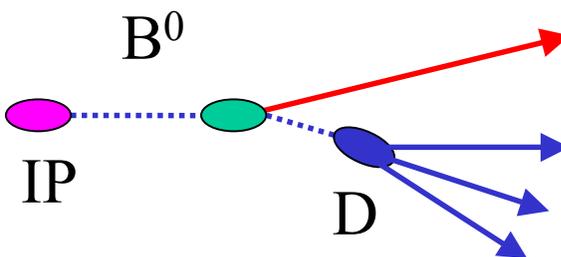


In SM: Δm_s signal "around the corner"

Measure Δm

$$\frac{\Delta m_s}{\Delta m_d} \approx \frac{1}{\lambda^2} \approx 20$$

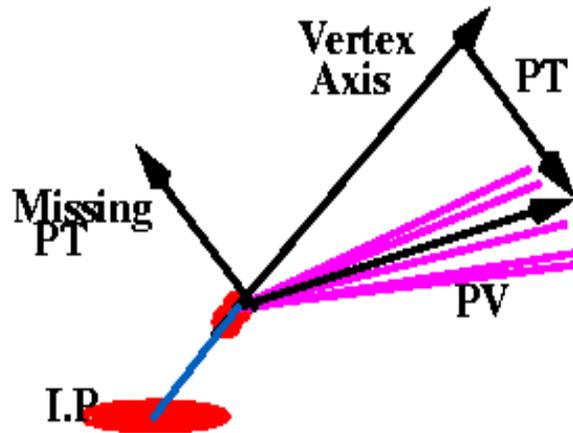
1. Select neutral B decays
2. Reconstruct B decay vertex & boost \Rightarrow determine proper time t
3. Determine B^0 or \bar{B}^0 flavor at production
4. Determine B^0 or \bar{B}^0 flavor at decay



B Event Selection

Search for vertices of tracks displaced from IP (using NN)

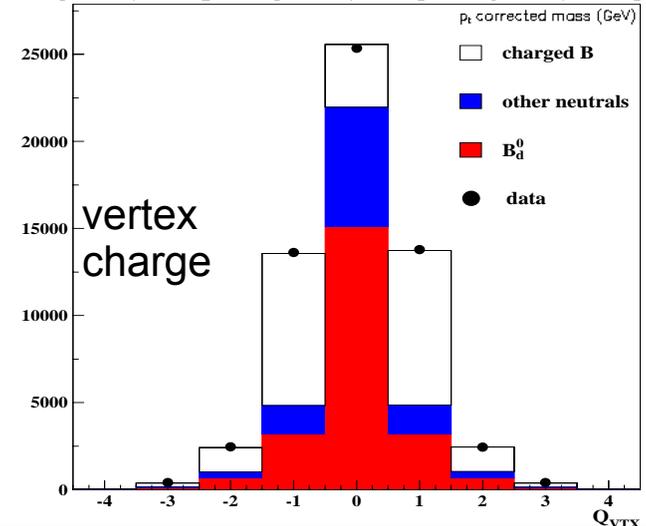
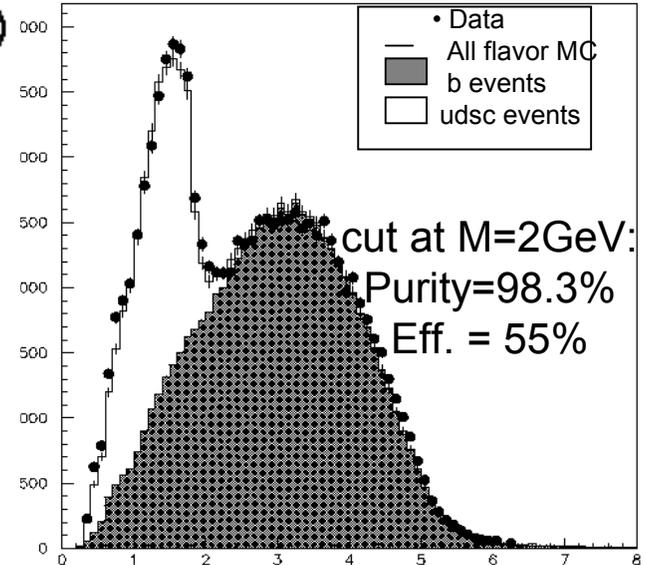
- Compute M_{raw} mass of tracks in secondary vtx (assign m_{π})
- Exploit additional mass information from kinematics :



⇒ Define P_T -corrected mass:

$$M = \sqrt{M_{raw}^2 + P_T^2 + P_T}$$

Select neutral vertices
(87% pure)



M

Initial State Tagging at SLD

1) Polarized forward-backward asymmetry

Efficiency = 100% mistag $w \cong 28\%$

2) Opposite-hemisphere Charge Tags

vtx charge, Jet Charge

Kaon charge $b \rightarrow c \rightarrow s$

Lepton charge $b \rightarrow l^-$

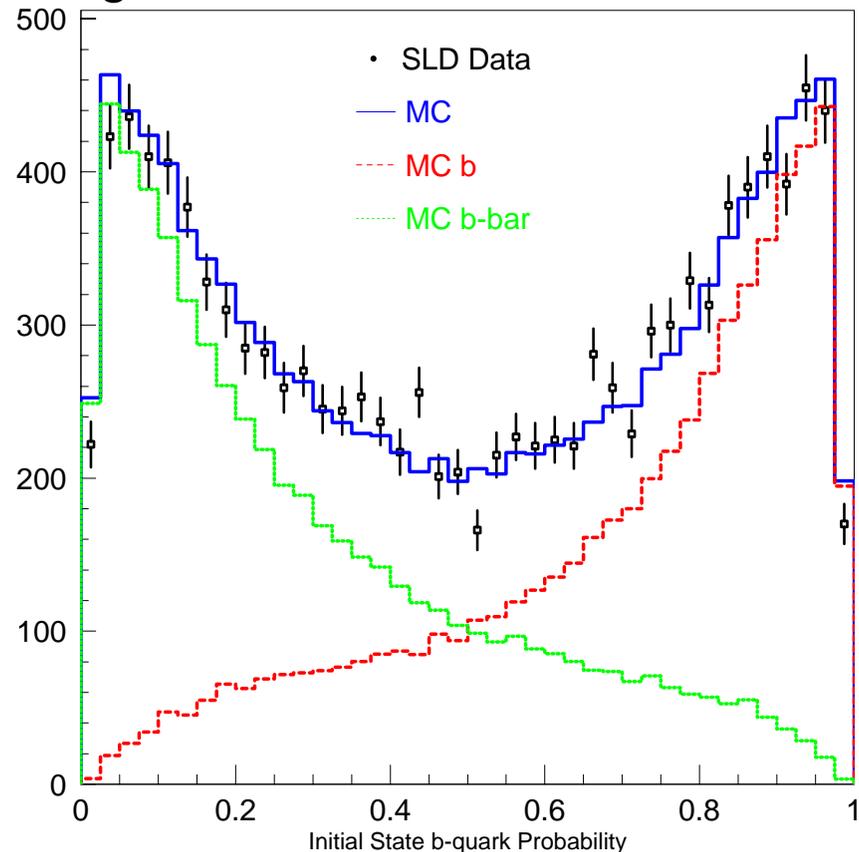
Dipole charge $dq = (Q_D - Q_B)$

Combined in Neural Net

FB asymmetry+NN:

average mistag $w \cong 22\%$

Event-by-event mistag probability



Bd mixing analysis

Kaon Tag: $B_d \rightarrow D^- / \bar{D}^0 \rightarrow K^+$

$\bar{B}_d \rightarrow D^+ / D^0 \rightarrow K^-$

Kaon ID: [SLD Cherenkov Ring Imaging Detector](#)

Fraction of events tagged as mixed:

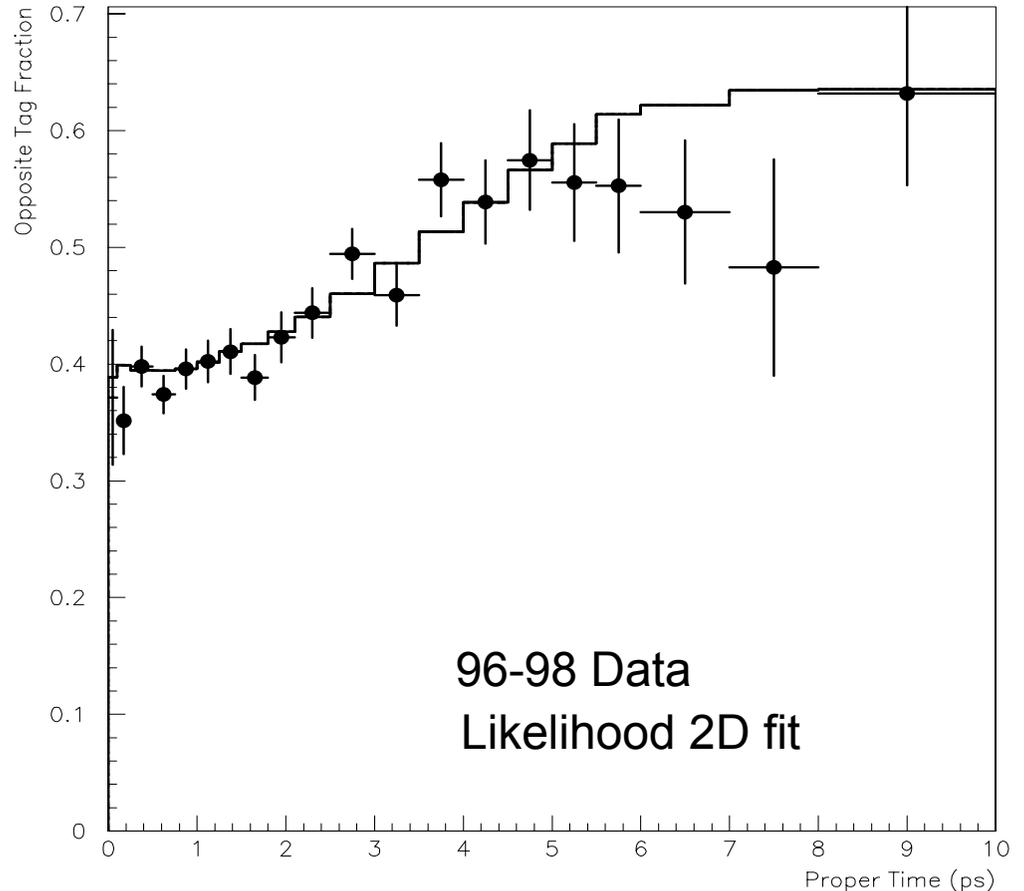
B_d Right Sign Fraction: $(82 \pm 5)\%$
(Argus)

Fit to Δm_d and B_d RSF
(96-98 data):

$\Delta m_d = 0.503 \pm 0.028$ (stat)
 ± 0.020 (syst) ps^{-1}

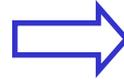
B_d eff. RSF = 0.797 ± 0.022

number of vertices: 7844



Measure Δm_s

1. Determine proper time t_{decay}
2. Tag B^0 or \bar{B}^0 at production
3. Tag B^0 or B^0 at decay



Experimental errors:

mistag w , resolution σ_t
 B_s fraction f_{B_s}

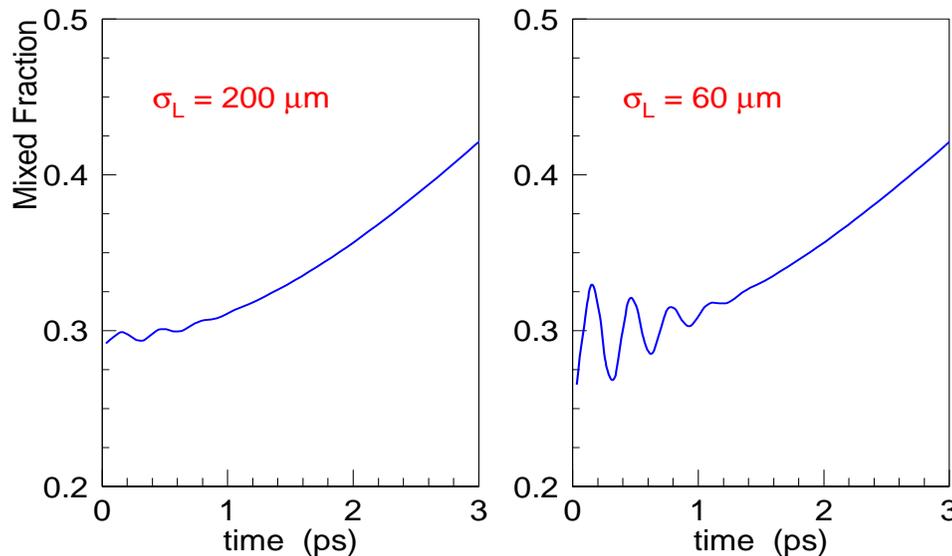
Significance (Signal/Noise) for B_s mixing signal:

$$S = \sqrt{\frac{N}{2}} f_{B_s} (1 - 2w) e^{-\frac{1}{2}(\Delta m_s \sigma_t)^2}$$

N: number of events

$$\sigma_t^2 = \left(\frac{\sigma_L}{\gamma \beta c} \right)^2 + \left(\frac{\sigma_p}{p} t \right)^2$$

Mistag = 0.25, $f_{B_s} = 0.18$, $\sigma_p/p = 0.10$ and $\Delta m_s = 20 \text{ ps}^{-1}$



Proper Time Reconstruction

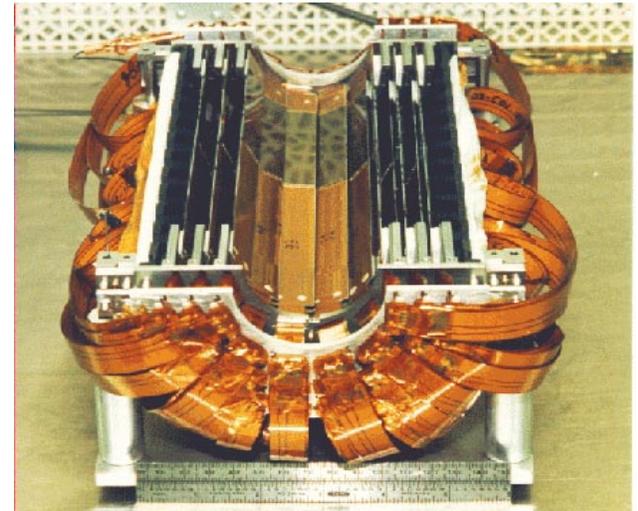
Reconstruct B vertex, determine decay length

CCD Vertex Detector (VXD3)

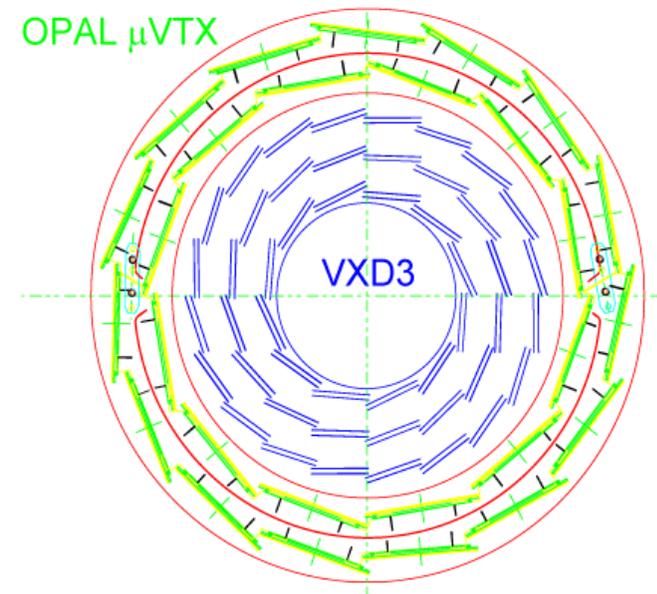
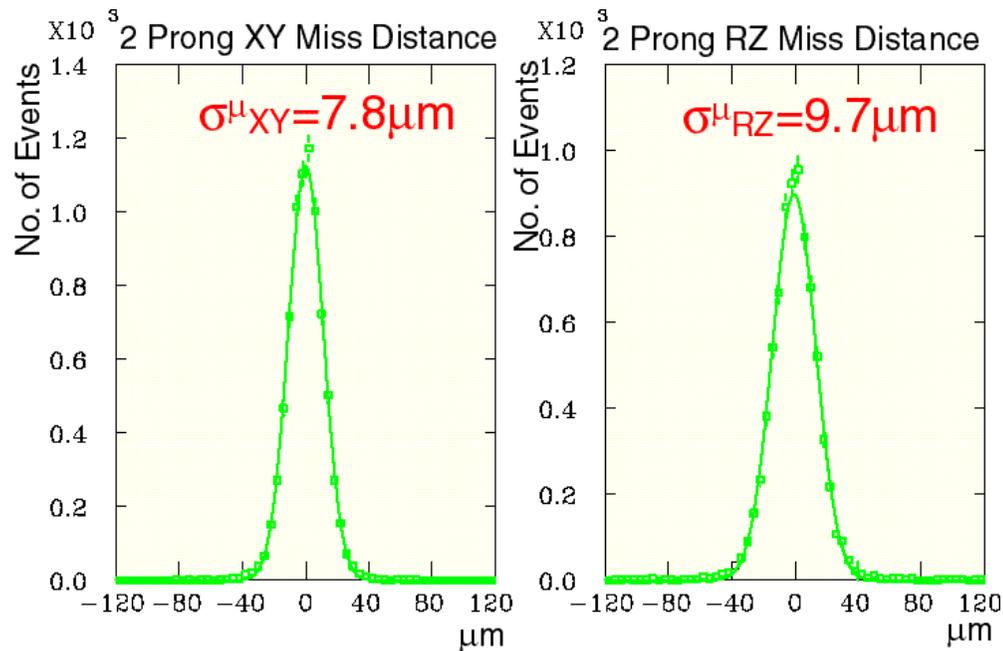
~300 Million pixels ($20\ \mu\text{m} \times 20\ \mu\text{m}$)

3 layers for self-tracking

X^0 / layer = 0.4%, inner radius = 2.7 cm



Tracking resolution $Z \rightarrow \mu^+ \mu^-$ data



IP measured w/ resolution $4 \pm 2\ \mu\text{m}$ (XY view)

SLD B_s Mixing Analyses

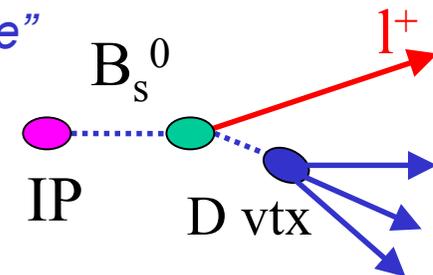
Final State Tag & Proper Time Reconstruction

3 different analyses at SLD
using 400K hadronic Z decays (1996-98 data)

Inclusive

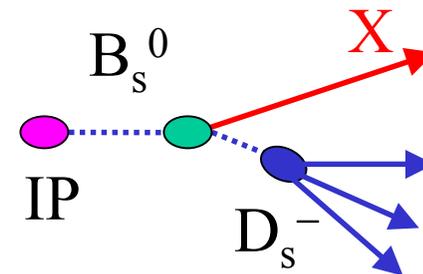
1) secondary & tertiary topological vtx “*Charge Dipole*”
11462 events

2) lepton + topological D vtx “*lepton+D*”
2087 events



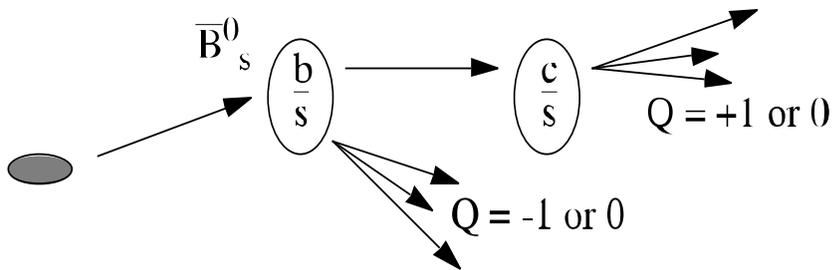
Semi-exclusive

3) $B_s \rightarrow D_s^- X$
 $D_s^- \rightarrow \phi\pi^-, K^{*0}K^-$ “*D_s+ tracks*”
361 events



(Inclusive) Charge Dipole analysis

FULLY inclusive reconstruction of secondary and tertiary vertices:

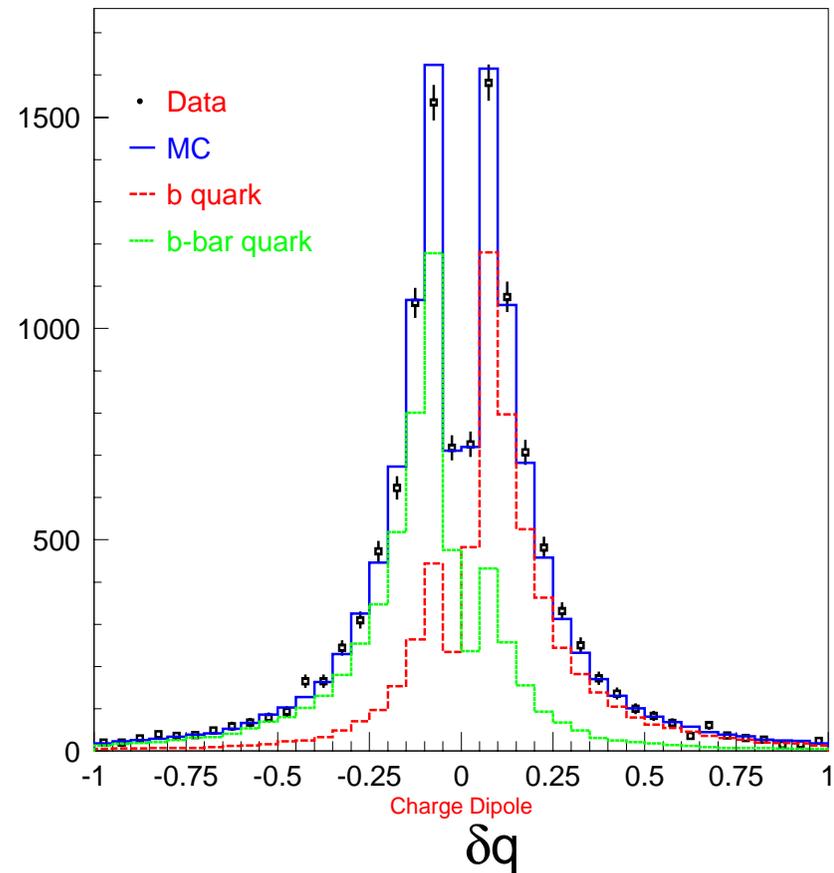


Tag B flavor with “charge dipole” δq

$$\delta q = \text{sign}(Q_D - Q_B) * \text{Distance}_{B \text{ to } D}$$

$\delta q > 0$ tags \bar{B}

$\delta q < 0$ tags B



Charge Dipole analysis (II)

Performance of the analysis:

Decay length resolution

$\sigma_L = 81 \mu\text{m}$ (60%) & $297 \mu\text{m}$

$\sigma_p / p = 0.07$ (60%) & 0.21

B_s purity

$f(B_s) = 16\%$ overall

Tagging

initial state mistag = 22%

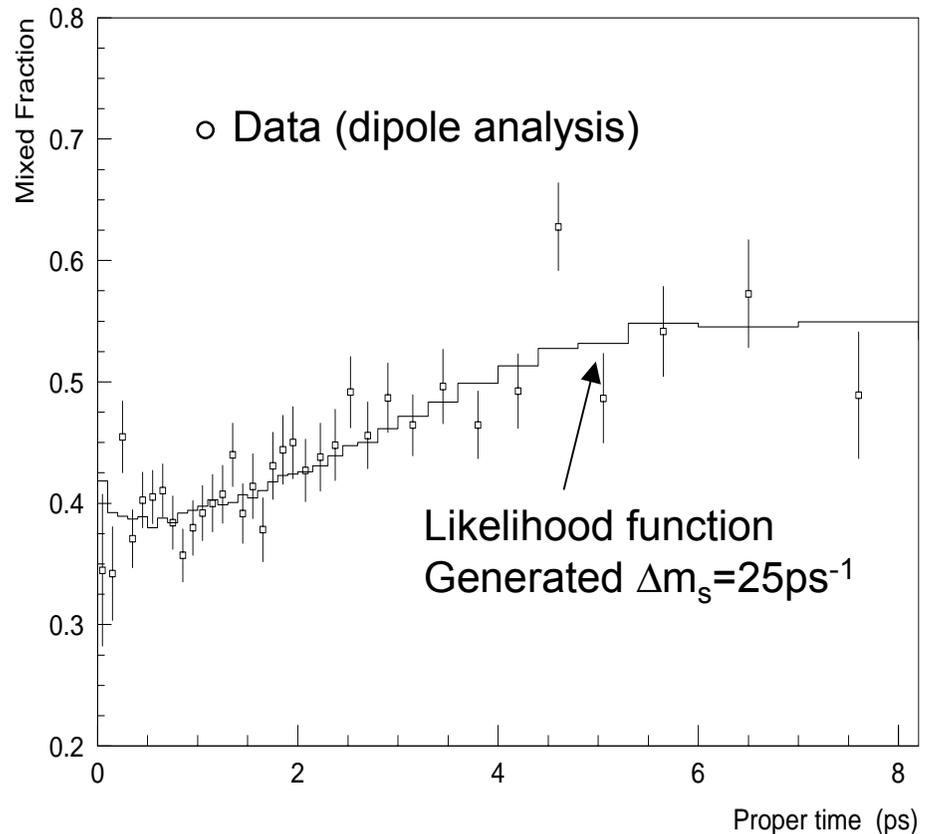
final state mistag for B_s decays:

$w = 22\%$ overall

$w = 9\%$ for $B_s \rightarrow D_s X$

$w = 47\%$ for $B_s \rightarrow D_{(s)} D X$

Fraction of decays tagged as mixed -vs- Proper Time



(Inclusive): lepton+D analysis

Select identified lepton

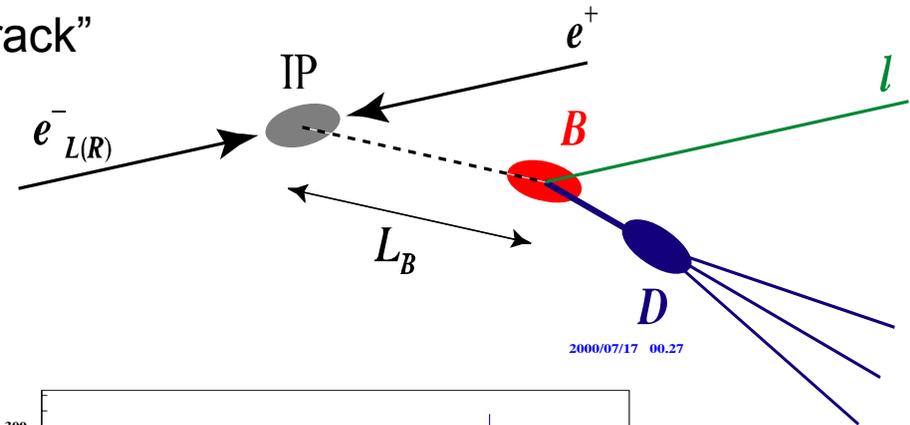
lepton tags decay flavor ($b \rightarrow l^-$)

Reconstruct D vertex inclusively

B vtx = intersection of lepton and D “track”

Neural Network: suppress ($b \rightarrow c \rightarrow l^+$)

→ very low mistag $w = 4\%$ (B_s)



decay length resolution

$\sigma_L = 54$ mm (60%) & 213 mm

$\sigma_p / p = 0.07$ (60%) & 0.17

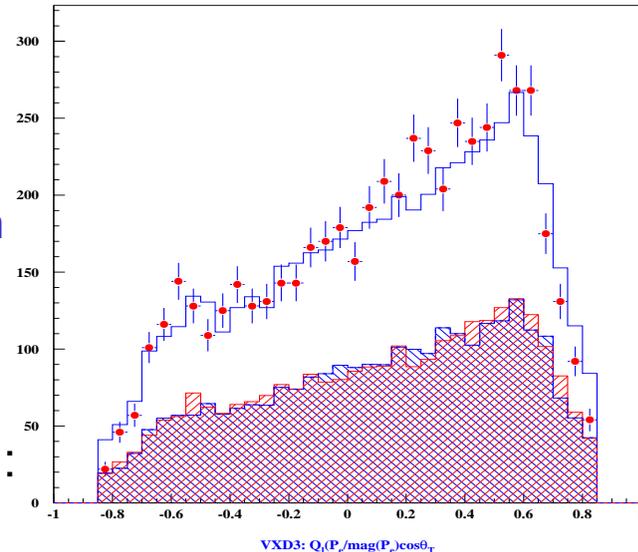
B_s purity

$f(B_s) = 16\%$ overall

$f(B_s) = 34\%$ in opposite-sign lepton-kaon subsample

Check tagging power:

Lepton signed forward/backward asym.:



(Semi-exclusive): D_s + tracks analysis

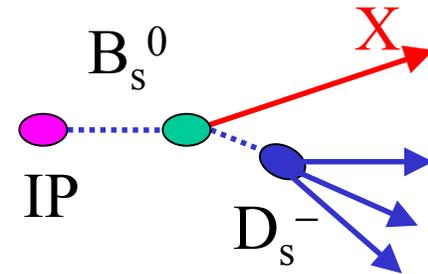
Reconstruct $B_s \rightarrow D_s^- X$

full reconstruction of D_s decay

$D_s^- \rightarrow \phi\pi^-, K^{*0}K^-$

particle ID with Cherenkov

Ring Imaging Detector (CRID)



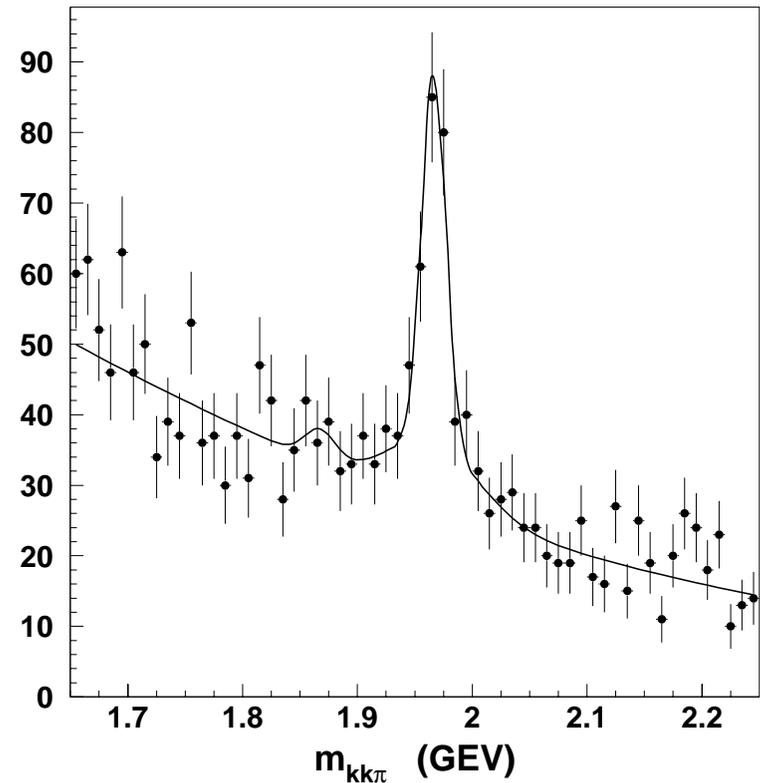
Neural Network D_s selection yields

280 $D_s^- \rightarrow \phi\pi^-$ candidates

81 $D_s^- \rightarrow K^{*0}K^-$ candidates

$B_s \rightarrow D_s^- l^+ X$ (39 events) and

$B_s \rightarrow D_s^-$ hadrons included



D_s + tracks analysis (II)

Performance of the analysis:

superb decay length resolution

$\sigma_L = 50 \mu\text{m}$ (60%) & $151 \mu\text{m}$

$\sigma_p / p = 0.08$ (60%) & 0.19

high B_s purity

$f(B_s) = 38\%$ overall

for D_s signal:

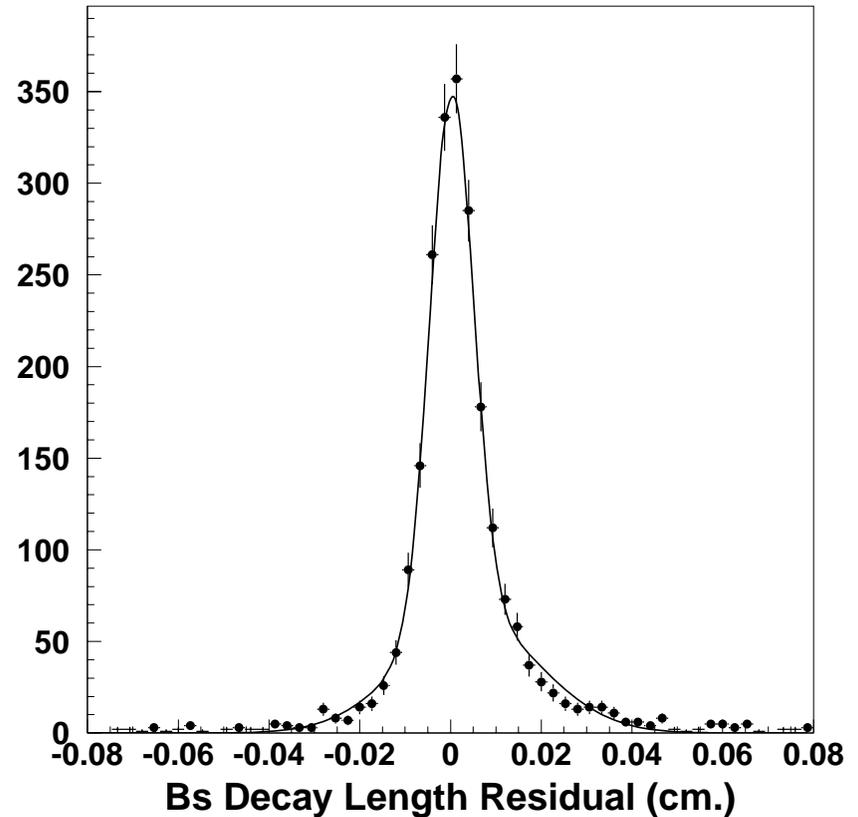
$f(B_s) = 65\%$ neutral sample (D_s + hadrons)

90% neutral sample (D_s + lepton)

D_s signal:

final state w = 13% (D_s + hadrons)

final state w = 5% (D_s + lepton)



Amplitude Fit Method

Time-dependent mixing generates periodic signal

⇒ ideally suited for Fourier Analysis [NIM A384, 491 \(1997\)](#)

In L function: $(1 \pm \cos \Delta m_s t) \rightarrow (1 \pm A \cos \Delta m_s t)$ **A**: normalized Fourier Amplitude

minimize $-\log(L)$ for **A** at fixed Δm_s

Expect **A = 1** at true Δm_s

A = 0 else

95% C.L. limit:

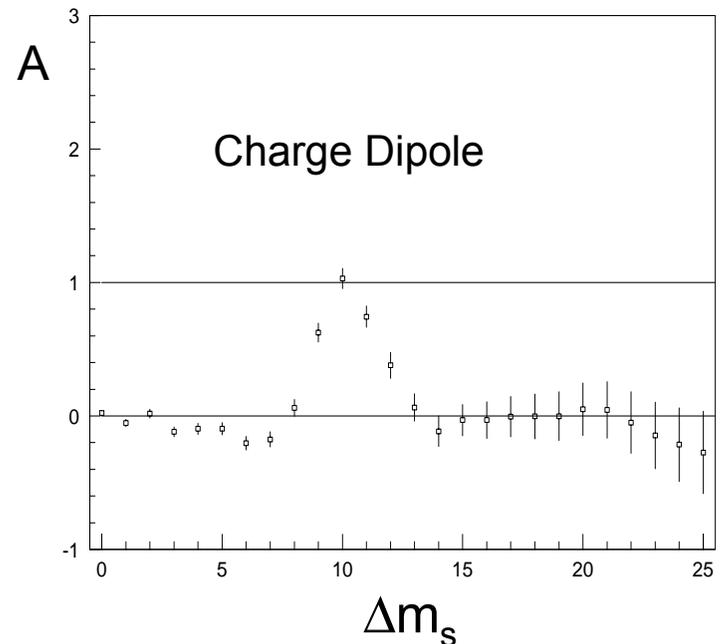
Δm_s value for which $A + 1.645 \sigma_A = 1$

“Sensitivity”:

Δm_s value for which $1.645 \sigma_A = 1$

→ σ_A increases with Δm_s due to limited σ_t

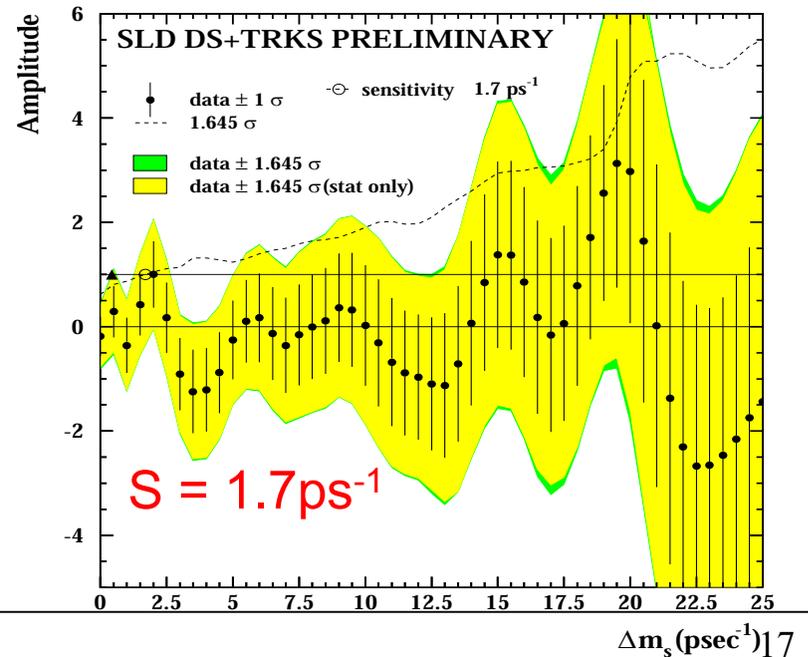
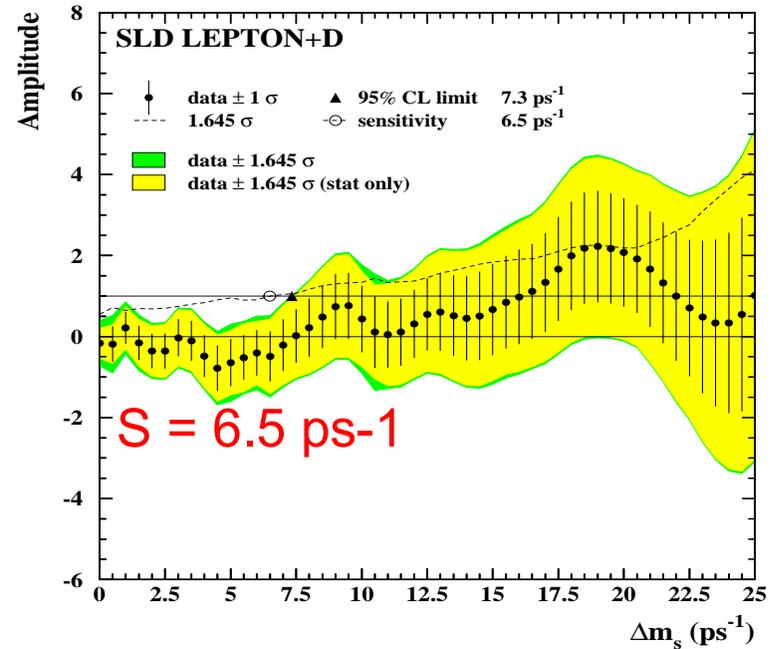
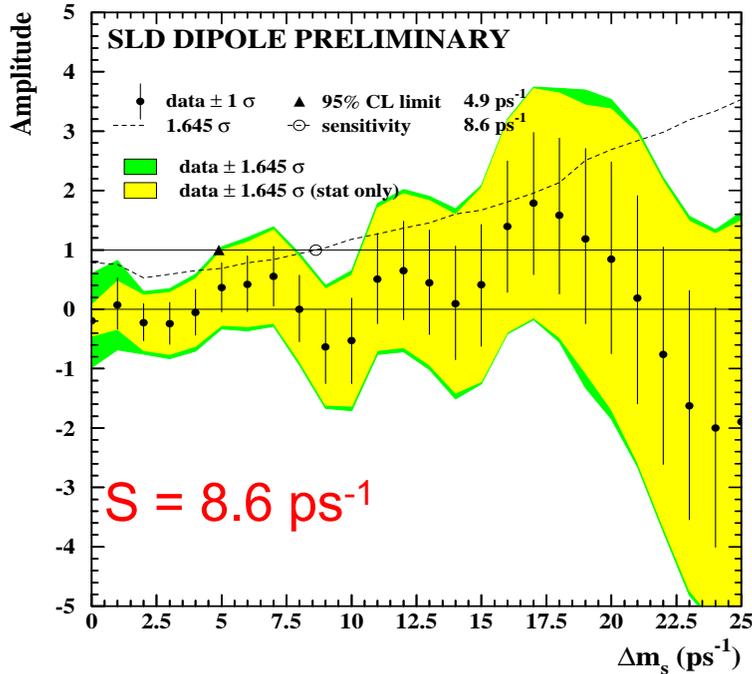
MC generated with $\Delta m_s = 10 \text{ ps}^{-1}$



Amplitude Fit results

3 SLD analyses

(Preliminary)



Combined SLD B_s Oscillation Amplitude

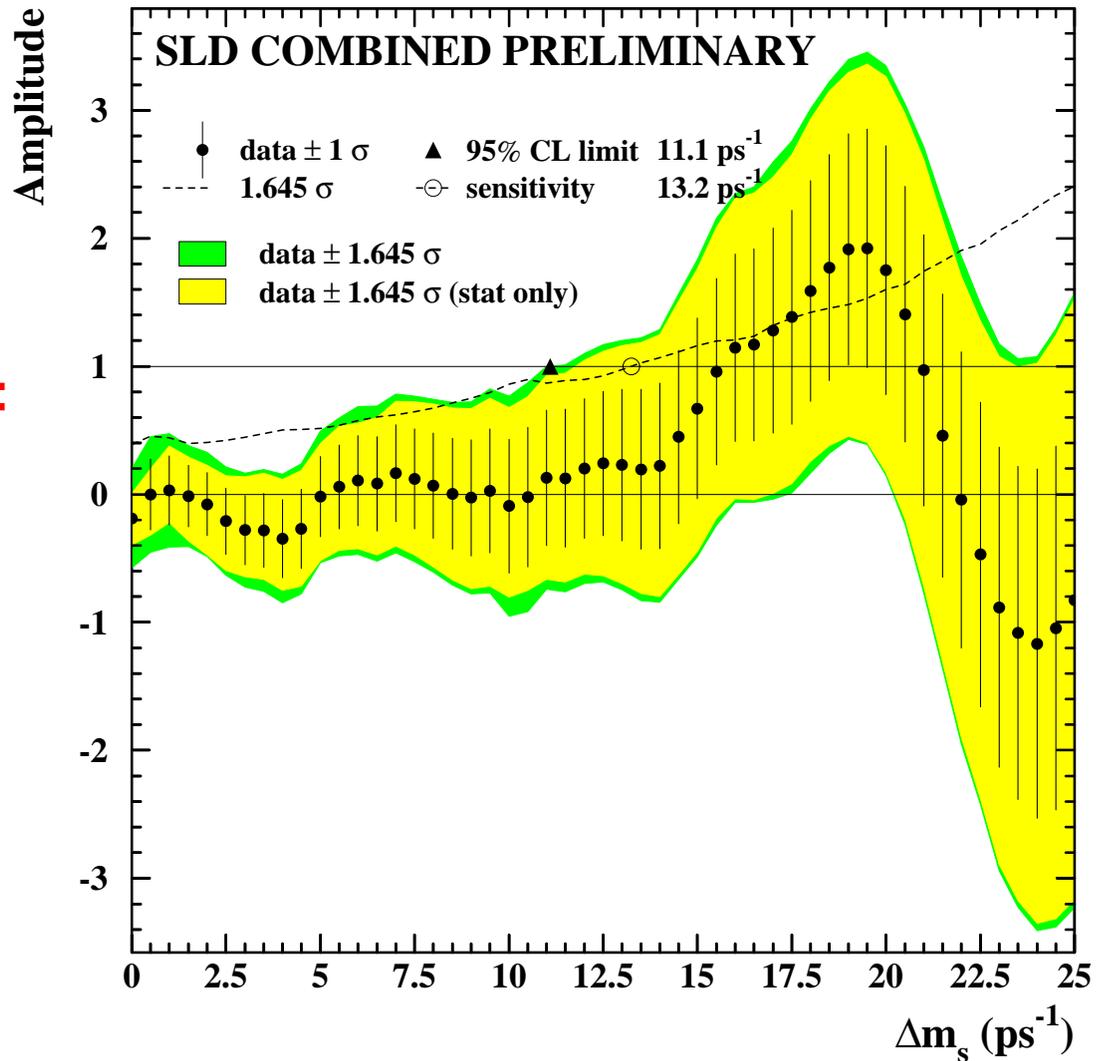
Preliminary result

SLD 400K Z^0 :

Sensitivity = 13.2 ps^{-1}

Excluded at 95% C.L.:

$$\Delta m_s < 11.1 \text{ ps}^{-1}$$



B Mixing at SLD: Summary

most precise determination of V_{td} → measure $\Delta m_s / \Delta m_d$

Preliminary results:

Δm_d :

Previous SLD average: $\Delta m_d = 0.526 \pm 0.043(\text{stat}) \pm 0.031(\text{syst}) \text{ ps}^{-1}$ (93-95 data)

New B_d mixing measurement using Kaon tag:

$$\Delta m_d = 0.503 \pm 0.028 (\text{stat}) \pm 0.020 (\text{syst}) \text{ ps}^{-1} \text{ (96-98 data)}$$

Δm_s :

- 3 analyses: charge dipole, lepton+D, D_s +tracks
- Powerful initial state tag using polarization and charged tags
- Superb decay length resolution: pixel VXD and small IP size

SLD Combined: Sensitivity = 13.2 ps^{-1}

Excluded at 95% C.L.: $\Delta m_s < 11.1 \text{ ps}^{-1}$