B_s Mixing at SLD

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Representing the SLD Collaboration

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Introduction

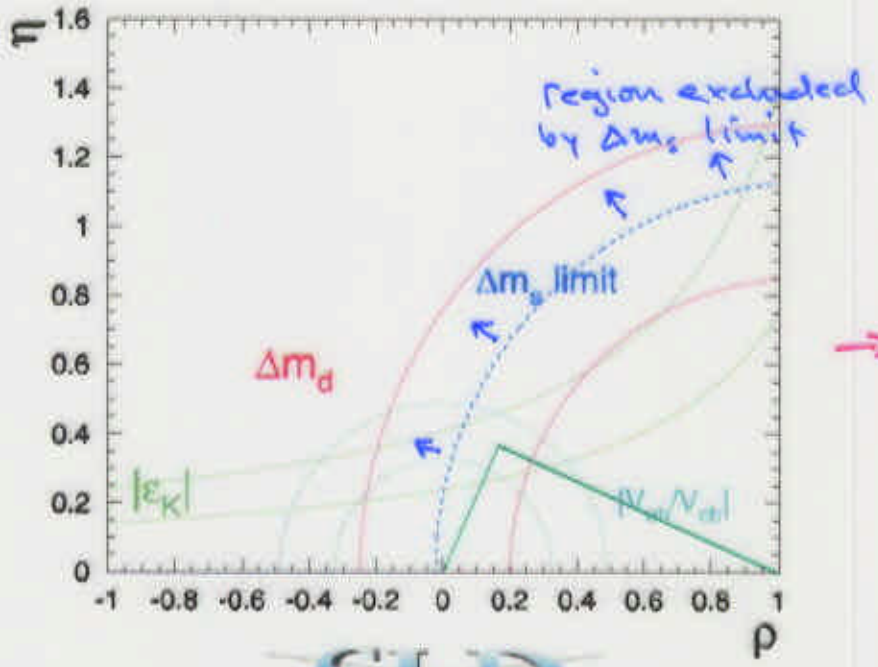
- **What are we trying to measure?**

$$\text{Prob}\,(B^0 \to B^0) = \tfrac{1}{4}\left(e^{-\Gamma_L t} + e^{-\Gamma_H t} + 2\,e^{-\Gamma t}\cos\Delta m t\right)$$
$$\text{Prob}\,(B^0 \to \overline{B}^0) = \tfrac{1}{4}\left(e^{-\Gamma_L t} + e^{-\Gamma_H t} - 2\,e^{-\Gamma t}\cos\Delta m t\right)$$

- **Why do we want to measure Δm_S?**

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s} f_{B_s}^2 B_{B_s}}{m_{B_d} f_{B_d}^2 B_{B_d}} \cdot \left|\frac{V_{ts}}{V_{td}}\right|^2 = (1.11 \pm 0.06)^2 \cdot \left|\frac{V_{ts}}{V_{td}}\right|^2$$

  - Coupled with Δm_D gives a value of V_{td} with little theoretical uncertaintity
  - Lower limit on Δm_S gives upper limit on V_{td}
  - With V_{ub}/V_{cb}, limits the uncertaintity in the vertex of the unitarity triangle.

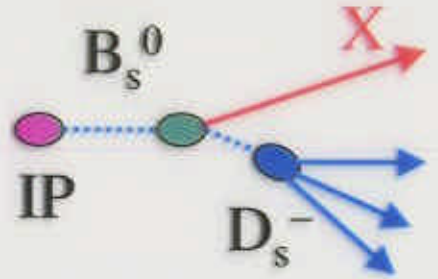


→ See next talk by A. Stocchi

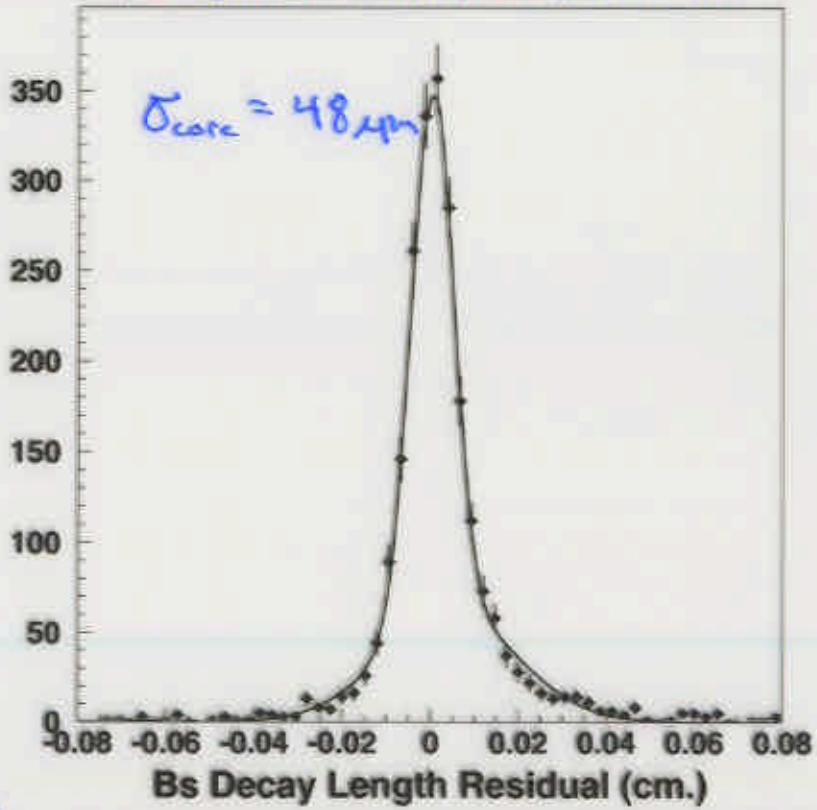
SLD

Measuring Δm_s at SLD

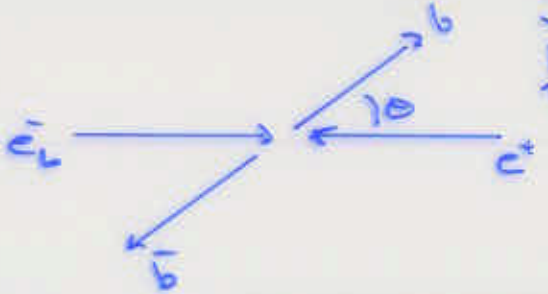
- **To measure Δm you need to:**
  - Tag the flavor of the initial and final B states.
  - Measure the proper time of the B decay by reconstructing the decay length and momentum
- **Take advantage of unique SLD features:**
  - Very high resolution 3D CCD vertex detector
    - Finds candidate decay vertices.
    - Coupled with small, stable IP position, measures decay length with superb resolution.
    - Determines B charge
  - Polarized electron beam
    - 100% efficient tag of initial state flavor
- **Report on three SLD Analyses:**
  - D_S + Tracks analysis
  - Lepton + D analysis
  - Charged Dipole Analysis
- **1996-1998 Data Runs:**
  - 400,000 Z^0 Decays, $\langle P_e \rangle = 72\%$

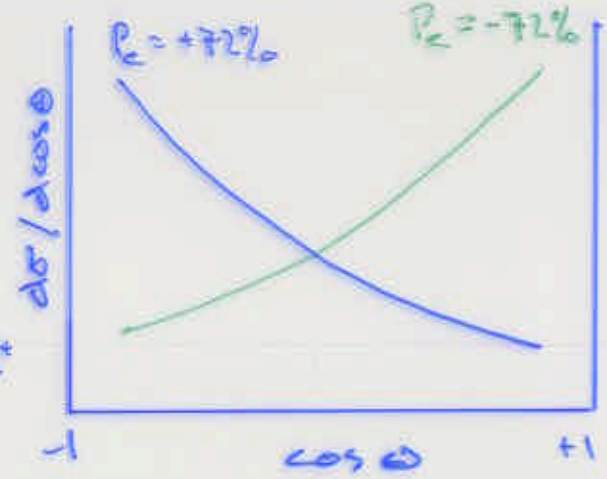


D_S + Tracks analysis
Decay Length Resolution
σ_1 = 48 μm (60 % core), σ_1 = 152 μm (40% tail)



Initial State Tag



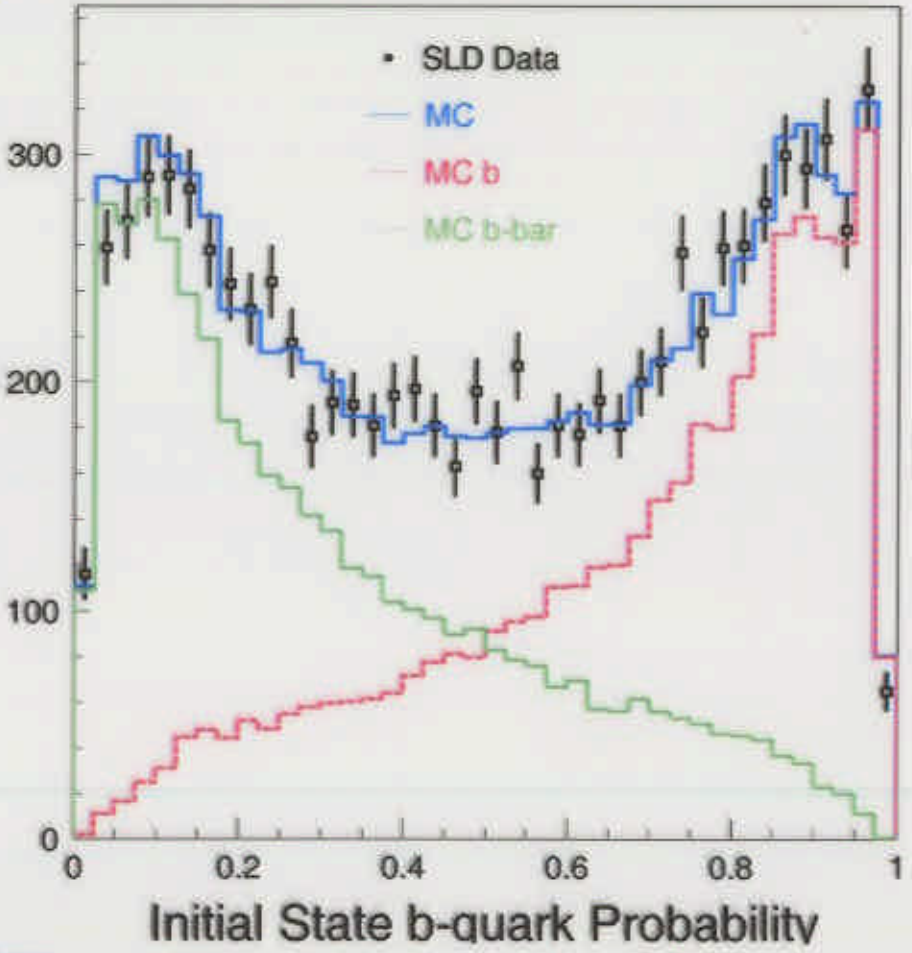


- **Polarized Forward-Backward Asymmetry (A_{FB})**
  - Efficiency = 100%
  - Correct-tag probability ≅ 72%
- **Opposite-hemisphere *Charge* Tags**

	efficiency	correct-tag probability
– Jet charge	100%	66%
– Vertex charge	43%	75%
– Kaon charge	16%	74%
– Lepton charge	9%	74%
– Dipole charge	17%	70%

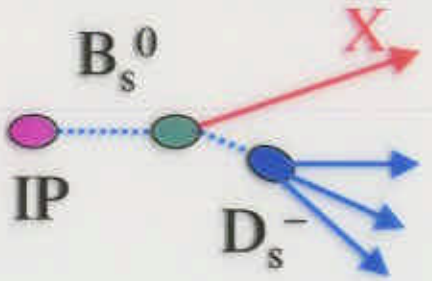
- **Tags combined to compute initial state b-quark probability**
  - Including correlations
- **Correct tag rates decay-by-decay**

  Correct tag rates ~0.75 - 0.78

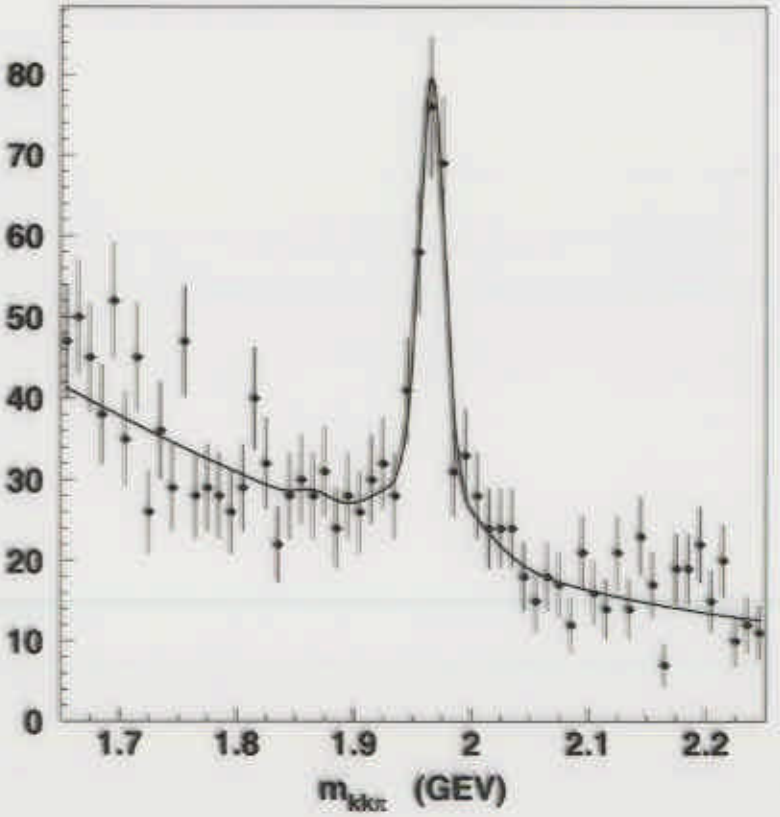


Semi-Exclusive Methods: D_s + Tracks Analysis

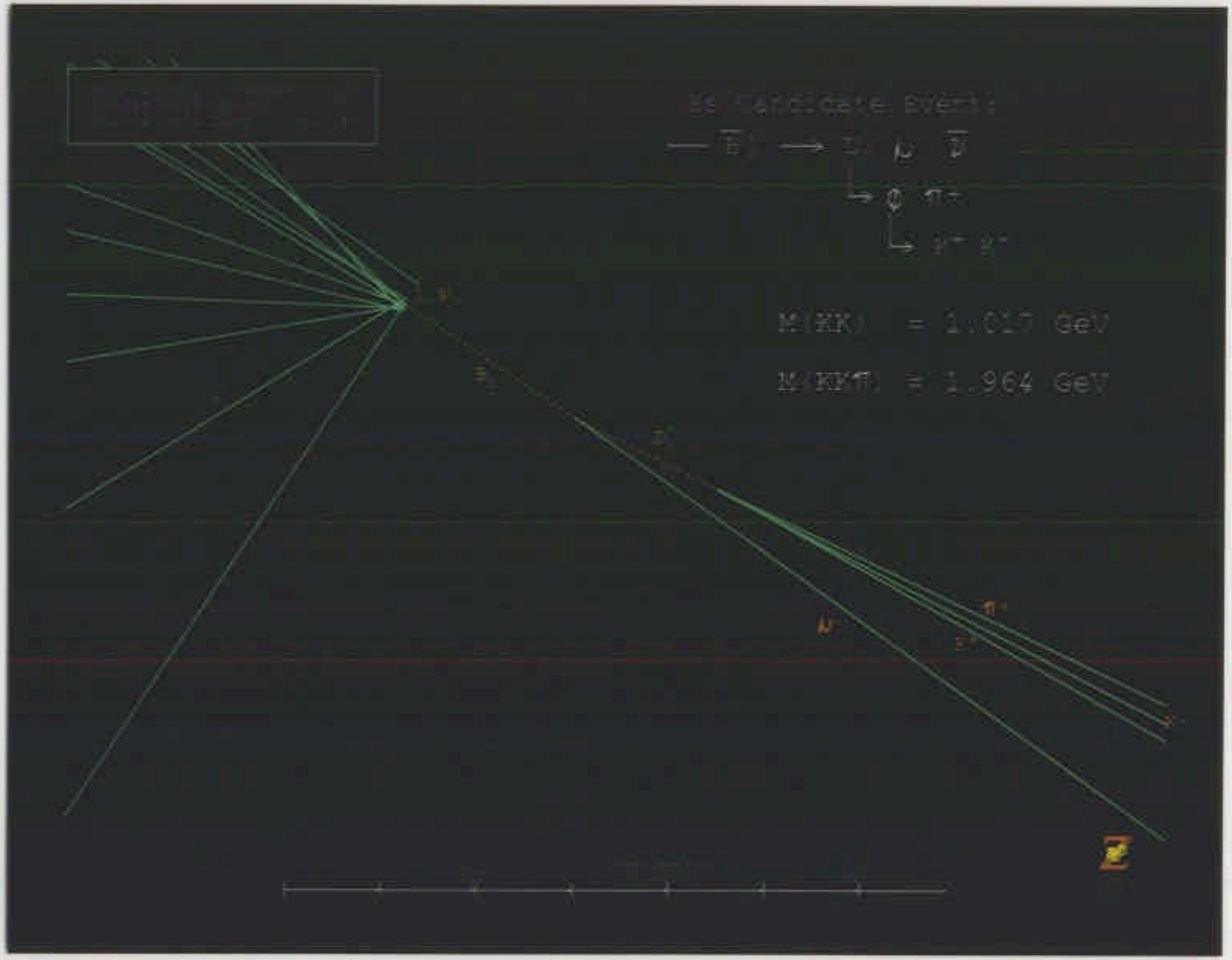
- **Partial reconstruction of $B_s \rightarrow D_s^- X$**
- **Full reconstruction of D_s decay $D_s^- \rightarrow \phi\pi$, $K^{*0}K^-$**
  - particle ID with Cherenkov Ring Imaging Detector (CRID)
- **Neural Network D_s selection yields 361 Decays**
  - 280 $D_s^- \rightarrow \phi\pi^-$ candidates
  - 81 $D_s^- \rightarrow K^{*0}K^-$ candidates
  - Includes 39 $B_s \rightarrow D_s^- l^+ X$ decays
- **Performance:**
  - Decay Length Resolution:
    - σ_L = 48 μm (60%) & 152 μm
  - Boost Resolution:
    - $\sigma_p / p = 0.08$ (60%) & 0.19
  - B_S Purity: f_{BS} = 38% Overall
    - For neutral B vertex sample ($m_{KK\pi} \pm 40$ MeV)::
      - $f(B_s)$ = 50% neutral sample (D_s + hadrons, 225 decays)
      - 75% neutral sample (D_s + lepton, 31 decays)



D_S Invariant Mass

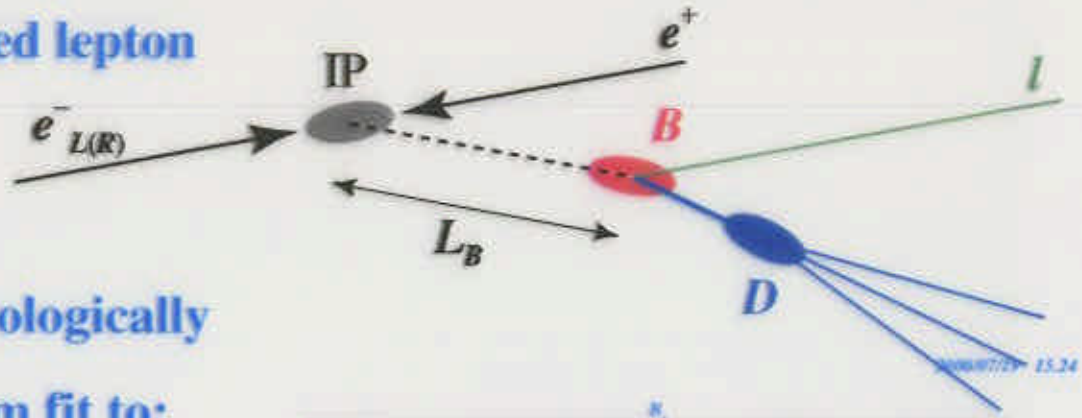


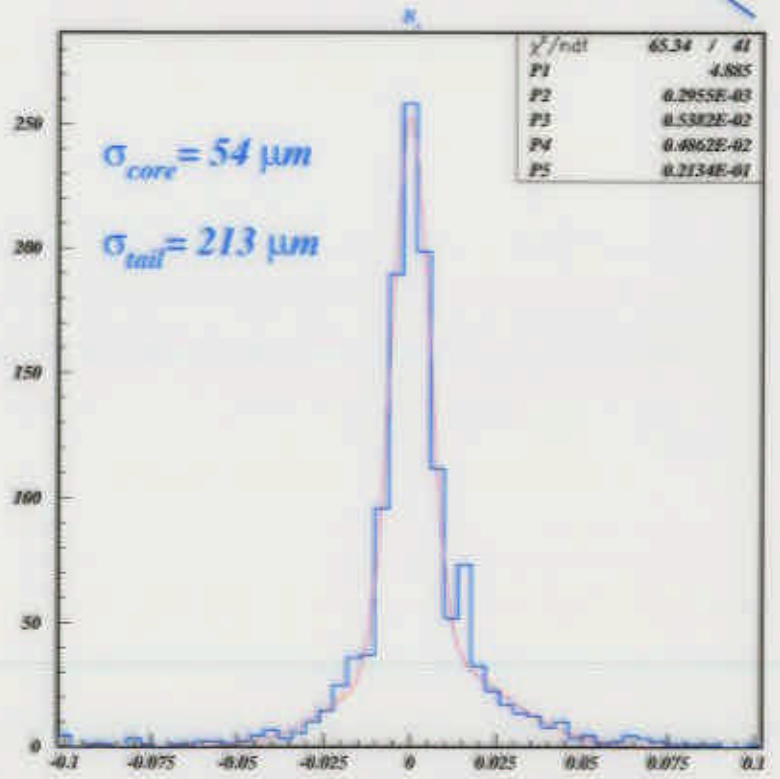
Semi-Exclusive Methods: D_s + Tracks Analysis



Inclusive Methods: Lepton + D Analysis

- **Select hemispheres with identified lepton**
  - Lepton tags $b \rightarrow l^-$
- **Reconstruct D meson vertex topologically**
- **Reconstruct B meson vertex from fit to:**
  - Lepton track
  - Resultant track from D vertex
- **Use Neural Network:**
  - Select neutral semi-leptonic B decays
  - Suppress ($b \rightarrow c \rightarrow l^+$)
- **Excellent proper time resolution:**
  - Decay Length: σ_L = 54 μm (60%) & 213 μm
  - Boost: $\sigma_p / p = 0.07$ (60%) & 0.17





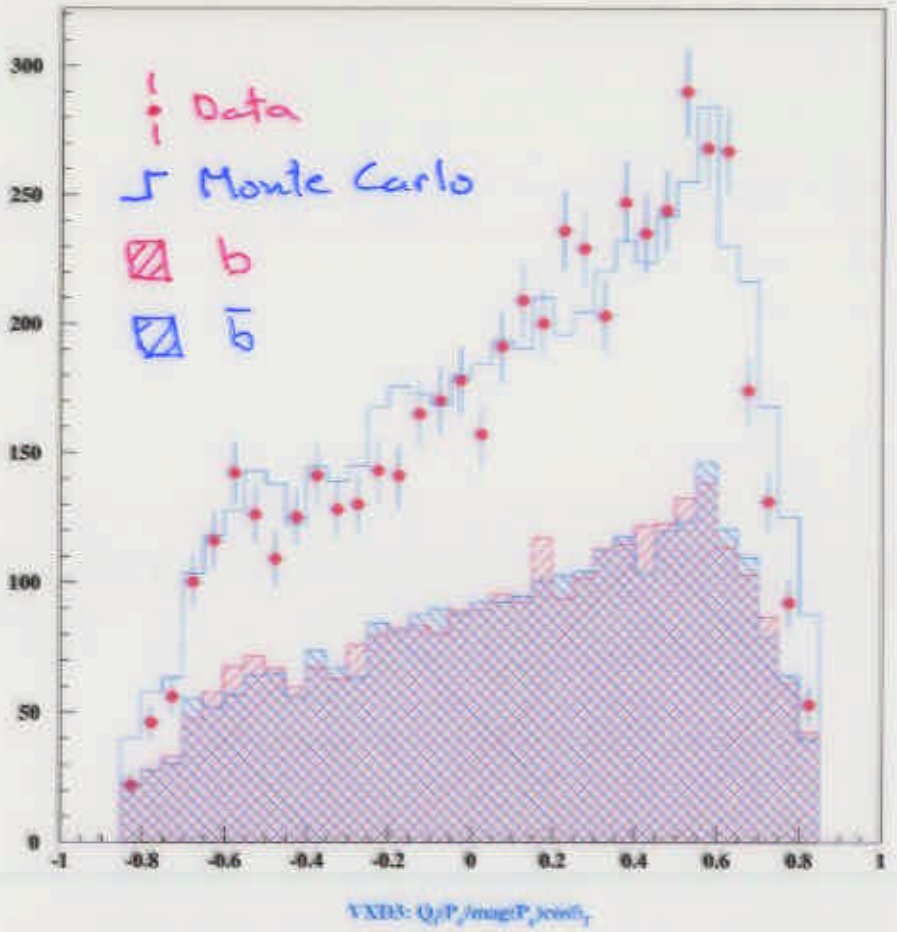
Decay Length Residuals (cm) for True B→Dl

Inclusive Methods: Lepton + D Analysis

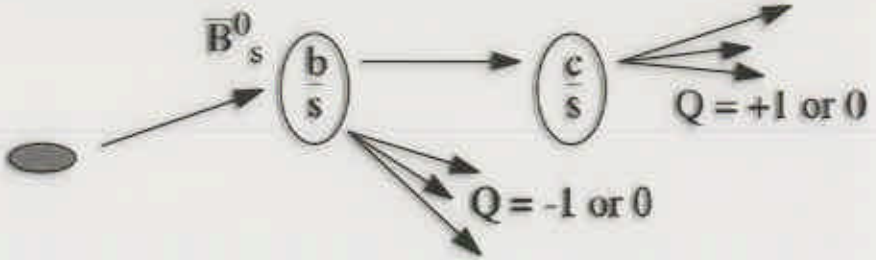
- **Good efficiency:**
  - Analysis selects 2087 neutral semi-leptonic B decay vertices
- **Good B_S Purity:**
  - $f(B_s) = 16\%$ overall
  - $f(B_s) = 34\%$ in opposite-sign lepton-kaon subsample
- **Excellent final state tagging:**
  - 91% correct tag overall
  - For B_S decays:

    96% correct tag
- **Polarized A_{FB} checks final state tag:**
  - Lepton signs A_{FB}
  - Gives polar distribution of b quark

Lepton signed polarized forward-backward asymmetry



Inclusive Methods: Charge Dipole Analysis

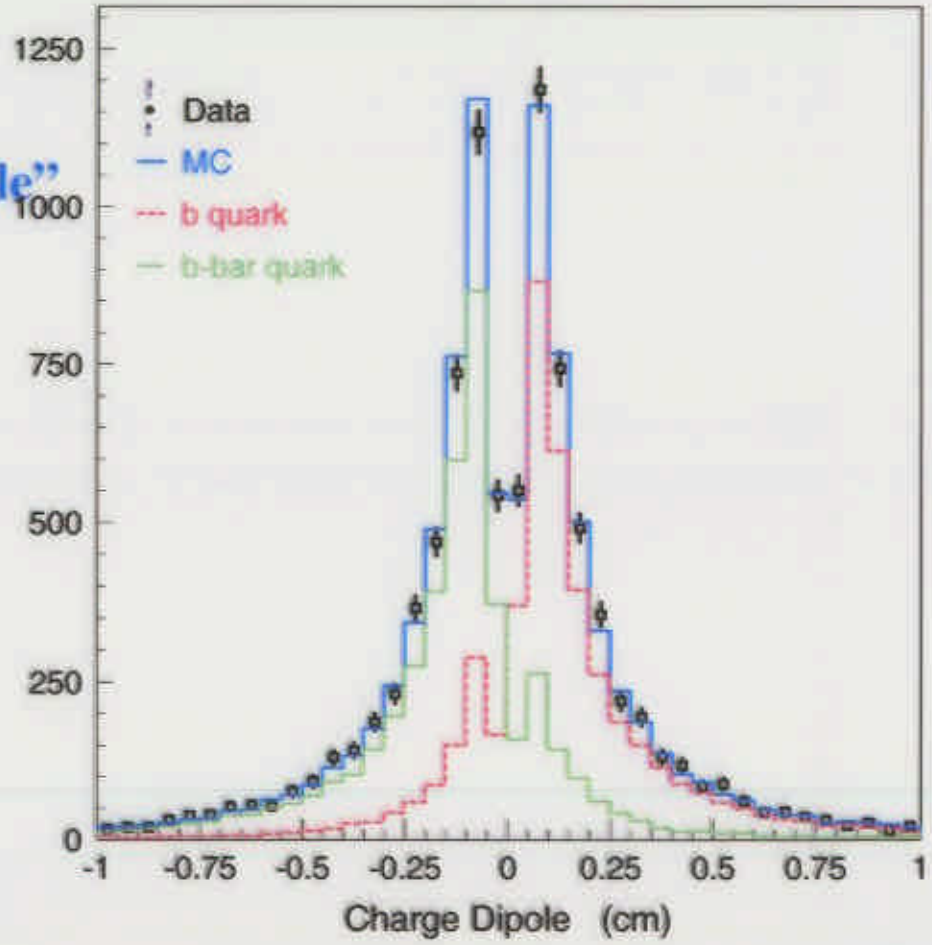


- **FULLY inclusive reconstruction**
  - Topological algorithm to reconstruct both secondary and tertiary vertices
- **Tag final state flavor with "charge dipole"**

$$dq = |Q_D - Q_B| * \text{Distance}_{B \text{ to } D}$$

- **Excellent efficiency:**
  - Select 8556 neutral decays

    Statistics ~4x higher than lepton+D analysis



Inclusive Methods: Charge Dipole Analysis

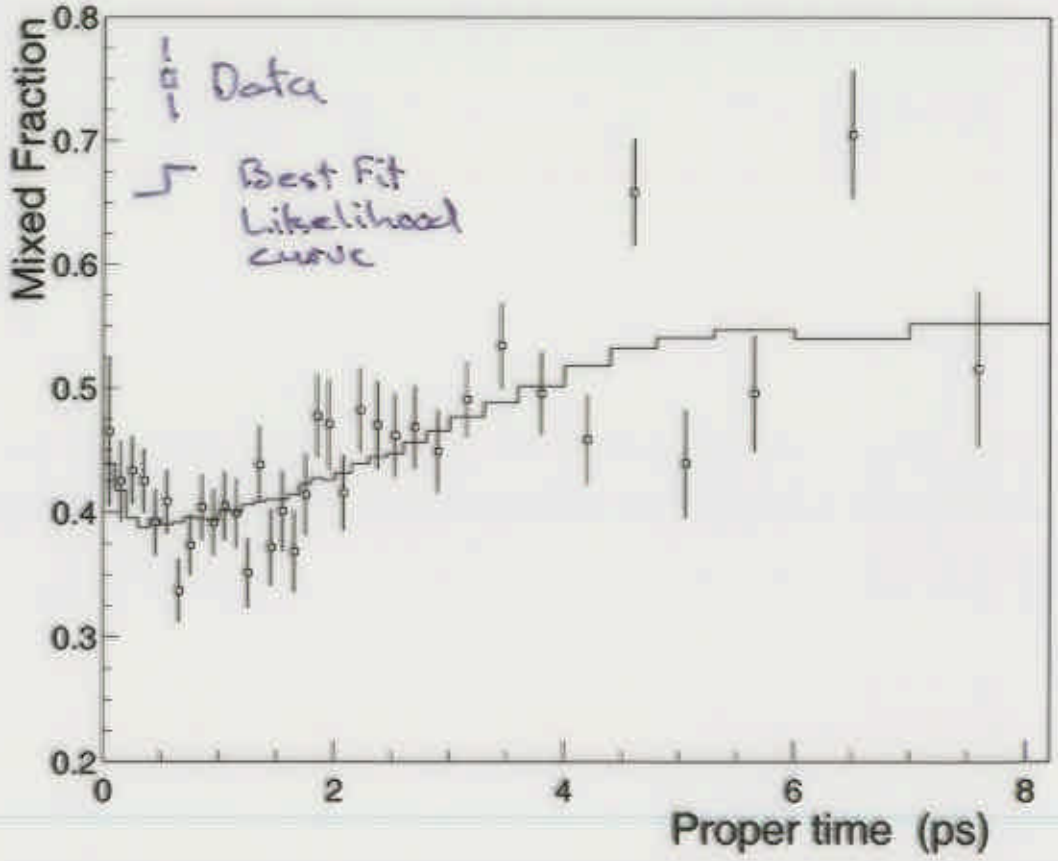
- **Good proper time resolution:**
  - Decay Resolution
    σ_L = 72 μm (60%) & 265 μm
  - Boost Resolution
    $\sigma_p / p = 0.07$ (60%) & 0.21

- **Good B_S purity:**
  - f(BS) = 15% overall

- **Good final state tagging:**
  - 76% overall for B_S decays
  - >92% for $B_S \rightarrow D_S$ X
    53% for $B_S \rightarrow D_S$ D X

- **Use B_D mixing to check tag:**
  - Measure Δm_D in the data:
    $\Rightarrow \Delta m_D = 0.495 \pm 0.032$ ps-1

Charge Dipole Analysis
Mixed Fraction -vs- Proper Time



Amplitude Fit Method

- **Measure oscillation amplitude A at fixed frequency:**

  ⇒Method pioneered by ALEPH (NIM A384, 491 (1997))

$$\text{Prob}\,(B_s^0 \to B_s^0) = \tfrac{1}{2}\Gamma e^{-\Gamma t}\left(1 + A\cos\Delta m_s t\right)$$

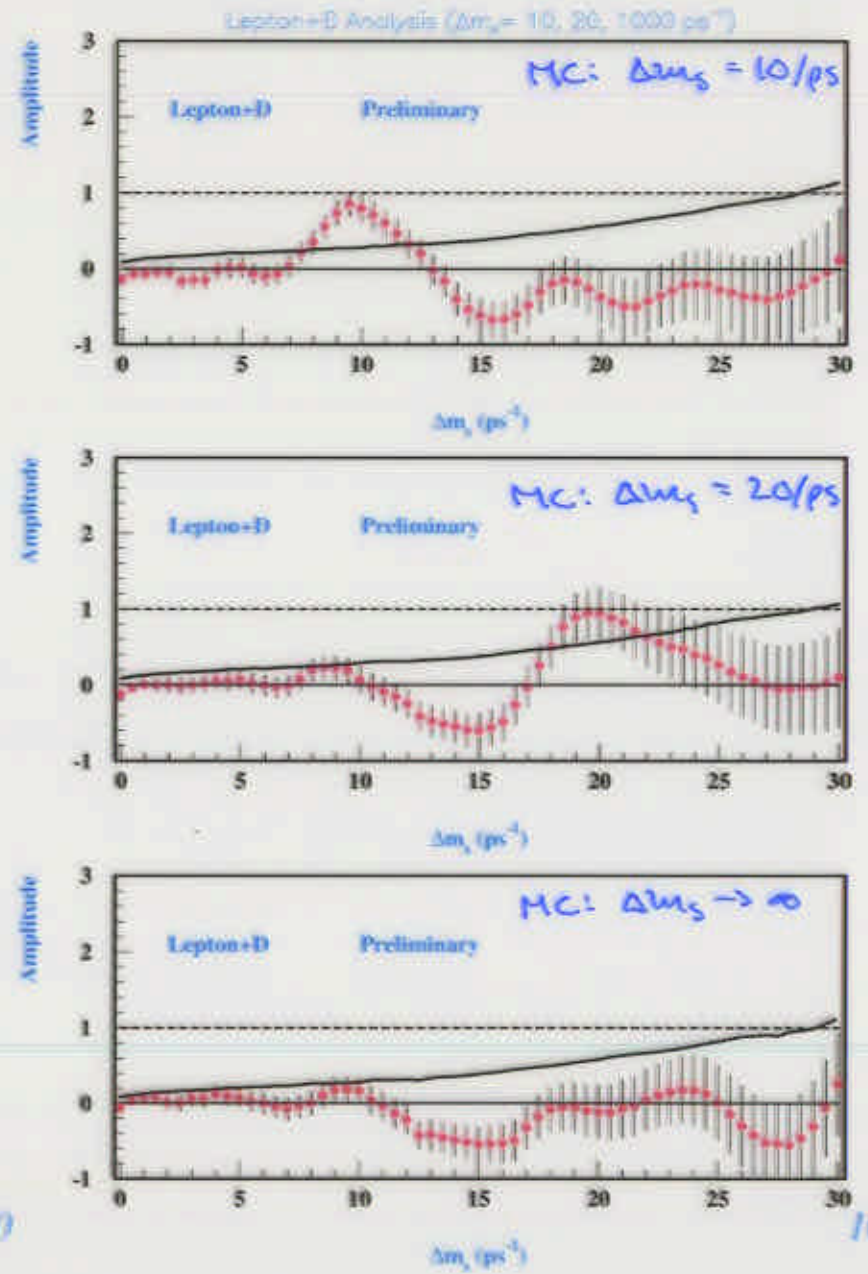
$$\text{Prob}\,(B_s^0 \to \overline{B}_s^0) = \tfrac{1}{2}\Gamma e^{-\Gamma t}\left(1 - A\cos\Delta m_s t\right)$$

  - Expect A = 1 for frequency = true Δm_s
  - Expect A = 0 for frequency ≠ true Δm_s

- **Set limits: 95% Confidence Level limit:**
  - Δm_s value for which A + 1.65 σ_A = 1

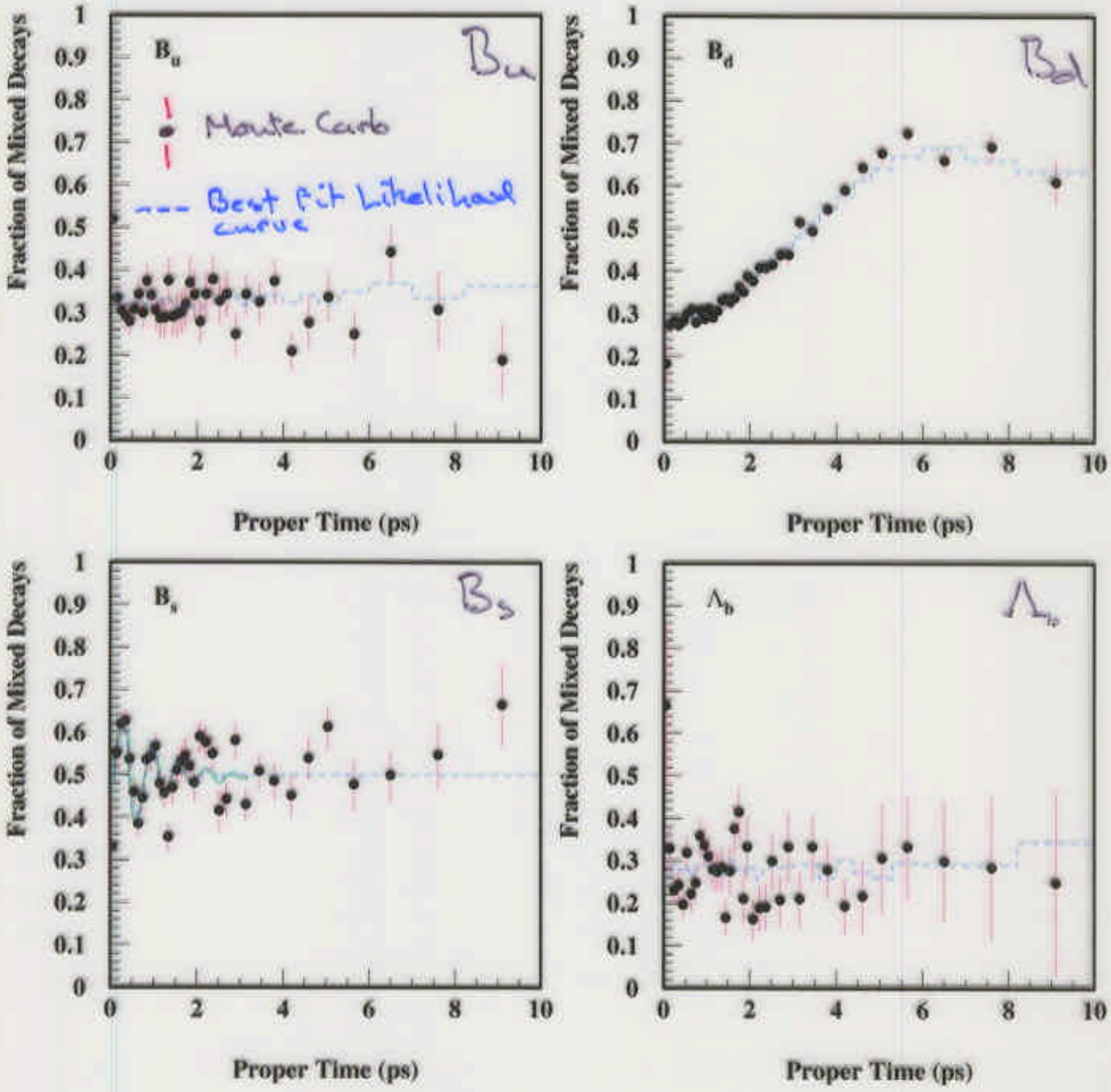
- **Determine sensitivity:**
  - Δm_s value for which 1.65 σ_A = 1

Monte Carlo: Lepton + D Analysis 25× Data

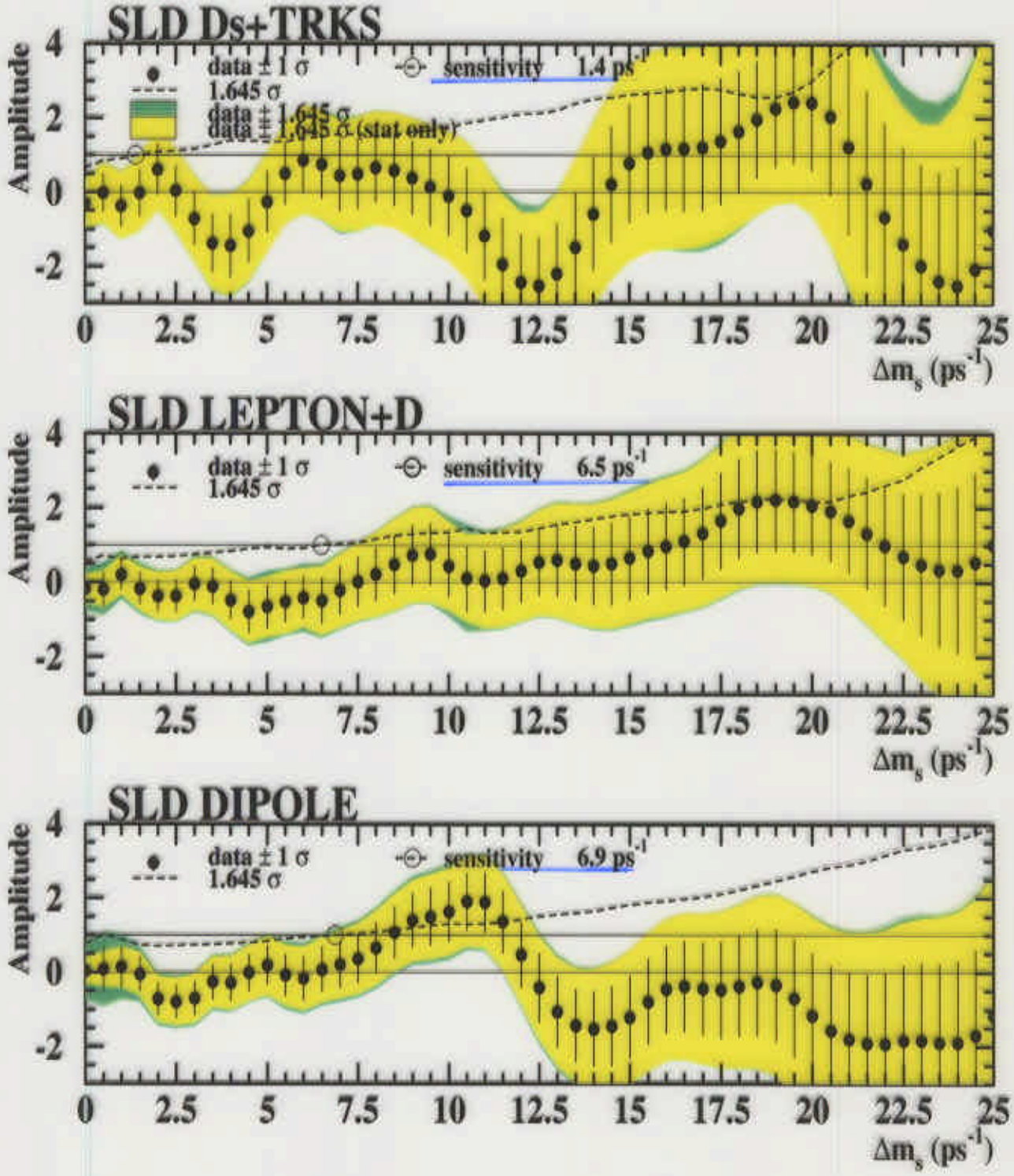


Amplitude Fit

Lepton + D Analysis
Mixed Fraction Plots by B type
Monte Carlo ($\Delta m_S = 10\ ps^{-1}$)

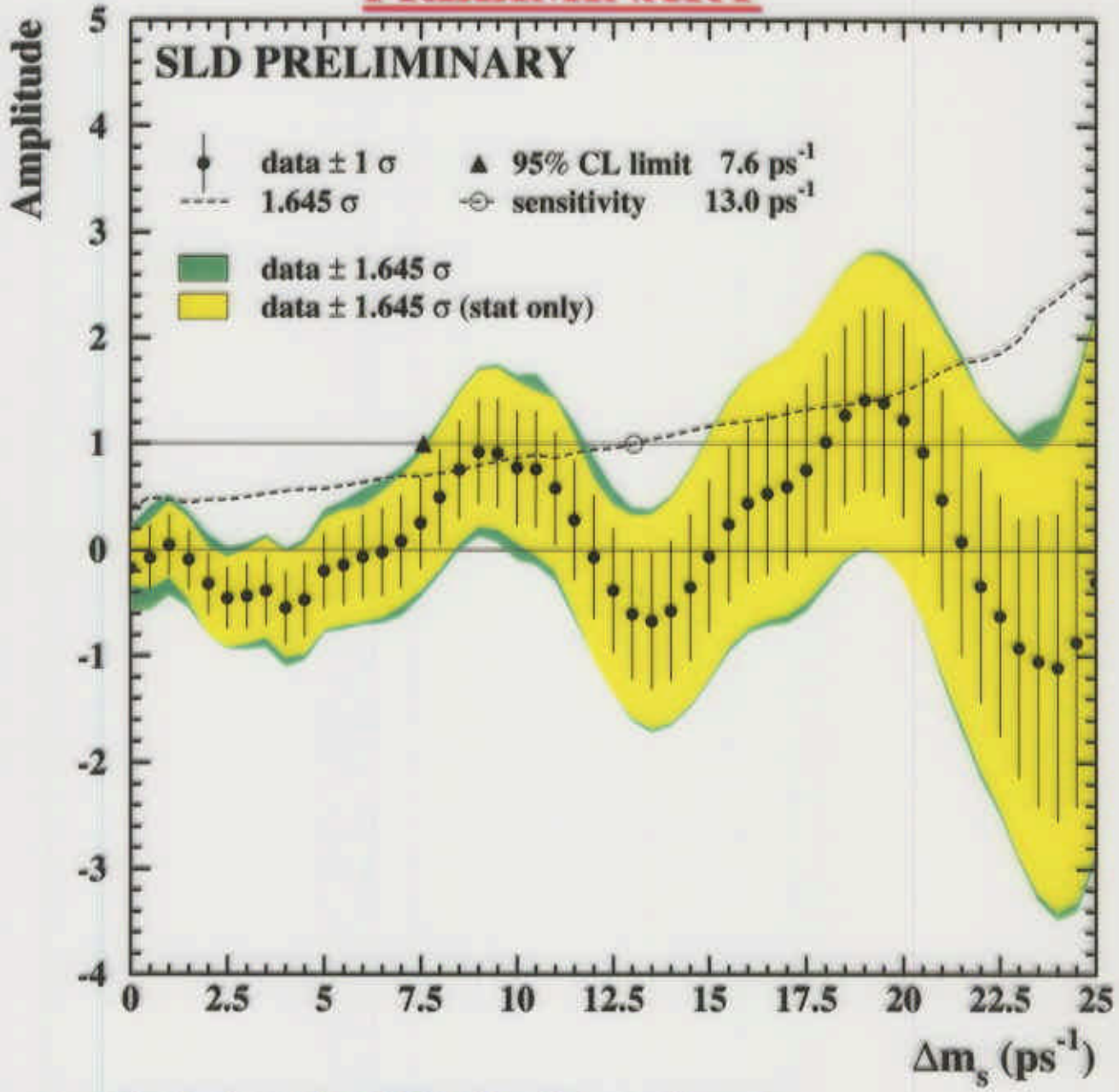


SLD Preliminary Results



SLD Combined Results

PRELIMINARY

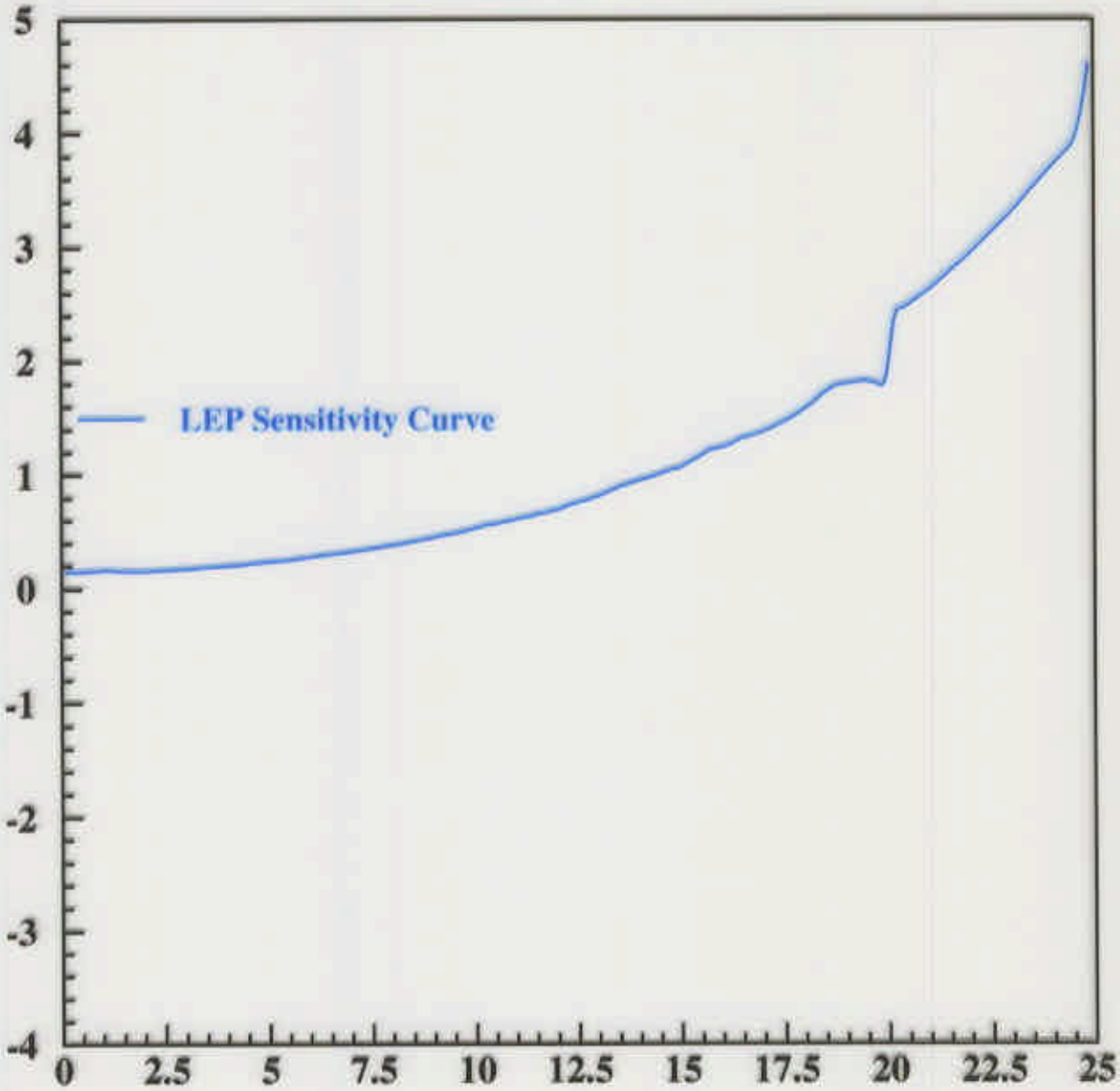


- **Exclude at the 95% Confidence Level**

$\Delta m_S < 7.6\ ps^{-1}$

$11.8 < \Delta m_S < 14.8\ ps^{-1}$ **(PRELIMINARY)**

- **Significant contribution to world average at high Δm_S**


LEP Sensitivity Curve
5
4
3
2
1
0
-1
-2
-3
-4
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25

Summary/Conclusions

- By exploiting the unique features of the SLC/SLD, SLD has achieved high sensitivity to Δm_s
  - Precision 3D CCD vertex detector
  - Polarized Electron Beam

  $\Rightarrow$Current combined sensitivity up to 13.0 ps^{-1}

- Combined analyses have pushed the limit on Δm_s:
  - Exclude at the 95% C.L.

    $\Delta m_s < 7.6\ ps^{-1}$ (PRELIMINARY)

    $11.8 < \Delta m_s < 14.8\ ps^{-1}$

- SLD contributes significantly to the world average at high Δm_s ($\Delta m_s > 15\ ps^{-1}$)

- Further improvements in sensitivity are expected:
  - Standalone vertex detector tracking
  - Increased statistics in Lepton+D analysis
  - Addition of another inclusive lepton analysis