Recent Results from SLD

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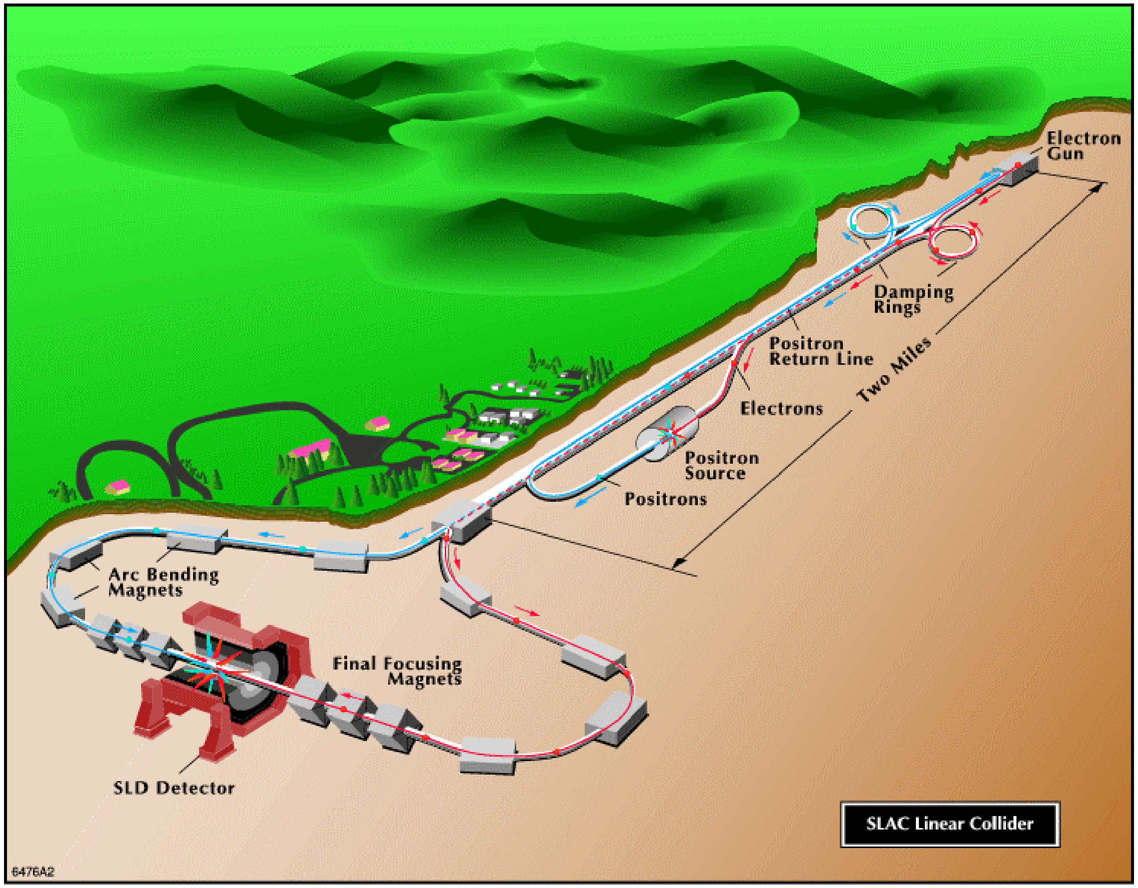
Stanford Linear Collider

- World’s first e^+e^- linear collider
  $E_{cm} = 91.2$ GeV (m_Z)
- collision rate: 120 Hz
- max Luminosity ≈
  $3 \times 10^{30}\ s^{-1}\ cm^{-2}$
- bunch size ≈ 4×10^{10}
- small, stable beamspot
  ≈ $1.5 \times 0.65\ \mu m$
- e^- beam polarization
  $|P_e| \approx 75\%$



Ideal environment for precision tests of the electroweak model.

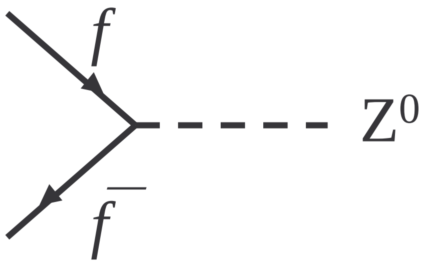
Electroweak Physics

The symmetry of the electroweak model is $SU(2)_L \otimes U(1)_Y$

weak isospin　　hypercharge

The weak neutral current is,

$$J_Z^\mu = \bar{f}\gamma^\mu(g_V^f - g_A^f\gamma^5)f$$



where,

$$g_V^f = I_3 - 2Q\sin^2\theta_W$$ (weak mixing angle)

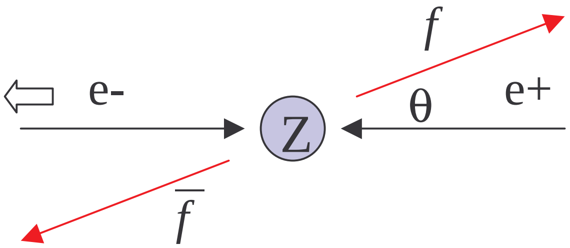
$$g_A^f = I_3$$

Vector and axial-vector couplings lead to *parity violation*. The extent of parity violation for fermion *f* can be expressed as,

$$A_f = 2g_V^f g_A^f \Big/ \left(g_V^{f\,2} + g_A^{f\,2}\right)$$

fermion	g_V	g_A	A_f
ν_e,ν_μ,ν_τ	½	½	1
e, μ,τ	$-\frac{1}{2}+2\sin^2\theta_W$	-½	0.15
u,c,t	$\frac{1}{2}-{}^4/_3\sin^2\theta_W$	½	0.67
d,s,b	$-\frac{1}{2}+{}^2/_3\sin^2\theta_W$	-½	0.94

Asymmetries at the Z^0



$$\frac{d\sigma_f}{d\cos\theta} \propto (1 - A_e P_e)(1 + \cos^2\theta) + 2A_f(A_e - P_e)\cos\theta$$

- Unpolarized Asymmetries: (LEP)

$$A_{FB}^f = \frac{\sigma(F) - \sigma(B)}{\sigma(F) + \sigma(B)} = \frac{3}{4} A_e A_f$$

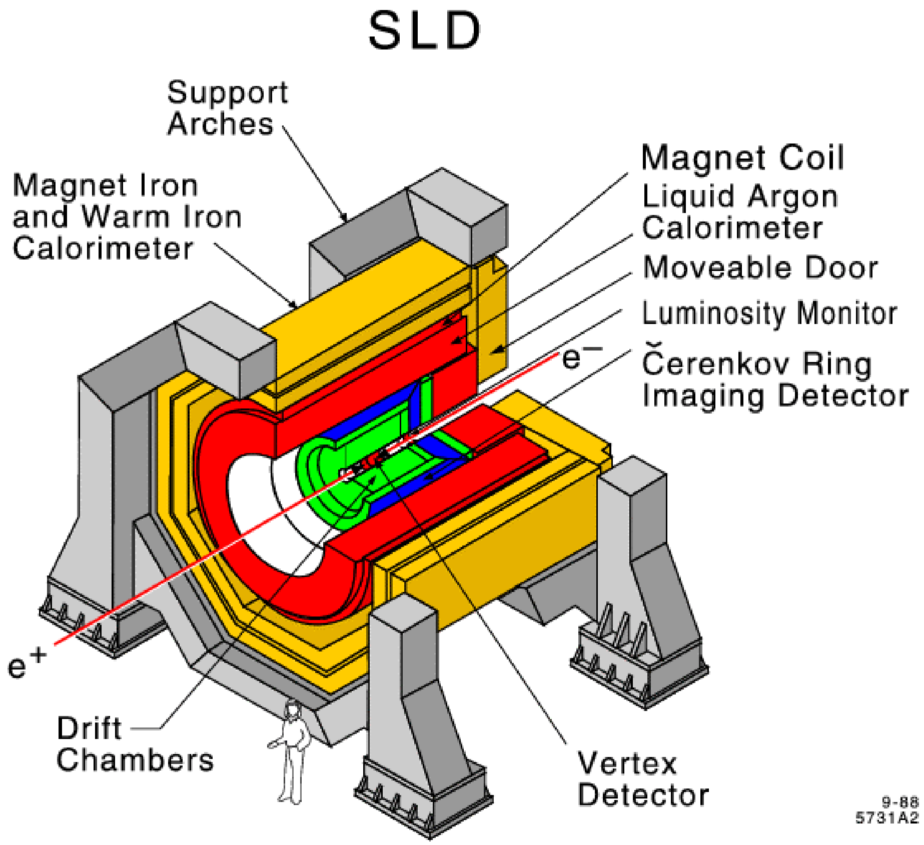
- Polarized Asymmetries: (SLD)

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = A_e$$

$$\tilde{A}_{FB}^f = \frac{[\sigma_L(F) - \sigma_L(B)] - [\sigma_R(F) - \sigma_R(B)]}{[\sigma_L(F) + \sigma_L(B)] + [\sigma_R(F) + \sigma_R(B)]} = \frac{3}{4} |P_e| A_f$$

Polarization gives SLD a statistical advantage of $(A_e/P_e)^2 \approx 25$.

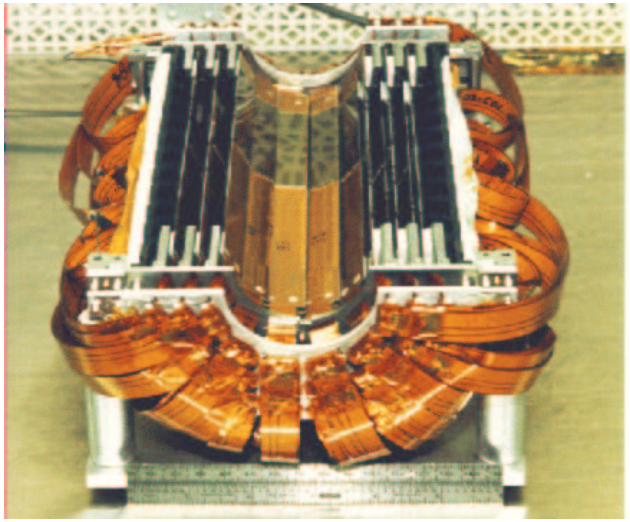
SLD Detector

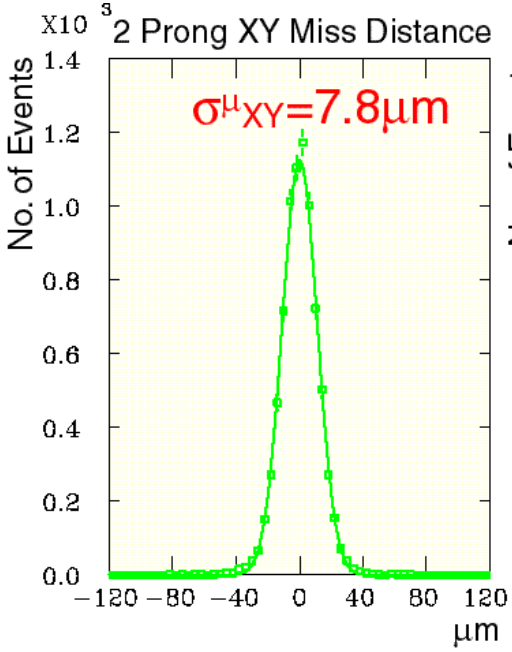


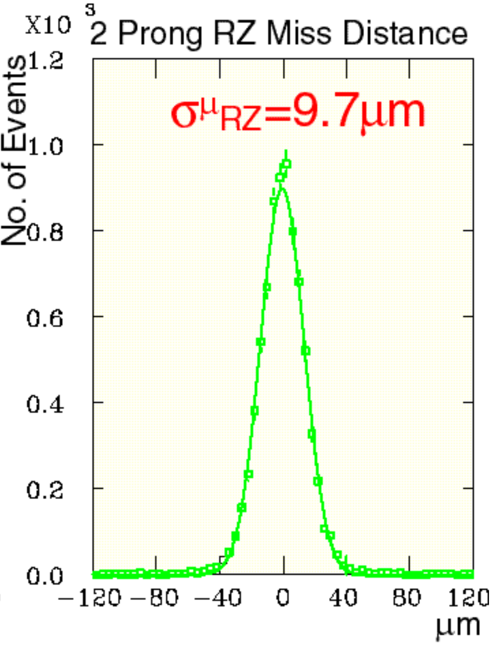
- CCD Vertex Detector
- Central Drift Chamber
- Cherenkov Ring Imaging Detector
- Liquid Argon Calorimeter
- Magnet Coil: 0.6 Tesla
- Warm Iron Calorimeter

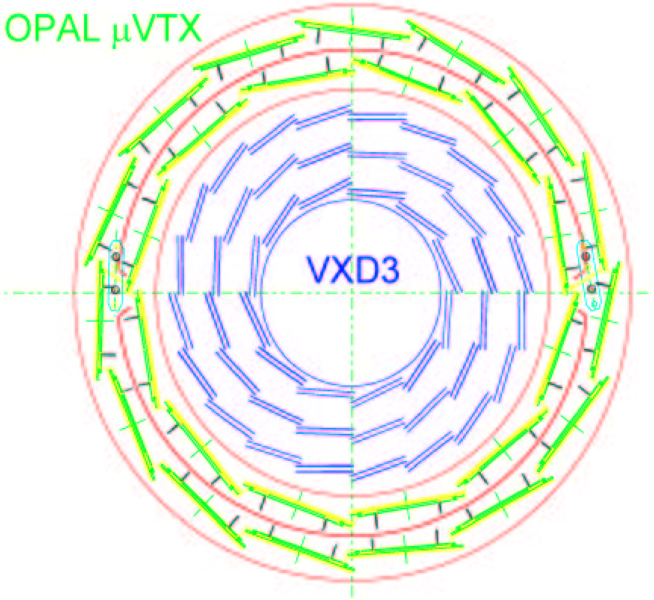
VXD3

- 307M pixels
- ≥ 3 hits/track
- inner radius = 2.7 cm
- max cosθ = 0.85
- X^0/layer = 0.4%
- single hit resolution = 4.5 μm

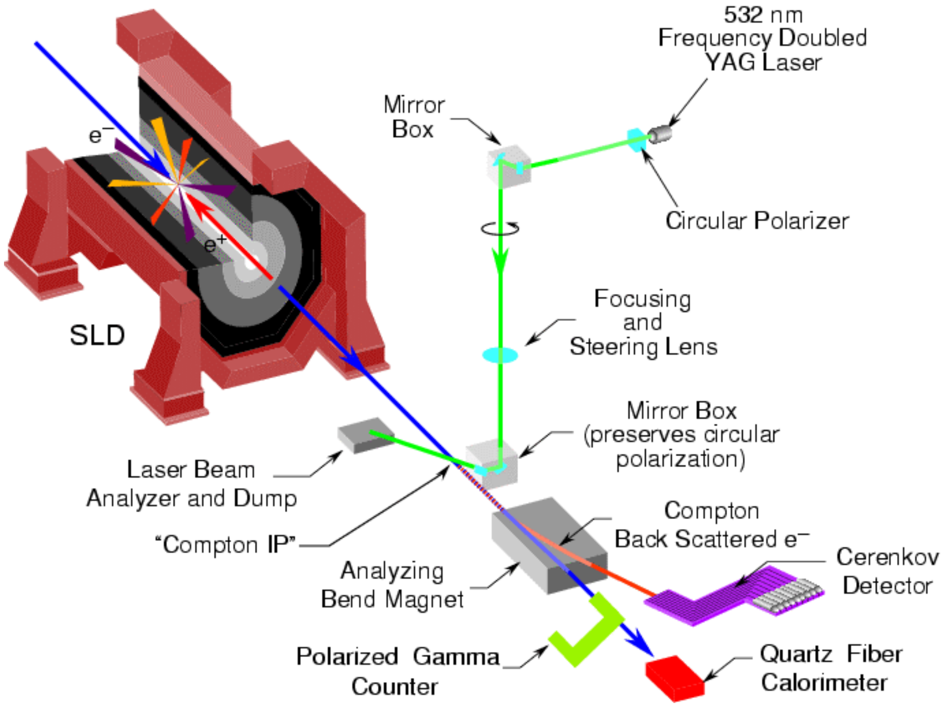








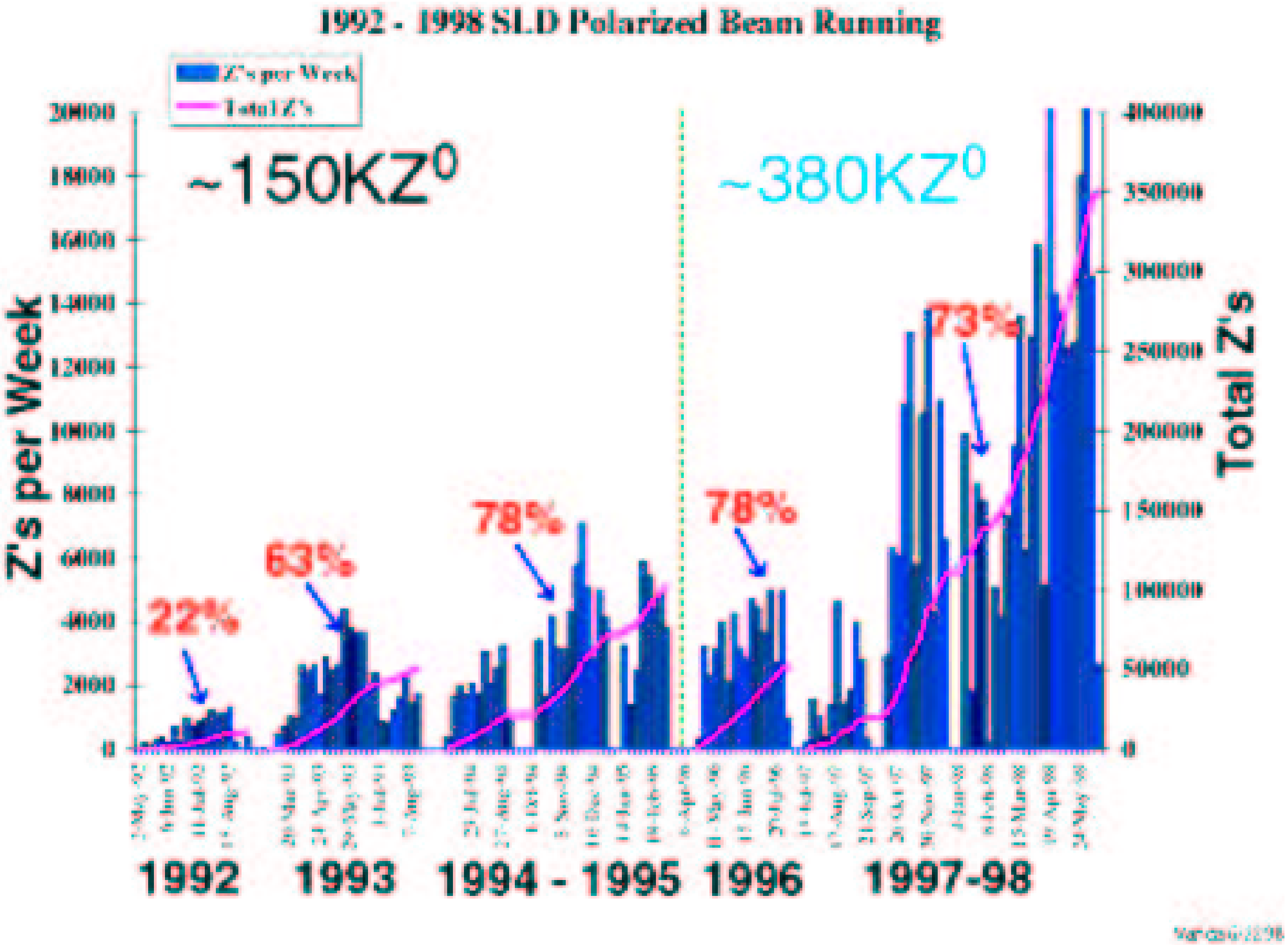
Compton Polarimeter



- Polarization is determined by compton scattering electrons off circularly polarized photons at "compton IP".
- Cross checks are performed with the Quartz Fiber Calorimeter and Polarized Gamma Counter.
- precision for a 3 min run is ≈ 2%.
- Positron Polarization was measured in 1998:

$$P_{e+} = -0.02 \pm 0.07\%$$

SLC Performance



Physics Outline

q *Electroweak Measurements*

A_{LR}
R_b and R_c
A_b and A_c

q *B Fragmentation Function*

q B^0 - $\overline{B^0}$ *Mixing*

A_{LR}

A_{LR} is the left-right cross section asymmetry in Z^0 production by e+e- collisions,

$$A_{LR}^0 \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = A_e$$

- We measure the raw asymmetry, $$A_m = \frac{N_L - N_R}{N_L + N_R} = |P_e| A_{LR}^0$$
- $N_{R(L)}$ = number of hadronic Z^0s produced with right (left) polarized e^- beams.
- $|P_e|$ is the luminosity-weighted average polarization.
- A_m is independent of absolute luminosity, acceptance, and efficiency.
- Corrections are applied for electroweak interference and Z^0 pole energy.
- Main systematics are polarization measurement and above corrections.

Final Result 92-98:

PRL 84:5945, 2000

$$A_{LR}^0 = 0.15138 \pm 0.00216$$

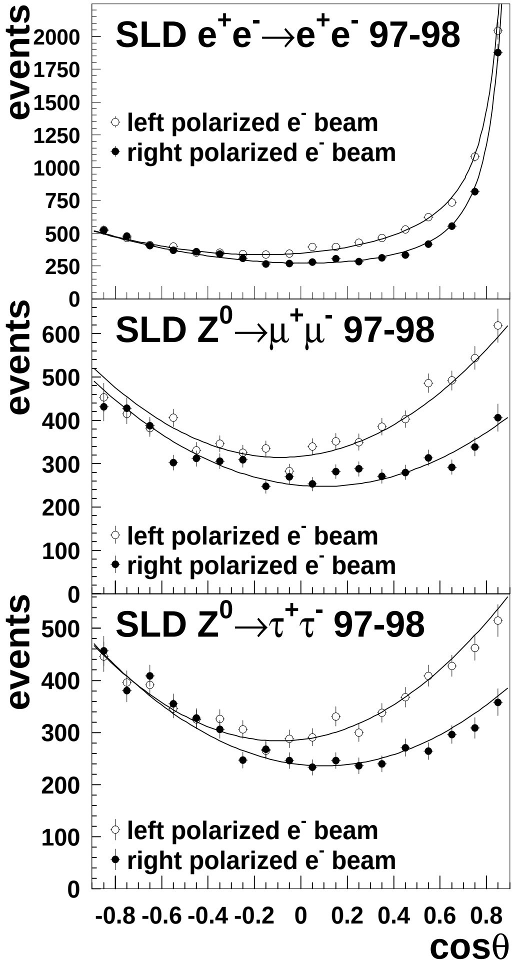
$$\sin^2\theta_W^{\text{eff}} = 0.23097 \pm 0.00027$$

(world's best measurement)

A_{lepton}

- Use leptonic final states and polarized FB asymmetry to measure A_l in $e^+e^- \rightarrow Z^0 \rightarrow l^+l^-$.
- Measure the differential cross section for P_e >(<) 0,

$$\frac{d\sigma_l}{d\cos\theta} \propto (1-A_eP_e)(1+\cos^2\theta)+2A_l(A_e-P_e)\cos\theta$$



$$A_e = 0.1544 \pm 0.0060$$
$$A_\mu = 0.142 \pm 0.015$$
$$A_\tau = 0.136 \pm 0.015$$

Consistent with lepton universality.

- Combine with A_{LR},

$$A_e = 0.1516 \pm 0.0021$$

PRL 86:1162, 2001

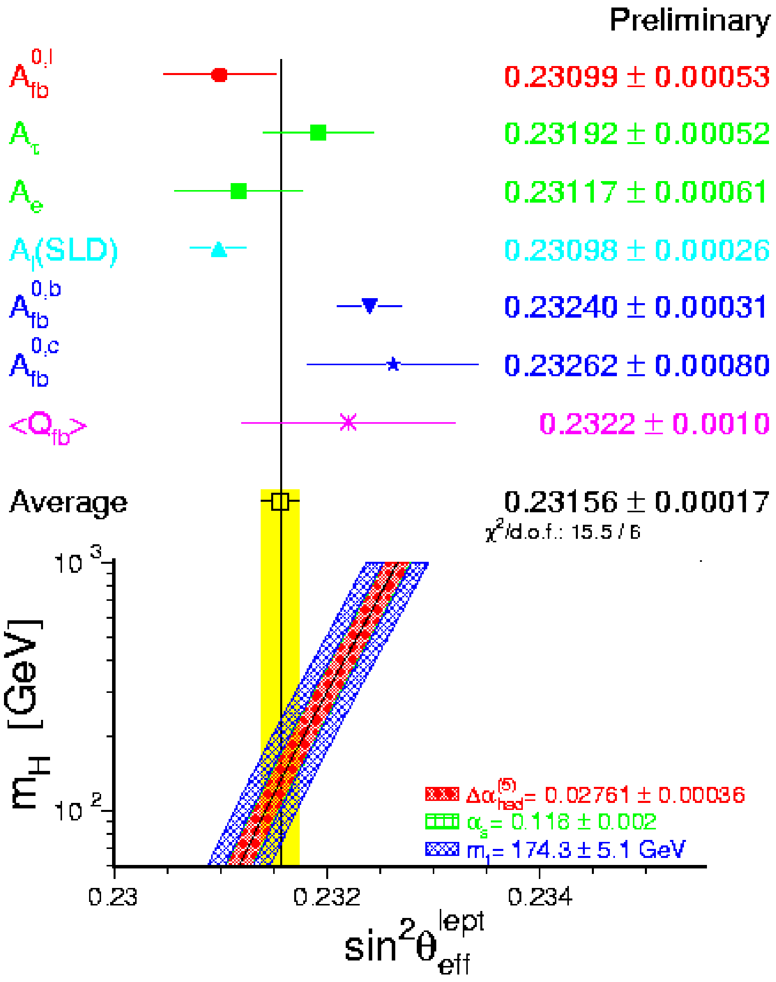
$$\sin^2\theta_W^{\text{eff}} = 0.23098 \pm 0.00026$$

$\sin^2\theta_W$ Comparisons

A_l can be used to calculate $\sin^2\theta_W$ in SM,

$$A_l = \frac{2\left(1-4\sin^2\theta_W^{\mathrm{eff}}\right)}{1+\left(1-4\sin^2\theta_W^{\mathrm{eff}}\right)^2}$$

There may be some discrepancy between leptonic and quark A_{FB} Measurements.



Higgs Mass Predictions

Effective weak mixing angle involves virtual radiative corrections including Higgs and new physics.

⇒ upper bound on SM Higgs mass

- SLD $\sin^2\theta_W$ only:

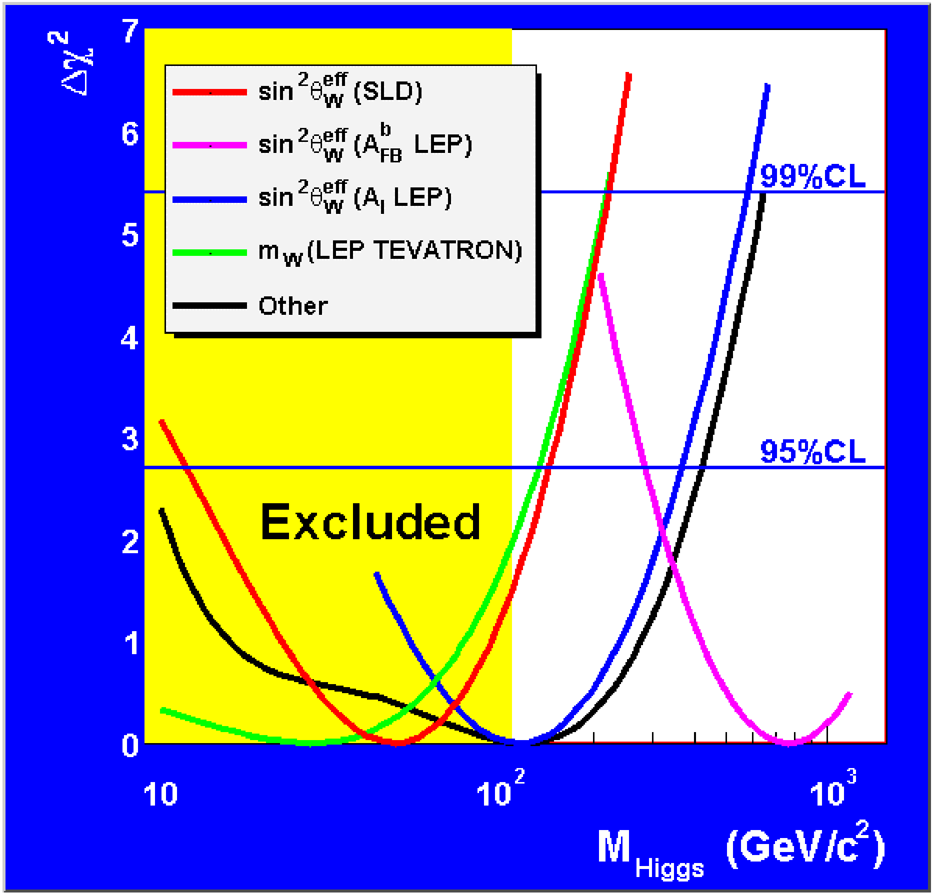
  $m_H < 133$ GeV (95% CL)

- LEP+SLD:

  $m_H < 220$ GeV (95% CL)

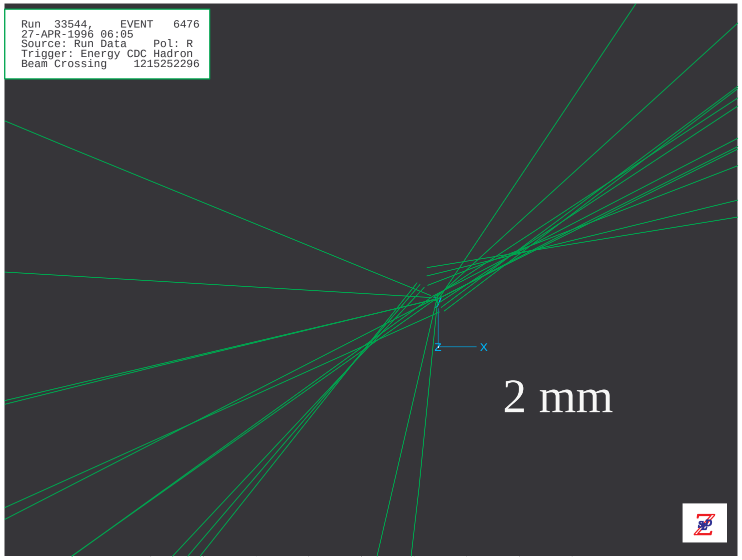
- LEP+SLD w/0 A^b_{FB}:

  $m_H < 145$ GeV (95% CL)

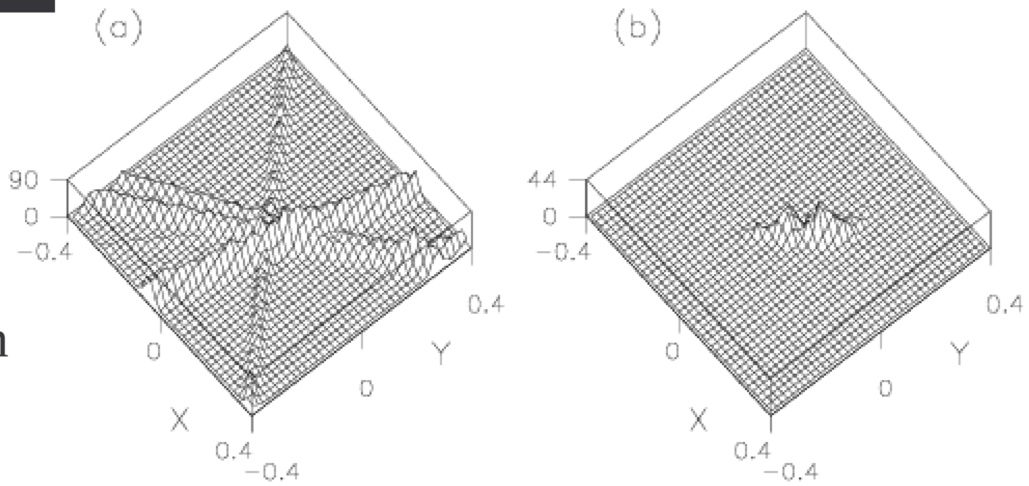


Topological Vertexing

NIM A388:247



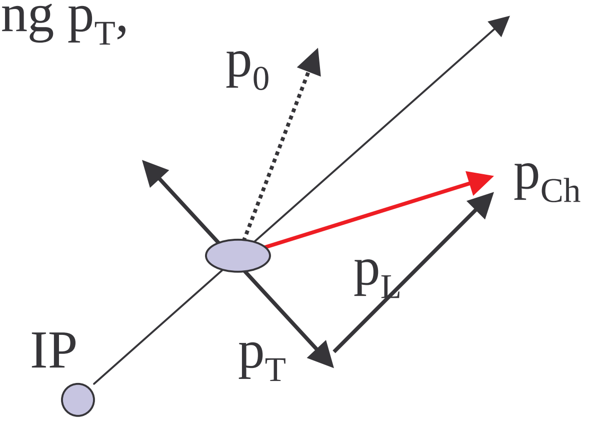
- Relatively long lifetime of B hadrons and large boost results in separated secondary vertices $\langle L \rangle \approx$ 2-3 mm.
- Exploit small, stable SLC beamspot and precision of VXD3 for *inclusive* topological vertexing.
  "seed" vertices ⇒ regions of high track overlap probability.

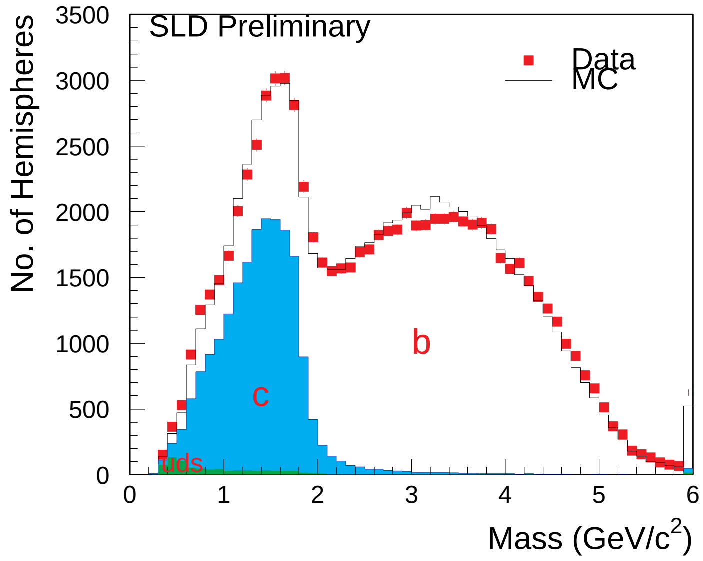


- Additional track attachment is performed by a NN on lesser quality tracks and VXD segments.
- A secondary vertex is located in
  73% of b hemispheres
  29% of c hemispheres.

Topological Vertexing (II)

Make a correction to invariant mass based on missing p_T,

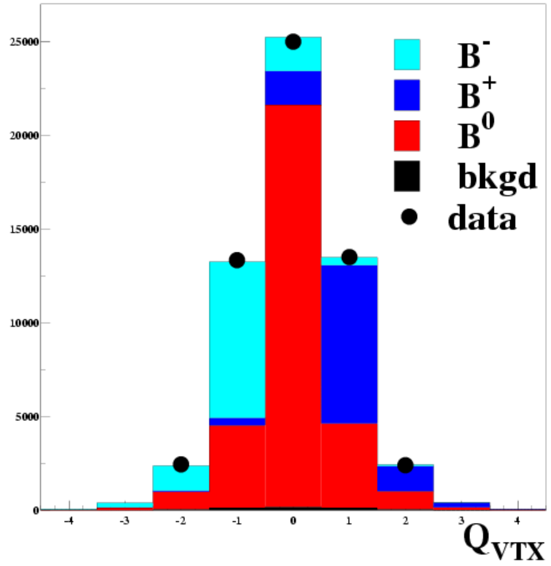




$$m_{pT} = \sqrt{m_{raw}^2 + p_T^2} + p_T$$

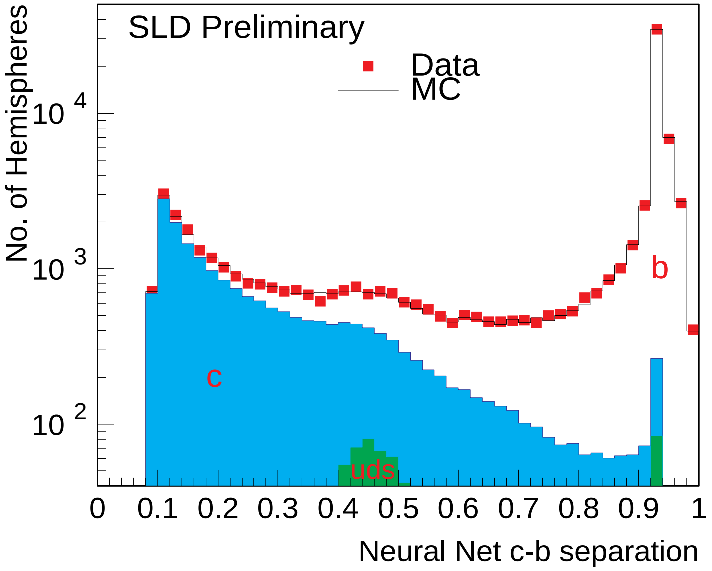
Vertex Mass Tag Typical Results:

cut m_{pT} at 2.0 GeV
B selection efficiency = 57%
B sample purity = 98%



R_b, R_c Analysis

$$R_q = \frac{\Gamma(Z^0 \to q\bar{q})}{\Gamma(Z^0 \to hadrons)}$$



Use Topological Vertexing with additional NN hemisphere selection:

- § Vertex M_{pT}
- § Vertex momentum
- § Decay Length
- § Charged track multiplicity

b Tag: NN >0.75
c Tag: NN < 0.3

Systematics are reduced by using double tags in both hemispheres to measure tag efficiency from data.

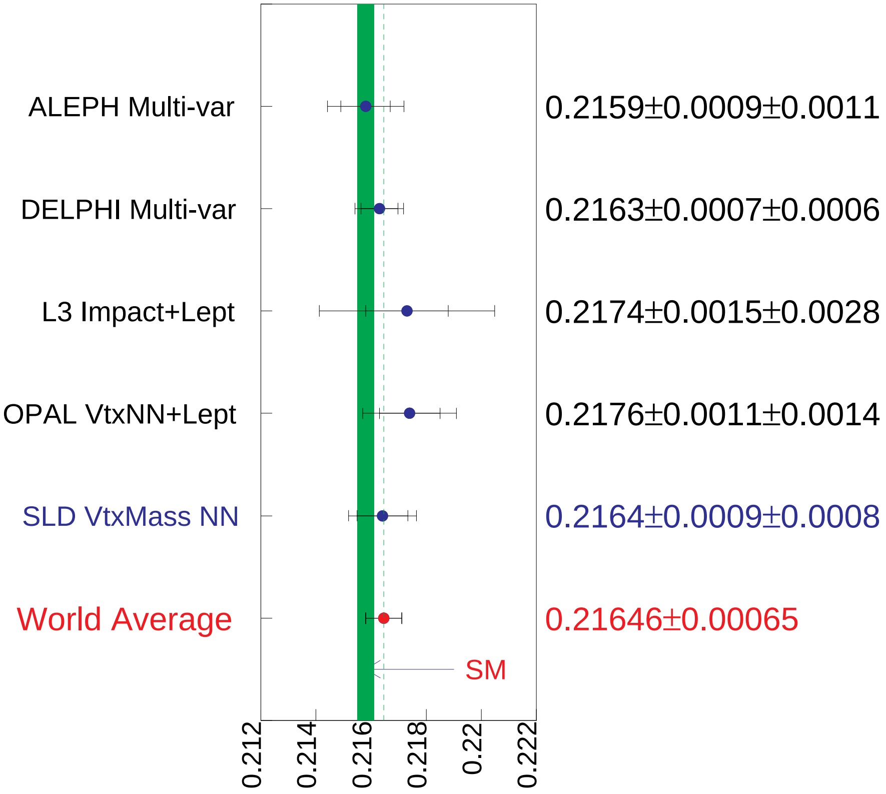
Tag Performance:

b: $\varepsilon = 62\%$ $\pi = 98\%$
c: $\varepsilon = 18\%$ $\pi = 84\%$

R_b Results

Recent Improvements

- Improved tracking resolution corrections.
- Better understanding of running b-quark mass effects on jet rates.
- new $g \rightarrow b\bar{b}$ correction.



R_b Measurements (Summer-2001)

SLD 93-98 data:

$R_b = 0.2164 \pm 0.0009_{stat} \pm 0.0006_{syst}$

R_c Results

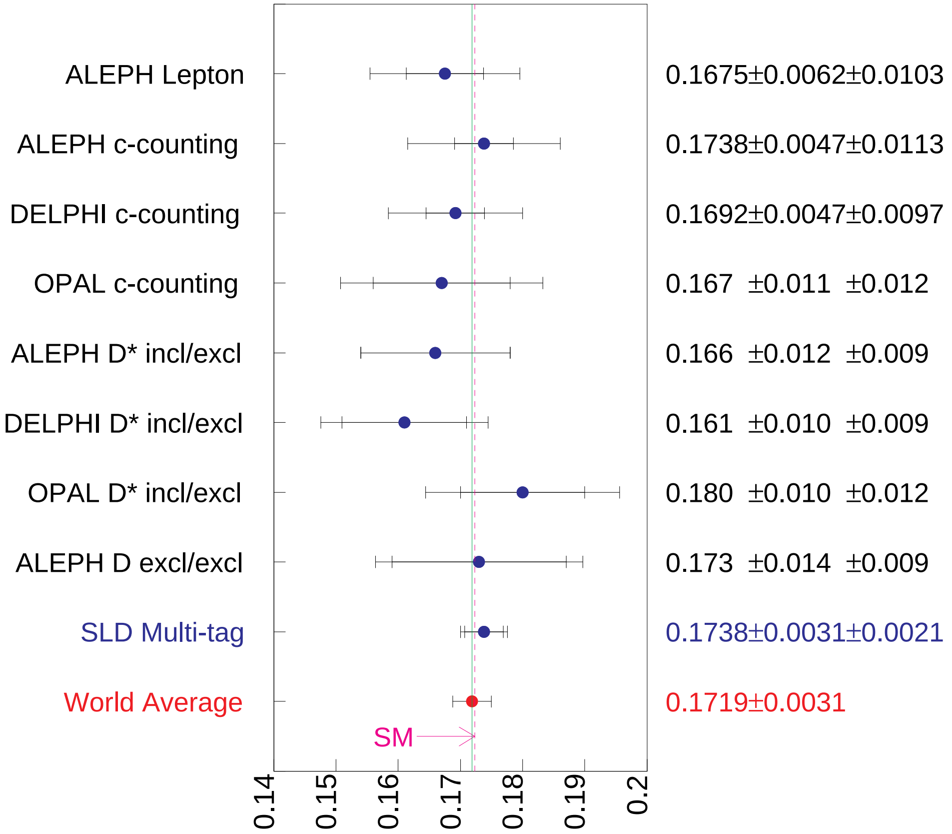
New multitag analysis:

- Includes the same “hard” c and b tags as R_b analysis,

  b Tag: NN > 0.75
  c Tag: NN < 0.3

- plus additional “soft” tags
  b-like Tag: 0.5 < NN < 0.75
  c-like Tag: 0.3 < NN < 0.5

- Tagging efficiency measured from double-tagged events in the data.



R_c Measurements (Summer-2001)

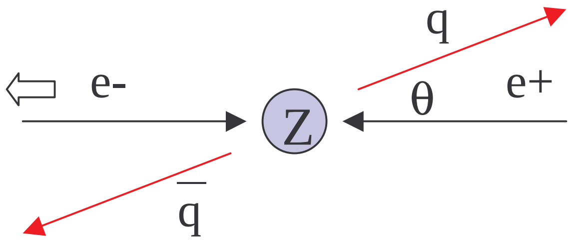
SLD Result:

$$R_c = 0.1738 \pm 0.0031_{stat} \pm 0.0021_{syst}$$

A_b, A_c Measurements

We want to measure parity violation in couplings $Z^0 \rightarrow q\,\bar{q}$ for b and c quarks ⇒ Use the polarized forward-backward asymmetry.

Measure the differential cross section *dN/d cosθ* for $q(\bar{q})$ with left and right polarized electrons to extract A_b/A_c.



A_b / A_c measurements must:

- ♦ Select pure bottom and charm hemispheres.
- ♦ Estimate the initial quark directions.
- ♦ Tag the quark flavor (q or $\bar{q}$) produced in each hemisphere.
  SLD has produced A_b and A_c results with several flavor tags including:

Jet Charge, Leptons, Kaons and Vertex Charge.

A_b with Jet Charge

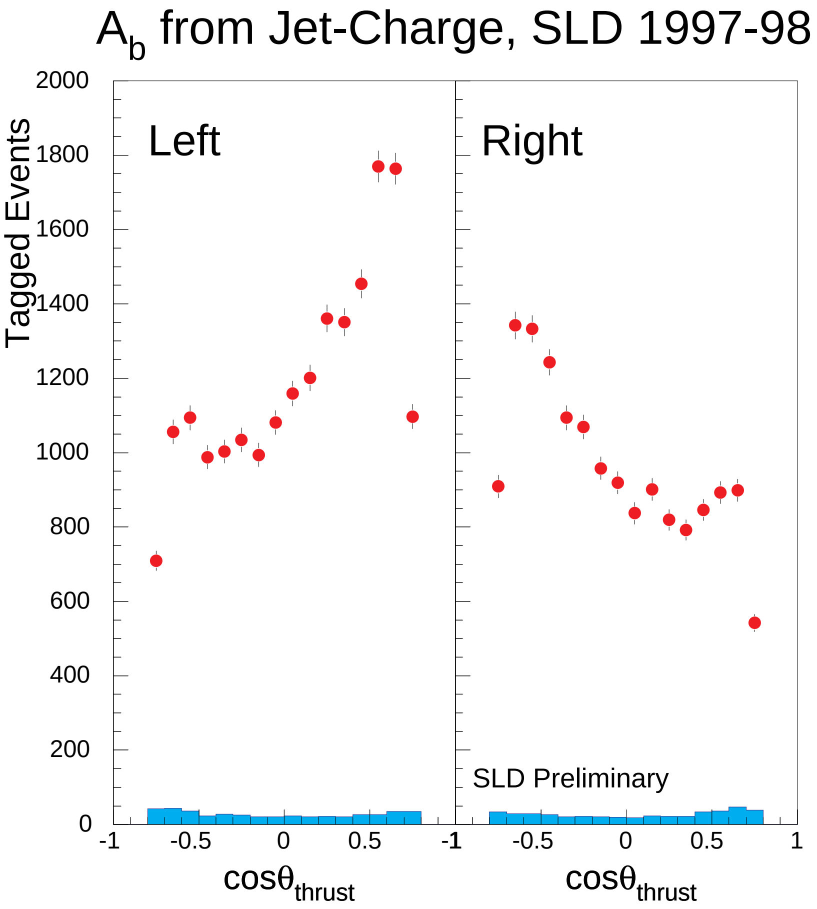
- Vertex Mass Tag to identify b hemispheres
- Thrust axis defines initial quark directions.
- b quark flavor tagged by Jet Charge,

$$Q_{Jet} = \sum_{i}^{Tracks} q_i \left| \vec{p}_i \cdot \widehat{T} \right|^{\kappa}$$

- Tag analyzing power is calculated from data.

Jet Charge Final Result:

$$A_b = 0.907 \pm 0.020_{stat} \pm 0.024_{syst}$$

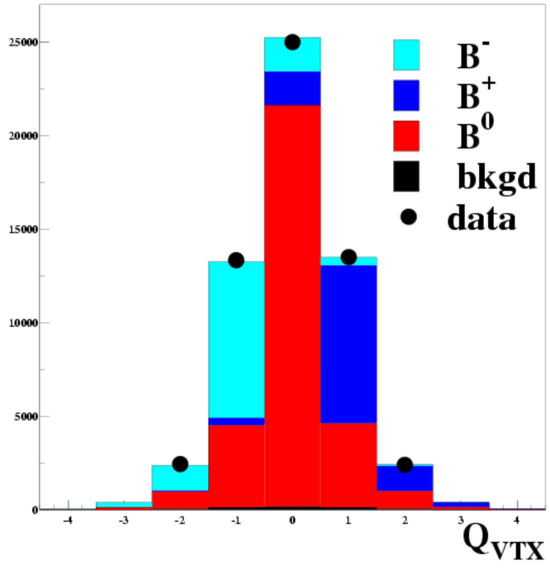


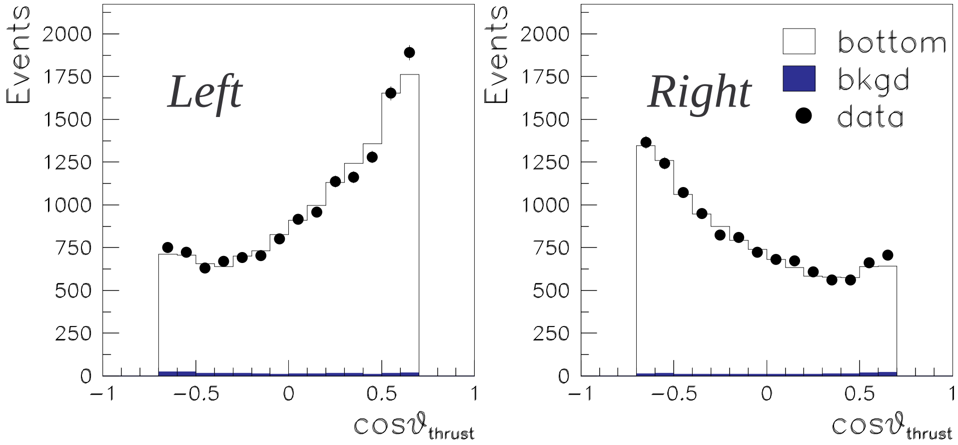
A_b, A_c with Vertex Charge

- Use Topological vertexing with NN c/b hemisphere selection as for R_b
- Use thrust axis as an estimate of initial quark directions.
- quark flavor is tagged by vertex charge ($Q_{VTX} \neq 0$). $K^{\pm}$ are also included for A_c.
- Extract A_b and A_c simultaneously.

Vertex Charge Results:

$$A_b = 0.921 \pm 0.018_{stat} \pm 0.018_{syst}$$
$$A_c = 0.673 \pm 0.029_{stat} \pm 0.024_{syst}$$





A_b, A_c with Leptons

- quark flavor tagged by lepton charge (e/μ) from semileptonic decays, $b,c \rightarrow X\, l\nu$
- Nearest jet axis defines quark direction (JADE $y_{cut} = 0.005$)
- Topological Vertexing
- A Neural Net is used to identify lepton source and mistag probability for electrons. Muons use a binned analysis,
  - lepton p, p_T with respect to jet axis
  - Vertex momentum, p_T corrected mass, and decay length significance
  - L/D of lepton

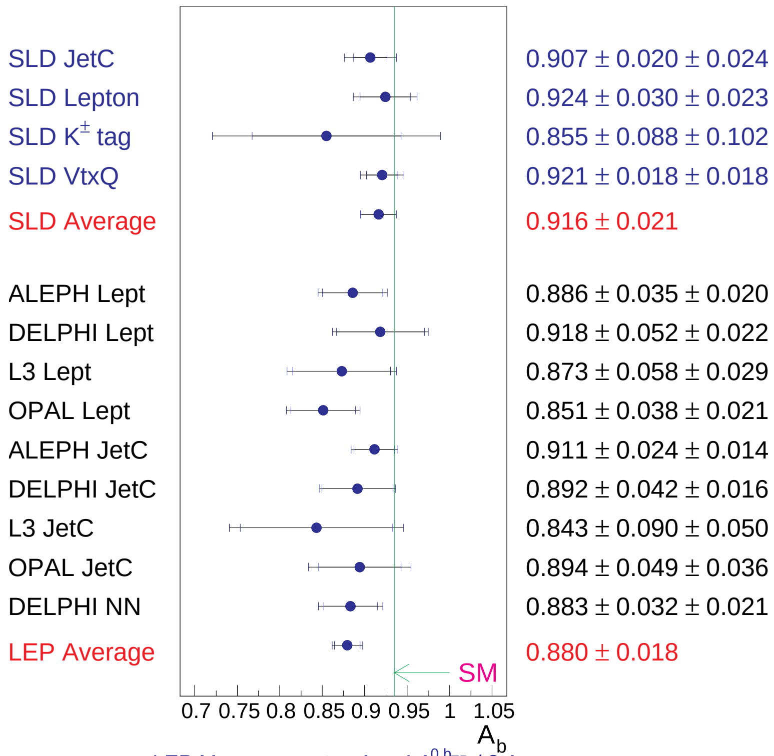
Lepton Final Results 93-98:

$A_b = 0.919 \pm 0.030_{stat} \pm 0.024_{syst}$

$A_c = 0.583 \pm 0.055_{stat} \pm 0.055_{syst}$

A_b, A_c Results

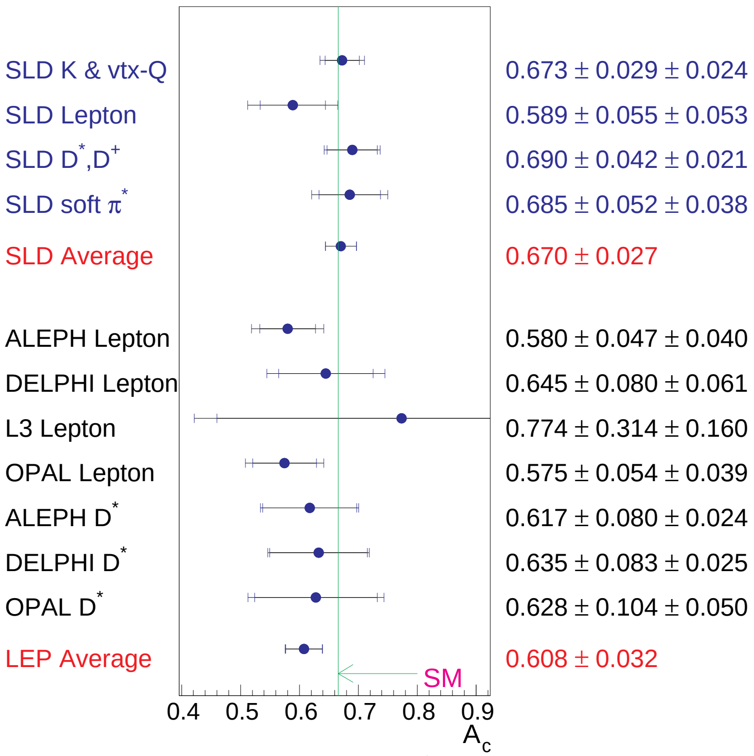
A_b Measurements (Summer-2001)



SLD JetC	0.907 ± 0.020 ± 0.024
SLD Lepton	0.924 ± 0.030 ± 0.023
SLD $K^{\pm}$ tag	0.855 ± 0.088 ± 0.102
SLD VtxQ	0.921 ± 0.018 ± 0.018
SLD Average	0.916 ± 0.021
ALEPH Lept	0.886 ± 0.035 ± 0.020
DELPHI Lept	0.918 ± 0.052 ± 0.022
L3 Lept	0.873 ± 0.058 ± 0.029
OPAL Lept	0.851 ± 0.038 ± 0.021
ALEPH JetC	0.911 ± 0.024 ± 0.014
DELPHI JetC	0.892 ± 0.042 ± 0.016
L3 JetC	0.843 ± 0.090 ± 0.050
OPAL JetC	0.894 ± 0.049 ± 0.036
DELPHI NN	0.883 ± 0.032 ± 0.021
LEP Average	0.880 ± 0.018

LEP Measurements: $A_b = 4 A^{0,b}_{FB} / 3 A_e$
Using A_e=0.1501±0.0016 (Combine SLD A_{LR} and LEP A_l)

A_c Measurements (Summer-2001)



SLD K & vtx-Q	0.673 ± 0.029 ± 0.024
SLD Lepton	0.589 ± 0.055 ± 0.053
SLD D^*,D^+	0.690 ± 0.042 ± 0.021
SLD soft π^*	0.685 ± 0.052 ± 0.038
SLD Average	0.670 ± 0.027
ALEPH Lepton	0.580 ± 0.047 ± 0.040
DELPHI Lepton	0.645 ± 0.080 ± 0.061
L3 Lepton	0.774 ± 0.314 ± 0.160
OPAL Lepton	0.575 ± 0.054 ± 0.039
ALEPH D^*	0.617 ± 0.080 ± 0.024
DELPHI D^*	0.635 ± 0.083 ± 0.025
OPAL D^*	0.628 ± 0.104 ± 0.050
LEP Average	0.608 ± 0.032

LEP Measurements: $A_c = 4 A^{0,c}_{FB} / 3 A_e$
Using A_e=0.1501±0.0016 (Combine SLD A_{LR} and LEP A_l)

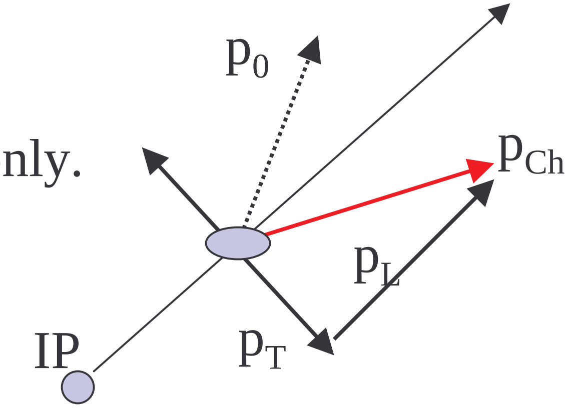
SLD Final Averages:

$A_b = 0.916 \pm 0.021$

$A_c = 0.670 \pm 0.027$

B Fragmentation

Measure the inclusive B hadron scaled energy distribution in Z^0 decays, $D(x_B)$, $x_B \equiv E_B/E_{beam}$.

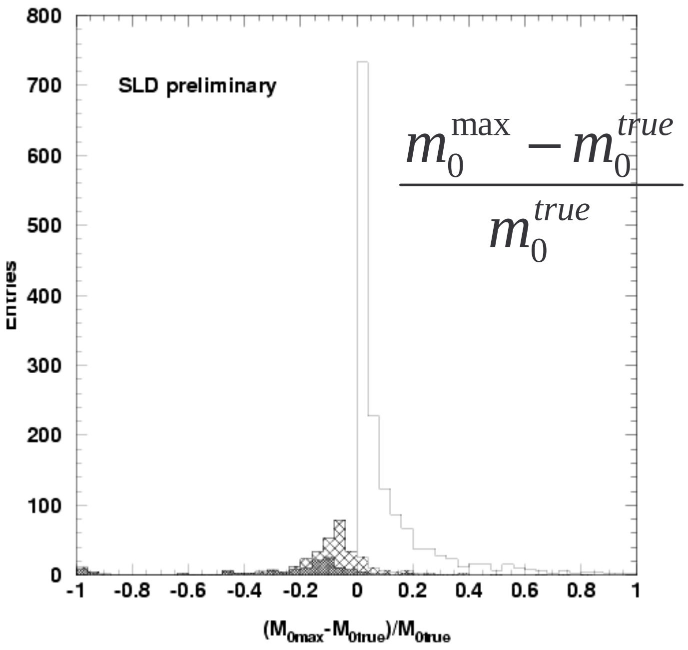


- Measure the B hadron energy using charged tracks only.
- Use standard Topological Vertexing.
- 2 unknowns: p^0_L, m^0. Use the m_B constraint to remove one and calculate an upper bound on m^0.
- In B rest frame,

$$m_B = \sqrt{m_{ch}^2 + p_T^2 + p_L^{ch2}} + \sqrt{m_0^2 + p_T^2 + p_L^{02}}$$

$$m_B \geq \sqrt{m_{ch}^2 + p_T^2} + \sqrt{m_0^2 + p_T^2}$$

$$m_0^2 \leq m_{0,\max}^2 \equiv m_B^2 + m_{ch}^2 - 2m_B\sqrt{m_{ch}^2 + p_T^2}$$

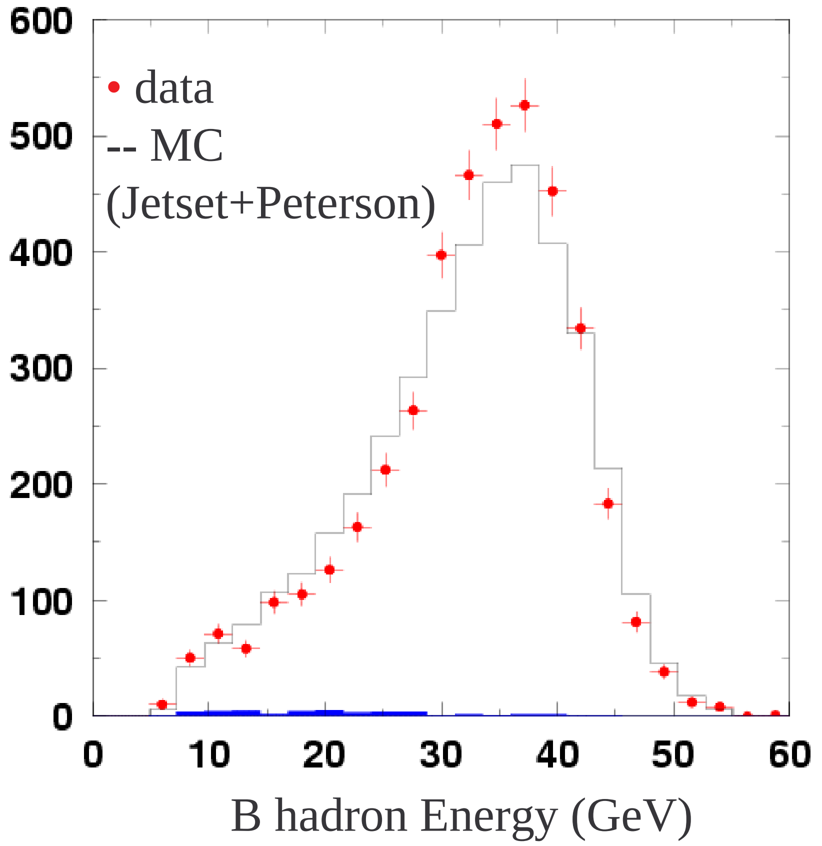


$$\frac{m_0^{\max} - m_0^{true}}{m_0^{true}}$$

$m_0^{\max}$ tends to be within 10% of true value.

B Fragmentation(II)

- select hemispheres with small $m_{0,max}$
  $\rightarrow$ set $m_0 = m_{0,max}$
- good energy resolution
  $\sigma_{core} \approx 9.6\%$ (83.6%)
- flat efficiency (4.17%) over the full range of x_B



Several fragmentation models and functional forms are inconsistent with the data (within Jetset):
BCFY, CS, Peterson, HERWIG
Consistent models:
Bowler, Lund, Kartvelishvili and UCLA

97-98 data:

$x_B = 0.710 \pm 0.003_{stat} \pm 0.005_{syst} \pm 0.004_{model}$

B Fragmentation(III)

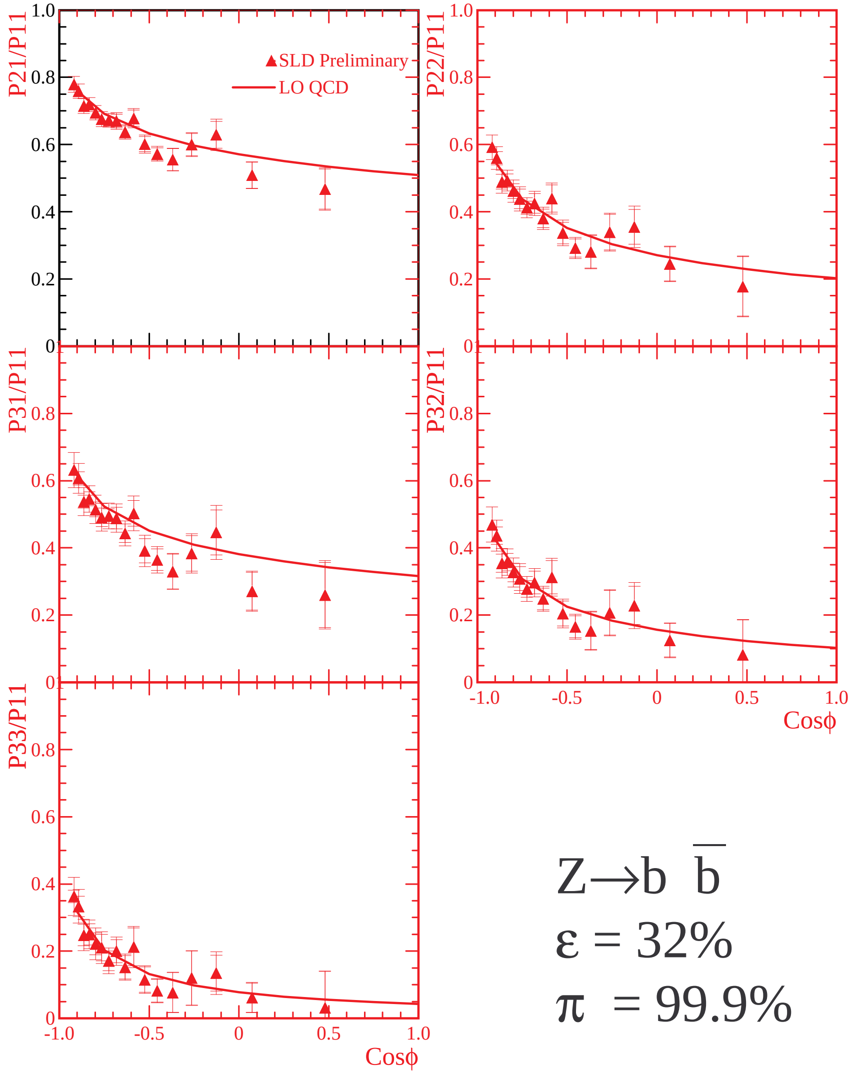
We have also studied B hadron energy correlations in the two hemispheres.

- Locate Jets with Durham ($y_{cut} = 0.015$)
- Require:
  - 2 secondary vertices in distinct jets
  - cosφ < 0.99 (angle between jets)
  - one vertex $M_{pT} > 2.0$ GeV
  - both $-1 < M^2_{0,max} < 12$ GeV^2
- calculate the moments,

$$D_{ij}^{rec}(\phi) = \iint x_{B1}^{i} x_{B2}^{j} \frac{d^2N(\phi)}{dx_{B1}dx_{B2}} dx_{B1}dx_{B2}$$

$$P_{ij}^{rec}(\phi) = D_{ij}^{rec}(\phi)\big/(M_i^{rec}\, M_j^{rec})$$

Results are consistent with factorization in pQCD.



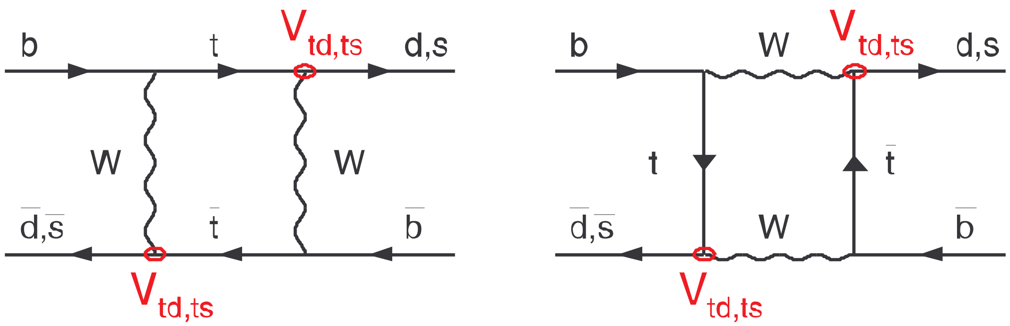
$Z \rightarrow b\,\bar{b}$

$\varepsilon = 32\%$

$\pi = 99.9\%$

$B^0 - \bar{B}^0$ Mixing

Neutral B flavor eigenstates (B^0, $\bar{B}^0$) are coupled by 2nd order weak interactions,



so that physical particles are the heavy and light state B_H and B_L. The result is particle/antiparticle oscillations with frequency $\Delta m = m_H - m_L$,

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

Δm_d is sensitive to the CKM matrix element V_{td},

$$\Delta m_d = \frac{G_F^2}{6\pi^2} B_{B_d} f_{B_d}^2 m_{B_d} \left| V_{tb}^* V_{td} \right|^2 m_t^2 f\left(\frac{m_t^2}{m_W^2}\right) \eta_{QCD}$$

Mixing Measurements

We want to measure the *mixed fraction* as a function of time,

$$mix \quad fraction = \frac{P_{mix}}{P_{mix} + P_{unmix}} = \frac{1}{2}\left(1 - \cos \Delta m t\right)$$

Mixing Ingredients:

§ Initial State Tag: determine b quark flavor at production

All SLD mixing analyses use the same combined initial state tag

§ Final State Tag: determine b quark flavor at decay

$$\text{SLD Analyses:} \quad \begin{array}{l} \text{Kaon Tag (} B_d \text{ mixing)} \\ \left.\begin{array}{l} D_s + \text{Tracks} \\ \text{Lepton+D} \\ \text{Charge Dipole} \end{array}\right\} B_s \text{ mixing} \end{array}$$

§ B Decay Time: measure B decay length and boost, $t = L/\beta\gamma c$

Mixing Initial State Tag

- *Polarization:* We exploit the large polarized forward-backward asymmetry of the b quark.

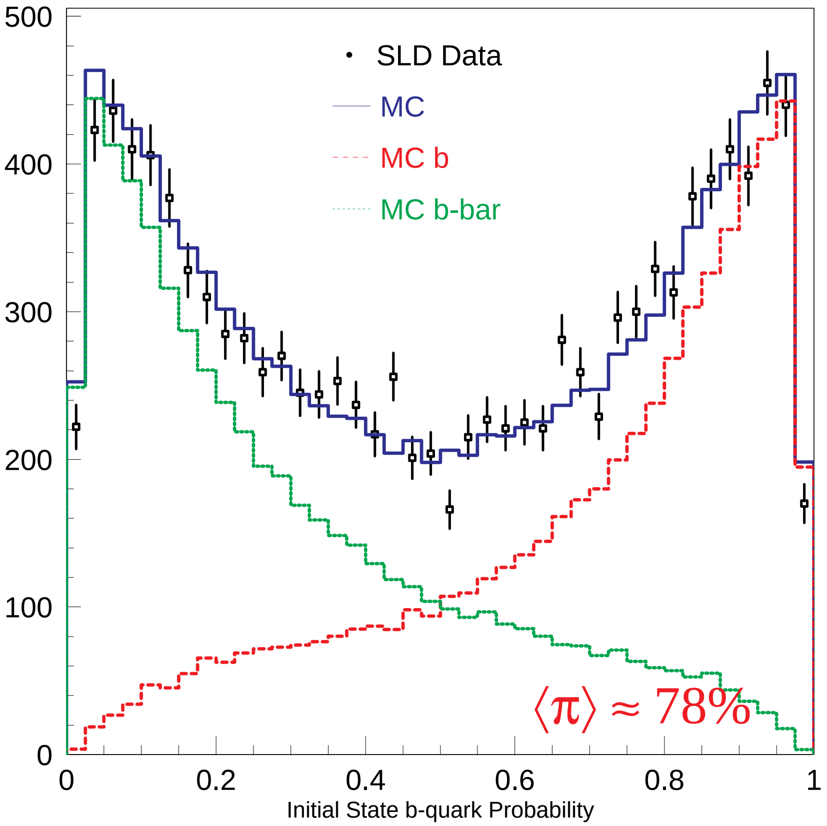
$$P_b^{pol} = \frac{1}{2}\left(1 + \tilde{A}_{FB}^{b}\right)$$

$\varepsilon = 100\%$ $\langle\pi\rangle \approx 72\%$

- *Charged Tags:* in opposite hemisphere (NN)
  - Jet Charge
  - high p_T lepton charge
  - Kaon charge
  - vertex charge
  - Charge Dipole

$\langle\pi\rangle \approx 71\%$

- event-by-event mistag probability



$\langle\pi\rangle \approx 78\%$

B_d Mixing Analysis

Final State tag from $K^\pm$ identified in Cherenkov Ring Imaging Detector

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

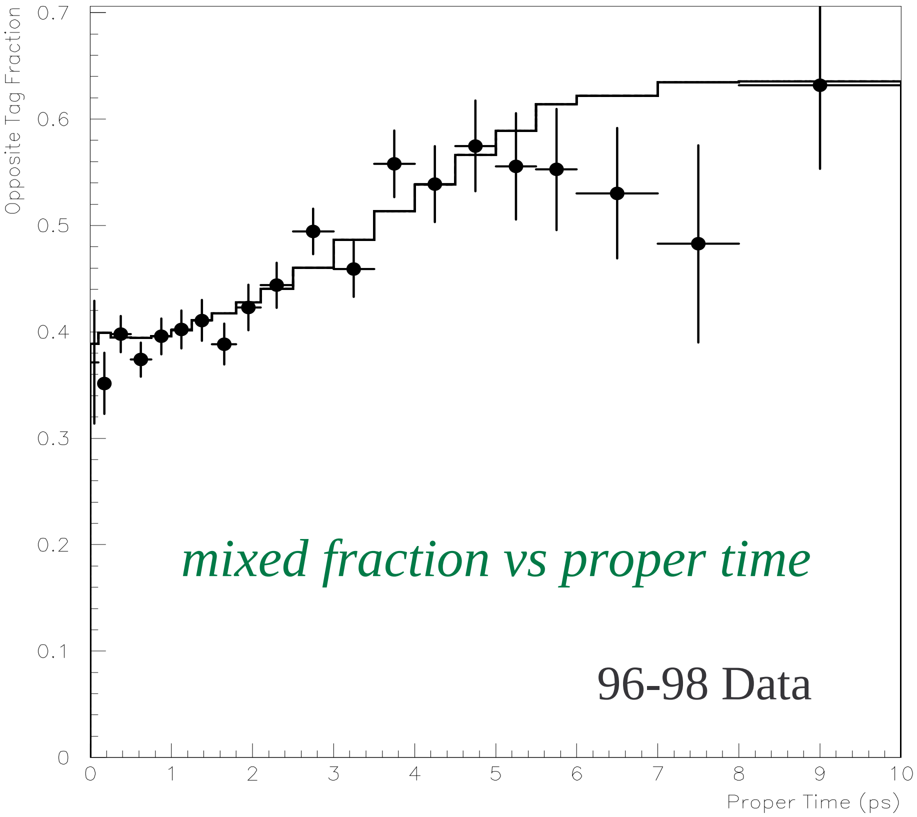
$K^\pm$ Right Sign Fraction: (82±5)%
(Argus)

2D likelihood fit for Δm_d and correct tag fraction:

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

Correct tag fraction = 0.797±0.022

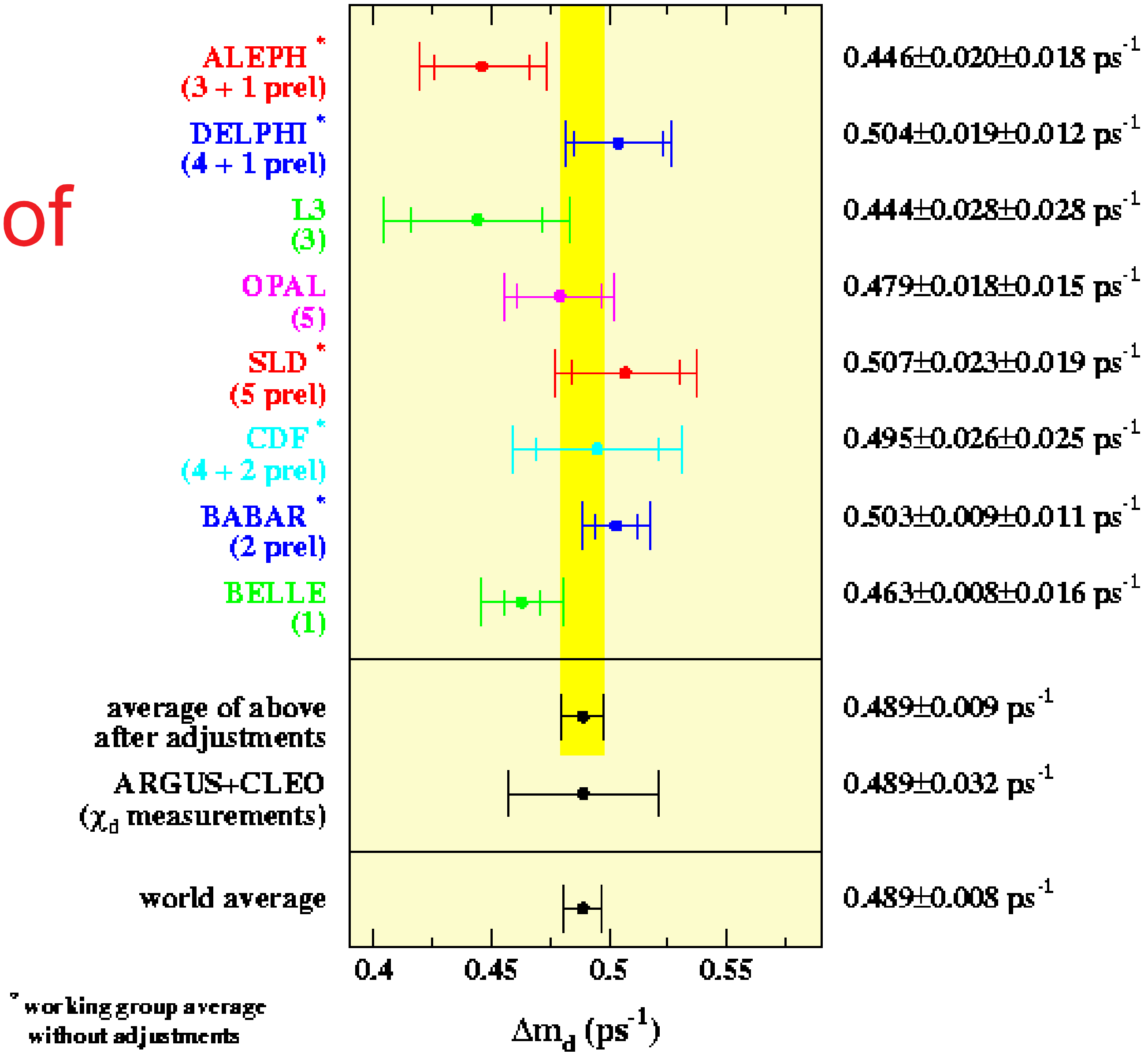
number of vertices: 7844



mixed fraction vs proper time

96-98 Data

Status of Δm_d



$B_s^0 - \bar{B}_s^0$ Mixing

In principle we can extract V_{td} from Δm_d but the theoretical uncertainty is large,

$$\Delta m_d \propto B_{B_d} f_{B_d}^2 m_{B_d} \eta_{QCD} \left|V_{tb}^* V_{td}\right|^2 \qquad \sqrt{B_{B_d}}\, f_{B_d} = 210 \pm 35 MeV$$

⇒ Measure Δm_s and form ratio

$$\frac{\Delta m_d}{\Delta m_s} = \xi^{-2} \frac{m_{B_d}}{m_{B_s}} \left|\frac{V_{td}}{V_{ts}}\right|^2 \qquad \xi = 1.11 \pm 0.06$$

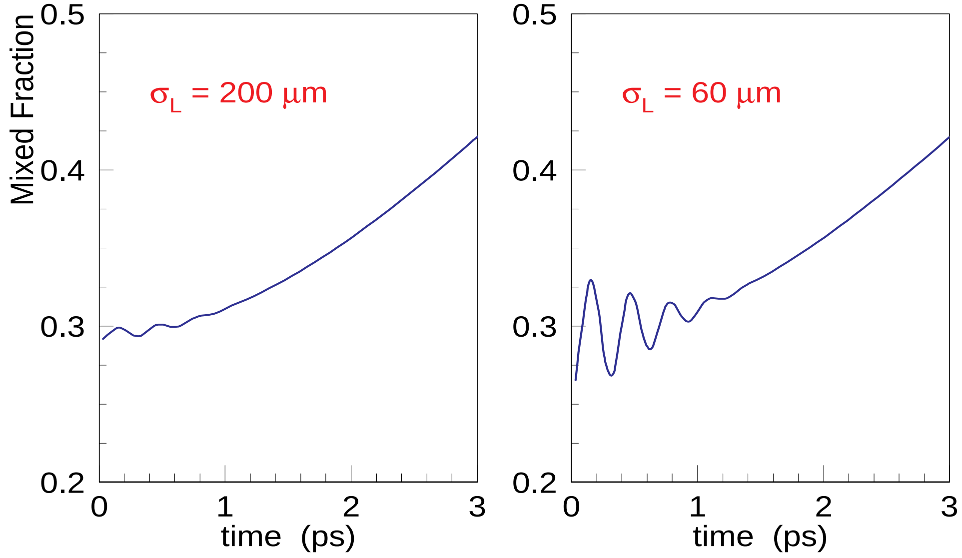
But B_s mixing is much harder,

- B_s fraction is smaller
  fraction $B_s(B_d) \approx 10\%(40\%)$
- Frequency is much larger

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

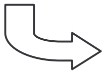
we need excellent proper time resolution.

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



$D_s^{\pm}$ + Tracks Analysis

- $B_s \rightarrow D_s^- X$ with full reconstruction of the D^-_s decay in 2 modes:

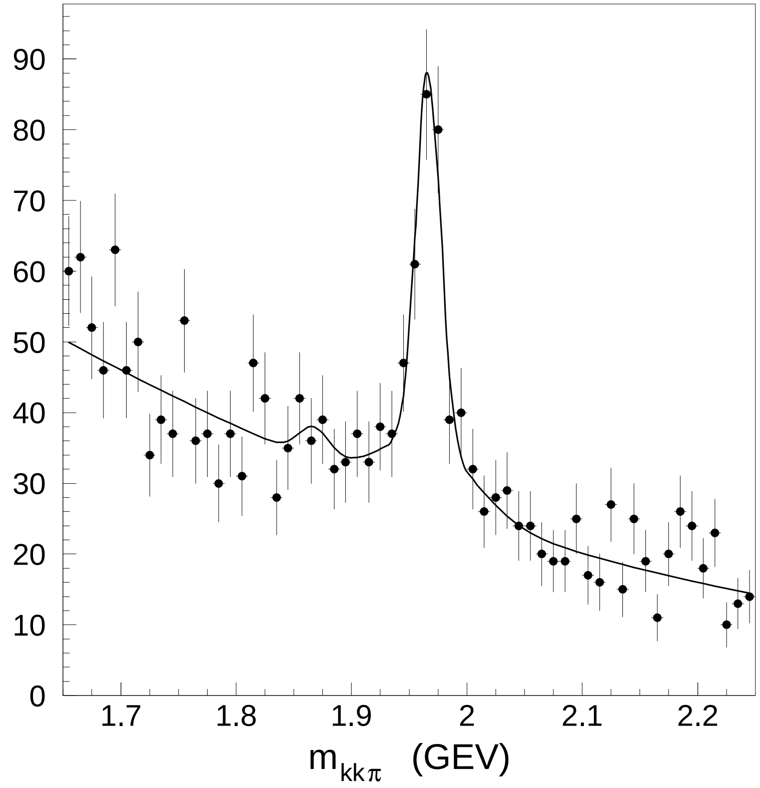


$D_s^- \rightarrow \phi\pi^-$ (280 candidates)

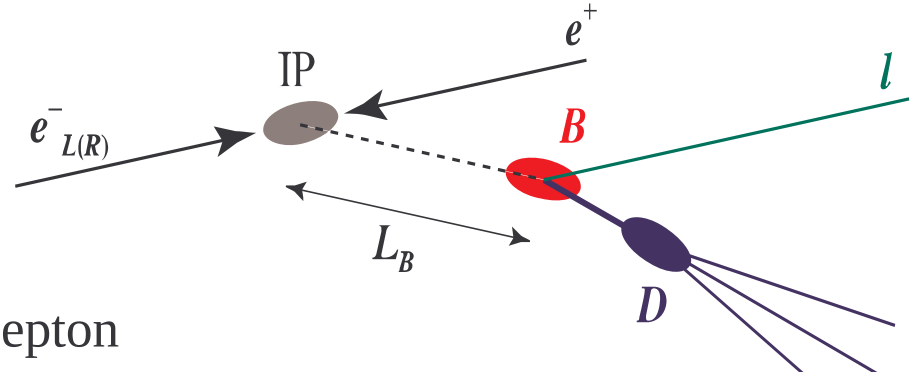
$D_s^- \rightarrow K^*K^-$ (81 candidates)

- Kaons identified in Cherenkov Ring Imaging Detector (CRID).
- Neural Network D_s selection.
- Final state b quark flavor determined by the charge of the D_s (mistag 13%, decreases to 5% with a lepton).
- B_s fraction increases to 38%
- Excellent decay length resolution,

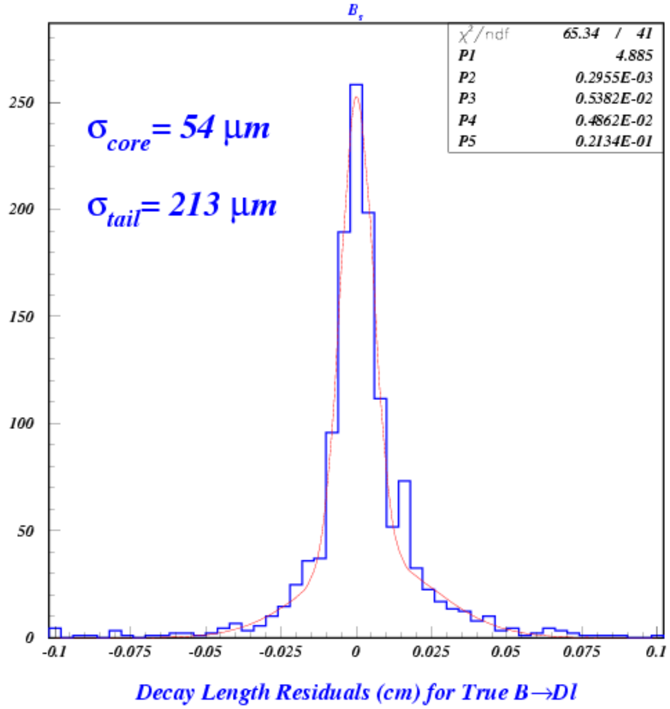
  core $\sigma_L = 50\ \mu m$ (60%)



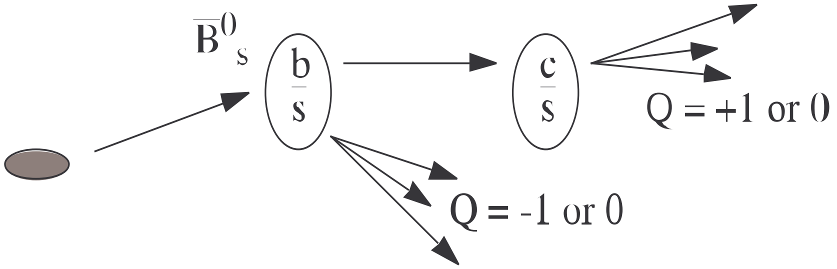
Lepton + D Analysis



- Identified e and μ tag the b quark final state, $\overline{B}_s \rightarrow D^+ l^- \nu$.
- Inclusive D vertex reconstruction.
- B vertex is the intersection of the lepton with the D "track".
- NN is applied to suppress $b \rightarrow c \rightarrow l$ (wrong sign) backgrounds.
  very low mistag ≈ 4% (B_s)
- excellent decay length resolution
  core σ_L = 54 μm (60%)
  tail σ_L = 213 μm
- B_s fraction 16% overall
  → 34% opposite sign l/k



Charge Dipole Analysis



- Fully inclusive reconstruction of secondary and tertiary vertices.
- Tag b quark decay flavor with "charge dipole":

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

- Final state mistag:

  22% overall

  9% for $B_s \to D_s X$

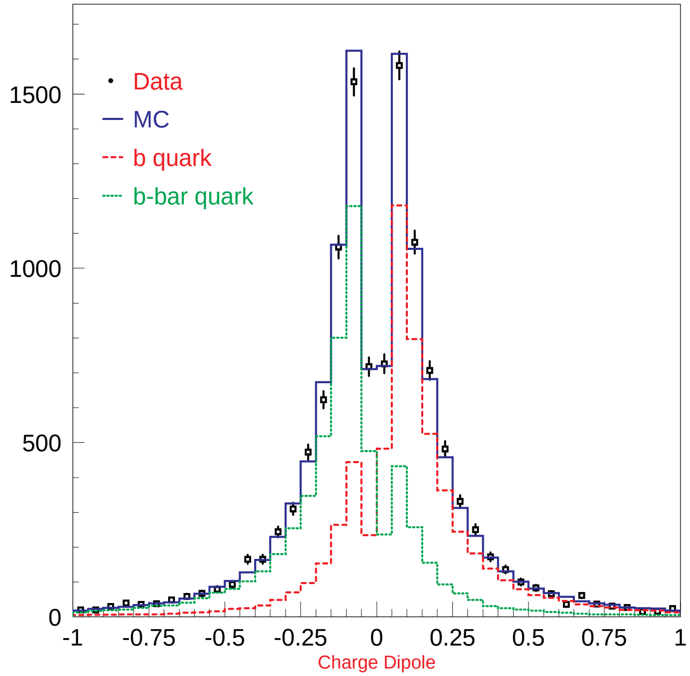
  47% for $B_s \to D_s D X$

- Good decay length resolution:

  core $\sigma_L = 81\ \mu m$ (60%)

  tail $\sigma_L = 297\ \mu m$

- Select neutral hemispheres, B_s fraction = 16%



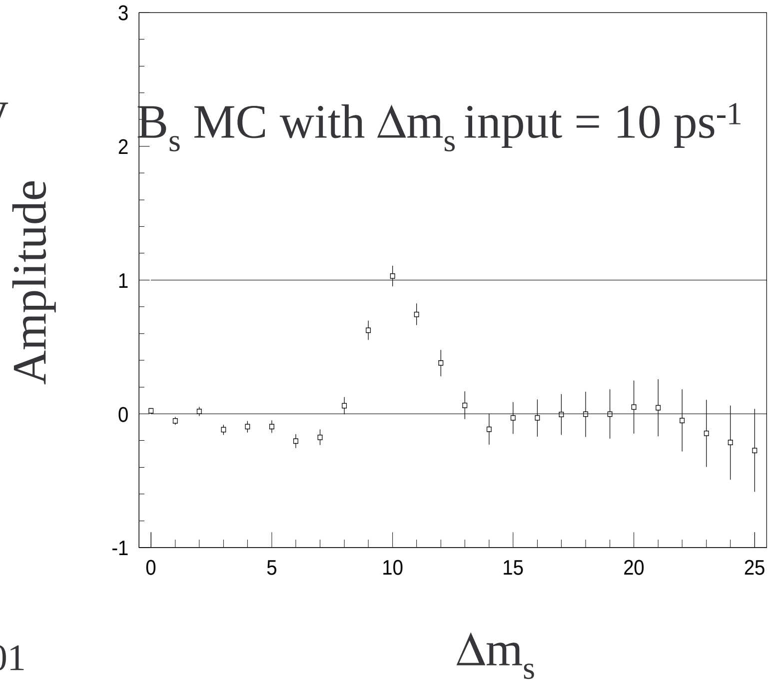
Amplitude Fit

NIM A384, 491 (1997)

Mixing is a periodic oscillation in the mixed fraction so we can measure the frequency spectrum. In the likelihood functions we insert the amplitude parameter A,

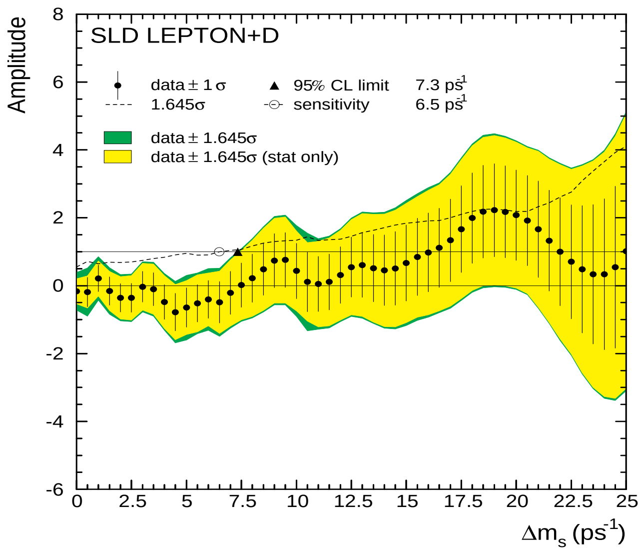
$$(1 \pm \cos\Delta m_s t\ ) \rightarrow (\ 1 \pm A\cos\Delta m_s t)$$

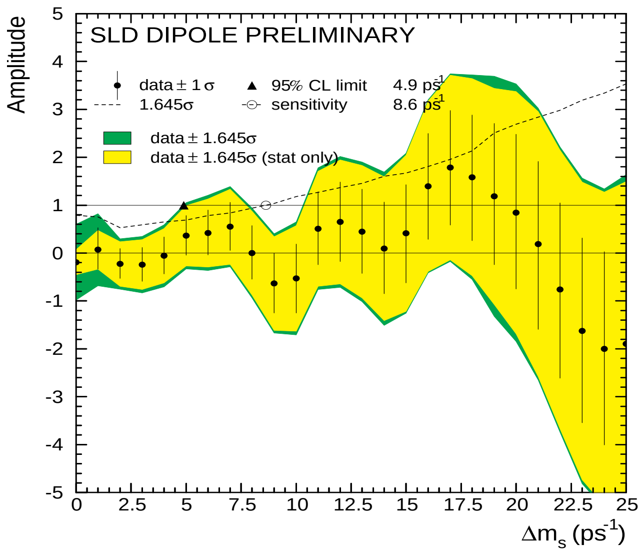
- For any value of the frequency Δm_s, we can perform a log-likelihood fit for A.
- A is the normalized Fourier Amplitude at frequency Δm_s.
- Expect $A \approx 1$ at the true mixing frequency and $A \approx 0$ far from the true value.
- σ_A grows as a function of Δm_s due to proper time resolution.
- Values of Δm_s where $A + 1.645\sigma_A < 1$ are excluded at 95% CL.
- The *sensitivity* of the experiment is the value of Δm_s where $1.645\ \sigma_A = 1$.

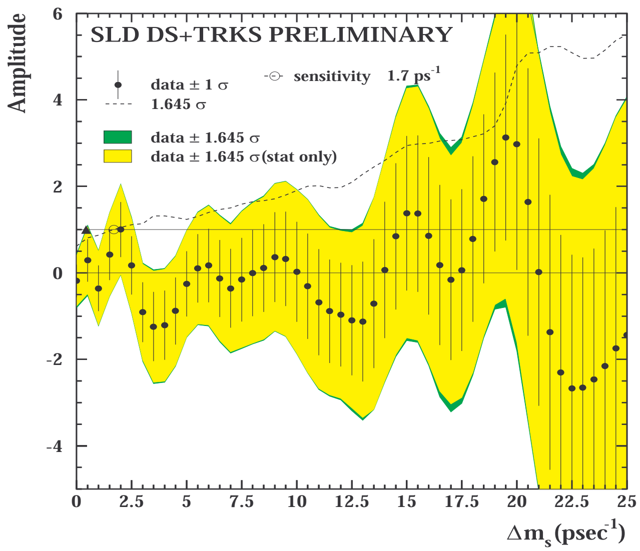


SLD Amplitude Fits

3 Preliminary Analyses







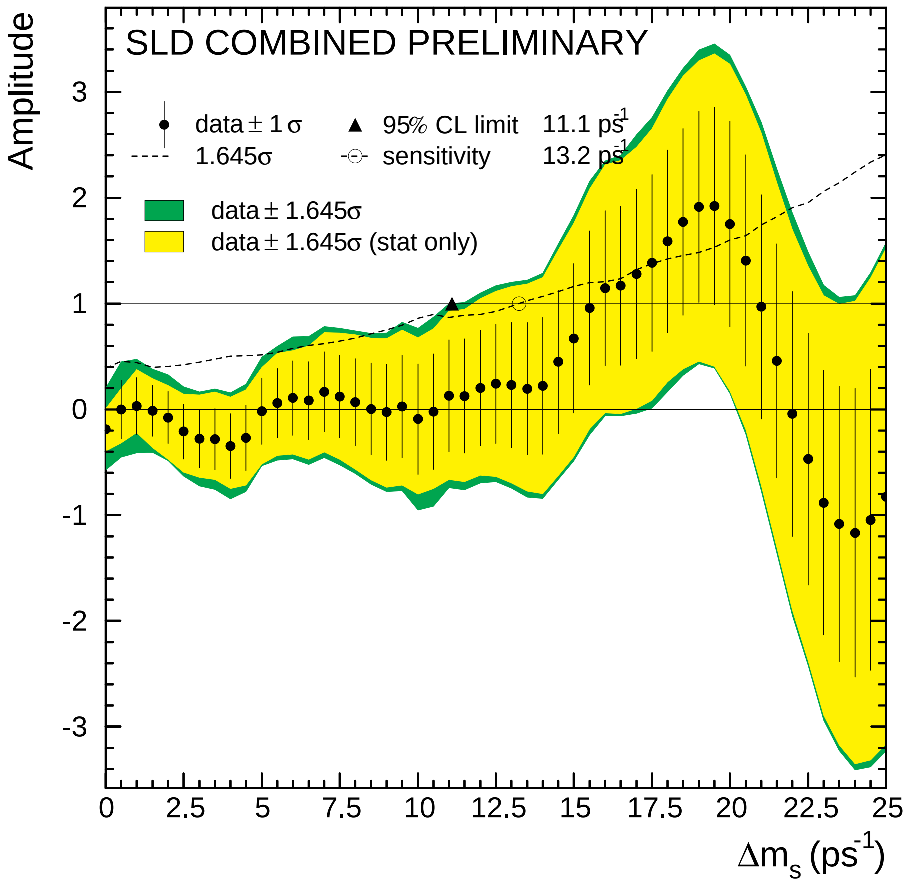
SLD Combined Amplitude

Preliminary result:

sensitivity = 13.2 ps^{-1}

Excluded at 95% C.L.:

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



World Average Mixing Results

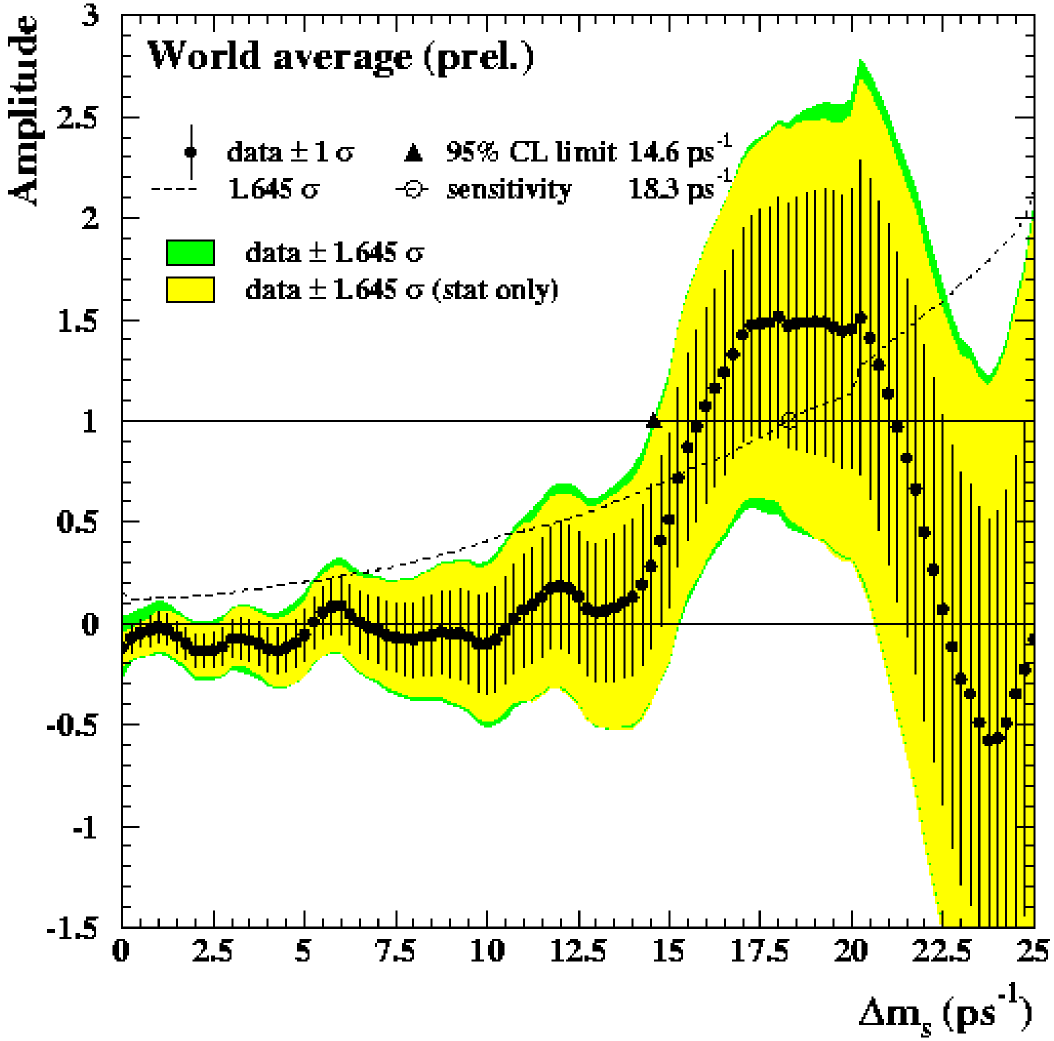
Contributions from:

- LEP
- SLD
- CDF

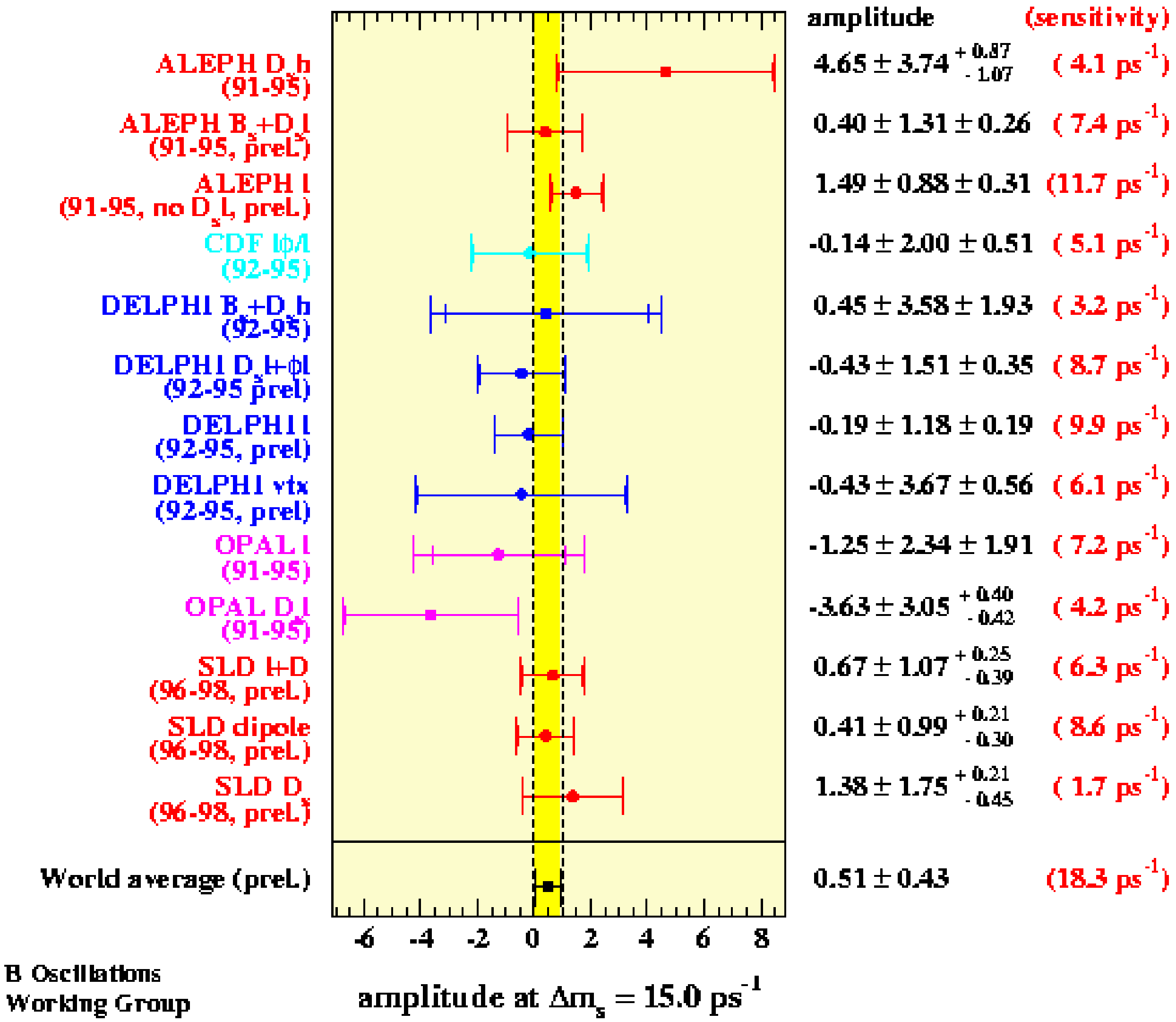
sensitivity = 18.3 ps-1

excluded at 95% CL:

$\Delta m_s < 14.6\ ps^{-1}$



Comparison at 15 ps^{-1}



	amplitude	(sensitivity)
ALEPH D_s h (91-95)	4.65 $\pm$ 3.74 $^{+0.87}_{-1.07}$	(4.1 ps^{-1})
ALEPH B_s+D_s l (91-95, prel.)	0.40 $\pm$ 1.31 $\pm$ 0.26	(7.4 ps^{-1})
ALEPH l (91-95, no D_s l, prel.)	1.49 $\pm$ 0.88 $\pm$ 0.31	(11.7 ps^{-1})
CDF lφ/l (92-95)	-0.14 $\pm$ 2.00 $\pm$ 0.51	(5.1 ps^{-1})
DELPHI B_s+D_s h (92-95)	0.45 $\pm$ 3.58 $\pm$ 1.93	(3.2 ps^{-1})
DELPHI D_s l+φl (92-95 prel)	-0.43 $\pm$ 1.51 $\pm$ 0.35	(8.7 ps^{-1})
DELPHI l (92-95, prel)	-0.19 $\pm$ 1.18 $\pm$ 0.19	(9.9 ps^{-1})
DELPHI vtx (92-95, prel)	-0.43 $\pm$ 3.67 $\pm$ 0.56	(6.1 ps^{-1})
OPAL l (91-95)	-1.25 $\pm$ 2.34 $\pm$ 1.91	(7.2 ps^{-1})
OPAL D_s l (91-95)	-3.63 $\pm$ 3.05 $^{+0.40}_{-0.42}$	(4.2 ps^{-1})
SLD l+D (96-98, prel.)	0.67 $\pm$ 1.07 $^{+0.25}_{-0.39}$	(6.3 ps^{-1})
SLD dipole (96-98, prel.)	0.41 $\pm$ 0.99 $^{+0.21}_{-0.30}$	(8.6 ps^{-1})
SLD D_s (96-98, prel.)	1.38 $\pm$ 1.75 $^{+0.21}_{-0.45}$	(1.7 ps^{-1})
World average (prel.)	0.51 $\pm$ 0.43	(18.3 ps^{-1})

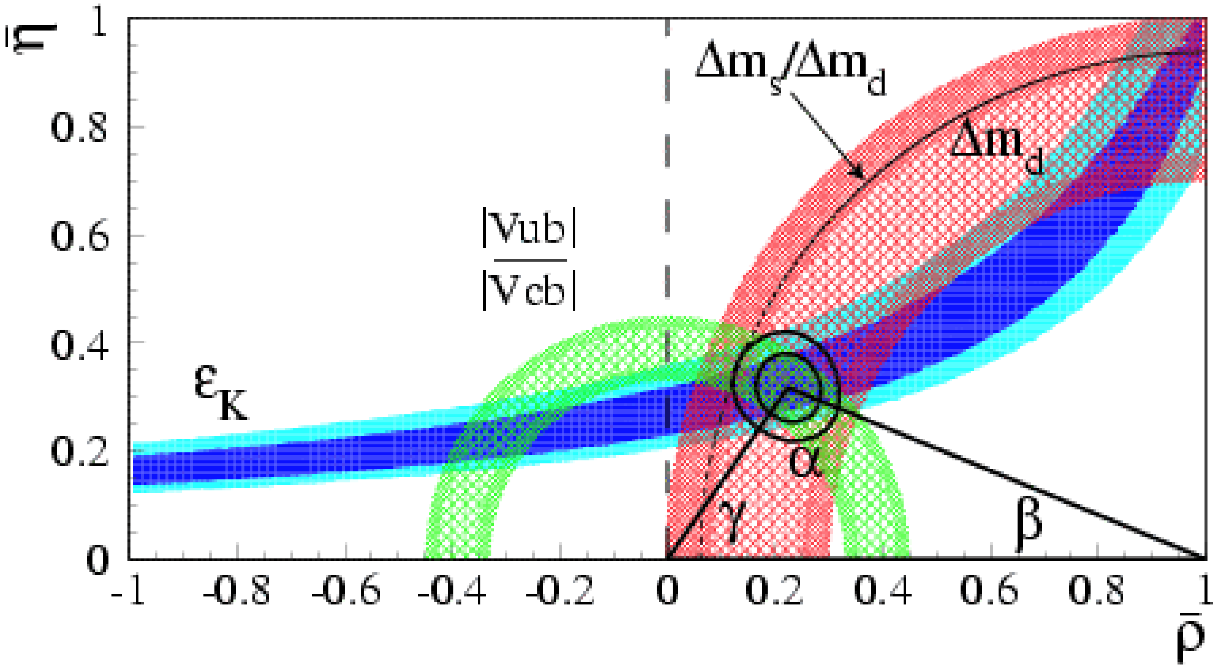
CKM Constraints

Mixing measurements are able to make powerful constraints on CKM matrix elements and CP violation.

- Δm_d and Δm_s can be represented as circular bands centered at (1,0) in the $\bar{\rho}$ - $\bar{\eta}$ plane.
- These constraints are orthogonal to the sin2β measurements from the B factories.

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

$$\Delta m_s \propto A^2 \lambda^4$$



Conclusions

- The SLD experiment has made large contributions in many areas of physics including electroweak, heavy-flavors, and QCD.
- The unique features of the SLC and SLD have resulted in many results that are one of a kind or represent the world's standard in precision.
- Precision tests of the Standard Model include:
  A_{LR}, R_b and R_c, A_b and A_c as well as others which I couldn't squeeze in.
- $B_s^0 - \overline{B}_s^0$ mixing measurements have contributed significantly to the world effort to constrain the quark mixing matrix and CP violation in the SM.
- Future linear colliders will build on the experience gained at the SLC and SLD.