Measurement of Quark Coupling Asymmetries at the SLD

Outline

1. Theoretical Overview
2. Unique Features of the SLD:
   - The SLC -- Polarization and Small Beam Spot
   - Vertex Finding
   - Particle Identification
3. Common Features of the A_q Measurements
4. A_b
5. A_c
6. A_s
7. Conclusions

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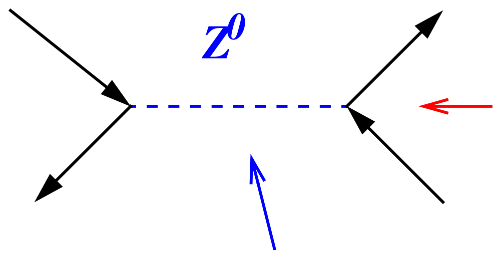
Theoretical Overview



$$\frac{-ig}{2\cos\theta_W}\gamma^{\mu}(c_V - c_A\gamma^5)$$

$$\frac{-i(g_{\mu\upsilon} - k_{\mu}k_{\upsilon}/M_Z^2)}{k^2 - M_Z^2}$$

The Matrix element has a propagator term and two vertex factors.

Definitions:

θ_W -- Weinberg Angle

g -- Electro-weak Coupling Constant

c_V, c_A -- Vector and Axial-Vector couplings

The Standard Model specifies the values of c_V and c_A as well:

$c_V = T_3 - 2Q\sin^2\theta_W$

$c_A = T_3$

Where Q is the fermion charge and T_3 is the 3rd component of the weak isospin.

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Theoretical Overview

For longitudinally polarized electrons the cross-section can be written as

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

Where θ is the polar angle from the beam, P_e is the polarization, A_e is the $Ze\bar{e}$ initial state coupling asymmetry and

$$A_f = \frac{2c_V^f c_A^f}{(c_V^f)^2 + (c_A^f)^2} = \frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}$$

is the final state coupling asymmetry of $Zf\bar{f}$.

Values of A_f for the different fermions (using $\sin^2\theta_W$=0.232)

Fermions	T_3	Q	c_A	c_V	A_f
ν_e,ν_μ,ν_τ	1/2	0	1/2	1/2	**1**
e,μ,τ	-1/2	-1	-1/2	-0.036	**0.155**
u,c,t	1/2	2/3	1/2	0.191	**0.667**
d,s,b	-1/2	-1/3	-1/2	-0.345	**0.935**

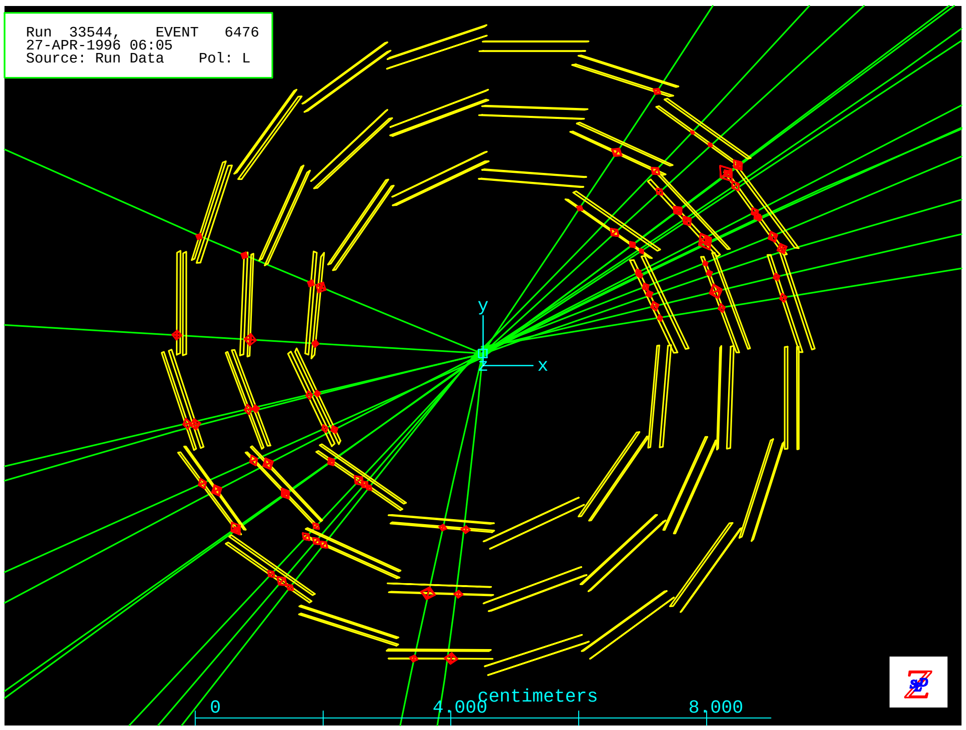
Unique Features of the SLD

The SLAC Linear Collider (SLC)

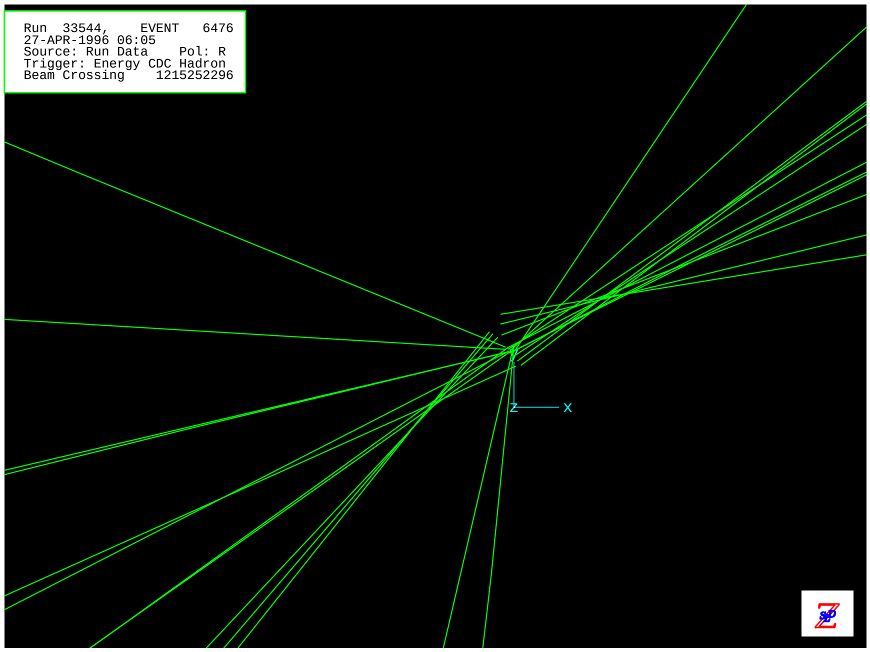
- Polarized Electron Beam (~63% in 1993, ~75% 1994-98)
- Small Beam Spot --1.5 x 0.8 x 700μm (x,y,z)

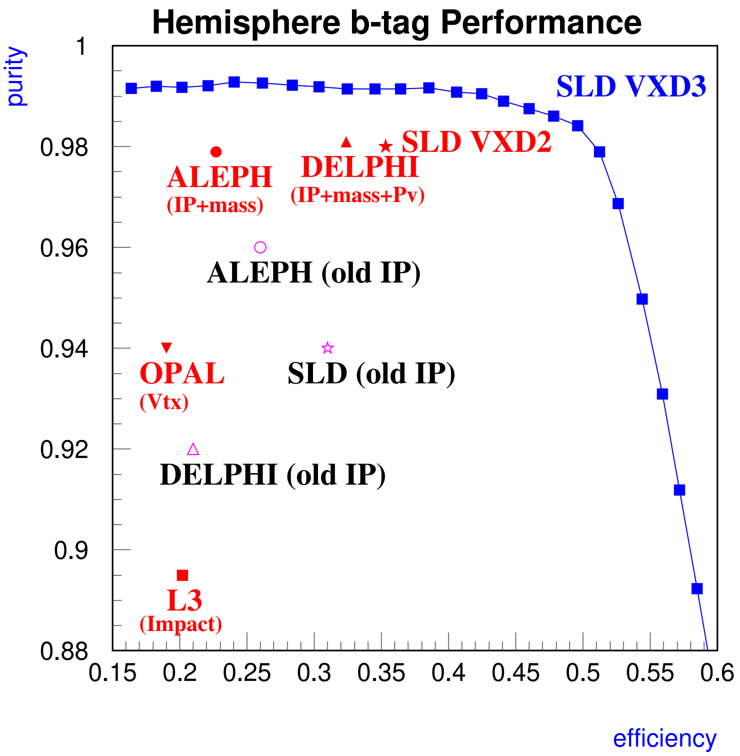
SLD's VXD3 (3D CCD Pixel Vertex Detector)

- 3 layers with 300M pixels
- 2 layer hits out to cosθ = 0.9
- Track impact parameter resolution of 11 x 23μm (rϕ x rz)



Unique Features of the SLD





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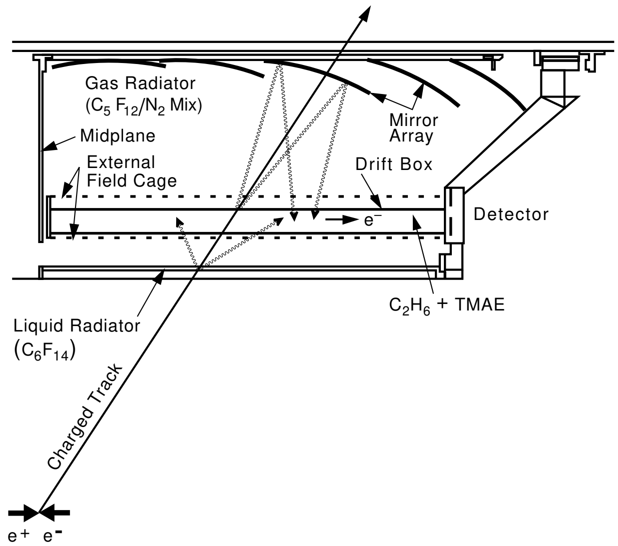
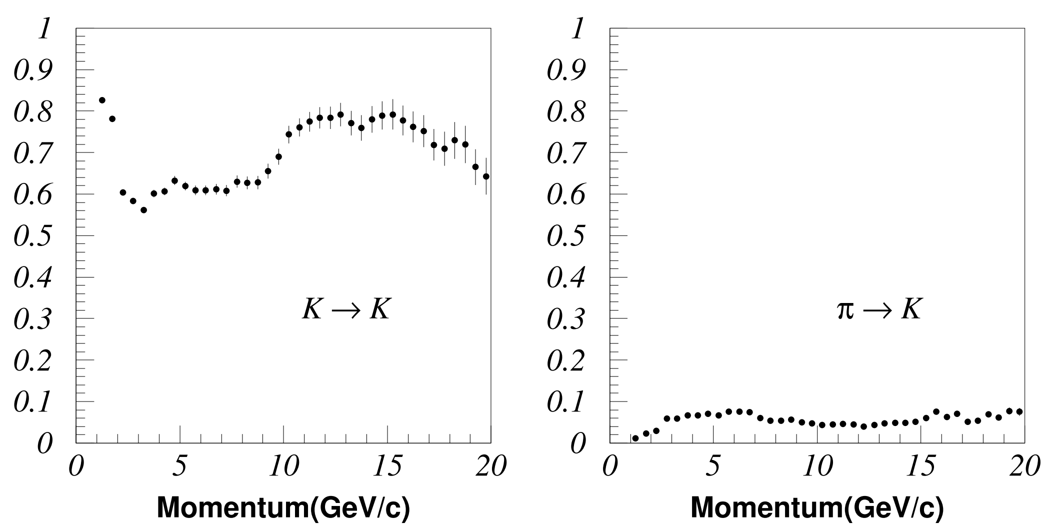
Unique Features of the SLD

SLD's Cherenkov Ring Imaging Detector (CRID)



Kaon ID efficiency



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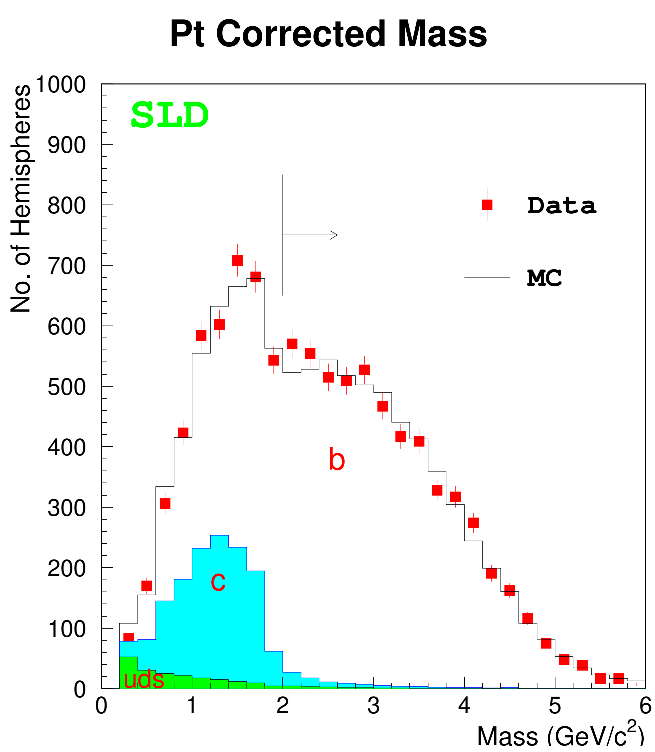
A_q

All measurements share a similar analysis flow:

1. Select Z^0 to hadrons events
2. Tag events with the correct quark flavor
   - Look for a displaced vertex with the appropriate mass (b,c)
   - Or with no displaced vertex (s)
3. Tag the quark charge (and direction)
   - By summing the track charge in the jet
   - Or with an identified e, μ, K, Λ, D^{*+}, D^+, D^0



A_q

The Executive Summary:

Quark Coupling Asymmetries at the SLD

Quantity Measured	**Analysis**	**Secondary Vertex Requirement**	**quark sign**
A_b	Jet Charge	$M_{vtx}>2.0\,GeV$	Jet Charge
	Kaon Tag	$M_{vtx}>1.8\,GeV$	Kaon
	Lepton Tag	(none)	e,μ
A_c	Lepton Tag	(none)	e,μ
	Inclusive Charm	$0.55<M_{vtx}<2.0\,GeV$ $P_{vtx}>5.0\,GeV$ $P_{vtx}-15M_{vtx}>-10\,GeV$	Kaon or Vertex Charge
	Exclusive Charm	$M_{vtx}<2.0\,GeV$	D^{*+}, D^{+}, D^{0}
A_s	Strangeness	Veto	Kaon, Lambda

(M_{vtx} -- Vertex Mass, P_{vtx} -- Vertex Momentum)

A_q

Most analyses use a Maximum Likelihood treatment:

$$L = (1+\cos^2\theta)(1-A_eP_e) + 2\cos\theta(A_e - P_e)$$

$$\times\Big\{A_b f_b (1-2\chi)(1-\Delta^b_{QCD})$$

$$+ A_c f_c (1-\Delta^c_{QCD})$$

$$+ A_s f_s (1-\Delta^s_{QCD})$$

$$+ A_{bkgd} f_{bkgrd}\Big\}$$

Where

χ is the b mixing fraction

$\Delta^q{}_{QCD}$ are the QCD corrections to the observed asymmetry

f_q are the fraction of events of type q

And the Maximum Likelihood is fit for the relevant A_q

A_b (Jet Charge)

Three Methods of tagging the charge of the *b*:

1. **Momentum Weighted Jet Charge** -- Construct

$$Q = -\sum_{tracks} q_i \cdot \mathrm{sgn}(\vec{p}_i \cdot \hat{T})\left|\vec{p}_i \cdot \hat{T}\right|^{\kappa = 0.5}$$

where $\hat{T}$ is the thrust axis. Positive Q indicates that a b quark lies along the thrust axis, negative Q -> $\bar{b}$.

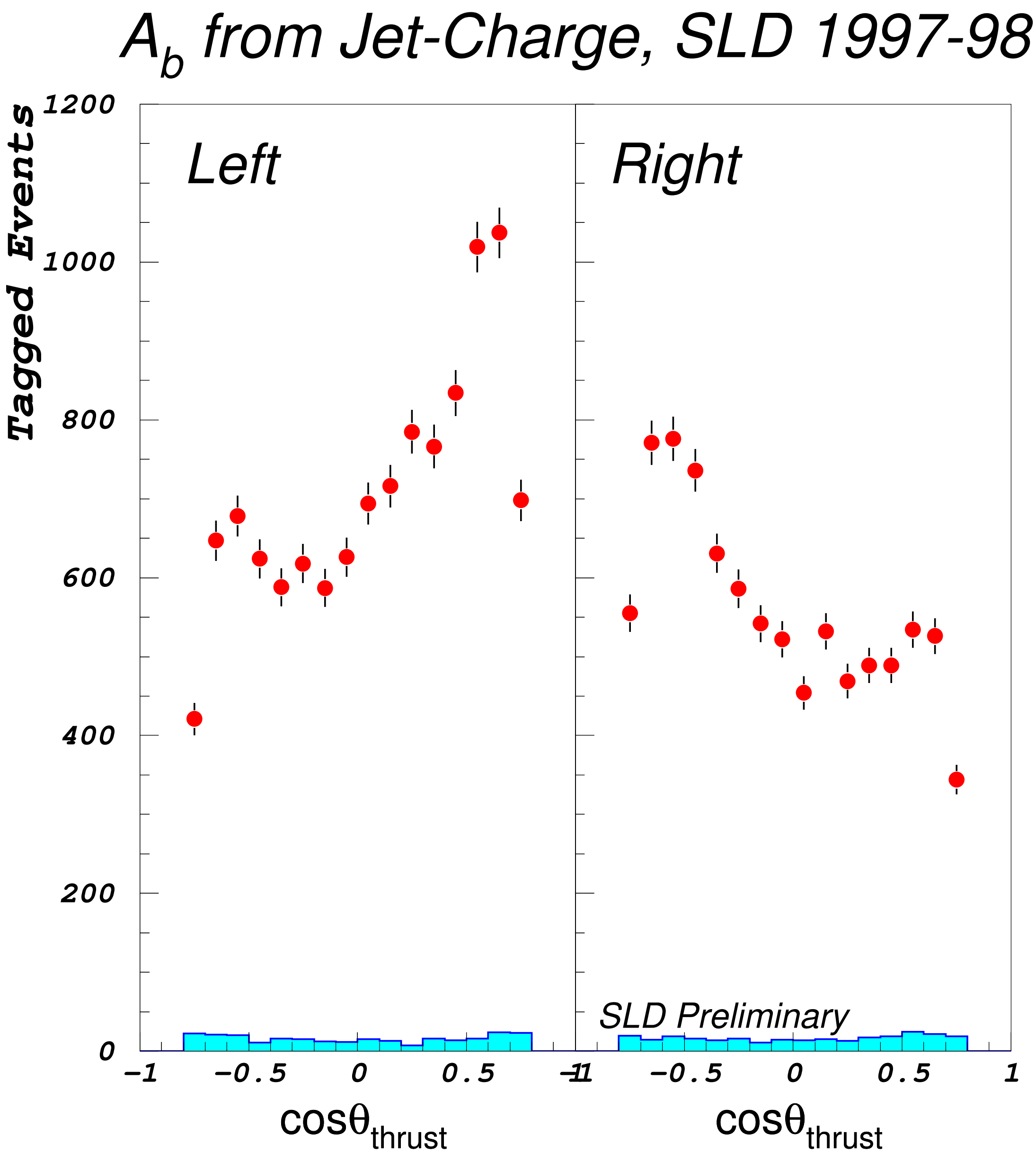
This analysis is *self-calibrating*: the probability of a correct tag can be estimated directly from the data.

Since Q is nearly Gaussian,

$$P_{corr}(|Q|) = \frac{1}{1 + \exp(-\alpha|Q|)}$$

and α can be found from the data as well.

A_b (Jet Charge)



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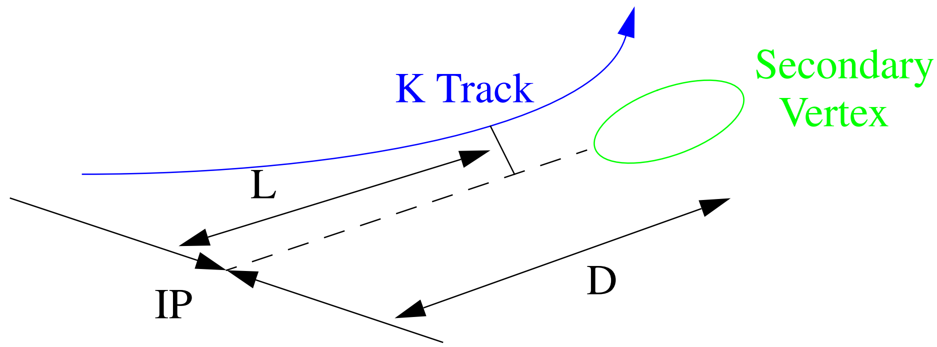
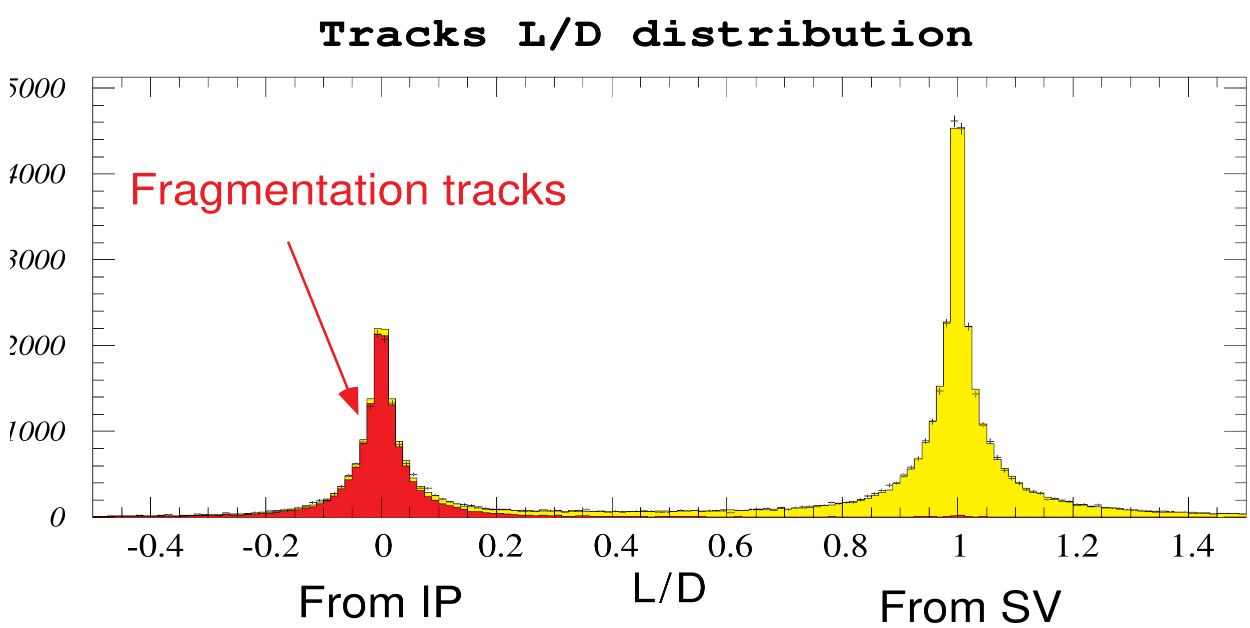
A_b (Kaon Tag)

2. **Kaon Tag** from the cascade decay of *b* -> *c* -> *s*

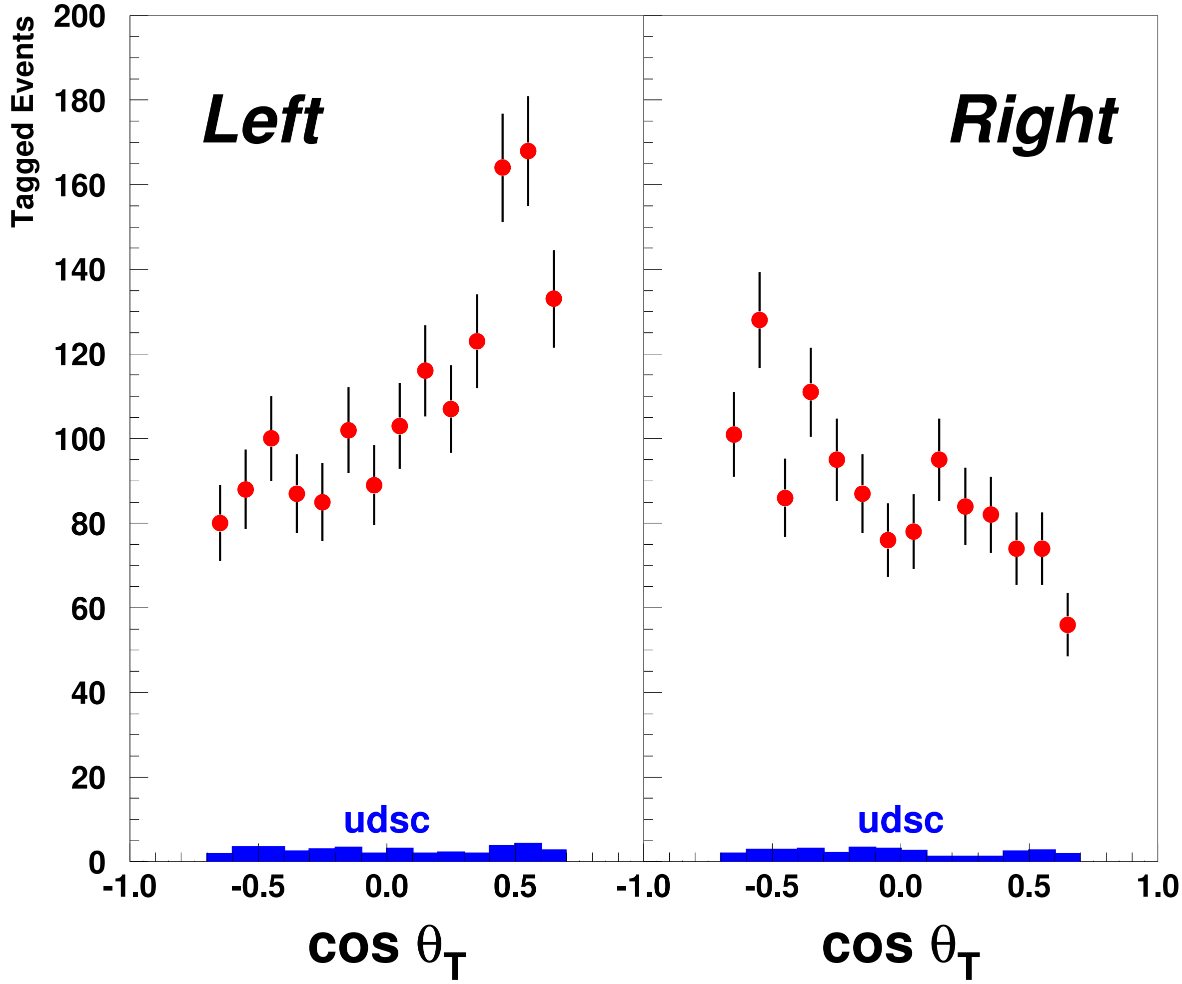


From CRID tagged kaon tracks:



A_b (Kaon Tag)

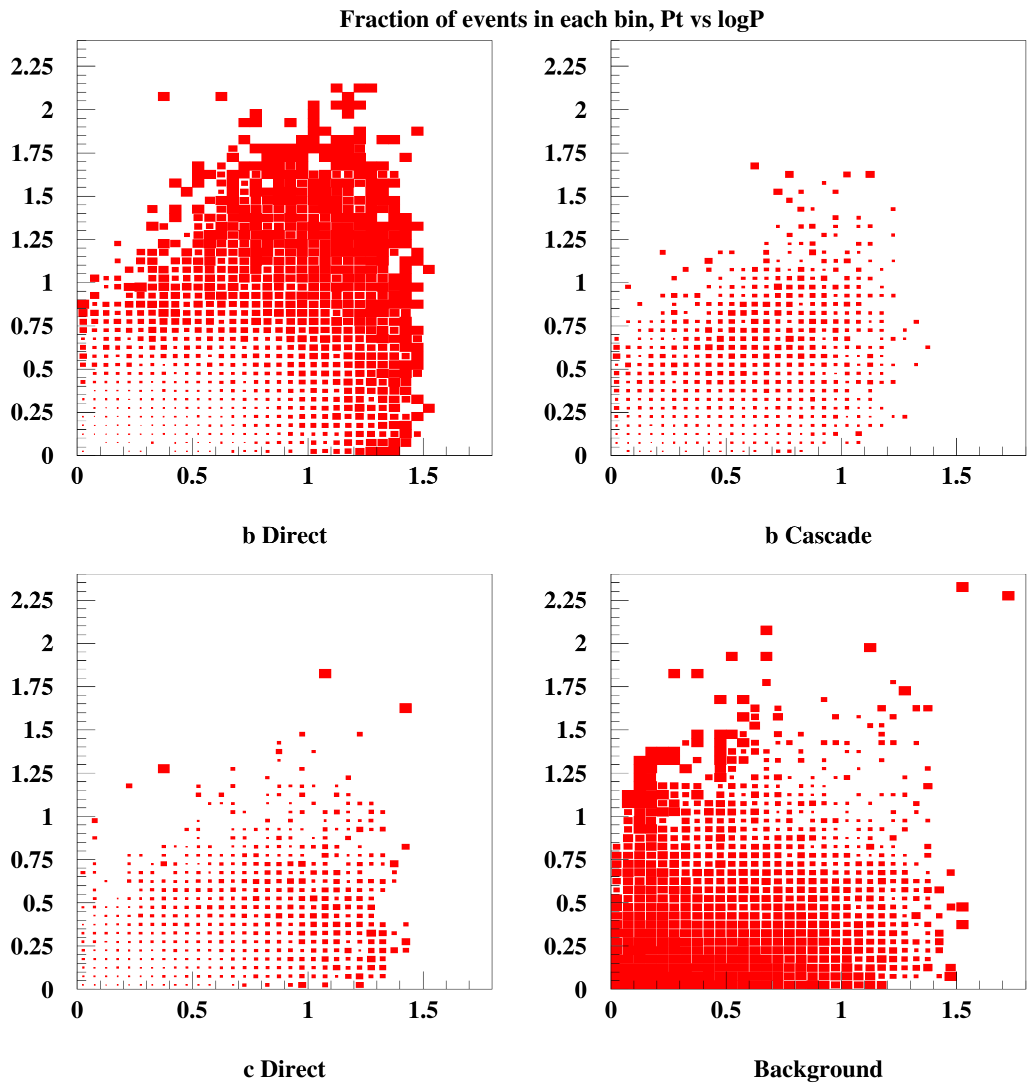
Kaon Tag A_b does not use a MaxLikelihood, but simply fits the $\cos\theta$ spectrum for Left and Right handed beams:



(The error is dominated by the $F(B^{-+}\text{->}K^{+-})$ systematic, which will improve soon.)

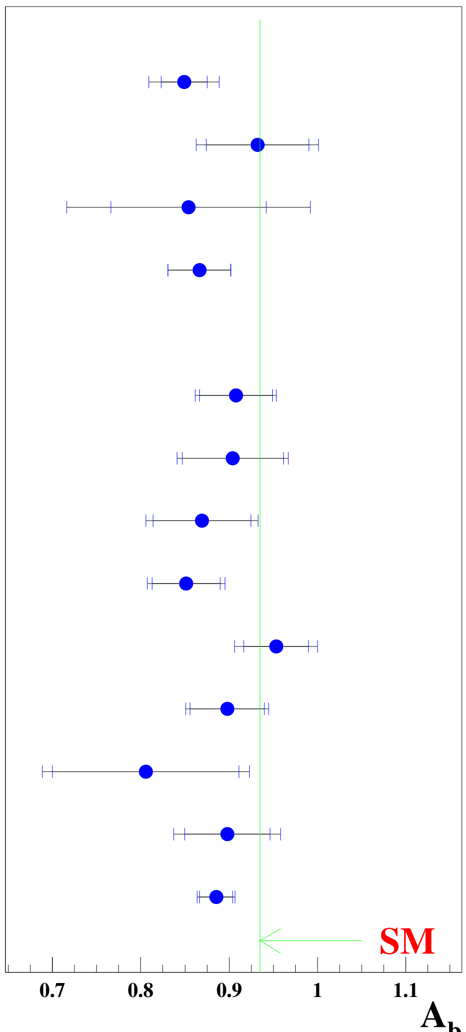
A_b (Lepton Tag)

3. Lepton Tag (e or μ) Both use CRID information when available. Events are classified as b direct, b cascade, c direct, and bkgrd by lepton momentum and momentum transverse to the associated jet. Electrons, e.g.:



A_b

A_b Measurements (Summer-98)



SLD JetC	$0.849 \pm 0.026 \pm 0.031$
SLD Lepton (New)	$0.932 \pm 0.058 \pm 0.038$
SLD $K^{\pm}$ tag (New)	$0.854 \pm 0.088 \pm 0.106$
SLD Average	0.866 ± 0.036
ALEPH Lept	$0.908 \pm 0.041 \pm 0.020$
DELPHI Lept	$0.904 \pm 0.057 \pm 0.026$
L3 Lept (New)	$0.869 \pm 0.055 \pm 0.030$
OPAL Lept	$0.851 \pm 0.038 \pm 0.021$
ALEPH JetC	$0.953 \pm 0.037 \pm 0.029$
DELPHI JetC	$0.898 \pm 0.042 \pm 0.021$
L3 JetC (New)	$0.806 \pm 0.106 \pm 0.051$
OPAL JetC	$0.898 \pm 0.0468 \pm 0.037$
LEP Average	0.885 ± 0.022

LEP Measurements: $A_b = 4\,A^{0,b}_{FB} / 3\,A_e$

Using A_e=0.1491±0.0018 (Combine SLD A_{LR} and LEP A_l)

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A_c

Three Methods --

1. Lepton Tag (above) -- The Lepton analysis does a simultaneous Maximum Likelihood fit for A_b, A_c
2. Inclusive Charm:
   - Charm Hemisphere Selection:

     $0.55 < M_{vtx} < 2$ GeV

     $P_{vtx} > 5$ GeV

     $P_{vtx} - 15M_{vtx} > -10$ GeV

     Vertex significance: $D/\sigma_D > 4$
   - Bottom Hemisphere Selection:

     $M_{vtx} > 2$ GeV

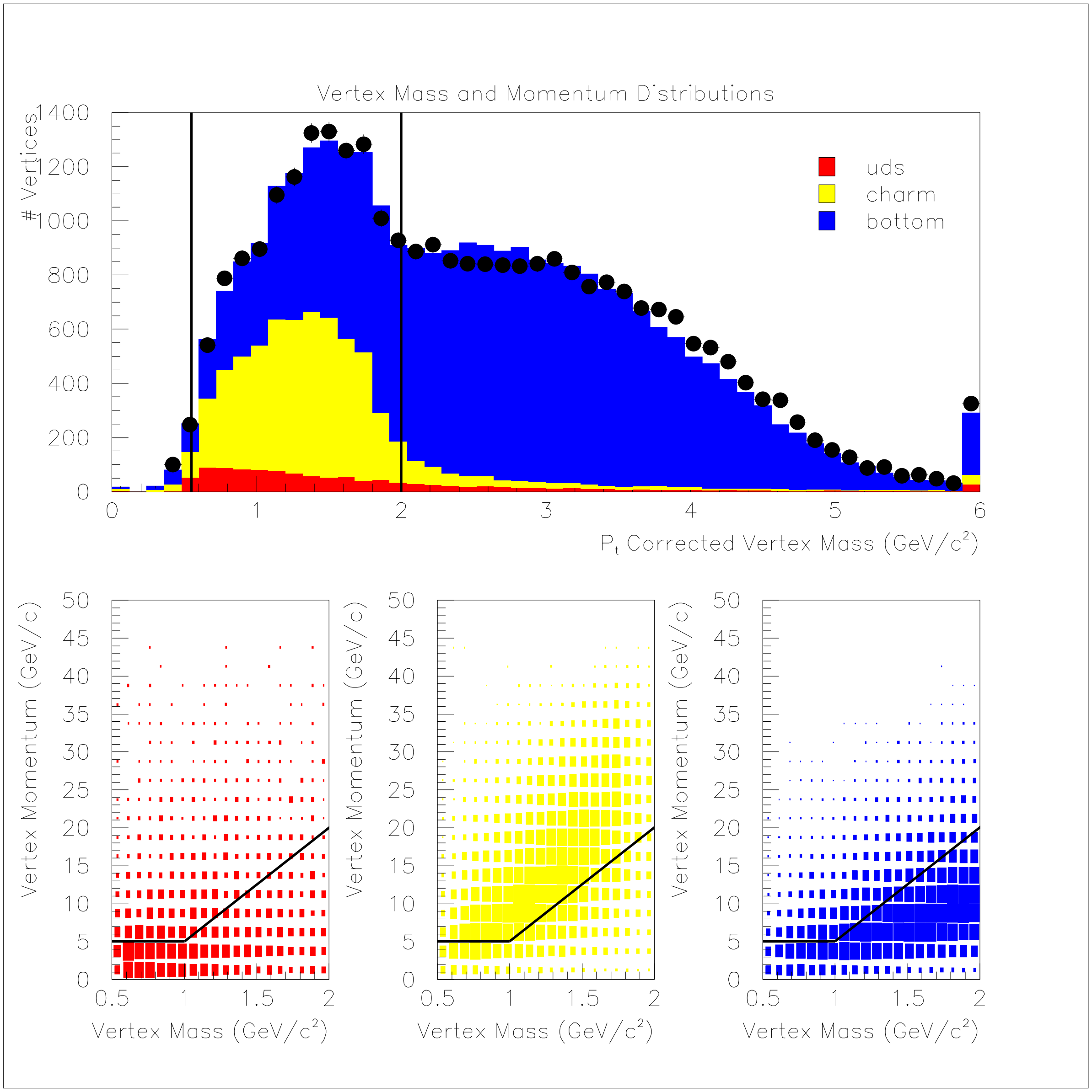
     $D/\sigma_D > 5$
   - Charm Event Selection:

     At least 1 hemisphere must pass charm selection

     Neither hemisphere can pass bottom selection
   - Quark charge is tagged by an attached kaon (~25%) or the charge of the vertex (~50%)

The charm and bottom tagging efficiencies can be calibrated by the single and double tag rates from the data.

A_c (Inclusive Charm Tag)



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A_c

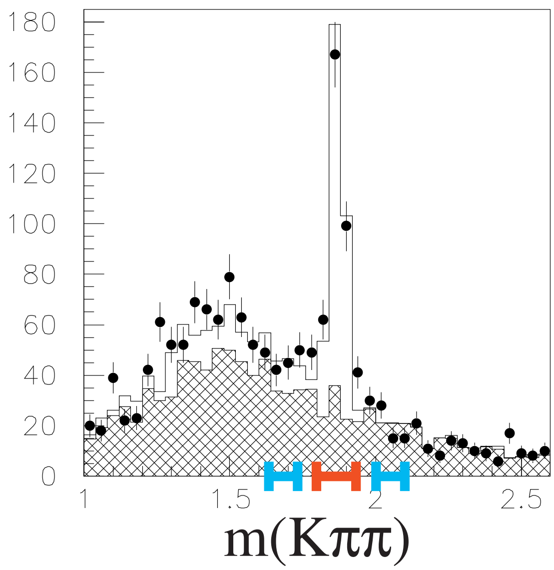
3. Exclusive Charm

- Reconstruct the charm sign in six modes:

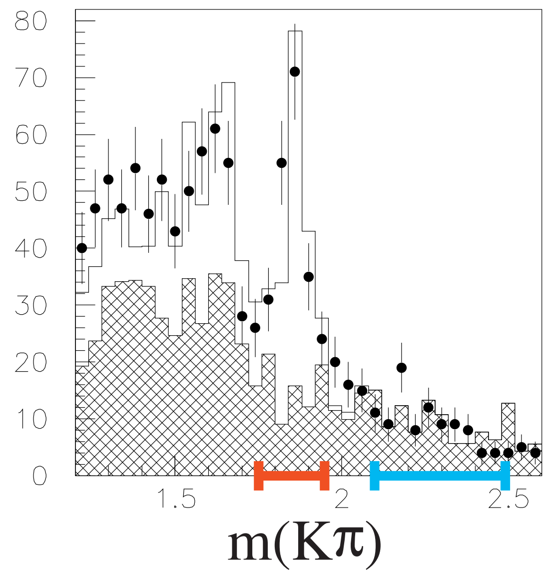
  1. $D^{*+} \to D^0 \pi^+ \quad (D^0 \to K^- \pi^+)$
  2. $D^{*+} \to D^0 \pi^+ \quad (D^0 \to K^- \pi^+ \pi^0)$
  3. $D^{*+} \to D^0 \pi^+ \quad (D^0 \to K^- \pi^+ \pi^+ \pi^-)$
  4. $D^{*+} \to D^0 \pi^+ \quad (D0 \to K^- l^+ \nu)$
  5. $D^+ \to K^- \pi^+ \pi^-$
  6. $D^0 \to K^- \pi^+$

- Reconstruction efficiency is low (~4%), but high analyzing power on the sign and direction of the underlying charm quark.

$D^+ \to K\pi\pi$

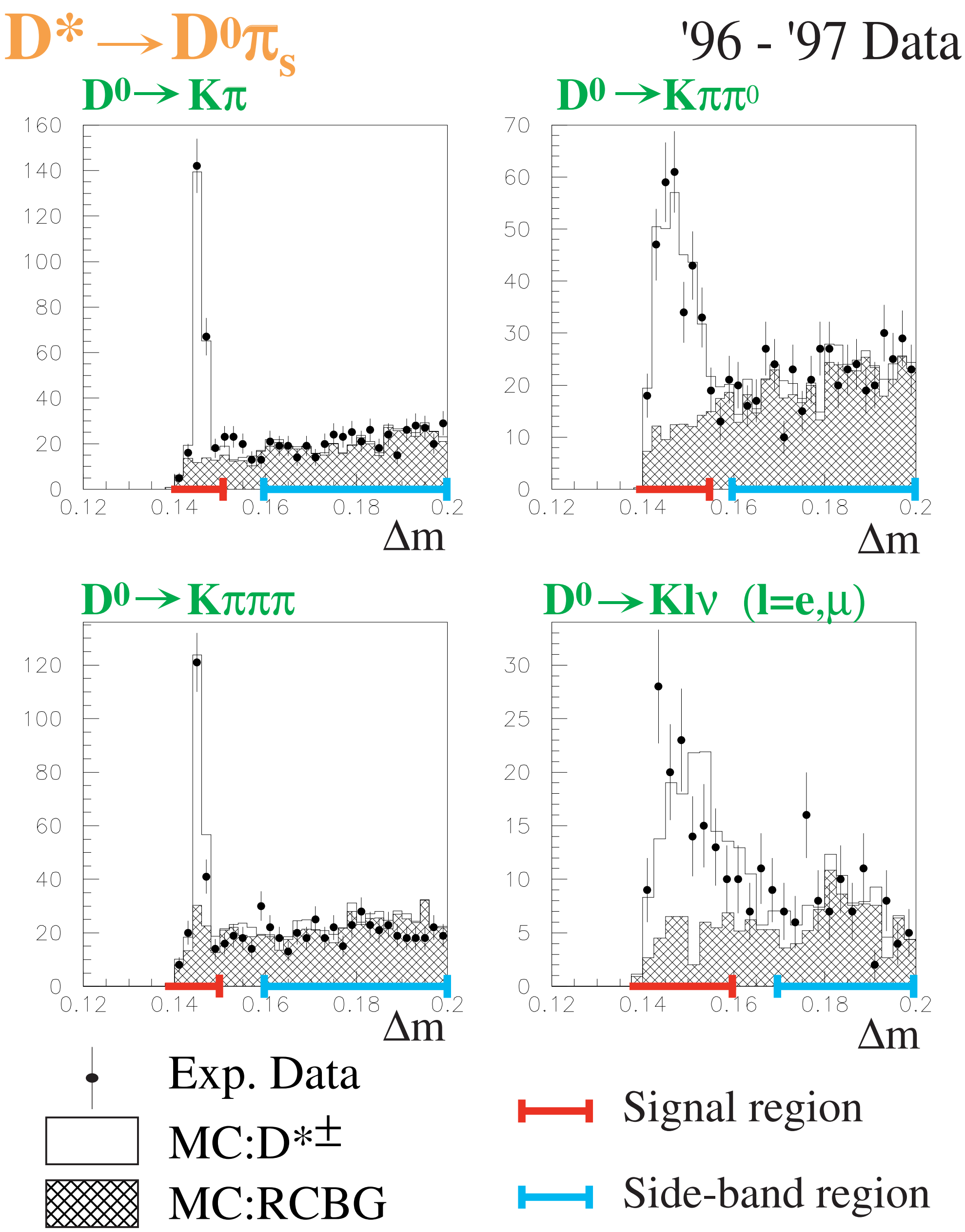


$D^0 \to K\pi$ (not from D^{*+})



A_c

Exclusive reconstruction of $D^{*\pm}/D^{\pm}/D^0$



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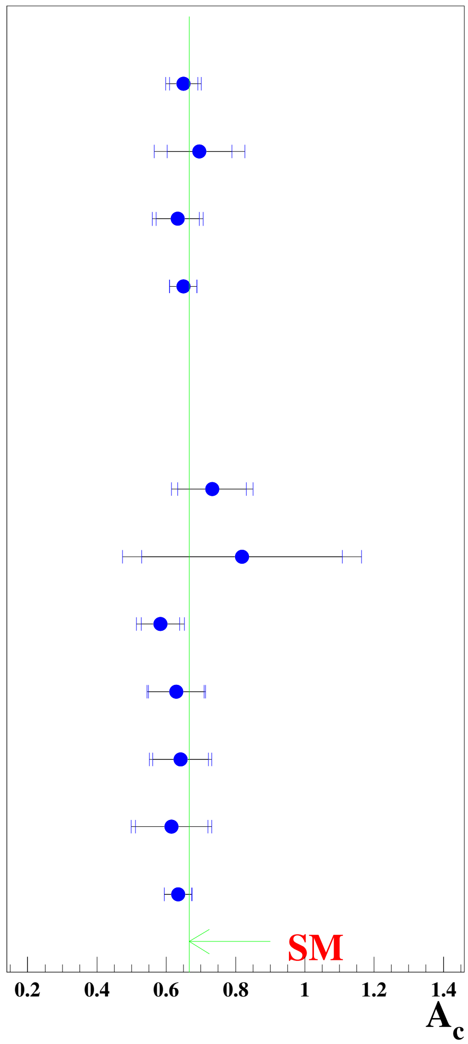
A_c

A_c Measurements (Summer-98)

SLD K & vtx-Q New	$0.65 \pm 0.04 \pm 0.03$
SLD Lepton New	$0.70 \pm 0.09 \pm 0.07$
SLD D^*, D^+	$0.63 \pm 0.06 \pm 0.04$
SLD Average	0.649 ± 0.040
DELPHI Lept New	$0.73 \pm 0.10 \pm 0.11$
L3 Lept	$0.82 \pm 0.29 \pm 0.19$
OPAL Lept	$0.58 \pm 0.06 \pm 0.04$
ALEPH D^*	$0.63 \pm 0.08 \pm 0.02$
DELPHI D^* New	$0.64 \pm 0.08 \pm 0.04$
OPAL D^*	$0.62 \pm 0.11 \pm 0.05$
LEP Average	0.634 ± 0.040



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Using A_e=0.1491±0.0018 (Combine SLD A_{LR} and LEP A_l)

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A_s

1. Strangeness Tag

- Select events with no detached vertices
- Tag fast strange particles

  K^{+-} with p > 9 GeV

  K^0_s and $\Lambda/\bar{\Lambda}$ with p > 5 GeV

- Require a tag in *both* hemispheres
- Require at least 1 signed tag (K^{+-}, $\Lambda/\bar{\Lambda}$). If both are signed, signs must be opposite. Use only the highest momentum strange particle in each hemisphere.

Mode	**Data**	**MC**	**Purity**	**Analyzing Power**
$K^+ K^-$	619	620	0.76	0.94
$K^+ \Lambda$, $K^- \bar{\Lambda}$	86	82	0.65	0.86
$\Lambda \bar{\Lambda}$	1	6	0.59	
$K^{+-} K^0_s$	502	531	0.64	0.58
ΛK^0_s, $\bar{\Lambda} K^0_s$	52	52	0.54	0.44
Total	**1260**	**1291**	**0.69**	**0.82**

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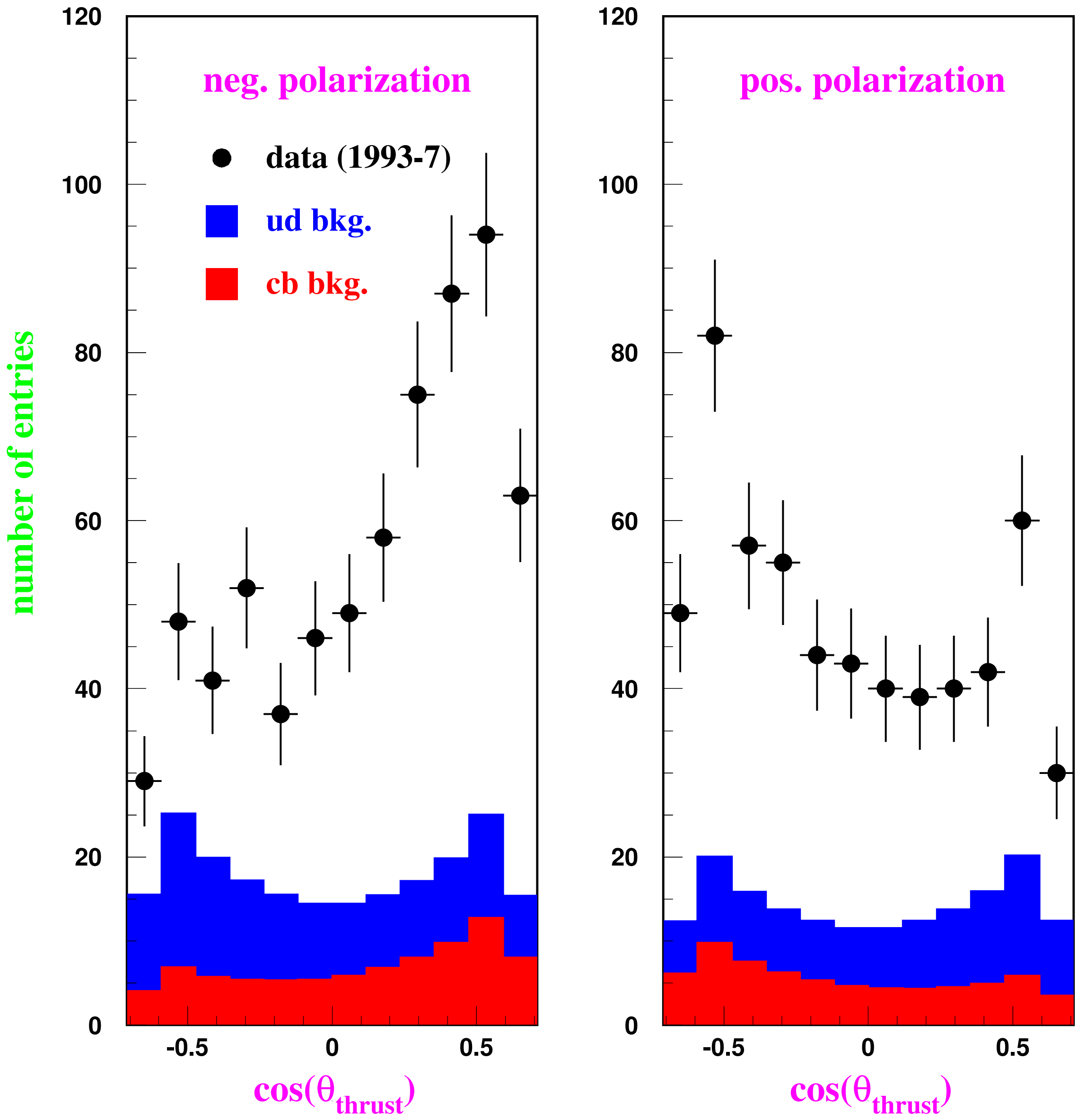
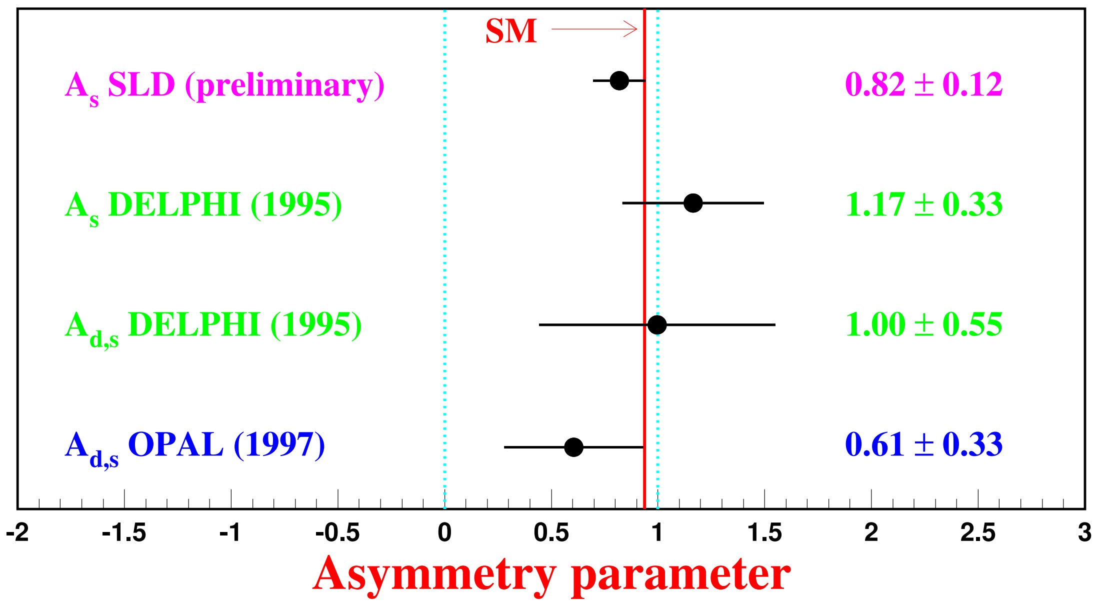
A_S



neg. polarization
pos. polarization
data (1993-7)
ud bkg.
cb bkg.
number of entries
120
100
80
60
40
20
0
-0.5
0
0.5
$\cos(\theta_{thrust})$

A_s



Leading Systematic Errors

Source	Comments	Variation	$\delta A_s / A_s$
s Analyzing Power	MC constrained by 3 K jets in data	0.82+-0.03	0.038
ud Analyzing Power	$a_s < a_{ud} < 0$	-0.41+-0.24	0.071
A_{ud}	Standard Model	-	
N_{ud} / N_s	MC constrained by 2 K jets in data	0.27+-0.03	0.037
All others			0.012
Total			**0.089**

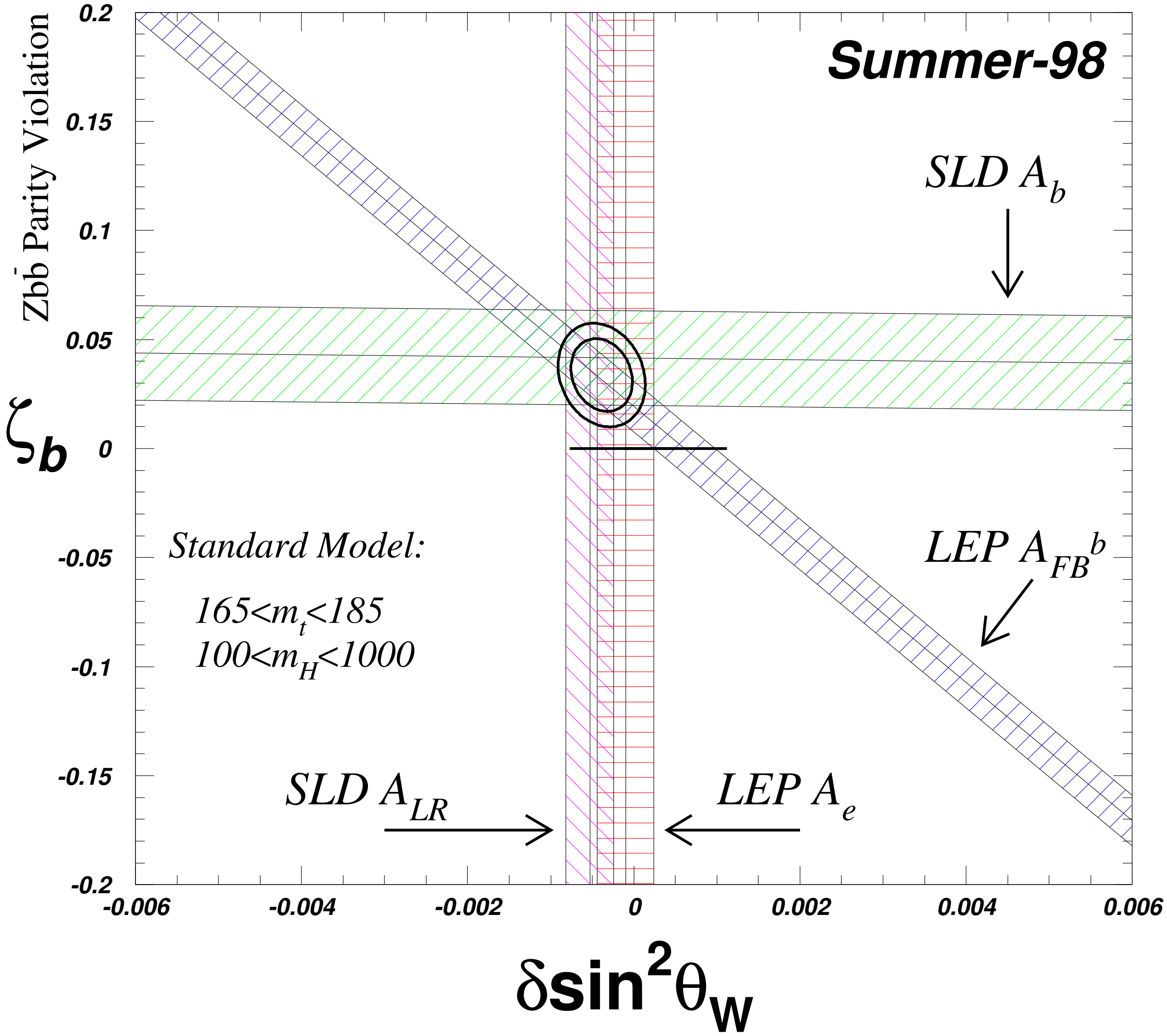
Final Notes

1. A_b converging to a lower than S.M. value?
2. A_s looks promising!
3. More Z^0 to be analyzed
   - Most analyses have at least 250K Z's ('98 data run) to go
   - New A_b analysis (vertex charge)
   - Lepton analyses incorporating vertex info to Likelihood fit
4. More Z^0 data to be recorded?
   - A 1 year run extension would result in an additional ~700K

The beam polarization and excellent vertexing at the SLD provide for a varied program of precise quark coupling asymmetry measurements.

A_b

After Takeuchi, Grant, and Rosner:



(0,0) determined by m_t=175, m_H=300,

α_s=0.117 α_{EM}=1/128.96