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Measurement of A_b and A_c from the Left-Right Forward-Backward Asymmetry of Leptons in Hadronic Events at the Z^0 Resonance *

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Abstract

The parity-violating parameters A_b and A_c are directly measured by the SLD experiment at the SLAC Linear Collider in e^+e^- collisions with polarized electrons at the Z^0 resonance. Leptons with distinctive total and transverse momenta are used to select and analyze $Z^0 \rightarrow b\bar{b}$ and $Z^0 \rightarrow c\bar{c}$ events. A_b and A_c are extracted by forming the left-right forward-backward asymmetry in electron beam polarization and quark polar angle. ¿From our 1993 sample of 1.8pb^{-1} of Z^0 decay data with an average electron beam polarization of 63% we find $A_b = 0.91 \pm 0.14$ (stat) $\pm$ 0.07 (syst) and $A_c = 0.37 \pm 0.23$ (stat) $\pm$ 0.21 (syst).

Measurements of fermion asymmetries at the Z^0 resonance probe a combination of the vector and axial vector couplings of the Z^0 to fermions, $A_f = 2v_f a_f/(v_f^2 + a_f^2)$. The parameters A_f express the extent of parity violation at the Zff vertex and provide sensitive tests of the Standard Model. The parameter A_b is particularly interesting theoretically, since it is sensitive at the 1% level to electroweak radiative corrections to the Zbb vertex but insensitive to propagator corrections which modify the weak mixing angle $\sin^2\theta_W$.

The Born-level differential cross section for the reaction $e^+e^- \rightarrow Z^0 \rightarrow f\bar{f}$ is

$$\sigma^f(z) \equiv d\sigma_f \,/\, dz \propto (1 - A_e P_e)(1 + z^2) + 2A_f(A_e - P_e)z\,, \tag{1}$$

where P_e is the longitudinal polarization of the electron beam ($P_e > 0$ for right-handed (R) polarization) and $z = \cos\theta$ is the direction of the outgoing fermion relative to the incident electron. The parameter A_f can be isolated by forming the left-right forward-backward asymmetry:

$$\tilde{A}^f_{FB}(z) = \frac{[\sigma^f_L(z) - \sigma^f_L(-z)] - [\sigma^f_R(z) - \sigma^f_R(-z)]}{[\sigma^f_L(z) + \sigma^f_L(-z)] + [\sigma^f_R(z) + \sigma^f_R(-z)]} \tag{2}$$

$$= |P_e| A_f \, 2z/(1 + z^2)\,. \tag{3}$$

In this analysis, we identify b-quarks and c-quarks through their decays into leptons. The lepton charge provides the quark-antiquark discrimination required to construct the left-right forward-backward asymmetry. Two complementary techniques are presented: (1) a simple asymmetry analysis extracts A_b from an enriched sample of $Z^0 \rightarrow b\bar{b}$ events obtained by selecting leptons with very high momentum and transverse momentum, and (2) a more sophisticated maximum likelihood analysis extracts both A_b and A_c from hadronic Z^0 decays containing leptons. In conjunction with a parallel analysis based on a momentum-weighted track charge technique [1], this result represents the first direct measurement of the magnitude of parity violation in $Z^0 \rightarrow b\bar{b}$ and $Z^0 \rightarrow c\bar{c}$ decays.

The operation of the SLAC Linear Collider with a polarized electron beam has been described in detail elsewhere [2]. During the 1993 run, the SLC Large Detector (SLD) recorded 1.8pb^{-1} of data at the Z^0 resonance with a luminosity-weighted electron beam polarization of $|P_e| = 0.63 \pm 0.01$.

Charged particle tracking and momentum analysis is provided by the Central Drift Chamber [3] and the CCD-based vertex detector [4], with combined momentum resolution $\delta p_\perp / p_\perp = \sqrt{(.01)^2 + (.0026\ p_\perp/GeV)^2}$ in the plane perpendicular to the beam axis.

The Liquid Argon Calorimeter (LAC) [5] measures the energies of charged and neutral particles and is also used for electron identification. The LAC is segmented into projective towers with separate electromagnetic and hadronic sections. In the barrel LAC, which covers the angular range $|\cos\theta| < 0.82$, the electromagnetic towers have transverse size $\sim (36 \text{ mrad})^2$ and are divided longitudinally into a front section of 6 radiation lengths and a back section of 15 radiation lengths. The barrel LAC electromagnetic energy resolution is $\sigma_E/E = 15\%/\sqrt{E(GeV)}$.

Muon tracking is provided by the Warm Iron Calorimeter (WIC) [6]. The WIC is 4 interaction lengths thick and surrounds the 2.8 + 0.7 interaction lengths of the LAC and SLD magnet coil. Sixteen layers of plastic streamer tubes interleaved with 2 inch thick plates of iron absorber provide muon hit resolutions of 0.4 cm and 2.0 cm in the azimuthal and axial directions respectively.

Events are selected by requiring at least 15 GeV of energy in the LAC and at least six tracks with $p_\perp > 250$ MeV. These requirements select a sample of 37,500 hadronic Z^0 events with negligible background.

Jets in Z^0 events are formed by combining calorimeter energy clusters according to the JADE algorithm [7] with parameter $y_{cut} = 0.005$. The jet axis closely approximates the b-quark direction in $Z^0 \rightarrow b\bar{b}$ events, with an angular resolution of ~ 30 mrad.

Electrons are identified by extrapolating tracks to the barrel LAC and comparing the energies in nearby calorimeter towers to the energy deposition expected for electromagnetic showers. Electron identification is attempted for tracks with $p > 2$ GeV in the angular range $|\cos\theta| < 0.72$. Cuts are made requiring electromagnetic energy consistent with track momentum $(-2\sigma < (E/p - 1) < 3\sigma)$, little or no hadronic energy leakage $(E_{HAD} < 0.25\,GeV)$, and a relatively large front/back electromagnetic energy ratio $(0.55 < (EM1\,sin\theta)/(EM1 + EM2) - .08\,ln(p) < 0.85)$. Electrons from photon conversions are identified and removed with 90% efficiency. Pion misidentification is less than 0.8% at low momentum, falls slowly with increasing momentum, and constitutes the most serious background in the electron sample. The electron identification efficiency depends strongly on track isolation, varying from roughly 50% for all electrons to 70% for the electrons with high momentum and transverse momentum used in the simple asymmetry analysis presented below.

Muons are identified by matching extrapolated tracks to hits in the WIC [8]. Muon identification is attempted for tracks with $p > 3$ GeV in the angular range $|\cos\theta| < 0.60$. The track error matrix, including the effects of multiple scattering, is used to make a comparison with the fitted muon track in the WIC. Full penetration of the WIC is required. With these requirements, pion punchthrough background is negligible. Muons from pion and kaon decays and hadronic showers are a significant background, but fall off rapidly with increasing momentum. The muon identification efficiency is 85% within the momentum and angular acceptance region.

A detailed Monte Carlo (MC) simulation of hadronic Z^0 decays is used to model the data. Z^0 decays are generated by the JETSET 6.3 program [9]. The B hadron decay model was tuned to reproduce existing data from other experiments. Semileptonic decays of B mesons are generated according to the ISGW formalism [10] with a 9% D^{**} fraction [11], while semileptonic decays of D mesons are generated according to the Mark III decay model [12]. Particularly important experimental constraints were provided by the $B \rightarrow D$ and $B \rightarrow lepton$ momentum spectra measured by CLEO [13], the $D \rightarrow lepton$ momentum spectrum measured by DELCO [14], and the $B \rightarrow hadron$ multiplicities measured by ARGUS [15].

The SLD detector response is simulated in detail using GEANT [16] and has been checked extensively against Z^0 data. A momentum-dependent efficiency correction of at most 4% was required to make the MC charged track multiplicity reproduce the data. In the electron analysis, the MC hadronic background was originally too large; agreement with the data was achieved by rescaling hadronic energies of early-showering pions by roughly -10% after the calorimeter simulation.

Distributions of lepton momentum (p) and transverse momentum (p_t) with respect to the nearest jet axis are shown in Fig. 1. The MC prediction for all lepton sources reproduces the data reasonably well. Leptons from b-quark decay clearly dominate at high p and p_t.

A direct method of measuring A_b is to observe the left-right forward-backward asymmetry in the angular distribution of a purified sample of $Z^0 \rightarrow b\bar{b}$ events containing leptons from semileptonic b decay with high p and high p_t. We perform this simple analysis in order to demonstrate the clear experimental asymmetry and to provide a crosscheck of the final result. An elliptical cut on p and p_t — $(p/18)^2 + (p_t/1.1)^2 > 1$ for muons and $(p/14)^2 + (p_t/1.0)^2 > 1$ for electrons — provides a sample of leptons predominantly from direct b decay. A total of 576 muons and 613 electrons are selected. The MC breakdown of the various sources contributing to the lepton sample is shown in table I. Roughly 70% of the selected leptons come from direct b-quark semileptonic decay.

The experimental left-right forward-backward asymmetry is calculated according to Eq. 2. The appropriate sign for each lepton in the asymmetry sum is determined by the beam polarization and the direction of the b-quark, which in turn is determined by the lepton charge and the direction of the jet nearest to the lepton, $z = \cos\theta_b = -Q\, \cos\theta_{jet}$. The experimental asymmetry is plotted in Fig. 2.

The parameter A_b is extracted from the experimental asymmetry by fitting the theoretical asymmetry function $\tilde{A}^b_{FB}(z)$ of Eq. 3 to the data, correcting for asymmetry dilution effects, and factoring out the luminosity-weighted beam polarization. The asymmetry dilution corrections are derived from the MC classification of lepton sources and their corresponding intrinsic asymmetries, detailed in table I. The result of the high (p, p_t) asymmetry analysis is $A_b(\text{muons}) = 1.04 \pm 0.22(\text{stat}) \pm 0.11(\text{syst})$ and $A_b(\text{electrons}) = 1.05 \pm 0.20(\text{stat}) \pm 0.13(\text{syst})$.

A maximum likelihood analysis of all hadronic Z^0 events containing leptons is used for the final determination of A_b and A_c. The likelihood function contains the following probability term for each lepton in the data:

$$P\,(p, p_t,\ P_e, z;\ A_b, A_c)\ \propto\ 1 + \left(\frac{A_e - P_e}{1 - A_e P_e}\right)\left(\frac{2z}{1+z^2}\right) \\ \times \left\{\ f_b\,(1-2\chi)\,[1+\Delta^b_{QCD}(z)]\,A_b\ +\ f_c\,[1+\Delta^c_{QCD}(z)]\,A_c\ +\ f_{bkg}\,A_{bkg}\ \right\}. \qquad (4)$$

The three signs governing the asymmetry — beam polarization P_e, lepton charge Q, and jet direction $\cos\theta$ — are incorporated automatically into the maximum likelihood probability function (recall $z = -Q\cos\theta$). The lepton source fractions (f_b, f_c, f_{bkg}) are derived by counting leptons in the MC with similar p and p_t to each lepton in the data. The f_b term combines direct and cascade b-quark decays, signed according to their asymmetry contributions. A correction factor $(1-2\chi)$ is applied to all b-quark lepton sources to account for asymmetry dilution due to $B^0\bar{B}^0$ mixing, with $\chi = .12$ taken from LEP measurements of the average mixing in $Z^0 \to b\bar{b}$ events [17]. The background asymmetry A_{bkg} is derived as a function of p and p_t from tracks in the data not identified as leptons. A QCD correction factor is applied to the theoretical asymmetry function to incorporate known QCD corrections to the cross section [18]. The QCD correction is as large as 5% at $z = 0$ and its inclusion decreases the asymmetry by 3% overall.

Systematic errors have been estimated for a number of sources, summarized in table II. Uncertainty in the jet axis simulation can affect the asymmetry measurement by distorting the lepton p_t spectrum. The accuracy of the $B^{\pm}$ and B^0 lepton spectra are directly related to the uncertainty in the D^{**} branching fraction reported by the CLEO collaboration [13].

The final maximum likelihood results are as follows:

$$
\begin{aligned}
\text{muons:} \quad & A_b = 0.92 \pm 0.20(\text{stat}) \pm 0.10(\text{syst}) \\
& A_c = 0.38 \pm 0.29(\text{stat}) \pm 0.18(\text{syst}) \\
\text{electrons:} \quad & A_b = 0.89 \pm 0.19(\text{stat}) \pm 0.12(\text{syst}) \\
& A_c = 0.35 \pm 0.36(\text{stat}) \pm 0.31(\text{syst}) \\
\text{combined:} \quad & A_b = 0.91 \pm 0.14(\text{stat}) \pm 0.07(\text{syst}) \\
& A_c = 0.37 \pm 0.23(\text{stat}) \pm 0.21(\text{syst}) \ .
\end{aligned}
$$

The combined final result takes into account the small statistical and large systematic correlations between the muon and electron analyses. The correlation between A_b and A_c is very small. The result for A_b is consistent with the high (p, p_t) asymmetry analysis after accounting for the statistical correlation between the analyses.

This result complements that of an independent analysis using a momentum-weighted track charge technique [1]. Taking into account small correlations between the two analyses yields a combined SLD measurement of $A_b = 0.89 \pm 0.09(\text{stat}) \pm 0.06(\text{syst})$.

Our results for A_b and A_c are in good agreement with the Standard Model predictions of $A_b = 0.94$ and $A_c = 0.67$ (for $\sin^2\theta_W^{eff} = 0.23$). The LEP experiments measure the forward-backward asymmetries $A_{FB}^f \propto A_e A_f$ [19] rather than the direct quark asymmetries A_f and obtain values also in agreement with the Standard Model, with relative errors on the order of 10% for $A_e A_b$ and 20% for $A_e A_c$.

FIGURES

FIG. 1. Distributions of momentum and transverse momentum with respect to the nearest jet axis for identified electrons and muons in the data (points), compared to the MC prediction (histograms) for various sources.

FIG. 2. Experimentally observed left-right forward-backward asymmetry $\tilde{A}^b_{FB}$ (data points with statistical errors); theoretical asymmetry function $|P_e|\, A_b\, 2z/(1+z^2)$ fit to data (solid curve).

TABLES

TABLE I. Composition of the high (p, p_t) lepton sample and corresponding contributions to the left-right forward-backward asymmetry.

Lepton Source	Muon fraction	Electron fraction	Asymmetry
direct $b \to l$	.73	.69	$(1-2\chi)A_b$
cascade $\bar{b} \to \bar{c} \to l$	.06	.07	$-(1-2\chi)A_b$
cascade $b \to \bar{c} \to l$	.01	.01	$(1-2\chi)A_b$
direct $\bar{c} \to l$	.07	.08	$-A_c$
$\gamma \to e^+e^-$	—	.02	0
hadron $\to l$	.02	.00	A_{bkg}
misidentified l	.11	.13	A_{bkg}

TABLE II. Systematic errors for the maximum likelihood analysis

Source	Parameter variation	$\delta A_b(\mu)$	$\delta A_b(e)$	$\delta A_c(\mu)$	$\delta A_c(e)$
Monte Carlo weights	f_b, f_c variation	.04	.08	.08	.18
Track efficiency	MC-data multiplicity match	.01	.02	.01	.01
Jet axis simulation	15 mrad smearing	.06	.05	.06	.13
Background level	$\pm 10\%$ variation	.02	.01	.03	.01
Background asymmetry	$\pm 50\%(\mu), \pm 100\%(e)$	.01	.01	.03	.09
BR($Z^0 \to b\bar{b}$)	$R_b = .220 \pm .003$	.01	.00	.00	.00
BR($Z^0 \to c\bar{c}$)	$R_c = .171 \pm .014$	.01	.00	.03	.03
$B^{\pm}, B^0$ lepton spectrum	BR $\pm$ 10% (D^{**})	.02	.05	.12	.14
B_s lepton spectrum	$D_s^{**} \pm 20\%$, Γ_{B_s}/Γ_B = 9–17%	.03	.02	.05	.05
Λ_b lepton spectrum	$\Gamma_{\Lambda_b}/\Gamma_B$ = 5–9%	.01	.01	.02	.03
D lepton spectrum	peak p = 0.4 – 0.6 GeV	.02	.02	.04	.10
Polarization	$< P_e >= .63 \pm .01$	.02	.02	.01	.01
Second order QCD	Δ_{QCD} uncertainty	.01	.01	.04	.04
B mixing χ	$\chi = .12 \pm .01$	.03	.03	.00	.00
Total		.10	.12	.18	.31

REFERENCES

[1] K. Abe *et al.*, SLAC-PUB-6644 (1994), submitted to Phys. Rev. Lett.

[2] K. Abe *et al.*, Phys. Rev. Lett. **73**, 25 (1994).

[3] M. Hildreth *et al.*, SLAC-PUB-6656 (1994), to be submitted to IEEE Trans. Nucl. Sci.

[4] G. Agnew *et al.*, SLAC-PUB-5906 (1992).

[5] D. Axen *et al.*, Nucl. Inst. Meth. **A328**, 472 (1993).

[6] A. Benvenuti *et al.*, Nucl. Inst. Meth. **A276**, 94 (1989); **A290**, 353 (1990).

[7] W. Bartel *et el.*, Z. Phys. **C33**, 23 (1986).

[8] D. Williams, Ph.D. Thesis, MIT, 72 (1994).

[9] T. Sjostrand, Comp. Phys. Comm. **43**, 367 (1987).

[10] N. Isgur, D. Scora, B. Grinstein, M. Wise, Phys. Rev. **D39**, 799 (1989); code provided by P. Kim and CLEO Collaboration.

[11] This D^{**} branching fraction is significantly lower than the CLEO measurement, but provides the best match in the SLD MC to the combined b and c lepton spectrum measured by CLEO.

[12] J. Adler *et al.*, Phys. Rev. Lett. **62**, 1821 (1989).

[13] D. Bortoletto *et al.*, Phys. Rev. **D45**, 21 (1992); S. Henderson *et al.*, Phys. Rev. **D45**, 2212 (1992); M. Thulasidas, Ph.D. Thesis, Syracuse (1993).

[14] W. Bacino *et al.*, Phys. Rev. Lett. **43**, 1073 (1979).

[15] H. Albrecht *et al.*, Z Phys. **C58**, 191 (1993).

[16] GEANT 3.15 program, CERN Applications Software Group, CERN Program Library (1993).

[17] D. Abbaneo, Rencontres de Moriond, Meribel, March 1994, published as report INFN PI/AE 94/05.

[18] A. Djouadi, J. Kühn, and P. Zerwas, Z. Phys **C46**, 411 (1990); G. Altarelli and B. Lampe, Nucl. Phys. **391**, 3 (1993); J.B. Shav and H.A. Olsen, private communication.

[19] ALEPH Collab., Z Phys. **C62**, 179 (1994); DELPHI Collab., Phys. Lett. **B276**, 536 (1992); OPAL Collab., Z. Phys. **C60**, 19 (1993); L3 Collab., Phys. Lett. **B292**, 434 (1992).

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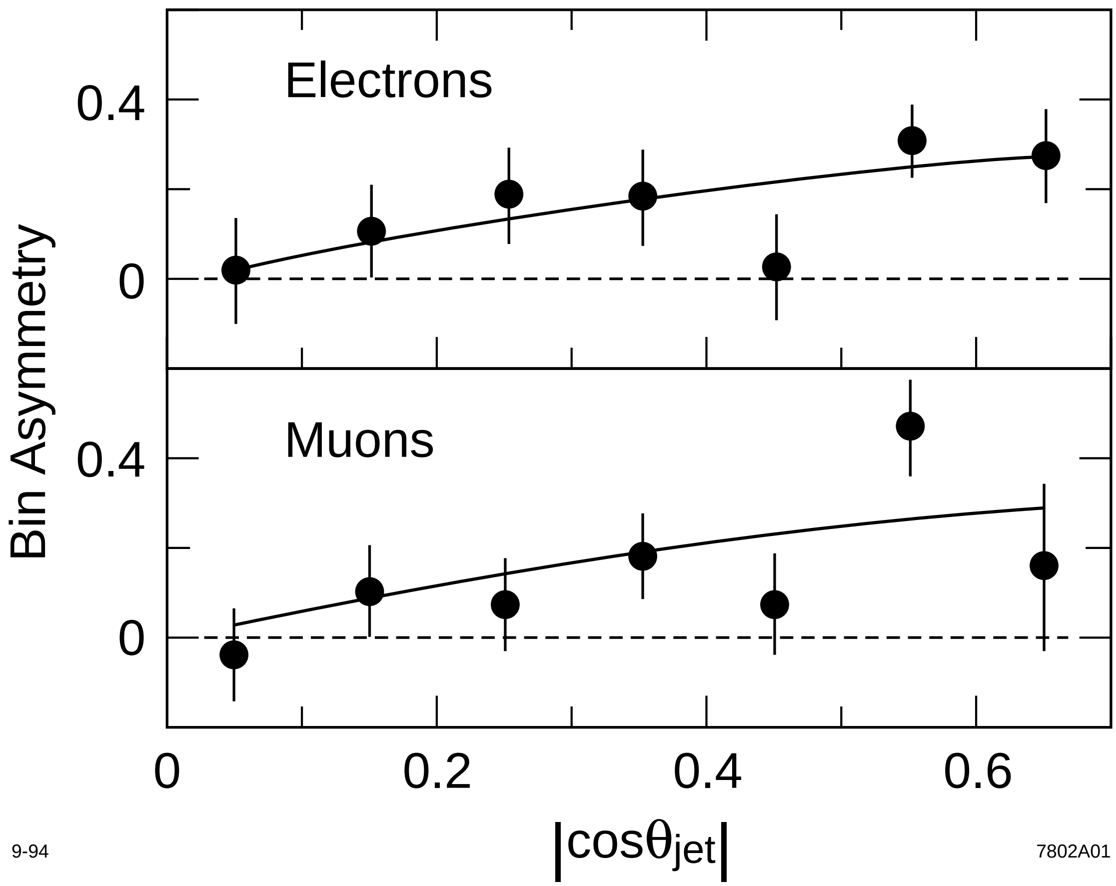
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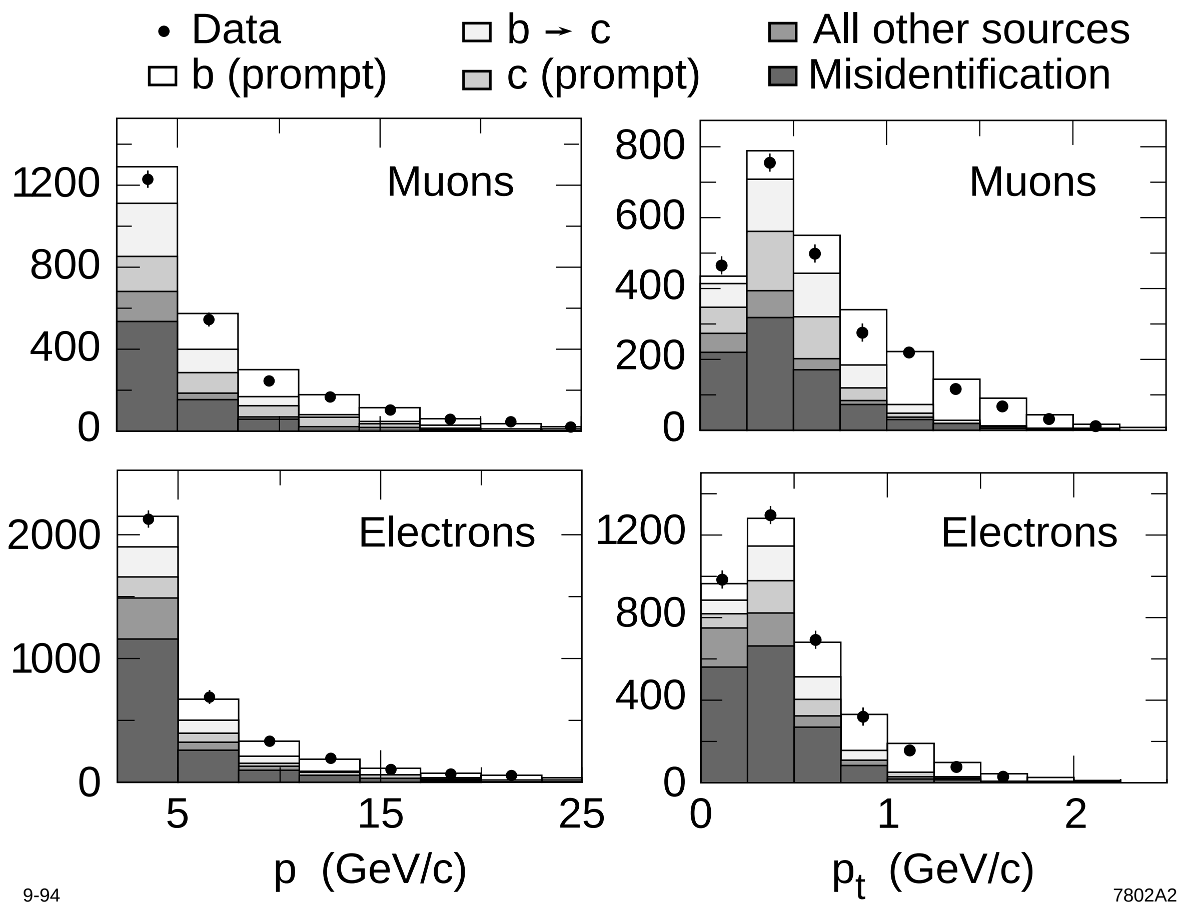
Figure 1



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Misidentification
Muons
Muons
Electrons
Electrons
1200
800
400
0
800
600
400
200
0
2000
1000
0
1200
800
400
0
5
15
25
0
1
2
p (GeV/c)
p_t (GeV/c)
9-94
7802A2

Figure 2