0/5-96 ✓S(1)

SLAC-PUB-6924
June 1995
CONF-950705--46

Measurement of the Charged Multiplicities of b, c and Light Quark Events from Z^0 Decays*

The SLD Collaboration**
Stanford Linear Accelerator Center
Stanford University, Stanford, CA 94309

ABSTRACT

Average charged multiplicities have been measured separately for b, c and light quark (u, d, s) events from Z^0 decays at SLD. Impact parameters of charged tracks were used to select enriched samples of b and light quark events, and reconstructed charmed mesons were used to select c quark events. We measured the charged multiplicities: $\overline{n}_{uds} = 19.80 \pm 0.09$ (stat.) $\pm$ 0.57 (syst.), $\overline{n}_c = 21.17 \pm 0.44$ (stat.) $\pm$ 1.01 (syst.) and $\overline{n}_b = 23.14 \pm 0.09$ (stat.) $\pm$ 1.03 (syst.) (PRELIMINARY), from which we derived the differences between the total average charged multiplicities of c or b quark events and light quark events: $\delta\overline{n}_c = 1.37 \pm 0.45$ (stat.)$\pm$0.86 (syst.) and $\delta\overline{n}_b = 3.34 \pm 0.13$ (stat.)$\pm$ 0.77 (syst.) (PRELIMINARY). We compared these measurements with those at lower center-of-mass energies and with QCD predictions.

Contributed to the International Europhysics Conference on High Energy Physics (HEP 95), Brussels, Belgium, July 27 - August 2, 1995

*This work was supported by Department of Energy contracts: DE-FG02-91ER40676 (BU), DE-FG03-92ER40701 (CIT), DE-FG03-91ER40618 (UCSB), DE-FG03-92ER40689 (UCSC), DE-FG03-93ER40788 (CSU), DE-FG02-91ER40672 (Colorado), DE-FG02-91ER40677 (Illinois), DE-AC03-76SF00098 (LBL), DE-FG02-92ER40715 (Massachusetts), DE-AC02-76ER03069 (MIT), DE-FG06-85ER40224 (Oregon), DE-AC03-76SF00515 (SLAC), DE-FG05-91ER40627 (Tennessee), DE-AC02-76ER00881 (Wisconsin), DE-FG02-92ER40704 (Yale); National Science Foundation grants: PHY-91-13428 (UCSC), PHY-89-21320 (Columbia), PHY-92-04239 (Cincinnati), PHY-88-17930 (Rutgers), PHY-88-19316 (Vanderbilt), PHY-92-03212 (Washington); the UK Science and Engineering Research Council (Brunel and RAL); the Istituto Nazionale di Fisica Nucleare of Italy (Bologna, Ferrara, Frascati, Pisa, Padova, Perugia); and the Japan-US Cooperative Research Project on High Energy Physics (Nagoya, Tohoku).

1 Introduction

Studies of heavy quark (Q=c,b) systems provide important tests of the theory of strong interactions, quantum chromodynamics (QCD). A large quark mass $M_Q \gg \Lambda_{QCD}$, where Λ_{QCD} is the QCD interaction scale, provide a natural cutoff in the parton shower evolution. This cutoff keeps the relevant space-time region compact enough to avoid the non-perturbative domain of the strong interaction. On the Z^0 resonance, where the center-of-mass energy $E_{CM} \gg M_Q \gg \Lambda_{QCD}$, one can expect a good description of many inclusive properties of hadronic jets by perturbative QCD. The difference in average charged multiplicity ($\delta\overline{n}_Q$) between heavy quark and light quark (u,d,s) events is particularly interesting. Within the context of perturbative QCD in the modified leading logarithm approximation (MLLA) [1, 2], the emission of gluons from quarks is suppressed in the forward direction $\Theta < \Theta_0 = M_Q/E_Q$. This region of suppressed radiation is known as the "dead cone" [2]. Further invoking the hypothesis of local parton hadron duality (LPHD) [3], this effect is then expected to manifest itself in a suppression of particle production accompanying the leading heavy hadron. In particular, it is expected that the difference between the average charged multiplicity in light quark events and the average charged multiplicity of non-leading hadrons in heavy quark events should be independent of center-of-mass energy. A test of this hypothesis provides the opportunity to verify an accurate prediction of perturbative QCD, and to probe the validity of perturbative calculations down to the scale M_Q^2. Furthermore, MLLA QCD + LPHD predicts $\delta\overline{n}_c \equiv \overline{n}_c - \overline{n}_{uds} = 1.7 \pm 0.5$ and $\delta\overline{n}_b \equiv \overline{n}_b - \overline{n}_{uds} = 5.5 \pm 0.8$, independent of center-of-mass energy [2]. Recently, in an alternative approach, Petrov and Kisselev have evaluated these quantities at the Z^0 energy and found $\delta\overline{n}_c = 1.01$ and $\delta\overline{n}_b = 3.68$ assuming M_c=1.5 GeV/c^2 and M_b=4.8 GeV/c^2 [4].

We reported the results of our measurement of the charged multiplicity of $Z^0 \to b\bar{b}$ events in [5], which were based on the sample of approximately 10,000 hadronic Z^0 decays collected by the SLD experiment in 1992. Here we present an improved measurement of the charged multiplicity of $b\bar{b}$ events, and new measurements for $c\bar{c}$ and

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

light quark ($u\bar{u}$, $c\bar{c}$ and $s\bar{s}$) events, based upon the sample of approximately 160,000 hadronic Z^0 decays collected between 1992 and 1995. All results in this paper are preliminary.

2 Apparatus and Hadronic Event Selection

The e^+e^- annihilation events produced at the Z^0 resonance by the SLAC Linear Collider (SLC) have been recorded using the SLC Large Detector (SLD). A general description of the SLD can be found elsewhere [6]. The trigger and selection criteria for isolating Z^0 boson decays are described elsewhere [7].

The analysis presented here used the charged tracks measured in the central drift chamber (CDC) [8] and in the vertex detector (VXD) [9]. A set of cuts was applied to the data to select well-measured tracks, which were used for multiplicity counting, and events well-contained within the detector acceptance. The well-measured charged tracks were required to have (i) a closest approach transverse to the beam axis within 5 cm, and within 10 cm along the axis from the measured interaction point; (ii) a polar angle θ with respect to the beam axis within $|\cos\theta| < 0.80$; and (iii) a momentum transverse to the beam axis $p_\perp > 0.15$ GeV/c. Events were required to have (i) a minimum of seven such tracks; (ii) a thrust axis [10] direction within $|\cos\theta_T| < 0.71$; and (iii) a total visible energy E_{vis} of at least 20 GeV, which was calculated from the selected tracks assigned the charged pion mass; 114,499 events passed these cuts. The background in the selected event sample was estimated to be $0.1 \pm 0.1\%$, dominated by $Z^0 \rightarrow \tau^+\tau^-$ events.

While the multiplicity measurement relied primarily on information from the CDC, the additional information from the VXD provided the more accurate impact parameter measurement and D meson tagging for selecting samples enriched in light (u,d,s) and b events, and c events, respectively. In addition to the requirements for well-measured tracks, "impact parameter quality" tracks were required to have (i) at least one VXD hit; (ii) a closest approach transverse the beam axis within 0.3 cm, and within 1.5 cm along the axis from the measured interaction point; (iii) at least 40 CDC hits, with the first hit at a radius less than 39 cm; (iv) an error on the xy impact parameter less than 250 μm; (v) a fit quality of the CDC track $\chi^2/d.o.f < 5$; and (vi) a fit quality of the combined CDC+VXD track $\chi^2/d.o.f < 5$. We also removed tracks from candidate K_s^0 and Λ decays and γ-conversions found by kinematic reconstruction of two-track vertices.

All impact parameters used in this analysis were for tracks projected into the plane perpendicular to the beam axis, and were measured with respect to an average primary vertex. The average primary vertex was derived from fits to ~30 sequential hadronic events close in time to the event under study, with a measured precision of $\sigma_{PV} = (7 \pm 2)\mu$m. The impact parameter δ was derived by applying a sign to the distance of closest approach such that δ is positive when the vector from the primary vertex to the point at which the track intersects the thrust axis makes an acute angle with respect to the track direction. Including the uncertainty on the average primary vertex the measured impact parameter uncertainty σ_δ for the overall tracking system approaches 11 μm for high momentum tracks, and is 76 μm at $p_\perp\sqrt{\sin\theta}$=1 GeV/c.

3 Selection of Flavor-Tagged Samples

We divided each event into two hemispheres separated by the plane perpendicular to the thrust axis. We then applied three flavor tagging techniques to each hemisphere. In order to reduce potential tagging bias we measured the average charged multiplicity in hemispheres opposite to those tagged. Impact parameters of charged tracks were used to select enriched samples of b or light quark hemispheres, and reconstructed charmed mesons were used to select c quark hemispheres, where charge-conjugate states are also implied.

In each hemisphere we counted the number of "impact parameter quality" tracks

		no tag	*uds*-tag	*c*-tag	*b*-tag
# tagged hem.		216,472	156,200	1,224	8,545
fractional composition	*uds*	0.607	0.748	0.073	0.012
	c	0.172	0.159	0.584	0.046
	b	0.221	0.093	0.343	0.942

Table 1. Number of tagged hemispheres and fractional compositions of *uds*, *c* and *b* quarks in the tagged hemispheres.

n_{sig} which have an impact parameter significance of $\delta_{norm} = \delta/\sigma_\delta > 3.0$. Figure 1 shows the distribution of n_{sig} upon which is superimposed a Monte Carlo sample in which the flavor composition is shown. For our Monte Carlo study we used JETSET 7.4 [11] with parameter values tuned to hadronic e^+e^- annihilation data [12], combined with a simulation of B-decays tuned to Υ(4s) data, and a simulation of the SLD. A more detailed discussion of flavor tagging can be found in [13, 14]. The Monte Carlo simulation reproduces the data well and shows that most light quark hemispheres have n_{sig}=0 and that the $n_{sig} \geq 2$ region is dominated by b quark hemispheres. Hemispheres were tagged as light or b quark by requiring $n_{sig} = 0$ or $n_{sig} \geq 3$, respectively. Table 1 shows the number of light and b quark tagged hemispheres and flavor compositions estimated from the simulation for each tagged sample.

The impact parameter method does not provide a high-purity sample of c quark events. For this purpose we required at least one prompt D^{*+} or D^+ meson[1] reconstructed in a hemisphere. This tag is described in detail in [15]. The D^{*+} mesons were identified using the decay $D^{*+} \to \pi_s^+ D^0$, where π_s^+ is a low-momentum pion and the D^0 decays via $D^0 \to K^-\pi^+$ ("three-prong"), $D^0 \to K^-\pi^+\pi^0$ ("satellite"), or $D^0 \to K^-\pi^+\pi^+\pi^-$ ("five-prong") modes. The D^+ mesons were indentified using the decay mode $D^+ \to K^-\pi^+\pi^+$. D meson candidates were formed from all conbinations of well-measured tracks with at least one VXD hit.

D^0 candidates were formed by combining two (for "three-prong" or "satellite"

[1]Charge-conjugate cases are always implied.

modes) or four (for "five-prong" mode) charged tracks with zero net charge, and by assigning the K^- mass to one of the particles and π^+ mass to the others. All tracks forming D^0 candidates were required to have p >1 GeV/c.

We required (i) the mass of the candidate D^0 to be in one of the ranges 1.765 GeV/c^2 < $M_{D^0}^{cand.}$ <1.965 GeV/c^2 ("three-prong"), 1.815 GeV/c^2 < $M_{D^0}^{cand.}$ <1.915 GeV/c^2 ("five-prong"), or 1.500 GeV/c^2 < $M_{D^0}^{cand.}$ <1.700 GeV/c^2 ("satellite"), (ii) $|\cos\theta^*| < 0.9$, where θ^* is the angle between the direction of the D^0 in the laboratory frame and the K^- in the D^0 rest frame, (iii) a mass difference $\Delta M = M_{D^*}^{cand} - M_{D^0}^{cand}$ <0.15 GeV/c^2, and (iv) a χ^2 probability>1% for a constrained vertex fit to the D^0 tracks for the "five-prong" mode.

D^* candidates were required to pass either a set of kinematic cuts or a set of decay length cuts to suppress combinatorial backgrounds and backgrounds from $B \to D^*$ decays. The kinematic cuts are: (i) $p_{\pi_s^+}$ >1 GeV, and (ii) $x_{E_{D^*}}$ >0.4 for the "three-prong" mode and $x_{E_{D^*}}$ >0.5 for the "five-prong" mode, where $x_{E_{D^*}} = 2E_{D^*}/E_{CM}$ and E_{D^*} is the D^* energy. The decay length cuts are: (i) χ^2 probabilities>1% for a constrained vertex fit to the D^0 tracks, (ii) a decay length significance L/σ_L >2.5, (iii) the two-dimensional impact parameter of the D^0 momentum vector to the interaction point <20μm, and (iv) $x_{E_{D^*}}$ >0.2.

Figures 2 a), b) and c) show ΔM for the three decay modes, upon which is superimposed the Monte Carlo sample in which the flavor composition is shown [2].

$D^+ \to K^-\pi^+\pi^+$ candidates were formed by combining two tracks of the same sign with one track of the opposite sign, where all three tracks were required to have p >1 GeV/c. The two like-sign tracks were assigned π^+ masses and the opposite sign track was given the K^- mass. A series of cuts was applied to reject background. We required (i) $x_{D^+} > 0.4$, (ii) $\cos\theta^* > -0.8$, (iii) the mass differences between $M(K^-\pi^+\pi^+)$ and $M(K^-\pi^+)$ were formed for each of the two pions and were required to be greater than

[2]In the Monte Carlo simulation the rates of the $D^0 \to K\pi$ and $D^0 \to K\pi\pi^0$ modes were adjusted to match the data in Fig. 2. The uncertainties on these rates were included in the systematic errors.

0.16 GeV/c^2, (iv) $L/\sigma_L > 3.0$ for the D^+ decay length, and (v) the angle between the D^+ momentum vector and the vertex flight direction to be less than 5 mrad in xy and less than 20 mrad in rz. After all selection criteria, $D^+ \to K^-\pi^+\pi^+$ candidates fall in the mass range 1.800 GeV/c^2 < $M(K^-\pi^+\pi^+)$ <1.940 GeV/c^2. Figure 2 d) shows the mass $M(K^-\pi^+\pi^+)$ distribution of the data upon which is superimposed the Monte Carlo sample in which the flavor composition is shown.

The union of the three samples of D^{*+} candidates and the sample of D^+ candidates was used to tag c quark hemispheres. The flavor composition of these tagged hemispheres is shown in Table 1.

4 Measurement of Charged Multiplicities

Well-measured charged tracks defined in section 2 were counted in the hemispheres opposite to those tagged. Figure 3 shows the distributions of measured hemisphere multiplicities m_i for a) light-, b) c- and c) b- tagged samples, compared with the corresponding Monte Carlo samples selected by the same criteria. The measured average hemisphere multiplicities $\overline{m}_i$ were found to be $\overline{m}_{uds} = 9.30 \pm 0.01$, $\overline{m}_c = 9.54 \pm 0.10$ and $\overline{m}_b = 10.28 \pm 0.04$ (statistical errors only).

The $\overline{m}_i$ are related to the true average hemisphere multiplicities $\overline{n}_i$ of uds, c and b quark events,

$$\overline{m}_i = P_{i,uds}C_{i,uds}\overline{n}_{uds} + P_{i,c}(C^{dk}_{i,c}\overline{n}^{dk}_c + C^{nl}_{i,c}\overline{n}^{nl}_c) + P_{i,b}(C^{dk}_{i,b}\overline{n}^{dk}_b + C^{nl}_{i,b}\overline{n}^{nl}_b) \qquad (1)$$
$$i = uds, c, b$$

where: $P_{i,j}$ is the fraction of quark type j in the i-tagged hemispheres; $C_{i,uds}$ is the ratio of the average number of measured charged tracks in light quark hemispheres opposite i-tagged hemispheres, to the average number of charged tracks in true light quark hemispheres; $C^{dk}_{i,j}$ ($j \neq uds$) is the ratio of the average number of measured charged tracks originating from the decay products of j-hadrons in hemispheres opposite to i-tagged hemispheres, to the average number of tracks originating from the decay products of

j-hadrons; $C^{nl}_{i,j}$ ($j \neq uds$) is the ratio of the average number of measured charged tracks originating from the non-leading particles in j-quark hemispheres opposite to i-tagged hemispheres, to the average number of tracks originating from non-leading particles in true j-quark hemispheres. The constants C were estimated from the Monte Carlo simulations and account for the effects of detector acceptance and inefficiencies, and for biases introduced by the event and tagged-sample selection criteria. The constants P were taken from Table 1. We have included in the generated multiplicity any prompt charged track with mean lifetime greater than 3×10^{-10}s, or any charged decay product with mean lifetime greater than 3×10^{-10}s of a particle with mean lifetime less than 3×10^{-10}s. For c and b quarks we separated $\overline{n}_i$ and C into *decay* and *non − leading* components. We fixed $\overline{n}^{dk}_c = 2.60 \pm 0.13$ and $\overline{n}^{dk}_b = 5.55 \pm 0.18$, using the measured values from [16, 17, 18], with an additional 0.10±0.10 and 0.11±0.11 tracks to account for the effects of higher mass states of heavy hadrons estimated from the Monte Carlo simulation.

Because of the exclusion of tracks with very low momentum or large $|\cos\theta|$, the constants $C_{i,j}$, $C^{nl}_{i,j}$ and $C^{dk}_{i,j}$ are dependent on the model used to generate Monte Carlo events. The fraction of tracks satisfying the "well-measured" criteria was found to be different between data and Monte Carlo. This is primarily due to a simplified simulation of the dependence of the CDC hit efficiency and resolution. The Monte Carlo was corrected to yield the proper fraction of charged tracks by randomly removing 2.9% of the tracks. The dependence of the correction on track $p_\perp$, $\cos\theta$, azimuthal angle and the angle with respect to the jet direction, was found to be small [14]. The resulting values for the constants C are listed in Table 2.

By solving eqns.(1) we obtained the average hemisphere charged multiplicities, $\overline{n}_{uds} = 9.90 \pm 0.05$, $\overline{n}^{nl}_c = 7.98 \pm 0.22$ and $\overline{n}^{nl}_b = 6.02 \pm 0.05$. Adding $\overline{n}^{dk}_c$ and $\overline{n}^{dk}_b$ to $\overline{n}^{nl}_c$ and $\overline{n}^{nl}_b$, respectively, and multiplying by two gives $\overline{n}_{uds} = 19.80 \pm 0.09$, $\overline{n}_c = 21.17 \pm 0.44$ and $\overline{n}_b = 23.14 \pm 0.09$, for uds, c and b events, respectively, where the errors are statistical only. Taking into account the fact that errors are correlated, the

j	*uds*	*c*		*b*	
i		*dk*	*nl*	*dk*	*nl*
uds	0.926	0.944	0.875	0.826	0.926
c	0.883	0.985	0.856	0.860	0.872
b	0.926	0.978	0.858	0.852	0.941

Table 2. The constants C estimated from the Monte Carlo simulation.

multiplicity differences between c and light quark events, and b and light quark events are, respectively

$$\delta\overline{n}_c = 1.37 \pm 0.45 \text{ (stat.)}$$
$$\delta\overline{n}_b = 3.34 \pm 0.13 \text{ (stat.)}$$

5 Systematic Errors

Systematic uncertainties from various sources have been estimated and are summarized in Tables 3 and 4. The experimental systematic errors arise from uncertainties in modelling the acceptance, efficiency and resolution of the detector. Systematic uncertainties also arise from errors on the experimental measurements that function as the input parameters to the modelling of the underlying physics processes, such as errors on the modelling of b and c fragmentation and decays of B and C hadrons.

The effect of uncertainty in the tracking efficiency was conservatively estimated from the difference between the values of multiplicities before and after the 2.9% overall correction to the Monte Carlo track multiplicities. In order to estimate the uncertainty in detector response near the lower limit of $p_\perp$ and upper limit of $|\cos\theta|$ we varied the former from 0.05 GeV/c to 0.25 GeV/c and the latter from 0.70 to 0.90. We found that our Monte Carlo simulation showed good agreement with the data for p and $p_\perp$ distributions in the hemispheres opposite to those tagged. The thrust axis containment cut was also varied within $0.6 \leq |\cos\theta_T| \leq 0.8$. To check for possible bias from our hemisphere tags the cut on the track significance δ_{norm} was varied from 2.0 to 4.0 for the light and b quark hemisphere tags, and D^* and D^+ mesons were considered

Source of Uncertainty	$\overline{n}_{uds}$	$\overline{n}_c$	$\overline{n}_b$	δn_c	δn_b
Tracking efficiency	0.55	0.64	0.62	0.08	0.07
Detector response	0.13	0.28	0.58	0.36	0.48
Hemisphere tag	0.09	0.33	0.12	0.40	0.17
Monte Carlo statistics	0.05	0.22	0.06	0.23	0.08
Total	0.57	0.80	0.86	0.59	0.52

Table 3. Systematic errors due to detector modelling.

separately as a c quark hemisphere tag. Finally, statistical effects from the limited Monte Carlo sample size were considered. These errors were added in quadrature to obtain a total systematic error due to detector modelling, shown in Table 3.

In order to estimate the systematic errors due to uncertainties in modelling b and c fragmentation we used an event re-weighting scheme to vary the multiplicity distributions in the Monte Carlo simulation and to obtain modified values of the constants C and P. We also account for the adjustment of the production cross section and branching fractions for the $D^0 \rightarrow K\pi$ and $D^0 \rightarrow K\pi\pi^0$ modes in the Monte Carlo by considering the errors on the relative fractions of these modes. Systematic uncertainties due to B and C hadron modelling are summarized in Table 4.

6 Summary and Conclusion

Combining systematic uncertainties in quadrature we obtain:

$$\begin{aligned} \overline{n}_{uds} &= 19.80 \pm 0.09 \,(\text{stat.}) \pm 0.57 \,(\text{syst.}) \\ \overline{n}_c &= 21.17 \pm 0.44 \,(\text{stat.}) \pm 1.01 \,(\text{syst.}) \qquad \text{PRELIMINARY} \\ \overline{n}_b &= 23.14 \pm 0.09 \,(\text{stat.}) \pm 1.03 \,(\text{syst.}) \end{aligned}$$

and

$$\begin{aligned} \delta\overline{n}_c &= 1.37 \pm 0.45 \,(\text{stat.}) \pm 0.86 \,(\text{syst.}) \\ \delta\overline{n}_b &= 3.34 \pm 0.13 \,(\text{stat.}) \pm 0.77 \,(\text{syst.}) \qquad \text{PRELIMINARY.} \end{aligned}$$

Figure 4 shows our measurements of a) $\delta\overline{n}_c$ and b) $\delta\overline{n}_b$ together with those from other experiments [19, 20, 21, 22, 23, 24], as functions of center-of-mass energy. Our results

Source of Uncertainty	Variation	$\overline{n}_{uds}$	$\overline{n}_c$	$\overline{n}_b$	δn_c	δn_b
b fragmentation	$\langle x_{E_b}\rangle$=0.700±0.011	0.01	0.04	0.55	0.03	0.56
B meson lifetime	τ_b=1.55±0.1 ps	<0.01	0.02	0.01	0.02	0.01
B baryon lifetime	τ_b=1.10±0.3 ps	<0.01	0.02	0.01	0.02	0.01
B baryon prod. rate	$f_{\Lambda_b} = 9\% \pm 3\%$	0.01	0.03	0.02	0.03	0.02
R_b (b fraction)	0.220±0.004	<0.01	<0.01	0.04	0.01	0.04
$B \to D^+ + X$ fraction	0.17±0.07	0.01	0.03	0.06	0.04	0.05
c fragmentation	$\langle x_{E_c}\rangle$=0.494±0.012	0.02	0.59	<0.01	0.59	0.02
R_c (c fraction)	0.170±0.017	0.03	0.10	0.01	0.12	0.03
$c\bar{c} \to D^+ + X$ fraction	0.20±0.04	0.01	0.02	<0.01	0.02	<0.01
$\overline{n}_c^{dk}$	2.60±0.13	<0.01	0.04	<0.01	0.04	<0.01
$\overline{n}_b^{dk}$	5.55±0.18	<0.01	0.02	0.04	0.02	0.03
$D^0 \to K\pi$, $D^0 \to K\pi\pi^0$ frac.	—	0.02	0.12	0.01	0.14	0.02
Total		0.05	0.62	0.56	0.62	0.57

Table 4. Systematic uncertainties due to B and C hadron modelling.

are consistent with the hypothesis of energy independence as predicted by MLLA QCD + LPHD, and with the QCD estimates of $\delta\overline{n}_c$ and $\delta\overline{n}_b$ quoted in Section 1.

Acknowledgements

We thank the personnel of the SLAC accelerator department and the technical staffs of our collaborating instutions for their outstanding efforts on our behalf.

References

[1] Yu.L. Dokshitzer *et al.*, 'Perturbative Quantum Chromodynamics', Ed. A. Mueller, World Scientific, Singapore, 1989; Yu.L. Dokshitzer *et al.*, 'Basics of Perturbative QCD', Ed. J.T.T. Vân, Editions Frontières, Gif-sur-Yvette, France, 1991.

[2] Yu. L. Dokshitzer *et al.*, J. Phys. **G17** (1991) 1481; *ibid* **G17** (1991) 1602.

[3] D. Amati and G. Veneziano, Phys. Lett. **B83** (1979) 87; Ya.I. Azimov *et al.*, Z. Phys. **C27** (1985) 65.

[4] V.A. Petrov and A.V. Kisselev, CERN-TH-7318-94 (1994).

[5] K. Abe *et al.*, Phys. Rev. Lett. **72** (1994) 3145.

[6] SLD Design Report, SLAC Report 273 (1984).

[7] K. Abe *et al.*, Phys. Rev. **D51** (1995) 962.

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

[9] C. J. S. Damerell *et al.*, Nucl. Inst. Meth. **A288** (1990) 288.

[10] S. Brandt *et al.*, Phys. Lett. **12** (1964) 57.
E. Farhi, Phys. Rev. Lett. **39** (1977) 1587.

[11] T. Sjöstrand, CERN-TH.7112/93 (1993).

[12] P.N. Burrows, Z. Phys. **C41** (1988) 375; OPAL Collaboration, M.Z. Akrawy *et al.*, *ibid.*, **C47** (1990) 505.

[13] SLD Collaboration, K. Abe *et al.*, SLAC-PUB 6687 (1994), submitted to Phys. Rev. Lett.

[14] SLD Collaboration, K. Abe *et al.*, SLAC-PUB 6569 (1994), submitted to Phys. Rev. D.

[15] SLD Collaboration, K. Abe *et al.*, SLAC-PUB 6681 (1995), submitted to Phys. Rev. Lett.

[16] MARK-III Collaboration, D. Coffman *et al.*, Phys. Lett. **B263** (1991) 135.

[17] B. Gittelman and S. Stone, in *High Energy Electron-Positron Physics*, edited by A. Ali and P. Söding (World Scientific, Singapore, 1988), p. 273.

[18] ARGUS Collaboration, H. Albrecht *et al.*, Z. Phys. **C54** (1992) 13.

[19] DELCO Collaboration, M. Sakuda *et al.*, Phys. Lett. **B152** (1985) 399.

[20] MARK-II Collaboration, P.C. Rowson *et al.*, Phys. Rev. Lett. **54** (1985) 2580.

[21] TPC Collaboration, H. Aihara *et al.*, Phys. Lett. **B134** (1987) 299.

[22] TASSO Collaboration, W. Braunschweig *et al.*, Z. Phys. **C42** (1989) 17.
M. Althoff *et al.*, Phys. Lett. **B135** (1984) 243.

[23] MARK-II Collaboration, B.A. Schumm *et al.*, Phys. Rev. **D46** (1992) 453.

[24] OPAL Collaboration, R. Akers *et al.*, Z. Phys. **C61** (1994) 209.

[25] B.A. Schumm *et al.*, Phys. Rev. Lett. **69** (1992) 3025.

List of Authors

** K. Abe,[29] I. Abt,[14] C.J. Ahn,[26] T. Akagi,[27] N.J. Allen,[4] W.W. Ash,[27]†
D. Aston,[27] K.G. Baird,[24] C. Baltay,[33] H.R. Band,[32] M.B. Barakat,[33]
G. Baranko,[10] O. Bardon,[16] T. Barklow,[27] A.O. Bazarko,[11] R. Ben-David,[33]
A.C. Benvenuti,[2] T. Bienz,[27] G.M. Bilei,[22] D. Bisello,[21] G. Blaylock,[7]
J.R. Bogart,[27] T. Bolton,[11] G.R. Bower,[27] J.E. Brau,[20] M. Breidenbach,[27]
W.M. Bugg,[28] D. Burke,[27] T.H. Burnett,[31] P.N. Burrows,[16] W. Busza,[16]
A. Calcaterra,[13] D.O. Caldwell,[6] D. Calloway,[27] B. Camanzi,[12] M. Carpinelli,[23]
R. Cassell,[27] R. Castaldi,[23][a] A. Castro,[21] M. Cavalli-Sforza,[7] E. Church,[31]
H.O. Cohn,[28] J.A. Coller,[3] V. Cook,[31] R. Cotton,[4] R.F. Cowan,[16]
D.G. Coyne,[7] A. D'Oliveira,[8] C.J.S. Damerell,[25] M. Daoudi,[27] R. De Sangro,[13]
P. De Simone,[13] R. Dell'Orso,[23] M. Dima,[9] P.Y.C. Du,[28] R. Dubois,[27]
B.I. Eisenstein,[14] R. Elia,[27] D. Falciai,[22] M.J. Fero,[16] R. Frey,[20] K. Furuno,[20]
T. Gillman,[25] G. Gladding,[14] S. Gonzalez,[16] G.D. Hallewell,[27] E.L. Hart,[28]
Y. Hasegawa,[29] S. Hedges,[4] S.S. Hertzbach,[17] M.D. Hildreth,[27] J. Huber,[20]
M.E. Huffer,[27] E.W. Hughes,[27] H. Hwang,[20] Y. Iwasaki,[29] D.J. Jackson,[25]
P. Jacques,[24] J. Jaros,[27] A.S. Johnson,[3] J.R. Johnson,[32] R.A. Johnson,[8]
T. Junk,[27] R. Kajikawa,[19] M. Kalelkar,[24] H. J. Kang,[26] I. Karliner,[14]
H. Kawahara,[27] H.W. Kendall,[16] Y. Kim,[26] M.E. King,[27] R. King,[27]
R.R. Kofler,[17] N.M. Krishna,[10] R.S. Kroeger,[18] J.F. Labs,[27] M. Langston,[20]
A. Lath,[16] J.A. Lauber,[10] D.W.G. Leith,[27] M.X. Liu,[33] X. Liu,[7] M. Loreti,[21]
A. Lu,[6] H.L. Lynch,[27] J. Ma,[31] G. Mancinelli,[22] S. Manly,[33] G. Mantovani,[22]
T.W. Markiewicz,[27] T. Maruyama,[27] R. Massetti,[22] H. Masuda,[27]
T.S. Mattison,[27] E. Mazzucato,[12] A.K. McKemey,[4] B.T. Meadows,[8]
R. Messner,[27] P.M. Mockett,[31] K.C. Moffeit,[27] B. Mours,[27] G. Müller,[27]
D. Muller,[27] T. Nagamine,[27] U. Nauenberg,[10] H. Neal,[27] M. Nussbaum,[8]
Y. Ohnishi,[19] L.S. Osborne,[16] R.S. Panvini,[30] H. Park,[20] T.J. Pavel,[27]
I. Peruzzi,[13][b] M. Piccolo,[13] L. Piemontese,[12] E. Pieroni,[23] K.T. Pitts,[20]

R.J. Plano,[24] R. Prepost,[32] C.Y. Prescott,[27] G.D. Punkar,[27] J. Quigley,[16]
B.N. Ratcliff,[27] T.W. Reeves,[30] J. Reidy,[18] P.E. Rensing,[27] L.S. Rochester,[27]
J.E. Rothberg,[31] P.C. Rowson,[11] J.J. Russell,[27] O.H. Saxton,[27]
S.F. Schaffner,[27] T. Schalk,[7] R.H. Schindler,[27] U. Schneekloth,[16]
B.A. Schumm,[15] A. Seiden,[7] S. Sen,[33] V.V. Serbo,[32] M.H. Shaevitz,[11]
J.T. Shank,[3] G. Shapiro,[15] S.L. Shapiro,[27] D.J. Sherden,[27] K.D. Shmakov,[28]
C. Simopoulos,[27] N.B. Sinev,[20] S.R. Smith,[27] J.A. Snyder,[33] P. Stamer,[24]
H. Steiner,[15] R. Steiner,[1] M.G. Strauss,[17] D. Su,[27] F. Suekane,[29]
A. Sugiyama,[19] S. Suzuki,[19] M. Swartz,[27] A. Szumilo,[31] T. Takahashi,[27]
F.E. Taylor,[16] E. Torrence,[16] J.D. Turk,[33] T. Usher,[27] J. Va'vra,[27]
C. Vannini,[23] E. Vella,[27] J.P. Venuti,[30] R. Verdier,[16] P.G. Verdini,[23]
S.R. Wagner,[27] A.P. Waite,[27] S.J. Watts,[4] A.W. Weidemann,[28] E.R. Weiss,[31]
J.S. Whitaker,[3] S.L. White,[28] F.J. Wickens,[25] D.A. Williams,[7]
D.C. Williams,[16] S.H. Williams,[27] S. Willocq,[33] R.J. Wilson,[9]
W.J. Wisniewski,[5] M. Woods,[27] G.B. Word,[24] J. Wyss,[21] R.K. Yamamoto,[16]
J.M. Yamartino,[16] X. Yang,[20] S.J. Yellin,[6] C.C. Young,[27] H. Yuta,[29]
G. Zapalac,[32] R.W. Zdarko,[27] C. Zeitlin,[20] Z. Zhang,[16] and J. Zhou,[20]

[1] *Adelphi University, Garden City, New York 11530*
[2] *INFN Sezione di Bologna, I-40126 Bologna, Italy*
[3] *Boston University, Boston, Massachusetts 02215*
[4] *Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom*
[5] *California Institute of Technology, Pasadena, California 91125*
[6] *University of California at Santa Barbara, Santa Barbara, California 93106*
[7] *University of California at Santa Cruz, Santa Cruz, California 95064*
[8] *University of Cincinnati, Cincinnati, Ohio 45221*
[9] *Colorado State University, Fort Collins, Colorado 80523*

[10] *University of Colorado, Boulder, Colorado 80309*
[11] *Columbia University, New York, New York 10027*
[12] *INFN Sezione di Ferrara and Università di Ferrara, I-44100 Ferrara, Italy*
[13] *INFN Lab. Nazionali di Frascati, I-00044 Frascati, Italy*
[14] *University of Illinois, Urbana, Illinois 61801*
[15] *Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720*
[16] *Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*
[17] *University of Massachusetts, Amherst, Massachusetts 01003*
[18] *University of Mississippi, University, Mississippi 38677*
[19] *Nagoya University, Chikusa-ku, Nagoya 464 Japan*
[20] *University of Oregon, Eugene, Oregon 97403*
[21] *INFN Sezione di Padova and Università di Padova, I-35100 Padova, Italy*
[22] *INFN Sezione di Perugia and Università di Perugia, I-06100 Perugia, Italy*
[23] *INFN Sezione di Pisa and Università di Pisa, I-56100 Pisa, Italy*
[24] *Rutgers University, Piscataway, New Jersey 08855*
[25] *Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX United Kingdom*
[26] *Sogang University, Seoul, Korea*
[27] *Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309*
[28] *University of Tennessee, Knoxville, Tennessee 37996*
[29] *Tohoku University, Sendai 980 Japan*
[30] *Vanderbilt University, Nashville, Tennessee 37235*
[31] *University of Washington, Seattle, Washington 98195*
[32] *University of Wisconsin, Madison, Wisconsin 53706*
[33] *Yale University, New Haven, Connecticut 06511*
† *Deceased*

[a]*Also at the Università di Genova*

[b]*Also at the Università di Perugia*

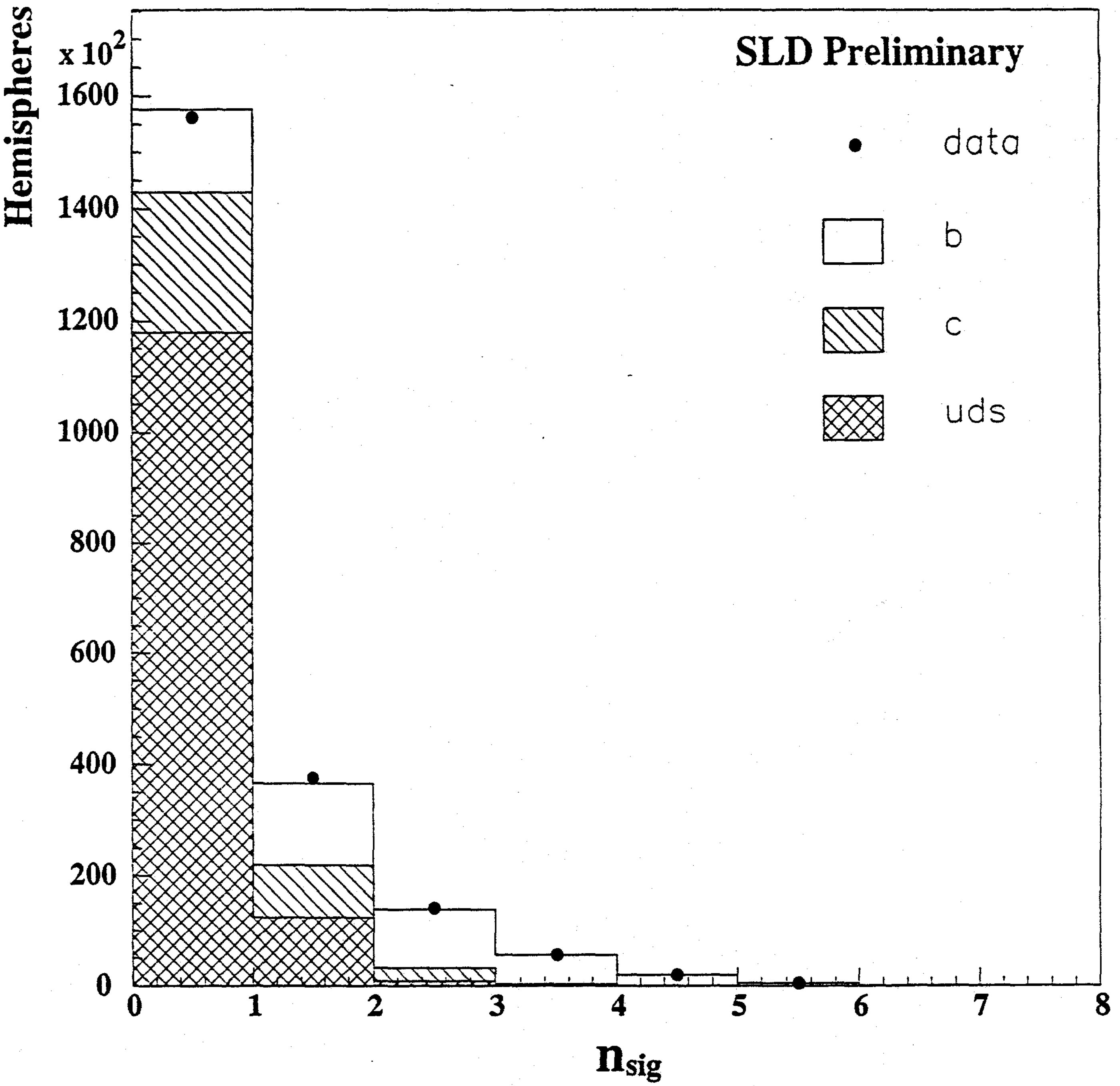
Figure captions

Figure 1. The number of tracks n_{sig} per hemisphere which miss the interaction point by more than 3σ in the x-y plane. The solid histogram represents the Monte Carlo sample, while the points represent the data distribution. The flavor composition of the Monte Carlo distribution is also shown.

Figure 2. The ΔM distribution for data and Monte Carlo for a) $D^0 \to K\pi$, b) $D^0 \to K\pi\pi^0$ and c) $D^0 \to K\pi\pi\pi$, and d) $M(K\pi\pi)$ distribution for $D^+ \to K\pi\pi$ (see text). The solid histograms represent the Monte Carlo samples, while the points represent the data distributions. The flavor composition of the distributions are also shown. The relative normalizations of the Monte Carlo and the data have been obtained from the total number of hadronic events.

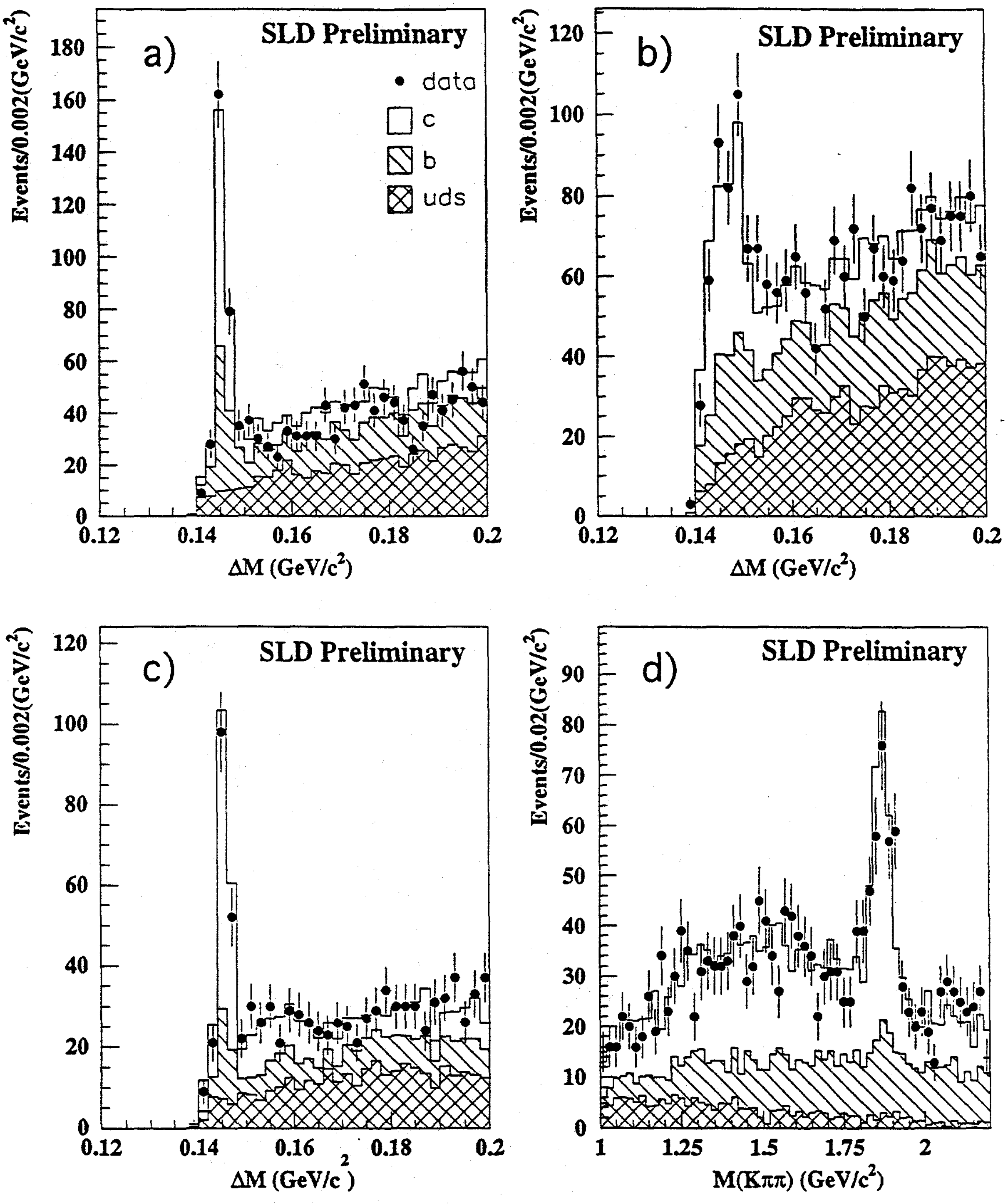
Figure 3. The number of measured tracks m per hemisphere opposite to the a) light-, b) c- and c) b-quark tagged hemisperes. The histograms represent the Monte Carlo, and the points the data, distributions.

Figure 4. Differences in average total multiplicities a) $\delta\overline{n}_c$ and b) $\delta\overline{n}_b$ as functions of center-of-mass energy. MLLA QCD + LPHD predictions are shown as the solid lines with the dotted lines indicating the uncertainties; higher order uncertainties [25] are not included. The predictions of Petrov and Kisselev are shown as stars.



SLD Preliminary
Hemispheres
x 10^2
1600
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
8
n_sig
data
b
c
uds

Figure 1



SLD Preliminary
a)
data
c
b
uds
Events/0.002(GeV/c²)
ΔM (GeV/c²)
b)
c)
d)
Events/0.02(GeV/c²)
M(Kππ) (GeV/c²)

Figure 2

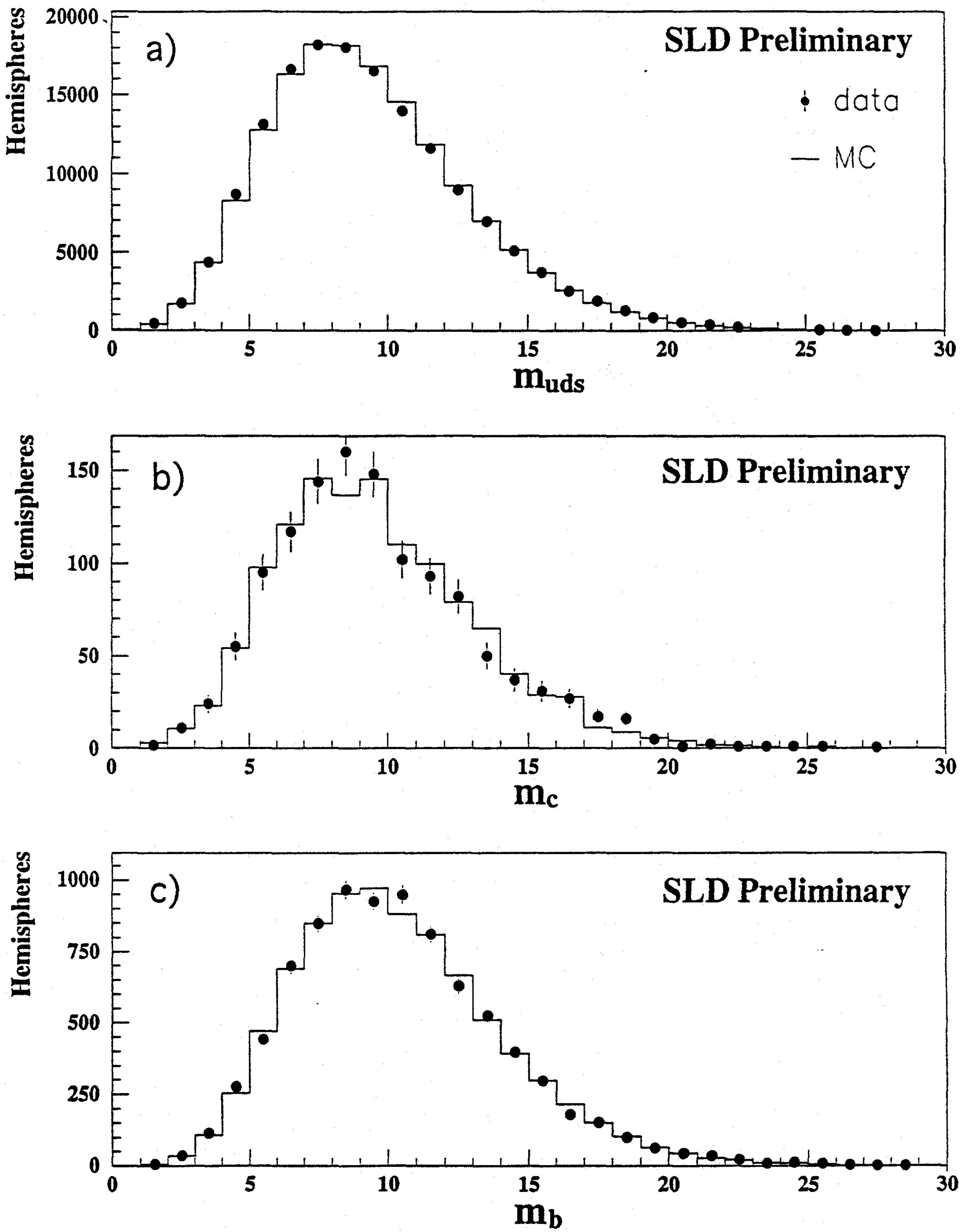
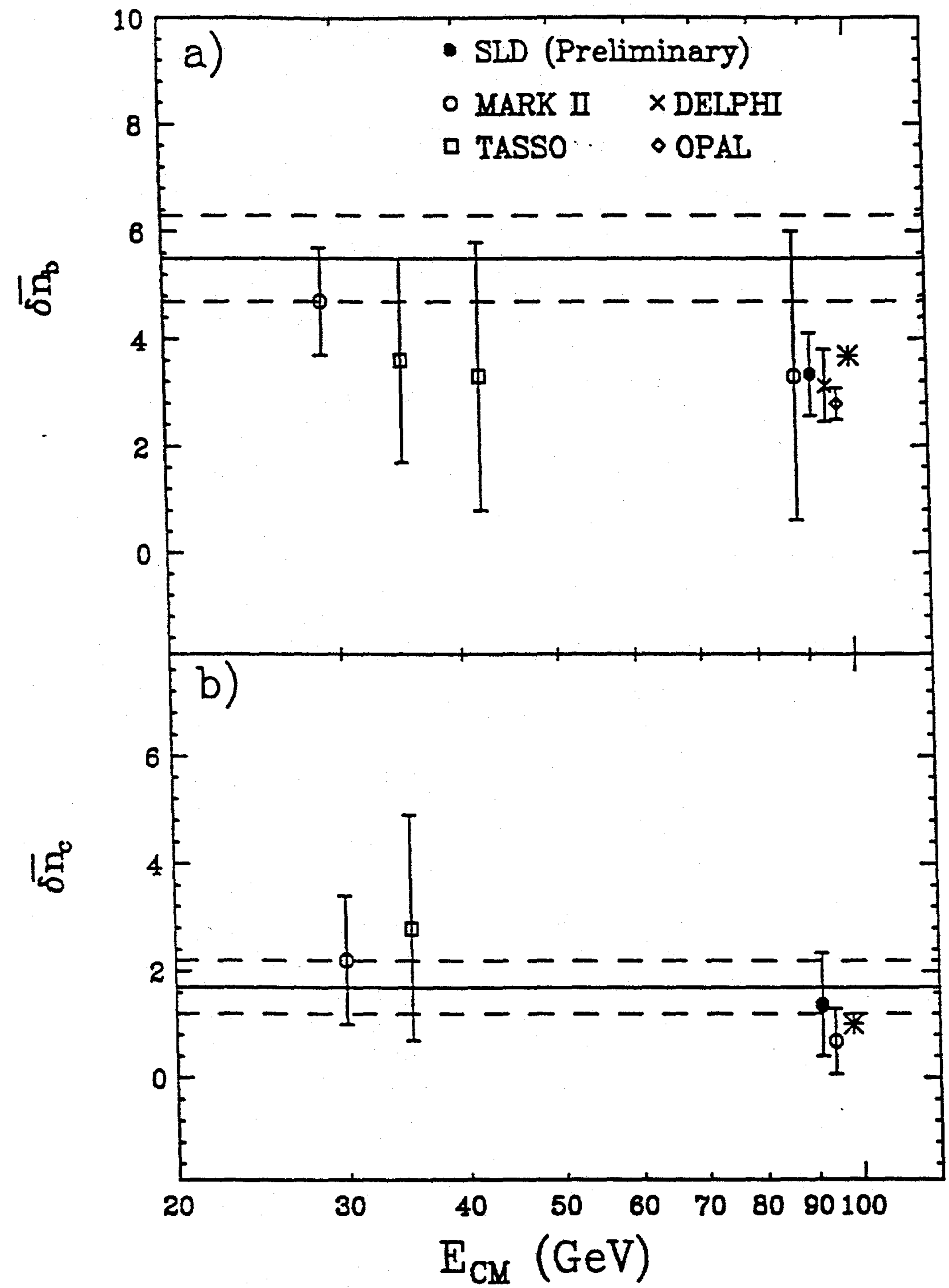

a)
SLD Preliminary
data
MC
Hemispheres
20000
15000
10000
5000
0
0
5
10
15
20
25
30
m_{uds}
b)
SLD Preliminary
Hemispheres
150
100
50
0
0
5
10
15
20
25
30
m_c
c)
SLD Preliminary
Hemispheres
1000
750
500
250
0
0
5
10
15
20
25
30
m_b

Figure 3



a)
SLD (Preliminary)
MARK II
DELPHI
TASSO
OPAL
b)
10
8
6
4
2
0
20
30
40
50
60
70
80
90
100
E_CM (GeV)

Figure 4