

**SLAC-PUB-6602**  
**August 1994**  
**(E)**

**MEASUREMENT OF THE CHARGED MULTIPLICITY  
OF  $Z^0 \rightarrow b\bar{b}$  EVENTS\***

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**ABSTRACT**

Using an impact parameter tag to select an enriched sample of  $Z^0 \rightarrow b\bar{b}$  events, we have measured the difference between the average charged multiplicity of  $Z^0 \rightarrow b\bar{b}$  and  $Z^0 \rightarrow \text{hadrons}$  to be  $\bar{n}_b - \bar{n}_{had} = 2.24 \pm 0.30(\text{stat.}) \pm 0.33(\text{syst.})$  tracks per event. From this, we have derived  $\bar{n}_b - \bar{n}_{uds} = 3.31 \pm 0.41 \pm 0.79$ . Comparing this measurement with those at lower center-of-mass energies, we find no evidence that  $\bar{n}_b - \bar{n}_{uds}$  depends on energy, in agreement with a precise prediction of perturbative QCD.

*Presented at the 8th Meeting of the American Physical Society, Division of Particles and Fields (DPF94), Albuquerque, NM, August 2-6, 1994.*

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\*Work supported by Department of Energy contract DE-AC03-76SF00515

Heavy quark systems are a particularly good laboratory for detailed studies of the strong interaction and tests of the theory of Quantum Chromodynamics (QCD). The large quark mass  $M_Q \gg \Lambda_{QCD}$ , where  $\Lambda_{QCD}$  is the QCD interaction scale, provides a natural cutoff in the parton shower evolution, which keeps the relevant space-time region compact enough to avoid the non-perturbative domain of the strong interaction. Recently it has been recognized that, within the context of perturbative QCD, this cutoff allows a stringent constraint to be placed on the difference in light hadron production between  $e^+e^-$  annihilation into heavy and light quarks.<sup>1</sup> In particular, it is expected that to  $O([\alpha_s(W^2)]^{1/2}(M_Q^2/W^2))$  ( $\simeq 0.1$  track at  $W = M_Z$ ), the difference between the total mean charged multiplicity in light quark ( $q = u, d, s$ ) events and the mean charged multiplicity of radiated ‘non-leading’ hadrons in heavy quark ( $Q = b, c$ ) events, excluding the decay products of the ‘leading’ long-lived heavy hadrons, should be *independent* of center-of-mass (cms) energy  $W$ . This is a striking prediction, in that the total multiplicity is known to grow faster than logarithmically with  $W$ . Furthermore, to  $O(\alpha_s(M_Q^2)\bar{n}_{uds}(M_Q))$  ( $\simeq 1.2$  tracks), this multiplicity difference should be equal to  $\bar{n}_{uds}(\sqrt{e}M_Q)$ , the mean charged multiplicity for  $e^+e^-$  annihilation to light quarks at the reduced cms energy  $\sqrt{e}M_Q$ , where  $\ln e = 1$ . 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  $M_Q^2$ .

The SLD is a multi-purpose particle detector and is described elsewhere.<sup>2</sup> Particle energies are measured over 98% of  $4\pi$  in the liquid argon calorimeter (LAC), and charged particles are tracked and momentum analyzed in the Central Drift Chamber (CDC). In addition, a silicon vertex detector (VXD), composed of 120 million  $22 \times 22 \mu m^2$  pixels in four concentric cylindrical layers of radius between 2.9 and 4.1 cm, provides an accurate measure of particle trajectories close to the beam axis. With the exception of the hadronic event trigger, this analysis relied exclusively upon the information from these two tracking systems.

While the multiplicity measurement relied primarily on information from the CDC, the more accurate impact parameter measurement provided by the addition of the VXD information to the CDC tracks was used to select a sample enriched in  $Z^0 \rightarrow b\bar{b}$  events. 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 (PV) derived from fits to events close in time to the event under study. The impact parameter  $d$  was derived by applying a sign to the distance of closest approach such that  $d$  is positive when the vector from the PV 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 PV, the measured impact parameter uncertainty  $\sigma_d$  for the overall tracking system approaches  $15 \mu m$  for high momentum tracks, and is  $80 \mu m$  at  $p_\perp \sqrt{\sin \theta} = 1 \text{ GeV}/c$ , where  $p_\perp$  is the momentum transverse to the beam axis, and  $\theta$  the angle relative to the beam axis.

Events were classified as hadronic decays of the  $Z^0$  provided that they contained at least 7 tracks which intersected a cylinder of radius  $r_0 = 5 \text{ cm}$  and half-length  $z_0 = 10 \text{ cm}$  surrounding the average PV, a visible charged energy of least 20 GeV, and a thrust axis satisfying  $|\cos \theta_{thrust}| < 0.7$ . The resulting sample contained 5449 events. Backgrounds in this sample were estimated to be  $\sim 0.1\%$ .

A  $Z^0 \rightarrow b\bar{b}$  enriched sample was selected by dividing each event into two hemispheres separated by the plane perpendicular to the thrust axis, and requiring two or more impact parameter quality tracks in one hemisphere with normalized impact parameter  $d/\sigma_d > 3.0$ .<sup>3</sup> Restricting the tag to tracks from a single hemisphere allowed potential tagging bias to be reduced by measuring the multiplicity in the hemisphere opposite to the tag. Monte Carlo (MC) studies indicate that this tag is 50% efficient at identifying hemispheres containing  $B$  hadrons in selected hadronic events, while providing an enriched sample of 72% purity. The tag selected 1829 hemispheres.

The uncorrected mean charged multiplicity for all hadronic events was found to be  $\bar{m}_h = 17.29 \pm 0.07$  tracks, while the mean charged multiplicity opposite tagged hemispheres was found to be  $\bar{m}_t = 9.28 \pm 0.09$  tracks. Combining<sup>3</sup> these values yields  $\delta\bar{n}_b = 1.94 \pm 0.30$ (stat.) tracks. We have investigated<sup>3</sup> a number of systematic effects which may bias the measured value of  $\delta\bar{n}_b$ . Applying these corrections, and combining the uncertainties in quadrature, we find

$$\delta\bar{n}_b = 2.24 \pm 0.30\text{(stat.)} \pm 0.33\text{(syst.)} \text{ tracks.}$$

Adding back in the world-average total hadronic multiplicity at the  $Z^0$  peak  $\bar{n}_{had} = 20.95 \pm 0.20$ <sup>4</sup> then yields  $\bar{n}_b = 23.19 \pm 0.30$ (stat.)  $\pm 0.37$ (syst.) tracks.

To test the energy independence of the difference between the total multiplicity in light quark events and the non-leading multiplicity in  $Z^0 \rightarrow b\bar{b}$  events, we make use of lower cms energy measurements of the  $e^+e^- \rightarrow b\bar{b}$  multiplicity from the PEP and PETRA storage rings. Assuming the energy independence of the decay multiplicity of  $B$  hadrons produced in  $e^+e^-$  annihilation, it is equivalent to test the quantity  $\Delta\bar{n}_b \equiv \bar{n}_b - \bar{n}_{uds}$ . Results for this quantity for the various lower cms energy experiments are summarized in Ref. 1. Applying the same procedure to the SLD measurement to remove the contribution from  $Z^0 \rightarrow c\bar{c}$ , we arrive at the result

$$\Delta\bar{n}_b = 3.31 \pm 0.41\text{(stat.)} \pm 0.53\text{(syst.)} \pm 0.58(\bar{n}_c) \text{ tracks.}$$

The latter uncertainty is due to the unknown  $Z^0 \rightarrow c\bar{c}$  multiplicity, which we have constrained to lie between  $\bar{n}_{uds}$  and  $\bar{n}_b$ , yielding  $\bar{n}_c = 21.9 \pm 2.0$  tracks.

Figure 1 shows  $\bar{n}_{had}$  and  $\Delta\bar{n}_b$  as functions of cms energy. The  $\Delta\bar{n}_b$  data, with the additional lever arm provided by the SLD measurement, are seen to be consistent with the hypothesis of energy independence, in marked contrast to the steeply rising total multiplicity data. This energy independence is in agreement with the precise perturbative QCD expectation, and indicates that QCD remains asymptotically free down to the scale  $M_B^2$ . Also shown is the perturbative QCD expectation for the value of  $\Delta\bar{n}_b$ . Averaging the SLD result with previous measurements,<sup>1</sup> we find that  $\delta\bar{n}_b^{comb} = 3.83 \pm 0.63$ , within 1.1 standard deviations of the perturbative QCD expectation of  $5.5 \pm 0.8 \pm 1.2$ ,<sup>1</sup> where the latter uncertainty is due to the  $O(\alpha_s(M_B^2)\bar{n}_{uds}(M_B))$  theoretical uncertainty on the QCD prediction for  $\delta\bar{n}_b$ .

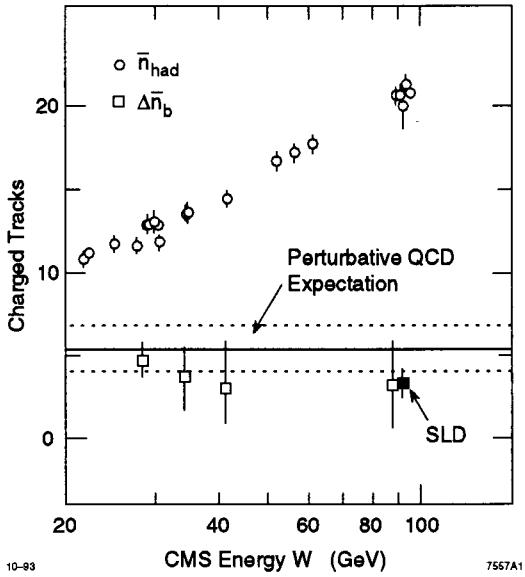


Fig. 1

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