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Results from HRS at PEP

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Introduction

The High Resolution Spectrometer (HRS)¹ has been collecting data at PEP since the end of 1981 and has now accumulated 120 pb^{-1} of integrated luminosity. I report here the results of our analysis in the following areas:

- QED and Electroweak tests
- Scalar Electron Search
- Inclusive Hadron Production
- D^0, D^+ and D^* Production
- Studies of Quark Fragmentation

Only the 20 pb^{-1} of integrated luminosity obtained during our first year of running has been completely analyzed and this provides the data sample for most of the above topics. For others I report a preliminary analysis of a total sample of 80 pb^{-1} .

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The Detector

The HRS detector, shown in Figure 1, is a new general purpose e^+e^- detector operating at PEP which very much emphasizes high quality charged particle tracking. It combines the elements of a 1.6 T. magnetic field, 2.0 m. tracking radius and 200μ spatial resolution with very low multiple scattering ($0.02x_0$ material) to achieve a momentum resolution of $\sigma_p/p = 0.1 \cdot p\%$ for all tracks with $p \geq 5$ GeV/c over 65% of the solid angle. For 90% of the total solid angle the momentum resolution for these tracks is better than $0.5 \cdot p\%$ which remains quite a respectable value by the standards of previous e^+e^- detectors even in their central regions.

The detector also incorporates electromagnetic shower calorimeters located inside the coil for γ and electron detection. These are $11x_0$ lead-scintillator sandwich modules which cover the "barrel" region ($60^\circ - 4\pi$) and the "end cap" region ($27^\circ - 4\pi$) with resolutions $\sigma(E)/E = 0.16/\sqrt{E}$ and $0.20/\sqrt{E}$, respectively. A single layer of proportional wire chambers with charge division provide spatial resolutions of $\Delta x, \Delta y \approx 2$ cm. and $\Delta\theta \approx 10$ mr.

Hadron identification is provided by time-of-flight measurements using the scintillator after $3x_0$ of the shower counters and also by 11 toroidal photo-ionization Cerenkov detectors shown in Figure 1. A time-of-flight resolution of $\sigma_t = 360$ psec. is achieved for minimum ionizing particles, enabling 1σ K/ π separation to 1 GeV/c momentum and p/K separation to 1.9 GeV/c. The Cerenkov counters are highly segmented (704 cells) and will permit $\pi/(Kp)$ separation in the range 1.5-6.0 GeV/c and p/(K π) separation for momenta greater than 6.0 GeV/c over 60% of the

solid angle. Installed and running for most of the second year's running, analysis of their signals is still underway and no results reported here use the information that they will soon provide.

The observed momentum distribution for Bhabha-scattered electrons, plotted in Figure 2, shows a resolution of $\sigma_p/p = 1.0 \times 10^{-3} \cdot p$ (GeV/c) which is dominated by measurement error, after unfolding radiative effects. These measurement errors, in turn, permit calculation of the expected momentum resolution for all momenta which is shown in Figure 3. Low momentum tracks are measured with resolutions σ_p/p of $\approx 0.3\%$ and $\approx 0.6\%$ for the first and second years running, respectively. The elements which provide this high resolution also make possible a high tracking efficiency which doesn't begin to fall off until polar angles below $\approx 26^\circ$ are reached, giving the detector a particularly large high resolution acceptance for charged particle resonant states.

QED Tests at 29 GeV

I present results² here on the processes:

$$e^+e^- \rightarrow e^+e^- \quad (1)$$

and

$$e^+e^- \rightarrow \mu^+\mu^- \quad (2)$$

Event selection proceeded from the 19.6 pb^{-1} sample of the first year's running by requiring 2 charged prongs, each with $p \geq 7.25 \text{ GeV/c}$, with a colinearity angle between them less than 25° . A good vertex was required ($r < 0.01\text{m}$, $|z| < 0.09\text{m}$) for all tracks and time difference cuts were applied to the two tracks for cosmic rejection. Muons and

electrons are distinguished in the HRS entirely by the electromagnetic shower calorimeter energy deposit. Tracks with energy deposited in the barrel calorimeter of <1.0 GeV are taken as $\mu^\pm$ candidates and those with barrel energy ≥ 0.4 p are taken as $e^\pm$. This selection resulted in 8915 Bhabha scattering events in the barrel region, 811 μ pair events in the barrel region and 168 μ pair events in the end cap region.

The response of the calorimeters to minimum ionizing particles and to Bhabha-scattered electrons is shown in Figure 4. The minimum ionizing tracks leave an average of 0.2 GeV of energy deposited in each system. Folding all 40 barrel modules, Figure 5 shows the azimuthal (ϕ) dependence in the modules where fiducial cuts were then imposed to eliminate 1° cracks at the edges. After making all the listed cuts, Figure 6 shows how well μ - e separation is accomplished without a muon detection system by plotting the total shower energy of the 2 charged tracks. There is clearly negligible feedthrough of electrons into the muon sample.

The results are then compared in detail with a Monte Carlo calculation based on the α^3 QED model including electroweak effects of Berends, Kleiss and Jadach.³ Figure 7(a) compares the measured acolinearity distribution for $e^+e^- \rightarrow e^+e^-$ with the predicted distribution and Figure 7(b) does the same for the acoplanarity distribution showing good agreement with theory. The observed angular distribution for $e^+e^- \rightarrow e^+e^-$ is then shown in Figure 8. The normalization here is arbitrary since these wide angle Bhabha events are used to determine the actual accumulated integrated luminosity of the experiment. Nonetheless the shape of the angular distribution can be compared with the α^3 QED

predictions where δ_{reals} in Figure 9 is the ratio of observation to prediction. Deviations from the theory may be characterized in terms of cutoff parameters Λ_+ , which can be related to modifications of the photon propagator or a finite size of the electron. Our values for the cutoff parameters are compared with other experiments in Table I.

The collinearity distribution for $e^+e^- \rightarrow \mu^+\mu^-$ is shown in Figure 10 and, once again, very good agreement is obtained with the Monte Carlo prediction. Using the luminosity from the Bhabhas, we measure for our acceptance $\sigma(e^+e^- \rightarrow \mu^+\mu^-) = 0.0353 \pm 0.0015$ nb, while the QED prediction for our solid angle from Berends, Kleiss and Jadach is 0.0352 ± 0.0008 nb. The comparison of these two numbers places limits on the cutoff parameters related to the size of the muon of $\Lambda_+, \Lambda_- > 172$ GeV (95% C.L.).

Measurement of the muon angular distribution in Figure 11 allows extraction of the electroweak parameters g_V^2 and g_A^2 . With g_V^2 constrained to the value of 0.00 ± 0.18 obtained from a global fit to all the Bhabha scattering and μ pair data, the μ pair data alone is fit to obtain a value for the axial coupling constant of $g_A^2 = 0.33 \pm 0.17$. The corresponding asymmetry in the μ^+ angular distribution is $A_{\mu\mu} = -0.084 \pm 0.043$ and these results are compared with the results of other experiments in Figure 12 and in Table II. Agreement is quite good although the world average remains dominated by the high statistics experiments of MAC,⁴ TASSO⁵ and Mark J.⁶

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Scalar Electron Search

Among the predictions of supersymmetric models, much discussed at this conference,⁷ are the existence of scalar partners to the electron which could be produced in e^+e^- annihilation via the diagrams shown in Figure 13. Neglecting the contributions of the Z^0 and its supersymmetric partner, the Zino, these diagrams can be calculated, assuming here a very light or massless photino. Since the scalar electron is expected to decay rapidly into an ordinary electron and the neutrino-like photino, the event signature would be a highly coplanar electron pair with substantial missing energy, (on average approximately half).

Event selection⁸ proceeded in a similar way as for the QED analysis described above: two prongs, required now to both be showering particles with $E(\text{Barrel}) > 0.3 \cdot p$, $p \geq 1.0 \text{ GeV}/c$ and $|\cos\theta| \geq 0.55$ to confine tracks to the barrel region. Similar vertex and cosmic time-difference cuts were made. Then the sum of the magnitudes of the reconstructed momenta $|\vec{p}|$ was required to be between $0.2E_{\text{cm}}$ and $0.95E_{\text{cm}}$. The lower limit is to eliminate beam-gas and two-photon backgrounds while the upper limit was to cut out what is the principle background for the search: radiative Bhabha scattering. The real handle against Bhabha scattered electron events with radiation is the acoplanarity which we require to be larger than 25° . In addition we require no observed hard ($E_\gamma \geq 0.4 \text{ GeV}$) photons observed in the event. With these cuts, 6 events survive out of the 1.4×10^7 triggers accumulated in the 19.6 pb^{-1} data sample. The α^3 QED Monte Carlo calculation predicts 4.8 radiative Bhabha events are expected, as well as a negligible 0.02 τ events.

Of the 6 surviving events, 4 are found by further examination to be entirely consistent with $e^+e^- \rightarrow e^+e^-\gamma$ with a calculated γ ray direction pointing directly at either the end or edge of a barrel counter which has recorded a substandard pulse height. The 5th event does not satisfy this interpretation but is quite consistent with a double radiative Bhabha process (α^2). Assuming colinear photons, as expected from the kinematics, the expected photons aim toward the very ends of 2 barrel modules which have in fact recorded substandard energy deposits. The remaining event has no struck barrel modules at all and is shown in Figure 14. It can also be interpreted as a double radiative event with photons directed toward the gap region between the barrel and end cap calorimeters, but because it cannot be classified definitively, this event forms the basis for our upper limit on scalar electron production. Using the predicted cross-section and our calculated acceptance, this upper limit is plotted in Figure 15 as a function of scalar electron mass. Masses between $1.8 \text{ GeV}/c^2$ and $14.3 \text{ GeV}/c^2$ can be ruled out at the 95% confidence level by this experiment for this simplest version of supersymmetric models.

Inclusive Hadron Production

The following section presents a preliminary analysis⁹ using time-of-flight techniques of the charge particle fractions in hadronic events at $E_{\text{cm}} = 29 \text{ GeV}$. Hadronic event selection required at least 5 reconstructed tracks be observed with good vertex ($|z| \leq 0.1\text{m}$ and $r \leq 0.02\text{m}$), scalar momentum sum $|\vec{p}| \geq 8.7 \text{ GeV}/c$ ($0.3 \cdot E_{\text{cm}}$) and total calorimeter energy deposit greater than 1.45 GeV ($0.05 \cdot E_{\text{cm}}$). The data

sample used was once again the 19.6 pb^{-1} from our first year's running and this selection resulted in 8200 hadronic events with 88200 tracks.

A further selection of tracks for time-of-flight applicability was made in the preliminary analysis of these events: Tracks to be used were required to have struck a barrel module and the struck barrel modules were required to have had 1 and only 1 track intersect the module. Furthermore it was also required that there was no photon (additional PWC cluster) in the module struck by the charged particle and that the 3 methods of determining its z position (TDC, DC track, PWC) were consistent. Barrel fiducial cuts were also applied resulting in a surviving sample of 10100 tracks with very clean time-of-flight measurements.

Charged particle identification for this analysis was then done on a statistical basis by comparing the reconstructed mass-squared distributions for various momentum bins with the calculated resolution curves expected for various mixtures of produced pions, kaons and protons. Knowledge of the shape of the expected resolution for a given particle and pathlength is well-understood from studying the shapes of well isolated minimum ionizing particles such as those in μ pair events. Examples of m^2 distributions and the fits to them to determine the a priori produced particle rates are shown in Figures 16(a),(b) and (c) for typical low, moderate and high momentum bins, respectively. These plots show clearly, that even without classical separation criteria being met, the presence of the heavy particles, even at the highest momenta covered by the analysis, result in statistically significant effects in the m^2 distributions which are fit by well understood resolution functions.

Detailed acceptance calculations which include all the effects of the track selection have not yet been done, but preliminary charged hadron fractions are plotted in Figure 17 and are compared there to results from the TASSO¹⁰ collaboration at $E_{cm} = 34$ GeV. In terms of cross section $d\sigma/dp$, these results are compared in Figure 18. Figure 19 shows a comparison of our proton cross sections with those of Mark II,¹¹ TASSO¹⁰ and JADE.¹²

D and D* Production

The search for different modes of charmed meson production has been performed with two different data samples. The first results were obtained from our completely analyzed data sample of 19.6 pb^{-1} and further preliminary results have been obtained from a special analysis of new data from the second year's running. When added to the 19.6 pb^{-1} , the second sample reaches a total integrated luminosity of $\approx 80 \text{ pb}^{-1}$. These samples correspond to 18% and 67%, respectively, of the data we have collected to date.

Hadron event selection for the 19.6 pb^{-1} sample proceeded as described in the previous section. No particle identification, however, has been applied in any of the resonance reconstruction presented here. Trying all tracks as both kaons and pions, the effective $K^-\pi^+$ mass distribution reconstructed in the HRS is shown in Figure 20(a) for $z_D \geq 0.4$ and 0.5 , respectively, where $z_D \equiv 2E_D/E_{cm}$. A clear D^0 signal is directly observed in this data at $m_{K\pi} = 1.861 \pm 0.005 \text{ GeV}/c^2$ containing 114 ± 25 events for $z_D \geq 0.4$. The observed width of $\sigma = 0.017 \text{ GeV}/c^2$ is consistent with our calculated mass resolution for this state.

A similar effective mass distribution for $K^-\pi^+\pi^+$ combinations is shown in Figure 20(b) for $z_D \geq 0.5$. It shows good evidence also for the D^+ with 52 ± 16 events observed at $m_{K\pi\pi} = 1.867 \pm 0.004 \text{ GeV}/c^2$. Both measured mass values for the D^0 and the D^+ are in good agreement with the particle data book values. The observed D^+ width ($0.011 \text{ GeV}/c^2$) is once again in good agreement with our calculation.

We have also measured D^* production using the now standard technique¹³⁻¹⁵ of exploiting the low Q available in

$$\begin{array}{c} D^{*+} \rightarrow D^0 \pi^+ \\ \quad \downarrow \\ \quad \rightarrow K^- \pi^+ \end{array} \quad (3)$$

to obtain good resolution in the $D^0\pi-D^0$ mass difference. Figure 20(c) shows that for the HRS this technique allows us to see a clear D^* signal without making any z_D^* requirement at all. Here 16 ± 4.5 events are observed with mass difference $\Delta = 0.1458 \pm 0.0015 \text{ GeV}/c^2$.

Measuring D^0 , D^+ and D^* in the same apparatus allows us to compare rates without problems of normalization between experiments. In the case of the previously observed $D^{*+} \rightarrow D^0$ transition, some reported cross sections¹³ have been extremely large with $R(D^{*+} \rightarrow \bar{D}^{*+})$ as high as 6.0 units. The latter value would exceed the total expected charm cross section of $R(c + \bar{c}) = 3.53$ units. We measure the ratio of produced D^0/D^* in the same interval of $z_D \geq 0.4$. This ratio is independent of the $D^0 \rightarrow K^-\pi^+$ branching fraction¹⁶ with its large systematic uncertainty and only weakly dependent upon the acceptance calculation but it still depends on the $D^{*+} \rightarrow D^0 \pi^+$ branching fraction¹⁷ which also has a large uncertainty. We obtain the value 1.7 ± 0.7 where 0.7 would be expected based on the D^{*+}

branching fraction¹⁷ if all D^0 's came from the D^*-D^0 transition. Thus with large errors, our results imply that there is probably some direct D^0 production in addition to that from D^* . A similar ratio D^0/D^+ is measured in the z_D interval $z_D \geq 0.5$ to be 2.3 ± 1.2 .

All three processes that we measure are related, of course, and together they place further constraints on D/D^* ratio and, therefore, the production mechanism for D and D^* production at PEP/PETRA energies. We show this in Figure 21 by plotting simultaneously the D^+/D^0 and D^{*+}/D^0 rates where by rates we mean the observed rates into the particular mode being detected. That is, in Figure 21 we have extracted the branching ratios with their significant systematic errors from the measurements and attached those instead to the "theoretical" curve also plotted in Figure 21. The theoretical curve simply connects the expectation for 100% D^* production at one extreme with 100% direct D production and the assumption of pure isospin conservation, $\sigma(D^+) = \sigma(D^0)$, at the other extreme. Here direct means D production which does not come from process (3). The 1σ and 2σ contours of our measurement in Figure 21 also indicate that some admixture of direct and indirect D production is favored over the hypothesis of all observed D 's coming indirectly from D^* production. The preferred admixture, once again, would seem to be approximately equal amounts of direct and indirect D production.

The fact that the measured point in Figure 21 appears to be below the "theoretical" line could, in principle, have significance in terms of the possible production mechanism(s) for D mesons. For example, the production of D mesons which are products of B meson decays would be a

potential natural isospin violating mechanism which could favor D^0 production over D^+ and give this effect. This is suggested by the diagrams shown in Figure 22 for B^0 and B^- decay which can give extra D^0 production if, instead of the spectator quarks, quarks from the W decay are used to make the outgoing D.

Figure 23 shows the D^0 data broken into z_D bins where we have performed a simultaneous fit to a smoothly falling background which is a function of both $m_{K\pi}$ and z_D to extract D^0 cross sections as a function of z_D . Due to the low background, extracting D^* cross sections as a function of z is a much easier task and the results for both particles are presented in Figure 24(a) as $D(z) \equiv 1/\sigma \cdot d\sigma/dz$. The D^0 and D^+ fragmentation functions, defined in this way, are in very good agreement with each other and can be simultaneously characterized by $\epsilon = 0.36 \pm 0.12$ where ϵ is the parameter in the form suggested by Peterson et.al.¹⁸ for heavy quark fragmentation functions. A comparison of $s \cdot d\sigma/dz$ for D^{*+} production with other experiments at PEP and PETRA energies is shown in Figure 24(b). There are clear normalization differences between experiments for D^* production and also some disagreement among experiments about the shape at low z .

We have used a variety of forms consistent with our observed z -dependence to extrapolate the observed cross sections to all z to obtain measurements of the total cross sections for D^0 , D^+ and D^* production. After full corrections including initial state radiation, we express these as ratios to the μ pair cross section:

$$R(D^0 + \bar{D}^0) = 3.25 \pm 1.2$$

$$R(D^+ + D^*) = 1.35 \pm 0.6$$

and, assuming from isospin $\sigma(D^{*0}) = \sigma(D^{*+})$,

$$R(D^{*+}\bar{D}^{*+}) = 1.9 \pm 0.7$$

Of these, $R(D^{*+}\bar{D}^{*+})$ can be compared with previous measurements. Our measurement is in good agreement with the value of $2.50 \pm .64 \pm .88$ obtained by TASSO¹⁴ but is substantially lower than Mark II's published value¹³ of 3.1 ± 1.55 for D^{*+} production alone. All experiments are consistent, however, within the large systematic errors.

Summing the above R -values for D^0 and D^+ production and dividing by $2 \cdot \sigma_{\mu\mu}$, I plot our measurement of the quantity R_D in Figure 25 along with the only previous measurements which were obtained at SPEAR energies. I also show here the prediction for R_c as a function of energy (dashed line). Within the error bar, our measurement is consistent with expectation for total charm production although one must allow also for some F and charmed baryon production as well.

Events from the second year's running, added to make the 80 pb^{-1} sample, have been obtained via an online "express" selection of hadronic events. This made the additional requirements of 23 trigger processor tracks and, more importantly, calorimetric energy deposit $\geq 4.8 \text{ GeV}$ ($0.17 \cdot E_{\text{CM}}$). With the improved statistics provided by the preliminary analysis of this data, Figure 26 shows the D^* signal is easily observable as a cluster in a 2 dimensional plot of $m_{K\pi\pi}$ versus mass difference Δ with $z_D \geq 0.2$. The projections of this plot on the two axes are shown in Figures 27(a) and (b). Figure 27(a) shows very clear D^* peak with most of the events falling in a single $1 \text{ MeV}/c^2$ bin in the mass difference Δ . A total of 66 ± 14 events are observed. With such

data the z -dependence can almost be read off the 2 dimensional plot of z_D^* versus Δ shown in Figure 28. Figure 29 shows the Δ plot for several bins of z_D^* . A clear signal is observed in the lowest z -bin of 0.2 to 0.4 which has not been observed previously. These data allow the cleanest high statistics determination of the D^* fragmentation function to date. This is shown in Figure 30 and can be characterized by the ϵ parameter in an empirical fit of $\epsilon = 0.29 \pm 0.10$. The preliminary cross section measured from the 80 pb^{-1} data sample is $R(D^* + \bar{D}^*) = 2.0 \pm 0.7$ and this is completely consistent with the value which was obtained from our completely analyzed 19.6 pb^{-1} sample, given previously.¹⁹

We have used this data to measure the D^* angular distribution which is plotted in Figure 31. An asymmetry is observed of $A = -0.25 \pm 0.18$ in these data for $z_D^* \geq 0.4$ where the standard model predicts an asymmetry of ≈ -0.09 for a pure c -quark sample. Before doing this analysis, careful systematic studies of possible asymmetries in the detection efficiency, done previously for the μ pair asymmetry measurement, have been extended to the hadronic event sample. Upper limits for such systematic effects are incorporated in the quoted error for the D^* asymmetry.

Study of Quark Fragmentation at 29 GeV

We have begun a systematic study of quark fragmentation at 29 GeV with two points of view in mind:

1. that quark fragmentation should be better understood before focussing on explicit effects of different QCD models,
2. a comparison of e^+e^- results with those of hadronic interactions may reveal new insights about both.

I report here preliminary results from the HRS on: (i) jet parameters and 2-jet selection, (ii) multiplicity, (iii) independent fragmentation tests, (iv) single particle distributions and (v) two particle correlations.

Hadronic event selection was as before: $\sum |\vec{p}| \geq 0.3 \cdot E_{cm}$, $E(\text{calorim}) \geq 0.05 \cdot E_{cm}$ and ≥ 5 tracks with good vertex. In addition, we have made a 2-jet requirement on the events used for this study. This was done by requiring the sphericity $S \leq 0.25$ and aplanarity $A \leq 0.1$ for these events. In addition, the thrust axis was required to be $\geq 45^\circ$ for fiducial containment and we also required $\sum |\vec{p}| \geq 2 \text{ GeV}/c$ for the momenta in each jet separately. Figure 32 shows a plot of sphericity versus aplanarity for hadronic events where the cuts described above are indicated. These resulted in a sample of 4183 2-jet events.

Comparison of our global jet parameters gives quite satisfactory agreement with many previously published results and I only show one example (in Figure 33) of our average sphericity. A preliminary measurement of the multiplicity distribution is plotted in Figure 34 scaled by the average value. We measure $\langle N_{ch} \rangle = 12.0 \pm 0.2$ and compare the distribution here to the KNO scaling behavior observed in $\bar{p}p$ and pp interactions. Clear differences between hadronic and e^+e^- interactions are indicated here.

The idea of independent fragmentation of the 2 jets in these events can be tested by studying the correlation between the mean multiplicity measured for each jet. This is shown for our data in Figure 35, where we have arbitrarily defined "forward" and "backward" jets relative to the thrust axis for the event. Figure 35 shows that the mean multiplicity

of the two jets is found to be quite independent of each other, especially when one has extracted the poorly measured $|y| \leq 1$ region. Comparison with 540 GeV $p\bar{p}$ results (solid line) shows quite different behavior is observed in the central region of hadronic interactions. This is probably explained by the fact that the hadronic case is effectively summing over the $q\bar{q}$ center of mass energy, which introduces the observed strong correlation. Our results in Figure 35 are quite consistent with the predictions of the Monte Carlo (dashed line) that we have used to correct the data. This Monte Carlo is based on the Lund model²⁰ using Feynman-Field fragmentation functions.

Figure 36 shows the rapidity distribution of single particles within the jets. We then define 2-body correlation functions

$$R = \frac{\rho_2(y_1, y_2)}{f\rho_1(y_1)\rho_1(y_2)} - 1 \quad (4)$$

where the particle densities are defined

$$\rho_2(y_1, y_2) = 1/\sigma \cdot d^2\sigma/dy_1 dy_2$$

$$\rho_1(y) = 1/\sigma \cdot d\sigma/dy$$

and

$$f = \langle N(N-1) \rangle / \langle N \rangle^2$$

Figure 37 shows plots of the measured 2-body correlation as a function of y_2 for different values of test region rapidity y_1 , as we scan y_1 from low to high values. For test rapidities in the central region ($0.5 \leq y_1 \leq 0.75$) we observe short-range correlations very similar to those observed in hadronic interactions with a correlation length of approximately one unit of rapidity. The 2-body correlations that we observe are, for all test regions, quite consistent with the Monte Carlo predictions.

A charge correlation function can be defined as

$$\begin{aligned} \phi(y_1, y_2) \propto & [\rho^{+-}(y_1, y_2) + \rho^{-+}(y_1, y_2)] \\ & - [\rho^{++}(y_1, y_2) + \rho^{--}(y_1, y_2)] \end{aligned} \quad (5)$$

with appropriate normalization. Taking a test region $2.5 \leq y_1 \leq 5.5$ which is as high a rapidity as possible in order to search for long range charge correlations, our results are shown in Figure 38. We do in fact observe here long range charge correlations beyond the strong short range peak corresponding to local charge compensation within the jet. The magnitude of the long range term is shown to be well reproduced by within the Monte Carlo which we have been using.

A final interesting comparison between our e^+e^- results and those of hadronic interactions comes from looking at the rapidity gap distribution between two particles in the events. For a flat, uniformly populated single particle rapidity distribution and a Poisson multiplicity distribution, one would predict a pure exponential distribution of rapidity gaps with a mean gap length of λ equal to the observed average particle rapidity density, $\Delta y_{\pi}/\langle N \rangle$. Our results show in Figure 40 very good consistency with this simple prediction (solid line) using the average density λ that we measure from the single particle rapidity data of Figure 36 of 0.48 ± 0.05 . This is in contrast to hadronic interactions which have reported non-exponential behavior here which has, in the past, been interpreted as the effects of low-mass clusters. No evidence for such clusters is observed in our data. This suggests that the hadronic effects, once again, are coming rather from the effects of summing over a wide range of center-of-mass energies and impact parameters.

In summary, we observe that: (i) quarks fragment independently, (ii) jets remember the charge of the primary quark, (iii) short range rapidity correlations very similar to those in hadron interactions are seen in e^+e^- and, finally, (iv) clusters do not seem to be seen in the e^+e^- data. This work marks the beginning of a systematic study of these and other related issues.

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Table I.

QED Cutoff Parameters

Experiment	A_+ (Gev)	A_- (Gev)
HRS	121	118
CELLO	83	155
JADE	112	106
MARK-J	128	161
PLUTO	80	234
TASSO	140	296

Table II.

Weak Interaction Parameters

Experiment	g_0^2	g_V^2	$\sin^2\theta_W$	C
HRS	0.33 ± 0.17	0.00 ± 0.18	0.17 ± 0.20	0.038
TASSO	0.35 ± 0.09	-0.04 ± 0.06	0.27 ± 0.07	0.018
JADE	0.39 ± 0.11	0.05 ± 0.08	0.25 ± 0.15	0.039
MARKJ	0.28 ± 0.08	0.01 ± 0.08	0.26 ± 0.09	0.021
CELLO	0.17 ± 0.17	-	0.21 ± 0.12	-
PLUTO	-	-	0.23 ± 0.17	0.060
MAC	0.31 ± 0.08	-	0.24 ± 0.10	-
MARKII	0.24 ± 0.16	0.05 ± 0.10	-	-

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Figure 6. Total Shower energy for 2 Track Events

Figure 7.(a) Acolinearity and (b) Acoplanarity for $e^+e^- \rightarrow e^+e^-$

Figure 8. Angular distribution for $e^+e^- \rightarrow e^+e^-$

Figure 9. Ratio of Measurement to Prediction for Bhabha Angular Distribution

Figure 10. Colinearity Distribution for $e^+e^- \rightarrow \mu^+\mu^-$

Figure 11. Angular Distribution for $e^+e^- \rightarrow \mu^+\mu^-$

Figure 12. Comparison of Muon Asymmetry from Different Experiments

Figure 13. Diagrams for Scalar Electron Production in e^+e^- Annihilation

H R S RUN=2327
 EVENT= 8897 ECODE = 0
 DCHITS = 49
 NPRNG = 2 TRIG.= F1 F2 F3 S6 A1 D1 D2
 SH SUM= 7.1 + 0.0
 TRACK MOMENTUM THETA
 1 -3.1 85.9
 2 2.9 116.1

Figure 14. Remaining Scalar Electron Event "Candidate", also consistent with double radiative Bhabha

Figure 15. Upper limit on Scalar Electron Cross-section versus Mass

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Figure 34. KNO Scaling Multiplicity Distributions

Figure 35. Charged Particle Multiplicity Correlations

Figure 36. Single Particle Rapidity Distribution

Fig. 37. Measurements of the 2-Particle Correlation Function of y_2 for (a) $0 < y_1 < 1.75$, (b) $1.75 < y_1 < 3.5$, (c) $3.5 < y_1 < 5.25$ and (d) $5.25 < y_1 < 7.0$

Figure 38. Long Range Charge Correlations

Figure 39. Rapidity Gap Distribution