MULTIPLICITY DISTRIBUTIONS IN e^+e^- ANNIHILATIONS AT PETRA ENERGIES

PLUTO Collaboration

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Measurements of the charged multiplicities for hadron production in e^+e^- annihilation in the center of mass energy range 9–32 GeV have been made. The average charged multiplicity has an energy dependence much stronger than ln s and similar to that reported for pp collisions. Quantitative differences are observed in the magnitude of both the average multiplicity $\langle n_{ch} \rangle$ and the dispersion D_{ch} for e^+e^- and pp interactions at the same center of mass energy. $\langle n_{ch} \rangle$ and the ratio $\langle n_{ch} \rangle / D_{ch}$ in e^+e^- annihilations are significantly larger than in pp collisions and are found to be in overall agreement with QCD predictions. KNO scaling is seen to be satisfied.

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In this letter we present a study of the charged multiplicities of the hadrons produced in e^+e^- annihilations at c.m. energies of 9.4, 12, 13, 17, 22, 27.6, 30, 31.6 GeV and for the interval 29.9–31.46 GeV in 20 MeV steps.

The detailed knowledge of the multiplicity distributions in e^+e^- processes is decisive for many models of particle–particle collisions [1–6]. An essential feature of these models is a consistent description of multiparticle production in different types of interactions (as e.g. hadron–hadron, lepton–lepton and lepton–hadron collisions). In particular, definite relations between the moments of the multiplicity distributions are predicted. E.g. within the framework of the Dual Unitarisation approach [1,2] one expects

$$\langle n_{ch}(s)\rangle_{pp} = 2\langle n_{ch}(\bar{s})\rangle_{e^+e^-} ,$$

$$[D_{ch}(s)/\langle n_{ch}(s)\rangle]_{pp} = (1/\sqrt{2})\, [D_{ch}(\bar{s})/\langle n_{ch}(\bar{s})\rangle]_{e^+e^-} ,$$

where $\langle n_{ch}\rangle$ is the average charged multiplicity, $D_{ch} = (\langle n_{ch}^2\rangle - \langle n_{ch}\rangle^2)^{1/2}$ is the dispersion of the charged multiplicity distribution, and $\bar{s} \approx s/5$, while in the quark exchange model [3] one gets

$$\langle n_{ch}(s)\rangle_{pp} \approx \langle n_{ch}(s)\rangle_{e^+e^-} .$$

Comparison of high energy e^+e^- data with pp results tests these relations and the underlying assumptions of the models. A quantitative prediction concerning $\langle n_{ch}\rangle$ and D_{ch} have been recently derived also in the perturbative QCD approach [4–6].

The research reported here was performed at PETRA with the PLUTO detector. The data points at 7.7 and 9.4 GeV were taken at DORIS [7]. Details concerning the detector can be found in earlier publications [7]. PLUTO detects charged particles in 87% of the full solid angle and neutrals in 94%. The average momentum resolution is $\sigma_p/p \approx 3\% p$ for charged particles above 3 GeV and $\sigma_E/E \approx 30\%/\sqrt{E}$ for neutrals (p and E in GeV). The particles originating from the interaction point traverse a vacuum pipe and 13 cylindrical proportional chambers, which represent a total of 0.25 radiation length.

Hadronic events for the present analysis were selected from a sample of events which satisfied our triggering conditions for hadronic events [8] but with the following conditions added:

(i) at least two tracks were required to form a common vertex, and

(ii) a total observed energy $\geqslant 0.4 \cdot \sqrt{s}$ ($\sqrt{s}$ = cms energy).

These selection criteria have been found to reduce the contamination from beam–gas, two-photon and QED interactions to a level below 10%.

In the selected sample of hadronic events the observed number of charged tracks does not necessarily correspond to the number of produced hadrons. Some hadron tracks are lost due to detection inefficiencies and pattern recognition problems, also some charged tracks are the products of γ conversions and decays of neutral hadrons, mainly K_s^0, Λ. To correct the observed charged multiplicity for these effects, a weighting procedure was devised and applied to each event. The weights were calculated with the help of a Monte Carlo program in which the events were generated according to the model of Ali et al. [9] ‡1, and then passed through a detector simulator. Using these Monte Carlo events, a distribution of the generated charged hadron number was obtained for each charged multiplicity observed after the detector simulator.

These distributions (each normalized to 1) were then used as the distributions of the weights for the observed charged track numbers in our data. The weights were calculated separately for each energy considered.

Such a procedure enabled us to correct the observed charged track number for:

(i) losses due to a limited acceptance,

(ii) losses due to imperfections of our track recognition and reconstruction programs,

(iii) losses of low momentum tracks ($p < 150$ MeV/c),

(iv) contamination from γ's converted inside the inner detector, and

(v) decays of $K_s^0 \to \pi^+\pi^-$ (when required in comparing data).

The final results depend slightly on the particular model used in the Monte Carlo generation and this uncertainty results in a systematic error of about 7% (for both the average charged multiplicity and the dispersion). We estimate that the overall correction factor for the average charged multiplicity, $\langle n_{ch}\rangle$, using such a

‡1 The model of Ali et al. incorporates the production of udsc(b) quarks and both soft and hard gluon emission. Initial state radiative corrections have been included.

procedure varies between 1.2 and 1.3 depending on energy.

The first two moments $\langle n_{ch} \rangle$ and D_{ch} of the corrected charged multiplicity distributions are given in table 1, together with the corresponding number of events at each energy ‡2. The errors are statistical only. For the purpose of comparing these results with those from other e^+e^- experiments at Frascati and SLAC [10] and at PETRA [11], the charged decay products of the K_S^0 were added to our $\langle n_{ch} \rangle$. This comparison is shown in fig. 1. The errors shown in this plot are the combined statistical and systematic errors. A much faster increase with energy, $\sqrt{s}$, is observed than would be expected from the behaviour at energies below $\sqrt{s} \approx 7$ GeV ($\langle n_{ch} \rangle \approx 2.1 + 0.85 \ln s$ [10]) and predicted by the Feynman scaling hypothesis [12].

Such a fast increase is expected on the basis of perturbative QCD calculations [5]. The asymptotic functional form of this increase proposed recently is [5,6]

$$\langle n_{ch} \rangle = a + b \exp [c(\ln s/\Lambda^2)^{1/2}] \ .$$

The best fit to the data ($\chi^2/N_{DF} = 1.3$) is obtained with the following parameters:

$$a = 2.38 \pm 0.09, \quad b = 0.04 \pm 0.01 ,$$

$$c = 1.92 \pm 0.07.$$

In this fit Λ was assumed to be 0.5 GeV. The value of

‡2 The energy interval 29.9–31.6 was divided into three bins with average energy values of 30.2, 30.7 and 31.3 GeV. In the plots these three points are merged into one.

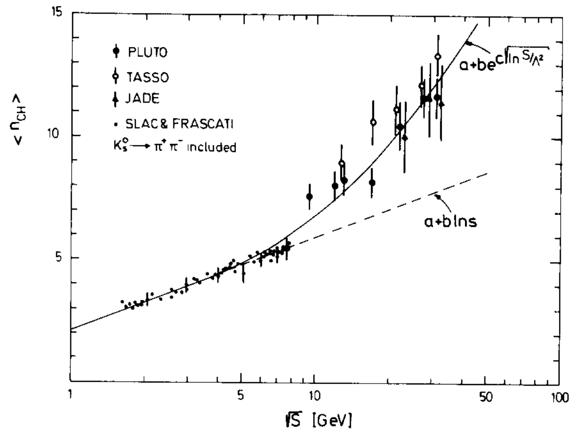

Fig. 1. Energy dependence of the average charged multiplicity for e^+e^- annihilations. Data below 7 GeV are from Frascati and SLAC [10] and at higher energies from DORIS [7] and PETRA [11]. Only for a few Frascati and SLAC points errors are marked. JADE points are the observed multiplicities. Both statistical and systematic errors are included. $K_S^0 \to \pi^+\pi^-$ decays are included.

the parameter c is different from its predicted asymptotic value of 2.4 [6]. But an acceptable fit can be obtained also with fixed $c = 2.4$. Also simpler functions fit the data equally well, like

$$\langle n_{ch} \rangle = (2.96 \pm 0.03) + (0.18 \pm 0.01)\ln^2 s$$

$$(\chi^2/N_{DF} = 1.5),$$

and

$$\langle n_{ch} \rangle = (1.73 \pm 0.03)s^{(0.34 \pm 0.01)} \quad (\chi^2/N_{DF} = 1.2).$$

Table 1
Average charged multiplicity and dispersion, corrected for detector inefficiencies, converted γ's and K_S^0 decays. The errors are statistical. Systematic errors on $\langle n_{ch} \rangle$ and D_{ch} are ≈7%.

cms energy (GeV)	Number of events	$\langle n_{ch} \rangle$	D_{ch}	$\langle n_{ch} \rangle / D_{ch}$
9.4	446	6.9 ± 0.1	2.2 ± 0.2	3.2 ± 0.2
12.0	244	7.4 ± 0.2	2.7 ± 0.3	2.7 ± 0.3
13.0	82	7.4 ± 0.3	2.5 ± 0.4	2.9 ± 0.5
17.0	99	8.0 ± 0.3	3.4 ± 0.5	2.4 ± 0.4
22.0	29	9.7 ± 0.7	3.3 ± 0.9	2.9 ± 0.9
27.6	178	10.4 ± 0.3	3.5 ± 0.4	2.9 ± 0.4
30.2	516	10.4 ± 0.2	3.8 ± 0.2	2.8 ± 0.2
30.7	213	10.6 ± 0.3	3.7 ± 0.4	2.9 ± 0.3
31.3	221	11.0 ± 0.3	3.9 ± 0.4	2.8 ± 0.3
29.9–31.6	950	10.6 ± 0.1	3.8 ± 0.2	2.8 ± 0.1

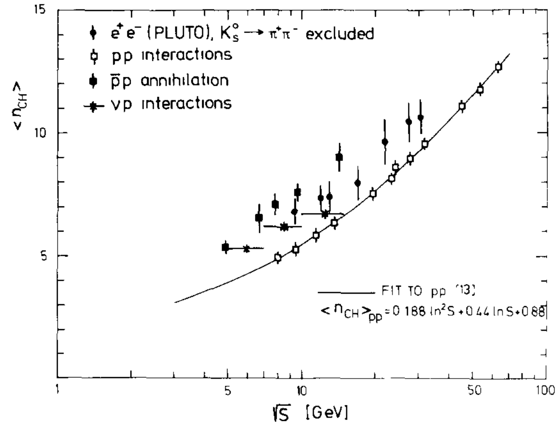

Fig. 2. Comparison of the average charged multiplicities in e^+e^- annihilations (PLUTO results, present study), pp interactions [13], $\bar{p}p$ annihilations [14] and νp [15] interactions. $K_s^0 \to \pi^+\pi^-$ decays are excluded.

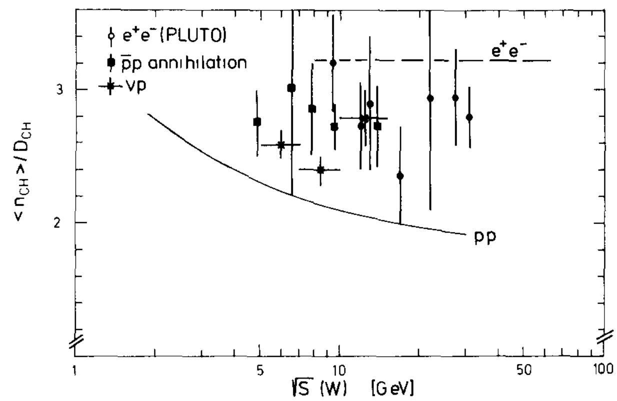

Fig. 3. Energy dependence of the ratio $\langle n_{ch}\rangle / D_{ch}$. For comparison data from pp [13], $\bar{p}p$ annihilations [14] and νp [15] interactions are also shown. The dashed line indicates the QCD prediction [4] for e^+e^-.

The comparison of $\langle n_{ch}\rangle$ [‡3] with the results from other types of interaction [13–15] is shown in fig. 2. Over the whole energy interval, ≈9–32 GeV, the pp data points lie systematically lower than those for e^+e^- interactions, although their overall energy dependence seems to be very similar. This would seem to suggest the presence of a strong long range correlation in e^+e^- interactions at high energies, as is observed in pp interactions [2]. Below $\sqrt{s} \approx 5$ GeV the points for e^+e^- and $\bar{p}p$ annihilations (not shown in fig. 2) coincide (both are well fitted by $\langle n_{ch}\rangle \approx 2.1 \pm 0.85 \ln s$), whereas at higher energies the $\bar{p}p$ data are higher by about 1 unit. The few high energy νp points seem to agree with the e^+e^- data.

The dispersion increases with energy roughly at the same rate as $\langle n_{ch}\rangle$ and thus the ratio $\langle n_{ch}\rangle / D_{ch}$ is approximately energy independent (see table 1). This is very similar to the situation observed in pp collisions, however, the values of the dispersion observed in e^+e^- collisions are systematically lower than those reported for pp interactions (a fit to pp data gives $D_{pp} = 0.58 \times \langle n_{ch}\rangle - 0.56$, with $D_{pp} \approx 4.8$ at $\sqrt{s} = 30$ GeV). This is not unexpected since particle production in pp collisions is believed to be more complex than in e^+e^-

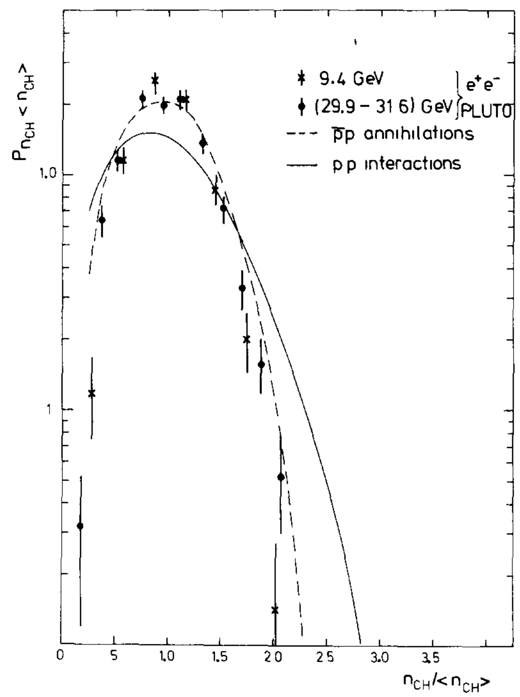

Fig. 4. KNO plot for e^+e^- annihilation (PLUTO data at 9.4 and 30.7 GeV). The dashed curve is the fit to $\bar{p}p$ annihilations [16] and the the full curve is for high energy pp collisions [13].

‡3 Note that our $\langle n_{ch}\rangle$ values do not include K_s^0 decay products as is also the case for most of the pp, $p\bar{p}$ and νp data (bubble chamber data).

annihilation. An even clearer difference between these two types of interactions can be observed in the ratio $\langle n_{ch} \rangle / D_{ch}$ shown in fig. 3. Despite large errors the e^+e^- points lie systematically above the pp curve [13] and fall in between the high energy $p\bar{p}$ and νp data [14,15]. This is inconsistent with the prediction of the Dual Unitarisation type models [1,2]. The observed value of $\langle n_{ch} \rangle / D_{ch}$ is in fair agreement with the QCD prediction of 3.2 [4].

The charged multiplicity distribution is shown in fig. 4 on a Koba–Nielsen–Olesen plot [17] in which $\langle n_{ch} \rangle P_{n_{ch}}$ is plotted versus $n_{ch}/\langle n_{ch} \rangle$ for the 9.4 and 30.7 GeV data, where $P_{n_{ch}}$ is the probability of observing the charged multiplicity n_{ch}. In this plot the multiplicity distribution at different energies should coincide if the Koba–Nielsen–Olesen scaling hypothesis is satisfied. Despite the 20 GeV difference between the cms energy, the data points at 9.4 and 30.7 GeV fall on each other. It can be also seen that the shape of the e^+e^- multiplicity distribution is quite similar to that observed in $\bar{p}p$ annihilations (dashed curve) and is narrower than the one for the pp case (full curve).

In summary, the average charged multiplicity observed in e^+e^- collisions at cms energies above ≈ 10 GeV increases with energy much faster than ln s, the ratio of the average charged multiplicity over the dispersion is approximately energy independent and KNO scaling seems to be satisfied. This is similar to the situation observed in pp collisions, but the actual values of both the average $\langle n_{ch} \rangle$ and the ratio $\langle n_{ch} \rangle / D_{ch}$ exceeds those reported for pp interactions, and are inconsistent with the predictions of e.g. the Dual Unitarisation type models. An overall agreement with the perturbative QCD predictions is observed.

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