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MULTIPLICITIES IN HIGH ENERGY INTERACTIONS

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Introduction

Charged particle multiplicities in hadronic collision have been measured for all energies up to $\sqrt{s}$ = 540 GeV in the center of mass. Similar measurements in e^+e^- annihilation cover the much smaller range - up to $\sqrt{s}$ = 40 GeV. Data is also available from deep inelastic neutrino scattering up to $\sqrt{s}$ ~ 10 GeV.

The experiments measure the mean charged multiplicity $< N_{ch} >$, the rapidity density at y = 0, and the distributions in prong number. The mean number of photons associated with the events can be used to measure the π^0 and η^0 multiplicities. Some information is also available on the charged pion, kaon, and nucleon fractions as well as the K^0 and Λ^0 rates and for the higher energy data, the Ξ fraction. We review this data and consider the implications of extrapolations to SSC energies.

Multiplicities

A fit to the available data on $< N_{ch} >$ for pp collisions using the form

$$< N_{ch} > = a + b \ln s + c \ln^2 s \quad , \qquad (1)$$

which represents the data up to ISR energies well gives a = 0.88 ± 0.10, b = 0.44 ± 0.05, and c = 0.118 ± 0.006 for $\sqrt{s}$ in GeV. This parameterization, shown by the full line in Fig. 1, gives $< N_{ch} >$ = 25.1 at $\sqrt{s}$ = 540 GeV in good agreement with the value of 26.8 ± 2.1 reported by the UA5 collaboration.[2] An a + b ln S form would be appropriate if the rapidity density remained constant and rapidity plateau merely widened as the available energy increases. Since a $\ln^2 S$ term is required, this simple expectation is not valid. At 40 TeV in the center of mass, Eq. (1) gives $< N_{ch} >$ = 63.2. This extrapolation may be an underestimate since the fraction of hard collisions which tend to populate the central region is increasing rapidly with energy and approaches unity for SSC energies.

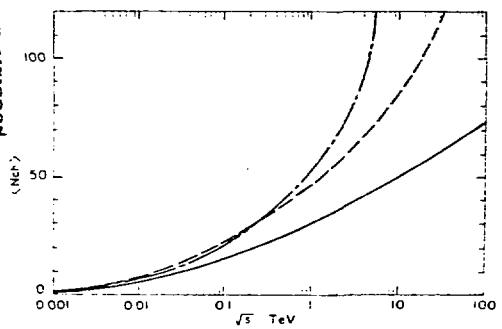

Fig. 1. Mean charged multiplicity in pp collisions (full line) and e^+e^- annihilation according to two parameterizations (dashed line and dashed-dotted line).

The e^+e^- data shows a somewhat faster increase with energy. A fit of the PETRA data[3] to Eq. (1) gives a = 3.33 ± 0.11, b = −0.4 ± 0.08, and c = 0.26 ± 0.01, shown as a dashed line in Fig. 1.[4] The expected asymptotic behavior of $< N_{ch} >$ in QCD[4] is

$$< N_{ch} > = a\{\ln \frac{Q}{\Lambda}\}^b \exp\{c\ln \frac{Q}{\Lambda}\}^{1/2} \quad , \qquad (2)$$

where for five flavors b = −0.492 and c = 6.26 with Λ = 0.25 GeV. Normalizing at $\sqrt{s}$ = 29 GeV to the HRS measurement[5] of $< N_{ch} >$ = 11.7 after removing charged particles from K^0 and Λ decay, gives a = 0.108. The parameterization is shown as the dashed-dotted line in Fig. 1. Both e^+e^- parameterizations give similar predictions up to 1 TeV, which is the region of interest for high $P_\perp$ jets at the SSC.

If events with two very high p_T jets gave multiplicities that just resulted from the addition of two e^+e^- jets to a minimum bias hadronic event, then the charged multiplicities for an event with, say, two 0.5 TeV jets would be ~ 80 + 63 = 143 charged particles. This is almost certainly an underestimate as it ignores all initial state radiation effects as well as the possibility of the spectator partons also being forced off shell and so radiating.

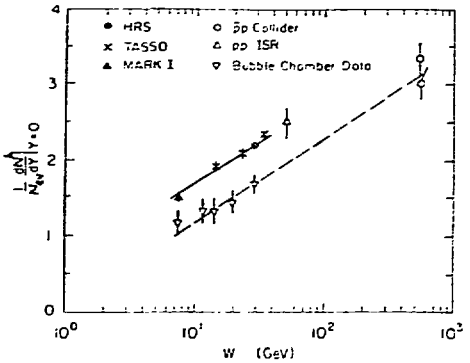

Fig. 2. Energy variation of rapidity density at y=0 for e^+e^- annihilation (full line) and pp collisions (dashed line).

The rapidity density at y = 0 increases with $\sqrt{s}$ as a + b ln $\sqrt{s}$, as shown in Fig. 2.[5] Extrapolating this data to $\sqrt{s}$ = 40 TeV gives dn/dy = 5.5 charged particles per unit of rapidity near y = 0.

At high energies, the number of γ rays increases linearly with N_{ch}. At $\sqrt{s}$ = 0.54 TeV, the data[6] can be fit by :

$$N_\gamma = (8 \pm 3) + (0.90 \pm 0.08)\ N_{ch} \quad . \qquad (3)$$

The correlation is similar to, but stronger than, that observed at Fermilab and ISR energies.

Heavy Particle Fractions

The fraction of heavier particles grows up with energy as shown in Fig. 3 with ratios K/π ~ 12% and $\bar{p}/\pi$ ~ 6% at 0.54 TeV. The lower energy e^+e^- data have relatively more heavy particles: for example, at 30

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GeV the average event contains 10 $\pi^{\pm}$, 1.8 $K^{\pm}$, 1.8 K^{o}, 0.7 $p\bar{p}$ and 0.025 Ξ^{-}. A recent observation of Ξ^{-} production by UA5 group[6] of $0.08 \pm {}^{0.03}_{0.02}$, however, is significantly higher than the above $e^{+}e^{-}$ value.

The $< p_T >$ value grows strongly above Fermilab energies, particularly for the heavier particles as shown in Fig. 4.[6]

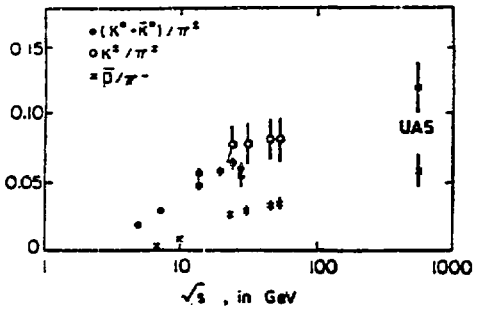

Fig. 3. Heavy particle fractions in pp and $\bar{p}p$ collisions.

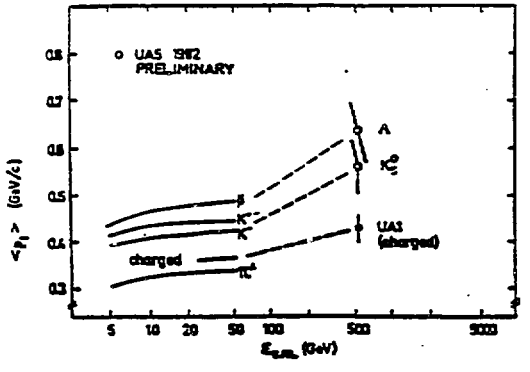

Fig. 4. $< p_T >$ values in pp and $\bar{p}p$ collisions.

Multiplicity Distributions

The hard and soft collisions show a major difference in the shape of the multiplicity distributions. The hard collisions have a much narrower prong distribution than do the non-diffractive pp collisions. The $< N_{ch} >/D$ ratio is = 3 for $e^{+}e^{-}$ annihilation and = 2 for pp and $\bar{p}p$ collisions as shown in Fig. 5.[3]

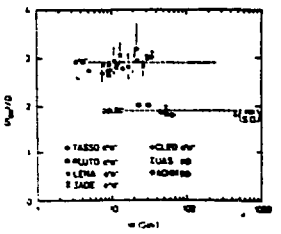

Fig. 5. $< N_{ch} > D$ ratios for $e^{+}e^{-}$ annihilation and pp, $\bar{p}p$ collisions.

Each set of data, however, separately satisfies KNO scaling: if $Z = N_{ch}/< N_{ch} >$, then $< N_{ch} > \sigma_n/\Sigma\sigma_n$ is a universal function $\psi(z)$.

Proton-proton data up to ISR energies satisfy this scaling quite well as shown by the energy variation of the moments $C_q = < n^q >/< n >^q$ in Fig. 6. At collider energies, however, the multiplicity distribution in the KNO form becomes much wider.[7] Furthermore, as seen in Fig. 7, the central region $|\eta| < 0.5$ is even broader than the total distribution $|\eta| < 5.0$. Liu and Meng[8] parameterize the KNO scale breaking in terms of a parameter α, where $\alpha = 1 - 6.8/< N_{ch_{2z}} >$, so that at very high energies $\alpha \sim 1$ and $\psi(Z) \sim 4Ze^{-2Z}$. This form fits the UA5 data for $|\eta| < 0.5$. If this is indeed the asymptotic form, then events with $Z = 5$ or $< N_{ch} > = 315$ will occur at the SSC with a frequency of 10^{-3}.

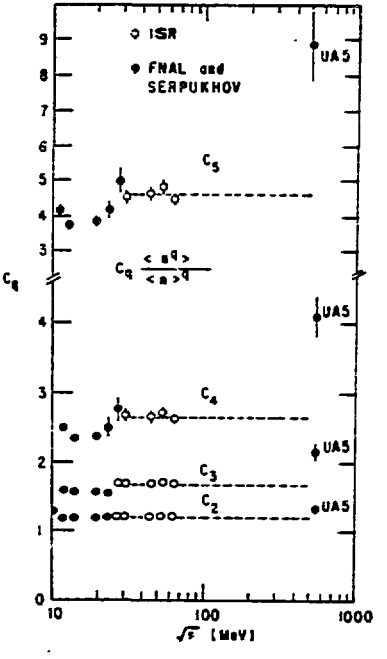

Fig. 6. Multiplicity distribution for $pp/\bar{p}p$ collisions.

There have been various attempts at understanding the KNO scaling phenomena, none of them completely convincing. A broader distribution will obviously result from the addition of several distributions with different mean values. Diffractive and non-diffractive interactions provide examples of two such processes[9] and, of course, the former is absent in $e^{+}e^{-}$ annihilation. The dual model in which the number of chains increases with energy offers another good explanation.[10]

Carruthers and Shih[11] have pointed out that the UA5 data can be fit with the negative binomial distribution, which in the KNO limit is:

$$< n > P_n^a = \frac{a_a}{(a-1)!} z^{a-1} e^{-az} \quad . \qquad (4)$$

This is the distribution expected from a, independent

identical sources with mean values $< n >/m$. The UA5 data is fit with m = 3, although m = 2, which gives the Liu and Meng form is also satisfactory. Present data does not measure a significant change of m with energy.

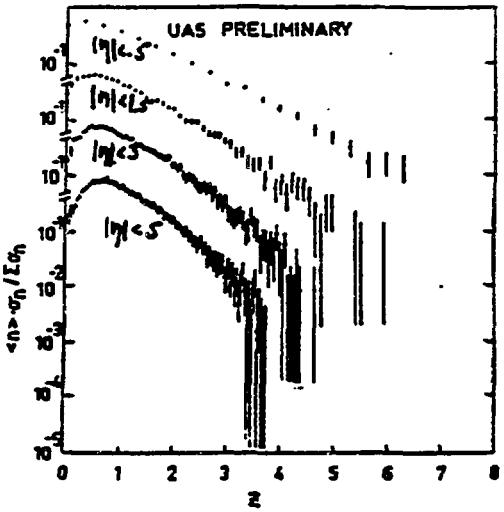

Fig. 7. KNO distribution for $\bar{p}p$ collisions at 540 GeV.

Correlations

A final major difference between e^+e^- data and hadronic beam jets is in the absence of forward:backward correlations in the former case as compared to the strong effects seen for the beam jets. The UA5 data[12] when fit by:

$$< N_F > = a + b\, N_B \qquad (5)$$

gives b = 0.57 ± 0.01. The slope parameter decreases linearly as a larger and larger rapidity gap is imposed between the F and B regions, but b ~ 0.1 even for a rapidity gap of 6 units. A similar but weaker effect is seen in the ISR data.

The correlations on the rapidity plateau, however, in both e^+e^- data and for all of the hadronic data shows a similar short-range effect over ≈ 1 unit of rapidity.

The hadronic F:B correlations, as well as the rapidity correlations can be jointly explained in a model of independent emission of low clusters.[13] This model, however, does not obviously explain the difference with the e^+e^- results. At the SSC, many events will contain two jets coming from hard collisions as well as the beam jets and so will provide a laboratory for exploring these diferences within a single experiment.

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