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INTERMITTENCY IN e^+e^- AND LEPTON-HADRON COLLISIONS

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ABSTRACT

The intermittency data in e^+e^- and lepton-hadron collisions are reviewed. The power-law behavior of the moments has been established by various e^+e^- experiments and a μp experiment. The intermittency in the two-dimensional space of rapidity and azimuthal angle is much stronger than in the rapidity space only. The neutrino-nucleus data indicate significant effects from nuclear reinteractions. The LUND parton shower model fits the data better than the matrix element model without special retuning. The relations among the moments of different orders are in good agreement with the predictions by the negative binomial and pure birth distributions. The origin of the intermittency in e^+e^- and μp collisions is consistent with the self-similar cascade mechanism of jet formation.

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The intermittency data in e^+e^- and lepton-hadron collisions are reviewed. The power-law behavior of the moments has been established by various e^+e^- experiments and a μp experiment. The *intermittency* in the two-dimensional space of rapidity and azimuthal angle is much stronger than in the rapidity space only. The neutrino-nucleus data indicate significant effects from nuclear reinteractions. The LUND parton shower model fits the data better than the matrix element model without special retuning. The relations among the moments of different orders are in good agreement with the predictions by the negative binomial and pure birth distributions. The origin of the intermittency in e^+e^- and μp collisions is consistent with the self-similar cascade mechanism of jet formation.

INTRODUCTION

The idea of intermittency for the multiparticle production in the high energy collisions[1] has generated a considerable enthusiasm partly because of a completely new way to look into the multiparticle production at high energies and partly because of its potential to see a new physics. Now we have a lot of data and phenomenologies. Therefore, it is time to summarize the experimental and theoretical status. In this talk, we briefly review the intermittency data only in e^+e^- and lepton-hadron collisions and compare them to various models. The intermittency is defined here as non-statistical fluctuations at different scales which do not occupy the full available phase space. It leads to a power-law dependence of factorial moments on a phase space resolution such as rapidity interval. This definition is purely experimental and the word "intermittency" does not necessarily mean a "new physics".

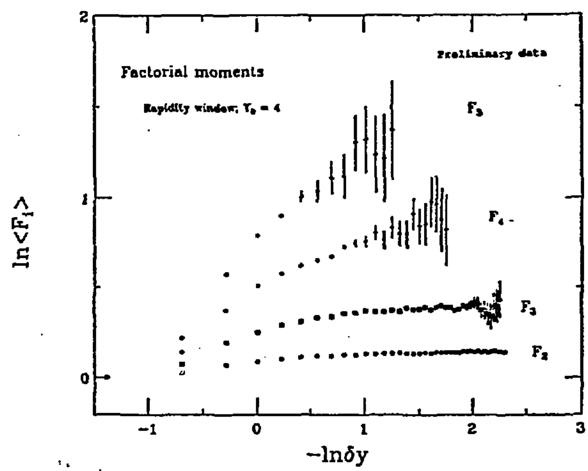

Fig. 1

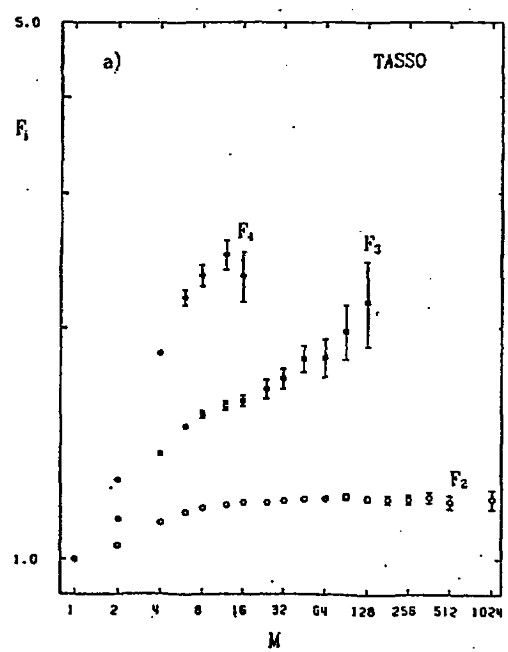

Fig. 2

EXPERIMENTAL RESULTS

There are results from four e^+e^- experiments (CELLO[2], DELPHI[3], HRS[4], and TASSO[5]), a μp experiment (EMC[6]), and a ν_μ Ne(D_2) bubble chamber experiment (WA59+E180[7]). The HRS data at $\sqrt{s}$ = 29 GeV are shown in Fig. 1 which clearly exhibit a power-law behavior (linear relation between ln F and ln δy) in the region of small rapidity intervals. The slopes increase as the moments become higher. The results are in good agreement with the TASSO data at $\sqrt{s}$ = 35 GeV shown in Fig. 2. The DELPHI data at $\sqrt{s}$ = 91 GeV shown in Fig. 3 and the CELLO data at $\sqrt{s}$ = 35 GeV shown in Fig. 4 also exhibit a linear rise in the region of $0.5 < -\ln\delta y < 2.0$ ($8 < M < 40$). The EMC data at W = 4 ~ 20 GeV are shown in Fig. 5 and the WA59+E180 data at $\langle W\rangle$ = 6.5 GeV in Fig. 6.

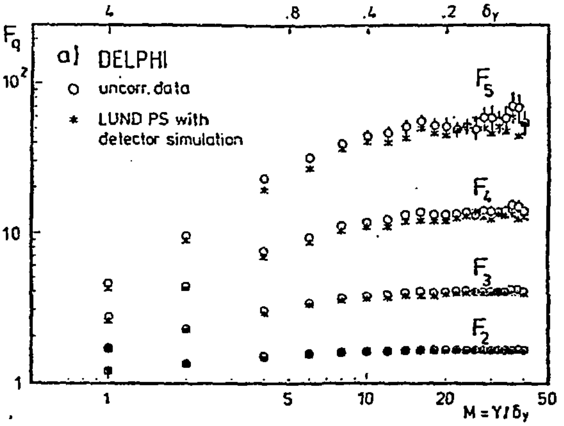

Fig. 3

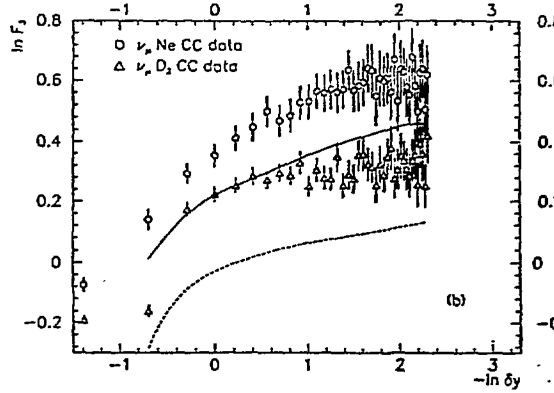

Fig. 6

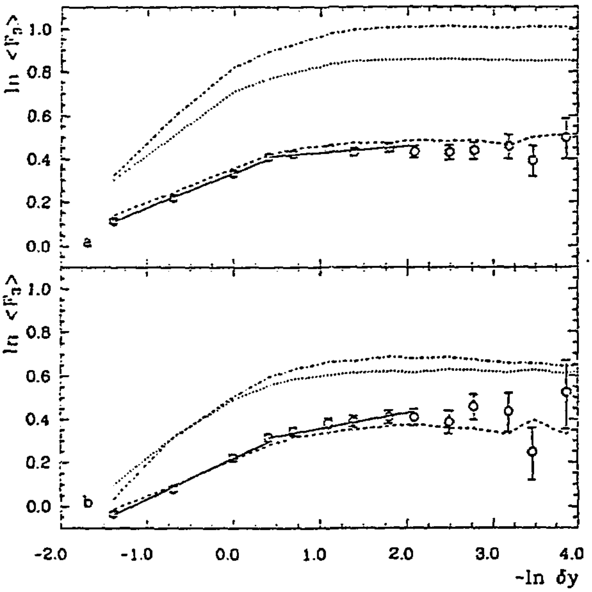

Fig. 4

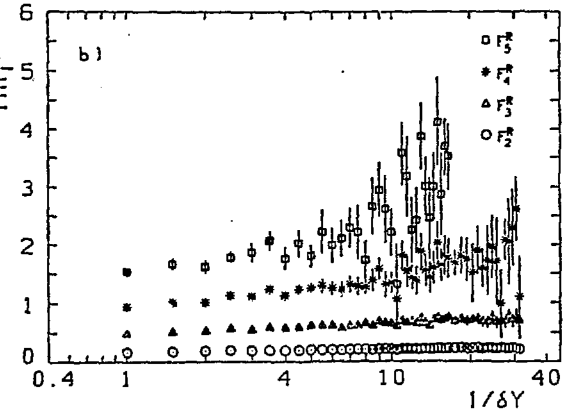

Fig. 5

The steep rise in the range of $-1.5 < -\ln \delta y < 0.5$ is mainly due to the decay particles of resonances such as ρ and ω, which have a typical correlation length of around 1 in rapidity. The moments saturate in the region of $2.0 < -\ln \delta y$, because of the detector resolution and the finite particle multiplicity.

There are several issues to be addressed before we obtain the intermittency slopes from the data. The HRS group studied the effects of different normalizations of factorial moments. The TASSO group and the HRS group used a slightly different formula from the rest of the groups. The difference was studied by the HRS group and it turned out to be an overall shift of moments to slightly lower values. There was no significant change in slopes between the two formulae.

Although the rapidity distribution between $y = -2$ and $+2$ is relatively flat, the raw data show a non-flat distribution due to a detector acceptance. The EMC group made the acceptance corrections to the moments statistically, which reduced all the slopes about 10%. The DELPHI group also studied the effect and reported that the correction would be less than 5% if applied.

A potentially large correction comes from the tracking errors; a lost track due to a chamber inefficiency or an insufficient reconstruction program would result in decreasing the moments, while a double counting of a track due to a chamber left-right ambiguity would result in increasing the moments. These corrections are specific to detectors. The TASSO group studied the effects comparing the generated Monte Carlo events to those after detector simulation. Their detector increased the moments about 10 ~ 15% after the detector simulation. The

CELLO group did a similar study and their detector decreased the moments about 15 ~ 30%. However, both groups showed that the slopes were unchanged.

The Bose-Einstein correlations among the identical bosons are expected to mimic the intermittency to some extent. In order to study the magnitude of this effect, the TASSO group looked at the moments of positive and negative charge particles separately. Both moments decreased only slightly meaning that the Bose-Einstein effects are small. The DELPHI group saw a similar trend and the EMC group had slightly increased moments. The CELLO group used a Monte Carlo program with the effects included and their moments shifted to slightly higher values than those without the effects. Therefore, the contribution from the Bose-Einstein correlations is estimated to be small, especially to the slope parameter.

In case of nuclear targets, an artificial intermittency may be induced by nuclear reinteractions. The WA59 + E180 group did a Monte Carlo study for the D_2 and Ne targets. They found that there appear noticeable slopes after the nuclear reinteractions alone, even though there are no slopes initially.

After having examined the possible biases to the intermittency slopes and having concluded that they are all small (< 10%) except the nuclear reinteractions, we can fit the data for the intermittency slopes in the e^+e^- and lepton-hadron collisions. The fitting range is usually $0.5 < -\ln \delta y < 2.0$ or $6 < M < 40$. The linear region is very limited because of the reasons mentioned previously. Since the data points in the region are highly correlated, one should take precautions in estimating the statistical errors. Some groups used only the diagonal elements of the covariance matrix. All the e^+e^- and μp data show definite slopes and they all agree with one another, thus establishing the intermittency in these collisions. The intermittency becomes stronger as the order of moments increases. The ν_μ Ne data show a similar intermittency strength but the ν_μ D_2 data indicate a weak intermittency.

The effects of intermittency are expected to be larger in the two-dimensional space of rapidity and azimuthal angle than in the rapidity space only.[8] The HRS data are shown in Fig. 7. The slopes of the two-dimensional moments are about eight times larger than those in the rapidity space alone. On the other hand, the moments in the azimuthal angle only are small and

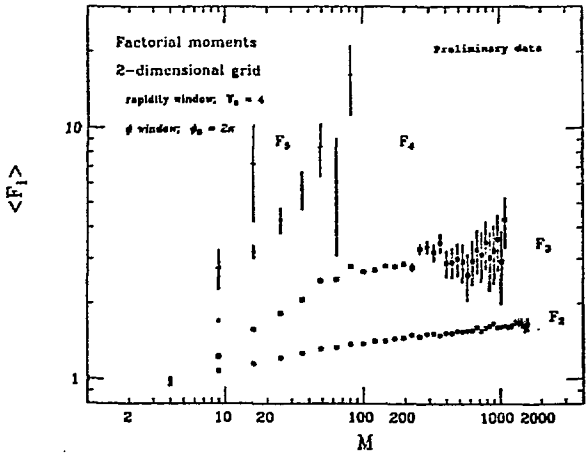

Fig. 7

flat. This is because the particles are almost uniformly distributed around the jet axis due to a local momentum conservation. The TASSO group and the EMC group report a similar enhancement.

There are also studies in other phase space variables. The HRS group measured the moments in the azimuthal angle around the beam axis (not the jet axis) and found a strong intermittency. This is because the events in e^+e^- collisions consist of well collimated jets of particles. Although the single particle distribution in this azimuthal angle around the beam axis is flat after averaged over many events, each event has narrowly grouped particles. The DELPHI group did a similar study by using a rapidity value with respect to the beam axis.

The HRS group measured the moments centered at various rapidity positions between -2 and 2. The moments at y=0 are consistent with those previously calculated from the k-values in the negative binomial distribution fit to the multiplicity distribution data.[9] The statistical errors are large due to a lack of horizontal averaging, but there is a hint that the moments depend on the position in the rapidity space.

PHENOMENOLOGY AND MODELS

The origin of intermittency has been investigated extensively. One intriguing possibility is a fractal structure in the multiparticle production. If quarks and gluons hadronize into particles through a cascading mechanism, there should be a self-similar structure. This hypothesis can be tested by calculating a quantity $A_i = 2 a_i/i(i-1)$ from the intermittency slopes a_i and the order of moments i. They are approximately independent from the order of moments and the energy, suggesting that the observed intermittency is a reminiscent of the fractal structure of cascading mechanism.

This fractal structure is further supported by Monte Carlo models. The CELLO and DELPHI groups studied that their data are well reproduced by the LUND parton shower model without specially retuning the parameters but not by the matrix element model. However, the DELPHI group reports that the matrix element model can be retuned to fit their data. The intermittency data, even if they do not signal a new physics, are useful and sensitive to tune the parameters in a model.

The relations among the moments of various orders are predicted based on the negative binomial distribution and the pure birth distribution.[10] The higher moments calculated from the F_2 data agree well with the data.

In the hadron-hadron collisions, the intermittency is also explained by a more conventional approach of two-particle correlations.[11] A similar method may fit the e^+e^- and lepton-hadron data well. The WA59 + E180 group analyzed their data for correlations and obtained a correlation length of 0.7 and a correlation strength of 0.1 ~ 0.2.

CONCLUSIONS

The intermittency in the e^+e^- and lepton-hadron collisions has been experimentally established. The slope increases as the order of moments becomes larger. The intermittency is strongest in the simple e^+e^- and μp reactions and is weakest in the nucleus-nucleus reactions. The intermittency slopes in the two-dimensional space are about 4 ~ 8 times larger than those in the rapidity space alone. The moments in the azimuthal angle around the jet axis are small and flat indicating an almost uniform distribution of particles due to a local momentum conservation. On the other hand, the moments in the azimuthal angle around the beam axis show strong behavior of intermittency because of the jet structure of events. The neutrino-nucleus data indicate a significant effects from nuclear reinteractions.

The origin of the intermittency in e^+e^- and μp collisions is consistent with the self-similar cascade mechanism of hadronization of partons. Some data are well reproduced by the LUND parton shower model without special retuning but not by the matrix element model. The relations among the moments of various orders are in agreement with the predictions based on the negative binomial and pure birth distributions.

In the future, analyses in the even higher dimensional space should be done with a careful choice of variables. The dependence on the position in the rapidity space and on the transverse momentum should be studied further. The connection to the fractal may open up a new way to understand the hadronization mechanism of quarks and gluons which is currently beyond the perturbative QCD.

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