第24卷 第3期 高 能 物 理 与 核 物 理 Vol.24, No.3
2000年3月 HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS Mar., 2000

On the Origin of the Negative Correlation Effect of Colour Reconnection *

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Abstract The negative correlation in $W^+ W^-$ hadronic decay, which has recently been proposed as a possible signal for the colour reconnection in these processes, is studied in some detail by using the random cascading α-model. The effect of colour reconnection is modeled by the particle exchange between two final state systems forming from two W's. The negative correlation given by Pythia event generator is recovered in this way, providing a physical picture for this effect.

Key words colour reconnection, factorial correlator, negative correlation

Recently, colour reconnection[1,2], which may happen between pairs of quarks and anti-quarks ($q_1\bar{q}_2$) and ($q_3\bar{q}_4$) originating from the decay of different W's, has drawn much attention[3]. It is because that color reconnection not only can influence the measurement of the W-mass in the fully hadronic $W^+ W^-$ decay channel at LEP2, but also can give essential information on the structure of the QCD vacuum and the space-time development of a $q\bar{q}$ system. However, no experimental evidence for it has ever been observed.

It is well known[3,4] that the averaged observables, such as the shift $\Delta\langle n_{ch}\rangle$ and $\Delta\langle x_p\rangle$ of the charged multiplicity and of the scaled momentum, the mean values of the thrust distribution $\langle 1-T\rangle$, the rapidity distribution relative to the thrust axis $P(y)$ were not particularly sensitive to the effects of colour reconnection. More recently, it is suggested[5] that the behaviour of factorial correlator[6] between the W^+ and W^- systems can be used as a sensible signal of colour reconnection. Using the Pythia event generator to simulate the hadronic decay of WW in LEP2, it is found that colour reconnection results in a negative correlation between the two momentum intervals taken from the W^+ and W^- systems respectively. The nearer the distance D between the two intervals, the stronger the negative correlation.

Since this effect is a promising one to be used as a signal of colour reconnection, it is interesting to ask the question: From where it comes? What is the physical mechanism that leads to the negative correlation? In order to answer this question, in this letter, we use α-model[6] to study the behaviour of factorial correlators of the two W^+ and W^- systems.

Received 7 September 1999
* Project (19575021) supported by NSFC
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The factorial correlators are defined as[6]

$$\langle F_{ij}^{mm'} \rangle = \frac{\langle n_m(n_m-1)\cdots(n_m-i+1)n_{m'}(n_{m'}-1)\cdots(n_{m'}-j+1)\rangle}{\langle n_m(n_m-1)\cdots(n_m-i+1)\rangle\langle n_{m'}(n_{m'}-1)\cdots(n_{m'}-j+1)\rangle}, \quad (1)$$

where n_m and $n_{m'}$ are the multiplicities in the mth and m'th bins respectively. In a fractal system, F_{ij} has the anomalous scaling property

$$\langle F_{ij} \rangle \propto (\Delta/D)^{f_{ij}}, \quad (2)$$

where D is the distance between the two bins.

Let us denote the factorial correlators between two bins m and m' coming from two different systems W^+ and W^-, respectively, as F_{ij}^{+-}. For the case without colour reconnection, the two systems are independent, and therefore the factorial correlator F_{ij}^{+-} will be independent of D and the scaling index f_{ij}^{+-} vanishes. On the other hand, for the case with colour reconnection, some correlation between the two systems will appear resulting in a non-vanishing f_{ij}^{+-}.

In order to be more definite, let us suppose that colour reconnection leads to particles moving from one system to the other between the two W^+ and W^- systems, or in other words, the colour flow between the decay products of the two W bosons results in a momentum shift in the multiparticle final state, It is understandable that small change in momentum is more easy to happen than larger ones, so in momentum space, the nearer the two bins, the larger the probability of particle exchange. It means that the particle exchange between the two systems has inhomogeneous probability density, decreasing with the increasing of the distance between the two bins.

We take two systems both producing from the random cascading α-model to simulate the multi-hadronic final states coming from W^+ and W^- respectively. This model describes each multiparticle system as a series of step, in which the initial phase space region Δ is repeatedly divided into $\lambda=2$ parts. After ν steps we get in total $M=2^\nu$ sub-cells of size $\delta=\Delta/M$. At each step s the particle density for each of the two parts is obtained by multiplication of the density in the step $s-1$ by a particular value of the random variable $\omega_{\upsilon j_\upsilon}$, where j_υ is the position of a sub-cell at the υth step $(1 \leq j_\upsilon \leq 2^\upsilon)$. The elementary fluctuation probability $\omega_{\upsilon j_\upsilon}$ is chosen as

$$\omega_{\upsilon,2j-1} = \frac{1}{2}(1+\alpha r_1), \qquad \omega_{\upsilon,2j} = \frac{1}{2}(1+\alpha r_2), \quad (3)$$

in which, r_1 and r_2 are random numbers distributed uniformly in the interval $[-1,1]$, α is a model parameter, characterizing the strength of fluctuations. In our calculation, we have chosen its value as $\alpha=0.3$.

Note that the elementary partition probability (3) is unnormalized, in contrast to the commonly used expression[7], which is normalized in each step. This is to avoid extra correlation between bins. Only at the last step the probabilities of the $M=2^\upsilon$ bins are normalized to unity.

For each of the two α-model systems, the total multiplicity is fixed at 19, which is near to the average charged multiplicity of each W[4]. The distribution of these particles in the M bins is determined by the probability distribution p_m ($m = 1, 2, \ldots, M$) through Bernoulli multinomial fluctuation.

The probability of colour recoupling can be estimated as about 20% to 38%[2]. In our model we take the recoupling probability to be 30%.

Our basic physical picture is that the colour flow between the decay products of the two W bosons results in a momentum shift in the multiparticle final state. This means that the main effect of colour reconnection is the moving of particles from the phase space region of one system to that of the other system. From the symmetry consideration it is natural to assume that in each event the chance for particle to move from the mth bin of W^+ to the m'th bin of W^- or from the m'th bin of W^- to the mth bin of W^+ is equal. This probability should be a monotonically diminishing function of the distance $d_{mm'}^{+-}$ between the mth and m'th bin. i.e. the smaller the $d_{mm'}^{+-}$, the bigger the probability of particle-moving. For simplicity we take the function as $e^{-d_{mm'}^{+-}}$. The unit of $d_{mm'}^{+-}$ is taken to be the bin-width δ.

We have calculated F_{11}^{++} of W^+ system and F_{11}^{--} of W^- system for both cases with and without colour reconnection, cf. Fig. 1. The F_{11}^{+-} for bins taken from W^+ W^- systems separately are shown in Fig. 2., also for both cases with and without colour reconnection.

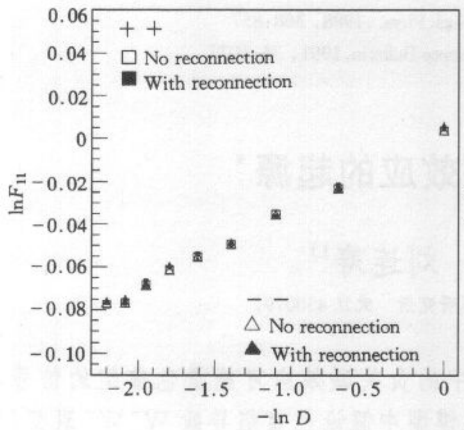

Fig. 1. The factorial correlator for a single system ——W^+ or W^-, with and without colour reconnection.

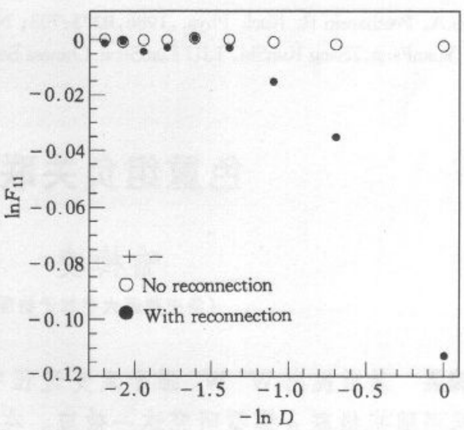

Fig. 2 The factorial correlator between two systems W^+ and W^-, with and without colour reconnection.

It can be seen from Fig. 1 that the factorial correlator F_{11} for a single system is always the same, no matter whether it is W^+ or W^- and whether there is colour reconnection or not. This means that colour reconnection does not affect the anomalous scaling property of each W system.

Fig. 2. shows clearly that without colour reconnection, the F_{ij}^{+-} are almost identical to unity,

while for the case with colour reconnection the F_{ij}^{+-} becomes smaller and falls down rapidly with the decreasing of bin-distance ,or the increasing of $-\ln D$. This means that colour reconnection leads to negative correlation and the smaller the distance between bins, the stronger the effect . This is consistent with the result of Pythia event generator.

In this letter the effect of colour reconnection is modeled by the particle exchange between the final state systems forming from the two W's. The probability density in momentum space for the particle exchange is proposed to be a monotonically diminishing function of the distance between bins, i. e. the smaller the distance between bins, the bigger the probability of particle-moving. In this way the behaviour of the factorial correlator obtained from Pythia Monte Carlo simulation is reproduced. This shows that a possible reason for the negative correlation in colour reconnection is that the colour reconnection causes particles to be redistributed between the two W-systems, moving from one W-system to the other with a probability bigger for nearer bins.

The authors are grateful to FU JingHua for helpful discussions.

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色重组负关联效应的起源

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摘要　最近提出 W^+W^- 强子衰变过程中的负关联效应可能是色重组的信号。采用随机级联 α 模型研究这一效应。在模型中假设色重组导致 W^+W^- 衰变形成的两个末态系统之间的粒子发生交换。根据这一物理图象可以再现 Pythia 事件产生器所得到的负关联。

关键词　色重组　阶乘关联矩　负关联

1999－09－07 收稿

* 国家自然科学基金资助项目(19575021)

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