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An investigation of screwiness in hadronic final states from DELPHI

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Abstract

A recent theoretical model by Andersson et al. proposes that soft gluons order themselves in the form of a helix at the end of the QCD cascades. The Authors of the model present a measure of the rapidity-azimuthal angle correlation, which they call screwiness. We searched for such a signal in DELPHI data, and found no evidence for screwiness.

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1 The screwiness model

In QCD, two colour charges moving apart from each other, will produce further colour radiation, gluons. At the end of the cascade one enters into a non-perturbative region, where perturbative QCD breaks up due to the small momentum transfer and hence large strong coupling constant α_s. There are non-perturbative models to describe the transition regime between the perturbative region and final state hadrons, in which the largest contributing Feynman diagrams are chosen based on the coherence of the gluons. The gluon emissions are ordered by the transverse momentum in the dipole model [1], and by emission angle in the Webber-Marchesini model [2]. The azimuthal angle of the gluons is taken to be uniformly distributed ignoring possible spin effects.

In a recent theoretical paper [3], it is studied what happens at the end of the QCD cascades. At the end of the cascade, the soft gluons have a transverse momentum which is of the same order as the mass of the emitter, leading to a situation in which a large recoil may spoil the original coherence. With the assumptions that:

- the effective coupling $\bar{\alpha}$ is large enough so that the number of emitted gluons is as large as possible;
- the emissions fulfil helicity conservation;

the Authors show that the closest packing of soft gluons at the end of the cascades is obtained by using the extra degree of freedom provided by the azimuthal angle and arranging the gluons along a helix.

The helix is described by the parameter $\tau = dy/d\phi$, where y is rapidity and ϕ is the azimuthal angle with respect to the original parton direction. The correlation between the azimuthal angle and rapidity can be tested by using a Fourier power spectrum, which is called screwiness S in Ref. [3] and defined as:

$$S(\omega) = \sum_e P_e |\sum_j \exp(i(\omega y_j - \phi_j))|^2, \tag{1}$$

where the second sum goes over the gluons, the first sum goes over all the events, and P_e is an event weight. Screwiness would then manifest itself as a peak in the power spectrum at $\omega = 1/ < \tau >$. If a large number of gluons were emitted isotropically, there should be no peak. Asymptotically screwiness should only depend of the number of emitted gluons at large values of ω.

2 Observable screwiness

Experimentally one observes stable final state particles instead of gluons. Moreover, in such an analysis it is convenient to use charged particles only, due to the better accuracy in the measurement of the momenta at low energy. Normalized screwiness can now be defined as

$$S(\omega) = \frac{1}{N_{event} < N_{particle} >} \sum_e |\sum_j \exp(i(\omega y_j - \phi_j))|^2, \tag{2}$$

where the second sum goes over the final state particles, and the first sum goes over all the events. Rapidity $y^\dagger$ and azimuthal angle ϕ are defined with respect to the thrust axis. Ordering of the final state particles would produce a peak in the $S(\omega)$ spectrum, with a maximum peak size of $S(\omega)_{max} =< N_{particle} >$ for maximal ordering. An isotropical particle emission would give asymptotically $S(\omega) \simeq 1$ at large values of ω, and no peak. When ω approaches to zero, screwiness measures the transverse momentum balance of the final state particles and it should approach to zero.

For a fixed center-of-mass energy, a certain finite rapidity interval is available. The central rapidity plateau is not flat, producing fluctuations in the power spectrum. Selecting the central rapidity region and using only charged particles with experimental acceptance cuts, the number of final state particles available to calculate the screwiness is reduced.

In Fig. 1, the rapidity distribution, particle multiplicity and screwiness are shown for two u-quark jet events generated with the JETSET Monte Carlo simulation program, with no final state cluster ordering included. No parton showering was used. Figures a and b show the effect of final state particle selections. In both cases, the power spectrum approaches asymptotically to one, and reduces at small values of ω.

A typical screwiness spectrum is shown in Fig. 2 where the parameter τ was set to 0.3, 0.5 and 0.7. Only charged particles with $p > 0.15$ GeV/c in $|y| < 2$ were retained. A clear peak can be observed at $\omega = 1/ < \tau >$ when $\tau = 0.7$. With a τ value of 0.5 there is still peak in the spectrum which could be observable, while with $\tau = 0.3$ the winding is too fast to be observed. The events were generated similarly as in Fig. 1, i.e. using a JETSET Monte Carlo simulation program, which did not contain parton showering, but in which a helix-ordering of the final state clusters was implemented. The average multiplicity of charged particles with the above selections was 5.2, which was roughly the same as with the default JETSET (see Fig. 3).

With soft gluons included in the event generator, the transverse momentum fluctuations event-by-event cause that the screwiness does not decrease when ω goes to zero if one considers a narrow window in rapidity space with a few particles. This can be seen in Fig. 3, which shows the screwiness for events generated with the JETSET 7.4 parton shower simulation program [4] with default parameters at the Z^0 center-of-mass energy. Two-jet events were selected with a thrust cut $T > 0.98$, and the final state was required to contain at least five stable particles. As can be seen from Fig. 3, the multiplicity of particles in the event affect the behaviour of the screwiness at small values of ω. At large values of ω the normalized screwiness approaches to one, depending thus on the number of particles in the event. There are no peaks in the screwiness distributions since there is no ordering of gluons in the azimuthal angle in the JETSET simulation program.

3 Analysis of data

A sample of hadronic Z^0 decays collected in 1994 were selected by requiring that the events contained at least five charged particles within the angular range of $|\cos\theta| < 0.96$, that the thrust axis was within the angular range of $|\cos\theta_T| < 0.7$, and that the thrust value was larger than 0.98. Charged particles were accepted if the measured momentum

$^\dagger y = \frac{1}{2}\ln\frac{E+p_L}{E-p_L}$, where the longitudinal momentum p_L is calculated versus the thrust axis, and each particle is assigned the pion mass.

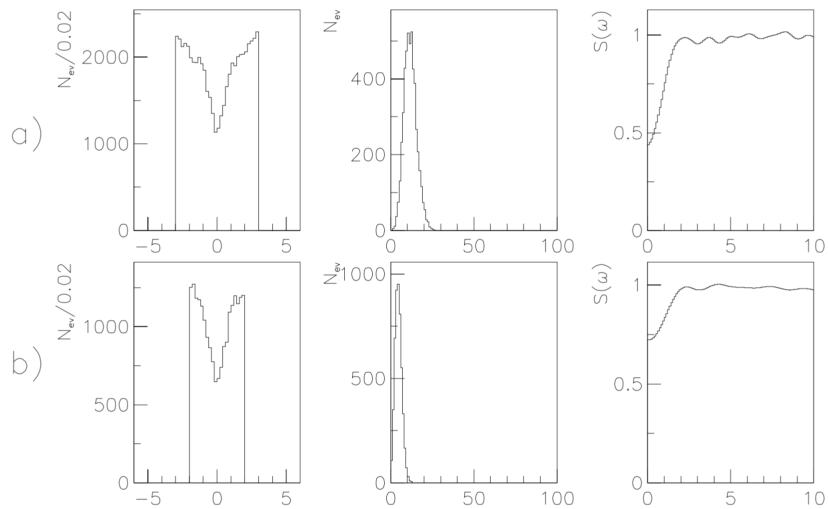

Figure 1: Rapidity distribution, particle multiplicity and screwiness for a) two u-quark jets generated with LU2ENT, retaining neutral and charged particles with $p > 0.15$ GeV/c in $|y| < 3$, and setting π^0's stable, b) events generated with LU2ENT, retaining only charged particles with $p > 0.15$ GeV/c in $|y| < 2$.

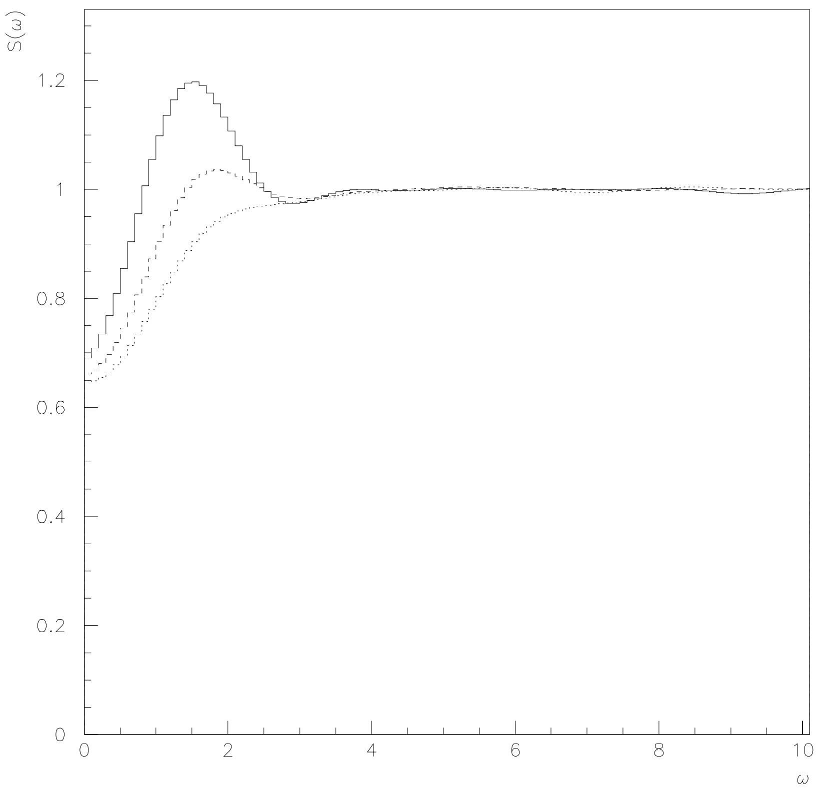

Figure 2: Power spectrum as in Eq. (2) for simulated data samples with $\tau = 0.7$ (full line), $\tau = 0.5$ (dashed line) and $\tau = 0.3$ (dotted line). Only stable charged particles with $p > 0.15$ GeV/c in $|y| < 2$ were retained.

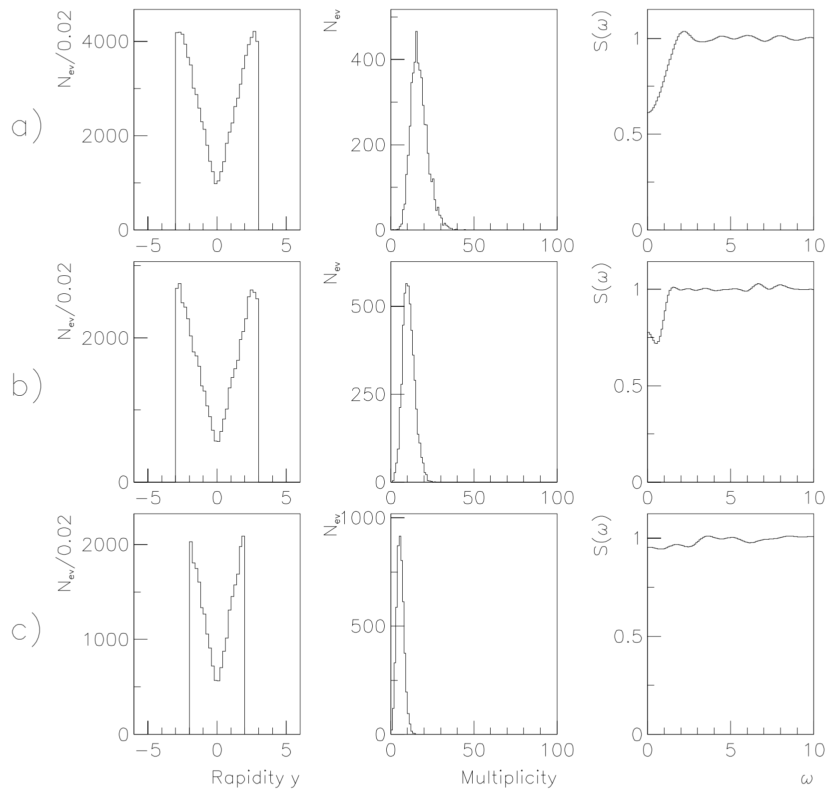

Figure 3: Rapidity distribution, particle multiplicity and screwiness for a) events generated with LUEEVT (parton shower), retaining neutral and charged particles with $p > 0.15$ GeV/c in $|y| < 3$, and setting π^0's stable, b) events generated with LUEEVT (parton shower), retaining only charged particles with $p > 0.15$ GeV/c in $|y| < 3$, c) events generated with LUEEVT (parton shower), retaining only charged particles with $p > 0.15$ GeV/c in $|y| < 2$.

was greater than 0.15 GeV/c, track length greater than 30 cm and the transverse and longitudinal impact parameters less than 5 and 10 cm, respectively. Particles within $|y| < 2$ were retained for the calculation of the power spectrum. The final selected sample used for this analysis consisted of 50,000 events.

Screwiness of the selected events, together with full simulation are shown in Fig. 4. The simulated data were generated with the JETSET 7.3 parton shower simulation program, using input parameters reproducing the main features of the DELPHI data [5]. The generated events were then simulated with the DELSIM full detector simulation program [6] and reconstructed as data. The data show no peak in the screwiness distribution, and the JETSET model, with random emission of soft gluons in the azimuthal angle, reproduces well the data distribution.

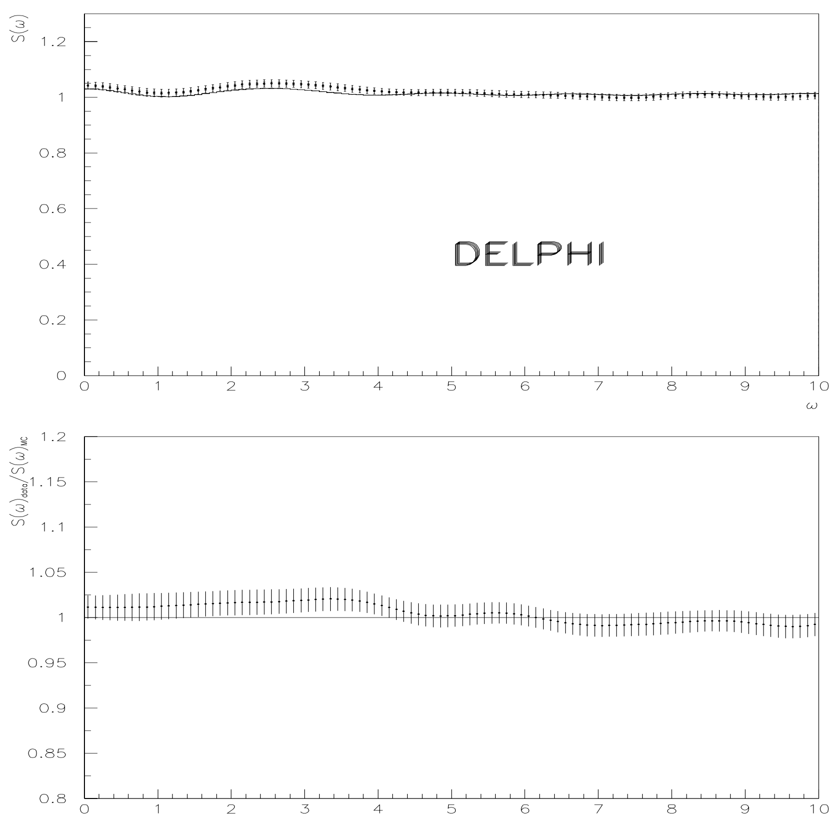

Figure 4: Upper: Power spectrum as in Eq. (2) for DELPHI data (points) compared to JETSET with full detector simulation (histogram). The inner error bars on the data points correspond to the statistical errors, the outer ones to the sum in quadrature of the statistical and systematic errors. Lower: ratio between data and simulation; the total error is shown.

The statistical error of the data was about 0.5%, computed as the standard deviation of a set of Monte Carlo simulation samples with the same population as the data. The systematic uncertainty was estimated to be around 1%. The main source of systematic uncertainty was expected to originate from the small differences in the rapidity distribution in data and simulation. The following procedure was used to estimate the inability of the simulated events to reproduce the data. The data were first weighted in such a way that the rapidity distribution was flat. The data were then weighted with the weights which would make the simulated rapidity distribution flat. The difference of the results, divided by the data distribution, was then the estimate of the relative systematic error.

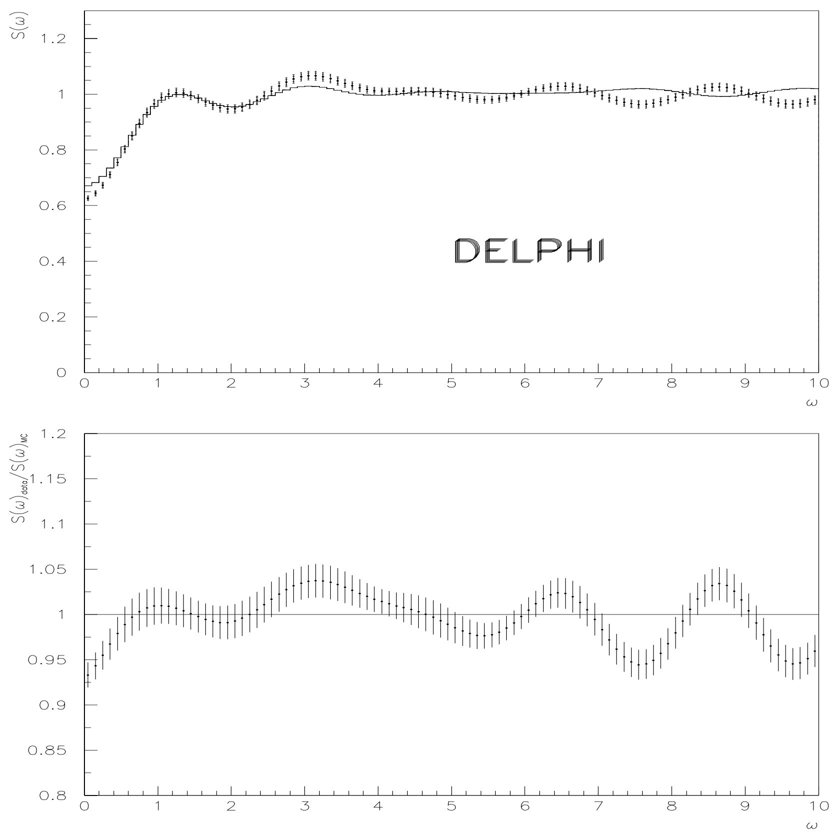

Figure 5: As in the previous figure, for events with at least five charged particles and a missing momentum component transverse to the thrust axis smaller than 1 GeV/c.

The same analysis was repeated by selecting only events with at least five charged particles with $|y| < 2$, but no effect was seen. Finally, 10,000 events were selected with at least five charged particles with $|y| < 2$ and such that the sum of the momenta of these particles had a momentum component transverse to the thrust axis smaller than 1 GeV/c (Fig. 5). The disagreement between data and simulation after these cuts is at the 5% level. The data does not show, however, a typical screwiness pattern.

4 Conclusions

Screwiness is a measure of ordering of soft gluons in azimuthal angle around the original parton. According to a recent model, soft gluons at the end of the QCD cascades order themself in the form of a helix in rapidity-azimuthal angle space, since this is an optimal close packing of gluons accounting for spin effects. Such an effect was searched for in hadronic final states of Z^0 decays in DELPHI. No evidence for screwiness was found, and results were consistent with random emission of gluons in the azimuthal angle. Given the DELPHI experimental sensitivity, it was found that the helix parameter $\tau = dy/d\phi$ cannot be larger than about 0.5.

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