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COHERENT PARTICLE PRODUCTION IN HADRONIC THREE-JET EVENTS FROM Z-DECAYS AT DELPHI

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The particle production in hadronic three-jet events from Z-decays is studied with data from the DELPHI-experiment. The topology dependence of the multiplicity produced with large angles to the event plane is compared with a LO prediction revealing a $1/N_c$-suppressed destructive gluon interference. The topology dependence of the total charged event multiplicity is compared with a MLLA prediction. A parameter fit to the data results in a precise measurement of the colour factor ratio $C_A/C_F = 2.261 \pm 0.014(\text{stat.}) \pm 0.036(\text{syst.}) \pm 0.052(\text{theor.}) \pm 0.041(\text{clus.})$. The multiplicity of two-gluon systems is extracted from the measured multiplicities over a wide range of energy scale, allowing for studies of the ratio of the multiplicities of $q\bar{q}$- and gg-systems and the ratio of the derivatives of the multiplicities w.r.t. energy.

1 Introduction

Three-jet events in e^+e^--annihilation reactions, containing two quark jets and one gluon jet, are an unique environment to study the differences in the fragmentation of quarks and gluons. Direct comparisons of identified gluon and quark jets require an explicit assignment of particles to jets. This assignment is not only dependent on the specific jet clustering algorithm used, it also neglects coherent radiation, i. e. the radiation of gluons by more than one of the primary partons. This coherent particle production in three-jet events will be addressed here with three-jet events recorded by the DELPHI experiment in the years 1992-1995 at $\sqrt{s} \simeq m_Z$. A detailed description of the experiment and its performance can be found in [1,2].

2 Multiplicity perpendicular to the event plane

Coherence effects are expected to be best visible for low energetic particles emitted perpendicular to the event plane. A LO calculation for the gluon radiation perpendicular to all emitters in a $q\bar{q}g$-ensemble [3] yields the result

$$N_3 = N_2 \cdot r_t \quad , \quad r_t = \frac{C_A}{4C_F}\left[(1-\cos\theta_{qg}) + (1-\cos\theta_{\bar{q}g}) - \frac{1}{N_C^2}(1-\cos\theta_{q\bar{q}})\right] \quad (1)$$

where N_3 denotes the multiplicity perpendicular of the event plane of a three-jet event and N_2 the multiplicity perpendicular to the event axis of a two-jet event. The topological factor r_t contains contributions from the quark–gluon colour dipole, the anti-quark–gluon colour dipole and a negative contribution suppressed by $1/N_C^2$ from destructive gluon interferences.

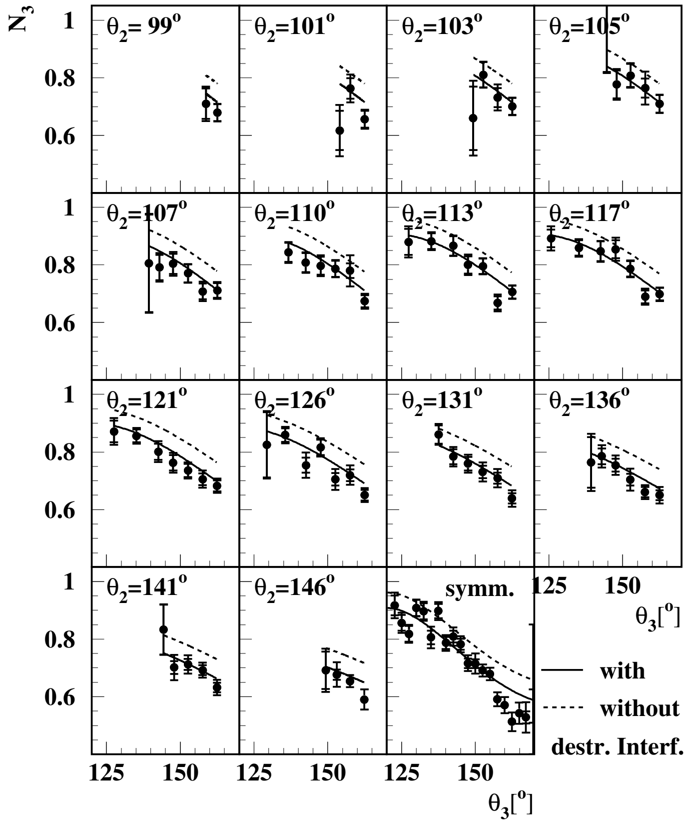

Figure 1. The multiplicity inside a 30° cone perpendicular to the event plane of a three-jet event as a function of θ_3. The solid line indicates the prediction Eq. (1), which is in good agreement with the data. Indicated by the dashed line is Eq. (1), where the destructive interference term has been omitted. Without interference, the multiplicity is significantly overestimated.

The multiplicity inside a 30°-cone perpendicular to the event plane of three jet events has been measured in dependence of the event topology [4]. Assuming massless jet kinematics, the topology of a three-jet event is determined by the inter-jet angles θ_1, θ_2 and θ_3. The angles are ordered by size with $\theta_1 < \theta_2 < \theta_3$. Three-jet events are planar, so the angles sum up to 360°. Therefore, two angles suffice to describe the event topology. Additionally, events with symmetric topology (i.e. $\theta_3 - \theta_2 < 5°$), which have an especially clear jet structure, are considered separately.

In Fig. 1 the multiplicity inside the cone is shown as a function of the inter-jet angle θ_3 for events with general topologies and varying θ_2, as well as for events with symmetric topology. The measurement has been obtained using the angular ordered Durham algorithm [5] with $y_{\rm cut} = 0.015$. The outer error bars indicate statistic plus systematic errors, to which effects of the cluster algorithm, varied $y_{\rm cut}$ and cone opening angle contribute. The solid line represents Eq. (1) which has been normalised by a measurement of N_2 performed with the respective values for cone opening and $y_{\rm cut}$. A very good description of the data by the prediction is observed except for extremely small angles θ_1 in symmetric events.

The dashed line indicates Eq. (1) without the destructive interference term. Without interference, the multiplicity is significantly overestimated. In order to give a more quantitative result, a factor k has been introduced to the $1/N_C^2$-interference term, so $k = 1$ corresponds to the complete prediction Eq. (1) and the solid line and $k = 0$ corresponds to the dashed line. k has been allowed to vary freely in a parameter fit with the result

$$k = 1.37 \pm 0.05(\text{stat.}) \pm 0.33(\text{sys.}) \quad \chi^2/N_{df} = 1.2 \tag{2}$$

for general and

$$k = 1.23 \pm 0.13(\text{stat.}) \pm 0.32(\text{sys.}) \quad \chi^2/N_{df} = 2.1 \tag{3}$$

for symmetric topologies with $\theta_1 > 48°$. Both results are in good agreement with the prediction $k = 1$ and significantly different from zero. The purely quantum-mechanical effect of destructive gluon interference, which is not included in the probabilistic parton-shower picture has been directly verified for the first time.

As the data are well described by Eq. (1), the topology factor r_t can be understood as a well-suited, one-dimensional scale variable to describe the topology of three-jet events with respect to radiation perpendicular to the event plane. Comparing the momentum distributions of particles inside the cone for different intervals of r_t, a scaling behaviour of the distributions is found for particle momenta < 1GeV confirming the LPHD-hypothesis for small momenta. A more detailed discussion of this analysis and the results can be found in [4].

3 Topology Dependence of the Three-Jet Event Multiplicity

The multiplicity of quark–anti-quark or two-gluon systems is usually compared in terms of the multiplicity ratio $r = N_{gg}/N_{q\bar{q}}$. In the limit of high energy, the ratio is expected to resemble asymptotically the QCD colour factor ratio C_A/C_F, where C_A and C_F can be interpreted as the effective colour charges of the gluon and the quark, respectively. However, multiplicity is an observable severely affected by non-perturbative effects. Therefore, the suggestion has been made to study rather the energy dependence of the multiplicity than the multiplicity itself, i. e. $r^{(1)} = N'_{gg}/N'_{q\bar{q}}$ instead of r, where the prime denotes the derivative with respect to energy [6]. A MLLA-calculation relates the energy dependence of the gluon and quark multiplicity [7]. Integrating this relation to obtain N_{gg} leaves free a constant of integration, which is taken from a direct measurement of N_{gg} at $\sqrt{s} \simeq 10$GeV [8]. The multiplicity of a three-jet event is then given by the expression [9]

$$N_{q\bar{q}g} = N_{q\bar{q}}(L_{q\bar{q}}, \kappa_{\text{L}u}) + \frac{1}{2} N_{gg}(\kappa_{\text{L}e}) \tag{4}$$

with

$$\kappa_{\text{L}u} = \ln\left(\frac{s_{qg}s_{\bar{q}g}}{s\Lambda^2}\right) = \kappa_{\text{L}e} + \ln\left(\frac{s_{q\bar{q}}}{s}\right) \quad \text{and} \quad L_{q\bar{q}} = \ln\left(\frac{s_{q\bar{q}}}{\Lambda^2}\right) \quad .$$

Coherence effects are taken into account in Eq. (4) by the proper choice of scales. The second argument of the quark contribution reflects the phase space restriction of the $q\bar{q}$-system due to the resolution of the gluon jet [7].

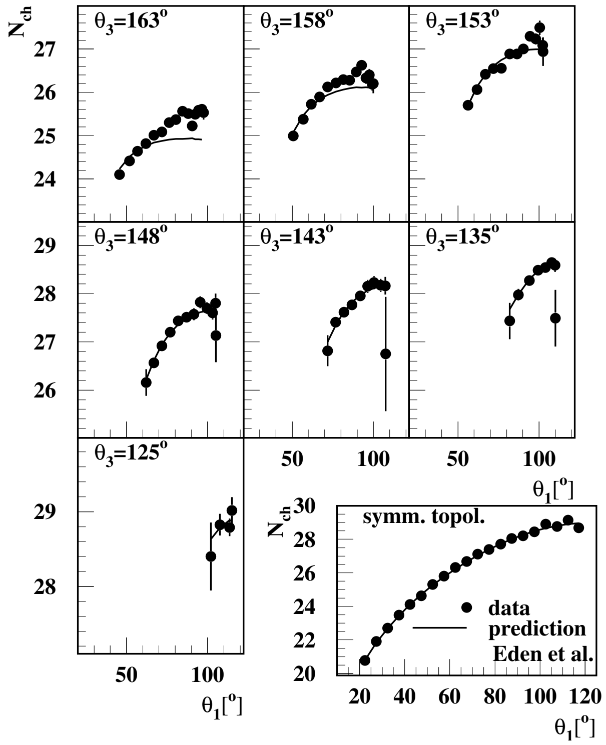

Figure 2. The charged multiplicity of three-jet events as a function of the event topology for general and symmetric topologies. The solid line indicates the prediction Eq. (4). The description of the data is excellent except for general topologies with large θ_3 in which also θ_1 is large, i. e. topologies in which jet 3 is only weak.

Assuming massless jet kinematics, the scales entering Eq. (4) can be expressed by the inter-jet angles giving the multiplicity as a function of the event topology. The prediction Eq. (4) is found in very good agreement with the data, as can be seen in Fig. 2. Deviations only occur in general topologies with large θ_3, in which also θ_1 is relatively large. This corresponds to rather two-jet like events, in which jet 3 is only weak. Note that all events are clustered into three-jets here, regardless of the value of y_{cut}. A parameter fit of the colour factor ratio C_A/C_F yields the result

$$\frac{C_A}{C_F} = 2.257 \pm 0.019_{\mathrm{stat.}} \pm 0.056_{\mathrm{exp.}} \pm 0.050_{\mathrm{theo.}} \pm 0.050_{\mathrm{clus.}} \tag{5}$$

for symmetric topologies and

$$\frac{C_A}{C_F} = 2.261 \pm 0.014_{\mathrm{stat.}} \pm 0.036_{\mathrm{exp.}} \pm 0.052_{\mathrm{theo.}} \pm 0.041_{\mathrm{clus.}} \tag{6}$$

for general topologies. Both values are in good mutual agreement and agree with the QCD expectation $C_A/C_F = 9/4$. This result is the most precise measurement of the colour factor ratio so far. Details of the analysis can be found in [10].

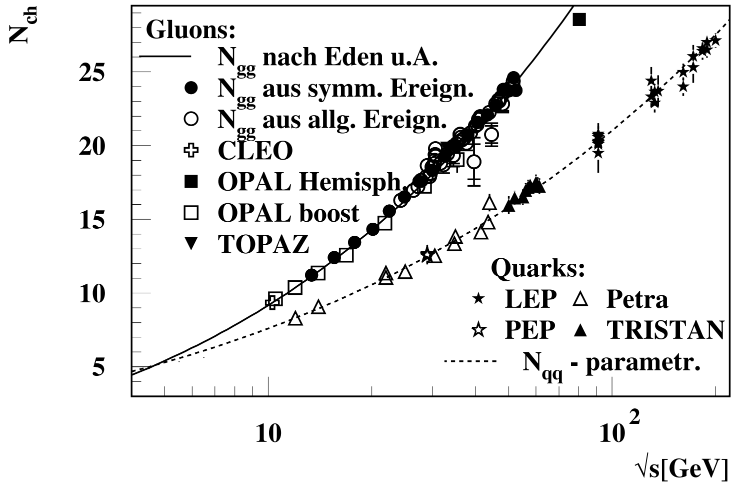

Figure 3. The multiplicity of $q\bar{q}$ and gg systems. The lines indicate a parametrisation fitted to $N_{q\bar{q}}$ and the prediction for N_{gg}.

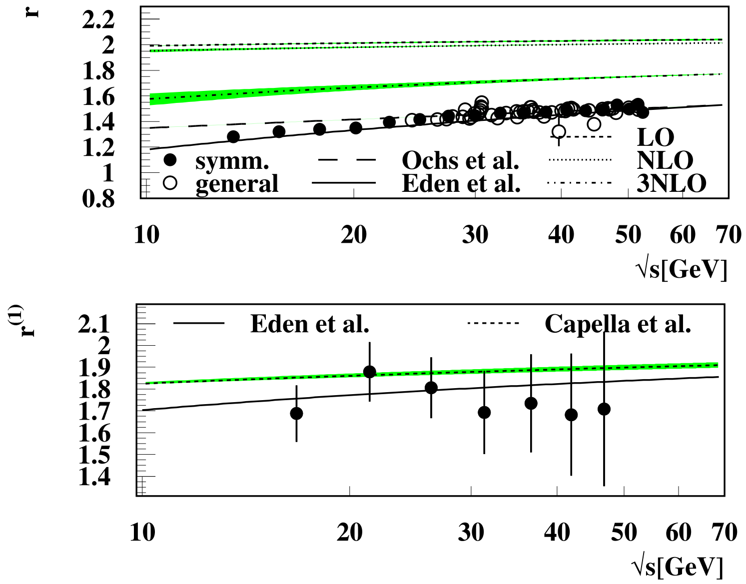

Figure 4. Up: The ratio r in comparison with perturbative calculations. Note that the calculation by Eden et al. is not purely perturbative, as a measurement of N_{gg} directly enters into it. Down: The ratio $r^{(1)}$ in comparison with perturbative calculations.

Instead of fitting C_A/C_F, Eq. (4) can be solved for N_{gg}. This allows for the extraction of the multiplicity of a two-gluon colour-singlet system from the three-jet multiplicity by subtracting the quark related multiplicity contribution. The obtained gluon multiplicities are shown in Fig. 3 in comparison with other measurements [8,11]. A good mutual agreement between the measurements and with the prediction [7] can be observed. This measurement of N_{gg} over a large range of energy allows for the study of r and $r^{(1)}$. The results are shown in Fig. 4. The upper plot shows the measurement for r in comparison with perturbative calculations in LO [12], NLO [13] and 3NLO [14] as well as with a numeric calculation [15]. Clearly, the perturbative calculations overestimate r significantly. The lower plot shows the measurement for $r^{(1)}$ in comparison with perturbative predictions [7,14]. Both calculations are in good agreement with the experimental result, confirming that $r^{(1)}$ is an observable superior to r as stated above. A more detailed discussion of this analysis and more results can be found in [10].

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