DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 81-054
September 1981

ENERGY DEPENDENCE OF EVENT SHAPES IN e^+e^- ANNIHILATION AT C.M. ENERGIES FROM 7.7 TO 31.6 GeV

by

PLUTO Collaboration

(Paper presented by J. Bürger
at the International Conference on High Energy Physics,
Lisbon, July 9-15, 1981)

NOTKESTRASSE 85 · 2 HAMBURG 52

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(presented by J. Bürger)

1. Supported by the BMFT, Germany
2. Now at University of Maryland, College Park, USA
3. Partially supported by the Norwegian Council for Science and Humanities
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5. Now at Institute of Nuclear Physics, Krakow, Poland
6. On leave from University of Glasgow, Scotland
7. Now at University of Rome, Italy; partially supported by INFN
8. Now at Heidelberg University, Germany
9. Partially supported by Department of Energy, USA
10. Now at Siemens AG., München
11. Now at Max Planck Institut für Limnologie, Plön, Germany

Abstract: The energy dependence of jet shape measures is studied at centre of mass energies from 7.7 to 31.6 GeV using the magnetic detector PLUTO. The strong coupling constant α_s was determined by a fit to perturbative QCD calculations and phenomenological assumptions on the non perturbative contributions. The result on α_s is compared with an analysis of three jet events at ~30 GeV.

1. Introduction

Jets have been found to be the most characteristic feature of hadronic events in e^+e^- annihilation above ~7 GeV centre of mass energies /1/. To describe the jet properties several measures have been developed. As far as these measures are infrared stable they have been calculated in perturbative QCD either in first (and sometimes in second) order or in all orders using leading log approximations (LLA). Most event shapes S are found in first order QCD to be $S = A \cdot \alpha_s/\pi$ where A is calculable and depends on the shape variable. Thus the shape variables are in principle straightforward measures of α_s. It is expected however that at lower energies the shape is dominated by fragmentation effects. These contributions can be parametrized by a simple phenomenological expansion in powers of $1/\sqrt{s}$. It turns out to be sufficient to take only the first order into account.

The energy dependence of the shape parameters is thus fitted to a two term formula

$$S = A \cdot \alpha_s/\pi + B/\sqrt{s} \qquad (1)$$

where B, as obtained by the fits, can be compared to various estimates. The energy dependence of α_s in first order QCD is

$$\alpha_s = 12\pi/(\ (33-2n_f) \cdot \ln(Q^2/\Lambda^2)\ ) \qquad (2)$$

where n_f is the number of flavours and Λ is the QCD cut off parameter.

A probably more realistic - but also purely phenomenological - approach to non perturbative contributions is to fold them with the perturbative part using Monte Carlo calculations. These models need, however, several free parameters which have to be adjusted.

2. Experimental setup

We analyse data obtained with the PLUTO detector in runs at the e^+e^- storage rings DORIS and PETRA at energies between 7 and 32 GeV. Both charged and neutral particles are measured by the detector in about ~90% of 4π. Data analysis was performed using the information of charged as well as of neutral particles. To obtain a sample of well reconstructed events some cuts were applied to suppress various backgrounds like QED, beam gas interactions and events from two photon physics. Details of the detector /2/ and the event selection /3/ are published elsewhere. We assigned pion mass to charged tracks and the photon mass to neutral energy clusters.

Standard Monte Carlo models have been used for corrections of the experimental results. The results given below are fully corrected for all experimental effects and for initial state radiation and thus can be directly compared to QCD predictions.

3. Event shape distributions

We determined three different jet shape measures at different energies i) thrust, T /4,5/; ii) the energy weighted jet broadness, $\sin^2\eta$, [1] a measure which is related to sphericity but can be calculated in QCD /6/; and iii) the mass of the heavy jet M_H, a measure which has been proposed recently /7/. Fig. 1 a-c shows the average values of the jet shape measures as a function of the centre of mass energy $\sqrt{s}$.

We fitted curves of the form of eq. (1) to the data for $<1-T>$, $<\sin^2\eta>$ and $<M_H^2/s>$ using the energy dependence (2) of α_s assuming $Q^2 = s$. α_s and the constant B were left free in the fit (Fig. 1a-c). In addition the pure QCD term $A \cdot \alpha_s / \pi$ (with α_s as obtained from the fit) is plotted as dotted curve.

At the highest energies (~30 GeV) the contribution of the fragmentation is much smaller than at lower energies but is still not negligible compared to the pure QCD term.

For $<1-T>$ and $<\sin^2\eta>$ the constant B is given in terms of the average total multiplicity $<n>$ and the transverse momentum $<p_\perp>$ (with respect to the jet axis) as $B = <n> <p_\perp>/2$ /8/ and $B = \pi \cdot C <p_\perp>$ /6/ respectively. C is the coefficient of the $\ell n\, s$ term in the total multiplicity $<n> = D + C \cdot \ell n\, s$. Thus both results of the fit can be compared with the experimental values. Table 1 shows the results from the fits for α_s and the fragmentation term. In addition the experimental values of $<p_\perp>$ or $C \cdot <p_\perp>$ are given.

All fits describe the data well. The obtained values for α_s agree within the errors. The fragmentation terms are in good agreement with the experimental values. The energy energy correlation in the central region (60 - 120°) /6/, which has been published recently by the PLUTO collaboration /9/ (Fig. 1d) shows the same behaviour as the shape measures. The fragmentation term used is of the same form as for $<\sin^2\eta>$. It is remarkable that the fitted parameters α_s and $C <p_\perp>$, which are quoted in Tab. 1, are in agreement with the results from $<\sin^2\eta>$.

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1) $\sin^2\eta = \sum(E_i \sin^2\delta_i/\sqrt{s})/N$ summing over N particles with energy E_i with angles δ_i w.r. to the jet axis.

4. Three jet events

The most direct way to determine α_s is measuring the rate of 3 jet events from hard gluon bremsstrahlung /10/. The PLUTO group did this at energies around 30 GeV /3/. The 3 jet events were separated using a cluster algorithm /11/ which defines the number of jets per event. Identifying the jets with the underlying partons a reconstruction of the parton kinematics is possible. The reconstruction of the energy and the relative angles of the parton is rather accurate, e.g. for the most energetic jet (x_1) of a 3-jet event the energy resolution is $\sigma(x_1)/x_1 = 3\%$.

The strong coupling constant has been determined by this method (assuming 1st order QCD) to be

$$\alpha_s = 0.16 \pm 0.02 \text{ (stat.)} \pm 0.02 \text{ (syst.)}$$

at $\sqrt{s} \approx 30$ GeV in good agreement with the results from other PETRA groups /10/. This can be translated into a value of Λ using eq. (2) and assuming $Q^2 = s$

$$\Lambda = (179 \pm {}^{151}_{99}) \text{ MeV}.$$

The error is purely statistical. If, however, the systematic error is included only the upper limit $\Lambda < 964$ MeV (at 95% C.L.) can be determined. This result agrees with the determination of α_s using the shape measures.

So far it has been assumed that the scale Q^2 is defined by the mass of the virtual photon, but assuming that one of the quarks subsequently radiates a gluon the scale is defined by the mass of the intermediate quark (Fig. 2, insert), Q^{*2} /12/. If the ordered relative jet energies are denoted by x_i ($x_i = 2E_i/\sqrt{s}$, $x_1 \geq x_2 \geq x_3$) then this "intermediate" quark has the mass $Q^{*2} = s(1-x_1)$. Classifying the measured events into two x_1 intervals, one can determine α_s at two Q^2 values as shown in Fig.2. Combining the two values one obtains $\Lambda = 101 \pm {}^{79}_{51}$ MeV (statistical errors only) and including the systematic error $\Lambda < 320$ MeV (95% C.L.).

Finally, we briefly discuss the influence of higher order contributions to the cross section $d\sigma/dx_1$ of the fastest parton. Recent theoretical evaluations for higher order contributions to shape parameter distributions /13,14/ are quite controversal at the time being. In Ref. /14/ a Sterman Weinberg type definition of the cross section is evaluated which is similar to the definition of a jet by the cluster method. The experimental values may be fitted using these calculations. The result of such a fit is $\alpha_s^{(2)} = 0.17$ /13/. This translates into a value of $\Lambda_{\overline{MS}} = 0.24$ GeV using the one loop approximation and $\Lambda_{\overline{MS}} = 0.48$ GeV using the two loop approximation. As can be seen the 2nd order corrections are small to this particular QCD quantities.

5. Conclusions

The energy dependence of various jet shape measures has been used to determine the strong coupling constant α_s. The results are in good agreement with a value of $\alpha_s \approx 0.18 \pm 0.02$ at 30 GeV. A similar value of α_s has been found using the three jet events as defined by a cluster method. It turns out that a phenomenological term describing the fragmentation of the partons which vanishes like $1/\sqrt{s}$ into hadrons is necessary in the fit. Even at the highest energy this term amounts to 20 - 30% of the total effect. At the time being there is no way to translate α_s into the QCD cut off parameter Λ in an unambigous way. For the determination of Λ the appropriate scale (Q^2) and influences of higher order contributions have to be taken into account in a consistent way.

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Table 1 — Determination of α_s ($\sqrt{s}$ = 30 GeV) using fits to jet shape measures (Eq. (1))

shape	A (from QCD)	α_s	B	fragmentation term (GeV)	χ^2/NDF	ref.
$<1-T>$	1.05	0.16±0.01	$\frac{1}{2}<n><p_\perp>$	$<p_\perp>$ = fit:0.33±0.02 exp: .35±0.01	7.5/6	/5/,/8/
$<\sin^2\eta>$	2.0	0.18±0.02	$\frac{\pi}{2}\cdot C\cdot<p_\perp>$	$C\cdot<p_\perp>$ = fit:0.76±0.12 exp: 1.1 ± 0.2	6.5/6	/6/
energy-energy-correlat.	$\int_{60^0}^{120^0} g(\theta)d\theta$	0.20±0.02	$\frac{\pi}{2}\cdot C\cdot<p_\perp>$	$C\cdot<p_\perp>$ = fit: 1.0±0.2	9.0/6	/6/,/9/

Figure captions

Fig. 1 Energy dependence of various shape measures: $<1-T>$ (a), $<\sin^2\eta>$ (b), $<M_H^2/s>$ (c) and the energy energy correlation in the central region (d) (taken from Ref. /9/). The full line is a fit to the data (Eq. (1)). The dotted line represents the pure perturbative QCD term of the fit.

Fig. 2 The strong coupling constant α_s as a function of the mass of the "intermediate" quark, Q^{*2}. The full line is the QCD result (1st order) assuming Λ = 100 MeV.

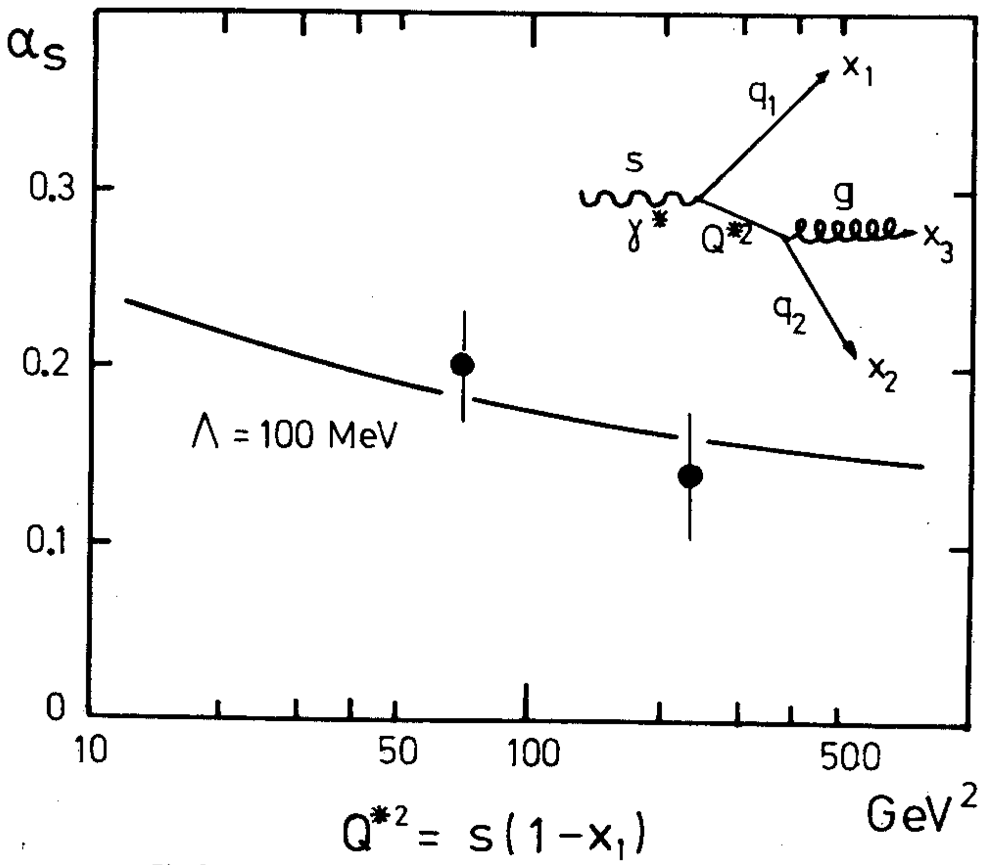

Fig.2

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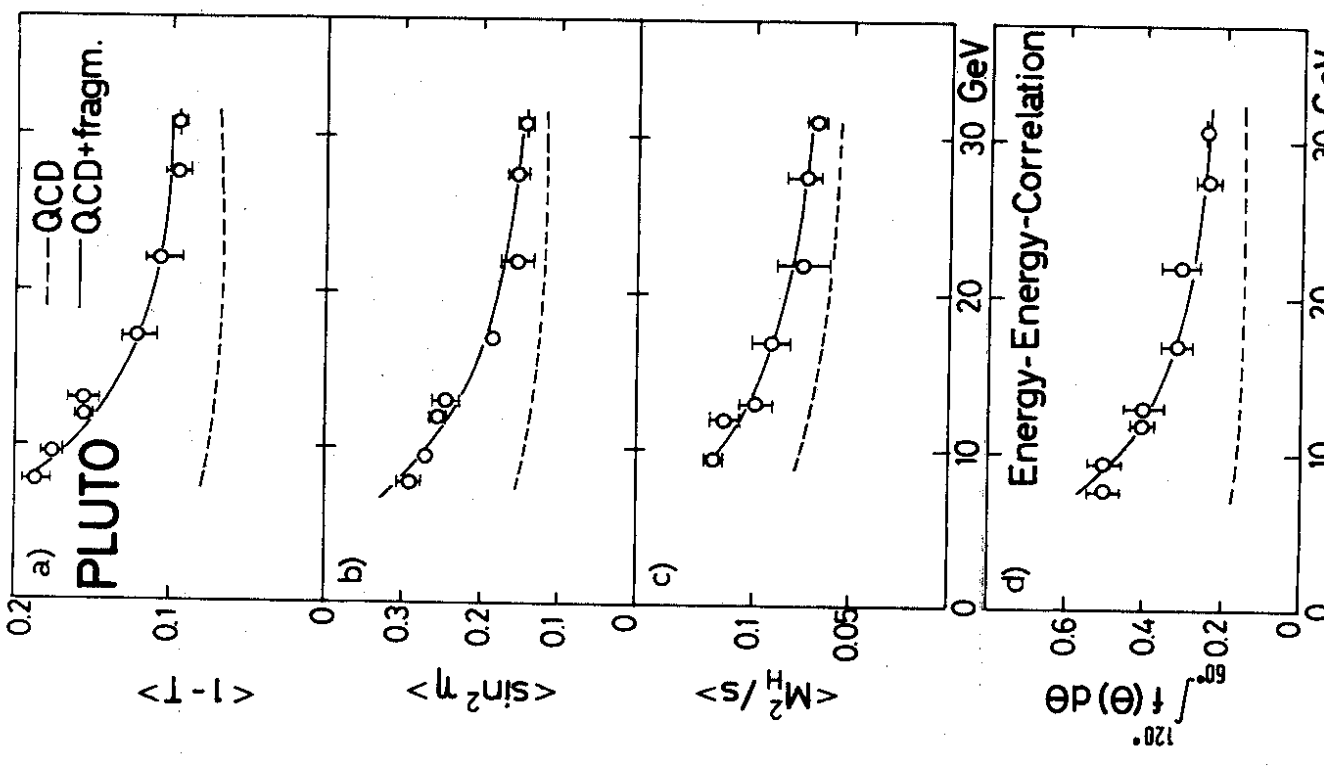

Fig.1