THE INFLUENCE OF FRAGMENTATION MODELS ON THE DETERMINATION OF THE STRONG COUPLING CONSTANT IN e^+e^- ANNIHILATION INTO HADRONS*

CELLO COLLABORATION [11] PRESENTED BY Y. DUCROS**

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The two extreme models (the Feynman-Field model and the string model) of hadronization are compared with the data taken by CELLO at 34 GeV/c.

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1. Introduction

Experimental observation of planar events in e^+e^- [1] annihilation into hadrons is interpreted as the emission of a hard gluon in addition to the two quarks production (Fig. 1).

Unfortunately the quantitative interpretation of those events is closely related to the influence of non perturbative effects which are responsible of the hadronization of the quarks and the gluon. In order to study the non perturbative effect in QCD we have compared two extreme models of hadronization:

— The Feynman-Field model [2],

— The string model [3].

Different algorithms are used to extract the strong coupling constant α_s from the comparison between data and Monte Carlo: the cluster method, the energy-energy correlation, and also the classical distributions as the thrust, the oblateness, the sphericity, and the aplanarity calculated from the charged particles.

The two fragmentation models correspond to the first order development in QCD. Then the values obtained for the strong coupling constant cannot be interpreted in the framework of the theory, since the renormalization scheme is not defined. However the effects of the quarks and gluons fragmentation can be compared for the two models which should give the same result if the α_s measurement is independent of the hadronization scheme.

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** Address: D.Ph.P.E., Saclay, BP No 2, Gif-sur-Yvette 91190, France.

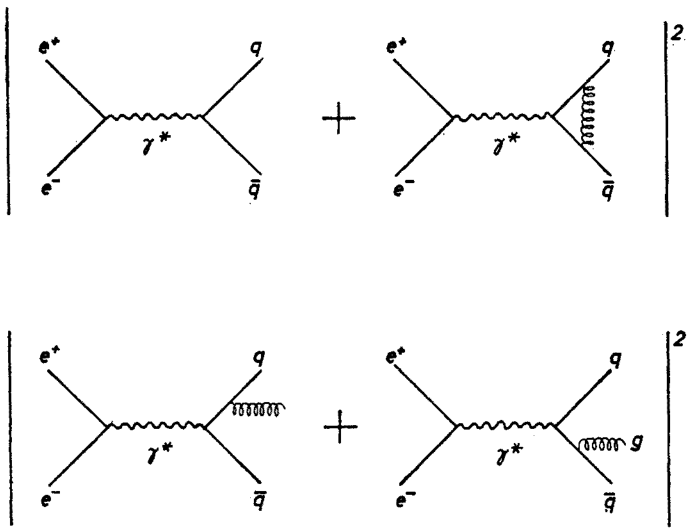

Fig. 1. Feynman graphs kept to study the two annihilation processes $e^+e^- \to q\bar{q}$ and $e^+e^- \to q\bar{q}\,g$ at the first order in α_s

These two models are compared with the data taken by CELLO at 34 GeV/c. The neutral are not taken into account and all the charged tracks are considered as pions. A total of 3021 hadronic events have been used.

We shall first describe the two models and then the results. The result obtained with the energy-energy correlation is shown at the end and compared with the previous values.

2. *The fragmentation models*

The two models described below correspond to different scheme of the fragmentation. The Feynman-Field model generates independent jet along the momentum of each parton in the center of mass of the reaction. The string model, on the contrary, corresponds to a jet development along the line joining a quark and an antiquark in the center of mass of these two partons. The gluon is made of two pairs of quark and antiquark.

2.1. The Feynman Field model (F.F. model)

The partons are fragmented independently of each other and the jet development is specified by the following fragmentation function: $F(z) = 1-a+3a(1-z)^2$ with $a = 0.77$ (z being the relative momentum of the hadron compared to the parton) for the u, d, s quarks and $a = 0$ for the c and b quark. The transverse momentum is taken gaussian, with a σ_q value fitted on the slim jet: $\sigma_q = 0.3$ GeV. The s/u ratio production is equal to 0.3 in order to reproduce the K^0 and $K^{\pm}$ distribution (CELLO has measured 1.13 ± 0.27 K^0 and $\overline{K^0}$ by event). Finally the production of vector bosons is equal to the one of pseudoscalar bosons $V/(P+V) = 0.5$. This value reproduces correctly the multiplicity and is in agreement with the Tasso results on ϱ^0 production [4].

2.2. The string model

In this model, strings are stretched between a quark and an antiquark. The strings fragment into hadrons in the $q\bar{q}$ center of mass with the probability $f(z) = (1+a)(1-z)^a$. The parameter a varies from 0.5 for the light quarks to 0.09 for heavy quarks. The main difference between the F.F. model and the string model occurs for events with one or more hard gluons emission. The σ_q and the (V/(P+V)) parameters are the same in the two models.

3. *Methods used*

The strong coupling constant α_s is obtained in comparing the data with the Monte Carlo simulation using either of these models. The production of the quark-antiquark-gluon events corresponds to an infinite cross section (as in QED for γ emission). Therefore it is necessary to define cuts. For that purpose we are using the variables described below [5, 6].

3.1. Sphericity tensor

For each event we define the tensor

$$M_{\alpha\beta} = \sum_{\substack{i \\ \text{particles}}} p_{\alpha i} \cdot p_{\beta i}, \qquad \alpha, \beta \equiv x, y, z.$$

The quantities $Q_k = \sum (\vec{p}_i \vec{n}_k)^2 / \sum (p_i^2)$ where n_k is an eigen vector, define the sphericity

$$S = \tfrac{3}{2}(Q_2 + Q_3),$$

the aplanarity:

$$A = \tfrac{3}{2}\, Q_3,$$

with $Q_1 \geqslant Q_2 \geqslant Q_3$.

3.2. Thrust and oblateness

The thrust is defined as follows

$$T = \operatorname*{Max}_{\vec{e}_1} \frac{\sum |\vec{p}_i \vec{e}_1|}{\sum |\vec{p}_i|}, \qquad (\tfrac{2}{3} < T < 1 \text{ for 3 partons}).$$

One defines also two additional variables

$$\text{Major} = \operatorname*{Max}_{\vec{e}_2 \perp \vec{e}_1} \frac{\sum |\vec{p}_i \vec{e}_2|}{\sum |\vec{p}_i|},$$

$$\text{Minor} = \frac{\sum |\vec{p}_i \vec{e}_3|}{\sum |\vec{p}_i|},$$

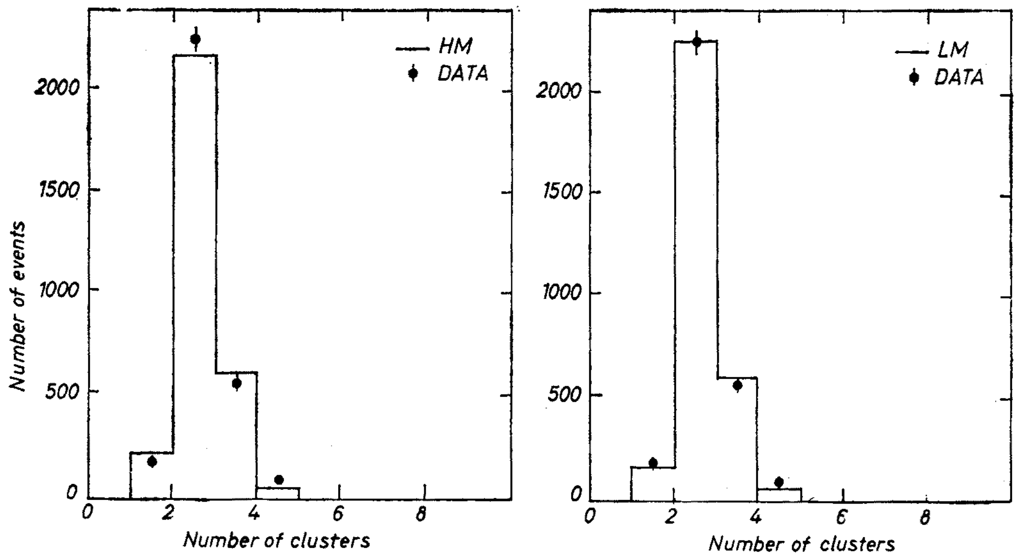

Fig. 2. Number of reconstructed clusters. H. M. stands for the Feynman Field model and L. M. for the string model

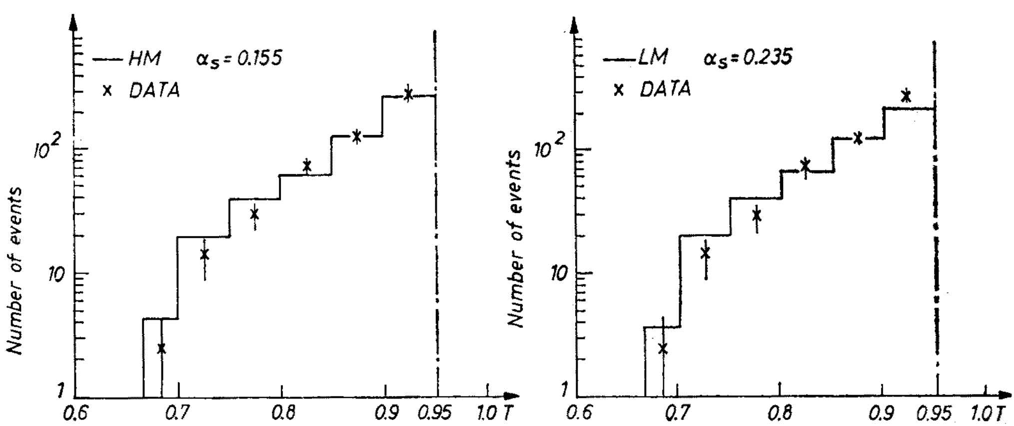

Fig. 3. Three clusters thrust distribution, obtained with both models. (Notation the same as in Fig. 2). The fullline is the best fit: $\alpha_s = 0.155 \pm 0.015$ for the Feynman Field scheme with a $\chi^2/DF = 5/4$, $\alpha_s = 0.235 \pm 0.025$ for the string model with a $\chi^2/DF = 9/4$

where $\vec{e}_1$, $\vec{e}_2$ and $\vec{e}_3$ correspond to an orthonormal reference. The oblateness is given by the relation

$$O = \text{Major} - \text{Minor}.$$

3.3. Cluster method

The two sets of variables described above are not free of non perturbative effects. Therefore a cluster analysis has been developed by several authors. The description of the algorithm used in this analysis is given in reference [6].

The fragmentation does not modify drastically the direction of the high energetic partons (mainly in the case of independent jet fragmentation), therefore a cluster analysis gives a good approximation of the number and of the momenta of the primary partons at high energy.

α_s is determined using the numbei of reconstructed clusters (Fig. 2 or the thrust of the 3 clusters events, Fig. 3).

4. *Results*

In order to obtain the α_s value, we define, f_{3j}, the "three jets events" fraction using one of the following criteria.

1) $S \geqslant 0.25$ and $A \leqslant 0.1$
2) $O \geqslant 0.20$
3) $O \geqslant 0.30$

The f_{3j} value is compared with the prediction of the two models.

Fig. 4 shows the sphericity distribution of the data and the Monte Carlo for the two models. A reasonable agreement is obtained for both. Fig. 5 corresponds to the variation of f_{3j} with α_s using (1). The string model needs a larger α_s value (0.28) compared to the F.F. model (0.19).

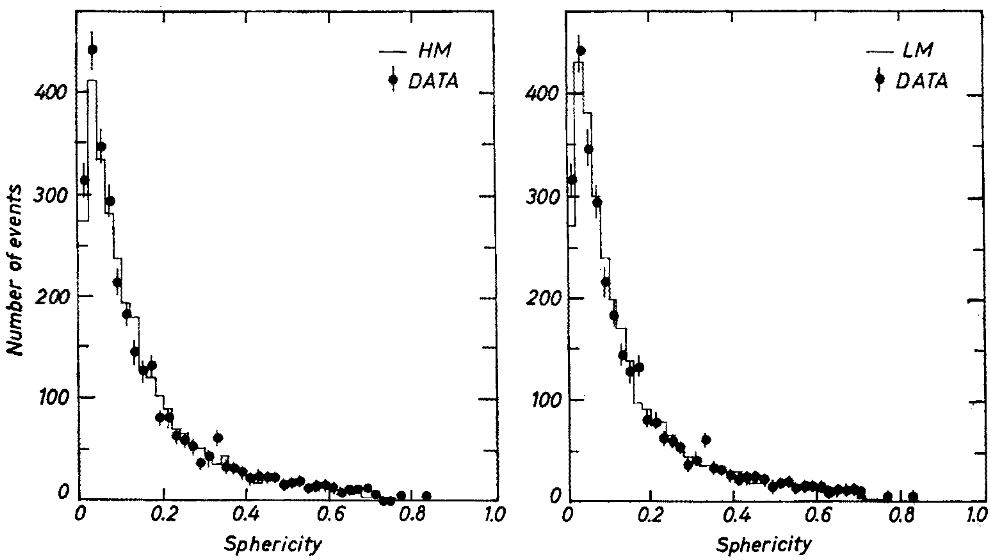

Fig. 4. Sphericity distribution. Comparison between data (black dot points with error bars) and models (histograms). The Feynman Field model (H. M.) corresponds to $\alpha_s = 0.17$, and the string model (L.M.) to $\alpha_s = 0.26$

On the other hand, α_s is obtained by fitting the thrust distribution of the 3 clusters events, or the distribution of the number of clusters.

The α_s values obtained with different methods are summarized in Table I with the

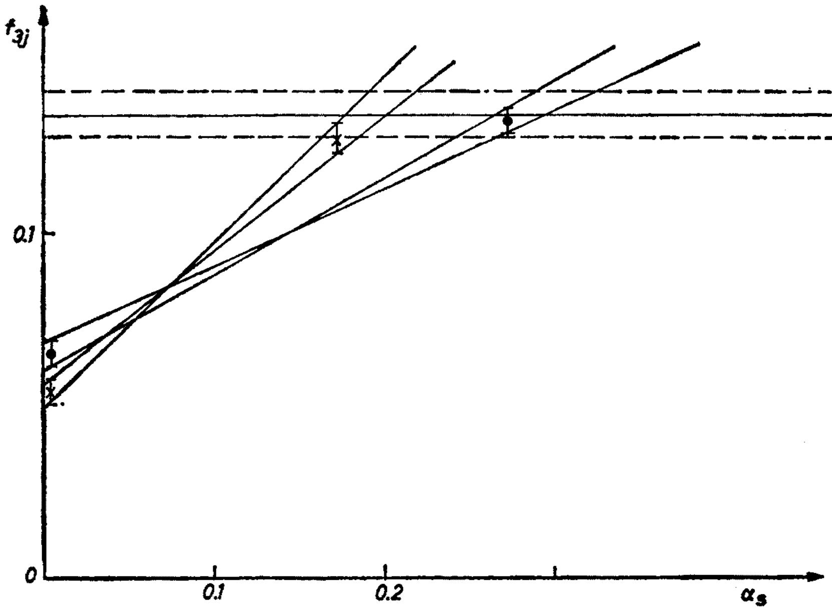

Fig. 5. Fraction of "3 jet events" f_{3j} versus α_s, for the Feynman Field model (H.M.) and the string model (L.M.) compared to data, for $S > 0.25$ and $A < 0.1$. × — Feynman Field scheme, ● — string model

ratio between the two models. We get systematic higher values with the string model; the ratio going from 1.28 to 1.62.

The variation of the results inside one model from one algorithm to another is of the order of fifteen to twenty per cent.

The large difference between the string model and the F.F. model ($\simeq 1.4$) cannot be explained by changing the parameter of each model. An investigation has been done

TABLE I

Method	$\sqrt{s} = 34$ GeV String model	$\sqrt{s} = 34$ GeV Feynman Field model	Ratio
$S > 0.25$ $A < 0.1$	0.280 ± 0.045	0.190 ± 0.030	1.47
$O > 0.30$	0.255 ± 0.050	0.200 ± 0.035	1.28
$O > 0.20$	0.260 ± 0.040	0.190 ± 0.020	1.37
Number of 3 clusters	0.235 ± 0.025	0.145 ± 0.020	1.62
Cluster thrust	0.235 ± 0.025	0.155 ± 0.015	1.52

to understand this effect. Fig. 6 shows the f_{3j} fraction using the string model, then a F.F. model with a gluon composed of 2 pairs of $q\bar{q}$, finally a F.F. model with the gluon treated as a q or an $\bar{q}$. We have still some difference with the original F.F. model developed

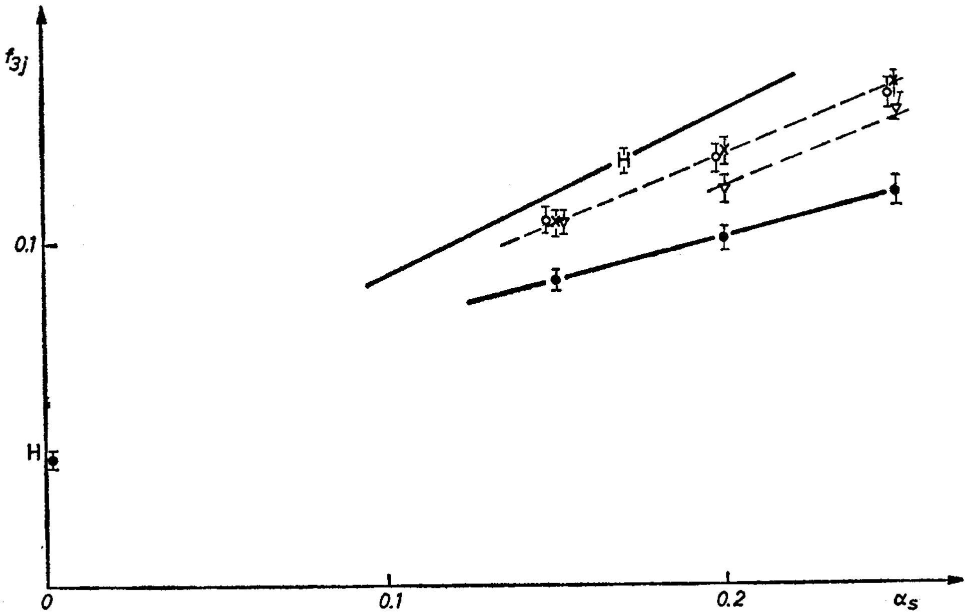

Fig. 6. Study of the influence of different fragmentation conditions with the following criteria $S > 0.25$, $A < 0.10$. ● — string model, $\sigma_q = 0.30$ GeV/c, V/(P+V) = 0.5; × — Feynman Field fragmentation and gluon as a quark $a_q = a_g = 0.77$; ○ — Item with $a_g = 1$; ▽ — Feynman Field fragmentation scheme but gluon as in the Lund model (string fragmentation); H — Feynman Field fragmentation scheme as taken in the Hoyer model

by Hoyer et al., but the results show clearly the main effect due to the choice of the fragmentation scheme. The remaining difference can be due to the treatment of the decay of heavy bosons.

5. α_s determination from the energy-energy angular correlation

The energy-energy correlation is defined as follows:

$$F(\theta) = \frac{1}{\sigma_T} \sum \int z_a z_b dz_a dz_b \frac{d^3\sigma}{dz_a dz_b d\theta} (e^+e^- \to \text{ab x}).$$

Different authors [7, 8, 9] have proposed to use $F(\theta)$ to measure perturbative QCD effects in $e^+e^- \to$ hadrons. CELLO has already published a measurement of α_s using the asymmetry of $F(\theta)$ [10]. An α_s value of 0.15 ± 0.02 has been obtained, with a difference of only 0.03 between the F.F. model and the string model. This result, somewhat in contradiction with the previous one, is based on the assumption that there is no difference in the asymmetry of the partons and the observable hadrons. Fig. 7 shows reasonable agreement for the F.F. model, but large discrepancy for the string model, specially in the region

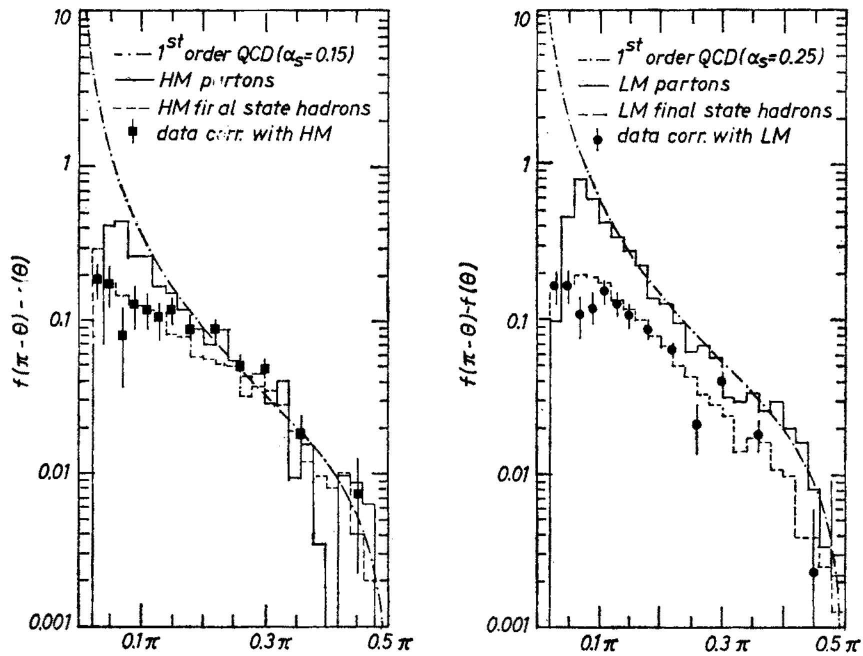

Fig. 7. Asymmetry $f(\pi-\theta)-f(\theta)$ at 34 GeV. Dashed curve — 1st order QCD formula [10]; Full line histogram — parton asymmetry; Dotted histogram — asymmetry from final state hadrons. (H.M.) for the Feynman Field scheme (L.M.) for the string model

$0.25\pi < \theta < 0.5\pi$. The string model gives systematic lower values for the final hadrons compared to the partons.

A least square fit to the asymmetry of the final state hadrons gives $\alpha_s = 0.15 \pm 0.02$ for the F.F. model and $\alpha_s = 0.25 \pm 0.04$ for the string model in agreement with the values obtained with the other methods.

6. *Conclusion*

The determination of α_s depends of the fragmentation scheme used in the Monte Carlo simulation. The string model shows systematic higher values compared to the independent jet fragmentation model. The difference is of the order of 30 to 50 per cent.

The variation of α_s, using different variables and methods within one model, is between 15 to 20 per cent.

At 34 GeV/c, $0.235 < \alpha_s < 0.28$ with the string model, $0.145 < \alpha_s < 0.20$ with the F.F. model.

Then either a large systematic error has to be included in the α_s determination, or better knowledge on the fragmentation of quarks and gluons is needed into final hadrons, for accurate α_s measurement.

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