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# The Influence of Fragmentation Models on the Determination of the Strong Coupling Constant in $e^+e^-$ Annihilation into hadrons

CELLO Collaboration

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

CELLO Collaboration

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Abstract: Hadronic events obtained with the CELLO detector at PETRA were compared with first order QCD predictions using two different models for the fragmentation of quarks and gluons, the Hoyer model and the Lund model. Both models are in reasonable agreement with the data, although they do not completely reproduce the details of many distributions. Several methods have been applied to determine the strong coupling constant $\alpha_s$. Although within one model the value $\alpha_s$ varies by 20% among the different methods, the values determined using the Lund model are larger by 30% or more (depending on the method used) than the values determined with the Hoyer model. Our results using the Hoyer model are in agreement with previous results based on this approach.

**Planar events, which have been observed in high energy e+e- annihilations into hadrons, are interpreted as 3 jets produced in the QCD process [1]:**

$$e^+e^- \longrightarrow q\,\bar{q}\,g \qquad (1)$$

In first order, the corresponding cross section is proportional to the strong coupling constant $\alpha_s$ [2].

Interpretation of the data in terms of parton distributions requires the use of models for hadronization of these partons. The question arises whether or not the determination of $\alpha_s$ depends on the way the fragmentation is treated in these models.

Here we present an analysis of multihadronic events obtained with the CELLO detector, using two different fragmentation models, the Lund model (LM) [3], and the Feynman-Field model in the Hoyer Monte Carlo (HM) [4]. Both generators correspond to the first order expansion in $\alpha_s$ for reaction (1).

The result of this analysis shows that the value of $\alpha_s$ depends significantly on the model used.

## I. Description of the models.

In the following we assume that QCD is the theory of the strong interactions. The goal of this paper is not to test this hypothesis. We have used only two models for the parton fragmentation, and we have not tried to modify the fragmentation processes.

In the HM [4], the partons fragment independently of each other according to the prescription of Feynman and Field (FF) [5]. The gluon is considered randomly either as a quark or an antiquark, carrying the total gluon energy. Only mesons are created in the final state.

The fragmentation in the LM is based on the string model [3]. In an e+e- ⟶ $q\,\bar{q}$ event, a colour string is stretched between the quark and the antiquark. New quark-antiquark pairs (or diquark-antidiquark pairs) are then produced along the string to yield mesons (baryons). For a $q\bar{q}g$ event, the gluon is split into two quark-antiquark pairs from which a first meson is built. The two remaining quarks then form two independent strings with the two primary quarks of process (1). These strings fragment in their own rest frames. Boosting the fragmentation products back to the laboratory frame causes the $q\bar{q}g$ event to look more 2-jet like. As a consequence of the boost and the way the gluon is treated, the value of $\alpha_s$ needed to explain the data is expected to be larger in this model than in the HM.

These models contain several parameters. The most important are the following:

- the mean transverse momentum, $\sigma_q$, the transverse momentum distribution for the quarks is generated according to a gaussian law: $\exp(-P_t^2/2\sigma_q^2)$*,
- the probability distribution f(z) for the longitudinal fragmentation. The longitudinal fragmentation function used in the Hoyer Model is

$$f(z) = 1 - a_f + 3a_f(1-z)^2$$

In the Lund Model we have

$$f(z) = (1+a)*(1-z)^a$$

Where $z=(E+P)_{meson}/(E+P)_{quark}$

- the relative production of u,d,s quarks for the dressing of the partons,

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* It has been suggested [6] that 3-jet events can be explained by a $q\bar{q}$ model with an exponential $P_t$ distribution. This would imply $\alpha_s = 0$. Although a pure exponential $P_t$ distribution does not reproduce the data (i.e. the energy-energy correlations between hadrons), $q\bar{q}$ and $q\bar{q}g$ production and fragmentation with a combination of a gaussian and exponential $P_t$ distribution as suggested by certains models [7] would lead to a lower value of $\alpha_s$. It is beyond the scope of this paper to try all these variations.

- the fraction of vector mesons produced : V/(P+V) (only vector mesons (V) and pseudoscalar mesons (P) are created in the fragmentation process).

As mentioned above, the LM generates mesons and baryons. The results of our analysis are not affected if only mesons are generated as in the HM.

## II. The analysis.

Data used for this analysis were taken at an average center of mass energy of 34 Gev with the CELLO detector. The details of the detector have already been presented elsewhere [8]. The analysis was done using only charged particles. The selection of the multihadronic events is the same as for the R measurement [9]. Further cuts on the fraction of visible energy and multiplicity were applied in order to suppress the background and contamination from other processes ($E_{vis}/E_{cm} \geq 0.25$, $N_{ch} \geq 7$ at 34 GeV). After these cuts, 3021 multihadronic events remained for an integrated luminosity of 11,600 $nb^{-1}$.

The residual contaminations and background ( $\leq 2\%$) do not influence the conclusion of the analysis, as far as the comparison between the two models is concerned.

In order to compare the generated events with the data, we have processed them through a realistic simulation of our detector and through the selection and reconstruction programs. Radiative corrections were taken into account [10]. The plane and the axis of an event were defined using the eigenvectors of the momentum tensor $M^{\alpha\beta} = \sum_i P_i^\alpha P_i^\beta$ .

### Values of the model parameters.

- The parameter $\sigma_q$ was obtained from the $P_t$ distribution of the charged particles in the slim jet. We found $\sigma_q$=0.30 GeV/c for both generators.
- In the Hoyer model, the parameters $a_f$ of the Feynman-Field probability distribution were left at the standard value of 0.77 for the light quarks, 0 for c and b quarks, and 1 for the gluon. In the Lund model, we have used the original values [3]. The exponent, a, varies with the quark mass from 0.5 for the u quark to 0.09 for the b.
- The s/u ratio was fixed by data on K°, K± production in hadronic events [11] ( s:u=0.3 ). For diquark production in the LM we have kept the values from ref.[3]
- The V/(P+V) ratio was set to 0.50. This value provides a good description of the multiplicity distribution which shows a strong dependence on this ratio.

## III. The Methods of Determination of $\alpha_s$.

A priori, any variable depending on $\alpha_s$ can be chosen for its determination. For this analysis, we have used three different methods:

- the fraction of 3-jet events obtained by applying topological cuts,
- the thrust distribution from events with 3 clusters defined by a cluster algorithm,
- the asymmetry of the energy weighted angular correlation.

### 1. Determination of $\alpha_s$ using the 3-jet fraction.

$\alpha_s$ can be measured using the rate of $q\bar{q}g$ events. Distinguishing between $q\bar{q}g$ and $q\bar{q}$ events is possible only when a hard gluon is emitted at a large angle. In order to increase the fraction of such events we applied sphericity (S), aplanarity (A) and oblateness (O) cuts [12], or we selected events with 3 reconstructed jets using a cluster method [13]. Three different criteria were used to select the "3-jet events":

1) $S \geq 0.25$ and $A \leq 0.1$
2) $O \geq 0.2$ or $O \geq 0.3$
3) cluster method: events with 3 reconstructed clusters.

For the criteria 1) and 2), we required at least two particles in each hemisphere defined by the plane perpendicular to the event axis.

We have defined the fraction of "3-jet events", $f_3$, as the fraction of the events satisfying one of the above criteria. Besides $\alpha_s$, this fraction depends on the values of the other parameters of the models, which have been adjusted to reproduce the data distributions as well as possible. In a study at the generator level, that is, using the 4-vector momenta of the final state particles generated by the Monte Carlo, we have observed that, for the LM, $f_3$ is not very sensitive to the $\sigma_q$ value. This does not seem to be true for the HM (Fig.1). We have also checked that, in the LM, $f_3$ is independent of the V/(P+V) ratio, although the multiplicity does depend on this ratio. So $f_3$ is a good variable to measure $\alpha_s$ in the LM.

The dependence of $f_3$ on $\alpha_s$ is shown in Fig.2, using the first selection criteria ($S \geq 0.25$, $A \leq 0.1$), for both models, and compared to the data at $\sqrt{s}=34$ GeV. A study at the generator level has shown that, to a good approximation, $f_3$ is linear in $\alpha_s$ in the range of the figure (see Fig.1). The dotted lines in Fig.2 represent the one standard deviation limit on the experimental value of $f_3$. As can be seen this value of $f_3$ corresponds to $\alpha_s = 0.19$ for the HM and 0.28 for the LM.

Table I summarizes the values of $\alpha_s$ obtained with the different topological cuts (only statistical errors are given). These values, when using the HM, are in good agreement with those measured previously using the FF fragmentation [14], but differ strongly from those we obtain using the LM.

Many distributions were plotted in order to check the overall agreement of the two models with the data. Although neither model can be said to describe the data well, in a strictly statistical sense, the gross features are certainly reproduced by both models (Fig.3 to 15). We could have defined $f_3$ by other topological cuts. From the distributions (e.g. Thrust, Fig.10), we see immediately that both models could give different values of $\alpha_s$. Nevertheless, the values obtained with the LM would be systematically greater by a factor of about 1.4 than those obtained with the HM.

The very different values of $\alpha_s$ found mean that in the LM a much higher rate of hard gluons emitted at large angle is necessary to explain the data than in the HM. As we shall see in Section III, the main difference between the $\alpha_s$ values we obtained is due to the fragmentation hypothesis.

### 2. Determination of $\alpha_s$ using the thrust distribution of 3 cluster events.

In this method, we measure $\alpha_s$ by selecting the 3 cluster events according to the algorithm described in [13], and by fitting the acceptance corrected thrust distribution of these events to the predictions of the two models.

The thrust of a 3 cluster event is defined using the angle $\theta_{ij}$ between the axes of clusters i and j projected into the event plane:

$$T = \mathrm{Max}(x_i) \quad \text{with} \quad x_i = \frac{2 \sin \theta_{jk}}{\sin\theta_{12}+\sin\theta_{23}+\sin\theta_{31}} ,$$

i,j,k= cyclic permutation of 1,2,3.

Both Monte Carlos were used to correct the observed events for acceptance and detector resolution. The corrections were found to be independent of the choice of LM or HM. The data could then be compared with the predictions of the models using the generated four vectors of the final state hadrons as input to the cluster algorithm. Least squares fits to the corrected thrust distributions were made to determine $\alpha_s$ for both models. The best fits obtained are shown in Fig.16 for the HM and the LM.

The corresponding values of $\alpha_s$ were:

with the HM $\alpha_s = 0.155 \pm 0.015$ ($\chi^2/DF = 5.0/4$)

with the LM $\alpha_s = 0.235 \pm 0.025$ ($\chi^2/DF = 9.0/4$)

This result disagrees with a previous comparison of the two models [15]. More detailed informations can be found in [16].

### 3. Determination of $\alpha_s$ from the energy weighted angular correlation of multihadrons.

We have reported previously [17] on a measurement of $\alpha_s$ using the asymmetry, $f(\pi-\theta) - f(\theta)$, of the energy weighted angular correlation in multihadronic events. An $\alpha_s$ value of $0.15 \pm 0.02$ for a center of mass energy of 34 GeV was obtained by fitting the first order QCD prediction [18], which is expected to be insensitive to fragmentation effects [18], to the corrected data. The acceptance corrections were calculated both with the HM and the LM, and the resulting difference in $\alpha_s$ was found to be less than 0.03. However, in the determination of $\alpha_s$, one makes the assumption that there is no difference between the asymmetries of the partons and the observable hadrons. This assumption is reasonably satisfied for the HM but is not true for the LM as can be seen in Fig.17. A difference between the asymmetries of partons and final state hadrons is expected in the LM since, compared to the partons, the final state hadrons are more two-jet like and therefore give a smaller asymmetry.

From a least squares fit to the asymmetry of the final state hadrons, one obtains an $\alpha_s$ value of 0.15 ± 0.02 for the HM, and 0.25 ± 0.04 for the LM. This last value for $\alpha_s$ is found to be insensitive to the precise value of $\sigma_q$.*

## IV. Study of the influence of the fragmentation with the Lund Monte-Carlo.

The results on the measurement of $\alpha_s$, using different methods, show that the value obtained with the LM is systematically higher than the one obtained with the HM. In this section we describe a study of the origin of the discrepancy between the two models done at the generator level, with the Lund Monte Carlo, applying the cuts used for real events.

We have mentioned previously that the fraction of 3-jet events, $f_3$, used to measure $\alpha_s$, is not very sensitive to a change either in $\sigma_q$ or in the V/(P+V) ratio, although the multiplicity varies with this last parameter. In addition, the way the heavy meson decays are treated can be significant for

the multiplicity distribution, but it was verified that this has no effect on $f_3$. In order to adjust the multiplicity distribution, no attempt was made to separate this effect from the one due to a change in V/(P+V). For the following study, $\sigma_q$ and V/(P+V) were set to 0.30 GeV/c and 0.50, respectively.

As we cannot explain the large difference between the HM and the LM by changing the above parameters, we have looked at the fragmentation processes. As described in section I, these processes are quite different in the two models. To investigate such effects, we have used the possibility in the Lund program of generating events according to the FF prescription as is done in the Hoyer model. We have proceeded in two steps:

- In the first step, the jets were fragmented according to FF, the $a_f$ parameter in the fragmentation function being set to 0.77. No change was made in the treatment of the gluon. As can be seen in Fig.18, we observed an increase in $f_3$.
- In the second step, we have, in addition, treated the gluon like a quark (antiquark), as in the Hoyer model. We observed that the $f_3$ ratio increases again, as shown in Fig.18.

The conclusion of this study is clear: independent fragmentation of the partons explains half the difference; treating the gluon as a quark or an antiquark explains part, but not all, of the remaining difference. We attribute the residual discrepancy to the treatment of heavy meson decays, the fact that the Lund program takes the quark masses into account in the matrix elements, and other detailed differences between the LM and HM and to differences in our teatment of radiative corrections for the two models.

We would like to stress that if $\sqrt{s} \longrightarrow \infty$, the difference between the string model and the FF model vanishes. In that limit, the mass of the particles becomes negligible, so the particles produced in the string c.m. frame will follow the parton direction in the laboratory frame after the Lorentz boost. But this is an asymptotic behaviour which is not reached at $\sqrt{s} \simeq 34$ Gev.

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* We have observed for both Monte Carlo generators that, due to the cuts on the QCD matrix element [19], f(θ) at the parton level does not agree with the first order QCD results. However, as can be seen in Fig.17, this discrepancy tends to cancel in the asymmetry.

## Conclusion

We have determined the value of the strong coupling constant, $\alpha_s$, from the analysis of multihadronic events by comparing them with two different models (the Hoyer model and the Lund model).

We find that for various methods used, a systematic fluctuation of ≃20% is observed within one model for the determination of $\alpha_s$, but that the Lund model yields an $\alpha_s$ value which is systematically larger by 30% or more (depending on the method used) than the value obtained from the Hoyer model. This is mainly attributed to the string picture and to the way the gluon is treated in the Lund model.

We should like to stress that our values of $\alpha_s$, as determined with the Hoyer model, cluster around $\alpha_s = 0.17$ with a systematic uncertainty of 15%. This result is in good agreement with previous measurements. Until now, the published values of $\alpha_s$ have been determined using models based on independent quark and gluon fragmentation.

At present, neither of the two studied models can be excluded. Therefore, we conclude that a rather large systematic uncertainty in the value of $\alpha_s$ has to be included due to our ignorance of the way quarks and gluons produce final state hadrons.

After the completion of this work, a study of different fragmentation models was pointed out to us [20]. In this study, it was shown that it is necessary to use a larger value of the QCD scale parameter $\Lambda$ in a string scheme ($\Lambda \simeq 1.4$ Gev) than in an independent parton fragmentation approach in order to reproduce the data. Conclusions similar to ours were also presented at the Paris Conference [21].

TABLE I

Value of $\alpha_s$ obtained at $\sqrt{s} = 34$ Gev with the Lund Model (LM) and the Hoyer Model (HM). ( first order in QCD )
The error in the determination of $\alpha_s$ using the 3 jet fraction (see text) is statistical only (including statistical Monte Carlo error).

| METHOD | LUND MODEL | HOYER MODEL | $\frac{\alpha_s(LM)}{\alpha_s(HM)}$ |
|---|---|---|---|
| $S \geq 0.25 \quad A \leq 0.1$ | 0.280 ± 0.045 | 0.190 ± 0.030 | 1.47 |
| $O \geq 0.20$ | 0.260 ± 0.040 | 0.190 ± 0.020 | 1.37 |
| $O \geq 0.30$ | 0.255 ± 0.050 | 0.200 ± 0.035 | 1.28 |
| # 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 |
| E.W.A.C* | 0.250 ± 0.040 | 0.150 ± 0.020 | 1.67 |

* Energy Weighted Angular Correlation

## References

[1] For a general review on experimental evidence for the existence of the gluon see e.g. :
P.Söding and G.Wolf, Ann.Rev.Nucl.Sci. 31(1981)231 and references there in.

[2] J.Ellis, M.K.Gaillard, G.G.Ross, Nucl.Phys. B111(1976)253
G.Kramer, G.Schierholz, J.Willrodt, Z.Phys. C4(1980)149

[3] B.Andersson, G.Gustafson, T.Sjöstrand, Z.Phys. C6(1980)235
T.Sjostrand, Lund Preprint, LU TP 80-3(1980)
B.Andersson, G.Gustafson, T.Sjostrand, Nucl.Phys. B197(1982)45

[4] P.Hoyer et al., Nucl.Phys. B161(1979)349

[5] R.D.Field, R.P.Feynman, Nucl.Phys. B136(1978)1

[6] C.K.Chen, Preprint(1980), Purdue University

[7] T.A.De Grand, Y.J.Ng, S.N.Tye, Phys.Rev. D16(1977)3251

[8] CELLO Coll., H.J.Behrend et al., Phys.Scripta 23(1981)610

[9] CELLO coll., H.J.Behrend et al., DESY 81-029(1981)

[10] G.Bonneau, F.Martin, Nucl.Phys. B27(1971)381

[11] TASSO coll., R.Brandelik et al., Phys.Lett. 94B(1980)91 and Phys.Lett. 105B(1981)75
JADE coll., W.Bartel et al., Phys.Lett. 104B(1981)325
MARK II coll., G.Goldhaber, J.M.Weiss, SLAC PUB-2810(1981)
The production of $K^0+\overline{K^0}$ measured with the Cello detector is $K^0+\overline{K^0}/Evt = 1.13\pm0.27$ (statistical error) at W=34 Gev (unpublished).

[12] S.Brandt, H.D.Dahmen, Z.Phys. C1(1979)61
E.Farhi, Phys.Rev.Lett. 39B(1977)1587
J.D.Bjorken, S.Brodsky, Phys.Rev. D1(1970)1416
G.Hanson et al., Phys.Rev.Lett. 35(1975)1609
MARK J coll., Phys.Lett. 89B(1979)139

[13] H.J.Daum, H.Meyer, J.Burger, Z.Phys. C8(1981)167

[14] CELLO coll., H.J.Behrend et al., Phys.Lett. 110B(1982)329 ; 113B(1982)427
JADE coll., W.Bartel et al., Phys.Lett. 91B(1980)142
MARK J coll.,D.P.Barber et al., Phys.Lett. 89B(1980)139 and Phys.Lett. 108B(1982)63
PLUTO coll., Ch.Berger et al., Phys.Lett. 97B(1980)459
TASSO coll., R.Brandelik et al., Phys.Lett. 94B(1980)437

[15] E.Elsen, PhD Thesis, University of Hamburg (1981)

[16] Y.Lavagne, These de 3$^{eme}$ CYCLE, University of Paris VII (1982)

[17] CELLO coll., H.J.Behrend et al., DESY 82-022(1982), submitted to Z. Physik C

[18] C.L.Basham, L.S.Brown, S.D.Ellis, S.T.Love, Phys.Rev.Lett. 41(1978)1585

[19] T.Sjöstrand (private communication)

[20] R.D.Field, Lecture given at the Conference on pertubative QCD, published in: Brookhaven 1981 Proceedings, Isabelle Vol.1,11-73
R.D.Field, S.Wolfram, Preprint UFTP 82-12(1982)

[21] S.D.Ellis, talk given at the XXI Int. Conf. on High Energy Physics, Paris, July 1982, and contributing paper to this Conference

## Figure Captions

Fig. 1 Generator study (same cuts as for data) :
$f_3$ versus $\alpha_s$ for different value of $\sigma_q$ for $S \geq 0.25$ and $A \leq 0.10$

- ● Lund Model $\sigma_q = 0.30$ GeV/c $V/(P+V) = 0.5$
- + Lund Model $\sigma_q = 0.32$ GeV/c
- o Lund Model $\sigma_q = 0.25$ GeV/c
- x Lund Model $\sigma_q = 0.39$ GeV/c
- H Hoyer Model with $\sigma_q = 0.32$ Gev/c
- h same, with $\sigma_q = 0.25$ Gev/c
- Ж same, with $\sigma_q = 0.30$ Gev/c (generation used to calculate $\alpha_s$).

The lines are drawn to guide the eye.

Fig. 2 Fraction of "3 jet events", $f_3$ versus $\alpha_s$, for HM and LM, compared to data, and for criterion n° 1 ($S \geq 0.25$ $A \leq 0.1$).

x Hoyer Model
● Lund Model

Fig. 3 to 15 Comparison between data (points with error bars) and Models (histograms). For the Hoyer Model, $\alpha_s = 0.17$ and for the Lund Model, $\alpha_s = 0.26$ .

Fig. 3 $x_{vis}$ = total energy of the charged particles divided by two times the beam energy for charged multiplicity ≥7.

Fig. 4 Charged multiplicity for events satisfying $x_{vis} \geq 0.25$.

Fig. 5 $P_t$ distribution of charged particles of the slim jet (a), and of the broad jet (b).
(the slim jet axis is taken as reference axis).

Fig. 6 (a) $P_{t\ in}$ distribution of charged particles.
(b) $P_{t\ out}$ distribution of charged particles.
The event plane is defined by the momentum tensor (see text)

Fig. 7 DN/DX distribution for charged particles where X= energy / E beam.

Fig. 8 Sphericity distribution.

Fig. 9 Aplanarity distribution.

Fig. 10 Thrust distribution.

Fig. 11 Oblateness distribution.

Fig. 12 Number of reconstructed clusters.

Fig. 13 Energy flow: symmetrized angular distribution weighted by the particle momentum. The angle is taken in the event plane and the reference axis is the slim jet axis. For this distribution further cuts have been applied in order to select $q\bar{q}g$ events:
$S > 0.20$ and $R_b \leq 0.12$ where $R_b$ is the ratio of the eigenvalues of the momentum tensor constructed with the projected momentum of the broad jet particles on the plane perpendicular to the reference axis.

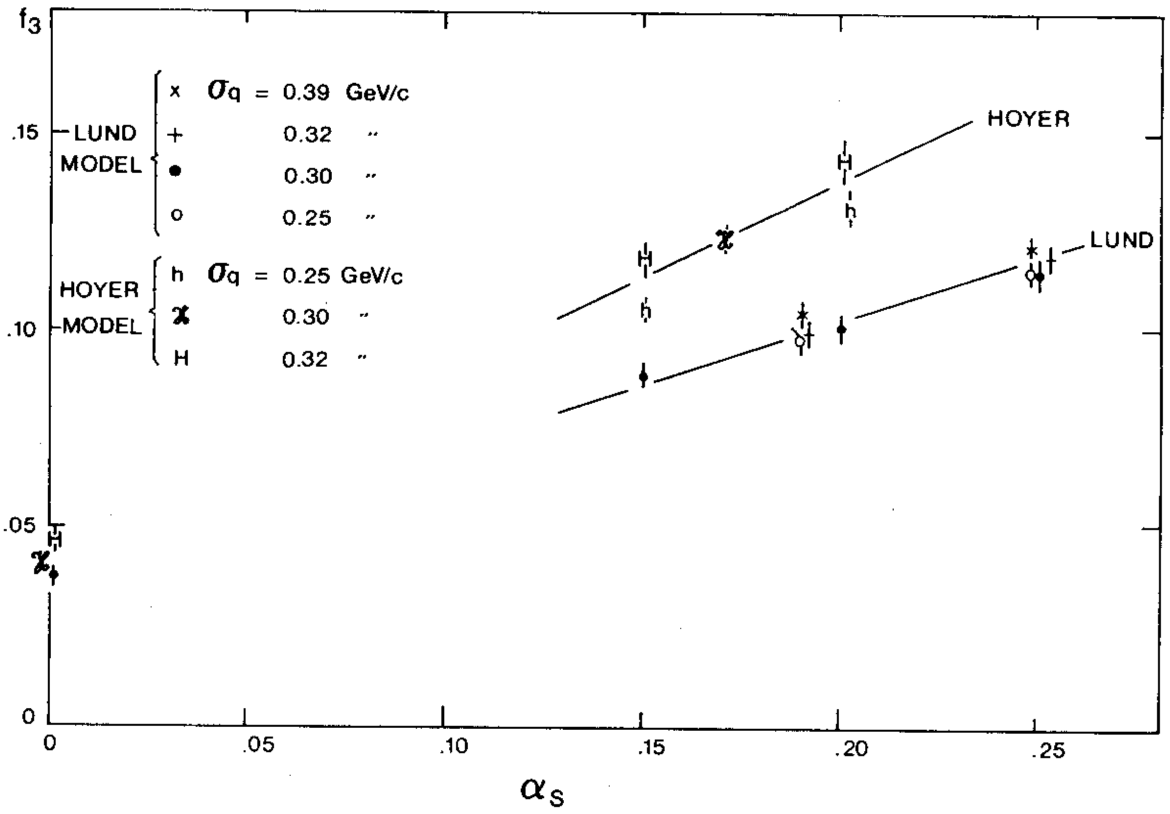
Fig. 14 Angular distribution in the event plane. Same cuts as above.

Fig. 15 $\sum_i |\cos\theta_i|/N$ per event. $\theta_i$ is the angle of the particle i with the event axis. N is the number of particles in an event.

Fig. 16 3 clusters thrust distribution. The full line histogram is the best fit to the data for the two models with:
$\alpha_s = 0.155 \pm 0.015$ for HM with a $\chi^2/DF = 5.0/4$
$\alpha_s = 0.235 \pm 0.025$ for LM with a $\chi^2/DF = 9.0/4$

Fig. 17
Asymmetry $f(\pi-\theta)-f(\theta)$ at 34 Gev :
dot dashed curve: 1st order QCD formula [18]
full line histogram: parton asymmetry
dashed histogram: asymmetry from final state hadrons
a) From Hoyer Model with $\alpha_s$=0.15
b) From Lund Model with $\alpha_s$=0.25

Fig. 18 Generator study (same cuts as for data) :
$f_3$ versus $\alpha_s$ for different fragmentation conditions ($S \geq 0.25$, $A \leq 0.10$):
● Lund Model $\sigma_q$=0.30 Gev/c V/(P+V)=0.5
x Lund program with FF fragmentation and gluon as a quark $a_g = a_f = 0.77$
o idem but $a_g$ = 1
▼ Lund program FF fragmentation but gluon as in LM
ℜ Hoyer Model with $\sigma_q$=0.30 Gev/c (generation used to calculate $\alpha_s$)
The lines are drawn to guide the eye.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.10
.05
0
LUND MODEL
x σq = 0.39 GeV/c
+ 0.32 ″
● 0.30 ″
o 0.25 ″
HOYER MODEL
h σq = 0.25 GeV/c
𝔥 0.30 ″
H 0.32 ″
HOYER
LUND
0
.05
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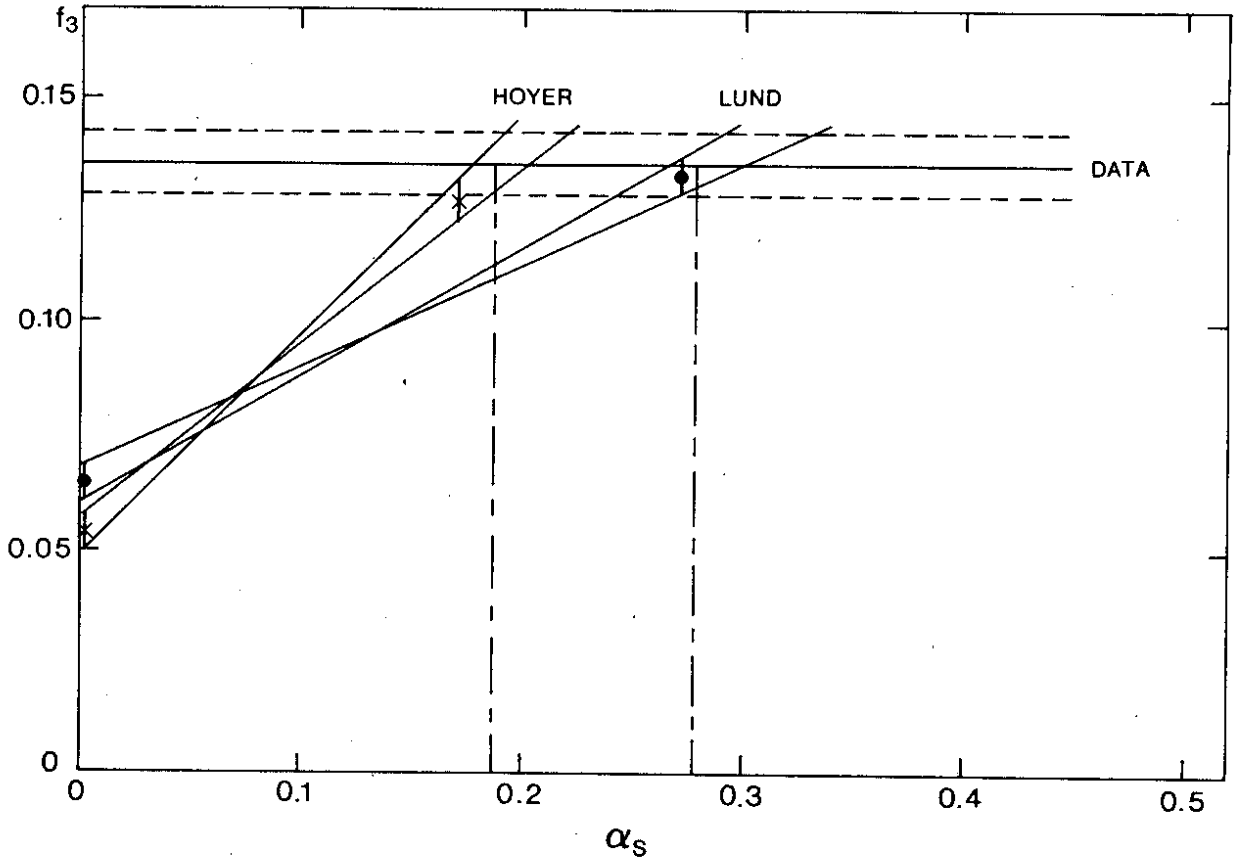
.20
.25
$\alpha_s$

Fig. 1


f3
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HOYER
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0.5
$\alpha_s$

Fig. 2

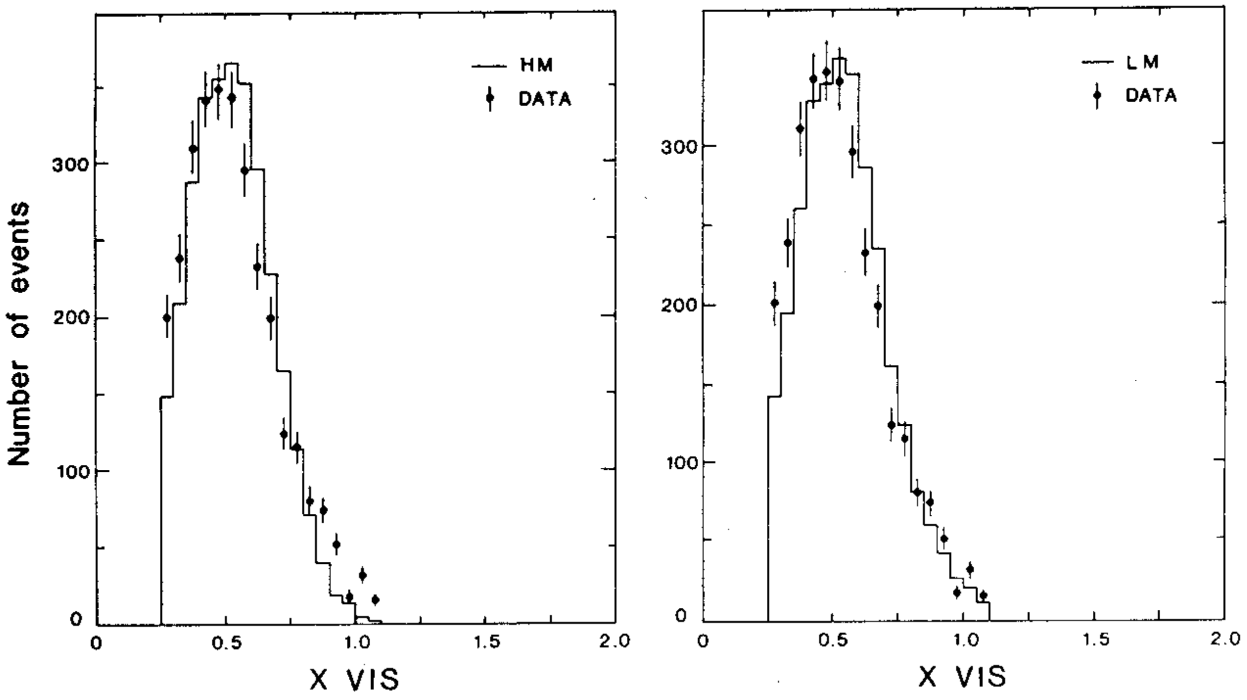

Number of events
0
100
200
300
0
0.5
1.0
1.5
2.0
X VIS
HM
DATA
LM
DATA

Fig. 3

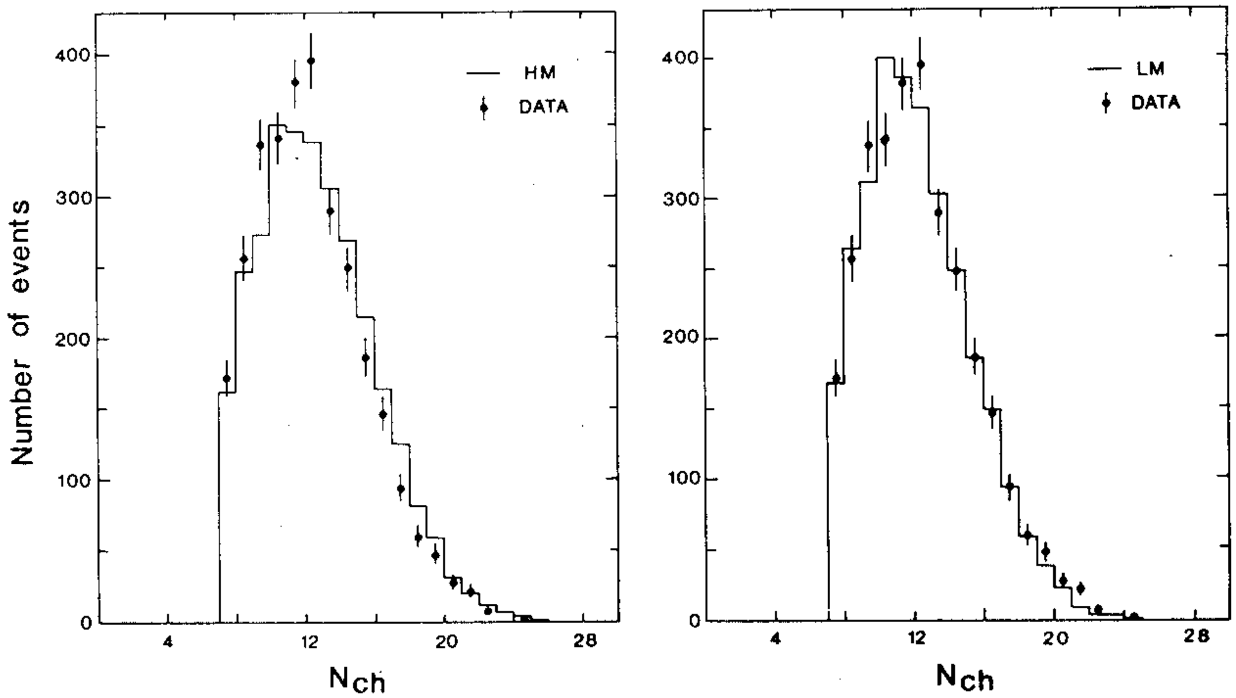

Number of events
0
100
200
300
400
4
12
20
28
Nch
HM
DATA
LM
DATA

Fig. 4

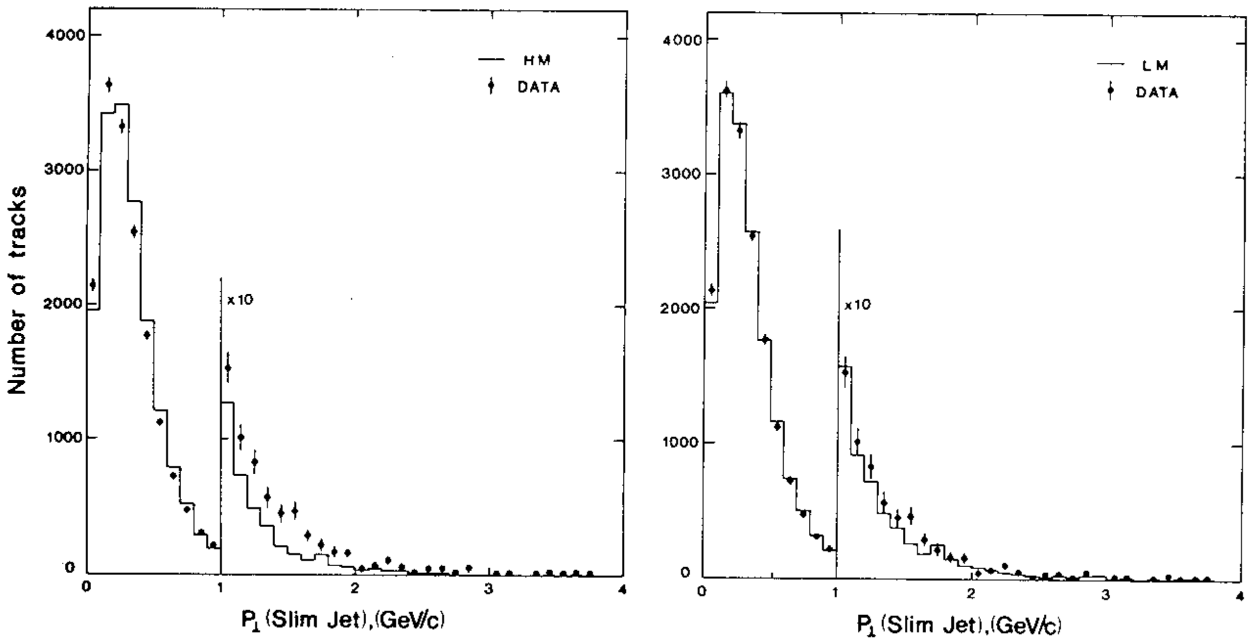

Number of tracks
4000
3000
2000
1000
0
HM
DATA
LM
DATA
x10
0
1
2
3
4
P$_\perp$ (Slim Jet),(GeV/c)
P$_\perp$ (Slim Jet),(GeV/c)

Fig 5a

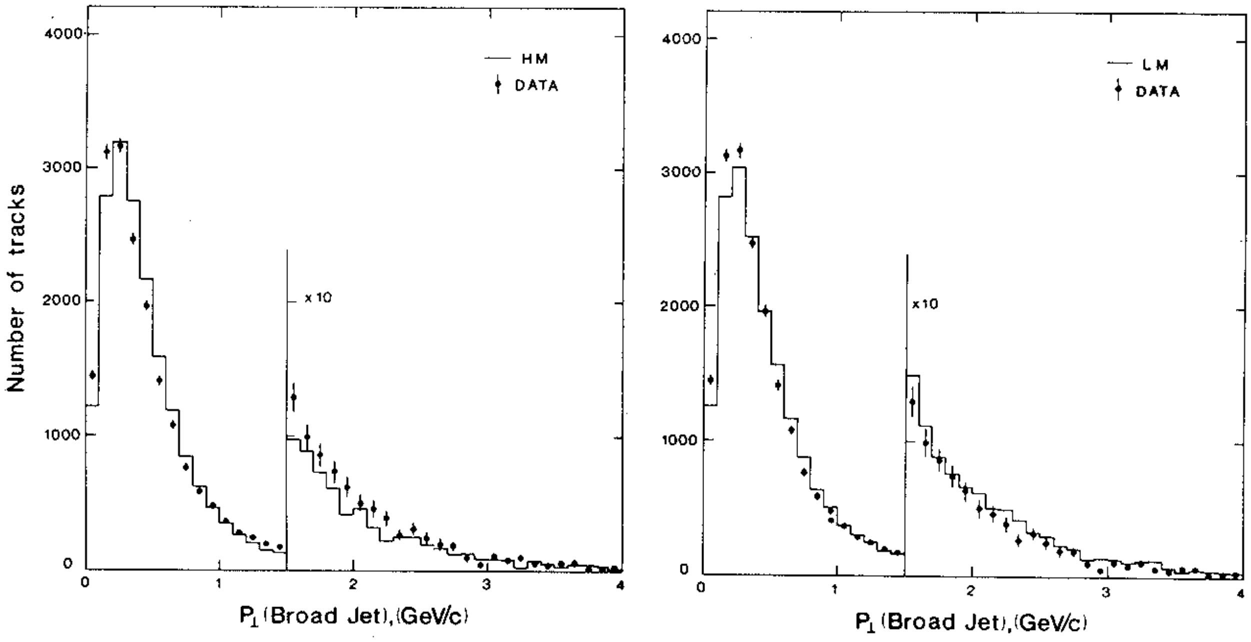

Number of tracks
4000
3000
2000
1000
0
HM
DATA
LM
DATA
x10
0
1
2
3
4
P$_\perp$ (Broad Jet),(GeV/c)
P$_\perp$ (Broad Jet),(GeV/c)

Fig 5b

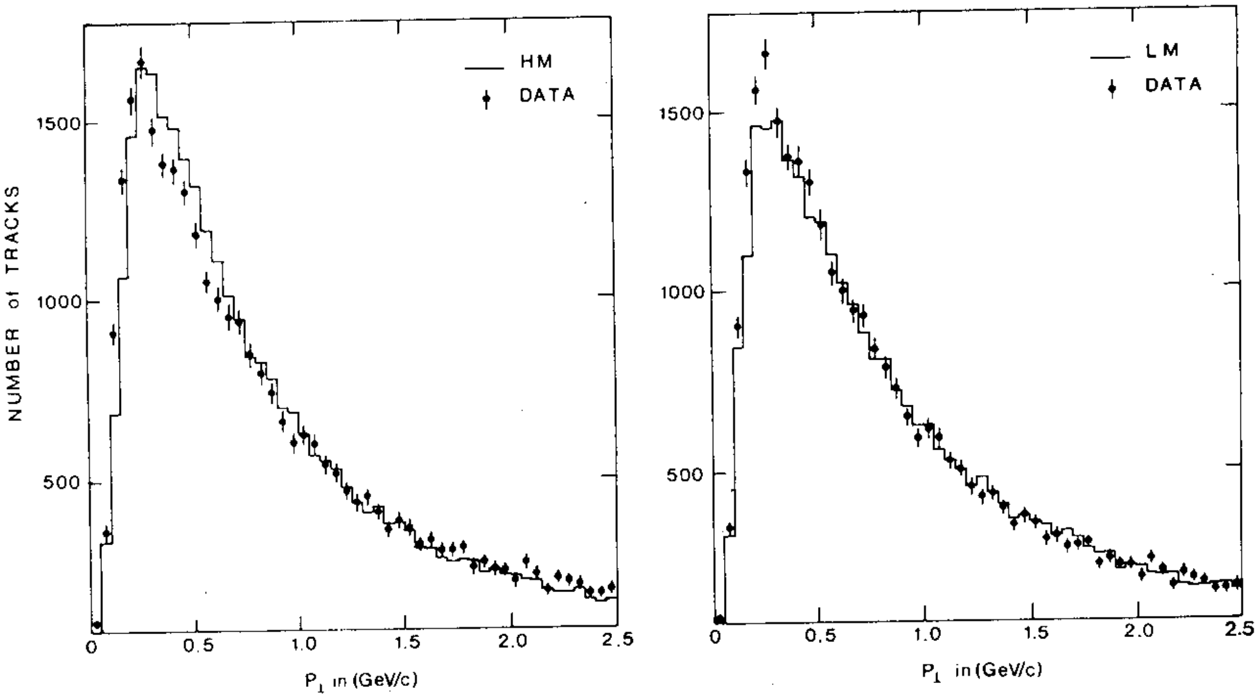

HM
DATA
NUMBER of TRACKS
1500
1000
500
0
0.5
1.0
1.5
2.0
2.5
P⊥ in (GeV/c)
LM
DATA
1500
1000
500
0
0.5
1.0
1.5
2.0
2.5
P⊥ in (GeV/c)

Fig 6a

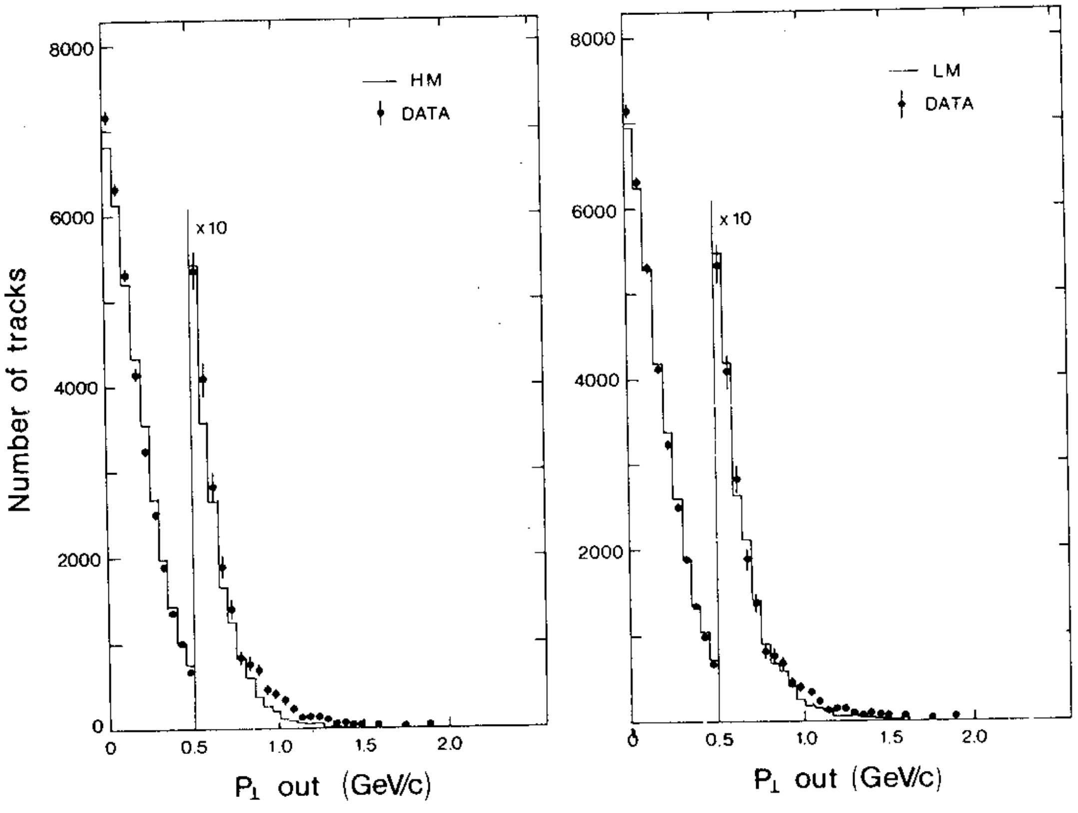
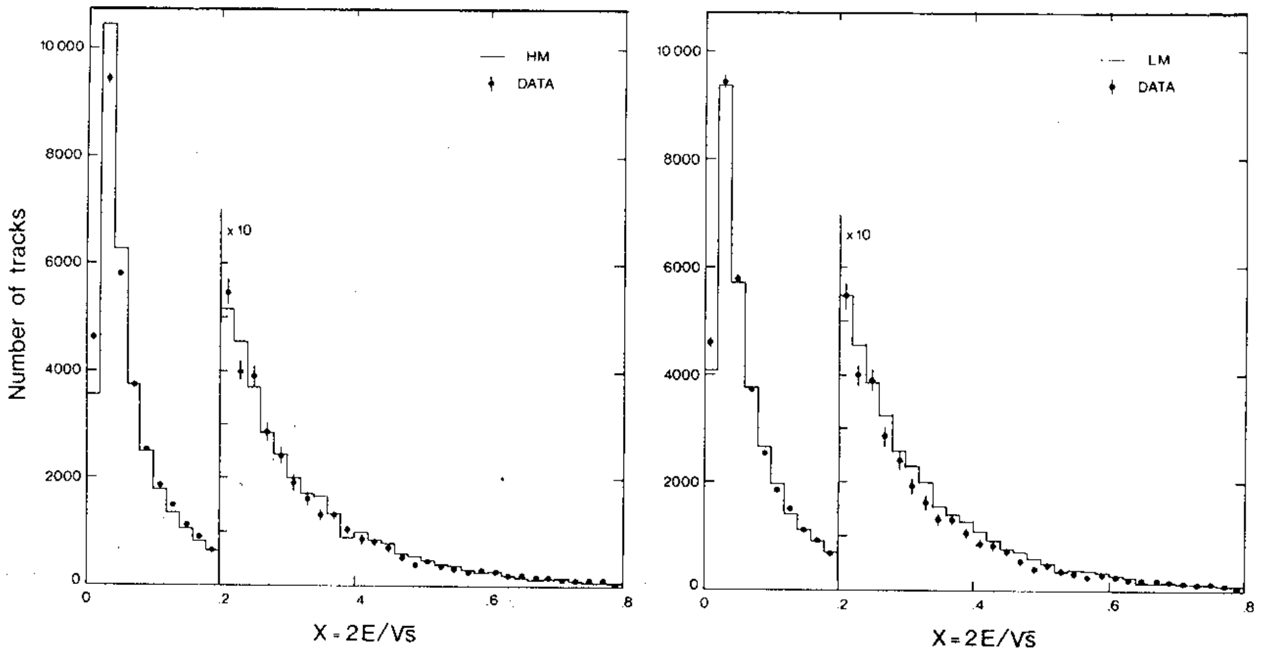
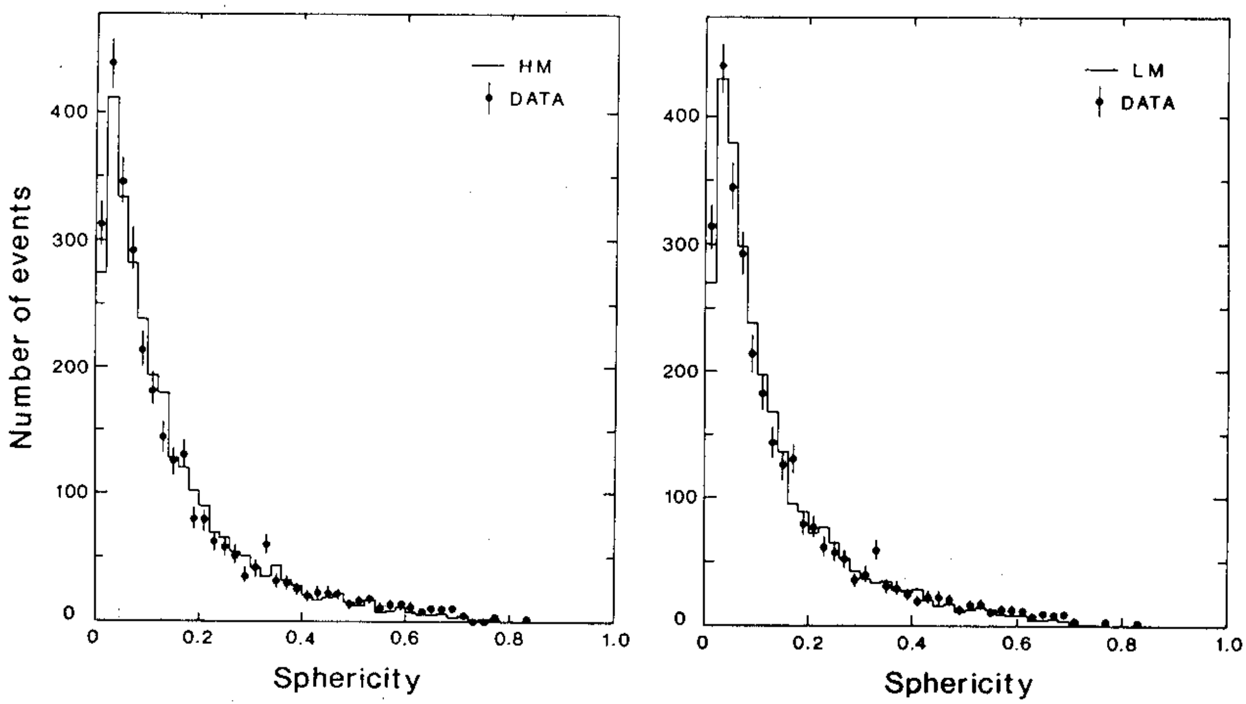

HM
DATA
x10
Number of tracks
8000
6000
4000
2000
0
0
0.5
1.0
1.5
2.0
P⊥ out (GeV/c)
LM
DATA
x10
8000
6000
4000
2000
0
0.5
1.0
1.5
2.0
P⊥ out (GeV/c)

Fig. 6b



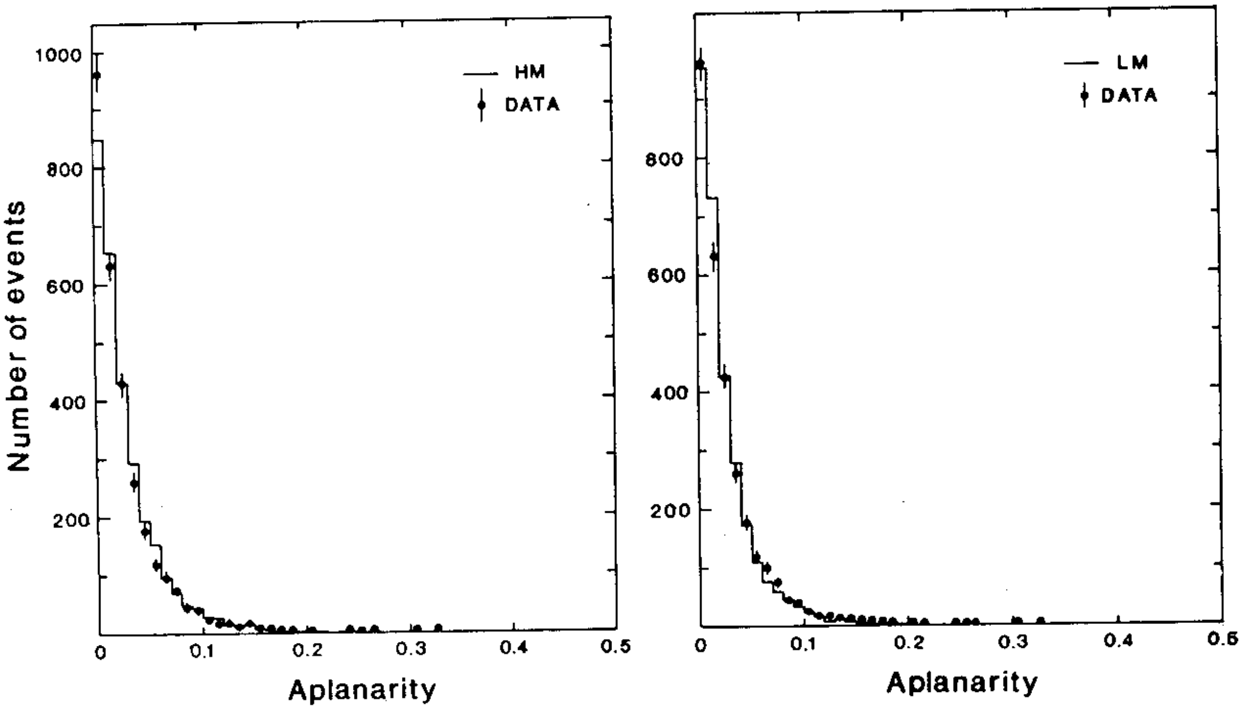
Number of tracks
10 000
8000
6000
4000
2000
0
HM
DATA
LM
DATA
x 10
0
.2
.4
.6
.8
X = 2E/√s

Fig. 7



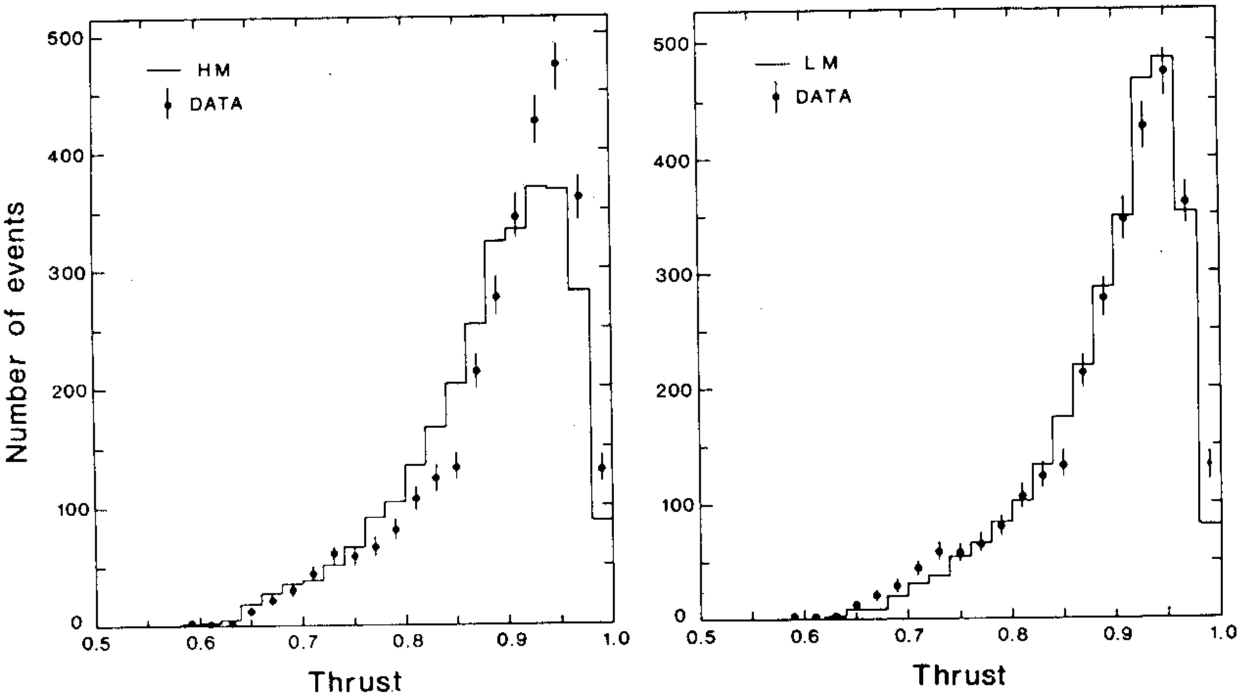
Number of events
400
300
200
100
0
HM
DATA
LM
DATA
0
0.2
0.4
0.6
0.8
1.0
Sphericity

Fig. 8



Number of events
1000
800
600
400
200
HM
DATA
0
0.1
0.2
0.3
0.4
0.5
Aplanarity
LM
DATA
800
600
400
200
0
0.1
0.2
0.3
0.4
0.5
Aplanarity

Fig.9



Number of events
500
400
300
200
100
0
HM
DATA
0.5
0.6
0.7
0.8
0.9
1.0
Thrust
500
400
300
200
100
0
LM
DATA
0.5
0.6
0.7
0.8
0.9
1.0
Thrust

Fig. 10

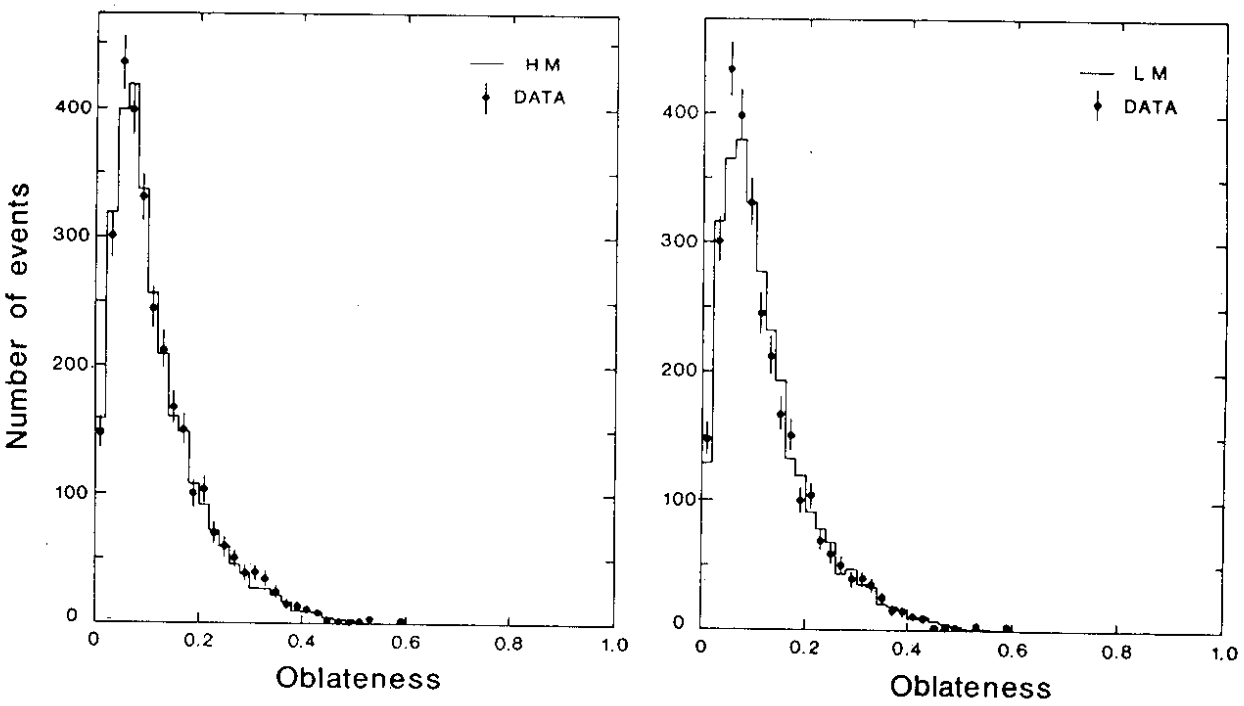

Number of events
Oblateness
HM
DATA
LM
DATA
0
100
200
300
400
0
0.2
0.4
0.6
0.8
1.0

Fig. 11

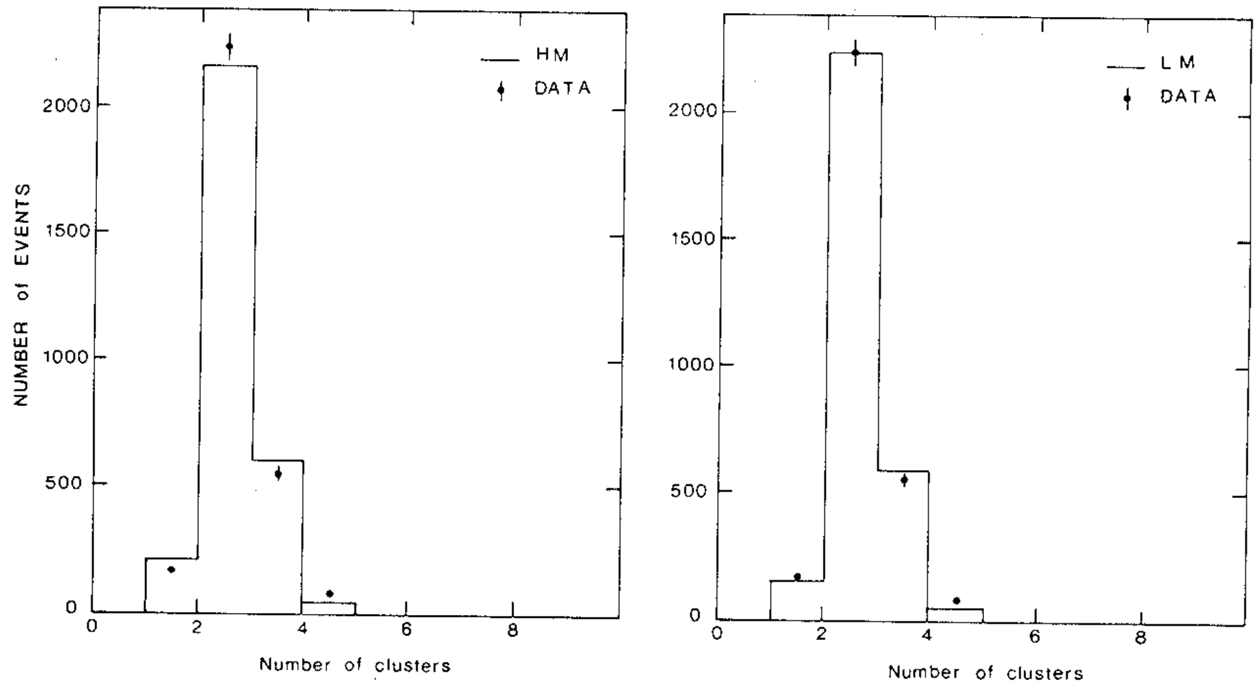
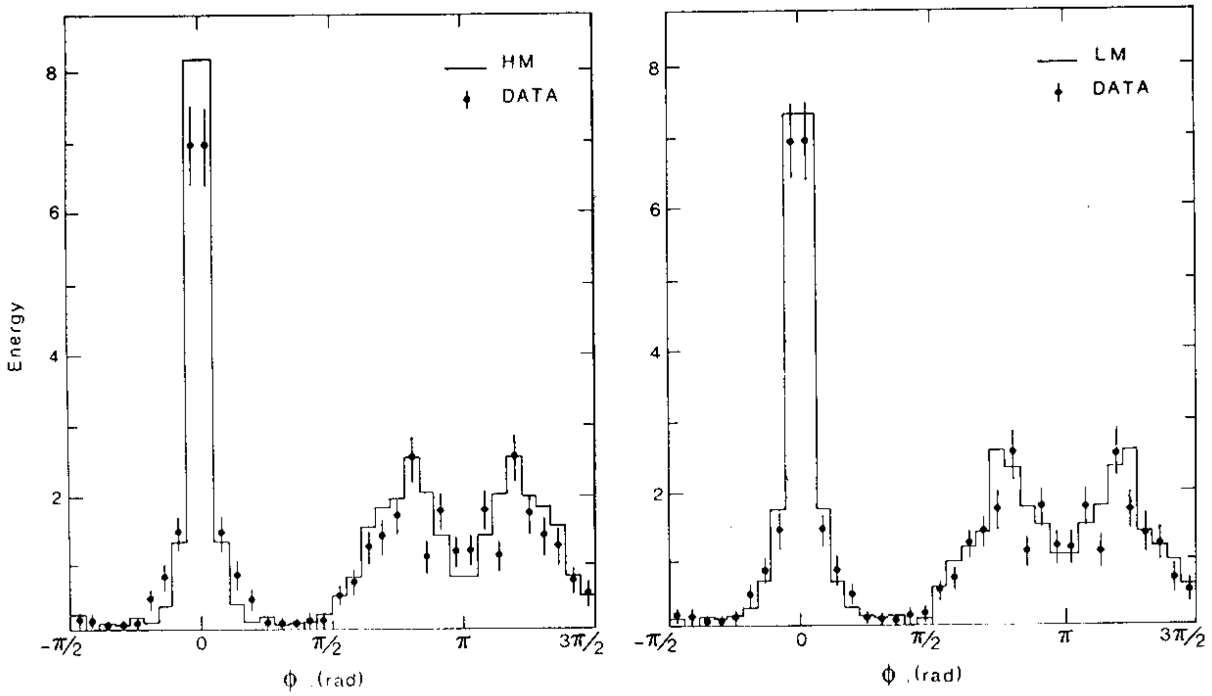
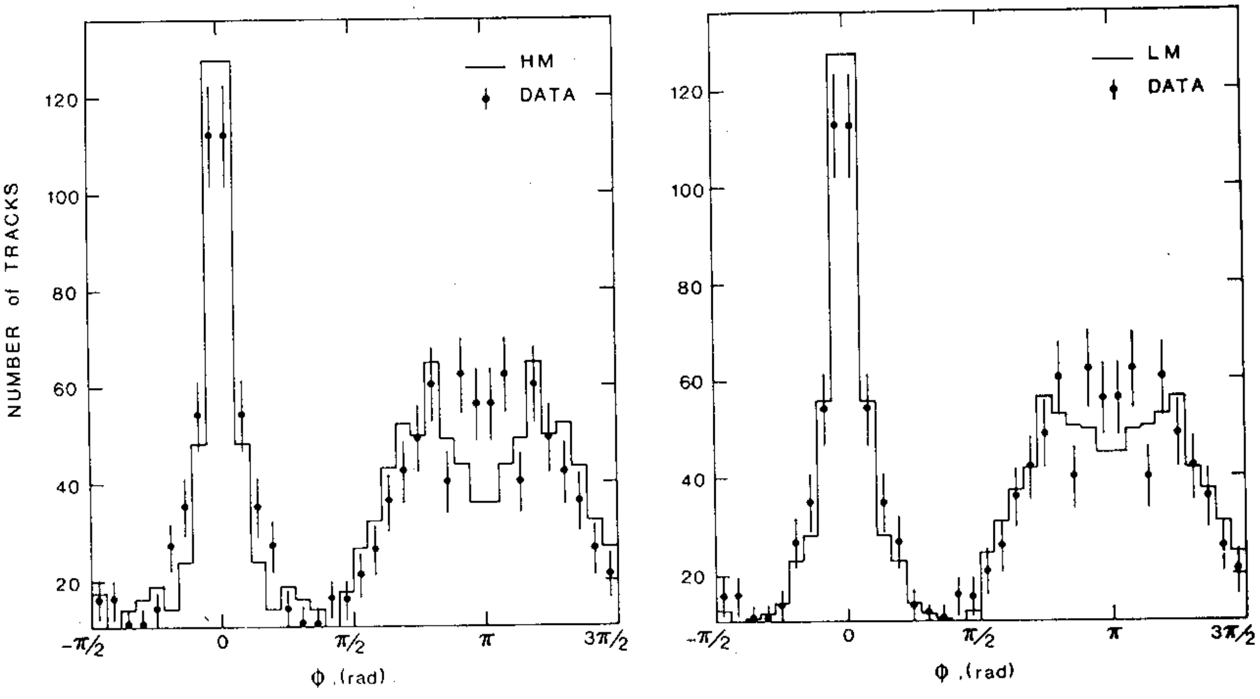

NUMBER of EVENTS
Number of clusters
HM
DATA
LM
DATA
0
500
1000
1500
2000
0
2
4
6
8

Fig. 12



HM
DATA
LM
DATA
Energy
8
6
4
2
-π/2
0
π/2
π
3π/2
φ ,(rad)

Fig.13



HM
DATA
LM
DATA
NUMBER of TRACKS
120
100
80
60
40
20
-π/2
0
π/2
π
3π/2
φ ,(rad)

Fig.14

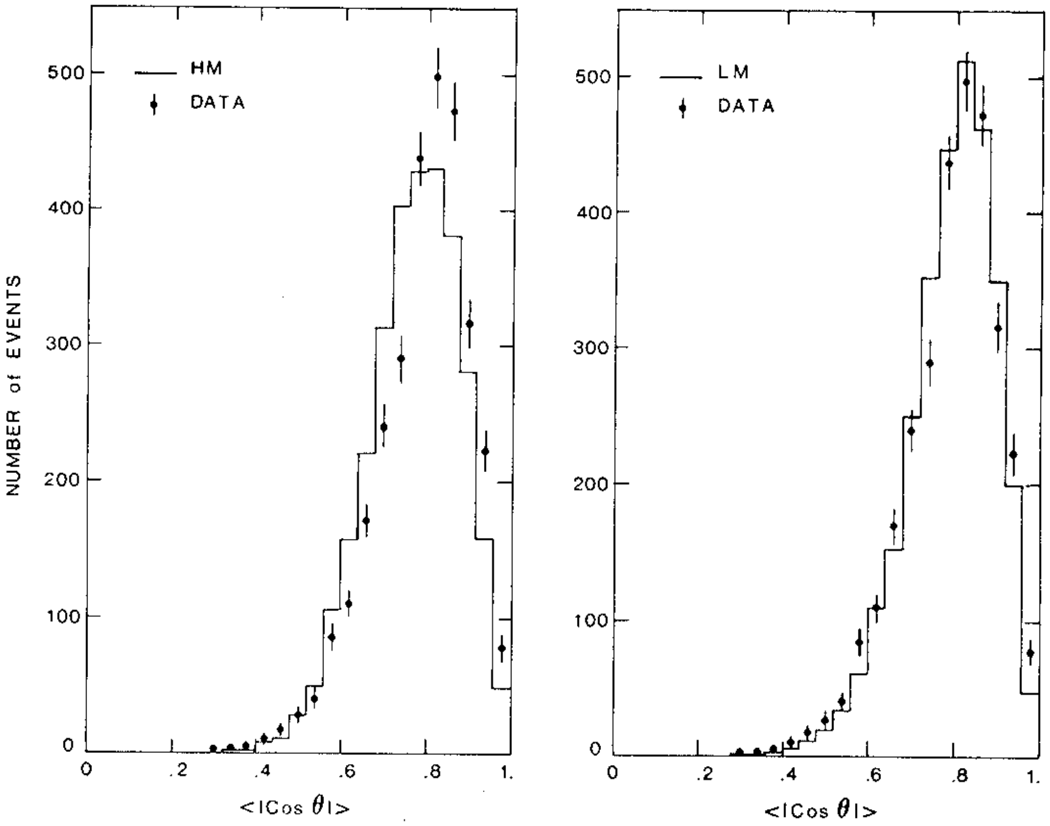

HM
DATA
NUMBER of EVENTS
500
400
300
200
100
0
0
.2
.4
.6
.8
1.
<ICos θI>
LM
DATA
500
400
300
200
100
0
0
.2
.4
.6
.8
1.
<ICos θI>

Fig. 15

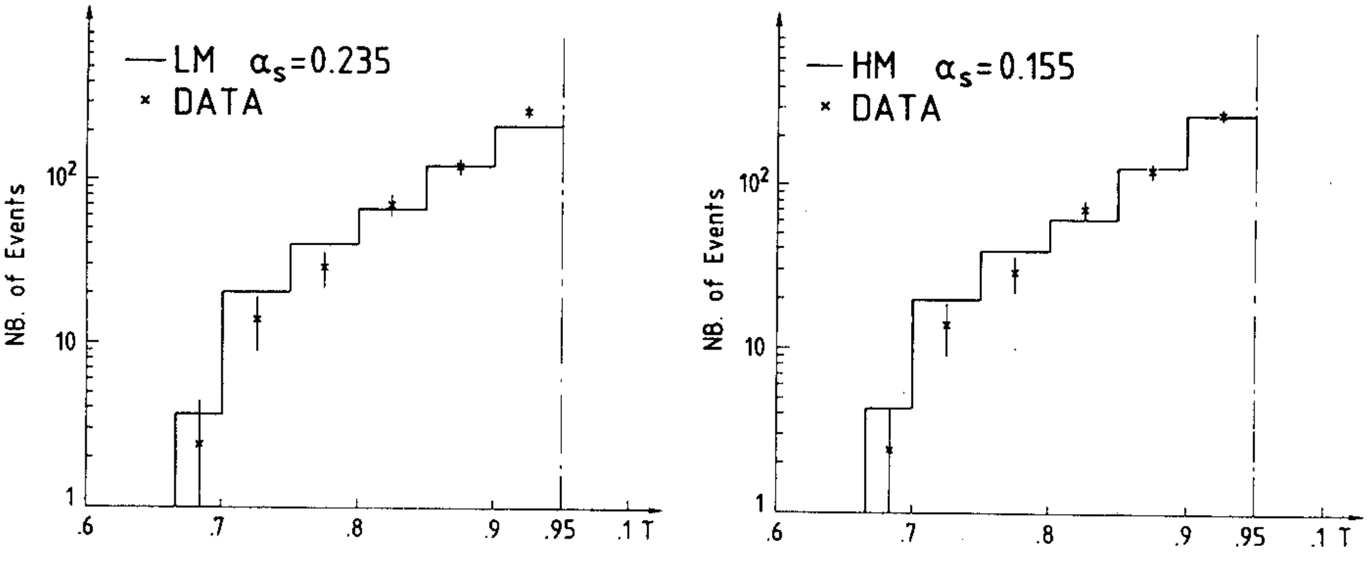

LM $\alpha_s$=0.235
DATA
NB. of Events
$10^2$
10
1
.6
.7
.8
.9
.95
.1 T
HM $\alpha_s$=0.155
DATA
NB. of Events
$10^2$
10
1
.6
.7
.8
.9
.95
.1 T

Fig. 16

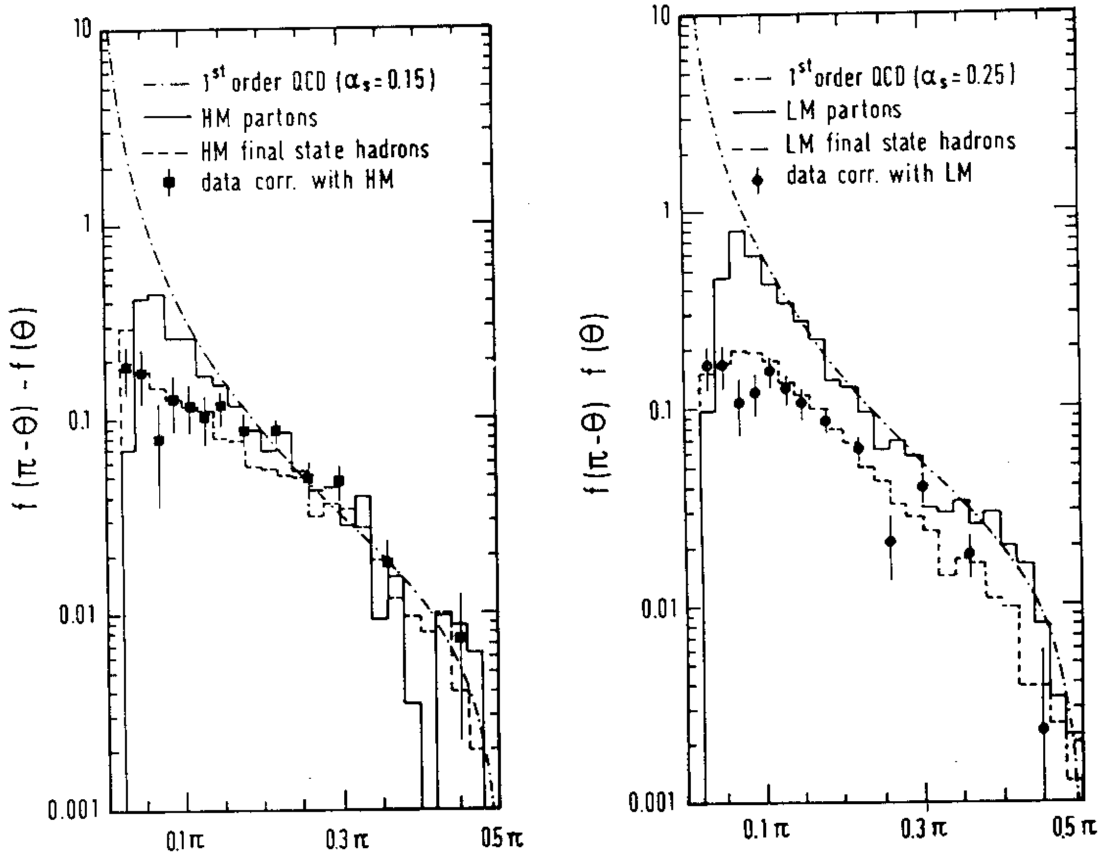

10
1
0.1
0.01
0.001
1st order QCD ($\alpha_s$ = 0.15)
HM partons
HM final state hadrons
data corr. with HM
f (π - Θ) - f (Θ)
0.1π
0.3π
0.5π
10
1
0.1
0.01
0.001
1st order QCD ($\alpha_s$ = 0.25)
LM partons
LM final state hadrons
data corr. with LM
f (π-Θ) f (Θ)
0.1π
0.3π
0.5π

Fig. 17

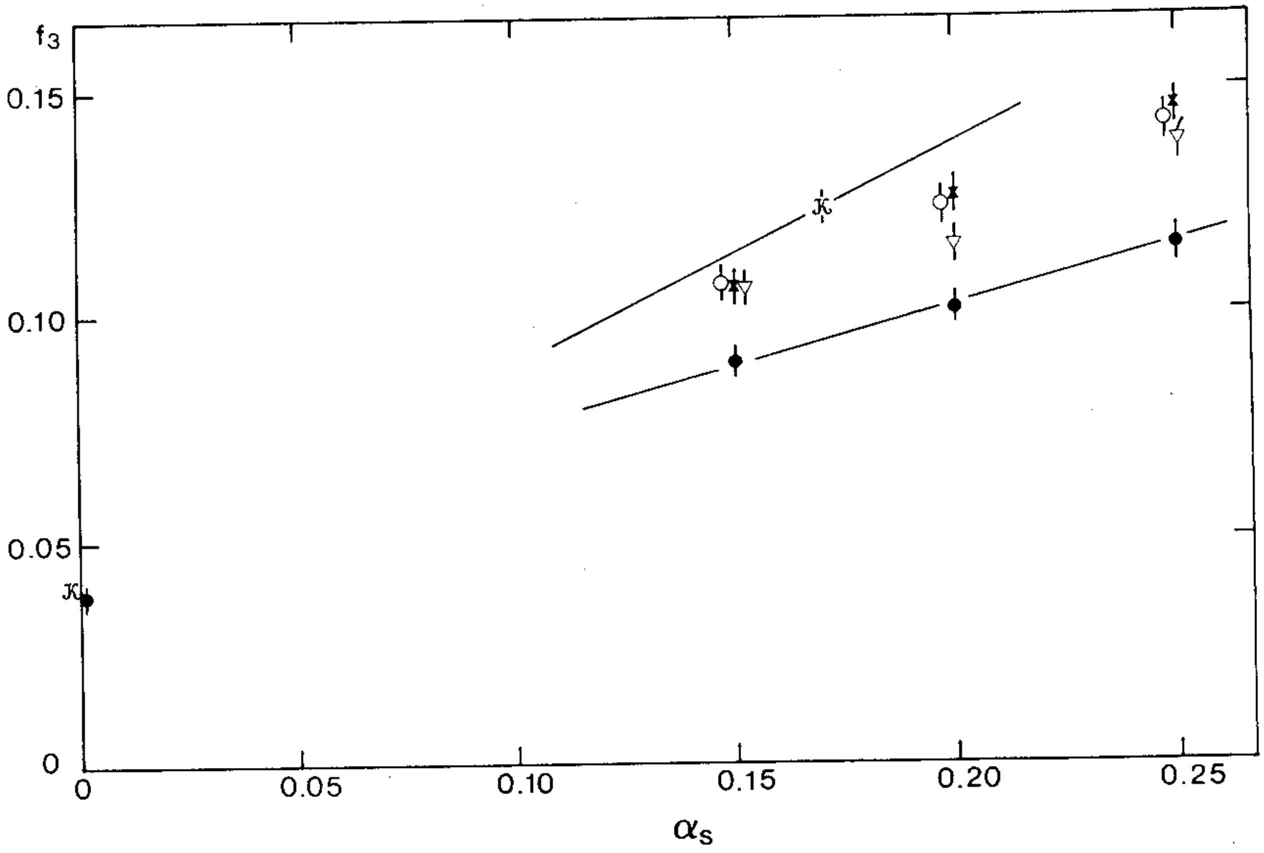

$f_3$
0.15
0.10
0.05
0
0
0.05
0.10
0.15
0.20
0.25
$\alpha_s$

Fig. 18