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Observation of Inclusive η Production in e^+e^- Annihilation at c.m. Energies of 34 GeV

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Abstract

The inclusive production of η mesons at c.m. energies around 34 GeV has been studied for e^+e^- annihilation into hadrons. The average number of η-mesons per event is found to be 0.72 ± 0.10 (stat.) ± 0.18 (syst.). The abundance of η's is studied as a function of event shape parameters and it is compared to the corresponding π° rates.

During recent years experimental evidence has been accumulated at high energy e^+e^- storage rings, which supports a simple scheme for electron positron annihilation into hadrons. Initially quarks and gluons are produced by a process which is well described by perturbative QCD $^{1)}$. Subsequently they fragment into ordinary hadrons. The fragmentation is a non perturbative process, which is not well understood theoretically. Therefore it is important to investigate experimentally the production of various particle species. Eta mesons are well suited to study the hadronization because it is expected that most of them will be produced in the fragmentation cascade and not by the decay of known particles.

Furthermore one might expect differences between quark and gluon fragmentation to be observable in the configuration of final state particles. Experimentally the gross features of quark and gluon jets observed in high energy e^+e^- annihilation are found to be similar. However, the JADE Collaboration reported that, on average, the transverse momentum of final state particles with respect to the jet axis is larger in gluon jets than in quark jets$^{2)}$. The copious production of baryons in the direct decay of heavy quarkonium states suggests a different composition for quark and gluon fragments$^{3)}$. It is also suspected that η-mesons may be more abundant in gluon jets than in quark jets$^{4)}$.

The JADE detector at PETRA with its fine grained electromagnetic shower detector covering more than 90% of the full solid angle, is well suited to reconstruct η-mesons decaying into two gamma rays and to determine their relative abundance in hadronic final states.

The present analysis is based on 18 865 hadronic e^+e^- annihilation events at centre-of-mass energies between 28 and 36 GeV with a weighted average of 34 GeV. The data were collected with the JADE detector at PETRA. A description of the detector, the trigger and the selection criteria for hadronic final states can be found in Ref. 5.

In this experiment, photons are observed as deposits of energy in clusters of adjacent lead glass counters, which are not linked to tracks of charged particles recorded in the central drift chamber. The photon energy is inferred from the cluster energy, which has to be corrected for the average energy loss in the material between the central detector and the lead glass, representing a thickness of about 0.8 radiation length. The energy resolution for photons is described by $\sigma(E)/E = 0.04/\sqrt{E(GEV)} + 0.015$.

The photon direction is reconstructed by fitting a three dimensional shower profile to the cluster. This procedure assumes that the observed energy deposit is due to a single gamma ray emerging from the principal event vertex. The free parameters of the fit are the coordinates of the impact point on the surface of the lead glass counters. The shower profile itself is described by an energy-dependent parametrization of electromagnetic cascades in lead glass (SF5), which is taken from Ref. 6.

The angular resolution varies slightly across the counter array as a function of the polar angle Θ ; on the average it is $\sigma(\Theta) = 0.6°$, $\sigma(\varphi) = 0.7°$.

For the present analysis only fits with $X^2/\text{D.O.F.} < 3$ for the single photon assumption were accepted as photons. This requirement rejected hadronic showers, which are not linked to a track in the central detector, and clusters which contain more than one primary photon. Eta mesons can be reconstructed up to momenta of $P_\eta < 12$ GeV even if they decay symmetrically.

In order to further purify the photon sample additional constraints were applied. The photon energy E_γ was required to be $E_\gamma > 200$ MeV

and the polar angle of the photon had to lie in the interval $-0.76 < \cos\delta_\gamma < 0.76$. This cut selects photons fully contained in the barrel part of the lead glass array.

The observed photon spectrum is shown in Fig. 1. The raw data were compared with a Monte Carlo simulation of hadronic final states in e^+e^- annihilation. This comparison was achieved by generating events according to the prescription of Ref. 7, including initial state radiation. The fragmentation parameters of the model were adjusted to fit the overall event structure[8]. The generated particles were then tracked through a detector simulation, which included the known features of the apparatus, and the artificial events were subjected to the same analysis programs as the real data. Good agreement between the observed and the simulated photon spectrum was obtained, as shown in Fig. 1, giving confidence in the use of the Monte Carlo generator for efficiency calculations.

The mass spectrum of those two photon combinations for which the total energy $E_{\gamma\gamma}$ exceeded 700 MeV is shown in Fig. 2a. In order to reduce the number of wrong combinations, only pairs of gammas belonging to the same event hemisphere were accepted. For this purpose every event was partitioned by a plane perpendicular to the sphericity axis. This requirement was essential for observing η-mesons decaying into two photons. Monte Carlo calculations coroborate that the reconstruction efficiency is well understood for all event topologies. The relative loss of efficiency due to the hemisphere condition is 11.5%.

The spectrum of Fig. 2a exhibits a clear $\pi°$ signal with a width of $\sigma(\pi°) = 18.8 \pm 0.6$ MeV above a smooth background. A structure becomes visible in the region of the η-mass, if all photons with $E_\gamma > 300$ MeV are removed, which contribute to a $\pi°$ band defined as $95 \text{ MeV} < m_{\gamma\gamma} < 175$ MeV. The resulting spectrum is shown in Fig. 2b.

In the range $300 \text{ MeV} < m_{\gamma\gamma} < 1000$ MeV the invariant mass spectrum was fitted with an empirical background function $f(m_{\gamma\gamma}) = (a + bm_{\gamma\gamma} + cm^2_{\gamma\gamma})/m^2_{\gamma\gamma}$ plus a Gaussian with variable width and central mass value. The η-signal remaining after background subtraction is shown in Fig. 2c. The width of the signal $\sigma(\eta) = 51 \pm 11$ MeV is compatible with the detector resolution. In total 694 ± 93 (stat.) η-mesons were observed.

For the determination of the η-yield, the overall detection efficiency was determined by Monte Carlo methods to be 5.2% for the quoted selection criteria. This number includes the two gamma branching ratio of the η-meson (39.1%) and the effects of initial state radiation from the beam particles. For the investigation of differential η distributions individual efficiencies were calculated.

The η-fraction at an average centre-of-mass energy of 34 GeV was found to be 0.72 ± 0.10 (stat.) ± 0.18 (syst.) η-mesons per event. The quoted systematic errors contain uncertainties in background subtraction, detector resolution and efficiency calculation. Comparing with low energy data, an increase in the η-fraction by about a factor of 5 is observed between 4 GeV[9) and 34 GeV centre-of-mass energy. This increase is similar in magnitude to that observed for other particle species. The proton yield goes up by a factor of 4, that for charged pions by a factor of 5 in the quoted energy range[10).

The differential η-yield as a function of momentum was obtained by fitting the two photon mass spectrum in three momentum bins. The resulting spectrum is shown in Fig. 3. The slope of the invariant cross section is steeper than that for charged pions and neutral kaons.
This comparison with the differential neutral kaon cross section[11) and charged pion cross section[10) is performed in Fig. 3.

In order to investigate whether the production of η-mesons is correlated with the event shape, the η-fraction is plotted as a function of the event sphericity in Fig. 4b together with the corresponding fraction of neutral pions [12). Both fractions increase with increasing sphericity. Whether the η yield rises faster than the π° yield is investigated in Fig. 4a, where the ratio between the η and π° fraction is shown with statistical errors only. It seems to increase as a function of sphericity; however, taking into account statistical errors and systematic point to point fluctuations the probability for a constant η/π° ratio is 28% and can thus not be excluded by the present experiment.

The same data may be analyzed in a different way by introducing other event shape categories. Two jet events are defined as events with a sphericity $S < 0.15$. Spherical events have $Q_1 > 0.06$, where Q_1 is the smallest eigenvalue of the normalized sphericity tensor $(Q_1 \leq Q_2 \leq Q_3)$ and flat events are characterized by $Q_1 < 0.06$ and $S > 0.15$. From the compilation in Table 1, it may be inferred that planar and spherical events have a higher fractional η-rate than two jet events. However also in this case taking into account point to point errors the probability for a constant η/π° ratio is as high as 21%.

In a further analysis step events were partitioned into a slim jet and a broad jet requiring the individual jet sphericities to obey the relation $S_{\mathrm{slim}} < S_{\mathrm{broad}}$. It was observed that for events with a total sphericity $S < 0.15$ representing the 2-jet class the η yields are 0.22 ± 0.06 (stat.) ± 0.06 (syst.) and 0.29 ± 0.08 (stat.) ± 0.07 (syst.), for the slim jet and the broad jet, respectively. For the complementary sample of non 2-jet events defined by $S > 0.15$ the corresponding rates are 0.43 ± 0.14 (stat.) ± 0.15 (syst.) for the slim jet and 0.96 ± 0.17 (stat.) ± 0.21 (syst.) for the broad jet. This indicates that an increase of the η-yield with increasing sphericity can mainly be attributed to the broad jet.

In summary, the production of η mesons in e^+e^- annihilation reactions into hadrons is observed at a rate of 0.72 ± 0.10 ± 0.18 η's per event at 34 GeV centre-of-mass energy. The data are suggestive that the η-rate is higher in events with a planar or spherical structure than in two jet events.

Acknowledgement

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Table Captions

Table I : η- and π° fraction as a function of event classification together with the corresponding detection efficiencies.

Figure Captions

Fig. 1 Inclusive photon spectrum. The full line is calculated according to the Lund model of Ref. 7, using the fragmentation parameters given in Ref. 8. The curve is normalized to the number of hadronic events.

Fig. 2 Two-photon mass spectrum.

a) All photons with cuts described in the text, π° region fitted to a Gaussian + 2^{nd} order polynomial

b) π° removed with $E_\gamma > 300$ MeV

c) η-signal background subtracted.

Fig. 3 Inclusive η-spectrum compared to K_o, $\bar{K}_o$ and $\pi^\pm$. (Error bars represent statistical error only).

Fig. 4 a) η/π°-ratio as a function of sphericity. The dashed line shows the prediction given by Ref. 7.

b) π°- and η-fraction as a function of sphericity (error bars represent statistical errors only).

References

1. P. Söding and G. Wolf, Ann. Rev. Nucl. and Part. Science, Vol. 31 (1981) 231

   G. Wolf, Proceedings of the 21st Int. Conf. on High Energy Physics, Paris 1982, p. C3-525

   D.H. Politzer, Proceedings of the 21st. Int. Conf. on High Energy Physics, Paris 1982, p.C3-653

2. JADE-Collaboration W. Bartel et al., Phys.Lett. 123B (1983) 460

3. DASP-Collaboration R. Brandelik et al., Nucl.Phys. B148 (1979) 189

   DASP2-Collaboration, H. Albrecht et al., Phys.Lett. 102B (1981) 291

   CLEO-Collaboration, F. Pipkin, Proceedings of the 21st. Int. Conf. on High Energy Physics, Paris 1982, p. C3-40

4. C. Peterson and R.F. Walsh, Phys.Lett. 91B (1980) 455

5. JADE Collaboration W. Bartel et al., Phys.Lett. 88B (1979) 171

6. E. Longo and I. Sestilli, Nucl. Instr. and Meth. 128 (1975) 283

7. B. Anderson, G. Gustafson, T. Sjöstrand, Phys.Lett. 94B (1980) 711

8. JADE-Collaboration W. Bartel et al., Phys.Lett. 101B (1981) 129

9. Crystal Ball Collaboration, R. Partridge et al., Phys.Rev.Lett.47 (1981), 760

10. TASSO Collaboration, M. Althoff et al., Z.Physik C17 (1983) 5

11. JADE Collaboration, W. Bartel et al., DESY 83-042, to be published in Z. Physik C.

12. JADE Collaboration, W. Bartel et al., to be published.

TABLE 1

Event-Class	2-jet	flat	spherical
Cuts in Sphericity and Q_1	$S < 0.15$	$S > 0.15$ $Q_1 < 0.06$	$S > 0.15$ $Q_1 > 0.06$
η-detection efficiency	5.2%	4.2%	7.1%
η-fraction (f_η)	0.50 ± 0.10 ± 0.09	1.42 ± 0.27 ± 0.31	1.64 ± 0.37 ± 0.42
π^o-fraction (f_{π^o})	3.88 ± 0.12 ± 0.31	6.16 ± 0.24 ± 0.69	7.85 ± 0.70 + 1.98
f_η/f_{π^o}	0.13 ± 0.03 ± 0.03	0.23 ± 0.04 ± 0.06	0.21 ± 0.05 ± 0.08

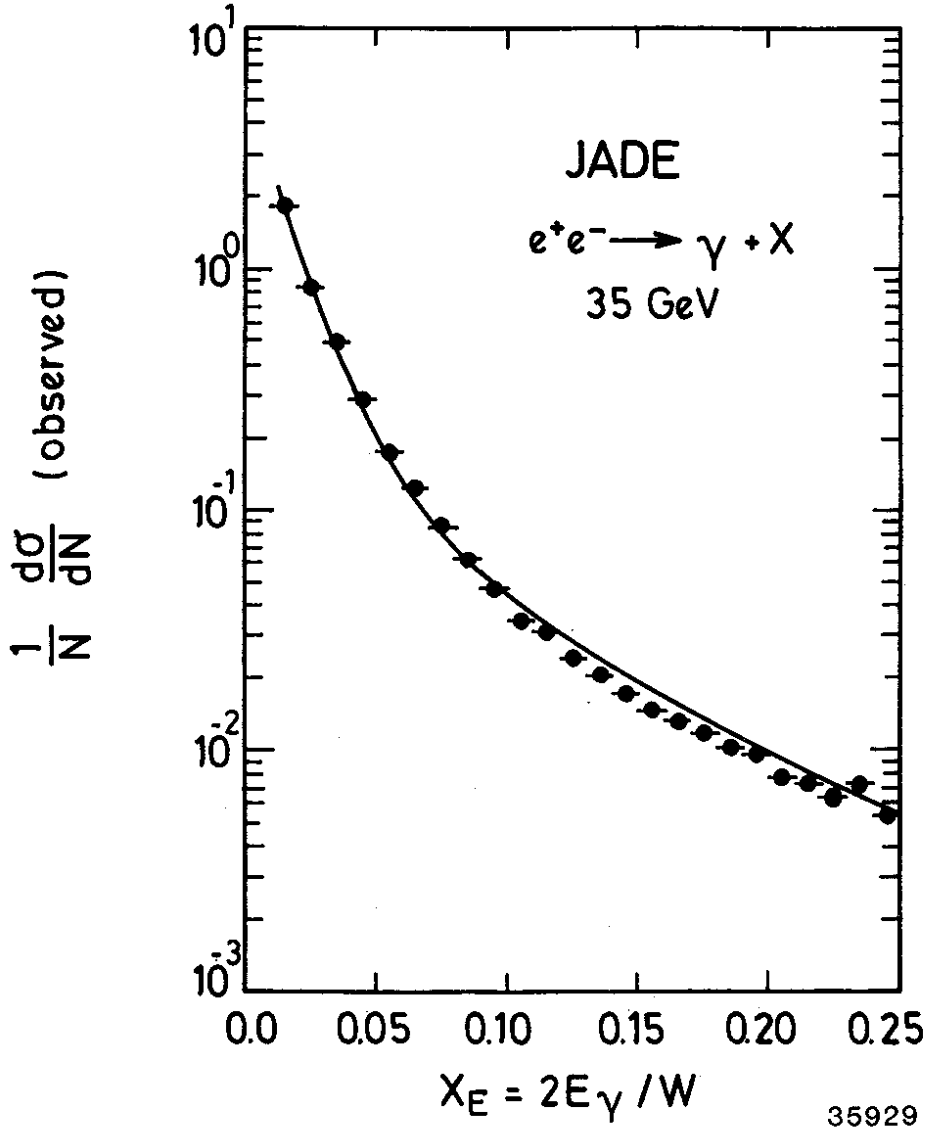
10^1
10^0
10^-1
10^-2
10^-3
1/N dσ/dN (observed)
JADE
e⁺e⁻ → γ + X
35 GeV
0.0
0.05
0.10
0.15
0.20
0.25
X_E = 2E_γ /W
35929

Fig. 1

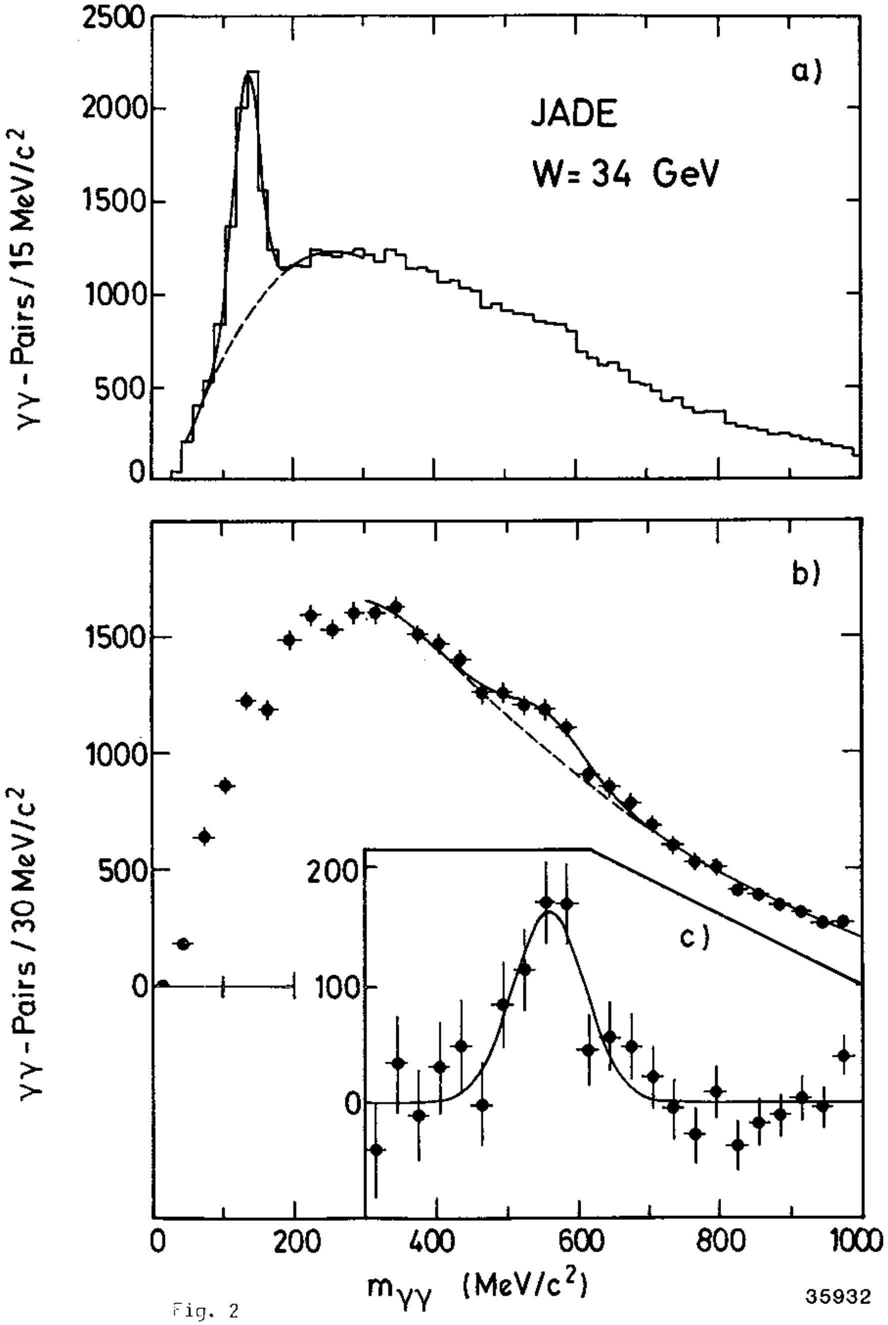
a)
JADE
W= 34 GeV
γγ - Pairs / 15 MeV/c²
2500
2000
1500
1000
500
0
b)
c)
γγ - Pairs / 30 MeV/c²
1500
1000
500
0
200
100
0
200
400
600
800
1000
m_γγ (MeV/c²)
35932

Fig. 2

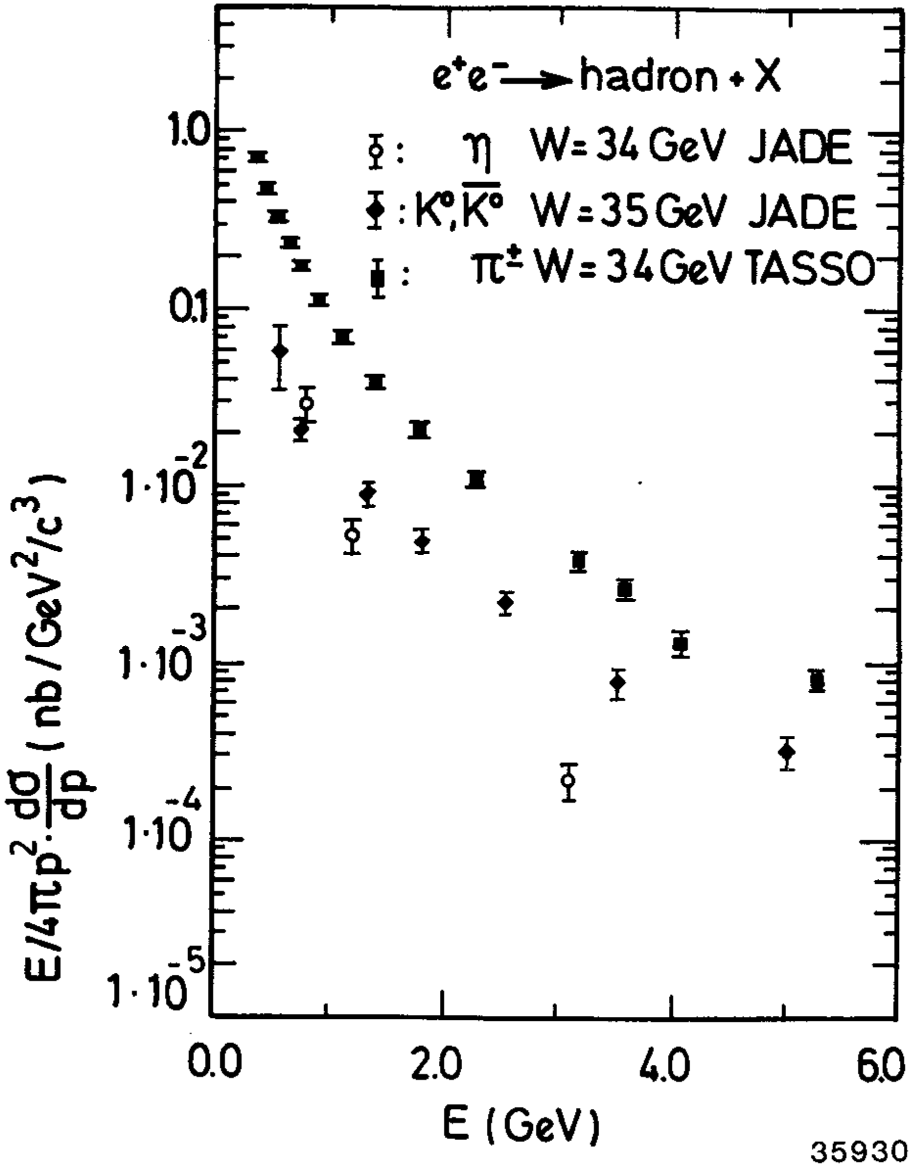
e⁺e⁻ ⟶ hadron + X
○ : η W = 34 GeV JADE
◆ : K°, K̄° W = 35 GeV JADE
■ : π± W = 34 GeV TASSO
1.0
0.1
1·10⁻²
1·10⁻³
1·10⁻⁴
1·10⁻⁵
E/4πp²·dσ/dp (nb/GeV²/c³)
0.0
2.0
4.0
6.0
E (GeV)
35930

Fig. 3

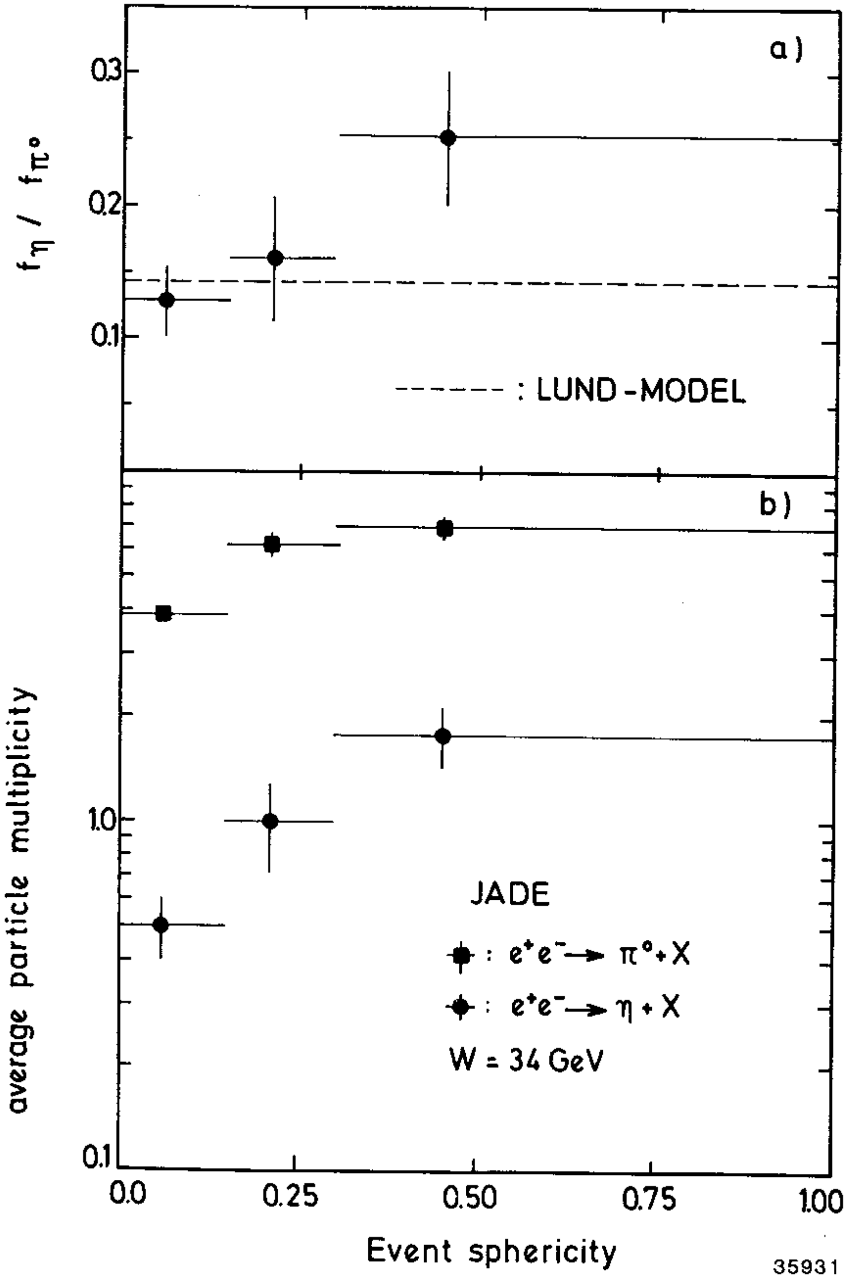
a)
0.3
0.2
0.1
f_η / f_π°
------ : LUND-MODEL
b)
1.0
0.1
average particle multiplicity
JADE
■ : e⁺e⁻ ⟶ π° + X
● : e⁺e⁻ ⟶ η + X
W = 34 GeV
0.0
0.25
0.50
0.75
1.00
Event sphericity
35931

Fig. 4