A SEARCH FOR HADRONIC EVENTS WITH LOW THRUST AND AN ISOLATED LEPTON

CELLO Collaboration

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Using the CELLO detector at the PETRA e^+e^- storage ring a search for hadronic events with low thrust and an isolated lepton has been carried out. The rate of such events and the thrust distribution of inclusive lepton events show no evidence for a threshold of new sources of inclusive lepton events at the highest PETRA energies. For $\sqrt{s} > 46.3$ GeV we observe one muon event of the above type, compared to an expectation of 0.8 ± 0.2 events from lower energy data. We do not observe any electron event of this class at the highest PETRA energies. The CELLO data thus do not support the observations of the MARK-J and JADE collaborations of an excess of muon events of the above type at $\sqrt{s} > 46.3$ GeV.

Introduction. The topology of multihadronic events in e^+e^- annihilation containing prompt leptons in the final state can be efficiently used as an indicator of new phenomena, e.g. the production of new heavy quarks. Using the CELLO detector [1] at the PETRA e^+e^- storage ring we have searched for inclusive lepton events with low thrust and an isolated lepton. Previous studies have already excluded the production of bound states of new heavy quarks of charge $\frac{2}{3}e$ up to a centre of mass energy of 46.78 GeV and the open production of new heavy quarks with charge $\frac{2}{3}e$ ($\frac{1}{3}e$) up to a centre of mass energy of 46.7 (46.3) GeV [2,3].

For centre of mass energies $\sqrt{s} > 46.3$ GeV the MARK-J and JADE collaborations have reported an excess of multihadronic inclusive muon events with low thrust [4,5]. MARK-J find eight events with thrust $T < 0.8$ whereas the prediction from their lower energy data allows for 1.9 events only. In addition, the muons in these eight events are "isolated": i.e. the angle δ between the muon and the thrust axis is large, $|\cos\delta| < 0.7$. JADE observe five muon events of this kind and expect 0.6 events from the extrapolation of lower energy data whereas they do not find such an excess in the inclusive electron channel.

Data collection and multihadronic event selection. The main features of the CELLO detector [1] relevant for efficient identification of leptons in multiparticle final states are the large and homogeneous acceptance for charged particles with a momentum resolution of $\Delta p_T/p_T = 1\% \cdot p_T$ [GeV/c] over a polar angle range of $|\cos\theta| \leqslant 0.91$, an electromagnetic calorimeter covering 99% of 4π and muon identification over 92% of 4π.

In CELLO multihadronic events are efficiently triggered by a combination of charged particle triggers and low threshold calorimeter triggers (for details see ref. [3]). Data are reduced offline by a filter program which verifies the trigger conditions and removes obvious background.

In the final selection, events are accepted as multihadrons if the following requirements are fulfilled:

- more than four charged particles are reconstructed within $|\cos\theta| \leqslant 0.865$,
- either the energy measured in the central calorimeter ($|\cos\theta| \leqslant 0.865$) is at least 1 GeV and the total visible energy of the event is bigger than $0.33\sqrt{s}$ or the energy of the charged particles exceeds $0.22\sqrt{s}$ and there is at least one charged particle in both the forward and the backward hemisphere with respect to the electron beam,
- the difference between the numbers of positively and negatively charged particles is not greater than six.

Data were taken in the energy ranges 38.3 GeV $< \sqrt{s} < 46.3$ GeV and 46.3 GeV $< \sqrt{s} < 46.78$ GeV. The integrated luminosities were 40.6 pb^{-1} and 2.1 pb^{-1}, giving 8046 and 332 multihadronic events, respectively, after selection. The background of events due to cosmic rays, beam–gas interaction, $\tau^+\tau^-$ and QED processes is determined by a visual scan to be less than 3%.

Muon identification. Muons are identified as

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charged particles with momentum above 1.6 GeV/c which penetrate 80 cm of iron in the magnet yoke and are subsequently detected in drift chambers with one layer of anode wires and two layers of slanted cathode strips. The muon chambers provide a spatial resolution of 0.6 cm matched to the multiple scattering of particles in the hadron absorber [1]. Backgrounds to the inclusive muon signal arise from hadron punch-through and decays, and associations of tracks in the central detector with random hits in the muon chambers. Because of the high rate of these random hits during the high energy scan at PETRA in the energy range 43.0 GeV $< \sqrt{s} <$ 46.78 GeV random associations were the dominating background, especially in the forward and backward regions. It is reduced by requiring correlated hits in the anode wires and both cathode layers of the muon chambers.

Two variables are used to quantify the quality of a track-hit association: the distance d between a reconstructed muon chamber hit and a track extrapolated from the central detector to the muon chambers and the quality Q of the association, which is d divided by the expected deviation of a muon from the extrapolated track. Tracks are accepted as muons, if $d < 40$ cm and $Q < 3.0$. The requirement for Q reduces efficiently the background from hadronic punch-through and decays.

Electron identification. Electrons are identified in the central part of the fine grained lead liquid-argon calorimeter [1] within a polar angle range of $|\cos\theta| \leqslant 0.8$. We require a momentum above 1 GeV/c matching the total energy deposited in the calorimeter. The lateral and longitudinal energy distribution has to be consistent with an electromagnetic shower and the shower axis is required to coincide with the particle trajectory. The lateral and longitudinal segmentation of the calorimeter provides a good electron–hadron separation even within the jets. The resulting overall electron detection efficiency after these requirements, including the acceptance, is about 60% of the detection efficiency for muons.

The background of events from deep inelastic electron–photon scattering and from inelastic Compton scattering, which contain isolated electrons, is reduced to a level of 5% by the multihadron selection criteria and by requiring the aplanarity of the event to be greater than 0.01. After the latter requirement 66% of the events with an identified electron are left.

Inclusive muon events with low thrust. For centre of mass energies $\sqrt{s} > 46.3$ GeV we find 25 inclusive muon events compared to an expectation of 26 ± 1 events from lower energy data from the numbers of hadronic events in the two energy ranges (see table 1). Thus the observed fraction of inclusive muon events is independent of the centre of mass energy in the range 38.3 GeV $< \sqrt{s} <$ 46.78 GeV and of the background conditions.

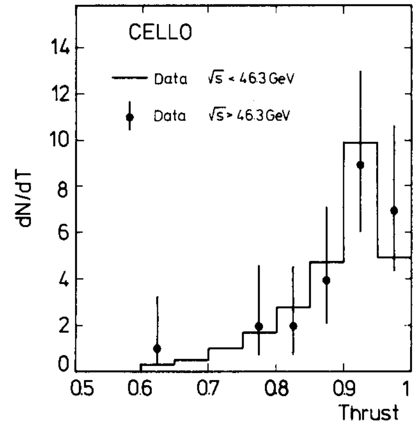
For the determination of the event thrust axis and the calculation of the thrust T, all reconstructed charged and neutral particles within $|\cos\theta| \leqslant 0.91$ and $|\cos\theta| \leqslant 0.99$, respectively, are taken, with the exception of the identified muon. It is excluded in order to get an unbiased determination of the event topology.

The thrust distribution of the inclusive muon events for $\sqrt{s} > 46.3$ GeV is shown in fig. 1 together with the distribution expected from data below $\sqrt{s} = 46.3$ GeV. The experimental distributions in the two energy ranges are in agreement with each other. In particular, there is no excess of inclusive muon events with low thrust for $\sqrt{s} > 46.3$ GeV (see table 1). We have used the Kolmogorov–Smirnov test to analyse the compatibility of the thrust distributions of high and low energy data without binning the data and without a cut in the thrust variable. The test gives a probability of 75% that the two distributions have the same shape.

As a measure of the isolation of a muon we use the angle δ between the muon and the thrust axis. The distribution of the inclusive muon events in the $T - |\cos\delta|$ plane is shown for both energy ranges in fig. 2 In dimuon events the muon with smaller $|\cos\delta|$ is considered. The cuts $T < 0.8$ and $|\cos\delta| < 0.7$ used by MARK-J and JADE to single out low thrust events with an isolated muon are indicated. For $\sqrt{s} > 46.3$ GeV we observe only one event (which is a dimuon event) in the region $T < 0.8$ and $|\cos\delta| < 0.7$ while we expect 0.8 ± 0.2 events from the extrapolation from lower energy data (see table 1). Furthermore, the thrust distributions of high and low energy inclusive muon events with $|\cos\delta| < 0.7$ agree with a probability of 78% according to the Kolmogorov–Smirnov test. The lower energy data sample able 1

omparison between inclusive muon data in the energy ranges 38.3 GeV$<\sqrt{s}<$46.3 GeV and 46.3 GeV$<\sqrt{s}<$46.78 GeV.

	Data with		Expectation for $\sqrt{s}>$46.3 GeV from $\sqrt{s}<$46.3 GeV
	$\sqrt{s}<$46.3 GeV	$\sqrt{s}>$46.3 GeV	
$\int \mathscr{L}\,dt$ (pb^{-1})	40.6	2.1	–
number of hadronic events	8046	332	–
number of inclusive muon events	626	25	26 ±2
number of muon events with $T<0.8$	82	3	3.4±0.4
number of muon events with $T<0.8$, $\lvert\cos\delta\rvert<0.7$	20	1	0.8±0.2
number of muon events with $T<0.8$, $\lvert\cos\delta\rvert>0.7$	62	2	2.7±0.4
number of muon events with $T>0.8$, $\lvert\cos\delta\rvert>0.7$	522	20	22 ±2
number of muon events with $T>0.8$, $\lvert\cos\delta\rvert<0.7$	22	2	0.9±0.2



g. 1. The thrust distribution of inclusive muon events at $\sqrt{s}$ 46.3 GeV compared to the expected distribution from data at s <46.3 GeV.

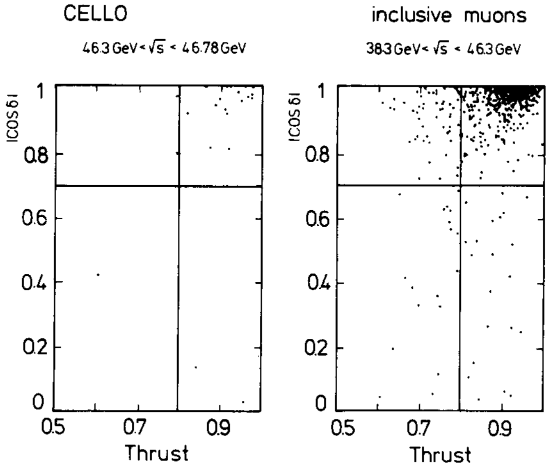


Fig. 2. The distribution of inclusive muon events in the T–$\lvert\cos\delta\rvert$ plane for centre of mass energies below and above $\sqrt{s}=46.3$ GeV.

ntains two dimuon events with $T<0.8$ and os$\delta\rvert<0.7$.

In order to check the sensitivity of the Cello detec- r for events with low thrust and an isolated muon e have passed the muon events observed by the ARK-J and JADE collaborations [6,7] in the gion $T<0.8$ and $\lvert\cos\delta\rvert<0.7$ at $\sqrt{s}>46.3$ GeV any times through our Monte Carlo program for tector simulation. We found our efficiencies for constructing these events in the same $T-\lvert\cos\delta\rvert$ gion to be similar to those determined by the ARK-J and JADE collaborations [6,7] for their tectors using the same procedure. From the com- parison of the luminosities of the different experi- ents and of the numbers of events expected from lower energies the effect observed by MARK-J and JADE should lead to at least five events of the above kind in our experiment.

The visible cross section for inclusive muon events with $T<0.8$ and $\lvert\cos\delta\rvert<0.7$ is shown in fig. 3 as a function of the centre of mass energy, giving no indication of a threshold of new sources of inclusive muon events. We observe no excess of events with low thrust and isolated muon at the highest PETRA energies, no matter how the cuts in thrust and $\lvert\cos\delta\rvert$ are chosen. This holds also for a softer multihadron selection, where the restrictions in $\cos\theta$ for charged and neutral particles used for the selection are removed, for various harder and softer muon iden-

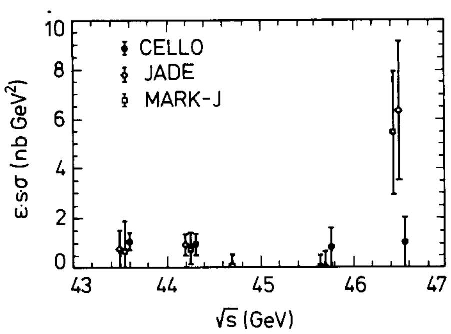


Fig. 3. The visible cross section for inclusive muon events with $T<0.8$ and $|\cos\delta|<0.7$ as a function of centre of mass energy.

tification criteria and for thrust calculation including the identifies muon. In each case good agreement is found between the two data samples.

Inclusive electron events. For centre of mass energies $\sqrt{s}>46.3$ GeV we observe 14 inclusive electron events whereas we expect 11 ± 1 events from lower energy data (see table 2). In the region $T<0.8$ and $|\cos\delta|<0.7$ we do not observe any electron event above $\sqrt{s}=46.3$ GeV compared to an expectation of 0.5 ± 0.1 events (see fig. 4). Even with much softer electron identification criteria we find no events with low thrust and isolated electron at the highest PETRA energies.

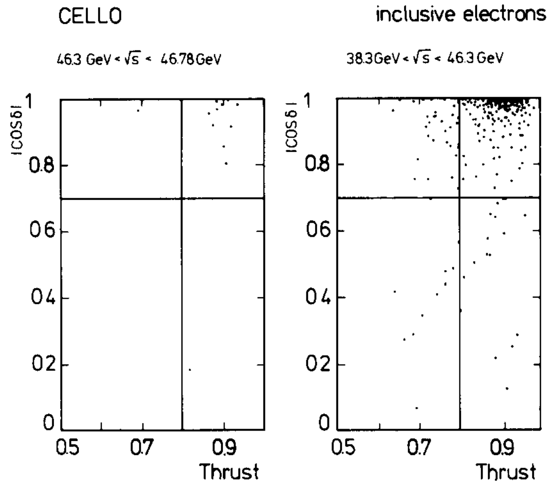


Fig. 4. The distribution of inclusive electron events in the T–$|\cos\delta|$ plane for centre of mass energies below and above $\sqrt{s}=46.3$ GeV.

Conclusion. No excess of multihadronic events with low thrust and isolated muon or electron has been observed at the highest PETRA energies. The CELLO results do not support evidence for such an anomaly at $\sqrt{s}>46.3$ GeV as found by the MARK-J and JADE collaborations in the inclusive muon production. If the effect is real, we would expect at least five isolated muon events with low thrust at $\sqrt{s}>46.3$ GeV in our experiment whereas we observe only one event of this kind, in agreement with the expectation from lower energy data.

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Table 2
Comparison between inclusive electron data in the energy ranges 38.3 GeV $<\sqrt{s}<$ 46.3 GeV and 46.3 GeV $<\sqrt{s}<$ 46.78 GeV.

	Data with		Expectation for $\sqrt{s}>46.3$ GeV from $\sqrt{s}<46.3$ GeV
	$\sqrt{s}<46.3$ GeV	$\sqrt{s}>46.3$ GeV	
$\int\mathscr{L}\,dt$ (pb^{-1})	40.6	2.1	-
number of hadronic events	8046	332	-
number of inclusive electron events	270	14	11 ±1
number of electron events with $T<0.8$	43	2	1.8±0.3
number of electron events with $T<0.8$, $\lvert\cos\delta\rvert<0.7$	11	0	0.5±0.1
number of electron events with $T<0.8$, $\lvert\cos\delta\rvert>0.7$	32	2	1.3±0.2
number of electron events with $T>0.8$, $\lvert\cos\delta\rvert>0.7$	209	11	9 ±1
number of electron events with $T>0.8$, $\lvert\cos\delta\rvert<0.7$	18	1	0.7±0.2

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References

[1] CELLO Collab., H.J. Behrend et al., Phys. Scr. 23 (1981) 610.

[2] CELLO Collab., H.J. Behrend et al., Phys. Lett. B 144 (1984) 297.

[3] CELLO Collab., H.J. Behrend et al., Phys. Lett. B 183 (1987) 400.

[4] A. Göhm, Proc. XXth Rencontre de Moriond (Les Arcs, 1985), ed. J. Tran Thanh Van, p.141;
MARK-J Collab., B. Adeva et al., Phys. Rev. D 34 (1986) 681.

[5] M. Kuhlen, Proc. XXIth Rencontre de Moriond (Les Arcs, 1986), ed. J. Tran Thanh Van, p.181.

[6] MARK-J Collab., B. Wyslouch, private communication.

[7] JADE Collab., M. Kuhlen, private communication.