ANL-HEP-CP--86-60

DE87 001549

Limit on τ Decay to 7-Charged Tracks

CONF-860701--36

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HRS Collaboration

OSTI

OCT 29 1986

Abstract

Using the complete data sample of 300 pb^{-1} from e^+e^- collisions at 29 GeV, the HRS collaboration has searched for τ decay to 7 charged particles and any number of neutrals. No events were found. The corresponding upper limit to the branching ratio is $B(\tau \to 7\pi^{\pm} + n\gamma + \nu_\tau) < 3.8 \times 10^{-4}$ at 90% confidence level. Using the final HRS data sample we also report updated branching ratios for $\tau \to 5\pi^{\pm} + \nu_\tau$ and $\tau \to 5\pi^{\pm} + \pi^{\circ} + \nu_\tau$.

Submitted to XXIII International Conference on High Energy Physics
16-23 July, 1986, Berkeley, California
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The High Resolution Spectrometer (HRS)[1] has now completed its data taking at PEP having accumulated a luminosity of 300 pb^{-1} using e^+e^- collisions at 29 GeV. In this paper we report new results of a search for τ decays to seven charged particles. We also update a previous paper reporting the first observation of τ lepton decay to five charged particles[2] by presenting our final results on 5π and 6π decays of the τ.

Features of the detector relevant for this analysis include charged-particle tracking over 90% of the solid angle in a solenoidal magnetic field of 16.2 kG, and measurement of electromagnetic shower energy with lead-scintillator calorimeters covering the angular intervals $|\cos\theta| < 0.60$ (barrel) and $0.70 < |\cos\theta| < 0.96$ (end caps), where θ is the angle with respect to the beam direction. The excellent momentum resolution means that tracks at large angles are measured to a relative error of better than 1%. The forty-module barrel shower-counter system has an energy resolution of $\sigma_E/E = 16\%/\sqrt{E}$ (E in GeV). The energy resolution for the forty-module end-cap system is $\sigma_E/E = 20\%/\sqrt{E}$.

The initial selection criteria used to isolate a sample of τ decay to five or seven charged particles were similar to those used to obtain the events corresponding to the one and three charged particle branching ratios reported in another paper.[3] For the present analysis the topology of the selected events was five or seven charged tracks in one hemisphere with a single charged track in the opposite hemisphere. The total net charge of the event was required to be zero. Because the single charged particle branching ratio of the τ is 86.9%, demanding a single charged track in the hemisphere opposite to that of the five or seven prongs greatly reduces the background from hadronic events while reducing the signal only slightly. In order to reduce backgrounds from beam-gas interactions and from two-photon interactions the scalar sum of the charged momenta was required to be greater than 7.25 GeV/c and the angle between the total momentum vectors in the two hemispheres had to be greater than 135 degrees. In addition to these criteria, the angle between the thrust axis of the event and the beam direction was required to satisfy $|\cos\theta| < 0.55$. This requirement selected events in

the central region of the detector, avoiding regions not fully instrumented. The effective mass of the five or seven charged particles, each considered a pion, is shown in Fig. 1. and Fig. 2. respectively.

It is apparent in Fig. 2 that all the events are of hadronic origin since no events have a mass less than that of the τ at 1.784 GeV/c^2. To verify this and to separate the τ signal from the hadronic events, we take advantage of the fact that, in the limit of first-order QED, τ-pair production leads to a unique momentum for each lepton. The thrust axis of the event is taken to be the direction of the produced τ pairs. The momentum, P^*, defined as the sum of all the charged hadronic decay products of the τ, in the τ rest frame, is measured by performing a Lorentz boost. For τ events, P^* is expected to be small because the mass difference between the hadronic decay products and the τ is small. Using a phase space model of 7-prong τ decay it is found that no τ events are expected to have a mass below 1.3 GeV/c^2. This largest mass difference for τ events corresponds to the largest expected P^* of ~ 400 MeV/c.

Fig. 3 shows the P^* distribution for the 7-prong events. There are no events below 1000 MeV/c. The τ events are expected in the region below 400 MeV/c. To measure the effect of the selection criteria on the 7-prong decay modes of the τ, a simple thermodynamic model[4] of the hadronic decay was used together with the full Monte Carlo τ-event simulator incorporating the Berends and Kleiss[5] lepton generator with α^3 QED corrections. It was found that 12% of the events were lost due to the P^* cut while the hadronic events were essentially eliminated. The acceptance including all the effects of the selection criteria was found to be .095 ± .010. This, along with the total number of τ pairs produced, (41 ± 2.5) X 10^3, yields an upper limit on the branching ratio for τ decays to seven charged particles of $B(\tau \to 7\pi^{\pm} \nu_{\tau} + n\gamma) < 3.8 \times 10^{-4}$ at 90% confidence.

Unlike the seven charged prong search, Fig. 1 and 4 show strong evidence for τ decay to five charged particles. The method of selecting the sample was discussed earlier. In order to measure the hadronic background to the 5-prong signal, the full data sample was searched for events with five charged tracks

in one hemisphere and any odd number of charged tracks (excluding the single-track events) in the opposite hemisphere. All the other selection criteria were identical to those used to select the τ sample. The resulting 5-prong mass distribution is shown in the dashed histogram of Fig. 1. The hadronic background distribution has been normalized to the τ sample in the mass region above 2 GeV/c^2 where the two distributions have the same shape. The hadronic background corresponds to 11 times the statistics of the τ event sample. The τ events are separated from the hadronic events by requiring $P^* < 600$ MeV/c. Fig. 4 shows a clear signal of thirty-four events in this region, of which seven are estimated to be of hadronic origin.

The hadronic background is reduced by the following: (1) requiring that the combined mass of the charged particle and photons in the hemisphere opposite to that of the 5-prong jet be less than 1.6 GeV/c^2. A Monte Carlo simulation of τ decay indicates that only 6% of the τ events are rejected by this cut, whereas 60% of the events in the solid histogram in Fig. 1 with a 5-prong mass greater than 2 GeV/c^2 are rejected. (2) We require that the combined mass of the charged particles and photons in the 5-prong hemisphere be less than 1.9 GeV/c^2. (3) We eliminated all Dalitz pairs and external photon conversions in the vertex region as will be described later. With these selections, the estimated hadronic background is reduced to 0.07 $\pm$ 0.05 events.

A second background to the five charged particle decay is from $\tau \to 3\pi^{\pm} + \pi^{\circ} + \nu_{\tau}$, in which one of the photons from the π° forms an e^+e^- pair either by a Dalitz conversion or by external conversion in the ~ 1.5% of a radiation length of material surrounding the interaction point. The estimated number of 5-prong events which include an e^+e^- pair is 11.1 found by use of the Monte Carlo simulation.

There are three properties of these e^+e^- pairs which allows them to be eliminated from the sample. (1) The tracks are low momentum because the original photon has on average half the momentum of its parent neutral pion and each electron has only half the momentum of its parent photon. (2) The effective mass of the pair is low: For Dalitz pairs the probability of forming a

mass larger than 85 MeV/c^2 is less than 1%. (3) The showering nature of the electron and positron yields two chances to distinguish at least one member of the pair as being nonhadronic. All events have been removed with neutral pairs (treated as electrons) whose invariant mass is less than 200 MeV/c^2 and which have at least one member that deposits an energy in the barrel shower-counter system within 3σ of the expected value for an electron. If neither member of the pair was energetic enough to hit the barrel shower counter then the event was also eliminated. If one member of the pair was nonshowering, depositing an energy consistent with a minimum-ionizing particle, then the event was accepted. With these criteria, twelve of the τ candidate events were found to contain e^+e^- pairs, which is consistent with the Monte Carlo estimate. The remaining conversion background is less than 0.05 ± 0.03 events.

The background from two photo interactions is small, and we refer the reader to our previous work[2] for details of the basic argument. Including all sources of background, 0.12 ± 0.06 events are expected in our sample of thirteen events. The acceptance for these events, including the solid angle, tracking efficiency, and all other cuts, are .193 ± .014 for the five charged π decays and .164 ± .013 for the five charged π accompanied by a single π°. A detailed examination of the thirteen candidate events shows that six of the events are accompanied by neutral energy in the barrel shower counters which is clearly separated from the charged tracks.

If we now include the neutral clusters in a recalculation of the invariant mass for these events and treat the clusters as having originated from the decay of a π°, none of the events is found to exceed the τ mass. With this interpretation of the events the resulting branching ratios of the τ are found to be $B(\tau^\pm \to 5\pi^\pm\nu_\tau) = (5.1 \pm 2.0) \times 10^{-4}$ and $B(\tau^\pm \to 5\pi^\pm\pi^\circ\nu_\tau) = (5.1 \pm 2.2) \times 10^{-4}$. Combining these results gives a 5-prong branching ratio of $B_5 = (10.2 \pm 2.9) \times 10^{-4}$.

This work was supported by the U. S. Department of Energy under DE-AC03-76SF00515.

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FIGURE CAPTIONS

1. The invariant mass of the five charged particles for the τ candidate events (solid line) and hadronic background events (dashed line).

2. The invariant mass of the 7 charged particles.

3. The measured momentum, P^* in the τ rest frame for the 7-prong sample.

4. The measured momentum P^* in the τ rest frame for the τ candidate events (solid line) and the hadronic background (dashed line).

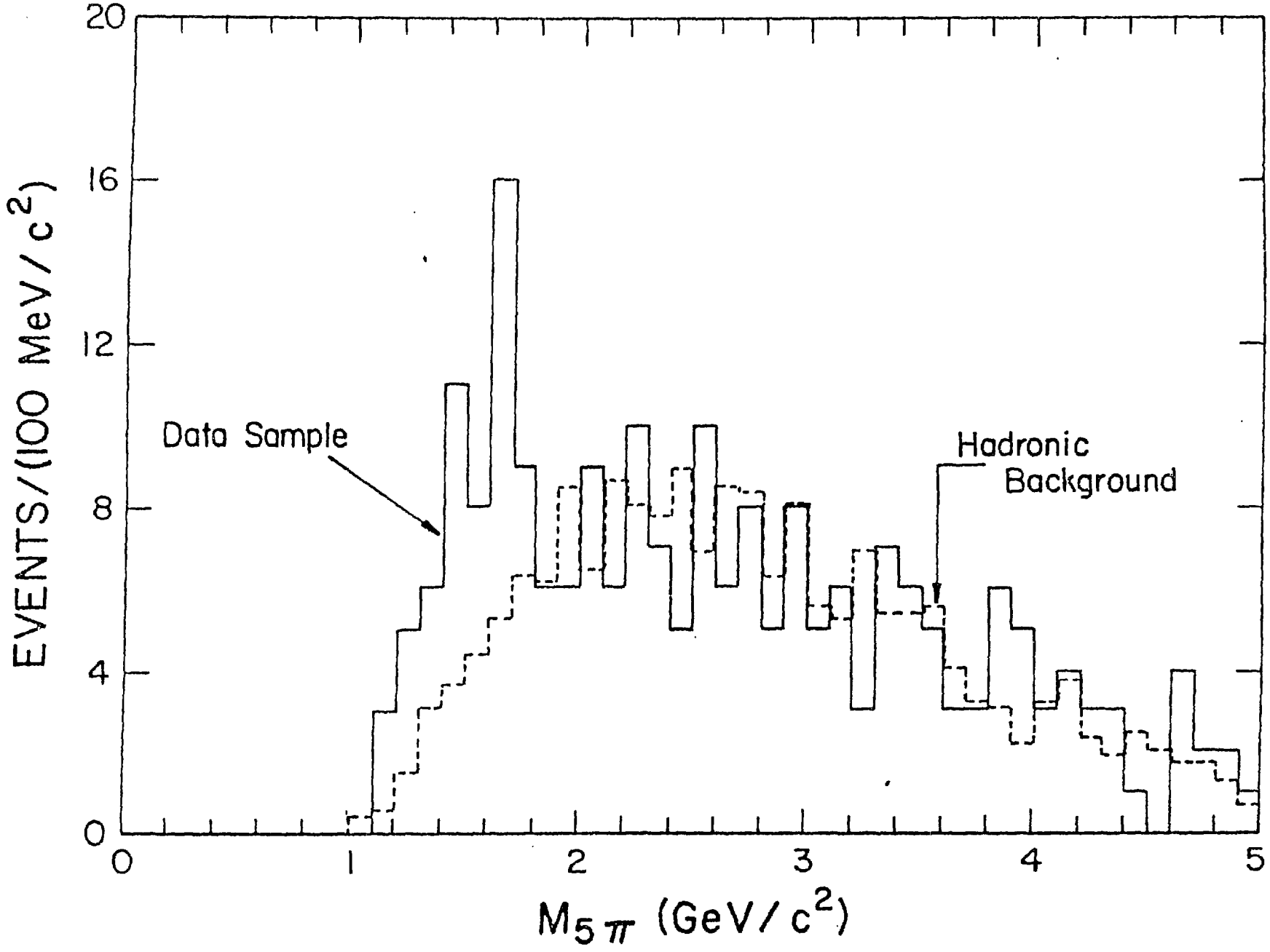
EVENTS/(100 MeV/c²)
20
16
12
8
4
0
Data Sample
Hadronic
Background
0
1
2
3
4
5
M5π (GeV/c²)

Figure 1

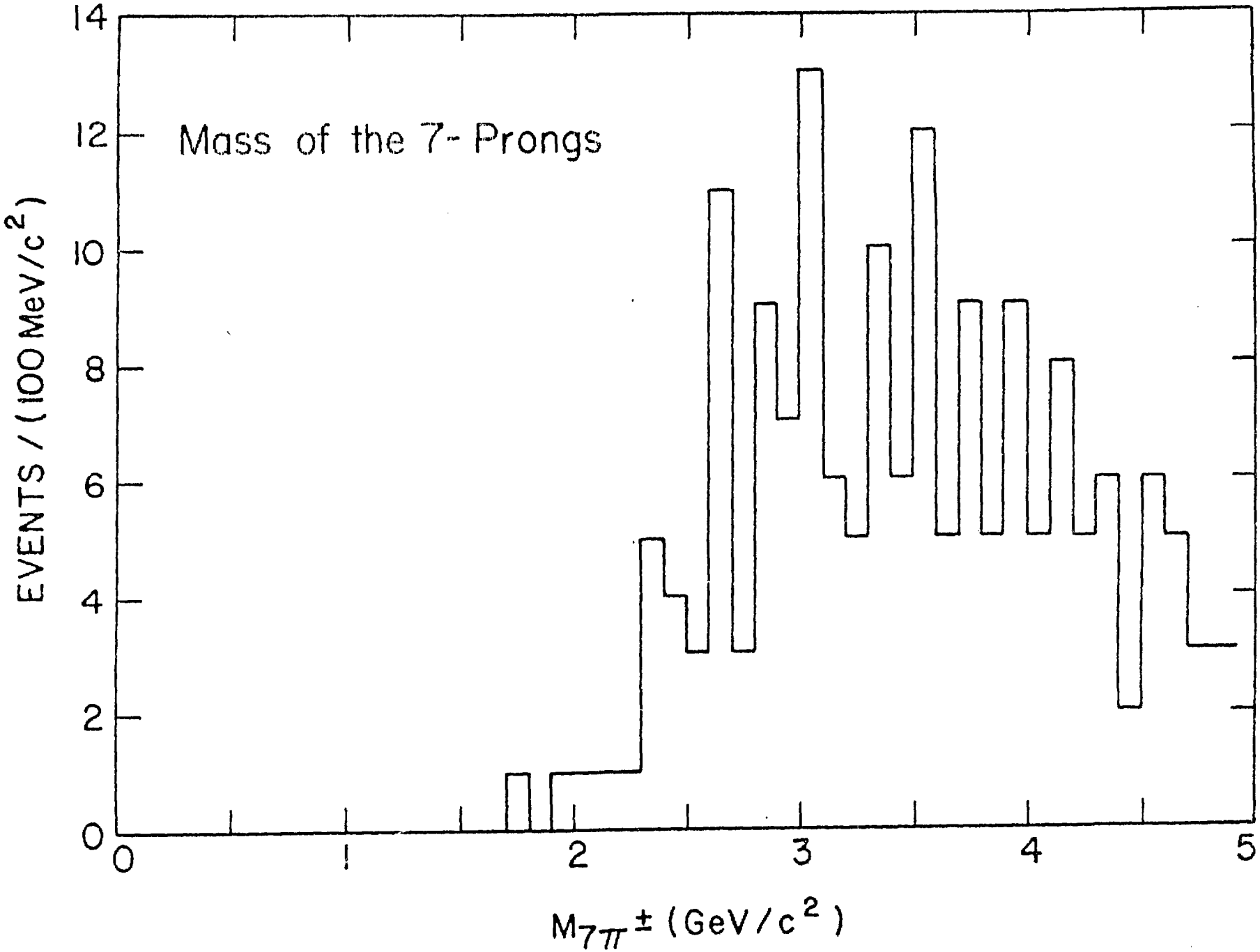
Mass of the 7- Prongs
EVENTS / (100 MeV/c²)
0
2
4
6
8
10
12
14
0
1
2
3
4
5
M7π± (GeV/c²)

Figure 2

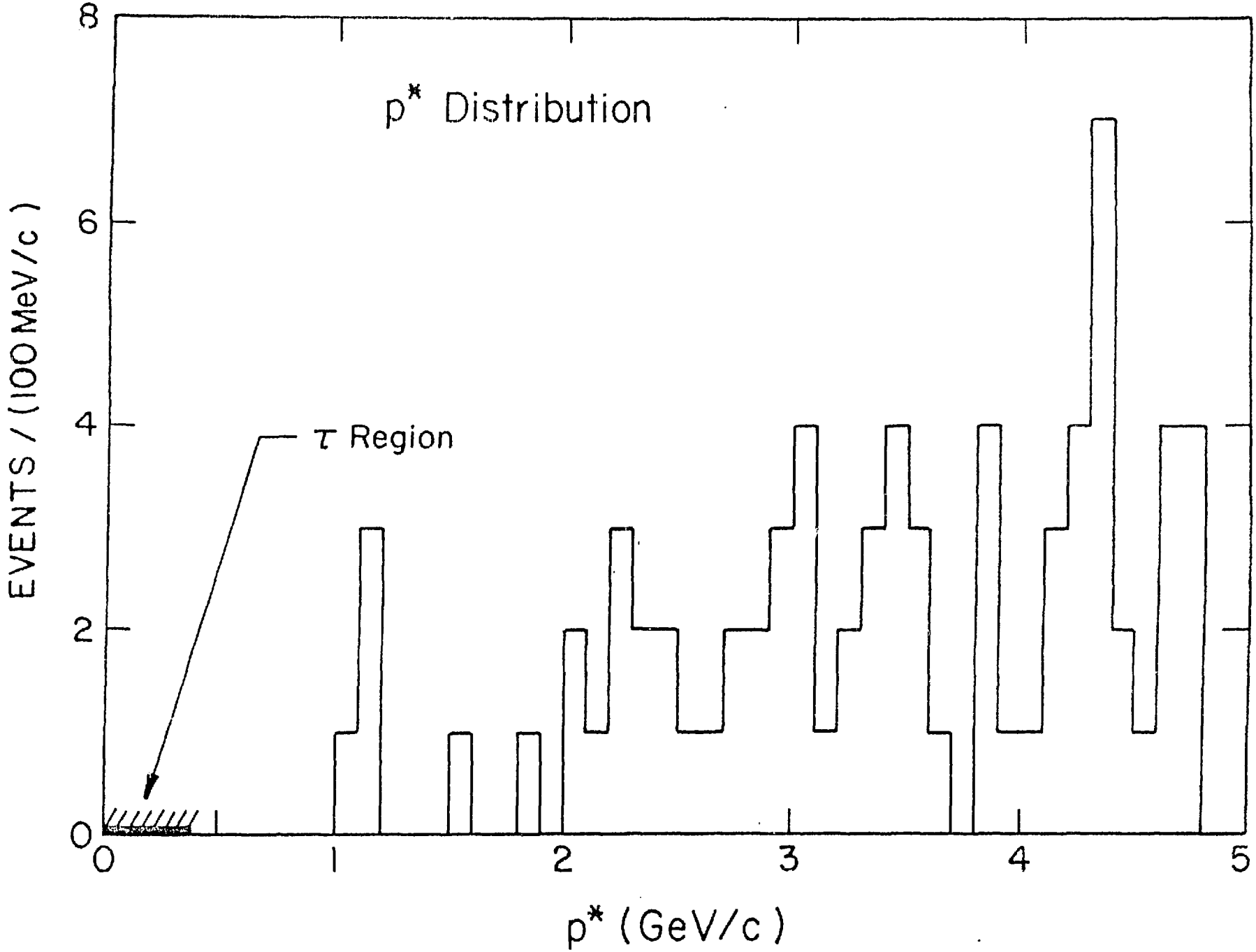

Figure 3

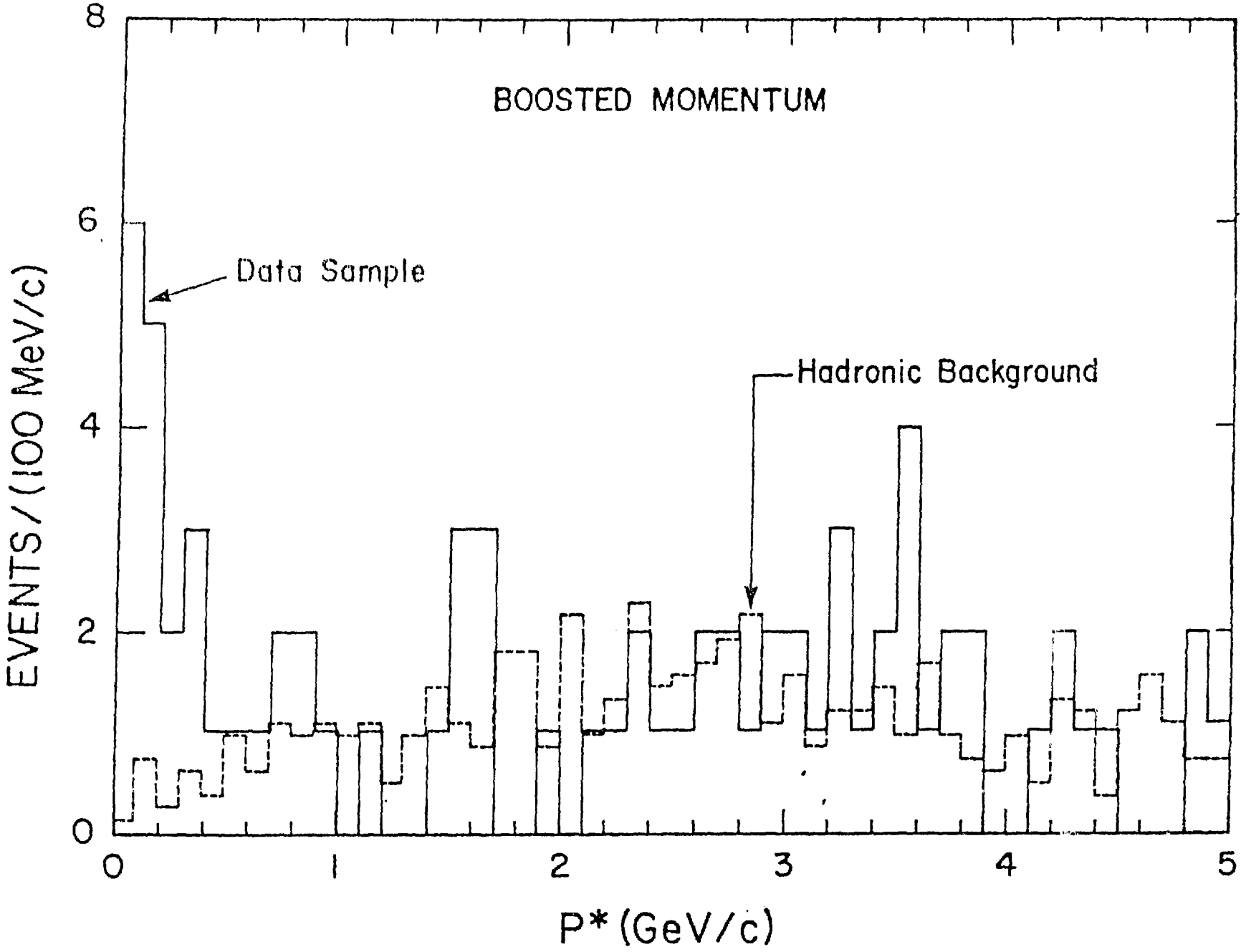
BOOSTED MOMENTUM
Data Sample
Hadronic Background
EVENTS/(100 MeV/c)
P* (GeV/c)
0
2
4
6
8
0
1
2
3
4
5

Figure 4

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