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Measurement of the Decay $\tau \rightarrow \rho\nu$ †

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Abstract

The decay $\tau \rightarrow \rho\nu$ is studied in τ pair production by e^+e^- annihilation at $\sqrt{s} = 3.77$ GeV, 0.20 GeV above $\tau\tau$ threshold. The branching fraction is measured to be $B(\tau \rightarrow \rho\nu) = (23.0 \pm 1.3 \pm 1.7)\%$. The measured distribution of the helicity angle of the charged pion from the ρ decay agrees with the theoretical prediction.

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Tau decays are well described by the standard model. However, there remains an unexplained discrepancy between the measured inclusive one-prong branching fractions and the summed branching fractions of the exclusive measurements.[1,2] Most of this difference has been attributed to channels containing one or more neutral mesons,[3] fueling the discussion about possibly yet undiscovered decay modes. The decay $\tau \to \rho\nu$, $\rho \to \pi\pi^0$ is the largest contribution to the one prong channel and thus merits a precise measurement in a detector with extremly good neutral energy detection capabilities. We report on the analysis of the decay of the τ lepton into $\rho\nu$ from the measurement of τ pairs in the reaction[4]

$$e^+e^- \longrightarrow \tau\tau \longrightarrow \ell\nu\nu \qquad ; \ \ell = e \text{ or } \mu$$
$$\hookrightarrow \rho\nu$$
$$\hookrightarrow \pi\pi^0$$
$$\hookrightarrow \gamma\gamma$$

The data were taken with the MARK III detector at the SLAC e^+e^- storage ring SPEAR. A total integrated luminosity of 9.4 pb^{-1} was collected at $\sqrt{s} = 3.77$ GeV, which is near the peak of the $\psi(3770)$ resonance and 0.20 GeV above $\tau\tau$ threshold.

This analysis is similar to our study of the leptonic decays of the τ.[5] Details of the detector performance have been discussed elsewhere.[5,6] Charged particles are identified by the time-of-flight (TOF) counters, the shower counters, and the muon detector. Electrons and muons are identified using the selection criteria in the previous analysis.[5] For optimum particle identification, electrons and pions are accepted only in the region where the TOF counters overlap with the shower counters, $|\cos\theta| < 0.76$, where θ is the polar angle with respect to the beam axis. Pions and electrons are separated with an algorithm using variables which parametrize the shape of showers in the finely segmented barrel shower counter.[7]

The criteria for selecting τ pair events leading to $e\pi\gamma\gamma$ and $\mu\pi\gamma\gamma$ final states are chosen to suppress leptonic backgrounds from QED processes and charm production.[5] Candidate events are required to have:

- two oppositely charged tracks, each with momentum $p < 0.75 \times p_{beam}$;
- one track identified as an electron or a muon, the other as a pion;
- an acollinearity angle, θ_{acol}, between the two charged tracks of $2.5^\circ < \theta_{acol} < 177.5^\circ$ and an acoplanarity angle $\theta_{acop} > 6^\circ$, where θ_{acop} is the angle between the planes spanned by the beam direction and the momentum vectors of the lepton and charged pion;
- exactly two isolated photons. An isolated photon, γ_{isol}, is defined as a shower separated from any charged track by more than 45 cm on the face of the shower counter (this corresponds to an angle of about 18° with respect to the charged track direction);
- the energy of the $\ell\pi\gamma\gamma$ system $> (0.4 \times E_{beam})$.

A total of 939 events pass these selection criteria. The two photon invariant mass combinations of these events are shown in Fig. 1(a). A clear π^0 signal with little background is observed. The two photons are constrained to the π^0 mass by a one-constraint kinematic fit. Events having fitted photon energies above 0.040 GeV and $\chi^2 < 6$ are retained, yielding 473 $e\pi\pi^0$ and 226 $\mu\pi\pi^0$ events. Figures 1(b) and 1(c) show the unfitted $\gamma\gamma$ mass spectra in the two channels for events that pass the fit.

Sources of background include τ pair production with decays into other final states, charm production and non-charm continuum events. The background from τ pair production is caused by feed-down from τ decays with more than one π^0 and by μ/π and e/π misidentification.

We estimate the background from multiple π^0 decays using our data, because of the uncertainty of the τ branching fractions in these modes.[3] Events with three, instead of two, isolated photons are selected and one photon is removed randomly. A Monte Carlo generation of $\tau\tau \rightarrow (\ell\nu\nu)(a_1(1270)\nu)$ and $\tau\tau \rightarrow (\rho\nu)(\rho\nu)$ is used to determine the ratio of $3\gamma_{isol}$ over $2\gamma_{isol}$-events accepted from these channels with two π^0. The $3\gamma_{isol}$-data are then used together with this ratio to calculate the expected backgrounds, $34 \pm 2^{+15}_{-6}$ and $14.5 \pm 1.3^{+6.6}_{-2.6}$ events in the $e\pi\pi^0$ and $\mu\pi\pi^0$ classes, respectively.

Other backgrounds from τ pair production arise through misidentification of particles. Muons with momentum below the detection threshold are called pions. High momentum pions can decay or punch through and be called muons. Pions are misidentified as electrons with up to 4% probability. The dominant sources of misidentification background are the τ pair decay channels $\tau\tau \to (\pi\nu)(\rho\nu)$ and $(\mu\nu\nu)$ $(\rho\nu)$. The contamination from these processes is computed by generating Monte Carlo events including the misidentification probabilities for $\pi \to e, \mu$ and $\mu \to \pi$. The $\tau\tau \to (\pi\nu)(\rho\nu)$ channel results in 7.5 ± 1.5 and 18.3 ± 2.6 background events for the $e\pi\pi^0$ and $\mu\pi\pi^0$ channels, respectively. The $\tau\tau \to (\mu\nu\nu)(\rho\nu)$ channel produces 3.3 ± 1.2 background events for the $e\pi\pi^0$ channel.

The background from charm production is estimated by considering specific $D\bar{D}$ production and decay channels. This background, including channels which can produce signal events by misidentification of particles, is found to be negligible. The continuum background is estimated by using our J/ψ data. A total of 10^5 events of the type $J/\psi \to$ (2 charged + neutrals) are subjected to the selection criteria. No events are found that pass these cuts and we conclude that the contamination by continuum events is also negligible.

In Figs. 1(b) and 1(c), the background-subtracted $m_{\gamma\gamma}$ spectra are compared with Monte Carlo spectra for the $\tau\tau \to (\ell\nu\nu)$ $(\rho\nu)$. They agree well for $m_{\gamma\gamma} <$ 0.25 GeV/c^2; we retain only these events. This cut removes 3.1% and 1.7% of the events, respectively, and its effects are included in the systematic errors. In addition, kinematic cuts are applied that retain only events that are compatible with $\tau\tau \to (\ell\nu\nu)(\rho\nu)$. These cuts remove 6 and 2 events respectively in the signal channels. Figures 2(a) and 2(b) show the $\pi\pi^0$ mass distributions with the above backgrounds subtracted. Clear ρ signals on small residual backgrounds are observed. The total signal in the two channels consists of $396.2 \pm 21.5 \pm 15$ $e\pi\pi^0$

and $186.2 \pm 15.1 \pm 6.6$ $\mu\pi\pi^0$ events.[8]

Background-subtracted momentum spectra for all final state particles are compared with Monte Carlo predictions for $\tau\tau \to (\ell\nu\nu)\ (\rho\nu) \to \ell\pi\pi^0$ in Fig. 3. The generated events, including radiative effects,[9,10] are passed through the detector simulation, and the same analysis programs as the data. The measured $\pi\pi^0$ mass distribution in Fig. 2 agrees also with the Monte Carlo calculation.

The detection efficiencies are found to be $0.189 \pm 0.003 \pm 0.008$ and $0.102 \pm 0.002 \pm 0.003$. After correcting for radiative effects which increase the cross sections by 8%, we obtain $\sigma(e^+e^- \to \tau\tau \to e\rho) = (0.242 \pm 0.013 \pm 0.013)$ nb and $\sigma(e^+e^- \to \tau\tau \to \mu\rho) = (0.211 \pm 0.016 \pm 0.012)$ nb, where a systematic error of 4% is included for the luminosity uncertainty. Using our previously reported cross sections ,[5] and the QED cross section, 2.85 nb, for $\tau\tau$ production, we obtain the branching fraction $B(\tau \to \rho\nu) = (23.6 \pm 1.6 \pm 1.7)\%$ from the $e\pi\pi^0$ channel, and $(21.4 \pm 2.4 \pm 1.6)\%$ from the $\mu\pi\pi^0$ channel. The weighted average of the two values is

$$B(\tau \to \rho\nu) = (23.0 \pm 1.3 \pm 1.7)\% \quad .$$

Comparing this branching fraction with our measurement of the electronic τ decay [5] yields the ratio 1.26 ± 0.08, in agreement with the theoretical prediction of 1.23.[1]

The helicity angle θ_H between the charged pion in the ρ rest frame and the ρ direction of flight in the laboratory is also measured. Figure 4 compares the prediction with the acceptance-corrected measured distribution in which the two signal channels are combined. This prediction contains the angular distribution including the τ-spin dependent terms,[11] as well as the relativistic ρ Breit-Wigner parameters, and yields a χ^2 per degree of freedom of 1.4.

In summary, the decay $\tau \to \rho\nu$ has been measured in the final state $e\pi\gamma\gamma$ and $\mu\pi\gamma\gamma$. Our measurement, $B(\tau \to \rho\nu) = (23.0 \pm 1.3 \pm 1.7)\%$ agrees with the world average[12] $(21.8 \pm 2.0)\%$ and also with the theoretical prediction. The distribution of the helicity angle is in agreement with the expected shape. However, while providing a precise measurement in a detector with good sensitivity to π^0, we cannot offer a solution to the τ branching ratio problem.[1,2]

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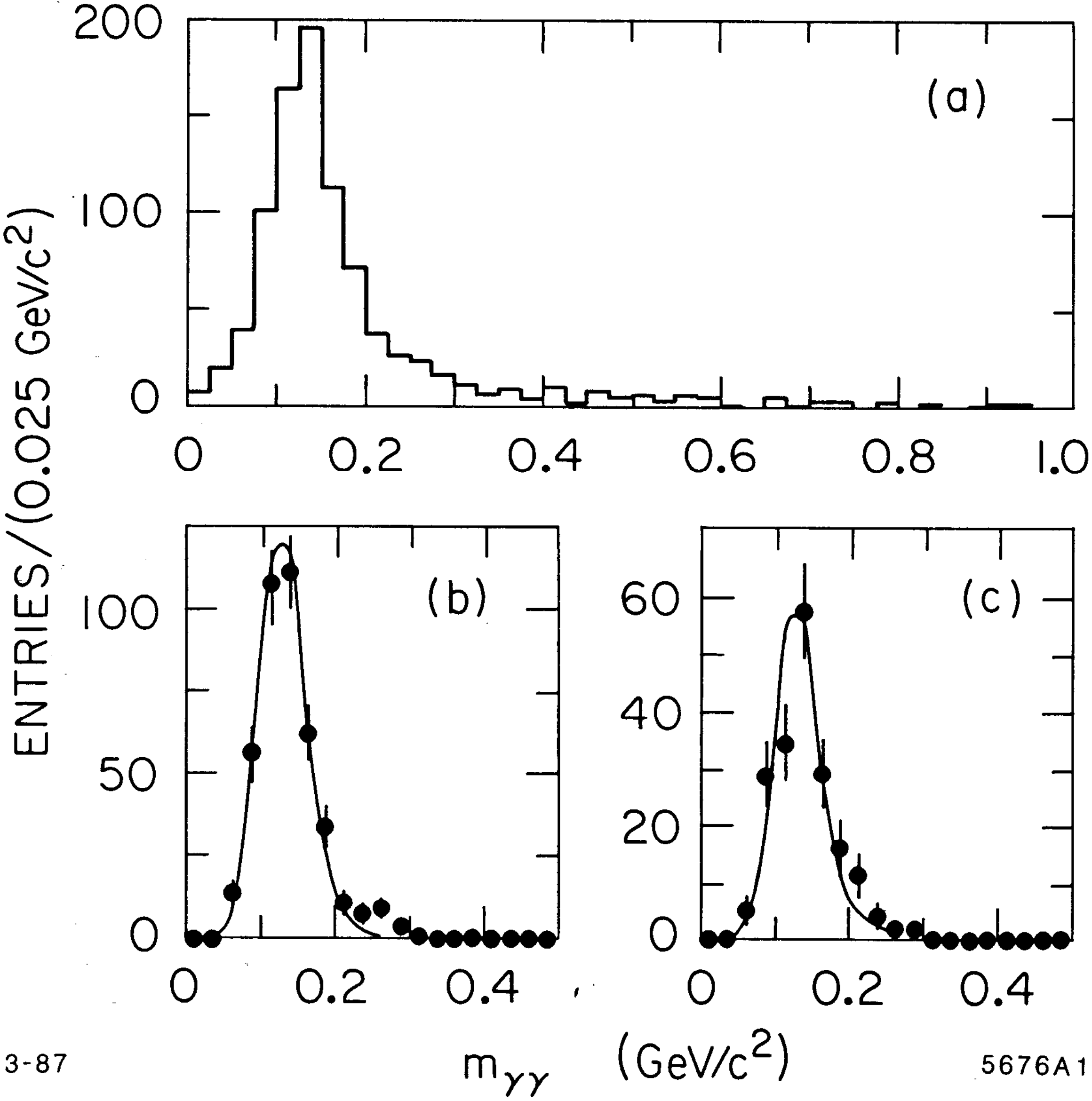
Figure Captions

Fig. 1. Invariant $\gamma\gamma$ mass distributions are shown for (a) all selected events before π^0 fit, (b) $e\pi\pi^0$ events after π^0 fit, and (c) $\mu\pi\pi^0$ events after π^0 fit. The curves show the Monte Carlo prediction.

Fig. 2. Invariant $\pi\pi^0$ mass distributions are shown for (a) $e\pi\pi^0$ events and (b) $\mu\pi\pi^0$ events. The backgrounds are subtracted from these spectra. The curves show the Monte Carlo prediction.

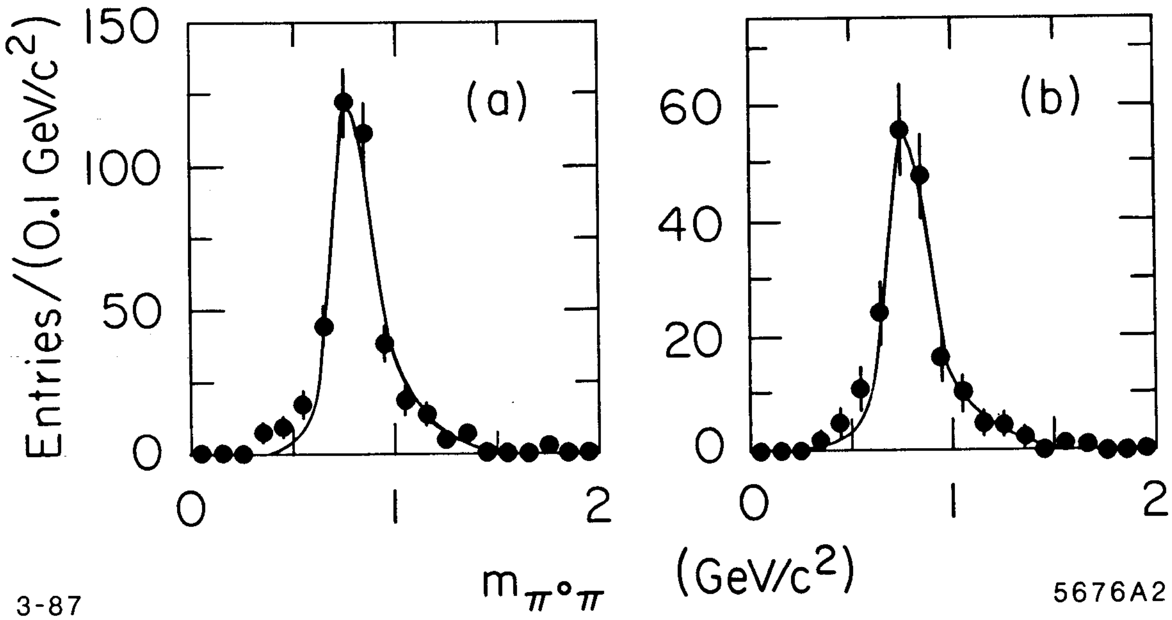
Fig. 3. Momentum spectra are shown for (a) e in $e\pi\pi^0$, (b) μ in $\mu\pi\pi^0$, (c) π in $e\pi\pi^0$, (d) π in $\mu\pi\pi^0$, (e) π^0 in $e\pi\pi^0$, and (f) π^0 in $\mu\pi\pi^0$ events.

Fig. 4. The acceptance-corrected distribution of $\cos(\theta_H)$ is shown. The curve, proportional to $(1 + 2.68 \cos^2\theta)$, is the Monte Carlo prediction.



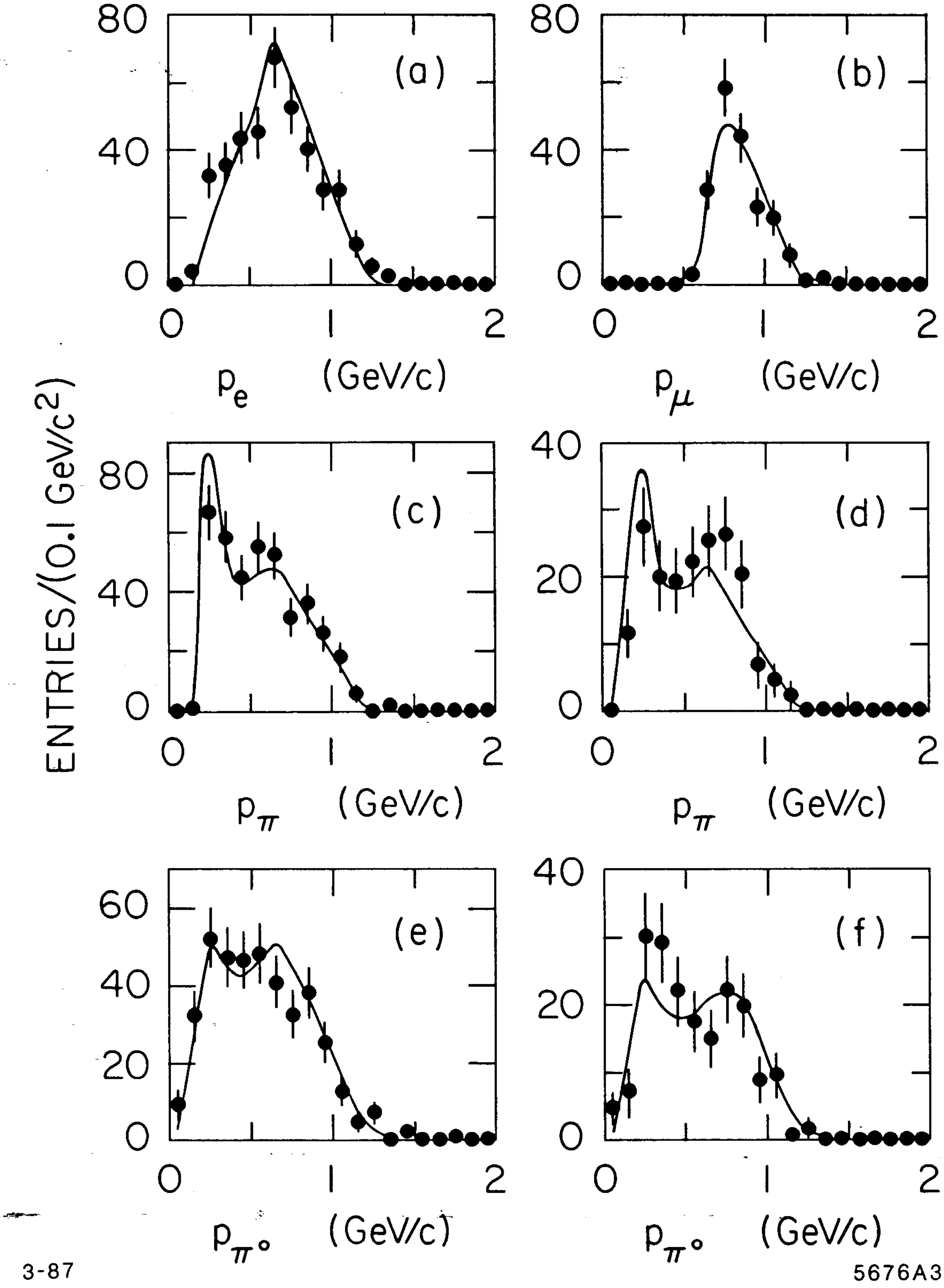
200
100
0
(a)
0
0.2
0.4
0.6
0.8
1.0
ENTRIES/(0.025 GeV/c²)
100
50
0
(b)
0
0.2
0.4
60
40
20
0
(c)
0
0.2
0.4
3-87
m_γγ (GeV/c²)
5676A1

Fig. 1



Entries/(0.1 GeV/c2)
150
100
50
0
(a)
0
1
2
60
40
20
0
(b)
0
1
2
3-87
mπ°π (GeV/c2)
5676A2

Fig. 2



ENTRIES/(0.1 GeV/c²)
(a)
(b)
(c)
(d)
(e)
(f)
p_e (GeV/c)
p_μ (GeV/c)
p_π (GeV/c)
p_π (GeV/c)
p_π° (GeV/c)
p_π° (GeV/c)
3-87
5676A3

Fig. 3

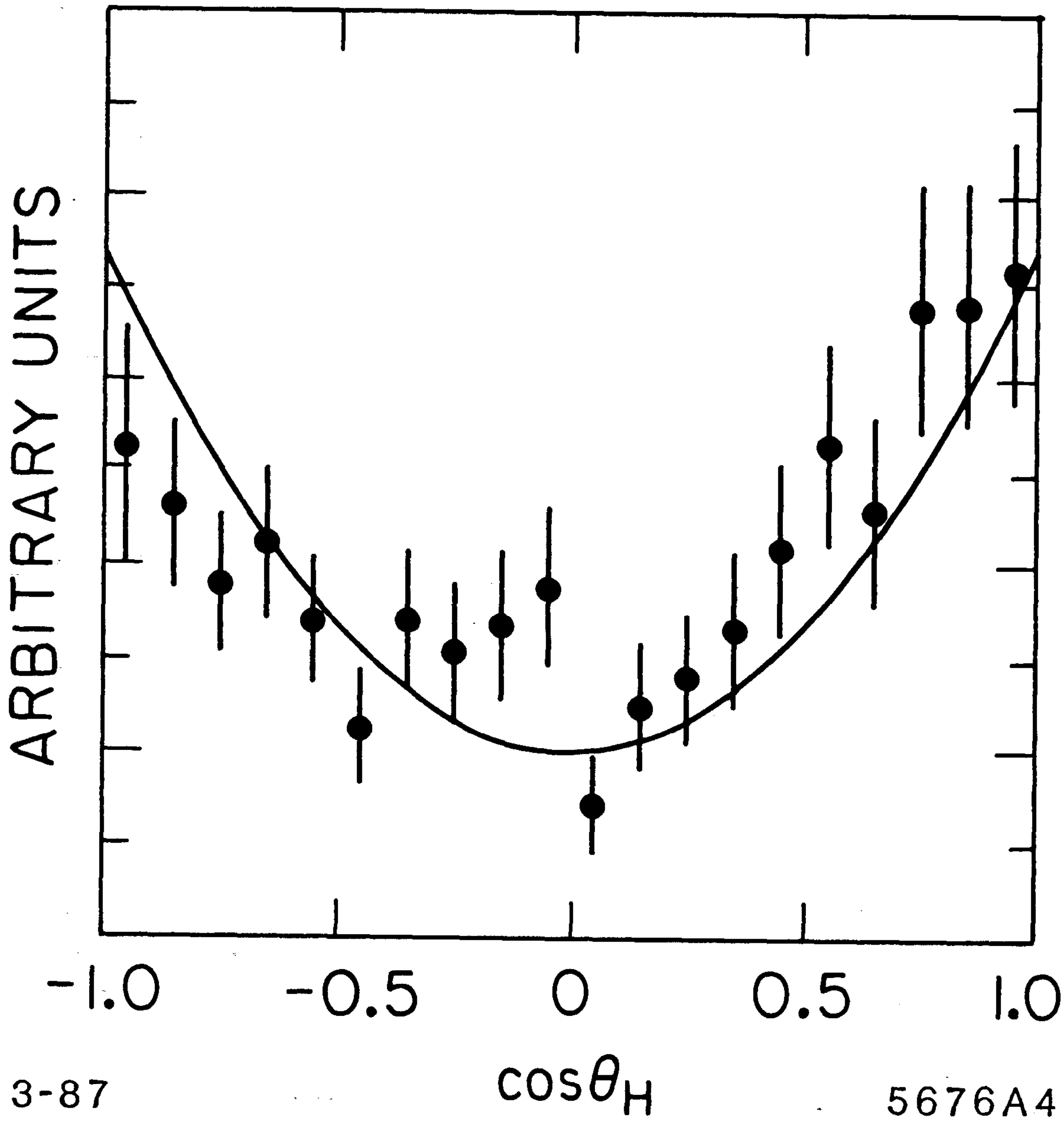


Fig. 4