MEASUREMENT OF THE BRANCHING FRACTION FOR $\tau \to \rho\nu$[*]

G. S. Abrams, M. S. Alam, C. A. Blocker, A. M. Boyarski, M. Breidenbach,
D. L. Burke, W. C. Carithers, W. Chinowsky, M. W. Coles, S. Cooper,
B. Couchman[**], W. E. Dieterle, J. B. Dillon, J. Dorenbosch, J. M. Dorfan,
M. W. Eaton, G. J. Feldman, H. G. Fischer[***], M. E. B. Franklin,
G. Gidal, G. Goldhaber, G. Hanson, K. G. Hayes, T. Himel, D. G. Hitlin[†],
R. J. Hollebeek, W. R. Innes, J. A. Jaros, P. Jenni, A. D. Johnson,
J. A. Kadyk, A. J. Lankford, R. R. Larsen, V. Luth, J. F. Martin[††],
R. E. Millikan, M. E. Nelson, C. Y. Pang, J. F. Patrick, M. L. Perl,
B. Richter, D. L. Scharre, R. H. Schindler, R. F. Schwitters[†††],
S. R. Shannon[**], J. L. Siegrist, J. Strait, H. Taureg, M. Tonutti[†],
G. H. Trilling, E. N. Vella, R. A. Vidal, I. Videau, J. M. Weiss, and
H. Zaccone

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

and

Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, California 94720

ABSTRACT

We present a measurement of the decay $\tau^- \to \rho^- \nu_\tau$ using data obtained
with the Mark II Detector at SPEAR. In the center-of-mass energy region
$4.5 \leq E_{cm} \leq 6.0$ GeV we observe 85 events in which a charged ρ was found
in coincidence with either an electron or a muon. We determine
$B(\tau^- \to \rho^- \nu_\tau) = (20.5 \pm 4.1)\%$ and the ratio $B(\tau^- \to \rho^- \nu_\tau)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e)$
$= 1.11 \pm 0.23$.

Submitted to Physical Review Letters
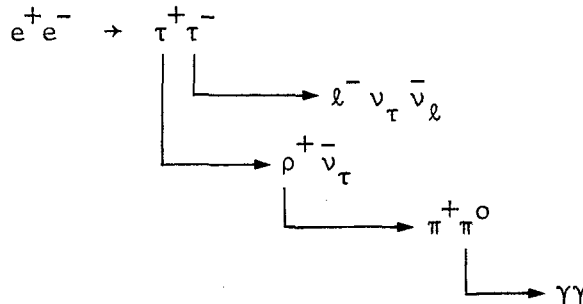

The existence of a new charged heavy lepton, τ, was first suggested[1] to explain the presence of events in which the only detected particles were an electron and a muon of opposite charge. The experimental evidence accumulated since that time strongly supports this interpretation and there now exists a coherent picture of the τ as a sequential heavy lepton with a small or zero mass neutrino which couples via the conventional V-A weak current.[2] In addition there are several precise measurements of the τ mass and branching ratios for leptonic and some hadronic decays.[3] We present below a measurement of the branching ratio for the decay $\tau^- \rightarrow \rho^- \nu_\tau$ as measured by the Mark II detector at SPEAR.[4] The decay $\tau^- \rightarrow \rho^- \nu_\tau$ involves only the vector part of the weak hadronic current. Comparison of this measurement with theoretical predictions, based on the coupling of the ρ to the electromagnetic current, constitutes a test of the validity of the conserved vector current hypothesis (CVC).

The detector has been described elsewhere[5] and we highlight only those detector elements which were crucial to the measurements described herein. The charged tracks were reconstructed from hits in the sixteen drift chamber layers and photons were detected in the eight liquid argon shower counters which surround the solenoidal coil. Typical photon detection efficiencies exclusive of geometrical effects were 15% at 100 MeV, 50% at 200 MeV and $\geq$ 90% above 400 MeV. Muons were detected in hadron absorption counters consisting of proportional tubes interleaved with iron slabs. The counters have a threshold momentum of 700 MeV/c. Muons headed for these counters which were above this threshold had a $\geq$ 98% detection efficiency and the probability that a pion was identified as a muon was 4% at 700 MeV/c, 11% at 900 MeV/c and 2% above 1.0 GeV/c,

at which point the muon has sufficient momentum to reach the second

detection layer. For momenta below 300 MeV/c electrons were identified

by a time-of-flight (TOF) measurement with a 300 picosecond RMS resolu-

tion. Above 300 MeV/c a series of cuts in the total shower energy,

longitudinal and transverse shower development together with TOF (below

500 MeV/c) were used to separate electrons and pions. These cuts were

determined with well identified electrons from photon conversions and

radiative Bhabha events, and with pions from $\psi \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^o$ decays. The

probability that a pion was identified as an electron was 7% at momenta

below 500 MeV/c, 4% at 600 MeV/c and 2% at 800 MeV/c with corresponding

electron efficiencies of 64%, 76% and 87% respectively.

To search for $\tau^- \rightarrow \rho^- \nu_\tau$ we looked for events having the following

topology:

$$
\begin{array}{l}
e^+ e^- \rightarrow \tau^+ \tau^- \\
\qquad \quad \vert \quad \vert \!\!\longrightarrow \ell^- \nu_\tau \bar{\nu}_\ell \\
\qquad \quad \vert \!\!\longrightarrow \rho^+ \bar{\nu}_\tau \\
\qquad \qquad \quad \vert \!\!\longrightarrow \pi^+ \pi^o \\
\qquad \qquad \qquad \quad \vert \!\!\longrightarrow \gamma\gamma
\end{array}
$$

which results in two oppositely charged particles and two photons in the

detector. Here ℓ^- represents either an electron or a muon which helps

provide a clean signature for τ pair production.

The data for these measurements come from an energy scan in the

region $4.5 \le E_{cm} \le 6.0$ GeV and correspond to an integrated luminosity of

3950 nb^{-1}, corresponding to approximately 11500 produced $\tau^+\tau^-$ pairs

calculated from the theoretical cross section. Events selected had two

oppositely charged tracks (with momenta ≥ 0.1 GeV/c) acoplanar[6] by at

least 20°, and two photons in the liquid argon shower counters with $E_\gamma \geq 0.1$ GeV.

The charged particle vertex was required to be within ±7.5 cm (along the beam direction) of the center of the e^+e^- beam overlap region. We removed photons which were within 36 cm, as measured at the liquid argon shower counter, of a charged track because in most cases these photons were due to the interaction of the charged particle in its passage through the shower counter and hence did not originate at the e^+e^- interaction vertex. Figure 1 shows the two photon invariant mass ($M_{\gamma\gamma}$) spectrum for events satisfying the above cuts. A clear π^o signal is seen. Events were accepted which had $0.08 \leq M_{\gamma\gamma} \leq 0.2$ GeV/c^2 and the measured photon energies were adjusted to constrain the mass to that of a π^o. We imposed a cut of $\chi^2 \leq 6$ for this one constraint fit.

We further required that one of the charged particles be either a muon or an electron and that the other be a pion. A $\pi^\pm$ candidate was any charged track which was not positively identified as a lepton, kaon or proton. Figure 2 shows the invariant mass, $M_{\pi^\pm\pi^o}$, of the $\pi^\pm$ and the π^o. We have fit the spectrum in Fig. 2 to a function which is the sum of a smooth background and a Breit-Wigner resonance. The fit, which is superimposed on the data in Fig. 2, has a χ^2 of 12.9/16 degrees of freedom and yields $M_\rho = 0.770 \pm 0.020$ GeV/c^2 and $\Gamma_\rho = 0.194 \pm 0.030$ GeV/c^2.

Events were selected in the mass range $0.27 \leq M_{\pi^\pm\pi^o} \leq 1.26$ GeV/c^2. There are 85 such events: 64 $\rho^\pm e^\mp$ and 21 $\rho^\pm\mu^\mp$ events.[7] Figure 3 shows the spectrum for $X_\rho = (E_\rho - E_{min})/(E_{max} - E_{min})$ of the 85 $\rho^\pm$ candidates, where E_ρ is the energy of the $\rho^\pm$, E_{min} and E_{max} are the minimum and maximum allowable energies for a ρ produced in the decay of a τ of mass 1.782

GeV/c^2 at the appropriate beam energy. The prediction of the Monte Carlo simulation program is superimposed on the data and the agreement is good.

We suffer an efficiency loss due to the requirement of two and only two photons. In order to detect low energy photons in the liquid argon counters, we run with a very low energy threshold. Hence the electronic noise in the preamplifiers generates some spurious photons. In many cases these spurious photons derive their energy partially from noise and partially from real charged or neutral tracks present in the event. To evaluate this loss we examined the reaction $\psi \rightarrow \pi^+\pi^-\pi^0$ which has a topology like that of the reaction under study, and which can be un-ambiguously identified from the charged tracks. Events were selected at the ψ using the identical kinematic cuts described earlier for the $\rho\ell$ events except that we removed the two photon requirement. The fraction of $\psi \rightarrow \pi^+\pi^-\pi^0$ events with two and only two photons was found to be (87.3 ± 7)%. We interpret this as implying a 12.7% loss of $\rho\ell$ events and corrected the data accordingly.

We have calculated that the maximum contribution to the $\rho\ell$ signal from charmed particle decays is 2 events. We have performed a check on this charm contamination estimate. In the same data set we should have observed two $\rho^\pm K^\mp$ events, one from charm and one from the τ itself and indeed we see exactly two such events. Two events of the type $\rho^\pm e^\pm$ were found which serve as a measure of the contamination from multi-hadron annihilation events. Accordingly, four events were subtracted from the $\rho^\pm e^\mp$ events for the purposes of calculating the $\tau \rightarrow \rho\nu$ branching fraction.

Given the above considerations we assumed that the remaining 81 $\rho\ell$ events were coming from τ decays only, and more specifically from

(a) $\tau \to \rho\nu$, (b) $\tau \to A_1\nu$ and (c) $\tau \to 4\pi\nu$. We have used a Monte Carlo

simulation program to study the contamination from (b) and (c). As input

to the Monte Carlo program we have used the estimate for $B(\tau \to 4\pi\nu)$ of

Gilman and Miller.[8] We predict that this mode contributes 2.5 ρe events

and 1 $\rho\mu$ event to our $\rho\ell$ sample. For the feed-down from $\tau \to A_1\nu$ we have

assumed a 10% branching fraction which is consistent with most theoretical

predictions[8,9] and a measurement by the PLUTO group of $B(\tau \to A_1\nu) =$

$(10.4 \pm 3.8)\%$.[10] There is also a SLAC-LBL measurement[11] for $\tau \to \pi^{\pm}\pi^{+}\pi^{-}\nu$

of $(7 \pm 5)\%$ which is in good agreement with our assumption. We find that

$\tau \to A_1\nu$ contributes 5.8 ρe events and 1.6 $\rho\mu$ events to our $\rho\ell$ sample.

Because of the uncertainties involved in these subtractions we have added

a 5% systematic error to our final result which corresponds to a 50%

error in our knowledge of $B(\tau \to A_1\nu)$. After all the corrections there

are 61.9 ± 11.2 ρe events and 20.5 ± 5.8 $\rho\mu$ events.

In order to extract the $\tau^{-} \to \rho^{-}\nu_{\tau}$ branching fraction from the $\rho\ell$

events, we need to know $B(\tau^{-} \to \ell^{-}\nu_{\tau}\bar{\nu}_{\ell})$. We have measured this branching

fraction with events which had an electron, a muon and no detected

photons ($e\mu$ events). The two charged tracks were required to be aco-

planar[6] by at least 10°, and the vertex requirement was the same as for

the $\rho\ell$ events. We have 95 such events, which we correct for losses due

to spurious photons. To determine this loss we measure the fraction of

cosmic ray events containing no photons and find this to be 94%, which

results in a corrected $e\mu$ signal of 101.5 events.

The efficiencies for detecting ρe, $\rho\mu$ and $e\mu$ events were found with

a Monte Carlo program to be $\varepsilon_{\rho e} = 6.4\%$, $\varepsilon_{\rho\mu} = 2.7\%$ and $\varepsilon_{e\mu} = 12.9\%$.

Combining these efficiencies with the number of produced $\tau^{+}\tau^{-}$ pairs and

the numbers of corrected events yields the following results:

$$B(\tau^- \to \rho^- \nu_\tau) \cdot B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = 0.0421 \pm 0.0090$$

$$B(\tau^- \to \rho^- \nu_\tau) \cdot B(\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu) = 0.0329 \pm 0.0100$$

and

$$\sqrt{B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) \cdot B(\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu)} = 0.185 \pm 0.015 \quad .$$

A correction for initial state radiation of 1% has been applied to these

results. The errors are based on the statistics of the uncorrected

events and the statistical error of the corrections and Monte Carlo

efficiencies. In addition systematic errors have been included to

account for uncertainties in the luminosity (6%), lepton tagging effici-

encies and misidentification probabilities (5%) and an uncertainty in the

calculation of the number of produced $\tau^+ \tau^-$ pairs due to initial state

radiation effects (5%). If we assume that $B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = B(\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu)$

then we obtain the following results:[12]

$$B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = (18.5 \pm 1.5)\%$$

$$B(\tau^- \to \rho^- \nu_\tau) = (20.5 \pm 4.1)\%$$

where we have now incorporated the systematic error associated with the

feed-down correction in our measurement of the $B(\tau \to \rho\nu)$. We further

obtain the ratio

$$B(\tau^- \to \rho^- \nu_\tau)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = 1.11 \pm 0.23 \quad .$$

In conventional models the τ^- couples via the strangeness — non-

changing vector current to produce $\tau^- \to \rho^- \nu_\tau$. Thacker and Sakurai,

Tsai[9] and Gilman and Miller[8] have used the CVC hypothesis and measurements

of $e^+e^- \to \rho^0$ to calculate the ratio $B(\tau \to \rho\nu)/B(\tau \to e\nu\bar{\nu})$. In particular Gilman and Miller,[8] under the assumption of $M_\tau = 1.8$ GeV/c^2 and the experimental restriction of $0.27 \leq M_{\pi^\pm\pi^o} \leq 1.26$ GeV/c^2, find this ratio to be 1.2 which is in good agreement with the data. These data are also in agreement with the measurement of $B(\tau \to \rho\nu) = (24 \pm 9)\%$ by the DASP group.[13]
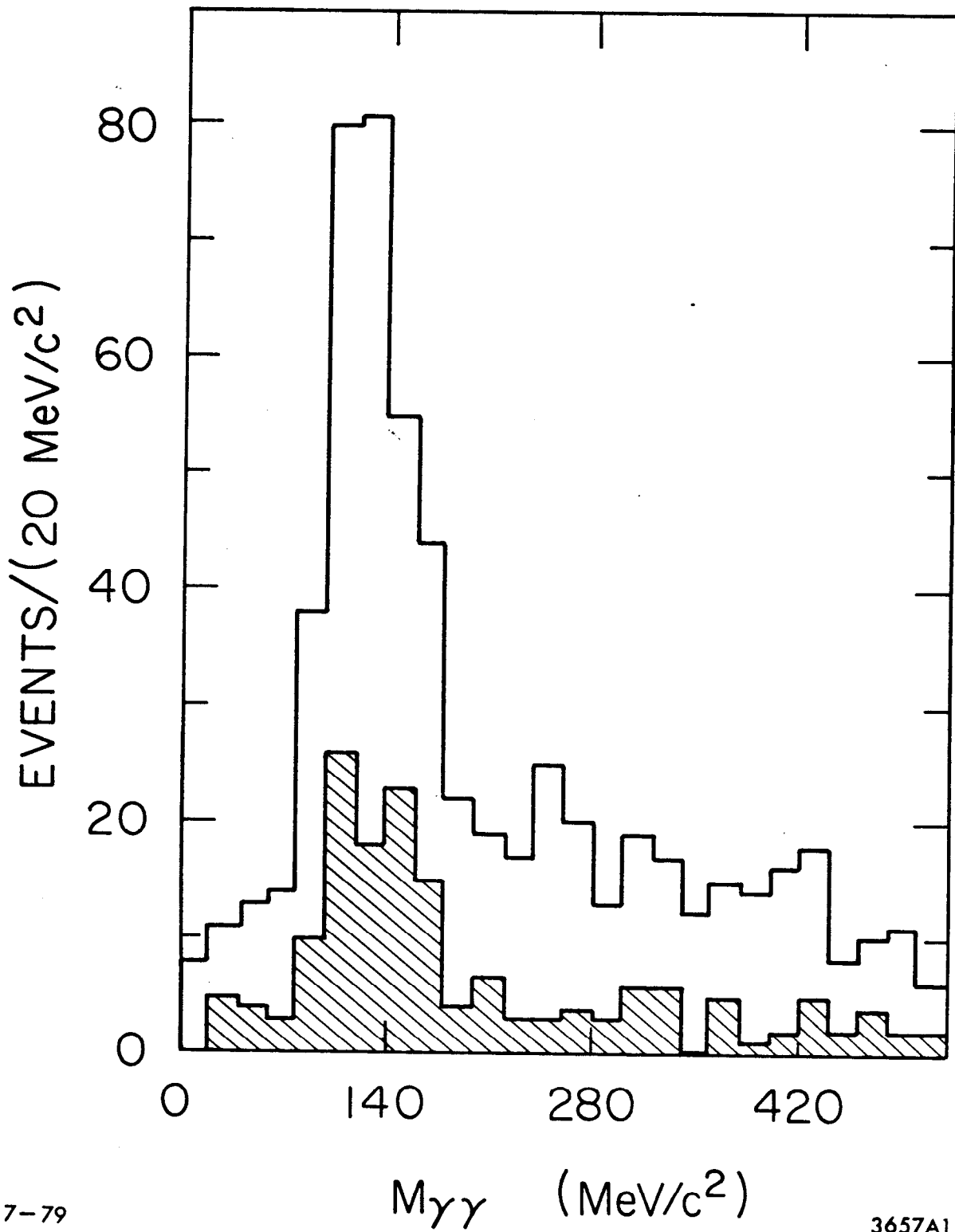
REFERENCES

1. M. L. Perl et al., Phys. Rev. Lett. 35, 1489 (1975); M. L. Perl et al., Phys. Lett. 63B, 466 (1976).

2. W. Bacino et al., Phys. Rev. Lett. 42, 749 (1979).

3. See for instance G. Feldman, Proceedings of the 19th International Conference on High Energy Physics, Tokyo, 1978, 777.

4. The notation $\tau^- \to \rho^- \nu_\tau$ and $\tau^- \to \ell^- \nu_\tau \bar{\nu}_\ell$, used throughout the text, imply also the charge conjugate reactions $\tau^+ \to \rho^+ \bar{\nu}_\tau$ and $\tau^+ \to \ell^+ \bar{\nu}_\tau \nu_\ell$.

5. G. S. Abrams et al., SLAC-PUB-2331 and LBL-9178.

6. The acoplanarity angle is defined as $(180-\delta\phi)^\circ$ where $\delta\phi$ is the difference in the azimuthal angles of the two charged particles.

7. There are fewer $\rho\mu$ events because of the 700 MeV/c momentum threshold of the muon tagging system; for comparison there are 25 ρe events with electron momenta above 700 MeV/c.

8. F. J. Gilman and D. H. Miller, Phys. Rev. D17, 1846 (1978).

9. H. B. Thacker and J. J. Sakurai, Phys. Lett. 36B, 103 (1971); Y. S. Tsai, Phys. Rev. D4, 2821 (1971).

10. H. H. Spitzer, in Proceedings of the 19th International Conference on High Energy Physics, Tokyo, 1978, 255.

11. J. A. Jaros et al., Phys. Rev. Lett. 40, 1120 (1978).

12. We wish to point out that this is not our definitive measurement of $B(\tau \to e\nu\bar{\nu})$. A more thorough study of this quantity will be published at a later date. We use it here to obtain $B(\tau \to \rho\nu)$ and $B(\tau \to \rho\nu)/B(\tau \to e\nu\bar{\nu})$ as some systematic errors, common to both measurements, cancel in these determinations.

13. R. Brandelik et al., Zeitschrift für Physik C1, 233 (1979).
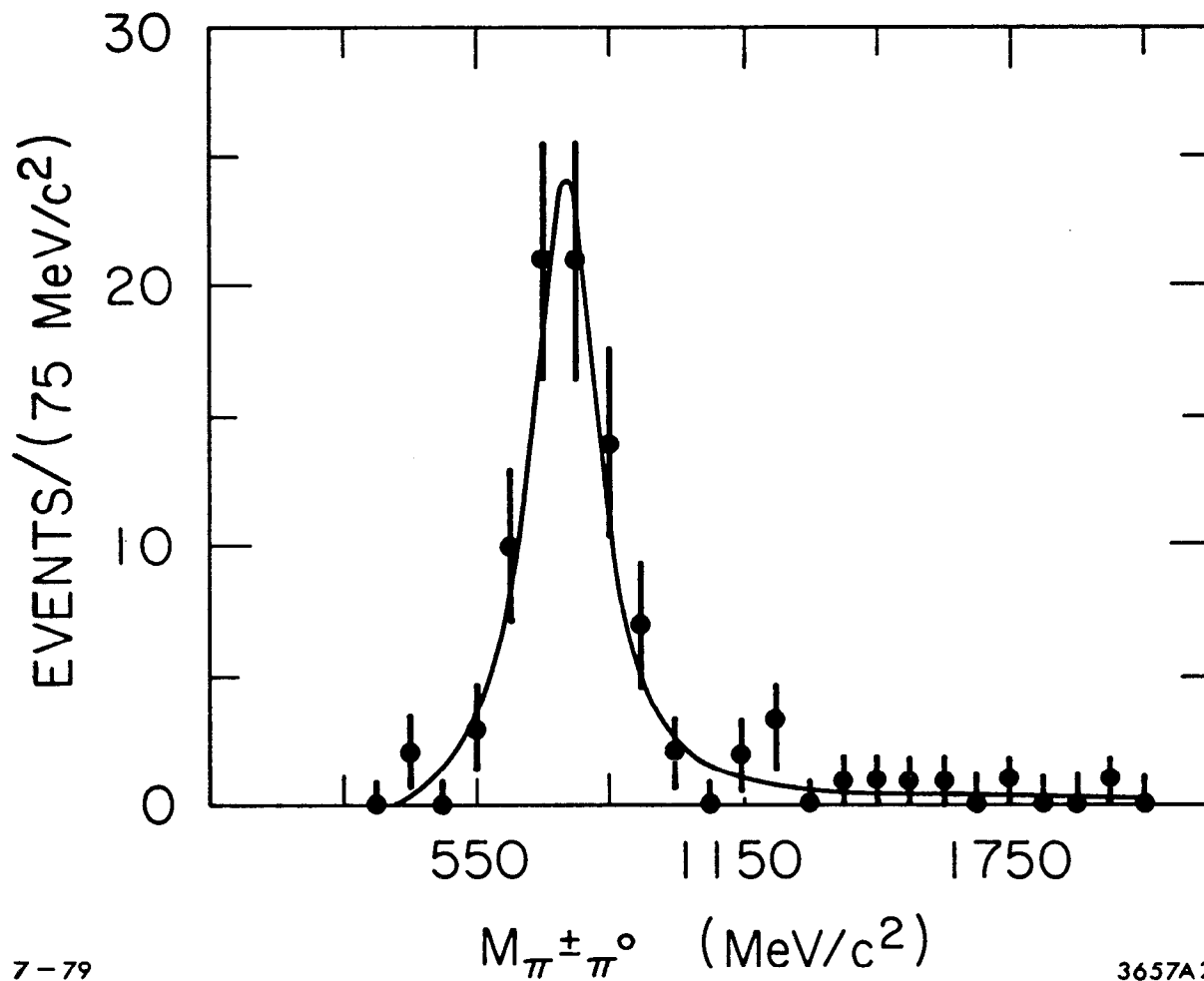
FIGURE CAPTIONS

1. Two photon invariant mass spectrum for $X^{\pm}\pi^{\mp}\gamma\gamma$ events where X represents either a pion or a lepton (ℓ). The shaded distribution is for the $\ell^{\pm}\pi^{\mp}\gamma\gamma$ events.

2. $\pi^{\pm}\pi^0$ invariant mass spectrum for $\ell^{\pm}\pi^{\mp}\pi^0$ events.

3. The distribution $X_{\rho} = (E_{\rho} - E_{min})/(E_{max} - E_{min})$ for the 85 $\rho^{\pm}$ candidates. Here $X_{\rho} = 0$ (1) corresponds to the minimum (maximum) energy allowed for the ρ in the decay $\tau \rightarrow \rho\nu$.
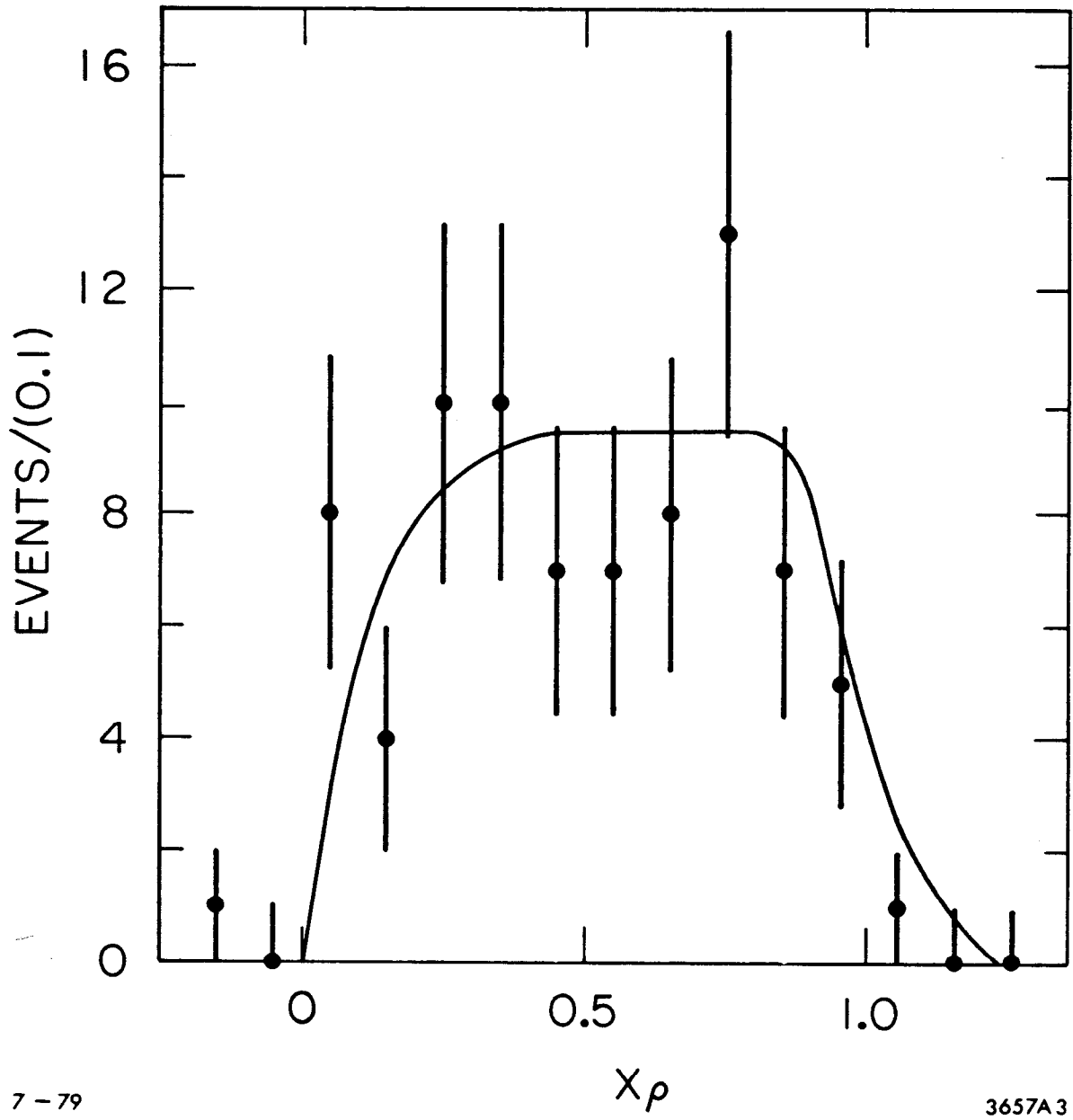
Fig. 1

7-79

3657A1

7-79

3657A2

Fig. 2

X_ρ

Fig. 3