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**OBSERVATION OF THE PRODUCTION OF η MESONS
IN TWO PHOTON COLLISIONS***

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Abstract

Using 2674 nb^{-1} of data taken at \sqrt{s} from 5.00 to 7.25 GeV with a trigger sensitive to decays of lower mass particles produced in two photon collisions, we have observed 56 ± 12 events consistent with the reaction $e^+e^- \rightarrow e^+e^-\eta$, $\eta \rightarrow \gamma\gamma$. Background has been subtracted using separated beam data. We obtain $\Gamma_{\gamma\gamma}(\eta) = .56 \pm .16 \text{ keV}$ and the pseudoscalar nonet mixing angle $\theta_{ps} = -17.6^\circ \pm 3.6^\circ$.

It is well known that e^+e^- colliding beam machines are also $\gamma\gamma$ colliding beam machines. Colliding photons can produce positive C parity mesons; a measurement of the cross section for production of a specific meson in $\gamma\gamma$ collisions determines its decay width to two photons ($\Gamma_{\gamma\gamma}$). Since photons couple to the charge of the quarks in a meson, such a study probes the quark structure of mesons in a given $SU(3)_{flavor}$ nonet.¹ In the case of the pseudoscalar nonet, several experiments² have measured $\Gamma_{\gamma\gamma}$ for the η' meson in $\gamma\gamma$ collisions, whereas $\Gamma_{\gamma\gamma}$ for the π^0 and until now, the η meson have only been measured employing the Primakoff effect.³ We present here the first observation of η production in two photon collisions.

The Crystal Ball detector has been described elsewhere,⁴ and we briefly mention here those aspects of the detector most relevant to this study. The main component is a spherical, segmented array of NaI(Tl) crystals for high-resolution measurements of the energy and position of electromagnetic showers. The mass resolution for η mesons decaying into two photons is $\sigma \sim 20$ -25 MeV, with a weak energy dependence. The solid angle covered by the main array is 93% of 4π sr, and is extended to 98% with additional NaI near the beam pipe. A small angle Bhabha counter measures the integrated luminosity. The central cavity of the Ball contains chambers for identifying charged particles. When the data for this study was being collected, the innermost of our central chambers consisted of a double layered spark chamber which had an angular coverage equivalent to that of the NaI in the main NaI array, not including endcaps. This was followed by a double layered proportional wire chamber (PWC) which covered 80% of the solid angle and a second double layered spark chamber covering 72% of the solid angle.

This study is based on 2674 nb^{-1} of data taken at SPEAR at e^+e^- center of mass energies (\sqrt{s}) from 5.00 to 7.25 GeV, in 250 MeV steps. A "Topology" trigger,⁴ designed especially to detect two photon collision events was used. It required approximate energy balance transverse to the beam axis; no such balance was demanded along the beam axis.

— A search was made for events from the reaction $e^+e^- \rightarrow e^+e^-\eta$ with the η

decaying to two photons, and the scattered electrons moving down the beam pipe undetected. A first selection required (1) the Topology trigger and (2) two separate deposits of energy in the Ball neither one of which was caused by a charged particle coming from the e^+e^- interaction point (IP). To ensure efficient identification of such charged particles, we required $|\cos\theta_{\gamma\text{-beam}}| < .8$ for both energy deposits (i.e., passage through the PWC). Events from the reaction $e^+e^- \rightarrow \gamma\gamma$ were removed by requiring the total energy in the Ball to be less than 3 GeV.

This selection yielded about 60,000 events. The vast majority were due to cosmic rays which passed through the Ball but not the IP, as indicated by the lack of correlation in time between the event trigger and the beam crossing. The invariant mass distribution for the selected events peaked at 450–475 MeV, because of the Topology trigger threshold and the large number of minimum ionizing cosmic rays which traverse the Ball non-radially. To remove the large cosmic ray background, a series of cuts was applied. At each stage, the number of cosmic rays remaining could be determined by examining the trigger timing distribution.

First, events were removed which were consistent with being charged cosmic rays passing through the central chambers but not through the IP. Events were rejected if more than 2 hits in the axial spark chamber and PWC wires were within 5 cm of a line connecting the two energy deposits (in the plane perpendicular to the beam). Because of noise in the chambers, a fraction of the truly neutral events were lost at this stage. In order to estimate the loss, events from the QED processes $e^+e^- \rightarrow e^+e^-$ and $e^+e^- \rightarrow \gamma\gamma$ were examined and compared with predicted cross sections.⁵ The number of $e^+e^- \rightarrow \gamma\gamma$ events observed (using the chamber hit cut described above) divided by the number expected, for each beam energy, was found to be approximately independent of the angle of scattering. That ratio was taken to be the efficiency of the chamber cut for retaining true final state $\gamma\gamma$ events. The efficiency was $(83 \pm 4)\%$ at $\sqrt{s} = 5.0 - 6.5$ GeV, but dropped to $(27 \pm 3)\%$ at $\sqrt{s} = 7.25$ GeV due to the larger number of noise hits at higher beam energies. The average efficiency for the entire data set was $(68 \pm 4)\%$.

Cosmic rays which traverse the Ball but miss the central chambers completely will survive the cut just described, but will have lateral energy deposition profiles which differ from those of photons originating from the IP. The former will leave elongated patterns while the latter will leave approximately circular deposition patterns. In addition, these cosmic rays will have high p_T^2 , in contrast to two photon events which are expected to peak at low p_T^2 (p_T^2 is the square of the vector sum of the transverse momenta of the two final state photon candidates). An energy pattern cut and a cut $p_T^2 < 10000 \text{ MeV}^2$ removed nearly all of the remaining cosmic ray events: the event trigger timing distribution indicated that after out-of-time events were removed, 5 ± 3 cosmic ray events contaminate the final in-time event sample.

143 events survive all cuts, 112 of which have an invariant mass ($M_{\gamma\gamma}$) between 400 and 700 MeV/c^2 . The $M_{\gamma\gamma}$ distribution for these events (not corrected for acceptance) is shown in figure 1(a). A clear peak near the η mass can be seen, on top of a background. The p_T^2 distribution for these events, figure 2(a), peaks at zero as expected for two photon collision events.

We have verified that the peak is not caused by the energy dependence of the Topology trigger. This dependence has been measured from data taken concurrently with a more restrictive trigger which had a lower energy threshold.⁶ The trigger efficiency calculated from that data, as a function of energy deposited in the main NaI array, is presented in figure 3. Also shown in that figure is the total deposited energy of (1) the events shown in figure 1(a) (histogram) and (2) those events with $500 < M_{\gamma\gamma} < 600 \text{ MeV}/c^2$. We conclude that the peak is not produced by the Topology trigger threshold.

There still remains a background due to beam-gas collisions. In order to estimate this background, the same cuts as described above were applied to data taken in the same period as the colliding beam data and under the same conditions, but with beams separated so that no e^+e^- collisions occurred. The colliding beam data contained 2.7 ± 0.3 times as many beam gas collisions as the separated beam data. This ratio was obtained by two different methods with good agreement in the results: (1) kinematically isolating beam-gas events

in both samples, and (2) comparing the quantity “PIT”, defined as the time integrated (vacuum pressure) \times (beam currents), for the two data sets, which should be proportional to the number of beam gas collision events in each data set. Figure 1(b) shows the 21 events which satisfy all cuts in the separated beam data. The p_T^2 distribution for these events, figure 2(b), is flat. A bin-by-bin subtraction was performed to obtain the data points of figures 1(c) and 2(c).

The final invariant mass distribution, figure 1(c), was fit with a simple Gaussian and a linear background. The mass (542 ± 6 MeV) and width ($\sigma_m = 21 \pm 3$ MeV) of the peak are consistent with previous Crystal Ball studies of the η meson in other production channels. The p_T^2 distribution for these events shows a clear peak at zero; it compares well with the predicted shape⁷ (shown as the histogram of figure 2(c), normalized to the number of events in the data). We therefore associate the 56 ± 12 events in the peak with the two photon production of η mesons.

Possible sources of single η meson decays other than from the reaction $\gamma\gamma \rightarrow \eta$ include feed-down from the reactions $\gamma\gamma \rightarrow \eta' \rightarrow \eta\pi\pi$ and $\gamma\gamma \rightarrow A_2 \rightarrow \eta\pi$ where the extra pion(s) go down the beam pipe undetected. We estimate that less than one event from these channels appear in our final sample. Events from the reaction $e^+e^- \rightarrow \gamma\gamma(\gamma)$ where a radiated photon carrying much of the total energy goes down the beam pipe contaminates our final sample at invariant masses above 1500 MeV; less than one event is estimated⁵ to remain with $M_{\gamma\gamma}$ below that value. The background from $\gamma\gamma \rightarrow \gamma\gamma$ (continuum)⁸ and double bremsstrahlung⁹ is estimated to be negligible, as are other sources from one- and two- photon channels. Electroproduction of η mesons by beam e^\pm colliding with the residual gas in the beam pipe is estimated (using “PIT”) to be the same order of magnitude as the background in figure 1(a). This process contributes to the separated beam data as well, and is therefore accounted for in the background subtraction.

We calculate $\Gamma_{\gamma\gamma}(\eta)$ using the following formula:

$$\Gamma_{\gamma\gamma}(\eta) = \frac{N}{L\sigma' B\epsilon_r\epsilon_n},$$

where N is the number of observed events (56 ± 12); L is the total integrated luminosity; σ' is the cross section for the reaction $e^+e^- \rightarrow e^+e^-\eta$ per unit $\gamma\gamma$ decay width of the η meson (calculated⁷ to be $.94 \pm .04$ nb/keV at an average \sqrt{s} of 6.1 GeV); B is the decay branching ratio of the η meson to $\gamma\gamma$ ($.391 \pm .008$);¹⁰ ϵ_r is the overall efficiency for reconstructing events from the reaction $e^+e^- \rightarrow e^+e^-\eta$ (determined by Monte Carlo calculations to be 15%);¹¹ and ϵ_n is the efficiency for retaining truly neutral events (determined as described above). We thus obtain $\Gamma_{\gamma\gamma}(\eta) = .56 \pm .12 \pm .10$ keV, where the first error is statistical and the second systematic. The systematic error includes the effects of changing the cuts, as well as changing the background subtraction normalization constant.

This result can be compared to previous measurements of this quantity by experiments which employed the Primakoff effect: photoproduction of η mesons in the Coulombic field of a nuclear target. A pioneering DESY experiment¹² yielded $\Gamma_{\gamma\gamma}(\eta) = 1.0 \pm .2$ keV, while a more recent Cornell experiment¹³ gave $\Gamma_{\gamma\gamma}(\eta) = .324 \pm .046$ keV. These experiments had high statistics, and their errors were dominated by systematic uncertainties in separating the component of η production in the Coulombic nuclear field from that in the hadronic nuclear field. In addition, the $\gamma\gamma$ decay width had to be extracted from the Coulombic cross section by estimating the nuclear electromagnetic form factor (the uncertainty in this calculation dominates the error in the Cornell result). This measurement of $\Gamma_{\gamma\gamma}$ using η production in $\gamma\gamma$ collisions at e^+e^- storage rings is, in principle, free from such theoretical uncertainties, but is limited by low statistics.

The $\gamma\gamma$ decay widths of neutral members of SU(3) nonets are related^{1,14} by the nonet mixing angle (θ_{ps} in the case of the pseudoscalar nonet). We take as input (1) our result $\Gamma_{\gamma\gamma}(\eta) = .56 \pm .16$ keV (errors added in quadrature), (2) $\Gamma_{\gamma\gamma}(\eta') = 5.3 \pm .6$ keV (world average from two photon experiments),¹⁵ and (3) the Particle Data Book¹⁰ value $\Gamma_{\gamma\gamma}(\pi^0) = 7.83 \pm .56$ eV. We obtain by χ^2 minimization $\theta_{ps} = -17.6^\circ \pm 3.6^\circ$, with a $\chi^2 = .01$ for one degree of freedom. Taking, instead, the Cornell value¹³ for $\Gamma_{\gamma\gamma}(\eta)$, as well as the above values of $\Gamma_{\gamma\gamma}(\pi^0)$ and $\Gamma_{\gamma\gamma}(\eta')$, yields $\theta_{ps} = -9.5^\circ \pm 2.0^\circ$, with a $\chi^2 = 2.4$ for one degree of freedom.

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References

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Figure Captions

1. Distribution of $M_{\gamma\gamma}$ for all events passing the cuts described in the text.
 - (a) Colliding beam data. Five events have invariant masses below 400 MeV, and 26 events have masses above 700 MeV.
 - (b) Separated beam data (the scale of the ordinate is adjusted to make the figure directly comparable to figure 1a). One event has an invariant mass below 400 MeV, and no events have masses above 700 MeV.
 - (c) Data points represent the background subtracted data, while the curve represents a fit to the data employing a simple Gaussian and a small amount of residual background.
2. Distribution of p_T^2 for events passing all cuts, with $500 < M_{\gamma\gamma} < 600$ MeV.
 - (a) Colliding beam data.
 - (b) Separated beam data (the scale of the ordinate is adjusted to make the figure directly comparable to figure 2a).
 - (c) Data points represent the background subtracted data, while the histogram represents the prediction of reference 6 for the Crystal Ball, normalized to the number of events in the data.
3. Data points show the efficiency for the Topology trigger as a function of total energy deposited in the crystals. The histogram (refer to the scale on the right) is the distribution of total energy deposited in the crystals by the η candidates. The shaded part of the histogram indicates those events with $500 < M_{\gamma\gamma} < 600$ MeV/c².

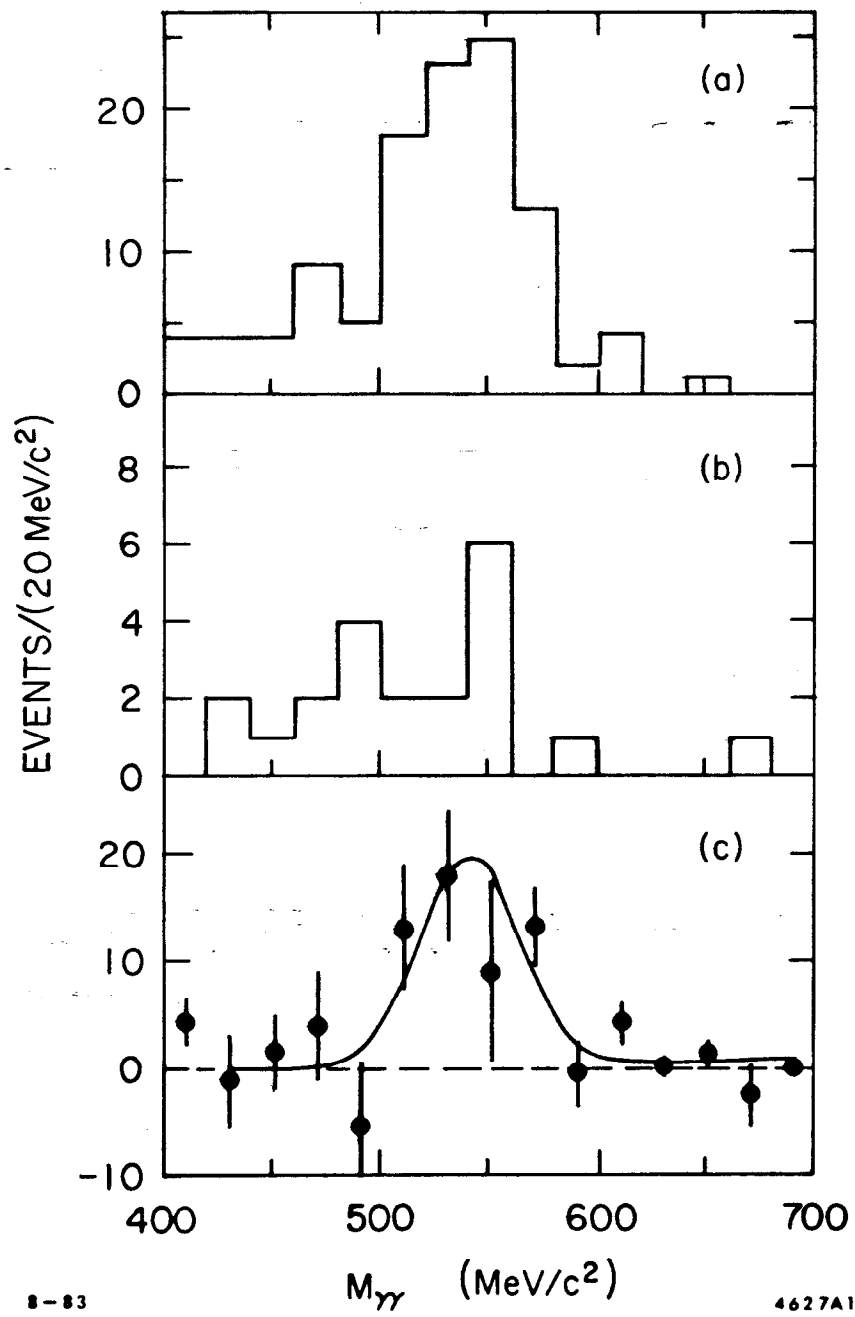


Fig. 1

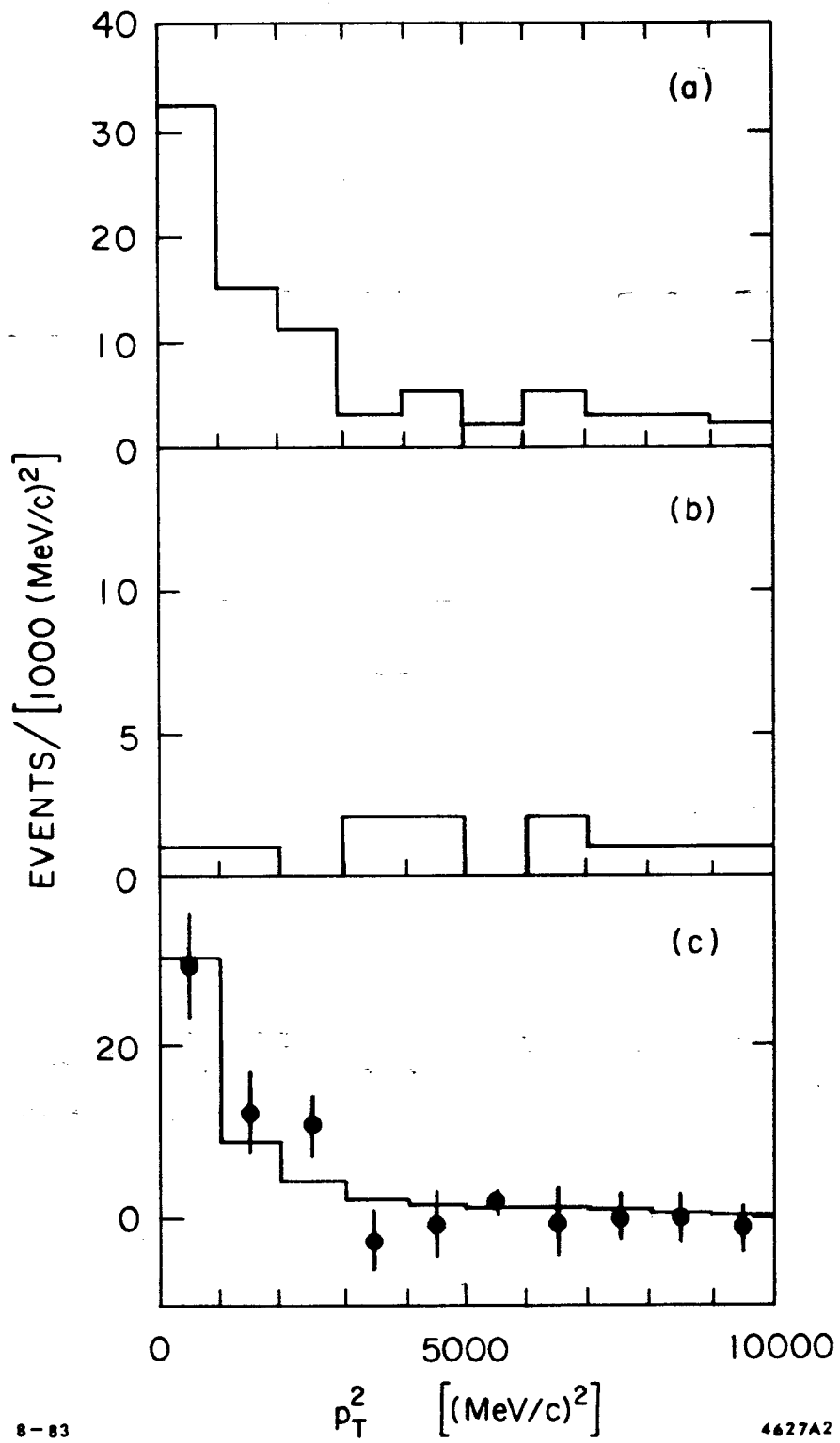


Fig. 2

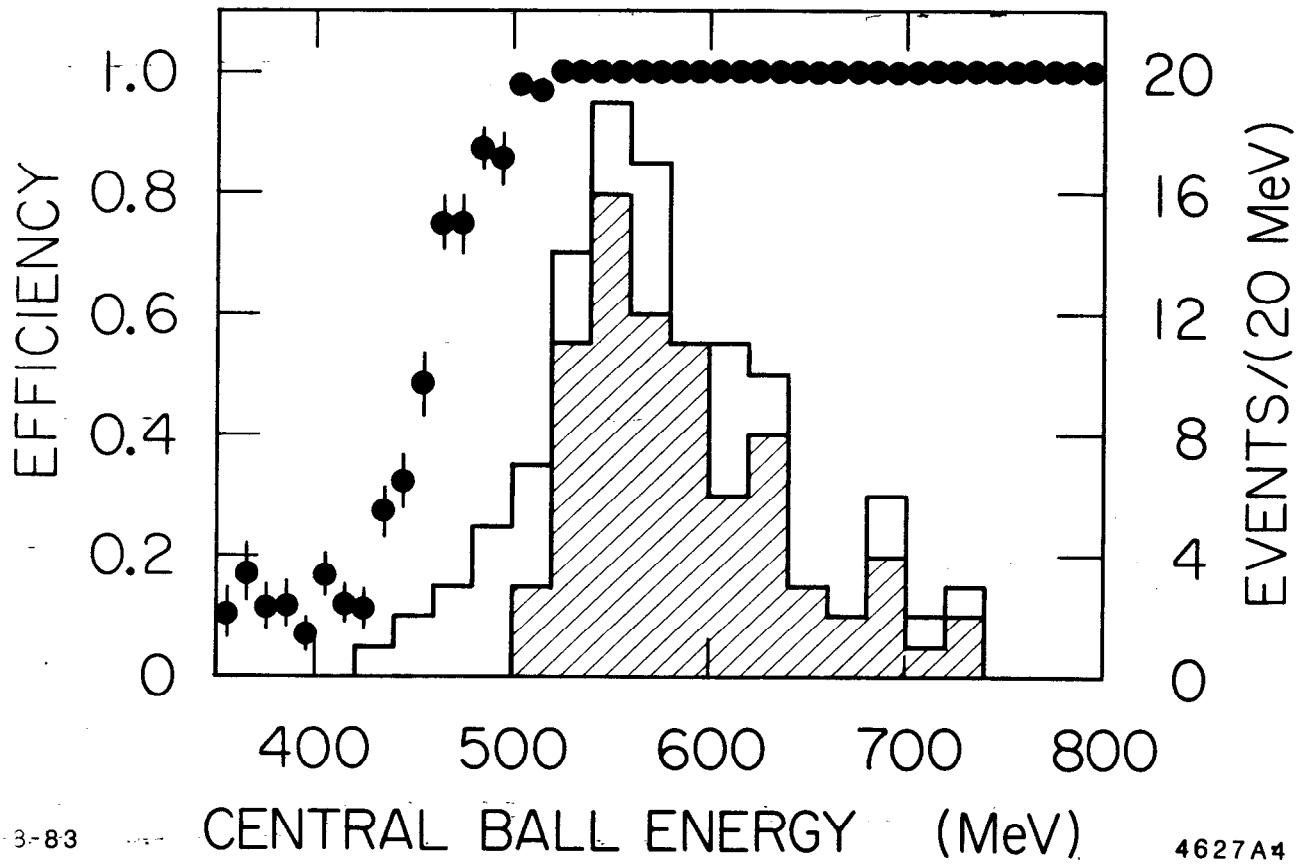


Fig. 3