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ABSTRACT

We have measured the production of $\rho + \omega$ and J vector mesons, through their dimuon decay modes, by high energy neutrons on nuclear targets at Fermilab. We determined the A-dependence to be $A^{.62}$ for $\rho + \omega$, $A^{.93}$ for J, and $A^{.85}$ for the continuum of dimuons between the $\rho + \omega$ and J masses.

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Several recent experiments at Fermilab, ISR, and Serpukhov have initiated the study of dilepton production in high energy hadron-hadron collisions.[1,2,3] These experiments established the presence of two strong resonances above a continuum, one due to the $\rho + \omega$ and the other due to the J .[4] Between these two masses the cross section decreases monotonically as the mass increases. Because of the relevance of dilepton production to several open experimental questions, such as the nature of J production in hadronic collisions, the contribution of dileptons to single lepton production, and the possible existence of the Drell-Yan process[5] for dilepton production, it is important to measure the features of dilepton production in greater detail than in previous experiments.

The primary purpose of this experiment was to measure the A-dependence of the total inclusive cross section for $\rho + \omega$, J and the continuum between those resonances in neutron-nucleus collisions. The second objective, which is discussed in a subsequent paper, was to determine the $p_{\perp}$ and X_f dependence of the invariant cross section for this process. By making measurements on four elements it was possible to extrapolate the yields to the cross section for production on a single nucleon. The details of the beam and the apparatus were reported in a previous publication.[1] The neutron beam was produced by the interaction of 400 GeV protons, rather than 300 GeV protons as in our previously published work.

We detected muon pairs only after they emerged from an absorber as shown in Fig. 1. The target was placed close to the absorber in order to limit the number of muon pairs from meson decays.

During this run the absorber consisted of 144 gm/cm^2 of Be, a steel-scintillator hadron calorimeter of mass 530 gm/cm^2, and an additional 760 gm/cm^2 of uninstrumented steel. The absorber was located 78 cm downstream from the target. The bulk of the data which were used to determine the A-dependence were obtained using Be, Al, Cu and Pb targets which were 15 cm long and which had a mass per unit area of 28.5 gm/cm^2. They were segmented in order to obtain equal length and density. Data were also taken with a solid Pb target of 86.5 gm/cm^2 and a solid Cu target of 54 gm/cm^2.

A neutron interaction in either the target or the absorber would generate an event trigger if there were a coincidence between the D counter and either 2H counters and 1V counter or 2V counters and 1H counter. The information on the event was recorded on tape if either $2\mu_H$ counters and $1\mu_V$ counter or $2\mu_V$ counters and $1\mu_H$ counter had counts in coincidence with the event trigger. The A counter was required to be off. Two or more hits were required in two of the three planes of proportional chambers P_2, P_3, and P_4. The target counter T was not used in the event trigger, although its status and the status of all other counters were recorded with the MWPC information.

Events which had two or more tracks extending from P_1 through P_4 were candidates for muon pairs. The distance of closest approach of the tracks was required to be less than 2.2 cm. The interaction point, the midpoint on the line segment connecting the two tracks at their distance of closest approach, was required to be within 2.5 cm of the axis of the neutral beam. The event was classified as a dimuon if three of the four muon counters which were intercepted by the tracks had counts.

The invariant mass of the pair was calculated in two ways. In both calculations the magnitudes of the momenta were determined from the deflection of the tracks in the magnet and then corrected for the energy loss in the absorber. The methods differed in their calculation of the opening angle of the muon pair. In the first method the mass, M_V, was calculated using the opening angle obtained from the directions of the tracks emerging from the absorber. This calculation did not depend on whether the dimuon was produced in the target or the dump. In the second method the mass, M_C, was calculated by assuming that the interaction point occurred in the target and exploiting the correlation between the deviation in the direction of the muon and the deviation of the muon position from the unscattered trajectory due to multiple scattering. We calculated the opening angle θ_{12} as the ratio of the separation of the tracks at a plane midway through the absorber to the distance from the mid-point of the target to this plane. The mass M_C is

$$M_C{}^2 = M_\mu{}^2 \left(2 + \frac{P_1}{P_2} + \frac{P_2}{P_1}\right) + P_1 P_2 \left(\theta_{12}\right)^2$$

The error in the mass due to multiple scattering in the second calculation was half the error of the first calculation. If the dimuon was actually produced in the absorber the second calculation yielded a mass value which was a factor of two too small due to the mistaken assumption that the dimuon was produced in the target. The value of M_c was taken to be the dilepton mass.

The difference between these two calculations, $|M_C - M_V|$, was very sensitive to the actual production point. For that reason it was used to determine if the event came from the target or from the absorber. If $M_C > 1.4$ GeV/c^2, then $|M_C - M_V|$ was required to be $< .48$ GeV/c^2. If $M_C < 1.4$ GeV/c^2 then $|M_C - M_V|$ was required to be $< .32$ GeV/c^2. On the basis of our Monte-Carlo calculation, if $M_C = 780$ MeV ($M_C = 3095$ MeV) this procedure excluded 19% (4%) of the events which came from the target and included 23% (< 1%) of the events which came from the absorber. In order to reduce the background of events from the absorber further it was required that T have a count if $M_C < 1.4$ GeV/c^2.

The yield of dimuons with charge zero and total momentum greater than 75 GeV/c subject to the preceeding restrictions, is shown in Fig. 2. If an event had three muons, both zero charge combinations were included. The fraction of events with more than two muons was less than 1%.

The A-dependence of the cross section was determined solely from the yield of dimuons from each target, normalized to the relative neutron intensity. In order to arrive at a statistically significant sample of events at a given mass, we have defined four mass regions as follows: $.60 < \rho < .90$, $1.10 < C_1$ (continuum) < 1.40, $1.40 < C_2$ (continuum) < 2.6, and $2.6 < J/\psi < 3.6$ The yield of events had to be corrected for background dileptons in only the first two regions.

The size of the background in the $\rho + \omega$ and C_1 mass regions was calculated in two separate ways. The first used the events with the T counter off, which provided a nearly pure sample of dimuons produced in the dump. The invariant mass, M_C, was calculated for these events using the incorrect hypothesis that the dimuon originated in the target. Since the dimuons from the absorber are the dominant source of background, the background was calculated by normalizing the T off spectrum to be equal to the T on spectrum in the region of .4 GeV/c^2 to .55 GeV/c^2. This resulted in a background subtraction of 10% at the $\rho + \omega$ mass and 10% in the C_1 mass region.

The second method used only the T on events, and fitted the mass spectrum to a sum of ρ, ω, and ϕ resonances and a background. The latter consisted of a term which decreased linearly as the mass increased and a term which was due to ρ production in the absorber. The fits were insensitive to the relative admixture of ρ and ω, due to our mass resolution, but did require a ϕ contribution to fit the shoulder in the mass spectrum near 1 GeV/c^2. This method gave identical results, within statistics, for the $\rho + \omega$ yield as method 1.

An additional source of background came from pion decays. The number of events which can be attributed to pion decay was approximately equal to the number of events which have charge two, if it was assumed that these events were due entirely to pion decay. No correction was made for this background since it was only 1/2% at the ρ mass.

The relative intensity of the neutral beam was determined from the counting rate in the D counter. The relationship between the counting rate in D and the neutron flux was established by comparing the counting rate of the hadron calorimeter, HC, and D during a special low intensity run. The D rate and the D rate gated by the live time of the electronics were recorded for each pulse. The latter was used to normalize the yield of dimuons.

During the high intensity running it was necessary to insert a 3.8 cm x 3.8 cm x 30.5 cm core of tungsten into the absorber in front of HC. This reduced the counting rate in D per incident neutron by a factor of 1.66. The relation between the neutron flux and D for this configuration was made by normalizing the yield of $\rho + \omega$ from the high intensity data to the moderate intensity data for similar targets.

No correction for electronic dead time was necessary since the gated D counting rate was proportional to the neutron flux during the live time. The yield for $M_C < 1.4$ GeV/c^2 was corrected for the 5.5% inefficiency of the T counter. This efficiency was determined from the ratio of the number of J events from the target which had the T counter on to all J which came from the target. In the J mass region the separation of target and dump is unambiguous.

We have fit the intensity normalized dilepton yields per nucleus for p > 75 GeV/c to the power law A^{γ}. We find values of γ of .62 ± .03 for the $\rho + \omega$ mass region, .85 ± .05 for C_1, .85 ± .04 for C_2, and .93 ± .04 for the J region.

The yields for the $\rho + \omega$ and J as a function of A are shown in Fig. 3a. Most of the increase in γ occurs in the mass interval between the ρ and 1.2 GeV/c^2 as can be seen from Fig. 3b. The variation in γ for larger masses is consistent with either a constant value of γ near .9 or a slow increase from .8 toward 1.0. In the $\rho + \omega$ region γ depends on $p_\perp$ as can be seen from Fig. 3c. This behavior has been observed for other hadrons by Cronin et al.[6] An examination of the J mass region showed that γ did not depend on $p_\perp$. We note that the dependence of γ on $p_\perp$ is very similar to its dependence on mass.

The dependence of γ on $p_\parallel$ in the $\rho + \omega$ mass region is also shown in Fig. 3c. γ did not depend on $p_\parallel$ in the J region to within statistics. Finally, we note that the A-dependence in the continuum region is 3 standard deviations away from an A^1 behavior, which might be expected if the only source of dileptons in this mass range were the Drell-Yan process.

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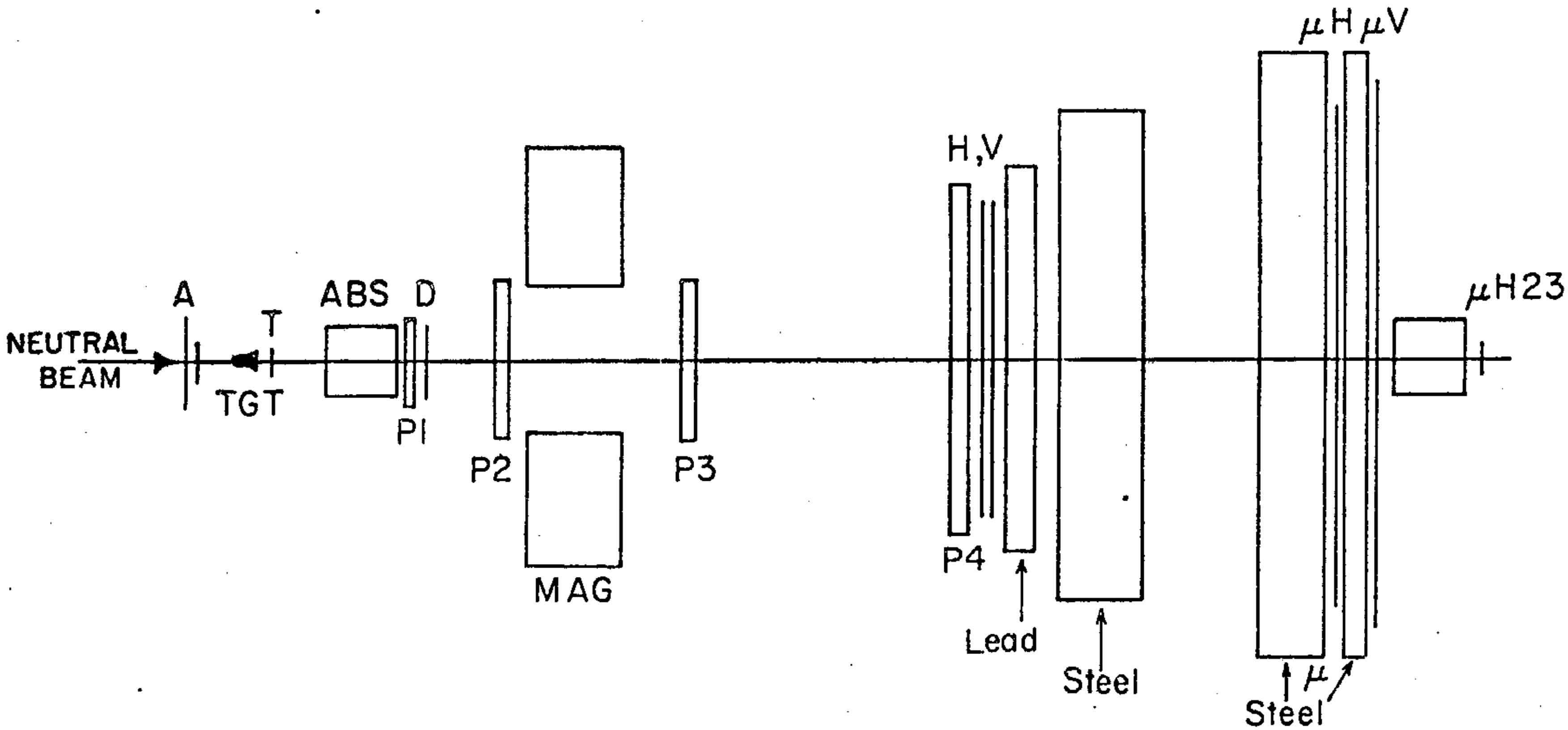

Fig. 1. Schematic Layout of Experimental Apparatus. A, T, D, H, V, μH, and μV are scintillation counters. P1, P2, P3, and P4 are multi-wire proportional chambers.

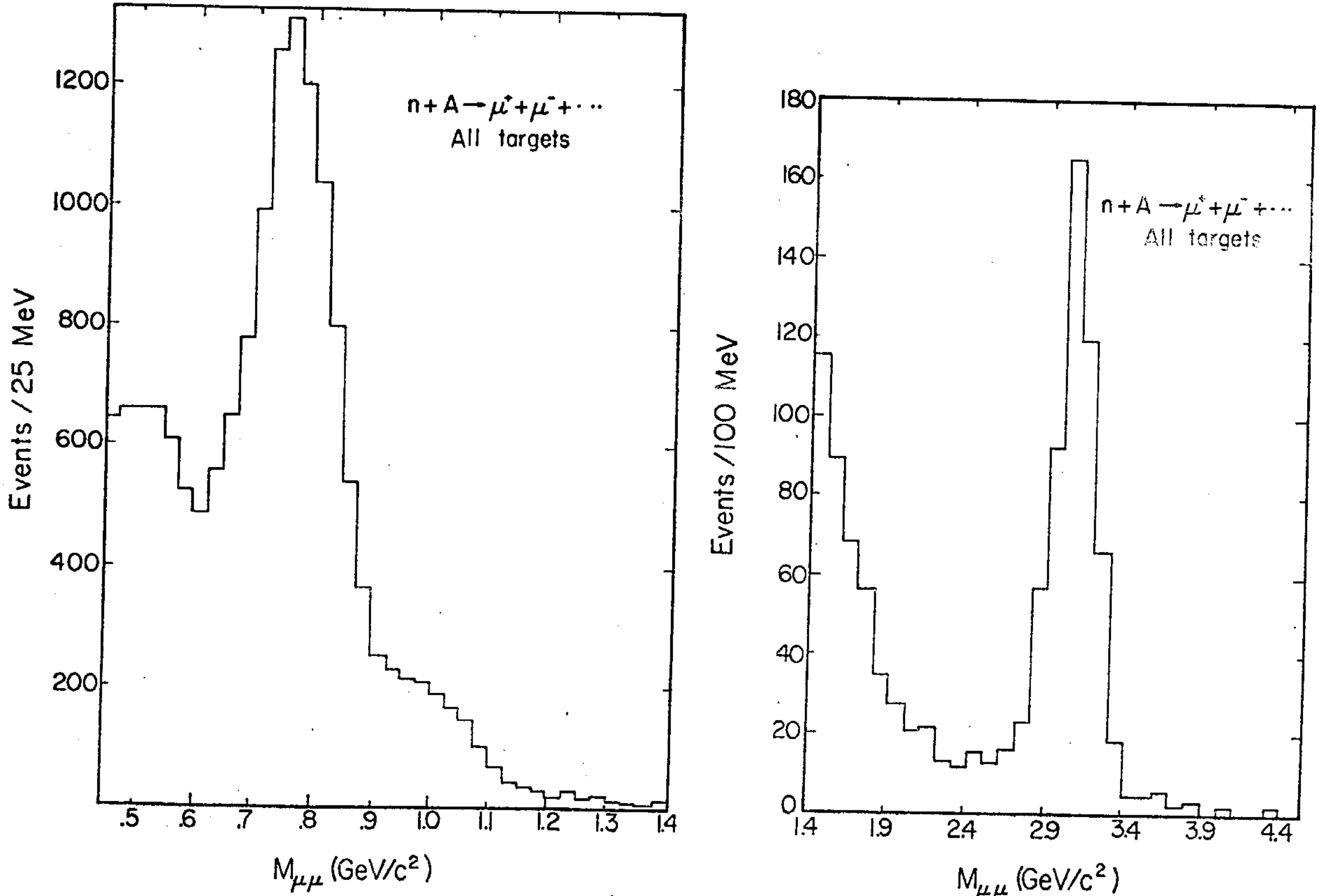

Fig. 2. Yield of dimuons from target of momentum > 75 GeV/c, events from all targets added. a) Mass < 1.4 GeV/c^2, b) Mass > 1.4 GeV/c^2. Flux in (b) = 2.5 × flux in (a).

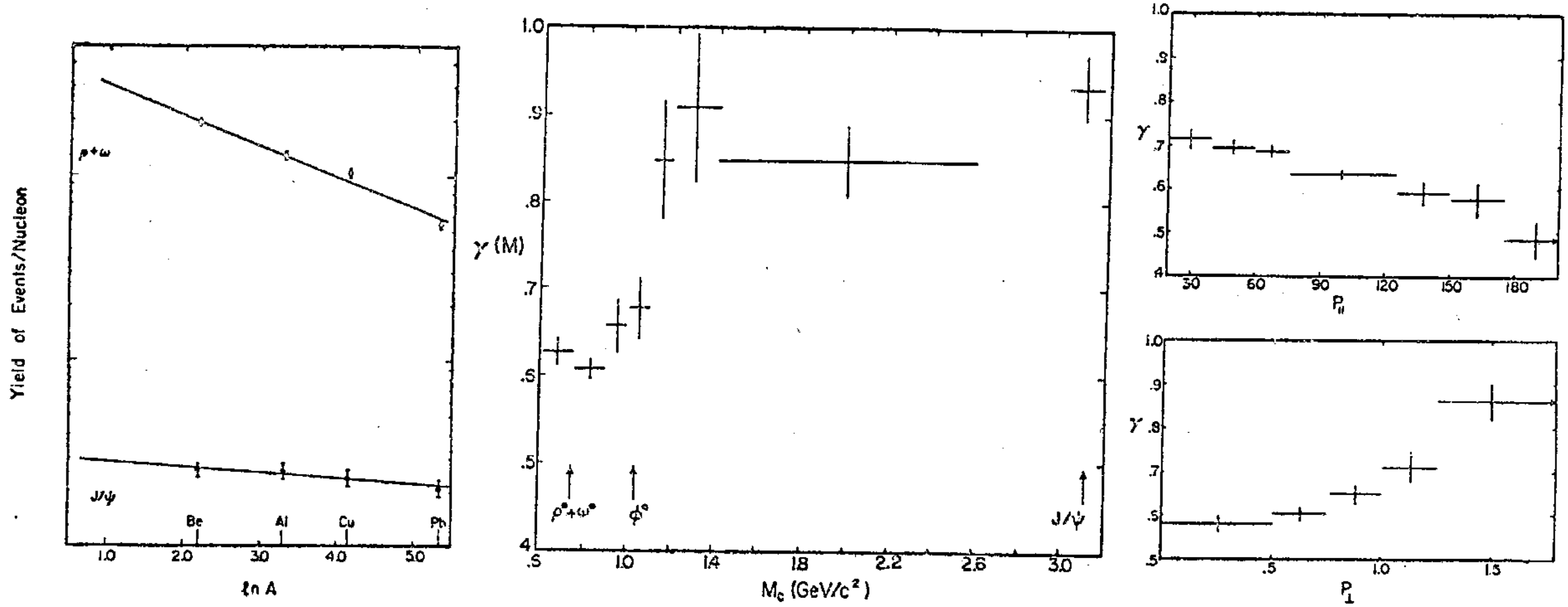

Fig. 3. a) A-dependence of yields of $\rho + \omega$ and J/ψ. Straight lines are least square fits to the data. Error bars are statistical only. b) A-dependence of the dilepton yield as a function of mass: cross-section per nucleus proportional to $A^{\gamma(m)}$. Vertical bars are statistical errors from least square fits. c) A-dependence of the dilepton yield in the $\rho + \omega$ mass region as a function of $p_{\parallel}$ and $p_{\perp}$ of the pair.