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The Production of J/ψ and Associated Particles in the Collision of 530 GeV/c Protons and Pions with Nuclear Targets*

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ABSTRACT

We have studied the production of the J/ψ and associated particles using the E672/E706 spectrometer at Fermilab. Preliminary results are presented from the first run in 1987-88 with 530 GeV/c p/π^+ and π^- beams on a variety of nuclear targets. The A-dependance of J/ψ production with π^- beam was found to agree with an A^α parametrization with $\alpha = 0.85 \pm 0.06$ for $x_F > 0.1$. We have found that $(41 \pm 22)\%$ of the J/ψ's produced in the p/π^+ beam are consistent with the radiative decay $\chi \rightarrow$J/$\psi+\gamma$. The future analysis goals of the experiment are also discussed.

1. Introduction

Experiment E672 at Fermilab was designed to study the production of J/ψ particles using proton and pion beams on nuclear targets at beam energies up to 800 GeV/c. The physics goals of the experiment include a study of the A-dependence of J/ψ production in nuclear targets, observation of radiative decays of the χ states, comparison of the production of different vector mesons (ρ, ω, ϕ and J/ψ), a study of the production of associated charged and neutral particles in events containing a vector meson (J/ψ in particular), and a search for b-quark decays to J/ψ states and double semileptonic $B\bar{B}$ decays to dimuons. The first run was conducted in 1987-88 with beam momenta of 530 GeV/c. We have a total sample of 2500 J/ψ events from this run.

At Fermilab, E672 shares the Meson West beam-line with experiment E706. In Fig. 1 we present a layout of the two experiments. The E672 muon spectrometer, located 30 meters downstream of the target, consists of a toroid magnet with an average p_T kick of 1.3 GeV/c, 15 planes of proportional wire muon tracking chambers, and 2 planes of scintillator hodoscopes with associated electronics to form the dimuon trigger.[1] The acceptance of the spectrometer is nonzero only for positive x_F and is maximum at $x_F \simeq 0.25$. The acceptance in p_T is flat in the J/ψ mass region. The E706 spectrometer, upstream of E672, contains a Cerenkov detector for beam tagging, 14 planes of silicon strips for beam tracking and vertex detection, a dipole magnet with an average p_T kick of 0.45 GeV/c for momentum measurement, 16 planes of proportional wire chambers for charged particle tracking, liquid argon electromagnetic and hadronic calorimetry, and forward calorimetry. Combined data from the two detectors were recorded for both dimuon triggers (E672) and direct photon triggers (E706).

Dimuon pretriggers for E672 were formed by coincidences between the two scintillator hodoscopes which have daisy-petal-shaped sections. For a pretriggered event, information from the muon tracking chambers were read in using a LeCroy PCOS III system. A fast trigger processor then calculated the effective mass of all muon-pair combinations in the event assuming they came from the target, typically in less than 10 μs.[2] The mass resolution of the trigger processor is about 700 MeV/c^2 in the J/ψ mass region, consistent with results from a Monte Carlo simulation.

The data from the first run were collected under two different running conditions. During Exposure 1, only the E672 dimuon spectrometer was used. About 750,000 triggers were accumulated during a 3 week run with 530 GeV/c π^- beam on 2" to 8" thick C, Al, Cu and Pb targets. The dimuon spectrum from this run is shown in Fig. 2. Since only the information from the muon spectrometer 30 meters downstream of the target was available, there is

considerable background from poor rejection of muons not originating at the vertex. Our data sample includes 1301 $\pm$ 66 J/ψ's after background subtraction, with a mass resolution of 550 MeV/c^2.

During Exposure 2, data from the full E672/E706 apparatus were recorded during a 6 week run. We ran with both π^- and p/π^+ beams of 530 GeV/c. A segmented target consisting of twenty 2 mm Be foils separated by 1.6 mm gaps was used. For part of the run, two 0.8 mm Cu foils upstream of the Be were also available. Muon tracks were reconstructed using information from the E672 muon spectrometer, the E706 PWC tracking chambers, and the silicon strip detectors. Only tracks which linked in the three detectors were considered. Multiple scattering and bending in the dipole and toroid magnets were taken into account. The dimuon invariant mass spectrum in the J/ψ region from a partial sample ($\sim$ 2/3 of the positive beam data) is shown in Fig. 3. The spectrum is relatively free of background and is mostly due to Drell-Yan processes or J/ψ production. The measured width of the J/ψ resonance is (120 $\pm$ 18) MeV/c^2, consistent with our expected resolution. We collected a sample of about 1200 J/ψ's during this run.

The invariant mass threshold for the dimuon trigger was set to 200 MeV/c^2. The complete dimuon mass spectrum for approximately 15% of the data is shown in Fig. 4 for $x_F > 0.1$. Evidence is seen for ρ/ω production, and possibly the ϕ resonance, in addition to the J/ψ peak.

The x_F distributions of J/ψ particles for positive and negative beams are shown in Figs. 5 and 6. These distributions have been corrected for the acceptance of our detector. A fit to the form $(1\text{-}x_F)^\beta$ is shown with $\beta = 4.58 \pm 0.54$ for the p/π^+ beam. The π^- data is fitt by $(1 - |x_F - 0.18|)^\beta$ with $\beta = 2.04 \pm 0.14$, consistent with previous experiments.[3]

2. A-dependence of J/ψ production

The A-dependence of J/ψ production in hadron-nucleus collisions is of great interest for the study of hadronic matter,[4] especially to understand the observed suppression of J/ψ production in nucleus-nucleus collisions at CERN, possibly indicative of the quark gluon plasma.[5]

The A-dependance of J/ψ production can be parametrized with $\sigma(hA \rightarrow \psi + X) = \sigma_0 \times A^\alpha$. Many experiments[6] have studied A-dependence at lower energies (up to $\sqrt{s}$= 24 GeV for π^- beams; for this experiment $\sqrt{s}$= 31.5 GeV). They find that α is less than 1 for large x_F and small values of p_T. Numerous explanations for this effect have been proposed, including the EMC effect, shadowing, and initial and final state scattering.[7]

The J/ψ production cross-sections from Exposure 1 are plotted as a function of the atomic weight of the four targets C,Al,Cu and Pb in Fig. 7. We find the value $\alpha = 0.85 \pm 0.06$. We do not observe any statistically significant dependence of α on x_F or p_T.

3. Search for radiative χ decays

Of the three p-wave charmonium χ states, χ_1 and χ_2 have large branching ratios to $\psi+\gamma$. A large fraction of the observed J/ψ's are expected to come from these decays. The fraction of J/ψ's coming from χ decays is an important number for theoretical calculations, including predictions of the formation of quark gluon plasma.[8] We present some preliminary results on χ production using the data from the E706 electromagnetic liquid argon calorimeter (EMLAC). At this stage of the analysis, the systematic errors in the data from the EMLAC are not fully understood for the photon energies that we are interested in.

The EMLAC was designed to detect and measure high-p_T direct photons and is described in reference [9]. Photon showers were reconstructed from the EMLAC by the E706 reconstruction program EMREC. Only γ's with energies greater than 5 GeV were used. Two cuts were used to clean up the sample of γ's: the ratio of front energy to back energy of the two depths of the calorimeter was restricted to be greater than 0.3 to reduce hadron contamination, and a p_T cut of 250 MeV/c was imposed on all γ's to reduce combinatorial background.

The J/$\psi\gamma$ invariant mass formed with dimuons in the mass range 2.7 GeV/c^2 $< M_{\mu\mu} <$ 3.5 GeV/c^2 for positive beam is shown in Fig. 8. The solid curve is an estimate of the combinatorial background calculated by combining J/ψ's and γ's from uncorrelated events. The background was normalized to have the same number of events in the non-χ mass regions $M_{\psi\gamma} < 3.4$GeV/c^2 and $M_{\psi\gamma} > 3.65$GeV/c^2. The distribution of J/$\psi\gamma$ invariant mass after subtracting the background is shown in Fig. 9. We observe an excess of 32 ± 17 events in the χ mass region 3.4 GeV/c^2 $< M_{\psi\gamma} <$ 3.65 GeV/c^2. Using a Monte Carlo simulation of the acceptance of the dimuon spectrometer and the EMLAC, we estimate $\sigma(\gamma\psi)/\sigma(\psi) = 0.41 \pm 0.22$. This value is in good agreement with lower energy fixed target experiments and higher energy SPS experiments.[4]

We would like to thank the E706 Collaboration[10] for providing the data from their magnetic spectrometer and EMLAC used in our analysis. We hope to continue our harmonious and fruitful relationship. This research was supported in part by the Department of Energy and the National Science Foundation.

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10. E706 Collaboration: *Delhi University, Fermilab, Michigan State University, University of Minnesota, Northeastern University, Pennsylvania State University, University of Pittsburgh, University of Rochester.*

FIGURE CAPTIONS

1) Layout of the E672/E706 spectrometer.
2) $\mu^+\mu^-$ mass using only the E672 dimuon spectrometer.
3) $\mu^+\mu^-$ mass in the J/ψ region using combined E672/E706 detector. Approximately 2/3 of positive beam data.
4) The complete $\mu^+\mu^-$ invariant mass spectrum showing various vector meson resonances.
5) x_F distribution for particles in the J/ψ region for p/π^+ beam, corrected for detector acceptance.
6) x_F distribution for particles in the J/ψ region for π^- beam corrected for detector acceptance.
7) The A-dependence of J/ψ production.
8) The J/$\psi\gamma$ invariant mass spectrum for p/π^+ beam. The solid curve is estimated background.
9) Background subtracted J/$\psi\gamma$ invariant mass.

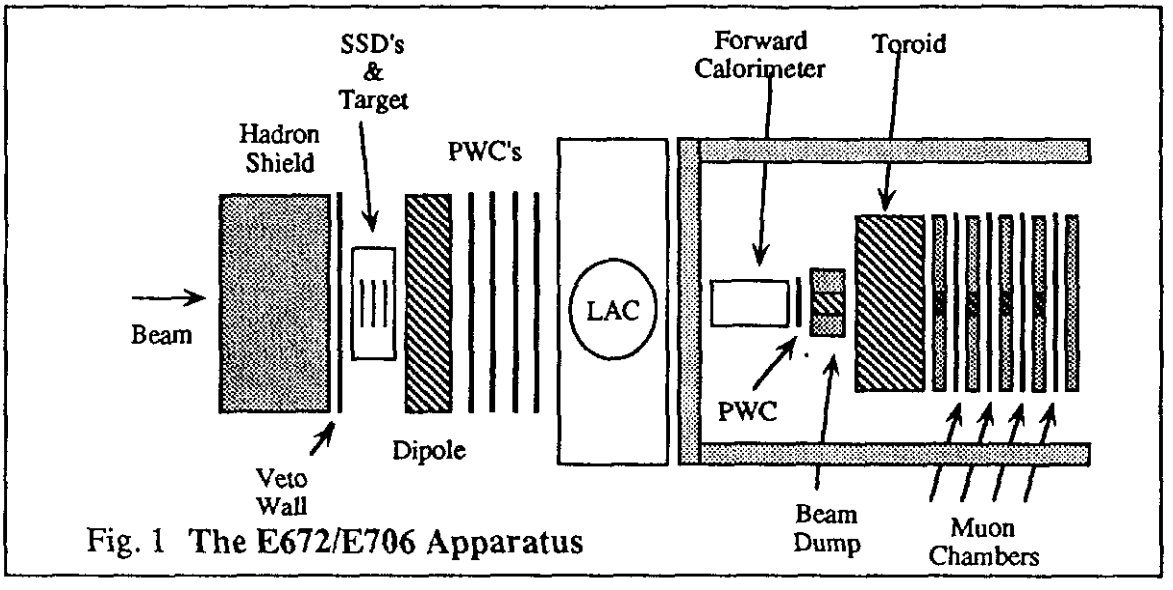

Fig. 1 The E672/E706 Apparatus

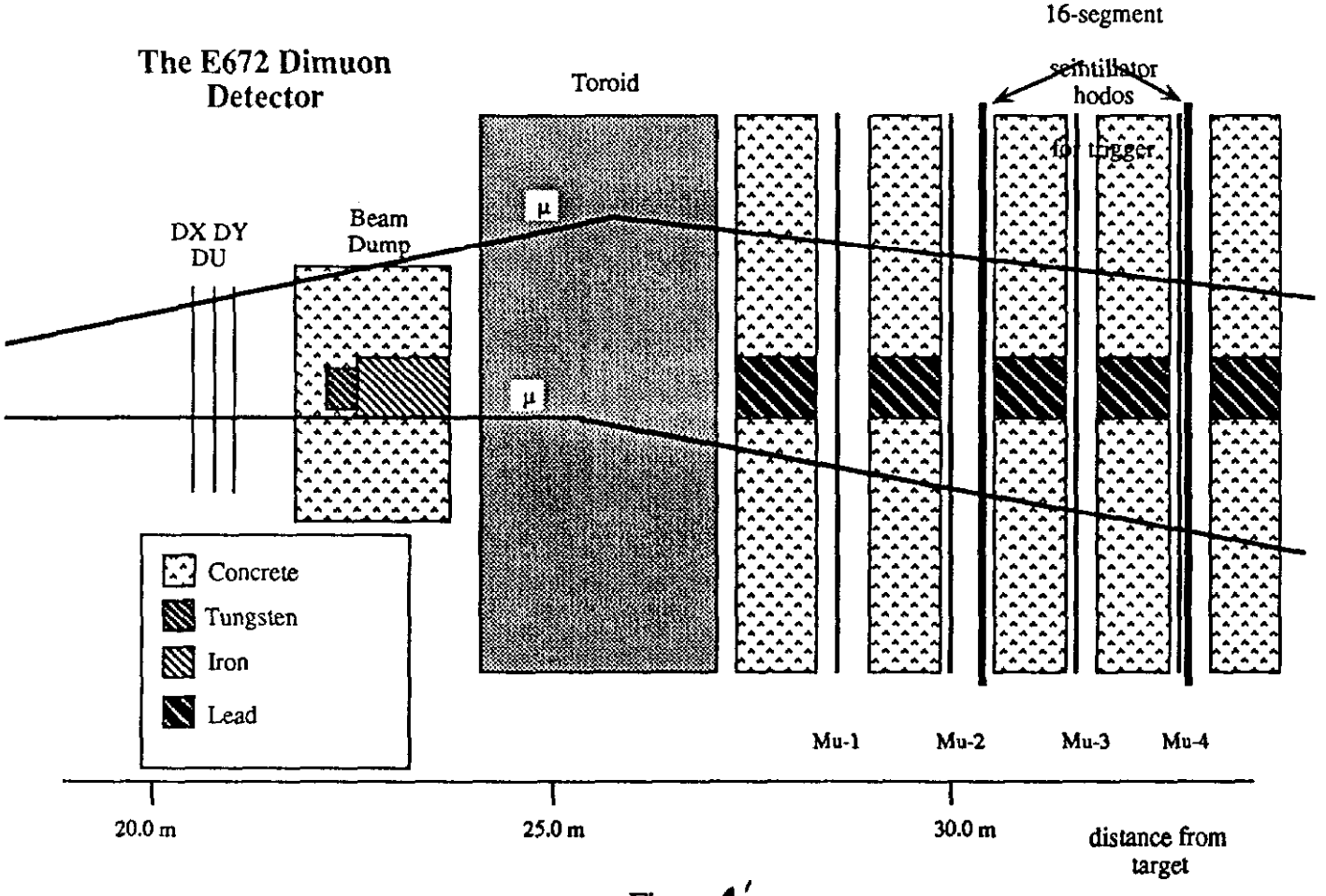

Figure 1'

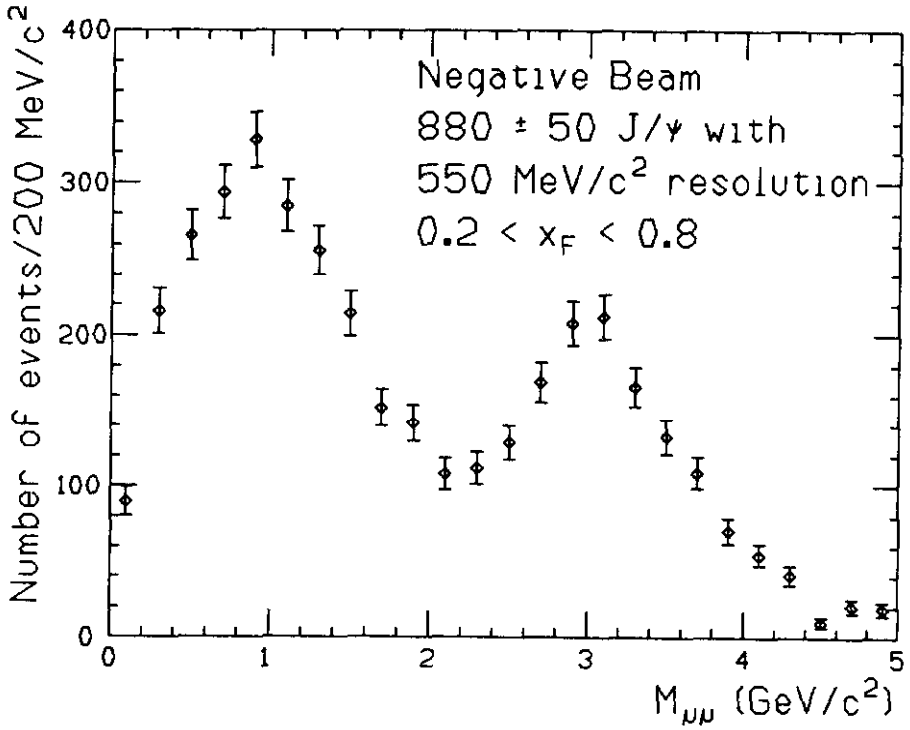

Fig. 2. Dimuon mass spectrum
(E672 spectrometer only)

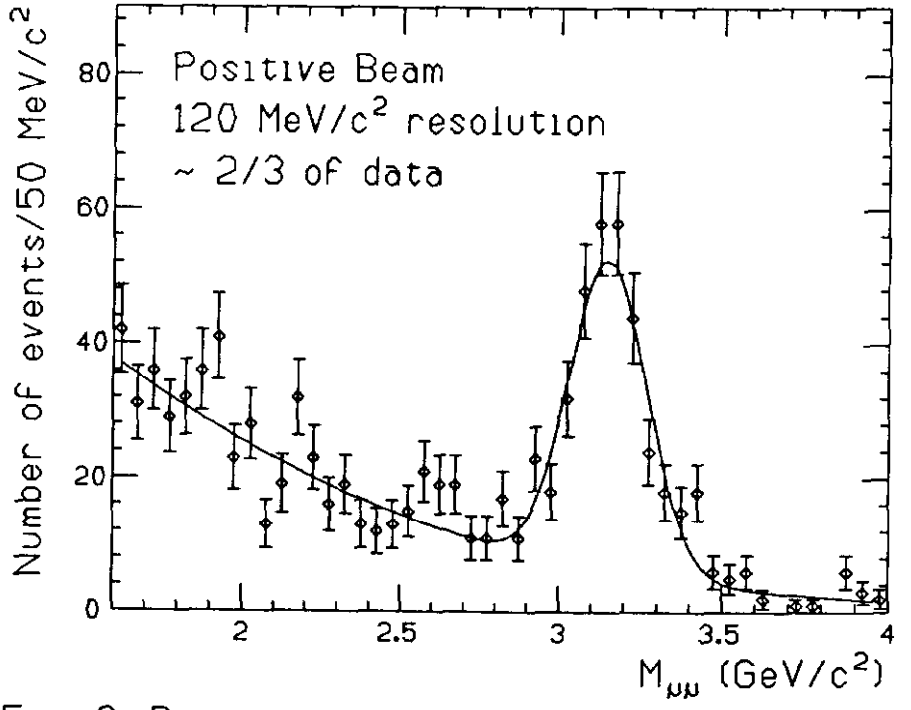

Fig. 3. Dimuon mass spectrum in the J/ψ Region
using combined E672/E706 detector

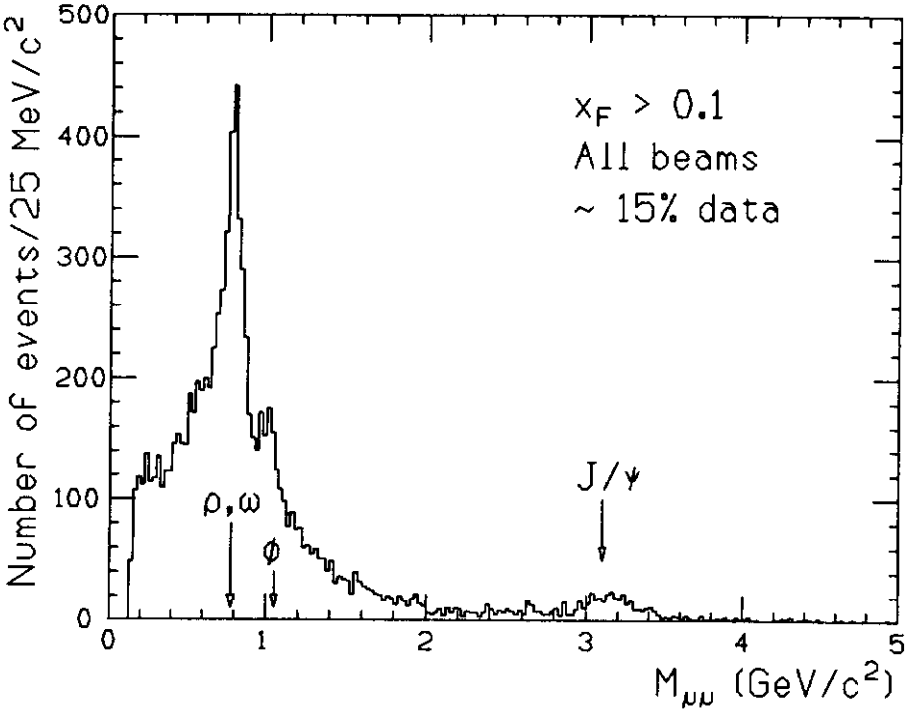

Fig. 4. The complete dimuon mass spectrum showing various vector meson resonances

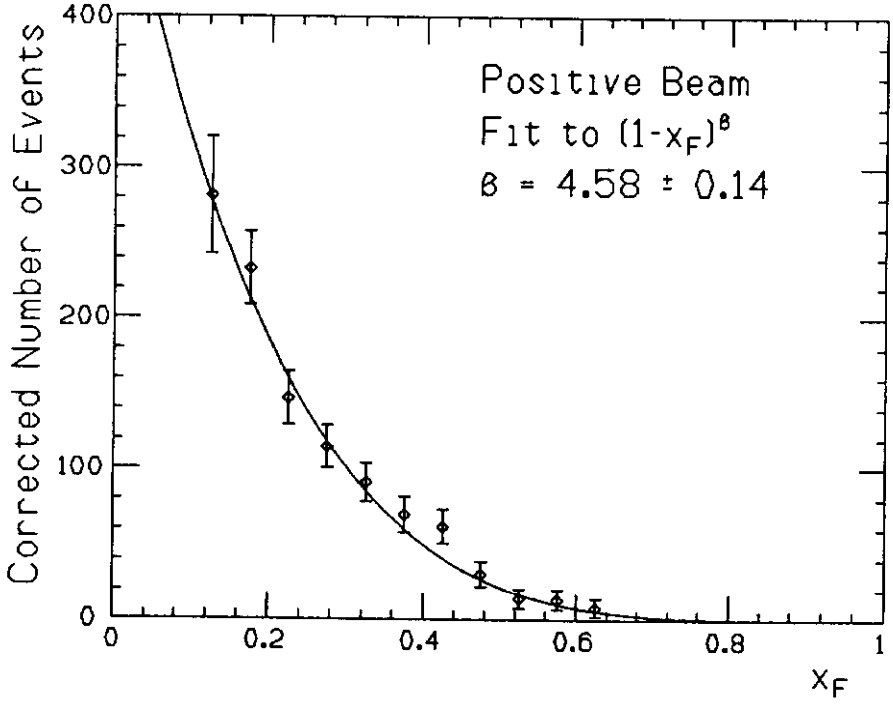

Fig. 5. x_F distribution in the J/ψ region

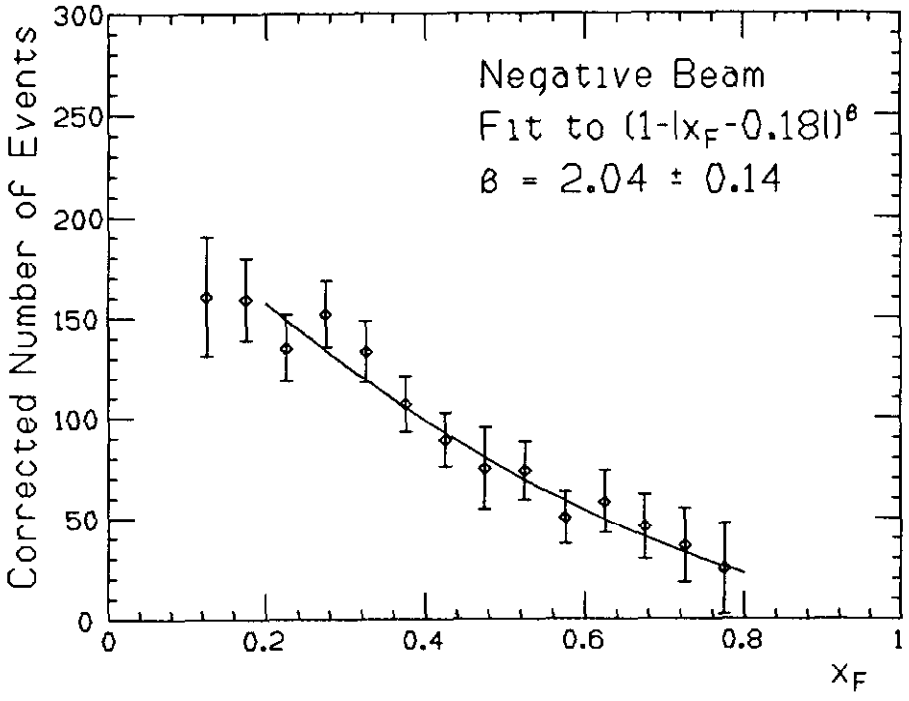

Fig. 6. x_F distribution in the J/ψ region

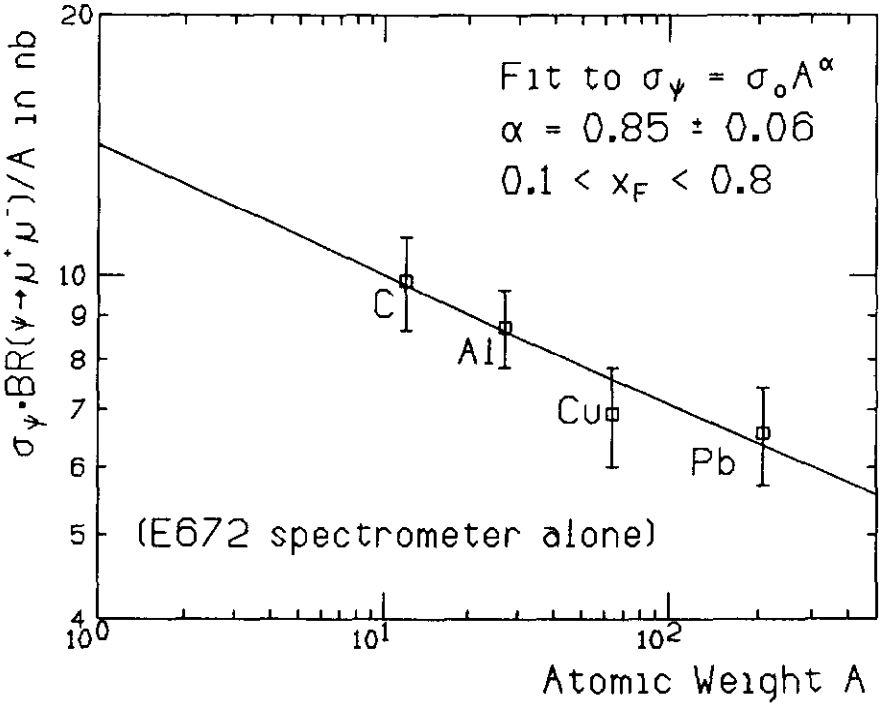

Fig. 7. The A-dependence of J/ψ Production

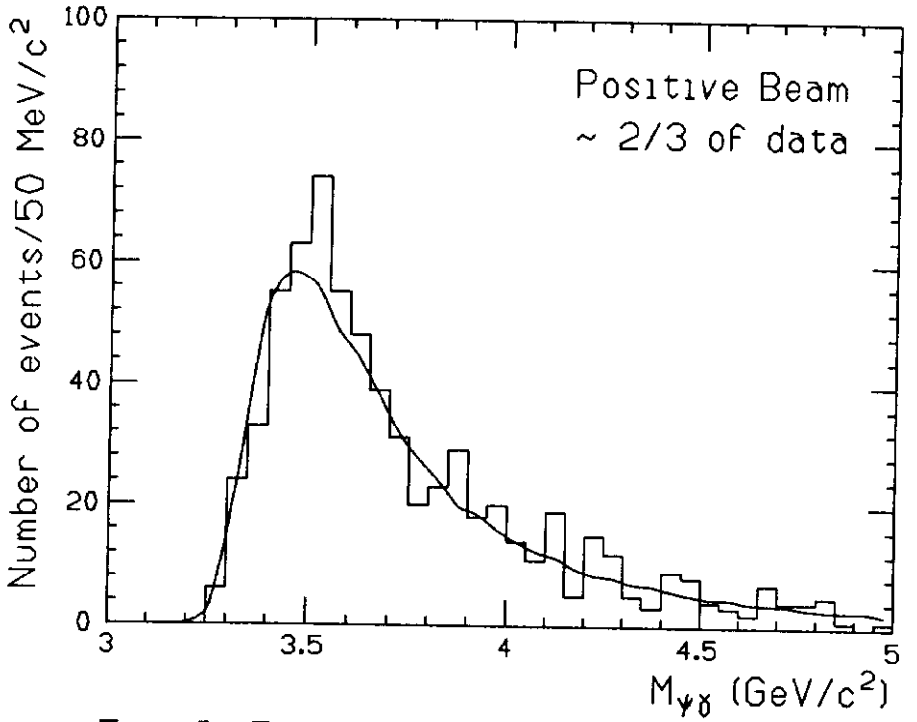

Fig. 8. The $\psi\gamma$ invariant mass spectrum (Solid curve is estimated background)

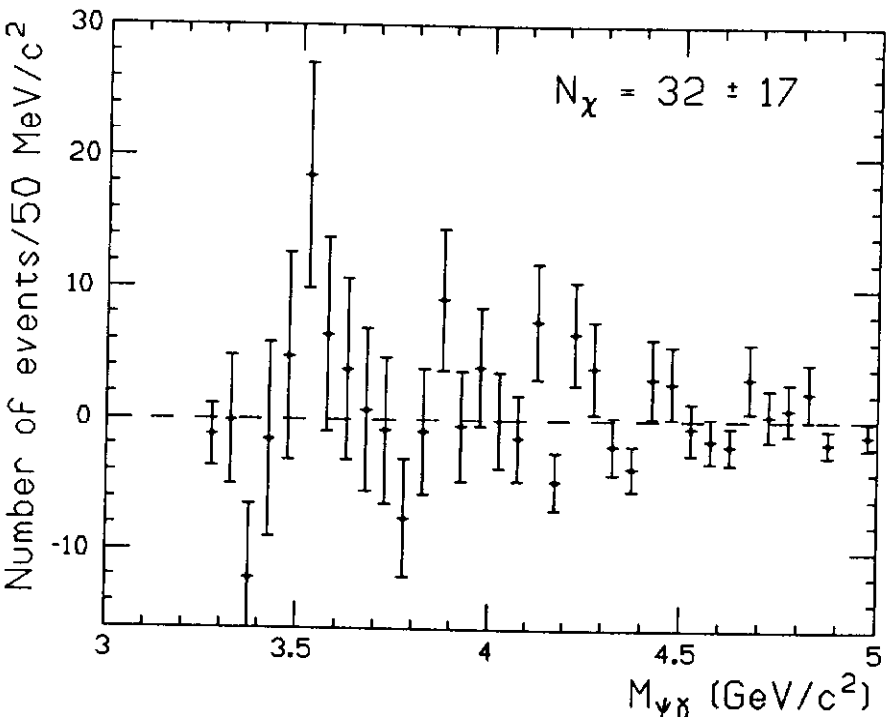

Fig. 9. Background subtracted $\psi\gamma$ invariant mass