DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 83-101
Oktober 1983

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by

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ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

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submitted to Physics Letters

Abstract

The reaction $e^+e^- \to \Upsilon' \to \Upsilon \pi^+\pi^-$, with $\Upsilon \to$ anything, has been measured using the ARGUS detector at DORIS. We obtain a mass difference $M(\Upsilon') - M(\Upsilon) = (562 \pm 3)$ MeV and a decay branching ratio $BR(\Upsilon' \to \Upsilon \pi^+\pi^-) = (17.9 \pm 0.9 \pm 2.1)\%$. The invariant mass spectrum of the $\pi^+\pi^-$ system differs from phase space, but is well described by a matrix element of the form $(M^2_{\pi\pi} - \lambda M^2_\pi)$ with $\lambda = 2.6 \pm 0.5$. We also report preliminary results on the exclusive decay $\Upsilon' \to \Upsilon \pi^+\pi^-$, with $\Upsilon \to e^+e^-$, and obtain $BR(\Upsilon \to e^+e^-) = (2.8 \pm 0.4 \pm 0.3)\%$.

We report here the first results obtained with the ARGUS detector at DORIS. ARGUS is a magnetic spectrometer consisting of a solenoid with a field of 0.8 T, a cylindrical drift chamber with 5940 sense wires arranged in 36 layers, a time-of-flight system with 64 scintillators in the barrel region and with 48 scintillators in each endcap, a shower detection system with 1280 lead-scintillator-sandwich counters in the barrel region and 240 in each endcap, and a muon identification system with 1744 proportional counter tubes. The spectrometer is shown schematically in Fig. 1, and details of its performance are given in Ref. 1.

The decay $\Upsilon'(10023) \to \pi^+\pi^- \Upsilon(9460)$ has been studied both theoretically and experimentally. The QCD description [2,3,4] of this process assumes that the excited $b\bar{b}$ system Υ' decays into the Υ state by the emission of two gluons in their lowest multipole state. This picture leads to a prediction for the invariant mass spectrum of the $\pi^+\pi^-$ system. Experimentally, the decay has been studied by two different methods. The first involves reconstruction of the secondary decays $\Upsilon \to e^+e^-$ and $\Upsilon \to \mu^+\mu^-$ with about 3% branching ratio each. The second method uses the missing mass spectrum of the $\pi^+\pi^-$ system which includes all secondary Υ decays and therefore increases the number of $\Upsilon' \to \Upsilon\pi\pi$ decays available for study by a factor of about 16.

Both methods have been used to determine the $\Upsilon' \to \Upsilon\pi^+\pi^-$ branching ratio [5,6,7]. Because of the high combinatorial background arising from the second method, only the first could be used to study the invariant $\pi\pi$ mass spectrum, but the data obtained was too limited for detailed tests. The good momentum resolution for charged particles in ARGUS, which presently is $\sigma(p)/p \approx 0.012 \sqrt{(1+p^2c^2/GeV^2)}$, allows us to apply the missing mass method for both the branching ratio and the invariant mass spectrum and to test the QCD prediction.

For this experiment, we have analyzed Υ' decays from a data sample with 13 events/pb and an off-resonance sample at 9.980 GeV with 1.6 events/pb. The events were collected requiring either one of three different triggers in coincidence with a bunch crossing signal :

1.) "E_{tot}", defined by an energy deposit of > 800 MeV in each of the two z-hemispheres (see Fig. 1) of the shower calorimeter,

2.) "$\geqslant$ 3 tracks", where each track is defined in two steps by a) a fast coincidence between groups of time-of-flight and shower counters, and b) a slow coincidence using track masks in the drift chamber. The shower counter information is used to require at least one track in each z-hemisphere. For the data sample analyzed here, all three tracks are required to lie in the barrel region with $|\cos\Theta| < 0.75$.

3.) "2 quasicollinear tracks", basically the same as trigger 2, except that events with only two tracks are accepted if these tracks differ in azimuth by more than 120°.

Typical trigger rates were 4 Hz, typical luminosities $10^{31}/cm^2/sec$. Multihadron events were selected off-line by requiring $\geqslant$ 4 reconstructed tracks in the drift chamber with an acceptable fit for five parameters Θ, φ, p_t, z_o and d_o. Θ and φ are polar and azimuthal angles, p_t is the transverse momentum, z_o is the z coordinate of the track's closest point to the z-axis, and d_o is the distance of this point to the z-axis. Cuts of $|z_o| < 8$ cm and $d_o < 1.5$ cm were applied to each track. This procedure yields 76825 multihadron events on the Υ' resonance and 5774 in the continuum at 9.98 GeV.

For the resonance events, $\pi^+\pi^-$ pairs are formed by combining all oppositely charged particles with $|\cos\Theta| < 0.90$ and $p_t > 80$ MeV/c. Energy loss in the beam tube and in the inner drift chamber wall is taken into account. The missing mass of each pair is calculated by assuming that the particles are

pions and that the Υ' is at rest with a mass of 10023.5 MeV [8,9]. The resulting distribution is shown in Fig. 2. We observe a prominent peak at the mass of the Υ, the FWHM of which is 7 MeV.

From the position of the peak, the Υ'-Υ mass difference is determined to be (562 ± 3) MeV. The error is purely systematic and arises mainly from the present uncertainty in the ARGUS magnetic field. The result agrees well with values from DORIS [10,11], CESR [12,13] and VEPP-4 [8] which were all obtained from beam energy measurements at the formation energies of the resonances. The results are compared in Table 1.

The number of entries in the peak determines the $\Upsilon' \to \Upsilon\pi^+\pi^-$ branching ratio. For this determination, we use a subsample of 7.48 events/pb, which contains N_r = 32084 selected multihadron events and 4637 entries in the 16 MeV wide missing mass range around the Υ peak. The combinatorial background under the peak is calculated from a third order polynomial fit to the mass spectrum on both sides of the peak. The fit gives 3111 ± 32 background entries, leaving $N_s(\Upsilon' \to \Upsilon\pi^+\pi^-) = 1526 \pm 75$ selected $\Upsilon' \to \Upsilon\pi^+\pi^-$ decays.

The evaluation of the branching ratio

$$BR(\Upsilon' \to \Upsilon\pi^+\pi^-) = \frac{N_s(\Upsilon' \to \Upsilon\pi^+\pi^-)/\eta(\Upsilon' \to \Upsilon\pi^+\pi^-)}{N_s(\Upsilon')/\eta(\Upsilon' \to \text{anything})}$$

requires the number of selected Υ' events, $N_s(\Upsilon')$, and the acceptance values η. $N_s(\Upsilon')$ is obtained from $N_s(\Upsilon') = N_r - N_c \cdot L_r/L_c$, where N_r was given above, N_c = 5774 is the number of selected multihadron events off resonance, and L_r/L_c is the ratio of the integrated luminosities on and off resonance. This ratio is obtained from Bhabha events in an angular range from 20 to 160 degrees. The contribution from τ pairs and two-photon reactions to N_r and N_c is not evaluated, since their cross sections are the same at the resonance and in the continuum. Beam-gas or beam-wall event contributions have been determined to be negligible from studies of separated beam runs. We obtain $N_s(\Upsilon') = 14615 \pm 310$.

The two acceptances are determined from a Monte Carlo calculation simulating detector performances, trigger conditions, event reconstruction and selection cuts. For the $\Upsilon' \to \Upsilon\pi^+\pi^-$ decays, the invariant $\pi\pi$ mass spectrum is generated according to phase space weighted by $(M_{\pi\pi}^2 - \lambda M^2)^2$, with $\lambda = 2$. This form is in agreement with our results as will be shown later. All decays are assumed to be isotropic. For the decays $\Upsilon' \to$ anything, we generate an appropriate mixture of e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ [14], ggg, $P_b\gamma$ [15] and $\Upsilon\pi\pi$ decays. The simulation gives $\eta(\Upsilon' \to \Upsilon\pi^+\pi^-) = 0.49$ and $\eta(\Upsilon' \to \text{anything}) = 0.84$ with systematic errors of ± 0.05 in both values.

We obtain $BR(\Upsilon' \to \Upsilon\pi^+\pi^-) = (17.9 \pm 0.9 \pm 2.1)\%$, where the first error is the statistical error in $N_s(\Upsilon' \to \Upsilon\pi^+\pi^-)$ including background subtraction, and the second error is systematic. The result is in good agreement with previous results as shown in Table 2.

All 76825 events on the Υ' resonance are used for a determination of the $\pi^+\pi^-$ invariant mass spectrum. For each pair of particles with opposite charges, fulfilling the above selection criteria, both the missing mass and the invariant mass are calculated. Missing mass spectra are plotted for 15 bins of the invariant mass, as shown in Fig. 3. The number of $\Upsilon' \to \Upsilon\pi^+\pi^-$ events in each missing mass spectrum is obtained in exactly the same way as was done for the branching ratio analysis. The result is shown in Fig. 4, where the errors are statistical only. The experimental resolution of the invariant mass is $\pm$ 4 MeV (RMS) as determined by the Monte Carlo simulation.
The $\pi\pi$ invariant mass spectrum in Fig. 4 is markedly different from the phase space distribution, shown by the dashed curve, but is similar to the spectrum found for the $\psi' \to J/\psi\, \pi^+\pi^-$ decay [16]. This similarity indicates that the theoretical methods [17,2,3,4] developed for describing ψ' decays are also applicable to Υ' decays. The QCD motivated models of Yan [2], Voloshin-Zakharov [3] and Novikov-Shifman [4] lead to very similar predictions for the $\pi\pi$ mass spectrum. We have compared these three parametrizations to our data, and all fit the data equally well as shown in Table 3. The solid curve in Fig. 4 represents the three best fits, since they are equal within the drawing precision. We conclude, that QCD describes the $\Upsilon' \to \Upsilon\pi\pi$ decay correctly, that there are differences between Υ' and ψ' decays (the latter preferring $\lambda \approx 4$), and that the $\pi\pi$ resonance description for ψ' decays [18] is not valid for Υ' decays.

Finally, we add a preliminary result obtained from the study of the exclusive decays $\Upsilon' \to \Upsilon\pi^+\pi^-$, $\Upsilon \to e^+e^-$. Using the Υ' subsample with 4.78 events/pb, we find 41 such exclusive events. The selection criteria for the pions have been described above, electrons are selected by comparing their momentum in the drift chamber to their energy in the shower counters. In order to minimize rejection due to radiation of the electrons, only a soft cut of $p(e^\pm) > 1.5$ GeV/c has been applied. The Monte Carlo simulation gives an acceptance of 0.51 ± 0.05 for the selected $\Upsilon' \to \pi^+\pi^-e^+e^-$ events. From these results and from our value for $BR(\Upsilon' \to \Upsilon\pi^+\pi^-)$, we obtain the electronic branching ratio of the Υ(9460) meson, $BR(\Upsilon \to e^+e^-) = (2.8 \pm 0.4 \pm 0.3)\%$, where the first error is statistical and the second error is systematic. Table 4 compares our result to earlier results. The derived world average is in good agreement with the average [21] for $BR(\Upsilon \to \mu^+\mu^-)$, $(2.7 \pm 0.4)\%$, thus confirming lepton universality in Υ decay.

Acknowledgements

We gratefully acknowledge the skillful and enthusiastic help of many engineers and technicians at DESY, Dortmund, Heidelberg and Moscow during the construction and start-up of the ARGUS detector. We thank Drs. K. Wille, H. Nesemann and the DORIS group for their efficient operation of the storage ring.
Also the continuous support of the DESY directorate with Profs. H. Schopper, G. Weber, E. Lohrmann, V. Soergel, P. Soeding and G.A. Voss was essential for our project. We thank Mrs. U. Djuanda for her assistance in processing the data. The Dortmund and Heidelberg groups acknowledge financial support from the Bundesministerium für Forschung und Technologie. The Canadian group acknowledges support from IPP and NSERC, Canada. The University of Kansas group was supported in part by the National Science Foundation, and thanks the University for a Faculty Research Improvement Award.
The Lund group acknowledges financial support from the Swedish Research Council. The South Carolina group was supported by the U.S. Department of Energy, Office of Energy Research, under contract No. DE-AS09-80ER10690.

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FIGURE CAPTIONS :

Fig. 1 Schematic view of the ARGUS detector. 1 = Muon chambers, 2 = shower counters, 3 = Drift chamber, 4 = Time-of-flight counters, 5 = Mini beta quadrupoles, 6 = Iron yoke, 7 = Solenoid coils, 8 = Compensation coils.

Fig. 2 Missing mass spectrum of the $\pi^+\pi^-$ combinations from 76825 selected events on the Υ' resonance assuming an Υ' mass of 10023.5 MeV.

Fig. 3 Missing mass spectra of the $\pi^+\pi^-$ combinations for 20 MeV wide bins of the invariant mass of these $\pi^+\pi^-$ combinations.

Fig. 4 Invariant mass spectrum of the $\pi^+\pi^-$ system from 4200 selected decays $\Upsilon' \to \Upsilon\,\pi^+\pi^-$, $\Upsilon \to$ anything, corrected for the weakly mass-dependent acceptance. The dashed curve is the phase space expectation, the solid curve corresponds to the three best fits of the QCD parametrizations given in Table 3. Both curves are normalized to the total number of events.

TABLE 1

The mass difference m(Υ') - m(Υ) as determined by different experiments (in MeV).

DASP-2 [10]	556 ± 10
LENA [11]	560 ± 10
CLEO [12]	560 ± 0.8 ± 3.0
CUSB [13]	559 ± 1 ± 3
VEPP-4 [8]	563.2 ± 0.6
this experiment	562 ± 3

TABLE 2

The branching ratio of the decay $\Upsilon' \to \Upsilon\, \pi^+\pi^-$ as determined by different experiments (in percent).

LENA [5]	19 ± 8
CUSB [6]	20 ± 7
CLEO [7]	19.1 ± 3.1 ± 2.9
this experiment	17.9 ± 0.9 ± 2.1

TABLE 3

The fit of three different QCD parametrizations to the $\pi\pi$ invariant mass spectrum in the $\Upsilon' \to \Upsilon\, \pi^+\pi^-$ decay.

	Rate / Phase Space	χ^2(NDF=13)	Result
Yan [2]	$(M_{\pi\pi}^2 - 2\,M_\pi^2)^2$ $+ \frac{1}{3}\frac{B}{A}\,(M_{\pi\pi}^2 - 2\,M_\pi^2)$ $\cdot\,[(M_{\pi\pi}^2 - 4\,M_\pi^2) + 2(M_{\pi\pi}^2 + 2M_\pi^2)K_o^2/M_{\pi\pi}^2]$ $+\, o\,(B^2/A^2)$, $(K_o = (M_{\Upsilon'}^2 + M_{\pi\pi}^2 - M_\Upsilon^2)/2M_{\Upsilon'})$	18.6	B/A = -0.09 ± 0.07
Voloshin-Zakharov [3]	$(M_{\pi\pi}^2 - \lambda\,M_\pi^2)^2$	18.5	λ = 2.6±0.5
Novikov-Shifman [4]	$[M_{\pi\pi}^2 - \varkappa(M_{\Upsilon'} - M_\Upsilon)^2$ $\cdot\,(1 + 2M_\pi^2/M_{\pi\pi}^2)]^2 + o\,(\varkappa^2)$	19.0	$\varkappa$ = 0.12±0.02

TABLE 4

The branching ratio of the decay $\Upsilon(9.46) \to e^+e^-$ as determined by different experiments (in percent)

PLUTO [19]	5.1 ± 3.0
LENA, CUSB, CLEO [20]	3.5 ± 0.8
this experiment	2.8 ± 0.4 ± 0.3
average	3.0 ± 0.4

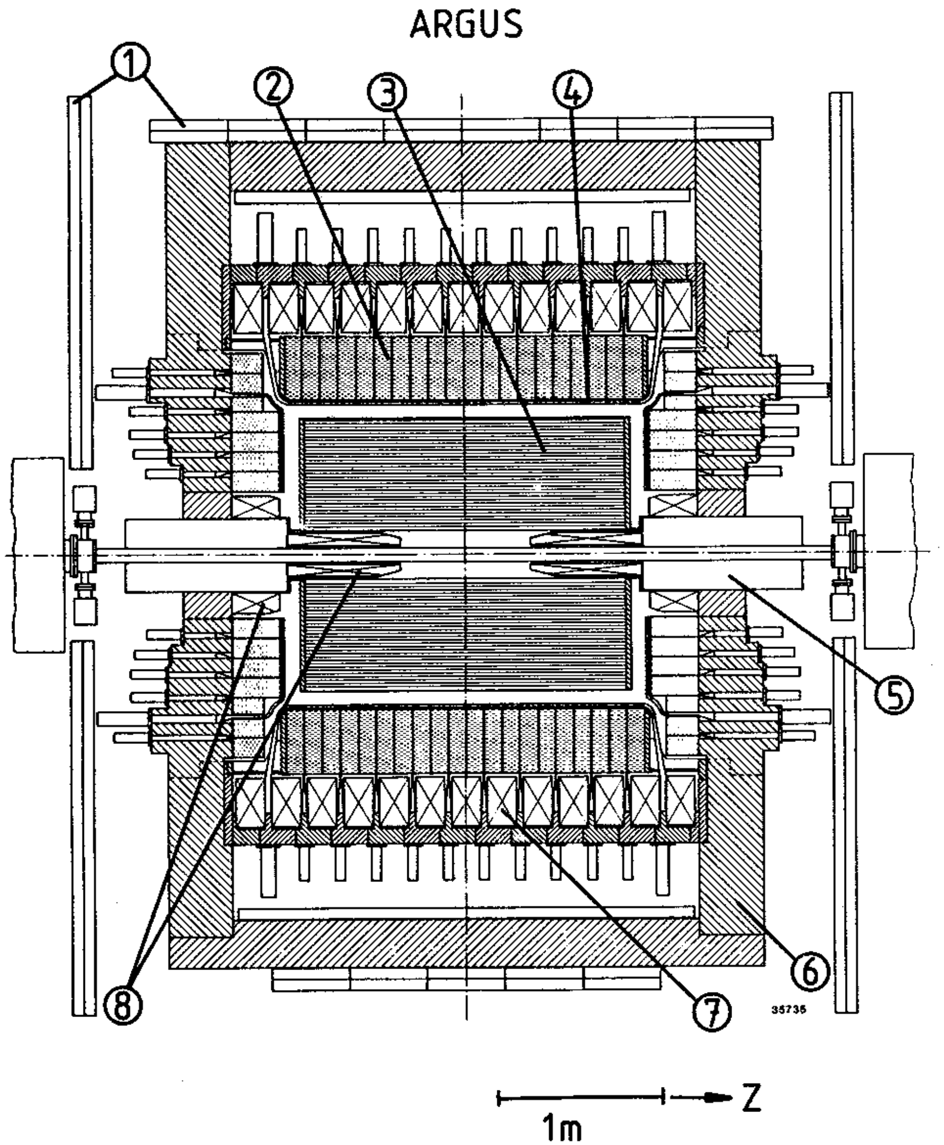
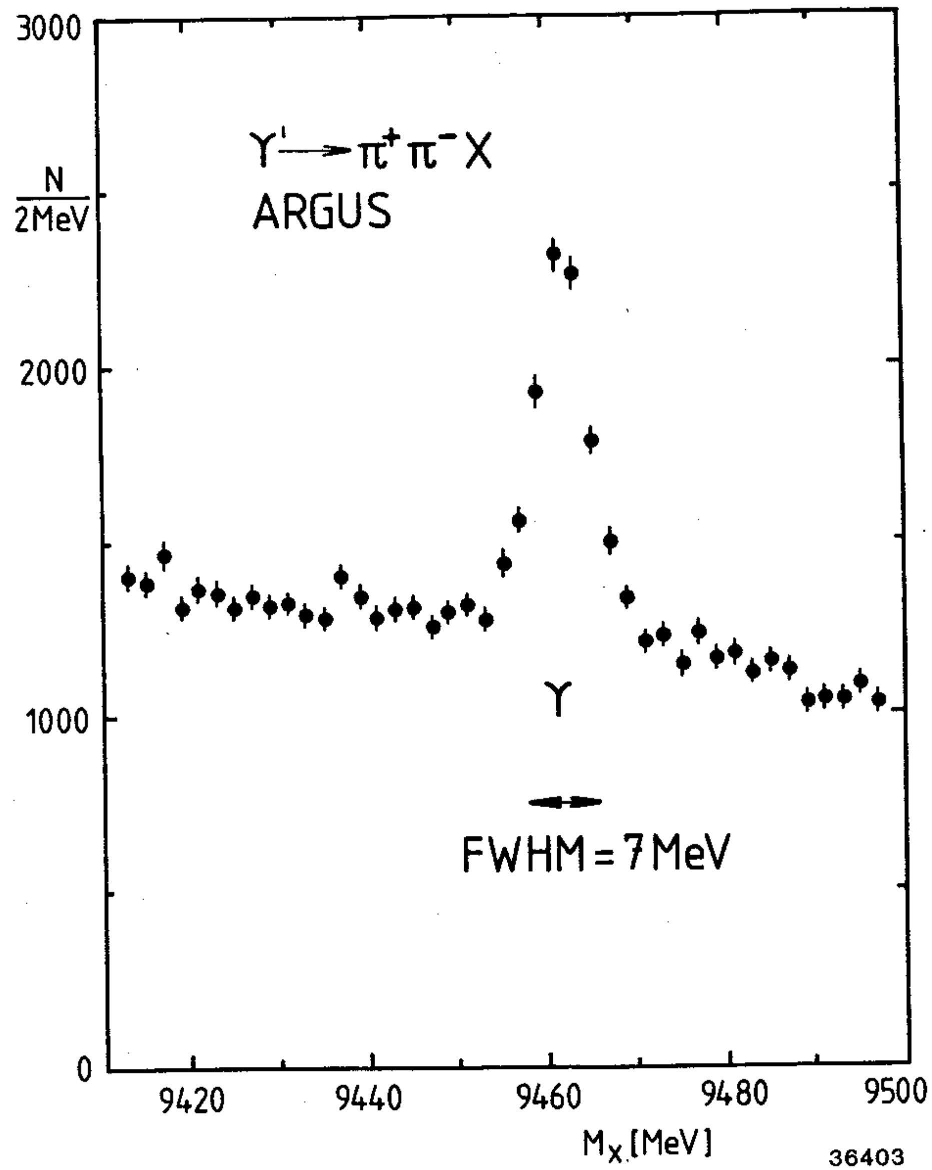

ARGUS
1
2
3
4
5
6
7
8
35735
1m
Z

Fig. 1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ARGUS
N/2MeV
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2000
1000
0
Υ
FWHM = 7 MeV
9420
9440
9460
9480
9500
Mx [MeV]
36403

Fig. 2

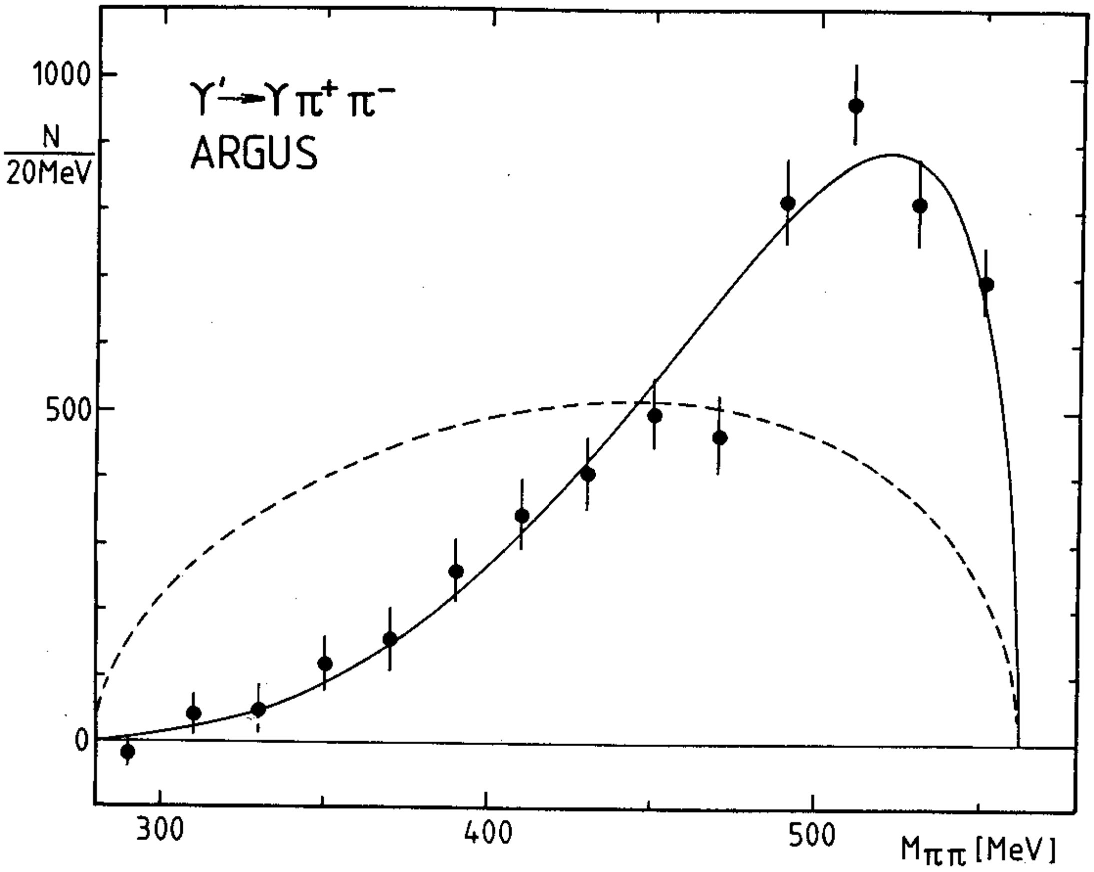
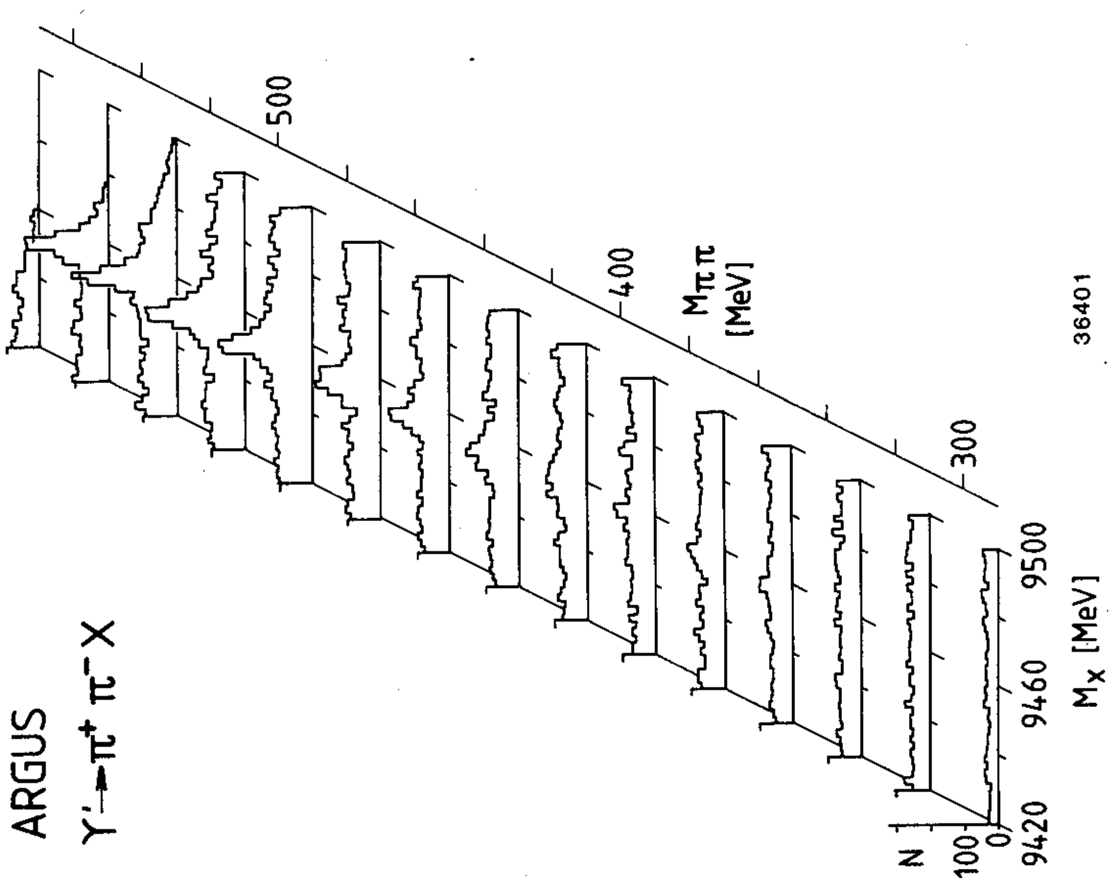


Fig. 4 36402



36401

Fig. 3