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**HADRONS AND GAMMAS ASSOCIATED  
TO DIMUONS AND  $J/\psi$  PARTICLES  
IN  $\pi^-C$  INTERACTIONS AT 38 GeV/c**

**RISK Collaboration**

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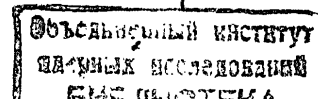
In this letter the preliminary results concerning the  $J/\psi$  production in the reaction

$$\pi^- {}^{12}\text{C} \rightarrow J/\psi + X,$$

which have been based on a part of total statistics and rough estimations of fraction of  $J/\psi$ 's resulting from radiative decay of the  $\chi$  and from decays of  $\psi'$  particles, are reported.

Several results exist for  $\chi_1(3510)$  and  $\chi_2(3555)$  production in  $\pi^-$  hydrogen and  $\pi^-$  beryllium interactions at energies  $\sim 200 \text{ GeV}^{1-7/}$  ( $M_\chi/\sqrt{s} \sim 0.2$ ,  $\sqrt{s}$  is the total energy in CMS) and the sole result has been obtained in the near threshold energy region at  $38 \text{ GeV}^{8/}$  ( $M_\chi/\sqrt{s} \sim 0.43$ ). As usual, only the sum of cross sections of  $\chi_1$  and  $\chi_2$  was measured since both high mass resolution of  $\gamma J/\psi$  system and high statistics are needed to separate  $\chi_1$  and  $\chi_2$ . Solely in recent experiments at 190 GeV and 225 GeV, the ratio of cross sections  $\sigma(\chi_1)/\sigma(\chi_2)$  has been established as  $(0.78 \pm 0.21)^{5/}$ ,  $(1.1 \pm 0.4)^{6/}$  and  $(0.96 \pm 0.64)^{7/}$ . Results of experiments<sup>1-8/</sup> for the fraction of  $J/\psi$ 's produced via  $\chi$ -states are summarized in the Table.

Another source of indirectly produced  $J/\psi$ 's is  $\psi'(3685)$  particle with  $\sim 56\%$  of its decays leading to final states containing the  $J/\psi$ . The measured cross section ratio of  $\sigma(\psi')/\sigma(\psi)$  at energies  $\sim 40 \text{ GeV}$  are contradictory. The SIGMA spectrometer<sup>9/</sup> reported the value of  $\sigma(\psi')/\sigma(\psi) = (0.14 \pm 0.05)$  for  $\pi^- \text{Cu}$  interactions at 50 GeV and OMEGA group<sup>10,11/</sup> received this value to be equal to  $(0.9 \pm 0.4)$  and  $(0.32 \pm 0.11)$  in  $\pi^- \text{p}$  and  $\pi^- \text{W}$ -interactions at 39.5 GeV, respectively.



T a b l e .

The fraction of  $J/\Psi$ 's produced via  $\chi$  states in the  $x_F > x_{Fmin}$  region at total CMS energy  $\sqrt{s}$ .

Interaction	$\sqrt{s}$ (GeV)	$x_{Fmin}$	Fraction	Ref.
$\pi^-p$	18	0.2	$0.11 \pm 0.04$	/1/
$\pi^-p$	20	0.45	$0.70 \pm 0.28$	/2/
$\pi^-P$	18	0.2	$0.36 \pm 0.05$	/3/
$\pi^-Be$	18	0.	$0.305 \pm 0.05$	/5/
$\pi^-Be$	20.4	0.	$0.37 \pm 0.09$	/6/
$\pi^-Be$	18	0.	$0.31 \pm 0.10$	/7/
$\pi^-p$	8.7	0.4	$0.44 \pm 0.21$	/8/

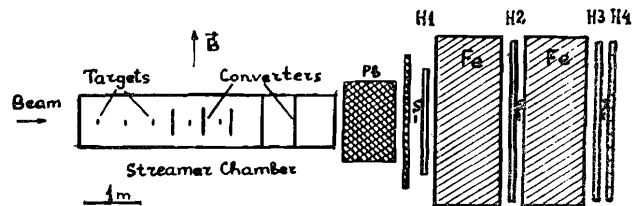


Fig. 1. Side view of apparatus: S - veto counters, H1, H2, H3 - vertical hodoscopes, H4 - horizontal hodoscope.

Thus, one can conclude that questions concerning the production of  $\Psi'$  and  $\chi$  states in near-threshold region of energies are still open.

The experiment was performed in IHEP Serpukhov, using an unseparated beam of negatively charged particles with momentum of 38 GeV/c and  $\Delta p/p = 1.5\%$ . A beam telescope consisted of six scintillation counters and four threshold Cerenkov counters. The composition of the beam was found to be  $\pi^- : K^- : \bar{p} = 100 : 1.8 : 0.3$ .

An apparatus for a detection of dimuon events is shown in Fig. 1. The central device of the spectrometer was a three gap streamer chamber (4.7 x 0.9 x 0.8) /12/. The chamber was filled with a neon-helium gas mixture (70%Ne/ 30%He) with the addition of isobutane and it worked at atmospheric pressure. Five carbon targets were placed in the chamber along the beam direction. The thickness of each target corresponds to 5% of pion absorption length and to 12% of radiation length. Lead glass converters in the chamber (~ 20% of radiation length each) were used for  $\gamma$ -detection.

A telescope for the muon pair detection consisted of 4 scintillation hodoscopes and 3 hadron absorbers. The 80 cm thick lead wall having an opening for the beam was placed behind the end of a streamer chamber. Next two iron absorbers had the thickness of 1.5 m each. All that determined an energy threshold of penetrating muons to the value of 5.3 GeV.

Vertical hodoscopes H1, H2 and H3 having sizes of  $2 \times 2 \text{ m}^2$ ,  $3 \times 3 \text{ m}^2$  and  $3 \times 3 \text{ m}^2$ , respectively, made from glass tubes of 32 mm in diameter filled by liquid scintillator (white spirit).

An arrangement of glass tubes in two planes in the hodoscope allowed to reach the space resolution of  $\sim 1.5$  cm and the  $\sim 100\%$  detection efficiency of relativistic particles<sup>/13/</sup>. Plastic scintillator counters 1.1 m long and (15-22) cm wide were used in the horizontal hodoscope H4.

Fast processor analyzed pulses coming from hodoscopes, beam telescope and veto counters and selected  $\mu\mu$ -candidates according to a set of trigger criteria<sup>/14/</sup>. In such a way, the number of triggers of a streamer chamber was reduced to one/pulse at beam intensities of  $(1. - 1.5) \times 10^6$  particles per second.

An off-line analysis of the trigger information gave the possibility of reconstructing muon trajectory in hodoscopes and to estimate a coordinate and an angle of muon track in the streamer chamber picture. The events satisfying the software trigger conditions were scanned and measured with the aim to select real  $\mu^+\mu^-$ -events produced in the target. After this procedure, in the case of positive solution all secondary tracks were measured including strange particles ( $K_s^0$ ,  $\Lambda^0$ ) and  $e^+e^-$ -pairs of  $\gamma$ -conversion.

To estimate the nonprompt background contamination ( $\pi \rightarrow \mu\nu$  decay) remaining in the dimuon sample we have analyzed measured events of  $\pi$ -C interactions in pictures from the 2 m propane bubble chamber of IVE-JINR. It has been calculated using Monte-Carlo simulations that (with use of the hardware, software and film processing criteria) the background does not exceed  $\sim 8\%$  and makes the contribution into the region of the invariant mass of dimuons  $\lesssim 1.5$  GeV/c<sup>2</sup>.

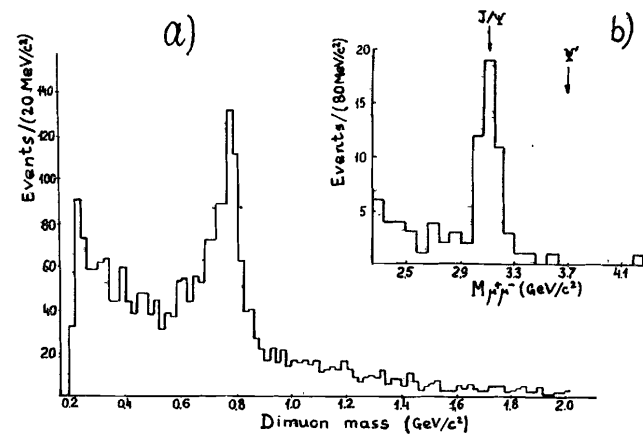


Fig. 2. Invariant dimuon mass distribution: a)  $M_{\mu^+\mu^-} \leq 2$  GeV/c<sup>2</sup>, b)  $M_{\mu^+\mu^-}$  in  $J/\psi$  region.

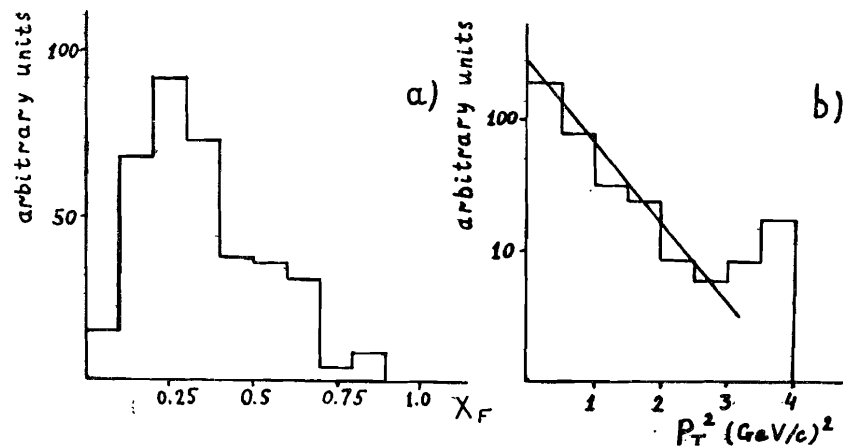


Fig. 3. a) Weighted  $x_F$  spectrum and b)  $P_T^2$  distribution of  $J/\psi$  particles. Full line  $\sim \exp(-1.4 P_T^2)$ .

Fig. 2 shows the invariant mass distribution of dimuons without taking into account the acceptance of the set-up. It should be pointed out that we concentrated our interest on the  $J/\Psi$  region in the first stage of analysis. It explains a relative decrease of number of  $M_{\mu\mu} \lesssim 0.6 \text{ GeV}/c^2$  events. Nevertheless, the presented mass spectrum agrees in the main features with the results of other experiments, e.g. /15,16/.

A clear peak of  $J/\Psi$  particles with the mean mass value  $\langle M_{J/\Psi} \rangle = (3.10 \pm 0.01) \text{ GeV}/c^2$  and with  $\sigma \approx 0.07 \text{ GeV}/c^2$  is observed in the invariant mass distribution of dimuons in the region  $M_{\mu\mu} > 2.2 \text{ GeV}/c^2$ . The background under the peak was estimated to the value  $\sim 10\%$ . The longitudinal momentum distribution (fig. 3a) in the  $J/\Psi$  peak (corrected for the acceptance of the set-up) with well dominated maximum in the region  $x_F \sim 0.3$  agrees by the form with the similar distribution obtained in papers /17,18/. The  $p_T^2$  distribution of  $J/\Psi$  particles (fig.3b) for  $x_F > 0.05$  may be described by an exponential behaviour  $\sim \exp(-1.4 p_T^2)$  in agreement with previous papers /17,18/ examining the same interval of  $x_F$ . The acceptance of the apparatus for the  $J/\Psi \rightarrow \mu^+\mu^-$  decay mode was calculated assuming the isotropic angle distribution in  $J/\Psi$  rest frame. The average detection efficiency of  $J/\Psi$  particles having  $x_F > 0$  equals to  $\langle \epsilon \rangle = 11\%$  and  $\epsilon$  increases with  $x_F$  and weakly depends on  $p_T$ .

A search for the radiative decay of the  $\chi$  has been performed in the mass spectrum of the  $\gamma J/\Psi$  system (fig. 4a). First of all one must reject all  $\gamma J/\Psi$  events containing a photon which in the combination with any other photon gives

Fig. 4. Invariant mass spectrum of  $\gamma J/\Psi$  system. Shaded area corresponds to events containing  $\Upsilon$ 's with  $p_T > 0.2 \text{ GeV}/c$ ; a) all  $\gamma J/\Psi$ 's with registered  $\Upsilon$ 's, b) after the subtraction of events with reconstructed  $\Upsilon^0$  meson ( $0.09 < M_{\Upsilon\gamma} < 0.18 \text{ GeV}/c^2$ ).

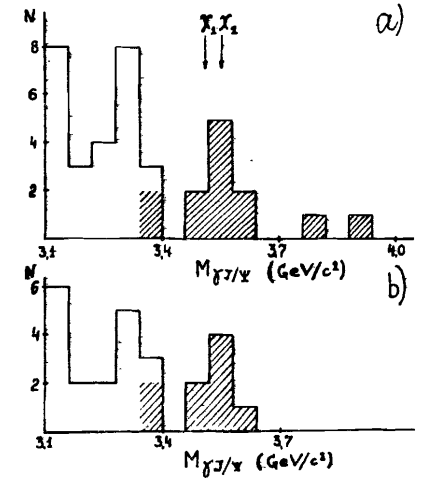
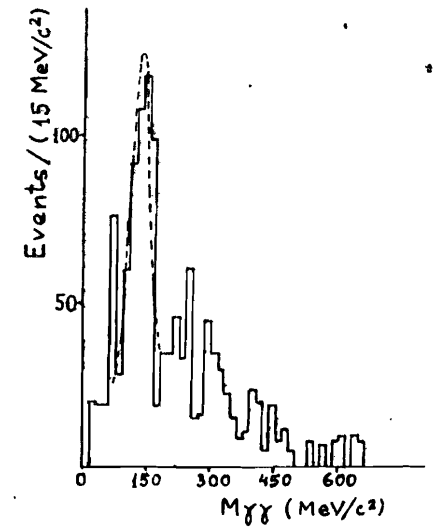


Fig. 5. Weighted mass distribution of two photons (over all dimuon mass range). Dashed line - gaussian fit with  $\langle M_{\gamma\gamma} \rangle = 131 \text{ MeV}/c^2$  and  $\sigma \approx 18 \text{ MeV}/c^2$ .



the effective mass in the  $\pi^0$  or  $\eta^0$  mass regions. The effective mass distribution of two gammas over all dimuon masses, taking into account the efficiency of the  $\gamma$ -detection in the streamer chamber ( $\sim 37\%$ ) is demonstrated in fig.5. The peak in  $\pi^0$  mass region is well reproduced using gaussian distribution with  $\langle M_{\gamma\gamma} \rangle = 131 \text{ MeV}/c^2$  and  $\sigma = 18 \text{ MeV}/c^2$  and, therefore, the events in the interval of  $90 < M_{\gamma\gamma} < 180 \text{ MeV}/c^2$  are interpreted as  $\pi^0$  mesons. The invariant mass distribution of the  $\gamma J/\psi$  system when  $\gamma$ 's produced via  $\pi^0$  decay have been subtracted is shown in fig.4b. There were no events in the  $\eta^0$  mass region.

The  $p_T^2$  distribution and energy spectrum of gammas accompanying the  $J/\psi$ 's are displayed in fig. 6a and 6b. One can see a pronounced maximum in fig.6a in the region of  $p_T^2 < 0.02 \text{ (GeV}/c)^2$  which is attributed to events with only one detected photon from  $\pi^0 \rightarrow \gamma\gamma$  decay.

A Monte-Carlo calculation of the  $\chi$  radiative decay has shown that in  $\sim 90\%$  of events the  $\chi$  produces a photon with  $p_T > 0.2 \text{ GeV}/c$  (see fig. 6c). Therefore, our main selection rule for the  $\chi$  states is a cut on  $p_T(\gamma) > 0.2 \text{ GeV}/c$  in contrast to the paper<sup>/8/</sup>, where the  $E_\gamma > 2 \text{ GeV}$  selection criterion has been used (see fig. 6b, 6d). The shaded area in fig. 4a,b and 6b corresponds to the  $\gamma J/\psi$  system containing the photon with  $p_T > 0.2 \text{ GeV}/c$ . One can see an accumulation of seven events between  $3.46$  and  $3.64 \text{ GeV}/c^2$  in fig.4b that could be attributed to the  $\chi_1$  and  $\chi_2$  decays and two background events at mass  $\sim 3.37 \text{ GeV}/c^2$ . The transverse momentum and energy distributions of gammas produced in these seven events are in

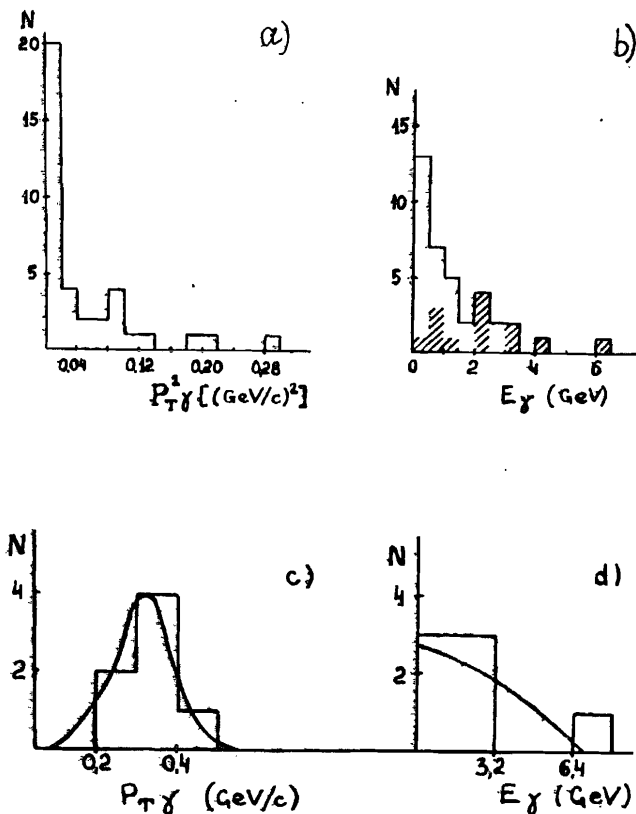


Fig. 6. Spectra of  $\gamma$ 's accompanying  $J/\psi$  particles: a)  $p_T^2$  distribution, b) energy distribution, shaded area corresponds to  $\gamma$ 's having  $p_T > 0.2 \text{ GeV}/c$ , c)  $p_T$  distribution and, d) energy spectrum of  $\gamma$ 's with the  $\gamma J/\psi$  mass between  $3.46 \text{ GeV}/c^2$  and  $3.64 \text{ GeV}/c^2$ . Full lines - result of Monte-Carlo calculation of  $\chi \rightarrow \gamma J/\psi$  decay.

fair agreement with calculated ones (fig. 6c,d). Preliminary Monte-Carlo examination has shown that one can expect about 1 background event in the  $\chi$  mass region. Taking into account the acceptance of the apparatus and detection efficiency of  $\gamma$ 's, the fraction of  $J/\psi$  particles produced via radiative decay of  $\chi_1$  and  $\chi_2$  states is estimated to be  $(0.5 \pm 0.3)$  (without subtraction of one possible background event).

Thus, assuming  $\sigma(\chi_1) \simeq \sigma(\chi_2)$  one can conclude that  $\sigma(\chi)$  is perhaps somewhat higher ( $\sim 2.5$  times) than a cross section of prompt  $J/\psi$  production. This conclusion is in agreement with the result at  $E_{\pi^-} = 38 \text{ GeV}^{/8/}$ , which was obtained using different experimental technique and also with results of investigations at higher energies<sup>/5-7/</sup> (see Table 1).

As mentioned above, the values of the cross section ratio  $\sigma(\Psi')/\sigma(\Psi)$  measured in<sup>/9-11/</sup> are contradictory. In these experiments the  $\Psi'$  was detected via  $\mu\mu$  decay contrary to our experiment where due to measurement of momenta of all particles associated to  $J/\psi$  it could be possible to detect the  $\Psi'$  in  $\pi^+\pi^- J/\psi$  decay mode. A yield of the  $\Psi'$  events in the latter case is about three times greater than in the former one. If one takes the result of paper<sup>/9/</sup> as an estimation of  $\sigma(\Psi')/\sigma(\Psi)$  then about two  $\Psi' \rightarrow \pi^+\pi^- J/\psi$  events would be expected in our experimental sample and the result<sup>/11/</sup> predicts  $\sim 13$  such events. These estimates have been done under the assumption that  $d\sigma/(dx_F dp_T)$  has the same behaviour for  $J/\psi$  and  $\Psi'$  particles.

The invariant mass distribution of  $\pi^+\pi^- J/\psi$  system is displayed in fig.7. There is a lack of any remarkable enhancement

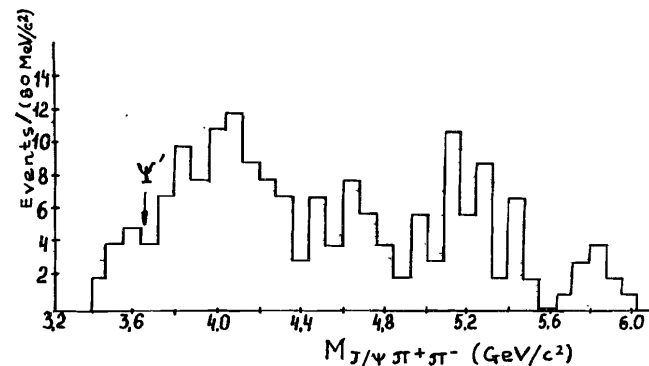


Fig. 7. Invariant mass distribution of  $\pi^+\pi^- J/\psi$  system.

above background in the  $\Psi'$  mass region. Moreover, one can see at most one event of  $\Psi' \rightarrow \mu^+\mu^-$  decay in fig.2b. These results together with a good mass resolution in a streamer chamber ( $\sigma \sim 40 \text{ MeV}/c^2$  for  $\pi^+\pi^- J/\psi$  system) allow to make a deduction that our data prefer the cross section ratio  $\sigma(\Psi')/\sigma(\Psi)$  obtained by SIGMA spectrometer<sup>/9/</sup>.

In conclusion, a streamer chamber is a useful experimental technique for the investigation of hadron and  $\gamma$ -accompanying of dimuons. The fraction of  $J/\psi$ 's resulting from radiative decay of  $\chi$  states has been estimated to  $(0.5 \pm 0.3)$  in the  $x_F > 0.05$  region. An investigation of the  $\pi^+\pi^- J/\psi$  mass spectrum has confirmed the result<sup>/9/</sup> obtained for the cross section ratio  $\sigma(\Psi')/\sigma(\Psi)$ .

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Адронное и  $\gamma$ -сопровождение прямых димюонов  
и  $J/\Psi$ -частиц, образовавшихся в  $\pi^-C$ -взаимодействиях при 38 ГэВ/с

На спектрометре РИСК (5-метровая стримерная камера, помещенная в магнитное поле) изучалось адронное и  $\gamma$ -сопровождение прямых мюонных пар в  $\pi^-C$ -взаимодействиях при 38 ГэВ/с. Представлены результаты по рождению  $J/\Psi$ -частиц в реакции  $\pi^-C \rightarrow J/\Psi + X$ . Распределение  $J/\Psi$  по продольному импульсу с учетом акцептанса  $L \rightarrow \mu^+\mu^-$

установки имеет максимум в области  $x_T \approx 0,3$ . Поведение  $J/\Psi$ -мезонов в зависимости от квадрата поперечного импульса хорошо описывается экспоненциальной кривой  $\sim \exp(-1,4p_T^2)$ . Измерены импульсные и угловые характеристики  $\gamma$ -квантов. В спектре эффективных масс  $2\mu$  наблюдается пик в области  $\pi^0$ -мезона. Сделана оценка вклада в образование  $J/\Psi$ -частиц радиационной моды распада  $\chi_c \rightarrow \gamma J/\Psi$  ( $0,5 \pm 0,3$ ). Использование канала  $\Psi' \rightarrow J/\Psi \pi^+\pi^-$  для определения отношения сечений рождения  $\sigma(\Psi')/\sigma(\Psi)$  показало согласие с данными, полученными на спектрометре СИГМА и разногласие с результатами установки ОМЕГА.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Hadrons and Gammas Associated to Dimuons and  $J/\Psi$  Particles  
in  $\pi^-C$  Interactions at 38 GeV/c

A study of dimuon's production in  $\pi^-C$  interactions has been performed with the 5 m streamer chamber of the spectrometer RISK-JINR at the accelerator U-70 of IHEP (Serpukhov). A contribution to the production of  $J/\Psi$ -particles from the radiative decay  $\chi_c \rightarrow J/\Psi \gamma$  has been estimated to  $(0,5 \pm 0,3)$  and an evaluation of the  $\Psi'$  production from  $\Psi' \rightarrow \pi^+\pi^- J/\Psi$  decay mode has been obtained being in agreement with the result reported by SIGMA spectrometer's group.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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