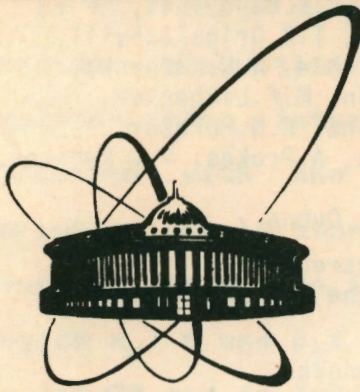


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**$\phi$ -MESON PRODUCTION IN NEUTRON-NUCLEUS  
INTERACTIONS AT 30-70 GeV**

**BIS-2 Collaboration**

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A.N.Aleev, V.A.Arefiev, V.P.Balandin, V.K.Berdyshev,  
V.K.Birulev, A.S.Chvyrov, I.I.Evsikov, T.S.Grigalashvili,  
B.N.Gus'kov, I.M.Ivanchenko, M.N.Kapishin, N.N.Karpenko,  
D.A.Kirillov, I.G.Kosarev, N.A.Kuz'min, M.F.Likhachev,  
A.L.Lyubimov, A.N.Maksimov, P.V.Moisenz, A.N.Morozov,  
V.V.Pal'chik, A.V.Pose, T.B.Progulova, A.Prokes, V.V.Rybakov,  
L.A.Slepets, A.I.Zinchenko  
Joint Institute for Nuclear Research, Dubna

A.F.Kamburyan, A.A.Loktionov, Yu.K.Potrebenikov  
Institute of High Energy Physics of the Kaz.SSR Academy  
of Sciences, Alma-Ata

K.Hiller, J.Klabuhn, H.Nowak, H.-E.Ryseck  
Institute of High Energy Physics of the GDR Academy of  
Sciences, Berlin-Zeuthen

A.S.Belousov, E.G.Devitsin, A.M.Fomenko, V.A.Kozlov,  
E.I.Malinovsky, S.Yu.Potashev, S.V.Rusakov, P.A.Smirnov,  
Yu.V.Soloviev, L.N.Shtarkov, Yu.A.Vazdyk, M.V.Zavertyaev  
Lebedev Physics Institute of the USSR Academy of Sciences,  
Moscow

E.A.Chudakov  
Institute of Nuclear Physics, Moscow State University, Moscow

V.D.Cholakov  
Hilendarski University of Plovdiv, Plovdiv

J.Hladky, M.Novak, M.Smizanska, M.Vecko  
Institute of Physics of the Czechoslovak Academy of Sciences,  
Prague

V.J.Zayachky  
Higher Chemical-Technological Institute, Sofia

V.R.Krastev  
Central Laboratory of Automation and Scientific  
Instrumentation of the Bulgarian Academy of Sciences, Sofia

D.T.Burilkov, P.K.Markov, G.G.Sultanov, P.T.Todorov,  
R.K.Trayanov  
Institute of Nuclear Research and Nuclear Energetics  
of the Bulgarian Academy of Sciences, Sofia

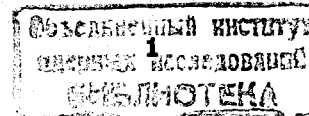
L.N.Abesalashvili, N.S.Amaglobeli, M.S.Chargeishvili,  
N.O.Kadagidze, V.D.Kekelidze, R.A.Kvatadze, G.A.Kvirikashvili,  
N.L.Lomidze, G.V.Melitauri, G.I.Nikobadze, T.G.Pitskhelauri,  
R.G.Shanidze, G.T.Tatishvili  
Institute of High Energy Physics, Tbilisi State University,  
Tbilisi

## 1. INTRODUCTION

In this paper we present the new data on the  $\phi$ -meson production in neutron-nucleus and neutron-proton interactions. The experiment was performed with the BIS-2 spectrometer at the Serpukhov accelerator.  $\phi$ -mesons detected by their favoured decay mode into  $K^+K^-$  refer to a kinematic region  $x_F > 0$  and  $p_T < 1$  GeV/c with the mean values  $\langle x_F \rangle = 0.28$  and  $\langle p_T \rangle = 0.35$  GeV/c. The effective beam spectrum for the detection of  $\phi$ -mesons begins at 30 GeV, has its maximum around 40 GeV and tail up to 70 GeV. The main components of the spectrometer are: momentum-analysing magnet, two sets of multi-wire proportional chambers and two multi-cell threshold Cherenkov counters used for  $K^\pm$ -selection.

## 2. A-DEPENDENCE OF INCLUSIVE $\phi$ -MESON PRODUCTION

The comparison of experimental data on the A-dependence of  $\pi, K$ -production /1/ with those of  $J/\psi$ -production /2/ shows that an exponent  $\alpha$  in an empirical form  $\sigma(A) = \sigma_0 \cdot A^\alpha$  increases for hadrons containing more heavy quarks. As  $\phi$ -meson is a nearly pure  $s\bar{s}$  state, it is interesting whether the A-dependence of  $\phi$ -meson production confirms this tendency.



In this analysis we compare the production of  $\phi$ -mesons on carbon, aluminium and copper targets. Unfortunately, similar comparison with our hydrogen data /3/ was difficult owing to the different systematic errors.

The  $K^+K^-$  effective mass spectra show signals of  $1190 \pm 80$ ,  $1320 \pm 85$  and  $1220 \pm 85$   $\phi$ -mesons for the carbon, aluminium and copper targets, respectively. A ratio of cross sections has been obtained with small systematic uncertainty to describe the A-dependence of the  $\phi$ -meson production. Normalizing to the cross section on carbon we get the ratios  $\sigma(\text{Al})/\sigma(\text{C}) = 1.91 \pm 0.21$  and  $\sigma(\text{Cu})/\sigma(\text{C}) = 3.85 \pm 0.40$ . Fitting the function  $(A_I/A_J)^\alpha$  to these ratios we obtain  $\alpha = 0.81 \pm 0.06$  for the  $\phi$ -production in the kinematic range  $x_F > 0$  and  $p_T < 1$  GeV/c. Using the same parametrization for the background below the  $\phi$ -signal we obtain  $\alpha = 0.65 \pm 0.03$ , significantly different from one obtained for the  $\phi$ -production and close to  $\alpha$  obtained for a  $\pi^\pm, K^\pm$ -production on nucleus /1/.

The result of the ACCMOR collaboration for the  $\phi$ -meson production by incident protons on Be and Ta targets is  $\alpha = 0.86 \pm 0.02$  /4/. The obtained parameter  $\alpha$  shows no significant dependence on  $x_F$

of  $\phi$ -mesons produced in the range  $0 < x_F < 0.3$ . Although our experiment covers the full forward range  $x_F > 0$  the agreement with the ACCMOR result is quite good.

The parameter  $\alpha = 0.96 \pm 0.04$  was obtained by a comparison of the hydrogen and beryllium data in the range  $0.11 < x_F < 0.24$  /5/. The deviation of this value from the other two measurements at nuclear targets is obviously a consequence of the difference between  $\sigma_0$  in an empirical form  $\sigma(A) = \sigma_0 \cdot A^\alpha$  and a hydrogen cross section  $\sigma(A=1)$ .

Generally, the parameter  $\alpha$  decreases with increasing  $x_F$  for the most of particles /1/. Figure 1 shows different value of  $\alpha$  in the proton and neutron beam experiments. There is the same indication that  $\alpha$  decreases with increasing  $x_F$  of  $\phi$ -mesons. However, the  $\alpha$ -values have been measured at a narrow range of  $x_F$  and the statistical and systematic accuracy is inadequate to draw clear conclusions. The curve in fig.1 represents a fit of a parabolic function to the  $\alpha$ -values obtained for  $\pi^\pm$  produced in proton-nucleus interactions /1/. The comparison of  $\alpha$  obtained for the  $\pi^\pm$ -data with those for  $\phi$  and  $J/\psi$  ( $\alpha \approx 0.94-0.96$ ) /2/ indicates the following correlation:  $\alpha(\pi) < \alpha(\phi) < \alpha(J/\psi)$ .

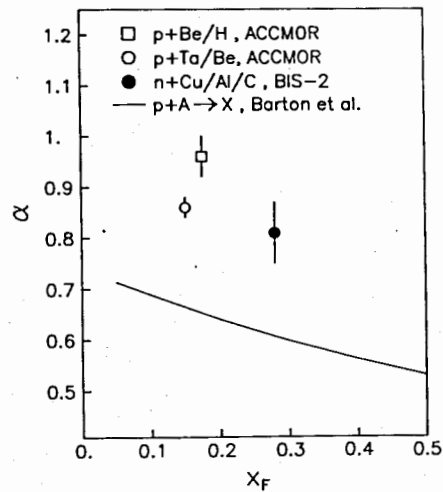


Fig.1 The parameter  $\alpha$  depending on the mean  $x_F$ -value of the detected  $\phi$ -mesons. The sensitive regions in  $x_F$  are  $0 < x_F < 0.3$  for the ACCMOR Ta/Be data /4/,  $0.11 < x_F < 0.24$  for the ACCMOR Be/H data /5/ and  $x_F > 0$  for the BIS-2 experiment. The parabolic curve describes the  $x_F$ -dependence of  $\alpha$  for the  $\pi^\pm, K^\pm$ -production cross sections /1/.

Thus we conclude that the exponent  $\alpha$  increases and accordingly an effective radius of hadron-nucleon interactions decreases with the increase of a mass of quarks forming the final hadron.

### 3. ASSOCIATED PRODUCTION OF $\phi$ -MESONS AND STRANGE PARTICLES

According to the Okubo-Zweig-Iizuka (OZI)-rule the single  $\phi$ -production without additional strange particles is strong forbidden in nonstrange beams. However the question whether OZI-allowed or forbidden processes dominate the hadronic  $\phi$ -production is still open /6/. Therefore the new experimental data on the production of  $\phi$  accompanied by extra strange particles are quite interesting.

The present analysis is based on the statistics of  $6600 \pm 180$  inclusive  $\phi$ -mesons produced on the nuclear and hydrogen targets. Extra neutral strange particles were identified by their decays  $\Lambda \rightarrow p\pi^-$  and  $K \rightarrow \pi^+\pi^-$ . To select events with extra charged kaons the information from the Cherenkov counters was used.

The rate of events with an additional  $\Lambda, K_S^0, K^+$  and  $K^-$  - their fraction to all events with  $\phi$  as a function of a  $K^+K^-$  mass is shown in fig.2. A definite increase of the strange particle rate can be observed when the  $K^+K^-$  mass passes the  $\phi$ -region. The observed rate excesses are  $0.40 \pm 0.07\%$  for  $\Lambda,$

$0.26 \pm 0.07$  % for  $K_S^0$ ,  $1.41 \pm 0.42$  % for  $K^+$  and  $0.41 \pm 0.14$  % for  $K^-$ . The rate of events containing  $\phi$ -meson and the extra strange particles to that containing  $\phi$ -meson is much larger, since one should take into account the background under the  $\phi$ -peak. So we obtain the rates  $2.2 \pm 0.3$  % for  $\Lambda$ ,  $1.6 \pm 0.4$  % for  $K_S^0$ ,  $8.6 \pm 1.9$  % for  $K^+$  and  $3.2 \pm 0.7$  % for  $K^-$ . These rates correspond to  $144 \pm 19$ ,  $94 \pm 20$ ,  $570 \pm 120$  and  $210 \pm 45$  events of the associated production of  $\phi\Lambda$ ,  $\phi K_S^0$ ,  $\phi K^+$  and  $\phi K^-$  systems, respectively.

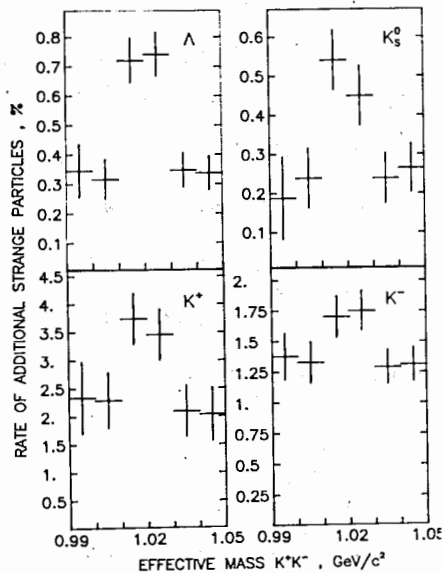


Fig.2 The fraction of  $\Lambda$ ,  $K_S^0$ ,  $K^+$  and  $K^-$  versus the invariant mass  $M(K^+K^-)$ . Clear enhancements are visible in the  $\phi$ -mass region.

The observed event numbers allow one to calculate the fraction of inclusive  $\phi$ -production accompanied by the extra strange particles. The nuclear target data was not considered because there could be an additional uncertainty for nuclear targets due to extrapolation to the cross sections on nucleon. The hydrogen sample contains about a half of the quoted event numbers.

It was proved that in our kinematical region the properties of the strange particles production can be well described by the LUND-model for low  $p_T$  processes /7/. It gives us a reason to use the LUND-model predictions for the extrapolation of the momentum spectra of the associative strange particles in the full kinematic region.

The calculating of the relative production rates should be corrected only by the ratio of the detection efficiencies of the considered reactions. Finally it was found that the detection efficiency of the  $\phi\Lambda$ ,  $\phi K_S^0$ ,  $\phi K^+$  and  $\phi K^-$  systems relatively to that of the inclusive  $\phi$ -mesons are 24 %, 9 %, 25 % and 11 %, respectively. Taking into account the branching ratios of the decays  $\Lambda \rightarrow p\pi^-$  and  $K_S^0 \rightarrow \pi^+\pi^-$  and the share of the  $K_S^0$  in relation to the  $K^0+K^{\bar{0}}$  we obtained that the extra  $\Lambda$ ,  $K^0+K^{\bar{0}}$ ,  $K^+$

and  $K^-$  are presented in  $20 \pm 4$  %,  $55 \pm 17$  %,  $33 \pm 11$  % and  $26 \pm 10$  % cases of the inclusive  $\phi$ -events, respectively. These results correspond to  $\phi$ -mesons produced in the kinematical region  $x_F > 0.1$  and  $p_T < 1$  GeV/c.

The rate of the OZI-allowed processes is a half sum of the above indicated rates taking into account double counting of some exclusive channels. So we conclude that at least  $67 \pm 12$  % of the  $\phi$ -mesons are accompanied by the extra strange particles. This value is a lower limit because  $\phi \Sigma^\pm$ -production is underestimated.

Thus our data show clear evidence that the inclusive  $\phi$ -production proceeds mostly by the OZI-allowed processes.

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Алеев А.Н. и др.

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Рождение  $\phi$ -мезонов в нейтрон-ядерных взаимодействиях при 30-70 ГэВ

Исследуется  $A$ -зависимость сечения инклюзивного образования  $\phi$ -мезонов и ассоциативное рождение  $\phi$ -мезонов со странными частицами. Зависимость сечения рождения  $\phi$ -мезонов от атомного веса мишени  $A$  в кинематической области  $x_F > 0$  и  $p_T < 1$  ГэВ/с описывается степенным законом  $\sigma(A) = \sigma_0 \cdot A^\alpha$  со значением показателя  $\alpha = 0,81 \pm 0,06$ . Также получено, что вклад ОЦИ-разрешенных процессов в сечение образования  $\phi$ -мезонов составляет по крайней мере 67%.

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Aleev A.N. et al.

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$\phi$ -Meson Production in Neutron-Nucleus Interactions at 30-70 GeV

An  $A$ -dependence of inclusive  $\phi$ -meson production and an associated production of  $\phi$ -mesons and strange particles by 30-70 GeV neutrons were investigated. The dependence of  $\phi$ -production cross sections on the atomic weight  $A$  in a kinematic region  $x_F > 0$  and  $p_T < 1$  GeV/c was obtained. This dependence is well fitted by an exponential form  $A^\alpha$  with  $\alpha = 0.81 \pm 0.06$ . It was obtained that at least 67% of the inclusive  $\phi$ -meson production proceeds by OZI-allowed processes.

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