COSY-Proposal

Study of the K^- and ϕ nuclear potentials in p+A reactions at ANKE

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Abstract

The aim of the proposed experiment is to study the K^--nucleus and ϕ-nucleus potentials via K^- and ϕ production in p+A reactions. We plan to obtain data on non-resonant K^+K^- and resonant $\phi{\rightarrow}K^+K^-$ production on ^{12}C, ^{108}Ag and ^{197}Au targets at maximum COSY energy of 2.83 GeV. The combined analysis of the non-resonant and resonant data will allow us to estimate the momentum dependence of the imaginary part of the K^- and ϕ potentials at normal nuclear density through the analysis of the A-dependence. The K^- spectra will be measured in a wide momentum range from 200 to 1100 MeV/c. The low momentum spectra are most sensitive to the antikaon-nucleus potential. The real part of the K^- nuclear potential will be derived from an analysis of the low momentum parts of the K^- spectra based on the effect due to the interplay between Coulomb and nuclear potentials. The ANKE spectrometer is ideally suited for the proposed measurements.

Contents

1 Introduction

The study of in-medium properties of hadrons in nuclear matter is an important topic of contemporary strong interaction physics. Embedding a hadron in the nuclear medium can cause a modification of their masses and couplings. Strictly speaking, the relation of energy and momentum of a certain excitation with quantum numbers of a given hadron is expected to change by its interaction with the medium. This change can be interpreted as a change of the effective mass. A mass modification of various hadrons has been predicted within different theoretical models such as QCD sum rules and chiral dynamics. Over the last decade a dropping in-medium mass has been considered as a precursor phenomenon of chiral symmetry restoration, as in particular exemplified by the Brown-Rho scaling [1] which anticipates a close relation of between the mass and the chiral quark condensate $< q\bar{q} >$. The second motivation for the study of in-medium properties of hadrons, and especially antikaons, is provided by the interest to understand the structure of large dense system. It was predicted [2] that antikaons may form a condensate in the dense interior of neutron stars.

Many present theoretical and experimental activities are devoted to the mass modification by the ambient medium or to explore chiral symmetry restoration. Evidences for the decrease of the ρ meson in-medium mass in heavy-ion collisions were first observed by the CERES collaboration at CERN PS [3] and more recently detected at the Brookhaven RHIC [4]. In addition, experiments on charged kaon production in nucleus-nucleus collisions at GSI [5, 6] have given evidence for the theoretically predicted lowering of the K^- mass in medium and weaker rising of the K^+ mass. A similar mass splitting effect was predicted for charmed $\overline{D}$ and D mesons [7] which will be explored in PANDA and CBM experiments at new FAIR facility [8]. While heavy-ion collisions probe the effect of vastly varying density and temperature, experiments with various projectiles impinging on a nucleus have the advantage to have a well defined, nearly static density and constant low temperature. In the latter case the density-dependent effects are expected to be smaller than those in heavy-ion reactions. However, the sizable - and hence measurable - medium effects of order 20-30 % were predicted within different theoretical approaches already at normal nuclear density.

It is thus of great interest to explore the in-medium hadron properties in the reactions on ordinary nuclei with various elementary probes. Recently, the first experimental data on in-medium change of the masses of hadrons and their interactions in the nuclear matter at normal density were obtained. The TAPS/CBELSA collaboration at Bonn reported on the first observation of the lowering of the ω meson mass in the γ + Nb$\rightarrow$ ω + X reaction [9]. The results of the experiment at SPring8 (LEPS) on the ϕ photo-production from different nuclear targets indicate evidence for a significant increase of the ϕ-nucleon cross section [10]. Here we focus on the investigation of the in-medium properties of mesons with open (K^-) and hidden (ϕ) strangeness produced in proton-nucleus collisions.

2 Motivation of the proposed experiment

Data on near threshold K^- production in hadron induced reactions are scarce. In 1998, the KaoS collaboration performed a series of experiments $p + A \rightarrow K^- + X$ at GSI with E_{beam} = 1.6 - 3.5 GeV and $A = C, Ni, Au$. The K^- were detected at laboratory angles from 32^o to 56^o. The results of these experiments are inclusive momentum spectra and estimates (based on extrapolation of the angular dependence) of the total K^- multiplicities [11, 12] (see appendix A).

The K^- yield at 10.5^o for a fixed momentum 1.28 GeV/c from p-Be and p-Al collisions at energies from 2.3 to 2.98 GeV has been measured at ITEP [13].

Similar measurements have been made at KEK for C, Al, and Cu targets at energies from 2 to 5 GeV, where the K^- were registered at 5.1^o with momenta of 1.0 and 1.5 GeV/c [14].

There is practically no experimental information on the low momentum part of the K^- spectrum (below 400 MeV/c), which is the most sensitive to the effects of the K^--nuclear interaction.

Only a single experiment has investigated ϕ meson production on C, Cu and Cd targets using a proton beam of energy 12 GeV [15], i.e. far above the NN treshold.

In heavy-ion collisions the K^- yield has been found to be tightly coupled to the ϕ yield [16]: the existing data on central Ni+Ni collisions are compatible with the conclusion that at least 20% of K^- originate from ϕ decays. To separate the resonant (via ϕ) and the nonresonant parts of the K^- spectrum, a cooperative study of K^+ and K^- mesons is necessary. The focus has to be put on K^- mesons which undergo much stronger in-medium modifications and much less known than K^+ mesons. The study of the K^- and ϕ production in p+A collisions provides an independent test of the K^- and ϕ potentials in nuclear matter at normal density. The advantage of the ANKE detector at COSY is its ability to measure low momentum spectra, which are expected to be more sensitive to in-medium modifications.

The proposed experiment aims to collect new data, complementary to the already available on the K^- and ϕ production in proton-nuclei reactions. The data will include low momentum parts of K^- and ϕ momentum spectra with the final goals to study the K^- and ϕ nuclear potentials and to test the theoretical ideas concerning the change of hadron properties in the nuclear matter of the normal density.

The in-medium properties of a meson can be described by a complex meson self-energy Π related to a complex nuclear optical potential U_{opt} as $\Pi/2\omega = ReU_{opt} + ImU_{opt}$, where ω is the meson energy. The investigation of the production and propagation of a hadron through nuclear matter provides the information on both real and imaginary parts of in-medium hadron potential. The in-medium mass is related to the real part of the potential $m^* = m + ReU_{opt}$, where m and m^* are in-medium and vacuum hadron masses, respectively. According to theoretical investigations the ϕ meson mass shift in matter is small and the main medium effect on the ϕ is a sizable increase of its width compared to the vacuum value of 4.4 MeV. This effect is mainly caused by the modification of the antikaon properties in the nuclear medium. Due to the interaction in nuclear matter the ϕ-meson acquires an additional width Γ which is connected with the imaginary part of the nuclear potential by the relation $\Gamma = -2ImU_{opt}$. It is well known that ImU_{opt} is responsible for a hadron absorption on their way out of the nucleus. Thus, the strength of the imaginary part of the optical potential for the ϕ can be deduced from the A dependence of the ϕ-production cross section. We intend to measure ϕ-meson spectra from carbon, silver and gold. As K^-spectra will be measured simultaneously with those for the ϕ, the same method will permit us to evaluate ImU_{opt} for K^- mesons which are not stemming from the ϕ decay.

In contrast to the ϕ, the in-medium mass shift for the K^- meson is expected to be large. That implies a significant strength of the nuclear optical potential. The cross section for the production of slow antikaons on different nuclear targets is expected to be most sensitive to the strength of the real part of the nuclear optical potential. We plan to measure the momentum dependence of the K^- spectra on different targets starting from the antikaon momentum 200 MeV/c.

The important advantage of ANKE is its ability to investigate simultaneously K^+K^- meson pairs stemming from ϕ decays and non-resonant kaon pair production. The detector system for negatively charged particles allows one to measure the K^- meson with momenta from 200 to 1100 MeV/c. The possibility to detect K^- with momenta less than 300 MeV/c where the effect of the K^- potential must be strongest, is a unique feature of ANKE.

2.1 ϕ width in nuclear matter

Modification of ϕ meson properties in baryonic matter is a subject of numerous theoretical investigations. The predictions for the change of ϕ properties inside normal nuclear density are collected in Ref. [17]. For example, an increase of the ϕ width by a factor five [18] to ten [19] at normal nuclear matter density have been predicted using different chiral approaches. Due to the strong coupling of the ϕ to the $\overline{K}K$ system, kaon and especially antikaon in-medium potentials play an important role. The decrease of the ϕ life time means that a sizable fraction of the ϕ mesons decays inside the nucleus. Naively, one would expect to see a clear effect in the width of the invariant mass distribution of K^+K^- mesons. However, final-state interactions can strongly influence the measured distributions and also Coulomb corrections and possible effects of the hadronic kaon potentials have to be taken into account. A calculation [20] for ϕ photoproduction shows difficulties for the evaluation of the in-medium mass of the ϕ meson in the K^+K^- invariant mass distribution under all possible selections. A recent investigation in a spectral function approach for pA reactions [21] is in line with the previous findings that, even when applying low-momentum cuts, it is not trivial to observe in-medium modification ϕ mass through the dikaon invariant mass distributions. Aside from theoretical studies, the experiment E325 at KEK found typical distributions (cf. Fig. 1) for the invariant K^+K^- mass [22]. The statistics is rather poor, so they sum up two lighter (CH_2,C) and two heavier targets (Cu, Gd). For the target mass dependence $\sigma(A) \sim A^\alpha$ they extract α=1 from the K^+K^- and a slightly higher value for the e^+e^- decay channel. The experiment was performed at a proton beam energy of 12 GeV which leads to a higher ϕ momentum in the lab system in comparison with ANKE. A heavy-ion Au+Au collision measurement with very high background (E917-AGS/BNL) at T_p=11.7 AGeV also extracts ϕ mesons with free properties [23]. However, both experiments are not well suited to observe effects in the invariant mass distributions.

Instead studying the in-medium ϕ mass, one can study the in-medium ϕ width through the distortion of the ϕ meson which depends on the target. The invariant

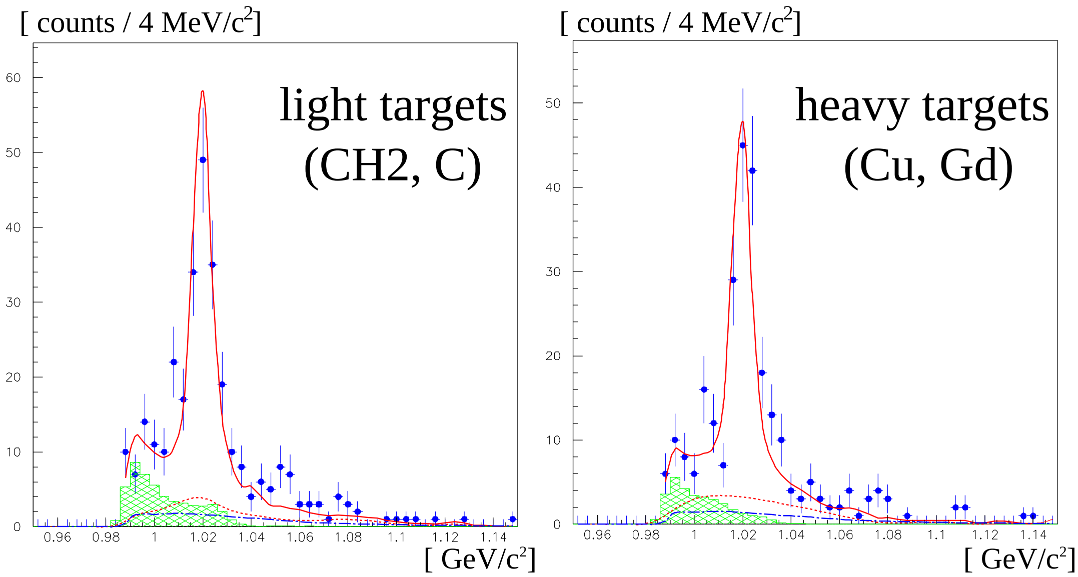

Figure 1: Measured invariant K^+K^- mass distributions from E325/KEK [15]. The two spectra show no significant difference in the invariant mass distributions.

mass of kaon pairs is used to deduce the number of the produced ϕ mesons. If, however, the kaon pair is created inside the nucleus there is a great chance that at least one particle of the pair is scattered or absorbed, thus, it cannot anymore signal the original invariant mass. Besides, the ϕ absorption via the $\phi N \to K^+ Y$ (Y = Lambda, Sigma, Sigma*(1385)) reactions results in additional reduction the number of detected ϕ-mesons. This effect will strongly depend on the size of the used nuclear system. Therefore, another possibility to investigate the ϕ width is to look for the loss of ϕ flux in the K^+K^- production process. One can expect for p+A reactions a typical dependence on the target-mass number A when measuring kaon pairs with an invariant mass of a ϕ meson. This dependence will significantly differ from that expected in the case when there are no medium effects.

In view of the present proposal, two calculations for the investigation of the target mass dependence of ϕ production were performed: (i) by a Group from Valencia using a chiral unitary approach [24] and (ii) a Group working at Rossendorf, using the Bolzmann-Uehling-Uhlenbeck (BUU) transport model [25].

The calculations of the Valencia group [24] find a strong A dependence which is tied to the distortion of the incident proton and to the absorption of the ϕ in its way out of the nucleus. The calculation of the ϕ absorption is based on a model which accounts for the modification of the $\overline{K}K$ decay channel in the medium by means of a careful treatment of the in-medium antikaon potential [18]. Although a proton initial state interaction is rather strong, even then the ϕ distortion is essential. The distortion of the ϕ in the nucleus was accounted for by the eikonal factor

$$P = exp\,[-\int_z^\infty dl \;\; \Gamma(p_\phi, \rho(\overrightarrow{r}'))/\beta]\,, \tag{1}$$

where $\overrightarrow{r}' = \overrightarrow{r} + l\,\overrightarrow{p}_\phi/p_\phi$, z is the ϕ production point, ρ is the nuclear density and β stands for the ϕ velocity in the target nucleus frame of reference. In this calculation Γ is 24 MeV at normal nuclear density [17]. Since the A dependence of the cross sections, and not so much the absolute value, is important to learn about the ϕ width, the cross sections for heavy nuclei normalized to a light one are presented in Fig. 2. It is seen that for heavy nuclei the cross section ratios are changed by about the factor of two. The ratio of the cross sections can be determined by ANKE with the accuracy less than 15 %. Besides, the measurement of the ratio has an experimental advantage to cancel out most of systematic uncertainties. The

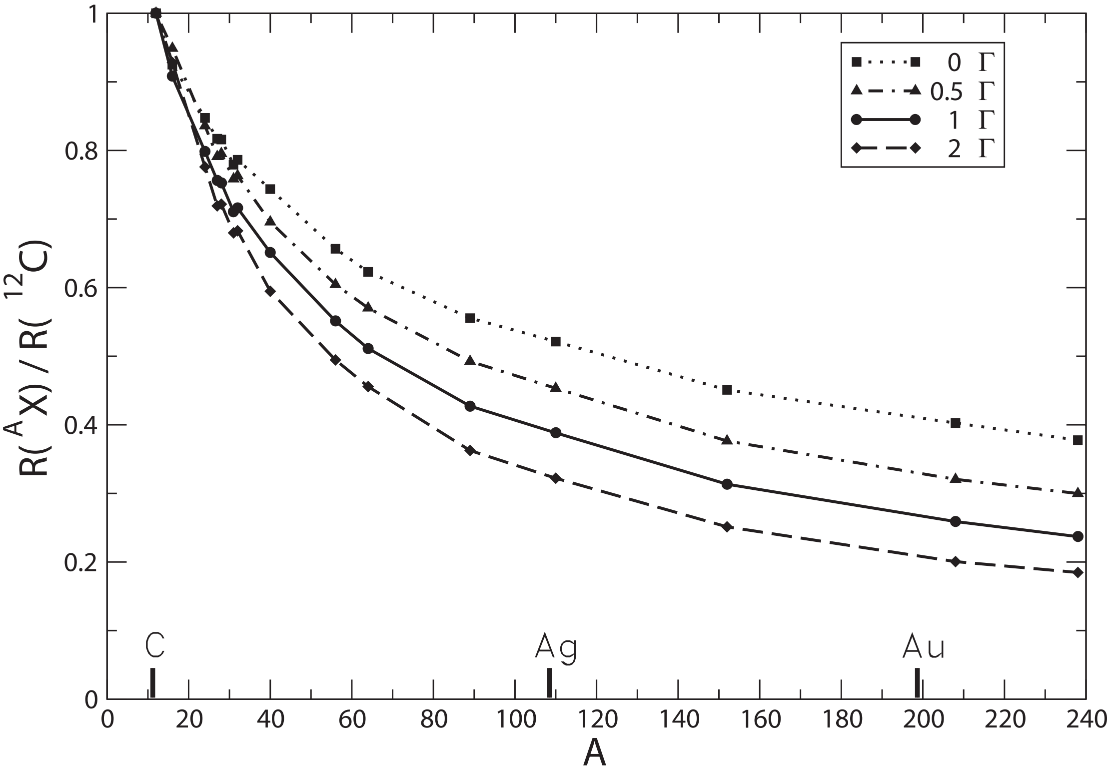

Figure 2: The calculated ratio of the nuclear cross section normalized to ^{12}C for T_p=2.83 GeV for different ϕ widths [24]. Γ here stands for the width of the ϕ in medium at $\rho = \rho_0$; $\Gamma = 24\,$MeV.

calculations are done in the energy range accessible at COSY, in particular at the energy T_p=2.83 GeV which is foreseen for the planned measurements at ANKE. In the calculations also higher order production processes ($pN \to \pi NN$; $\pi N \to N+\phi$) are considered but at the production energy of T$_p$=2.83 GeV - above the free NN threshold T$_p$=2.58 GeV - these contributions only play a minor role for the target mass dependence. This is in line with recent results within the ROC model (see appendix B) and the calculations [26] employing an empirical spectral function.

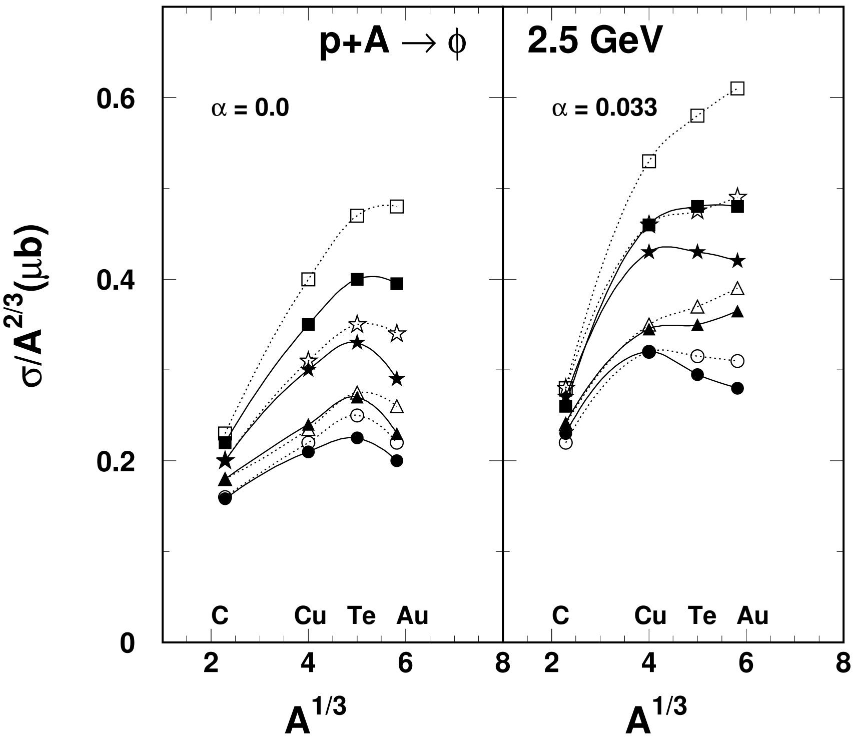

Figure 3: Rescaled cross sections for ϕ meson production as a function of the target mass for different kaon potentials. The left picture shows the result without change of the ϕ mass while the right considers a mass shift. The cross sections are reconstructed from electron pairs (open symbols) and from kaon pairs (full symbols), respectively. Squares–without K^- potential, stars–with a moderate K^- potential, triangles–with momentum dependent potential, and circles–strong momentum independent potential (detailed description in [25]). The lines are to guide the eye.

So determing the A dependence of the cross sections bears valuable information on the ϕ width in the nuclear medium. The foreseen data allows us to evaluate the imaginary part of the ϕ nuclear optical potential. We shall apply the same method to the target atomic mass dependence for the K^- mesons which will be also measured (see section 2.2). It should be noticed that measurements in the wide momentum range will permit us to study the momentum dependence of ImU_{opt} for ϕ as well as for K^- mesons not stemming from ϕ decay. Thus, the evaluation of the imaginary part of the nuclear optical potential will be done using the well known method based on the multiple scattering theory of Glauber.

Another calculation of the A dependence has been performed by a Rossendorf group within the BUU approach. In this case the decay width is effected by the change of the potentials of the ϕ, K^+, and K^- mesons in the medium. The calculation show that strong and attractive K^- potentials lead to a measurable change of the behavior of the cross section as a function of the target mass (cf. Fig. 3). In this calculation also a shift of the ϕ mass was considered and the results are shown in the figure. The parameter $\alpha = 0$ (left pannel) and $\alpha = 0.033$ [17, 19, 27, 28, 29] (right pannel) corresponds to no mass shift and maximum predicted mass shift, respectively.

In both theoretical studies the expected changes in the cross section (Fig. 3) and the cross section ratios (Fig. 2) are large enough to be observed experimentally. From these results we expect a clear effect of the increased width of the ϕ meson to be seen in the A dependence of the ϕ production cross section.

2.2 K^- spectra in pA reactions

An enhanced antikaon to kaon ratio in nucleus-nucleus collisions has been observed at GSI by the KaoS and FOPI collaborations [5, 6]. This finding has stimulated the theoretical activity, directed to the determination of the K^+ and K^- potentials in matter. It was found that in-medium effects are essential already at the densities of normal nuclei. Therefore it is useful to study also proton-nucleus collisions as a further source of information.

The real part of the K^- nuclear potential has been studied in several approaches such as using effective Lagrangians, QCD sum rules, quark-meson coupling or the Nambu-Jona-Lasino model. All these investigations agree qualitatively in establishing that, in medium, the K^- mesons feel a strong attractive potential. It is still controversial how large this attraction is. In addition, part of recent theoretical investigations demonstrate a strong momentum dependence of the potential. Theoretical predictions concerning the real part of the antikaon nuclear potential at normal nuclear density are collected in Table 1.

One can see that the magnitude of the potential is spread over wide range and might be even repulsive for high antikaon momenta [30]. Further co-operative theoretical and experimental efforts are needed to better determine the potential as its strength

Table 1: Overview on the theoretical predictions for the real part of the antikaon potential at normal nuclear density

U, MeV	Mom.dep.	Date	Reference
-200	no	1991	G.E. Brown, M.Pho, Phys.Rev.Lett.66 (1991) 2720
-200	no	1994	G.E. Brown et al., Nucl.Phys.A567 (1994) 937
-180	no	1995	G.Q. Li at al., Nucl.Phys.A594 (1995) 460
-200	no	1996	W. Weise, Nucl.Phys.A610 (1996) 35
-180	no	1997	C.J. Batty et al., Phys.Rep.287 (1997) 385
-160	no	1997	J. Schaffner-Bielich et al, Nucl.Phys.A625 (1997) 325
-(140-50)	yes	1998	A. Sibirtsev, W. Cassing, Nucl.Phys.A641 (1998) 476
-150	no	1998	T. Tsushima et al., Phys.Lett.B429 (1998) 239
-90-+40	yes	2000	J. Schaffner-Bielich et al., Nucl.Phys.A669 (2000) 153
-(57-38)	yes	2000	A. Ramos, E. Oset., Nucl.Phys.A671 (2000) 481
-(87-50)	yes	2001	L. Tolos et al., Nucl.Phys.A690 (2001) 547
-55	no	2001	A. Cieply et al., Nucl.Phys.A696 (2001) 173

has not really been constrained by the available data.

Deeply bound narrow $\overline{K}$ nuclear states have been predicted by Y.Akaishi and T.Yamazaki in 2002 [31]. According to the model the presence of such states results from a strong attractive $\overline{K}N$ interaction in the isospin I=0 channel which causes not only a strong binding of K^- in nuclei but also significant shrinking of the surrounding nuclear matter. Similar strong shinkage effect and deeply bound nuclear states have also been predicted in the Relativistic-Mean-Field approach for antiprotons [32, 33], which also feel strong attraction in nuclear medium.

Recently two indications for strange tribarions in ${}^4He(K^-_{stopped}, p)$ and ${}^4He(K^-_{stopped}, n)$ reactions with mass 3115 MeV/c^2 and 3140 MeV/c^2, respectively, have been observed at KEK [34]. Both states are remarkably narrow with a width less than 21.6 MeV/c^2. The binding energies are found to be 193 MeV/c^2 (3115) and 169 MeV/c^2 (3140) which are much larger than the average nucleon binding energy of 6 MeV.

Also the FINUDA collaboration has obtained an indication of the formation of the previously predicted [35] K^-pp state in the $(K^-_{stopped}, N)$ reaction on different nuclear targets. The authors studied the $K^-pp \to \Lambda + p$ decay channels and found that the invariant mass distribution of the decay products suggests that the K^-pp system are characterized by a large amount of binding energy of 115 MeV [36]. The collaboration FOPI at GSI has started the analysis of data directed onto the search for the formation of the predicted bound states in Al+Al collisions [37].

Despite the experimental indications for deep potential from KEK and FINUDA the validity of the calculations [31] is a matter of hot theoretical debates now. Investigation using chiral unitary approach also find such a states but with sizably smaller binding energy and bigger width [38]. Thus, the strength of antikaon nuclear potential is still unknown and further experimental studies are required. We suggest an alternative way to investigate the magnitude of the K^- nuclear potential - to study the low momentum non-resonant K^- production by protons on light and heavy nuclei.

We plan to measure the momentum spectra for forward K^- production from carbon and gold targets in a wide momentum range from 200 MeV/c till 1100 MeV/c.

As it was shown in [30, 39, 40], the low momentum part of the K^- spectra is most sensitive to the strength of the real part of the nuclear optical potential. Calculations based on different versions of the folding model provide the same conclusion [13, 41]. ANKE has experience in the interpretation of the relative phenomemon in K^+ production on nuclear targets. The differential cross section for K^+ production in proton induced reaction have been measured, in particular, on carbon and gold targets in the momemtum range 170-600 MeV/c [42]. It was observed that the ratio of the cross section on gold to that on carbon increases with kaon momentum, passes a maximum at about 260 MeV/c and falls down at higher momentum. Such a specific behaviour results from the interplay of Coulomb and nuclear potentials. Recall that the influence of the Coulomb potential on soft (less than 100 MeV/c) π^+ and π^- production from nuclear targets is a well known effect. However, the Coulomb potential alone is not enough to match the experiment. The calculation using the BUU transport model allowes one to quantify the real part of the repulsive K^+ potential as $\sim$(+)20 MeV [43], with an uncertainty of $\pm$3 MeV only. We plan to perform a similar analysis of the Au/C cross section ratios for the K^- mesons.

The impact of the nuclear medium on slow K^- differs from that on K^+ due to the attractive nature of both Coulomb and nuclear potentials for K^-. The Coulomb potential will enhance the low momentum range while the influence of the nuclear potential depends sensitively on its strength. One can expect that in the case of a weak potential the production of the K^- and its interaction with a target nucleus are similar to those in free space. In such a case the yield of the K^- mesons will be suppressed due to their strong absorption via the $K^- + N \rightarrow \Sigma + \pi$ reaction which has a large free cross section at low K^- momenta. In such a case one can expect that the Au/C ratio will stay constant or even decrease with lowering K^- momentum.

In the case of a strong potential the production of low momentum K^- will be enhanced due to sizable decrease of the in-medium antikaon mass. A more realistic scenario of the absorption has to include the nuclear density effect on the K^- [44]. One source of density dependence comes from Pauli blocking, which prevents the scattering to intermediate nucleon states below the Fermi momentum. This lead to a weaker in-medium K^-N interaction compared to that in free space. Besides, the masses of all the mesons and baryons participating in the absorption process are modified in nuclear matter. This changes the threshold energy of different meson-baryon channels. In the case of a strong K^- potential exceeding 100 MeV and an even moderate nucleon potential, the absorption of K^- mesons plays a minor role, because of the main absorption channel $K^- + N \rightarrow \Sigma + \pi$ is energetically almost closed. This will lead to an enhanced K^- yield with low momenta espesially from heavy nuclei.

Calculations [39] performed within the BUU approach show that an attractive potential of 120 MeV may results in an increase of the K^- cross section in the low momentum range by about an order of magnitude.

Thus, the low momentum behaviour of the Au/C ratio depends sensitively on the strength of the real part of the K^- nuclear potential and should be determined experimentally.

It is important to note that the magnitude of $ReU_{opt}(K^-)$ is expected to be several times larger than $ReU_{opt}(K^+)$. As a consequence, even more energetic K^- will be influenced by the potential which results in sizable part of the K^- spectrum up to 400 MeV/c - and hence higher statistics - will be used for the analysis. Thus, we expect to collect enough statistics in low momentum K^- spectra for the reliable evaluation of the real part of K^- nuclear potential.

3 Status of the ANKE spectrometer

The ANKE spectrometer (Fig. 4) has been initially designed for K^+ detection in the presence of a large background. A detailed description of the device can be found in Ref. [45]. In 2002, a new detector system for negatively charged particles has been mounted inside the return yoke of the D2 magnet, and partially outside of it [46, 47]. It encompasses 20 start and 22 stop fast scintillator counters as well as 11 curved Čerenkov counters [48] and two multi-wire proportional chambers (identical to those on the positive side) for a precise momentum reconstruction. It allows to register negatively charged ejectiles with momenta from 0.2 to 1.1 GeV/c with $\Delta p/p \sim 2.5\%$ in forward direction, and is able to discriminate between π^- and K^- mesons in the momentum range $0.2 - 0.50$ GeV/c by the time-of-flight difference, and in $0.50 - 1.1$ GeV/c by using the veto signals from the Čerenkov counters [48]. At present, there is no independent K^- trigger; the detection system is triggered by an identified K^+ in the telescopes of the positive side.

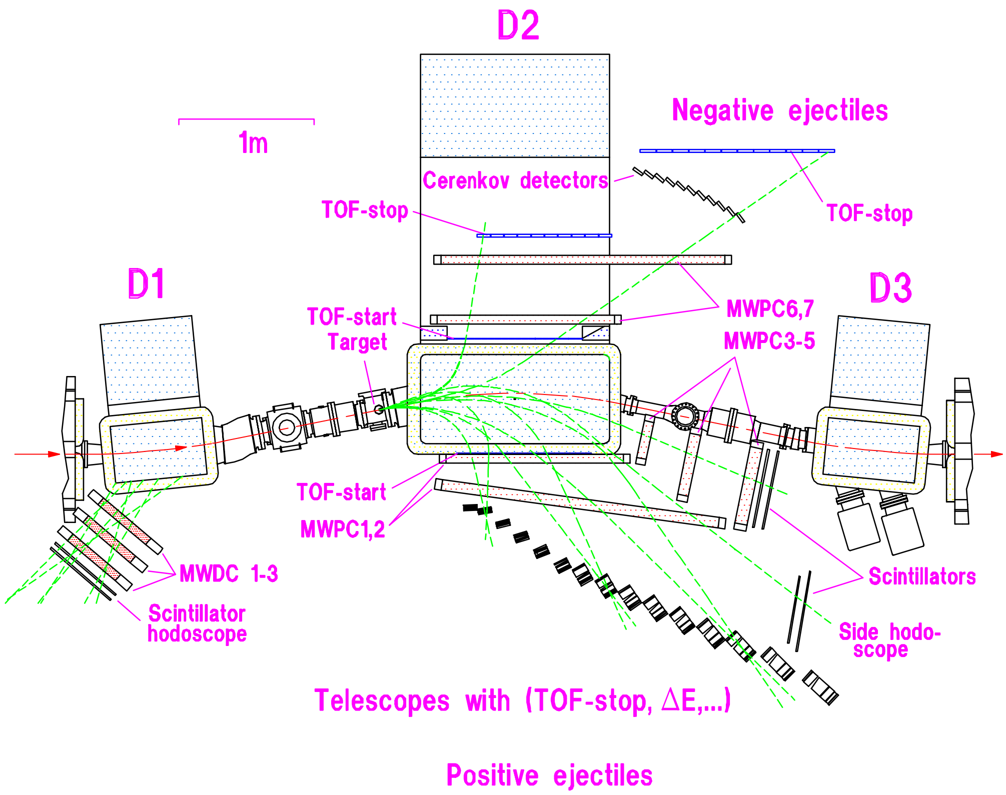

Figure 4: Current ANKE setup. The negative-particle detection system is shown in the upper part above the beam line.

4 Simulations of the proposed measurements

For the simulations of the proposed measurements the following event generators have been employed:
(i) RQMD version 2.4 (http://tonic.physics.sunysb.edu/program/rqmd.html) with minor user-interface modifications.
(ii) BUU code used for simulating the $\phi-$meson production dynamics as described in section 2.1.
(iii) ROC model [49] used already for an earlier COSY proposal # 21 [50]. During the past years, the ROC model has been adapted to the most recent K^+K^- production data. The latest version (Dec. 2002) describes the preliminary $K^\pm$ data from KaoS within a factor of 2 (see Appendix A).

The BUU generator was used to parameterize the momentum distribution of ϕ-mesons produced in $p^{12}C$ collision at 2.5 GeV. The obtained distribution was then used as input for the GEANT 3.21 implementation of the ANKE spectrometer, and the kaons from the decay-in-flight of the ϕ mesons have been traced through the spectrometer. With the two other event generators 6.15×10^{10} effective events [1] from the same reaction have been generated. Table 2 summarizes the results of these simulations.

Table 2: Events generated and registered within ANKE acceptance

From 6.15×10^{10} events:	RQMD	ROC
events with K^- and/or ϕ in 4π	1075800	1488435
K^+ in ANKE acceptance	27487	37756
K^- in ANKE acceptance	84084	84911
K^+K^- in ANKE acceptance	2456	3933
K^+K^-p in ANKE acceptance	154	481

With the results from Table 2 we now proceed to estimate the expected counting rates.

[1] In the case of RQMD, a total of 4.6×10^8 events in the $x - z$ plane have been generated and subsequently 133 random orientations have been produced; in the case of ROC the Monte-Carlo probability for creation of $K^\pm$and ϕ has been increased by a factor of 25, and from each of the generated 1.1×10^8 events 24 different random orientations have been produced.

4.1 Count rates

The expected counting rates for the particle x depend on the luminosity L, the cross-section σ, the acceptance of the spectrometer Δ and the efficiency ε of the detection system:

$$N_x = L\sigma_x\Delta_x\varepsilon_x \,. \tag{2}$$

In view of the time-of-flight between the target and the stop detector of the order of several nanoseconds, a significant number of kaons decay in flight before being detected. The effect of these losses on the registration efficiency can only be estimated by detailed simulations, as done above.

4.1.1 Luminosity

When using solid strip targets, the COSY beam is steered such that its periphery overlaps with the target tip. The degree of overlap is controlled by a feedback from the detection system. With typical target thickness of 40 μg/cm^2 - 1.5 mg/cm^2 and beam intensities of $(2-4)\times 10^{10}$ stored protons the achievable luminosity is limited not by the conditions of the stability of the COSY beam but by the maximal tolerable load on the MWPCs of ANKE side detector systems [45]. Thus, the luminosities previously considered in Ref. [50], although in principle achievable, are too high and would lead to a rapid deterioration of the MWPC performance. The experience with ANKE so far indicates that the upper limit of the luminosity still digestible for the MWPCs is about $(3-5)\times 10^{31} cm^{-2}s^{-1}$, hence for the proposed experiment $p(2.5GeV)$ + ^{12}C we assume a luminosity of $L = 3\times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. For heavier targets the situation with the side MWPCs is less crucial. Here a twice higher beam intensity can be used.

4.1.2 Cross sections

As discussed above, the data on cross-sections for K^- production in proton-nucleus collisions at energies close to and below the pp threshold are very scarce. For this reason, one has necessarily to resort to model calculations and/or order-of magnitude estimates. Sibirtsev and Cassing [39] calculate the K^- production cross section $p(2.5GeV)$ + ^{12}C as 4.2 μb. Our adaption of RQMD-2.4 simulations result in a total cross section of 4.9 μb (taking the ^{12}C and proton interaction radii as 2.61 fm and 0.86 fm, respectively). The corresponding ROC result is 6.8 μb. On the other hand from the measurements of the KaoS collaboration for $p(2.5GeV) + {}^{12}$C the K^- multiplicities can be estimated. Using them with the above carbon and proton interaction radii one obtains a K^- production cross section of 4.8 μb. One observes a remarkable consistency between the above estimates, with the exception of the previous ROC prediction which is somewhat larger. Since this is not the only case where previous ROC results tend to overestimate K^- production data [13], it seems reasonable to accept a conservative value of 4.5 μb for the $p^{12} + C \rightarrow pXK^+K^-$ reaction cross section at the projectile energy of 2.5 GeV.

4.1.3 Efficiencies

As discussed in [46], the efficiency of the positive side detector can be estimated as $\sim 85\%$. The negative side detector is comparable.

The dead time of the ANKE DAQ system may be neglected.

4.1.4 Acceptances and count rates

The acceptances of ANKE can be deduced from Table 2. In the simulations the decay in flight, small angle scattering and energy losses are included. With the values of the luminosity and the cross-section estimated above, one expects 140 K^- produced per second into 4π. The resulting expected counting rates per second are summarized in Table 3.

Table 3: Estimated counting rates per second.

particles	RQMD	ROC	mean	efficiency	efficiency+veto
K^+	3.3	3.3	3.3	2.8	0.5
K^-	11	8	9.3	8.1	1.2
K^+K^-	0.3	0.4	0.33	0.24	0.04
K^+K^-p	0.02	0.04	0.032	0.02	0.003

The count rates for incident proton energy 2.83 GeV are approximately the same as those for 2.5 GeV since the raise in the production cross section with increase of the proton energy is almost totally compensated by the decrease of the ANKE acceptance.

4.2 Particle identification and background suppression

The background conditions for the positive and forward detectors are not different from those for previous pA kaon production experiments at similar energies [51, 42]. There are two main sources of background in the negative side detector: the π^- and protons scattered by the construction materials and into the direction of the negative side detector. These scattered protons are easily identified and discarded by the momentum reconstruction system using the information from the negative side MWPCs. In most cases the negative pions will also be properly identified and discarded as discussed above.

One drawback of the current ANKE setup is that no independent K^- trigger exists. Hence, one has to trigger on detected and identified kaons in the positive side, which, due to the lower acceptance of the positive detector, results in a further reduction of the counting rates for K^-, K^+K^- and K^+K^-p by a factor of $2-3$. On the other hand, the K^+ trigger has the advantage that it allows one to distinguish between π^- and K^- based on the time-of-flight from target to stop counters instead of start-stop TOF. With a reliable K^+ identification on the positive side, the target-stop TOF difference between π^- and K^- becomes large enough so that an unambiguous identification of the K^- is possible. Thus, the background on the negative side is mainly determined by misidentified K^+ on the positive side. Using the veto counters in the telescopes, this can be held $\leq 10\%$, which, with a coincidence window of 50 ns, translates into $\simeq 0.4$ random coincidences per second. However, in contrast to the antikaons, these random coincidences have very wide TOF distribution and contribute only several percent within the sharp K^- TOF windows.

Instead of a two particle trigger K^+X^- including the delayed VETO time information one can also use a three particle K^+K^-p coincidence without the delayed VETO time (cf. Tab. 3). The yield of collected K^- will be similar (see also chapter 6).

4.3 Momentum spectra

The momentum distribution of the K^+ and K^- mesons will be measured in coincidence, because of the necessity of using the available fast K^+ trigger.

In Figs. 5 and 6 results are shown from ROC and RQMD simulation of the $p(2.5GeV) +^{12} C$ reaction. Only K^+ which are accompanied with K^- in the same

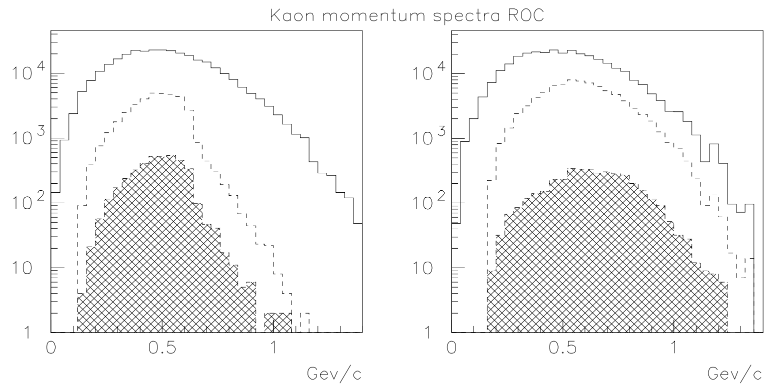

Figure 5: Momentum spectra for K^+ (left) and K^- (right) as obtained from ROC + GEANT. Solid histograms: events generated in 4π; dashed histograms: events registered in the corresponding detector system; hatched area: events registered in coincidence.

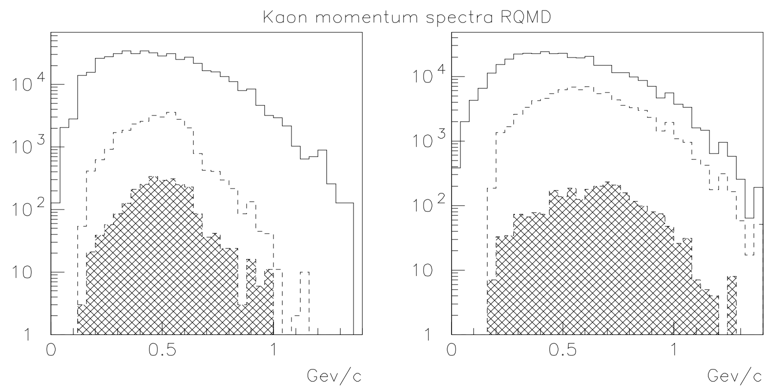

Figure 6: As Fig. 5 but using RQMD + GEANT.

event are included. The solid histograms represent all generated K mesons, the dashed ones are for kaons detected in start and stop counters of the respective detector systems, and the shaded histograms depict the K^+ and K^- mesons detected in coincidence. It is apparent that the two models produce very similar results. The ANKE spectrometer acceptance is smooth enough not to distort the kaon momentum distributions.

5 Normalization

The ratio $R(A_1/A_2)_{p_K}$ of the K^- production cross sections of heavy (A_1) and light (A_2) targets for a given K^- momentum p_K can be calculated from the observed number of K^+K^- pairs n:

$$R(A_1/A_2)_{p_K} = \left[\frac{n_{A_1}}{n_{A_2}}\right]_{p_K} \times \frac{L_{A_2}}{L_{A_1}} \,. \tag{3}$$

L_{A_1} and L_{A_2} denote the integrated luminosities during data taking with a particular target. The luminosity ratio can be obtained from the number $n(\pi^+)$ of 500 MeV/c pions, measured during pion calibration runs for each energy and for each target.

$$\frac{L_{A_2}}{L_{A_1}} = \left[\frac{A_1}{A_2}\right]^{1/3} \times \left[\frac{n_{A_2}(\pi^+)}{n_{A_1}(\pi^+)}\right]_{p_\pi=500\,\mathrm{MeV/c}} \,. \tag{4}$$

All numbers of detected pions and kaons in Eq. (3) and Eq. (4) should be individually normalized to the relative luminosities during the corresponding runs. This relative normalization can be obtained by monitoring the interaction of the proton beam with the target using four-fold coincidence between the stop counters 2–5 of the positive arm of the spectrometer directly looking at the target [52]. Thereby they select ejectiles, which passed the spectrometer dipole. Pion-production cross sections in proton-nucleus reactions have been measured by several groups in the forward direction in the 0.73–4.2 GeV energy range [53, 54, 55]. The combined analysis of these data showed that, to within 10%, the ratios of the pion production cross sections can be scaled with the target mass number as $A^{1/3}$ [56]. This is used in Eq. (4).

The absolute cross section values can be obtained from the number of detected kaon pairs after correction for luminosities, detection efficiencies in the scintillators and MWPCs, kaon decays between the target and the counters, and angle-momentum acceptances [42]. For the cross section ratios absolute values are not needed and many uncertainties of the efficiency corrections cancel out.

6 First data on ϕ production on a CH_2 target at ANKE

In a test beam time at ANKE (COSY proposal no. 130) in spring 2003, data were collected with an open three-particle time-of-flight trigger at a proton beam energy of T=2.88 GeV on a CH_2 target. A first analysis of these data selecting K^+K^-p correlations are shown in Fig. 7. In the upper part of the left side the missing mass distribution of K^+K^-p is shown, derived under the assumption of production on a target nucleon at rest. The strong narrow peak on the top of the distribution originates from hydrogen. The wide distribution underneath the H_2 peak is caused by the carbon inside the poly-ethylene target and is smeared out by Fermi motion. The tail in the lower mass region comes mainly from background, but also higher order production processes can contribute here. In the right upper part of the figure, the corresponding invariant K^+K^- mass is shown for missing masses above 0.8 GeV/c^2. In this rough analysis the Čherenkov counters in the negatively charge particle detection system for the $\pi^- - K^-$ separation were not included in the analysis. The use of the Čherenkov counters can improve the background conditions for the high momentum part of the K^- spectrum drastically but not in the low momentum part. The spectra show that a reasonable missing mass resolution of about 10 MeV FWHM and an invariant mass resolution of about 7 MeV FWHM can be achieved.

If one considers the conditions of this beam time e.g. luminosity, efficiencies etc., the number of K^+K^-p events agree inside the uncertainties with the counting rate estimates from the simulations.

Momentum distributions for the K^+ and K^- mesons are presented in the lower part of Fig. 7. The area below the arrow in the right panel contains 811 K^- events in the momentum range 0.2-0.4 GeV/c, which is of particular interest for the determination of the K^- potential. The number of events in the lowest momentum interval 0.20 - 0.25 GeV/c is 60. The analysis of the TOF spectra shows that here the background contributes about 30% and decreases gradually with antikaon momentum. We plan a two week measurement with a carbon target aiming at increasing the statistics by a factor of 2. According to our experience the use of heavy targets leads to a decrease of the luminosity by an order of magnitude due to multiple scattering of the beam protons. However this effect is partially compensated by the strong target mass dependence of the K^+K^- production cross section. Thus, to obtain a comparable statistics for light and heavy nuclei a three week measurement with a gold target is required. The biggest uncertainty in the ratio of the cross section for K^- production on Au to that on C can be estimated as 20 - 25% for the momentum range 0.20 - 0.25 GeV/c and less than 20% for the momentum range 0.25 - 0.4 GeV/c. It is sufficient to draw a conclusion about the behavior of the ratio within the K^- momentum range from 0.2 to 0.4 GeV/c. It should be noted that the above estimate assumes no influence of the nuclear matter on the soft K^- production. In the case of a strong K^- potential the number of events in the low momentum part of the spectra might be strongly enhanced, especially for the gold target.

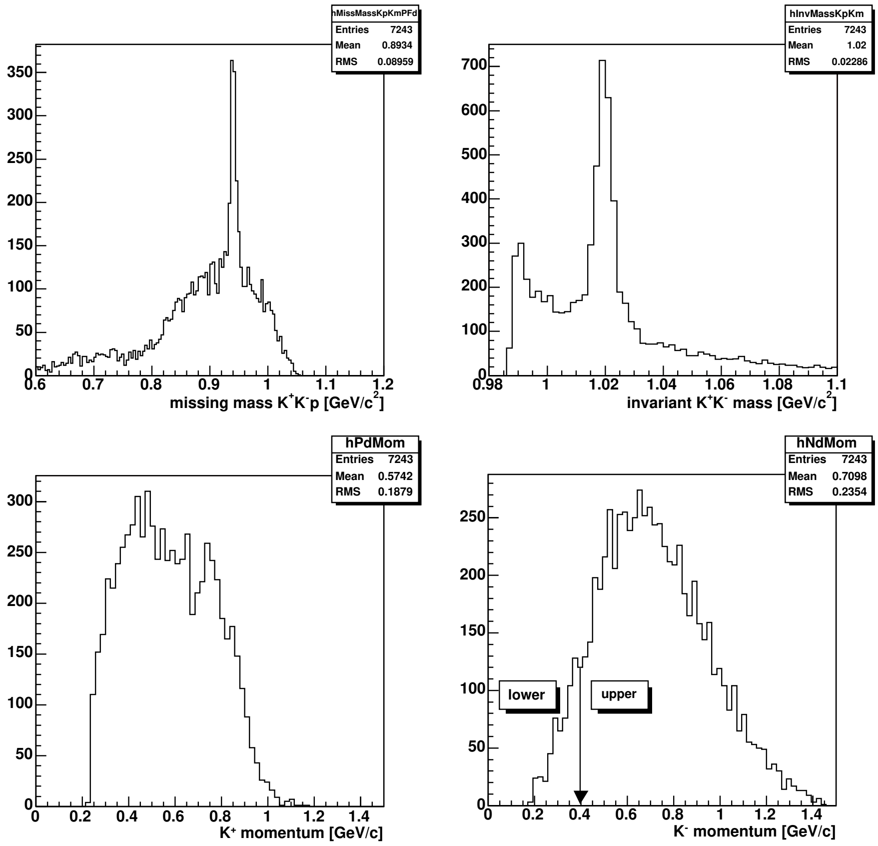

Figure 7: Left upper part: measured missing mass distribution of K^+K^-p. Right upper part: invariant K^+K^- mass for missing masses above 0.8 GeV/c^2. Lower parts: the K^+ and K^- momentum distributions.

7 Conclusion

The proposed experiment aims to obtain data which provide new information on the modification of the K^- and ϕ meson properties in nuclear matter of normal density which can be described by using the meson nuclear potentials. The cross sections for uncorrelated K^+K^- pair production on carbon, silver and gold targets will be measured simultaneously with those for K^+K^- pairs arising from a ϕ decay. The imaginary part of the potential for both K^- and ϕ mesons and its momentum dependence will be deduced from experimental data using the model-independent method. The real part of the K^- nuclear potential will be derived from the analysis of very soft parts of the K^- spectra based on the effect due to the interplay between Coulomb and nuclear potentials.

The ANKE spectrometer is optimally suited for the suggested measurements.

8 Required beam time

We propose to measure the momentum distributions and target mass dependencies for the K^- and ϕ production in pA collisions at maximum COSY energy 2.83 GeV. We ask for a beam time of six weeks to collect data on three targets - ^{12}C (2 weeks), ^{108}Ag (1 week) and ^{197}Au (3 weeks). For the ^{12}C and ^{197}Au targets more beam time is requested in order to collect sufficient statistics in the low-momentum K^- spectra. This will be needed to extract the real part of the K^- nuclear potential. The one week beam time on the ^{108}Ag target will complement the study of the target mass dependence. This will provide a better understanding of the imaginary part of the potential for both K^- and ϕ mesons.

The beam time should take place in autumn 2006.

A Appendix

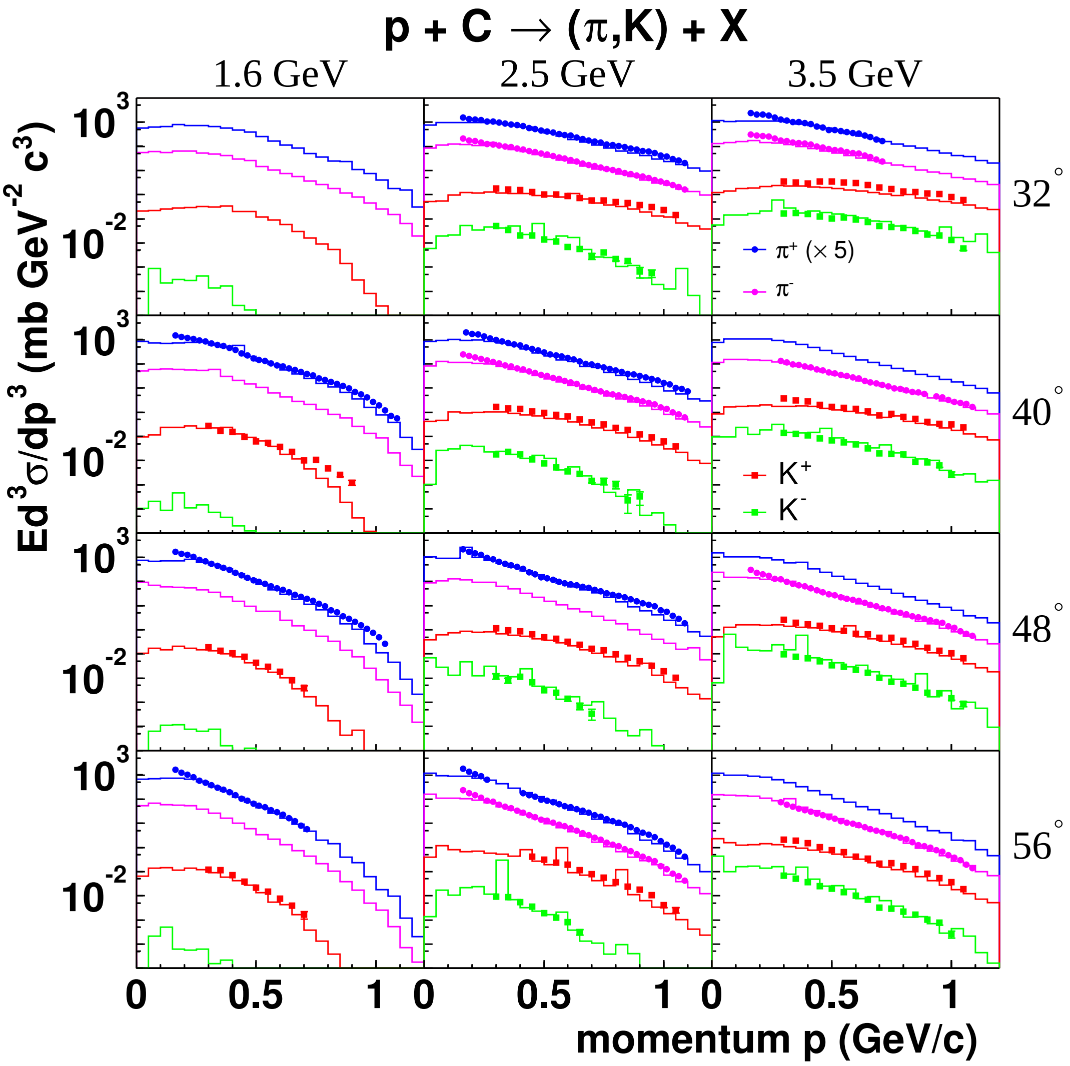

Figure 8: KaoS data on carbon target (symbols) in comparison with ROC calculations (histograms).

B Appendix

The results of ROC calculations - figures 9, 10, and 11 - shows the fraction of higher order processes in comparison with the direct production. The calculation cover the energy range from 2.3 GeV up to 2.83 GeV.

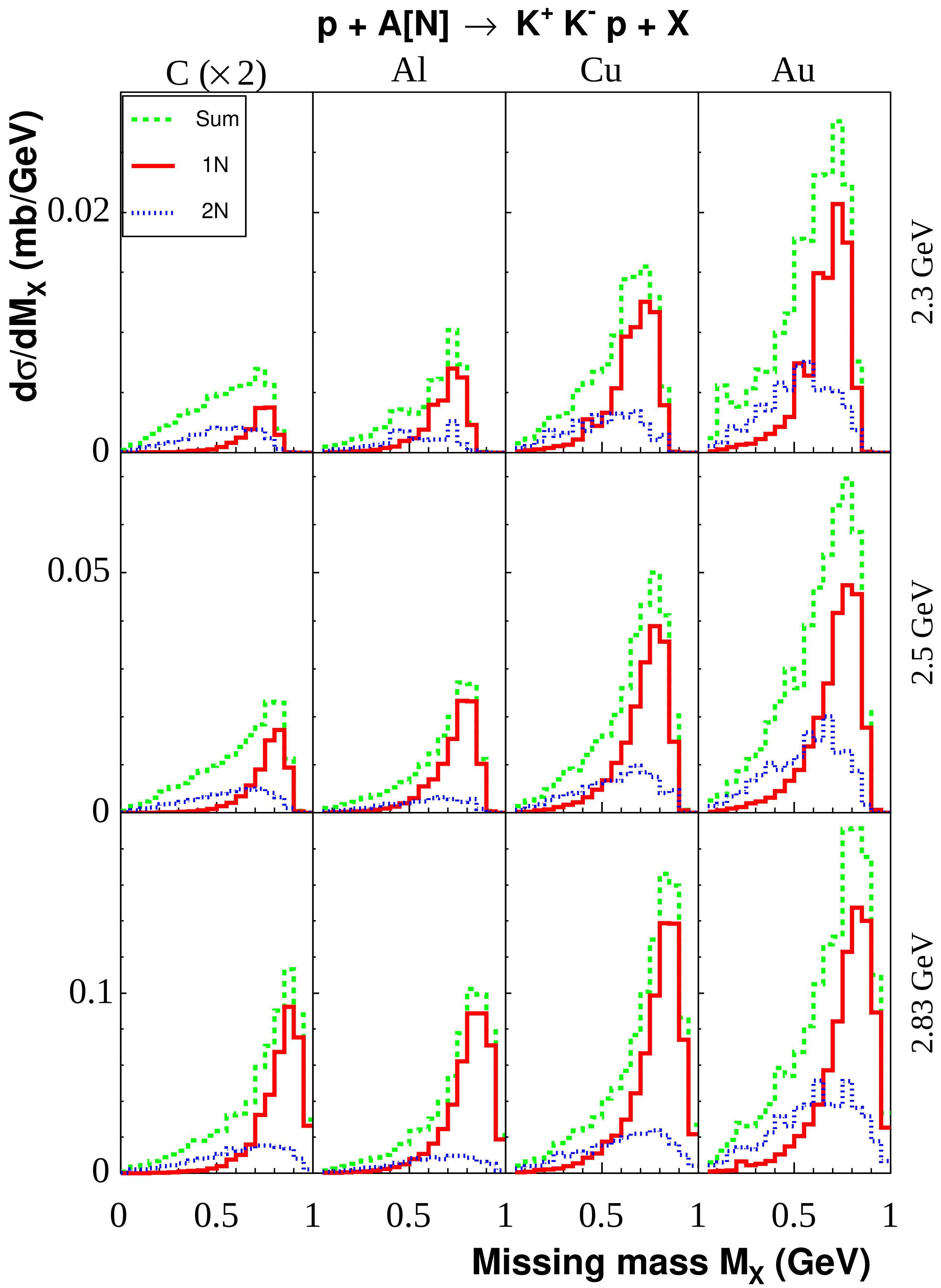

Figure 9: Missing mass K^+K^-p distributions for the fraction of higher order processes, direct production and the total sum.

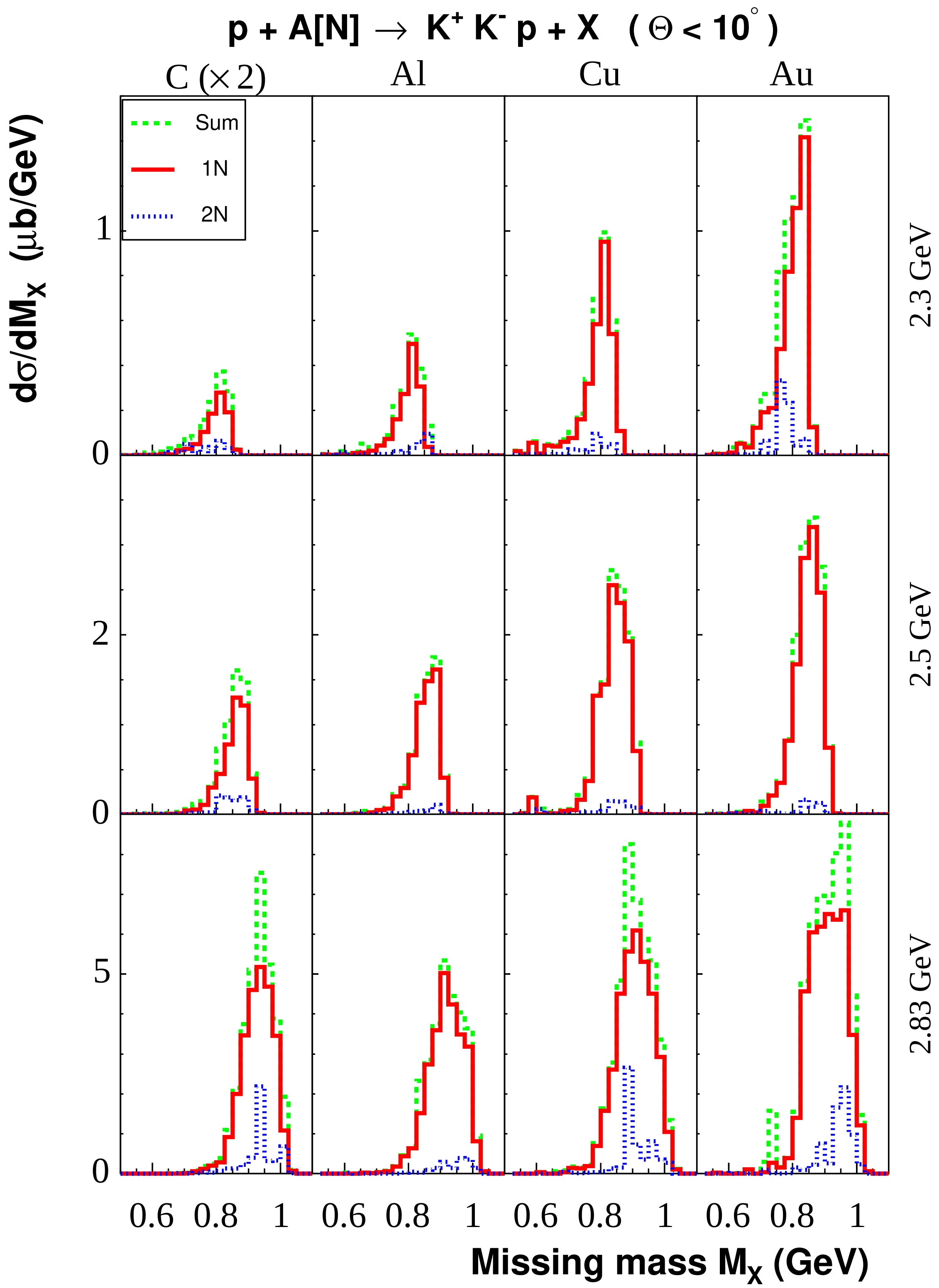

Figure 10: Like fig. 9 but restricted for polar angle smaller 10^o which consider roughly the ANKE acceptance.

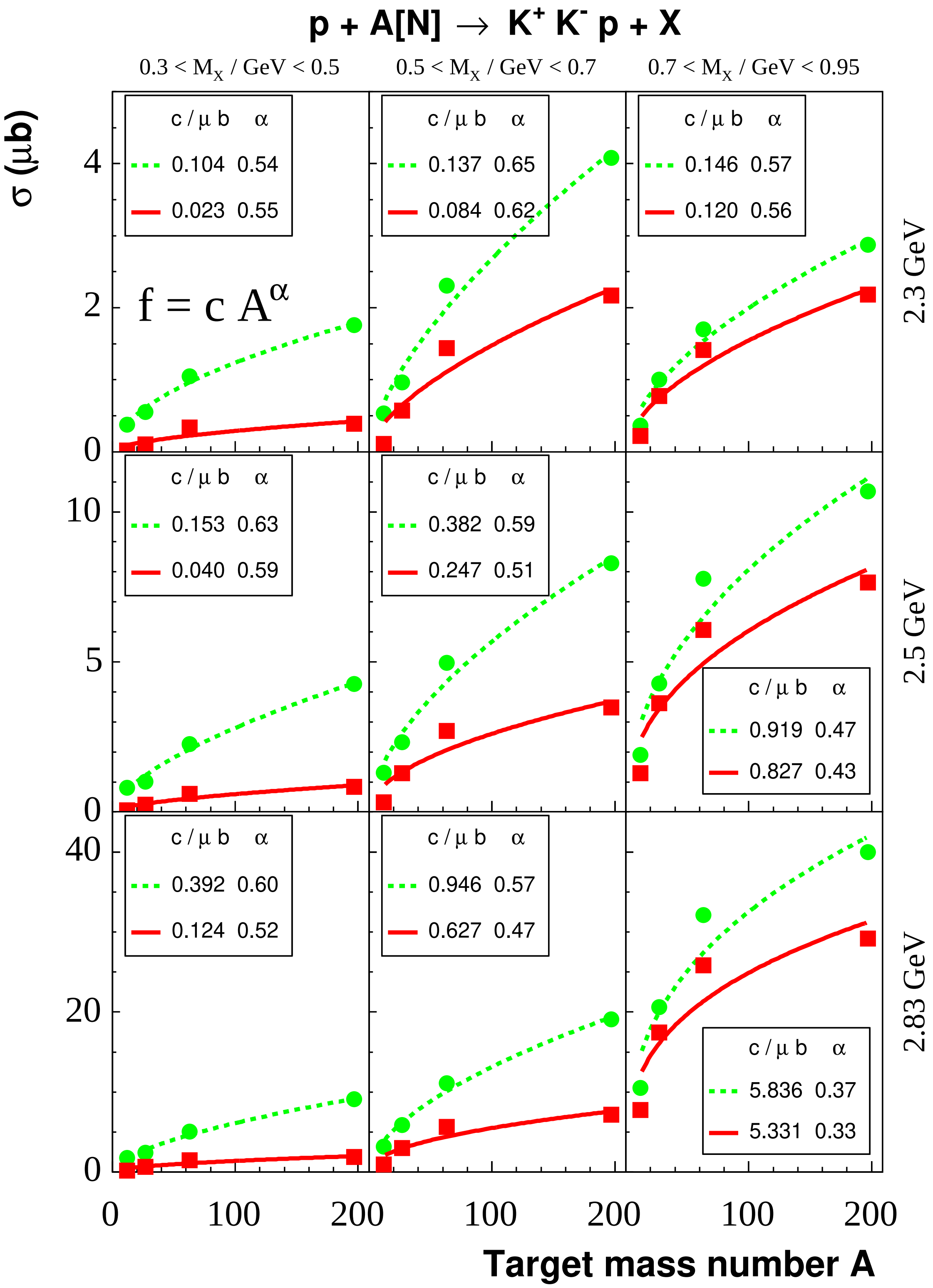

Figure 11: The total amount of direct and higher order production depending from the target mass number A for different ranges of missing K^+K^-p masses. K^+K^-p.

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