BEAMTIME REQUEST

ANKE: Study of the Subthreshold K^+ Mesons Production

– measurements with heavy nuclei –

Abstract

A beamtime of three weeks is requested to complete measurements of K^+ inclusive double-differential cross section from proton-nucleus interactions below the threshold of the elementary reaction. A-dependence deduced from measurements of K^+ spectra from Al, Cu, Pb (proposal COSY-18) in combination with data obtained earlier from C-target will be a critical test for the mechanism of this reaction. A nearly linear A-dependence will indicate on a multi-step production mechanism, whereas the trend following the geometrical model predictions will confirm the subthreshold kaon production directly from pN interactions. Measurements will be done at beam energies 2.3 GeV, 1.2 GeV and 1.0 GeV. As a by-product, it is also proposed during three days of the requested time to do a precise K$^+$ mesons lifetime measurement with an accuracy 3-4 times better than the current world average. This measurement will be done at 2.3 GeV using a Cu or Pb target.

1 Motivation

One of the goals of the research program at ANKE is the investigation of the nuclear medium and its influence on elementary processes from double differential cross section measurements of K^+ mesons produced in proton-nucleus collisions at energies below the threshold of elementary pN reactions (subthreshold kaon production).

Inspite of the long, nearly 20-years history of the subthreshold K^+ production, the process is not yet completely understood and every experiment, done in new kinematical conditions, opens questions about the mechanism of the subthreshold production.

After the first measurements of subthreshold kaon production in interactions of 1 GeV protons with different nuclei [1] and studies of this process in the $0.8-1.0$ GeV projectile energy range two main alternatives for the reaction mechanism were discussed [2]:

- a direct production on a single nucleon inside a nucleus with a high Fermi momentum component (one-step mechanism),
- intermediate pion production followed by a $\pi N \to K^+\Lambda$ reaction in the same nucleus (two-stop process).

Subsequent theoretical studies [3] predicted that at energies above 1.2 GeV the one-step mechanism is most important whereas at lower energies the two-step processes become dominant (fig. 1).

In order to check these conclusions and to get further information on nuclear medium effects more detailed experimental data such as double differential cross sections [4] and K^+d correlation spectra [5] will be necessary.

The lowest energy at which double differential cross sections were measured up to now is 1.2 GeV [6, 7]. At CELSIUS [7] measurements have been performed in the range of small K$^+$ meson momenta and at 90°. At SATURNE [6] the high momentum part of the kaon spectra (> 0.5 GeV/c) was measured at 40° emission angle and at 2.5 GeV, 1.5 GeV and 1.2 GeV projectile energies (fig. 2). At 2.5 GeV another (kaon high momentum)

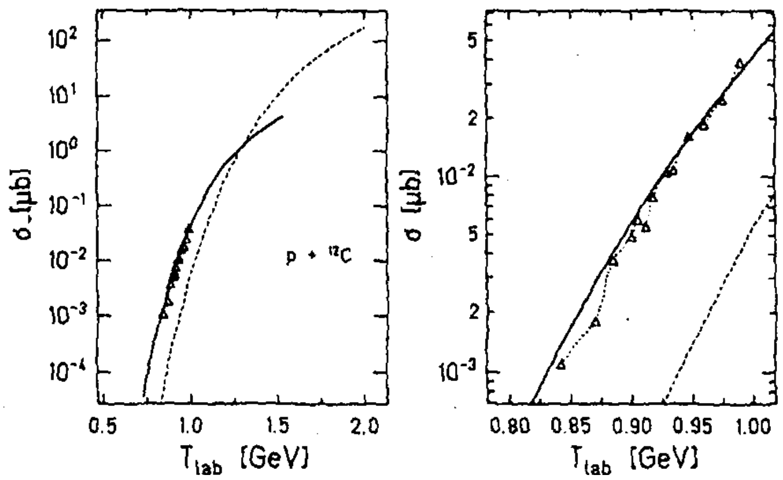

Figure 1: Cross section for K^+-production in $p\,C^{12}$ reactions as a function of the laboratory energy T_{lab}. The dashed line is the result of calculations from one-step processes $p\,N \rightarrow N\,\Lambda\,K^+$ [3] while the solid line represents the yield emerging from secondary processes $\pi\,N \rightarrow K^+\,\Lambda$. The experimental data from Koptev et al. [2] are given by triangles.

mode of the subthreshold kaon production was realized, where the projectile energy is above the threshold of the elementary reaction but kaon momenta at a selected emission angle are higher than the maximal momentum of kaons from the elementary reaction at this angle (fig. 3).

The basic conclusion of this work [6] agrees with the results of previous studies [2, 3]: the deeper below the threshold, the stronger the importance of the two-step mechanism. Calculations presented in this work show that at the most energetic part of the kaon spectra (close to the hyper-nuclei formation) the one-step mechanism is expected to be negligible.

Recently, new data on the kaon high momentum subthreshold production were published [8]. In this experiment the production of kaon with the momentum of 1.28 GeV/c from $p\,Be$ collisions was measured at the emission angle of 10.5° in the energy range from 1.65 GeV (close to Be-hyper-nuclei formation at the adjacent angle) to 2.4 GeV (fig. 4). The authors of this work, in contrast to [6], showed that all their data can be described in the frame of the one-step process taking into account the nuclear nucleon momentum distribution with a high momentum admixture of 2 % of the conventional Fermi movement.

The same conclusion was obtained in a subsequent theoretical work [9],where all previous data were also analysed. From this analysis it follows that the relative role of the two mechanisms depends on the kinematics realized in the experiment.

As a conclusion, the above discussion shows that new experiments in this field of physics should present maximally complete kaon spectra in both near and deep subthreshold kinematical regions and it is desirable if they include some specific mechanism features.

For the light nuclei (Be or C) it is the $K^+\,d$ - correlation experiment which has been

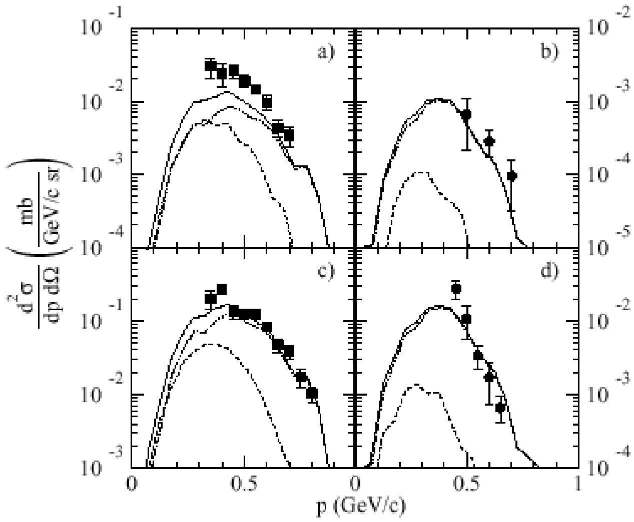

Figure 2: Measured and calculated kaon production cross sections [6] in proton-nucleus collisions. **a)** - $p\,C$ at 1.5 GeV, **b)** - $p\,C$ at 1.2 GeV, **c)** - $p\,Pb$ at 1.5 GeV, **d)** - $p\,Pb$ at 1.2 GeV. The dashed line are kaons produced in first chance collisions, the dotted line - kaons from $\pi\,N \rightarrow K\,Y$ processes and the solid line is the sum of both components.

proposed at ANKE [4] and is now under preparation to be performed in the near future as a separate beamtime request. An observation of the rather narrow deuteron peak in correlation with low and high energetic kaons in the forward direction will be a fingerprint of the two-step mechanism. Strong deuteron disintegration will make the deuteron peak invisible for heavy nuclei.

Another approach, more effective for heavy nuclei, has also been presented as one of the goals in the COSY-18 proposal. It is the A-dependence study of double differential cross sections of kaon production at small angles and at projectile energies below 1.58 GeV. Close to linear A-dependence will prove a multi-step mechanism whereas agreement with the geometrical model predictions ($\sigma \approx A^{\frac{2}{3}}$) will indicate that kaon are produced in primary collisions.

For double-differential cross sections this dependence or, in particular, the experimental ratio of the cross sections from Pb/C-targets at 1.5 GeV-energy agrees with the geometrical factor (7.5 ± 1.0 [6]). Due to statistical limitations and because of only two nuclei (heavy and light) used in experiment the authors could not present this ratio at 1.2 GeV. The total cross section measurements at 1.0 GeV exhibit a much stronger than geometrical A-dependence but it is mostly provided by low energetic kaons with momenta less than 0.25 GeV/c (fig. 5).

In contrast to the previous works the ANKE-spectrometer can measure nearly complete forward direction kaon spectra with the momenta from 0.10 GeV/c to 0.65 GeV/c in the wide projectile energy range down to 1.0 GeV. The A-dependence can be measured for low and high kaon momentum parts of the double-differential cross sections.

Three weeks of beamtime are requested to perform such measurements at projectile energies of 2.3 GeV, 1.2 GeV and 1.0 GeV using Al, Cu and Pb targets.

At 2.3 GeV necessary calibrations and background studies will also be done. Since the count rate of the detected kaons is estimated to be $15-20$ kaons/s, it is proposed as

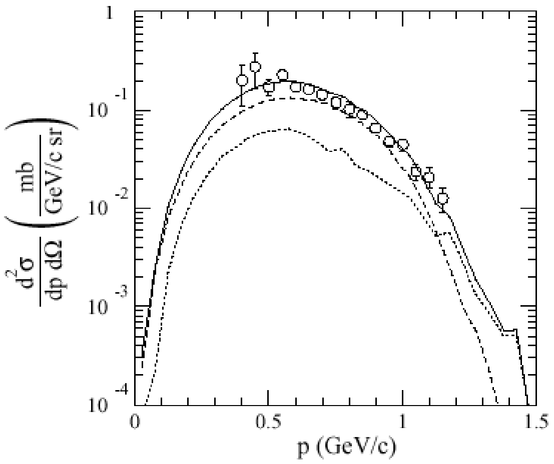

Figure 3: Measured and calculated kaon production cross sections [6] in pC collisions at 2.5 GeV. The dashed line are kaons produced in one step collisions, the dotted line - kaons from $\pi N \to KY$ processes and the solid line is the sum of both components.

a by-product of measurements with heavy nuclei to perform a measurement of the K^+ meson lifetime with an accuracy 3-4 times better than the current world average.

Three days of the requested three weeks are foreseen for these measurements at the projectile energy of 2.3 GeV with a Cu or Pb target.

2 Status of ANKE

The proposed experiments will be performed with the K^+-meson part of the ANKE-spectrometer (fig. 6).

It consists of three dipoles ($D1$, $D2$, $D3$), a strip-target station, the vacuum chamber with 0.5 mm thin Al-windows and the positively charged ejectiles-detector.

The central dipole magnet, $D2$, with the maximum field strength of 1.6 T, pole shoes of $461 \cdot 1240\,\mathrm{mm}^2$ and a gap of 200 mm can analyse K^+ mesons with up to $\pm 7°$ vertical and $\pm 15°$ horizontal emission angles in the $0.1 - 0.8$ GeV/c momentum range of the telescope and side hodoscope direction.

The K^+ mesons detector includes:

- 23 start counters have plastic scintillator of $(0.5 - 2.0) \cdot 50 \cdot 280\,\mathrm{mm}^3$ close to the Al-window along the $D2$ side direction, each of them provides a horizontal angle acceptance of $6° - 2°$ depending on the position of ejectiles at the focal surface of the $D2$;

- 15 telescopes are placed at the $D2$ focal surface to detect positively charged ejectiles in the momentum range from 0.1 GeV/c to 0.6 GeV/c, a horizontal angle acceptance of any telescope can vary from $\pm 1°$ to $\pm 15°$ depending on the hardware or off-line individual coincidences with the corresponding start counters, every telescope is composed of stop, ΔE, veto scintillation counters and Cu-degraders, telescopes number 7 to 15 contain also lucite Cherenkov counters;

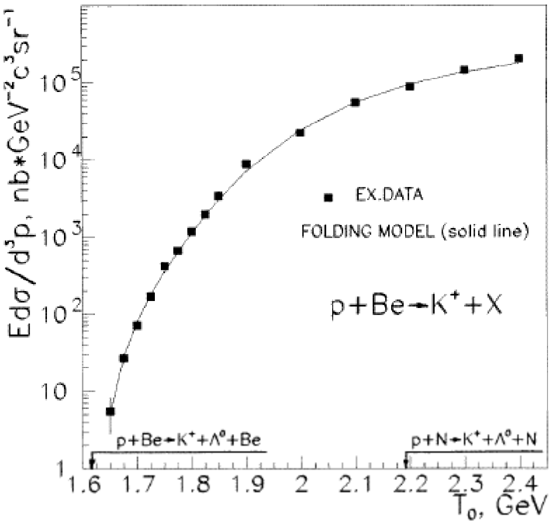

Figure 4: Invariant cross sections for subthreshold production of K^+ with the momentum of 1.28 GeV/c on a Be target as a function of incident proton kinetic energy [8]. The right arrow indicates the threshold energy for the production of K^+ in pN collisions, while the left arrow shows the absolute kinematical limits for K^+ production on a Be nucleus.

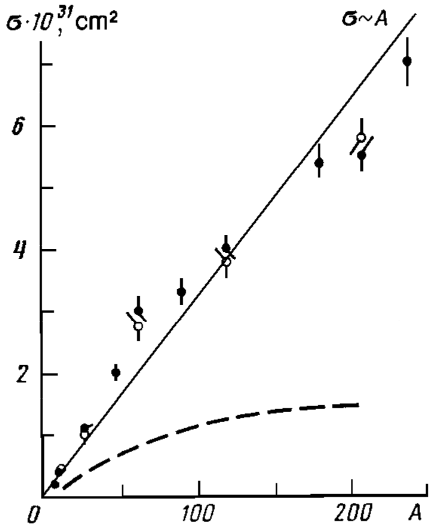

Figure 5: Dependence of experimental (black circles) cross sections for K^+ production on the target-nucleus mass number A at $T_p = 990$ MeV, compared with calculations by the two-step mechanism, in which pion production in the process $NN \to \pi NN$ (open circles) and $NN \to \pi d$ (dashed line) are taken into account [2].

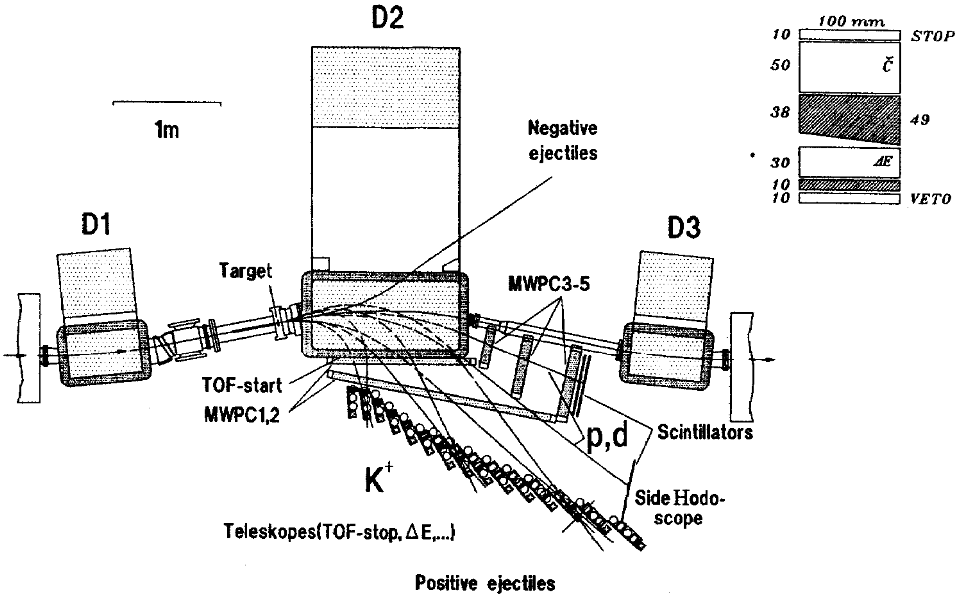

Figure 6: Floor plan of ANKE. Right hand side: typical setup of a stop telescope.

- 2 multi-wire proportional chambers (MWPC1 and MWPC2) with sensitive areas $35 \cdot 130\,\mathrm{cm}^2$ and $60 \cdot 196\,\mathrm{cm}^2$ are used to reconstruct the track of ejectiles, each of them has three anode planes (vertical and $\pm 30°$ inclined) with tungsten wires of 20 μm in diameter and 1/10" wire distances. The cathodes are made of Al-covered 18 μm Mylar foils.

Two additional hodoscopes of plastic scintillation counters (SD and FD) are used to detect protons and deuterons from single pion production reactions in the $0.3 - 0.6$ GeV projectile energy range during calibration experiments. In future SD and FD in cooperation with the forward multi-wire proportional chambers MWPC3-5 will be used in $K^+\,p$ and $K^+\,d$ coincidence experiments to detect $0.6-3.0$ GeV/c protons and deuterons in coincidence with kaons.

All plastic scintillators are read out by two photomultipliers followed by standard electronics. In order to achieve good time resolution (0.60 ns FWHM), specially designed mean-timers and discriminator are used. The readout from the MWPC's is performed with a highly integrated chamber-mounted system [10]. The data acquisition is based on a system of PC's and can write up to 10000 events/s on DLT tapes.

In spring 1998 ANKE with the described detector set-up was moved into the COSY-ring, commissioned and calibrated with pions from the $p\,p \to d\,\pi^+$ reaction. The calibrations were done at 15 projectile energies in the energy range of $0.31 - 0.55$ GeV in order to move the peak of nearly monoenergetic forward pions from one telescope to another or to provide a 1% momentum shift of these pions within one telescope. The calibrations confirmed the spectrometer characteristics of $D2$ predicted from simulation calculations with the accuracy better than 1%.

From autumn 1998 to spring 1999 the K^+ spectra from $p\,C$ interactions were measured at the projectile energies of 2.3, 2.0, 1.8, 1.5, 1.2 and 1.0 GeV for different COSY-beam, target and kaon-detector conditions.

The final measurements (spring-summer 1999) of kaon spectra in the momentum range $0.1 - 0.6$ GeV/c were done with a carbon-strip target (polycrystalline diamond, $d \approx 1 - 2\ \mu$m) at luminosities of $(1-2) \cdot 10^{32}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$. The count rate of all start counters together amounted to about $6 \cdot 10^5\,\mathrm{s}^{-1}$. The coincidence rate of all stop counters with the proper start counters was about $10^5\,\mathrm{s}^{-1}$, which is more than 10^6 times higher than the kaon count rate at $T_p = 1.0$ GeV. About 80% of the observed particles are pions and protons from the target. The remaining particles are mostly protons (p_B in fig. 7 and fig. 8) scattered from the vacuum chamber and rescattered on $D2$. To identify kaons and to suppress background (to less than 1000 counts/s) a fast hardware trigger based on the following criteria was used:

1. the ejectile momenta are defined within $\approx$ 10% by the 10 cm wide telescopes at the focal surface of $D2$. They were kept constant in the wide proton beam energy range by fixing the $D2$ magnetic field strength and the relative target-$D2$-detector geometry. For a new energy, ANKE is moved perpendicular to the beam direction in order to have optimal COSY-beam transportation conditions for a new $D2$ deflection angle;

2. for a given momentum, pions, kaons and protons have different ranges. The thicknesses of the scintillation counters and of the Cu-degraders in the telescopes were chosen such that protons from the target are stopped before they reach the ΔE counters. Kaons are stopped in the second degraders or in the far end of the ΔE counters whereas pions and p_B-protons with the same velocity as kaons traverse all counters of the telescopes if they have not nuclearly interacted in-between. Cu-degraders installed before $\Delta\, E$ counters are tapered to compensate momentum spread across each telescope and to optimise the energy loss difference between kaons and other particles in $\Delta\, E$ counters;

3. fast coincidences between the start counters at $D2$ and the stop counters in the telescopes allow to select particles with the same momentum but different emission angles and to set narrow gates on the TOF regions for kaons;

4. as in previous studies [1, 2, 11] the decay of kaons with a mean life time of 12.4 ns has been used as a strong criterion for the selection of K^+ candidates. In the analysis performed so far, only events have been accepted with signals in the veto counters delayed by more than 1.3 ns with respect to the stop and ΔE counters of the same telescope.

A combination of these criteria with the off-line analysis of the information obtained from the MWPC's (particles stemming from the target have characteristic vertical emission angles) and of energy losses in all scintillation counters permitted to identify kaons in presence of very intense background. The effect of different cuts is shown in fig. 7 and fig. 8.

The target pions and protons are strongly suppressed by the hardware criteria and after fine tuning of start and stop energy losses spectra so that mostly the p_B are left as the background (fig. 7 d, e).

These protons have the same velocity as kaons but about twice higher momentum. Their energy losses in ΔE or veto counters are different from energy losses of kaons or delayed muons and pions and in most cases can be strongly suppressed by off-line analysis

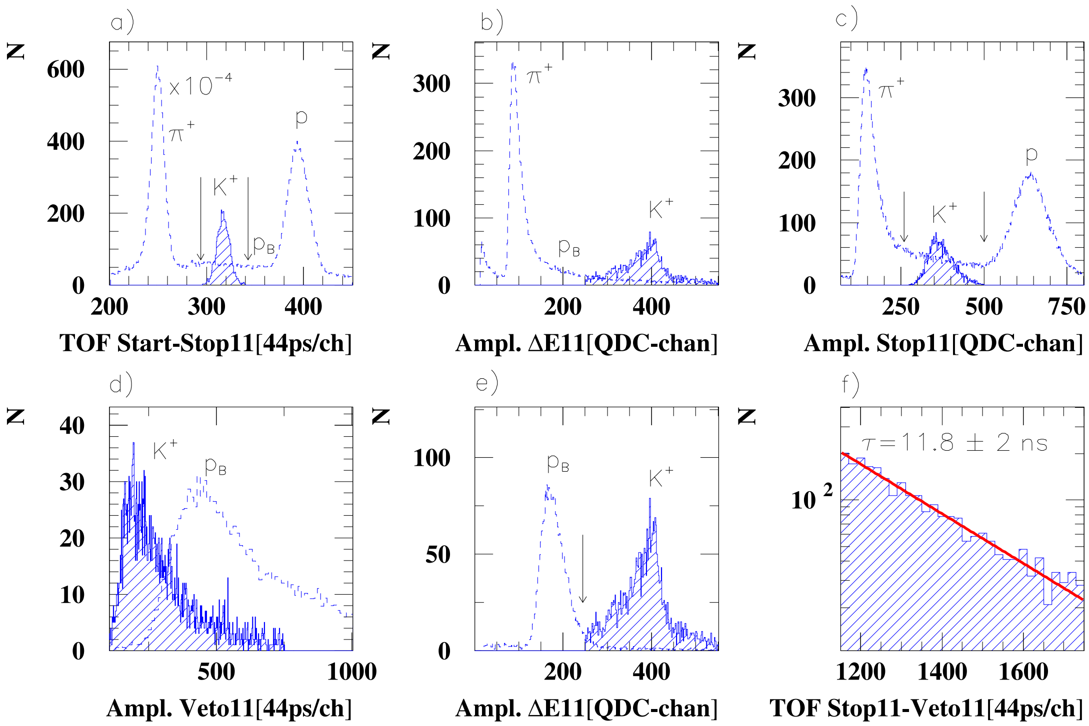

Figure 7: **a), b), c)** - TOF and energy loss distribution of kaons and background particles for Start, Stop and ΔE counters for telescope 11. (π,p - pions and protons from the target p_B - protons rescattered from D2 and vacuum chamber). **d), e), f)** - TOF and energy loss of delayed pions and muons (in Veto counter) and kaons (in ΔE counters) after TOF and energy loss cuts in all the counters are applied. In comparison background protons are shown after cuts in TOF and energy loss in Start and Stop counters are applied.

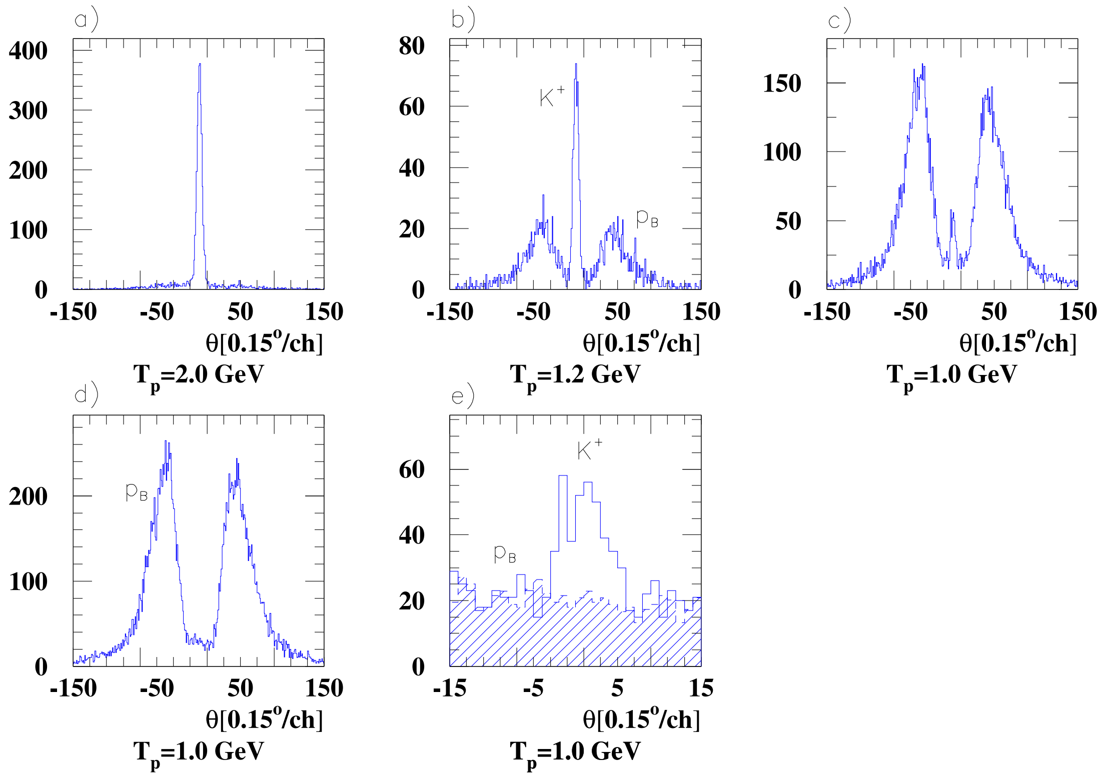

Figure 8: Vertical angle θ distributions, obtained from MWPC information, **a), b), c)** for 1.0, 1.2 and 2.0 GeV proton beam energies after all the hardware, energy loss and TOF criteria are applied, **d)** background protons (same cuts as in a), b), c) except delay criteria), **e)** comparison of the central part of distributions in c), d) in the vertical angle interval $\pm$ 2.3°.

of the corresponding energy losses spectra. However the strongest criteria to reject these protons is a vertical angle cut, based on analysis of the MWPC information. The ejectiles (kaons and target protons and pions) have the characteristic dependence between the vertical coordinate and the vertical angle so that they form a narrow peak around this angle (shifted to zero in fig. 8). The p_B-protons don't have such a characteristic dependence (fig. 8 e) and therefore they are either nearly homogeneously spread around zero (the background from the $D2$ entrance fig. 8 e) or form broad distributions at another angles (left and right wings in fig. 8 are the p_B-protons from the $D2$ pole shoes).

After applying all the criteria K^+ mesons have been clearly identified at all projectile energies. The K^+ momentum spectra for different energies are shown in fig. 9.

These are the numbers of the identified kaons in the individual telescopes not yet corrected for the K^+-detection efficiency in each telescope.

Experience from the first measurements at ANKE show that the device can select K^+ mesons out of the huge flux of background particles. Large solid angle and features at ANKE detection system permit not only to study small cross reactions but also to perform high statistics experiments such as precise measurements of the K^+ mesons lifetime. This has been shown during the experiments at 2.3 GeV. As a by-product of these measurements, the statistics of 100000 exponentially distributed delayed muons and pions from kaon decay was taken. The statistical uncertainty of 0.3% or only two times worse than the world averaged accuracy was achieved for a short period of beamtime.

The distribution, presented in fig. 10, was obtained during studies of different trigger possibilities which were not most optimal conditions for the lifetime measurements. At that moment veto counters were not included into the trigger and the efficiency of the beamtime use was 25%, since only 4000 of 16000 triggered events were taken on tape.

During the A-dependence measurements signals from veto counters will be switched into trigger and K^+ mesons will be produced from heavy targets with cross sections 6-7 times higher than for C-target at 2.3 GeV. At these conditions it is possible to increase K^+ counting rate up to $15 - 20$ events/s and after three days to provide statistical accuracy of $0.07 - 0.05\%$ equivalent to 3-4 times better than the world average.

3 Beamtime Request

No changes in the ANKE detection system will be done to study the A-dependence of kaon spectra from Al, Cu and Pb at the energies 2.3, 1.2 and 1.0 GeV.

Some changes in the hardware trigger and electronics will be useful to make the K^+ mesons lifetime measurements more efficient. For these measurements it is better not to use the criterion of the delayed muons and pions.

The experiment will be done without or with any of signals from veto counters in the trigger. To reduce the p_B-background and the trigger count-rate the hardware thresholds will be increased in the ΔE-counter up to the level marked by the arrow on fig. 7. The price will be $15 - 20\%$ of additional losses of kaon count rate. The profits are:

- together with the 3 ns fast start-stop coincidences that will reduce the trigger count rate from 16000 events/s to $2000 - 3000$ events/s;
- the other off-line criteria (fig.7 a), b), c) and fig.8) will reduce significantly the prompt peak background and will permit to see a homogeneously spread accidental (or any other) background left side the exponential time distribution (fig.10 b).

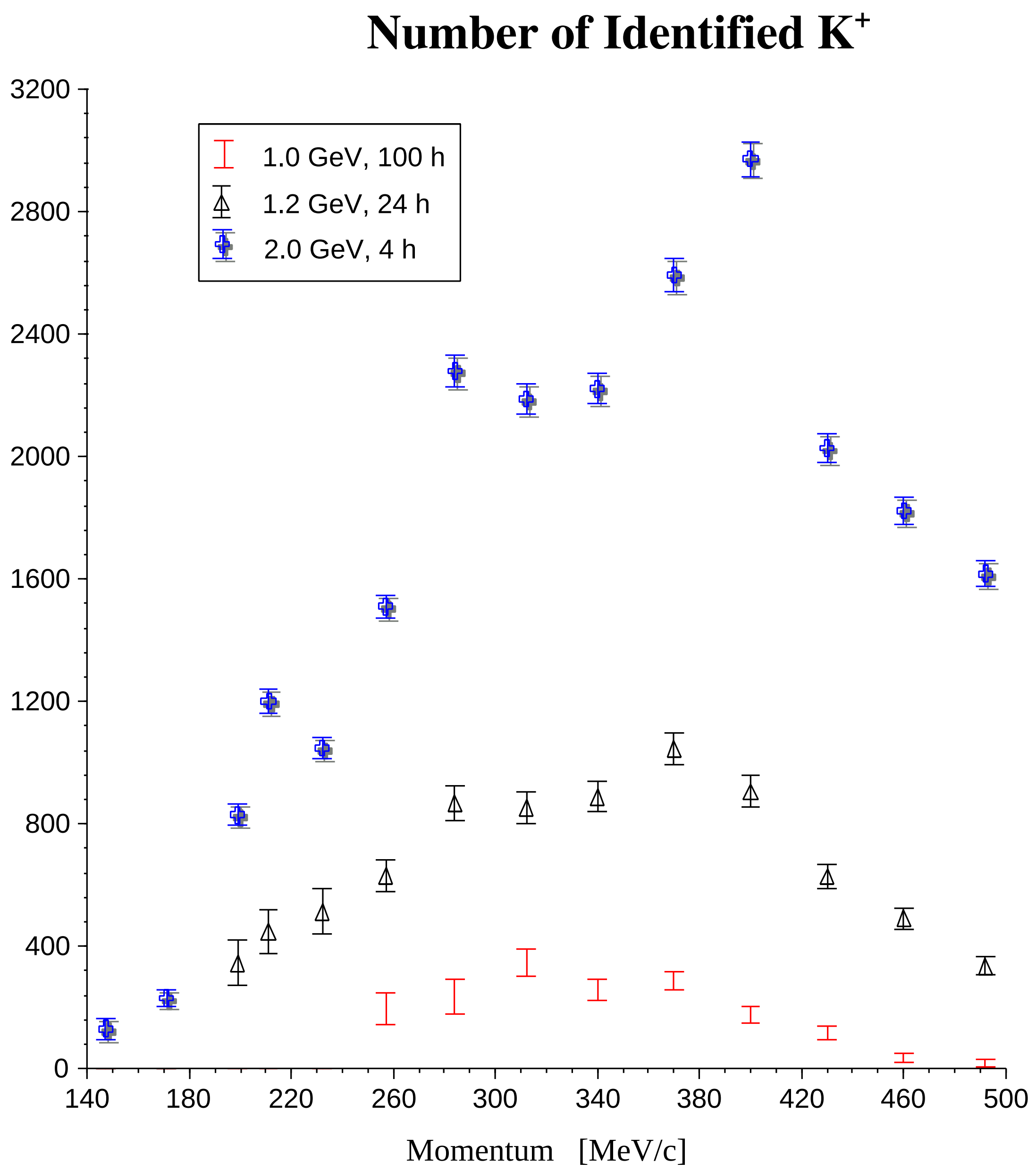

Figure 9: K^+ momentum spectra at 1.0, 1.2 and 2.0 GeV proton beam energy are shown. The numbers of identified K^+ in each telescope are not yet corrected for the kaon-detection efficiencies.

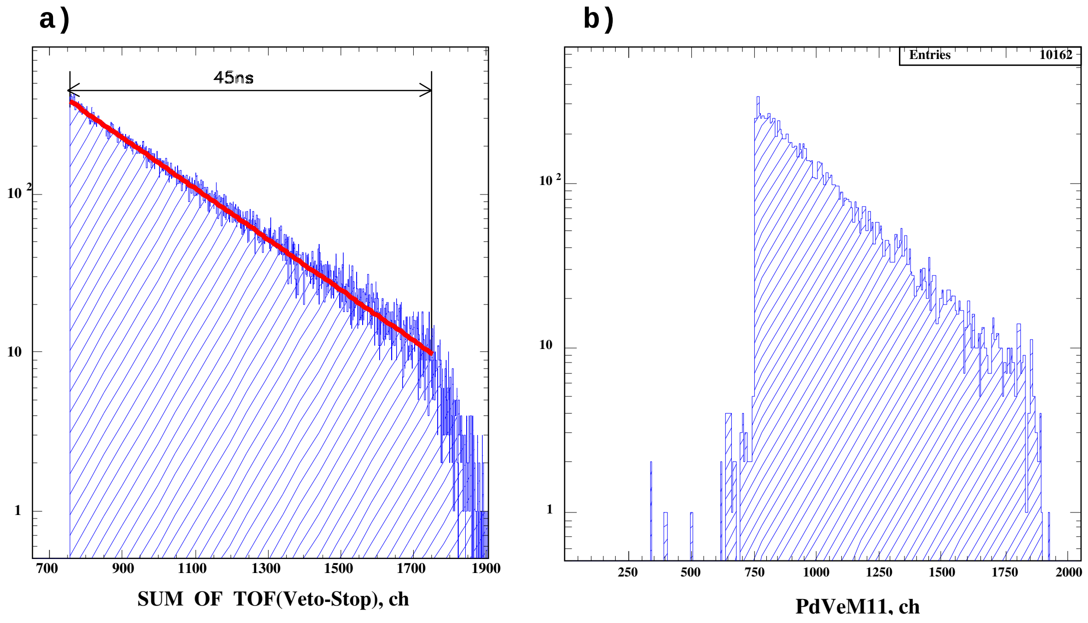

Figure 10: Exponential distribution of delayed muons and pions from kaon decay detected by **a)** all telescopes after applying of all the TOF and energy loss cuts and requesting 1.3ns delay in Veto counter in respect to prompt particles. $T_p = 2.3$ GeV, measuring time $t = 20$ h, $N_{K+\rightarrow\mu+} = 104000$ events. The fit to the exponential slope gives $\tau_K = 12.21 \pm 0.05$ ns (statistical error) with χ^2=1.077. The current world average K^+ meson lifetime is 12.386 ± 0.024 ns [12], **b)** telescope 11 after all the cuts of a) except the 1.3 ns delay criterion. It is seen that the cuts cast out background particles like pion which would otherwise cause an intense prompt peak in this spectrum.

This innovation will be checked during the calibration runs at 2.3 GeV with any target.

To simplify the data analysis one additional high-quality TDC will be used for measurements of the summarised time distribution of the delayed muons and pions from all the telescopes. The total time range of this TDC will be of $150 - 175$ ns with the bin width of $40 - 50$ ps and the differential nonlinearity of $0.2 - 0.3\%$. In parallel to this spectra the similar information will be taken the 15 existing veto TDC of individual telescopes as the cross-check of the results.

For measurements with three targets (Al, Cu, Pb) at three energies (2.3, 1.2 and 1.0 GeV) it is requested:

2.3 GeV	calibrations and 5h*3=1day
1.2 GeV	16h*3=2days
1.0 GeV	4d*3=12days
lifetime	3days
beam development and possible beamtime losses	3days
totally	3weeks

The beam conditions and the COSY optics are requested to be similar to those realized in June 1999. They are the following:

1. Beam intensity is not less than $(2.5\text{-}3.0)\cdot 10^{10}$ particles per cycle at proton beam energies from 1.0 to 2.3 GeV.
2. Cycle time: 45s.
3. Duty cycle: not less than 80% of cycle time.
4. Vertical steering and feed-back loop is used to ensure not less than 95% of the time-isotropic spread beam intensity.
5. Beam transportation through ANKE and background conditions are such that without the strip target only background from cosmics is seen by the side detector during the "plateau-time".
6. Same target position as during the June 1999 beam time.

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