# Subthreshold $K^+$-Production Studies with ANKE at COSY-Jülich*

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**Abstract.** The spectrometer ANKE at the synchrotron COSY-Jülich allows to momentum analyze ejectiles emitted from an internal target at forward angles $\varphi \simeq 0°$ with large angular acceptance ($\Delta\Omega \simeq 50$ msr). In first measurements the $K^+$-production in pA collisions at beam energies from 1.0 GeV, far below the nucleon-nucleon threshold of 1.58 GeV, up to 2.3 GeV was investigated. The experimental challenge at 1.0 GeV is to measure the $K^+$-production with cross sections of about $10^{-34}$ cm$^2$ at a background cross sections level of $10^{-27}$ cm$^2$. Data on the target-mass dependence of the differential cross section for kaon momenta $p_{K+} = 150...510$ MeV/c and three different targets, C, Cu and Au, are presented and compared with theoretical predictions.

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# I THE ANKE SPECTROMETER

The spectrometer ANKE [2–4] is located in one of the two straight sections of the race-track shaped accelerator ring COSY [5]. Its three dipole magnets guide the circulating beam out of its nominal path towards the target and back into the standard orbit. The spectrometer dipole D2 deflects forward-emitted ejectiles from proton-induced reactions on strip targets of C, Cu and Au from the circulating beam and allows the determination of their emission angles and momenta with the $K^+$-detection system, see Fig. 1 a). The 20 cm gap of the dipole D2 provides a vertical acceptance in the range of $3.5° < |\vartheta| < 5.5°$; the horizontal acceptance amounts to $\varphi \sim -12° \ldots 12°$.

The $K^+$-detection system consists of: *i)* 23 Start counters close to the 500 $\mu$m thick Al vacuum window at the side of D2. *ii)* 15 telescopes along the focal surface of D2 to detect positively charged particles in the momentum range from 110 to 525 MeV/c at $B_{D2} = 1.3$ T. The telescopes, see Fig. 1 b), comprise an active part (Stop-, $\Delta E$-, Veto scintillation- and lucite Cherenkov counters (only telescopes 9–15)) and two passive Cu degraders. *iii)* 2 multi-wire proportional chambers MWPC1 and MWPC2 which are used to reconstruct ejectile trajectories. They have each three sensitive anode planes with vertically and ±30° inclined tungsten wires.

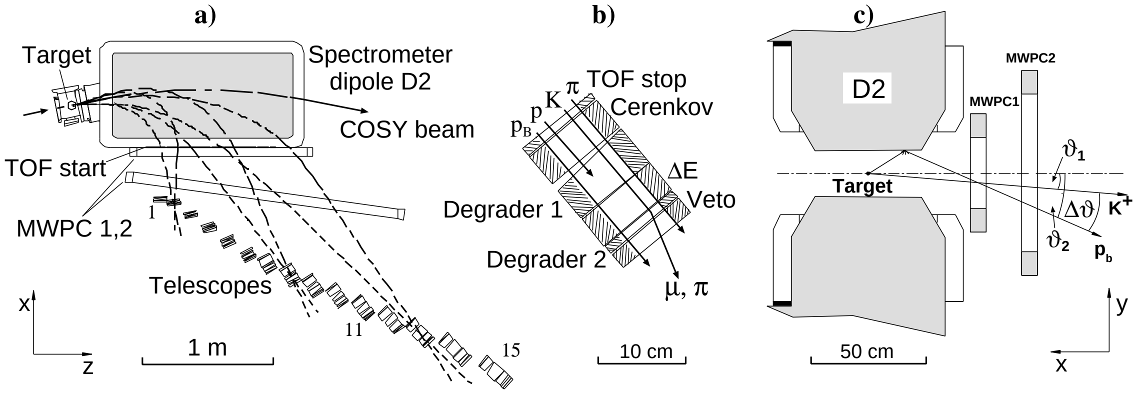


**FIGURE 1. a)** Top view of the ANKE spectrometer. **b)** Setup of telescope #14. **c)** Side view of ANKE; rescattered particles $p_b$ have angles ($\vartheta_2$) different from target particles ($\vartheta_1$) and may cross MWPC1 at the same point.

The $K^+$-identification procedure is briefly described in the following — see [2,3] for more details: Pions and protons from the target are strongly suppressed by appropriate time of flight (TOF) criteria between the Start- and Stop counter and the energy-loss cuts in these counters. The first degrader optimizes the energy-loss ratio of kaons to pions in the $\Delta E$ counter and stops protons originating from the target. The second degrader prevents kaons from reaching the Veto counter. This offers the possibility to use the $K^+$-decay as a criterion for the discrimination against background: the $K^+$-decay products, mainly monoenergetic pions or muons, can be detected with a characteristic delay with respect to the signal in the Stop counter of the same telescope. Exploiting the information from the scintillation counters one can suppress nearly all the background from the target. The remaining background, mostly rescattered protons $p_b$ (Fig. 1 c)), can effectively be discriminated with wire chambers since particles from the target at a vertical angle $\vartheta$ are grouped in a narrow peak in the $\Delta\vartheta$ distribution, mainly defined by multiple Coulomb scattering. Similar distributions for rescattered particles turn out to be flat.

# II A-DEPENDENCE OF THE $K^+$ CROSS SECTION

The measurements were performed at proton beam energies of $T = 1.0$, 1.2, 1.5, 1.8, 2.0 and 2.3 GeV with carbon targets. At $T = 1.0$ and 2.3 GeV the kaon production was also studied with gold and copper targets. In Fig. 2 the number of identified kaons in the different telescopes from the three targets are presented. Absolute values of the cross sections will be obtained by normalization of $N_{K^+}$ to the known pion production cross section [6–8].

In addition, it is also necessary to correct the spectra for the angular-momentum acceptances and the detection efficiencies of the telescopes and wire chambers. The corresponding measurements were carried out and are currently evaluated. These calibration constants are equal for all measurements and do not influence the cross-section ratios for kaon production from different targets. The corresponding ratios for pion production are known with an accuracy of 3–10% [6–8].

To improve the statistical accuracy of the cross-section ratios, the corresponding spectra of the different telescopes have been summed up. Fig. 3 shows the distribution for $\Delta\vartheta$ for the C target at $T = 2.3$ GeV and for C, Cu and Au at 1.0 GeV. At 2.3 GeV there is almost no background left after the scintillation-counter information is applied. At 1.0 GeV the kaon-to-background ratio decreases with increasing target mass number. Table 1 compares the momentum-integrated ratios of cross sections with theoretical expectations. At 2.3 GeV theoretical models [9–12] predict that $K^+$-production takes place in a single proton-nucleon collision. In this

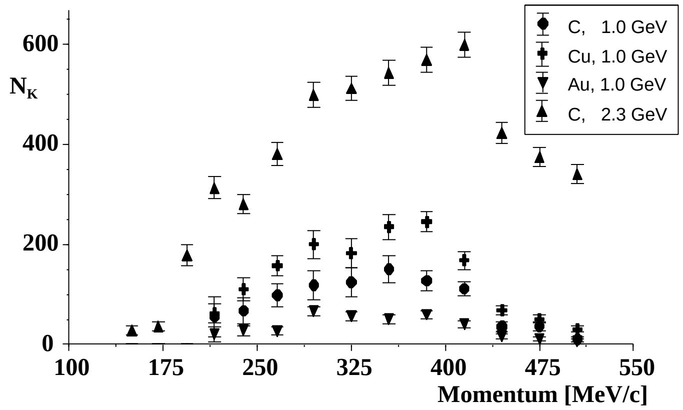


**FIGURE 2.** Number of identified kaons for Au, Cu and C targets at 1.0 GeV and for C at 2.3 GeV. Statistical errors are indicated. Each data point corresponds to the number of kaons in one telescope, the first telescope has been omitted because of a too high background level.

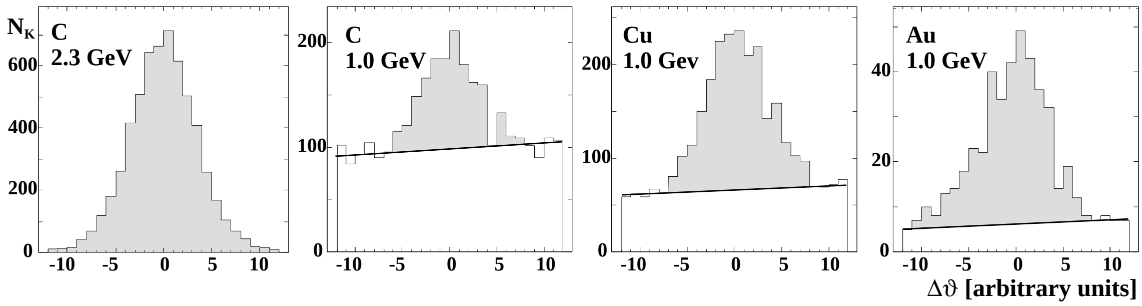


**FIGURE 3.** Distribution of $\Delta\vartheta$ for the C target at 2.3 GeV and for the targets C, Cu and Au at 1.0 GeV beam energy. The distribution of background can be described with straight lines. Its slopes have been determined in a detailed analysis.

case a scaling of the total $K^+$-production cross section with $A^{2/3}$ is expected from a simple geometrical model. The experimental results are in good agreement with that model. At 1.0 GeV the $K^+$-production should occur mainly via two-step mechanisms where in a first proton-nucleon collision an intermediate pion is produced. Such mechanisms imply a scaling of the $K^+$ cross section with A. The ratio Cu/C is in accordance with this assumption while the ratio Au/C does not seem to fit the model. Currently detailed calculations are in progress to find out whether the rescattering of the kaons in the heavy gold target leads to a reduced $K^+$ yield.

**TABLE 1.** Comparison of measured cross-section ratios with theoretical predictions for different targets and different energies.

| Energy [GeV] | $(Cu/C)_{exp}$ | $(Cu/C)_{theory}$ | $(Au/C)_{exp}$ | $(Au/C)_{theory}$ |
|---|---|---|---|---|
| 1.0 | 5.6±0.5 | 5.3 | 9.2±1.2 | 16.3 |
| 2.3 | 3.6±0.4 | 3.0 | 6.6±0.6 | 6.5 |

# REFERENCES


1. See `http://ikpd15.ikp.kfa-juelich.de:8085/doc/Anke.html`
2. S. Barsov et al., *Nucl. Phys.*, **A663–664**, 1107 (2000)
3. S. Barsov et al., *Nucl. Phys.*, **A675**, 230 (2000)
4. S. Barsov et al., *submitted to NIM A*, (May 2000)
5. R.A. Maier, *Nucl. Phys. News* **7** No. 4, (1997)
6. D.R.F. Cochran et al., *Phys. Rev.* **D6**, 3085 (1972)
7. J. Papp et all., *Phys. Rev. Lett.* **34**, 601 (1975)
8. V.V. Abaev et al., *J. Phys.* **G14**, 903 (1988)
9. V.P. Koptev et al., *JETP* **67**, 2177 (1988)
10. W. Cassing et al., *Phys. Lett.* **B238**, 25 (1990)
11. A. Sibirtsev et al., *Z. Phys.* **A347**, 191 (1994)
12. E.Ya. Paryev, *Eur. Phys. J.* **A5**, 307 (1999)



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