Addendum to Proposal # 171: "Study of energy dependence of the $pp \to K^+\Sigma^+n$ reaction close to threshold"

Yu. Valdau (*Spokesperson*), V. Koptev , M. Nekipelov, H. Ströher, C. Wilkin

and the ANKE collaboration

April 5, 2007

In Fig. 1, the World data set on the total cross sections for the $pp \to K^+n\Sigma^+$ reaction, $\sigma(\Sigma^+)$, are compared to the parameterisations for the $pp \to K^+p\Lambda$ and $pp \to K^+p\Sigma^0$ reactions [1]. In contrast to the other light hyperon channels, the energy dependence of $\sigma(\Sigma^+)$ shows a surprisingly strong near–threshold enhancement that may violate isospin invariance by more then a factor ten. The new ANKE data point coincides with one of those measured with the COSY–TOF detector [5] (for the details of the ANKE analysis, please see the attached paper [6]) and falls well within the boundaries fixed by the isospin relations. Taking all the data points together, including results measured at COSY–TOF, there is a clear indication for a large close–to–threshold anomaly, which we propose to investigate further using the ANKE spectrometer [7].

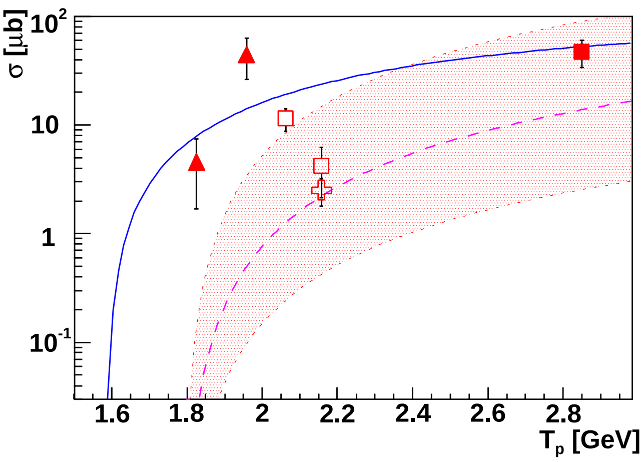

Figure 1: Total cross sections for the $pp \to K^+n\Sigma^+$ reaction are shown by the symbols: triangles [2], open squares [5], Swiss cross [6], closed square [4]. The lines show the normalised three–body phase–space dependence for the $pp \to K^+p\Lambda$ (solid line) and $pp \to K^+p\Sigma^0$ (dashed line) reactions, corrected for the FSI effect in the case of the Λ. The hatched area indicates the possible range of $\sigma(\Sigma^+)$ restricted by the isospin relations.

It is proposed to measure Σ^+ production at five energies close to threshold [7]. For the analysis of these data it is planned to apply all the methods used for the ANKE data at 2.16 GeV, as reported in Ref. [6]. In this document we will only present the results of simulations for the proposed experiment at two energies. Data collected at other energies will be analysed using the same procedures.

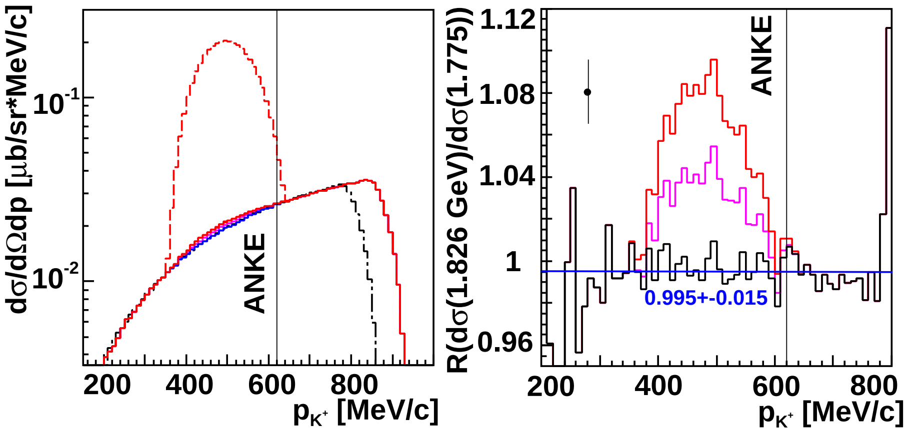

Figure 2: Left Panel: Simulations of the K^+ inclusive double–differential cross sections at 1.826 GeV and 1.775 GeV averaged over the 12°. The dashed line uses the value of $\sigma(\Sigma^+)$ at 1.826 GeV, as reported in Ref. [2]. The solid line is plotted assuming $\sigma(\Sigma^+) = \sigma(\Sigma^0)$. The double–differential cross section for K^+ production at 1.775 GeV, *i.e* below the Σ threshold, is shown by the dot–dashed line. Right Panel: shows the ratio of the double–differential cross sections measured at 1.826 GeV and 1.775 GeV. The value from the Λ channel is shown by the solid line, while the contributions from Σ^0 and Σ^+ are shown by the dotted and dashed lines, respectively. The expected error is indicated by the dot with an error bar. The momentum range available at ANKE is also shown.

Simulations of the double–differential cross section at 1.826 GeV is shown in Fig. 2. Two scenarios are envisaged. If $\sigma(\Sigma^+)$ is as high as found by COSY–11 at this energy [2], then the $pp \to K^+ n \Sigma^+$ reaction will be the dominant contribution to the K^+ inclusive spectra. If, on the other hand, $\sigma(\Sigma^+)$ is rather close to $\sigma(\Sigma^0)$, this can easily be found out during the run. To distinguish this contribution then from the others by using the inclusive spectra, we will have to replace a measurement at one of the energies by one below the Σ^+ threshold. Simulations of the double–differential cross section at 1.775 GeV (corresponding to $\varepsilon = -5$ MeV in the $K^+ n \Sigma^+$ system) are shown in the Fig. 2 by the dash–dotted line. This observable is almost the same in shape and absolute value as the contribution of the Λ reaction channel expected at 1.826 GeV. The ratio of the double–differential cross sections at these two energies is presented in Fig. 2. After two days of measurements at each energy, we will determine this ratio with a precision of 1.5% and thus fix the Σ^+ total cross section with an accuracy of better then 50% even if $\sigma(\Sigma^+)$ is as small as $\sigma(\Sigma^0)$. It is important to emphasise that the inclusive measurements at these low energies will hardly depend at all on any model, since almost all of the K^+ from Σ^0 and Σ^+ production are in the ANKE acceptance. The inclusive acceptances for the different Σ reaction channels are presented in Table 1.

In parallel to the measurements of the inclusive spectra, we shall also collect statistics for the K^+p and $K^+\pi^+$ correlations. Total geometrical acceptances for the different reaction channels estimated, using phase space simulations, are shown in Table 1.

Simulations of the expected K^+p missing–mass and π^+ momentum spectra corresponding to two days of beam time are shown in the Fig. 3 for the two different assumptions about $\sigma(\Sigma^+)$. At all five energies planned for this experiment, the π^+ momentum spectra look very similar. We therefore show only one of them. It is obvious that if the Σ^+ total cross sections are as high as found by COSY-11 [2], this channel will strongly influence both experimental spectra.

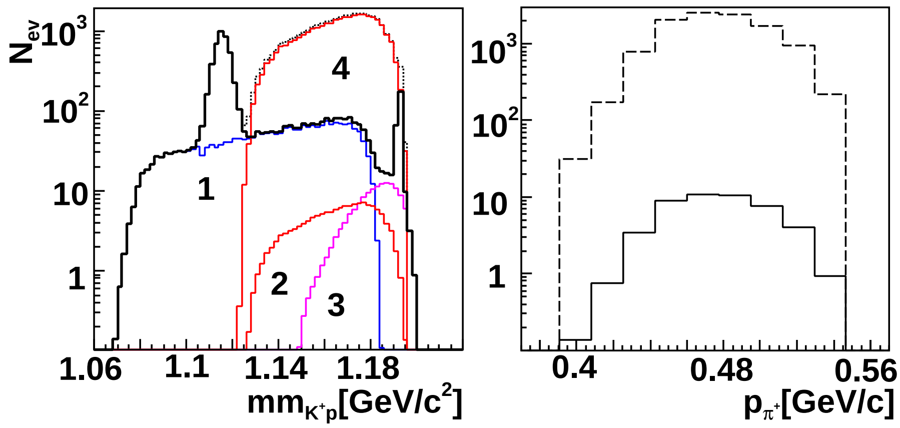

Figure 3: Left Panel: Simulations of the K^+p missing mass spectra proposed to be measured with ANKE at 1.826 GeV. In addition to the two peaks corresponding to vertex protons from reactions with Λ and Σ^0, contributions of secondary protons arise from the $pp \to K^+p(\Lambda \to p\pi^-)$ (curve 1), $pp \to K^+p(\Sigma^0 \to \gamma\Lambda \to p\pi^-)$ (curve 3), and $pp \to K^+n(\Sigma^+ \to p\pi^0)$ (curve 2) reactions. All the contributions are normalised to the total cross sections taken from Fig. 1. For the Σ^+, two possible scenarios are considered, *viz.* if $\sigma(\Sigma^+) \sim 1.5 \times \sigma(\Sigma^0)$ (curve 3), or if the cross section is as large as suggested by the results of Ref. [2] (curve 4). The sum of all contributions for both assumptions about the Σ^+ total cross section are shown by the solid and dotted histograms. Right Panel: Simulations of the momentum spectrum of the π^+ when these are correlated with K^+ coming from the $pp \to K^+n\Sigma^+$ reaction at 1.826 GeV. The scenarios when $\sigma(\Sigma^+)$ is as quoted in Ref. [2] and when $\sigma(\Sigma^+) = \sigma(\Sigma^0)$ are shown by the dashed and solid lines, respectively.

Simulations of the K^+p missing–mass and K^+ inclusive spectra at 1.958 GeV are shown in the Fig. 4 with the two assumptions for $\sigma(\Sigma^+)$. The missing–mass spectra at this energy are very similar to those at 1.826 GeV and, if the value of $\sigma(\Sigma^+)$ is indeed high, this spectrum will change drastically. The influence of a possible strong $n\Sigma^+$ final state interaction, in the case of high $\sigma(\Sigma^+)$, can be investigated using inclusive spectra at 1.826 GeV, where the ANKE acceptance for the K^+ correlated with Σ hyperons is $\sim 65\%$. In this case the K^+ production double–differential cross section can be built for the different θ angles in a range $0° \div 12°$ with step $\sim 1.5°$. The experimental spectra expected at 1.873 GeV and 1.920 GeV are very similar to those at 1.958 GeV. Therefore, the same procedure for the analysis of these data will be used. The measurement at 2.02 GeV is very important for the comparison with the lowest data point measured with the COSY–TOF detector [5]. At this

Table 1: Total acceptances for different reaction channels at three energies. It should be noted that the Kaon decay probability is not included.

T_p (GeV)	$acc_{\Sigma}(K^+)$	$acc_{\Sigma^+}(K^+\pi^+)$	$acc_{\Lambda}(K^+p)$	$acc_{\Sigma^0}(K^+p)$	$acc_{\Sigma^+}(K^+p)$
1.826	0.65	2.2×10^{-2}	2.8×10^{-3}	6.5×10^{-2}	4.5×10^{-2}
1.958	0.13	4.4×10^{-3}	1.1×10^{-3}	8.0×10^{-3}	8.0×10^{-3}
2.020	0.10	3.3×10^{-3}	8.3×10^{-4}	3.75×10^{-3}	5.0×10^{-3}

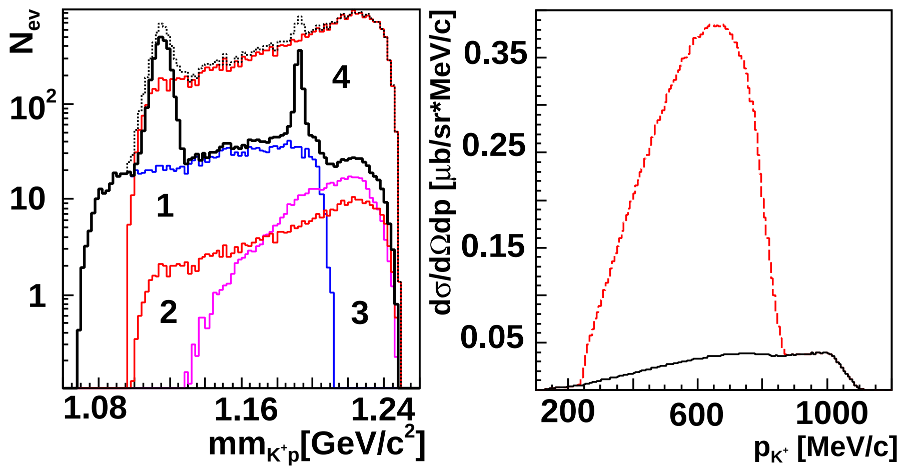

Figure 4: Left Panel: Same as Fig. 3 but for a beam energy of 1.958 GeV. Right Panel: Same as Fig. 3 but for the K^+ spectrum at 1.958 GeV.

energy the expected spectra are closer to those at 2.16 GeV [6], but we expect a factor of ten more statistics after only one day of measurement.

Summarising, we ask PAC for the approval of the proposal and an allocation of **two weeks** of beam time, including **four days** for machine development, in **Autumn 2007**.

References

[1] A. Sibirtsev, J. Haidenbauer, H.–W. Hammer and S. Krewald, Eur. Phys. J. A **27** (2006) 269.

[2] T. Rożek *et al.*, Phys. Lett. B **643** (2007) 251..

[3] T. Rożek , PhD thesis, University of Silesia in Katowice (2005), Jül-4184, ISSN 0944-2952.

[4] R.I. Louttit *et al.*, Phys. Rev. **123** (1961) 1465.

[5] M. Wagner, PhD thesis, University of Erlangen–Nürnberg (2002);
P. Schönmeier, PhD thesis, University of Dresden (2003);
L. Karsch, PhD thesis, University of Dresden (2005).

[6] Yu. Valdau *et al.*, submitted to PLB, nucl-ex/0703044.

[7] Yu. Valdau *et al.*, COSY proposal #171 (2006);
http://www.fz-juelich.de/ikp/anke/en/proposals.shtml.

[8] A. Sibirtsev, J. Haidenbauer, H.–W. Hammer and U.-G. Meißner, (*in preparation*).

[9] W.-M. Yao *et al.*, J. Phys. G **33** (2006) 1.