Strangeness Production at COSY

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The first results of COSY experiments concerning strangeness production in elementary pp-interactions are presented. Data have been taken for hyperon- as well as η'- and K^+K^--production. Preliminary total cross sections in the threshold region are given. The data demonstrates the high quality of the COSY-beam and the high sensitivity of the detection systems at COSY.

1. Introduction

The cooler synchrotron COSY, see fig. 1, has been designed for precision experiments in the medium energy region. It is a storage ring with phasespace cooled beams like IUCF and CELSIUS.

The importance of such a high quality beam has been demonstrated by the $pp\pi^0$ data of IUCF [1] which have led to an improvement of the theoretical understanding for the pion production channel . Data of similar precision are expected from COSY for other reaction channels especially those which include strangeness production.

Some parameters of COSY are given in Table 1.

Table 1
Parameters of COSY

circumference	184 m
momentum range (protons)	295 to 3450 MeV/c
RF (h=1)	0.4 to 1.6 MHz
ramping (1 T/s)	$\leq 2 \cdot 1.6$ s
space charge limit	$2 \cdot 10^{11}$ protons
stripping injection	H^- (polarized possible)
electron cooler	295 to 645 MeV/c (25 to 100 kV)
stochastic cooling	1.5 to 3.5 GeV/c ; W = 3 GHz
beam emittance	$< 1\,\pi\, mm\, mr$
momentum resolution	$< 10^{-4}$

Presently unpolarized H^- beams are frequently used and polarized beams are under development. In the near future also a deuteron beam will be available. The momentum range starts at 295 MeV/c, far below the pion production channels and goes up to 3.45

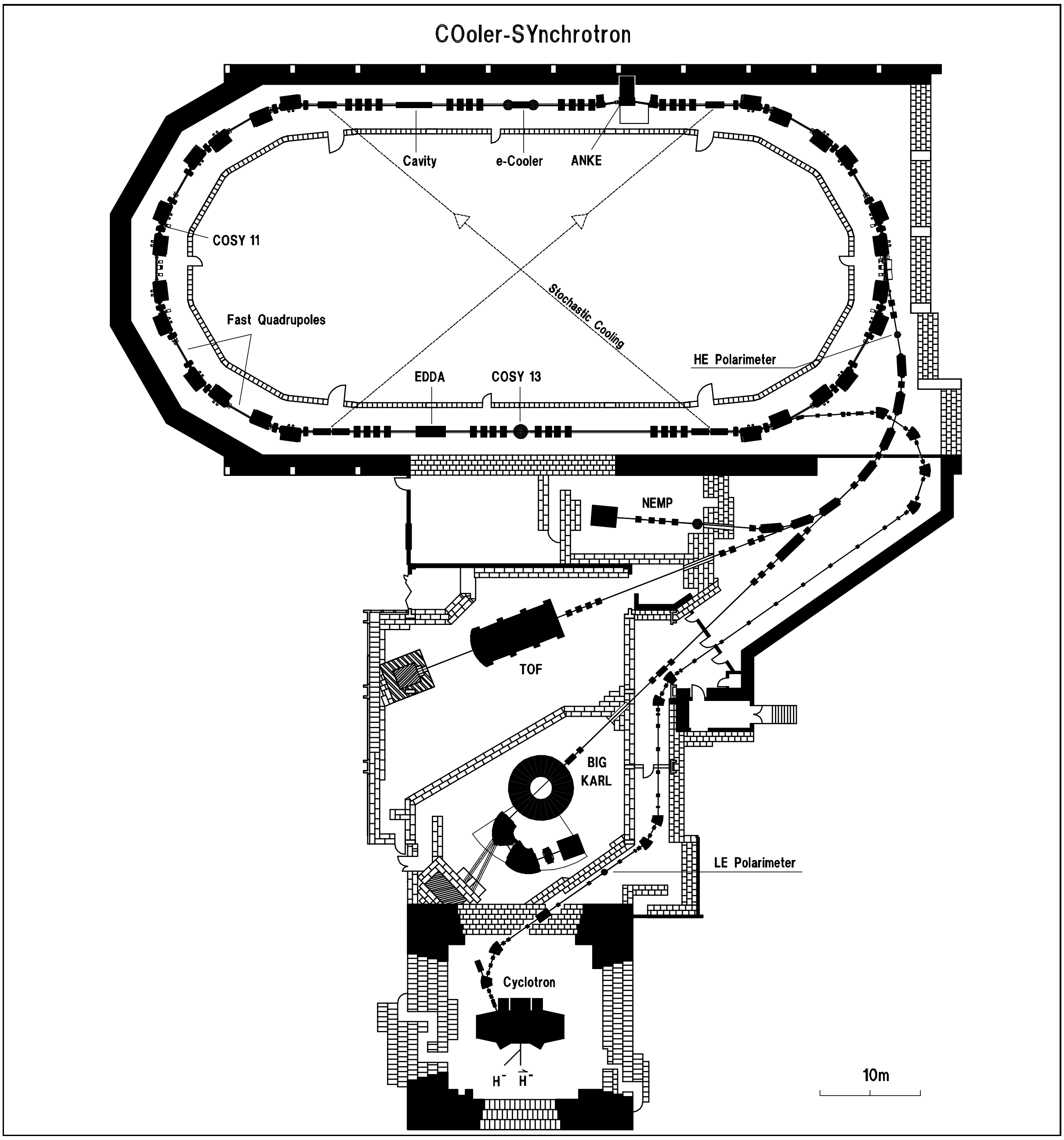


Figure 1. Sketch of the COSY ring with injector cyclotron and the experimental facilities.

GeV/c which allows the associated strangeness production in elementary interactions like $pp \to pK^+\Lambda$ or $pp \to ppK^+K^-$. Due to the space charge limit at injection momentum the number of stored protons is limited to $2{\cdot}10^{11}$ protons. The momentum resolution $\Delta p/p$ will be below 10^{-4} for a cooled beam where electron cooling as well as stochastic cooling is installed. The experimental results presented in this contribution were performed without cooling which reduces the momentum resolution to values of $\Delta p/p = 5 \cdot 10^{-4} - 10^{-3}$.

At COSY internal and external target stations are available. The external installations are TOF [2], a large time of flight spectrometer, and BIG KARL, a magnetic spectrometer, whose geometrical acceptance is extended by additional detector components in the target area. Furthermore the low energy measurement place, NEMP, was used for studies of energy loss distributions in tissue equivalent materials needed for proton therapy.

Three internal experiments are in operation. EDDA was designed for the measurement of elastically scattered protons. Recently a large set of unpolarized data were published [3] and in the near future data with polarized beams on a ppolarized atomic beam target will be taken. COSY-13 is a device for studies of the Λ lifetime in the nuclear medium by measuring heavy Λ-hypernuclei production and their delayed Λ induced fission [4]. The COSY-11 installation is mounted in a bending section of COSY in front of a machine dipole which is used as a magnetic spectrometer [5].

A fourth internal installation, ANKE, will be installed in the end of 1997 [6]. It is a large $0°$-facility of the chicane type allowing a flexibe operation by variation of the bending power independently of the COSY magnets.

The main topic of the physics at COSY is the structure of mesons and baryons in the confinement regime of the QCD studied by items like threshold production of mesons, associated strangeness dissociation, investigation of medium effects, search for exotics, analysis of meson meson interaction and reaction mechanisms.

Entrance channels as pp, pd, p^3He, $p\alpha$ and pA are covered by running experiments or submitted proposals. In the exit channel elastic and quasi-elastic reactions as well as the production of instable or excited hadrons are analyzed.

Strangeness production which is the topic of this contribution, is considered in different experiments at COSY where elementary interactions and in nuclear medium effects are studied.

2. Motivation

The motivation for the associated strangeness production at COSY has different aspects.

In the meson production studies in $pp \to ppX$ or $pd \to^3\mathrm{He}X$ with X being a neutral meson like η' and Φ or a kaon system like K^+K^-, information on the structure of the mesons can be extracted. Especially the ratio of Φ/ω-production will contribute to this item since the $\Phi - \omega$ mixing will give information wether Φ is a pure $s\bar{s}$ and ω a pure non $s\bar{s}$ state. Also the question of the strangeness content of the proton arises in such studies.

Studies of the $K\bar{K}$ channel will contribute to study the structure of the scalar objects f_0 and a_0 which is still under discussion, to be of $q\bar{q}$, $K\bar{K}$ molecule or other exotic nature.

The associated strangeness production via the (KY)-channel, i.e. $pp \to pK^+\Lambda$ or $pp \to pK^+\Sigma$ is addressed to questions like $s\bar{s}$-dissociation and reaction dynamics or more general the QCD in the confinement region. Furthermore cross sections for the elementary interactions are needed as input for calculations of the $s\bar{s}$-creation in heavy ion collisions which is an essential input to the physics of the possible quark-gluon plasma production. An enhancement of strangeness is supposed to be a signal for the phase transition.

Nucleon resonances are always very broad and are characterized by a dense spectrum on the energy scale. The strangeness containing ΛK^+ decay branch is very useful for the decomposition of these broad overlapping resonances. By measuring this decay channel only a few specific resonances with a high branching ratio into ΛK^+ as it is the case for the $N^*(1710)$ resonance are selected. Such studies are under preparation at COSY using a heliumtarget. Due to the spin and isospin =0 structure of the α particle such reactions are very selective and can be considered as elementary if the α particle remains in the ground state during the reaction process. Considering the isospin selection rules the excitation of a Δ-resonance is not possible in such reactions which drastically reduces the background in contrast to the NN interaction with its dominant Δ-excitation.

The strangeness production in the nuclear medium is studied at the COSY-13 experiment, a setup for the study of hypernuclei, and will be extensively investigated at ANKE considering the kaon production.

From measurements of heavy hypernuclei informations on the medium modification can be extracted. The influence on the Λ-lifetime or more generally the ΛN interaction in nuclear medium can be seen.

The analysis of the kaon yield especially for the subthreshold production will contribute to questions on the reaction mechanism and the contribution of high momentum components can be examined. Compared to pions, kaons have a much larger interaction length in the nuclear medium and therefore they yield nearly undisturbed information from the center of the nuclei.

From the experimental point of view measurements of strangeness containing particles have great advantages. Strange mesons and baryons can be well separated from u- and d-quark systems due to the large mass difference. The decay of hyperons allows very selective triggers. The decay length of the Λ and the charged Σ hyperons are in the order of a few cm ($c\tau_\Lambda = 7.89\,cm$, $c\tau_{\Sigma^+} = 2.4\,cm$, $c\tau_{\Sigma^-} = 4.4\,cm$) and therefore the decay is measurable. The Λ has the special feature of a self analyzing decay. By measuring the charged decay products p and π^- the polarization of the Λ can be determined, which allows a very detailed analysis with a polarized beam and target.

In the following only the measurements of the elementary interactions are discussed.

3. Results

The first results of elementary reactions have been obtained at COSY-11 and at TOF. At COSY-11 threshold measurements in the following strangeness containing channels have been performed: $pp \to pp\eta'$, $pp \to ppK^+K^-$, $pp \to pK^+\Lambda$ and $pp \to pK^+\Sigma^0$. At TOF the $pp \to pK^+\Lambda$ reaction at higher excess energies was studied.

The COSY-11 installation is an internal setup in a bending section of the COSY ring, fig. 2 shows a sketch of the experiment.

In front of a machine dipole a hydrogen cluster target is installed. Positively charged reaction products which have a reduced momentum compared to the primary proton beam are bent to the inner region of the ring and detected with a system of drift chambers and scintillators. To show the typical event detection tracks for some $pp \to ppK^+K^-$ events generated by a Monte Carlo program are plotted. Negatively charged ejectiles are detected by a silicon pad detetor arrangement in the dipole gap which is not seen in the figure.

Events are analyzed by tracing the tracks back to the target through the known magnetic field. With the additional time of flight information from the scintillator hodoscopes

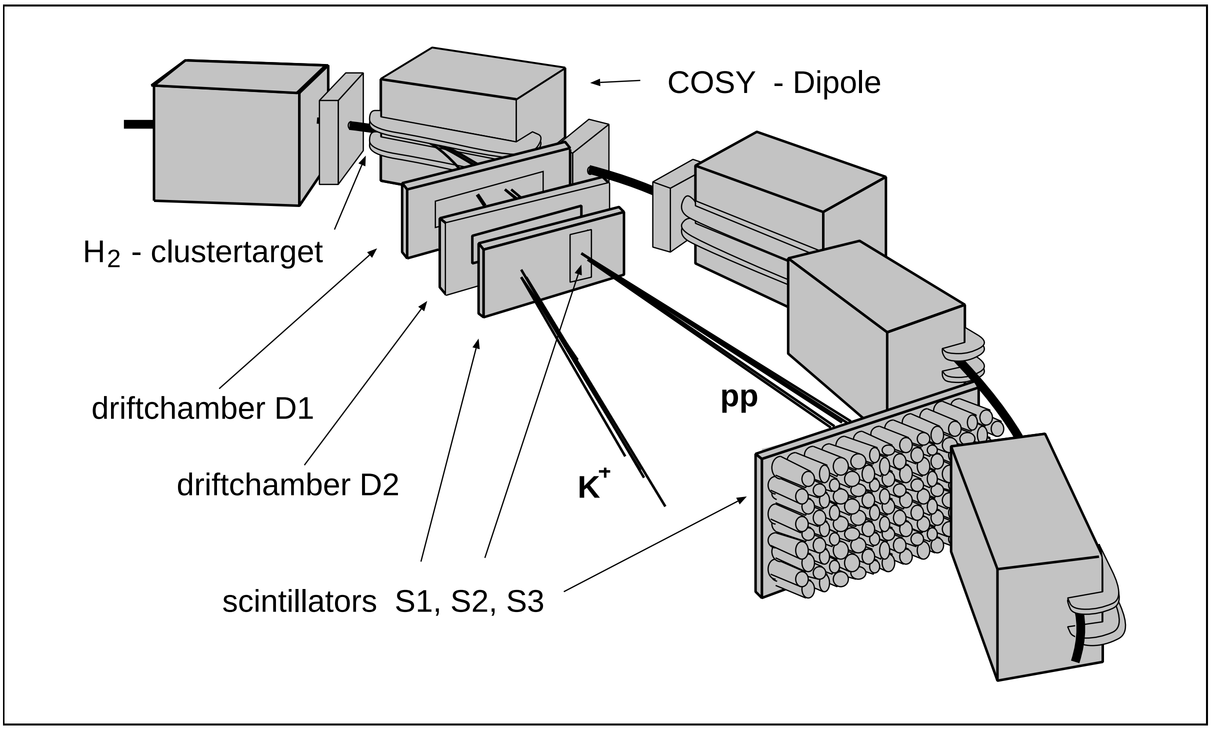


Figure 2. The COSY-11 installation in a bending section of the COSY ring. The ejectile momenta are reconstructed using the track information from the drift chambers D1, D2 and time of flight from the scintillator hodoscopes S1, S2 and S3. The plotted tracks result from MC calculations of some $pp \rightarrow ppK^+K^-$ events at an excess energy of 2 MeV.

the 4-momentum components of the measured ejectiles are determined.

The performance of this detector system is demonstrated in fig. 3 which shows events from a beam time for the $pK^+\Lambda$ measurement.

Events with an identified proton and an additional positively charged ejectile are selected. The squared mass of this second charged particle m_2^2 determined from the reconstructed momentum and the velocity is plotted versus the squared missing mass calculated from energy and momentum conservation. The different ejectiles, pion, kaon and proton are clearly separated and also different reaction channels like $pp\pi^0$ or $pK^+\Lambda$ are distinguishable already from these raw data.

The COSY-11 system is designed for threshold measurements at which the whole center of mass solid angle is confined to a forward cone in the laboratory system. Therefore at threshold a large center of mass solid angle coverage is achieved in spite of the limited gap height.

A very much larger solid angle coverage also for high excess energies is the advantage of the large non magnetic time of flight spectrometer TOF.

A cut view of the complete system is given in fig. 4 with a total length of about 8 m at a diameter of about 3.5 m. TOF is a modular flexible system which consists of three

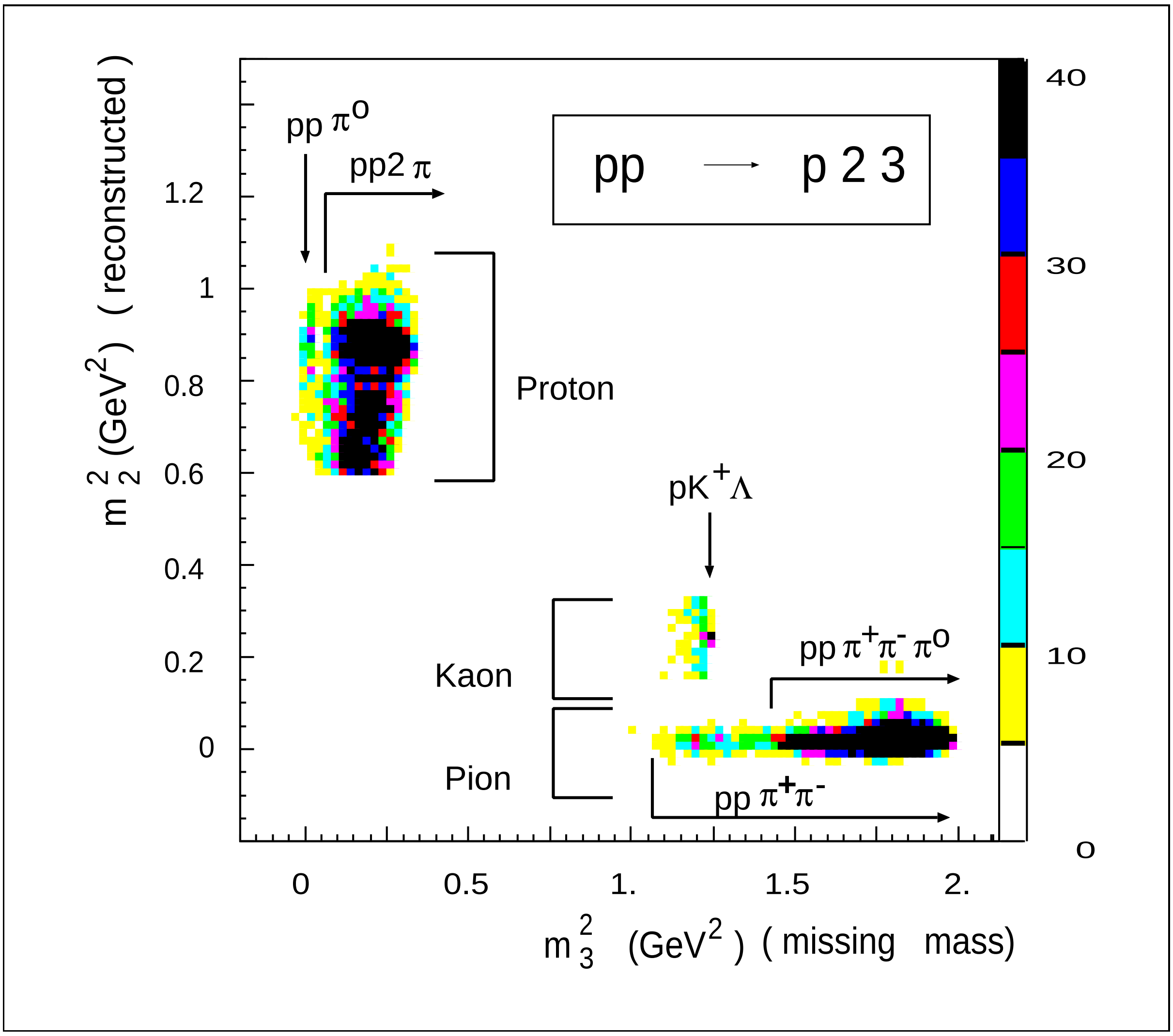


Figure 3. Event analysis with the COSY-11 detection system. Events of a measurement for the $pK^+\Lambda$ production are sorted in a two dimensional plot. Particle identification as well as a separation of different reaction channels is possible from these data.

barrel hodoscopes with plastic scintillators closed by an end cap with a ring and a central hodoscope. Presently one barrel hodoscope and the end cap, central and ring hodscope, is in operation.

For the strangeness production in the $pK^+\Lambda$ reaction only the central hodoscope shown in fig. 5 was used. Three scintillator layers, wedges, right and left twisted spirals [7], yielded the hit position of the charged ejectiles. In the target area an additional start detector, see fig. 6 was installed for the triggering on the delayed Λ decay of the $pK^+\Lambda$ events. In the first layer only the primary proton and the kaon are detected whereas in the second layer also the charged Λ-decay products, proton and pion, are measured.

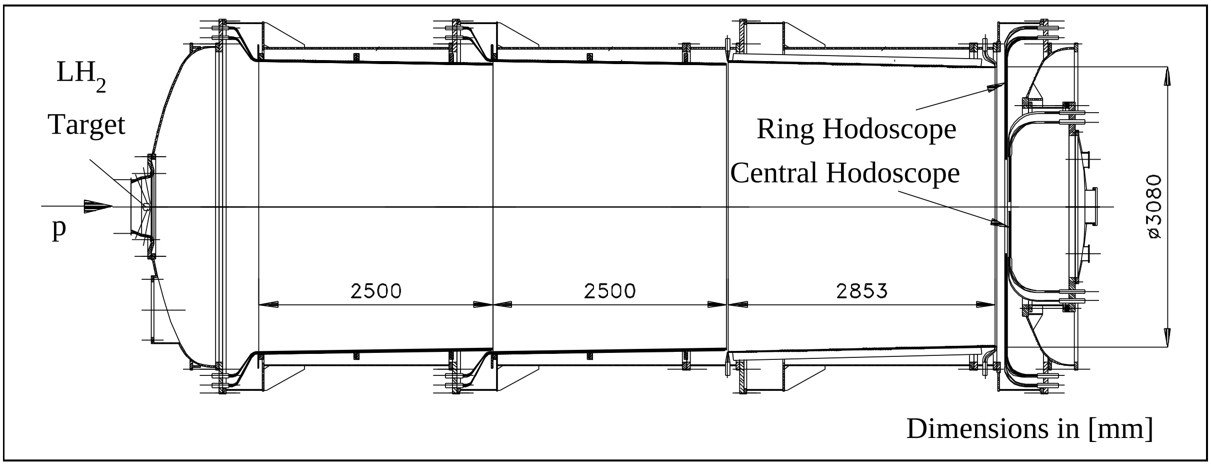


Figure 4. The time of flight spectrometer TOF in the final version with three barrel hodoscopes and the endcap detectors.

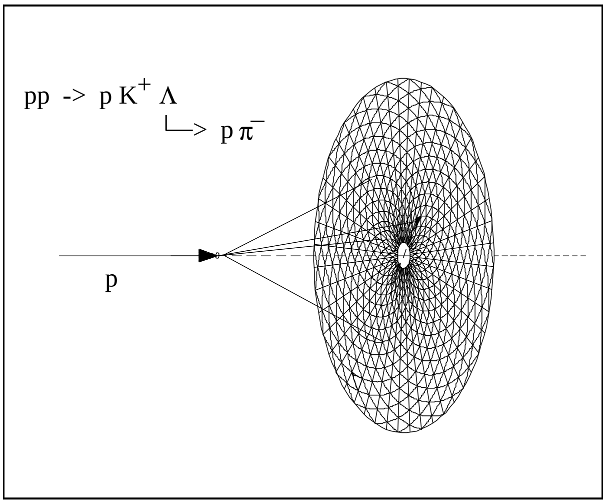


Figure 5. Central hodoscope of the TOF-spectrometer with three scintillator layers, one layer with wedges and two layers with right and left twisted spirals.

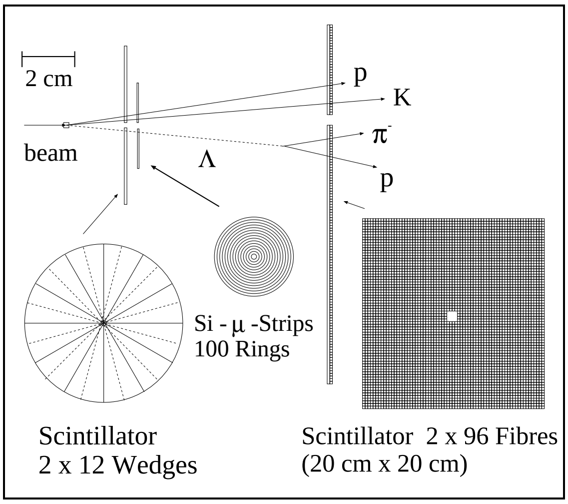


Figure 6. Start detector setup for the $pK^+\Lambda$-measurements with silicon microstrip and scintillation fibre detectors.

3.1. Λ production in $pp \to pK^+\Lambda$

In fig. 7 the available data set of the $pp \to pK^+\Lambda$ reaction up to an excess energy of 200 MeV is shown.

The lowest data point for the total production cross section was at $\approx$ 160 MeV excess energy. (Inclusive K^+ production for a limited angular range was performed at Saturne for lower excess energies [8].) In the threshold region several data have been added by

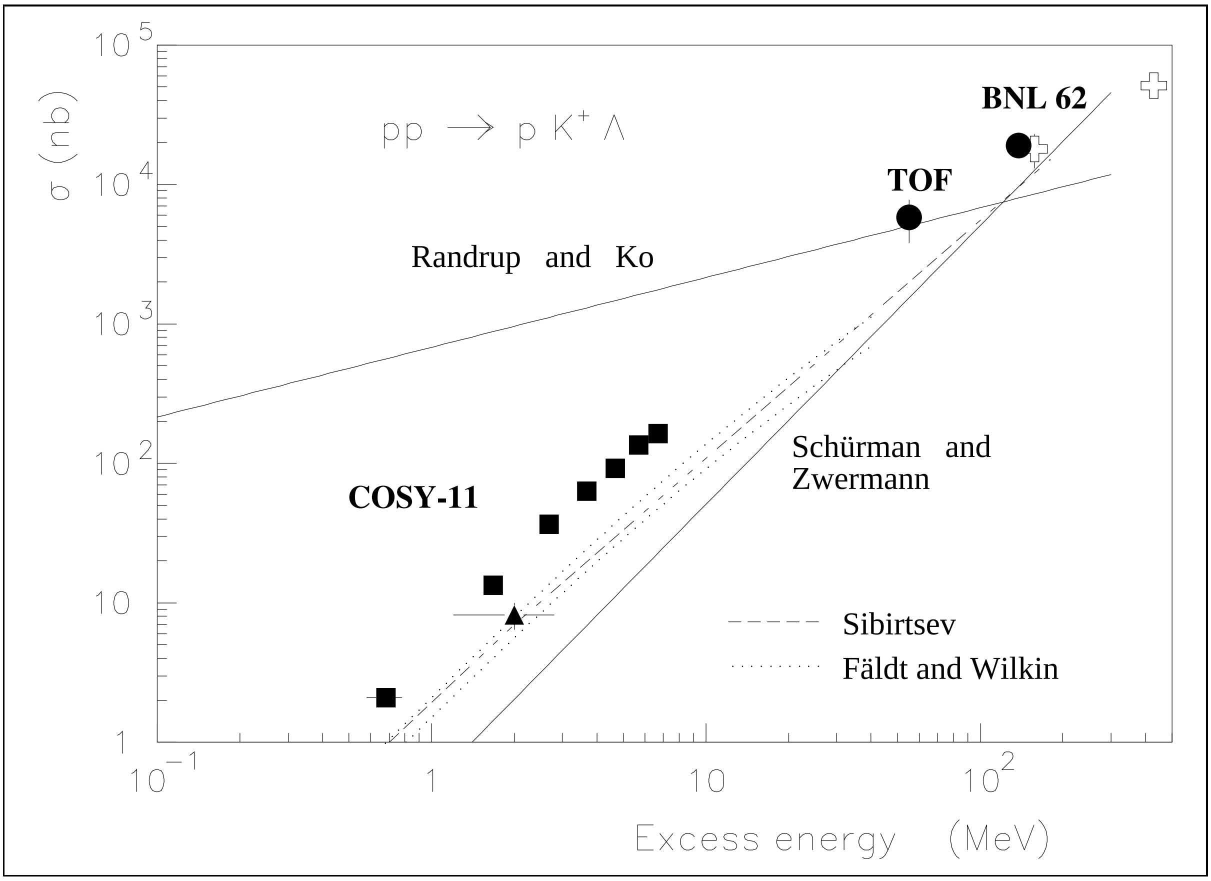


Figure 7. Existing data set in the threshold region for the $ppK^+\Lambda$ production. The COSY data are consistent with the lowest bubble chamber data point. The parametrisations of Randrup and Schurmann (solid lines) and new calculations of Fäldt and Wilkin (range between dottet lines) and Sibirtsev (dashed line) are shown.

experiments at COSY where the result at the highest momentum is consistent with the lowest bubble chamber data. The solid lines represent semiempirical parametrisations for the cross section fitted to the high energy data. Randrup and Ko used a very simple model [9] with a $\sqrt{\epsilon}$ dependence and Zwermann [10] assumed a ϵ^2 dependency. A much better description within meson exchange models is achieved by Sibirtsev [11] (dashed line) and by Fäldt and Wilkin [12] (range between dotted lines). Fäldt and Wilkin calculated the cross section with a one pion exchange in analogy to the η production. Beside the direct graph a dominant contribution via the $N^*(1650)$ excitation is introduced. The difference between the η- and $K^+\Lambda$- production is given by the different amplitudes for $\pi^0 p \to K^+\Lambda$ and $\pi^0 p \to p\eta$. The amplitude for the $\pi^0 p \to K^+\Lambda$ which is not accessible directly is deduced from $\pi^- p$ data. The caculations of Sibirtsev are similar but additionally he includes the exchange of heavier mesons and all nucleon resonances with masses below 2 GeV/c^2. The data are still preliminary but shoud not vary by more than a factor of two.

A crucial point for measuring cross sections in the threshold region is the exact knowledge of the beam momentum which is the dominant error for the excitation curve. The COSY-11 data were used by itself for the calibration of the beam momentum. The absolute momentum setting for a fixed COSY-optics is limited to the order of 10^{-3} due to the insufficient knowledge of the orbit length of the COSY beam. The relative error for a momentum change at the same optics however is negligible. Therefore a data set taken in one run with a fixed optics can be used for the calibration. The data are fitted by a phase space distribution including $p\Lambda$-final state interaction and the Coulomb correction for the pK^+-system from which the correct excess energy could be extracted. The deviation from the nominal excess energy given by COSY was as little as 0.2 MeV [13].

For a check of the validity of a meson exchange model for this strangeness production the final analyis has to be awaiten and further more detailed analysis are needed.

In spite of the large errors bars of the data, already at this stage they give a drastic improvement for the elementary cross section used for the calculations of heavy ion collisions compared to the parametrizations in use.

3.2. Σ production in $pp \to pK^+\Sigma^0$

The next elementary interaction on the beam momentum scale in the hyperon field is the Σ production via $pp \to pK^+\Sigma^0$ which will be interesting in comparison to the Λ production. The cross section is expected to be much lower ($\sigma_\Sigma \sim 0.1\sigma_\Lambda$). First test measurements proved that the sensitivity of the COSY-11 setup seems to be sufficient for the detection of the Σ production within a few MeV above threshold. Measurements of the $pp \to pK^+\Sigma$ excitation function in the threshold region have been started and the first data are presently analysed.

The data of the Σ production also include the events from Λ production at higher excess energy which should show the interesting cusp effect in the cross section induced by the $p\Lambda \leftrightarrow p\Sigma$ coupling. In the ΛN scattering coupled channel calculation an enhancement in the cross is expected at the Σ threshold.

In the three body system $pK^+\Lambda$, the cusp effect should be observable in the kaon momentum spectrum at a fixed beam momentum which reflects the excess energy distribution in the Λp system. In fig. 8 the expected momentum spectrum of the kaons is shown [14]. Also here the cusp effect induced by the $N\Lambda \leftrightarrow N\Sigma$ coupling is visible which is dominated by the D wave contributions.

Experimentally this cusp was seen for the first time in inclusive K^+ data measured at SATURNE [8].

3.3. Threshold meson production

In the field of meson production at threshold data have been taken for $pp \to pp\eta'$ and $pp \to ppK^+K^-$ at COSY-11.

3.3.1. Production of η'

The structure of the η' meson is accepted to include a dominant contribution of strange quarks : $\eta' = |u\bar{u} + d\bar{d} + 2s\bar{s}>$. An additional gluonium component in the wave function proposed by Rosner [15] is still under discussion. Different experiments concerning the amount of such a gluonium component are contradictory.

Another interesting question for the η' production is the value of the coupling constant $g_{NN\eta'}$. In analogy to the η production the dominant graphs for the η' production could be

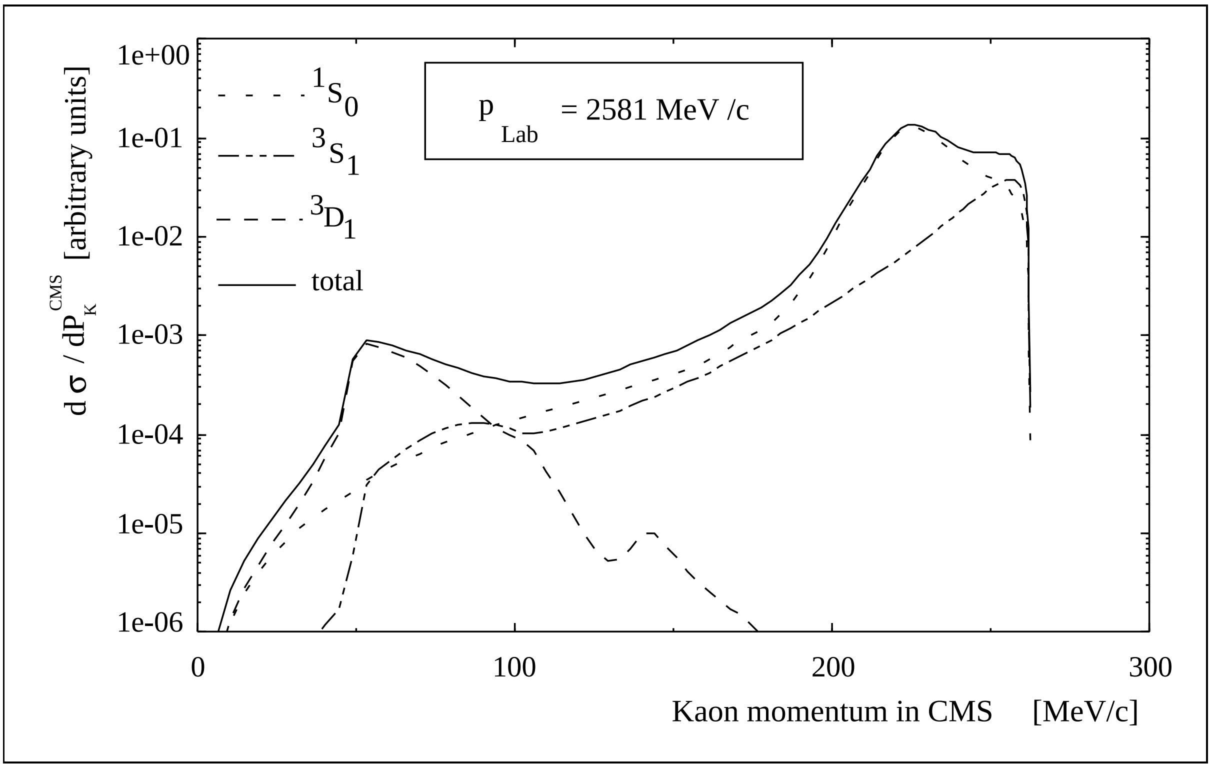


Figure 8. Momentum distribution of the kaons at a fixed beam momentum of 2.581 GeV/c. The $N\Lambda \leftrightarrow N\Sigma$ coupling induces an enhancement of the cross section dominated by the D wave contribution.

thought of being the direct born term and the meson exchange term with an N^* excitation. However, no N^* resonance with a strong deacy branch into $N\eta'$ is known except some weak indications in the $D_{13}(2080)$ resonance [16].

At threshold only s wave contributions are important and excitation of higher resonances like the D_{13} are supressed. Consequently for a threshold measurement the assumption of a pure direct process should be realistic and thus an extraction of the coupling constant appears to be possible. A comparison with the coupling constant predicted by QCD models will give the strenght of up to now not identified nucleon resonances which couples to the η'.

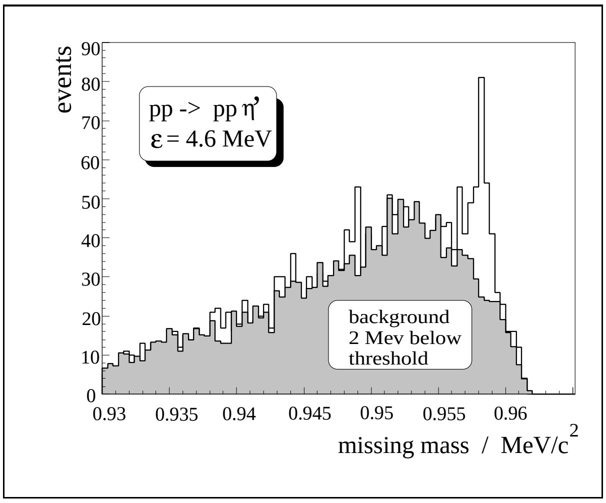
The production of η' has been measured at COSY-11 in the pp-interaction,see fig. 9.

A preliminary cross section of $\approx$ 25 nb is extracted for an excess energy of $\approx$ 4 MeV. Further cross section data for excess energies at 1.5, 1.7 and 2.9 MeV are still being analyzed. These data will permit a comparison with theoretical calculations.

3.3.2. Production of K^+K^-

The production of a K^+K^- meson pair is very interesting in view of the existence of $K\bar{K}$ molecules and especially for the structure of the objects f_0 and a_0.

The interpretations for the f_0 range from a genuine meson with pure $q\bar{q}$ structure, a



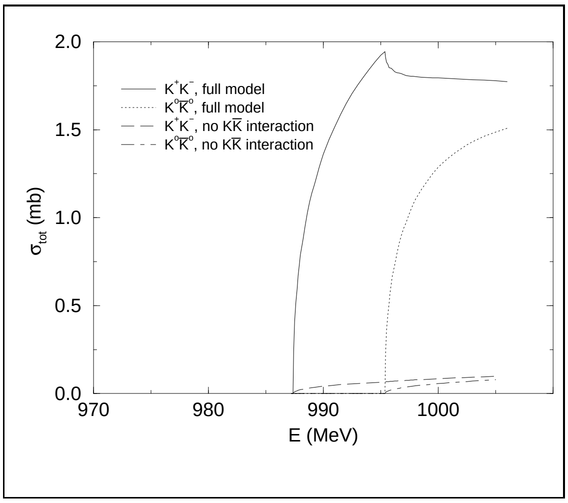


Figure 9. Missing mass spectrum for $pp \to ppX$ events at 3.222 GeV/c beam momentum corresponding to an excess energy of $\approx$ 4 MeV for the η' production. At $m_X = 958$ MeV in accordance to the η' mass of 957.75 MeV a clear peak is observed from which a preliminary cross section of $\sim$ 25 nb is extracted.

Figure 10. S-wave cross section dependence of the $\pi\pi \to K\bar{K}$ scattering on the beam energy. The magnitude of the cross section above the $K\bar{K}$ threshold depends strongly on the $K\bar{K}$ interaction strength.

$K\bar{K}$ molecule or a more exotic object like a four quark state $q\bar{q}q\bar{q}$, a glueball or a hybrid. [17], [19], [18]. As first discussed by Isgur and Weinstein the Jülich meson exchange model interprets the f_0 as a $K\bar{K}$ molecule [20], [21]. Calculations of the $\pi\pi \to KK$ scattering within this model show a drastic increase of the cross section by including a strong $K\bar{K}$ coupling, see fig. 10.

A similar effect of the $K\bar{K}$ coupling is expected for the $pp \to ppK^+K^-$ reaction. Thus even total cross section data in this channel would be sufficient for a check of this model.

The first results on the K^+K^- meson pair production in pp-reaction are shown in fig. 11 and 12.

The data result from a run at 3.321 GeV/c which corresponds to an excess energy of 6 MeV. Two events could be selected with a clear signature for the K^+K^- production. In the control measurement with a comparable luminosity below threshold no event was observed. The resulting cross section is $\approx 500pb$.

Calculations of this channel in the meson exchange model are complicated due to the four particle final state channel but the work is in progress.

At COSY-11 further data on the K^+K^- production have been taken at different excess energies with an expected yield of some ten events for each momentum setting. The data are under evaluation and will give an excitation curve in the threshold region which will be sufficient for a first comparison to theoretical calculations.

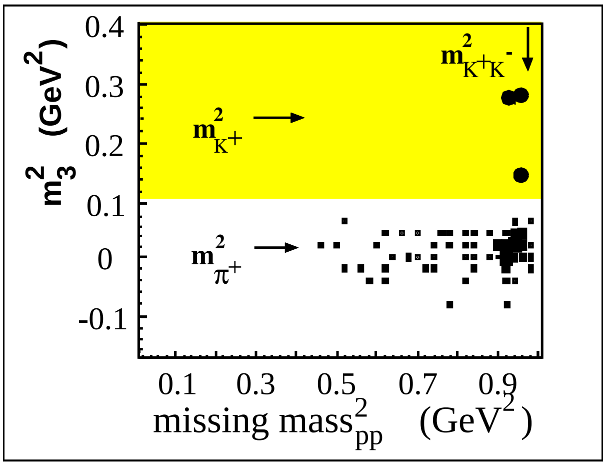


Figure 11. Squared invariant mass of the third charged ejectile versus the squared missing mass in the pp-system for data at 3.3211 GeV/c beam momentum. The gray region indicates the invariant mass range which is accepted for the kaons in the further analysis. The arrows indicate the position of a perfect event.

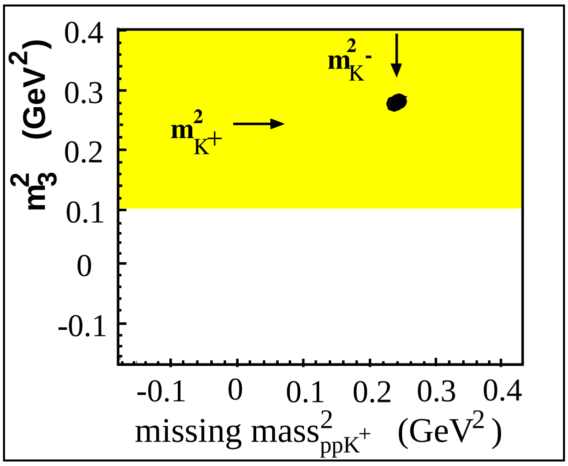


Figure 12. Squared invariant mass of the third particle versus the missing mass in the ppK^+-system. Two events are left which are consistent with a $pp \to ppK^+K^-$ hypothesis. The observed deviations are consistent with the errors on momentum reconstruction and time of flight measurement.

4. Summary

In fig. 13 cross section data in the various strangeness containing channels measured at COSY are summarized and compared to values in the literature. Most of the data are preliminary.

Plotted are the cross section data for different exit channels in pp scattering. Beside the strangeness containing channels also the total and elastic cross sections and for a comparison with nonstrange channels the $d\pi^+$ and the $pp\eta$ rates are shown. The figure demonstrates the high sensitivity of the COSY experiments which results from detection systems with sufficient resolution and more important from the beam quality. A further improvement of the beam quality will be given with the cooling systems in use.

The presented data are just the starting point in the investigations of strangeness containing channels at COSY which are at least three-body exit channels.

An extension of the data set will allow the filling of Dalitz plots which are needed for a much more detailed analysis of the different reaction channels. From this many body exit channels also subsystems can be analyzed which are not accessible in a direct reaction at COSY. For instance in the $pK^+\Lambda$ reaction the $p\Lambda$-subsystem can be studied if the reaction mechanism is sufficiently understood.

During the up-coming years a large number of data will be produced at COSY which will help for the understanding of various physical questions, especially when the phase-space cooling and the polarisation of the beam will come into full operation.

REFERENCES

1. H.O. Meyer et al., Nucl. Phys. A 539 (1992) 633
2. R. Bilger et al., Acta Phys. Pol. 27 (1996) 2953
3. D. Albers et al., Phys. Rev. Lett. 78 (1997) 1652
4. H. Ohm et al., Phys. Rev. C55 (1997)
5. S. Brauksiepe et al., Nucl. Instr. & Meth. A376 (1996) 629
6. O. Schult et al., Nucl. Phys. A583 (1995) 629
7. M. Dahmen et al., Nucl. Instr. & Meth. A348 (1994) 97
8. R. Frascaria et. al., Nuovo Cimento 102A (1989) 561
9. J. Randrup, C.M. Ko, Nucl. Phys. A343 (1980) 519
10. W. Zwermann, Mod. Phys. Lett. A3 (1997) 251
11. A. Sibirtsev et al., Phys. Lett. B359 (1995) 29
12. G. Fäldt, C. Wilkin, Z. Phys. A357 (1997) 241
13. J. Balewski et al., to be published
14. C. Hanhart, J. Haidenbauer, J. Speth, private communication
15. J. Rosner, Phys. Rev. D27 (1983) 1101
16. J. F. Zhang et al., Preprint RPI-N-100, hep-ph/9506238
17. F. E. Close, Rep. Prog. Phys. 51 (1988) 833
18. J. Weinstein, N. Isgur, Phys. Rev. D41 (1990) 2236
19. R. L. Jaffe, Phys. Rev. D15 (1977) 267, 281
20. O. Krehl et al., Phys. Lett. B390 (1997) 23
21. G. Janssen et al, Phys. Rev. C52 (1995) 2690

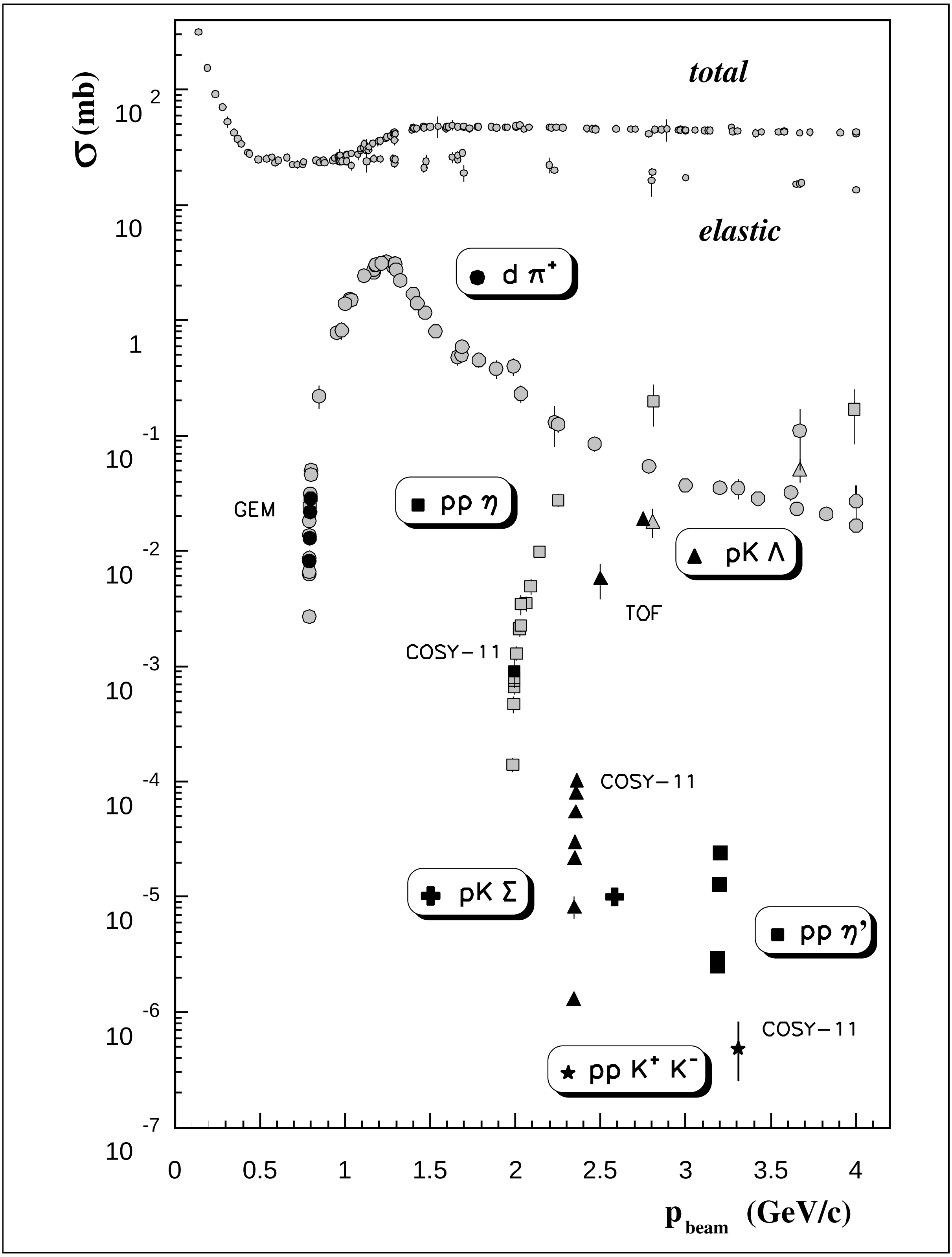


Figure 13. Cross sections for pp induced rections as a function of the beam momentum. The black symbols represent COSY-data and the gray symbols are data from the literature.