MESON PRODUCTION IN $p+p$ INTERACTION AT THRESHOLD*

J.T. BALEWSKI[a], R. BILGER[b], A. BUDZANOWSKI[a], H. CLEMENT[b], K.H. DIART[c], H. DOMBROWSKI[d], K. FÖHL[b], C. GOODMAN[e], D. GRZONKA[f], H. GUTSCHMIDT[c], K. HEITLINGER[b], L. JARCZYK[g], M. JOCHMANN[c], M. KARNADI[f], A. KHOUKAZ[d], K. KILIAN[f], M. KÖHLER[c], A. KOZELA[a], T. LISTER[d], P. MOSKAL[g], R. NELLEN[f], W. OELERT[f], C. QUENTMEIER[d], R. SANTO[d], D. SCHAPLER[b], G. SCHEPERS[d], U. SEDDIK[h], T. SEFZICK[f], J. SMYRSKI[g], M. SOKOŁOWSKI[g], A. STRZAŁKOWSKI[g], M. WOLKE[f], G.J. WAGNER[b], K.H. WATZLAWIK[f], P. WÜSTNER[c], K. ZWOLL[c]

[a] Institute of Nuclear Physics, Cracow, Poland
[b] Phys. Inst. der Universität Tübingen, Germany (for the d' measurement)
[c] ZEL, KFA Jülich, Germany
[d] IKP, Westfälische Wilhelms-Universität, Münster, Germany
[e] IUCF, Bloomington, Indiana, USA
[f] IKP, KFA Jülich, Germany
[g] Institute of Physics, Jagellonian University of Cracow, Poland
[h] NRC, Atomic Energy Authority, Cairo, Egypt

(Received October 9, 1996)

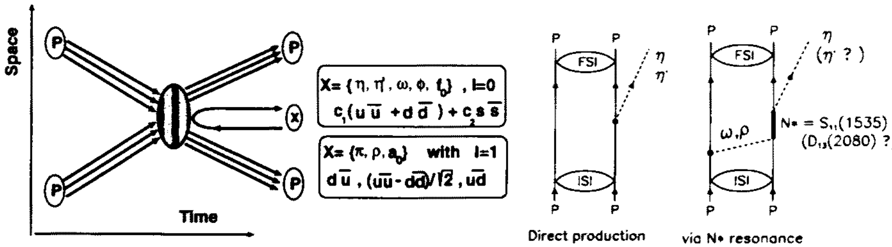
First results of the COSY-11 collaboration are presented in this paper. The motivation for the investigation of meson production is discussed. The description of the COSY-11 experimental apparatus, including the method of particle identification and luminosity monitoring will be shown. Preliminary results of first test measurements for the production of $(\pi^+\pi^-)$, η, η', and (K^+K^-) mesons in the $p+p$ interaction will be given. Furthermore, the results of a test for the $pp \to pK^+\Lambda$ reaction is presented.

PACS numbers: 13.60. Le

1. Motivation

The proton–proton system was chosen for the investigation of the nucleon–nucleon and nucleon–meson interaction, because it is the most elementary

* Presented at the "Meson 96", Workshop Cracow, Poland, May 10–14, 1996.



(a) (b) (c)

Fig. 1. (a) Quark diagram of the meson(s) in the p+p collision. Direct (b) and resonance (c) production models of the η meson.

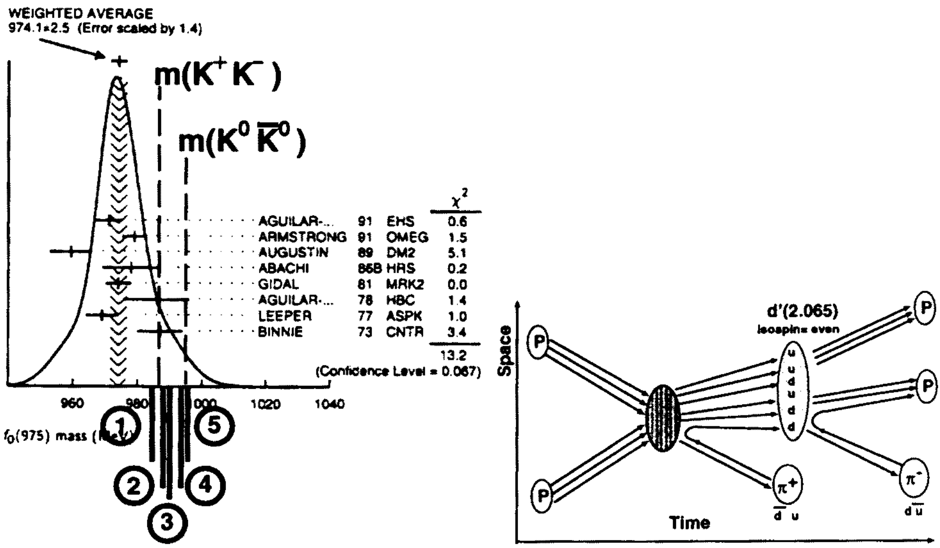
hadronic system in the entrance channel available at COSY. The initial state is prepared in such a way, that the creation of meson(s) with very small energy excess is possible (see Fig. 1a). Therefore, in the theoretical description of the final state interaction (FSI) only few partial waves contribute.

Starting from $E_{\mathrm{CMS}} >$ 300 MeV new $q\bar{q}$ pairs can be created. At the COSY-11 installation, the production of mesons ranging from π^0 up to the Φ can be investigated.

The first measurements were performed for the η meson production, since due to its large production cross section, we can learn not only about the η structure, but also test and calibrate our experimental apparatus. The η meson may be produced either in a direct emission from one of the incoming protons (Fig. 1b), or through the excitation of the S_{11} resonance caused by the exchange of ρ or ω mesons (Fig. 1c). The proton-proton FSI is rather well known and can be included in the theoretical interpretation, but for the extraction of the amplitude for the η-proton FSI further experimental data are needed.

In the case of the η' meson, the possible resonance involved in the production could be the D_{13}, but due to its spin of 3/2 this mechanism is suppressed close to threshold. So, the direct production mechanism seems to be the dominant one. However, till now there are no data concerning the production of η' mesons in $p+p$ collisions, except the prediction given in Ref. [1] according to which the cross section $\sigma(pp \rightarrow pp\eta')$ is two or three orders of magnitude smaller than $\sigma(pp \rightarrow pp\eta)$.

The ω meson is a mixture of nonstrange quarks $u\bar{u}$ and $d\bar{d}$, while the Φ meson is almost a pure $s\bar{s}$ state. Therefore, according to the OZI rule, the probability for ω meson production should be about 10^3 times larger than in the Φ meson case. In contrast, latest results at SATURN [2] show that in the $p+d$ interaction, the ratio of ω/Φ production is only 16 ± 1. A



(a) (b)

Fig. 2. (a) The structure of the f_0 meson is still under discussion. Numbers 1–5 refer to the chosen beam momenta. (b) Quark diagram for the production of the d' dibaryon.

measurement of this ratio in the $p+p$ interaction is important. Results of such measurements could give some insight into the supposed presence of $s\bar{s}$ quarks in the proton state.

In case of the scalar meson f_0 it is still an open question, whether it is a $K\overline{K}$ molecule or whether a $q\bar{q}$ or $2q2\bar{q}$ state. The mass plot of the f_0 meson from the Particle Data Group is shown in Fig. 2a. By measuring a $p+p$ induced excitation function throughout the f_0 mass region, answers to this questions are expected.

Turning to more exotic states, the observation of the predicted [3] dibaryon state d' is planned (Fig. 2b). Its expected mass is 2.06 GeV, width of 0.5 MeV and isospin odd, with the lowest possible decay channels of d' $\rightarrow (pp\pi^-)$, $(pn\pi^0)$, $(nn\pi^+)$.

2. The experimental setup and the method of detection

The proton beam is accelerated in the synchrotron COSY Jülich [5]. The available beam momentum ranges from 0.3 up to 3.4 GeV/c, $\Delta p/p < 10^{-3}$, emittance of $\varepsilon = 1.7$ mm mrad and intensity up to few times 10^{16} particles/sec.

An internal cluster target has been installed in front of a normal C-type COSY bending magnet. The diameter of the hydrogen cluster beam is 9 mm with a density of up to 10^{14} atoms/cm^2. The overall obtained luminosity has been about 10^{30} cm^{-2} s^{-1}.

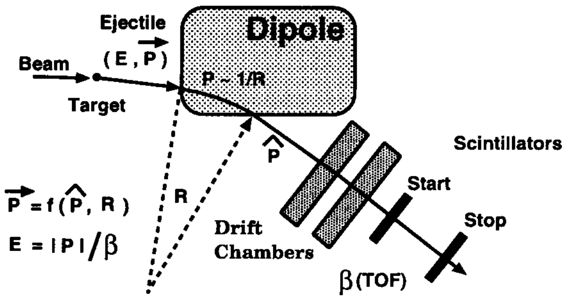


Fig. 3. The reconstruction of the four-momentum of an ejectile.

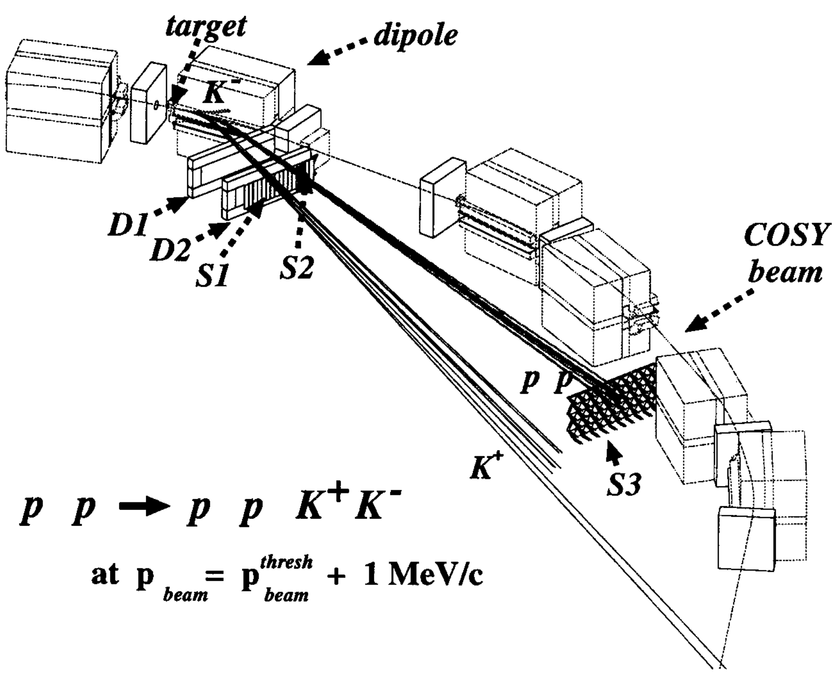


Fig. 4. Perspective view of the COSY-11 setup. There are shown particle tracks resulting from the Monte Carlo simulation of the reaction $pp \to ppK^+K^-$ at a beam momentum of 1 MeV/c above threshold.

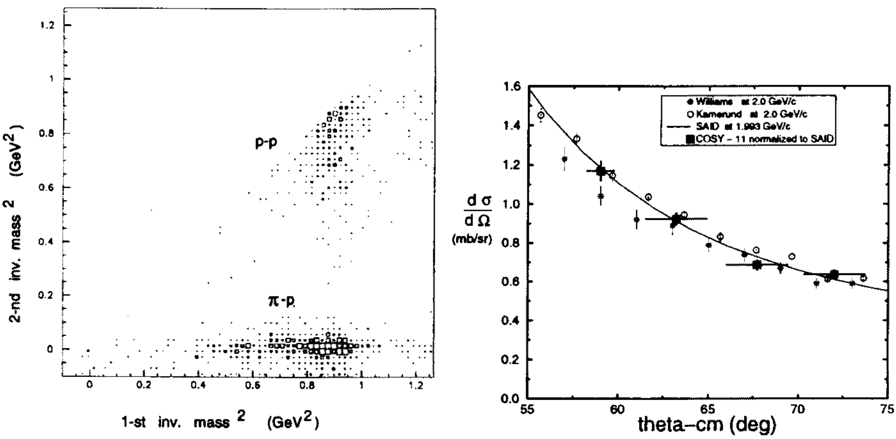
In order to reconstruct the four-momentum vectors of the produced charged particles we use a system of magnetic field, drift chambers and scintillators. As shown schematically in Fig. 3, a charged ejectile is deflected in the dipole and detected in the drift chambers. The momentum vector $\vec{p}$ is reconstructed from backtracing through the magnetic field. Two fast scintillators measure the time of flight (TOF) and enable the mass identification (see also Fig. 5a). For each reaction we measure a sufficient number of observables to determine its kinematics completely. Details of the COSY-11 setup are described in [4]. A perspective view is shown in Fig. 4.

The COSY dipole is used not only for the momentum determination, but primarily to separate reaction products from the proton beam. Therefore, the COSY-11 system is working as a 0° facility. The two drift chambers D1, D2 consist of 14 planes with an active area of 180×40 cm^2. A track is detected in each plane with a resolution of 0.3 mm. The segmented scintillator S1, located behind D2, acts as a start detector for the TOF measurement. The scintillator wall S3 (220×100 cm^2), positioned 9 m downstream, serves as a stop detector. The silicon detector is installed inside the dipole gap for the detection of negatively charged ejectiles.

3. Calibration

The COSY-11 facility is in operation since April 95. An example of the excellent particle identification for 2-track events is shown in Fig. 5a. The invariant mass ($m = |\,\vec{p}\,|/\beta\gamma$) of the first track is plotted versus that of the second one. A very good separation of p–p and π–p events is visible.

The simultaneously measured p+p elastic scattering is used for the determination of the luminosity. One elastically scattered proton is detected in the S1 scintillator, the other one in the additional silicon counter. The solid angles of the detectors were determined by means of Monte-Carlo simulation. Measured angular distributions were normalized to the existing experimental data or the phase space parameterization of SAID [6]. As an example, four points of the angular distribution, measured with a beam momentum of 1.993 GeV/c, are shown in Fig. 5b. The error in the determination of the luminosity is less than 5%. The measured shape of the differential cross section agrees well with the prediction of SAID, this proves the reliability of the applied method.



(a) (b)

Fig. 5. (a) — Particle identification for 2-tracks events. The smaller invariant mass is on the y-axis, the larger one on the x-axis. (b) — The $p+p$ elastic scattering is used for the determination of the luminosity. The vertical bars correspond to the statistical error, the horizontal ones to the bin size.

4. Results

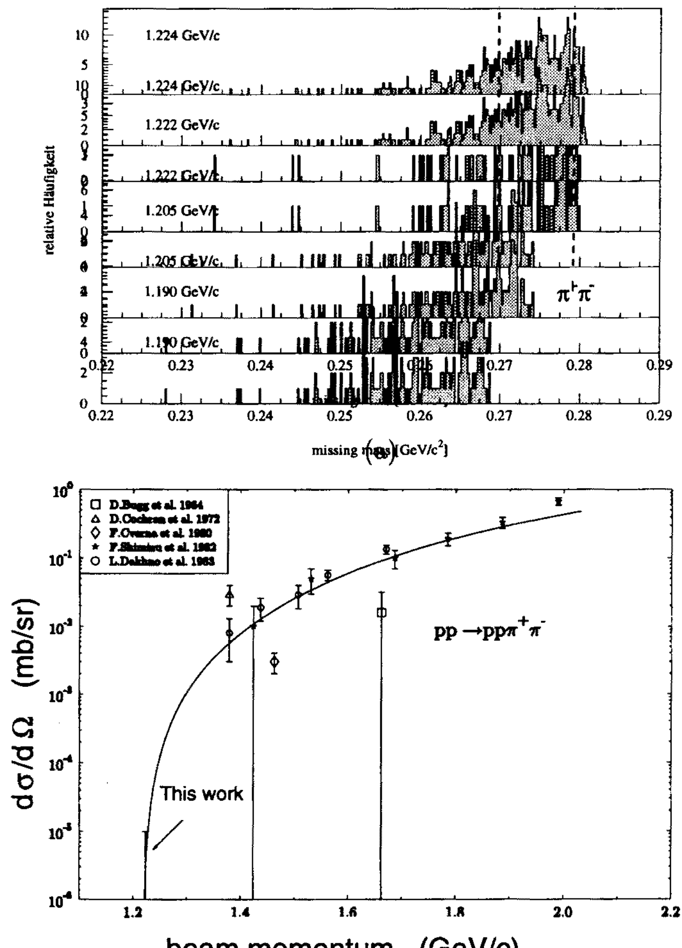
$pp \to pp\pi^+\pi^-$

The study of the $\pi^+\pi^-$ meson production was performed at various beam momenta: below, between and above the $2\pi^0$ and $\pi^+\pi^-$ production thresholds. Two protons were detected in coincidence, the obtained missing mass spectra are shown in Fig. 6a.

The statistics was very low and no significant enhancement in the $\pi^+\pi^-$ region was observed. Therefore, only an upper limit of the cross section for $\pi^+\pi^-$ production was estimated (Fig. 6b). These results [9] are in agreement with other experimental measurements [7, 8], extrapolated to the threshold region according to the phase space volume [10].

$pp \to pp\eta$

The production of η mesons was measured at the beam momentum of 1.993 GeV/c, *i.e.* at $Q = 3.8$ MeV. The missing mass spectrum, corrected due to the acceptance of the COSY-11 detectors, is shown in Fig. 7a. The enhancement in the region of the η mass is obvious. No such structure is observed in the similar spectrum (Fig. 7b), measured below the η meson



(b)

Fig. 6. Measurements close to the $\pi^+\pi^-$ threshold, (a) missing mass spectra for different beam momenta, (b) measured cross section compared with world data.

production threshold. The resulting total cross section for the η production is $0.9 \pm 0.25\,\mu$b. Our values agree well with other measurements [11–13], as shown in Fig. 8.

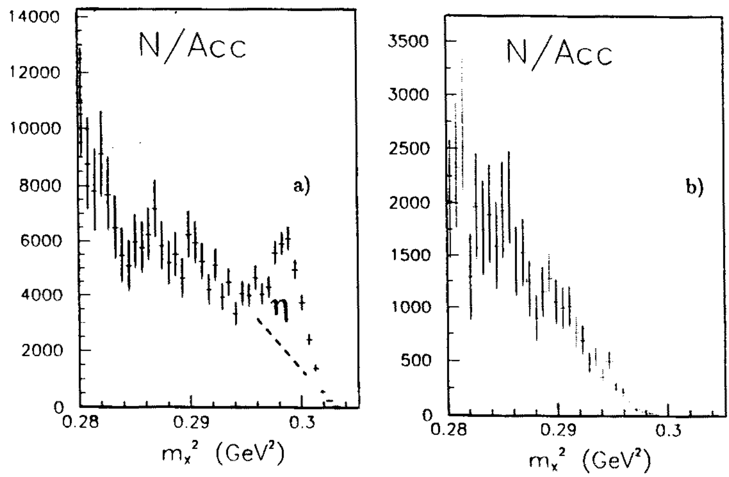


Fig. 7. Missing mass spectra for $p(p,pp)X$ measurements, close above η threshold at $Q = 3.8$ MeV (a) and 0.7 MeV below threshold (b). The acceptance of the COSY-11 detectors is already corrected. Vertical bars depict the statistical error.

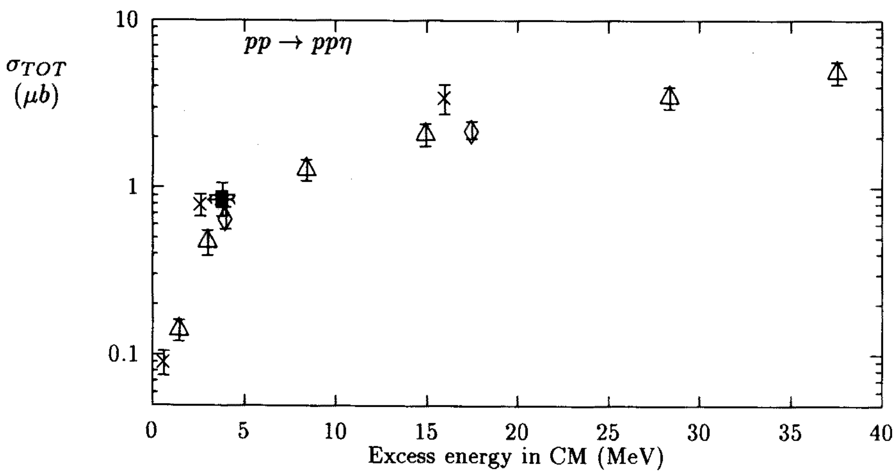
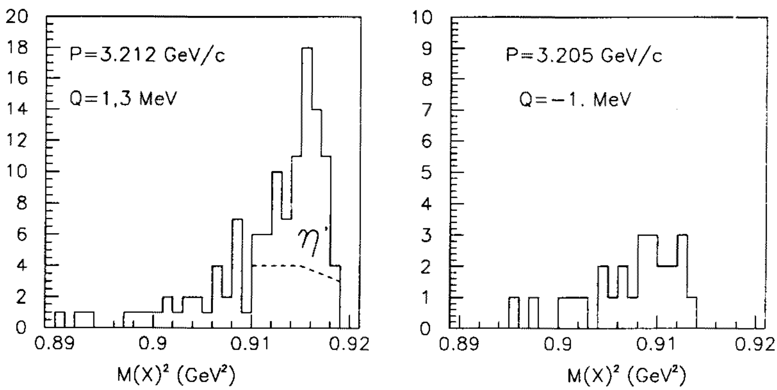


Fig. 8. Cross section for $pp \to pp\eta$ reaction. The COSY-11 point (black box) is consistent with results of Calén (Δ), Chiavassa ($\times$) and Bergdolt Diamond). The following errors are included in the vertical bar: statistical of 3 %, background subtraction of 20%, acceptance of 20% and luminosity of 4.5%. The horizontal bar depicts uncertainty of the determination of the COSY beam momentum.

$pp \to pp\eta'$

Only a test measurement of the η' meson production was performed slightly above its threshold, at $Q = 1.3$ MeV. In the missing mass spectrum (Fig. 9a) we can see an enhancement at the η' mass region, which is not present on the spectrum measured below η' threshold (Fig. 9b). Since spectra a) and b) are normalized to each other, the number of the η' events was estimated to 50 counts. Up to now, the luminosity has not been determined accurately, however, a preliminary estimation of the η' production cross section is in the order of 1 nb.



(a) (b)

Fig. 9. Missing mass spectra for $p(p,pp)X$ measurements, close above η' threshold at $Q = 1.3$ MeV (a) and 1 MeV below threshold (b).

$pp \to ppK^+K^-$

The investigation of K^+K^- correlation is one of the main goals of the COSY-11 collaboration. Measurements were performed at different beam momenta (see Fig. 2a). Preliminary spectra of $p(p,ppA)B$ events have been shown in Fig. 10a. The invariant mass of the particle A is on the y-axis, the corresponding missing mass of two protons on the x-axis. The $p(p,ppK^+)K^-$ events are localized around $x = (m_{K^+} + m_{K^-})^2$, $y = m^2_{K^+}$.

Selected events with the third particle identified as a K^+ (the area between dashed lines in Fig. 10a) were plotted in Fig. 10b. The missing mass of the (ppK^+) subsystem (*i.e.* mass of B) is plotted versus the invariant mass of K^+. The $p(p, ppK^+)K^-$ events are localized around $y = m^2_{K^-}$, $x = m^2_{K^+}$.

The preliminary number of reconstructed $pp \to ppK^+K^-$ events is 6, leading to a production cross section of 0.1 nb.

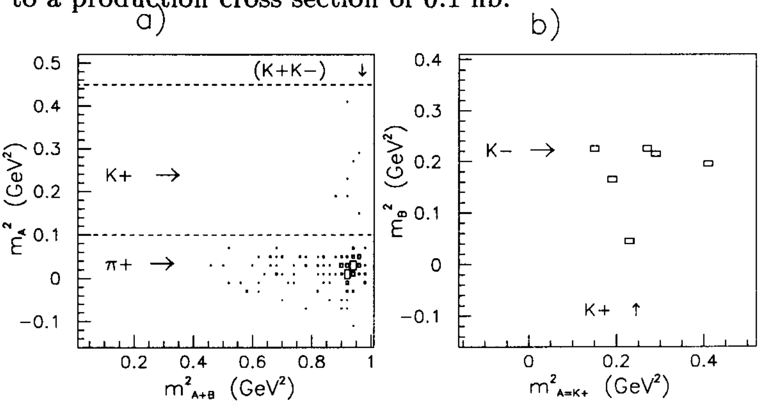


Fig. 10. The $p(p, ppA)B$ events measured at a beam momentum of 3.308 GeV/c. The smallest box corresponds to a single event. a) The invariant mass of A is plotted vs. the missing mass of two protons. b) Subset of $p(p, ppK^+)B$ events. The mass of the unmeasured particle B is plotted versus the invariant mass of K^+.

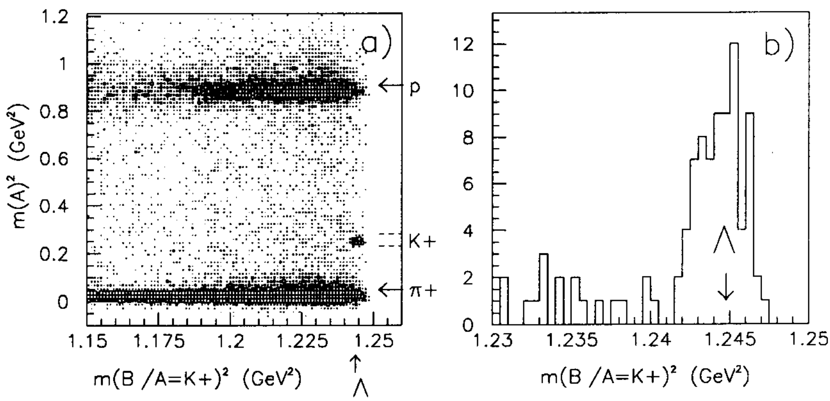


Fig. 11. The $p(p, pA)B$ events measured at beam momentum of 2.345 GeV/c. a) The invariant mass of the particle B is plotted on the y-axis. The missing mass of the (pK^+) subsystem is on the x-axis (assuming, that $A \equiv K^+$). The largest box corresponds to 10 events. b) Selected events from the area between the dashed lines in Fig. a).

$pp \to pK^+\Lambda$

The measurement slightly above the threshold of the $pp \to pK^+\Lambda$ reaction was originally foreseen only as a test for the kaon identification technique. A very clean set of 60±10 events of $p(p,pK^+)\Lambda$ was reconstructed. In the analysis we search for two track events with the first one identified as a proton. The well separated island in Fig. 11a corresponds to these events. The preliminary value of the cross section is 10 nb (± factor 2). This seems to be somewhat larger than the extrapolation of measurements at higher beam momenta (2.8–3.8 GeV/c) given by [14], extrapolated to the threshold according to the volume of a phase space.

5. Conclusions

The COSY-11 experiment is in operation since April '95. Up to now, first test measurements close to the reaction thresholds of the production of various mesons, were performed. For several reaction channels more detailed measurements concerning the statistics as well as the study of excitation function are planned, in order to investigate the underlying physical questions. The table below summarizes our achievements and plans for the near future.

Reactions under investigation

Reaction	Q (MeV)	Acc[a] (%)	L*T/10^{33} (cm^{-2})	N	σ (nb)	plans
$p\,p \to p\,p\,\pi^+\,\pi^-$	1.1 1.8	5.1 1.7	0.31 2.33	0 0	<30.[b] <10.[b]	
$p\,p \to p\,p\,\eta$	3.8	8.	14.	1010	900.±250.	high statistic run with cooling of COSY
$p\,p \to p\,p\,\eta'$	1.3	72.	~ 65.	~ 50	~ 1.[c]	σ(E) 2 weeks in '96
$p\,p \to p\,p\,K^+\,K^-$	1. 2. 6.	20.[d]	~ 8. ~ 225 ~ 170	~ 6	~ 0.1[c]	σ(E), search for f_0, a_0 2 weeks in '96
$p\,p \to \pi^+\,d' \searrow p\,p\,\pi^-$	4.		-	-	~ 7% of $(\pi^+\pi^-)^e$	σ(E), test run 1 week in 1996
$p\,p \to p\,p\,\omega$	26.	5.	-	-	~ 1000.[f]	σ(E), test run few days in '96
$p\,p \to p\,K^+\,\Lambda$	2.	10.	108	60	~ 10.[c]	$\sigma(E)$, Λ polarization proposal for '97

Table: Q = energy excess in CM, Acc = acceptance, L*T = integrated luminosity, N = number of events, σ = cross section. [a] FSI_{pp} not included, [b] upper limit of σ calculated with CL=90% , [c] under evaluation, [d] for detection of ppK^+ , [e]estimated at CELSIUS, [f] measured at SPES3 at SATURN.

REFERENCES

[1] Y.Le. Bornec, IPNO-DRE 90.07
[2] R. Wurzinger *et al.*, Dec 95, preprint.
[3] W. Brodowski *et al.*, *Z. Phys.* **A** to be published.
[4] S. Brauksiepe *et al.*, accepted for publication in *Nucl. Instr. Meth.*
[5] R. Maier *et al.*, EPAC 94, Proc. of the Conf., 1994, p.165.
[6] R.A. Arndt, I.I. Strakovsky, R.L. Workman, *Phys. Rev.* **C50**, 2731 (1994).
[7] L.G. Dakhno *et al.*, *Sov. J. Nucl. Phys.* **37** 4, (1983).
[8] F. Shimizu *et al.*, *Nucl. Phys.* **A386**, 571 (1982).
[9] A. Khoukaz, Ph.D. 1996, Westfälische Wilhelms–Universität, Münster.
[10] K.J. Bystricki *et al.*, *J. Phys.* **18**, 1901 (1987).
[11] A.M. Bergdolt *et al.*, *Phys. Rev.* **D48**, R2969 (1993).
[12] H. Calén *et al.*, ISV/TSL-95-0124, Uppsala University 1995.
[13] E. Chiavassa *et al.*, *Phys. Lett.* **B322**, 270 (1994).
[14] V. Flamino *et al.*, CERN-HERA 84-01.