History of collaboration between PNPI – COSY.

Collaboration between physicists from Petersburg Nuclear Physics Institute (PNPI, Gatchina) and Research Center "Jülich" (Germany) began in 1991 after agreement about carrying out of fundamental and applied researches in nuclear and particle physics. That document has been signed by the leaders of both institutes. It had several prolongations and will be valid till March 2013. Within the framework of this collaboration in the period from 1991 to 1998 a joint work on projecting, manufacturing and tuning of ANKE magnetic spectrometer for internal beam of COSY synchrotron have been done. Spectrometer allows one to identify positively and negatively charged particles in the momentum range fron 200 up to 3000 MeV/c with 2% averaged resolution. One of the distinctive feature of ANKE is unique method of K^+-mesons identification using delayed signal from products of their decays (π-mesons or muons). This method has been developed earlier in PNPI. In parallel to this activity in 1994 joint work on production of polarized source of hydrogen (and deuterium) atoms has been started. This source was planned to be used in experiment for observation of a polarization effects in *pp-, pd-* and *dd*-collisions. The work was successfully finished in 2004. A nuclear polarization of 80% together with beam intensity of $6 \cdot 10^{16}$ atoms/s has been reached in 2004.

Main results of PNPI — ANKE collaboration.

Investigation of K^+-mesons production below threshold of elementary reaction.

First series of research, which has been done on ANKE spectrometer, was connected with investigation which started in PNPI in 1978 – 1986 on K^+-meson production. Mesons production in proton-nucleus collision with proton energy lower than threshold of free nucleon-nucleon collisions gives an access to collective degrees of freedom in nuclei and to high momentum part of nuclean wave function in nuclei.

At ANKE spectrometer several unique measurements of double differential cross sections for K^+-mesons production on different types of target and different energies of beam protons have been done. It was demonstrated that effects of final state interactions for K^+-mesons play an important role in the measurements of double differential cross sections. This experiment allows to determine kaon-nuclear potential with a precision of 3 MeV. An importance of taking into account Coulomb repulsion was also shown.

Also in the framework of this topic a correlation K^+d (and K^+p) experiments were done for the

first time in world practice. That measurements proves an existance of two-step production mechanisms for K^+-mesons in nuclei, which goes through an intermediate $pn \to d\pi$ reaction. Together with this conclusion an evidence of existing of cluster mechanisms has been also presented. A part of cluster mechanism could be up to 30% of two-step production.

Investigation of φ- and ω-meson production in pN-collisions and experimental test of Okubo-Zweig-Izuka rule.

In framework of this topic a measurements of cross section for the reactions of type $pp \to ppM$ and $pn \to dM$ (where $M = \omega, \varphi$) have been done for excess energies less than 100 MeV.

A production of ω-mesons has been studied in $pp \to pp\omega$ (with excess energies 60 end 92 MeV) and $pn \to d\omega$ (28 and 57 MeV) reactions. Measurements for the first reaction gave an information about unstudied range of excess energies. Investigation of second reaction has been done first time in world practice. It allows to fix unknown sign of coupling constant $g_{\rho\pi\omega}$ (see. *Phys. Lett. B vol.648 (2007) p.351*). Close-to-threshold measurements of cross section for reactions $pp \to pp\varphi$ (for 18.5, 34.5 и 75.9 MeV excess energies) and $pn \to d\varphi$ (in range from 0 to 80 MeV) has been also done for a first time and allow to obtain a ratio of yields for ω- and φ-mesons as a function of excess energies. According Okubo-Zweig-Izuka rule, which tells about suppesion of the reaction with disconnected quark lines, this ratio should be $R_{OZI}=\sigma_\varphi/\sigma_\omega=4.2\cdot10^{-3}$. This were in good agreement with high energy world data (for example in πp-interactions), with the exception of annihilation of stopped antiprotons in hydrogen. The data of LEAR collaboration (CERN), which characterized S-wave initial state shows ration of cross sections 30 – 70 times higher than R_{OZI}. For the explanation of this fact a model of polorized stangeness component in the nucleon wave function was developed. Close-to-threshold vector meson production in nucleon-nucleon interactions is also characterized by initial S-wave state. A modern (model dependent) calculations demonstrate that including dynamics of processes and without model of polarized strangeness $\sigma_\varphi/\sigma_\omega$ could be 4.5 times higher than R_{OZI} (see *Eur. Phys. J. A vol.23 (2005) p.291*). An obtained ratio of total cross section is in average $(6\pm2)\cdot R_{OZI}$ in *pp*-channel and does not depend on excess energy, which is in an agreement with model's calculation. For *pn*-channel tha ratio of yields of vector mesons also agrees with model (within statistical uncertainty).

Investigation of K^+K^--pairs production

As a result of experiments total and differential cross section for the reactions $pp \to pp\{K^+K^-\}_{non-\varphi}$, $pp \to d\{K^+K^-\}_{non-\varphi}$, $pp \to dK^+K^0$-bar, $dd \to {}^4\mathrm{He}K^+K^-$ have been determined

for the low (<110 MeV) excess energies. This energy range was not studied before. We studied an influence of scalar resonances ($a_0(980)$ and $f_0(980)$) as well as influence of antikaon-nucleon (and antikaon-nuclear) interactions on reaction mechanisms.

The result was that S-wave state is dominant in kaon-antikaon system, but there were no other indication on a role of scalar resonances. It was also shown that the effects of final state interaction in K^-p-, K^-pp- and K^-d systems is very important for description of these reactions. K^-p scattering length has been measured. Also an effect of $K^+K^- \leftrightarrow K^0K^0$-*bar* re-scattering was found and described. It allowed to measure isoscaler and isovector contributions (for K^+K^- system) in the reaction $pp \to pp\{K^+K^-\}_{\text{non}-\varphi}$.

Hyperons production

A momentum range of COSY synchrotron allows one to study light hyperons (Λ and $\Sigma^{0,\pm}$) production in *pp*- and *pn*-collisions.

A production of Σ^+-hyperons has been investigated in the reaction $pp \to nK^+\Sigma^+$ at excess energies less than 130 MeV. A reason for this studies was anomaly cross sections presented by COSY-11 collaboration (see *Phys. Lett. B vol. 643 (2006) p.251*). Results obtained at the ANKE spectrometer disproves that measurements. ANKE cross sections has been obtained by four independent experimental methods. In parallel a total cross sections for $pp \to pK^+\Lambda^0$ as well as for $pp \to pK^+\Sigma^0$ reactions have been obtained.

Exotic baryon production

As ANKE detection systems provide very good identification of K^+-mesons it was used for searching of strange exotic barions such as $\Lambda(1405)$ and pentaquark $\Theta(1530)$. This resonances were being searching in *pp*-collisions. During data analysis a new information about production cross section as well as about lineshape of $\Lambda(1405)$-resonance has been obtained. A pentaquark state has not been not found, an upper limit for its production cross section was given.

Also during the measurement an evidence on new exotic state with mass 1480 МэВ/c^2 has been found.

Other topics

Besides described studies in which physicists from Petersburg Nuclear Physics Institute play an important role, ANKE collaboration made a lot of scientific publication on other physical topics

such as:

- diproton physics (deuteron break-up, bremsstrahlung and π-mesons production), when two detected protons are in $^1S_0$ state;
- investigations of η-mesons productions in *pp*-, *pn*- and *pd*-collisions and η^3He final state interaction;
- polarization effects in elastic scattering, charge exchange reactions and π-mesons production;
- studies of depolarization of protons on electrons for small relative energies.

Physicists from PNPI took part in these experiments and discussion of the results.