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STUDIES OF THE η MESON WITH WASA AT COSY AND KLOE-2 AT DAΦNE

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One of the basic motivations of the KLOE-2 and WASA-at-COSY experiments is the test of fundamental symmetries and the search for phenomena beyond the Standard Model in the hadronic and leptonic decays of ground-state mesons and in particular in decays of the η meson. At COSY these mesons are produced in collisions of proton or deuteron beam with hydrogen or deuterium pellet target, and at DAΦNE η mesons originate from radiative decays of ϕ meson or from the fusion of virtual gamma quanta exchanged between colliding electrons and positrons. This contribution includes brief description of experimental techniques used by KLOE-2 and WASA-at-COSY as well as some of physics aspects motivating investigations of production and decays of η mesons.

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1. *Introduction*

Investigations of η meson production and decay constitute part of the experimental programmes realized with WASA at COSY and KLOE-2 at DAΦNE experimental facilities. The cooler synchrotron COSY enables production of mesons in the hadronic interactions and the electron-positron collider DAΦNE facilitates production of mesons in the electromagnetic interactions. Thus realization of the two experimental programmes provides complementary results obtained with not only different detectors but also with utterly different physical and instrumental backgrounds.

The η and η' mesons possess many interesting features making them particularly suitable for investigations of e.g. (i) discrete symmetries, (ii) anomalies of quantum chromo dynamics (QCD) and (iii) hadronic interactions. Studies of properties of these mesons open many possibilities for searching of new kind of matter, as e.g. mesic-nuclei, dark matter bosons, gluonium content in mesons, and give a chance to observe processes which are not described in the framework of the standard model (SM). A comprehensive and detailed description of physics motivations for studies of η and η' mesons production and decays is included in physics reports of KLOE-2 [1] and WASA-at-COSY [2] experiments. Therefore in this contribution we will only briefly and in general terms discuss some of physics aspects of these experiments, and for the details, the interested reader is referred to the abovementioned articles.

In the KLOE experimental campaign, completed in the year 2005, about 10^8 events with the η mesons have been collected and this ensamble will be increased to about 10^9 within next three/four years of the KLOE-2 running. Similarly, WASA-at-COSY has collected so far about 3×10^8 events with the η meson and expects to increase this sample up to about 10^9 events within next four years of running.

2. *KLOE-2 at DAΦNE*

The KLOE-2 experimental setup [1, 3] is a successor of KLOE [4 − 6], which is at present being upgraded by new components in order to improve its tracking and clustering capabilities as well as in order to tag $\gamma\gamma$ fusion processes. The detector, shown schematically in the left panel of Fig. 1 consists of a ~ 3.5 m long cylindrical drift chamber with a diameter of about 4 m surrounded by the sampling electromagnetic calorimeter [4 − 6]. Both these detectors are immersed in the axial magnetic field provided by the superconducting solenoid. The detector surrounds the crossing of the positron and electron beams circulating in the rings of the DAΦNE collider. Each out of 120 bunches of positrons and electrons collides with its counterpart once per turn in the center of the KLOE-2 detector [7]. In the

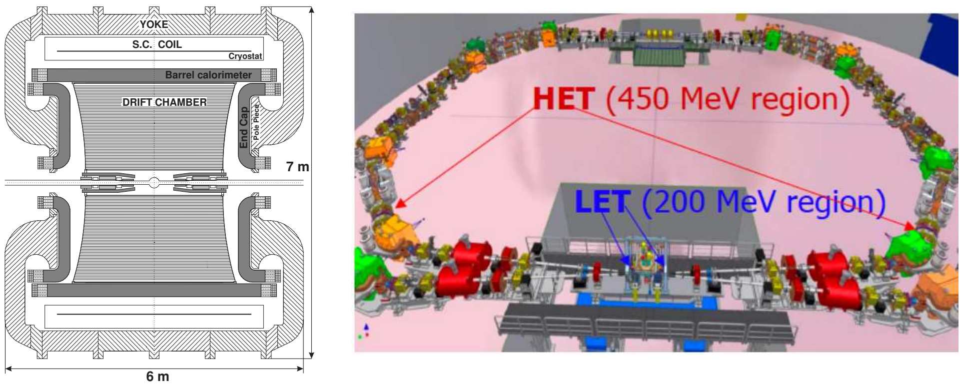

Fig. 1. (Left) Cross section of the KLOE detecor. (Right) Scheme of the DAΦNE collider with positions of low energy taggers (LET) and High energy taggers (HET) indicated by arrows. The average energy of electrons and positrons covered is also shown.

year 2009, the new electron-positron interaction region, based on large Piwinski angle, small beam sizes at the crossing point, and *Crabbed Waist* compensation of the beam-beam interaction has been successfuly commissioned [8]. This new solution allowed the increase of the collider luminosity by a factor of three with respect to the performance reached before the upgrade, and DAΦNE will deliver up to 15 pb^{-1} per day giving possibility to achieve about 20 fb^{-1} within the next $3-4$ years of data taking by means of the KLOE-2 detector. In addition, exclusive measurements of the $\gamma\gamma$ reactions will be possible by the low and high energy taggers [9] allowing for registration of electrons and positrons originating from $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$ reaction. Right panel of Fig. 1 shows the scheme of the DAΦNE rings with position of taggers indicated by arrows. First commissioning runs with KLOE-2 started in the spring of 2010 and, after collection of statistics corresponding to the integrated luminosity of about 5 fb^{-1}, the next phase of installation of new detectors, including inner tracker and internal calorimeters, shall commence by the end of the year 2011.

3. *WASA at COSY*

WASA-at-COSY [2] is a successor of WASA/CELSIUS experiment which was operated until 2005 at the CELSIUS light-ion storage ring in Uppsala [10]. The detector was optimized for studies of π^0 and η decays involving photons and electrons [11]. In the year 2006 it was installed at the beam of the cooler synchrotron COSY in Jülich [12, 13]. Cooler synchrotron COSY is equipped with electron and stochastic cooling, providing low-emittance polarized and unpolarized proton and deuteron beams with momentum of up to 3.7 GeV/c. Therefore the transfer of the WASA detector from CELSIUS to COSY opened possibilities to study the production and decays of mesons heavier than the η with masses up to the mass of the ϕ meson, and permitted to extend the studies to the spin degrees of freedom. It is also important to stress that COSY allows for the continuous variation of the beam momentum within one cycle which is crucial for reduction of uncertainties in studies of excitation functions of the meson production processes. The WASA detector system (shown schematically in Fig. 2) consists of the forward detector used

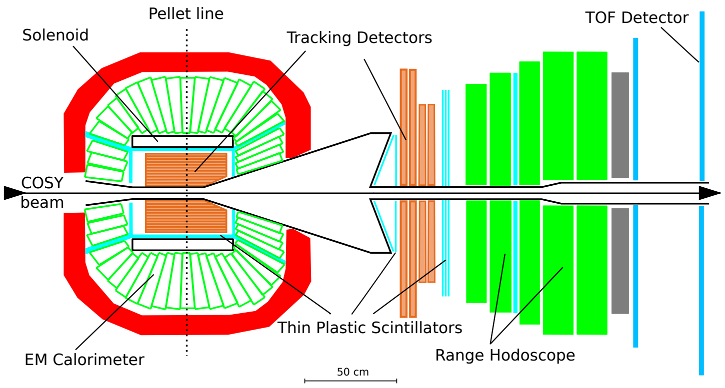

Fig. 2. Scheme of the WASA detector setup installed at COSY.

for tagging of meson production, the central detector used for the registration of the decay products, and the pellet target system. The production of the η mesons occurs in the middle of the central detector at the intersection of COSY beam with the vertical beam of pellets. The interaction region is surrounded by the multi-layer cylindrical drift chamber immersed in the axial magnetic field produced by the superconducting solenoid. The outermost sensitive part of the central detector is the electromagnetic calorimeter covering 96 percent of the whole solid angle. Particles registered in the forward detector are identified based on the energy loss in the layers of the scintillator detectors and their direction of flight is reconstructed based on signals measured in the multi-layer drift chambers.

The production of the η meson is conducted only a few tens of MeV above the kinematical threshold. The relatively small excess energy allows for the efficient separation of decay products emitted into a large solid angle from the forward boosted protons and helium ions.

4. *Tagging of η mesons*

At the DAΦNE collider, η mesons are created in the center of the KLOE-2 detector via radiative decays of ϕ meson produced in the electron-positron collisions ($e^+e^- \to \phi \to \eta\gamma$) and via the fusion of virtual gamma quanta exchanged in the e^+e^- interaction ($e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-\eta$). Production of η meson is tagged, respectively, via the registration of mono-energetic gamma quantum in the calorimeter or via registration of electrons and positrons in low and high energy taggers. Left panel of Fig. 3 presents the capability of the KLOE detector for the clear identification of the η meson via the detection of the monoenergetic γ quantum from the $\phi \to \eta\gamma$ decay.

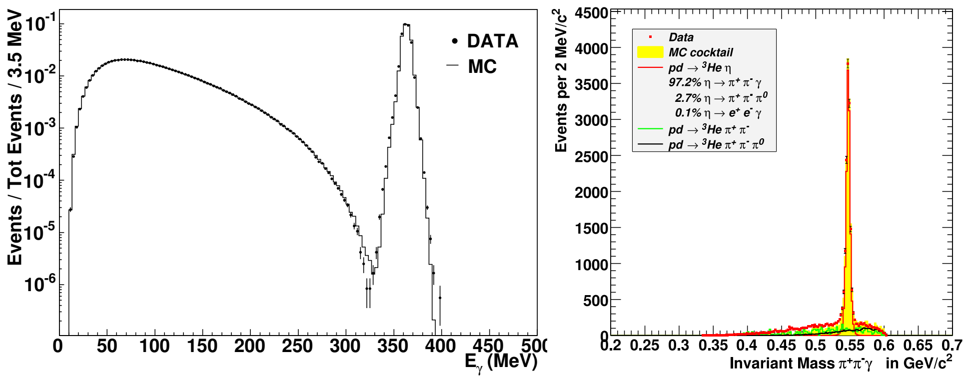

Fig. 3. (Left) KLOE: Energy spectrum for γ quanta from events $\phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$, showing the 363-MeV tagging photon well separated from those from π^0 decay [14]. (Right) WASA-at-COSY: Missing mass spectrum for the $pd \to ^3\mathrm{He}, X \to ^3\mathrm{He}\,\pi^+\pi^-\gamma$ [15], showing a clear maximum at mass value equal to the mass of the η meson.

At the cooler synchrotron COSY η mesons are produced in the middle of the central part of the WASA detector in collisions of circulating proton or deuteron beam with the stream of frozen hydrogen or deuterium pellets. In particular, $pp \to pp\eta$ and $pd \to ^3\mathrm{He}\,\eta$ reactions are used and the production of the η meson is tagged by the registration of protons or helium ions in the forward part of the WASA detector. An example of the missing-mass spectrum of the $pd \to ^3\mathrm{He}\,X$ reaction, showing the capability of the WASA-at-COSY detector setup, is presented in the right panel of Fig 3.

5. *Discrete symmetries and QCD annomalies*

Both η and η' mesons are eigenstates of operators of parity (P), charge conjugation (C) and combined CP parity (with eigenvalue of $P = -1$, $C = +1$ and $CP = -1$). Therefore, studies of their decays constitute a valuable source of information regarding the degree of conservation of these symmetries in strong and electromagnetic interactions. In this context particularly interesting is the η meson, since all its strong and electromagnetic decays are forbidden in the first order [16]. The most energetically favourable strong decay of η into 2π is forbidden due to P and CP invariance. Its decay into 3π is suppressed by G-parity and isospin invariance [17], and it occurs due to the difference between the mass of u and d quarks, thus permitting the study of these masses since electromagnetic effects are expected to be small [18, 19]. Besides, strong decay into 4π is suppressed due to the small available phase space and again due to P and CP invariance. The first-order electromagnetic decays, like $\eta \to \pi^0\gamma$ or $\eta \to 2\pi^0\gamma$ break the charge-conjugation invariance, and $\eta \to \pi^+\pi^-\gamma$ is also suppressed because charge-conjugation conservation requires odd (and hence nonzero) angular momentum in the $\pi^+\pi^-$ system. Moreover, this radiative decay at a massless-quark limit is driven by the QCD box anomaly (Fig 4). In addition, in the massless quarks limit also the second-order electromagnetic decay $\eta \to \gamma\gamma$ is forbidden [20, 21, 16], and it occurs only due to the QCD triangle anomaly [22, 23] (Fig. 4). The abovementioned features of the η meson makes it especially suitable for the test of discrete symmetries in strong and electromagnetic interactions and for investigations of QCD anomalies. The QCD triangle and box anomaly, involved correspondingly in the $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\gamma$

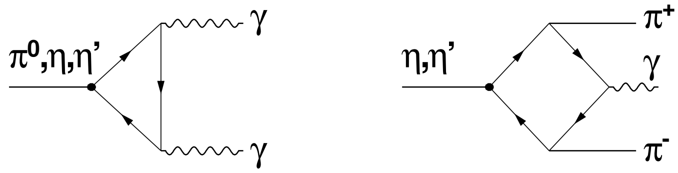

Fig. 4. Diagrams for the triangle and box anomalies.

decays, may also be studied via leptonic and semi-leptonic decays of meson in which the virtual γ quantum converts internally into e^+e^- pair, e.g. via Dalitz or double

Dalitz decays: $\eta \to \gamma^*\gamma \to e^+e^-\gamma$, $\eta \to \gamma^*\gamma^* \to e^+e^-e^+e^-$, as shown in Fig. 5, or via semi-leptonic decay, as e.g. $\eta \to \pi^+\pi^-\gamma^* \to \pi^+\pi^-e^+e^-$. The $\eta \to e^+e^-\pi^+\pi^-$ process is interesting also because it permits to study the flavour-conserving CP violation not predicted in the framework of the standard model, and not constrained by the experimental limits on $\eta \to \pi\pi$ decays or on the electric dipole moment of the neutron. The violation of the CP symmetry in the $\eta \to e^+e^-\pi^+\pi^-$ decay would manifest itself as an angular asymmetry between pion and electron decay planes. A possible mechanism leading to such asymmetry could be an interference between the electric and magnetic transition leading to the linear polarisation of the γ quantum from the $\eta \to \pi^+\pi^-\gamma^* \to \pi^+\pi^-e^+e^-$ process [24, 25]. In the case of the K_L meson, such asymmetry was observed by the KTeV collaboration [26].

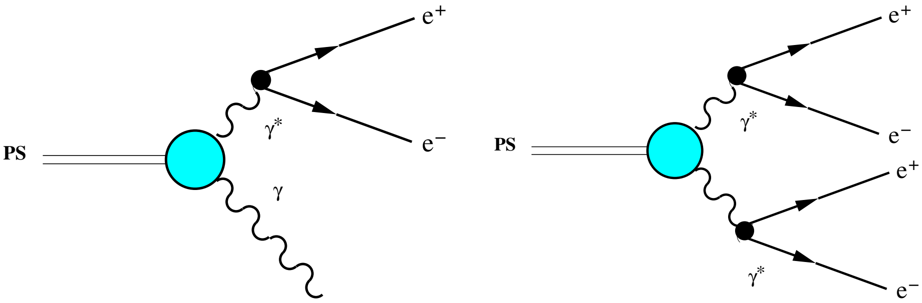

Fig. 5. Diagram for Dalitz (left) and double Dalitz decays (right) of pseudoscalar mesons.

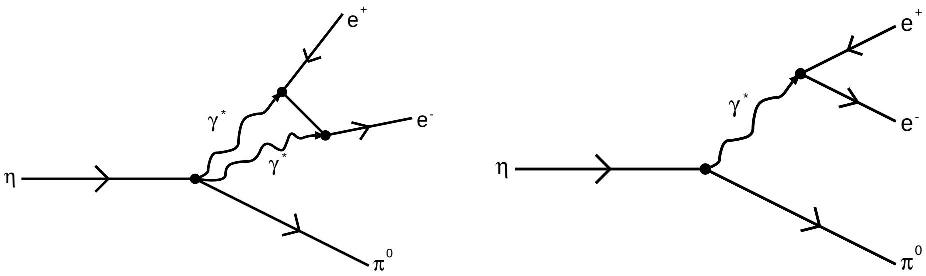

Fig. 6. (Left) Second order electromagnetic C-conserving transition: $\eta \to \pi^0\gamma^*\gamma^* \to \pi^0e^+e^-$. (Right) Diagram for the C invariance violating first order electromagnetic process: $\eta \to \pi^0\gamma^* \to \pi^0e^+e^-$.

As regards the C-symmetry conservation, so far it was not extensively investigated in electromagnetic and strong interactions. It may be tested in η decays into odd numbers of gamma quanta, such as e.g. $\eta \to 3\gamma$, $\eta \to \pi^0\gamma$, $\eta \to 3\pi^0\gamma$ etc. Also, the conversion decays, such as $\eta \to \pi^0e^+e^-$ may be used for the test of charge conjugation invariance. As shown in Fig. 6, in the framwework of the standard model, this process may proceed via C-conserving exchange of two virtual γ quanta ($\eta \to \pi^0\gamma^*\gamma^* \to \pi^0e^+e^-$) with the branching ratio of about 10^{-8}, but in principle it may also be realized with only one γ quantum in the intermediate state (Fig 6), thus breaking C invariance and increasing the branching ratio. At present the empirical upper limit determined for the BR($\eta \to \pi^0 e^+ e^-$) amounts to 4.5 x10^{-5}. Present upper limits for other C-violating decays (e.g. BR($\eta \to \gamma\gamma\gamma$) < 1.6 10^{-5} [27]) are at the same level. One may also test the C invariance in hadronic decays, as e.g. $\eta \to \pi^0\pi^+\pi^-$, where it can manifest itself as an asymmetry in the energy distributions for π^+ and π^- mesons in the rest frame of the η meson. The studies of the asymmetries in the population of the Dalitz plot for this decay permits also to study the isospin symmetry breaking and test the chiral perturbation theory [2, 28, 29, 11].

Both KLOE-2 and WASA-at-COSY aim at a significant improvement of sensitivity of the tests of the discrete symmetries in the decays of η and η' mesons beyond the presently achieved limits. In some cases, like the tests of P, C, or CP symmetries, with an expected number of about 10^9 η tagged, an improvement by more than one order of magnitude is expected.

6. *Spatial distributions of* η *and* η'

Due to the short life time of the flavour neutral mesons, their structure as well as interaction cannot be studied by means of classical scattering experiments. In addition, due to the positive charge conjugation of pseudoscalar mesons, their structure cannot be studied based on processes with the exchange of one photon. Therefore in order to investigate the spatial distribution of the meson charge, one has to study its decays into two photons, out of which at least one is virtual as it is e.g. in Dalitz or double Dalitz decays. The internal conversion of the virtual photon leads to the creation of the l^+l^- pair with a square of the invariant mass equal to the square of the four-momentum vector of the virtual photon (q^2). Deviations of the l^+l^- invariant-mass distributions from the predictions based on the assumption of point-like meson (which may be conducted in the framework of the quantum electrodynamics) deliver information about the meson structure and the dynamics of the process. These deviations are characterized by the transition form factors which in general depend on the square of the four-momentum of the involved photons. Distributions of the transition form factors as a function of q^2 allow to investigate the contribution to the process from e.g. triangle QCD anomaly or vector dominance mechanism (see Fig. 7). The studies of the conversion decays

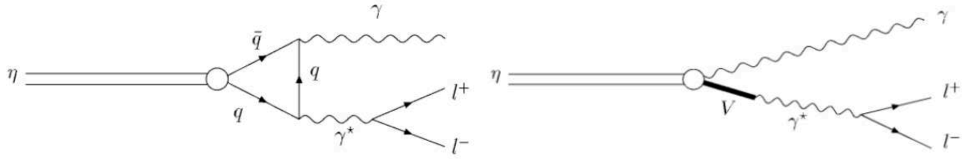

Fig. 7. Diagram representing the decay of the η meson into γ quantum and lepton anti-lepton pair: (left) in the framework of the quark model and (right) in the framework of the vector meson dominance model (VDM) [30].

give information about the time-like region of the form-factor with positive q^2 equal to the square of the invariant mass of the l^+l^- pair. The information about the space-like region with the negative values of q^2 is accessible via cross section of mesons production in $\gamma^*\gamma^*$ fusion realized in e.g. $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-\eta$ reaction. It is important to stress that the knowlegde of the transition form factors for pseudoscalar mesons is of crucial importance for the studies of the anomalous magnetic moment of the muon $a_\mu = (g_\mu - 2)/2$ which constitutes one of the most precise test of the standard model. a_μ was measured with the precision of 0.5 ppm [31], and FNAL experiment [32] plans to improve this accuaracy to 0.14 ppm in the near future. However, the predictions for the value of a_μ based on the SM are limited by the accuracy of the determination of the hadronic contributions. The accuracy of pseudoscalar transition form factors dominates the precision in determination of hadronic light-by-light contributions via terms shown in Fig 8, and therefore the precise studies of transition form factors is of importance for the SM predictions of the anomalous magnetic moment of the muon.

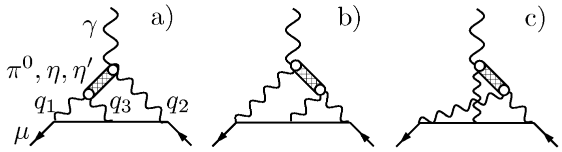

Fig. 8. Pseudoscalar exchange contribution to the light by light scattering.

7. Search for the U boson

The measurement of radiative decays of mesons (in particular of the η meson) is interesting also in the context of the search for the explanation of the recent astrophysical observations of excess of e^+e^- annihilation γ quanta from the galactic center observed by the INTEGRAL satellite [33], the excess in the cosmic ray positrons reported by PAMELA [34], the total electron and positron flux measured by ATIC [35], Fermi [36], and HESS [37], and the annual modulation of the DAMA/LIBRA signal [38]. In one of the considered scenarios, which may be reconciled with the observations [1], the origin of this kind of enhanced stream of radiation may be explained assuming that positrons are created in an annihilation of the dark matter particles into e^+e^- pairs, and that this process is mediated by the U boson with the mass in the GeV scale [39 – 42, 1]. The existence of such U boson could manifests itself as a maximum in the invariant mass distribution of e^+e^- pairs originating from the radiative decays as e.g. $\eta \to \gamma\mathrm{U} \to \gamma e^+e^-$ [43]. In addition, there are several possible signatures of U boson which may be searched for at e^+e^- collider DAΦNE, such as $e^+e^- \to e^+e^- + \gamma$, $e^+e^- \to \mu^+\mu^- + \gamma$, $e^+e^- \to E_{\mathrm{missing}} + \gamma$, $e^+e^- \to E_{\mathrm{missing}} + e^+e^-$, or events with 4 or 6 leptons in the final state [1]. Existence of such boson would also influence the branching ratio for rare processes such as e.g. $\pi^0 \to e^+e^-$ and $\eta \to e^+e^-$. The latter process was never observed till now. The present empirical upper limit set by the WASA/CELSIUS experiment [44] is still by four orders of magnitude larger than SM predictions (10^{-9}). Small probability for this decay make it especially sensitive to any hypothetical interactions from beyond the standard model. For detailed overview of phenomenology and possibilities of the search for the dark matter particles in the low-energy facilities at the GeV scale, the interested reader is referred to article [1].

8. Search for the eta-mesic nuclei

The negatively charged pions and kaons can be trapped in the Coulomb potential of atomic nucleus forming the so called pionic (kaonic) atoms. Observations of such atoms allow for studies of strong interaction of pions and kaons with atomic nuclei on the basis of shifts and widths of the energy levels [45, 46]. It is also conceivable that a neutral meson could be bound to a nucleus. In this case the binding is exclusively due to the strong interaction and hence such object can be called a *mesic nucleus*. Here the most promising candidate is the η-mesic nucleus since the ηN interaction is strongly attractive. We may thus picture [47] the formation and decay of the η-mesic nucleus as the η meson absorption by one of the nucleons, leading to the creation of the $N^*(1535)$ and then its propagation through the nucleus until it decays into the pion-nucleon pair which escapes from the nucleus. Predicted values of the width of such states range from ~ 7 to ~ 60 MeV [48 – 51]. The search of the η-mesic nucleus was conducted in many inclusive experiments via reactions induced by pions [52, 53], protons [54 – 58], and photons [59 – 61]. Many promising indications of the existence of such an object were reported, but so far none was independently confirmed. Experimental investigations with high statistical sensitivity and the detection of the $N^*(1535)$ decay products are being continued at the COSY [57], JINR [54], J-PARC [62], and MAMI [61] laboratories. For comprehensive description of the interpretation of present results, the interested reader is referred to the recent theoretical publications from the international symposium on mesic-nuclei [63 – 67]. Here we only report on the searches of the η-mesic helium carried out by means of the WASA detector at COSY [57]. We conduct a search via an exclusive measurement of the excitation functions for the $dd \to {}^3\mathrm{He}\, p\, \pi^-$ and $dd \to^3 \mathrm{He}\, n \pi^0 \to {}^3\mathrm{He} n\gamma\gamma$ reaction varying continuously the beam momentum around the threshold for the $d\,d \to^4 \mathrm{He}\, \eta$ reaction. Ramping of the beam momentum and taking advantage of the large acceptance of the WASA detector allows to minimize systematical uncertainties making the WASA-at-COSY a unique facility [57] for such kind of exclusive experiments. The ${}^4\mathrm{He} - \eta$ bound state should manifest itself as a resonant-like structure below the threshold for the $dd \to {}^4\mathrm{He}\, \eta$ reaction.

In the first experiment conducted in June 2008, no structure was found which would indicate the existence of the eta-mesic helium, and an upper limit for the eta-mesic helium production via the $dd \to (\eta\, {}^4\mathrm{He})_{\mathrm{bound}} \to {}^3\mathrm{He}\, p\, \pi^-$ reaction was determined to be about 20 nb on a one sigma level. In November 2010 the statistics was increased by a factor of about 40 and the data are now under evaluation.

9. *Gluonium content*

In the quark model, the η and η' mesons are regarded as a mixture of the singlet and octet states of the SU(3)-flavour pseudoscalar nonet. A small pseudoscalar mixing angle implies that the percentage amount of various quark flavours in both mesons is almost the same [68]. Nevertheless, their physical properties are unexpectedly different. The $\eta'(958)$ meson mass is almost two times larger than the mass of the $\eta(547)$ meson. The branching ratios for the decays of B and D_s mesons into the η' meson exceed significantly those into the η meson, and the standard model predictions, especially in processes requiring involvement of gluons [69, 70]. There exist excited states of nucleons which decay via emission of the η meson, yet none of the observed baryon resonances decays via the emission of the η' meson [71]. Their production cross sections in the collisions of nucleons differs by more than order of magnitude [68, 72] and also their hadronic interaction with nucleons differs significantly [73]. Due to the small mixing angle, the η' meson remains predominantly the SU(3)-flavor singlet and therefore it may include pure gluon states to a much larger extent than the η and all other pseudoscalar and vector mesons.

Recently, the gluonium fraction of $(12 \pm 4)\%$ in the η' meson has been extracted by fitting the widths of the magnetic dipole transition $V \to P\gamma$, where V are the vector mesons ρ, ω, ϕ and P the pseudoscalar mesons π^0, η, η', together with the $\pi^0 \to \gamma\gamma$ and $\eta' \to \gamma\gamma$ partial widths, and using the KLOE measurement of $R_\phi = BR(\phi \to \eta'\gamma)/BR(\phi \to \eta\gamma)$ [74]. The accuracy of the fit depends among others also on the uncertainty of the natural width of the η' meson. The total width of the η' meson extracted by PDG [71] is strongly correlated with the value of the partial width $\Gamma(\eta' \to \gamma\gamma)$ [71], which causes serious difficulties when the total and the partial width have to be used at the same time, like e.g. in studies of the gluonium content of the η' meson [75]. In this context it should be mentioned that the inaccuracy of $\Gamma_{\eta'}$ limits not only the extraction of the η' gluonic content, but it limits also investigations of many other interesting physics issues, as for example the quark mass difference $m_d - m_u$ [77, 17, 78], isospin breaking in quantum chromodynamics (QCD) [79, 77], or the box anomaly of QCD [80]. This is because the branching ratios of the η' meson decay channels are typically known with a relative precision of more than an order of magnitude better than the present accuracy with which $\Gamma_{\eta'}$ is extracted [71] [1].

With the KLOE-2 data-taking above the ϕ peak, e.g., at $\sqrt{s} \sim 1.2$ GeV, it is possible to measure the η' decay width $\Gamma(\eta' \to \gamma\gamma)$ through $\sigma(e^+e^- \to e^+e^-(\gamma^*\gamma^*) \to e^+e^-\eta')$. The measurement at the 1% level of both the cross section and the $BR(\eta' \to \gamma\gamma)$ would bring the fractional error on the η' total width, $\Gamma_{\eta'} = \Gamma(\eta' \to \gamma\gamma)/BR(\eta' \to \gamma\gamma)$, to $\sim$1.4% [1], and can reduce the uncertainty of the gluonium content determination by about a factor of three.

The gluonic admixture of η' influences also the η'-nucleon interaction and production processes via the U(1) anomaly [82]. The range of the glue-induced η'-

[1] Recently the COSY-11 collaboration extracted the total width of the $\Gamma_{\eta'}$ directly from the mass spectra and obtained: $\Gamma_{\eta'} = 0.226 \pm 0.017(\text{stat.}) \pm 0.014(\text{syst.})$ MeV/c^2 [81]. The result does not depend on knowing any of the branching ratios or partial decay widths.

nucleon interaction, if determined by the two-gluon effective potential, would be about 0.3 fm [83]. This range is large enough to be important in the threshold production of the η' meson, e.g. via the $pp \to pp\eta'$ reaction which occurs at distances of the colliding nucleons in the order of 0.2 fm. At such small distances, the quark-gluon degrees of freedom may play a significant role in the production dynamics of the η and η' mesons. Therefore, additionally to the mechanisms associated with meson exchanges, it is possible that the η' meson is created from excited glue in the interaction region of the colliding nucleons [82, 84], which couple to the η' meson directly via its gluonic component or through its SU(3)-flavour-singlet admixture. The production through the colour-singlet object, as suggested in Ref. [82], is isospin independent and should lead to the same production yield of the η' meson in the $pn \to pn\ gluons \to pn\eta'$ and $pp \to pp\ gluons \to pp\eta'$ reactions after correcting for the final and initial state interaction between the nucleons. Such studies were conducted in the case of the η meson [85, 86]. The ratio $R_\eta = \sigma(pn \to pn\eta)/\sigma(pp \to pp\eta)$ has been measured for quasifree η production from a deuteron target up to 109 MeV above threshold [85, 86]. One finds that R_η is approximately energy independent with a value of ~ 6.5 in the energy range of $16 - 109$ MeV signifying a strong isovector exchange contribution to the η production mechanism.

The existing predictions for the $R_{\eta'}$ differ drastically depending on the model [87, 88]. Yet, the ratio $R_{\eta'}$ has not been measured to date, and only recently an upper limit has been determined [89], but this can be significantly improved by the WASA-at-COSY experiment.

10. Spin observables

In the last decade, a vast set of the unpolarised observables has been established at the facilities CELSIUS, COSY and SATURNE for the η meson production in the collisions of nucleons [68, 72]. The data comprise in principle a lot of interesting information concerning the production mechanism and the η-nucleon interaction. These, however, could have not been derived unambiguously due to the lack of the knowledge about the relative contributions from the partial waves involved. One of the interesting unsolved problem as regards the $pp \to pp\eta$ reaction is the difficulty in reproducing the pp invariant mass distributions [90 − 92, 76]. Calculations which include NN FSI and $N\eta$ FSI do not match existing data [76]. To explain the unexpected shape of the distribution, possibility of higher partial waves is considered. Taking into account a P-wave contribution, one could reproduce the pp invariant mass distribution, but not the close to the threshold cross section dependencies [93]. To solve this discrepancy, a D_{13} resonance has been included [94] in the calculations. However, the data collected so far are insufficient for the unambiguous extraction of the S-wave or P-wave contributions. Up to now there are only three measurements of the analysing power for the $\vec{p}p \to pp\eta$ reaction which have been performed with low statistics, and the determined value of analysing power is essentially consistent with zero [95 − 97] within large error bars of about ± 0.15.

Therefore recently, the azimuthally symmetric WASA detector and the polarised proton beam of COSY have been used [98] to collect a high statistics sample of $\vec{p}p \to pp\eta$ reactions in order to determine the analysing power as a function of the invariant mass spectra of the two particle subsystems and subsequently to perform the partial-wave decomposition with an accuracy by far better than resulting from measurements of the distributions of the spin-averaged cross sections. The expected result should shed a light on the still not explained origin of structures in the invariant mass distributions observed independently by the TOF [90], COSY-11 [76, 92], and CELSIUS/WASA [91] collaborations. It is worth to stress that similar shapes of the invariant mass distributions have also been observed recently in the case of the η' meson [99]. In both the η and the η' case, the intricate structure remains so far unexplained.

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PROUČAVANJE η MEZONA S WASA UZ COSY I KLOE-2 UZ DAΦNE

Jedan od osnovnih poticaja za eksperimente KLOE-2 i WASA-uz-COSY su provjera osnovnih simetrija i traženje pojava izvan standardnog modela u hadronskim i leptonskim raspadima osnovnih stanja mezona, posebno u raspadima η mezona. Ti se mezoni u COSY proizvode u sudarima protona ili deuterona sa zrnastim protonskim ili deutronskim metama, a u DAΦNE mezoni nastaju u radioaktivnom raspadu ϕ mezona ili spajanjem virtualnih gama kvanata koji se izmjenjuju među elektronima i pozitronima u sudaru. Ovaj rad daje kratak opis eksperimentalnih tehnika što se primjenjuju u KLOE-2 i u WASA-uz-COSY, te neke fizikalne razloge koji potiču istraživanja tvorbe i raspada η mazona.