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Search for the rare $\eta \to \pi^{0} e^{+} e^{-}$ decay and study of the $\eta \to \pi^{0}\gamma\gamma$ decay.

Proposal for the CELSIUS/WASA collaboration

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SEARCH FOR THE RARE $\eta \to \pi^0 e^+ e^-$ DECAY AND STUDY OF THE $\eta \to \pi^0 \gamma\gamma$ DECAY: Preprint ITEP 10 – 03.
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We propose to perform a search for the rare $\eta \to \pi^0 e^+ e^-$ decay, which is a sensitive probe of C and CP violation in electromagnetic interactions of hadrons. The first stage of 12 effective days of data taking will be required to get ~2000 $\eta \to \pi^0 \gamma\gamma$ decays, which will allow improving of the statistical accuracy of the $\eta \to \pi^0 \gamma\gamma$ decay width by a factor two compare to the existing measurements. This needs in order to elucidate the best theoretical description for the $\eta \to \pi^0 \gamma\gamma$ decay and improve significantly the accuracy of the parameters that enter theoretical calculations of the C-conserving contribution to the decay $\eta \to \pi^0 e^+ e^-$. This running will also allow improving of the present upper limit on the branching ratio $\eta \to \pi^0 e^+ e^-$. The final stage of 130 effective days of data taking will be required to search for the $\eta \to \pi^0 e^+ e^-$ decay with a sensitivity of about $\sim 10^{-9}$.

Поиск редкого распада $\eta \to \pi^0 e^+ e^-$ и исследование распада $\eta \to \pi^0 \gamma\gamma$.
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Предлагается провести поиск редкого распада $\eta \to \pi^0 e^+ e^-$, который является чувствительным тестом С и СР нарушений в электромагнитных взаимодействиях адронов. На первом этапе, за 12 дней набора статистики, предлагается получить ~2000 распадов $\eta \to \pi^0 \gamma\gamma$, чтобы измерить ширину распада со статистической точностью вдвое лучшей современной мировой и определить наилучшее теоретическое описание распада $\eta \to \pi^0 \gamma\gamma$, тем самым, значительно улучшить точность параметров, которые входят в теоретические расчеты сохраняющего С-четность вклада в распад $\eta \to \pi^0 e^+ e^-$. Одновременно будет улучшен существующий верхний предел на распад $\eta \to \pi^0 e^+ e^-$. На втором этапе, за 130 дней набора статистики, - провести поиск распада $\eta \to \pi^0 e^+ e^-$ с чувствительностью к относительной вероятности распада на уровне $\sim 10^{-9}$.

Ref. – 28 names.

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Introduction

We propose to perform a search for the rare $\eta \to \pi^{\circ} e^{+} e^{-}$ decay, which is a sensitive probe of C and CP violation in electromagnetic interactions of hadrons. The decay is particularly well suited for searching new C-violating interactions. It can provide a signal of CP-violation phenomena and, perhaps, a window into physics beyond the Standard Model. Therefore we propose to:

- search for the $\eta \to \pi^{\circ} e^{+} e^{-}$ decay with a sensitivity down to branching ratios around $\sim 10^{-9}$;
- measure the decay width of the $\eta \to \pi^{\circ} \gamma\gamma$ and the Dalitz plot distribution in order to elucidate the best theoretical description for the $\eta \to \pi^{\circ} \gamma\gamma$ decay and improve significantly the accuracy of the parameters that enter theoretical calculations of the C-conserving contribution to the decay $\eta \to \pi^{\circ} e^{+} e^{-}$.

This will be accomplished by:

- much higher number $(\sim 3 \times 10^{9})$ of produced η mesons than obtained in previous experiments.

Scientific justification

The present Standard Model (SM) of elementary particles and their strong, electromagnetic and week interactions is extremely successful in explaining vast amounts of experimental data. Nevertheless the SM cannot be considered as a fundamental theory since it contains too many parameters. Searches for processes, which are forbidden within the SM, or tests of basic symmetries are interesting for the revelation of a deeper theory. The symmetries of the forces under reflection of spatial coordinates, parity (P), particle-antiparticle conjugation (C) and time reversal (T) are of special interest in this context. They are considered to hold in electromagnetic and strong interactions while parity and particle-antiparticle conjugation are not conserved in weak processes.

CP violation was discovered in the K_L° weak decays, in 1964 [1]. This discovery shook the foundations of particle physics. It had previously been assumed that the combination of C and P (CP) left all known particle interactions invariant [2]. The discovery prompted consideration of our knowledge about the symmetries. It has been found that commonly assumed conservation of the symmetries quite often suffered from experimental justification. Over the following three decades CP violation in the K_L° system was measured with ever increasing precision in an attempt to pin down its source.

P violation is escorted by C violation in weak interactions [3]. Therefore only an observation of C-violating effects with a strength much greater than due to the usual weak interaction H_{wk} would be an evidence for a new interaction called H_F, which violates C invariance and conserves strangeness and parity. Historically, H_F was suggested for explanation of the $K_L^{\circ} \to \pi^+\pi^-$ decay as a process that can occur through the second-order expression $H_F H_{wk}$ [4]. It was pointed out a long time ago that the decays of η mesons are particularly appropriate for a sensitive test of such an interaction [5-7]. Because the strong decays of η mesons are suppressed by G-parity, new C-violating interactions, if they exist, get a better opportunity to display themselves. At present H_F is not required to explain CP violation. However searches for a C-violating part of strong and electromagnetic interactions are nevertheless very interesting [8].

One of the best tests of C and CP conservation in electromagnetic interactions is the upper limit for the decay $\eta \to \pi^{\circ}e^+e^-$, the final lepton-antilepton pair being coupled to one intermediate virtual photon (see Fig.1a). The decay $\eta \to \pi^{\circ}e^+e^-$can however occur without violation of C invariance through the intermediate state $\pi^{\circ}\gamma^*\gamma^*$ (see Fig.1b). This intermediate state has the same C number, +1, as that of the η meson. If C invariance is violated, there could also be extra contributions to the decay through the intermediate state $\pi^{\circ}\gamma^*$ having C = -1 thus changing the rate as calculated for the C-conserving case. The present experimental upper limit of the branching ratio for the decay [9] is three orders of magnitude higher then the theoretical estimate $\sim 10^{-8}$ based on conventional decay mechanisms.

The decay $\eta \to \pi^{\circ}e^+e^-$ has been studied in Ref. [10-13] through a C-conserving, two-photon intermediate state $\eta \to \pi^{\circ}\gamma^*\gamma^* \to \pi^{\circ}e^+e^-$. More then three decades ago, Cheng [11] calculated the $\eta \to \pi^{\circ}e^+e^-$ decay in the limit $m_e = 0$ using a Vector-Meson Dominance (VMD) model. The unitary bound for the decay of $\eta \to \pi^{\circ}e^+e^-$ was calculated by Ng and Peters [12]. The input parameters were the two transition form factors in the amplitude of the radiative decay $\eta \to \pi^{\circ}\gamma\gamma$. They were calculated using the VMD model plus an exchange of the pseudoscalar $a_0(980)$ meson. In principle, the model dependence can be eliminated by separate measurements of the transition form factors. The same authors obtained an estimate by calculation of the quark-box diagrams in the framework of the constituent quark model [13]. The theoretical predictions are given in Table 1.

Table 1. Theoretical predictions of the decay $\eta \to \pi^0 e^+ e^-$.

Prediction	Reference	$\Gamma(\eta \to \pi^0 e^+ e^-)$ (μeV)	$\mathrm{Br}(\eta \to \pi^0 e^+ e^-)$
Cheng	[11]	13	$\approx 1.1 \times 10^{-8}$
Ng and Peters	[12]	3.5±0.8	$(2. \pm 0.6) \times 10^{-9}$
Ng and Peters (Box)	[13]	1.2÷7.3	$(1 \div 6) \times 10^{-9}$

More precise knowledge of the C-conserving contribution through the two-photon intermediate state $\eta \to \pi^0 \gamma^* \gamma^* \to \pi^0 e^+ e^-$ to the $\eta \to \pi^0 e^+ e^-$ decay is highly desirable for the proper interpretation of the intended experiment.

The major source of the uncertainties in the theoretical predictions [11-13] lies in insufficient knowledge of the radiative decay $\eta \to \pi^0 \gamma\gamma$. The $\eta \to \pi^0 \gamma\gamma$ decay has long dramatic history, nicely reviewed in Ref. [14]. The situation, both experimental and theoretical, is still unclear. Despite considerable experimental effort, only a few reliable measurements exist at present. Fairly reliable experimental data concerning the $\eta \to \pi^0 \gamma\gamma$ decay are summarized in Table 2.

Table 2. Experimental results for the $\eta \to \pi^0 \gamma\gamma$ decay.

Experiment [reference] (year)	Reaction, energy	$\Gamma(\eta \to \pi^0\gamma\gamma)$ (eV)	$\mathrm{Br}(\eta \to \pi^0\gamma\gamma)$	Number of signal events of the process	Detection efficiency for signal	Number of η mesons in data sample
GAMS-2000 [15] (1986)	$\pi^- p \to n\eta$ $p_{beam} = 30\mathrm{GeV/c}$	0.84±0.19	$(7.1\pm1.7)\times10^{-4}$	38	13%	0.6×10^6
SND [14] (2001)	$e^+e^- \to \phi \to \eta\gamma$ $E_{CM} = 980 \div 1060\mathrm{MeV}$	< 0.99	$< 8.4\times10^{-4}$	$7.0^{+12.9}_{-6.5}$	13.1%	0.258×10^6
Crystal Ball [16] (2001)	$\pi^- p \to n\eta$ $p_{beam} = 720\mathrm{MeV/c}$	0.42±0.14	$(3.2\pm0.9)\times10^{-4}$	~500	13.4%	18.9×10^6

The decay width given by GAMS-2000 is a factor two higher than the recent result of the Crystal Ball collaboration. This problem may possibly be associated with eliminating background from other much more intense neutral modes such as $\pi^- p \to n\pi^0\pi^0$ and $\eta \to 3\pi^0$.

Various theoretical estimates are given in Table 3. As is obvious the present theoretical situation is uncertain and an increase in precision is definitely needed. Although the low-energy amplitudes are calculable in ChPT, these amplitudes cannot at present be calculated without model ambiguities. This leads to uncertainty in theoretical estimates of the width $\eta \to \pi^{\circ}\gamma\gamma$. Example on this is the existing disagreement between the theoretical estimates of the $a_0(980)$ contribution. The experimental determination of the coupling constants $g_{a\eta\pi}$ and $g_{a\gamma\gamma}$ is ambiguous, because it depends on the magnitude of the true width of the $a_0(980)$ decay. The $a_0(980)$ lies close to the opening of the $K\tilde{K}$ channel to which it couples

Table 3. Theoretical estimates of the decay $\eta \to \pi^{\circ}\gamma\gamma$.

Prediction	Reference	$\Gamma(\eta \to \pi^{\circ}\gamma\gamma)$ (eV)
Ametller et al. (ChPT)	[17]	0.42 ± 0.20
P. Ko	[21]	0.47 ± 0.20
Ng and Peters	[12]	$0.14 \div 0.60$
Ng and Peters (Box)	[13]	0.70 ± 0.12
Bellucci and Bruno (ENJL)	[22]	0.58 ± 0.3
M. Jetter (ChPT)	[23]	0.77 ± 0.16
Nemoto et al. (NJL)	[24]	0.92
E. Shabalin	[20]	$0.83^{+0.09}_{-0.11}$

strongly. This gives an important cusp-like behavior in the resonant amplitude. Hence, its width parameter is strongly distorted. As a result of this, the true width of the decay of the $a_0(980)$ meson takes values between 50 and 300 MeV due to differently applied models. From a theoretical point of view, the $\eta \to \pi^{\circ}\gamma\gamma$ decay provides a stringent test of higher order corrections in ChPT. Unfortunately these corrections cannot be calculated without model ambiguities. The present theoretical situation is discussed in Ref. [18-20].

The study of the spectra of photon energy and of two-photon invariant mass, which have different shapes for different models, will allow the separation of different contributions to this decay mode. A new and better measurement is needed to settle the experimental decay width and clarify the present theoretical discrepancies (model dependence). A measurement of the Dalitz plot distribution will help to elucidate the best theoretical description for the $\eta \to \pi^{\circ}\gamma\gamma$ decay. Such studies require high statistics measurements. The proposed measurement using CELSIUS/WASA can clarify the situation. A better knowledge of this decay is needed in order to get a reliable estimate of the C-conserving contribution to the $\eta \to \pi^{o} e^{+} e^{-}$ decay.

The rare decay $\eta \to \pi^{o} e^{+} e^{-}$ has not yet been observed. The present experimental upper limit, $Br(\eta \to \pi^{o} e^{+} e^{-})|_{Exp} < 4 \times 10^{-5}$ is still far away from the expected Standard Model signal, and the prospect for getting a sensitivity of about 10^{-9} is rather encouraging. The observation of a non-zero branching ratio for the decay $\eta \to \pi^{o} e^{+} e^{-}$ would be extremely interesting. Provided sufficient statistics could be obtained, it would be possible to test also CP and CPT by exploring not only the value for the branching ratio but also various differential decay distributions.

The information is also essential for interpreting the directly CP-violating weak $K_L^{o} \to \pi^{o} e^{+} e^{-}$ decay that is on the programme at Fermilab (experiment KAMI) and Brookhaven.

Experimental details

The measurement is proposed to carry out using the high-luminosity CELSIUS/WASA facility, which is composed of a proton storage ring, CELSIUS, a novel internal target technology developed in Uppsala and a close to 4π detector setup. The layout of the experimental set-up is shown in Fig. 2. The WASA setup [25] consists of a forward detector part (FD) covering $3^{\circ} - 18^{\circ}$ for measurements of charged target recoil particles and scattered projectiles and a central detector part (CD), which is optimized for measurement of electrons, photons and charged pions, produced in η meson decays.

A modular CsI(Na) electromagnetic calorimeter is part of the CD. The calorimeter uses 1012 individual scintillating crystals covers scattering angles from $20^{\circ} - 169^{\circ}$ (96% of 4π steradians). The length of the crystals varies in the different parts of the calorimeter from 30 cm ($16.2 X_0$ - radiation lengths) in the central part to 25 cm in the forward part and 20 cm in the backward part. The energy resolution for 100 MeV photons is 10% and for a stopped charged particles 3%.

An extremely thin-walled superconducting solenoid magnet is placed within the calorimeter. Its wall thickness corresponds to $0.18 X_0$. There is a cylindrical Mini Drift Chamber (MDC) inside of the solenoid. The MDC consists of 1738 thin (25 μm) aluminized mylar straw tubes in 17 cylindrical layers. The straws are assembled around the beryllium beam pipe, 60 mm in diameter. The wall thickness of the pipe is only 1.2 mm ($0.0034 X_0$) to minimize the photon conversion in it. A thin layer of 146 plastic scintillators surrounds the MDC. The MDC serves in conjunction with the solenoid magnet as a momentum spectrometer, covers an angular range $24^\circ \div 159^\circ$ and measures momenta of charged particles.

The forward detector measures energy and scattering angles of the protons from the $pp \to ppX$ reaction. This information allows for reconstruction of the kinematics of the produced system by the missing-mass technique and provides the fast trigger signals for the data acquisition. The forward detector consists of 16 drift chamber planes (also of the straw type) and a 50 cm thick stack of 216 plastic scintillators. A multilayer forward absorber will be installed to improve the trigger efficiency (from ~23% to ~85%) and the signal-to-background ratio in trigger rate (~30% improvement) for the $pp \to pp\eta$ reaction at the beam energy 1360 MeV. The resolution in scattering angle is less than 0.2° and in energy ($\Delta E/E$) in the range 3 – 6 % (FWHM). The two-proton missing mass spectra for 2γ or $3\pi^0$ detected by the central detector shows the very sharp η peak (6 MeV FWHM) [26]. The good missing-mass resolution is important in the proposed experiment.

To obtain characteristics of the WASA set-up in the proposed experiment a Monte-Carlo (MC) simulation of the $\eta \to \pi^0 e^+ e^-$ decay was carried out using real parameters of the CELSIUS ring and taking into account the efficiencies and the resolution of the detectors. The magnetic field was 1 Tesla. The $\eta \to \pi^0 e^+ e^-$ decay was simulated according to the approximate analytical expression for the imaginary part of the amplitude given in Ref. [12, 13]. The event generator has the following form

$$
\begin{array}{l}
pp \to pp\,\eta \\
\qquad\quad |\; -- > e^+ e^- \pi^0 \\
\qquad\qquad\qquad\qquad |\; ---> \gamma\gamma.
\end{array}
\tag{1}
$$

As a result, there are two charged particles (e^+e^-) and two photons in the final state. A primary selection of the events for the process (1) was done according to the following criteria:

- an event must contain exactly two protons in the forward detector, two photons and two charged particles (e^+e^-) in the central detector;
- the kinetic energy of any proton lies within the interval $115 \div 510$ MeV and the sum of the kinetic energies of the two protons lies within the interval $430 \div 770$ MeV;
- the polar angle of any proton is less than 15.5° and the opening angle of the two protons is less than 27.5°;

- the two-proton invariant mass, M_{pp}^{inv}, lies within the interval $1876 \div 1930$ MeV and the two-proton missing mass lies within the interval $520 \div 570$ MeV;
- the polar angle of any photon lies within the interval $25^{\circ} \div 165^{\circ}$ and the polar angle of the electron (positron) lies within the interval $25^{\circ} \div 159^{\circ}$;
- the energy of any photon is more than 25 MeV and the momentum of the electron (positron) is more than 25 MeV/c;
- the total deposited energy $E_{ppe^+e^-\gamma\gamma}^{tot}$ lies within the interval $915 \div 1485$ MeV.

The MC simulation resulted in a total detection efficiency of about 22%.

Taking into account the smallness of the decay there should be strong restrictions on the background processes. This put stringent requirements on the knowledge of the resolution functions and efficiency of the WASA setup, because most of the processes can contribute to the background mainly from events that show up in the tails of the experimental resolutions. One of the ways to improve the signal-to-background ratio is to apply cuts on the sample of collected events. However, one must realize that this leads to smaller statistics and to an increase of the systematic uncertainties.

The processes, which can contribute to the background to the decay $\eta \to \pi^{o} e^{+} e^{-}$, are given in Table 4. These processes can contribute to the background primarily through the following mechanisms: (a) external conversion of a photon, (b) two charged pions are misidentified as an electron-positron pair, (c) one photon escapes or two photons overlap, (d) one photon is reconstructed as two photons.

We have performed extensive studies of possible background to the $\eta \to \pi^{o} e^{+} e^{-}$ decay using MC simulations. The additional selection criteria were optimized to reject background events to a level less than 10^{-8}. On the other hand we have tried to keep the detection efficiency for the $\eta \to \pi^{o} e^{+} e^{-}$ decay as a high as possible. The following selection criteria were determined from the analysis of the Monte Carlo sample:

- the two-proton missing mass must be equal to η mass within a narrow tolerance ($m_{\eta} \pm 7.5$ MeV);
- the opening angle of the $e^{+}e^{-}$ –pair must be more than 12°;
- the opening angle of the photon pair must be more than 22°;
- the sum of the energies of the photons must exceed the π^{0} mass;
- the two-photon invariant mass, $M_{\gamma\gamma}^{inv}$, must fall within the interval $70 \div 185$ MeV;
- the invariant mass $M_{e^+e^-\gamma\gamma}^{inv}$ must fall within the interval $450 \div 600$ MeV.

The second cutoff leaves less than 10^{-5} of the background events due to the photon conversion. The third, fourth and fifth conditions suppress the background events, in which one photon is misreconstructed as two photons.

Events, where an electron-positron pair has been produced by external conversion of a photon, are reduced by an order of magnitude by means of the reconstruction of its production vertex. This is a rather conservative estimate. The stronger rejection factor for events, where one photon is reconstructed as two photons, can be obtained by improving the reconstruction of photons from the showers in the calorimeter. The described selection criteria reduce the background processes to the $\eta \to \pi^\circ e^+ e^-$ branching ratio to a level of up to a few times 10^{-9} (see the second column of the Table 4). The detection efficiency for the $\eta \to \pi^\circ e^+ e^-$ events decreases from 22% to 17% due to the applied selection criteria.

Table 4. Sources of background to the $\eta \to \pi^\circ e^+ e^-$ decay.

Process	Upper limit on the process contribution into the branching ratio	Comment
$pp \to pp\pi^\circ \to ppe^+e^-\gamma$	0.48×10^{-9}	events, where a single photon is misreconstructed as two photons
$pp \to pp\eta \to ppe^+e^-\gamma$	2.5×10^{-9}	
$pp \to pp\pi^\circ \to pp\gamma\gamma$	4.0×10^{-9}	events, where one photon converts into an electron-positron pair and the other one is misreconstructed as
$pp \to pp\eta \to pp\gamma\gamma$	0.52×10^{-9}	
$pp \to pp\eta \to pp\pi^\circ\gamma\gamma$	3.5×10^{-12}	events in which one photon escaped or two photon clusters overlap and one photon is converted into e^+e^-
$pp \to pp\pi^\circ\pi^\circ \to pp\gamma\gamma\gamma\gamma$	5.4×10^{-9}	
$pp \to pp\pi^\circ\pi^\circ \to pp\gamma\gamma e^+e^-\gamma$	2.6×10^{-9}	events in which one photon escaped or two photons overlap
$pp \to pp\pi^+\pi^-\pi^\circ$	2×10^{-9}	events in which charged pions are misidentified as an electron and a positron
$pp \to pp\eta \to pp\pi^+\pi^-\pi^\circ$	2.3×10^{-9}	
$pp \to pp\eta \to pp\pi^+\pi^-\gamma$	$<0.5 \times 10^{-9}$	events, where two charged pions are misidentified as an e^+e^- pair and a single photon misreconstructed as two photons

A further rejection of the background can be obtained by fitting of the retained events to a number of hypotheses, corresponding to the processes listed in Table 4, and then applying a series of cutoffs based on hypothesis probabilities. According to simulations a search sensitivity of about $\sim 10^{-9}$ is within reach when considering the full background.

However, there is a non-reducible source of background due to "subthreshold" production of $\rho-$ and $\varpi-$mesons, accompanied by their decays into the $\pi^{\circ}e^{-}e^{-}$ channel. The tails of these resonances give a small but finite contribution to the production cross section in the region of the eta mass and this contribution cannot be distinguished from the desired signal. We have evaluated the cross sections of $\rho-$ and $\varpi-$mesons production in the tails of their resonant masses around the η meson ($m_{\eta} \pm 5$ MeV) [27]. Using the cross sections calculated for these tails and the branching ratios of $\rho-$ and $\varpi-$ decays into the $\pi^{\circ}e^{+}e^{-}$ channel the resulting background to the $\eta \to \pi^{\circ}e^{+}e$ decay is

$$\frac{\sigma_{pp\to pp\rho}\cdot Br(\rho\to\pi^{\circ}e^{+}e^{-})}{\sigma_{pp\to pp\eta}} = 0.32\times10^{-9} \text{ and } \frac{\sigma_{pp\to pp\varpi}\cdot Br(\varpi\to\pi^{\circ}e^{+}e^{-})}{\sigma_{pp\to pp\eta}} = 2\times10^{-9}$$

respectively. It should be pointed out that the level of this background may be estimated from its level at two-proton missing masses just below and above the eta mass region.

The decay

$$\eta \to \pi^{\circ}\gamma\gamma \qquad (2)$$

was simulated according to the approximate analytical expression given in Ref. [12-13]. Nevertheless, the most realistic estimate of the detection efficiency for the $\eta \to \pi^{\circ}\gamma\gamma$ events can be obtained from the experience of the previous experiments [14-16], because the final detection efficiency depends on the problem of eliminating the background from other much more intense neutral modes. The electromagnetic calorimeter of the WASA set-up is very similar to ones used in previous experiments [14, 16], and therefore the most reliable estimate of the final detection efficiency for the $\eta \to \pi^{\circ}\gamma\gamma$ decay can be assumed to be around 13% (see Table 2).

The experiments [14-16] clearly demonstrated the experimental difficulties in the studies of the $\eta \to \pi^{\circ}\gamma\gamma$ decay caused mainly by the background $\eta \to 3\pi^{\circ}$. This background is most dangerous, because it produces a fake peak in the $\eta-$mass region. A merging of photons is a main reason why $\eta \to 3\pi^0$ decays may imitate the $\eta \to \pi^0\gamma\gamma$ process, and another reason is a loss of photons because of inefficient measurement in the calorimeter. The WASA calorimeter consists of 1012 individual crystals with solid angle coverage 96% of 4π (the Crystal Ball calorimeter has 672 crystals and 94% coverage). The high granularity of the WASA calorimeter ensures a rather good angular resolution for photons.

Another significant background comes from the $\pi^0\pi^0$ – production, which contributes to the background mainly from events that show up in the tails of the experimental resolutions. The $\pi^0\pi^0$ – background does not produce a peak in the region of the η –mass. However, knowledge of the shape of this background under the η –peak is important for the determination of the number of events from the $\eta \to \pi^0\gamma\gamma$ decay. This background is suppressed by an order of magnitude after the invariant masses of photon pairs are restricted to exclude the presence of a second π^0 meson. Although the Crystal Ball experiment, using a π^- –beam, provides a better production ratio $\eta / \pi^0\pi^0 \sim 1$ than the proposed CELSIUS/WASA experiment, where $\sigma_{pp\to pp\eta} / \sigma_{pp\to pp2\pi^0} \sim 1/82$, the rejection of the $\pi^0\pi^0$ – production by means of the two-proton missing mass is very effective. The rejection factor varies from 85, if the two-proton missing mass lies within the interval $520 \div 570$ MeV to ~320 for missing mass within a narrow 15 MeV bin (m_η ± 7.5 MeV). Therefore the WASA setup may provide background condition for the study of the $\eta \to \pi^0\gamma\gamma$ decay comparable to those of the experiments [14-16].

Estimates of event rates are based on the reaction $pp \to pp\eta$ at a proton beam energy of $E^{kin}_{beam} = 1360\,\text{MeV}$ where the cross section $\sigma_{pp\to pp\eta}$ is around 5μb [28].

To clarify the experimental situation concerning the decay width of the $\eta \to \pi^0\gamma\gamma$ decay we need to have about $(1 \div 2) \times 10^3$ decays for a first stage of the experiment. Assuming a branching ratio of 3.2×10^{-4}, a luminosity of $10^{31}\,\text{cm}^{-2}\text{s}^{-1}$ and an efficiency of 13 % results in 12 effective days of data taking using a 1360 MeV proton beam onto a hydrogen pellet target. This running will provide about 5×10^7 η mesons, which will allow improving of the present experimental upper limit on the branching ratio $\eta \to \pi^0 e^+e^-$, since this decay can be measured simultaneously. To perform a search for the $\eta \to \pi^0 e^+e^-$ decay with a sensitivity of around 10^{-8} we need to have an experimental data sample of about 10^9 η mesons. For this final stage we will need a luminosity of $10^{32}\,\text{cm}^{-2}\text{s}^{-1}$. At this luminosity 500 η mesons, tagged by means of the two-proton missing mass, will be produced every second. Using the efficiency of 17% it is found that about 85 useful etas will be produced per second. Hence 130 effective days of data taking will be required to have 10^9 η mesons which are required for a search for the $\eta \to \pi^o e^+ e^-$ decay with a sensitivity of about $\sim (4 \div 9) \times 10^{-9}$.

Background

In comparison with previous experiments, the search for the $\eta \to \pi^o e^+ e^-$ decay and the study of the $\eta \to \pi^o \gamma\gamma$ decay using the CELSIUS/WASA facility has the following advantages:

- the beam-target luminosity of the CELSIUS/WASA setup is about $10^{32}\,cm^{-2}s^{-1}$ and a large sample of etas can be obtained;
- using the hydrogen pellet target eliminates background due to empty target;
- an effective tagging of the etas is providing by means of the two-proton missing mass;
- the CELSIUS/WASA facility allows the simultaneous measurement of charged and neutral particles, which has not been done in previous electronics experiments (see for example [9]).

In conclusion, the rare decay $\eta \to \pi^o e^+ e^-$ has not yet been observed; the CELSIUS/WASA setup provides a unique possibility to observe this very rare decay.

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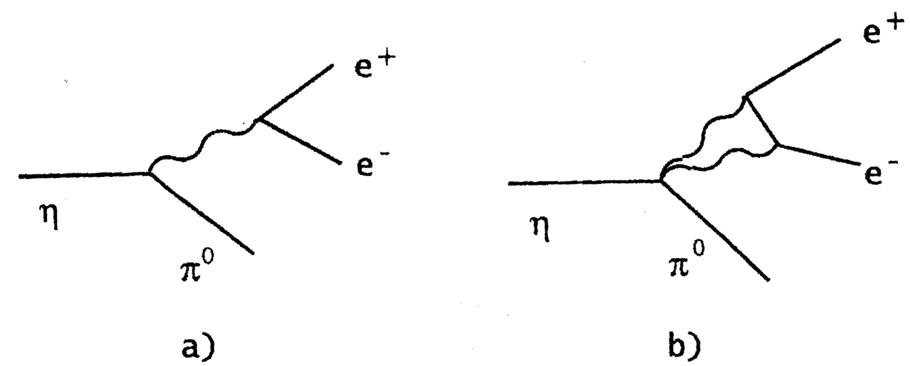

Figure 1. (a) – one photon exchange violates C and CP invariance,
(b) – two photon exchange conserves C and CP invariance .

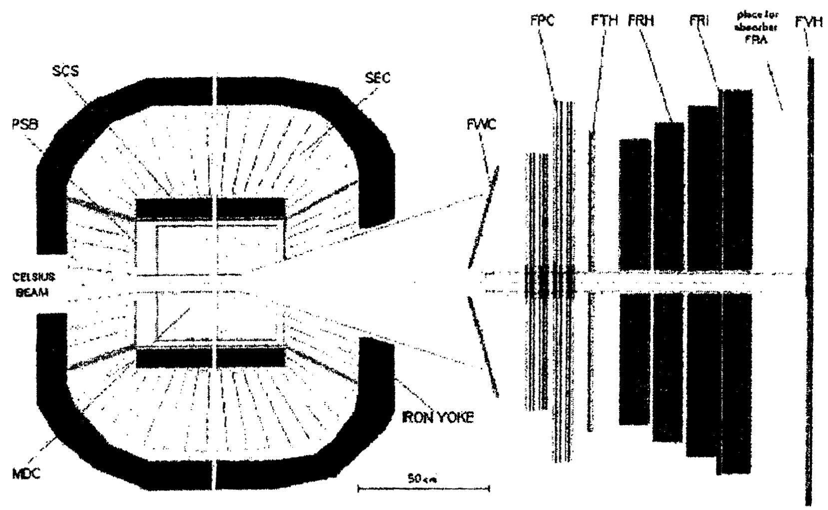

Figure 2. Plan view of the CELSIUS/WASA facility. The Super Conducting Solenoid (SCS) and the iron yoke for the return path of magnetic flux is shown shaded. Plasic scinillators are situated in the Plastic Scintillator Barrel (PSB), Forward Window Counters (FWC), Forward Trigger Hodoscope (FTH), Forward Range Hodoscope (FRH), Forward Range Interleaved planes (FRI) and Forward Veto Hodoscopes (FVH). Cesium Iodide scintillators are situated in the Scintillator Electromagnetic Calorimeter (SEC). Proportional wire drift tubes, straws, make up the Mini Drift Chamber (MDC) and the Forward Proportional Chambers (FPC).