η decay into $\pi^+\pi^-e^+e^-$ measured in $pd \to {}^3\mathrm{He}\eta$ reaction.

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The reaction $pd \to {}^3\mathrm{He}\eta$ has been studied with WASA setup at CELSIUS. We present preliminary results on the observation of the $\eta \to \pi^+\pi^-e^+e^-$ decay. The η mesons were produced from proton-deuteron interactions at 893 MeV incident proton energy with ${}^3\mathrm{He}$ measured in zero-degree spectrometer.

1 Introduction

Experimental informations on the η meson decays with lepton pair(s) are scarce. The $\eta \to \pi^+\pi^-e^+e^-$ channel is of special interest because it can be used to put new limits on unconventional mechanisms of the CP violation in flavour non conserving sector which would show up as an asymmetry in the distribution of angle between the $\pi^+\pi^-$ and e^+e^- decay planes [1]. In addition the same decay channel, as well as the $\eta \to \pi^+\pi^-\gamma$ with real photon in the final state, can probe the interplay between diagrams involving intermediate ρ and the contact term. The current PDG value of the branching ratio: $(4.^{+11.}_{-2.7}) * 10^{-4}$ has been based on the observation of five events only: one event by Grossman et al. [2] and the four by Akhmeshin et al [3].

2 The experimental method

The reaction $pd \to^3$Heη close to threshold as a source of ηs was first employed for eta decay experiments at Saturne II synchrotron at Saclay [4]. The production of η was tagged in a very clean way by measuring ^{3}He in a spectrometer at 0°. The η production cross section in the reaction raises very quickly from threshold to a plateau value of 0.4 μb at 2 MeV excess energy, while background from prompt $pd \to^3$He$\pi^+\pi^-$ reaction remains at the percent level [5]. This tagging method enables to collect simultaneously very clean data sample of all eta decays. The main problem with the reaction is the rather low cross section.

The studies of η decays using the $pd \to^3$Heη reaction close to threshold require detection of outgoing ^{3}He ions at 0° angle. That should provide a signal for the trigger and a measurement of the ^{3}He energy which gives a precise determination of the η momentum.

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For CELSIUS/WASA we used accelerator dipole magnets as a filter to deflect ^{3}He recoils and measured their kinetic energies in a tagging telescopes, an internal semiconductor HP-Ge [6] detector, placed in the beam pipe vacuum. The spectrometer has an energy resolution better than 1 MeV for ^{3}He kinetic energies less than 420 MeV and the acceptance at 1 MeV above threshold is 50%. The tagging detector provides trigger and very clean signal of ^{3}He ions with kinetic energy consistent with the kinematics of $pd \to ^3$Heη reaction (Fig. 1). The corresponding missing mass resolution is 150 keV.

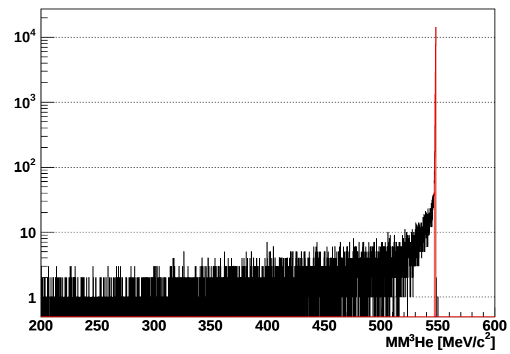

Fig. 1. Missing mass to ^{3}He with resolution of 150 keV.

The products of the η decays were measured with the WASA detector at the CELSIUS accelerator. The main components are shown in Fig. 2 and described in detail in [7]. For the studies of $\eta \to \pi^+\pi^- e^+e^-$ decay mostly the Central Detector was used, where charged particles momenta were measured by the Mini Drift Chamber (MDC) in the presence of the axial magnetic field of 1T supplied by a superconducting solenoid (SCS). The energies of the particles were measured in the Plastic Scintillator Barrel (PSB) and the Scintillator Electromagnetic Calorimeter (SEC).

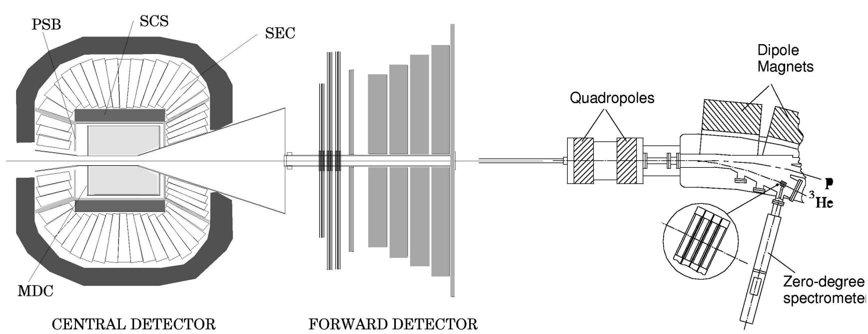

Fig. 2. The cross section of the WASA apparatus with Central Detector built around interaction point, Forward Detector and zero-degree spectrometer. (The scale of the spectrometer's plot was intensionally increased and adjusted to fit the figure.)

The internal pellet target system with deuterium was available on regular basis from Spring

2004. The trigger rate of the tagging system during the operation with the deuterium pellets and the proton beam with luminosity $5\times10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$was few Hz, yielding on average 1η event per second in the data acquisition.

The quality of the tagging in $pd \to {}^3\mathrm{He}\eta$ reaction can be tested by the decay $\eta \to \gamma\gamma$. The process has over-constrained and very simple kinematics since the η is nearly at rest in the center of mass system. The sum of energies of the photons is constant and equal to 604 MeV and momenta of the photons are coplanar with the beam. The velocity (β) of the η can be reconstructed from the photon scattering angles alone. The β is given by a simple formula:

$$\beta = \frac{\sin(\theta_1 + \theta_2)}{\sin\theta_1 + \sin\theta_2} = 0.42$$

where $\theta_{1,2}$ are scattering angles of the photons in the experiment determined from the impact point in the calorimeter under assumption of beam target interactions (z =0). The experimental β distribution is show in (Fig. 3(left))for events with correct photon energies. The flat background is due to beam-rest gas interactions as illustrated in Fig. 3(right) where relation between vertex position along the beam axis and the reconstructed β is plotted for MC simulation. Tagging by measurement of ^{3}He at 0° tends to enhance beam rest gas contribution since it is not sensitive to the position of the interaction point – in principle all events along CELSIUS straight section are accepted. The background can be removed by a constrain on the vertex position for the decays with charged particles. Since the trigger is not biased by a particular eta decay channel it is enough to determine the vertex point distribution for one decay channel to be able to take it into account in the MC for all remaining channels. An unbiased trigger allows also to determine total number of eta decay events collected in the experiment from the number of observed $\eta \to \gamma\gamma$ events. Using that method it was found that data used in the analysis below corresponds to 250000 of eta events.

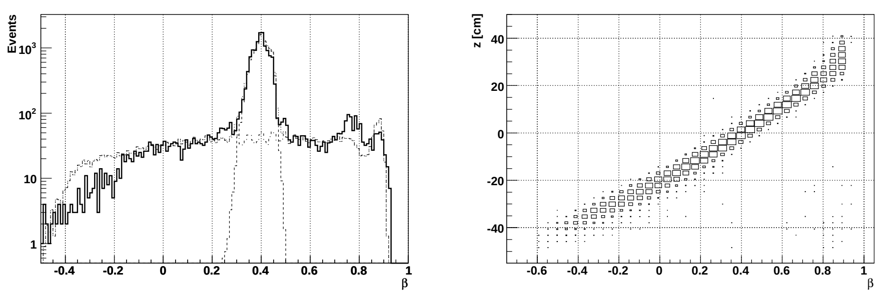

Fig. 3. (Left) Reconstructed β distribution from $\eta \to \gamma\gamma$. Thick solid line – experimental data, thin lines – Monte Carlo simulations of beam-rest gas and vertex interactions. (Right) Correlation of reconstructed β vs vertex position along the beam – Monte Carlo studies.

3 Analysis and results

The method of tagging ^{3}He recoils emitted in a narrow forward cone close to 0^o with a magnetic spectrometer provides an almost background free η production. The only background for the

$\pi^+\pi^-e^+e^-$ decay are other decays with charged particles. The main background was identified with Monte Carlo studies as $\eta \to \pi^+\pi^-\pi^0$ with subsequent Dalitz decay of π^0, ($\pi^0 \to e^+e^-\gamma$), or with a photon conversion in the beam pipe.[3]

The event candidates for the η decay into $\pi^+\pi^-e^+e^-$ were selected by requiring four charged tracks in the central drift chamber, with two tracks carrying positive and two negative charge. Small fraction of events with additional tracks in the Forward Detector was discarded to diminish the possibility of overlapping of chance-coincidence events. The unassociated clusters in the calorimeter (SEC) were however allowed in order to keep high acceptance, since the presence of the neutral cluster can be due to split-offs.

In order to distinguish between pions and electrons, the value of the opening angle between two particles with opposite charge was calculated. With two positively and two negatively charged particle, there are four combinations to be tested. Based on the Monte Carlo simulations, the pair with the smallest opening angle is most likely a positron-electron pair. The effectiveness of the particle separation based on that method is demonstrated in Fig. 4. In more than 85% cases the separation was correct for a Monte Carlo data sample of $\eta \to \pi^+\pi^-e^+e^-$. In addition a ΔE-P method of particle identification was applied for particles escaping the MDC using the energy deposits in the PSB and/or the SEC.

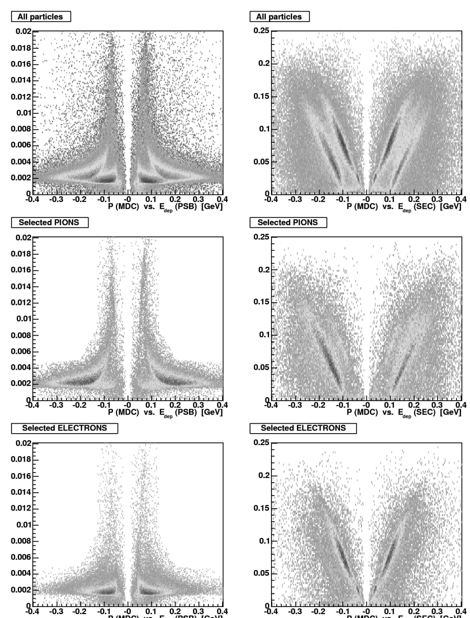

Fig. 4. Particle separation based on the opening angle for Monte Carlo data sample of $\eta \to \pi^+\pi^-e^+e^-$. (First row) ΔE-P distributions for all reconstructed charged tracks with energy deposition in the PSB (left) and in the SEC (right). On the X axis is plotted signed particle momentum obtained from the MDC. Pion- and electron-bands are well separated. (Two lower rows) The particles were separated based on opening angle condition (π^+/π^- - middle row, e^+/e^- -lowest row) and the separation is better than 85%.

[3]Beam pipe is made of beryllium with the wall thickness of 1.2 mm (0.0034 X_0).

In order to suppress the background, the following selection criteria were applied to the data sample:

- cosine of the opening angle between e^+e^- pair greater than 0.5
- total missing mass within the range from -0.14 GeV to 0.04 GeV.

In case of events with an unassociated cluster in the calorimeter, the invariant mass of $e^+e^-\gamma$, $\mathrm{M}_{(e^+e^-\gamma)}$, was calculated and required to be within the range from 0.11 GeV to 0.16 GeV. The necessity of this constrain is illustrated in Fig. 5, where one see a clear π^0 peak in the invariant mass spectrum for the experimental data as expected from $\eta \rightarrow \pi^+\pi^-\pi^0$ decay.

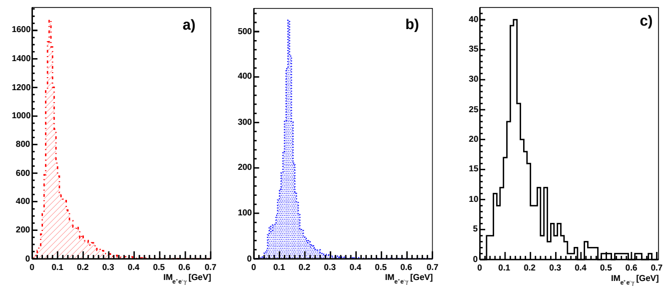

Fig. 5. Invariant mass of $e^+e^-\gamma$, $\mathrm{M}_{(e^+e^-\gamma)}$, calculated for η decay into $\pi^+\pi^-e^+e^-$ (a), $\pi^+\pi^-\pi^0$ (b), and data (c). The significant admixture of the background events in the data manifests itself by a pronounced π^0 peak in the mass spectra.

Fig. 6 shows the distribution of the invariant mass $\mathrm{M}_{(\pi^+\pi^-e^+e^-)}$ for the data after applying these selection criteria. The spectrum is well understood by superposition of the Monte Carlo simulations of the signal ($\eta \rightarrow \pi^+\pi^-e^+e^-$) and the background ($\eta \rightarrow \pi^+\pi^-\pi^0$) decays. We identified 22$\pm$7 candidates for $\eta \rightarrow \pi^+\pi^-e^+e^-$ decay. The detection efficiency was estimated to 20%.

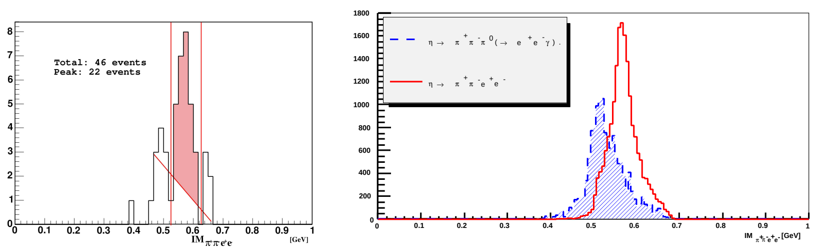

Fig. 6. Invariant mass $\mathrm{M}_{(\pi^+\pi^-e^+e^-)}$ for $pd \rightarrow {}^3\mathrm{He}\eta$, $\eta \rightarrow \pi^+\pi^-e^+e^-$ after all constrains (top). The spectrum can be well understood by superposition of Monte Carlo simulations of signal ($\eta \rightarrow \pi^+\pi^-e^+e^-$) and background ($\eta \rightarrow \pi^+\pi^-\pi^0$) decays (bottom).

4 Conclusion

The method of tagging ^{3}He recoils using zero degree magnetic spectrometer provides an almost background free η production. We presented the preliminary analysis of the $\eta \to \pi^+\pi^-e^+e^-$ decay using the total data sample measured in the WASA detector, where 22 $\pi^+\pi^-e^+e^-$ events were observed.

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