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ANALYSIS OF η DECAY INTO $\pi^+\pi^-e^+e^-$ IN THE $pd \to {}^3\mathrm{He}\eta$ REACTION[1]

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Analysis of $\eta \to \pi^+\pi^-e^+e^-$ decay channel is discussed and preliminary results are presented. The η mesons were produced in $pd \to {}^3\mathrm{He}\eta$ reaction at 892.5 MeV incident proton energy with ^{3}He measured in zero-degree spectrometer.

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1 Introduction

Experimental information on decays of η meson with lepton pair(s) are scarce. Decay channel $\eta \to \pi^+\pi^-e^+e^-$ has recently received special attention with relation to tests of combined parity and charge conjugation symmetry (CP) in flavour conserving interactions. An unconventional CP violating mechanism can show up as asymmetry in a distribution of angle between the $\pi^+\pi^-$ and e^+e^- decay planes in the decay [1]. In addition the decay $\eta \to \pi^+\pi^-e^+e^-$, together with closely related $\eta \to \pi^+\pi^-\gamma$ channel, can probe interplay between vector meson description (involving an intermediate ρ exchange) and contact term arising from Quantum Chromodynamics anomaly (see eg. [2]). Current value of the branching ratio of the $\eta \to \pi^+\pi^-e^+e^-$ decay is $(4.0^{+11.}_{-2.7}) \times 10^{-4}$, as given by Particle Data Group [3], and it is based on observation of only five events in two experiments [4] and [5].

2 The experimental method

The reaction $pd \to {}^3\mathrm{He}\eta$ close to threshold as a source of ηs was first employed for eta decay experiments at the SATURNE II synchrotron at Saclay [6]. The production of η was tagged by measuring ^{3}He in a spectrometer at 0°. The η production cross section raises very quickly from threshold to a plateau value of 0.4 μb at 2 MeV excess energy, while background, mainly from reaction $pd \to {}^3\mathrm{He}\pi^+\pi^-$, remains below one percent level [7]. This tagging method enables to collect simultaneously very clean data samples of all η decay channels. The main drawback is low cross section of the reaction as compared with other sources of etas.

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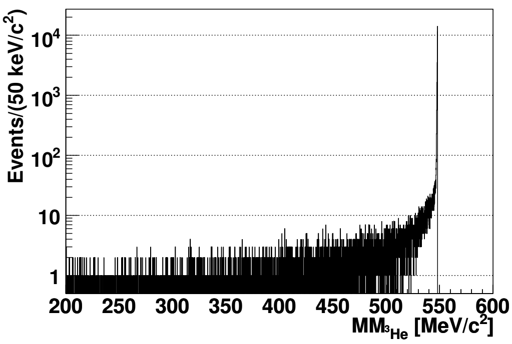

Fig. 1. Missing mass to ^{3}He measured in the tagging spectrometer.

In an experiment performed by WASA group at CELSIUS storage ring with internal deuterium pellet target, accelerator dipole magnets were used as a filter to deflect ^{3}He recoils. Kinetic energies of the ^{3}He were measured in a tagging telescope, an internal semiconductor high purity Germanium detector [8], placed in the beam pipe. The energy resolution is better than 1 MeV for ^{3}He kinetic energies less than 420 MeV and the acceptance at 1 MeV above $pd \rightarrow {}^3\mathrm{He}\eta$ reaction threshold is 50%. The tagging detector provides the trigger signal and ^{3}He ions are cleanly identified using $\Delta E - E$ method. Consistence of ^{3}He kinetic energies with $pd \rightarrow {}^3\mathrm{He}\eta$ reaction can be checked by calculation of missing mass to ^{3}He (Fig. 1). The resulting resolution of the eta peak is 150 keV/c^2 (full width at half-maximum).

The products of η decays are measured in WASA detector. The main components of the detector are shown in Fig. 2 and are described in detail in [9]. For the studies of the $\eta \rightarrow \pi^+\pi^-e^+e^-$ decay mostly Central Detector is used and momenta of charged particles are measured in Mini Drift Chamber (MDC) in presence of an axial magnetic field of 1 Tesla supplied by a superconducting solenoid (SCS). Other components of the Central Detector are plastic scintillator ΔE detector (PSB) and electromagnetic calorimeter (SEC).

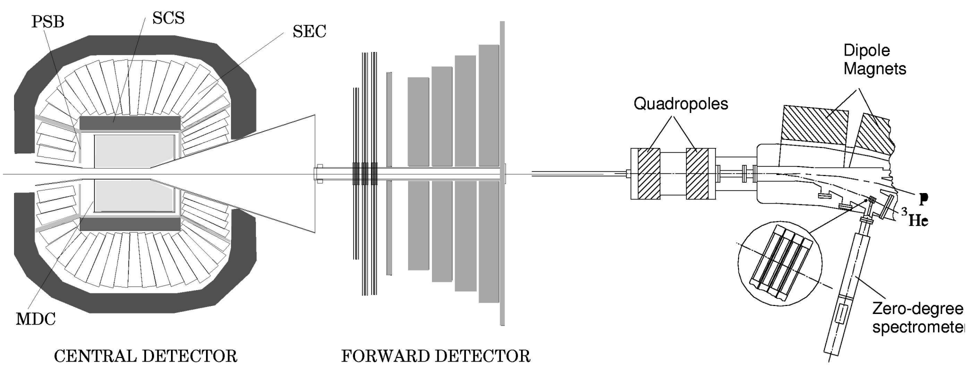

Fig. 2. Cross section of WASA apparatus with Central Detector, Forward Detector and zero-degree spectrometer (The spectrometer is not in the scale.)

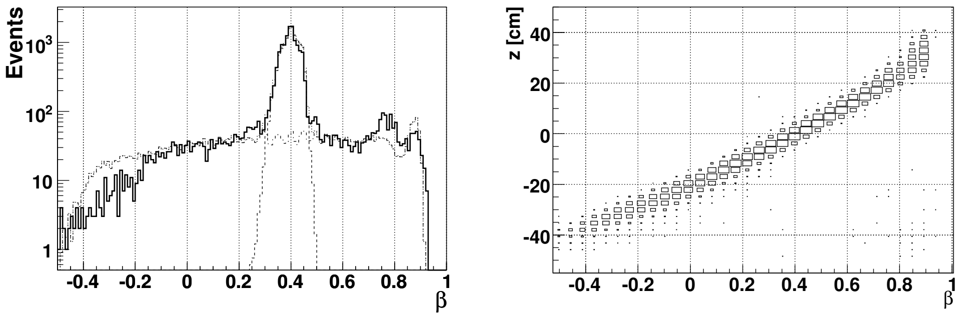

Fig. 3. (Left) Reconstructed β distribution for $\eta \rightarrow \gamma\gamma$ events. Thick solid line – experimental data, thin lines – Monte Carlo simulations of beam-rest gas interactions and beam target interactions. (Right) Correlation of reconstructed β with vertex position along the beam – Monte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

Deuterium pellet target was introduced to the WASA detection system in spring 2004 and $pd \rightarrow ^3\mathrm{He}\eta$ experiments were carried out during fall 2004 and spring 2005. The trigger rate of the tagging system during operation with the deuterium pellets and the proton beam with luminosity $5\times10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$was a few Hz, yielding on average 1η decay event per second.

The quality of the tagging in the $pd \rightarrow ^3\mathrm{He}\eta$ reaction can be tested by decay $\eta \rightarrow \gamma\gamma$. The process is over-constrained and has very simple kinematics since η is nearly at rest in the center of mass system. The sum of energies of the photons is constant (equal to 604 MeV) and the momenta of the photons are coplanar with the beam. Velocity (β) of the η can be reconstructed from the photon scattering angles alone. The β at the threshold 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 the scattering angles of the photons. The angles are determined from photon cluster coordinates in the calorimeter and under the assumption that interaction originates from target region (z =0). The experimental β distribution is shown in Fig. 3 (left), for events with photon energies consistent with decay $\eta \rightarrow \gamma\gamma$. 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 the Monte Carlo (MC) data. Measurement of ^{3}He at 0° tends to enhance the contribution since it is not sensitive to the position of the interaction point. For eta decays with charged particles the rest gas events can be removed by constrains on reconstructed vertex position. The unbiased trigger allows to determine the total number of eta decay events collected in the experiment by counting $\eta \rightarrow \gamma\gamma$ events and applying correction for the acceptance. The data sample corresponds to about 250000 eta events.

3 Analysis and results

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

In order to distinguish between pions and electrons, opening angle between two particles with opposite charges was calculated. With two positively and two negatively charged particles, there are four combinations to be tested. Based on the MC simulations, the pair with the smallest opening angle is most likely a positron-electron pair. The efficiency of such separation is demonstrated in Fig. 4. In more than 85% cases the separation was correct for a MC 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.

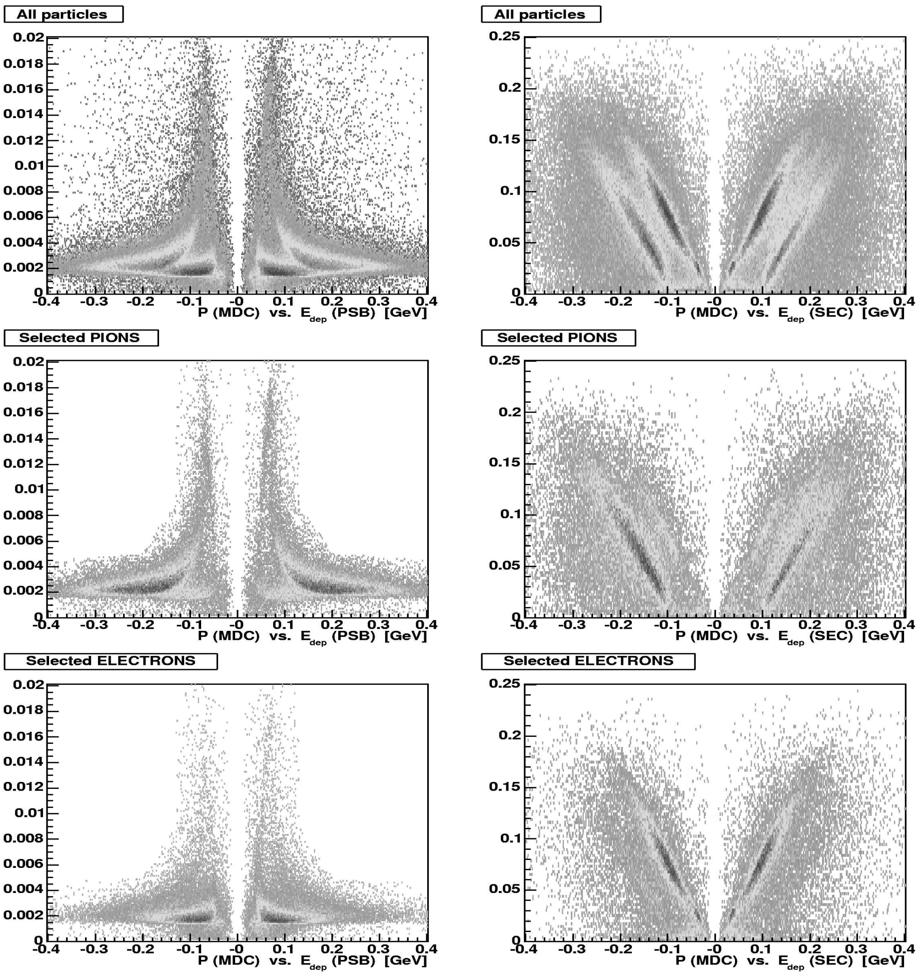

Fig. 4. Particle separation based on the opening angle for MC data sample of $\eta \to \pi^+\pi^-e^+e^-$. (First row) ΔE-P distributions for all reconstructed charged tracks with energy deposition in the PSB (left) and in the SEC (right). On the horizontal axis particle momentum (times sign of the charge) is plotted. (Two lower rows) The same plots after the separation – π^+/π^- (middle) and e^+/e^- (bottom).

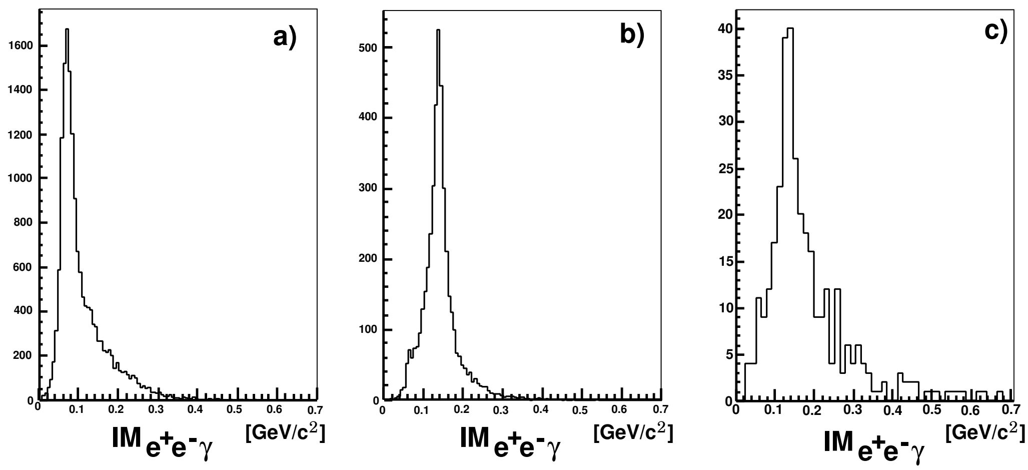

Fig. 5. Invariant mass of $e^+e^-\gamma$, $M_{(e^+e^-\gamma)}$, calculated for η decay into $\pi^+\pi^-e^+e^-$ (a), $\pi^+\pi^-\pi^0$ (b), and data (c). Admixture of the background events in the data manifests itself as a peak corresponding to π^0 mass.

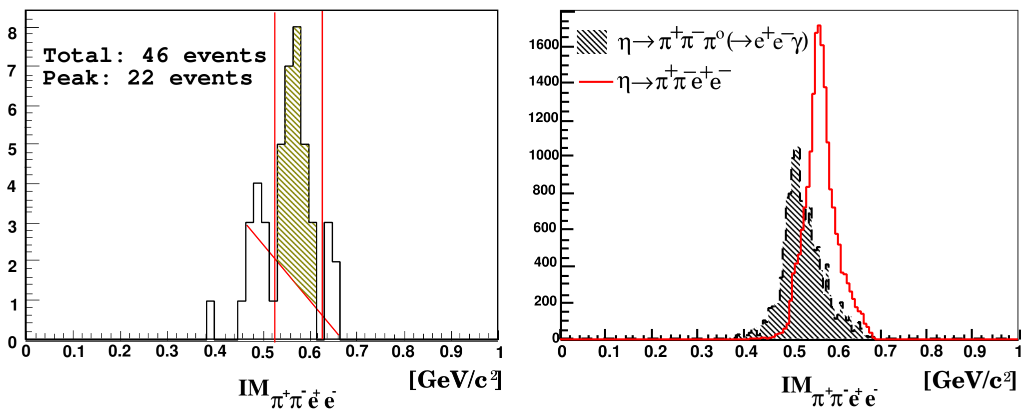

Fig. 6. Invariant mass $M_{(\pi^+\pi^-e^+e^-)}$ for $pd \to {}^3\mathrm{He}\eta$, $\eta \to \pi^+\pi^-e^+e^-$ after all constrains (left). The spectrum is well described by superposition of Monte Carlo data for the signal ($\eta \to \pi^+\pi^-e^+e^-$) and background ($\eta \to \pi^+\pi^-\pi^0$) (right).

In the previous section it was shown that due to very clean method of tagging in $pd \to {}^3\mathrm{He}\eta$ the only background for the $\pi^+\pi^-e^+e^-$ decay can consist of other eta decays with charged particles in the final state. The main contribution to the background was identified with MC studies as $\eta \to \pi^+\pi^-\pi^0$ decay where π^0 decays into $e^+e^-\gamma$ (Dalitz decay) or one of the photons from $\pi^0 \to \gamma\gamma$ convert in the beam pipe[4]. In order to suppress the background, the following selection criteria were applied to the data sample:

- opening angle between e^+e^- pair less than 60°

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

- total missing mass within the range from -0.14 GeV/c^2 to 0.04 GeV/c^2.

For events with an unassociated cluster in the calorimeter, invariant mass of $e^+e^-\gamma$ system (M$_{(e^+e^-\gamma)}$) was calculated and it was required to be within range from 0.11 GeV/c^2 to 0.16 GeV/c^2. Importance of this constrain is illustrated in Fig. 5, where, as expected from $\eta \rightarrow \pi^+\pi^-\pi^0$ decay, there is a clear π^0 peak in the invariant mass distribution for the experimental data.

Fig. 6 shows distribution of the invariant mass M$_{(\pi^+\pi^-e^+e^-)}$ for the data after all selection criteria. The spectrum is well understood by a superposition of the MC simulations of the signal ($\eta \rightarrow \pi^+\pi^-e^+e^-$) and the background form ($\eta \rightarrow \pi^+\pi^-\pi^0$) decays. In the preliminary analysis 22±7 event candidates for $\eta \rightarrow \pi^+\pi^-e^+e^-$ decay were identified. The detection efficiency is estimated to be about 20%.

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