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STATUS OF THE η MASS MEASUREMENT WITH THE CRYSTAL BALL AT MAMI[1]

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This article is dedicated to the current status of the η mass measurement with the Crystal Ball detector at the MAMI facility in Mainz. The reaction $\gamma + p \rightarrow p + \eta$ is used for the determination of the eta production threshold. The two main η decay modes are analysed. The energy calibration of the tagger microscope shows that the error for the η mass determination has improved in comparison to the previous Mainz experiment.

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1 Motivation

Before 2000, three different experiments were dedicated to the eta mass measurement, which gave a weighted average of 547.3±0.12 MeV. In 2002 the NA48 collaboration published a very precise measurement. The value of this measurement, 547.84±0.05 MeV [1], deviated significantly from the world average reported in the PDG 2002. Including this measurement in the average the PDG 2004 [2] reports the value 547.75±0.12 MeV, that is almost 0.5 MeV higher than the previous one. This created the motivation to repeat the previous Mainz measurement, especially after another precise measurement by the GEM collaboration had been carried out, 547.3±0.03 MeV [3], in agreement with the old measurements (see Fig. 1).

2 The η mass experiment in Mainz

The previous Mainz experiment [4] used the η photoproduction reaction $\gamma + p \rightarrow p + \eta$. The photons were produced by the bremsstrahlung process with the electrons from the MAMI accelerator (see Fig. 2). The absolute electron energy E_0 of the incoming electron beam was determined in the third race track microtron of the MAMI accelerator with an accuracy of about 160 keV (FWHM). Scattering in the radiator, the electrons emit bremsstrahlung photons, which go straight to the detector, while the electrons are deviated by a magnetic field and hit the focal plane detector of plastic scintillators at different positions according their energy. Making a coincidence between the reaction products in the experiment and the electron in the tagger, one

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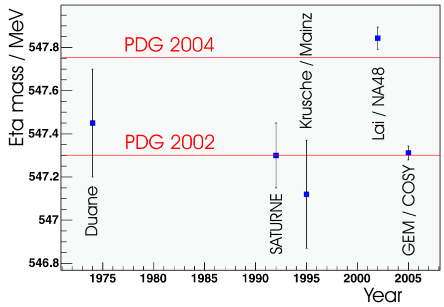

Fig. 1. Overview of the previous η mass measurements. The two lines indicate the world average published by the Particle Data Group in 2002 and 2004.

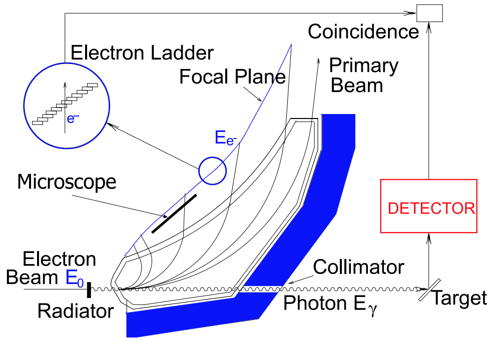

Fig. 2. The top view of the tagger for producing bremsstrahlung photons [5], [6]. The tagger microscope with the higher energy resolution is shown in front of the main ladder of the plastic scintillators.

can determine the energy of the photon E_γ as the difference between the main beam energy E_0 and the electron energy E_{e^-} measured with the tagger: $E_\gamma = E_0 - E_{e^-}$ (the recoil of the nucleus can be neglected). The aim was to determine the production threshold of the reaction $\gamma + p \rightarrow p + \eta$. Knowing the production threshold one can obtain the mass of the η particle from the formula:

$$m_\eta = -m_p + \sqrt{m_p^2 + 2 \cdot m_p \cdot \frac{E_\gamma^{thr}}{c^2}}, \tag{1}$$

where m_p is the proton mass and E_γ^{thr} the η production threshold.

In the new experiment, in addition to the standard electron ladder, the tagger microscope, shown in Fig. 2, was installed for a more precise measurement of the electron energy E_{e^-}. The tagger microscope consists out of 96 scintillator fibres (3 mm wide and 2 mm thick). Each

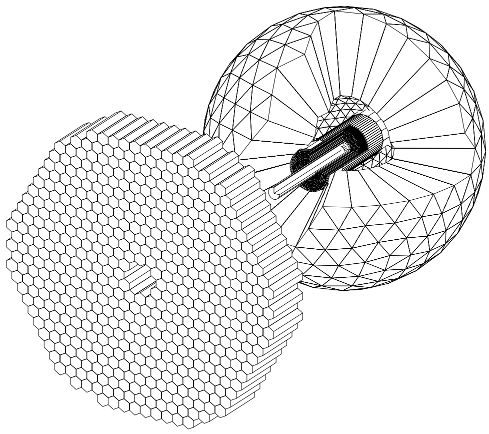

Fig. 3. The Crystal Ball setup at MAMI [7]. A particle identification detector is shown inside the Crystal Ball. The TAPS detector [8] in front is used as a forward wall detector.

single fibre overlaps to one third with its neighboring fibre and this overlap region defines one microscope detector channel (96 single fibres, 191 detector channels). The tagger microscope has a higher resolution per channel (0.3 MeV) compared to the standard electron ladder (2 MeV). The device was positioned very close to the focal plane of the tagger so that it covered electrons energies from 155 MeV to 209 MeV. At a beam energy E_0=883 MeV this corresponds to a tagged photon interval ranging from 674 to 728 MeV. The eta production threshold is expected at an energy of about 706 MeV.

3 The η mass measurement with the Crystal Ball detector at MAMI

Since the previous η mass measurement, the MAMI facility was significantly improved, resulting in a more precisely known beam energy and a much higher beam stability. In addition, online monitoring of the electron and photon beams position in front and after the photon tagging system was introduced. With the higher energy resolution provided by the tagger microscope and the large acceptance of the Crystal Ball detector (see Fig. 3), the uncertainty of the η mass measurement is expected to be reduced by a factor of 2-4 compared to the previous η mass determination.

4 The tagger microscope energy calibration

The important part of the new experiment was the energy calibration of the tagger microscope. The tagger microscope was calibrated in two ways. One was based on a direct position measurement of the electron beam for three different energies E_0 (180, 195 and 210 MeV) in the microscope under a magnetic field close to that in the experiment. Varying the tagger dipole field slightly around the nominal field, a few data points for each of the three available energies were taken. A fit to these points showed a linear dependence between the microscope channel (μch) and the electron energy.

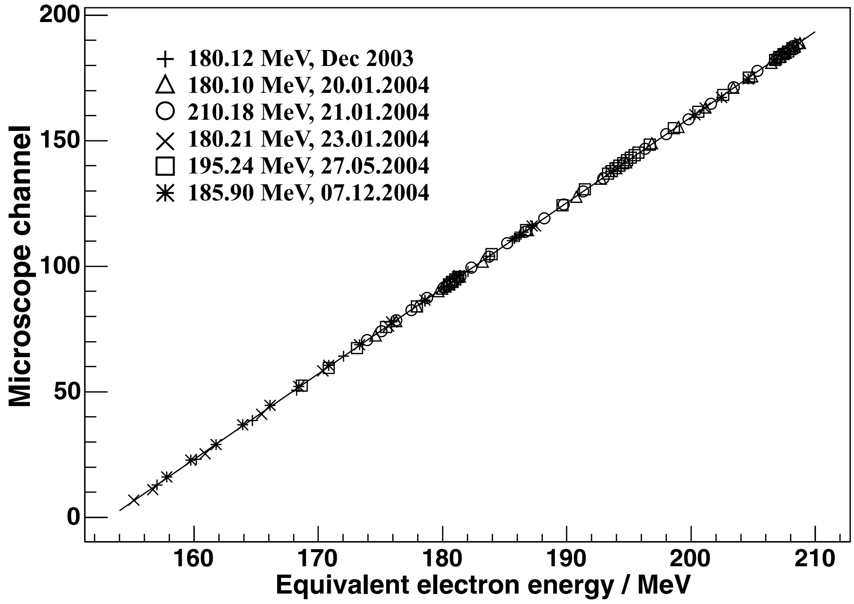

Fig. 4. The microscope channel (μch) vs. the electron energies. The scans are in a good agreement.

Varying the dipole field in a larger range leads to another calibration relying on beam scans. The six scans with different energies and different dipole fields gave 139 data points (see Fig. 4). Both calibrations are in a very good agreement. The difference in the electron energy determination between the calibrations does not exceed $0.1\ \mu ch$ which corresponds to 30 keV in electron energies.

Tab. 1. List of contributions to the combined uncertainty of the microscope hit position. The uncertainties were converted to the microscope channels (μch).

Source of uncertainty	Uncertainty	$\sigma(\mu ch)$
MAMI energy	160 keV (FWHM)	0.23
Beam spread	30 keV (FWHM)	0.04
Beam position	0.1 mm	0.05
Dipole resolution	60 keV	0.12
Scattering by the tagger vacuum chamber	0.22 mm	0.11
Combined standard uncertainty σ_C		0.29

The sources of the microscope hit position uncertainty are summarized in Tab. 1. The combined uncertainty of the electron energy determination with the tagger microscope estimated

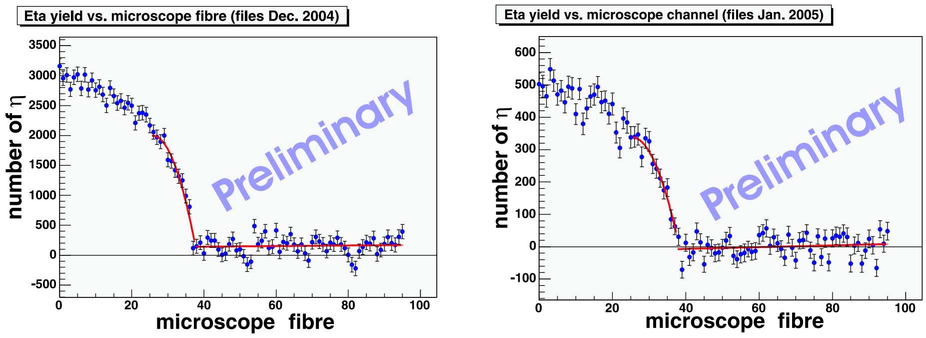

Fig. 5. Preliminary yield of the η particles from the decay modes $\eta \rightarrow 2\gamma$ (left) and $\eta \rightarrow 3\pi 0$ (right). The η production threshold can be seen between the microscope fibres 35 and 40. Note that the microscope fibre differs from the microscope channel by a factor of two.

from the experiment parameters is $0.29\ \mu ch$. The uncertainty was also calculated for each scan individually and the mean value of $\sigma = 0.27\ \mu ch$ is believed to include all effects except the uncertainty of the MAMI energy. Combining this value with the $0.23\ \mu ch$ caused by the incoming electron beam energy uncertainty one derives a combined uncertainty of $0.35\ \mu ch$. This corresponds to a 103 keV uncertainty in the photon energy determination.

5 The experimental method

The η mesons are identified via their two main decay modes $\eta \rightarrow 2\gamma$ and $\eta \rightarrow 3\pi^0$ with the Crystal Ball detector, which measures energies and emission angles of particles. The photons from both decays are identified in the detector by eliminating charged particles with a particle identification detector. This allows one to separate both η decay modes by selecting the events with two and six photons respectively. The $\eta \rightarrow 2\gamma$ decay events are identified by a cut on their invariant mass. A plot of the number of detected η particles versus the microscope fibre is shown in Fig. 5 on the left (at this stage the microscope fibre is used instead of the microscope channel in order to improve the statistics). One can see the η production threshold, though there is still some background below. Events from the $\eta \rightarrow 3\pi^0$ decay mode are identified via six coincident photons in the detector. The six photons are arranged in three pairs so that each pair has an invariant mass close to the π^0 mass. If this combination is possible, the event is considered an η meson. A plot of the number of detected η particles versus the microscope fibre is shown in Fig. 5 on the right.

6 Summary

The calibration of the tagger microscope showed that the error for the new η mass measurement has been improved in comparison to the previous Mainz experiment. By analysing the invariant masses of the events with two and six photons the two main η decay modes were identified.

For both channels the η production threshold has been obtained, but no value for the η mass is published here due to the preliminary status of the analysis.

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