Beam Proposal and Request

For Lab. use

Exp. No.:	Session No.
187	**34**

Title of Experiment: **Precision Measurement of the η Mass at COSY**

Collaborators: Institute:

The ANKE collaboration

and

The COSY Accelerator Group

(Continue on separate sheet if necessary)

Spokesman for collaboration: Name: A. Khoukaz

Address:

Institut für Kernphysik

Universität Münster

Wilhelm-Klemm-Str. 9

48149 Münster

Is support from the LSF program of the EC requested?

No

Date: November-19-2007

Phone: _+49-251-83-34934__ Fax: _+49-251-83-34962_ E-mail: _khoukaz@uni-muenster.de_

Total number of particles and type of beam (p,d,polarization)	Momentum range (MeV/c)	Intensity or internal reaction rate (particles per second)	
		minimum needed	maximum useful
polarized d Int.> $3 \cdot 10^9$	3118 - 3185	$L \sim 1 \cdot 10^{30}$ $cm^{-2}s^{-1}$	
Type of target	**Safety aspects (if any)**	**Earliest date of installation**	**Total beam time (weeks)**
H_2, Cluster jet		January 2008	3 weeks

What equipment, floorspace etc. is expected from Forschungszentrum Jülich/IKP?

ANKE spectrometer

Summary of experiment (do not exceed this space):

It is proposed to determine the mass of the η-meson in a precision measurement at COSY in a new and innovative way. The experiment will make use of a polarised deuteron beam incident on an unpolarised cluster jet target inside the COSY-ring. The reaction to be exploited is d(pol)p→ ^{3}Heη, which will be identified by ^{3}He detection in the magnetic spectrometer ANKE and a missing-mass analysis. The techniques which will be employed are:

- ramping of the deuteron beam energy across the η production threshold
- ^{3}He identification with full acceptance over the full energy range
- determination of the excess energy from kinematics (`radius method')
- determination of the absolute deuteron beam momentum (`spin resonance method')

All of these steps have been tested in previous experiments at COSY and have been shown to work. Taking the uncertainty limits, which have already been achieved (and which may still be improved further), we expect the final uncertainty of the η-mass to be less than 50 keV/c^2, i.e. equivalent to or better than the best existing measurements. The experiment will thus help to resolve the discrepancy between the BIG-KARL and other recent η-mass determinations.

Attach scientific justification and a description of the experiment providing the following information:

For proposals:

Total beam time (or number of particles) needed; specification of all necessary resources

For beam requests:

Remaining beam time (allocations minus time already taken)

Scientific justification:

What are you trying to learn?
What is the relation to theory?
Why is this experiment unique?

Details of experiment:

Description of apparatus.
What is the status of the apparatus?
What targets will be used and who will supply them?
What parameters are to be measured and how are they measured?
Estimates of solid angle, counting rate, background, etc., and assumptions used to make these estimates.
Details which determine the time requested.
How will the analysis be performed and where?

General information:

Status of data taken in previous studies.
What makes COSY suitable for the experiment?
Other considerations relevant to the review of the proposal by the PAC.

EC-Support:

The European Commission supports access of new users from member and associated states to COSY. Travel and subsistence costs can be granted in the frame of the program Access to Large Scale Facilities (LSF).

COSY Proposal / Beam Request

Precision Measurement of the η Mass at COSY

The ANKE Collaboration
and
The COSY Accelerator Group

Spokesperson: A. Khoukaz (khoukaz@uni-muenster.de)

November 19, 2007

Abstract

It is proposed to determine the mass of the η–meson in a precision measurement at COSY in a new and innovative way. The experiment will make use of a polarised deuteron beam incident on an unpolarised cluster jet target inside the COSY-ring. The reaction to be exploited is $\vec{d}p \to^3 \mathrm{He}\eta$, which will be identified by ^{3}He detection in the magnetic spectrometer ANKE and a missing–mass analysis. The techniques which will be employed are: — ramping of the deuteron beam energy across the η production threshold — ^{3}He identification with full acceptance over the full energy range — determination of the excess energy from kinematics ('radius method') — determination of the absolute deuteron beam momentum ('spin resonance method'). All of these steps have been tested in previous experiments at COSY and have been shown to work. Taking the uncertainty limits, which have already been achieved (and which may still be improved further), we expect the final uncertainty of the η–mass to be less than 50 keV/c^2, *i.e.* equivalent to or better than the best existing measurements. The experiment will thus help to resolve the discrepancy between the BIG–KARL and other recent η–mass determinations.

1 Introduction

The mass of the η meson was quite poorly known until its measurement in the 1990s at SATURNE using the $pd \to {}^3\mathrm{He}\,\eta$ reaction [1]. This changed the PDG average by as much 1.5 MeV/c^2. Since then there have been several measurements with much higher claimed precision and the results are summarised in the following table:

$$
\begin{array}{llllll}
m_\eta^{\mathrm{SATN}} & [1] = 547.3 & \pm & \pm 0.15_{\mathrm{total}} & \mathrm{MeV/c^2} & \\
m_\eta^{\mathrm{NA48}} & [2] = 547.843 & \pm 0.030_{\mathrm{stat}} & \pm 0.041_{\mathrm{syst}} & \mathrm{MeV/c^2} & \\
m_\eta^{\mathrm{GEM}} & [3] = 547.311 & \pm 0.028_{\mathrm{stat}} & \pm 0.032_{\mathrm{syst}} & \mathrm{MeV/c^2} & \\
m_\eta^{\mathrm{KLOE}} & [4] = 547.873 & \pm 0.007_{\mathrm{stat}} & \pm 0.031_{\mathrm{syst}} & \mathrm{MeV/c^2} & \\
m_\eta^{\mathrm{CLEO}} & [5] = 547.785 & \pm 0.017_{\mathrm{stat}} & \pm 0.057_{\mathrm{syst}} & \mathrm{MeV/c^2} & \\
m_\eta^{\mathrm{MAMI}} & [6] = 547.76 & \pm 0.10_{\mathrm{stat}} & \pm 0.07_{\mathrm{syst}} & \mathrm{MeV/c^2} & (\mathit{preliminary}).
\end{array}
\tag{1}
$$

From the results shown above it is seen that the measurement carried out at BIG–KARL by the GEM collaboration [3], also using the same $pd \to {}^3\mathrm{He}\,\eta$ reaction, lead to an η–mass value that is many standard deviations different from the results reported by four other experimental groups. Since these use a variety of different methods and since they are all consistent with a value of $m_\eta \approx 547.80$ MeV/c^2, the BIG–KARL result must be (and is) questioned.

Unfortunately this result is often labelled in the other publications merely as 'COSY'.

If we assume that the origin of the discrepancy is with BIG–KARL, there seem to be only two possibilities. Either there is some unknown error in the experiment or the analysis or there is something peculiar about the $pd \to {}^3\text{He}\,\eta$ reaction since both groups who used it obtained a low mass value. Though highly speculative, one possibility is that the multipion background is disturbed near the η position through its coupling to the η channel *via* for example $\eta\,{}^3\text{He} \leftrightarrow \pi^+\pi^-\,{}^3\text{He}$. This might then lead to one not identifying correctly the central η mass. Either way, if the problem can be investigated more precisely at COSY then it should be done. We show here that this is indeed possible by combining the capabilities of the ANKE spectrometer with special features of the handling of polarised particles in the COSY ring.

The ANKE magnetic spectrometer has full geometrical acceptance for the $dp \to {}^3\text{He}\,\eta$ reaction within at least 11 MeV of threshold in the centre-of-mass excess energy Q [7, 8]. For an energy in this range it is possible to determine the c.m. momentum p_η by measuring the locus of the $dp \to {}^3\text{He}\,\eta$ events measured in the ANKE magnetic field. Any dependence on the calibration of the magnet is minimised by carrying out the measurement at a range of values in Q and then extrapolating to $Q = 0$. In this way we are just using kinematics and are thus insensitive to any variations of the cross section yield with momentum or angle. Doing the experiment at a range of values of Q is made easier by exploiting the COSY continuous ramp mode. However, the method would work as well for a large number of flat–top momenta combined into one supercycle.

In order to convert a precise value of Q into one for the mass of the η meson, the beam momentum has to be determined with great accuracy. At first sight it seems anomalous that this can be done far better for a polarised beam but one can calculate the position of the depolarising resonances in terms of the beam energy to six significant figures. The Spin@COSY collaboration has shown that this can indeed be done in practice for deuterons [9, 10].

Before writing any proposal we had to be certain that we could in practice combine the ramp with the resonance depolarising technique. Also we needed to know the precision with which the deuteron beam momentum could be obtained at the η threshold. Both these goals were achieved through measurements made during last month's beam time. It was only when these results were available that this document could be written and this accounts for our very late submission. We would therefore earnestly crave the Committee's indulgence in this matter.

2 Precision measurement of the η mass at COSY

2.1 Determination of the production threshold

In measurements carried out by the ANKE collaboration in 2005 using an unpolarised deuteron beam [7, 8] it was demonstrated that it is possible to identify the production threshold for the $dp \to {}^3\mathrm{He}\,\eta$ reaction with high precision with respect to the excess energy Q. This was achieved by studying the reaction using a beam whose energy was ramped slowly and linearly in time, from an excess energy of $Q = -5.05\,\mathrm{MeV}$ to $Q = +11.33\,\mathrm{MeV}$. The ^{3}He were selected by the $\Delta E/E$ method, with the η meson being subsequently identified through a peak in the missing–mass distribution. The η c.m. momentum p_η at a particular time during the ramp was found from the size of the ^{3}He momentum locus in the c.m. frame.

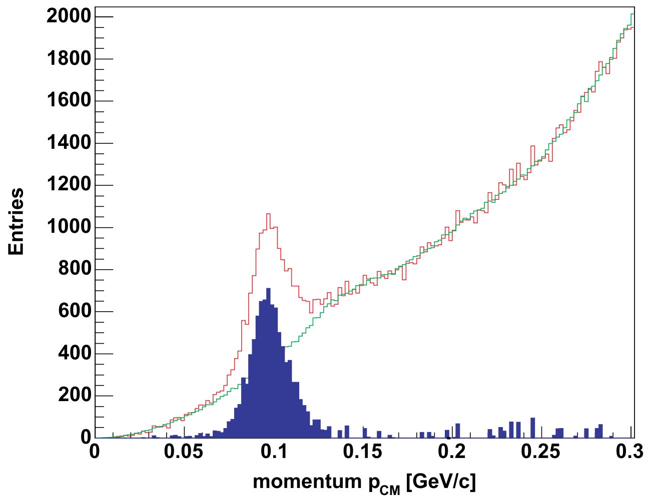

Figure 1: Centre–of–mass momentum of ^{3}He nuclei at an excess energy of 10.0 MeV. The background below the signal from the $^3\mathrm{He}\,\eta$ final state was deduced from the sub–threshold data.

In Fig. 1 the centre–of–mass momentum distribution of ^{3}He nuclei is displayed for an excess energy of 10.0 MeV. The background below the signal from the $^3\mathrm{He}\,\eta$ final state, originating mainly from multi-pion production reactions as well as misidentified protons from deuteron break–up, is described well by data obtained at sub–threshold energies.

Figure 2a presents the extracted values of p_η in terms of the ramp time.

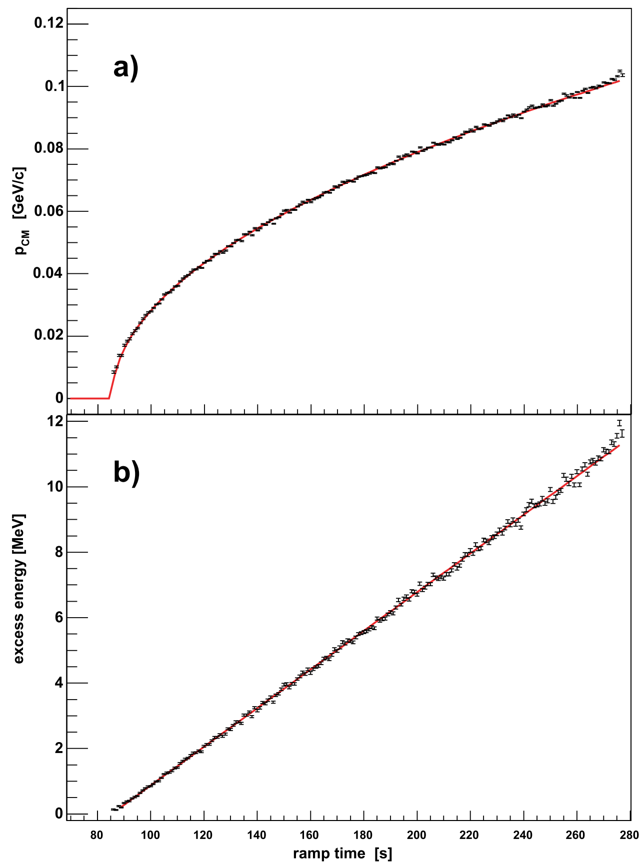

Figure 2: Centre–of–mass momentum of ^{3}He nuclei (a) and extracted excess energy (b) of the $dp \to {}^3\mathrm{He}\,\eta$ reaction as functions of the cycle time within the COSY ramp. The solid lines correspond to a fit to the data assuming a linear increase of the COSY beam momentum with time [7, 8].

The solid line corresponds to the assumption that the COSY beam momentum rises linearly over the ramp. In Fig. 2b it is demonstrated that the values of $Q = p_\eta^2/2m_{red}$, where m_{red} is the $\eta\,{}^3$He reduced mass, follows the expected linear variation of the beam energy with ramp time. Using this method it was possible to identify the production threshold in the time ramp with an accuracy of $\Delta t \approx 0.16\,$s corresponding to an excess energy resolution at threshold of $\Delta Q_{\rm thresh} = 9\,$keV. The major advantage of this method for determining the reaction threshold is the fact that no information about the energy or angular dependence of the cross sections are needed to extract the radius of the centre–of–mass momentum locus. Unlike, for example, the measurement at MAMI [6], we are not measuring the energy dependence of a yield. Thus, the threshold can be identified in a model–independent way. Since, due to the uncertainty in the orbit length, the absolute beam momentum was not known to better than about 3 MeV/c, this excellent measurement of Q could not at the time be translated into an accurate value of the η mass.

2.2 Absolute beam momentum determination

It was recently shown that a very precise determination of the absolute beam momentum is possible by a spin–resonance method [9, 10, 11]. For this purpose a polarised proton or deuteron beam stored in a storage ring is spin flipped by sweeping the frequency of an rf dipole or solenoid through an rf spin resonance. In the absence of horizontal magnetic fields the spin of each beam particle precesses around the vertical fields of the dipole magnets. The spin tune ν_s, defined as the number of spin precessions during one turn around the ring, is proportional to the energy of the particle:

$$\nu_s = G\,\gamma, \tag{2}$$

where $G = (g-2)/2$ is the gyromagnetic anomaly of the particle ($G_d = -0.142987$) and γ is the Lorentz energy factor for the particle. The vertical polarisation can be distorted by a horizontal rf magnetic field and this can lead, under appropriate conditions, to a spin flip of the stored particles. For such a spin flip the resonance frequency f_{res} is given by

$$f_{\rm res} = f_0(k \pm \nu_s), \tag{3}$$

where f_0 is the circulation frequency of the stored beam and k is an integer. With k=1 Eqs. (2) and (3) result in

$$\gamma = \frac{1}{|G|}\left(1 - \frac{f_{\rm res}}{f_0}\right)\,. \tag{4}$$

In a very recent measurement at ANKE (October 2007) the $\vec{d}p \to {}^3\mathrm{He}\,\eta$ reaction has been investigated to study the dependence of the production amplitudes on the deuteron beam polarisation [12]. Just as in the previous unpolarised studies, these new measurements were performed using a slowly ramped COSY beam, which will again allow us to determine the production threshold with respect to the excess energy with high accuracy. However, in order to obtain precise information also about the absolute beam momentum, the previously discussed spin–resonance method was applied at the beginning of the COSY ramp.

Preliminary results of this measurement are presented in Fig. 3. These show the **vector** polarisation of the stored deuteron beam as a function of

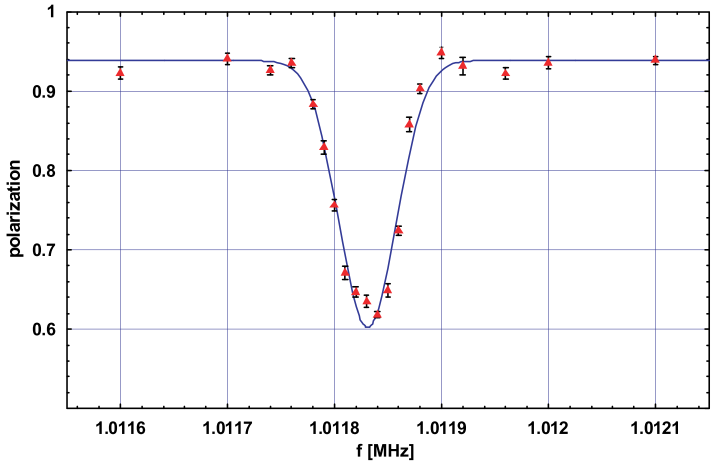

Figure 3: Polarisation of the COSY deuteron beam as function of the spin resonance frequency f_{res} [11].

the resonance frequency $f_{\rm res}$. The position of the spin flip was determined with a precision of $\Delta f_{res} = 10^{-6}$ MHz. Taken together with the extracted revolution frequency of the stored deuterons, which was determined with an accuracy of $\Delta f_0 = 10^{-5}$ MHz, the mean Lorentz energy factor and hence the absolute COSY deuteron beam momentum were determined to be

$$\gamma = 1.93906 \pm 0.00004\,, \tag{5}$$

$$p_d = 3.11598 \pm 0.00005 \text{ GeV/c}. \tag{6}$$

The numbers quoted here are still under evaluation and should be considered as *preliminary*.

2.3 Determination of the mass of the η-meson

For the two-body reaction $\vec{d}p \rightarrow {}^3\mathrm{He}\,\eta$, the excess energy Q can be written as

$$Q = \sqrt{2m_p\sqrt{p_d^2 + m_d^2} + m_p^2 + m_d^2} - m_\eta - m_{He} \tag{7}$$

The combination of the previously discussed techniques to determine both the reaction threshold ($Q = 0$) and the absolute beam momentum p_d offers the possibility to extract the η meson mass with high accuracy. Inverting Eq. (7), the η-mass is given by

$$m_\eta = \sqrt{2m_p\sqrt{p_d^2 + m_d^2} + m_p^2 + m_d^2} - m_{He} - Q\,. \tag{8}$$

Obviously the contribution of the uncertainty of the threshold determination ΔQ_{thresh} on the η-mass extraction is given immediately by

$$\Delta m_{\eta,Q=0} = \Delta Q_{\text{thresh}}\,. \tag{9}$$

The uncertainty in the absolute beam momentum Δp_d gives an additional contribution of

$$\Delta m_{\eta,\text{COSY}} = \left(\frac{\partial m_\eta}{\partial p_d}(p_{\text{thresh}})\right)\,\Delta p_d\,. \tag{10}$$

Inserting $\Delta p_d/p_d = 3\times 10^{-5}$ into Eq.(6), this leads to the following uncertainties for the η–mass determination:

$$\Delta m_\eta = \begin{cases} \pm 9\ \text{keV/c}^2 & : \ \text{Q} = 0 \text{ determination} \\ \pm 25\ \text{keV/c}^2 & : \ \text{COSY beam momentum} \end{cases} \tag{11}$$

3 Proposed new measurements at ANKE

The accuracy given in Eq. (11) is based on the quality of the beam momentum determination reached during the ANKE beam time in October 2007. A considerable improvement seems to be possible by using electron cooling at injection energies [13]. Furthermore, the precision of the given threshold determination is based on the results from the unpolarised ANKE beam time in 2005 where more than 400,000 $^3\text{He}\,\eta$ events have been collected. However, the data from the recent polarised ANKE beam time in October 2007 will not be sufficient to reach the quoted precision due to the limited number of $\approx 60,000$ collected events. This is due to the experimental optimisations for **tensor** analysing power measurements as well as problems with the polarised COSY beam during the one week of beam time. In a dedicated measurement, optimised for a high precision η-mass determination, only vector polarised and unpolarised beams are required and these have higher source intensities. The high capabilities of the ANKE spectrometer to perform a precision measurement have been proven and the qualities of the COSY are ideal for its success. All the experimental conditions are ready to undertake such an experiment as soon as the beam time can be allocated.

To reach at least the precision quoted in Eq. (11) ($\Delta m_\eta = \pm 9\,\text{keV/c}^2 \pm 25\,\text{keV/c}^2$)

THREE WEEKS OF BEAM TIME

are requested.

References

[1] F. Plouin et al., Phys. Lett. B **276**, 526 (1992).

[2] A. Lai et al., Phys. Lett. B **533**, 196 (2002).

[3] M. Abdel-Bary et al., Phys. Lett. B **619**, 281 (2005).

[4] F. Ambrosino et al., arXiv:hep-ex/0707.4616.

[5] D.H. Miller at al., Phys. Rev. Lett. **99**, 122002 (2007).

[6] A. Nikolaev, 24^{th} Student's Workshop on Electromagnetic Interactions, Bosen (Saar), 9 - 14 September 2007; http://wwwa1.kph.uni-mainz.de/Bosen/

[7] T. Mersmann et al., Phys. Rev. Lett. **98**, 242301 (2007).

[8] T. Mersmann, doctoral thesis, University of Münster, (2007).

[9] A.D. Krisch et al., Phys. Rev. STAB **10**, 071001 (2007).

[10] V.S. Morozov et al., Phys. Rev. STAB **8**, 071001 (2005).

[11] R. Gebel, B. Lorentz, R. Maier, D. Prasuhn, H. Stockhorst, private communication (2007).

[12] T. Rausmann & A. Khoukaz, COSY proposal #157 (2006); www.fz-juelich.de/ikp/anke/en/proposals.shtml.

[13] D. Prasuhn, private communication (2007).