# $\eta$ Production with a Polarized Proton Beam in the Proton–Proton Scattering at COSY–11

**Proposal 108:**


COSY–11 Collaboration[1]

*IKP, Forschungszentrum Jülich, D-52425 Jülich, Germany*
*ZEL, Forschungszentrum Jülich, D-52425 Jülich, Germany*
*Institute of Physics, Jagellonian University, PL-30-059 Cracow, Poland*
*IKP, Westfälische Wilhelms–Universität, D-48149 Münster, Germany*
*Institute of Nuclear Physics, PL-31-342 Cracow, Poland*
*Institute of Physics, University of Silesia, PL-40-007 Katowice, Poland*

Spokespersons: Peter Winter and Jurek Smyrski
p.winter@fz-juelich.de, smyrski@if.uj.edu.pl



## Abstract

After the successful performance of a feasibility study on the $\vec{p}p \to pp\eta$ reaction at an excess energy of Q = 40 MeV [1] a new beam time is requested for the measurements of the $\eta$ production in proton–proton collisions with transversally polarized proton beams equivalent to excess energies of Q = 10 MeV and Q = 40 MeV.
The physics' aim is to investigate the influence of higher partial waves in the $\vec{p}p \to pp\eta$ reaction through a determination of the $\eta$ analyzing power $A_y$ and to test newly predictions [2].


## 1. Introduction

Meson production in $pp \to ppX$ reactions (with $X = \pi^0, \eta, \omega, \phi$) is a process of strong inelasticity in proton–proton scattering. Near threshold, such reactions involve only a few partial waves since the relative momentum between any of the three particles in the exit channel is limited.
The transferred momenta in $pp \to ppX$ reactions are large and therefore such investigations are sensitive to the short–range part of the interaction and might allow to study the nucleon–nucleon interaction in a regime where the nucleons start to overlap.

The production of $\eta$ mesons near threshold has been measured by different groups [3–6]. Very close to threshold only S–waves are supposed to contribute to the production process and in fact the S–wave production is large due to the presence of the $N^*(1535)S_{11}$ resonance which seems to act as an intermediate state.

Measurements indicated the influence of higher $\eta$ partial waves through the observation of a non–isotropic angular distribution at an excess energy of Q = 37 MeV [7]. In addition, both TOF [8] and COSY–11 [9] took recently rather high statistics data on the $\eta$ production at Q $\approx$ 16 MeV with fairly flat angular distributions as expected for an S–wave production. Still – whether some data suggest or don't suggest – differential cross section measurements might

[1]see attached list

to be too insensitive to reveal small $Sd$–contributions, where $S = L_{pp}$ is the angular momentum between the two protons in the exit channel denoted by the first capital– and $d = l_\eta$ for the second small letter the angular momentum of the η–meson in the center of mass system. Data using a polarized beam, however, might indicate effects arising from an interference term of the kind:

$$2Re\{A_{Ss}A^*_{Sd}\}\ cos2\theta_\eta \tag{1}$$

where $A_{Ss}$ is the amplitude for the production of a final $pp$ pair with angular momentum $L_{pp} = 0$ and $l = 0$ while for $A_{Sd}$ the η meson has an angular momentum of $l_\eta = 2$.
The importance of d–waves in η production is well known from both $\pi^- p \to \eta n$ [10] and $\gamma p \to \eta p$ [11] reactions and the fact that this interference term is negative suggests that the η–production in proton–proton scattering is governed mainly by ρ–exchange [7]. It is our aim to investigate the presence of this and other higher partial waves through the study of the analyzing power $A_y$ after the first feasibility study was successful.

Though we shall study the asymmetry also with respect to the final proton directions, the s–d interference contributes significantly to the η analyzing power defined as:

$$A_y := \frac{\mathrm{Tr}(\mathcal{M}\,\sigma_y\,\mathcal{M}^\dagger)}{\mathrm{Tr}(\mathcal{M}\,\mathcal{M}^\dagger)} \tag{2}$$

with the transition matrix element $\mathcal{M}$ and the Pauli matrix $\sigma_y$.

To lowest order in the η d–wave amplitude, the analyzing power is proportional to the imaginary part of the $s$–$d$ interference [12],

$$A_y \approx 2\,\frac{Im\{A_{Ss}A^*_{Sd}\}}{|A_{Ss}|^2} \tag{3}$$

where $\phi_\eta = 0$ corresponds to the plane of COSY (perpendicular to the polarization direction). On angular momentum grounds, this signal is expected to very like $(p^{cm}_\eta)2$, *i.e.* roughly like Q.

The $P_{11}(1440)$ resonance could also be of importance for the η production [13], leading to p–waves in the final state. The interference between the $Ps$ and $Pp$ amplitudes gives an analyzing power proportional to:

$$A_y \approx 2\,\frac{Im\{A_{Ps}A^*_{Pp}\}}{|A_{Ss}|^2} \tag{4}$$

and such a signal has been observed in the $pp \to pp\pi 0$ reaction at low energies [14]. The presence of the three $p$–waves in the interference might suppress such a term close to threshold for η production, and no unambiguous signal for them has been seen in the unpolarized differential cross section. Nevertheless we must be prepared for their existence. The $Ss$–$Sd$ interference gives a maximal $A_y$ signal for $\theta_\eta \approx 450$ and vanishes at 900, whereas the $Ps$–$Pp$ signal should be largest at this point.

Both the differential cross section and the analyzing power will be studied in order to detect effects associated with the onset of higher partial waves. It should be noted that the effects of incomplete acceptance are much less of a problem for $A_y$ than for the $d\sigma/d\Omega$ measurement provided that the beam characteristics of the two polarization states are similar, what in fact has been proven by EDDA and COSY–11 in pervious runs. Finally, the results should help to settle the on–going discussion of whether the η production is dominated by ρ [15–18], ω [19] or η [20] exchange.

## 2. First Measurements at COSY–11

Data on the η meson production with a polarized proton beam in the reaction have been taken at the internal experiment facility COSY-11. The measurement was performed with a proton beam momentum $\vec{P}_p = 2.096\,\mathrm{GeV/c}$ corresponding to an excess energy of $Q = 40\,\mathrm{MeV}$. Due to interference effects, polarization observables – such as the analyzing power $A_y$ – are very sensitive to the influence of higher partial waves. Especially in the threshold region, where the s–wave meson production is expected, the onset of p– and d–waves could be observed.

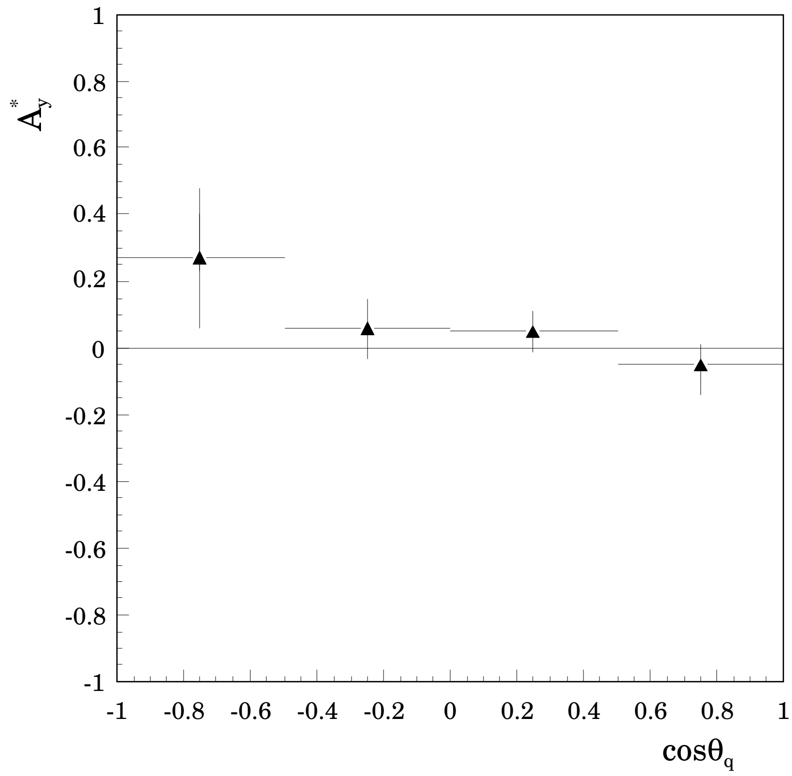


Figure 1. Angular dependence of the analyzing power $A_y$ in the center of mass system for the reaction $\vec{p}p \rightarrow pp\eta$.

The event selection requires the identification of two protons in the exit channel. The four–momentum determination of positively charged ejectiles allows a full kinematical reconstruction for the $\vec{p}p \rightarrow ppX$ reaction. An identification of the meson $X$ is done via the missing mass method.

The averaged beam polarization was measured simultaneously at the internal experiment EDDA [21] and amounted to $\vec{P}_{beam} \approx 50\%$. The analyzing power was determined as a function of the polar angle $\theta_q$ of the η meson in the center of mass system [1]. The relative luminosity of both spin states was extracted based on the simultaneous measurement of the elastic proton-proton scattering. The angular dependence of $A_y$ is shown in Figure 1. Though the data are consistent with $A_y = 0$ within the error bars given, there seems to be a slight increase of $A_y$ towards backward scattering angles.

In Figure 2 a comparison of the data (solid triangles) with theoretical predictions for $Q = 37\,\mathrm{MeV}$ from Fäldt and Wilkin [2] (dotted line) and Nakayama [22] (solid line) is shown. In addition, the theoretical calculations for $Q = 10\,\mathrm{MeV}$ are plotted. Both models are based on the one meson exchange model. While Fäldt and Wilkin predict a dominance of ρ exchange, Nakayama concludes a dominant π and η exchange.

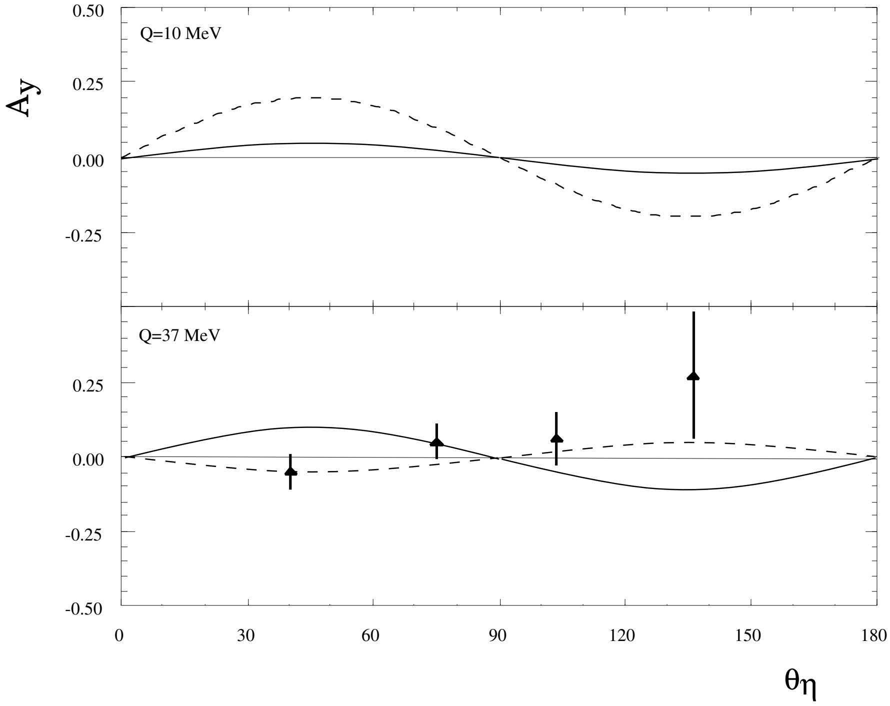


Figure 2. Theoretical predictions for the analyzing power according to [2] (dotted line) and [22] (solid line) for $Q = 10$ and $37\,\mathrm{MeV}$. The solid triangles represent the measured values [1] at $Q = 40\,\mathrm{MeV}$.

First results of the analyzing power – deduced from the very first feasibility study run – suffer from statistics but tend to differ from both theoretical calculations, although the predictions of [2] show a quite good match. For a more precise statement further measurements are needed which could benefit from higher polarization now available at COSY. Therefore, smaller error bars with the same statistics can be achieved.

Besides a measurement at $Q = 40\,\mathrm{MeV}$ for higher statistics, a new run at $Q = 10\,\mathrm{MeV}$ is motivated by a theoretically expected higher value of $A_y$ [2]. Furthermore, the sign of the analyzing power should change in case of dominant ρ exchange (see Fig. 2).

**3. Beam Time estimate**

During the COSY–11 experiment (Proposal 77.1) over a period of seven days the average beam polarization was unfortunately only $\vec{P}_{beam} \approx 0.487$. This run took place at the very beginning after the new years break and by now typical values of the polarization are expected to be as high as $\vec{P}_{beam} \geq 0.7$.
The average luminosity was in the order of $L = 5 \times 10^{29}$.

Under these conditions COSY–11 extracted the values for a separation of
a) the ($P_p$–$P_s$) interference term ($G_1^{y0}$) from
b) the ($P_p$–$P_p$) and ($S_s$–$S_d$) terms ($H_1^{y0}$) and ($I^{y0}$)
to be [1]:

$$\underline{G_1^{y0} = \mathbf{(0.006 \pm 0.004)}\,\mu\mathbf{b}} \quad \text{and} \quad \underline{H_1^{y0} + I^{y0} = \mathbf{-\,(0.008 \pm 0.005)}\,\mu\mathbf{b}.}$$

It is essential that a significantly improved measurement has to be done and therefore we ask for additional beam time with the aim to reduce the uncertainties by a factor of three to four. After our former experiment was carried out, the publication [2] appeared with the interesting graph shown here in figure 3.

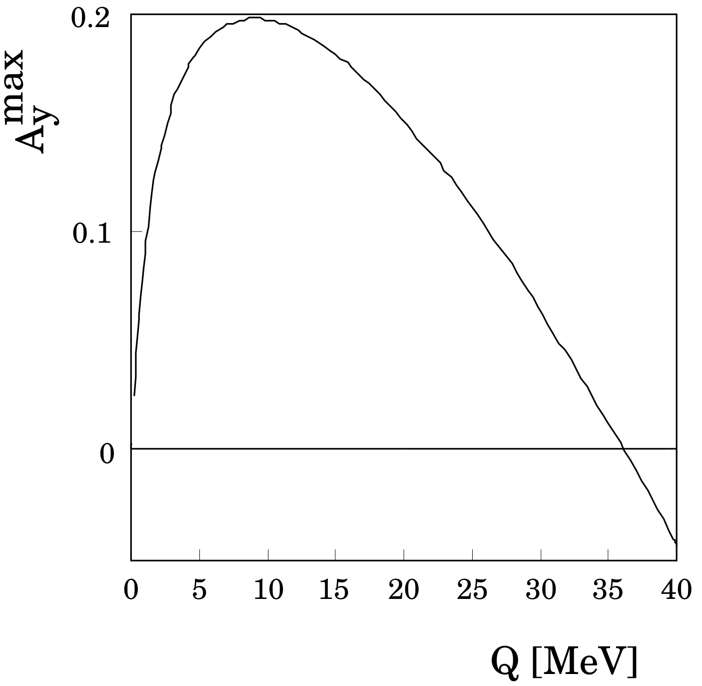


Figure 3. Predictions of the analyzing power as function of the excess energy for the reaction $\vec{p}p \to pp\eta$ from reference [2].

The beam time we are asking for should
 i) repeat our former experiment at an excess enegy of Q = 40 MeV and
 ii) motivated by figure 3 measure at Q = 10 MeV,

since here the maximum of the analyzing power in the threshold region is expected if the ρ–meson exchange is dominant.
In addition, the COSY–11 acceptance is larger at this second excess energy.
Regarding the angular dependence of the analyzing power as given in figure 2 the interesting comparison between the two models – where model [2] shows a phase change between the two excess energies depicted and model [22] does not – gives a convincing motivation for a precise study.

It is obvious that long beam times are needed for these investigations. Based on the experience of COSY–11 we would like to ask for:

**A) Three weeks of beam time**
**at a momentum of the polarized proton beam of**
$\vec{P}_p = 2.096$ **GeV/c**
**equivalent to an excess energy of Q = 40 MeV.**
**and**
**B) Three weeks of beam time**
**at a momentum of the polarized proton beam of**
$\vec{P}_p = 2.009$ **GeV/c**
**equivalent to an excess energy of Q = 10 MeV.**

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**REFERENCES**

1. P. Winter, Diplomarbeit, Universität Bonn, December 2001
2. G. Fäldt and C. Wilkin, Phys. Scripta **64** (2001) 427
3. A.M. Bergholt et al., Phys. Rev. **D 48** (1993) R2969
4. F. Hibou et al., Phys. Lett. **B 438** (1998) 41
5. H. Calén et al., Phys. Lett. **B 366** (1996) 39
6. J. Smyrski et al., Phys. Lett. **B 474** (2000) 182
7. H. Calén et al., Phys. Lett. **B 458** (1999) 190
8. TOF–Collaboration, to be published
9. P. Moskal et al., to be published
10. W. Deinet et al., Nucl. Phys. **B 11** (1969) 495
11. B. Krusche et al., Phys. Rev. Lett. **75** (1995) 3736,
    Phys. Rev. Lett. **75** (1995) 3023
12. C. Wilkin, private communication
13. T.S. Lee and Ch. Hanhart, private communication
14. H.O. Meyer et al., IUCF-UP-UWM-WMU preprint, nucl-ex/9807002 Jul 1998
15. J.-F. Germond and C. Wilkin, Nucl. Phys. **A 518** (1990) 308
16. J.M. Laget et al., Phys. Lett. **B 257** (1991) 254
17. A.B. Santra and B.K. Jain, Nucl. Phys. **A 634** (1998) 309
18. E. Gedalin et al., Nucl. Phys. **A 634** (1998) 368
19. T. Vetter et al., Phys. Lett. **B 263** (1991) 153
20. M. Batinic et al., Phys. Scripta **56** (1997) 321
21. M. Altmeier et al., Phys. Rev. Lett., 85 (2000) 1819 and
    F. Bauer, private communication.
22. K. Nakayama, e-Print archive: nucl-th/0108032 (2001)