Study of the $\eta$ meson production with polarized proton beam

M. Zieliński, P. Moskal, I. Schätti-Ozerianska

WASA-at-COSY Collaboration

SPIN 2014, Beijing, October 21st, 2014
Motivation for $\eta$ studies

Why study such particle like $\eta$?
Motivation for $\eta$ studies

*Why study such particle like $\eta$?*

1. Learn about the interaction of the $\eta$ meson with nucleons
Motivation for $\eta$ studies

Why study such particle like $\eta$?

1. Learn about the interaction of the $\eta$ meson with nucleons
2. Determine the mechanism of the $\eta$ meson production
Motivation for $\eta$ studies

Why study such particle like $\eta$ ?

1. Determine the mechanism of the $\eta$ meson production

2. Learn about the interaction of the $\eta$ meson with nucleons

- Gives an unique opportunity to study the strong interaction in the low energy region
- $\eta$ meson is a still an „exotic“ particle with many intriguing questions
η production in pp interactions

\[ pp \rightarrow pp \, \eta \]

Possible mechanisms:
1) pseudo-scalar meson exchange
2) vector meson exchange model

Excitation function does not give any hint on the production dynamics
How to learn about the mechanism?

Use polarization observables such as analyzing power $A_y$

Theoretical predictions for the $A_y$ value are sensitive to the assumption on the type of exchanged meson.

$$\sigma(\theta, \varphi) = \sigma_0(\theta) \cdot \left(1 + \sum_{i=1}^{3} P_i A_i(\theta, \varphi)\right)$$

- Cross section with polarization
- Cross section without polarization
- Polarization
- Analyzing power $P \neq 0$
Results from COSY-11 experiment

Data sample contained 2000 $\eta$ mesons

Prediction for $A_y$ value in vector meson exchange model

$A_y(\theta_\eta) = A_{y,\text{vec}}^{\text{max}} \sin 2\theta_\eta,$

Results from COSY-11 experiment

Data sample contained 2000 $\eta$ mesons

Prediction for $A_y$ value in vector meson exchange model

Qualitative conclusion (only):
1) Most probably one can exclude the mechanism with the vector meson exchange and the mechanism is dominated with pion exchange.
2) The $A_y$ values are within calculated uncertainty equal zero therefore the $\eta$ meson is predominantly produced in $s$ wave

Results from COSY-11 experiment

Data sample contained 2000 $\eta$ mesons

Prediction for $A_y$ value in vector meson exchange model

How to improve and learn more about η production?
How to improve and learn more about $\eta$ production?

Do more precise and high statistics experiments!
How to improve and learn more about $\eta$ production?

Do more precise and high statistics experiments!

WASA-at-COSY

(azimuthally symmetric detector)
Experiment with WASA at COSY

Reaction of polarized proton beam and unpolarized proton target:

<table>
<thead>
<tr>
<th>P beam (MeV/c)</th>
<th>Q (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2026</td>
<td>15</td>
</tr>
<tr>
<td>2188</td>
<td>72</td>
</tr>
</tbody>
</table>

Two reactions measured at the same time:

- $pp \rightarrow pp \eta$
- $pp \rightarrow pp$
  (elastic scattering)

Two spin modes (up and down) and additional control runs without polarization.
Experiment with WASA at COSY

Reaction of polarized proton beam and unpolarized proton target:

$$pp \rightarrow pp \eta$$

Two reactions measured at the same time:

$$pp \rightarrow pp$$

(elastic scattering)

<table>
<thead>
<tr>
<th>P beam (MeV/c)</th>
<th>Q (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2026</td>
<td>15</td>
</tr>
<tr>
<td>2188</td>
<td>72</td>
</tr>
</tbody>
</table>

Two spin modes (up and down) and additional control runs without polarization.
Analysis steps

With the WASA detector we have gathered $5 \cdot 10^5 \eta$ mesons (for comparison with COSY-11 it was 2000 events).

$$A_y(\theta_\eta) = \frac{1}{P} \frac{N_+^{\uparrow}(\theta_\eta) - L_{rel} N_-^{\uparrow}(\theta_\eta)}{N_+^{\uparrow}(\theta_\eta) + L_{rel} N_-^{\uparrow}(\theta_\eta)}.$$
**Analysis steps**

With the WASA detector we have gathered $5 \cdot 10^5 \eta$ mesons (for comparison with COSY-11 it was 2000 events).

\[
A_y(\theta_\eta) = \frac{1}{P} \frac{N^\uparrow(\theta_\eta) - L_{rel}N^\downarrow(\theta_\eta)}{N^\uparrow(\theta_\eta) + L_{rel}N^\downarrow(\theta_\eta)}. 
\]

1. $\bar{pp} \rightarrow pp$
   
   Using elastic scattering first we have to determine polarization,

2. and second step calculate the luminosity
**Analysis steps**

With the WASA detector we have gathered $5 \cdot 10^5 \eta$ mesons (for comparison with COSY-11 it was 2000 events).

$$A_y(\theta_\eta) = \frac{1}{P} \frac{N^\uparrow_+(\theta_\eta) - L_{rel} N^\uparrow_-(\theta_\eta)}{N^\uparrow_+(\theta_\eta) + L_{rel} N^\uparrow_-(\theta_\eta)}.$$  

<table>
<thead>
<tr>
<th></th>
<th>$\bar{p}p \rightarrow pp$</th>
<th>$\bar{p}p \rightarrow pp \eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Using elastic scattering first we have to determine polarization, and second step calculate the luminosity</td>
<td>Knowing the polarization and the luminosity one can calculate the analysing power as a function of the $\eta$ emission angle</td>
</tr>
</tbody>
</table>
Step 1: polarization determination
(analyzing power for elastic scattering)

Database for cross sections and analysing power in elastic pp scattering

\[ P = \frac{1}{A_y(\theta)} \cdot \frac{N_+(\theta, \varphi) - N_-(\theta, \varphi)}{N_+(\theta, \varphi) + N_-(\theta, \varphi)} \]

Ay (from EDDA)

Step 1: polarization determination
(elastic events selection)

We use angular $\theta$ range 30-38 deg in CM, divided into two bins of 4 deg width each.
Step 1: polarization determination
(asymmetry calculation)

\[
\theta^{FD} (30-34)
\]

\[
\theta^{FD} (34-38)
\]

\[pp \rightarrow pp\]

\[ P = \frac{1}{A_y(\theta)} \frac{N_+(\theta, \varphi) - N_-(\theta, \varphi)}{N_+(\theta, \varphi) + N_-(\theta, \varphi)} \]

asymmetry
Step 1: polarization determination
(asymmetry calculation – example plots)

Spin UP mode

Spin DOWN mode
Step 1: polarization determination

(Vertex position – systematic effects studies)

Polarization value can change with the vertex position!

Monte Carlo simulations how the change of the vertex position influences the polarization value.
Step 1: polarization determination

(Vertex position – systematic effects studies)

Polarization value can change with the vertex position!
We used coplanarity method to determine the interaction region.

\[
C = \frac{(\vec{p}_1 \times \vec{p}_2) \cdot \vec{p}_{beam}}{|\vec{p}_1 \times \vec{p}_2| \cdot |\vec{p}_{beam}|}
\]

Monte Carlo simulations

Experimental Data
**Step 1: polarization determination**

(Vertex position – systematic effects studies)

Based on the MC simulations we have determined the vertex position in our experiment.

Vertex position is stable for whole beam run

<table>
<thead>
<tr>
<th>vertex</th>
<th>unpolarized $P_{beam} = 2.026$ GeV/c</th>
<th>$P_{beam} = 2.026$ GeV/c</th>
<th>$P_{beam} = 2.188$ GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_v$</td>
<td>-0.1164±0.0052</td>
<td>-0.1230±0.0011</td>
<td>-0.2834±0.0010</td>
</tr>
<tr>
<td>$y_v$</td>
<td>0.1119±0.0052</td>
<td>0.1099±0.0011</td>
<td>0.1551±0.0010</td>
</tr>
</tbody>
</table>
Step 1: Results for polarization

- Not polarized control sample ($P = 0$)
- Polarization very stable over the whole beam run (2 weeks)
Step 2: $\eta$ identification

Analysis has started. We search for the reaction chain:

$$pp \rightarrow pp \eta$$

We did the basic preselection of events under the condition:

2 charged particles in FD and $\geq 2$ neutral particles in CD
**Step 2: $\eta$ identification**

- Selection of protons in FD (by dE-E method)
- Selection of 2 gamma in CD (invariant mass)
Step 2: $\eta$ identification

$pp \rightarrow pp \eta$

Example missing mass from around 15% of all data

With COSY-11 we had 2000 $\eta$ mesons

now

with WASA we have around $5 \times 10^5$ $\eta$ mesons
Outlook and perspective

- The polarization studies are finished
- Now we are evaluating the luminosity
- and at the same time will be finishing the $\eta$ selection
- Calculation of the $A_y$ value
- Confrontation of the results with the theoretical prediction
Thank you!
Madison convention