Study of η- and η'-Meson Production in the Reactions pd$\rightarrow^3$He X at COSY-11

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Renewal of the COSY-11 proposal 11.6: Production of η and η' via pd$\rightarrow^3$He η,η' at COSY-11

1 Abstract

We propose to investigate the reactions pd$\rightarrow^3$He η and pd$\rightarrow^3$He η' near threshold using the COSY-11 installation. The identification of the outgoing ^{3}He and determination of the four momentum will be provided by using drift chambers and scintillation walls. With this information it is possible to calculate the missing mass of the unobserved particle X of the reaction pd$\rightarrow^3$He X, which leads to a full event reconstruction in the case of the above mentioned two particle final states of interest. The new deuterium regeneration system for both the experiments COSY-11 and ANKE will be used during the deuterium cluster beam operation.
Since the installation COSY-11 takes advantage of the internal cluster target (single particle interaction, no target windows) in combination with a stochastically cooled beam, in view of its high luminosities this experimental setup is suited well for taking high precision data in the near threshold region.

2 Introduction

The near threshold production of mesons in nucleon-nucleon collisions is of fundamental interest and provides a possibility to study various theoretical models of production processes. Close to threshold only few partial waves are involved and due to the low relative momenta of the ejectiles, final state interactions can be studied in more detail.
At the cooler synchrotron COSY various near threshold measurements have been performed

using the internal installation COSY-11 [1]. In the case of the η-meson production in proton-proton collisions measurements have been performed at excess energies below threshold up to Q = 6.8 MeV [2] and the obtained cross sections are in very good agreement with existing data [3, 4, 5, 6]. In the case of η'-mesons data have been taken in proton-proton collisions at excess energies from Q = 1.5 MeV to Q = 25 MeV [7]. Two further data points are available from the SPES3 collaboration at Q = 3.7 MeV and Q = 8.3 MeV [9]. These data sets in the near threshold region are valuable for the development of theories on η- and η'-meson production in the elementary nucleon-nucleon scattering and the verification of their predictions, which may also be important in the context of understanding the production processes for these mesons in heavy ion collisions.
In addition to the elementary nucleon-nucleon reactions the production of mesons on heavier targets provides the possibility to study reaction processes with more than only one involved target nucleon. A suitable reaction channel for this is pd$\rightarrow$^{3}He X with X being the produced meson(s). One aim of the physics program of the COSY-11 collaboration is to extend the previous discussed data by using deuterium as target and to study both the η and the η' production in pd collisions. The main emphasis is the η' production in pd collisions, with this proposal we also ask for beam time for the η production. The η data will extend the existing data base and will allow a more detailled comparison of both reaction channels with the same experimental setup minimizing systematic errors. From the elementary pp interaction there are speculations that the ηN and the η'N interactions are attractive and repulsive, respectively [8]. Therefore, a verification in the ^{3}He-meson system would be of great interest. Furthermore, during this measurement it will be possible to record data of the reaction pd$\rightarrow$pdη (η') leading to first cross sections in the near threshold region.

3 Physics

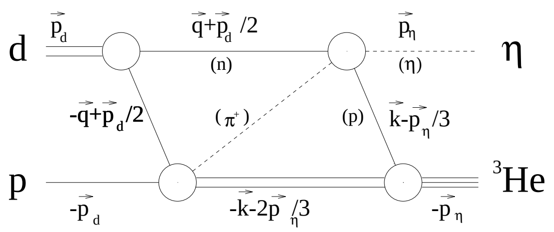

Figure 1: Double-scattering diagram for pd$\rightarrow$^{3}He η according to [13].

The production of η-mesons in the pd$\rightarrow$^{3}He η reaction has been studied at Saclay in the near threshold region [11, 10] and shows remarkable features. In spite of the much higher momentum transfer, the observed threshold amplitude f_η for the η-production is comparable to that for the pd$\rightarrow$^{3}He π^0 reaction at its respective threshold [11]. In addition, while being consistent with S-wave production, $|f_\eta|^2$ decreases by a factor of three over an η c.m. momentum of 70 MeV/c. A possible explanation of this decrease could be a large η-nucleus scattering length, but this interpretation fails to verify the absolute value of the cross section. One promising Ansatz to describe the reaction process is to take into account both nucleons from the target and to consider also double-scattering diagrams [12]. Calculations by Fäldt and Wilkin [13] follow this approach and describe the pd$\rightarrow$^{3}He η reaction as an initial pp$\rightarrow$dπ^+ production followed by π^+n$\rightarrow$ ηp. A sketch of such a double-scattering diagram can be seen in Fig. 1. Taking also final state interaction into account these calculations lead to a prediction of the spin averaged threshold amplitude squared $|f|^2 = 0.69$ μb/sr. Defining the unpolarized c.m. cross section as

$$\frac{d\sigma}{d\Omega}(pd \rightarrow^3 He\,\eta) = \frac{p_\eta}{p_d}|f(pd \rightarrow^3 He\,\eta)|^2, \tag{1}$$

with the spin averaged amplitude [10], [14]

$$f = \frac{f_B}{1 - ip_\eta \cdot a} \qquad \text{a: scattering length;} \qquad p_\eta\text{: momentum of } \eta \text{ in the c.m.} \tag{2}$$

a comparison of these calculations with existing threshold data is possible. Despite underestimating the measured results by a factor of 2.3, the shape of the energy dependence is well reproduced as can be seen in Fig. 2.

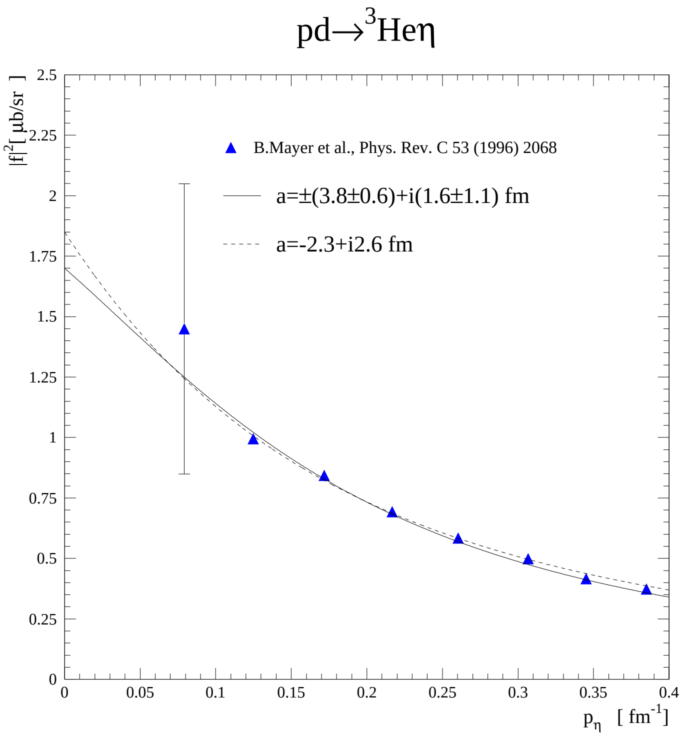

Figure 2: Spin-averaged amplitude squared $|f|^2$ for the reaction pd$\rightarrow^3$He$\,\eta$ near threshold. The dashed line was computed on the basis of a scattering length obtained from a calculation using an ^{3}He$\,\eta$ optical potential [15]. The solid line results from the fit of the scattering length to the data [10].

The available near threshold cross section data for the η production, including preliminary data from COSY (GEM) and CELSIUS, can be seen in Fig. 3 [16]. Both fit curves are calculated on basis of equations 1 and 2 using values for the scattering length according to Fig. 2. While the energy dependence of the Saclay cross sections (Q $<$ 7 MeV) are in agreement with these calculations, the up to now preliminary cross sections at higher energies seem to

be underestimated.
For further experimental verification more data especially in the near threshold region between Q = 7 MeV and Q = 40 MeV are needed.

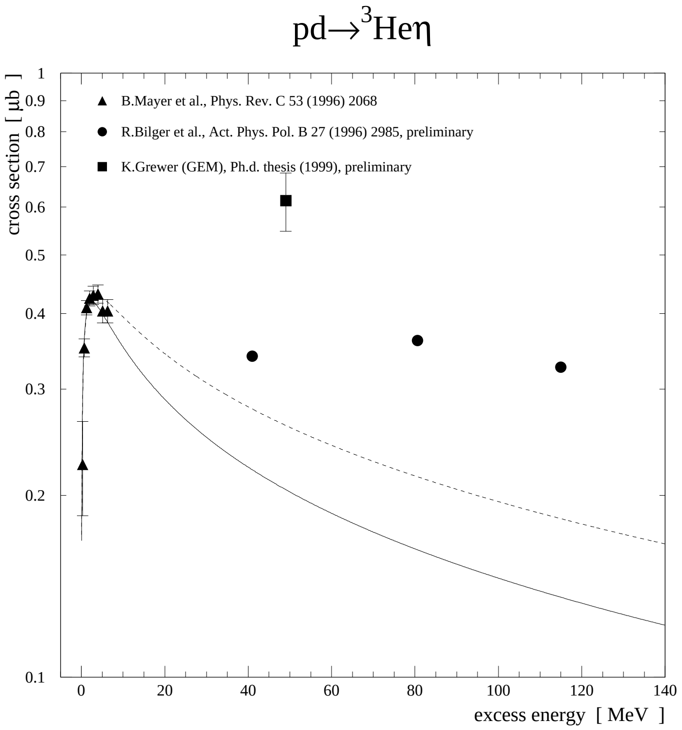

Figure 3: Available near threshold data to the reaction pd→^{3}He η. Both fit curves are calculated on basis of equations 1 and 2 using values for the scattering length according to Fig. 2.

To provide a broader basis of the experimental data set the COSY-11 collaboration plans to take data from threshold up to an excess energy of Q = 40 MeV to guarantee an overlap with existing data.
For the similar reaction pd→^{3}He η' there exists up to now only one absolute cross section of 0.23 nb at Q = 0.4 MeV from Saclay [17, 18]. In the context of the discussed theoretical situation data close to threshold are desirable to study the corresponding reaction processes. Therefore, within the COSY-11 collaboration additional measurements to this reaction channel are planned in order to provide data to both the η- and the η'- production in pd collisions in the near threshold region at similar Q values. Similar to ^{3}He η, for the reaction pd→pdη a two step production model has been introduced [19], in which a pion is created in the first vertex and an η-meson in the second. Near threshold data to the reaction channels pd→pdη (η'), recorded in parallel during the proposed measurements, will allow to proof predictions of these calculations.

4 Experiment

The proposed measurements on η- and η'-production in pd collisions will be carried out using the COSY-11 installation at COSY, which is optimized for studies on meson production in the near threshold region. Instead of using hydrogen, for these kind of measurements the installed Münster cluster target will be operated with deuterium. To minimize operation costs, a closed deuterium system for both the ANKE and the COSY-11 experiment is under construction at the IKP Münster and will be available in summer 1999.

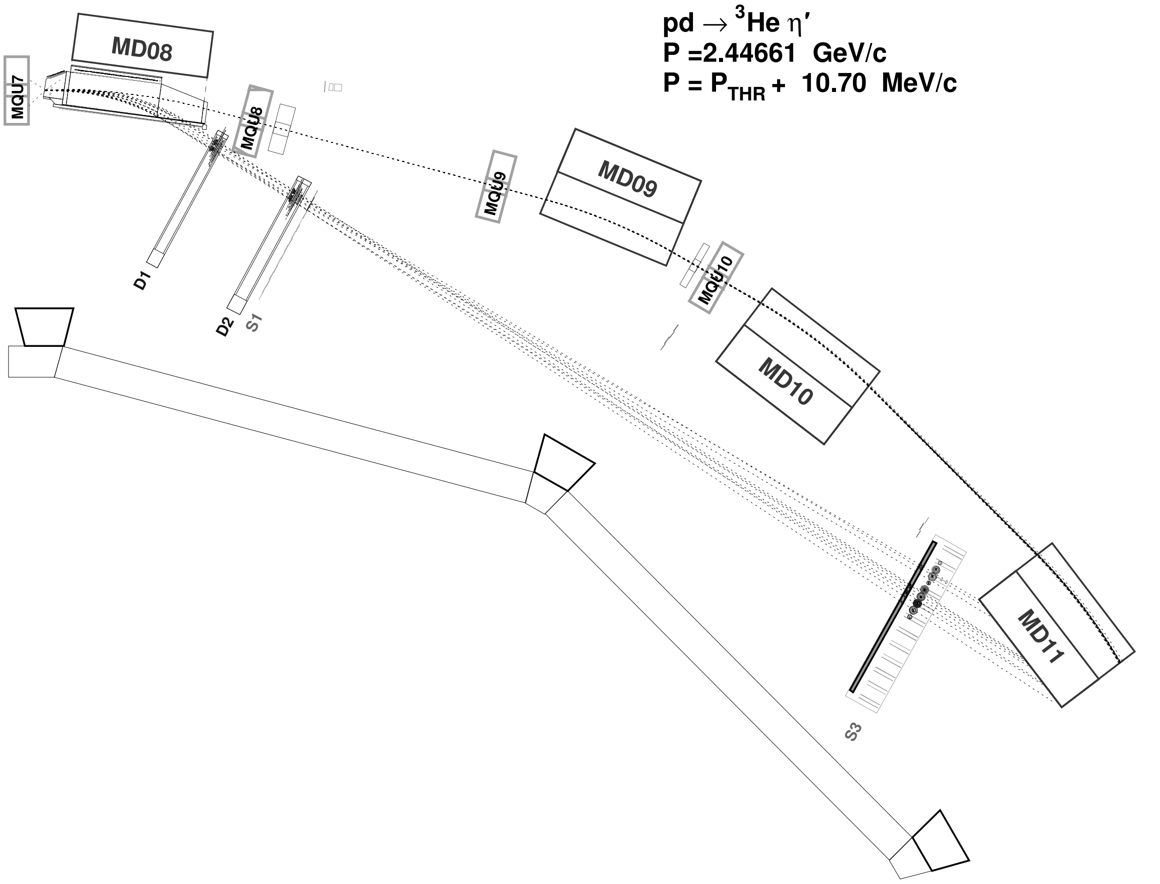

Figure 4: Monte-Carlo simulation of the reaction pd$\rightarrow$^{3}Heη' at an excess energy of Q = 5 MeV.

4.1 The reactions pd$\rightarrow$^{3}Heη and pd$\rightarrow$^{3}Heη'

Detailed Monte-Carlo simulations for both reactions have been performed and verify the feasibility of the experiments. In Fig. 4 a sketch of the COSY-11 installation with generated Monte-Carlo events for the η'-production on deuterium at an excess energy of Q = 5 MeV is shown. Due to their high mass, in the laboratory system the outgoing ^{3}He are emitted in a narrow cone, resulting in a high detection efficiency even at higher Q-values. While the η'-meson is unobserved, the ^{3}He passes a system of drift chambers (D1 and D2) and two following scintillation walls (S1 and S3), acting as a time-of-flight detector (TOF). Reconstructing the track using the drift chamber information, the momentum vector $\vec{p}$ is determined by backtracing the track through the magnetic field to the interaction point. In combination with the TOF information, a particle identification and a determination of the four-momentum vector can be performed. In the case of the proposed two-body reactions this leads to a kinematically complete event reconstruction.

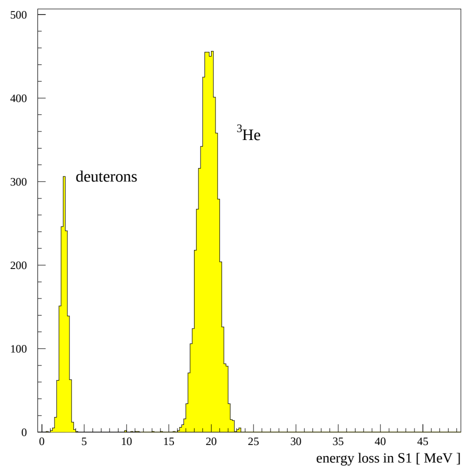

Figure 5: Energy loss of ^{3}He in the S1 detector for η'-production, simulated at an excess energy of Q = 2 MeV. The deuteron distribution corresponds to the pd elastic scattering at the same beam momentum.

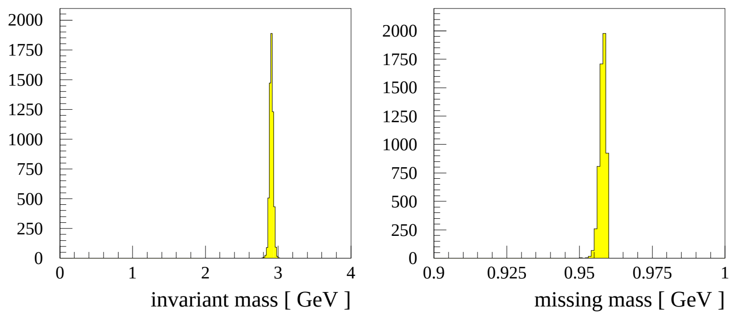

Figure 6: Invariant mass of the detected ^{3}He (left hand side) and calculated missing mass of the unobserved η'-meson (right hand side) at an excess energy of Q = 2 MeV.

In Fig. 5 the energy loss of ^{3}He in one scintillation segment of S1 is shown for the η'-production at Q = 2 MeV. Due to this high energy loss the ΔE information of detected particles in the S1 detector can be used in addition to the time-of-flight information for an on-line discrimination of ejectiles which leads to a drastically reduced background of protons and pions.

As already mentioned, for the proposed two-body final states a full event reconstruction and the identification of the X meson is possible if the four momentum vector of the outgoing ^{3}He is known. For the reaction pd$\to^3$He$\,\eta'$ this situation is demonstrated in Fig.6 for simulated events at an Q-value of 2 MeV. On the left hand side of the figure the invariant mass of the detected particle, calculated on basis of the reconstructed momentum and the TOF information, is presented. As expected, the particles can unambiguously be identified as ^{3}He. The corresponding missing mass distribution for these events is plotted on the right hand side of that figure, resulting in a sharp peak at the mass of the produced η'-mesons. These simulations result in an expected missing mass resolution of 1.2 MeV, which is comparable to the achieved ones for both the η and η' production in pp-collisions at COSY-11.

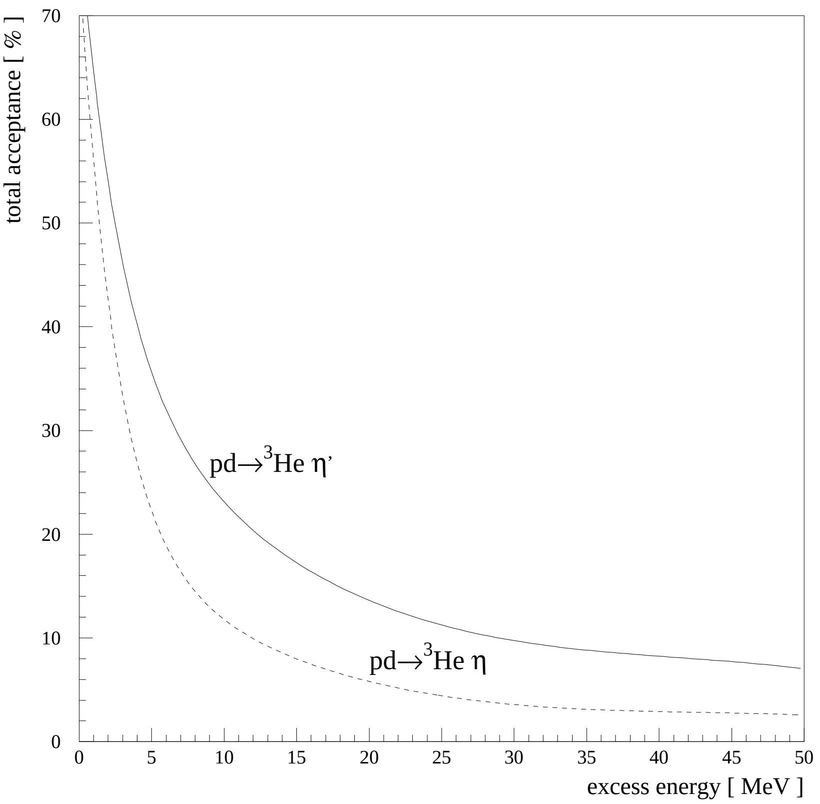

Figure 7: Total acceptance of the COSY-11 installation for the η- and η'-production in pd-collisions.

Due to the high luminosity and large acceptance, even at higher Q-values (Fig.7), at COSY-11 it is possible to study reactions with small cross sections from threshold up to high excess energies in a reasonable time scale.
The interpretation of recorded data will take advantage of the large acceptance for charged ejectiles. Monte-Carlo simulations, with respect to the scattering angle θ of ^{3}He in the c.m.

system, result in a broad covered range. In Fig.8 the result of such a calculation for the η'-production at Q = 2 MeV is shown. Due to the large exit window of the scattering chamber at COSY-11 the whole range of the c.m. scattering angle θ is covered, which is also the case for higher Q values.

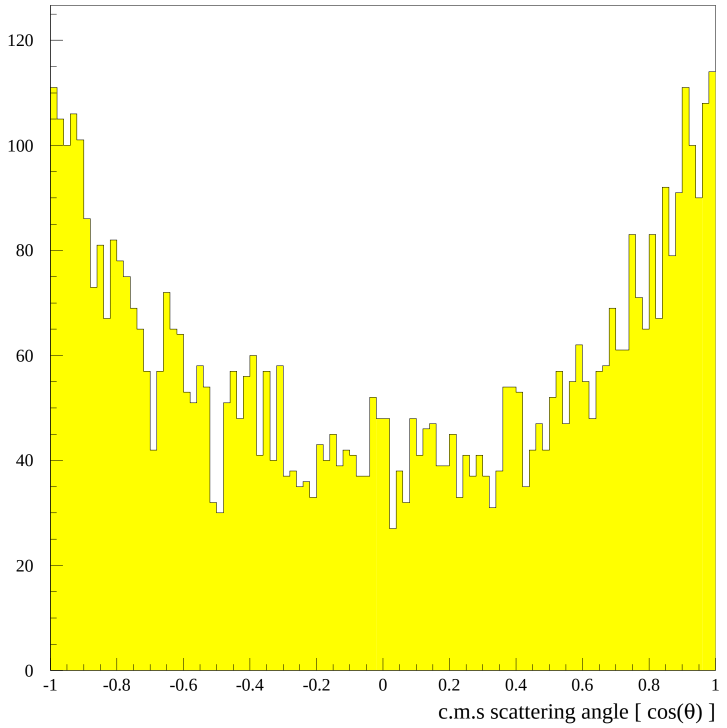

Figure 8: Center of mass scattering angle $\cos(\theta)$ of detected ^{3}He for the reaction pd$\rightarrow{}^3$Heη' at an excess energy of Q = 2 MeV.

4.2 Normalization

For the proposed measurements the normalization of the data will be performed using the pd elastic scattering. Equivalent to low momentum transfers deuterons with high scattering angles will be detected in a silicon pad monitor detector, while corresponding proton hits are required in both the S1 and the S3 detector. Protons are identified via a four-momentum determination as described for ^{3}He. Events to the pd elastic scattering can unambiguously be identified using the correlation of the proton hit position in the S1 detector and the corresponding position of the deuteron hit in the monitor detector as can be seen in Fig.9 (left hand side). The corresponding c.m. scattering angles of the protons are shown in the same figure (right hand side). This method of data normalization is well-established at COSY-11 in the case of the pp elastic scattering and is described in more detail in [20].

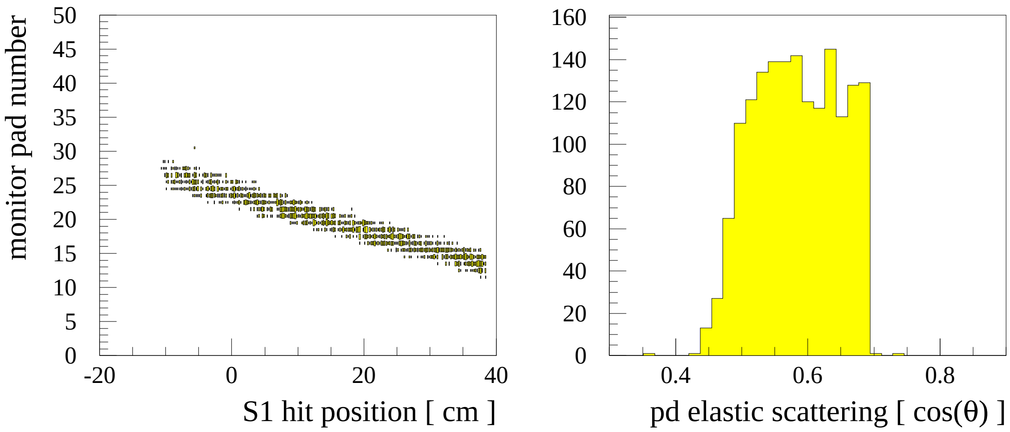

Figure 9: Deuteron hit position in the monitor detector versus hit position of protons in the S1 detector for the pd elastic scattering at 2.440 GeV/c (left hand side) and the corresponding c.m. angular distribution of the detected protons (right hand side).

5 Beam time request

With these standard values of a target density of 10^{14} atoms/cm^2 and a COSY beam intensity of $2{\cdot}10^{10}$ stored protons we have a luminosity of L = $3{\cdot}10^{30}$ cm^{-2}s^{-1} for the proposed measurements, corresponding to an event rate of $\sim 2.6{\cdot}10^5$/day$\cdot\mu$b.
According to Tab.1 we propose five days of beam time in total to obtain high quality data to the reaction pd$\to^3$He η. For all Q-values the expected number of measured events was roughly estimated using the available cross sections (see Fig.3).
In case of the corresponding reaction for the η' production we ask for additional nine days of beam time to receive cross sections at five different Q-values. Since there exists only one data point of 0.23 nb at Q = 0.4 MeV [17] for this reaction, we calculated the expected number of detected events under the assumption of an increase of the cross section according to phase space.

pd$\to^3$He η			**pd$\to^3$He η'**		
Q [MeV]	**time [d]**	**expected events**	**Q [MeV]**	**time [d]**	**expected events**
1.0	0.5	27900			
2.0	0.5	24400	2.0	1	78
5.0	1	23000	5.0	2	141
10.0	1	12500	10.0	2	145
20.0	1	6000	20.0	2	113
40.0	1	3000	40.0	2	100
5 days			**9 days**		
total beam time request: 14 days					

Table 1: Beam time request for the production of η- and η'-mesons in pd-collisions. The threshold momenta are 1.5704 GeV/c and 2.4341 GeV/c, respectively.

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