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MESON PRODUCTION STUDIED WITH THE GEM DETECTOR *

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Measurements of proton induced meson production on hydrogen and deuterium targets using the GEM-detector at COSY are described. Preliminary estimates of the total cross section are presented. Results of the $pp \to d\pi^+$ and $pp \to pp\pi^0$ cross section are in agreement with previous findings. The total cross section of $pd \to {}^3\mathrm{He}\pi^0$ is consistent with results from pion absorption but a surprisingly large value was found at a beam

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momentum of 750 MeV/c. The reaction $pd \to {}^3\mathrm{He}\eta$ was measured at two beam energies and was identified by missing mass technique.

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1. Introduction

The near threshold production of mesons was studied with the GEM-detector at the COoler SYnchrotron COSYin Jülich. The GEM detector consists of the Magnet–Spectrometer *Big Karl* and an acceptance extending semi–conductor–detector referred to as *Germanium–Wall*. The $pp \to d\pi^+$ reaction was previously measured at excess energies between 0.275 MeV and 3.86 MeV with almost 4π acceptance using only the spectrometer *Big Karl* [1, 2]. In the present work, differential and total cross sections were measured at larger excess energies employing the *Germanium–Wall* for the first time. The investigated reactions and the corresponding beam momenta are listed in Table I.

TABLE I

Reactions studied with the GEM-detector. Also shown are the beam momenta of the incident proton beams.

Reaction studied	$\boldsymbol{P}_{\mathrm{beam}}$(MeV/c)
$p + p \to d + \pi^+$	850
$p + p + \pi^0$	850
$p + d \to {}^3\mathrm{H} + \pi^+$	850, 800, 750
${}^3\mathrm{He} + \pi^0$	850, 800, 750
${}^3\mathrm{He} + \eta$	1740, 1675

2. Experiment

The COSY proton beam was focused onto the target at the pivot point of the 3Q2DQ magnetic spectrometer *Big Karl*. The target was a cell [3] containing liquid hydrogen or deuterium and had a thickness of 4.4 ± 0.2 mm for the measurement of $pd \to {}^3\mathrm{He}\eta$ and 6.5 ± 0.2 mm for the other measurements. The target windows were made of Mylar with a thickness of 1 μm. The beam spot had dimensions of less than 1 mm and divergences of better than 4 mrad. Beam-halo events were suppressed using a plastic scintillator as a veto counter with a 4–mm–diameter inner hole in front of the target. Reaction ejectiles with large scattering angles were detected by

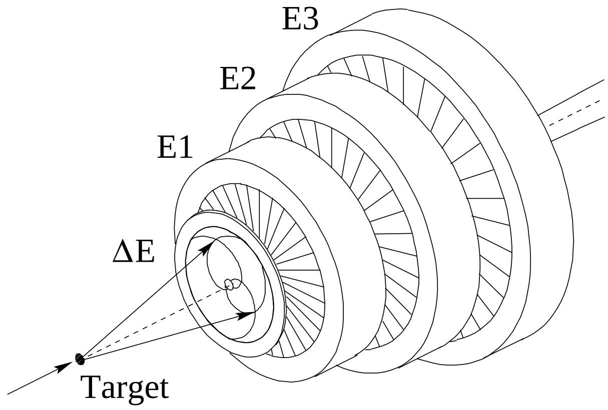

Fig. 1. Schematic view of the *Germanium Wall* . The first detector is used for ΔE measurements and precise determination of the scattering angle of the ejectiles. The following three 32-fold segmented E-detectors resolve reconstruction ambiguities and allow energy measurements with a resolution of better than $\Delta E/E = 4\times10^{-3}$. During the experiments described here only the ΔE, E_1 and E_3 detectors were available for measurements.

the *Germanium–Wall*. A schematic view of this detector is shown in Fig. 1. Three of the four position sensitive high purity germanium detectors were used in the set–up of the *Germanium-Wall*. The first 1.3 mm thick ΔE detector had on each side a structure of 200 Archimedes' spirals with opposite orientation, thus allowing precise reconstruction of the particle tracks up to an angle of 275 mrad. Each of the other germanium detectors, E_1 and E_3, had a thickness of 17 mm and a segmented structure of 32 wedges. The energy resolution of these detectors was better than $\Delta E/E = 4 \times 10^{-3}$. All detectors had central holes which served as an exit for the primary beam and the reaction particles under small scattering angles. These particles were detected with the magnetic spectrometer at zero degree. The particle trajectories were measured in the focal plane with a stack of two multi-wire drift chambers (MWDC). A track resolution of 0.2 mm was achieved. The drift chambers were followed by two scintillator–layers with a distance of 2.5 m in between. The technique of delayed coincidence was used for time of flight measurement and for generating the event trigger.

3. Results

The reconstruction of momentum vectors at the target from the measured tracks in the focal plane is described elsewhere [4]. Particles which were detected by the *Germanium–Wall* were identified by their charac-

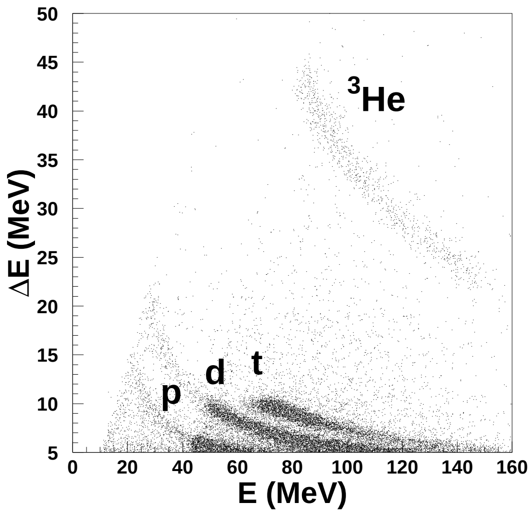

Fig. 2. ΔE *vs.* E spectrum obtained during $p+d$ runs at a beam momentum of 850 MeV/c. Clearly visible are the energy loss loci of protons (p), deuterons (d), tritons (t) and ^{3}He.

teristic energy-loss distributions in the ΔE and E_i detectors (see Fig. 2). Four-vectors were calculated from the total energy deposit E and the position information from the ΔE detector. In the further analysis only particles stopped in the *Germanium–Wall* were taken into account. The background was reduced by applying a gate around the reconstructed meson mass with a width of 3 times the experimental resolution and by subtracting the distribution obtained from *empty-target* measurements. The four-vectors were transformed into the c.m. system and the resulting angular distribution was fitted with Legendre polynomials in order to extract differential and total cross sections. The absolute normalisation was achieved by measuring simultaneously elastically scattered beam protons with calibrated scintillators. Acceptance and efficiency corrections were performed through the analysis of Monte Carlo simulated events, taking the complete geometrical set-up into account.

3.1. $p+p$ reactions

The $pp \to d\pi^+$ data were analysed in terms of the barrier penetration model by Gell–Mann and Watson. For this reaction the differential cross section can be parametrised by $4\pi d\sigma/d\Omega = A_0P_0(\cos\theta_{\rm cm}) + A_2P_2(\cos\theta_{\rm cm})$. Here, A_0 represents the total cross section and A_2 mainly the p–wave contribution. Furthermore, the total cross section can be expressed by the expression $\sigma(\eta) = \alpha_0\eta + \alpha_1\eta^3$, where $\eta = p_{\rm cm}/m_\pi$ is the pion c.m. momentum in units of it's rest mass and α_0 and α_1 are the s–wave and p–wave contribution, respectively. In Fig. 3 we compare our result with other data. Data obtained with *Big Karl* alone were taken in the range $0.062 \leq \eta \leq 0.22$. The point marked with an arrow at $\eta = 0.513$ (see Fig. 3) was measured with *Big Karl* and the *Germanium–Wall*. Total cross sections for the same reaction are from Ref. [5], while data from the time reversed $\pi^+ d \to pp$ reaction are taken from Ref. [6] and were transformed applying detailed balance. Also shown are data from the $np \to d\pi^0$ reaction [7] multiplied by a factor of 2 due to isospin symmetry. The solid curve corresponds to our earlier results for $\alpha_0 = 0.191 \pm 0.006$ mb and $\alpha_2 = 0.971 \pm 0.023$ mb [1, 2]. The newly measured data point is in very good agreement with our previous result and confirms the experimental method of extracting absolute cross section data.

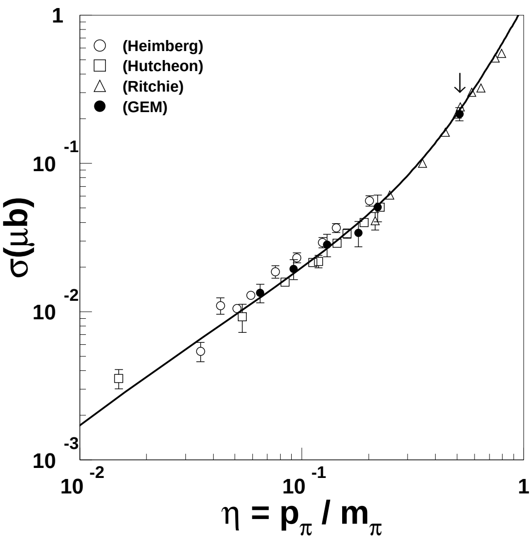

Fig. 3. Total cross section of the $pp \to d\pi^+$ reaction (indicated by the arrow) as function of $\eta = p_{\rm cm}/m_\pi$, with η being the maximum c.m. pion momentum in units of its rest mass. Also shown are data of the same reaction from Ref. [5]. Data from the time reversed $\pi^+ d \to pp$ reaction are taken from Ref. [6] and were transformed applying detailed balance, while $np \to d\pi^0$ data from Ref. [7] were multiplied by a factor of 2 due to isospin symmetry. The solid curve corresponds to our previous results for $\alpha_0 = 0.191 \pm 0.006$ mb and $\alpha_2 = 0.971 \pm 0.023$ mb [1, 2].

Simultaneously to the $pp \to d\pi^+$ reaction, two prong proton events from the $pp \to pp\pi^0$ reaction were recorded and analysed. Due to the final state interaction of the two outgoing protons, small relative momenta are favoured and therefore, in determining the Monte Carlo corrections, the final state interaction was taken into account via an effective range expansion [8]. In

Fig. 4 our preliminary estimate of the total cross section is shown in comparison to other published data. Our value is within the error bars consistent with results from Ref. [9] and Ref. [10]. A more elaborate data analysis will also provide information on angular distributions and reduce the size of the error bar significantly.

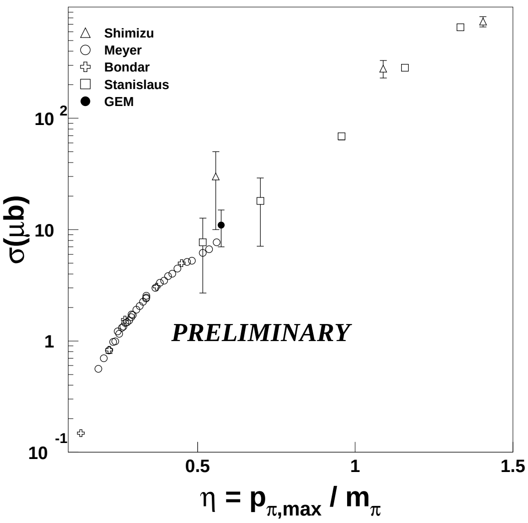

Fig. 4. Total cross section of the reaction $pp \to pp\pi^0$ compared to other data. Our data point at $\eta = 0.575$ is in agreement with results from Ref. [9] and Ref. [10]. See also caption of Fig. 3.

3.2. $p + d$ reactions

Investigation of the reaction $pd \to {}^3\text{He}\pi^0$ and its isospin symmetry related counterpart $pd \to {}^3\text{H}\pi^+$ can deliver important information on the understanding of the underlying reaction mechanisms of meson production on light nuclei. Several authors proposed that the excitation function is dominated in a similar way as found in the momentum dependence of $NN \to d\pi$. Recently Canton and Schadow [11] have incorporated experimental data of the reaction $pp \to d\pi^+$ into their model calculations and found an overall good agreement with existing data above $\eta = 0.8$. However, the rather large cross sections below $\eta = 0.5$ of Ref. [12] and Ref. [13] are not described and the apparent discrepancy between $\eta = 0.4$ and $\eta = 0.8$ needs to be investigated further. The aim of our investigations was therefore to extend the cross section data where almost no data from direct measurements existed ($0.4 \leq \eta \leq 1.2$), by detecting simultaneously both the ^{3}He and ^{3}H recoils over the full angular domain. In Fig. 5 first results of the

$pd \to {}^3\mathrm{He}\pi^0$ measurements performed at three beam energies from $\eta = 1.2$ down to $\eta = 0.8$ are presented. Also shown are data of the same reaction from Refs [12, 14, 15]. Results from the isospin symmetry related reactions are from Refs [16–18], while cross sections from pion absorption measurements are from Refs [19, 20]. All data not from the direct $pd \to {}^3\mathrm{He}\pi^0$ reaction were transformed assuming isospin symmetry and time reversal invariance. The curves shown are from the calculations of Ref. [11] and differ amongst each other due to the different NN potentials used for the bound state particle description. Despite the different potentials used in the calculations the general trend of the total cross section data is reproduced. Our

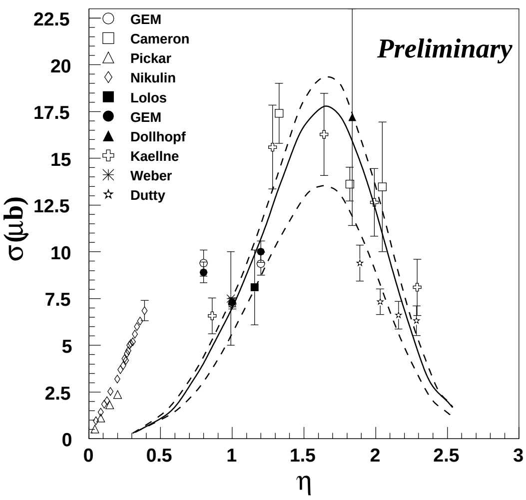

Fig. 5. Total cross sections of the reaction $pd \to {}^3\mathrm{He}\pi^0$. Data, other than from the direct measurement, were corrected assuming isospin invariance and applying detailed balance. The surprisingly large cross section at $\eta = 0.8$ cannot be explained and will be investigated closer in further experiments.

data at $\eta = 0.8$ might indicate the possible existence of a local maximum in the excitation function. However, the analysis of the data is still preliminary and there are no existing theoretical calculations explaining such an effect. An experimental verification is highly desirable and is foreseen in the near future.

The production of the η meson was studied with the GEM-detector through the reaction $pd \to {}^3\mathrm{He}\eta$ at 1675 MeV/c and 1825 MeV/c. Unambiguous identification of the ^{3}He recoils was achieved through their large energy deposits in the *Germanium–Wall*. Physical background from multipion production was determined and subtracted by means of the missing-mass technique. In Fig. 6 the reaction $pd \to {}^3\mathrm{He}\eta$ is clearly identified by the strong peak around 550 MeV/c^2. Our first estimates of the total cross section are of the same order of magnitude as found in Ref. [21], but further analysis is needed to extract precise and reliable values.

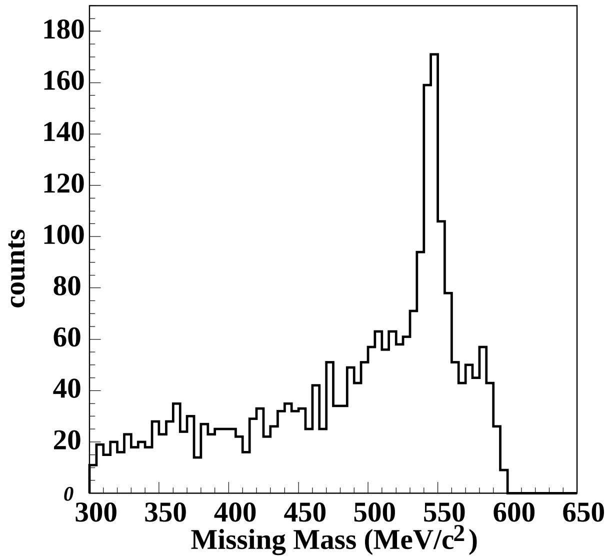

Fig. 6. Missing-mass plot for the reaction $pd \to {}^3\mathrm{He}\eta$. The reaction is clearly identified by the peak around the η mass, superimposed on a strong physical background, mainly from multi pion production.

4. Summary

Measurements of the meson production cross section employing the recently installed GEM-detector at COSY were described. The results from $pp \to d\pi^+$ and $pp \to pp\pi^0$ reactions are in agreement with previous experiments and confirm the experimental method of determining the absolute cross sections. First results from $pd \to {}^3\mathrm{He}\pi^0$ suggest the possible existence of a local maximum in the excitation function around $\eta = 0.6$. Further experiments are scheduled to address this phenomenon. The reaction $pd \to {}^3\mathrm{He}\eta$ could be identified despite a large physical background. In the future an extracted cooled beam will help to improve the quality of the data using the present set-up. Such measurements with polarized beams will provide a deeper insight into the mechanisms involved in nuclear reactions leading to meson production.

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