Proposal and Beam Request

Measurement of the cross section and analysing power of the quasi–free $\vec{p}n \to \{pp\}_s\pi^-$ reaction at ANKE

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Abstract

We propose to measure the differential cross section ($\mathrm{d}\sigma/\mathrm{d}\Omega$) and the proton analysing power (A_y) of the quasi–free $\vec{p}n \to \{pp\}_s\pi^-$ reaction at a beam energy of $T_p = 353$ MeV and for excitation energies of the final di–proton (E_{pp}) of less than 3 MeV. The experiment would be carried out at the ANKE spectrometer using a polarised proton beam and unpolarised deuterium cluster–jet target. These measurements are in line with the proposals outlined in the ANKE spin document and the results will be of relevance for Chiral Perturbation Theory.

The proposal requires in total **TWO weeks** of beam time at the single proton beam energy of $T_p = 353$ MeV.

Contents

1 Introduction

We submitted to the Autumn 2005 PAC meeting a comprehensive document outlining future plans for experiments involving polarised beams and targets to be performed with the ANKE facility [1]. The PAC graciously welcomed this general programme and approved its aims with high priority for the coming years at COSY. Since then we have shown that we can successfully study reactions with polarised proton [2] and deuteron beams [3, 4].

We have already argued at length why one needs to measure the $\vec{p}p \to \{pp\}_s\pi^0$ reaction at low excitation energies $E_{pp} < 3$ MeV of the final pp system, here denoted by $\{pp\}_s$ [5]. The observables ($\mathrm{d}\sigma/\mathrm{d}\Omega$ and A_y) that will be measured in this approved experiment at $T_p = 353$ MeV can be directly related to the spin–dependent amplitudes in the isospin $I = 1$ channel. We here propose to measure $\mathrm{d}\sigma/\mathrm{d}\Omega$ and A_y for the quasi–free $\vec{p}n \to \{pp\}_s\pi^-$ reaction at the same beam energy as for π^0 production. The comparison of the two reactions would allow us to extract information on the $I = 0$ amplitudes for the $NN \to \{pp\}_s\pi$ reaction. This is the primary aim of the current proposal.

1.1 Motivation for the $\vec{p}n \to \{pp\}_s\pi^-$ reaction

One of the major challenges in today's physics is to relate the properties of few–nucleon systems and nuclei to the theory of strong interactions, QCD. Over recent years there has been significant theoretical progress in establishing an effective field theory that, while having a clear cut connection to QCD, allows one to study processes involving strongly interacting particles within a well defined perturbative scheme. It is chiral symmetry that provides the preconditions for the construction of an effective field theory, called χPT [6, 7].

It was recently observed that there is one modification necessary to the standard chiral perturbation theory when this is applied to pion production in NN collisions. The large scale, introduced by the initial momentum, has to be considered explicitly [8, 9]. Thus, a proper expansion scheme for pion production is now established and a complete calculation for the reactions $NN \to NN\pi$ is currently under way. However, what is also needed is reliable few–nucleon wave functions, which are based on the same chiral effective theory. Fortunately, these wave functions, or the interactions necessary to generate them, do exist [10]. Furthermore, the extension to few–nucleon systems has been accomplished [11], allowing processes on light nuclei to be studied in the future.

One important step forward in our understanding of pion reaction at low energies [12] will be to establish that the same short–range $NN \to NN\pi$ vertex contributes to both p–wave pion production and to low energy three–nucleon scattering, where a crucial role is played by the identical production operator [8, 11]. In the chiral Lagrangian, at leading and next–to–leading order, all but one term can be fixed from pion–nucleon scattering. The missing term corresponds to an effective $NN \to NN\pi$ vertex, where the pion is in a p–wave and both initial and final NN pairs are in relative S waves.

To second order in the pion momentum, nine observables would be required to perform a full amplitude analysis in order to extract in a completely model–independent way the effective coupling constant. Two of these were measured in the $pp \to \{pp\}_s\pi^0$ differential cross section at CELSIUS at a beam energy around 350 MeV. The quasi-free measurements of $pn \to \{pp\}_s\pi^-$ from TRIUMF potentially provide another five but, as will be seen, these were carried out over a restricted angular range. The COSY–ANKE facility offers the exciting possibility of extending this angular range into regions of greater sensitivity and, eventually, to complement these measurements through the study of spin correlations. In this way we hope to extract the pion–production amplitudes in a way that minimises the model dependence so as to determine reliably a vital parameter for chiral perturbation theory.

2 Detailed physics case

The spin structure of the $pp \to \{pp\}_s\pi^0$ or $np \to \{pp\}_s\pi^-$ reaction is that of $\frac{1}{2}^+\frac{1}{2}^+ \to 0^+0^-$. There are only two independent spin amplitudes and these may be written in terms of unit vectors along $\boldsymbol{m} = \boldsymbol{k} - \boldsymbol{k}'$, $\boldsymbol{n} = \boldsymbol{k} \times \boldsymbol{k}'$, and $\boldsymbol{l} = \boldsymbol{n} \times \boldsymbol{m}$ as

$$\mathcal{F} = \frac{i}{\sqrt{2}}\, u_2^T\, \sigma_y \left\{ A\, \boldsymbol{\sigma}\cdot\hat{\boldsymbol{l}} + B\, \boldsymbol{\sigma}\cdot\hat{\boldsymbol{m}} \right\} u_1\,, \tag{2.1}$$

where $\boldsymbol{k}$ is the initial proton cm momentum and $\boldsymbol{k}'$ that of the emerging di–proton, and the u_i are Pauli spinors describing the initial protons. Taking a coordinate system where $(\hat{\boldsymbol{l}},\, \hat{\boldsymbol{n}},\, \hat{\boldsymbol{m}}) = (\hat{\boldsymbol{x}},\, \hat{\boldsymbol{y}},\, \hat{\boldsymbol{z}})$, the double–polarised differential cross section becomes

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_0 \times \tag{2.2}$$
$$\left[1 + P_yA_y^P + Q_yA_y^Q + P_yQ_yA_{yy} + P_xQ_xA_{xx} + P_zQ_zA_{zz} + P_xQ_zA_{xz} + P_zQ_xA_{zx}\right]\,,$$

where $\boldsymbol{P}$ and $\boldsymbol{Q}$ are the beam and target polarisations. The observables are then expressed in terms of the two amplitudes through

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_0 = \tfrac{1}{4}\left(|A|^2 + |B|^2\right)\,, \quad A_y^P = A_y^Q = -\frac{2\,Im(A^*B)}{|A|^2+|B|^2}$$

$$A_{xx} = -A_{zz} = \frac{|B|^2-|A|^2}{|A|^2+|B|^2}\,, \quad A_{yy} = 1, \quad A_{xz} = A_{zx} = -\frac{2\,Re(A^*B)}{|A|^2+|B|^2}\,\cdot \tag{2.3}$$

From this it is seen that, up to a two–fold ambiguity, the measurement of the differential cross section, the analysing power, and one spin correlation coefficient is sufficient to extract magnitudes of the two amplitudes and their relative phase. Such amplitude information can then be compared with theoretical models in a much more transparent way than through the direct use of observables.

Due to spin–parity constraints applied to the $pp \to \{pp\}_s\pi^0$ reaction, the orbital angular momentum of the pion must be even and that of the initial protons odd.

Therefore at low energies one can expect the dominant partial–wave contributions to the amplitudes of Eq. (2.1) to come from the transitions ${}^3P_0 \to {}^1S_0 s$, ${}^3P_2 \to {}^1S_0 d$, and ${}^3F_2 \to {}^1S_0 d$. It is interference between these s– and d–waves that gives rise to the forward dip seen in the $pp \to \{pp\}_s\pi^0$ cross section [13–16].

In Ref. [12] it was shown that the differential cross section and analysing power for the reaction $np \to \{pp\}_s\pi^-$ is sensitive to an interference of the s–wave pion–production amplitude, ${}^3P_0 \to {}^1S_0 s$, and the p–wave amplitudes, ${}^3S_1 \to {}^1S_0 p$ and ${}^3D_1 \to {}^1S_0 p$. The four–nucleon contact interaction, with strength parameter d, contributes to both. Thus, once a proper chiral perturbation theory calculation is available for the s–wave pion production, the reaction $np \to \{pp\}_s\pi^-$ close to the production threshold might well be the best reaction from which to extract the parameter d. The contributions from isovector initial states can be deduced from the $pp \to \{pp\}_s\pi^0$ measurements being discussed in this proposal. For the isoscalar initial state, the Δ–nucleon intermediate system does not contribute before pion emission. Secondly, the leading p–wave amplitude is the one of interest, in contrast to $pp \to pn\pi^+$, where p–wave pion production is completely dominated by the transition ${}^1D_2 \to {}^3S_1 p$ involving production through the Δ.

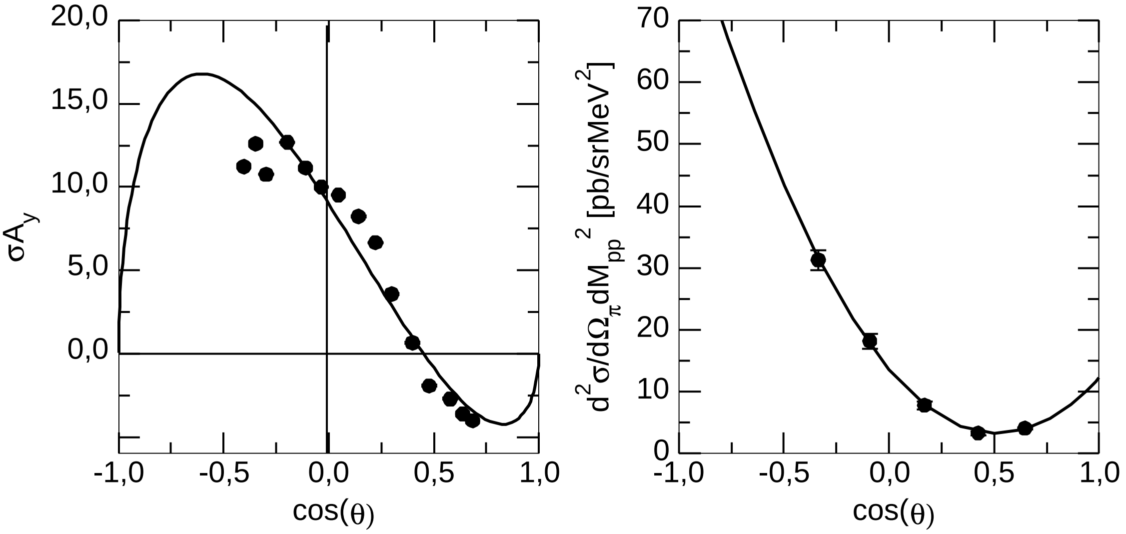


Figure 1: Analysing power and differential cross section of the $np \to pp\pi^-$ reaction at $T_n = 353$ MeV and $E_{pp} < 1.5$ MeV. The experimental data are from Ref. [17] and [18]. The curves are polynomial fits up to second order in the pion momenta.

One eventual goal of the ANKE pion–production measurements is therefore to provide the missing observables needed to determine the amplitudes for the transitions ${}^3S_1$–${}^3D_1 \to {}^1S_0 p$ [1]. The TRIUMF $np \to \{pp\}_s\pi^-$ data [17,18], shown in Fig. 1, are consistent with the assumption that at a neutron beam energy of $T_n = 353$ MeV only terms up to quadratic in the outgoing pion momentum need to be kept in the expressions for the observables, though it must be stressed that their angular range does not include the regions where the signals should be the strongest. The

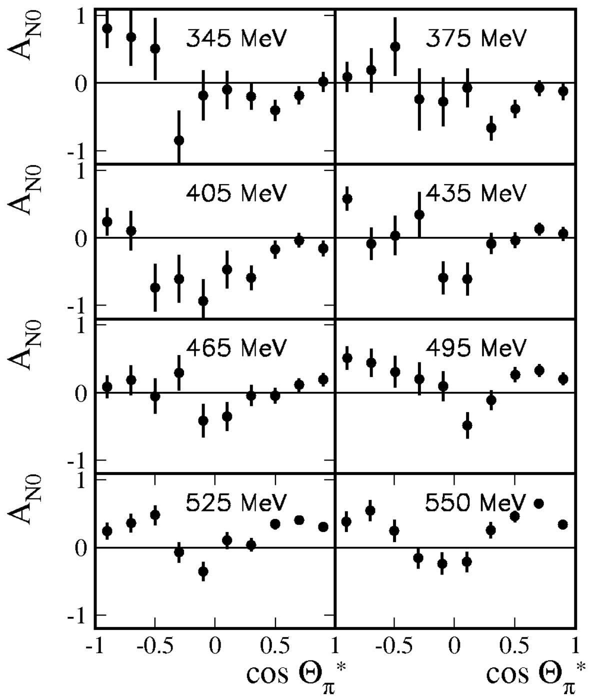


Figure 2: Analysing powers (A_{N0}) for quasi–free $np \rightarrow \{pp\}_s\pi^-$ reaction with the cut $E_{pp} < 6$ MeV. Picture is taken from Ref. [19].

TSL $pp \rightarrow \{pp\}_s\pi^0$ differential cross section [13] is also quadratic in $\cos\theta$. Hence the restriction to the consideration of five partial wave amplitudes in total seems justified.

There are analysing power data available from PSI [19] and these are shown in Fig. 2. However they were selected using the cut $E_{pp} < 6$ MeV, which risks contamination from the pp triplet p-waves. Even with this larger energy cut, the results in the backward pion hemisphere have large error bars at $T_n = 345$ MeV. Unpolarised cross section data for the $dp \rightarrow p_{\rm sp}pp\pi^-$ reaction in this energy region have also been produced by the COSY-TOF collaboration [20]. Although the *pp fsi* was observed, the statistics would not allow a sharp cut to be placed upon E_{pp}.

To establish the fit parameters for both the differential cross section and analysing power with good precision, it is necessary to have robust data closer to the forward and backward directions, as is evident from the two panels of Fig. 1. This is the purpose of the present proposal.

3 Experimental Facilities

3.1 The ANKE spectrometer

In this section it is discussed how the quasi–free $\vec{p}n \rightarrow \{pp\}_s\pi^-$ reaction can be studied using the ANKE spectrometer in connection with the spectator detection system. The whole apparatus is described in Ref. [21] and we now merely discuss details of its additional features.

The reactions that are relevant to the study are:

- $pd \to p_{sp}\{pp\}_s\pi^-$, $pd \to {}^3\mathrm{He}\,\pi^0$, $pd \to {}^3\mathrm{H}\,\pi^+$,
- quasi–free $pp \to d\pi^+$ and $pn \to d\pi^0$,
- quasi–elastic $pp \to pp$ and elastic $pd \to pd$ scattering.

The above reactions can, in principle, be measured using just the information obtained from the ANKE Forward Detector (FD) system [22,23]. However, in order to increase the acceptance in detection of 'di–proton' pairs, we plan to include also in the trigger the Positive side Detection system (PD) [21]. We will employ the ANKE Silicon Telescope System (STT) [24] to identify reactions on a 'neutron' target via the detection of low energy recoil protons (spectator protons). Additionally, detection of π^- in the Negative side Detector (ND) [21] provides an alternative scheme for the identification of the $pd \to p_{sp}\{pp\}_s\pi^-$ reaction.

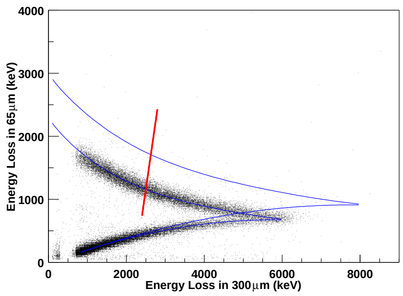
The FD system comprises a set of three multi-wire proportional drift chambers and a two–plane scintillation hodoscope, consisting of vertically oriented counters (8 in the first plane and 9 in the second). The hodoscope system is capable of measuring TOF differences and thus identify pairs of particles, such as the protons emerging from the $\boldsymbol{pp \to \{pp\}_s\pi^0}$ reaction [15,16]. The same method is applicable for the positive detection system.

3.2 Spectator proton detection

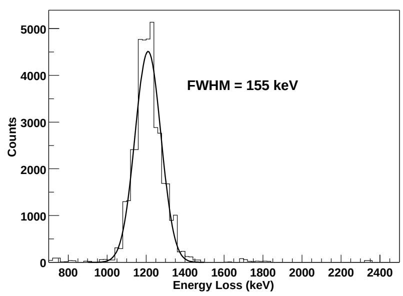
The extraction of quasi-free pion production from the $pd \to p_{sp}\{pp\}_s\pi^-$ reaction, requires not only the identification of the low energetic proton emitted from the deuterium target but also the reconstruction of its three-momentum. This can be achieved if the particle is detected in two position sensitive detectors with a good enough energy resolution. As the spectator proton momentum distribution has a maximum in vicinity of 50 MeV/c, the thickness of first detector, through which the protons have to penetrate, should be chosen as small as possible. Each of the Silicon Tracking Telescopes we plan to use in this experiment consists of three double–side segmented detectors.

- 1^{st} layer: 65 μm thick, $66.18\times51.13\,\mathrm{mm}^2$ active area, 316 vertical strips with 210 μm pitch one one side and 256 horizontal strips with 200 μm pitch on the other side.
- 2^{nd} layer: 300 μm thick, identical geometry compared with 1^{st} layer.
- 3^{rd} layer: 5000 μm thick, $64 \times 64\,\mathrm{mm}^2$ active area, 96 strips each side at a pitch of 666 μm.

When using the $\Delta E/E$-method for particle identification, the energy range of the setup is naturally divided into two subsets. The first is the one where particles



(a) $\Delta E 65\,\mu$m vs. $\Delta E 300\,\mu$m



(b) energy resolution

Figure 3: (Left panel) The energy loss in the 65 μm layer *versus* the energy loss in the 300 μm thick detector shows only the proton-band, because it is situated at backward angles. In addition to the experimental data, SRIM calculations for the energy losses of protons and deuterons are drawn. (Right panel) The projection on the indicated slice results in an energy resolution of about 160 KeV FWHM.

pass through the 65 μm thick detector and are stopped in 300 μm silicon. This corresponds to proton kinetic energies of $2.5 - 6$ MeV. Protons going through the 300 μm detector and being stopped in the 5 mm thick detector cover an energy range of $6.5 - 30$ MeV.

In view of the steady decrease in the Fermi–motion momentum distribution above about 50 MeV/c, the first and the second detectors deliver about 70% of total statistics. Figure 3(a) shows the energy loss in the first 65 μm thin layer versus the energy loss in the second 300 μm thick layer under experimental conditions where only protons could be detected. The results obtained coincide well with the calculated energy-loss proton band. Furthermore, the energy resolution along the slice indicated in figure 3(a) is about 160 KeV FWHM (fig. 3(b)). Thus the proton and deuteron bands are expected to be separated by about 10 σ. The capability of the two-dimensional spatial resolution allows the full tracking of particles back to the target.

More details about the spectator detection capabilities at ANKE can be found in the recently accepted proposal on ω-production in pd collisions (Exp.#175) [24].

4 Measurements at ANKE

To obtain the results aimed for one needs to use a detection system with a proper acceptance, which would allow one to identify the $pd \to p_{sp}\{pp\}_s\pi^-$ reaction and to reconstruct the kinematics of the process with sufficient precision. Additionally, for the extraction of the cross-section and the analysing power, it is necessary to have tools for absolute normalisation and for the determination of the proton beam polarisation. In this section we will show how one can fulfill these requirements in the proposed experiment.

As a first step of our polarised pion production programme, measurements with a polarised proton beam incident on the unpolarised proton cluster target were performed in October 2007. During the one week of beam time, measurements were carried out at five beam energies, including $T_p = 353$ MeV [5]. The data obtained will be used further to confirm our ability to identify the particles in the final proton pair and select events from the $pN \to \{pp\}_s\pi$ process. Unfortunately, the time of the measurement with a proton beam of reasonable (40%) polarisation and intensity was limited to a mere five hours. Nevertheless, as is shown below, these data allow us determine the proton beam polarisation with a 1% statistical precision.

4.1 ANKE acceptance

The acceptance of the Forward and Positive detector systems of ANKE is shown in Fig. 4 in terms of the particle momentum *versus* the projection (Θ_{xz}) of the emission angle onto the horizontal plane XZ of the spectrometer. The curves correspond to the parts of kinematical loci for the reactions denoted which fall within the FD and PD acceptance. The vertical acceptance is $\pm 3.5°$. The angular interval accepted in the forward detector has been optimised for the $pN \to \{pp\}_s\pi$ process by making use of the transverse positioning possibilities of the D2 magnet.

At $T_p = 353$ MeV, proton pairs from the $pn \to (pp)\pi^-$ reaction with small excitation energy ($E_{pp} < 3$ MeV) can be registered in the ANKE positive side (PD) and forward detection (FD) systems. These protons have momenta typically around 400 MeV/c and, for these, a 2% momentum and a 0.4° angular resolution were assumed in the simulation. It is seen from the predicted ANKE acceptance as a function of the π^- polar angle ($180^0 - \Theta_{pp}^{cm}$) shown in Fig. 5, that there are no blind spots in the angular distribution. The acceptance has been calculated in two configurations. The first of these includes the detection of the spectator proton with an energy in the range of $(2.5 - 6)$ MeV in two layers of STT. In the second case, the detection of the π^- in the Negative Detector is required. In both cases the final proton pair has to be registered in FD or PD so that the complete kinematics of the reaction can be reconstructed. One can see that these two configurations cover complementary angular ranges. It is important to note that in the case of π^- detection the acceptance is quite high in the forward hemisphere, where the cross section is expected to be low (see Fig. 1).

4.2 Proton beam polarisation and luminosity

The procedure for measuring the beam polarisation has been developed and successfully applied earlier at ANKE in experiments with proton [2] and deuteron beams [4]. The polarisation of the proton beam with spin oriented along the vertical y axis, can be found through the simultaneous detection of processes for which the analysing power A_y^p is known. For the energy of interest, $T_p = 353$ MeV, the most suitable reactions for the ANKE conditions are elastic pp scattering and the $pp \to d\pi^+$ reaction. Both processes are well identified by the momenta and by the ionization losses of the particles. Reliable values of the corresponding cross sections and analysing powers are available from the SAID data base [25].

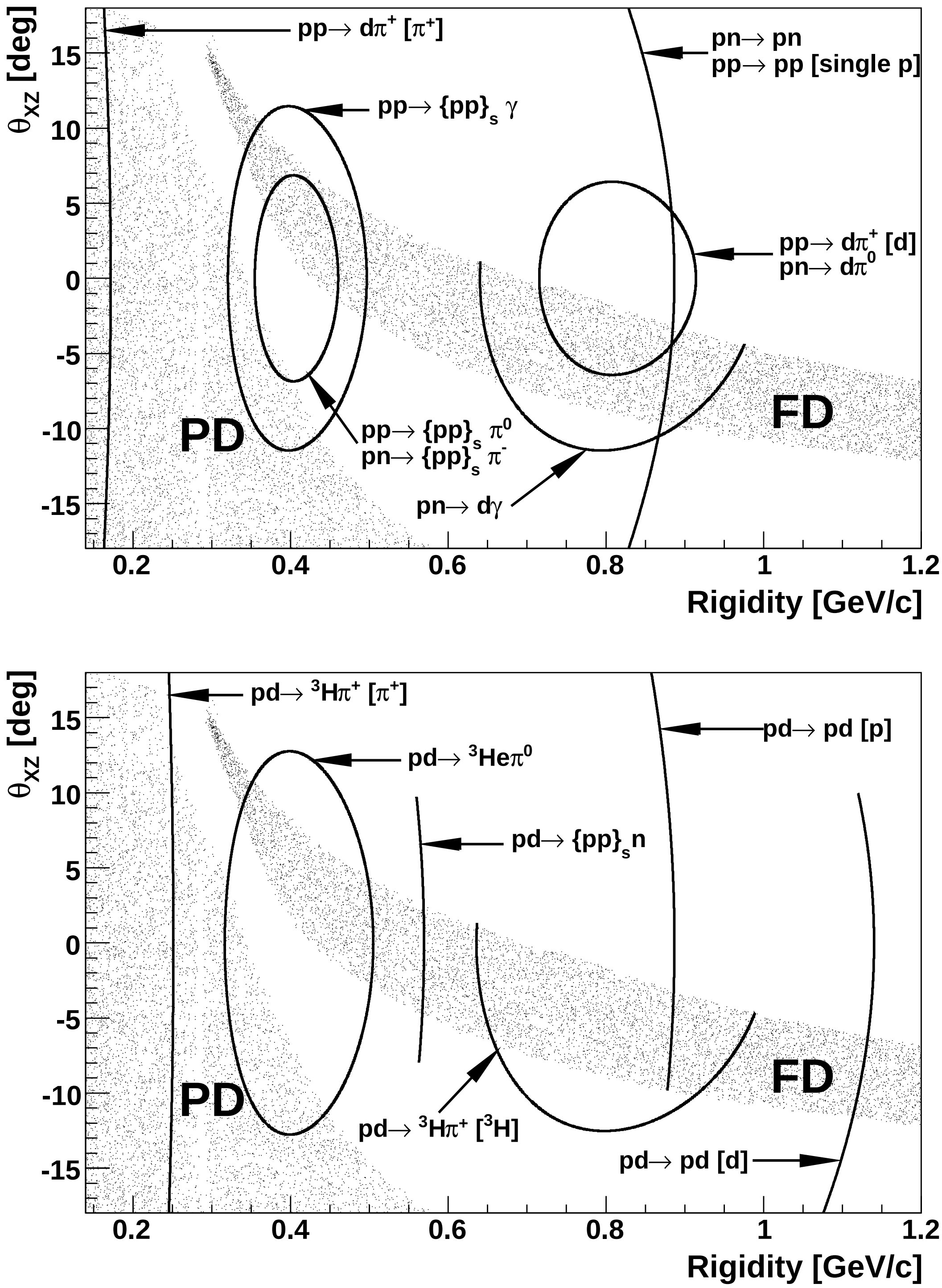


Figure 4: Simulated acceptance of ANKE Forward (FD) and Positive (PD) detection system in the horizontal angle *versus* momentum plane at a proton beam energy $T_p =$ 353 MeV. The curves show kinematical loci for several two–body and quasi–two–body reactions. In the evaluation of these curves, the $\{pp\}_s$ pair was taken to have zero excitation energy. The upper panel shows location of events from free and quasi-free pN interaction while the lower panel contains processes from pd interaction. The particles detected are noted in square brackets; in other cases, all charged particles in the final state are detected.

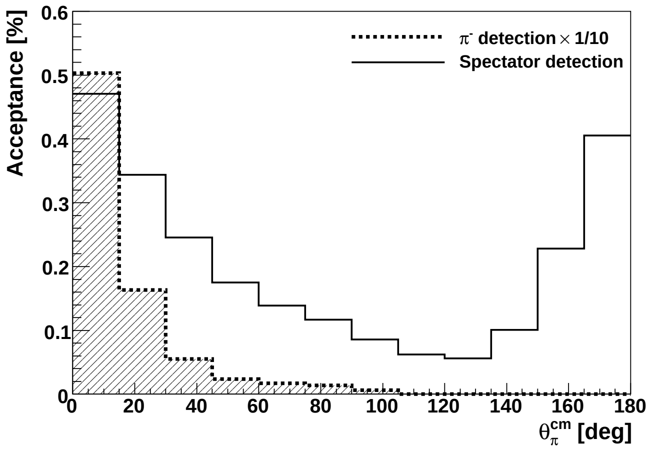


Figure 5: Simulated ANKE acceptance of the $pn \to \{pp\}_s\pi^-$ reaction as a function of the pion polar angle including the coincidence of proton pairs detected in both FD&PD (i) with spectator protons detected in STT (solid histogram), as well as (ii) in coincidence with Negative Detector (ND) (dashed histogram). Note that in the latter case the results have been scaled down by a factor of ten.

With the deuterium target one can use the corresponding quasi-free processes. Quasi-free pp-elastic scattering can be identified by detecting the recoil proton in the STT and, in the quasi-free $pp \to d\pi^+$ reaction, the π^+ can be detected in PD in addition to the deuteron being detected in the FD. The $pn \to d\pi^0$ channel can be separated by detection of the spectator proton in the STT.

Due to the absence of left–right symmetry in the ANKE spectrometer, the polarisation cannot be determined through a left–right count–rate asymmetry. Data have instead to be taken with both spin directions of the beam. This method has been used during the study of the $\vec{p}p \to \{pp\}_s\pi^0$ reaction with the 353 MeV polarised proton beam (Exp.#158, October 2007). The results of the beam polarisation measurements obtained after a short five hour run using pp elastic scattering and the $pp \to d\pi^+$ reaction, are shown in Fig. 6. The values of the COSY proton beam polarisation P_y extracted from both reactions are consistent and are about 40%.

The luminosity determination using the $pp \to pp$ and $pp \to d\pi^+$ reactions recorded in FD was applied for the October 2007 $\vec{p}p \to \{pp\}_s\pi^0$ data. The difference between the luminosities extracted from the two reactions did not exceed 4%. This method was also used in our previous works [15,16], where a more detailed description of the data processing can be found.

4.3 Identification of the $pd \to p_{sp}\{pp\}_s\pi^-$ process

In a case when two particles are detected in different counters of FD or PD, these particles can be identified by the difference of their time-of-flight from the target. At T_p = 353 MeV such identification is possible for about 90% of $pN \to \{pp\}_s\pi$ events with the proton pair excitation energy below 3 MeV.

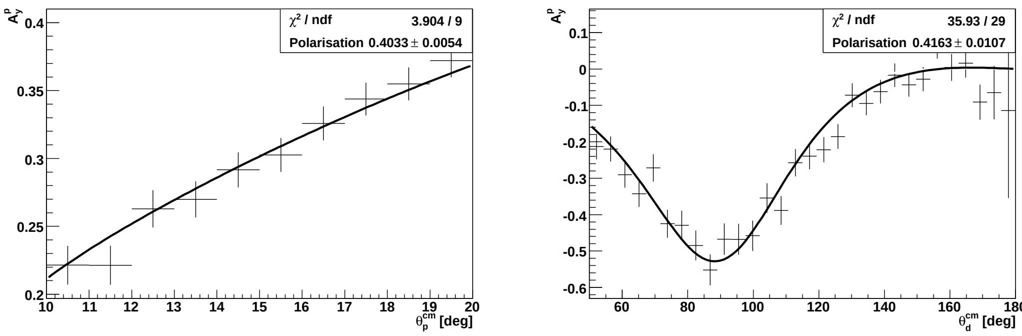


Figure 6: Analysing power of the $\vec{p}p \to pp$ (left panel) and $\vec{p}p \to d\pi^+$ (right panel) reactions measured at ANKE during the data–taking of the $\vec{p}p \to \{pp\}_s\pi^0$ experiment [5] at 353 MeV. The polarisation was obtained by scaling experimental asymmetries to fit the SAID predictions [25] shown by solid lines.

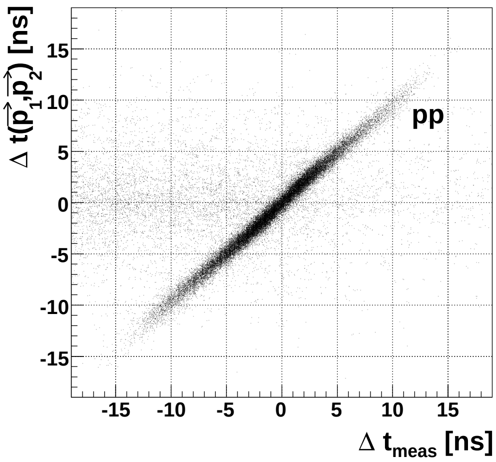
Figure 7 shows the arrival–time differences for the two particles in the hodoscope $\Delta t(\vec{p_1}, \vec{p_2})$ (calculated after momentum and trajectory reconstruction under the assumption that both particles were protons) *versus* the measured difference of the two time signals from the scintillators Δt_{meas}. To show an example of such identification with a D_2 target, the data obtained at the close beam energy of 500 MeV [2] are presented. The two protons from the $pd \to ppX$ reaction should lie along the diagonal, with the other pairs being found elsewhere. Such off–diagonal events are mirrored above the diagonal.

The $pd \to p_{sp}\{pp\}_s\pi^-$ events can be selected from among the events with an identified proton pair by the value of the missing mass of the undetected particle. In the case of spectator proton detection in the STT such a particle would be a π^- and in the case of π^- detection in the Negative Detector it would be the spectator proton. The error of the missing mass value is dominated by the uncertainty in the three-momenta of the fast forward going protons. Thus, the results for the $pp \to ppX$ process, obtained with the hydrogen target, can serve as a confirmation of our capability to select the process $pd \to p_{sp}\{pp\}_s\pi^-$.

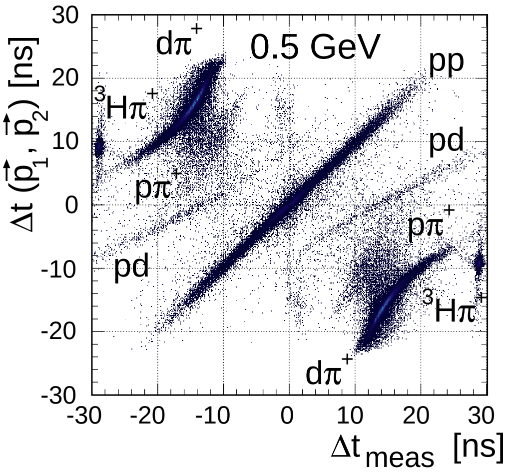
Figure 8 presents a missing–mass–squared distribution for the $pp \to ppX$ process measured at $T_p = 353$ MeV with the H_2 target, built for events with $E_{pp} < 3$ MeV. A very clean π^0 peak is observed at a position consistent with m_{π^0} to within the experimental uncertainties of about ± 10 MeV/c^2. There is an additional peak at $M_x^2 \approx 0$ which corresponds to the $pp \to \{pp\}_s\gamma$ reaction. The details of the analysis of these high energy bremsstrahlung data will be given in a publication which is currently in preparation.

4.4 Resolution

To select the $pd \to p_{sp}\{pp\}_s\pi^-$ events with the final proton pair in $^1S_0$ state one has to impose a strict cut on the proton pair excitation energy $E_{pp} < 3$ MeV. This requires correspondingly high resolution in E_{pp}. On the other hand, obtaining the



(a) H_2 target at $T_p = 353$ MeV



(b) D_2 target at $T_p = 500$ MeV

Figure 7: Time difference $\Delta t(\vec{p_1}, \vec{p_2})$ of the two detected charged particles, calculated assuming that they are both protons, *versus* the measured time difference Δt_{meas}. Proton pairs are located on the diagonal of the plots. The left panel shows data from a measurement with a hydrogen target [5], and the picture in the right panel was taken with a deuterium target [2].

cross section and the analysing power as functions of scattering angle implies a good resolution in this angle.

Figure 9 shows the expected angular resolution for the pion, as well as the resolution in the excitation energy of the two protons from the $pn \to \{pp\}_s \pi^-$ reaction with the cluster target. The results, $\sigma(E_{pp}) \approx 0.1 - 0.4$ MeV, coincide with the ones obtained in our previous works. This precision lets us select reliably the proton pairs with $E_{pp} < 3$ MeV (or less if desired).

4.5 Precision and count rate estimation

A complete simulation of the detection scheme of the $pd \to p_{sp}\{pp\}_s\pi^-$ process at ANKE has been performed. A realistic setup description based on the GEANT program package was used, with all the experimental smearing factors taken into account. The spectator proton momentum was randomised according to the Fermi-motion distribution and the off-shell kinematics effect taken into account with the help of the Pluto reaction generator. The fast proton pair was required to hit the FD or PD and either the spectator proton with a kinetic energy in the $2.5 - 6$ MeV range must have been detected in two layers of STT, or a π^- had to be in the acceptance of the ND.

The polynomial fits of the cross section and A_y presented in Fig. 1 were used for count–rate estimation. A luminosity of $L = 1.0 \times 10^{30}\,\text{s}^{-1}\text{cm}^{-2}$ and a COSY beam polarisation of $P = 60\%$ were assumed. In Fig. 10 the relative error in the

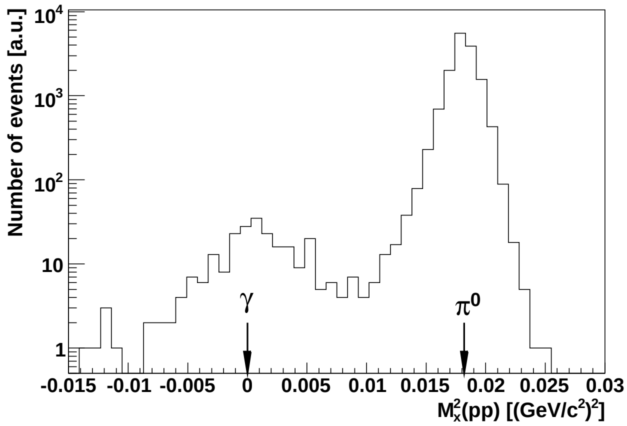


Figure 8: Missing–mass–squared distributions of the $pp \to ppX$ reaction at T_p=353 MeV for events with $E_{pp} < 3$ MeV showing evidence for π^0 and single photon production. Note that these are preliminary results!

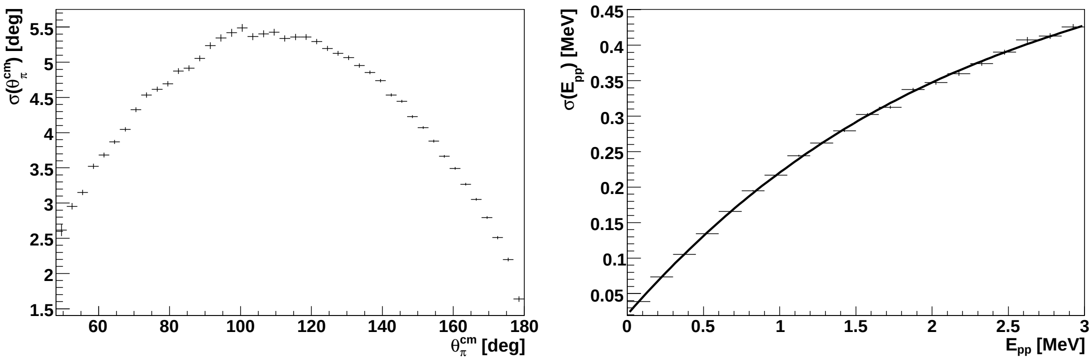


Figure 9: Simulation results for the resolution in the pion polar angle (left panel) and in excitation energy E_{pp} (right panel) for the $pn \to \{pp\}_s\,\pi^-$ reaction with a cluster target and a beam energy of $T_p = 353$ MeV.

differential cross section and the accuracy of the analysing power are presented for the statistics to be collected in two weeks of measurement. The systematic errors are expected to be smaller than the statistical ones presented. In total, after two weeks of data taking $\sim$ 6000 events are expected to be recorded with a spectator proton detected and $\sim$ 4500 events with a π^- detected with $E_{pp} < 3$ MeV.

5 By–products of the investigation

Even at the low energy requested here, data on other reactions will be taken simultaneously. Since these are not to be taken as primary motivations for the current proposal, they are only noted here to show that we will not forget about them in the analysis!

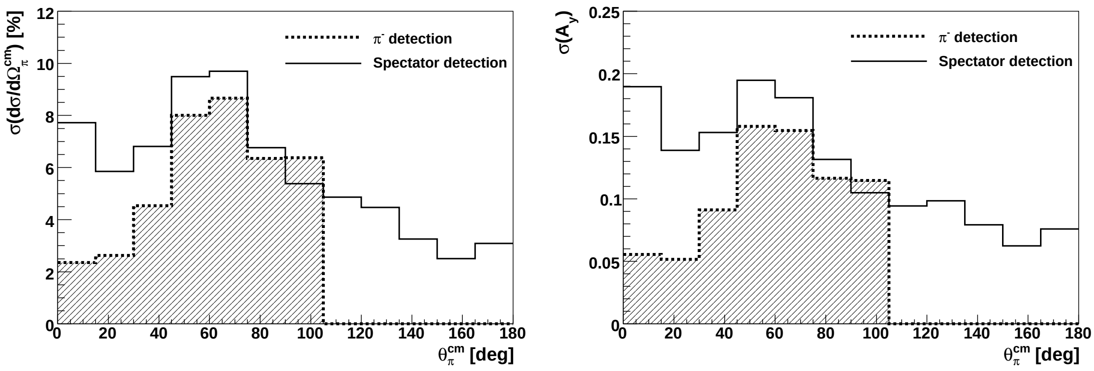


Figure 10: Estimation of the statistical uncertainties of the differential cross section (left panel) and analysing power (right panel) of the $pd \to p_{sp}\{pp\}_s\pi^-$ process after two weeks of measurement. The empty histogram (solid line) corresponds to the detection of a spectator proton in the STT while the filled one (dashed line) stands for the case of π^- detection.

The following are some of the reactions that fall within our acceptance: $\vec{p}d \to {}^3\mathrm{He}\,\pi^0$, $\vec{p}d \to {}^3\mathrm{He}\pi^+$, $\vec{p}d \to \{pp\}_s n$, $\vec{p}d \to {}^3\mathrm{He}\,\gamma$, and $\vec{p}n \to d\gamma$.

The $\vec{p}d \to \{pp\}_s n$ charge-exchange reaction will be studied at both large and small momentum transfers, the former by detecting the two fast protons in the ANKE magnetic spectrometer and the latter by registering both slow protons in one or both of the STT modules. The latter should have a very high counting rate and not be subject to the restrictive angular acceptance imposed by the FD and PD.

The most intriguing of the above reactions seems, though, to be $\vec{p}n \to d\gamma$, where the cross section is about two orders of magnitude higher than that for $pp \to \{pp\}_s\gamma$, which we have successfully measured at ANKE. One might even hope eventually to measure also the spin correlation in $\vec{p}\vec{n} \to d\gamma$.

6 Beam time request

6.1 Expected luminosity

In order to estimate the beam time required for the proposed measurements, we assume a luminosity of $L = 1.0 \times 10^{30}\,\mathrm{s}^{-1}\mathrm{cm}^{-2}$ (with $\approx 5 \times 10^9$ stored polarised protons, $f_{\mathrm{rev}} = 1.1\,\mathrm{MHz}$, and a target density of $d_t = 2 \times 10^{14}\,\mathrm{cm}^{-2}$). The COSY beam polarisation is assumed to be $P = 60\%$. In order to obtain the differential cross section $\mathrm{d}\sigma/\mathrm{d}\Omega$ over the full range of pion angle (and especially in the forward/backward directions) with an accuracy of 10% and the angular dependence of the analysing power A_y with an accuracy of about 5%, TWO weeks of beam–time is required.

6.2 Request

- The **proposal requires TWO weeks of beam time** for data taking in order to determine the $\mathrm{d}\sigma/\mathrm{d}\Omega$ and vector analysing power A_y for the quasi–free $\boldsymbol{\vec{p}n \to \{pp\}_s\pi^-}$ reaction at energy of $T_p = 353$ MeV. With the **PRESENT request** the collaboration asks for approval and allocation of the beam time in ONE block with the requested beam time (Exp.#158.2) with the cluster jet–target. Both experiments needs to be done with a polarised proton beam and the same beam energy.

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