Proposal and Beam request

For Lab. use

Exp. No.:	Session No.
#	#37

Title of Experiment

Absolute measurement of *pp* elastic scattering at ANKE-COSY using the Schottky technique

Collaborators: ANKE Collaboration

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Total number of particles and type of beam (p,d,polarization)	**Energy range (GeV)**	**Intensity or internal reaction rate (particles per second)**	
unpolarized protons	1.0, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8	minimum needed $\geq 10^{30}$	maximum useful
Type of target	**Safety aspects (if any)**	**Earliest date of installation**	**Total beam time (weeks)**
Hydrogen Cluster Target		January, 2010	2 weeks

Summary of experiment:

The ANKE collaboration and the COSY machine crew have jointly developed an independent and very accurate method for determining absolutely the luminosity in an experiment at an internal target position of COSY. The technique relies on measuring the energy losses due to the electromagnetic interactions of the beam as it repeatedly passes through the target by studying the Schottky spectrum. The aim of the present proposal is to use this powerful tool in the measurement of proton-proton elastic scattering in the energy range from 1.6 to 2.8 GeV.

Very little is known experimentally on either the *pp* → *pp* differential cross section or the proton analysing power in this energy range for centre-of-mass angles $10^o<\theta_{cm}<30^o$. What cross section data that do exist seem to fall systematically below the predictions of the SAID data analysis program! Under these kinematic conditions the fast proton emerging at small angles from the unpolarised hydrogen cluster target can be measured well in the ANKE magnetic spectrometer. The slow recoil proton emerging at large angles can be measured independently in one of the Silicon Tracking Telescopes. Both these devices have very high acceptance for this range of angles and energy and, taken together, valuable cross checks of the systematics can be achieved.

It is important to note that, in order to measure well the luminosity using the Schottky technique, one must have a target that is not too thick. This is not ideal for the determination of the proton analysing power where, in view of the much weaker polarised ion source, thicker targets are desirable in order to get reasonable counting rates. We would therefore first measure the cross sections at the different energies with a target that is optimised for the Schottky approach. At a later date we would change the conditions to measure the proton analysing power.

The proposal requires in TOTAL **two weeks** of beam time to determine the energy and angular dependence of the unpolarised differential cross section $d\sigma/d\Omega$, and the analysing power A_y of proton-proton elastic scattering in the angular range $10^o<\theta_{cm}<30^o$ at seven equally spaced energies in the range $1.6 < T_p < 2.8$ GeV. The overall uncertainty is estimated to be less than 6%. In addition we would carry out a cross section measurement at one lower energy (1.0 GeV), where there are good data in order to demonstrate the validity of our approach. However, since the experimental conditions for the cross section and analysing power measurements are different, we are now requesting only **one week** for the cross section determinations.

These experiments could be extended at some time in the future, through the use of a polarised gas cell target, so as to measure the spin-correlation parameters C_{xx} and C_{yy}. These conditions are not ideal for either the $d\sigma/d\Omega$ or Ay experiment and so it would not be sensible to try to combine these three precision studies.

COSY Proposal and Beam Request

Absolute measurement of *pp* elastic scattering at ANKE–COSY using the Schottky technique

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Jülich, July 24, 2009

Abstract

The ANKE collaboration and the COSY machine crew have jointly developed an independent and very accurate method for determining absolutely the luminosity in an experiment at an internal target position of COSY. The technique relies on measuring the energy losses due to the electromagnetic interactions of the beam as it repeatedly passes through the target by studying the Schottky spectrum. The aim of the present proposal is to use this powerful tool in the measurement of proton-proton elastic scattering in the energy range from 1.6 to 2.8 GeV.

Very little is known experimentally on either the $pp \to pp$ differential cross section or the proton analysing power in this energy range for centre-of-mass angles $10^\circ < \theta_{cm} < 30^\circ$. What cross section data that do exist seem to fall systematically below the predictions of the SAID data analysis program! Under these kinematic conditions the fast proton emerging at small angles from the unpolarised hydrogen cluster target can be measured well in the ANKE magnetic spectrometer. The slow recoil proton emerging at large angles can be measured independently in one of the Silicon Tracking Telescopes. Both these devices have very high acceptance for this range of angles and energy and, taken together, valuable cross checks of the systematics can be achieved.

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The proposal requires in TOTAL **two weeks** of beam time to determine the energy and angular dependence of the unpolarised differential cross section $d\sigma/d\Omega$, and the analysing power A_y of proton-proton elastic scattering in the angular range $10^\circ < \theta_{cm} < 30^\circ$ at seven equally spaced energies in the range $1.6 < T_p < 2.8$ GeV. The overall uncertainty is estimated to be less than 6%. In addition we would carry out a cross section measurement at one lower energy (1.0 GeV) where there are good data in order to demonstrate the validity of our approach. However, since the experimental conditions for the cross section and analysing power measurements are different, we are now requesting only **one week** for the cross section determinations.

These experiments could be extended at some time in the future, through the use of a polarised gas cell target, so as to measure the spin-correlation parameters C_{xx} and C_{yy}. These conditions are not ideal for either the $d\sigma/d\Omega$ or A_y experiment and so it would not be sensible to try to combine these three precision studies.

Contents

1 Introduction

The ANKE collaboration submitted to the PAC in 2005 and 2008 comprehensive documents outlining future plans for experiments involving polarised beams and targets to be performed at the facility [1, 2]. This general programme was approved with high priority for the coming years at COSY since the measurements will greatly expand the nucleon-nucleon database. Apart from their intrinsic importance for the study of nuclear forces, nucleon-nucleon data are also necessary ingredients in the description of meson production and other nuclear reactions at intermediate energies. It is incumbent on any facility that can make a significant and new contribution to this important database of knowledge to do so. This was the underlying philosophy of the very successful COSY-EDDA collaboration.

There are at least two unique ways by which ANKE can push this project forwards:

- **Neutron–proton scattering**.

  One important element of the NN programme that has already started involves the measurement of proton-neutron elastic scattering observables. In the ANKE experiments the deuteron beam or target provides the source of quasi-free neutrons and the residual proton is detected as a spectator particle. Within the framework of COSY proposals #125, #152, #172, we have shown that we can successfully investigate at ANKE reactions with a polarised deuteron beam and polarised hydrogen target. The production run of four weeks with the polarised beam and target will be conducted in Autumn 2009. However, the use of a deuteron beam at COSY limits the energy range to below 1.15 GeV per nucleon.

  In order to extend the study of neutron-proton scattering at ANKE by providing precise data in up to 2.8 GeV, it is necessary to use a polarised proton beam incident on a polarised deuterium target. It is therefore planned to present at the next COSY PAC session (#38, 2010) a new proposal for the study of small momentum transfer deuteron charge–exchange breakup reaction $\vec{p}\vec{d} \to \{pp\}_s n$, using the Silicon Tracking Telescope (STT) system (four modules).

  In order to use the np data to deduce information on the isospin $I = 0$ observables, it is necessary to have equally robust data on the $I = 1$ (*i.e.*, pp) in the same angular range. However, there are some questions to be answered here.

- **Proton–proton scattering**.

  One of the biggest challenges facing physicists performing experiments at internal target stations of storage rings such as COSY is the evaluation of the cross section normalisation, *i.e.*, the beam-target luminosity. As a consequence, cross sections are often measured only relative to one that has been determined in a more absolute way. Proton-proton elastic scattering has commonly been used as such a calibration standard but there are serious concerns about the quantity and reliability of these data and their parameterisation over the domain of small angles that falls within the ANKE acceptance. This has a knock-on effect on the evaluation of cross sections that have used this calibration standard.

  The ANKE collaboration and the COSY machine crew have jointly developed an independent and very accurate method for determining absolutely the luminosity in an experiment at an internal target position of COSY. The technique relies on measuring the energy losses due to the electromagnetic interactions of the beam as it repeatedly passes through the target by studying the Schottky spectrum [3].

  Very little is known experimentally on either the $pp \to pp$ differential cross section or the proton analysing power in this energy range for centre-of-mass angles

$10^\circ < \theta_{cm} < 30^\circ$ and, what cross section data that do exist, seem to fall systematically below the predictions of the SAID data analysis program [5]. A fast proton elastically scattered at small angles from the unpolarised hydrogen cluster target can be measured well in the ANKE magnetic spectrometer. The slow recoil proton emerging at large angles can be measured independently in one of the Silicon Tracking Telescopes. Both these devices have very high acceptance for much of this range of angles and energy and, taken together, valuable cross checks of the systematics can be achieved.

The luminosity L inside COSY can be measured by studying the energy losses of the circulating beam. These change the revolution frequency of the machine, though this effect is too small to be measured accurately at COSY for protons that have energies between about 1.0 and 1.6 GeV [3]. Outside this region, and up to the maximum COSY energy of 2.8 GeV, the measurement of the frequency shift can determine L with high precision. We believe that, for well chosen conditions of target thickness *etc.*, we are now in a position to evaluate the luminosity to about 3%. In view of its fundamental importance, we want to use this feature to measure absolutely proton-proton elastic scattering at ANKE.

The aim of this proposal is therefore to measure the *pp* elastic differential cross section and proton analysing power in the c.m. angular range from 10° to 30° between 1.6 to 2.8 GeV in 200 MeV steps, with an overall uncertainty of 6%. The reaction will be studied with two separate but linked detection systems. The fast forward proton will be registered in the ANKE forward detector (FD) and the recoil proton in the silicon tracking telescopes (STT). Both of these have upper limits of about 20°-30° cm (the first for geometrical reasons and the second from the need to stop the proton in the thickest silicon layer). Although in our original publication we quoted a 10% accuracy [3], the simpler acceptance/efficiency of the STT and the cross checks available between the FD and STT systems will lead to a precision closer to that of the luminosity ($\approx 3\%$). Since most of the systematic effects cancel when measuring the proton analysing power, the biggest uncertainty there will arise from that in the beam polarisation, which will be determined using the polarisation export technique [6].

The experimental programme would be divided into two parts:

1. In the first stage, we would use an unpolarised proton beam incident on an unpolarised hydrogen cluster target of a thickness that is optimised for the measurement of the luminosity using the Schottky technique. This would lead to reliable absolute values of the differential cross section.

2. At a later date we would request a second week where we would use a polarised proton beam but with a thicker target to minimise the statistical errors. The polarisation of the beam at different energies will be determined with the export technique [6].

The development of the software and analysis modules for this type of experiment is also an important step for the spin-filtering study at COSY (and later at the AD ring) that will use the same type set-up.

We believe that eventually these experiments could be profitably extended by using a polarised proton beam and hydrogen target in order to extract data on the spin-correlation parameters in *pp* elastic scattering. These are particularly important in any amplitude analysis — but any proposal for this must be for another day!

1.1 Motivation of the new measurements for pp elastic reaction

The complete investigation of the NN interaction needs precise elastic scattering data as input to a phase–shift analysis (PSA), from which the scattering amplitudes at fixed angles can then be reconstructed. A full data set involves experiments with both beam and target particles polarised in the initial state, as well as the determination of the polarisation of one of the final state nucleons [4]. Experiments of this type have been carried out for the pp system up to about 3.0 GeV [5]. The well-known EDDA experiment at COSY has produced a very extensive and important data set of $pp \to pp$ differential cross sections and the various single and multi–spin observables [7] which has allowed the construction of reliable isospin $I = 1$ phase shifts up to at least 2 GeV [5]. The evidence for the dominance of the EDDA data over the SAID data base, is seen from Fig. 1, where the kinematic conditions under which the differential cross section and analysing power have been measured are shown as abundancy plots.

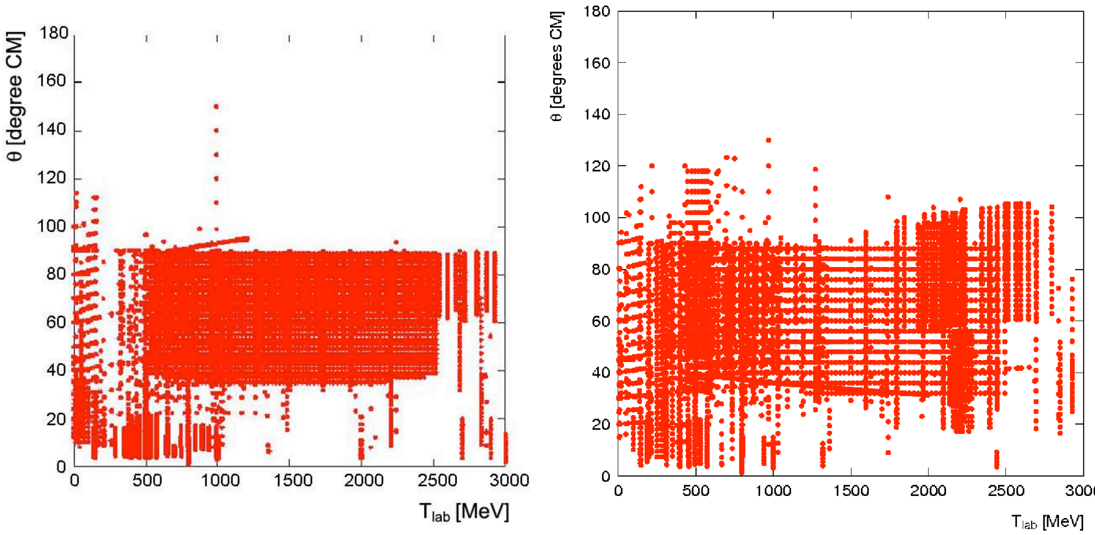

Figure 1: Abundancy plots of the pp differential cross section $d\sigma/d\Omega$ (left) and analysing power A_y (right) extracted from the SAID [5] and NN-online [8] databases. The points show the positions in energy and centre-of-mass angle of existing measurements. It is important to note that in the energy range of $0.5 < T_p < 2.5$ GeV the plot is largely dominated by the very precise COSY–EDDA data [7] but that these only cover the range in scattering angle $\approx 35^\circ < \theta_{cm} < 90^\circ$.

However, while preparing our publication on the Schottky method [3], it became clear to us that there were severe problems with the small angle predictions from the SAID analysis program above 2.5 GeV. These do not describe well either the ANKE or other published data without introducing an overall scaling factor, but this merely shifts the problem to the larger angle data. Basically, the shapes of the SAID predictions do not seem accurately to reflect reality. As seen from the results shown in the left panel of Fig. 2, our data fall about 25% below the SAID predictions at 2.65 GeV and a similar disagreement is found with the results of Ref. [9] at the slightly higher energy of 2.83 GeV. The variation of the discrepancy with energy is illustrated in the right panel of Fig. 2, which shows the ratio of experiment to the SAID prediction averaged, where possible, over the angular range $10^\circ < \theta_{cm} < 30^\circ$. This proves that further precise measurements are required at the upper end of the COSY range. This is confirmed by the disclaimer in the recent SAID update, which states that *'our solution should be considered at best qualitative between 2.5 and 3 GeV'* [5].

On the other hand, in the 1 GeV region the SAID analysis reproduces reasonably well all the available reliable differential cross section data. Since the Schottky methodology should work well in this region, to demonstrate the validity of our procedures we should

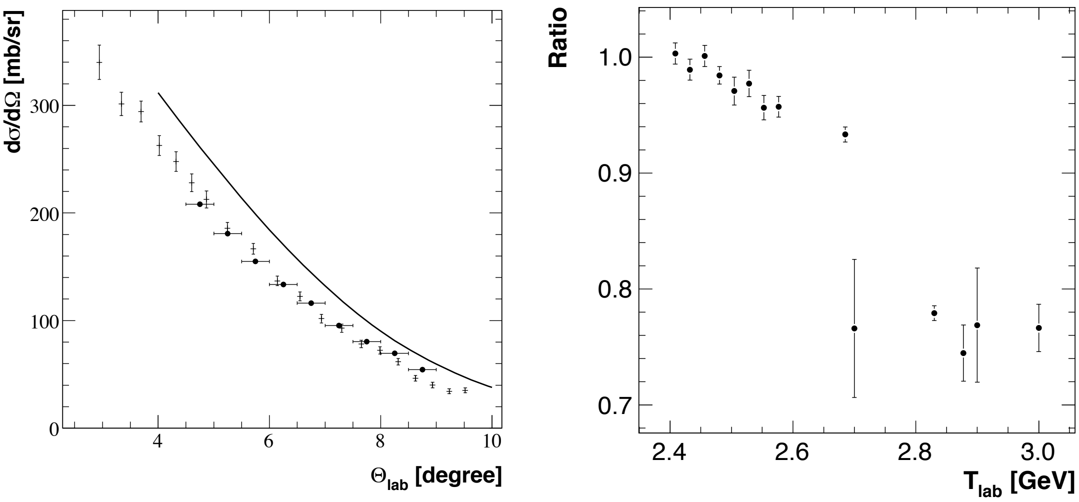

Figure 2: Left: Laboratory differential cross section for elastic proton-proton scattering at 2.65 GeV. The ANKE points, shown by closed circles with bin widths, have systematic uncertainties of ±12% [3]. The curve is the SP07 solution from the SAID analysis group [5] and the crosses are experimental data at 2.83 GeV taken from Ref. [9]. Right: Ratio of experimental data on the *pp* elastic differential cross section to the SAID predictions, both sets of information being taken from the SAID database [5]. Only data in the angular range $10° < \theta_{cm} < 30°$ are considered and, where possible, an average over this range is reported.

first measure the cross section around 1 GeV before taking data at the higher energies.

Turning now to the analysing power, the SAID program describes the data around 1.0 GeV but has far more problems around 2.5 GeV, as shown by the comparison with experimental data in Fig. 3.

1.2 Potential impact on the amplitude analysis

Within the framework of the SAID partial wave analysis [5] it is possible to introduce extra simulated data and find the possible changes in one of its single-energy solutions (SES) caused by the new data. Such a procedure has very kindly been carried out for us by R. Arndt and I. Strakovsky [10]. Pseudo-data were generated at 2.1 GeV in 2° intervals from 10° to 30° with 6% errors. For this purpose the supposed ANKE points were taken to lie along the curve of the existing SES, but randomly displaced by the 6% uncertainties. It is found from such exercises that the SAID phase shifts hardly move at all! The origin of this non-effect is the claim that the current SAID phase shifts already fix the values of the differential cross sections at these angles with a precision of 2%, despite there being essentially no real data in this angular domain. It is stated that this feature comes about because of the analyticity of the scattering amplitudes [10]. One therefore has to ask what the model dependence of the analysis procedure is rather than asking for the statistical precision.

Professor Rentmeester of Nijmegen NN-online advised as follows: *'For a single-energy analysis, only the lower partial wave phase shifts are free parameters. For the higher waves, fixed values are chosen from one-pion exchange, assuming that OPE is 'known' (strength as well as the mechanism) and that in the wave where OPE-only starts, the non-OPE contribution cannot be determined with statistical significance. The latter could be tested*

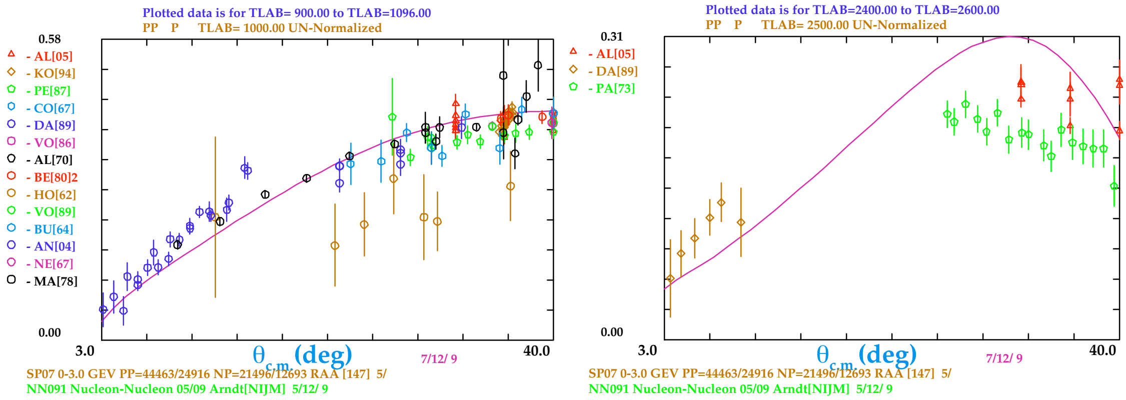

Figure 3: Experimental data on the proton analysing power in pp elastic scattering for $\theta_{cm} < 40^\circ$ taken from the SAID database [5] are compared to the current SAID predictions in the vicinity of 1.0 GeV (left panel) and 2.5 GeV (right panel).

if data at small angles, where currently no data exist, enable the determination of a new phase shift in an analysis. The 2% predicted uncertainty mentioned is very dependent on the parametrisation (constraints imposed by physics as well model input) and the set of data that are used to determine the free parameters. If pseudo-data are generated with the predicted angular shape as the source, such input would only provide a confirmation of the prediction and, depending on the uncertainties of the pseudo-data, the values for the phase shifts would stay the same; only their uncertainties might change'. [11].

To investigate this latter point in a very naive way, we have fitted polynomials in $\cos^2\theta$ to all available data at 2.1 GeV, including a SAID point at 5° to simulate the information that one might expect from the optical theorem. In our angular domain, where there are no data, the curves generated in this way do depend, of course, on the order of the polynomial, with variations of at least 10% while keeping reasonable values of χ^2/ndf. For a given order of the polynomial. the addition of simulated ANKE points changes the situation only marginally. However, if these pseudo-data are all shifted down systematically by 10%, the situation changes more drastically and, independent of the polynomial degree, the fit also reduces by about 10% in our domain, as one would naively expect when new data are introduced in a region where there are none.

However, the standard SAID procedure of minimisation generally introduces a free scaling parameter per experimental data set whose value is then fitted, effectively ignoring the 10% shift. If the normalisation error is put to zero then Arndt finds $\chi^2/\text{ndf} = 1597/896$ with the current data base compared to 1417/896 if a 6% normalisation error is assumed [10].

In summary, we can only say what impact the data will have once we have the results. If they fall on the SAID predictions, they will merely provide reassurance. If they are say 10% lower then, as Rentmeester opines, this will possibly show that one of the higher phase shifts can be determined and should be fitted rather than being fixed by a model.

1.3 Expected accuracy in luminosity

The repeated passage of a coasting ion beam of a storage ring through a thin target induces a shift in the revolution frequency due to the energy loss in the target. Since the frequency shift is proportional to the beam-target overlap, its measurement offers the possibility of determining the target thickness and hence the corresponding luminosity in an experiment.

This effect has been investigated with an internal proton beam of energy 2.65 GeV at COSY using the ANKE spectrometer and a hydrogen cluster-jet target [3]. The systematic sources of error, especially those caused by the residual gas in the ring and hydrogen gas in the region around the target, were carefully studied, resulting in an accuracy of 5% for the target thickness. The luminosity $L = n_T n_B$, given by the target thickness times the accurately measured proton particle current, was used in conjunction with parallel measurements in the ANKE forward detector, to determine the cross sections for elastic proton-proton scattering. The result is compared to published data as well as to the predictions of a phase shift solution in Fig. 2a.

Extended investigations of the parasitic contribution of the residual gas as well as of the nonlinear machine behaviour, especially at the higher beam energies, will result in an uncertainty in the luminosity of not more then 3%.

2 Experimental Facilities

2.1 The ANKE detection system

We consider here the possibility of studying *pp* elastic scattering on the windowless internal cluster target using the ANKE spectrometer. This apparatus is described in Ref. [12] and we shall merely discuss here the details of its additional features. The reaction can be identified by the detection of the one of the scattered protons in either the ANKE Forward Detector (FD) or in the Silicon Tracking Telescope (STT), as well as by the detection of both protons simultaneously. The last option allows a valuable cross-check between these two detection systems and significantly improves the accuracy and reliability of measurements [14].

The FD comprises a set of three multi-wire proportional chambers (MWPCs) and a three–plane scintillation hodoscope, consisting of vertically oriented counters (8 in the first plane, 9 in the second, and 6 in the third). The use of the FD alone has the following limitations:

- The FD acceptance covers the angular range $4^\circ - 10^\circ$ in the laboratory system, which corresponds $10^\circ - 30^\circ$ in c.m.
- The angular resolution is about $0.2^\circ - 0.3^\circ$ (in the laboratory).
- The background depends strongly on the beam transport.

These drawbacks can be alleviated through the use of the Silicon Tracking Telescopes.

2.2 Silicon Tracking Telescope

For the identification and tracking of slow protons and deuterons emerging from a hydrogen or deuterium target, Silicon Tracking Telescopes (STT) have been developed that can be placed inside the vacuum chamber [15]. By putting them as close to the target as 3 cm, they can provide an angular acceptance of up to 1 sr. The basic concept of the STT combines particle identification with tracking over a wide range in energy. The tracking is accomplished by three layers of double–sided micro–structured silicon strip detectors. A picture of the STT is shown in Fig. 4.

Measuring the energy loss in the individual layers allows the identification of stopped particles by the $\Delta E/E$ method. A particle is registered when it passes through the inner layer and is stopped in one of the others. With the 70 μm thickness of the innermost detector, the STT allows the identification and the full energy reconstruction for protons

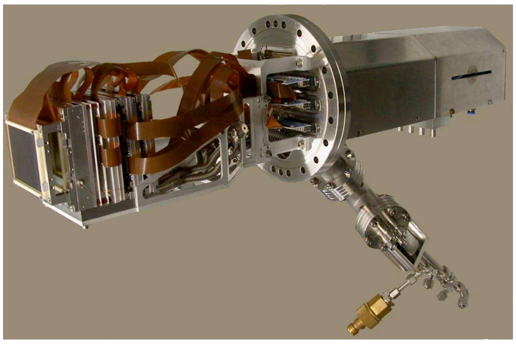

Figure 4: Picture of the Silicon Tracking Telescope (STT), consisting of three detector layers of different thickness.

kinetic energies between 2.5 and 35 MeV. Despite the tracking angular resolution for such protons being limited to between the 6-1° (FWHM), respectivelty, because of the small-angle scattering in the first detector, in the case of *pp* elastic scattering, the scattering angle can be determined with much better ($\approx 0.02°$) resolution due to the high ($150 - 300$ keV FWHM) accuracy of the energy reconstruction.

The STT has self–triggering capabilities. It identifies a particle's passage within 100 ns and provides the possibility for fast timing coincidences with other detector components of the ANKE spectrometer. In this way accidental coincidences can be suppressed significantly. The high rate capabilities of the STT will be especially important for the study of elastic scattering. Moreover, the self-triggering option allows us to extend the angular acceptance for small angular range down to $\theta_{cm} \approx 5°$, where the FD has no coverage.

2.3 The Schottky technique and its application in the experiment

The use of the Schottky technique for the luminosity determination puts some requirements on the parameters of the accelerator to guarantee the intended accuracy. To be able to measure the frequency shift sufficiently well, the luminosity should not be very high, so that the beam intensity should be $1 - 2 \times 10^{10}$ protons with a target thickness of $4 - 6 \times 10^{14}$ atoms/cm^2. To minimise the frequency shift arising from the residual gas in the ring, the vacuum away from the target section should be better than 10^{-9} mbar and any air leakages must be avoided. During the early use of the Schottky method [3], we have learned that in the long cycles the frequency shift is no longer linear, which complicates the determination of the target thickness and thus reduces the accuracy. Cycles with 300 s length will be most appropriate for the current study. For energies between 1.6 and 2.8 GeV the maximum ANKE field of 1.52 T will be used to get a high resolution for the momentum reconstruction and largest angular range for the FD system. Due to technical reasons, the study at the minimum energy of 1 GeV requares a lower ANKE magnetic field of 1.3 T.

2.4 Sequence of measurements

During the day, all the preparations for the specific energy will be made and the measurements taken of the necessary machine parameters, mostly without target. The frequency shift measurements will be done with the existing Schottky pick up and the analyzer (sweeping type) of the stochastic cooling system. The harmonic $h = 1000$ will be used. Care has to be taken that the frequency resolution is appropriate for the different energies and that all the additional analyzer parameters are recorded. For quick and short checks of the frequency shifts we use the HP real time analyzer (fast FFT type). Unfortunately, a direct data transfer to the ANKE data acquisition system is not yet possible. We should mention here that a new device of the same type but with modern data transfer capabilities would be extremely helpful for future experiments; it would also improve the accuracy of the results.

Besides the systematic corrections, the main source of inaccuracy is related to the determination of the centroid of the Schottky profiles. The expected frequency shift is comparable to the $\Delta p/p$ width of the Schottky signal. It is therefore clear that a smaller Schottky width would increase the accuracy of the centroid determination. A smaller starting emittance is also advantageous in view of the beam-target overlap. One general option to increase the accuracy of the frequency measurements is to use a cooled proton beam. Whether electron cooling at injection (the same condition for all energies) or stochastic cooling at the energy of the experiment (a time-consuming procedure to prepare longitudinal and transverse cooling for each single energy) is an ongoing point of discussion.

3 Measurements at ANKE

As already discussed in the previous sections, there are many requirements to be controlled before and during the experiment in order to get a highly accurate measurement of the *pp* cross section. It is also important to have as much an angular range as possible so as to get closer to the existing data for cross checks [17].

3.1 Acceptance

Monte Carlo simulations were carried out in order to estimate the angular acceptance of the detector systems (FD and STT). As mentioned in Sec. 2.3, for high resolution for the momentum reconstruction and maximum angular coveratge it is preferable to work with the maximum magnetic field. Taking this into consideration together with the beam momentum defines the ANKE deflection angle. Since 2007 the FD system has been fixed to the ANKE platform and its positions are defined by the deflection angle. Therefore for all energies with maximum ANKE magnetic field, the FD positions are also fixed and there is no possibility to make additional acceptance adjustments. The STT, which is located inside the target chamber, covers the angular range $0° - 60°$ fully satisfying the experimental requirements.

The results of the MC simulations for three different energies are listed in Table 1. The STT alone can detect protons with an energy higher than 2.5 MeV defining the minimum acceptance angle $\theta_{cm} = 5°$. Momentum reconstruction with the STT is only possible if the particle is stopped in the third layer. With the current setup of the STT (70 μm, 300 μm, and 5 mm) protons with kinetic energies up to 35 MeV can be stopped. For higher energy protons, only track informations are available resulting in a much poorer angular resolution of $1 - 2°$ and also problems of particle identification.

Energy [GeV]	θ_{cm} (FD)	θ_{cm} (STT)	θ_{cm} (STT tracks)
1.0	$10° - 28°$	$5° - 21°$	$21° - 70°$
1.6	$10° - 28°$	$5° - 17°$	$17° - 60°$
2.8	$10° - 32°$	$5° - 13°$	$13° - 50°$
Resolution	$0.5° - 0.8°$	$0.05°$	$2.7° - 5.7°$

Table 1: Angular acceptance and resolution of the FD system and the STT

3.2 Reaction identification

The *pp*-elastic reaction frequently has been used in ANKE experiments to determine the luminosity. It can be identified with small background ($\lesssim 5\%$) using the FD system alone. For the current experiment, by using the STT in coincidence with the FD, the background level will be negligible. Furthermore the STT will provide much better resolution in the scattering angle, which is very important for a differential cross section that changes rapidly with angle. For small angles we will use the STT alone as the FD cannot cover this range. There are no obvious sources of physical background and so the identification just with the STT should not pose a serious problem. The estimations of the systematic uncertainties for the angular range $5^\circ < \theta_{cm} < 30^\circ$ are shown in Table 2. This is a region where momentum of the particle is recontructed using the FD or/and STT detector systems.

For the region where we will have only track information and no particle identification from the STT. We simulated $pp \to pp\pi^0$ and $pp \to d\pi^+$ reactions to see how they would contribute to the background under these conditions. Deuterons from the second reaction will have fast momentum and would not go into the STT and the π^+ would also have high momenta and, because of their very small mass, won't be seen in the STT. Protons from π^0 production can be also separated using the kinematic restrictions.

Uncertainty	[%]
Track reconstruction efficiency	$\lesssim 3$
Acceptance correction	$\lesssim 4$
Momentum reconstruction	1
Data-taking efficiency	1
Background subtraction	1
Luminosity	3
Total	$\lesssim 6.1$

Table 2: Estimations of systematic uncertainties in the measurement of the cross section for *pp* elastic scattering in the angular range $5^\circ < \theta_{cm} < 30^\circ$. (events with momentum reconstruction)

4 Requested Beam Time

As the cross section of the *pp* elastic reaction is high, the collection of enough statistics for the data analysis will not be a problem. However, for a high precision measurement it is important to avoid very high count rates. The dead times of the DAQ should be kept below 10%, *i.e.*, one to two thousand events per second. With one night of measurement time per energy, statistical errors typically less than 1% per degree will be achieved. This will be sufficient for either the cross section or the analysing power determination. The proposal requires in TOTAL **2 weeks** of beam time to measure the energy and angular dependence of the unpolarised differential cross section $d\sigma/d\Omega$ and the analysing power A_y for *pp* elastic scattering in the energy region of $T_p = 1.0, 1.6 - 2.8$ GeV. In the framework of the PRESENT request, the collaboration asks for **1 week** of beam time to carry out the first part of the measurements at eight energies with an unpolarised proton beam and an unpolarised hydrogen cluster target.

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References

[1] A. Kacharava, F. Rathmann, and C. Wilkin for the ANKE Collaboration, COSY Proposal #152, *Spin Physics from COSY to FAIR*, arXiv:nucl-ex:0511028.

[2] ANKE Collaboration, *Status and Future Issues of the Physics Program at COSY with Polarised Hadronic Probes*, July 2008; available from http://www.fz-juelich.de/ikp/anke/proposals.shtml.

[3] H.J. Stein *et al.*, Phys. Rev. ST Accel. Beams, **11** (2008) 052801.

[4] J. Bystricky *et al.*, Nucl. Phys. A **444** (1985) 597.

[5] R.A. Arndt *et al.*, Phys. Rev. C **50** (1994) 2731;
R.A. Arndt *et al.*, Phys. Rev. C **56** (1997) 3005,
R.A. Arndt *et al.*, Phys. Rev. C **62** (2000) 034005,
R.A. Arndt, W.J. Briscoe, R.L. Workman, and I.I. Strakovsky,
Interactive on-line program: http://gwdac.phys.gwu.edu/analysis/

[6] S. Yaschenko *et al.*, Phys. Rev. Lett. **94** (2005) 072304.

[7] M. Altmeier *et al.*, Phys. Rev. Lett. **85** (2000) 1819.

[8] NN-online available from http://nn-online.org

[9] I. Ambats *et al.*, Phys. Rev. D **9** (1974) 1179.

[10] R.A. Arndt and I.I. Strakovsky, (private communication, July 2009).

[11] M. Rentmeester, (private communication, July 2009).

[12] S. Barsov *et al.*, Nucl. Instr. Meth. A **462** (2001) 364.

[13] S. Dymov *et al.*, Part. Nucl. Lett. **1** (2004) 40.

[14] D. Chiladze *et al.*, Phys. Rev. ST Accel. Beams, **9** (2006) 050101.

[15] R. Schleichert *et al.*, IEEE Trans. Nucl. Sci. **50** (2003) 301.

[16] I. Lehmann *et al.*, Nucl. Instr. Meth. A **530** (2004) 275.

[17] A. J. Simon *et al.*, Phys. Rev. C **48** (1993) 662.