# COSY Proposal

For Lab. use

| Exp. No.: | Session No. |
|---|---|
| 198 | 36 |

Title of Experiment

**Optimisation of Machine Acceptance for Spin-Filtering Experiments at COSY**

Collaborators: PAX and ANKE collaboration


Spokesperson for collaboration: Frank Rathmann (IKP-FZJ)
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**Support from the LSF program of the EC is requested**

Date: 22.10.2008


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| Total number of particles and type of beam (p,d,polarization) | Momentum range (MeV/c) | Intensity or internal reaction rate (particles per second) | |
|---|---|---|---|
| | | minimum needed | maximum useful |
| p or d | 293.5 (injection) | $5 \cdot 10^9$ | $5 \cdot 10^{10}$ |
| Type of target | Safety aspects (if any) | Earliest date of installation | Total beam time (weeks) |
| ANKE $H_2$ or $D_2$ Cluster | - | Fisrt half 2009 | 1 week |

**Summary of experiment**:

Using a method based on a movable aperture close to the ANKE cluster target position, we have accurately determined the machine acceptance with electron-cooled proton beam at injection energy of 45 MeV. With the deduced acceptance a measured beam lifetime is nicely reproduced by the calculated one due to single Coulomb scattering losses. The measured values of 14.55±1.50 μm and 14.17±1.48 μm of horizontal and vertical acceptances are much smaller than expected. To meet the requirements of the envisaged spin filtering experiments, measures have to be taken to increase the acceptances.

## Request:

We request one week of beam time in the first half of 2009 to carry out a measurement of the machine acceptance of COSY with electron-cooled beam at injection energy of $T_p$=45 MeV using the scraper system and the movable large aperture system at ANKE.

Attach scientific justification and a description of the experiment providing the following information:

**For proposals:**

Total beam time (or number of particles) needed; specification of all necessary resources

**For beam requests:**

Remaining beam time (allocations minus time already taken)

**Scientific justification:**

What are you trying to learn?
What is the relation to theory?
Why is this experiment unique?

**Details of experiment:**

Description of apparatus.
What is the status of the apparatus?
What targets will be used and who will supply them?
What parameters are to be measured and how are they measured?
Estimates of solid angle, counting rate, background, etc., and assumptions used to make these estimates.
Details which determine the time requested.
How will the analysis be performed and where?

**General information:**

Status of data taken in previous studies.
What makes COSY suitable for the experiment?
Other considerations relevant to the review of the proposal by the PAC.

**EC-Support:**

The European Commission supports access of new users from member and associated states to COSY. Travel and subsistence costs can be granted in the frame of the program Access to Large Scale Facilities (LSF).

Proposal to COSY
on

# Optimisation of Machine Acceptance for Spin–Filtering experiments at COSY

(ANKE and $\mathcal{PAX}$ Collaborations)

Jülich, October 2008

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# Optimisation of Machine Acceptance for Spin–Filtering experiments at COSY

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**Abstract**

Using a method based on a movable aperture close to the ANKE cluster target position, we have accurately determined the machine acceptance with electron–cooled proton beam at injection energy of 45 MeV. With the deduced acceptance a measured beam lifetime is nicely reproduced by the calculated one due to single Coulomb scattering losses. The measured values of $14.55 \pm 1.50\,\mu$m and $14.17 \pm 1.48\,\mu$m of horizontal and vertical acceptances are much smaller than expected. To meet the requirements of the envisaged spin filtering experiments, measures have to be taken to increase the acceptances.

## Spokespersons:

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# Contents

# 1 Determination of the machine acceptance

We had reported in our previous proposal [1] that the observed beam lifetimes with and without target at injection energy ($T_p$ = 45 MeV) are substantially shorter than those expected from the theoretically calculated machine acceptance. One goal of the machine studies carried out in September 2008 was to quantitatively understand the observed lifetimes of the electron–cooled beam with and without target.

## 1.1 Geometrical acceptance determination using the kicker

In Fig. 1, we show the result of a kicker measurement carried out during the September 2008 run. At COSY, the kicker is available only in the horizontal plane. The measurement yields an acceptance of approximately 40$\mu$m.

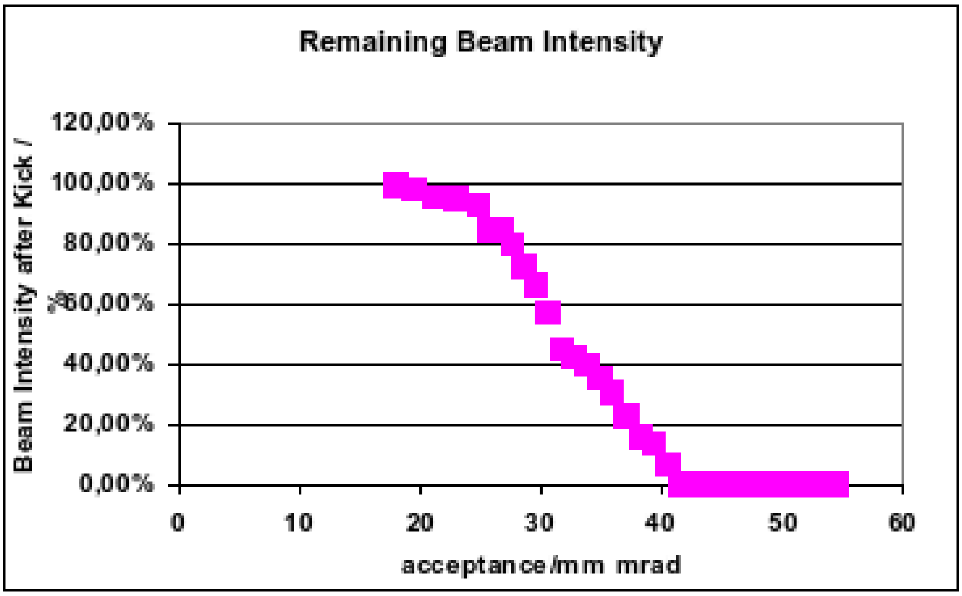


Figure 1: Acceptance measurement with fast horizontal kicker magnet, showing the fractional beam intensity versus machine acceptance. The acceptance is calculated from the used kick angle and the Twiss functions at the location of the kicker, yielding approximately 40$\mu$m.

## 1.2 Machine acceptance determination with electron-cooled beam

Based on a method outlined in detail in a recent manuscript [2], we have determined the machine acceptance with electron beam at injection energy. The results of the measurements are shown in Fig. 2. When one or the other edge of the rectangular aperture (width along x: 50 mm, height along y: 25 mm), depicted in Fig. 4 of ref. [2], is moved into the acceptance of the machine, the square root of the beam lifetime drops linearly as a function of the position. As long as the aperture restriction is located outside of the machine acceptance, the beam lifetime is not affected.

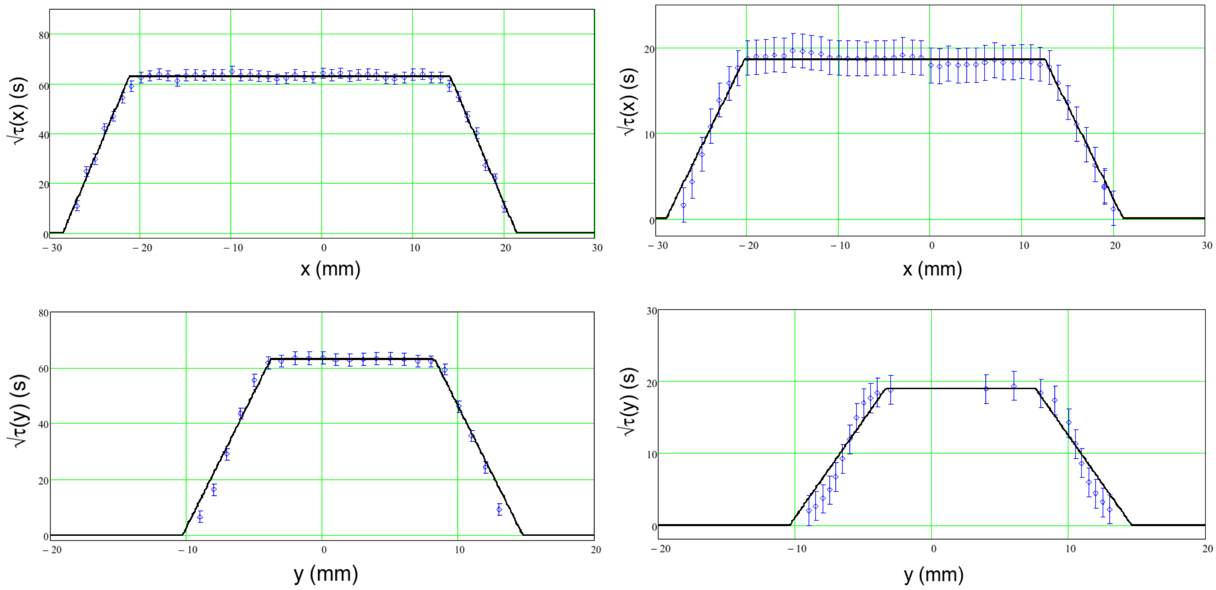


Figure 2: Scans with the aperture system of ANKE [2]. Measurements were performed with the electron-cooled beam along the horizontal direction (top panels) and along the vertical one (bottom). The panels on the left show measurements without target, those on the right with the cluster target providing a target thickness of about $1.2 \times 10^{14}$ cm$^{-2}$.

The results of the measurement of Fig. 2 are summarised in Table 1. The resulting parameters with target on and off agree quite well with each other. Therefore, we averaged

| Scan along | $\sqrt(\tau)$ (s) | offset (mm) | half width $p$ of plateau region (mm) |
|---|---|---|---|
| X with target–off | $62.86 \pm 0.36$ | $-3.60 \pm 0.07$ | $17.66 \pm 0.13$ |
| X with target–on | $18.69 \pm 0.35$ | $-3.88 \pm 0.23$ | $16.40 \pm 0.42$ |
| Y with target–off | $62.90 \pm 0.63$ | $2.24 \pm 0.06$ | $6.03 \pm 0.12$ |
| Y with target–on | $19.03 \pm 1.16$ | $2.12 \pm 0.17$ | $5.46 \pm 0.51$ |

Table 1: Results of the machine acceptance measurement using the aperture system of ANKE. The column labelled $\sqrt(\tau)$ denotes the square root of the beam lifetime in the plateau region, the deviation of the beam from the centre of the target chamber is the offset, also listed is the the half-width of the plateau region.

target–on and target–off values of the half width $p$ of the plateau region. The machine acceptance is determined by subtracting half of the plateau widths in Fig. 2, $p$, from half of the base of the trapezoid (which corresponds to the height (25 mm) and width (50 mm) of the large aperture at ANKE). Together with the $\beta$–functions at the location of the scraping aperture, the resulting horizontal and vertical machine acceptances are given in Table 2. Using the measured machine acceptances from Table 2, it is possible to determine

| | half width $p$ of plateau (mm) | half width $w$ of free aperture (mm) | $\beta$–function at the ANKE scraper (m) | $\Delta\beta/\beta$ | machine acceptance $w^2/\beta$ ($\mu$m) |
|---|---|---|---|---|---|
| $X$ | $17.62 \pm 0.10$ | $25 - p$<br>$7.38 \pm 0.10$ | 3.74 | 0.1 | $14.55 \pm 1.50$ |
| $Y$ | $5.98 \pm 0.10$ | $12.5 - p$<br>$6.52 \pm 0.10$ | 3.00 | 0.1 | $14.17 \pm 1.48$ |

Table 2: Results of the machine acceptance measurement using the aperture system of ANKE. The horizontal ($X$) and vertical ($Y$) machine acceptance is determined using the deduced half width of the observed free aperture $w$, and the lattice model based $\beta$–functions at the location of the scraper. The error is calculated using the uncertainties of $w$ and an assumed uncertainty of the $\beta$–function of 10%.

the horizontal and vertical acceptance angles at the location of the ANKE cluster target using the $\beta$–functions at the target, which are slightly smaller than at the scraper. In order to compare the measured beam lifetimes to the theoretically expected ones, we make the following ansatz

$$\frac{1}{\tau(\theta^{\mathrm{acc}})} = \frac{1}{\tau(\theta_x^{\mathrm{acc}})} + \frac{1}{\tau(\theta_y^{\mathrm{acc}})} \,. \tag{1}$$

Since the beam lifetime due to single scattering losses is proportional to the square of the acceptance angle, we obtain for the acceptance angle at the ANKE target

$$\theta^{\mathrm{acc}} = \sqrt{\left(\frac{1}{(\theta_x^{\mathrm{acc}})^2} + \frac{1}{(\theta_y^{\mathrm{acc}})^2}\right)^{-1}} \tag{2}$$

$$= 1.51 \pm 0.08 \text{ mrad}\,. \tag{3}$$

| | $\beta$–functions at the ANKE target (m) | $\Delta\beta/\beta$ | acceptance angle (mrad) |
|---|---|---|---|
| $X$ | 3.60 | 0.1 | $\theta_x^{\mathrm{acc}} = \sqrt{\frac{A_x}{\beta_x}} = 2.01 \pm 0.15$ |
| $Y$ | 2.69 | 0.1 | $\theta_y^{\mathrm{acc}} = \sqrt{\frac{A_y}{\beta_y}} = 2.30 \pm 0.17$ |

Table 3: Horizontal and vertical acceptance angles at the location of the ANKE target.

The Hydrogen target density of $d_t = 1.20 \times 10^{14}\ \mathrm{cm}^{-2}$ was determined using the energy loss method, described in ref. [3]. Using the Coulomb-loss cross section

$$\Delta\sigma_C = \frac{4\pi \cdot r_p^2}{\beta_{\mathrm{lab}}^4 \cdot \gamma_{\mathrm{lab}}^2 \cdot (\theta^{\mathrm{acc}})^2}\ , \tag{4}$$

where $r_p$ denotes the classical proton radius, $\beta_{\mathrm{lab}}$ and $\gamma_{\mathrm{lab}}$ are the relativistic parameters, the beam lifetime is calculated via

$$\tau = \frac{1}{\Delta\sigma_C \cdot f_{\mathrm{rev}} \cdot d_t} \tag{5}$$

$$= (1219 \pm 133)\ \mathrm{s}\ , \tag{6}$$

where the error reflects the uncertainty of the acceptance angle, given in Eq. (3).

The measured beam lifetime under these conditions was of $\tau = (1004 \pm 1.4)$ s, see Fig. 3. The good agreement between both values shows that we are on the way to a quantitative understanding of the reason for too short lifetimes of the electron cooled beam, *i.e.* the small ring acceptance. How far the electron beam alone is responsible for

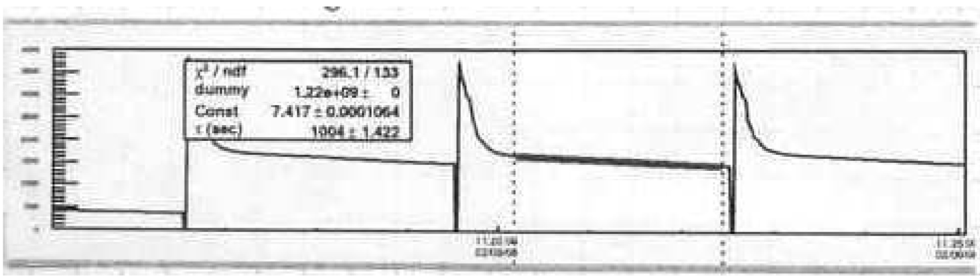


Figure 3: Measured beam lifetime of $\tau = (1004 \pm 1.4)$ s.

this was investigated by acceptance measurements of an uncooled beam.

## 1.3 Machine acceptance determination with uncooled beam

To determine the machine acceptance without electron beam, a cooled beam is first prepared, and then the electron beam is switched off. Due to emittance growth proton beam size increases until the acceptance of the ring is reached. Target was used to let the beam fill the acceptance faster. To avoid additional effects from energy losses and dispersion, the beam was slightly bunched with the RF cavity. When the aperture frame is moved into the beam with a known velocity, here 1.66 mm/s, the decrease of the beam current, recorded on an oscilloscope, yields the beam profile.

About 50 s after switching of the electron cooler off the beam decay becomes purely exponential, showing that the acceptance limit is reached where the beam losses are dominated by multiple Coulomb scattering. In Fig. 4 we present the measurements taken 60 s

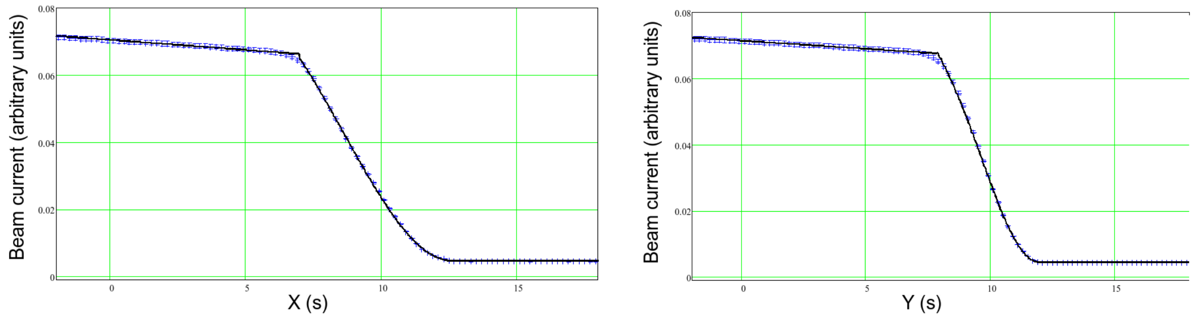


Figure 4: Measurement with the aperture system of ANKE along $X$ (left panel) and $Y$ (right) 60 s after the electron beam was switched off and the beam size had reached its maximum.

after the electron beam was switched off. The distance between the first reduction of the beam current due to the contact with aperture and the point where the beam is completely scraped yields the full beam size and with the Twiss $\beta$ the acceptance. The results are given in

| | beam size $w$ (mm) | machine acceptance ($\mu$m) |
|---|---|---|
| $X$ | 9.41 | $23.68 \pm 2.37$ |
| $Y$ | 6.87 | $15.73 \pm 1.26$ |

Table 4: Results of the machine acceptance measurement of the uncooled beam using the aperture system of ANKE.

While the vertical acceptances of the electron–cooled and uncooled beams are the same within measurement errors, the horizontal case exhibits almost a factor of two difference.

## 2 Beam Request

We quantitatively understand the measured electron–cooled beam lifetime with target. It is restricted by the machine acceptance of $\sim 14\,\mu$m in both planes, and present a major drawback and a limitation for the envisaged spin filtering studies in its present state. In order to make progress towards longer beam lifetimes, the machine acceptance with electron–cooled beam has to be improved.

One explanation for this small value is the fact that the uncooled proton beam at the electron cooler is wider than the electron beam diameter of 25 mm. Expanding the electron beam on its way from gun to cooling solenoid can increase the geometrical acceptance of the electron beam. Magnetic fields of 0.15 T in gun and collector solenoid together with 0.05 T in the cooling solenoid should be technically feasible. The expansion factor of $\sqrt{0.15/0.05} = 1.6$ would increase the electron beam diameter from 25 to 60 mm. An additional measure could be to operate the ring in mode where the dispersion in COSY telescopes is zero. A natural consequence of that mode is that horizontal and vertical $\beta$-functions at the electron cooler are almost equal, about 14 m, compared to 6 and 25 m in the lattice setting of our last experiments.

So far no special care has been taken to avoid large orbit distortions in the ring, especially in the horizontal plane. Appropriate orbit corrections could increase the geometrical acceptance of the ring itself. The difference between the acceptances of uncooled beam determined with the kicker ($\sim 40\,\mu$m) and the scraper ($\sim 24\,\mu$m) can be explained by the fact the the kicker measurement is done shortly after the start of a new cycle whereas in the scraper measurements dynamic effects have time to develop. It can be expected that dynamic aperture effects are diminished when the orbit distortions are minimised.

**We request one week of beam time in the first half of 2009** to carry out a measurement of the machine acceptance of COSY with electron–cooled beam at injection energy of $T_p = 45$ MeV using the scraper system and the movable large aperture system at ANKE.

# References

[1] P. Lenisa and F. Rathmann for the PAX collaboration, *Proposal Machine Acceptance Studies with electron–cooled Beam*, COSY Proposal #190, 2008, available from `http://www.fz-juelich.de/ikp/pax/`.

[2] K. Grigoriev *et al.*, *Machine acceptance studies for the development of storage cells for the ANKE facility of COSY*, submitted for publication. The manuscript is available from `http://www.fz-juelich.de/ikp/anke/en/publications/Beamprofile_NIM_V7.pdf`

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