# A NOVEL BEAM PROFILE MONITOR BASED ON A SUPERSONIC GAS JET

K.-U. Kuehnel[1,*], M. Putignano[1,3], C.P. Welsch[1-3], C.D. Schröter[1] and J. Ullrich[1]
[1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
[2]Kirchhoff Institut für Physik, Universität Heidelberg, 69120 Heidelberg, Germany
[3]Gesellschaft für Schwerionenforschung, 64291 Darmstadt, Germany

*Abstract*

At very low residual gas pressure below $10^{-12}$ mbar, as foreseen in future low-energy storage rings currently under development at the MPI-K and FAIR, conventional residual gas beam profile monitors cease to work with reasonable count rates. One possible way to overcome this restriction is the use of a supersonic gas jet as a profile monitor. Such a jet could be shaped as a thin curtain, thus providing a uniform target with a variable target density extended over the whole beam. A possible setup of such a device taking into account vacuum considerations, expected count rates and an envisioned detection scheme is presented in this contribution.

## INTRODUCTION

At present, novel electrostatic storage rings for low energy ion beams in the range of 20 – 300 keV/u are developed at the Max-Planck-Institut für Kernphysik (MPI-K) and the future facility for antiproton and ion research (FAIR) [1,2]. Due to the electrostatic concept, these rings are capable of storing most different kinds of ions from protons or antiprotons up to heavy highly charged ions or heavy molecular ions. A picture of the CSR ring, which will be operated at a temperature of 2 K is shown in figure 1. These ions open up a completely new range of experiments involving ion-atom collisions. At these low energies, especially charge transfer reactions take place, which are substantially interesting e.g. the understanding of interstellar plasmas. Up to now fully differential cross sections from these reaction could only be obtained in a single shot mode experiment, where the projectile is dumped behind the target zone. Since especially highly charged ions are difficult to produce in sufficient quantities at such energies, the integration of such experiments in storage rings gives the advantage of obtaining much higher count rates as compared to a single shot experiment.

In recent years reaction microscopes have been improved considerably becoming a perfect tool for the investigation of such reactions [4]. Quite recently a worldwide first in-ring reaction microscope has been operated successfully at the ESR at GSI, although at much higher energies between 17 and 400 MeV/u [3].

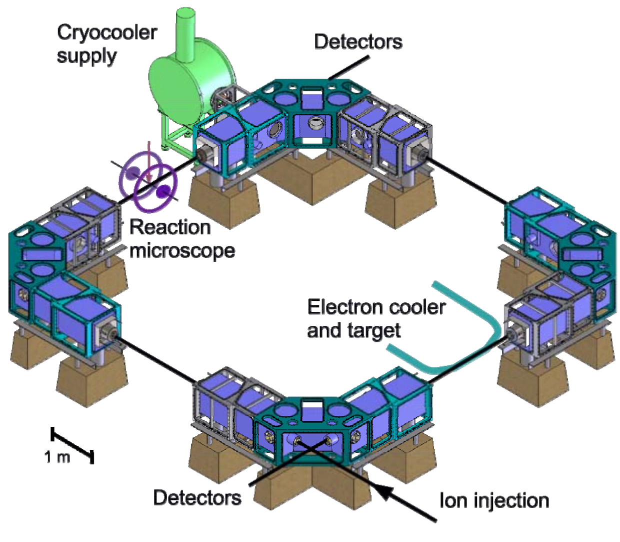


Figure 1: The storage ring CSR.

## REACTION MICROSCOPE

Reaction microscopes allow for the kinematically complete study of ion-atom collisions by coincident measurement of the momenta of both the recoiling target ion and all electrons created in the collision. By measuring the charge exchanged projectile in coincidence, charge transfer reactions can be identified and investigated in great detail [4].

In a reaction microscope a supersonic gas jet is crossed with the incident projectile beam. Using a homogeneous electric field, the recoil ions are guided to a large-area position-sensitive detector consisting of a microchannel plate combined with a delay line anode. A schematic drawing of the experimental setup can be seen in figure 2. By measuring the position on the detector along with the time of flight, the initial momentum of the ion can be derived. The momentum resolution achieved so far in these experiments is as low as 0.07 atomic units. Electron detection under a full solid angle of $4\pi$ is obtained by a superimposed additional magnetic field, which acts on the whole flight path and forces the electrons on spiral trajectories to the detector. Using a common time base, all these fragments can be measured in coincidence.

*kai-uwe.kuehnel@mpi-hd.mpg.de

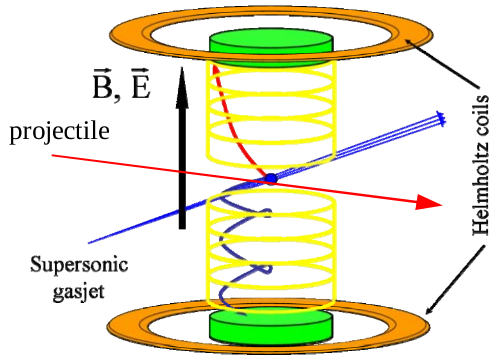


Figure 2: Schematic drawing of a reaction microscope.

The implementation of the reaction microscope into one of the straight sections of a low-energy storage ring requires substantial design modifications. Although the preferred extraction direction for the recoil ions is along the symmetry axis of the reaction, which is the projectile direction in the case of ion-atom collisions, the reaction microscope will be oriented perpendicular to the incident beam. This geometry has several advantages in terms of the mechanical realisation of the spectrometer. In addition, an axial extraction would need moveable detectors, since the beam diameter can be as large as 80 mm during injection in the ring. Since the storage time for highly charged ions will be in the order of only a few seconds, this would lead to a dramatic decrease of the beam time available for measurements.

The transverse extraction requires, however, both electric and magnetic fields perpendicular to the beam, which have to be corrected. To optimize both the spectrometer and the correction elements needed to reach a stable orbit, simulations were performed using the OPERA-3D code. A model of one quarter of the CSR ring including the reaction microscope is shown in figure 3.

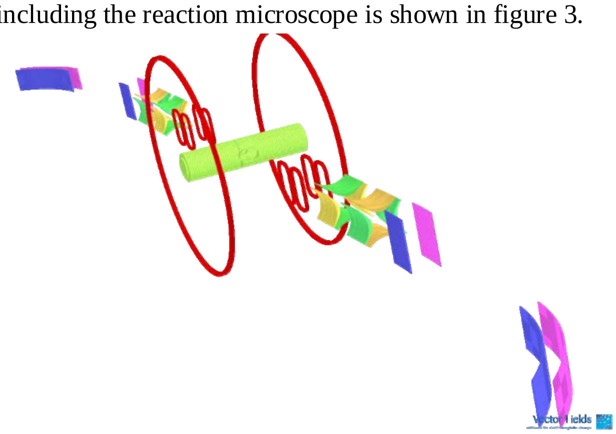

Figure 3: OPERA-3D model of the planned CSR in-ring reaction microscope.

## BEAM PROFILE MONITOR

In both, the cryogenic storage ring (CSR) sketched in figure 1 and the ultra-low energy storage ring (USR) at the facility for low energy antiproton and ion research (FLAIR), the residual gas pressure sets an upper limit to accessible storage times. Therefore extremely high vacua in the range of $10^{-13}$ to $10^{-15}$ mbar have to be realized. Residual gas beam profile monitors cannot be used in these rings, since the expected count rates are much too low. One way to overcome this problem could be the use of the gas target of the reaction microscope to strongly increase the target density in a well-localized area.

This requires a modification of the supersonic gas jet so that it can be shaped into a thin curtain with a variable thickness. By changing both, the shape and thickness of the target, the count rates can be varied over a wide range. Using a curtain shaped target crossing the beam at an angle of 45° with respect to the incident projectile beam, one detector would be sufficient to measure both, the horizontal and vertical beam profiles, simultaneously. Figure 4 shows a schematic drawing of such a beam profile monitor. A similar approach using a magnetically focused $O_2$ gas curtain has been successfully used at KEK by the group of Hashimoto [5] for beams in the MeV range at much higher residual gas pressures.

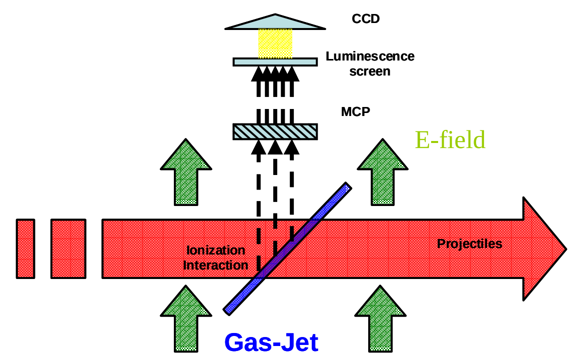


Figure 4: Schematic drawing of the beam profile monitor.

Given a typical cross section for an antiproton collision with e.g. argon in the order of $10^{-16}$ $cm^2$ one can estimate the expected event rates resulting from the curtain target for such a beam profile monitor. The corresponding data for a cw antiproton beam with $10^6$ particles circulating through a 50m ring at 20 keV energy is shown in figure 5.

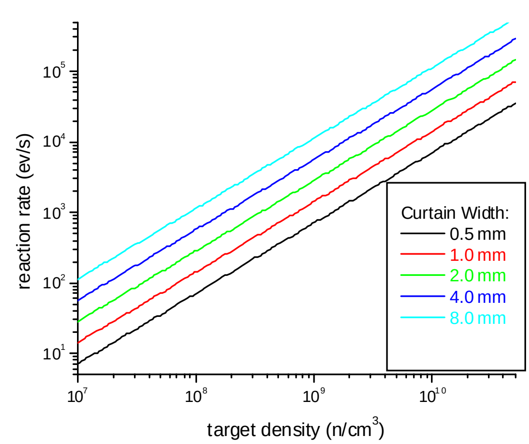


Figure 5: Expected count rates for a 20 keV antiproton beam.

# THE JET TARGET

In the target, the gas is cooled via free expansion. During the expansion of the compressed gas into vacuum the thermal energy of the gas atoms is transformed into kinetic energy along the propagation direction of the jet. Thus, the atoms are cooled to temperatures in the order of a few Kelvin. This corresponds to a very low velocity spread in the target, which is necessary for the experiments in the reaction microscope, since the uncertainty in initial velocity directly influences the resolution of the momentum measurement. For the beam profile monitor the target temperature is less important. After the expansion in a first stage the gas jet is skimmed and then collimated in several differential pumping stages. After it crosses the interaction region, it is again differentially pumped before it is guided into a jet dump to avoid a back flow of gas into the experimental vacuum. To investigate the influence of a non-circular geometry of both nozzle and skimmer, numerical simulations were performed using the Gas Dynamic Tool (GDT) code [6]. For examples one can simulate the distribution of the gas velocity in a jet formed with a slit shaped nozzle and a rectangular skimmer, a geometry which could be used to form a gas curtain.

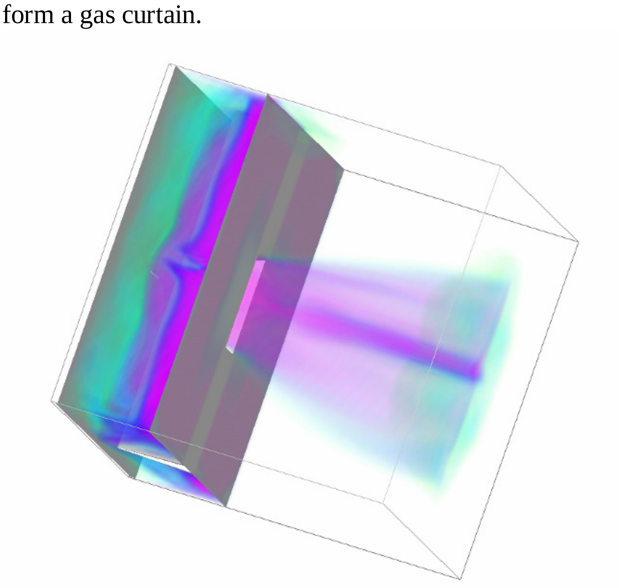

Figure 6: 3-dimensional visualization of the velocity distribution of an expanding jet obtained from a GDT simulation

The resulting velocity distribution can be seen in the above figure 6, where the green colour corresponds to the lowest and the red colour to the highest gas velocity.

# SUMMARY AND OUTLOOK

In this paper, a conceptual design of a new neutral beam scanner based on a reaction microscope was presented. While the general concept of a central, cold gas jet with surrounding detectors is closely related, the profile monitor requires a number of new developments, in particular for what concerns a highly-flexible gas shaping scheme.

Further numerical studies with the GDT code will be performed in the near future to better the behaviour of an asymmetric jet expansion.

The support of the Helmholtz Association of National Research Centres (HGF) under contract number VH-NG-328 and of the Gesellschaft für Schwerionenforschung (GSI) in Darmstadt is acknowledged.

# REFERENCES

[1] D. Zajfmann et al., Journal of Physics Conference Series **4** (2005) 296-299.
[2] C.P. Welsch et al., Nuclear Instruments and Methods in Physics Research **A546** (2005) 405-417.
[3] D. Fischer et al., GSI Scientific Report 2006 243
[4] J. Ullrich et al., Rep. Prog. Phys. **66** (2003) 1463-1545.
[5] Y. Hashimoto et al., Nuclear Instruments and Methods in Physics Research **A527** (2004) 289-300
[6] see http://www.cfd.ru.
[7] R.B. Miles et al., Measurement Science and Technology **12** (2001) R33-R51.
[8] D. Mitchell et al., 16th Australasian Fluid Mechanics Conference (2007) 217-224.