NEW PROJECTS AT CRYRING

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Abstract

Major recent developments at CRYRING include the installation of a superconducting gun solenoid on the electron cooler one and a half years ago, the construction of a gas target for studies of fast ion–atom collisions that will be operating in the late spring of this year, and an ECR ion source on a high-voltage platform that will be used as an additional injector into CRYRING. Smaller projects relate to the continuous requests for new atomic and molecular ions in the ring, including now negative ions, which leads to a demand for new detector positions and, since these ions often are difficult to produce in an ion source, also to improvements of the diagnostics of weak beams in injection lines and in the ring.

1 ELECTRON COOLER

The electron cooler was rebuilt during the summer of 1997 for the installation of a superconducting gun solenoid and a new electron gun of 4 mm diameter [1]. The aim with this modification was to reduce the transverse electron temperature further and to improve the conditions for experiments with electron–ion recombination.

The superconducting magnet has a nominal maximum field of 5 T, but it is usually run at 3 T together with 300 G in the rest of the cooler magnets. This gives an adiabatic electron-beam expansion with a factor of 100 and, theoretically, a reduction of the transverse energy spread of the electrons from 100 meV to 1 meV. With the new electron gun of 4 mm diameter, the electron-beam diameter in the cooling section will then be 40 mm as before the introduction of the beam expansion.

Some measurements of the longitudinal drag force with the 100 times beam expansion have been performed. They showed an increase in the drag force compared with the data for 10 times beam expansion by 25–50% at relative velocities in the vicinity of the drag-force maximum. This increase is presumably larger than the measurement errors, but it is possible that the longitudinal electron temperature in the new measurements was lower than in those with 10 times expansion since the new electron gun is of a different construction. This may then explain some of the effect. The longitudinal drag force thus still agrees reasonably well with a binary-collision model with a value of $kT_\perp$ approximately equal to 3 meV [2]. Note, however, that this model does not include the effect of the magnetic field in the cooler, and the comparison thus does not necessarily mean that $kT_\perp$ actually is 3 meV.

Preliminary studies with the new cooler where the expansion ratio has been changed have also been made, and here the difference between 10 and 100 times expansion was of the same size as the measurement errors.

To some extent, information about the transverse drag force can be obtained by studying so-called transverse Hopf bifurcations [3–4]. When an angle is introduced between the ion and the electron beam, a transverse instability will occur at an angle where the transverse electron velocity (relative to the ion beam) exceeds the velocity where the transverse drag force has its maximum. The ions will then start to perform transverse oscillations with an amplitude that depends on the electron-beam angle.

We measured the oscillation amplitude using a beam profile monitor and compared the measured profile with tracking results. These profiles have the form of two distinct peaks whose separation corresponds to the oscillation amplitude and weaker intensity between the peaks. The tracking program uses a drag force calculated in three dimensions according to the model described in ref. [2] and include such effects as betatron oscillations, dispersion, the space charge of the electron beam, and the position and alignment of the electron beam relative to the ion beam.

Figure 1 shows a preliminary comparison between measurements and tracking simulations. The shape of the curves are reasonably similar, showing a sharp threshold for the onset of the transverse oscillations, and again the measurements seem to agree with the binary-collision model with a $kT_\perp$ somewhere in between 1 and 10 meV.

The most accurate way of measuring the electron temperature is to look at the peak shape of sharp recombination resonances. The asymmetry of such peaks that occur provided that the relative energy between ions and electrons is sufficiently low makes it possible to determine the transverse and longitudinal temperature simultaneously. In order to be sensitive to temperatures as low as around 1 meV, the recombination resonances should be at a relative energy of at most 10 meV, preferably lower. In addition, the peak should be well apart from other resonances and must have a narrow natural line width. The best systems studied so far at CRYRING is C^{3+} [5] and F^{6+} [6], where the two latter criteria are essentially fulfilled, but where the resonance energy is somewhat too high (0.17 and 0.12 meV, respectively). Although the high resonance energy gives some uncertainty, the best fits to the peak shapes gave a transverse electron-energy spread of about 3 meV in both cases.

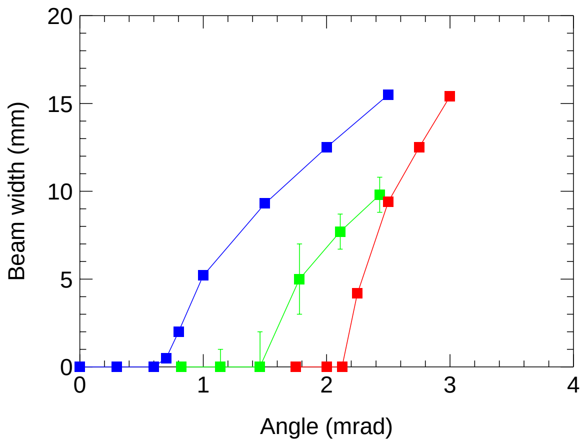

Figure 1: Beam width, defined as the peak separation (see text), as a function of electron-beam misalignment. The left curve is tracking results with a theoretical drag force and $kT_{\perp}$=1 meV and the right curve with $kT_{\perp}$=10 meV. The middle curve represents measured values.

Several facts thus points at a transverse energy spread that is higher than the expected 1 meV, but there remains to make a conclusive measurement. It could also be noted that we do not expect that the straightness of the magnetic field in the cooling solenoid (which was carefully measured when the cooler was built) or a misalignment between ion and electron beams could explain the observed transverse temperature.

2 ECR ION SOURCE

An ECR ion source has now been installed at the laboratory. The source as such has been tested, and work with the beamlines that will connect it to the experimental facilities is in progress. We expect that it will be able to deliver ions to the storage ring next year.

The ion source is a single stage HYPERNANOGAN device delivered by Pantechnik. It has an operating frequency of 14.5 GHz and a maximum rf power of 2 kW. The solenoidal field is generated by an electromagnet, while the hexapolar field is given by permanent magnets. The magnetic structure enables a future upgrade to 18 GHz. Extraction voltages of up to 30 kV can be used.

The ECR source with its cw beams of heavy ions in intermediate charge states will serve as a complement to the present EBIS source both for injection into the ring and for atomic collision and surface physics with the ions directly from the source. It will also be able to deliver singly charged atomic and molecular ions, for which the high-voltage platform will facilitate injection into the ring in some cases.

In order to improve the injection into the ring and to allow a wider range of experiments using ions directly from the source, the ECR is mounted on a 300 kV high-voltage platform. On the platform, and separated from the source by an einzel lens, is a 102º double-focusing analysing magnet. Due to space restrictions and ripple and leakage current considerations, the 300-kV platform is separated into two units. The 350-kVA motor-generator unit and the 300-kV 2.5-mA Glassman high-voltage supply are placed in another hall and connected to the ECR platform by 40 m long high-voltage cables. The platform will be fully enclosed in a metal cage, and in order to limit the risk for flashover and to protect personnel, the inner cage will in addition be enclosed in an outer cabinet, separated by a least 60 cm from the inner shield.

After installation on the platform, an acceptance test of the source was performed. The three injection systems, gas only (Ar), furnace for molten metals (Pb), and sputtering for metals and compounds (Ta) were tested, and the currents obtained were in fair agreement with the values guaranteed by the manufacturer. Table 1 shows some of the results of these tests, as well as the result when the source was running in the so-called afterglow mode.

Table 1: Examples of measured ion currents in electrical µA during the acceptance test for various charge states *q*. *Afterglow mode in which case the current in continuous mode was 24 µA.

q	8	11	12	14	20	24	25
Ar	300	125	60	8			
Ta					26	24	
Pb							30
Ar*		60					

3 GAS TARGET

A gas-jet target to be installed in CRYRING later this spring has been designed and constructed in a collaboration between the Physics Department of Stockholm University, the Manne Siegbahn Laboratory, Frankfurt University, GSI, and Freiburg University [7]. The main purpose of the gas-jet target is detailed investigations of collisions between the fast CRYRING ions and the molecules or noble-gas atoms of the gas jet by means of the technique of COLd Target Recoil-Ion-Momentum Spectroscopy (COLTRIMS).

The target is designed for helium for which the aim is to create a cold (<5 mK) target with a density of about 10^{12} cm^{-3} in a 1.0 mm narrow jet at the point of intersection with the ion beam. At the same time the ultra-high vacuum of the CRYRING should remain unaffected.

The target operates such that precooled (30 K) gas expands through a 30 µm nozzle from a container with a helium pressure of p_0=2 bar into an expansion chamber, where a pressure of the order of 10^{-3} mbar is maintained by means of a 1000 l/s turbomolecular pump. After this a beam is formed by narrow skimmers before the interaction region is reached. Finally the jet is disposed of in a three-stage differentially pumped jet dump.

The target has been tested off-line with the helium-gas container at room temperature. In one particular test, the load of helium in the collision chamber was measured by means of a commercial He leak detector while the jet was running. In this way, the load of helium gas lost to the collision chamber and thereby affecting the CRYRING vacuum was found to be less than 5×10^{-10} mbar l/s, which with the increased helium pumping capacity (as discussed below) corresponds to a pressure increase of less than 10^{-12} mbar in CRYRING. This load is expected to increase by a factor of $10^{1/2}$ when the gas is pre-cooled to 30 K.

By blocking the jet with a scraper in the collision chamber, the full load of the jet (2×10^{6} mbar l/s) was measured by the leak detector, and the jet diameter was determined by considering the load as a function of the scraper position. The diameter of the jet was found to be 1.0 mm as expected. From the full jet load, the diameter and the expected jet velocity, the He density at the intersection point was found to be about 3×10^{10} cm^{-3}. The density is expected to increase by a factor of 10 when the gas is pre-cooled to 30 K, so it seems that we will not quite achieve the desired density with this choice of gas-target parameters. On the other hand, with this parameter choice we are on the safe side regarding the CRYRING vacuum conditions, and a density of 3×10^{11} cm^{-3} will be sufficient for all planned experiments. If, at a later stage, a higher density is needed, a wider nozzle and improved pumping of the expansion chamber seem to be the most feasible alternative.

4 OTHER PROJECTS

The rest gas in CRYRING, where the average pressure is around 1×10^{-11} mbar, consists to 90% of hydrogen. However, it is to a large extent the remaining 10% that reduces beam lifetime and increases the experimental background in studies of processes like ion–electron recombination. Furthermore, with the use of helium in the gas-jet target, there will inevitably be some increase in the helium pressure in the ring, and this helium is not pumped efficiently neither by the NEG (non-evaporable getter) pumps nor by the ion pumps used at present. In fact, the memory effects of the ion pumps will lead to an increased helium background even long after the gas target has been turned off.

For these reasons, the vacuum system of the ring will be upgraded with eight high-compression turbomolecular pumps. On the high-pressure side of each of these pumps a smaller turbo pump will be connected, providing a backing pressure of around 10^{-6} mbar, and mechanical forepumps to each of these turbo-pump assemblies. On the low-pressure side there will be NEG strips to reduce the outgassing of H_2 from the turbo pumps themselves.

A complete reconstruction of the vacuum chambers after the electron cooler (the dipole chamber behind the cooler and the straight section up to the following dipole) has been made in order to allow detection of a wider range of ions that have undergone charge exchange in the cooler. Now there are detector positions that allow the interception of almost all ions with charge states from 1 to around 55 that have decreased the charge by one unit in the cooler. There are also manipulators in the dipole magnet after the cooler for the detection of ions that have increased their charge state (i.e. that bend more than the primary beam in the dipole), and for ions whose charge has changed sign (that bend in the opposite direction). These detector positions are particularly interesting for the study of charged fragments produced in dissociative recombination of molecular ions.

Since several years there have been proposals for experiments with negative ions in CRYRING. When the ring was constructed, this option was foreseen, and it is fairly straightforward to change the polarity of magnets and electrostatic deflectors. Tests with negative ions in the ring will be performed during the spring, and if these tests are successful, a dedicated ion source for negative atomic and molecular ions will be purchased.

Finally the efforts to improve the sensitivity of the diagnostics in the beam lines and in the ring are continuing. These include the installation of sensitive electronics for strip detectors in the injection lines [8], the use of integrating CCD cameras with image processing at fluorescent screens, and improvement of the noise level of the amplifiers for the electrostatic pickups in the ring. For the latter, the use of state-of-the-art integrated-circuit amplifiers and an input stage with several low-noise field-effect transistors in parallel have reduced the noise level to less than 1 nV/Hz$^{1/2}$.

5 REFERENCES

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