NEW DEVELOPMENTS AT CELSIUS

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Abstract

The CELSIUS electron-cooler storage-ring is used for physics experiments using very thin internal targets (of elements ranging from hydrogen to xenon) and stored beams of argon, neon, oxygen, and nitrogen ions as well as protons, deuterons and alpha particles. New developments of the accelerator include automatic feed-back control of the position and direction of the incoming beam, new stripper foil shape for improved injection of argon, improved orbit correction by means of singular value decomposition technique, control of momentum spread of electron cooled ion beams through modulation of the electron beam energy, and a novel proton beam profile measurement using the so-called "tracker" of the WASA/PROMICE detector. The WASA 4π detector facility with superconducting solenoid and hydrogen pellet target is being installed in the ring.

1 AUTOMATIC FEEDBACK OF POSITION AND DIRECTION OF INCOMING BEAM

Highly repetitive operation of CELSIUS requires constant position and direction of the incoming beam, which is subject to drifts of the many parts of the beam transport system. We have constructed beam position monitors that measures the beam position at two longitudinally different positions just before the injection and a feedback system to stabilise these [1].

2 STRIPPER FOIL

Stripping injection is the preferred injection method at CELSIUS [2-4]; it is used for injection of protons, deuterons, alpha particles, as well as nitrogen, oxygen, neon, and argon ions and gives satisfactory intensities for experiments. The intensities of nitrogen, oxygen, neon and argon ions are built up by accumulation with electron cooling.

Thus, to inject protons and deuterons, beams of H_2^+ and D_2^+ molecular ions are accelerated through the cyclotron, whereas to inject alpha particles and fully stripped nitrogen, oxygen, neon, and argon ions He^{1+}, N^{5+}, O^{5+}, Ne^{6+}, and Ar^{9+} are used respectively.

A new stripper foil mechanism has been installed. It has space for three different stripper foils, all to be placed just outside of (to the left of) the circulating beam when used, and with their inner (right) edge unsupported to allow the particle trajectories to “travel” from the surface of the foil to the free aperture to the right of the foil. Much thicker stripper foils are required for the injection of argon than for the lighter ions. On the other hand, a second traversal of the foil is not allowed for argon ions (the energy loss is too large) whereas protons can go through their stripper foil hundreds of times. In order to increase the probability for argon ions to miss the stripper foil on subsequent passages, the stripper foils intended for argon injection have been made with horizontal as well as vertical unsupported edges, see figure 1.

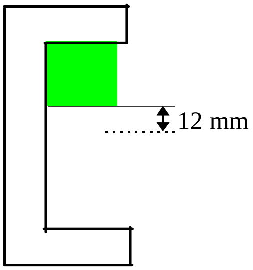

Figure 1: Stripper foil for argon ions, with two unsupported edges.

3 CLOSED ORBIT CORRECTION PROGRAM

A new closed-orbit correction program has been written [5]. It uses a Singular Value Decomposition (SVD) method for solving the set of linear equations describing the changes of the beam position monitor readings due to changes of corrector excitations.

The SVD method has turned out to be especially well suited for the vertical closed orbit correction, for which the response matrix is degenerate.

The use of the SVD algorithm has also made it straightforward to find optimal solutions of underdetermined as well as overdetermined sets of equations by solving the weighted least-squares problem, viz. minimising the rms. of the residual closed orbit deviations at the beam position monitors or the corrector excitations.

4 MODULATION OF ELECTRON BEAM ENERGY TO IMPROVE STABILITY OF ELECTRON COOLED ION BEAMS

Coasting ion beams of high intensity tend to become longitudinally unstable if electron-cooled to small momentum spread. The instability is manifested as a spontaneous bunching of part of the beam, observable with pickup electrodes and Schottky noise monitor. Such instabilities are a disturbance to experiments at CELSIUS, and force us to limit the stored beam ion intensity to lower values, than would otherwise be possible.

We have started trying an idea of V.V. Parkhomchuk [6] to put a minimum limit on the momentum spread of electron cooled ion beams by modulating the cooling electron beam energy. This is done by modulating the voltage on the drift tube (a metallic structure, which acts as conducting environment of the electron beam along the electron cooling interaction section). The frequency of the modulation is chosen to be much higher than the cooling rate; we have typically operated with 1 kHz. Through an audio hi-fi amplifier any waveform can be applied, in particular we have tried square and triangular wave modulation.

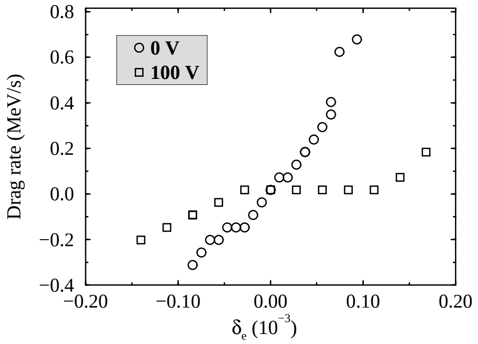

Figure 2: Measurement of the effect of modulation on the cooling drag rate which is plotted vs. proton and electron relative momentum.

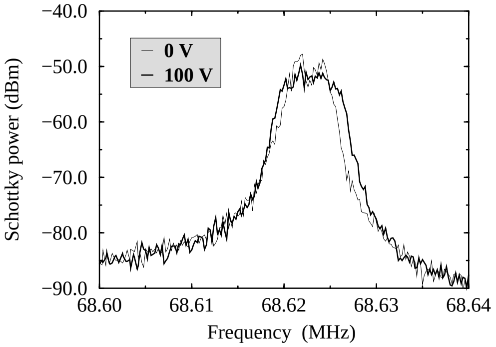

Figure 3: Comparison of longitudinal Schottky spectra of 477 MeV protons cooled with modulated and not modulated electron beam.

We have seen that such modulation of the electron beam energy indeed helps to stabilise high-intensity proton beams, which otherwise tend to self-bunch. Figure 2 shows the effect on the cooling drag rate for small momentum deviations and figure 3 shows the corresponding longitudinal Schottky spectra for a case where 477 MeV protons were cooled with 150 mA electrons, modulated with 100 V square wave.

5 QUICK TURN-OFF OF ELECTRON-COOLER BEAM CURRENT

After accumulation with electron cooling, the electron beam must be turned off in order not to disturb the stored beam during the acceleration. The electron beam current is controlled by the voltage on the gun anode. The gun anode power supply has a voltage multiplier output and therefore can only act as a source of current and not as a current sink. The time needed, for this power supply, to reach zero is of the order of 200 ms. During that time, the space charge depression, which reduces the kinetic energy of the electrons, gradually decreases. Thus, the velocity of the electron beam is briefly higher than it was during the accumulation. Experience has shown, that the drag force exerted by the electron beam on heavy ions is strong enough, that the short interval of unintended acceleration of the ion beam, which is done by the electron beam drag force while going to zero, is enough to create beam loss.

A circuit to quickly turn off the electron beam of the electron cooler has been developed. The capacitance of the gun anode and the conductors to it, is discharged through a 40 kV triode tube [7].

6 BTF-MEASUREMENTS

Longitudinal and transverse beam transfer function measurements have been performed and machine impedance of CELSIUS have been determined [8]. The measurements were made with proton and argon beams at different energies. The transfer functions were obtained by exciting the beam with a noise generator and measure the response with a digital oscilloscope. The signals have been smoothed by time gating technique.

7 THE WASA/PROMICE DETECTOR SET-UP AS A PROFILE MONITOR

The straw-chamber tracker and the Jülich hodoscope [9] can detect both the elastically scattered proton and the recoiling proton in elastic events caused by a proton beam passing through hydrogen rest gas in the region from 45 to 70 cm downstream from the cluster-jet target. Tests have been made, which have established a technique to get on-line beam profile and position information from such data. In experiments with a hydrogen cluster-jet target, there will normally be enough hydrogen rest gas in the relevant region for count rates in the profile spectra higher than 10 counts per second at typical proton beam intensities of a few mA and, in addition to on-line information, off-line beam conditions can be obtained from the data tapes.

Events having a trigger signature of two charged particles in the forward direction are studied and selection criteria are applied, so that only those events are kept, which have both scattering angles larger than 30° and vertices well distinguished from the cluster-jet region. In a straw chamber plane there is then two well defined hits, corresponding to the scattered and recoiling protons, and thus beam position and profile information can be obtained. Figure 4 shows an example of such profiles of an uncooled beam of 400 MeV protons.

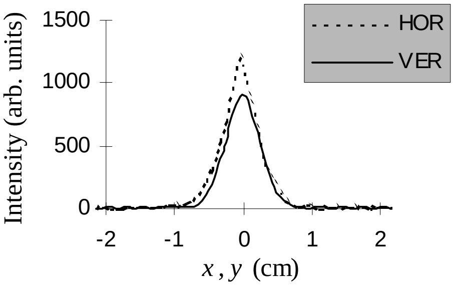

Figure 4: Profile of uncooled 400 MeV proton beam, measured with the WASA/PROMICE detector setup.

8 INTERNAL CLUSTER-JET TARGETS

In addition to already developed cluster-jet targets [4], a cluster beam of helium has been produced in spite of expected difficulties due to the low temperatures required. The cooling when the helium gas is expanding through the nozzle into vacuum is evidently sufficient to give the conditions for cluster formation. An effective target thickness of 6×10^{13} atoms/cm^2 has been determined by measuring the energy loss of the circulating beam. However, the low pumping speed for helium of the ion pumps in the quadrants close to the target gives high pressure which results in a substantial fraction of the effective target thickness. The home-built cryo-pump used as target-beam dump together with the surrounding turbo-pumped vessel has been shown to be very efficient also for helium.

9 INTERNAL PELLET TARGETS

The pellet-target system [10] has already been described to fulfil all major requirements put by the WASA experiments. The developments made during the last two years include the production of smaller pellets, 30 µm instead of 40 µm, the production of deuterium pellets in addition to the hydrogen pellets, and improvements of the diagnostic systems for alignment and tracking of the pellet stream.

10 THE WASA 4π PROJECT

In order to exploit the possibilities to study rare processes at CELSIUS, the WASA 4π detector facility is now being prepared for experiments [11]. The research programme is focused on rare decays of light neutral mesons produced in proton-proton and proton-deuteron reactions. Of interest are π^0 and η decays but other mesons such as the ω and η' may be studied provided the CELSIUS maximum energy is increased. The goal is to produce and measure 10^{10} η-mesons and 10^{11} π^0-mesons per year. With the anticipated precision, basic aspects of the Standard Model, such as conservation of basic symmetries, Chiral Perturbation Theory and very rare electromagnetic decays can be tested.

The WASA detector is designed to:

- handle luminosities of about 10^{32} cm^{-2} s^{-1} using frozen pellets of H_2 and D_2 as targets, in a coasting beam of about 10^{10} protons.
- measure charged particles and photons over a solid angle close to 4π with high accuracy in energy, charge and track co-ordinates.
- minimise the photon conversion probability in the target, in the beam tube and in the vertex detector.
- provide a fast trigger for the selection of rare events.

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