RECENT ACTIVITIES AT CELSIUS

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Abstract

The CELSIUS ring is used for nuclear and particle physics experiments with stored ion beams interacting with thin internal targets. The target that has been used until now for physics is a cluster-jet target, producing beams of elements from hydrogen to xenon. An electron cooling system is used to accumulate beams that are only delivered with a low intensity from the injector, the Gustaf Werner Cyclotron, and often also to cool the beams after acceleration to improve the conditions for the experiments. A target consisting of a stream of frozen hydrogen micro-spheres (pellets) has been installed, and first tests of the interaction between this target and stored and cooled proton beams have been done and are promising.

1 GENERAL

The CELSIUS ring at the The Svedberg Laboratory in Uppsala, Sweden [1, 2] is intended for high-precision intermediate-energy physics experiments with stored ion beams interacting with very thin internal targets. The ring is operated in cycles with intervals for injection, acceleration, flat (or ramped) top, and return to the injection level. During the cycles, which have a typical duration between two and five minutes, the magnet power supplies and the rf. frequency and voltage are controlled by function generators containing vector tables. An electron cooling system [3], with voltage up to 300 kV and current up to about 1 A is used for accumulation of heavy ions and often also to cool beams after acceleration.

2 BEAMS

The beams in CELSIUS range from protons to argon ions. At present, the maximum rigidity is 7 Tm, corresponding to 1360 MeV protons or 470 MeV/*u* ions with charge-to-mass ratio of ½. A proposal to increase the magnetic fields by 30 %, in order to reach 9 Tm, has been submitted.

Stripping injection is the preferred injection method for light ions [4], usually giving quite high stored beam intensity; typically 1×10^{11} for protons, 1×10^{10} for deuterons, alpha-particles and $^{14}N^{7+}$ ions, 5×10^{9} for $^{16}O^{8+}$ ions, and 1×10^{9} for $^{20}Ne^{10+}$ ions. These intensities are reached with a single shot from the cyclotron for the cases of protons, deuterons, and alpha particles, and with accumulation with electron cooling for the heavier ions. Multi-turn injection without stripping has been used to store small intensities of polarised [5] as well as unpolarised protons, molecular ions (D_2^+) and $^{40}Ar^{18+}$ ions.

3 INTERNAL TARGETS

CELSIUS has two internal target stations [6], a cluster-jet target, which has delivered target beams of elements ranging from hydrogen (0.2 ng/cm^2) to xenon (3 ng/cm^2) for nuclear physics experiments since 1989, and a hydrogen pellet target [7], which will be used by the WASA collaboration [8] for high-precision experiments on rare decays of light mesons. This target produces a stream of about 7×10^{4} hydrogen pellets per second. These have a diameter of 30 μm and a velocity of 60 m/s. The effective

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target thickness can be adjusted with skimmers to the desired value 5×10^{15} cm^{-2}.

4 INSTRUMENTATION

4.1 Automatic closed orbit corrections

The horizontal and vertical positions of the closed orbit in CELSIUS are measured with a total of 10 beam position monitors [9]. The data are displayed and saved for further processing by programs running under the main control system [10].

Closed-orbit corrections make use of an inverted measured response matrix. The horizontal closed orbit corrections work very well, especially after the installation of a “radial loop” which is a feedback system that adjusts the main magnet power supply to keep the closed orbit centred at a monitor which is placed where the dispersion is large. The vertical closed orbit corrections on the other hand used to be plagued by near singular response matrices. This is due to closely spaced correctors, which are almost degenerate, and consecutive beam position monitors without vertical correctors between them. This has been solved by using a “singular value decomposition method” [11] which removes the near-singular subspace of the response matrix at the expense of a residual closed orbit deviation. This method also minimises the rms. excitation of the correctors.

4.2 Automatic tune measurement and correction system.

An automatic tune measurement system has been developed [12], see figure 1. To do a measurement the beam is excited with a magnetic kicker, which is mounted at 45° with respect to the horizontal plane to excite the beam horizontally and vertically at the same time. The resulting oscillations of the beam are measured by a beam position monitor and the tunes are found by FFT-analysing the signals. To make this as fast and simple as possible, the frequency range containing one betatron sideband is mixed down to a low frequency range (0-140 kHz). By letting the mixing signal, formed in a synthesiser, follow the expected tune frequency the FFT analysis is made over the same frequency range all the time, and is independent of the rf. frequency and the tune itself. Thus, what is actually measured is the deviation of the tune from the expected tune. The sampling and the FFT calculation is done by a digital oscilloscope, with a calculation time of less than a second. The result is sent to the control computer, in which improved vector tables for the quadrupoles are calculated. It is possible to measure the tunes once per second with an error of ± 0.001.

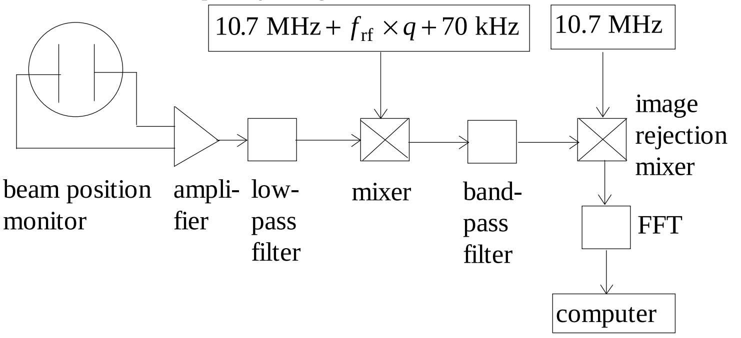

Fig. 1. Simplified schematic of the measurement part of the tune measurement system. The FFT is performed in a digital oscilloscope.

4.3 Magnesium-jet beam profile monitor

A magnesium-jet beam profile monitor has been built for CELSIUS by the Budker Institute for Nuclear Physics at Novosibirsk according to a principle of operation that was developed already for the NAP-M ring [13]. It can be used both to measure beam profiles and to measure cooling times, and has been found to be a useful tool for correctly setting up electron cooling [14].

4.4 H^0 beam profile monitor

Neutral hydrogen atoms, H^0 or D^0, are emitted in the forward direction in the electron cooler while cooling protons or deuterons. The nuclei of these atoms penetrate a thin window and reach a silicon strip detector with a thickness of 485 μm. There are 40 strips with a pitch of 1 mm on each side of the detector. These are horizontal on one side and vertical on the other to allow simultaneous recording of horizontal and vertical profiles.

4.5 New DC beam current transformer

The old DCCT at CELSIUS, which was bought second hand from the decommissioned ISR, has worked very well over many years now. However, the space that it occupies is claimed by the WASA 4π-detector [8]. Therefore, and at the same time to improve the performance, a new parametric current transformer has been built for CELSIUS [15].

5 EXPERIMENTS

The present experimental program at CELSIUS is focused on intermediate-energy physics with internal targets [16]. Several features of the storage ring are being exploited:

- The use of *ultra-thin internal targets* in the experiments allows the measurement of reaction products, that would be stopped in a solid target. An example is the measurement of heavy nuclear fragments from heavy ion collisions. This will be exploited by the CHICSi collaboration [2]. The fact that the internal cluster-jet target is pure and windowless makes the target-related background minimal. This feature is taken advantage of by the WASA/PROMICE collaboration, which has an extensive program on meson production in light-ion collisions. They make measurements using a comprehensive experi-

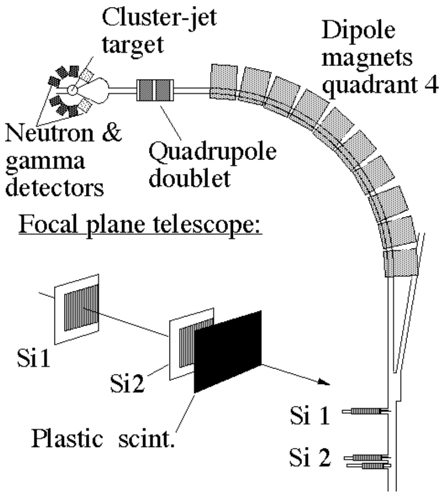

Fig. 2. Schematic picture of an experiment that uses the magnets after the target as a magnetic spectrometer. Si1 and Si2 are silicon strip detectors.

mental set-up [2, 17-19] to study reaction mechanisms and meson-nucleon interactions.

- *Electron cooling* provides excellent beam energy definition, which is a prerequisite for threshold measurements. This has been used e.g. by the WASA/PROMICE collaboration to make precision measurements on the onset of π^0 production in $p + p$ collisions [17].
- Part or all of the quadrant following the target is used by several groups as a *magnetic spectrometer* for recoiling systems emitted at zero degrees [2, 20], see fig. 2. Examples of reactions that have been studied are ($d + d \rightarrow {}^4He + 2\pi^0$), ($p + d \rightarrow {}^3He + \eta$), and the giant resonance in (${}^{17}O + Xe$).
- *Slow ramps* of the beam energy is used by several groups as an easy way to cover a large energy range [21].
- A *compact spectrometer*, CLAMSUD [22], from INF-Catania has recently been installed in the cluster-jet target region. The primary goal is to measure subthreshold kaon production in proton-nucleus and nucleus-nucleus collisions. Its solid angle acceptance is 14 msr with a momentum acceptance of ± 20 % up to 270 MeV/*c*. Scattering angles between 30° and 90° can be covered. The INF-Catania group offers the use of this spectrometer as a part of the CELSIUS facility to other groups.

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