STATUS OF THE CELSIUS PROJECT

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Abstract: A cooling-storage ring called CELSIUS is being brought into operation at The Svedberg Laboratory (T.S.L.) in Uppsala. The ring will store, accelerate, and cool particles (from protons to ions with $A \approx 100$, including polarized protons and deuterons) accelerated in the Gustaf Werner Cyclotron, and will be used for nuclear and particle physics with high resolution using thin internal targets. Beams with velocities lower than $0.78c$ (up to 550 MeV for protons, all energies in question for other particles) will be cooled in a 10 - 300 keV, 2.8 A, 2 cm diameter electron beam. The maximum rigidity of the ring is presently 7 Tm, corresponding to 2.1 GeV/c. A general purpose experimental station with a cluster gas-jet target and a fibre target has been installed in the ring. The cluster gas-jet target presents a target thickness up to $3 \cdot 10^{14}$ atoms/cm^2. The target has been tested with hydrogen, nitrogen, and argon, showing well-bounded intensity profiles. Fibres of carbon and refractory metals show promising properties as internal targets for high-luminosity experiments. A "pellet" target (to be developed) will produce solid hydrogen pellets with a diameter of about 20 µm. First beam tests with the ring, running beam through three of the four quadrants, have started.

General

CELSIUS [1] is a cooler storage ring for particles, accelerated in the Gustaf Werner Cyclotron [2], see fig. 1.

This ring is intended for high resolution nuclear and particle physics with cooled and stored beams interacting with thin internal targets.

Since the cyclotron's internal PIG ion source will be supplemented both with an external ECR ion source and with an external polarized ion source, the particles will range from protons up to ions with $A \approx 100$, and will include polarized protons and deuterons.

The maximum magnetic rigidity is 7.0 Tm (1 T · 7 m) corresponding to a momentum per charge of 2.1 GeV/c or a kinetic energy of 1360 MeV for protons and 470 MeV per nucleon for particles with charge to mass ratio 1/2.

The layout of the CELSIUS ring is shown in fig. 2. The ring consists of four 90° bends and four straight sections. The circumference is 82 m. Each bend consists of 10 bending magnets which share a common coil. One straight section contains the injection elements, and has space reserved for a possible future addition of an extraction system. The next straight section is almost filled with diagnostics equipment, but may in the future also contain a second experimental station. The third straight section contains the electron cooler with its magnetic guiding system, a compensation solenoid and the accelerating rf cavity. The fourth straight section is the main experimental straight section which will hold one out of several internal targets, see below. A few lattice parameters are given below:

Q_x, Q_y	1.68,	1.90	
Q_x', Q_y'	−5.07,	−2.18	
γ_{tr}	2.67		
β_x, β_y, D_x (diagn., target s.s.)	1.13,	1.29,	6.61 m
β_x, β_y, D_x (inj., cooling s.s.)	8.06,	5.84,	−1.58 m
β_x, β_y, D_x (max)	25.18,	17.98,	9.84 m

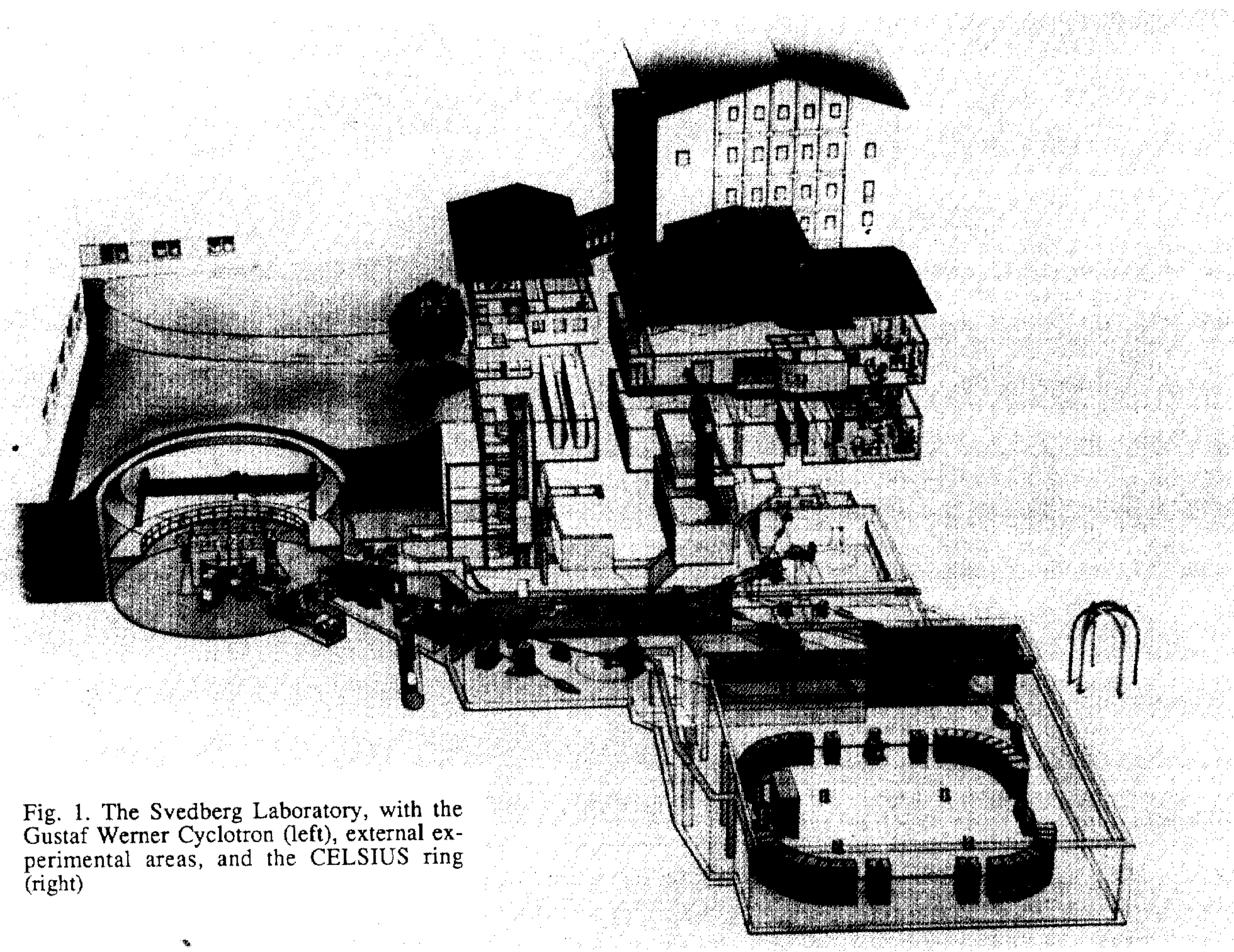

Fig. 1. The Svedberg Laboratory, with the Gustaf Werner Cyclotron (left), external experimental areas, and the CELSIUS ring (right)

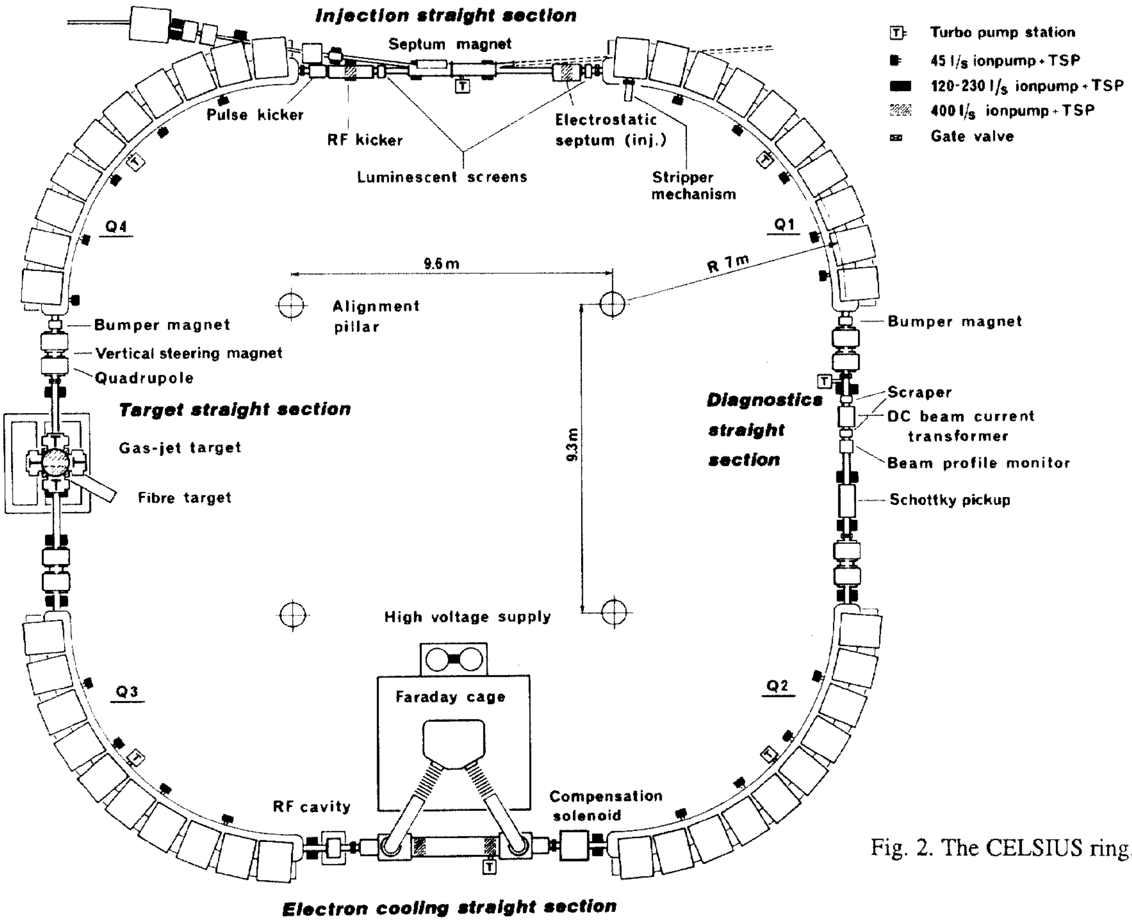

Fig. 2. The CELSIUS ring.

The magnet system in CELSIUS is reflection symmetric about centers of opposing straight sections. Thus there are four quadrants with identical lattice functions (disregarding the influence of the electron cooler and its magnetic guiding system). The beam has narrow waists (small β) at the centers of the target and diagnostics straight sections, and is relatively parallel (large β) on the injection and cooling straight sections.

There are quadrupole doublets at the beginning and end of the target and the diagnostics straight sections.

Vertical closed orbit control will be assured by vertical steering magnets, which are placed in the center of each quadrupole doublet.

No chromaticity correction is foreseen.

The (linear) transverse acceptance is about 120 π mm mrad in both planes.

Time cycles

CELSIUS will normally be operated in cycles with duration 1-100 s. There is a time window for injection, during which a beam pulse should be received from the cyclotron. Before acceleration the beam will be cooled at the injection energy in order to require less dynamic aperture during the acceleration. Sometimes it may be advantageous to stack several cyclotron pulses, and to cool them in between. The acceleration will typically take 12 s if the magnetic field is to be increased by a factor of about three, i.e. for acceleration of protons from their typical injection energy of 185 MeV to their maximum energy of 1360 MeV. At the experimental field level the beam will be exposed to the internal target and cooled (except for protons with energy above 550 MeV, which travel faster than electrons of the maximum energy of 300 keV, and will only be cooled at the injection energy). After a certain period of time, determined by the life-time and the required preparation time of the beam, the magnetic fields will return to the values for injection, and a new beam will be injected from the cyclotron.

Dipole magnets

The dipole magnets in CELSIUS were previously used in the ICE ring at CERN [3]. They are solid-core combined function magnets, with quadrupole strength of ± 0.13 m^{-2}.

The maximum field is presently 1.0 T, limited by the power supply. Magnetic field measurements have been performed up to this field level.

The magnetic field distributions have been computed for higher field levels. It turns out that saturation effects influence the field distribution significantly at field levels above 1.2 T, which would correspond to a maximum momentum of 2.52 GeV/c , or a maximum kinetic energy for protons of 1.75 GeV.

The bending radius is 7.0 m. There are pole-face windings in four D-magnets per sector. These will be used to adjust the sextupole- as well as the quadrupole-field in these magnets. There are also back-leg windings in three magnets in each sector for horizontal closed orbit control.

During the acceleration the field in the magnets rises. Eddy currents are induced in the solid-core steel of the magnets [4]. These eddy currents tend to delay the change of the magnetic field, and to influence the magnetic field distribution in the magnets, and therefore have to be compensated. A set of pick-up coils is permanently installed in one of the quadrants of CELSIUS, and will be used to measure the magnetic field once every 500 milliseconds during the whole cycle at three different radial positions in each magnet. The information obtained by integrating the output voltage from these pick-up coils will be used to create tables in the control computer of how the dipole, quadrupole, and sextupole components of the field varied during the measured cycle as a function of time. From these data new and better function-generator tables for the main magnet power supply and the pole-face winding power supplies will be computed. They will also be used to program the quadrupole magnet power supplies such that the currents in the quadrupole magnets will always be proportional to the average field strength in the dipole magnets. Injection into CELSIUS will only be attempted once several such iterations have been performed. Each time the experimental conditions are to be changed a few new iterations have to be performed (unless appropriate tables are known from previous experience).

Injection

Two different injection methods will be employed: *Normal multi-turn injection* and *stripping (charge-exchange) injection. Normal multi-turn injection* will be used for protons and light ions, which are fully stripped during acceleration in the cyclotron. The closed orbit will first be displaced on the injection straight section to a position close to the "septum", which separates the injection path from the circulating beam. The injection will take place during the time when the closed orbit is allowed to return quasi-exponentially to its normal position. It is expected that particles can be stored with this *normal multi-turn injection* method during about 10 revolutions.

Also during *stripping injection* the closed orbit will be displaced with the bumper magnets to one side of the vacuum chamber at the beginning, and it will be gradually moved back to the center of the vacuum chamber during the injection process. In this case the particles will hit a stripping foil placed in the first CELSIUS bending magnet that is passed by the injected particles. There they will loose the last one or few electrons and become fully stripped. With *stripping injection* it will be possible to gain about one order of magnitude in the number of revolutions. This injection method will be used for such particles which are not fully stripped during acceleration in the cyclotron, and can be stripped of one or several electrons when they are injected into CELSIUS.

Diagnostics

There are 8 combined horizontal and vertical electrostatic pickups to measure the position of the beam at the beginning and end of each bending section. They will be used to measure the position of the closed orbit, and one of them will be used in a servo loop involving the radio-frequency system.

There is a DC beam current transformer [5], which will be used for measuring the intensity of the stored beam, and has a resolution of 10 μA (corresponding to $3\cdot10^7$ protons at 2 MHz).

A wall-gap monitor will provide the most sensitive beam current monitor for bunched beams [6].

There is a Schottky pickup. It will be used together with a spectrum analyzer for measurements of the momentum spread, the horizontal and vertical tunes and chromaticities, and the transverse rms. beam size.

A pulse kicker (0.3 μs pulse length) and a transverse rf. kicker provide alternative possibilities to excite the beam, e.g. for tune measurements.

Electron cooler

The construction of the electron cooler takes place at the Royal Institute of Technology (KTH) in Stockholm. The electron beam will be completely immersed in a homogeneous longitudinal magnetic field of up to 0.18 T (typically about 0.15 T) produced by straight solenoids on the 2.5 m long interaction region and on the gun and collector parts, and by magnetic toroids in which the electron beam will be deflected in and out of the circulating beam by a superimposed dipole field.

The electron beam voltage will be up to 300 kV. For voltages above 40 kV the beam current will be up to 2.8 A. The electron beam diameter will be 20 mm.

Extensive computer modeling studies of the electron gun and the electron collector have been made [7].

A pencil electron beam (0.05-0.1 mm diameter, 4 kV, 20 μA) will be used to determine the shape of the magnetic field lines in the electron cooler. Transverse field components that are 10^{-4} of the longitudinal field can be measured by this method.

Experimental stations and targets

A general-purpose experimental station, including a cluster gas-jet target, a fibre target, and a common scattering chamber, has been installed on the target straight section.

The cluster gas-jet target consists of a differentially pumped beam source where the cluster beam is formed by pushing a gas through a cooled nozzle. After passing a skimmer and a set of collimators the beam enters the scattering chamber. It is finally collected in a cryogenic beam dump. The cross section of the target beam at the intersection with the circulating CELSIUS beam, 250 mm from the nozzle, is oval-shaped, defined by the oval skimmer, with a length of 8 mm along the circulating beam and 5 mm across. The target beam profiles are shown to be very well bounded. Target thicknesses of $3\cdot10^{14}$, $5\cdot10^{13}$ and $2.4\cdot10^{13}$ atoms/cm^2 have been obtained for hydrogen, nitrogen and argon, respectively. The gas pressure in the scattering chamber with the target beam running was 10^{-7} mbar.

Fibre targets, mounted vertically in a holder, may be introduced into the same scattering chamber. Fibres of the refractory elements carbon, molybdenum and tungsten, and of carbide compounds, with diameters of about 5 μm show promising properties for use as internal targets in high-luminosity experiments. The target thicknesses are locally very high, of the order of 10^{19} atoms/cm^2, but taking into account the fraction of the circulating beam covering the fibres and the sweeping of the beam over the fibres, the effective target thicknesses become in the range from 10^{14} to 10^{16} atoms/cm^2.

This is true also for a proposed "pellet" target, in which the stored beam will be exposed to a beam of frozen hydrogen spheres of 20 μm diameter [8].

Ultra-high vacuum

CELSIUS is designed for a degree of vacuum of 10^{-11} mbar [9]. This degree of vacuum is required for operation with heavy ions, in particular when they are not fully stripped. Therefore all materials that are exposed to the vacuum are metallic, ceramic, or glass, and most parts of the vacuum chambers are made from stainless steel grade AISI 316 LN, which retains both its hardness (particularly necessary in the Con-Flat knife-edges) and its non-magnetic properties even after the so-called vacuum firing (heat treatment at 950°C for 2 hours in vacuum of 10^{-5} mbar or better), which is necessary in order to reduce the content of hydrogen in the stainless steel.

The entire vacuum system will be baked to 300°C except for a few components, which are limited to 200°C.

Installation and start-up status (June 1988)

All magnetic elements of the ring and the beam line to CELSIUS have been installed, aligned, and mapped. All vacuum chambers have been installed in the beam line, and in the first three quadrants of CELSIUS. A straight beam pipe is installed in the place of the electron cooler, which will be installed in the ring during 1989. The gas-jet target and the fibre target are in place.

The vacuum chambers will be installed in the fourth quadrant in September, when the testing of the system to compensate for the eddy current effects in the magnets will be completed.

Tests to transport a beam of protons through the beam transport system and the first three quadrants of the CELSIUS ring are in progress (June 1988).

The fall of 1988 will mainly be used to test the two injection methods and acceleration with protons.

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