CELSIUS AS AN η FACTORY

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Abstract

The CELSIUS ion storage ring at the The Svedberg Laboratory is in operation since 1989 for light-ion and heavy-ion nuclear-physics experiments in the interme-diate energy region. High-precision experiments on rare decays of light mesons are currently being prepared within the WASA project - a high-luminosity experiment using a close to 4π detector configuration. A crucial component in the project is a novel internal-target system producing a stream of frozen hydrogen microspheres (pellets). With an effective target thickness of $5x10^{15}$ atoms/cm^2 and with 10^{10} protons in the ring, the luminosity will be of the order of 10^{32} cm^{-2} s^{-1}. The cross section for η production for 1.36 GeV protons is 5 μb, giving a production rate of 30 million η mesons per day at a 75% duty cycle. The CELSIUS ring with the pellet-target system will thus serve as an efficient η factory.

1 THE CELSIUS RING

The CELSIUS ring [1, 2], shown in Fig. 1, is a combined accelerator and storage ring with a circumference of 81.8 m. The ring consists of four 90º magnet quadrants and four straight sections. The latter are used for injection of the ions from the Gustaf Werner cyclotron, electron cooling of the ions, and experiments at two target stations with a cluster-jet [3] and a pellet target [4], respectively.

Each quadrant is built up of 10 dipole magnets which share a common coil. The four quadrants have identical lattice functions. At the beginning and end of the two target straight sections, quadrupole doublets are used to focus the beam on the targets and for control of the working point. The maximum field in the dipole magnets is at present 1.0 T which together with the radius of 7.0 m give a maximum rigidity of 7.0 Tm. This corresponds to maximum energies of 1360 MeV for protons and 470 MeV/*u* for ions with a charge-to-mass ratio of 1/2.

Ion beams ranging from protons to $^{20}Ne^{10+}$ have been stored and accelerated in CELSIUS following stripping injection. In the case of protons, of main interest in the present applications, 96 MeV singly charged hydrogen molecules H_2^+ are brought to CELSIUS and stripped in a 30 μg/cm^2 carbon foil. The number of stored protons in the ring is typically $1x10^{11}$.

Following acceleration of the stored beam, the data taking is made during the flat (or ramped) top, after which the magnets are returned to the injection level, ready to accept the next injection. The cycle period is optimized with respect to the integrated luminosity.

The beam properties may be improved by the electron cooling working up to energies of 550 MeV/*u*.

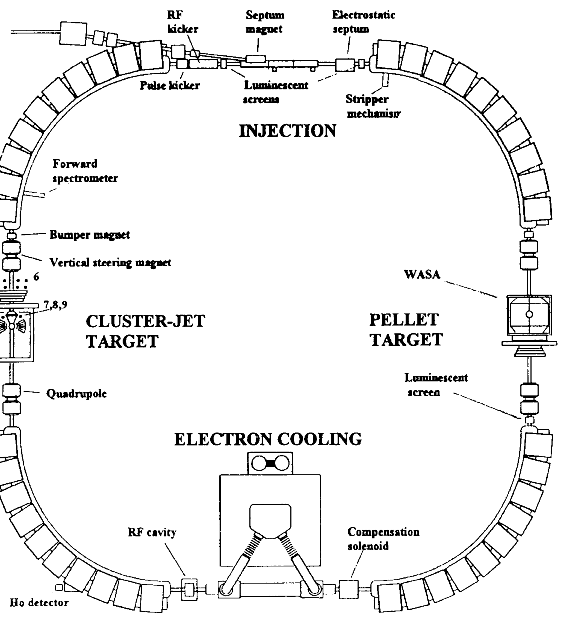

Fig. 1 Layout of the CELSIUS storage ring with the its four magnet quadrants and four straight sections used for injection, electron cooling and experiments. The WASA experimental station housing the pellet target is located to the right.

2 THE PELLET TARGET

The target system to be used in the WASA experiments has to fulfil a number of strong requirements, like giving a high target thickness, about 20 times that of the cluster-jet target [3] at CELSIUS; to fit the detector system geometrically, i.e. a target beam travelling about 2 m in a narrow tube through the central detector; and to give a good vertex definition, an acceptable pertubation to the stored beam and to the ring vacuum. S. Kullander [5] has proposed a stream of frozen hydrogen microspheres (pellets) to fulfil these requirements. A prototype for the production of microspheres of hydrogen and injection into vacuum has been developed by B. Trostell [6]. This system has now been modified and is included in the pellet-target facility [4] installed at the CELSIUS ring (see Fig. 2).

The production of the pellets by breaking up a liquid jet into droplets at triple point conditions and the injection into vacuum is described in detail in Ref. 6. The pellets of 40 μm diameter, later reduced to 30 μm by using a more narrow injection nozzle, have a speed of 60 m/s and a total flow of about 7×10^4 per second. The pellet stream moves with an angular divergence of $\pm 0.04^o$ about 4 meters before being trapped in a cryogenic beam dump. On its way, it is passing an experimental chamber connected to the ring. The new computer-controlled coordinate tables for directing the droplets into the vacuum-injection capillary and for directing the pellet stream down through the pellet system to the beam dump have been of greatest importance in optimizing the pellet-target system. The development of diagnostics systems for alignment of the pellet stream and for tracking individual pellets is in progress. Computer simulations of a vertex-finding system for the pellet target have been performed by S. Golberg and L. Gustafsson [7]. The pellet-target system is connected to the TSL general control system, and all main parameters may be adjusted either locally at the CELSIUS hall or remotely from the CELSIUS control room.

The hydrogen pellets have been exposed to 200, 310 and 900 MeV protons and 570 MeV deuterons circulating in the CELSIUS ring. The full flow of 40 μm pellets gave an effective target thickness of about 1×10^{17} atoms/cm^2 and a pressure in the scattering chamber of 1×10^{-5} mbar. The life-time of a 310 MeV proton beam was about 1 s. The pellet stream, and thus the effective target thickness, has been reduced by installing a skimmer of 1 mm diameter 0.78 m downstream the nozzle. Variations of the pellet stream may furthermore be obtained by slightly changing the alignment.

The results from the CELSIUS test experiments show that an optimal target thickness of 5×10^{15} atoms/cm^2 will give acceptable half-lives of the circulating ion beam, a few minutes at energies around 1 GeV, as well as acceptable vacuum conditions, about 10^{-6} mbar, in the scattering chamber.

All major requirements on the target system to be used in the WASA experiments have been shown to be fulfilled by the hydrogen pellet target. Future develop-ments concern the diagnostics for the pellet tracking, and the production of deuterium pellets.

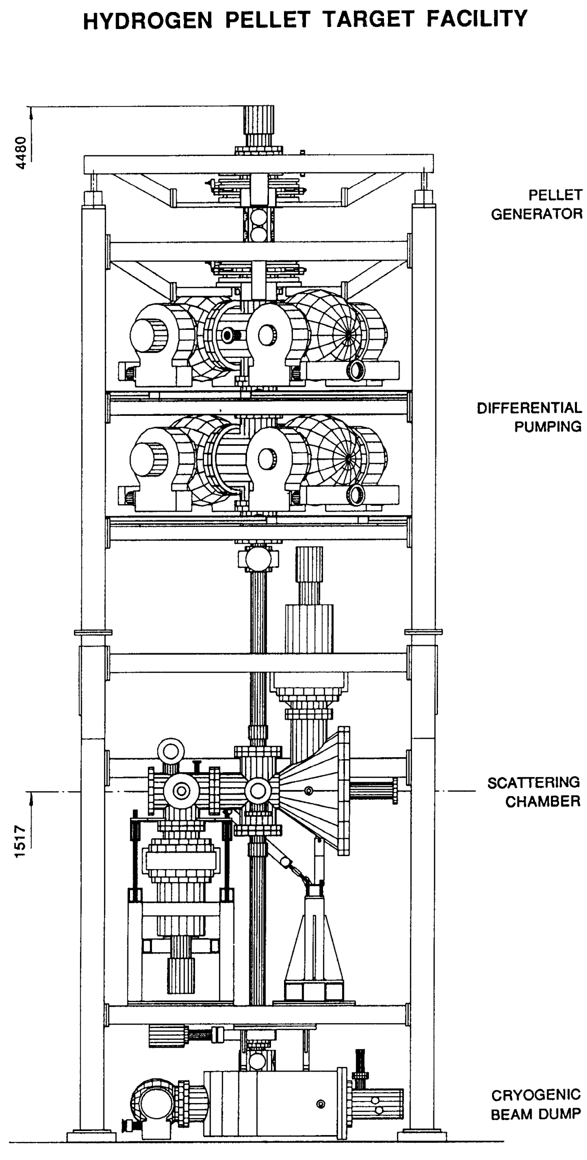

Fig. 2 The pellet-target facility installed at the CELSIUS storage ring. The pellets, produced in the pellet generator, are passing a differentially pumped system to interact in the scattering chamber with the ions in the ring at a distance of about 2.5 m from the nozzle, and to be collected in a cryogenic dump 1.4 m further down.

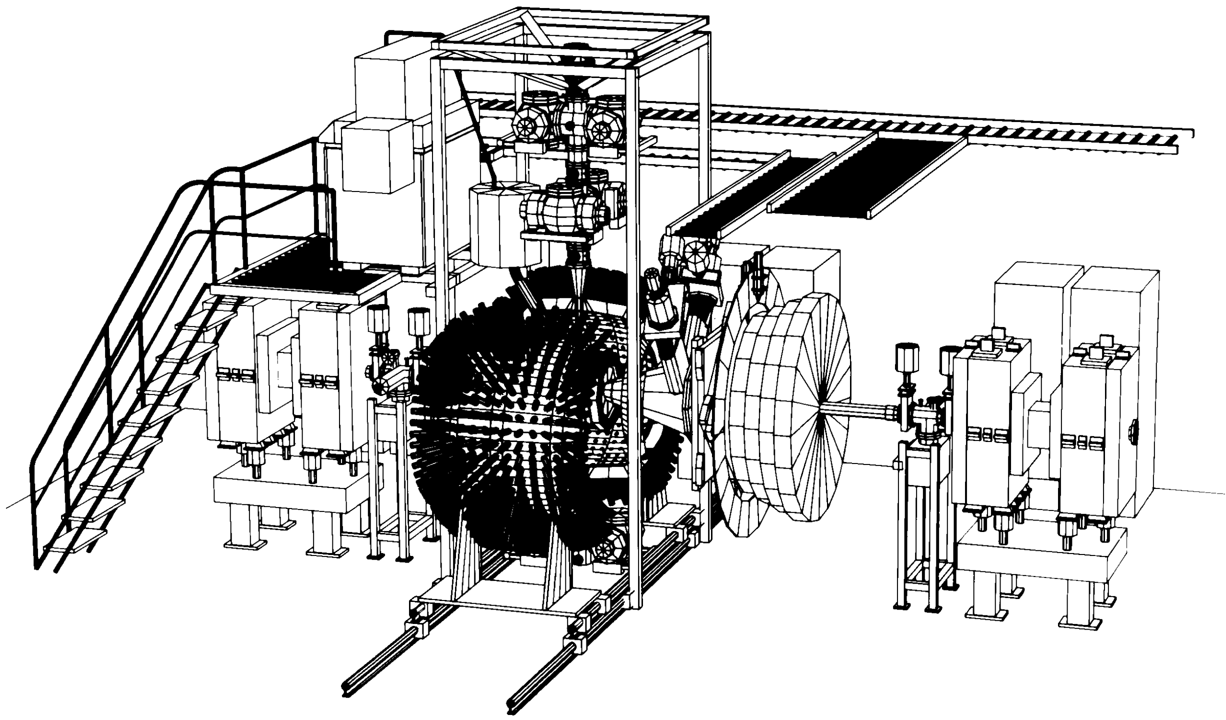

Fig. 3 Layout of the WASA experimental setup with the forward detector to the right, the pellet generator on top and the cryogenic system for the solenoid to the left. The iron yoke for magnetic field return with the CsI calorimeter PM tubes sticking out is seen in the center. The two yoke halves are mounted on a rail system to enable access to the scattering chamber and the central part of the detector.

3 THE WASA PROJECT

The research progam of the WASA 4π project [1, 8] is focused on rare decays of light mesons produced in reactions between protons in the CELSIUS ring and hydrogen pellet targets. The rare decays of neutral mesons will serve as probes of fundamental symmetries. With the anticipated precision, basic aspects of the standard model can be tested.

The WASA experimental setup (see Fig. 3) includes the pellet-target system described above, a central detector for particles scattered isotropically, a forward detector for particles scattered at angles below 18^o and a tagging spectrometer located in the magnet quadrant following the WASA setup for He recoils emitted at 0^o. The scattered beam and target particles are emitted preferentially in the forward direction whereas the meson decay products are emitted more isotropically.

The main emphasis of the WASA experimental programme is put on the decay channels of the η meson. The CELSIUS ring with the pellet target will serve as an efficient η factory producing about $3x10^7$ η mesons per day at a luminosity of 10^{32} cm^{-2} s^{-1} and a duty cycle of 75%. A positive outcome of the developments of deuterium pellets will increase the production rate about a factor of 5, and in the case of the pd --> $^3He\eta$ reaction close to threshold give a clean tagging of the η production.

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