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COMMISSIONING OF THE NEW HIGH INTENSITY 72 MEV INJECTOR II FOR THE SIN RING CYCLOTRON.

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Summary

Commissioning of the SIN Injector II cyclotron started in spring 1984 and by spring 1985 a proton beam current of 0.55 mA was extracted. The performance of the principal components of the overall injector can be summarized as follows: (1) The nominal ion source extraction voltage is 60 kV and the maximum current from the 860 keV Cockcroft-Walton pre-injector is presently about 10 mA DC; (2) a phase acceptance up to 40 deg can be achieved without a buncher, but making use of a third harmonic flattopping RF-system; (3) the 100 turns in the cyclotron are completely separated leading to an extraction efficiency of more than 99.9%

Initial tests in combination with our 600 MeV ring cyclotron have resulted in a 0.18 mA beam on target. The majority of future operation of the 600 MeV cyclotron is scheduled to be with Injector II.- The next steps toward higher intensity are improvements of the ion source proton efficiency and the addition of a buncher in the injection line. The ultimate intensity limit is thought to be in the mA region due to an instability from longitudinal space charge forces.

Introduction

In 1978 SIN obtained the green light from the Swiss government to construct a second injector for its main ring cyclotron. The Injector I multipurpose isochronous cyclotron, serves not only as a real injector, but also delivers variable energy beams of light ions for 11 weeks per year, during which period the main facilities at SIN (with all its secondary beam lines for pions and muons) are sitting idle. The purposes of the new injector are firstly,to gain these "low energy" weeks for the "high energy"-mode and secondly to boost up the intensity level by an order of magnitude; this latter in view of the fact that the 590 MeV ring cyclotron did not show any sign of intensity limit up to 0.19 mA, the maximum current available from Injector I. The concept of Injector II has been described at previous conferences [1,2,3,4] and fig.1 shows the completed cyclotron with its injection line.

History of commissioning Injector II

Commissioning of the Cockcroft-Walton pre-accelerator started in December 1983 and of the Injector II in spring 1984. In June 1984 the first protons were extracted at 72 MeV and by the end of the year a beam of 0.45 mA (about one third of the design current) was obtained with extraction losses of 1% . After a shutdown, the cyclotron operation continued in March 1985. Following some preliminary optimization, the intensity record (as of early May) stands at 0.55 mA. The installation of an electrostatic extraction septum (see figure 2) has reduced the losses to less than 0.1% . With the present configuration a current of approximately 1 mA is expected soon.

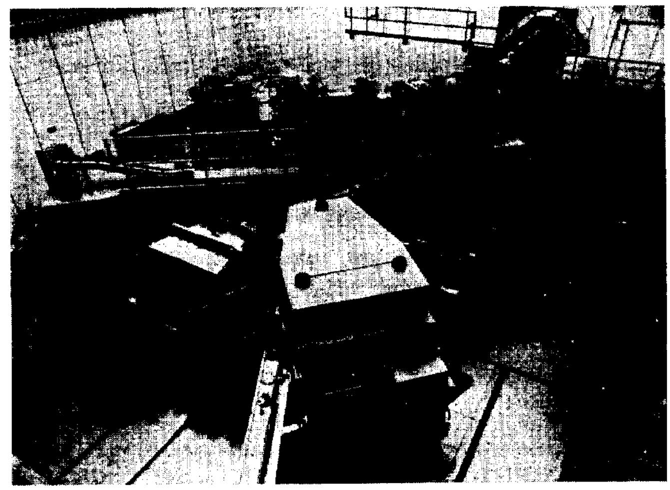

Figure 1: View of Injector II cyclotron. The 860 keV proton beam from the Cockcroft-Walton pre-accelerator enters the vault in the upper part of the picture and is injected vertically into the center of the cyclotron. A 50 MHz resonator, between two of the four sector magnets, can be seen on the left lower part of the picture. Extraction of the 72 MeV beam is towards the right hand side.

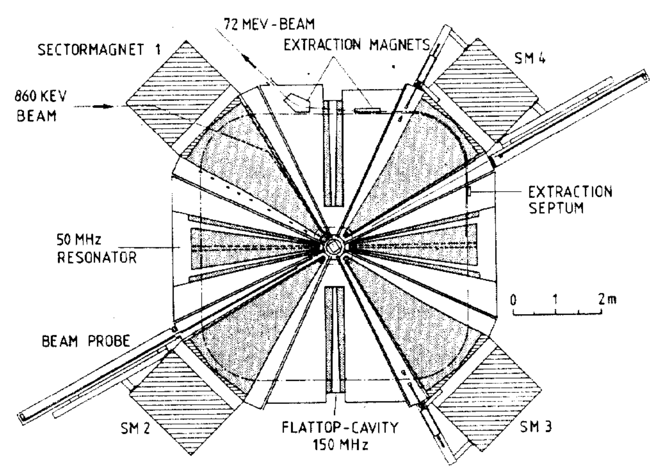

Figure 2: Layout of Injector II cyclotron. The four sector magnets produce the 'almost- square' shaped orbits.The two 50 MHz resonators are responsible for the acceleration over 100 revolutions to 72 MeV, while the two flattop cavities (operating at 150 MHz) produce a practically monoenergetic beam.

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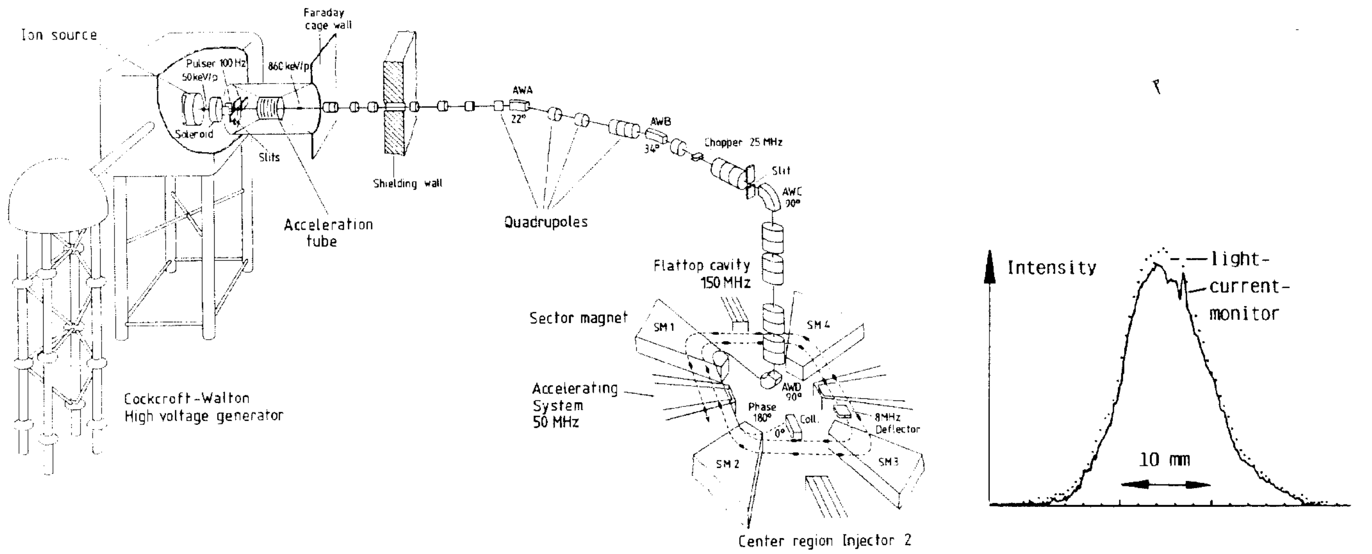

*Figure 3: Schematic view of the Cockcroft-Walton pre-accelerator, 860 keV beamline and vertical injection into center region of cyclotron. The picture on the right hand side shows a 860 keV beam profile measured by two independent methods. The solid curve was obtained with a current measurement by a metallic finger. The dots are the result of a measurement of the light emmitted by the residual gas hit by the beam. The beam current was 0.8 mA and the pressure was 10**-5 Torr. Agreement between the two methods is excellent.*

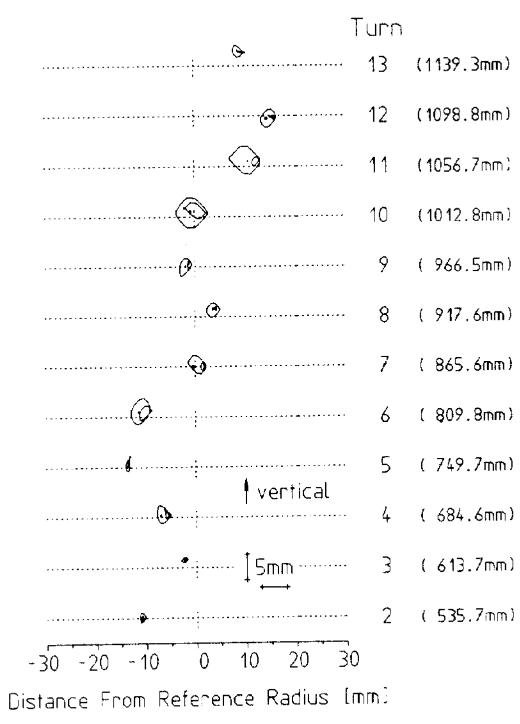

Figure 4: Beam cross sections of turns 2-13 in Injector II. Plotted are the contour lines corresponding to 20 and 50% of the peak intensity, reconstructed tomographically from a three finger beam probe. For demonstration purposes the beam was injected with a large horizontal oscillation amplitude of 7 mm. The imperfect phase space matching results in a pumping of the beam diameter. Deviations of the beam center from the calculated reference points allow a calibration of the voltage profile for the RF resonators.

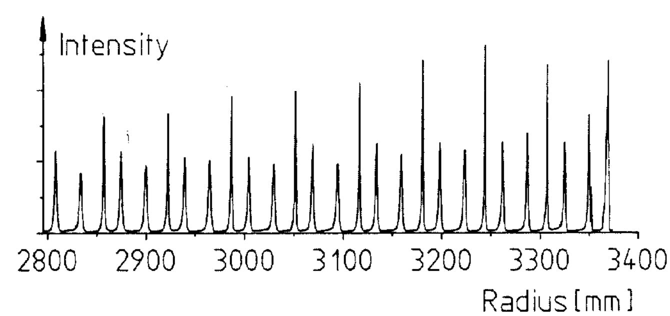

Figure 5: Turns 75 - 101 in the extraction region of Injector II. Clearly visible is the superperiod of 3 turns, resulting from a small phase space mismatch and the horizontal focusing frequency being close to Qr=4/3.

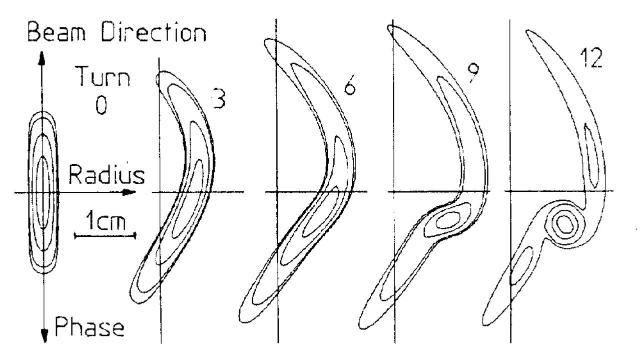

Figure 6: Distortion of beam bunches at the low energy end of Injector II, simulated with the space charge program PIC2 . During acceleration the bunches of constant phase width increase in physical length with radius and get a continuous curvature from the time dependent energy gain. The general tilt at turn 3 and 6, the kink in turn 9 and the thickening of the bunch center at turn 12 are due to space charge forces.

Results of beam tests

Since both the new injector as well as the ring cyclotron operate in the so called single turn mode, we have now a one to one imaging of the ion source to the meson production target through a 8 km long beam path. The front end of this transport system consists of ion source, acceleration tube and 860 keV injection system, as outlined in figure 3. Commissioning of the pre-accelerator has been described in [5]. The ion source is of the multicusp type with a 4 electrode extraction system. It operates at 60 keV giving a CW-beam of 10 mA protons but in addition 30 mA of unwanted molecular hydrogen ions. The reason for this low proton ratio of 25% is not known and will be investigated in an ion source test stand. To preserve the excellent emittance of pi*0.4 mm mrad (normalized) of the practically mono-energetic beam we decided initially not to use a buncher, but with the source current presently being limited to 10 mA, we plan to try out a buncher later this year. Most of the parasitic molecular beam is eliminated by focusing the proton beam through a 6 mm diameter hole in front of the acceleration tube. In this way the tube can be kept free of stray particles hitting the tube electrodes, which helps to reduce the number of flashovers to less than one per day. Maintenance of the source is possible without breaking the tube vacuum, which is 10**-7 Torr. The radiation level at the exit of the tube is as low as 1 mr/h thanks to an electron trap of 6 kV. The measured beam envelopes agree quite well with the calculated ones assuming a beam neutralization of more than 99% outside the tube and full space charge forces inside it. For tuning the 860 keV beam line one likes to work with the peak intensity equivalent to DC-operation, but at a low average current. This is achieved by pulsing the beam at 60 keV with a repetition rate of 500 Hz and duty cycle as low as 5% . Presently this is done with an electrostatic deflector. Since electric fields effect neutralization we plan to install a magnetic deflector this summer. The 860 keV beam transport system into the center of the cyclotron works very reliable. Profile measurement with metallic fingers works up to currents of 2 mA. An optical profile measuring system is under development and has given promising initial results (see figure 3).

A moveable phase collimator placed after half a turn in the cyclotron (see fig.3) eliminates all particles with the wrong phase and also serves as an intensity knob. Figure 4 shows the result of a novel beam measurement technique [3] in the center region of the cyclotron. Tomographic reconstruction of the beam cross-section with a three wire probe allows the simultaneous determination of horizontal and vertical coherent and incoherent oscillations as well as the effective energy gain per turn. The third harmonic flattop system is a very important tool to obtain clearly seperated turns (see fig.5) for a wide phase range. Since the energy gain per turn increases by a factor of 2 from injection to extraction we have a corresponding phase compression (or adiabatic bunching) by the same factor [6]. This effect helps to increase the phase acceptance at injection and values of up to 40 deg have been achieved. In order to compensate at least the linear part of the longitudinal space charge forces, it is necessary to shift the phase between the third harmonic flattop RF-system and the fundamental 50 MHz system. At an average current of 0.5 mA a phase shift of about 3 deg (measured in the 150 MHz system) with respect to the low current phase value was optimal. This agrees quite well with theoretical predictions [7]. Numerical simulations of space charge forces have been carried out with the computer code PIC2 [8] which uses the method of "particles in cell". These calculations predict a spiralling instability due to nonlinear forces in the 1-2 mA region (see figure 6). Preliminary measurements have shown that the emittance and energy spread of the extracted beam indeed increases with current, but it is not yet clear if this effect is due to the increased phase width or due to the space charge forces. An 8.4 MHz pulse-deflector installed on the first revolution (see figure 3) allows transmission of either only every third or every sixth beam bunch. In this way the full space charge forces can be examined at reduced average intensity levels. First tests with this pulser have been carried out successfully.- It is of vital interest to show soon that currents of the order of 1.5 mA are feasable, since both the spallation neutron source project [3] as well as the possible extension of the SIN facilities towards a high intensity proton synchrotron [9] rely on such a beam current.

Future developments

The present flattop cavities (see figure 2) start to effect the beam only after about the eighth revolution. This is a disadvantage, because the onset of the above mentioned spiraling instability could be shifted to higher currents if the flattop system would effect the beam from the first turn. It is therefore planned to install in the future an additional 150 MHz resonator acting over the first few turns. In addition the main effort for the next few months will be to increase the current from the ion-source to install and commision the buncher.

The present 590 MeV beam dump is capable of handling a current of about 0.3 to 0.4 mA. The first of the two meson production targets has been upgraded recently, but unfortunately the installation of the second high intensity target and of a new beam dump is still a few years away. Hence the potential of Injector II can not yet be fully exploited for the experimental facilities.

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