THE CERN HEAVY ION PROGRAM

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ABSTRACT

Apart from protons, antiprotons, electrons and positrons, ions start to play a more and more important role at CERN. This paper reviews briefly ion acceleration at CERN and presents the plans for heavy ions in the future.

Contribution to a publication edited on the occasion of the 60th birthday of Prof. H. Klein, Univ. of Frankfurt/M
Linear Accelerator

Ion Source

The selected ECR ion source will provide 100 μA (electrical) of lead ions with a charge state of 28+. With the proposed scenario this performance will provide intensities well above the 5 x 10^7 required by the experiments.

The choice of this source with its high charge state allows to minimize the cost of the linear accelerator, still providing the required intensity. Higher charge states could be possibly achieved, also with other sources, but would unfortunately drastically reduce the intensity.

Low energy acceleration

The energy of the ions at the exit of the ion source is of the order of 2.5 keV/u. For further acceleration of the slowly moving ions a RFQ (Radio Frequency Quadrupole) with its electric focusing is nowadays the obvious choice. A design (10) very similar to the one done by IAP (Frankfurt) for GSI could be adopted.

High energy acceleration

For further acceleration of the ions two structures are of main interest: a modified Alvarez structure or an interdigital H structure. The latter has been developed and used at Munich and other places. GSI is planning to build an accelerator using this structure to accelerate ions of a similar energy range and with a charge to mass ratio close to the CERN requirements. The advantages of this structure are the smaller dimensions and the lower RF power consumption. The disadvantages are the difficulties in calculating the structure and the RF tuning to achieve the desired field distribution.

This structure is also more likely to suffer from small variations of RF levels and phases, especially if the energy range of acceleration is large. This is of particular importance because GSI requires an output energy of 1.4 MeV/u, whereas the CERN scheme (11) calls for an energy of 4.2 MeV/u requiring three accelerating structures as compared to the one of GSI. Hence the CERN set-up will be much more sensitive to RF variations. Detailed calculations are under way to quantify these problems.

Another solution is the beta-lambda / 2 beta-lambda Alvarez hybrid structure (12) which is shown in Figs. 3 and 4. The period is N x beta-lambda long with 2 quadrupoles in a FODO configuration, housed in drift tubes in the 2 x beta-lambda cells and separated by (N-4)/2 beta-lambda cells each containing an "empty" drift tube.

It should be mentioned that the selected output energy of 4.2 MeV/u stems from a careful optimization and several reiterations. As the subsequent machines need at least one intermediate stripping to reach sufficiently high energies, and because any intermediate stripping provokes drastic intensity losses, only one place has been selected for intermediate stripping: the exit of the Linac. The energy there determines the charge state for the subsequent machines and hence the necessary vacuum conditions, the particle velocities and the required upgrading of pulsed elements.

Intensity losses

Severe intensity losses with heavy ion beams can occur due to the capture or loss of electrons by interaction with a residual gas. Both effects change the charge to mass ratio and result in immediate loss of the particle concerned in a synchrotron and will spoil the beam quality in a linear accelerator. In general, loss of electrons is dominant at high energies and recombination is important at low energies, the transition between these two regimes depending on the ionisation energy of the ion.

Some data of the relevant cross-sections are available from GSI and from LBL. There are also empirical formulae from both laboratories for interpolation and extrapolation of the measurements. Applying this knowledge to the acceleration cycles of PSB and PS results in a certain transmission as function of the vacuum in these machines (Fig. 5).

Further acceleration in the Synchrotrons

Beam transport lines, injection and ejection elements need, in general, upgrading to cope with different magnetic rigidities and pulse lengths.

Booster

The maximum frequency swing (2.95 - 8.05 MHz) of the PSB (Proton Synchrotron Booster) accelerating cavities is not sufficient to cope with the variation of the relativistic β-factor of the lead ions. Therefore, a change of the harmonic number from 17 to 10, involving debunching and adiabatic recapture on an intermediate flat top of the magnet cycle is required. The main modifications this machine will need is, however, the improvement of the vacuum from at present about 1 to 2 x 10^-6 to ~10^-7 mbar.

Proton Synchrotron

The 40 bunches from the PSB will be captured by 20 buckets using the standard ferrite tuned RF cavities in the PS ring.

No transition crossing will be required. Extraction from the PS will be carried out as a standard single turn fast extraction. The stripping foil will be located in the transfer line PS-SPS. The average pressure in the PS, after a recent upgrading to cope with the
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Abstract
Apart from protons, antiprotons, electrons and positrons, ions start to play a more and more important role at CERN. This paper reviews briefly ion acceleration at CERN and presents the plans for heavy ions in the future.

Introduction
CERN started out as a laboratory for doing physics with high energy protons. It took some decades until antiprotons as well as electrons and positrons were used in several machines of the CERN accelerator complex. Light ions (i.e. deuterons and alpha particles) were produced only during very short periods and without major modifications to the accelerators. These runs however prompted the request for even heavier ions.

The CERN heavy ion program which is now (almost) underway, is the result of the strong push from groups of nuclear and high energy physicists together with accelerator and ion source experts. The IAP Frankfurt has played an important role in trying to find ways and means to accelerate (1) and to produce (2) heavy ions.

Recent history of ions at CERN
Deuterons and alpha particles
First machine experiments to accelerate deuterons with the CERN 50 MeV proton Linac were already carried out in 1964. As it was not possible to increase the electric and magnetic fields in the Linac by a factor two, the so-called 2.8A mode (where the particles move with half the proton velocity) was used. This test was merely a machine experiment with no apparent interest from the physics point of view. Later on deuterons were actually stored in the Intersecting Storage Rings (ISR) and experiments were carried out with them. The results prompted a request for α-particle beams from the ISR. Some development work was carried out to produce He^+ beams and subsequent stripping on a pulsed gas jet target resulted in high intensity alpha particle beams. Thirty percent stripping efficiency at the energy of the pre-injector (130 keV/u) produced more than 10 mA at the output of the Linac (3).

It was quite clear, from that moment onwards, that this Linac was obviously able to accelerate any fully stripped ions (up to about calcium) as long as they could be provided for at the input (neglecting recombination losses in case of very heavy ions due to the imperfect vacuum). The subsequent machines had no major difficulties, except for the change of the harmonic number and the lower intensity of the beams. Some work was started along the lines of the electron beam ionization source (EBIS) (2) but dropped later on due to the apparent lack of physics interest.

The construction of the new CERN 50 MeV Linac (called Linac 2) eased considerably the ongoing development work on the old Linac (Linac 1).

Oxygen and sulphur ions
Following a letter of intent (4) addressed to the Proton-Synchrotron and Synchro-Cyclotron Committee (PSCC) at CERN, a detailed study (5) was launched. With moderate investments, it seemed possible to accelerate ions considerably heavier than in the past, with the existing CERN machines.

The scenario envisaged consisted of an ion source yielding highly stripped ions at moderate intensity, an upgraded Linac 1 (capable of accelerating not-fully-striped ions in the 2.8A mode), full stripping at the end of the Linac and improved instrumentation in the PS Booster and in the PS itself. The instrumentation was also improved in the SPS, because the experiments were finally carried out at higher energies than available at the PS.

To implement the required changes to the CERN accelerators, a collaboration was created between GSI (Darmstadt, Germany), LBL (Berkeley, USA) and CERN (6).

GSI provided the ion electron cyclotron resonance source (ECR) (built by R. Geller, Grenoble) and beam transport elements in the low energy area, LBL built the RFQ and CERN supplied matching cavities between the RFQ and the first Alvarez tank of Linac 1 (see Fig. 1). CERN also dealt with the necessary upgrade of Linac 1 and with the instrumentation of the different accelerators.

Fig. 1. Oxygen injector on Linac 1

One of the major problems proved - not unexpectedly - to be the RF voltage holding capability especially of tank 1. A 10,000 l/s cryopump had been installed on tank 1 to ease these problems. Nevertheless, pollution with pump oils showed up several times as a major difficulty. Conditioning of the tanks, and in particular of tank 1, was only possible by use of a computer program which would raise or lower the RF voltage as a function of vacuum pressure, breakdown rate and previous RF history.

Stripping by means of a carbon foil was done at the end of the Linac yielding a fairly pure beam of O^8+.

The intensities in the SPS were usually well above 10^9 charges per pulse. Subsequent upgrading of the ion source resulted (1987) in a somewhat increased intensity for the oxygen beam with a large amount of S^12+ ions. The majority of these ions was converted with the stripper foil at the end of the Linac to a S^16+ beam and accelerated in the PSB together with the oxygen beam. The PS accelerated also both beams up to transition energy and was then able to selectively continue with the sulphur beam (7).

The program for lead-ion acceleration
After some initial studies (8) a possible scheme has been worked out (9). The proposed scenario is presented in Fig. 2. The linear accelerator for this facility has to be a completely new machine and is the only one in the CERN accelerator complex exclusively adapted to the heavy ions and cannot reasonably be used for protons. The subsequent machines need only certain improvements to cope with the lead ions.
acceleration of leptons, is at present $7 \cdot 10^{-9}$ mbar. To achieve an average pressure of $10^{-9}$ about 150 titanium sublimation pumps will be installed.

Super Proton Synchrotron

Four batches of lead ions from the PS will be used to fill the SPS. To avoid changes in the harmonic number and the correspondingly high losses, a scheme of acceleration on a “non integer” harmonic number has been proposed. To circumvent the limitations imposed by the limited frequency range of the SPS cavities, it is foreseen to operate them at a constant frequency and to adjust their phase after each revolution of the lead beam.

Intensive upgrading of the instrumentation will be required.

Conclusion and Outlook

The proposed scheme for Pb-ion acceleration is based on the experience gained with previous light ion acceleration and tailored to the CERN accelerator complex.

Again, like in the case of the O- and S-ion acceleration, major parts of the equipment needed will come from other laboratories, the exact distribution still being under discussion.

Further intensity increases, satisfying the requirements of the Large Hadron Collider (LHC), which may be installed in the LEP tunnel, seem feasible (13).

Acknowledgements

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