THE SIS HEAVY ION SYNCHROTRON PROJECT

K. Blasche, D. Böhne, B. Franzke, H. Prange
GSI Darmstadt, West Germany

Summary

The status of the SIS 18 synchrotron project is described along with recent modifications and supplements: the modifications of the Unilac and the experimental storage ring.

Introduction

After the completion of the Unilac in 1976, part of the accelerator builders at GSI became reorganized in a study group for a heavy-ion synchrotron as an evident choice to satisfy the foreseeable demand for higher energy beams. The maximum bending power was selected as 12 T • m, just to attain enough energy for Uranium ions, 0.5 GeV/u, to strip off all electrons for a large fraction of the primary beam. A superconducting high energy synchrotron (10 GeV/u) was envisaged as a second stage, but it was not designed in detail.

Later, a particular users' initiative requested the availability of the high energy beam as soon as possible. A one stage conventional 100 T • m ring was proposed in 1979 and the energy doubling of the Unilac, which evidently had to function as injector, was initiated. This 250 m diameter ring, named SIS 100 [1], would have been a difficult machine: the injection field still was low, the only partly stripped ions required a sophisticated UHV system, the envisaged beam intensity, hence the decently rapid cycling rate resulted in costly rf systems and magnet power supplies.

The community of the nuclear physics users criticized the poor beam quality and extraction efficiency in the energy range of 20 - 100 MeV/u and argued for a two stage concept, with the potential of high proton currents. This revived the former SIS 12. The aperture was increased, the lattice redesigned in favour of a variable transition energy, the option of increased beam energies by going from 1.2 to 1.8 T by branching power supplies in parallel, was introduced. This two-stage concept [2] was officially proposed in 1981. The SIS 18, described below, is the unaltered version of the booster [3] in this two-stage concept.

This proposal was not accepted by the funding agencies because of the high cost and the presumably high scientific risk of the relativistic high energy research with heavy ions. Instead, the funding of the SIS 18 was considered to be feasible and relativistic heavy ion beams should be explored in the PS complex at CERN. The latter recommendation is actively pursued jointly by GSI and LBL. If this research field really proves fruitful, a superconducting collider, with the SIS 18 as injector, would be the most reasonable extension of the GSI facilities.

To become independent of the fate of the synchrotron plans, the heavy-ion fusion study group at GSI designed in 1983 a small experimental storage ring in order to investigate instability phenomena of intense beams at non-relativistic energies. The nuclear physics community quickly recognized the potential of an experimental ring, when combined with the SIS 18 and supplemented with a stripping target or a production target for exotic nuclei between both rings. In 1984 the storage ring was enlarged and altered as a result of the continuously increasing variety of applications. Many similar rings are under design or construction around the world, but the experimental storage ring, ESR, at GSI is the only one having the reference parameter of storing completely stripped Uranium ions. This led to a maximum bending power of 10 T • m.

The acceptance of this unique facility was such unanimous among the users' community that the funding procedure went decently fast. In April 1985 the official authorization was obtained. The SIS 18 continues to be the work horse in the future extension of the accelerator facilities.

Scope of the Project

The extension of the GSI installation comprises 5 subprojects (percentage of total investment given as well).

1. Modification of the Unilac 8%
   - energy switching
   - high current injector
   - transfer line Unilac - SIS
2. SIS 18 synchrotron and control system for the whole complex 28%
3. Experimental storage ring ESR 12%
4. Beam transfer between both rings and target hall, production target and separator 8%
5. Buildings, including supplies and utilities 44%

The total investment amounts to 160 MDM, additional 35 MDM for the initial experimental installation will be available as well. Figures do not include inflation and manpower. Fig. 1 gives a plan view of the two rings and the target hall.

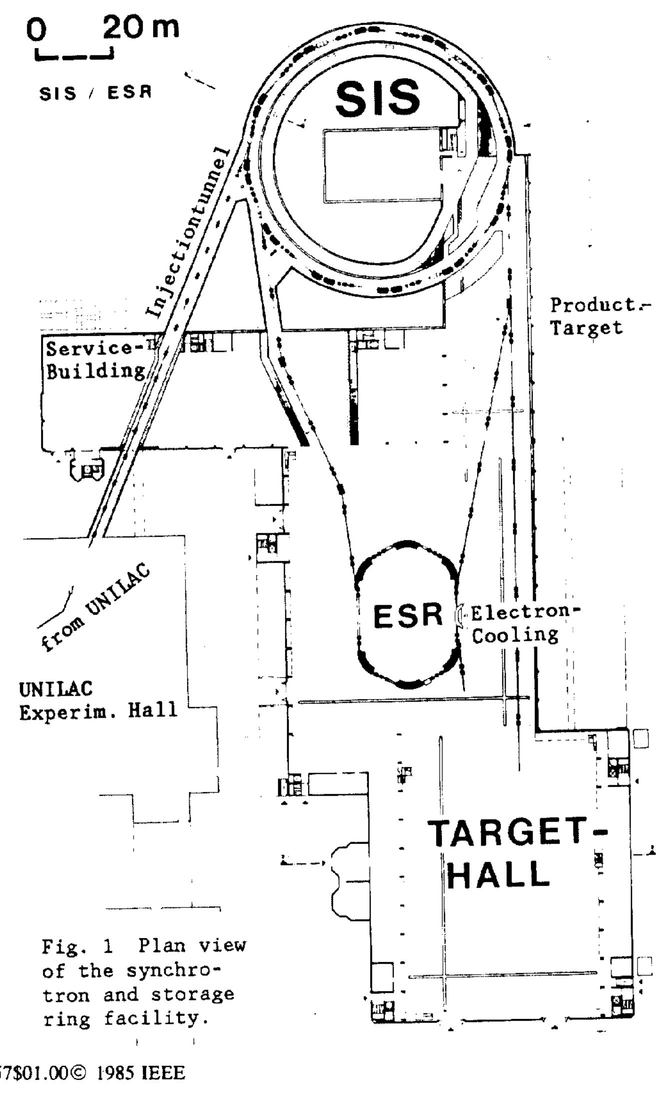

Fig. 1 Plan view of the synchrotron and storage ring facility.

Modification of the Unilac

Energy switching

The cycling rate of the SIS is typically 3 c.p.s. At those intervals the Unilac must deliver a beam burst into the transfer line to the ring. The energy of this burst should be kept at a decently high value in order to obtain high charge states behind the stripper in the transfer line and should stay independent of the frequent variations of the remaining 47 beam pulses delivered to the low energy users in the present experimental area. Since the energy setting is accomplished by exciting an appropriate number of the four Alvarez cavities with the additional adjustment of an appropriate number of the 17 single gap cavities at the end of the linac, the SIS beam burst should be accelerated by all four tanks and none of the single gap cavities. In this case phases and amplitudes of the individual rf amplifiers can stay constant and the final beam energy setting is an on/off switching.

The transverse beam optics in the Alvarez tanks and individual cavities, however, must be switched between the excitation level for the injection burst at 11.3 MeV/u and the selectable value appropriate to the variable energy demand between 3.5 and 20 MeV/u. The aim of beam optics calculation was to determine the minimum number and the most suitable positions of switchable elements without sacrificing a noticeable quantity of the transverse acceptance. The envisaged acceptance bandwidth should additionally account for a future variation of charge over mass ratios, but this dual ion species operation will not be applied in the first year because of the required major alterations in the charge separator device between pre- and poststripper section.

The beam transport calculations resulted in the necessity of changing 29 quadrupoles and 8 steering magnet pairs both in drift tubes and in inter-tank matching sections in favour of a laminated core design. The power supplies have to be replaced as well. All parts are on order and will be installed in extended maintenance periods over the next two years.

Apart from a multiplexing front end of the beam diagnostic controls, also the so far intercepting probes must be replaced in the context of the energy switching program.

High current injector

The presently used high charge state ion sources do not seem to have the peak current performance for the SIS filling burst for mass numbers beyond Argon. For the commissioning of the SIS the same Penning source is envisaged in the existing second injector, allowing for a much smaller duty factor and independent current tuning for the SIS beam, the ion species being identical to that for the high duty factor low energy beam.

To attain the space charge limit of the ring for ions heavier than Argon, a third injector is foreseen. This device will start with a high intensity and low charge state source, with an RFQ section thereafter of about 20 m in length and a stripper and charge selector in front of the inflection into the second Wideröe tank. The source is available for gaseous elements and the existing first part of the RFQ will gradually be extended.

Transfer line Unilac - SIS

The beam line form the high energy end of the Unilac to the matching section in the SIS tunnel is about 100 m long and traverses the existing experimental area, a connecting tunnel and the SIS service building. All components of this line are on order and a first section of 20 m will be commissioned in fall of this year. The purpose of this section is an on-line surveillance of energy and position stability of the Unilac beam and the training of the operators for the future dual beam mode. The lenses, bending magnets and power supplies already incorporate the switching feature for an ion species variation between two subsequent SIS pulses. A beam chopper for shaping the number (or fraction) of SIS injection turns will be located in the transfer line, but its design was not yet initiated.

The SIS 18

Since the last presentation [3] of the ring lattice the optical parameters remain unchanged. The transition form triplet focusing at injection to a doublet configuration during the acceleration ramp will be maintained, the triplet lens will be DC-excited. The variable grouping from twelve to six focusing periods, originally conceived for the feature of a variable transition energy, will be maintained as well, in order to match the dispersion function in case of the extraction of a high momentum spread beam after a fast bunching or in order to cope with the requirements of an eventual electron cooling insertion. Also the scheme of grouping the dipole power supplies in series for a 10 T/s ramp up to 1.2 T and a paralleling of each two of the four supplies for a reduced ramp rate of 4 T/s up to 1.8 T is still pursued. The before mentioned flexibilities certainly require a more expensive cable routing and probably a more complex synchronisation of power supplies. The maximum beam energy versus atomic charge number is given in Fig. 2. The maximum beam current versus ejection energy is seen in Fig. 3. From Table I the percentage of the maximum intensity versus extraction energy and required beam emittance can be derived.

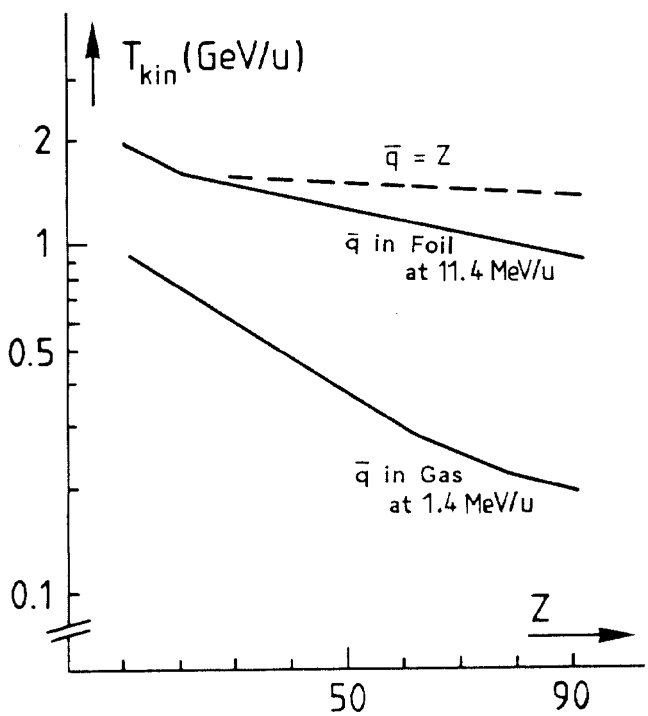

Fig. 2 Maximum beam energy of the SIS 18 versus atomic charge number.

The following items have been changed in respect to previous publications:

a) The ring circumference was increased by 5% in order to match the 2:1 circumference condition in respect to the ESR. The latter ring otherwise would have had marginal space for experimental insertions. Beam

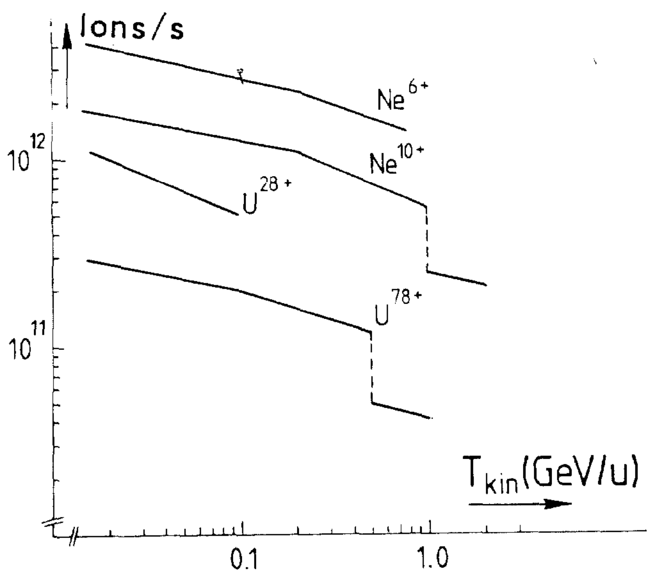

Fig. 3 Beam intensity of the SIS 18, when filled up to the space charge limit at injection. The drop at 0.5 GeV/u comes from the reduced ramping rate when power supplies are paralleled.

diagnostic probes in the SIS ring will benefit from the space increase, they originally had to fit into the pumping chambers.

b) The envisaged beam manipulation between both rings requires a fast ejection and reinjection. The 7 kicker modules for a pulse rise of 90 ns and a variable pulse length present problems in the module design and in the location in the ring. Space for the bulky PFN items also is difficult to find.

c) The originally planned rf system II, conceived for the synchronous capture of the Unilac bunches, satisfying the demand for a highly confined time structure of the extracted beam, is postponed. Instead, an rf extraction out of the SIS or a cooling/bunching manipulation in the ESR are envisaged.

d) The so far supposed direct feeding of the 30 MVA ramped power supplies was not definitively conceded by the power company, especially not in the typical cycle range of 1 to 3 Hz. Instabilities of the power grid, originating from periodic reactions of the turbine governors may turn out to be serious. The situation is now that a large scale experiment with variable ramp rates and grid configurations will support the decision whether the load fluctuations are tolerable. If yes, a new local substation combined with a dynamic compensator for the reactive power is indispensable for reducing the voltage fluctuation in the local area. Or, if the load fluctuations turn out to be intolerable, a motor generator set must be installed at GSI. In this case provisions for inhibiting voltage fluctuations are not required at all.

This unpleasant situation will result in a reduced ramping rate for the first year of operation, and in consequence, in about one third of the specified average beam intensity.

Status of component procurement

The magnet assembly will be done at GSI, because the UHV conditioned vacuum chambers have to be installed after the magnetic measurement and disassembly of the cores. Therefore coils and steel work are subcontracted separately. Prototypes are foreseen for every magnet type in order to check the assembly procedure, not primarily for field quality determination.

Extraction Energy	N/N_o (%)		
MeV/u	ε = 1	ε = 2	ε = 5
50	6,9	18,6	37,6
100	10,0	26,6	46,5
200	14,6	33,7	59,0
500	25,0	46,5	83,0
1000	38,0	60,5	100

Table I Percentage of the maximum beam intensity versus extraction energy when different emittances ε in π mm mrad are assumed.

Prototype cores for the dipole and quadrupols are ready. A quantity of 1000 tons of steel is on order, the stamping contract as well. A first dipole coil is on hand, the contract for the series is negociated. First coils for the quadrupoles and sextupoles will arrive mid of this year. The automated measurement procedure for all magnets is well advanced.

The specifications for the main magnet power supplies are nearly complete. It is presently expected that a single contractor for the whole delivery can be found, including the responsibility of an eventual compensator system.

A prototype rf station is under investigation since many years and a few mechanical alterations still have to be included in the design of the two final units.

Sample pieces for the magnet vacuum chambers are on hand. The decision between a corrugated version or a straight tube with stiffening ribs is still pending. The wall thickness is restricted to 0.3 mm. Pumping and beam probe chambers are readily designed and most of the catalogue items have been selected and partly tested. The baking concept and the control system is in a study phase. Still much has to be done in standardizing and specifying of production and treatment procedures for the relatively large quantity of individual vacuum units.

The component design for injection and slow extraction is complete. A prototype electrostatic septum is subjected to a test phase, before the final design documents can be released. A laborious development for the 7 kA bumper power supply with a variable decay time of 20 to 500 µs is complete. The fast extraction kicker is still in an early study phase. Procurement problems for appropriate ferrite material and PFN cables have to be considered. A high power test facility for the kicker development, reusing original CERN/ISR components, is available.

The beam diagnostic system, based on the requirements of commissioning, machine studies and routine operation, has been specified. Position probes and beam transformers are in an early development phase. Problems with the UHV compatibility still may arise.

The control system, originally conceived for operating requirements typical for synchrotron data cycles, must now cover the additional requirements of the Unilac operation with the 50 Hz repetition rate. The present Unilac computer systems is due to be replaced in a few years.

The control network architecture comprises three levels:

a) On the highest level about 3 VAX computers are connected by an Ethernet link.
b) Via a MIL bus communication up to 30 VME processors can be addressed.
c) Each VME processor can talk to 15 control units. Those were developed at GSI. On this level the event timing is supplied. A control unit is connected to

few or many interface boards, where the individual features of the connected hardware are respected.

The commercial availability of the above mentioned or similar computer and communication hardware will influence the final choice.

The Experimental Storage Ring (ESR)

Requirements

The following functions and applications were considered in the conceptual design of the ring:

1. Accumulation of fully stripped ions up to Uranium. A stripping target and a charge separator will be located in the beam line between the SIS and the ESR. The requirement to obtain, a large fraction of the primary beam also for the heaviest projectile (60% for Uranium), determined the bending power of 10 T • m, corresponding to 560 MeV/u for U^{92+} ions. After sufficient accumulation and an eventual treatment, the beam can be transferred to the SIS for further acceleration (1.3 GeV/u for Uranium) or deceleration for atomic physics experiments with highly stripped ions at low energies.
   The study of a plasma under extreme density conditions will benefit from a high intensity beam burst, formed in the ESR by accumulation and cooling and by fast bunching subsequently in the SIS.

2. A more sophisticated storage scenario is required, when the primary beam from the SIS is fragmented in a production target and the resulting exotic nuclei (neutron rich or deficient) are accumulated in the ring until a useful beam is prepared. The phase space property of fragmentation products is relatively poor and a stochastic precooling, a repetitive rf stacking and an electronic stack cooling must be applied. The processing time of those preparation steps must compete with the usually short life time of the nuclei.

3. In case of precious beams, an internal target in the ring is obviously the reasonable choice. Losses in phase space density can be compensated for by cooling. The dispersion function in the target section and cooling section can be made zero. In this case different charge states, originating from stripping in the target, can be kept orbiting as a useful beam in the ring.

4. The option for experiments with crossing beams [4], orbiting in the same direction and having slightly different energies, equally determined the ring optics and the operational features.

5. To satisfy the traditional demand of a time structure of less than 1 ns in the external beam, simultaneous cooling and bunching could be a way to accomplish this beam property. The scheme was demonstrated during the ICE ring experiments. Various stability limitations might determine the useful beam intensity.

6. Finally, when all the before mentioned intensity and quality improvements of the beam become a routine, the ESR will be an ideal intermediate step towards a high energy superconducting collider facility.

Layout of the ESR

In the evolution of the lattice design, space for in-ring experiments played the dominant role. Now, in the final design, shown in Fig. 4, a magnet free length of 9.5 m and a few shorter sections on both sides of the electron cooling insertion were accepted by the users as being adequate.

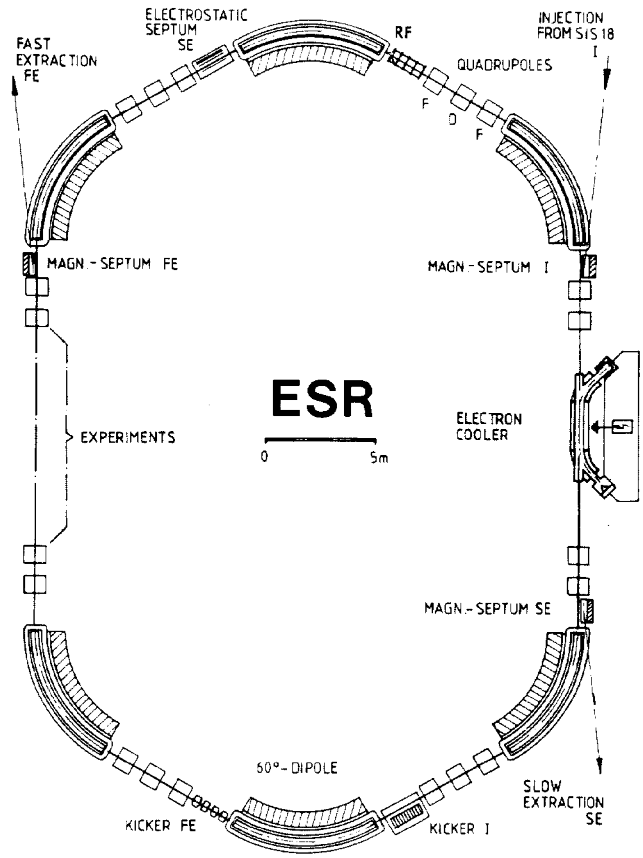

Fig. 4 Ring configuration of the experimental storage ring ESR.

The circumference is 103.2. m, half of that of the SIS, leading to a clear bunch transfer between both rings. There was a strong recommendation from machine builders, to make the circumference of both rings identical. Since none of the SIS components could have been used for the ESR, because of different apertures, and the installation in a hall would have been expensive, and the circulating beam current would have been one half, the price for simplifying the beam handling between both rings seemed to be much too high.

The operation mode with the crossing beams and the demand for efficient acceptance for secondary beams led to a large acceptance. There are three optical tuning modes: equally distributed dispersion function, zero dispersion on both straights and large dispersion on the straight section. The acceptance figures being largest at the first setting: 135 π mm mrad for $\Delta p/p$ = 2%. The geometrical aperture is largest in the lenses and the straight section, about 0.3 m.

The six bending magnets have a C-shaped cross section in order to have generous access to the vacuum chamber for pumping ports, beam probes and outlet windows for photons. The large air gap of 200 x 90 mm^2, where the field homogeneity stays in 5 • 10^{-4}, results in a broad pole piece, hence a large yoke and a total weight of each magnet of 96 tons.

Only a smooth field ramping of 1 T/s for an energy adjustment is foreseen and a single 1.5 MW supply excites all six dipoles. The quadrupoles with their different tuning configurations are powered by 5 supplies, the total power being 50% larger than that for the dipoles.

The rf system, used for stacking or bunching the accumulated beam prior to transfer, has the same frequency range as that in the SIS, the harmonic number being half the SIS figure. For three reasons the design differs largely from the SIS cavities: the aperture is much larger, the length much more restricted, and due to the large circulating current (several Amps) the broad band impedance should be low.

The susceptibility of heavy ions to charge exchange, especially when partly stripped and at low energies, limits the lifetime of the beam to a few minutes, even when the ultimate pressure value of 10^{-11} Torr (average over the circumference !) can be reached. A bake-out temperature of 300°C is foreseen. The compact size of the ring results in a dense positioning of sophisticated structures inside the vacuum, some being inherently gas releasing. Space for pumping ducts is scarce as well. The feature of an experimental ring and the limited space implies quite naturally a frequent breaking of the vacuum, not only in the straight section devoted to experiments. A particular approval procedure for in-ring components, procured by outside users, must be set up.

The electron cooling device, originally considered as an experimental equipment, now became a permanent installation of the ring, in design and operation under the responsibility of the machine physicists. Geometrical properties and current density comply with elsewhere existing models, but the electron energy must be raised to 310 keV. Except for the UHV aspects, most of the technology is available at GSI in the ion source group, operating bulky and power consuming ion source platforms at 320 kV. The diagnostics for electron and ion temperature and the various phenomena of electron trapping seem to be the most innovative aspect involved.

Status

Unlike an accelerator, which is specified by a couple of traditional properties of the external beam, the layout of an experimental ring must respect the sometimes contradictory requirements of the many classes of experiments. This game came to an end last fall. Now the beam optical requirements are in a process of being translated into component configuration and tolerance analysis. The search for hidden space in the ring circumference will continue for a long time. The space for the stochastic cooling kickers has not yet been identified.

The magnetic elements have been calculated, the mechanical design is under way and the procurement of the long-termed components will start early next year. As a scheduling rule, the ESR will be assembled one year later than the SIS, that means in late 89.

Beam transport

The length of the beam lines between both rings and between the rings and the target hall is larger than the circumference of both rings and the accumulated bending angle equals to about one circle. Since it was anticipated that the beam transport not simply is a pipeline from here to there, characterized by the emittance and energy of the beam supplying machine, this task was separated from the rings as a subproject of its own. There are production targets, separators, beam trimmers, beam dumps and beam quality measurement devices to be properly located. After that, one or the other user gets the idea that his target station would really fit into or near the beam line, and the debate about the beam height restarts again. At the time being, the creative phase about the beam line architecture is not nearly terminated. Certainly, except for an explicitly scheduled beam dump for the running-in phase of the SIS, beam lines can slowly be extended and need no commissioning phase.

Buildings

A later extension of the Unilac installation by a synchrotron facility was already considered in the early laboratory concept and an appropriate site is available in principle. Because the site is located in a forest area, there was a strong tendency to keep the new construction compact and close to the existing laboratory buildings. Only a marginal augmentation of the staff can be expected and therefore very few offices and laboratory space is included in the new buildings. The technical infrastructure and utilities will greatly rely on the existing capacity.

The floor of all new buildings is at the surface level, the SIS ring tunnel will be covered by earth. The magnet ring is placed at the outer wall in order to ease future injection and extraction lines and bulky equipment for in-ring experiments can be placed near the present extraction area, where the shielding is movable. The service building for the SIS and ESR supplies and controls is located between both rings (Fig. 1). There will be one control room for the new equipment and two counting rooms for the ESR experiments are near by. In a much later phase, the consoles for the Unilac control will be relocated into the new building. On both sides of the ESR and the target hall, equipment aisles are foreseen in three stories. A later extension of the target area is possible.

The documents for building authorisation have been supplied to the local agencies and to a state agency in charge of environmental and health physics approval. It is needless to mention, what kinds and how many obstacles might be encountered during this approval procedure. Building occupancy is already on the critical path of the project. When all things go well, ground breaking takes place next spring and the ring tunnel and the service buildings can be completed two years later.

Acknowledgement

The authors wish to express their thanks to K.H. Reich and K. Schindl and to their many colleagues at CERN, who took part in the machine design with their continuous advice and their effort during review meetings.

References

[1] K. Blasche et al., "An Accelerator Facility for Relativistic Heavy Ions", in Proceedings of the 11th International Conference on High Energy Accelerators, Geneva, July 7-11, 1980, p. 220.

[2] K. Blasche et al., "A Two Stage Synchrotron Facility for Heavy Ions", in Proceedings of the 1981 Particle Accelerator Conference, Washington DC, IEEE Transactions on Nuclear Science, Vol. NS-28 Nr. 3, June 1981.

[3] K. Blasche et al., "A Variable Transition Energy Lattice for SIS 12/18", in Proceedings of the 1983 Particle Accelerator Conference, Santa Fee, N.M., IEEE Transactions on Nuclear Science, Vol. NS-30 Nr. 4, August 1983.

[4] B. Franzke and Ch. Schmelzer, "U-U Collisions Near the Coulomb Barrier by Crossing Two Co-circulating Beams", these proceedings.