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Report of RIKEN RI Beam Factory International Technical Advisory Committee on the Design of the MUSES Facility and especially the Accumulator Cooling Ring

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Summary of the main observations and conclusions

- The committee encourages the design group to conceive MUSES as an evolving machine complex where some of the deferred functionality might be restored in future upgrades.
- It would appear, that the ACR ring design is approaching the advanced state which is necessary to permit the building design to be frozen and the detailed engineering of ring components to begin.
- The committee recognizes the value of a multipurpose ring, recommends however that the ACR be optimized for the accumulator mode. Other options should not compromise the ACR design for the very challenging accumulator task. Transfer of some of the options to the collider or to an additional ring could be considered.
- The present accumulation and cooling scheme is an excellent starting point. But further R&D work is necessary to make sure that the highest possible stacking rate can be obtained. This R&D program can continue in parallel with building construction work, provided that sufficient flexibility is maintained to permit incorporation of further improvements.
- One could consider transferring part of the accumulation function to the collider ring and also investigate the benefit of adding (perhaps later-on) a second ACR ring.
- International cooperation will be an important asset for the MUSES project. Major equipment could be developed and possibly also built in the framework of collaborations with institutes having expertise and/or projects in similar fields.

1. Introduction

The committee had been asked to review the technical aspects of the Multiple USe Experimental Storage rings (MUSES) with emphasis on the design of the Accumulator Cooler Ring (ACR). It met at RIKEN on Nov. 20 - 22, 2000. The meeting was held in the form of a workshop where the context of the Radio Isotope Beam Factory and the design of MUSES were presented by members of RIKEN especially by the MUSES team. The Agenda of these presentations is appended to this report. Three of us (F.C. B.F. D.M.) also took part in a workshop on stochastic cooling in the ACR which was held in Minakami on Nov. 23.

The committee had several documents at its disposal including the new MUSES Conceptual Design Report in a draft version dated Nov. 2000.

2. General Remarks

The committee encourages the design group to conceive MUSES as an evolving machine complex where later-on further possibilities can be added. A flexible design that permits later improvement, modification and additions is an efficient contribution to long term cost savings.

3. Physics possibilities with the ACR

Apart from its key role of collecting and accumulating radio isotope (RI) beams for electron-ion collisions in the separate ion collider ring, the ACR is foreseen to serve a rich program of auxiliary functions such as internal target experiments, mass measurement and accumulation of intense primary beams.

The committee sees the interest of a multipurpose ring, recommends however that the machine is rigorously optimized for the accumulator mode. It is reasonable to keep the door open for the other options, but only to the extent that this does not compromise the very challenging task of the accumulator mode.

Proton scattering and mass measurements have been included in the design in a convincing manner as "natural extensions" of the accumulator role. An isochronous optical setting --although at the price of reduced acceptance-- will make advanced mass measurements feasible. The solution found requires different currents in the quadrupoles but not removal or shift of major hardware. It looks thus perfectly compatible.

Internal target experiments would benefit from a low beta insertion. Together with the detector this requires precious space which will not be available when the ring works as accumulator for RI-e colliding beams. The high intensity mode is interesting, especially in conjunction with the unique synchrotron light available from the electron ring of the RI-eollider. However highest intensity demands special measures including strict control of the beam-environment coupling impedances. Some of these measures are difficult to reconcile with the accumulator/cooler function.

It should thus be considered whether some of the options (e.g. internal target experiments) could be transferred to the Collider Ring. Particle physics experiments with colliding beams or internal targets impose very special requirements: The design of the storage ring and the detector cannot be separated but needs a joint overall optimization. This has many consequences for the layout. To mention just one example: It may be necessary to break the lattice symmetry in order to provide a chicane for access to forward (0 degree) reaction products.

Thus a close collaboration between the ring- and the detector designers is important to solve the question of where and how to accommodate the different experiments.

4. Generation and transport of the RI beam to the ACR

The design of the new Radio Isotope Product Separator (Big-RIPS) reveals the outstanding expertise of the planning group for fragment production for in-flight experiments. To serve MUSES the emphasis has to be upon the specific requirements of the ACR. Big-RIPS will be part of the injection beam transport line, where several important beam manipulations take place. The preparation of the desired isotope has to be optimized with respect to:

i) highest population density in the phase space accepted by ACR ,

ii) high purity of the beam

This optimization may lead to "settings" different from those for direct experimental use of the RI beam. The TAC recommends a close cooperation between the groups working on the RIPS and the team responsible for beam transport and injection to the ACR. Adequate matching of Big-RIPS to the ACR is of key importance and measurements on the existing RIPS could give important hints.

The idea to interchange the relatively large horizontal and the small vertical beam emittances before injection to the ACR is an excellent and important step towards high efficiency of RI accumulation. The strong field solenoid proposed for this transformation seems viable, although higher order effects arising from the end fields have to be further investigated. It seems worthwhile to consider alternative solutions e.g. a longer solenoid where the end fields are less important or rotated quadrupole magnets.

The simulation of the debunching/rebunching should be extended to include the degrader effects in Big-RIPS. This could have an influence on the final parameters of the debuncher and the momentum spread after multi-turn injection.

Purity of the beam is important because the presence of unwanted ions tends to reduce the efficiency of stochastic cooling and accumulation of the main isotope. The estimates for ACR injection appeared to neglect the cleaning effect of the degrader in Big-RIPS. Thus some of the problems might not be as severe as assumed. Simulation of the isotopic background should be further refined to include this cleaning effect and also the decay time of the contaminants.

5. The ACR Lattice

The ACR design has made significant progress in the past few months, with evidence of much careful thought going into the design tradeoffs to optimize this ring for its many functions. For example the asymmetrical lattice reduces the transition energy locally and provides optimal conditions in the arc between stochastic pickups and kickers to improve conditions for transverse stochastic cooling.

Elsewhere the design provides the long straight sections with low dispersion which is desirable for electron cooling, and also the spaces for the multiple rf cavities used for stacking and acceleration-deceleration. The injection straight is tailored to the needs of both multiturn and rf stacking, while the horizontal fractional tune has been set near the quarter integer condition desirable for the multiturn injection.

The acceptance in momentum and in transverse phase space is appropriately large for efficient collection of the output from the Separator (Big-RIPS). In addition to the principal lattice parameters, attention has been given to the sextupole families needed for chromaticity reduction, and the design has been checked by tracking simulations for dynamic aperture restriction resulting from the associated non-linearities. The closed orbit centering requirements have been checked to define the alignment tolerance, and to identify locations for position pickups and steering elements.

It appears that the ACR ring design is approaching the advanced state which is necessary to permit the building design to be frozen and the detailed engineering of ring components to begin.

6. Stochastic cooling and stacking in the ACR

Stochastic cooling is one of the most challenging tasks in the MUSES scheme. In fact the ACR uses multiturn injection of new beam, followed by RF stacking and thereafter very fast stochastic cooling, before the batch is deposited into the final stack held by electron cooling. In this situation stochastic cooling is confronted with two intrinsic difficulties, stemming from constraints on the usable bandwidth and from the presence of the intense stack.

For fast momentum cooling of batches of typically 10^5 ions, the notch filter method is in principle well suited. However the maximum frequency is limited to roughly half of the value, where the Schottky bands start to overlap. In a regular high acceptance machine of the size and the energy of the ACR and with the $\Delta p/p$ after RF-stacking this leads to a severe limit for the maximum frequency and hence the bandwidth. In fact the band exploitable for the ACR turns out to be only few 100 MHz wide instead of the several GHz desired. In view of this difficulty it would be advisable to examine different momentum cooling methods like 'time of flight-' and 'Palmer schemes' which are less restricted in bandwidth. It would be of great advantage if these could be incorporated as a supplement to the filter system, that can use large bandwidth in the later part of the cooling cycle.

The second problem is the compatibility of the large final stack with the fast stochastic pre-cooling of the batches. The cooling time is essentially proportional to N/W i.e. determined by the number N of particles seen by the system and by its bandwidth W. Apart from large W it is therefore essential to "hide" the stack, with up to 10^3 times more intensity than the batch to be cooled.

A clean solution would be to add a second ring to the ACR and accumulate the stack in this second ring. This is the route chosen for antiproton accumulation at FERMILAB and also envisaged for radioactive ions at GSI. An "intermediate" solution could be to stack a small number of batches in the ACR and then transfer this smaller stack into the collider ring where further stacking takes place. This requires certain modifications in the collider ion ring. But in any case, the possibility of repetitive 'topping up' of the beam in the collider looks advantageous for operation with high-integrated luminosity independently of the advantage of alleviating the task of the ACR.

A possible strategy consists in starting with a single ACR, but foresee the possibility to add a second ring later on. In fact the CERN antiproton source started with a single antiproton accumulator. Then -although for reasons partly different from the present ones - a second ring was added after a few years of operation to gain a factor of 5 to10 in stacking rate.

In summary we believe, that the present accumulation and cooling scheme is an exellent starting point. Further R&D work is however necessary to make sure that the highest possible stacking rates and luminosities can be obtained. This R&D program can continue in parallel with the excavation and construction work, provided that sufficient flexibility is foreseen from the start to include further improvements. Again international collaboration with labs. working in the field of stochastic cooling can be an asset. The constitution of an "international task force for cooling in MUSES" was mentioned in our meeting.

7. Electron cooling

Expansion of the electron beam is considered in the MUSES concept report: a gun section with a 4T superconducting solenoid is discussed. This design is well suited for atomic physics experiments, which need a very low temperature "electron target" interacting with the co-moving ions. However for cooling, expansion in order to reduce the transverse electron temperature (T_t), does not present a clear advantage. Due to the large emittance of the beam after multiturn injection, the cooling speed will not significantly depend on T_t. In fact, expansion can even be harmful because the loss of ions due to recombination with cooling electrons tends to increase with decreasing T_t.

The TAC therefore recommends a re-examination of a simple cooling device with non-expanded field. It is true that the atomic physics experiments foreseen do require a low and tunable temperature electron target. But perhaps these experiments can be moved to Collider Ring and receive a dedicated electron target there.

A rich experience in the physics and technology of electron cooling exists in laboratories like INP Novosibirsk, JINR Dubna, GSI Darmstadt and IUCF Bloomington. A bi- or multilateral collaboration for MUSES seems possible and beneficial. Design and fabrication of key components like solenoid, gun, and collector as well as diagnostic devices like field probes and dedicated beam profile monitors could be tackled in a concerted effort.

The components of the cooler have to be tested before their installation in the ring. A bench for a test of the full cooler assembly is costly and perhaps not necessary. It rather seems sufficient to test critical components like gun and collector individually or in a simplified assembly once these elements are manufactured. After individual tests one can e.g. connect the gun directly to the collector without inserting toroidal- and cooling sections for 'full scale' tests of electron beam generation and collection.

8. Ion Source development

The MUSES facility will profit from any increase in the intensity of the primary beam impinging on the production target. The stacking and cooling scheme of the ACR requires pulses with a length of 20 - 30μs, high repetition rate (up to ~ 100 Hz), strong beam intensity (> 1 pmA) and high charge state (q/A > 0.15 even for the heaviest ion species). This motivates the investigation of high peak current ion sources.

RIKEN has started an active R&D program on the Laser Ion Source (LIS). A 10 J /50 ns CO_2 laser is operational now. The interaction vacuum chamber has been installed, and the first measurements of the laser produced plasma of Al ions look very promising. An electrostatic charge state analyzer (ion spectrometer) has been contracted to ITEP-Moscow and will be operational in 2001. Completion of the first phase of the program will give basic information on a LIS adapted to the requirements of the RIKEN accelerator complex.

Here again, international cooperation can be an important advantage. We therefore encourage contacts of RIKEN with other groups (ITEP-Moscow, TRINITI....) that have experience in tackling similar problems. Major equipment both for the tests and for the final source can be developed in international cooperation. Sub-contracting the detailed design and possibly also the construction of components could be envisaged. The collaboration could include other types of ion sources such as EBIS and ECR and especially the combined LIS/ECR source under development in the frame of a JINR-Dubna - ITEP-Moscow collaboration.

9. The collider rings

For lack of time, the committee limited the examination of the e- and RI collider rings to a brief overview. It could conclude that the layout and the magnetic structure of the rings look reasonable. The proposed scheme works at relatively low energy and is thus 'cost effective'. Then the luminosity goal is very challenging, but not out of reach, provided that the ACR works with the desired high stacking rate.

In the preceding paragraphs we have repeatedly mentioned the concept of transferring to the collider some of the tasks originally foreseen for the ACR (internal targets, additional stacking...). While moving on into the detailed collider design, the situation including these options could be assessed in collaboration with detector specialists.

APPENDIX:

Agenda of
the Fourth International Technical Advisory Committee Meeting on the Accumulator Cooler Ring in MUSES Project at RIKEN RI Beam Factory

Nov. 20 – 22, 2000

The Second floor Meeting Room at Nishina Building of RIKEN

Nov. 20 (Mon.)

Session 1 (9:30-10:40) Chairman D. Möhl

9:30 Opening (T. Katayama, RIKEN)
9:40 Overview and Status of RIKEN RIBF (Y. Yano, RIKEN)
10:10 Overview and Status of MUSES Project(T. Katayama, RIKEN)
10:40 *Coffee Break*

Session 2 (11:00-12:50) Chairman A. Skrinsky

11:00 Proton Scattering at ACR (H. Sakaguchi, Kyoto Univ.)
11:20 Mass Measurement at ACR (H. Sakurai, Univ. of Tokyo)
11:50 Plasma Physics on ACR (A. Sakumi, RIKEN)
12:10 e-A Colliding Experiment (T. Suda, RIKEN)
12:30 X-ray-RI Colliding Experiment (M. Wakasugi, RIKEN)
12:50 *Lunch*

Session 3 (14:00-15:00) Chairman B. Franzke

14:00 RI Beam Separator for MUSES (C. Yun, RIKEN)
14:20 Beam Transport to ACR (M. Okamura, RIKEN)
14:40 Quality of RI Beams in ACR (N. Inabe, RIKEN)
15:00 *Coffee Break*

Session 4 (15:30-16:20) Chairman R. Pollock

15:30 Design of the ACR Lattice (K. Ohtomo, RIKEN)
16:00 COD Correction and Tuning of ACR (T. Watanabe, RIKEN)

Nov. 21 (Tue.)

Session 5 (9:30-10:30) Chairman F. Caspers

9:30 Stochastic Cooling at ACR (M. Wakasugi, RIKEN)
10:00 Electron Cooling at ACR (T. Tanabe, RIKEN)

10:30 *Coffee Break*

Session 6 (11:00-12:00) Chairman I. Meshkov

11:00 Beam Instability in ACR (M. Takanaka, RIKEN)

11:20 Storage of Intense Ion Beam in ACR (P. Zenkevitch, ITEP)

11:40 Machine Control System (T. Tanabe, RIKEN)

12:00 *Lunch*

Session 7 (13:30-14:40) Chairman D. Möhl

13:30 Design of e-RI collider (N. Inabe, RIKEN)

14:00 R&D study for Stochastic Cooling (M. Wakasugi, RIKEN)

14:20 R&D study for Electron Cooling (I. Watanabe, Toshiba)

14:40 *Coffee Break*

Session 8 (15:10-16:30) Chairman B. Sharkov

15:10 R&D study of Fast Kicker Magnet (T. Ohkawa, RIKEN)

15:30 R&D study of RF Cavity (K. Ohtomo, RIKEN)

15:50 R&D study of Laser Ion Source (T. Takeuchi, RIKEN)

16:10 Space Charge Effect in RIKEN Cyclotron (S. Vorojtsov, JINP)

18:00 Banquet at Hirosawa Club

Nov. 22 (Wed.)

9:30 TAC Closed Session

11:00 *Coffee Break*

11:30 Discussion with TAC and RIKEN

12:40 *Lunch*

14:30 Comments from Committee

15:00 End of TAC Meeting