SNOWMASS96-Session on Acceleration Systems for the μ^+-μ^- Collider

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ABSTRACT

We report the discussions of acceleration systems for the μ^+-μ^- Collider, as presented in a working group session at Snowmass (Tuesday, July 9, AM). Recirculating-linac and rapid-cycling scenarios were discussed, as well as the components (rf systems and magnets) and injection/extraction constraints. Directions for future study and development were discussed.

I. INTRODUCTION

A session was devoted to discussion of acceleration systems for the μ^+-μ^- Collider. The discussions were led by presentations on critical topics in μ-acceleration, which included:

D. Neuffer - Feasibility Study Acceleration Scenario
Q.-S. Shu - rf and SRF Systems for μ^+-μ^- Acceleration
E. Willen - Magnets for μ^+-μ^- Acceleration
D. Summers - Alternative Acceleration Schemes
H. Kirk - Injection Considerations

and these were followed by general discussion. In the present report we present an overview of these presentations and the resulting discussions. More detailed discussions are in the μ^+-μ^- Collider Feasibility Study [1] and will be in the Snowmass proceedings, and other publications.

The central requirement of the acceleration system is that it must accelerate the μ's to full energy before they decay, and that constrains the acceleration to intrinsically fast systems.

II. OVERVIEW OF THE FEASIBILITY STUDY RLA SCENARIO AND VARIATIONS

In the Feasibility Study, an acceleration scenario is presented which consists of an ~1 GeV linac injecting into a sequence of 4 recirculating linacs (RLAs), each of which increases beam energy by ~ an order of magnitude, and which accelerates beam up to 2 TeV for injection into a collider ring. Figure 1 shows a conceptual overview of a 4-RLA system and table 1 displays parameters of the various RLA systems.

The basic accelerating unit in this scenario is the recirculating linac, which consists of two linacs with return arcs in a racetrack configuration. In a recirculating linac (RLA) the beam is accelerated and returned for several passes in the same linacs, but with separate return paths for each pass. At the end of a linac the beam passes through beam-separation optics which directs the beam to an energy-matched return arc. At the end of the arc the various energy transports are recombined for further acceleration in the following linac. The beam passes through arcs and linacs until full energy is reached, and it is then transferred to the next RLA or the collider.

The RLA permits economic multipass acceleration, but it requires a separate transport for each turn, and cost and complexity considerations limit the number of turns to ~10—20 per RLA, which is very compatible with the μ lifetime constraint. Counterrotating μ^+ and μ^- bunches can also be accelerated in the same RLAs. In the baseline scenario, the rf frequency increases from RLA to RLA as the beam increases in energy, and the bunch length is correspondingly shortened to match final collider requirements.

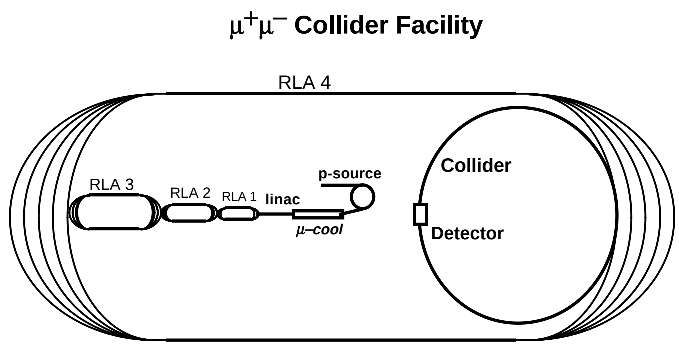

Figure 1. Overview of a μ^+-μ^- collider system, which includes a linac plus sequence of 4 recirculating linacs (RLA's) which accelerate the μ^+-μ^- beams from the end of μ-cooling to full energy, where it is injected into the collider.

In the session, simulation results which demonstrated the basic feasibility of the baseline scenario were presented. Beam can be accelerated from 1 GeV to 2 TeV with <20% decay loss and <10% longitudinal phase-space dilution. Simulations also show that relatively large wake fields could be tolerated within the RLA beam dynamics. [2]

There is a considerable degree of variation which can be developed in RLA scenarios. The number of RLA's and the rf frequencies can be varied to match available hardware or cost constraints. As an example, a three-RLA scenario (with 100→400→1600 MHz and 2→20→200→2000 GeV) was also presented.

III. RF AND SRF ACCELERATION SYSTEMS

Q. S. Shu led the discussion on the rf systems needed for the accelerator. In the baseline scenario, rf systems at 100, 350, 800 and 1350 MHz are needed. While Cu cavities are suitable for the ~100 MHz RLA, the higher-energy RLA′s require a relatively long acceleration pulse for multipass acceleration and high-efficiency.

SRF (superconducting rf) systems can supply the required acceleration: the pulse length and beam power delivered are roughly the same as being designed for the TESLA SRF e^+-e^- collder. Also the relatively large apertures of SRF cavities are ideal for containing the large-emittance μ-beams and can reduce the wake-fields for the high-intensity μ bunches to an acceptable level.

Significant difficulties in the adaptation of this SRF technology to μ^+-μ^- acceleration may exist. High-power HOM loads will be needed and the beam transport and SRF cavities must accommodate any spillage from μ-decay. SRF cavities should also be designed to minimize wake-fields from the high-intensity bunches.

An experiment is being planned on a CERN SRF cavity (Fig. 2) to determine whether it can be adapted to μ^+-μ^- acceleration. The plan is to apply pulsed high-power processing to a CERN 350 MHz cavity, and then to operate it in pulsed mode to determine its gradient limit. If fully successful, CERN cavities could be used in a future μ^+-μ^- accelerator. In any case, guidelines for SRF design that is μ^+-μ^- optimized will be developed.

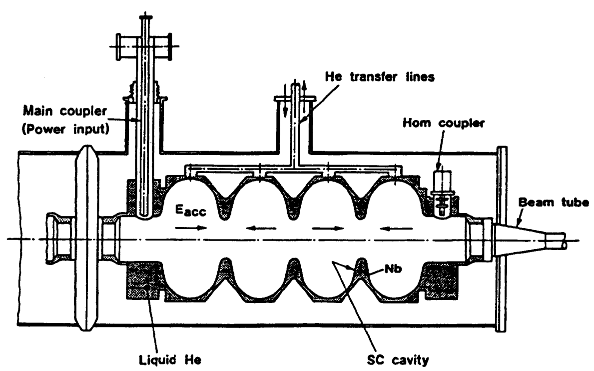

Figure 2. Cross-section of a CERN 350 MHz SRF cavity

IV. MAGNET SYSTEMS - FIXED FIELD

The acceleration system will need various magnets for focusing and steering the beam, and these were discussed. In RLA scenarios, multiple-aperture magnets for the various passes have been designed. Figure 3 shows a 9-aperture dipole magnet for a 10 pass RLA, with 0.7 to 7T fields in the various apertures. Other designs with 16 or 20 passes were presented.

The RLA also requires beam separation and matching sections between the linacs and the arcs. These have not yet been explicitly designed and could be expensive.

V. RAPID-CYCLING SYNCHROTRON SCENARIOS

The fixed-field RLA requires separate return arcs for each pass. Cost savings could be obtained if the return arc transports could be used for several turns. This would require a change in the bending field from turn to turn. Various possible magnet designs which incorporate a changing field were discussed, led by E. Willen and D. Summers.

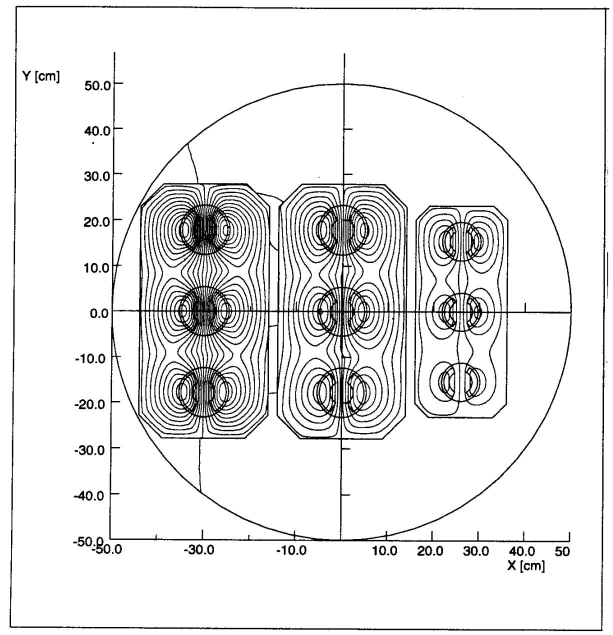

Figure 3. A 9-aperture fixed field superconducting magnet with 0.7 to 7T fields in the various apertures.

. In the limit where the accelerator has single return arcs, and the magnets cycle from low-field to high field in one acceleration cycle, one obtains a rapid-cycling synchrotron. Because only one ring (per accelerator) is required, cost optimization maximizes the number of passes per ring to a limit (30 to 50 turns) above which μ decay becomes prohibitive. The increase in number of turns would correspondingly increase power demands on rf cavities (while reducing their number), and would therefore change rf design choices.

E. Willen presented designs for pulsed conductor dominated magnets; in particular. a design that cycles from low field to 4T in 360 μs (matched to accelerating μ's to 250 GeV in 40 turns) was presented.

Ferrite-dominated cycling magnets are limited to ±2 T. However the mean field could be somewhat larger by intermingling high-fixed-field dipoles (8T) with ±2T magnets. Scaling from the KAON booster and using 0.1mm laminations and grain-oriented silicon steel, 250 Hz and 125 Hz dipoles were presented by D. Summers and incorporated into a two ring rapid-cycling synchrotron concept taking the beam to 2 TeV.

Permanent magnets are also limited to ~±2 T fields. Rapid-cycling using counterrotating permanent magnets could also be obtained and incorporated into a similar hybrid magnet design for very rapid-cycling synchrotrons..

VI. INJECTION CONSIDERATIONS

The μ^+-μ^- accelerator will need an injector to take the μ^+-μ^- beams from the end of the cooling system to the beginning of the multiturn accelerator. Its specifications depend upon the final cooling scenario. In the most recent scenario, the beam is cooled with a final-stage phase-space exchange in a Li lens to very low energy (20MeV) with a bunch length of σ_z = 0.7 m. This could be immediately captured and bunched by a multiharmonic rf system (30—100 MHz). High gradient is needed to avoid μ decay. This case would be easier than the previous scenario, which had final phase-space exchange in wedges, and obtained a 25 MeV beam with 6m (!) bunch lengths. That would require an initial induction linac acceleration to 100 MeV and σ_z < 1m followed by a multiharmonic bunching linac to GeV, and would have larger decay losses.

VII. DISCUSSION

Further discussion followed on the various acceleration options. Considerable interest was expressed in the possibility of pulsed or rapid-cycling magnet scenarios in the belief that a rapid-cycling scenario, with its reduction in number of transport lines and increase in number of turns, would greatly reduce costs. A hybrid scenario with RLA's for initial acceleration and a rapid-cycling high-energy end may be optimal.

Several key R&D goals were identified. The CERN 350 MHz cavity experiment would provide useful data on use of SRF in pulsed modes suitable for μ^+-μ^- acceleration. Design and construction of a pulsed magnet suitable for a rapid-cycling acceleration would also be desirable. Further design on multiaperture magnets, including RLA beamseparation and recombination modules, woould also be desirable. Hybrid magnets could also be designed and tested. An optimized rapid-cycling scenario should be generated and compared with the baseline RLA scenario.

VIII. REFERENCES

[1] $\mu^+\mu^-$ Collider - A Feasibility Study, BNL-52503, Fermi-Lab-Conf.-96-092, LBNL-38946 (1996), presented at the Snowmass workshop.

[2] D. Neuffer, to be published in NIM A (1996).

Table 1: Parameters of a 4-RLA scenario, which accelerates μ^+-μ^- to 2TeV

Linac	Buncher 1	RLA 1	Buncher 2	RLA 2	Buncher 3	RLA 3	Buncher 4	RLA 4
Energy in (GeV)	1	1	9.6	9.6	70	70	250	250
Energy out (GeV)	1	9.6	9.6	70	70	250	250	2000
Nturns		9		11		12		16
V_{rf} per linac (GV)	0.08	0.5	0.86	3	2.64	8	10	56
ϕ_s (°)	90	20	90	15	90	16	90	14
rf frequency (MHz)	100	100	350	350	800	800	1300	1300
gradient (MV/m)	5	5	10	10	15	15	20	20
L(linac) (m)	16	100	86	300.0	176.0	533.3	500	2800
Arc length (m)		30		175		520		3500
B_{arc} (T)		3.4		4.2		5.2		6.0
M_{56} per arc (m)	6.0	0.4→1.9	1.5	0.1→0.6	1.5	0.15→0.6	0.8	0.3→2.3
Time in module (μs)		7.8		35		84.2		672
Decay Losses(%)		9.0		5.2		2.4		3.6
Bunch Length (cm)	25→8.3	4.8	1.4	1.3	0.72	0.59	0.30	0.29
ΔE_{rms} (GeV)	0.05	0.09	0.31	0.34	0.61	0.80	1.5	1.5
emittance (eV-ms)	13.6	14.0	14.0	14.1	14.0	15.1	15.0	14.2