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RF SYSTEM REQUIREMENTS FOR A MEDIUM-ENERGY ELECTRON-ION COLLIDER (MEIC) AT JLAB *

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Abstract

JLab is studying options for a medium energy electron-ion collider that could fit on the JLab site and use CEBAF as a full-energy electron injector. A new ion source, linac and booster would be required, together with collider storage rings for the ions and electrons. In order to achieve the maximum luminosity these will be high current storage rings with many bunches. We present the high level RF system requirements for the storage rings, ion booster ring and high-energy ion beam cooling system, and describe the technology options under consideration to meet them. We also present options for staging that might reduce the initial capital cost while providing a smooth upgrade path to a higher final energy. The technologies under consideration may also be useful for other proposed storage ring colliders or ultimate light sources.

INTRODUCTION

The Medium-energy Electron Ion Collider (MEIC) proposed by JLab requires a very high luminosity to meet the physics goals [1,2]. The collider will be a "ring-ring" configuration [3,4], figure 1, with polarized electrons coming from CEBAF [5], and polarized ions from a new ion complex. The general design philosophy is closer to that used for the B-factories [6,7] than for traditional hadron colliders, namely employing a large number of bunches with short bunch length, reasonable charge per bunch, and acceptable beam-beam tune shift. Due to the large crossing angle envisaged in the detectors a crab crossing scheme is proposed. These parameter choices define the RF system requirements that, though demanding, can be fulfilled by existing state of the art systems or reasonable extrapolations thereof. Recent re-baselining of the project has resulted in the adoption of the former PEP-II high-energy ring (HER) as the basis for the MEIC electron collider storage ring. This necessitates a change in the baseline RF frequency so the other storage ring RF systems must now also be harmonics of the PEP-II frequency (476 ± 0.5 MHz). Tables 1 and 2 list the high-level parameters of the new RF systems for MEIC.

MAJOR SYSTEMS

Electron Ring

The electron ring will be based on the PEP-II HER, reusing major components such as the magnets, vacuum chambers and RF systems, and operate up to 10 GeV [8].

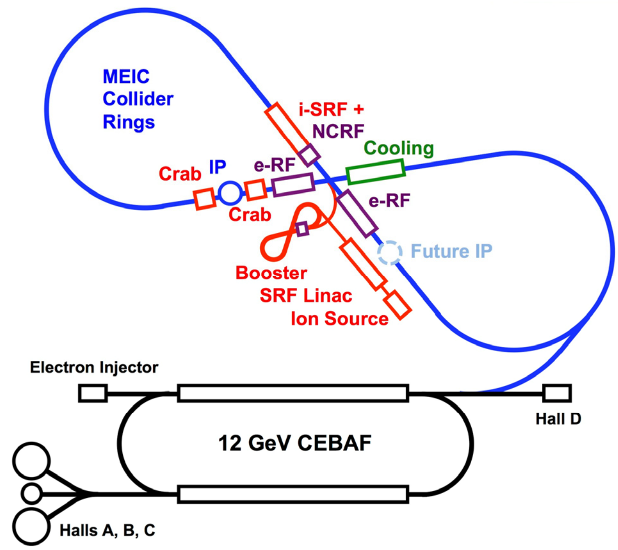

Figure 1: Schematic layout of figure-8 MEIC.

The circumference of the new baseline design figure-8 ring is similar to the PEP-II ring but since there is more total curvature the bending in each dipole is slightly higher than for PEP-II. At high energy the synchrotron radiation power density on the vacuum chamber wall in the arcs limits the current. The assumed vacuum chamber limit is 10 kW/m, and the maximum total synchrotron radiation power is chosen to not exceed 10 MW. 34 single-cell HOM-damped cavities and 13 1.2 MW klystrons are available from PEP-II, figure 2. At least 26 cavities and 10 klystrons will be needed for MEIC, though more may be installed to give operational margin.

Table 1: High Level MEIC RF Parameters

System	Frequency MHz	Total Voltage	Total Power
Booster	0.817-1.274	32 kV	98.5 kW
Ion capture	1.248-1.255	111 kV	357.4 kW
Ion-ring	952.6	18.94 MV	1.65 MW
e-ring	476.3	20.56 MV	12.8 MW
Crabbing	952.6	32.48 MV	~200 kW
Cooler ERL	952.6	56 MV	120 kW
Cooler inj.	952.6	10 MV	2.00 MW

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Table 2. Main RF Parameters for the MEIC Baseline

	cavity type	Frequency MHz	Vc MV	Pc kW	Ib A	# cav.	# CM	Vtot MV	total power kW
ion booster	NC/Ferrite	0.817-1.274	0.016	41.2	0.5	2	-	0.032	98.5
ion ring	NC/Ferrite	1.248-1.255	0.016	27.5	0.5	7	-	0.111	357.4
ion ring	SRF	952.6	1.18	109.9	0.5	16	4	18.94	1647
e-ring	NC/PEP-II	476.3	0.79	497.8	3.0	26	-	20.56	12792
i-crab	SRF	952.6	2.41	12.5	0.5	12	4	28.96	150
e-crab	SRF	952.6	1.68	12.5	3.0	4	2	3.52	50
cooler ERL*	SRF 5 cell	952.6	14	30	0.2	4	1	56	120
Cool. booster	SRF 1 cell	952.6	2.5	500	0.2	4	1	10	2000
Total:						**75**	**12**	**138.12**	**17215**

*Assuming 200 mA source, 10 MeV booster, 50 MeV ERL

Ion Ring

The ion ring will be a new ring using super-ferric magnets up to 3T to reach a maximum energy of 100 GeV [9]. The ring will have approximately the same circumference and footprint as the electron ring and share the same tunnel. Path length variations with energy will be accommodated by harmonic jumps and local path length adjustments. The ion ring will use low frequency tuneable ferrite or Metglas™ loaded cavities [e.g. 10,11] to capture and accelerate the beam in 8 long bunches. Once at collision energy the beam will be re-bucketed into a high frequency bunch train using SRF cavities at 952.6 MHz. A barrier-bucket RF system may also be used to facilitate re-bucketing and to create the abort gaps needed. To achieve the short bunch lengths (~12 mm) in the ion ring a high installed voltage is needed. The high stored current (0.5 A) requires strongly HOM damped cavities. More details can be found in [12]. Multi-cell cavities would be more space efficient if the impedance of HOMs and same pass-band modes can be managed. These studies are on going. In order to maintain luminosity during collisions continuous high-energy electron cooling is envisaged. As this is well beyond the energy reach of DC coolers a bunched-beam cooling scheme is being considered [13].

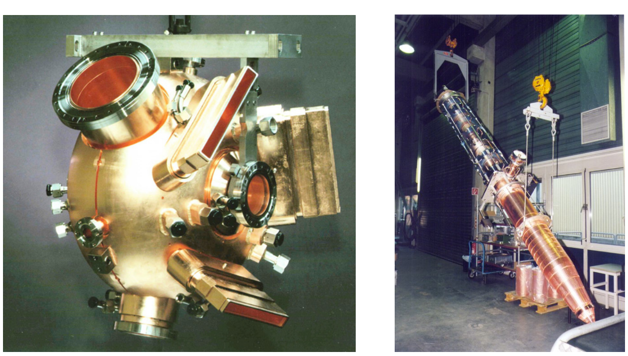

Figure 2: PEP-II RF cavity and 1.2 MW klystron.

Crab Cavity System

Due to the large crossing angle in the detectors a strong crabbing voltage is needed to preserve the luminosity. The crab cavity proposed is based on the "RF dipole" concept developed at Old Dominion University (ODU) [14], figure 3. Two cavities each side of the interaction point are needed in the electron ring and six each side in the higher-energy ion ring. The frequency of the cavities needs to match the bunch frequency of 476.3 MHz or be a higher harmonic. In this case 952.6 MHz is a convenient frequency allowing for compact structures and permitting later upgrade of the bunch frequency if new 952.6 MHz e-ring SRF cavities are installed. The main parameters of the crab system are listed in table 3.

Figure 3: "RF dipole" crab cavity developed by ODU.

Table 3: Crab System Parameters

Parameter	Units	Electron	Proton
Beam Energy	GeV	10	100
Bunch Frequency	MHz	952.6	
Crossing Angle	mrad	50	
Beta Function at IP	cm	10	
Beta function at crab cavity	m	200	750
Integrated kick voltage/side	MV	1.76	14.48
Number of cavities per side		2	6
Total number of cavities		4	12

Electron Cooling Systems

To maximize the luminosity, DC coolers are envisaged in the booster and collider rings. However at collision energy DC cooling is impractical so higher energy bunched-beam cooling is proposed [13]. In this case the cooling mechanism is the same as the DC cooler but the beam has a bunch structure matching the stored ion beam. This allows the beam to be accelerated to the desired energy in an SRF linac. In order to produce low emittance high charge bunches a photocathode gun is desirable, followed by rapid acceleration in an SRF booster, however the beam must be magnetized (originate in a solenoid field at the cathode), in order to be matched into the cooling solenoid in the ion ring.

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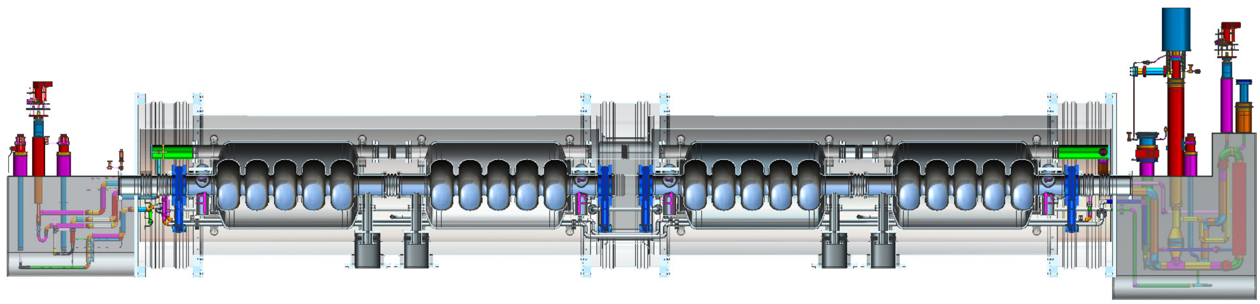

Figure 4: Concept for a versatile modular cryostat to house various MEIC SRF cavities (ERL concept shown).

For energy efficiency and to minimize the power to be dissipated in the beam dump, an energy recovery linac (ERL) configuration is proposed. Figure 5 shows the conceptual layout. At the proposed energy and beam current multi-cell strongly HOM damped cavities are needed, Figure 6. Figure 4 shows one possible configuration of the ERL cryomodule. The SRF booster would be a short version containing single cell cavities similar to those in the ion storage ring, but with high-power couplers. Similar cryomodule concepts are proposed for the ion ring cavities and crab cavities.

One potential option or upgrade would be to recirculate the bunches a small number of times in a circulator or stacking ring before returning them to the linac. This would maximize the cooling rate and/or reduce the demands on the electron source. This scheme would require ultra-fast kickers or an RF separation scheme. R&D into these components is under way [15].

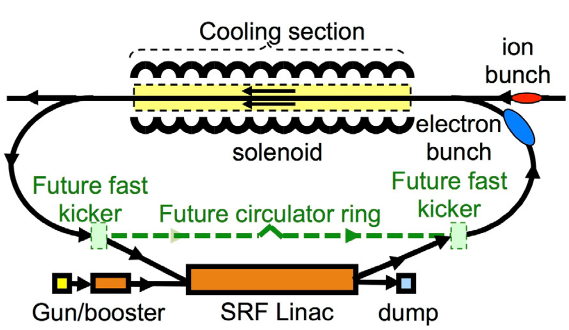

Figure 5: schematic of bunched beam cooler with option for future recirculation.

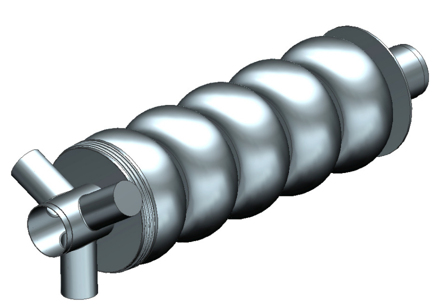

Figure 6: Concept for ERL cooler cavity.

Ion Linac and Booster

The ion beams will be provided by a new source and injector linac. In the present baseline this is a versatile SRF linac capable of accelerating all ion species up to Pb, based on a design by Argonne National Lab. Such a machine will provide efficient filling of the booster at 285 MeV for protons (112 MeV/u for lead ions), and hence the storage ring as needed. The SRF requirements of the linac will not be discussed further in this paper. The booster will be a smaller figure-8 ring capturing, accelerating and transferring one bucket at a time into the collider ring using a single low-frequency RF system.

STAGING OPTIONS AND UPGRADES

It may be possible to stage parts of the machine to provide a more acceptable cost profile or to fit a ramping up of energy reach in several phases. An initial lower energy and lower luminosity configuration could be achieved using less installed RF, fewer cavities, and reduced or no electron cooling. The full design luminosity would be achieved by incrementally installing these components.

Upgrading to higher energy can be achieved by upgrading the magnets in the ion ring and adding more RF. Eventually the PEP-II RF stations may be phased out and new 952.6 MHz superconducting cavities installed in the e-ring. Once the last 476 MHz systems are retired the bunch rate may be doubled to the full 952.6 MHz rate, allowing higher luminosity.

CONCLUSION

A baseline design has been established that meets the requirements of the community for a high luminosity electron ion collider. The RF requirements are demanding but achievable within the state of the art. Incorporating the PEP-II high-energy ring and RF systems can reduce costs without compromising performance. The high level parameters of the systems have been defined and R&D on subsystems and key technologies is under way. Options for cost reduction or staging are being considered.

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REFERENCES

[1] "Science requirements and conceptual design for a polarized medium energy electron-ion collider at Jefferson lab", S. Abeyratne et. al., edited by Y. Zhang and J. Bisognano, arXiv:1209.0757 (2012).

[2] "Electron Ion Collider: The Next QCD Frontier - Understanding the glue that binds us all", A. Accardi et al., http://arxiv.org/abs/1212.1701

[3] "MEIC Design Summary", January 12, 2015, J. Krafft editor, to be published.

[4] "Progress on the Design of the Polarized Medium-energy Electron-Ion Collider at JLab", F. Lin et al., these proceedings.

[5] "Concepts for Using CEBAF as a Full-energy Injector for the MEIC Electron Ring", J. Guo et al., these proceedings.

[6] "Last Year of PEP-II B-Factory Operation", J. T. Seeman, SLAC, EPAC08.

[7] "KEKB Performance", Y. Funakoshi et al., Proc of EPAC 2004, Lucerne, Switzerland (2004), p. 707.

[8] "Update on the MEIC Electron Collider Ring Design", F. Lin et al., these proceedings.

[9] "Status of the MEIC Ion Collider Ring Design", V. Morozov et al., these proceedings.

[10] "RF System of The CSNS Synchrotron", H. Sun, X. Li, F. C. Zhao, W. L. Huang, H.S hi, C. L. Zhang, W. Long, Proc. of IPAC2013, Shanghai, China (2013).

[11] "Present Status of J-PARC Ring RF Systems", M. Yoshii, S. Anami, E. Ezura, K. Hara, Y. Hashimoto, C. Ohmori, A. Takagi, M. Toda, Proc. of PAC07, Albuquerque, New Mexico, USA (2007).

[12] "Capture, Acceleration and Bunching RF Systems for the MEIC Booster and Storage Rings", S. Wang et al., these proceedings.

[13] "Studies of Beam Cooling for MEIC", Y. Zhang et al., these proceedings.

[14] "Compact Superconducting RF-Dipole Cavity Designs For Deflecting And Crabbing Applications", S. U. De Silva, J. R. Delayen, A. Castilla, Proc. IPAC2013, Shanghai, China (2013).

[15] "Harmonic Resonant Kicker Design For The MEIC Electron Circular Cooler Ring", Y. Huang et al., these proceedings.

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