RF Systems for the Low Energy RHIC Electron Cooling Project

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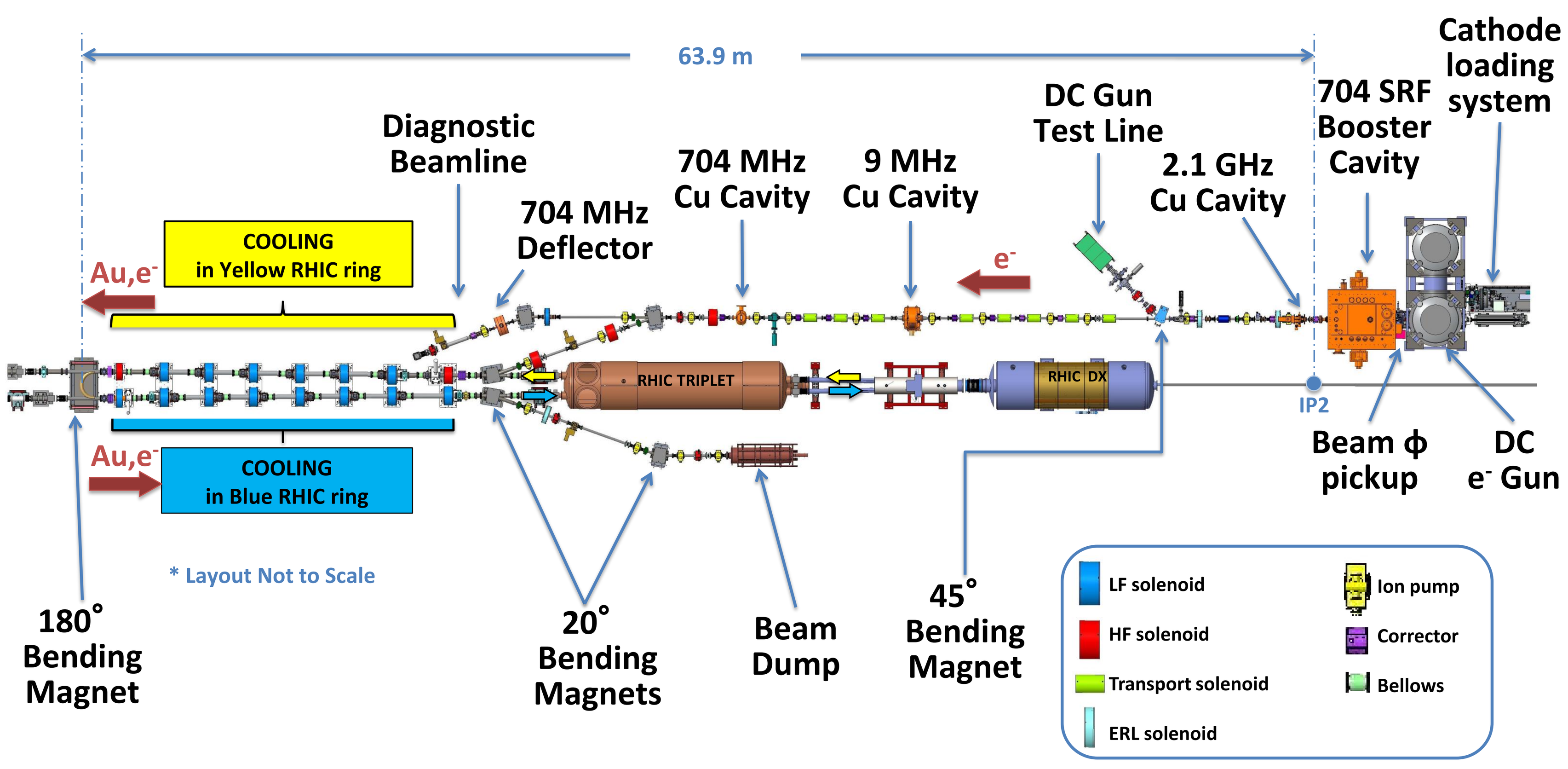
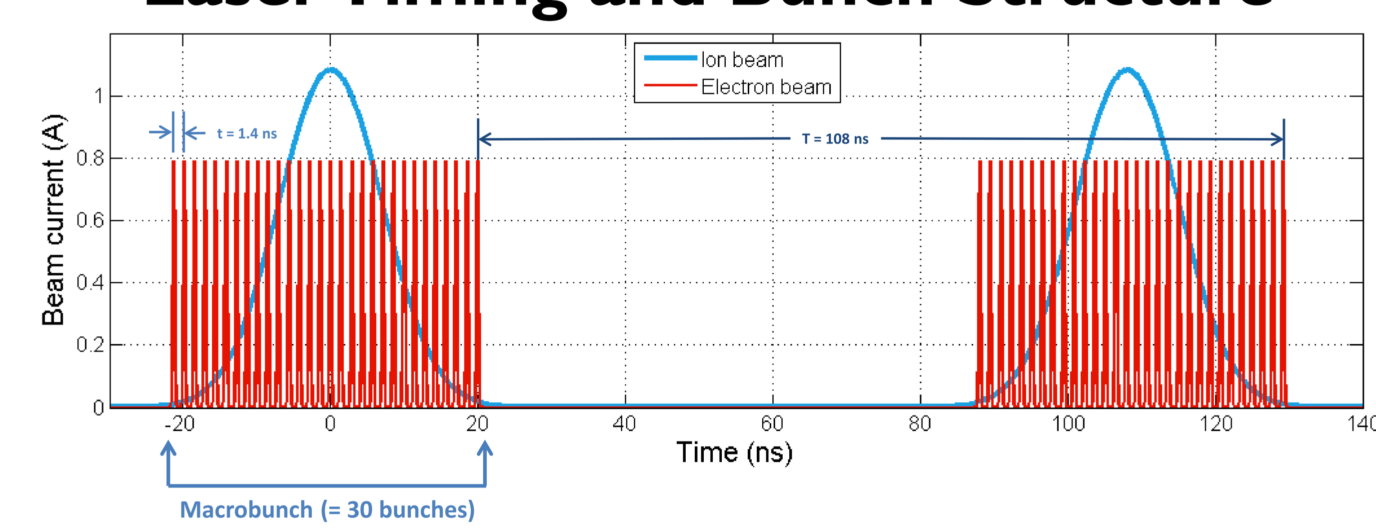
The Low Energy RHIC Electron Cooling (LEReC) project aims to provide significant luminosity improvement for RHIC operation during the BES-II (Beam Energy Scan II) running period. In this mode, RHIC operates below its nominal injection energy to provide Au-Au collisions at center-of-mass energies of 7.7 – 11.5 GeV/n to support the search for the QCD critical point. The electron beam for cooling is required to have the same velocity as the ion beam, corresponding to kinetic energies of 1.6 – 2.6 MeV, at a current of 10 - 50 mA and with an energy spread of less than 5e-4. The RF system consists of 4 cavities which accelerate the electron beam and a transverse deflecting cavity for the longitudinal phase space diagnostic. These cavities must accelerate the beam from the 400 keV DC photogun, provide an energy chirp for ballistic stretching in the transport, linearize the bunch energy with a 3rd harmonic cavity, and then remove the energy chirp to minimize energy spread.

LEReC Component Layout



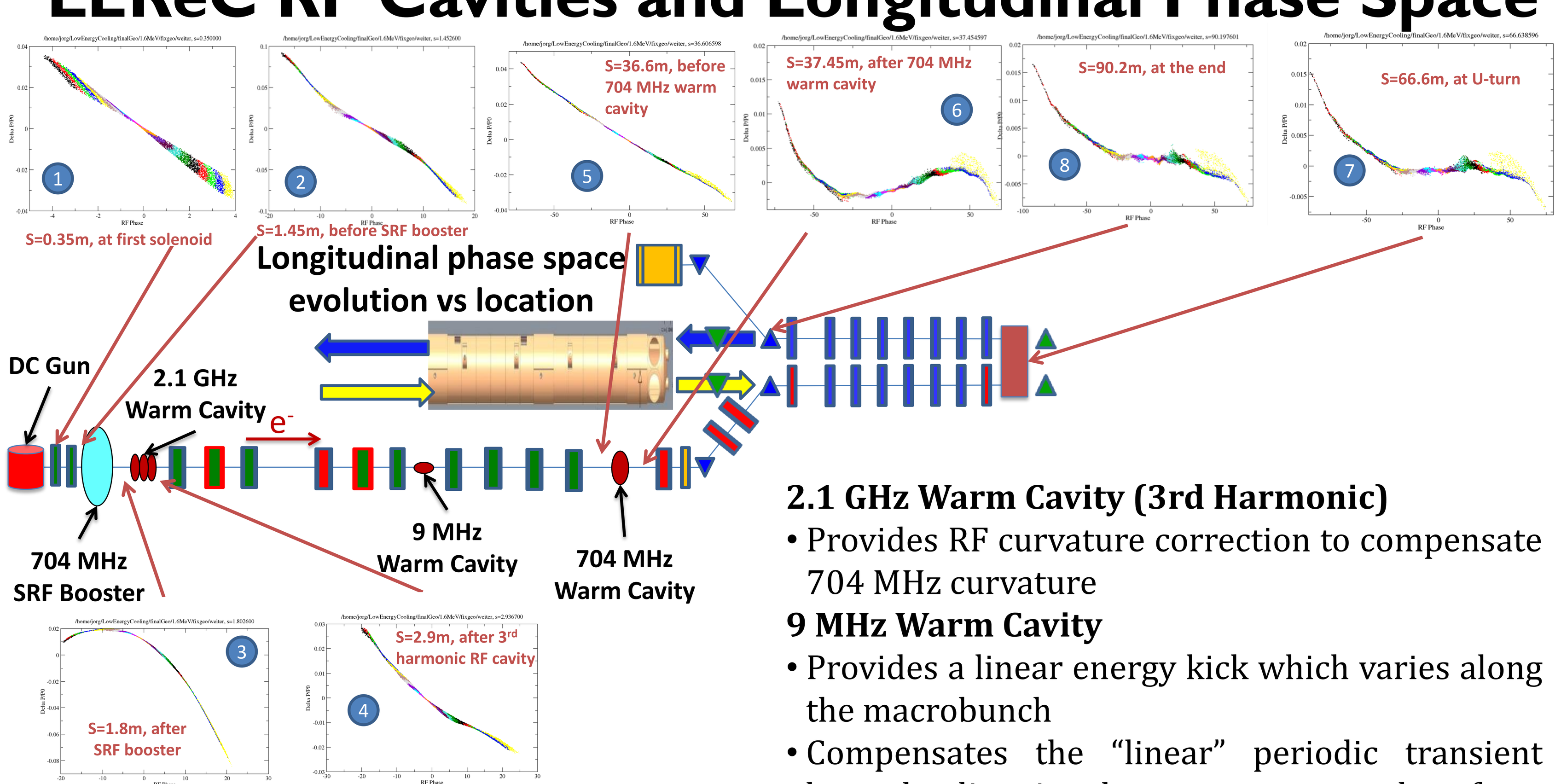
Laser Timing and Bunch Structure



Electron bunches are generated in the DC gun with a repetition rate of 704 MHz. Macrobunches (consisting of ~30 bunches) repeat at the 9 MHz ion bunching frequency. These frequencies are both harmonics of the RHIC ion revolution frequency, but the 704 MHz harmonic is not an integer multiple of the 9 MHz harmonic.

A Mach-Zehnder electro-optical modulator (EOM) creates the macrobunch structure on the drive laser. This EOM is driven with new hardware that consists of a Xilinx Zynq evaluation board with a custom FMC daughtercard and Picosecond Pulse Labs driver amplifier. The transmitter section of one of the Zynq GTX gigabit transceivers is used to generate a serial data stream which corresponds to the on-off pattern of the laser.

LEReC RF Cavities and Longitudinal Phase Space



704 MHz SRF Booster Cavity

- Acceleration to desired beam energy
- Produces an energy chirp to stretch the electron bunches (to reduce space charge effects)

2.1 GHz Warm Cavity (3rd Harmonic)

- Provides RF curvature correction to compensate 704 MHz curvature

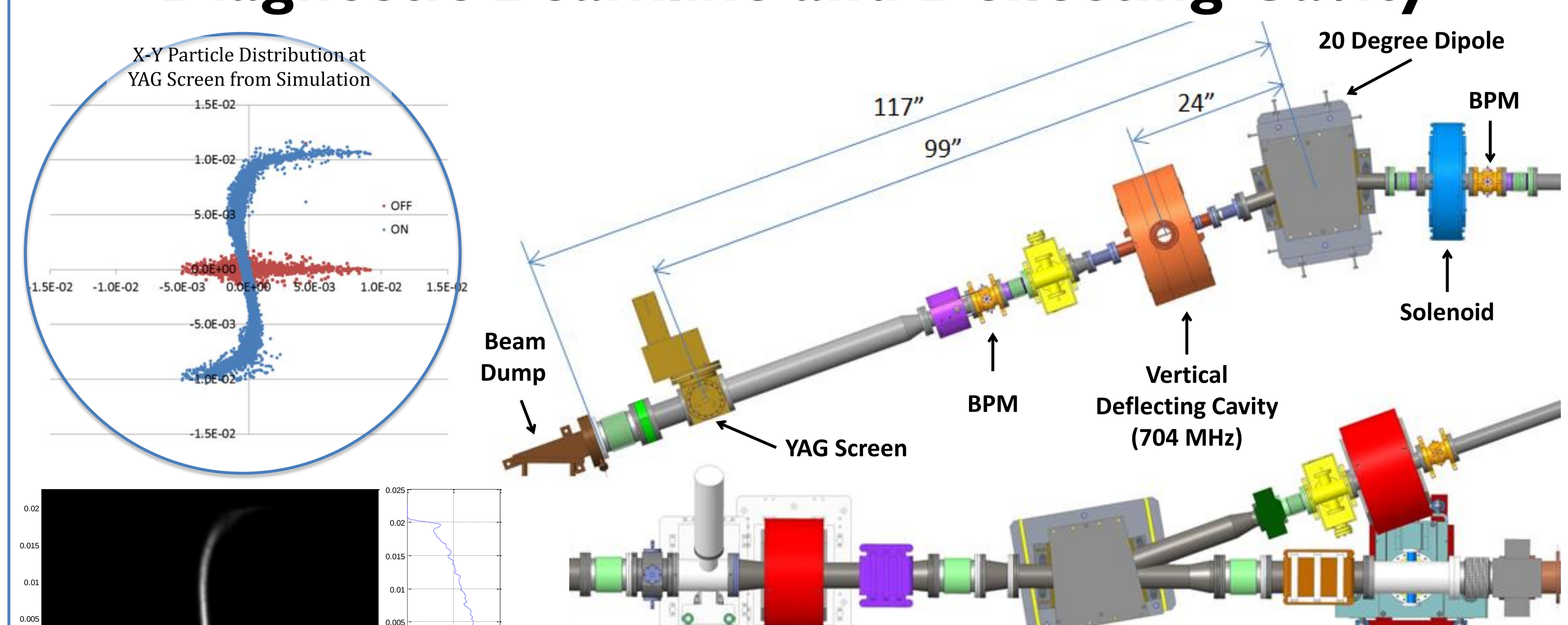
9 MHz Warm Cavity

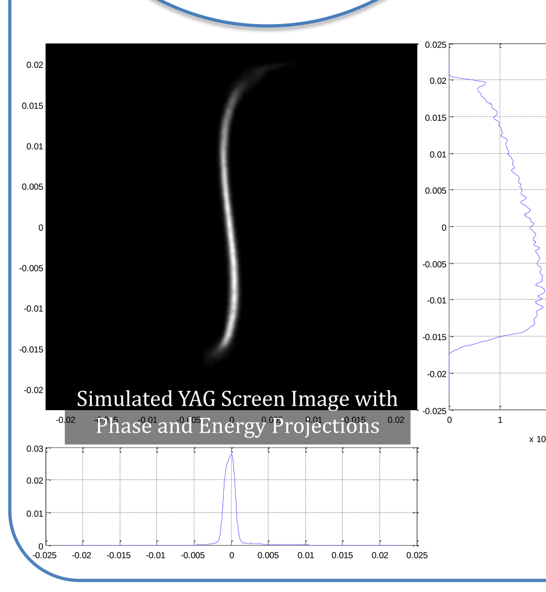
- Provides a linear energy kick which varies along the macrobunch
- Compensates the "linear" periodic transient beam loading, i.e. the average energy loss from the first to the last bunch of a macrobunch

704 MHz Warm Cavity

- Removes the energy chirp from the 704 MHz Booster Cavity

Diagnostic Beamline and Deflecting Cavity

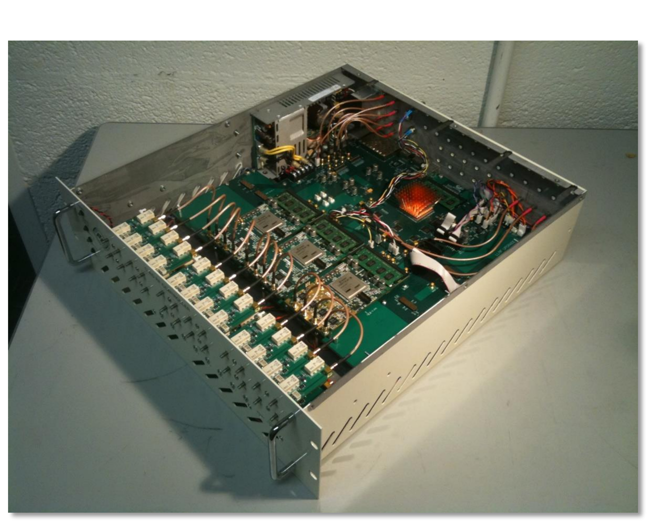


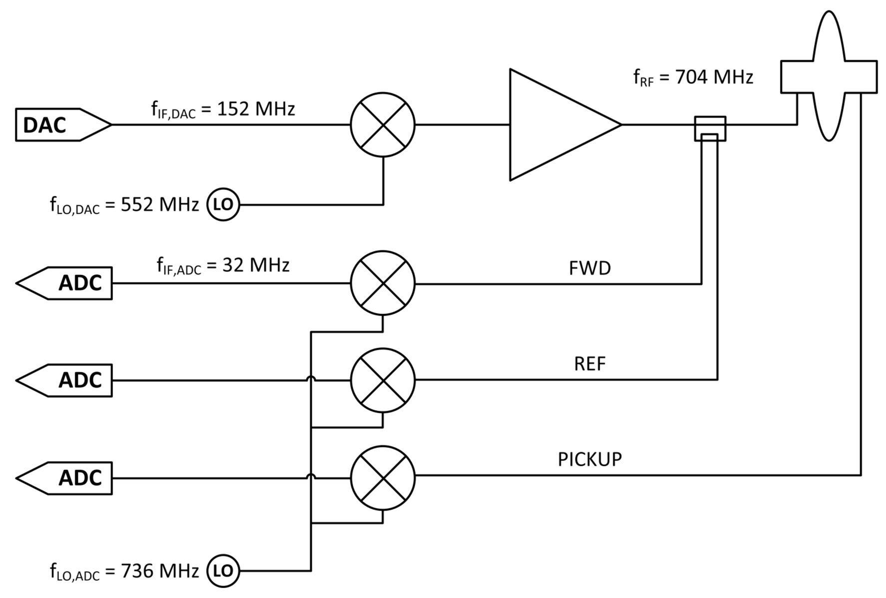


The **704 MHz Vertical Deflecting Cavity** is used in the diagnostic beamline for measuring longitudinal phase space. It produces an RF phase dependent vertical kick to streak the beam on a YAG screen. Dispersion from a dipole provides (relative) energy measurement. Analysis code will "slice" the image to get energy and energy spread as a function of RF phase. We are working on an online model to allow fast simulation of effects of RF changes on the diagnostic line image.

Cavity Control

Each cavity has a dedicated cavity controller chassis built with the common components of the FPGA-based RHIC LLRF Platform – a chassis carrier board, DAC daughtercard, ADC daughtercard(s), and a tuning (stepper motor) controller daughtercard. This hardware system is now used across the entire C-AD accelerator complex (the Electron Beam Ion Source, 200 MeV H-Linac, Booster, AGS, RHIC, the CeCPoP experiment, and the SRF cavity test facility), with associated firmware and software to implement direct digital synthesis and digital down conversion of RF waveforms, cavity field control via I/Q feedback, cavity resonance (tuning) control, and fast cavity protection interlocks. The LEReC system is built on this existing base, with some additional features to be added (such as adaptive feedforward transient beam loading compensation).





Energy Correction and Stability

Effective cooling of the RHIC ion beam requires that the velocity of the ions and electrons match. This defines the required energy of the electrons and leads to an rms energy spread requirement of $\frac{\Delta E}{E_0} < 5 \times 10^{-4}$ rms. Tolerance studies were performed using PARMELA and GPT to determine the following stability requirements necessary to maintain the required energy spread.

	704 MHz Booster	2.1 GHz Warm	704 MHz Warm	DC Gun	Drive Laser
$^{\Delta A}/_{A}$ (rms)	3×10^{-4}	2.5×10^{-3}	2.5×10^{-3}	5×10^{-4}	–
$\Delta\varphi$ (rms)	0.25°	0.75°	0.25°	–	0.25°

The RHIC LLRF Platform has demonstrated short-term (f > 1 Hz) noise and jitter performance of $^{\Delta A}/_{A} \approx 2 \times 10^{-4}$ rms and $\Delta\varphi < 0.1°$ rms with the 704 MHz 5-cell cavity in the ERL experiment. To help address long-term stability, all critical LLRF electronics will be installed in temperature controlled racks and cable bundles for the cavity pickup and loopback reference signals will run through temperature controlled conduit from the RHIC tunnel to the service building that houses the LLRF.

Ultimately, long-term drift will be compensated with beam-based energy correction using dedicated measurements in the diagnostic line (which cannot be done while cooling) and real-time feedback based on average energy measurements using the 180° dipole magnet as a spectrometer (which operates while beam is sent to the cooling section).

Acknowledgements

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