BNL C-AD LLRF Status and Activities

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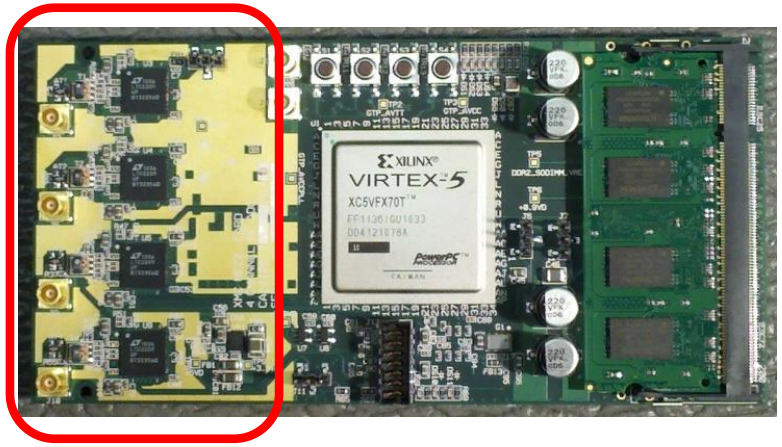
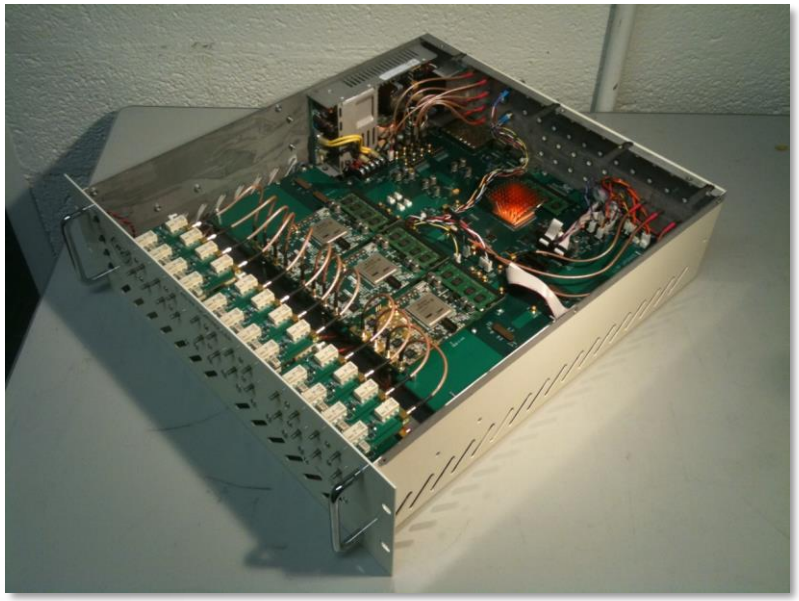
RHIC/C-AD LLRF Platform

- Architecture described at previous workshops and conferences. Concept described in 2005, prototypes in 2007-2008, first operation for RHIC LLRF beam control in 2009, rolled out to other machines over 2010 to ~2015.
- Now used in all C-AD operational accelerators and for most RF testing. We have about 90 platform chassis in operation, plus 8 Update Link Masters.
- The platform comprises several major sub-components
  - Platform Carrier Board
  - Three XMC Daughtercards
    - 4 CH High Speed DAC Board
    - 4 CH High Speed ADC Board
    - Baseband 1 DAC / 3 ADC / digital IO (used for tuning control)
  - The Update Link
    - Downstream deterministic (i.e. fixed latency) 2 Gbps serial link distributes encoded events (timing) and data
    - Update Link Master chassis generates link, also operates as a fanout and concentrator (up to 34 outputs, 16 inputs)
  - Fixed Frequency Reference Clock
    - All RF DACs/ADCs used fixed clock frequency
    - RF synchronous clocking used for certain applications (triggers, “rev ticks,” etc.)

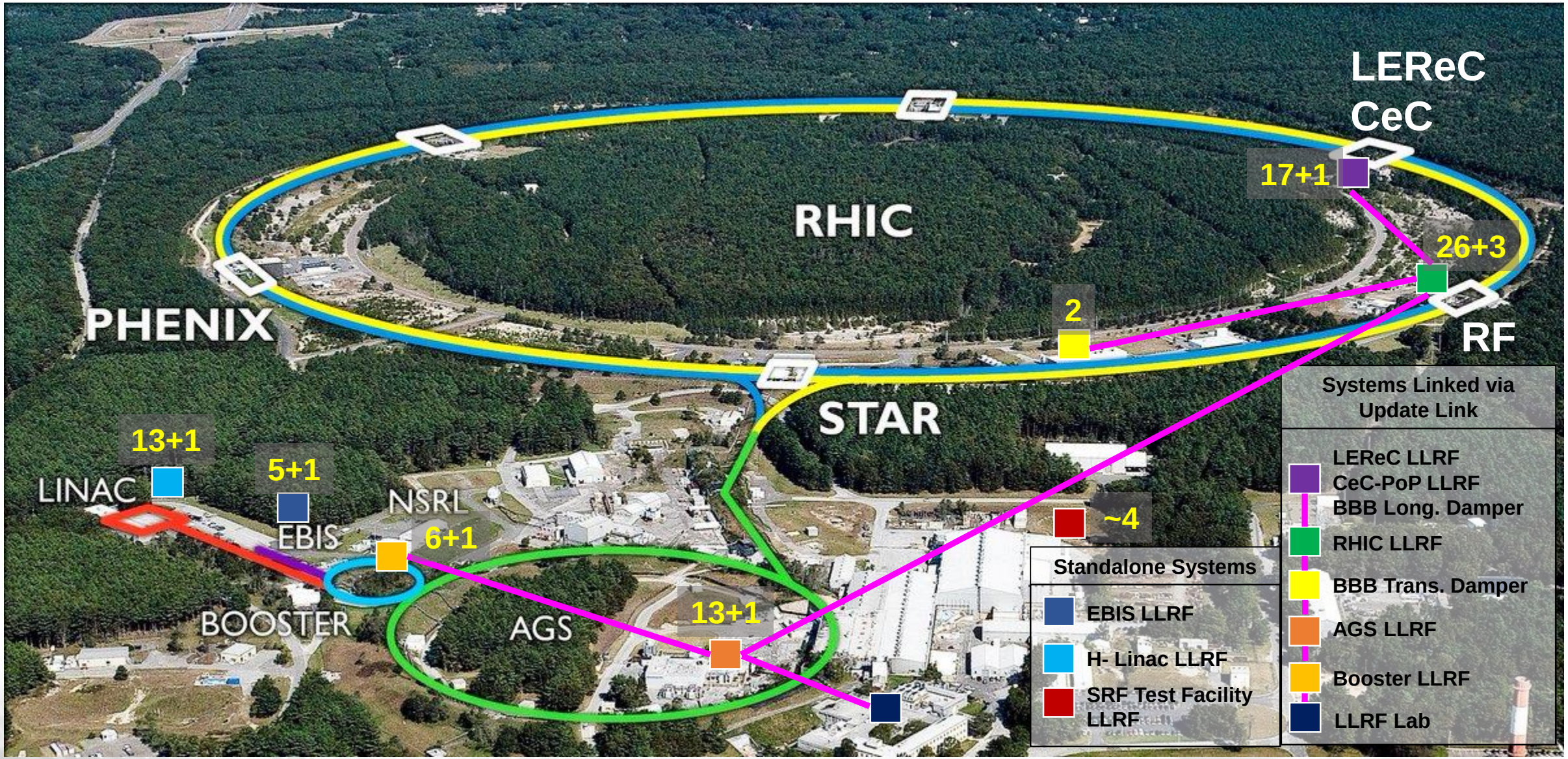


Platform XMC 4CH High Speed ADC Board
Daughter Cards only differ inside RED box



Platform Chassis showing Carrier Board, 2 DAC Daughter Boards and 1 ADC Daughter Board.

C-AD Complex

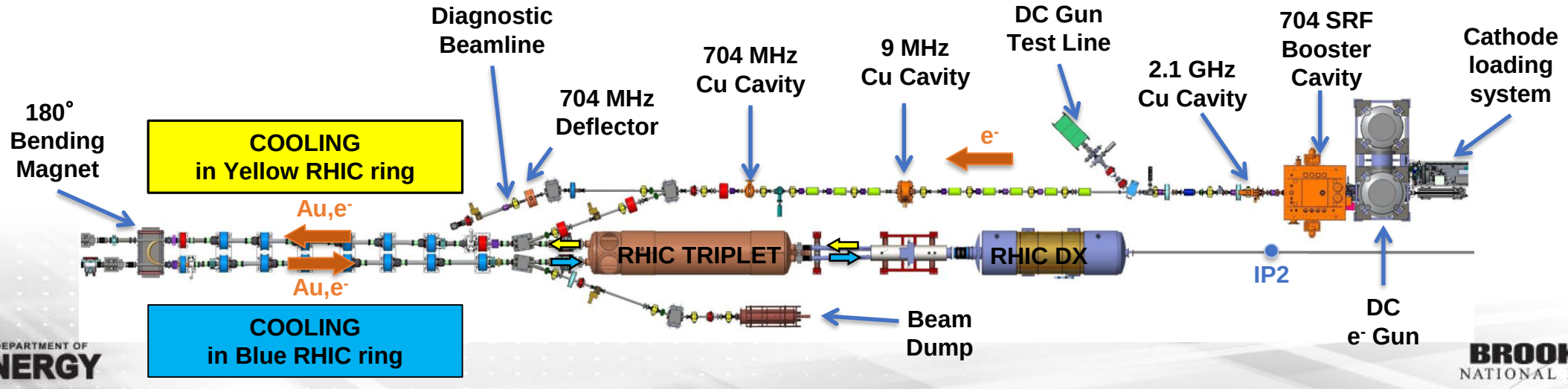

LEReC
CeC
17+1
RHIC
26+3
PHENIX
2
RF
STAR
13+1
LINAC
5+1
EBIS
NSRL
6+1
~4
BOOSTER
AGS
13+1
Systems Linked via Update Link
LEReC LLRF
CeC-PoP LLRF
BBB Long. Damper
RHIC LLRF
BBB Trans. Damper
AGS LLRF
Booster LLRF
LLRF Lab
Standalone Systems
EBIS LLRF
H- Linac LLRF
SRF Test Facility LLRF

Major Activities since LLRF2017

- RHIC Run 18
  - “Isobar” program with Ru-96 and Zr-96 – due to concerns about systematic errors in detectors switched ion species every day leading to RHIC “mode switching”
  - Au-Au collisions at intermediate energies for physics and CeC proof-of-principle experiment
  - Low Energy RHIC electron Cooling (LEReC) accelerator commissioning
- RHIC Run 19
  - Beam Energy Scan II (BES-II) – a 3 year program of Au-Au collisions at or below nominal RHIC injection energy (9.8, 7.3, 5.7, 4.6, 3.85 GeV/n)
  - Completed physics runs at 9.8 and 7.3 GeV/n
  - Commissioning of ion beam and electron cooling at 3.85 and 4.6 GeV/n, and took small initial physics datasets
  - 11 different operating modes in the RHIC collider
- Operational support of injector chain frequent reconfiguration for different modes

New RF Systems since LLRF2017

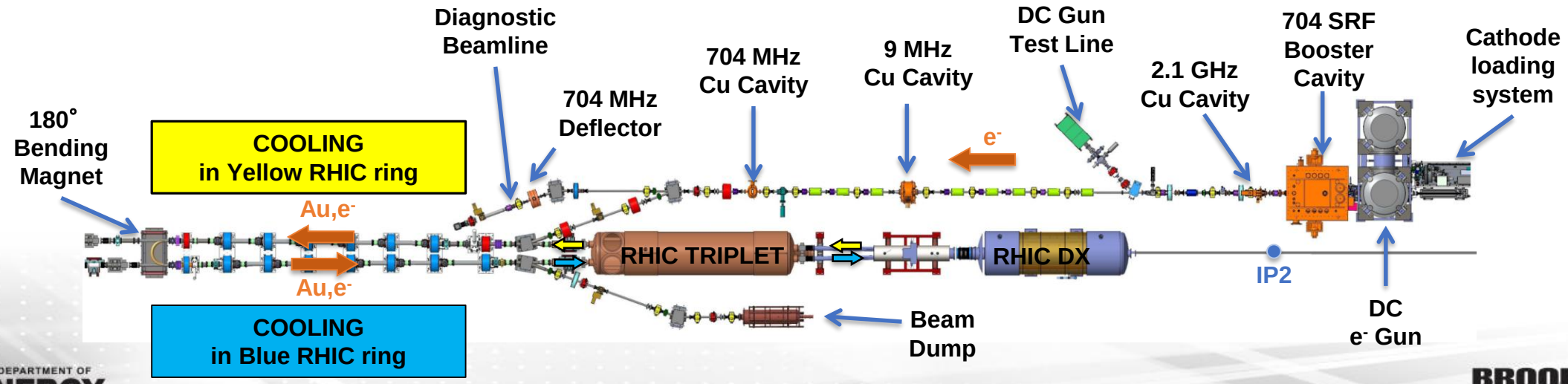
- RHIC 9 MHz cavities
  - Lower frequency cavities to support long bunches at low energy
    → minimize space charge effects, improved beam lifetime
  - 3 new cavities in each RHIC ring
- Low Energy RHIC electron Cooling (LEReC)
  - Electron cooling for the two lowest energies of BES-II (3.85 and 4.6 GeV/n)
  - LEReC is the first RF linac-based electron cooler with bunched beam cooling



LEReC

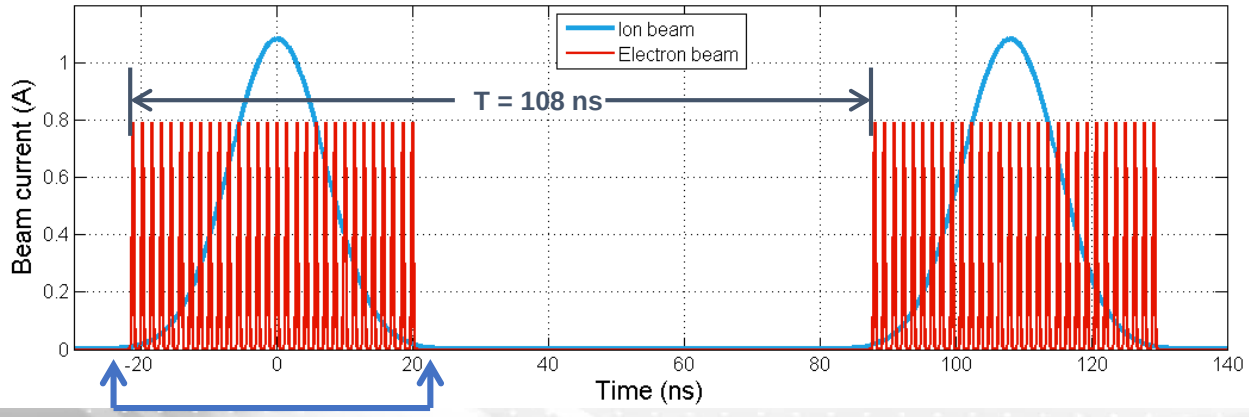
5 RF cavities, integration with RHIC RF and timing, plus various integration and support activities for other subsystems:

- Timing signal generation for Laser/Instrumentation/Controls
- Electronics support for other Laser subsystems, including beam-based feedback on laser intensity to control beam current
- Support for DC gun power supply limitations, including design of digital regulator using LLRF platform
- Operations and commissioning support plus general engineering support for commissioning and debugging of many other subsystems

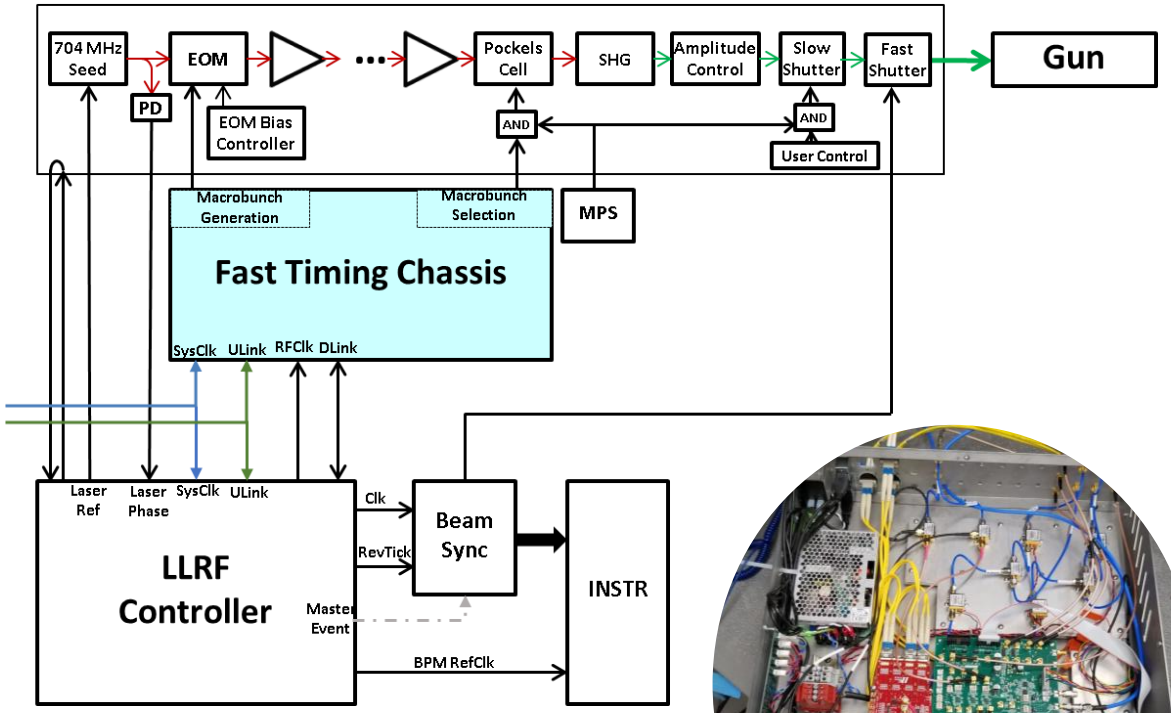


LEReC Laser Timing System

- 704 MHz laser reference
- EOM control for generating macrobunch structure (~30 pulses at 704 MHz, repeat at 9 MHz ion bunch frequency)
- Pockels cell control for gating macrobunches for various beam operating modes (1 Hz pulsed, 76 kHz pulsed, 9 MHz CW)
- System based on Zynq ZC706 eval board with custom FMC daughtercard



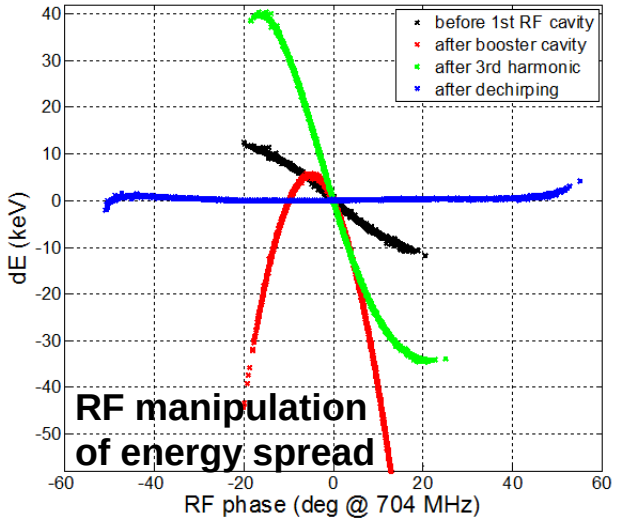
Macrobunch (= 30 bunches)

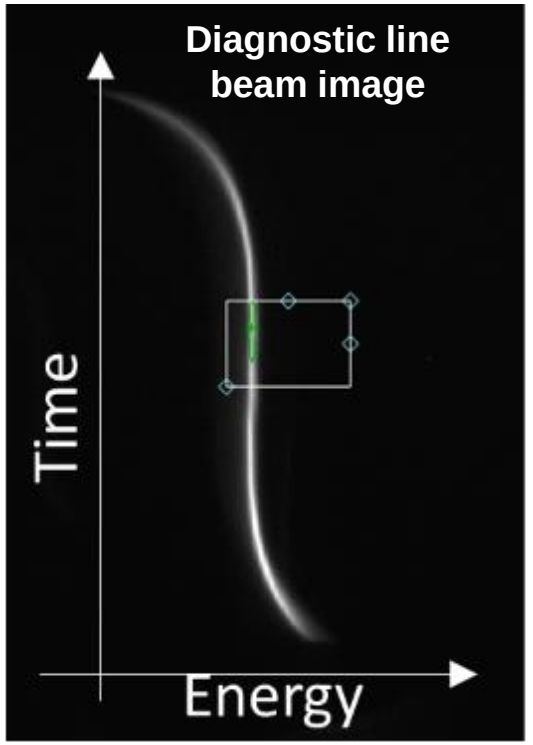


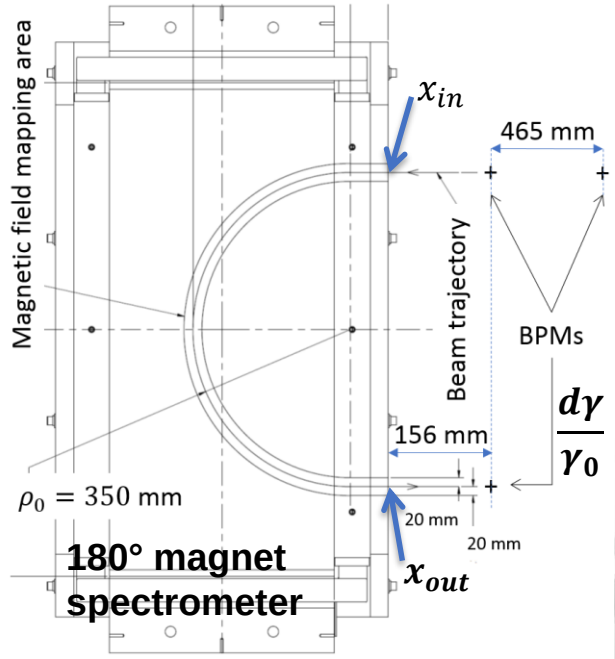
Geetha Narayan Poster: Development of a Zynq-based Laser Timing System for LEReC

LEReC Energy Control

- Cooling rate is a function of the velocity difference between ions and electrons in the beam frame
- Need minimal energy spread and stable energy (keep e- matched to ions)
- Cavities perform chirp/dechirp to reduce energy spread
- Dedicated diagnostics for measuring energy spread (transverse deflecting cavity and a dipole map longitudinal phase space to x-y on YAG screen) and average beam energy (spectrometer built around 180° bending magnet)
- A beam-based energy feedback system is planned to be implemented for 2020





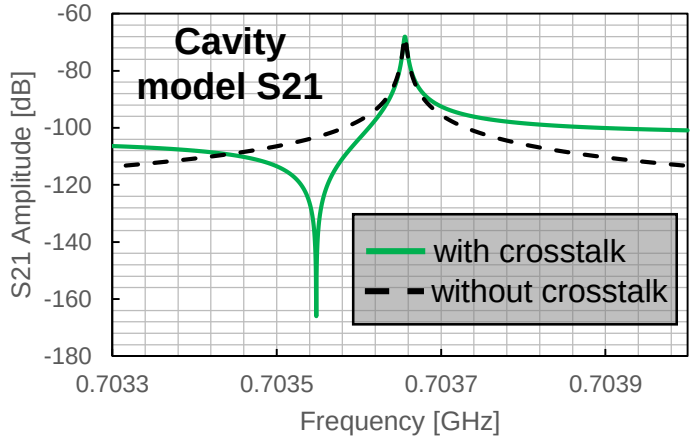


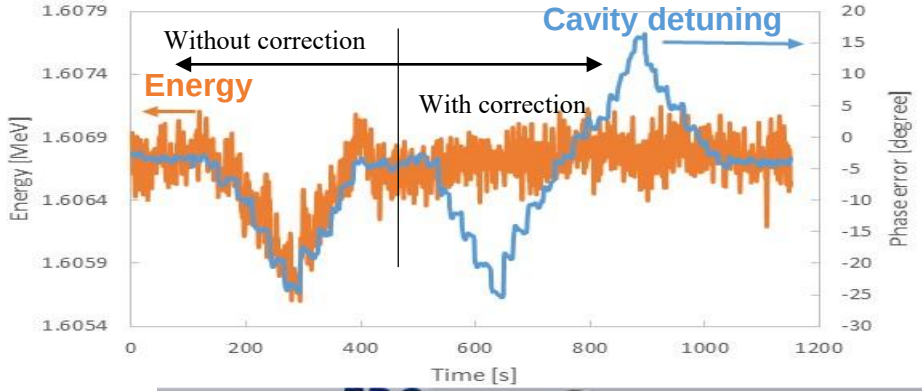
Kevin Mernick Poster: Energy Measurement and Stabilization for LEReC

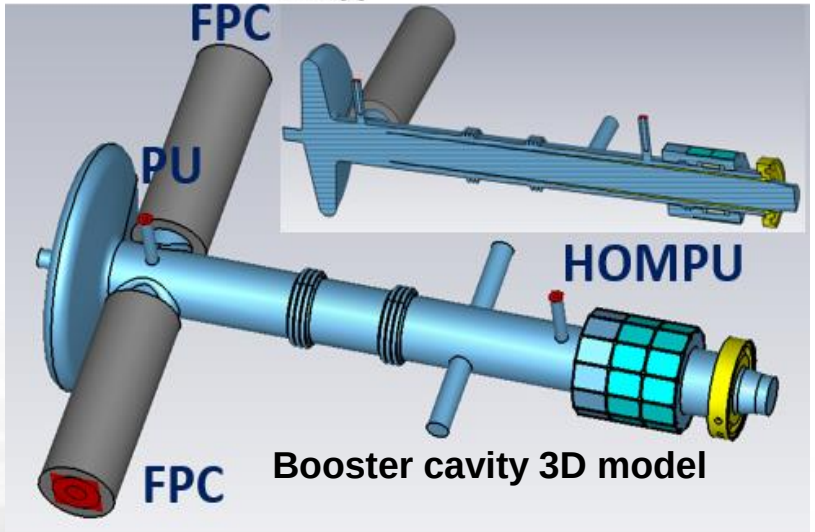
$$\frac{d\gamma}{\gamma_0} \approx \frac{{\gamma_0}^2 - 1}{{\gamma_0}^2}\left(\frac{B - B_0}{B_0} - \frac{B}{B_0}\frac{x_{out} + x_{in}}{2\rho_0}\right)$$

LEReC Booster Cavity Crosstalk

- Cavity was modified from the Energy Recovery Linac (ERL) SRF Photocathode Gun to a SRF Booster Cavity for LEReC.
  - Two FPCs, Pickup (PU) couplers and HOM couplers all located on same side of the cavity.
  - Direct capacitive coupling (crosstalk) between FPCs and PU can lead to voltage fluctuations that exceeds the total energy spread requirement of LEReC.
- LLRF feedback works to regulate amplitude and phase of field probe pickup signal. Crosstalk pollutes V_{pu} signal, so it is no longer a good representation of the cavity accelerating field. Use FPC fwd/rev signals to calculate crosstalk real time to use for correcting feedback path.
- With correction applied, measured energy error is reduced by a factor of ~20







Freddy Severino talk:
Low Level RF Correction of the Crosstalk Effect in the LEReC Booster Cavity
Thursday morning

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Upcoming Work

- LEReC transition to operations
- RHIC & injectors continuing operations support
- CeCPoP experiment, 56 MHz SRF cavity recommissioning for Run21+
- Next generation LLRF Platform development

Talks/Posters this week

- Kevin Smith Tutorial: LLRF for Rings and Colliders Tuesday AM
- Geetha Narayan Poster: LEReC Laser Timing System
- Kevin Mernick Poster: LEReC Energy Measurement and Stabilization
- Freddy Severino Talk: LEReC Booster Crosstalk Correction Thursday AM