Overview and Status of the Low-Energy RHIC Electron Cooling Project (LEReC)

Lee Hammons for the LEReC Team

Deputy Directorate Chief Operating Officer for Nuclear and Particle Physics

Collider-Accelerator Department
Brookhaven National Laboratory

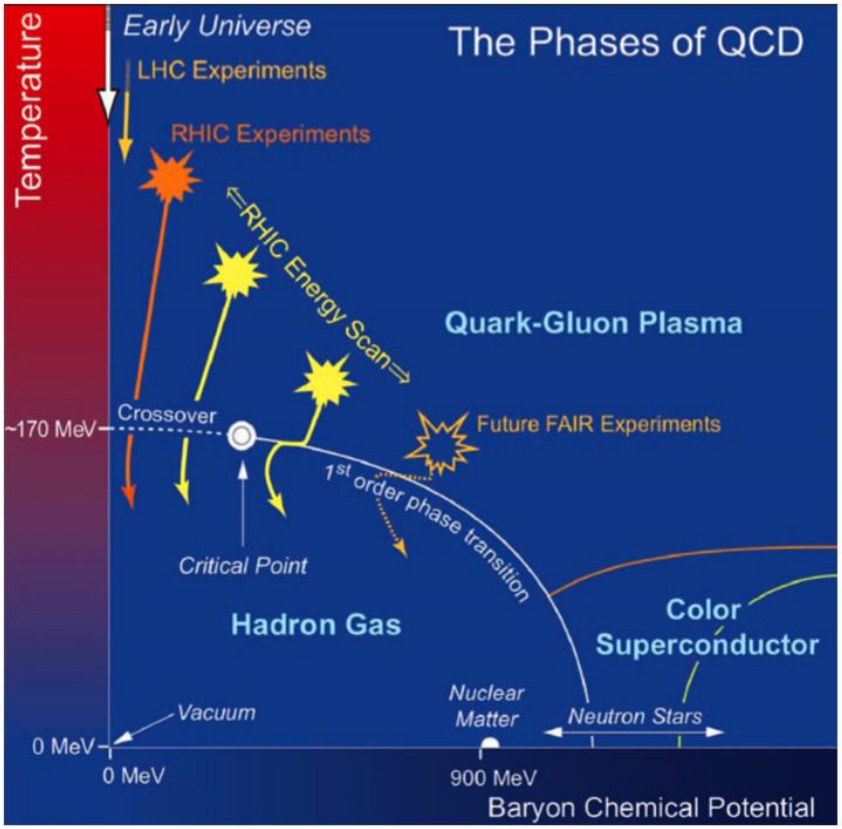
70 YEARS OF DISCOVERY

A CENTURY OF SERVICE

U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY

The QCD Landscape



From: ***Studying the Phase Diagram of QCD Matter at RHIC***, STAR White Paper, June 2014

- A central goal of high-energy nuclear collisions:
  - Map of phase diagram of nuclear matter
- Phase diagram is fundamental feature of QCD
  - Nuclear collisions at various energies allow map of QCD phase structure
- RHIC is highly versatile collider
  - Large range of energies
  - Large range of detector acceptance

Mapping the QCD Phase Diagram
The Beam Energy Scan Program

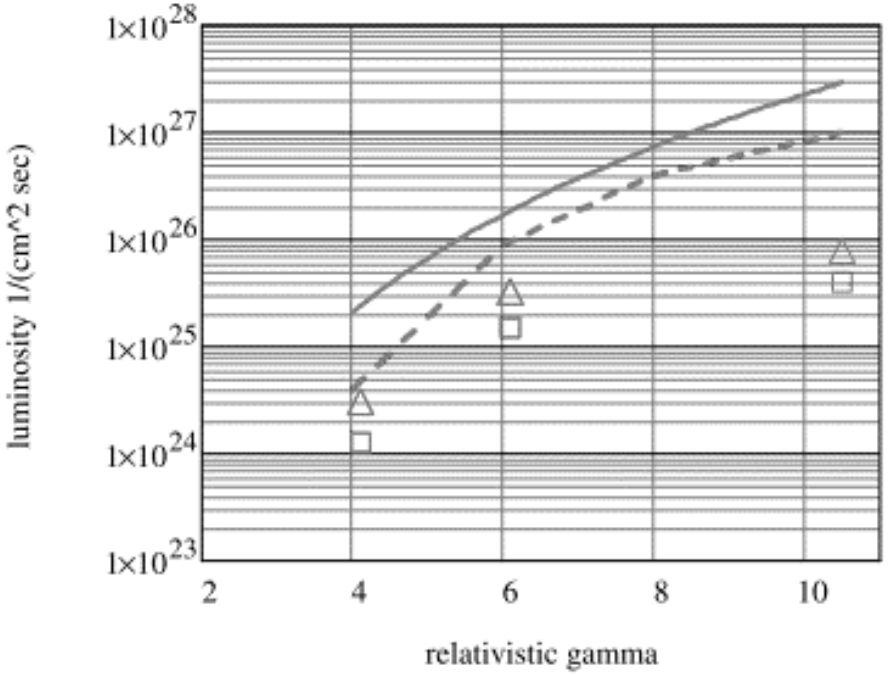
- BES-I Energies:

E ($\sqrt{s_{NN}}$ GeV)	7.7	11.5	19.6	39
γ	4.1	6.2	10.7	28.2

- BES-II Energies:

E ($\sqrt{s_{NN}}$ GeV)	7.7	11.5	20
γ	4.1	6.2	10.7

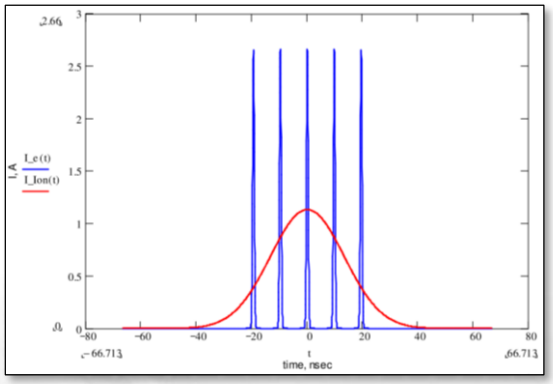
- High event statistics required
- At low energies, space charge dominates:
  - Increases emittance
  - Lowers luminosity
- Over long store, intrabeam scattering also causes emittance dissolution
  - Lower luminosity

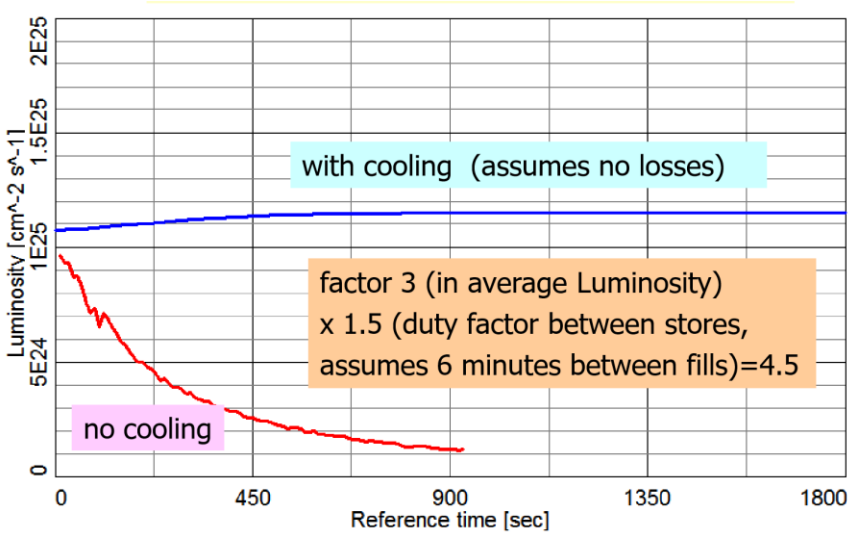


Square: measured average per store luminosity in BES-I
Triangle: measured maximum luminosity during BES-I
Dashed: expected luminosity improvement with cooling and present 28 MHz RF system
Solid: cooling and long ion bunches (with proposed new low-frequency RF system

Electron Cooling

- Method of increasing phase-space density of hadron beams
- “Cold” electron beam merged with “hot” ion beam
  - Drag force on hadron beam applied by electron beam
  - Cooled through Coulomb interactions
- Requires co-propagating electron beam with same average velocity as hadron beam

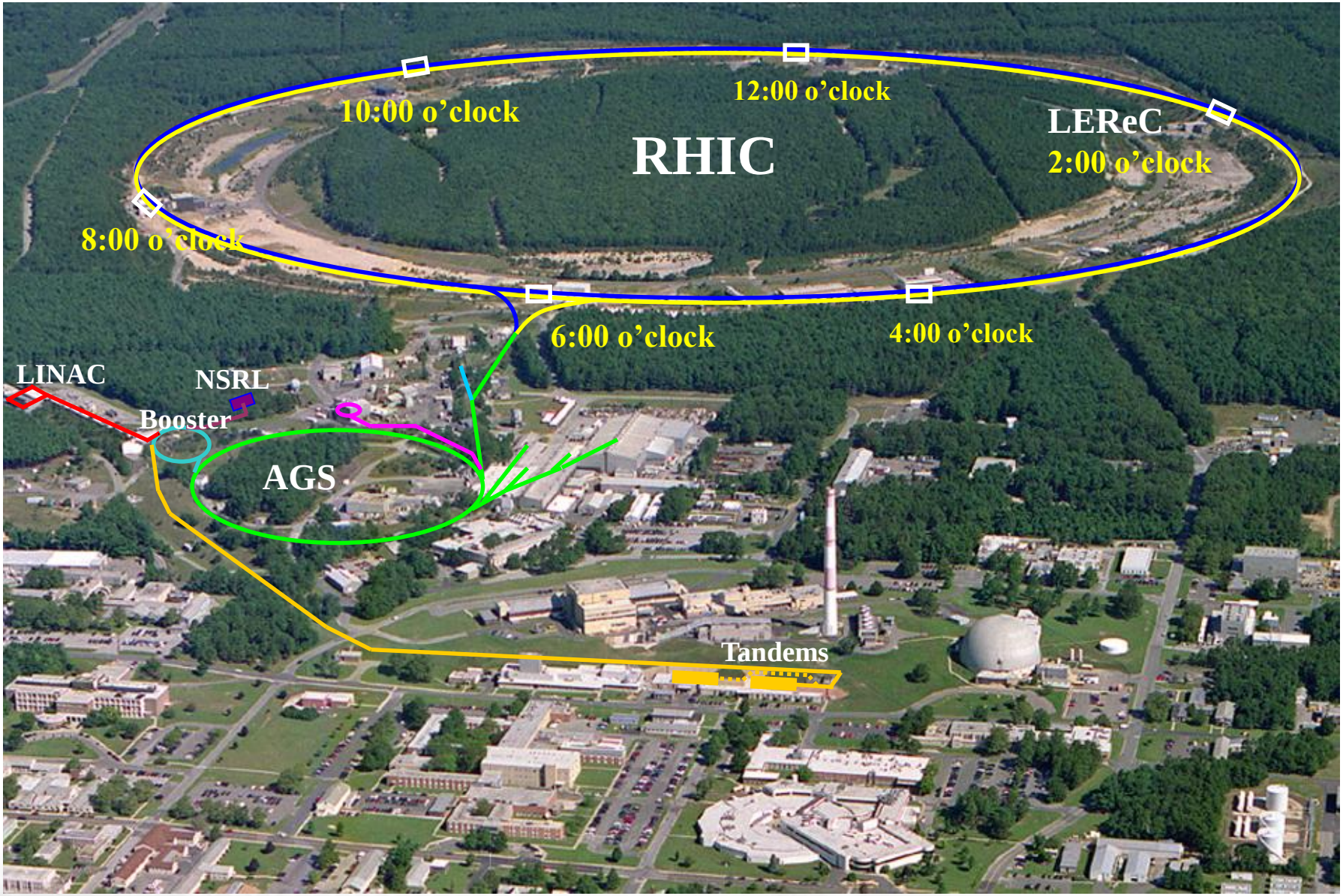




Simulation of luminosity with electron cooling at beam energy of 3.85 GeV/n ($\sqrt{s_{NN}}$ =7.7 GeV)

Goals of the LEReC Project

- A high-power electron accelerator has been added to the RHIC and is being commissioned
- LEReC is first LINAC-based electron cooler operating on bunched hadron beams at high energies
- Goal of commissioning is to achieve electron beam parameters suitable for ion-beam cooling in RHIC
  - Characterize beam parameters from DC gun
  - Commission and calibrate all RF cavities
  - Generate, accelerate and transport beam from DC gun to beam dump
  - Commission instrumentation
  - Measure and improve beam quality
  - Demonstrate cathode lifetime
- Commissioning being conducted in stages

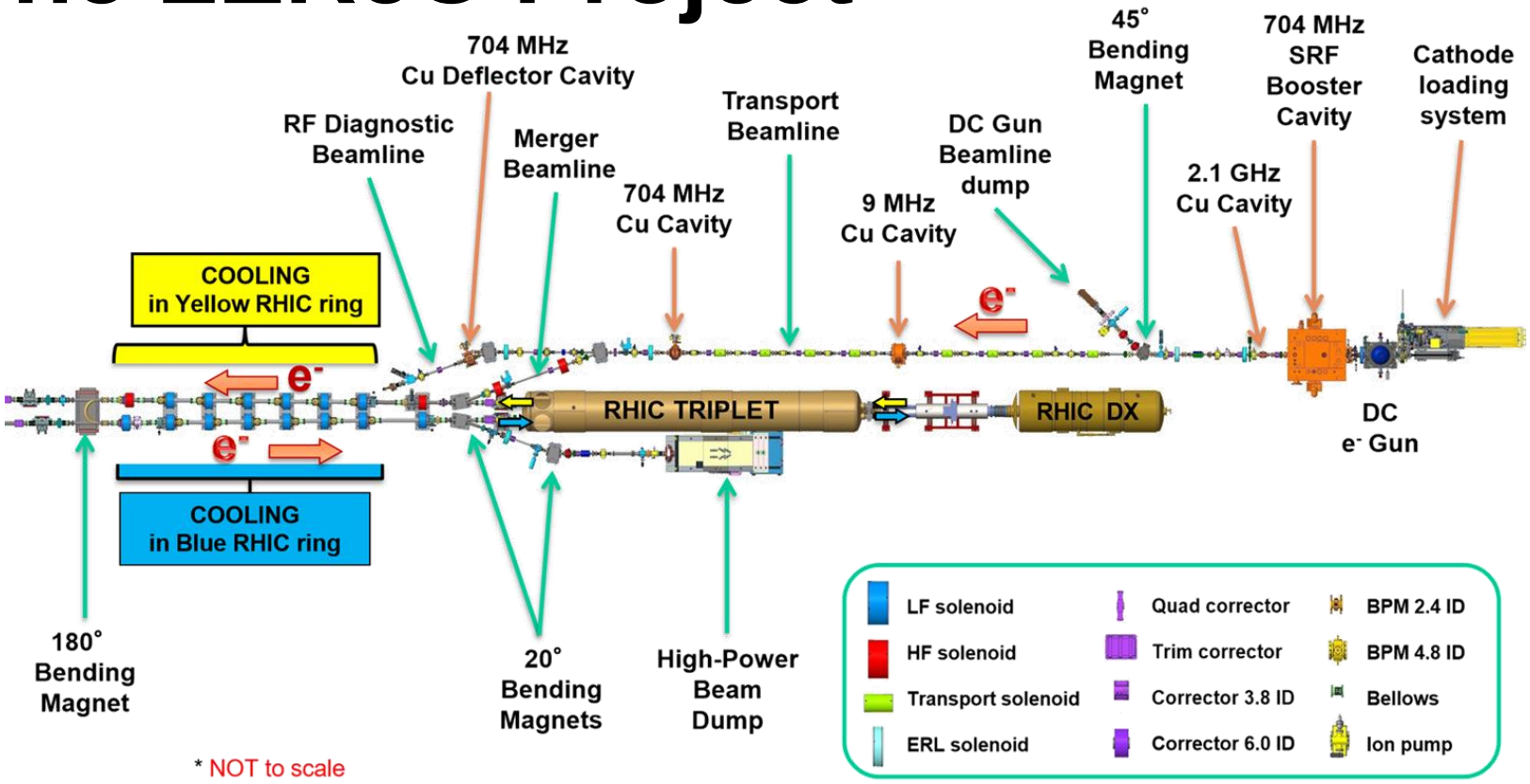

10:00 o'clock
12:00 o'clock
RHIC
LEReC
2:00 o'clock
8:00 o'clock
6:00 o'clock
4:00 o'clock
LINAC
NSRL
Booster
AGS
Tandems

Electron Beam Operation Parameters

Electron beam requirement for cooling			
Kinetic energy, MeV	1.6*	2	2.6
Cooling section length, m	20	20	20
Electron bunch (704 MHz) charge, pC	130	170	200
Effective charge used for cooling, pC	100	130	150
Bunches per macrobunch (9 MHz)	30	30	24-30
Charge in macrobunch, nC	4	5	5-6
RMS normalized emittance, μm	< 2.5	< 2.5	< 2.5
Average current, mA	36	47	45-55
RMS energy spread	$< 5\times10^{-4}$	$< 5\times10^{-4}$	$< 5\times10^{-4}$
RMS angular spread	< 150 μrad	< 150 μrad	< 150 μrad

*CW mode at 704 MHz without macrobunches is also being considered (with even higher average current up to 85 mA)

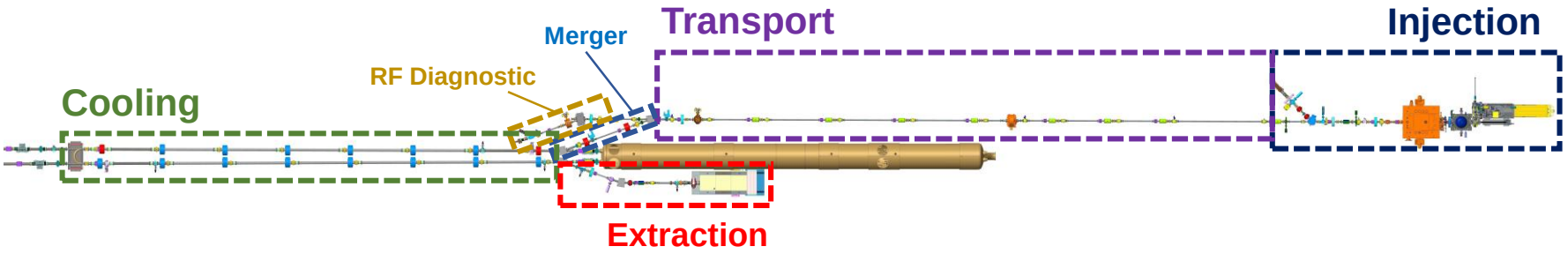
The LEReC Project



* NOT to scale

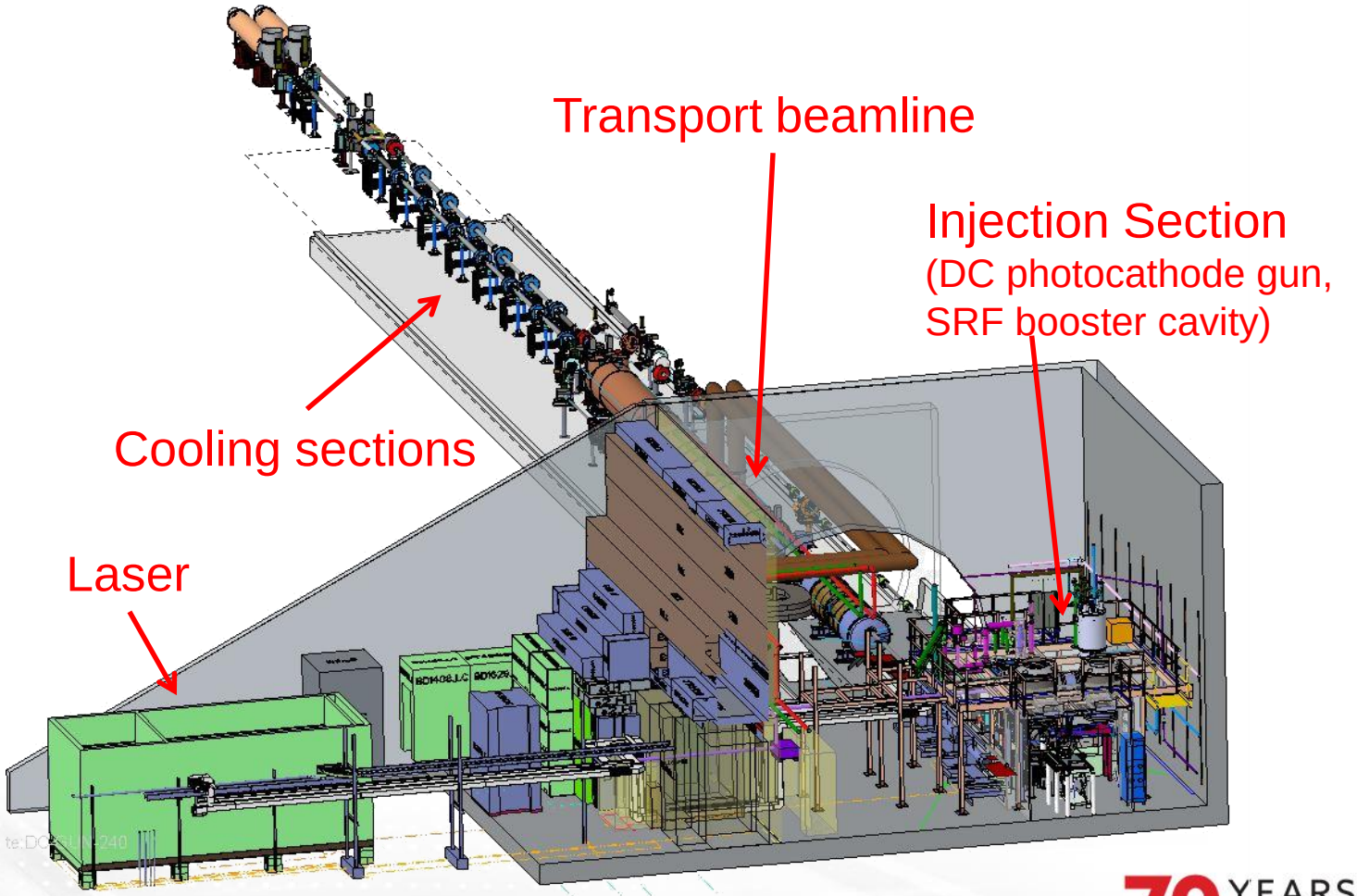
- **704 MHz SRF Booster Cavity**
  - Accelerator, Energy Chirp for Bunch Stretching
- **2.1 GHz Cu Cavity**
  - RF Curvature Correction
- **9 MHz Cu Cavity**
  - Macrobunch beam loading compensation
- **704 MHz Cu Cavity**
  - Removal of Energy Chirp
- **704 MHz Transverse Deflecting Cavity**
  - Longitudinal Phase Space, Vertical Deflection to Provide Head-to-Tail Streak

Commissioning Plan



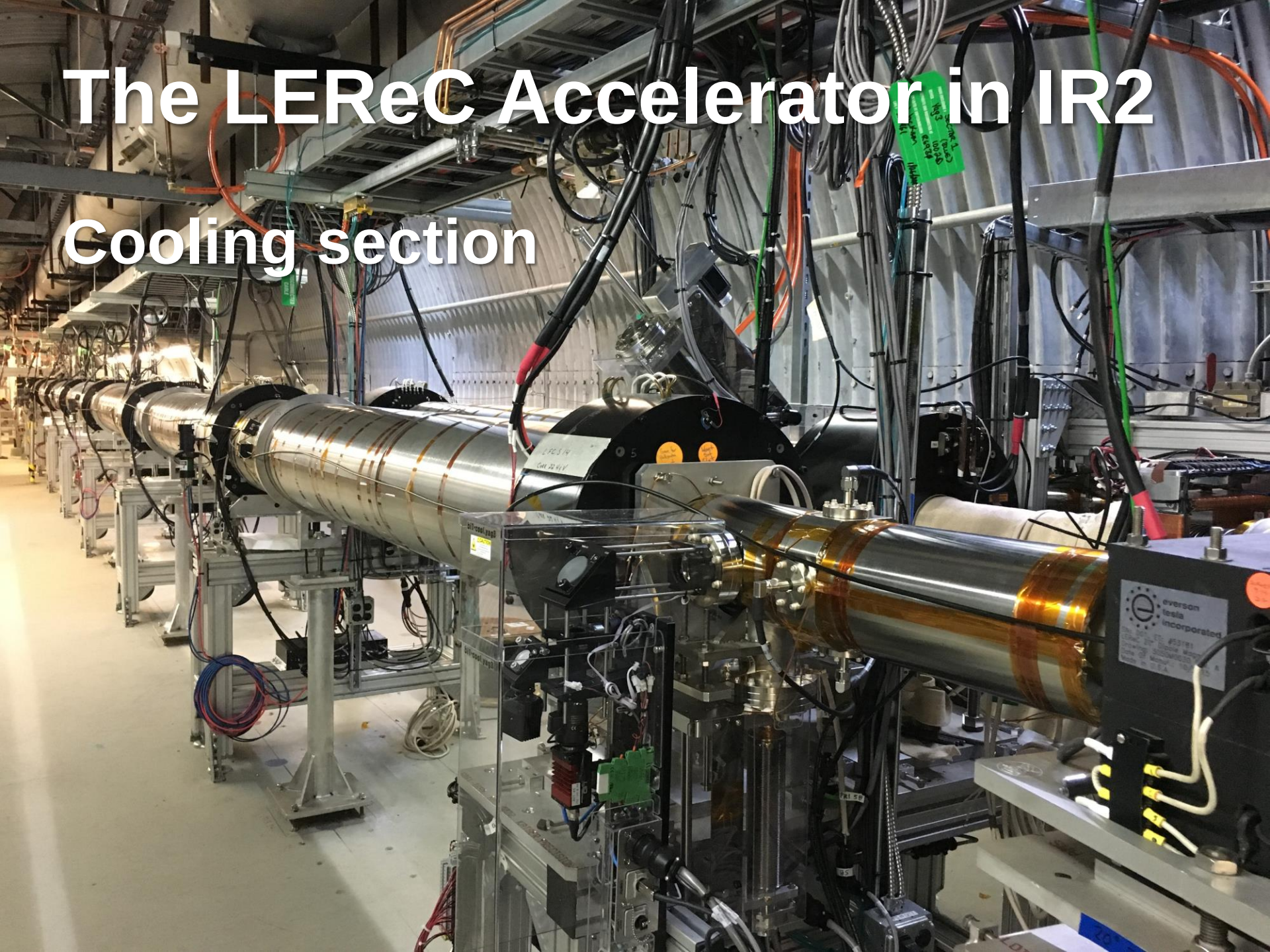
- **Commissioning of Full LEReC**
  - Begin at 1.6 MeV/0.1 mA
  - Pulsed mode / CW mode
    - Injector
    - Transport and merger
    - RF Diagnostic line
    - Cooling
    - Extraction
  - MPS Commissioning
  - Instrumentation Commissioning
  - Energy spread
  - Beam optics
- **Higher-Current Commissioning**
  - Operational stability at higher current thresholds:
    - 1 mA
    - 10 mA
    - 30 mA
  - Beam Loading
  - Cathode Lifetime
  - Transient Effects
- **Higher-Energy Commissioning**
  - Operational stability at higher energy:
    - 2 MeV
    - 2.6 MeV
  - Beam synchronization

LEReC Layout in RHIC Tunnel and IR2



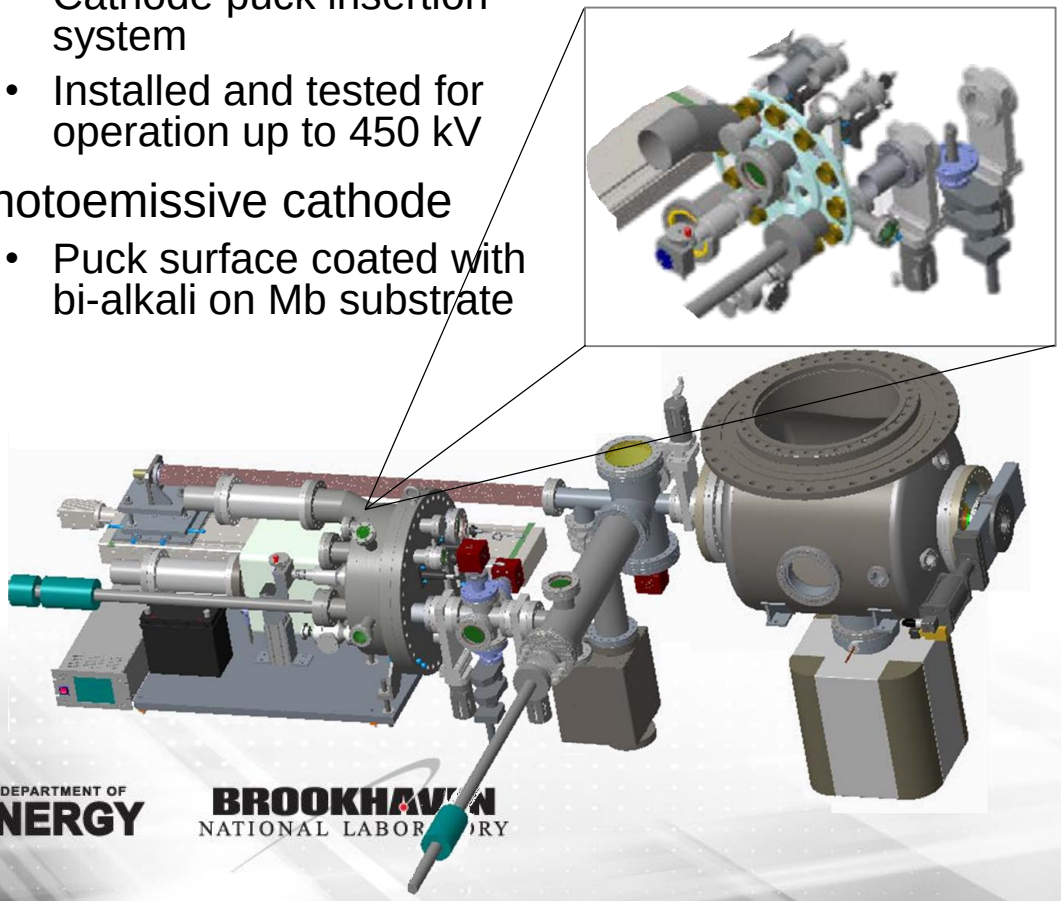
The LEReC Accelerator in IR2

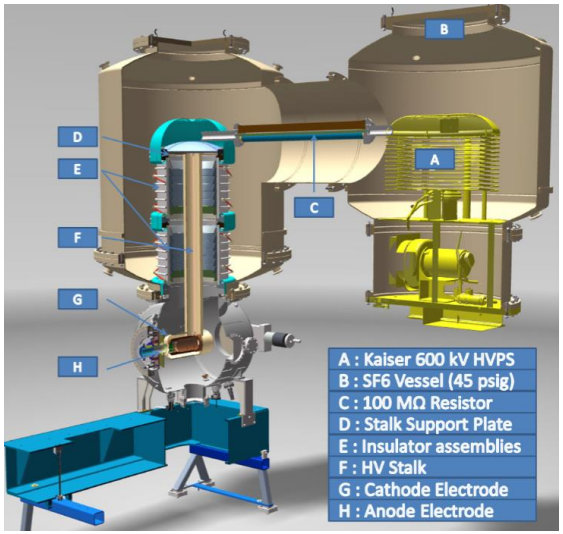
Cooling section



Major LEReC Components

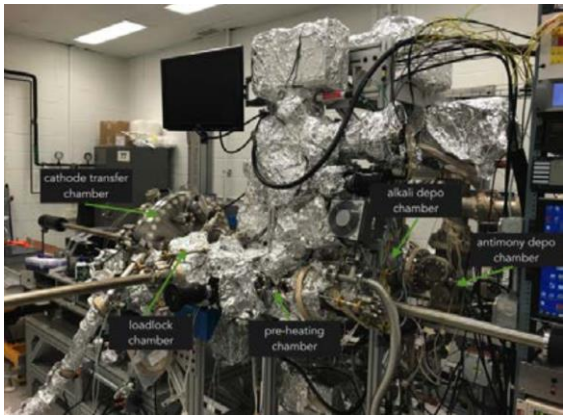
- DC Electron Gun
  - 600 kV power supply
  - Two pressure vessels filled with pressurized SF_6
  - Laser injection port
  - Cathode puck insertion system
  - Installed and tested for operation up to 450 kV
- Photoemissive cathode
  - Puck surface coated with bi-alkali on Mb substrate

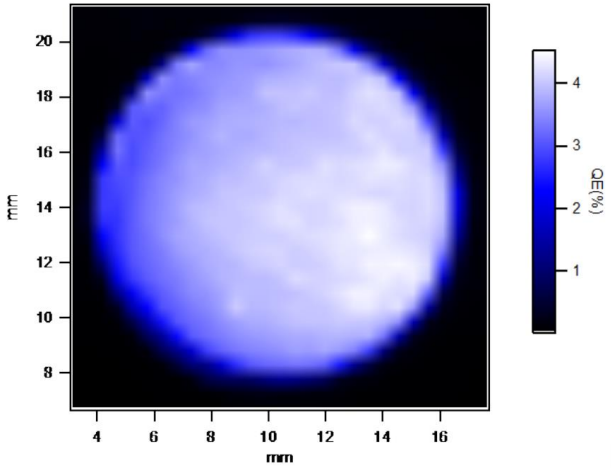


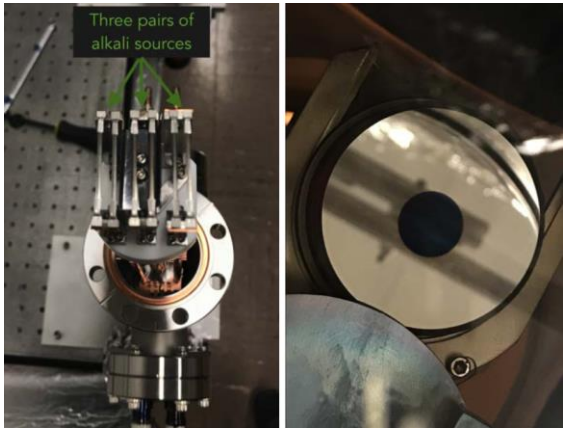


Multi-Alkali Photocathodes

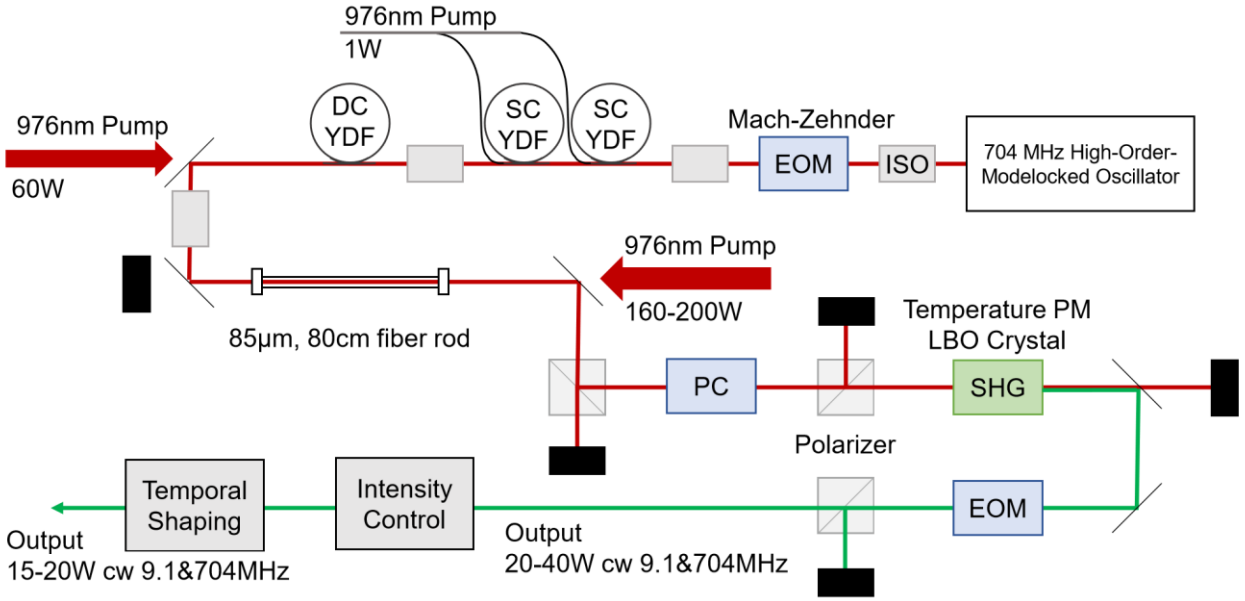
- Bi-alkali photocathodes provide long lifetime and high QE at visible wavelengths
  - System developed to provide 24/7 operation without significant interruption
- Photocathode recipe:
  - Cesium
  - Potassium
  - Antimony
- Typical QE after production: 3-6%
- Typical QE before insertion: 2-5%





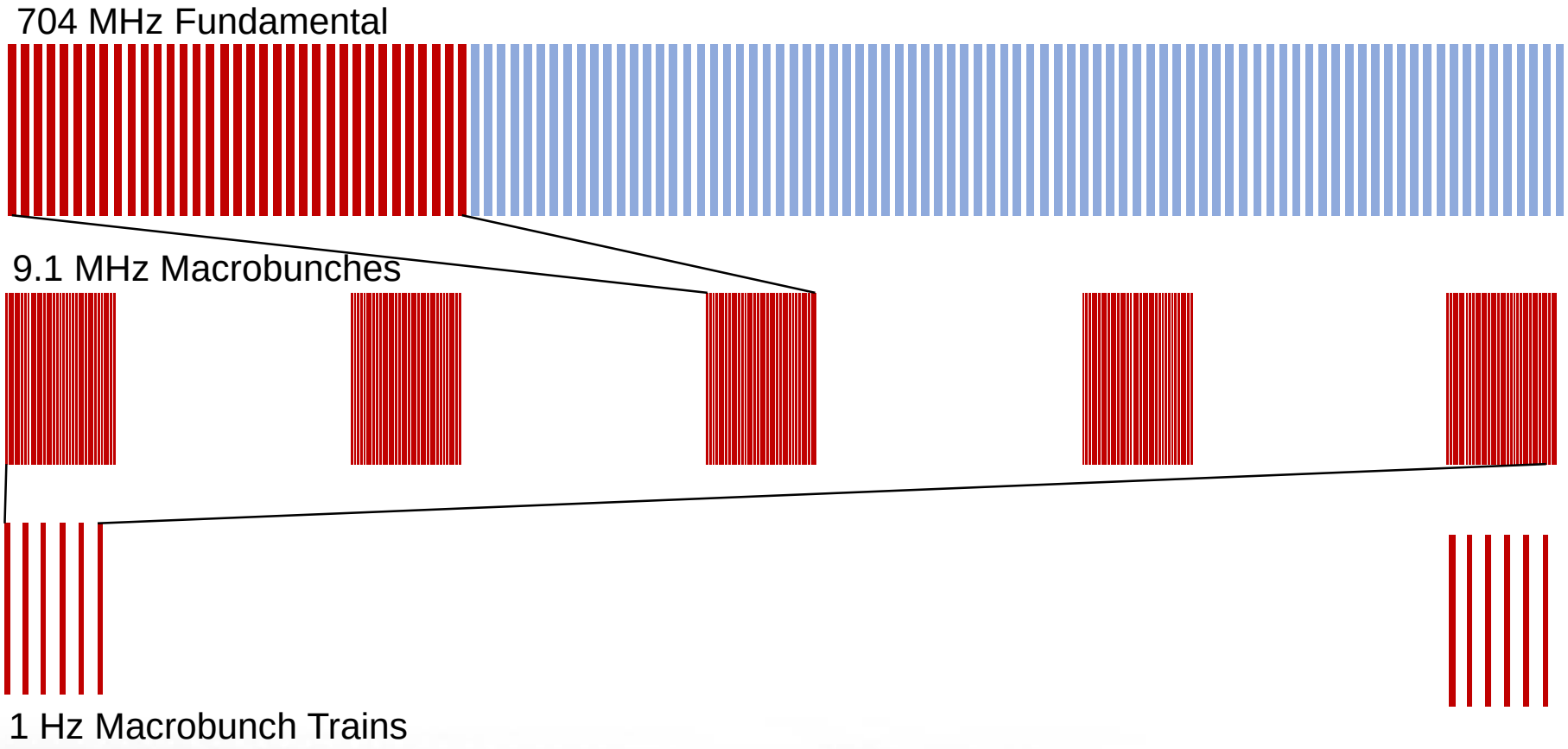


Laser System



Laser Mode	704 MHz	9.1 MHz	1 Hz
Beam Size Trailer (mm)	1 – 5		
Gun Table (mm)	3 – 5		
Laser Power Trailer (W)	40 – 80 (IR) 20 – 40 (520nm)	40 – 80 (IR) 20 – 40 (520nm)	40 – 80 (IR) << 1 (520nm)
Gun (W)	< 10	< 10	<< 1

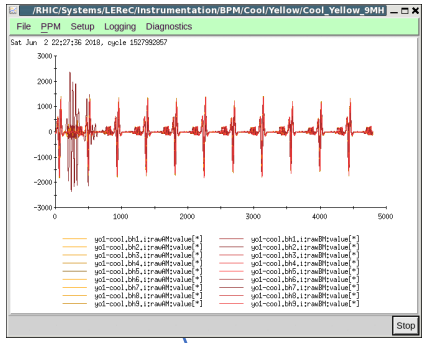
Laser Timing Structure

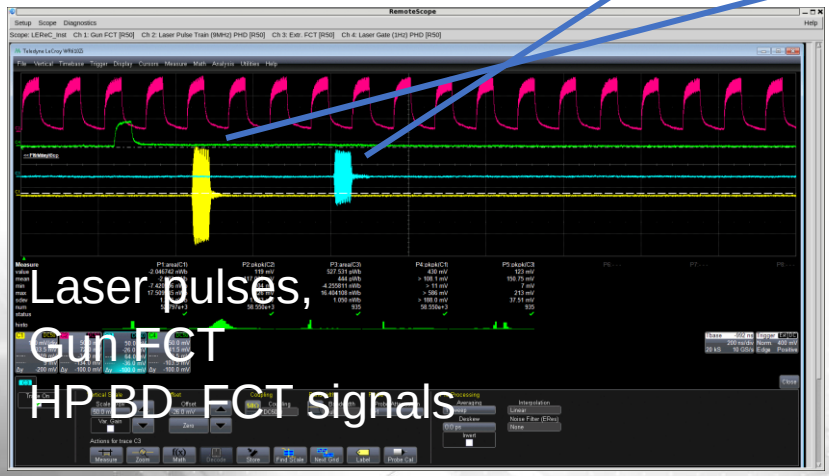


Timeline of Commissioning Progress

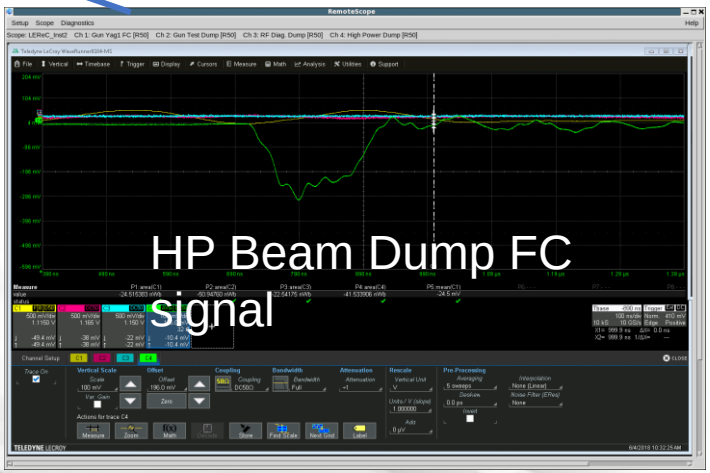
March 5	DOE approval to start LEReC commissioning
March 22	Start commissioning SRF booster with beam
March 23	Beam accelerated to first LEReC design energy of 1.6 MeV, delivered to injection line beam dump
April 2	1.6 MeV beam into RF diagnostic line
April 25	First beam in RHIC cooling section (pulsed mode)
April 26	1.2 mA CW operation
May 11	17 mA CW, 500 keV at dump
June 2	Electron beam propagated through cooling sections to high-power beam dump
June 5	First observation of ion-electron interaction in cooling section

LEReC Beam Propogation to Dump





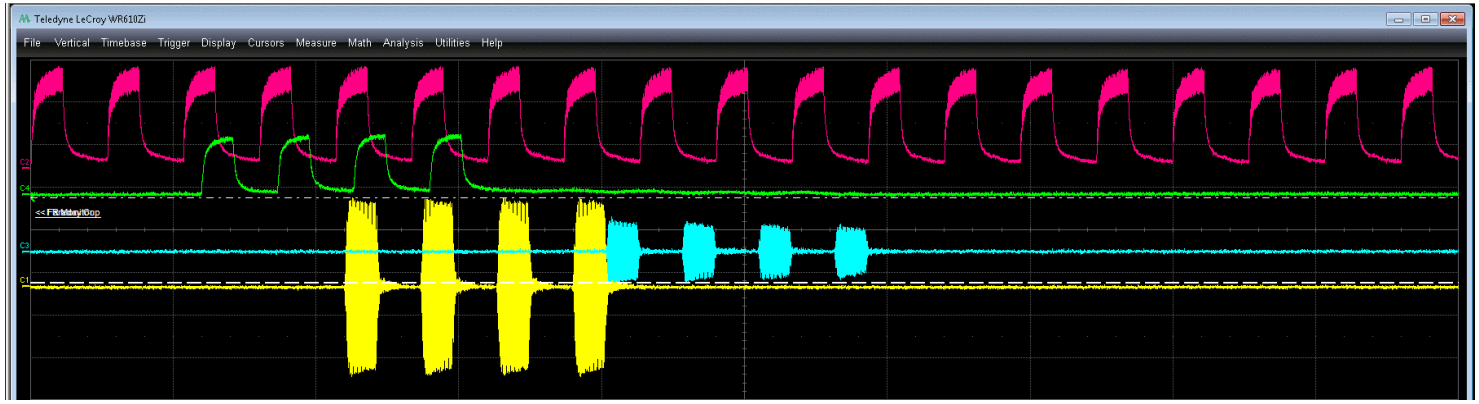
Laser pulses, Gun FCT
HP BD FCT signals



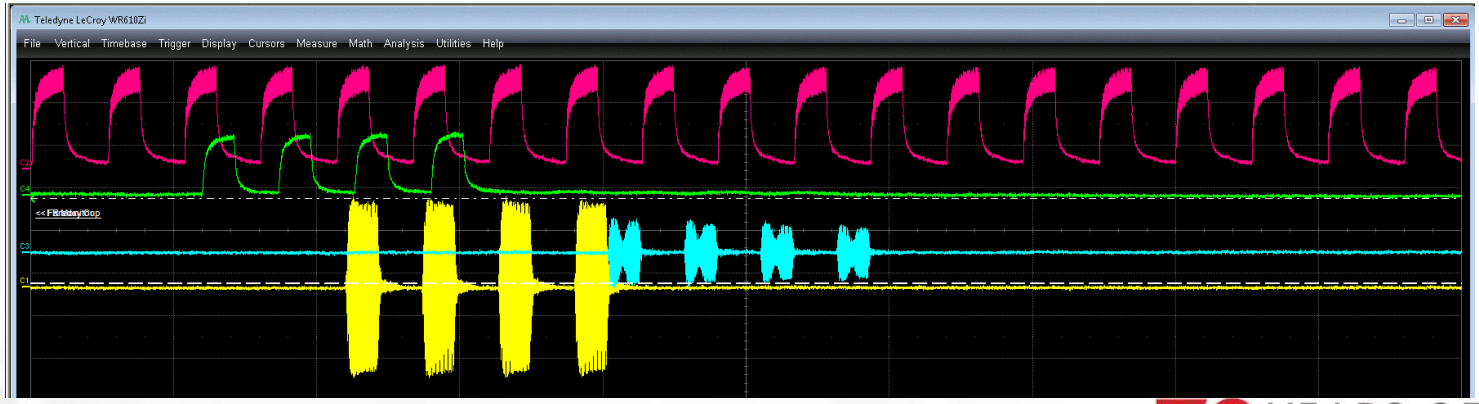
HP Beam Dump FC signal

Electron-Ion Interaction in Cooling Section

No ion interaction



Electron-ion interaction



Summary

- Commissioning effort has been very successful
- Many newly commissioned systems
  - RF cavities
  - Laser system
  - Instrumentation
  - Machine Protection System
- Beam has been delivered through entire accelerator
- Commissioning continues through summer
- Commissioning of cooling on track for 2019