Low Energy RHIC electron Cooling (LEReC)

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on behalf of the LEReC team

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BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Low-energy RHIC operation

Electron cooling technique:

- "cold" electron beam is merged with ion beam which is cooled through Coulomb interactions
- electron beam is renewed and velocity spread of ion beam is reduced in all three planes

requires co-propagating electron beam with the same average velocity as velocity of hadron beam.

At low energies in RHIC luminosity has a very fast drop with energy, with low lifetime driven by various effects.

Electron cooling can help to improve luminosity lifetime by counteracting Intra-Beam Scattering (IBS).

Energy scan of interest:

$\sqrt{s_{NN}}$ = **7.7, 9.1, 11.5, 14.6, 19.6 GeV**

LEReC : 1.6 – 2.6 MeV (electrons kinetic energies)

Luminosity improvement without electron cooling (needed RHIC performance demonstrated in 2016)

LEReC Project Mission/Purpose

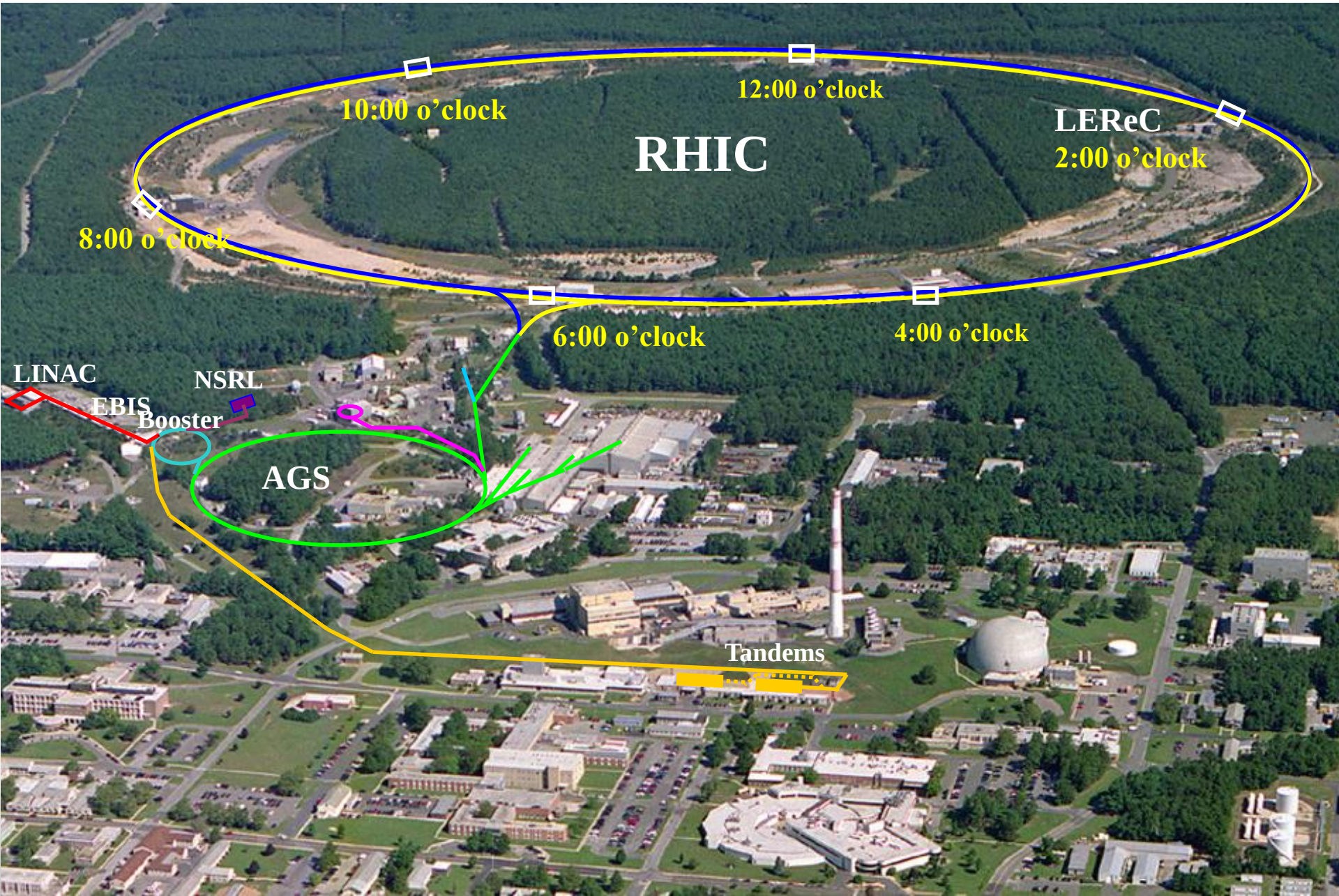
The purpose of the LEReC is to provide luminosity improvement for RHIC operation at low energies to search for the QCD critical point (Beam Energy Scan Phase-II physics program).

LEReC will be first RF linac-based electron cooler (bunched beam cooling).

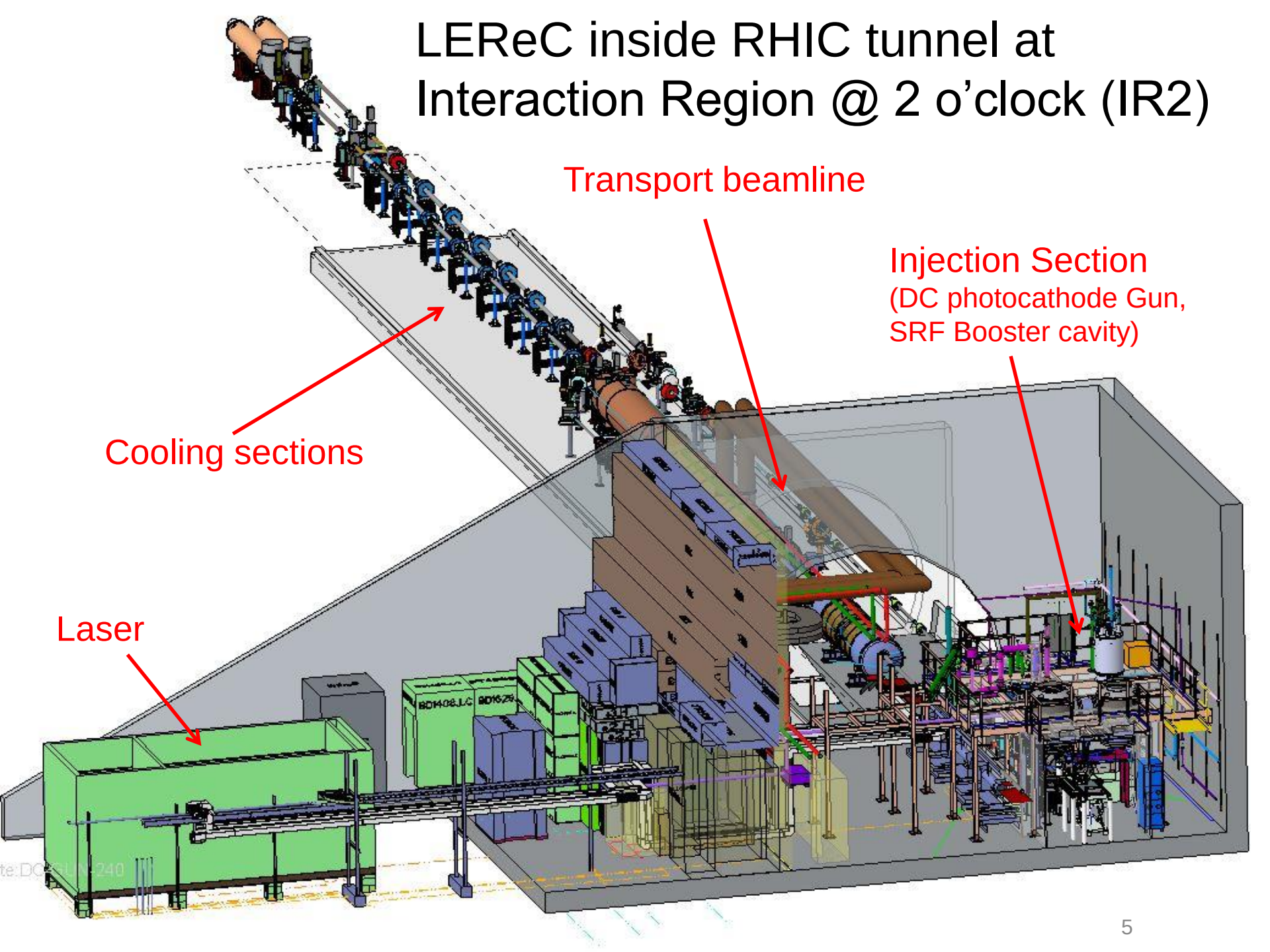
To provide luminosity improvement with such approach requires:

- **Building and commissioning of new state of the art electron accelerator**
- Produce electron beam with beam quality suitable for cooling
- Transport with RF acceleration maintaining required beam quality
- Achieve required beam position and energy stability in cooling sections
- Commissioning of bunched beam electron cooling
- Commissioning of electron cooling in a collider

RHIC @ BNL, Long Island, New York

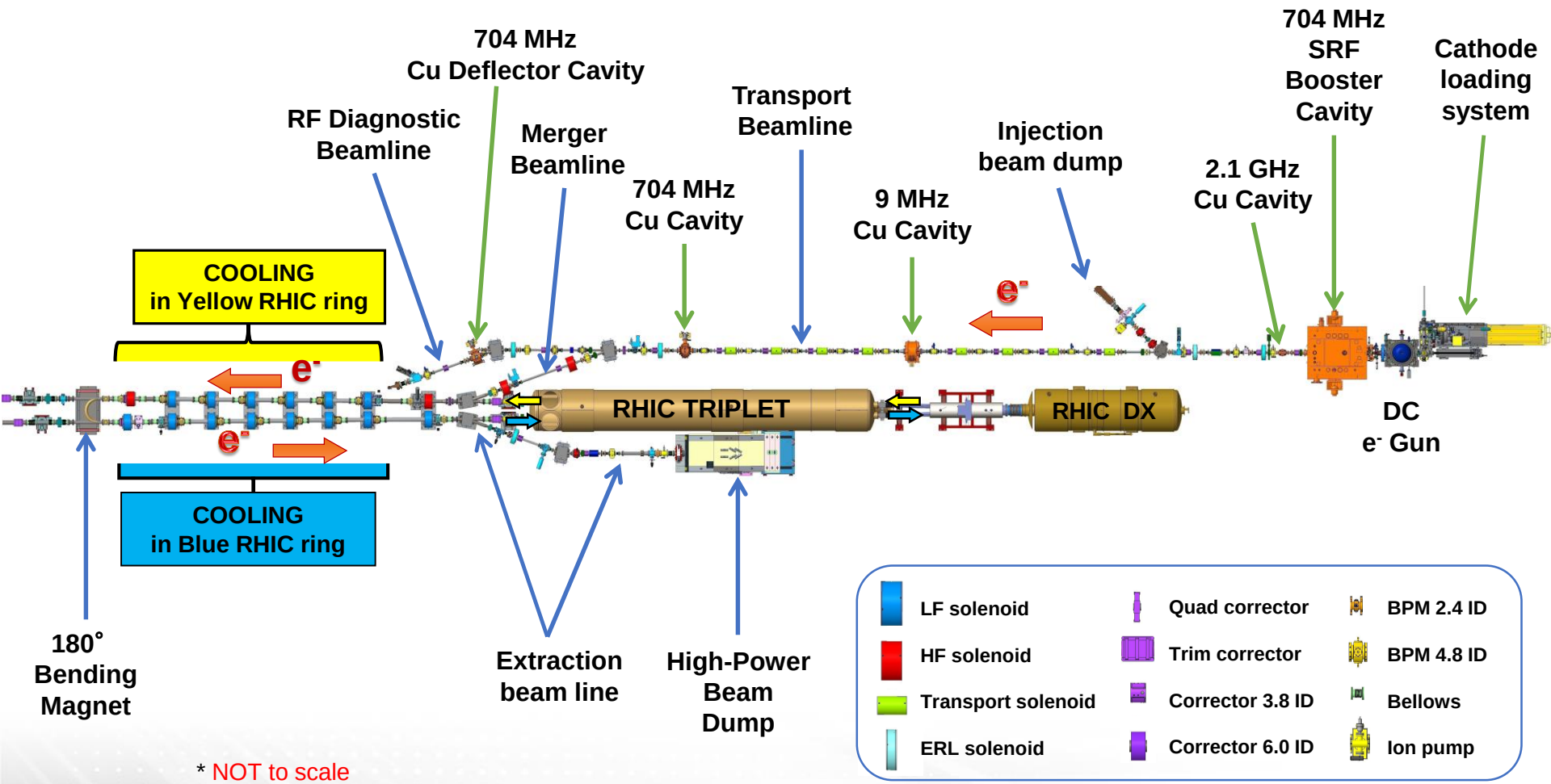


LEReC inside RHIC tunnel at Interaction Region @ 2 o'clock (IR2)



LEReC Accelerator

(100 meters of beamlines with the DC Gun, high-power fiber laser, 5 RF systems, including one SRF, many magnets and instrumentation)



* NOT to scale

LEReC electron beam parameters

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

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

Bunched beam electron cooling for LEReC

- Produce electron bunches suitable for cooling by illuminating a multi-alkali (CsK_2Sb or NaK_2Sb) photocathode inside the Gun with green light using high-power laser (high-brightness in 3D: both emittance and energy spread).

- The 704 MHz fiber laser will produce required modulations to overlap ion bunches at 9MHz frequency with laser pulse temporal profile shaping using crystal stacking.

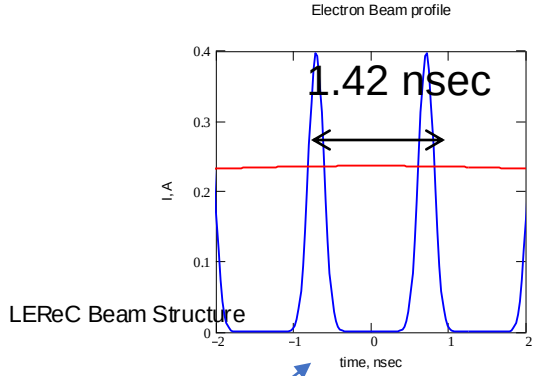
- Accelerate such bunches with RF and use RF gymnastics (several RF cavities) to achieve energy spread required for cooling. Deliver and maintain beam quality in both cooling sections.

- Electron bunch overlaps only small portion of ion bunch. All amplitudes are being cooled as a result of synchrotron oscillations.

LEReC beam structure in cooling section

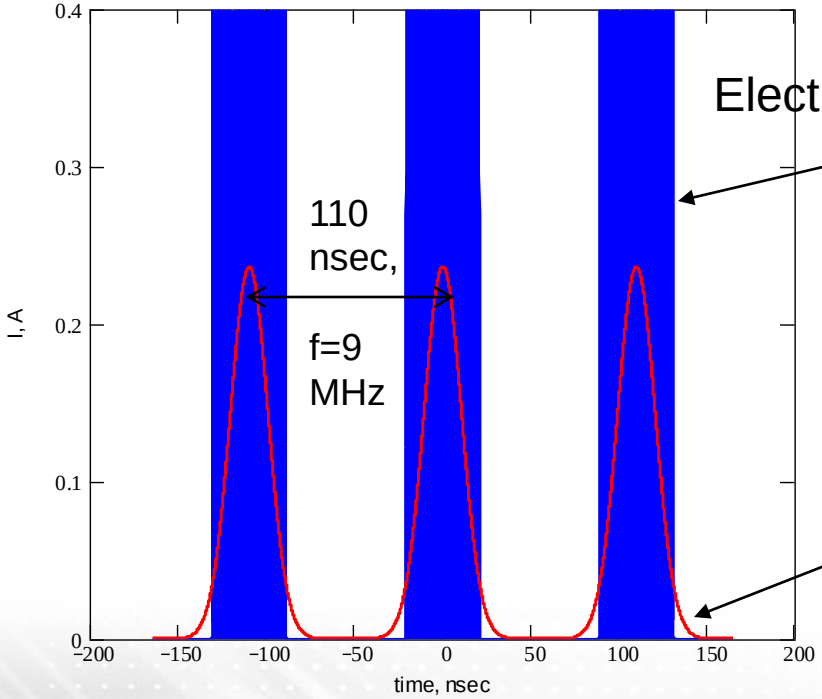
Ions structure:
120 bunches
f_rep=120x75.8347 kHz=9.1 MHz
N_ion=5e8, I_peak=0.24 A
Rms length=3.2 m

Electrons:
f_SRF=703.5 MHz
Q_e=100 pC, I_peak=0.4 A
Rms length=3 cm

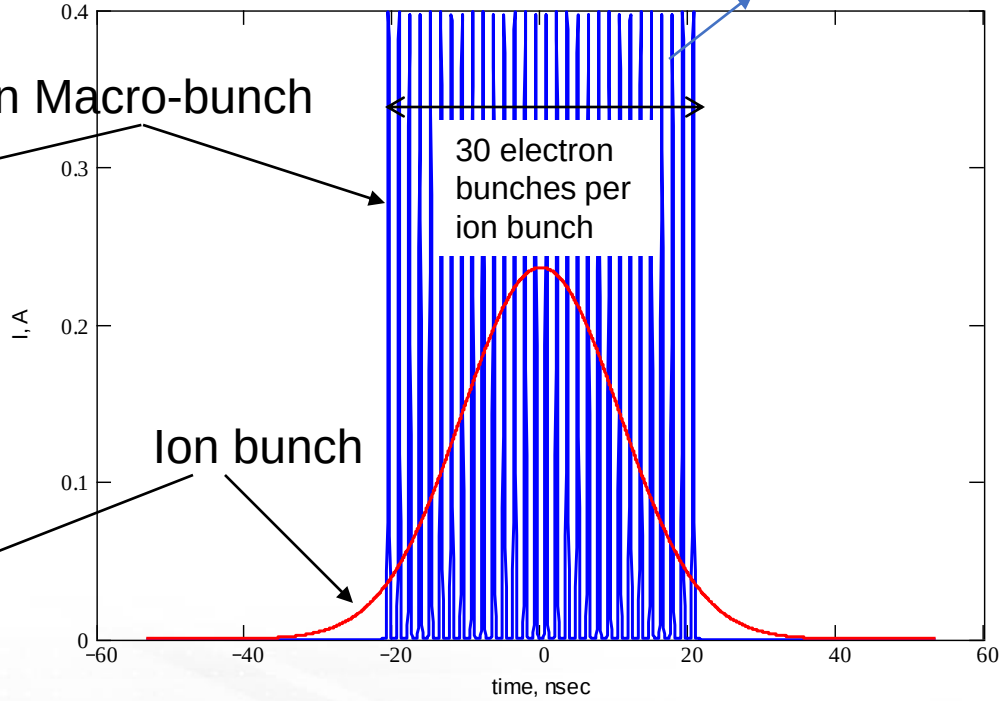


LEReC Beam Structure

9 MHz bunch structure



Electron Macro-bunch



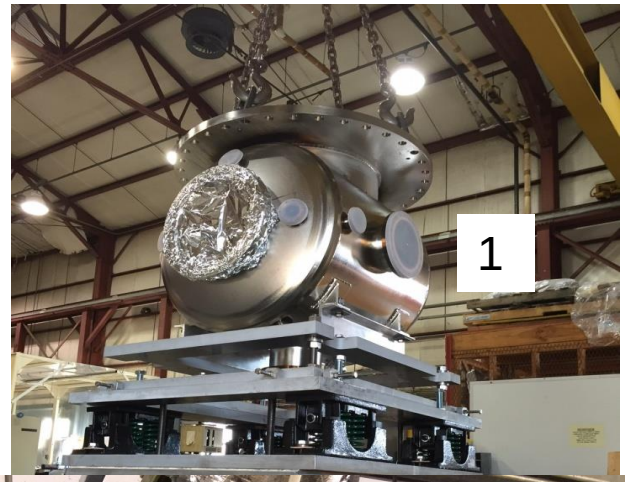
Producing electron beam suitable for cooling

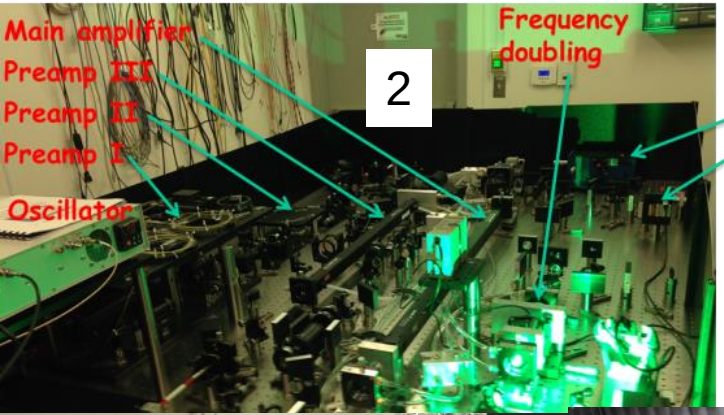
LEReC is based on the State of the Art Physics and Technology:

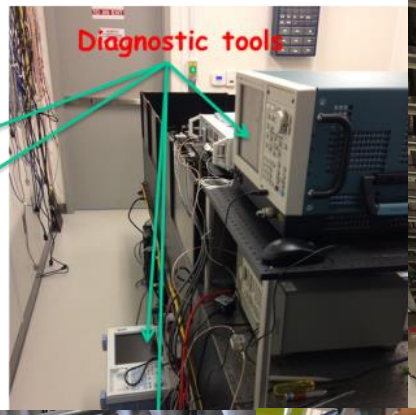
- Photocathodes
- High power fiber laser
- Laser beam shaping
- Operation of HV DC gun with high charge and high average current
- RF gymnastics and stability control to maintain energy spread of electron beam suitable for cooling

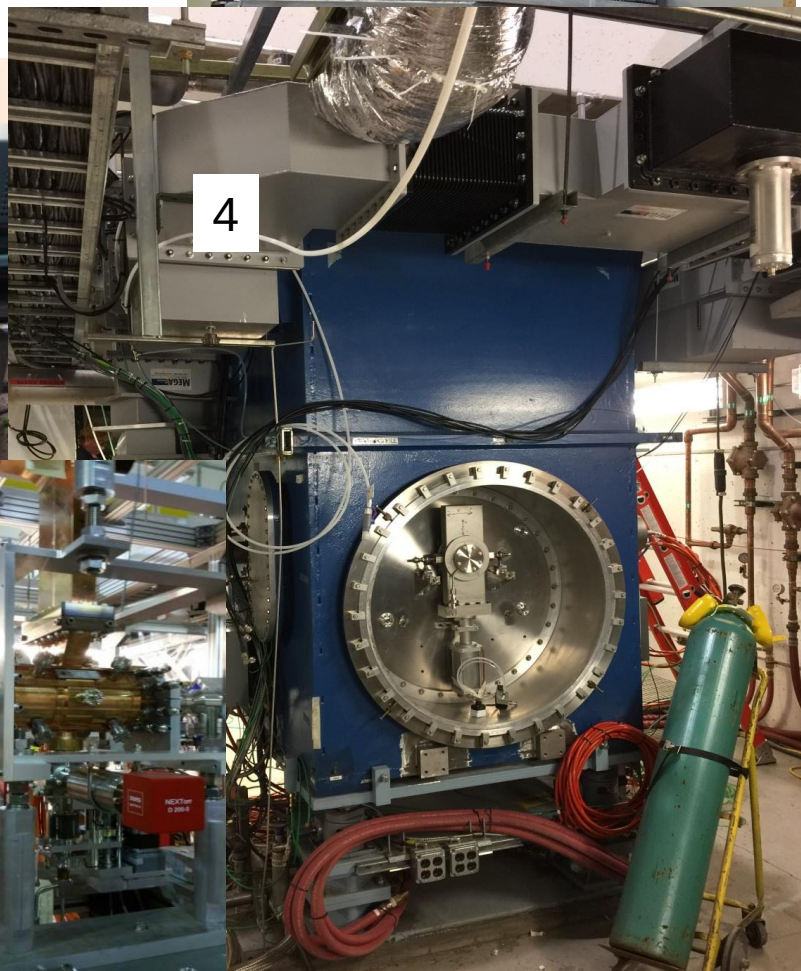
LEReC Critical Technical Systems

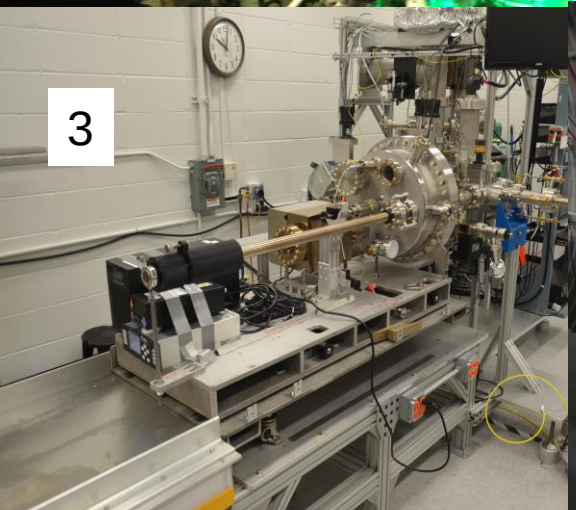
1. DC photocathode electron gun and HV PS
2. High-power fiber laser system and transport
3. Cathode production deposition and delivery systems
4. SRF Booster cavity
5. 2.1 GHz and 704 MHz warm RF cavities

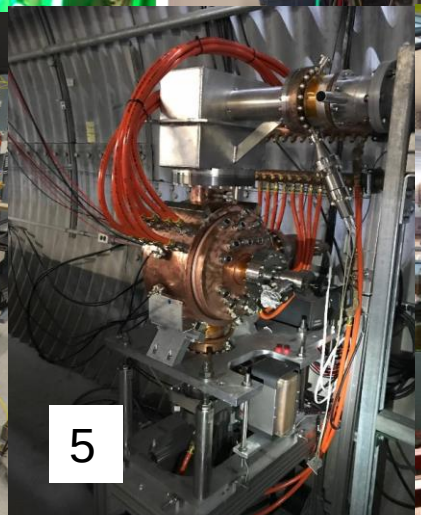




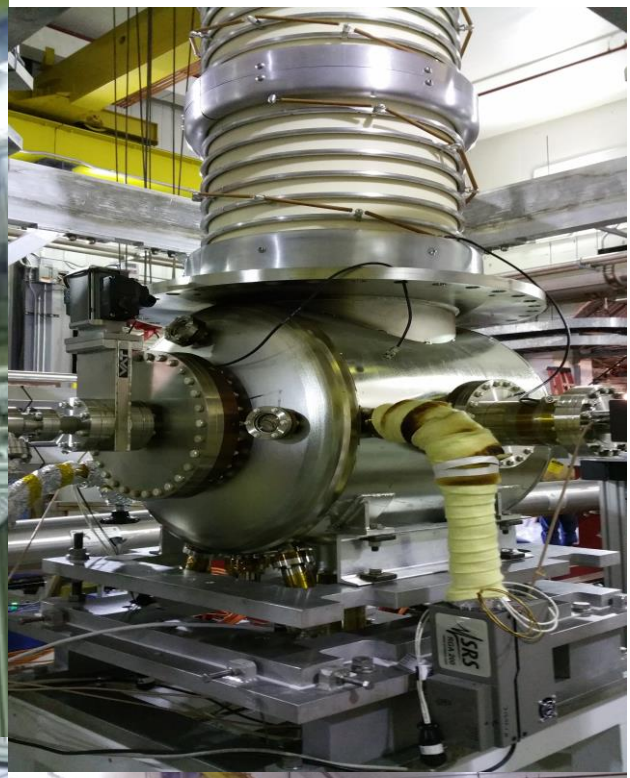


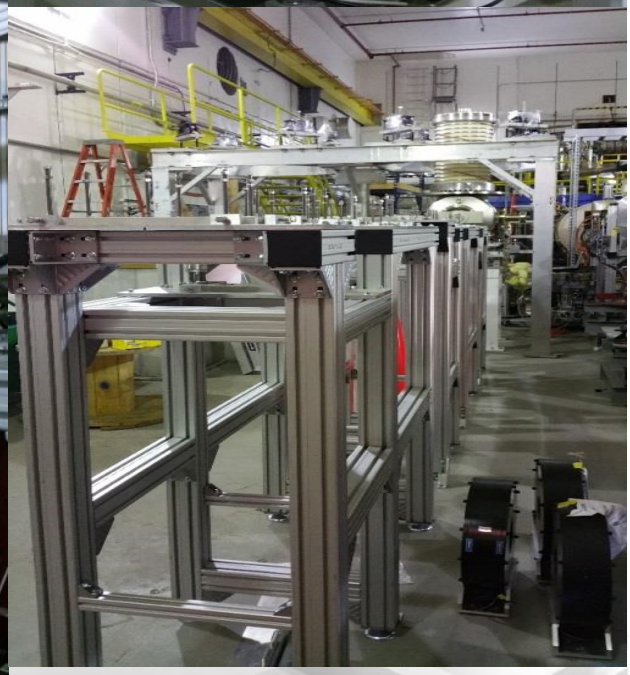




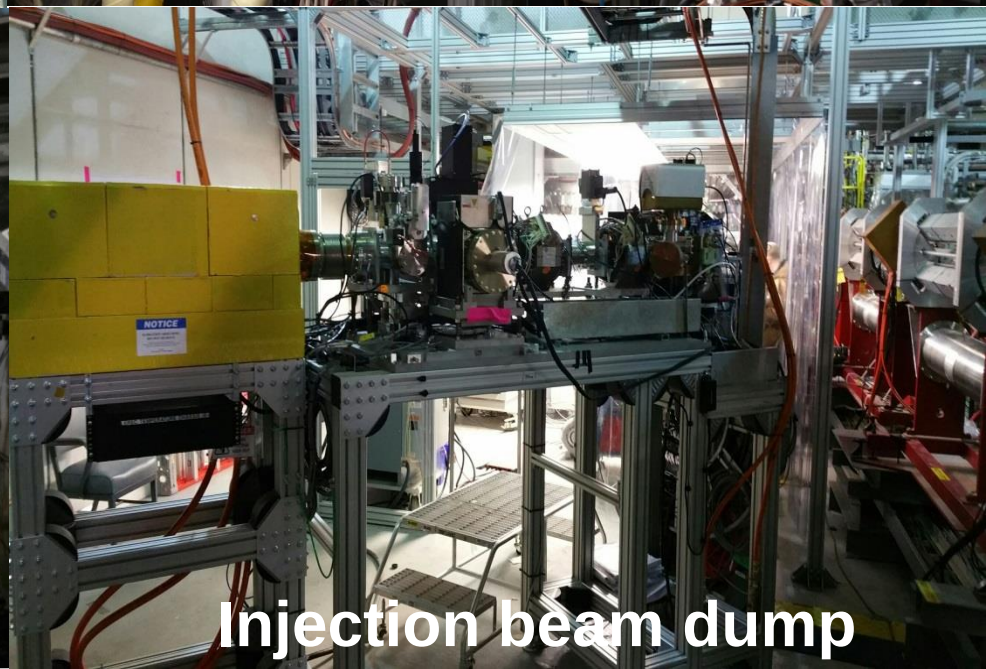


LEReC construction 2016

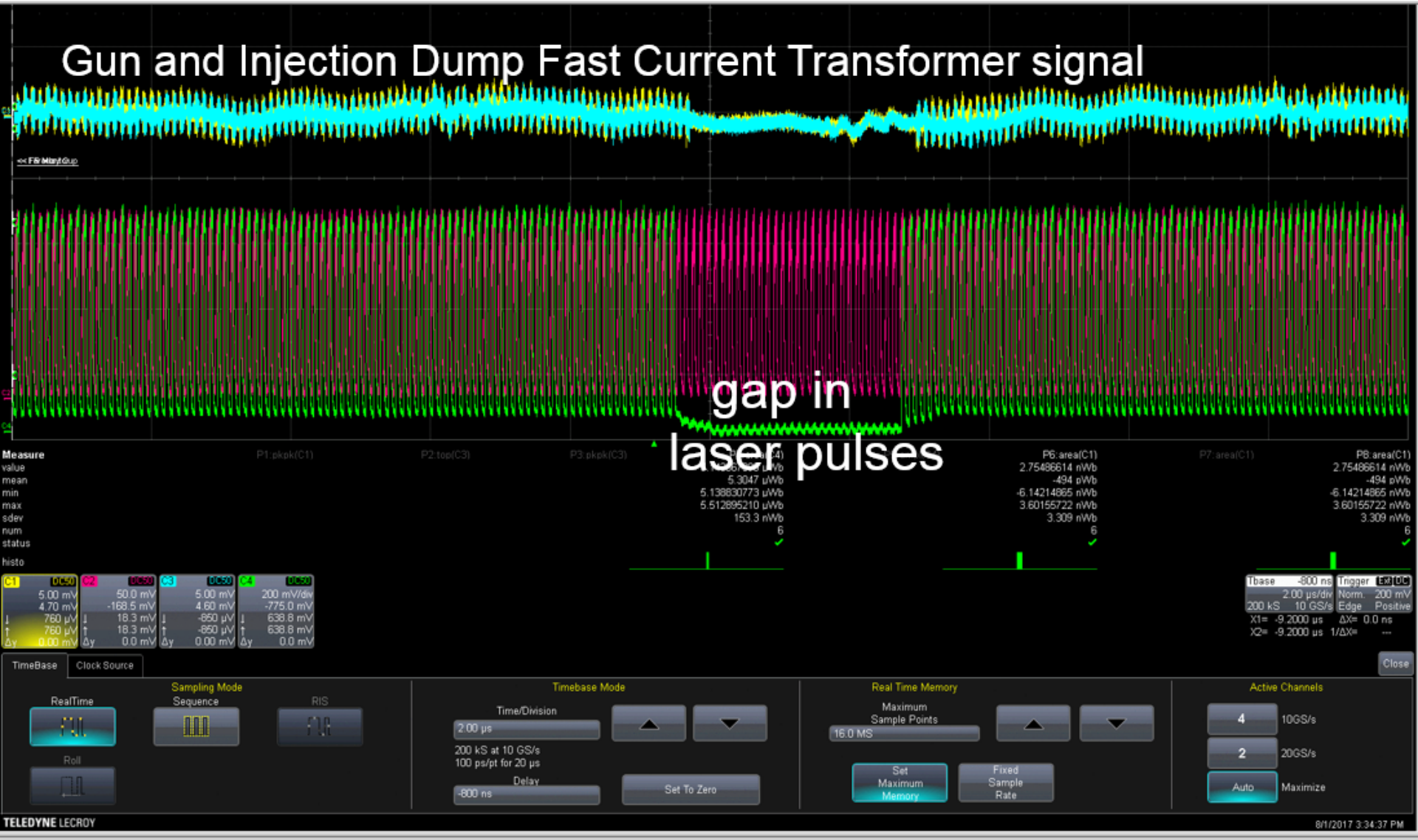




LEReC DC Gun test beamline (2017)

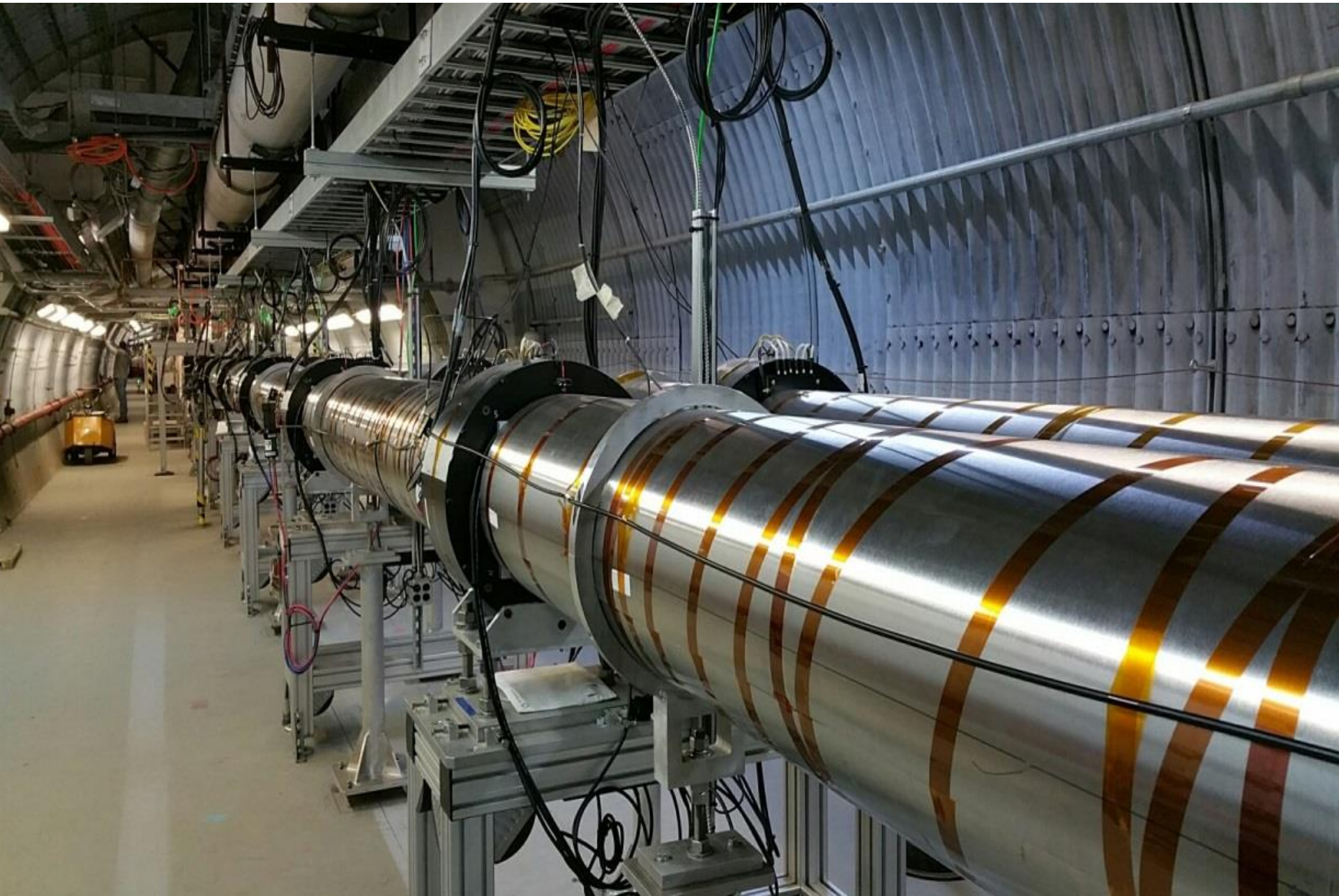


First CW operation in Gun Tests (August 1, 2017)



Full LEReC Installation (October 2017)

LEReC cooling sections fully installed (2018)



Stages of LEReC Commissioning

- **Phase 1:** DC Gun tests

  (April-August 2017): DC Gun tests in temporary configuration

  (January-February 2018): DC Gun tests in final configuration

- **Phase 2** (March-September 2018): Full LEReC commissioning

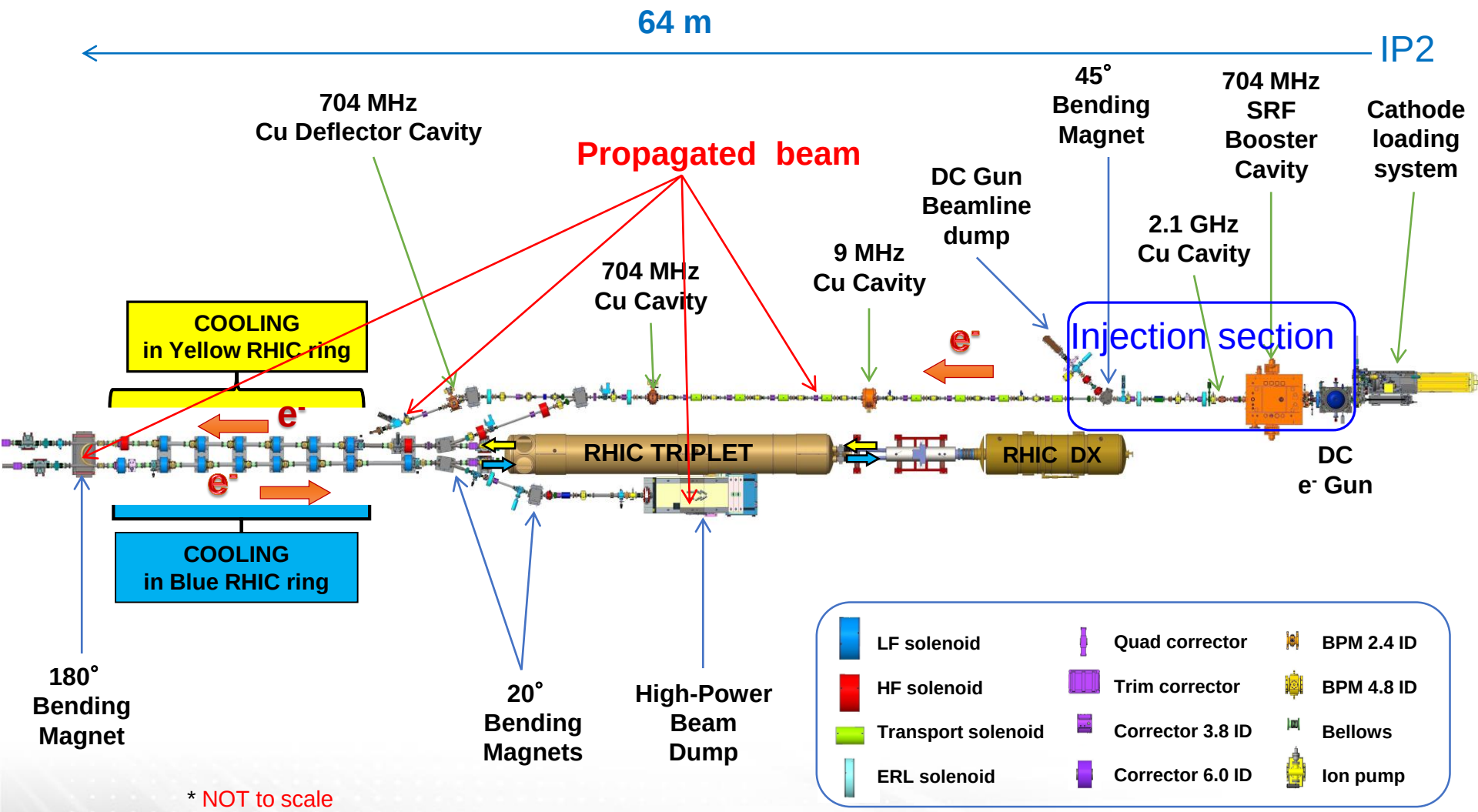
Goals: Achieve stable high-current operation of accelerator with electron beam parameters suitable for cooling.

- **Phase 3** (2018-2019): Transition to operations

Goals: Commissioning LEReC for operation at higher energies. Achieve needed stability (energy, orbit) of electron beam. Develop necessary stability feedbacks.

- **Phase 4** (2019-2020): Commissioning of cooling – requires Au ions at the same energy.

LEReC commissioning 2018



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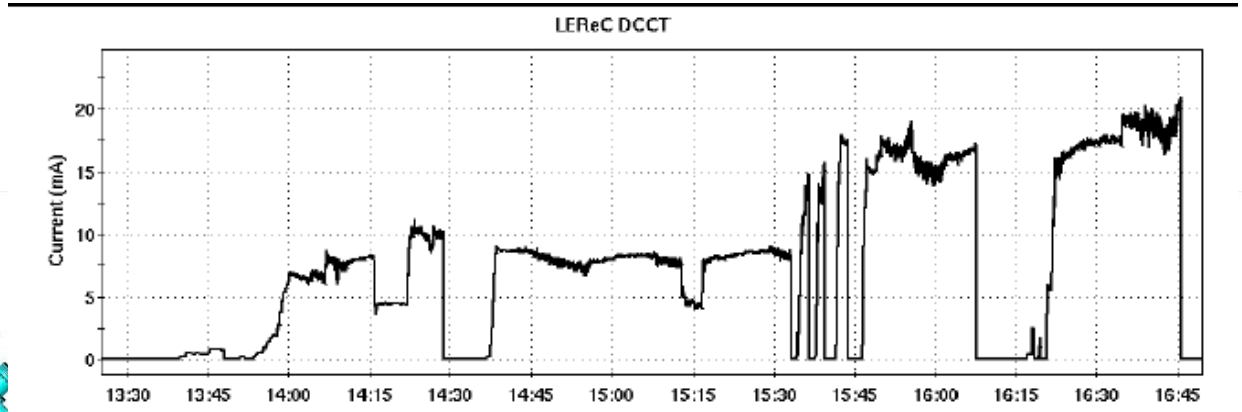
LEReC Injection section (June 6, 2018)



Injection
10kW dump

DC Gun

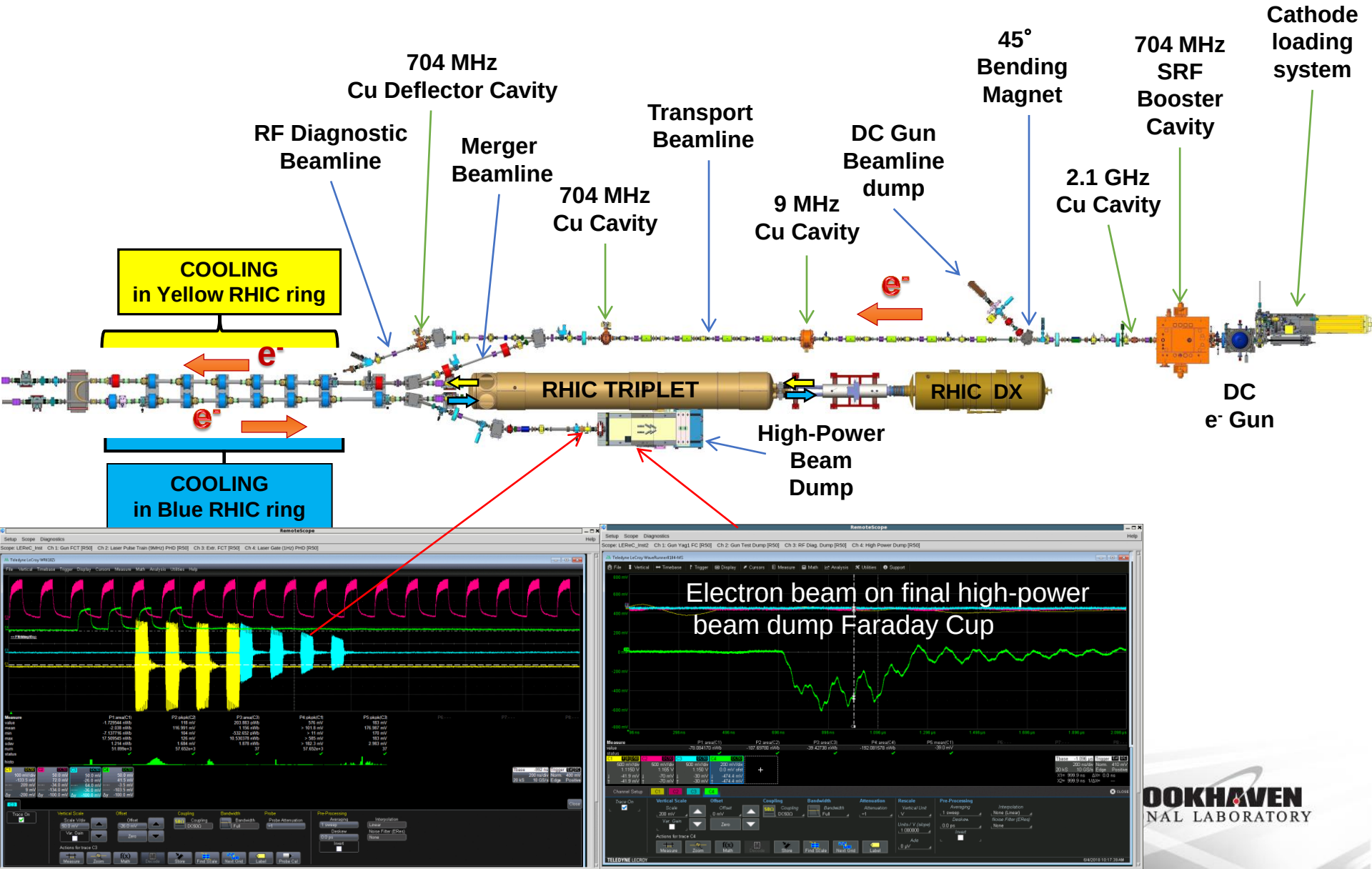
Reached 20mA current (limited by injection section dump power of 10kW). Design current 30-55mA.

2.1 GHz RF cavity

SRF Booster cavity

7 m

LEReC: beam propagated all the way to final beam dump



LEReC Commissioning progress

- Commissioning of electron accelerator is progressing well.
- Propagated electron beam through all beamlines, including both cooling sections and to all beam dumps (injection, RF diagnostics and high-power beam dumps).
- Achieved design bunch charge (4nC/macro-bunch) including transverse laser shaping (3mm iris).
- RF cavities are synchronized and are being used for RF gymnastics and longitudinal phase space optimization.
- Started high-current CW commissioning in injection section. Reached 20mA current (limited by injection section dump power of 10kW). Design operational current 30-55mA.

LEReC is also a testbed of high-energy cooling

- Production of high-brightness electron beams in 3-D.
- RF-based electron cooler.
- Transport of such electron bunches maintaining “cold” beam.
- Control of electron angles in the cooling section to a very low level required for cooling.
- Various aspects of bunched beam electron cooling.

Electron cooling in a collider:

- Control of ion beam distribution, not to overcool beam core.
- Effects on hadron beam.
- Interplay of space-charge and beam-beam in hadrons.
- Cooling and beam lifetime (as a result of many effects).

LEReC project timeline

May 2015:	**Project approved by DOE for construction**
April 2016:	**High-power laser assembled**
October 2016:	**DC gun delivered to BNL**
December 2016:	**DC gun successfully conditioned in RHIC IR2**
February 2017:	**Gun Test beamline installed in RHIC**
April-Aug. 2017:	**First Gun tests with beam**
July-Dec. 2017:	**Installation of full LEReC accelerator**
January-Feb. 2018:	**Systems commissioning (RF, SRF, Cryogenics, Instrumentation, Controls, etc.)**
March-Sept. 2018:	**Commissioning of full LEReC accelerator with e-beam**
2019:	**Commissioning of cooling with Au ion beams during RHIC Run-19.**

Summary

- LEReC will be first electron cooler based on the RF acceleration of electron beam.
- It will be the first application of electron cooling in a collider.
- Installation of electron accelerator is complete.
- Commissioning with electron beam of full LEReC accelerator started in March 2018 and is progressing well.
- Commissioning of cooling process will start in Run-19.

Acknowledgement

LEReC project greatly benefits from help and expertise of many people from various groups of the Collider-Accelerator and other Departments of the BNL.

As well as FNAL, ANL, JLAB and Cornell University.

Thank you!