Low Energy RHIC electron Cooling (LEReC)

LEReC

challenges and needs

Alexei Fedotov

LEReC RHIC Retreat
July 27-28 2015

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

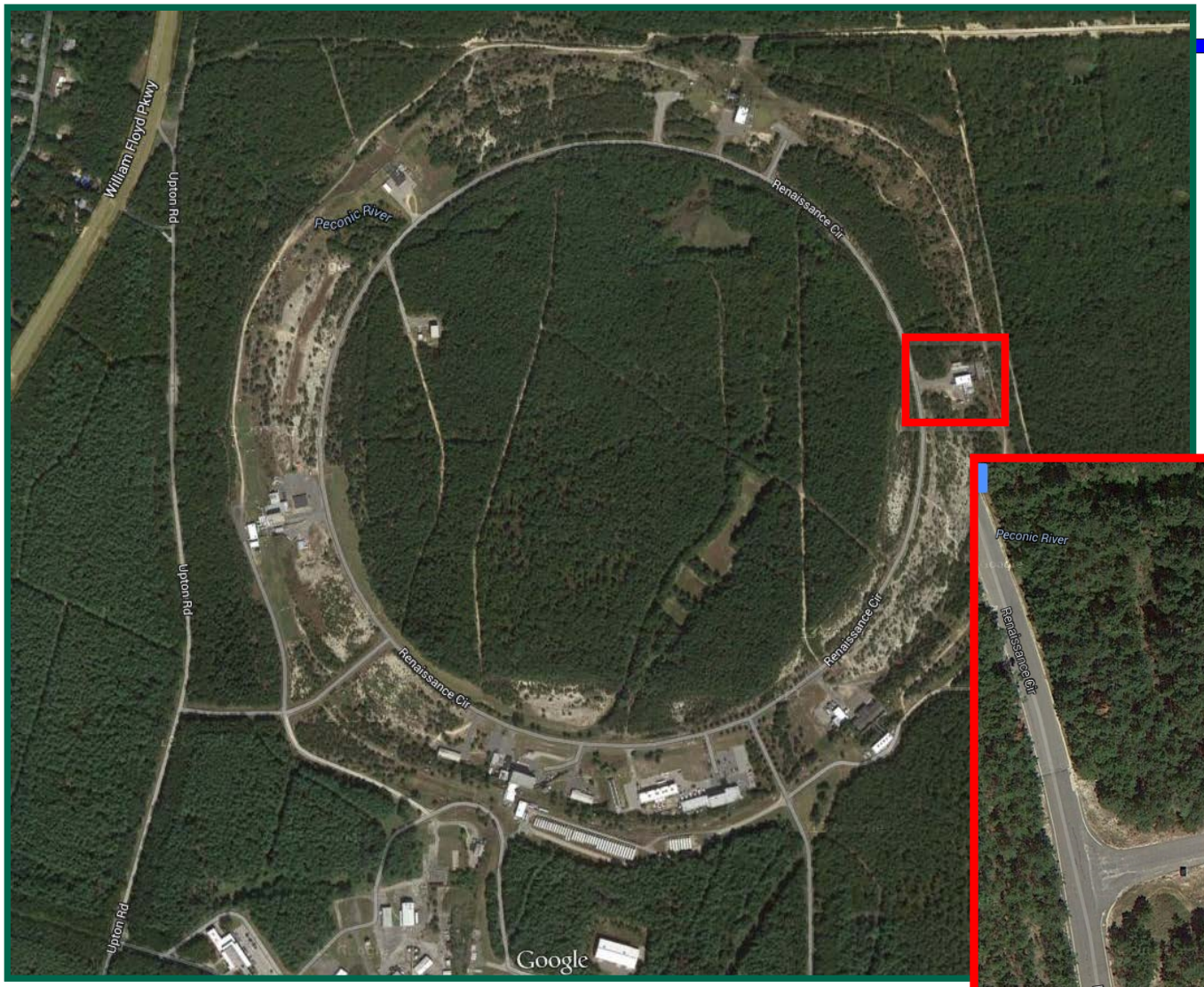
Office of Science
U.S. DEPARTMENT OF ENERGY

LEReC Project Mission/Purpose

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

- This requires:
  - building and commissioning of new state of the art electron linear accelerator; LEReC will be first linac-based electron cooler.
  - produce and transport high-brightness electron beam with electron beam quality suitable for cooling.
  - commissioning first bunched beam electron cooler.
  - commissioning first electron cooling in a collider.
- Many new accelerator systems will need to be built, installed and commissioned, including several RF systems, magnets, beam instrumentation, etc.

Location – RHIC 02:00 Region (IR2)



BES Phase II Proposal

LEReC Phase-I

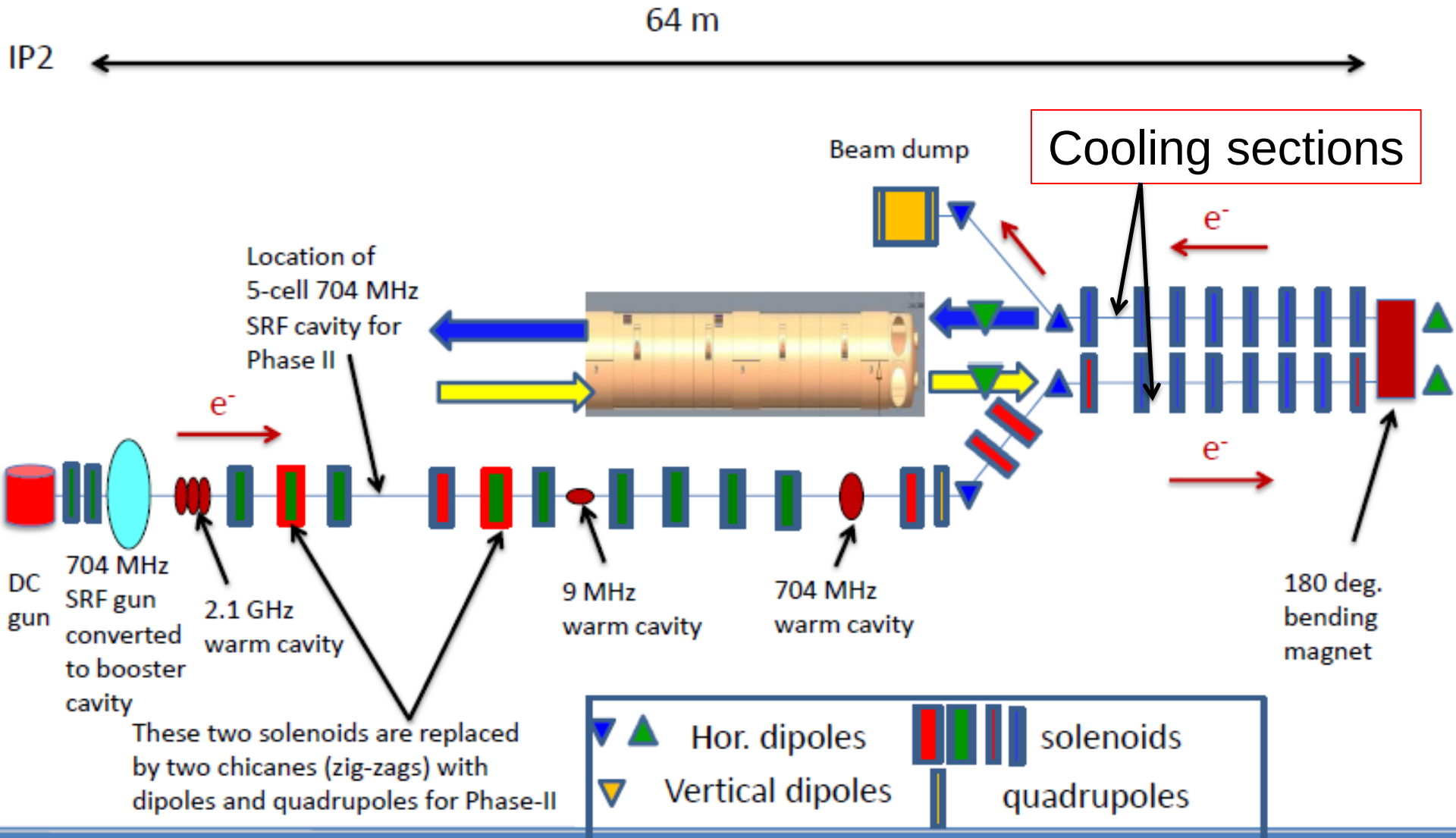
LEReC Phase-II: energy upgrade

E_{ke} (MeV)	1.6	2.0	2.6	3.5	4.9
$\sqrt{s_{NN}}$ (GeV)	**7.7**	**9.1**	**11.5**	**14.5**	**19.6**
μ_B (MeV)	420	370	315	250	205
BES I (MEvts)	4.3	---	11.7	24	36
Rate(MEvts/day)	0.25*	0.6%	1.7*	2.4%	4.5*
BES I $\mathcal{L}$ (1×10^{25}/cm^{2}sec)	0.13	0.5%	1.5	2.1%	4.0
BES II (MEvts)	100	160	230	300	400
eCooling (Factor)	4	4	4	8	15(4)
Required Beam (weeks)	**14**	**9.5**	**5.0**	**2.5**	**3.0+**

Luminosity is especially low at lowest energies.

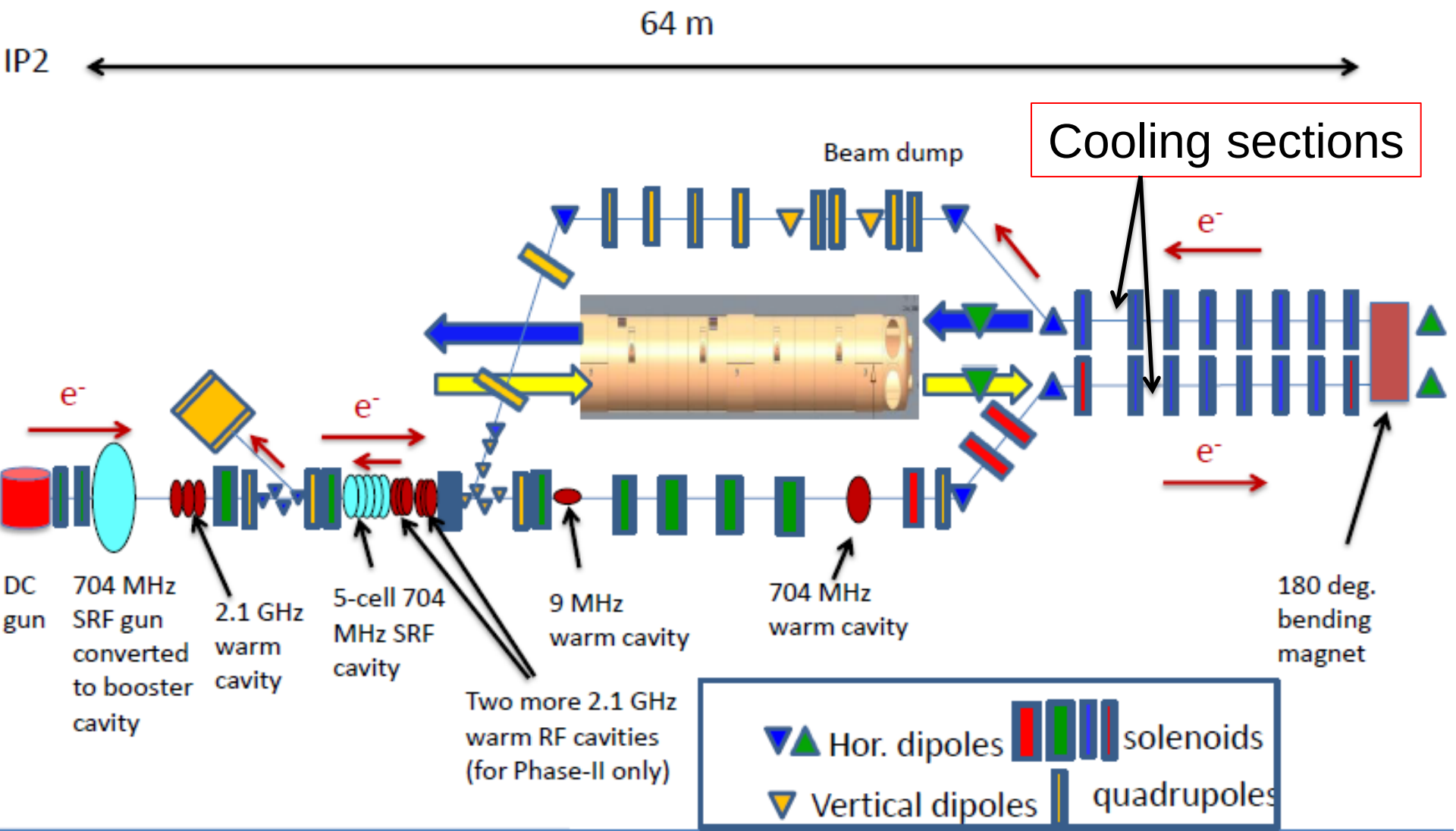
LEReC Phase-I (electron beam energies 1.6-2MeV): Gun-to-dump mode

July 8, 2015

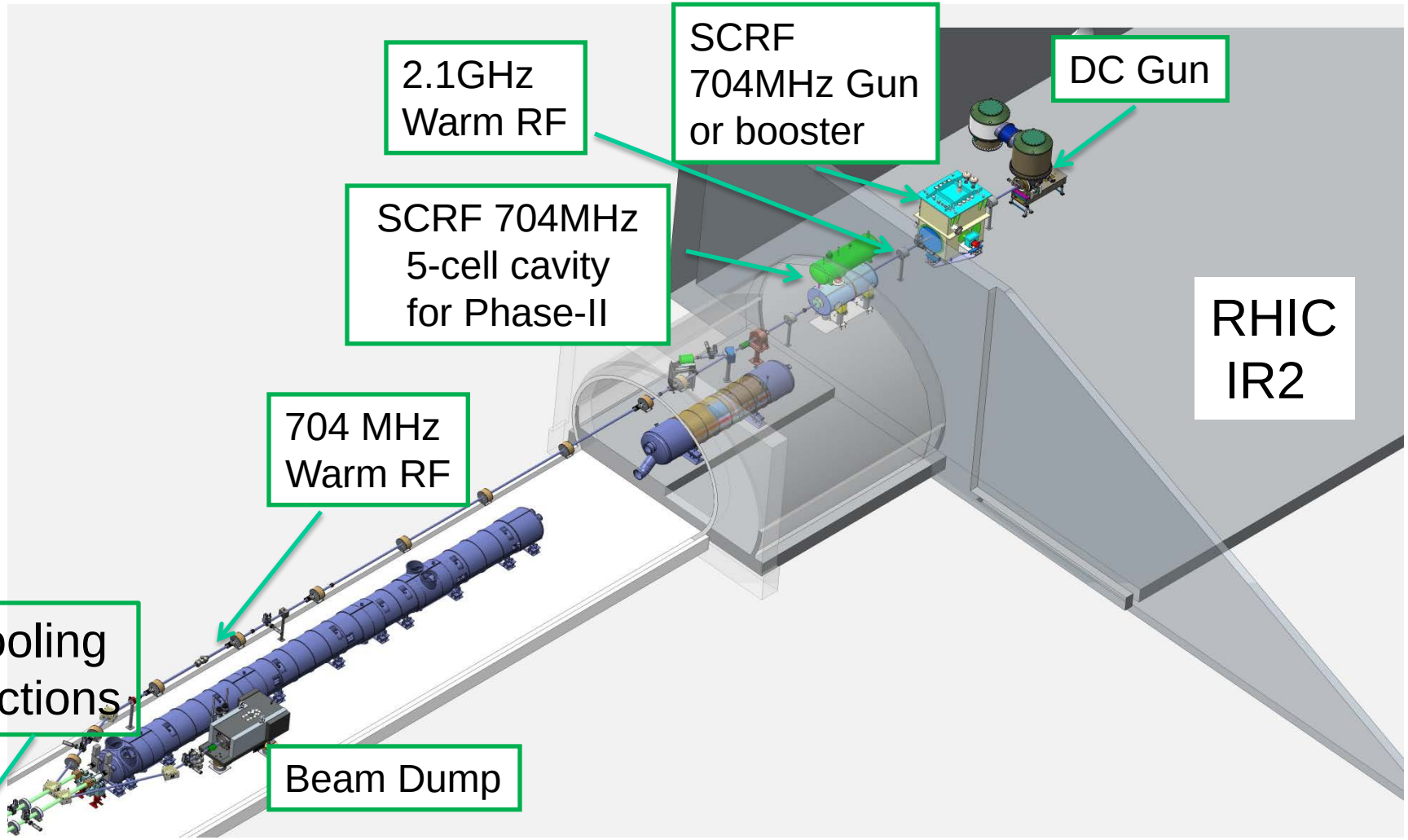


LEReC Phase-II (electron beam energies up to 5MeV): ERL mode

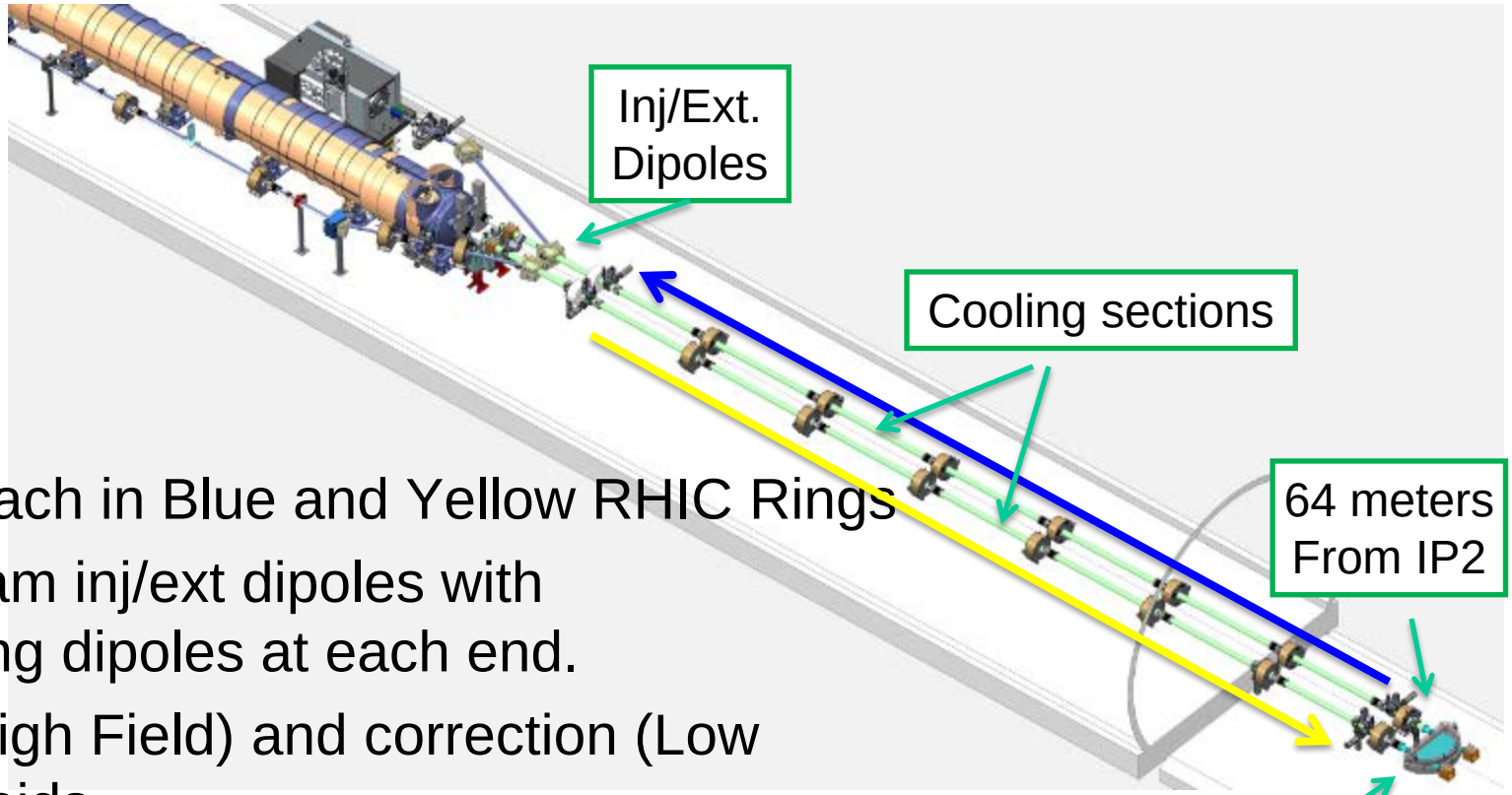
July 8, 2015



LEReC Phase-I layout – electron Gun and transport line system



LEReC Phase-I layout: cooling sections in RHIC



- 18 Meters each in Blue and Yellow RHIC Rings
- Electron beam inj/ext dipoles with compensating dipoles at each end.
- Matching (High Field) and correction (Low Field) solenoids.
- RHIC “warm” beam tube with NEG coating and μ metal shielding.

LEReC Phase-I is approved by ONP DOE for construction

Project Execution Plan

for the

Low Energy RHIC electron Cooling Accelerator Improvement Project (LEReC AIP)

at the

Brookhaven National Laboratory
Upton, NY

Office of Nuclear Physics (SC – 26)
Office of Science
U.S. Department of Energy

May 2015

Submitted by:

Alexei Fedotov — Date: 5/4/15
Alexei Fedotov, LEReC Contractor Project Manager

Wolfram Fischer — Date: 5/4/15
Wolfram Fischer, AIP Manager, Collider-Accelerator Department
Brookhaven National Laboratory

Wolfram Fischer (acting chair) — Date: 5/4/15
Thomas Roser, Chair, Collider-Accelerator Department
Brookhaven National Laboratory

Approval:

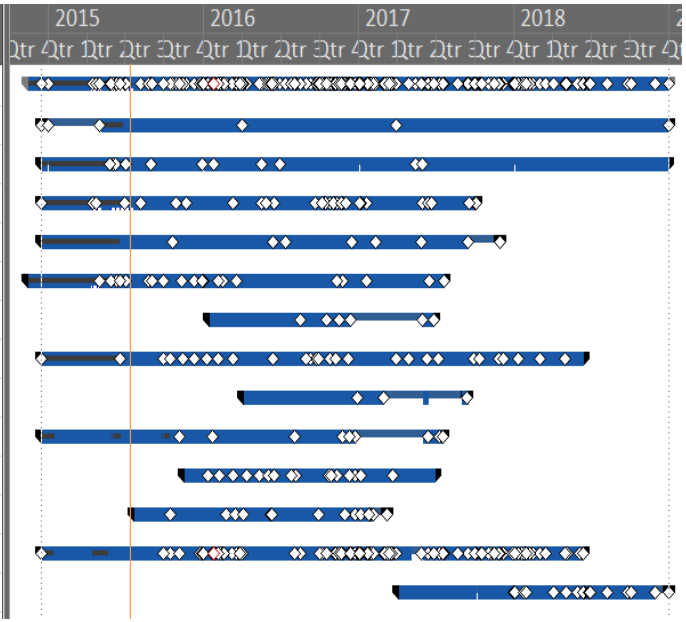
Date: 5/12/15
Jehanne Gillo, Director for Facilities & Project Management Division
Office of Nuclear Physics, Office of Science, DOE

BROOKHAVEN NATIONAL LABORATORY

Office of Science U.S. DEPARTMENT OF ENERGY

LEReC Phase-I project schedule

	WBS	Name	Cost	Start	Finish
0	1.	Low Energy RHIC electron Cooling (LEReC)	$6,716,291	Fri 8/15/14	Sun 9/30/18
1	1.1	Project Management	$496,034	Mon 9/15/14	Sun 9/30/18
15	1.2	Physics Support	$0	Mon 9/15/14	Fri 9/28/18
40	1.3	Gun & Cavities	$1,352,262	Mon 9/15/14	Mon 7/3/17
221	1.4	RF Amplifiers & LLRF	$1,432,417	Mon 9/15/14	Mon 8/28/17
277	1.5	Magnets	$866,842	Fri 8/15/14	Wed 4/19/17
380	1.6	Power Supplies	$269,846	Thu 10/15/15	Tue 3/28/17
406	1.7	Beam Instrumentation	$889,977	Mon 9/15/14	Tue 3/13/18
562	1.8	Beam Dump	$40,518	Mon 1/4/16	Wed 6/14/17
595	1.9	Beam Line Vacuum	$718,642	Mon 9/15/14	Mon 4/17/17
710	1.10	Controls	$264,907	Mon 8/17/15	Wed 3/29/17
941	1.11	Cryogenic Systems	$95,649	Tue 4/21/15	Tue 12/6/16
1063	1.12	Civil Construction & Installation	$289,197	Mon 9/15/14	Tue 3/13/18
1571	1.13	Commissioning	$0	Tue 1/3/17	Sun 9/30/18



Start of commissioning with electron beam: 3/30/18

Commissioning of cooling of Au ions beams: Fall 2018

LEReC scope

(**green** – existing equipment under commissioning in Bldg. 912/ERL)

- DC photoemission gun **with the 704 MHz SRF gun used as booster cavity.**
- **704 MHz SRF 5-cell cavity (acceleration to 5 MeV in ERL mode for Phase-II).**
- 2.1 GHz (3rd harmonic of the SRF frequency) warm cavity for energy spread correction; 704 MHz warm cavity; 9 MHz warm cavity (RHIC bouncer cavity) for beam loading correction**.**
- Electron beam transport from IP2 region to cooling sections
- Cooling sections in Yellow and Blue RHIC rings – about 20 m long with space-charge compensating solenoids.
- U-turn 180 deg. dipole magnet between cooling section in Yellow and Blue RHIC Rings
- Beam Instrumentation **(some from ERL).**
- **Electron beam dump.**

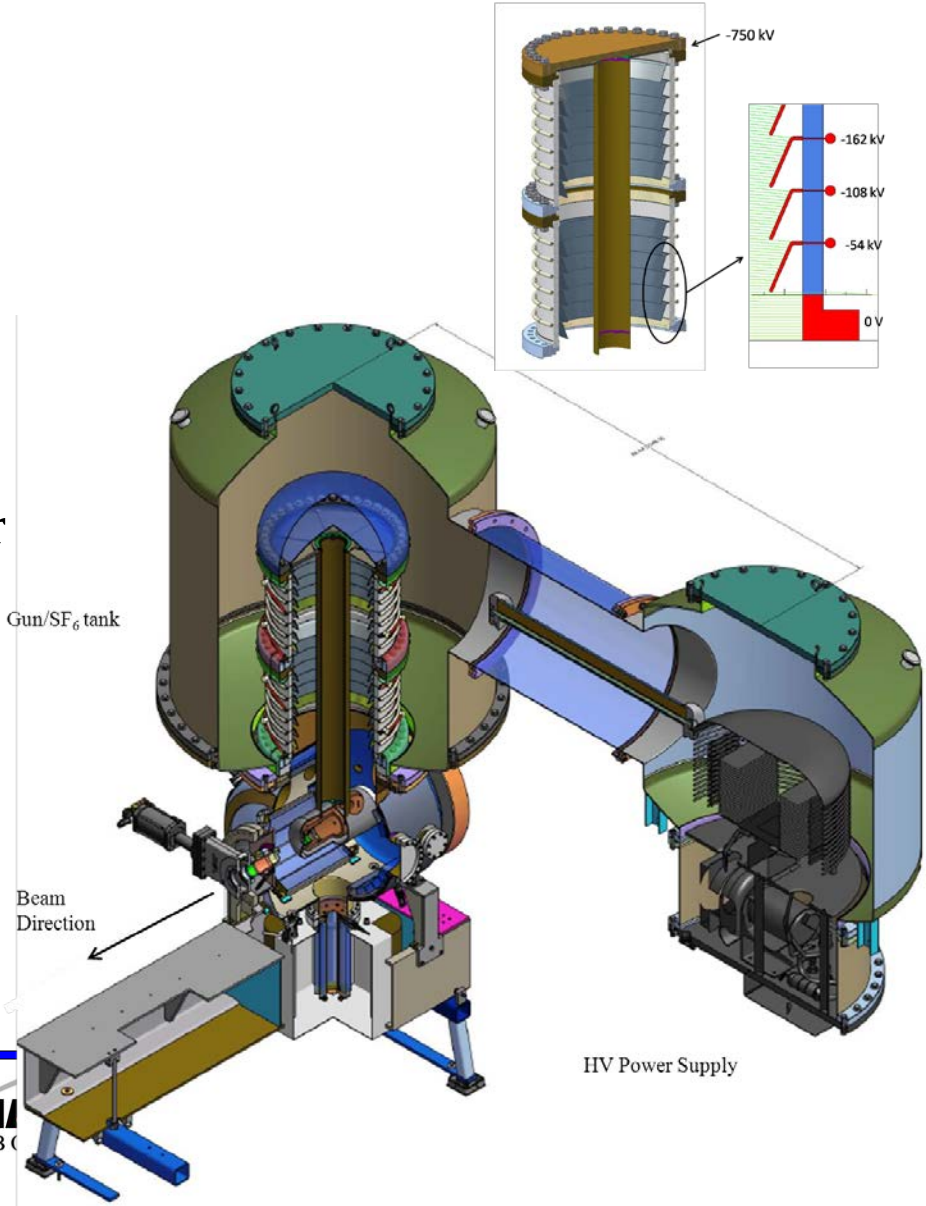
see talk by Joe Tuozzolo for details on equipment and installation

BROOKHAVEN NATIONAL LABORATORY

Contract with Cornell to build DC gun for LEReC (identical to existing Cornell's gun #2)

Includes engineering and design support for gun, power supply, cathode design, cathode changing mechanism, and cathode coating chamber.

- Construction of DC photoemission gun is in progress
- Available spare power supply and high voltage assembly
- Cornell fabrication of critical components
- BNL fabrication and procurement of other components
- BNL installation interface, safety calculations, and reviews
- Assembly and testing at Cornell
- Installation and commission by BNL w/Cornell support



Challenges and needs

- The LEReC project requires construction, commissioning and achieving stable operation of high-brightness high-current electron CW SRF accelerator (ERL in Phase-II) on a very short time scale.

- For any comparable photo-injector it took several years to complete technical accelerator design and then several years of commissioning studies to finally achieve electron beam parameters required.

- For LEReC all the commissioning and establishing all electron beam parameters required for cooling and operation has to be completed in a few month.

- LEReC should be an operational facility which is different from stand-alone R&D test facility.

LEReC-I (1.6-2MeV) and LEReC-II (up to 5MeV) requirements

Ion beam parameters	Full region of energies	
Gamma	4.1	10.7
RMS bunch length	3.2 m	2 m
N_{au}	0.5e9	2e9
I_peak	0.24 A	1.6 A
Frequency	9.1 MHz	9.34 MHz
Beta function@cooling	30 m	30 m
RMS bunch size	4.3 mm	2.7 mm
RMS angular spread	140 urad	90 urad
Electron beam cooler requirement		
Cooling sections	2x20 m	2x20 m
Charge per ion bunch	3 nC (30x100pC)	5.4 nC (18x300pC)
RMS norm. emittance	2.5 um	2 um
Average current	30 mA	50 mA
RMS energy spread	5e-4	5e-4
RMS angular spread	150 urad	100 urad

Example of similar facilities and expertise

- JLAB FEL/ERLs – successful operation with significant CW current of 9mA (LEReC needs 50mA) but not with electron beam parameters needed for LEReC. Control of longitudinal stability, but not to the level needed for LEReC. Built on many years of experience at R&D tests.

- Compact ERL (cERL) in KEK (similar in scale to LEReC). The accelerator construction started in 2012 with stable operation established in 2015. Major commissioning consisted of three periods: 1) injector commissioning, 2) achieving accelerators stability (gun, feedbacks, etc.) required for operation, 3) commissioning of transport lines and energy recovery. Average current presently used in operation is still factor of 100 less than needed for LEReC (administration limit).

- Cornell University R&D CW photo-injector: The only place where high current operation with high charge and small transverse emittances needed for LEReC was demonstrated. But not with the longitudinal beam parameters needed or long beam transport or 24/7 operation.

List of areas which have serious challenges and require special attentions

- Electron beam transport at such very low energies
- Very careful design of each beam transport element due to effects of wake fields on energy spread
- Attainment and control of very low energy spread through entire very long beam path
- Design, construction and commissioning of new state of the art warm RF cavities for energy spread correction
- RF gymnastics with precise control and stability
- Beam instrumentation
- Precise beam alignment
- Operational controls, feedbacks and stability
- Commissioning of high-current CW SRF electron accelerator

Once above challenges are addressed challenges with cooling itself to follow…

Electron beam transport

- Very low energies of operation (1.6-2 MeV) require stretching electron beam bunches to keep energy spread growth due to the longitudinal space charge to an acceptable level (below 5e-4).
- RF gymnastics is used to achieve very low energy spread within electron bunch: SRF 704 MHz cavity creates energy chirp for bunch stretching; warm 704 MHz cavity removes liner energy spread; warm 2.1 GHz cavity removes 2^{nd} order energy chirp. Such corrected energy spread should be accurately measured.
- Quality of the beam should be preserved through the entire beam transport and through both cooling sections.
- Due to very strict requirement on energy spread every beam line element has to be accounted for and properly designed to minimize total impedance budget.

Instrumentation needs

- The electron cooling process effectiveness of which depends critically on precise knowledge and control of the electron beam parameters.
- The energies, time structures, orbits and transverse dimensions of the electron and ion beams in the cooling sections have to be carefully matched.
- The cooling rate depends on the inverse cube of the relative velocities between ion and electron beam which requires energy spread of the electron beam to be at 0.0005 level.
- Repeatability of electron beam transport at low energies.
- Need to develop diagnostics not just for operation but also for commissioning
- JLAB ERL experience: Need lots of longitudinal/time of flight/bunch length/energy diagnostics

Instrumentation challenges

- To obtain energy matching between ion and electron beam to about 0.1% to allow for further tuning based on the cooling process (recombination of heavy ions and longitudinal Schottky monitor). Separate absolute energy measurements (to 0.1-0.2% accuracy) are being considered.
- Need voltage calibration of RF cavities (TOF measurements with BPMs at low energies; energy spectrometer for higher energies).
- Energy spread correction by a very large factor due to RF gymnastic has to be achieved/measured and maintained. Use of dispersion sections, special 180 deg. spectrometer magnet as well as deflecting cavity for the longitudinal phase space measurement are being considered.
- Operational aspects: energy stability to 0.0001 level and feedbacks.
- High-current beam diagnostics

LEReC commissioning challenges

- It will require a lot of efforts to commission such electron accelerator and to achieve electron beam parameters required for cooling.
- It will require very careful beam alignments of every beam element and phasing of all the RF cavities. Very accurate procedures have to be developed and implemented.
- Needed for LEReC expertise is being presently developed through ERL commissioning (as well as at CEC, especially timing and matching of ion and electron beams). This includes but not limited to laser, cathodes, beam instrumentation, controls, LLRF and beam commissioning.
- R&D ERL offers a possibility to develop expertise in areas which are required for LEReC, as well as to test and commission most of the hardware to be used for LEReC (see talk by Wencan Xu).

Summary

- LEReC Phase I (1.6-2 MeV electron beam energies) is approved by DOE for construction
- LEReC Phase II (energy upgrade/ERL mode) detailed design and schedule is yet to be prepared and submitted for DOE approval
- LEReC is a very challenging project
- Expertise in many areas is needed and has to be developed

Your help is needed to make this project a success !