

Coherent electron Cooling Proof of Principles

Vladimir N. Litvinenko for CeC team

C-AD, Brookhaven National Laboratory, Upton, NY, USA

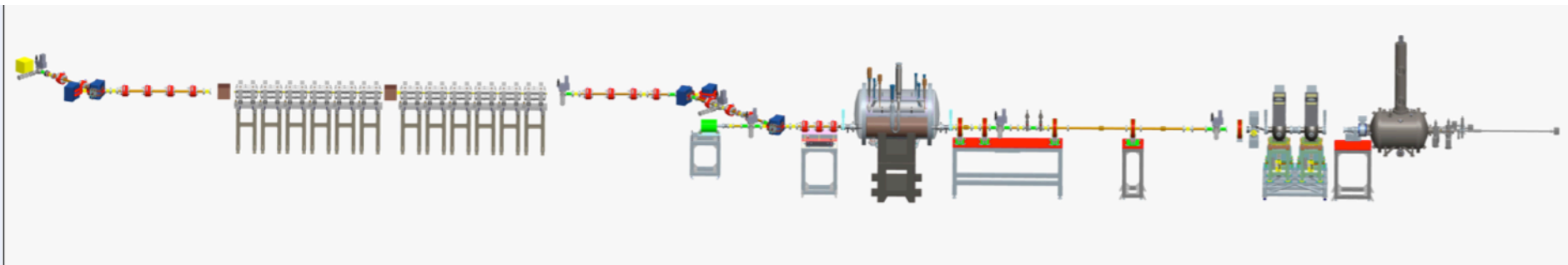
Stony Brook University, Stony Brook, NY, USA

Niowave Inc., Lansing, MI, USA

Tech X, Boulder, CO, USA

Budker Institute of Nuclear Physics, Novosibirsk, Russia

STFC, Daresbury Lab, Daresbury, Warrington, Cheshire, UK



Supported by BNL (LDRDs & PD), C-AD AR&DD, and NP DoE office Accelerator R&D grant

CeC is novel and untested technique
& clearly requires proof-of-principle facility

Goals of CeC PoP system

Demonstrate energy cooling with CeC

Compare with the theory and simulations

Cool entire beam

– then

Use for advanced CeC

Use for linac-ring beam-beam effects studies

Dec. 4-5, 2012, External Review

Oliver Brüning (Chair), Valeri Lebedev, Robert Palmer, Hasam Padamsee,

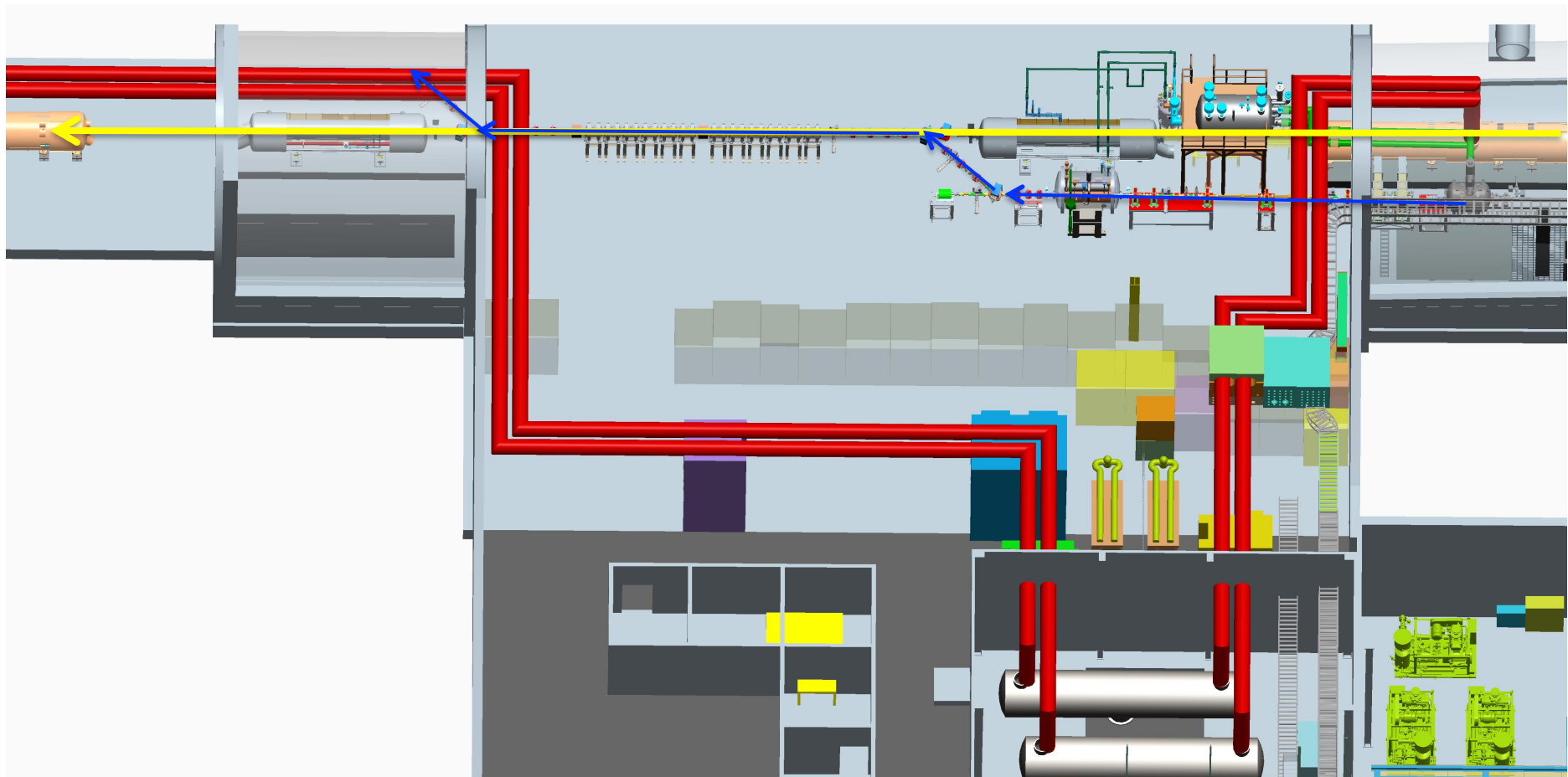
Start Time	Topic	Presenter	Duration
8:30	Executive Session		0:30
9:00	Welcome	T. Roser/I. Ben-Zvi	0:15
9:15	Coherent Electron Cooling	V.N. Litvinenko	0:30
9:45	CeC PoP Project Overview	I. Pinayev	0:30
10:15	CeC Analytical Modeling	G. Wang	0:30
10:45	Coffee Break		0:15
11:00	Numerical Simulations of CeC	K. Paul, Tech X	0:30
11:30	e-Beam Dynamics in CeC accelerator	D. Kayran	0:30
12:00	Drive Laser & Photocathode Development	B. Sheehy	0:30
12:30	Lunch		1:00
13:30	CeC PoP Engineering	J. Tuozzolo	0:25
13:55	SRF and RF systems for CeC PoP	S. Belomestnykh	0:25
14:20	RF transmitters and LLRF	A. Zaltsman	0:20
14:40	CeC PoP layout and design	J.C. Brutus	0:20
15:00	Coffee Break		0:15
15:15	Cryogenic System for CeC PoP	P. Orfin / J.Huan	0:30
15:45	CeC PoP beamline	G. Mahler	0:30
16:15	Diagnostics	T. Miller	0:25
16:40	Control System for CeC PoP Experiment	K. Brown	0:20
17:00	Executive Session		1:15

Executive Summary

Coherent Electron Cooling (CeC) is a very appealing fundamentally new concept that could offer an impressive increase in cooling power for high energy bunched hadron beams (e.g. three orders of magnitude wrt stochastic cooling in RHIC). The CeC PoP is a major component of the R&D for a high luminosity Electron-Ion Collider at BNL (eRHIC).

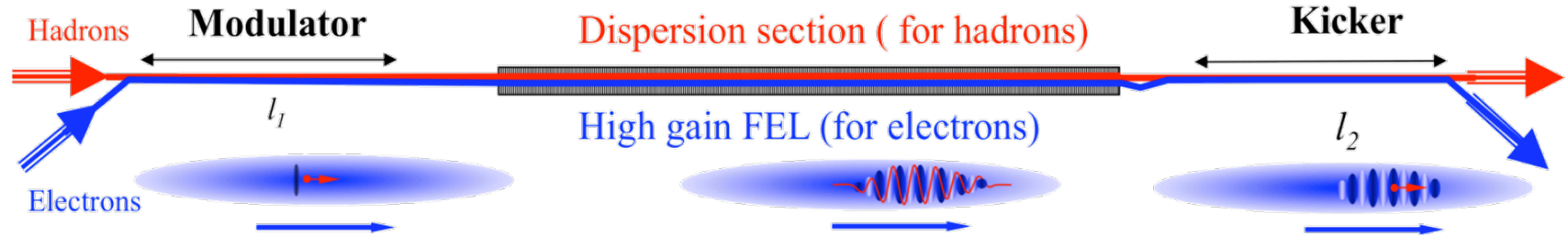
Next DoE Review: Nov. 12-13, 2015

CeC Proof-of-Principle Experiment

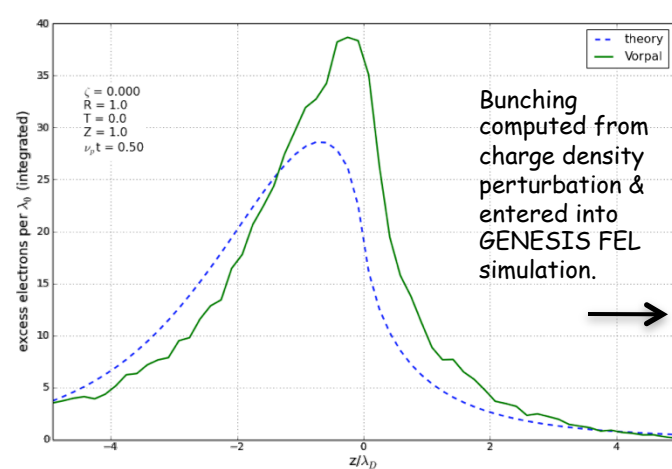


Coherent electron *Cooling* PoP

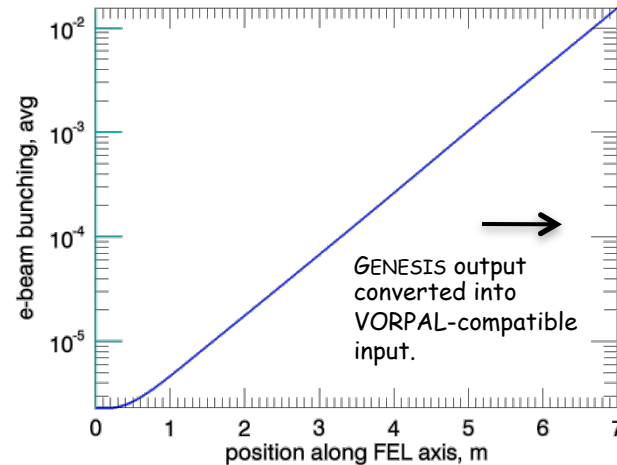
Our PoP is based on an economic version of CeC:
it limits strength of the wiggler a_w to about 0.5
but it is very cost effective



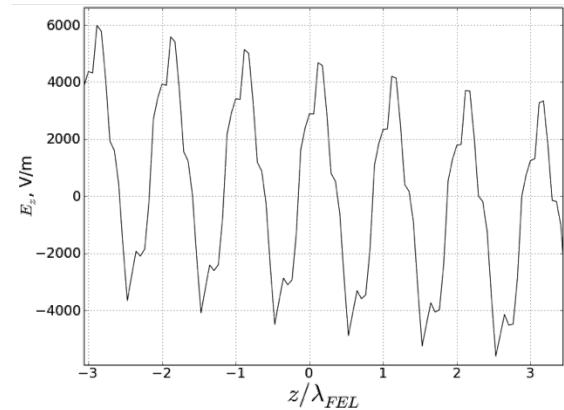
Param.'s from 40 GeV proof-of-principle exp. at BNL



VORPAL 3D δf PIC computation of e- density perturbation near Au^{79} ion (green) vs. idealized theory (blue). On Cray XE6 cluster at NERSC.



GENESIS parallel computation of electron beam bunching in free electron laser (FEL) shows amplification of modulator signal.



VORPAL prediction of the coherent kicker electric field E_k due to e-density perturbation from modulator, amplified in the FEL.

Simulations by Tech-X

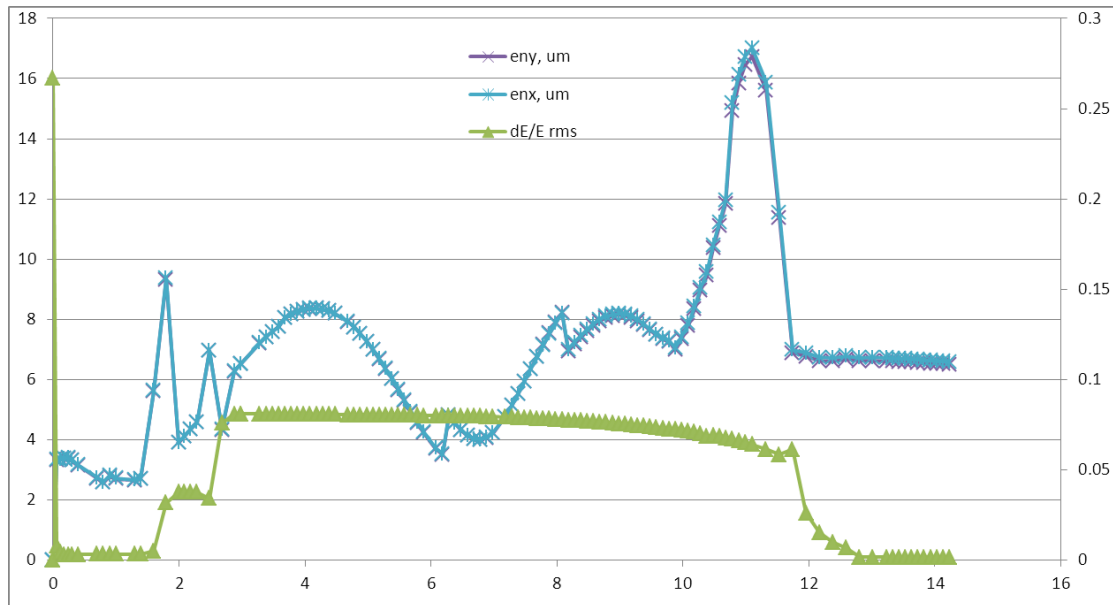
Electron Beam and FEL Parameters

Electron Beam	
RMS Energy Spread	$\leq 1 \times 10^{-3}$
Normalized Emittance	$\leq 5 \text{ } \mu\text{m}\cdot\text{rad}$
Peak Current	60-100 A
FEL	
Wiggler Length	$3 \times 2.5 \text{ m}$
Wiggler Period	40 mm
Wiggler Strength, a_w	$0.5 +0.05/-0.1$
FEL Wavelength	$13.6 \text{ } \mu\text{m}$

Main Beam Parameters for CeC Experiment

Parameter	Value
Species in RHIC	Au ⁺⁷⁹ ions, 40 GeV/u
Relativistic factor	42.96
Number of particles in bucket	10 ⁹
Electron energy	21.95 MeV
Charge per e-bunch	0.5-5 nC
Rep-rate	78.17 kHz
Average e-beam current	0.39 mA
Electron beam power	8.6 kW

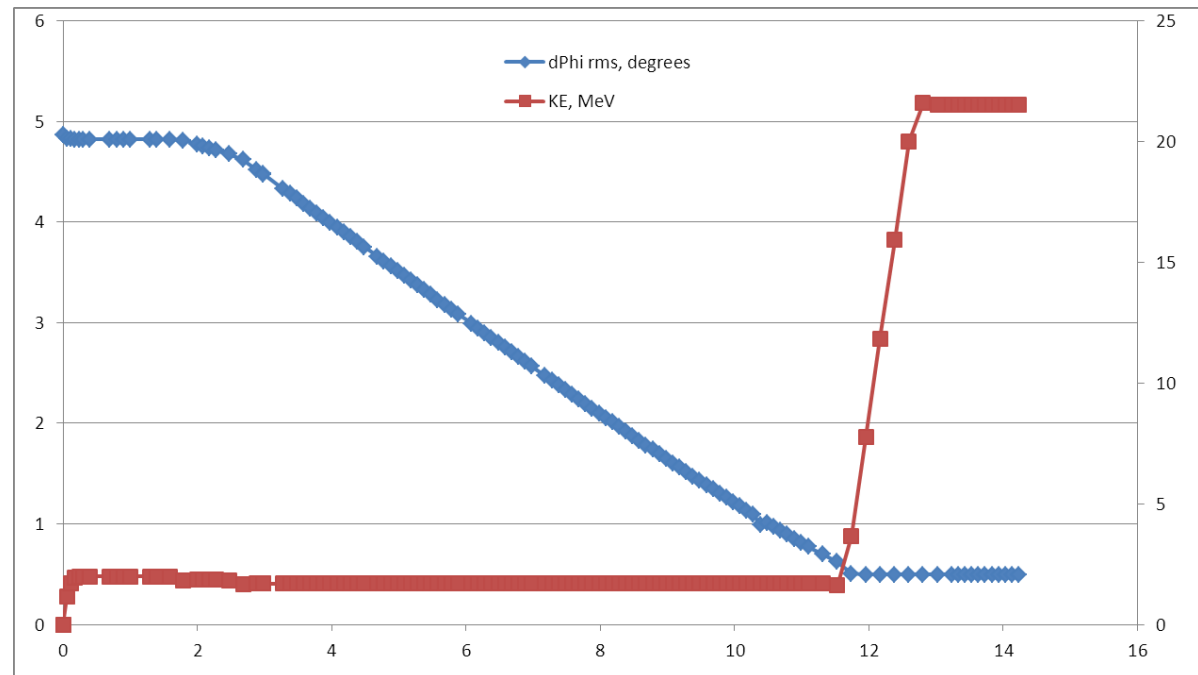
Expected Electron Beam Parameters



Calculations are done for
2 nC bunch
Core charge is 1.3 nC
Emittance is 8.6 μm , core
emittance is 3.3 μm

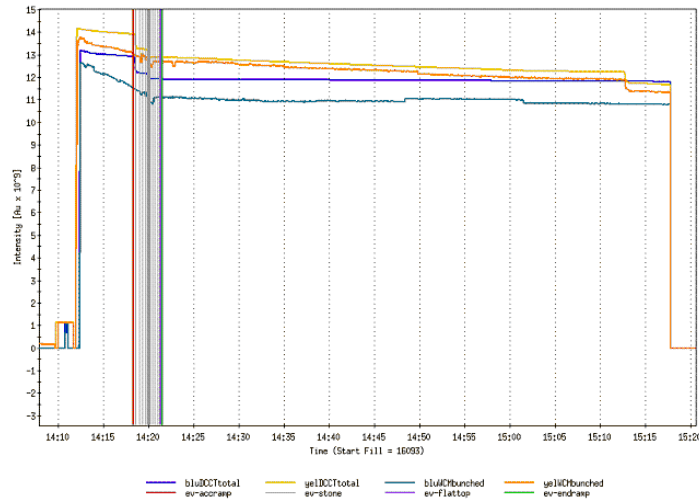
Relative energy spread is
 2×10^{-3} , relative energy
spread in the core is
 3×10^{-4}

Courtesy D. Kayran



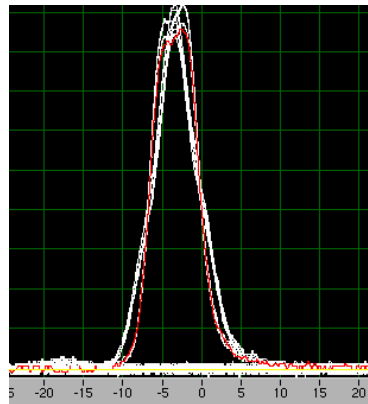
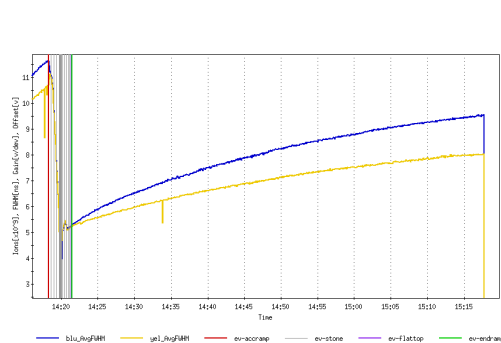
CeC PoP RHIC Ramp Development

Ramp : beam intensity

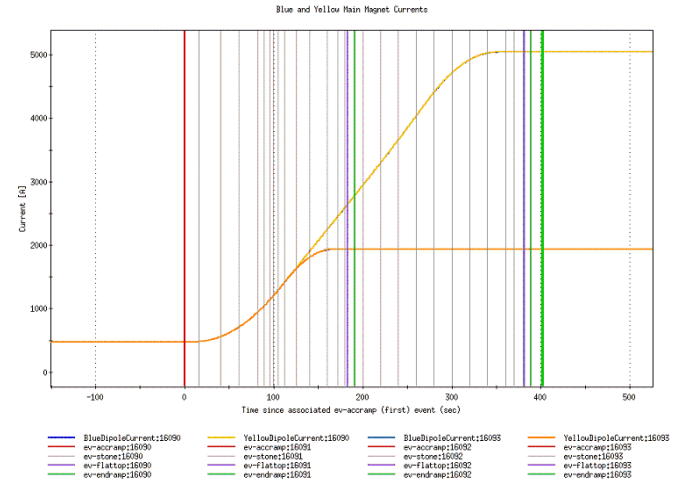


APEX on RUN 11: 2pm-4pm, June 20th, 2011 Fill: 16093

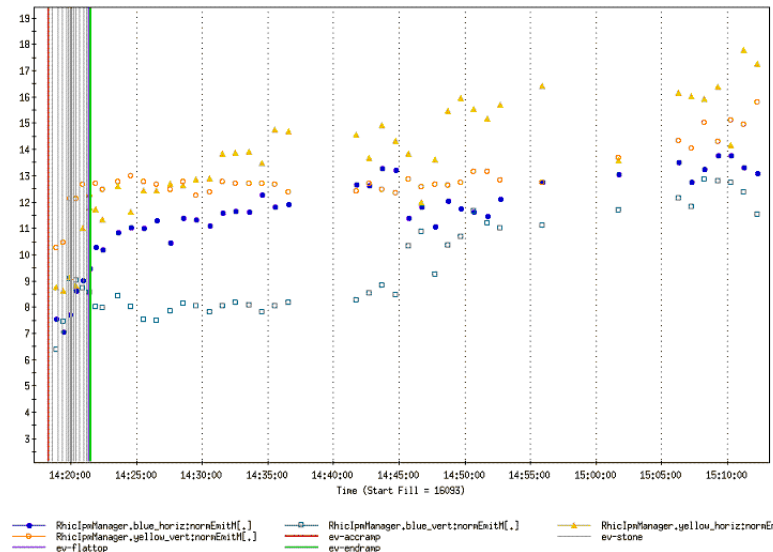
Bunch length and profiles at 40 GeV



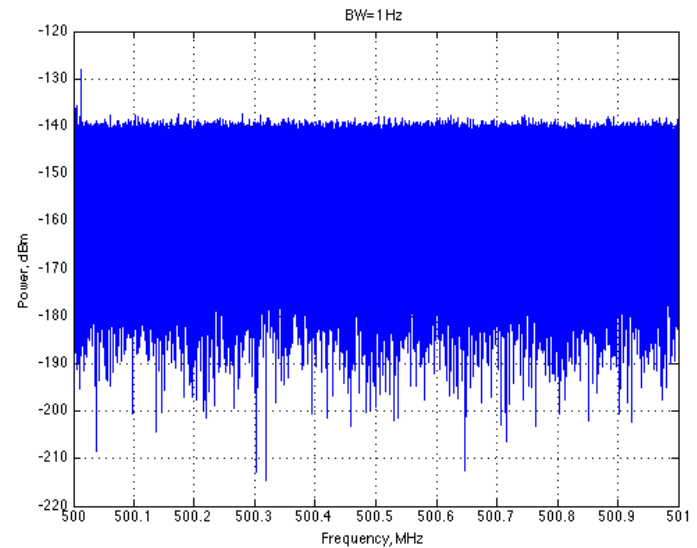
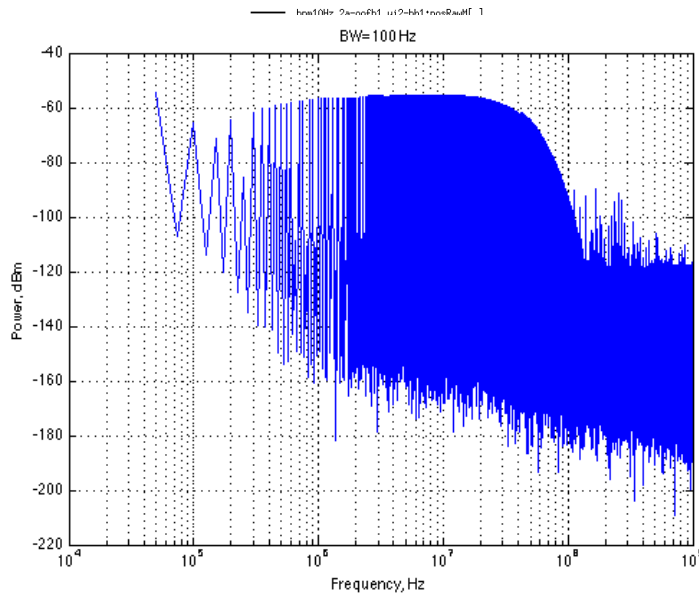
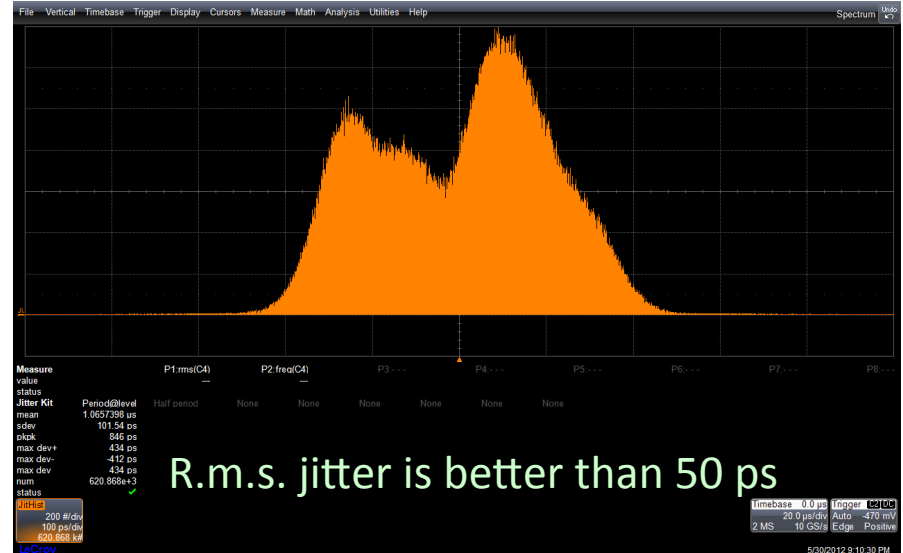
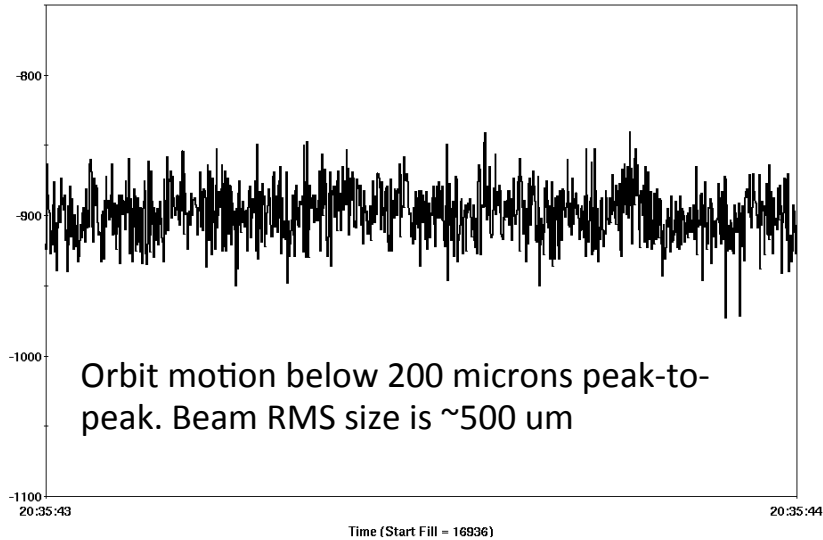
Ramp : Magnets currents



Emittance growth at 40 GeV



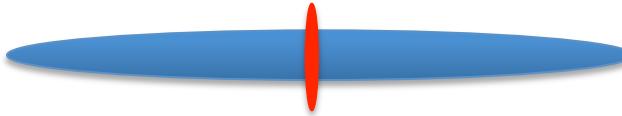
Ion Beam Parameters Characterization



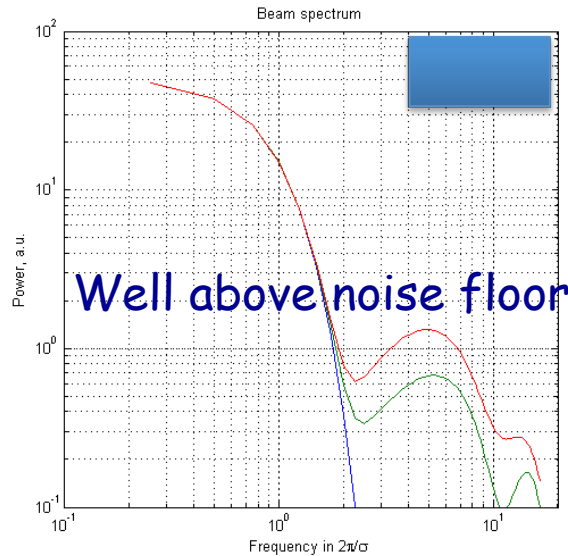
Noise floor is 80 dB below the signal at revolution frequency.

Anticipated Beam Dynamics

Electron bunch - 10 psec

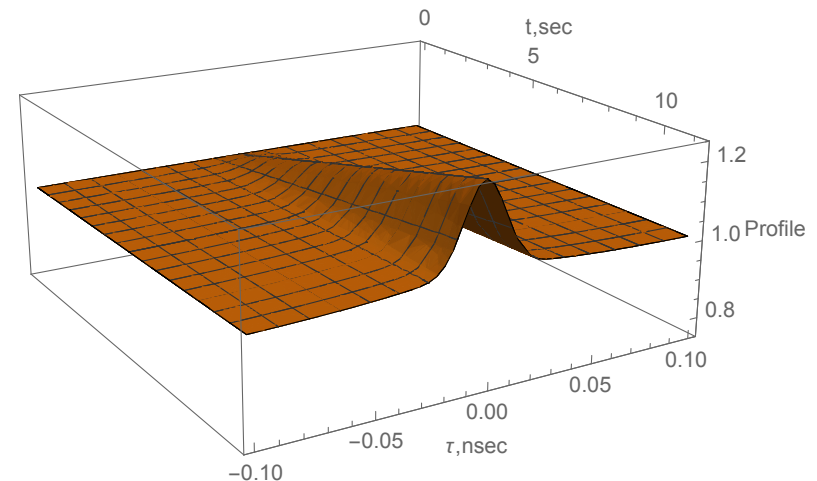
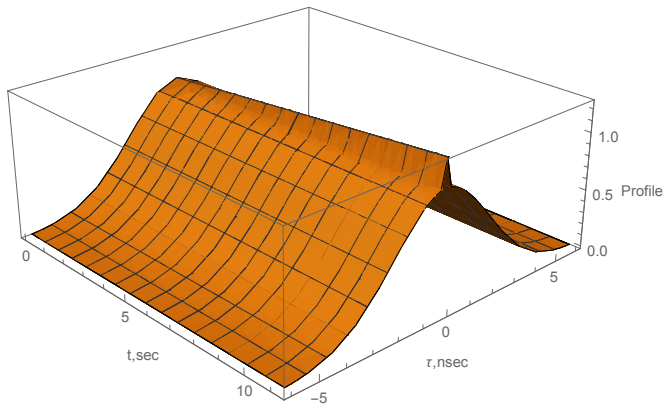


Ion bunch - 2 nsec

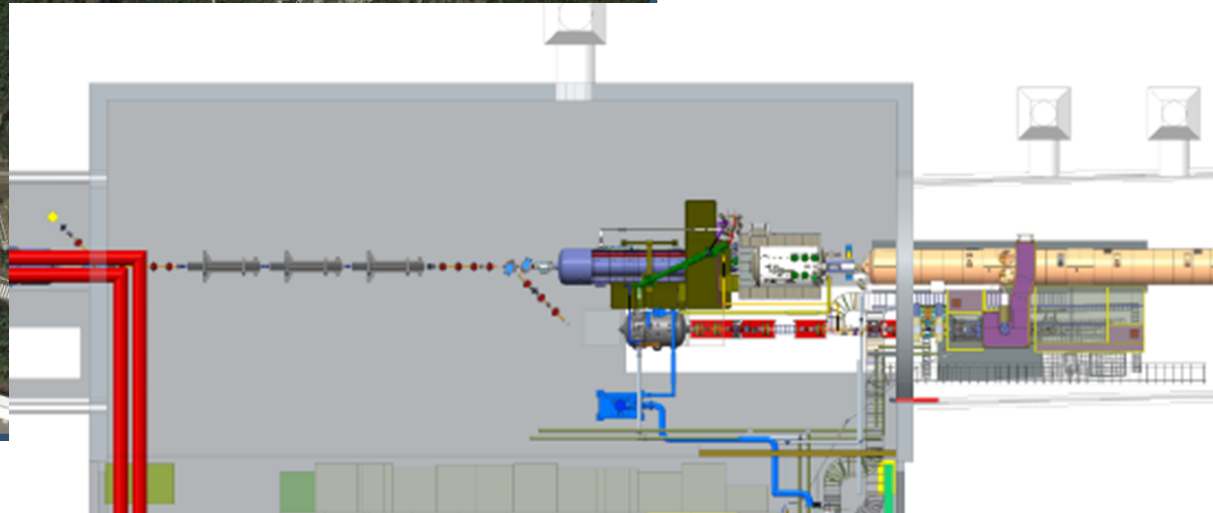
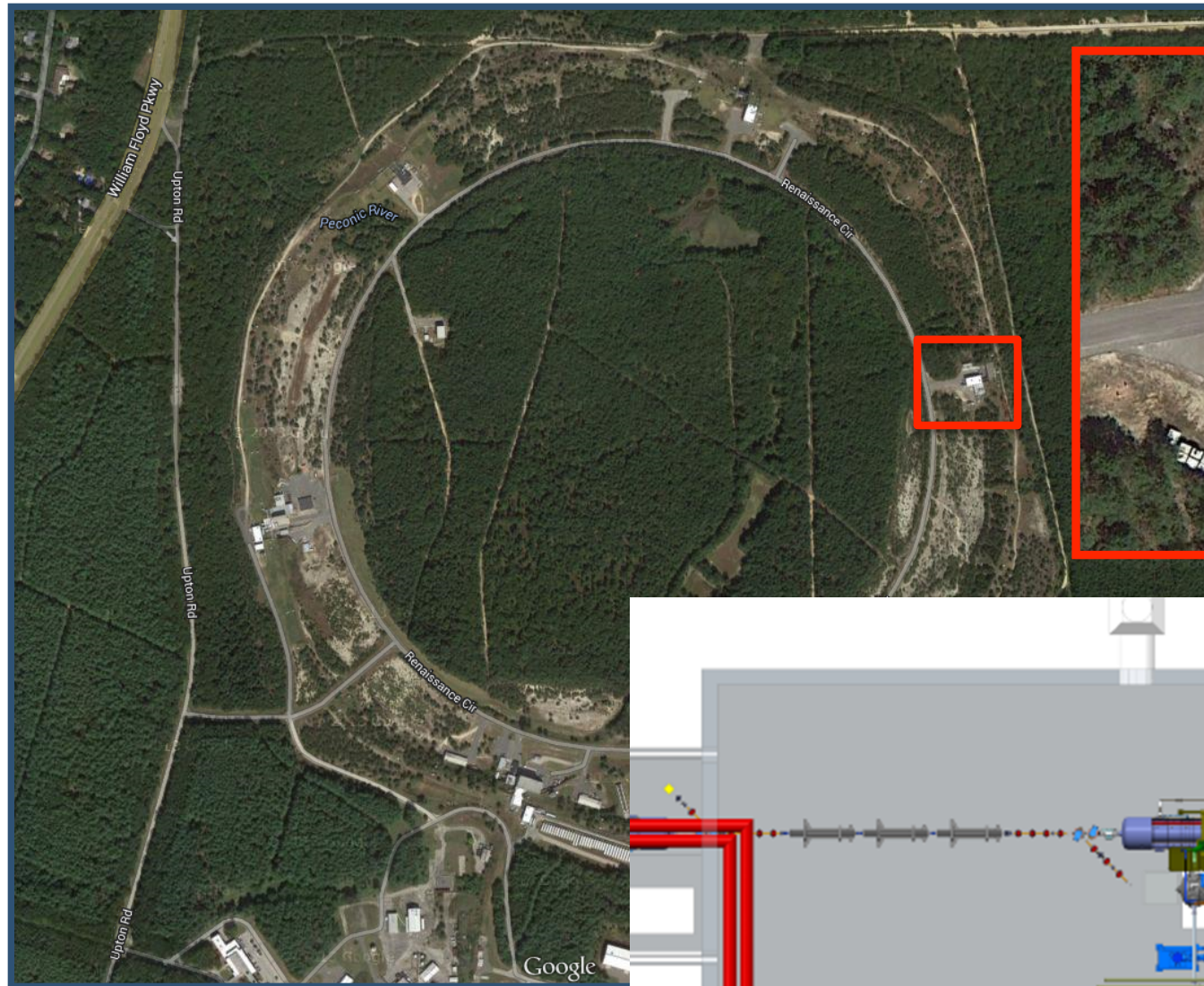


r.m.s. length of the cooled part 80-120 ps.
The cooling effects can
2 GHz (or more)
bandwidth using
spectrum analyzer or
digital scope

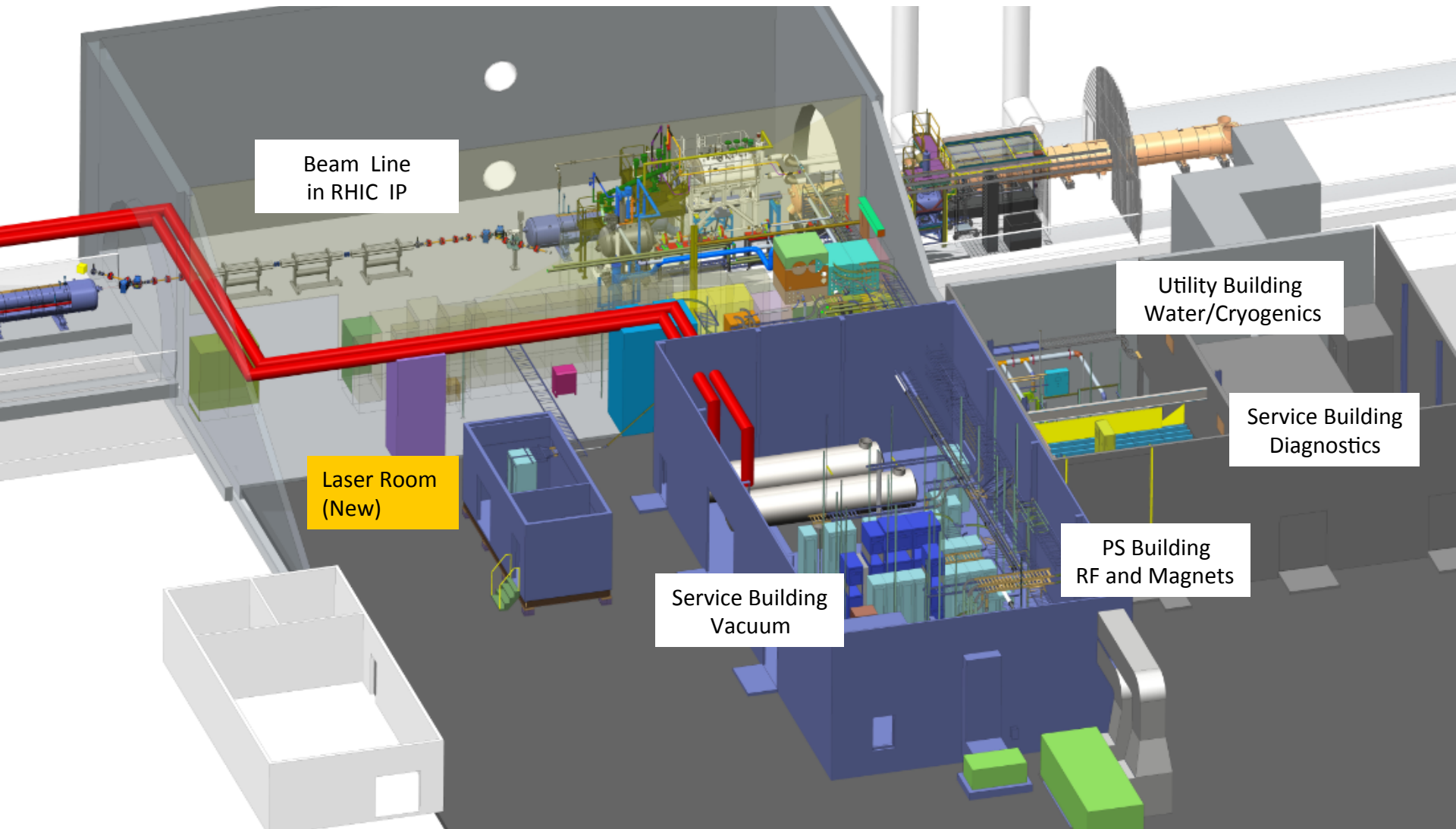
Simulated beam profile evolution with CeC PoP parameters



Location – RHIC 02:00 Region



CeC PoP Final Configuration

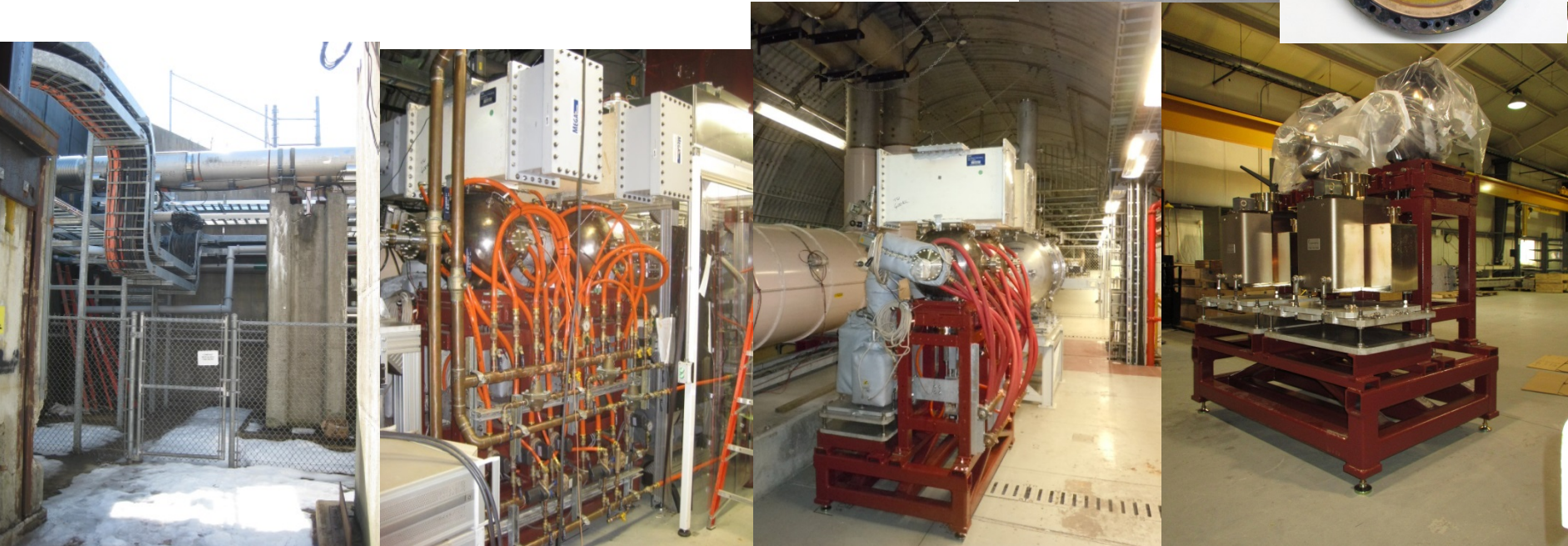


Coherent electron *Cooling* PoP

Phase "0"

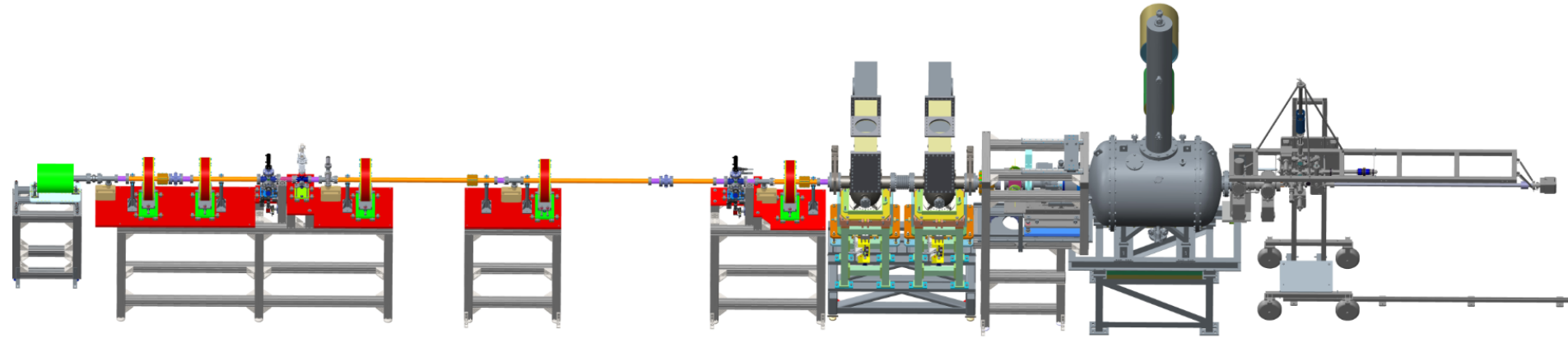
Refurbish, Install and Test Buncher Cavities.

- Total rebuild: new cooling lines, cleaned and resealed windows, new seals, vacuum pumps and valves, rebuilt tuner drive.
- Cleanroom prepped and vacuum baked.
- New PA installed.
- New RF Coax installed.



Coherent electron *Cooling* PoP

Phase 1 – Beamline installation and 112 MHz Cavity Testing



CeC Phase 1 goals:

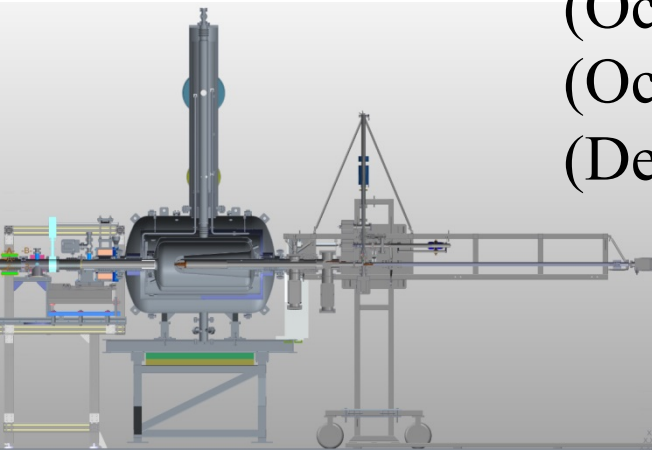
- Install 112 MHz Cavity, Support Systems, and Cathode
- Install Beamline and Low Intensity Dump
- Make 112 MHz Cavity Cold and Test

(October 20) “dry run”, ASSRC walk through

(October 27) cold test

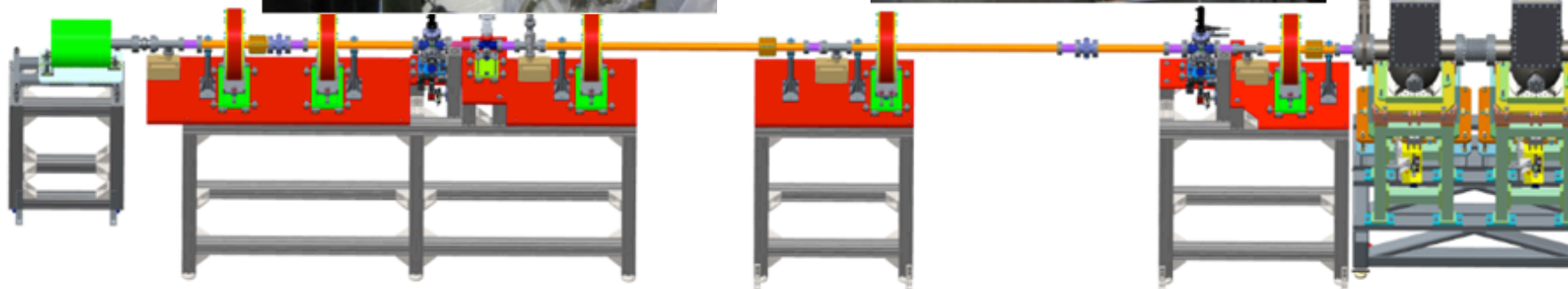
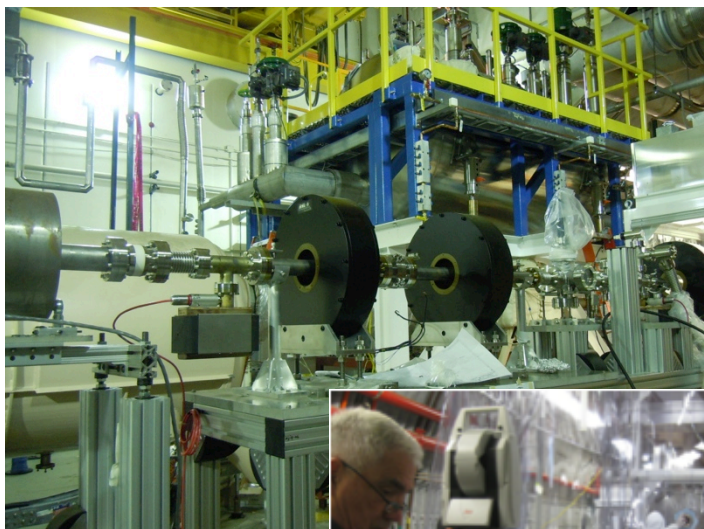
(October 30) conditioning underway

(December 4) **2 MV !!**



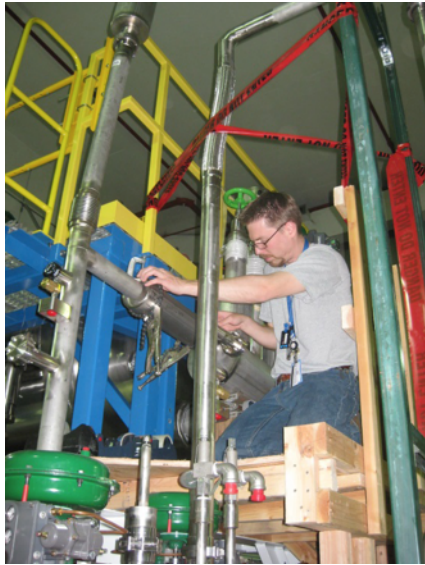
Coherent electron *Cooling* PoP

Phase 2.1: Buncher to Dump Beamline



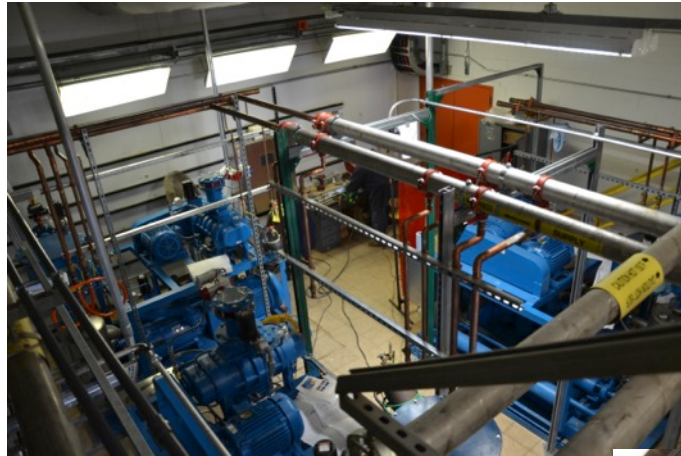
Coherent electron *Cooling* PoP

CeC PoP @ IP2

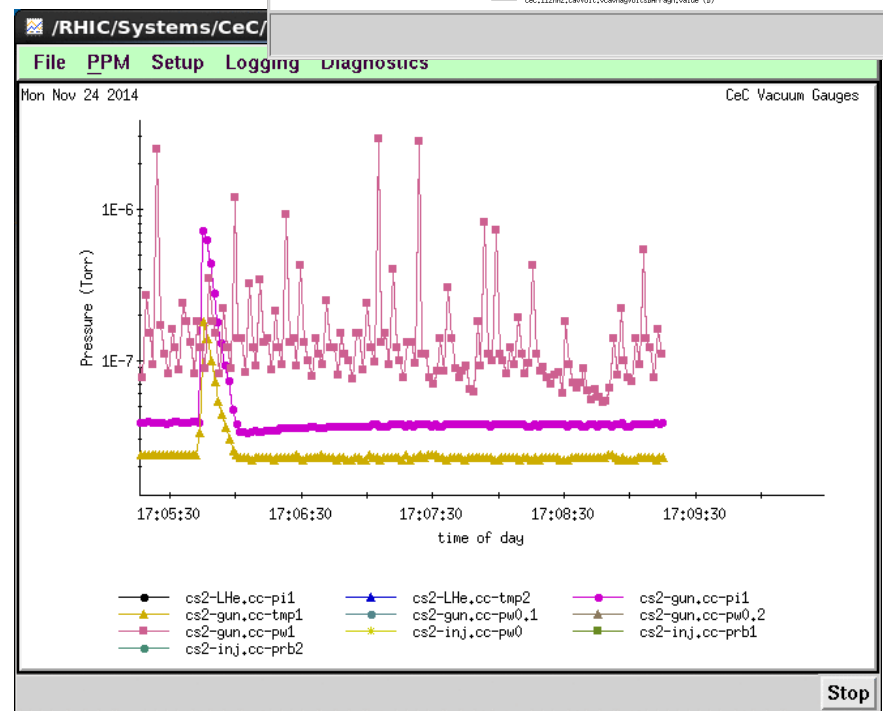
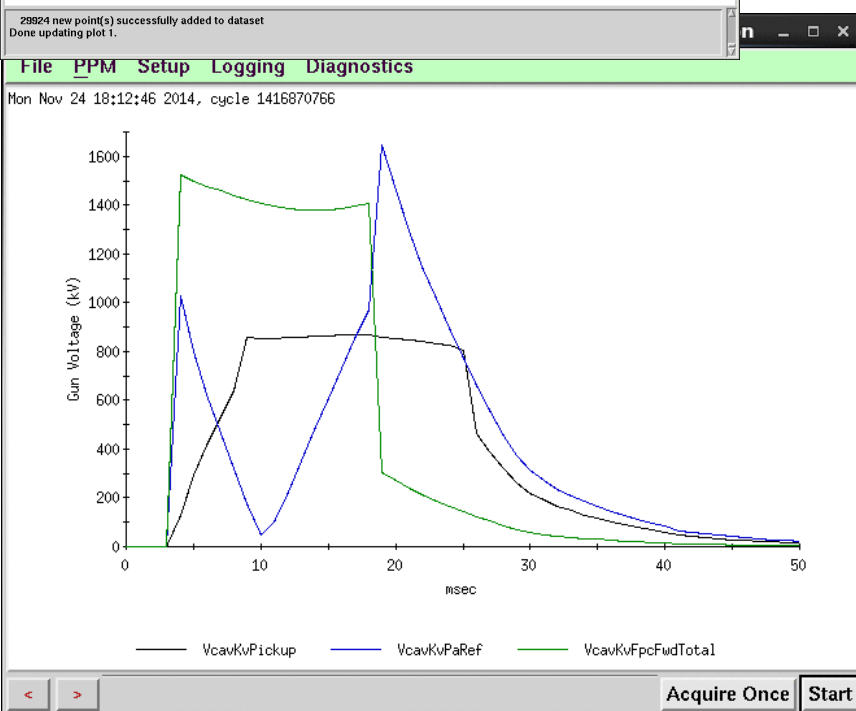
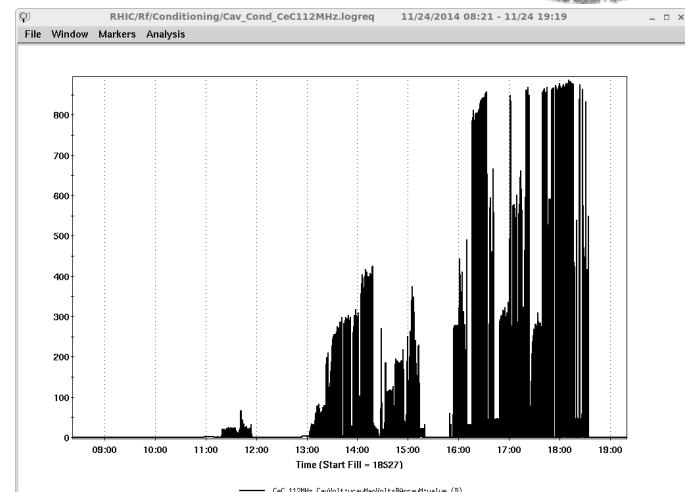
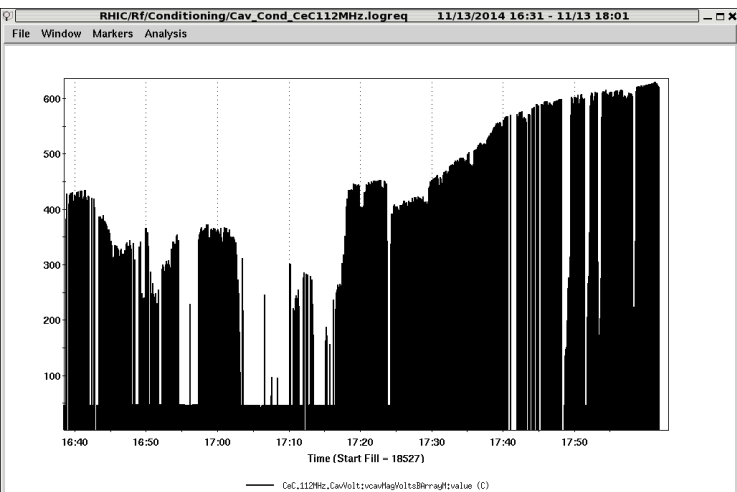


Coherent electron *Cooling* PoP

Infrastructure



Phase 1 conditioning 112 MHz Cavity



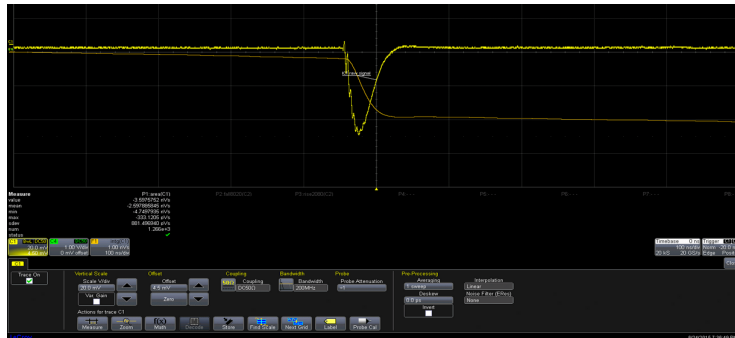
Coherent electron *Cooling* PoP

Results of our success with 112 MHz gun

1.6-1.7 MeV (kinetic energy) e-Beam with 3 nC in CW mode

2 MeV in pulse mode

25 MV/m at photocathode



Milestones Q3 FY15

Demonstrating operation of 112 MHz SRF gun with 3 nC charge per bunch, 1.6 to 1.7 MeV kinetic energy in CW mode and above 2 MeV in pulsed mode.

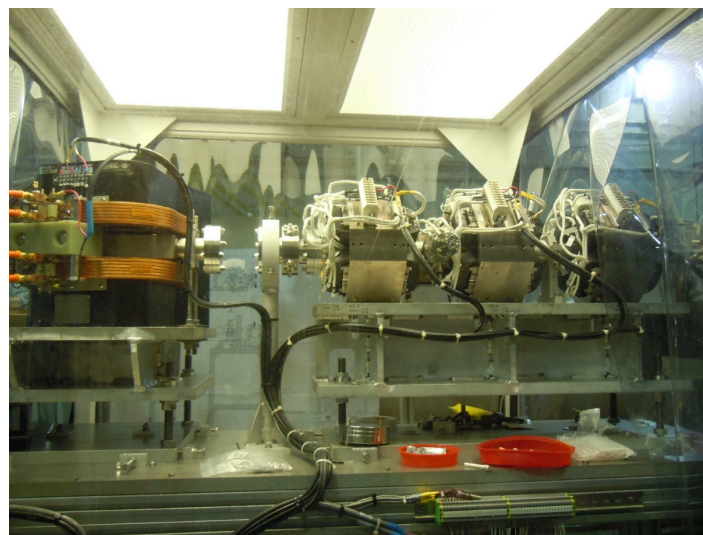
Production of high QE photocathodes for 112 MHz SRF gun.

Receiving helical wiggler system for CeC PoP FEL amplifier

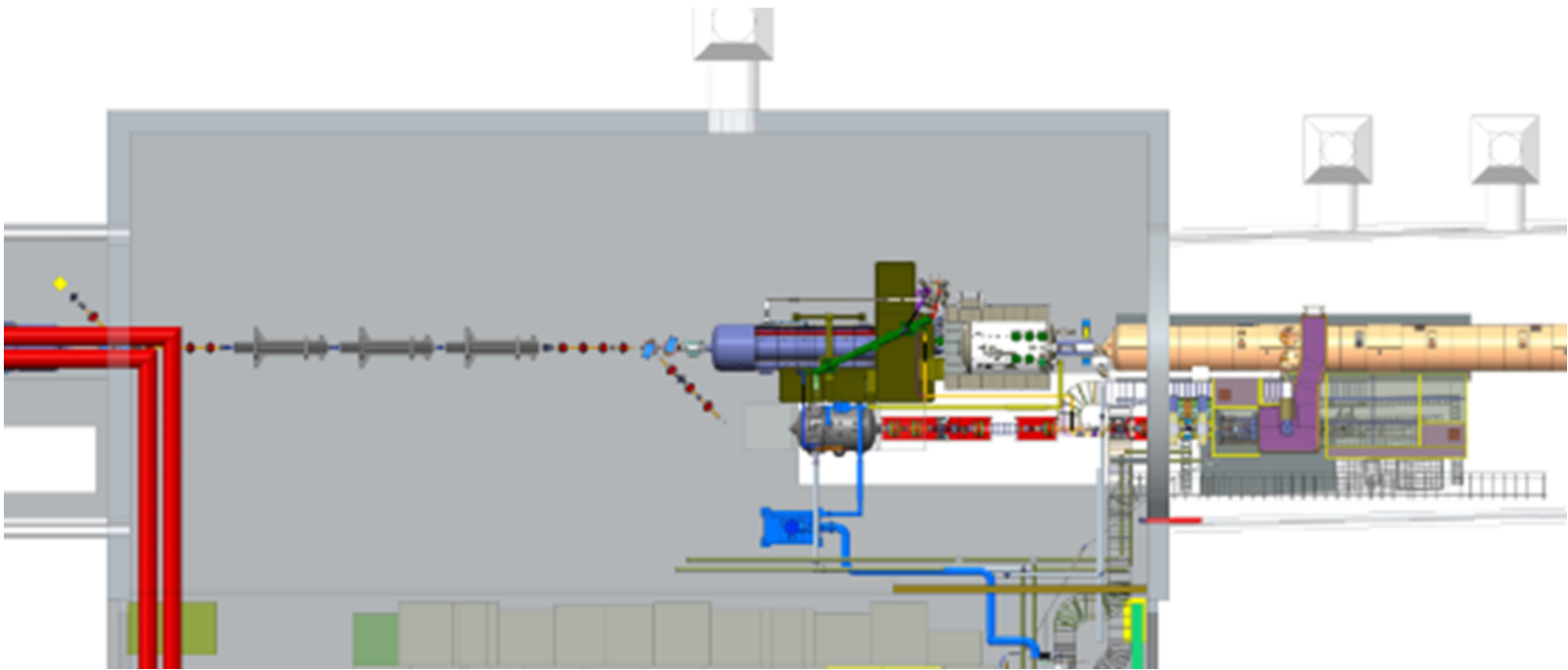
Completion of the 704 MHz SRF linac cryo-module at NioWave Inc.

Completing the low energy transport beam line and its control system.

System in place



Phase 3: Full Energy Beam Line Installation - 2015



- Install 704 MHz Systems and supporting cryogenic system
- Install Wiggler Magnets
- Install RHIC beam line components: dipoles, quads, correctors, vacuum
- Install beam diagnostics (Toby)
- Modify and install RHIC DX-DO chamber for FEL light diagnostics
- Move CeC beam dump line to final location

Phase 3 - 704 MHz 5 Cell Cavity From Niowave

Delivery from Niowave – July 15, 2015

Coax in house being installed

FPC welding at AES is finished



Coherent electron *Cooling* PoP

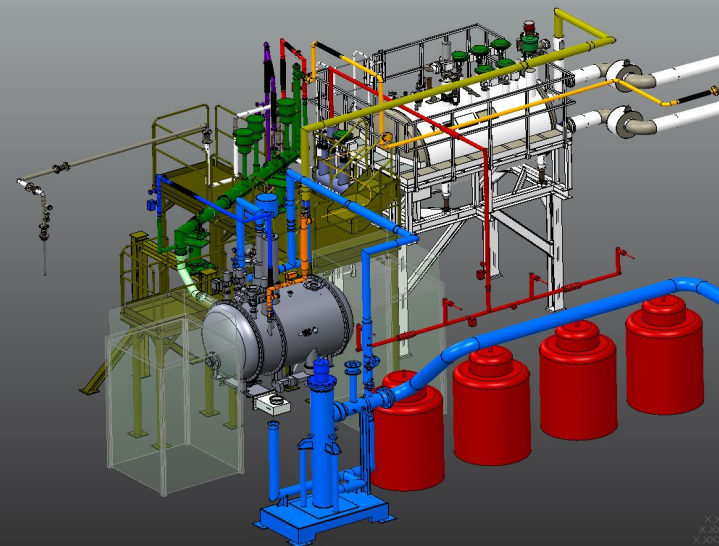
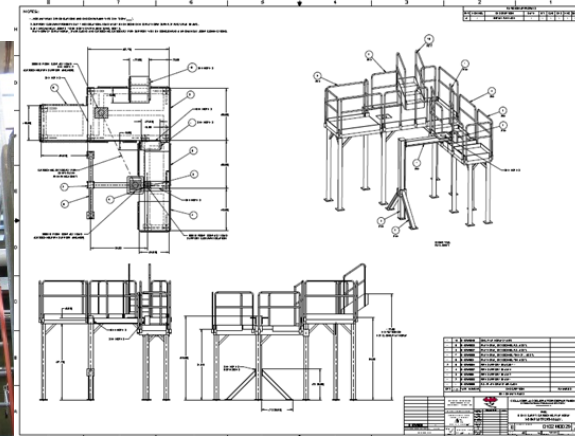
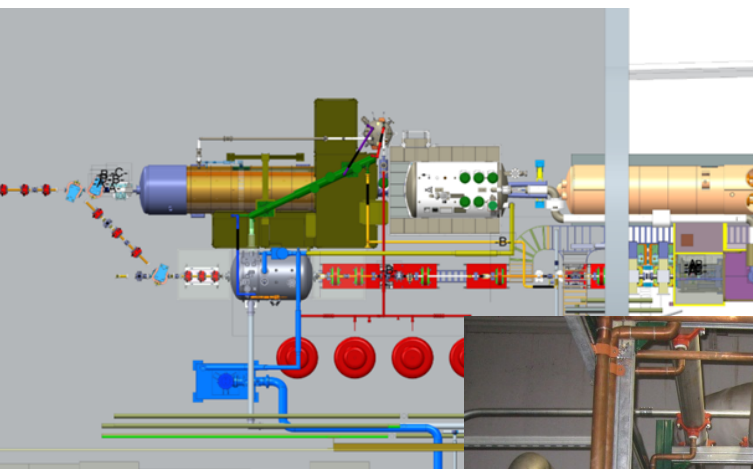
Wigglers at BNL

BINP team just left



Phase 3 - 704 MHz Cryogenics

- Integration with LEReC supply and return requirements complete
- All components ordered: VJP (green monster), heater return (blue), cooldown return (lime green to QHS heater), heater skid.
- Warm return vacuum header installation
- 704 MHz scaffold order



Coherent electron *Cooling* PoP

Schedule

Delivery of 704 MHz linac to BNL	✓	30-Jul-15
Assembling and tuning helical wigglers	✓ + 1/3	15-Aug-15
Install 704 MHz in RHIC tunnel	x	15-Nov-15
Install helical wigglers in RHIC tunnel	x	01-Dec-15
CW laser is commissioned	x	01-Dec-15
Beam diagnostics is intalled		15-Dec-15
Optical diagnostics is installed		15-Dec-15
Complete CeC beam-line	x	15-Dec-15

Schedule cont..

Commissioning			
SRF cavities cold	x	15-Feb-16	Has to be synchroniozed with RHIC crun
Complete cavity conditioning	X	15-Mar-16	
Generating fist beam	X	01-Apr-16	Assuming that SRF gun is working with photocathode pack
Measuring beam parameters	x	15-Apr-16	
Propagate beam to the beam dump	x	01-May-16	
Test co-propagation with ion beam	X	15-May-16	
Demonstrate FEL amplification	X	Before the end of the run	
First cooling attempt	X	Before the end of the run	Dedicated 5 days of running, dates have to be adjusted to the end of the RHIC run

Will need Control room support in conditioning/training SRF cavities

Re-establishing 40 GeV Au RHIC ramp

e-Beam commissioning can be parasitic

Establishing CeC conditions (ion + electron beam) would require APEX (or dedicated) RHIC beam time - 4-6 hours each APEX section

We request to consider CeC to be a RHIC experiment, e.g. have right for short accesses between maintenance periods

We would need 5 days of dedicated RHIC running to test CeC

Resources needed for 2 years

Funding for hardware - \$1.2M

Personnel - an estimate is about 20 men-years

(to be determined when resource loaded schedule is finalized)

People involved: VL, I. Pinayev J. Tuozzolo, J. Skaritka, Y. Hao, Y. Jing, G.Wang, D. Kayran, B. Xiao, B. Sheehy, E. Wang, T. Rao, Z. Altinbas, S.A. Belomestnykh, K.A. Brown, J.C. Brutus, A.J. Curcio, L. DeSanto, C. Folz, D.M. Gassner, C. Ho, R.L. Hulsart, M. Ilardo, J.P. Jamilkowski, F.X. Karl, N. Laloudakis, R.F. Lambiase, G.J. Mahler, M. Mapes, W. Meng, R.J. Michnoff, T.A. Miller, M.G. Minty, G. Nayara, P. Orfin, F. Randazzo, , J. Sandberg, K.S. Smith, L. Snyderstrup, A.N. Steszyn, R. Than, C. Theisen, R.J. Todd, D. Weiss, M. Wilinski, A. Zaltsman R. Kellerman, T. Xin, D. Ravikumar, Y. Wu (definitely missed somebody!)

Summary



- Progress continues on component installation and commissioning.
- 112 MHz generated electron beam during RHIC run 15
- Critical deliveries: 704 MHz cavity and undulator magnets had been made
- Installation summer 2015
- Main uncertainty is introduced by potential p-A operation during Run16

CeC PoP



**Where scientists and engineers
work together !**

BACK-UP

Schedule cont

Making necessary up-grades/ improvement	01-Jul-16	31-Dec-16	Improving and updating diagnostics, optical system as well as installing buncher for ACeC test
SRF cavities cold	x	15-Feb-17	Has to be synchroniozed with RHIC crun
Complete cavity conditioning	X	01-Mar-17	
Recreating operational conditions	X	21-Mar-17	
Start CeC PoP experiments (using APEX shifts)	X	07-Apr-17	
Demonstrate microbunching amplification	x	30-May-17	
Demonstrate CeC PoP cooling	X	30-Jun-17	
CeC cooling experiments end	X	30-Jun-17	dates have to be adjusted to the end of the RHIC run