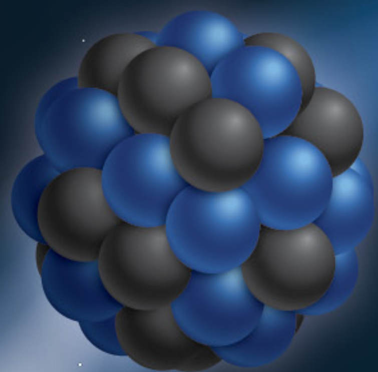
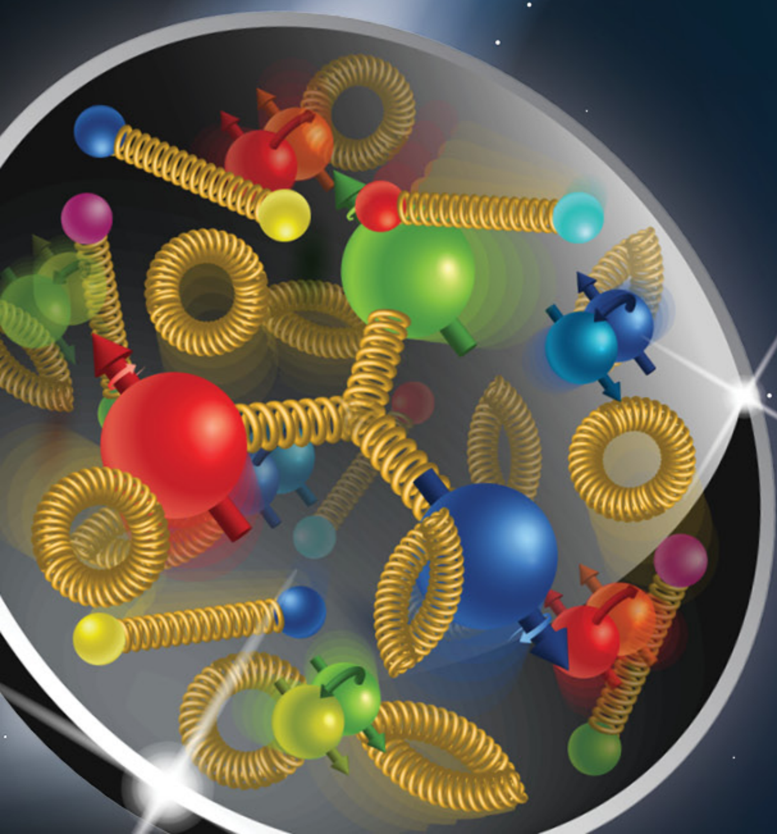




ERL developments for eRHIC

Vladimir N Litvinenko
Stony Brook University

ERLs are needed eRHIC's linac-ring design as well as for any efficient hadron cooling

Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

Content

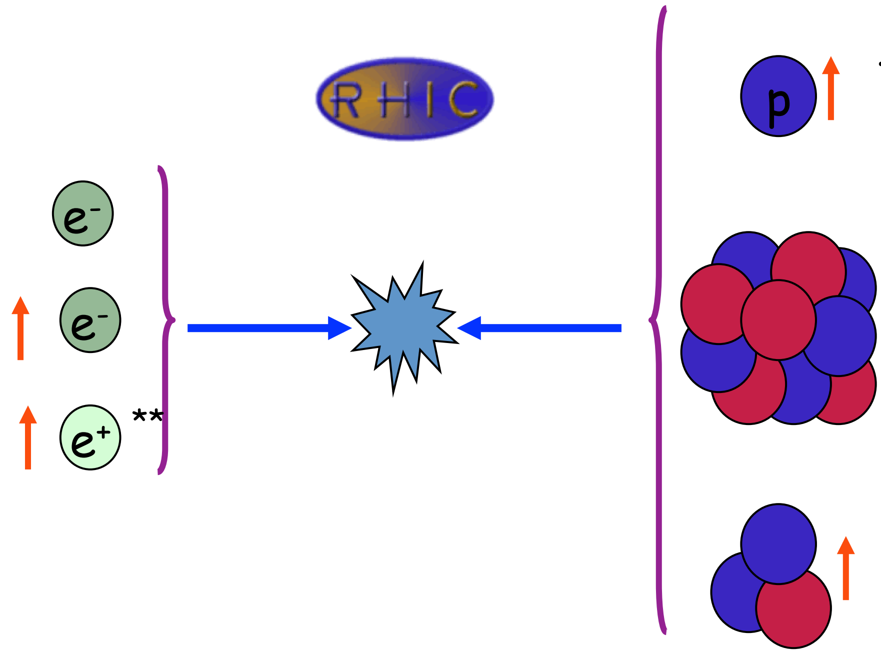
- Generalities
- ERL-based eRHIC design
  - and its challenges
- ERL developments for eRHIC
  - High current, high charge electrons sources
  - Coherent electron Cooling, developing
  - Novel SRF electron guns and accelerator cavities

Note: I do not plan to repeat presentation done by previous speakers about eRHIC relevant ERLs such ass eRHIC ERL desing, C-beta , ERL at CEBAF, BNL R&D ERL… (V. Ptitsyn, D. Kayran, F. Meot, G. Hoffstaetter) and will focus on other ERL-related developments at BNL and Stony Brook University

ERL-based eRHIC

Add electron accelerator to the existing $2B RHIC

80% polarized electrons,
5-20 (30) GeV

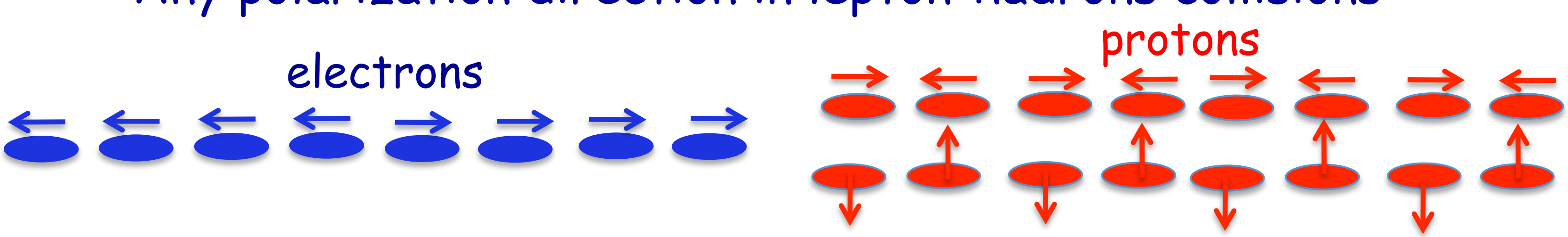


70% polarized protons
100-250 (275*) GeV

Light ions (d,Si,Cu)
Heavy ions (Au,U)
50-100 (110*) GeV/u

Polarized light ions
(He^3) 167 (184*) GeV/u

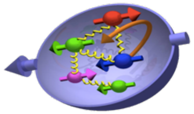
Center of mass energy range: 30-145 GeV
Any polarization direction in lepton-hadrons collisions



What is needed for?

Office of Nuclear Physics
Exploring Nuclear Matter - Quarks to Stars

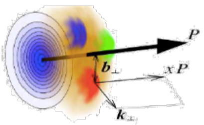
spin physics



- what is the polarization of gluons at small x where they are most abundant
- what is the flavor decomposition of the polarized sea depending on x

determine quark and gluon contributions to the proton spin at last

imaging

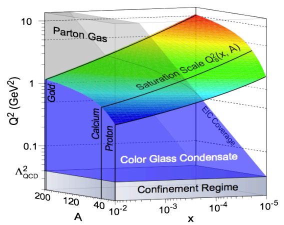


- what is the spatial distribution of quarks and gluons in nucleons/nuclei
- understand deep aspects of gauge theories revealed by k_T dep. distr'n

possible window to orbital angular momentum

physics of strong color fields

quantitatively probe the universality of strong color fields in AA, pA, and eA

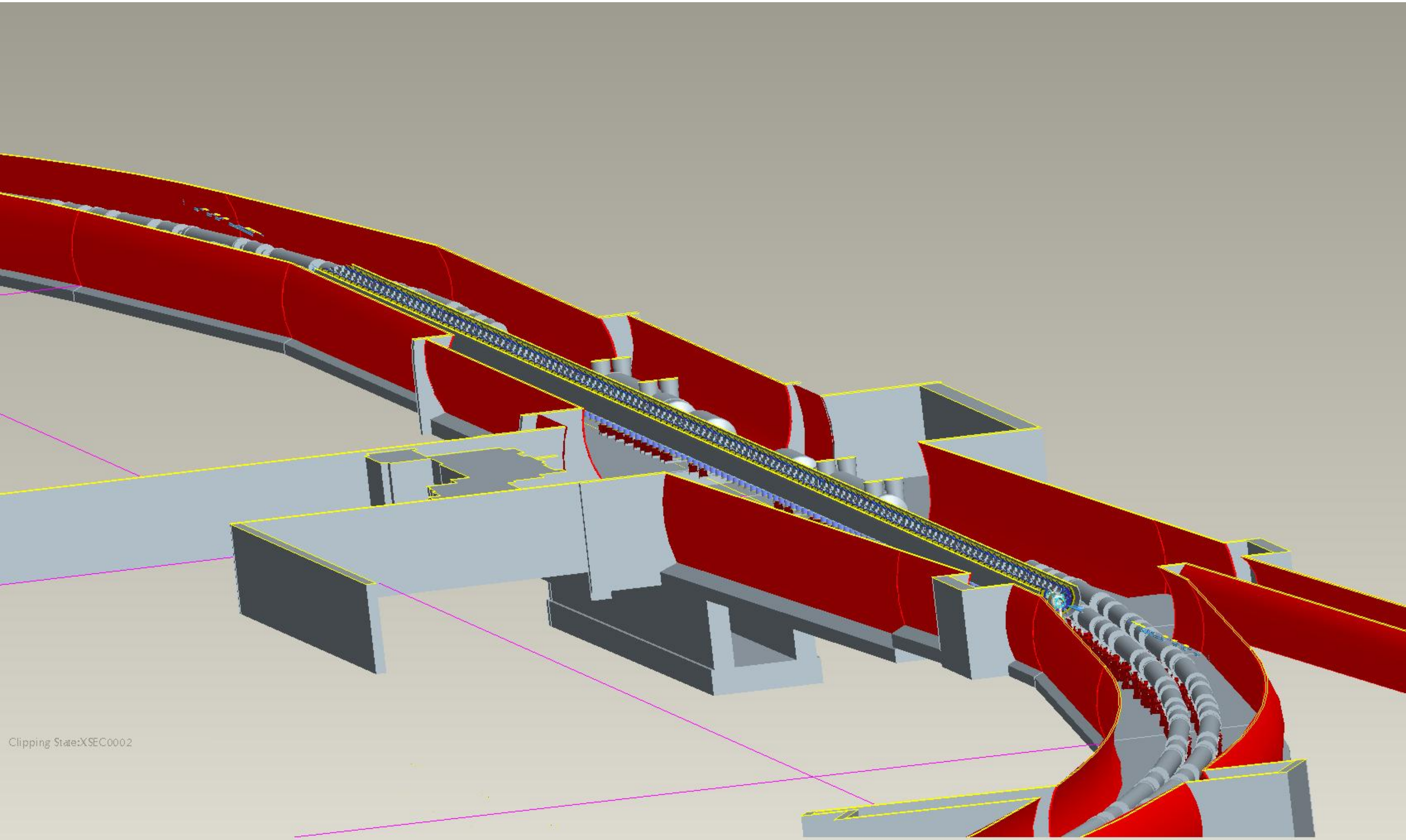


- understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
- how do hard probes in eA interact with the medium

Courtesy of E.-C. Aschenauer

eRHIC design and related R&D

- Adding a 18 GeV electron accelerator to the existing RHIC operating 100 GeV/n ions and 275 GeV polarized protons
- Two high luminosity linac-ring eRHIC designs with regular and FFAG arcs had been completed and studied in depth
- Dedicated BNL team is working out a detailed design of eRHIC ring-ring option
- R&D
  - A dedicated Proof-of-Principle experiment is underway at RHIC to demonstrated a novel Coherent electron Cooling technique
  - We are continuing performing R&D on the feasibility of a high current polarized gun (both Gatling gun and a single cathode option)
  - BNL, in collaboration with Cornell, is constructing a high intensity multi-pass 150 MeV test-ERL with an FFAG return loop, called CBETA
  - Prototyping SRF cavities and effective HOM dumpers
  - Crab cavities
  - Prototyping magnets for eRHIC IR
  - Theoretical/numerical studies of ERL-based eRHIC (mostly at CASE/SBU)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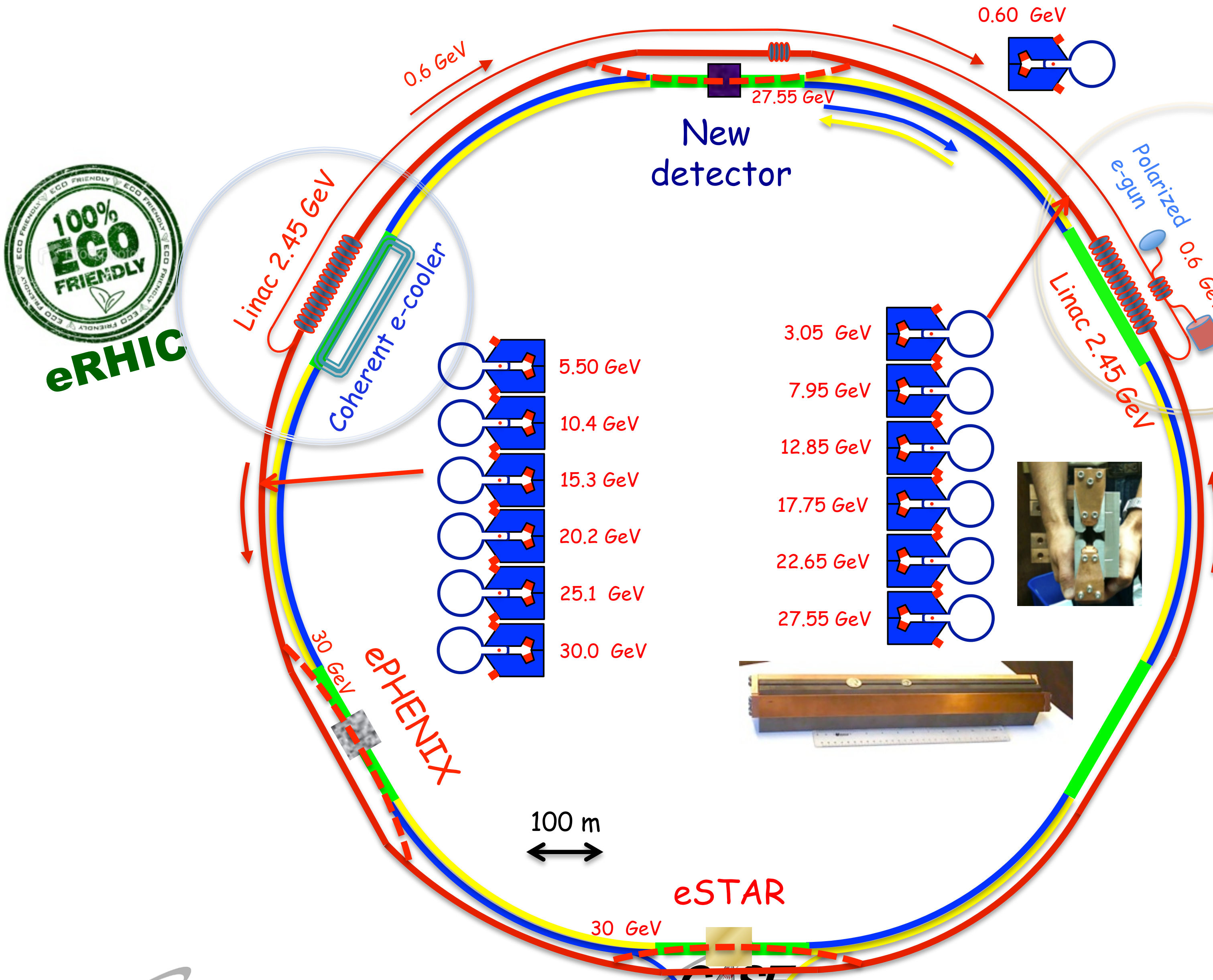
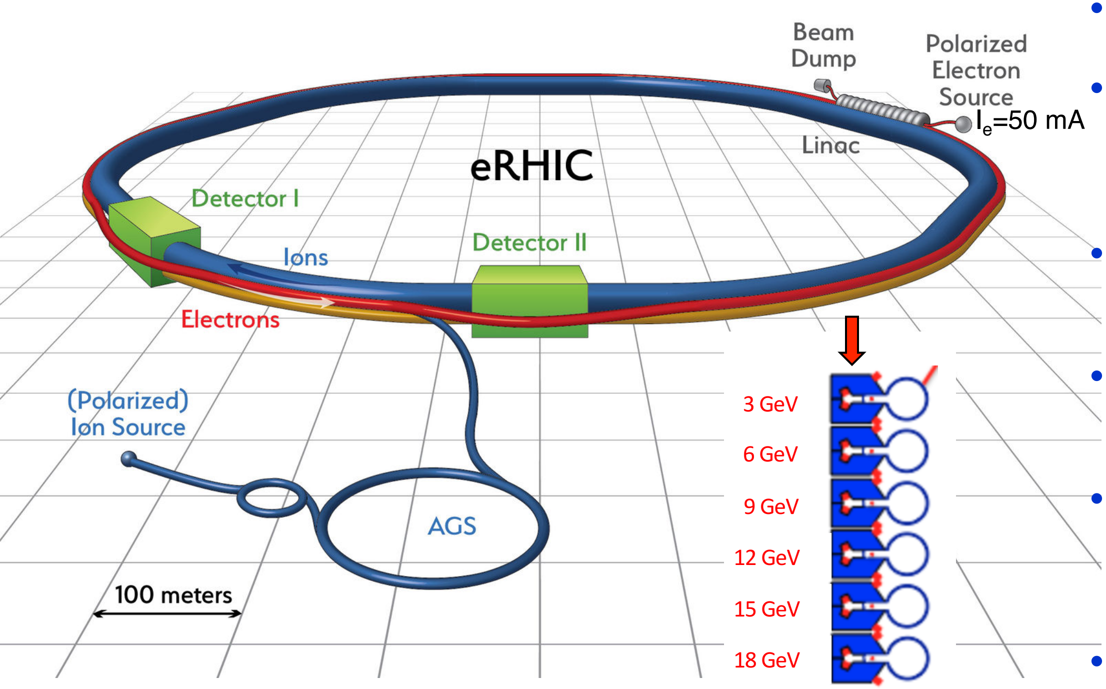
eRHIC: polarized electrons with $E_e \le 30$ GeV will collide with either polarized protons with $E_e \le 250^*$ GeV or heavy ions $E_A \le 100^*$ GeV/u



Small gap magnets
5 mm gap
0.43 T @ 30 GeV

Lower cost ERL-Ring Design Features

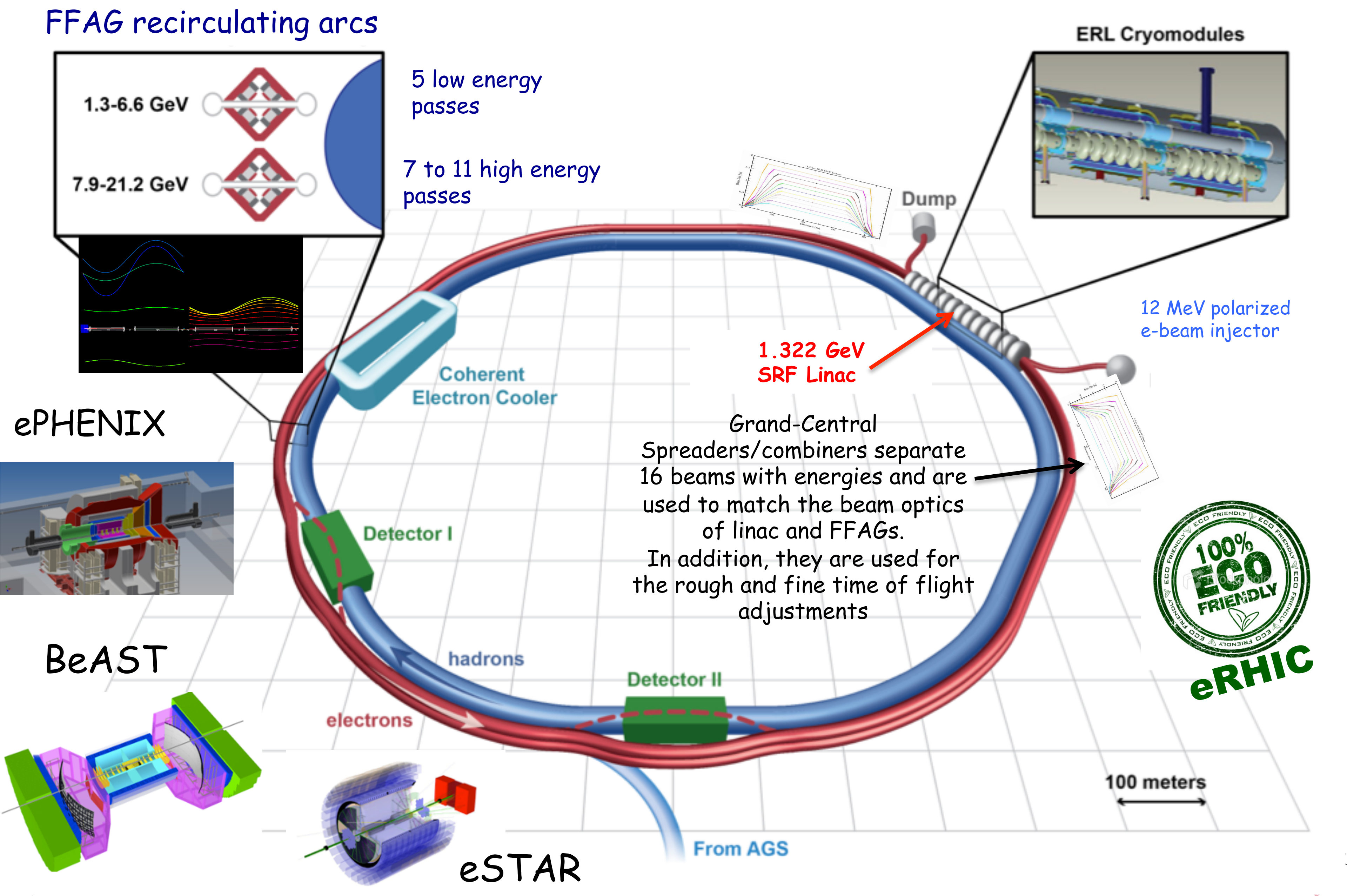
- Based on re-circulaitng electron linac (12 GeV CEBAF) and high current Energy-recovery linac technologies.
- Beyond present state-of-the-art: 50 mA polarized electron source and high-energy high-power ERL.
- Single collision of each electron bunch. No limit of electron beam-beam effect on luminosity.
- Small electron beam emittance.



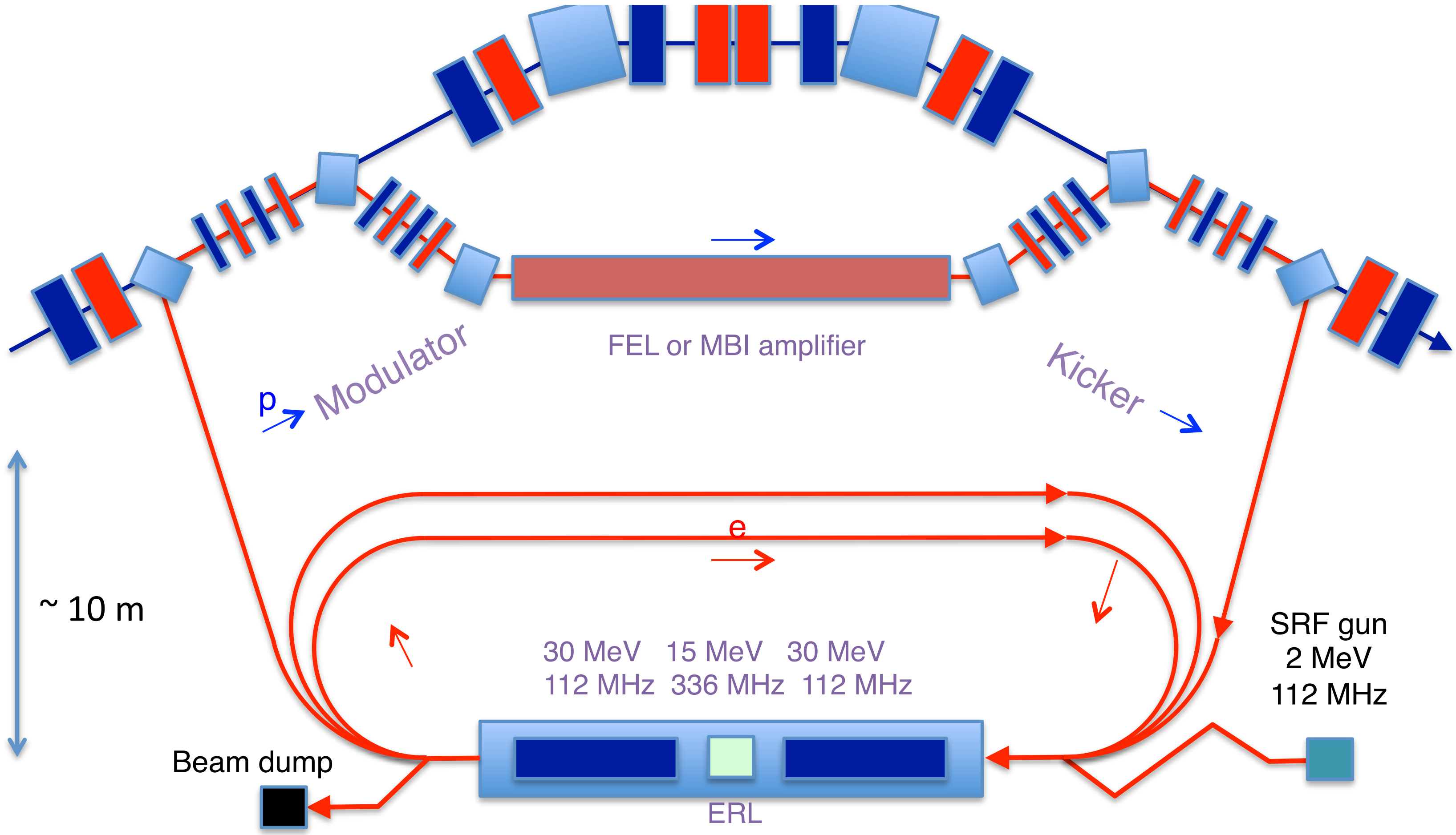
- Maximum electron energy: 18 GeV
- 50 mA polarized electron source employing merging electron current produced by multiple electron guns
- Main ERL SRF linac(s): 647 MHz cavities, 3 GeV/turn
- Six individual re-circulation beamlines based on electromagnets
- For very high luminosity (~10^{34} cm^{-2} s^{-1}) with hadron cooling system (CeC)
- Interaction region design with crab-crossing satisfying detector acceptance requirements

From V. Ptitsyn talk

eRHIC circa 2015 with 15.8/21.16 GeV FFAG ERL



ERL will be needed for a real eRHIC Coherent Electron Cooler

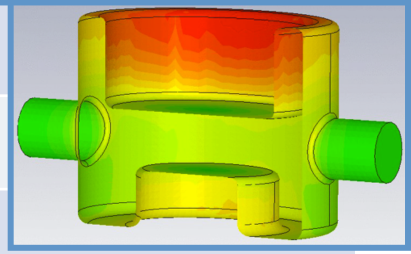


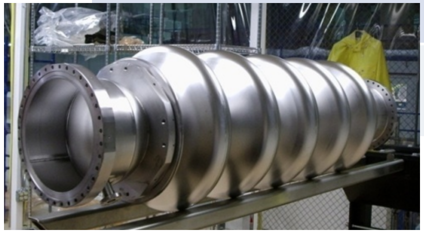
Center for Accelerator Science and Education

Accelerator R&D for eRHIC

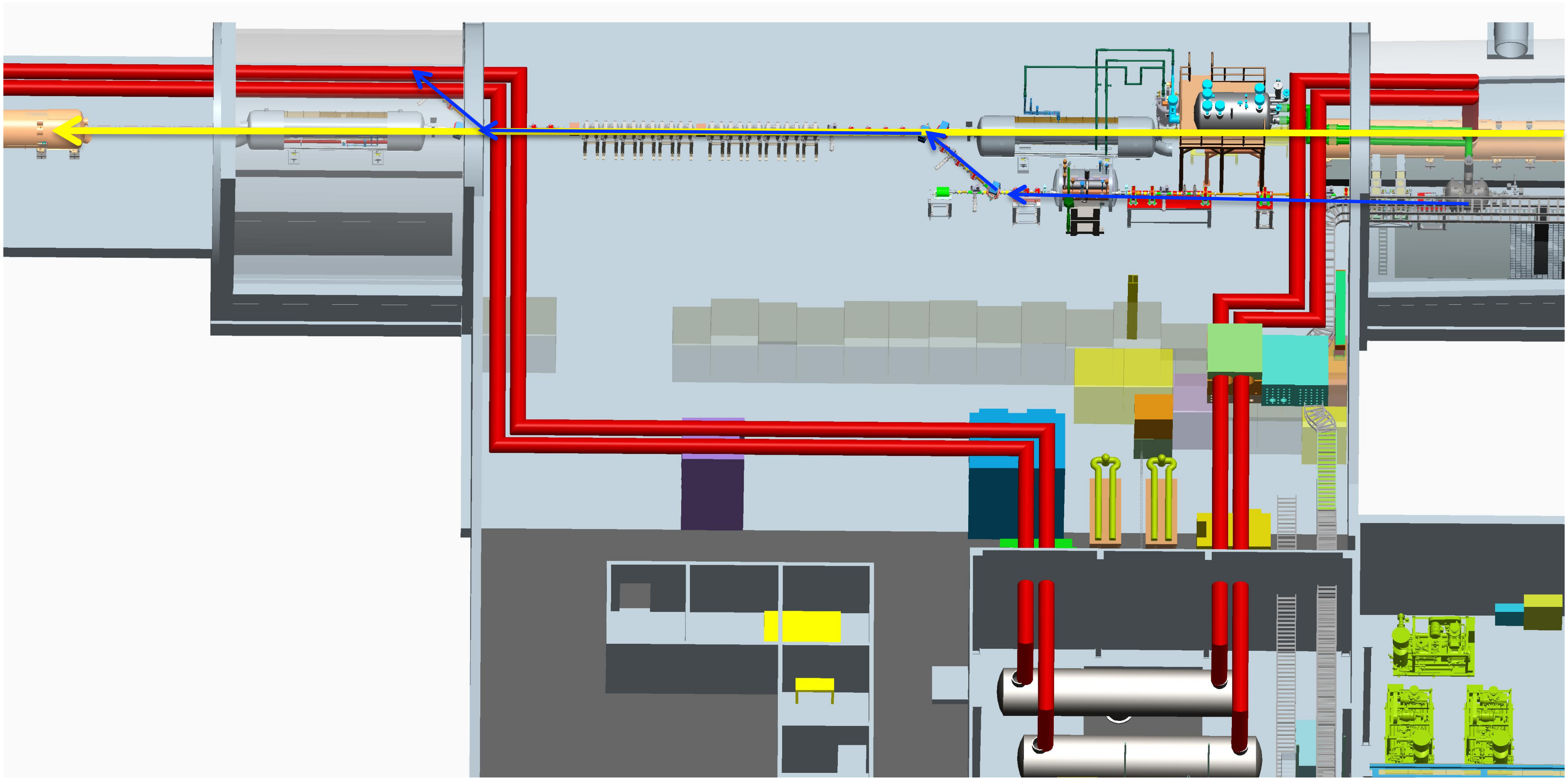
Polarized electron gun
Coherent Electron Cooling
Multi-pass SRF ERL
Crab crossing
Polarized ^{3}He production
Linac-ring beam-beam affects
β^*=5 cm
FFAG arcs with splitters/combiners
HOM damped SRF cavities

QWR crab-cavity design (BNL





Coherent electron Cooling (CeC) Demonstration Experiment



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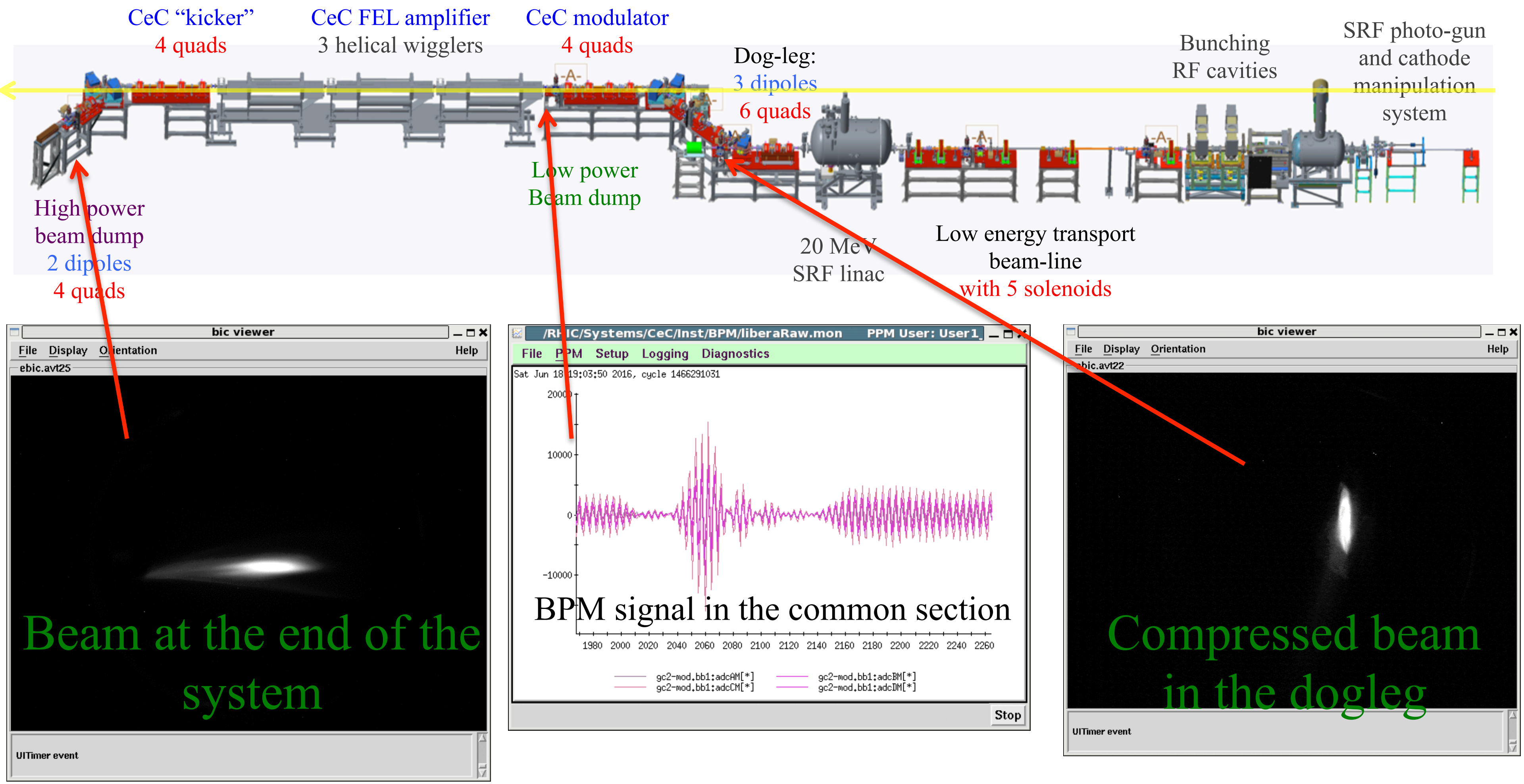
Stony Brook University

Main highlights

- CeC SRF accelerator is commissioned and will be used for demonstration of coherent electron cooling during RHIC run 18
- 113 MHz SRF gun with room-temperature CsK_2Sb cathodes demonstrated excellent performance
  - CsK_2Sb cathodes survived for months of operation (and exhibit QE improvement during operation)
  - Beam with up to 4 nC chrage per bunch were demonstrated
  - Projected normalized emittance of 0.32 mm mrad was demonstrated for 0.5 nC bunches
- World's fist 2K cryostat with superfluid heat exchanger for 5-cell 704 MHz demonstrated excellent performance and good microphonics isolation (Δf~10 Hz p-to-p)

The CeC system commissioning

Common section with RHIC



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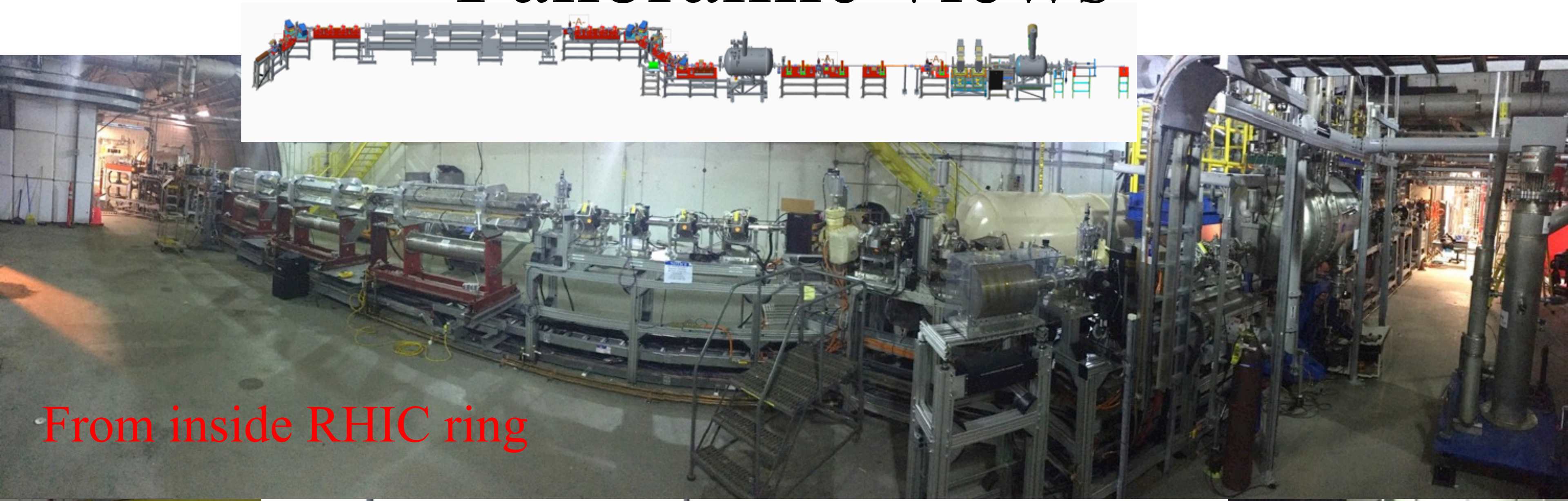
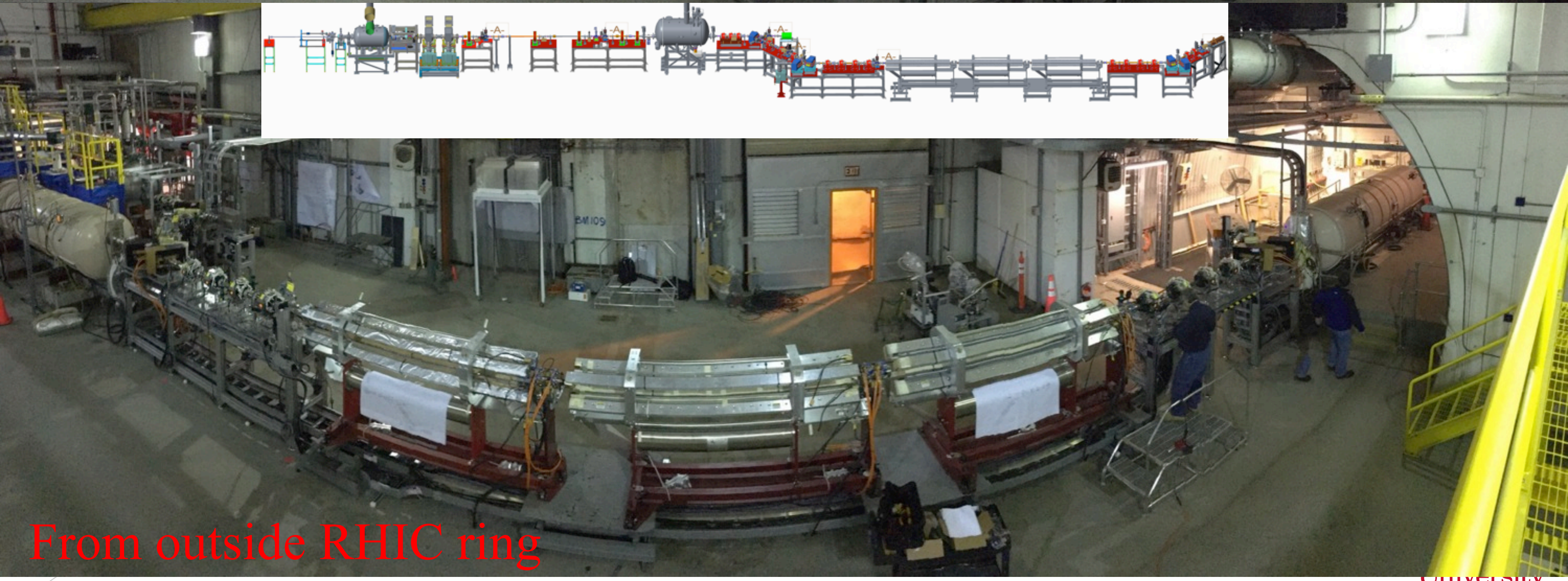
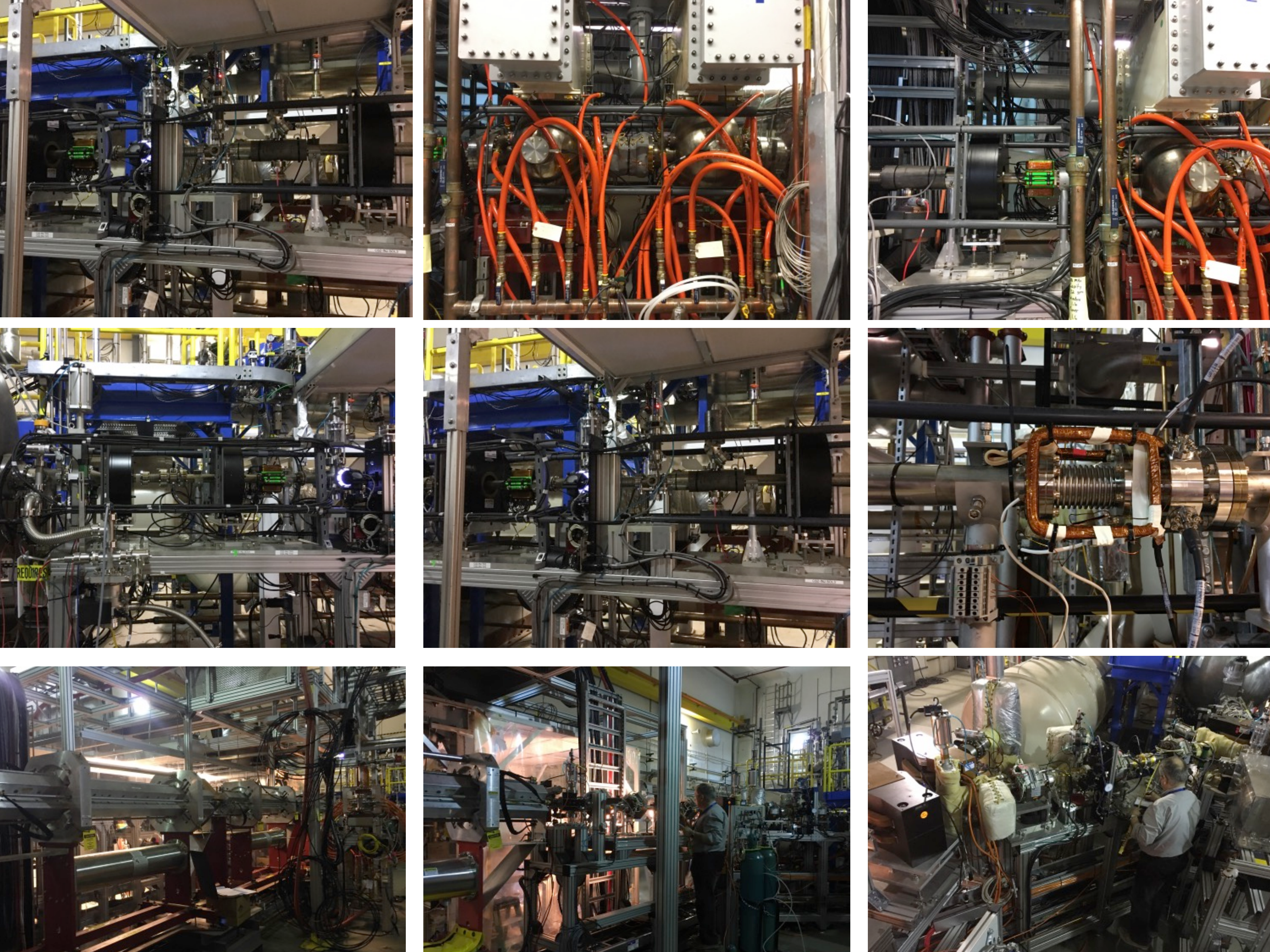
Panoramic views



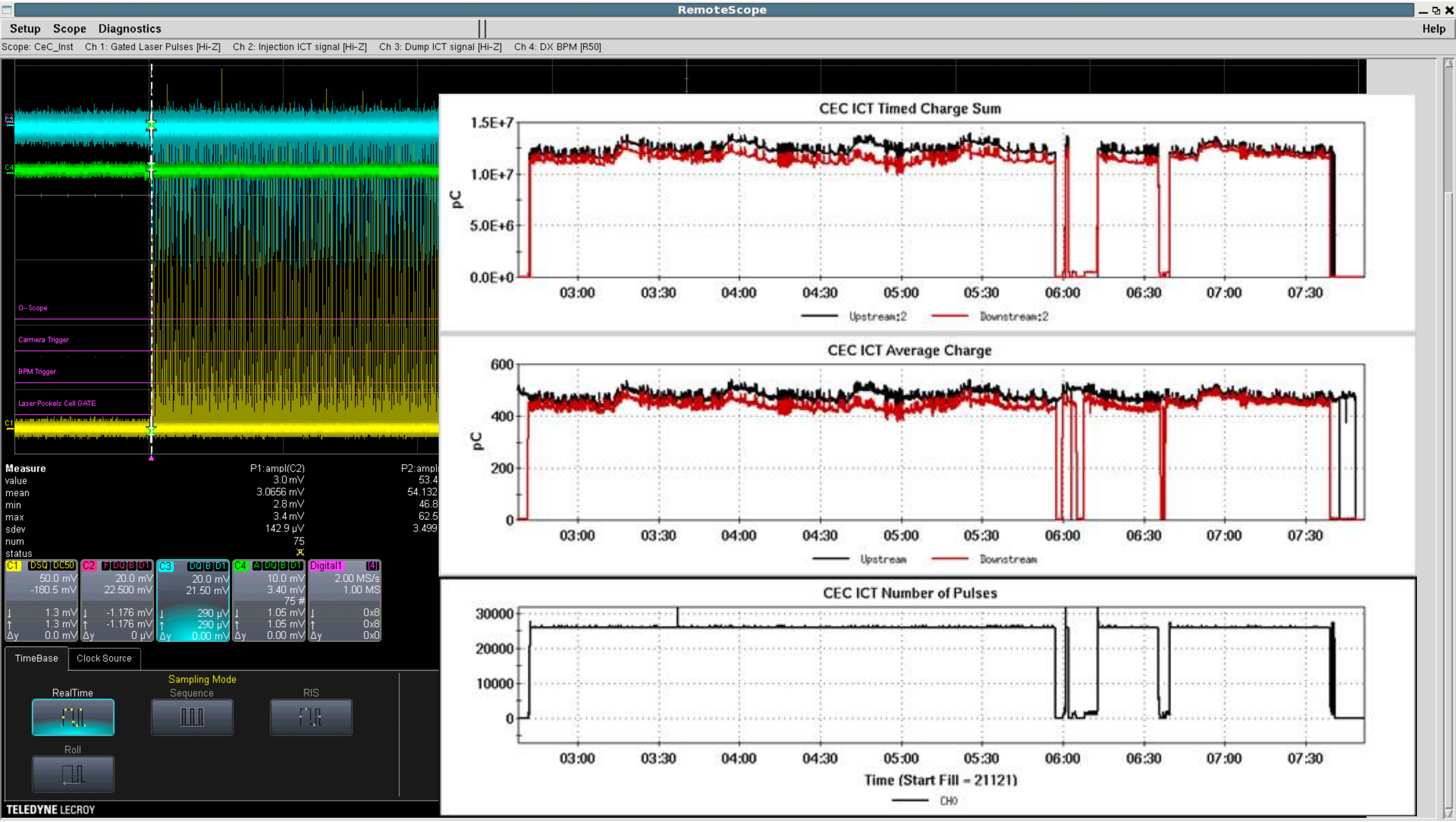
From inside RHIC ring



From outside RHIC ring


REQUIRES

Operating in CW mode



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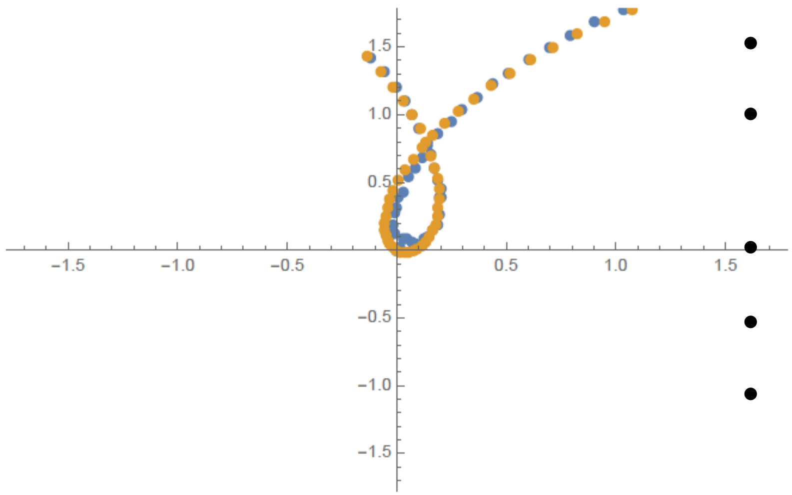
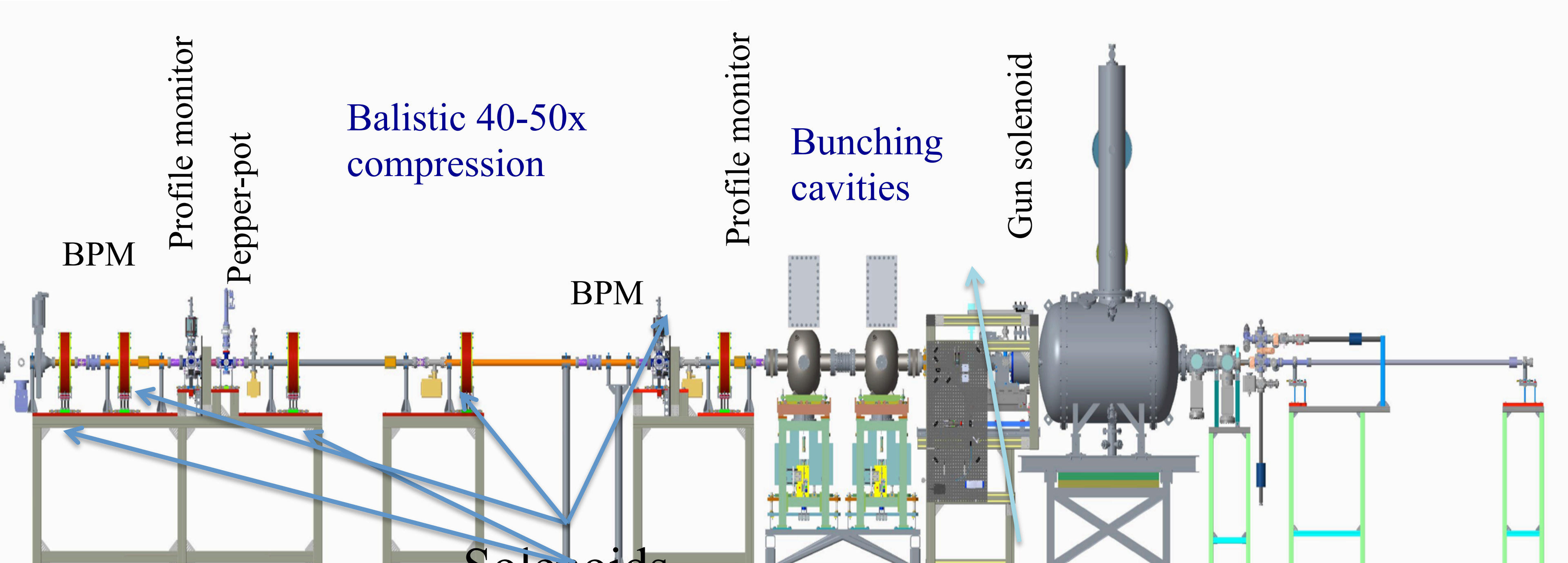
Low Energy Beam Line

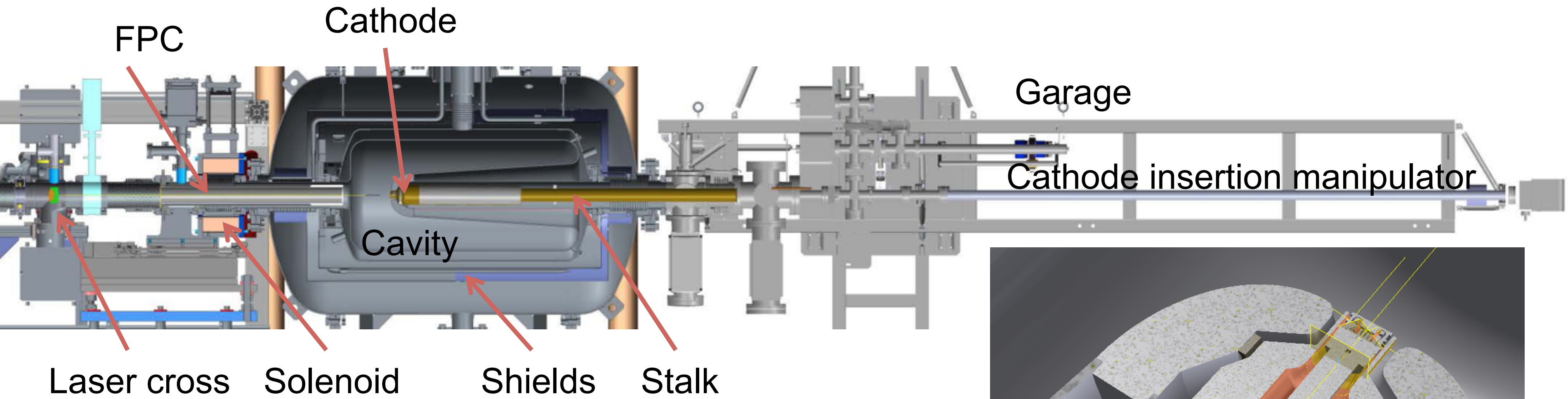


Blue measurements, yellow – solution

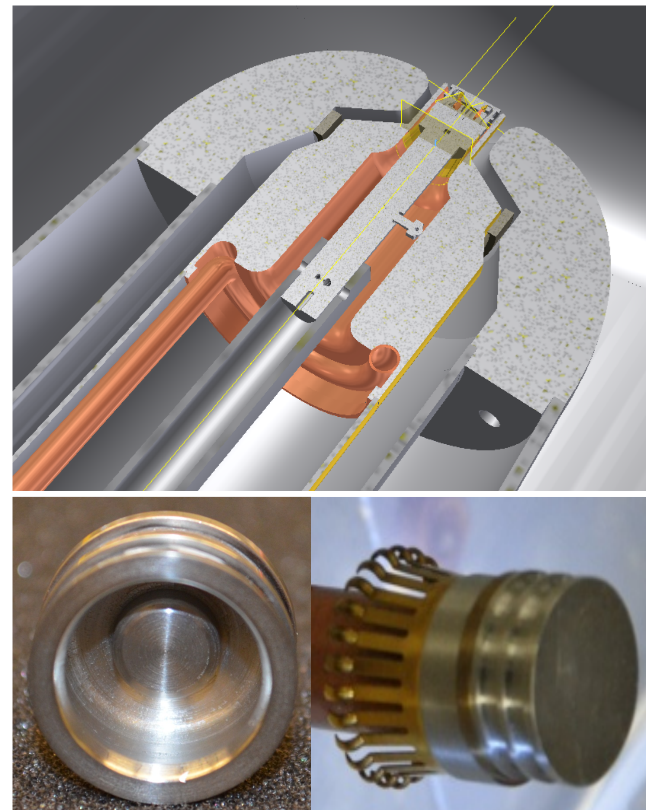
- Integrating current transformer (1.25 nV s/nC)
- Two beam profile monitors with 1.3 megapixel cameras
- Pepper-pot in front of the second profile monitor
- Two BPMs
- We successfully used solenoids BBA which uniquely define both beam position and angles at each solenoid entrance



CeC SRF Gun with CsK_2Sb photocathode



- Quarter-wave cavity
- 113 MHz operating frequency
- 4 K operating temperature
- Manual coarse tuner
- Fine tuning is performed with fundamental power coupler (FPC)
- 4 kW CW solid state power amplifier
- CsK_2Sb Cathode is at room temperature
- Cavity field pick-up is done with cathode stalk (1/2 wavelength with capacitive pick-up)
- Up to three cathodes can be stored in garage for quick change-out



Photocathode end assembly

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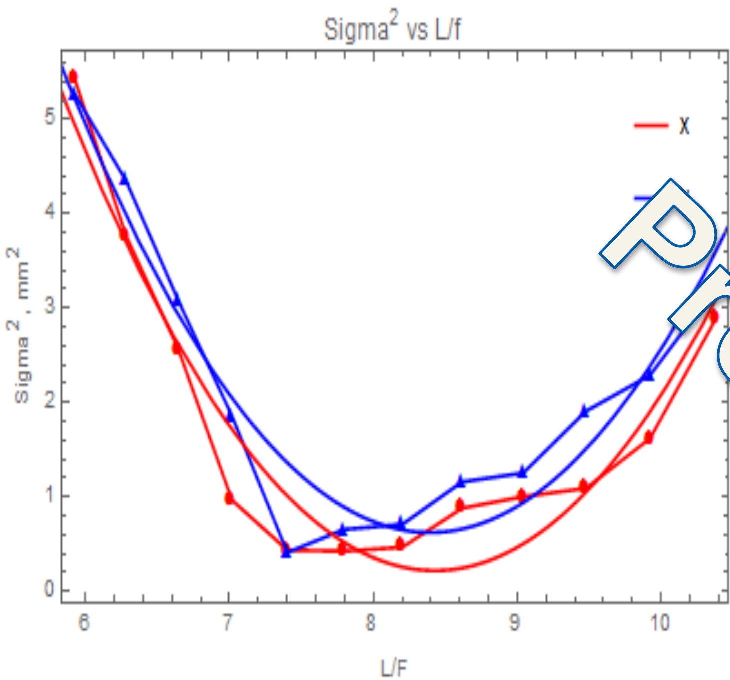
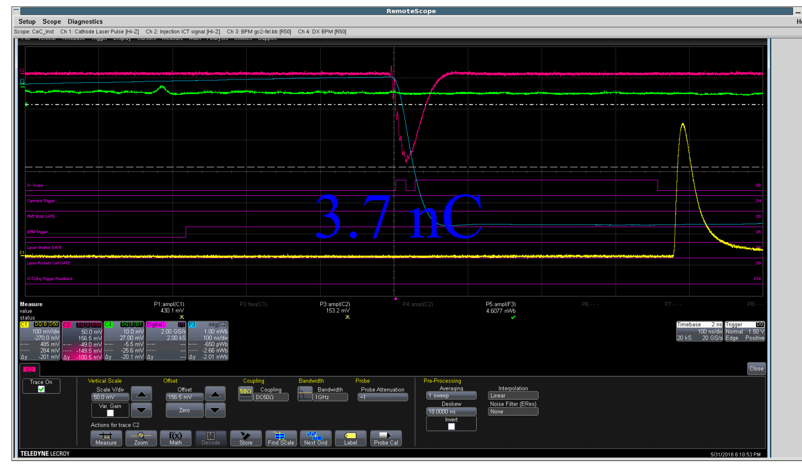
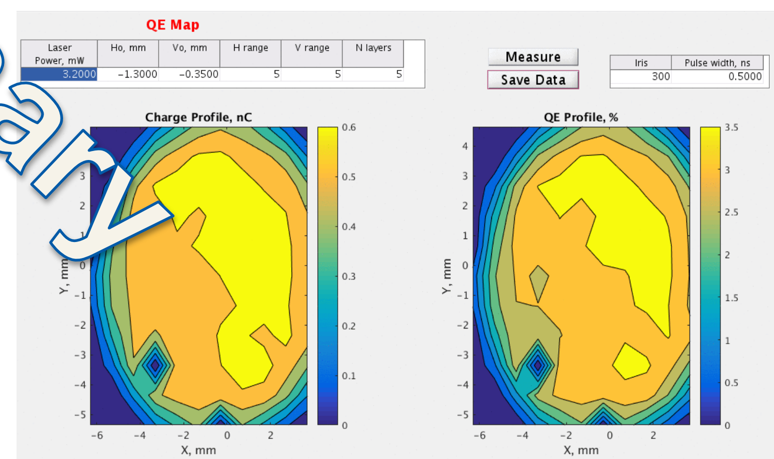
Record performing 113 MHz SRF photo-electron gun:
now cathodes keep high QE for months



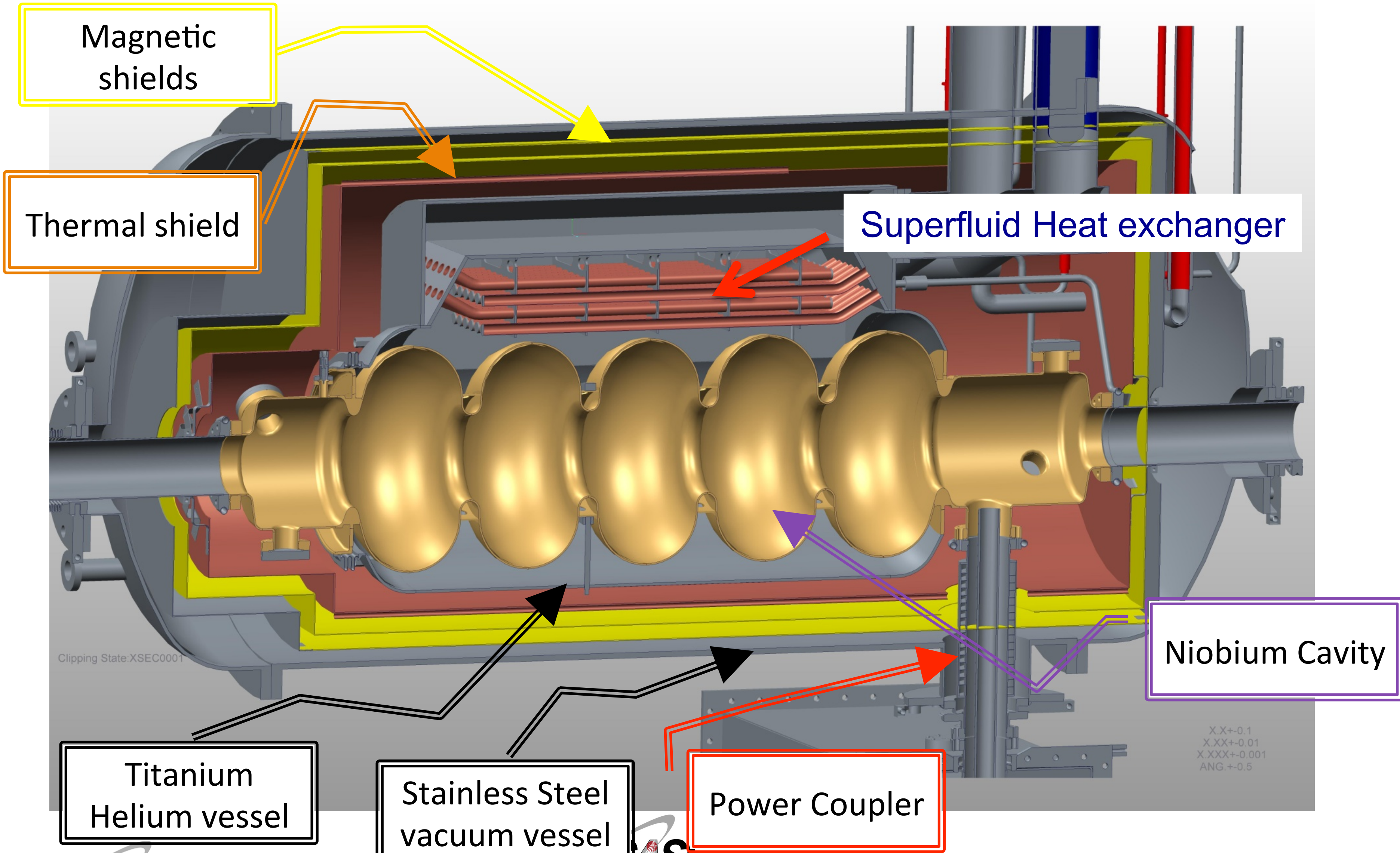
Best result so far:
Gun Solenoid and YAG1 profile monitor
0.32 mm mrad normalized emittance at
0.5 nC/bunch





Preliminary

704 MHz 5-cell linac cryostat with superfluid heat exchanger: microphonics < 10 Hz p-to-p



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Current parameters CeC Experiment

Parameter	Value	Status
Species in RHIC	Au^{+79} ions, 40 GeV/u	✔
Particles/bucket	10^8 - 10^9	✔
Electron energy	21.95 MeV	✔ **15 MeV***
Charge per e-bunch	0.5-5 nC	✔ (0.1- 4 nC)
Pulse duration, psec	10-50	12 at 0.5 nC
Rep-rate	78.17 kHz	26 kHz**
e-beam current	Up to 400 μA	40 μA
Electron beam power	< 10 kW	600 W

***Will be changed to 78 kHz after retuning the gun frequency*

Beam parameters are sufficient for the CeC demonstration experiment

It take the village… the CeC team – never can get all your pictures

…

……

Stony Brook University

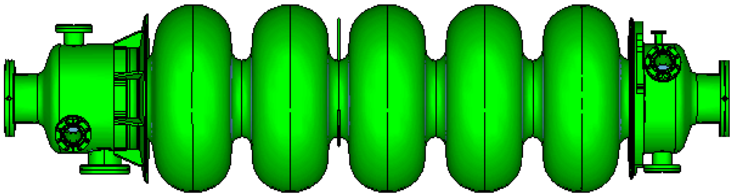
Next steps

- SRF CeC accelerator system will be used for demonstration experiment during RHIC run 18
- We are considering various scenarios of "post-CeC-demonstration" for SRF CeC accelerator
  - We definitely plan to explore unique SRF photo-emission gun and bring it to "perfection"
  - One of the option includes turning it into an ERL using arc hardware from BNL

Dedicated (LDRD) SRF cavities development for eRHIC ERLs

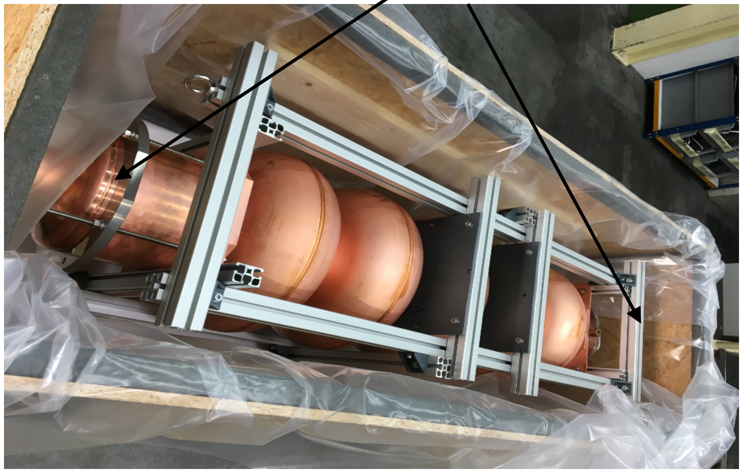
- The Cavity was designed for good HOM damping capability, with enlarged beam pipe to propagate HOMs but attenuate the fundamental mode.
- The cavity has to be tuned up to 173 kHz to match different collision proton energy (40-250 GeV), which mechanical tuning length is 2.2 mm.
- Two 650 MHz cavities are fabricated by RI: one Nb cavity for cavity's performance study (goal: Q0=3e10@18 MV/m), and one Cu cavity with demountable end-group for HOM measurement.

Nb cavity (expect to complete in early July)



Parameters	5-cell
Frequency [MHz]	647
Geometry factor [Ω]	273
(R/Q)/Cavity [Ω]	502
Epeak/Eacc	2.27
Bpeak/Eacc [mT/MV/m]	4.42
Coupling factor [%]	2.8
Cavity length [m]	1.72
Loss factor @ rms 3mm [V/pC]	2.6

Detachable end-group for HOM damper study



Cu cavity delivered to mid June

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Courtesy of W. Xu

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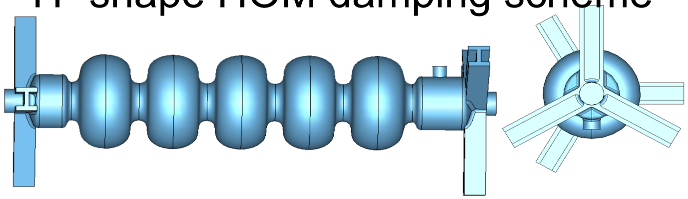
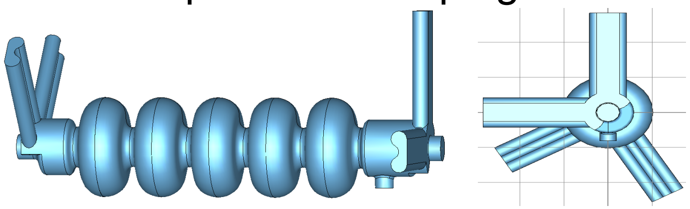
High power HOM damping for ERL-SRF linac

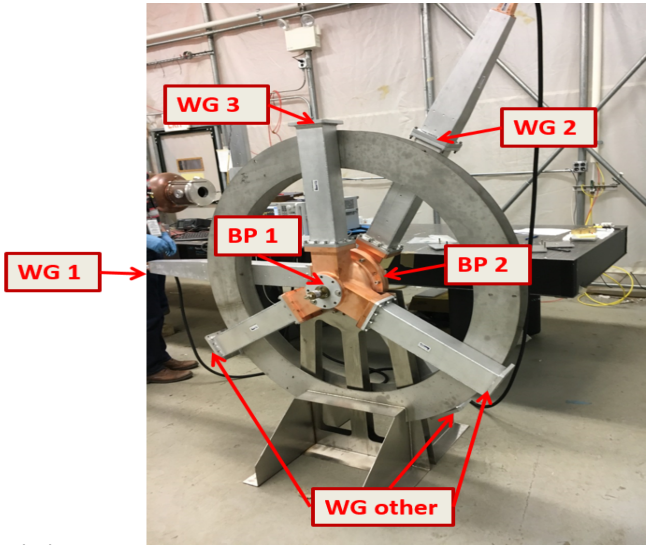
- The average HOM power is 8 kW per cavity, and it can be up to 10s kW when HOM spectrum is overlapped with beam spectrum.
- Tremendous HOM damper optimization was carried out based on ridge waveguide HOM damper.
  - ✓ A ridge waveguide has all the pros properties of a regular/rectangular waveguide, such as natural high pass filter, capability of high power transmission, broadband.
  - ✓ Except for that, a ridge WG has following benefits: i) wider bandwidth, ii)smaller size (1/4) than regular WG, iii) lower conduction heat load and easier to cool.
- We converged to two versions of the HOM damping schemes: 1) 6 dual ridge (H-shape) waveguides per cavity 2) 4 round ridge (B-shape) waveguide per cavity (*favor!*).
  - ✓ B-shape damper has around 4 times lower HOM power than the H-shape damper
  - ✓ BBU threshold of the B-shape HOM damper is 50% higher than the H-shape HOM damper.
- Parts of the prototype have been built to be measured with Cu cavity on our 3-D bead pull test stand.

H- shape HOM damping scheme



B- shape HOM damping scheme





Courtesy of W. Xu

Conclusions

- At BNL we competed developing two ERL-based designs for eRHIC, one with regular magnetic arcs and second with FFAG arcs
- We identified main challenges for these machines and aggressively pursuing (wiht help from our friends) retiring them one by one: CeC, polarized electron gun, ERL with FFAG arcs (C-Beta)…
- The most advanced stage is reached by the innovative CeC SRF accelerator and gun, built for demonstrating coherent electron cooling
- We continue research on HOM-damped SRF cavities for high current multi-pass ERLs
- Theoretical and numerical ERL studies continue at Center for Accelerator Science and Education (SBU/BNL)
- While being developed for eRHIC, many of innovations (such as high brightness SRF photo-emission gun) will find application far beyond use for eRHIC

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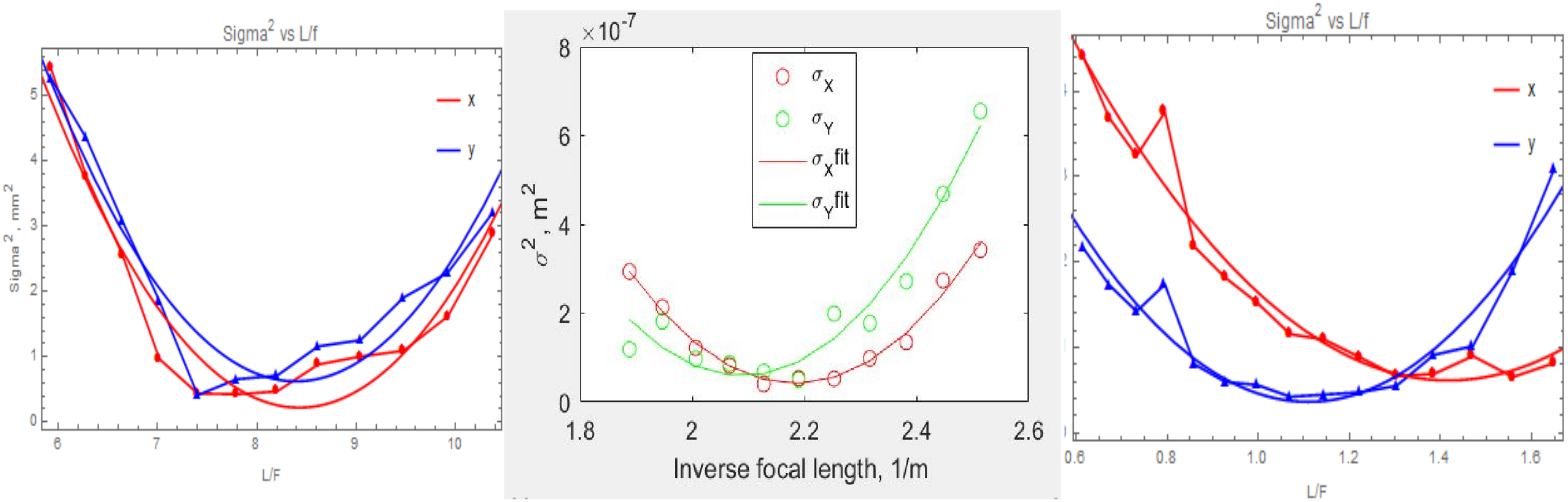
Back-up

Beam Kinetic Energy	Charge per Bunch
1.05 MeV	0.5 nC

- # Solenoid-Scan Results



(a) (b) (c)

Fig: Results of Three Emittance Measurements Performed Using Three Different Solenoid's Scans: (a) the Gun Solenoid and YAG1 Profile Monitor; (b) the LEBT1 Solenoid and YAG1 Profile Monitor; (c) LEBT3 Solenoid and YAG2 Profile Monitor (a), (b), (c) gave 0.32, 0.94, 0.54 mm mrad normalized emittance

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Potential CeC effect on eRHIC/EIC design

- **Short term:** If CeC is successful and is fully operational, eRHIC linac-ring would reach 2×10^{33} luminosity with 5 mA polarized electron current.

- It removes main uncertainties in LR eRHIC design
- 50 mA, 5 nC of polarized e-beam -> 5 mA, 0.5 nC/bunch
  - 100x lower HOM power
  - 10x lower TBBU threshold
  - 3x shorter hadron bunches
  - 3x higher frequency of crab cavities -> 1/3 of the voltage
  - Up to 3x smaller β^*
  - 10x lower SR losses
  - 10x lower SR back-ground
- and many positive effects for EIC detector

- **Final goal: eRHIC/EIC with 2×10^{34} luminosity**