State University of New York at Stony Brook
PHY554: Fundamentals of Accelerator Physics

SRF System for Coherent electron Cooling

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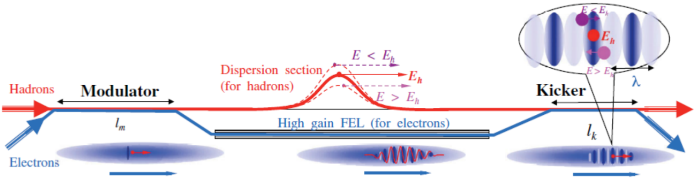
Content

Cooling:

reduces beam phase space volume, emittance and momentum spread in order to improve beam quality.

How does it work:

- In the modulator, each hadron induces density modulations in electron beam;
- Density modulation is amplified in the high-gain FEL;
- In the kicker, hadrons interact with the self-induced electric field of the electron beam and receive energy kicks toward their central energy;
- The process reduces the hadron's energy spread, i.e. cools the hadron beam.



V.N. Litvinenko et.al., Coherent Electron Cooling Demonstration Experiment

Goal:

demonstration of longitudinal (energy spread) cooling of a single bunch of 40 GeV/u Au ions in RHIC

In order for the CeC to work, it is requered for the electron and hadron beams to have the same velocity:

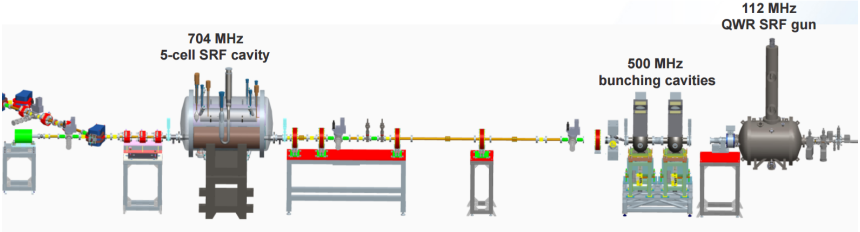
$$\gamma_e = \gamma_h = \frac{1}{\sqrt{1-(v/c)^2}}$$

$$E_e = \gamma_h \cdot m_e c^2 \approx 22 \text{ MeV}$$

Introduction
SRF system layout

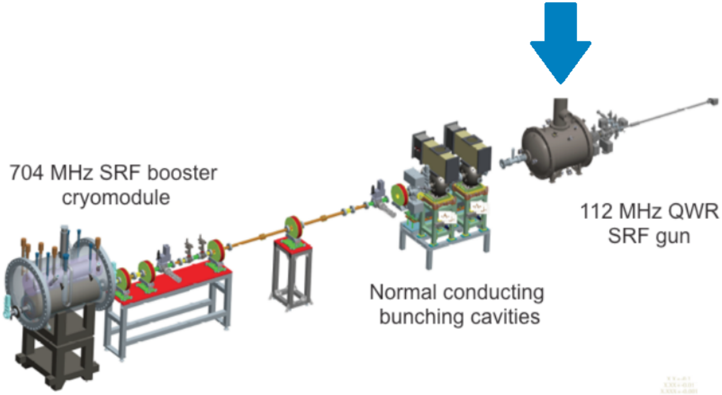
From right to left:

- The SRF gun operating at 112 MHz will generate 2 MeV high-charge (several nC), low repetition rate (78 kHz) electron beam;
- Two single cell normal conducting bunching cavities operating at 500 MHz frequency will provide required energy chirp in the beam creating velocity difference along the bunch;
- The 704 MHz 5-cell SRF cavity (BNL3) is used to achieve desired energy of 22 MeV.



S. Belomestnykh et.al., SRF and RF systems for CeC PoP experiment

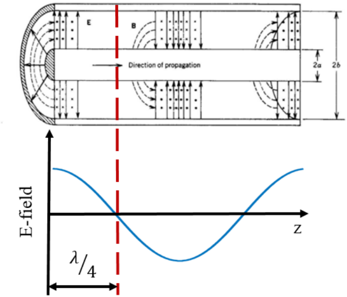
112 MHz QWR SRF Gun

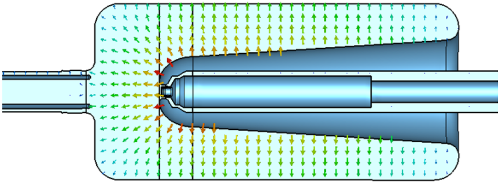


S. Belomestnykh et.al., SRF and RF systems for CeC PoP experiment

112 MHz QWR SRF Gun

Quarter Wave Resonator (QWR)





Frequency was chosen to be 112 MHz because:

- It is a harmonic of RHIC 28 MHz RF system;
- Low frequency $\Rightarrow$ long bunches $\Rightarrow$ reduced space charge effect;
- Short accelerating gap $\Rightarrow$ almost constant field;

Table: Parameters of the SRF Gun

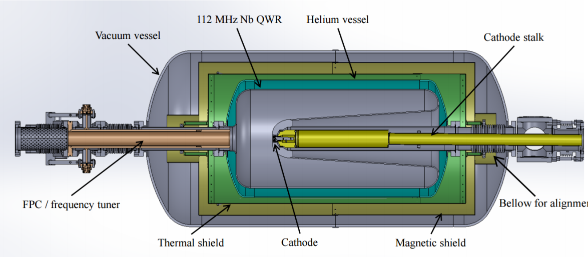
Frequency	112 MHz
Geometry factor	38.2 Ohm
R/Q	126 Ohm
Quality factor w/o cathode	$3.5 \cdot 10^9$
Operating temperature	4.5 K
Accelerating voltage	1.5 to 2.0 MV

Reminder:

Quality factor: $Q_0 = \frac{\omega_0 U}{P_c}$

Geometry factor: $G = \frac{\omega_0 \mu_0 \int_v |\vec{H}_0|^2 dV}{\oint_v |\vec{H}_0|^2 dA}$

Shunt Impedance: $R = \frac{V_{rf}^2}{P_{loss}}$

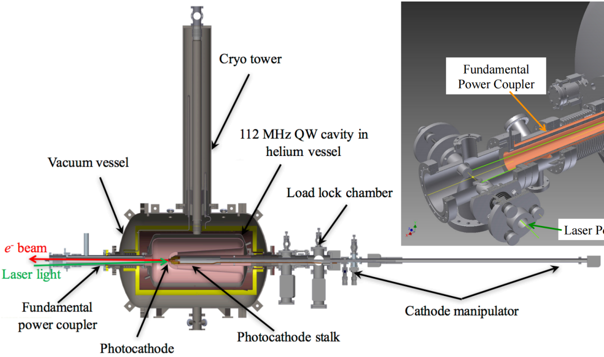


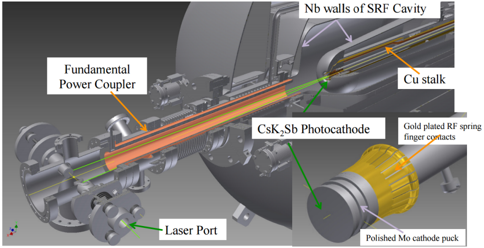
J.C. Brutus et.al., Mechanical Design of 112 Mhz SRF Gun FPC for CeC PoP

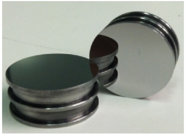
112 MHz QWR SRF Gun

Gun Setup

- Fundamental RF power coupling and fine frequency tuning is accomplished via a coaxial beam pipe at the beam exit port;
- With the travel of ±2 cm, the tuning range will be ∼ 4 kHz;



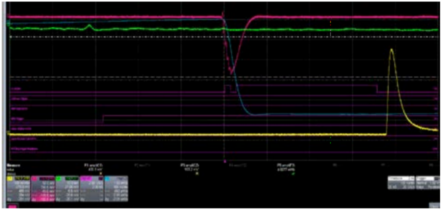




S. Belomestnykh et.al., Commissioning of the 112 MHz SRF Gun

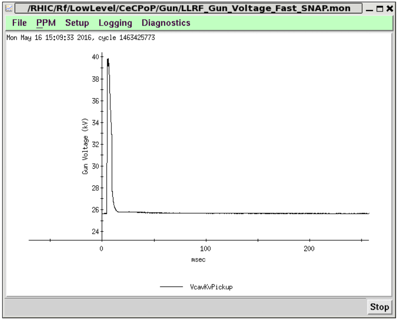
- A small cathode puck is inserted inside the stalk and can be replaced when necessary with a new one.

112 MHz QWR SRF Gun
Gun Performance



I. Pinayev et.al.,Commissioning of the CeC PoP

- 3.7 nC beam charge was observed during the commissioning;
- achieved cavity voltage was 1.2 MV;
- duration of the laser pulse was 1 ns.

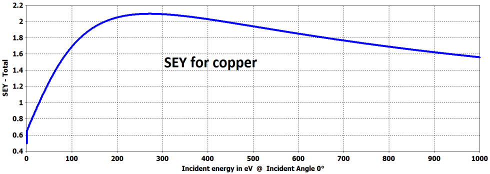


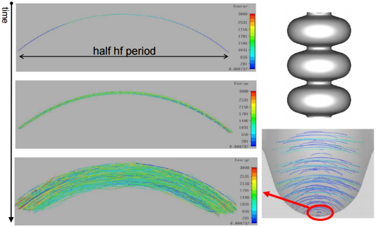
CeC Run'16 eLog

When turning on the RF power strong multipacting was observed, which substantially reduced quantum efficiency of the cathode.

Multipactor discharge (multipacting) is a resonant process in which an electron avalanche builds up within a small region of the cavity surface and is determined by the following factors:

- Electric field levels;
- Geometry of the cavity;
- material properties — Secondary Emission Yield (SEY).





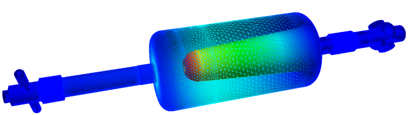
CST PS Manual

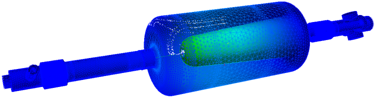
An electron avalanche absorbs large amounts of RF power and deposits it as a heat ⇒ lower quality factor.

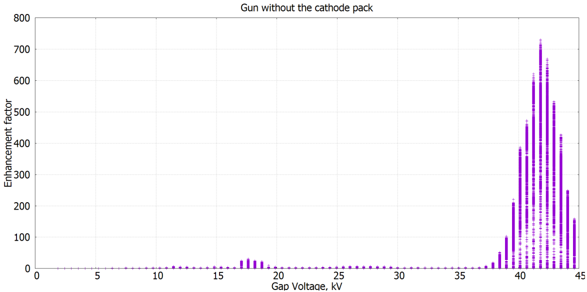
112 MHz QWR SRF Gun

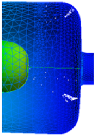
Multipacting Simulations

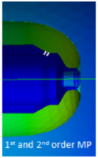
Calculate EM fields → Define emitting surface → Define SEY → Analyse EF and Trajectories









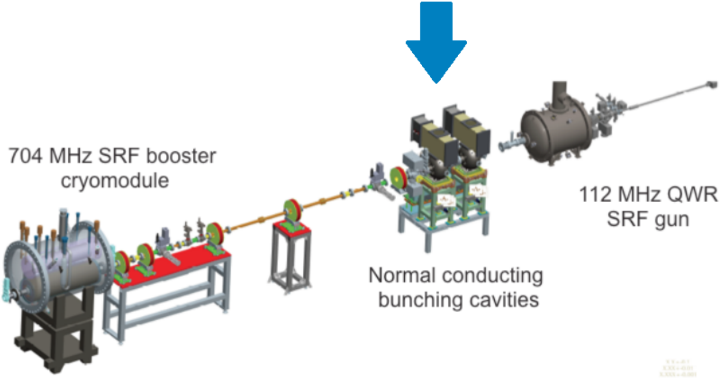


112 MHz QWR SRF Gun

What is next?

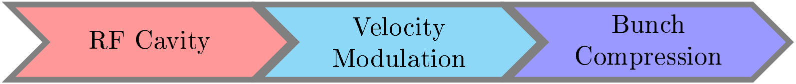
- Perform multipacting simulations with all factors present during the experiment: cathode position, external magnetic field, etc.;
- Continue improvement of the emittance and achieve higher energy during Run 2017.

500 MHz bunching cavities

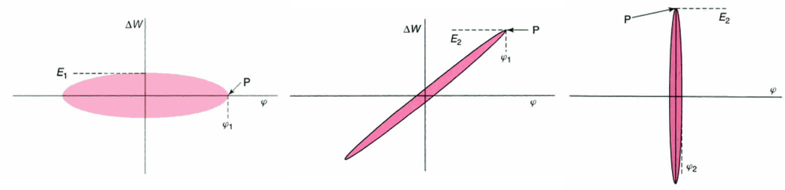


S. Belomestnykh et.al., SRF and RF systems for CeC PoP experiment

500 MHz bunching cavities
Bunching Cavities



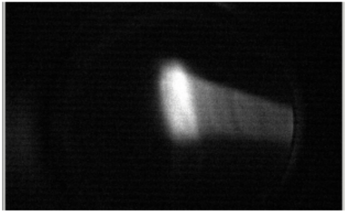
- The reference particle ($\varphi = 0, \Delta W = 0$) arrives at the center of a cavity when the voltage is rising in time and is zero $\Rightarrow$ zero average gain;
- The buncher cavity delivers a phase-dependent kick which changes an upright ellipse to a tilted one;
- After passing a proper drift space, the ellipse is rotated by 90° in phase space.



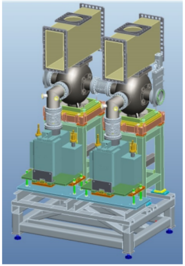
500 MHz bunching cavities
CeC Bunching Cavities

Table: Parameters of the 500 MHz bunching cavity

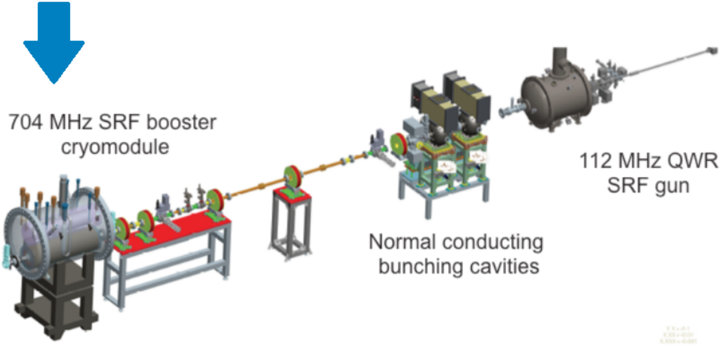
RF Frequency	500 MHz
Accelerating voltage	0.3 MV
R/Q	178.5 Ohm
Geometry Factor	38.2 Ohm
Quality Factor	31000



CeC Run'16 eLog



704 MHz accelerating cavity



S. Belomestnykh et.al., SRF and RF systems for CeC PoP experiment

704 MHz accelerating cavity
BNL3 Cavity

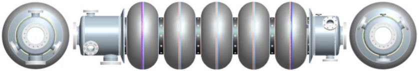


Table: Parameters of the BNL3 cavity

Parameter	Value
RF Frequency	704 MHz
Accelerating voltage	20 MV
R/Q	506.3 Ohm
Geometry Factor	283 Ohm
Quality Factor	$2 \cdot 10^{10}$
Operating Temperature	1.9 K

Performance

- Desired beam energy of 22 MeV was not achieved during the experiment due to the strong heat load on the cryogenic system accompanied by substantial radiation levels; Most likely the cavity was contaminated during installation.
- The fast piezoelectric tuner was damaged and stepper motor driven broke during operation.

Conclusion

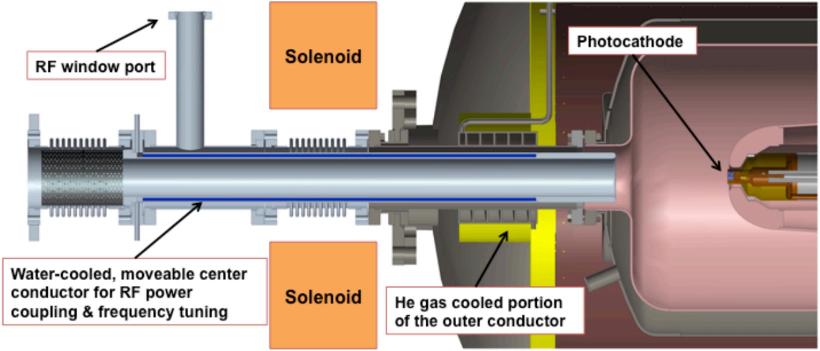
- The CeC PoP SRF system commissioning has started;
- It has been proven experimentally that SRF gun can operate with high efficiency CsK_2Sb photocathode and generate CW electron beam with record-high charge per bunch;
- Most systems of CeC PoP (instrumentation, SRF gun, 500 MHz cavities, magnets) operated without substantial problems;
- To be continued in 2017...

Thank you for your attention! Questions?

References

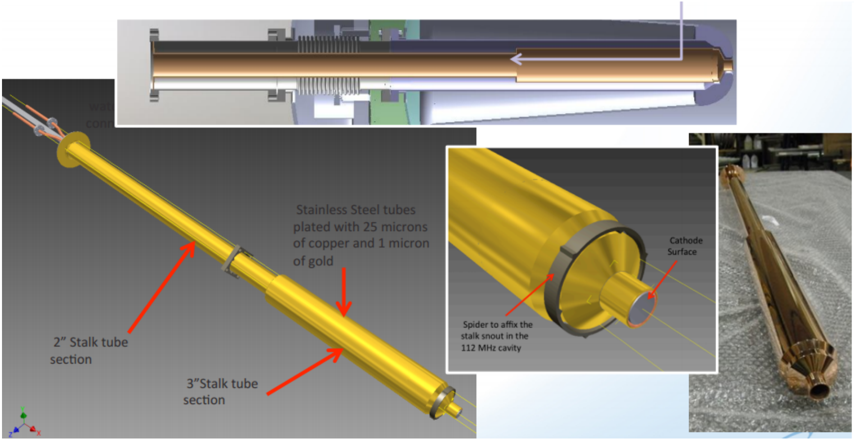
- Vladimir N. Litvinenko and Yaroslav S. Derbenev, *Coherent Electron Cooling*, Physicsl Review Letters, March 2009;
- V.N. Litvinenko et.al., *Coherent Electron Cooling Demonstration Experiment*, IPAC'11, San Sebastian, Spain, 2011;
- S. Belomestnykh et.al., *SRF and RF systems for CeC PoP experiment*, NA-PAC'13 Pasadena, CA, 2013;
- I. Pinayev et.al., *First results of the SRF gun test for CeC PoP*, IPAC'16, Busan, Korea, 2016;
- I. Pinayev et.al., *Commissioning of the CeC PoP accelerator*, NAPAC'16, Chicago, IL, 2016;
- S. Belomestnykh et.al., *Commissioning of the 112 MHz SRF gun*, SRF2015, Canada, 2015;
- I. Pinayev et.al., *Performance of CeC PoP Gun During Commissioning*, NAPAC'16, Chicago, IL, 2016;
- H. Padamsee, *RF Superconductivity*, 2009;
- T.P. Wangler, *RF Linear Accelerators*, 2008.

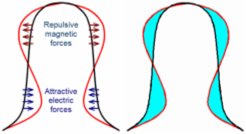
Back-up
FPC



RF window port
Solenoid
Photocathode
Water-cooled, moveable center conductor for RF power coupling & frequency tuning
Solenoid
He gas cooled portion of the outer conductor

Back-up
Stalk





$$P_{Rad} = \frac{1}{4}\left(\mu_0 H^2 - \varepsilon_0 E^2\right)$$