Commissioning of SRF gun at BNL

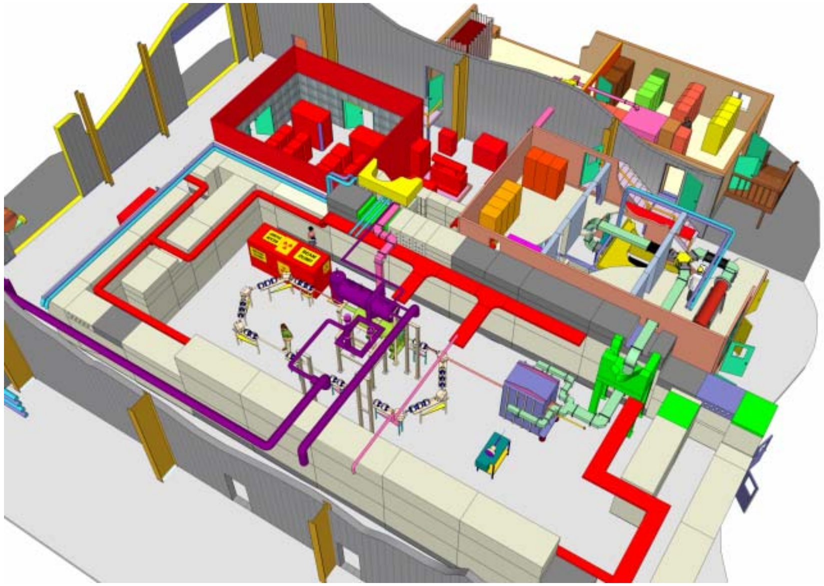
Wencan Xu & Sergey Belomestnykh

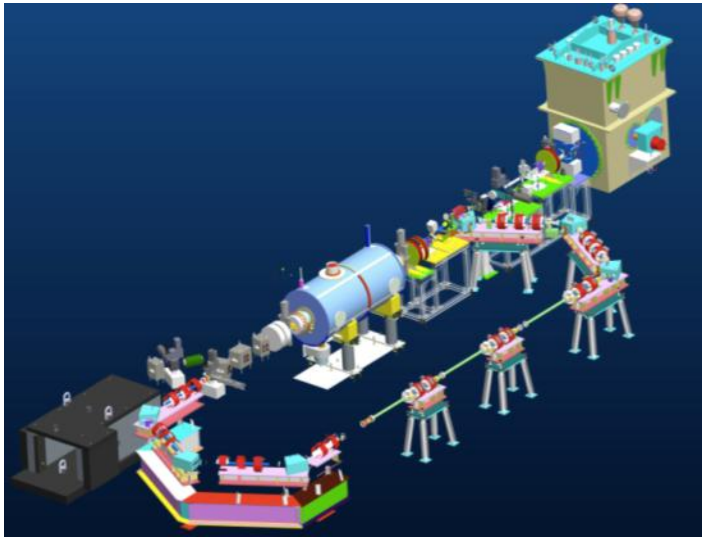
Collider-Accelerator Department, BNL

Outline

- Introduction of the R&D ERL
- SRF gun design
- SRF gun commissioning
- Summary

The R&D Energy Recovery Linac at BNL

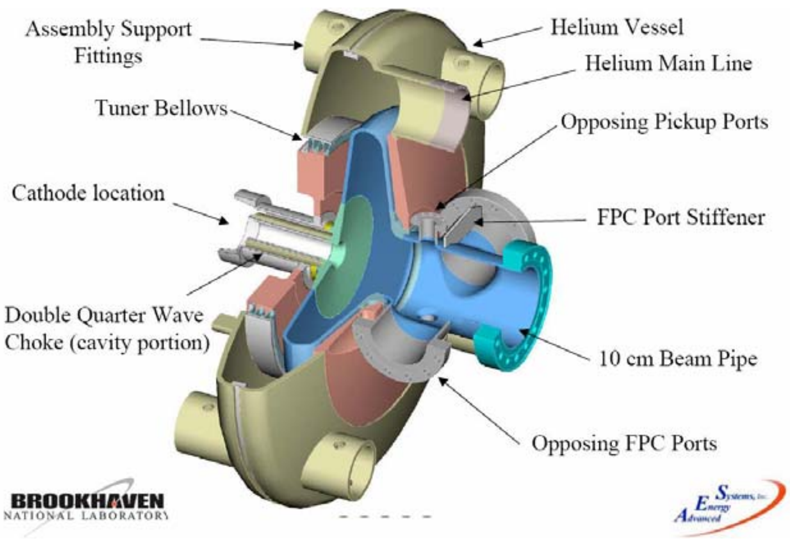




- The prototype ERL will demonstrate main parameters of the electron beam required for high energy electron cooling and for electron-ion colliers.
- We are at the stage of commissioning the SRF Gun.
- An injection merger is being installed to test the concept of emittance preservation in a beam merger.
- Then the recirculation loop will be completed to demonstrate energy recovery with high charge per bunch and high beam current.
- This facility will serve as a test-bed for new range of beam parameters whose application will extend well beyond the goals set forward by Collider Accelerator Department at BNL.

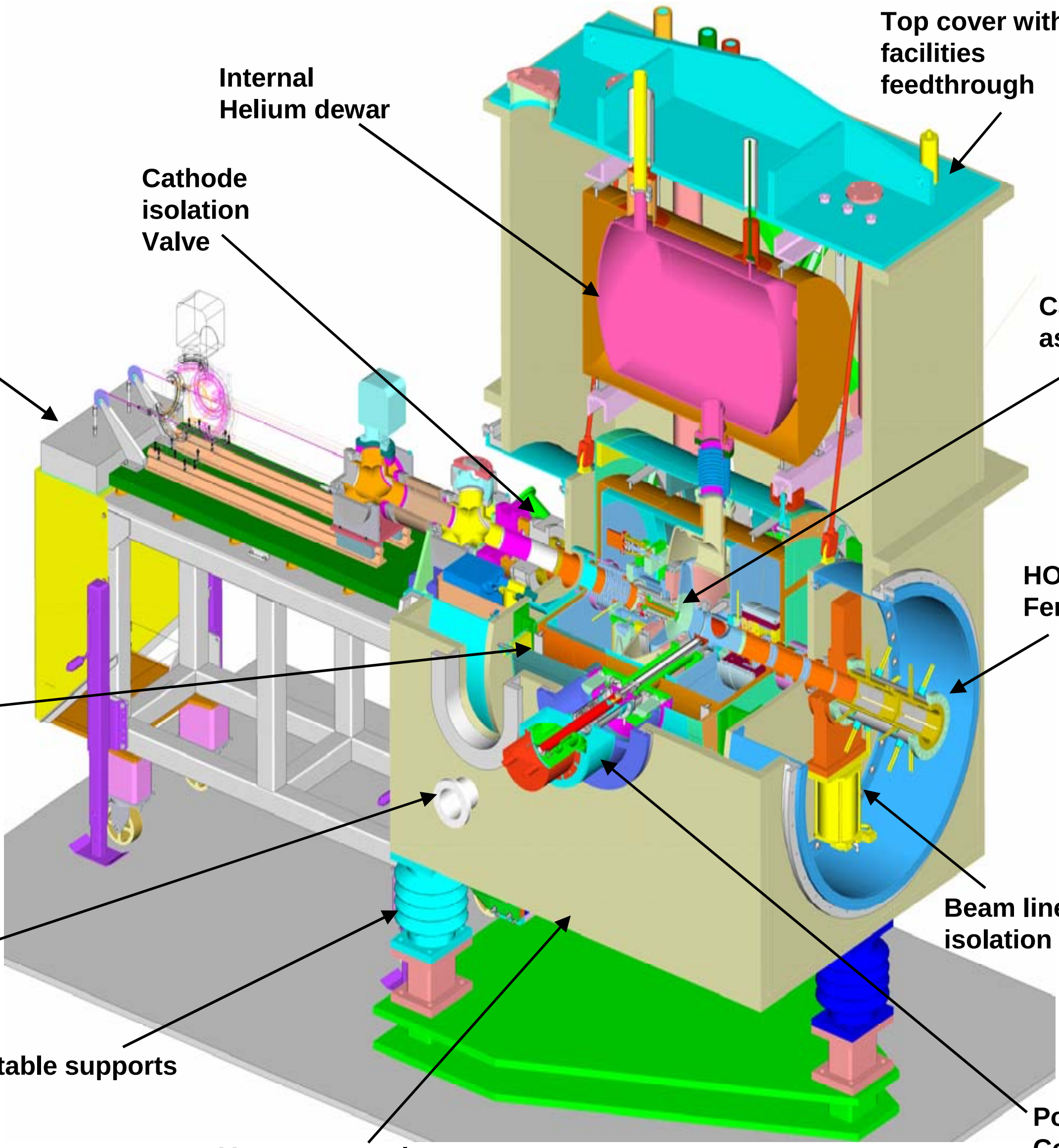
SRF gun

Parameter	Units	Value
Frequency	MHz	703.5
Beam kinetic energy	MeV	2
Peak electric field	MV/m	35.7
Peak magnetic field	A/m	58740 (73mT)
Stored energy	Joule	8.37
QRs (geometry factor)	Ohm	112.7
R/Q	Ohm	96.2
Qext		55000
Max. RF power	MW	1
Maximum current	mA	500
Emittance at 1.4 nC	μm rms normalized	1.4
Cathode spot size	mm diameter	5
Longitudinal loss factor	V/pC	0.7



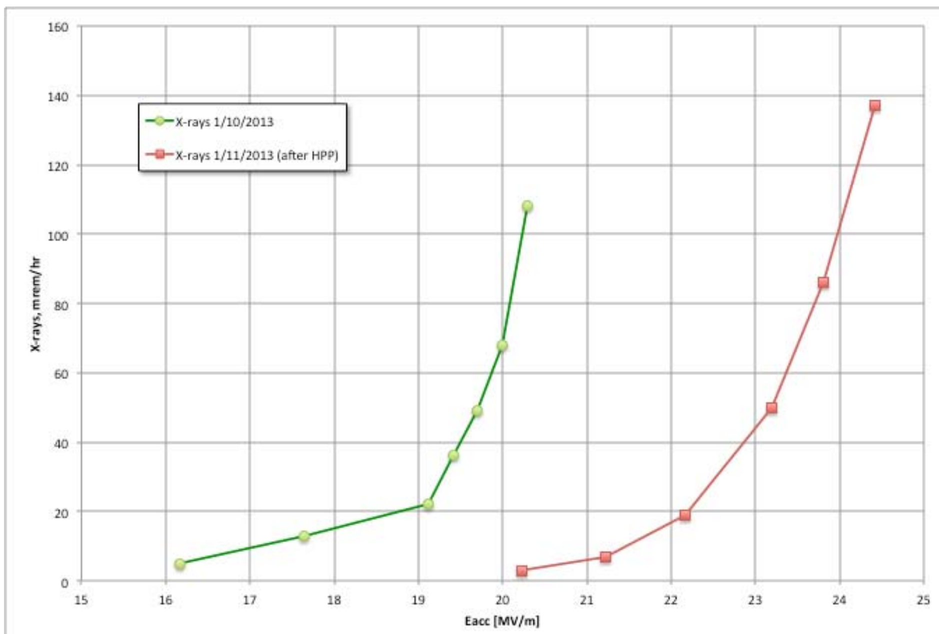
- ½ cell SRF injector with an independently cooled demountable cathode stalk designed for use with CsK_2Sb photocathode;
- Ability to couple 1 MW of RF power to the gun via 2 coaxial couplers;
- Pringle tip FPC to improve coupling and reduce beam effect on beam;
- Designed to deliver up to 500 mA average current from the gun;
- A quarter wavelength RF choke joint for the cathode insertion;
- High Temperature Superconducting Solenoid.

704 MHz SRF gun



- The 703.75 MHz ½ - cell SRF gun has two Fundamental input Power Couplers (FPCs) allowing to deliver 1 MW of RF power to a 0.5 A electron beam at energy gain of 2 MeV.
- The cavity active length is 8.5 cm, tuning range is 1.2 MHz (1 mm of cavity deformation).
- HOM damping is provided by an external beamline ferrite load with a ceramic break.

Commissioning of SRF gun w/o a cathode insert



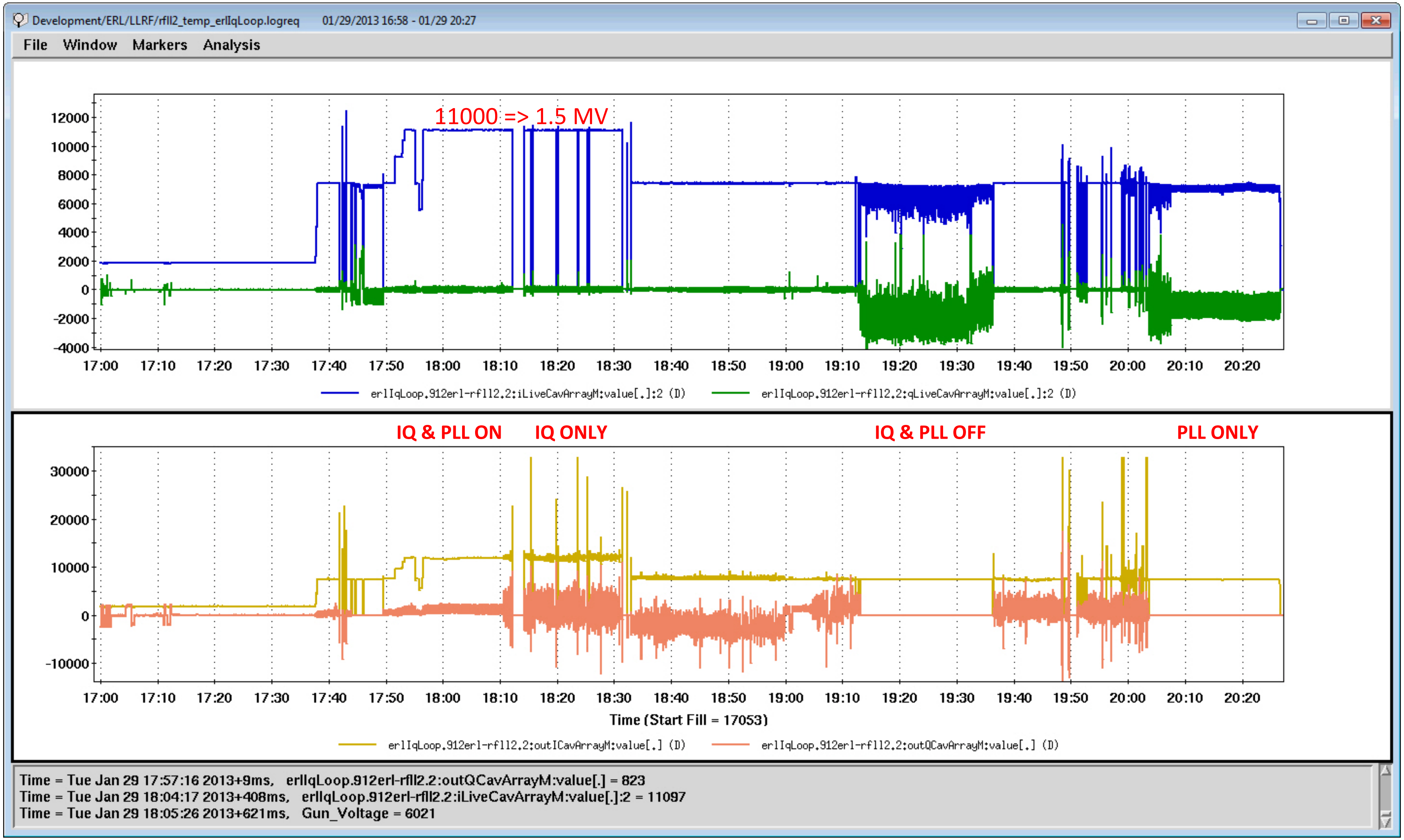
- Prior to assembly into the gun cryomodule, its two FPCs were conditioned off-line in standing wave mode with full reflection at variable RF phase. Maximum power was 250 kW in pulse mode (limited by klystron collector) and 125 kW in CW (administrative limit).
- The gun cryomodule was assembled last year and is installed in the ERL block house. Its 1 MW CW klystron, cryogenic system and other ancillary systems are fully operational.

The initial commissioning of the gun without a cathode is complete (Nov. 2012 to Mar. 2013) with the gun cavity achieving 2 MV (the original design voltage) and 220 kW of RF power in CW mode.

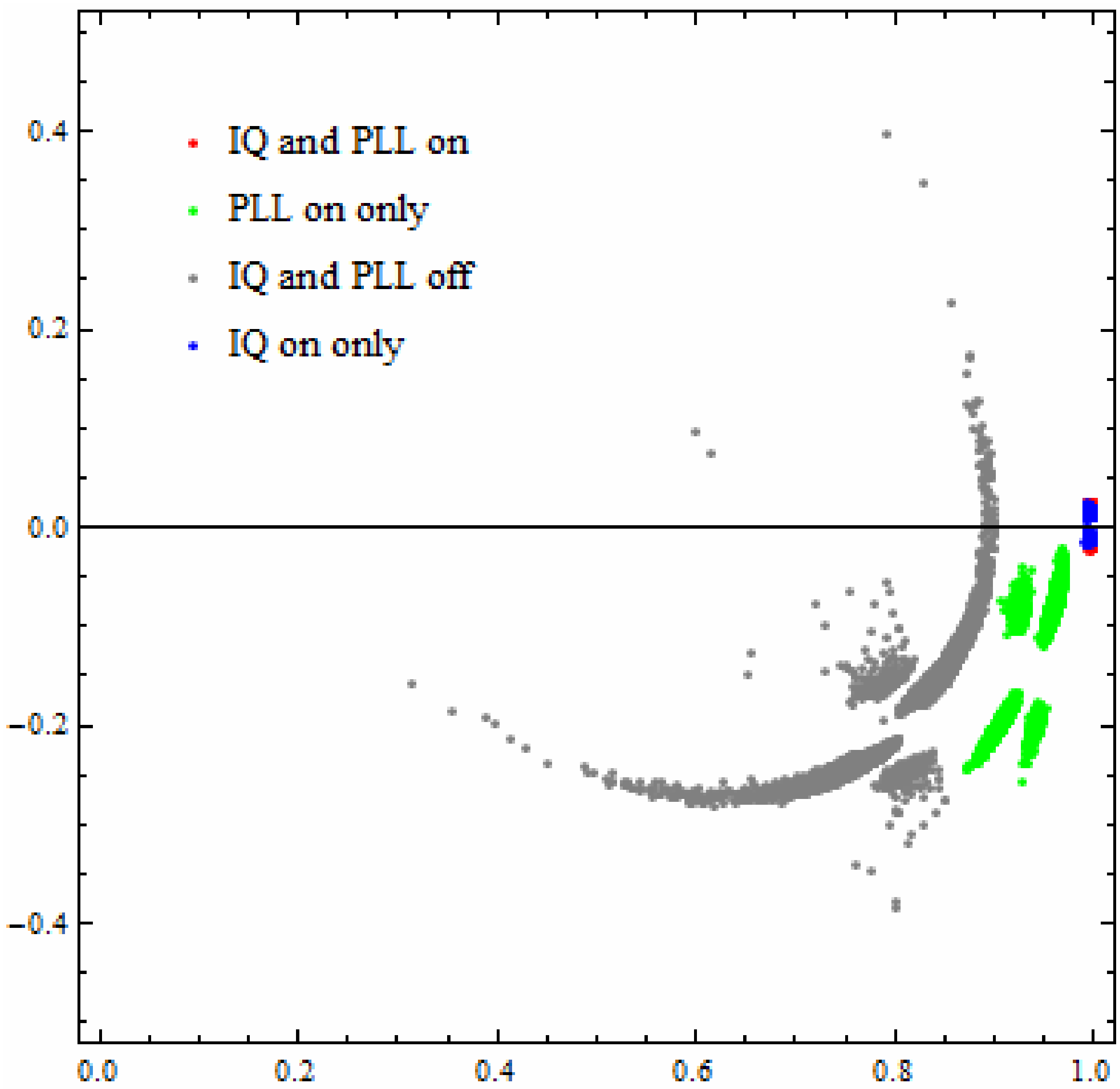
In pulsed mode, with a 0.7 ms pulse duration and 1 Hz repetition rate, the RF power was up to 400 kW. This allowed to do high-power RF processing of field emission in the cavity.

Amplitude & Phase Stability

with IQ feedback loop and phase locked loop

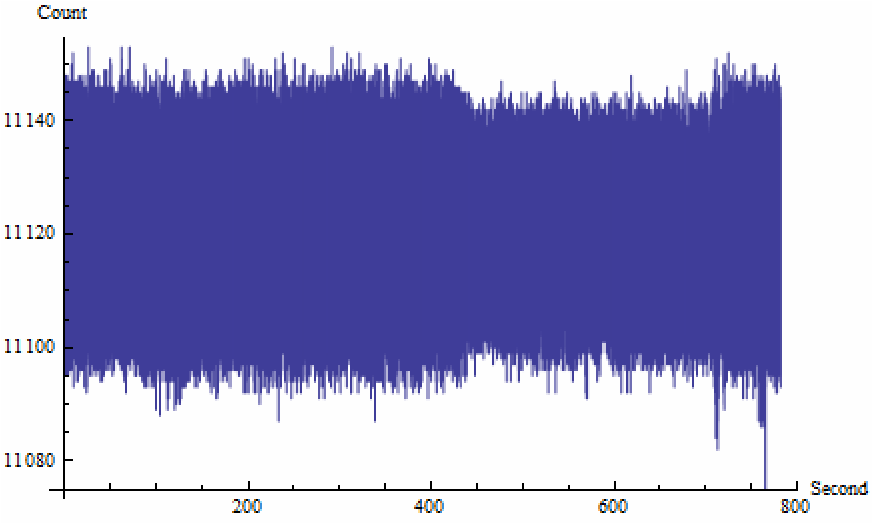


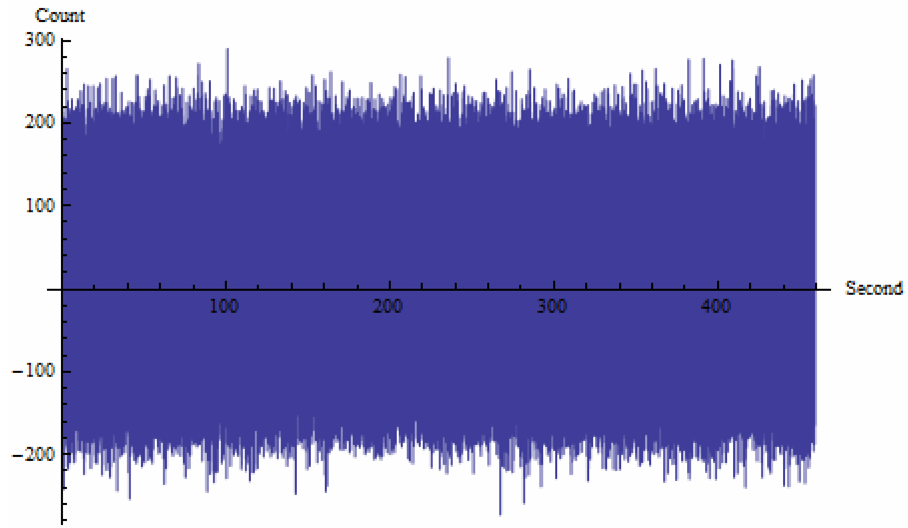
Comparison of controls



Amplitude and Phase stability

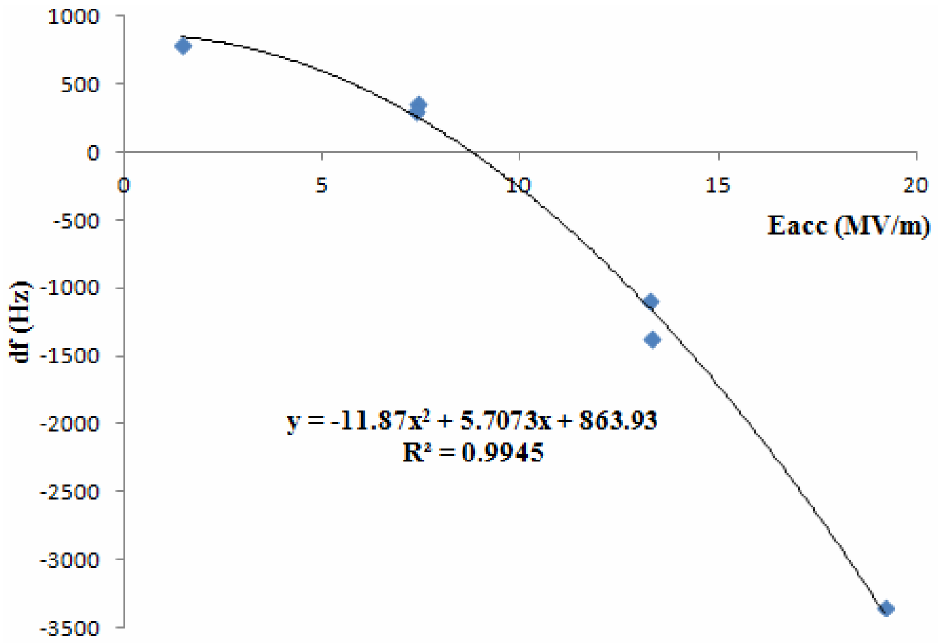
The measurements were taken with both IQ and PLL on at V = 1.5 MV

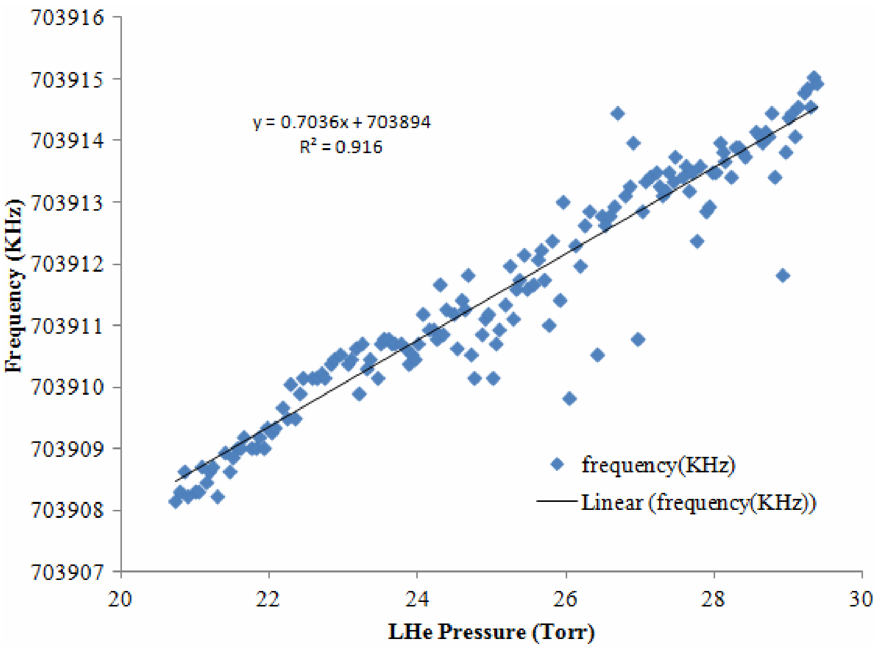




- The amplitude stability is 2.8E-3 (peak-to-peak), or 2.3e-4 (rms).
- The phase stability is 0.42° (peak-to-peak), or 0.035° (rms).

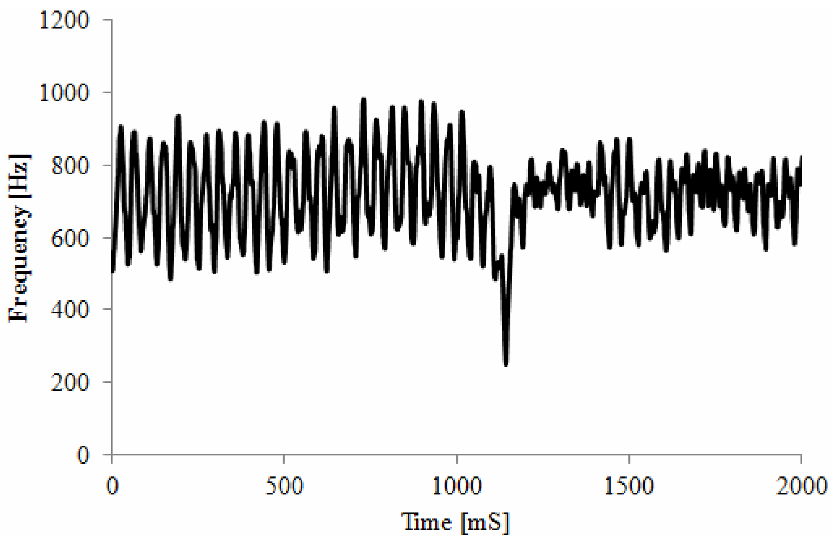
LFD & sensitivity to He pressure

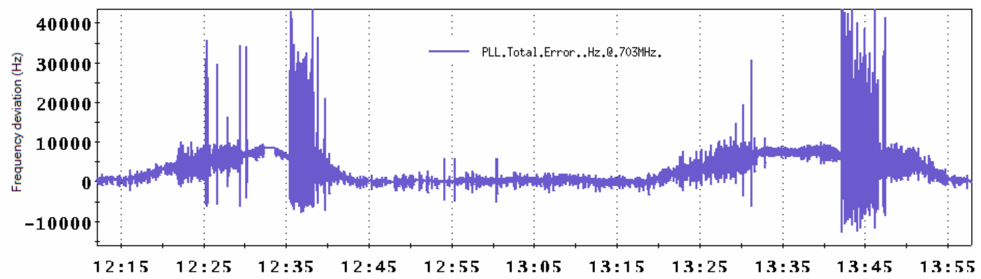


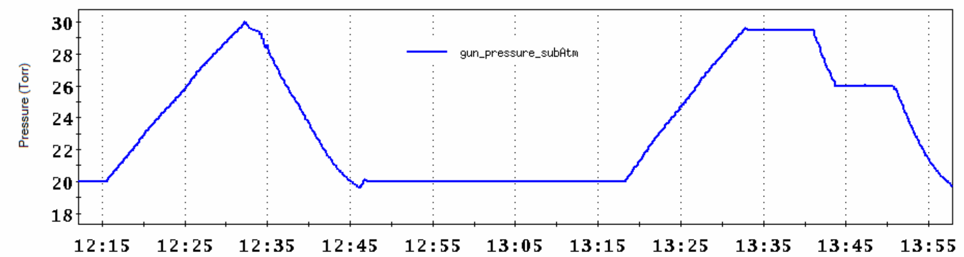


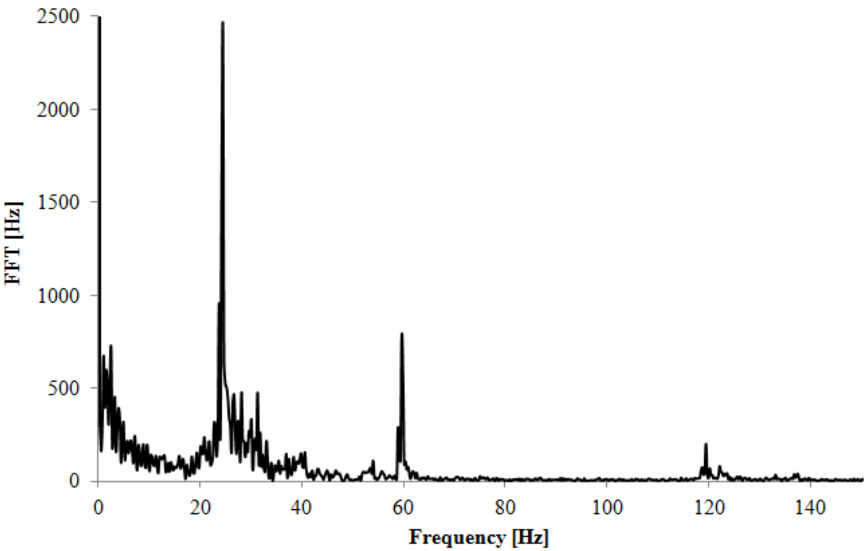
- The Lorentz force detuning coefficient is -11.9 $Hz/(MV/m)^2$.
- The cavity frequency is very sensitive to He bath pressure fluctuations: 704 Hz/Torr.

Microphonics spectrum



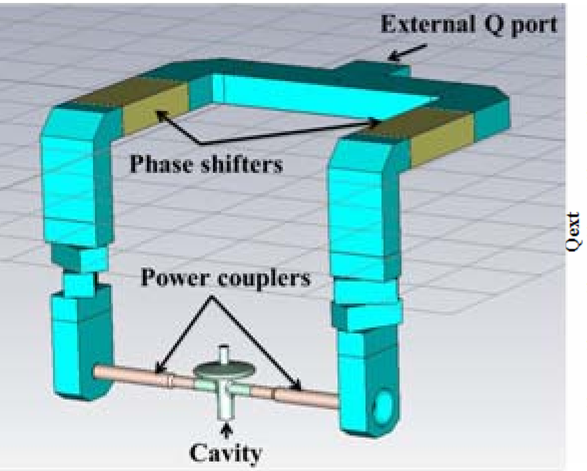


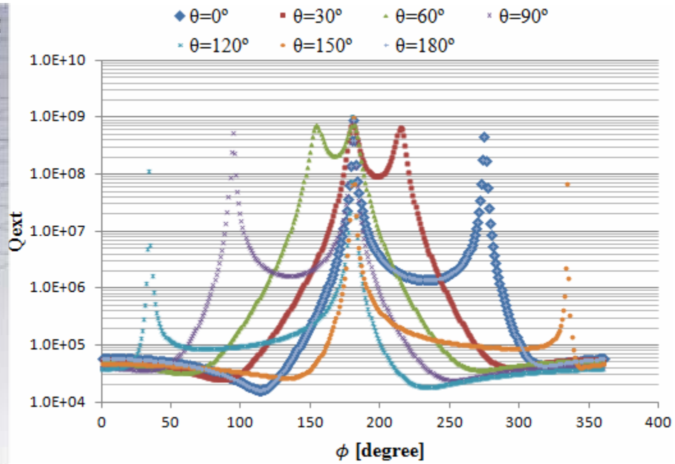


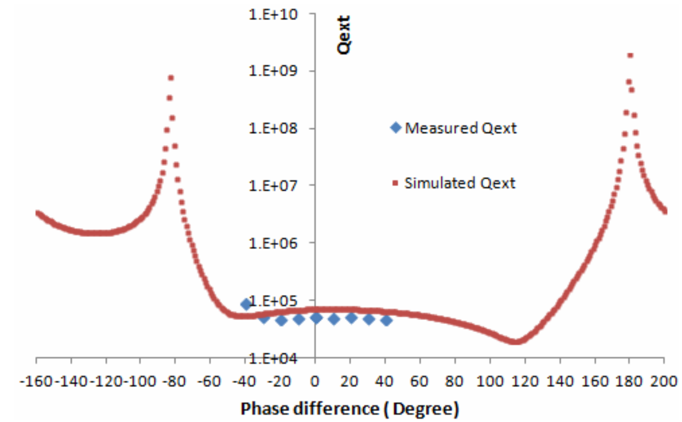


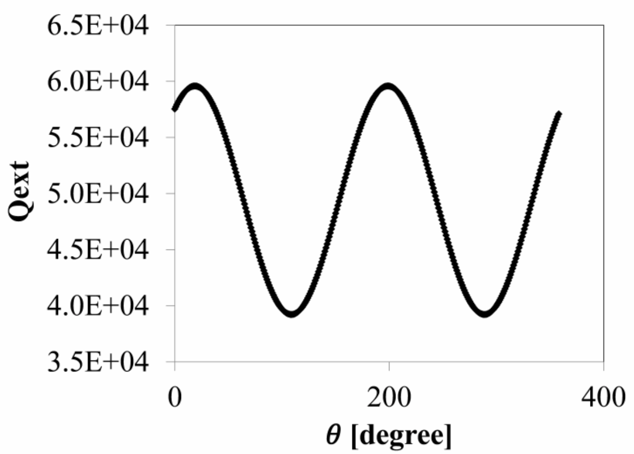
- The microphonics caused frequency detuning (peak-to-peak) is about 700 Hz, which is comparable with the cavity bandwidth.
- Shutting off the pumping line doesn't help to calm down the spectrum.
- The dominant 24 Hz line is the system's mechanical resonance.

Q_{ext} vs. phase shift





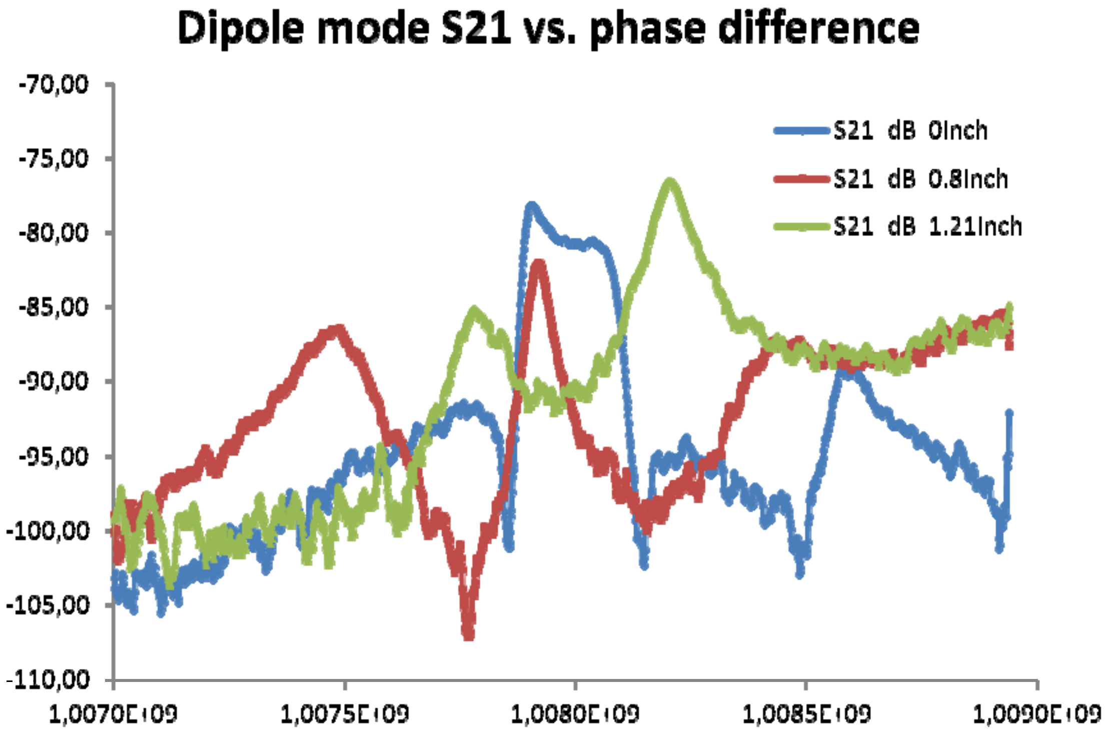




- We use a shunt T to split RF power equally between two waveguide arms.
- The phase difference between the two arms affects the external *Q* value.
- Simulation results show that there are always two external *Q* factor peaks within one period (360°). One peak is fixed at 180° for all conditions and the other one would move with periodically with period of 180°.
- When both phase shifters are adjusted simultaneously, *Q* periodically changes with a period of 180°. This would allow adjustment of ±20%
- When both phase are at 0°, the Q_{ext} factor of the system is measured as 5.75×10^4. The phase shifter in each arm is only able to shift the phase by 40°.
- Measured Q_{ext} versus phase shift in the actual ERL SRF gun setup is compared with simulations . Measurements were carried out at both high power (via LLRF) and low power with network analyzer, producing the same results.

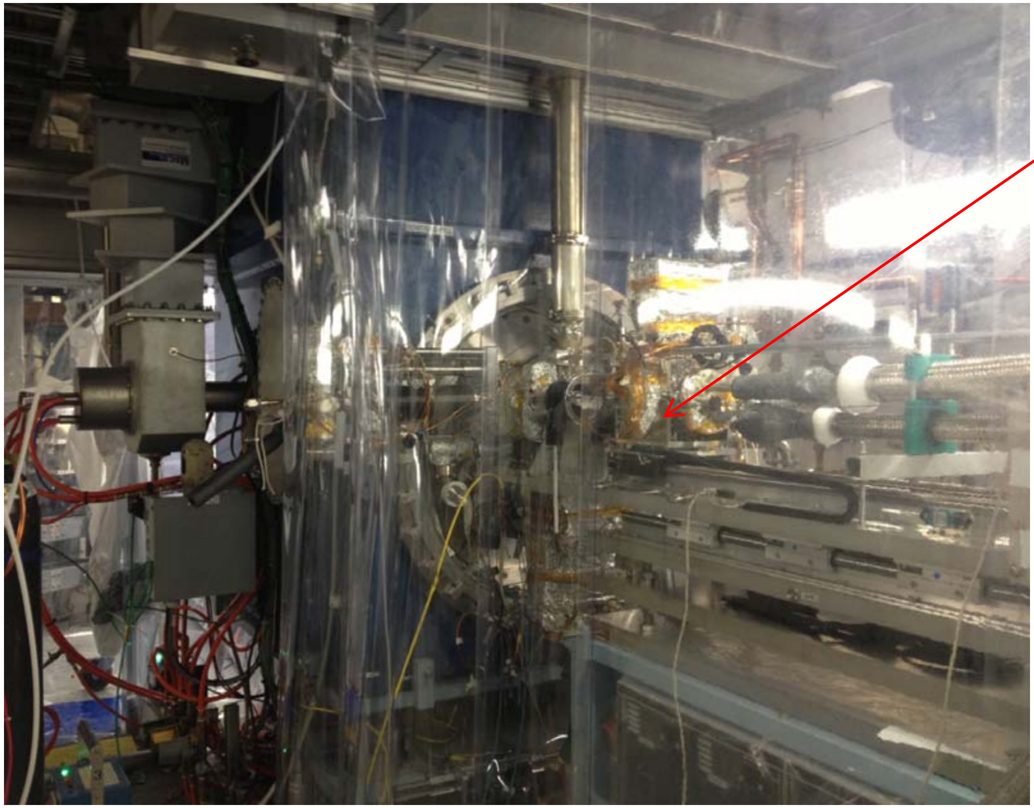
HOM damping by FPC

Mode	Frequency (GHz)	Q_L	Mode type
1	1.00827	47,600	D
2	1.47795	800,000	M
3	2.1459	76,000	D



- The HOMs of SRF gun cavity were studied along with the damping capabilities of the FPCs.
- Currently, the ferrite HOM damper is not installed yet.
- The two lowest dipole modes are damped pretty well by FPCs.
- The phase different in the two waveguide arms affect the HOM damping as well.

SRF gun commissioning with cathode stalk



Cathode inserted

- Presently the SRF gun is under commissioning with a copper cathode stalk.
- As of last Friday, we have reached 1.8 MV with an RF pulse duration of 40 ms; 2.2 MV at 500 us. The pulse repetition was 10 Hz in both cases.

Summary

- The SRF gun cryomodule has been assembled and successfully commissioned w/o a cathode, reaching an accelerating voltage of 2 MV in CW.
- The gun is under commissioning with a copper cathode.
- The first beam from the SRF gun is expected in about two months.