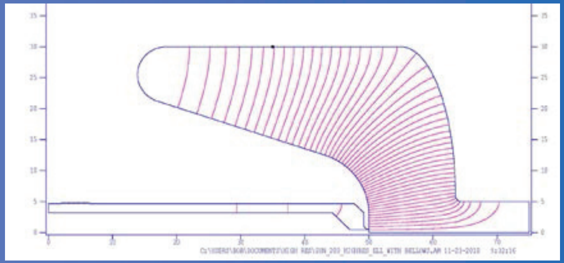
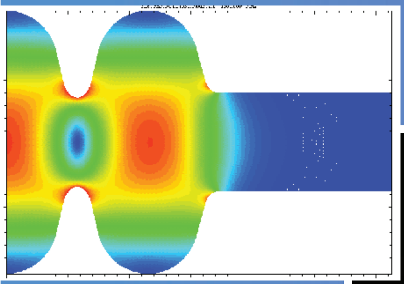


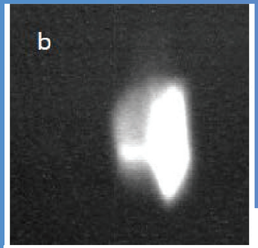
Progress in SRF guns

Sergey Belomestnykh

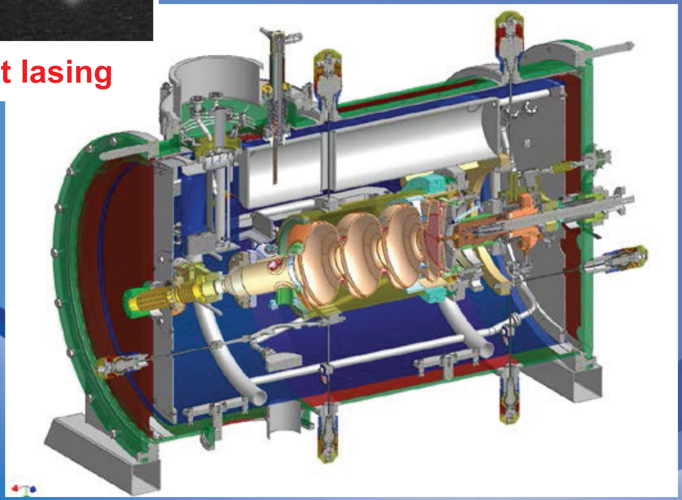
Collider-Accelerator Department, BNL

August 27, 2013





first lasing



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Talk outline

- Overview
- SRF gun types
- Cathode type
- Recent progress at facilities around the world
- Summary

Overview

- Superconducting RF has become the technology of choice for accelerating systems of many high-intensity accelerators. As the technology matured, it is now finding applications other than simply accelerating structures.
- One of such applications is photocathode RF guns. SRF has advantage over other electron gun technologies in CW mode of operation, where it potentially can provide higher rate of acceleration, generating high-charge bunches and high average beam currents.
- The first SRF guns were developed using elliptical cavity geometries (conventional shapes of high-β SRF cavities).
- Quarter Wave Resonator (QWR) option is gaining popularity. QWRs are especially well suited for producing beams with high charge per bunch.
- After brief review of the gun and photocathode types, I will describe particular projects and their recent achievements: DC-SRF gun at PKU; elliptical SRF photoinjecors at Rossendorf (MOOBNO02, MOPSO76), BERLinPro, and BNL ERL; QWR guns at BNL, NPS (TUPSO08, WEPSO83), and University of Wisconsin.

Challenges and issues

- In SRF photoinjectors we are merging together such complex technologies as high QE photocathodes, superconducting RF, high repetition rate synchronizable lasers.
- Among the challenges imposed by these technologies are maintaining UHV environment for the cathodes, maintaining cleanliness of the cavity RF surfaces while allowing operation and replacement of the cathodes, designing low RF loss and low heat leak interface between the cold cavities and warmer cathodes, synchronizing high repetition rate lasers with RF.
- **Low emittance**: high acceleration rate; focusing near a cathode; place the first solenoid as close to the cavity as possible; precise synchronization of a laser with RF; transverse and temporal bunch shaping.
- **High bunch charge at high repetition rate**: high QE photocathode with long life time; high average power, high repetition rate lasers.
- **For semiconductor (or other high QE) photocathodes to be able to operate in the SRF cavity environment**: at least one type of photocathodes, Cs_2Te, was demonstrated to have long lifetime, more studies needed for other types.
- **Cavity preparation:** etching/cleaning a cavity with small opening on one side is challenging; effect of the NC cathodes on SRF performance is still unclear.
- **Demonstrate stable operation in an accelerator**: high RF power, coupler kick, HOM excitation.

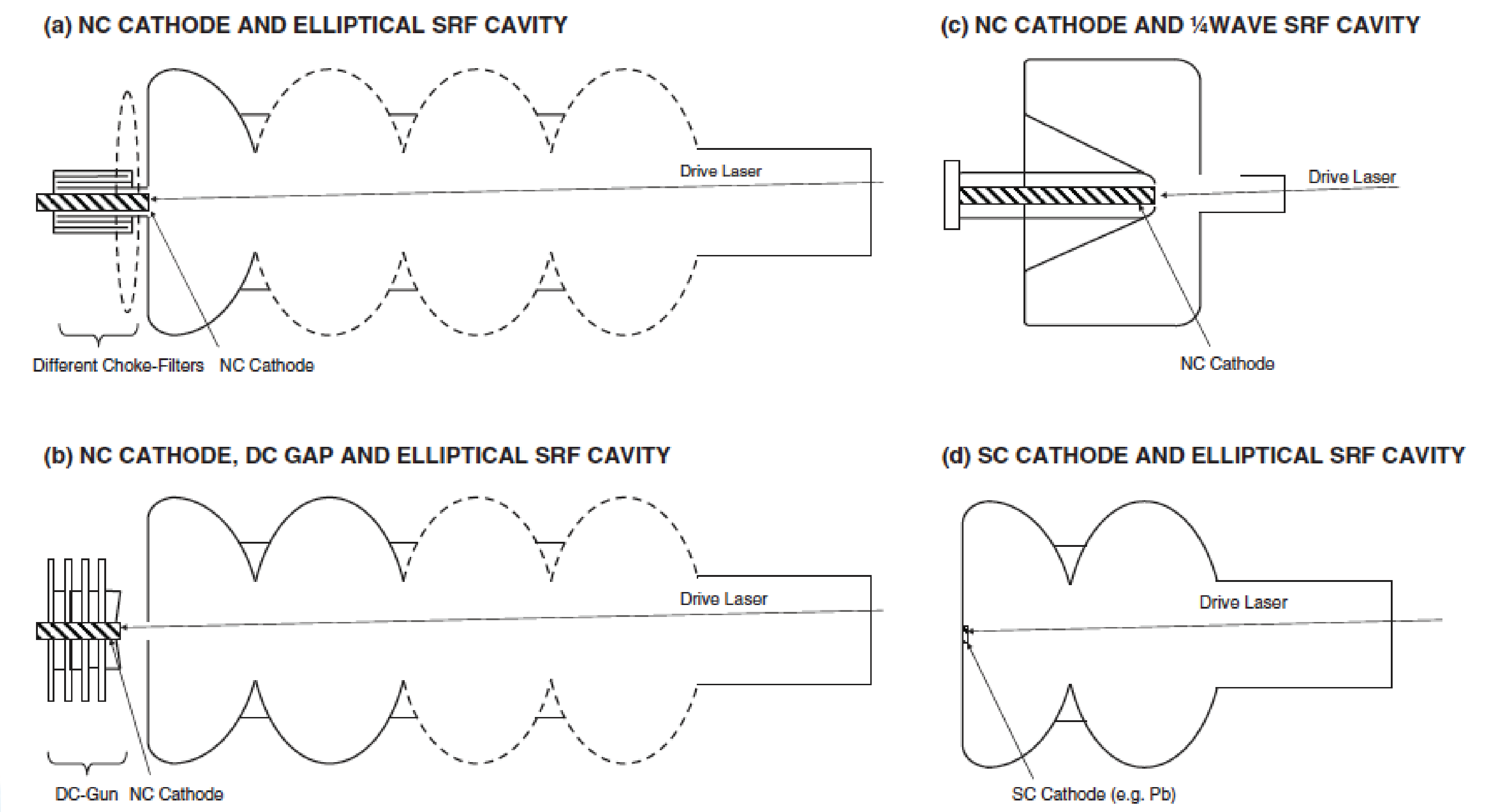
SRF gun types

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **14**, 024801 (2011)

Overview on superconducting photoinjectors

A. Arnold* and J. Teichert

Forschungszentrum Dresden-Rossendorf (FZD), P.O. Box 510119, 01314 Dresden, Germany
(Received 29 November 2009; revised manuscript received 21 October 2010; published 2 February 2011)



SRF gun types (2)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **14**, 024801 (2011)

Overview on superconducting photoinjectors

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Forschungszentrum Dresden-Rossendorf (FZD), P.O. Box 510119, 01314 Dresden, Germany

(Received 29 November 2009; revised manuscript received 21 October 2010; published 2 February 2011)

TABLE I. Comparison of all presently known SRF gun projects and whose expected parameters. Most of the information was provided by the expert named first in the last row. Values taken from other references are additionally marked by an index in the table. Values marked by # are calculated out of V_C and U and those that are marked by * are calculated using P_{diss} and Q_0. Still open parameters are filled in with tbd (to be determined).

		Elliptical cavity + NC cathodes			DC-SC	Quarter wave SRF guns			Elliptical cavity + SC cathodes	
						NPS	WiFEL	BNL		
Parameter	Units	FZD	BNL/AES	HZB BerlinPro	PKU gun	500 MHz	200 MHz	112 MHz	Pb/Nb hybrid gun	HZB HoBiCat
Beam kinetic energy, V_c	MeV	9.4	2	≤ 3.5	5	1.2	4.58	2.7	~5	≤ 3.5
Maximum bunch charge, q_{max}	nC	1/0.077	5/1.4[1]/0.7	0.077	0.1	1	0.2	5	1	0.015
Normalized transverse emittance, $\varepsilon_{n,r}$	mm mrad	2.5/1	5/2.3[1]/1.4	1	1.2	4	0.9	3	1	1
Average beam current, I_b	mA	0.5/1	50/500[1]/500	100	1–5	1	1.0	50	<1 rather 0.1	0.0045
Peak current, I_{pk}	A	67/20	166/70[1]/35	5	20	50	50	18.5	50	6
Photocathode		Cs_2Te	CsK_2Sb	CsK_2Sb	Cs_2Te	tbd	Cs_2Te	tbd	Pb	Pb
Quantum efficiency, QE	%	1	18	10	1–5	tbd	1	tbd	0.0017	5×10^{-2}
Driving laser wavelength, λ	nm	263	355	527	266	tbd	266	tbd	213	260
Pulse duration (FWHM)	ps	15/4	30/20[1]/20	≤ 20	5	10–40	4	270	<20	2 to 3
Bunch repetition rate, f_{rep}	MHz	0.5/13	10/352[1]/704	≤ 1300	81.25	10^{-5}–100	5	9.4	<1 rather 0.1	0.030
Gun frequency, f_0	MHz	1300	703.75	1300	1300	500	200	112[1]	1300	1300
Operating temperature	K	2	2	2	2	4.2	4.2	4.2[1]	2	2
Dissipated power, P_{diss} at the intrinsic Q_0 of	W	26 @ 1×10^{10}	4.2 @ 1×10^{10}	12.1[3] @ 1×10^{10}	···	8.6 @ 9.5×10^8	42 @ 3.2×10^9	16.6[1] @ 3.5×10^9	143 @ 5×10^9	12.1[3] @ 1×10^{10}
Active cavity length, l_{activ}	cm	50	9.5	17.1	41.7	8	19	20	18.4	17.1
R_{shunt}/Q_0, r (R_{shunt} from accelerator definition)	Ω	334	96 95.5#	189[4], $\beta = 1$ 101.4#	418, $\beta = 1$	185, $\beta = 1$ 176.3#	155.7#	126.8[1] 126.6#	170, $\beta = 1$ 35.2#	189, $\beta = 1$ 101.4#
Transit time factor, V_c/V_0	TTF	0.715	0.888[2]	0.54[3]	0.74[4]	0.94	0.87	0.99[1]	···	0.54[3]
Stored energy at E_{pk}, U	J	32.4	8.4/9.5*	14.8[3]	···	2.6	107.2	81.4*	87	14.8[3]
Electric cathode field E_{cath}	MV/m	30	20	≥ 10	~5[4]	25	45	19.7[1]	50–60	≥ 10
Peak electric field, E_{pk}	MV/m	50	35.7	≤ 50	31.8	44	59	51.0	50–60	≤ 50
Peak magnetic flux, B_{pk}	mT	110	74	116	74.5	69.1	90.7	97.8[1]	104–125	116
Peak magnetic field, H_{pk}	A/m	87 535	59 000	$\leq 92\,600$	59 285	55 000	72 165	78 000	$(87–99) \times 10^3$	$\leq 92\,600$

Elliptical + NC cathodes

DC-SC

QWRs

Photocathodes for SRF guns

- IR to UV lasers are readily nowadays with wide variety of pulse durations and average power of up to several tens of watts.
- This enables possible use of many materials belonging to two classes: metals and semiconductors.
- Metal photocathodes (Cu, Mg, Pb, Nb) are robust, but have low QE ($<10^{-3}$) and are suitable only for use in the initial phases of an SRF gun development, when high beam intensities / high duty factors are not required.
- Coating of metal cathodes with a thin (~18 nm) layer of CsBr can increase the QE to $7 \cdot 10^{-3}$.
- Superconducting (niobium or lead) photocathodes have been used in small R&D SRF guns as a way to avoid introduction of a special cathode plug and to reduce RF losses.
- Semiconductor photocathodes are the preferred option for many projects as they can provide very good QE, 10% and higher. However, they are very sensitive to contamination and require UHV conditions for operation.
- The most developed semiconductor photocathodes for SRF gun applications are GaAs(Cs), Cs_2Te, and CsK_2Sb.
- GaAs(Cs) is the only one of the three suitable for producing polarized electrons, but it is the most sensitive to ion back bombardment, requires an extremely good vacuum, and has a short lifetime.
- Cs_2Te is the most robust and has demonstrated a very long lifetime in an SRF gun at HZDR, but requires the use of UV lasers.
- CsK_2Sb can be used with green lasers. It demonstrated very good performance in DC guns and holds the world record of average beam current produced from an RF photoinjector. It is the most preferred option for SRF guns at present.
- A potential alternative is NaK_2Sb, which has a similar to CsK_2Sb production recipe, but proved to be more robust in experiments with a DC gun at Cornell University.

Photocathode types

Cathode R&D for future light sources☆

D.H. Dowell [a,*], I. Bazarov [b], B. Dunham [b], K. Harkay [c], C. Hernandez-Garcia [d], R. Legg [e], H. Padmore [f], T. Rao [g], J. Smedley [g], W. Wan [f]

Nuclear Instruments and Methods in Physics Research A 622 (2010) 685–697

Metal photocathodes

Table 2
Properties of metal photocathodes.

Metal cathodes	Wavelength & energy: λ_{opt} (nm), $\hbar\omega$ (eV)	Quantum efficiency (electrons per photon)	Vacuum for 1000 h operation (Torr)	Work function, ϕ_W (eV)	Thermal emittance (microns/mm(rms))	
					Eq. (3)	Expt.
Bare metal						
Cu	250, 4.96	1.4×10^{-4}	10^{-9}	4.6 [34]	0.5	1.0 ± 0.1 [39] 1.2 ± 0.2 [40] 0.9 ± 0.05 [3]
Mg	266, 4.66	6.4×10^{-4}	10^{-10}	3.6 [41]	0.8	0.4 ± 0.1 [41]
Pb	250, 4.96	6.9×10^{-4}	10^{-9}	4.0 [34]	0.8	?
Nb	250, 4.96	$\sim2\times10^{-5}$	10^{-10}	4.38 [34]	0.6	?
Coated metal						
CsBr:Cu	250, 4.96	7×10^{-3}	10^{-9}	~2.5	?	?
CsBr:Nb	250, 4.96	7×10^{-3}	10^{-9}	~2.5	?	?

The thermal emittances are computed using the listed photon and work function energies in Eq. (3) and expresses the thermal emittance as the normalized rms emittance in microns per rms laser size in mm. The known experimental emittances are given with references.

Diamond-amplified photocathodes

Semiconductor photocathodes

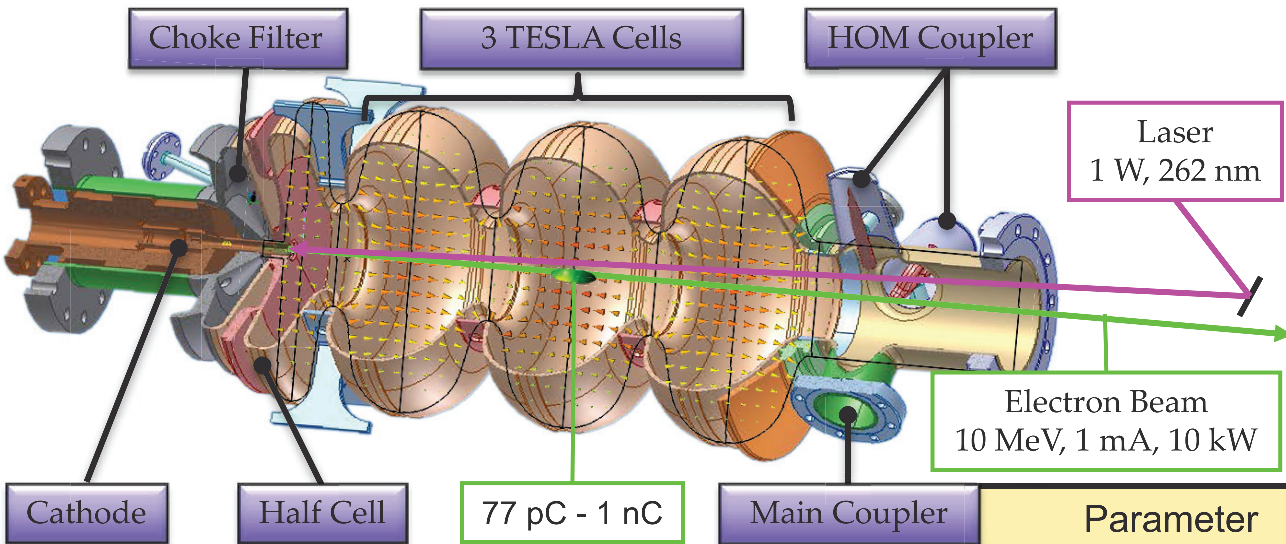
Table 3
Properties of semiconductor cathodes.

Cathode type	Cathode	Typical wavelength & energy, λ_{opt} (nm), (eV)	Quantum efficiency (electrons per photon)	Vacuum for 1000 h (Torr)	Gap energy + electron affinity, E_G+E_A (eV)	Thermal emittance (microns/mm(rms))	
						Eq. (7)	Expt.
PEA: mono-alkali	Cs_2Te	211, 5.88	0.1	10^{-9}	3.5 [42]	1.2	0.5 ± 0.1 [35]
		264, 4.70	–	–	"	0.9	0.7 ± 0.1 [35]
		262, 4.73	–	–	"	0.9	1.2 ± 0.1 [43]
	Cs_3Sb	432, 2.87	0.15	?	1.6+0.45 [42]	0.7	?
	K_3Sb	400, 3.10	0.07	?	1.1+1.6 [42]	0.5	?
	Na_3Sb	330, 3.76	0.02	?	1.1+2.44 [42]	0.4	?
	Li_3Sb	295, 4.20	0.0001	?	?	?	?
PEA: multi-alkali	Na_2KSb	330, 3.76	0.1	10^{-10}	1+1 [42]	1.1	?
	$(Cs)Na_3KSb$	390, 3.18	0.2	10^{-10}	1+0.55 [42]	1.5	?
	K_2CsSb	543, 2.28	0.1	10^{-10}	1+1.1 [42]	0.4	?
	$K_2CsSb(O)$	543, 2.28	0.1	10^{-10}	1+ < 1.1[42]	~0.4	?
NEA	GaAs(Cs,F)	532, 2.33	0.1	?	1.4 ± 0.1[42]	0.8	0.44 ± 0.01[44]
		860, 1.44	0.1	?		0.2	0.22 ± 0.01[44]
	GaN(Cs)	260, 4.77	0.1	?	1.96+?[44]	1.35	1.35 ± 0.1[45]
	$GaAs(1-x)Px$ $x\sim0.45$ (Cs,F)	532, 2.33	0.1	?	1.96+?[44]	0.49	0.44 ± 0.1[44]
S-1	Ag–O–Cs	900, 1.38	0.01	?	0.7[42]	0.7	?

The thermal emittances are computed using the listed photon, gap and electron affinity energies in Eq. (7) and expresses the thermal emittance as the normalized rms emittance in microns per rms laser size in mm.

SRF gun for ELBE at HZDR

MOOBNO02, MOPSO76

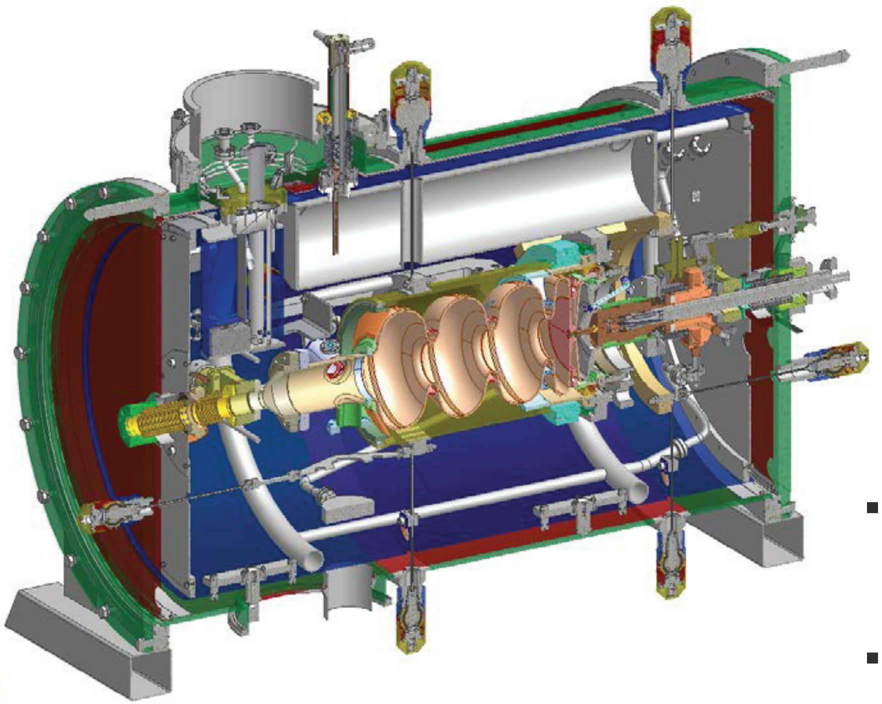


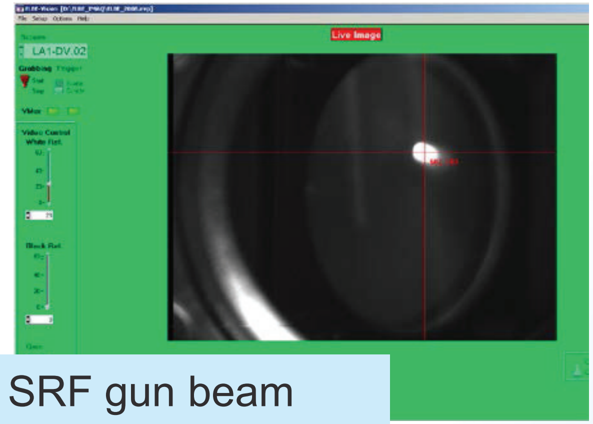
Application

- high peak current operation for CW-IR-FELs with 13 MHz, 80 pC
- high bunch charge (1 nC), low rep-rate (<1 MHz) for pulsed neutron and positron beam production (ToF experiments)
- low emittance, medium to high charge with short pulses for THz-radiation and x-rays by inverse Compton backscattering

Parameter	ELBE	High Charge
final electron energy	≤ 9.5 MeV	
RF frequency	1.3 GHz	
operation mode	CW	
Photo cathode	Cs_2Te	
bunch charge	77 pC	1 nC
repetition rate	13 MHz	500 kHz
laser pulse (FWHM)	4 ps	15 ps
transverse rms emittance	1 mm-mrad	2.5 mm-mrad
average current	1 mA	0.5 mA

SRF gun for ELBE at HZDR





First SRF gun beam
in ELBE on Feb. 5, 2010

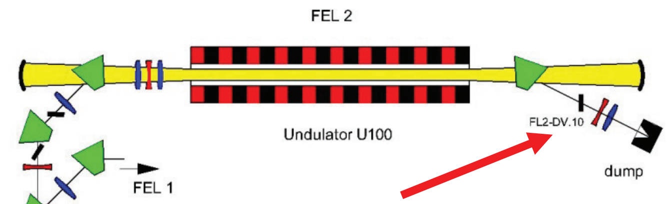
- The 3½ cell SRF gun is the first SRF gun in the world to inject a beam into an accelerator and also the first to provide beam for FEL lasing.
- Maximum bunch charge injected and accelerated in ELBE: 120 pC @ 50 kHz (6 μA); with 100% transmission: 60 pC @ 125 kHz.

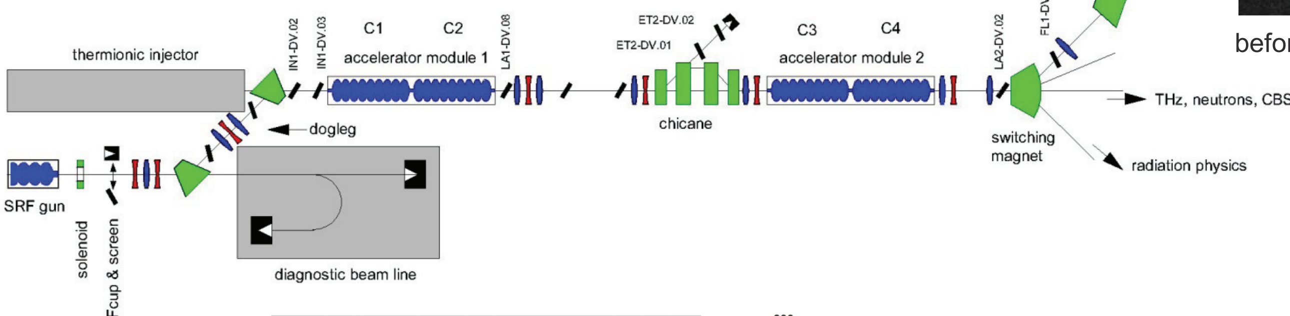
- Very good performance of Cs_2Te photo cathodes demonstrated: life time of ~1 year with QE ~1%.
- Maxiumum average beam current to date is 400 μA.
- CW operation of the gun is limited to 3.3 MeV kinetic energy due to FE in the cavity.
- The cryomodule for the new gun is ready. The cavity reached 43 MV/m peak field during a cold test at JLab.

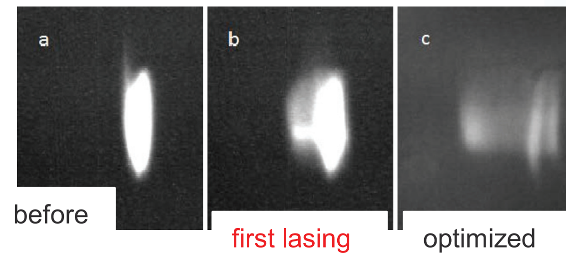
First FEL operation with SRF gun at ELBE

E_{kin} at gun exit	3.3 MeV
Micro pulse repetition rate	13 MHz
Macro pulse repetition rate / length	1.25 Hz / 2 ms
Beam energy at FEL	27.9 MeV
Bunch charge / beam current	20 pC / 260 μA
Photo cathode	Cs_2Te
RMS bunch length	1.6 ps
Normal. RMS emittance	1 mm mrad

ELBE infrared FEL (20 – 250 μm)

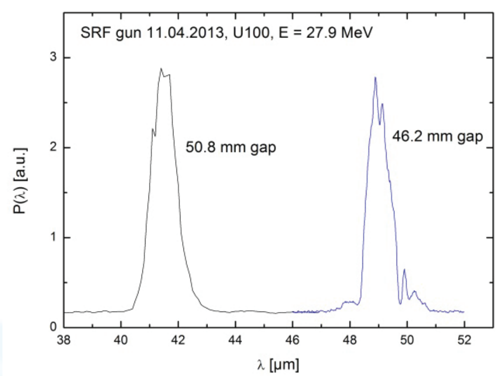




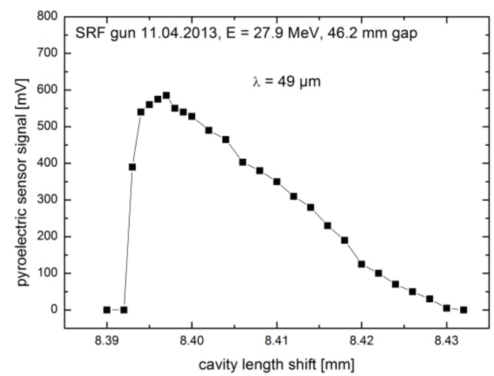


April 11, 2013

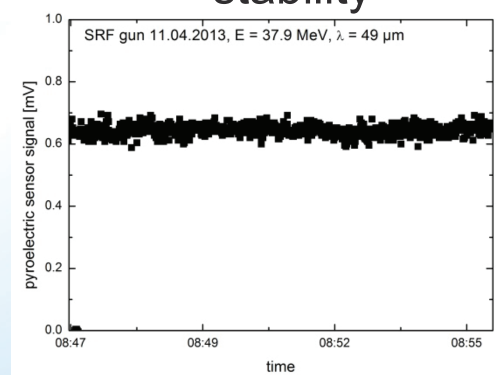
stability



FEL spectra

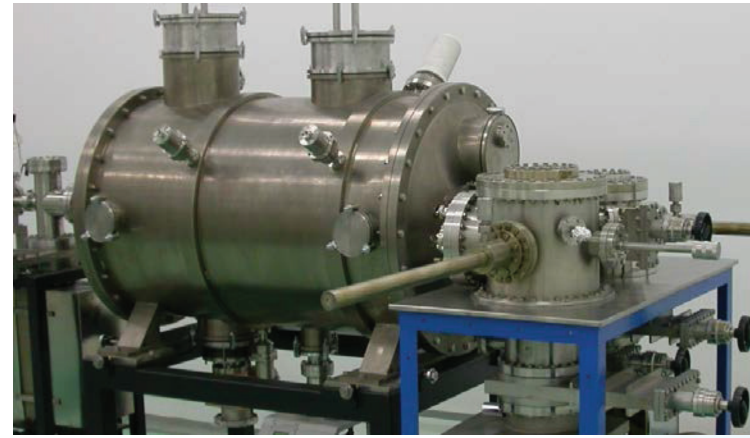


FEL detuning curve

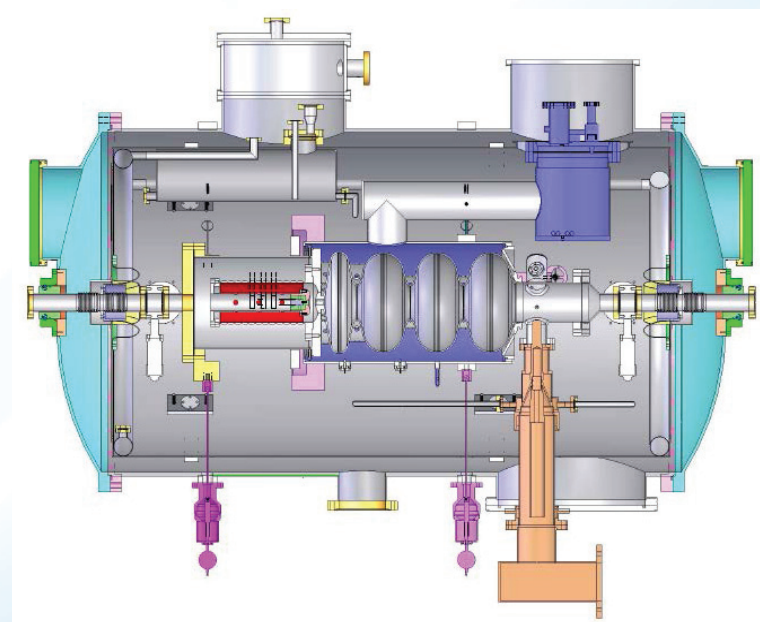


3.5-cell DC-SRF photoinjector at Peking University

- A hybrid DC–SRF gun has been developed for the Superconducting ERL Test Facility (SETF) at Peking University
- The unique design combines a compact 90 kV Pierce DC gun equipped with a Cs_2Te photocathode and a 3½ cell, 1300 MHz SRF cavity.



Drive laser		
Pulse length（FWHM）	**10ps**	
laser spot（FWHM）	**3.0mm**	
Repetition rate	**81.25MHz**	
Bunch charge distribution	**transverse uniform , longitudinal Gaussian**	
Injector	**ERL mode**	**THz mode**
gradient	**13 MV/m**	**15MV/m**
Bunch charge	**60~100 pc**	**20pc**
energy	**5MeV**	**<5MeV**
Transverse emittance (rms)	**1.2mm·mrad**	**2.1 mm·mrad**
Longitudinal emittance (rms)	**15 deg—KeV**	**3.0deg—KeV**
Bunch length（rms）	**3ps**	**0.55ps**
Rms beam spot	**0.3mm**	**1.7mm**
Energy spread	**～0.5%**	**0.55%**



DC-SRF gun status

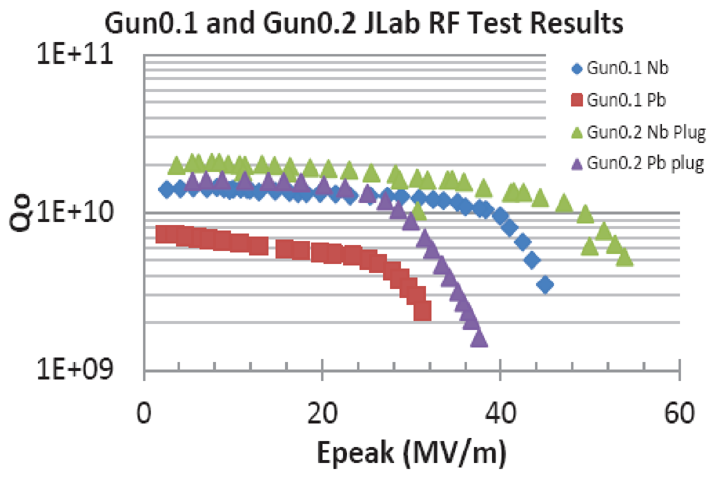
- A series of experiments have been carried out with the DC-SRF injector at 2 K.
- ~300 μA CW electron beam was obtained with emittance of about 3 mm-mrad.
- THz radiation will be produced with this DC-SRF injector and a new beam line.

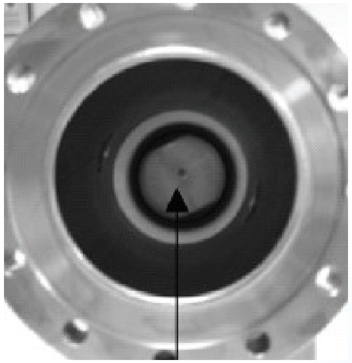
SRF guns for B*ERL*inPro at HZB

- Performance reqs for B*ERL*inPro:
  - Beam dynamics: need good control on the transverse and longitudinal beam parameters. Mainly determined by field on cathode and setup of focusing elements.
  - Average current of 100 mA: need cathode with high QE, which can operate in SRF environment.
  - Average power: need to couple P_{avg} = 100 mA x E_b power into the cavity.
- Accordingly, three stages:
  1. Gun0.1 and Gun0.2 are beam demonstrator experiments with SC Pb cathodes to study beam dynamics, cavity performance.
  2. For Gun1 add NC cathode with high QE, study cathode lifetime, slice/projected emittance performance.
  3. For Gun2 add RF input power coupler for 200 kW, study high power operation.

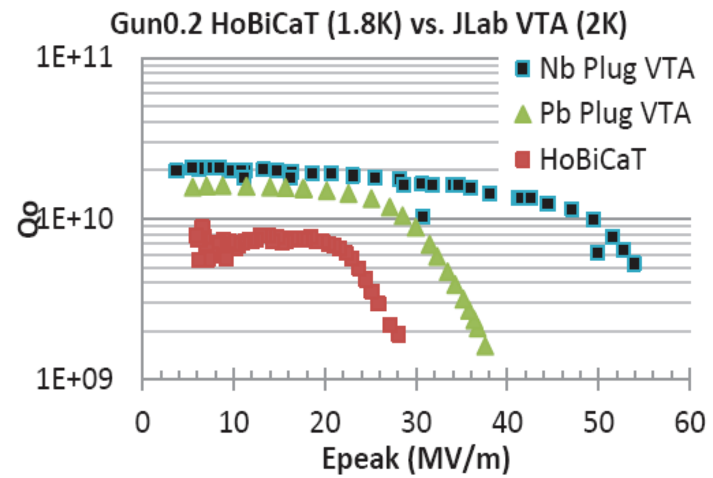
	HoBiCaT Guns 0.1 and 0.2	**Source lab Gun1**	**BERLinPro Gun2**
Goal	Beam Demonstrator	Brightness R&D gun	Current Production gun
Electron energy	≥ 1.5 MeV		
RF frequency	1.3 GHz		
Design peak field	≤ 50 MV/m		
Operation launch field	≥ 10 MV/m		
Bunch charge	≤ 77 pC		
Repetition rate	30 kHz	54 MHz / 25 Hz	1.3 GHz
Cathode material	Pb	CsK_2Sb	CsK_2Sb
Cathode QE	$5*10^{-4}$	10^{-1}	10^{-1}
Laser wavelength	258 nm	532 nm	532 nm
Laser pulse energy	0.15 µJ	1.8 nJ	1.8 nJ
Laser pulse shape	Gaussian	Flat-top	Flat-top
Laser pulse length	2.5 ps FWHM	≤ 20 ps	20 ps
Average current	0.5 µA	≤10 mA / 0.1 mA	100 mA

Guns0: hybrid Nb/Pb gun cavities

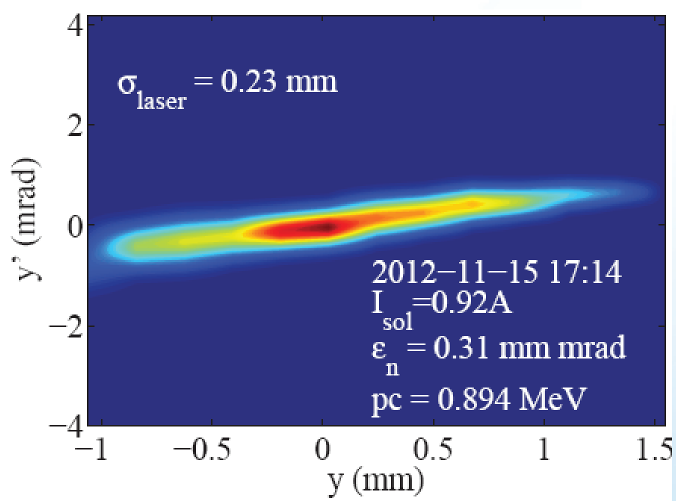


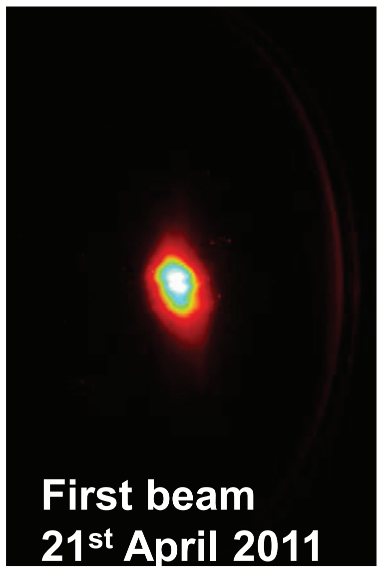


- Gun0.1 had a thin layer of lead deposited on the back wall of niobium cavity.
- Gun0.2 had lead deposited on a niobium plug cathode, which allows decoupling of the cavity preparation from the cathode deposition.
- Both guns generated beams the bunch charge and beam current were limited by low QE of the lead photocathodes (10^{-5} to 10^{-4}) and available UV laser power.



A. Burrill, et al., Proc. of IPAC 2013, WEPWO002





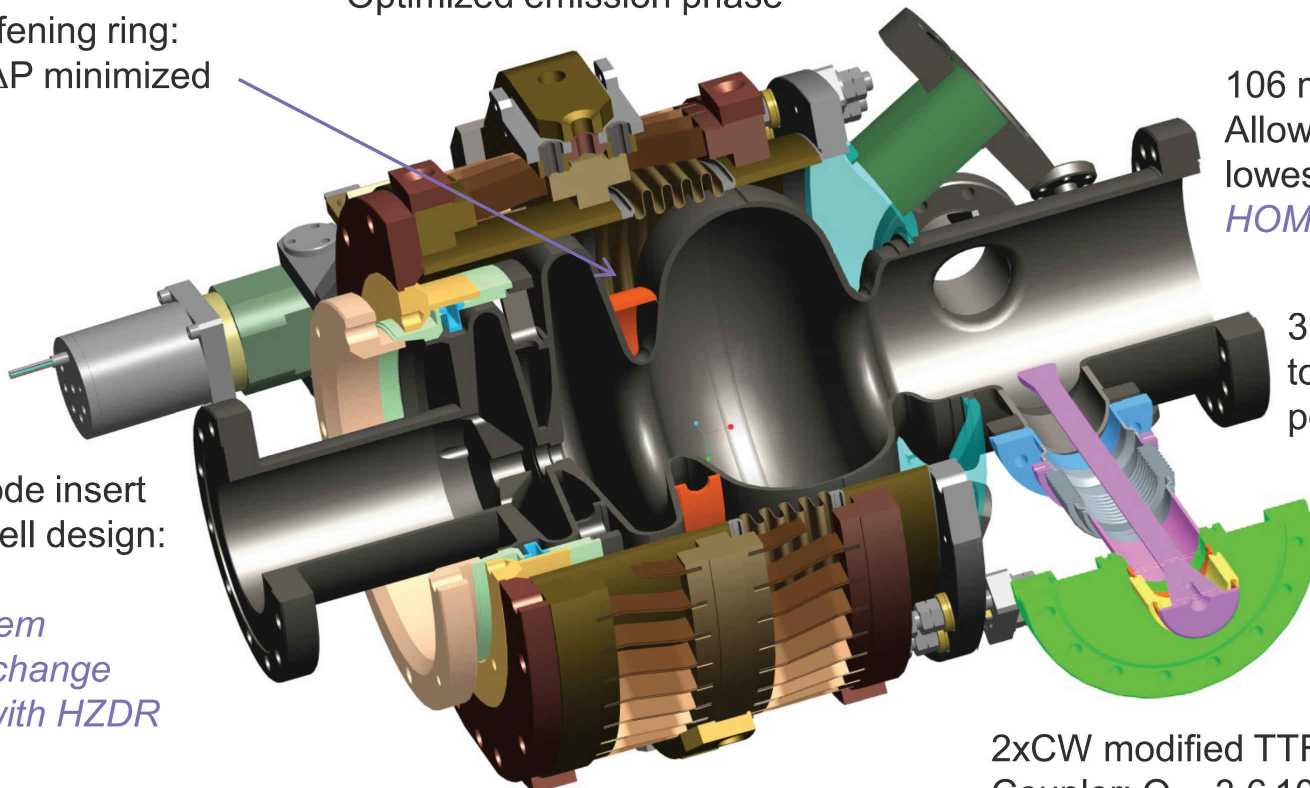
Gun1 design

Chimney 22 cm²~35 W at 1.8 K
about E_{peak}=45 MV/m at $Q_0=3.5\cdot10^9$

0.4·λ cell + full cell:
Optimized emission phase

Stiffening ring:
Δf/ΔP minimized

106 mm beam tube:
Allow propagation of lowest TM_{110} mode:
HOM studies



3 pick-up antennas to measure HOM polarization

HZDR cathode insert and choke cell design:

Proven system
Cathode exchange developed with HZDR

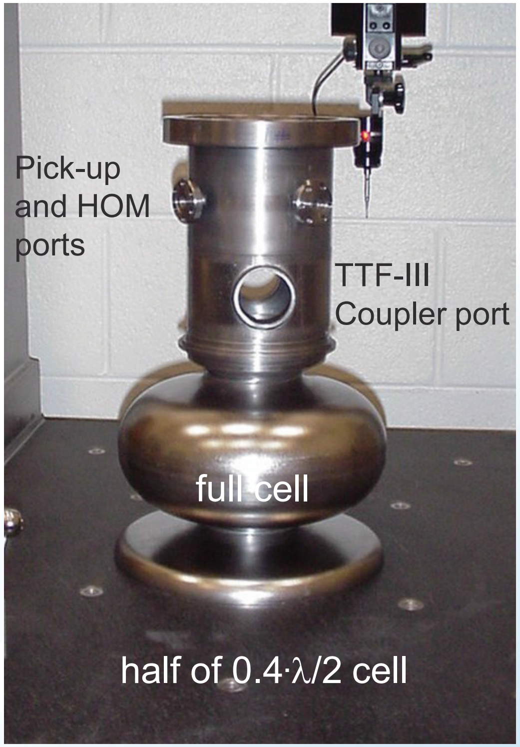
Blade tuner with motor and piezo tuner:
Microphonics compensation

2xCW modified TTF-III Coupler: Q_{ext} $3.6\cdot10^6$ for up to I_{avg}=4 mA, 10 kW each
Study 2 coupler operation

Gun1 parameters and status

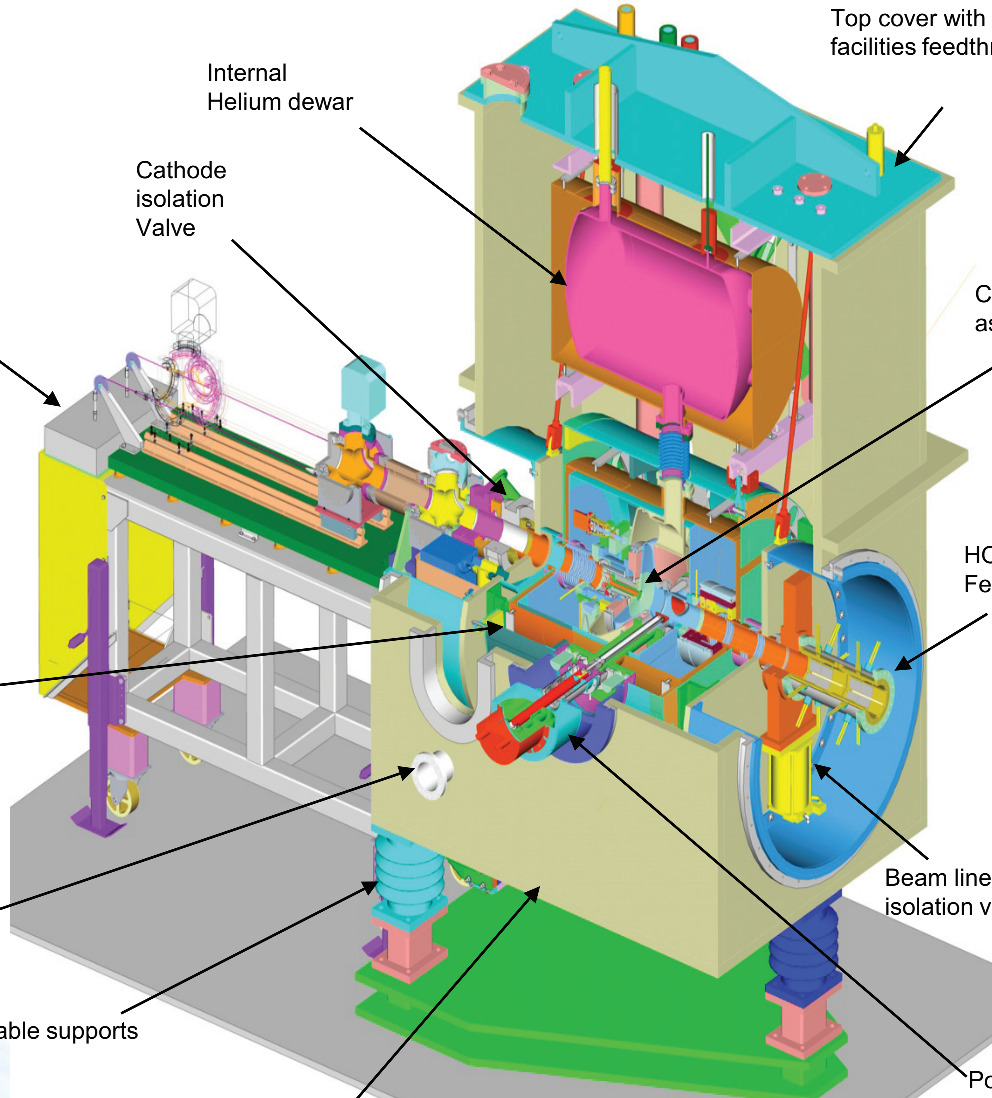
- The cavity is being fabricated, processed and vertically tested at JLab.
- The cold mass including a SC solenoid and a beam tube HOM absorber is assembled at JLab as well.
- First horizontal tests, module mounting and first beam tests will be done at HZB.
- The gun will be able to support 4 mA beam current.

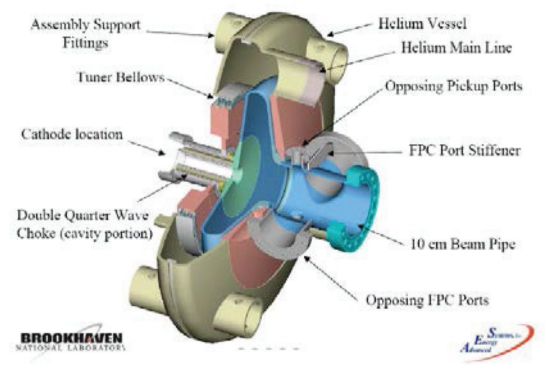
Parameter	Cavity 1.1
$R/Q(\Omega)$	150-149.5
E_{peak}/E_0	1.5-1.45
$E_{cathode}/E_0$	1-0.58
H_{peak}/E_{peak} (mT/(MV/m))	2.2
$\Phi_{launch}(E_{kin,max})$ (deg.)	60-50
E_{launch} (MV/m)	26-13.3
E_{kin} (MeV)	2.6
k_{cc} (%)	1.6
Q_{ext}	$3.6 \cdot 10^6$
$f_{1/2}$(Hz)	185
$P_{forward}$ (kW)	8.4
Δf_{peak} (Hz)	20 (expected)



Stacked Cavity with beam tube

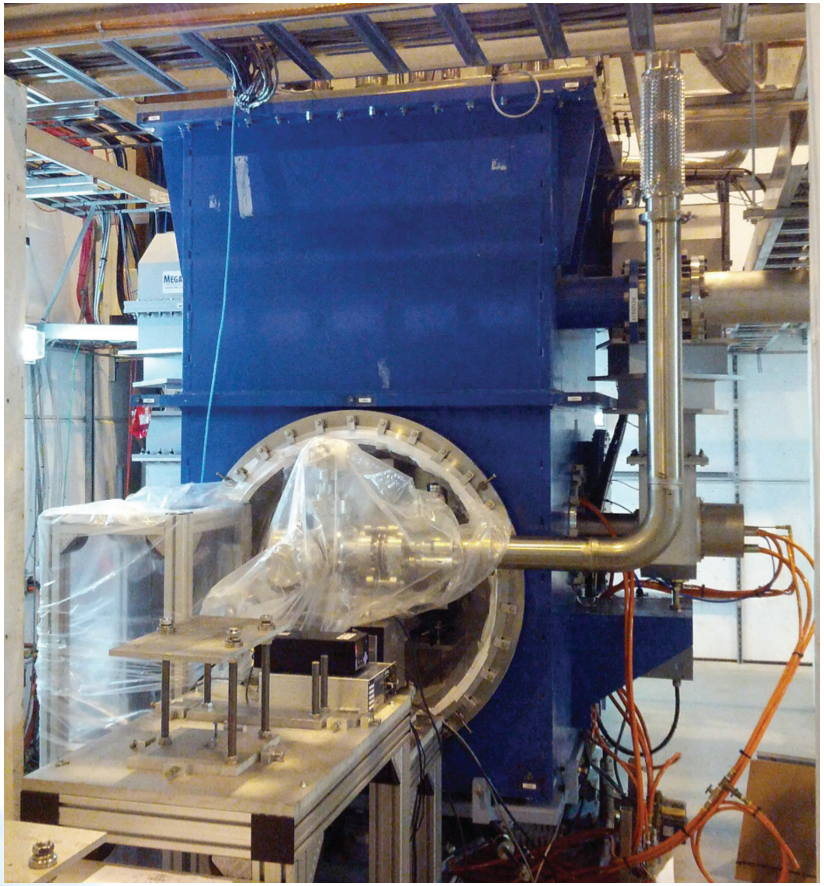
704 MHz SRF gun for BNL's ERL





- The 704 MHz elliptical half-cell SRF gun will produce an electron beam from a multi-alkali photocathode illuminated by a synchronized laser with rep. rate of up to 9 MHz.
- The goal is to demonstrate average beam current of 300 mA and bunch charge of 3.5 nC at 2 MeV.
- Its two Fundamental Power Couplers (FPCs) are capable to deliver 1 MW of RF power to a 500 mA electron beam at an energy gain of 2 MeV.
- HOM damping is provided by an external beamline ferrite load with ceramic break.
- A HTS solenoid is housed inside the cryomodule.

704 MHz SRF gun status



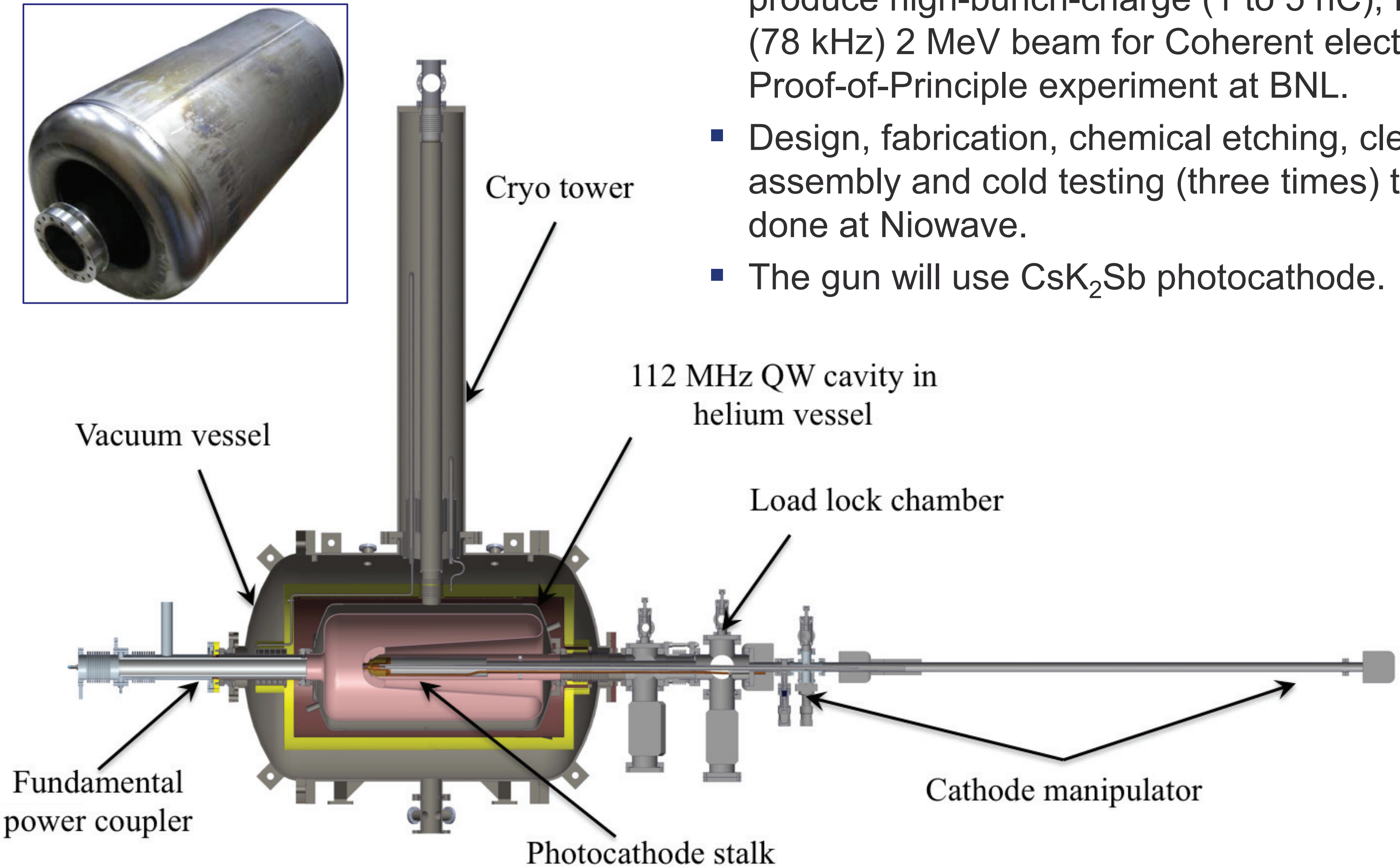
- Prior to assembly into the gun cryomodule, the two FPCs were conditioned off-line in standing wave mode with full reflection at variable RF phase. Maximum power was kW in CW (administrative limit).
- The gun cryomodule was assembled last year and is installed in the ERL block house. Its 1 MW CW klystron, cryogenic system and other ancillary systems are fully operational.
- The initial commissioning of the gun without a cathode is complete with the gun cavity achieving 2 MV (the 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.
- Currently the SRF gun is being conditioned with a copper cathode.
- The next step will be to test it with a high quantum efficiency multi-alkali photocathode and generate first beam (October/November).

Quarter Wave Resonator SRF guns

	BNL	U. W.	NPS
Frequency [MHz]	112	200	500
Beam tube aperture [cm]	10	10	6.35
Cavity diameter [cm]	42	60	24
Cavity length [cm]	110	50.3	20.3
Beam kinetic energy [MeV]	2	4	1.2
Peak electric field [MV/m]	38	53	51
Peak magnetic field [mT]	73	80.4	78
Peak cathode field [MV/m]	2.63	1.31	1.8
Geometry factor [Ohm]	38	85	125
R/Q [Ohm]	126	147	195
Q_0 (no cathode, 4.5 K)	3.7×10^9	3.3×10^9	1.2×10^9

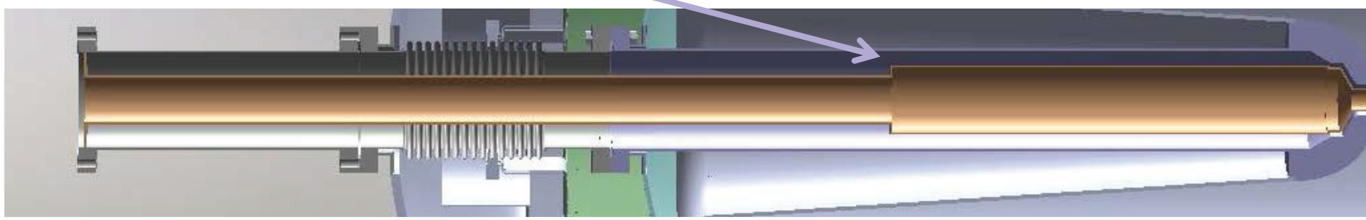
112 MHz QWR SRF gun

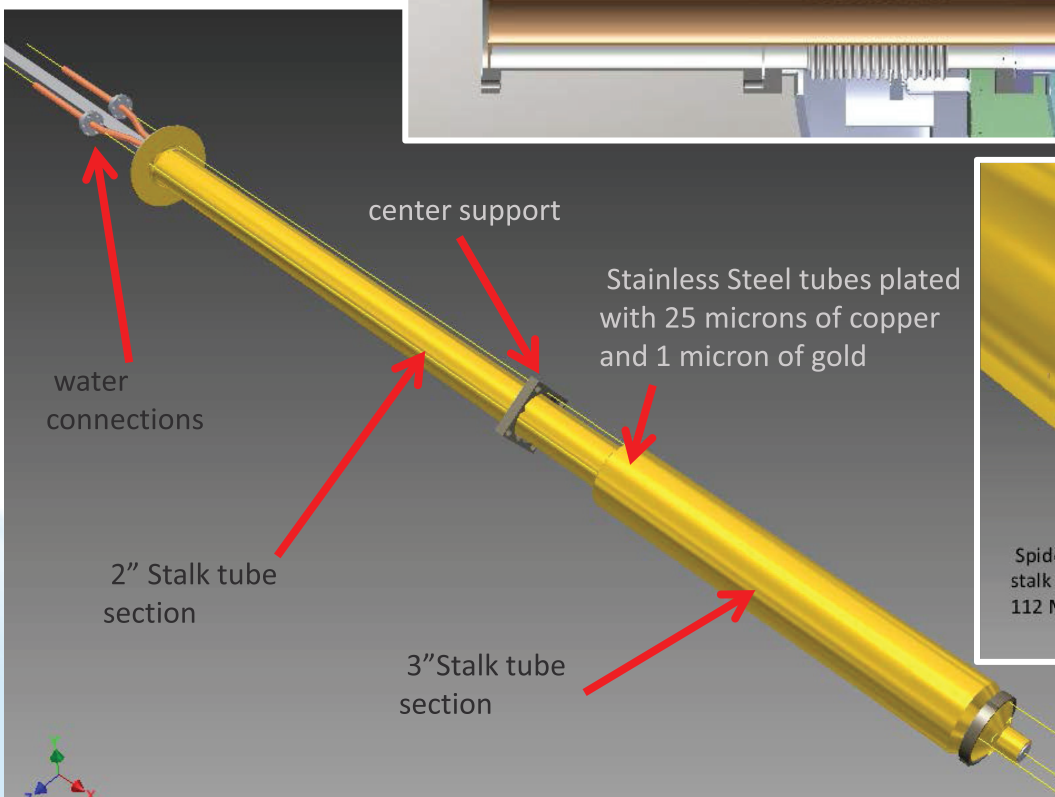
- Superconducting 112 MHz QWR was developed to produce high-bunch-charge (1 to 5 nC), low rep rate (78 kHz) 2 MeV beam for Coherent electron Cooling Proof-of-Principle experiment at BNL.
- Design, fabrication, chemical etching, cleaning, assembly and cold testing (three times) to date were done at Niowave.
- The gun will use CsK_2Sb photocathode.

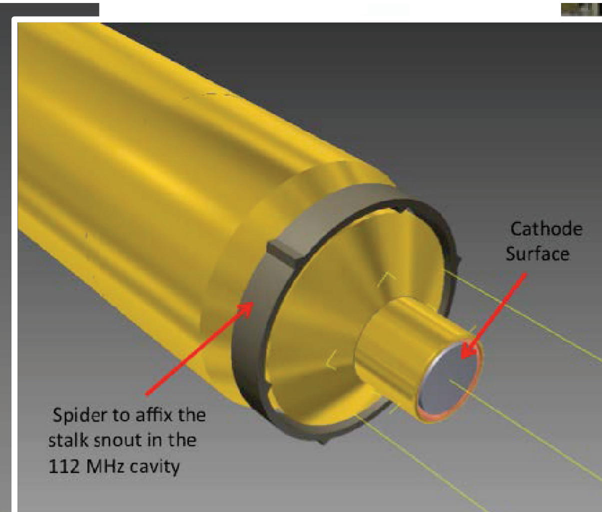


Cathode stalk design

- The cathode stalk is a hollow center conductor of the coaxial line formed by the stalk and the cavity.
- The stalk is shorted at one end and is approximately half wavelength long. It will be permanently installed in the gun.
- A step at $\lambda/4$ from the short creates a quarter-wave impedance transformer and reduces RF losses in the stalk from ~65 W to ~25 W.
- The gold plating is aimed to reduce radiation heat load from the RT stalk to the cold (4.5 K) niobium.
- A small cathode puck is inserted inside the stalk and can be replaced when necessary with a new one.

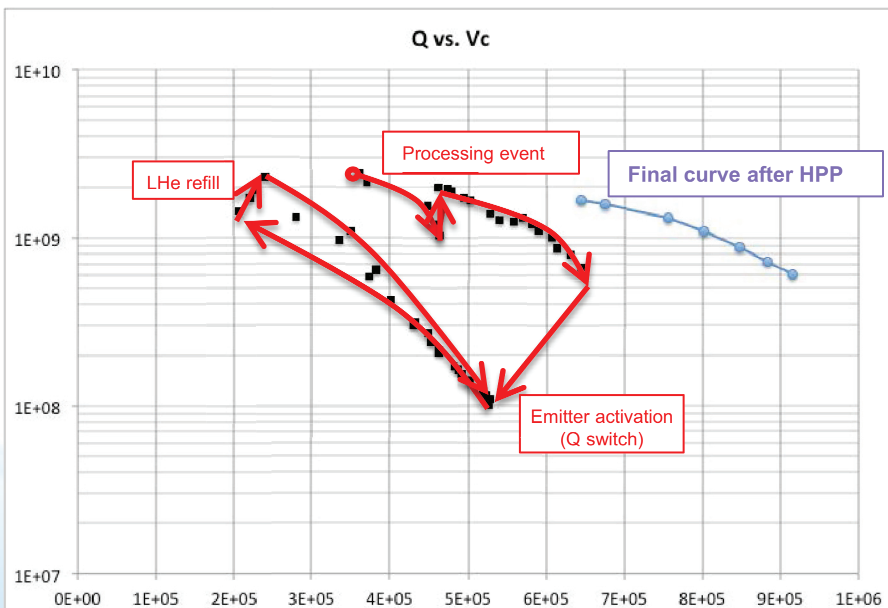






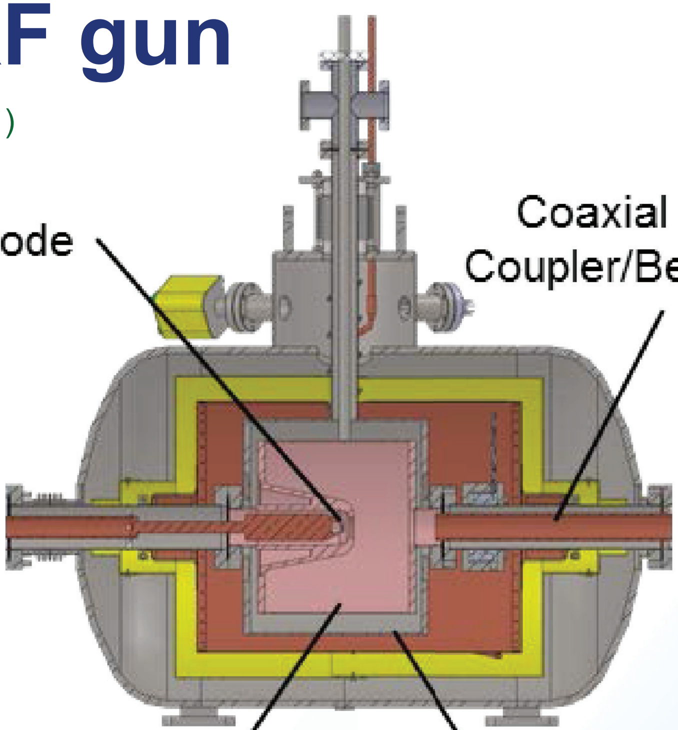
112 MHz SRF gun test results & plans

- The last cold test of the gun (in a new cryostat) w/o a cathode was successfully completed at Niowave last February.
- The gun reached 0.92 MV, limited by insufficient radiation shielding at Niowave.
- With no radiation shielding issue in the RHIC tunnel we should be able to reach higher gun voltage.
- The gun is currently in the RHIC tunnel, being prepared for installation into its final location. Testing at BNL will begin later this year / early next year.



500 MHz (Mk I) NPS SRF gun

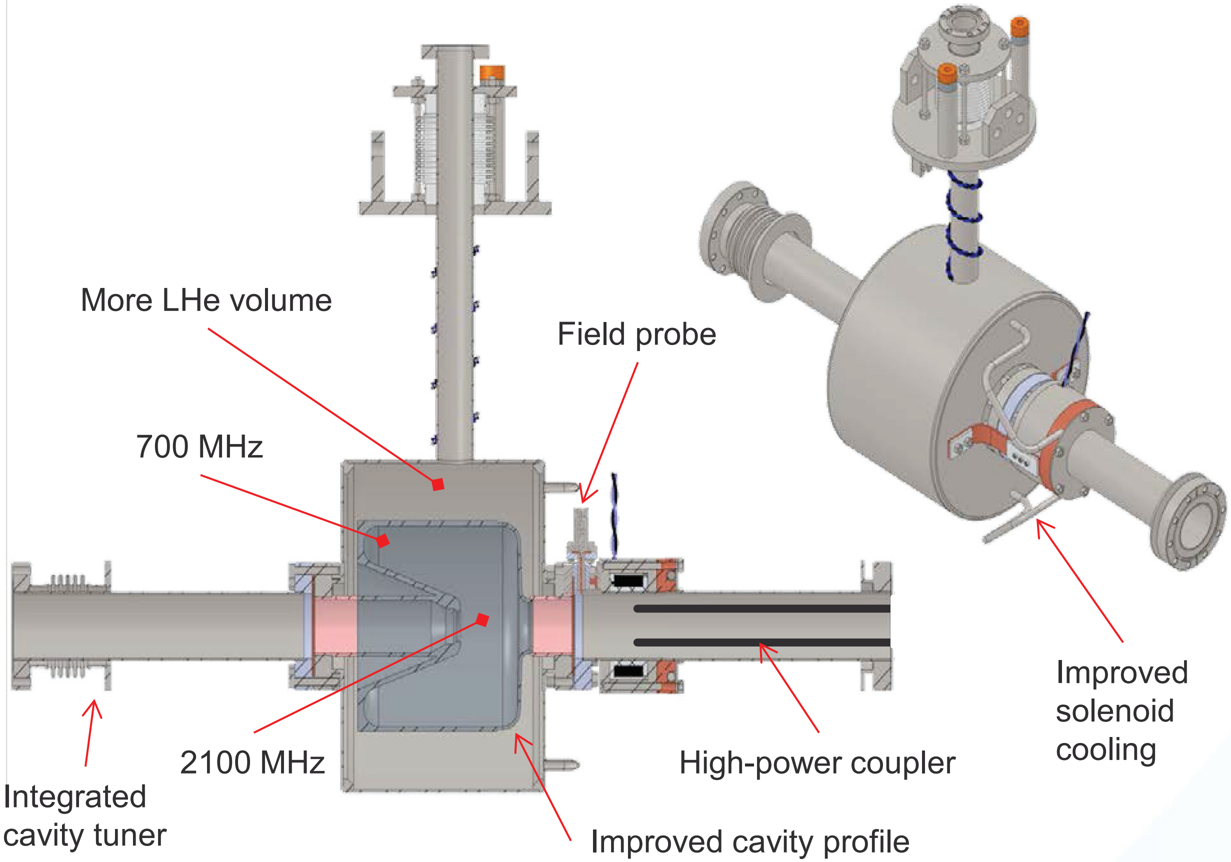
J.R. Harris, et al., *Phys. Rev. ST Accel. Beams* **14**, 053501 (2011)



- Built by and tested at Niowave, Inc.
- Nb cathode on Cu stalk.
- Initial results (not optimized):
  - Beam energy > 460 keV
  - Bunch charge > 70 pC
  - Normalized rms emittance ~5 mm-mrad
- **First** operation of SRF Quarter Wave gun.
- Successful Navy/Industry/Academia partnership.

700 MHz (Mk II) NPS SRF gun

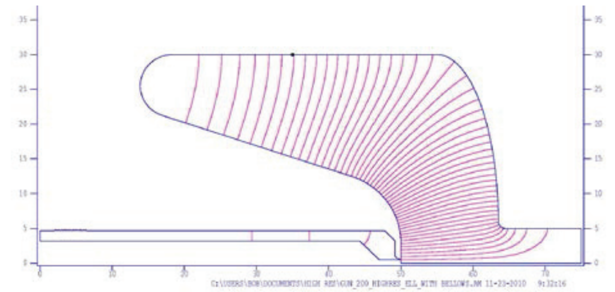
TUPSO08, WEPSO83

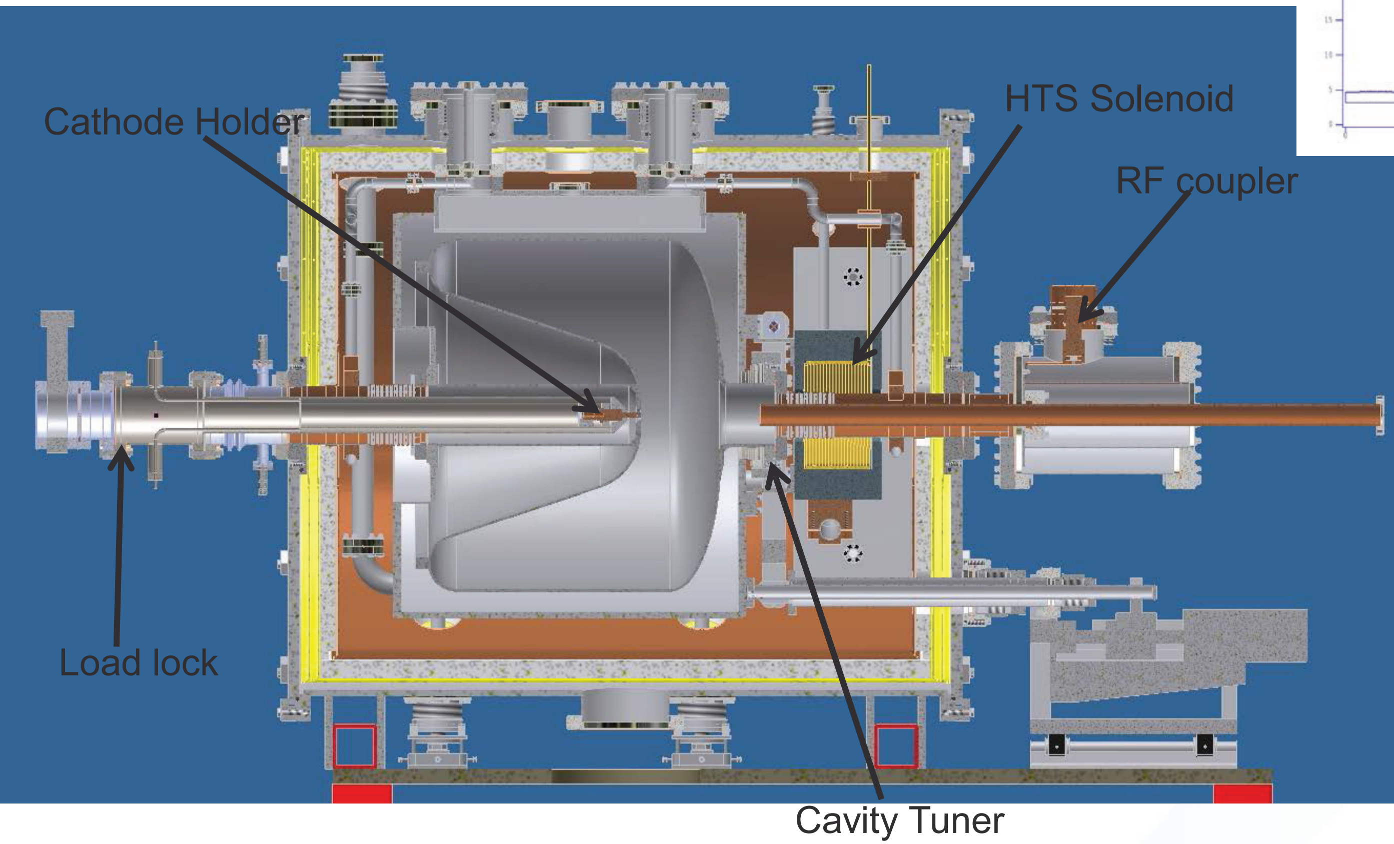


- This follow-on design includes a number of improvements over the Mark I design.
- The gun is presently under testing at Niowave.
- It was conditioned to 500 kV cavity voltage, accelerated electron bunches to 260 keV, generated bunch charge >35 pC from a Nb cathode and UV laser.
- A single FE tip (tungsten) was tested and produced 100 nA average beam current.

- After testing at Niowave is complete, the gun will be shipped to Los Alamos, where it will be installed it in the LEDA tunnel for further testing.
- Studies at LANL will focus on increasing the operating gradient; measuring beam properties as a function of various parameters; and testing high-QE cathodes.
- This performance information will be needed to design the next generation of quarter-wave SRF guns with significantly increased performance

WiFEL 200 MHz SRF gun





Design parameters

- Cathode field: 40 MV/m
- Kinetic energy: 4 MeV
- Bunchcharge: 200 pC
- Normalized transverse emittance: 1 mm-mrad
- Average beam current: 1 mA

- Low frequency allows operation at 4.2 K; QWR geometry chosen to reduce the size of the cavity.
- Goal: to demonstrate single bunch beam dynamics and operation of the SRF gun.
- Low repetition rate drive laser allows option of using doubled or tripled Ti:Sapphire laser.
- Cu cathode will be used for initial operation: little chance of cavity contamination from evaporated cathode material; cathode will not degrade over time like semiconductor; no cathode preparation chamber needed.
- The first beam was generated on August 1, 2013; results will be reported at NA-PAC’13.

Summary

- SRF photoinjectors have made significant progress during the last several years.
- Several guns generated their first beams.
- First in the world FEL lasing was achieved with an at HZDR.
- ELBE gun demonstrated feasibility of the SRF gun concept with a normal-conducting cathode. Cs_2Te demonstrated very good performance with life time of ~1 year. O degradation of the cavity performance was noticed.
- For high average current / high bunch charge operation CsK_2Sb is preferred as it can operate with green lasers (unlike UV lasers needed for the Cs_2Te), which makes it easier to build laser/optics systems.
- Other photocathodes are being developed, most notably diamond-amplified.
- Several QWR guns were developed with three producing beams already. These guns are very promising for high bunch charge operation.
- Thus far SRF guns generated bunch charges up to ~100 pC. The average beam currents are still below 1 mA. More efforts are needed to boost these parameters.
- The field is very active. More experiments are coming soon, promising new and exciting results.

Acknowledgement

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