SRF Gun Development for High Brightness, Short Pulse Applications

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Ultra Fast Beams and Applications, Yerevan, Armenia

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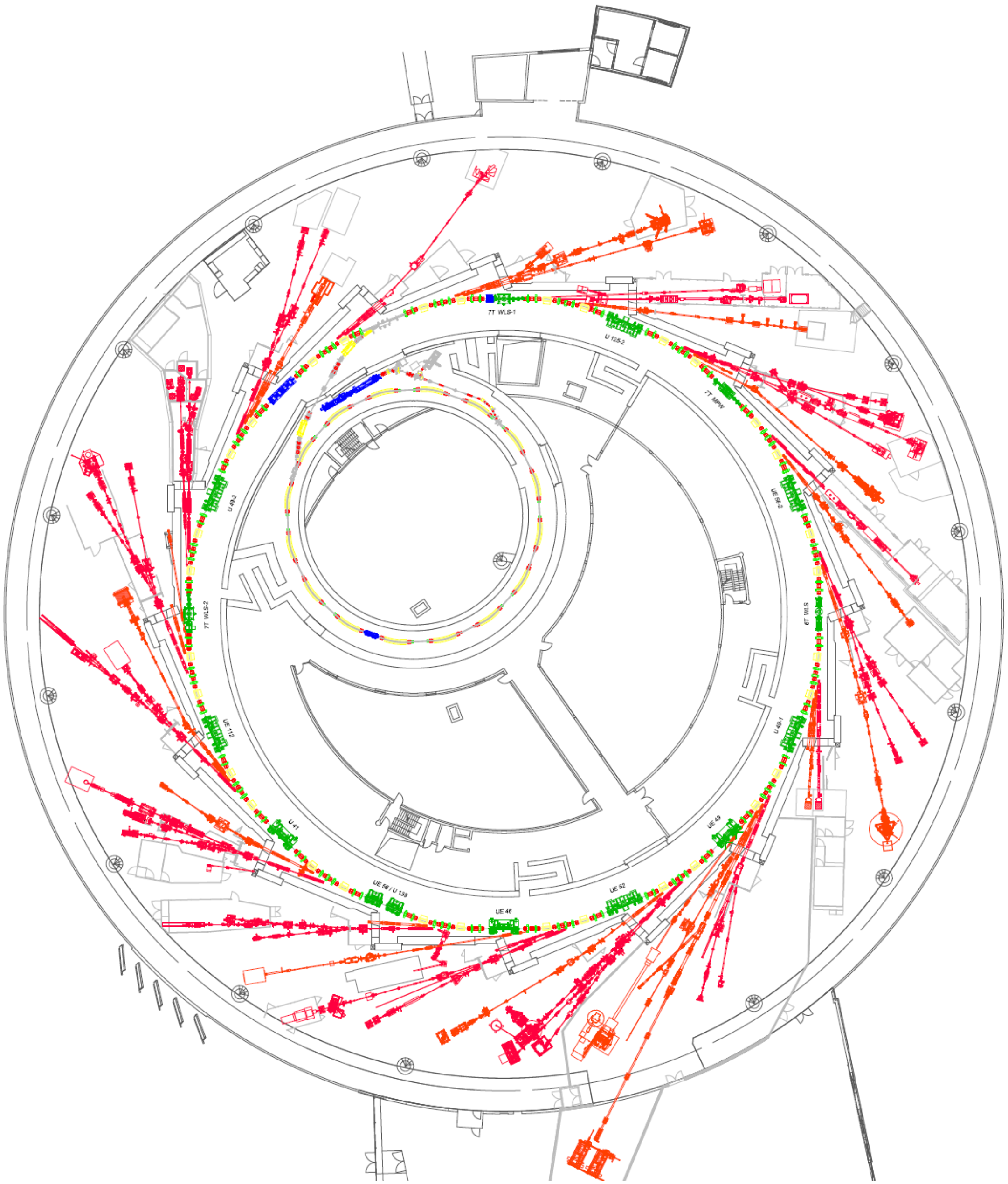
Contents

Bessy II



Soft X-ray storage ring light source Bessy II (in operation since 1999)

Bessy II Parameters	
Energy	1.7 GeV
Circumference	240 m
Horizontal emittance	5 nm rad
Beam current	300 mA
RF frequency	500 MHz
max. RF voltage	2 MV
Bunch length (rms) low-α	15 ps 2 ps
Mom. Comp. factor low-α	7.5×10^{-4} 3.5×10^{-5}

Spectral range → soft X-rays
Short pulses with low-α and femtoslicing
Diverse user community

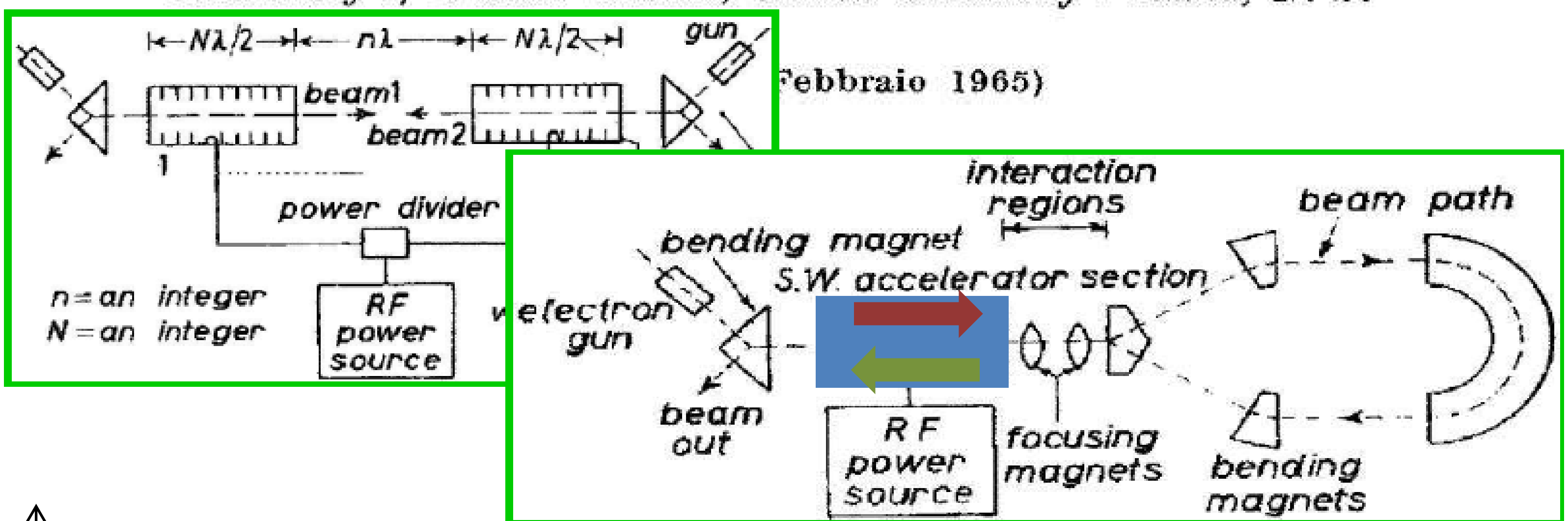
An alternative approach: Energy-Recovery Linac

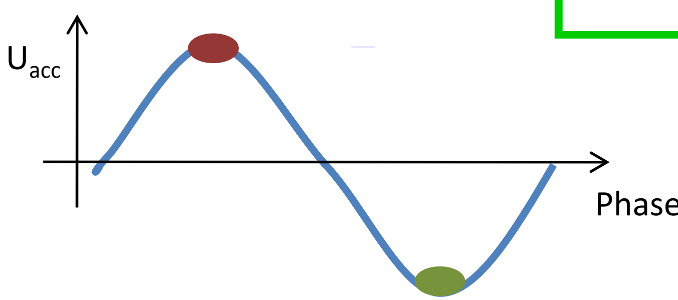
A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER

Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

(…Febbraio 1965)





The promise:

Acceleration of high average currents with linear accelerator

→ High brightness for photon users

Future Light Sources ↔ Electron Beam Properties

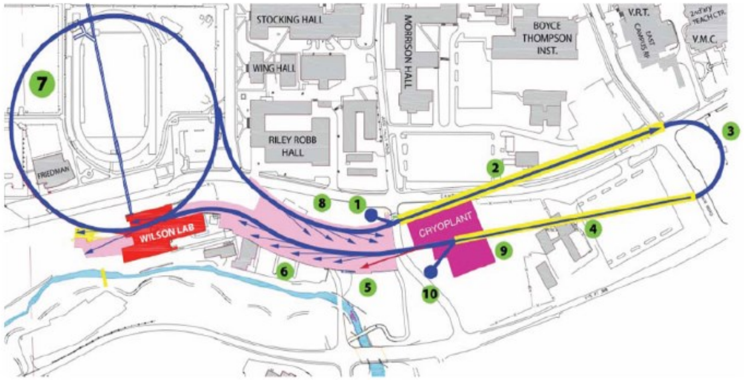
Light source	Beam parameter	Storage ring	Energy-Recovery Linac
		$\frac{\sigma_E}{E} \propto \frac{\gamma}{\sqrt{\rho}}$	$\frac{\sigma_E}{E} \propto \frac{1}{\gamma}$
Coherent flux	$I/\varepsilon_x\varepsilon_y$	$\varepsilon_x \propto \gamma^2/N^3$, $\varepsilon_y = \kappa \cdot \varepsilon_x$	$\varepsilon_{x,y} = \frac{\varepsilon_o}{\gamma}$
Pulse length	σ_t	$\sigma_t \propto \sqrt{\frac{\alpha}{V'}} \cdot \frac{\sigma_E}{E}$	$\sigma_t = f(\sigma_{to})$

Storage ring: equilibrium beam dimensions, growing with increasing beam energy

Energy-Recovery Linac: adiabatic damping of beam dimensions, beam manipulation

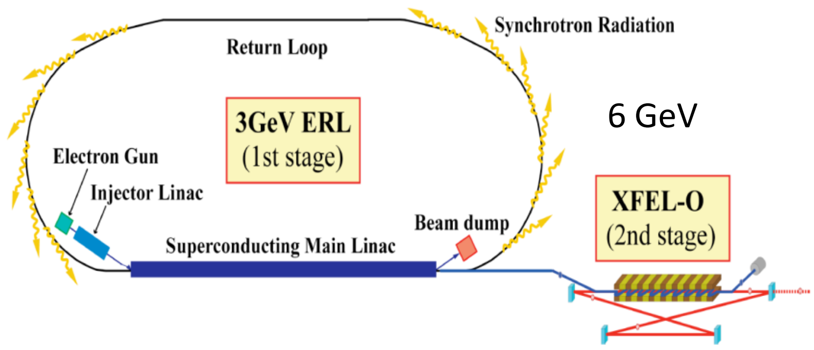
Large scale light source ERLs - proposals

Cornell ERL

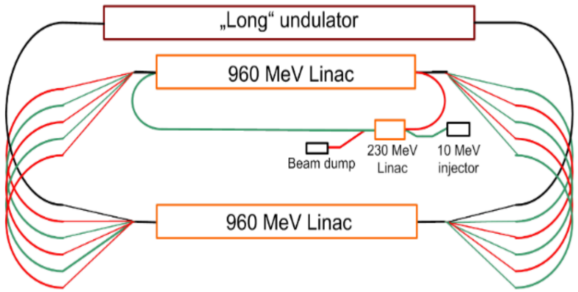


5 GeV, 100mA, ε = 8 pm rad
(ε_n = 0.08 μm (@77pC) , 2ps)

KEK ERL



3 GeV, 100mA, ε = 17 pm rad
(ε_n = 0.1 μm (@77pC) , 2ps)



Femto Science Facility (FSF)

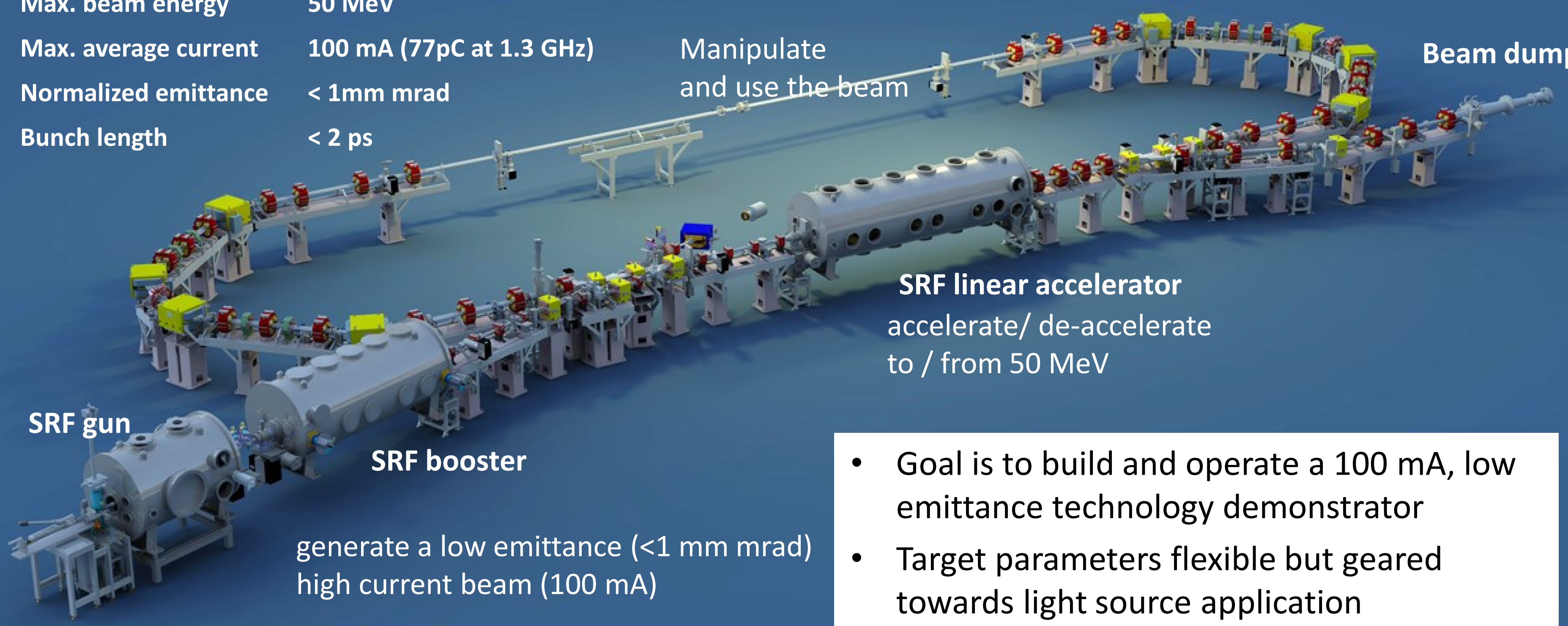
(multi turn, split linac), A. Matveenko et al., HZB

6 GeV, 20/5 mA, ε = 8/40 pm rad
(ε_n = 0.1/0.5 μm (@15/4 pC), < 1 ps / 10 fs)

Courtesy Reuters, LHC, CERN

bERLinPro – Berlin Energy Recovery Linac Project

Max. beam energy	**50 MeV**
Max. average current	**100 mA (77pC at 1.3 GHz)**
Normalized emittance	**< 1mm mrad**
Bunch length	**< 2 ps**

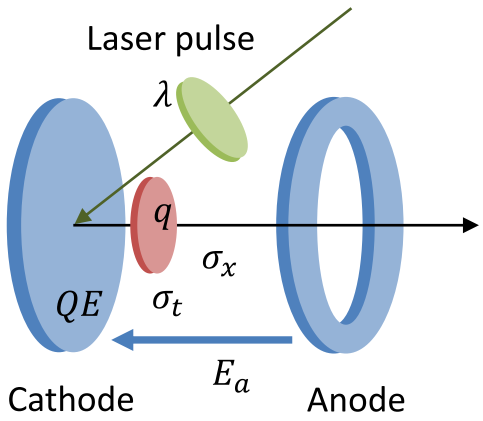


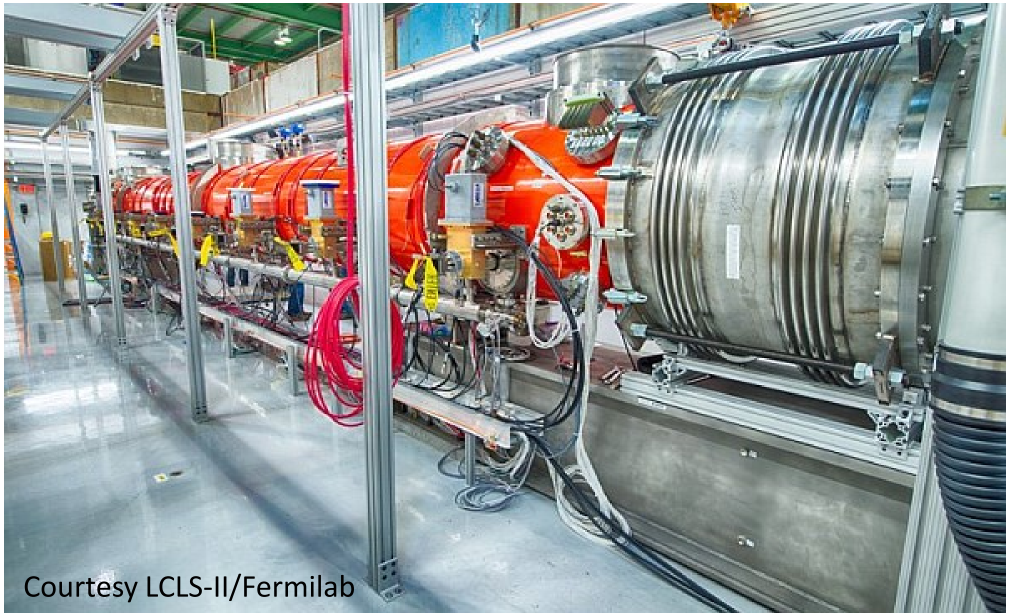
- Goal is to build and operate a 100 mA, low emittance technology demonstrator
- Target parameters flexible but geared towards light source application
- Project started in 2011, total investment 41 MEUR, fully funded by HGF, HZB and the state of Berlin

Source development for energy recovery linacs
the quest for brightness and average current

The strategy towards high brightness at high average current

Embed a cathode with high QE and low workfunction in a high electric field and illuminate it with short laser pulses at high wavelength. Then accelerate quickly to relativistic energies.

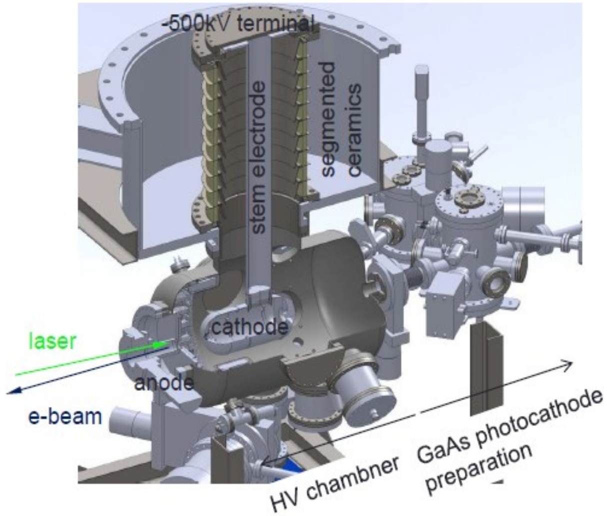


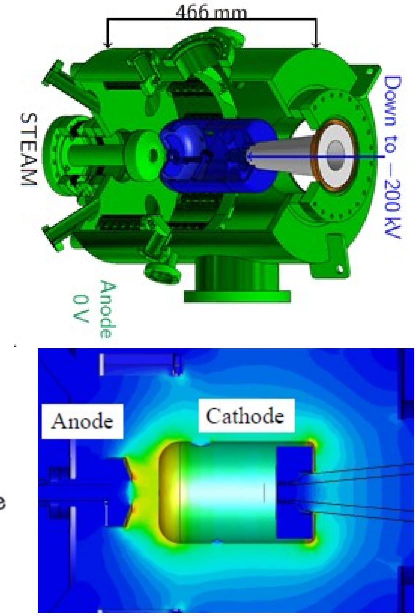


The DC gun

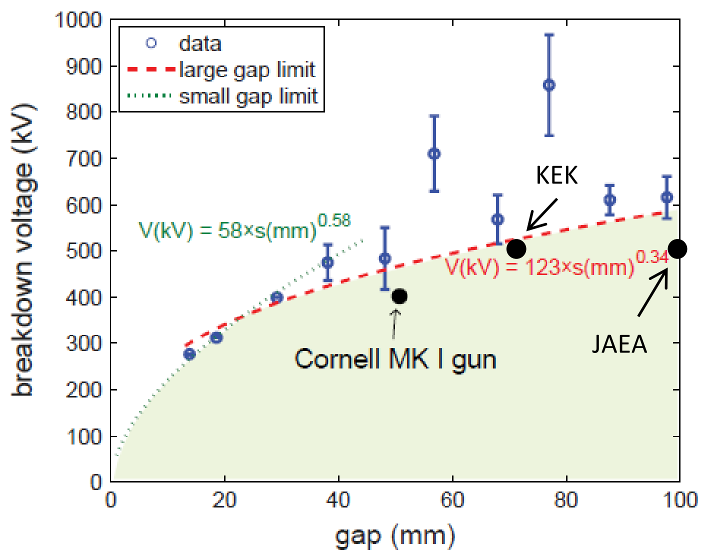
- DC operation at 350…500 kV achieved at Cornell and JAEA/KEK
- Excellent vacuum conditions for high QE photocathodes
- Cornell achieved currents in excess of 60 mA
- Control of dark current from halo
- Low exit energy requires prompt acceleration and beam conditioning
- Gradients > 10 MV/m challanging

JAEA DC gun. N. Nishimori





STEAM MESA DC gun, K. Aulenbacher

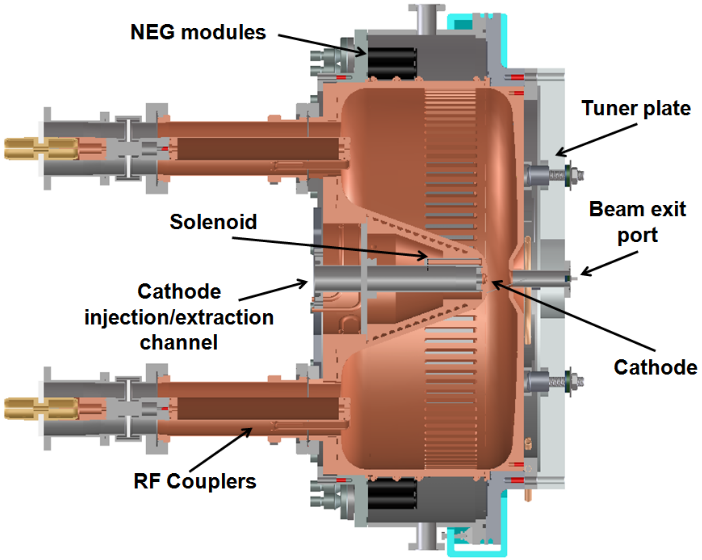


Vacuum interruptor data and DC guns

Original plot taken from J. Maxson (Cornell). Data point for KEK from M. Yamamoto and for JAEA from N. Nishimori, both presented at ERL 2015

The NCRF gun

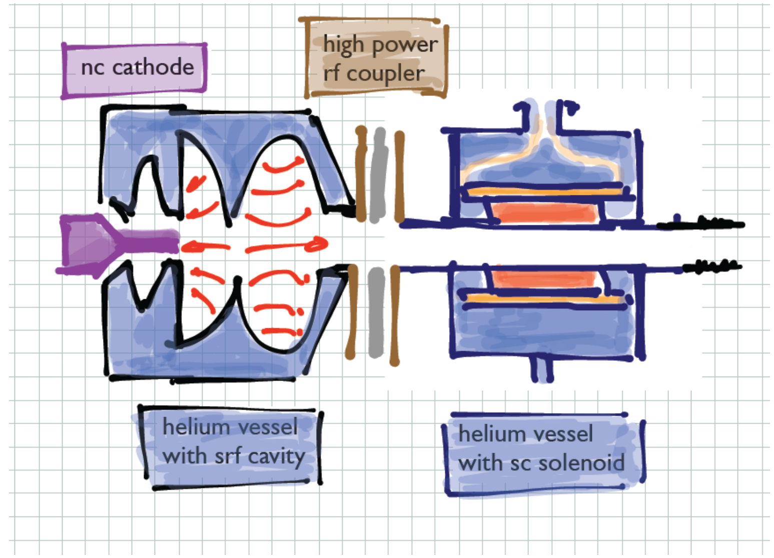
- Very succesful as sources for FELs (FLASH, LCLS) with very high gradients > 100 MV/m
- Operation in CW mode at high current (32 mA, Boeing) possible, at MHz repetition rates with gradients of 20 MV/m (LBNL)
- Compatible with high QE photocathodes (Cu, Cs_2Te, CsK_2Sb) → large volume (helps also cooling), low frequency
- Control of dark current issues (fieldemission)
- Very high currents (100 mA) together with high exit energy (> 1 MeV) difficult due to ohmic power losses



K. Baptiste, et al, NIM A 599, 9 (2009)
F. Sannibale, et al., PRST-AB 15, 103501 (2012)

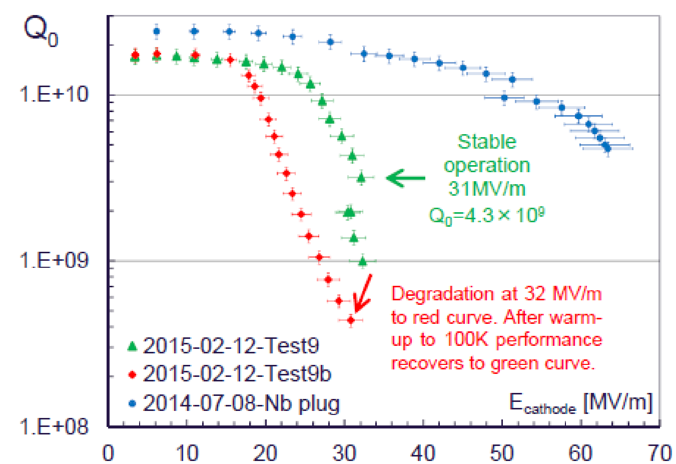
The SRF gun

- Potential for high cathode gradient (several tens of MV/m)
- CW operation at 100% duty cycle possible
- Relatively young technology, need more experimental setups
- Control of multipacting and dark current from field emission
- Implications due to high QE cathode/ SRF cavity interface → impact on cavity performance

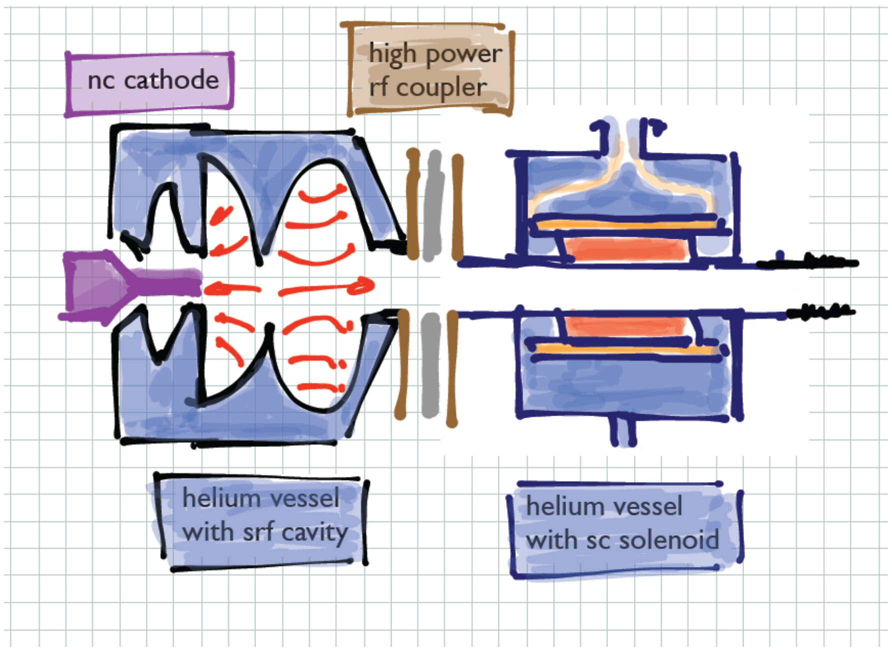


Courtesy D. Kostin

D. Kostin, et al., presented at SRF 2015

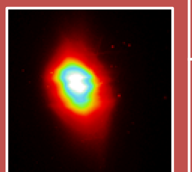


Push limits of SRF gun performance for bERLinPro
Sketch the idea and make first design choices

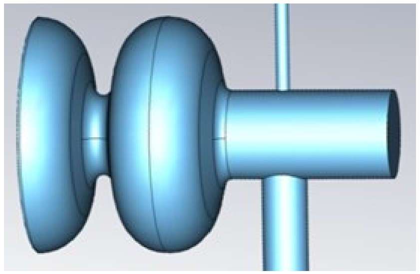


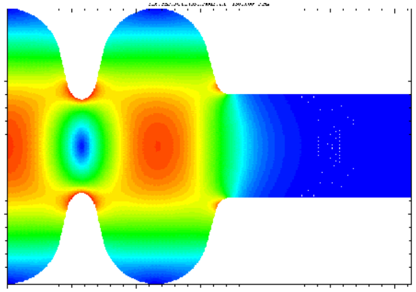
1. Gun cavity with 1.5 cells to compromise between gradient (> 10 MV/m) and exit beam energy (1 MeV< E < 2.3 MeV)
2. Twin couplers, each good for 115 kW average power → maximum exit energy of 2.3 MeV
3. Superconducting solenoid close to gun cavity
4. Normal-conducting photocathode with high QE in the visible (for 100 mA and 532 nm → 25W%)

Staged approach

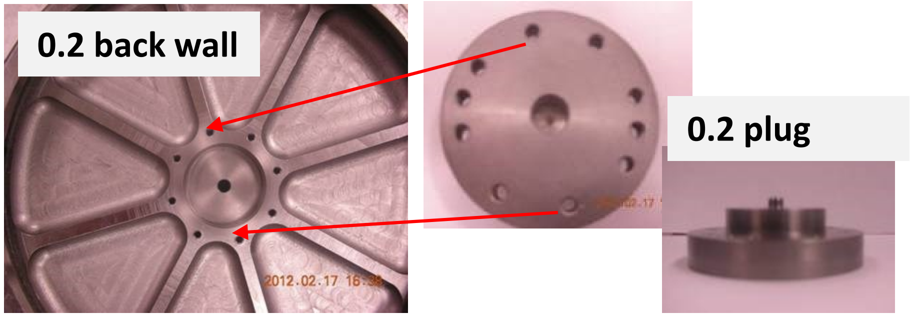
Gun System No.	Cavity	Cathode	Interface	Achievements / Goals
Gun0 **2010 - 2013** 	0.1: 1.6cell with standard TESLA geometry	Pb 10^{-4} at UV	Pb film coated on backwall by plasmonic arc deposition	First beam, Emittance studies, Cathode QE studies and manipulation with laser cleaning
	0.2: 1.6cell with standard TESLA geometry	Pb	Plug with Pb film fitted into hole of cavity backwall	Emittance studies, Beam energy of 2.5 MeV (27 MV/m)

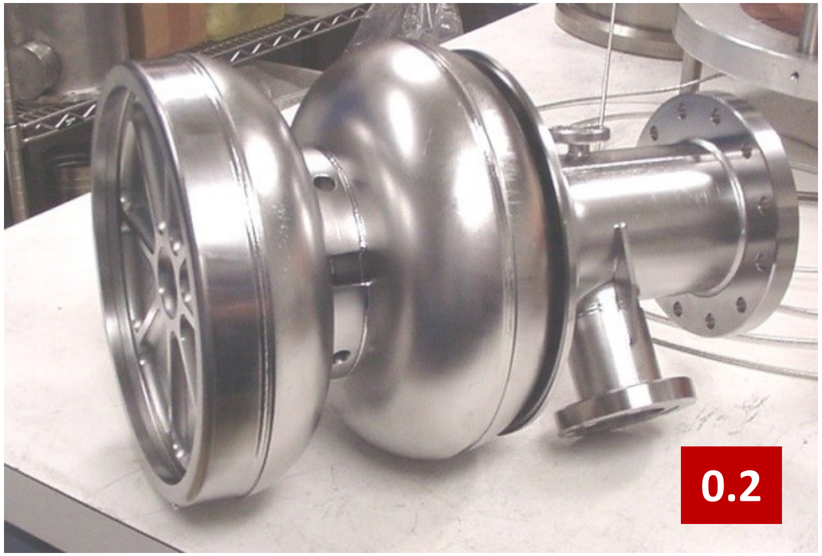
Gun0: two gun cavities for the hybrid Pb/Nb gun built by P. Kneissel at JLAB





Frequency π mode	1300 MHz
E_{pk}/E_{acc} (β=1)	1.86
H_{pk}/E_{acc}	4.4 mT/(MV/m)
Geometric factor	212 Ω
R/Q (linac, β=1)	190 Ω



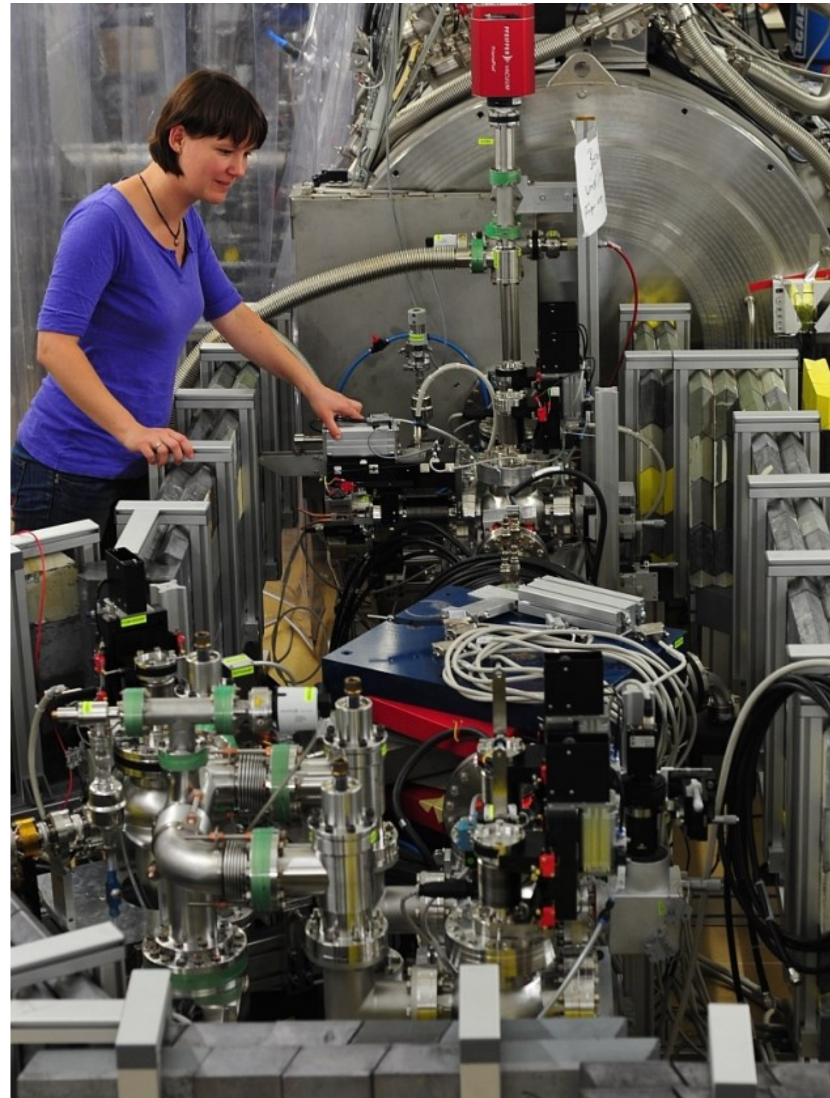


Gun0: setup and beam diagnostics

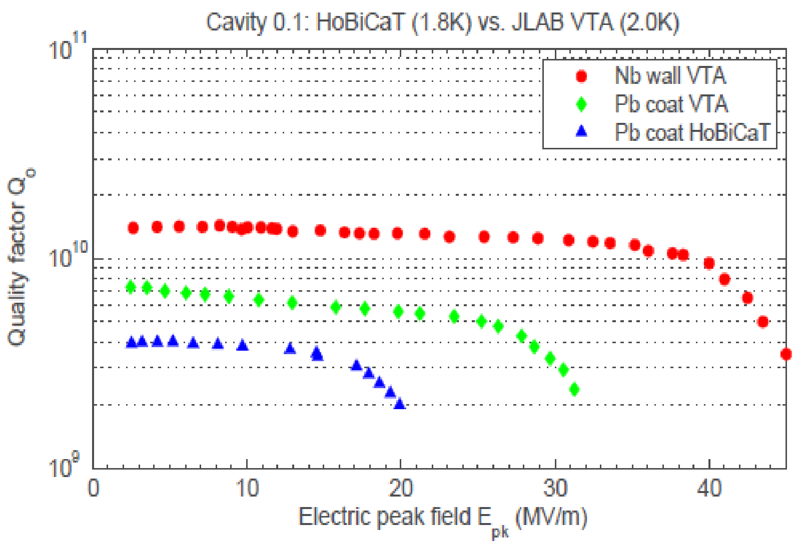
Upgrade to HoBiCaT –
horizontal bi-cavity test stand
Drive laser
(258 nm, 2..3 ps fwhm, 8 kHz)
GunLab diagnostics beamline

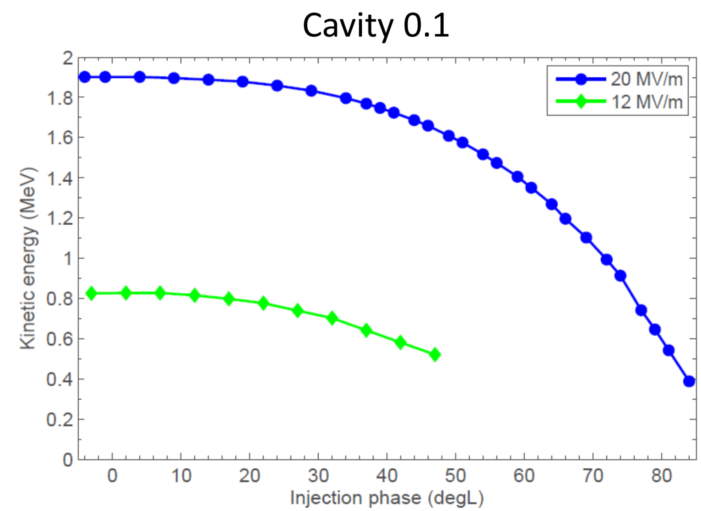
ARPES/XPS beamline at Bessy II
Field Emission Setup (FES) at HZB
PhotoathodeLab

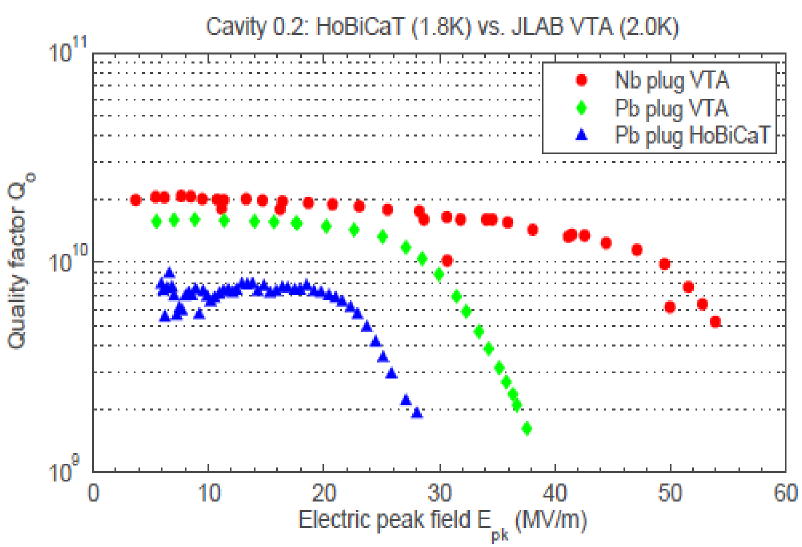
SEM/EDX at Fritz-Haber Institute
(MPG-FHI)
Compact QE vacuum setup at HZDR

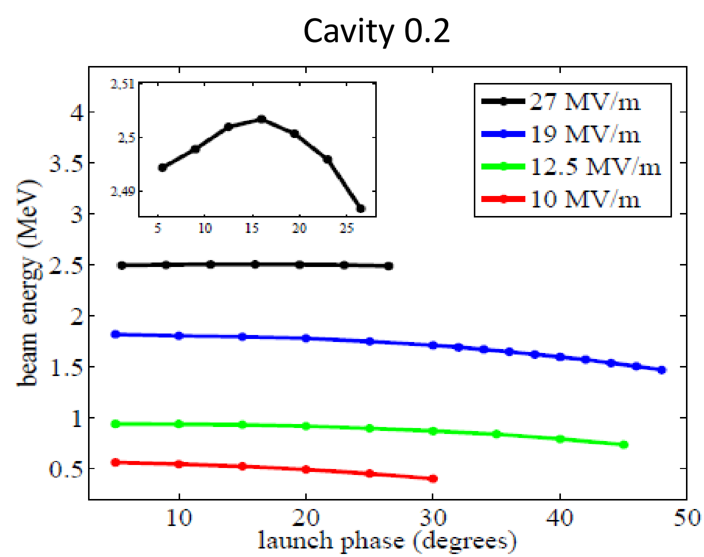


Results from RF measurements





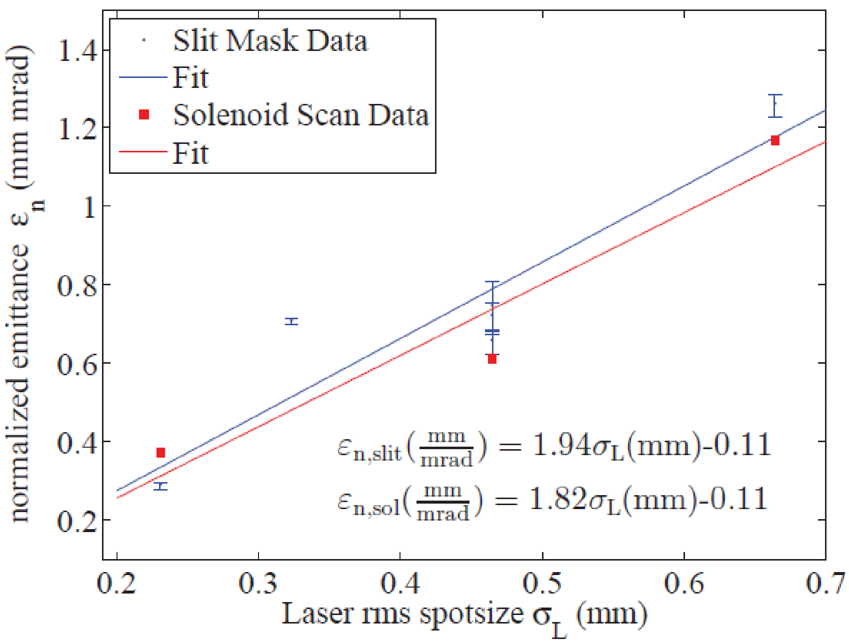


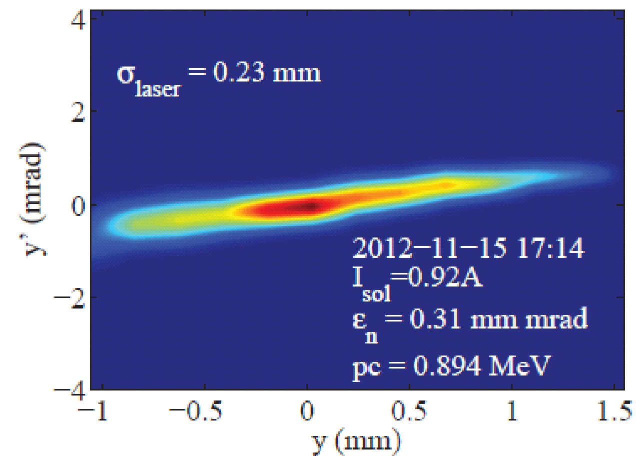


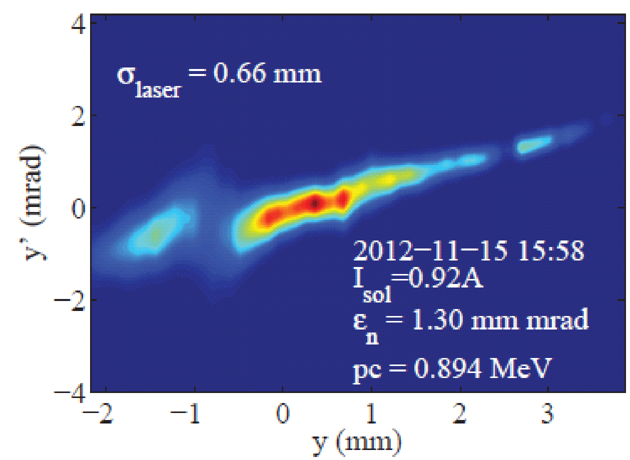
T. Kamps, et al., Prof. of IPAC 2011
A. Neumann, et al., Prof. of IPAC 2011
M. A. H. Schmeißer, et al., Proc. of IPAC 2012
A. Burrill, et al., Proc. of IPAC 2013

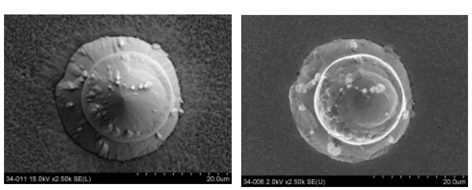
Beam emittance measurements

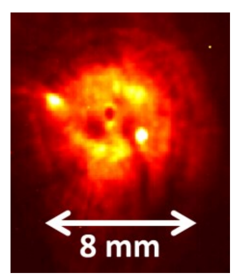
Emittance and phase space measurements with solenoid scan and slit mask method





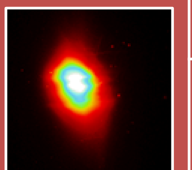


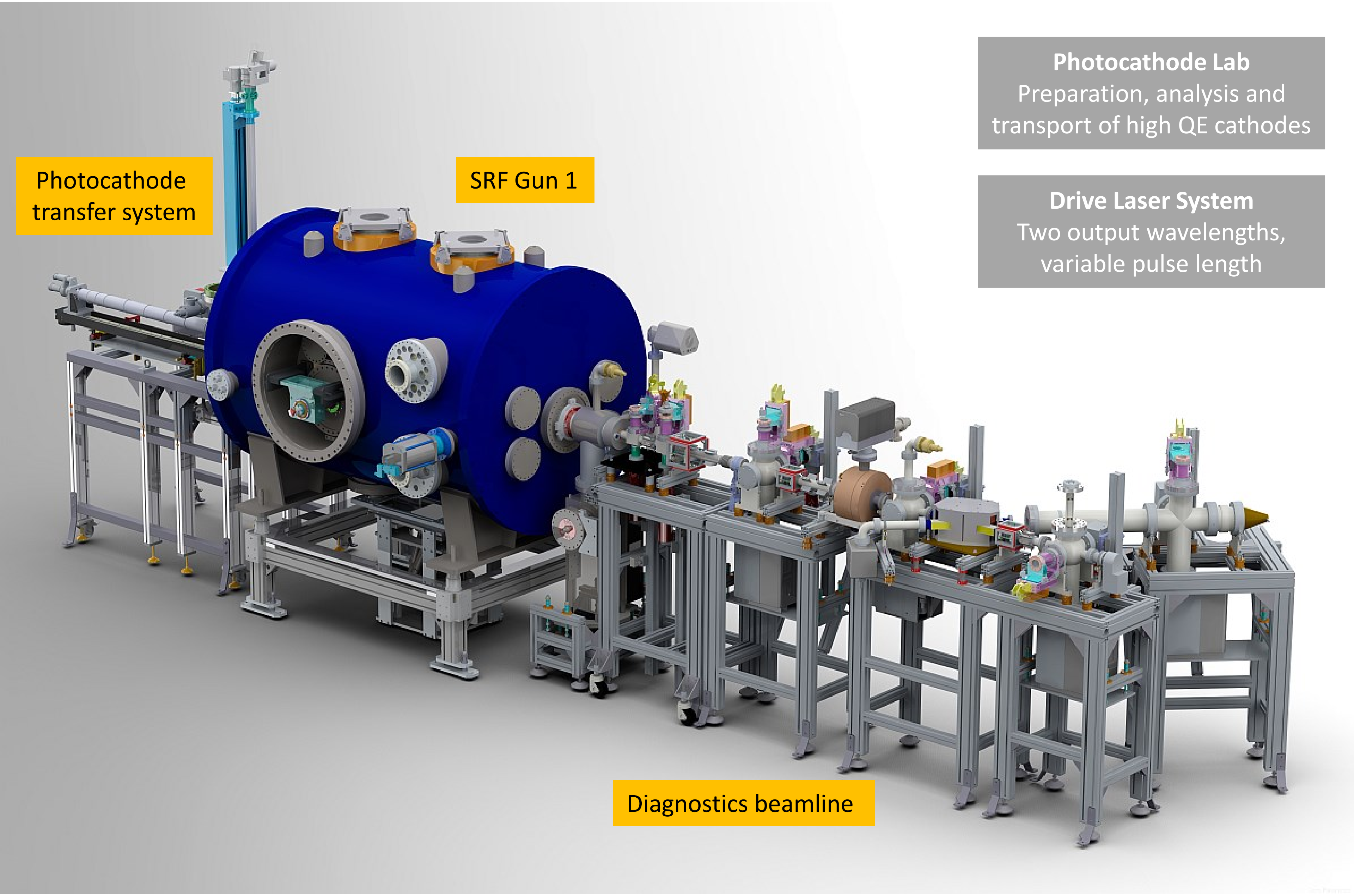




M. A. H. Schmeißer, et al., Proc. of IPAC 2013

Staged approach

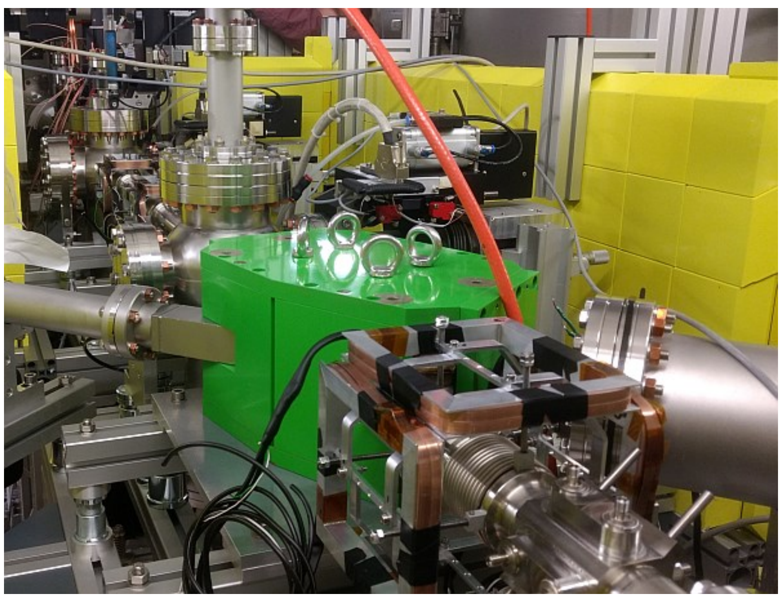
Gun System No.	Cavity	Cathode	Interface	Achievements / Goals
Gun0 2010 - 2013 	0.1: 1.6cell with standard TESLA geometry	Pb 10^{-4} at UV	Pb film coated on backwall by plasmonic arc deposition	First beam, Emittance studies, Cathode QE studies and manipulation with laser cleaning
Gun0 (cont.)	0.2: 1.6cell with standard TESLA geometry	Pb	Plug with Pb film fitted into hole of cavity backwall	Emittance studies, Beam energy of 2.5 MeV (27 MV/m)
Gun1 	1.1: 1.4cell optimized for ERL class gun with CW coupler	CsK2Sb 10^{-2} at Green	Electrically and thermially insulated cathode insert	High brightness beam from high QE cathode up to 5 mA
Gun1 (cont.)	1.2: 1.4cell as 1.1	CsK2Sb	Cathode insert	(cont.)
Gun2	2.1: 1.4cell optimized for ERL class gun with high power coupler	CsK2Sb or other multi-alkali	Cathode insert	High average current up to 100 mA
Gun2 (cont.)	2.n:	...	...	(cont.)

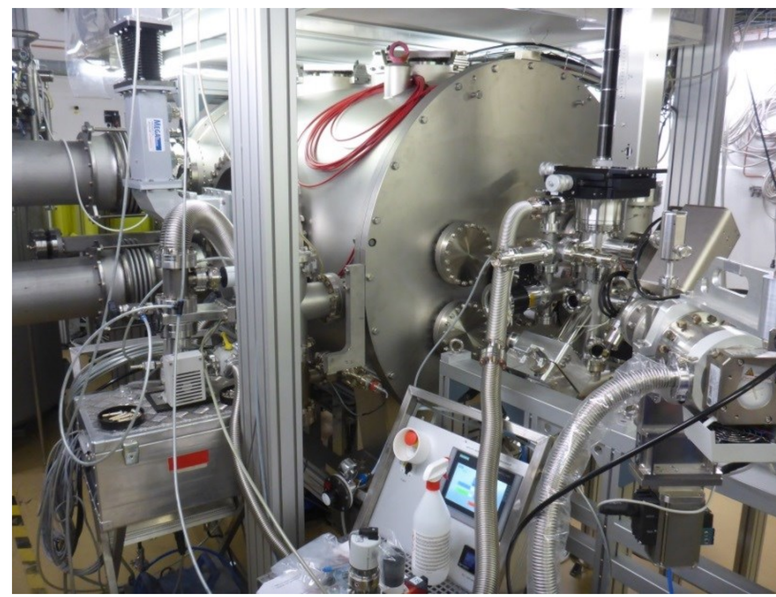


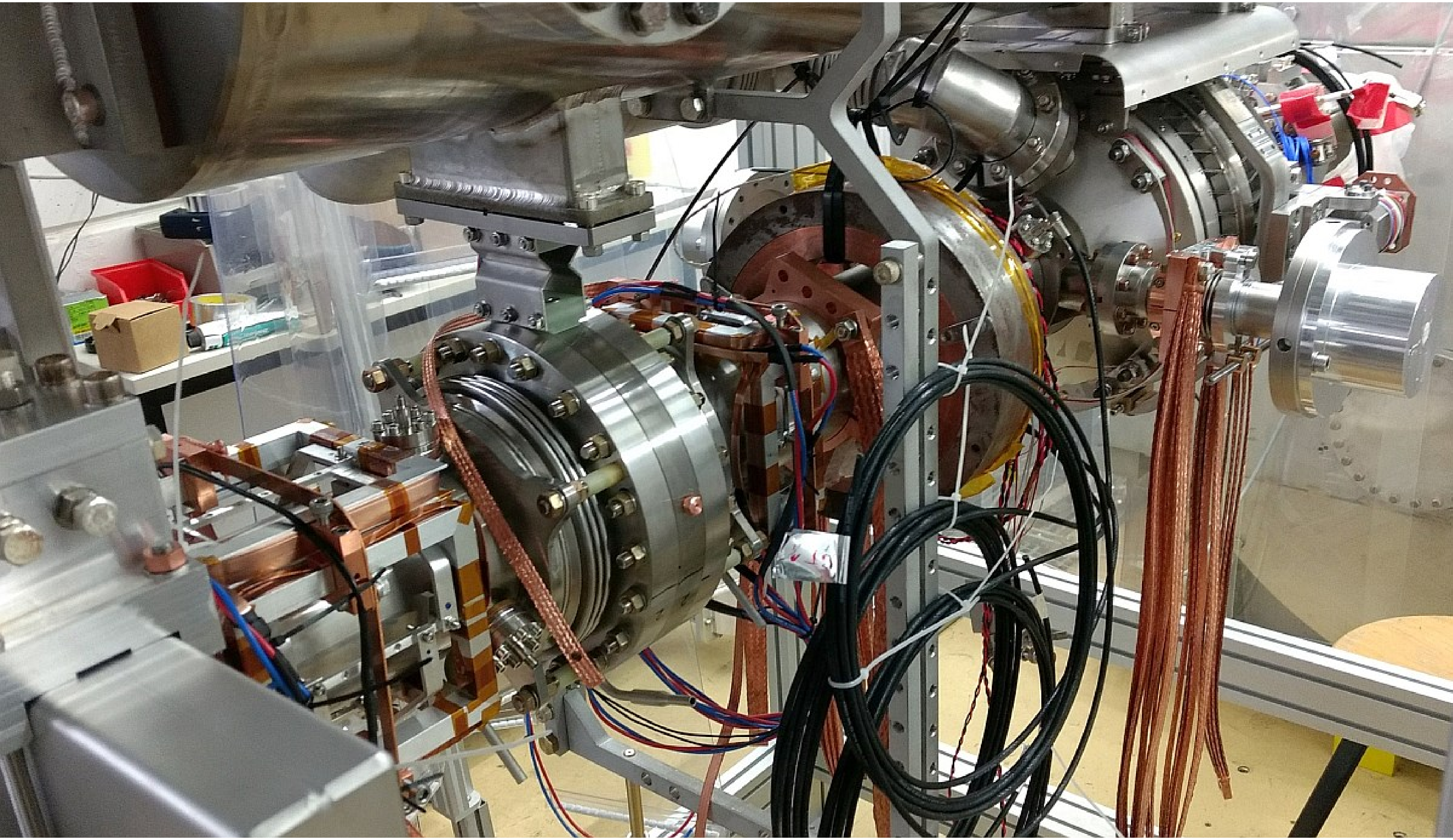
Photocathode Lab
Preparation, analysis and transport of high QE cathodes

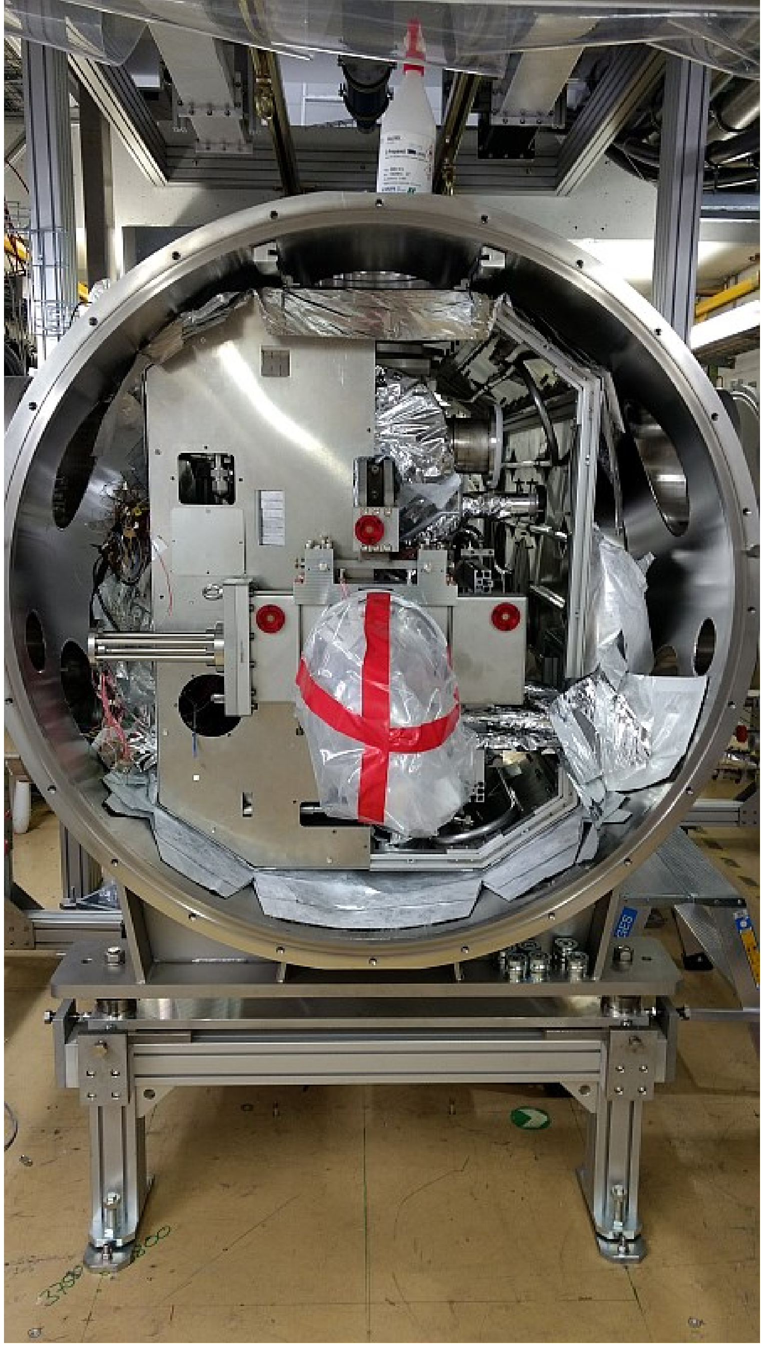
Drive Laser System
Two output wavelengths, variable pulse length


Linde

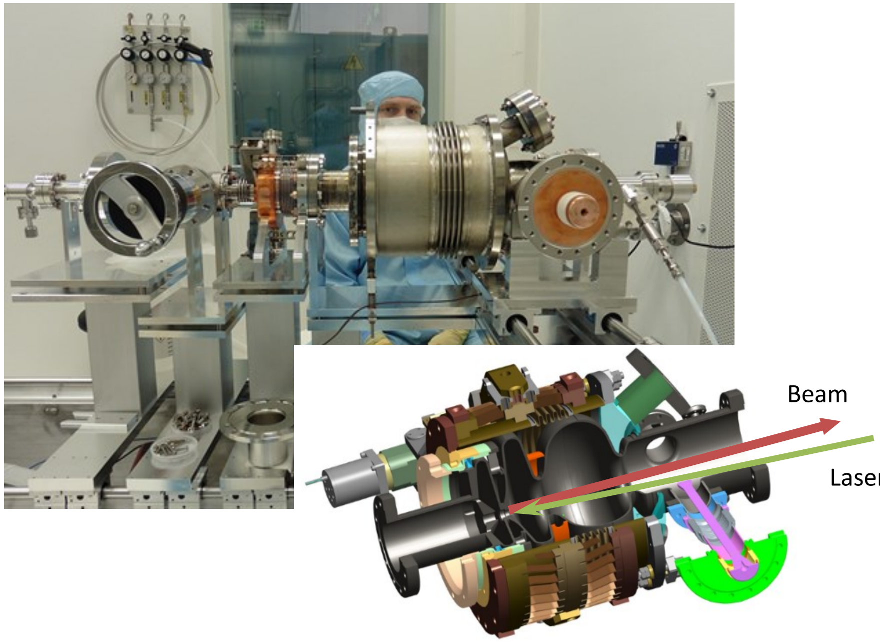


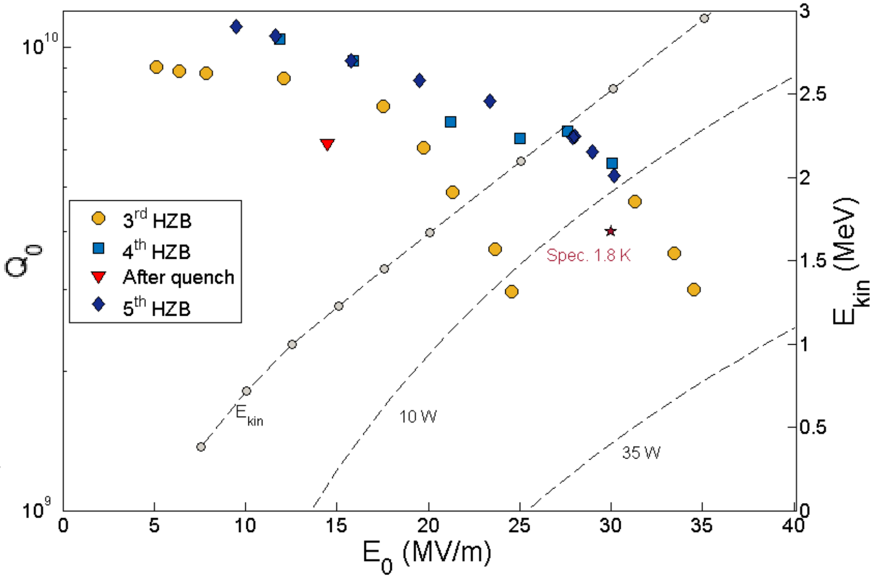






SRF Gun 1

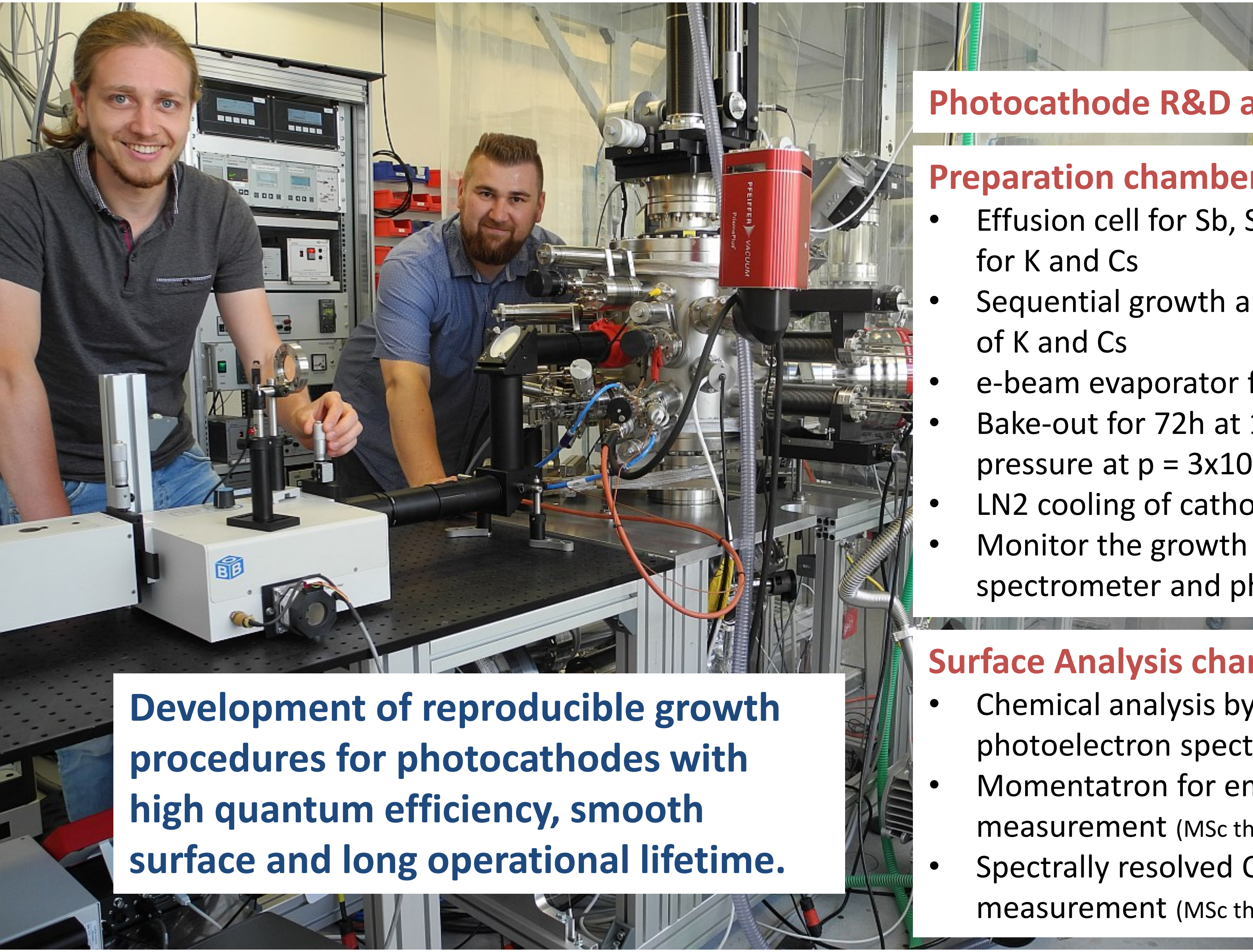




Parameter	VTA JLab	HTA HZB	Cold string HZB	Module
E_0 (MVm^{-1})	34.9	34.5	28.5§	-
E_{peak} (MVm^{-1})	58	57.3	47.3	-
B_{peak} (mT)	111.8	110.4	91.2	-
low field Q_0	$1.2\cdot10^{10}$	$1.1\cdot10^{10}$	$9.6\cdot10^{9}$	-
$\Delta f/\Delta E_0^2$ (HzMV^{-1}m)^2	-4.7	-3.7	-3.4	-
$\Delta f/\Delta P_{LHe}$ (Hzmbar^{-1})	-561	150	33	-
$\Delta f/\Delta l$ (Hz/step)	-	-	2.3 (1.8 K)	3.8 (300 K)

A. Neumann, ERL 2017

Photocathode R&D



Photocathode R&D at HZB

Preparation chamber

- Effusion cell for Sb, SAES Dispenser for K and Cs
- Sequential growth and co-deposition of K and Cs
- e-beam evaporator for Mo
- Bake-out for 72h at 120°C, base pressure at $p = 3\text{x}10^{-10}$ mbar
- LN2 cooling of cathode substrate
- Monitor the growth process by mass spectrometer and photocurrent

Surface Analysis chamber

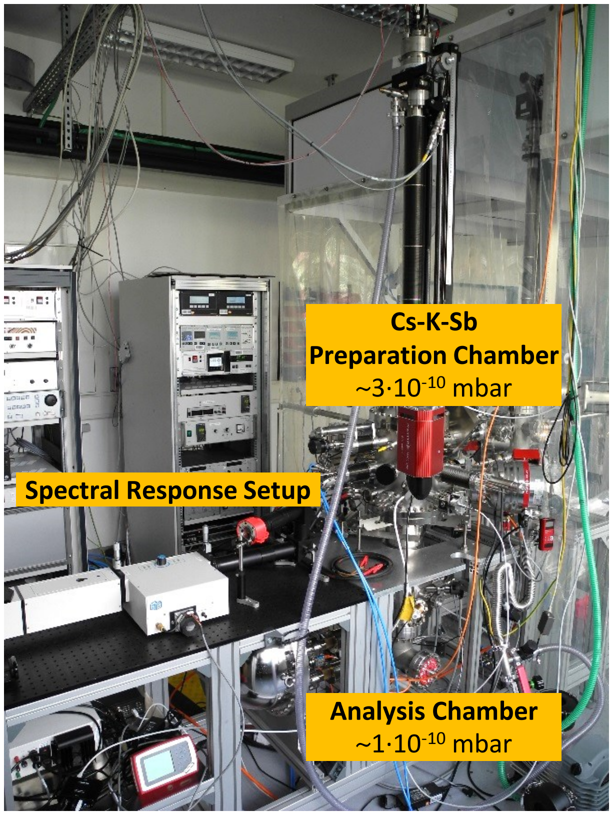
- Chemical analysis by X-ray photoelectron spectroscopy (XPS)
- Momentatron for emittance measurement (MSc thesis, M. Schmeißer)
- Spectrally resolved QE response measurement (MSc thesis, H. Kirschner)

Development of reproducible growth procedures for photocathodes with high quantum efficiency, smooth surface and long operational lifetime.

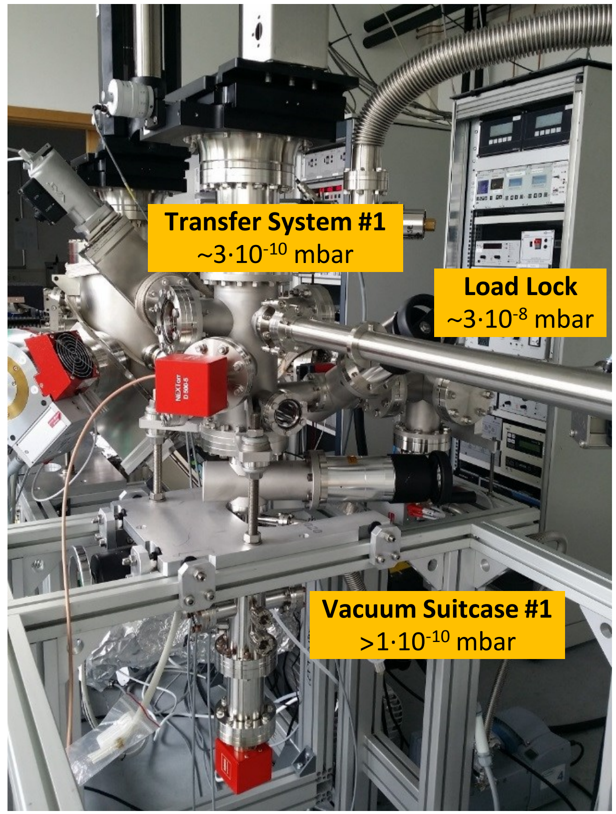
J. Kühn, M. A. H. Schmeißer, H. Kirschner, T. Kamps

Photocathode R&D Infrastructure

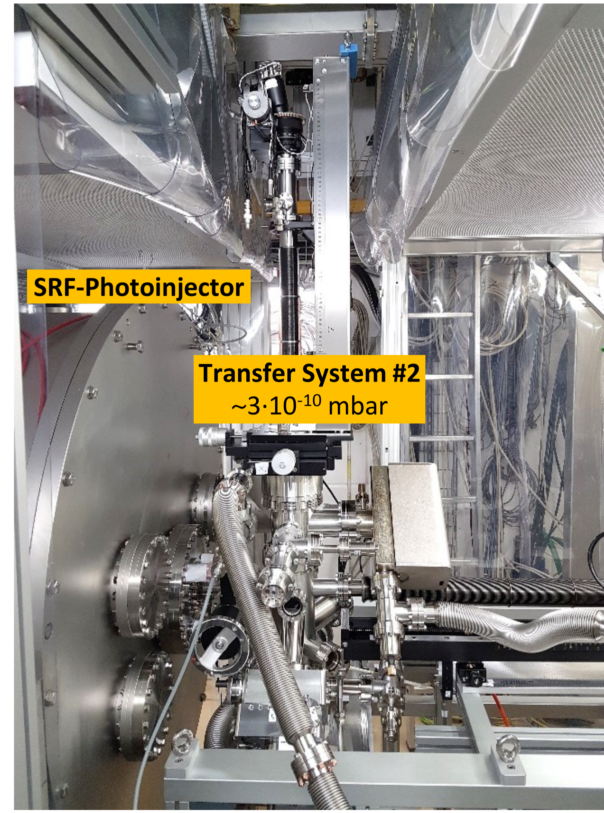
Preparation & Analysis System (PAS) w/ spectral response setup



Transfer system #1 at the PAS w/ vacuum suitcase

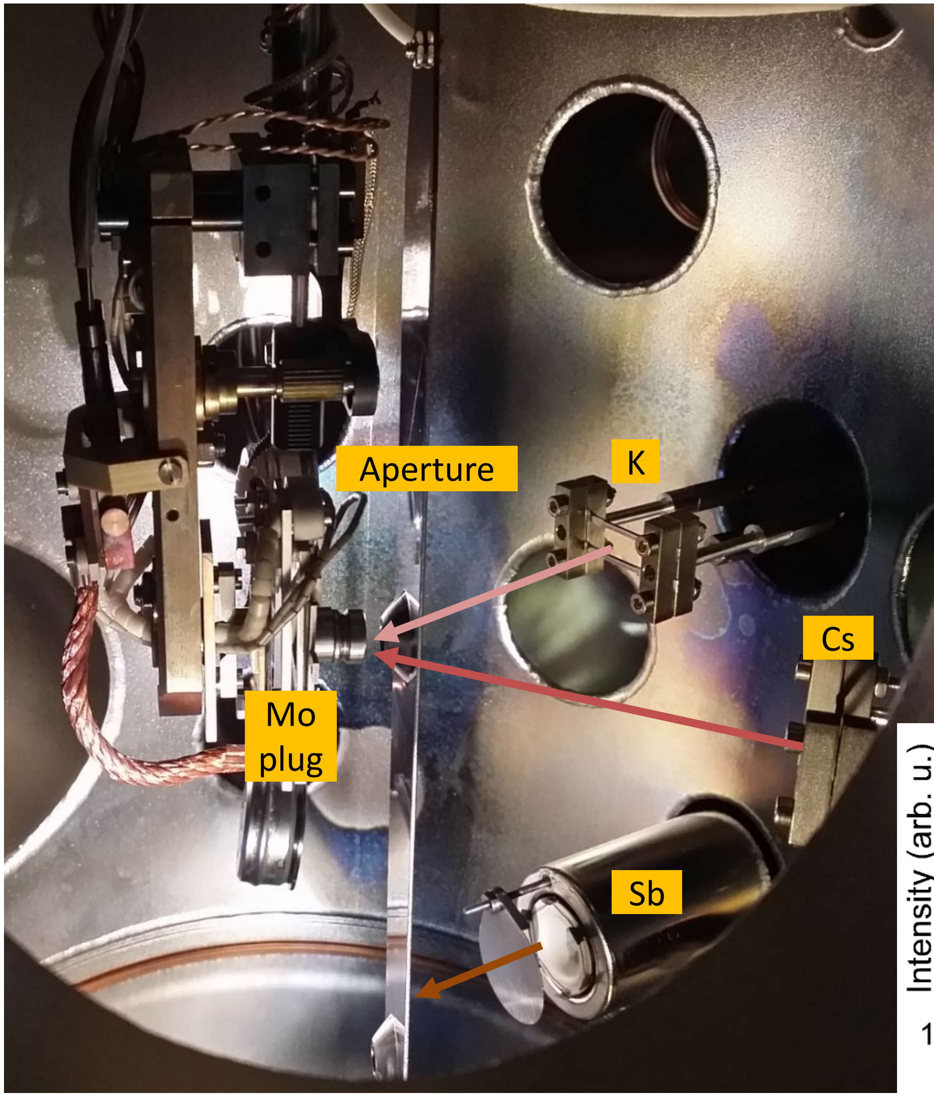


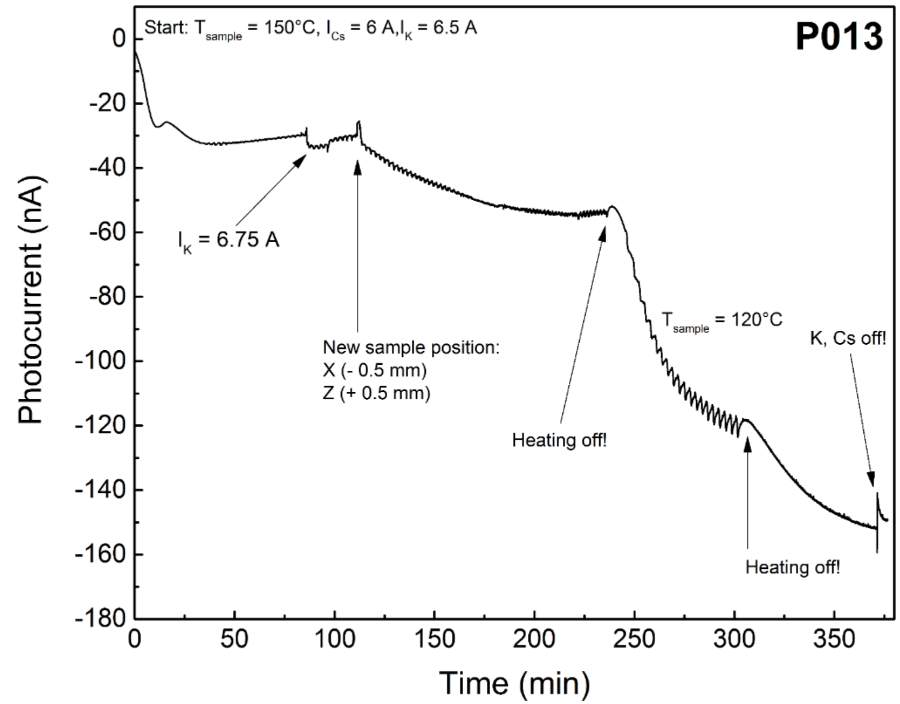
Transfer system #2 at the SRF-photoinjector module

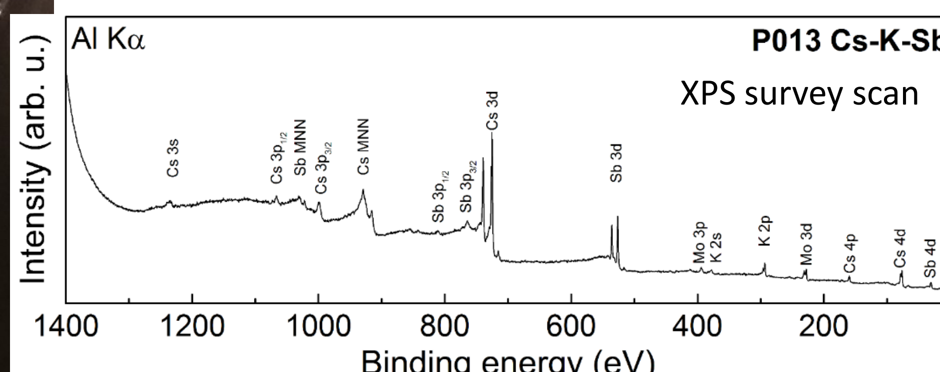


J. Kuehn *et al*, IPAC 2017.

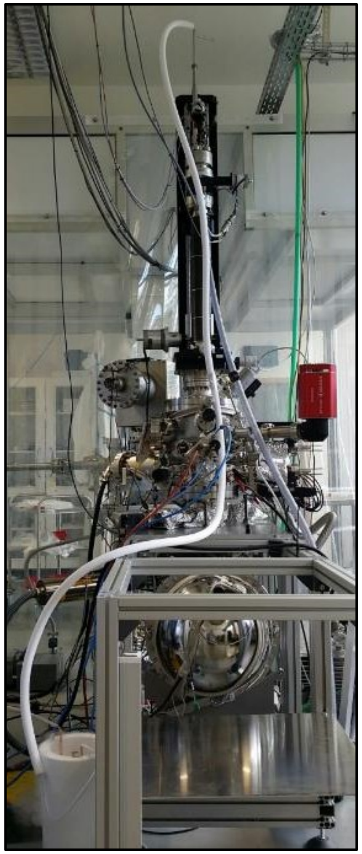
Inside the preparation chamber

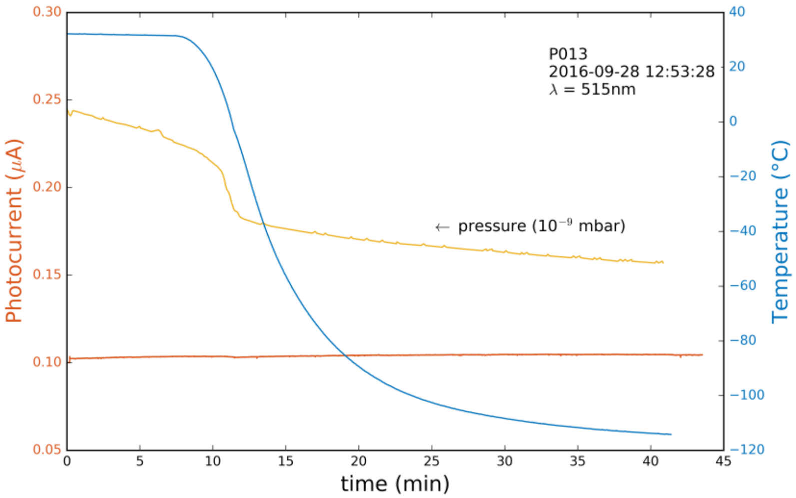


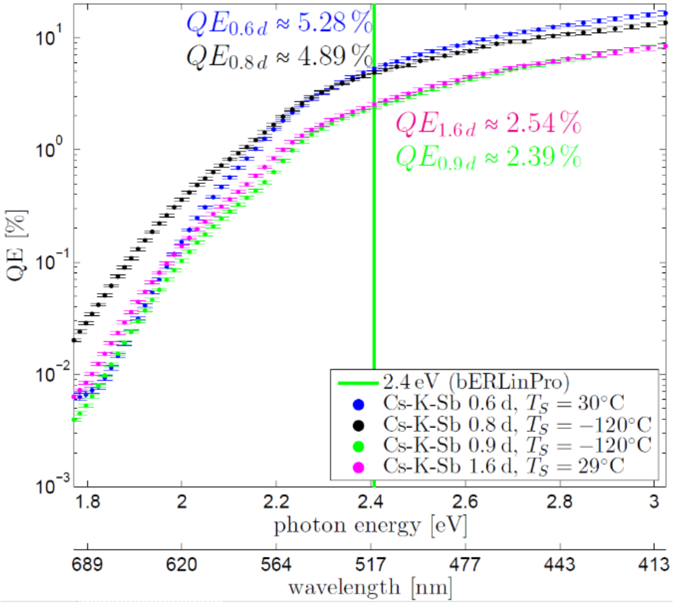




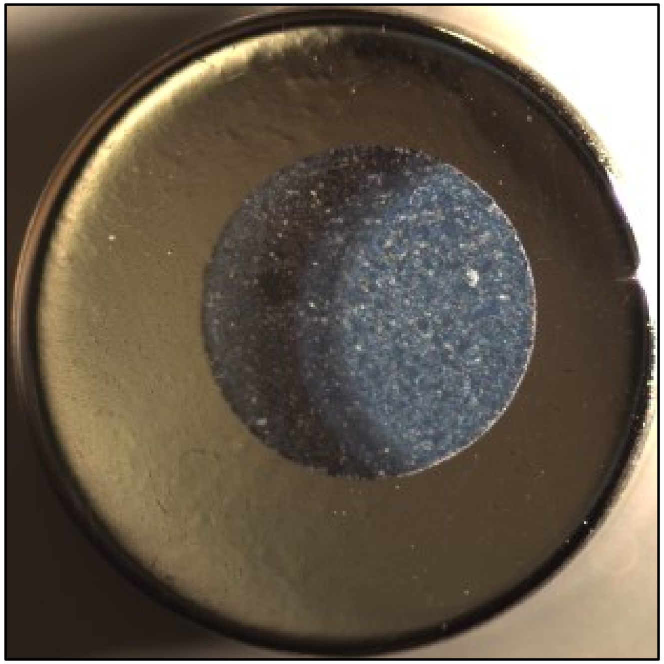
P013: Cooldown with liquid N2

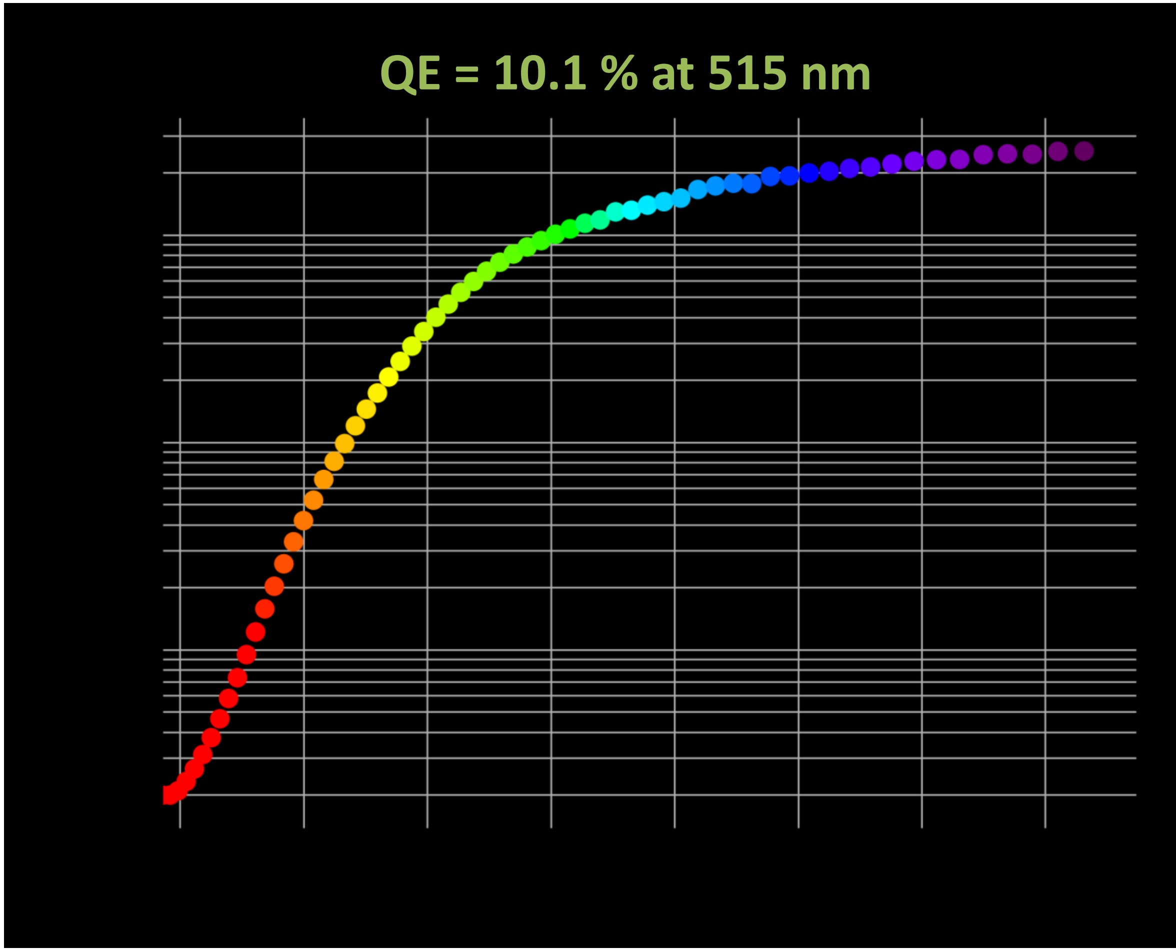






P014



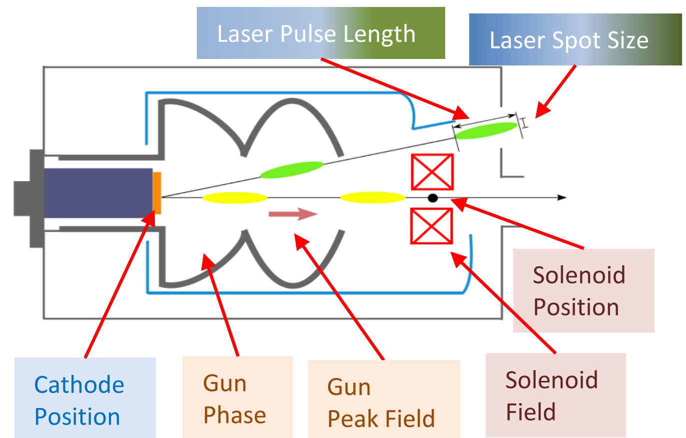


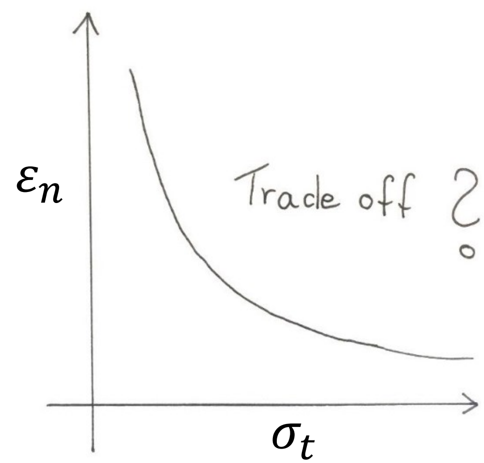
Beam dynamics optimization

Multi-objective, multi-parameter (pareto) optimzation of SRF gun design

ERL mode
bERLinPro
ps bunch length,
Low emittance

UED mode
UED@GunLab
fs bunch length,
High coherence





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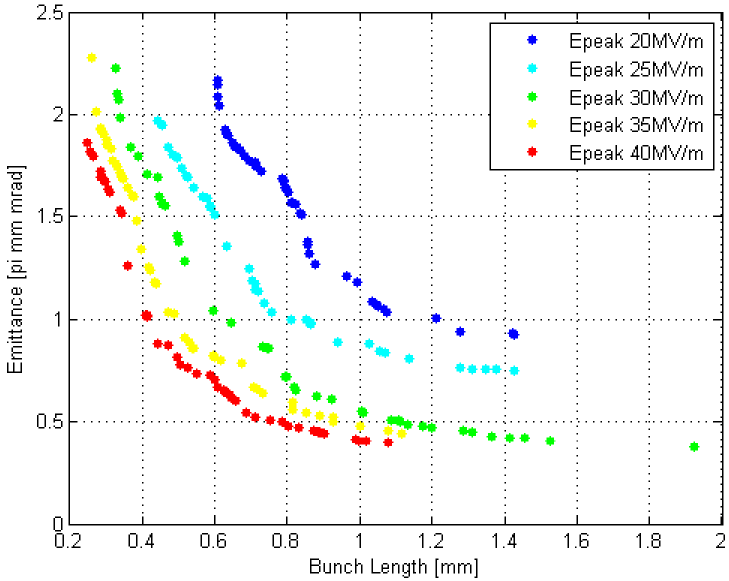
Beam dynamics optimization

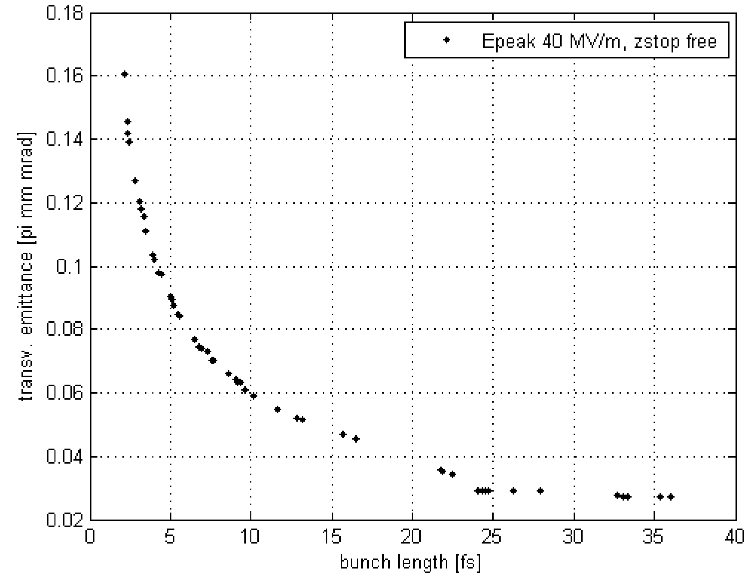
bERLinPro mode

77 pC bunch charge
Emittance/bunch length at 2.8 m



UED@GunLab mode

10 fC bunch charge
Emittance/bunch length at 2.8 m



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Summary and outlook

- Start operation with Gun1 in GunLab
- Optimize SRF gun for ERL (UED, FEL) applications
- Realize the potential of bERLinPro
- Consolidate and extend photocathode R&D (to EMIL)
- Perform UED at MHz rep rate with GunLab
- Maintain and expand Bessy II and Bessy VSR

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