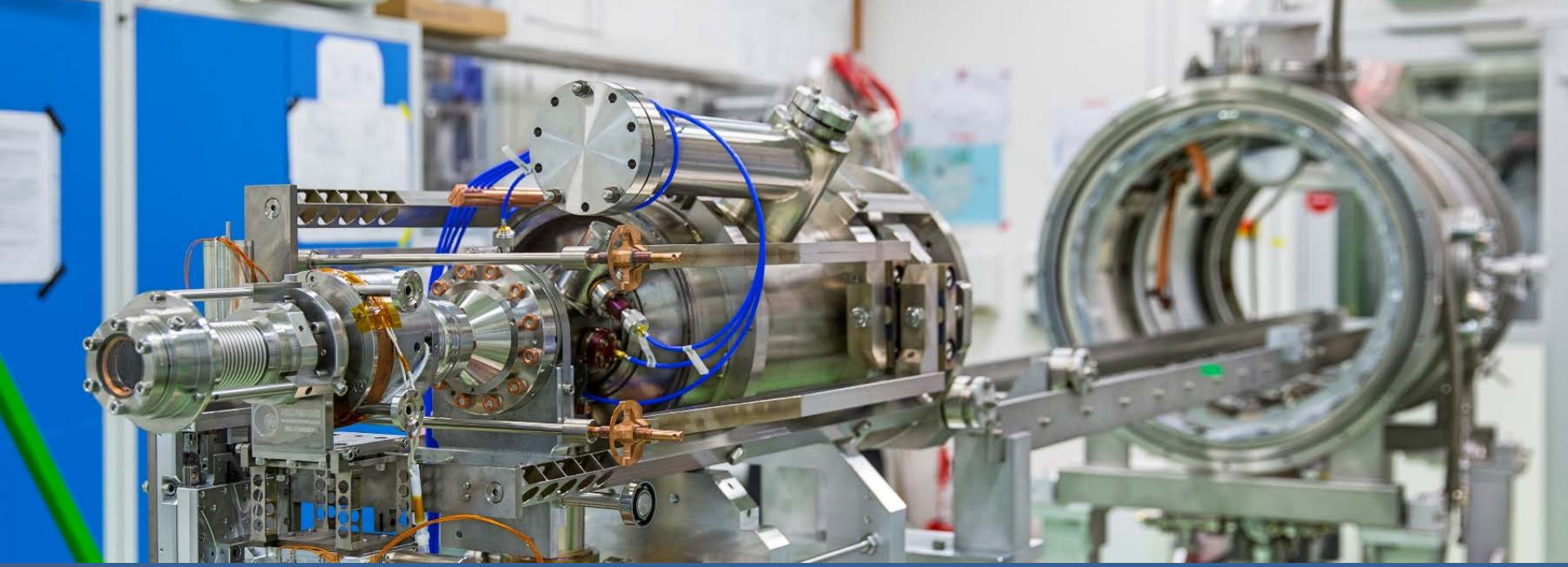


Superconducting Applications

J. Teichert, A. Arnold, S. Ma,
P. Murcek, A. Ryzhov, J. Schaber, R. Xiang,

EWPAA 2019
11 -13 September 2019
Paul Scherrer Institut, Villingen

The „first“ two SRF Gun Questions:

Survive the SRF gun cavity the photocathode?

Survive the photocathode the SRF gun cavity?

Outline

1. Superconducting Guns and Their Applications
2. Applied Photocathodes
3. Multipacting
4. Cathode Cooling
5. Photocathode Quality Management

ELBE.

HZDR

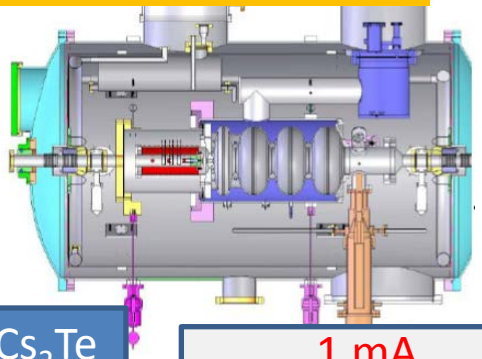
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

1. Superconducting guns and their applications

Production of high-brighness electron beams
in CW mode for high average currents or/and up to MHz pulse repetition rates

Guns in operation

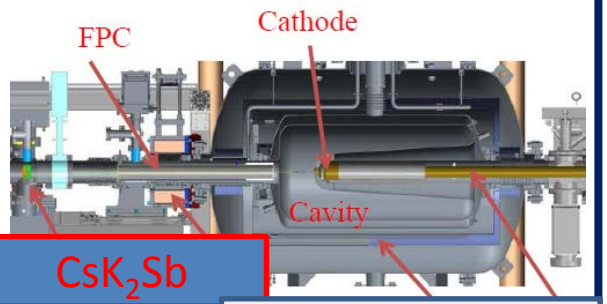
Peking Uni DC SRF gun



Cs_2Te

1 mA
THz, UED demo

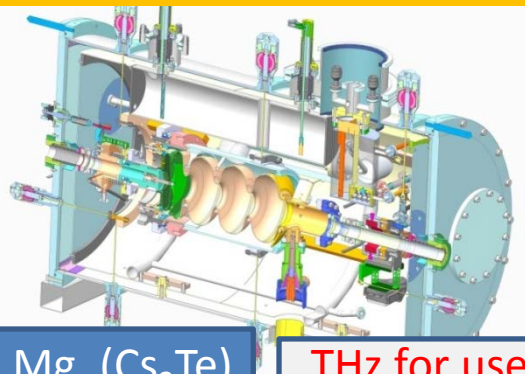
BNL 113 MHz CeC gun



CsK_2Sb

CeC experiments since 2016

HZDR 3.5 cell ELBE gun II

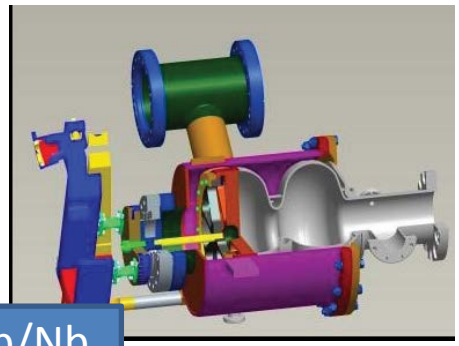


Mg, (Cs_2Te)

THz for users since 2018

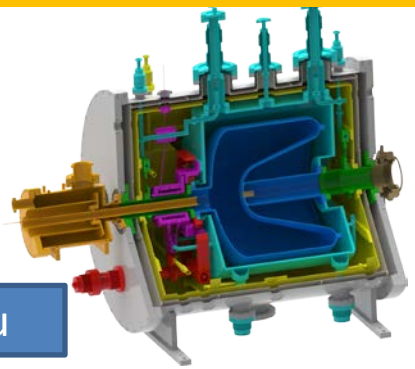
Test operation

HZB/DESY 1.5 cell gun



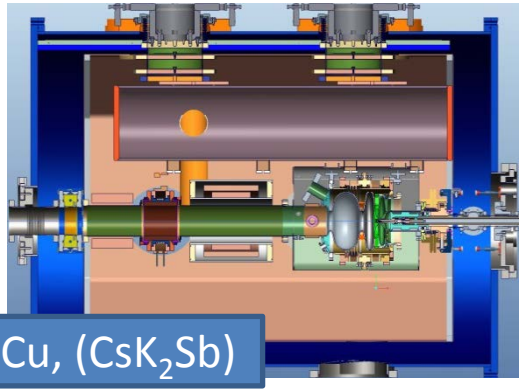
Pb/Nb

UW/SLAC 200 MHz WiFEL gun



Cu

HZB 1.5 cell ERL gun



Cu, (CsK_2Sb)

1. Superconducting guns and their applications

Projects with SRF Gun applications - CW with high pulse repetition rate

- **XFELs**
  - European XFEL CW upgrade (DESY) 25 µA, 20-250 pC, 0.4-0.8 µm
  - LCLS-II High-energy upgrade (ANL,SLAC) 50 µA , 100 pC, 0.1 µm

- **IR – VUV FELs and THz radiation sources**
  - ELBE superradiant THz source upgrade with SRF gun III 50 µA, 500 pC
  - PolFEL project THz – IR, UV (
  - ELBE II (DALI) project high pulse energy THz, VUV 1 mA, 1 nC

- **Ultrafast Electron Diffraction (UED) with MeV electrons & MHz**
  - SLAC project with WiFEL gun <1 µA, fC

- **Energy Recovery Linacs (ERLs)**
  - KEK ERL Project 100 mA, 80 pC, 0.6 µm
  - bERLinPro ERL prototype (HZB) 100 mA, 77 pC, <1 µm

- **Electron Cooling of Ion Maschines (CeC)**
  - BNL coherent electron cooling 150 µA, 0.1-10.7 nC, 0.15-5 µm

2. Applied photocathodes – Overview

METALS

superconducting

Nb

10^{-5} @ 260 nm

Pb/Nb

$3x10^{-4}$ @ 260 nm

low current

- UV laser
- vacuum robust
- laser cleaning
- no RF heat
- no loadlock

normal conducting

Cu

10^{-5} @ 260 nm

Mg

$1\text{-}3x10^{-3}$ @ 260 nm

low current

- UV laser
- vacuum robust
- laser cleaning
- cooling needed
- loadlock

SEMICONDUCTORS

UV

Cs_2Te

1 – 10 %

1 – 10 mA
UV laser limit

- 10^{-9} – 10^{-10} mbar
- cooling needed
- loadlock

GREEN

CsK_2Sb

>10 %

~100 mA

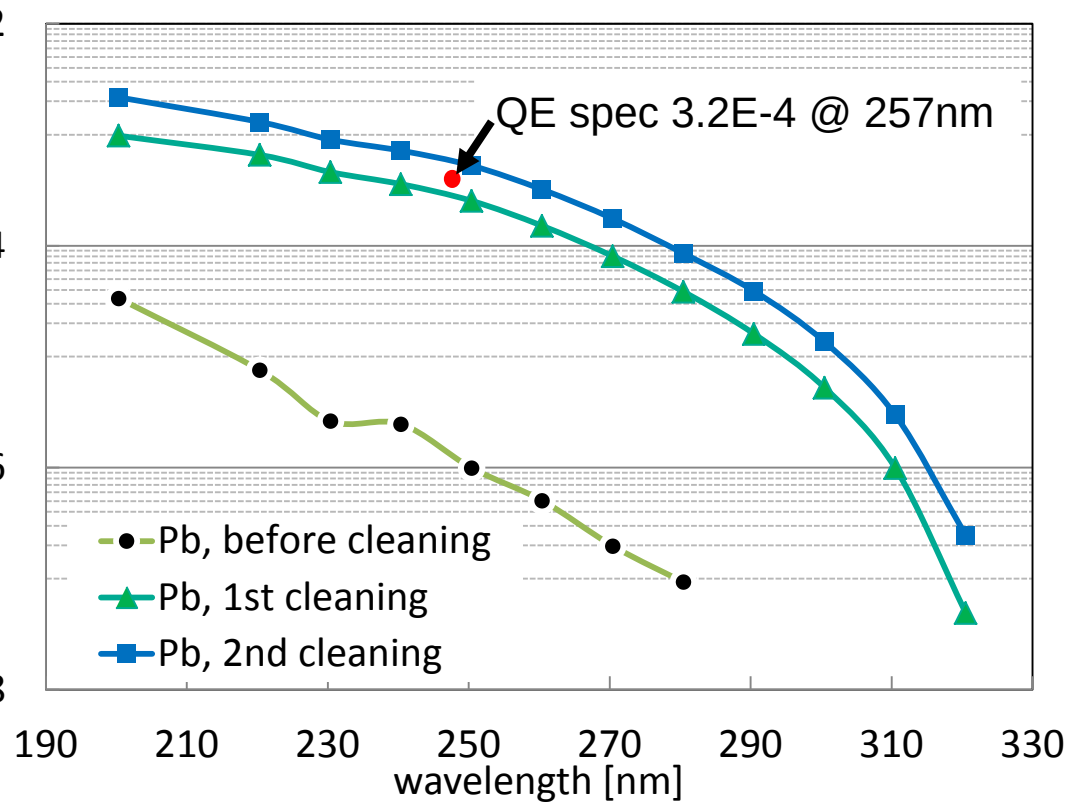
- powerful lasers
- laser shaping
- $<10^{-11}$ mbar
- cooling needed
- loadlock

Jochen teichert | Institute of Radiation Physics | j.teichert@hzdr.de

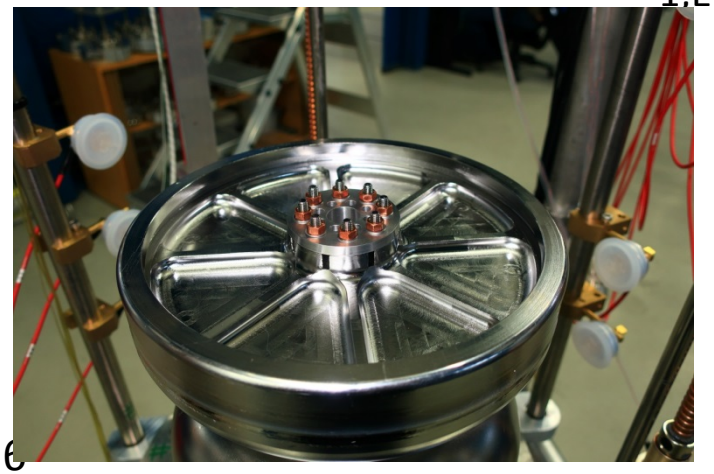
2. Applied photocathodes – Superconducting PC

All Superconducting Gun – DESY, NCBJ Swierk, BNL

BNL all Nb gun



- higher QE of Pb (J. Smedley)
- deposited spot in cavity
- test in HoBiCat at HZB
- gun for PolFEL & CW EXFEL

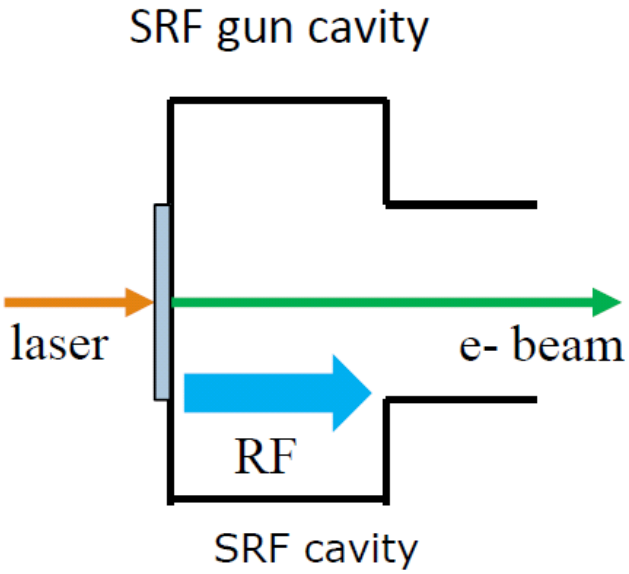


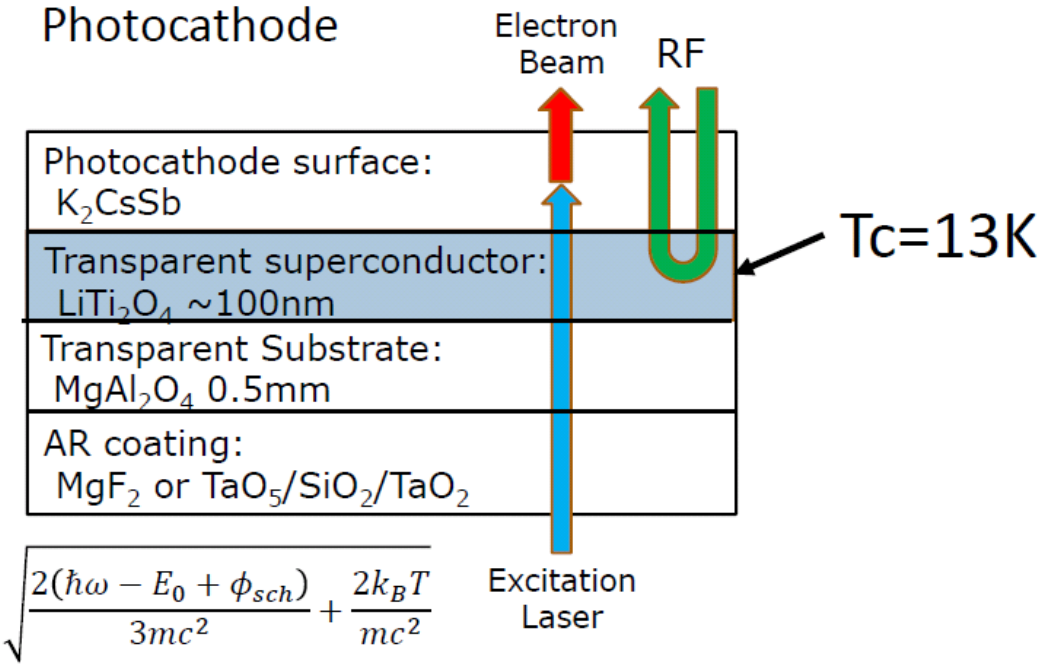
Screw in Nb plug with Pb layer
UHV arc deposition of Pb
Assembly in cavity after treatment and cleaning
simple cryomodule design
no cathode loadlock, support and cooling system

2. Applied photocathodes – Superconducting PC

Transparent superconducting PC with CsK_2Sb layer

exchangeable
high photo current (100 mA)





Thermal emittance: $\varepsilon_n = \frac{R}{2}\sqrt{\frac{2(\hbar\omega - E_0 + \phi_{sch})}{3mc^2} + \frac{2k_BT}{mc^2}}$

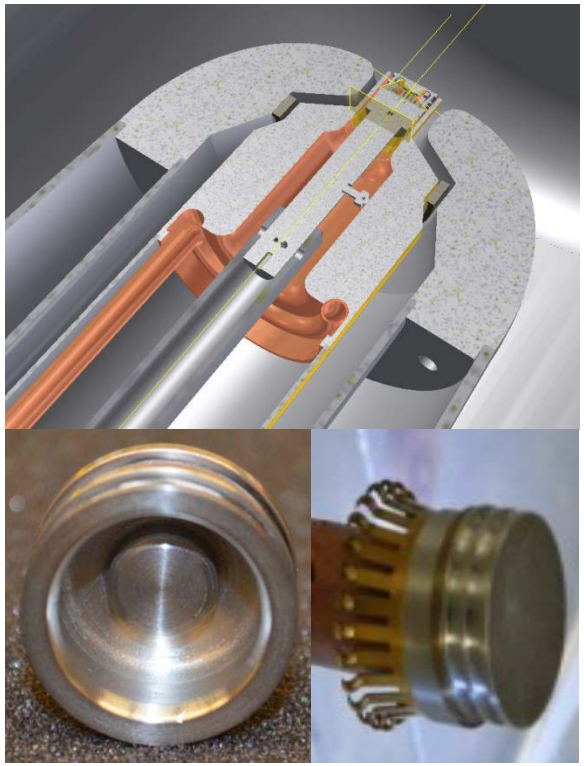
- reduced RF losses
- laser from backside

KEK, T. Konomi, SRF 2019

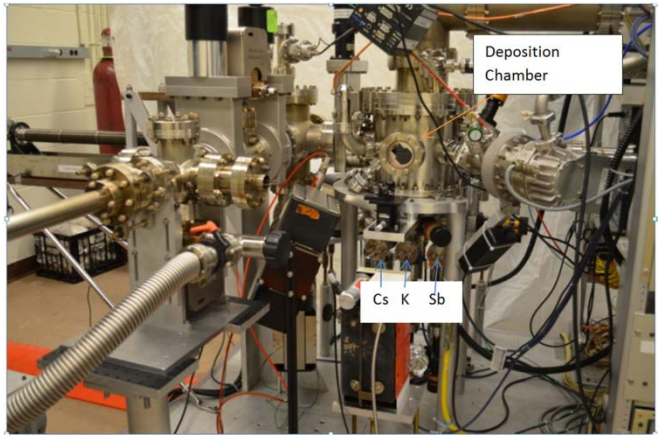
2. Applied photocathodes – Semiconductor PC

High current applications (ERL) need green PC

- higher QE
- higher laser power
- easy laser shaping



Development of CsK_2Sb PC at HZB and BNL for ERL application



BNL
cathode assembly,
prep chamber,
and suite case

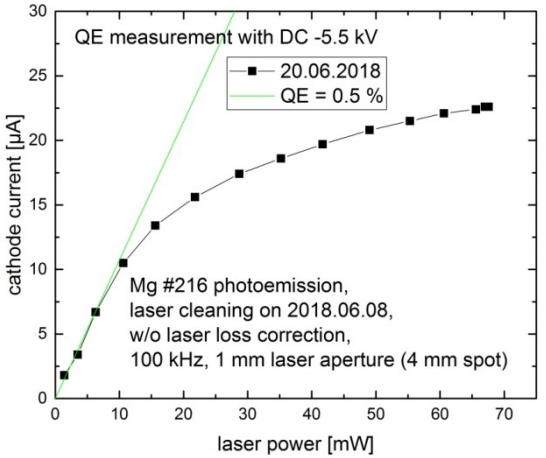
E. Wang

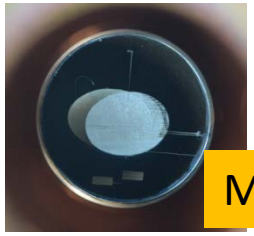
First succesful long-term operation of vacuum sensitive CsK2Sb photocathodes in superconducting RF photo gun at BNL in CeC accelerator

2. Applied photocathodes – Mg Photocathode

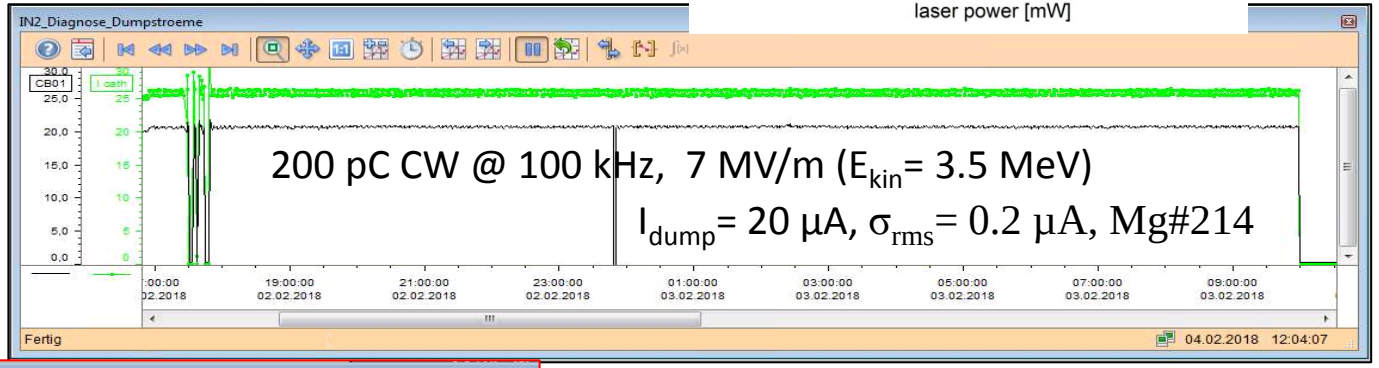
Mg cathodes work routinely in ELBE SRF gun at HZDR

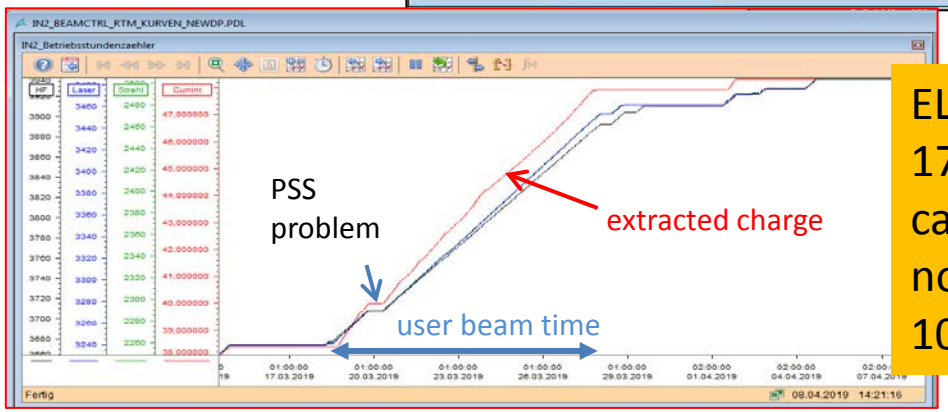
- bulk Mg plugs, polished and chem. cleaned
- UV laser cleaning (drive laser)
- best QE 0.3 % … 0.5 %
- low risk of cavity contamination
- extremely long life time in 10^{-9} mbar vacuum
- cleaning can be several times repeated





Mg #214





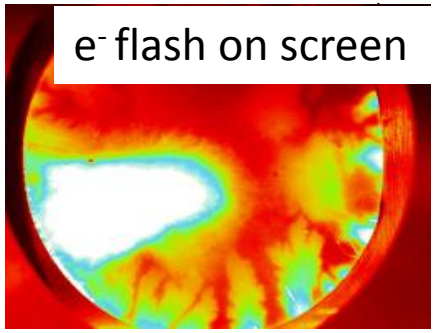
ELBE run spring 2019
17 x 12 h shifts for external users
ca. 200 h beam time in CW
no break due to gun problems
10 C charge extracted

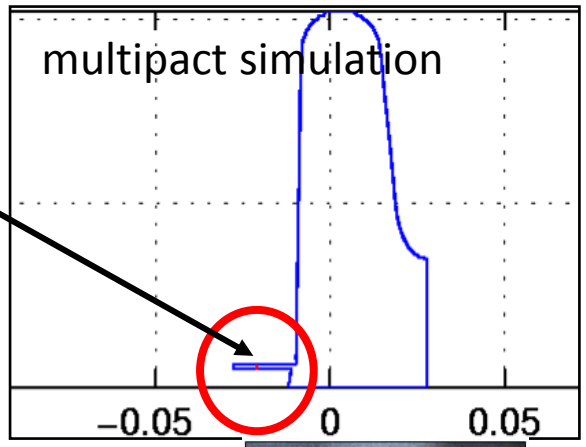
3. Multipacting

Multipacting: unstable RF operation and RF discharges can destroy photocathodes

Photocathode and corresponding choke design causes multipacting

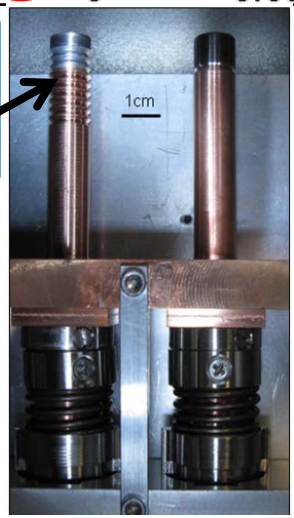
HZDR: MP was expected in the gap between cathode and cavity at surface fields of 0.1-0.2 kV/m since the early design stage!





solution: cathode bias up to -7 kV and „clean“ PCs (low SEY)

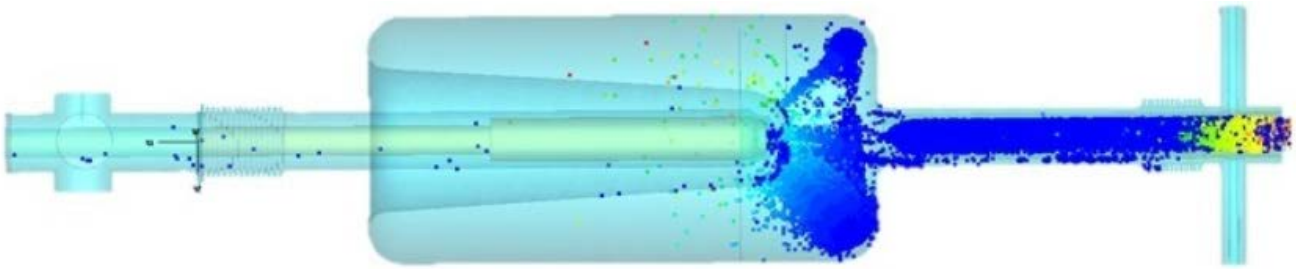
grooves did not help

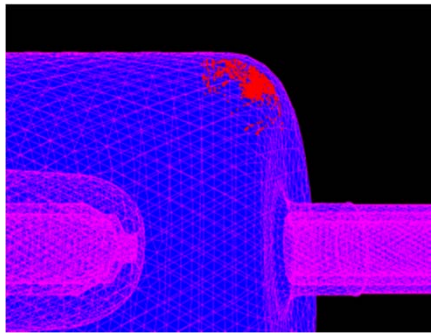


3. Multipacting

Multipacting barriers in superconducting cavity

BNL 112 MHz SRF gun cavity





40 keV multipacting in simulation

MP at 2 kV, 22 kV, 30 kV, 40 kV predicted by simulation an encountered in real.
Can kill cathode if not supressed.
Solution for mitigation:

- strong coupling with adjustable fundamental power coupler
- LLRF implemented automated turning on script to prevent excessive trap time.

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4. Cathode Cooling

$$W_{PC} = W_{magnetic} + W_{dielectric} + W_{laser}$$

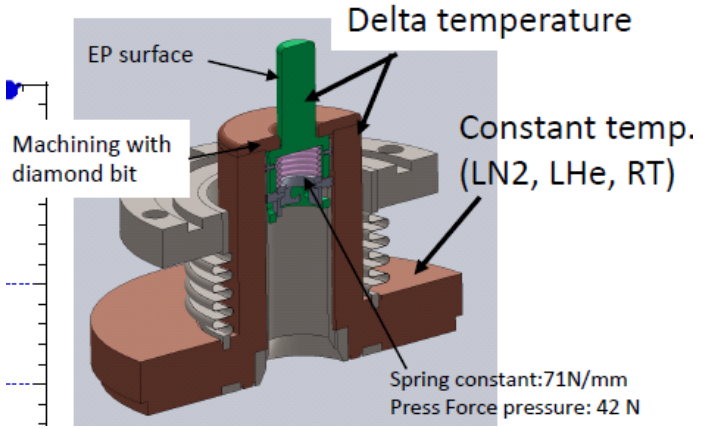
small on axis
allows NC material

small
thin layer

Superconducting PC

no RF heating, but liquid He cooling needed

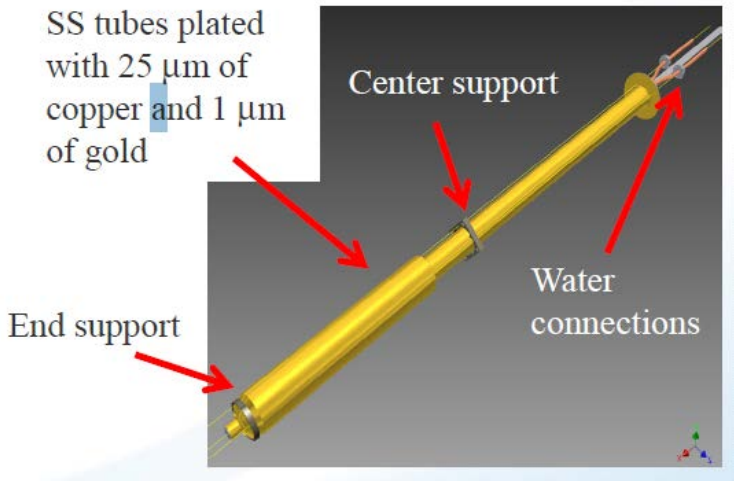
Thermal contact test at KEK



Normal-conducting PC

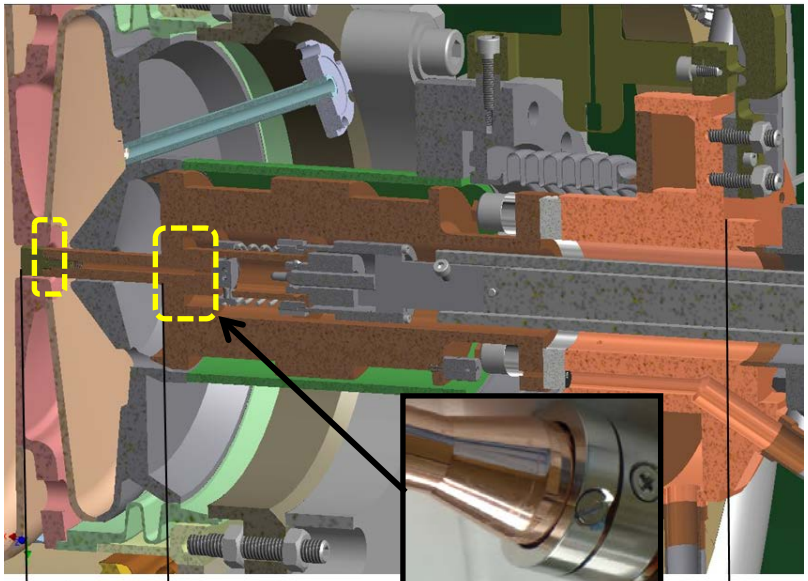
PC operates at room temperture: BNL 112 MHz gun
water cooled cathode stark

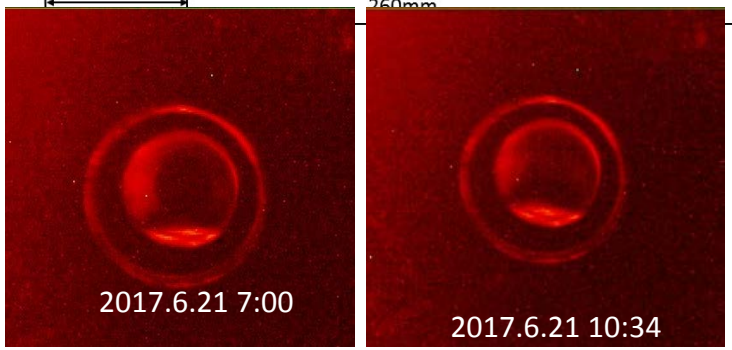
PC at 77 K: HZDR ELBE SRF Gun, HZB bERLinPro gun
liquid N2 cooled

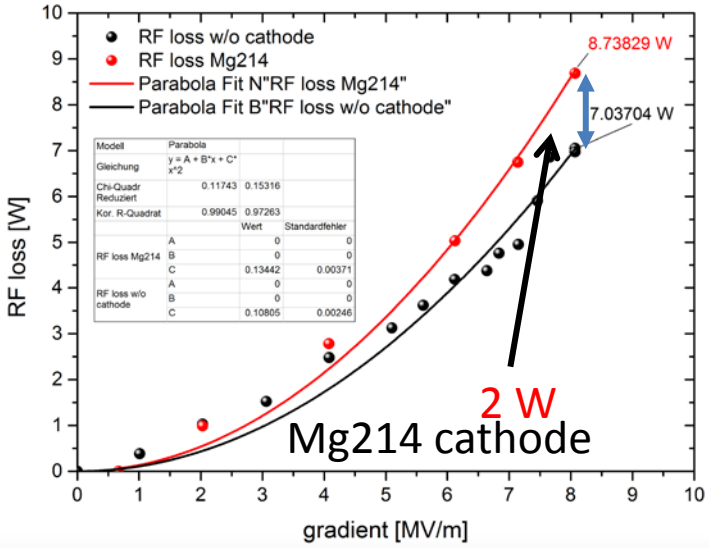


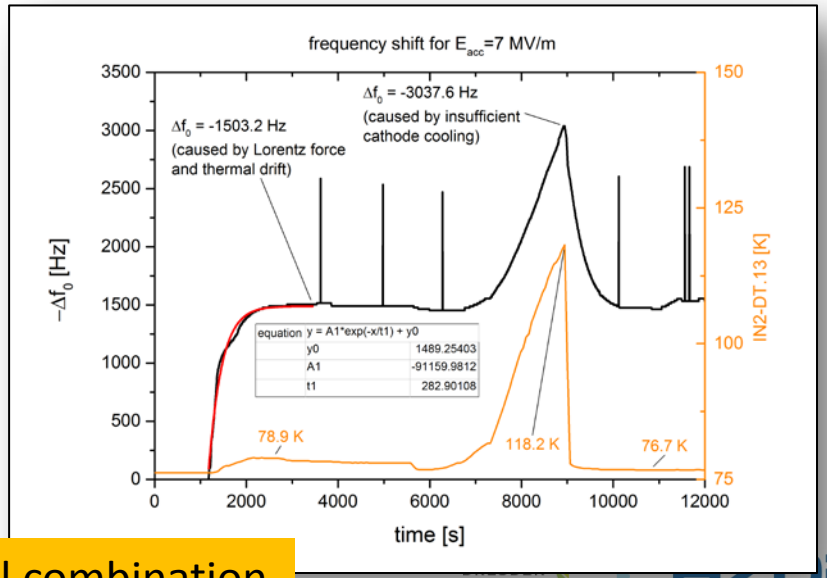
4. Cathode Cooling

Thermal contact problem with Cs_2Te photo cathodes in ELBE SRF Gun









evaperation of Cs2Te layer due to
bad thermal contact plug – cathode body

improved by better material combination

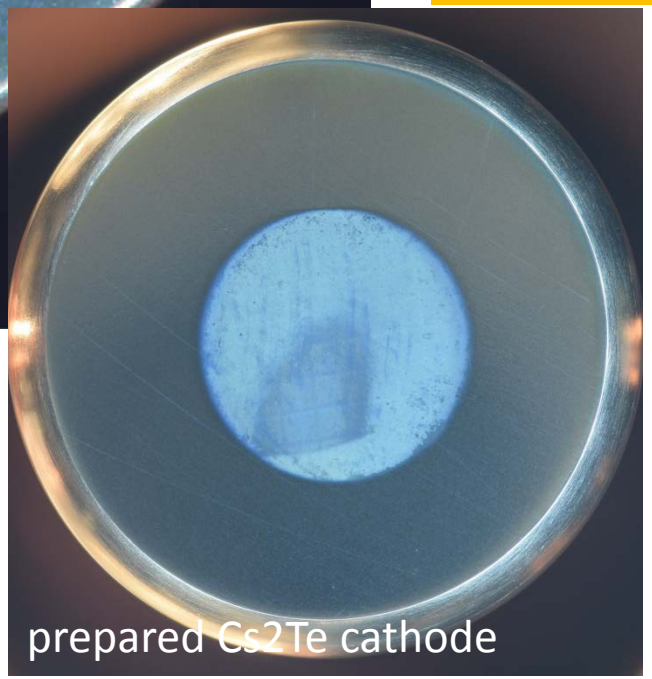
5. Photocathode Quality Management

For SRF photo injector the quality of photo cathodes has two important impacts:

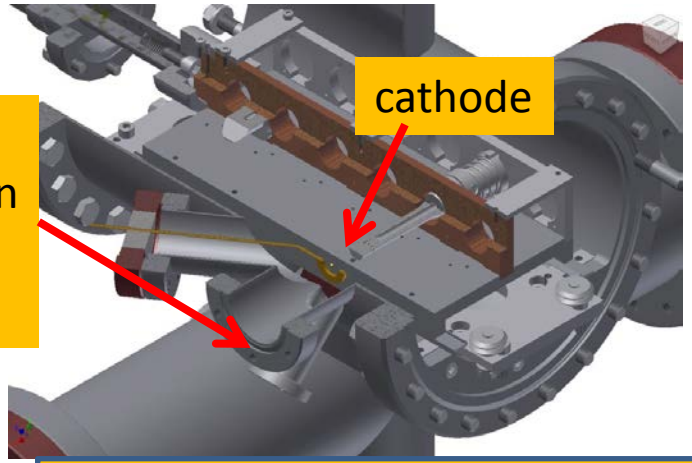
- electron beam quality (QE, therm. emittance, roughness, …)
- sustaining the SC cavity performance (particle pollution, field emitters, layer quality, …)

Inspection of plugs, before & after preparation before use in SRF gun

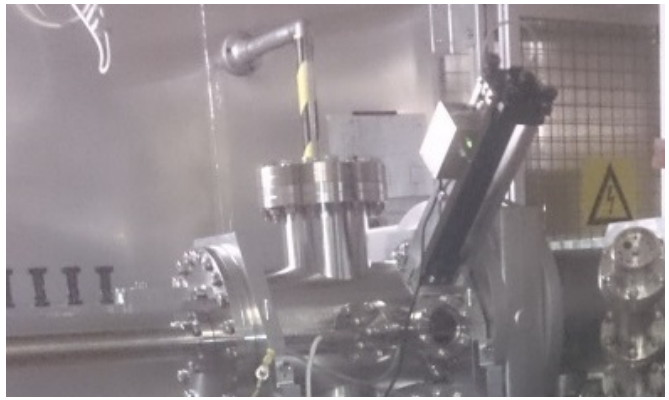
counting scratches and particles, layer quality, QE, QE scan, ...



window for visual inspection with high-resol. camera



modified transport chamber



QE measurement with UV LED

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Thank you for your attention!

Thanks to the ELBE team
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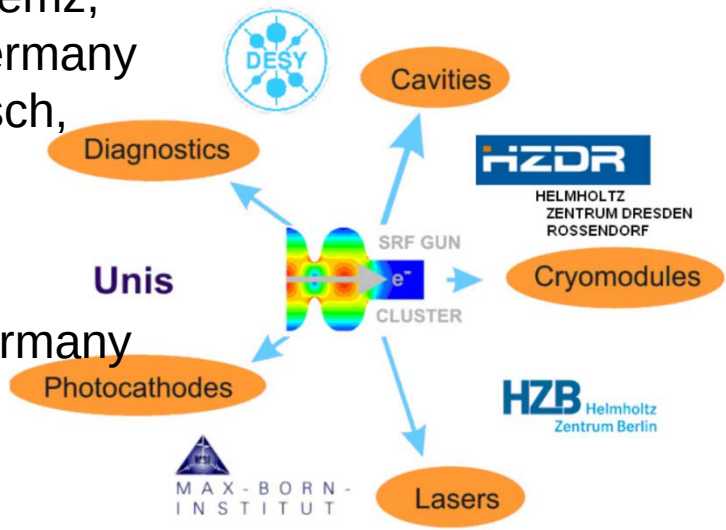

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LA³NET
Bundesministerium für Bildung und Forschung

DRESDEN concept
HZDR