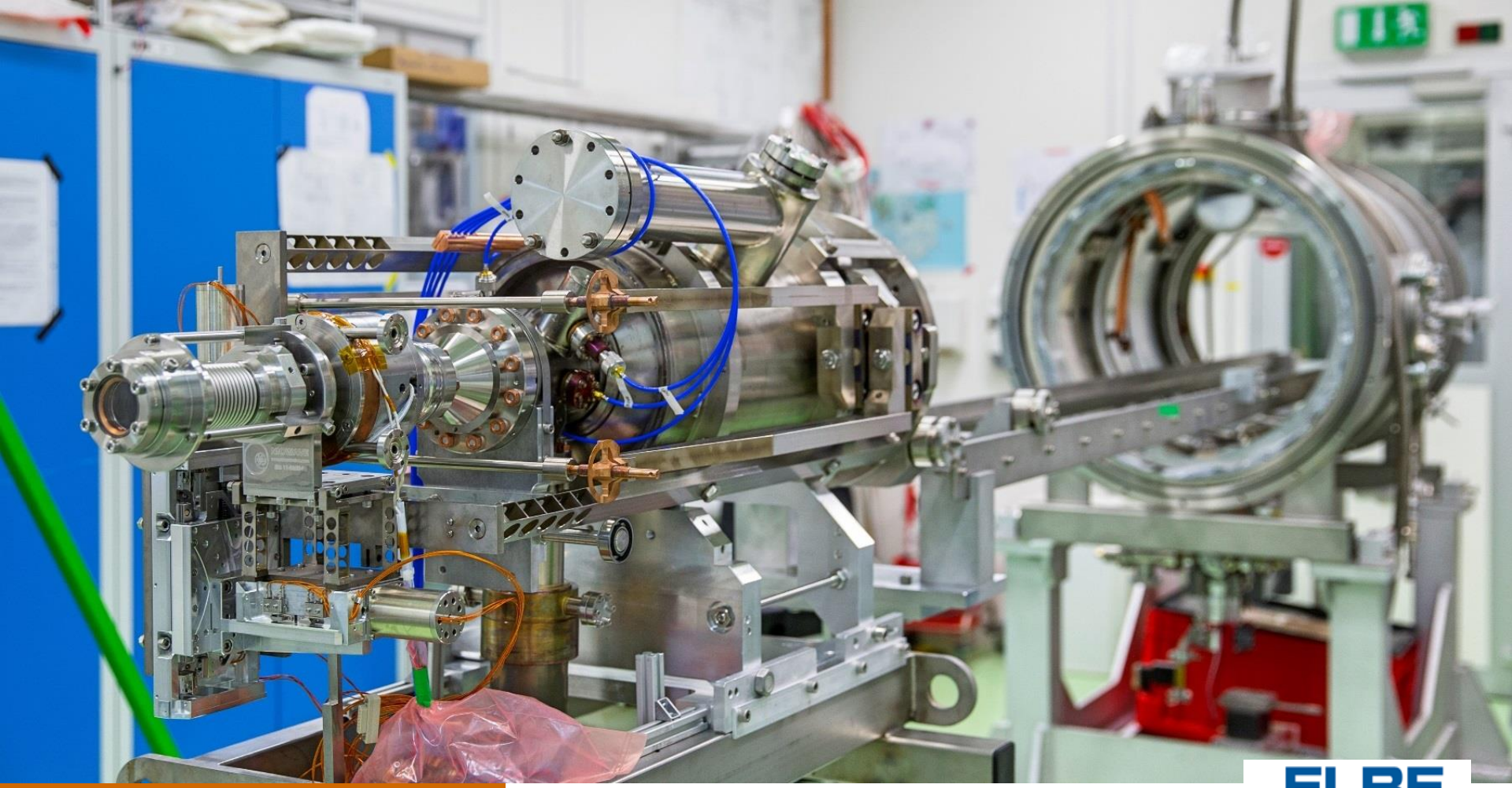


Metal and semiconductor photocathodes in HZDR SRF gun

Rong Xiang on behalf of the SRF Gun Group

19. Sep. 2019 ERL2019, Berlin

Outline

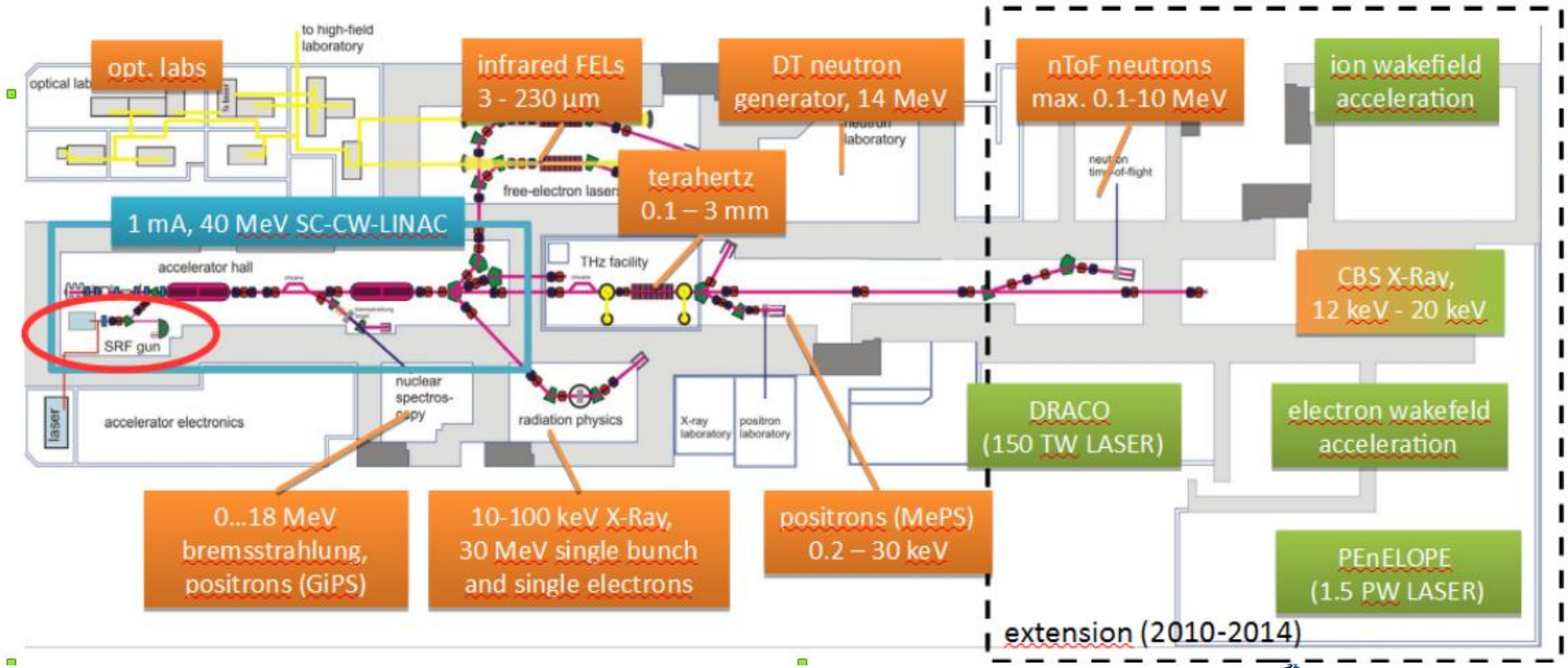
1. Status of SRF gun-II
2. Photocathodes for HZDR SRF gun
   - Metal photocathodes: Cu, Mg
   - Semiconductor photocathodes: Cs_2Te, GaN
3. Summary and outlook

ELBE.

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

- user facility with ~5500h of beam time and an efficiency of >90% each year
- electron accelerator is based on superconducting Linac in **CW operation**
- average current of **1 mA**, beam energy up to **40 MeV**
- two injectors: **250 kV DC gun, SRF gun**



DRESDEN concept

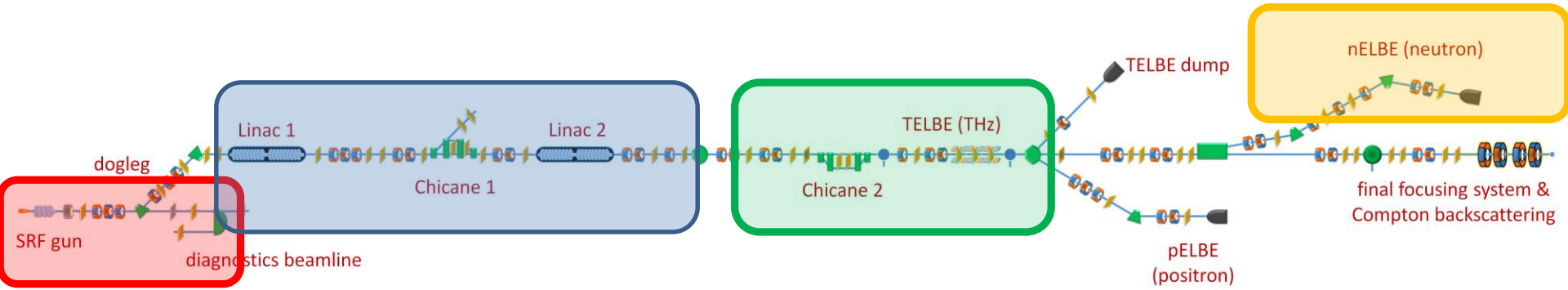
- ELBE user requirements for SRF gun

user application	bunch charge	norm trans. emitt.	Final bunch length	beam size at IP	average current
THz radiation (100 kHz)	300 pC		300 fs		30 µA
Neutrons (100 kHz)	100-500 pC				10-50 µA
Positrons (500 kHz)	200 pC				100 µA
Radiation physics (100 kHz)	10 pC				1 µA
IR FELs (13 MHz)	77 pC	2.2 µm	< 1 ps		1 mA
CBS x-rays (10 Hz)	450 pC		1 ps	30 µm	4.5 nA

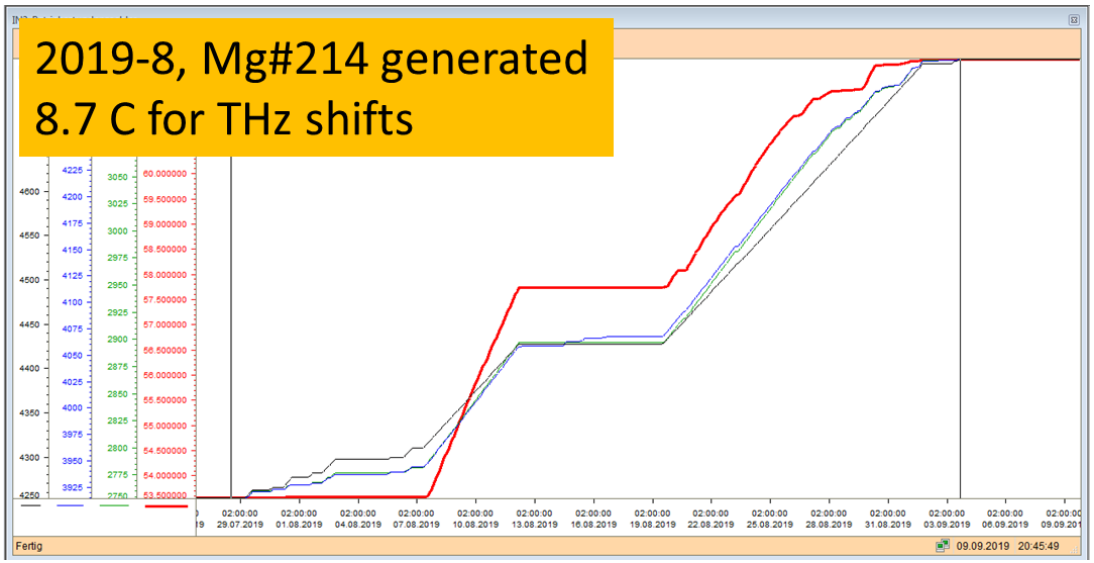
1. Status of ELBE SRF gun-II

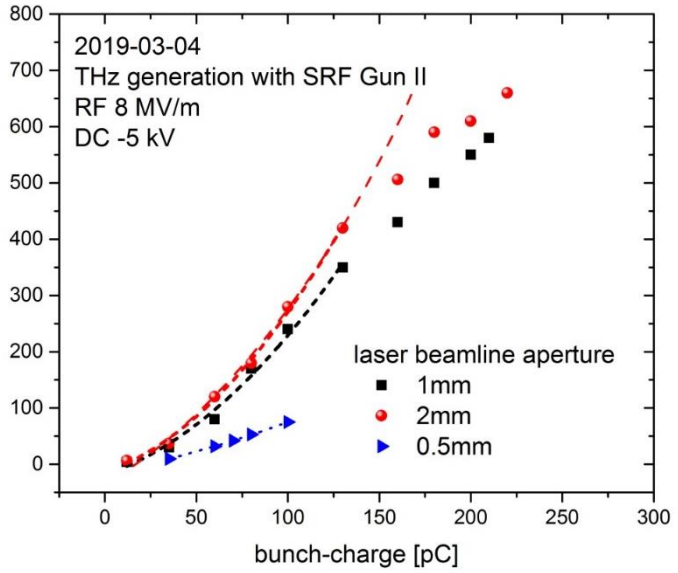
A.Arnold Poster WEPNEC08

superradiant THz and neutron beamtime (TELBE, nELBE)



SRF-Gun **SC-LINAC** **THz @ ELBE** **neutron @ ELBE**



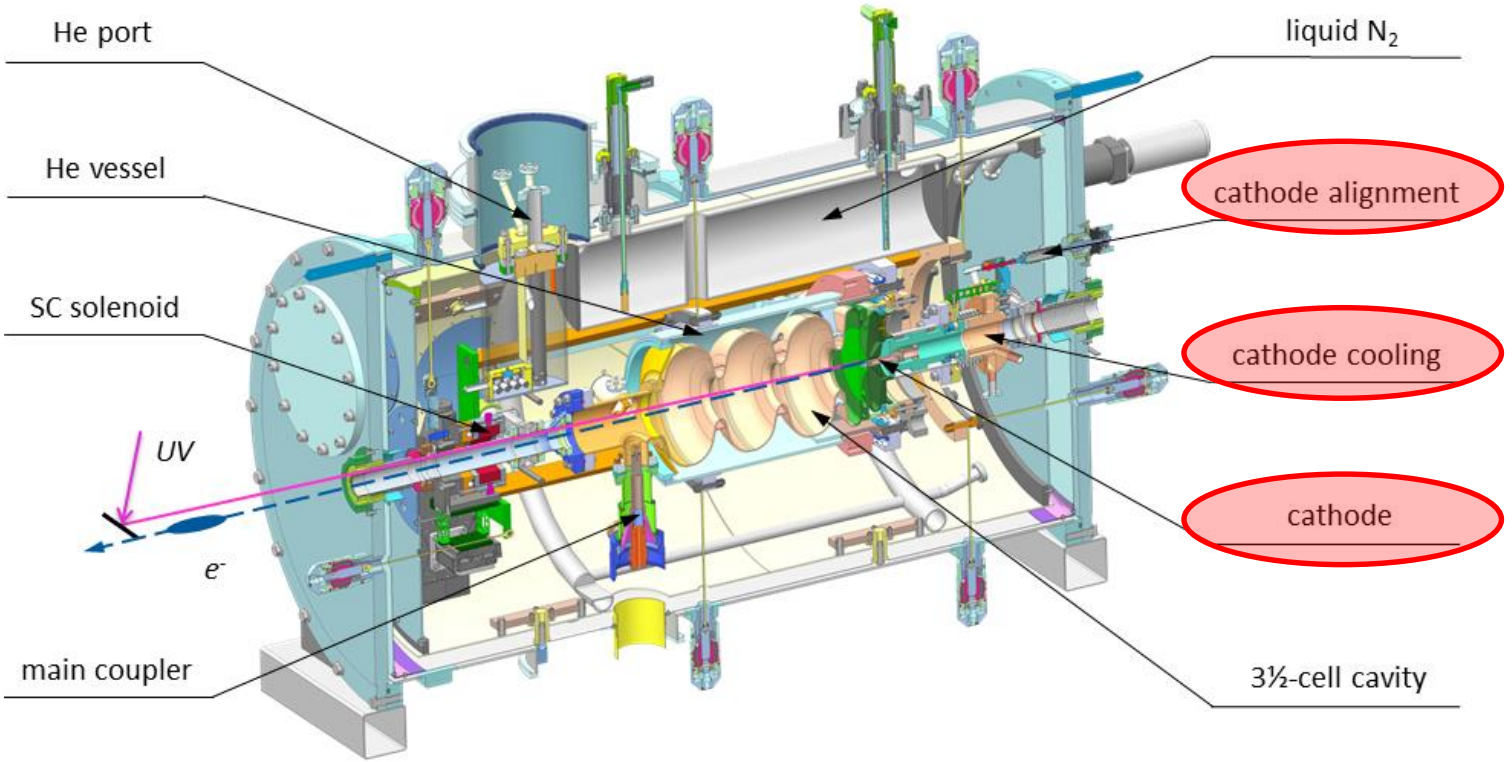


1. Status of ELBE SRF gun-II

	Milestones of SRF gun II
Jun. 2010	cavity manufacture finish in JLab
Aug. 2014	commissioning at HZDR
Feb. 2015	first CW beam with Cu cathode
Nov. 2016	Mg cathode in operation
Mar./Jun. 2017	Cs_2Te (Mo) in gun
Since 2017	stable operation with Mg

SRF Gun-II in ELBE hall

1. Status of ELBE SRF gun-II

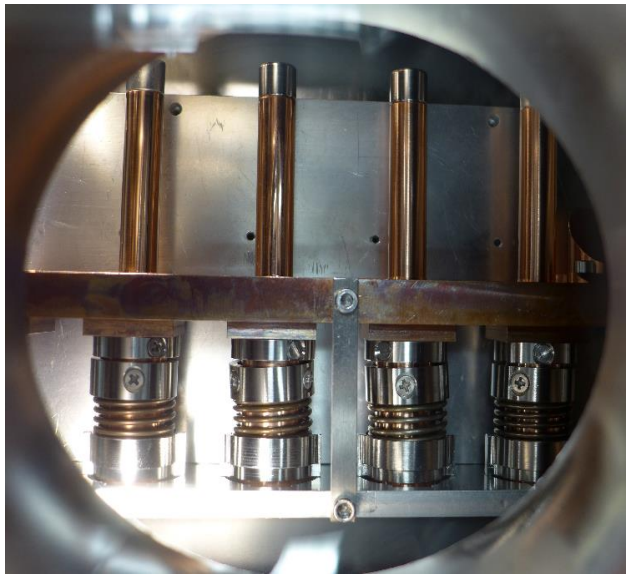


parameters of SRF gun II in operation

E_{acc} = 8 MV/m CW (20 MV/m peak field on axis)
$E_{cathode}$=12 MV/m (field on cathode)
I_{dark} ~ 30 nA @8 MV/m
4 MeV kinetic energy, bunch charge < 0.4 nC

2. Photocathodes for HZDR SRF gun

Keyword: NC cathode for SC cavity



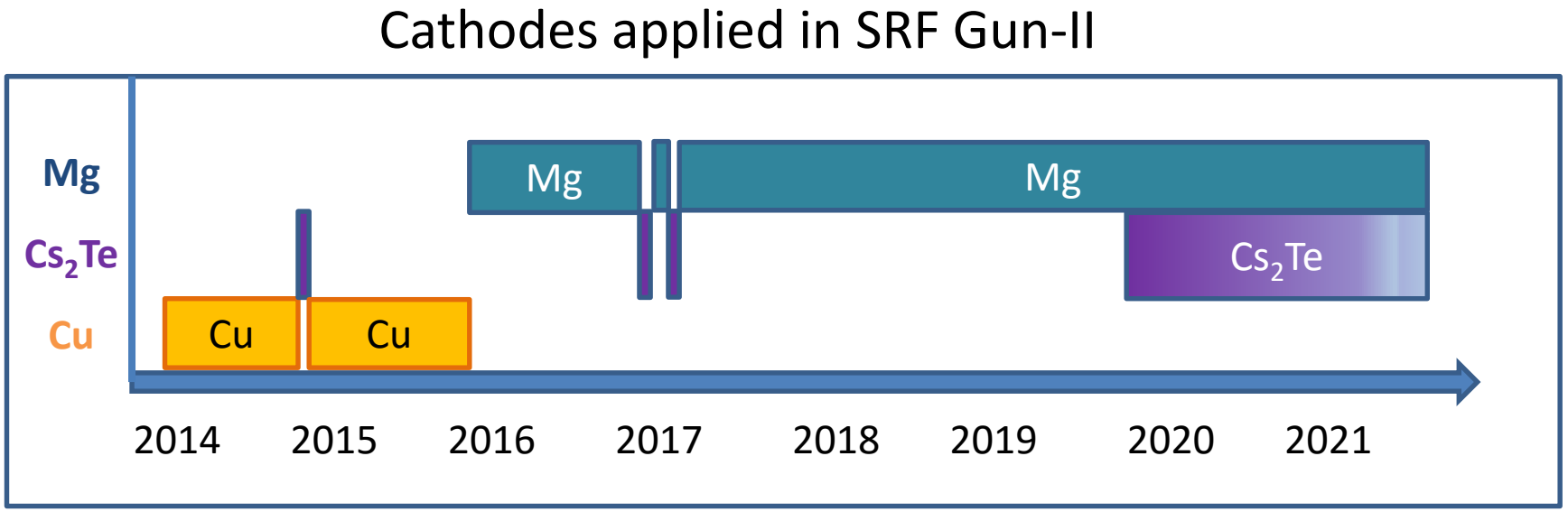
Semiconductor photocathodes

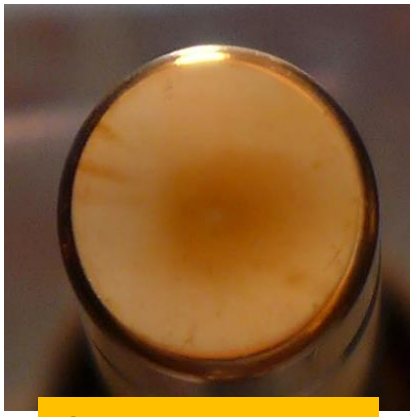
- high risk of contamination
- vacuum demanding
- preparation system
- high quantum efficiency (QE)
- less laser power required

Metallic photocathodes

- good compatibility with Nb cavity
- robust, long lifetime
- fast response
- low QE
- high UV laser power required

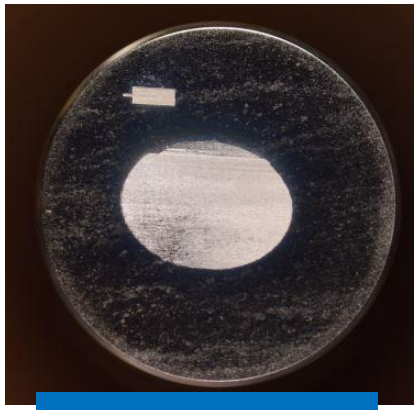
2. Photocathodes for HZDR SRF gun





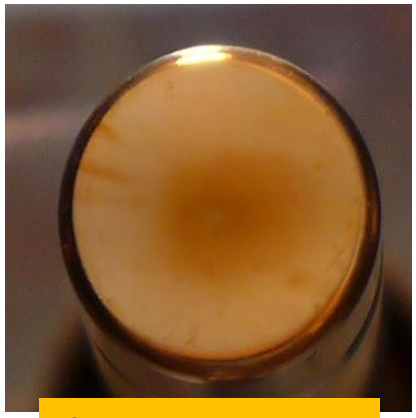
Cu plug (used)

Cs_2Te on Mo plug

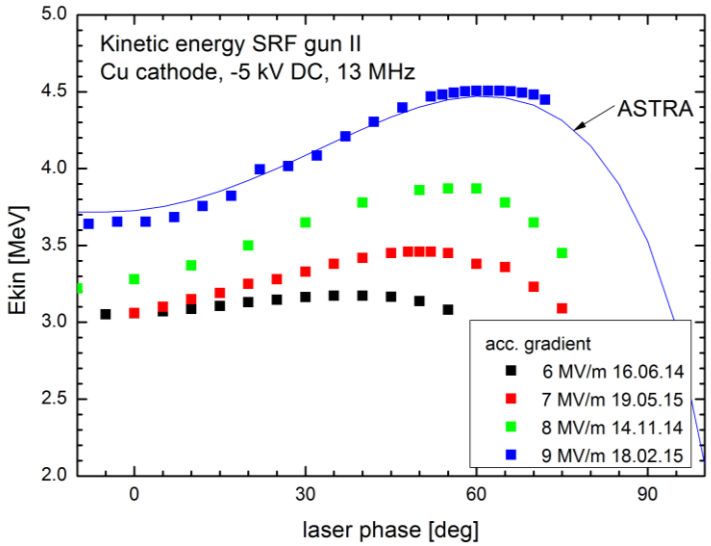


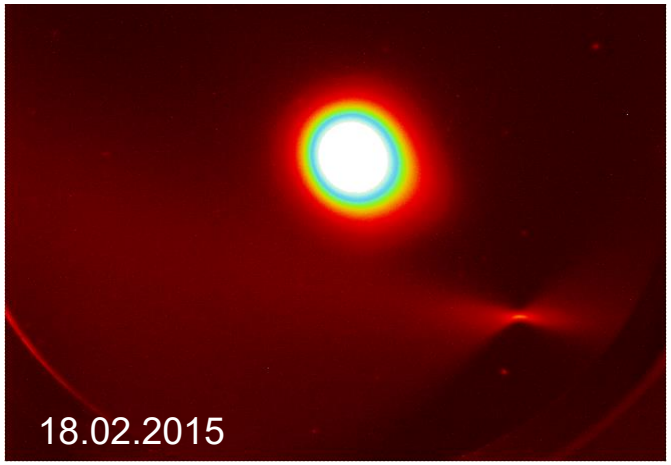
Mg pug #216

2. Photocathodes for HZDR SRF gun: Cu

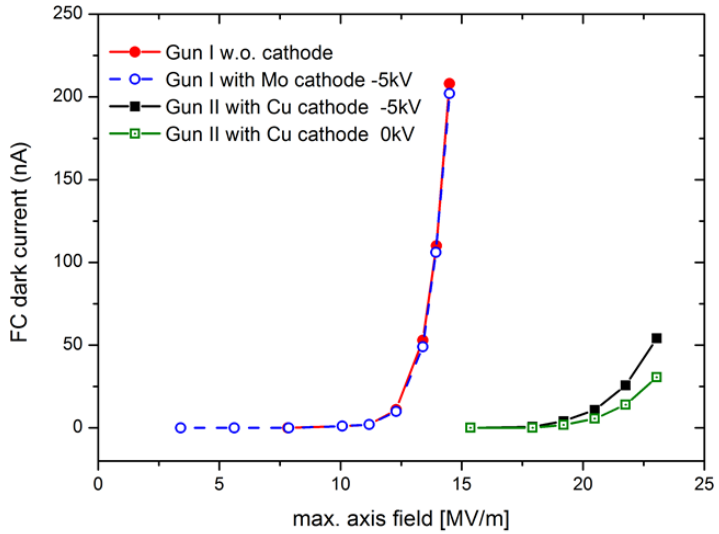


Cu plug (used)





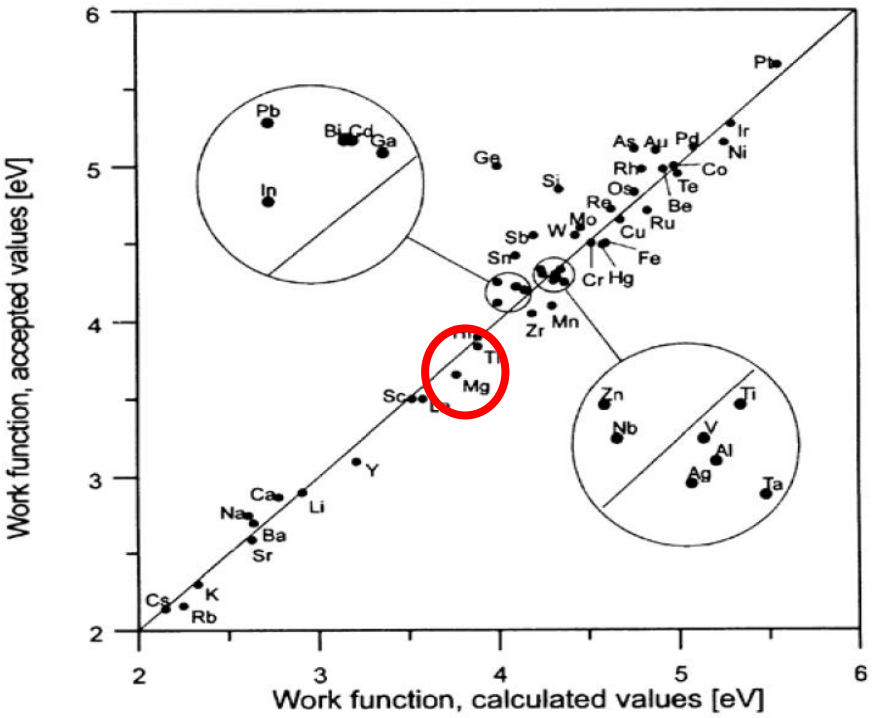
beam 200 nA and dark current 53 nA
at 9 MV/m (23 MV/m peak)



2. Photocathodes for HZDR SRF gun: Mg

a „Clean“ (Cs-free) cathode for SRF gun

Metal (polycrystalline)	QE (%)	ϕ (eV)
Cu	10^{-6} - 10^{-5}	4.6
Mg	10^{-6} - 10^{-4}	3.6
Mo	10^{-6}	4.5
Nb	10^{-6}	4.3
Pb	10^{-6}	4.25

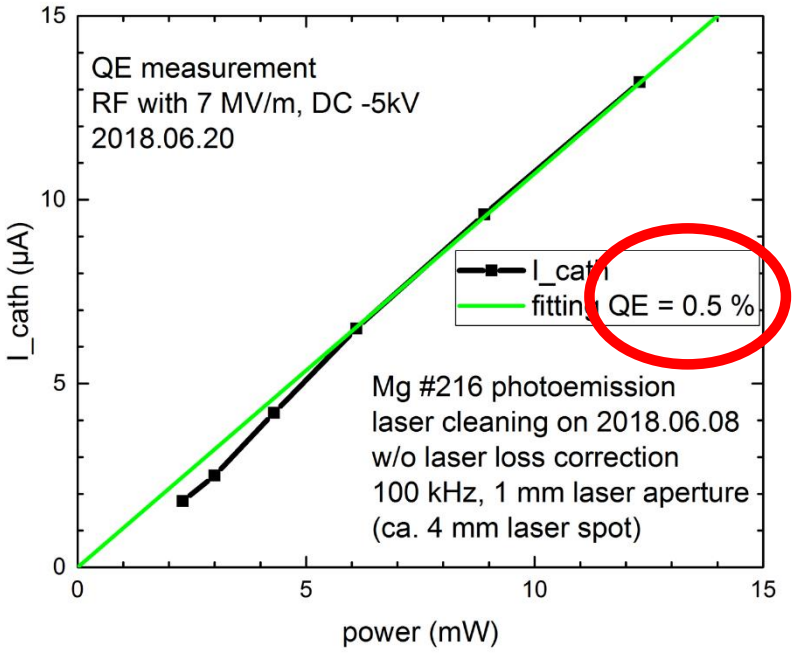


Lide, D. R.. Properties of Solids, in: *CRC Handbook of Chemistry and Physic, Internet Version 2005*. Boca Raton, FL: CRC Press; 2005, P. 124

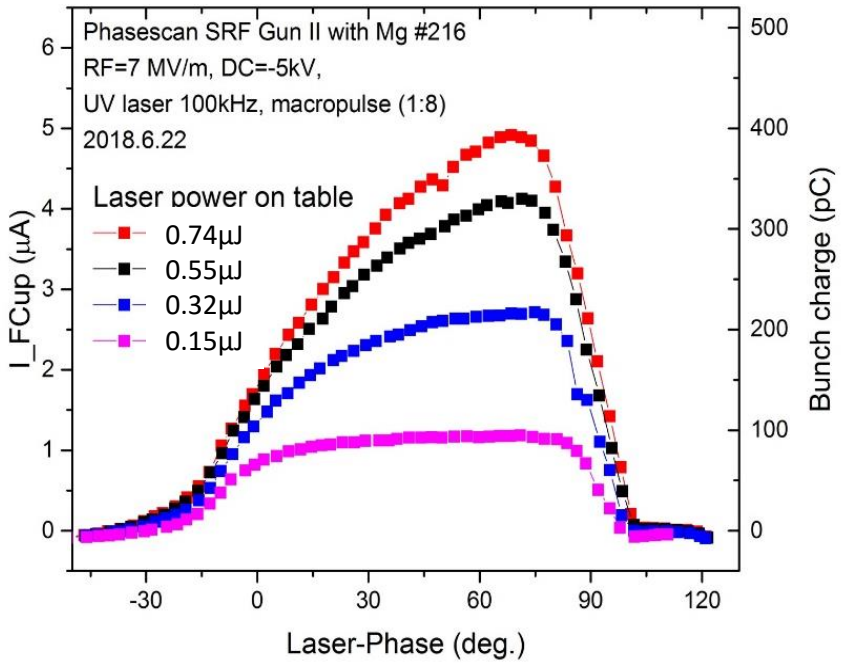
S. Halas, Materials Science-Poland, Vol. 24, No. 4, 2006

2. Photocathodes for HZDR SRF gun: Mg

- ✓ 0.1%-0.3% @ 258nm after laser cleaning



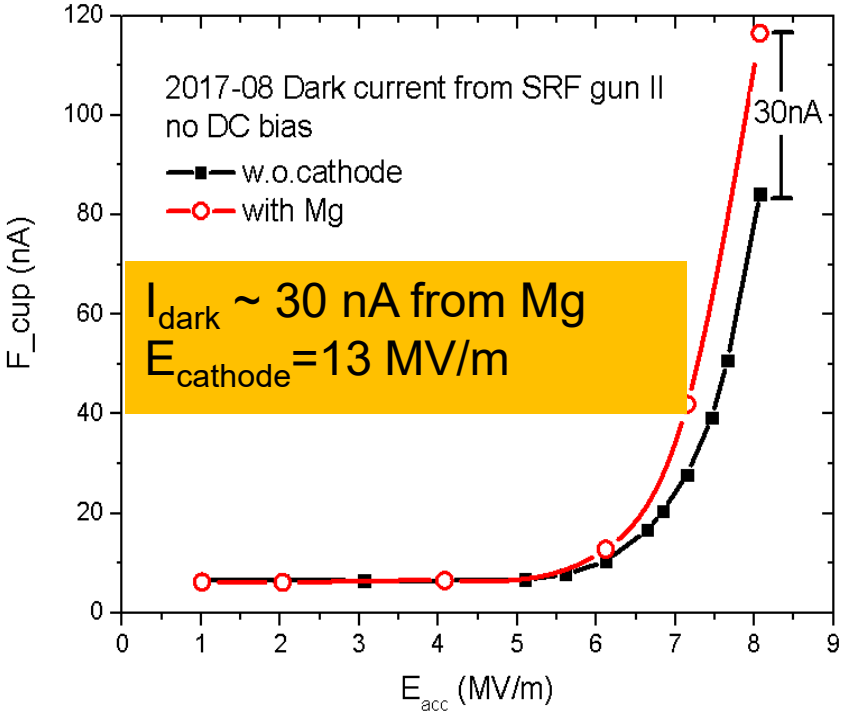
- ✓ Bunch charge up to 0.3 nC

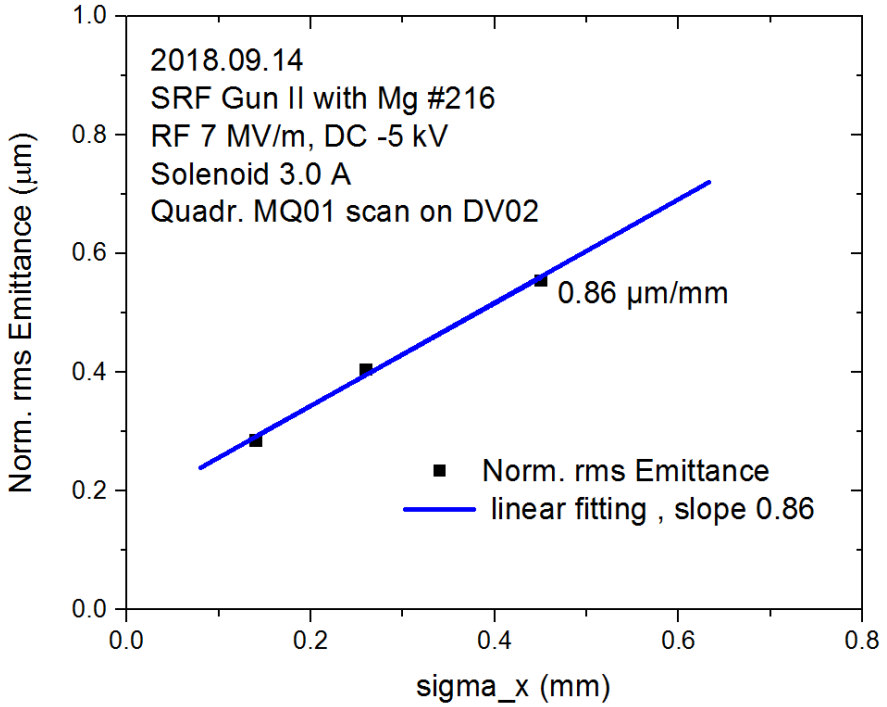


2. Photocathodes for HZDR SRF gun: Mg

- ✓ No multipacting problem
- ✓ acceptable dark current

? Thermal emittance

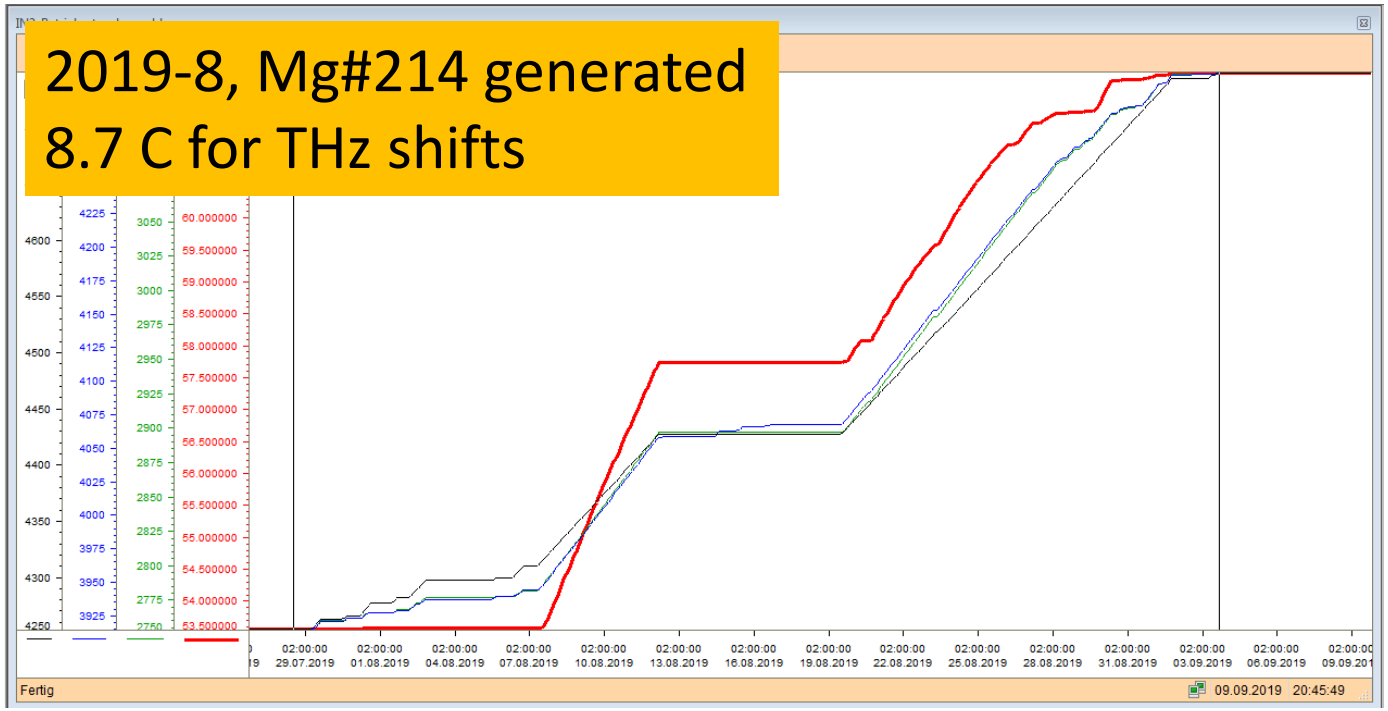




H.J.Qian et al., Appl. Phys. Lett. **97**, 253504 (2010)

2. Photocathodes for HZDR SRF gun: Mg

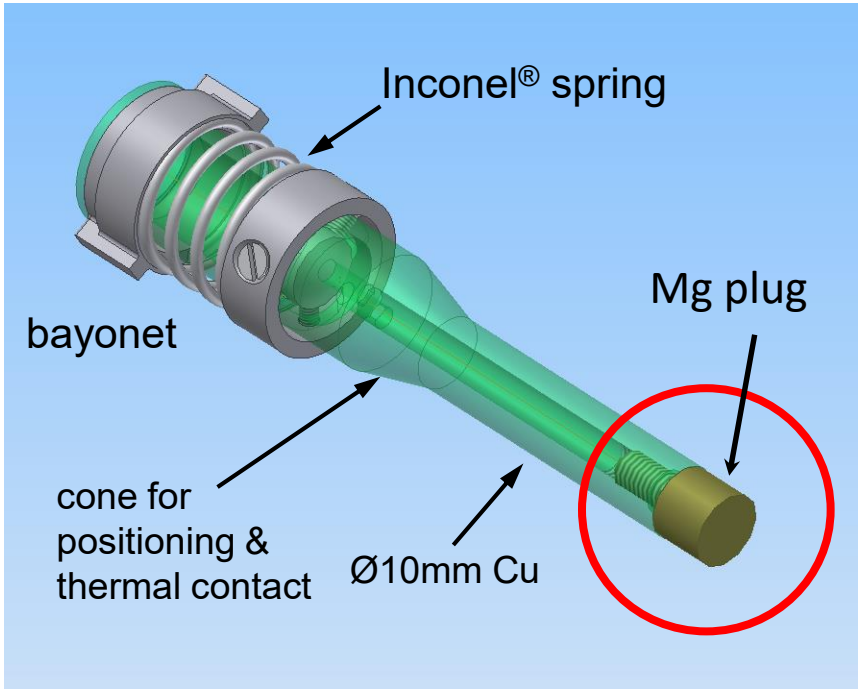
- ✓ Robust in SRF gun
- ✓ Replaced only due to vacuum issue in injector

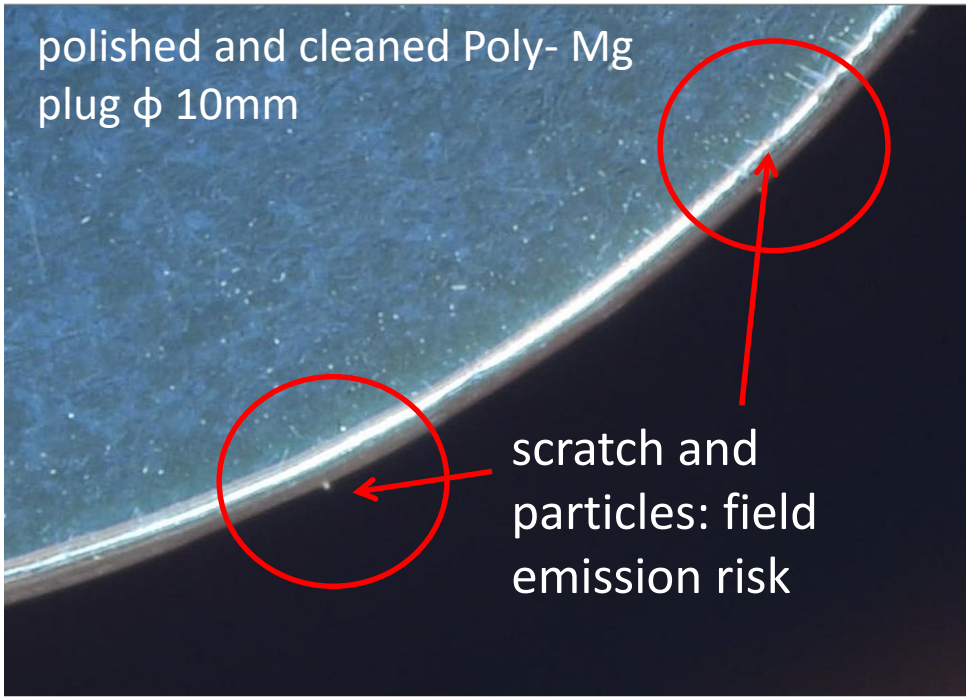


2. Photocathodes for HZDR SRF gun: Mg

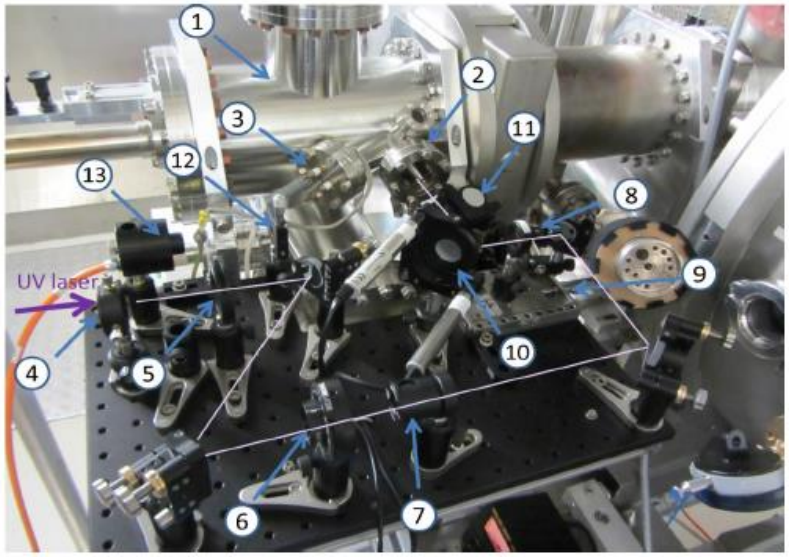
Prepare Steps:

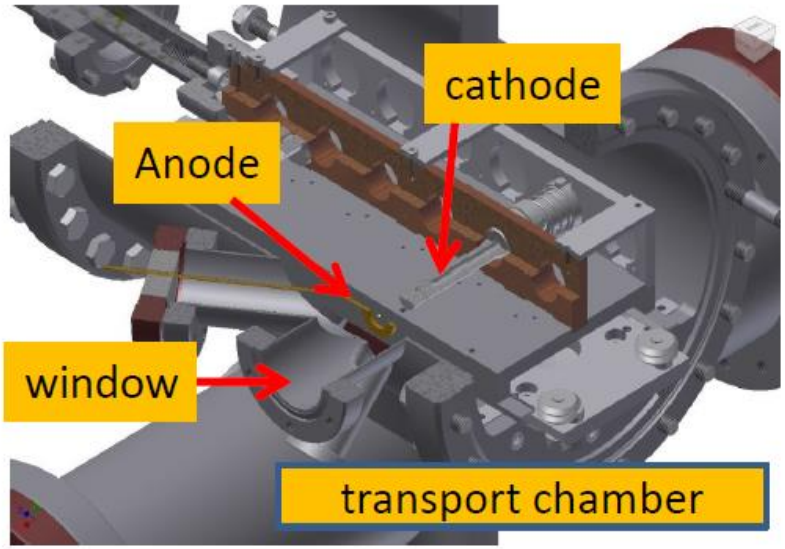
- Machine bulk plug of Mg (Goodfellow & MaTecK)
- Optical polishing
- Remove oxide layer & clean in cleanroom
- Install in transport chamber and check quality
- Cleaning with **ps UV laser**



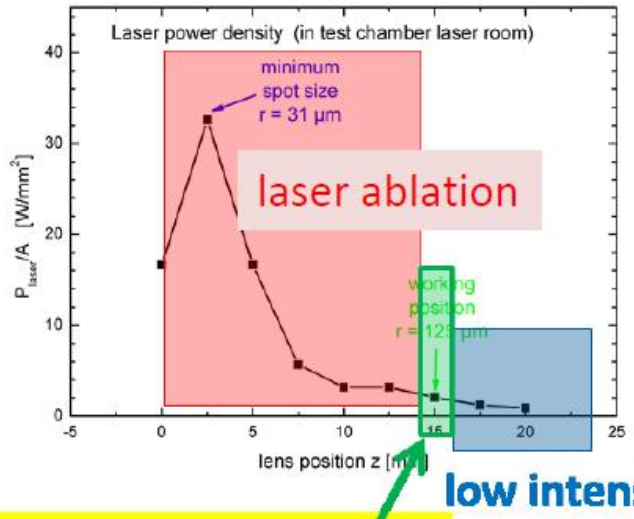


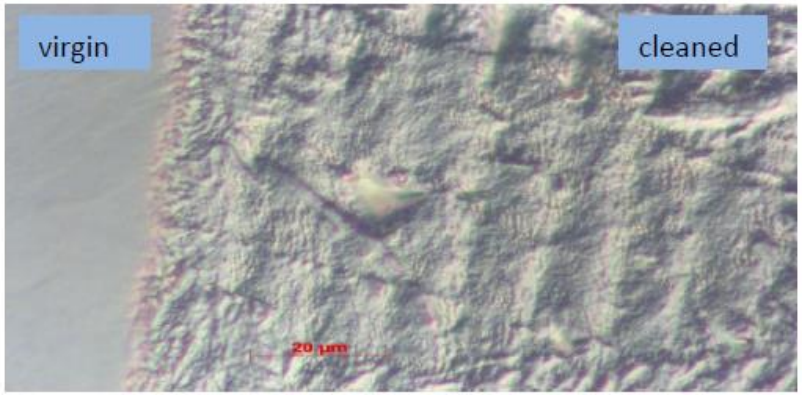
2. Photocathodes for HZDR SRF gun: Mg





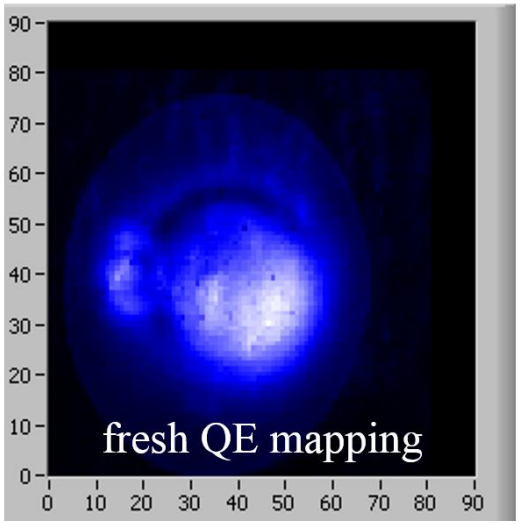
Laser cleaning set-up at transport chamber at SRF gun
using the UV drive laser (100 mW, 100 kHz CW)



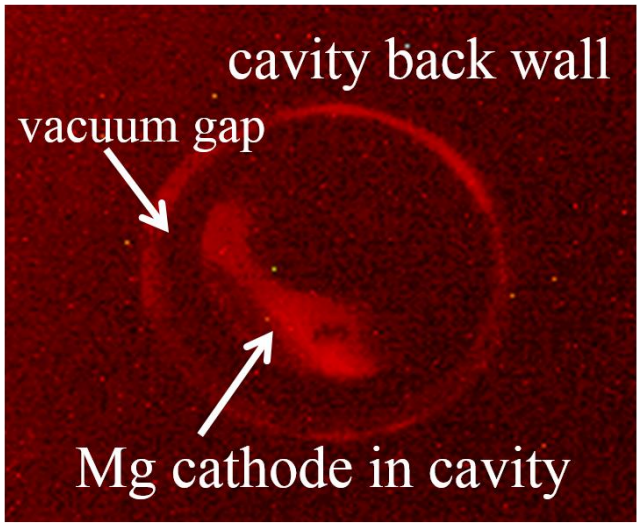


2. Photocathodes for HZDR SRF gun: Mg

cleaning time: ~ 2 hours
12 µm x 12 µm step size,
100 ms dwell time

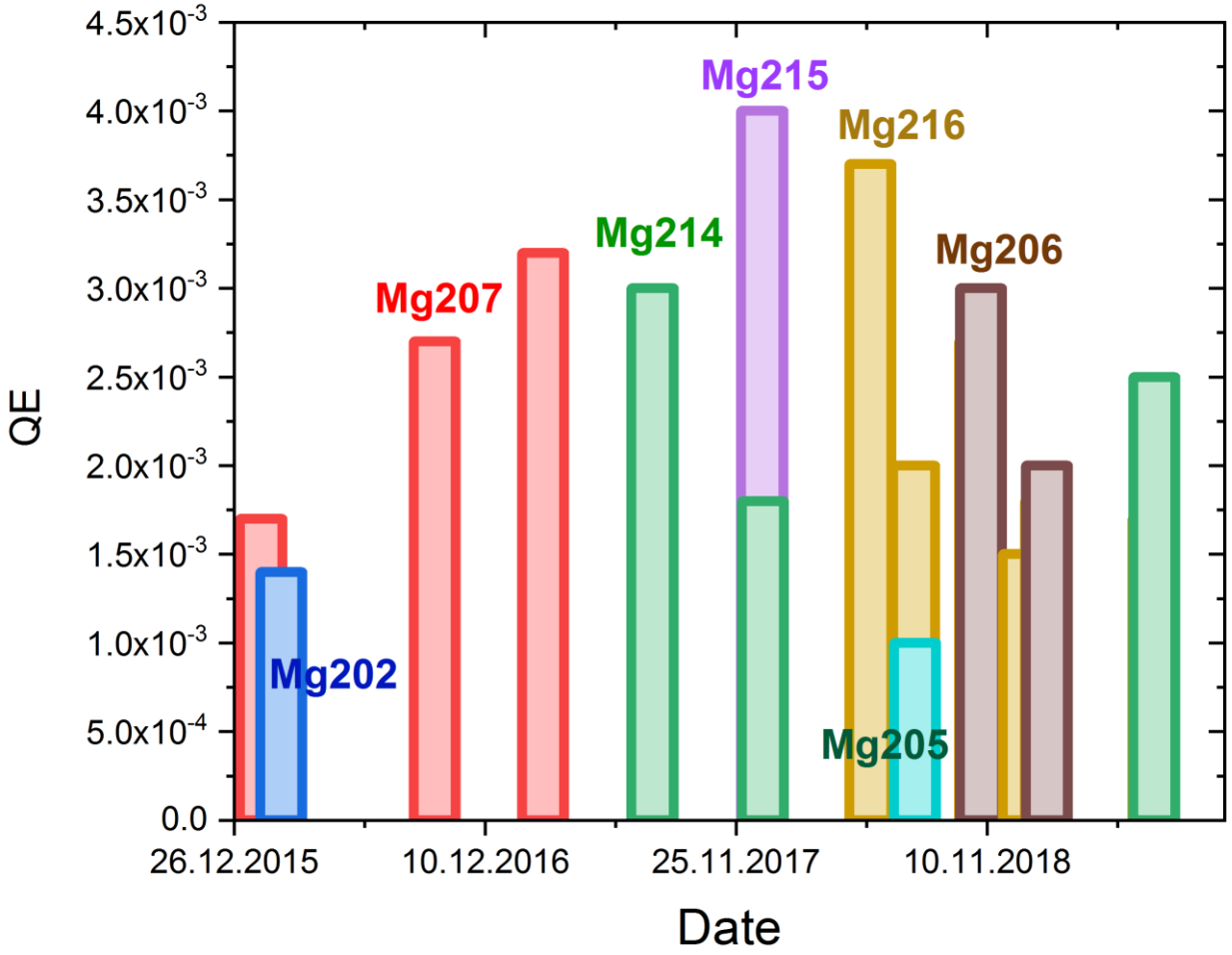


QE mapping
with low laser power



Mg plug in cavity

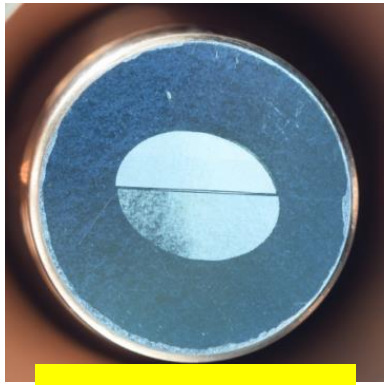
2. Photocathodes for HZDR SRF gun: Mg



QE measured in transport chamber with DC bias

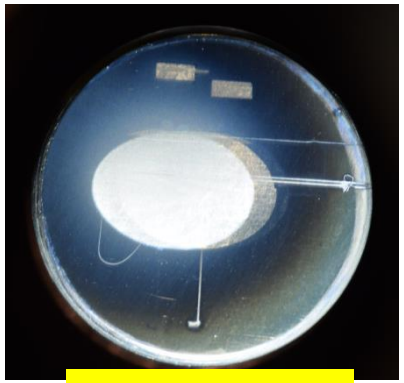
2. Photocathodes for HZDR SRF gun: Mg

Part of examples



2016.03 **Mg #201**

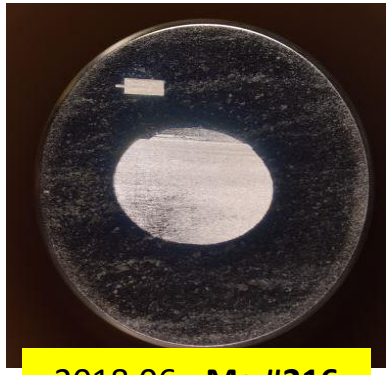
2016.11 **Mg #207**



2017.8 – **Mg #214**

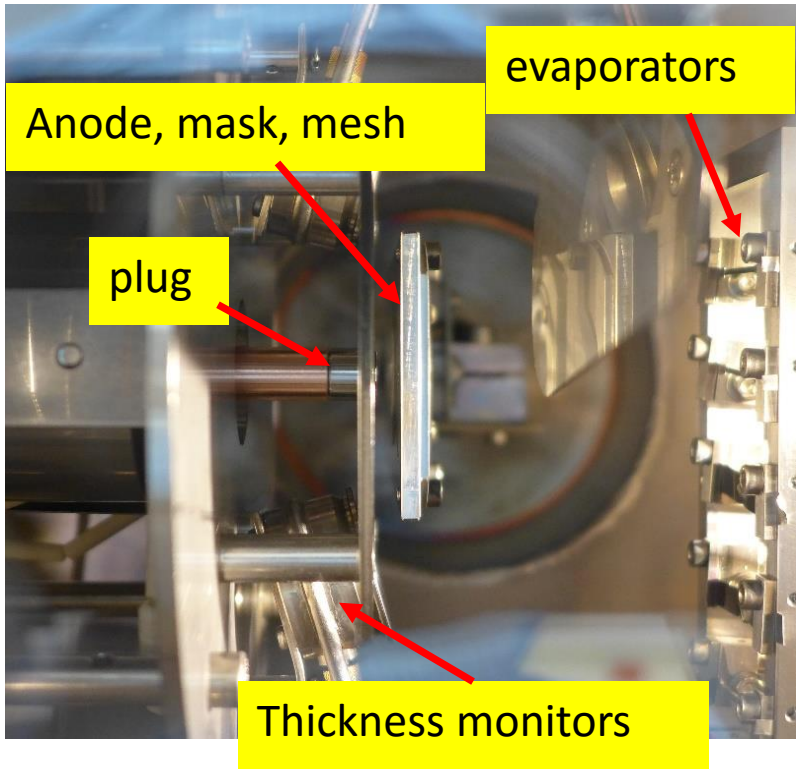
2018.1 – **Mg #214**

2018.01 - **Mg #215**



2018.06 - **Mg #216**

2. Photocathodes for HZDR SRF gun: Cs_2Te



For SRF Gun I

- 35 Cs_2Te photo cathodes produced
- QEs of most fresh cathodes are 8% ~ 15%.
- 8 Cs_2Te ever worked in SRF gun I.

- Contribute 30% of the total dark current
- Thermal emittance (QE of 1%)
  0.6 ~ 0.7mm·mrad/r(mm).

Mo plug ϕ 10 mm x 8mm on Cu-stem
Polished Mo surface R_a: 8 ~10 nm
Cleaning and baking
Deposition Te +Cs: standard, co-evaporation
Transport to Gun

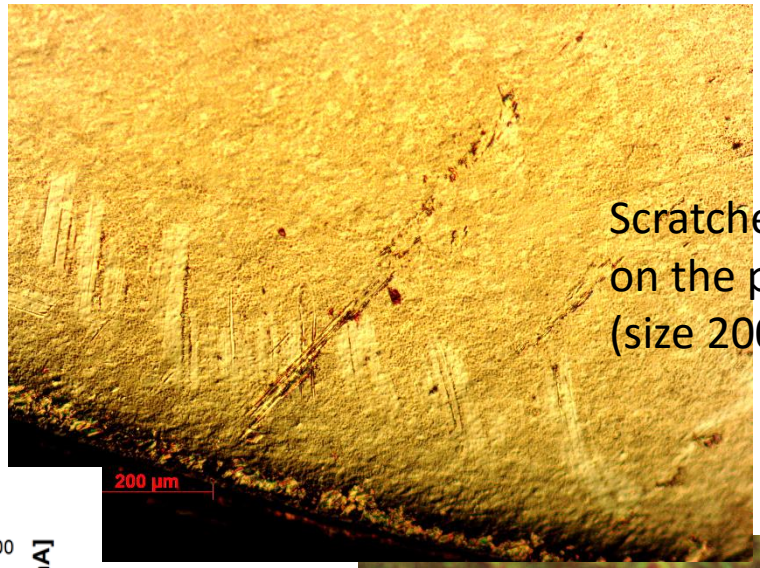
Cathode #17.04.2012 Cs_2Te
•fresh QE 8.5%, in gun 0.6%
•beam time ~2100 h
•extracted charge > 264 C

Proceedings of FEL2010,Malmoe,Sweden
PhysRevSpecialTopics_13_043501

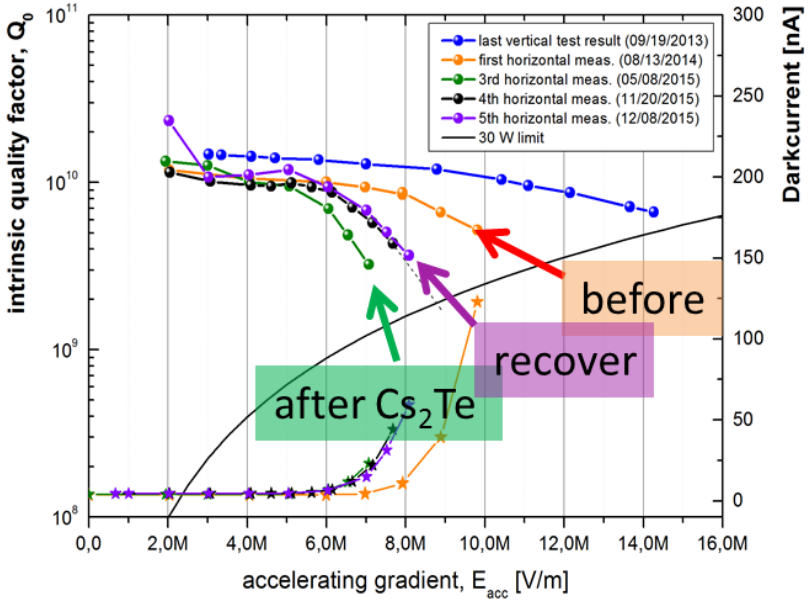
2. Photocathodes for HZDR SRF gun: Cs_2Te

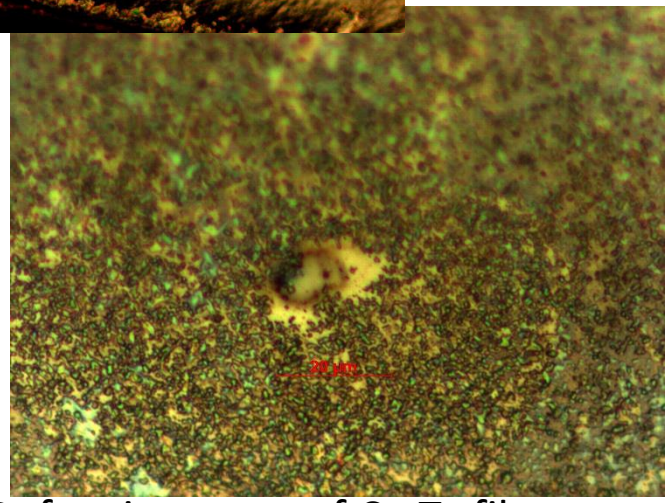
For SRF Gun II

2015.02 the 1st Cs_2Te cathode produced field emission due to scratches and particles



Scratches and particles on the plug rim (size 200 µm level)

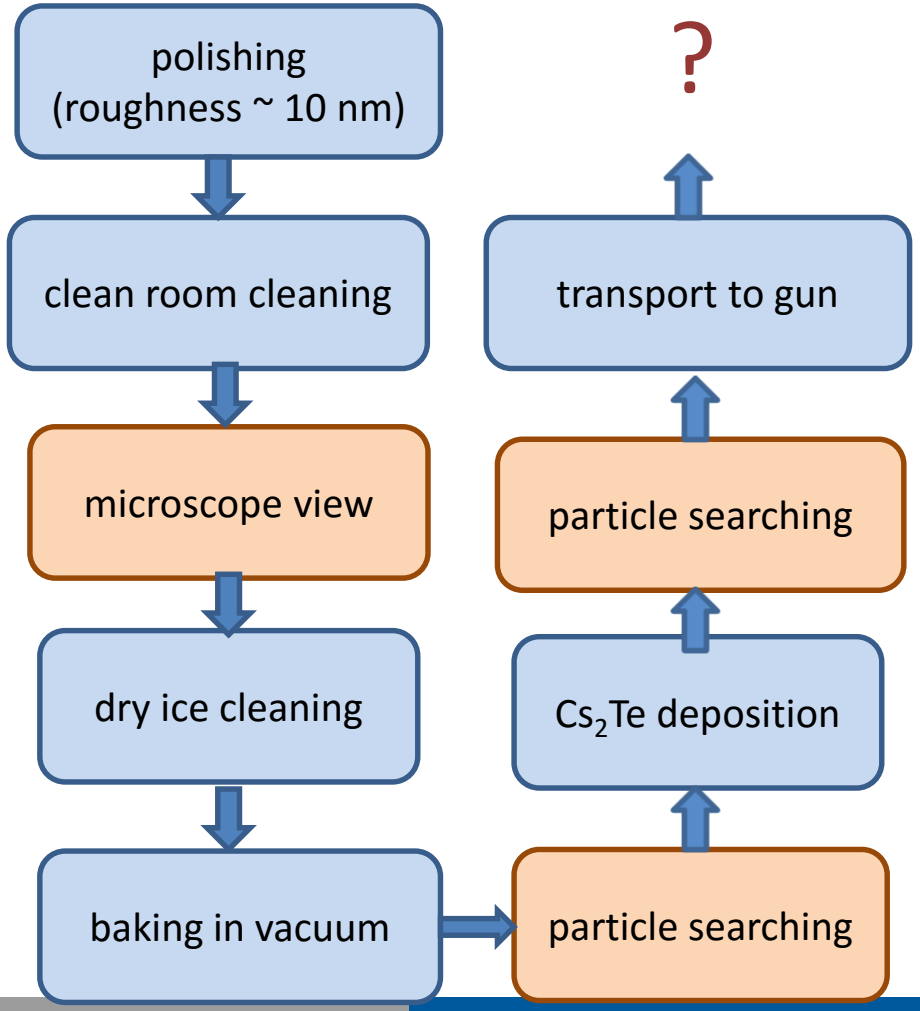


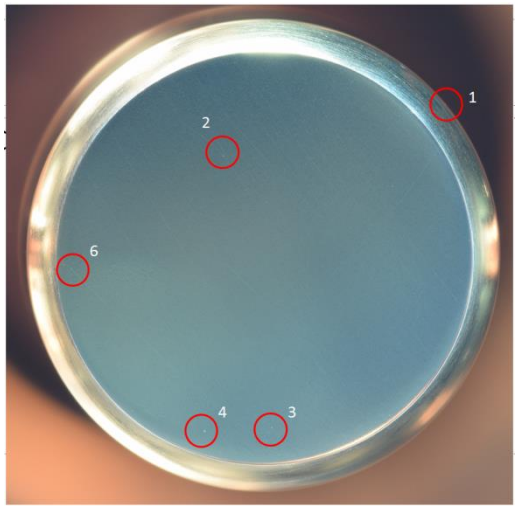


Defect in center of Cs_2Te film (size 20 µm)

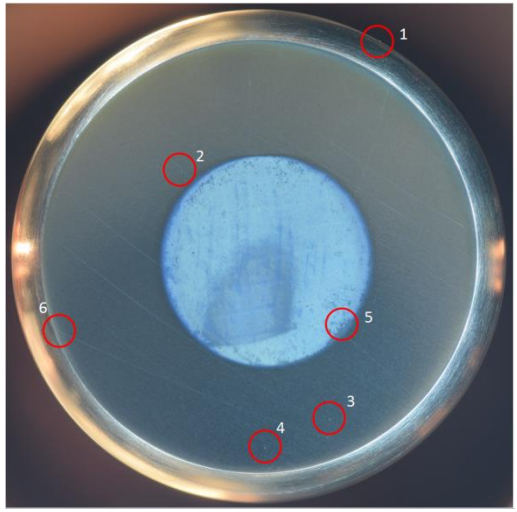
2. Photocathodes for HZDR SRF gun: Cs_2Te

Modify preparation chamber, improve plug quality check to solve paticle problem





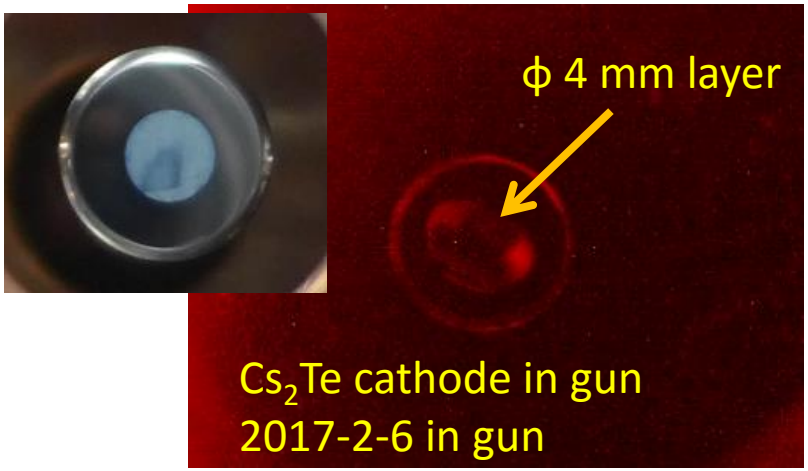
before deposition



after deposition

2. Photocathodes for HZDR SRF gun: Cs_2Te

in 2016, second try with Cs_2Te in SRF gun II
2 cathodes disappeared after two-week beam time



QE 1.7%, low dark current
produced 200 µA beam

two weeks later

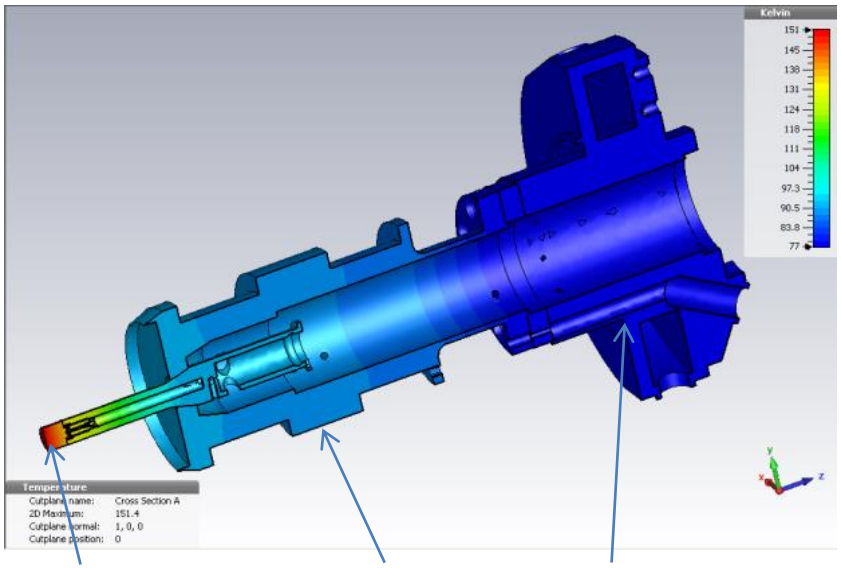
No QE, high dark current,
cavity polluted
Mo plug overheated T > 300°C

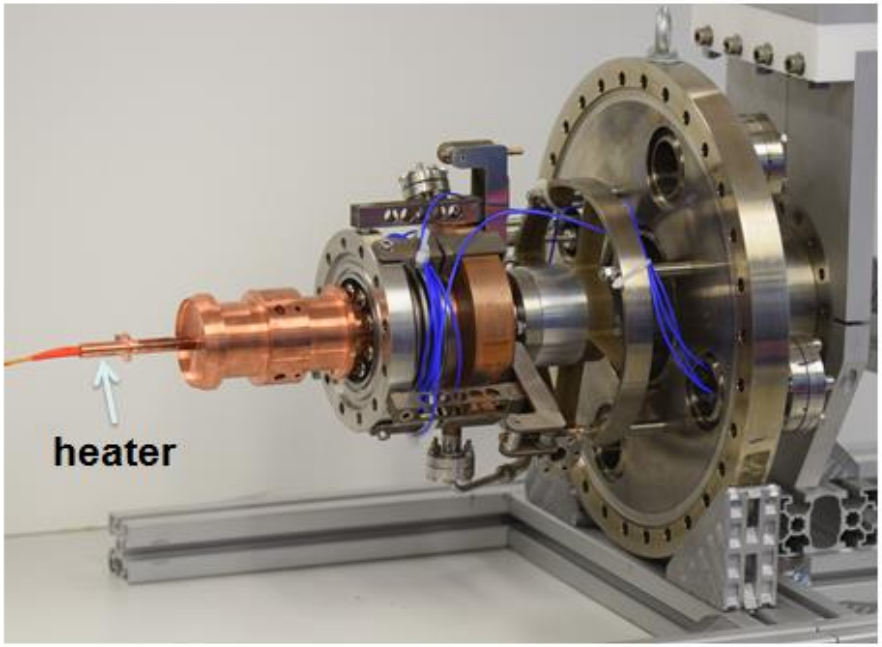
2. Photocathodes for HZDR SRF gun: Cs_2Te

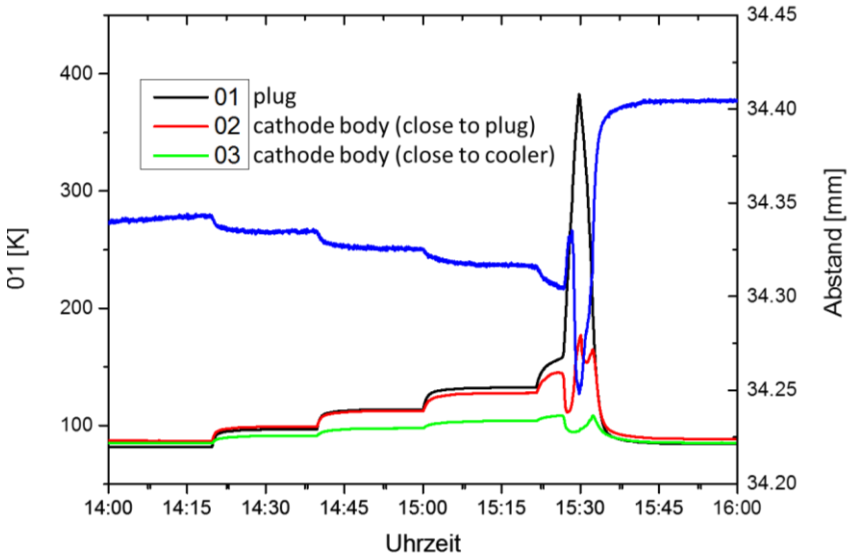
Reason of cathode overheating

- Thermal expension coefficent
- Connection methodes

By A.Arnold

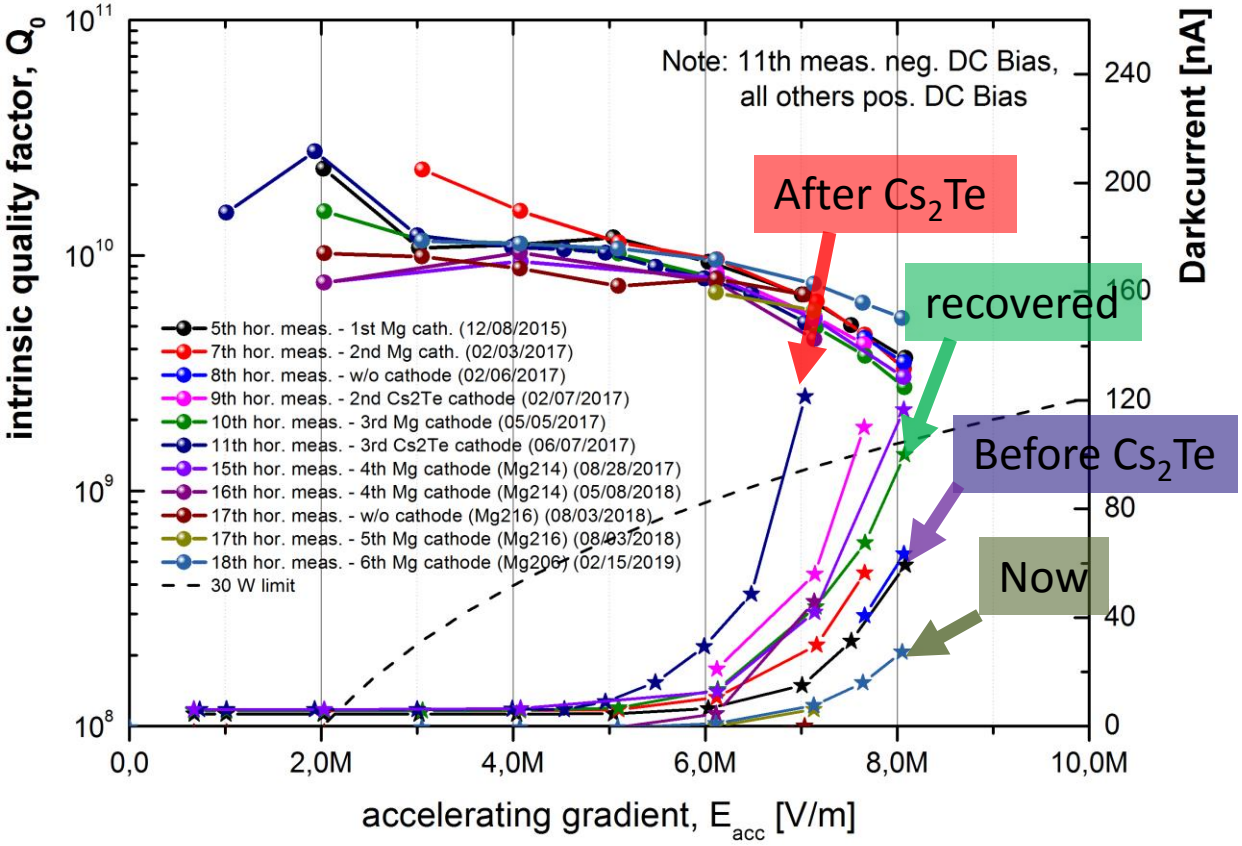






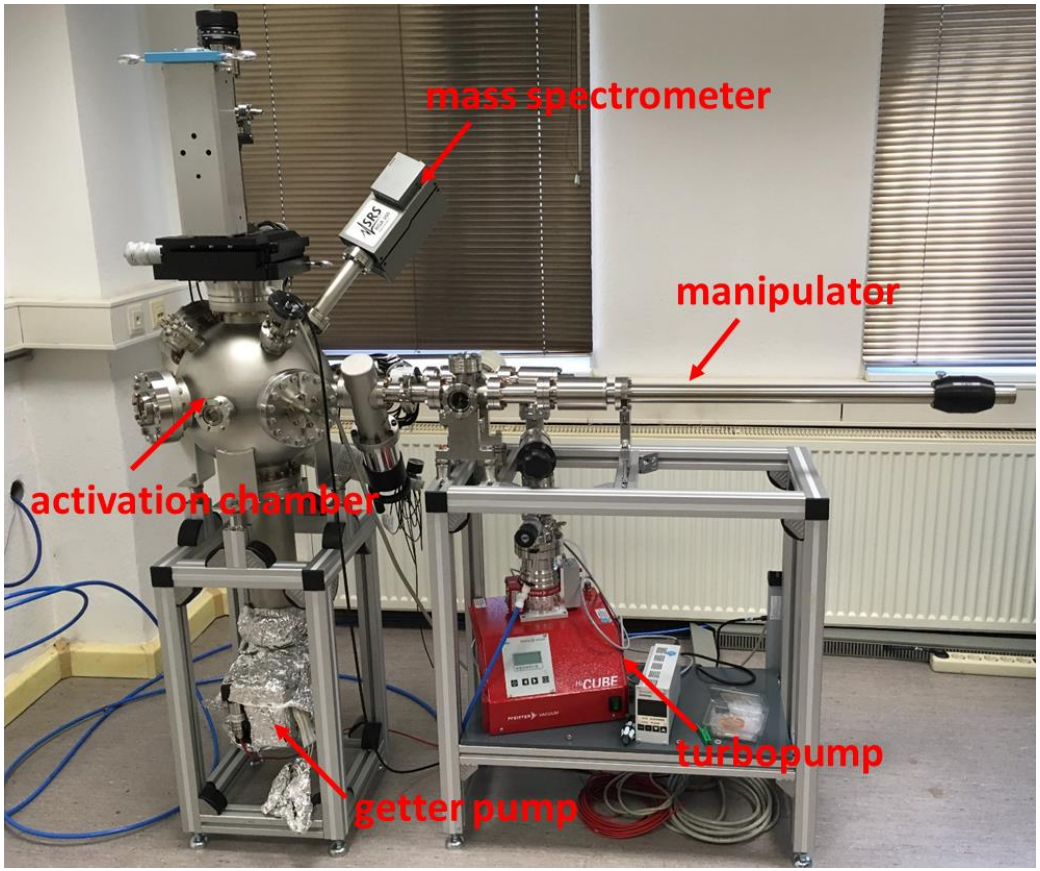
2. Photocathodes for HZDR SRF gun: Cs_2Te

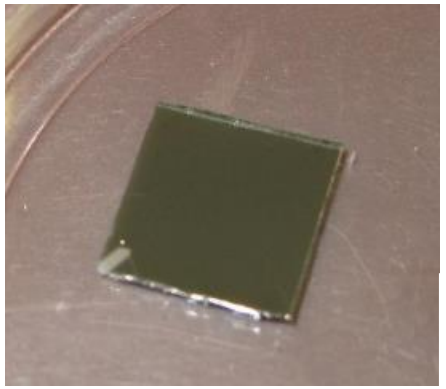
Influence of Cs_2Te tests to cavity



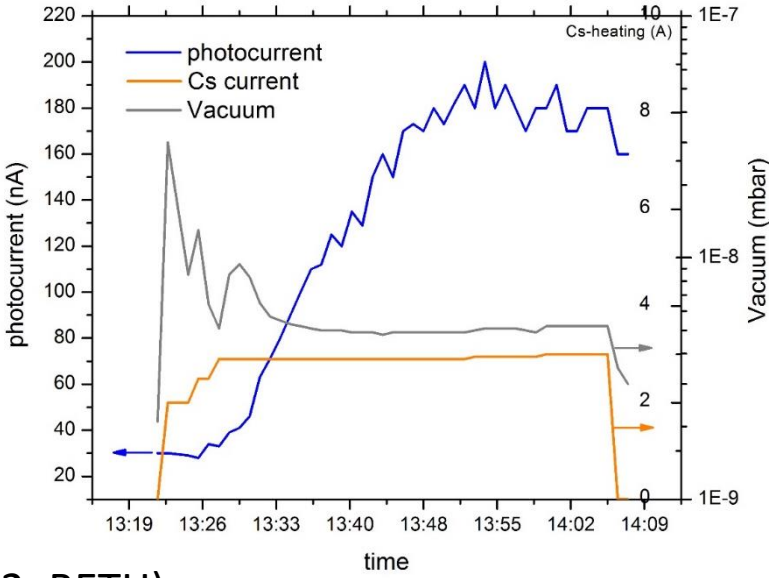
2. Photocathodes for HZDR SRF gun: new idea

OnGoing work- GaN(Cs)





P-GaN on sapphire



BMBF cooperation with Univ. Siegen, JG Mainz (HOPE2, BETH)

3. Summary and outlook

- **Mg photocathodes operate successfully in SRF gun**
  - Mg can reach high QE of $1\sim5\times10^{-3}$
  - no multipacting and low dark current (<30 nA)
  - robust

- **Medium / high currents require semiconductor photocathodes**
  - Cs_2Te is still the choice for medium current (1 mA)
  - suitable substratum for better thermal contact: Cu
  - study new material (GaN)

- **Photocathode handling for SRF gun application**
  - careful quality check for cathodes
  - mechanic to avoid particle production

Thank you for your attention!

Thanks to the ELBE team and our cooperators!