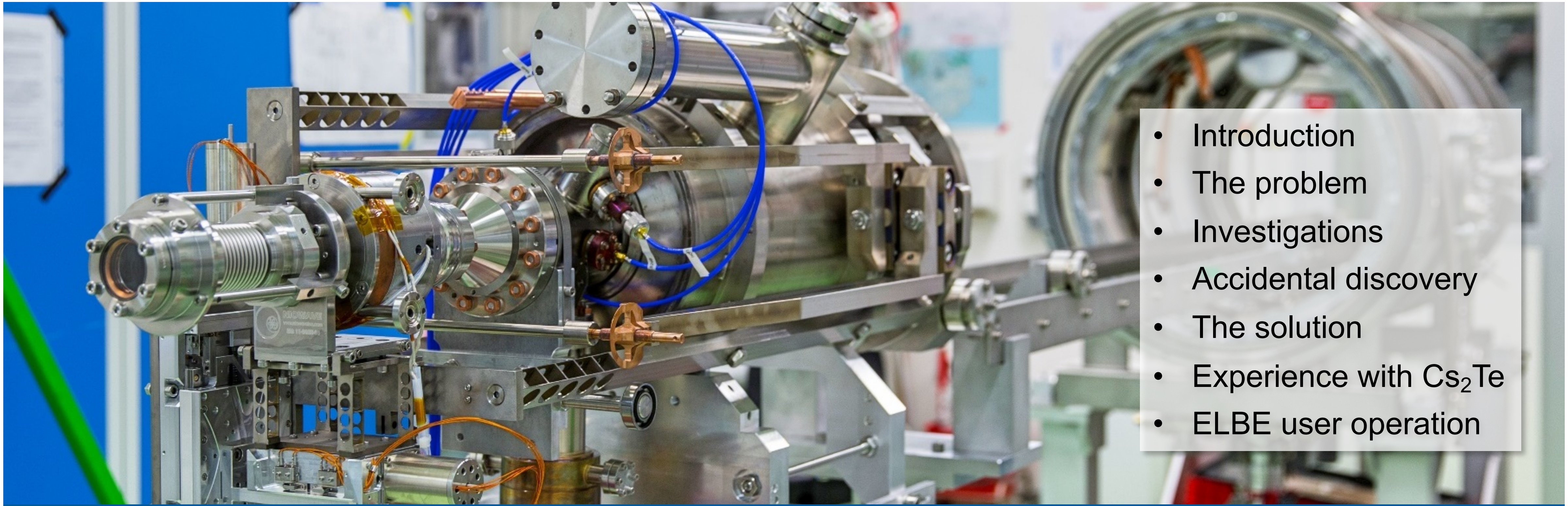
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF



- Introduction
- The problem
- Investigations
- Accidental discovery
- The solution
- Experience with Cs_2Te
- ELBE user operation

Solving overheating of Cs_2Te cathodes in the ELBE SRF gun

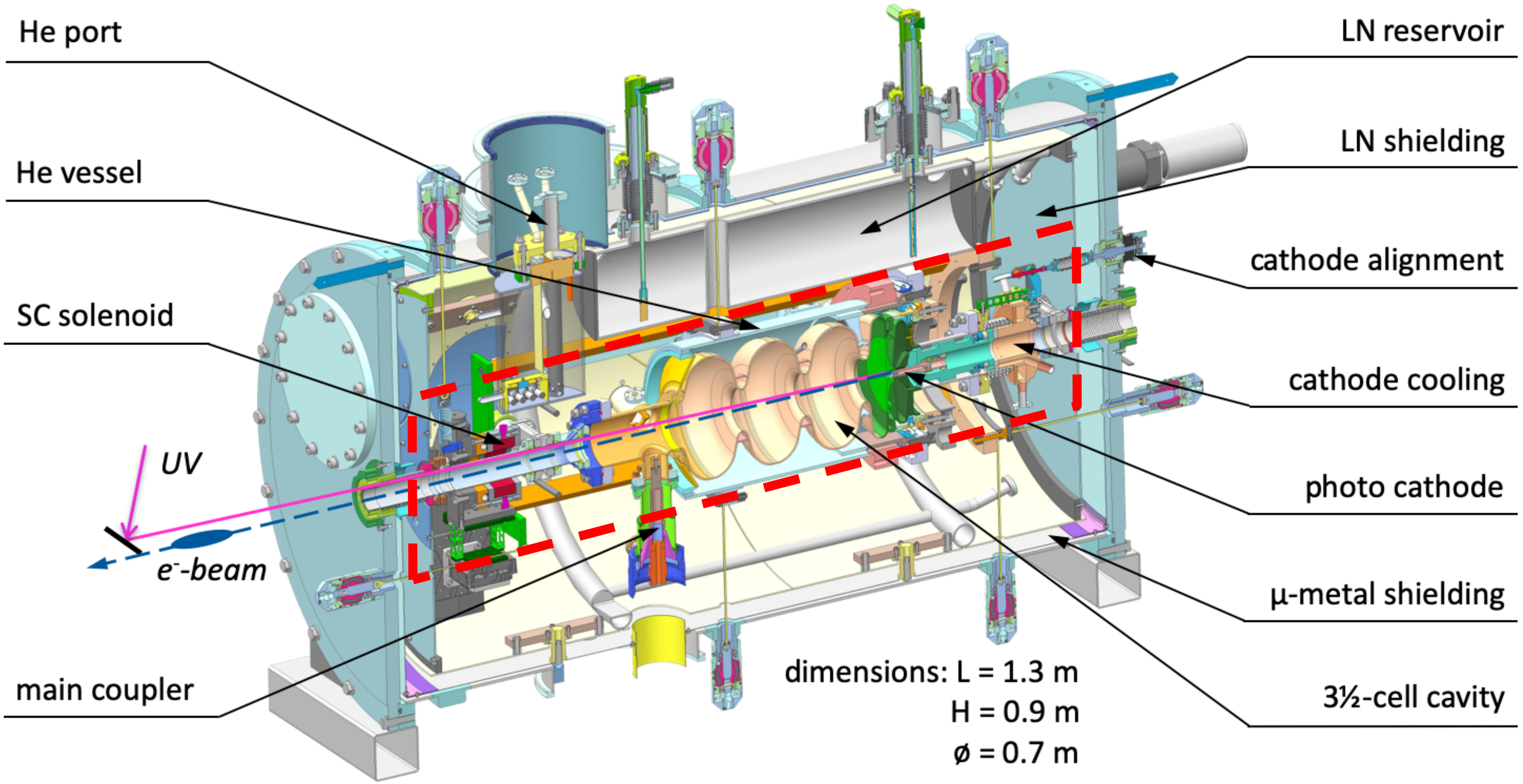
7th virtuell MT meeting - 2 Feb 2021- 3 Feb 2021

On behalf of the whole ELBE team

Institute für Strahlenphysik · FWKE / ELBE · Dr. André Arnold · a.arnold@hzdr.de · www.hzdr.de

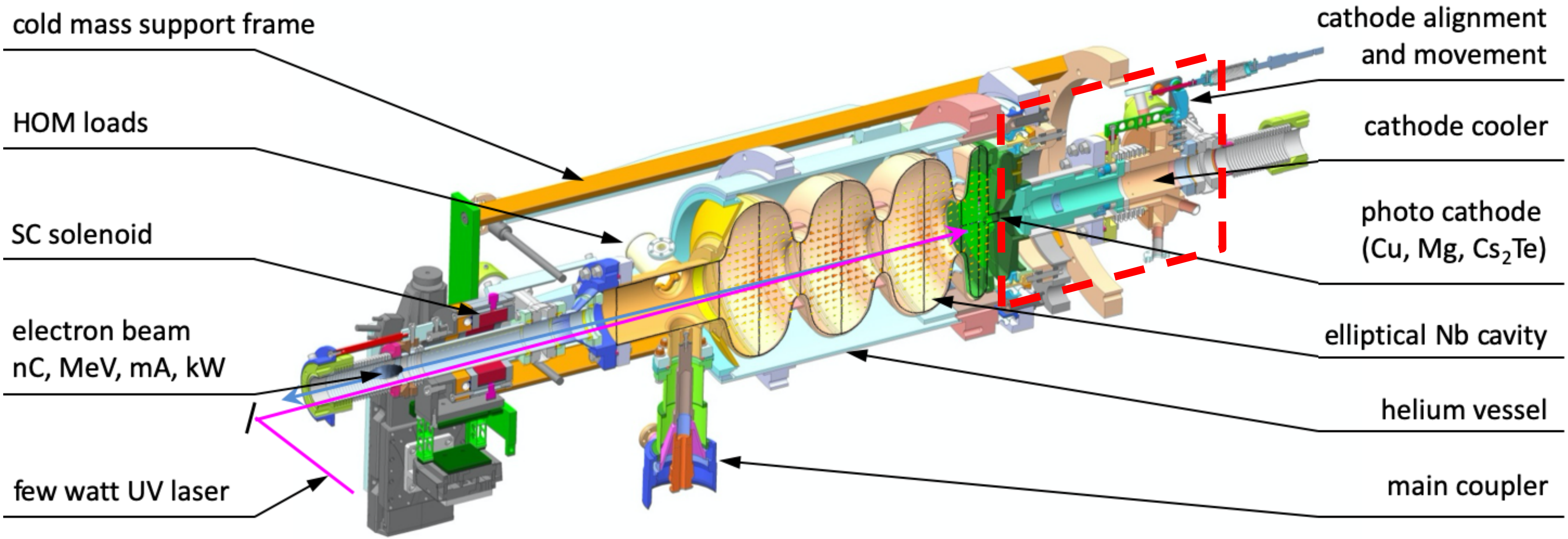
Introduction

Cryomodule



Introduction

Coldmass

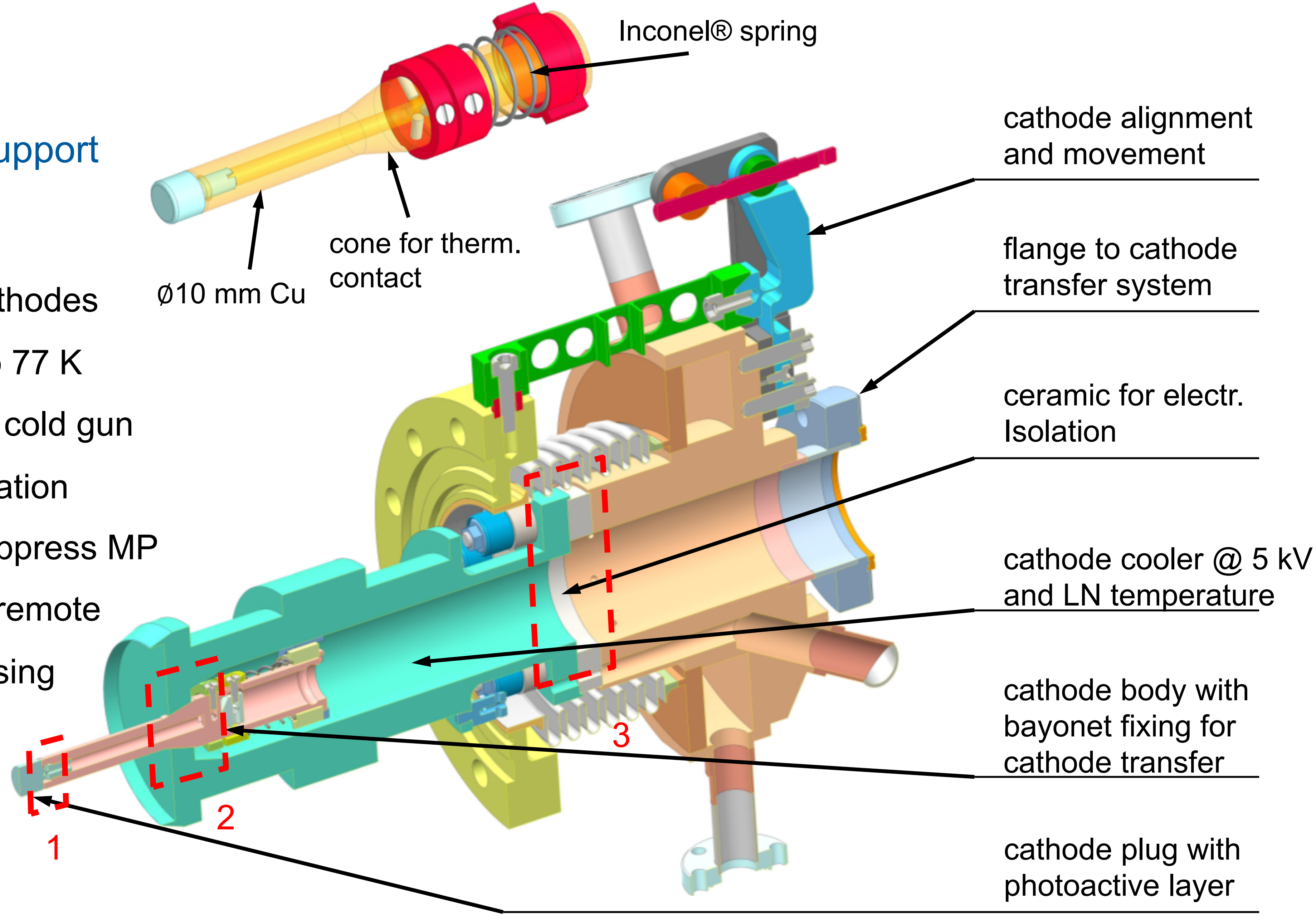


DRESDEN concept HZDR

Introduction

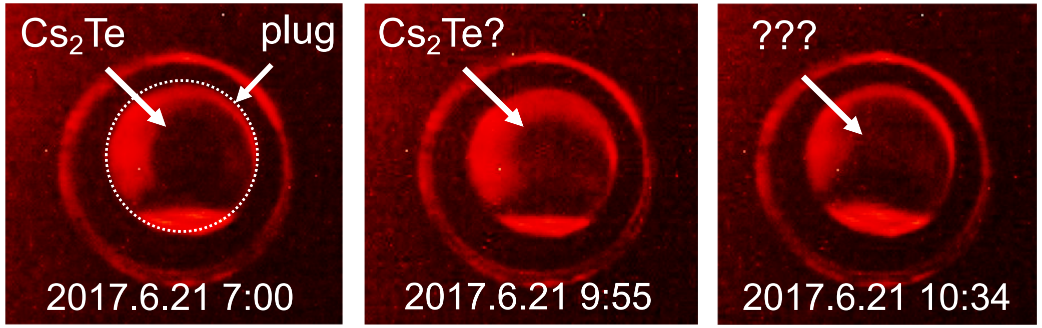
Cathode cooling and support

- Cs_2Te, Cu, GaAs, Mg cathodes
- cathode cooling by LN to 77 K
- cathode transfer into the cold gun
- therm. and electrical isolation
- DC bias up to 7 kV to suppress MP
- moveable (±0.6 mm) by remote stepper for best RF focusing

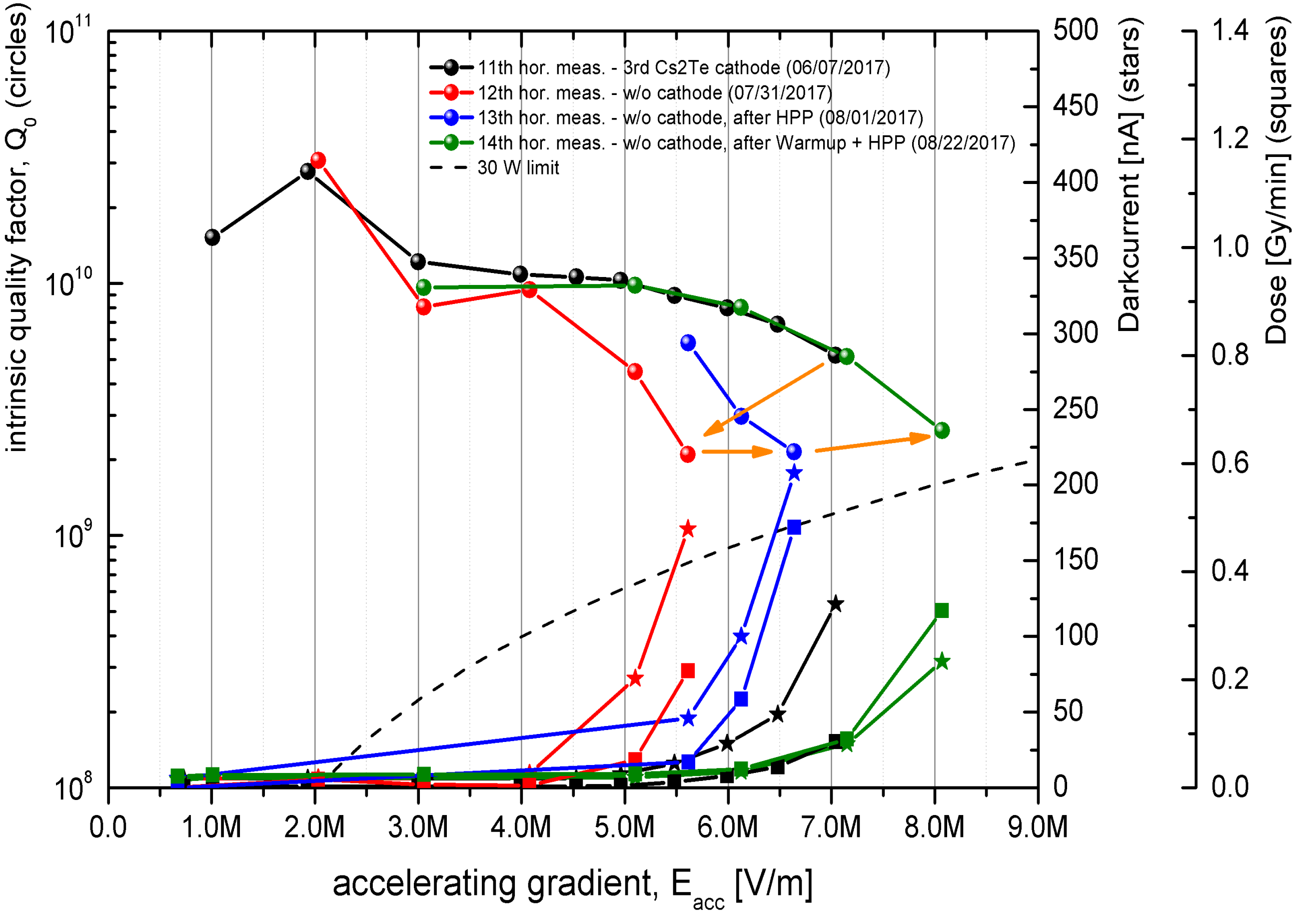


The problem

Cathode disapeared in the second week of operation



Recovery of Cs contamination by complete thermal cycle

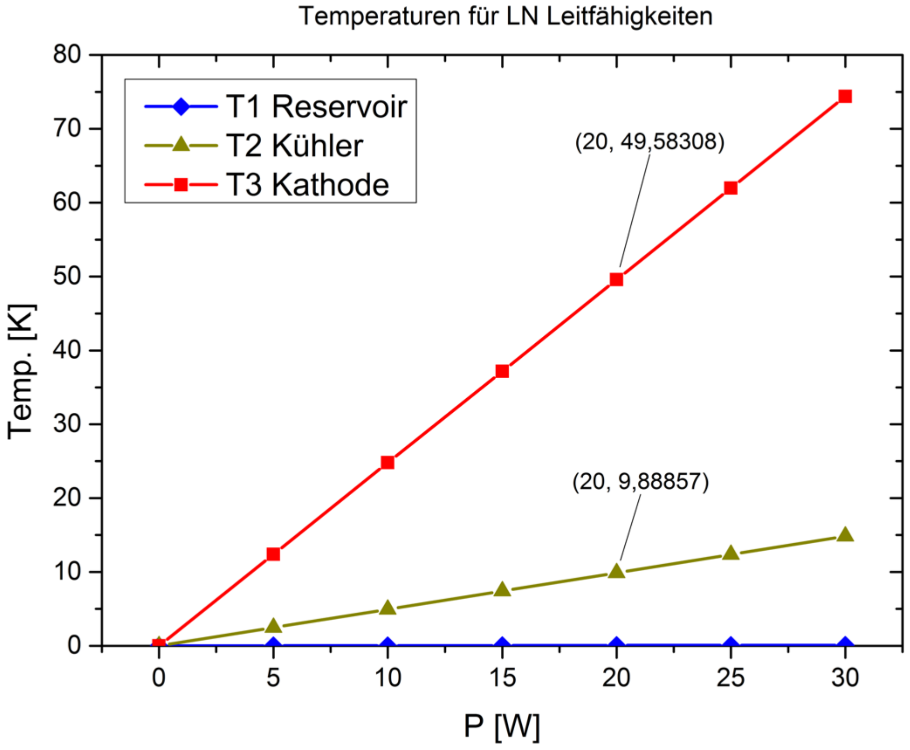


- After one week of stable RF operation unforeseen total loss of Cs_2Te layer in the gun

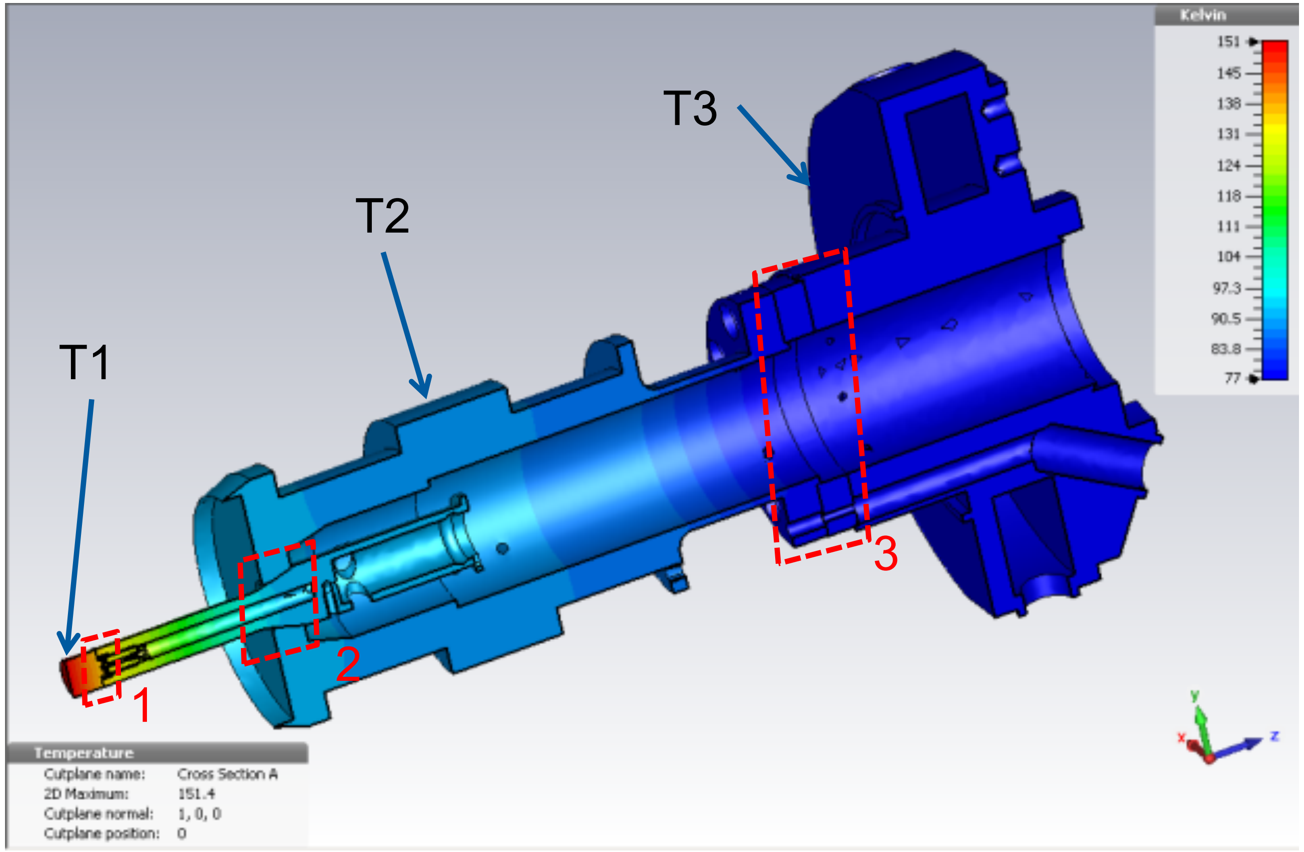
- Accompanied by
  - strong quantum efficiency (QE) drop
  - strong frequency drift not caused by Lorentz force detuning, but maybe by thermal expansion of the cathode
  - increase of dose and darkcurrent (FE)
  - loss of cavity performance (QvsE)

Investigation

Simulation for ideal thermal contacts



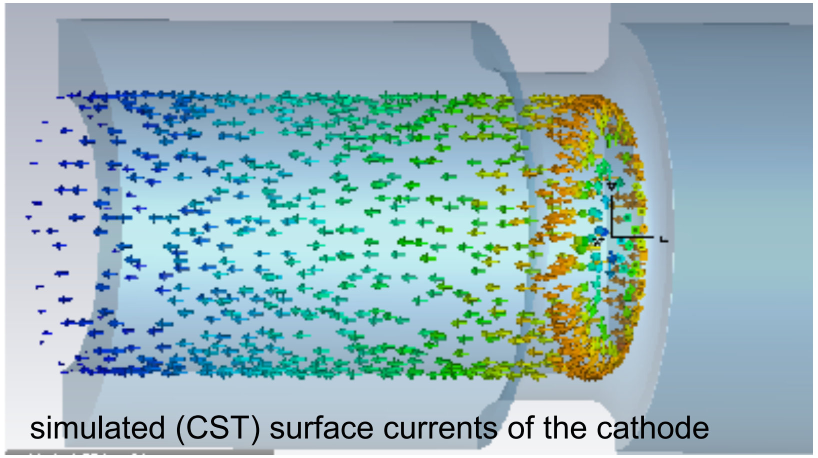
(W/m.K)	@ room temperature	@ LN temperature
Cu	401	~ 500
Mo	138	~ 220
Mg	156	~ 200
Al_2O_3	30	~ 200



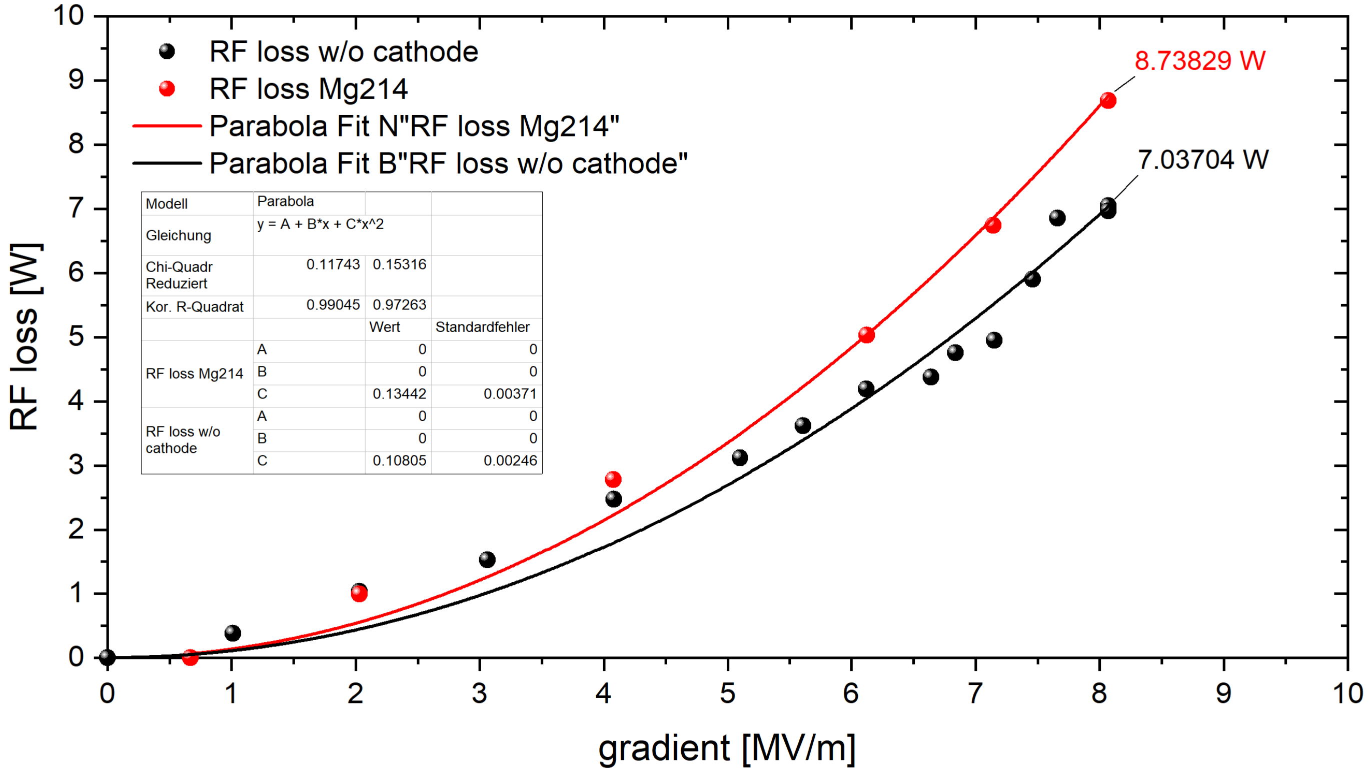
- For ideal thermal contacts a critical temperature rise was not found and thus basic cooling concept is suitable
- But loose therm. contact responsible for the temp. rise?
- Or the heat input higher than expected from simulation?

Investigation

Measured RF loss into a Mg cathode



simulated (CST) surface currents of the cathode



- gas flow meter to measure N2 gas from the combined shield, FPC (coupler) and cathode cooling
- dynamic heat load for 8 MV/m is 7 W (w/o cathode) and 8.7 W with cathode → **1.7 W** dissipated into cathode
- From simulation for same field and Mg @ 77K*) we got **2.0 W**
- Side note: all recently measured Cs_2Te cathodes showed very similar RF losses (0.5 W from Cu and 1.5 W from Cs_2Te)

*) $\boldsymbol{\rho}_{Mg}$=2e8 S/m @ 77K, $\boldsymbol{\rho}_{Cu}$=5e8 S/m @ 77K

Investigation

Guess: Issue with thermal contacts

intended purpose of the cooling system

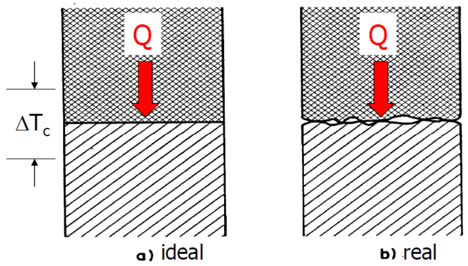
- mechanical support
- electrical isolation
- thermal cooling
- axial movement

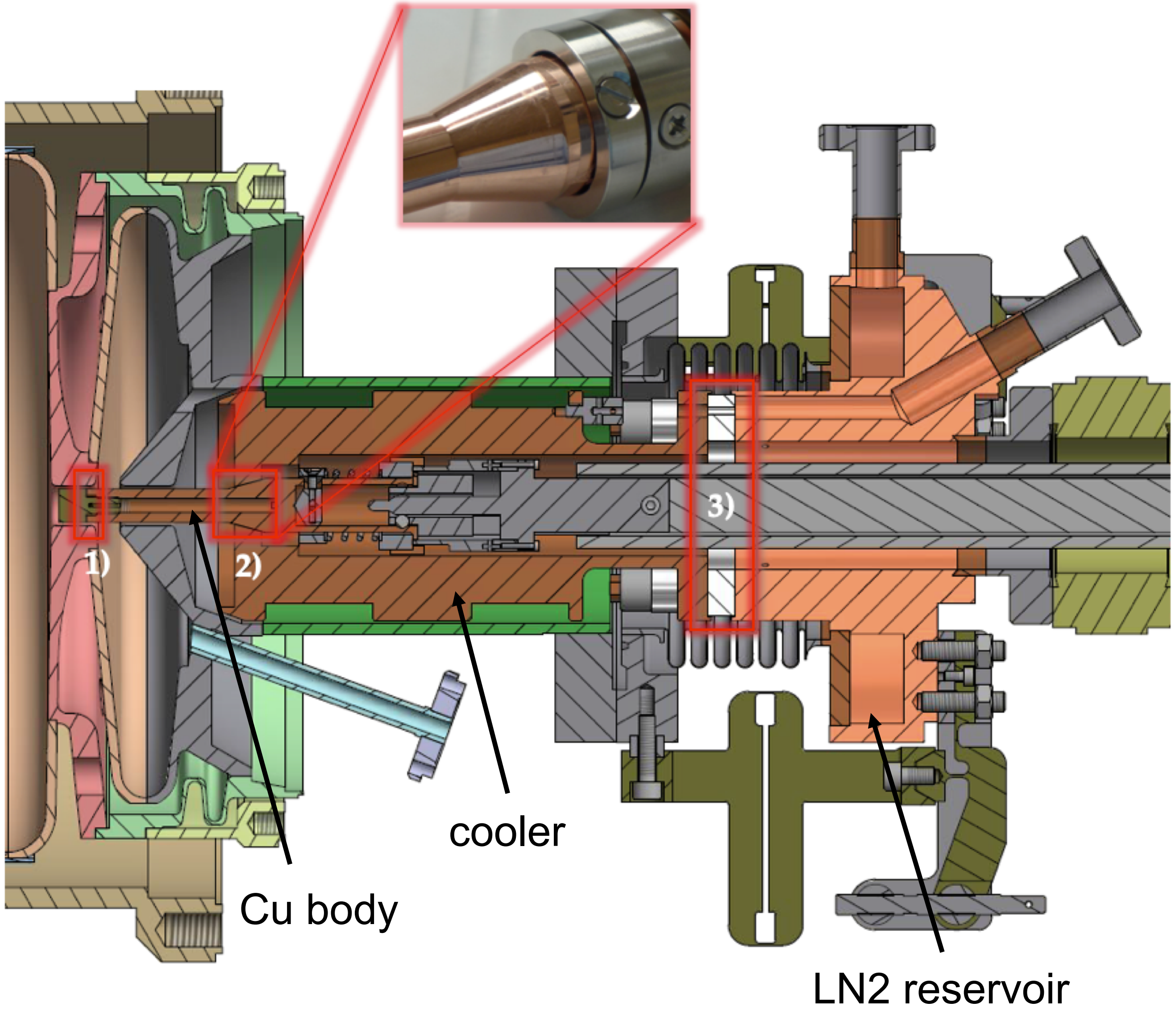
thermal contacts

1. Mo plug and Cu body (screw)
2. Cu body and Cu cooler (spring)
3. Cu cooler and LN2 reservoir via ceramic (screws)

note: heat transfer depends on

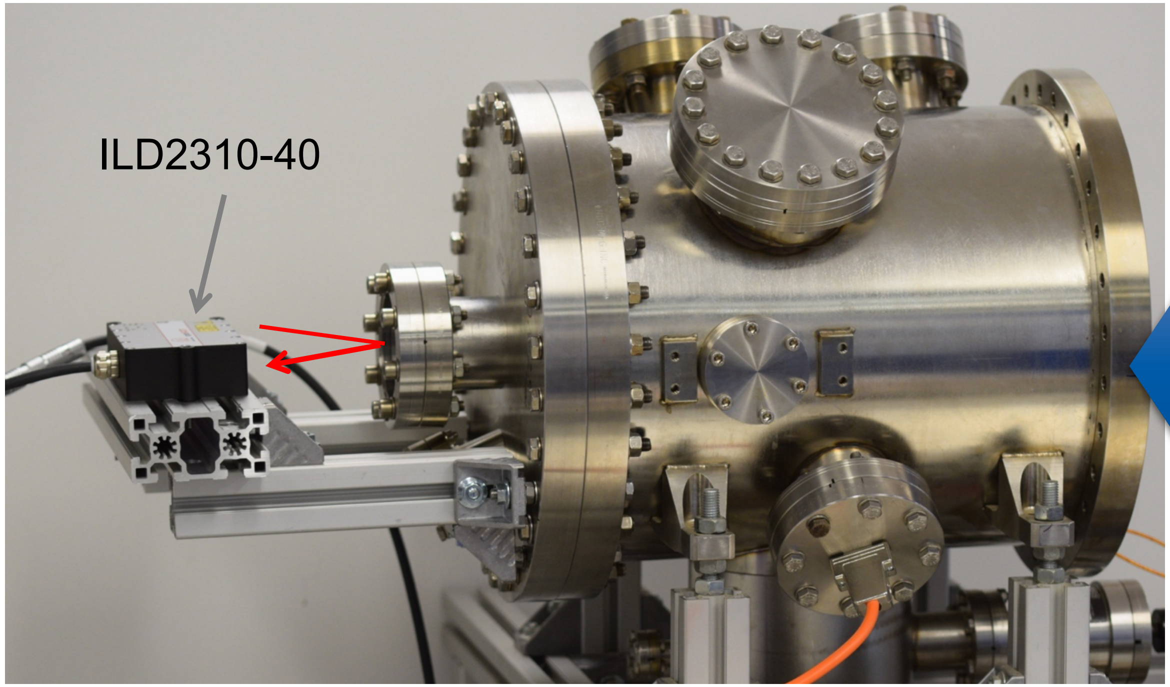
- interface area
- surface conditions
- temperature difference
- pressure

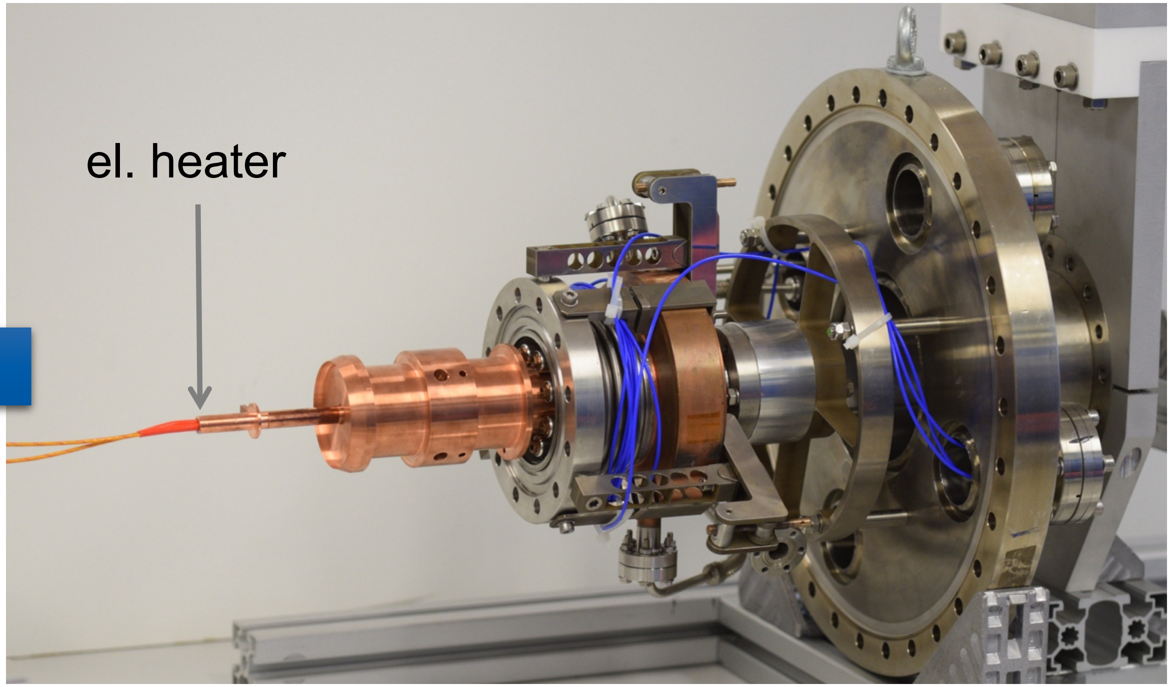




Investigation

Thermal contact experiment

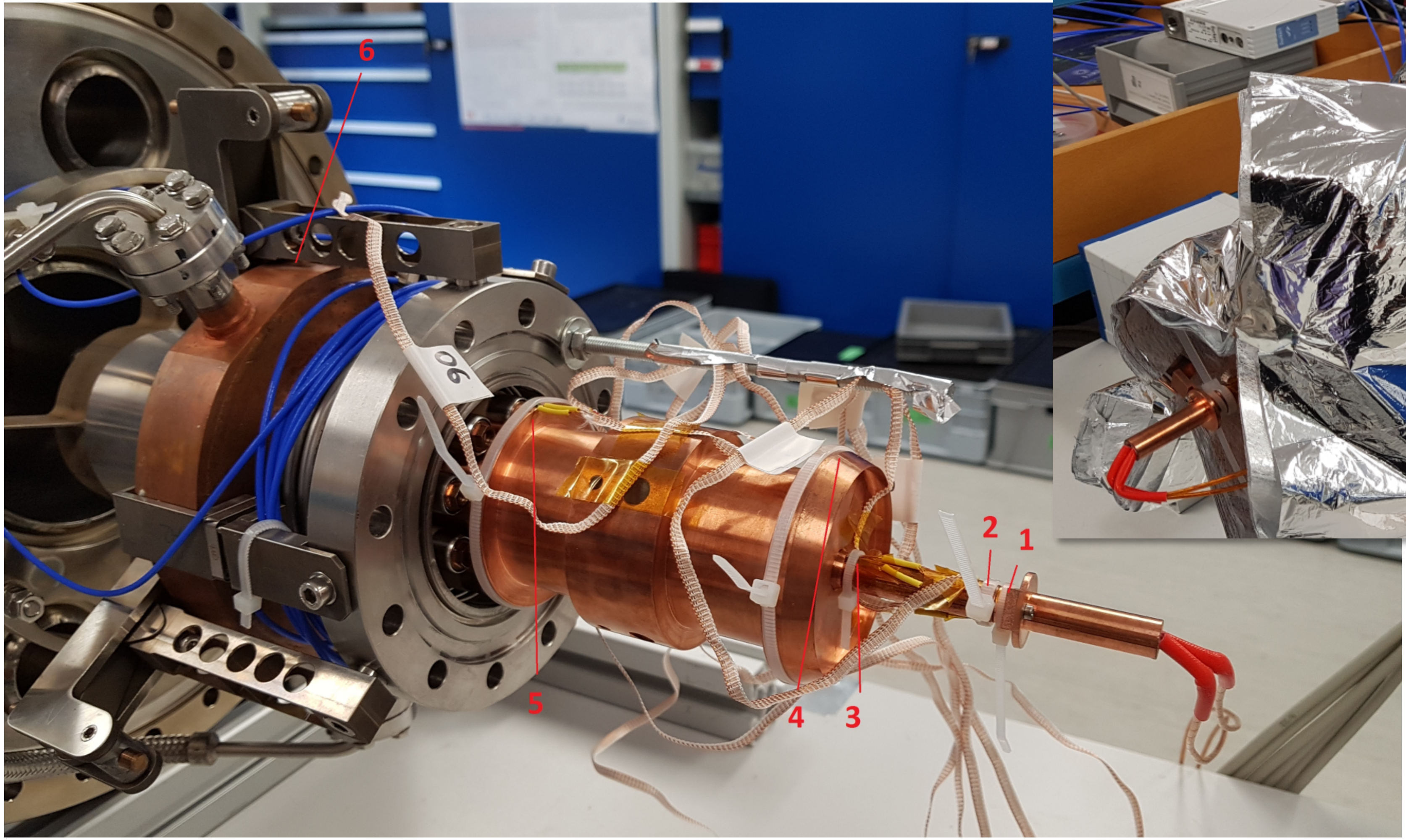


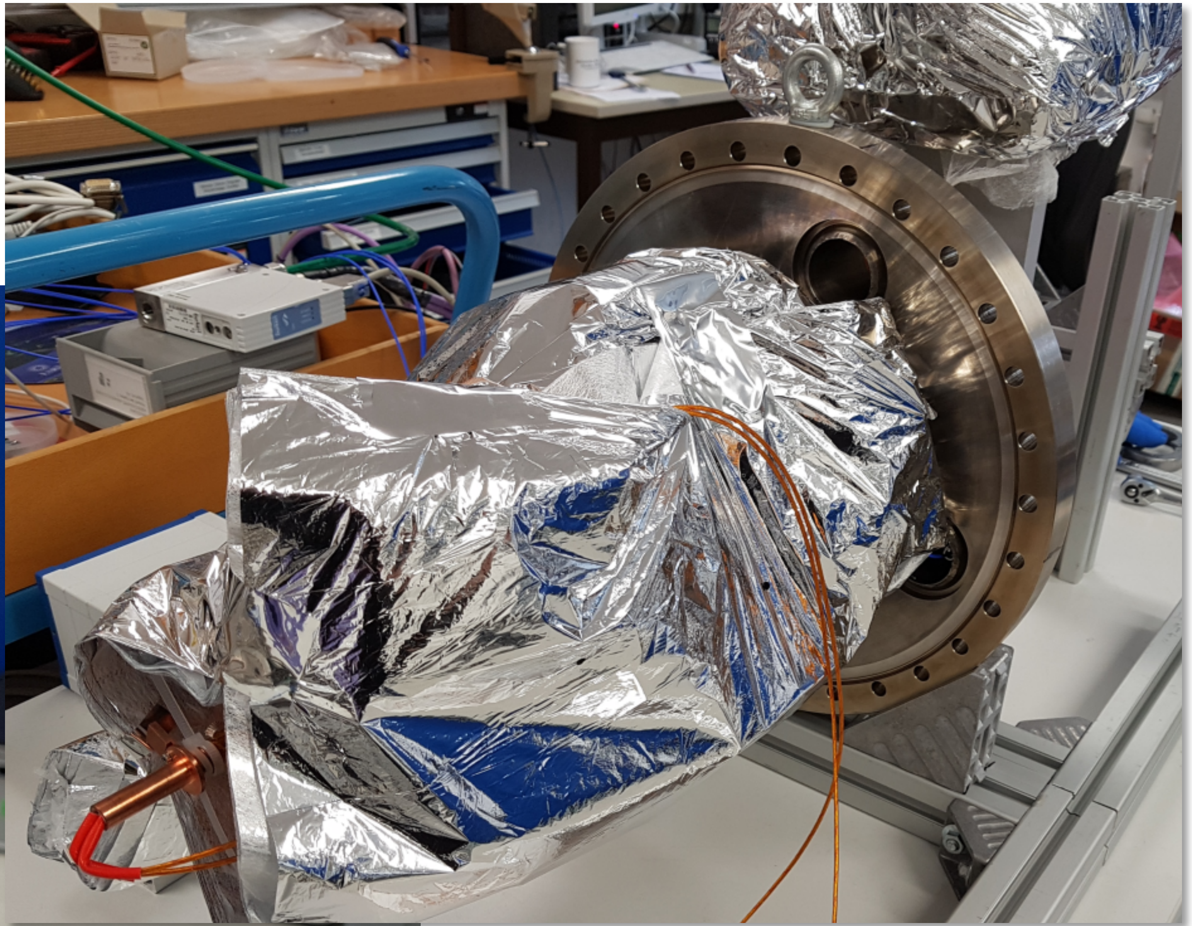


- complete cathode system assembled in vacuum chamber, evacuated to 8e-6 mbar and cooled down to 77K
- Electrical (ohmic) heater (up to 40 W) at cathode tip for gradual increase of thermal load (instead of RF load)
- 6 PT100 sensors to measure temperature difference on each contact to evaluate thermal contact resistance
- length change measurement via ILD2310-40 laser triangulation

Investigation

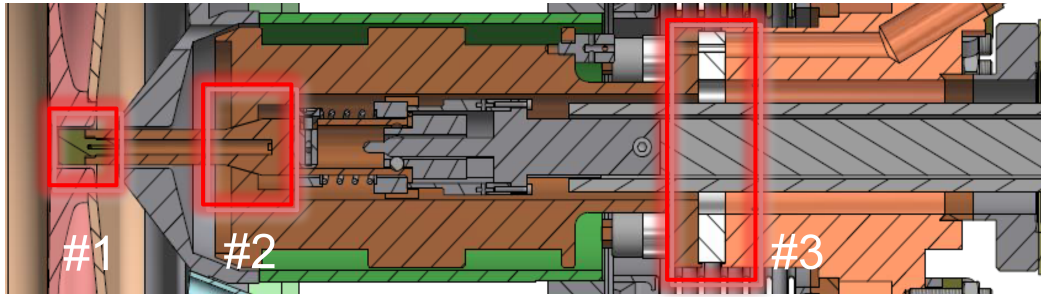
Thermal contact experiment





Findings

„Smoking gun“ in only one out of seven tests

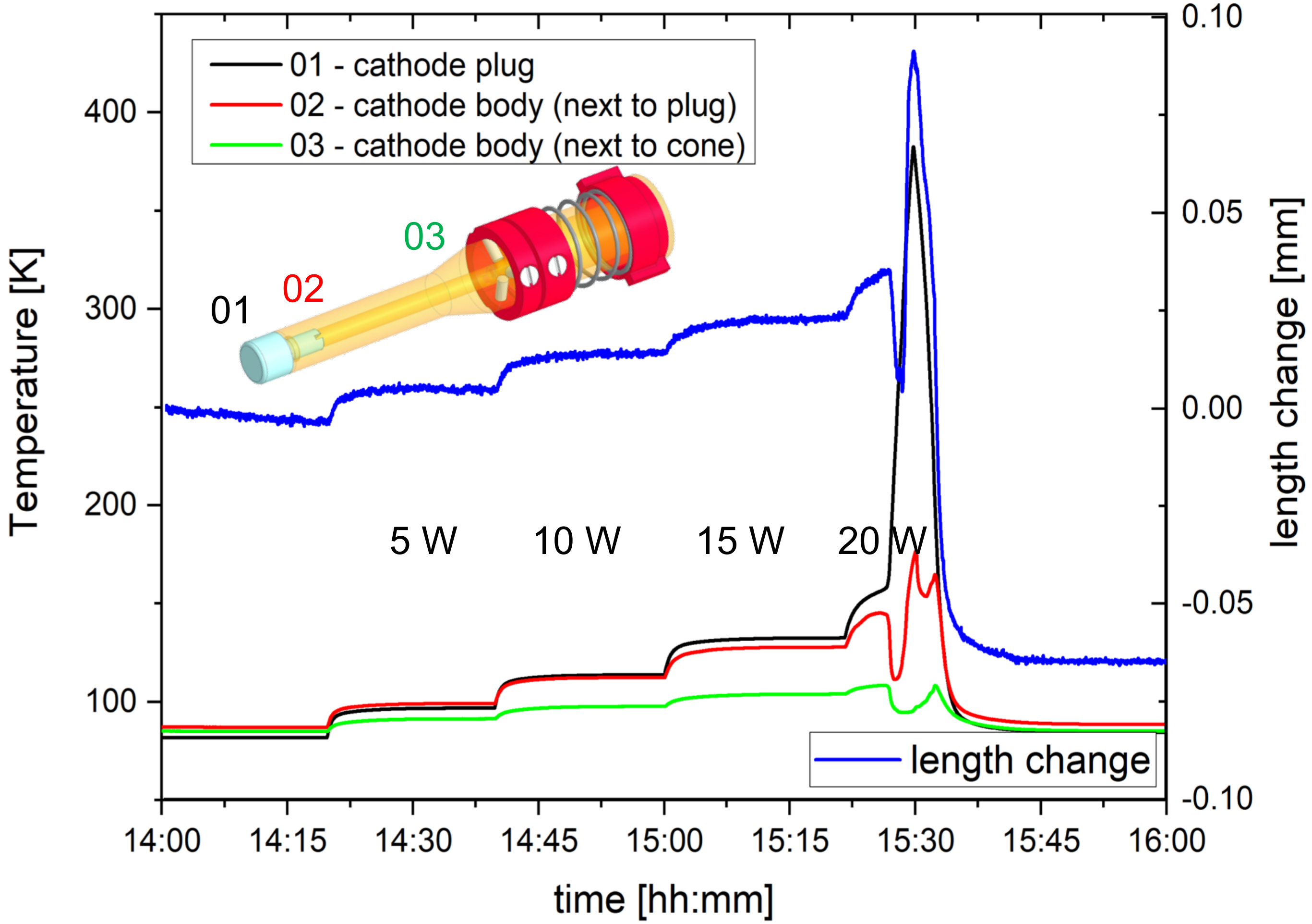


- Originally, thermal transition #2 between cathode body and cooler was suspected because the bayonet spring became soft after 400°C baking

Former degassing temp. 200°C

todays degassing temp. 400°C

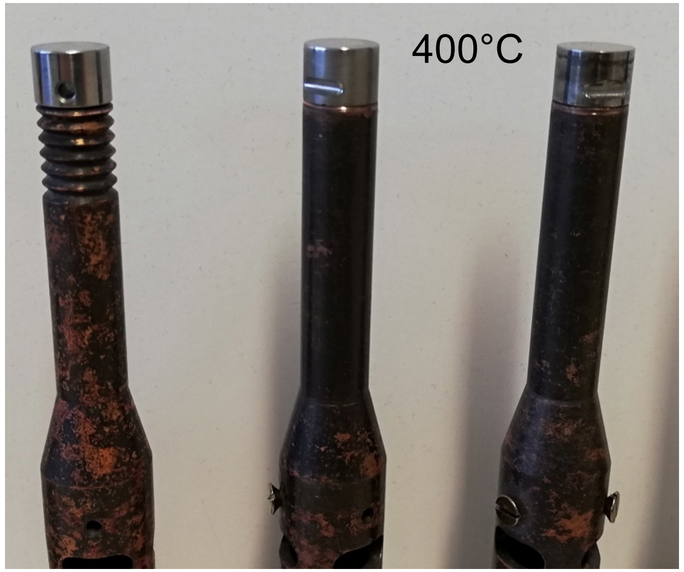
- but in 6 (out of 7) tests neither indication of a mal-function nor cathode overheating was found
- but in one test, however, the plug itself heated up to 400K within minutes, while cathode body became even colder at the same time
- Loss of thermal contact btw. plug and body!



Findings

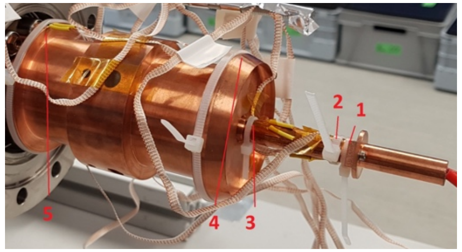
Plugs getting loose because of therm. cycle!

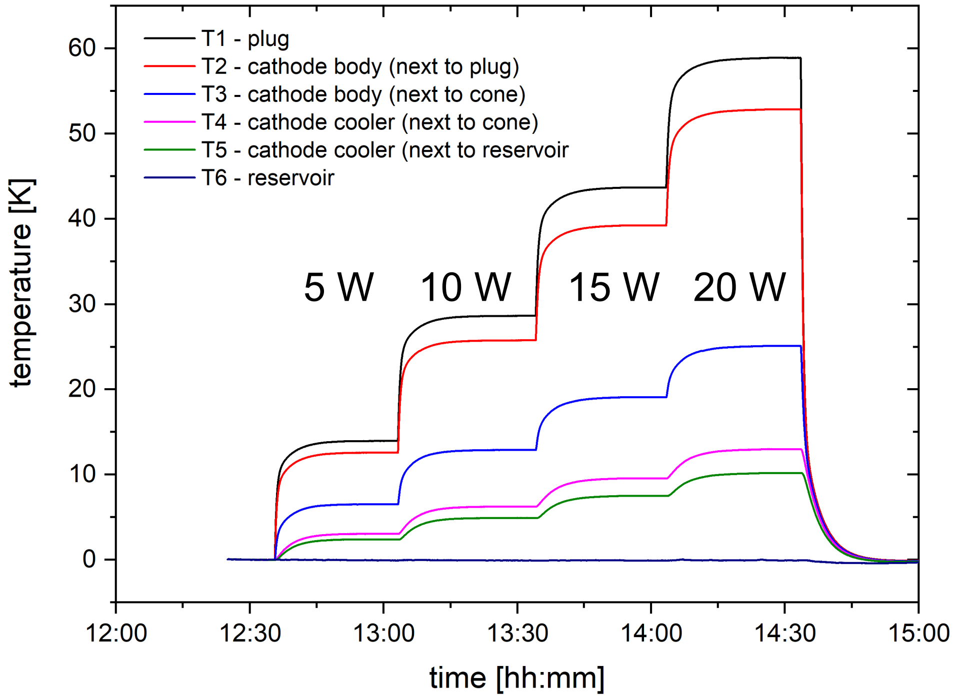
- Hypothesis: Mo plugs getting loose after heating to 400°C (for degassing) and following cool down to 77K in the SRF gun!
- Reason: different expansion coefficients of Mo (plug, 5.2e-6/K), Cu (cathode, 16.5e-6/K) and Mg (26.0e-6/K)
- Test with thermal cycle of 2.5 Nm torqued Mo and Cu plugs proved this because all Mo plugs loosened after therm. cycle (torgue <0.4 Nm), but all Cu plugs remained tight (torgue >2 Nm)
- Never observed this in gun I because degassing was done at 200°C and never for Mg plugs because of its higher expansion coefficient than Cu, Mg plug is getting tight after cooldown to 77K
- **Solution: Although more sophisticated technical solutions might be possible, we opted for the simplest by choosing Cu plugs torqued with 2.5 Nm on cathode body!**
- Additionally also bayonet spring was changed to thermally more robust Inconel® material

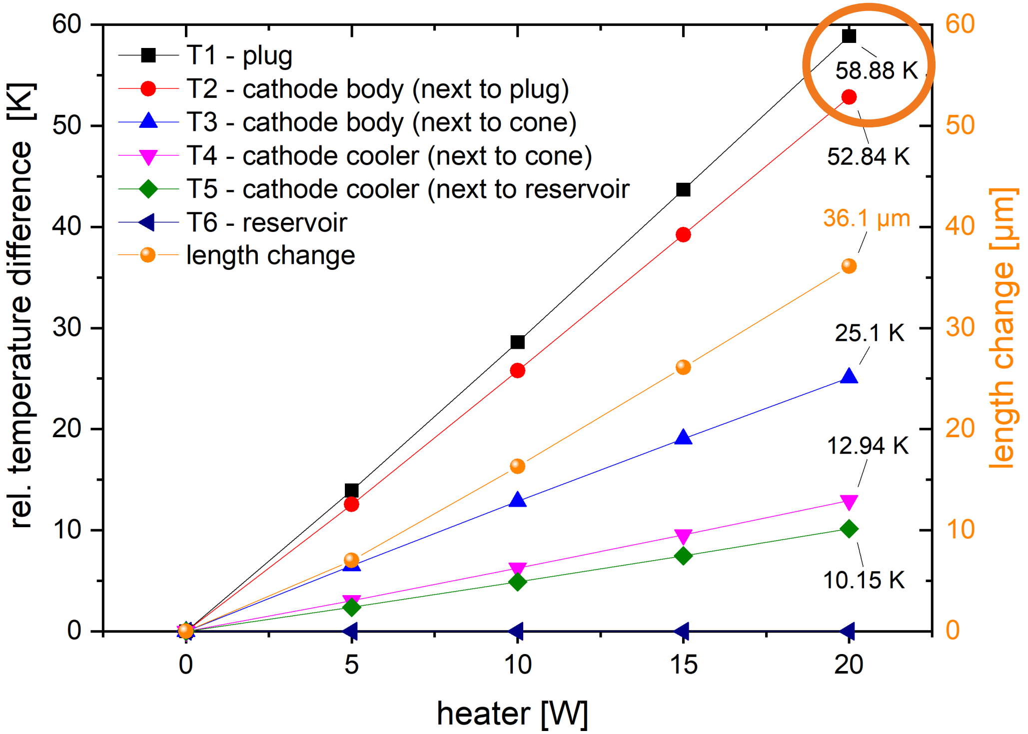


Solution

Final test with 2.5 Nm torqued Cu plug and strong 50 N inconel® spring



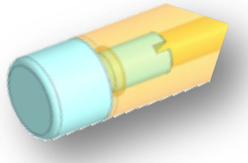


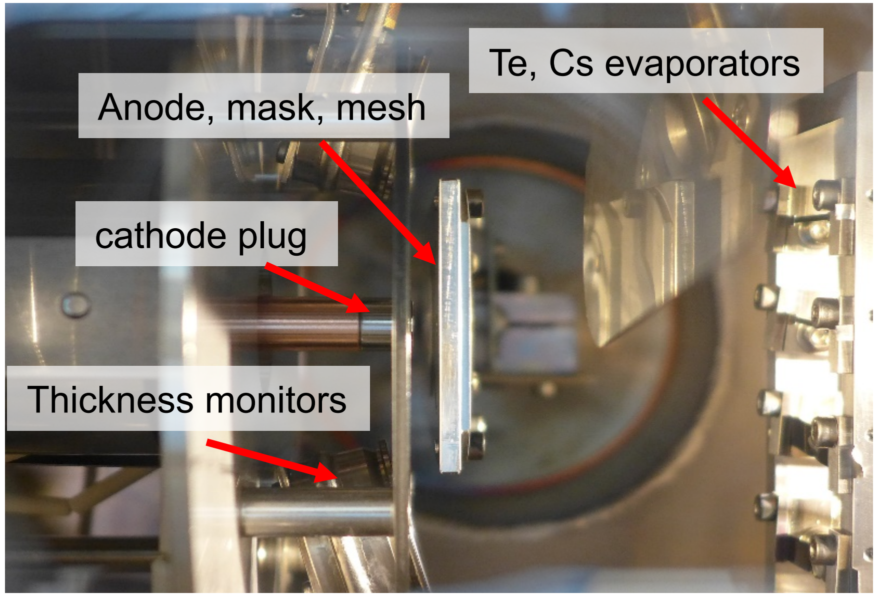


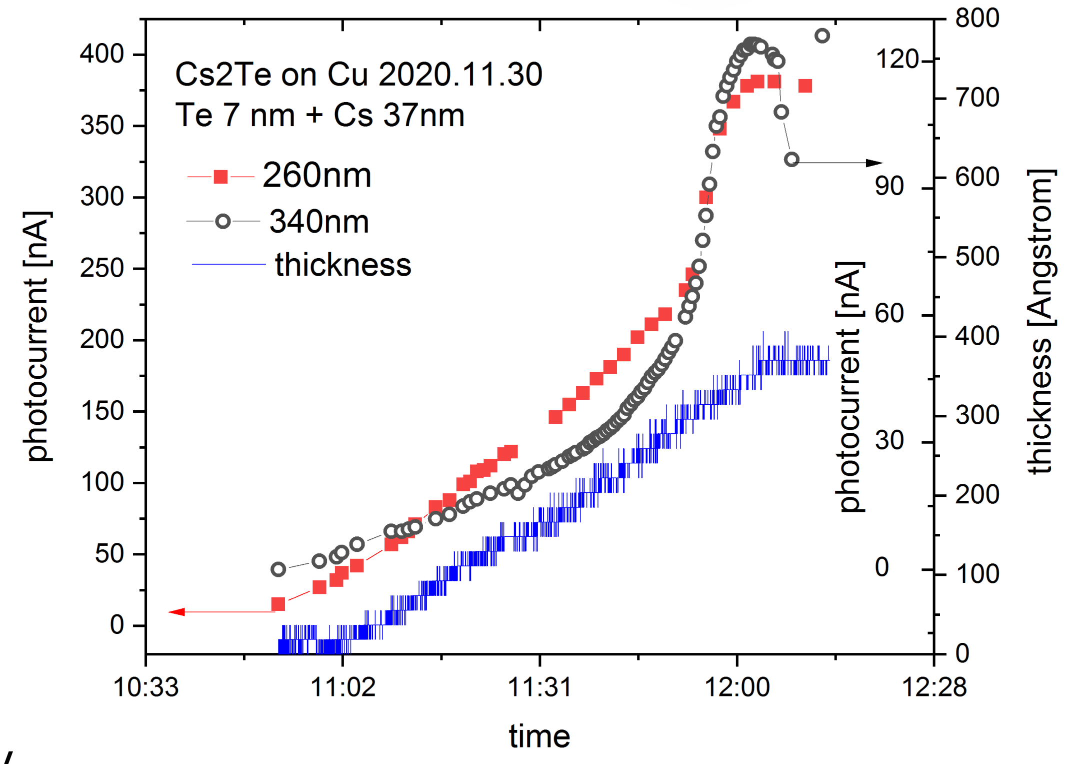
- ΔT for 20W at plug is just 59 K and thus close to 50 K known from simulation with ideal thermal contacts
- The cooling concept has been proven to work with an anticipated heat load of a few watts and can even handle up to 100 W while maintaining the cathode at room temperature -> risk of overheating is eliminated
- Next step: preparing Cs_2Te on copper substrate

Experience with Cs_2Te in the gun

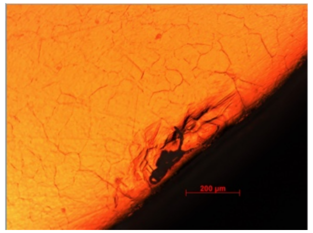
Cathode preparation

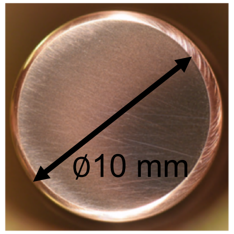


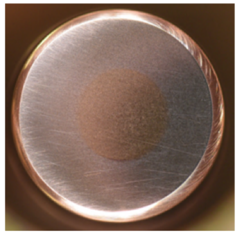


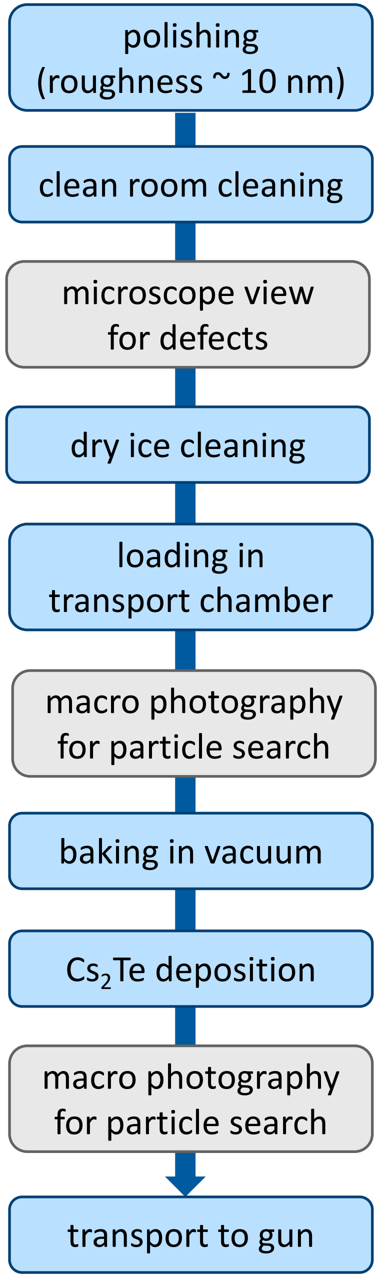


- Baking 350˚C before preparation
- Deposition Te + Cs activation, sequentially
- photocurrent with 260 nm / 340 nm LED
- Deposition until peak of photo current is reached
- Storage into transport chamber at UHV of 10^{-11} mbar together with another 2 Cs_2Te cathodes









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Experience with Cs_2Te in the gun

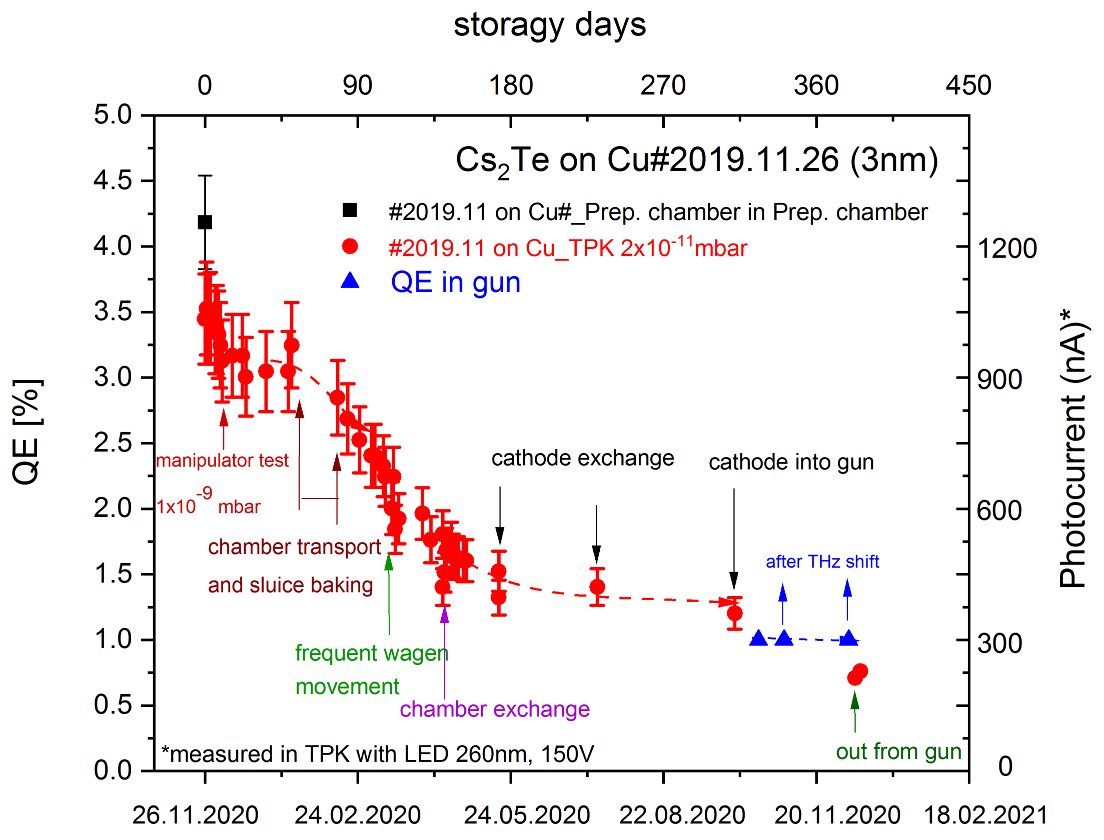
Cathode transfer and operation

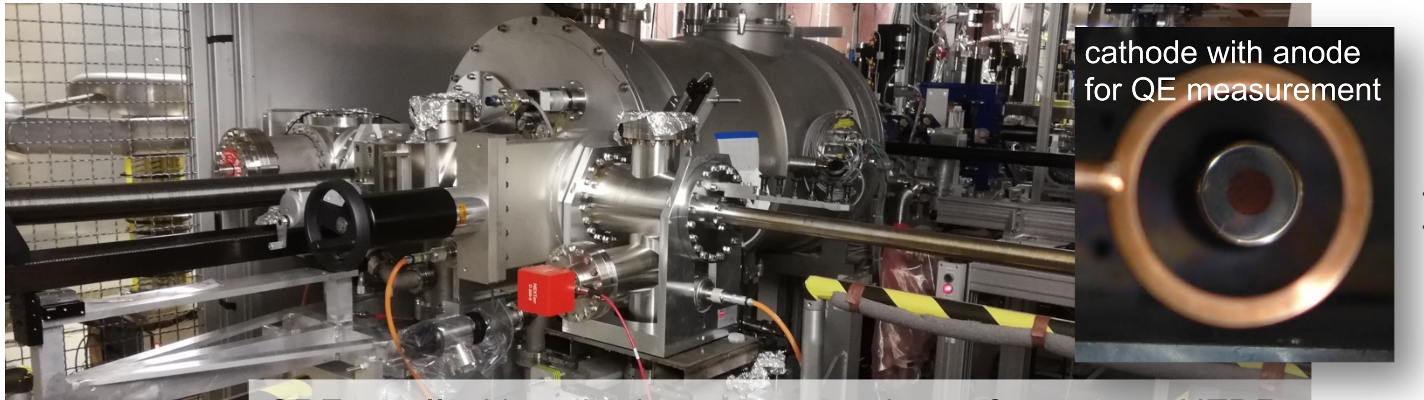
- three Cs_2Te on copper prepared and stored next to gun
- all have been transferred into cold gun under UHV and w/o particle contamination (QE measurement before insertion)

chamber transport

QE	#2020.03.04	#2020.02.26	#2019.11.26
after preparation	5.5%	6%	4%
before insertion	3.5%	2.5%	1.25%
in the gun	3%	2.5%	1%
after operation	**<1%**	**<1%**	1% stable

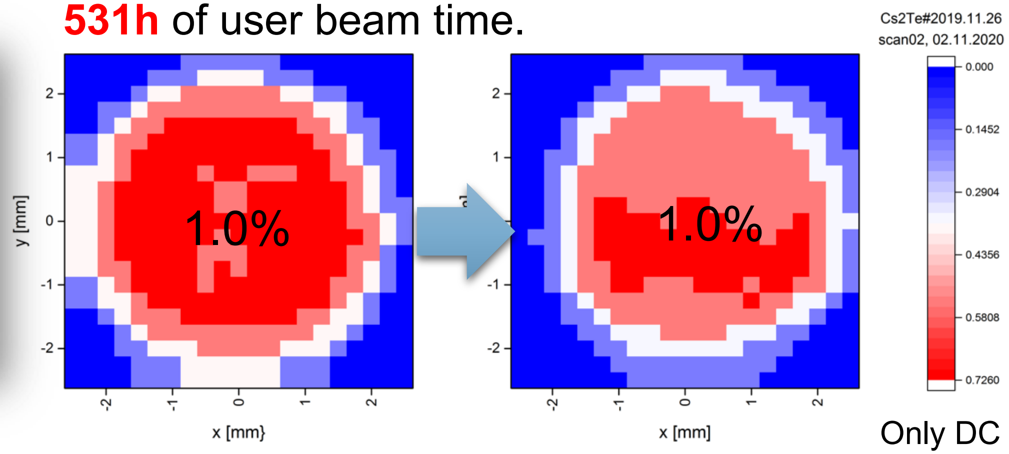
- degradation after operation is independent of total charge but more related to the storage time in the gun





SRF gun II with cathode transport and transfer system, HZDR

QE maps before and after emitting **12.4 C** during **531h** of user beam time.



Only DC

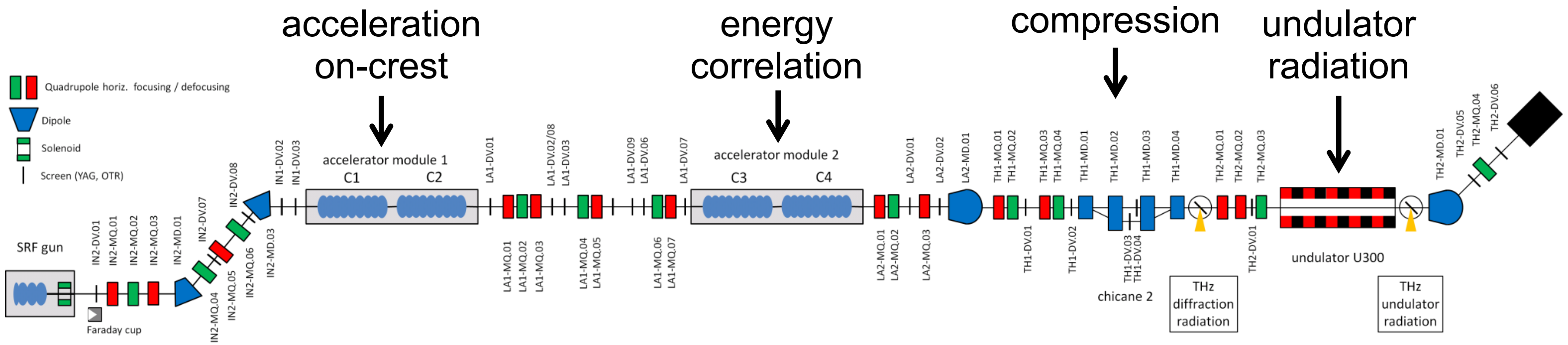
ELBE user operation

THz generation

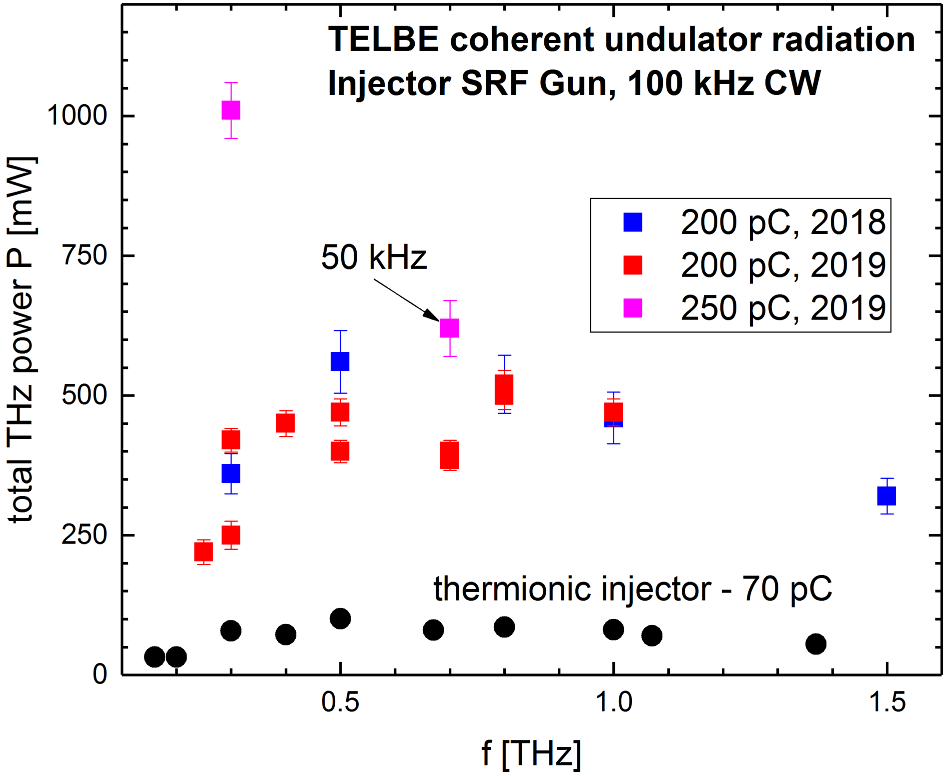
$$E_{THz} \sim F(\omega, \sigma_z) N^2$$

higher bunch charge (200 pC)

shorter bunch length (~100 fs)



- SRF gun delivers 4 MeV beam with 200 - 250 pC
- CW operation with 50, 100, 250 kHz rep.-rate
- Acceleration to 26 MeV, imprint of correlated energy spread and compression to some 100 fs in the undulator
- THz radiation with frequencies 0.05 – 1.5 THz
- Up to 10 times higher THz power with much better amplitude stability (σ=0.03, μ=1) and much less time jitter than therm. injector (UV laser 140 fs, acc. field 100 fs, both 1 Hz -1 MHz)



J. Teichert et al., "Successful user operation of the superconducting radio-frequency photo electron gun with Mg cathodes at ELBE", submitted to PRAB 2020

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ELBE user operation

Summary of user beamtime 2019/2020

- Very reliable and stable gun operation, among others possible by optimization of the 4th harmonic laser module that resulted in much better long-term stability
- 2019/20: 234 user shifts, 2850 h, 25% ELBE beamtime
- 57.0 C from two Mg cathodes (2019 – May 2020)
- 26.3 C from three Cs_2Te cathodes (since May 2020)
- Increasing user demand in 2021 (e.g. neutron shifts)

- 20 cathodes since 2014, in detail 2 Cu, 12 Mg, 6 Cs_2Te
- **No cavity degradation despite all these cathode exchange is proving that SRF guns and normal conducting cathodes can have fruitful coexistence**