Photocathode preparation and characterization at HZB

Sonal Mistry

High Brightness Electron Beams
Institute for Accelerator Physics (FG-IA)

ERL'19
15.09.19-20.09.19

OUTLINE

1. Motivation
2. Commissioning SRF photoinjector
3. Photocathode Cooling Performance in the gun
4. Photocathode Lab
   - Lifetime studies
   - PAS upgrade
5. HU Collaboration
6. Summary and Outlook

Prof. Thorsten Kamps
HBEB group leader
/HU Phyiscs

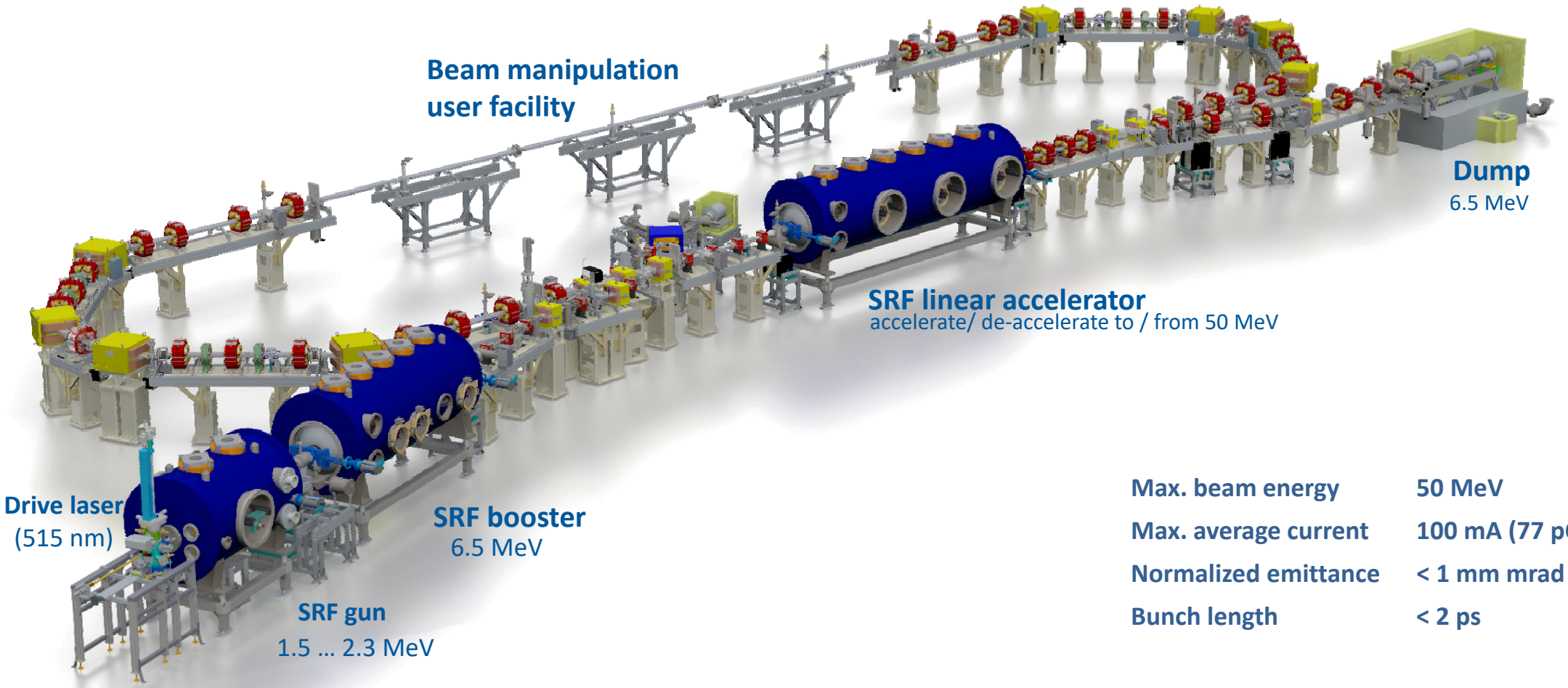
Dr. Julius Kühn

Dr. Sonal Mistry
Oct 2017

Dr. Martin Schmeißer

Nawar Al-Saokal

BERLIN ENERGY RECOVERY LINAC PROTOTYPE: bERLinPro



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

Goal: Build and operate a 100 mA, low emittance technology demonstrator

PHOTOCATHODE *CHALLENGES* FOR bERLinPro

I *High quantum efficiency* Cs-K-Sb photocathodes

- high bunch charge and current up to 100 mA

II *Smooth* substrate and photocathode

- low field emission and low emittance

III *Reproducible* growth procedure & *robust* lifetime

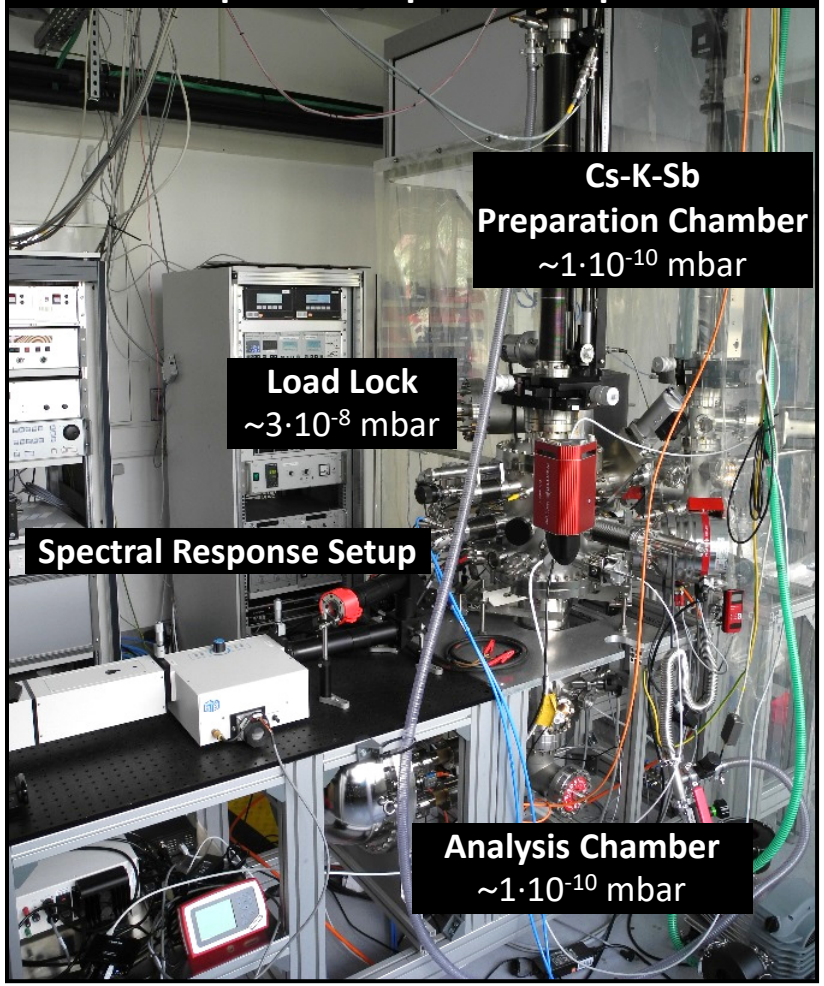
- necessary for accelerator operation

IV Photocathode transfer into *superconducting* RF photoinjector

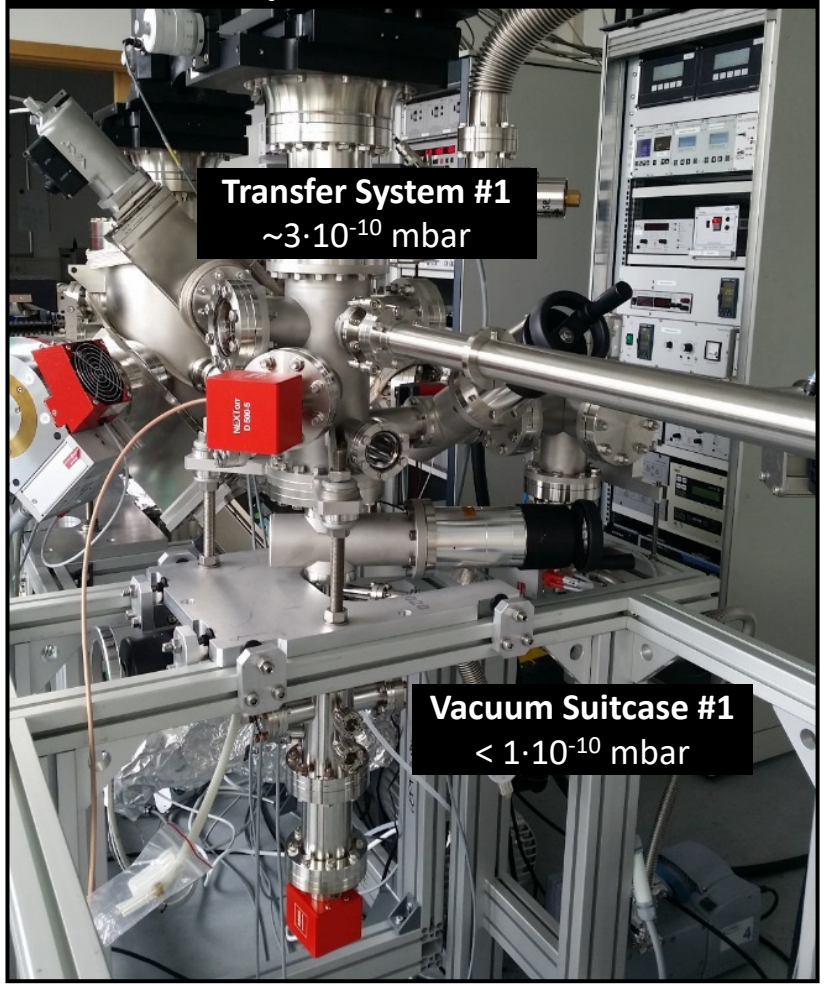
- permanent UHV conditions during Cs-K-Sb photocathode transfer
- avoiding contamination of superconducting Nb-cavity

PHOTOCATHODE INFRASTRUCTURE FOR BERLINPRO

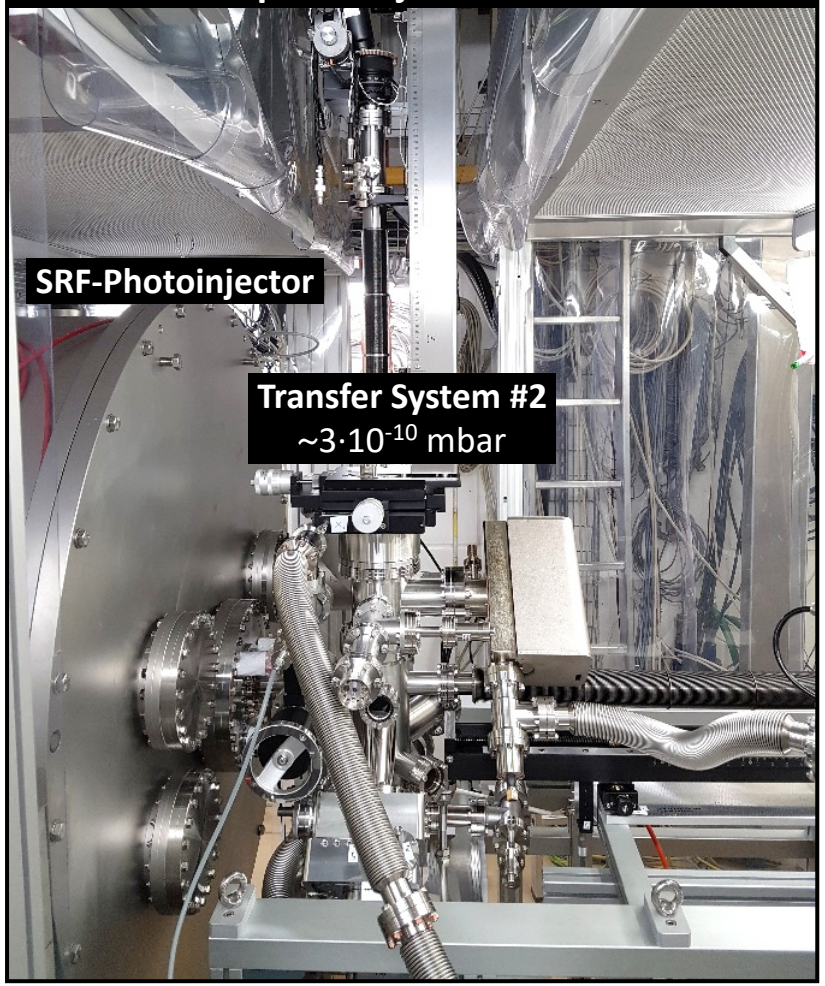
Preparation & Analysis System (PAS) w/ spectral response setup



Transfer system #1 at the PAS w/ vacuum suitcase



Transfer system #2 at the SRF-photoinjector module

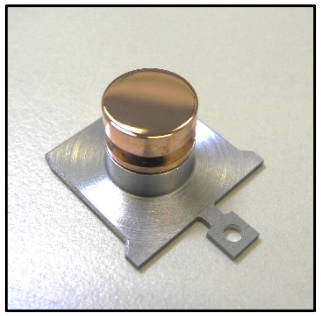


Aug-Sept 2017

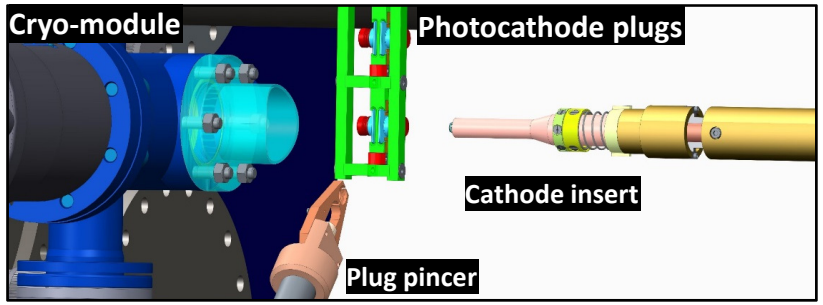
COMMISSIONING OF SRF PHOTOINJECTOR WITH CU PHOTOCATHODE

Plug preparation | **Transfer** | **Insertion**

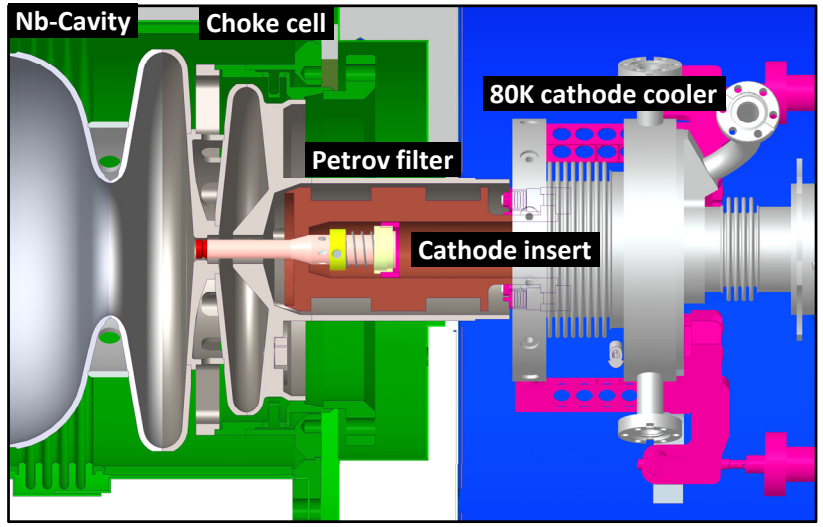
Plug selection and cleaning:

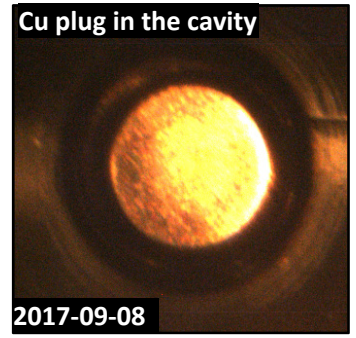


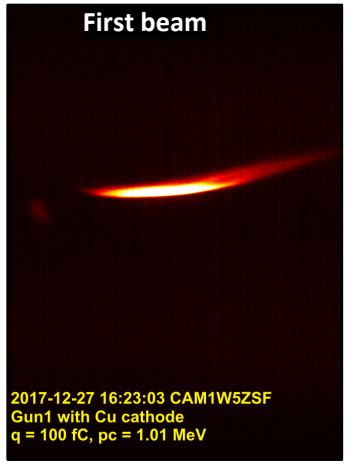
- Plug design developed in-house
- Snap-fastener mechanism on modified omicron sample holder
- Surface cleaning in UHV
- Transfer via vacuum suitcase to transfer system at the SRF photoinjector

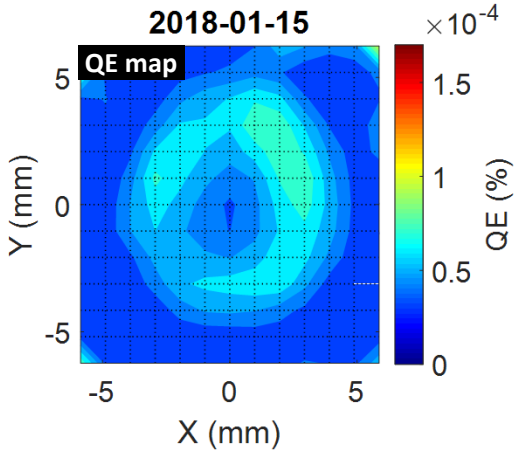


Cathode / Cavity Interface:









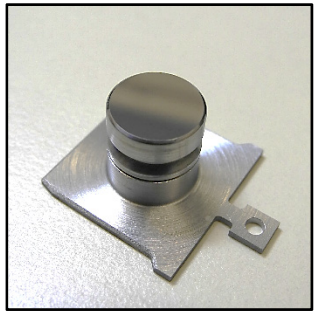
J. Kühn et al., Proc. of IPAC 2017

Jan 2018

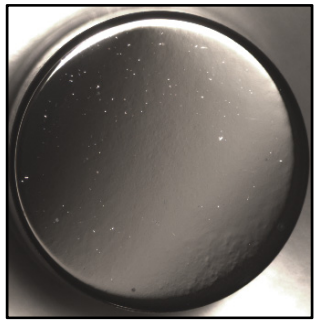
SEMICONDUCTOR PHOTOCATHODE PREPARATION AND TRANSFER

Plug preparation | **Cs-K-Sb growth** | **Transfer** | **Plug exchange** | **Insertion**

Plug selection and cleaning:



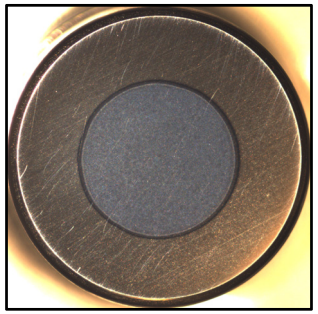
Mo Plug in UHV:

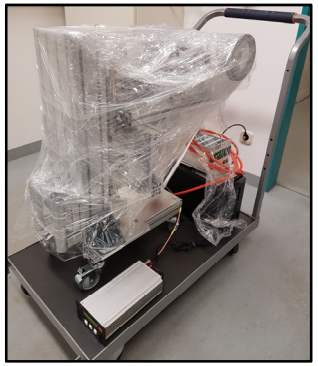


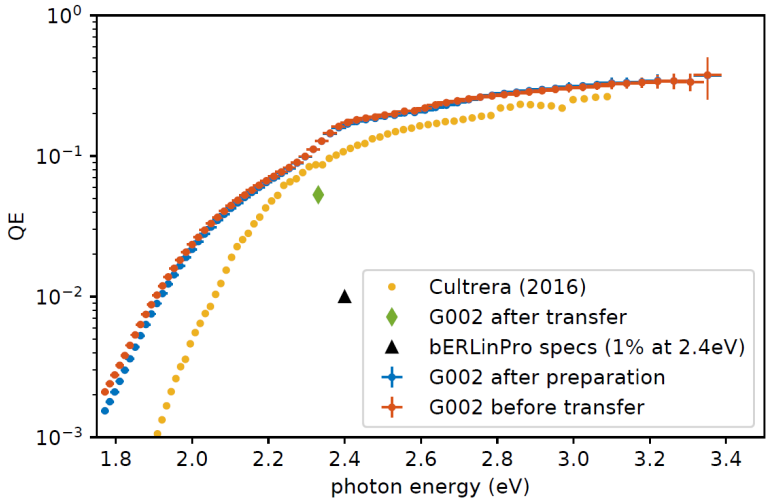
1. Sb-layer
2. Cs-K co-deposition
+ photocurrent
+ spectral response

Keep in darkness!

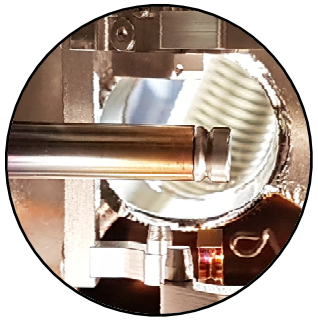
G002 Cs-K-Sb/Mo:

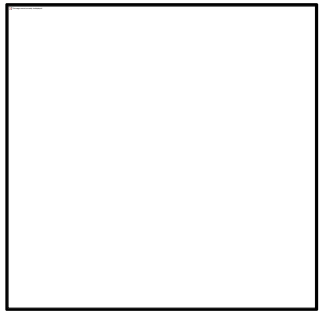






M. Schmeisser et al., PRAB. 2018





From a thin film in the lab to a functional device in the SRF photoinjector.

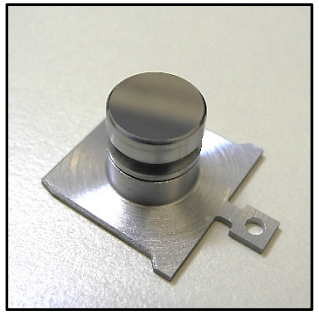
Operation failed due to malfunction of the cathode insert.

Jan 2018

SEMICONDUCTOR PHOTOCATHODE PREPARATION AND TRANSFER

Plug preparation | **Cs-K-Sb growth** | **Transfer** | **Plug exchange** | **Insertion**

Plug selection and cleaning:



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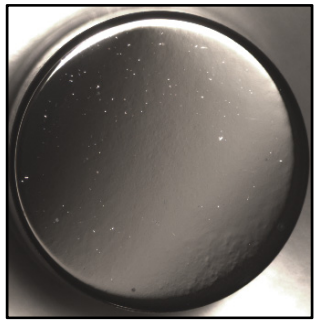

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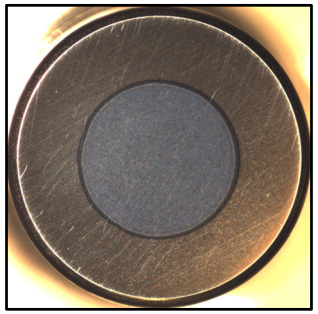
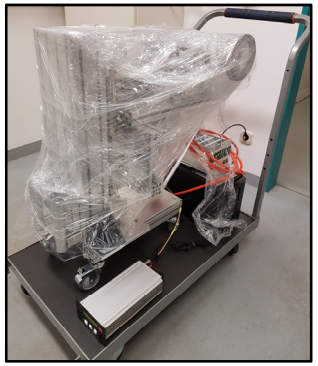
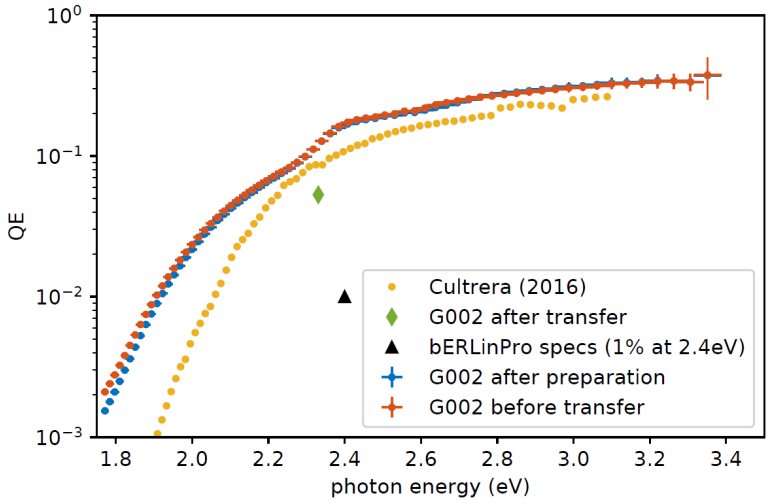
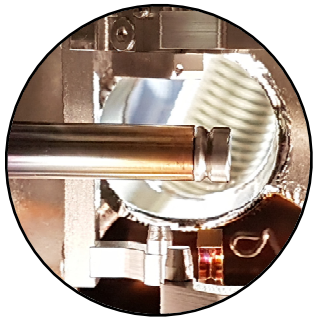
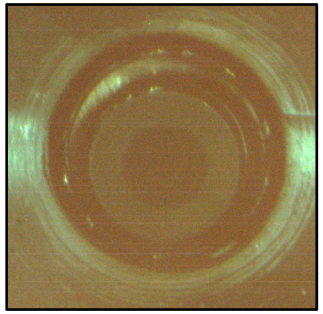






M. Schmeisser et al., PRAB. 2018

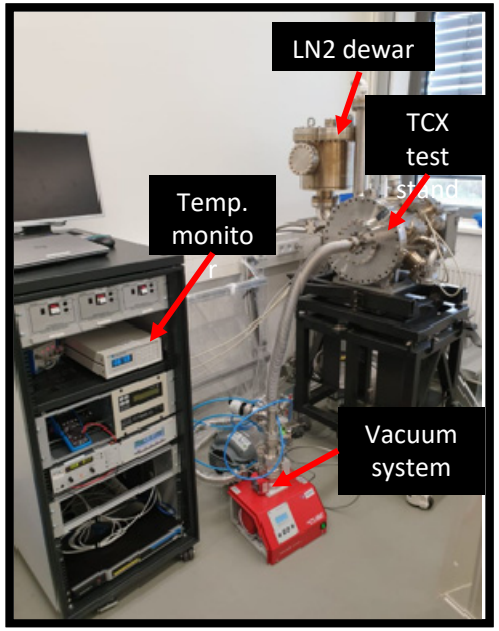


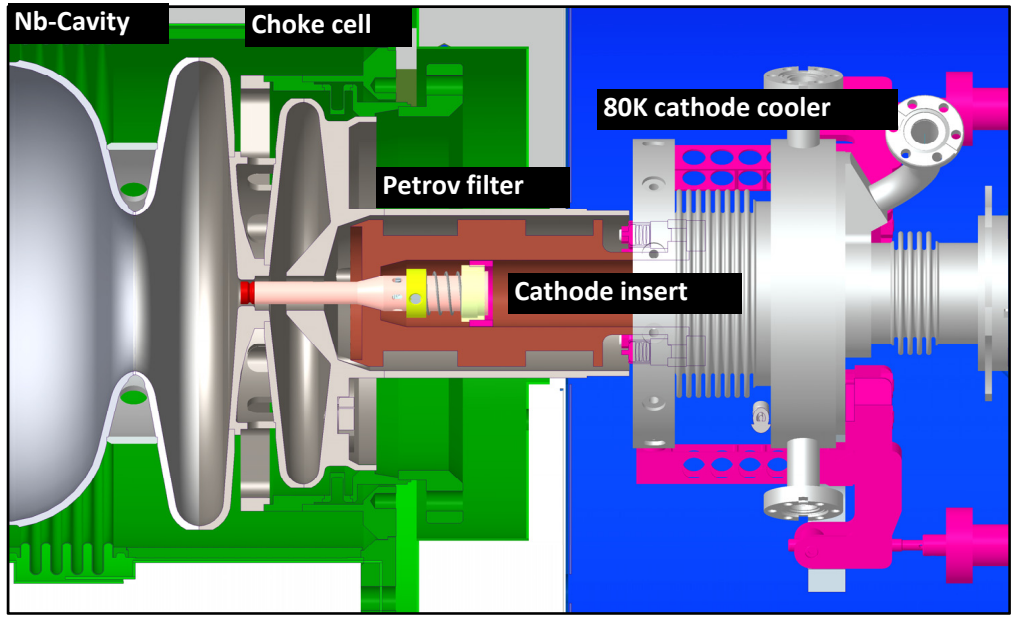


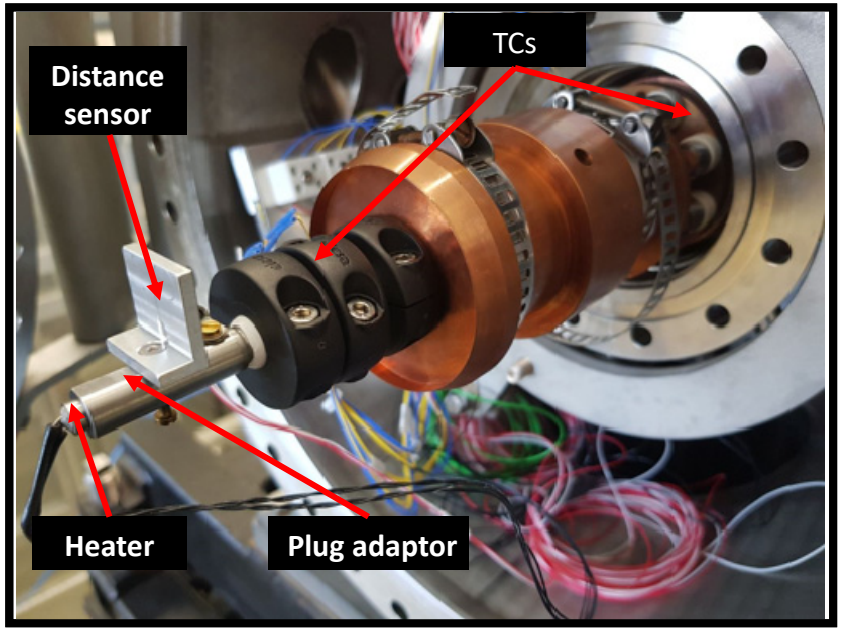
Photocathode insert found to be damaged due to a technical malfunction.
→ Poor thermal contact between plug and insert

PHOTOCATHODE COOLING PERFORMANCE IN THE GUN

Thermal Contact Experiment (TCX) is a test experiment of the photocathode cooling system based on the original components. Designed to test the thermal contacts of the cooling system.
-***Masters thesis of Nawar Al-Saokal-*** ***completed Sept 2019***







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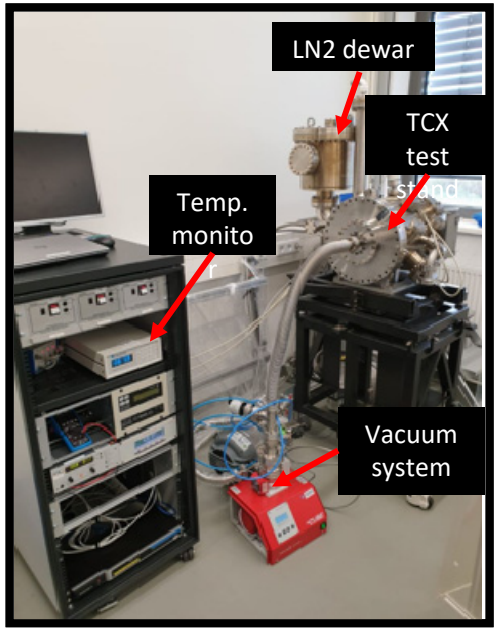
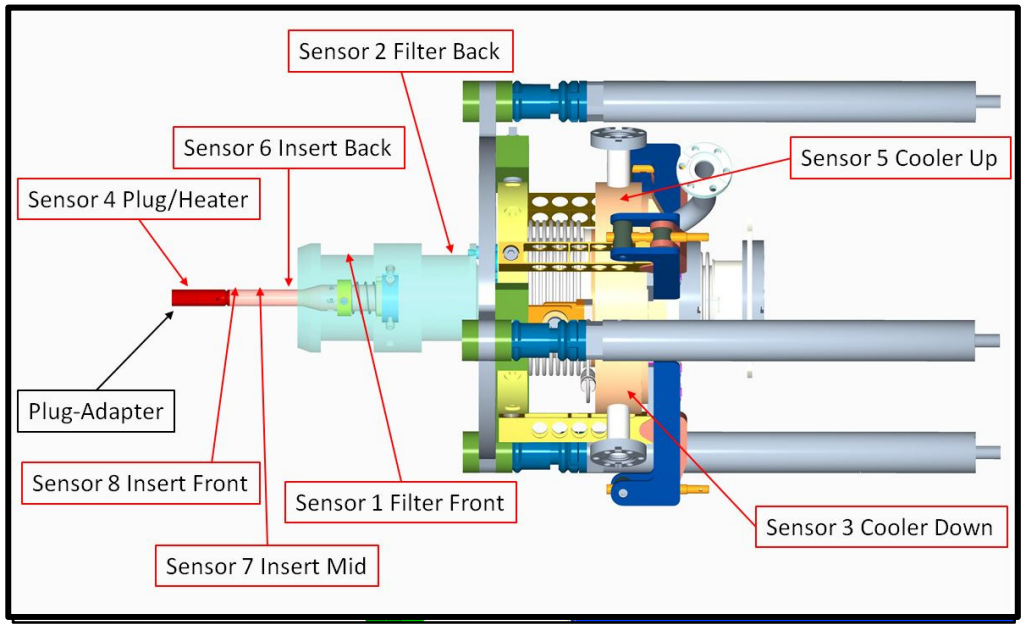
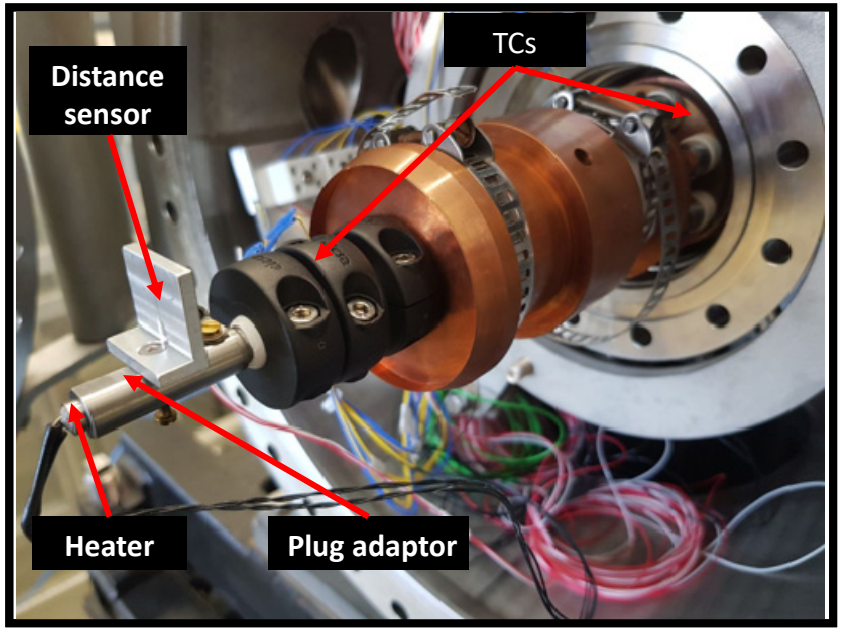
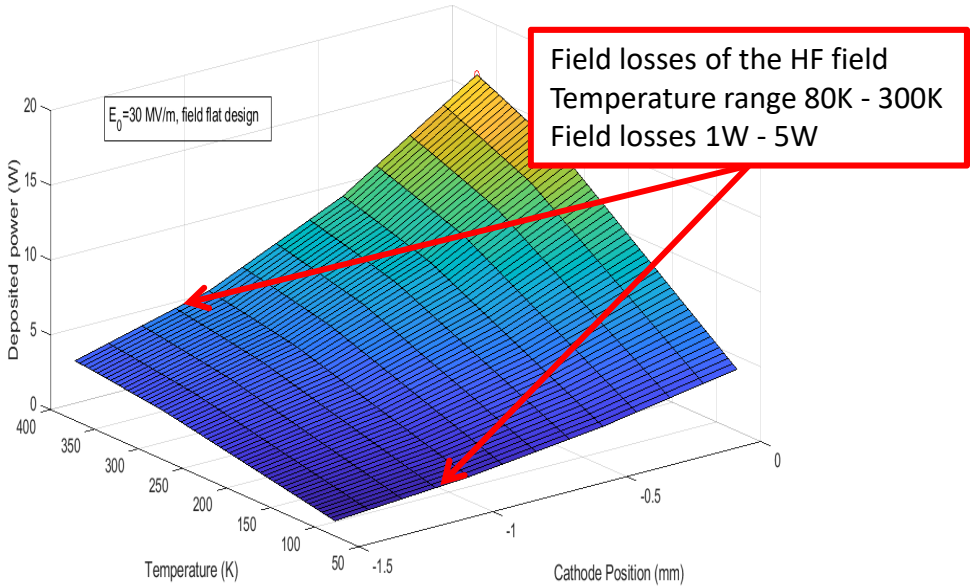




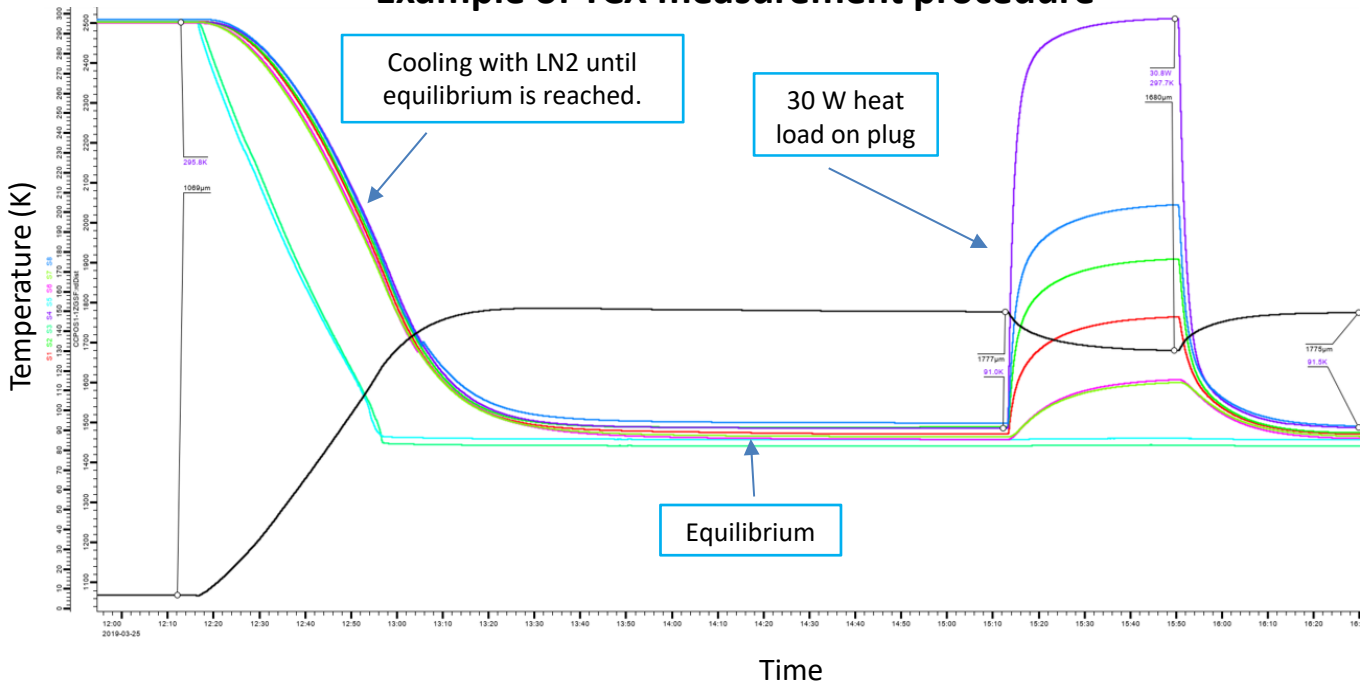


THERMAL CONTACT EXPERIMENT (TCX)

What is the expected heat load?



Example of TCX measurement procedure



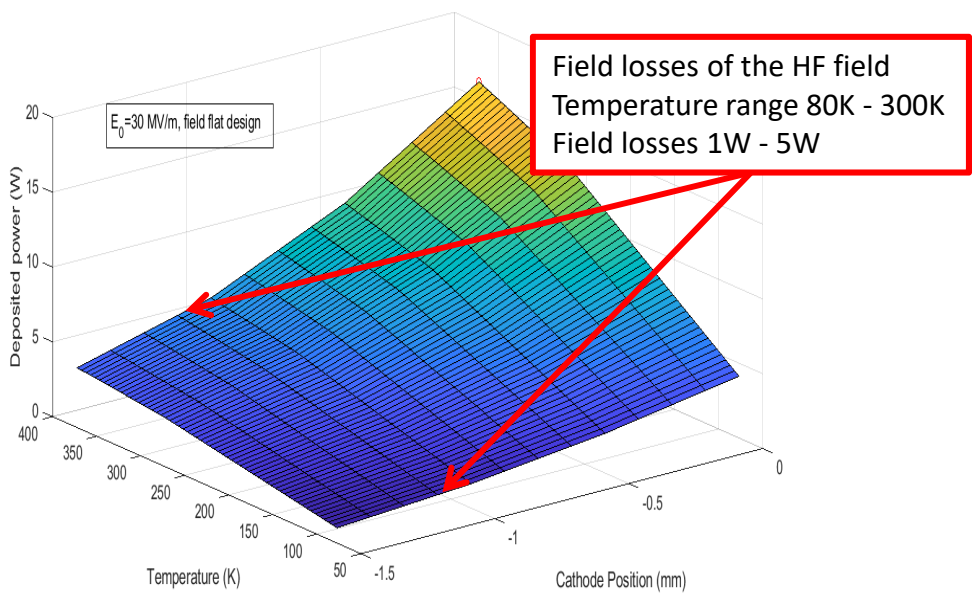
- Simulations estimate RF power losses for a retracted cathode (-1 mm) to be 1-5 W

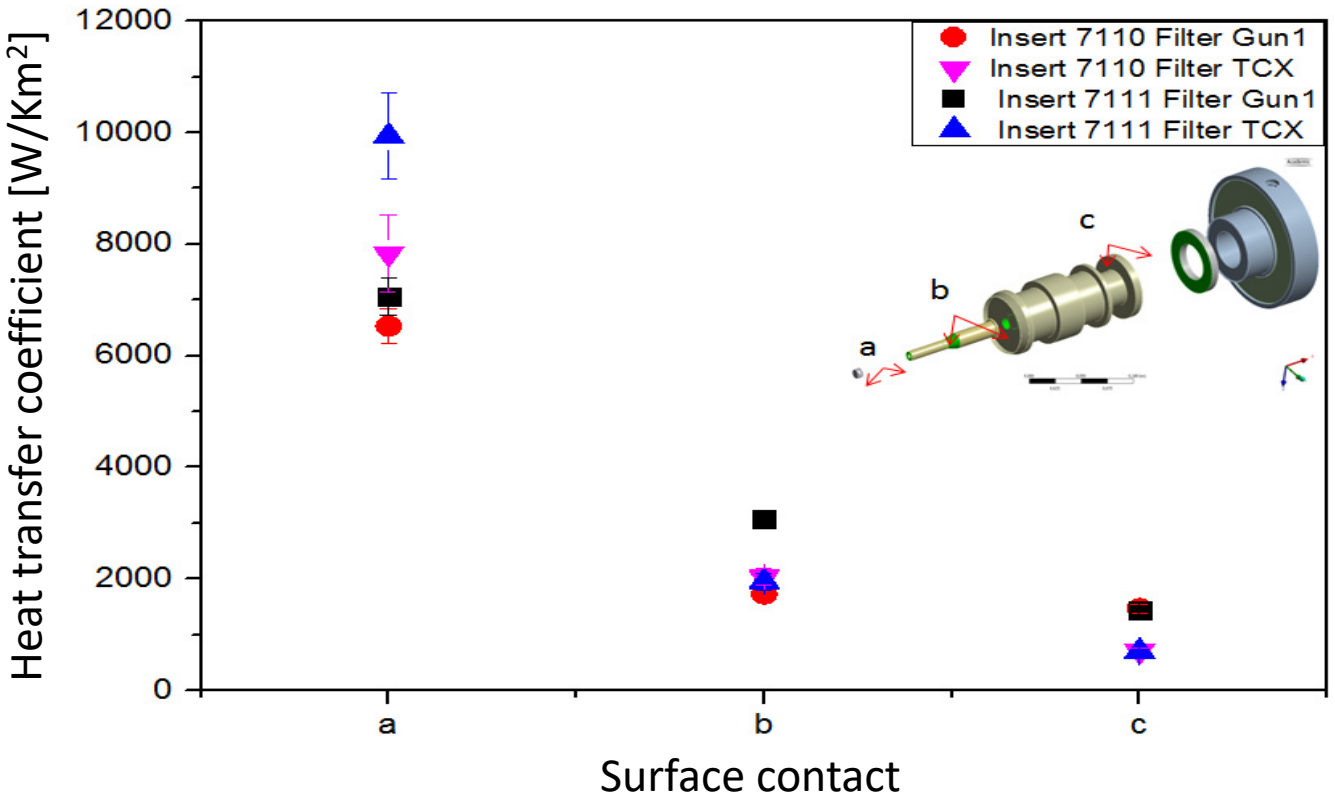
$$QE = \frac{I[A]}{P[W[} \frac{1240\ eVnm}{\lambda[nm]}$$

- To achieve 100 mA with a ~1% QE cathode require 25 W laser power

THERMAL CONTACT EXPERIMENT (TCX)

Heat load





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J. Kuehn et al., Proc. Of SRF 2019

- **30 W heat load upper limit for safe operation of Cs-K-Sb**
- **Exchange mechanism of insert can handle thermal load of 30 W**

OUTLINE

1. Gunlab Recap

2. Photocathode Cooling Performance in the gun

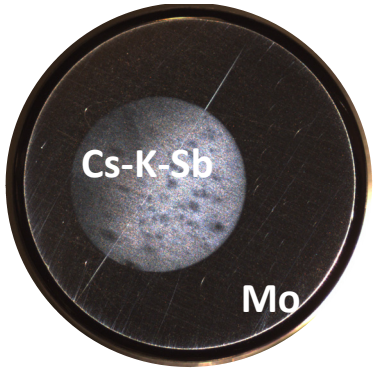
3. **Photocathode Lab**
   - **Lifetime studies**
   - **PAS upgrade**

4. HU Collaboration

5. Summary and Outlook

Jan 2019

LIFETIME STUDIES

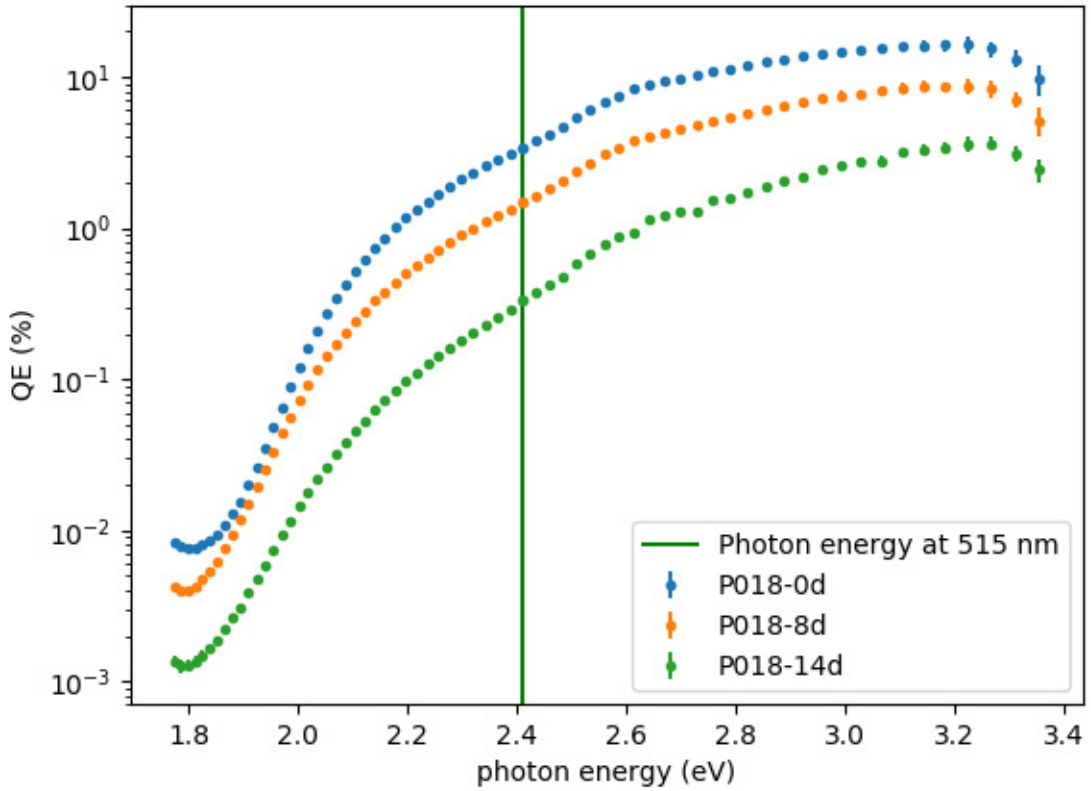


Require photocathode to have as long a lifetime as possible for accelerator operation

What lifetime can we expect from a Cs-K-Sb photocathode?

- Baseline lifetime experiment for P018
- $P_{PC} = 1 \cdot 10^{-10}$ mbar
- During growth: $P_{PC} = 6 \cdot 10^{-9}$ mbar ; $P_{H20} = 4 \cdot 10^{-10}$ mbar
- Alkali co-deposition

P018	QE @ 515 nm
0 days	3.4 %
8 days	1.5 %
14 days	0.3 %

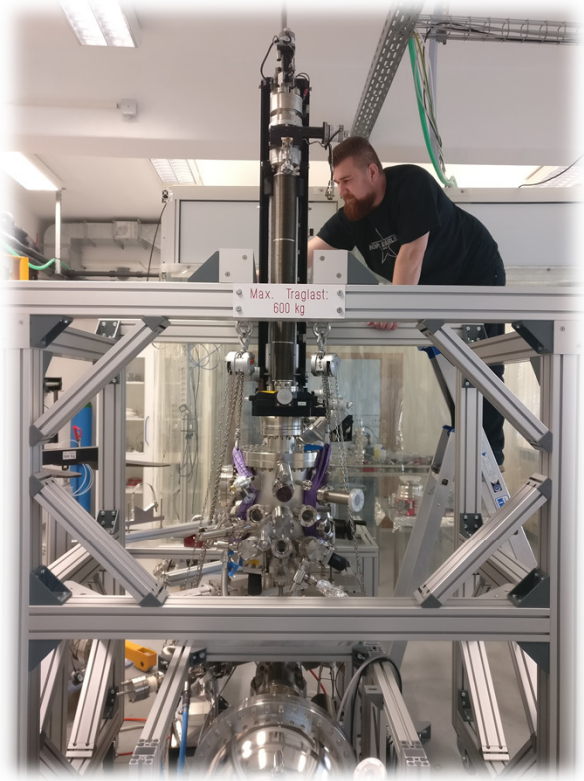


1/e lifetime = 8.4 days, 202 hours

- Repeat experiment with recently upgraded system
- Investigate alternative materials / combinations
  - Na-K-Sb
  - Multialkali antimonides

March 2019

PHOTOCATHODE LAB: MANIPULATOR UPGRADE

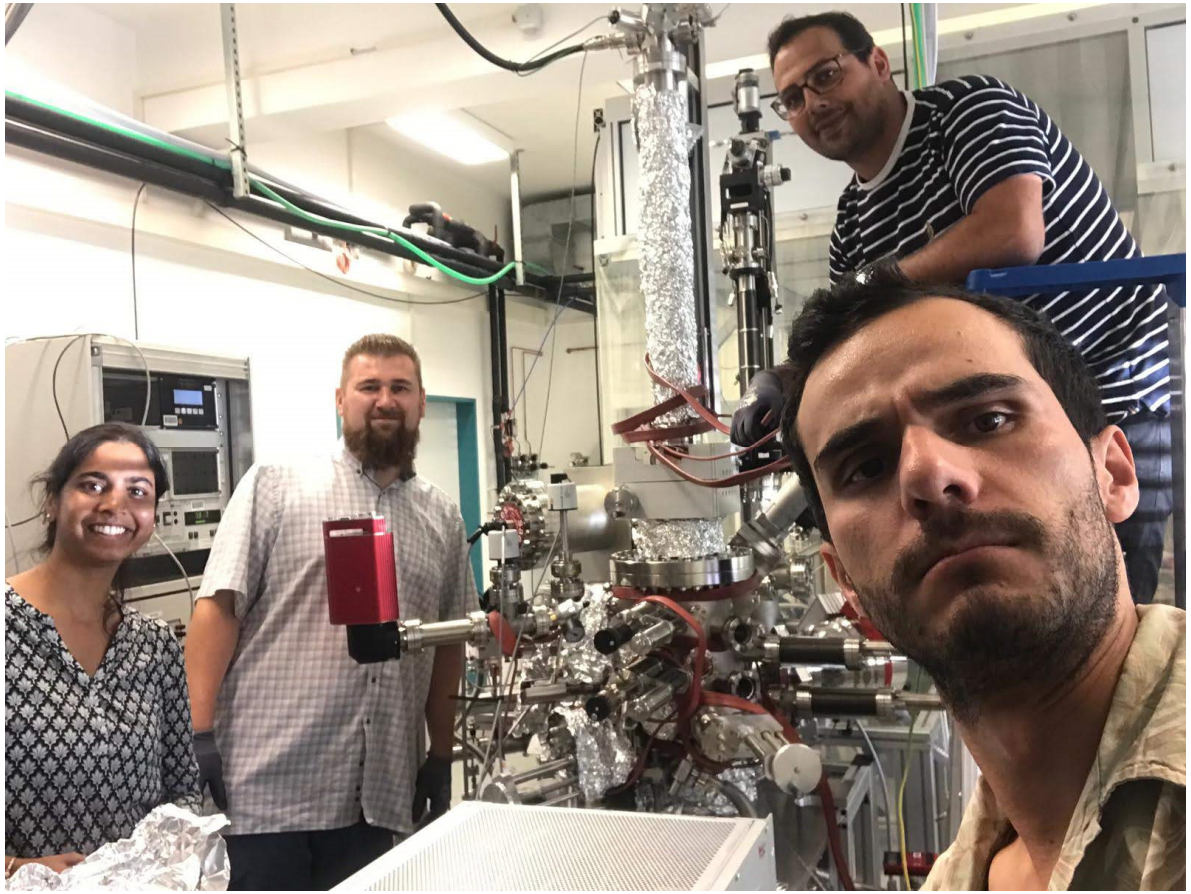


- New UHV Design Multicentre manipulator
- XYZφ
- Radiative heating
  - Ta foil heater
  - Heats back of flag style sample plate
- LN2 cooling tank
  - Cu coil heat exchanger
- Improved vacuum

STEP CLOSER TO A PRODUCTION SYSTEM

Jun-Aug 2019

SUMMER INTERN



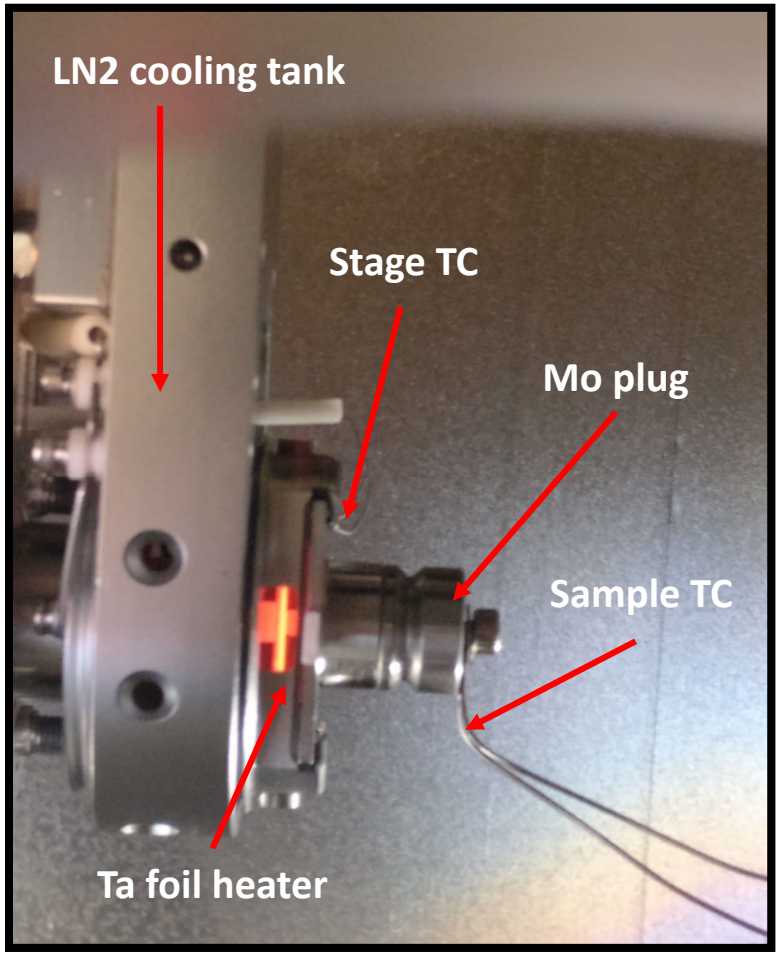
David Pavel Juarez Lopez,
Daresbury Laboratory

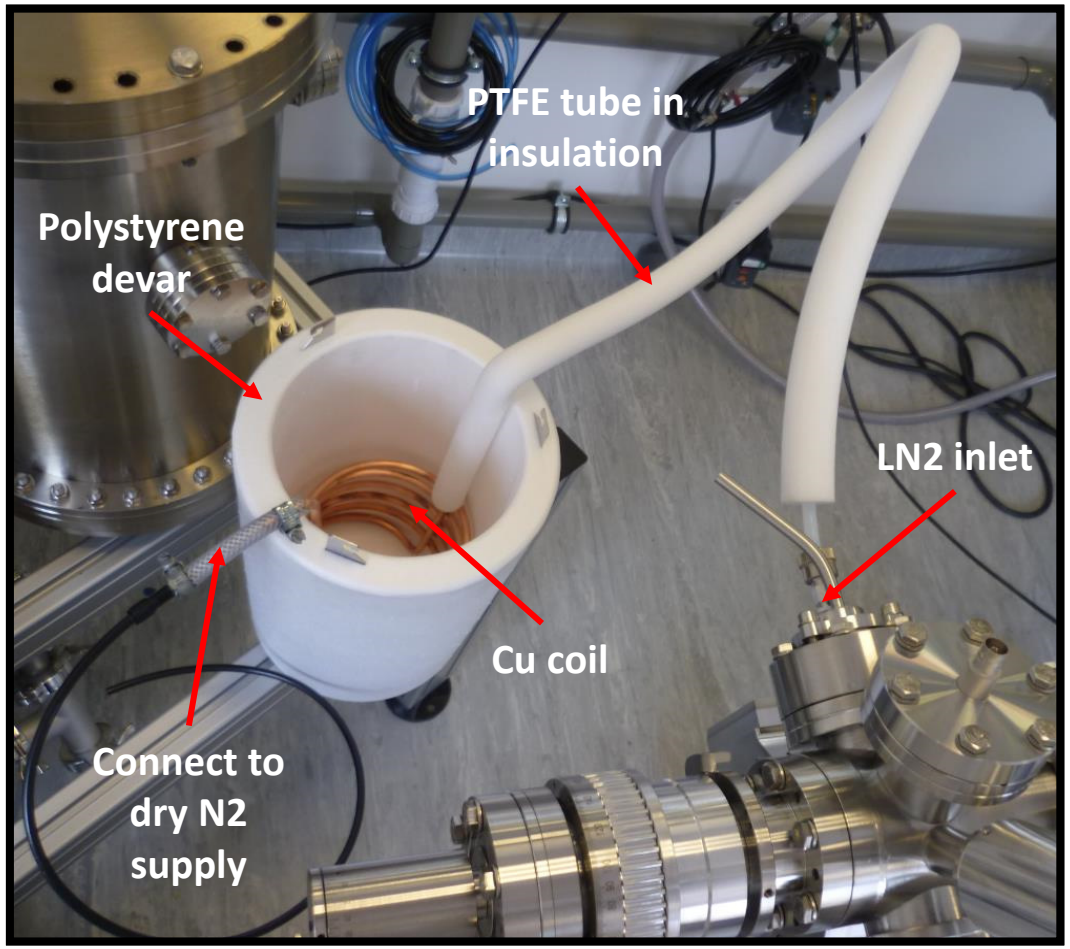
3 month internship at HZB

DAAD

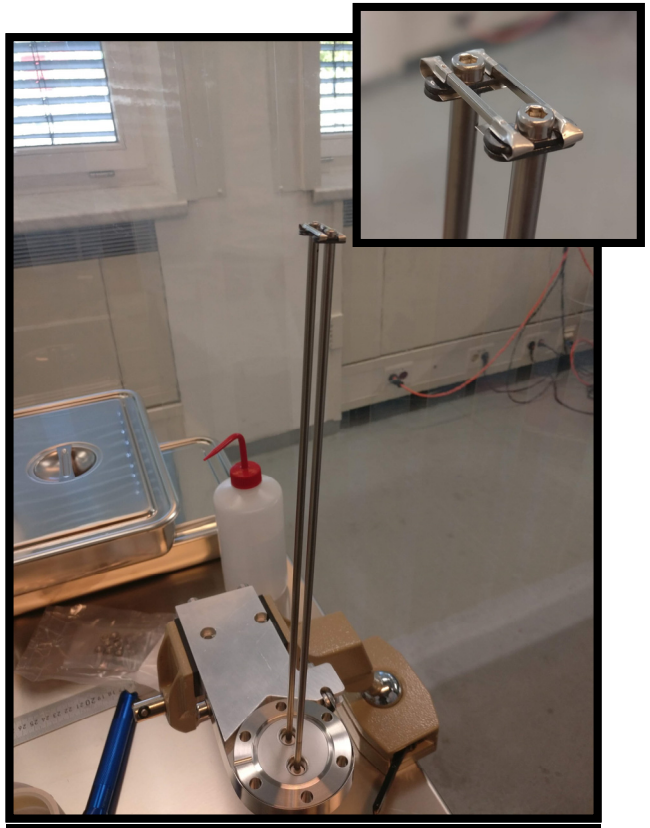
RISE professional Research Internships in Science and Engineering

PHOTOCATHODE LAB: HEATING AND COOLING CALIBRATION

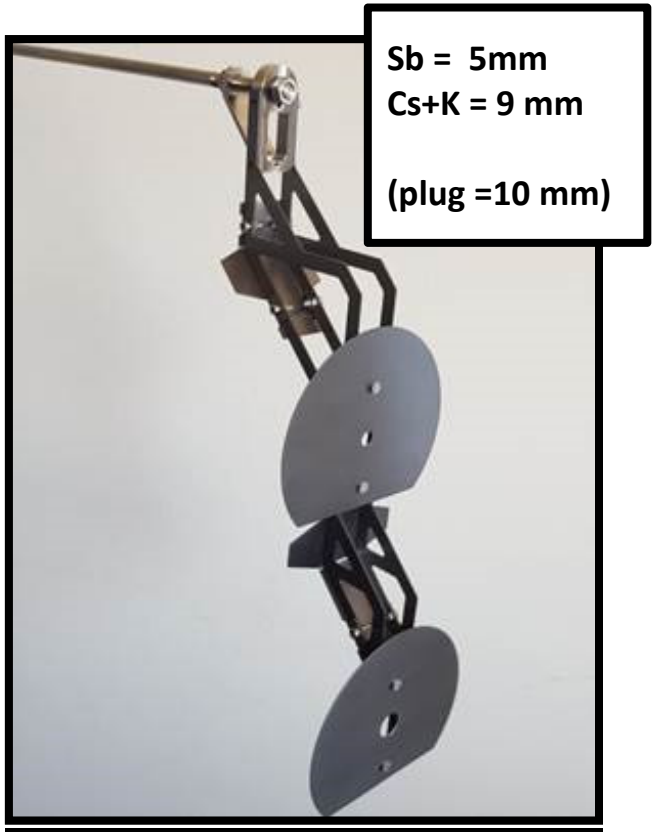




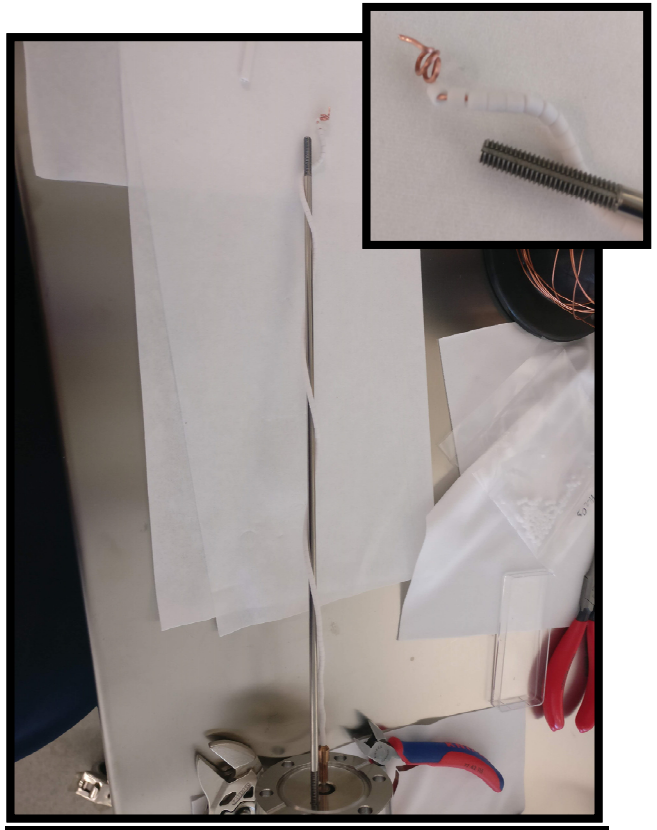
PHOTOCATHODE LAB: SYSTEM UPGRADE



New dispenser feedthrough



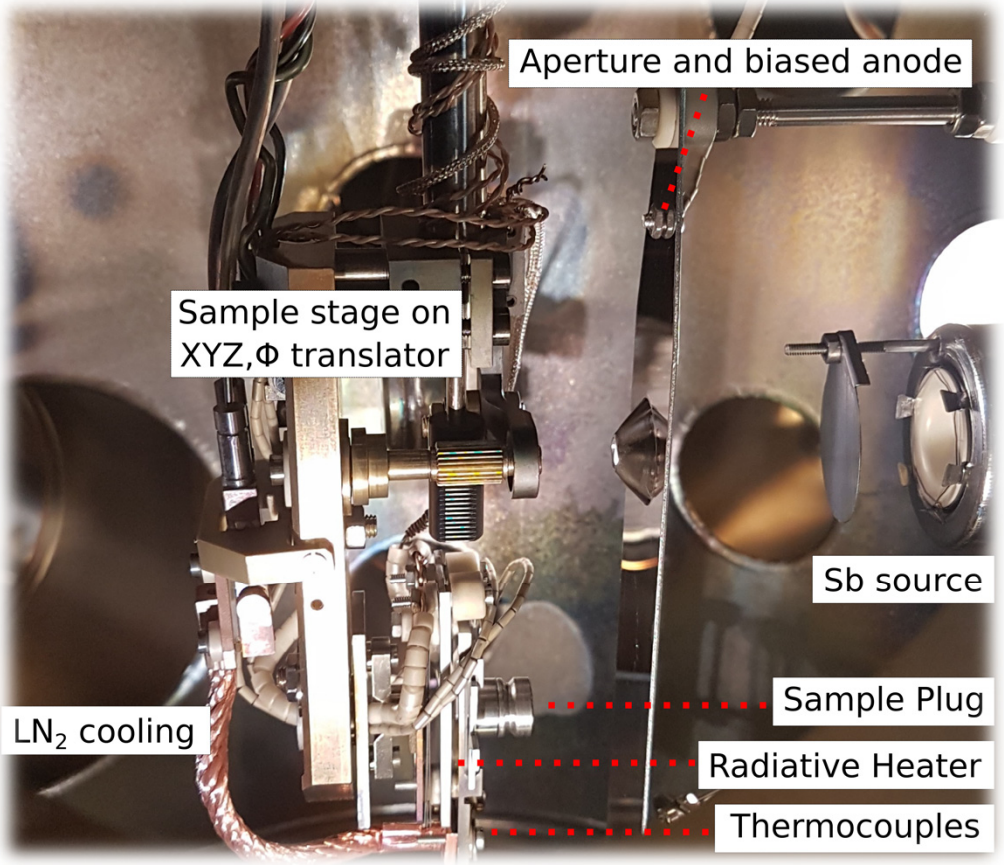
New aperture design



New anode

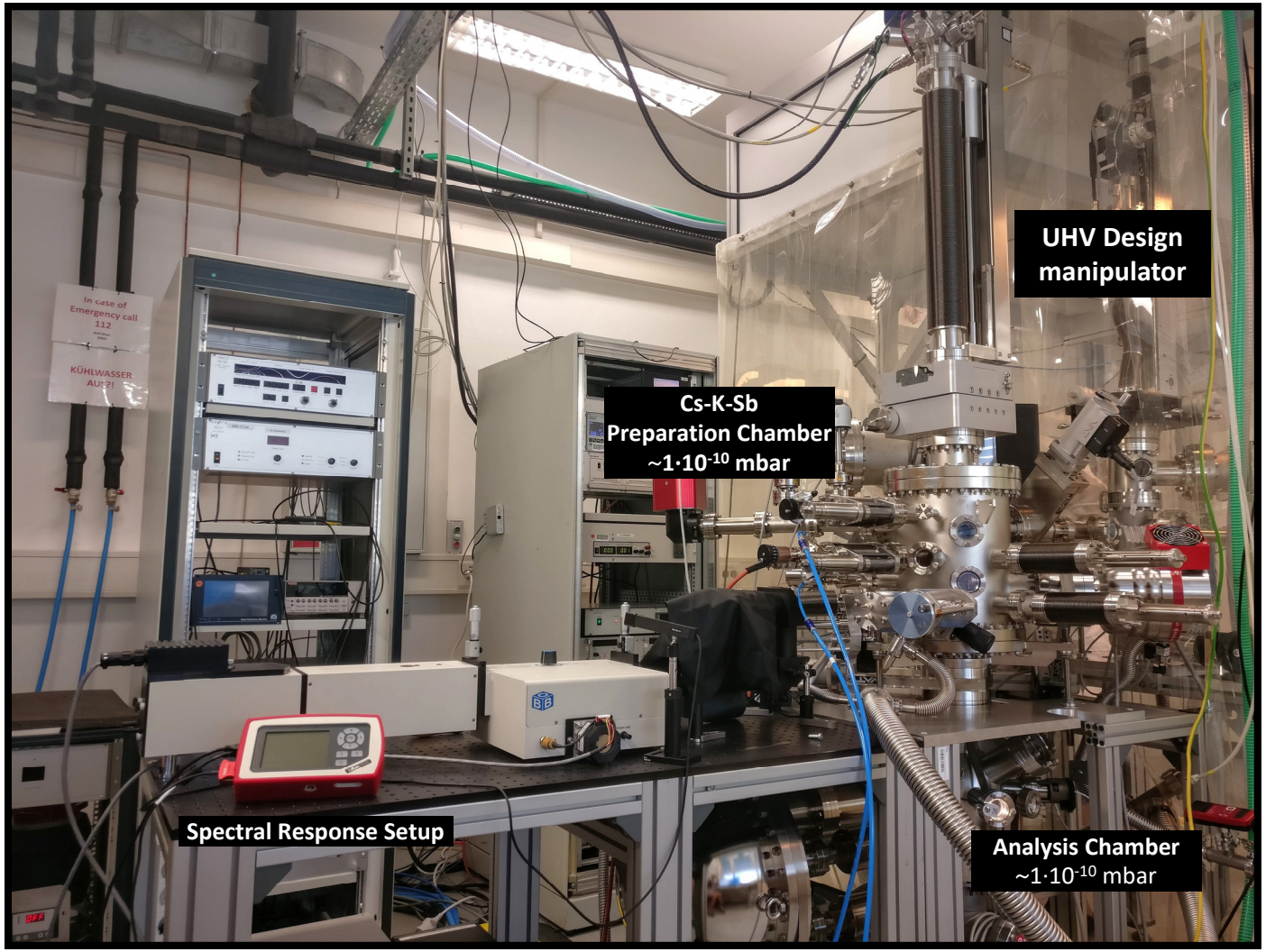
Previous design combined aperture and anode- not suitable!

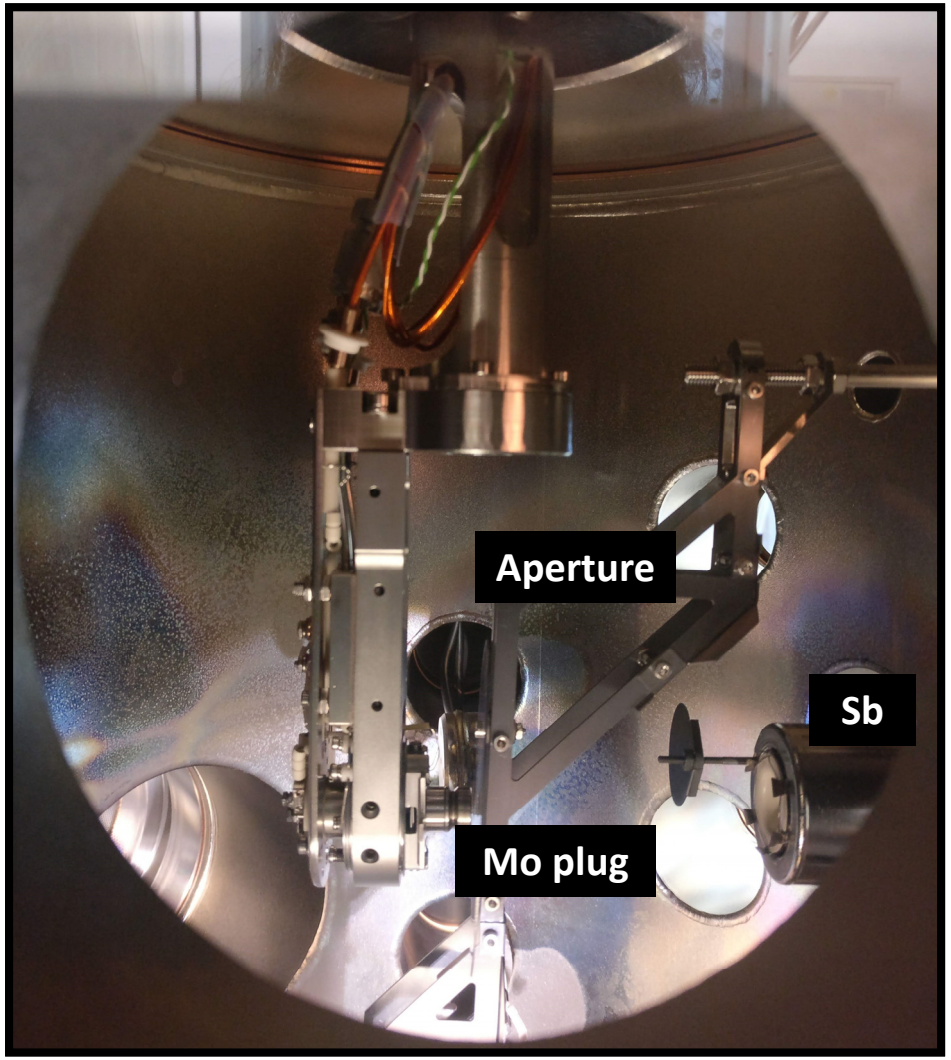
PHOTOCATHODE LAB: THEN



Aug 2019

PHOTOCATHODE LAB: NOW





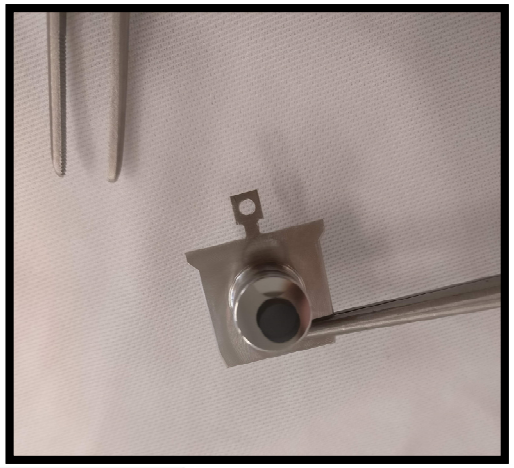
Aug 2019

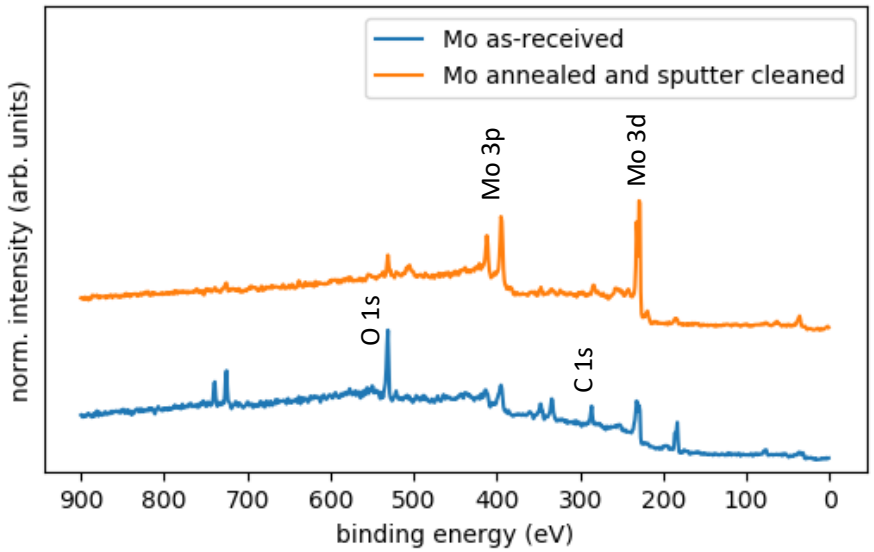
FIRST GROWTH AFTER UPGRADE 28.08.2019

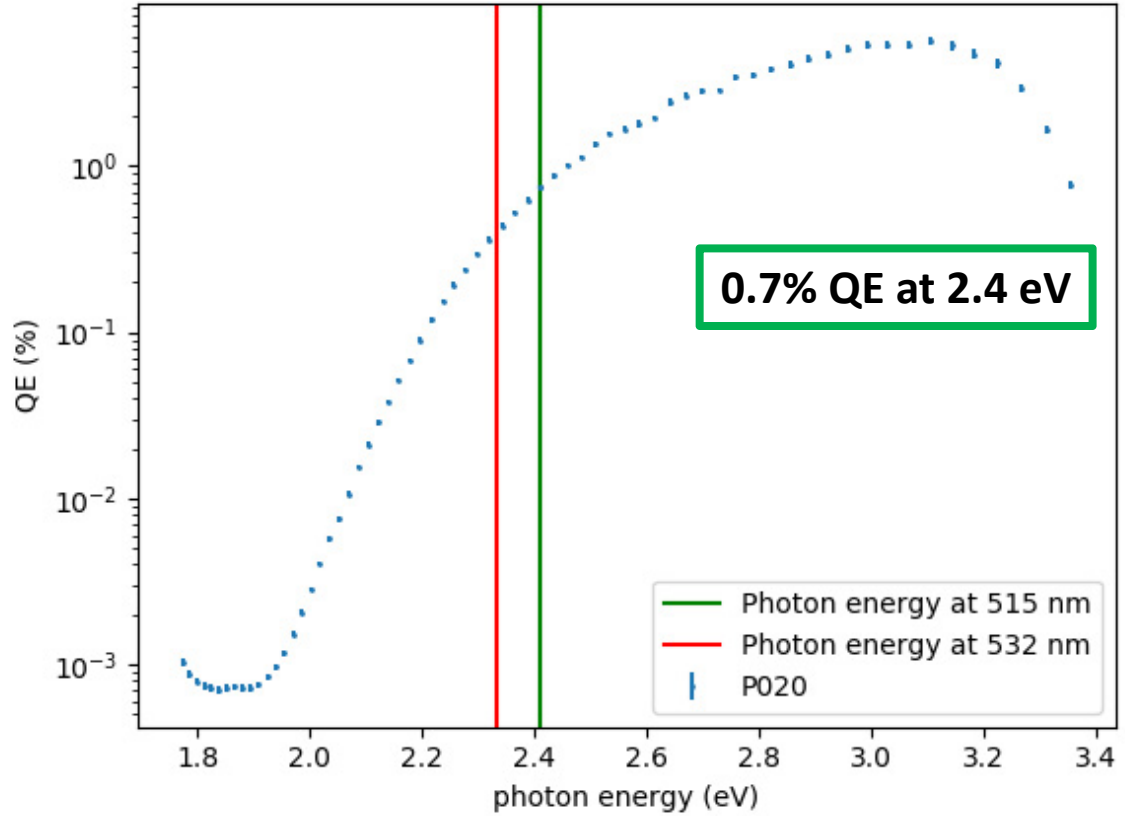
Mo Sb Cs-K-Sb

Next steps for optimising growth

- Sb layer
- Sample temperature, positions
- Mo plug roughness







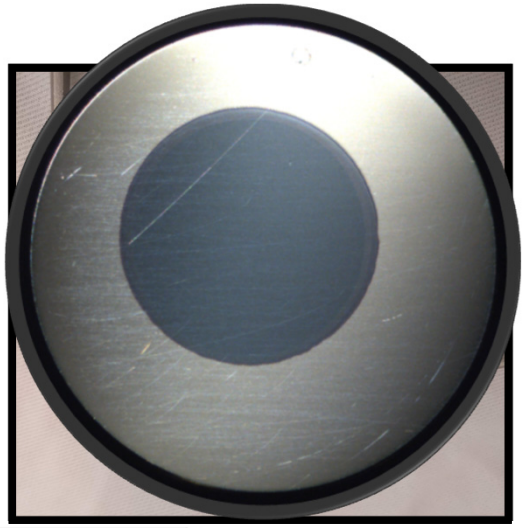
Aug 2019

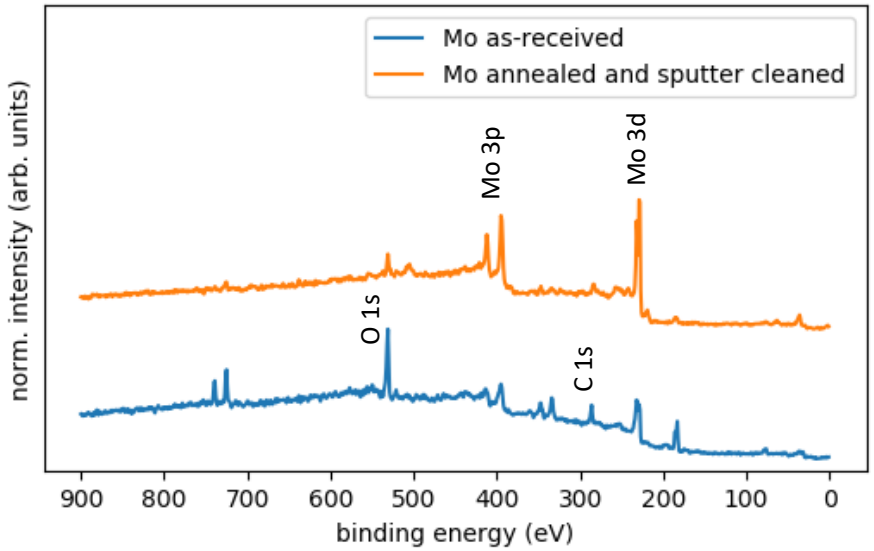
FIRST GROWTH AFTER UPGRADE 28.08.2019

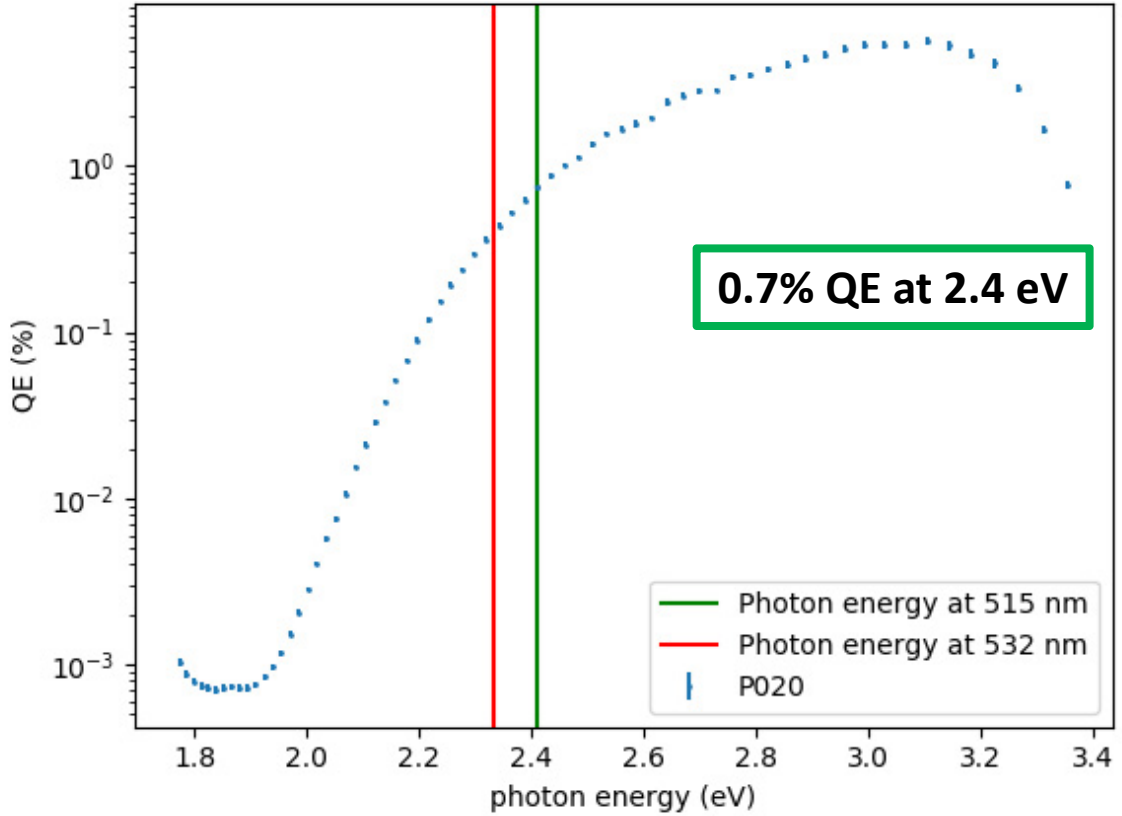
Mo Sb Cs-K-Sb

Next steps for optimising growth

- Sb layer
- Sample temperature, positions
- Mo plug roughness

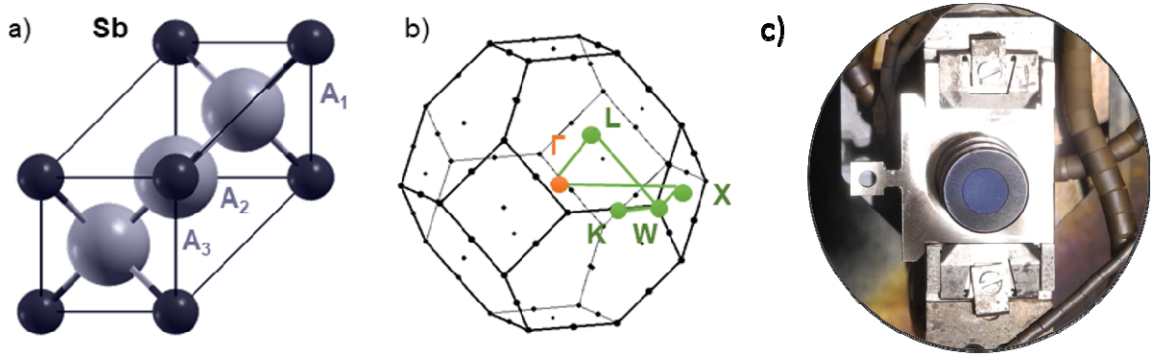


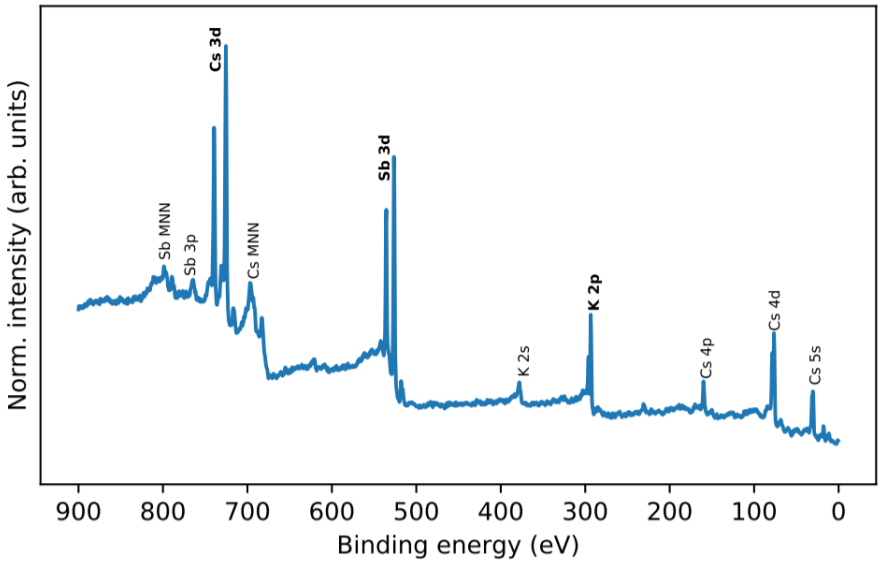




COLLABORATION WITH HUMBOLDT UNIVERSITÄT

Aim: Establish correlations between calculated and measured data on core electronic states of Cs-K-Sb





- Computed electronic properties of: Cs_3Sb, CsK_2Sb and Cs_2KSb
- Core level BE‘s computed from DFT
- For K 2p and Sb 3d sizable shifts in BE between the different stoichiometeries (2 eV and 0.5 eV)
- XPS spectra show distinct peaks for K 2p and Sb 3d states typically considered in analysis
- **Maximum associated with the K 2p state could be monitored as a fingerprint!**

C. Cocchi et al, Submitted 07.08.2019

SUMMARY AND OUTLOOK

1. Cathode Cooling performance in the gun
   - RT reached with 30 W heat load
   - Continue experiment with 80 K He (g) cooling

2. Photocathode Lab
   a) Lifetime studies
      - Baseline experiment for Cs-K-Sb before upgrade
      - 1/e lifetime approx. 8 days
      - Repeat measurement post upgrade
      - Comparison study with Na-K-Sb
   b) PAS upgrade
      - Successful commissioning
      - First (and second) cathode grown

HIGH PRIORITY GOAL: DELIVERY OF HIGH PERFORMANCE PHOTOCATHODES FOR bERLinPro & GUN STUDIES WITH BI-ALKALI ANTIMONIDE PHOTOCATHODES

THANK YOU FOR YOUR ATTENTION