WP12.5:
Characterise and optimise performance of Diamond Amplifier Cathode solutions for SRF guns

Thorsten Kamps, Julius Kühn, Martin Schmeißer, Hans Kirschner, (Roman Barday), Helmholtz-Zentrum Berlin

Jochen Teichert, Rong Xiang, Petr Murcek, Helmholtz-Zentrum Dresden

Zihao Ding, John Smedley, Erdong Wang, Brookhaven National Lab

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

OUTLINE

Motivation
Basic idea of DAC
Status of DAC R&D
Idea for DAC implementation in SRF Guns
- BNL design
- EuCARD2 design

Big questions
Preparation of primary cathode for EuCARD2 design
Tests of primary cathode under cryogenic conditions
An idea: passive back-illuminated cathode
Summary and outlook

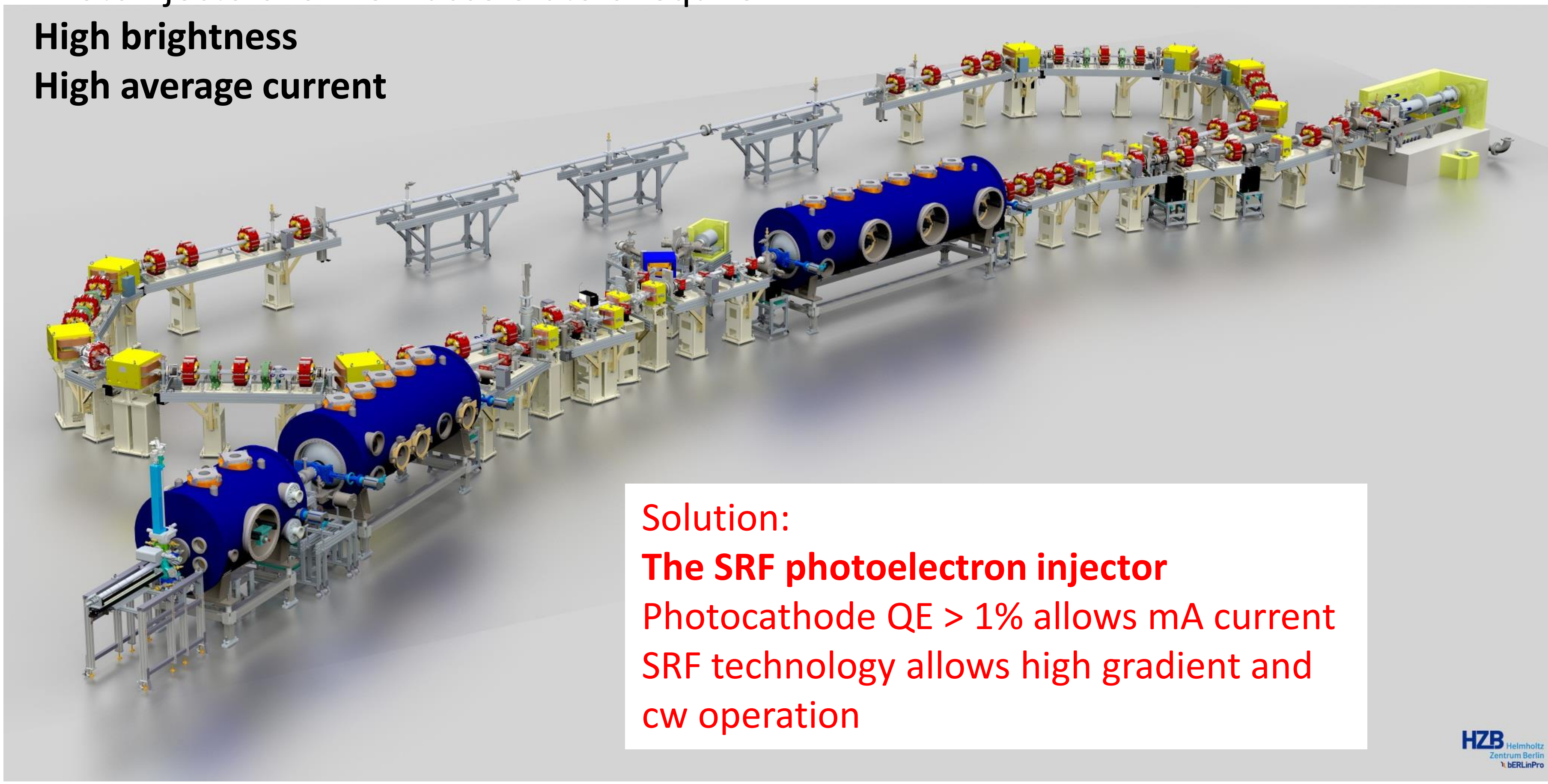
MOTIVATION: HIGH-CURRENT PHOTOINJECTORS

HZB Helmholtz Zentrum Berlin
bERLinPro

Photoinjectors for new accelerators require

High brightness

High average current



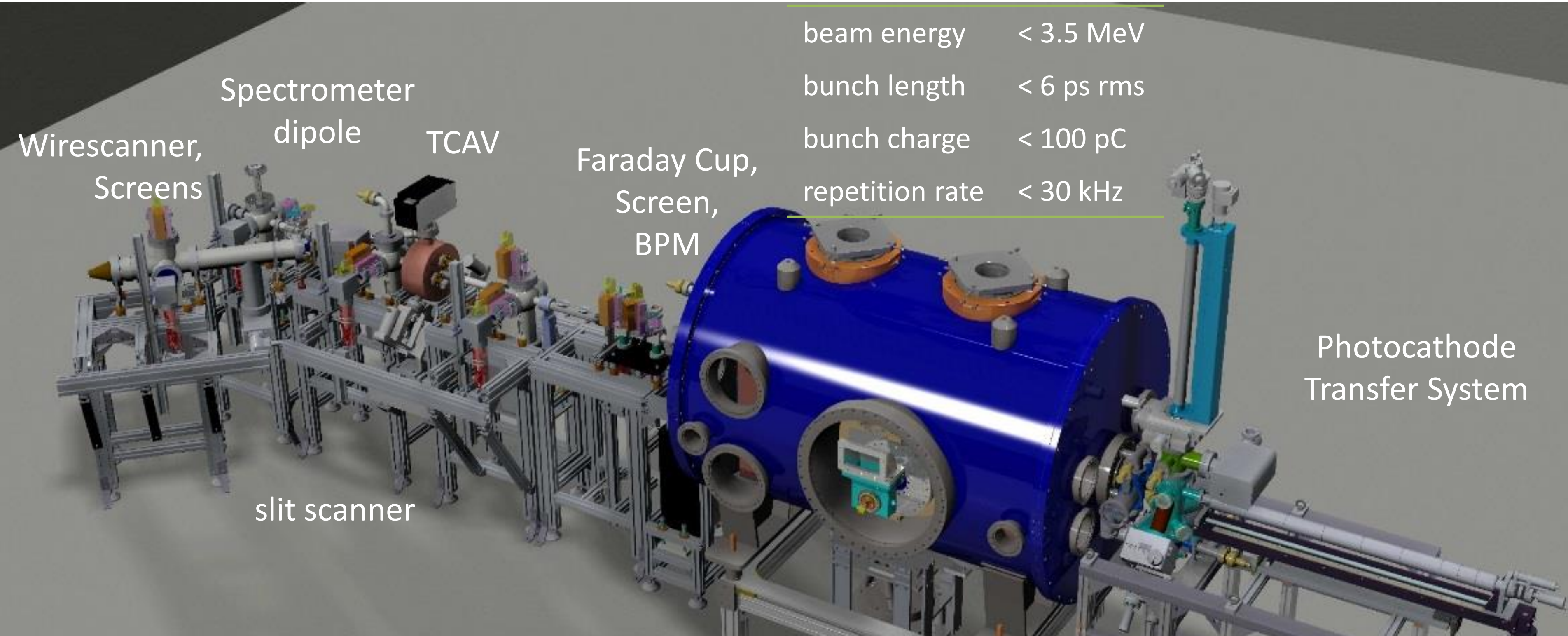
Solution:

The SRF photoelectron injector

Photocathode QE > 1% allows mA current

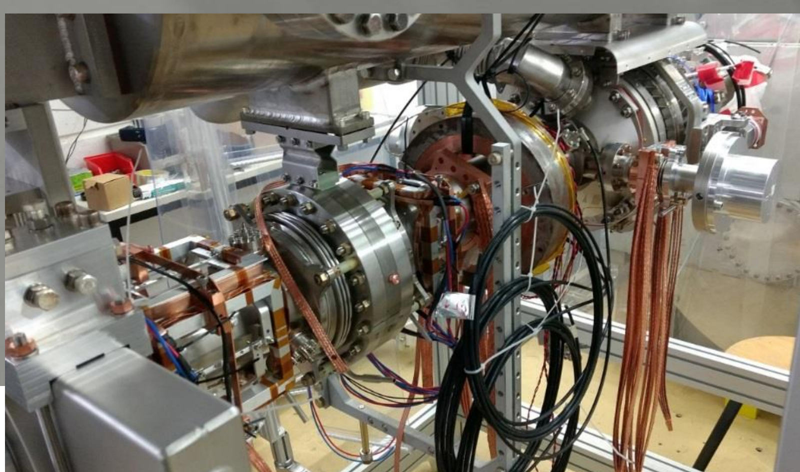
SRF technology allows high gradient and cw operation

GUN1 AND GUNLAB AT HZB



beam energy	< 3.5 MeV
bunch length	< 6 ps rms
bunch charge	< 100 pC
repetition rate	< 30 kHz

Goal: operate high QE photocathode in SRF Gun system

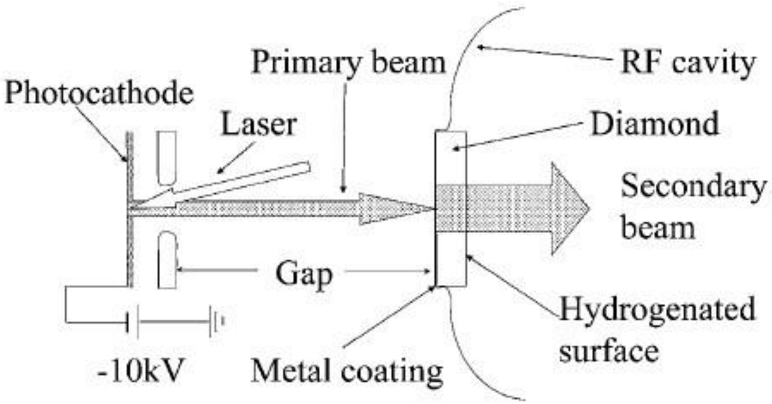


Cold string of Gun1 at HZB

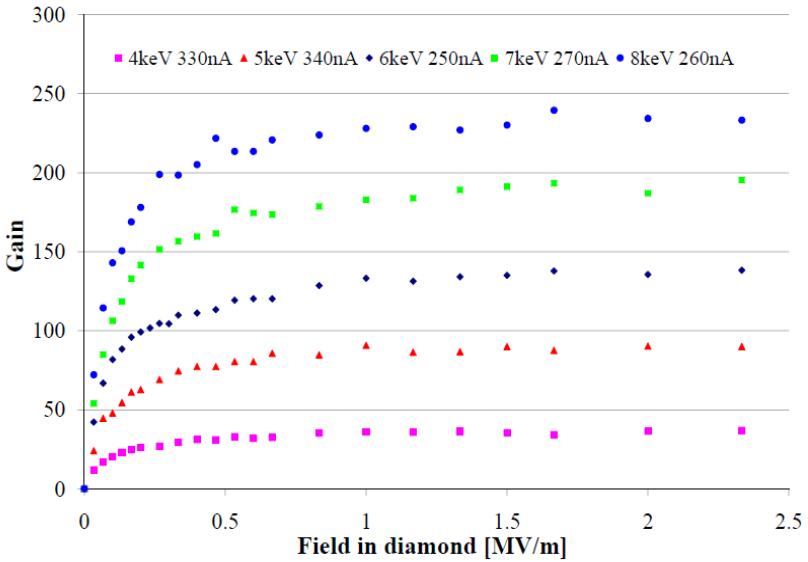
BASIC IDEA OF DAC

Generation of very high average current (>100 mA) well above what is currently achievable with high QE multi-alkali photocathodes

- Diamond amplifier cathode (DAC) is a promising option.
- Diamond is very robust wrt. radiation, current density, thermal load
- very linear response
- H coated or (111) surface has negative electron affinity



X. Chang et al, PRL 105, 164801 (2010)



Courtesy J. Smedley

STATUS OF DAC R&D

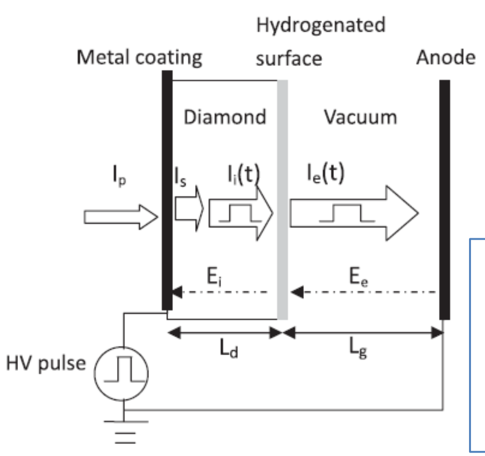
DAC proposed by BNL (T. Rao, et al.) in 2004

Main features

- Gain → Reduction of laser power on cathode
- NEA surface, thermalization → Low thermal emittance
- emitting layer protected → cavity-cathode interface
- encapsulated system

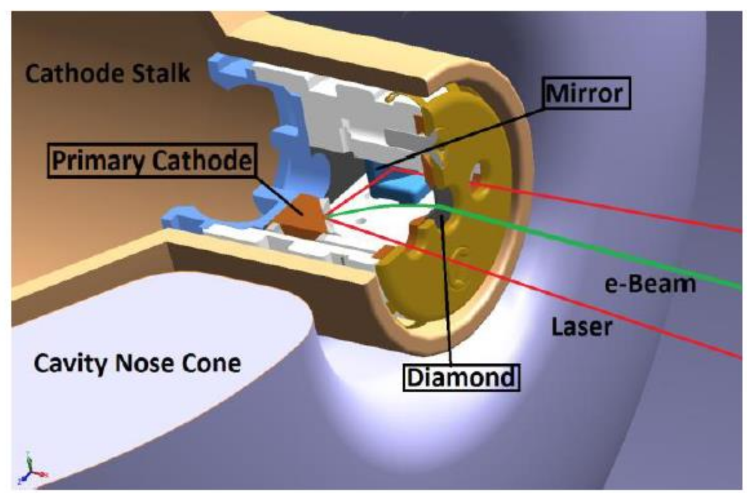
Main focii of R&D at BNL

- Observation of emission from DAC (PRL 105, 164801, 2010)
- Secondary emission from hydrogen-terminated diamond (PRST-AB 14, 061302, 2011)
- Design of cathode system for SRF Gun (PAC 2013)



Push-pull high voltage switch to draw electrons and reject trapped surface charge

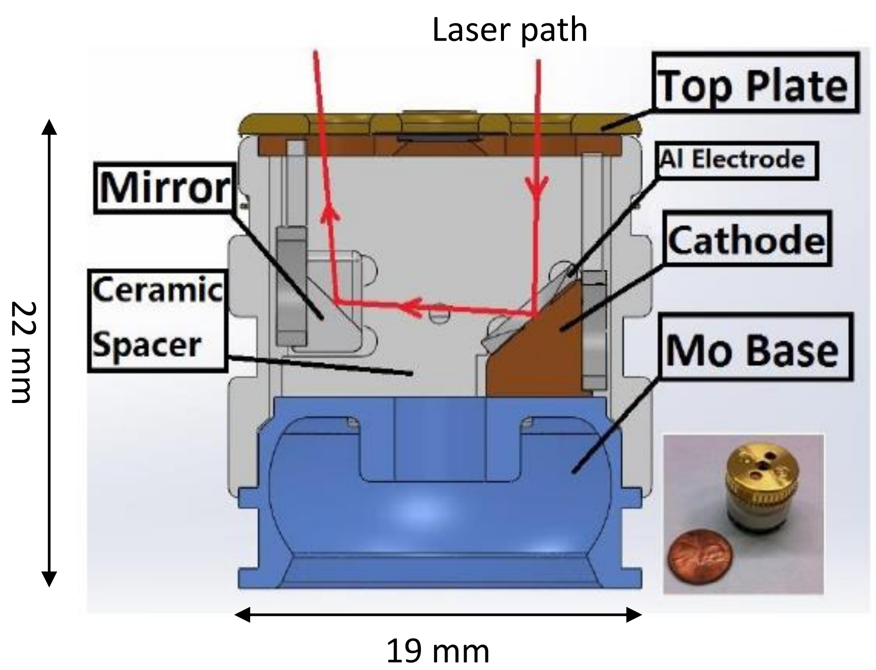
DAC capsule in the back of SRF gun cavity



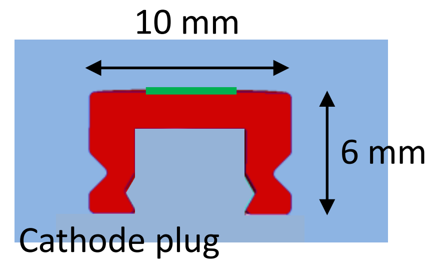
DAC IMPLEMENTATION INTO SRF GUN

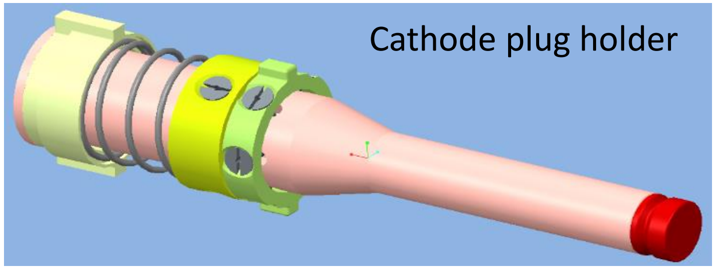
BNL designed and built a DAC capsule compatible with BNL SRF gun
For HZB/HZDR SRF gun design needs to be more compact

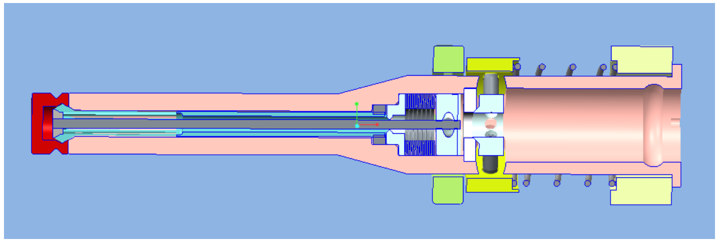
BNL DAC capsule



HZB/HZDR cathode plug



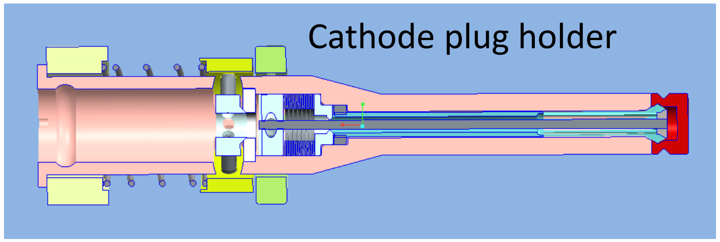


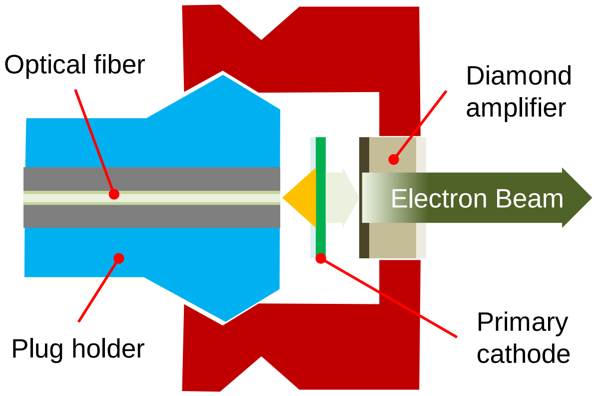


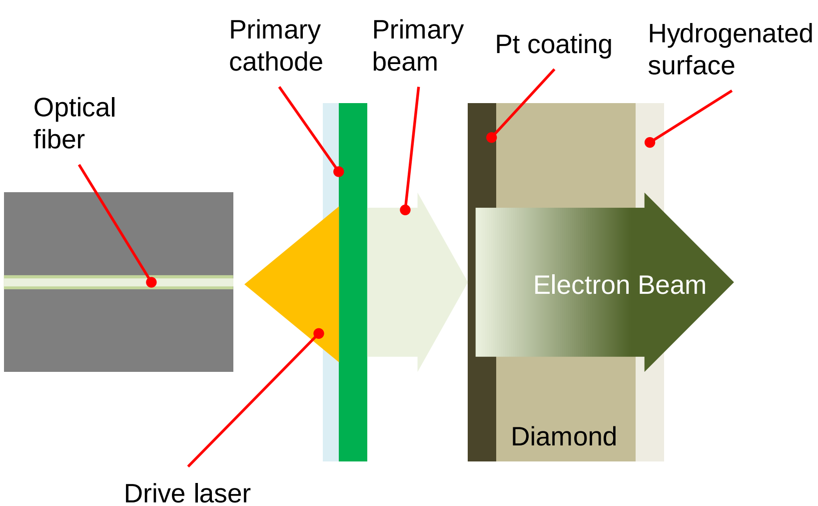
DAC IMPLEMENTATION INTO HZB/HZDR CATHODE PLUG

HZB Helmholtz Zentrum Berlin bERLinPro

HZB/HZDR cathode plug







EuCARD2 DAC plug
for HZB/HZDR SRF gun

Mitigation of risk by front entry of drive laser light of BNL design

→ Back-illumination with optical fiber based laser transport.

→ Enables adaption of DAC for HZB/HZDR cathode plug

BIG QUESTIONS

DAC design compatible with HZB/HZDR SRF gun seems feasible

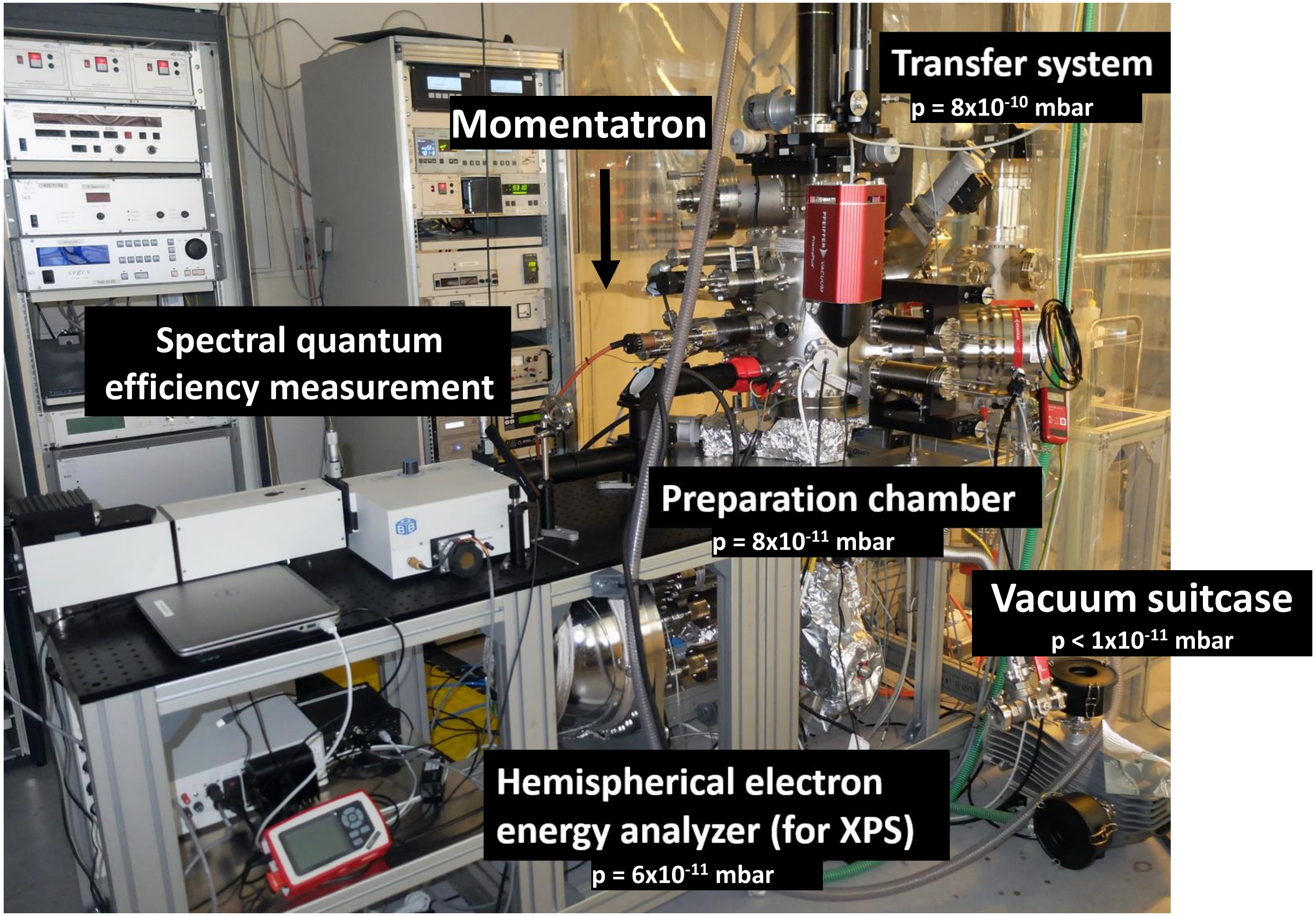
Challenges in EuCARD2

- **Preparation of primary cathode (candidate CsK2Sb)**
- **Characteristics of primary beam, thermal emittance**
- **Thermal management, primary cathode at cryogenic temperatures**
- Engineering of optical fiber path from module feedthrough to plug
- Engineering of compact ultra-high vacuum high-voltage capsule design

Within EuCARD2 address questions related to primary cathode and primary beam characteristics

Spoiler: We did not reach the engineering stage

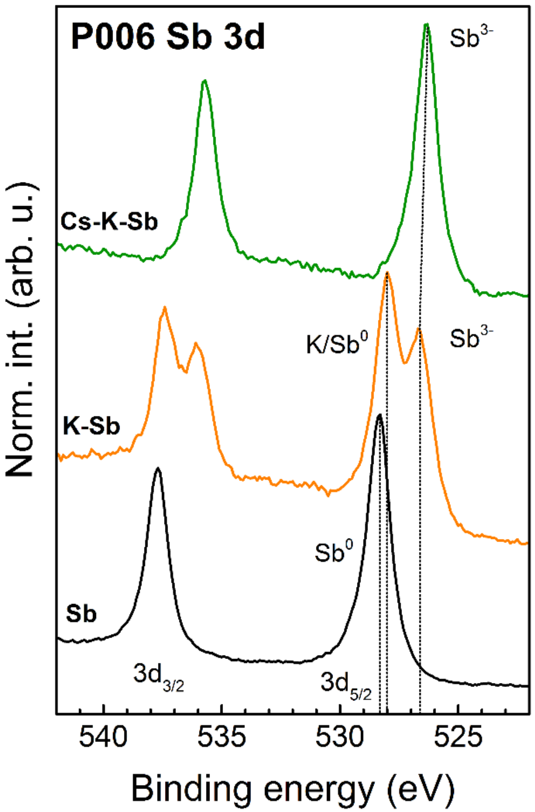
PRIMARY CATHODE - ALKALI CO-DEPOSITION PROCESS



Photocathode preparation and analysis system at HZB

ALKALI CO-DEPOSITION PROCESS

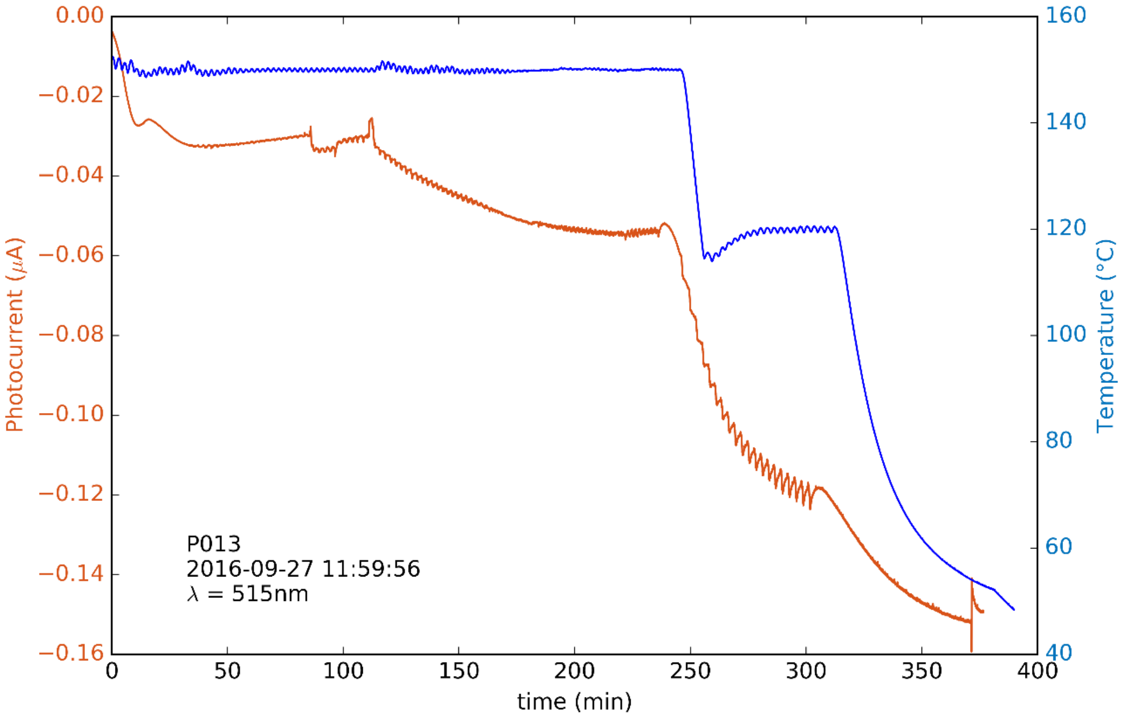
- Conventional process (sequential growth of Sb, K, Cs) leads to good results when K-Sb material has only partially reacted
- Alkali co-deposition (K+Cs on Sb) yields good sample performance and is easier to reproduce

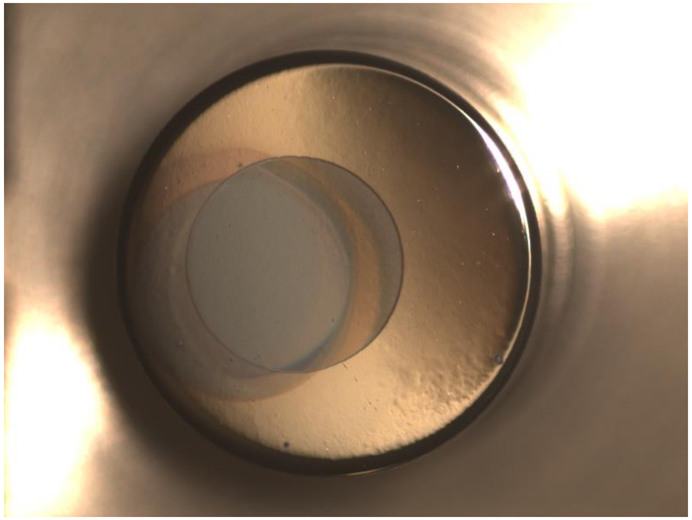


RECENT RESULTS FROM CO-DEPOSITION

HZB Helmholtz Zentrum Berlin
bERLinPro

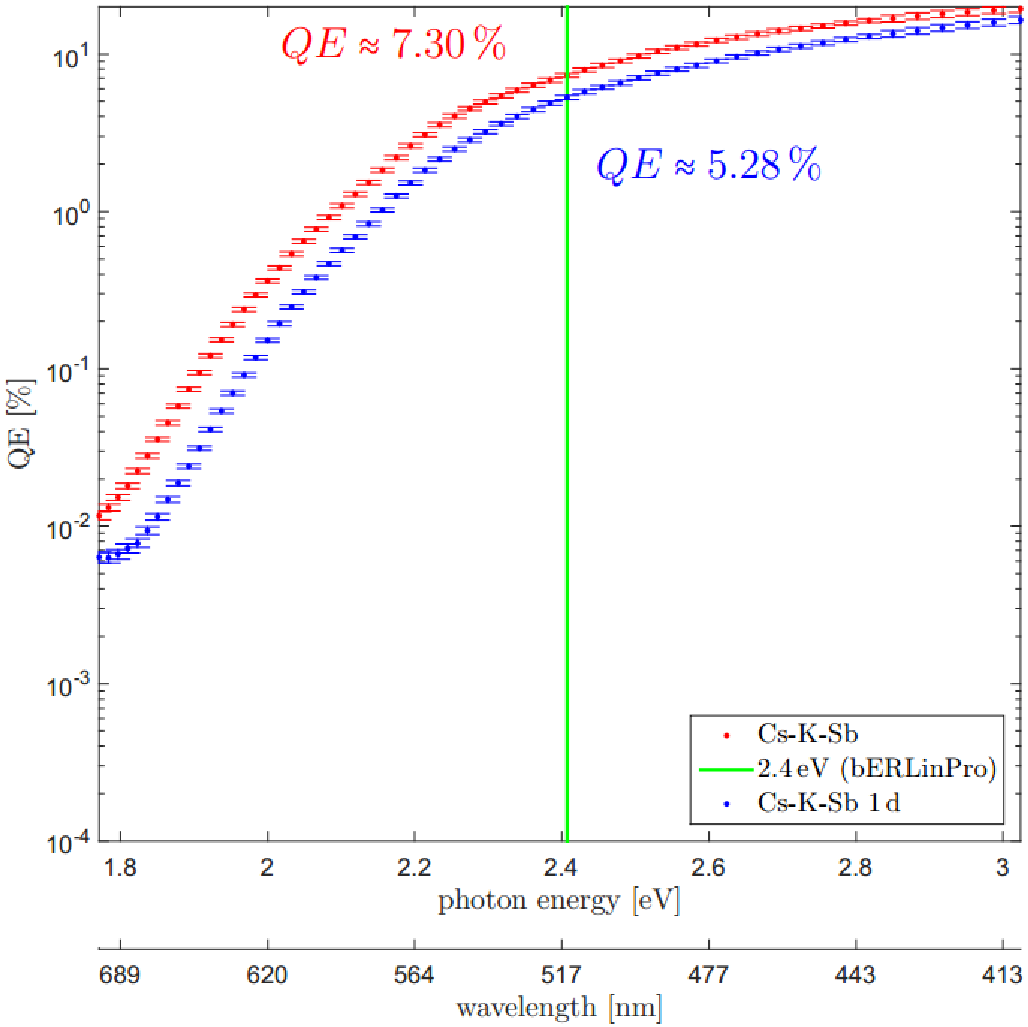
Photocathode P013 grown on a Mo substrate:
30nm Sb deposition at 150°C
K + Cs co-deposition at 150°C, reduce to 120° after 250min, finally let cool

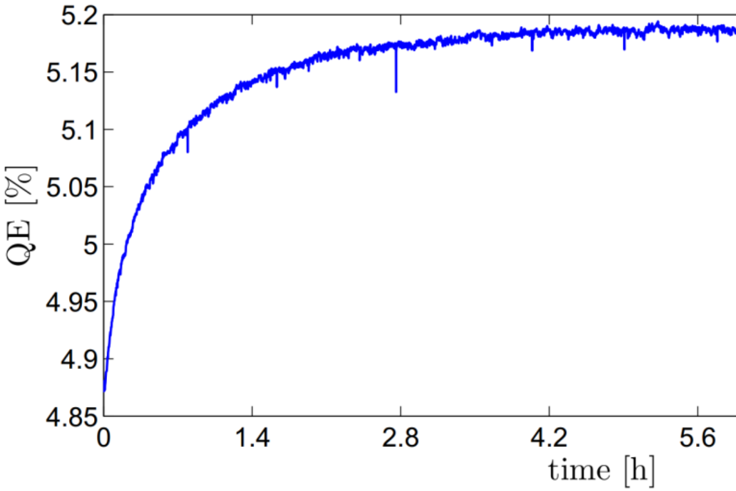




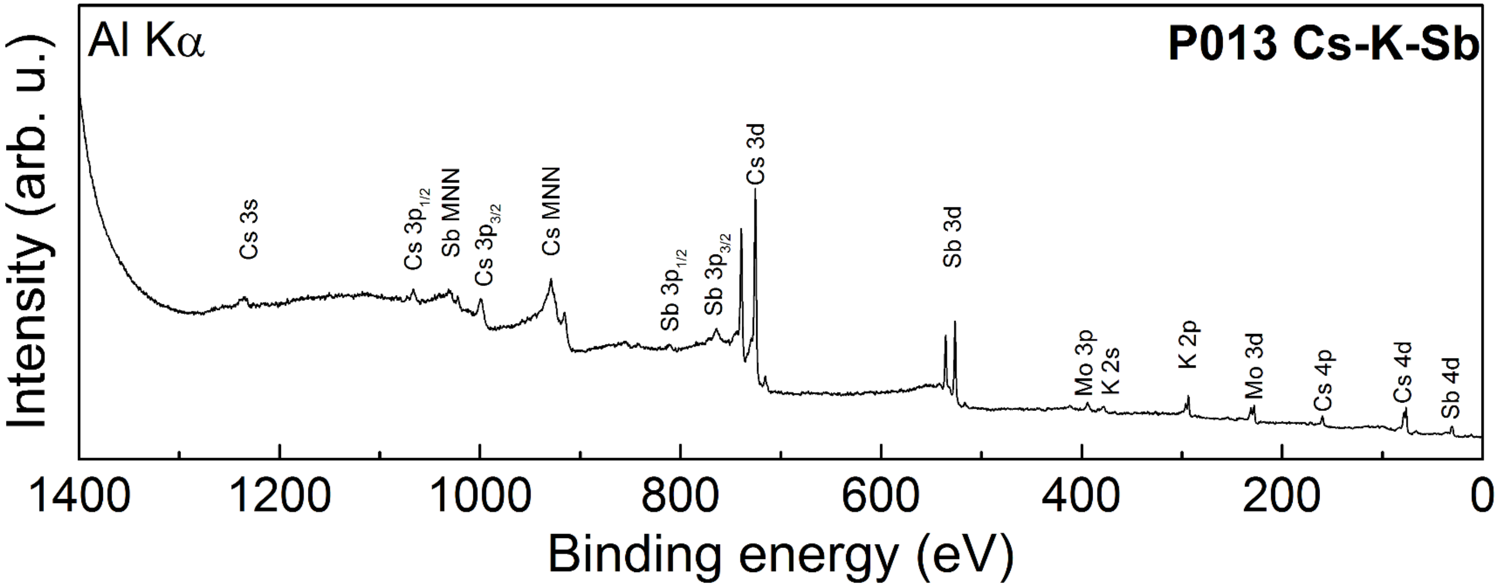
P013 SPECTRAL RESPONSE AFTER PREPARATION AND AFTER 12 HOURS

HZB Helmholtz Zentrum Berlin bERLinPro





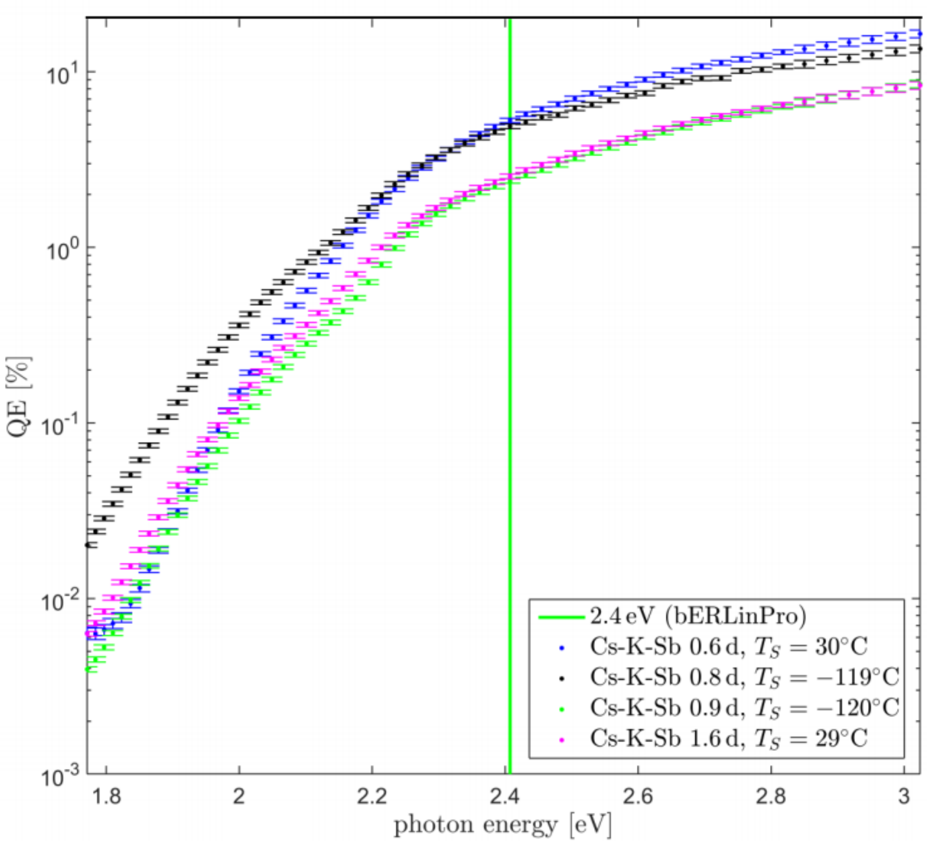
P013 - CS-K-SB SURVEY SPECTRUM (XPS)

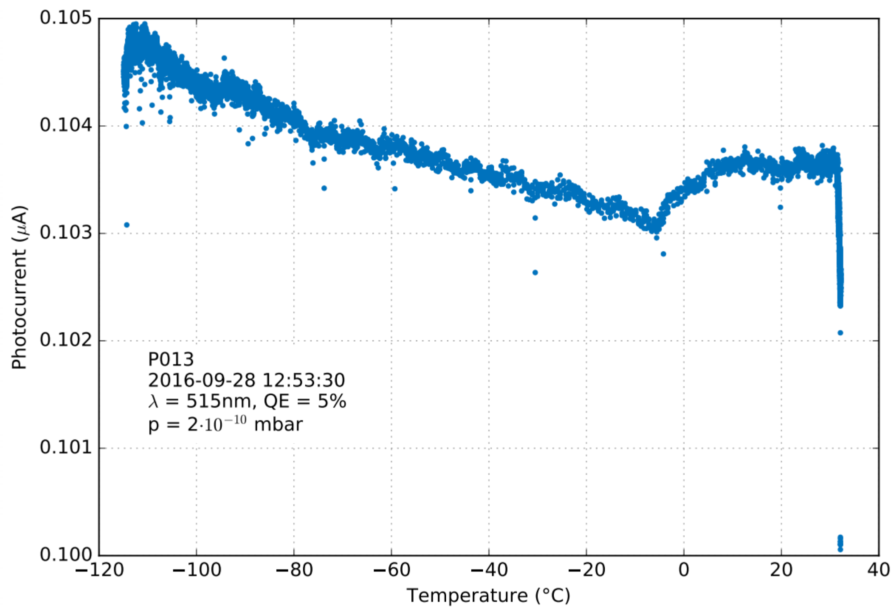


- Cs 3d, Sb 3d, K 2p regions from survey spectra used for **quantitative analysis**
    - P013 composition: „$\mathbf{Cs_{3.2}K_{1.1}Sb}$“
- Quantification routine needs improvement due to Sb3d/O1s overlap

XPS information depth $z_{95\%}$: ID_{Sb3d} = 10.5 nm

PRIMARY CATHODE AT CRYOGENIC TEMPERATURE



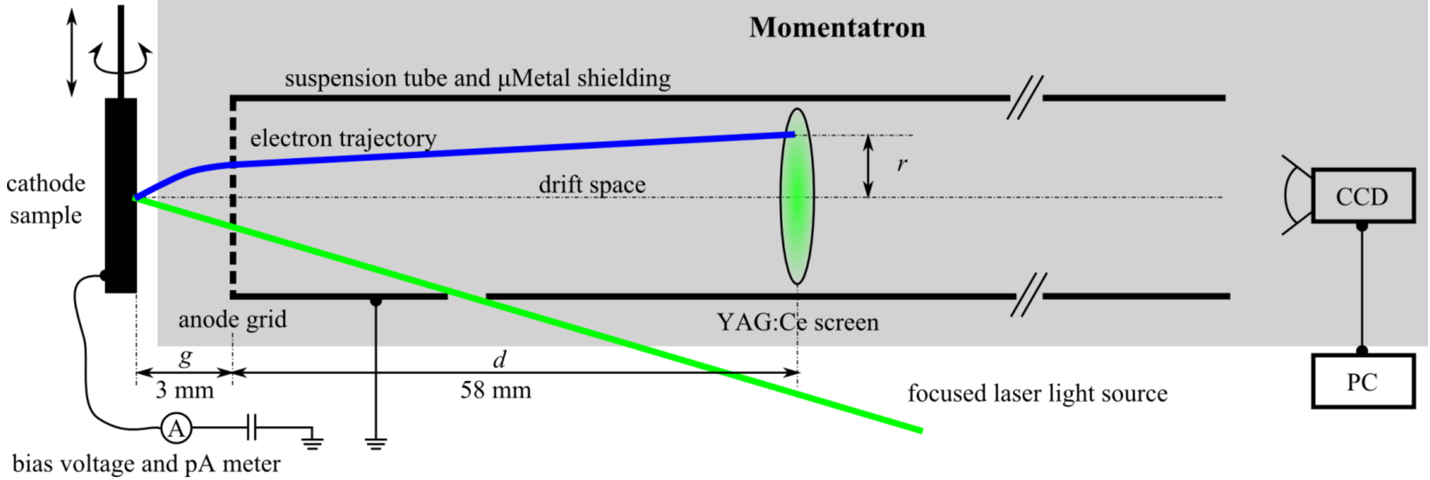


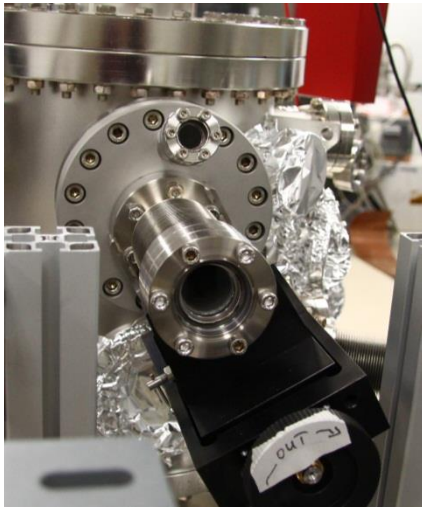
No degradation of the performance was observed during cooling to -120°C.

Movement of the cold sample (exposure to p > 10^{-9} mbar) results in loss of QE.

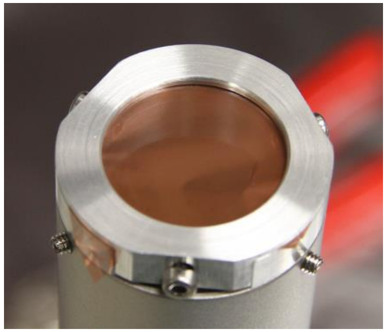
MOMENTATRON:

THERMAL EMITTANCE OF PRIMARY CATHODE





$$\frac{p_x}{mc} = \frac{r}{2g + d}\sqrt{\frac{2eU}{mc^2}}$$



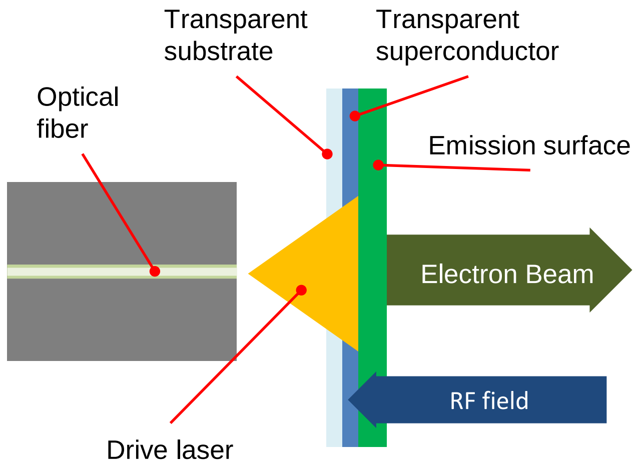
AN IDEA: PASSIVE BACK-ILLUMINATED CATHODE

HZB Helmholtz Zentrum Berlin
bERLinPro

Primary cathode prepared, QE of 7% at 515 nm reached → sufficient for DAC
QE at 515 nm stable during cooldown → compatible with SRF gun
Measurement of thermal emittance still open… to be continued

Many issues regarding engineering of ultra-high vacuum high-voltage capsule with diamond disc, pull-push voltage system requires many feedthroughs

First step/alternative approach: construct passive back-illuminated design (follows idea from KEK for their SRF gun project, E. Kako, et al.)



Photocathode is sandwich of
emission surface CsK2Sb,
transparent superconductor LiTi2O4, and
transparent substrate MgAl2O4
Drive laser transmitted through backside
RF penetrates emission surface and superconductor

Robust interface towards cavity
No high voltage feedthrough / no gain

SUMMARY / OUTLOOK

Implementation of a diamond amplifier cathode (DAC) at the HZB/HZDR SRF gun system seams feasible.

Restricted size of HZB/HZDR cathode plug requires re-design of the BNL DAC or even completely new design.

An implementation plan has been developed utilizing a back-illumination scheme mitigating some issues connected to the HZB/HZDR cathode plug.

Progress has been achieved towards preparation of the primary cathode, operation at cryogenic temperature and characterization of the primary beam.

Next steps (after EuCARD2):

Feasibility study and engineering design for passive back-illumation scheme.