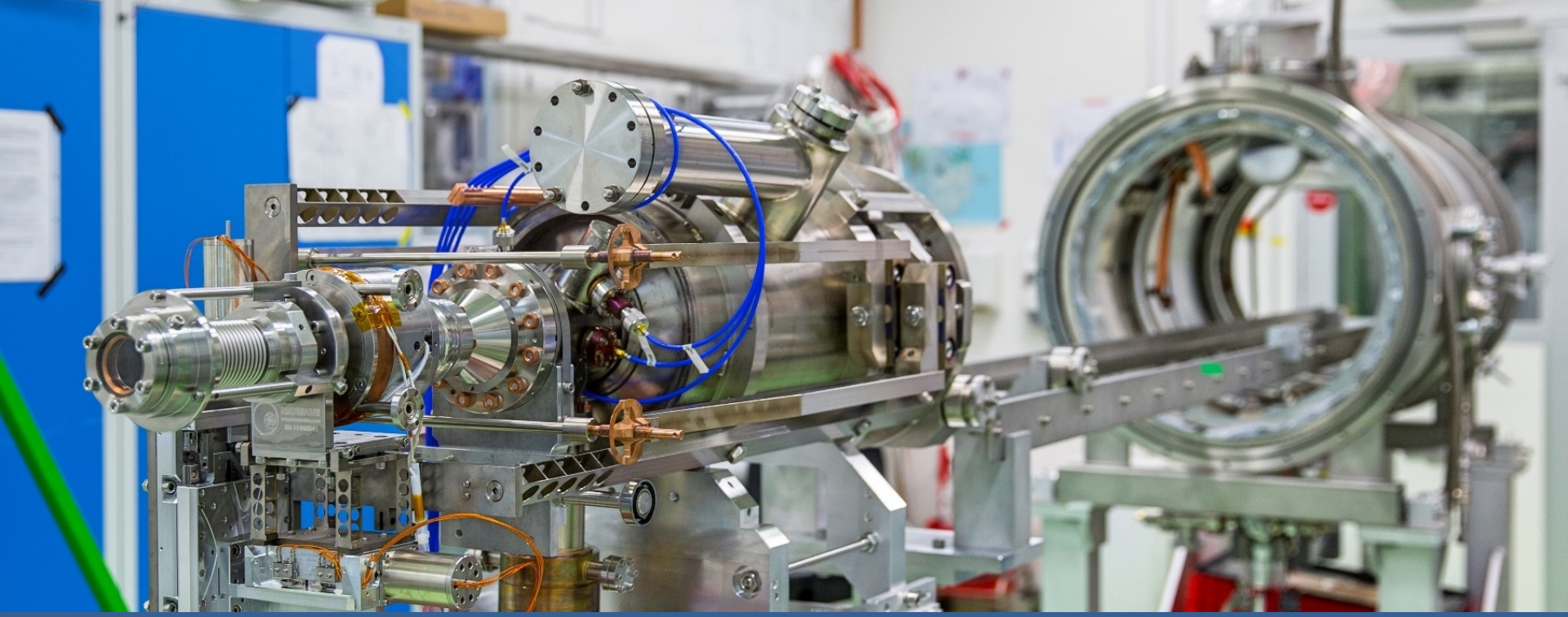


Metal and Semiconductor Photocathodes in the HZDR SRF Gun

J. Teichert, A. Arnold, P. Lu, P. Murcek

H. Vennekate and R. Xiang

ELBE.

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

EuCARD²

Partner von DRESDEN concept exzellenz-dresden.de

Outline

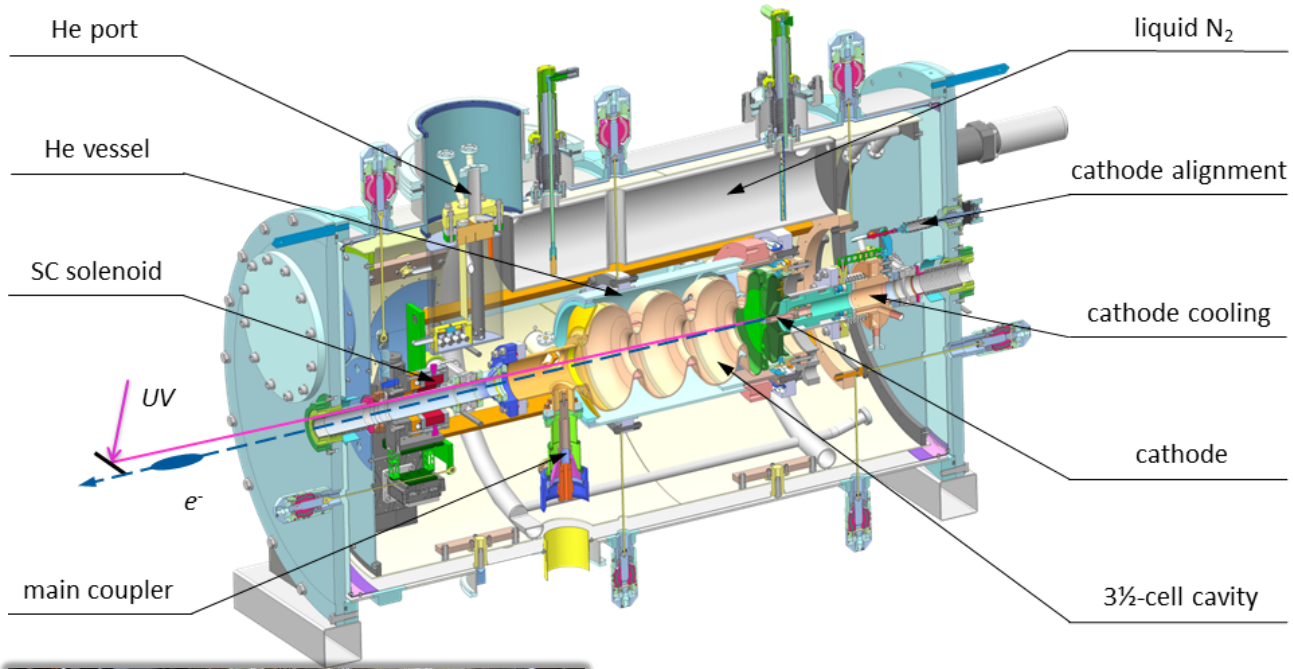
1. Introduction
2. Preparation, laser cleaning and application of Mg cathodes
3. Preparation and operation of Cs2Te cathodes
4. Summary

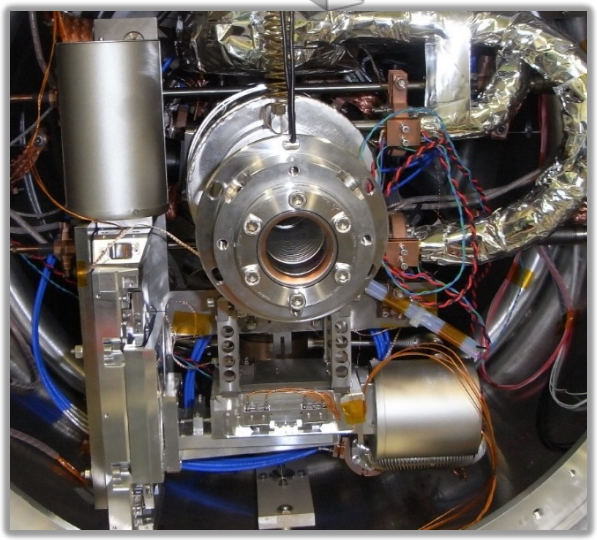
ELBE.

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

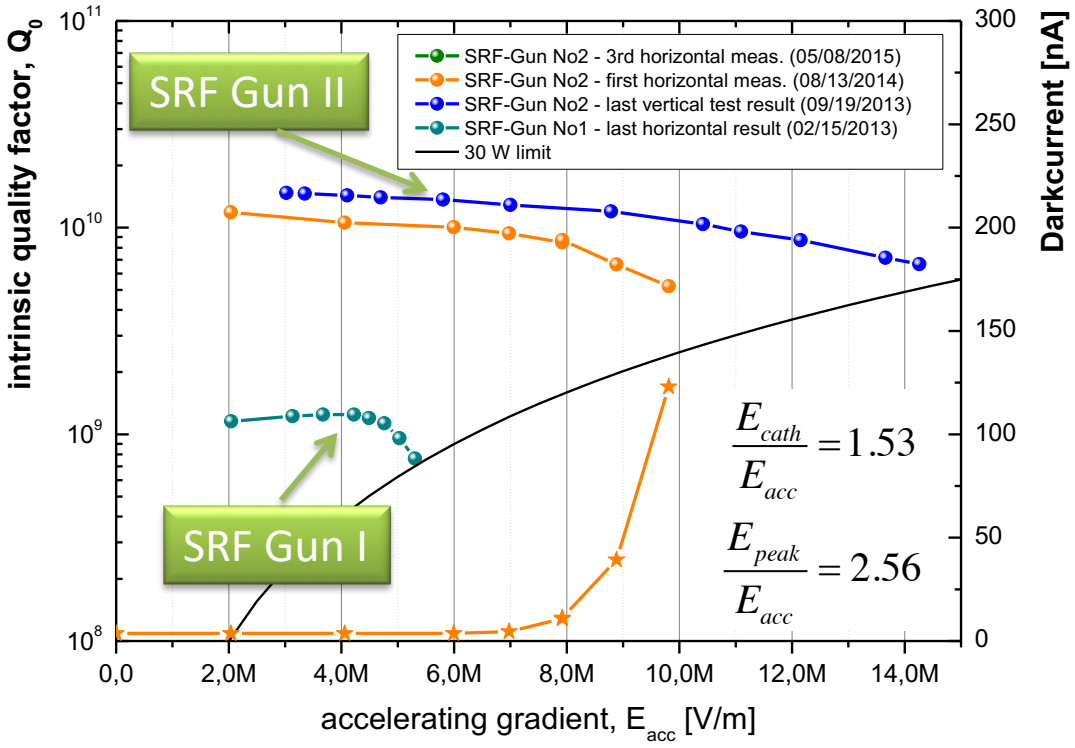
Introduction - ELBE SRF Gun II Cryomodule



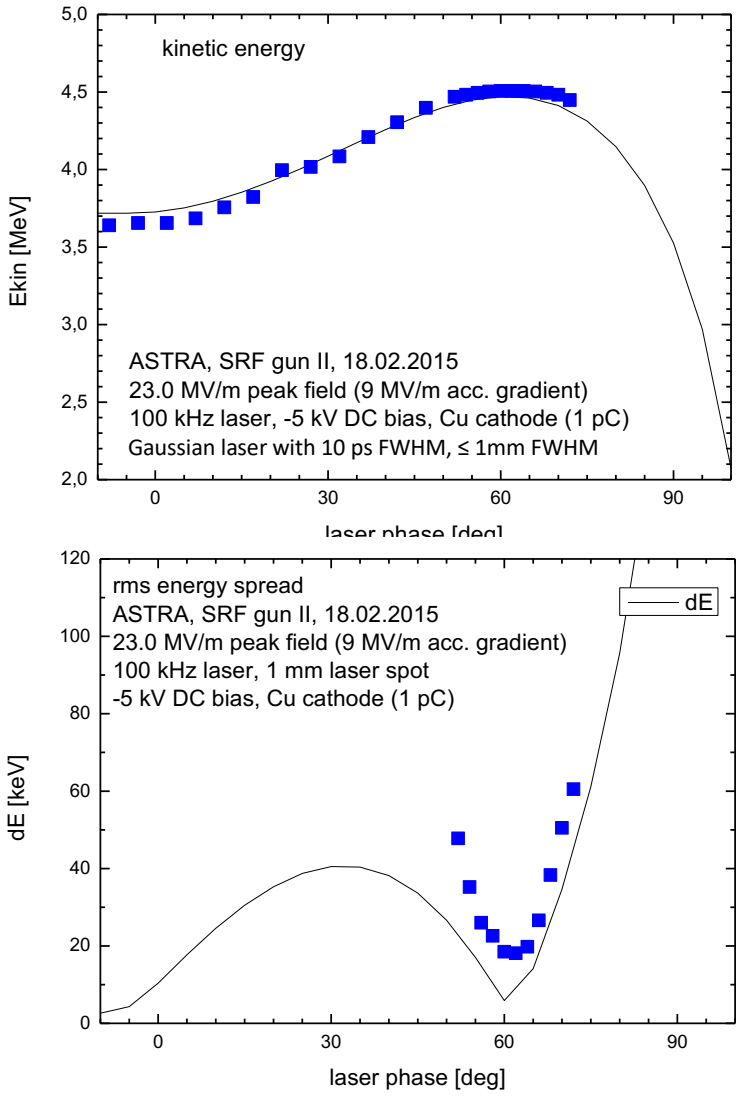


- New cavity - fine grain Nb, produced, treated, tested at JLab
- New cryomodule
  10 cm longer, fabricated and assembled at HZDR
- Integration of a superconducting solenoid

Introduction - SRF Gun II Performance



1st beam test with Cu photo cathode



- **30% performance loss** compared to the last vertical test, but twice the gradient of SRF gun I
- tuner resolution <1 Hz/step, no hysteresis
- field profile and external couplings as designed
- pressure sensitivity and microphonics not critical
- **but high LF detuning**: 1.5 Hz/(MV/m)^2 for peak el. field compared to 0.25 Hz/(MV/m)^2 for TESLA cavity

E_{kin} = 4.5 MeV - world record for SRF-Gun generated CW beam!

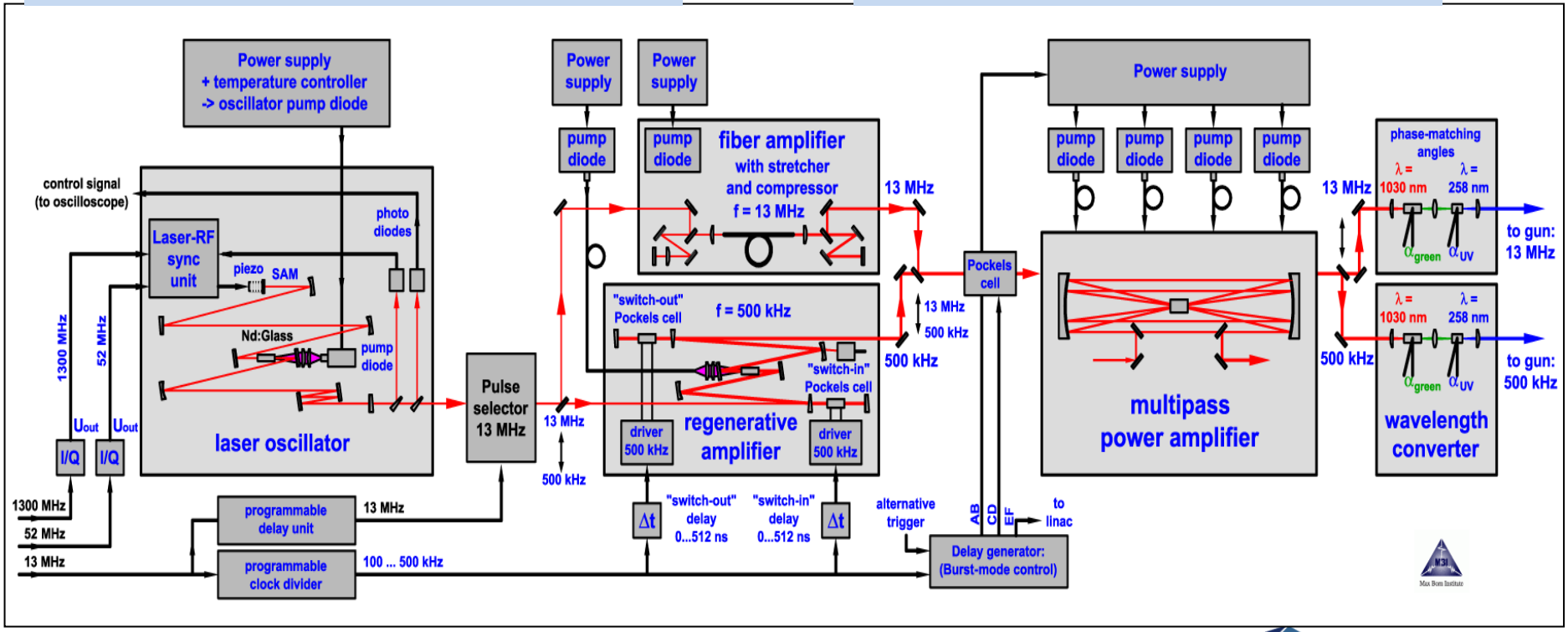
Introduction UV Laser System

UV Laser system developed by MBI:

- CW operation with large flexibility in repetition rate and time structure (burst)
- Conversion to the UV (λ = 263 nm) at appr. 0.5 W power
- Gaussian temporal shape
- Different repetition rates + different pulse durations:
  a) 13 MHz: 3 ps FWHM b) **100**/250/500 kHz: 6 ... 15 ps FWHM

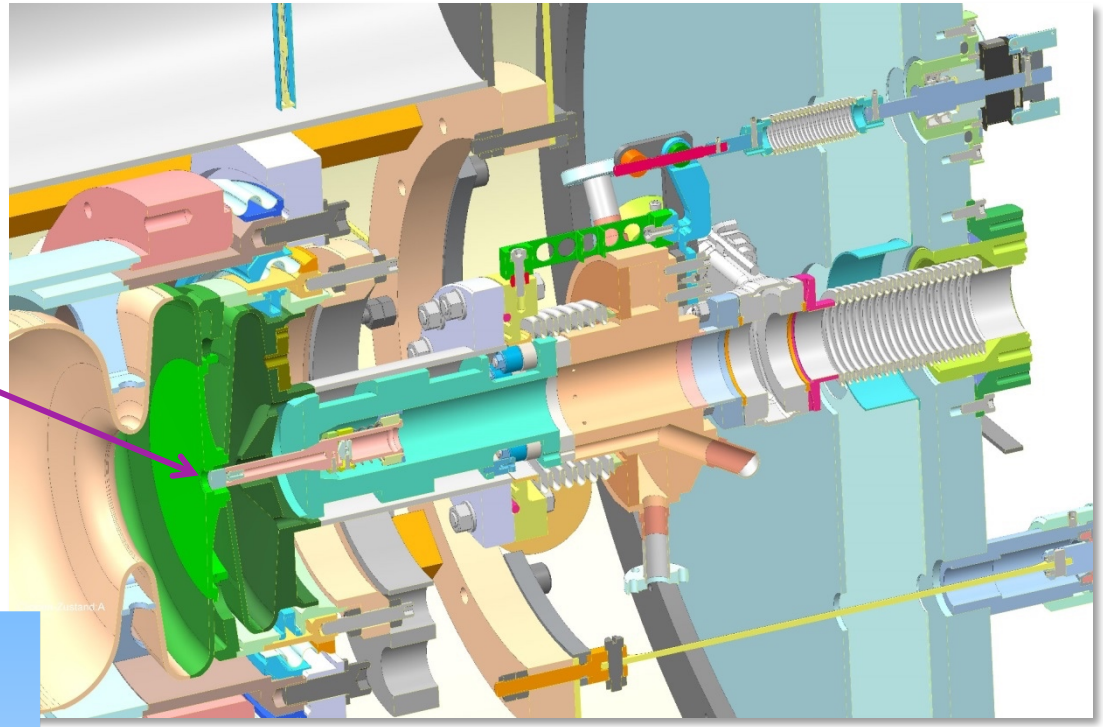
0.3-0.5 W / 0.02-0.04 µJ -> 80 pC @ 1 % QE

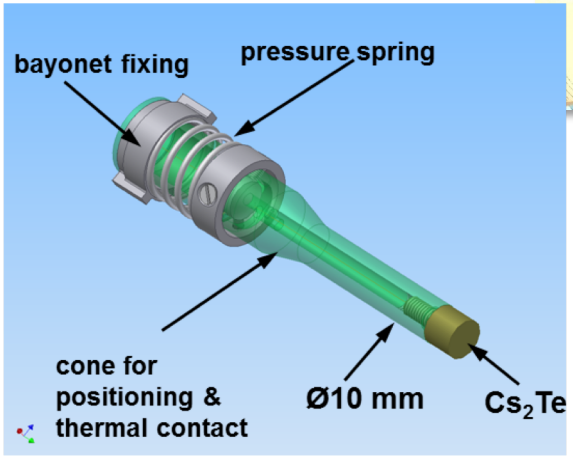
0.3-0.5 W / 3-5 µJ -> 1 nC @ 0.1 % QE



Introduction – NC Photocathodes in SRF Gun II

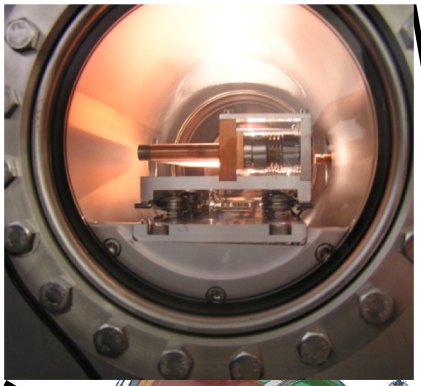
UV laser @ 263 nm



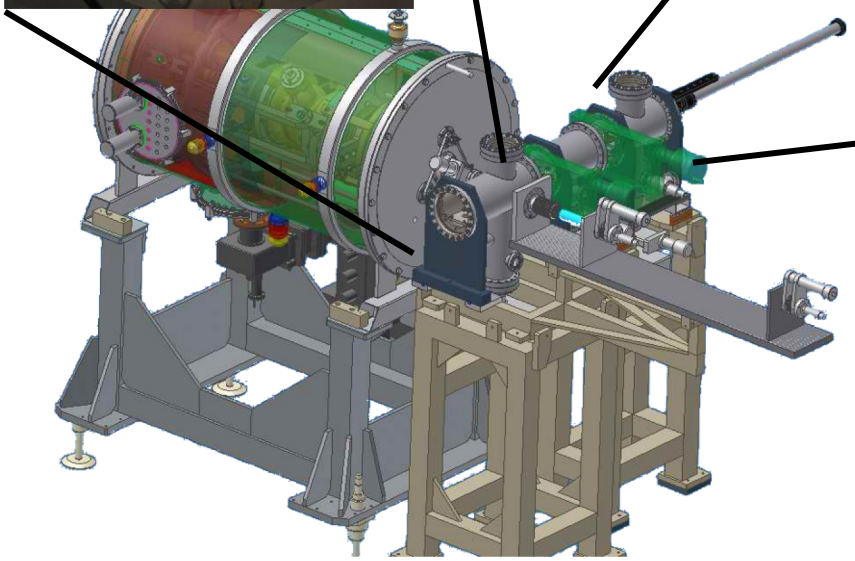


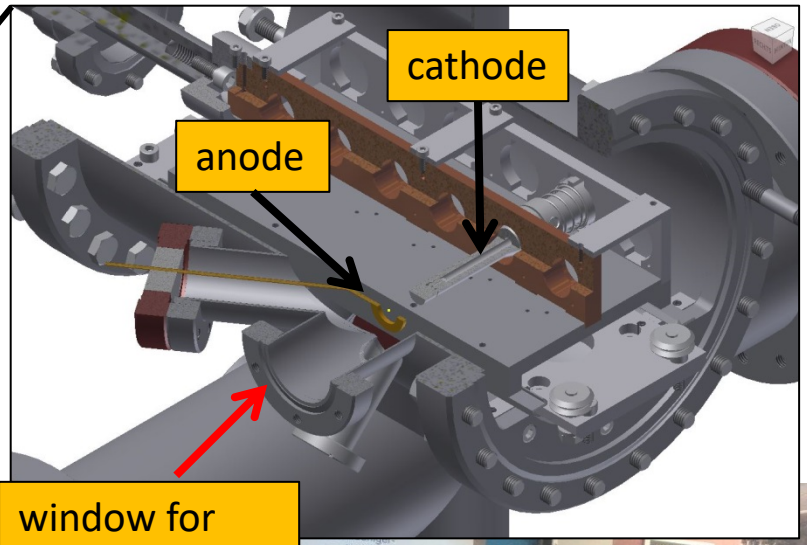
- normal conducting - low RF losses on axis
- vacuum gap - thermally and electrically isolated
- axis alignment (by hand)
- remote controlled positioning +- 0.6 mm range
- retracted RF focussing
- cathode exchange in cold gun

Introduction – NC Photocathodes in SRF Gun II



improved chamber
for PC quality checks





- Gun installation finished in May 2014
- Photo cathode exchange system ready in January 2015

Introduction – photo cathode history in SRF gun II

Type	Time	QE	Q / I_{cw}	Remarks
Cu	June 14 – Feb. 15	$2x10^{-5}$	3 pC / 300 nA	Inserted during clean-room assembly of the gun
Cs_2Te	Feb. 15	2 % ↓ 0 %		**strong multipacting** & field emission cavity polution
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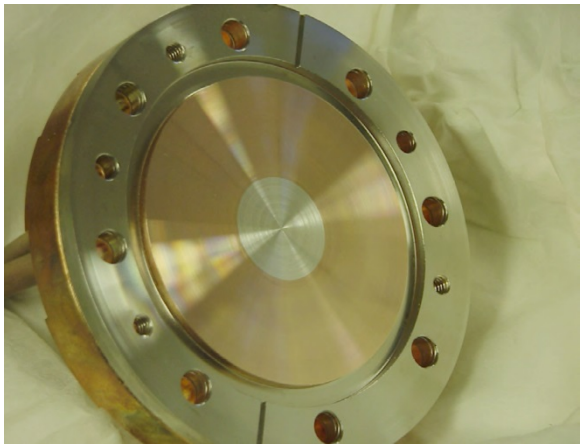
1. Mg photo cathodes - motivation

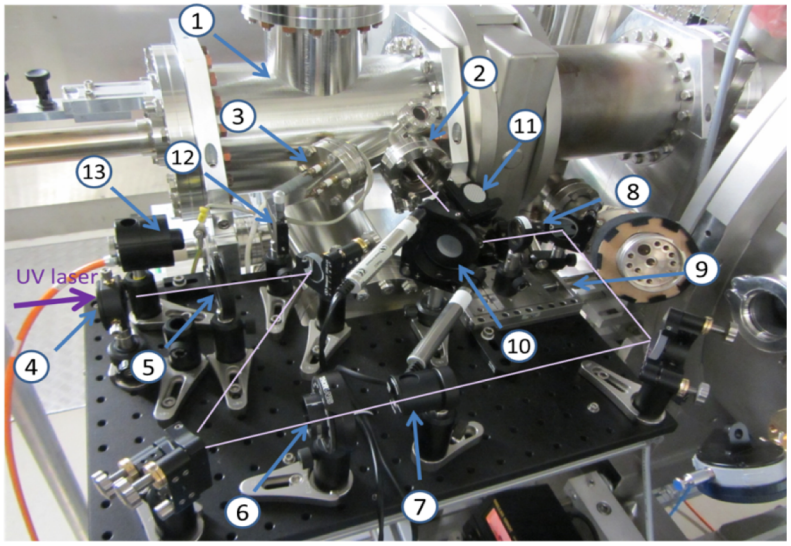
- Mg **has the highest QE** of a (machinable) metal of **0.2 %** @ 260 nm
  work fuction is 3.66 eV
- Oxide layer removal by in-situ ion beam sputtering, backing or laser cleaning
  (in transfer system of SRF Gun)
- excellent life time in UHV
- low dark current
- bulk material cathodes can be cleaned perfecty in clean room,
  no cavity contamination
- allow bunch charges up to 300 pC (limit of SRF gun II) with 30 µA (needs 75 mW laser at PC) and 100 kHz CW
  - user beam requirements for THz and neutron production at ELBE

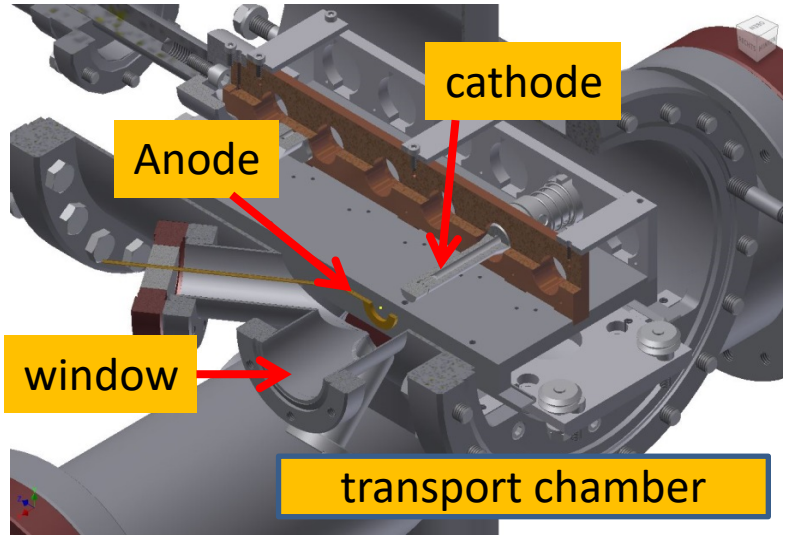


Mg photo cathodes in use in NC RF guns at BNL, Tokyo Uni.

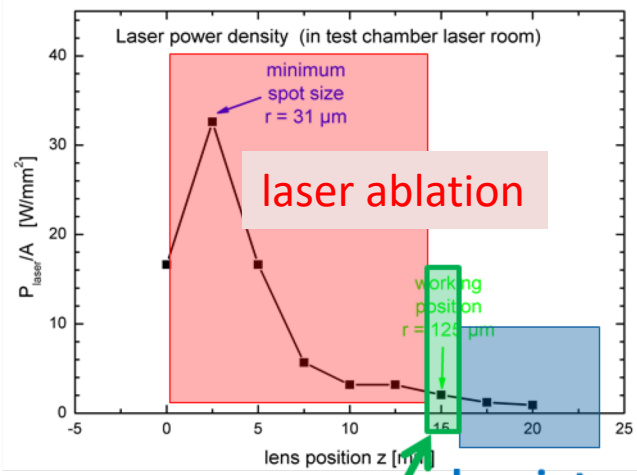
SRF gun Mg plugs

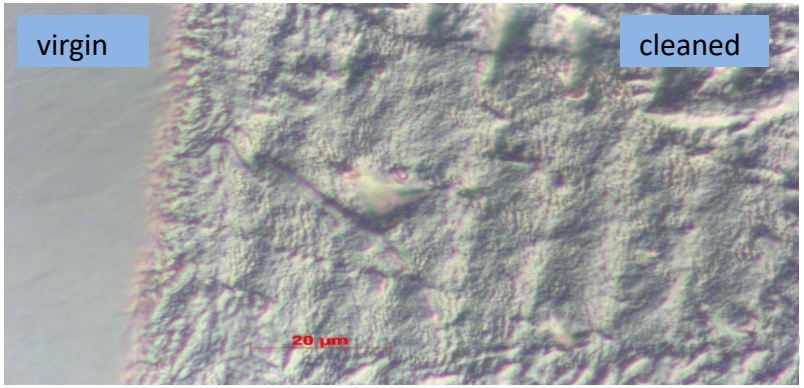
Mg Photocathodes – Laser Cleaning





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





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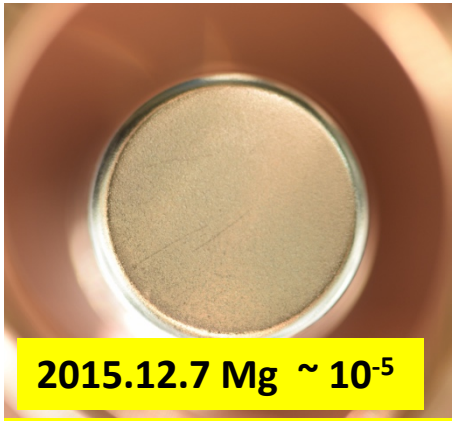
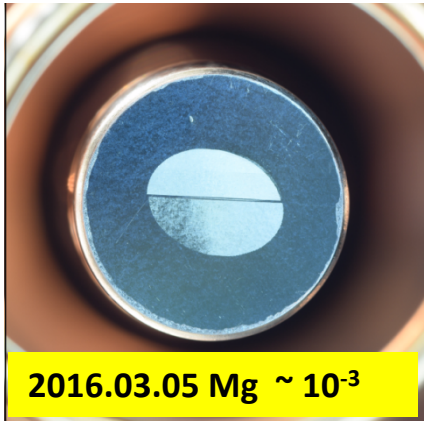
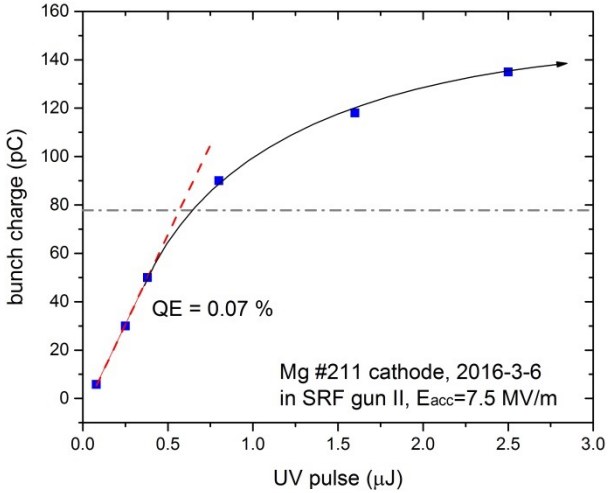
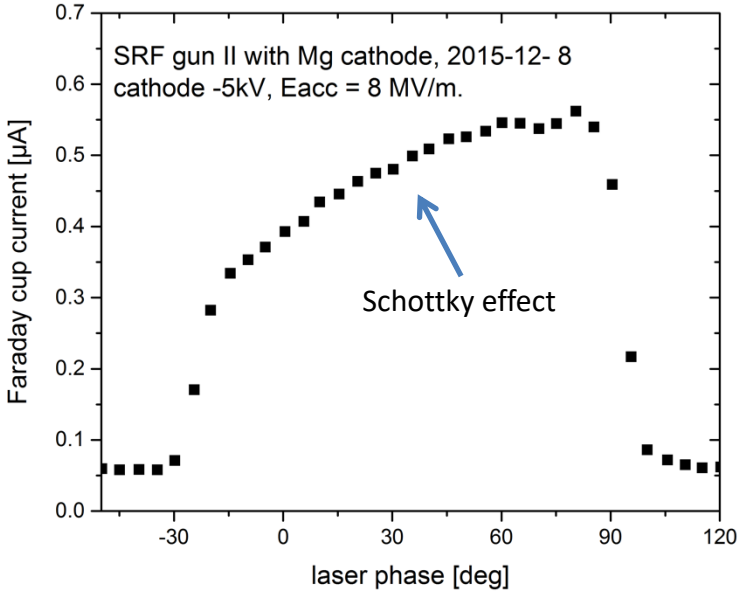
Mg photocathodes - in SRF gun II

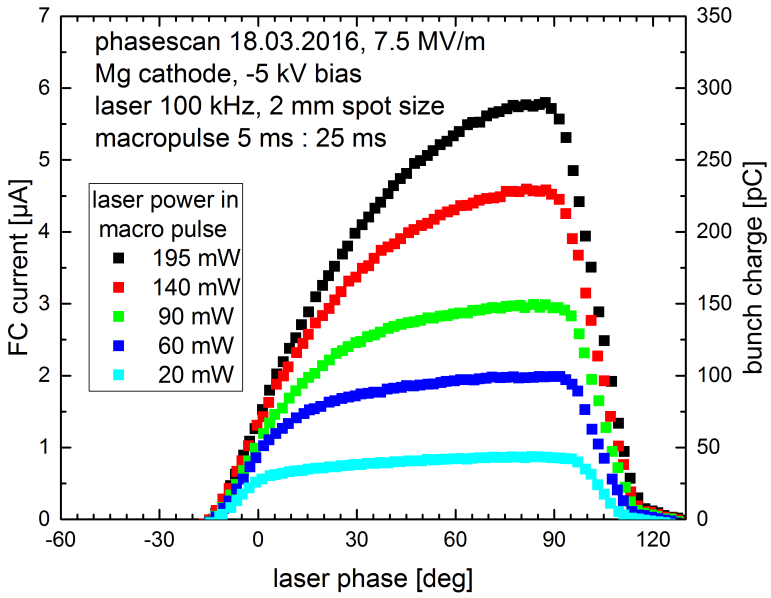
Laser phase scan and QE of Mg photo cathode in SRF gun





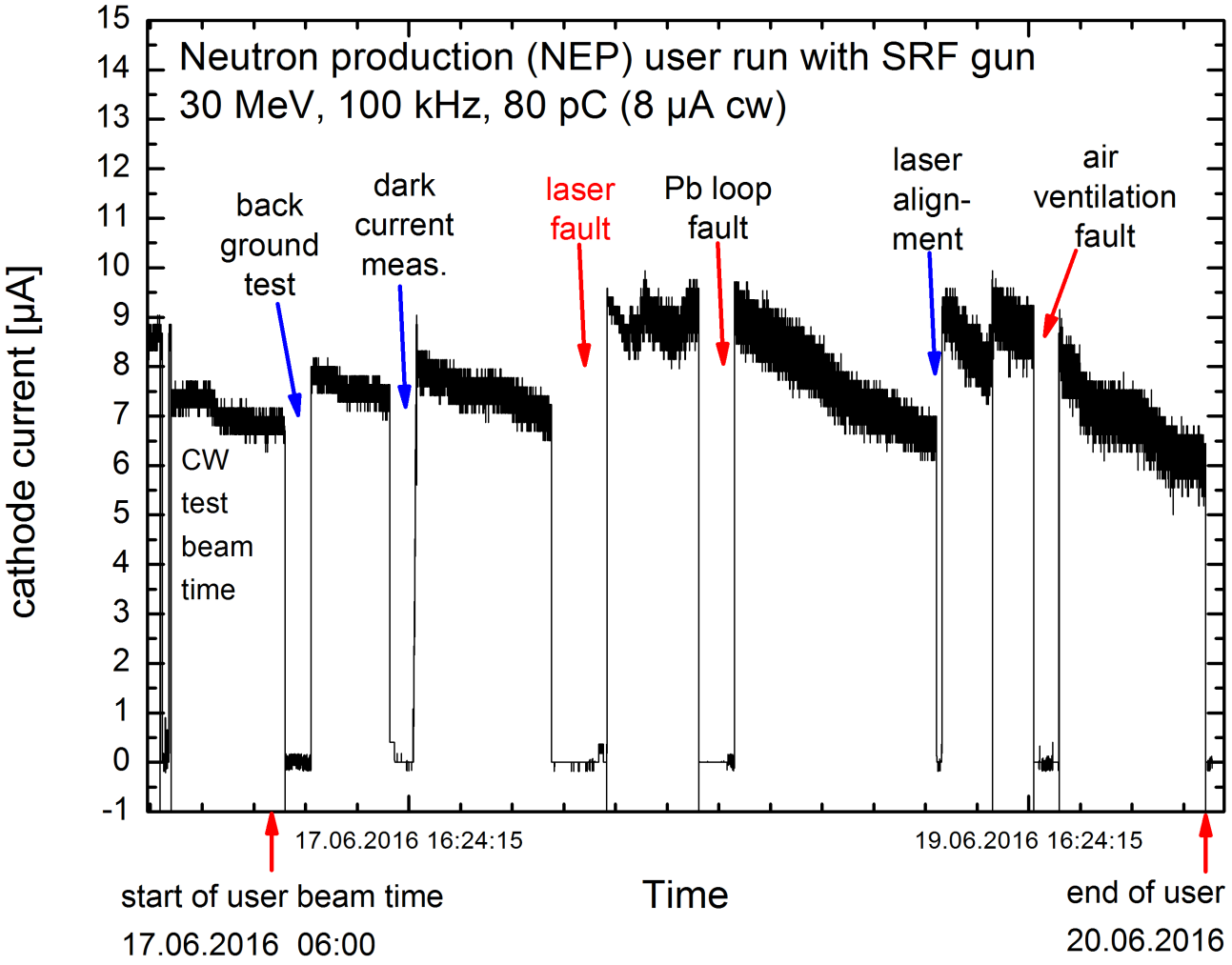






SRF gun for neutron production beam time in ELBE

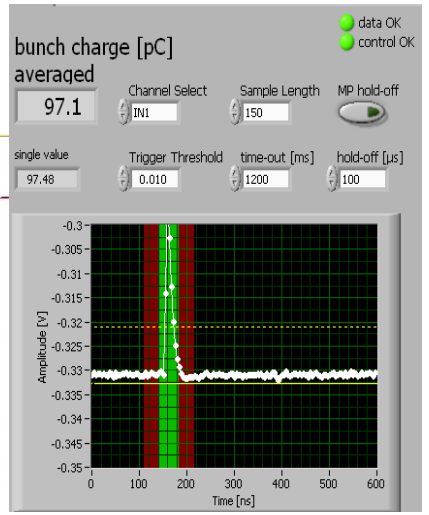
June 2016: successful 6 x 12 hours user shifts
limited by diagnose mode <10 µA for SRF gun in ELBE

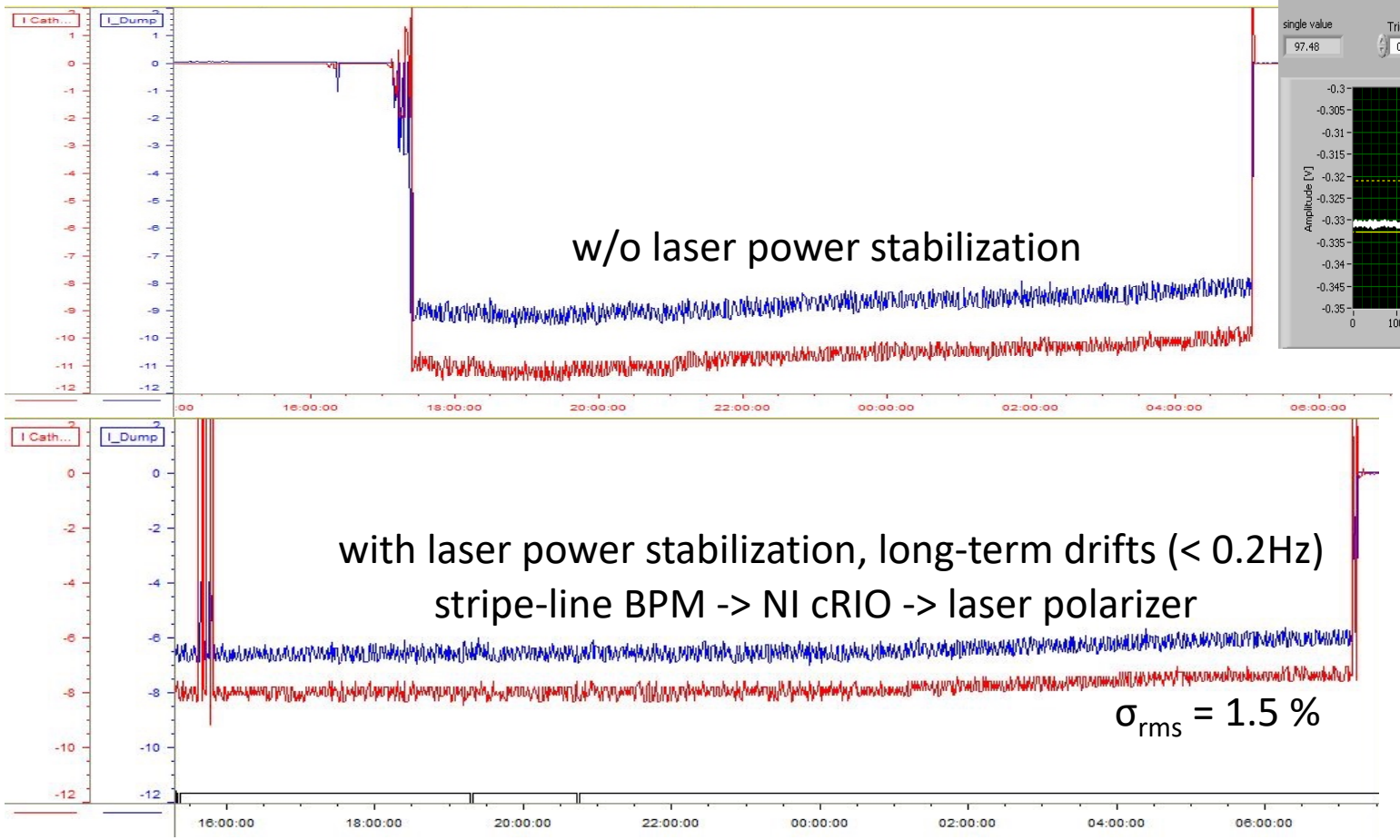


Mg photocathodes - in SRF gun II

Beam for the ELBE accelerator:
several 12h-shifts for user setting preparation, test, and measurement
with 100 kHz CW, 80 -100 pC

ICT in ELBE





w/o laser power stabilization

with laser power stabilization, long-term drifts (< 0.2Hz)
stripe-line BPM -> NI cRIO -> laser polarizer

σ_{rms} = 1.5 %

Mg cathode in gun March - August 2016, 270 h beam time, no QE decrease

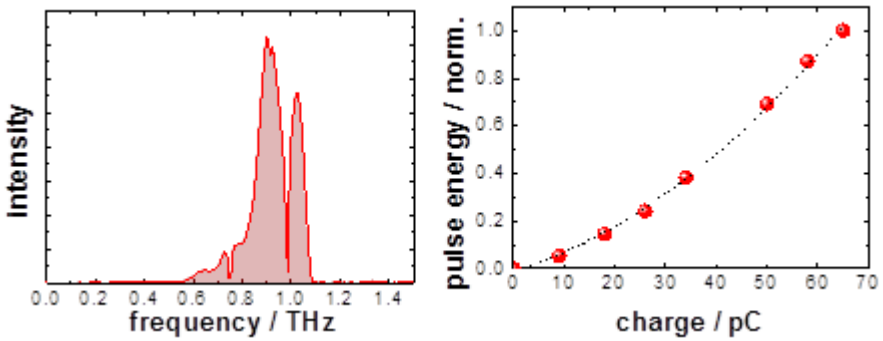
Mg photocathodes - in SRF gun II

see also
POSTER
A. Arnold et. al.

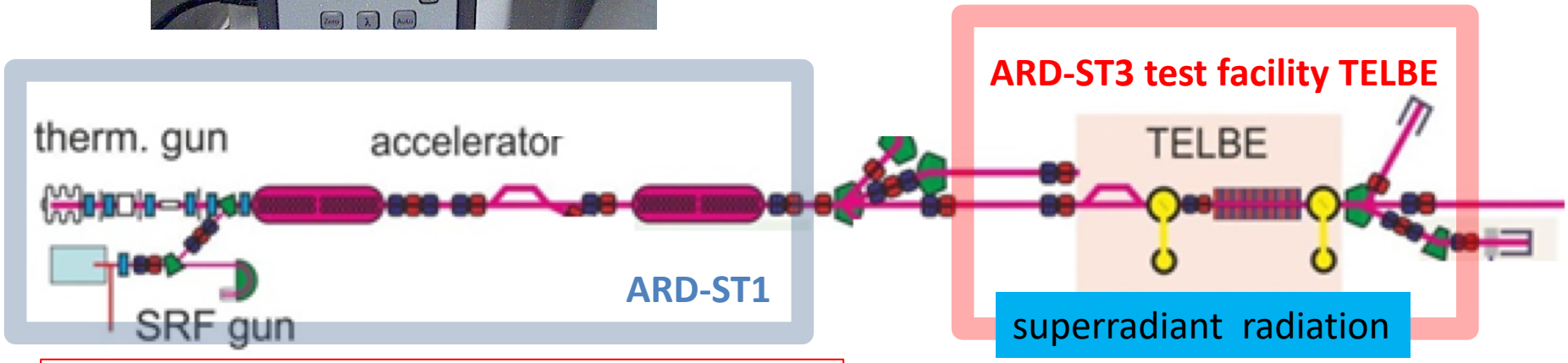
4 x 12 h user shifts for **THz radiation production**

- 80 – 100 pC, E_{kin} = 4 MeV, 100 kHz
- 10 mW @ 1 THz
  32 mW@ 0.5 THz
- next: shorter bunches wanted

THz spectrum and charge dependence



first THz radiation 3.12.2016!



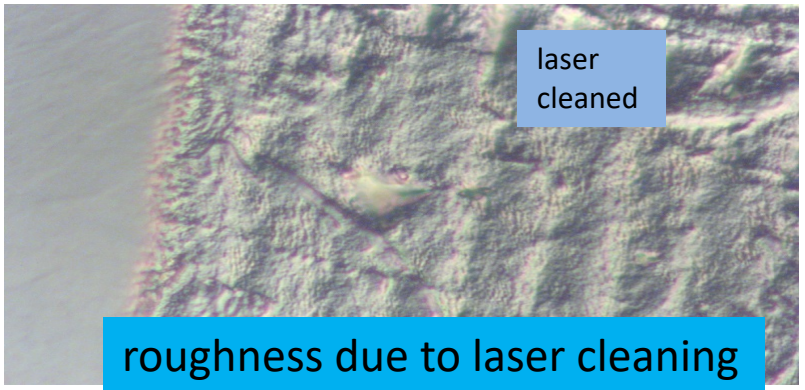
MuT /ARD Subtopics ST1 „SRF“ & ST3 „ps-fs“

DRESDEN concept HZDR

Mg Photocathodes – alternative cleaning methods

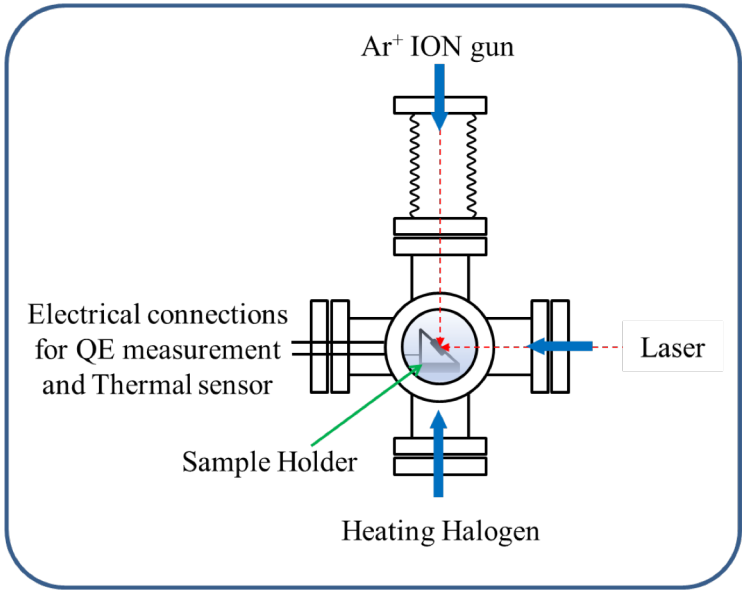
Methods for MgO layer removal

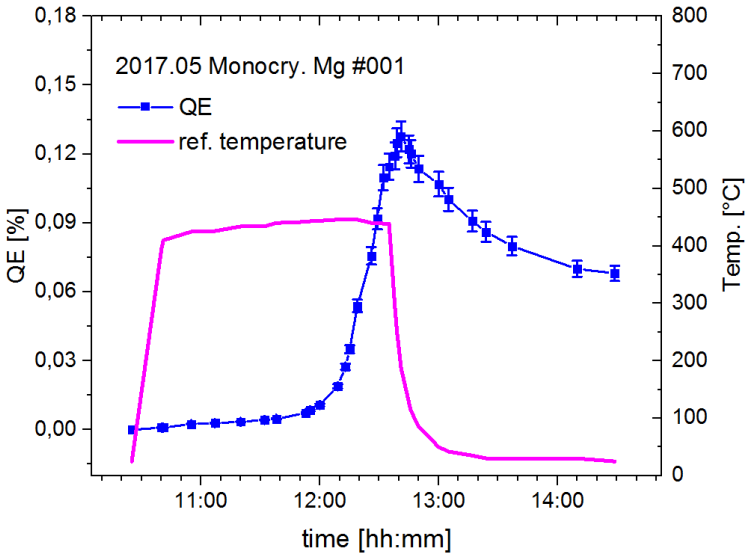
- laser cleaning
- heat cleaning
- ion beam sputtering



roughness due to laser cleaning increases thermal emittance

heating of Mg plugs in test chamber

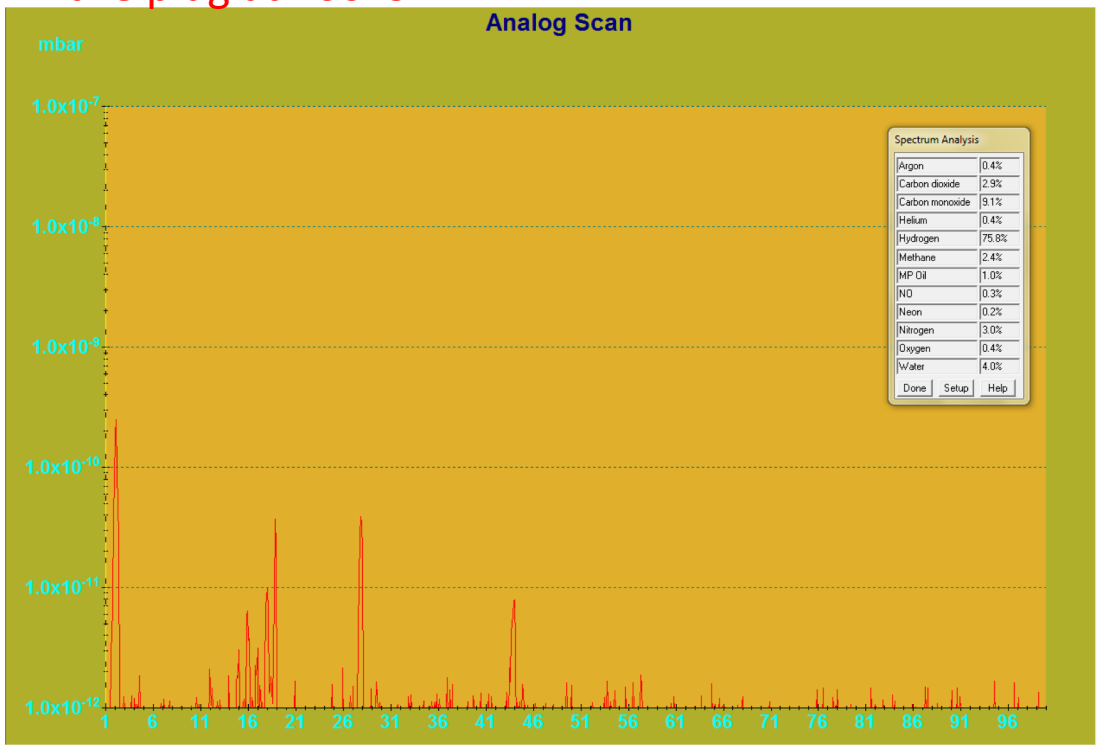


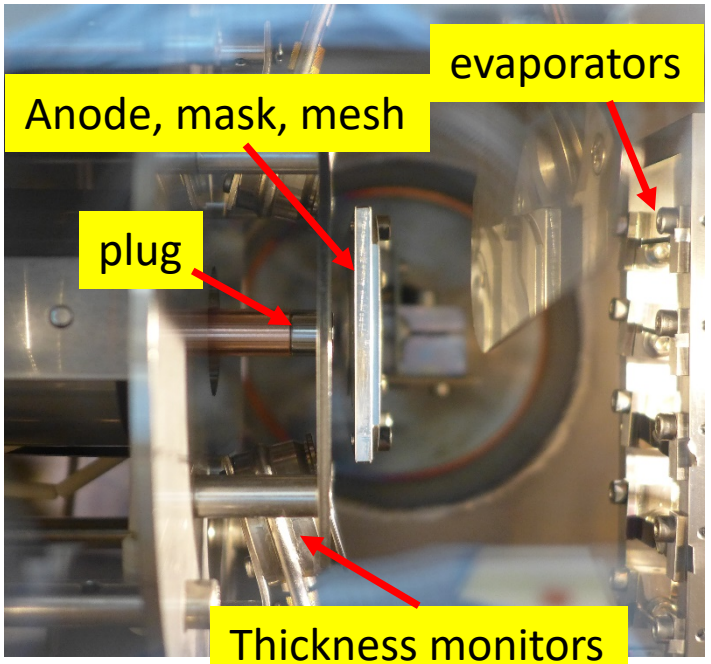


Cs_2Te photocathodes – preparation system

Upgrate of Cs2Te preparation system

dry-ice cleaning of cathode body and plug
Improve vacuum 10^{-9} mbar -> 10^{-10} mbar
Remove particle sources & hydrocarbon sources
low Cs polution of cathode body, ϕ 4 mm mask
Bake plug at 400°C





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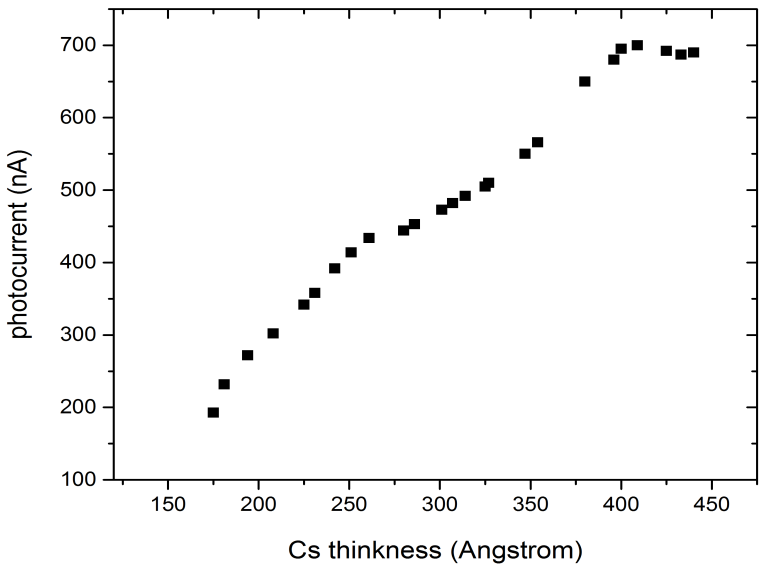

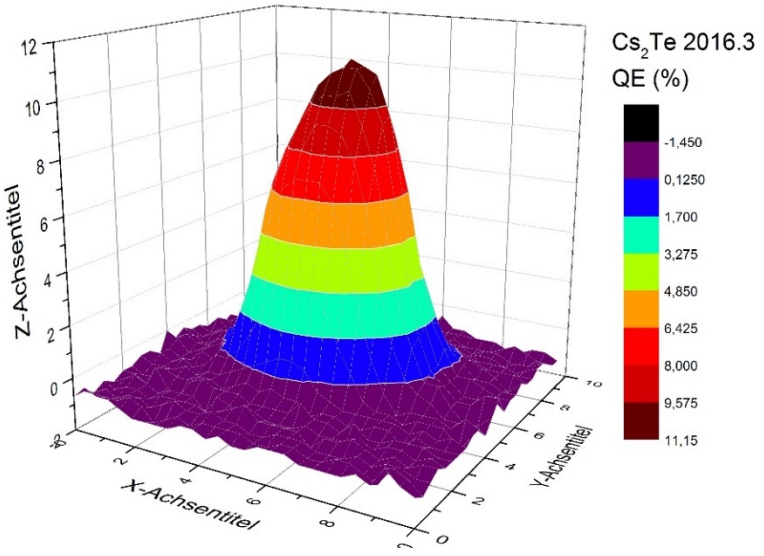

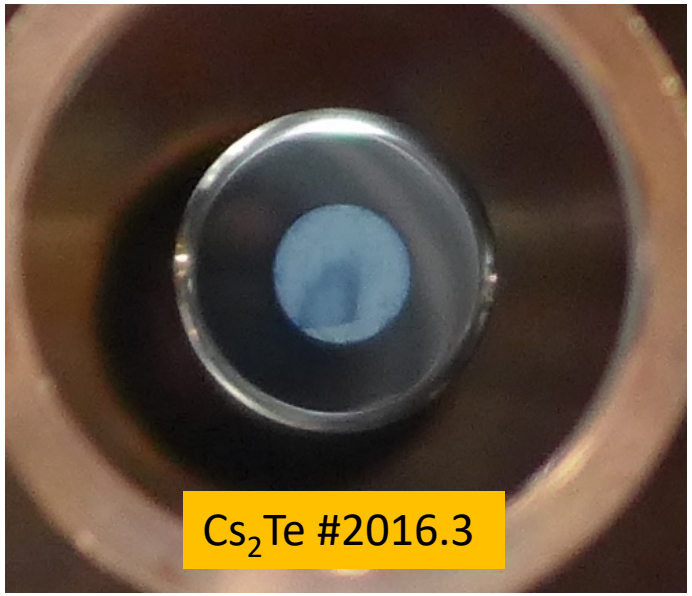

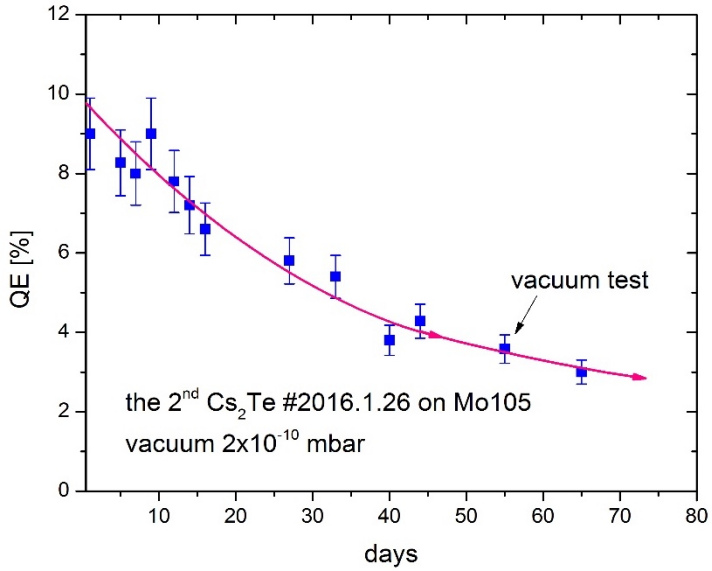

Introduction – photo cathode history in SRF gun II

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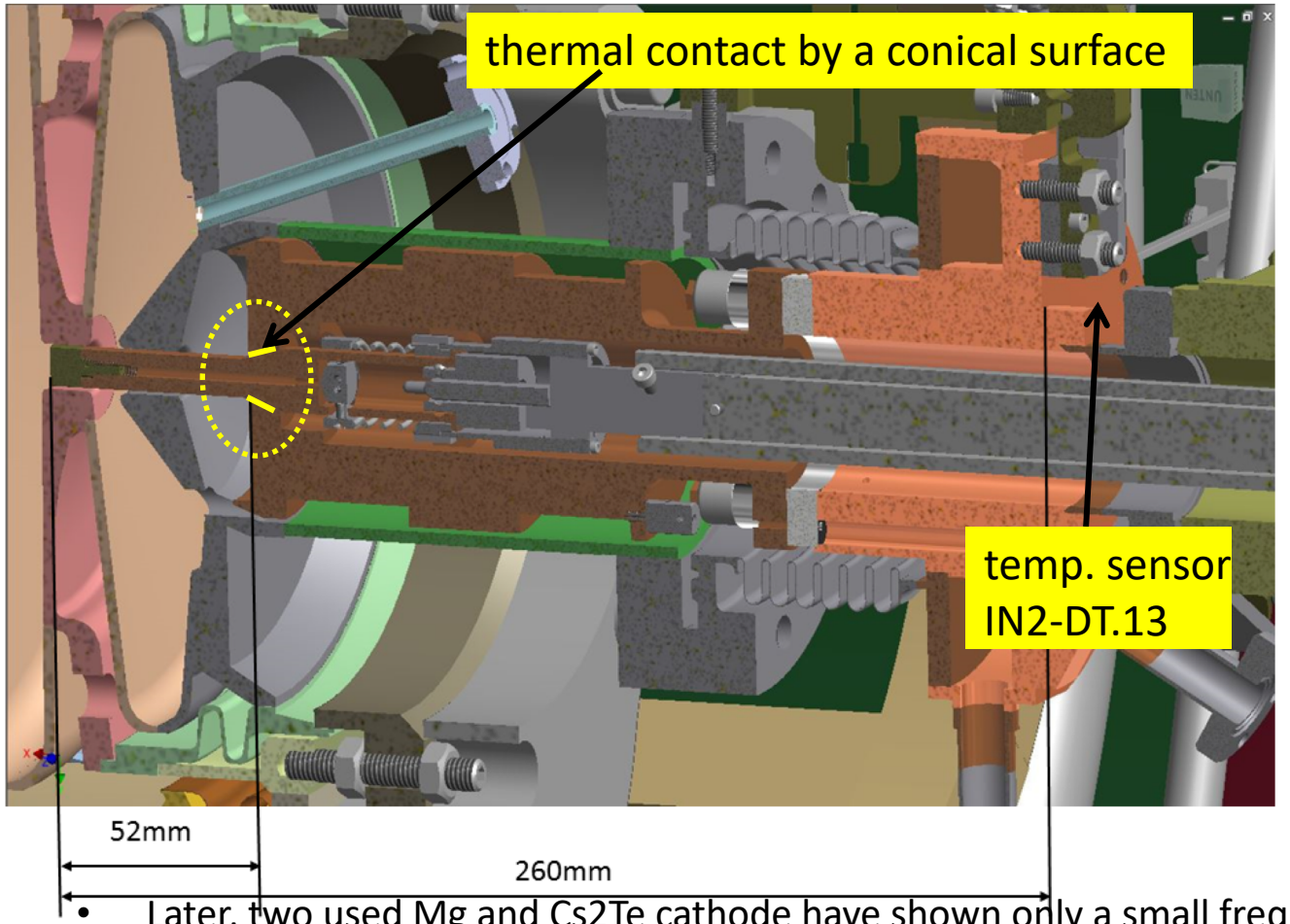
Cs_2Te photocathodes – operation in SRF Gun II

cathode position



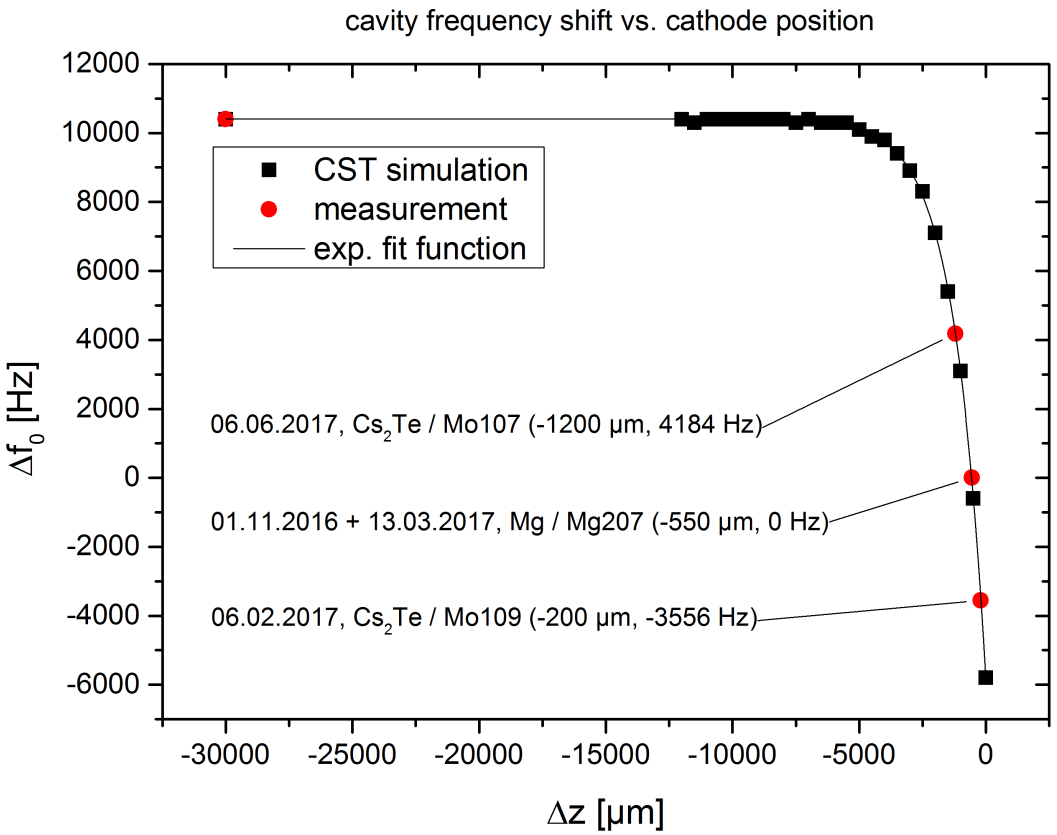
defines
- beam optics - RF focusing
- RF field strength at cathode

depends on
cathode plug length
assembly of cold mass
difficult to adjust & measure during assembly

- Later, two used Mg and Cs2Te cathode have shown only a small frequency drift (<100 Hz), which indicated a proper thermal contact and sufficiently cooled cathodes!

Cs_2Te photocathodes – operation in SRF Gun II

cathode position measurement

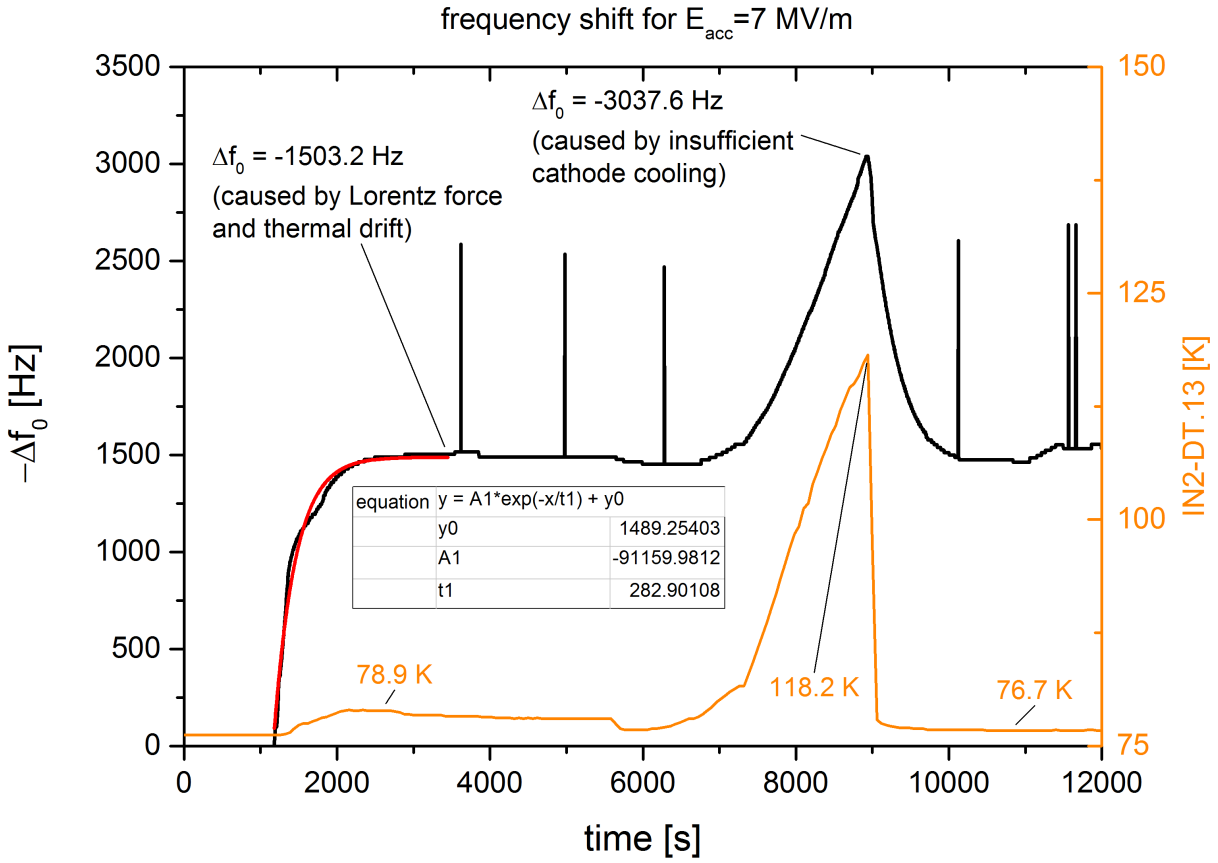


Comparison of the simulated frequency shift with the measured frequency shift after inserting a photo cathode of a certain length into the SRF gun

Cs_2Te photocathodes – operation in SRF Gun II

frequency drift due to cathode heating

- we observed frequency drifts than are not caused by Lorentz force detuning, but can be explained by thermal expansion of the cathode due to RF heating



1th drift
LF detuning (-630 Hz) plus thermal expansion (-870 Hz)
temperature rise of +120 K
RF heat loss of ~16 W

2nd drift
thermal expansion only (-1.5 kHz)
problem of LN2 cooling
length change +170 µm

heating up destroyed the QE of the cathode, a proper thermal contact is needed

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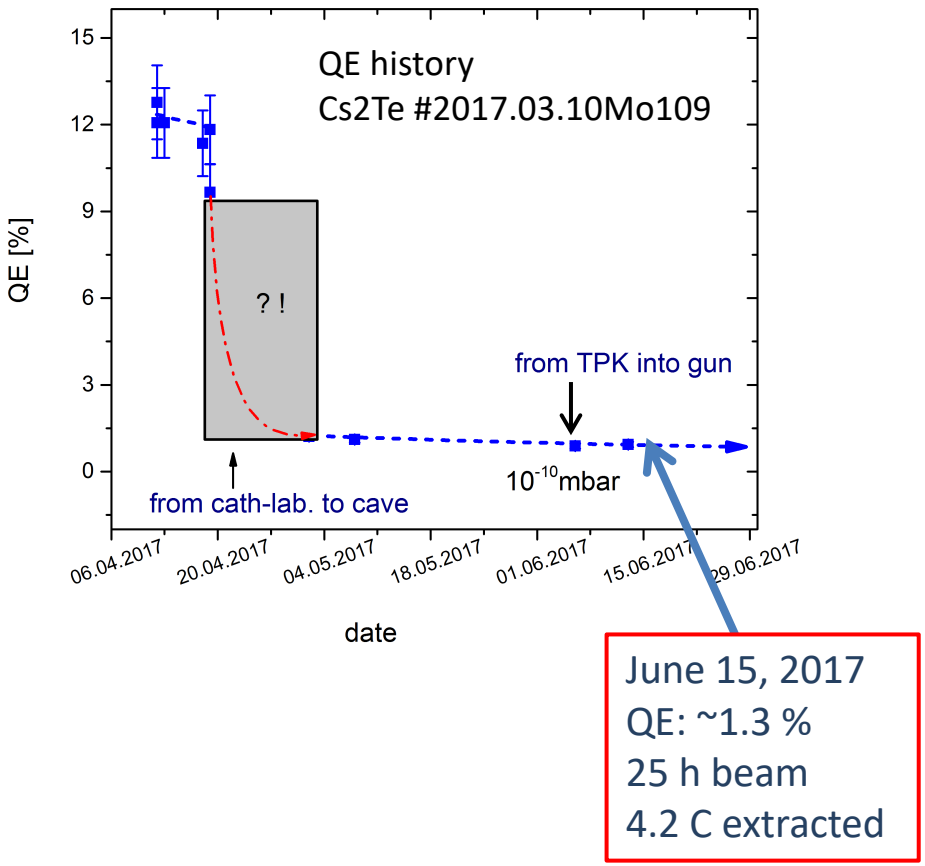
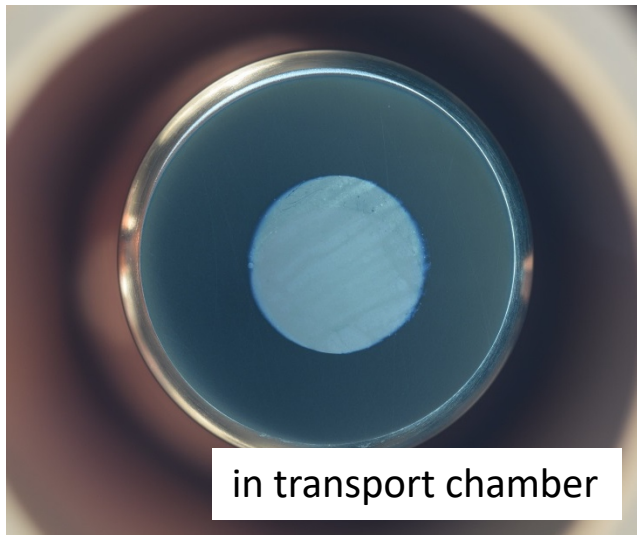
Cs_2Te	Feb. 15	2 % ↓ 0 %		**strong multipacting** & field emission cavity polution
Cu	Mar. 15 – Feb. 16	$2x10^{-5}$	3 pC / 300 nA	high dark current from cavity, no multipacting
Mg (#201)	Mar. 16 – Aug. 16	0.2 %	200 pC / 20 µA	no multipacting, no dark current from Mg, stable (user) operation, no QE decrease
Mg (#207)	Nov. 16 – Dec. 16	0.1 %	80 pC / 8 µA	no multipacting, no dark current from Mg, stable (user) operation, no QE decrease
Cs_2Te	Feb. 17	1.7 %	300 pC / 30 µA	no multipacting, no dark current from PC, **QE drop down after 2 weeks**, overheating
Mg (#207)	Mar. 17 – May 17	0.2 %	150 pC / 15 µA	cathode laser cleaned 3rd time, stable beam operation
Cs_2Te	since June 17	1.3 %	15 pC / 200 µA	13 MHz CW no multipacting, no dark current from PC prelimary results after 1 week

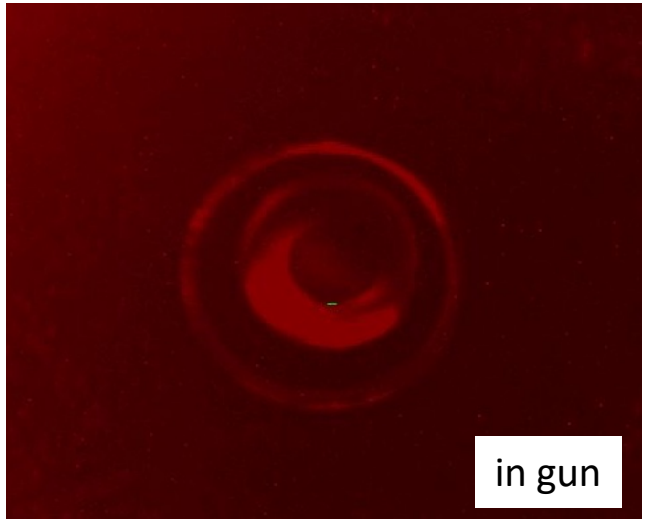
Cs_2Te photocathodes – in SRF Gun II

June ´17 Cs2Te 2017.03.10Mo109



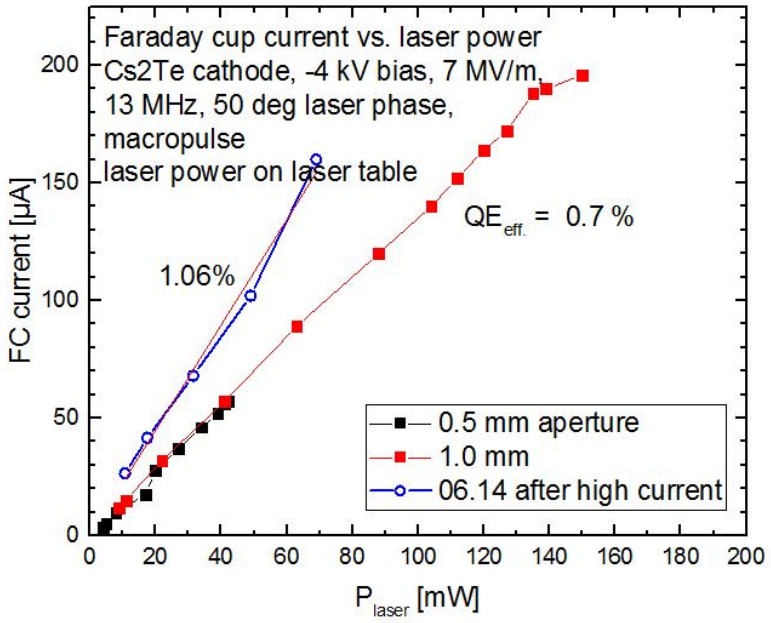
June 15, 2017
QE: ~1.3 %
25 h beam
4.2 C extracted

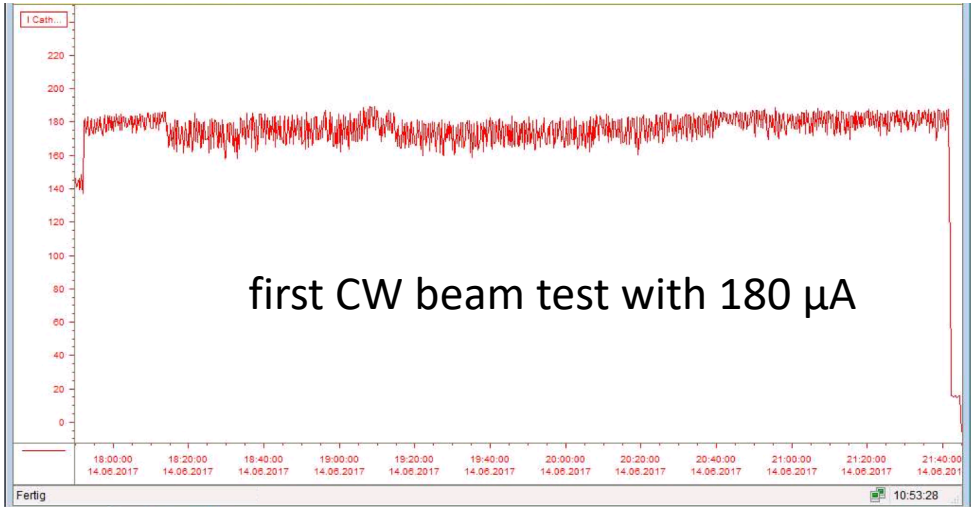


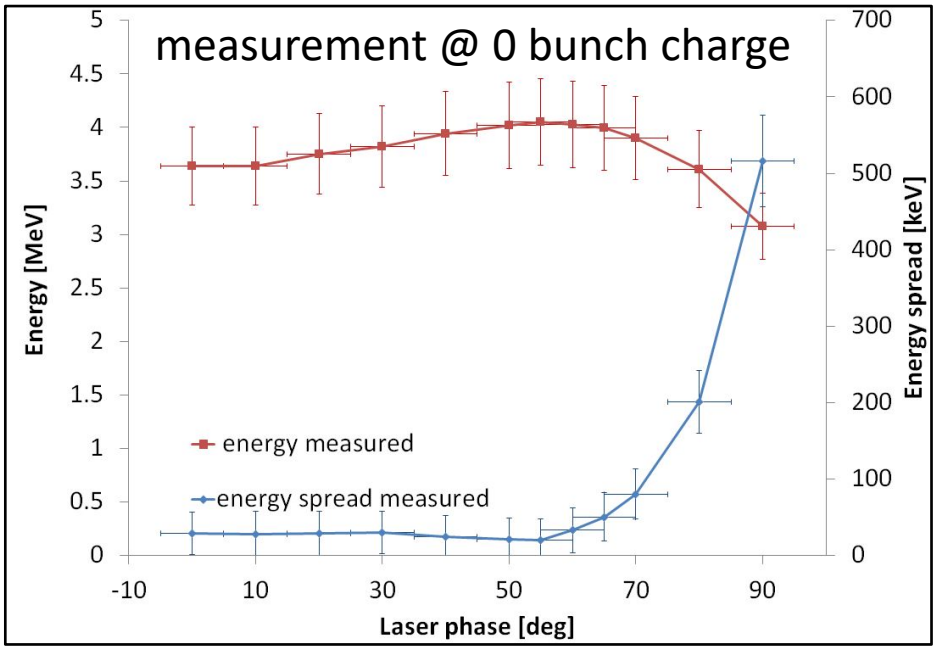


Cs_2Te photocathodes – in SRF Gun II

June ´17 Cs2Te 2017.03.10Mo109



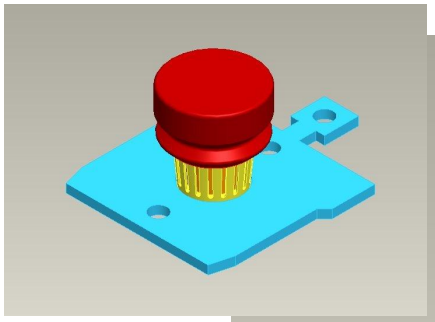


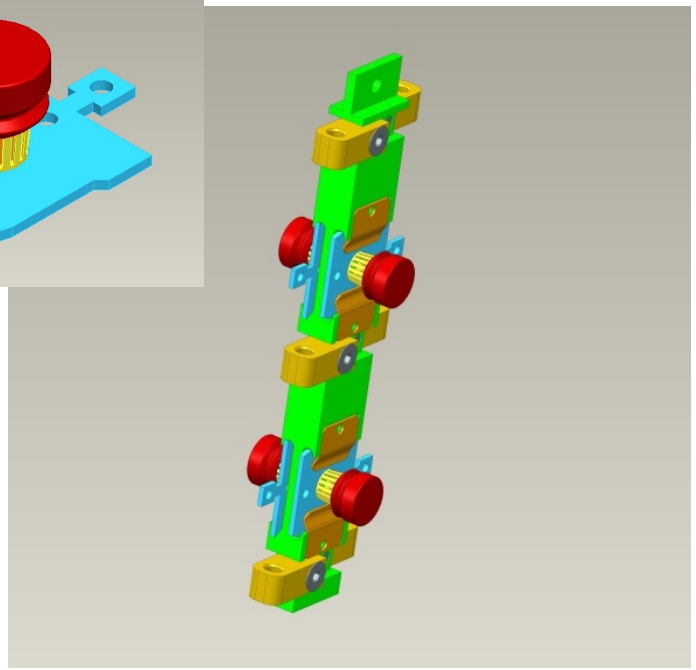


Cs_2Te photocathodes – future transfer system

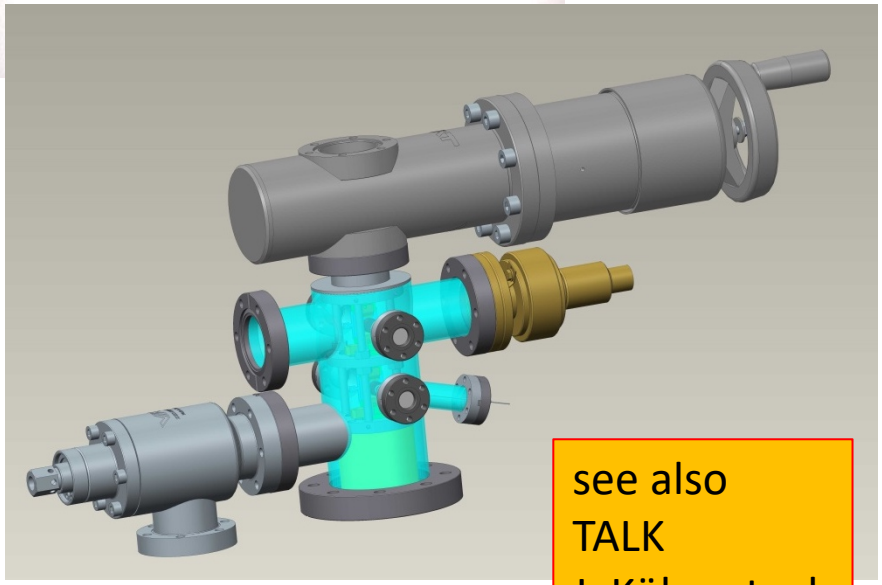
PCHB cooperation – HZB, HZDR, JGU Mainz

New cathode structure (HZB style).





New cathode plug carrier (green). The plugs are fixed with CuBe springs (in yellow) on the flags (in fabricating).



see also
TALK
J. Kühn et. al.

Summary

- Normal contacting photo cathodes operate successfully in SC cavities
- Photocathode exchange and operation are a high risk for cavity contamination
  - careful quality check of cathodes
  - improved mechanics to avoid particle production
- Metallic photocathodes can easily be used in SC cavity
  - Mg can reach high QE of 10^{-3} , suitable for current application < 100 µA
  - no multipacting and low dark current (<10 nA)
  - robust and easy in handling
  - stable long-term operation for users
- Medium and high currents require semiconductor photocathodes
  - Cs2Te + UV light is still our choice for medium currents (1 mA)
  - multipacting could be prevented – no Cs polution of side walls
  - thermal contact and cooling essential for PC lifetime
  - Cs2Te PCs still have a storage lifetime problem
    vacuum or polution of plugs and evaporator sources?
  - QE drop down problem during transport must be solved

Thank you for your attention!

Thanks to the ELBE team

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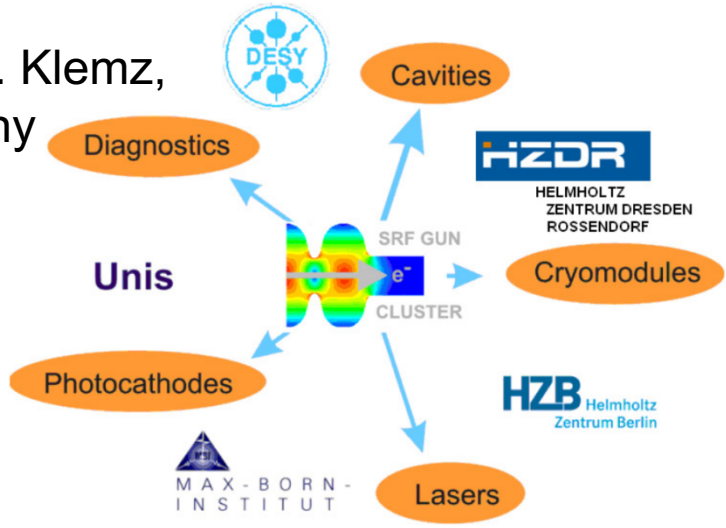

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