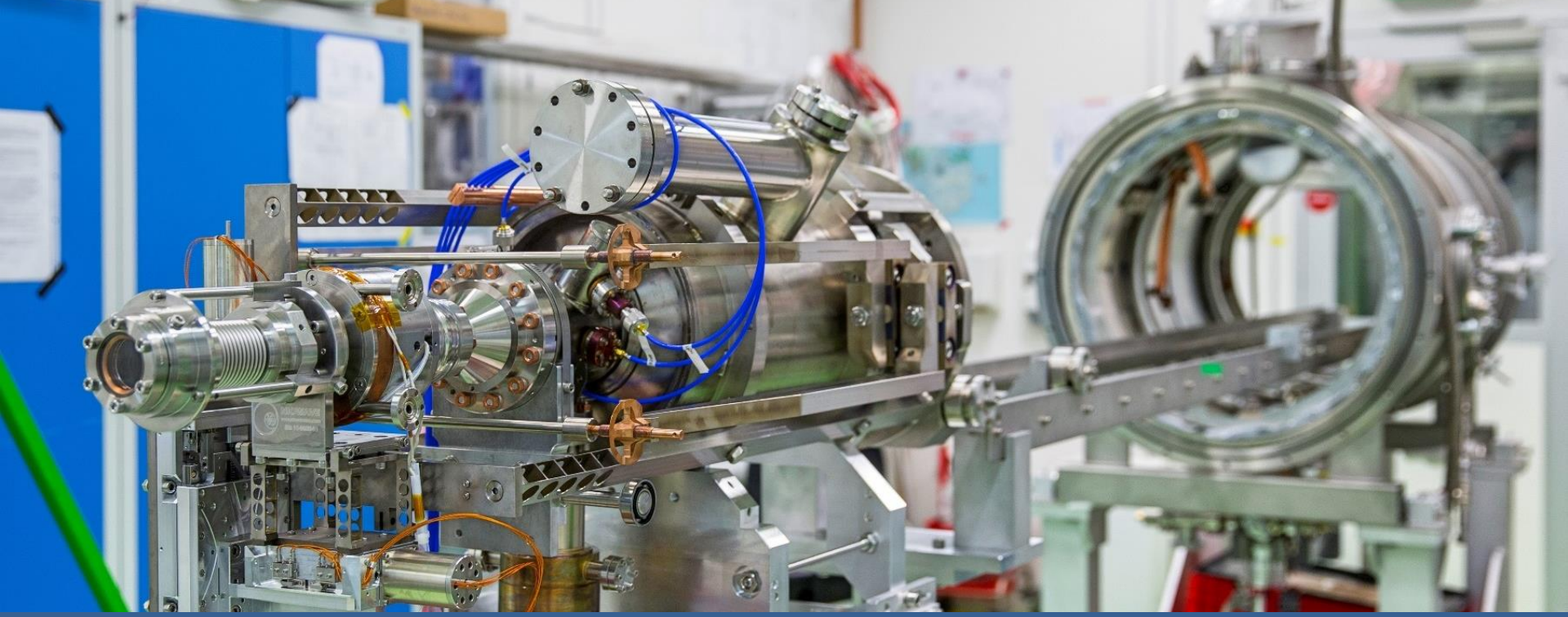


Semiconductor cathodes in SRF guns
Cathode challenges and update for cathode operation in SRF guns

Jochen Teichert & Rong Xiang

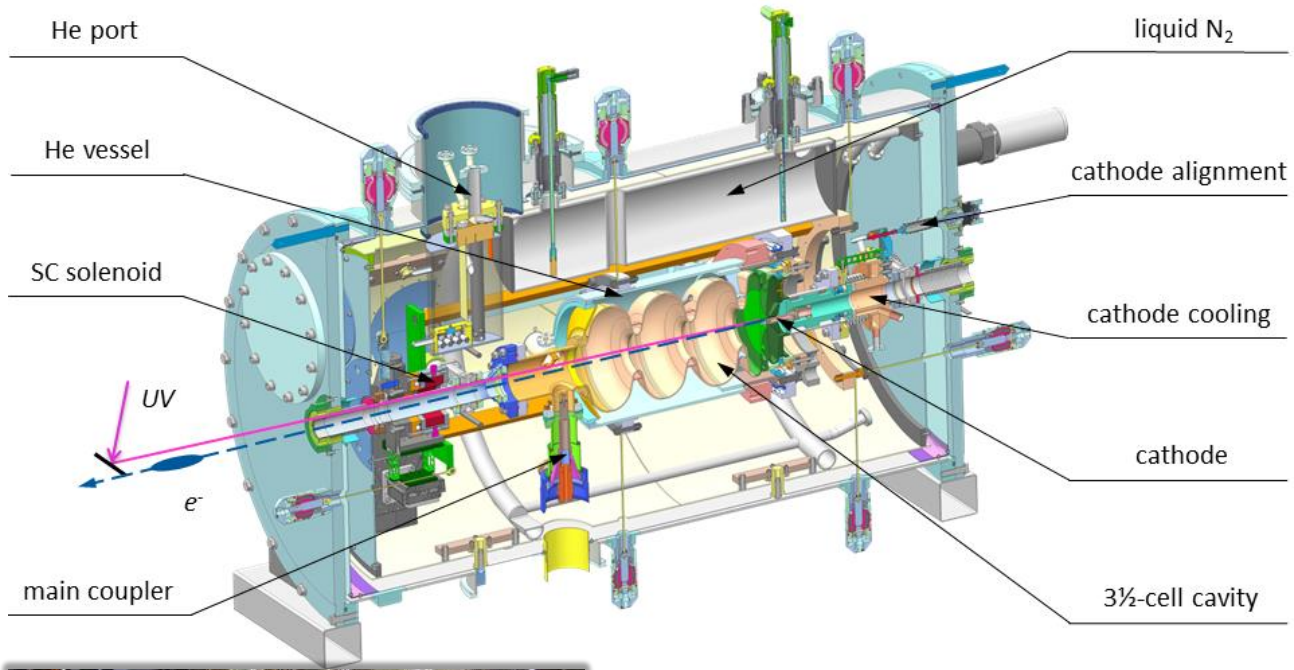
on behalf of the SRF Gun Crew at ELBE

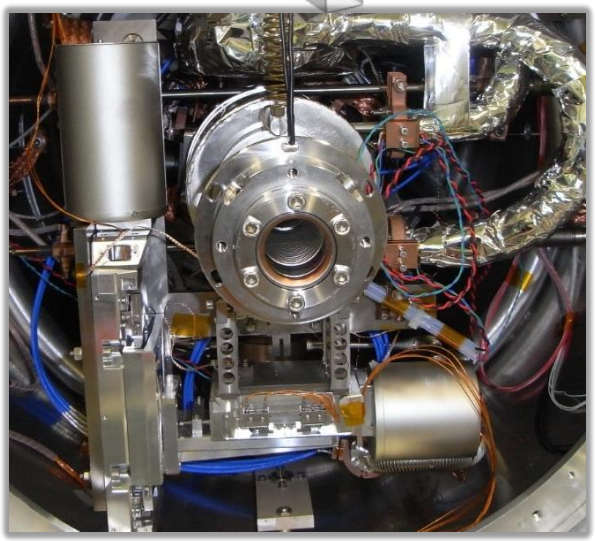
P3 Workshop, Jefferson Lab, Oct. 17-19, 2016

Outline

1. ELBE SRF Gun II
2. Mg & Cs_2Te Photocathodes
3. Multipacting & Dark Current
4. Summary

ELBE SRF Gun II - Cryomodule

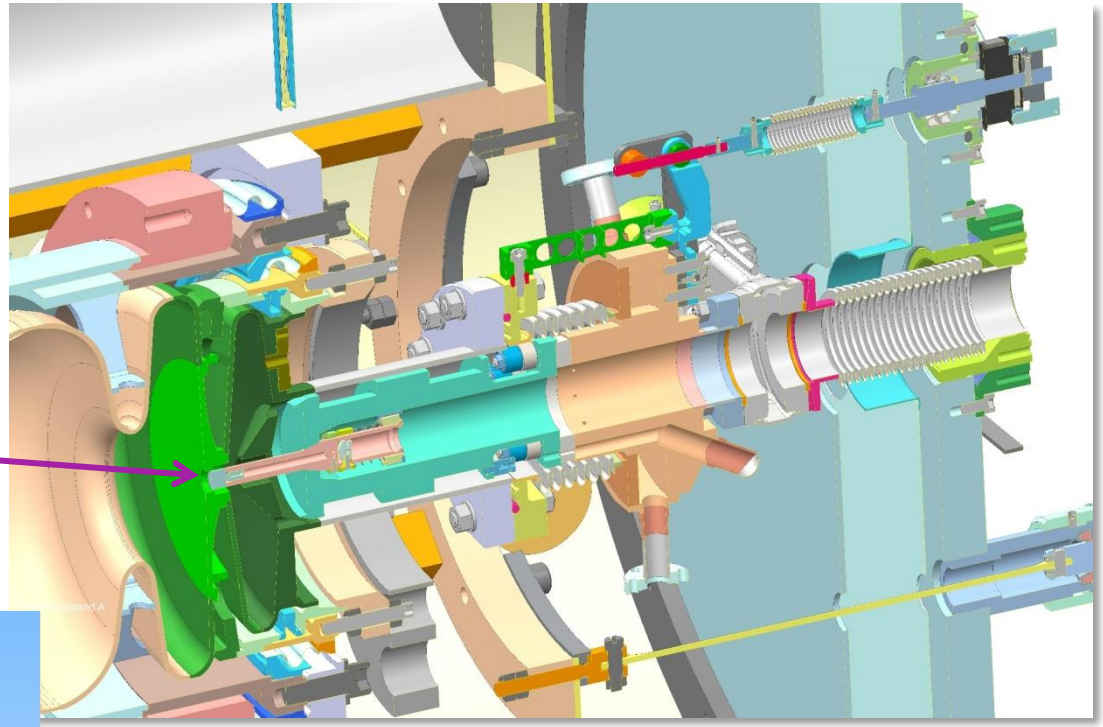


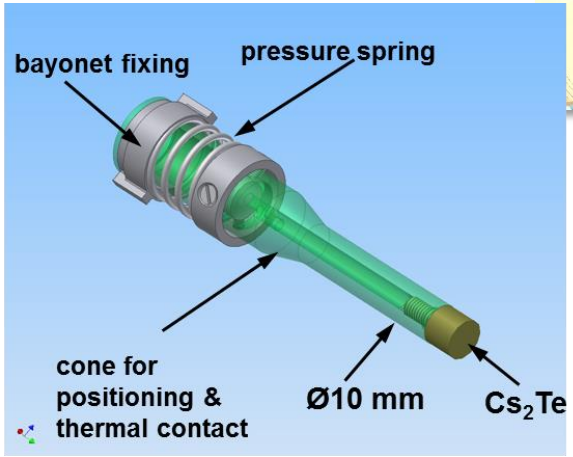


- New cavity - fine grain Nb, produced, treated, tested at JLab
- New cryomodule
  10 cm longer, fabricated and assembled at HZDR
- Integration of a superconducting solenoid

ELBE SRF Gun II – Photocathode

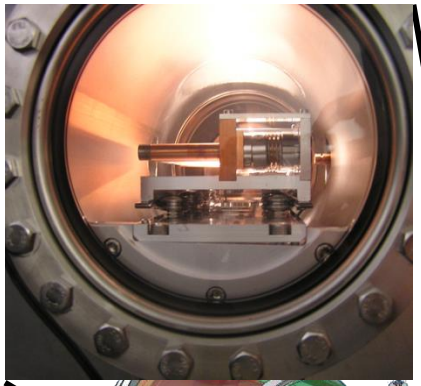
UV laser @ 258 nm
0.5 W CW
100 kHz, ≤ 5 µJ
Gaussian 12 ps FWHM



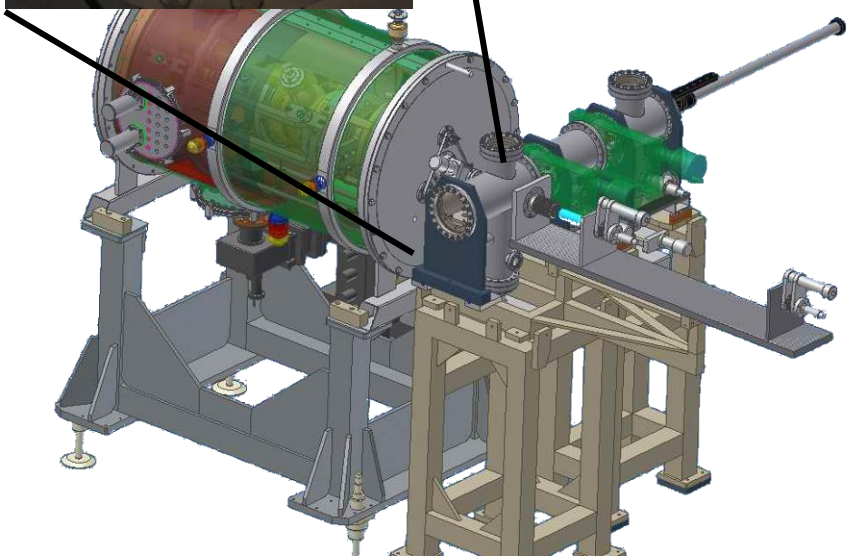


- normal conducting - low RF losses on axis
- vacuum gap - thermally and electrically isolated
- axis alignment (by hand)
- remote controlled positioning +- 0.6 mm range
- retracted RF focussing
- cathode exchange in cold gun

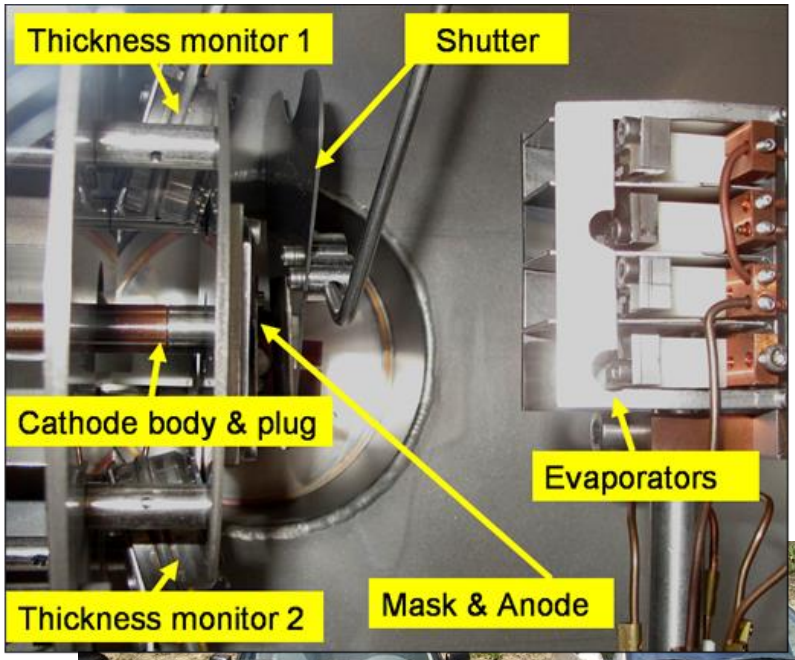
ELBE SRF Gun II – Photocathode



refurbished
cathode exchange
system of SRF Gun I



Cs_2Te preparation system

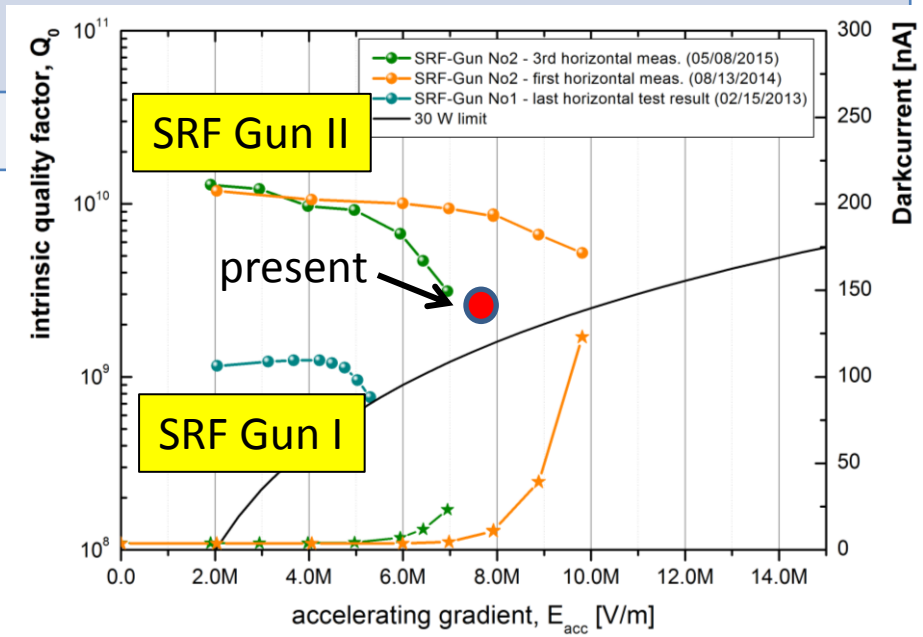


- Gun installation finished in May 2014
- Photo cathode exchange system ready in January 2015

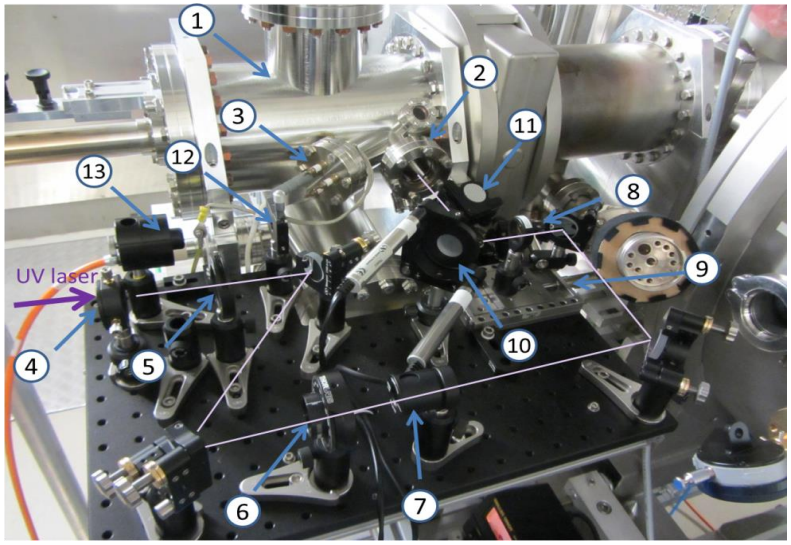
ELBE SRF Gun II – Photo cathode history

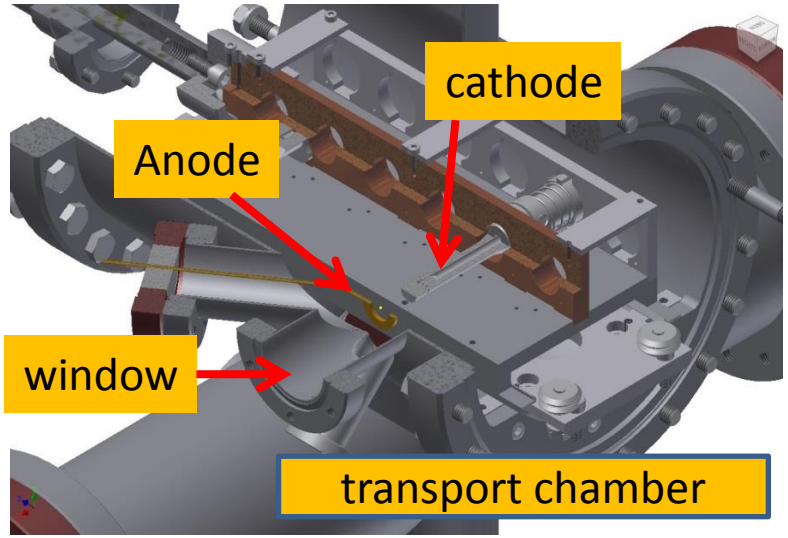
Type	Time	QE	Q / I_{cw}	Remarks
Cu	June 14 – Feb. 15	$2x10^{-5}$	3 pC / 300 nA	Inserted during clean-room assembly of the gun
Cs_2Te	Feb. 15	2 % ↓ 0 %	0	strong multipacting & field emission cavity polution
Cu	March 15 – Feb. 16	$2x10^{-5}$	3 pC / 300 nA	high dark current from cavity, no multipacting
Mg	March 16 – Aug. 16	0.2 %	200 pC/ 20 µA	no multipacting, no dark current from Mg, stable (user) operation, no QE decrease
Mg	Oct 16 – Dec. 16			
Cs_2Te	Feb. 17 ->			

Present gun operation
8 MV/m acc. gradient
20.5 MV/m cavity peak field
12 MV/m field at cathode
4 MeV kinetic energy

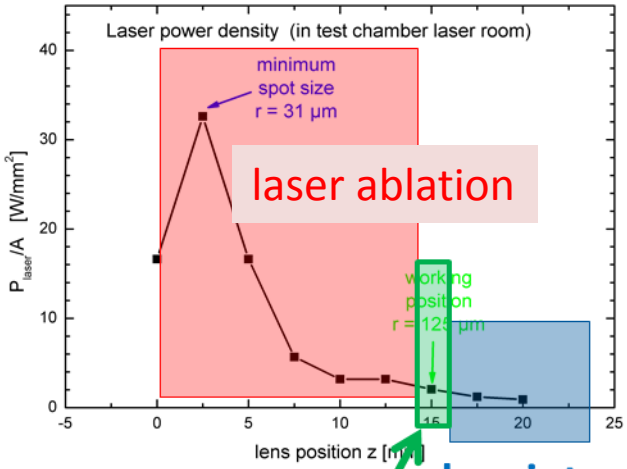


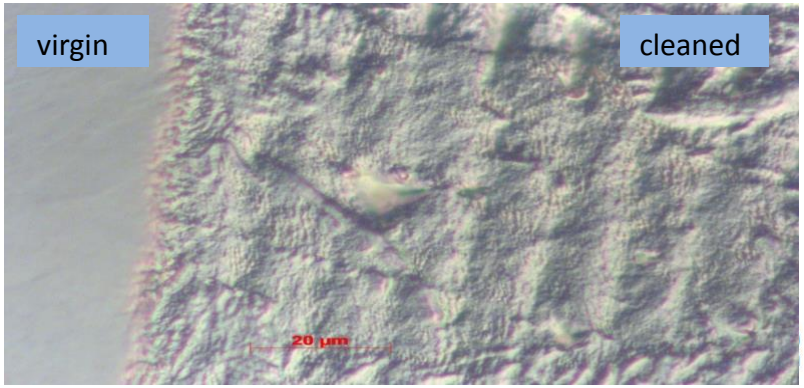
Mg Photocathodes – Laser Cleaning





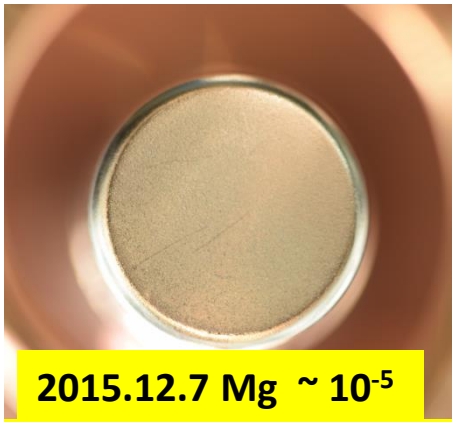
Laser cleaning set-up at transport chamber at SRF gun
using the UV drive laser (100 mW, 100 kHz CW)

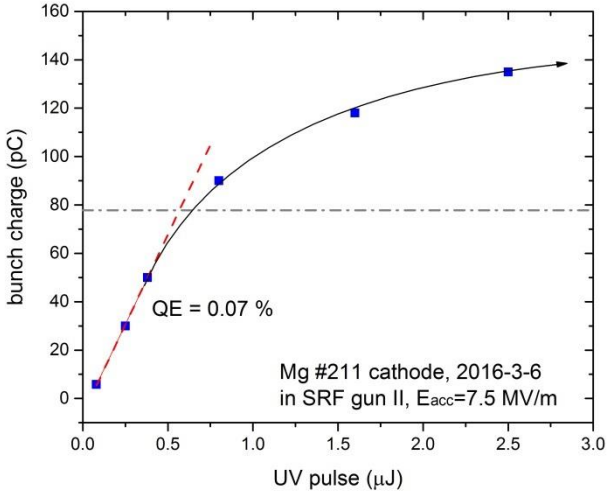


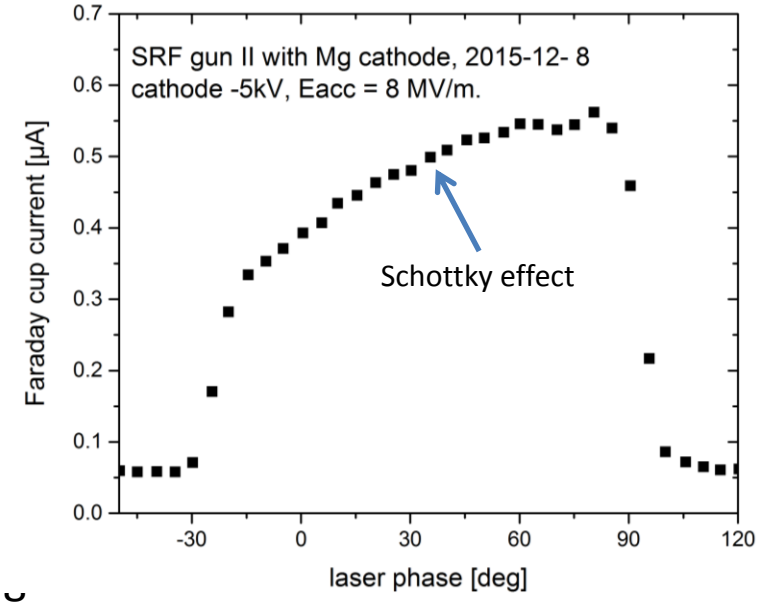


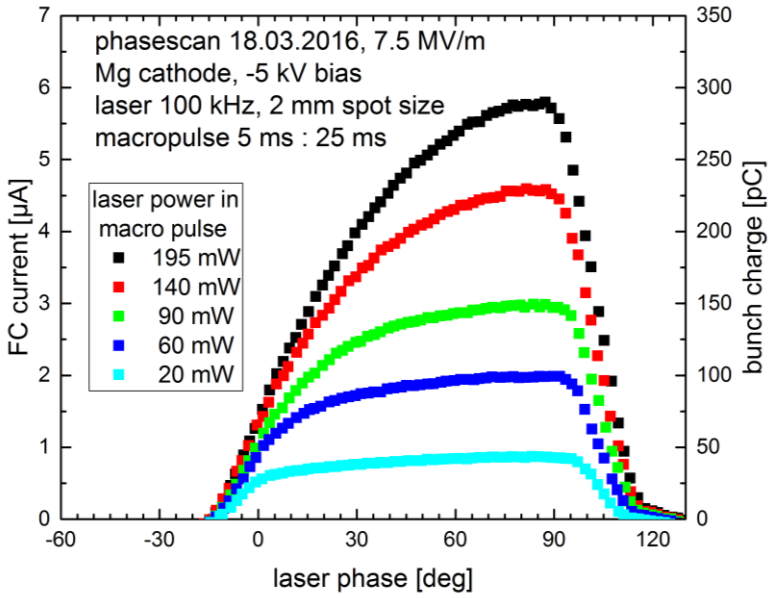
Mg photocathodes - in SRF gun II

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





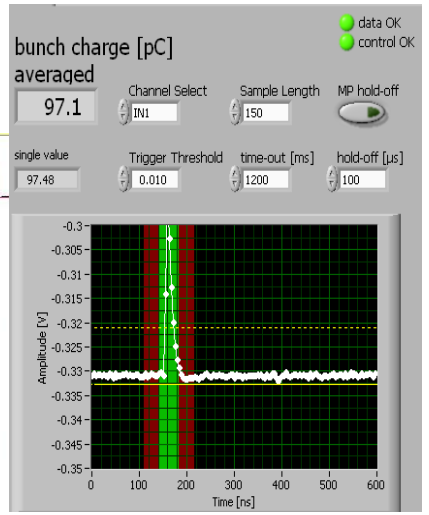


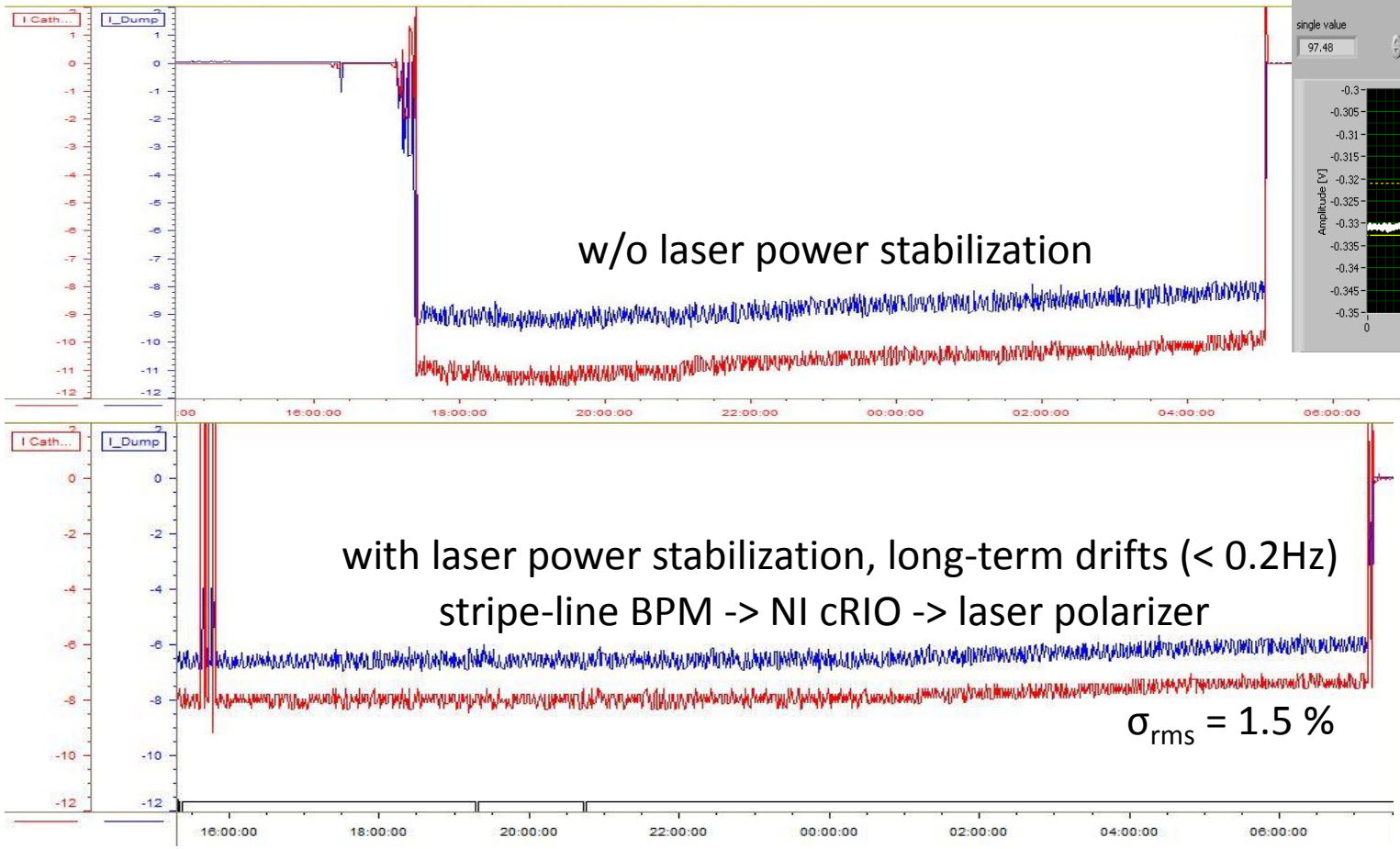


Mg photocathodes - in SRF gun II

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

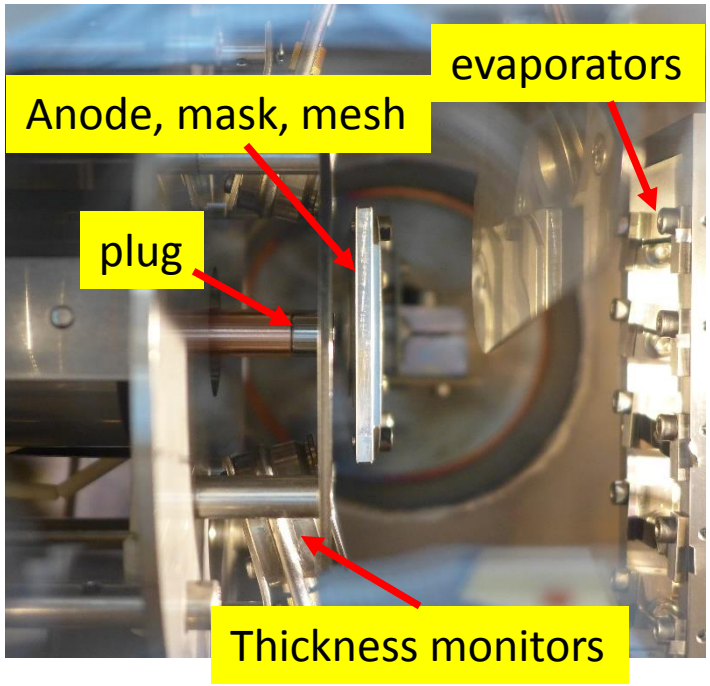
ICT in ELBE





Mg cathode in gun since March 3rd, 2016, 270 h beam time, no QE decrease

Cs_2Te photocathodes



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).

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

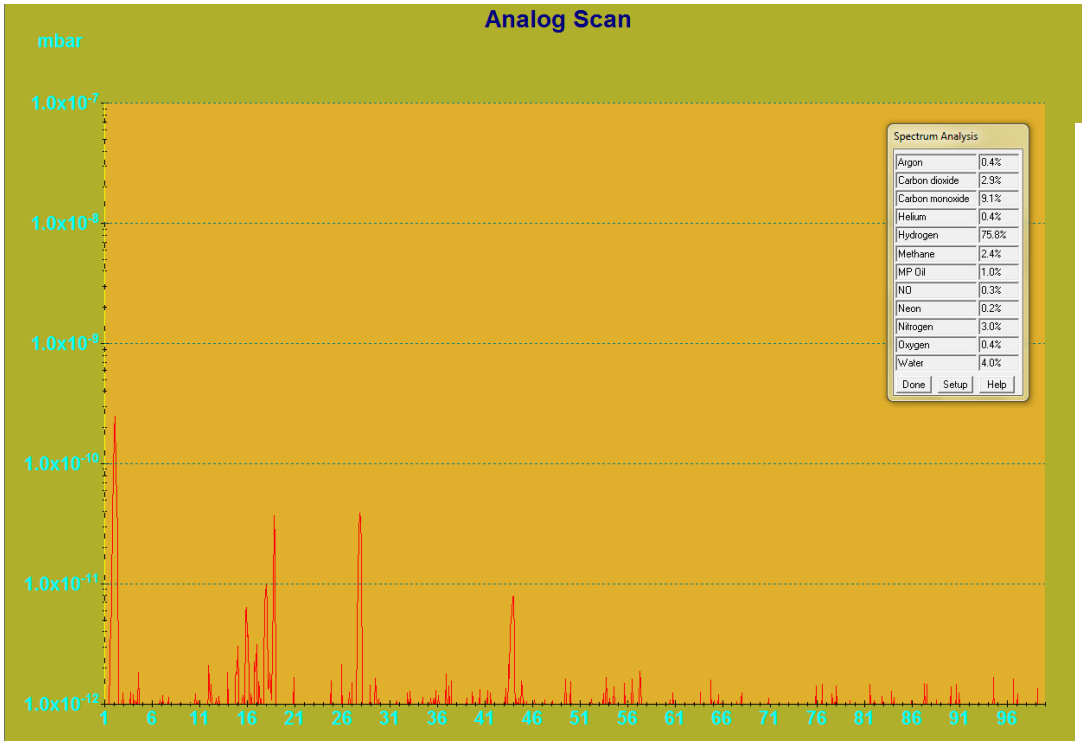
Mo plug ϕ 10 mm x 8mm on Cu-stem
Polished Mo surface R_a: 8 ~10 nm
Cleaning and baking
Deposition Te +Cs: standard, co-evaporation
Transport to Gun

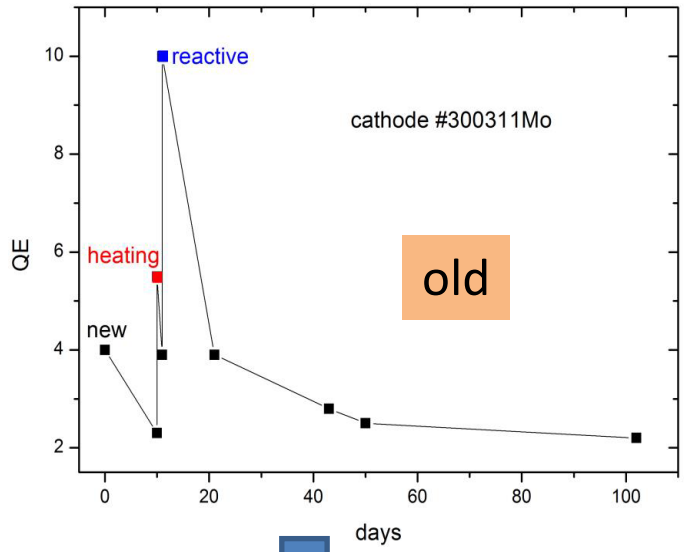
Proceedings of FEL2010,Malmö,Sweden
PhysRevSpecialTopics_13_043501

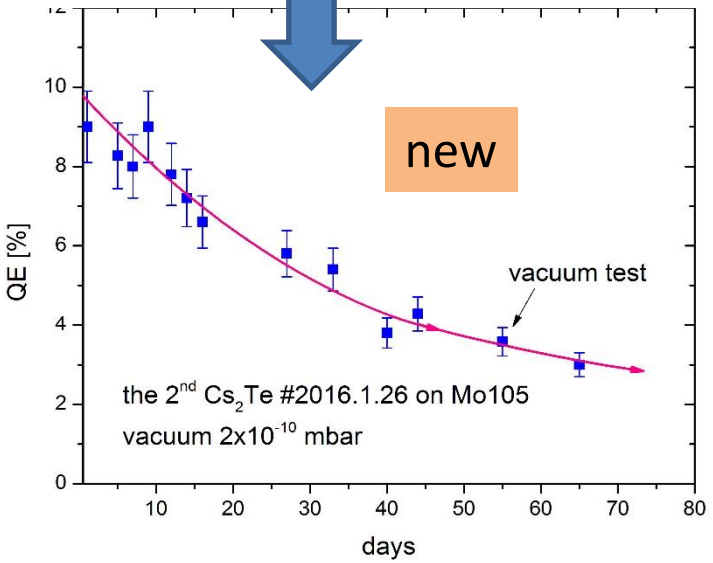
Cs_2Te photocathodes

For SRF - Gun – II

Improve vacuum 10^{-9} mbar -> 10^{-10} mbar
Remove particle source & hydrocarbon source
Bake plug at 400°C



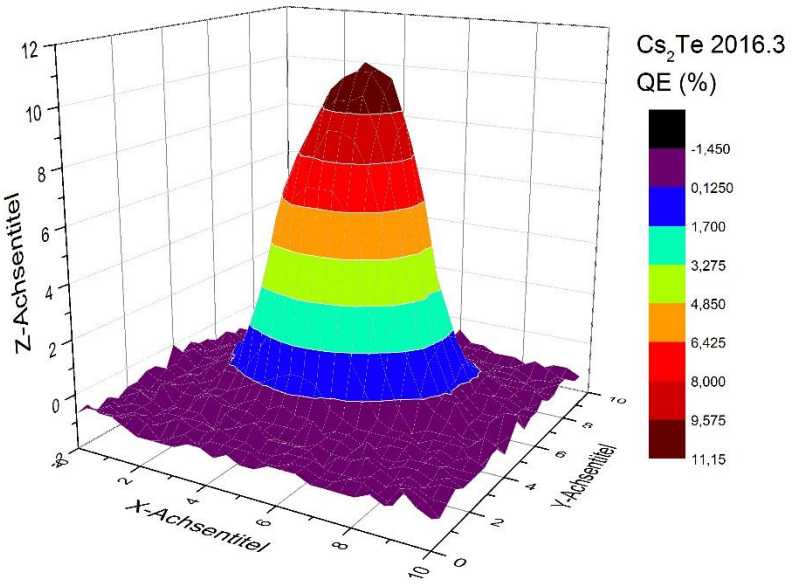




Cs_2Te photocathodes

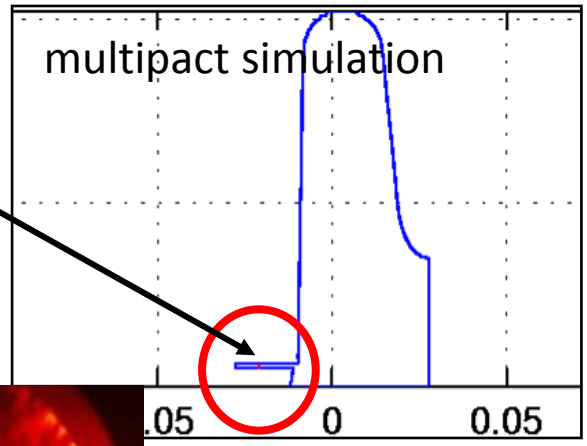
For SRF - Gun – II

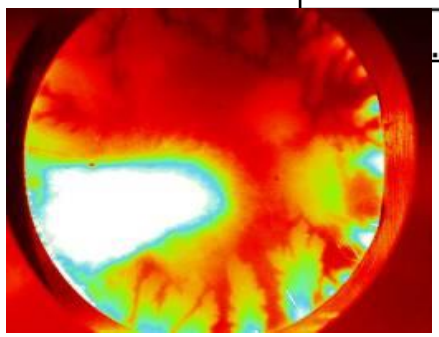
9 Cs_2Te produced in prep. Chamber



Cathode Properties - Multipacting

- MP was expected in the gap between cathode and cavity at surface fields of 0.1-0.2 kV/m since the early design stage!
- So biasing of the cathode up to -7 kV was considered in the cathode design (el. isolated)
- Characterized by high current (>1 mA, rectified) at the cathode and electron flash at view screens
- Biasing of the electrically isolated cathode often works, but is not straight forward.

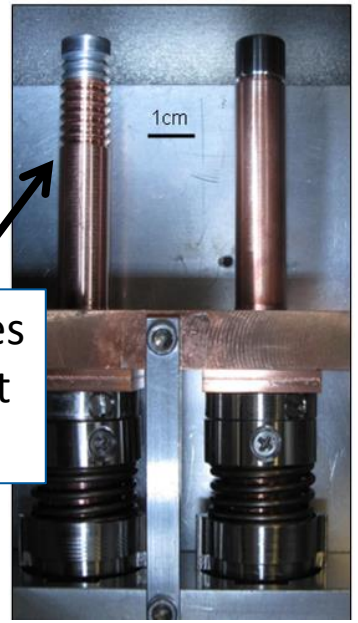




Cs_2Te: Strong MP effects, required a permanent adoption of cathode bias (-1 … -7 kV)
- experience with first SRF gun

Cu & Mg: **no** MP
one of the advantages of Mg cathodes!

Multipacting needs an interplay of geometry and increased SEY



grooves did not help

Cathode Properties - Multipacting

Future approaches of MP suppression for Cs_2Te cathodes:

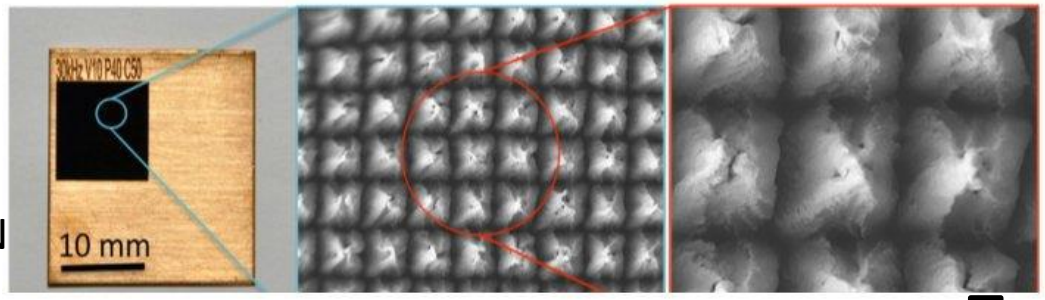
- Sustaining the low SEY by screening the cathode side walls during Cs2Te layer preparation

- Sub-mm structuring of cathode tips
  CST simulation results University of Rostock

- Laser treatment of tip side walls
  laser-engineered surface structures

„black copper“

also reduced SEY
e-cloud mitigation @ CERN



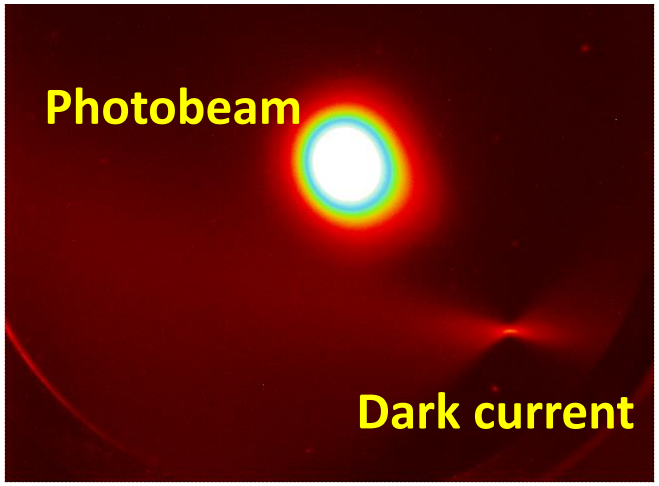
A. Gillespie, A. Abdolvand, University of Dundee

R. Valizadeh, O. Malyshev, Daresbury Lab.

LA^{3}NET conference, Mallorca 2015

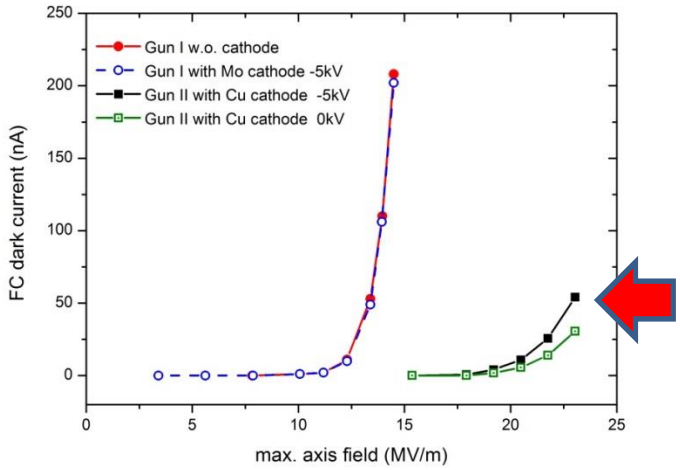
Cathode Properties - Dark Current

Dark current is produced by field emitters (FE) on photocathodes and in gun cavities.



sources connected to photocathodes (PC):

- FE produced during photo layer deposition,
- scratches and particles on PCs,
- particles produced during PCs transport and insertion,
- FE activated due PCs exchange and movement,
- FE produced by RF due to discharges,
- FE due to layer peeling-off, aging …

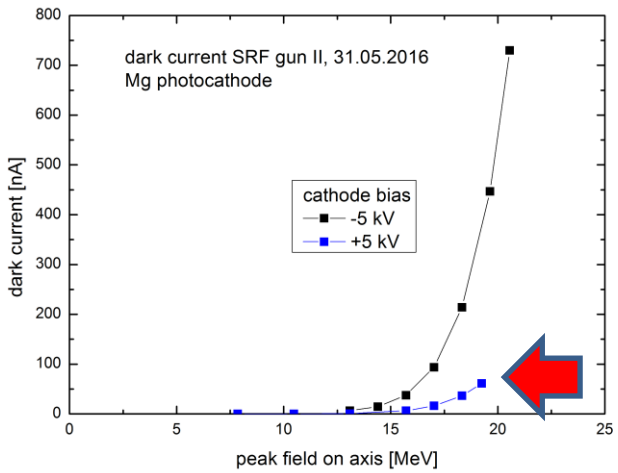


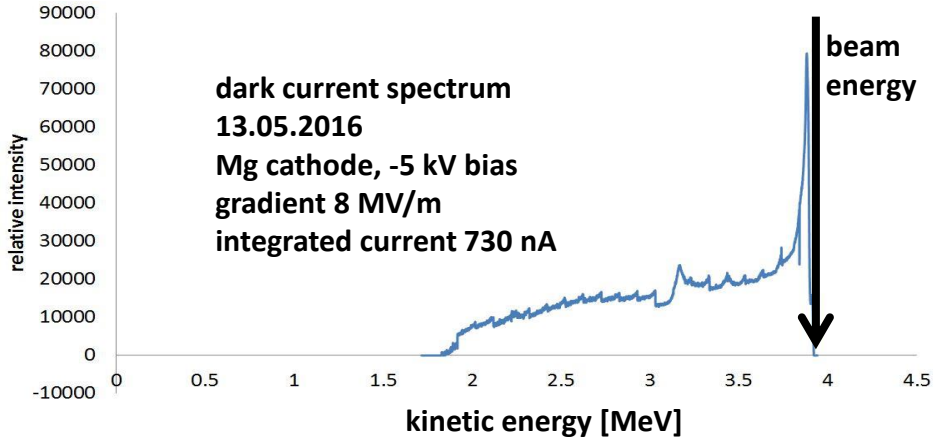
SRF Gun II, 2014
Cu photo cathode
FE on cavity surface

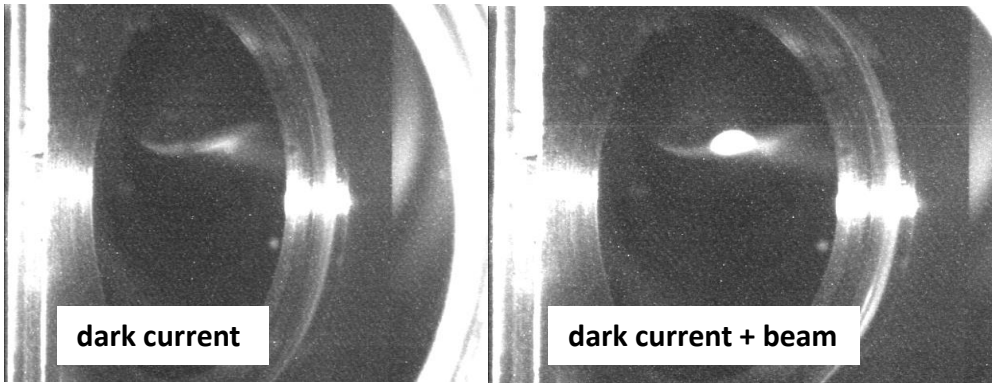
Cathode Properties - Dark Current

May 12th, 2016

activation of an existing field emitter due to photocathode movement







YAG screen in front of ELBE accelerator module

FE on cathode (?)

has “right ” energy,
dark current is accelerated and transported to target station,
high back ground for users,
significant suppression by positive cathode bias.

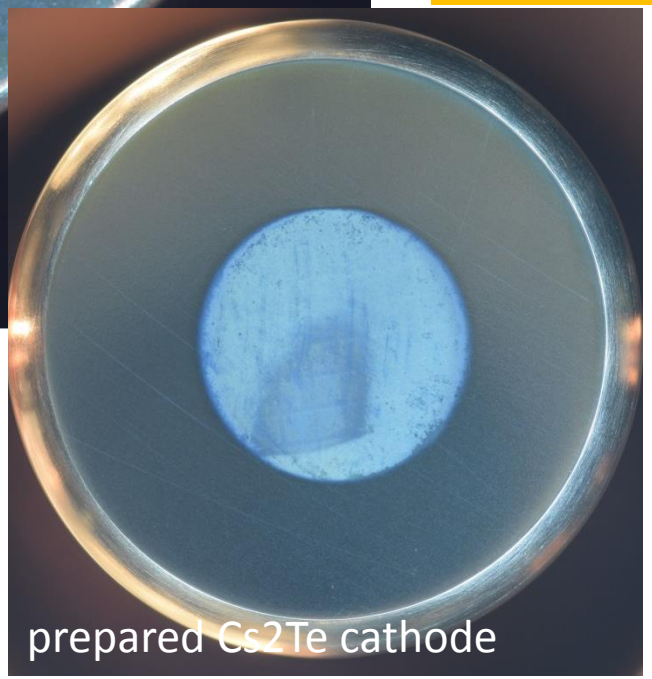
Photocathode Quality Management

For SRF photo injector the quality of photo cathodes has two important impacts:

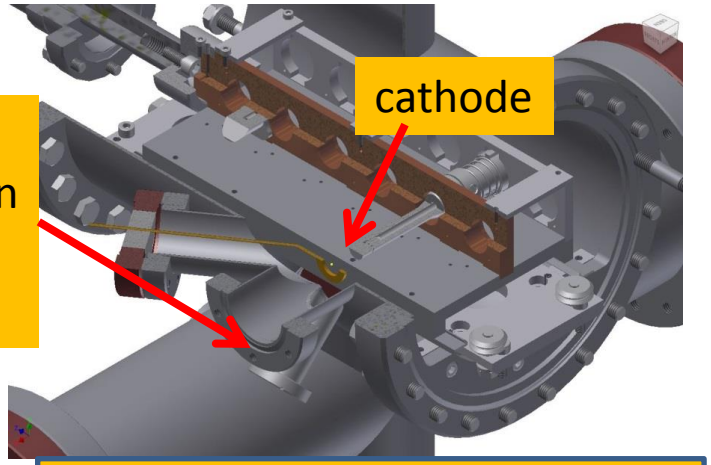
- electron beam quality (QE, therm. emittance, roughness, …)
- sustaining the SC cavity performance (particle pollution, field emitters, layer quality, …)

Inspection of plugs, before & after preparation before use in SRF gun

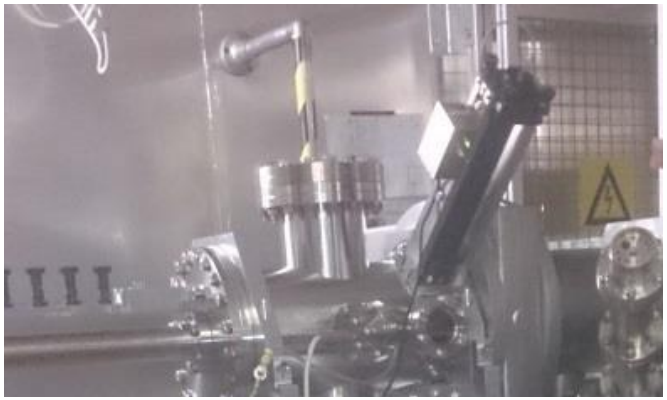
counting scratches and particles, layer quality, QE, QE scan, ...



window for visual inspection with high-resol. camera



modified transport chamber



QE measurement with UV LED

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)
- Medium and high currents require semiconductor photocathodes
  - Cs2Te + UV light is still the choice for medium currents (1 mA)
  - multipacting seems to be related to high QE (cesiation)
  - new design or new materials to avoid multipacting

Thank you for your attention!

Thanks to the ELBE team
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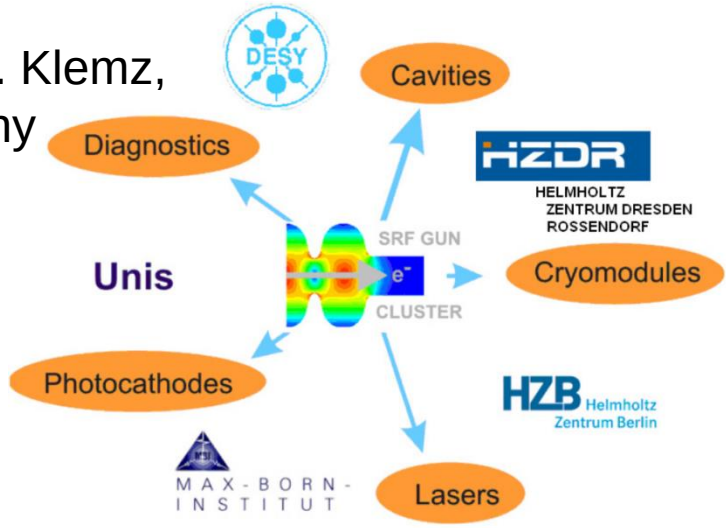
R. Nietubyć NCBJ, Świerk/Otwock, Poland
U. van Rienen, Uni Rostock, Germany



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