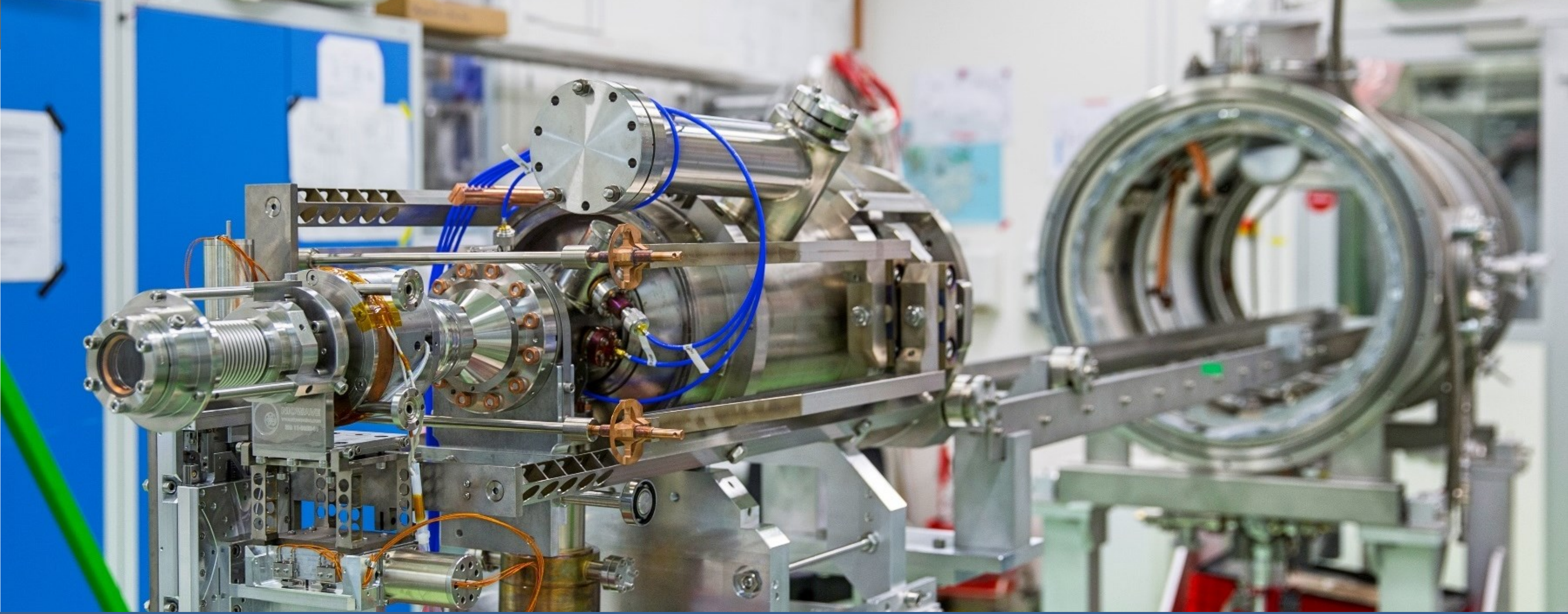


Operational Aspects of Photocathodes for SRF Guns

ELBE.

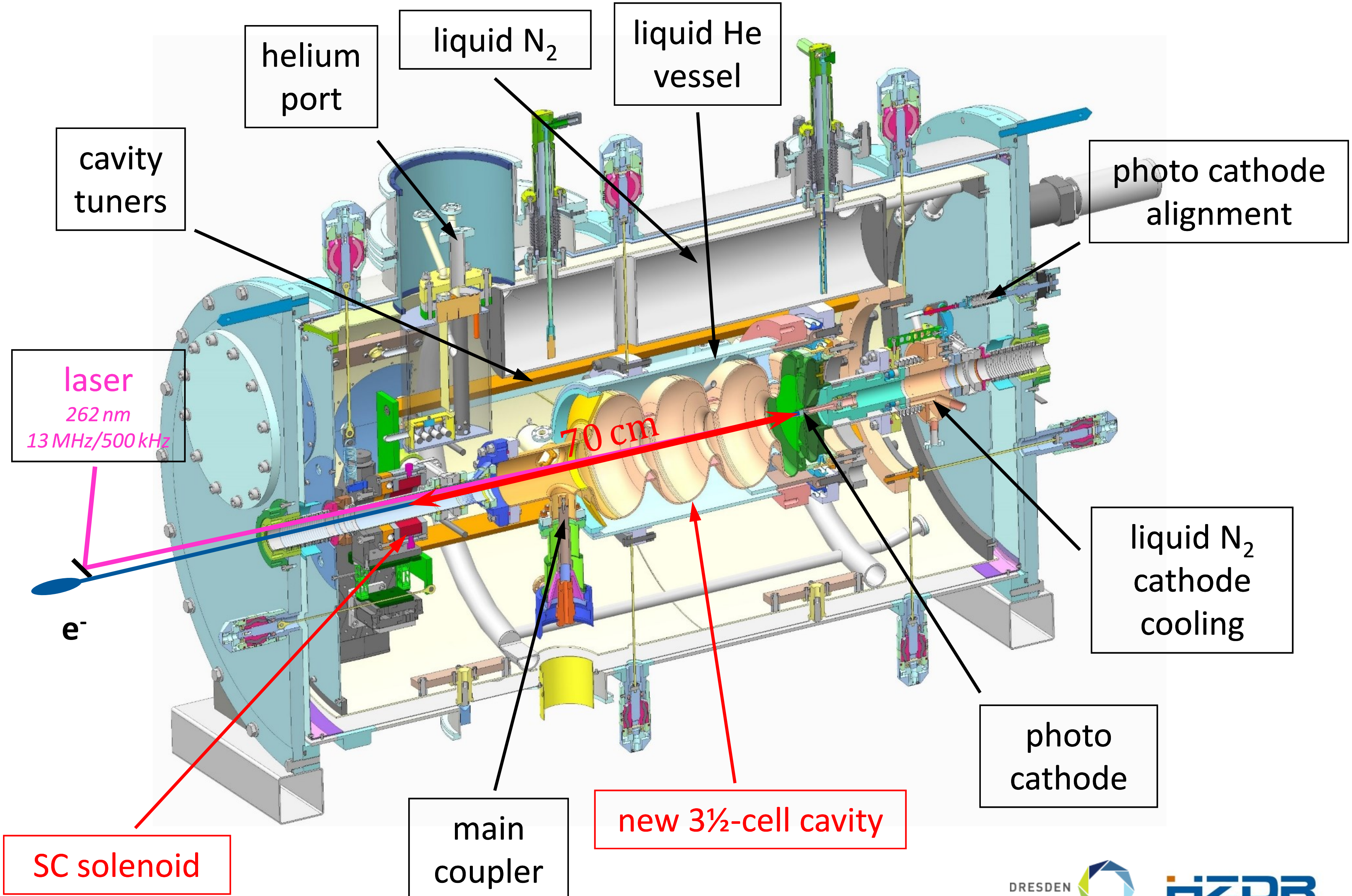
Jochen Teichert & Rong Xiang
on behalf of the SRF Gun Crew at ELBE

EWPAA 2017 Berlin, 20 – 22 September 2017

HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

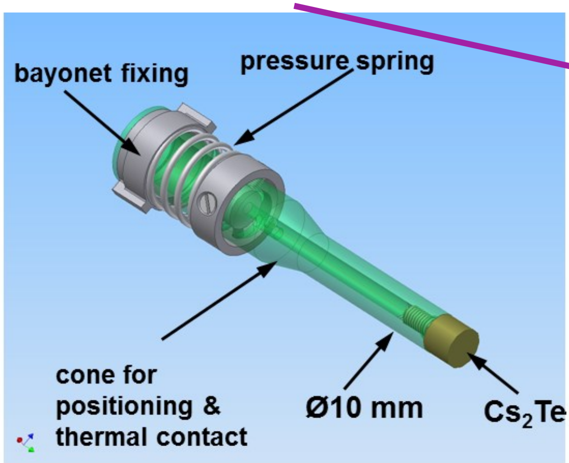
Outline

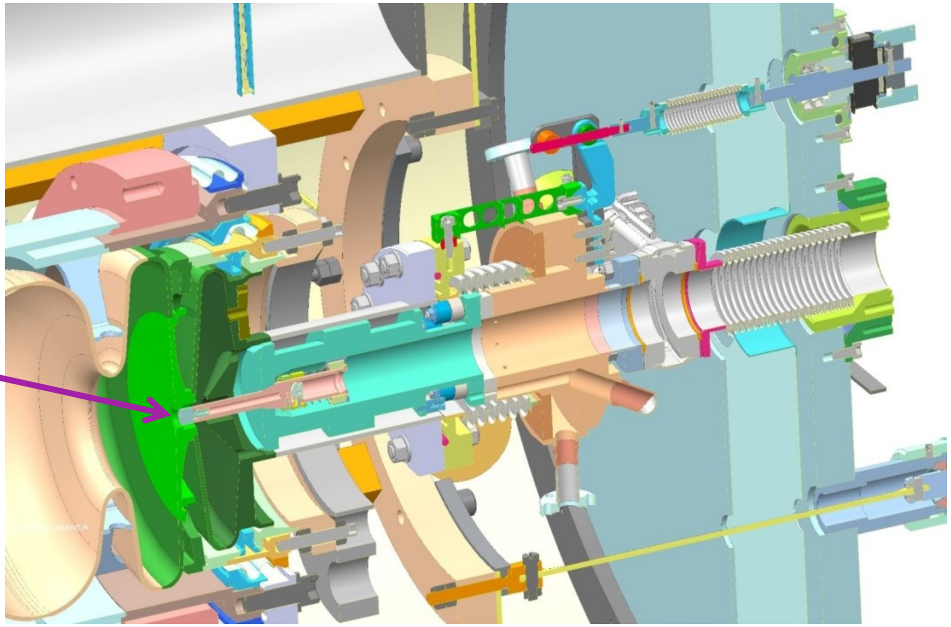
1. Introduction – ELBE SRF Gun II design



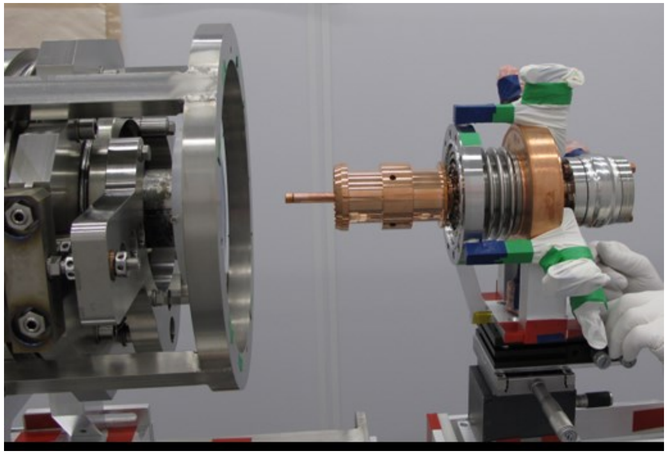
1. Introduction – Photocathode support and cooling

UV laser @ 258 nm
0.5 W CW
100 kHz, ≤ 5 µJ
or 13 MHz, ≤ 0.04 µJ
Gaussian 5-6 ps FWHM



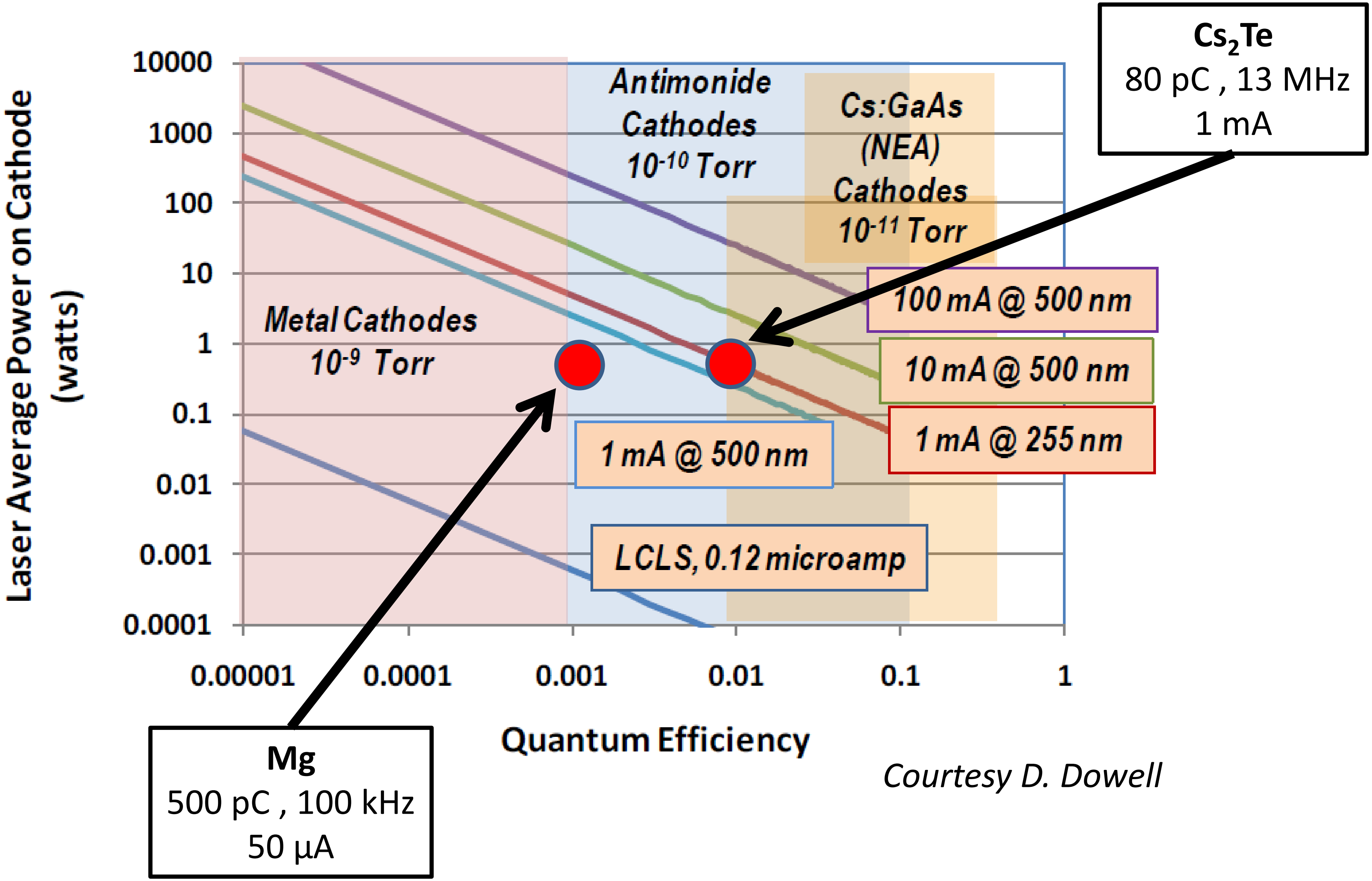


- normal conducting - low RF losses on cavity axis
- vacuum gap - thermally and electrically isolated
- axis alignment (by hand)
- remote controlled positioning +- 0.6 mm range
- retracted RF focussing
- cathode exchange in cold gun



Jochen Teichert I HZDR

1. Introduction – Photocathodes for ELBE SRF Gun II



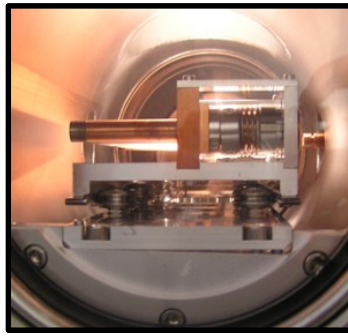
Courtesy D. Dowell

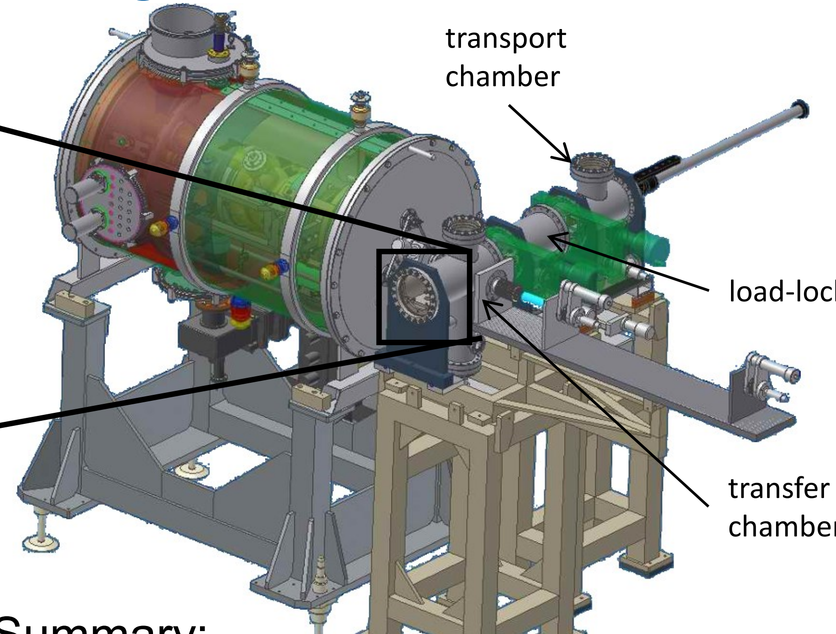
1. Introduction – Photocathodes for ELBE SRF Gun II

Promising Cs_2Te cathode results for former gun

Requirements for Transfer:

- Load lock system with < 10^{-9} mbar to preserve QE ≥ 1 %
- Exchange w/o warm-up, in short time and with low particle generation





Cathode	Operation Days	Charge	QE in gun
#090508Mo	30	< 1 C	0.05%
#070708Mo	60	< 1 C	0.1%
#310309Mo	109	< 1 C	1.1%
#040809Mo	182	< 1 C	0.6%
#230709Mo	56	< 1 C	0.03%
#250310Mo	427	35 C	1.0%
#090611Mo	65	< 1 C	1.2%
#300311Mo	76	2 C	1.0 %
#170412Mo	447	264 C	~ 0.6 %

Summary:

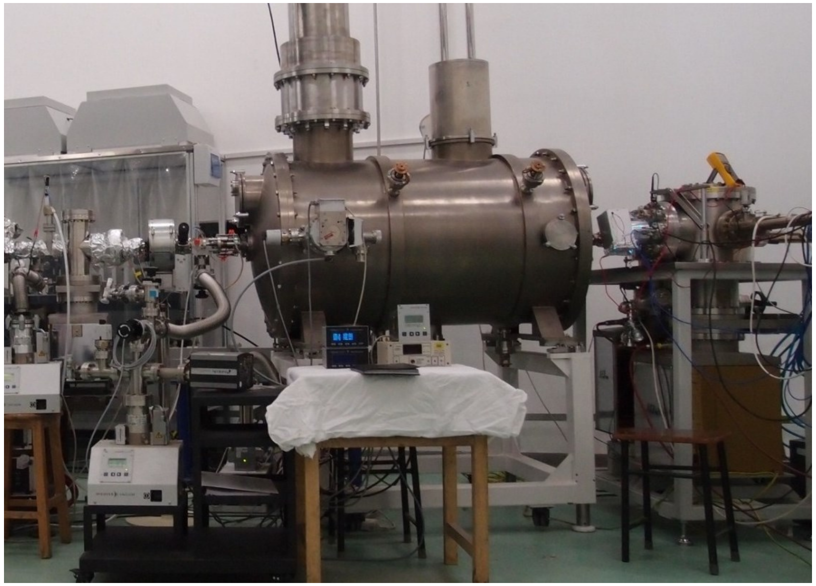
- 9 different Cs_2Te cathodes used
- QE drops remains const. in the gun
- All cathodes died because of unexpected vacuum breakdown
- $\varepsilon_{thermal}$ ~ 0.7 mm·mrad/r(mm)

fresh QE 8.5%, in gun 0.6%
total beam time ~600 h
extracted charge 264 C
max beam current 400μA

2. Photocathode handling – PC exchange systems

Vacuum chamber (PC suitcase) and loadlock system for cathode exchange

- limited space and access to accelerator tunnel (24 h user operation)
- fast exchange of PCs from storage
  PC preparation systems are outside for continuous R&D work or even on another institute



PC preparation system connected to gun at Peking University, Courtesy K. Liu

QE requires: Vacuum must retain on the 10^{-9} (10^{-10}) mbar level al the time

successfully demonstrated:

Cs_2Te: INFN-LASA Milano deposited PCs (2011) for APEX Gun (2014) with QE = 16 %

D. Sertore, et al., J. Vac. Sci. Tech. A32 031602 (2014)

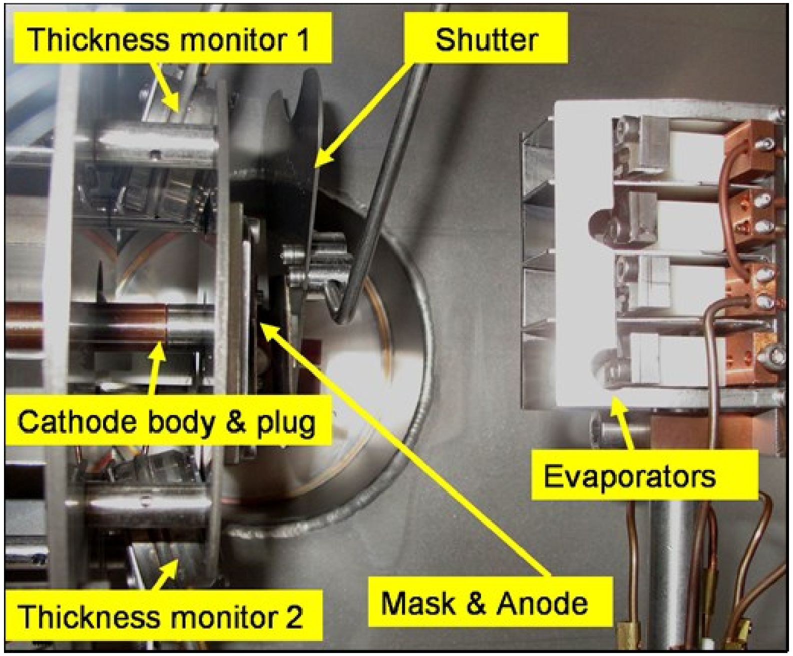
D. Filippetto, et al., APL 107, 042104 (2015)

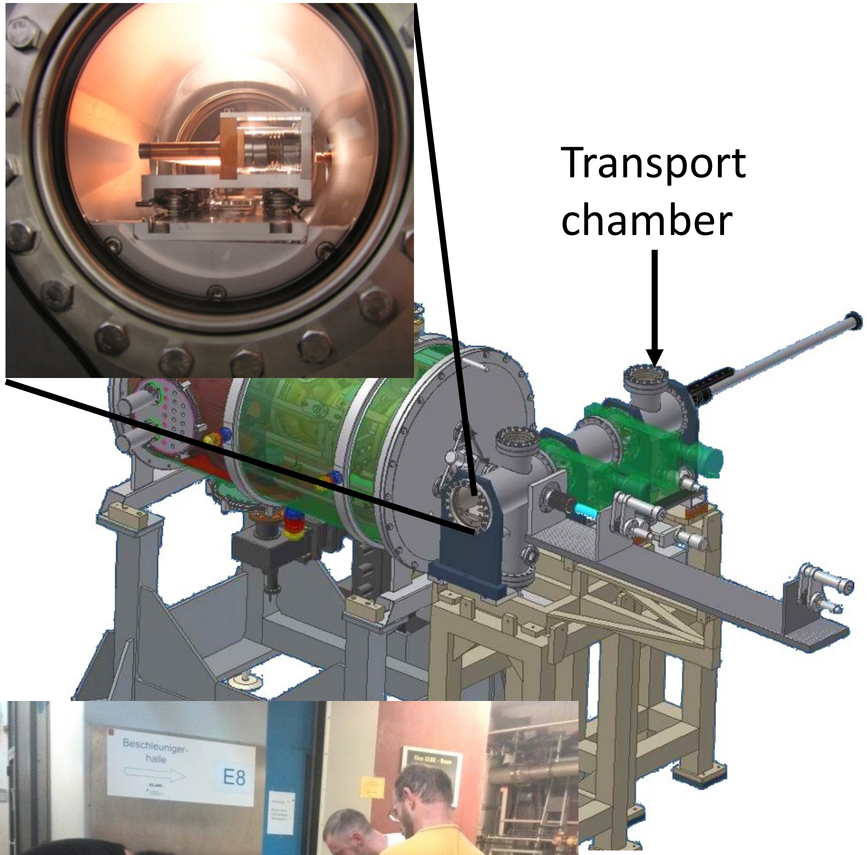
K_2CsSb: BNL produced PCs for Jlab, transportation at ~10^{-11} Torr, QE > 1 % @532 nm

R.R. Mammei, et al. Phys. Rev. STAB 16,033401 (2013)

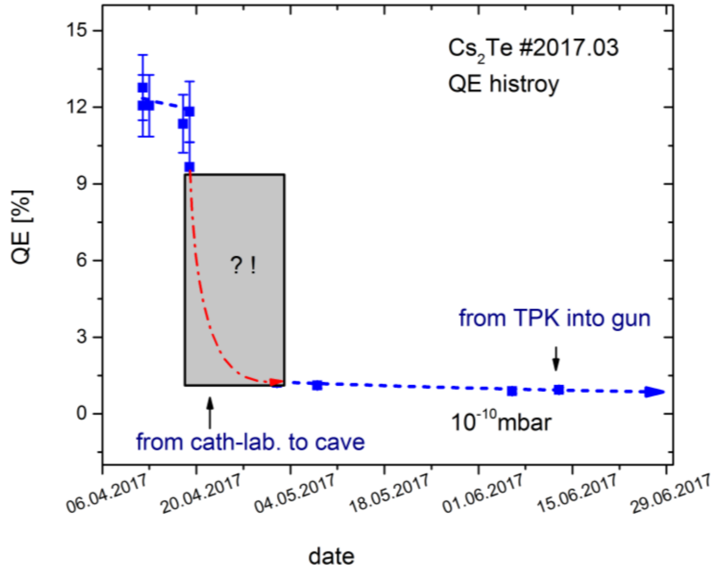
2. Photocathode handling – PC exchange systems

Cs_2Te preparation laboratory



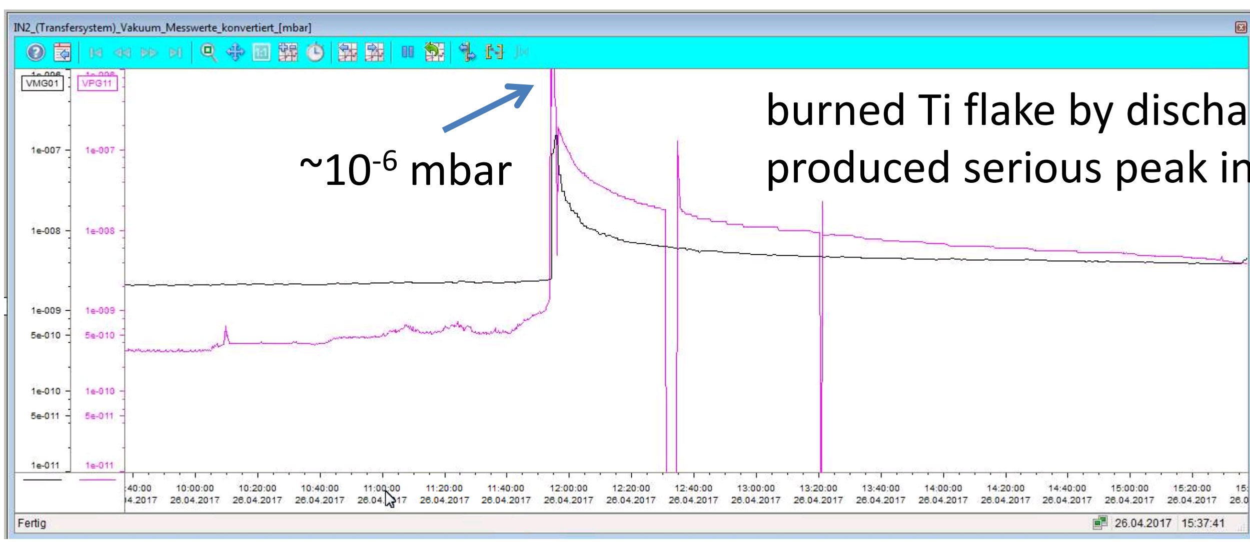


2. Photocathode handling – PC exchange systems



Monitoring of QE and vacuum during the vacuum chamber transportation

- unlucky selection of ion getter pump type
- load-lock backing w/o transport chamber cooling
- valve opening produced vacuum peaks
- heavy chamber prone to vibrations and shocks

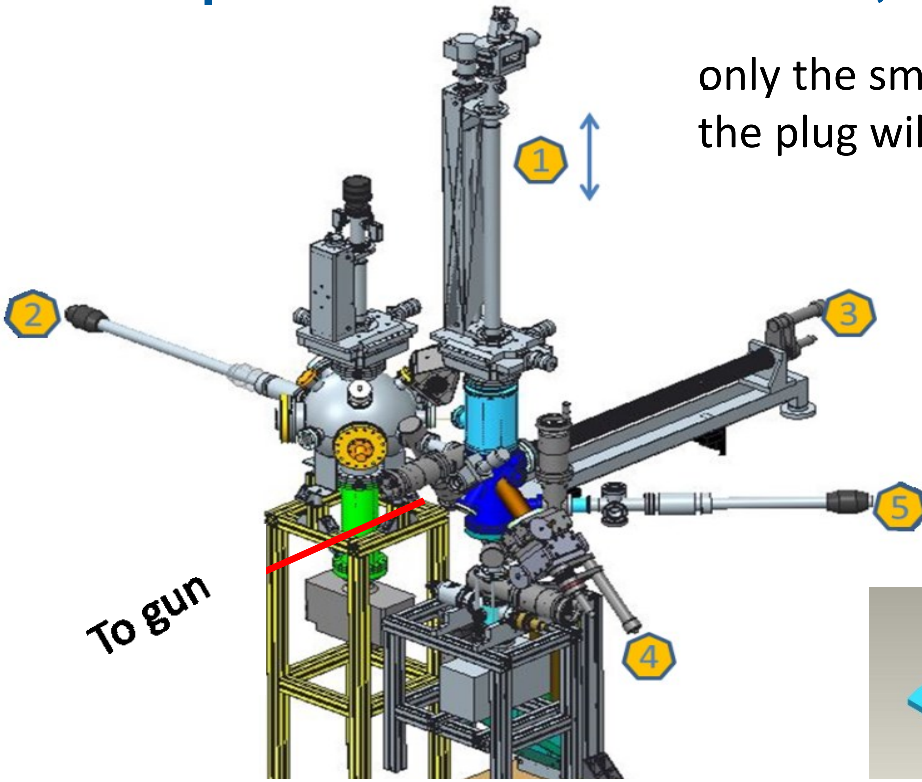


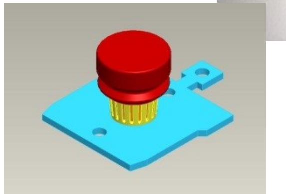
burned Ti flake by discharge
produced serious peak in vacuum pressure

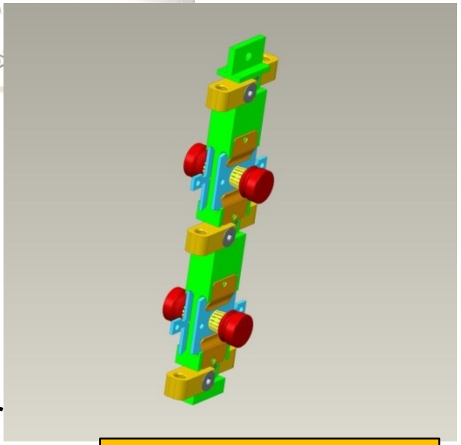
2. Photocathode handling – PC exchange systems

New cathode transportation system
developed in PCHB collaboration, HZB, HZDR, JGU Mainz

only the small plug (red) on the flag (blue) is transported
the plug will be monted on the cathode body at the gun







1. vertical movement of the plug carrier
2. shift of one cathode plug on jaw from the GaAs preparation chamber to plug carrier
3. transfer of the photo cathode into the electron gun
4. plug exchange between carrier and cathode body
5. movement of one flag from the load-lock to the plug carrier with jaw.

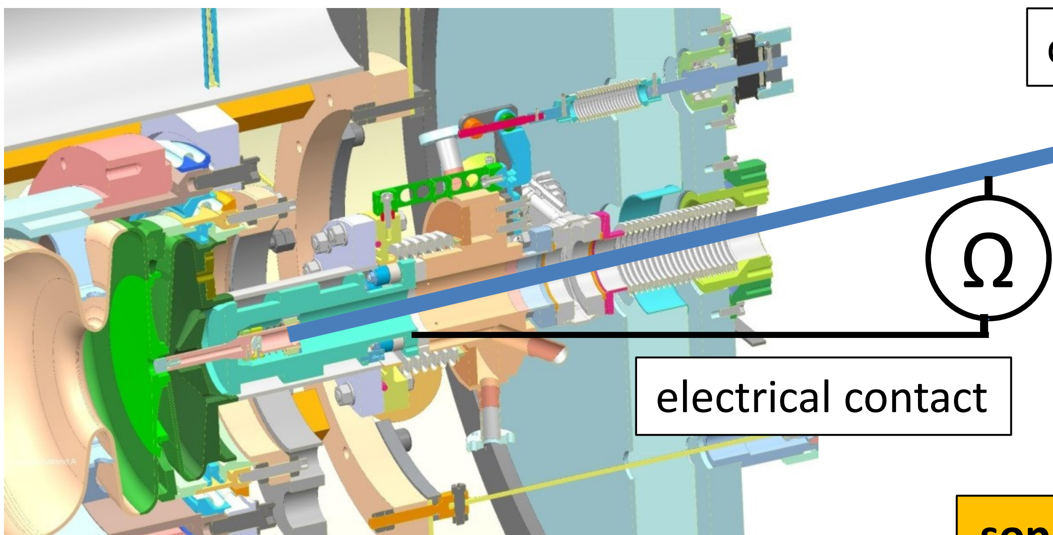
realized at HZB see tour

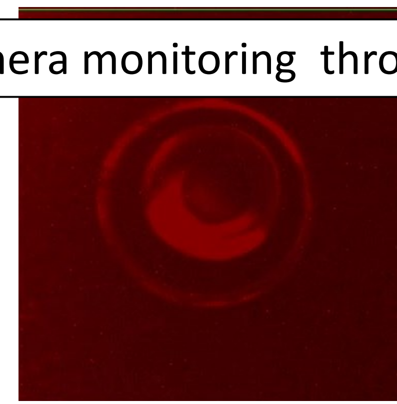
2. Photocathode handling – PC exchange systems

Photo cathode exchange in the SRF gun

Our experience:

- all the decrease in cavity performance and increase in field emission is connected to PC exchange
- exchange without particle generation
- precise alignment of transfer rod required
- mechanical design preventing that PC head hits the cavity

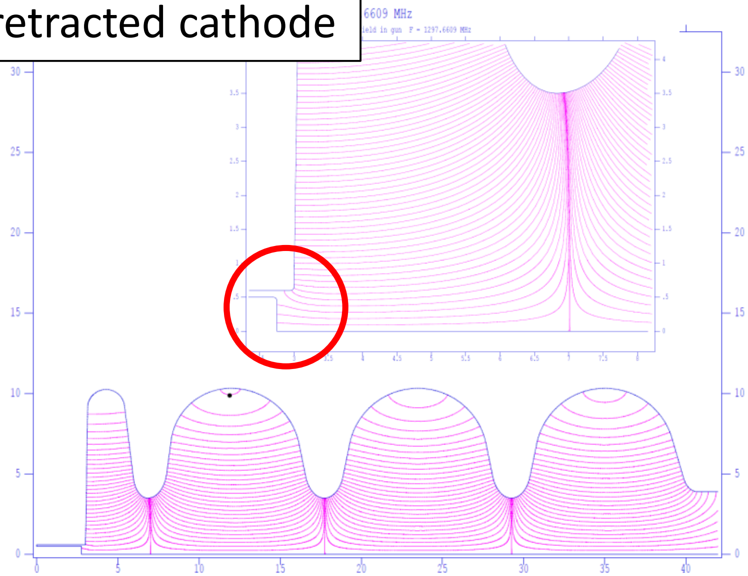




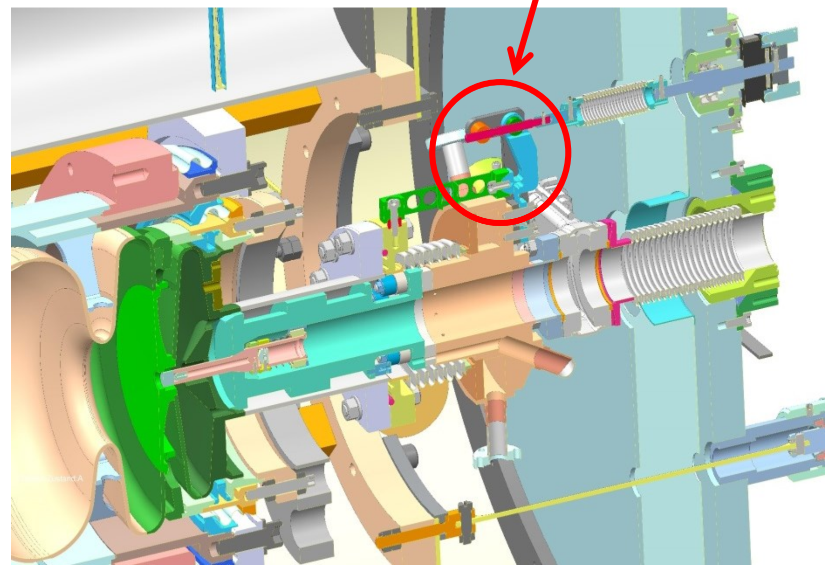
sophisticated optical system at HZB
see tour

2. Photocathode handling – PC positioning

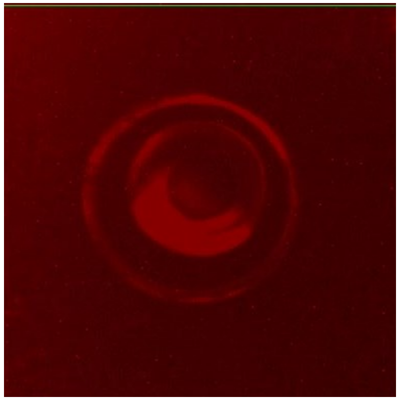
RF focussing effect
by retracted cathode



position tuners ±0.6 mm



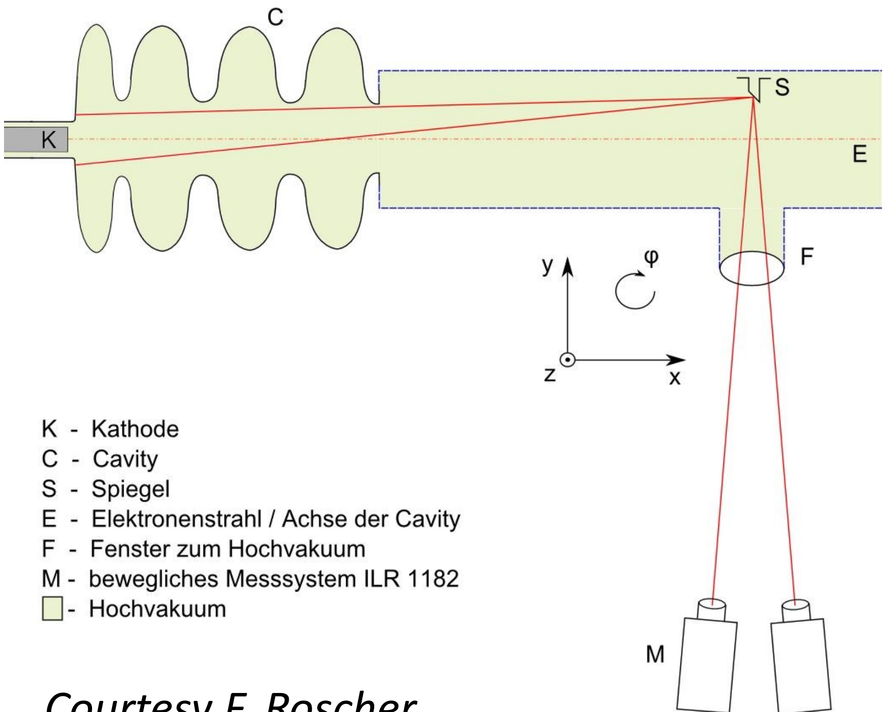
- PC position (-1 … -3 mm) is one of the important optimization parameters
- hard to adjust and to measure exactly
- cavity fabrication accuracy, treatment, and warm tuning causes length errors



centering with camera image

2. Photocathode handling – PC positioning

optical measurement



K - Kathode
C - Cavity
S - Spiegel
E - Elektronenstrahl / Achse der Cavity
F - Fenster zum Hochvakuum
M - bewegliches Messsystem ILR 1182
- Hochvakuum

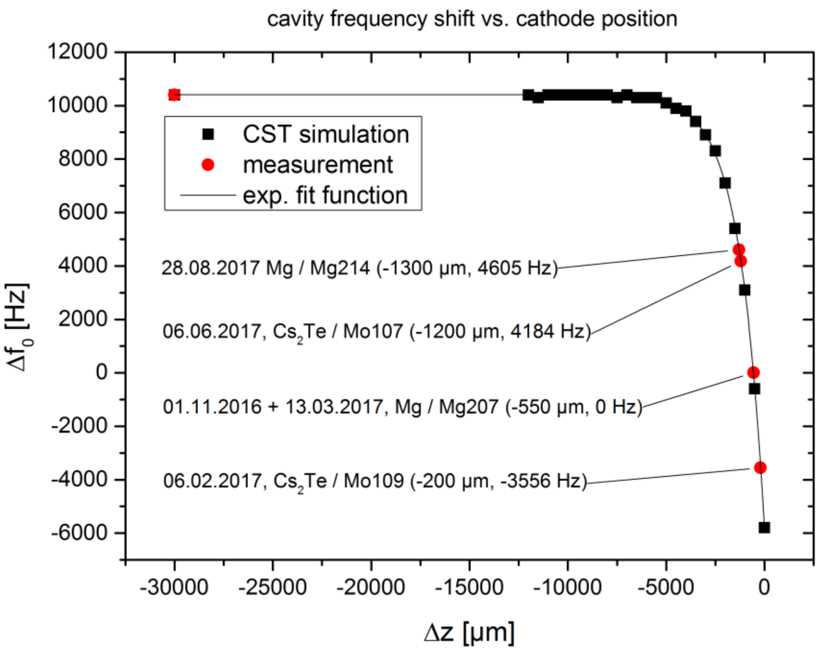
Courtesy F. Roscher

MICRO-EPSILON
long range laser sensor

depth profile of the cavity back wall

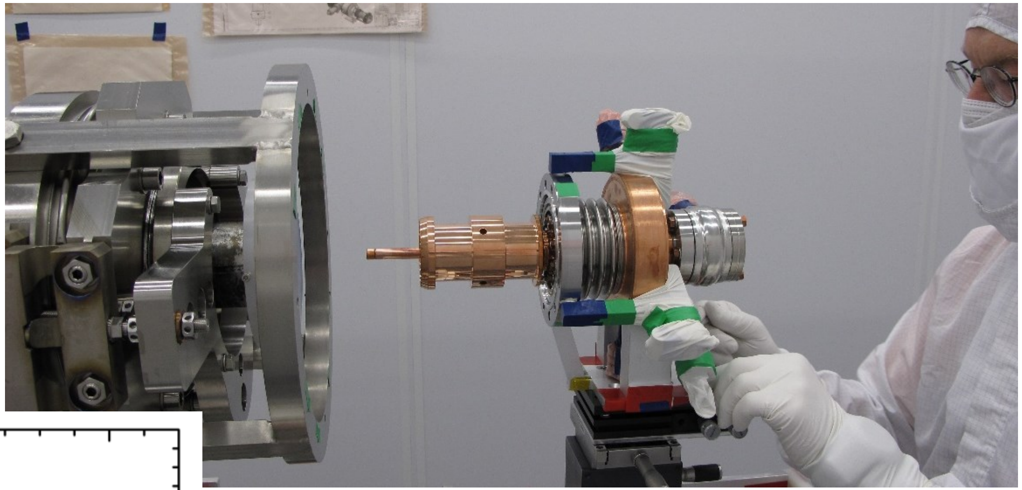
RF measurement

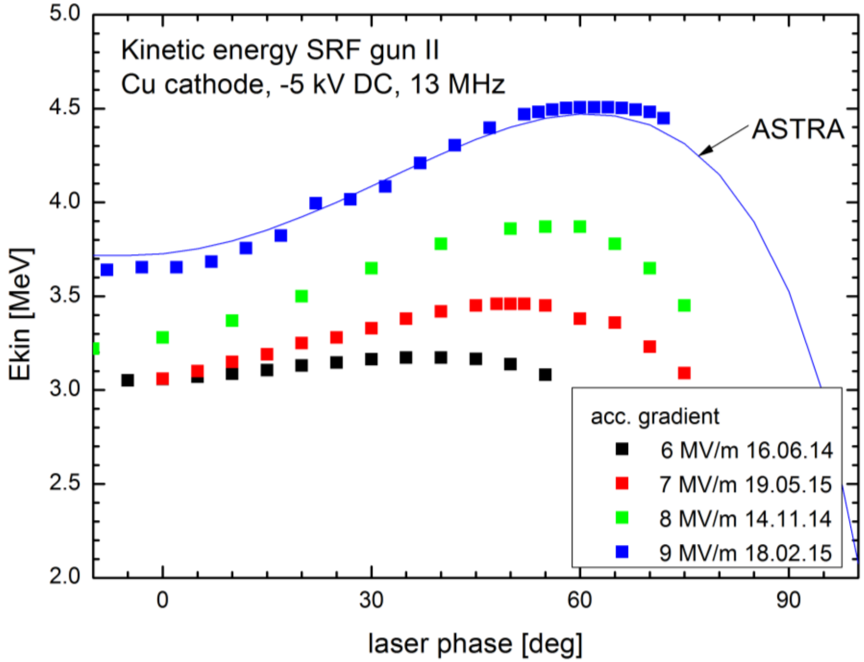
cavity resonance frequeency shift with and without cathode



3. Metallic photocathodes - Cu

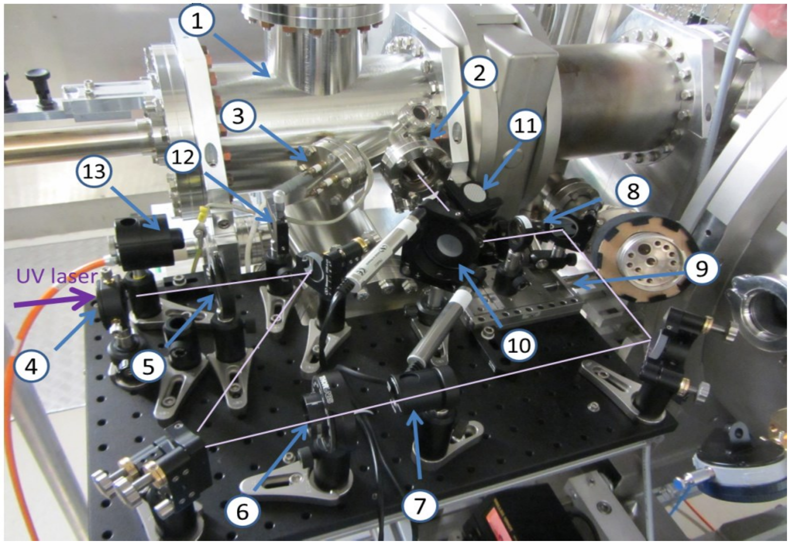
clean- room assembly
of the cathode cooling system
with Cu cathode



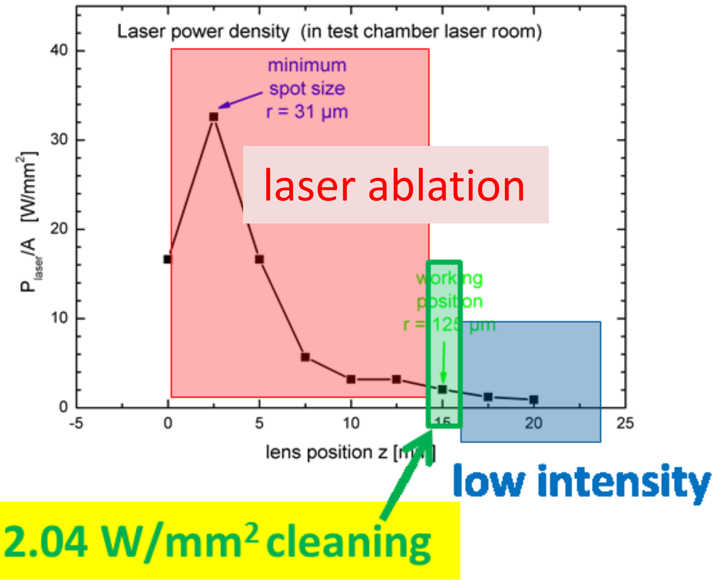


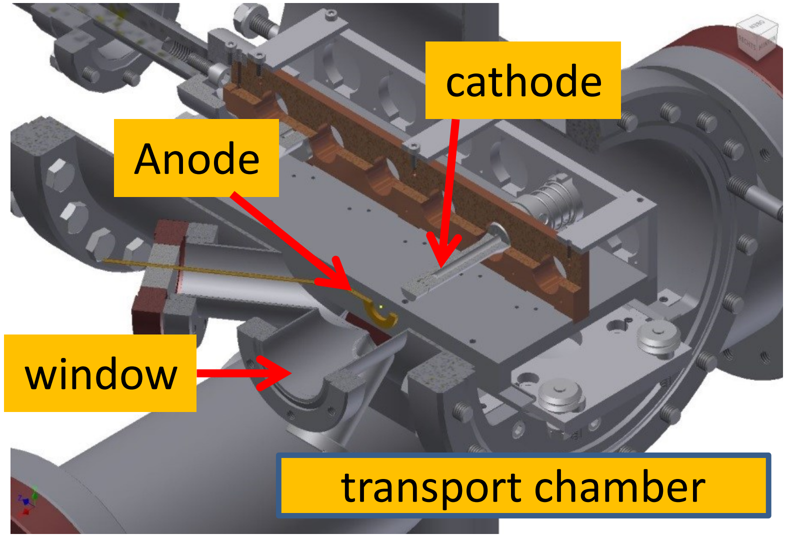
Cu PC Perfect for gun commissioning
no contamination risk
RF and beam tests without
cathode exchange system

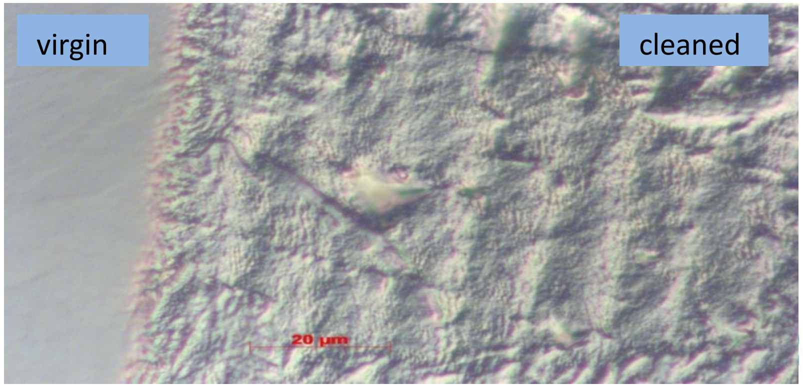
3. Metallic photocathodes - Mg
Laser cleaning set-up - PC in transport chamber



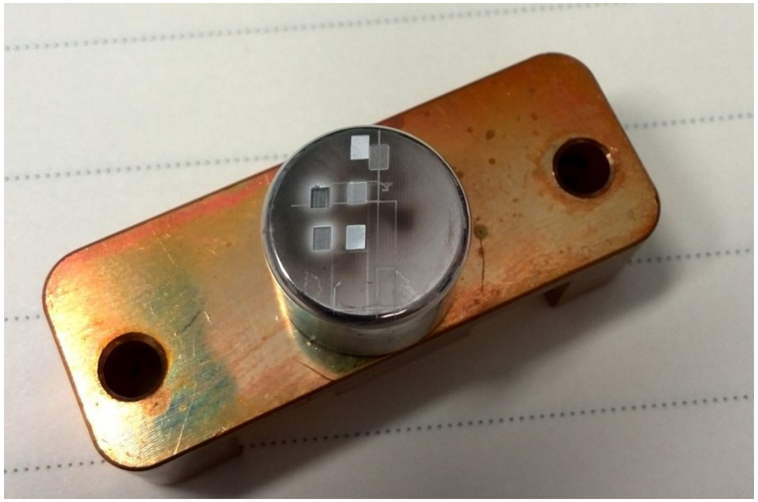
Laser cleaning set-up at transport chamber at SRF gun
using the UV drive laser (100 mW, 100 kHz CW)



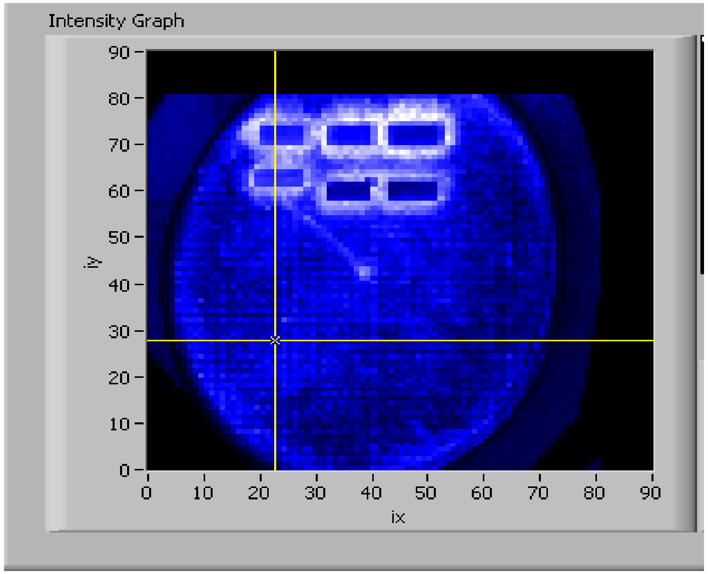


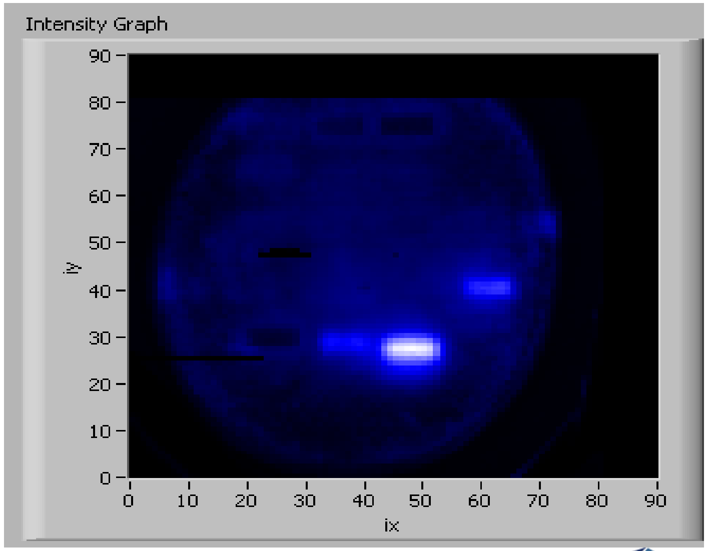


3. Metallic photocathodes - Mg



Plug Mg No. 1

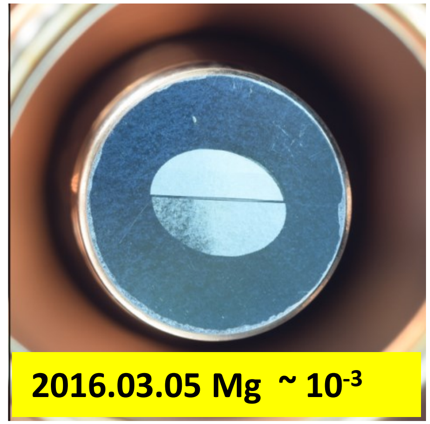


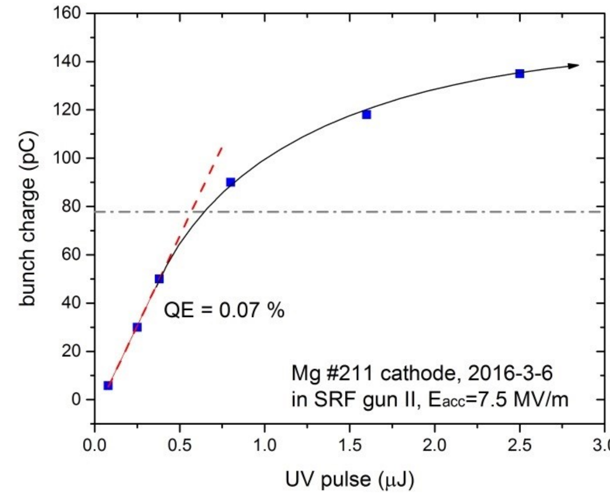


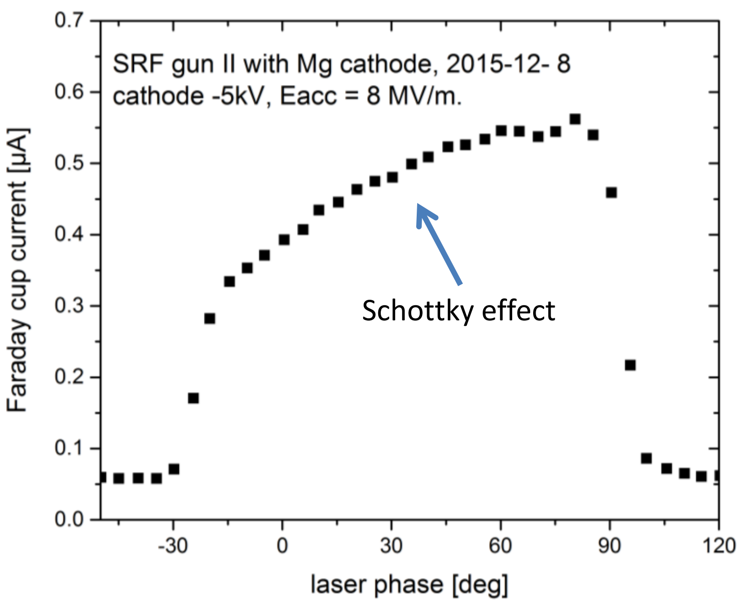
Mg test sample
an QE scans
using the UV
photocathode laser

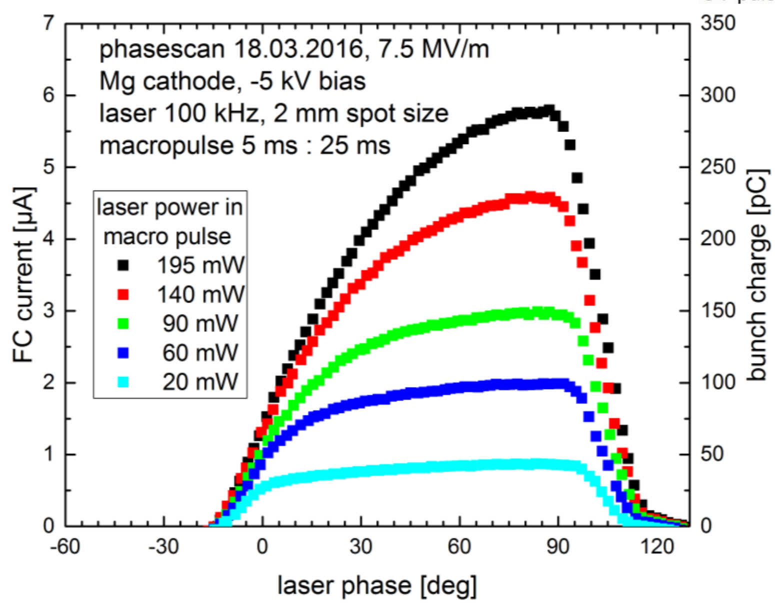
Mg photocathodes - in SRF gun II

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









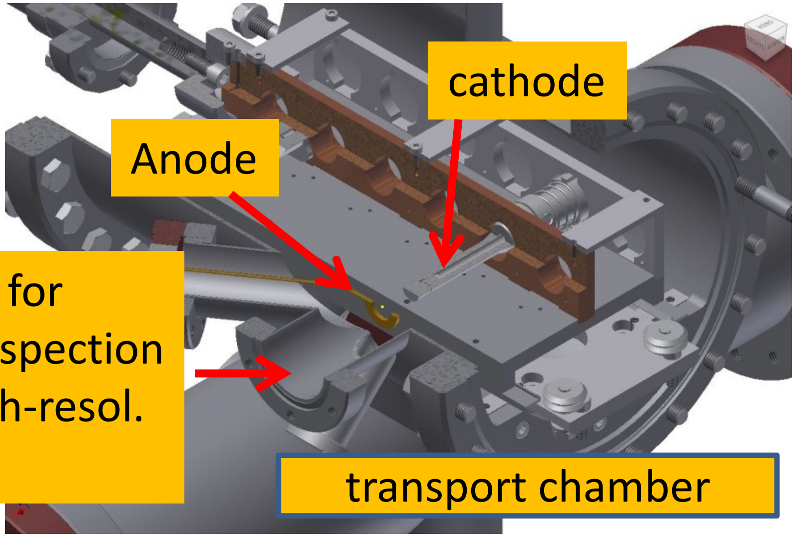
4. Quality management

Preparation lab
- dry-ice cleaning of PCs
- visual inspection: scraches & particles
- repeating dry-ice cleaning
- visual inspection: scratches & particles
- PC preparation
- QE measurement in prep chamber
- visual inspection: scraches , particles
  & layer quality
- regularly QE and QE-scan

In transportation chamber at gun
- visual inspection: scraches , particles
  & layer quality
- regularly QE and QE-scan

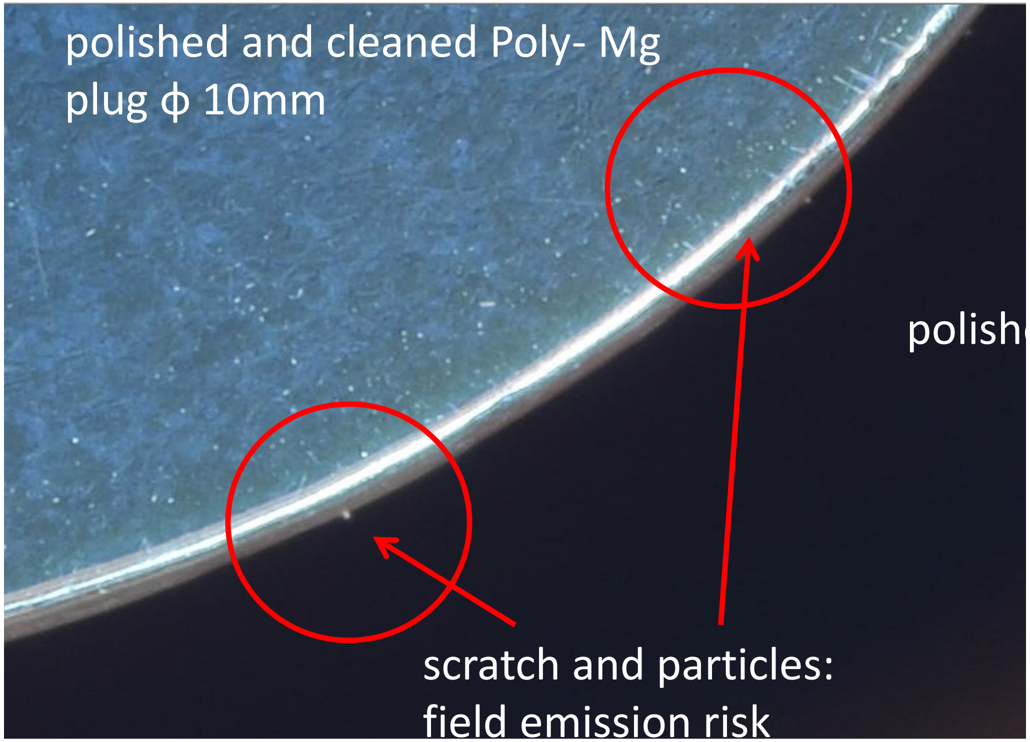
In Gun
- DC voltage QE-scan
- RF test, cavity losses, multipacting
- field emission/dark current
  FC cup and energy spectrum
- QE and QE-scan with gradient

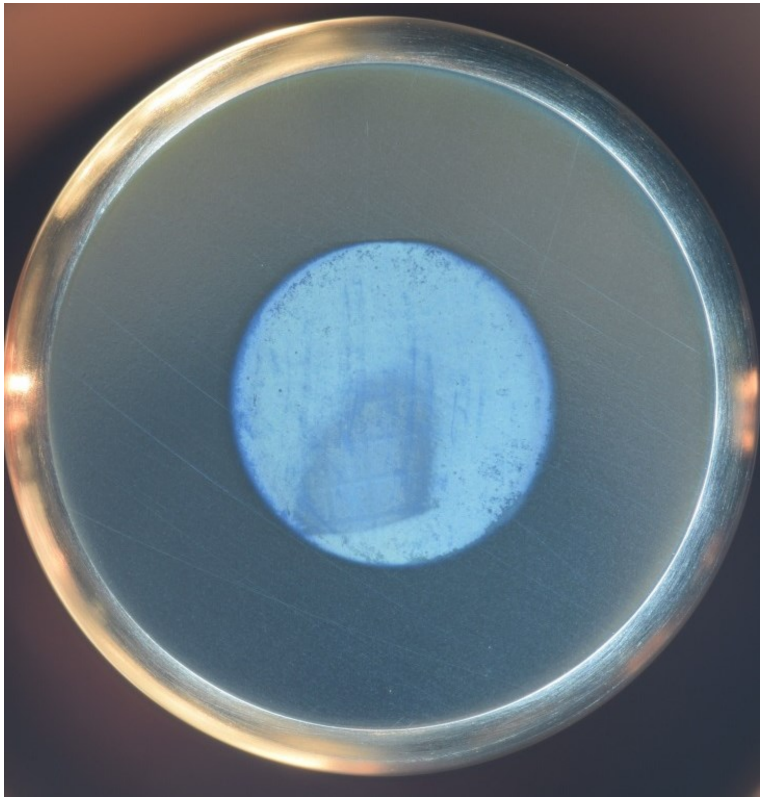
Modified transport chamber



accurate QE measurement with LED

4. Quality management





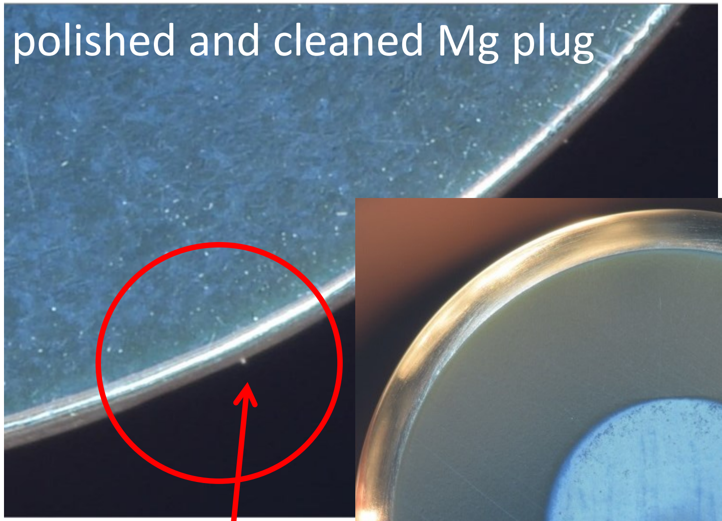
counting
scratches
and particles,
layer quality,
QE, QE scan, ...

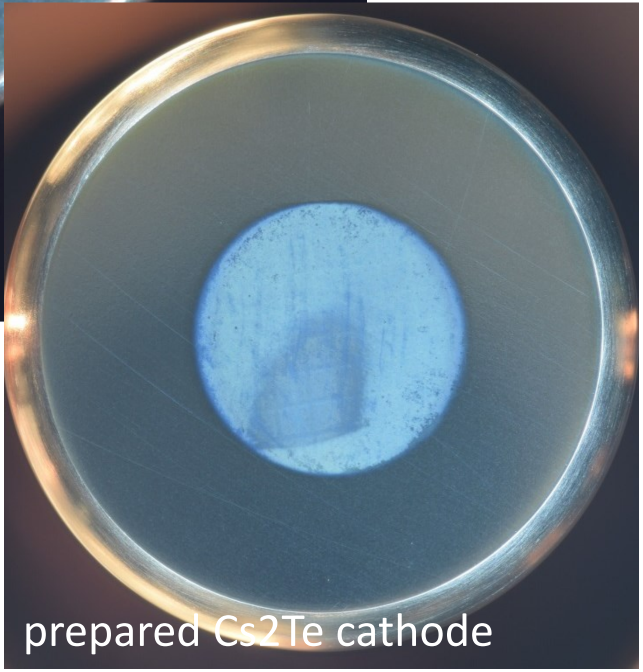
Photocathode Quality Management

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, …)

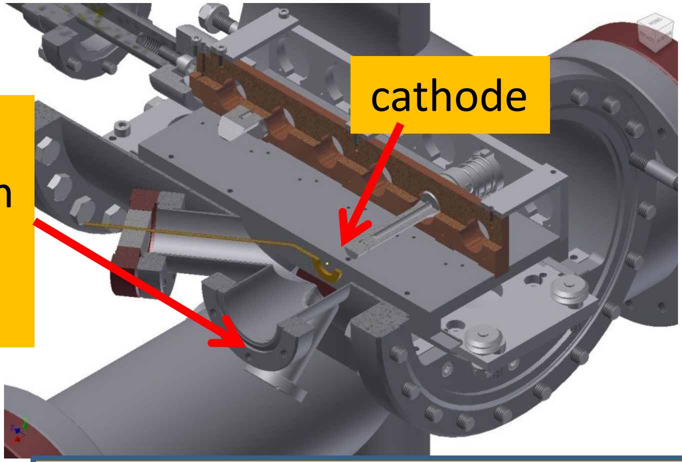
Inspection of plugs, before & after preparation before use in SRF gun



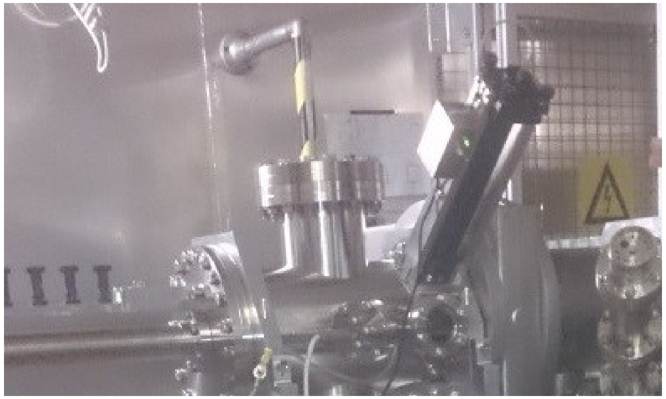


counting scratches and particles, layer quality, QE, QE scan, ...

window for visual inspection with high-resol. camera



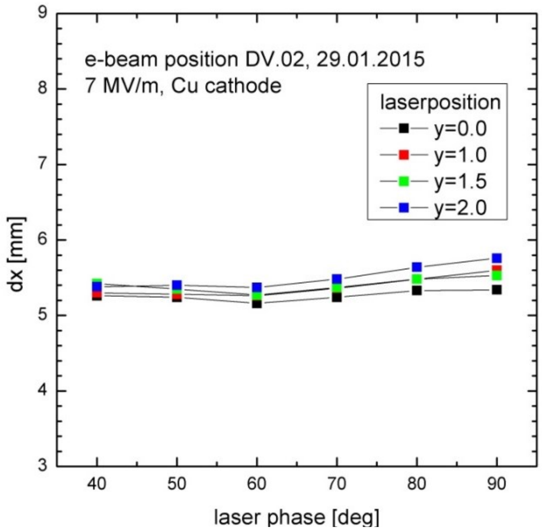
modified transport chamber

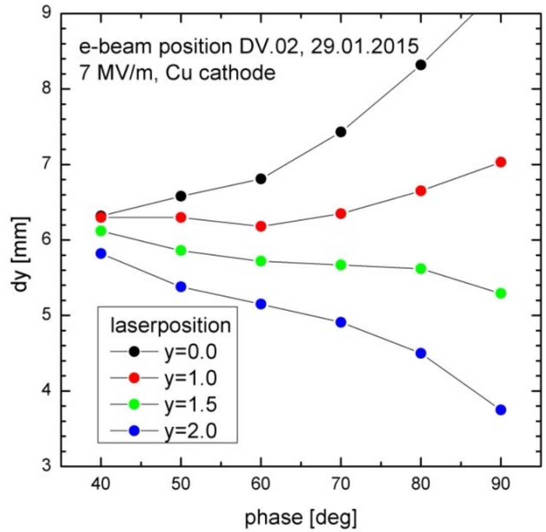


QE measurement with UV LED

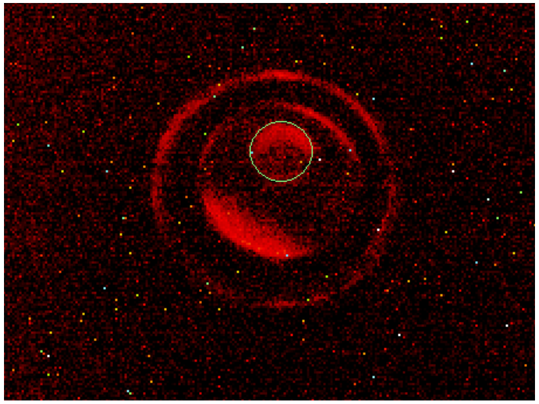
5. Operation – Laser adjustment

Adjustment of laser spot on photo cathode

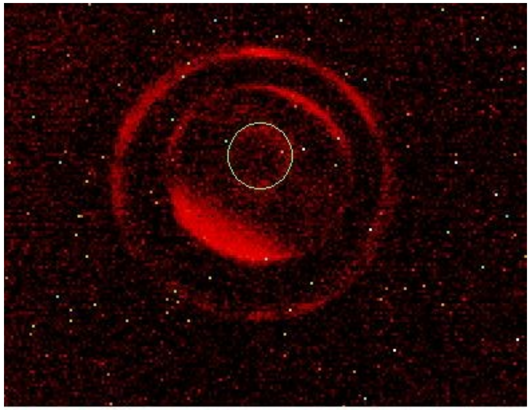


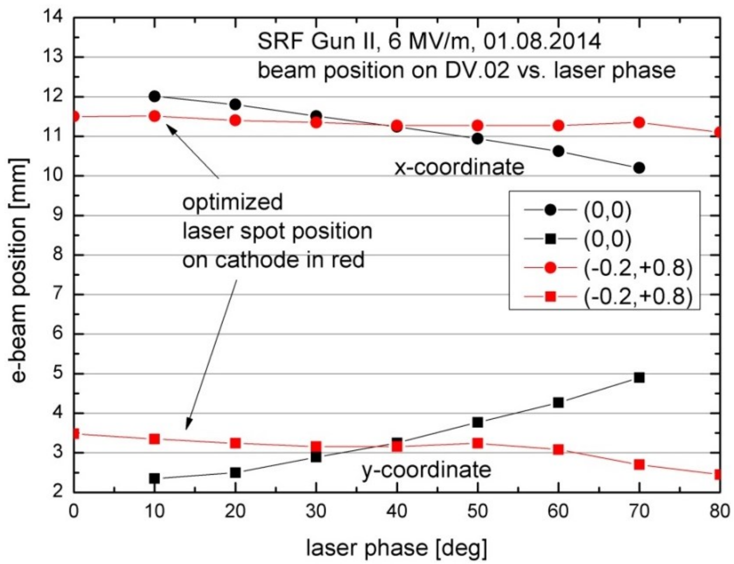


initial



final





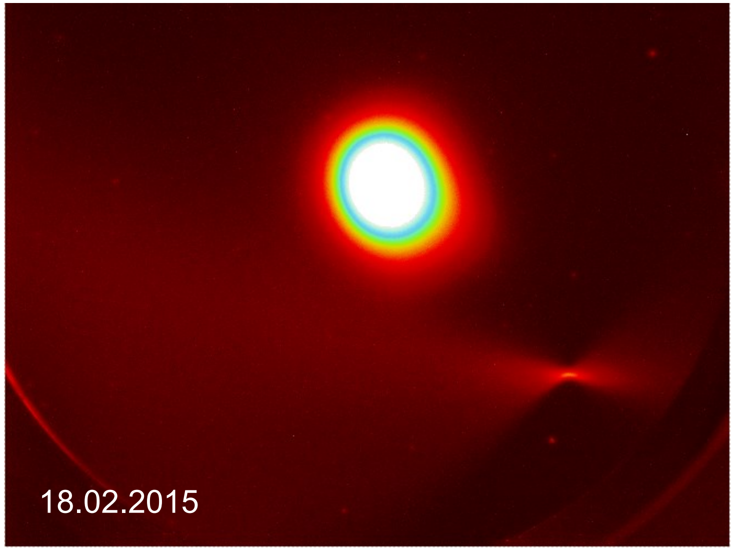
solenoid, quads, steerers are switched of,
accuracy of positioning: ~ 100 µm,
effect on emittance for Δx = 100 µm is less
than measurement accuracy (for Cu with ~ 1 pC)

5. Operation - dark current

dark current: field emitters in cavity and on photo cathode

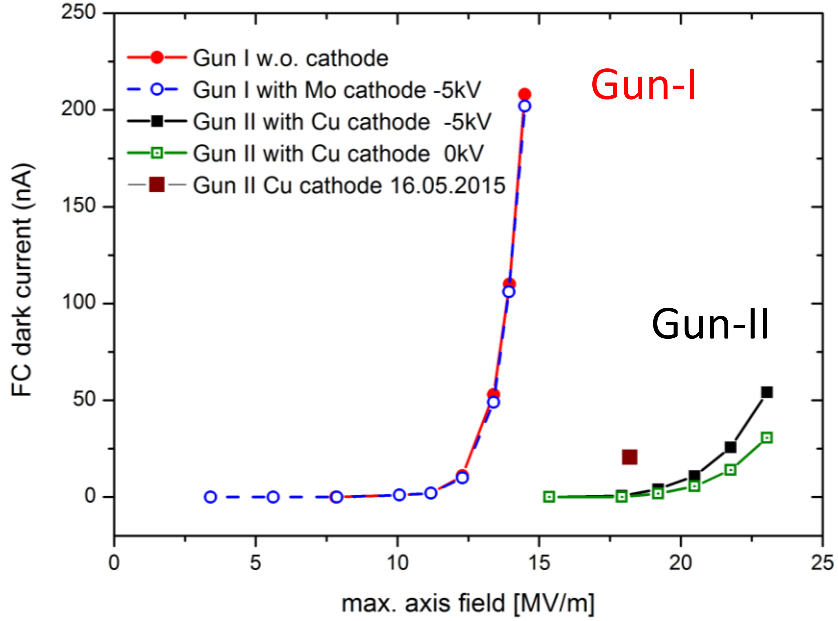
cavity: quality of treatment and cold mass assembly
particle contamination during cathode exchange !
only emitters near cathode and on iris contribute (beam direction &energy)

photo cathode:
emission layer roughness, effects of discharges, coating adhesion, particle pollution
not measured here



beam spot 200 nA and dark current 53 nA
at 9 MV/m (23 MV/m peak)

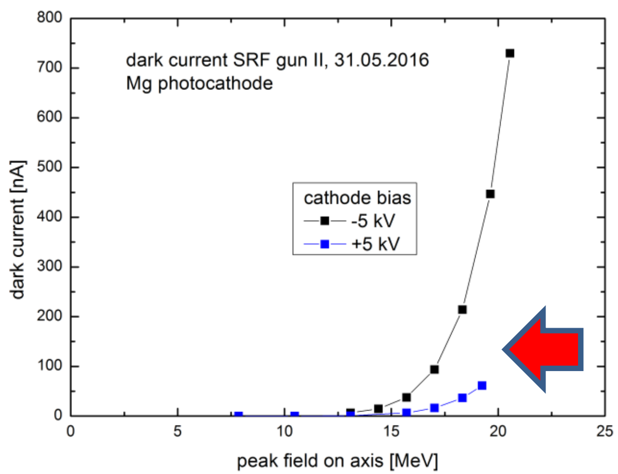
comparison of dark current
SRF guns I & II for „clean" cathodes

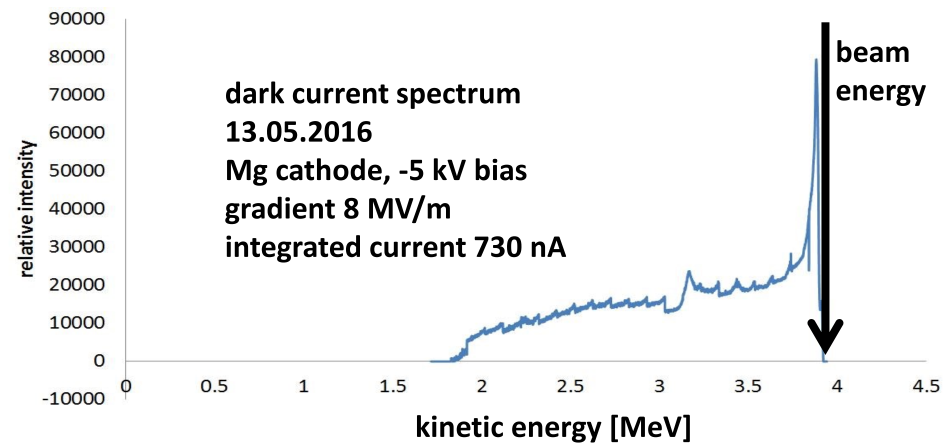


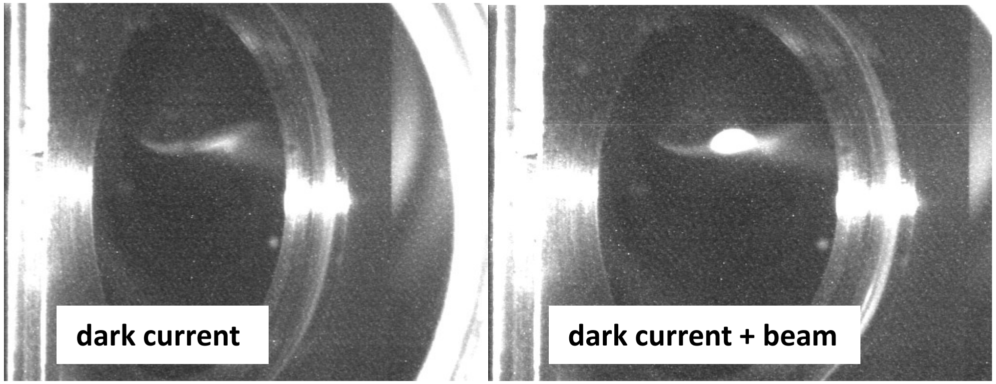
5. Operation - dark current

May 12th, 2016

activation of an existing field emitter due to photocathode movement







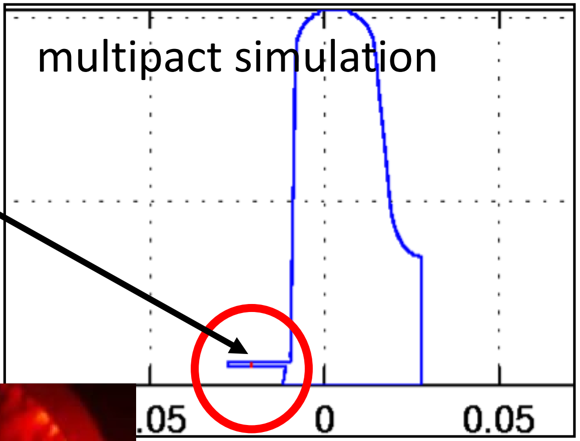
YAG screen in front of ELBE accelerator module

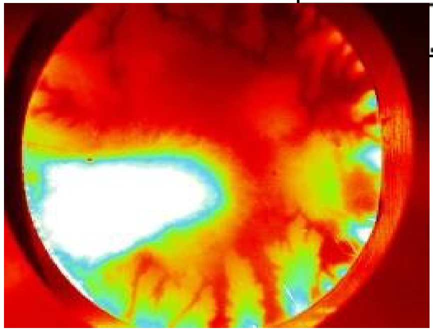
FE on cathode (?)

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

5. Operation - 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.

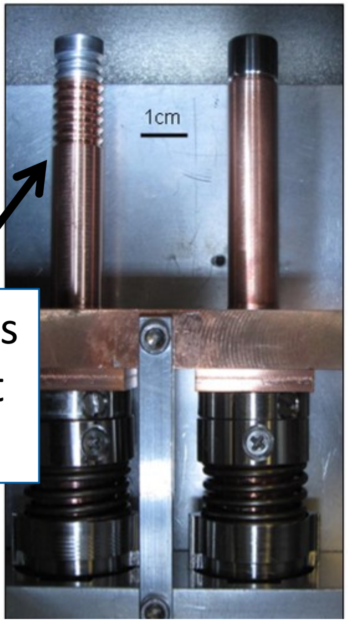




Cs_2Te: Strong MP effects, required a permanent adoption of cathode bias (-1 … -7 kV)
- **experience with first ELBE SRF gun**

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

Multipacting needs an interplay of geometry and increased SEY



grooves did not help

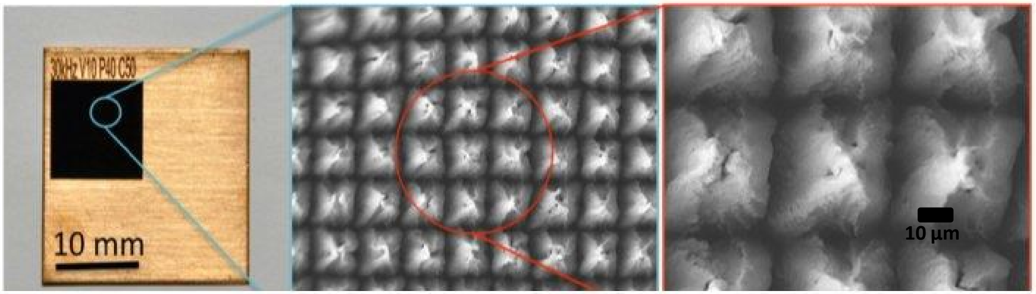
5. Operation - multipacting

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

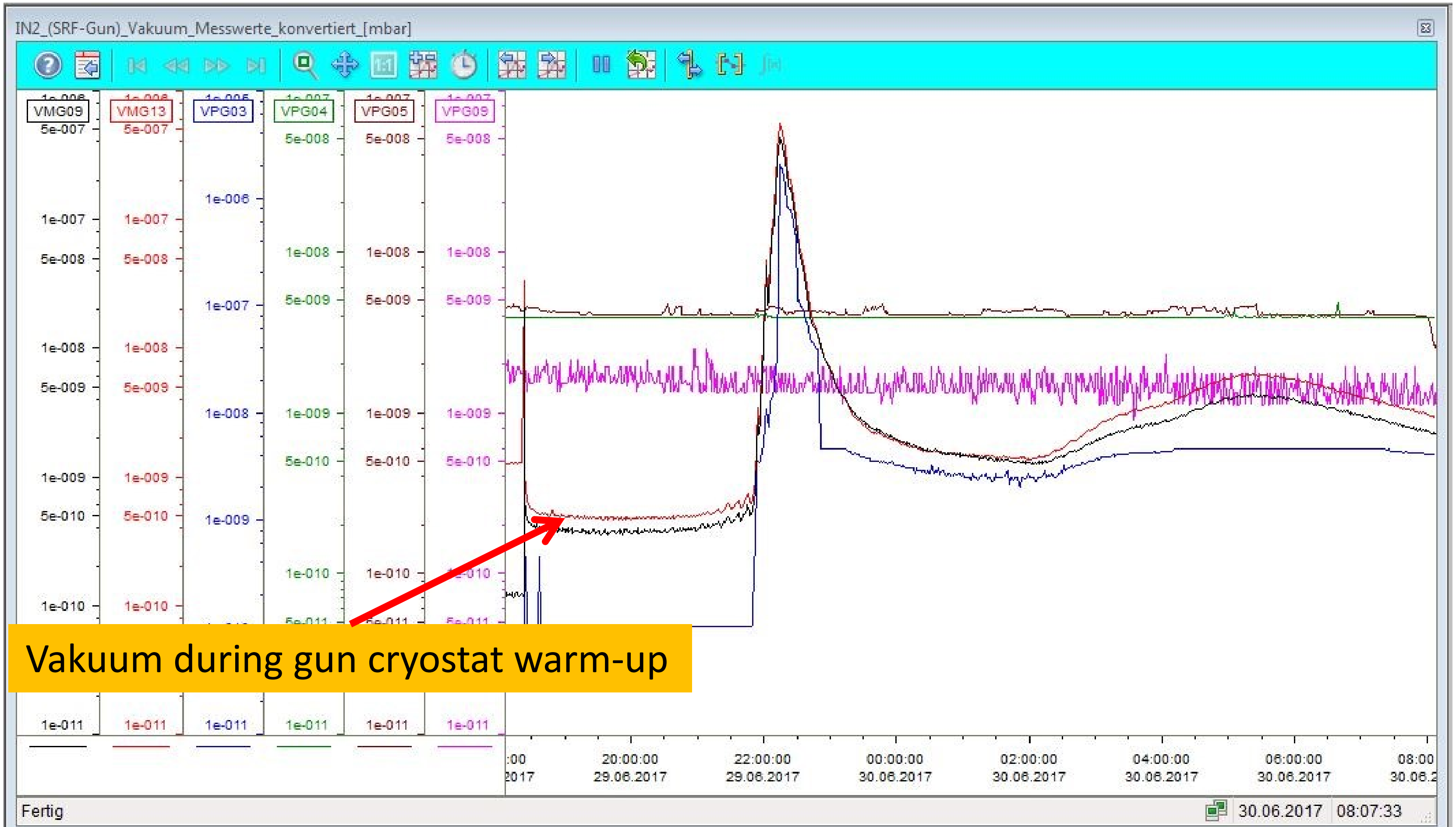


A. Gillespie, A. Abdolvand, University of Dundee
R. Valizadeh, O. Malyshev, Daresbury Lab.
LA[3]NET conference, Mallorca 2015

At present the „clean“ cathode - improved shielding in PC prep. chamber - works well for SRF gun II

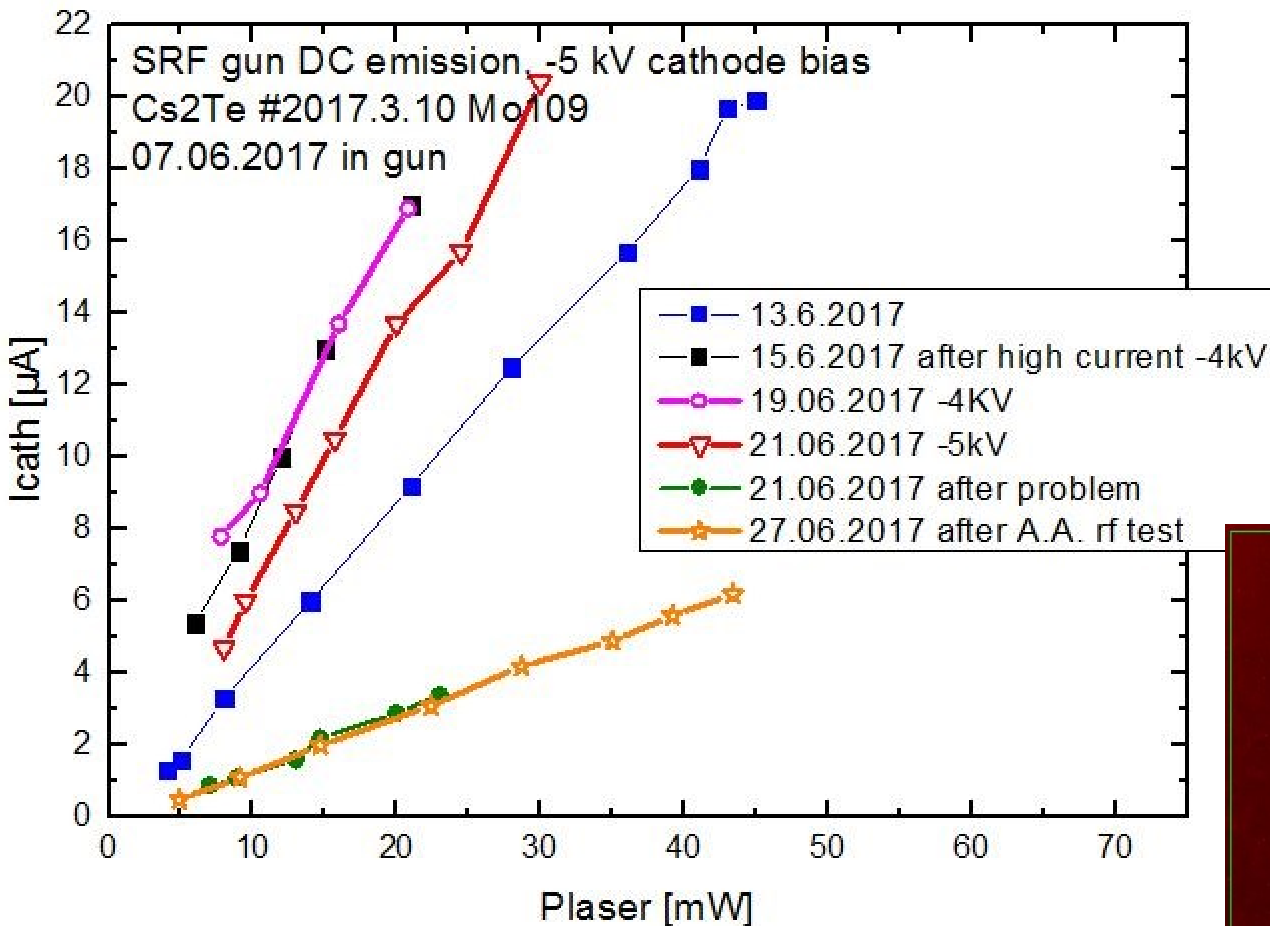
5. Operation – cavity temperature

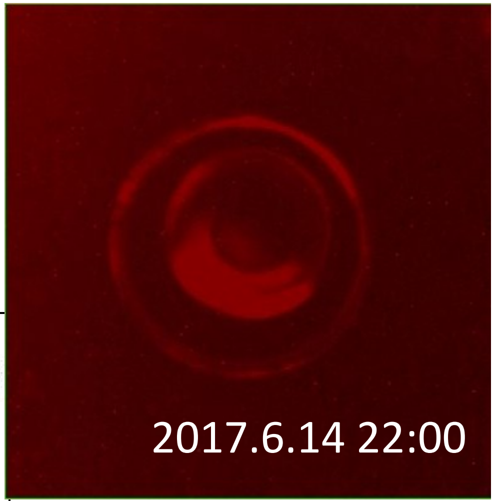
Release of collected gas destroys the PC
Moving PC in transport chamber before He refrigerator maintenance

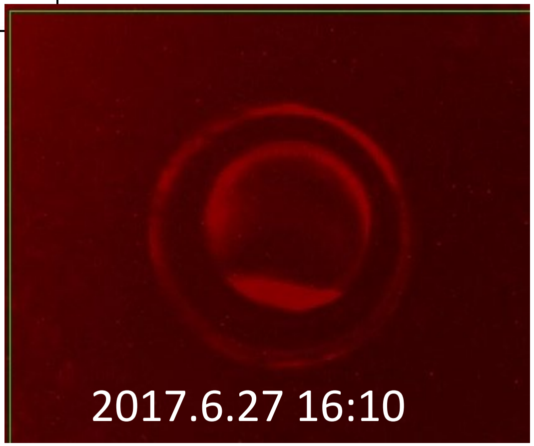


5. Operation – Cs_2Te cathode cooling

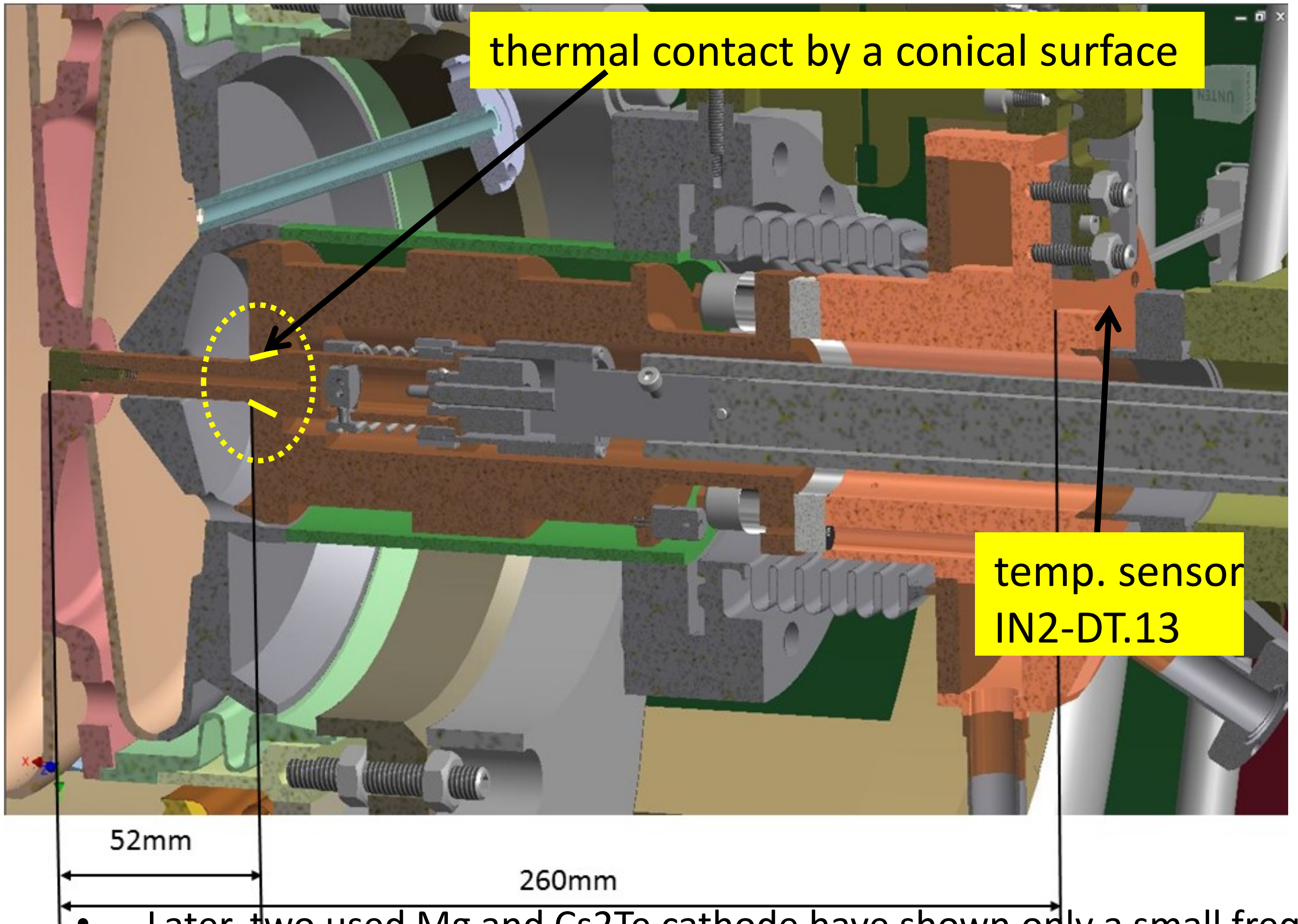
QE drop down for Cs2Te photocathode afer about two weeks operation in SRF-Gun II







5. Operation – Cs_2Te cathode cooling



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

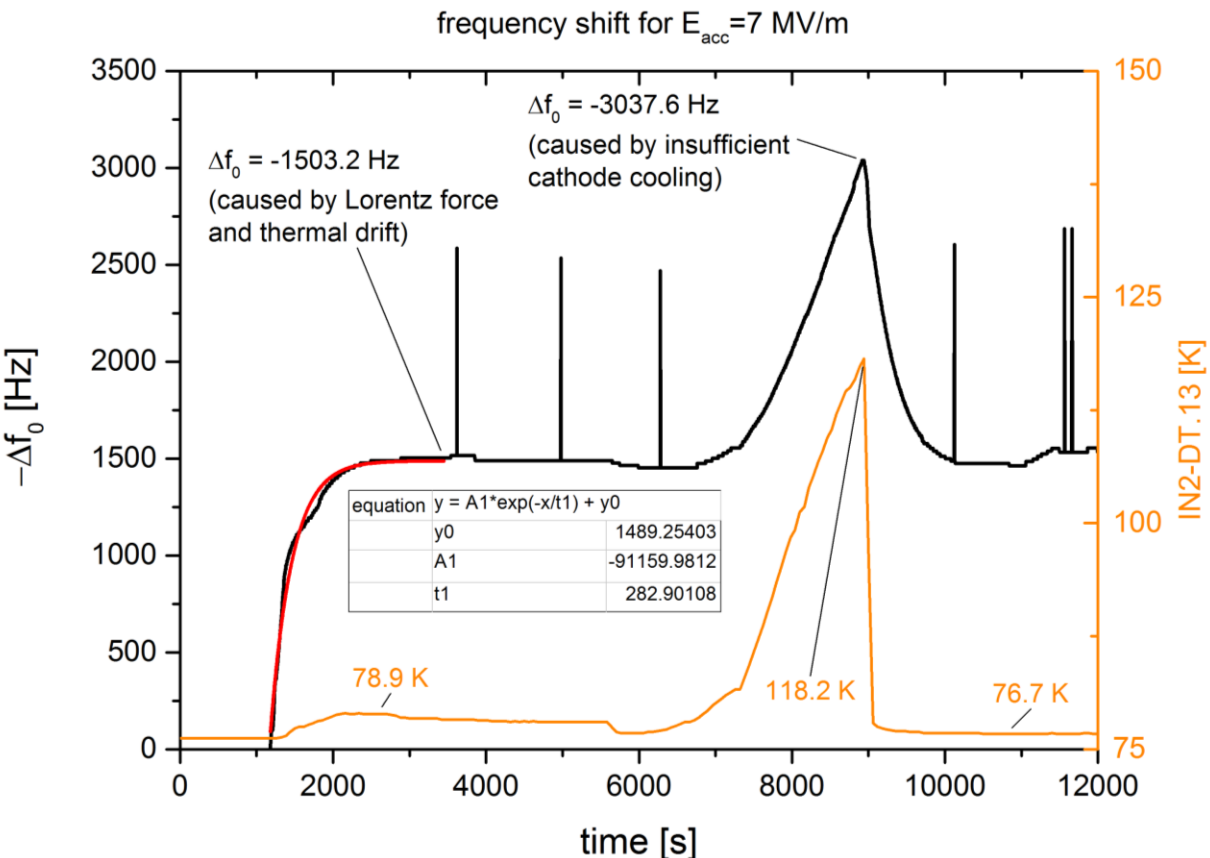
depends on
cathode plug length
assembly of cold mass
difficult to adjust & measure during assembly

- 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!

5. Operation – Cs_2Te cathode cooling

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
details why this happens in SRF Gun II and not in the former gun are unclear

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
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 **(#2017.3.10)**	June 17 – June 17	1.3 %	15 pC / 200 µA	13 MHz CW ,no multipacting, no dark current **again QE drop down after 2 weeks**, overheating! showed same behavior as Cs2Te in Febr. 2017
Mg (#214)	August 17 →	0.2 %	400 pC/ 40 µA	no multipacting, no dark current from Mg, stable operation up to **400 pC / 100 kHz** **gradient 8 MV/m (20.5 MV/m peak) Ekin = 4 MeV**

Thank you for your attention!

Thanks to the ELBE team

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and our co-workers

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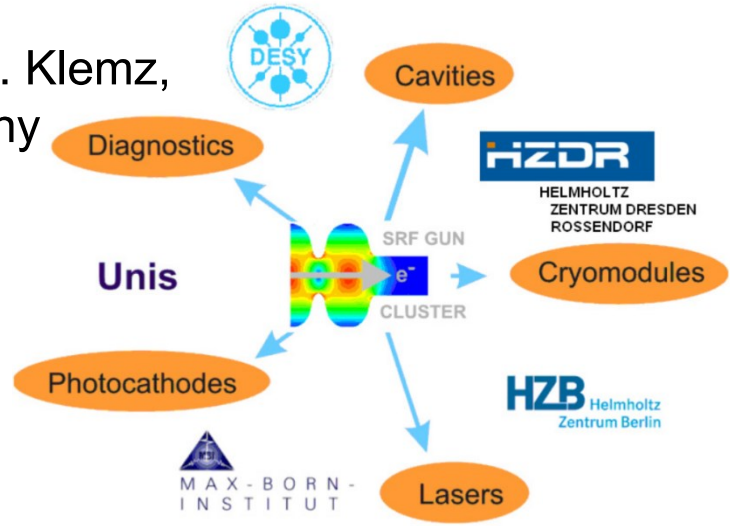

EuCARD² LA3NET Bundesministerium für Bildung und Forschung

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