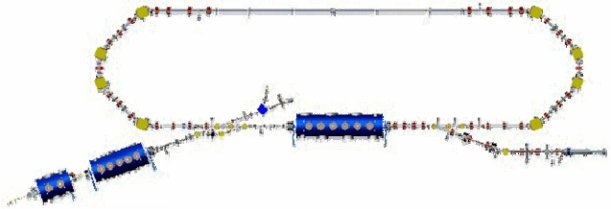
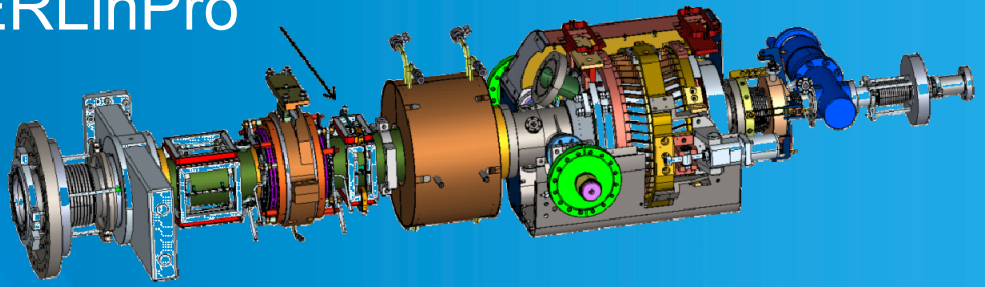
bERLin 2019

HZB Helmholtz Zentrum Berlin

bERLinPro

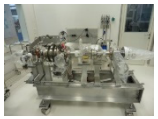


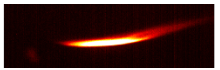
Status of SRF Gun for bERLinPro



Axel Neumann, Nawar Al-Saokal, Daniel Böhlick, Alexander Büchel, Markus Bürger, Pablo Echevarria, Andre Frahm, Hans-Walter Glock, Frank Goebel, Svenja Heling, Karsten Janke, Andreas Jankowiak, Sascha Klauke, Guido Klemz, Jens Knobloch, Georgios Kourkafas, Julius Kuehn, Oliver Kugeler, Nicole Leuschner, Alexander N. Matveenko, Sonal Mistry, Nina Ohm, Eva Panofski, Henry Plötz, Stefan Rotterdam, Martin Anton Helmut Schmeisser, Michael Schuster, Hannes Stein, Yegor Tamashevich, Jan Ullrich, Andriy Ushakov, Jens Voelker, Thorsten Kamps

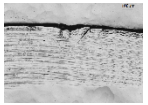
Outline:



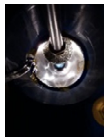


- Reminder: Layout and parameter of bERLinPro's SRF Gun

- Results: First RF and beam operation of the SRF Gun module
- Setbacks: Failures, obstacles and lessons learned

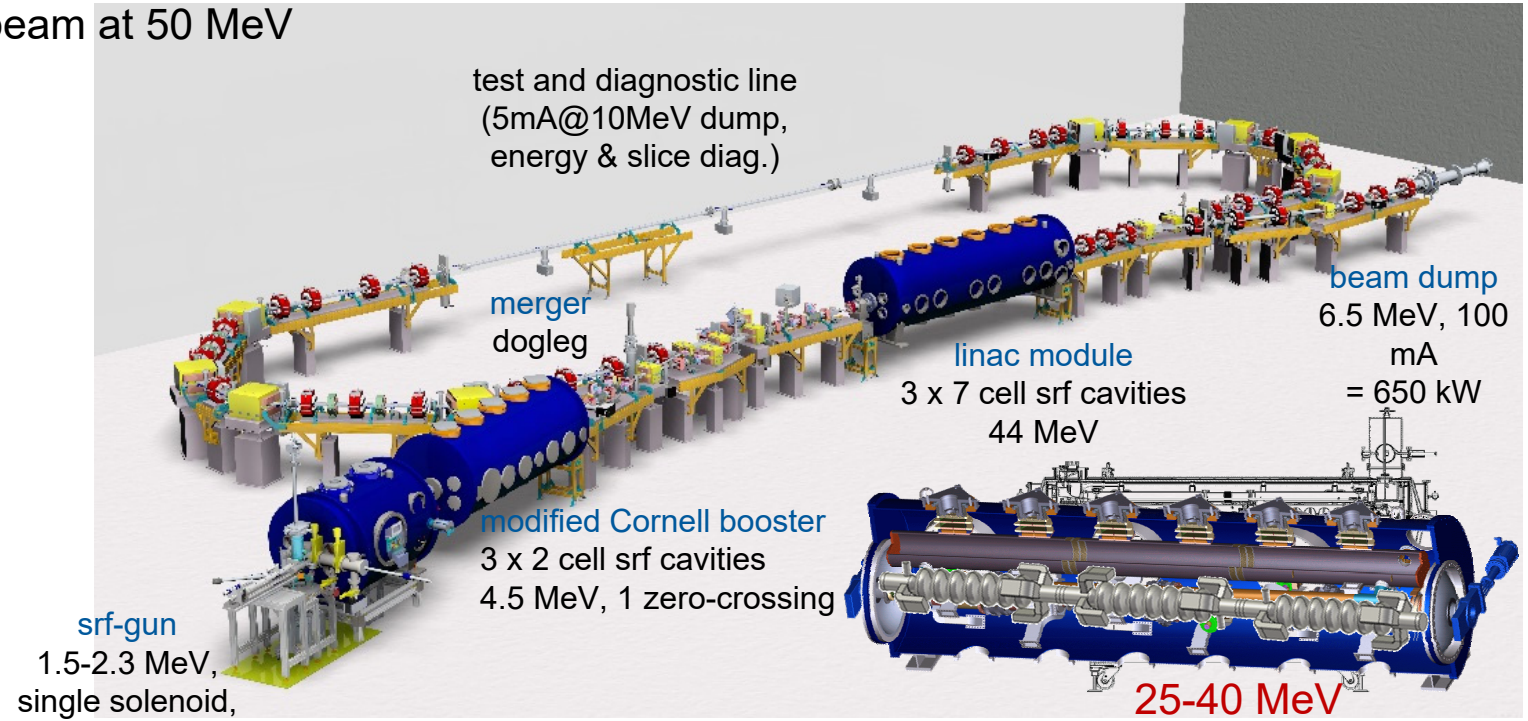


- Total recall: Understand, do new, do better



Reminder: bERLinPro

Main goal: 100 mA ERL with 1µrad normalized emittance and 2 ps bunch length beam at 50 MeV

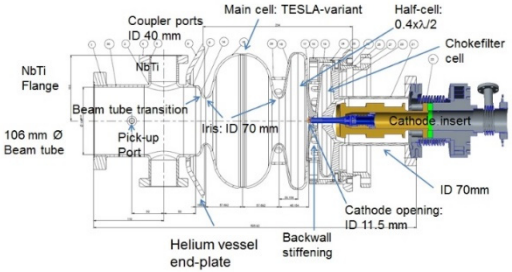


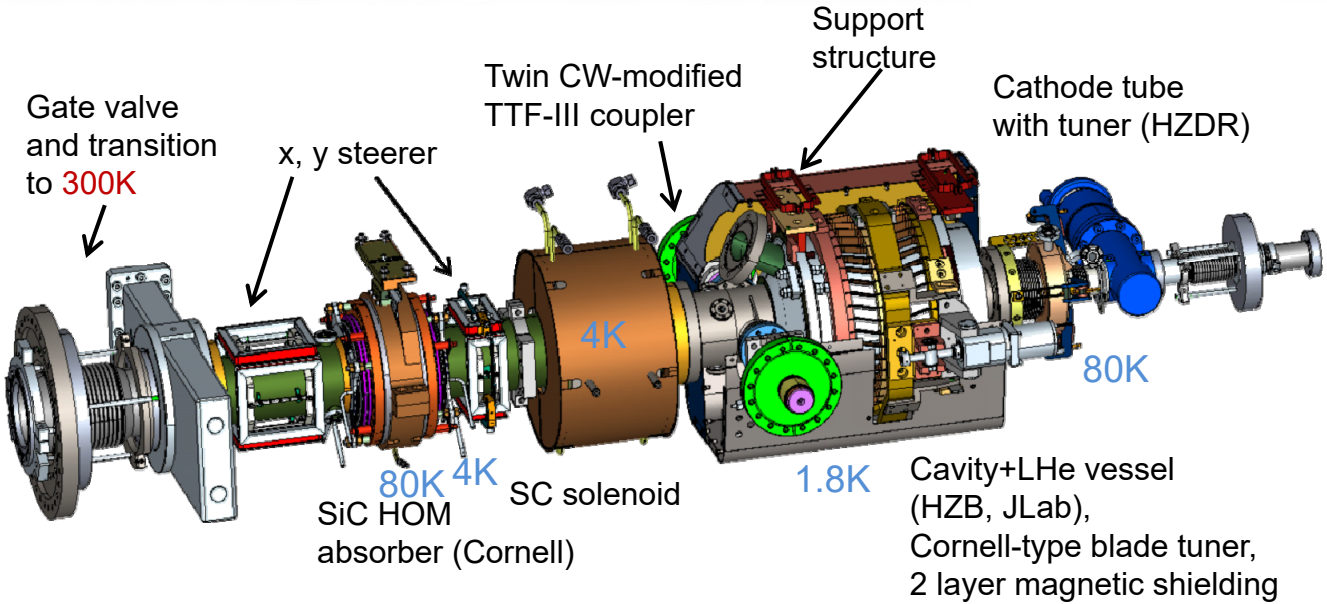
MESA@bERLinPro: 5 mA (?) with 1µrad normalized…….etc

BBU threshold > 10 mA for MESA, see MOPGW025 at IPAC19

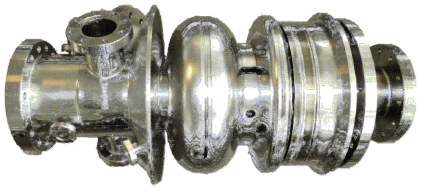
Reminder: Cold String layout of bERLinPro SRF Gun

Parameter	Design	As built
TM_{010} freq. (MHz)	1300	1300
$R/Q(\Omega)$ $\beta = 1$	150	132.5
$G(\Omega)$	174	154
$P_{forward}$ max. (kW)	20	20
E_{peak}/E_0	1.45	1.66
B_{peak}/E_{peak} (mTMV^{-1}m)	2.27	2.18
E_{kin} (MeV)	3.5	2.5-3





1.4xλ/2 cells + Choke cell



Parameter	VTA JLab*	HTA HZB*	Cold string HZB*
E_0 (MVm^{-1})	34.9	34.5	28.5‡
E_{peak} (MVm^{-1})	58	57.3	47.3
B_{peak} (mT)	111.8	110.4	91.2
low field Q_0	$1.2{\cdot}10^{10}$	$1.1{\cdot}10^{10}$	$9.6{\cdot}10^{9}$
$\Delta f/\Delta E_0^2$ (HzMV^{-1}m)^2	-4.7	-3.7	-3.4
$\Delta f/\Delta P_{LHe}$ (Hzmbar^{-1})	-561	150	33

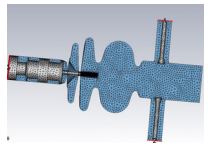
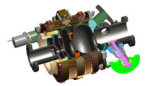
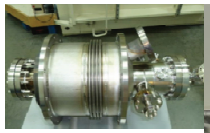
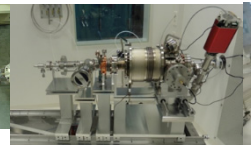
*15-20% higher found by beam energy measurements

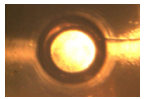
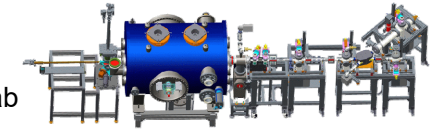
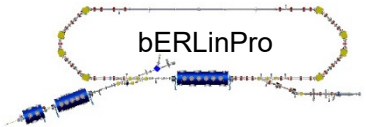
Reminder: Evolution of the first Gun module/cavity

This talk

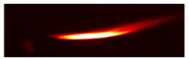
HZB | Jefferson Lab Thomas Jefferson National Accelerator Facility | HZB | HZB

PC | VTA | VTA/HTA | HTA | Gunlab | bERLinPro

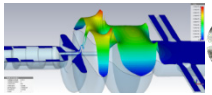





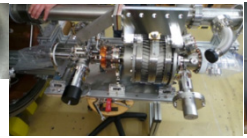





1st Beam



- Decommissioning
- Refurbish
- Rebuild



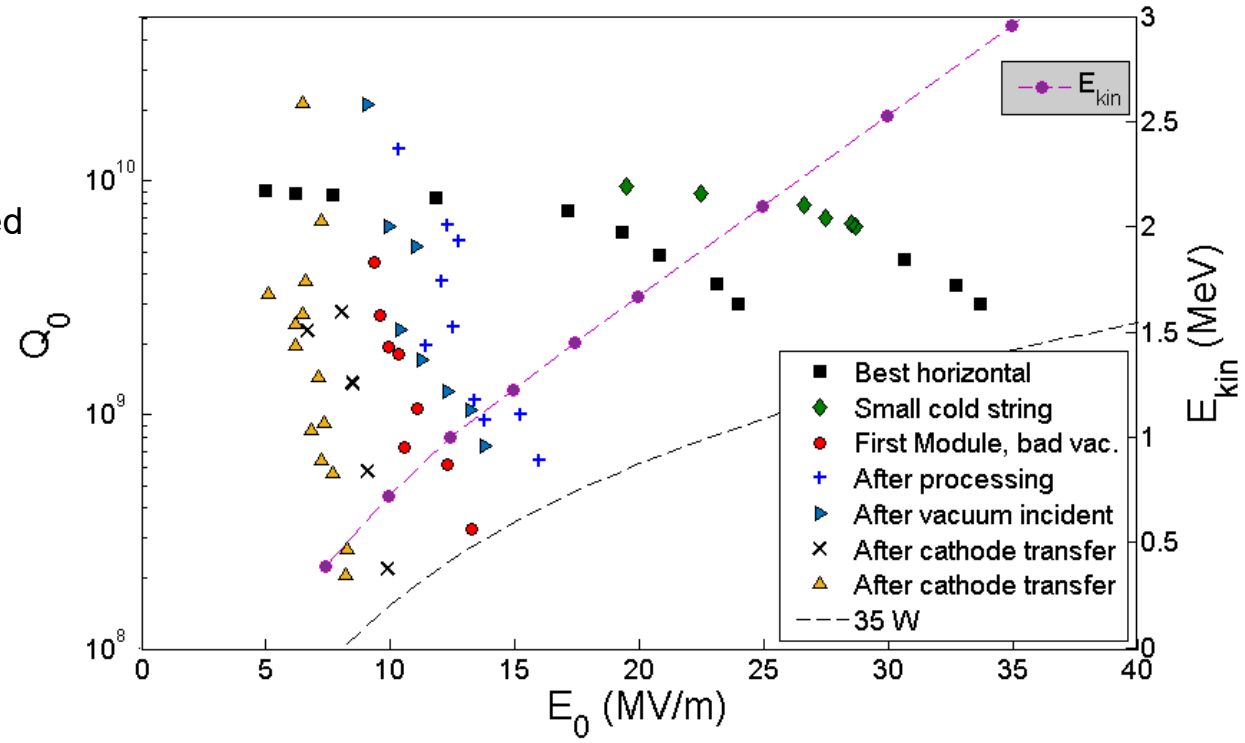
Cathode transfer

Design	Manufacture	Test/Assembly	String test	String/Cold mass	Module assembly	Commissioning
2011-2012	2013	2014-2016		2016	2017/2018	2018-2020

Time

Results: Evolution of Q_0 vs. E_0

- This cavity was built too short in half-cell
  → Impacts Multipacting
- This cavity always showed strong field emission
- Clean procedures kept during all installations
- Strong degradation after opening to beamline + cathode transfer



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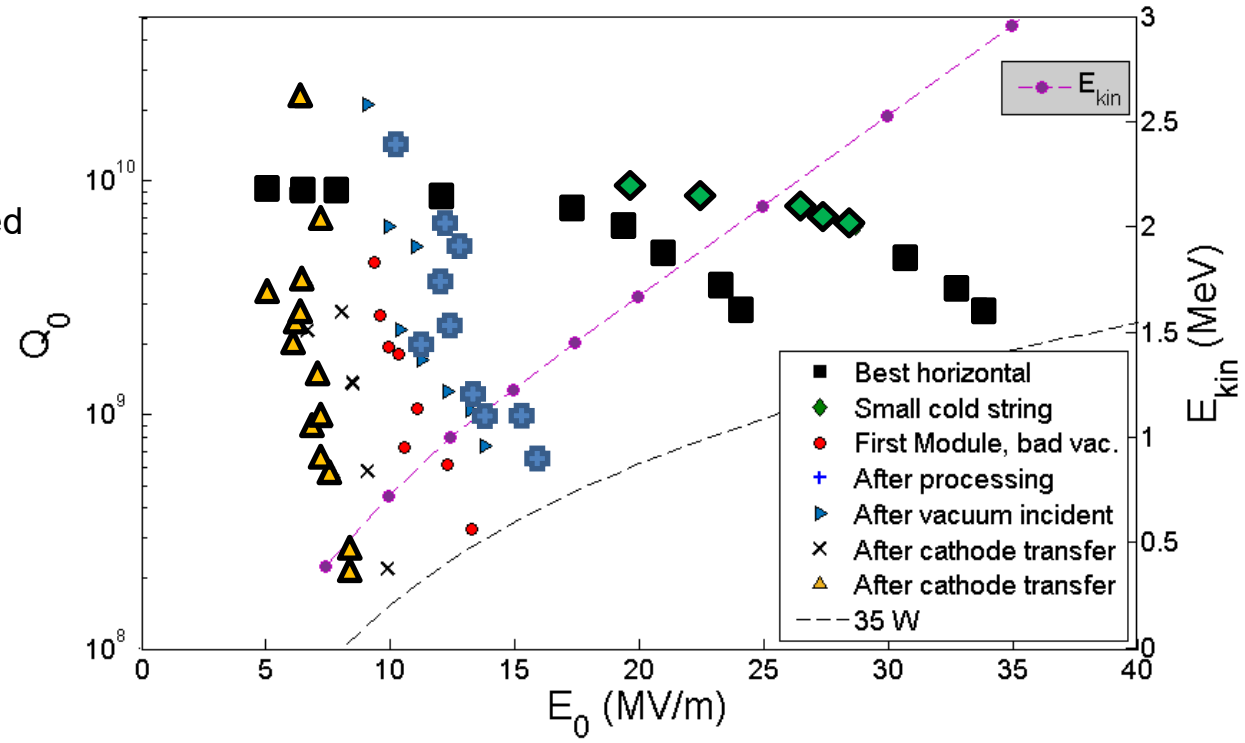

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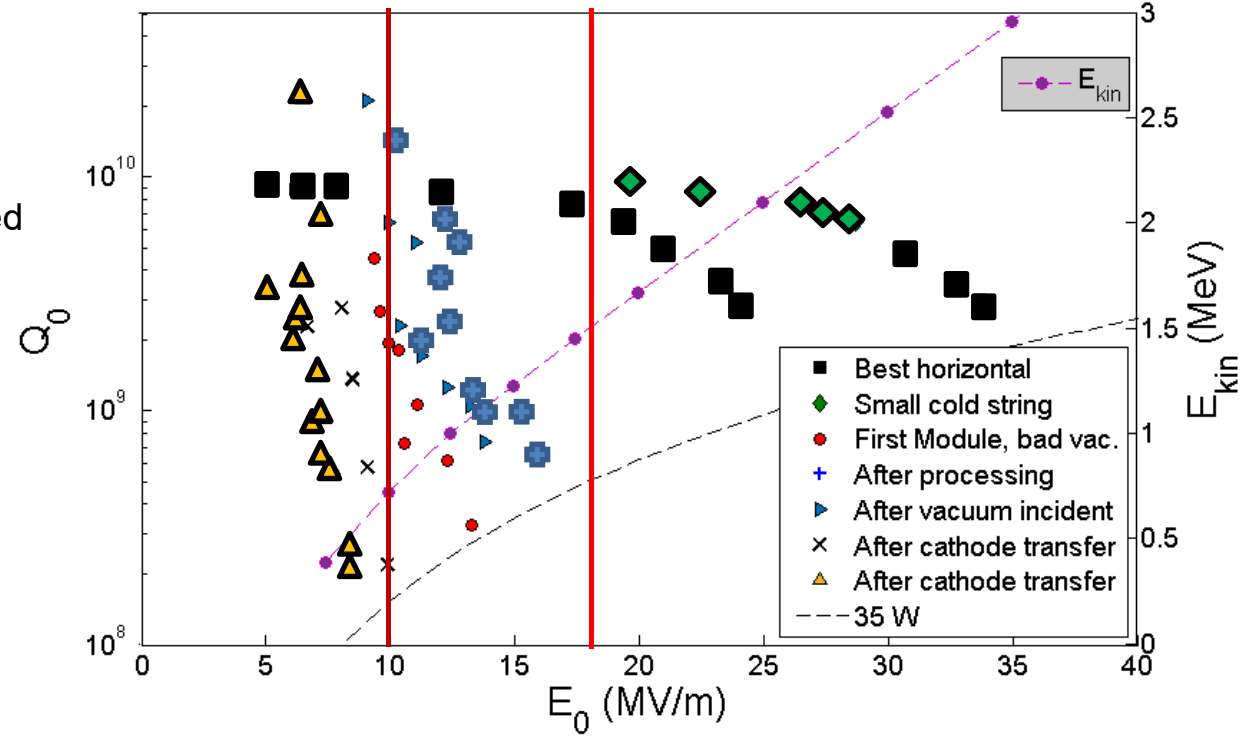

- For beam dynamics program: $E_0 \geq 18$ MV/m, eventually 16 MV/m
- For QE, i.e. cathode program: $E_0 \geq 10$ MV/m
- The field level displayed here is eventually 20% higher (given dark current energy measurement was correct)

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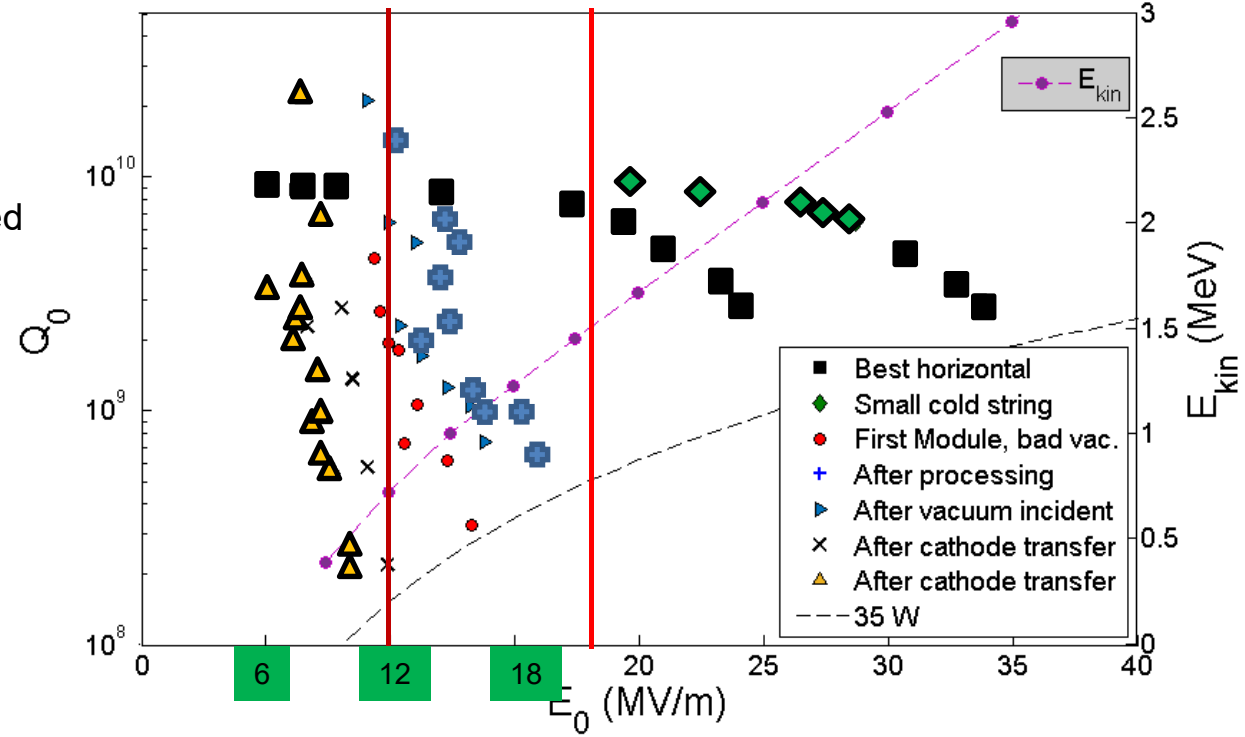

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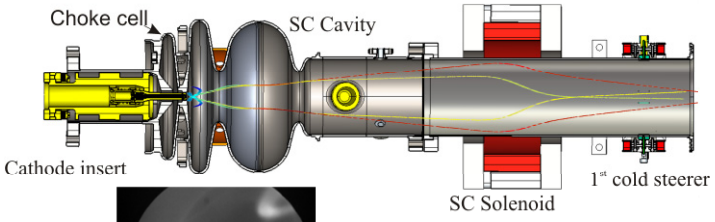
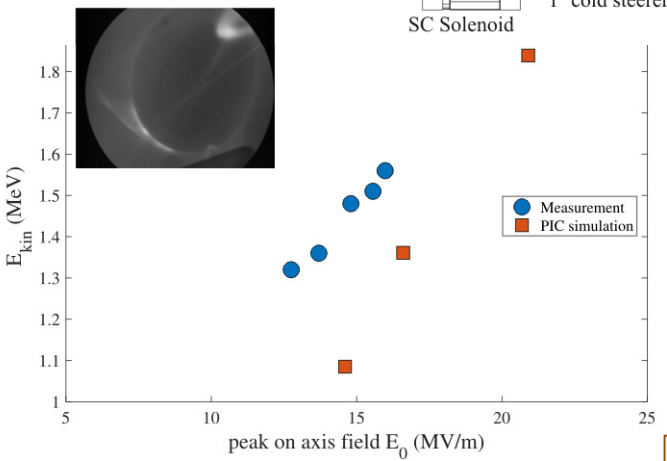
Results: Evolution of Dark current

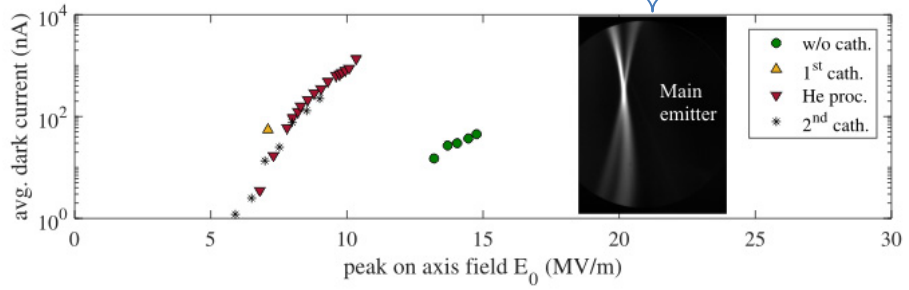
(with and without cathode)

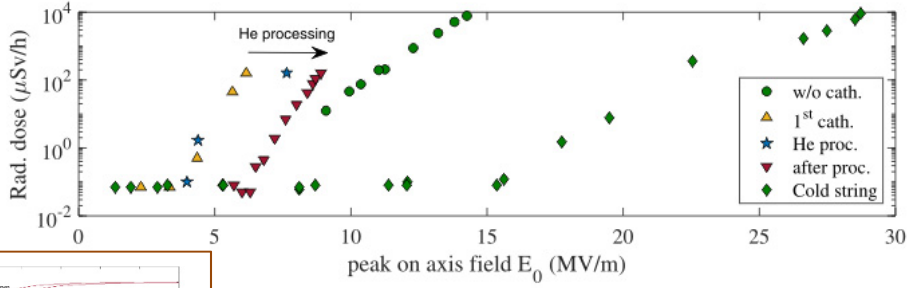


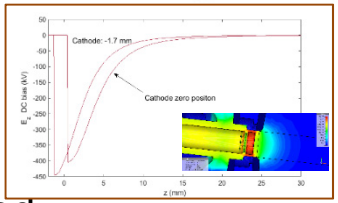


Imaging of cathode opening on 1st screen by solenoid, used for field correction of RF calibration
→ Field 15-20% higher than expected

E_0=7.0 MV/m p_z = 0.86 MeV/c and 0.82 MeV/c, 75% of total current



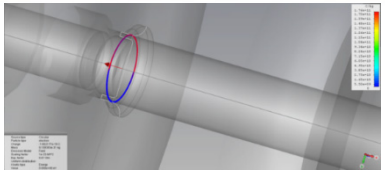




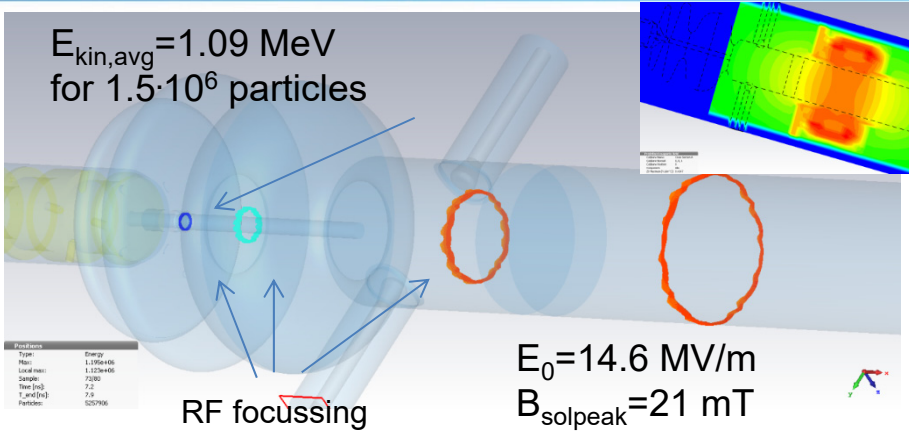
DC bias

As seen with Q_0 measurements, field emission got worse with each step
Helium processing helped gaining about 2 MV/m

Results: Dark current to calibrate field level



Ring emitter on cathode opening



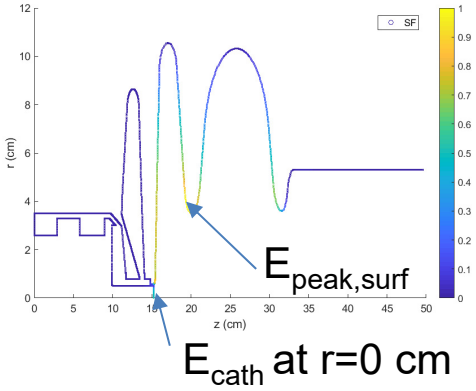
Solenoid field

Simulation setup

1st measured Dark current in Gunlab/ bERLinPro SRF gun

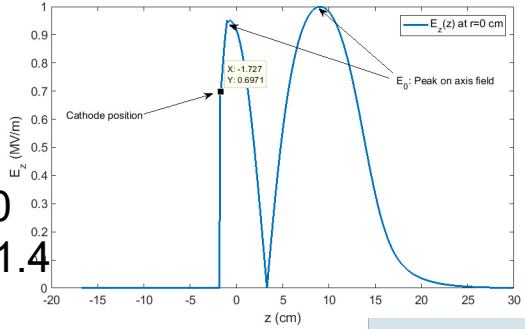
Dark current image on first viewscreen with scanning the solenoid field

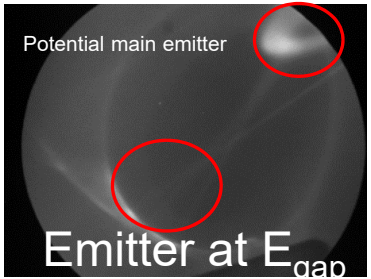
Results: Dark current, where does it come from?

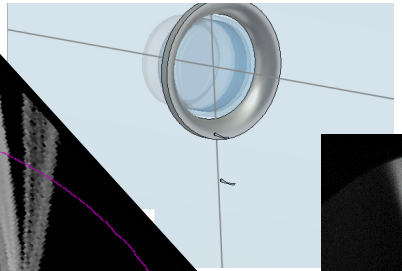


$|E_{surf}|$ normalized to max($|E_{surf}|$)

E_{cath}/E_0=0.70
$E_{peak,surf}/E_0$=1.4







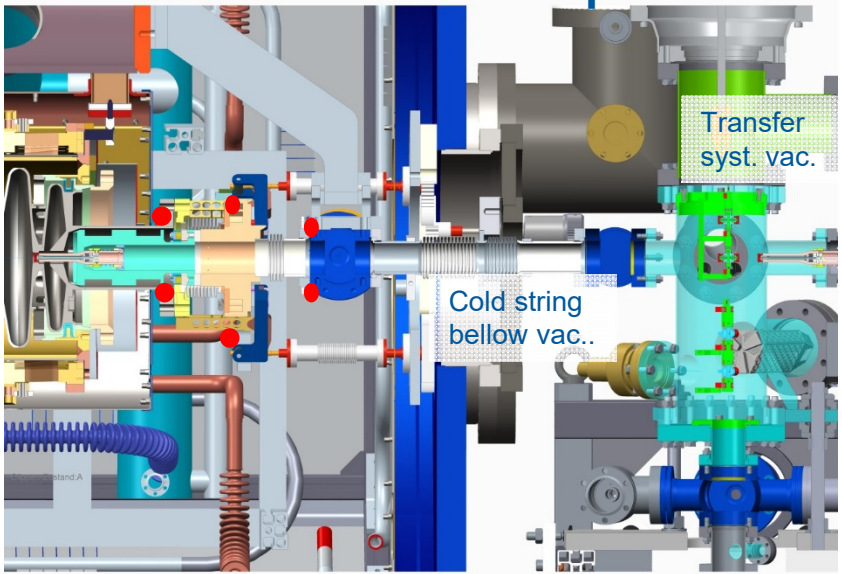
CST PIC model

→Correct E_0 from RF with proper energy scaling
→ Determine ratio of E at emitter location to E_0
E.g.: E_{cath}=0.7*E_0,
E_{gap}=0.9*$E_{peak,surf}$=0.9*1.4*E_0=1.3*E_0

Simulation

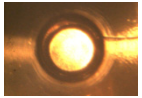
Results: Cathode transfer procedure

Cathode transfer is the most critical procedure after clean room assembly!

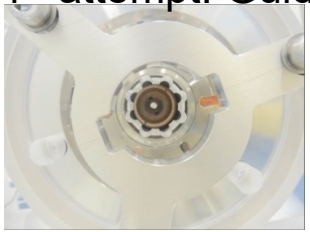


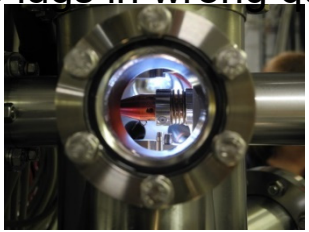
Diagnostics for transfer:

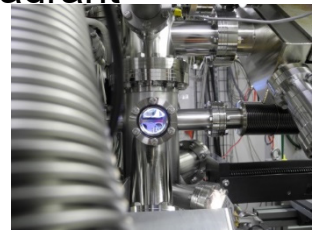
- Vacuum gauges
- Temperature sensors
- 2K Helium flow
- Capacitive positioning sensors (3)
- TM_{010} passband and Choke cell eigenmode frequencies
- Electrical contact
- Cathode camera
- Scale



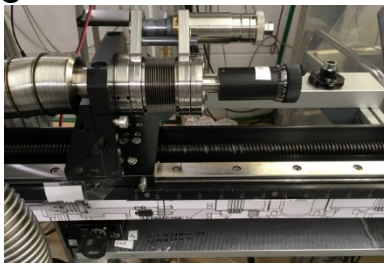
1st attempt: Guide lugs in wrong quadrant





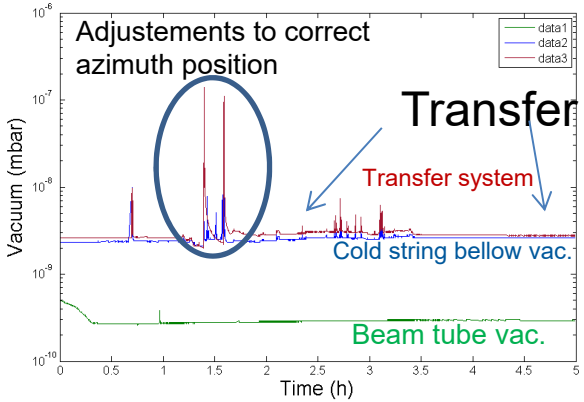


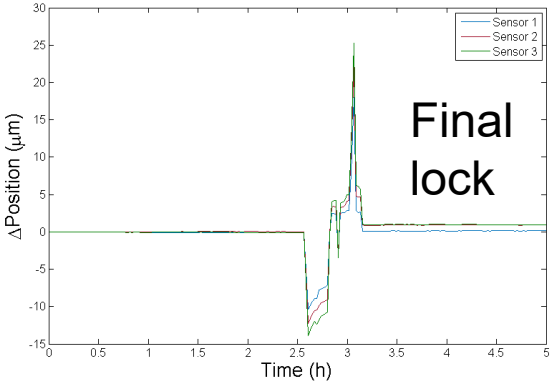
2nd time corrected



Cathode transfer: Observations 2nd try

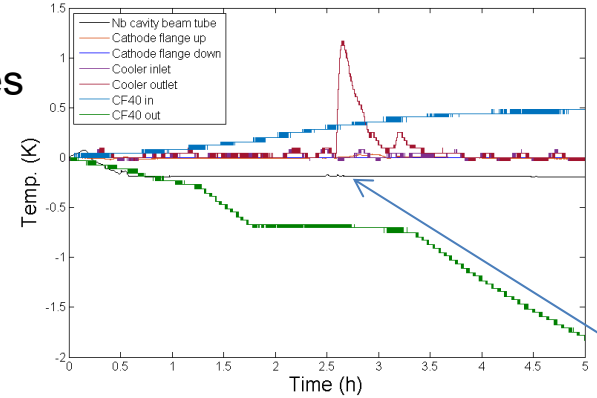
Vacuum

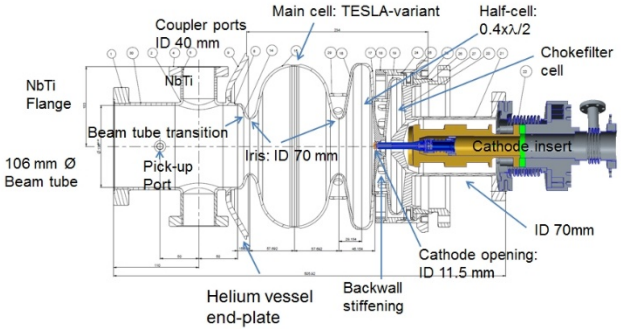




Measurement by capacitive position sensors

Temperatures

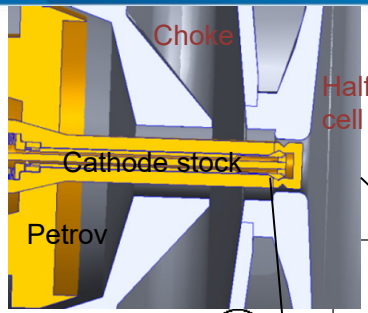




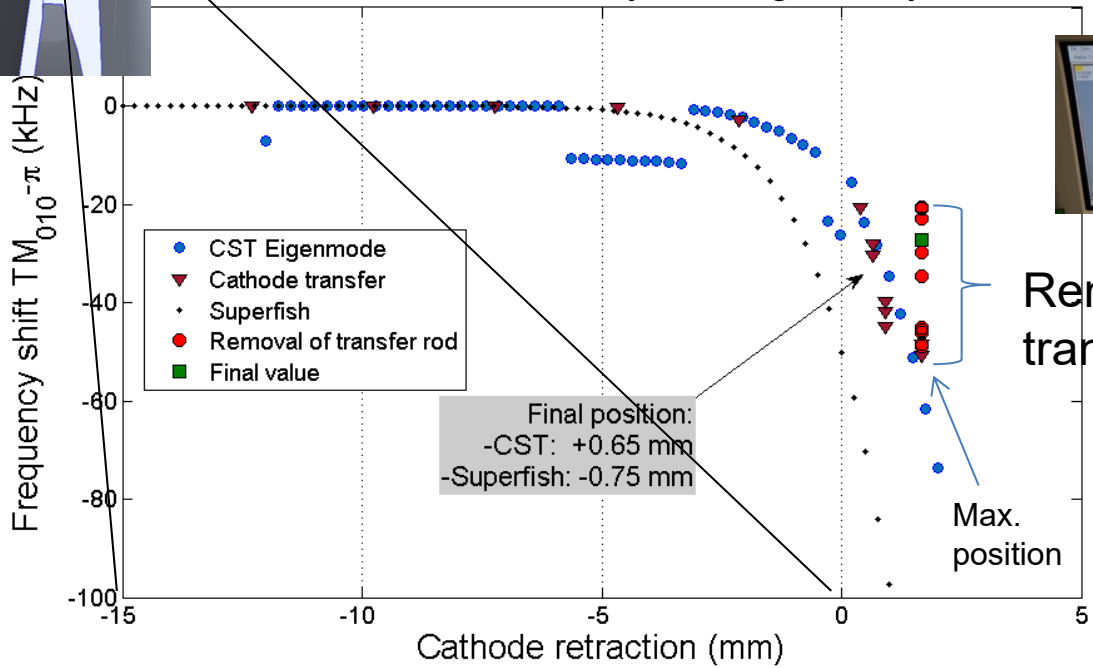
Geometry

Cathode stock moves into cone of Petrov filter/cooler

Cathode transfer: Resonator's response

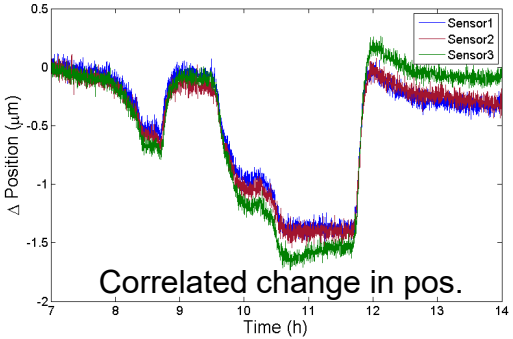


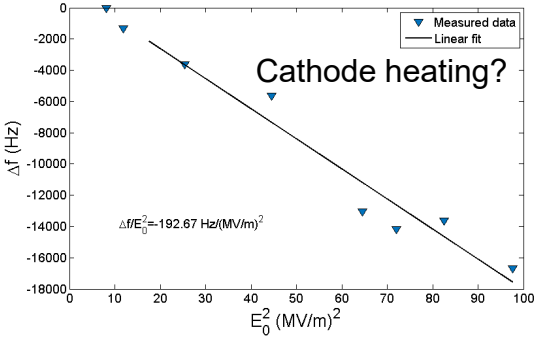
- For the cathode transfer no absolute positioning measurement possible/available at that time
- Used shift of Choke cell eigenmode and TM_{010}-π mode to obtain frequency shift vs. Cathode position (S_{21} FPC-Choke)
  Simulation inaccuracy: Exact geometry of half-cell

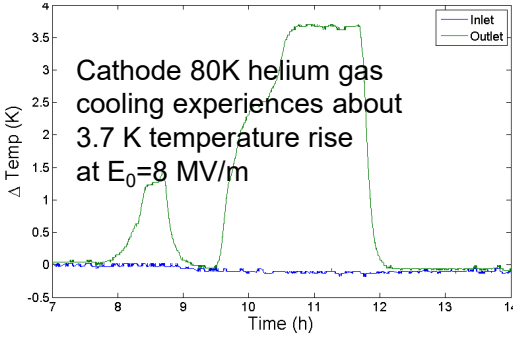


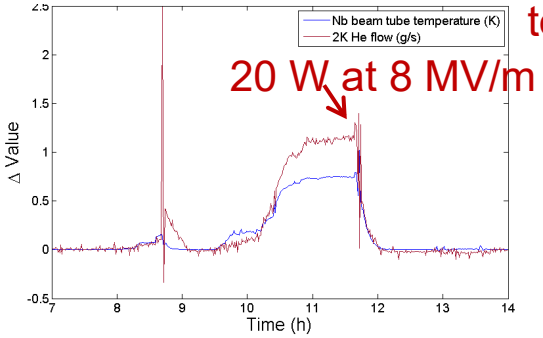
Removal of transfer rod

Results: RF response with cathode









Lorentz force detuning is about -3.4 HZ/(MV/m)²:
Here -200 Hz/(MV/m)²
→ cathode too far in?
Shift by ≃ +0.5 mm to +1.2 mm!

High beam tube temperature increase hints at higher level of field emission

Two possible explanations:

- Cathode too far in, elevated field level at cathode and increased losses along cathode carrier
- Bad surface quality (rather not) and loose thermal contact between plug and cathode carrier, sputtering by gap at cathode

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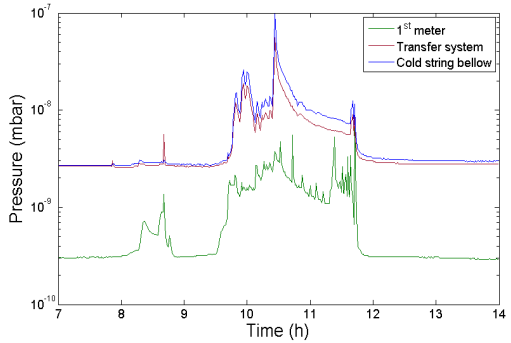

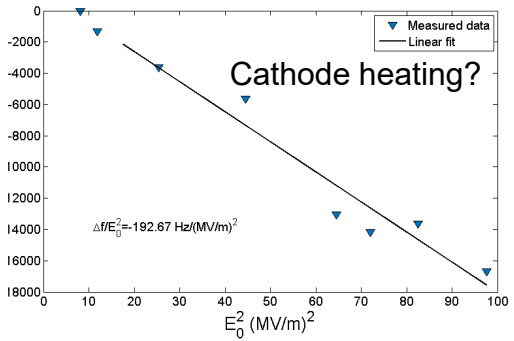

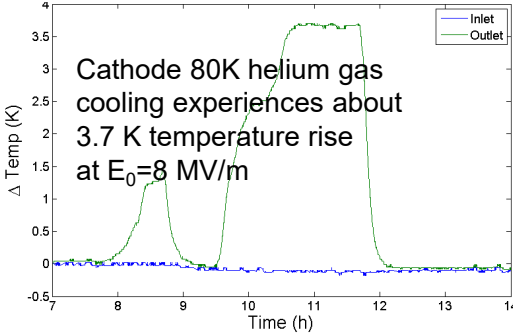

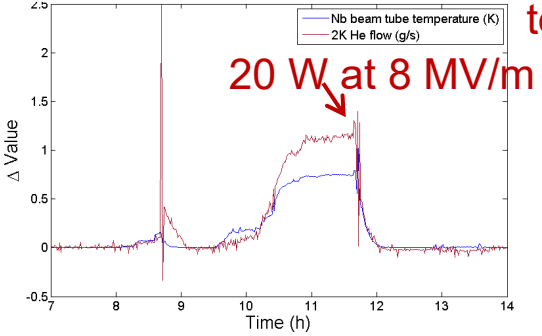

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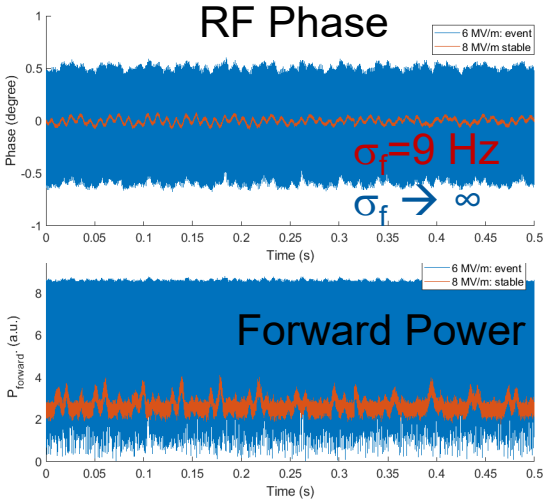
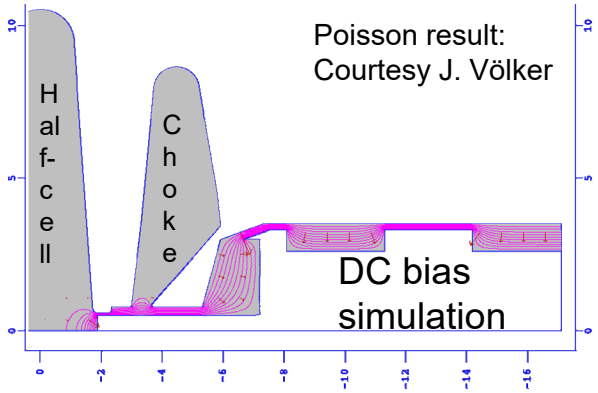
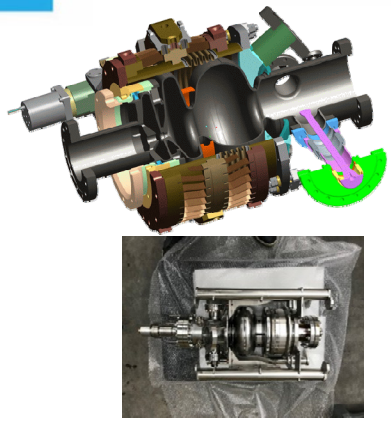
SRF gun LLRF operation with Cathode

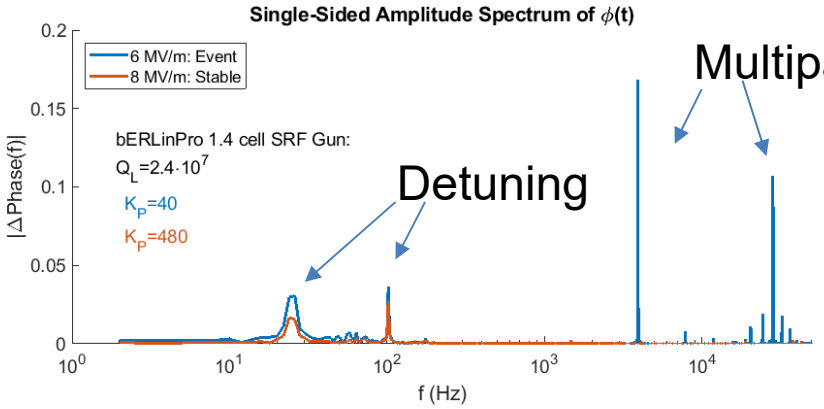




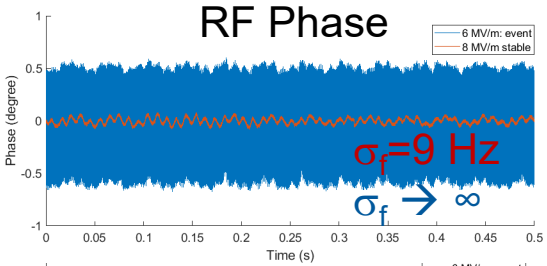


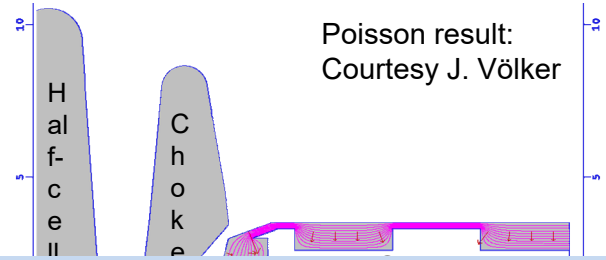
- This instability was affected by DC bias voltage in cathode channel
- This is used to mitigate Multipacting
- Strong correlation with vacuum activity
- Piezo in lowpass PI loop

No direct correlation to loop gain!

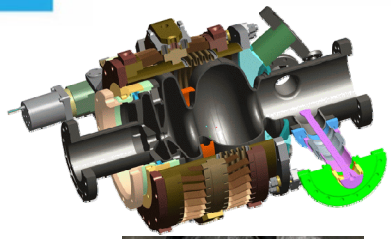


SRF gun LLRF operation with Cathode





Poisson result:
Courtesy J. Völker



Detuning rms: 9.8 Hz
Peak detuning ± 20 Hz
Main contribution first mechanical eigenmode,
Candidate for active resonance control
Stability: σ_ϕ=0.03 deg., $\sigma_A/A=1.5\cdot10^{-4}$

- This instability was affe
  by DC bias voltage in
  cathode channel
- This is used to mitigate
  Multipacting
- Strong correlation with
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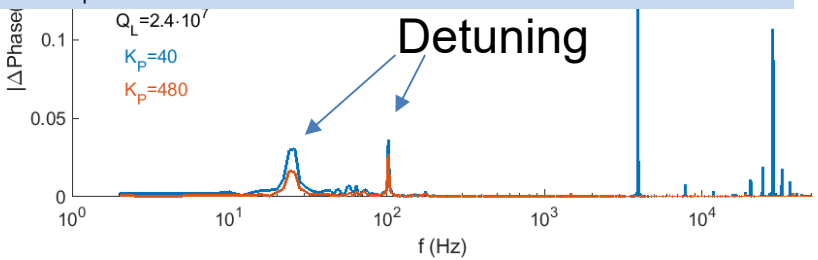
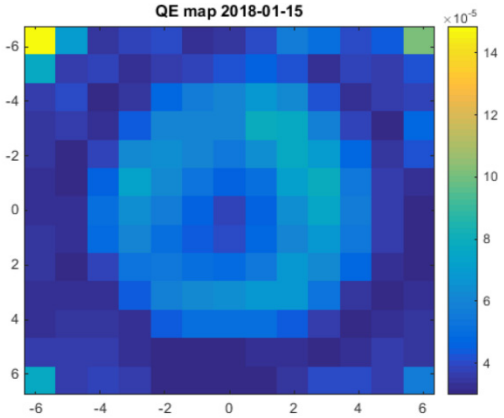


n to loop gain!

pacting?

Increased
SEY by Cu?

Results: First beam properties with Cu cathode



Laser + cathode

- QE scan (laser power vs current)
- QE map (laser spot position vs current)

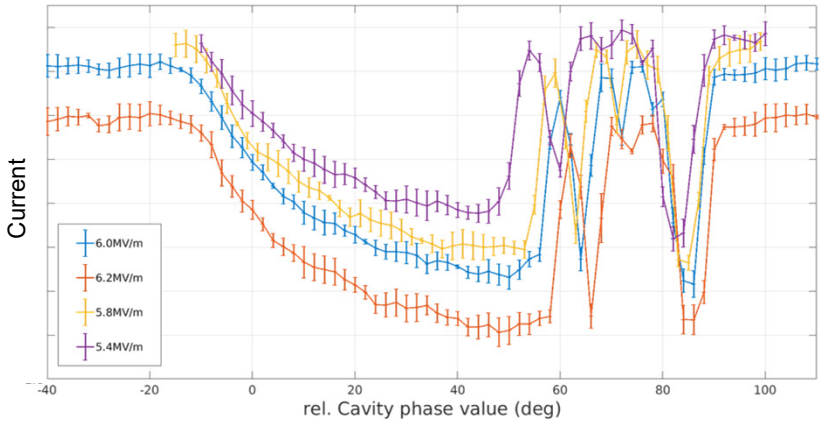
Cu at 80K
QE around some $1 \cdot 10^{-5}$

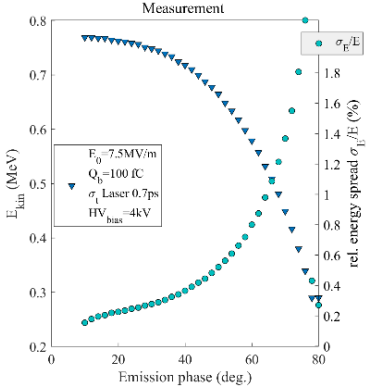
Current

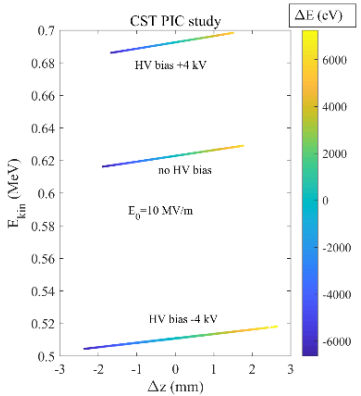
- Shottky scan (current vs gun phase)
- Fowler-Nordheim scan (dark current vs gun gradient)
- DC-bias scan (dark current vs high-voltage bias)

Momentum (spread)

- momentum scan (momentum vs gun phase)





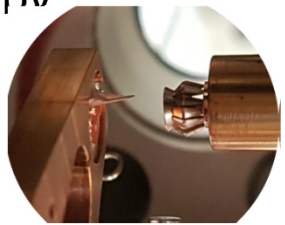


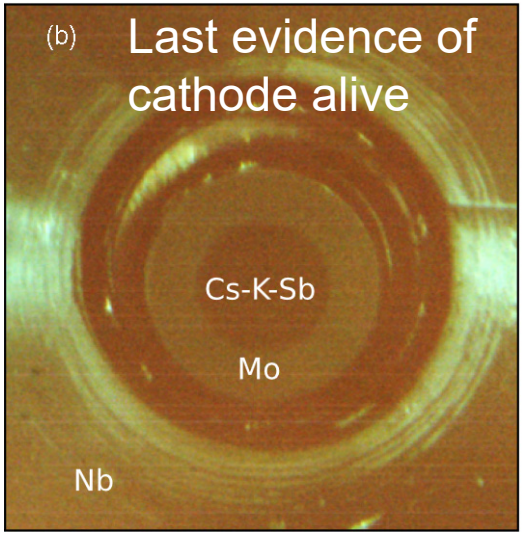
IPAC18, tupmf002,tupml053

Setbacks: Loss of cathode

During operation with Cu cathode obviously we had some activity on-going (Vacuum events, multipacting, heating after first transfer)

- We observed some issues with the cathode holder, but were not aware about the severity of damage.
- Given project boundaries and a high QE cathode of CsK2Sb on Mo (12.7% at 2.33eV or 532nm) we decided for a transfer into the gun.
- It was lost when releasing the transfer rod from the insert.
- Later we saw damage to the holding mechanism and Cu cathode eventually caused by high temperatures and sputtering





doi:10.1103/PhysRevAccelBeams.21.113401

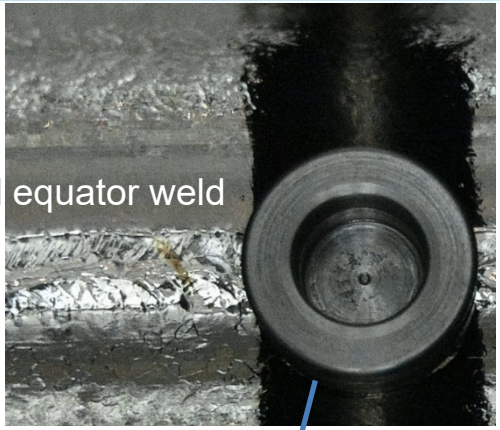
Cathode talk: Sonal Mistry, Wednesday

What now?

- We obtained a large collection of experience, somehow the amount of problems observed at other labs squeezed into 1-2 years
- We had a SRF gun with a cathode inside the half-cell
  → Can we salvage the cathode w/o further damaging the cavity?
  → Do we observe any issues by cathode sputtering
  → Do we even find remnants of the shattered screen?

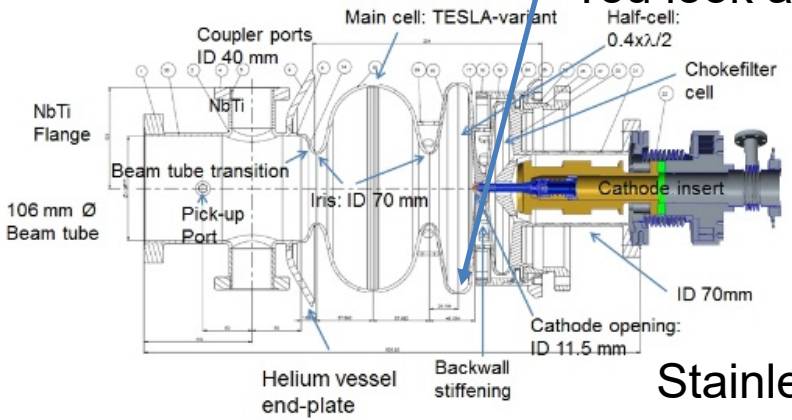
- What is the status of our second Gun Cavity?
  → We already know, that it was mistreated during production ("overtuning", blown up in ultra-sonic bath), not field-flat
  → It showed some not understood Q_0 slope at higher fields (no field emission)

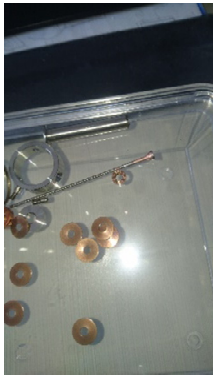
Setbacks: How to salvage a cathode?



- The cathode Mo Plug was found by optical inspection and removed with replica method
- Inspection of cathode surface by laser scanning confocal microscopy as well as the surface of cathode opening
- We found defects, which explain dark current as shown before

You look at here



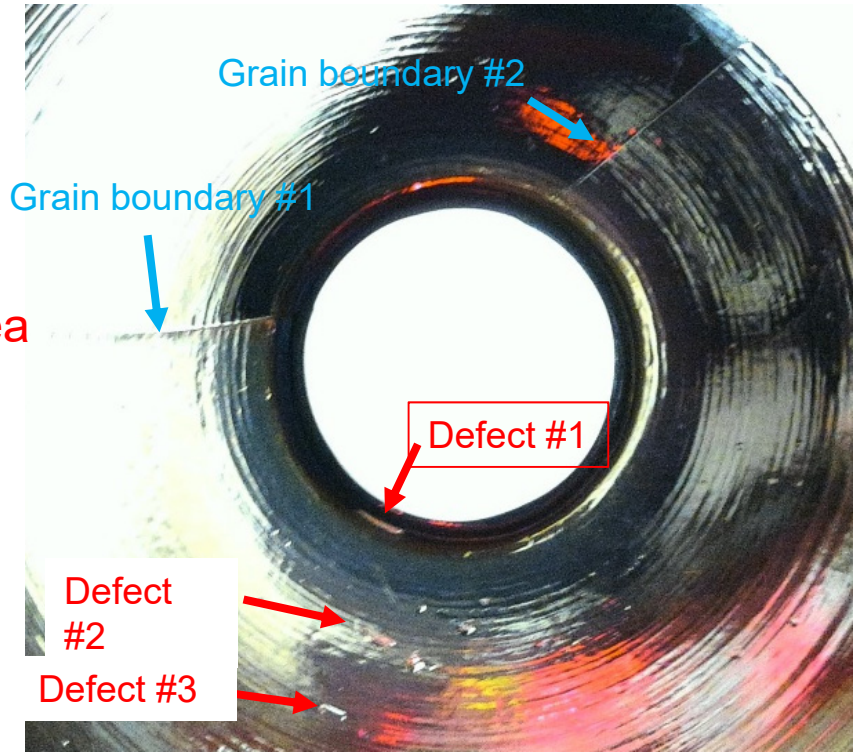


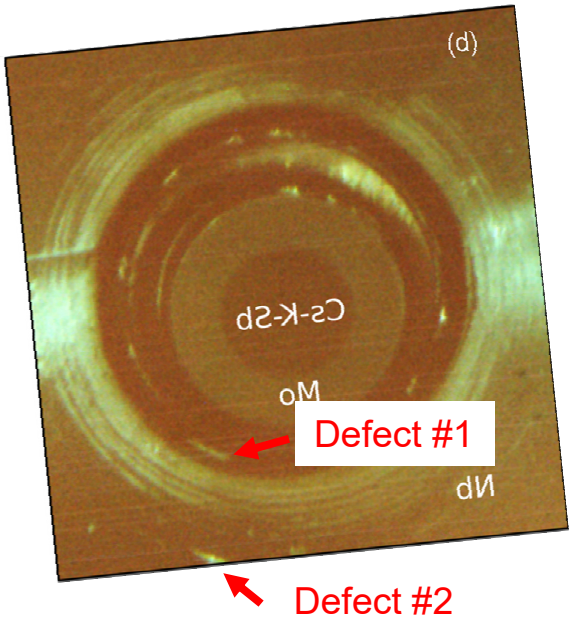
Damaged cathode holder

Stainless steel parts were sputtered by Copper cathode

Setbacks: Check cathode area for defects

Inspection was continued and defects visible by eye were found around cathode opening (Y. Tamashevich, J. Ullrich, A. Neumann)





Compare cathode camera pic in:
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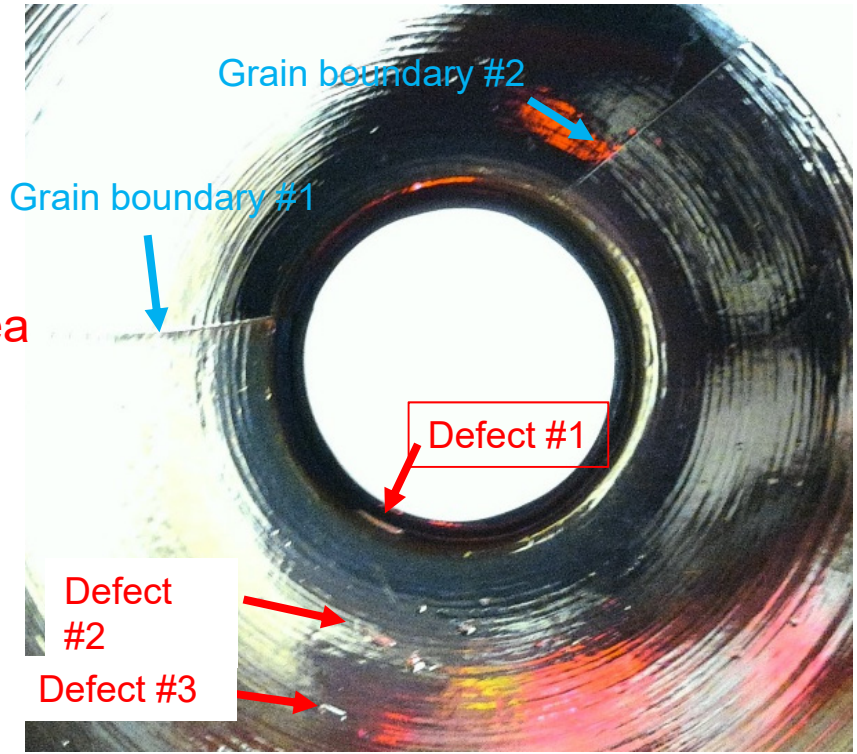
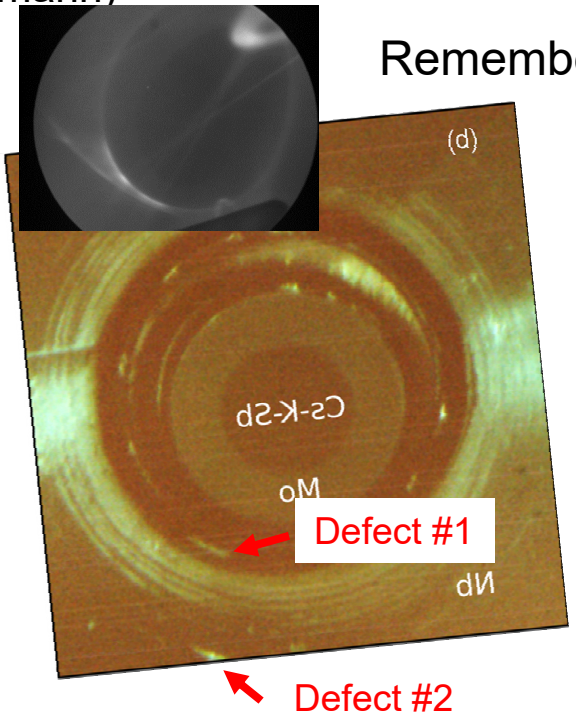


Remember!



Compare cathode camera pic in:
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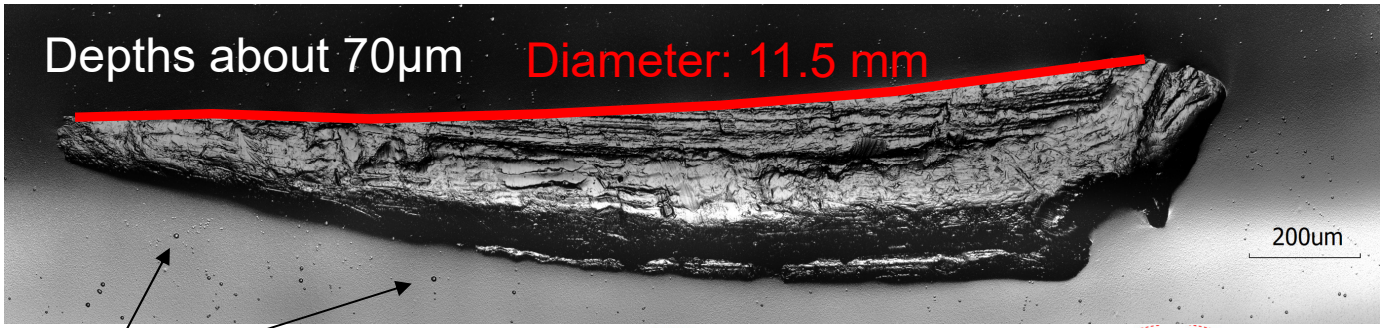
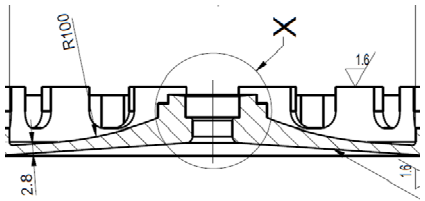
Setbacks: Type of defects

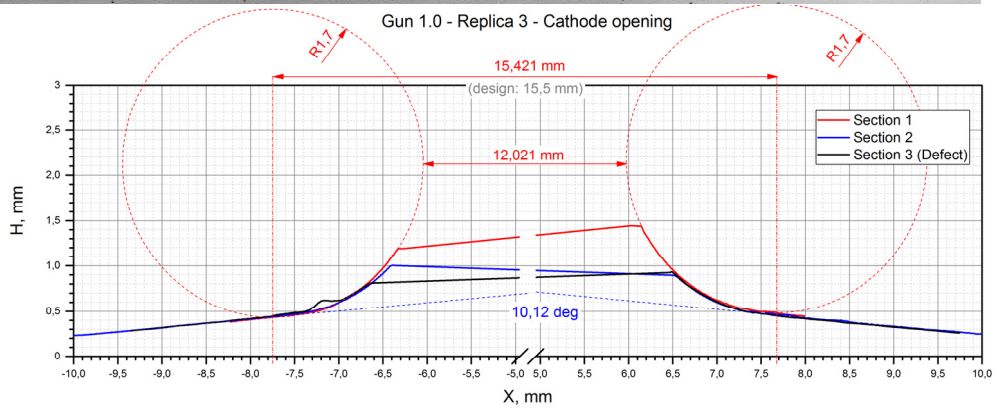
Laser scanned height map of replica taken from the defect close to the cathode opening



Alien^{TM}?

Etching pits (BCP)

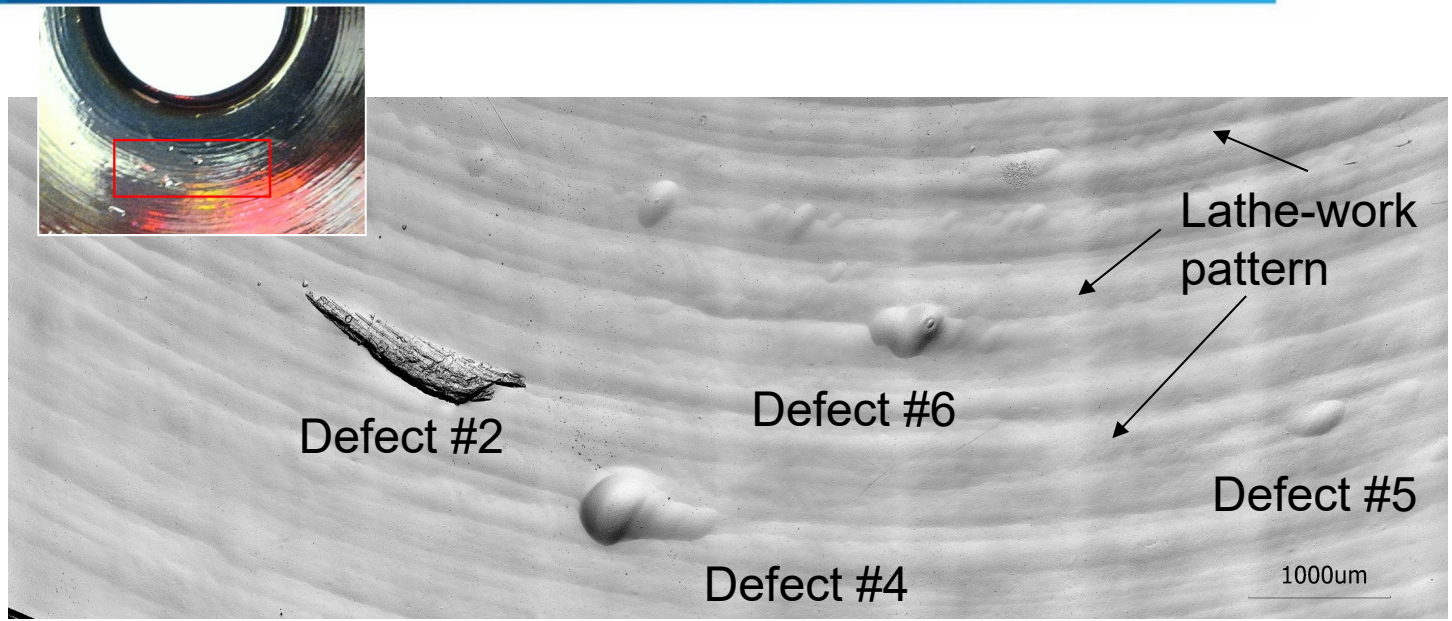




Radius of cathode opening blends show a BCP removal of about 300µm, about double the cavity surface

No etching visible on the defect surface

Setbacks: Type of defects Part 2

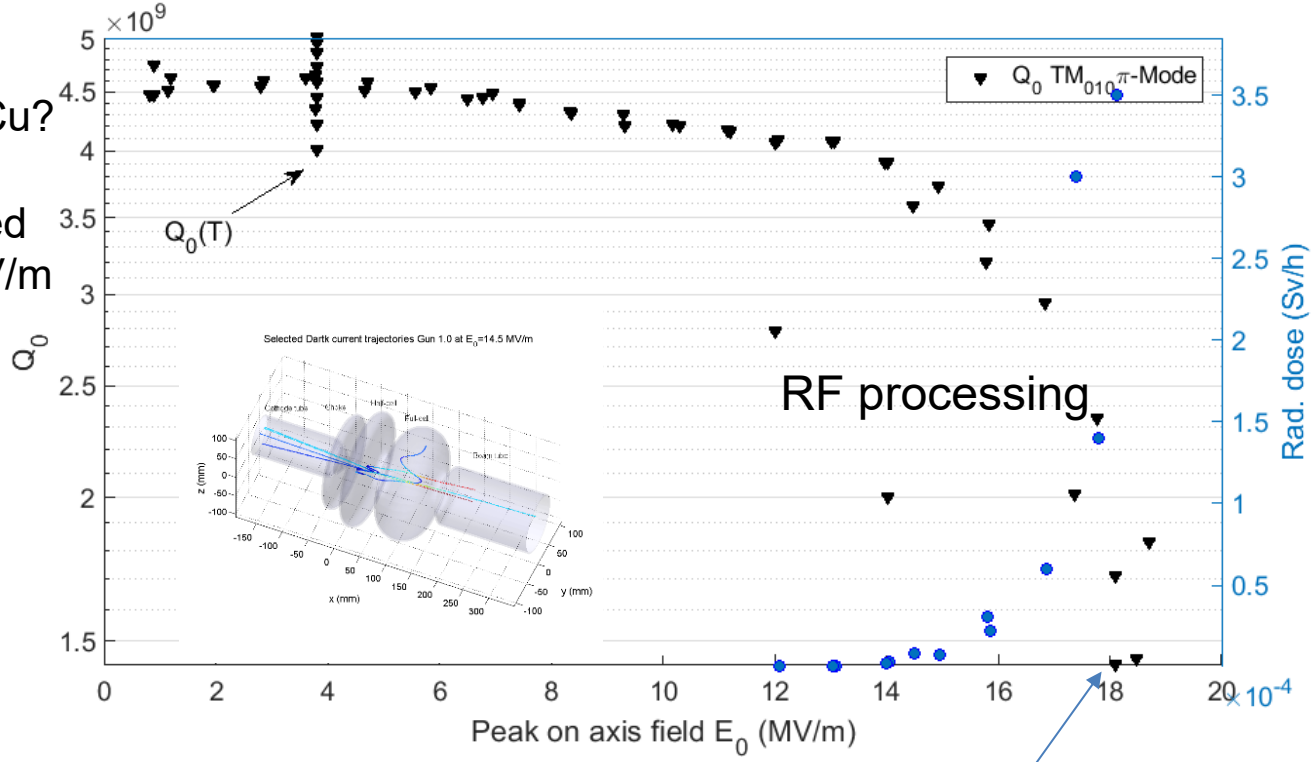


Defects 4-6 are very smooth, they saw etching by BCP. Those happened during production, opening of voids while machining the ingot material?
Defect 1 and 2 appeared after final BCP, currently check cavity history, but field emission was present from Test 1 and BCP happened also afterwards.

Recover: π-Mode result after High Pressure Water Rinsing

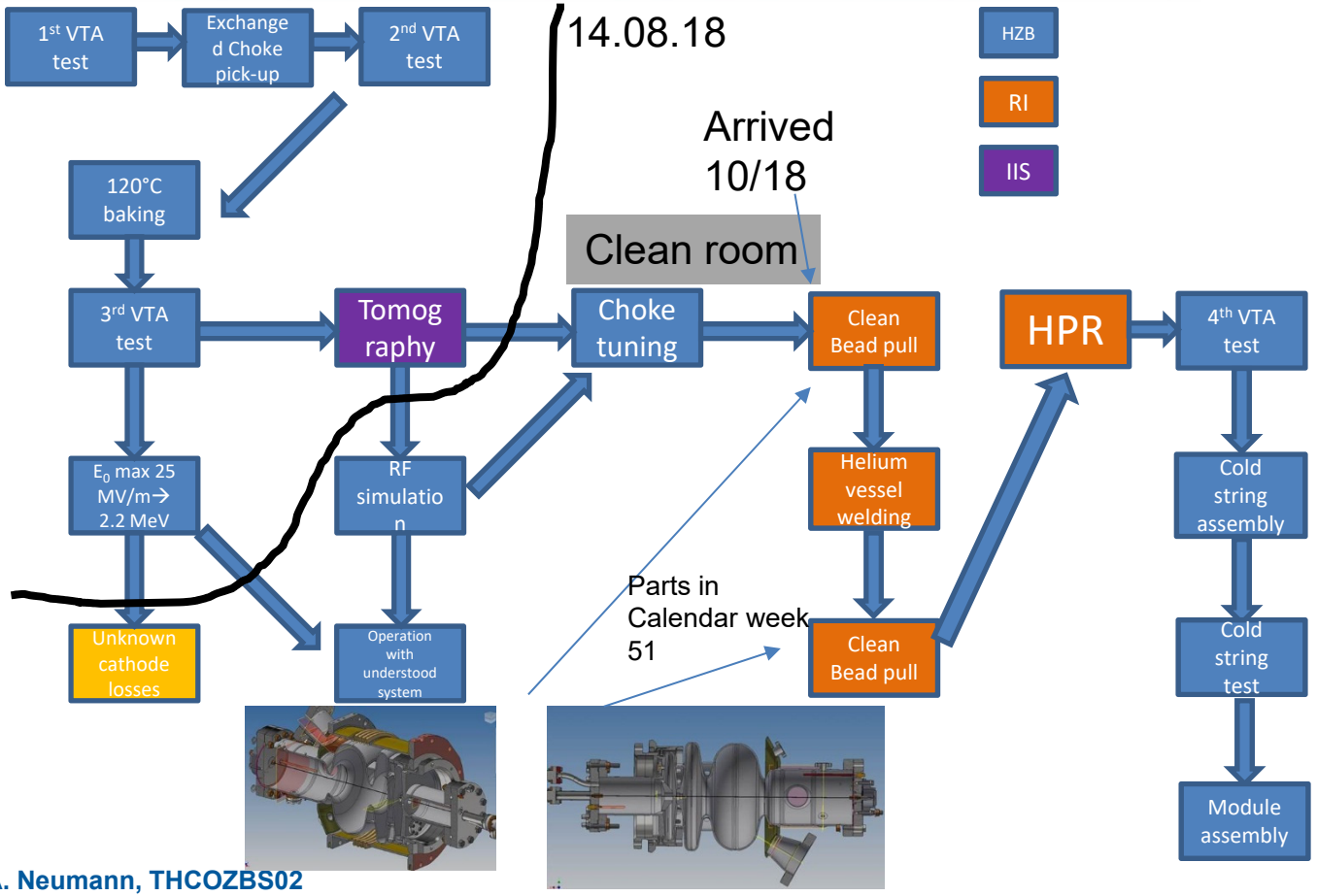
Lowered Q_0 by sputtered Cu?

FE onset shifted from 7→14 MV/m



Cavity undercoupled $0.2 \leq \beta_c \leq 0.7$→error bar! P_{diss}=11.5 W

Status of Gun Cavity 1.1 → to be used in Module



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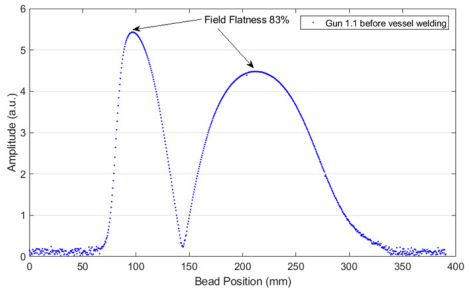

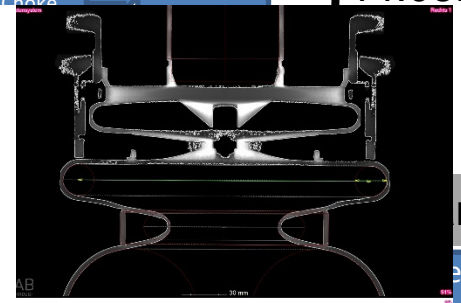

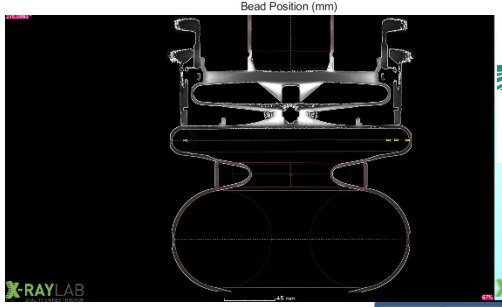

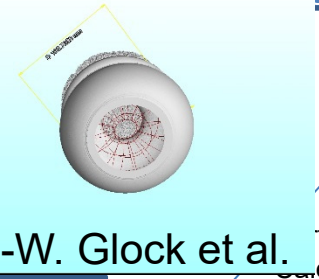

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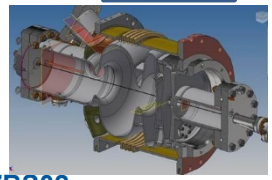
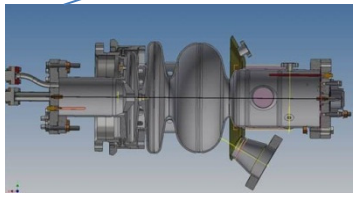




1st VTA → Exchange d Choke → 2nd VTA → 14.08.18

Arrived 10/18

HZB

RI

IIS

n room

Clean Bead pull → Helium vessel welding → Clean Bead pull

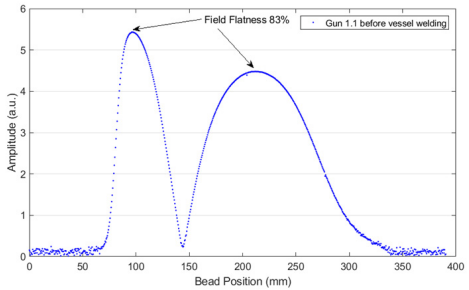
HPR → 4th VTA test → Cold string assembly → Cold string test → Module assembly

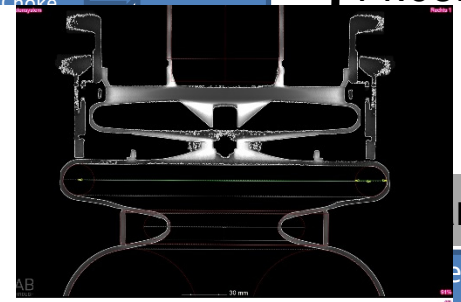
Unknown cathode losses

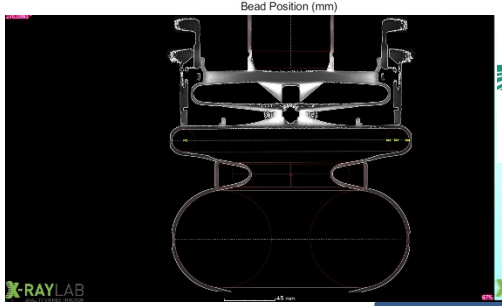
Operation with understood system

ts in
endar week
51

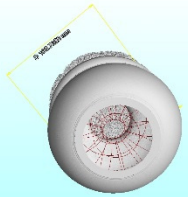
Status of Gun Cavity 1.1 → to be used in Module







Fraunhofer IIS



H.-W. Glock et al.

1st VTA → Exchange d Choke → 2nd VTA

14.08.18

19.12.18

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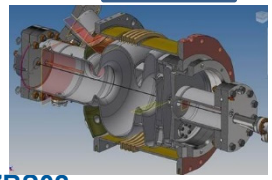

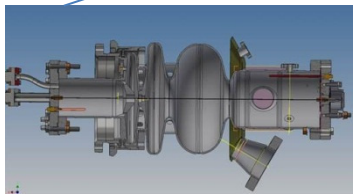

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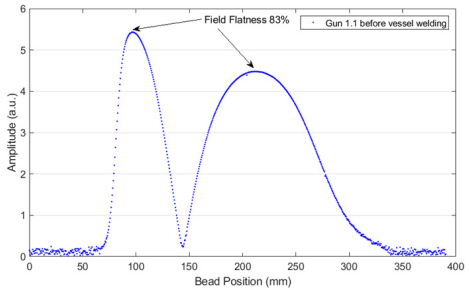
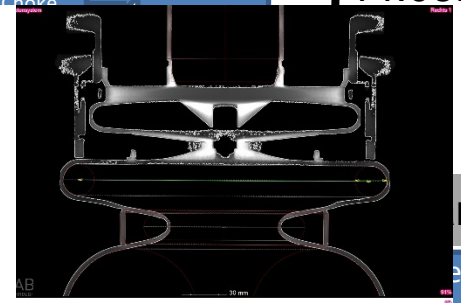
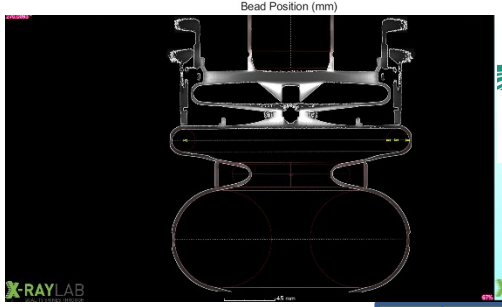
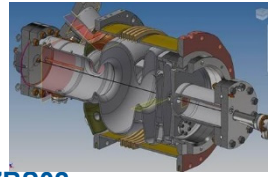
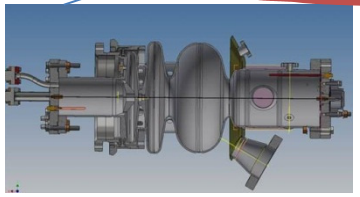










1st VTA → Exchange d Choke → 2nd VTA

14.08.18

19.12.18

10.04.19

HZB

RI

IIS

Arrived 10/18

n room

Clean Bead pull

HPR

4th VTA test

Helium vessel welding

Cold string assembly

Cold string test

Module assembly

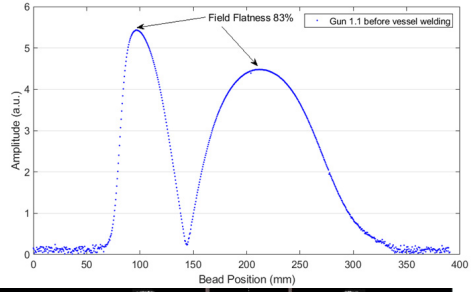
Clean Bead pull

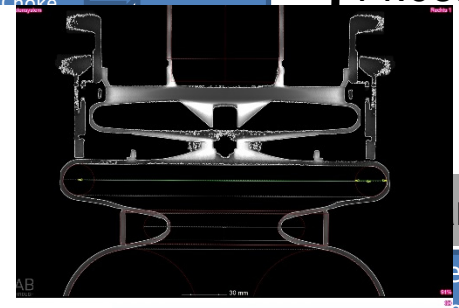
ts in
alendar week
51

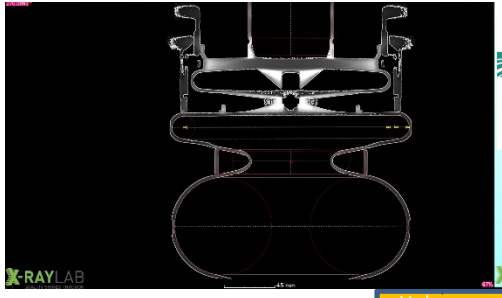
Unknown cathode losses

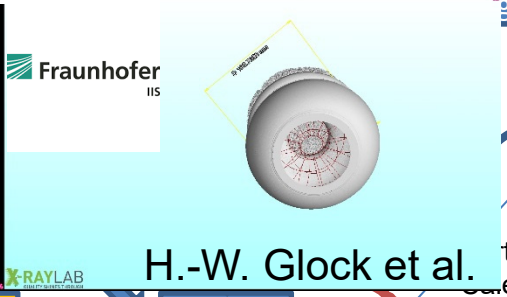
Operation with understood system

Status of Gun Cavity 1.1 → to be used in Module









H.-W. Glock et al.

1st VTA → Exchange d Choke → 2nd VTA

14.08.18

Arrived 10/18

19.12.18

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19.05.19

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n room

Clean Bead pull

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HPR

4th VTA test

Cold string assembly

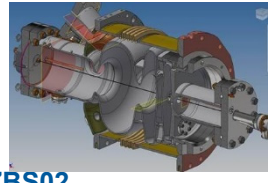
Cold string test

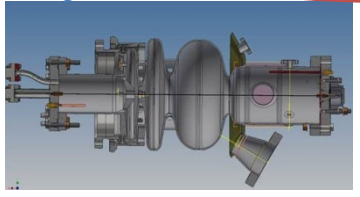
Module assembly

ts in
alendar week
51

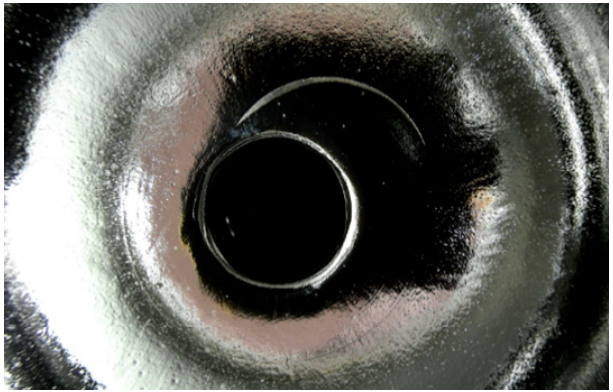
Unknown cathode losses

Operation with understood system



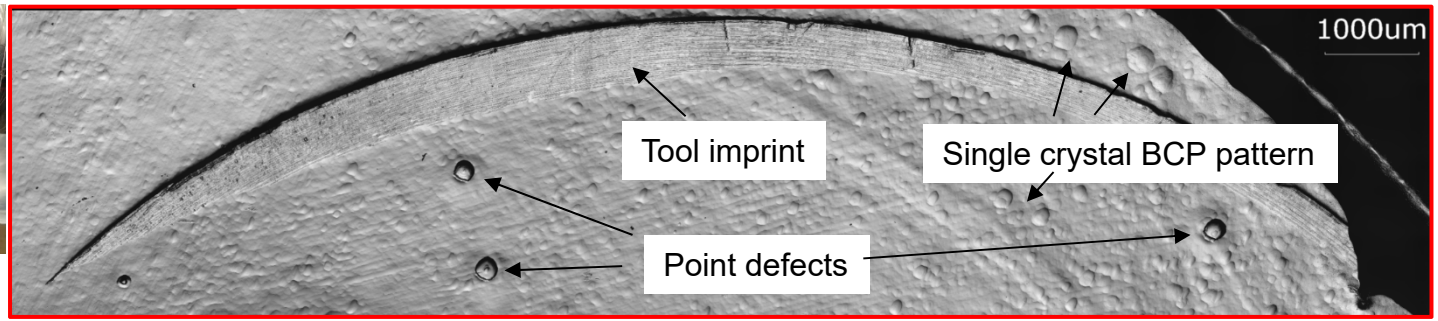


What now about Gun 1.1????



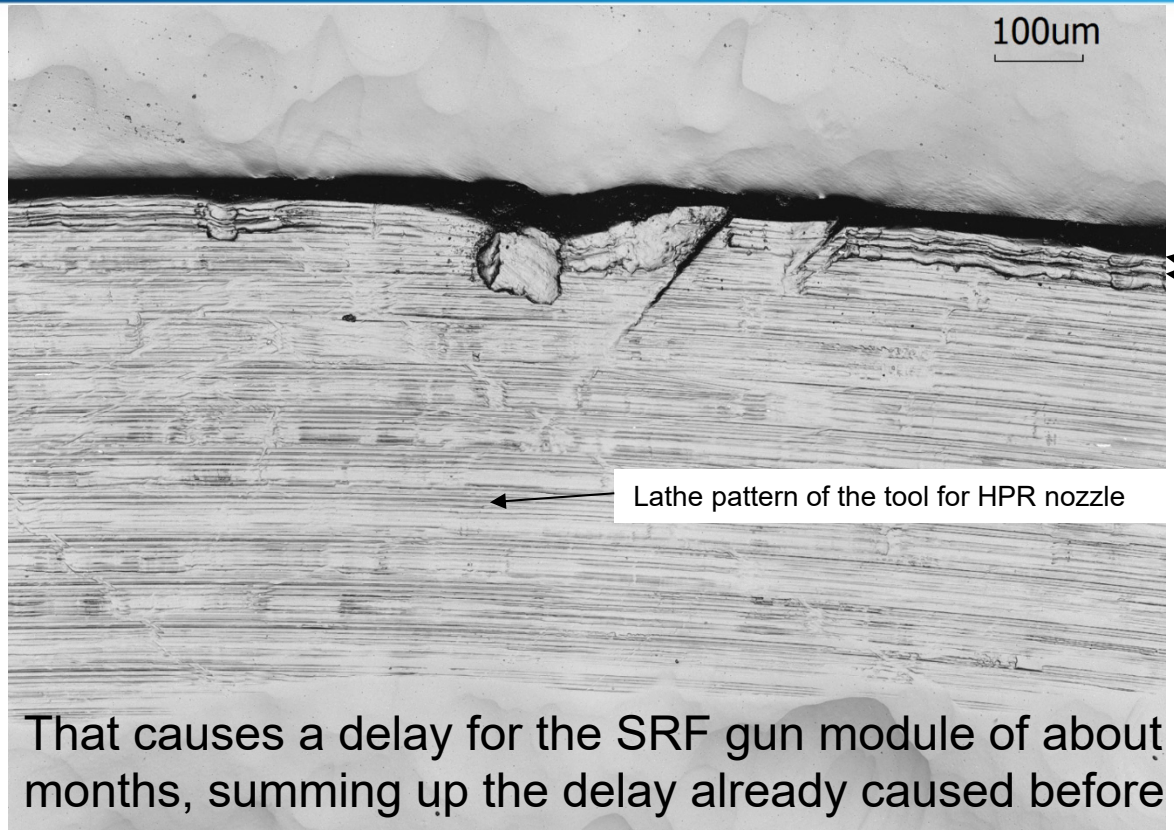
Optical inspection
Replica of the defect area (Y. Tamashevich et al)

- Confocal laser scanning microscopy of defect area
  Develop repair plan:
- Grinding of defect area
- BCP of surface to locally remove 10-20µm
- Clean room bead pull to evaluate field profile
- Cleaning and high pressure water rinsing
- Vertical test to confirm RF results



"Luckily" the first Gun 1.0 we operated with beam in Gunlab showed smaller, but similar defects → Goes through this procedure as a pilot (…to explore unknown territory no SRF cavity has seen before)

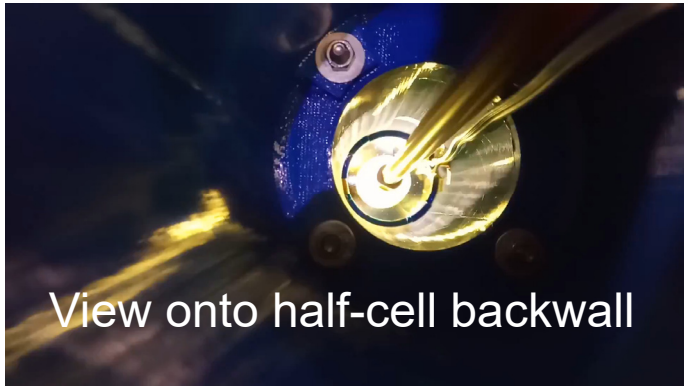
Gun 1.1: A closer look



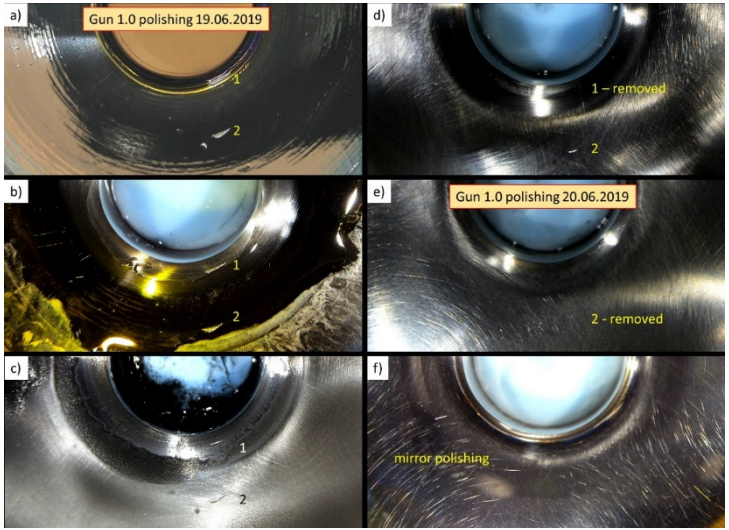
3x chipping
– vibration
after contact
– not slow move

That causes a delay for the SRF gun module of about 6-8 months, summing up the delay already caused before that

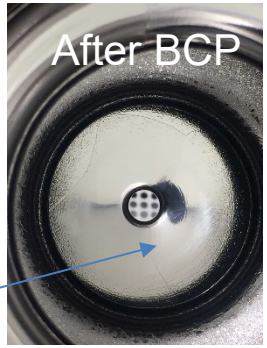
Repair attempts to recover both(!) SRF Gun Cavities



Y. Tamashevich et al



- The defects were removed by grinding using special polish liquid
- This took about two working days for the grinding alone
- Gun 1.1 will require much longer work
- Defects were not visible with replica
  → Gun 1.0 w/o FE now?



Damage layer still present

1st BCP too low removal, 2nd step required. Follow-up HPR and 120°C baking
→ VTA test will show level of success

Summary

- After assembly of the module, we operated our 1st SRF gun cavity within a dedicated beam teststand.
- Beam experiments with Cu cathode were performed and showed a limit of usable field level by RF losses, multipacting mainly caused by damaging the cathode holder during the very first run
- Field emission was always an issue, but the cavity experienced several issues: 1st view-screen broke, accidently venting via transfer system improper material combination of insert for Cu cathode
- Our back-up cavity got damaged at the vendor during final HPR
- Currently, the first gun, showing defects as main cause of field emission, acts as a pilot for repair attempt.
- We plan to start cryo-module commissioning summer 2020.

Acknowledgements

Thanks for your attention!

We would like to acknowledge:

J. Teichert, A. Arnold, P. Murcek, R. Rimmer, A. Burrill, F. Marhauser, S. Belomestnykh, E. Zaplatin, E. Kako, R. Eichhorn, J. Sekutowicz, P. Kneisel, G. Ciovati, A. Matheisen, B. van-der-Horst, M. Schmökel, W.A. Clemens, C. Dreyfuss, D. Forehand, T. Harris, R.B. Overton, L. Turlington, M. Schalwat, S. Lederer, V. Volkov,
+many more
HZB technical support