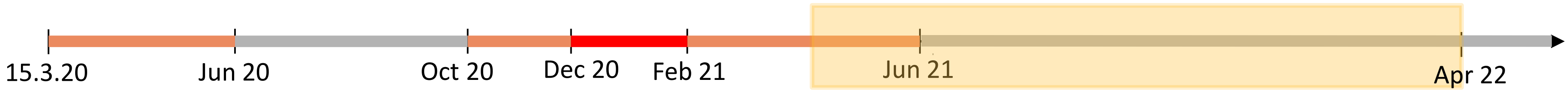
20th Meeting of the Scientific Advisory Committee for the Radiation Source ELBE
June 2, 2022

P.Michel

Operational & Technical Report Runs II/21 – I/22

- *Covid-19 restrictions and impact on the ELBE user operation*
- *Irradiation experiment for 99-Mo production sucessful in February 2022*
- *achievements & work in progress*
    - *Update SRF Gun progress and future plans*
    - *Feedback loops for arrival time jitter reduction*
    - *Fast emtittance measurement*
- *beamtime statistics/publications*
- *requested/available shifts Run III&IV / 2022*

Effects of the Corona restrictions on the ELBE operation



HZDR measures during the Corona restictions

- No face-to-face meetings at HZDR
- Home office (if possible)
- No business trips
- No guests
- Canteen closed (later with registration, seating arrangement…)
- HZDR offers free Corona tests
- HZDR offers Covid vaccination

→ No verifiable corona outbreak at HZDR so far

Special and additional regulations at ELBE

- Reduction of the number of people in the control room (max 3 people)
- the daily 1:45 pm meeting has completely become an online meeting
- Frequent disinfection in the control room (keyboards, mouse…..)
- all people not needed on site in the home office
- observation and control of special machine parameters online from home (e.g. cryogenics)

Effects of the Corona restrictions on the ELBE operation

- In contrast to 2020/1, no corona-related changes to the proposal in 2021/22

- No loss of beam time due to corona infections or corona-related precautionary measures by the staff

- **ELBE was in full operation throughout the entire reporting period**

accelerator based production of radio isotopes

- HZDR signed cooperation contracts with **Lighthouse** consortium
- Replacement of reactor-based production of radioisotopes (Mo-99/Tc-99m)
- High societal relevance
- ELBE is a perfect test device for various key technological components
- ~ 10 % of ELBE user beamtime within next 2 years
- Use of 10 % directors disposal (without evaluation by SAC)

Lighthouse consortium
IRE / Begium
Research Instruments / Germany
DEMCON / Netherlands
ASML / Netherlands

Cooperation contracts with HZDR (2019/2020)

- **Test of target technology (DEMCON)**
- **Test of accelerator components (Research Instruments)**
- **Technology transfer from HZDR to industry**

Accelerator based production of Mo-99

- Tc-99m most commonly used medical isotope
- Radioactive tracer for CT's

Reactor Mo-99/Tc-99m production

Uranium target production → Reactor irradiation → Uranium target processing

Risk of proliferation

Aging reactors

Nuclear waste

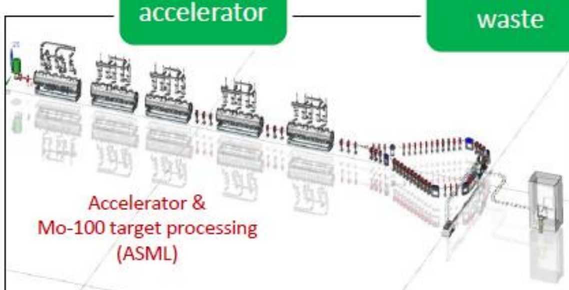
Accelerator Mo-99/Tc-99m production

Mo-100 target production → Accelerator irradiation → Mo-100 target processing

No risk of proliferation

Innovative accelerator

Negligible waste



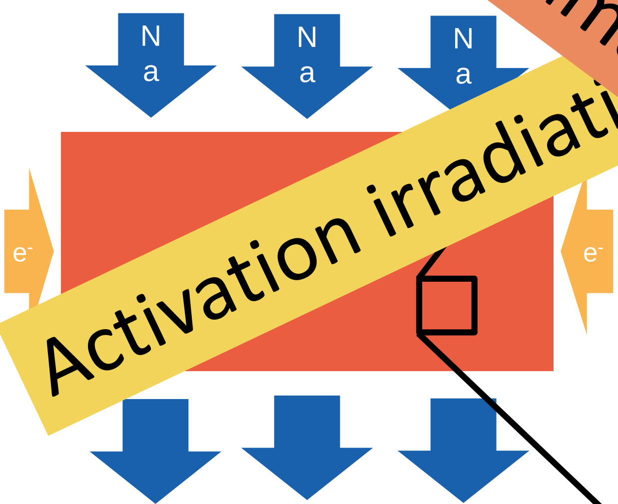
→ Generator → Radio-Pharmacy / Hospital

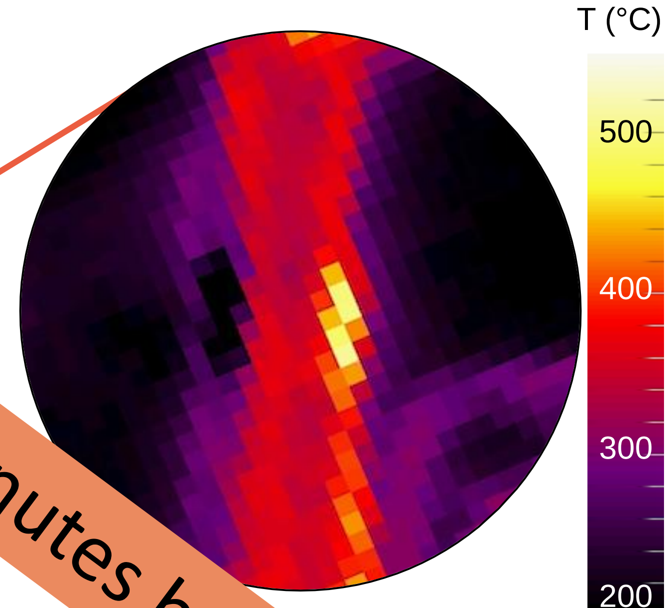
Su…essful SAT of 1:1000 demonstrator

Target tube damaged after a few minutes beam

Activation irradiati… a few day‘s) in run 4/21

SMART expos… | **Dem…** | **Beam on target**





Courtesy of J. Jobst/DEMCON

Ma… 1

First full power be… on target (a few seconds)

Accelerator based production of Mo-99

Next attempt in February 2022 with new target

- Revised ramp up regime
- Beam size tuning and monitoring
- Active beam-position control

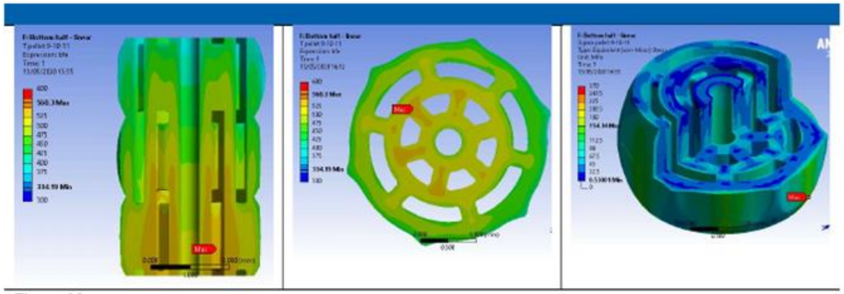
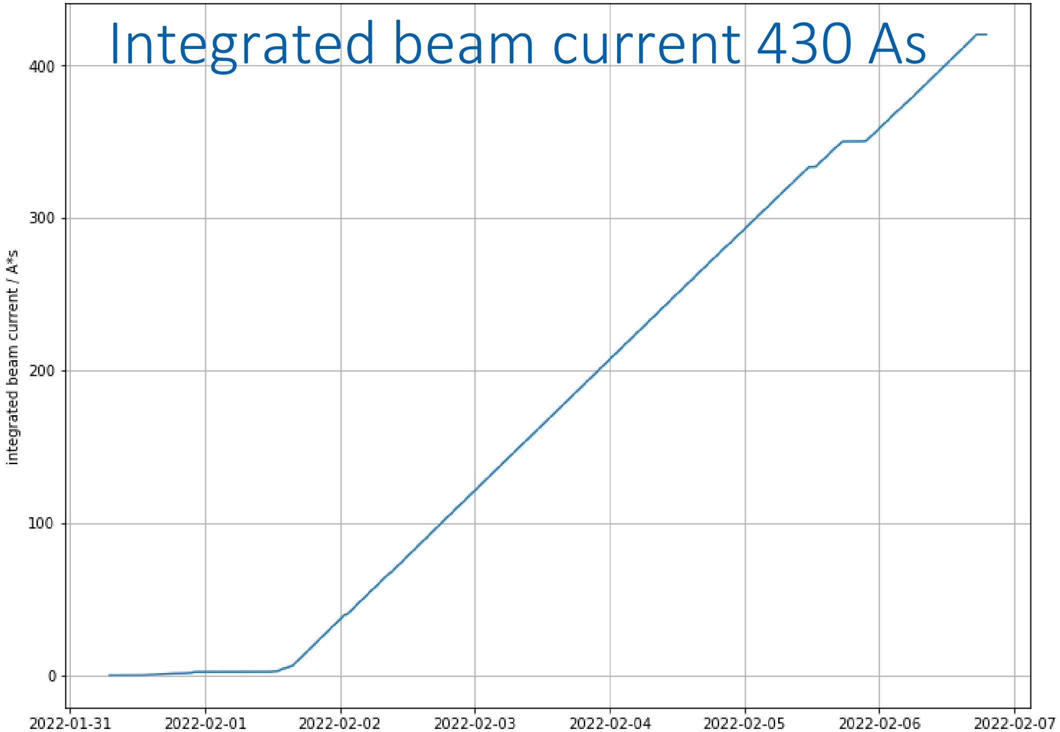


Figure 99: *Real pellet stack (only pellet 9,10,11 shown)*
Left: temperature XY plane. Middle: temperature XZ plane. Right: pellet stress
Flow rate: 73 g/s, Tin=150 degC



- Power denisity 10 GW/cm^2
- 120h CW 30MeV/1.0mA

  = 3.6 MWh or 13 GJ

Corresponds to the kinetic energy of a fully loaded Boing 747-400 at maximum speed

High-power test bench for dedicated facility Lighthouse/SMART project

DRESDEN concept HZDR

Three key successes on accelerator side

Beam spot size control

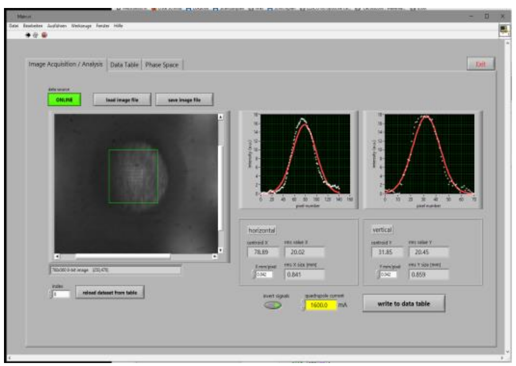
- Pre-determined absolute beam size value
- **s**=0.5 mm (tuning regime)
- **s**=0.9 mm (power regime)

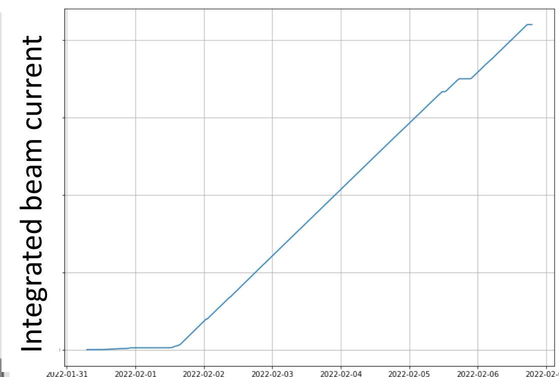
Closed-loop beam position control

- Sensor: Beam Position Monitor close to the target
- Actuator: steerer magnet
- Labview PID controller
- Dx (y) < 100µm

contineous operation

- No trips !!
- Only minimal parameter corrections





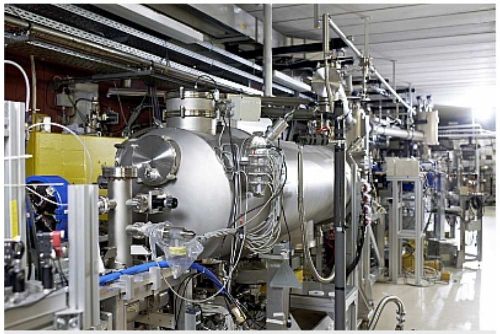
120 hours

Pressemitteilung vom 22. Februar 2022

Medizinische Radioisotope bei extremer Ene

Kooperation erreicht Meilenstein mit erfolgreichem Be

Für die Diagnose von Krebs und anderen Erkrankungen spielt Moly nach einigen Stunden zu Technetium-99m, das in Bildgebungsverfa Menschen weltweit untersucht werden. Jedoch birgt das gegenwär Probleme, wie etwa alternde Reaktoren und Umweltbelastungen. Fo Produktion. Am Helmholtz-Zentrum Dresden-Rossendorf (HZDR) is Erzeugung von Mo-99 mithilfe des supraleitenden Linearbeschleun



Mit diesem Hauptmodul der Strahlungsquelle ELBE können Wissenschaftler*innen Elektronen auf nahezu Lichtgeschwindigkeit beschleunigen. Im Experiment von SMART treffen die Elektronen auf ein winziges Molybdän-Target. Es entsteht elektromagnetische Bremsstrahlung, die aus den Atomkernen je ein Neutron herausschlägt, sodass das Radioisotop Mo-99 als Produkt übrigbleibt.
Bild: HZDR/Jürgen Jeibmann
Download

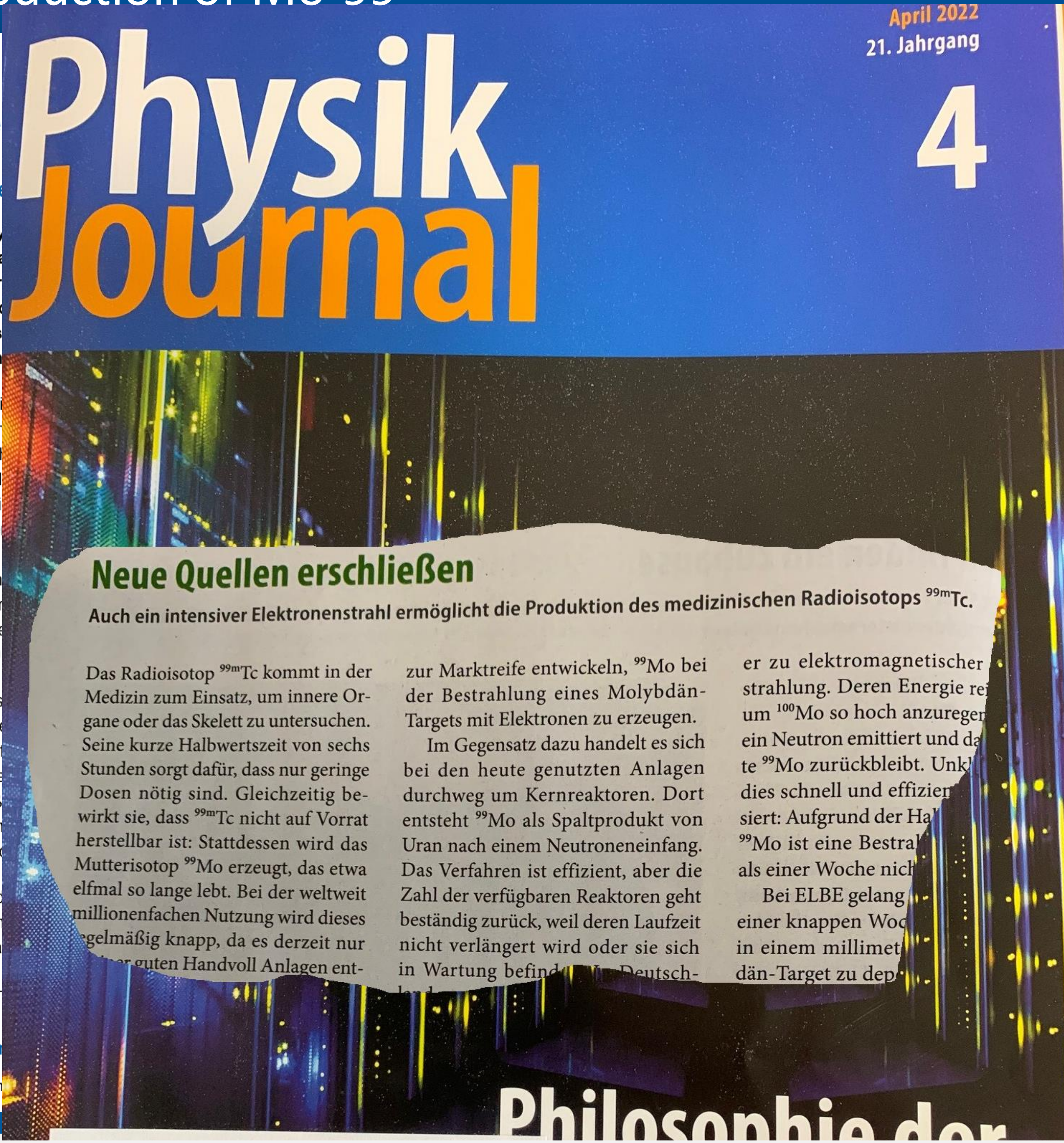
„Wir haben di
Target besteh
Kilowatt-Strah
Prof. Peter M
Energie von i
ist in etwa ve
747-400, die
Diese extrem
hervorzurufen
Atomkern je e
Molybdän-99

Während das
war das niede
Aufbau feder
RadioisoTope
weltweit größ
gemeinsam m
aus Wissensc

„Der ELBE-Beschleuniger ist die einzige Forschungsanlage in Europa, d ausreichend hohe Strahlqualität vorgefunden haben, die wir auch über n leitender Ingenieur für mechatronische Systeme bei Demcon. „Ausschla Zusammenarbeit zwischen den Partnern. In Bezug auf ELBE haben wir wissenschaftlichen Knowhow und dem großen Engagement des ELBE-T

Komplexer Versuchsaufbau: Kühlung mit flüssigem Natrium

Aufgrund der extremen Bedingungen war das Experiment für die Forsch



April 2022
21. Jahrgang
Physik Journal
4

Neue Quellen erschließen

Auch ein intensiver Elektronenstrahl ermöglicht die Produktion des medizinischen Radioisotops ^{99m}Tc.

Das Radioisotop ^{99m}Tc kommt in der Medizin zum Einsatz, um innere Organe oder das Skelett zu untersuchen. Seine kurze Halbwertszeit von sechs Stunden sorgt dafür, dass nur geringe Dosen nötig sind. Gleichzeitig bewirkt sie, dass ^{99m}Tc nicht auf Vorrat herstellbar ist: Stattdessen wird das Mutterisotop ^{99}Mo erzeugt, das etwa elfmal so lange lebt. Bei der weltweit millionenfachen Nutzung wird dieses [r]egelmäßig knapp, da es derzeit nur [ei]ner guten Handvoll Anlagen ent-

zur Marktreife entwickeln, ^{99}Mo bei der Bestrahlung eines Molybdän-Targets mit Elektronen zu erzeugen.

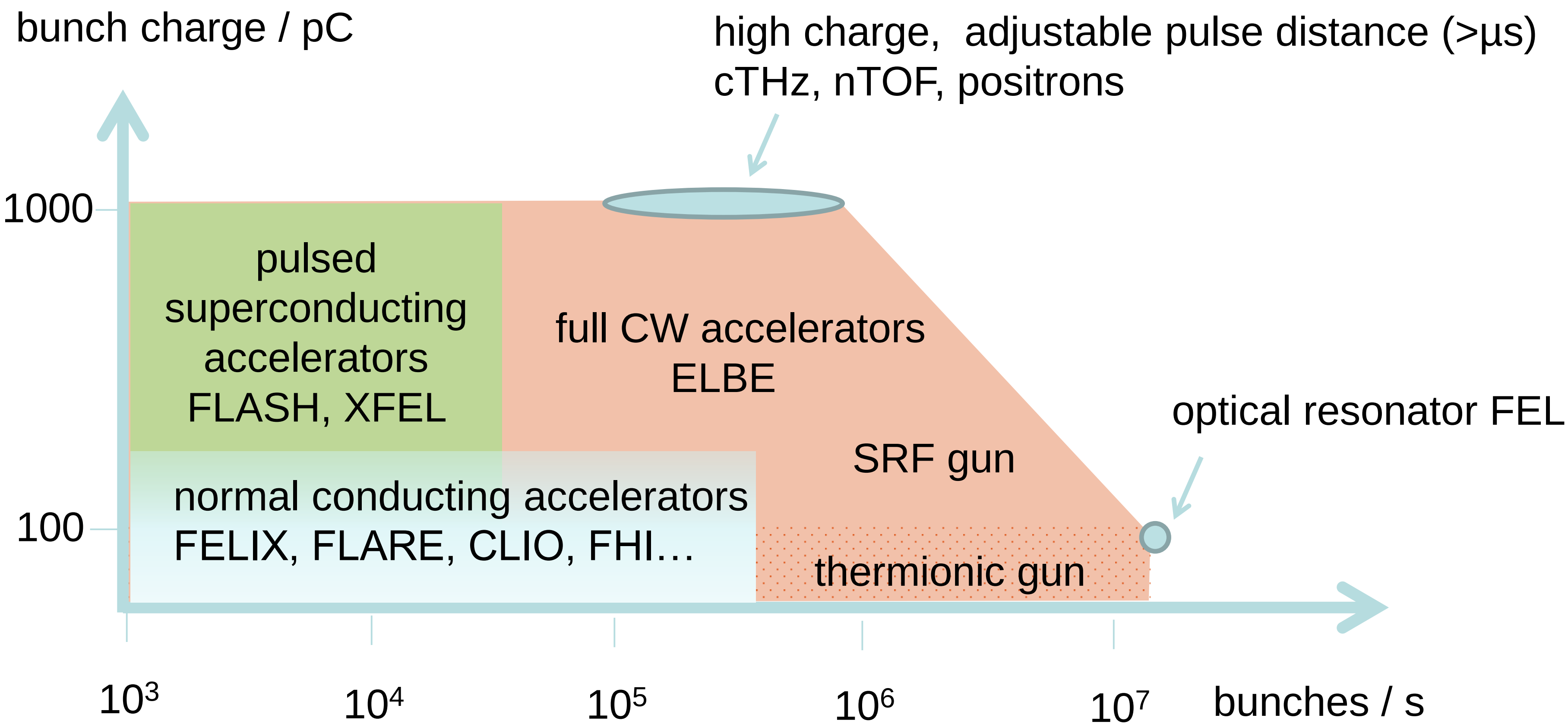
Im Gegensatz dazu handelt es sich bei den heute genutzten Anlagen durchweg um Kernreaktoren. Dort entsteht ^{99}Mo als Spaltprodukt von Uran nach einem Neutroneneinfang. Das Verfahren ist effizient, aber die Zahl der verfügbaren Reaktoren geht beständig zurück, weil deren Laufzeit nicht verlängert wird oder sie sich in Wartung befind[en] ... Deutsch-

er zu elektromagnetischer strahlung. Deren Energie rei um ^{100}Mo so hoch anzuregen ein Neutron emittiert und da ^{99}Mo zurückbleibt. Unkl te ^{99}Mo zurückbleibt. Unk dies schnell und effizien siert: Aufgrund der Ha ^{99}Mo ist eine Bestral als einer Woche nich

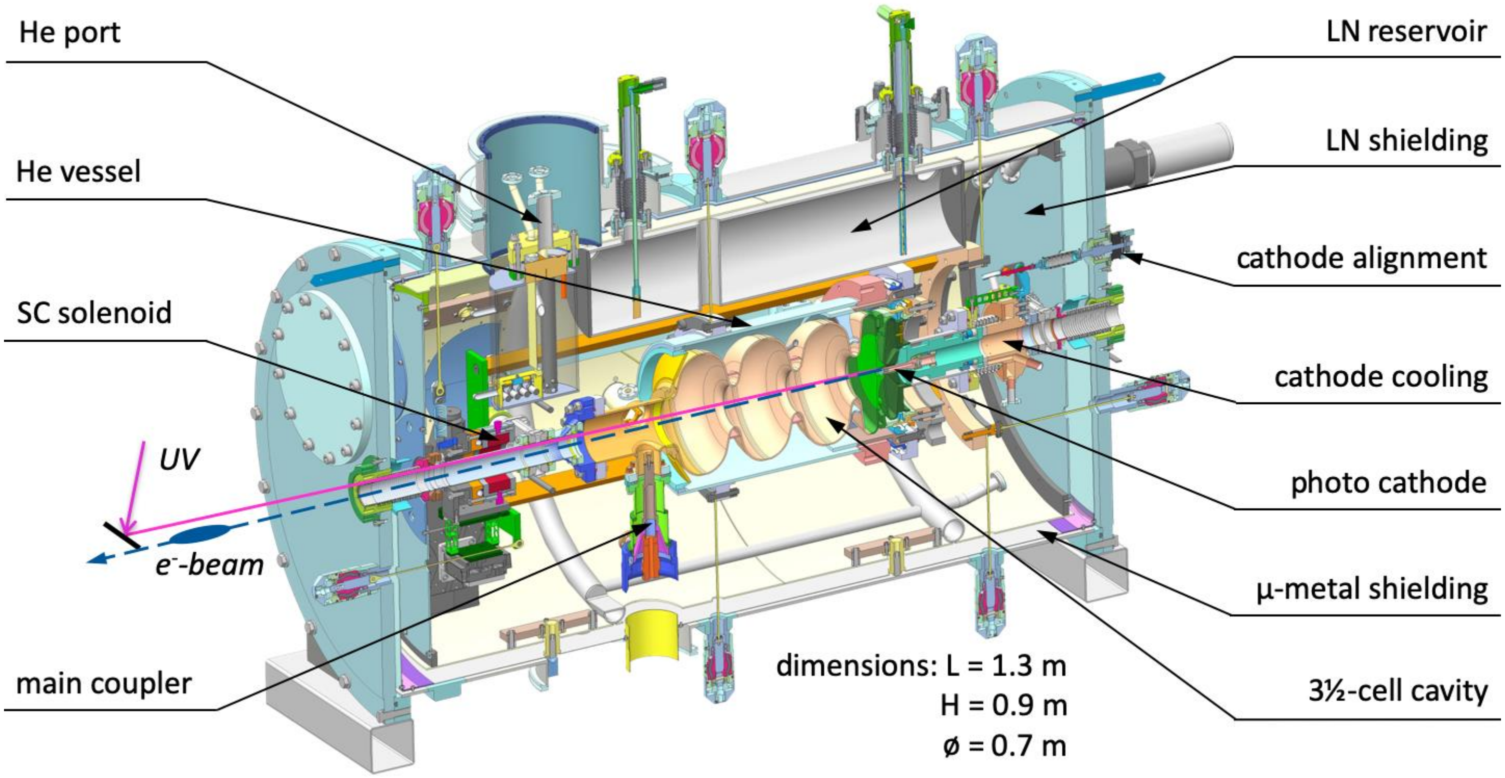
Bei ELBE gelang einer knappen Wo in einem millimet dän-Target zu dep

Philosophie der

What is unique at the ELBE accelerator ?

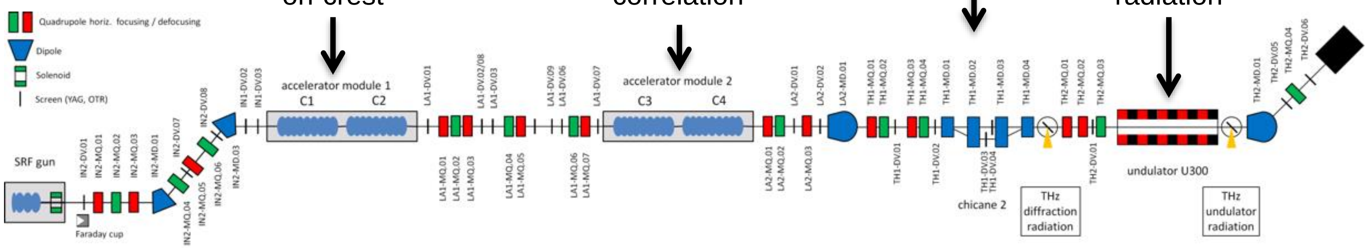


HZDR SRF Gun II

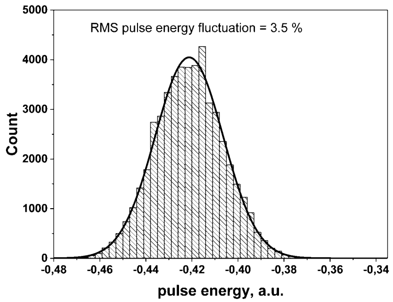


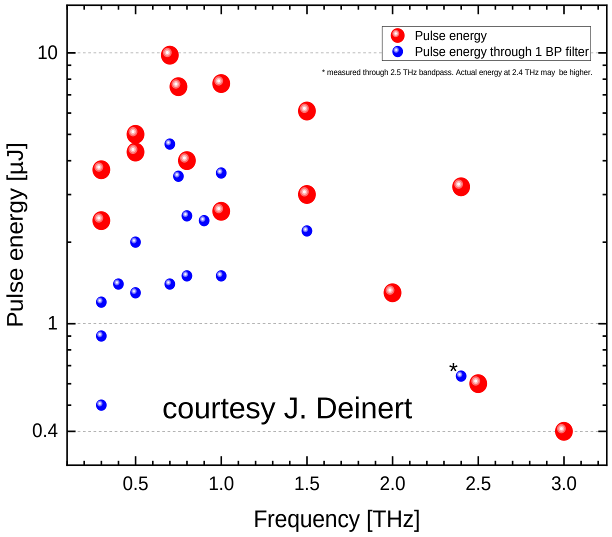
THz generation

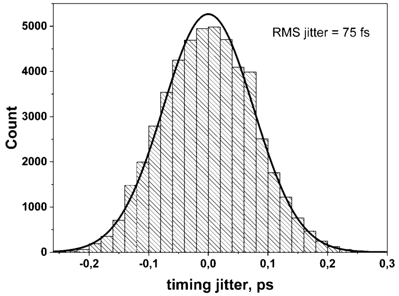
$E_{THz} \sim F(\omega, \sigma_z) N^2$



- SRF gun delivers 4 MeV beam with 200 - 250 pC
- CW operation with 10, 50, 100, 250 kHz rep.-rate
- acceleration to 26 MeV, imprint of correlated energy spread and compression to some 100 fs
- THz radiation with frequencies 0.05 – 2.5 THz
- pulse energies ≤ 10μJ (≤ 1 THz), few μJ (≤ 2.5 THz)
- pulse energy fluctuations are typ. 3.5 %
- synchronization to external systems typ. 75 fs (including the laser jitter, w/o feedback)
- stable and very reliable SRF gun operation





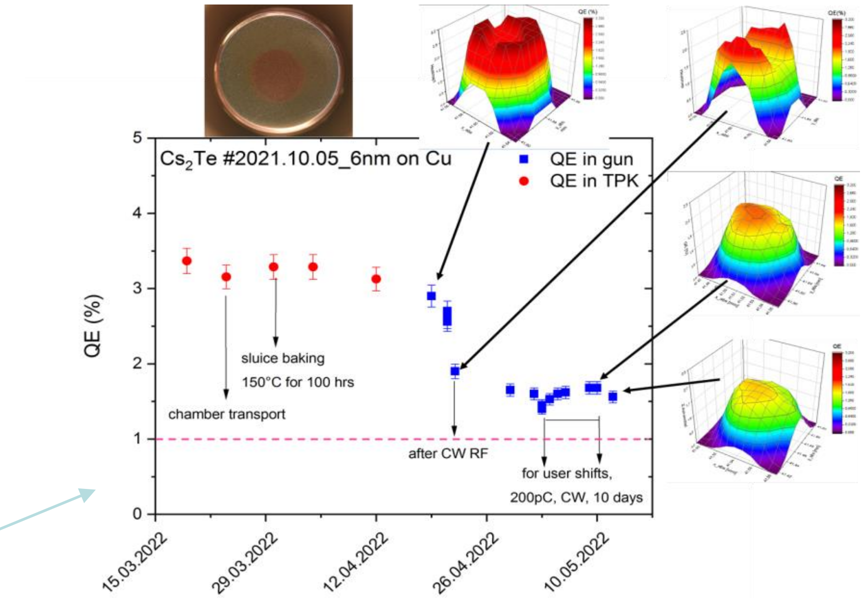


100% of all THz shifts and up to 36% of all ELBE user shifts are provided by SRF gun

J.Teichert et al. PRAB 24, 033401 (2021)

Stable operation of Cs_2Te photocathode in SRF gun-II

Cathode No.	Time in gun	Beam time/hr	Extract Charge/C
Cs2Te#2019.11.26	2021.05 ~ 2021.07	350	14.0
Cs_2Te#2021.06.11_7nm	2021.07 ~ 2021.09	492	15.3
Cs_2Te#2021.06.09_10nm (diamond turning plug)	2021.09 ~ 2021.12	529	16.9
Cs_2Te #2021.06.07_8nm	2022.01 ~ 2022.03	262	7.1
Cs_2Te #2021.10.05_6nm	*2022. 03 ~ ______*	*205 +*	*7.2+*



Study on the degradation during operation is ongoing:

1. Photoelectrons & unwanted beam hit cavity wall, release gases, which contaminate the cathode surface. ⇨ Study the influence of stoichoimetric Cs/Te & film thickness to robustness
2. Released gas moleculars are ionized by photoelectrons & unwanted beam, and ions back bombard cathode. ⇨ Simulation of dark current in gun and ion bombardment process

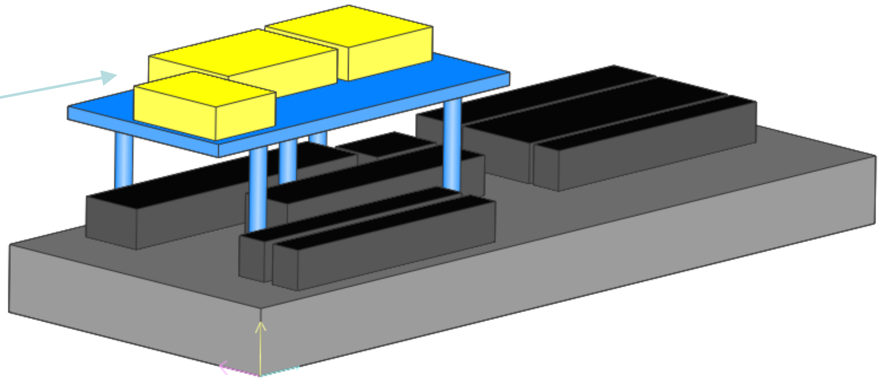
Study on alternative high QE photcathodes (GaN)

PHD work of Jana Schaber

J.Schaber et al., Influence of surface cleaning on quantum efficiency, lifetime and surface morphology of p-GaN:Cs photocathodes, Micromachines, special issue: Nano/Microscale Thin-Film Photocathodes: Materials and Applications, 2022 (under peer-review)

DRESDEN concept

New photocathode laser from "Amplitude"



Actual status:

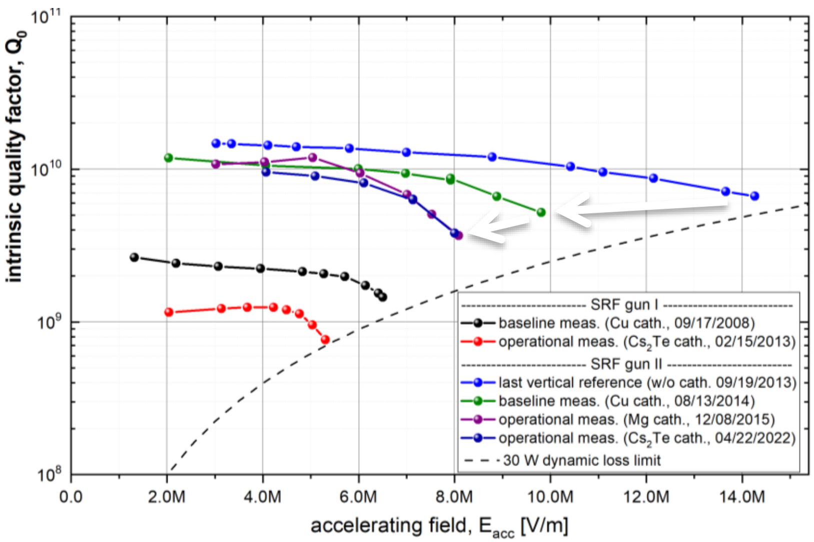
- New laser (yellow blocks) and old laser (black blocks) installed on one table in two levels.
- Flipping one mirror allows to quickly switch between two laser for operation with the SRF-gun.
- First delivery of the new laser in summer 2020.
- Since then, a critical issue with the synchrolock and a number of other minor issues have been solved together with Amplitude.
- Now, the oscillator demonstrates significantly lower jitter than the old one (70 vs 150 fs in 10 Hz – 1 MHz)
- Temporal pulse shape is under study right now

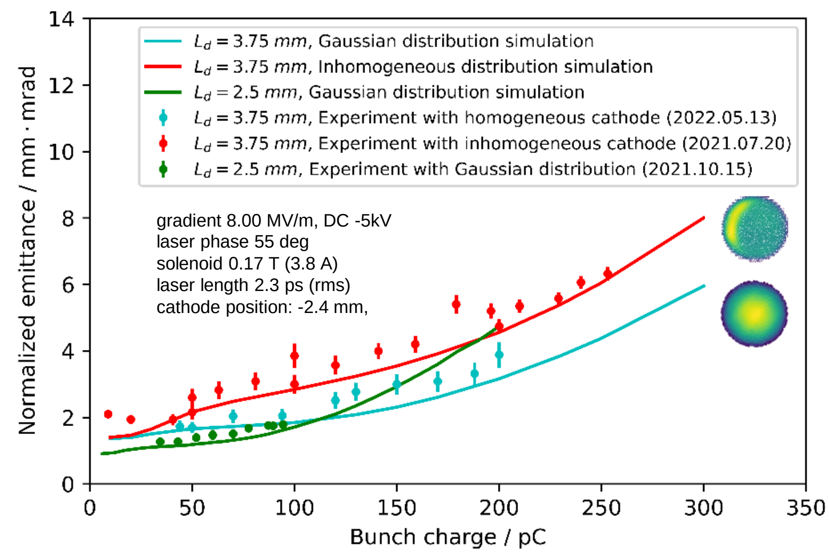
Parameter	Old laser (MBI)	New laser (Amplitude)
4th harmonic wavelength	262 nm	257 nm
Oscillator	52 MHz, free space	39 MHz, fiber
Pulse rep. rate	10…500 kHz in 7 steps, 13 MHz	0…1 MHz (any divider of 39 MHz)
UV pulse energy	5 µJ @ 100 kHz	>10 µJ @ 100 kHz >2 µJ @ 1 MHz
UV pulse length (FWHM)	5 ps	Up to 7 ps, variable
Integrated jitter, measured from 10 Hz–1 MHz with ELBE reference)	150 fs	70 fs

Gun II - performance

- although loss of acc. field after last vertical test likely due to clean room assembly and a problem with the 1st CsTe cathode, no additional cavity degradation despite the 24 different cathodes in the gun btw. 2015-2022
- measured norm. emittance for homogeneous and inhomogeneous cathode (QE map) almost same as in simulation with same parameters

parameter	SRF gun II
energy (pc)	4.5 MeV
SRF gun gradient	8 MV/m
cathode field	14.4 MV/m
bunch charge	0 – 250 pC
transv. emittance	1.3 – 6.3 µm
energy spread	5 – 25 keV
micro pulse rate	25 – 250 kHz
beam current (CW)	25 µA
laser pulse length	2.3 ps
dark current	<100 nA

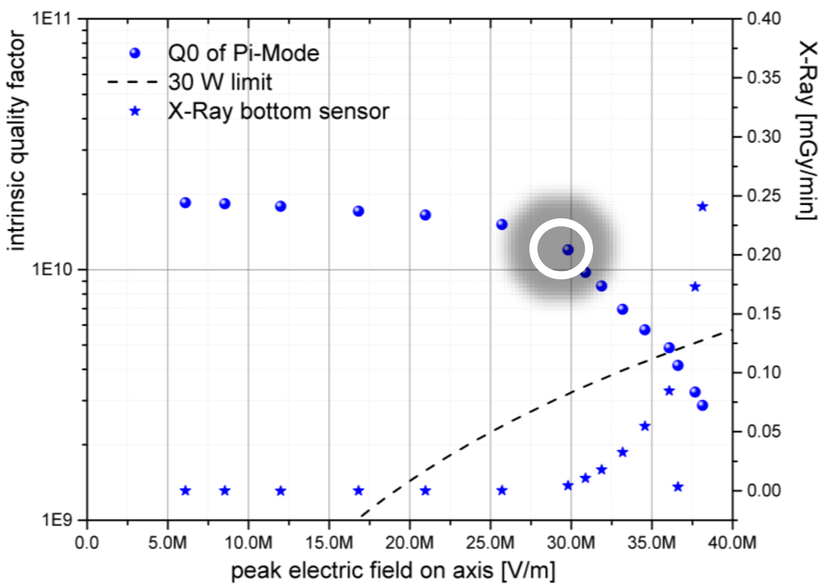




DRESDEN concept HZDR

SRF Gun III – path to higher gradient

- high pressure ultra pure water rinsing (HPR) with special nozzle for gun cavities and vertical test of refurbished SRF gun I cavity by using HZB infrastructure to **re-establish 30 MV/m**
- cold mass cleanroom assembly at HZB or HZDR
- high power RF test of complete cryomodule at HZDR's SRF lab



QvsE, measured in 2016 at DESY for SRF gun I

HPR with special gun nozzle

Cryomodule and gun test stand (SRF lab)

2K-Helium supply [ready]

Laser lab [ready]

SRF gun III cold test in the bunker (w/o cavity)

Universal test facility for cryomoduls and SC cavities:

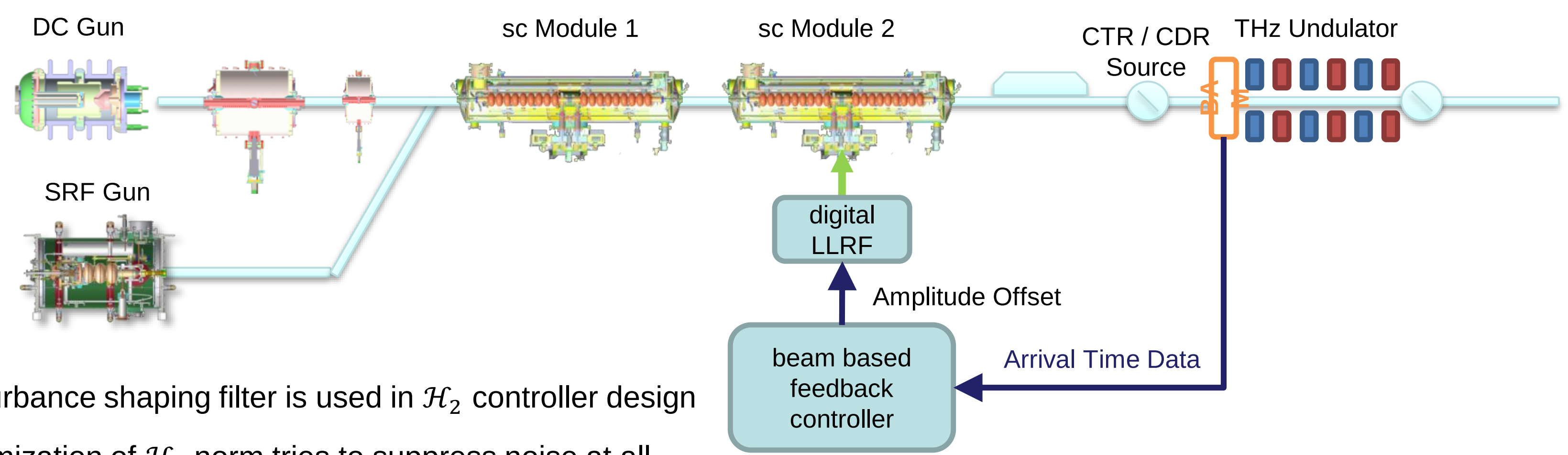
Infrastructure :

- 1.6 - 1.8 K Helium [tested]
- 50 W@1.8 K possible dynamic load [tested]
- pressure stability < +/- 0.1mbar [tested]
- LN2 [tested]
- Laser hut [ready, laser to be installed]
- RF, instrumentation, control [under construction]

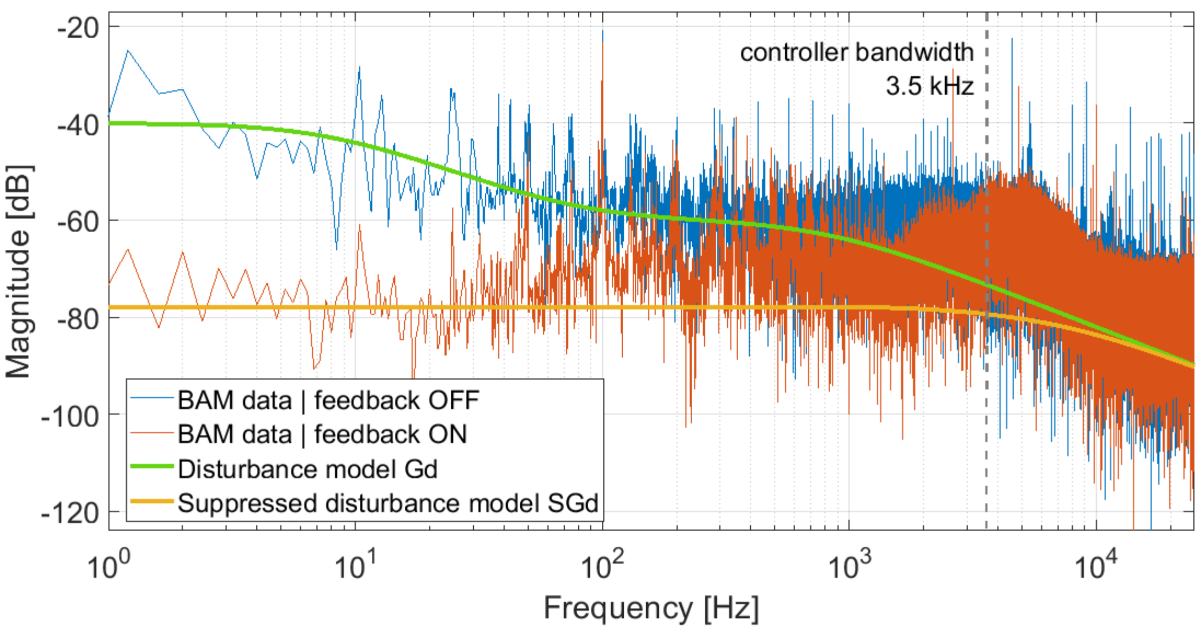
Test facility for:

- SC magnets in SRF gun cryomodules (done)
- accelerator moduls and cavities (short term)
- SRF gun cryomodules (short term)
- beam characterization of SRF guns with diagnostic beamline [radiation shielded bunker] (mid term)
- possibility of future use as UED user lab (mid term)

Beam-based Feedback – Beam Arrival Time stabilization

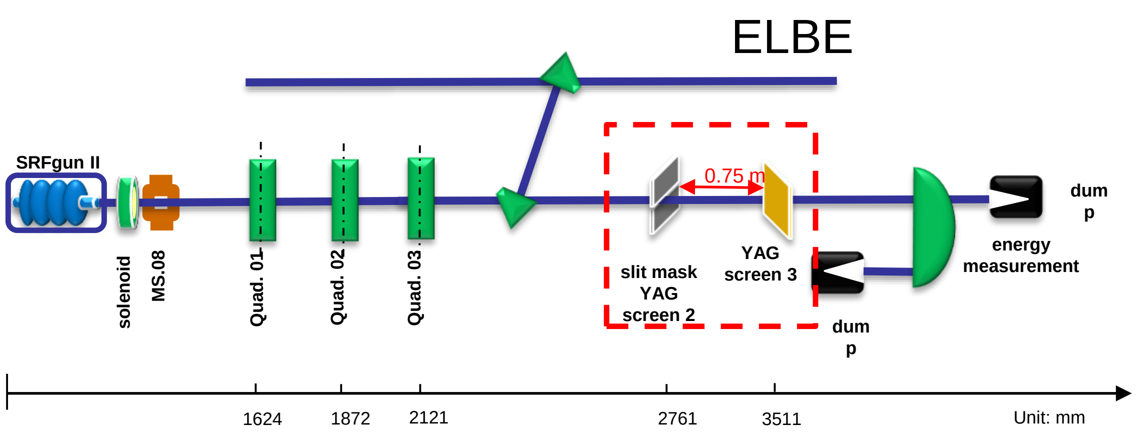


- Disturbance shaping filter is used in $\mathcal{H}_2$ controller design
- Minimization of $\mathcal{H}_2$ norm tries to suppress noise at all frequencies



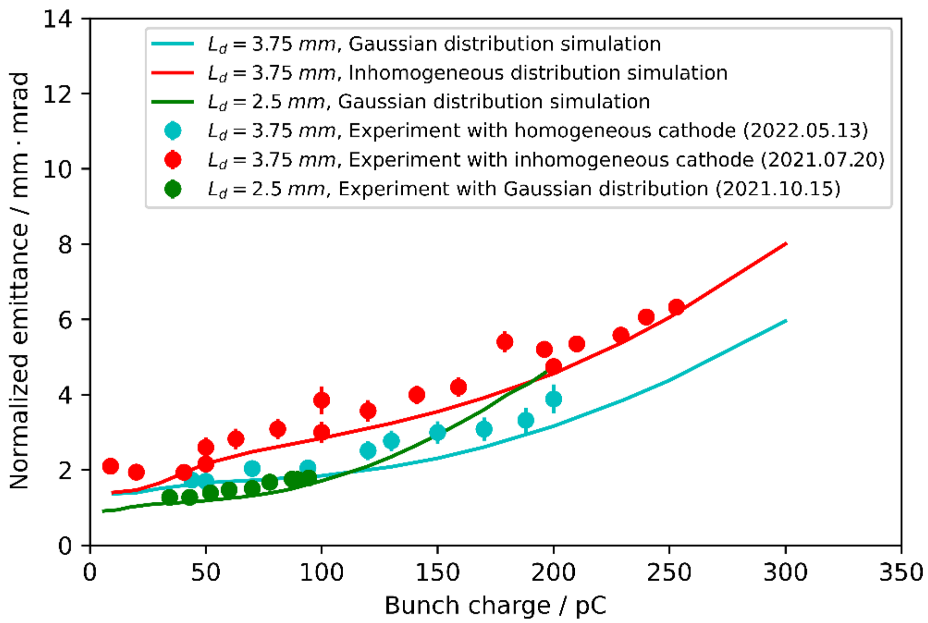
PHD work of Andrej Maalberg

- Maalberg, A. et al., **Simulation of RF Noise Propagation to Relativistic Electron Beam Properties in a Linear Accelerator**. In Proc. 21st IFAC World Congress, Berlin, Germany, July 11–17 2020, doi:10.1016/j.ifacol.2020.12.184.
- Maalberg, A. et al., **Regulation of the Linear Accelerator ELBE Exploiting Continuous Wave Mode of a Superconducting RF Cavity**. In Proc. Am. Control Conf., Atlanta, GA, USA, June 8–10 2022, accepted.



PHD work of Shuai Ma

S. Ma et al., Emittance measurements with fast moving slit and deep learning procedure *submitted to Phys Rev Accelators and Beams*

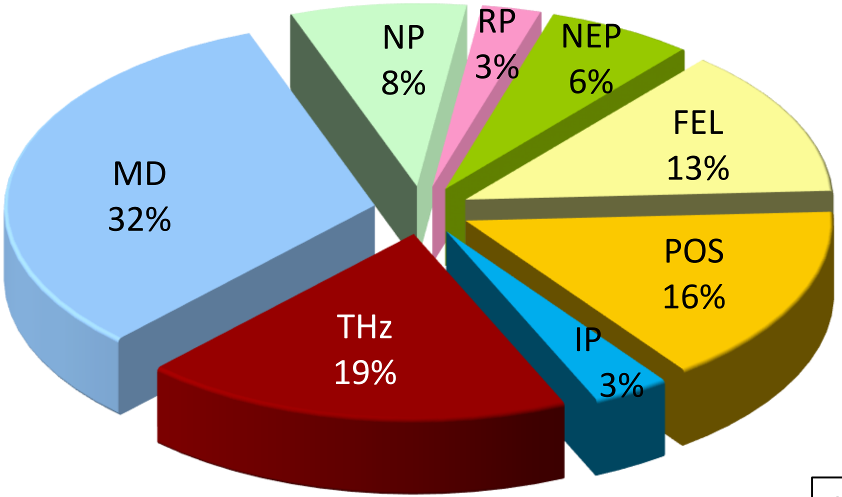


Parameters:

- Slit width 100 um, scan step 100 um
- YAG screen resolution 25.3 um
- Distance between slit and screen 0.75 m
- L_d: laser spot diameter on cathode

- One measurement takes about 90 s

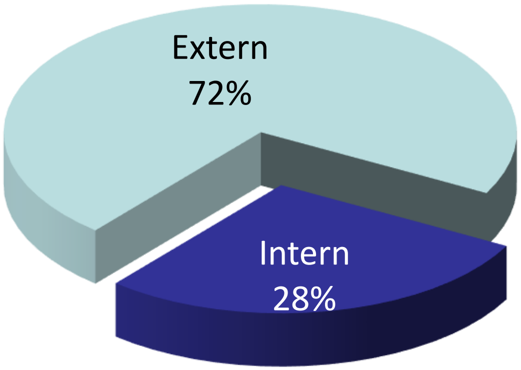
Beamtime distribution 2021/22

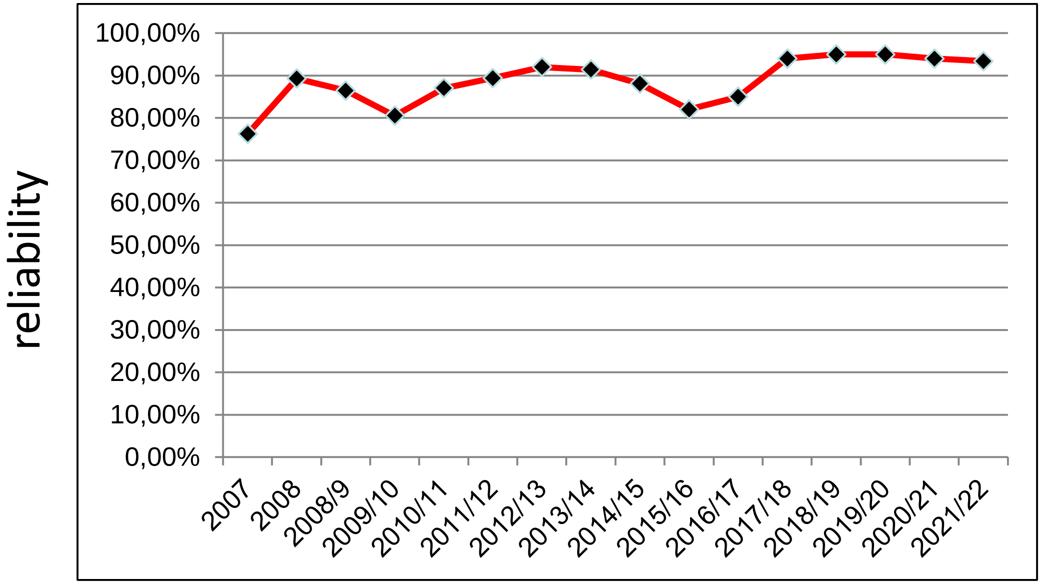


hours in total:

Scheduled	**5699**
Used	**5322**
Reliability	**93%**
External users:	**72 %**

External/internal use (beamtime)





Most common causes of technical problems

With longer interuption of beamtime (> 1 h..shifts)

- Leaks on the water cooling system of magent power supplies → new power supplies will be ordered 2022

- Failure of the SRF gun cathode laser
- Vacuum leak at the BPM in neutron beamline
- Failure of temperature sensors in the cryo plant
- Failure of turbo pumps on acclerator module (isulating vacuum)

With short interuption of beamtime (< 1 h)

- Problems an coolant towers (sensors, filters…) → replacement of tower 3 and 4 in planning (2023, ~ 1 M€)
- WinCC trouble (WinCC-OPCUA-digital LL RF server)
- High voltage sparkover at parallel operation with SRF gun

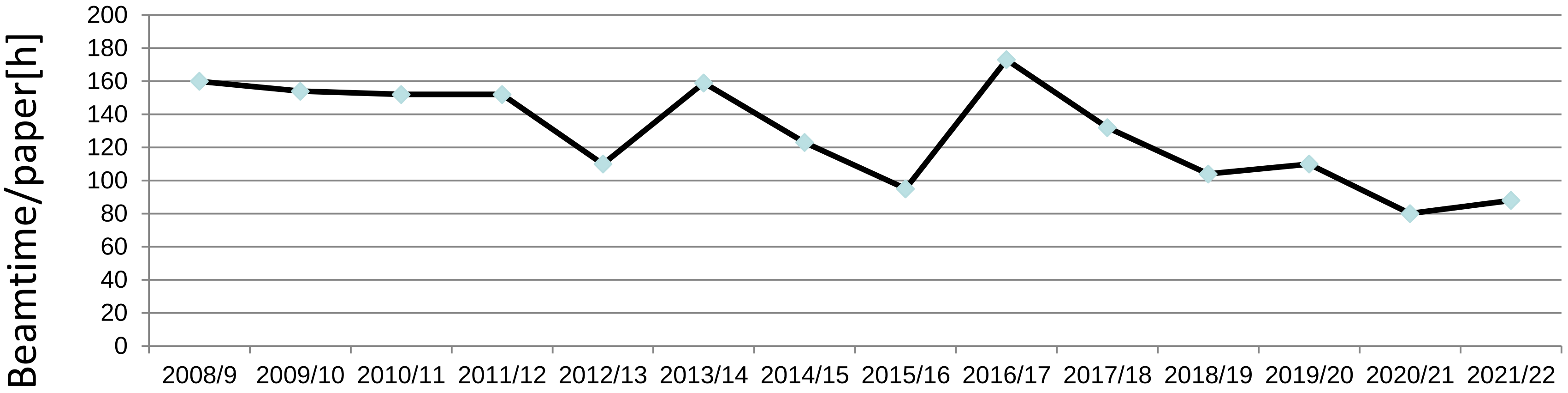
ELBE publications 6/2021 – 6/2022

(Nature, ACS Photonics, Nanotechnology, Nanoscale, Rev. Sci. Instr., Minerals, Phys. Rev. Mat., APL´Photonics, J. of Physics, Advanced Mat. Interfaces, J. of Mat. Chemistry, NIM, Eurp. Polymer J., J. of Alloys and Compounds, J. of Spectroscopy, J. of Synchr. Rad., Optics Letters, Apll. Phys. Letters, Rev., , Synchr. Rad., Rev. Mod.Phys., Sci. Reports, Phys. Rev. Spec. Topis,)

Nuclear physics	3
FEL	6
THz	3
Detectors	3
Neutron physics	1
Positrons	21
Radio biology	1
Machine physics	5
	Σ 43

~ 88 user beamtime hours per paper

(3807 h user beam time)



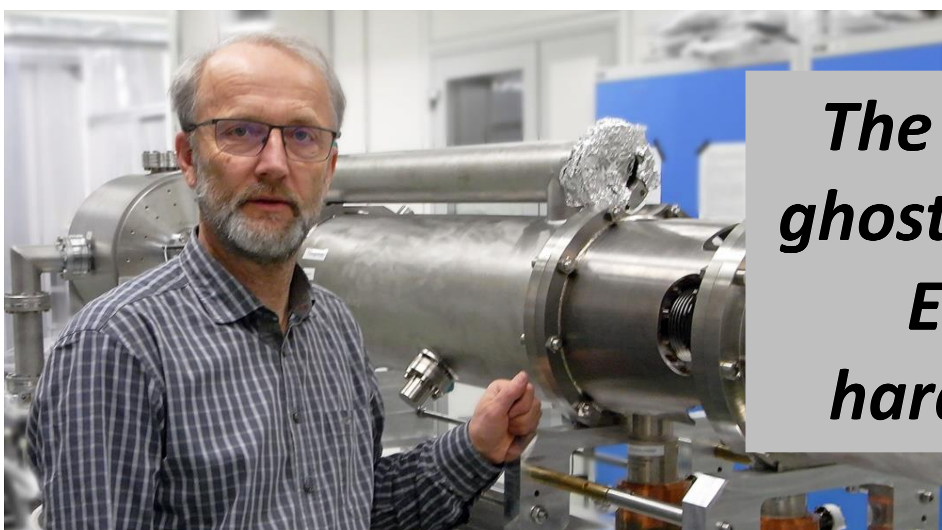
FELs of Europe Topical Workshop on Selected Problems in FEL Physics: from soft X-rays to THz
Apr 25 – 27, 2022 Dresden/hybrid ~ 80 participants
hosted by HZDR (M.Helm)

E-Linac Reliability Workshop (ERW)
May 9 – 10, 2022 Virtual , ~ 50 participants (incl. Industry)
hostet by TRIUMF, KEK, HZDR

Staff issues

- 10 operators for 24/7 regime is very tight !
- E.g. in August 2022 several operators are not available
  (medical certificate for no night shifts, rehabilitation cure, parental leave …)
  …..possibly engineers /physisits temporary working in night shifts

- Operational engineer Michael Freitag will be retired next year !
  successor has to be clarified soon !



The „good ghost" of the ELBE hardware

Beamlime request Run 4/2021

	shifts
available in run 4/2021	259
- 25 % machine development (64)	195
- 10 % at the disposal of the director (26)	169
User shifts available	**169**
sum of requests	**318**

Overbooking 1.9

Thank you for attention

Thanks for contributing: C.Schneider, M.Kuntzsch, R.Schurig, M.Justus, M.Freitag, R.Xiang, A.Arnold, B.Schramm, U.Lehnert, J.Schaber, A.Maalberg, S.Ma