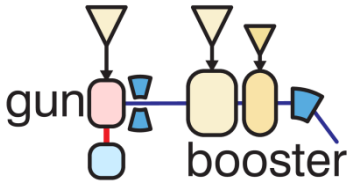
XFEL Accelerator R&D Proposal
Extension RP-212: SRF photoinjector (Ts4i)

Elmar Vogel and Dmitry Bazyl

December 15th 2023

Scope of the R&D activity (1/2)

- high gradient photoinjector operating CW for the European XFEL High Duty Cycle (HDC) operation

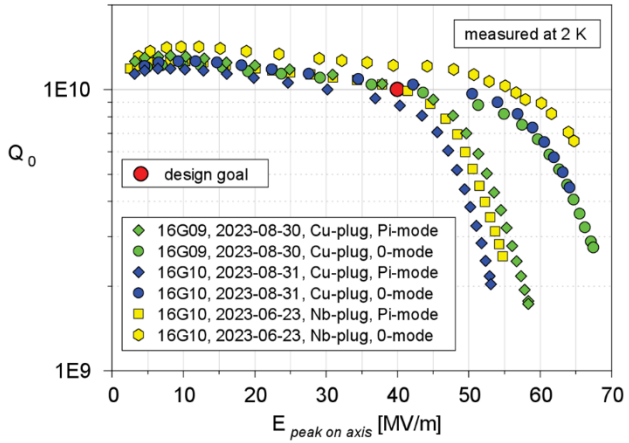


- direct matching into subsequent linac
- no buncher cavity!
- possible with L-band SRF technology

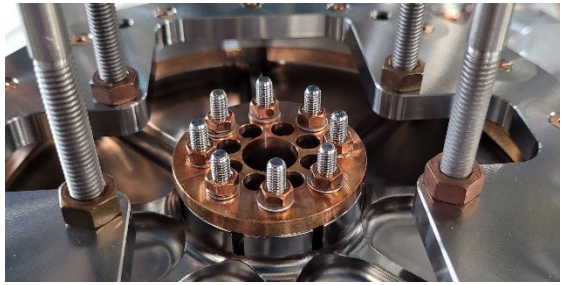
- interfaces with other XFEL R&D: R&D Pillar CW

- promised deliverables: SRF gun cavities with peak field on axis ≥ 40 MV/m

- **with copper cathode plugs ≥ 50 MV/m obtained** arXiv:2310.02974v1 [physics.acc-ph] 4 Oct 2023

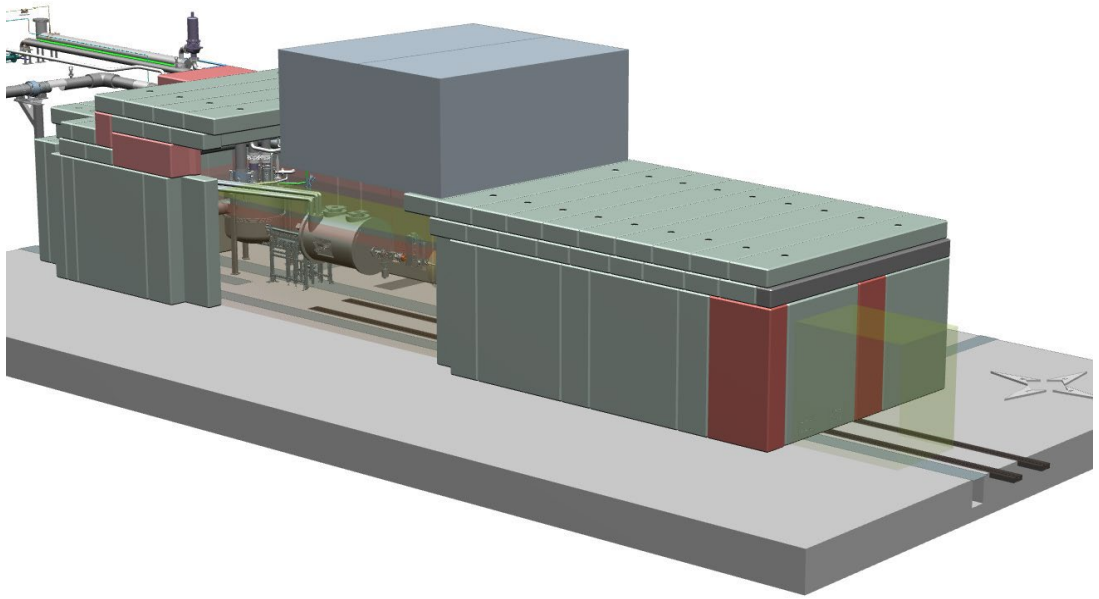


- It is counter intuitive – NC part in SC cavity – but the magnetic field vanishes near the cathode area!



Scope of the R&D activity (2/2)

- Now, we have the building blocks of a high gradient photoinjector in hand!
- The next step required is the production and characterization of electron beam!



- small test accelerator Ts4i in the AMTF for
  - testbed for the various new technologies needed
  - demonstration of the production of beam with the desired properties
  - later with an Eu XFEL CW injector in user operation: qualification of the SRF photoinjector cryostat assemblies before tunnel installation
- further improvement of SRF photoinjector cavities
  - cathode plug sealing
  - meeting all the various tolerances due to beam dynamics
  - improving the quality factor at high gradients
- R&D activity closely linked
  - the here presented R&D topic is closely linked to the topic "Nanostructured and other metal photocathodes"

Some remark(s)

- this work is supported by a lot of committed, very good and very professional working colleagues
  - in the last years this was concentrated on the SRF gun cavities: MSL + external collaborators like KEK, HZDR, HZB
  - now, the complete DESY accelerator division is involved, in particular
    D3 + FS-LA + MCS + MDI + MEA + MHF + MIN + MKS + MPC + MPS + MSK + MSL + MVS + Z_PITZ + MKK + IT + …

- **Thank you very much to all contributors!**

Deliverable of the R&D Proposal and it's benefit for the XFEL

- final deliverables with completion of R&D activity
  - test accelerator Ts4i in the AMTF producing first beam
  - SRF photoinjector cavity "design finalized"
- foreseeable extension proposal benefiting from Ts4i
  - study of beam properties
  - study of (beam based) alignment procedures
  - study of in situ cathode preparation methods
  - study of different cathodes (e.g. with nano-structuring) and cathode preparations
  - study different cathode laser manipulations
  - common goal: improving the beam quality
  - …
- potential extension proposal(s)
  - we will most likely propose continuing the R&D to further improve the SRF photoinjector cavities and assemblies (tank, tuner, etc.)
  - we may also propose to further develop other components of the SRF photoinjector like the solenoid magnet
  - we may also propose to further develop the Ts4i installation like the beam diagnostics
- further away extension proposal
  - CW injector in second XFEL injector tunnel starting 2028?
- benefit of this proposal for the XFEL
  - high gradient photoinjector operating CW for the XFEL
  - offering direct matching of beam to subsequent linac

Timeline of this R&D activity

Milestone Description	Target MTH/QTR
official approval to continue with the SRF photoinjector R&D and launching Ts4i	Q4/2023
all required resources (personnel) available to the project	Q4/2023
Ts4i bunker structure layout reviewed and fixed	Q1/2024
production readiness review of cryogenic supply (JC-box, cryo-lines, …)	Q1/2024
design readiness review of SRF cavity tank and tuner	Q1/2024
production readiness review of SRF photoinjector (prototype) cryostat	Q2/2024
mechanical layout (incl. all accessories) of warm beam-line reviewed and fixed	Q2/2024
Ts4i integration complete (cabling, position of cabinets, …) reviewed and fixed	Q3/2024
Ts4i bunker structure adaptation started	Q1/2025
construction work on cryogenic supply started	Q1/2025
construction work on laser installation started	Q2/2025
construction work on warm beam line started	Q3/2025
start of first cyo-module assembly	Q1/2026
Ts4i construction work finalized	Q2/2026
start commissioning	Q3/2026

Personnel resource needs of the R&D project

Skill or Task Description	FTE	from	to
available: personnel already allocated to the current RP-212	see budget book	2024	2026
new*: Technical Coordinator (TC)	3	2024	2026
new*: Project Administrative Assistant (project office)	see budget book	2024	2026
new*: Mechanical Engineer (cold integration)	3	2024	2026
new (hire in progress): PostDoc to develop setup for transverse slice emittance measurements	3	2024	2026
new: PostDoc taking care of the integration of Ts4i beam diagnostics into the control system	3	2024	2026
available (started working in September 2023): Cathode Laser Engineer	3	2024	2026
new (hire in progress): Scientist for Superconducting Magnets	see budget book	2024	2026
sum value:	**33**	**2024**	**2026**

Additionally, this R&D project needs the support of personnel occasionally available elsewhere within the XFEL accelerator operation at DESY spread over various groups and OPs/RPs. According to our budget book, this additional available personnel in other groups/OPs/RPs amounts to 30 FTEs in three years.

* either by immediate new hire or by re-allocation of qualified colleagues within DESY to the R&D project

Expenditure

Items to be purchased / Task Name	When	Cost/k€
ongoing cavity R&D, tank and tuner dev., initial parts for Ts4i	2024 to 2026	1 033
cryomodule, cryogenic supply, cold mass, cold beam line, etc.	2025	1 067
warm beam line incl. diagnostics and controls, PSUs, RF control	2024 to 2026	1 137
power RF and cathode laser system incl. laser hutch	2024 to 2026	1 460
bunker infrastructure and safety systems	2025	537

Resource and Cost Profile of Proposal

Year	FTE	Invest + Recurrent / k€	Comment
2024	11	1 210	see below
2025	11	2 814	see below
2026	11	1 210	see below

If personnel is not acquired timely, this cost profile may change drastically and the total project time until reaching the goal commissioning and "first beam" will be extended.

Summary

- We have the building blocks of a high gradient photoinjector for direct matching into the subsequent linac in hand!

- The next step required is the production and characterization of electron beam!

- The small accelerator Ts4i in the AMTF producing first beam requires
  - three years, if personnel is made fully available in time
  - 33 FTE directly accounted to the activity
  - 30 FTE of support of personnel occasionally available
  - about 5 234 k€ invest

- foreseeable extension proposals
  - study of beam, cathodes and the cathode laser properties including various manipulations
  - further improve the SRF photoinjector cavities and cavity assemblies

- the work is the basis for
  - starting 2028 with the installation of a CW injector in the second XFEL tunnel
  - more detailed planning of XFEL HDC upgrade