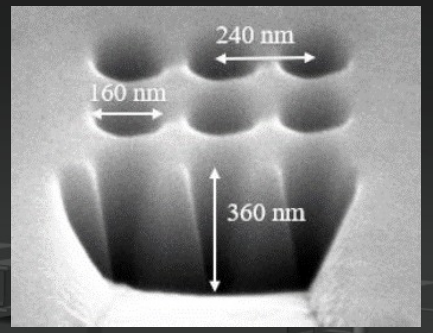
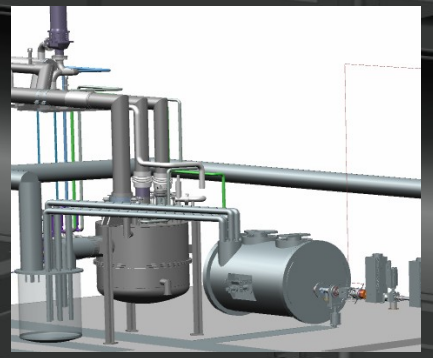
CW Photoinjector for the Future CW and HDC Eu XFEL





Elmar Vogel for all colleagues and collaborators contributing to the CW photoinjector for the HDC Eu XFEL

TTC Meeting, IRIS-IBS, Daejeon, Korea on April 8-11, 2025

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

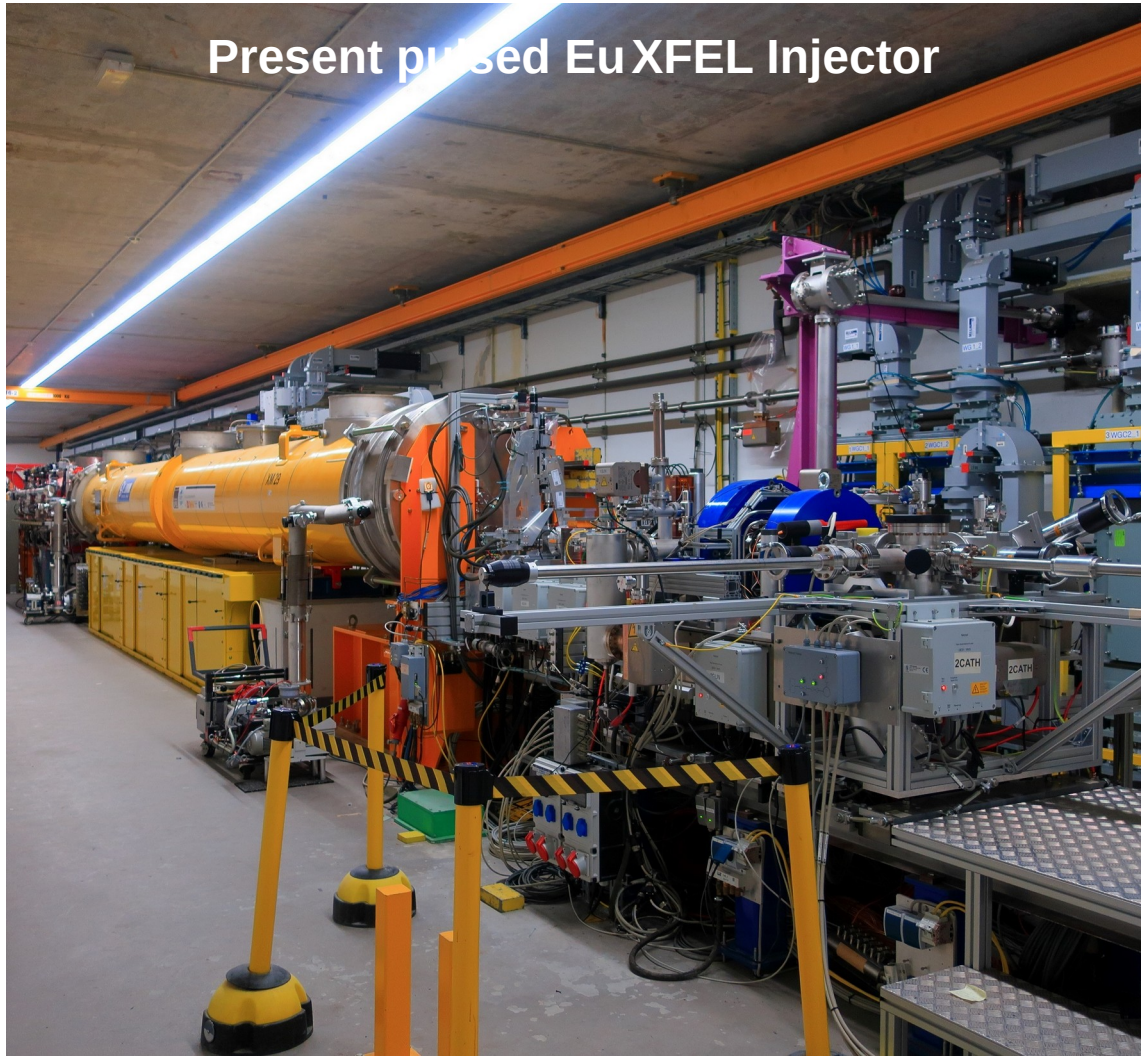
European XFEL

DESY.

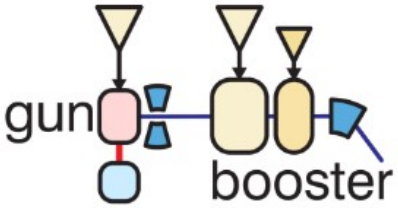
Introduction

Direct injection into subsequent L-band module

replicating the beam dynamics of the present pulsed Eu XFEL photoinjector



CW Injector for High Duty Cycle (HDC) Eu XFEL



- direct matching into subsequent booster linac
- no buncher cavity!
- possible with L-band SRF technology
- cathode screwed to backwall for optimal cleaning

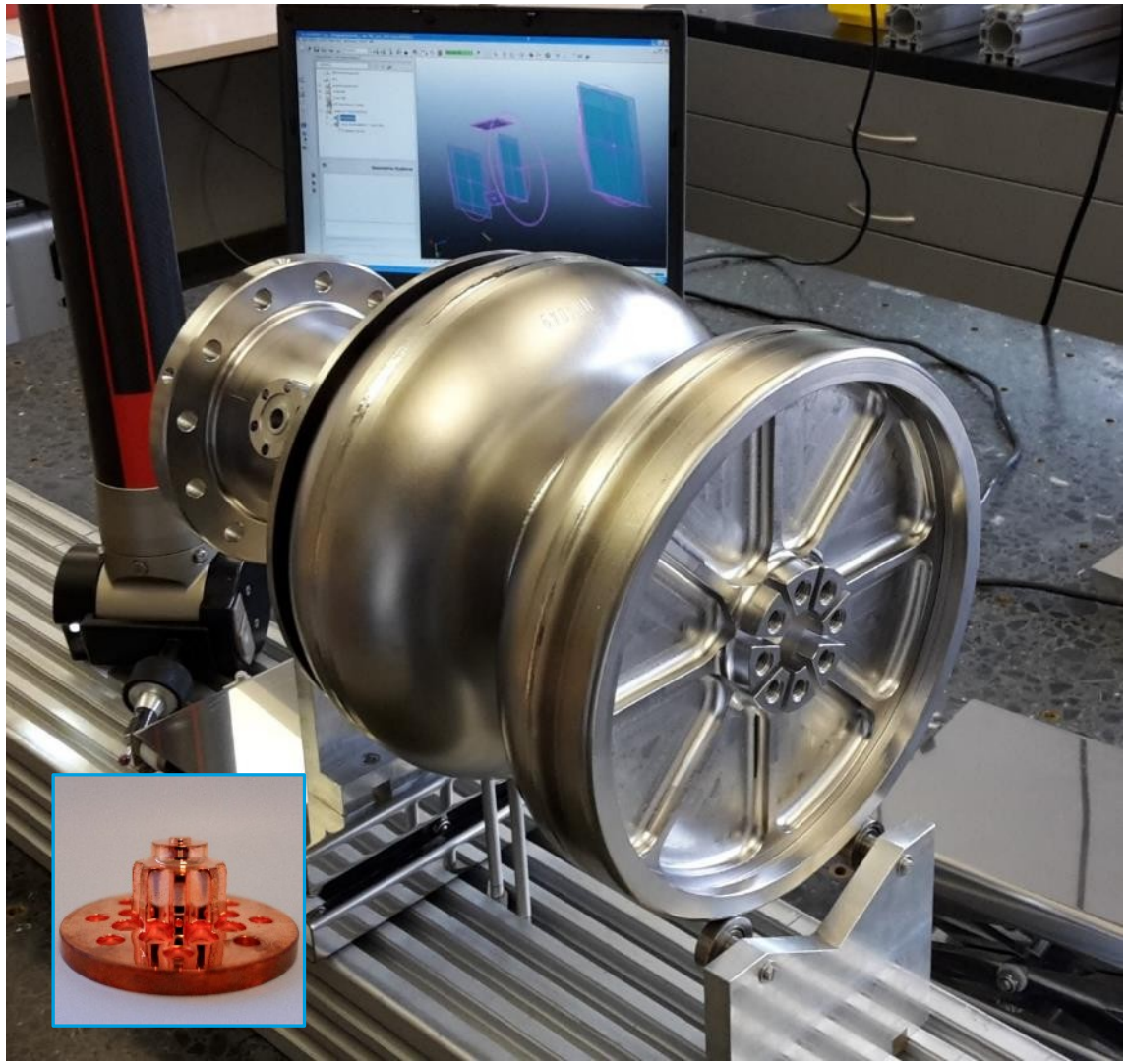
- prerequisite:
  SRF gun cavities with peak field on axis ≈ 50 MV/m

overview on SRF injectors around the world:
https://indico.fnal.gov/event/60446/contributions/275114/

Full metal setup of SRF cavity & cathode

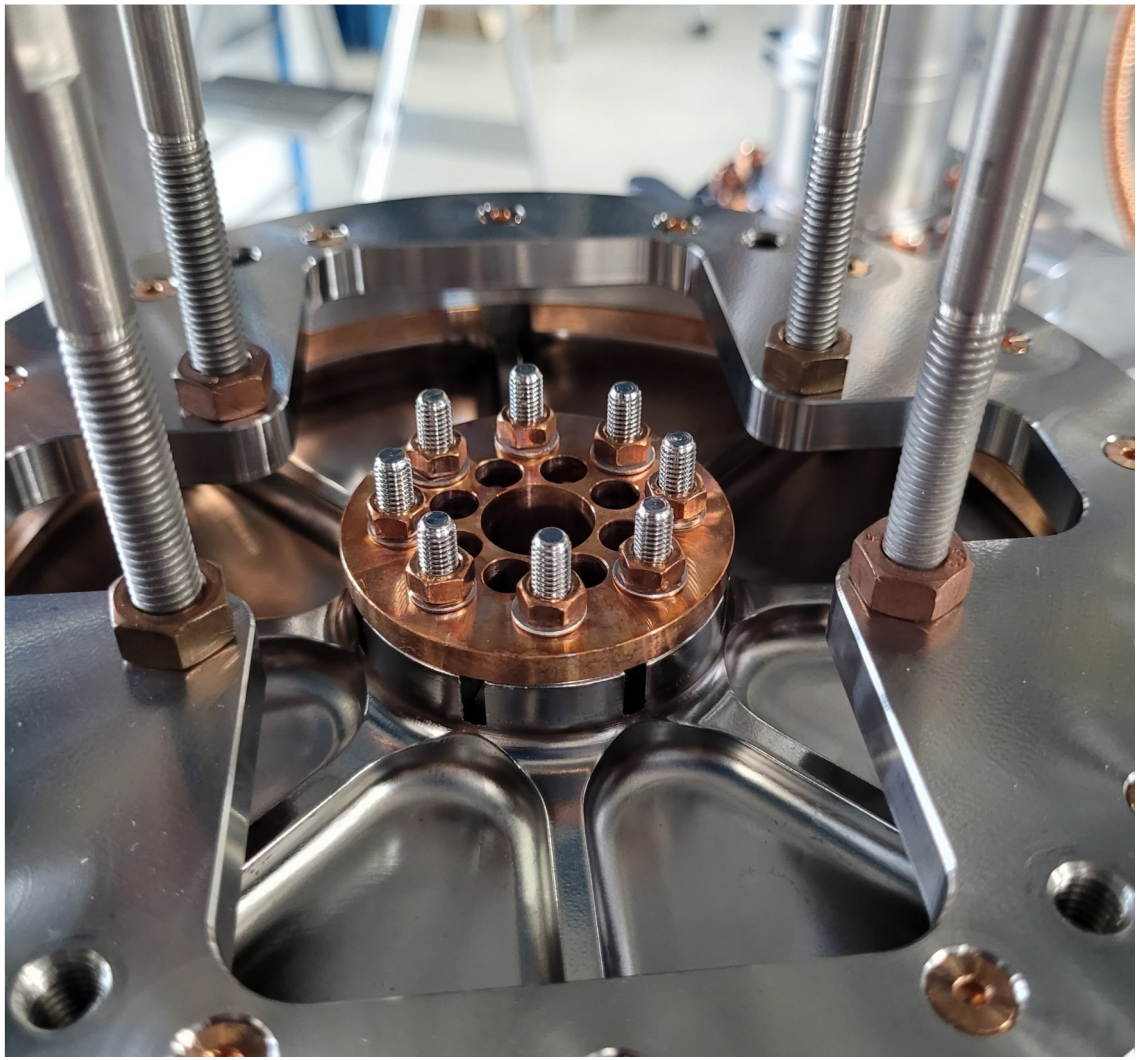
design parameters and setup, comparison to present pulsed NC cavity setup

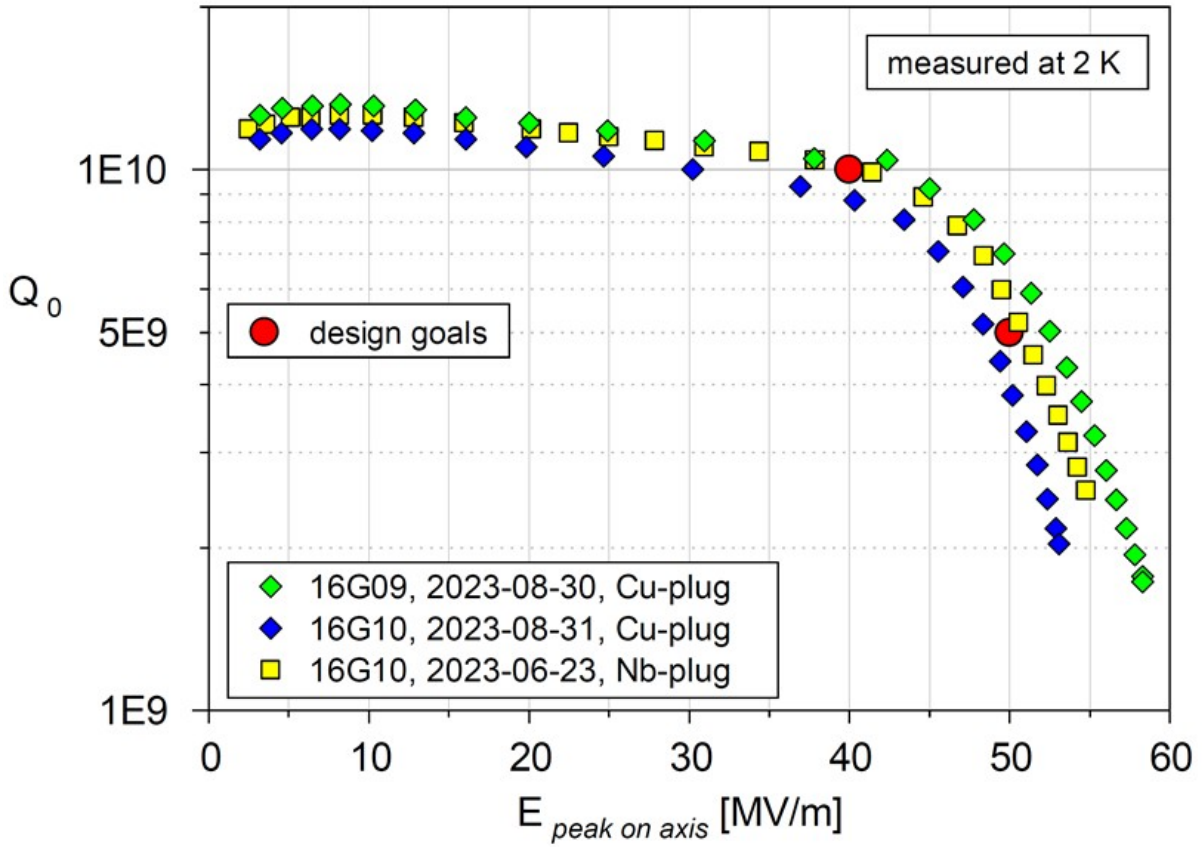
design beam parameters	SRF Gun	NC Gun
bunch repetition rate [kHz]	100 - 1000	up to 4500
bunch charge [pC]	20 to 100	20 to 1000
transverse emittance [µm]	0.2 to 0.4	0.2 to 1.0
beam energy at gun exit [MeV]	≈ 5	≈ 6.1
RF parameters		
duty cycle [%]	100	≈ 1
operation frequency [GHz]	1.3	1.3
accelerating gradient [MV/m]	≈ 28	≈ 31
electric field at cathode [MV/m]	≈ 42	≈ 60
peak on axis field [MV/m]	≈ 50	≈ 62
Cathode		
material	copper	Cs_2Te
assembly	screwed to back-wall	load lock system



SRF performance of the cavities

copper cathode plug screwed to niobium cavity backwall





for details visit https://arxiv.org/abs/2310.02974

Cold Integration

topics asked to be addressed in this TTC working group

Cryogenics and cryomodule

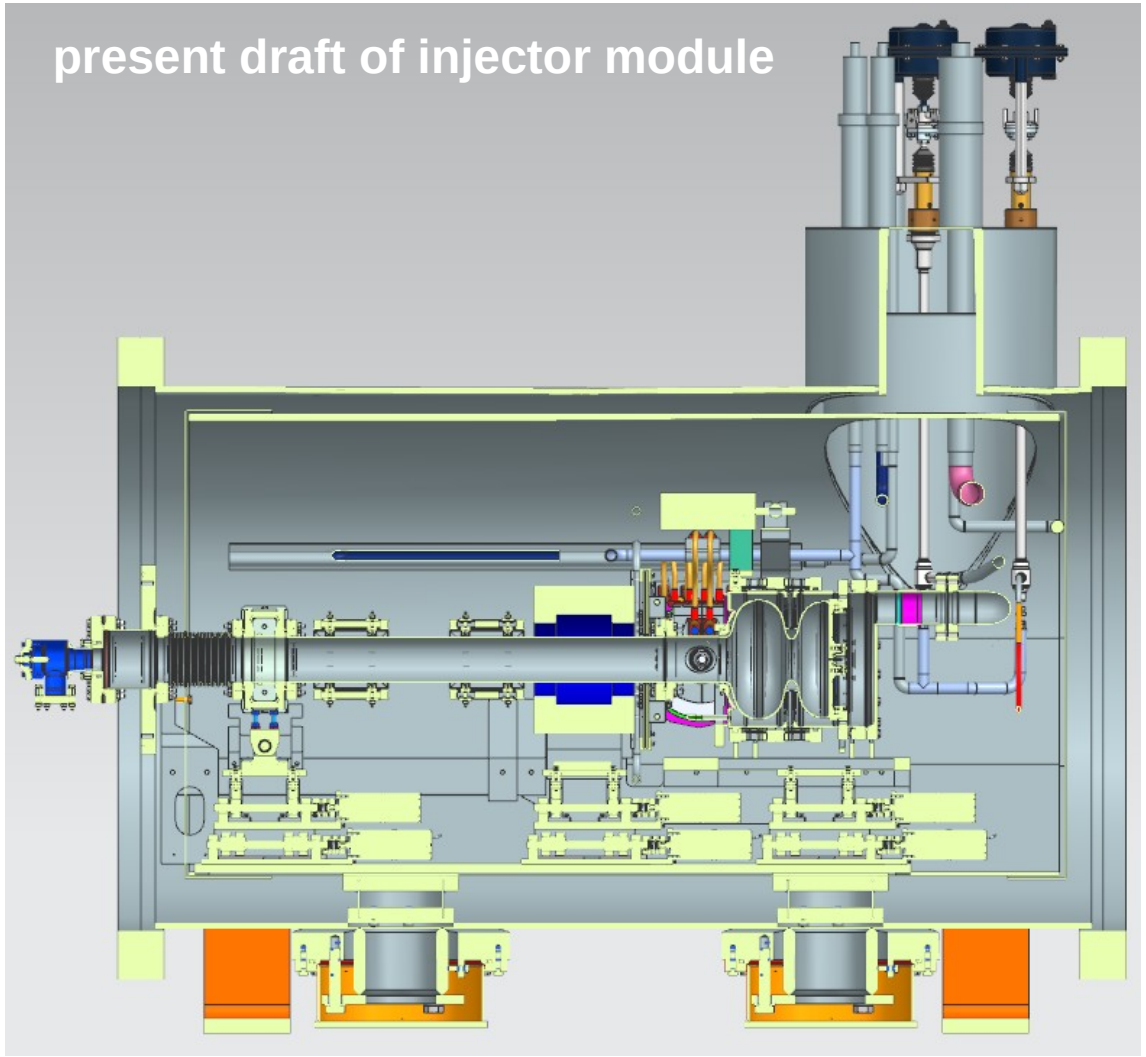
design choices and implementation

Design parameters

- 25 W at 2 K for cavity cooling (dynamic)
- 5 W at 2 K for cathode cooling (heated by the laser)

Basic implementation

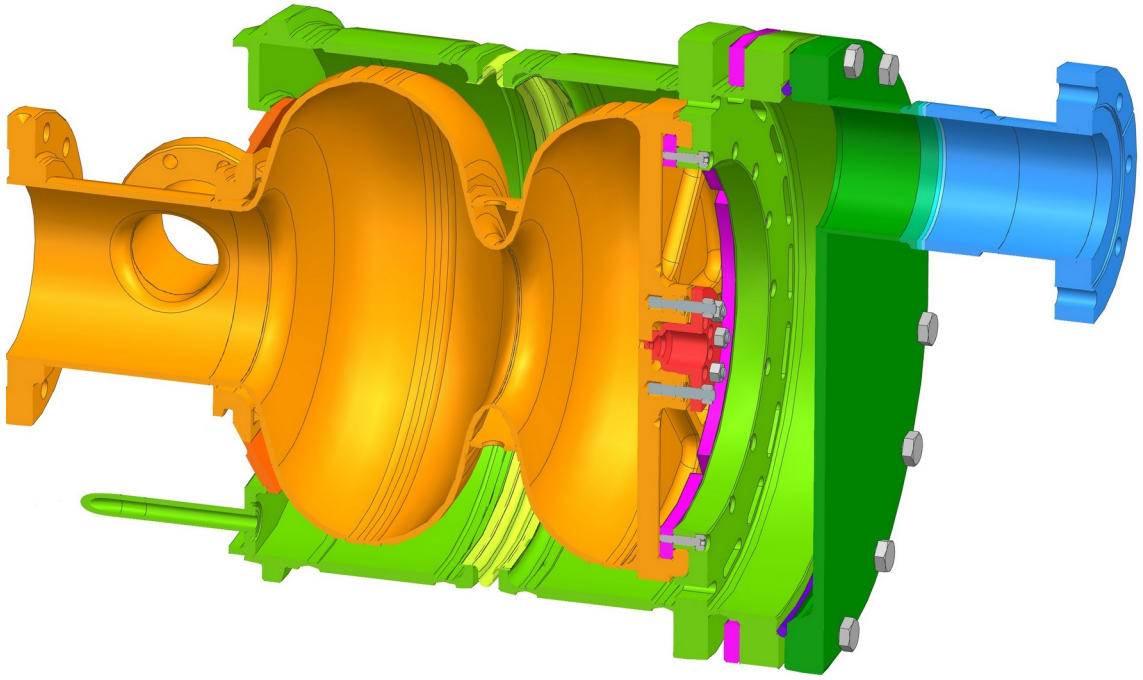
- cooling with helium only (no nitrogen pre-cooling)
- lines with Johnston-type coupling to distribution box for frequent exchange
- cold beam line components supported from below
- the cold warm transition design followed considerations on all assembly steps from the clean room up to connecting the module to the subsequent beam line



Cathode exchange and helium vessel design

exchange in clean room followed by ultrapure high pressure water rinsing

draft of helium vessel



Cathode exchange

- in clean room
- followed by cleaning by high pressure rinsing with ultrapure water

Helium vessel

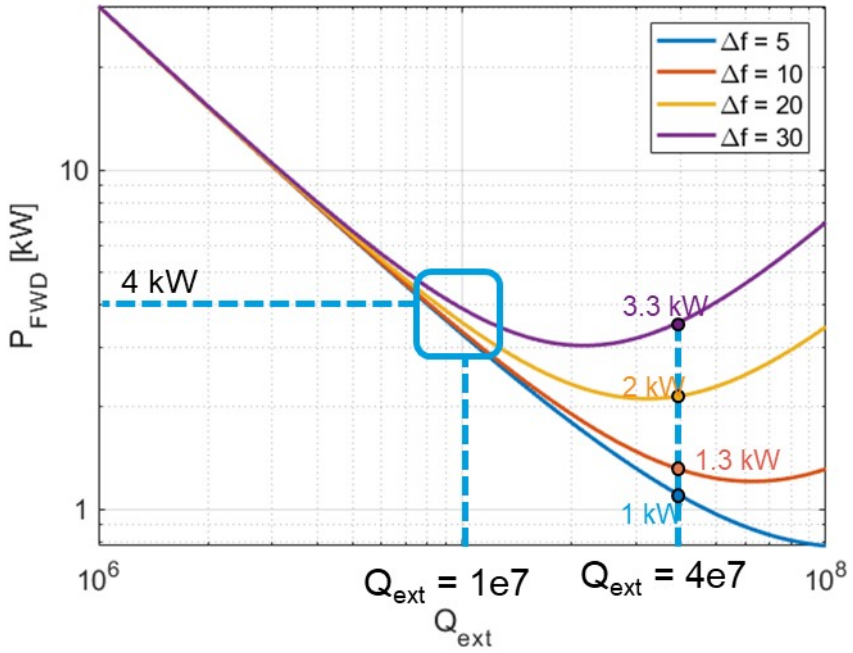
- helium vessel bellows inside (protected) to avoid damage during assembly
- backside sealed with flange connection
- filing line opposite "chimney"
- fixtures of cavity at cavity backside with slits large enough for 25 W at 2 K cooling

Frequency tuner & RF control

compact design using blade tuner, piezos in series to the mechanical tuner

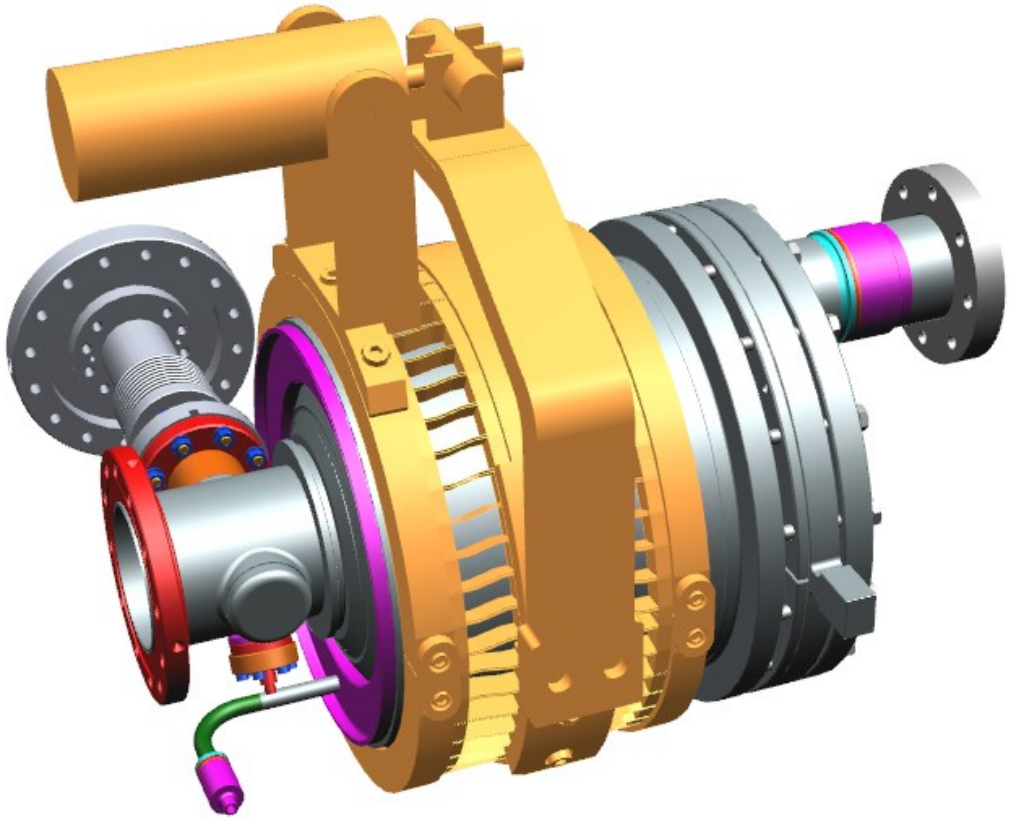
Concerning operation and RF control

- starting with $Q_L = 1 \times 10^7$ keeps the demand on the piezo tuning reasonable



- ramping up gradient with self-excited loop may reduce tuner motor movements

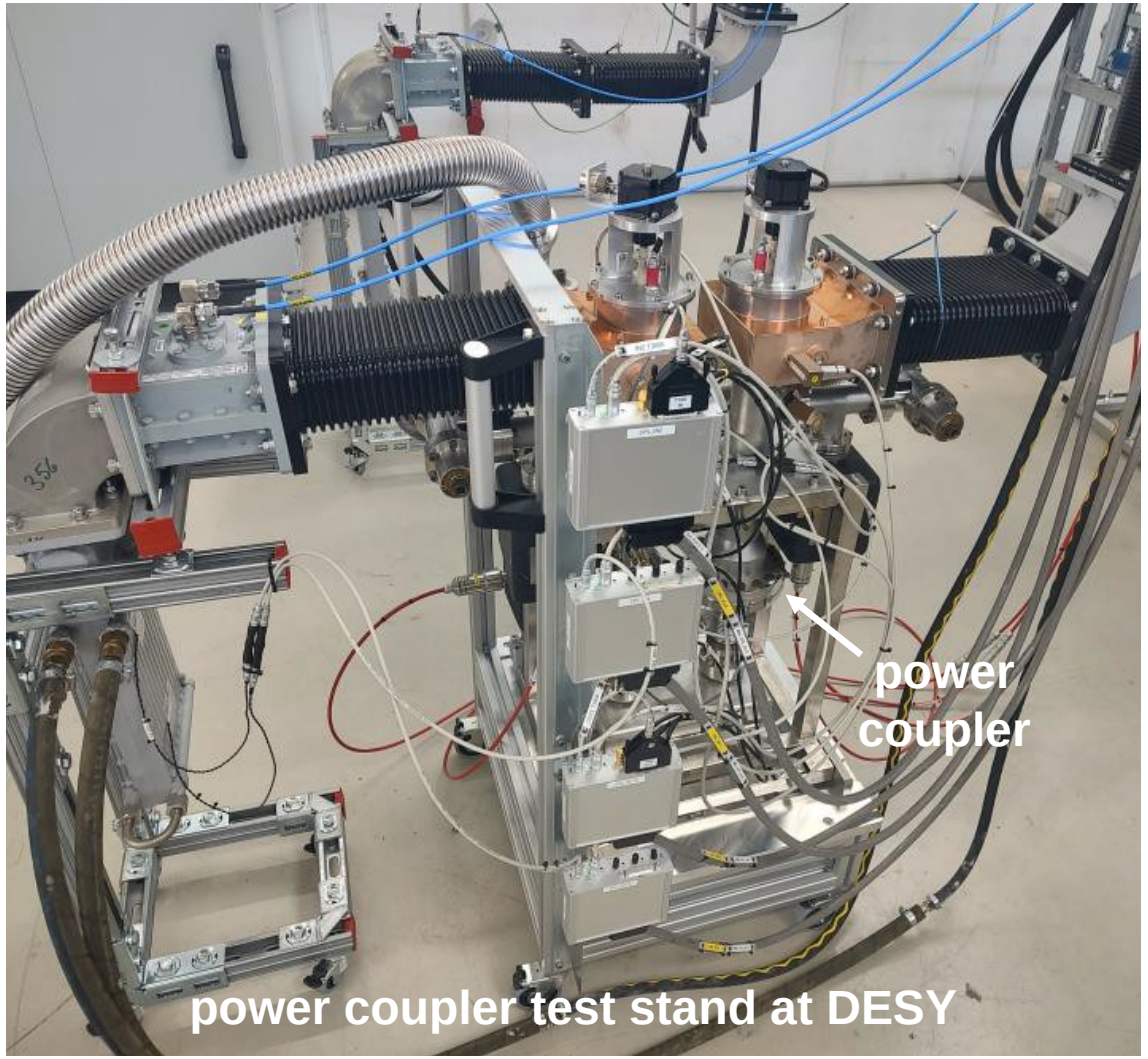
draft of the tuner (yellow)



tuner design by colleagues of INFN Milan

Fundamental high-power coupler (FPC)

keeping measures of power coupler tube and flange like at XFEL 9-cell cavities



Key features

- keeping dimensions of power coupler tube and flange similar to the XFEL 9-cell cavities
- inner antenna of standard XFEL power coupler cut by 20 mm
- power coupler has motor to move the antenna in and out
- Q_L range from 4×10^6 to 4×10^8

Status

- antenna at two existing (XFEL type) couplers cut
- successfully conditioned and tested

Coupler kick compensation & HOMs

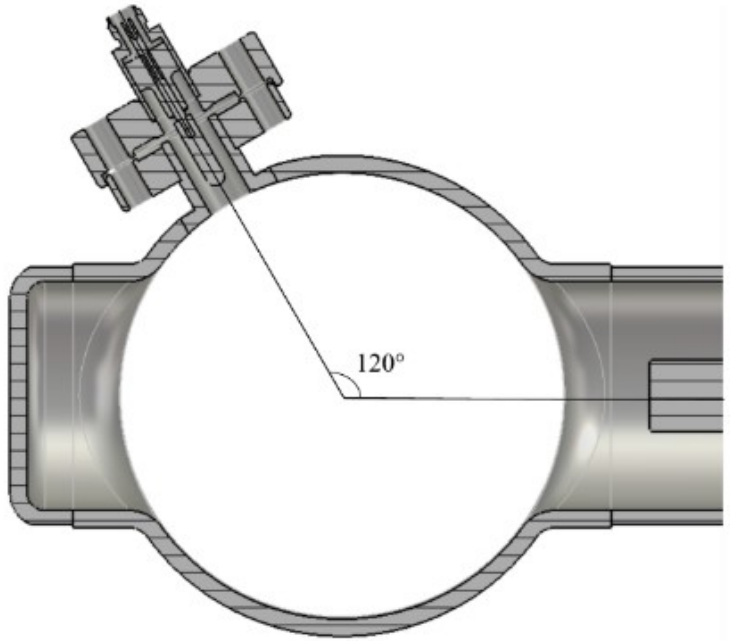
keeping (XFEL 9-cell cavity) beam pipe diameter unchanged

design ideas for the cavity end group

- keeping it as simple as possible
- avoid HOM couplers causing kicks

topics investigated

- coupler kick compensation
- higher order modes (HOMs)
  - calculations
  - studies with beam at FLASH if HOMs can be detected via PU
- position of PU antenna



design and studies presented at IPAC 2023
https://www.desy.de/~evogel/files/wepa144.pdf

potentially dangerous HOMs

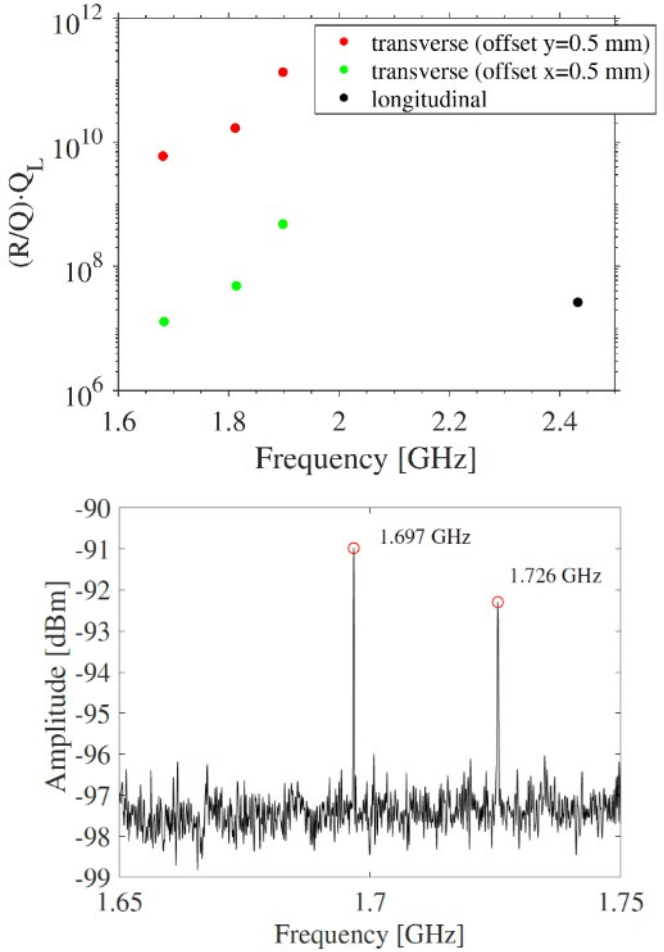


Figure 6: Spectrum analyzer output displaying two distinct peaks at the noise level, corresponding to two modes in the passband of TE111.

Solenoid magnet and magnetic shielding

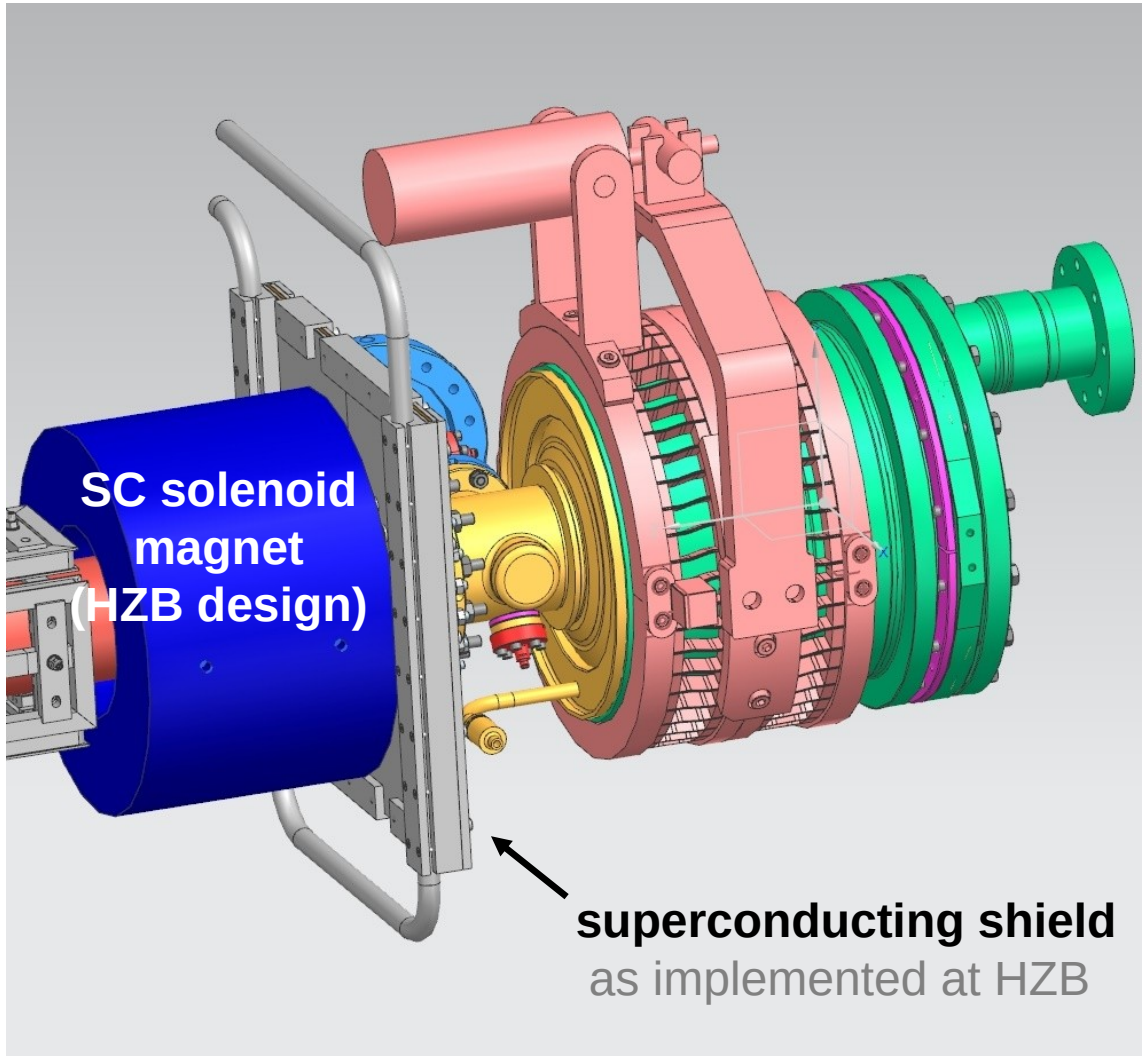
focusing directly after SC cavity

Key items

- at NC cavities focusing by solenoid around cavity
- at SC cavity impossible due to Meisner effect
- focusing directly after beam exit the cavity

Concept of the magnetic shielding

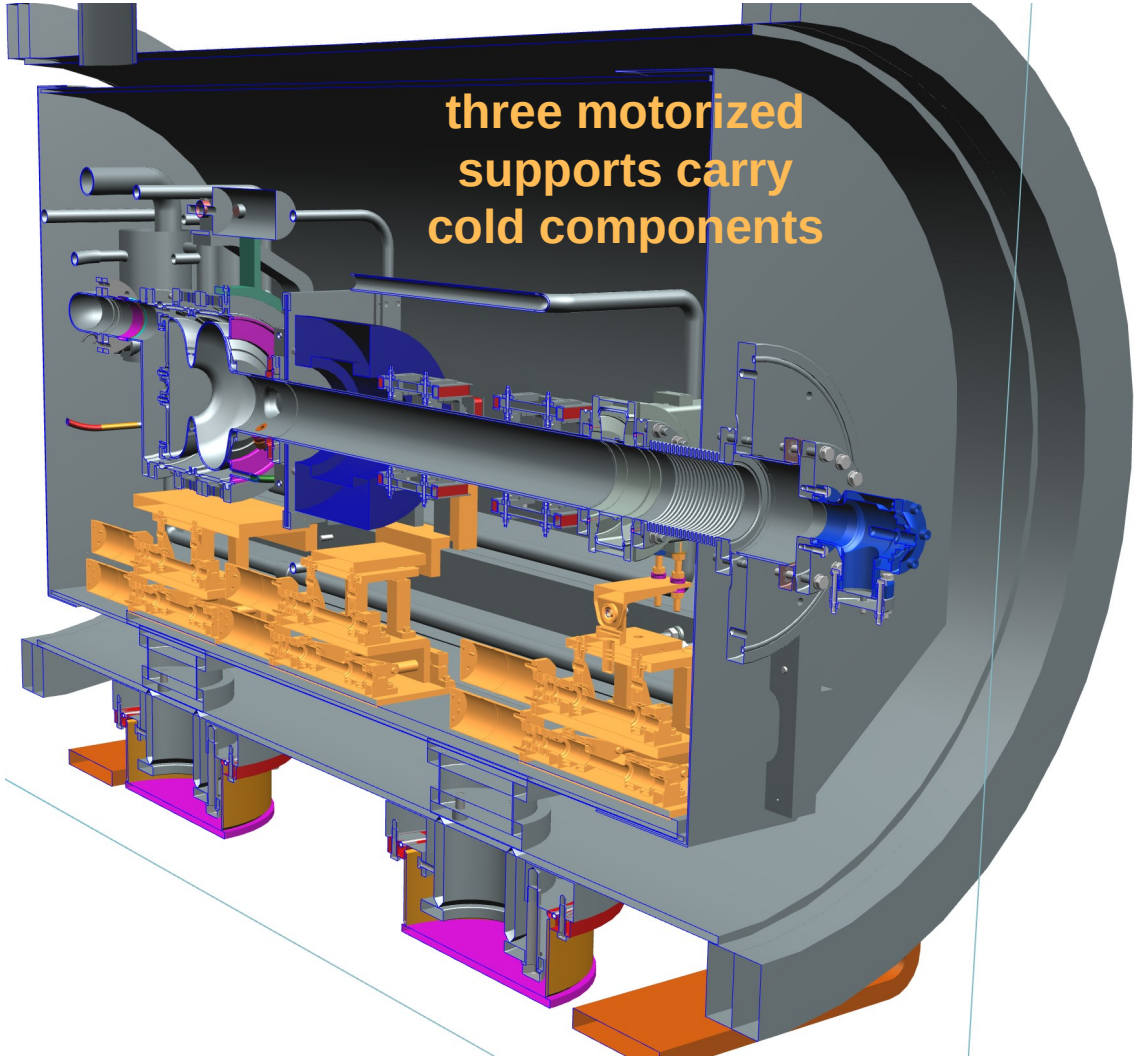
- cryo-perm around the cavity to shield the earth magnetic field
- superconducting shield next to solenoid to prevent cryo-perm saturation by solenoid field



see SRF2021 conference contribution form HZB:
https://accelconf.web.cern.ch/srf2021/papers/weptev003.pdf

Beam alignment considerations

motorized setup inside cryostat



XFEL requirements/experience

- assembly & installation max. deviation ±0.5 mm
- motorized setup in cryostat with target ±2 mm

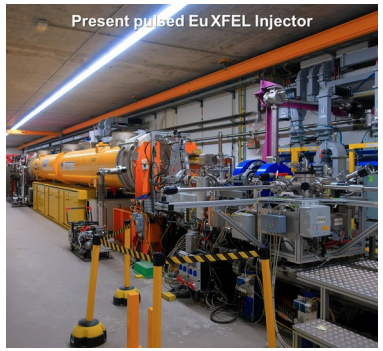
Concept

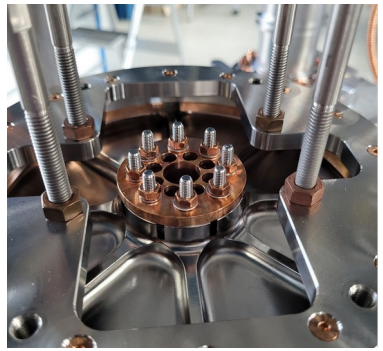
- three motorized supports using "cold tuner motors" at cavity, solenoid and gate valve
- movements: left-right, up-down, only slight tilt of cavity plus cold beam line assembly possible

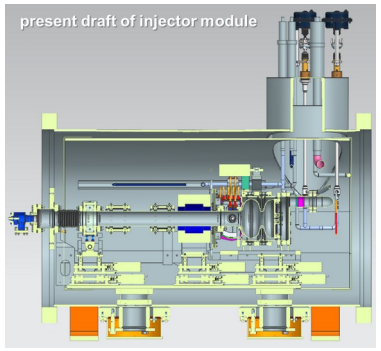
Summary & Outlook

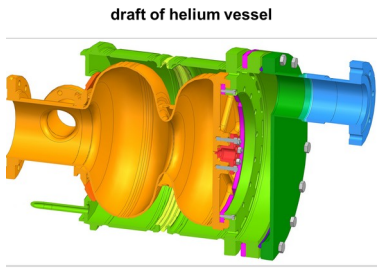
Essential cold parts presented

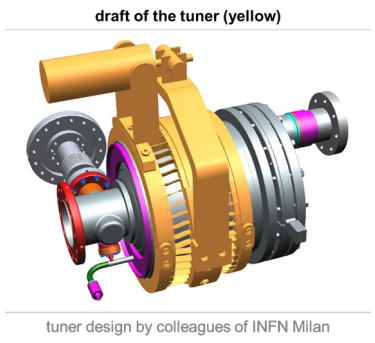
putting it all together

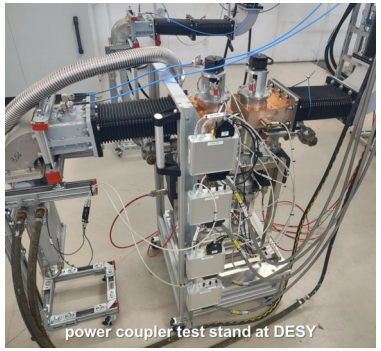


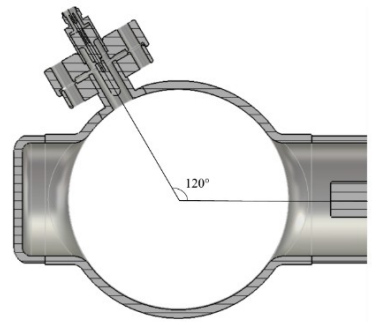


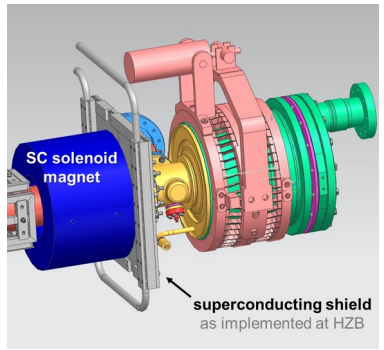


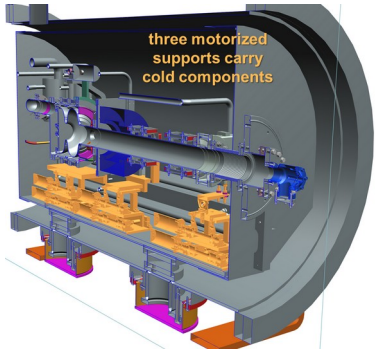


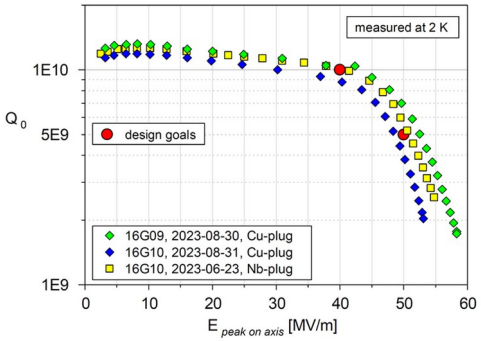












Key items

- we foresee direct injection
- we reach high gradients
- the cold integration is in progress, next steps are
  - finalizing He-tank design and fabrication
  - finalizing tuner design, fabrication and testing
  - design and fabrication of the cold string assembly tooling for clean room
  - and other items

Next major goal

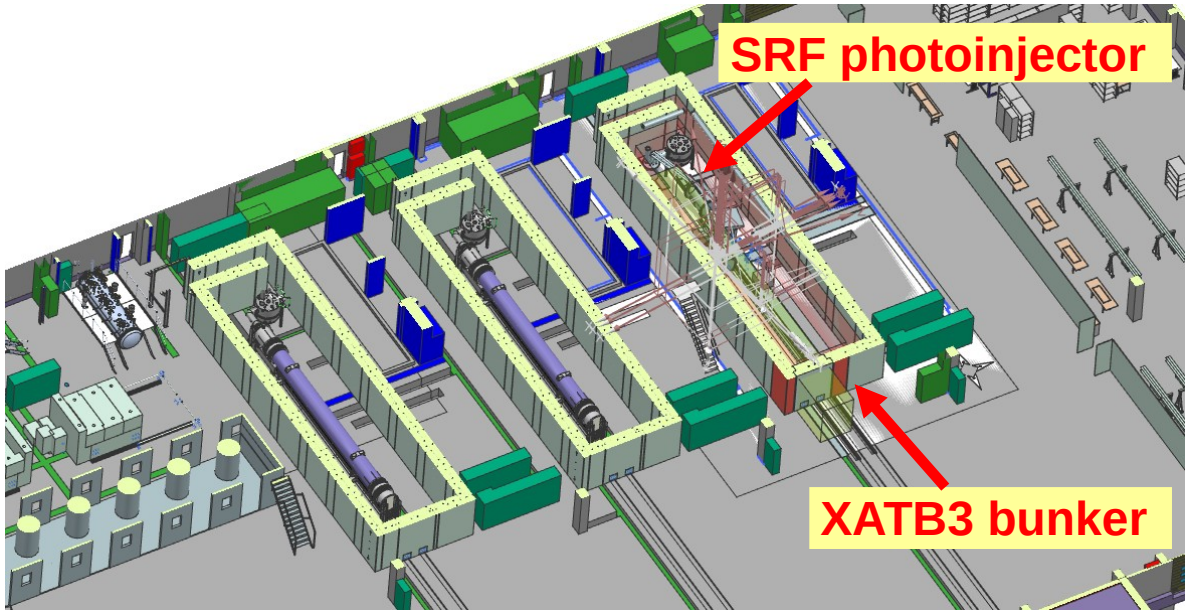
beam production and characterization

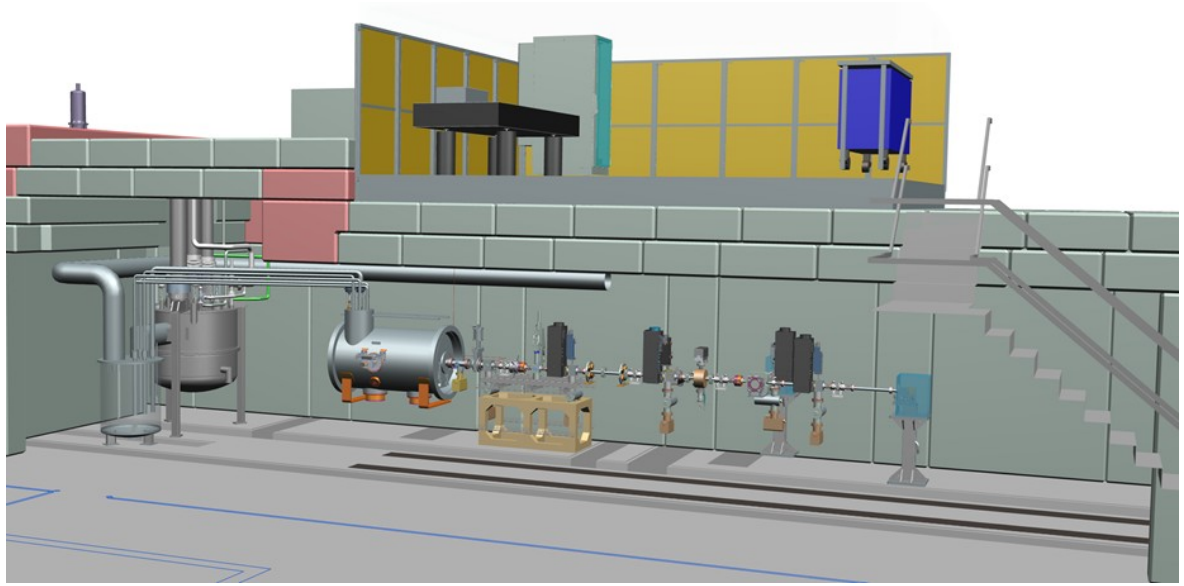
Photoinjector test stand Ts4i

producing and testing beam

New test facility at DESY

- electron beam diagnostics line
- CW concept requires major technology development
- bunker layout & radiation safety
- cathode laser and laser hutch
- infrastructure





Thank you for your attention!

Questions?

First beam with the SRF gun at SEALAB (HZB)

Friday, April 4, 2025, the colleagues from HZB reported about first beam

Thorsten Kamps:

"Just right now we are at 14 MV/m and 3.5 µA average current. Cathode, laser, and SRF still look healthy. There will be a talk at IPAC on this result."

press release: https://www.helmholtz-berlin.de/pubbin/news_seite?nid=29826&sprache=en&seitenid=1