DESY CW SRF photoinjector for EuXFEL

Dmitry Bazyl on behalf of the SRF photoinjector team
MSL, DESY

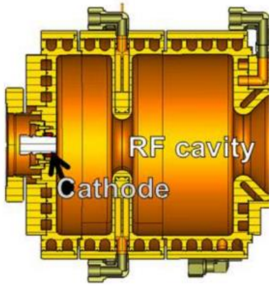
04.12.2023

CW injector for the EuXFEL

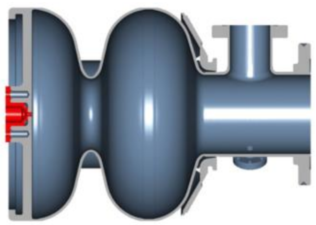
CW L-band SRF gun as the electron source

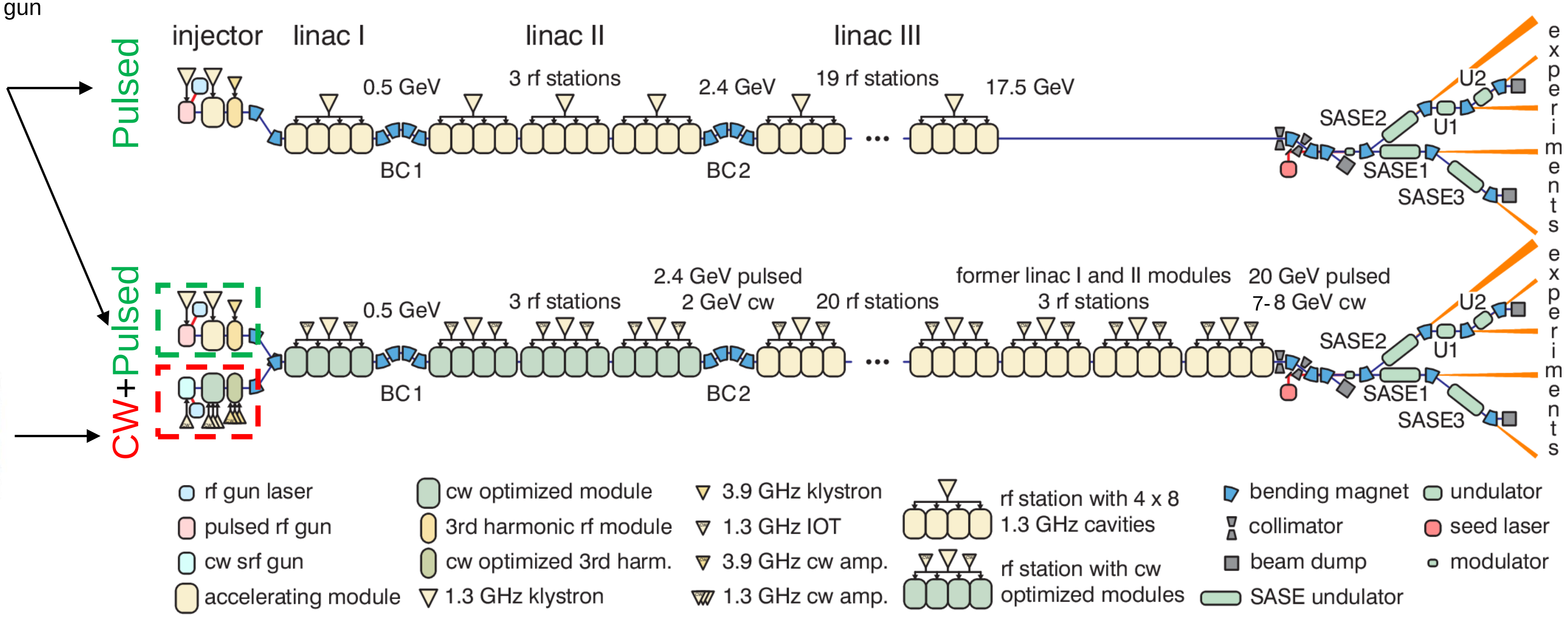
- CW SRF gun as the electron source for CW/High Duty cycle EuXFEL

Normal conducting 1.3 GHz RF gun



SRF 1.3 GHz gun





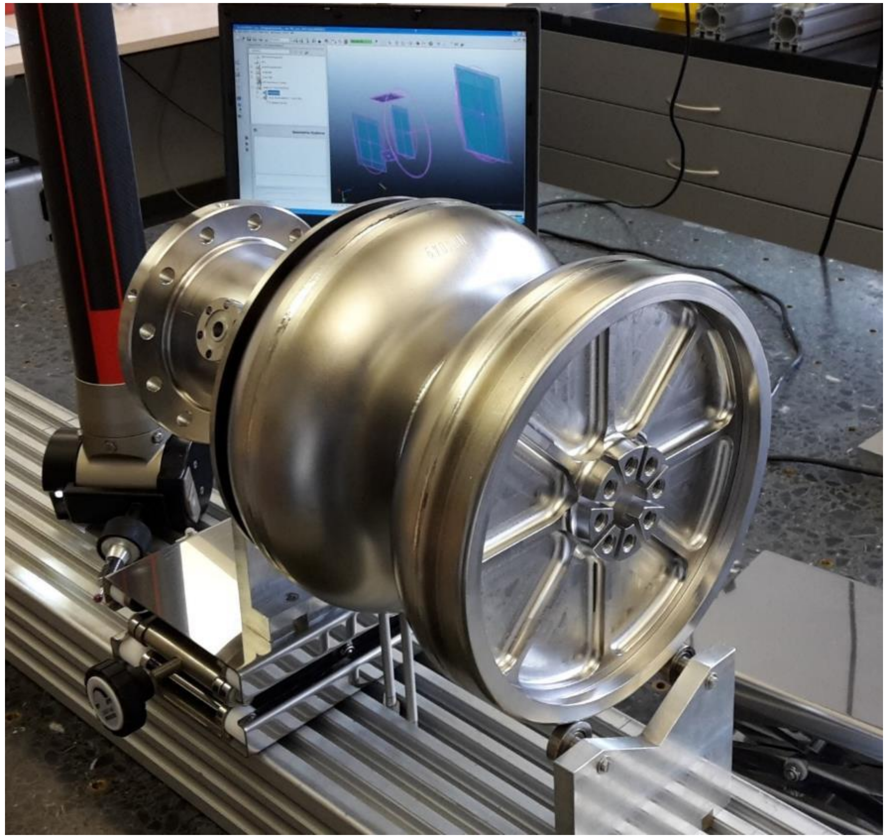
Prospects for CW and LP operation of the European XFEL in hard X-ray regime, R. Brinkmann, E. A. Schneidmiller, J. Sekutowicz, M. V. Yurkov

DESY CW L-band SRF gun cavity

DESY CW L-band SRF gun cavity

Basic parameters

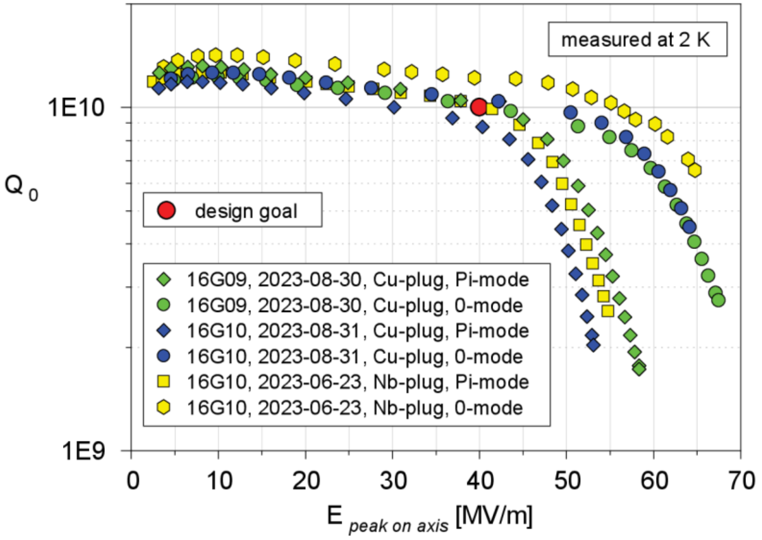
design beam parameters	1.6 cell SRF Gun cavity
bunch repetition rate [kHz]	1000 -100
bunch charge [pC]	20 to 100
transverse emittance [µm]	0.2 to 0.4
beam energy at gun exit [MeV]	> 4
RF parameters	
operation frequency [GHz]	1.3
accelerating gradient [MV/m]	> 21
electric field at cathode [MV/m]	> 40
Peak on axis field [MV/m]	> 42
Cathode	
material	metal: Cu (baseline), Nb?, Pb, Mg?
assembly	screwed to back-wall



DESY CW L-band SRF gun cavity

Highlights of the present status of the RnD

- Enhanced Mechanical Stability, optimized Production Process, and improved Surface Treatment (EP & BCP) led to desired Frequency, Field Flatness, stable Back Wall
  - Peak field on axis up to 55 MV/m on axis (with Cu cathode inserted)
- End Group has been reviewed and finalized w.r.t RF and Beam Dynamics
  - Shortened antenna of the FPC to match Qext = 1e+007
  - Coupler kick compensation and strategy to deal with HOMs
- Remaining challenges:
  - Preparation of the upcoming cavities for potential HT (G09 and G10)
    - ► hitting the cathode laser frequency acceptance of 1300 MHz ± 0.25 MHz is essential
  - Impact of TM010 (0-mode) on the longitudinal emittance
  - Evaluating strategy for HOMs (monitor and avoid excitation)

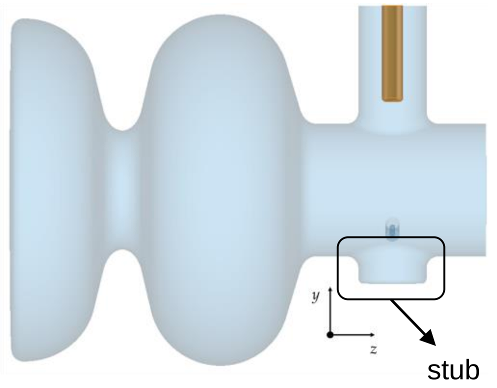


DESY CW L-band SRF gun

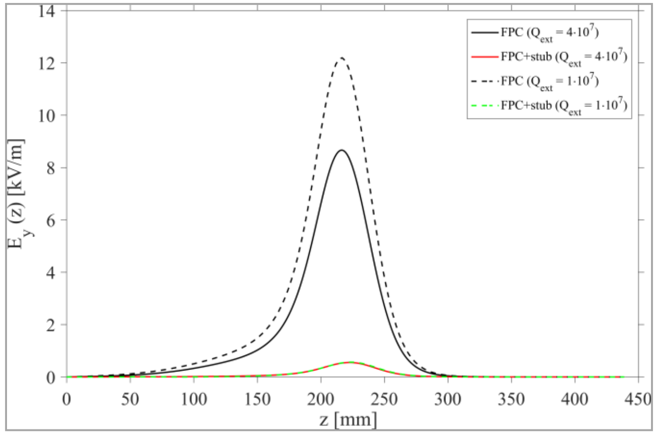
Coupler kick compensation

- Asymmetric design of the input power coupler leads to an unwanted transverse electric field on the central axis of the cavity
- Verification using 3D field maps for particle tracking in Reptil (E. Gjonaj, TEMF, TUD)
- Particles tracked from cathode until exit from booster
- Introducing the stub allows to significantly reduce the transverse kick (factor of 15 and larger)

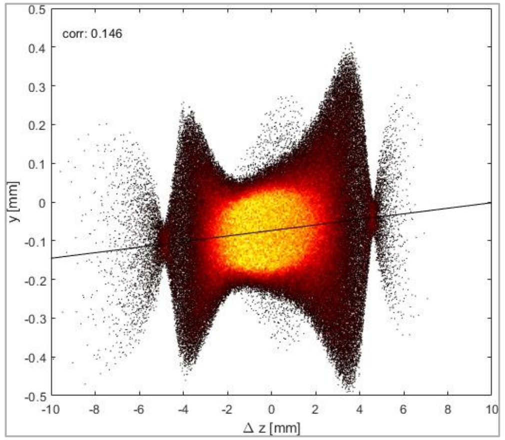
RF design (optimized by A. Sulimov (MSL)



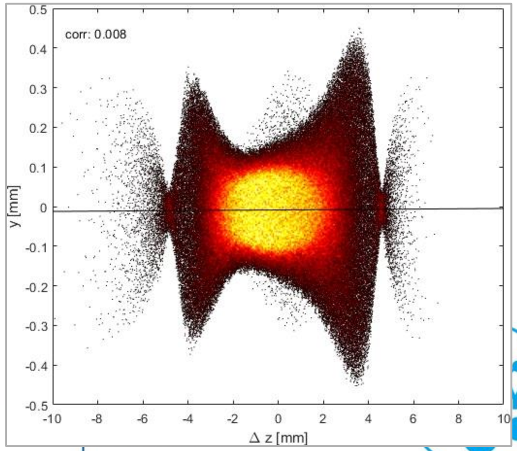
Comparison of the transverse electric field on axis



Uncompensated coupler kick



Compensated coupler kick

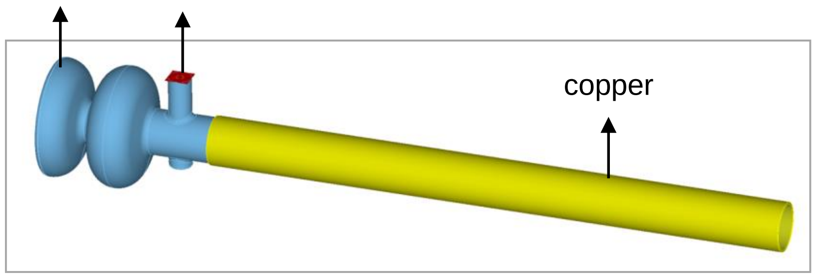


DESY CW L-band SRF gun

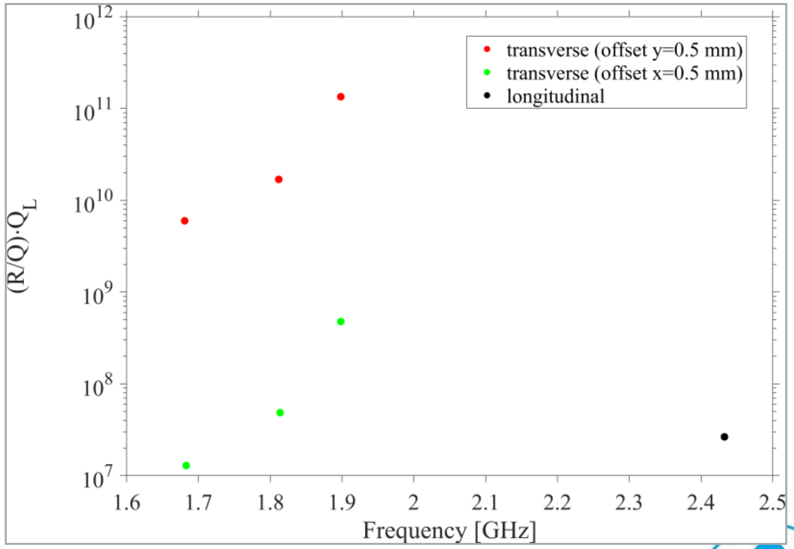
Higher Order Modes

- Eigenmode Analysis: 1.6 GHz to 2.5 GHz
  - Identify and characterize potentially dangerous HOMs
  - RF model: SRF gun cavity, a 1-meter long copper tube and port at the FPC
- Four potentially dangerous HOMs: three dipole modes (two polarizations considered); one monopole mode
  - 0-mode of the fundamental passband requires attention
    - ► Excitation must be avoided to prevent negative impact on longitudinal emittance (energy spread)
- Dipole HOMs: Impact on transverse beam quality
  - Trapped in the gun cavity
  - Damping approach: increasing beam tube diameter
    - ► Approach abandoned due to re-qualification requirement of the production process
  - Findings of W. Ackermann are of interest for the case if future generation will incorporate HOM coupler

RF model



(R/Q)•Q_L



Air-stable photocahode

Air-stable photocahode

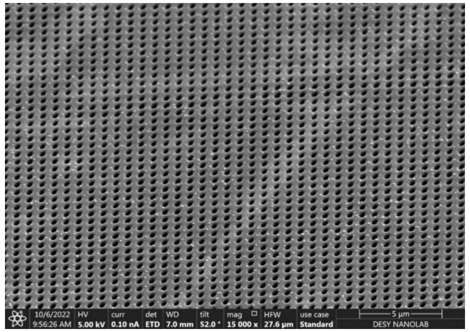
- Semiconductor cathodes can not be implemented
    - Only noble metals
- QE measurements at low field, study laser cleaning
- target QE > 1e-04

Advanced photocathode R&D

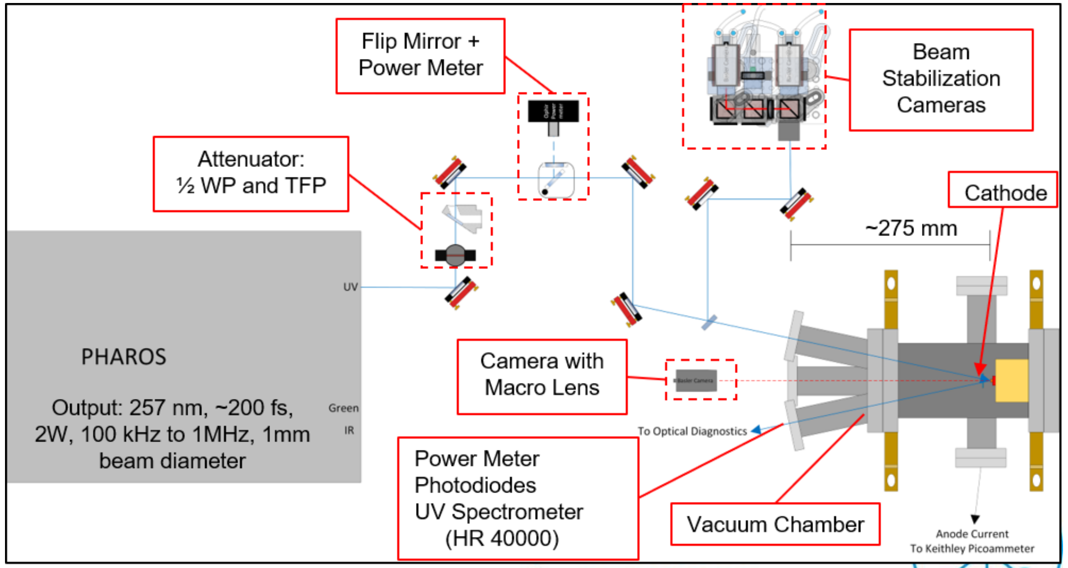
- PhD student is working on the topic since 04.23
- ideas to be evaluated in the RF gun environment at REGAE

(Photo credit: Birte van der Horst, Manuela Schmoekel)

(Credit: DESY NanoLab)



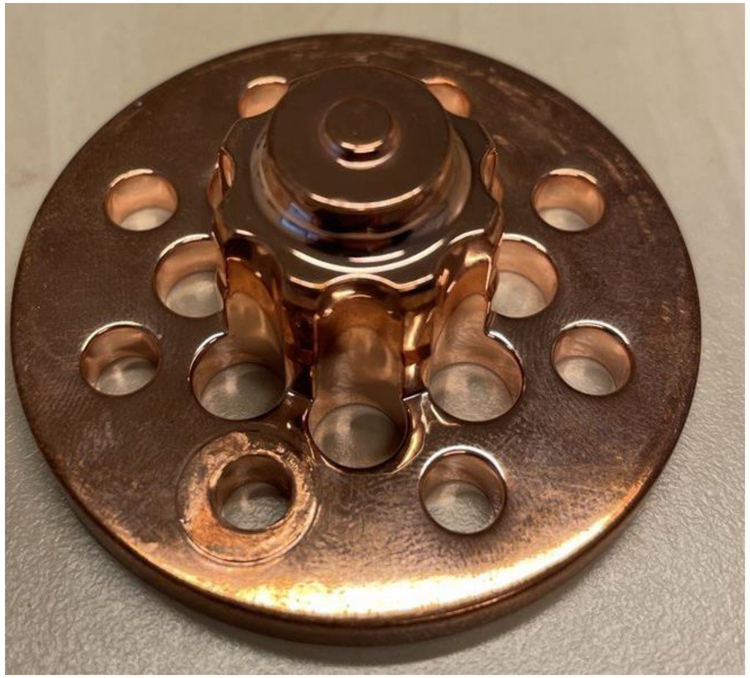
Setup for QE measurements / laser cleaning studies:



Air-stable photocahode

Nb cathode plug

Cu cathode plug



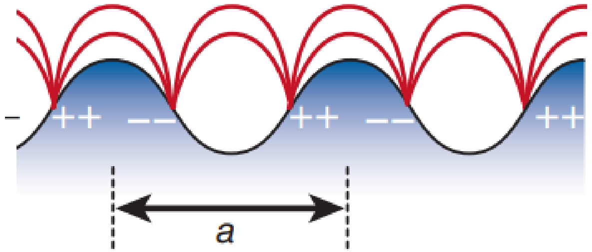
Cu plug and the cavity backwall

(Photo credit: Birte van der Horst, Manuela Schmoekel)

Air-stable photocahode

Vacuum chamber with the ‘cold finger’

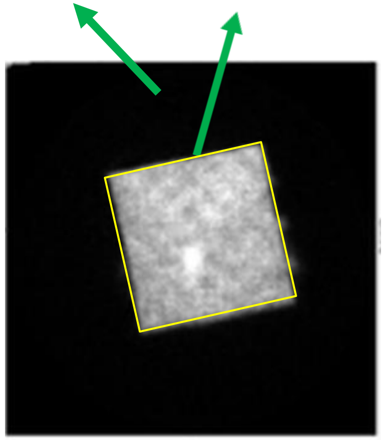
Novel approaches to increase QE of metal cathodes (one example: plasmon enhanced photoemission)



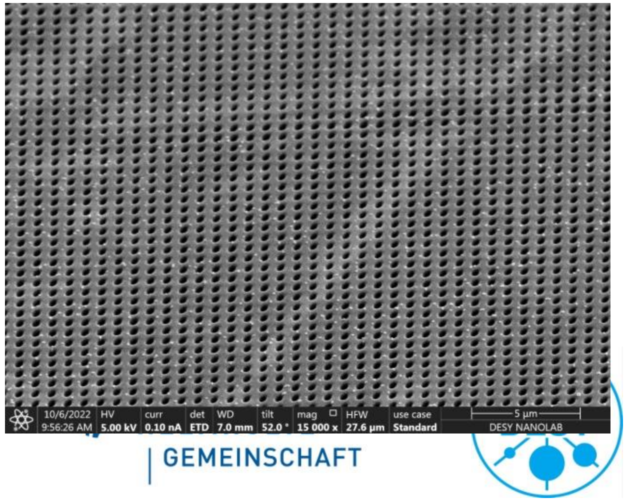
[Image from Barnes et al., Nature 424, 824]

First test at DESY (with support of NanoLab, CFEL and FLA):

Flat surface Nanostructured



x10 more electrons extracted from structured surface



Beam Diagnostics and Test Stand

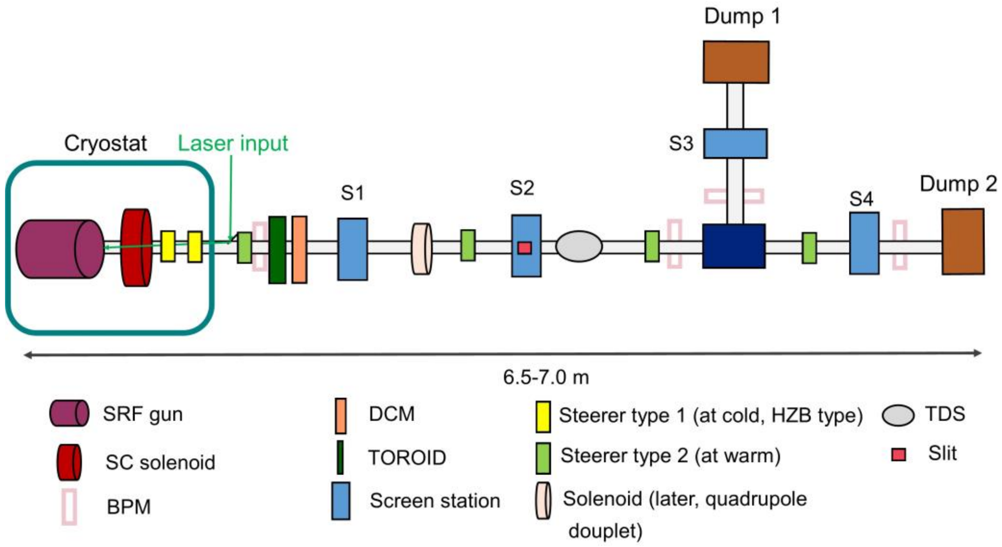
AMTF bunker XATB3:

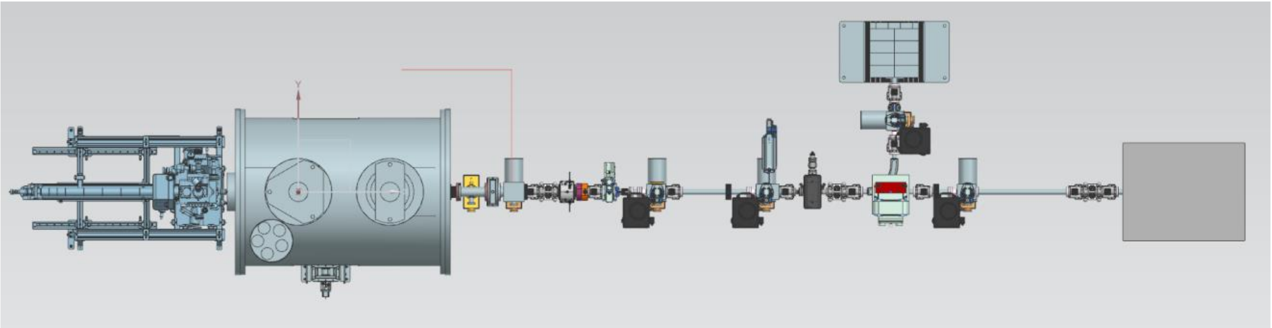
Beam Diagnostics and Test Stand

Present status

Diagnostics

- layout of warm beam line is finalized and collectively reviewed from physics point of view
- Measurements: charge, dark current, **transverse slice emittance**, energy + energy spread, bunch length





DESY CW L-band SRF gun cavity

Simulation related challenges

- Gun cavity asymmetries and their impact on beam quality
  - Emittance growth budget
- Accurate EM simulations for surface modulated objects
  - Special photocathodes
- Beam dynamics questions (incl. wakefield analysis)
- Field profile of the gun cavity with nanostructured photocathode surface
  - For beam dynamics simulations

Summary

- DESY CW SRF injector based on the L-band SRF gun can fulfil the requirements of the HDC EuXFEL
  - Cathode, low mechanical tolerances, alignment of the gun and of the solenoid, laser shaping – critical
  - Great result with QE vs E test with Cu plug inserted – 55 MV/m on axis achieved in VT

- Air-stable cathode that sustains high-pressure water rinsing
  - Improve and expand related R&D
  - Explore novel approaches

- Operational test stand is crucial
  - Assumes readiness of every related aspect on time
  - CW/HDC is a novel experience for majority of groups