bERLinPro

HZB Helmholtz Zentrum Berlin

HUMBOLDT-UNIVERSITÄT ZU BERLIN

The Berlin Energy Recovery Linac Project

Progress and Recent Achievements

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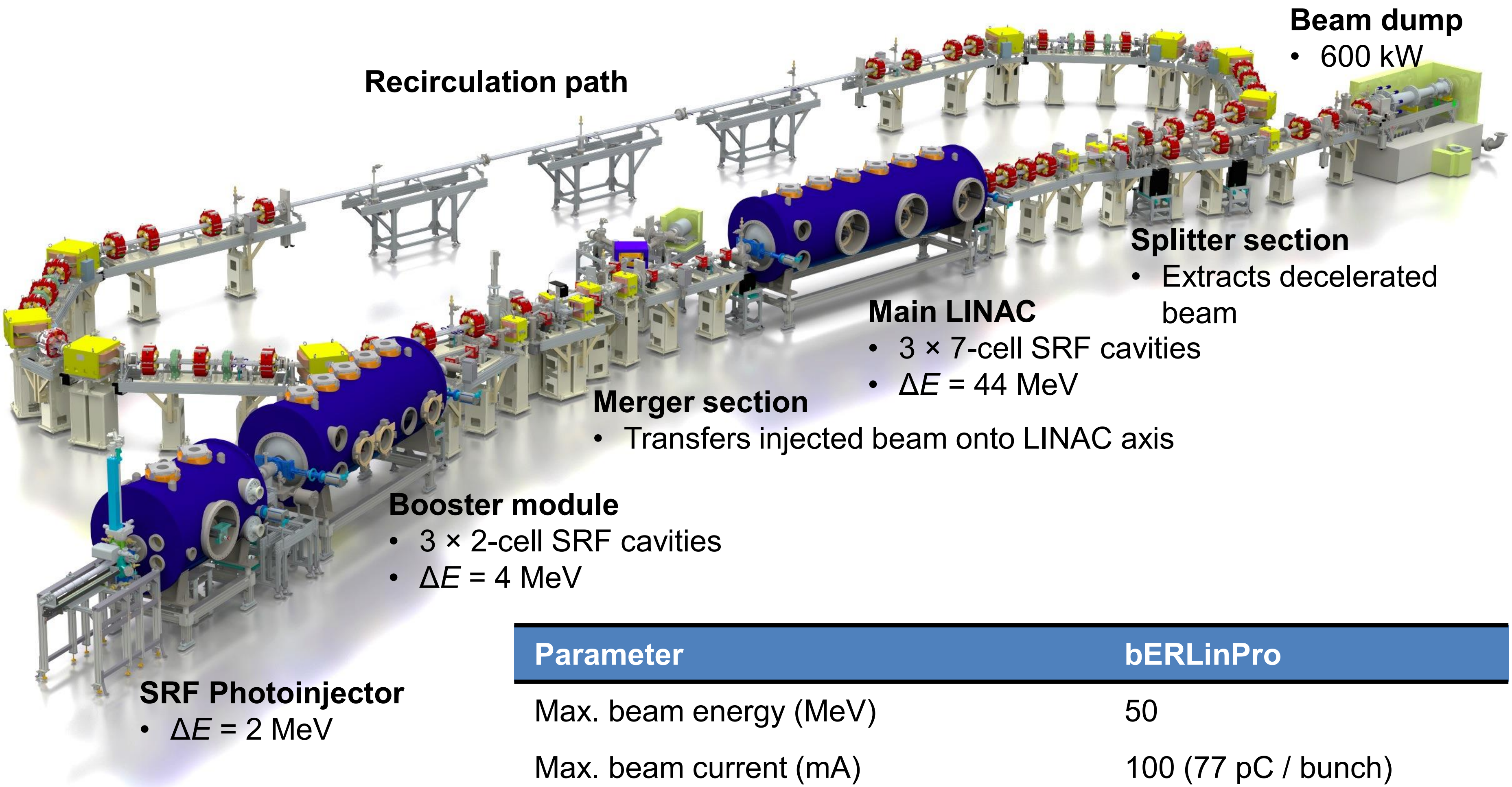
on behalf of the bERLinPro project team
Helmholtz-Zentrum Berlin

ERL17 CERN

59th ICFA Advanced Beam Dynamics Workshop
on Energy Recovery Linacs – ERL17
CERN / Geneva, 21.06.2017

bERLinPro: an ERL R&D facility



42 Mio€ (including building), fully funded, project start 2011

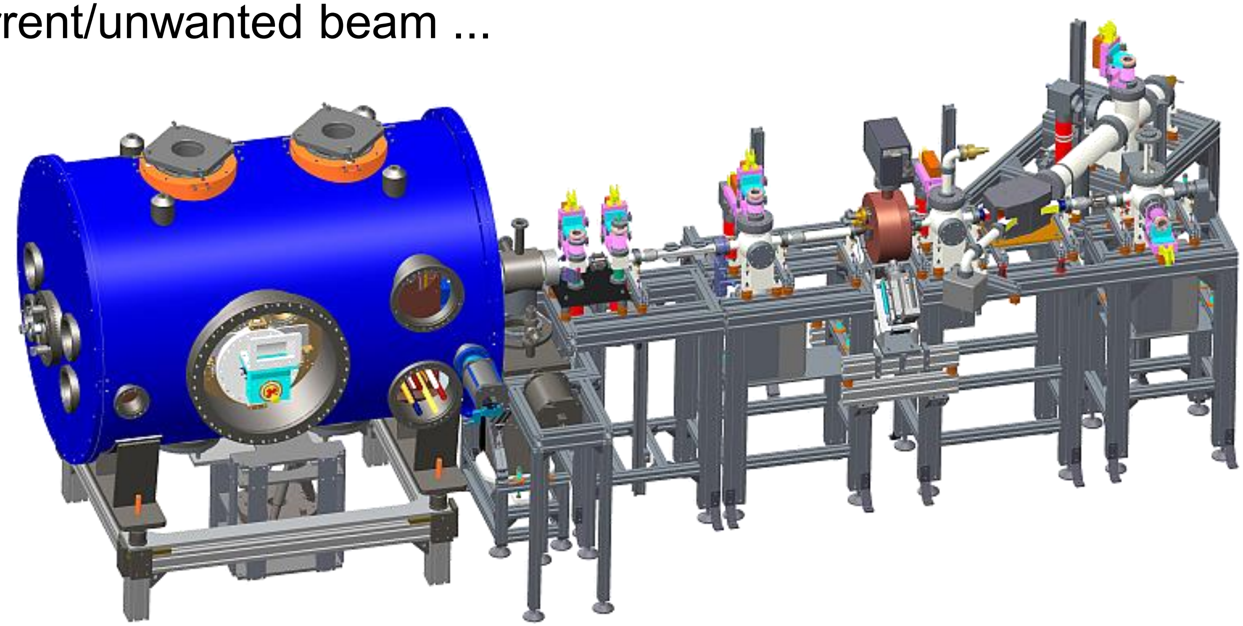
Parameter	bERLinPro
Max. beam energy (MeV)	50
Max. beam current (mA)	100 (77 pC / bunch)
Frequency (GHz)	1.3
Normalized emittance (mm mrad)	1 (ca. 0.5 in simulations)
Bunch length (ps)	< 2 ps (100 fs)
Beam losses	<< 10^{-5} @ 100 mA

Prioritization of activities to …

(a) to maximize scientific output at earliest possible stage
(b) Separate out challenges into manageable parts
(c) make optimal use of available resources in various groups

Stage 1: High-brightness beam from an SRF Injector (Gun1)

- Injector cavity performance
- Cathode performance/lifetime
- Intrinsic beam limits (emittance, energy spread, bunch length …)
- Dark current/unwanted beam ...



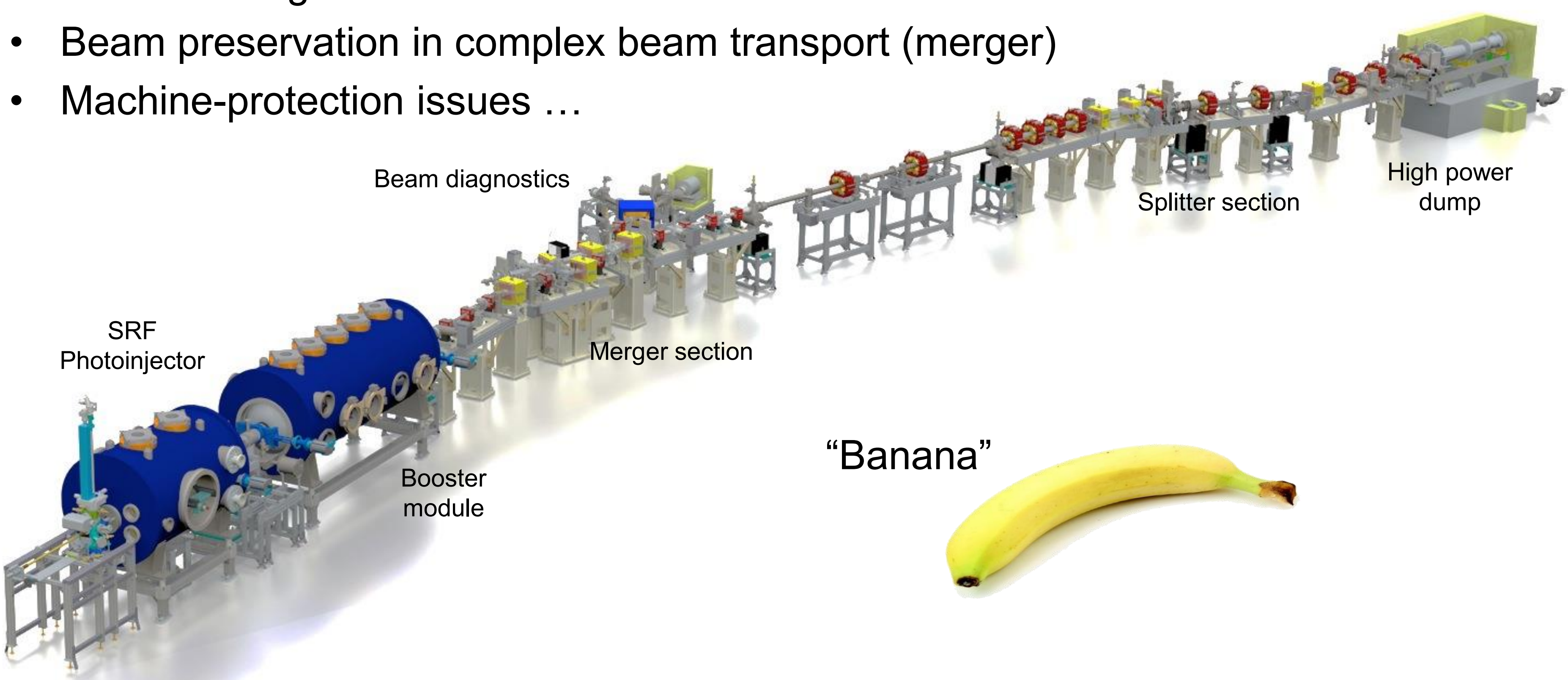
Gun1 with 2 adjustable TTF3 couplers; power limited to ~ 20 kW

Prioritization of activities to …

(a) to maximize scientific output at earliest possible stage
(b) Separate out challenges into manageable parts
(c) make optimal use of available resources in various groups

Stage 2: medium-power beam transp. through “banana”

- Technology development
- Beam-loading issues
- Beam preservation in complex beam transport (merger)
- Machine-protection issues …

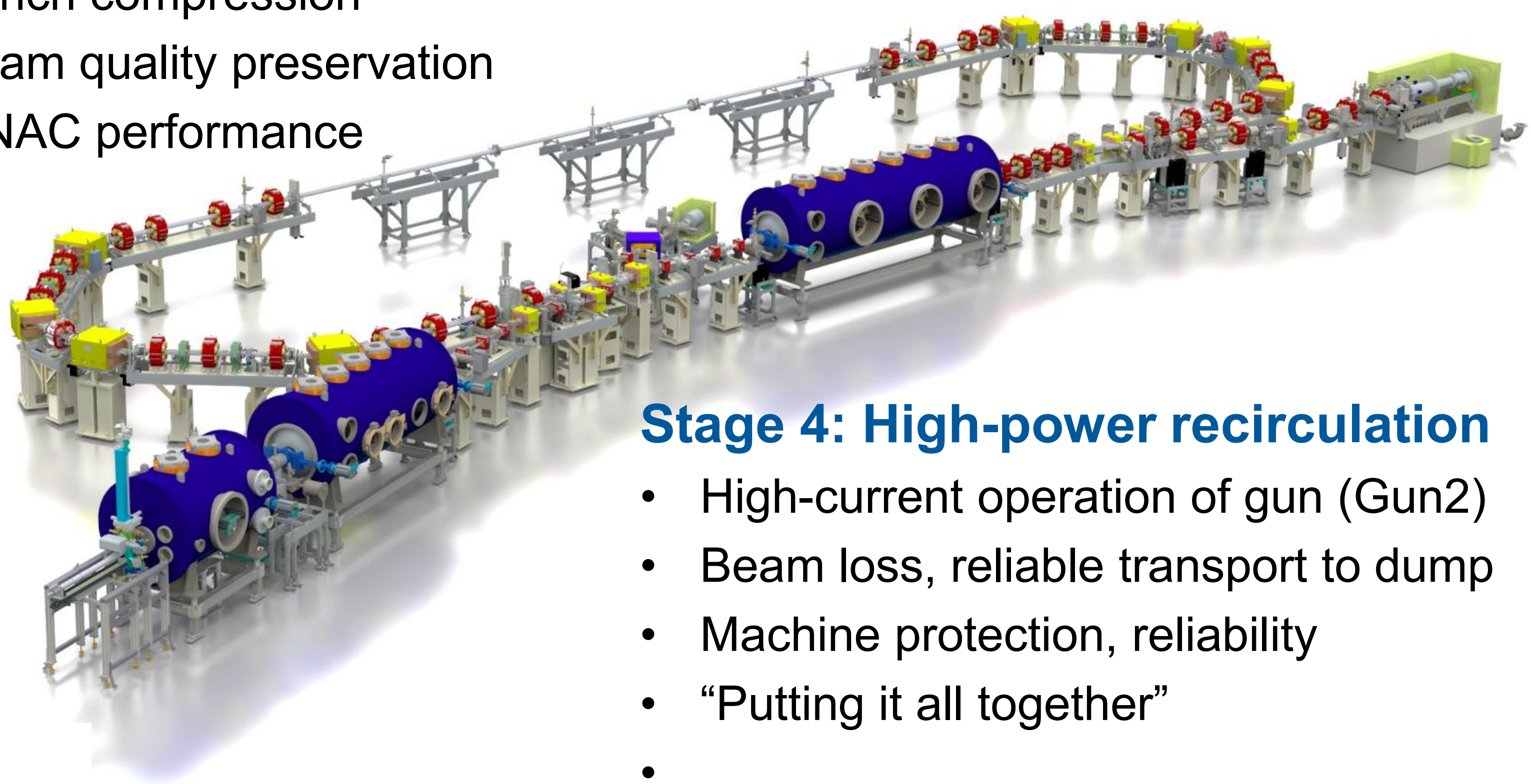


Prioritization of activities to …

(a) to maximize scientific output at earliest possible stage
(b) Separate out challenges into manageable parts
(c) make optimal use of available resources in various groups

Stage 3: High-brightness recirculation

- Recovery efficiency
- Bunch compression
- Beam quality preservation
- LINAC performance



Stage 4: High-power recirculation

- High-current operation of gun (Gun2)
- Beam loss, reliable transport to dump
- Machine protection, reliability
- “Putting it all together”
- …

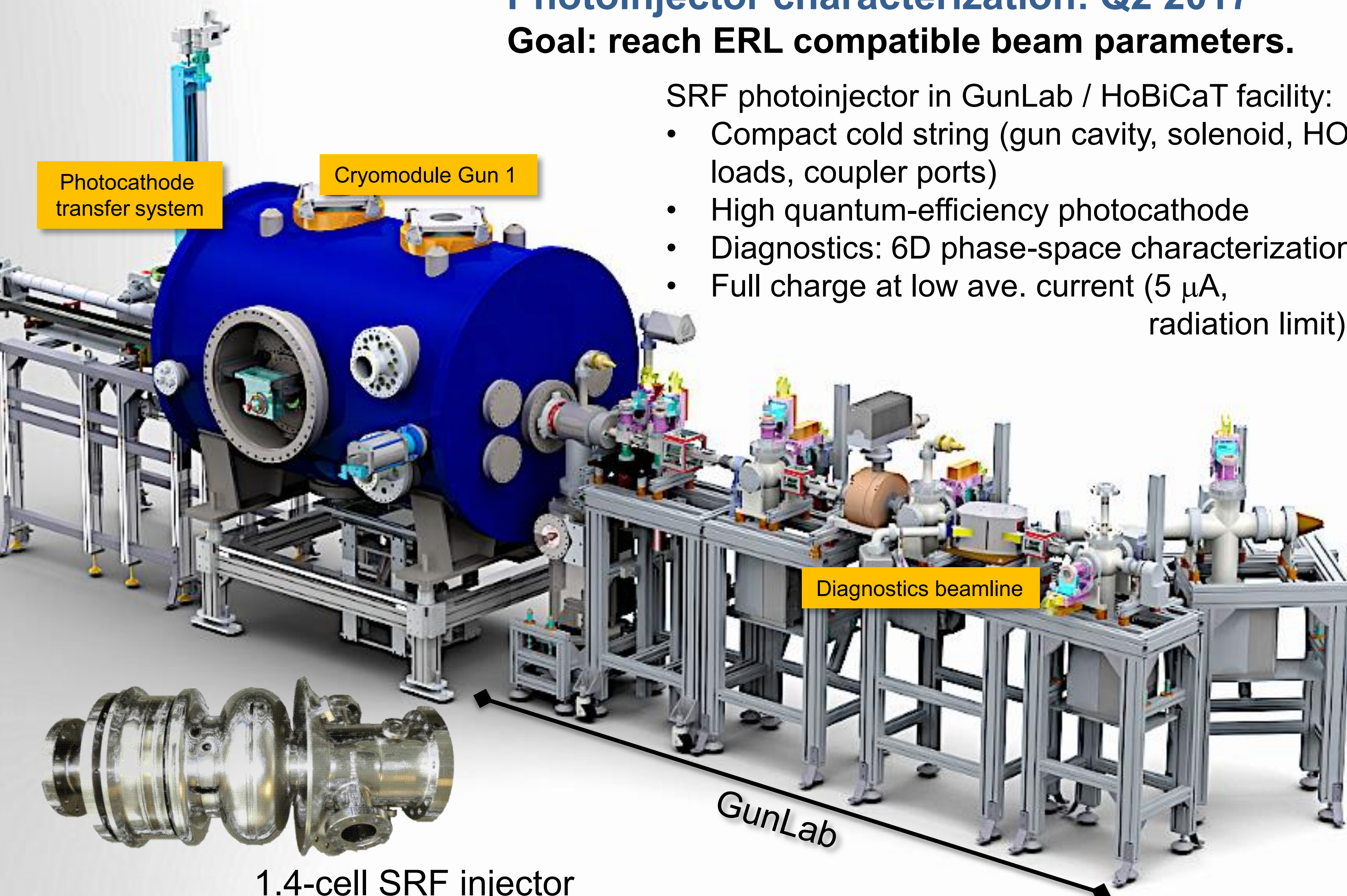
Stage 1: SRF injector characterization

Photoinjector characterization: Q2 2017

Goal: reach ERL compatible beam parameters.

SRF photoinjector in GunLab / HoBiCaT facility:

- Compact cold string (gun cavity, solenoid, HOM loads, coupler ports)
- High quantum-efficiency photocathode
- Diagnostics: 6D phase-space characterization
- Full charge at low ave. current (5 μA, radiation limit)

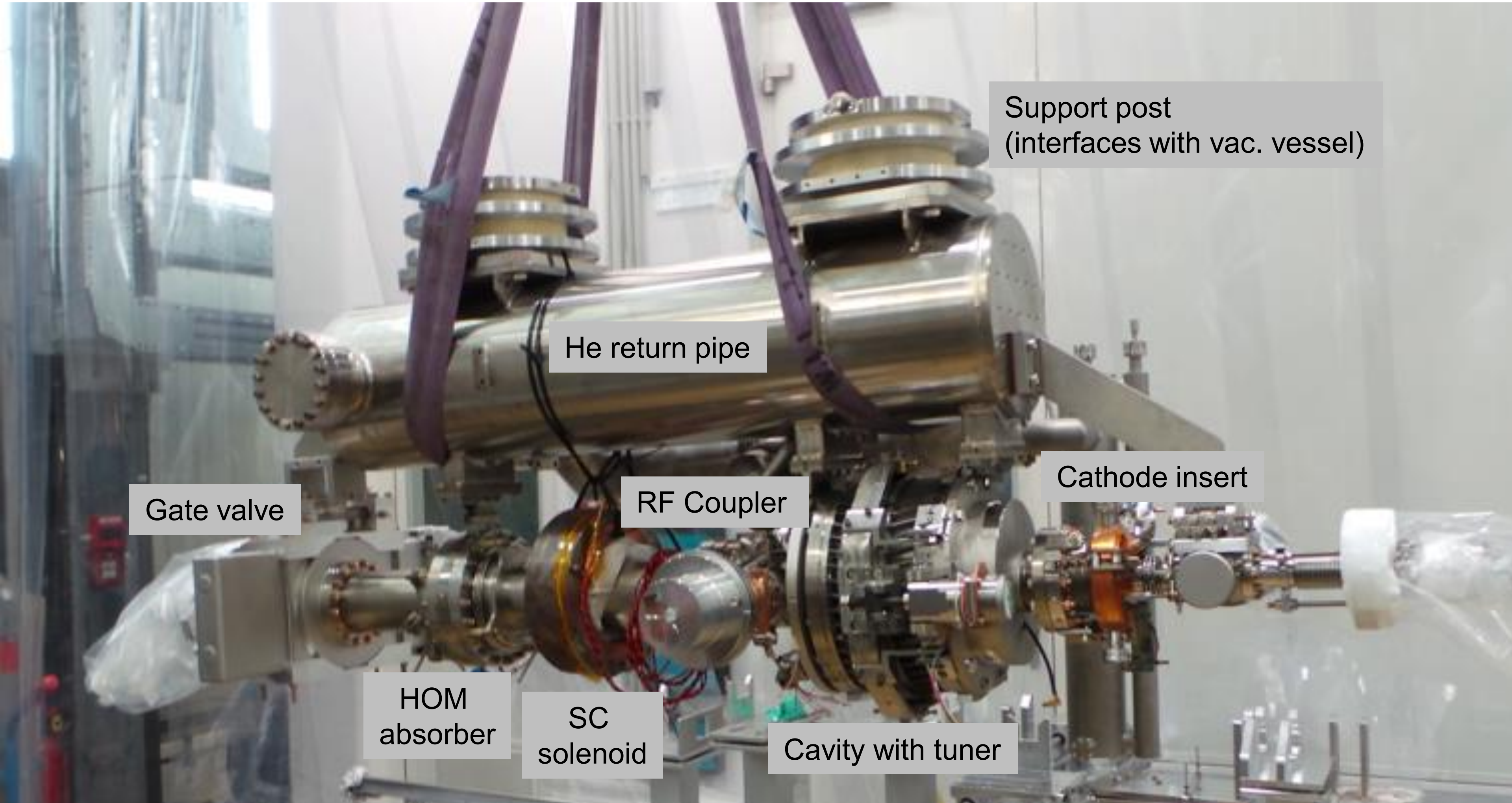


1.4-cell SRF injector

Stage 1: SRF injector characterization

Final assembly including HOM load and superconducting solenoid

- Followed successful acceptance test in HoBiCaT of cold string that qualified HZB infrastructure and assembly techniques (with support of DESY colleagues)



Stage 1: SRF injector characterization

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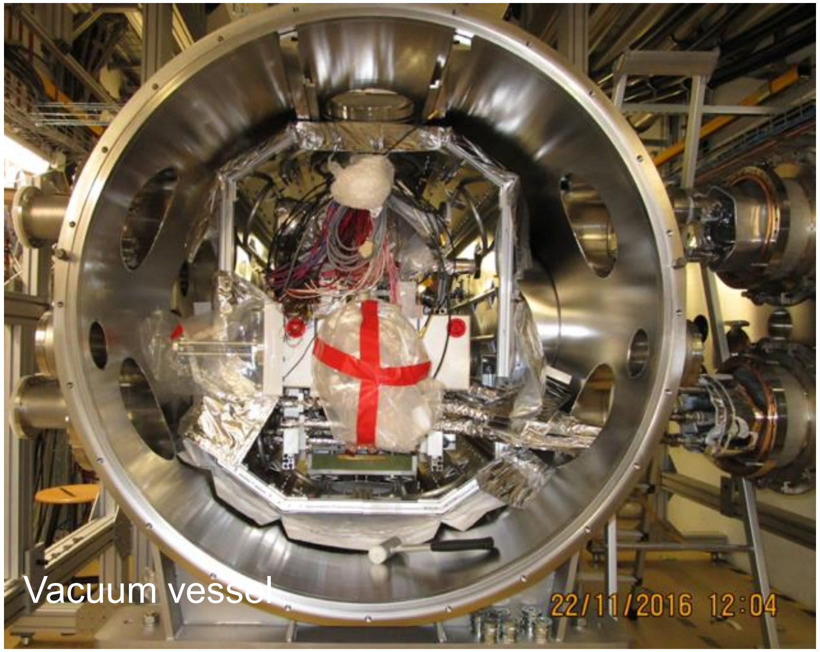

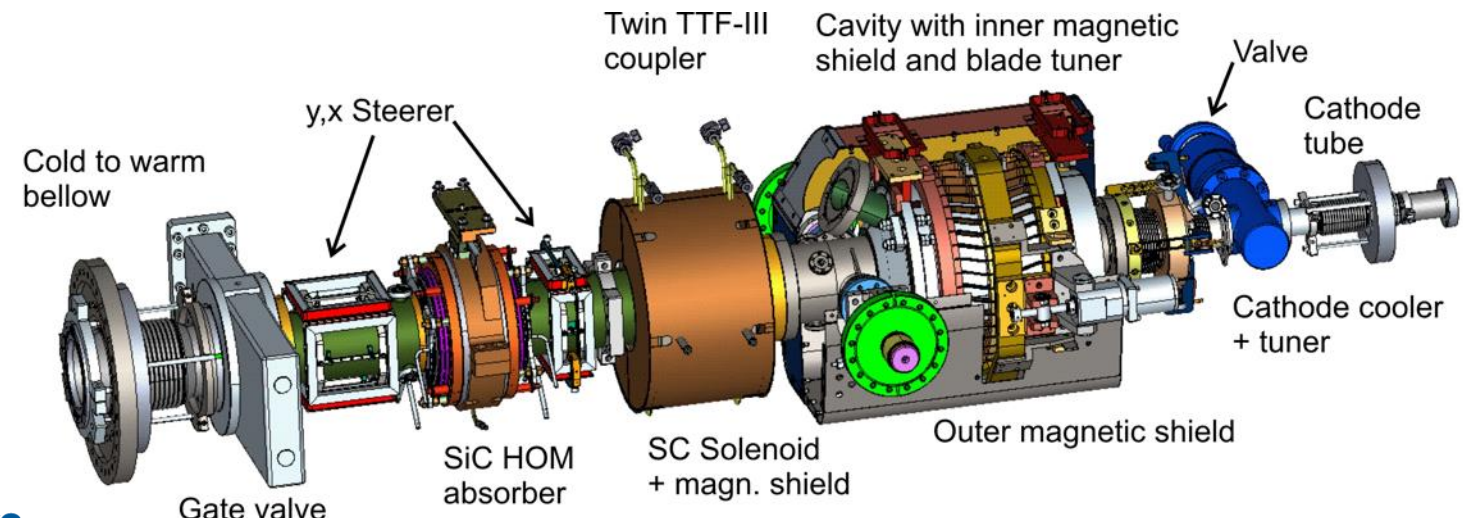

Stage 1: SRF injector characterization

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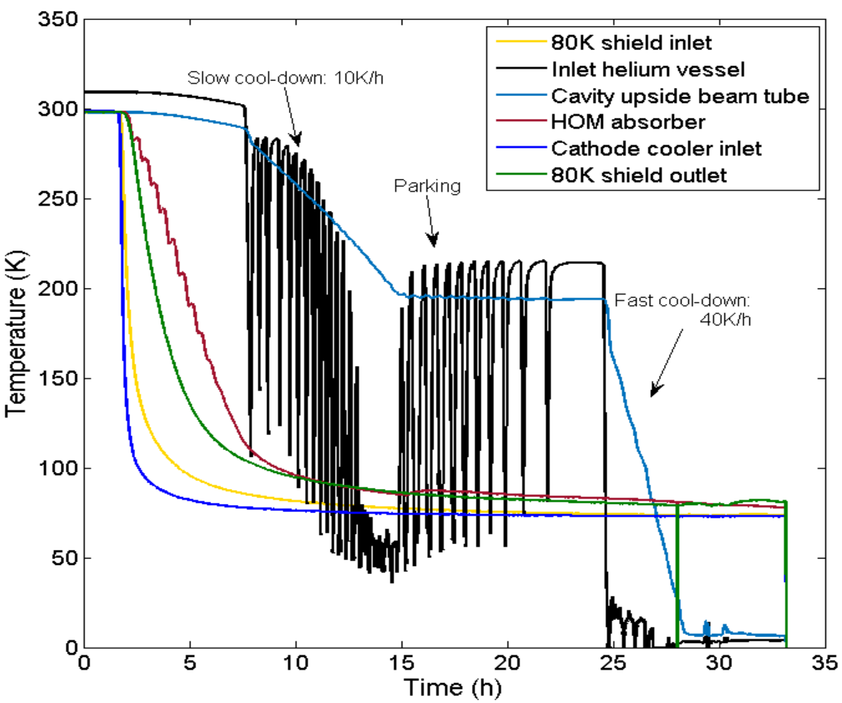
Photoinjector characterization commencing …

- Some delays due to “out of tolerance” SRF cavity, vendor deliveries, tight space in HoBiCaT …
- Installation complete, radiation permit for <u>beam</u> operation issued
- Module is cold; RF characterisation started (last talk of today, Axel Neumann)



Photocathode R&D: Infrastructure

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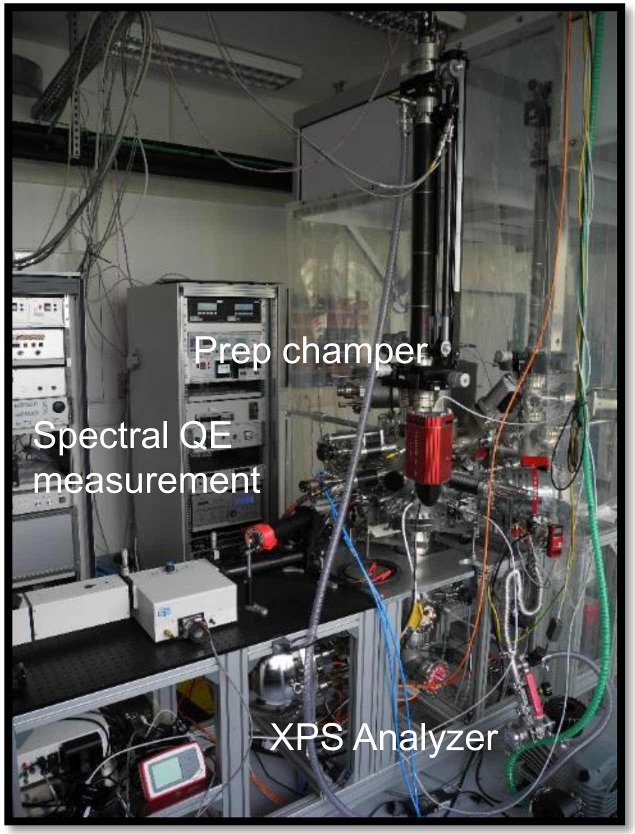
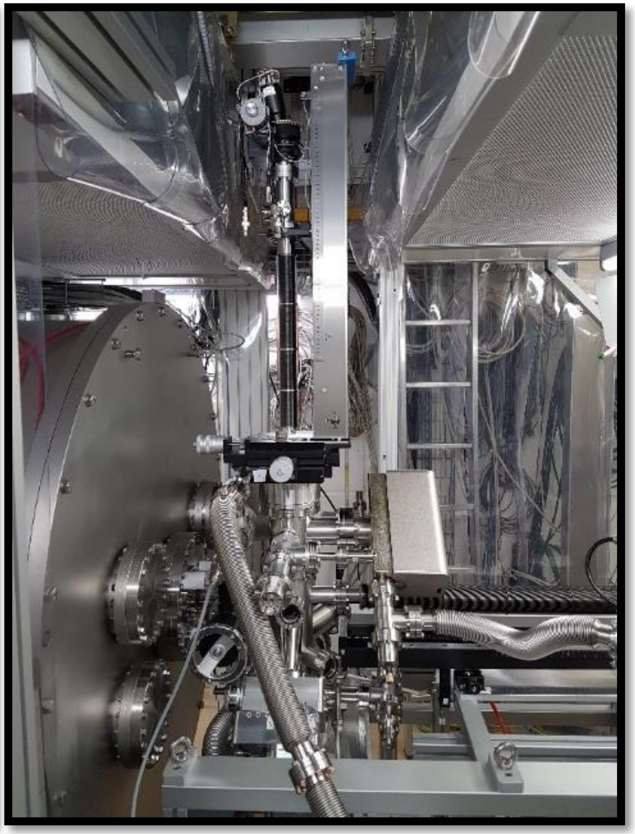
- Cathode development is running and producing good results
  (talk Julius Kühn, Monday)



Preparation & Analysis System (PAS) w/ spectral response setup

Transfer system #1 at the PAS w/ vacuum suitcase



Transfer system #2 at the SRF-photoinjector module

Produce cathode → Transfer out & transport → Insert into injector

Photocathode R&D: Latest results

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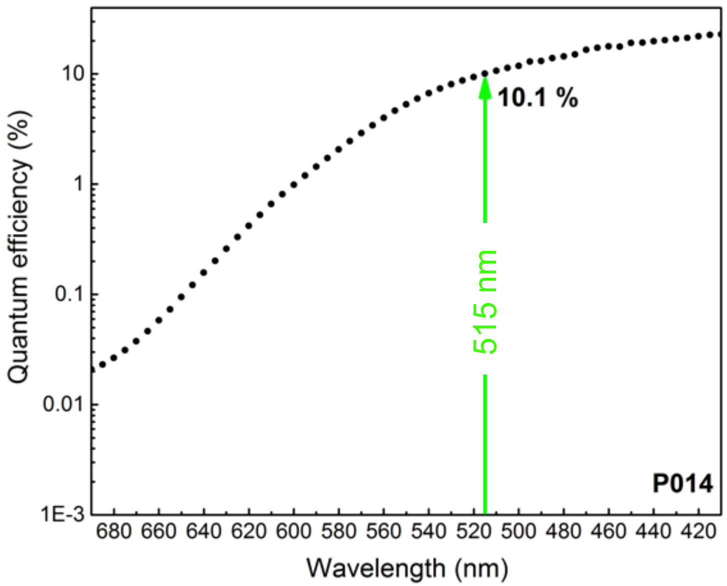
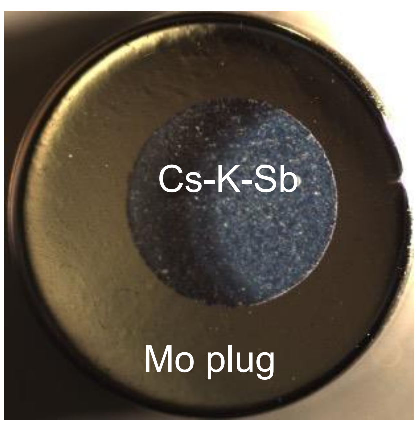
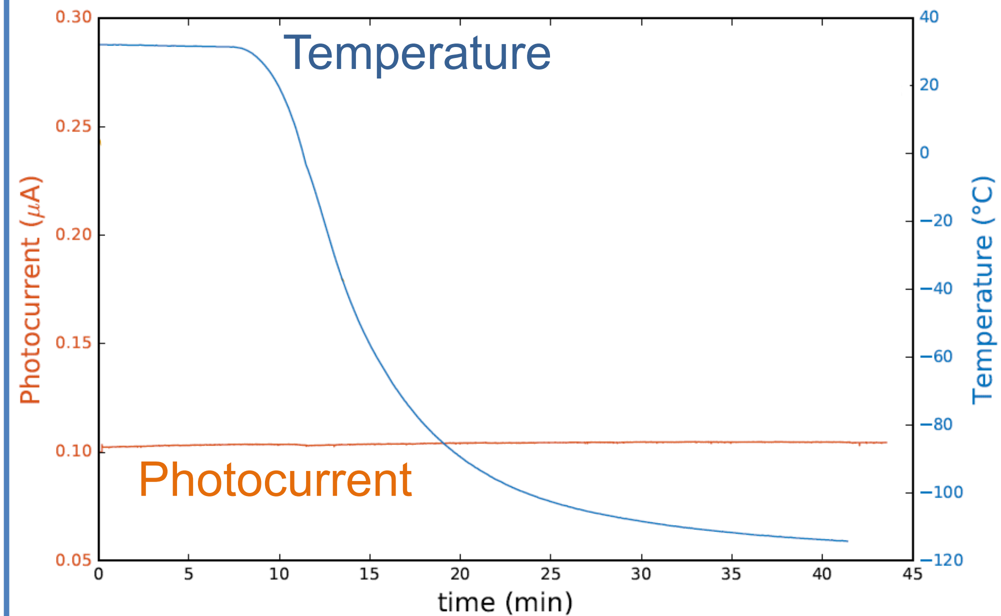
QE of a Cs-K-Sb photocathode

Co-deposition improves performace





Effects of cold operation

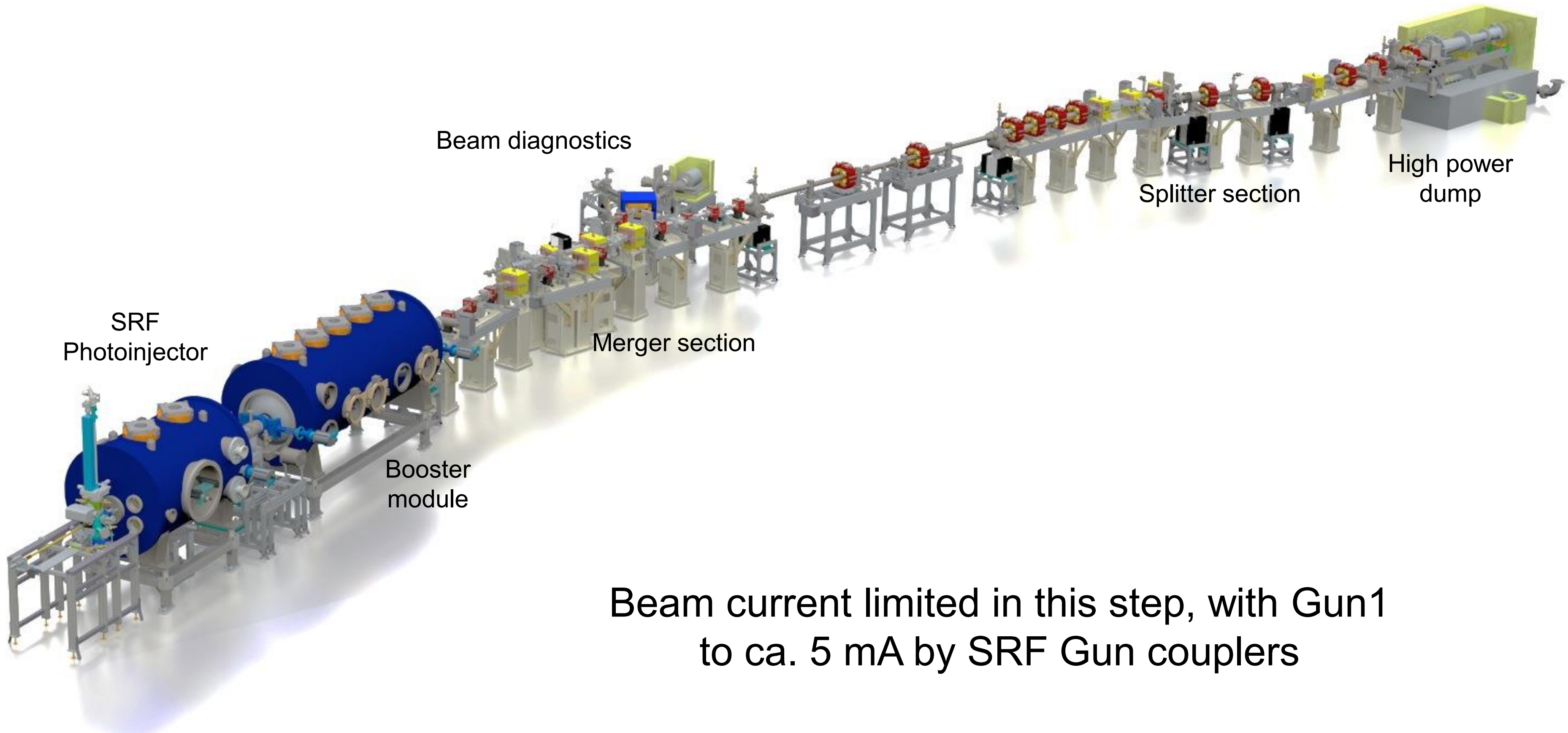


- Quantum efficiency preserved during cooldown/warmup (provided the cathode is not moved while cold)

Stage 2: Beam through "banana"

"High current" (> 1 mA) through low energy "banana"

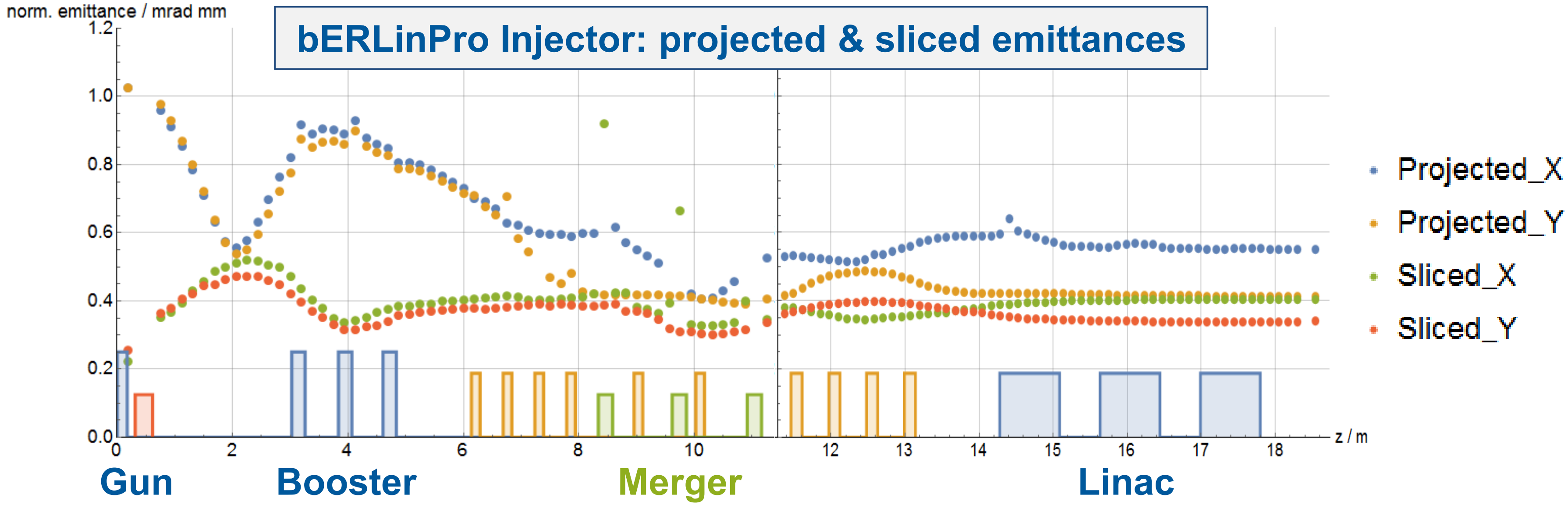
- Requires installation of booster, vacuum system, diagnostics, and magnets in bERLinPro building (most likely will start 2018 with "gun only", followed by booster in 2019)



Beam current limited in this step, with Gun1 to ca. 5 mA by SRF Gun couplers

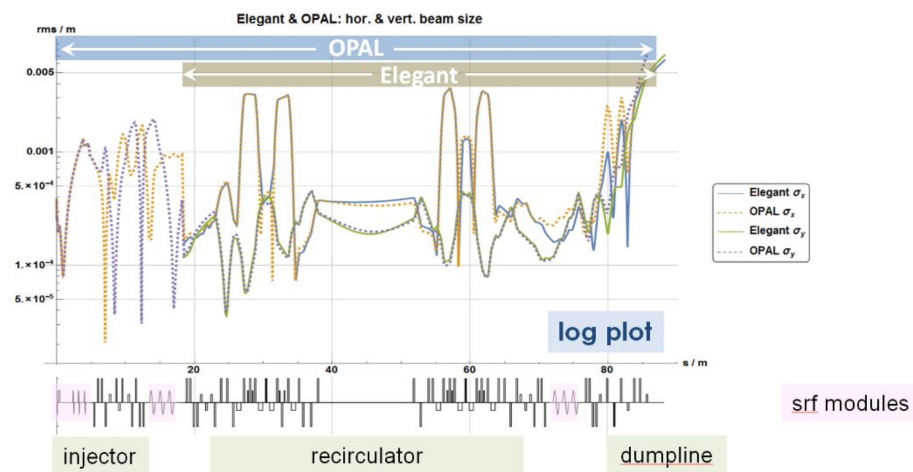
Stage 2: Beam through "banana"

bERLinPro Injector: projected & sliced emittances

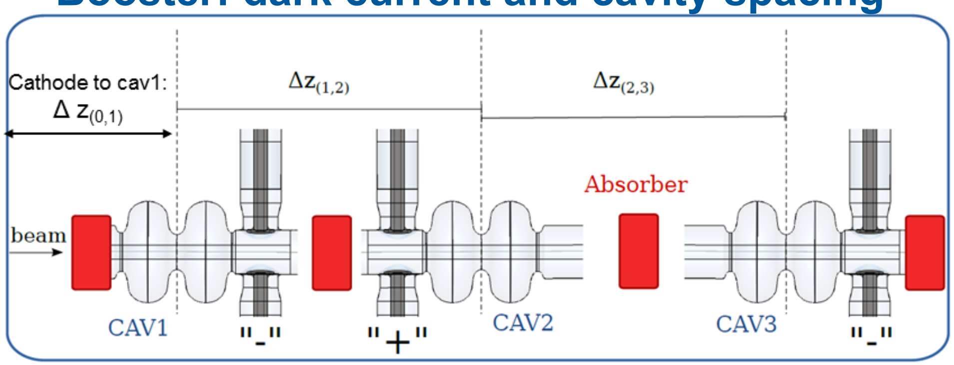


see talk M. Abo-Bakr, today
M. McAteer, tomorrow

OPAL vs Elegant

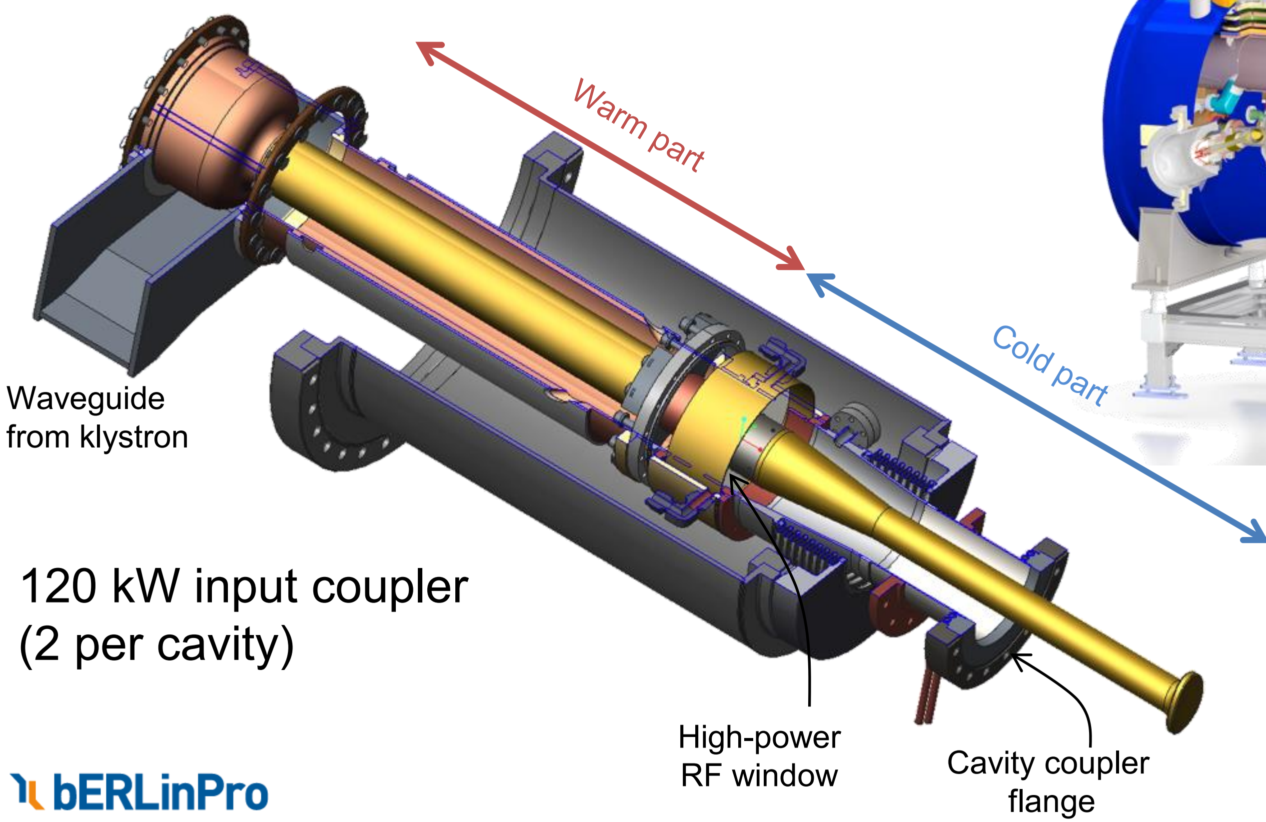


Booster: dark current and cavity spacing

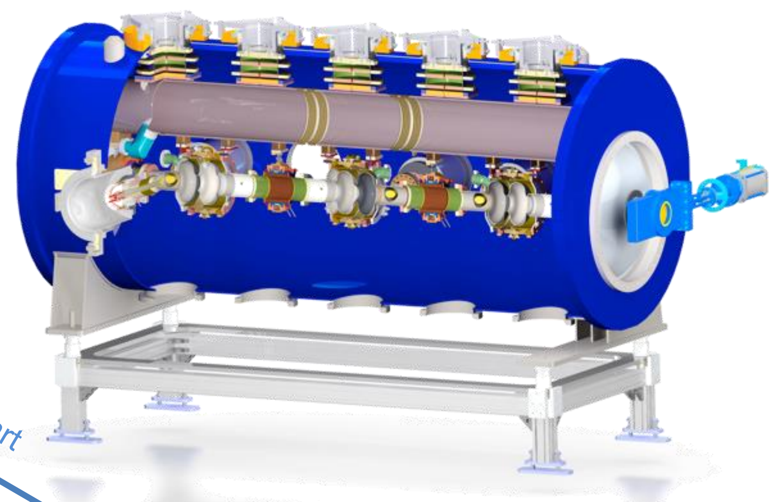


Stage 2: Booster module

- As gun technology activities wind down booster activities increase
- Module design based on gun module (originally adapted from Cornell).
- Final acceptance tests for booster cavities being prepared in HoBiCaT.
- Critical path: Both warm and cold parts of the 120 kW input couplers (critical component) are in production
  - Delivery Oct. 2017



120 kW input coupler (2 per cavity)

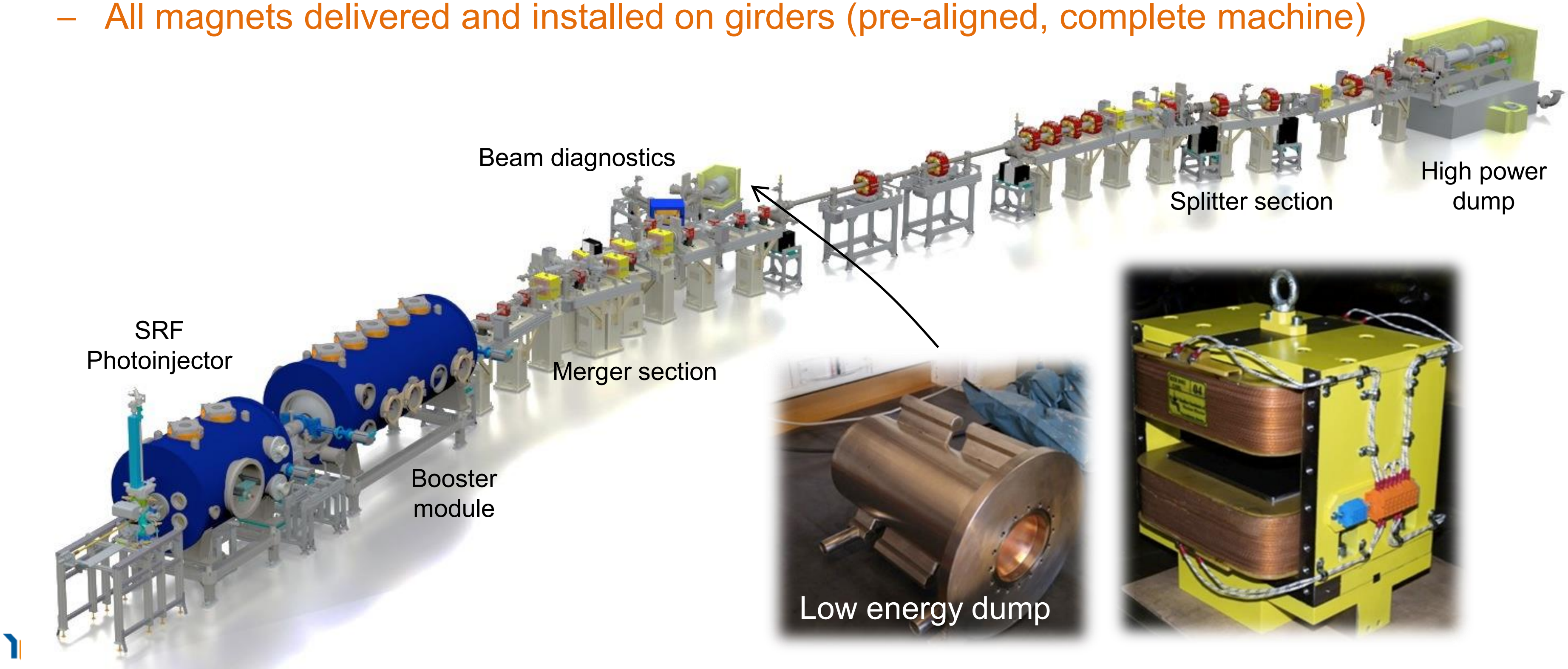


HPC also used for Gun2

Stage 2: Vacuum system & magnets

Beam transport for “banana”

- ISO 5 & UHV ready vacuum system in production, 6 months delay to 12/17
  - Difficulty in welding complex aluminum chambers
  - Repeated cracking of SMA ceramic feedthroughs of striplines. Solution: EB-Welding.
  - Manufacturer underestimated the complexity of the system
- Installation @bERLinPro by vendor 1/2018; system operational 4/2018
- Magnet & girders (& low-energy dump) production by Budker Institute.
  - All magnets delivered and installed on girders (pre-aligned, complete machine)



Stages 3 & 4: Recirculation

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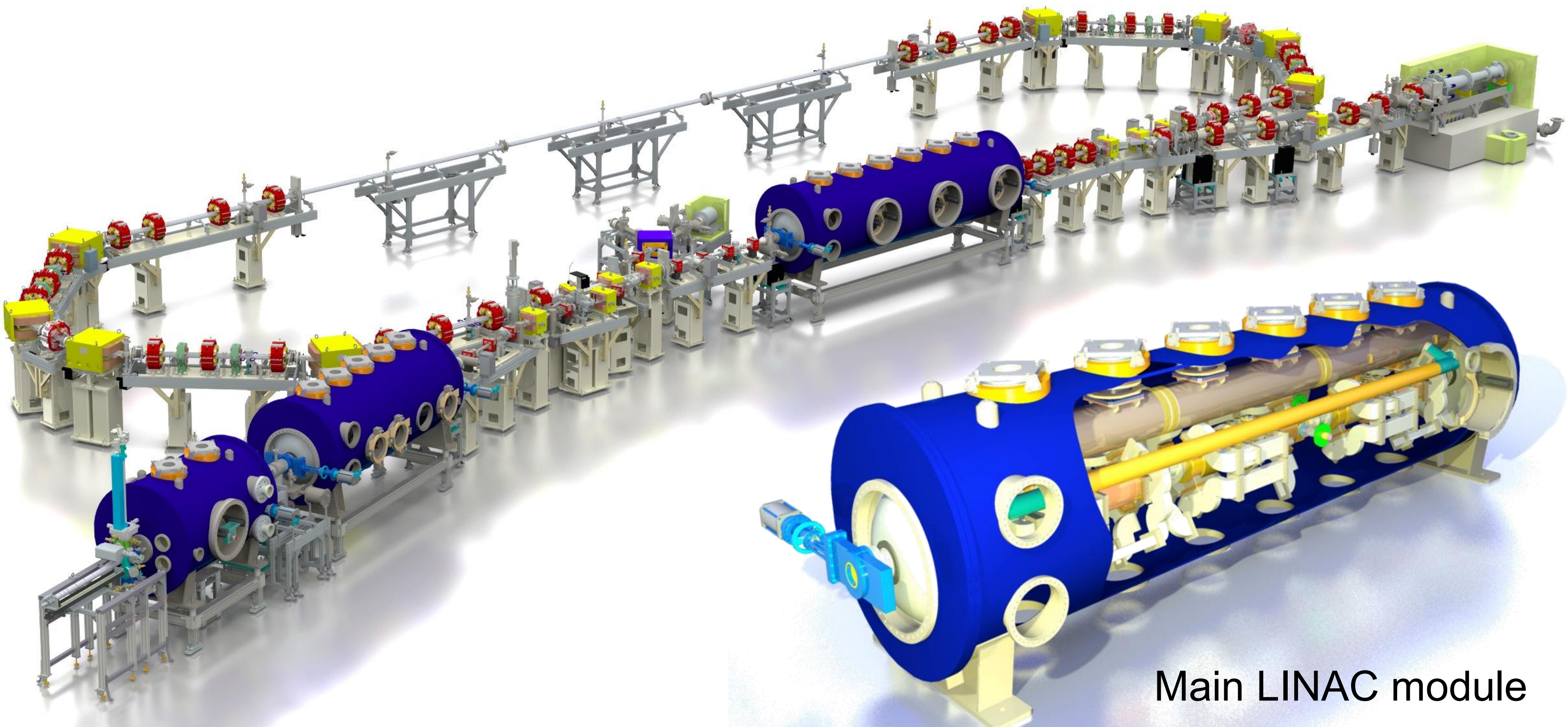
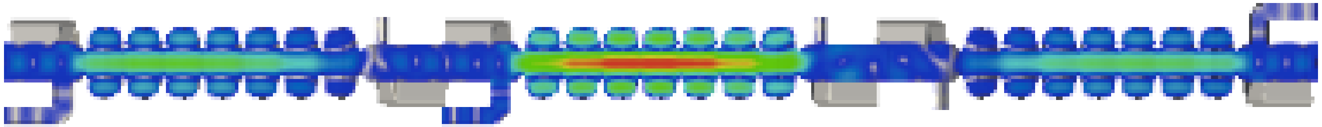
High-brightness beam recirculation followed by high current ops.

Requires

- Installation of LINAC module --- long lead item!
- Installation of vacuum systems of recirculation loop
- Installation of Gun2, high power gun



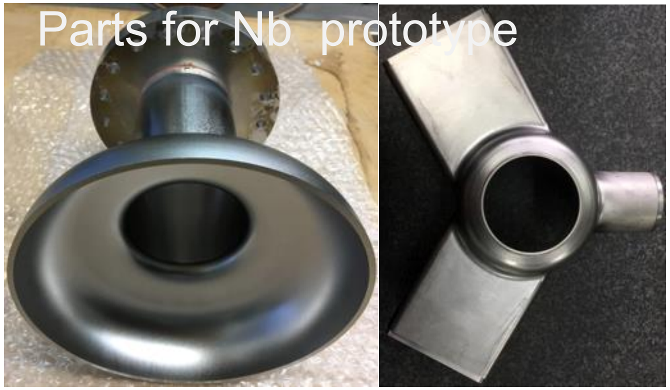
Stages 3 & 4: LINAC module

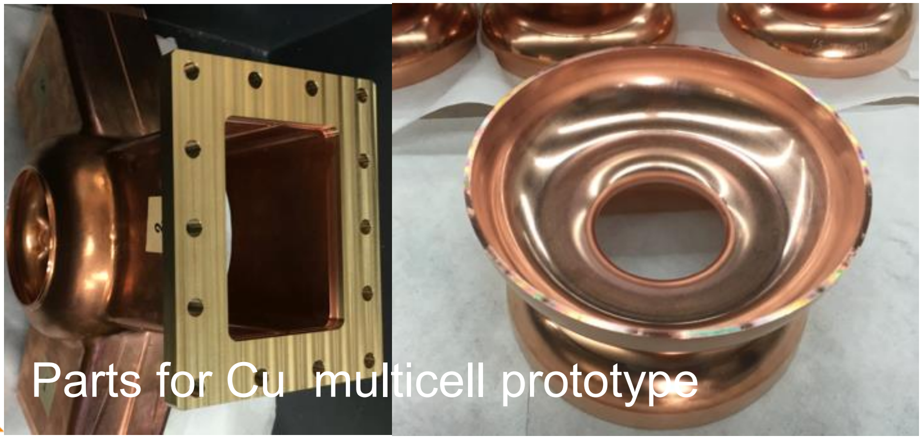


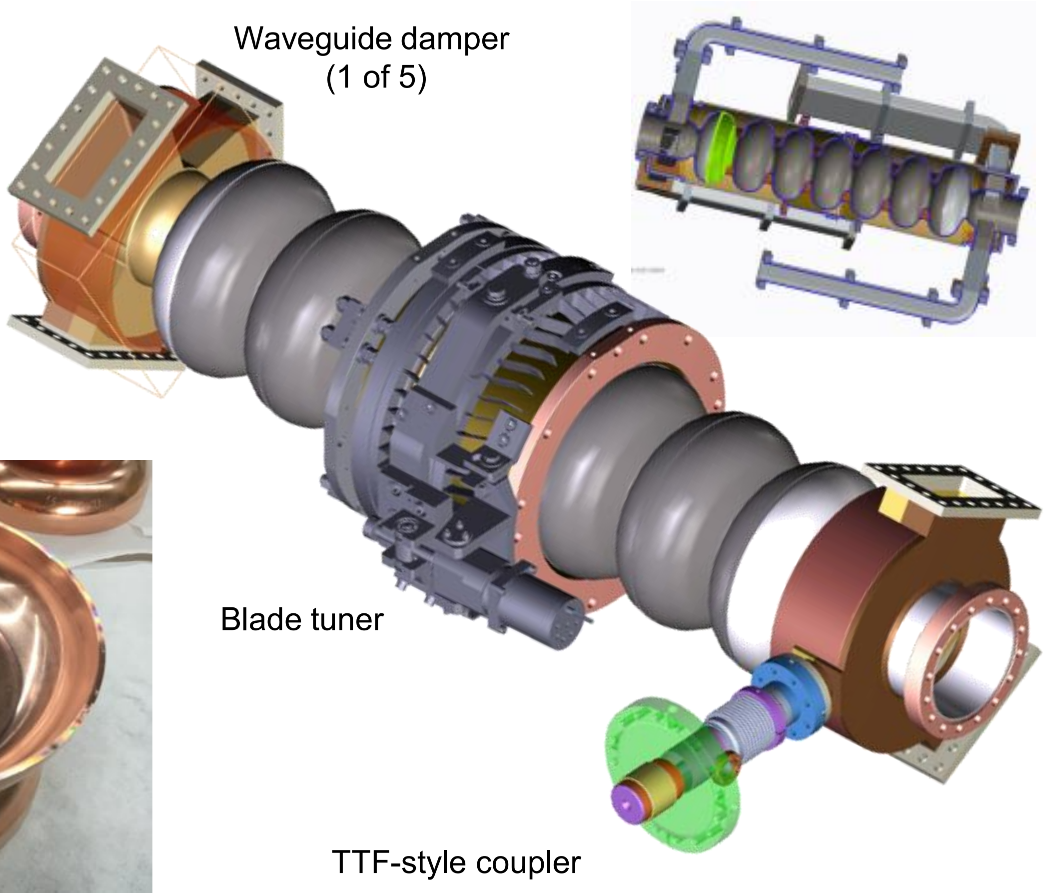
Linac cavity

- RF design and RF concatenation studies of whole module completed
- Similar prototypes Nb & Cu for the **BESSY VSR** upgrade project near delivery
- Waveguide damper & thermal management study complete

BESSY VSR Prototypes







Stages 3 & 4: LINAC module

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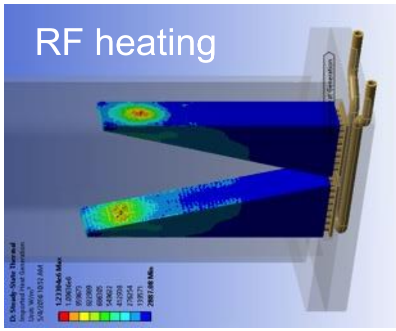
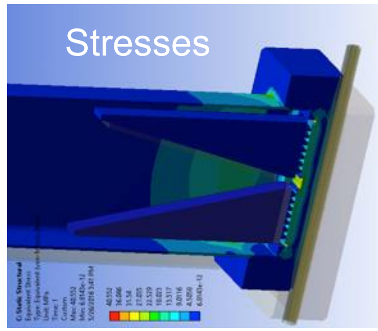
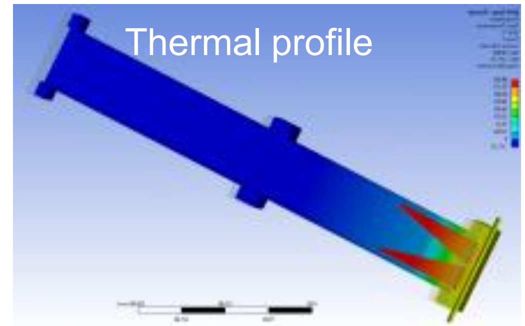
HOM absorber concept: Synergy with BESSY VSR

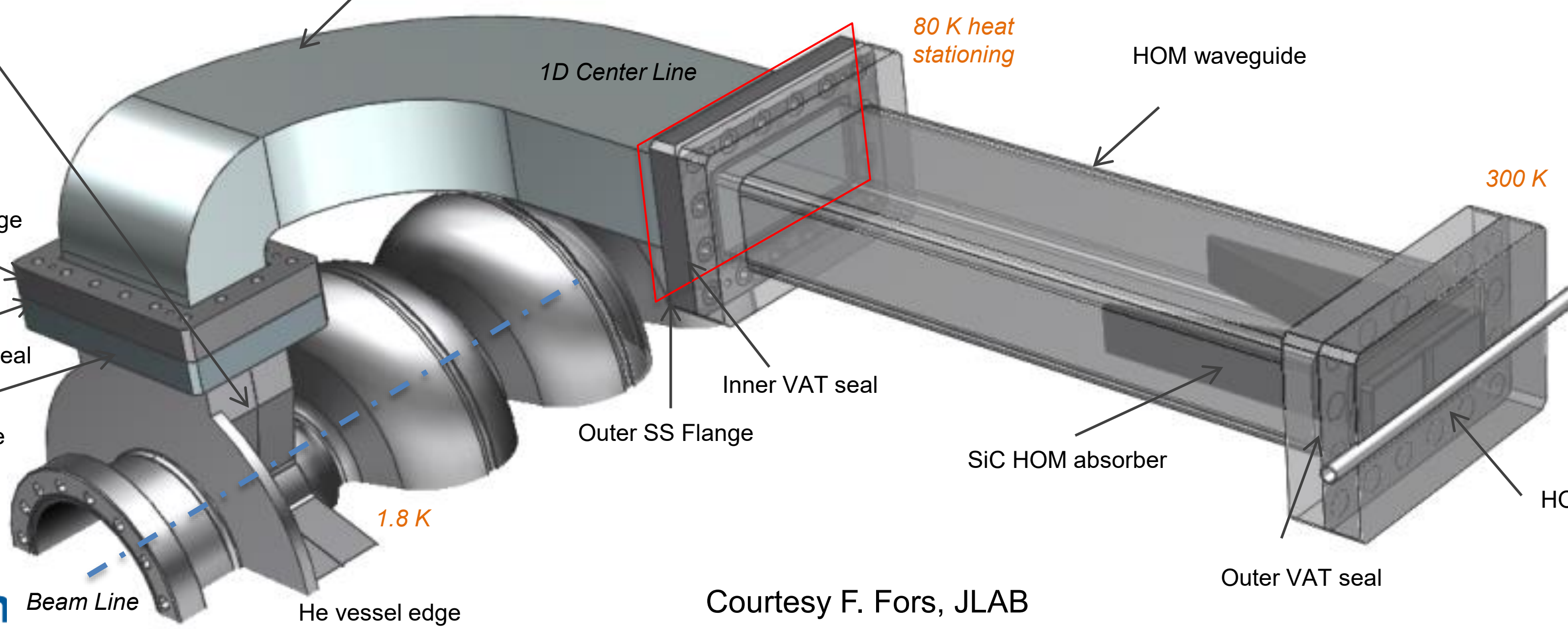
Jefferson Lab Thomas Jefferson National Accelerator Facility

- Collaboration with Jefferson Lab
- Complex thermal & stress management with high heat load to LHe







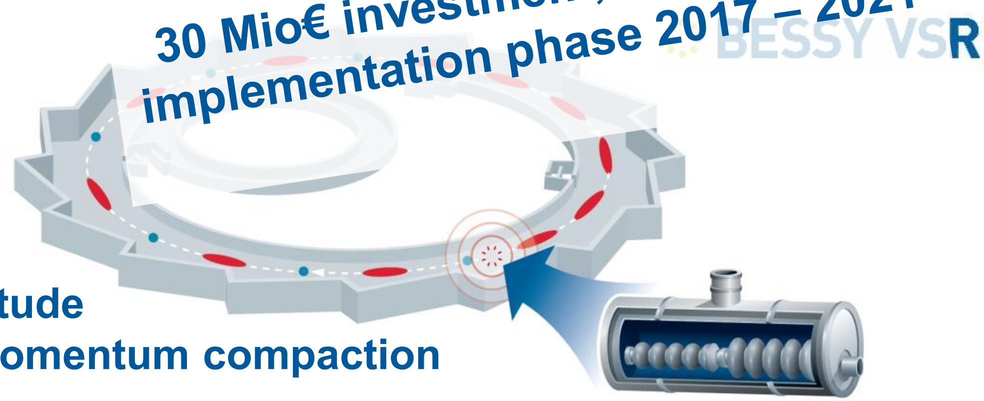


Courtesy F. Fors, JLAB

BESSY VSR – variable pulse length storage ring upgrade to BESSY II

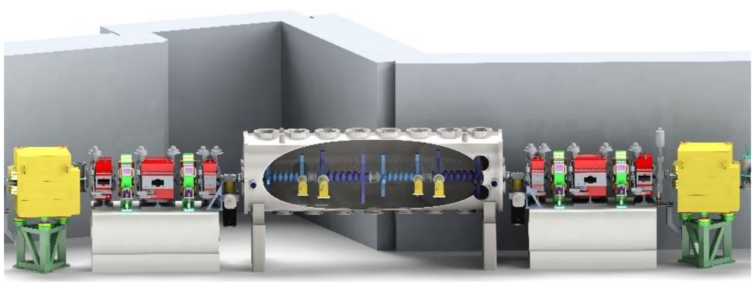
$$\sigma \propto \delta_0 \sqrt{\frac{E_0}{f_0} \cdot \frac{\alpha}{\dot{V}_{rf}}} \quad I \propto \alpha$$

30 Mio€ investment, fully funded implementation phase 2017 – 2021

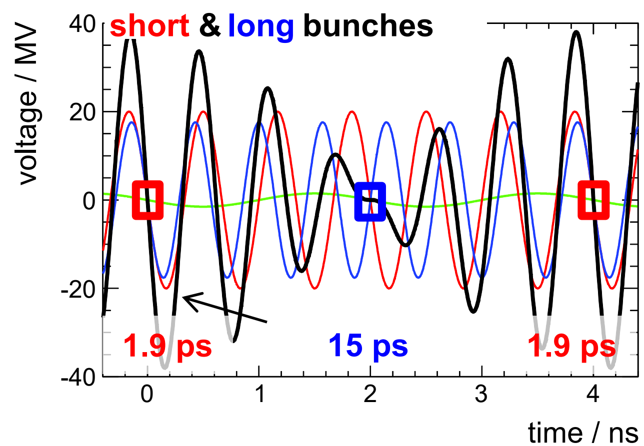


high voltage (20 MV/m) cw multi-cell SC cavities allow to increase the total voltage gradient by to orders of magnitude → ca. 1/10 bunch length @ constant momentum compaction

Combining two RF systems with different frequencies (1.5 GHz & 1.75 GHz) generates long and short buckets, which can be filled individually to generate optimized fill pattern.



One cryo-module with:
2 x 4 cell @ 1.5 GHz & 2 x 4 cell @ 1.75 GHz
operating at **1.8 K LHe** temperature
active length: **1.50 m** with **20 MV/m**
total gradient: **2π 50 MV×GHz (x 60 increase)**



Installed voltage: 16 MV @ 1.5 GHz
14 MV @ 1.75 GHz

Building construction started 02/2015

Building construction

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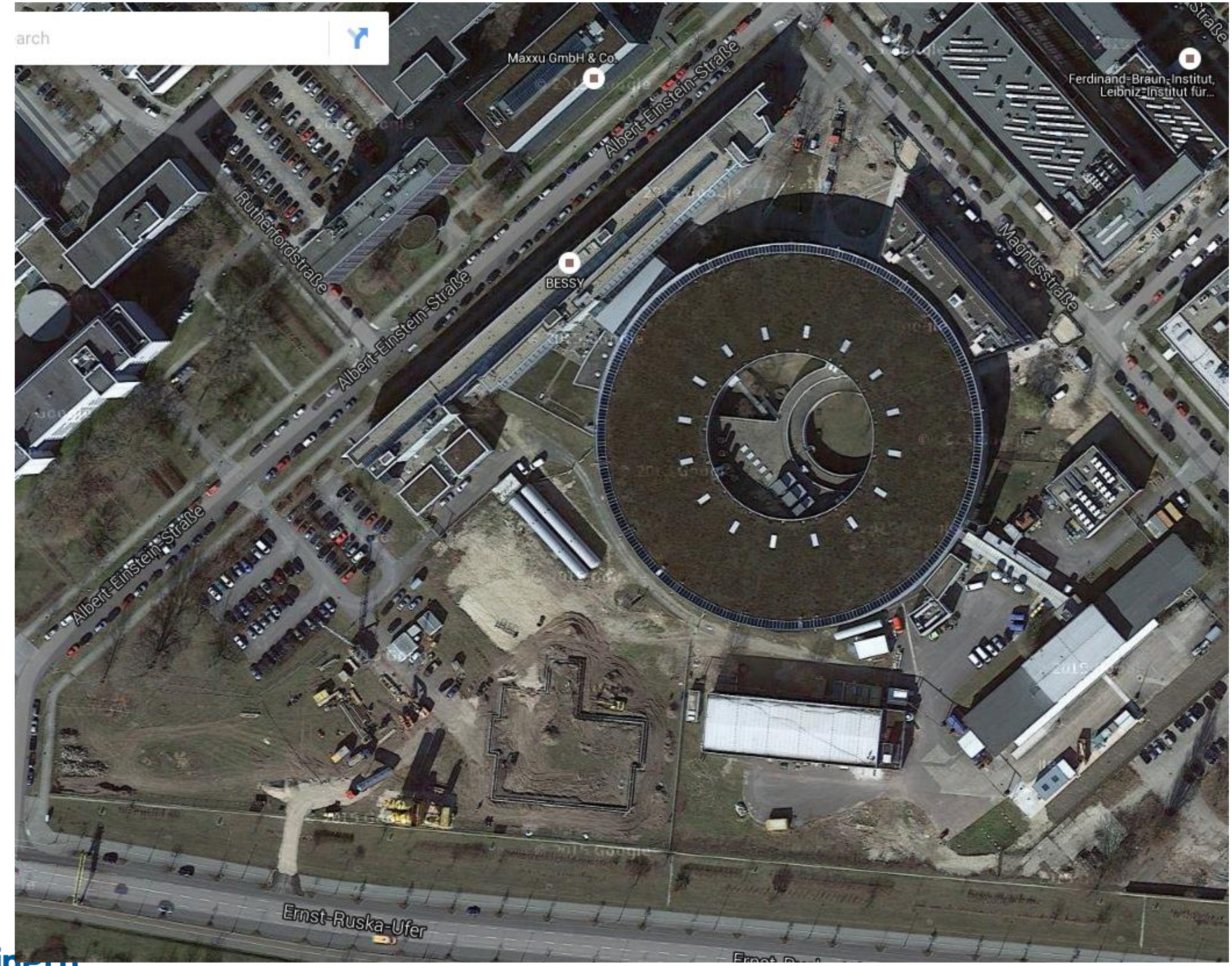

Building construction

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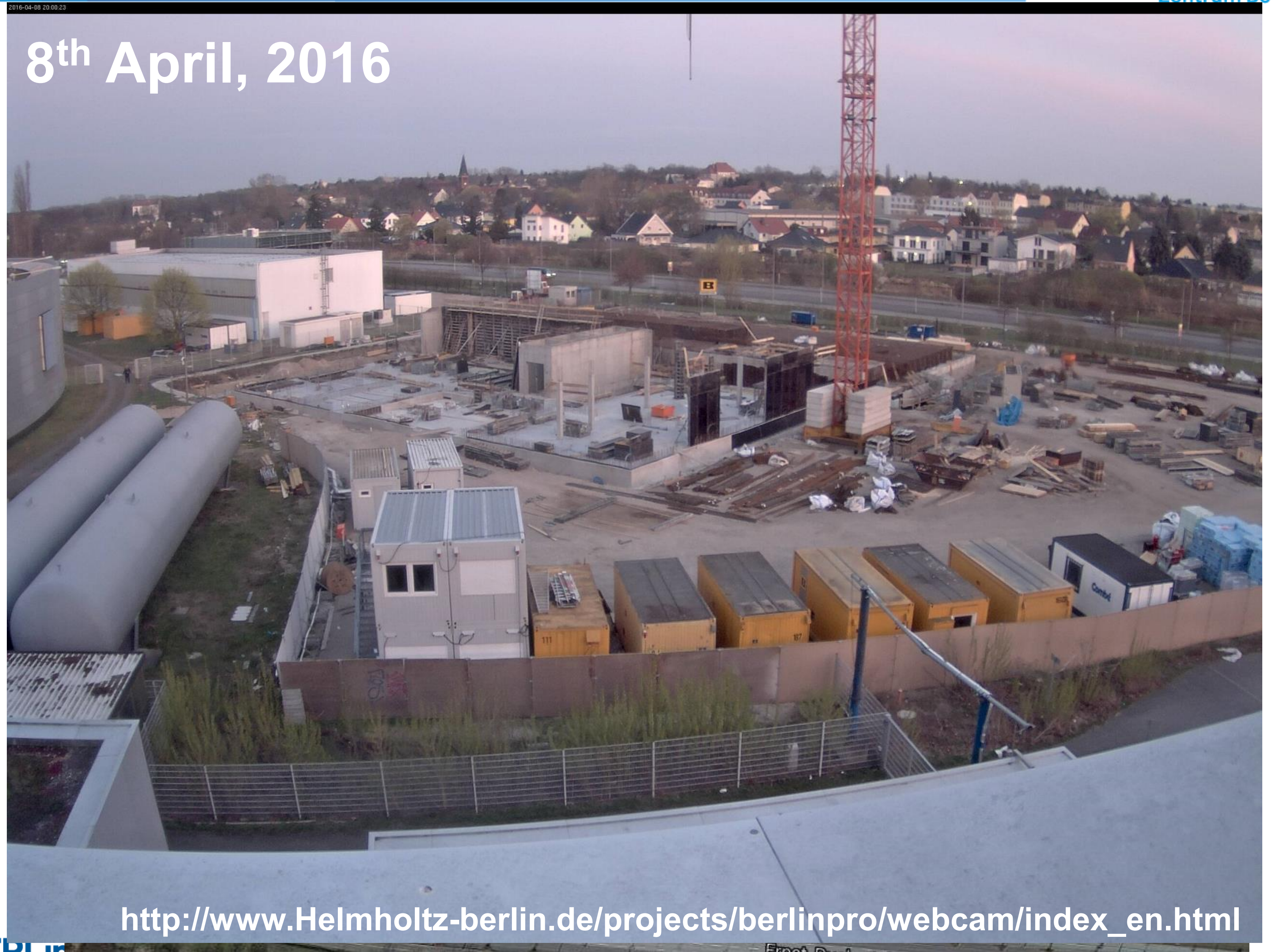

Building

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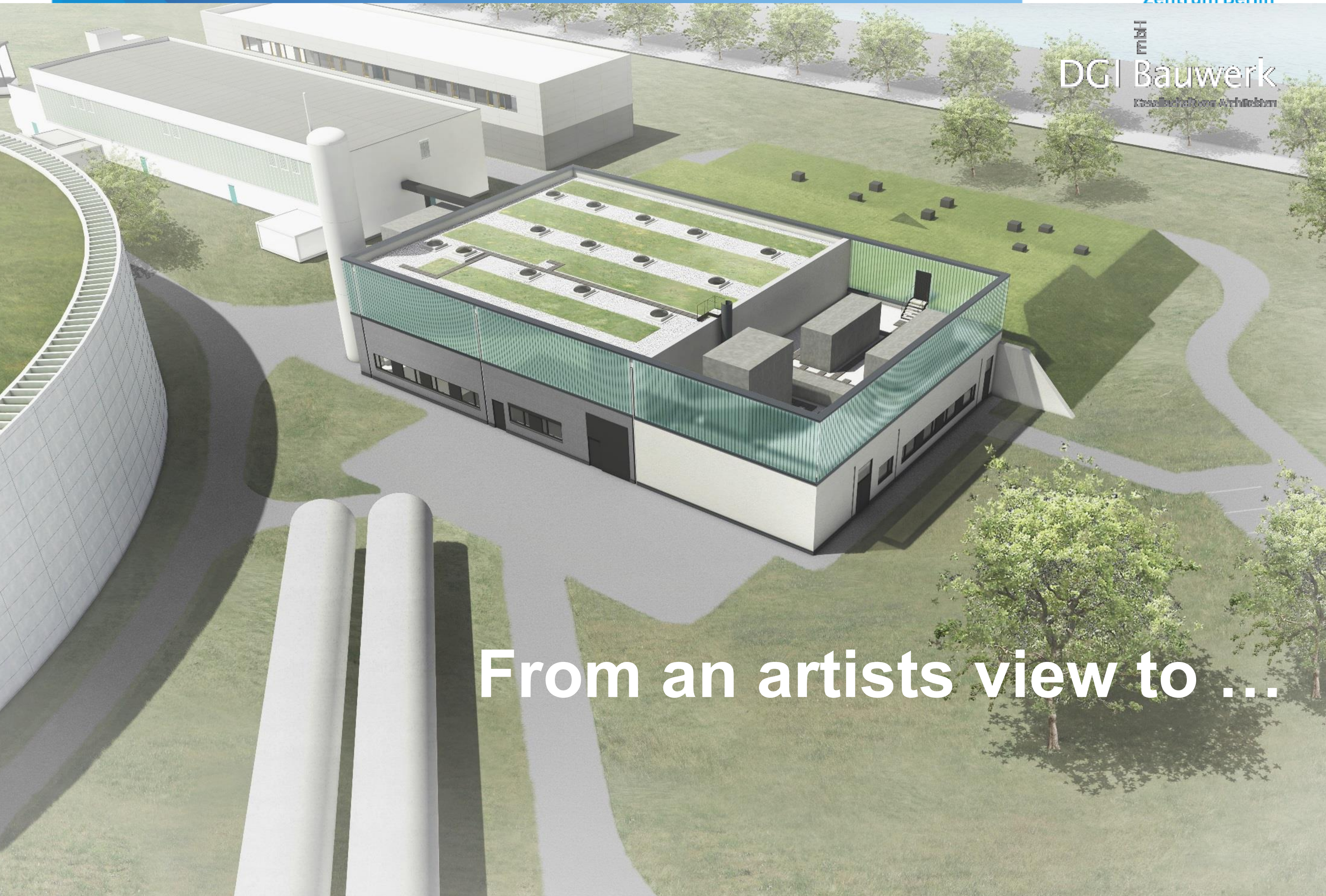

From an artists view to …

Building

View north-west

Building

View south-east

Building

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Empty underground accelerator hall (not a swimming pool)

Installation beam transport

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Installation of Magnets (manufactured by BINP) and Girders by staff from Budker Institute

- February 2017: installation of all magnets; pre-alignment

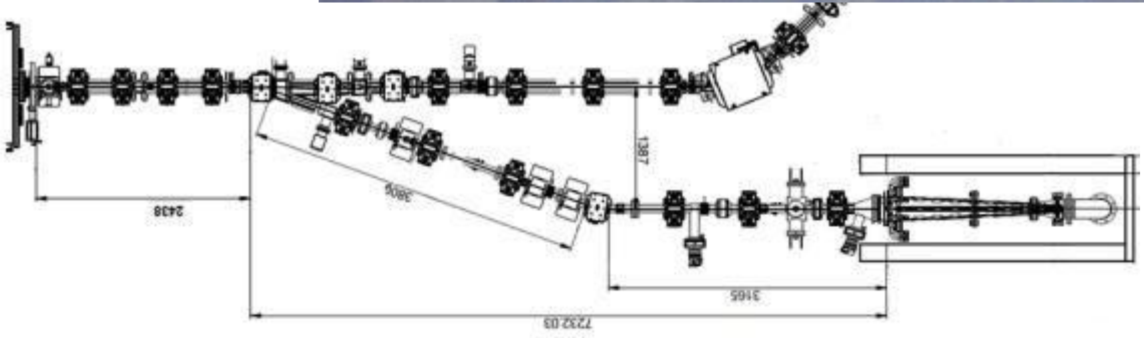
Budker staff in Feb 2017 @ bERLinPro

- Installation of (particle free) vacuum system together with vendor @ bERLinPro by February 2018
- Q2 2018: Finalize banana magnets + first recirculator installation with Budker Inst.

Magnet/Girder installation

Installation of Magnets and Girders

- Feb/March 2017: Finalization of dump-line girder and magnet-line



Magnet/Girder installation

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Accelerator hall (Feb/March 2017)

Some recent photographs (June 2017)

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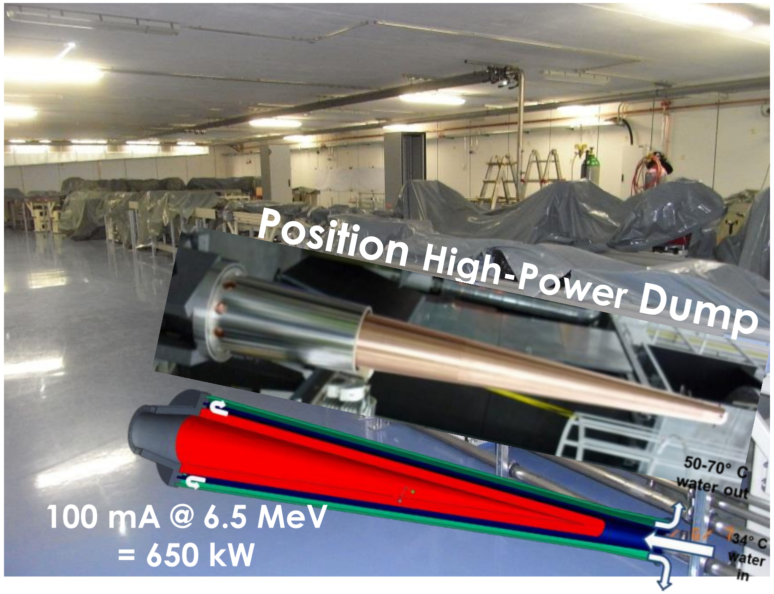

Schedule

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Milestone	Estimated complete date
Stage 1: First electrons @ GunLab	07/2017
"Banana" installed	04/2018
Cryogenic commissioning starts	03/2018
Stage 2: > 1 mA through "Banana"	01/2019
Stage 3+4: First recirculation + high current	**Re-evaluation ongoing**

- Schedule slippage is occurring
  - bERLinPro has significant R&D aspects → technical issues from which we learn! This is one goal of bERLinPro which also benefits BESSY VSR
  - BESSY VSR upgrade project activities are tasking resources
  - Difficulty in predicting reliably first recirculation + energy recovery

Thank you for your attention.

And many thanks to all colleagues contributing to this project

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Institute for SRF Science and Technology, HZB
Young Investigator Group ERL Simulation, HZB
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