bERLinPro

HZB Helmholtz Zentrum Berlin

The Berlin Energy Recovery Linac Project

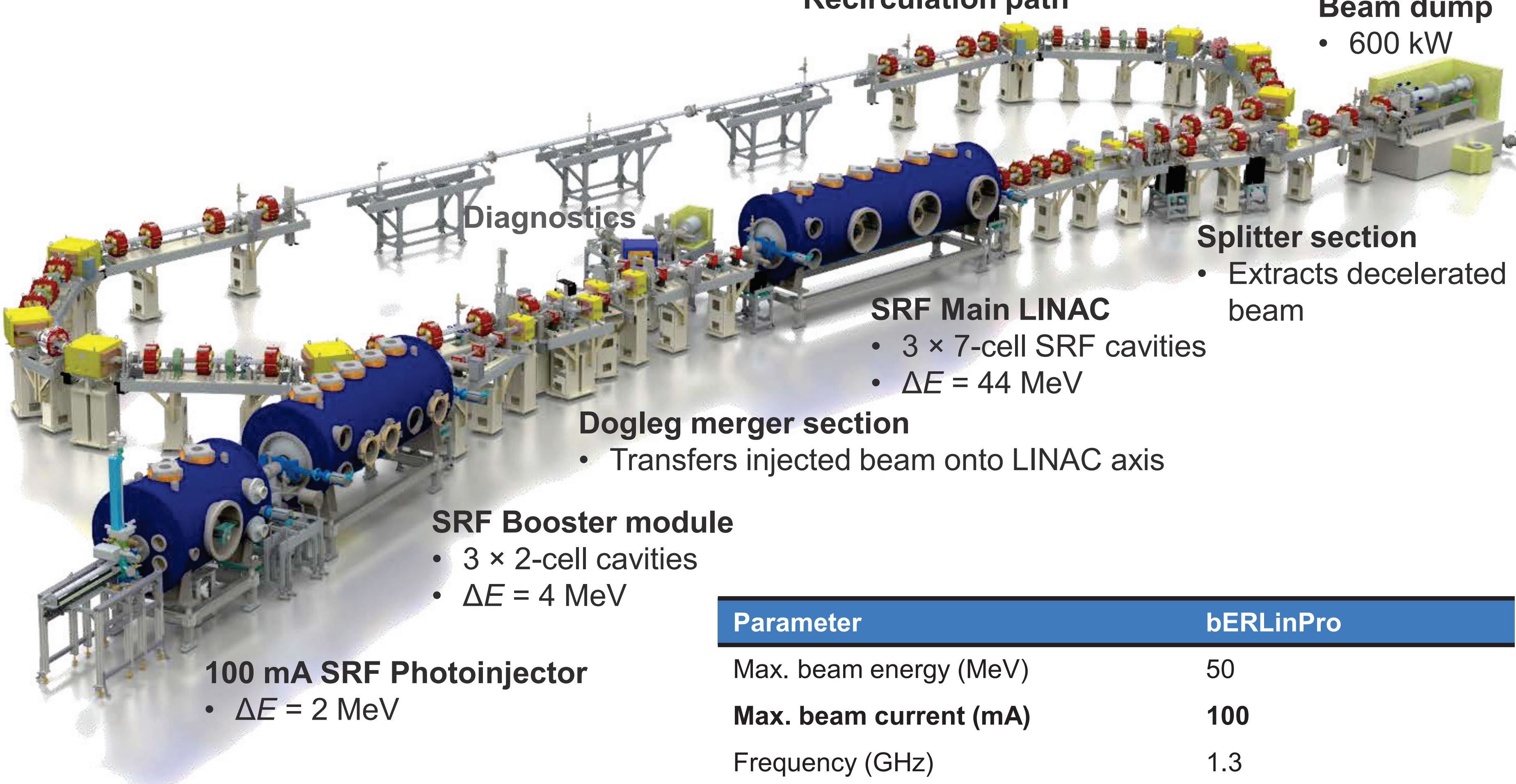
bERLinPro - Status, Plans, Future Opportunities

Andreas Jankowiak
on behalf of the bERLinPro project team
Helmholtz-Zentrum Berlin

bERLin 2019 ICFA

63rd ICFA Advanced Beam Dynamics Workshop
on Energy Recovery Linacs – ERL´19
HZB / Berlin, 16.09.2019

bERLinPro – an ERL / accelerator physics / SRF R&D facility



Parameter	bERLinPro
Max. beam energy (MeV)	50
Max. beam current (mA)	**100**
Frequency (GHz)	1.3
Normalized emittance (mm mrad)	**1 (< 0.6 in simulations)**
Bunch length (ps)	**< 2 ps (100 fs @ 10mA)**
Beam losses	<< 10^{-5} @ 100 mA

- project start 2011
- fully funded, 42 Mio€

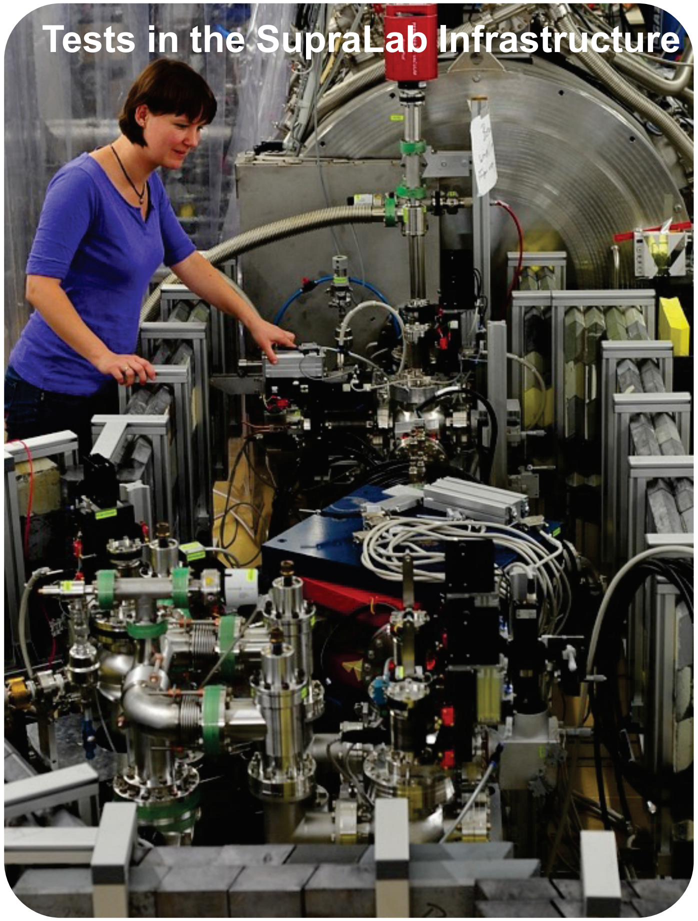
First full superconducting RF photo-injector

Mark 1 Version beam test 04 – 08, 2011

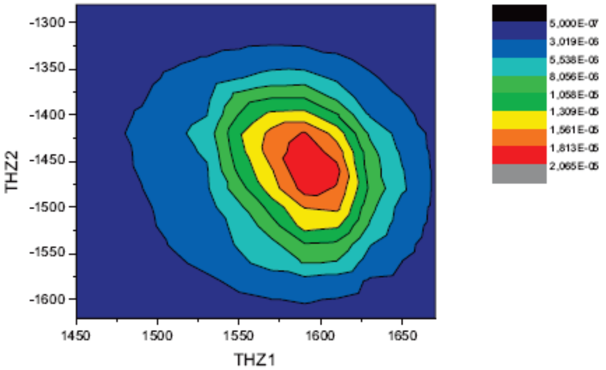
Mark 2 Version beam test 09 – 10, 2012

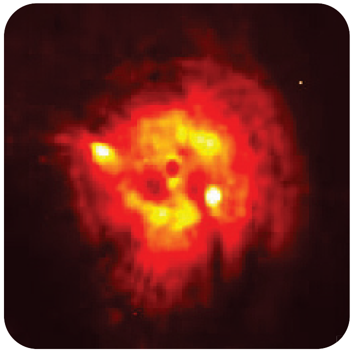
Mark 1 SRF gun

First beam 21st April 2011
(< 24 mo after project start)



QE Map and image of emission area for metallic Pb cathode





Jefferson Lab
Thomas Jefferson National Accelerator Facility

MAX-BORN-INSTITUT

EuCARD

BROOKHAVEN NATIONAL LABORATORY

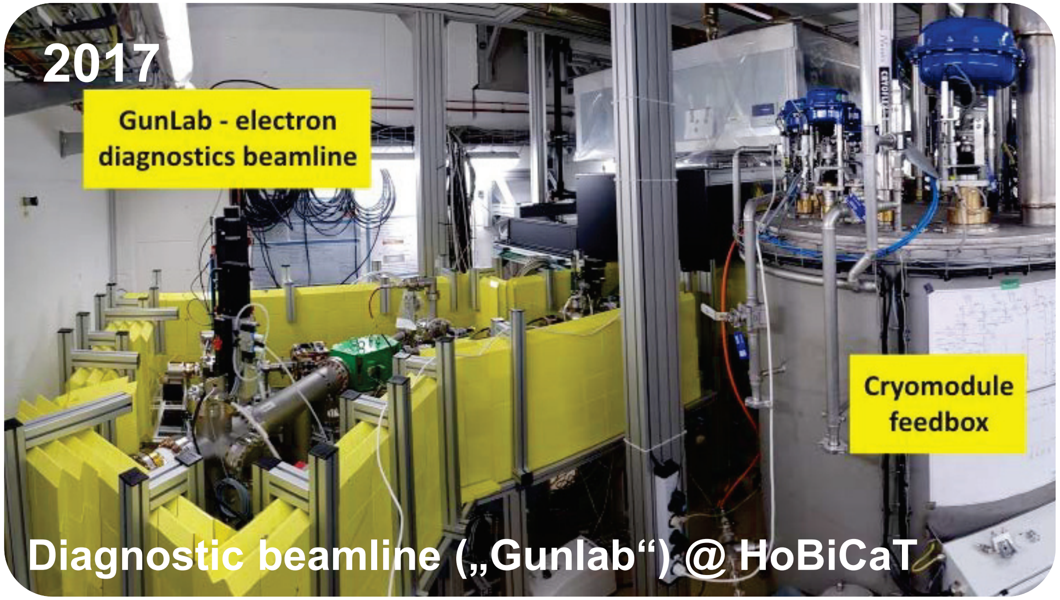
NARODOWE CENTRUM BADAŃ JĄDROWYCH Świerk

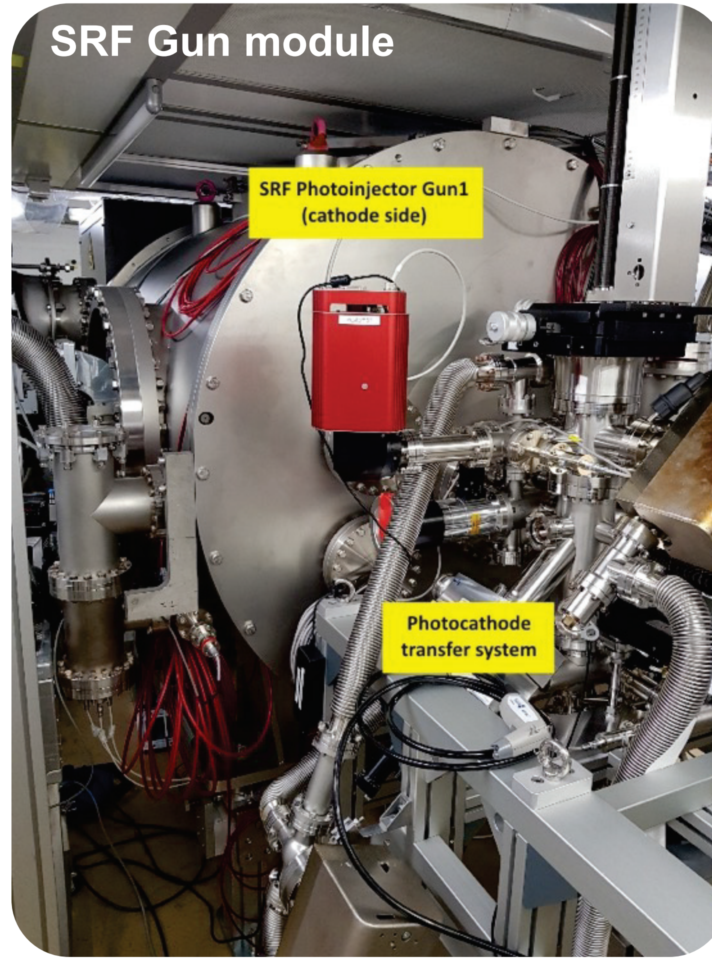
HZDR

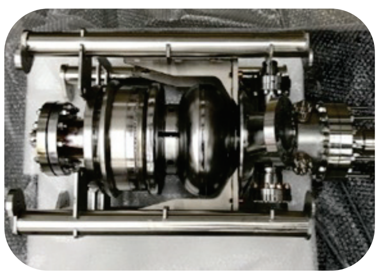
DESY

This is the technology now pursued at DESY for CW operation of E-XFEL

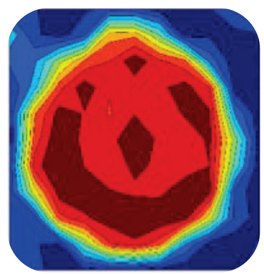
First beam tests of the bERLinPro SRF photo-injector







First beam 12/2017



QE map Cu cathode

First 1.6 cell SRF Gun
with exchangeable high-QE cathode

01/2018 Operation with high QE cathode failed,
as cathode plug „dropped“ into Gun cavity ☹

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LOMONOSOV MOSCOW STATE UNIVERSITY

Jefferson Lab
Thomas Jefferson National Accelerator Facility

High QE photo cathodes & drive laser development

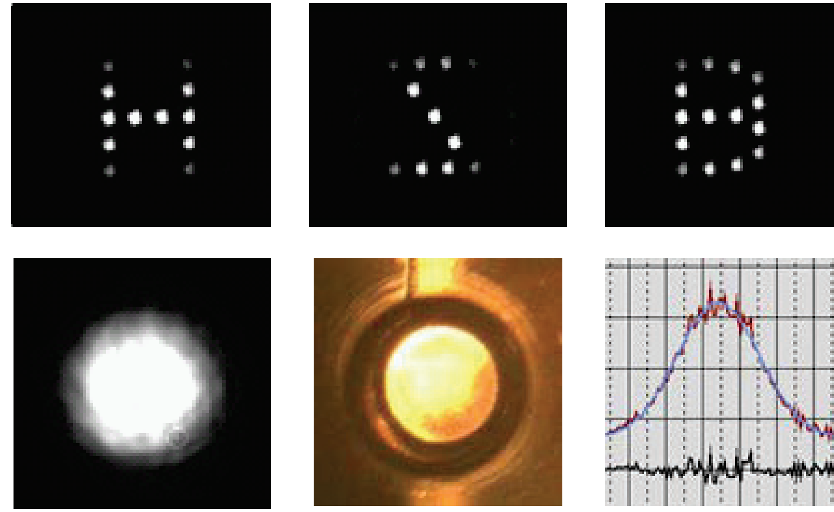
Drive laser development:
- online control of laser parameters (transverse shape and pulse length)
- tools to monitor photocathode
- high power (> 40 W @ 515 nm) 1.3 GHz laser with 3 to 12 ps pulse length

BROOKHAVEN NATIONAL LABORATORY

CORNELL UNIVERSITY FOUNDED A.D. 1865

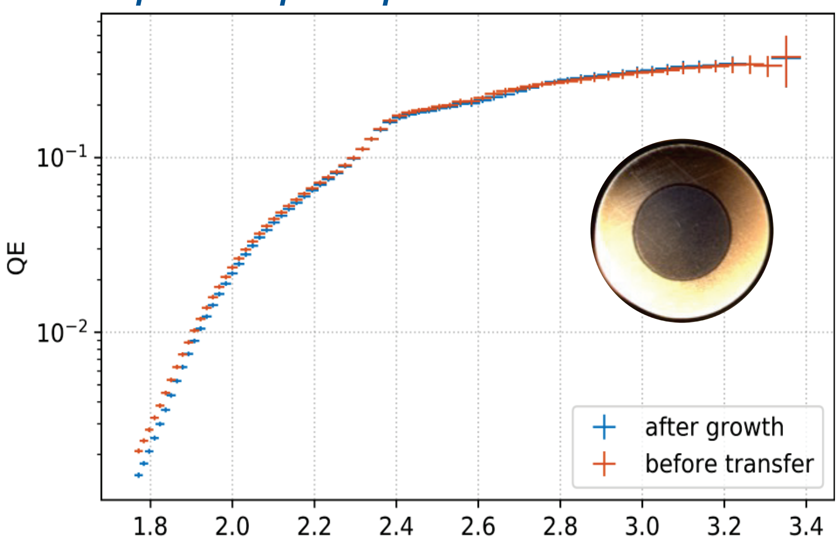
MBI MAX-BORN-INSTITUT

Klemz, Ohm-Krafft



Virtual cathode *Real cathode* *Laser pulse length*

Sepctral response photocathode P017



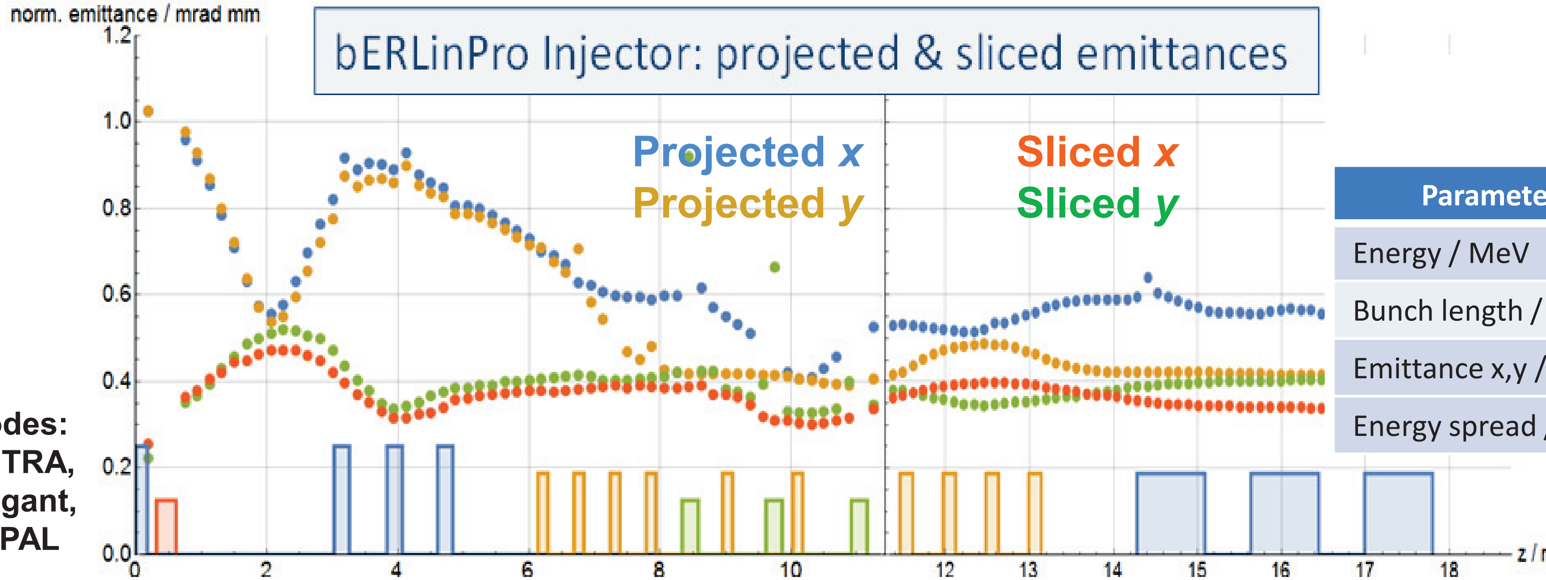
Kühn, Schmeisser, Mistry

Photocathode preparation and analysis laboratory up and running since 2015

- insight into growth process with material science studies in parallel
- **achieved quantum efficiency of 16.8% at 515 nm (specs 1%) with CsKSb**
- successful transfer from cathode lab to SRF gun
- demonstrated, that cooling of cathode to 120 K do not harm quantum efficiency (unlike prediction by other researchers!)

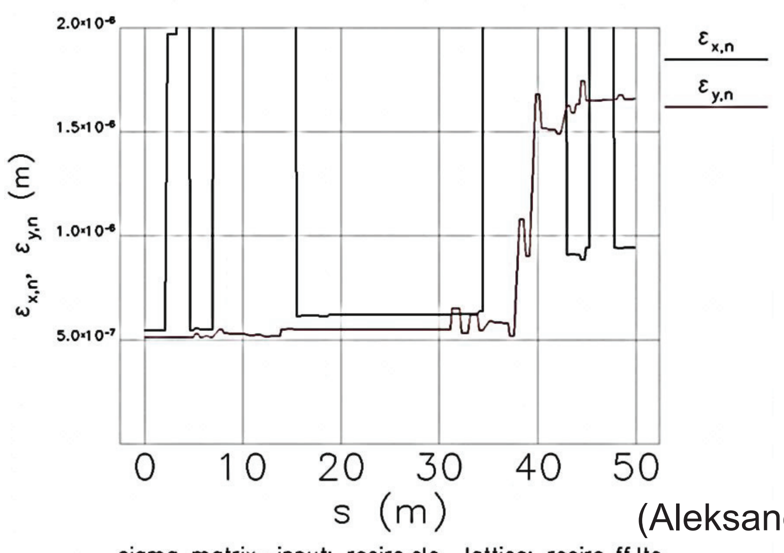
Low emittance / short bunches

codes:
ASTRA,
elegant,
OPAL

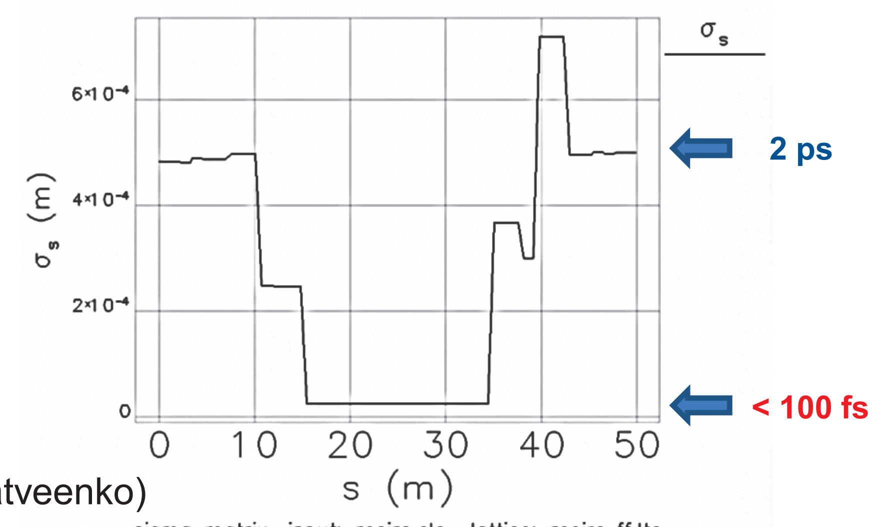


Parameters at LINAC exit	
Energy / MeV	50.1
Bunch length / ps	4.65
Emittance x,y / µm	0.58/0.41
Energy spread / keV	254

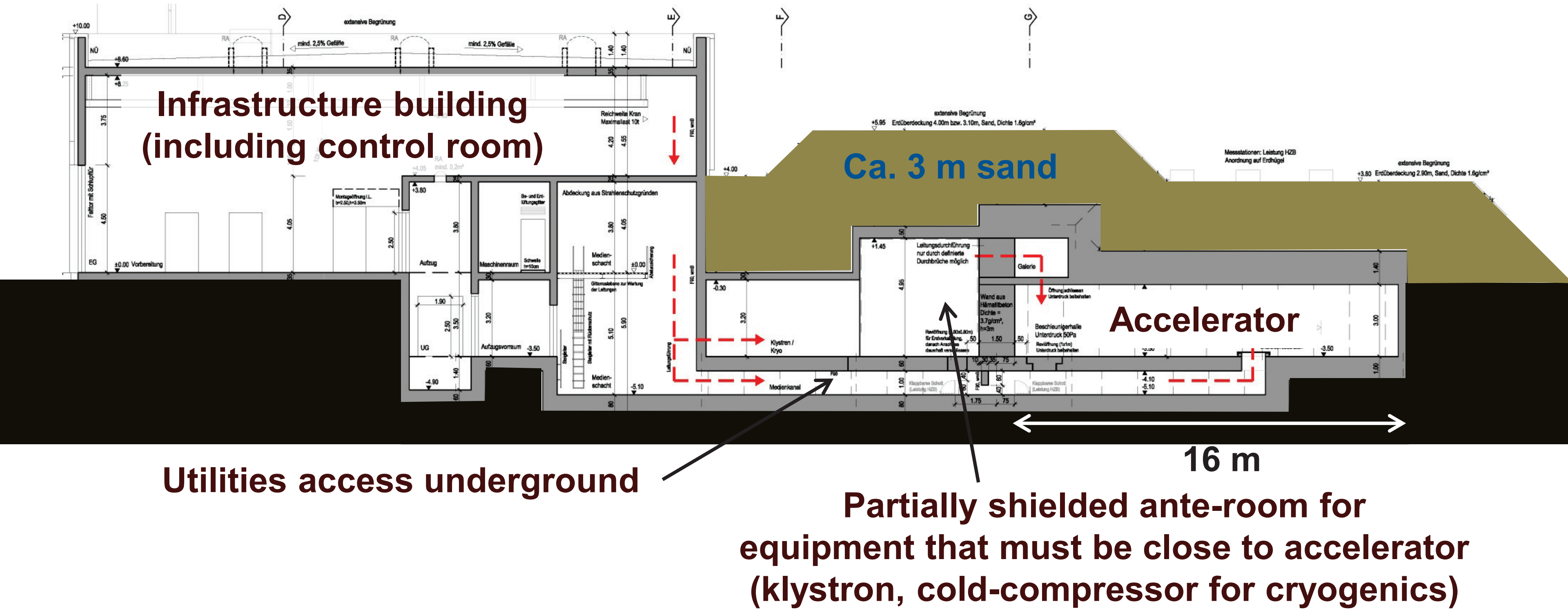
Optics (Short Bunch Mode, 10 pC): Bunch size & Emittance



(Aleksandr Matveenko)



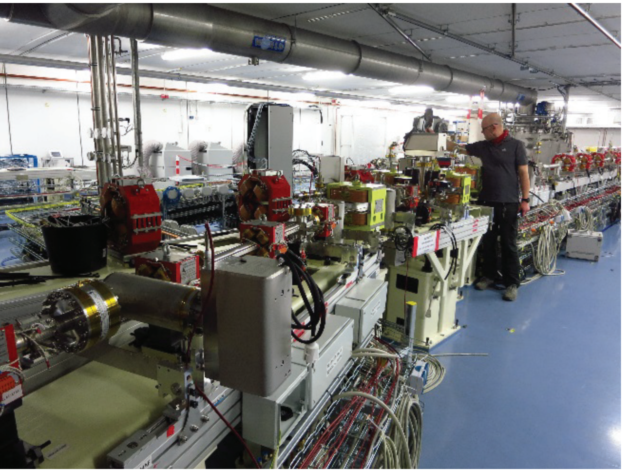
bERLinPro – building construction started 02/2015

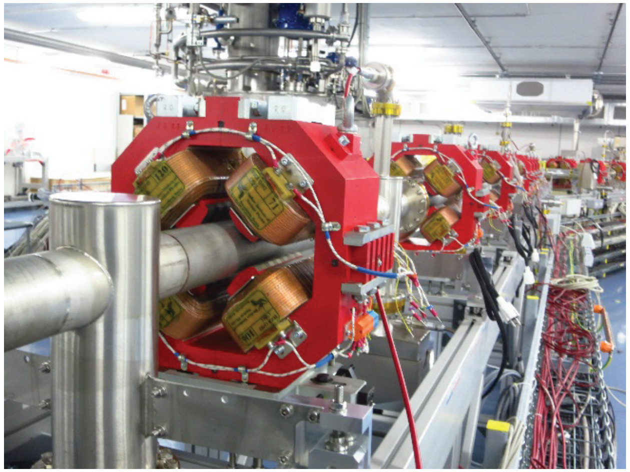


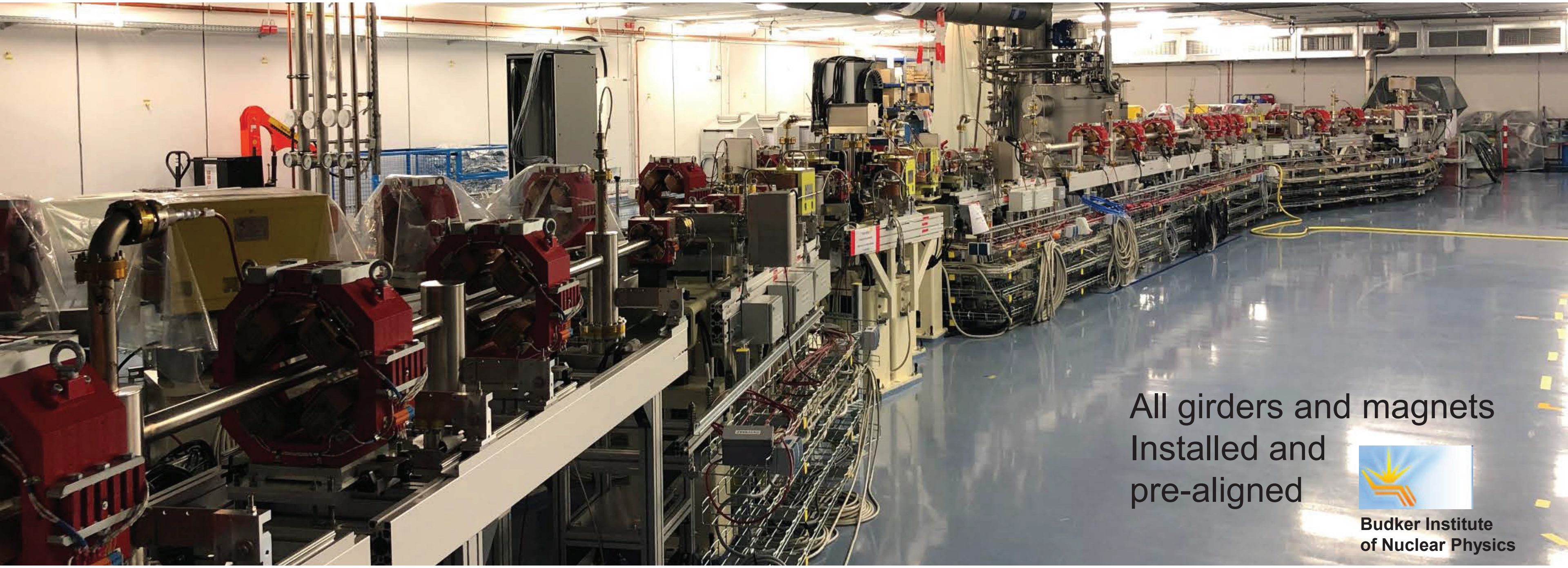
bERLinPro – building + technical infrastructure nearly finished (not really)

Underground accelerator hall – 12/2016

Underground accelerator hall – machine installation in full swing



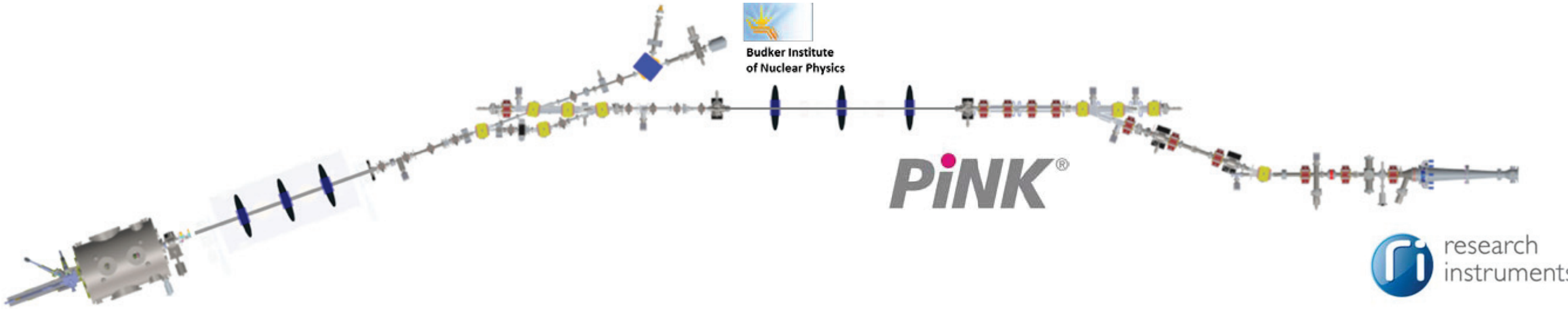


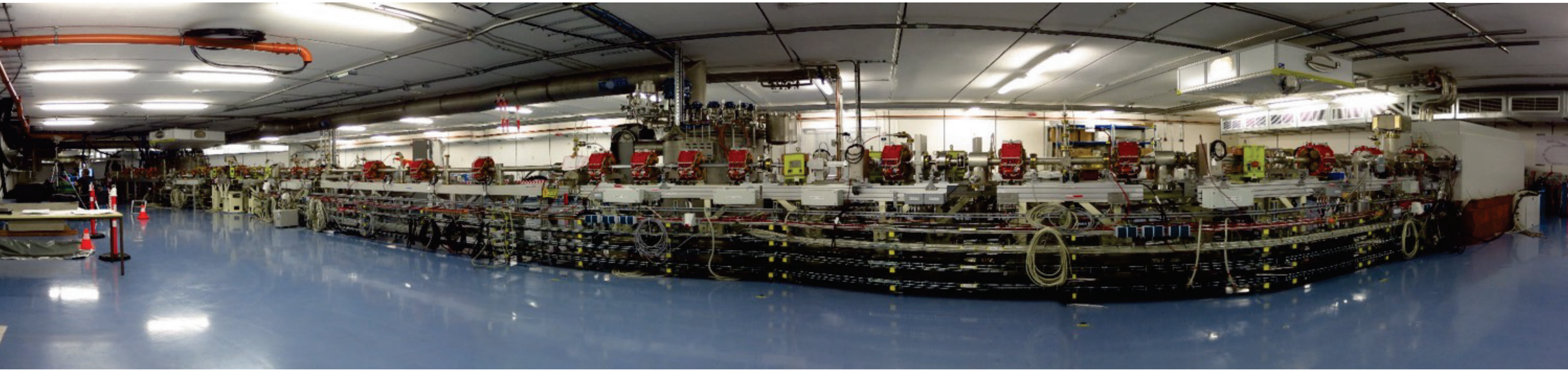


All girders and magnets
Installed and
pre-aligned

Budker Institute
of Nuclear Physics

“SRF ready” particle free UHV system





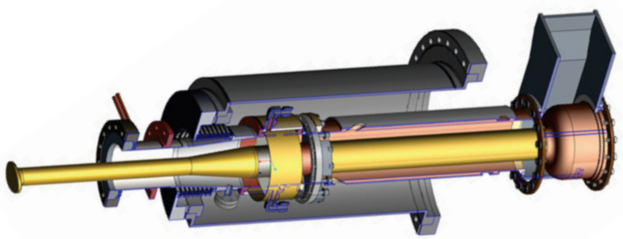
Particle-free UHV vacuum system & high power beam dump

- Designed by HZB, manufactured by German Industry
- ISO 5 qualified, < 10^{-10} mbar, including 650 kW high power beam-dump
- Pre-assembled modules and Installation at accelerator hall by vendor
- Complex NEG coated system from stainless steel and aluminum
- Now in operation and meets the design specifications.

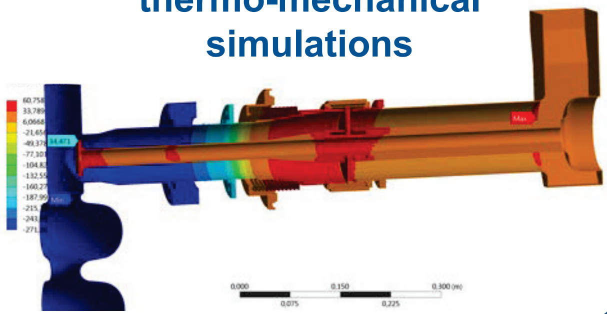
High current booster – cavities, couplers, module

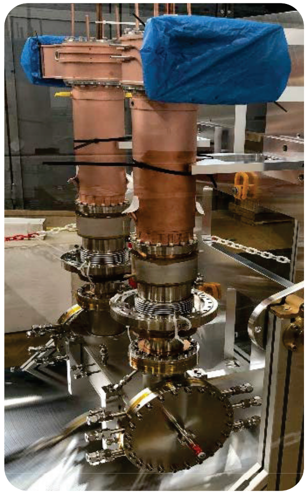
- Pre-accelerator for highest beam power: up to 500 kW_{CW}, max. 240 kW/cavity
- Collaboration Cornell University (USA), Jefferson Lab (USA), KEK (Japan)
- Cavity design: Cornell / production: Jefferson Lab (USA) (4 x 2 cell)
- High power RF coupler for up to 120 kW CW
- Coupler production: warm parts - FMB (Berlin) / cold part – Toshiba/Canon (Japan)

RF coupler design @ HZB

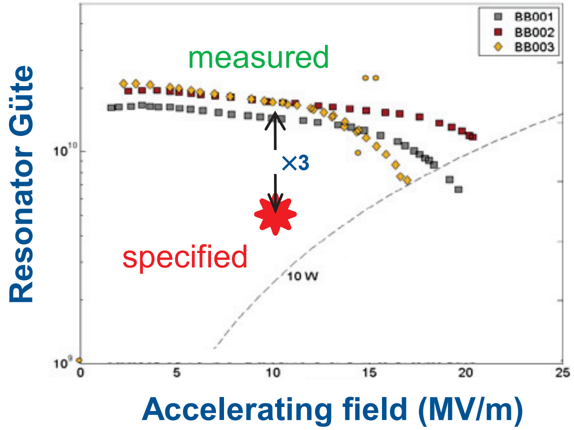


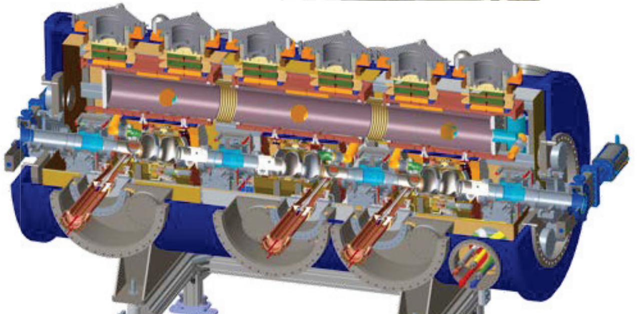
thermo-mechanical simulations





2 cell SRF booster cavity

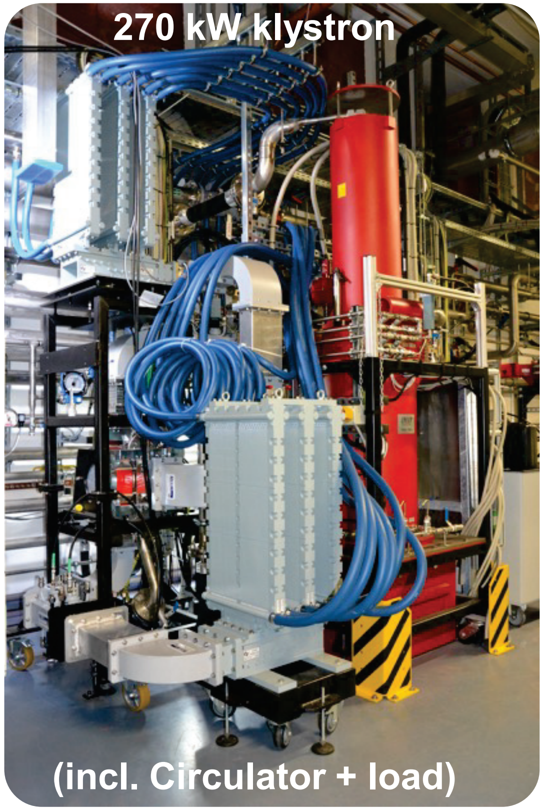




Booster Module
3 x 2 cell cavity

CW high power klystrons & auxillaries

- Developed at CPI (USA) together with HZB and TRIUMF (Canada)
- 270 kW_{CW} @ 1.3 GHz at present only available @ HZB, TRIUMF
- Essential part of future SupraLab@HZB infrastructure
- First klystron tested up to max power @ bERLinPro

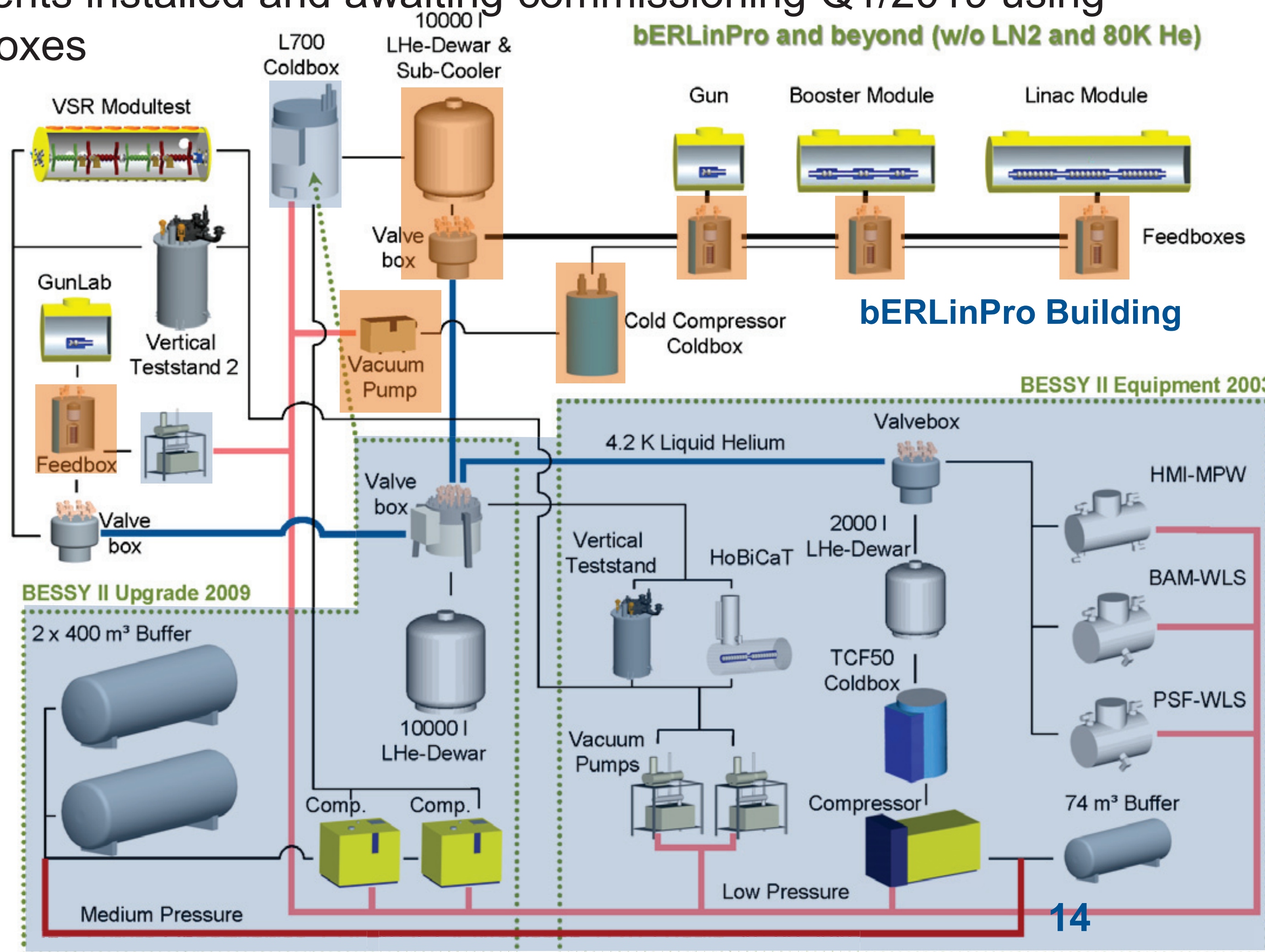


1.8 K cryo plant

- ca. 300 W capacity at 1.8 K with cold compressors and existing L700
- Additional connection in bERLinPro building for module tests (BESSY VSR)
- Integrated in BESSY-wide system, incl. VSR for redundancy
- All new components installed and awaiting commissioning Q1/2019 using heaters in feedboxes

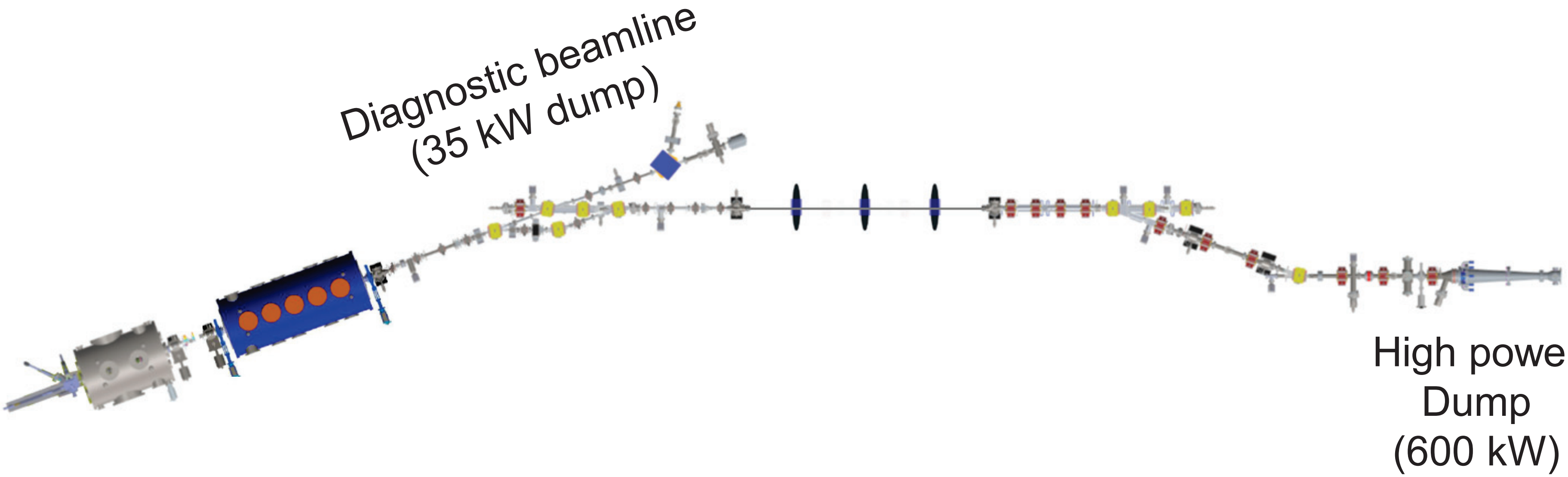
Existing equipment

New purchase for BP



Commissioning plan bERLinPro (as it was) – Stage 1/2

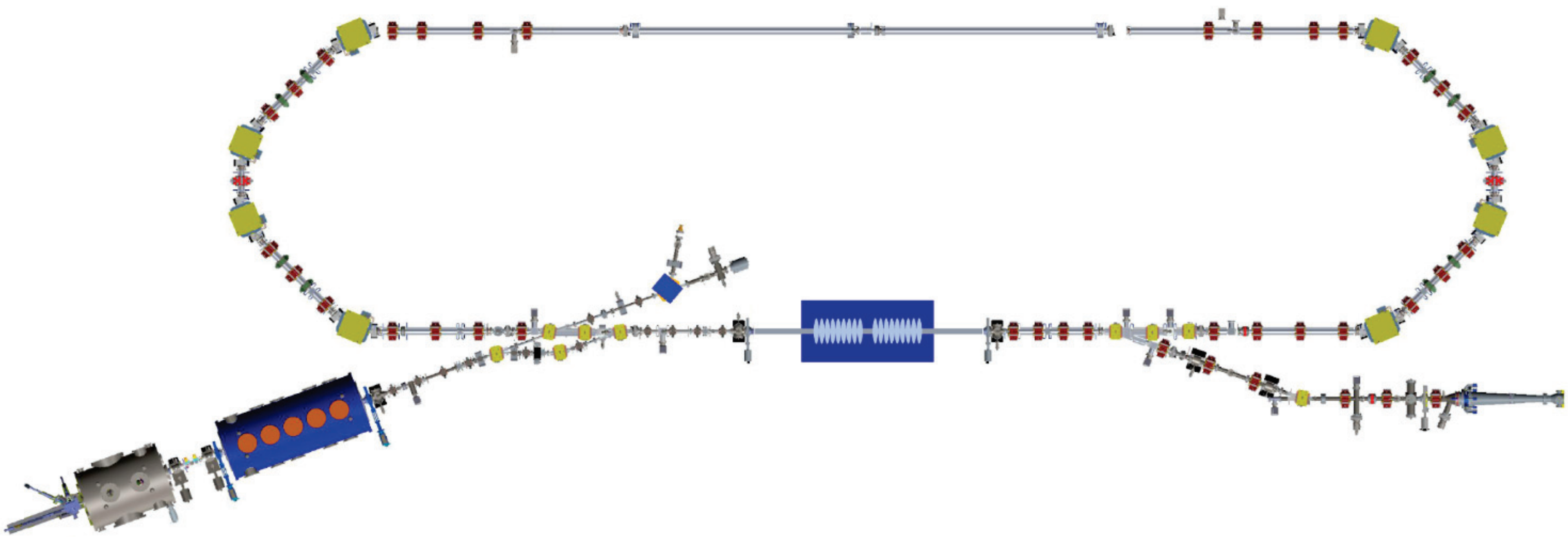
Stepwise startup foreseen
to separate challenges / for load balancing / to get early scientific output



(1) First beam Gun1 in bERLinPro building (2019)
medium power, up to 5 mA → diagnostic beamline

(2) Add booster module (2020)
up to 5 mA → diagnostic beamline & high power dump

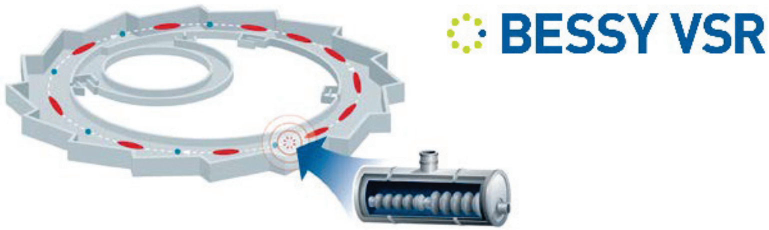
Commissioning plan bERLinPro (as it was) – Stage 3/4



(3) Add HOM damped linac module and demonstrate recirculation and energy recovery (2021)
medium power (5 mA, 50 MeV) → recirculation

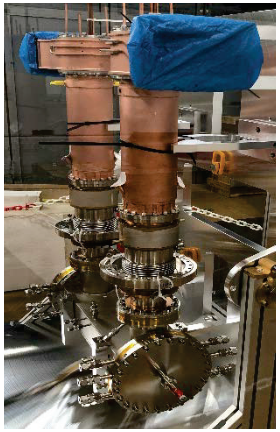
(4) Replace Gun1 by Gun2 and go for high power recirculation (202?)
up to 100 mA, 50 MeV → recirculation

Reality took over

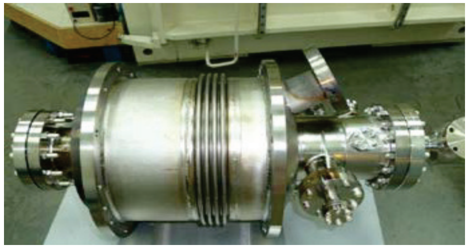


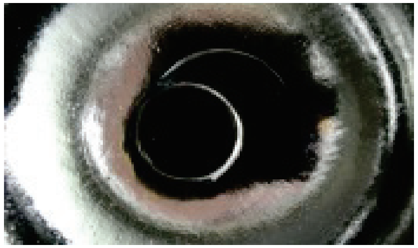
BESSY VSR upgrade (2017 – 2026) has higher priority than bERLinPro
→ no Gun2 module, no linac module

Cold parts of booster HPC were delayed, warm parts even more severe (need to be re-manufactured)



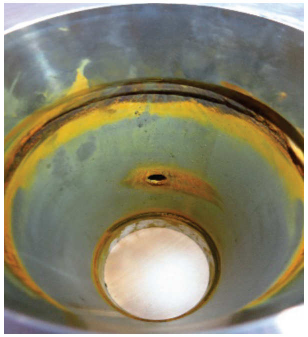
→ conditioning not before Q2/2020, delay of booster module





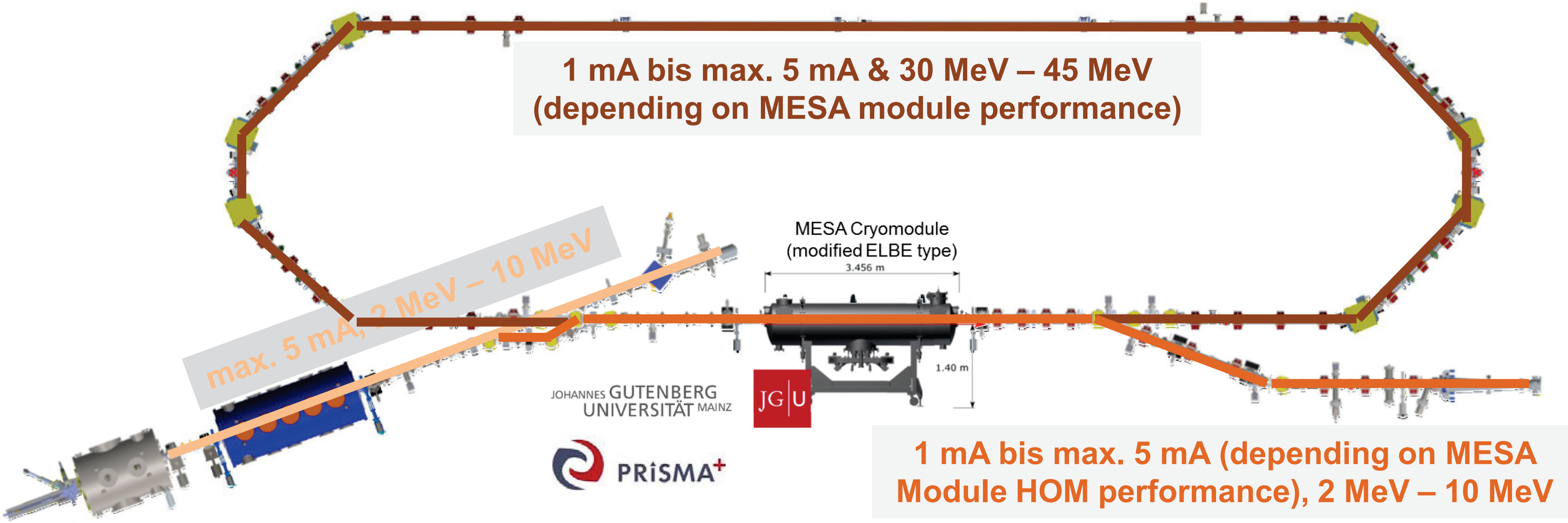
- Gun1.0 cavity not usable in bERLinPro due to “drop” of cathode in cavity (etc.)
- Gun1.1. cavity got scratch during final HPR at manufacturer

→ attempt to repair by grinding ongoing, delay (min. 5 months) of Gun module



Rust in de-ionized water cooling circuits of bERLinPro, nearly complete system needs to be exchanged
→ delay in commissioning cryo-system, coupler tests, …

Present planning – no contingency / still many uncertainties



06/2020 Gun1 cool down and RF commissioning (no beam tests)

10/2020 start installation of re-circulator vacuum (to be finished 03/2021)

12/2020 booster module installed

01/2021 MESA module installed (collaboration JGU Mainz, 2 x 9 cell)

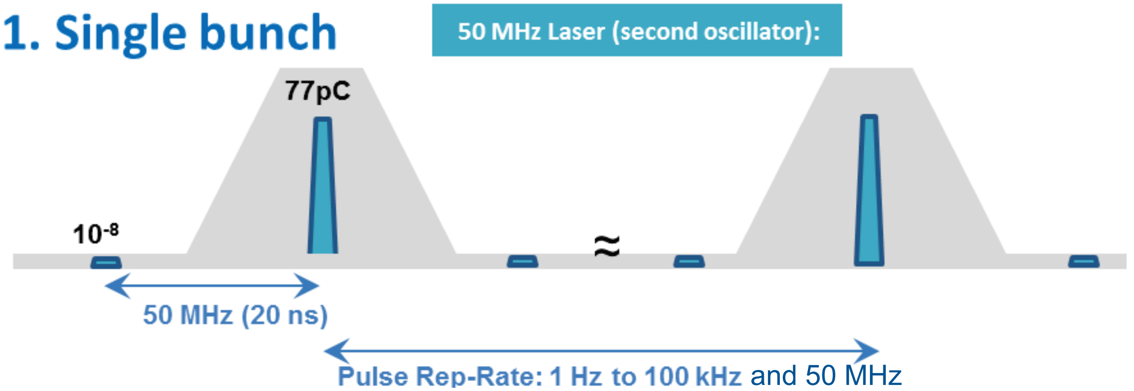
06/2021 First beam possible, with subsequent re-circulation + recovery

Re-circulation test period limited, as MESA module back to Mainz 07/2022
and start of VSR module tests in bERLinPro hall ca. 09/2022.
Funding for 2000 h / a of operation secured till end of 2022.

Pulse Pattern Options

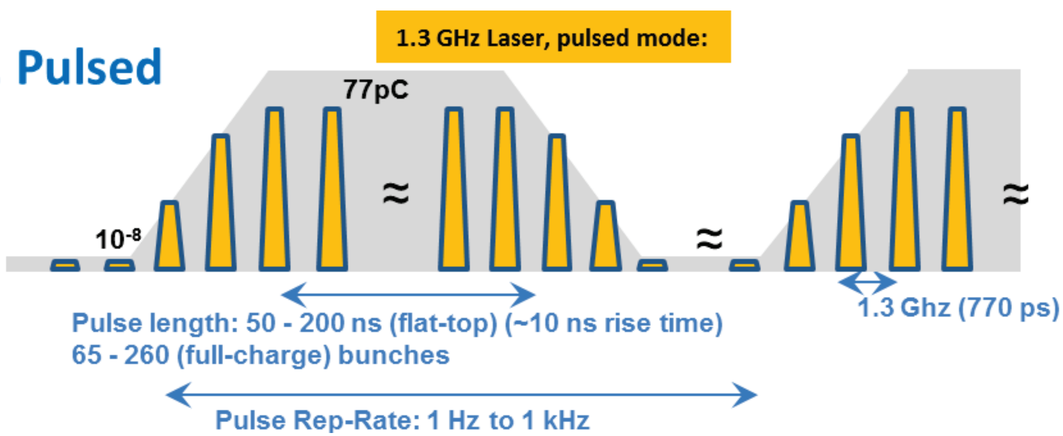
- 2 laser systems by MBI: 50 MHz & 1.3 GHz, 510 – 540 nm, extinction ration 10^{-8}

1. Single bunch



I_{max}~ 5 mA

2. Pulsed



I_{max} ~ 20 µA

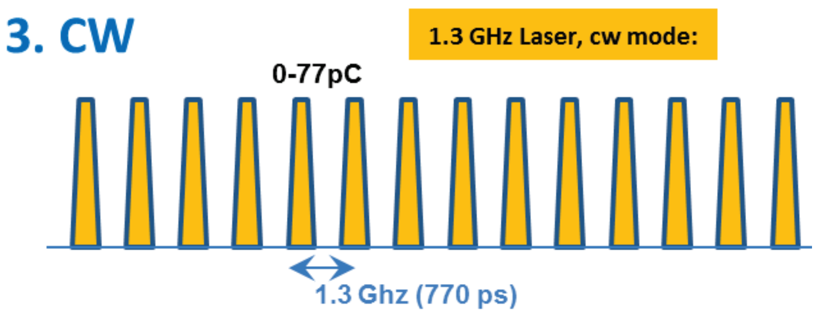
Pulse length: adjustable 3 ps – 12 ps (rms), 7 ps (rms) baseline,

Operational modes – pulse patterns

Pulse Pattern Options

- 2 laser systems by MBI: 50 MHz & 1.3 GHz, 510 – 540 nm, extinction ration 10^{-8}

maximum current will be limited by gun (couplers, 5mA at present) or MESA BBU thresholds; bunch charge by cathode QE



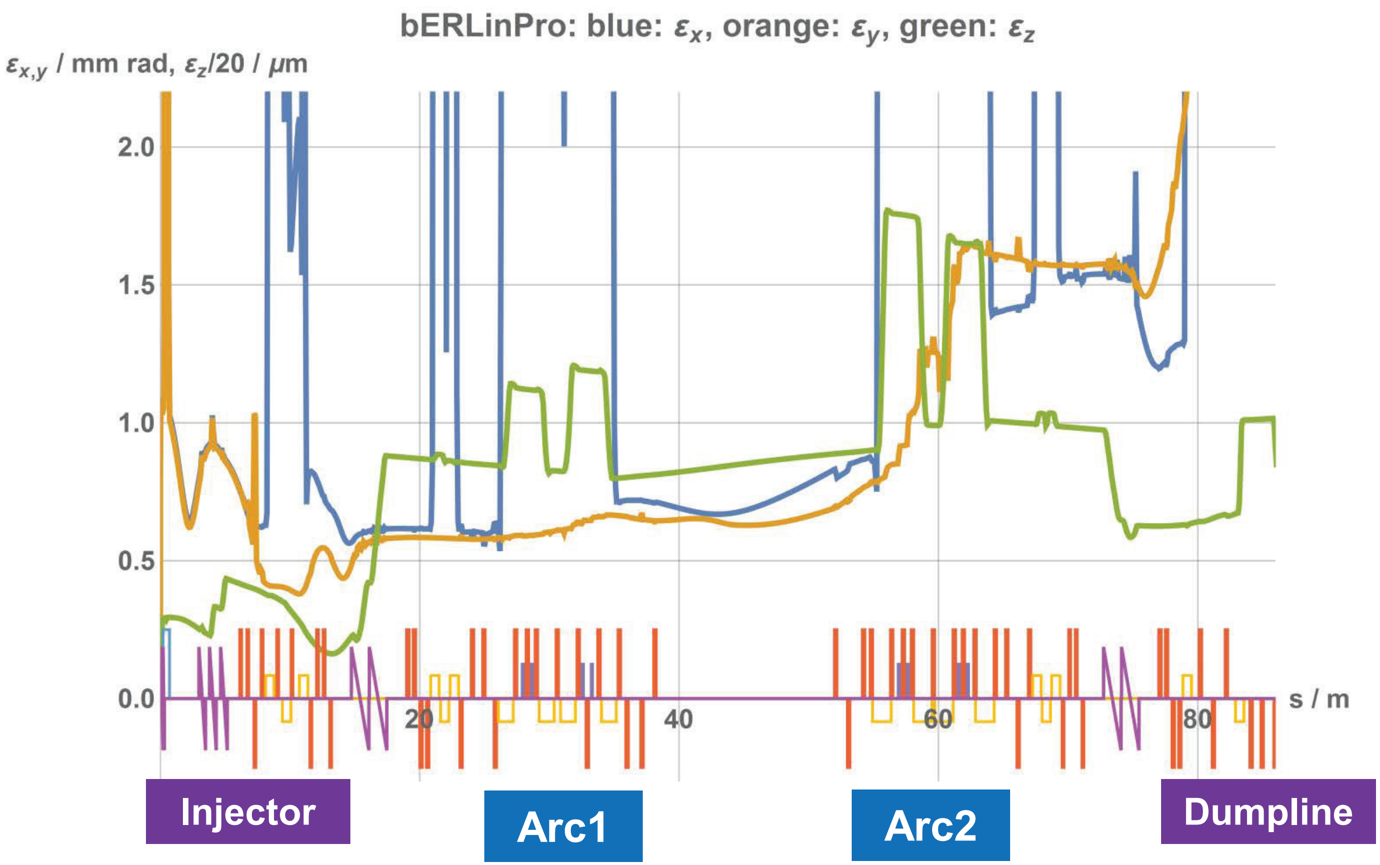
I_{max} ~ 100 mA

> 40 W cw power

Pulse length: adjustable 3 ps – 12 ps (rms), 7 ps (rms) baseline,

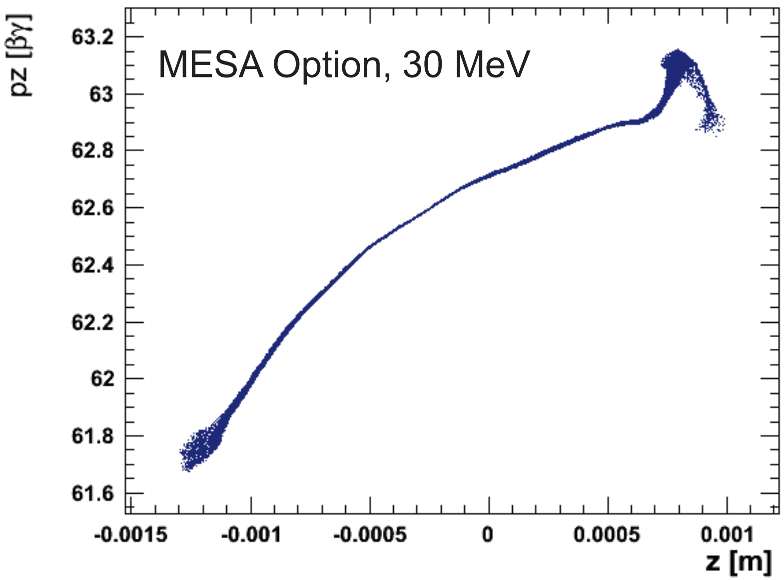
Beam Optics

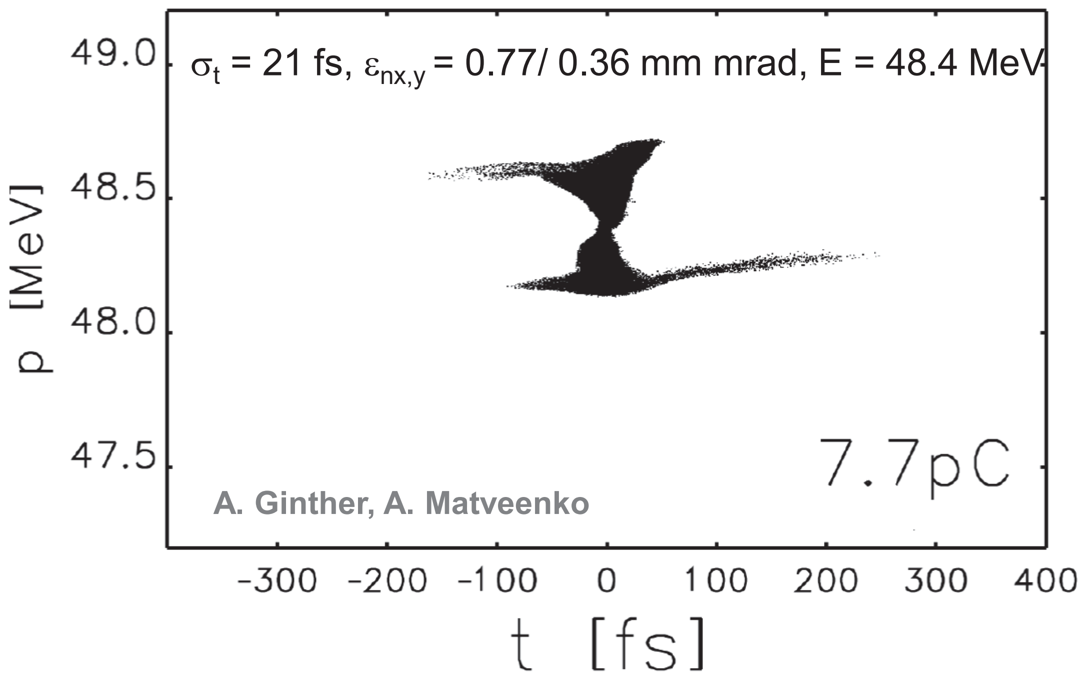
- Astra, Elegant, OPAL simulation including space charge & CSR
- emittance compensation, bunch compression studies, beam pass length & phasing
- emittance preservation below 1 mm mrad confirmed



Short pulses

- standard operation: s_t = 2 ps @ Q_b = 77 pC
- dedicated short puls mode: s_t ~ 100 fs @ reduced bunch charge

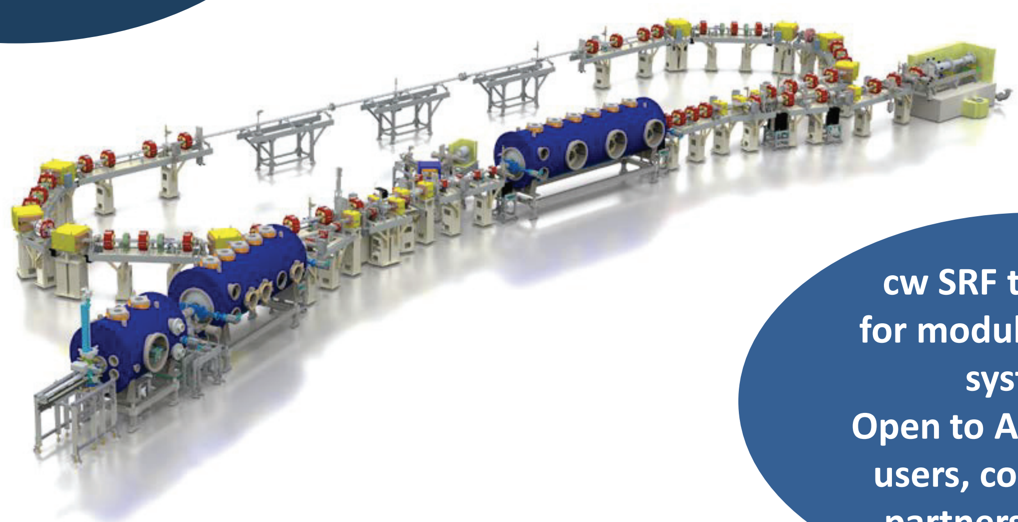




bERLinPro as an R&D test facility in the future ...

THz pilot facility,
High quality, high power radiation schemes (THz, X-rays, e- pump/probe)

Exotics
Dark matter search
Isotope production
EUV facility tests



cw SRF test facility for modules, cavities, systems.
Open to ARD, external users, collaboration partners, industry.

ERL / Gun test accelerator, test bed for undulators, impedance tests, …

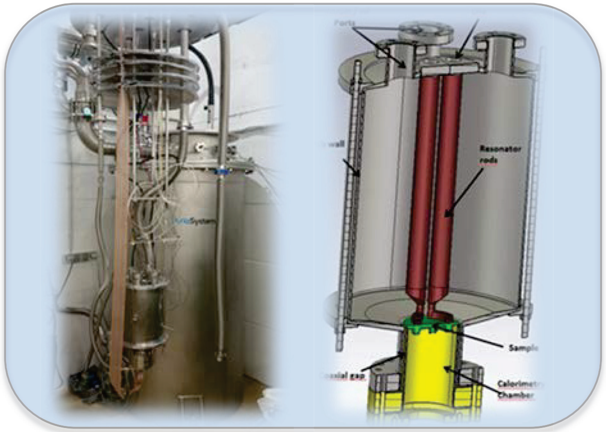
Teaching and education

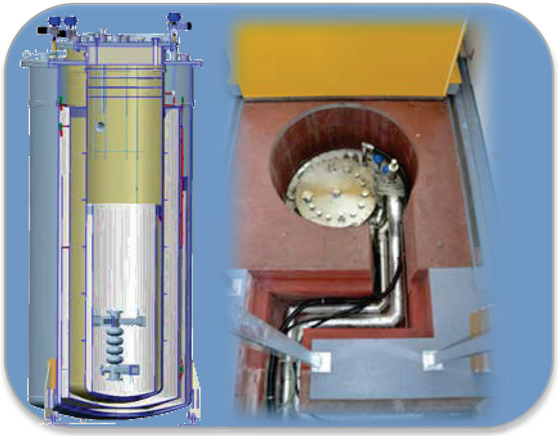
SupraLab@HZB – Facilities for cw SRF development & tests

A one stop shop for the full CW SRF development chain

- From new characterization of new materials, to prototypes (cavities, modules), to beam tests in bERLinPro

Sample testing (QPR) → **1-cell prototype testing (SVTA)** → **Full cavity testing (LVTA)**



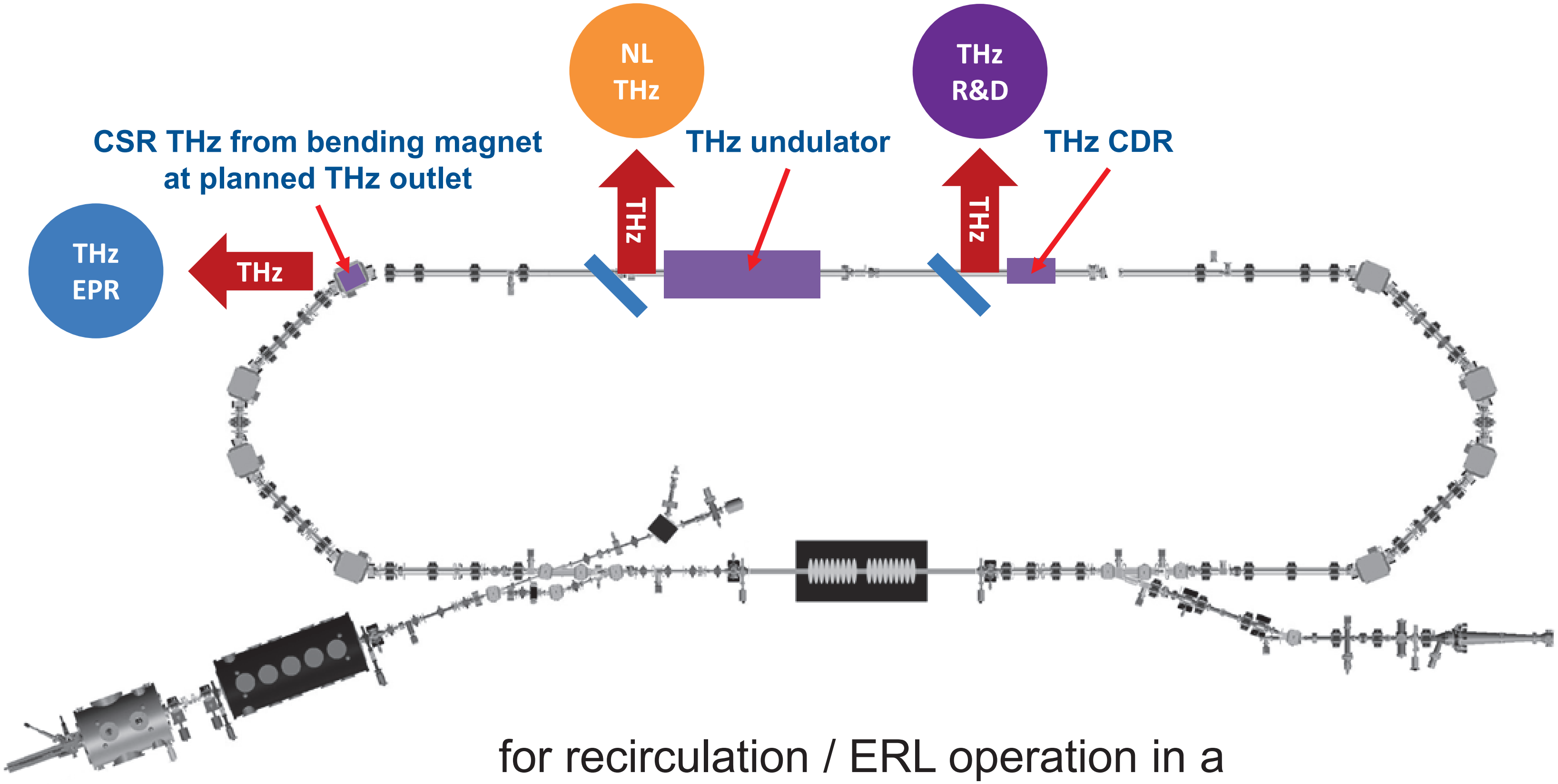


Beam operation in bERLinPro ← **Full module tests (MTF)** ← **Dressed system (HoBiCaT)**

For users, partners, industry

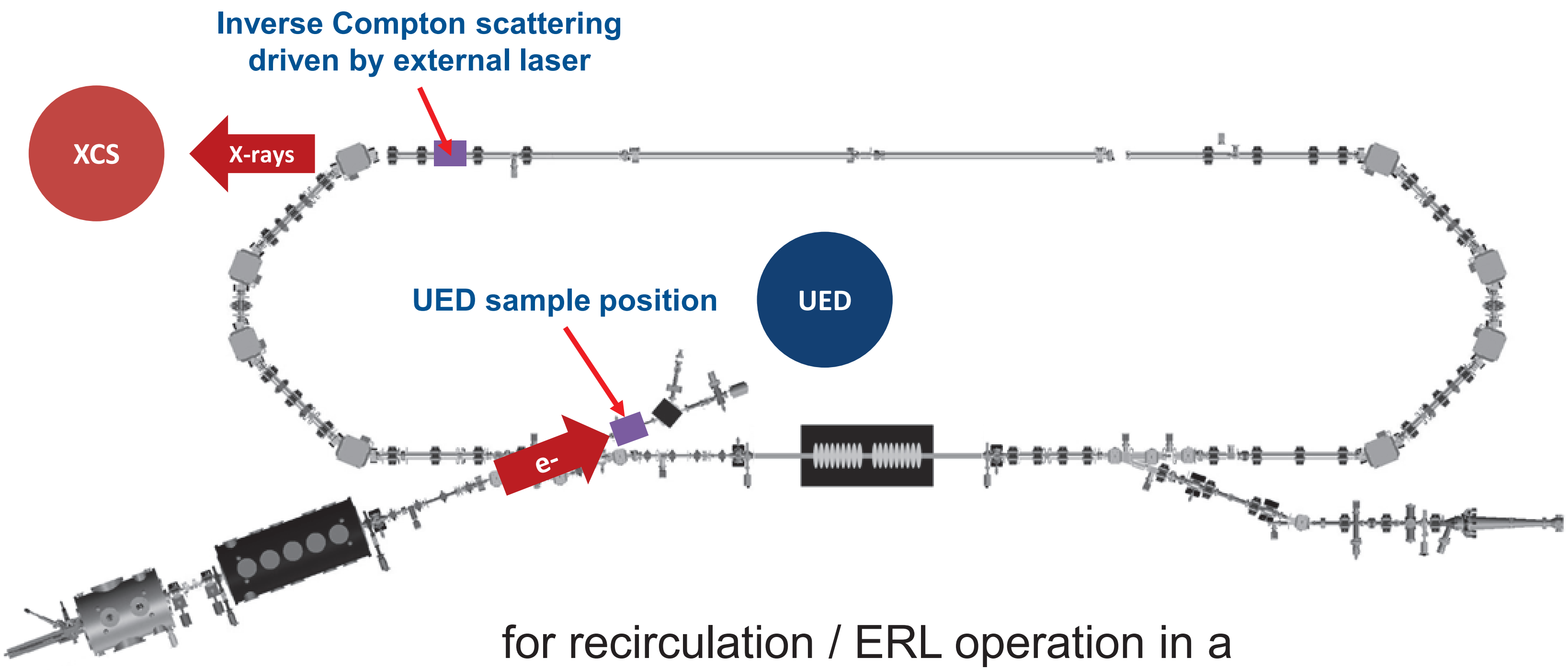
EUROPÄISCHE UNION
Europäischer Fonds für regionale Entwicklung
Investition in Ihre Zukunft ...eine Chance durch Europa!
EFRE

Some first ideas - THz opportunities at THz@SupraLab/bERLinPro



for recirculation / ERL operation in a
“post MESA@bERLinPro time” (from 2022/23 on)
we need a “linac module”

Some first ideas – X-ray / e- opportunities at THz@SupraLab/bERLinPro



for recirculation / ERL operation in a
“post MESA@bERLinPro time” (from 2022/23 on)
we need a “linac module”

See you at the bERLinPro 2020+ BarCamp on Tuesday evening!

In case that you are interested to join in:
contact Thorsten Kamps

&

= BarCamp (?)

Thank you for your attention.