Synchrotron Radiation Sources

Quo vadis (@HZB) ?

Andreas Jankowiak
Institute for Accelerator Physics
Helmholtz-Zentrum Berlin

GFA & SwissFEL
Accelerator Seminar

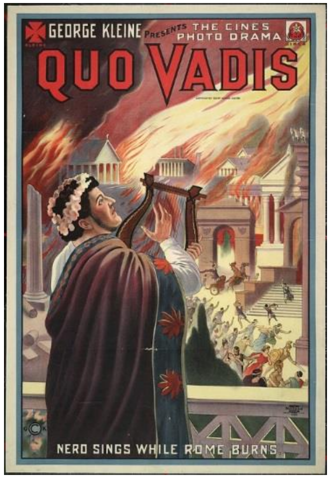
13.07.2015

The menu

- **Accelerators @ HZB**
  BESSY II, Metrology Light Source

- **Accelerator Physics @ HZB**
  bERLinPro, the Berlin Energy Recovery Linac Project

- **The midterm to long-term future**
  From BESSY II to BESSY VSR to BESSY III



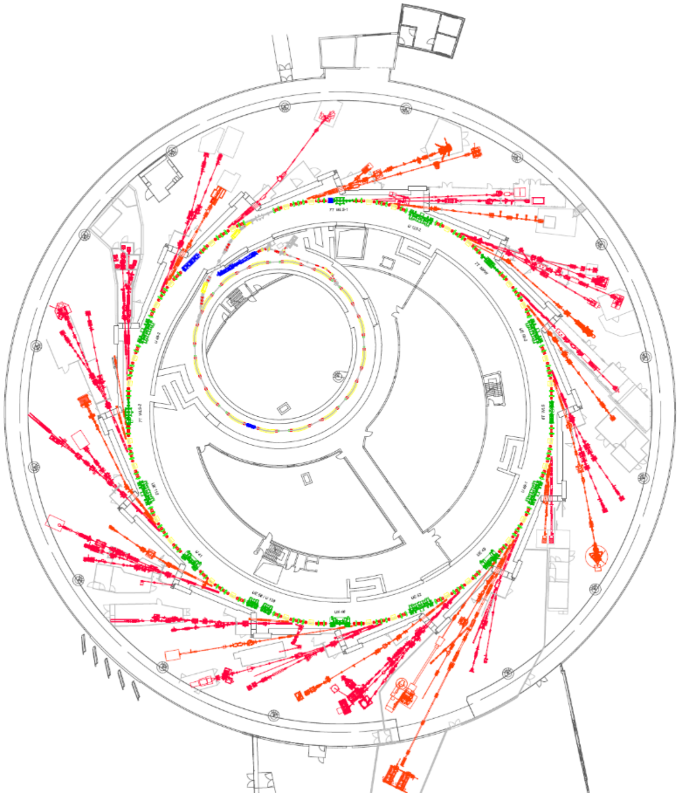
1913, Enrico Guazzoni, Italy
First blockbuster in history of cinema!

BESSY II – 3rd generation light source (UV / XUV / Soft-X-Ray)

Successor of BESSY I, construction 1992 – 1998, user operation since 1999

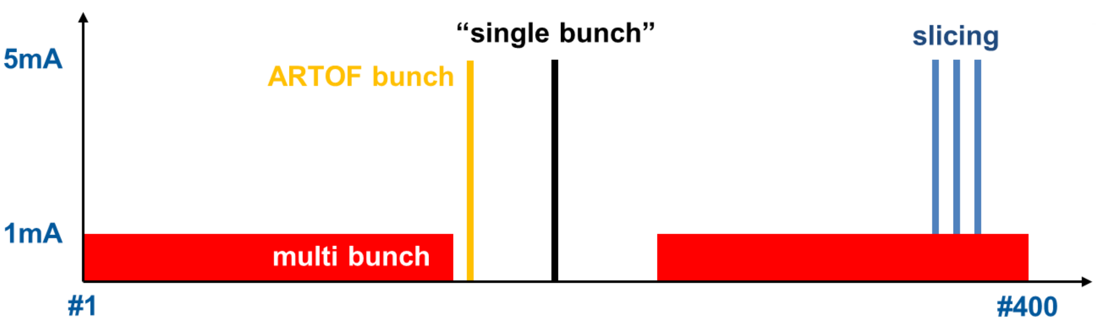
Energy/current	1.7GeV / 300mA
Emittance	4/6 nm rad
Pulse length	15 ps (rms)
Circumference	240 m
Straight sections	16
Undulators / MPW+WLS	12 / 1+2
Beamlines	36 (25 simultaneous)

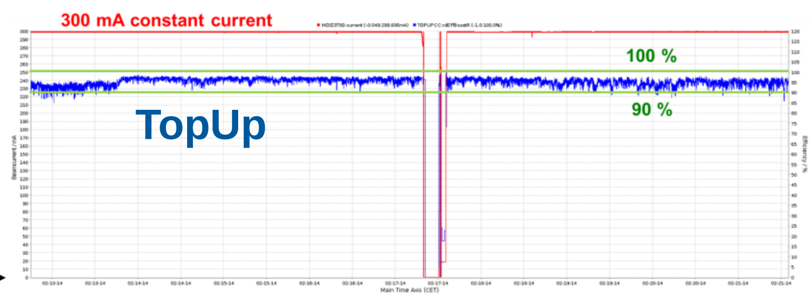
5000 h user operation, 3000 user visits / a



specialties

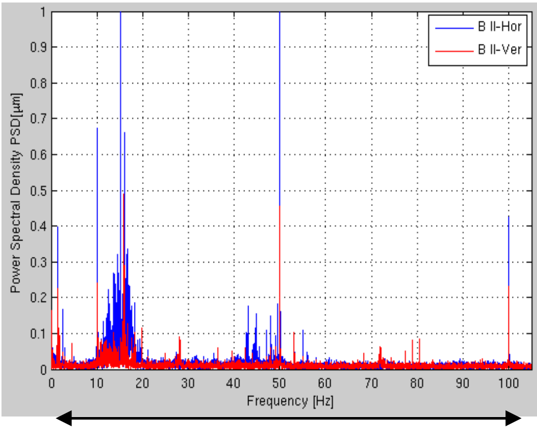
low-α operation	ps beams, CSR, THz
femto-slicing	50 fs, polarised x-rays

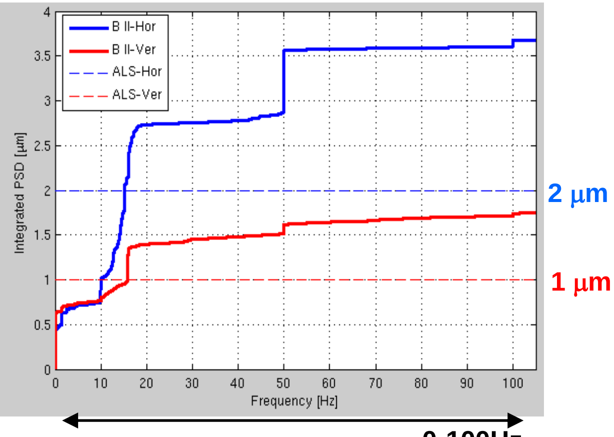




9 days

BESSY II – continuing up-grade + modernisation



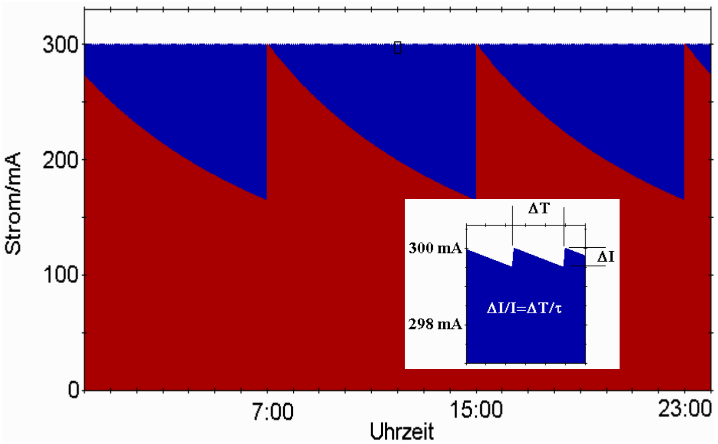


(Ernst Weihreter, Terry Atkinson, Dirk Schüler)

Fast Orbit Feedback (“not so slow”, significant improvement < 10 Hz) = 150 Hz correction 120 BPMs / 112 correctors

in operation since 24.09.2012 → **Phase II (2015+): new digital BPMs**

(Roland Müller, Andreas Schälicke, Rainer Görgen)



TopUp + new 50 MeV injector linac instead of injections all 8h and decaying beam 300 mA – 180 mA constant beam current 300 mA – 299.5 mA

(in operation since 29.10.2012)

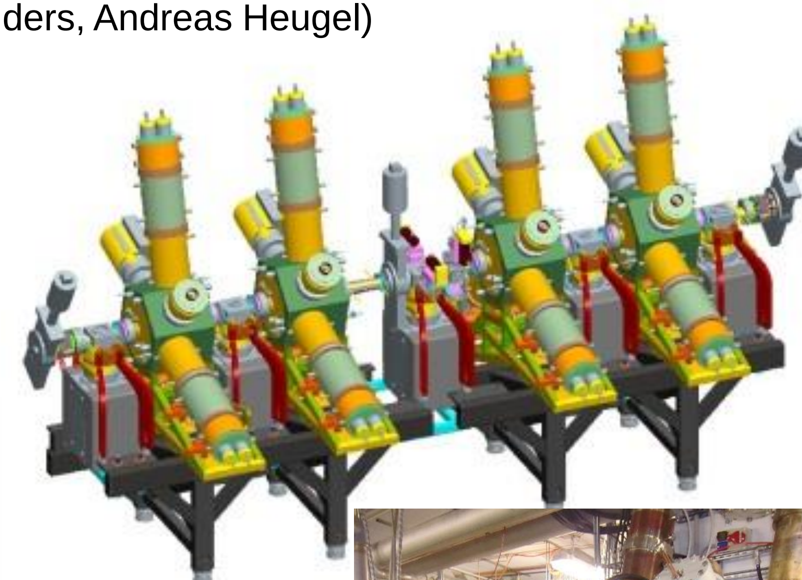
injection efficiency > 90% required by radiation protection (routinely > 95 % reached)

→ **Phase II: transparent Injection**

(Peter Kuske)

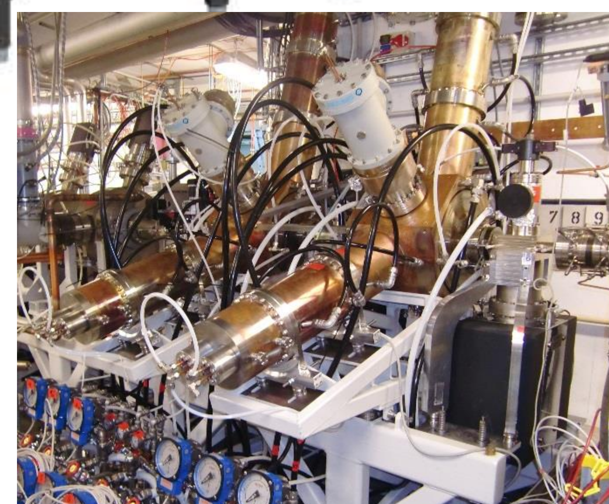
BESSY II – continuing up-grade + modernisation

New solid state 500MHz transmitter
(storage ring 4 x 75 kW + booster 25kW)
2012 – 2015
three transmitters installed, completion winter shutdown 2015
(Wolfgang Anders, Andreas Heugel)

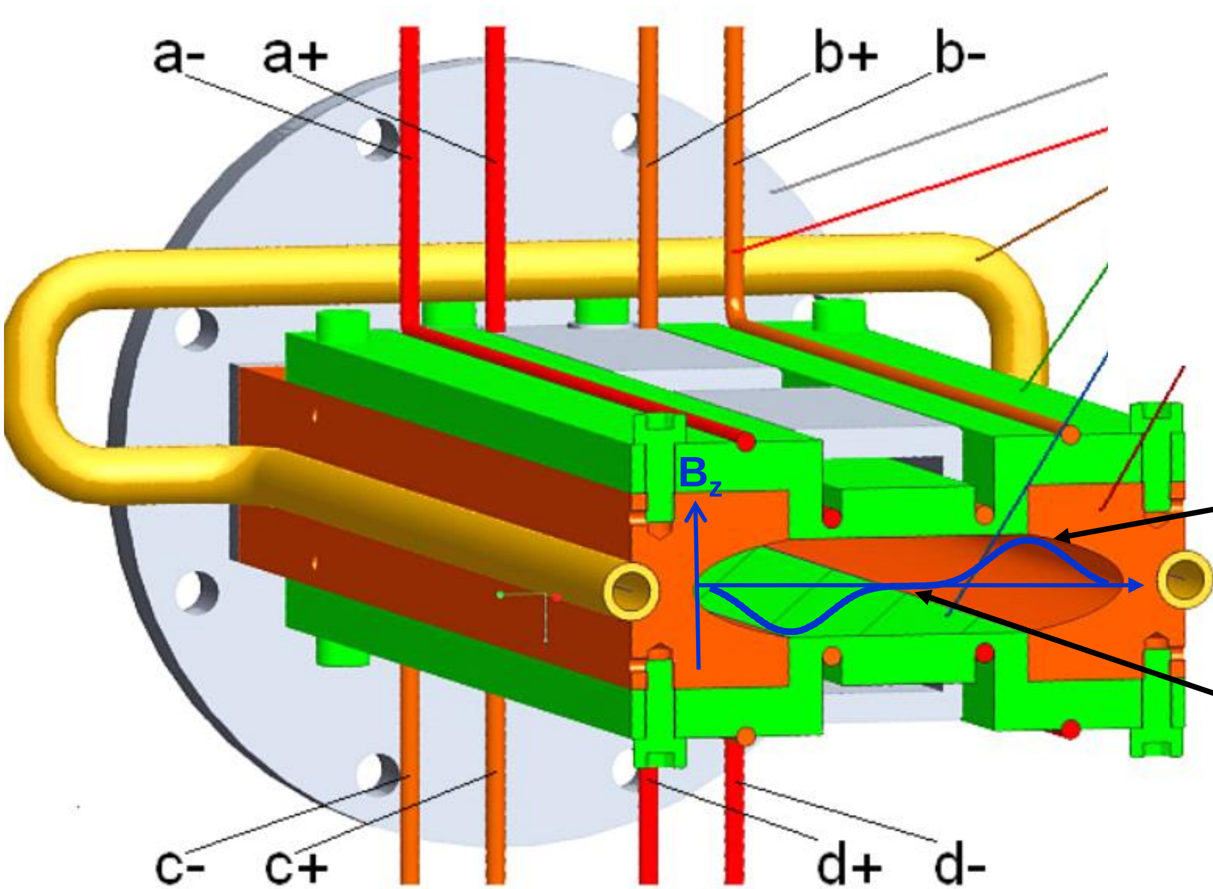


2010 – 2015
up-grade + modernisation
total 12 Mio€

New HOM damped storage ring cavities
(4 x 400 kV = 1.6 MV total voltage + spare)
2011 – 2015
first 2 cavities installed 2013,
final 2 cavities in winter shutdown 2015
(Ernst Weihreter, Wolfgang Anders,
Volker Dürr, Jörg Kolbe, Hans-Georg Hoberg)



“Non-linear kicker” = disturbance free injection by zero field on axis



field maximum
→ kicks the injected beam

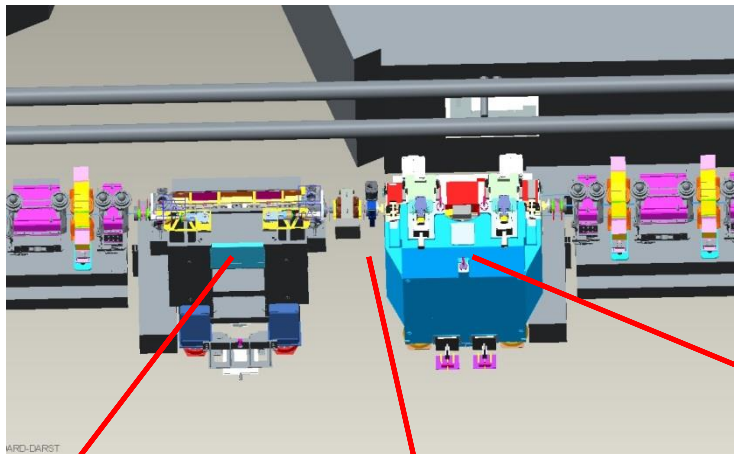
zero field on axis
→ no kick to stored beam

Peter Kuske, Olaf Dressler, Marc Dirsat,
Helge Rast (TU Do), Terry Atkinson

Results of prototype tests:
perturbation of the stored beam
~3 μm horizontal and < 1 μm vertical
with 80% injection efficiency

Two independent undulators for a broad energy range (60 – 8000 eV)

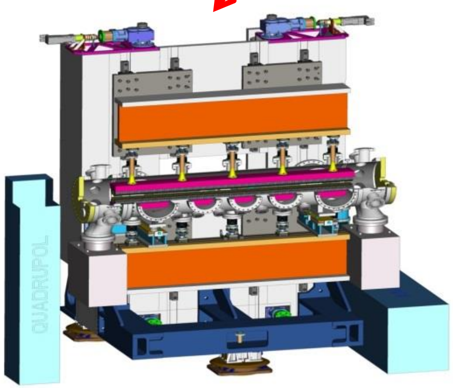
- UE48 APPLE II undulator
- CPMU17 cryo cooled PrFeB-based in-vacuum undulator (5 mm gap)
- optic modification for “shifted vertical low beta waist” at CPMU17



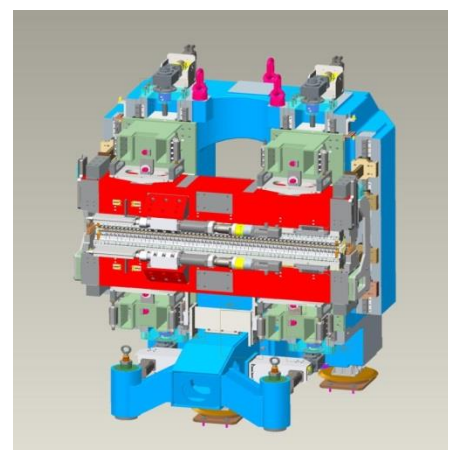
CPMU17 developed & built in collaboration with FMB Berlin

UE48 APPLE built in house; inclined mode 4 movable rows

Johannes Bahrdt



quad. & dipole, 2mrad canting

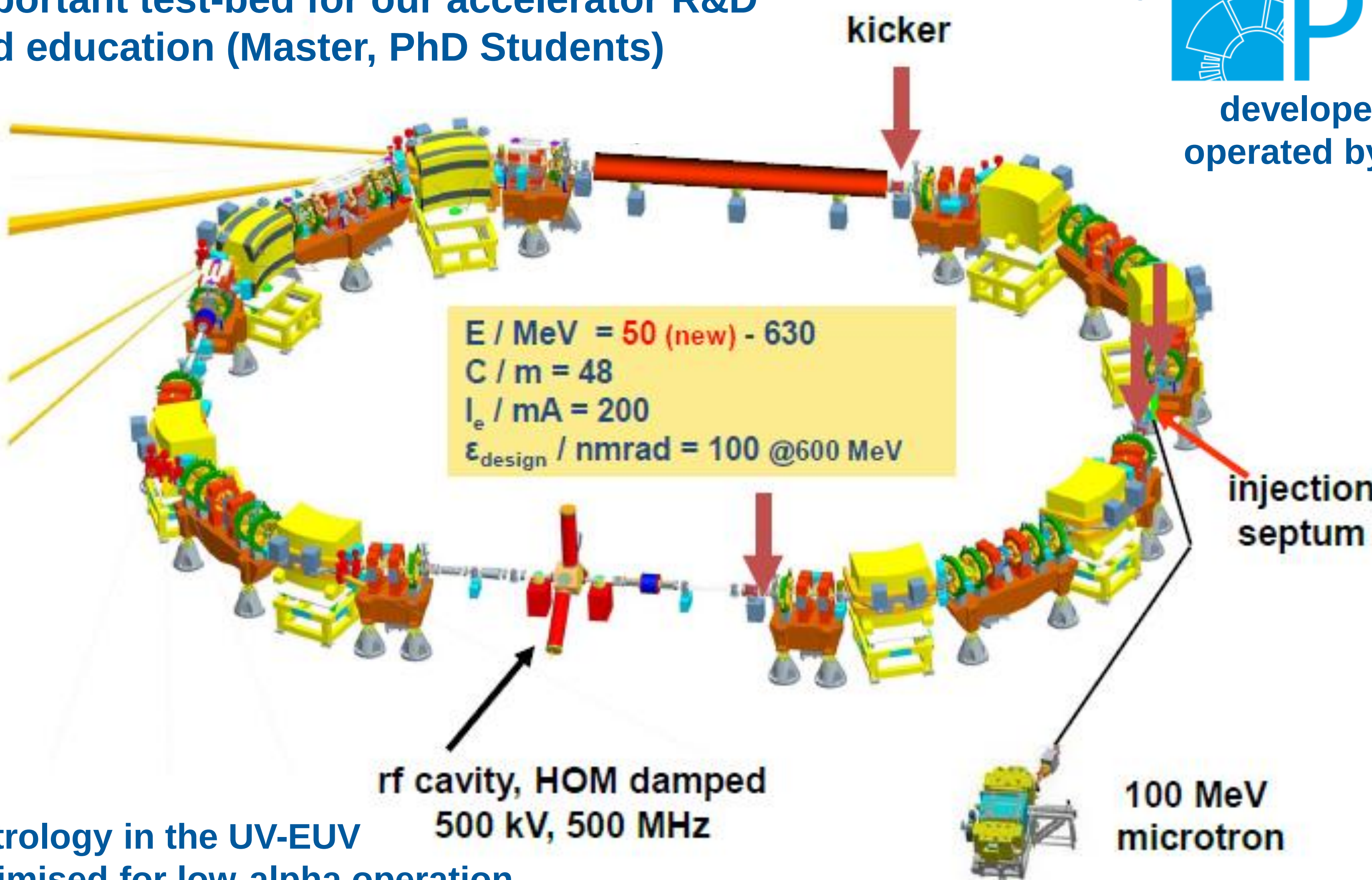


Metrology Light Source (MLS)

important test-bed for our accelerator R&D and education (Master, PhD Students)

owned by PTB

developed and operated by HZB



- metrology in the UV-EUV
- optimised for low-alpha operation (IR / THz generation)
- EUV reflectometry (ZEISS)

Accelerator Research and Development (ARD)

six Helmholtz centres + partners,
ca. 32 M€ / a, thereof 7 M€ / a @ HZB
(2015 – 2019, Program Oriented Funding)

DESY JÜLICH HI Jena HIM HZB HZDR KIT GSI

Four main research topics identified within ARD:

BESSY VSR

bERLinPro

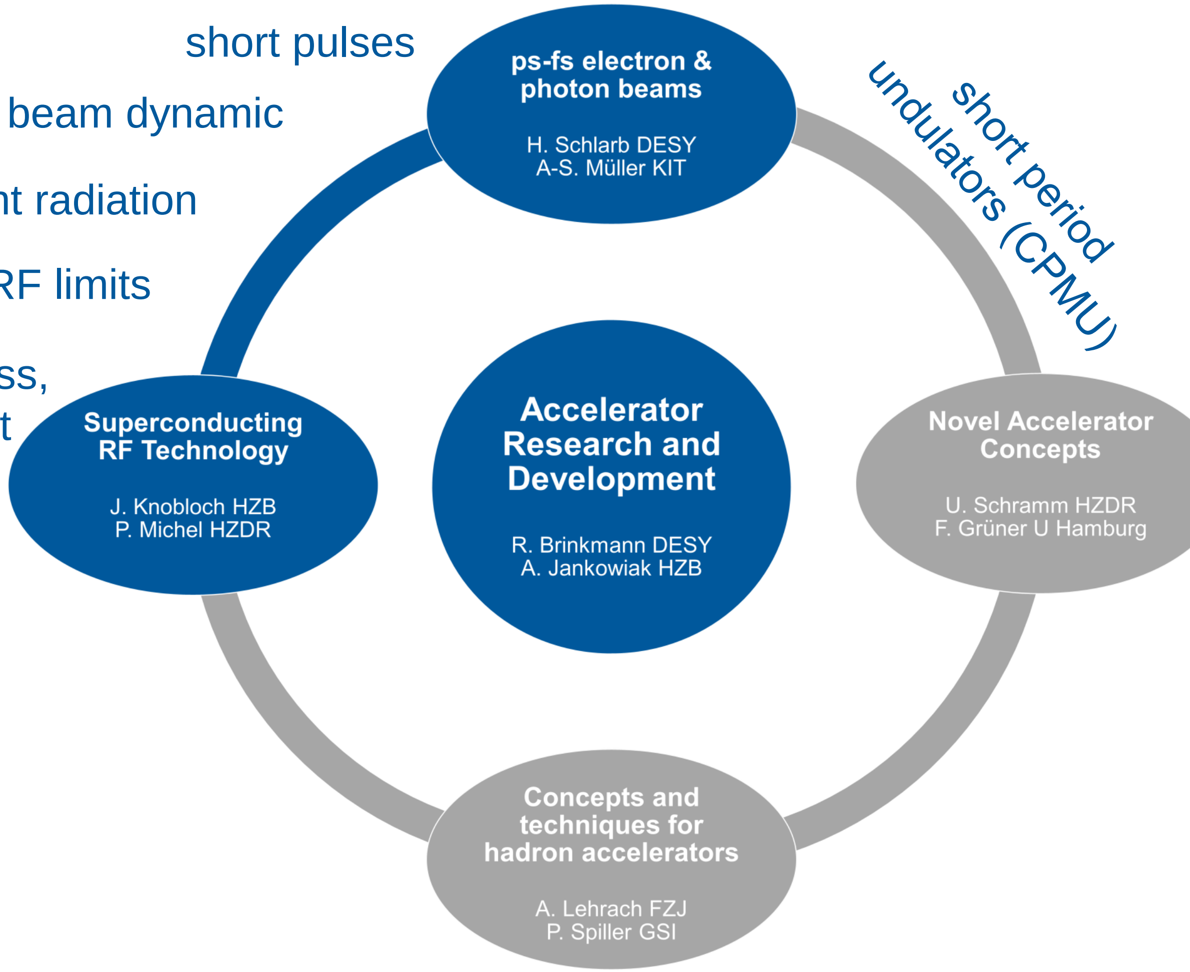
short pulses

beam dynamic

coherent radiation

pushing CW SRF limits

high brightness,
high current
injectors



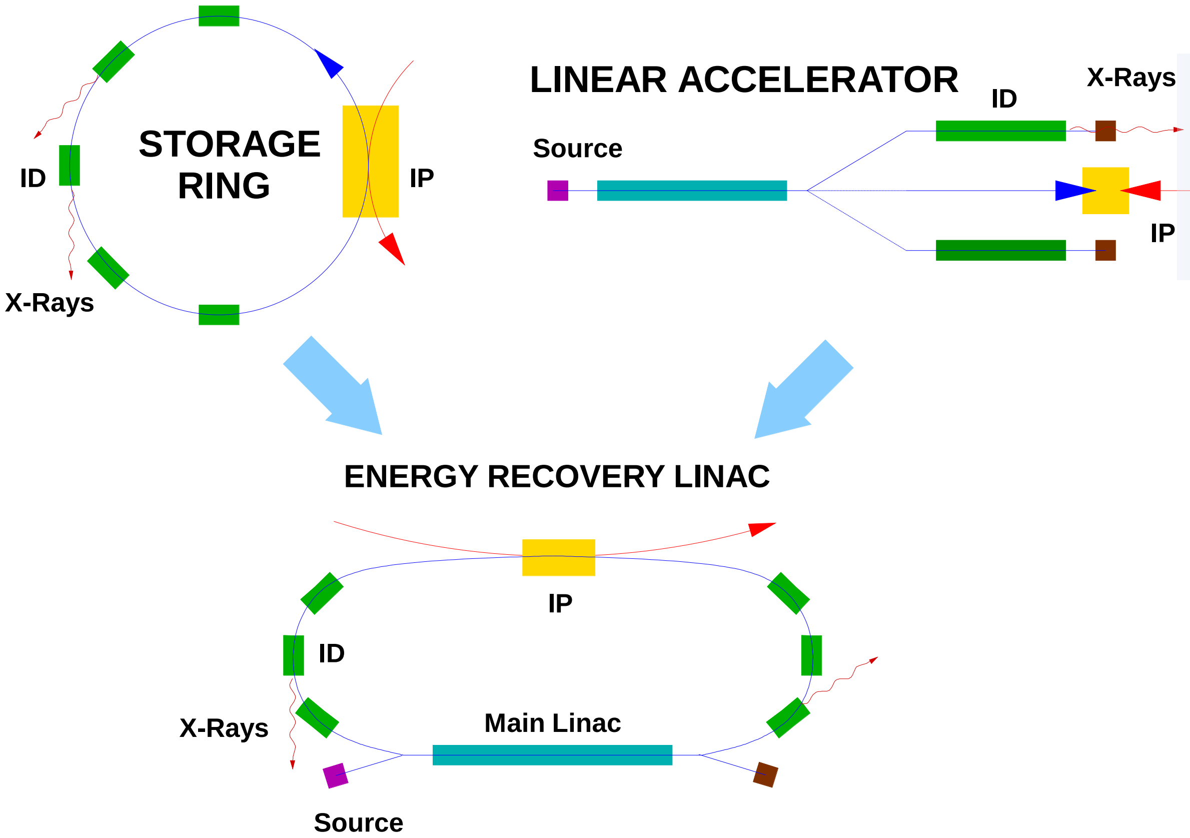
HZB contributions

Energy Recovery Linacs – The idea

- high average („virtual“) beam power (up to A, many GeV)
- many user stations
- beam parameter defined by equilibrium

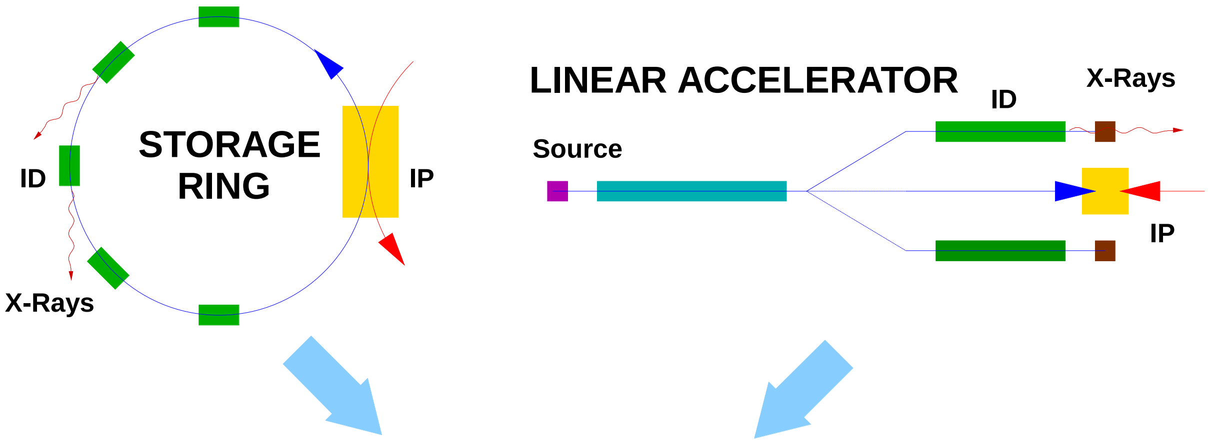
- outstanding beam parameter
- single pass experiments
- high flexibility
- low number of user stations
- limited average beam power (<<mA)

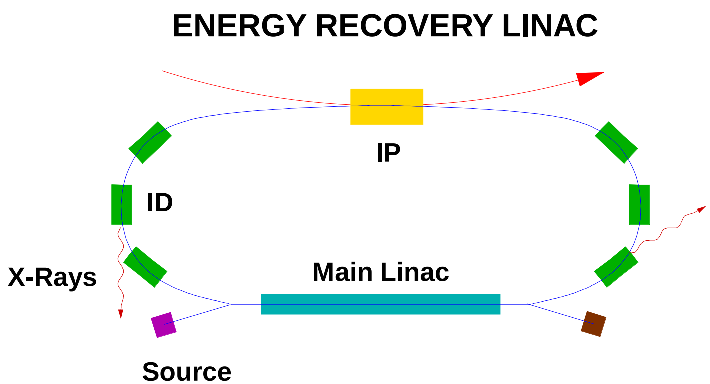
e.g. ESRF:
6 GeV, 200 mA
1.2 GW
virtual power,
stored energy
only 3380 J



e.g. XFEL:
17.5GeV, 33 μA
“only” ~ 600kW,
but real power

Energy Recovery Linacs – The idea





$$\varepsilon \sim \frac{1}{\gamma} \cdot \varepsilon_{source}$$

intrinsic short bunches, high current

high average beam power for single pass experiments,
excellent beam parameters, high flexibility, multi user facility

many challenges
e.g. high current / low emittance source, HOM damped SRF cavities, beam loss control
still to be solved ! (cERL/KEK, BNL, Cornell, and HZB)

Application of ERL Technology

Next generation multi-user light source
(diffraction limited, short pulses, ID tailored beam parameters)

High energy electron cooling of bunched proton/ion beams
(Energy ~ 100 MeV + high current → rules out VdG or SR)

Ultra high luminosity electron – ion collider (EIC, LHeC)
(beam-beam effect electron ring limits luminosity)

Compact radiation sources
(FEL, Compton sources,
next generation lithography)

and more …

Challenges to be solved

Electron source:

high current, low emittance (100 mA – A cw with ε_{norm} < μm rad) not yet demonstrated

(big step forward: Cornells 80 mA)

Injector/Booster:

100 mA @ 5 – 15 MeV = 500 – 1500 kW beam loading (coupler, HOM damper, beam dump)

Main-Linac:

100 mA recirculating beam $\rightarrow$ beam break up (BBU), higher order modes (HOM),
highest cw-gradients (>15 MV/m) with quality factor > 10^{10} $\rightarrow$ reduce cryo costs

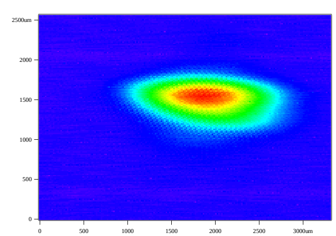
Beam dynamics / optics:

recirculation, flexible optics, bunch compression schemes = flexibility

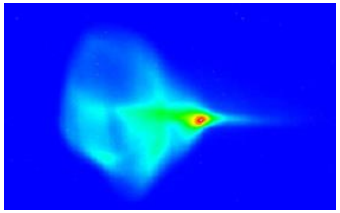
Control of beam loss

unwanted beam = dark current fromcathode, gun, cavities due to field emission, stray light laser
beam halo, collimation schemes !?

Storage ring:
nearly Gaussian
~ pA losses typical
~ 10 nA maximum



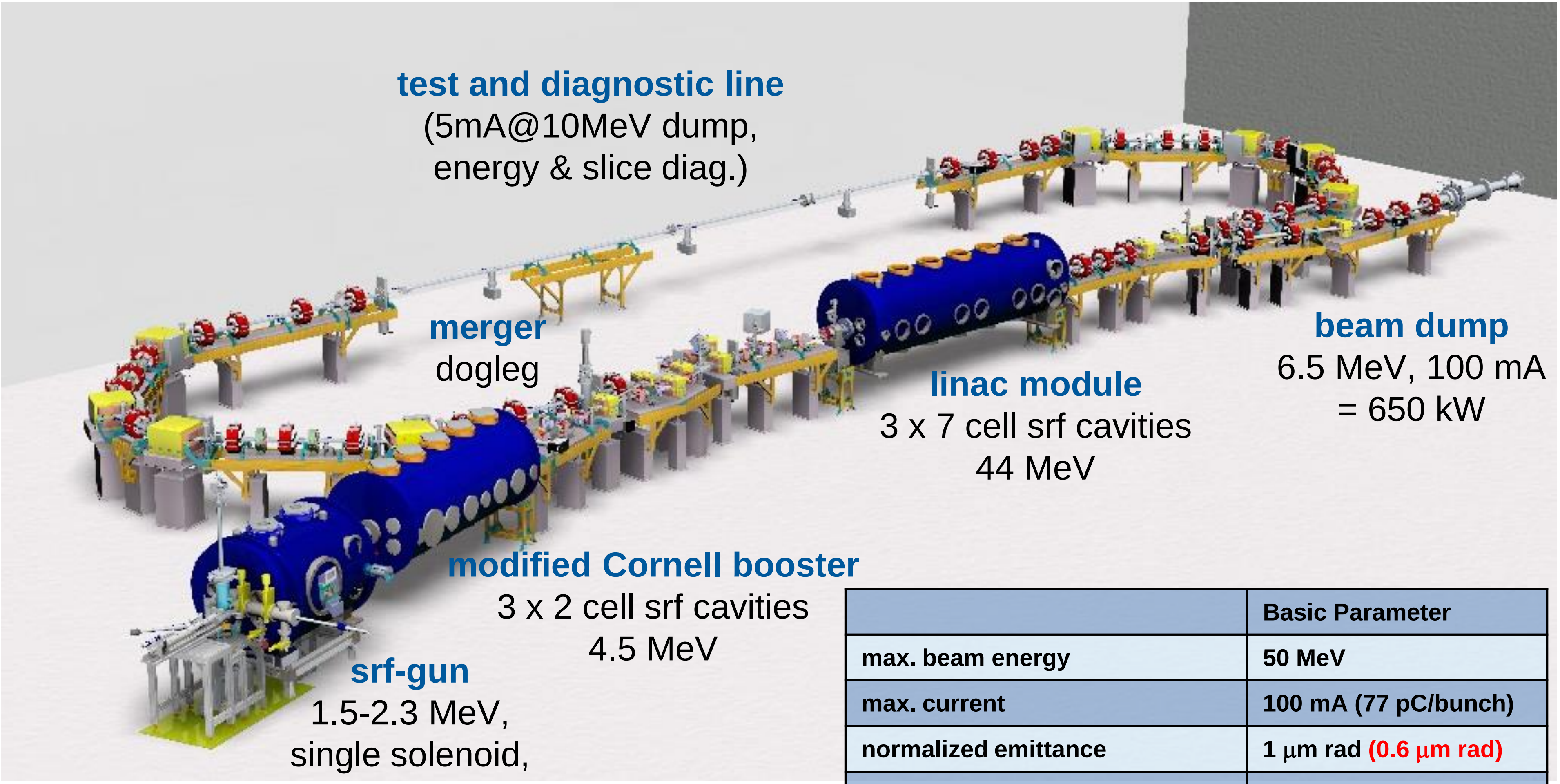
ERL:
no dead mathematician
some 100 μA losses possible



The "hummingbird"
P. Evtushenko, JLAB

bERLinPro = Berlin Energy Recovery Linac Project

100 mA / low emittance technology demonstrator (covering key aspects of large scale ERL)



	Basic Parameter
max. beam energy	50 MeV
max. current	100 mA (77 pC/bunch)
normalized emittance	1 μm rad (0.6 μm rad)
bunch length (straight)	2 ps or smaller (100 fs)
rep. rate	1.3 GHz
losses	< 10^{-5}

Project started @ HZB in 2011
total investment (including building) ~ 41 Mio€

bERLinPro – Project goals

Produce and accelerate an electron beam with

emittance: **1 π mm mrad (normalized) or better** **(0.6 mm mrad in reach)**
current: **100mA cw**
(1.3GHz, 77pC bunch charge)

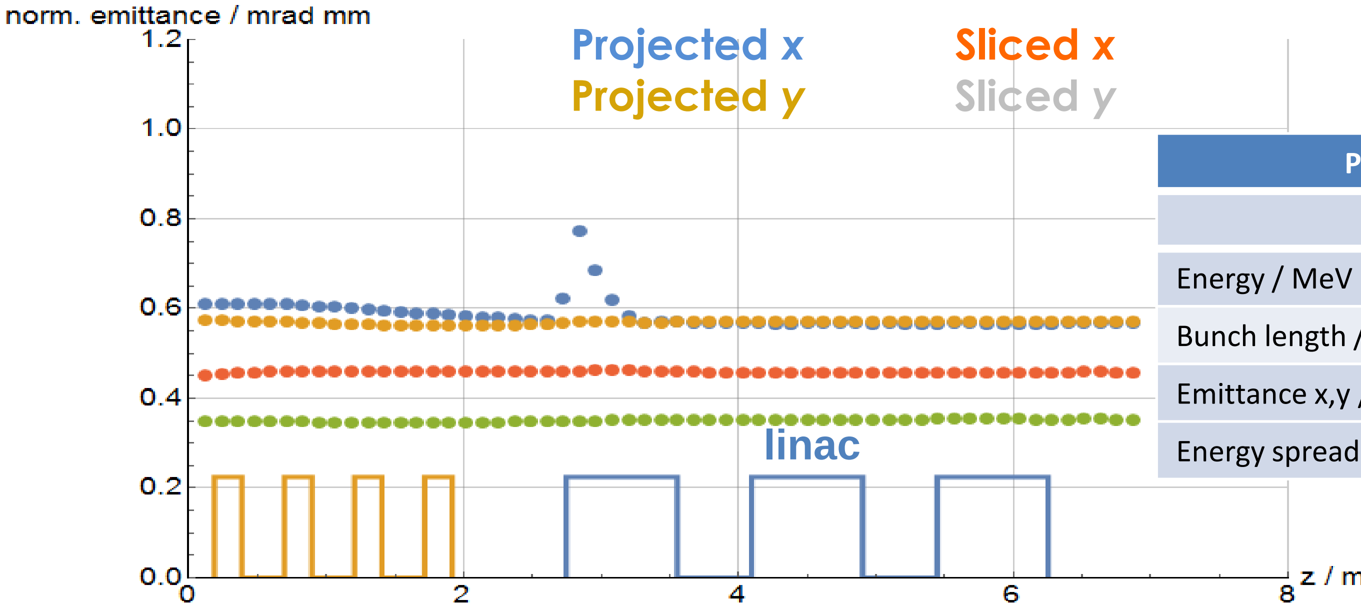
pulse length: **2 ps** **(down to 100 fs @ 10pC in special short pulse mode)**

at reasonable energy (50MeV) in „user quality" (low losses in recirculation) with stable and reliable operation

→ Facility for ERL beam tests and developments

- develop the required srf technology (gun / booster / linac)
- explore the parameter space of emittance, charge and pulse length
- understand to avoid / control "unwanted" beam(loss)
- educate accelerator physicists, engineers and technicians
- acquire expertise to be prepared for future large scale projects
- foster international collaboration on ERL technology

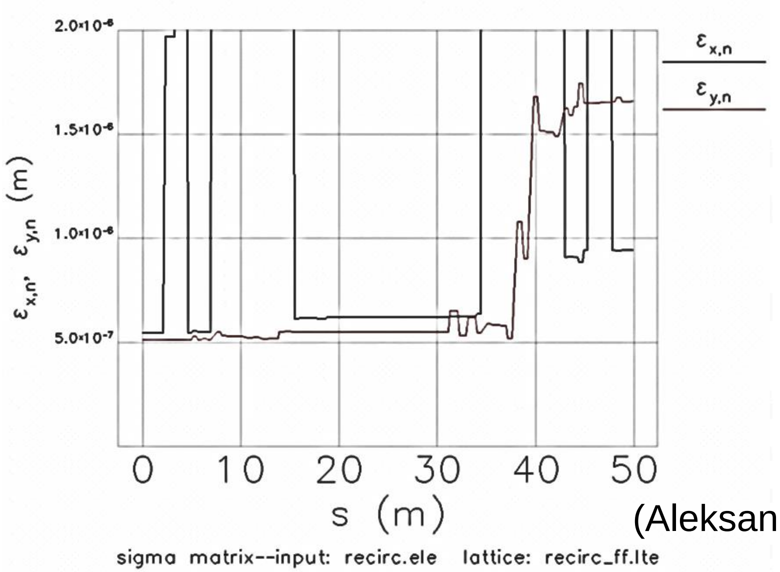
bERLinPro – performance parameter (simulations)



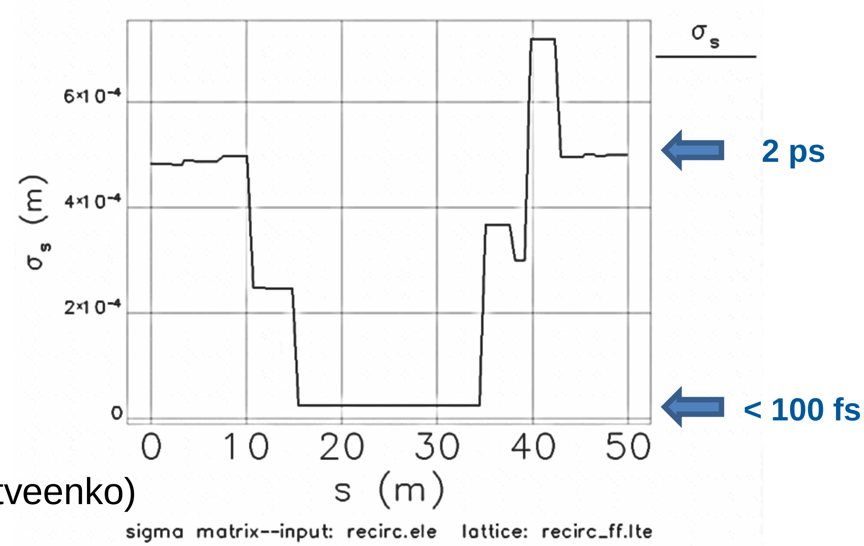
(Bettina Kuske)

Parameters at LINAC exit	2015	2014
Energy / MeV	50.1	49.98
Bunch length / ps	4.65	4.67
Emittance x,y / µm	0.57/0.57	0.77, 0.54
Energy spread / keV	254	254

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

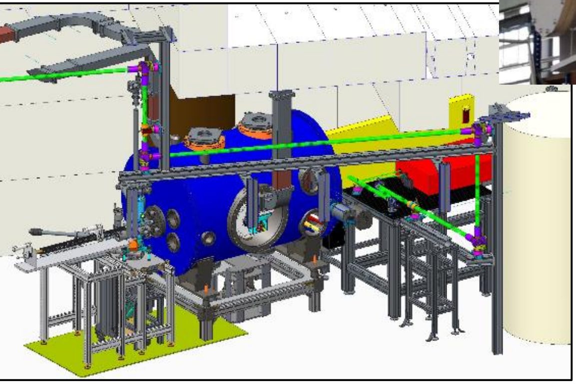


(Aleksandr Matveenko)

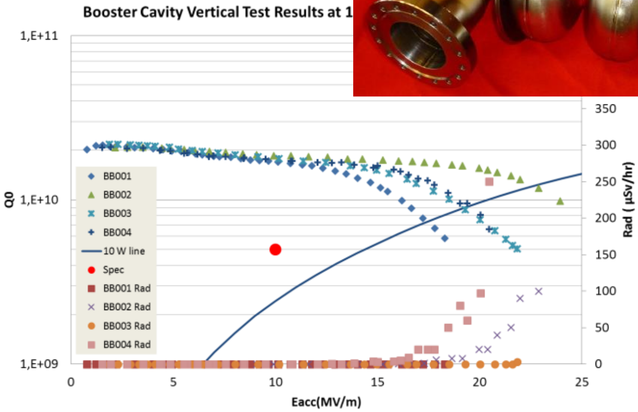


bERLinPro – some hardware impressions

Gun1, 1.4 cell, choke filter
(first cavity JLAB, second RI for risk mitigation)
CsK_2Sb cathode

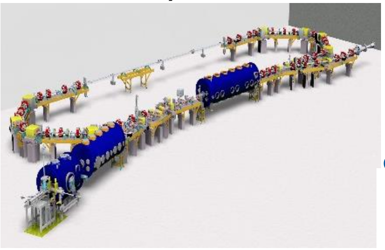


4 x 2 cell booster cavities
Cornell design,
built @ JLAB
(Andrew Burrill)



cathode preparation and analysis system @ HZB (Julius Kühn)

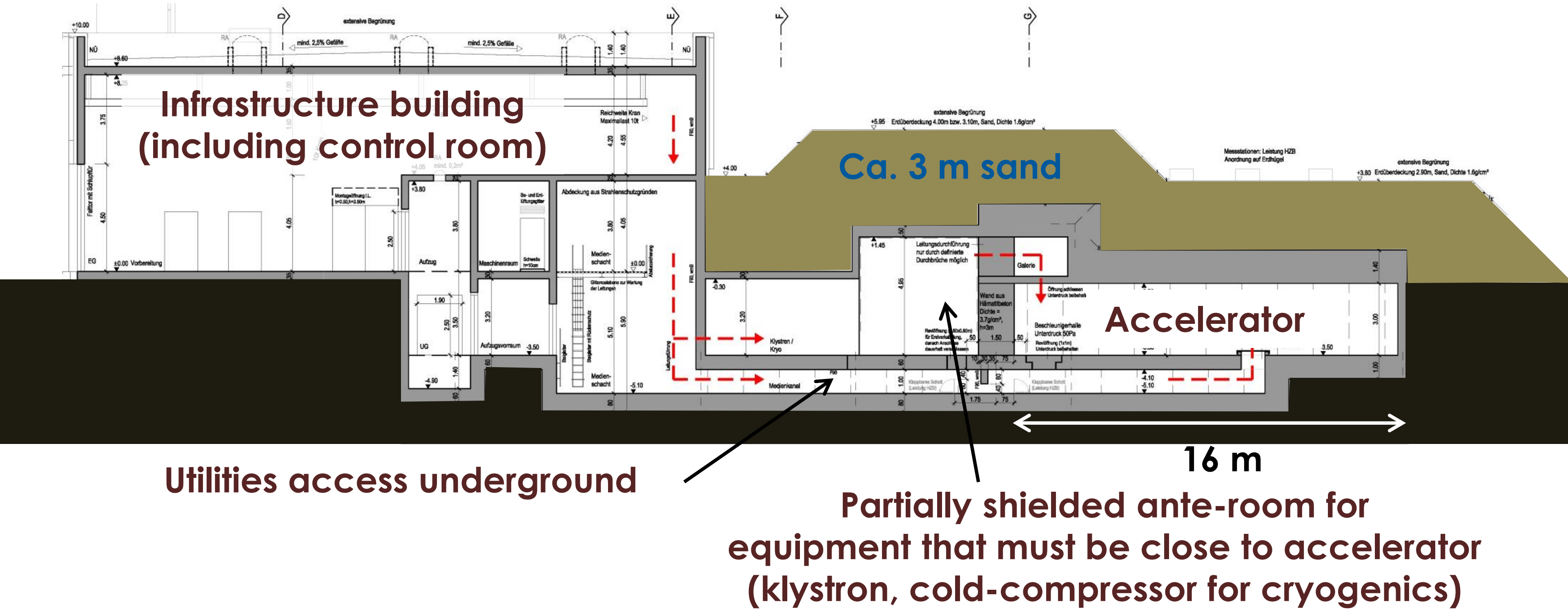
first 270 kW, 1.3 GHz high power transmitter



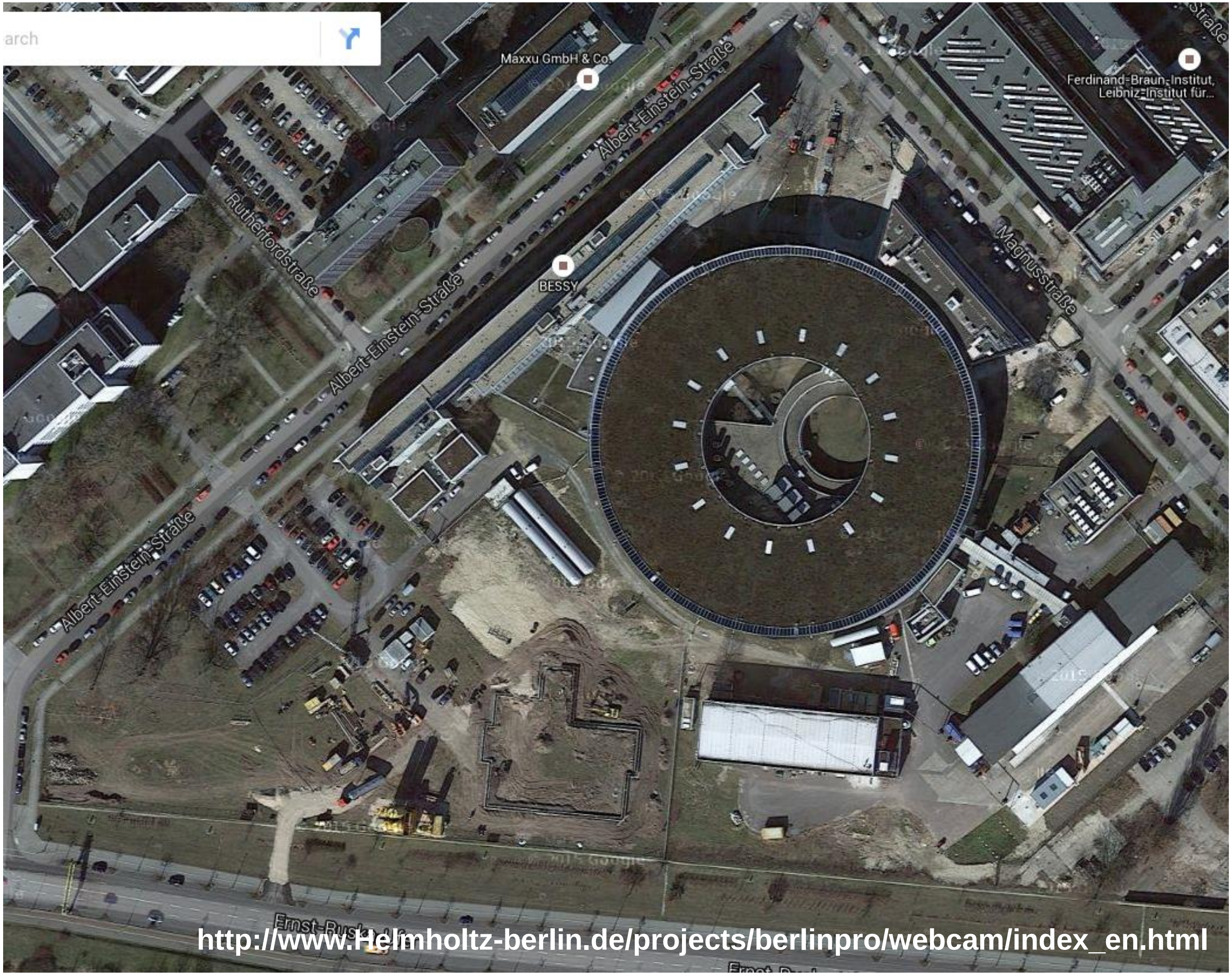
Budker Institute of Nuclear Physics

all magnets and girders designed and ordered @ BINP
design vacuum systems / diagnostics finished (> 90%)

bERLinPro – building construction started 02/2015



bERLinPro – building construction started 02/2015



http://www.Helmholtz-berlin.de/projects/berlinpro/webcam/index_en.html

bERLinPro – milestones

01/2011 project start

04/2011 first electrons from SRF gun (Gun Version 0, lead film on back wall)

till 2014 preparatory phase (detailed design of components and building)

02/2015 start building construction

06/2016 first electrons from SRF gun with nc CsK_2Sb cathode
SRF Gun Mark-I (2 x adjustable TTF3 10 kW coupler) GunLab/HoBiCaT

12/2016 building ready for machine installation,
start installation 1.8 K cryo system

11/2017 start SRF operation gun and booster in bERLinPro building

05/2018 first electrons through gun and booster (with Mark-I gun, < 10 mA)

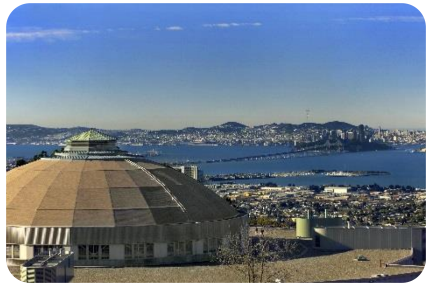
05/2019 linac & recirculation system ready installed

09/2019 first recirculation and energy recovery

03/2020 start operation with SRF Gun Mark-II (2 x 115 kW coupler), 100 mA

3rd Generation Storage Ring Light sources – the 90ies ++


ESRF / France, 1993

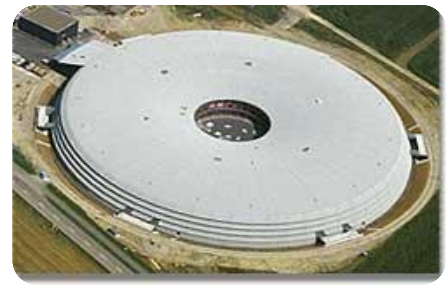

ALS / USA, 1993


ELETTRA / Italy, 1994


APS / USA, 1996

SPring-8 / Japan, 1997

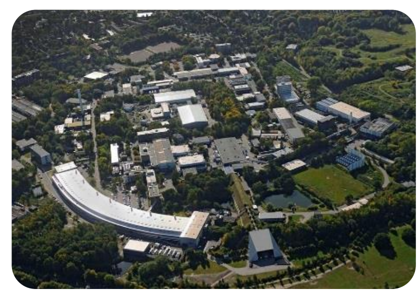

BESSY II / D, 1998


SLS / Switzerland, 2001


GCHQ / UK, 2003


SOLEIL / France, 2006


DIAMOND / UK, 2007

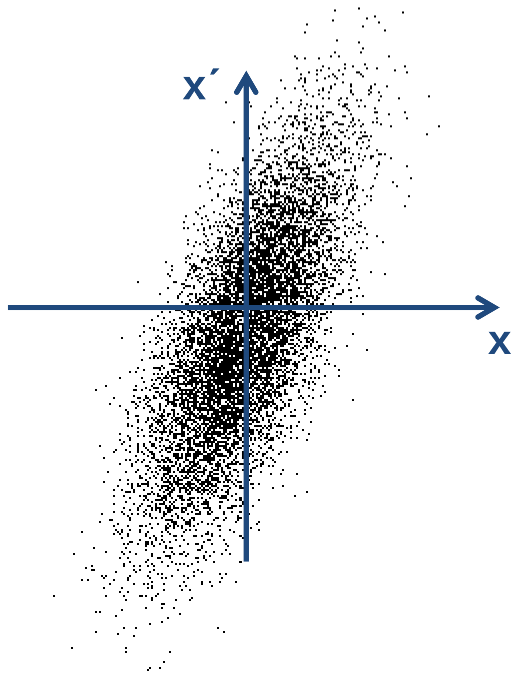

PETRA III / D, 2010

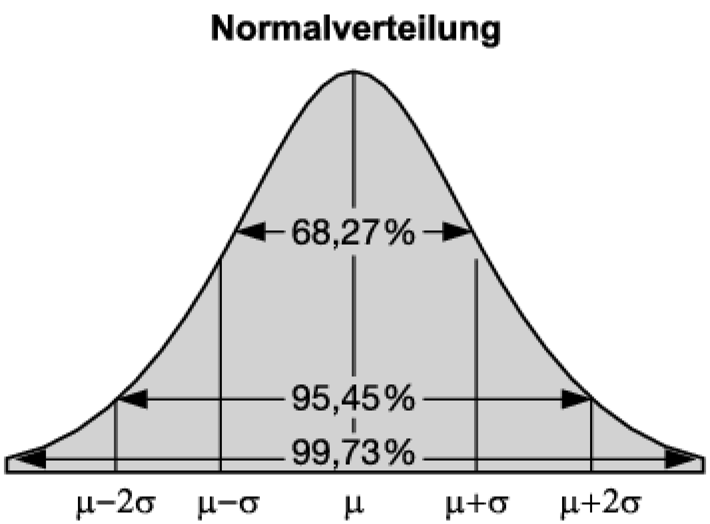

ALBA / Spain, 2010

Energy:	**1.7 GeV – 8 GeV**
Beam Current:	**100 mA – 500 mA**
Natural Emittance:	**1 nm rad – 20 nm rad (coupling down to << 0.1% = 5 pm rad vertical)**
Pulse Length:	**~ 30 ps (~ ps in low-α and 100 fs slicing @ strongly reduced current)**

Quo vadis storage rings?

transversal typical: ~ nm rad **longitudinal typical: ~6mm = 20ps**





equilibrium between (synchrotron) radiation damping and heating (defined by magnet lattice e.g. DBA, TBA, and "damping wigglers")

$$\varepsilon_x = C_\gamma \cdot \frac{\gamma^2}{J_x} \cdot \frac{\left\langle \frac{1}{R^3} H(s) \right\rangle}{\left\langle \frac{1}{R^2} \right\rangle} \sim \frac{\gamma^2}{N^3}$$

$$\sigma_s \sim \sqrt{\frac{\alpha}{V'}} \cdot \sigma_E$$

$$I_{beam} \sim \alpha$$

$$\varepsilon_y \sim 1/100 \cdot \varepsilon_x \text{ (coupling)}$$

One driving factor – increase in brilliance and coherence

Brilliance

defined by insertion device, beam energy

$$B_{average}(\lambda) = \frac{N_{photon}(\lambda)}{4\pi^2 \cdot \left(\varepsilon_x \oplus \varepsilon_{photon}(\lambda)\right) \cdot \left(\varepsilon_y \oplus \varepsilon_{photon}(\lambda)\right)\left(s \cdot 0.1\%BW \cdot A\right)}$$

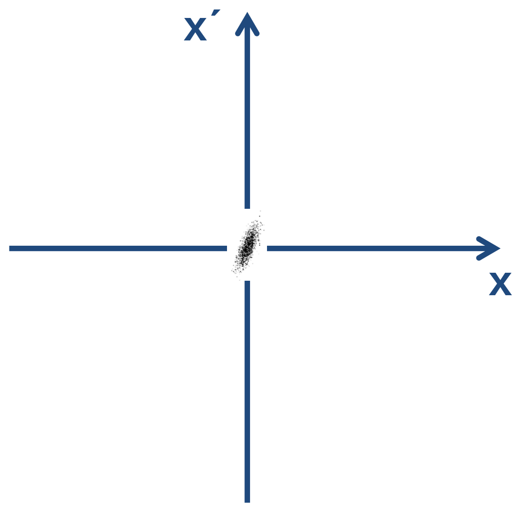
defined by lattice="beam optics", beam energy

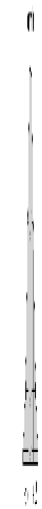
$$\varepsilon_{photon}(\lambda) = \frac{\lambda}{4\pi} \text{ (Gaussian)}, \ \frac{\lambda}{2\pi} \text{ (undulator)} \quad : \text{photon beam emittance}$$

Electron beam emittance for diffraction limited radiation:

$$\varepsilon_{x,y}(\lambda) = \frac{\lambda}{4\pi} \qquad f_{coh}(\lambda) = \frac{\varepsilon_{photon}(\lambda)}{\varepsilon_x \oplus \varepsilon_{photon}(\lambda)} \cdot \frac{\varepsilon_{photon}(\lambda)}{\varepsilon_y \oplus \varepsilon_{photon}(\lambda)} \quad \sim 44\%$$

λ = 10 nm (124 eV) → ε = 800 pm rad
λ = 1 nm (1.240 keV) → ε = 80 pm rad
λ = 1 A (12.4 keV) → ε = 8 pm rad





transversal: 10 – 300 pm rad

longitudinal: < 1mm ~ 400 fs – ps

New beam optics
“multi bend achromat lattice”
DLSR = Diffraction Limited Storage Ring

low-α operation
BESSY VSR

Many existing SR facilities in the second decade of their operational life are aiming for an emittance/brilliance/coherence upgrade
(ESRF, Spring-8**,** APS, ALS, SLS, …**)** **following DLSR concepts**

Need to go for multi-bend achromat lattices
new magnet systems, new vacuum system due to smaller apertures, sometimes new injector, lifetime issues = radiation issues, …
→ significant dark time for users (e.g. ESRF = 19 months)

At HZB we are following an different upgrade path for BESSY II
Conserving photon brilliance for all user and
add short pulse operation (@ all beam lines) in parallel
→ **BESSY-VSR**

BESSY-VSR – short pulse operation

$$\sigma \propto \sqrt{\frac{\alpha}{\dot{V}_{rf}}} \qquad I \propto \alpha$$

$$I \propto \dot{V} \quad (\sigma = \text{const.})$$

Today: short pulses, low flux

1.5 MV @ 500 MHz rf-systems = 2π 0.75 MV GHz

→ reduce α by 100 = low-alpha operation with 1/10 bunch length

→ limited average current (~ 1/100)

→ only 10 days of user operation

Future: short pulses, high flux

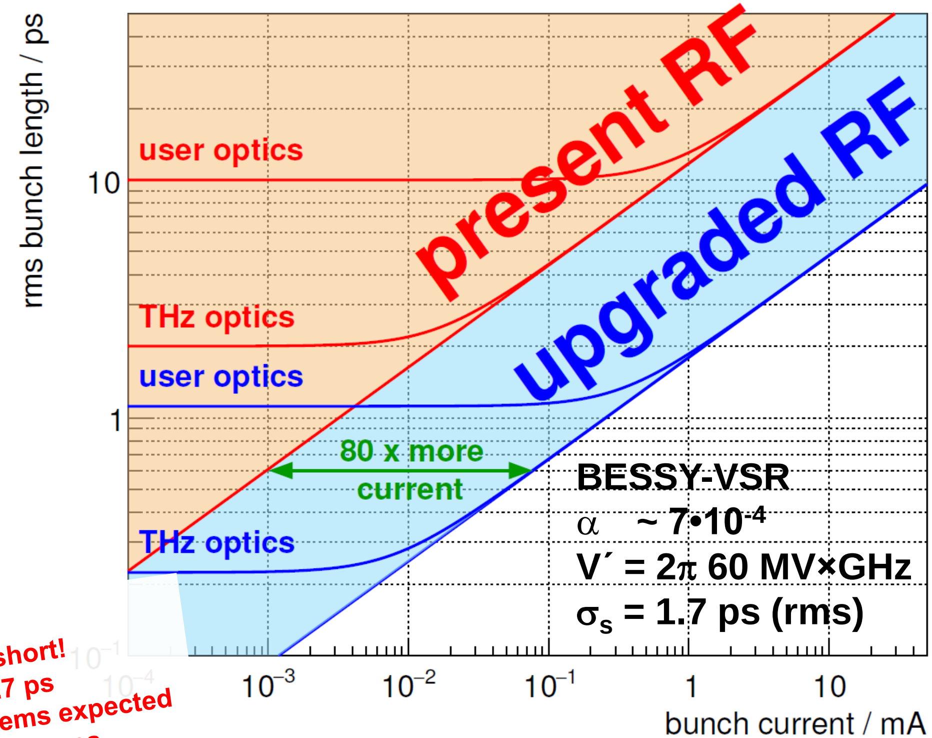
supply additional high voltage at high frequency: 40 MV @ 1.5 GHz

→ short 1.7 ps pulses with same current as in standard user op.

→ forced low-alpha mode permits even ~ 400 fs

But:
all bunches will be short!
350 x 0.86mA @ 1.7 ps
→ severe impedance problems expected
→ liftetime / radiation issues

searching for more flexible solution



G. Wüstefeld et al., HZB, EPAC06 & IPAC11

BESSY-VSR – first ideas

Proceedings of EPAC 2006, Edinburgh, Scotland MOPCH053

TOWARDS SUB-PICOSECOND ELECTRON BUNCHES: UPGRADING IDEAS FOR BESSY II *

J. Feikes, P. Kuske, G. Wüstefeld[1], BESSY, Berlin, Germany

Abstract

Sub-picosecond electron bunches are achieved wit BESSY low alpha optics and their lengths are mea [1]. The current in these short bunches is limited to th cro Ampere level, to avoid current dependent bunch le ening. An upgrade of the BESSY II rf system is gested to overcome this low current limitation by 2 o of magnitude. Intense, picosecond bunches could th achieved already at the regular user optics. The r ing short and very intense electron bunches are use generate short X-ray pulses and powerful THz radi Expected parameters of bunch length and current ar cussed.

INTRODUCTION

There is an increasing interest in short electron bu in storage rings as sources of synchrotron radiatio

Proceedings of IPAC2011, San Sebastian, Spain

Simultaneous Long and Short Electron Bunches in the BESSY II Storage Ring

G. Wüstefeld, A. Jankowiak, J. Knobloch, M. Ries, HZB, Berlin, Germany

Abstract

We present first ideas of a scheme to develop BESSY II into a variable electron pulse length storage ring. The final goal is, to fill BESSY II with short bunches of 1.5 ps length (rms) and long bunches of 15 ps length simultaneously in the presently applied user optics. All insertion devices are operated as usual, i.e. the helical undulators and 7 T-field insertions. Long bunches of 1.5 mA current per bunch, twice the value of the present user optics, are filled in each second bucket. The other buckets can be filled with short bunches of max. 0.8 mA. The lower current value is required to avoid increase in the bunch length and bunch energy spread, predicted by scaling laws. The total current is e.g. limited by the HOM damping cabailities of the sc-cavities and the machine impedances.

This scheme is achievable with recent developments in sc-rf cavity technology driven by requirements of high current cw applications like for the energy recovering linacs (ERLs). These developments seem to make it feasible to install high gradient HOM damped multi-cell cavities in electron storage rings. With an appropriate choice of the frequencies we get a beating pattern of the effective voltage at the different stable fixed points locations, leading to alternating short and long bunches.

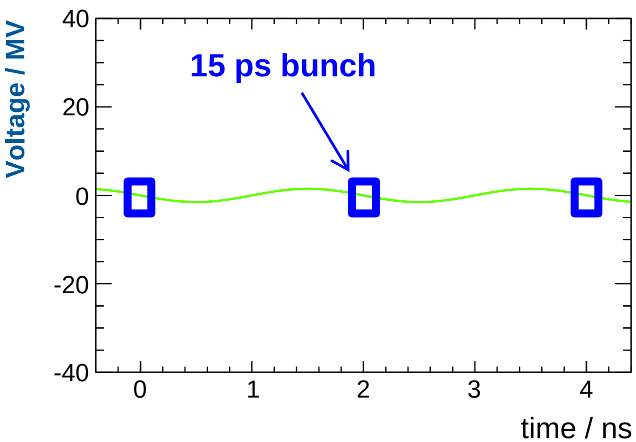
From the well established theory of zero current bunch length we expect 10 times shorter bunches by this rf-focusing. The maximum achievable current is kept just below the bursting instability limit, derived by scaling laws. For a fixed bunch length, the predicted threshold current for bursting is increased by a factor 100 compared to the present situation. The transverse beam optics does not change, the BESSY user optics or the BESSY low-α optics can be applied. For the coherent THz radiation a power increase of up to 10^4 is expected. In this note we estimate rf-cavity parameters, bunch length and the current limit.

ALTERNATING BUNCH LENGTH SCHEME

In case of low currents ("zero current limit") the bunch length σ_0 can be reliably calculated. This length is a function of α and the rf-voltage gradient taken with respect to the longitudinal position $\partial V/\partial z = V' = 2\pi V f_{rf}/c$ given

The beauty of beating sine waves

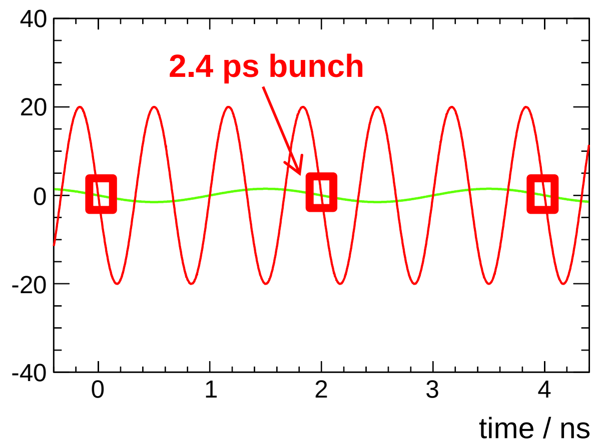
Present



Installed voltage: 1.5 MV @ 0.5 GHz

$$\dot{V} \propto V \times \varpi_{rf} = 2\pi\, 0.75\, \mathrm{MV} \times \mathrm{GHz}$$

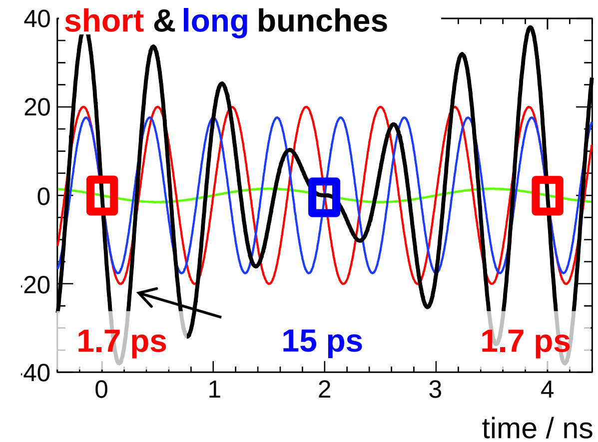
+ 3rd harmonic



Installed voltage: 20 MV @ 1.5 GHz

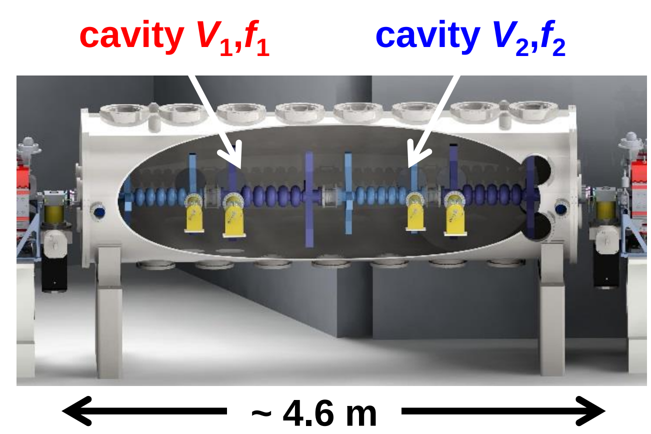
$$\dot{V} \propto V \times \varpi_{rf} = 2\pi\, 30\, \mathrm{MV} \times \mathrm{GHz}$$

+ 3.5 harmonic

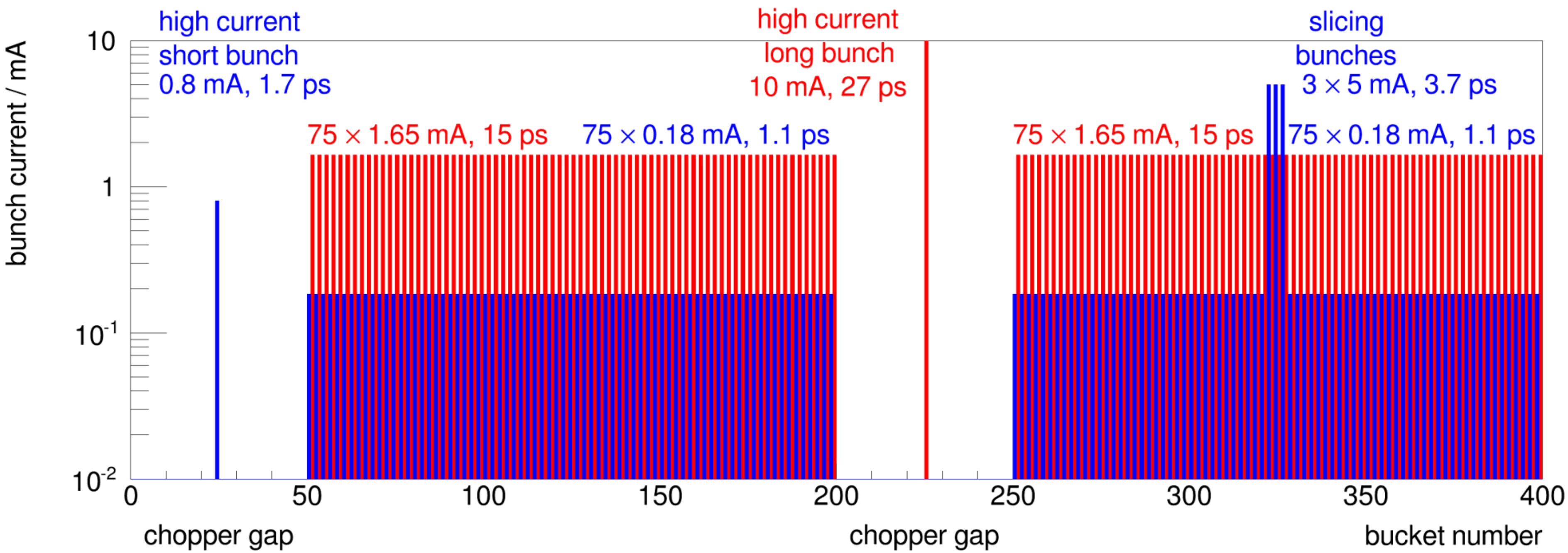


Installed voltage: 20 MV @ 1.5 GHz
17.1 MV @ 1.75 GHz

$$\dot{V} \propto V \times \varpi_{rf} = 2\pi\, 60\, \mathrm{MV} \times \mathrm{GHz}$$



BESSY-VSR – project parameters



- 300 mA average current
- camshaft single bunches (short and long) in gaps
- 100 ns gaps → for single bunch separation by chopper

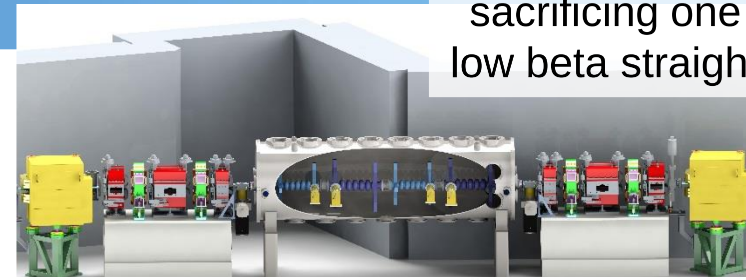
in low alpha mode
400 fs @ 0.04 mA / bunch

multi functional hybrid mode

ps short single bunch, high current single bunch, slicing bunches, high average brilliance, background of intense CSR/THz radiation

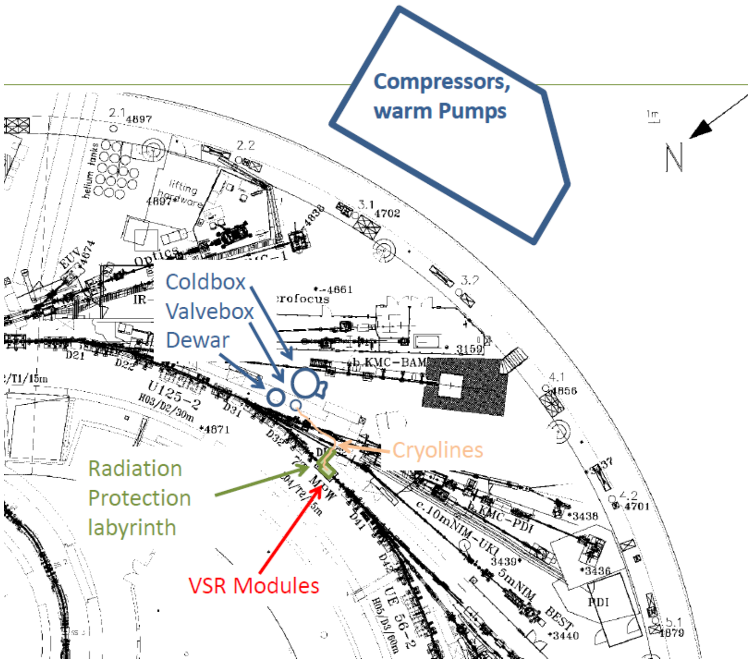
preserving BESSY II emittance and TopUp
→ 5 nm rad, lifetime > 5h, average inj. eff. > 90%

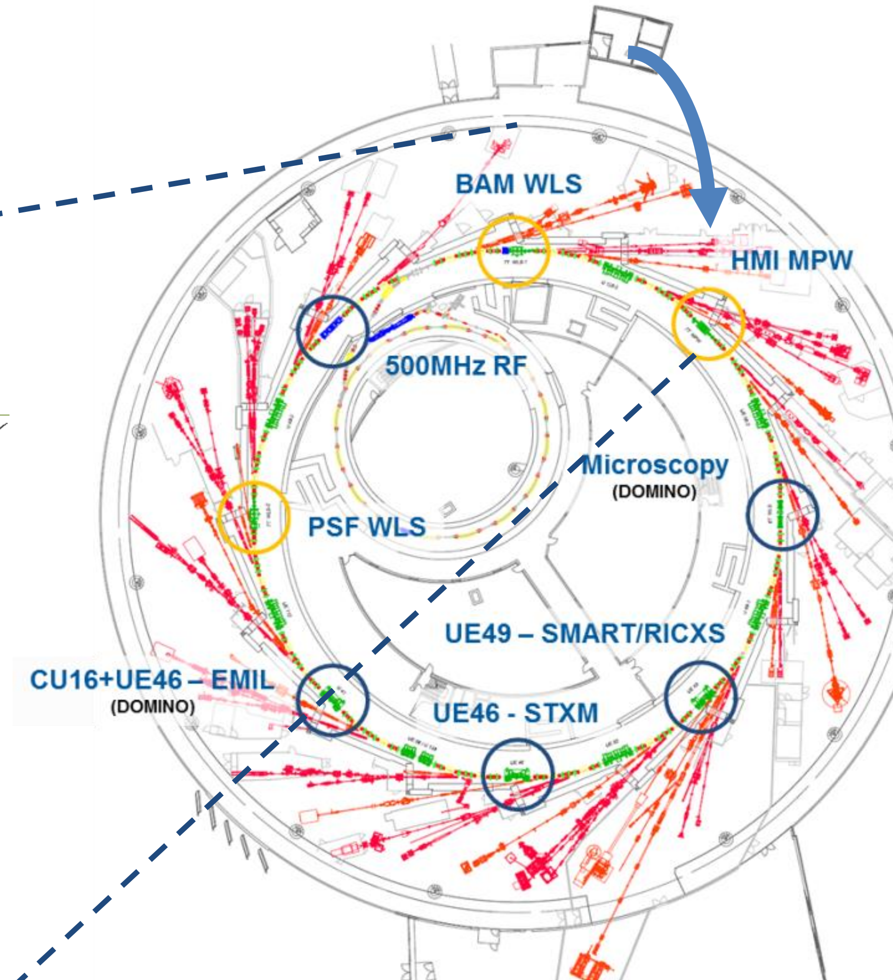
BESSY-VSR – technical realisation



One cryo-module with:
2 x 5 cell @ 1.5 GHz & 2 x 5 cell @ 1.75 GHz
operating at **1.8 K LHe** temperature
active length: **1.86 m** with **20 MV/m**
total gradient: **2π 60 MV×GHz (x 80 increase)**

Installation of 1.8 K Cryo-System



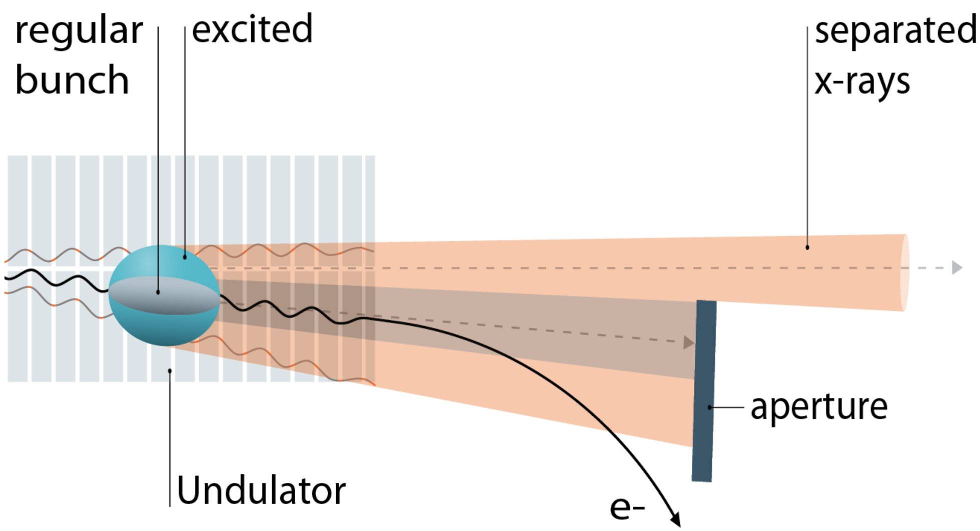


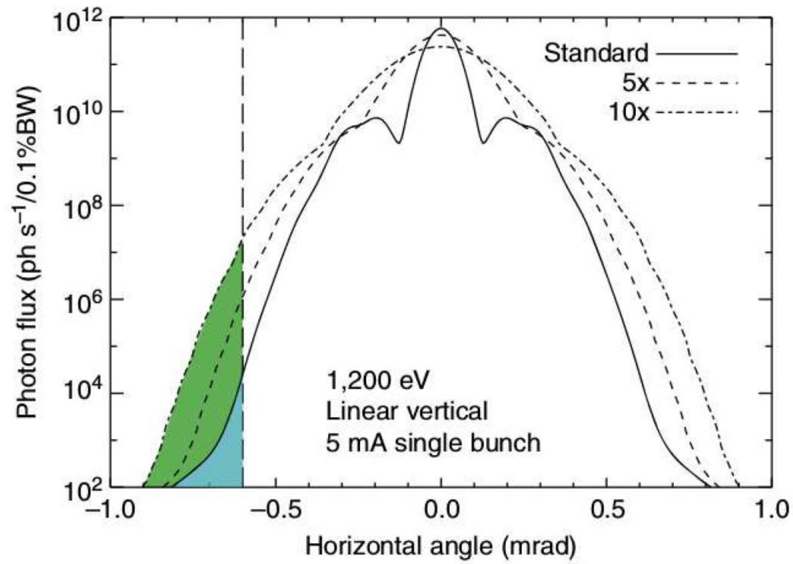
Bunch Separation – Resonant X-Ray Pulse Picking = RXPP

DONE

How to separate single bunch light from batch of bunches ?

weak bunch excitation + small orbit bump to separate batch from bunch with aperture





- bunch weakly excited horizontally at ca. 190 kHz (incoherent) with strip line kicker
- orbit bump and aperture properly set

→ single bunch signal with purity better 1e3 reached @ by 1e3 reduced intensity

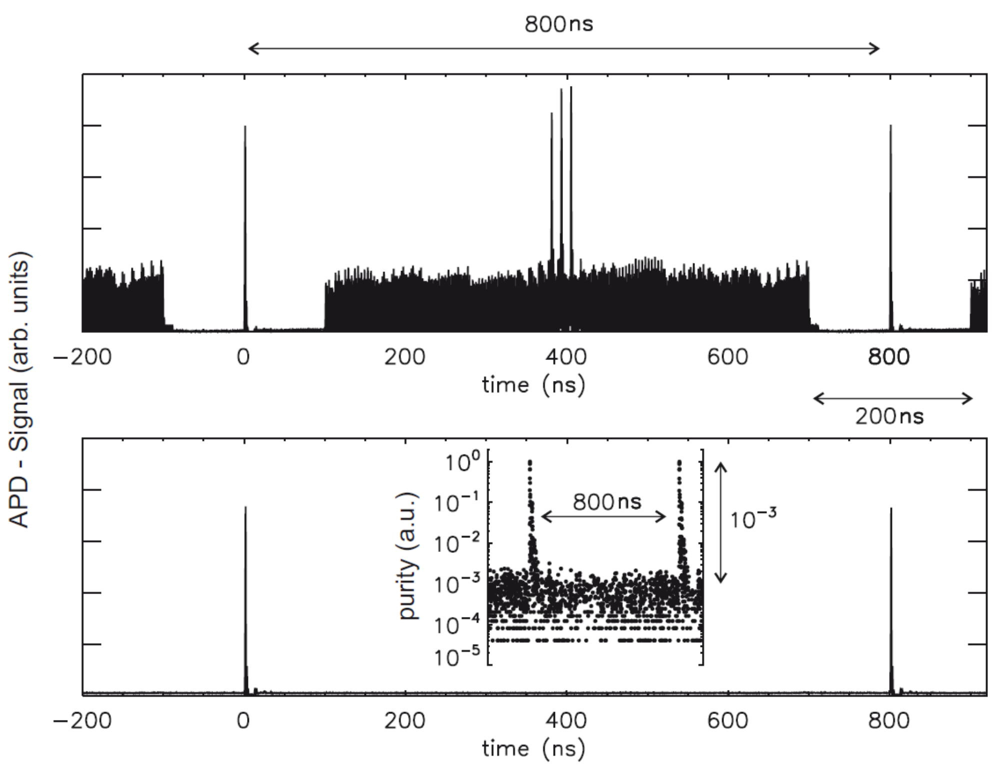
→ ARTOF spectra (experiments) measured at two ID beamlines (UE52 and UE56/2)

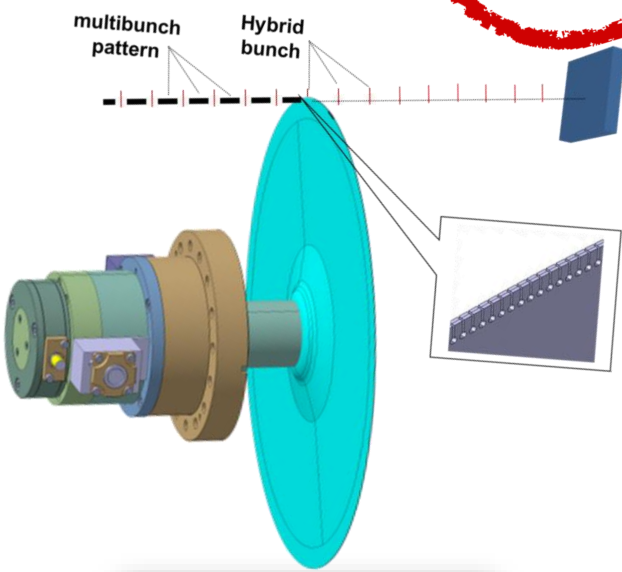
nature COMMUNICATIONS

Single bunch X-ray pulses on demand from a multi-bunch SR source
K. Holldack et al.
Nature Communications 5, 4010, doi: 10.1038/ncomms5010, 30.05.2014

Bunch Separation – MHz chopper

fast rotating mechanical chopper wheel allows to pick out a real single bunch within a gap of a long bunch train with nearly infinite purity

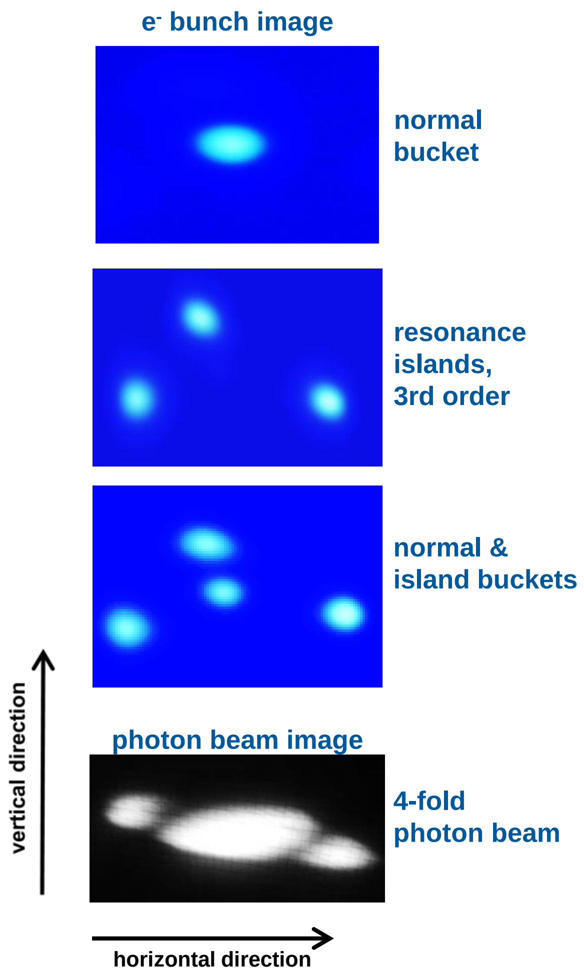




B.Lindenau, D. Förster, M. Leyendecker, C. Winkler, J. Kirschner, A. Föhlisch, K.Holldack, *MHz Mechanical Chopper for X-ray Pulse Separation*, (2014) in preparation.

Bunch Separation – resonance island buckets

Population of various buckets
MLS dipole source point monitor



<u>Resonance islands</u> are presently investigated at the MLS & BESSY II

operate near 1/integer tune values

Advantages

- minor change of user optics
- quasi stable beam storage
- bunch size comparable to user optics

Disadvantages

- bunch current is splitted in several islands, less average photon flux
- island beam position + intensity stability sensitive to magnetic fields - (tunes, sextupoles, insertion devices)

M. Ries, P. Goslawski, G. Wüstefeld et al., IPAC15

BESSY-VSR – Main challenges

- **verification of the scaling behaviour bunch-length versus current**

- **development and operation of high gradient superconducting cavities**
  1.5 GHz and 1.75 GHz @ 20 MV/m gradient cw
  → 200W @ 1.8 K cooling plant (30% margin)
  → particulate free (clean) vacuum around cavity straight, 10^{-10} mbar

- **control of coupled bunch instabilities**
  induced by higher order modes of sc cavities
  → proper HOM damping design of sc cavities
  → sufficiently strong bunch by bunch feedback

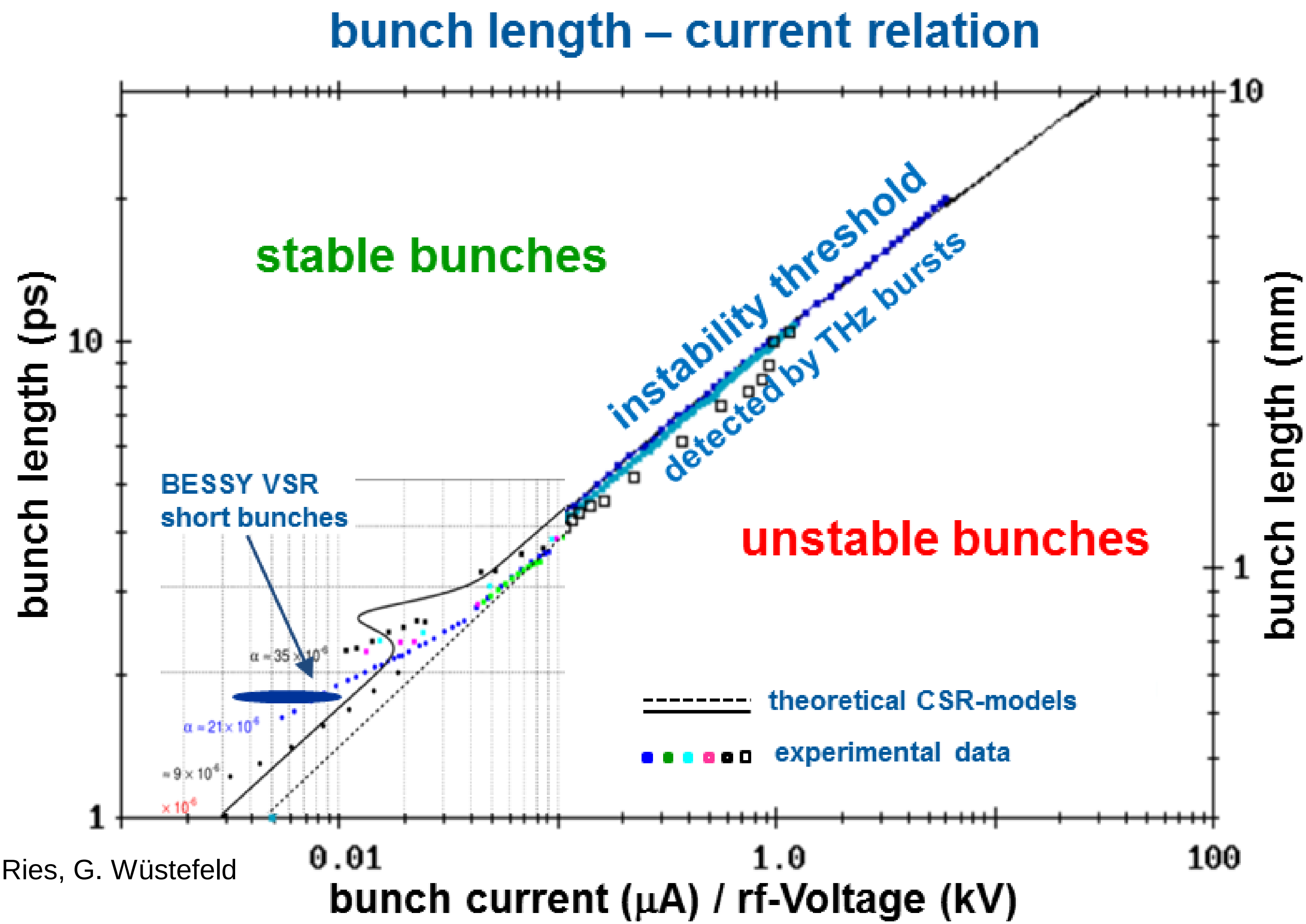
- **operation with large (transient) beam loading and in regime of possible Robinson instability**
  lifetime reduction, phase shift over bunch train, losses
  → careful set up and control of RF-parameters
  → appropriate low-level RF-control
  → control of vertical phase space

- **top up operation: injection from booster in short VSR bunches, lifetime**
  bunch length in booster 42 ps, injection efficiency > 90%
  → bunch "compression" in booster up to $\frac{\sigma_{booster}}{\sigma_{VSR}} < 8$

Bunch length / current scaling

Highly charged short bunches are limited by the CSR bursting instability

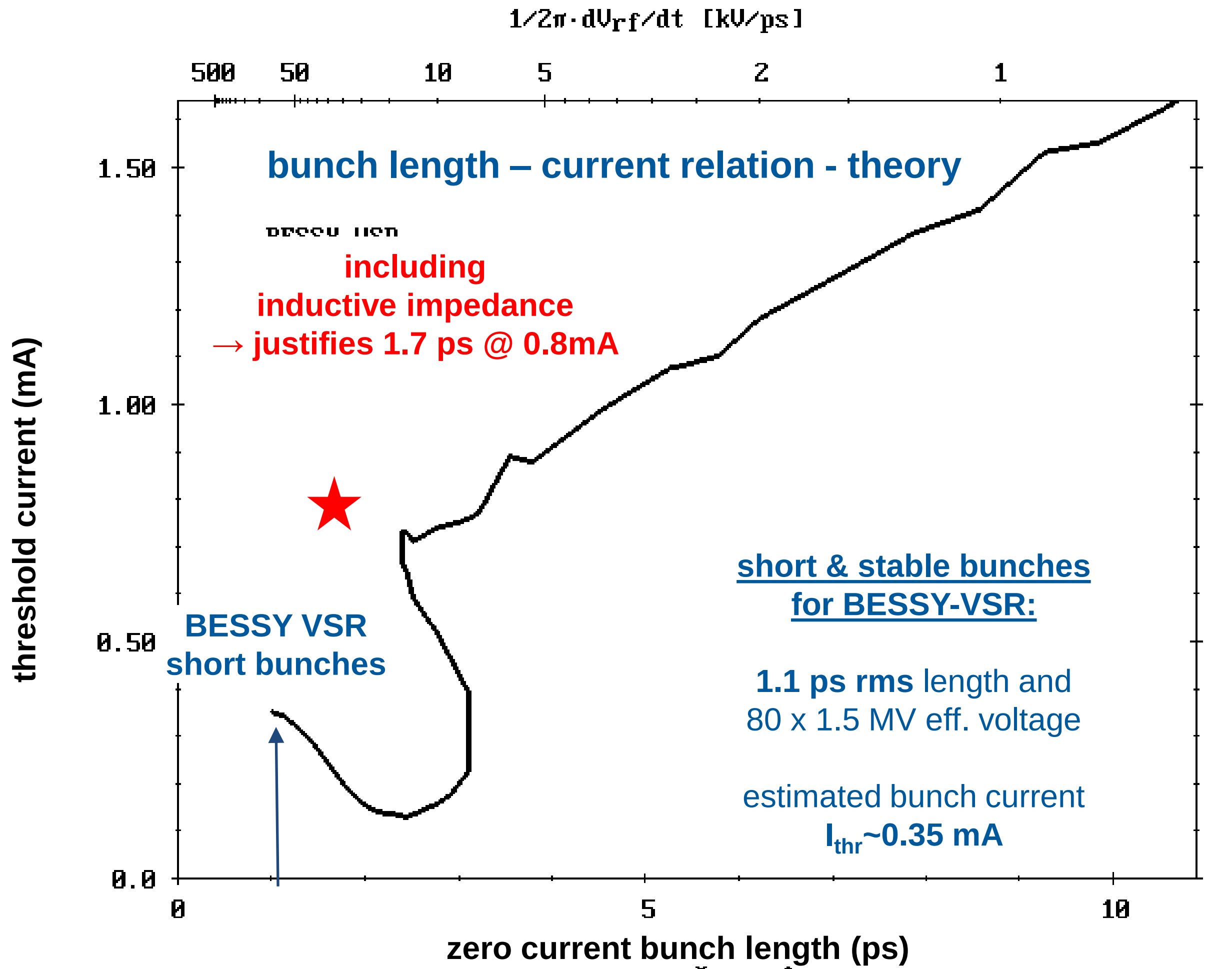
⇨ unstable bunches are not lost, they blow up in energy spread and length



P. Kuske, M. Ries, G. Wüstefeld

Bunch length / current scaling

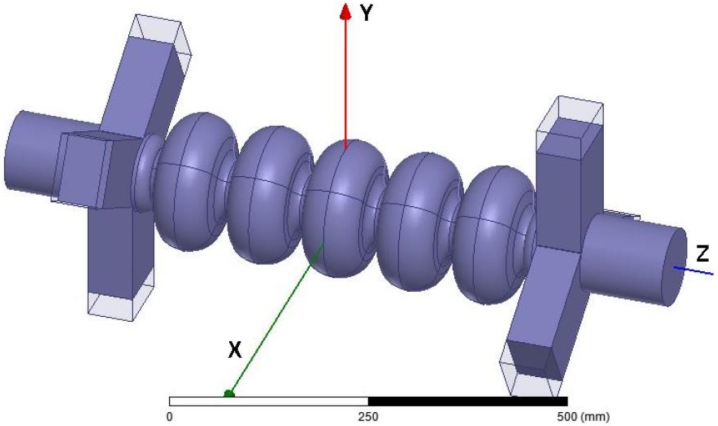
theory (numerical solution of the Vlasov-Fokker-Planck equation with shielded CSR-wake) applied to BESSY-VSR case:

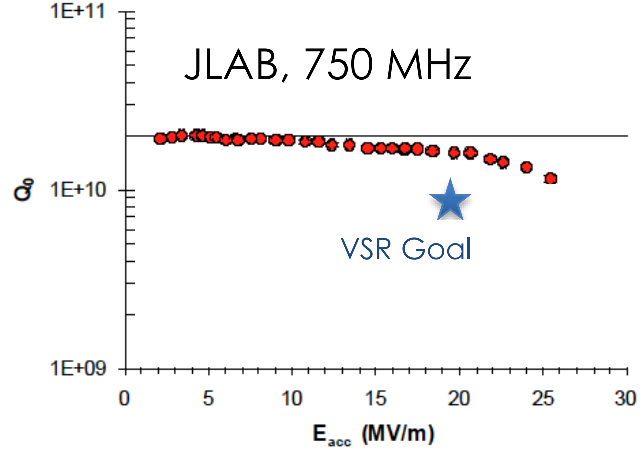


P. Kuske, IPAC13, Shanghai, China, 2013, p. 2041

Waveguide-damped cavities for heavy HOM damping

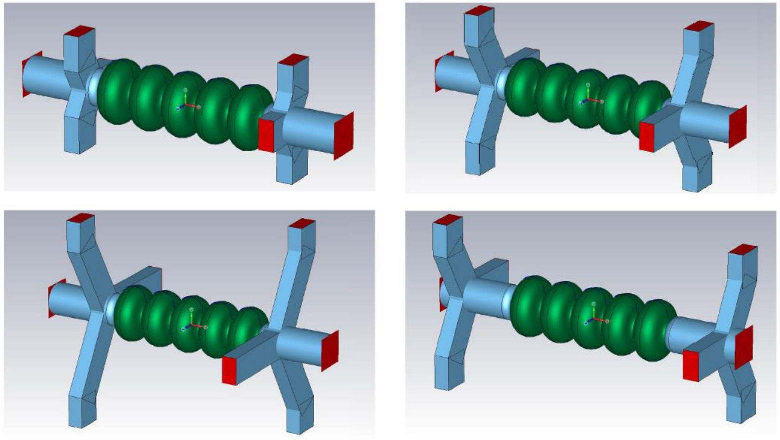
- Past performance of similar systems consistent with BESSY-VSR
- Optimization of design for maximum damping
- Calculation of HOM spectra for BBU analysis





R. Rimmer et al., PAC 2007

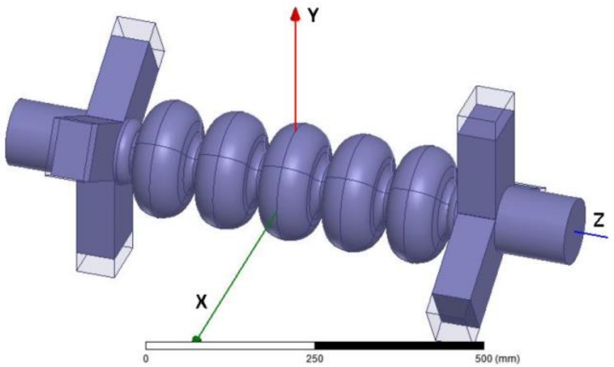
Cavity parameter	Design goal	HZB
E_{pk}/E_{acc}	≤ 2.3	2.29
B_{pk}/E_{acc}	$\leq 5.3\,\mathrm{mT/(MV/m)}$	$4.4\,\mathrm{mT/(MV/m)}$
R/Q	$\geq 500\,\Omega$	$525\,\Omega$
K for π-TM_{010}	$\geq 3\%$	3.3%
μ_{ff} for π-TM_{010}	$\geq 97\%$	98.2%

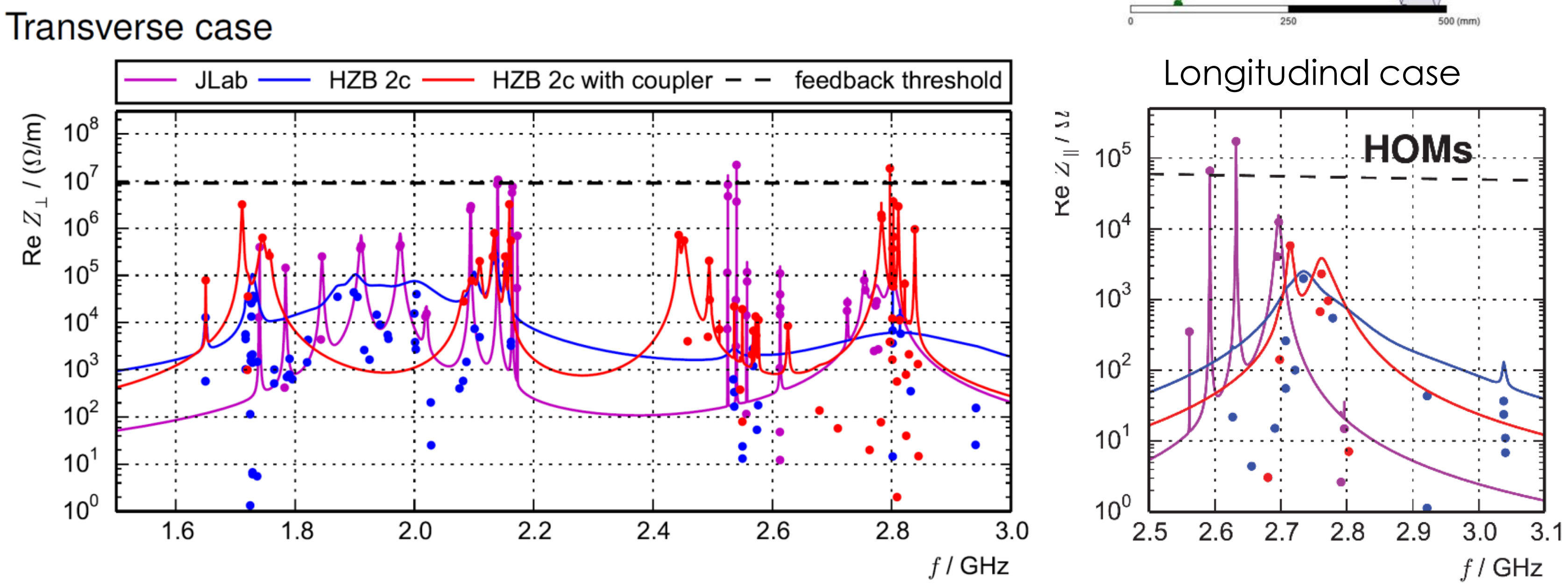


A. Neumann et al., IPAC14, Dresden, Germany, 2014,
A. Velez et al., IPAC15, Richmond, USA, 2015

HOM data from cavity design used for CBI analysis

– Latest design provides a high safety margin for onset of CBI in both planes (with feedback system on)

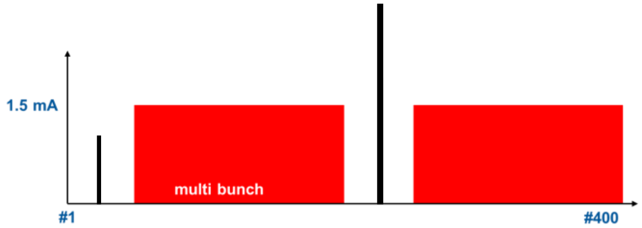




M. Ruprecht, IPAC14, Dresden, D
A. Vélez, A. Neumann et al.

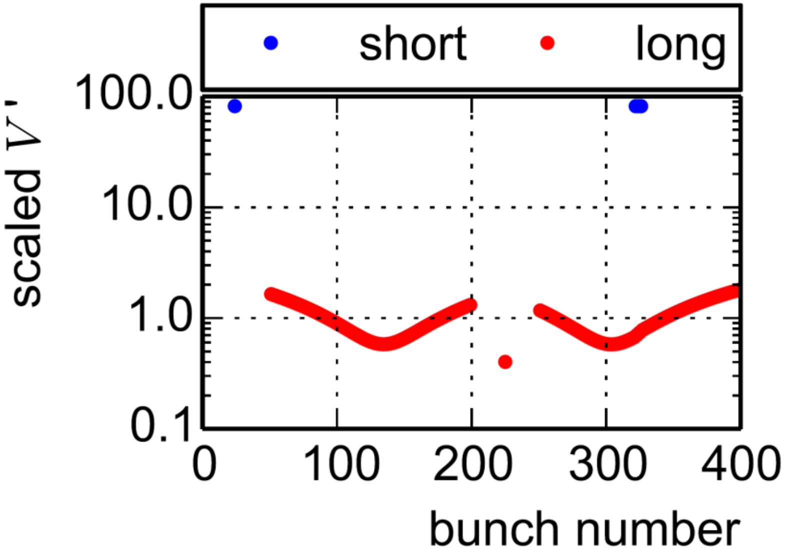
Transient beam loading and lifetime

BESSY-VSR hybrid fill with two 100 ns gaps

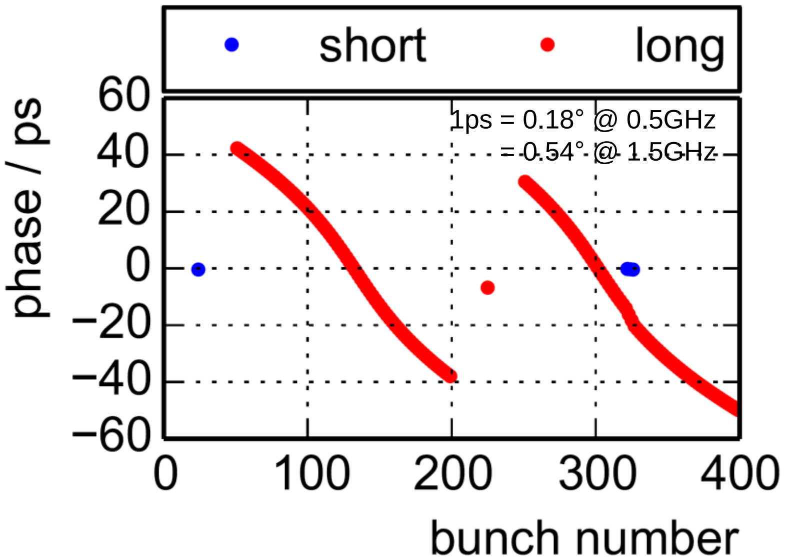


- Required for bunch separation with chopper
- SRF cavity impedance is purely reactive
- Abrupt changes in beam current result in phase change that cannot be compensated by the RF (insufficient power, limited bandwidth)
- Focusing gradient (and hence bunch length) of long bunches varies along the bunch train, short bunches are nearly un-affected.

Normalized to zero current bunch length

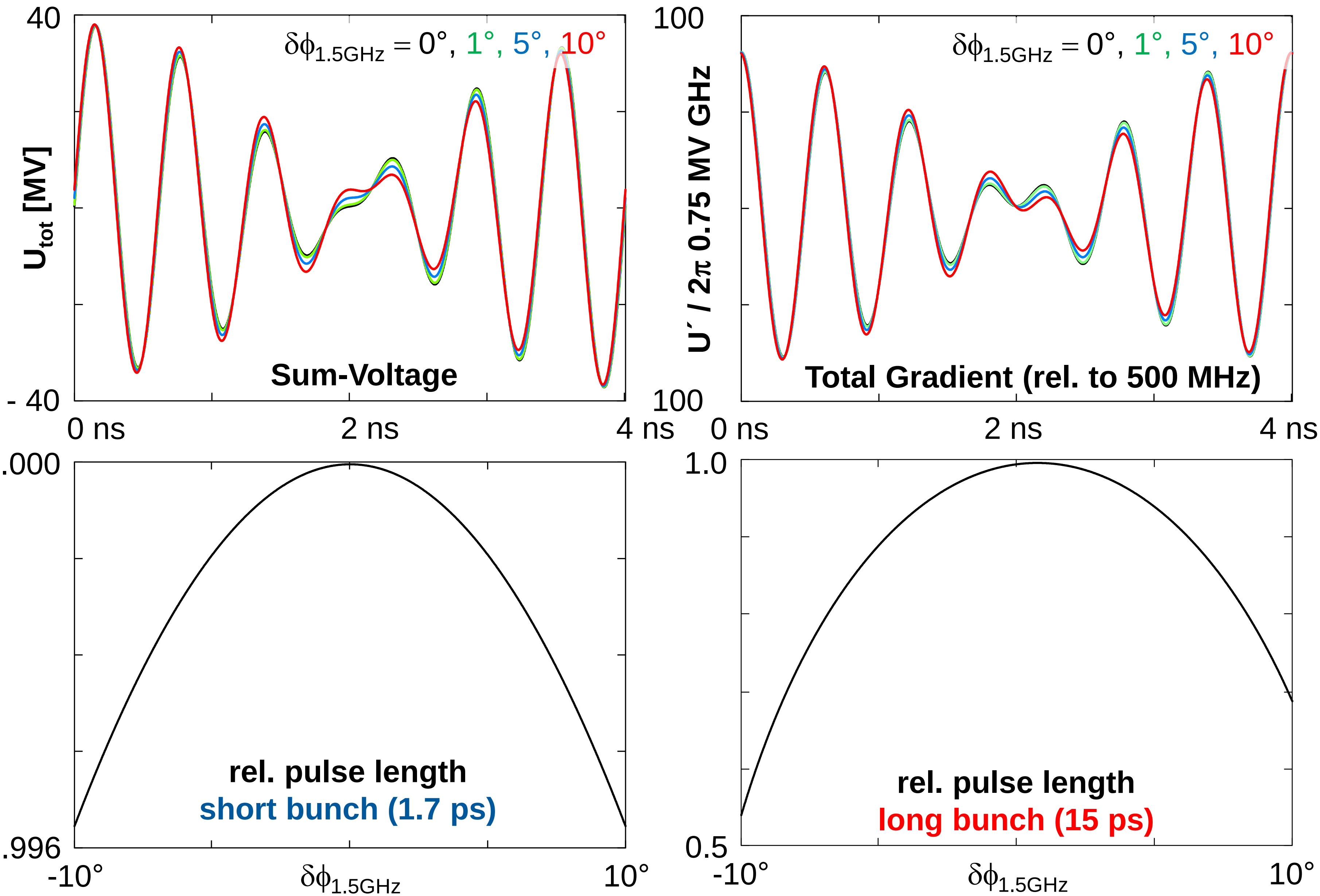


Phase transient



Martin Ruprecht

e.g. gradient / bunch length versus phase shift 1.5 GHz system



Fulfilling TopUp conditions - Lifetime

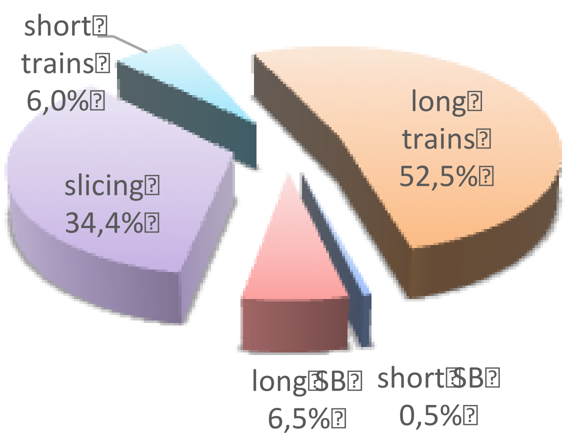
TopUp capabilities are essential, radiation safety requirements

- Average lifetime > 5h mandatory
- 4-h average injection efficiency > 90% mandatory
- Instantaneous injection efficiency > 60% mandatory

Calculated Touschek lifetimes do not meet requirements

- Improvement by vertical excitation of beam size (all bunches or dedicated bunches by a DB2BFB)
- Improve by adjustment of charge in e.g., slicing bunches.

hybrid fill with THz bunches
Touschek lifetime ~ **1.7 h** (± 50%) / BESSY standard: 4 h



Markus Ries

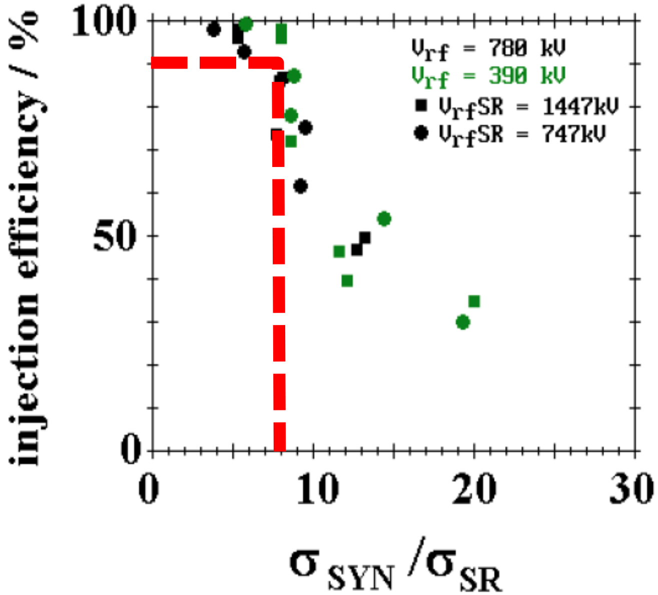
TopUp capabilities are essential, radiation safety requirements

- Average lifetime > 5h mandatory
- 4-h average injection efficiency > 90% mandatory
- Instantaneous injection efficiency > 60% mandatory

Measurements at BESSY II

- To maintain 90% ave. injection efficiency requires $\sigma_{booster}/\sigma_{BESSY\ II} < 8$!
- With new booster RF $\sigma_{booster}/\sigma_{VSR\text{-}short} = 40$

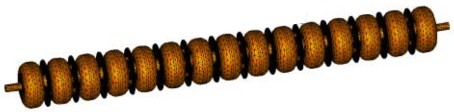
→ Injection into short bunches not possible!

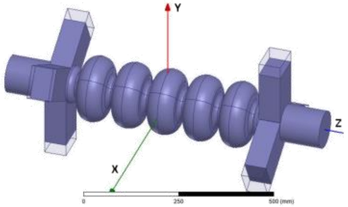


P. Kuske,
P. Goslawski et al.

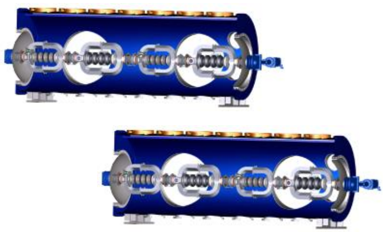
Solution: Modification of Booster

- Installation of NC 3-GHz RF (4 MV) system
  or installation of SC 1.5 GHz (8 MV) system
  + possibly modify momentum compaction
- 6D emittance exchange ?





BESSY-VSR – project costs (i)



1 + 1 (spare) cryo-modules incl. auxiliaries + prototyping

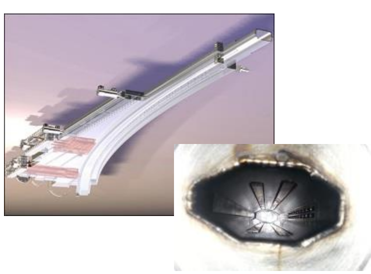
2.9 Mio€ cavities + HOM absorber (2 x 5 cavities in total)
1.7 Mio€ cryo-module + auxiliaries
0.7 Mio€ coupler
Σ=5.3 Mio€

1.8 K cryo-system (incl. testing)

7.8 Mio€ L700 + coldbox + cold-compressors + cryo-lines
0.5 Mio€ move / adapt TCF-50 for testing
1.3 Mio€ cryo connection to module test stand
Σ=9.6 Mio€

4 + 2 (spare) transmitters (each 16 kW) incl. auxiliaries

3.2 Mio€ transmitters
0.5 Mio€ waveguide systems
0.2 Mio€ LLRF
Σ=3.9 Mio€



Vacuum + impedance upgrade

0.6 Mio€ clean vacuum chambers near new cavity straight
0.3 Mio€ impedance up-grade of the ring
Σ=0.9 Mio€

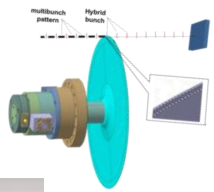
Diagnostics and feedback

0.9 Mio€ streak camera, THz beam-line, fast diodes + bolometer

0.7 Mio€ DB2BFB (electronics + kicker), computing, BII+booster

1.7 Mio€ Digital BPM System

Σ=3.3 Mio€



MHz Chopper Development, X-ray diagnostric, timing, PSB kicker

0.8 Mio€ chopper development 100 ns (dipole + ID)

0.5 Mio€ PSB kicker development

0.3 Mio€ timing distribution

0.5 Mio€ beamline for method development

0.4 Mio€ X-Ray diagnostics for beamlines

Σ=2.5 Mio€

Booster upgrade (nc S-Band cavity system)

3.2 Mio€ 4 MV @ 3 GHz

0.2 Mio€ modification of straights

Σ=3.4 Mio€

total investment machine and experimental basics: 28.9 Mio€

BESSY-VSR – time line

doi:10.54442/R0001

2013	**VSR Science Workshop**
2014	**Strong Support from POFIII evaluation**
March 2015 **April 2015**	**Technical Design Study finished** **successful BESSY VSR review**
June 2015	**application to Helmholtz Association submitted (strategic investment, 26 Mio€ + 3 Mio€ HZB)** **scientific evaluation of application, organised by Helmholtz**
2016	**ranking of all applications from all research fields decision about funding**
2018	**first tranche of money available**
2018	**completion of a preparatory phase (1.5 GHz module)**
2020	**start of full user operation**

BESSY-VSR – schedule

Date	Action
2015	**Begin preparatory phase** Goal: Technical evaluation of one VSR module with beam • Two 1.5-GHz cavities operating at 4.4 K (3.5 MV/m max): 4.4 K operation avoids costly installation of 1.8 K cryogenics Useful tests of • Pulse compression/scaling • Transparent “parking” of cavities if VSR needs to be “switched off” • HOM damping scheme and efficacy • Stable operation with one of the two SRF cavities in the “Robinson unstable” configuration (needed later for 1.75 GHz) • Establish diagnostics and feedback systems
2018	**Beam test of module** • ca. 7 weeks dark time for system installation and commissioning **Full BESSY VSR funds available from Strategic Invest** • Procurement of 1.8 K cryoplant, 1.75 GHz SRF system, 2^{nd} module, modified vacuum system etc.
2020	**Full VSR installation / commissioning / start user operation** • ca. 22 weeks of dark time • single bunch pulse separation with chopper and RXPP • ongoing upgrade of beamlines and IDs

Summary BESSY-VSR

combines high brilliance with short pulses,
→ structure and dynamics

opens a new regime of storage ring operation,
→ future combination of DLSR + VSR ? (in a certain energy range)

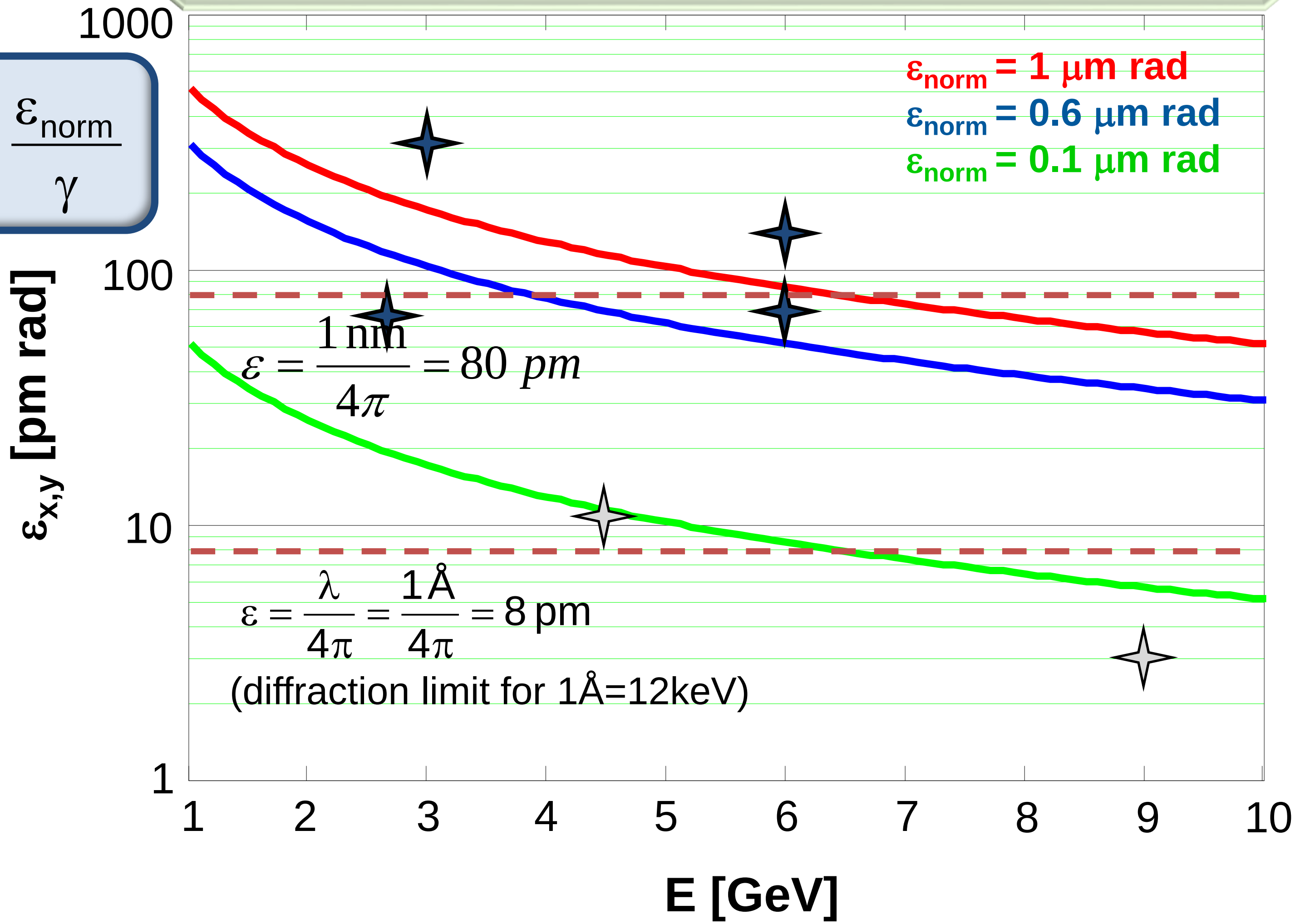
is attractive for the portfolio of light sources,
→ unique, complementary to FEL sources

is the ideal and cost effective upgrade of BESSY II.
→ addressing the needs of the existing user community, attracting new users

Quo vadis ?

3rd generation light sources in operation (selection):
ALBA (5 nm@3 GeV), SOLEIL (4 nm@2.7 GeV), DIAMOND (3 nm@3 GeV), ESRF (4 nm@6 GeV), APS (3 nm@7 GeV), SPring8 (3nm@8 GeV) ALS (2.2 nm@1.9 GeV), PETRAIII (1 nm@6 GeV / 0.16nm@3GeV)

$$\varepsilon = \frac{\varepsilon_{norm}}{\gamma}$$



MBA ultra low emit. lattices:

320 pm, MAX IV
(under construction)
147 pm, ESRF II
(2020 back in op.)
65 pm, APS
(design phase)
~70 pm SLS, ALS
(design phase)

11 pm, PEPX
(design study)

3 pm, tUSR
(design study)

Quo vadis HZB?

BESSY III: VUV / soft to tender X-ray range
- diffraction limited (in this energy range)
- pulse length < ps to ~ 100 ps
- additional short pulse facility < 100 fs

2015 – 2019 Science case, definition of facility, Conceptual Design Report

2023 Technical Design Report

2024+ Realisation