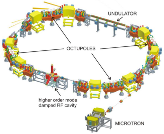
Bunch Separation with Reconance Island Buckets

P.Goslawski, J.Feikes, T.Goetsch, J.Li, M.Ries, M.Ruprecht,
A.Schälicke, G.Wüstefeld

and the BESSY VSR design team

Helmholtz-Zentrum Berlin



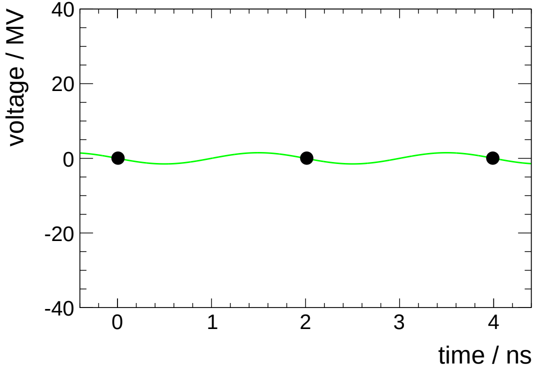
November 26th, 2014
ESLS XXII, Grenoble

Concept of BESSY VSR

Short and long bunches simultaneously

Zero current bunch length:

$$\boxed{\sigma_0 = \frac{\alpha\,\delta_0}{2\pi\ f_s} = \delta_0 \sqrt{\frac{E_0}{f_0}\,\frac{\alpha}{\mathbf{U'}}}}$$



Cavity system for gradient manipulation

- Normal rf cavity

  $U' = 2\pi\ 0.5\ 1.5\,\mathrm{GHz\,MV}$

Concept of BESSY VSR

Short and long bunches simultaneously

Zero current bunch length:

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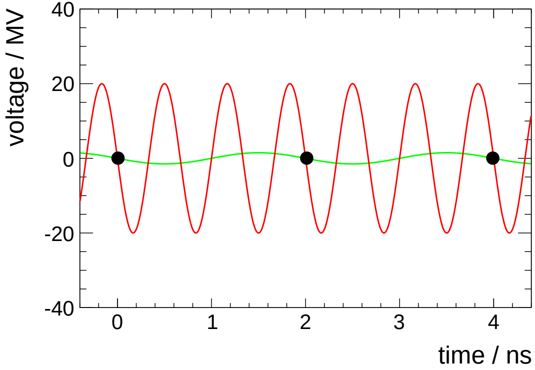


Cavity system for gradient manipulation

- Normal rf cavity

  $U' = 2\pi\ 0.5\ 1.5\,\mathrm{GHz\,MV}$
- 1^{st} sc cavity
  3rd harmonic

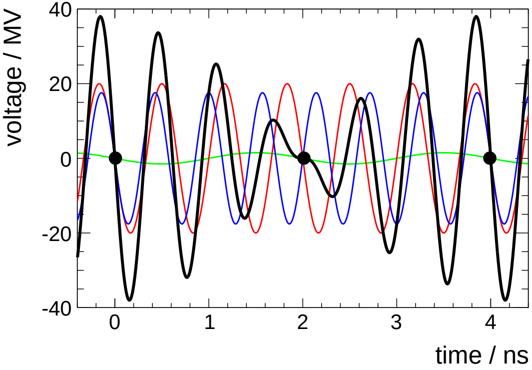
  $U' = 2\pi\ 1.5\ 20\,\mathrm{GHz\,MV}$

Concept of BESSY VSR

Short and long bunches simultaneously

Zero current bunch length:

$$\boxed{\sigma_0 = \frac{\alpha\,\delta_0}{2\pi\ f_s} = \delta_0\sqrt{\frac{E_0}{f_0}\,\frac{\boldsymbol{\alpha}}{\mathbf{U'}}}}$$



Cavity system for gradient manipulation

- Normal rf cavity

  $U' = 2\pi\ 0.5\ 1.5\,\mathrm{GHz\,MV}$
- 1^{st} sc cavity

  3rd harmonic

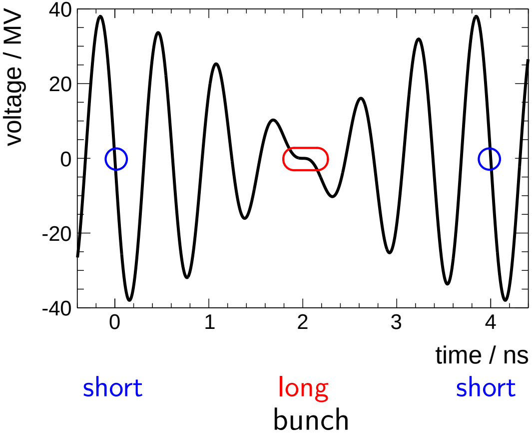
  $U' = 2\pi\ 1.5\ 20\,\mathrm{GHz\,MV}$
- 2^{nd} sc cavity

  3.5th harmonic

  $U' = 2\pi\ 1.75\ 17.1\,\mathrm{GHz\,MV}$
- Beating pattern, large and small gradient U'

Concept of BESSY VSR

Short and long bunches simultaneously

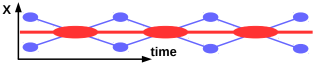


- Beating pattern, large and small gradient U'
- Short and long bunches
- Short $\sigma_{0,s} = 1.1\,\mathrm{ps}$
- Long $\sigma_{0,l} = 10\,\mathrm{ps}$

→ **V**ariable Pulse Length **S**torage **R**ing

Separation of short and long synchrotron pulses ...

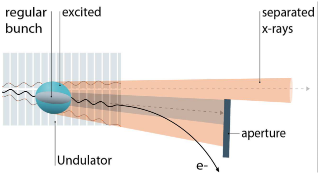
... or electron bunches



Transverse separation !

Dynamic methods
→ disturbing

1. Pulse picking, established!

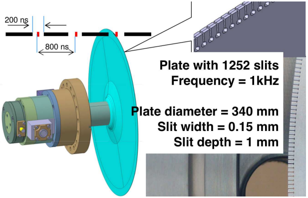


K. Holldack et.al., Nature Com. 5, 4010, 2014

2. Pulse excitation
   → Fast kicker
   → Transverse deflecting cavity

Static methods
→ non-disturbing

1. Chopper system, established!



FZ Jülich and BESSY

2. **Resonance Island Buckets**
   → **Next slides**

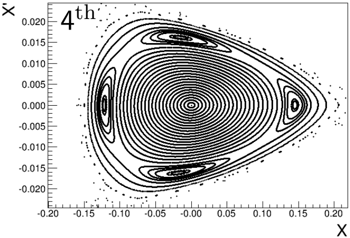
Resonance island buckets at MLS

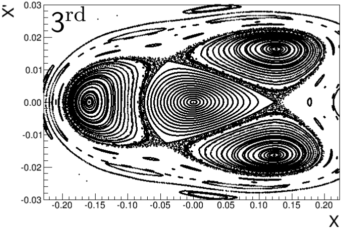
Examples of islands - (x', x) phase space simulations

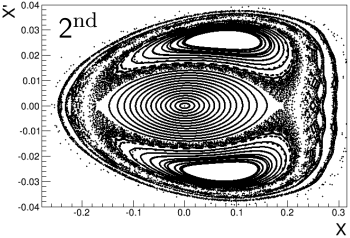
Near resonance

- Additional stable buckets
- Number of buckets = order of resonance

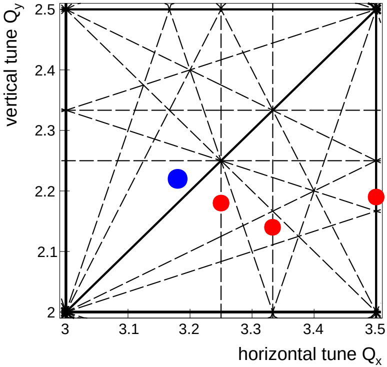
→ Resonance island buckets







Experiments with resonance island buckets at MLS



● Working point (3.18, 2.22)

● Resonance tunes

4^{th} order resonance ($Q_x = 3.25$, $Q_y = 2.18$)
3^{rd} order resonance ($Q_x = 3.33$, $Q_y = 2.14$)
2^{nd} order resonance ($Q_x = 3.5$, $Q_y = 2.19$)

Operating machine close to resonance

- Minor impact on linear beam optics

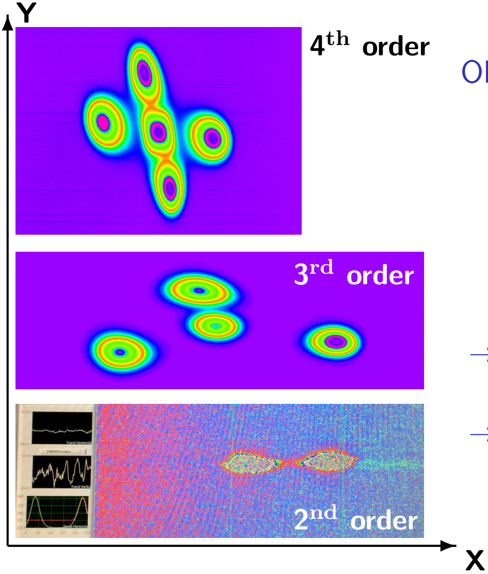
→ Only small de-tuning needed to move on resonance

→ No big change of β functions and dispersion

- Manipulation of resonance impact using sextupoles

Experiments with resonance island buckets at MLS

Imaging with source point monitor (x, y)



Observation and results

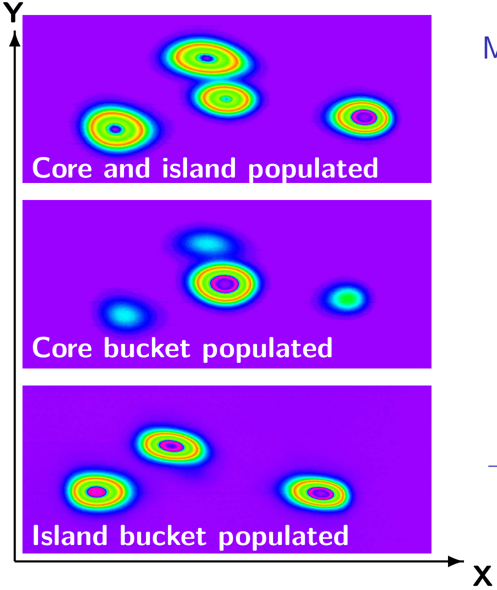
- At MLS beam was stored stable in 2nd, 3rd, and 4th order resonance buckets
- Recipe: Move tune towards resonance and manipulate resonance impact using sextupoles

→ Lifetime, loss rate, source point monitor, tune

→ Lifetime and source size (emittance) comparable with standard working point setting

Experiments with resonance island buckets at MLS

3rd order buckets best studied



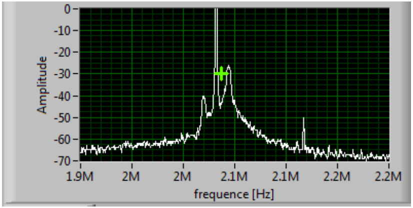
Manipulating the buckets

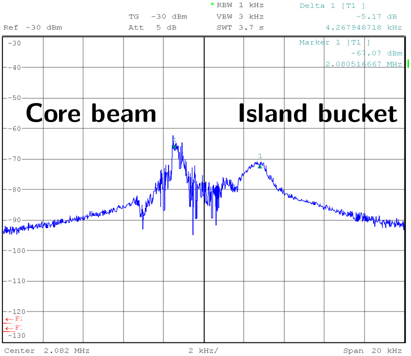
- Position of island shifts by quads, sextupoles, octupoles
- Rotated by skews, i.e., x-y coupling
- Tunes of core and island bucket different and separated by resonance
- Current manipulation by transverse excitation

→ Single bunch in resonance island using Bunch-to-Bunch Feedback

Experiments with resonance island buckets at MLS

3rd order buckets best studied





```
                                    * RBW  1 kHz        Delta 1 [T1 ]
                       TG   -30 dBm   VBW  3 kHz                -5.17 dB
Ref  -30 dBm           Att   5 dB     SWT  3.7 s         4.267948718 kHz
                                                        Marker 1 [T1 ]
                                                               -67.07 dBm
                                                         2.080516667 MHz
Center  2.082 MHz              2 kHz/                      Span  20 kHz
```

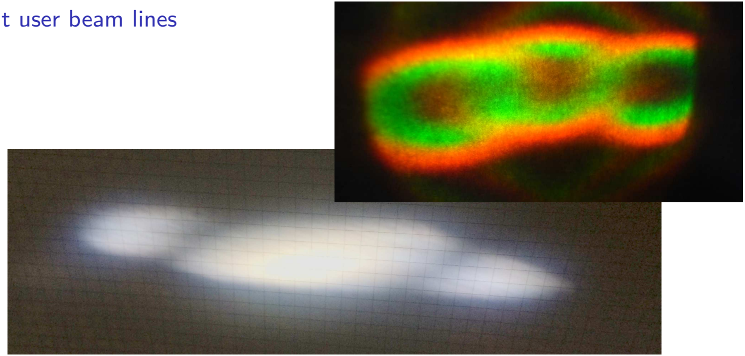
Tunes

- Deformation when moving towards resonance
- Sharp peak at resonance position → Separator
- Up to now tune separation of 20 - 30 kHz
  More possible? Stability?

- High current test 150 mA with lifetime $>3\,\mathrm{h}$
- Undulator (planar)

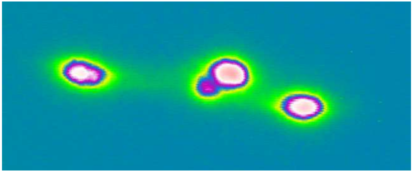
Experiments with resonance island buckets at MLS

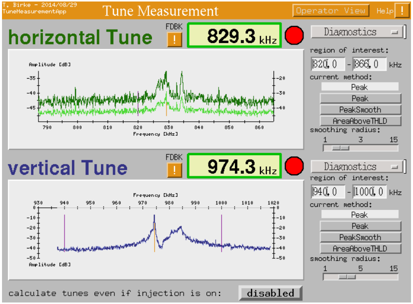
Separation at user beam lines



Photon beam generated by 3er order resonance buckets

Experiments with resonance island buckets at BESSY II





T. Birke – 2014/08/29
TuneMeasurementApp

Tune Measurement

horizontal Tune 829.3 kHz

region of interest: 820.0 - 866.0 kHz

current method: Peak

smoothing radius: 3

vertical Tune 974.3 kHz

region of interest: 940.0 - 1000.0 kHz

current method: Peak

smoothing radius: 5

calculate tunes even if injection is on: disabled

First measurements

- Tests with 50 mA
- 3rd order resonance at $f = 833\,\mathrm{kHz}$
- Core tune $f_{qx} = 835\,\mathrm{kHz}$
- Island tune $f_{qx} = 825\,\mathrm{kHz}$

→ Experiences of MLS experiments helped a lot

→ Identifying the effective knobs

Summary & Conclusions

Bunch separation with resonance island buckets

- Motivated by BESSY VSR

→ Separate short and long bunches in the transverse plane

- Operating MLS on 2nd, 3rd (BESSY II) or 4th order resonance

- In progress:

→ Beam size comparison (emittance)

→ Lifetime and diffusion rate of island/core beam

→ Distributing current bunch by bunch

→ Injection into island buckets

Thank you for your attention

Additional Slides

Additional Slides

Current status

What's going on

Project BESSY VSR

- Strong support from HZB directory board and BESSY II users

→ Next workshop: *"From Pico to Femto"*, January 2015

- Now: Writing the technical design study (TDS)

→ TDS + application for strategic invest in mid 2015 (25 M€)

→ 2018 preparatory phase (4.5 M€), 2020 full operation (20 M€)

- Preparing BESSY II for VSR

→ Cavities: design, interplay of beam and sc cavity
Short bunches: injection, current limits, **Separation**, etc.

Short bunches in storage rings

Adjusting bunch length - longitudinal phase space

Zero current bunch length σ_0

$$\boxed{\sigma_0 = \frac{\alpha\, \delta_0}{2\pi\ f_s} = \delta_0 \sqrt{\frac{E_0}{f_0} \frac{\boldsymbol{\alpha}}{\mathbf{U'}}}}$$

with $f_s^2 = f_0\ \frac{\alpha\ eU'}{4\pi^2\ E_0}$

f_0 - revolution frequency
δ_0 - natural energy spread
α - mom.comp. factor
$U' = 2\pi\ f_{rf}\ U_0$ - voltage gradient

$$\boxed{\sigma_0 \sim \sqrt{\frac{\alpha}{U'}}}$$

Bunch length at BESSY VSR

$$\boxed{U'_{\mathrm{VSR}} = 80 \cdot U'_{\mathrm{BII}} \qquad \sigma_0^{\mathrm{VSR}} = 0.11 \cdot \sigma_0^{\mathrm{BII}}}$$

$$U'_{\mathrm{BII}} = 2\pi\ 0.75\,\mathrm{GHz\ MV}$$

$$U'_{\mathrm{VSR}} = 2\pi\ 60\,\mathrm{GHz\ MV}$$

	Standard	Low-α
emittance ε	5 nm rad	40 nm rad
mom.comp. α	$7.3 \cdot 10^{-4}$	$3.5 \cdot 10^{-5}$
σ_0^{BII}	10 ps	2 ps
σ_0^{VSR}	1.1 ps	0.25 ps

Concept of BESSY VSR

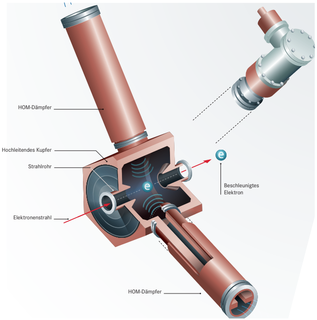
Cavity system

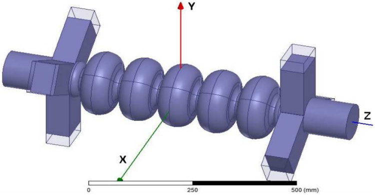
1^{st} sc cavity: $U' = 2\pi\ 1.50\ 20\,\mathrm{GHz\,MV}$

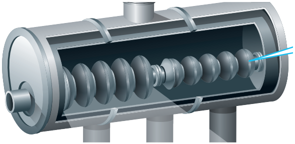
2^{nd} sc cavity: $U' = 2\pi\ 1.75\ 17.1\,\mathrm{GHz\,MV}$

Normal rf cavity:

$U' = 2\pi\ 0.5\ 1.5\,\mathrm{GHz\,MV}$



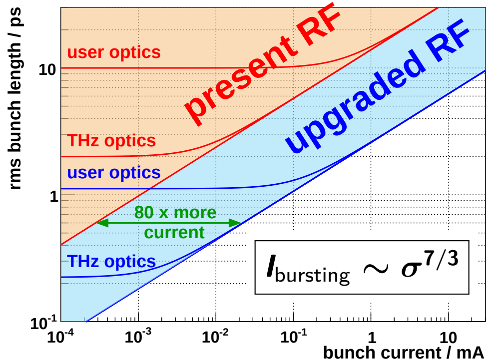




Current in short bunches

Bursting threshold - single bunch instability

J. Feikes, EPAC 2006



Current in short bunches

- From theory: $I_b \sim \alpha$
- Bunch length: $\sigma_0 \sim \sqrt{\frac{\alpha}{U'}}$
- For constant σ_0, then

$$\boxed{I_b \sim U'}$$

→ 80× rf gradient U'_{VSR}

→ 80× more current I_b

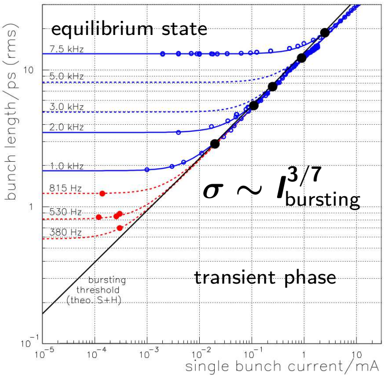
→ Shifted CSR bursting threshold to higher currents

Current in short bunches

Bursting threshold - single bunch instability

Measurements at BESSYII

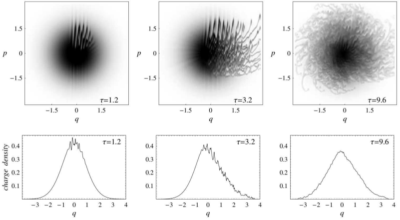
J.Feikes, EPAC 2004



- streak camera measurements
- THz data, fourier transform
- bursting threshold of CSR signals

Bunch instability from csr wake fields

SLAC-PUB-11955, July 2006, Robert L. Warnock



periodic stochastic

bursting emission

- Single bunch instability, increase of

→ bunch length

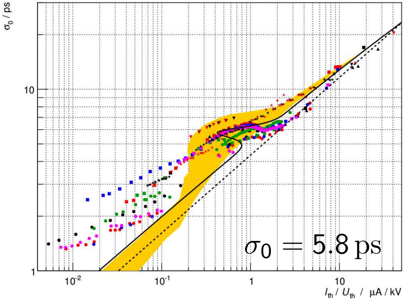
→ energy spread (heat up)

→ spoils beam quality

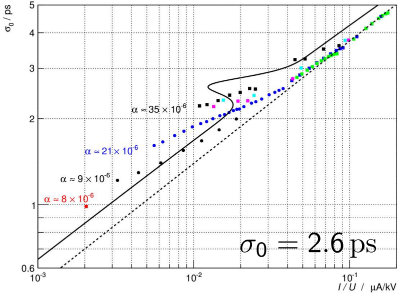
Current in short bunches

Measurements of bursting thresholds at BESSYII and MLS

Thresholds at MLS



Thresholds at BESSYII



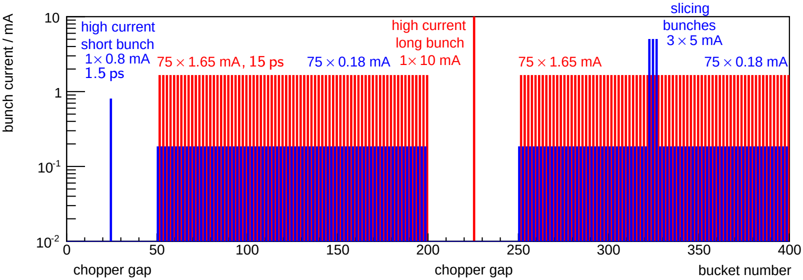
M. Ries, PhD thesis, HU Berlin, 2014

- → Anomaly appears due to modification of gaussian beam profile
- → Deviations between measurements and theory below anomaly ?

BESSY VSR

Project goals

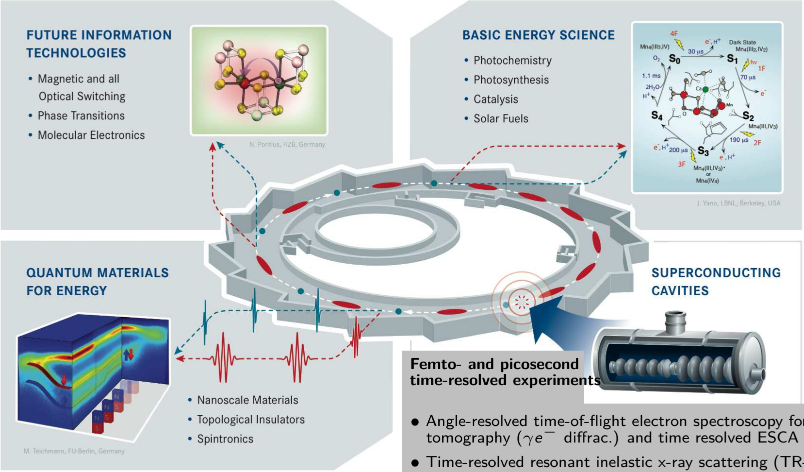
Fill pattern



- Standard user: Short bunch 1.5 ps with 0.8 mA
- Low α operation: Short bunch $\approx 0.5\,\mathrm{ps}$ with 0.02 mA

Why short bunches in storage rings

Demands of users - Science case



FUTURE INFORMATION TECHNOLOGIES

- Magnetic and all Optical Switching
- Phase Transitions
- Molecular Electronics

N. Pontius, HZB, Germany

BASIC ENERGY SCIENCE

- Photochemistry
- Photosynthesis
- Catalysis
- Solar Fuels

J. Yano, LBNL, Berkeley, USA

QUANTUM MATERIALS FOR ENERGY

- Nanoscale Materials
- Topological Insulators
- Spintronics

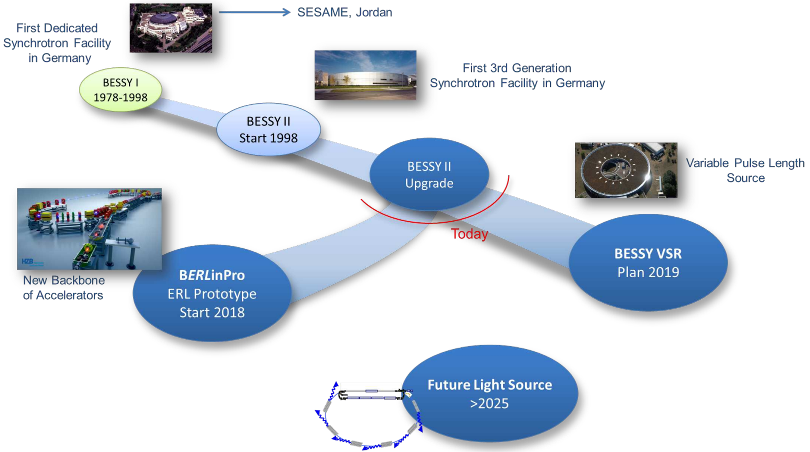
M. Teichmann, FU-Berlin, Germany

SUPERCONDUCTING CAVITIES

Femto- and picosecond time-resolved experiments

- Angle-resolved time-of-flight electron spectroscopy for orbital tomography (γe^{-} diffrac.) and time resolved ESCA (ArTOF)
- Time-resolved resonant inelastic x-ray scattering (TR-RIXS)
- Time-resolved photoemission microscopy (TR-PEEM)
- Broad band THz electron paramagnetic resonance (THz-EPR)

Accelerator physics at HZB



First Dedicated Synchrotron Facility in Germany

BESSY I
1978-1998

SESAME, Jordan

First 3rd Generation Synchrotron Facility in Germany

BESSY II
Start 1998

BESSY II
Upgrade

Today

Variable Pulse Length Source

BESSY VSR
Plan 2019

New Backbone of Accelerators

***BERL*inPro**
ERL Prototype
Start 2018

Future Light Source
>2025