Time Resolved Experiments at BESSY II - Today and in the Future with BESSY VSR

Peter Kuske, with the help of the VSR project team,
special thanks to A. Jankowiak and P. Goslawski

Institute for Accelerator Physics Helmholtz-Zentrum Berlin and Humboldt-Innovation GmbH

4-5 December 2017
PHANGS, Photons at the Next Generation Synchrotron Facilities, ICTP, Trieste, Italy

Overview

- BESSY II @ HZB (Helmholtz-Zentrum Berlin)
  - BESSY overview
  - BESSY specialties: Time resolved user experiments
    - Slicing
    - Mechanical chopper
    - Pulse picking
    - Island buckets
    - Few bunch operation
    - Multi-bunch mode
    - Shorter pulses – low alpha mode

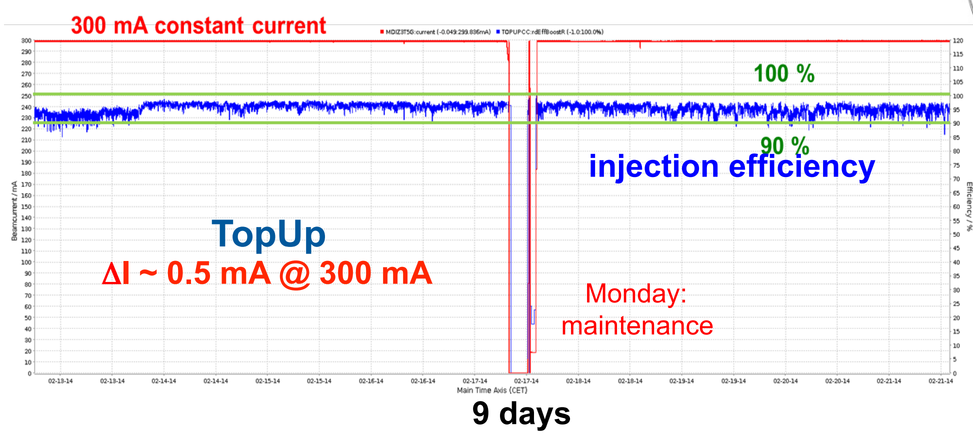
- From BESSY II to BESSY VSR
  - BESSY VSR – The Variable Pulse Length Storage Ring

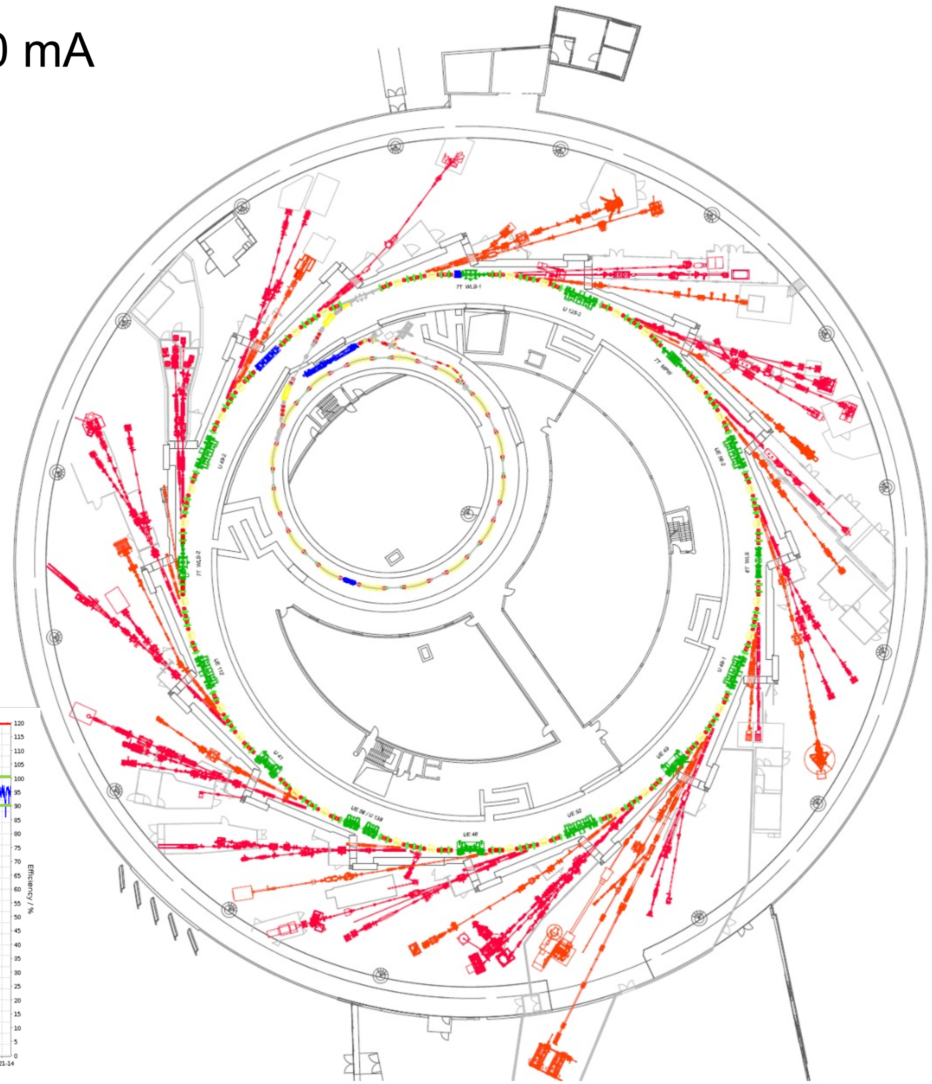
BESSY II: 3rd generation light source (UV / XUV / Soft X-Ray)

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

• Energy / Current	1.7 GeV / 300 mA
• Circumference	240 m (DBA)
• Emittance	5 nm rad
• Pulse length	15 ps
• Straight sections	16 / 14
• Undulators/W+WLS	12 / 1+2
• Beamlines (ID, Bend)	30, 20

5000 h user operation and
3000 user visits / year



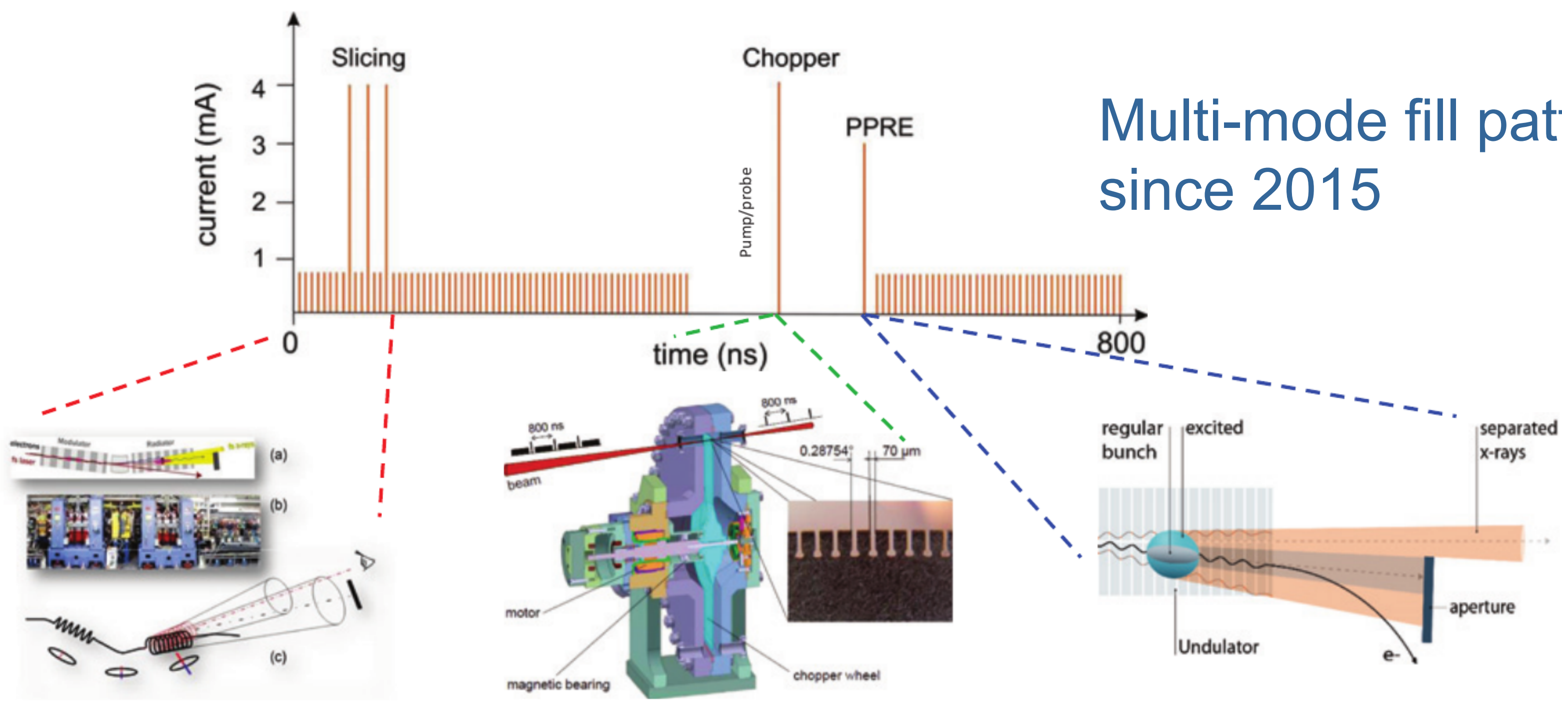


BESSY II specialities: fill pattern

R.Müller et al., Proceedings of IPAC2016, Busan, Korea, WEPOW011

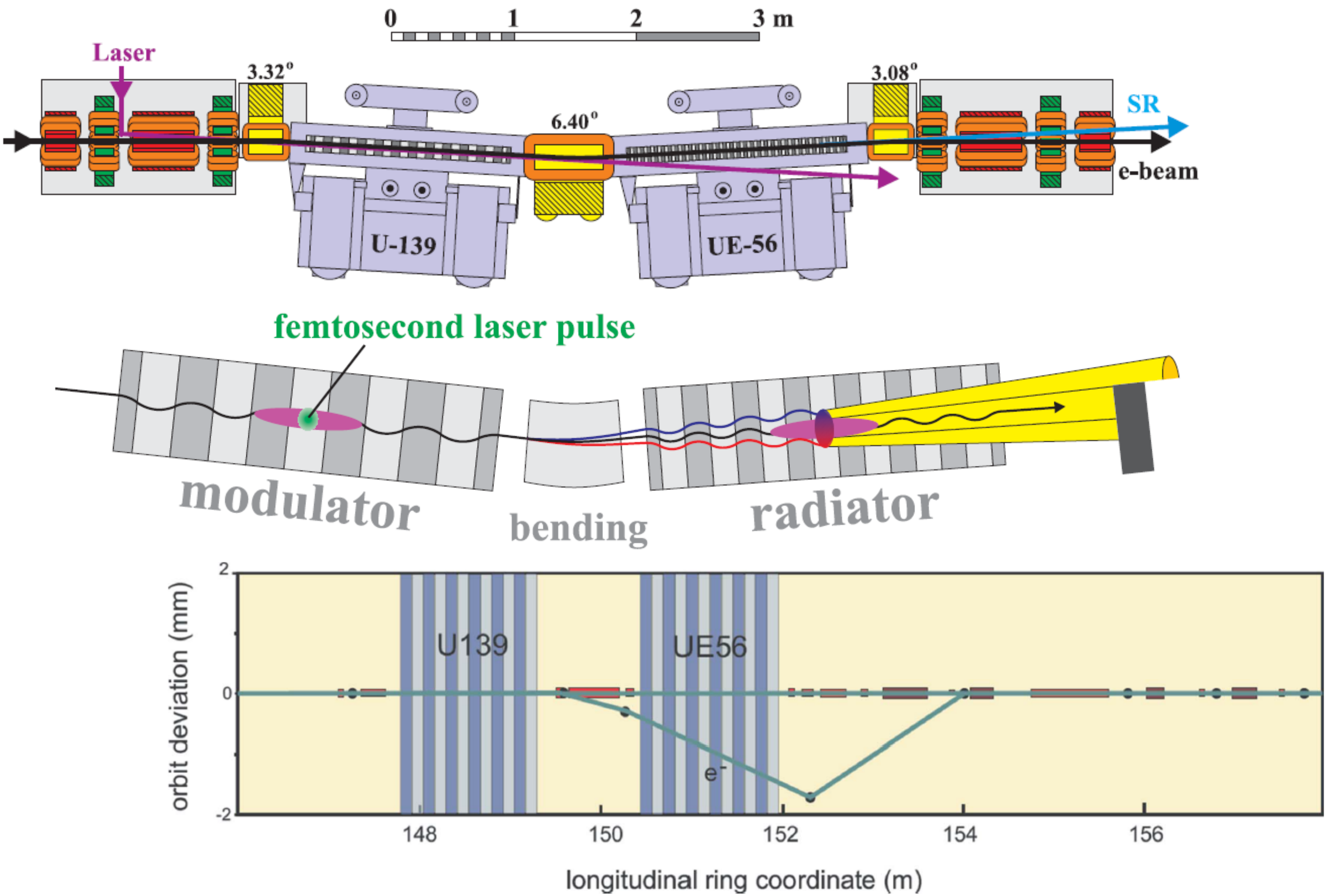
Timing Experiments are well supported @ BESSY II

- Multi Bunch Hybrid Fill pattern since 2015, multi-mode fill pattern
  - 300x multi bunch: 0.9 mA / bunch, 10 ps
  - 1x camshaft bunch: 4 mA, 17 ps, purity > 10^4 (pump, probe)
  - 1x PPRE bunch: 1.25 MHz, 800ns, 10^7 - 10^9 photons/s 0.1%BW for ARTOF setup
  - (Pulse Picking Resonant Excitation)
  - 3x fs-slicing bunch: 4 mA / bunch, 17 ps -> 100 fs photon pulses,
  - 10^6 photons/s 0.1%BW

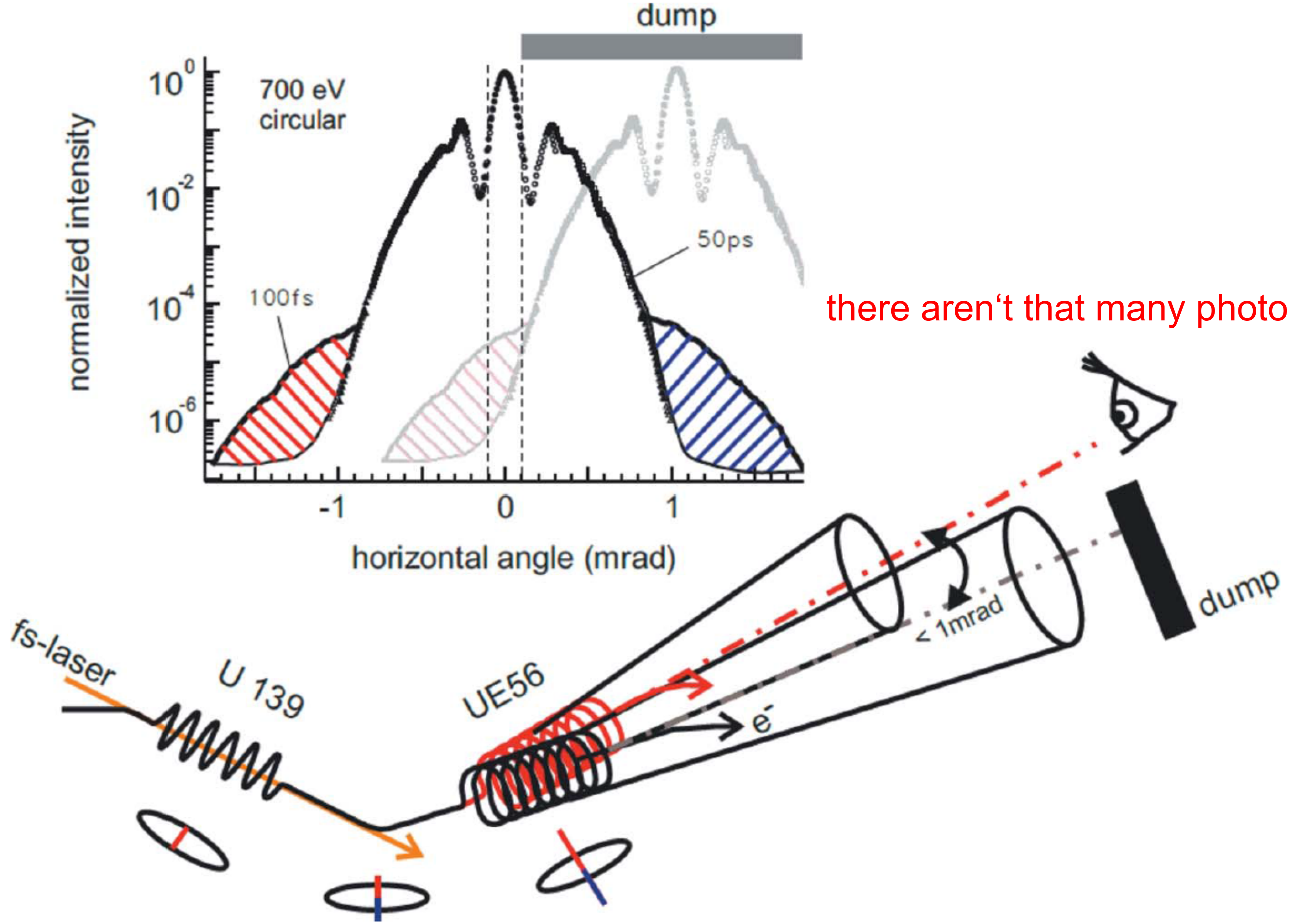


Multi-mode fill pattern since 2015

BESSY II specialities: slicing



BESSY II specialities: slicing



there aren‘t that many photons

BESSY II specialities: slicing

FEMTOSPEX

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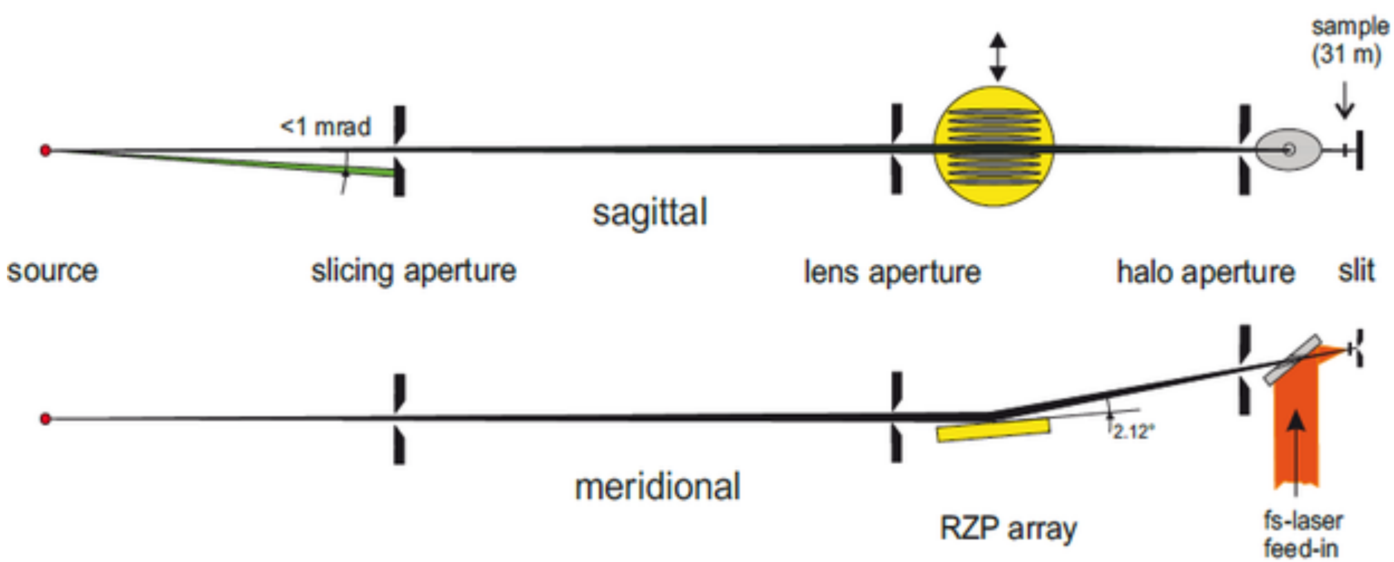
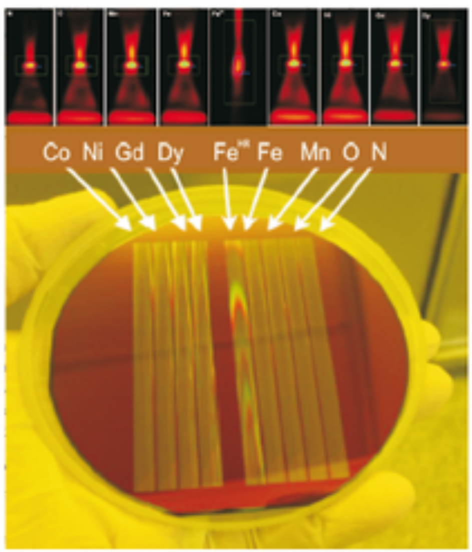
FemtoSpeX: a versatile optical pump–soft X-ray probe facility with 100 fs X-ray pulses of variable polarization

Karsten Holldack,[a]* Johannes Bahrdt,[a] Andreas Balzer,[a] Uwe Bovensiepen,[b] Maria Brzhezinskaya,[a] Alexei Erko,[a] Andrea Eschenlohr,[b] Rolf Follath,[a,c] Alexander Firsov,[a] Winfried Frentrup,[a] Loïc Le Guyader,[a] Torsten Kachel,[a] Peter Kuske,[a] Rolf Mitzner,[a] Roland Müller,[a] Niko Pontius,[a] Torsten Quast,[a] Ilie Radu,[a] Jan-Simon Schmidt,[a] Christian Schüßler-Langeheine,[d] Mike Sperling,[a] Christian Stamm,[e,a] Christoph Trabant[d,a]‡ and Alexander Föhlisch[a]¶

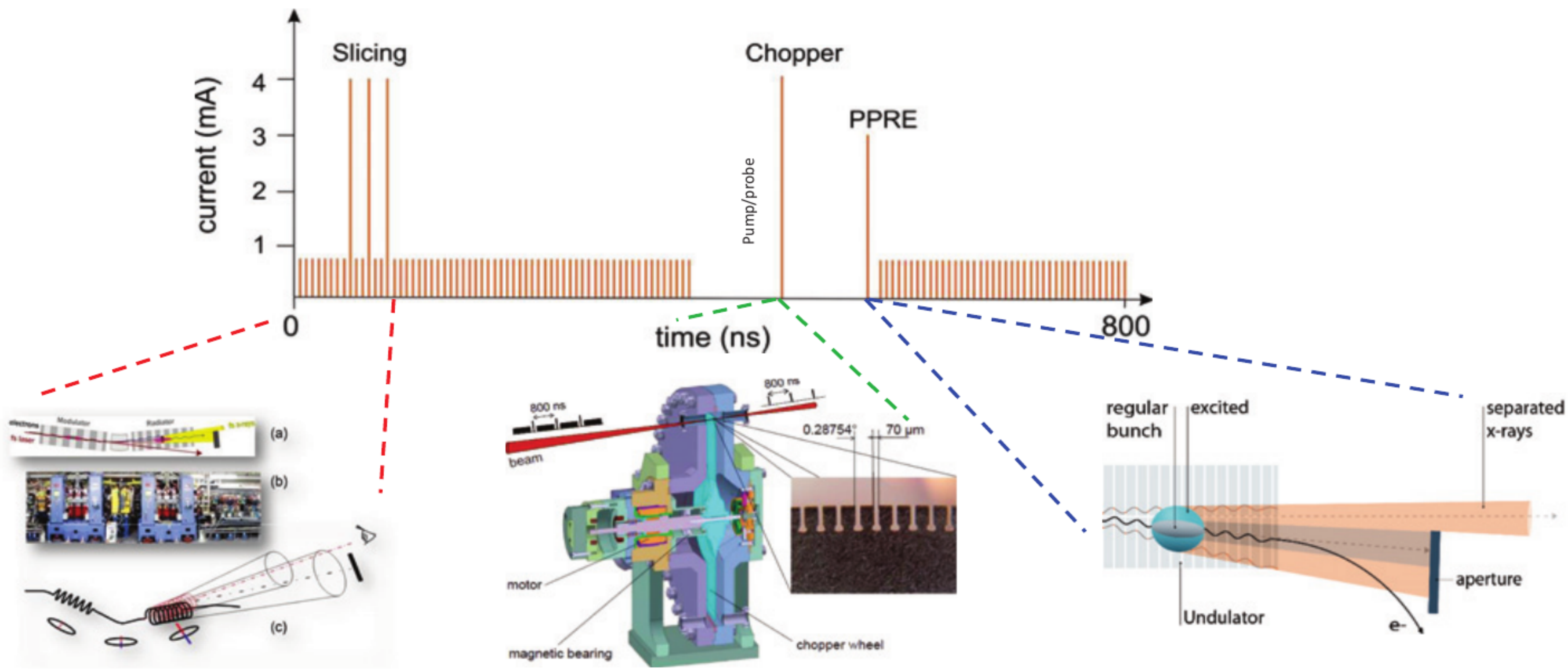
Features:

- 6 kHz femtosecond-laser
- 10^6 photons s^{-1} (0.1% bandwidth)
- 250 to 1400 eV with variable polarization
- high transmission (up to 21 %) single element monochromator with reflection zone plate (RZP)
- Pump-probe experiments
- Sample environment: temperatures down to 6 K, magnetic fields up to 0.5 T



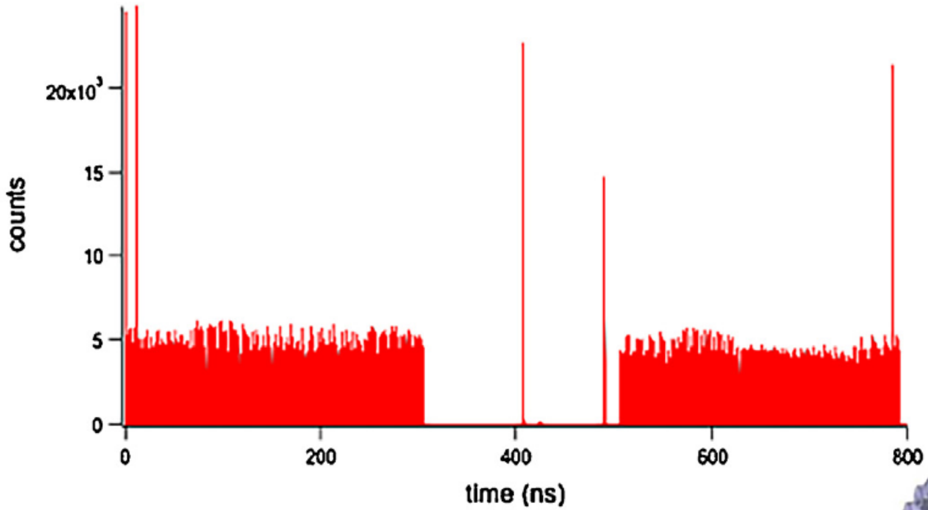


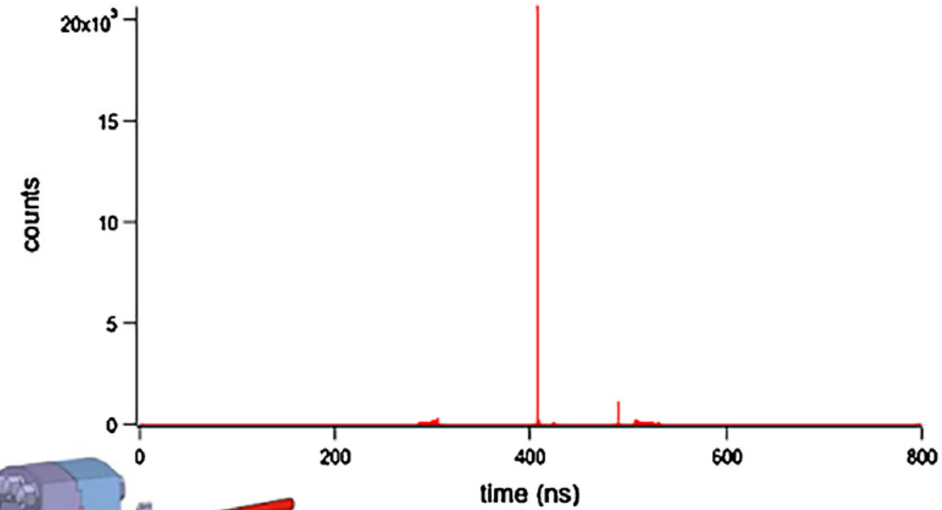
BESSY II specialities: chopping the camshaft bunch

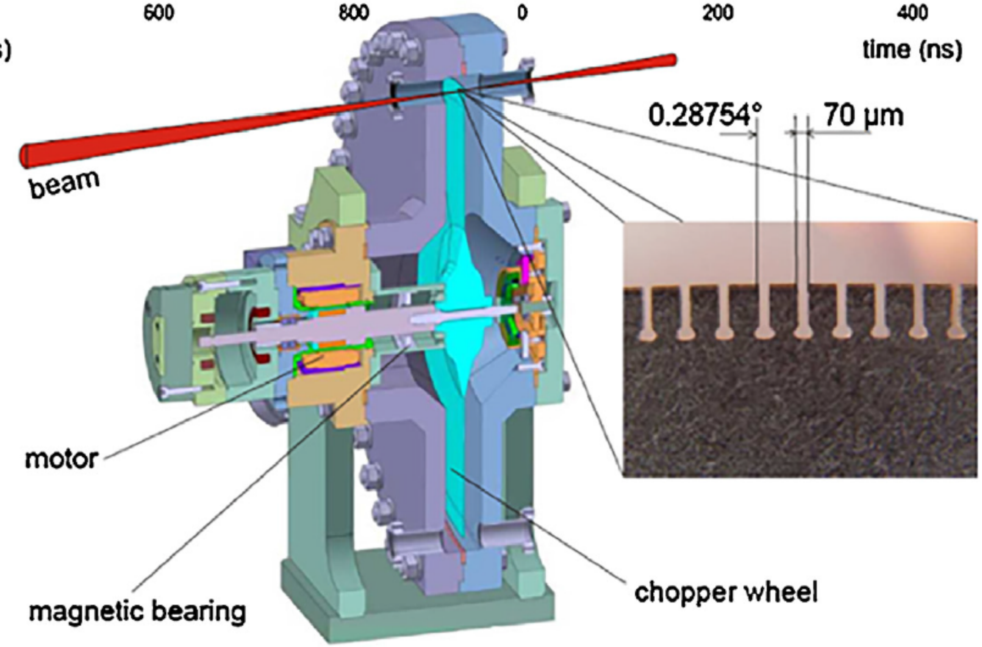


Alternative – electronic gating of detector

BESSY II specialities: chopping the camshaft bunch

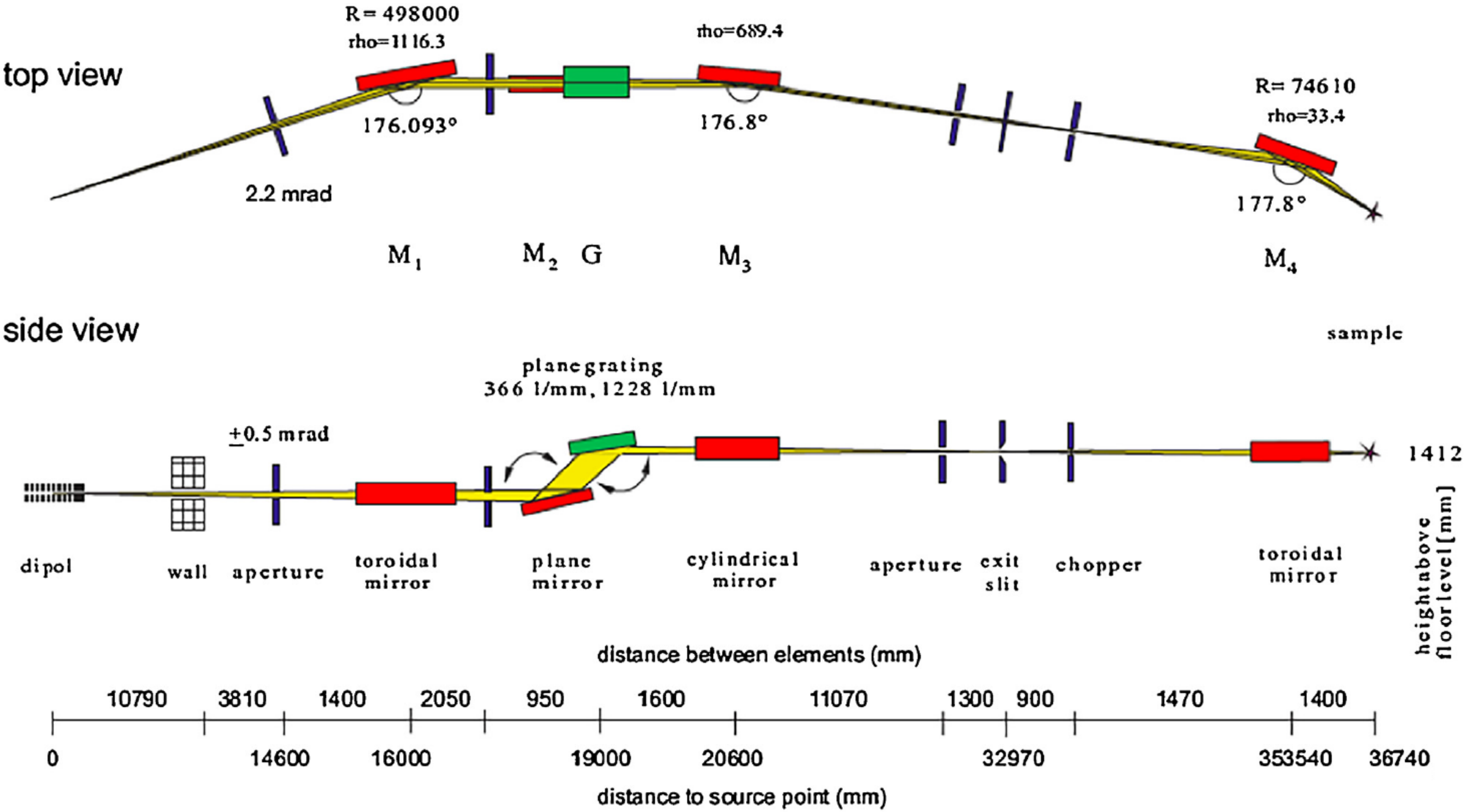






article in press: E. Giangrisostomi, et al., Low Dose Photoelectron Spectroscopy at BESSY II: Electronic structure of matter in its native state, J. Electron Spectrosc. Relat. Phenom. (2017), http://dx.doi.org/10.1016/j.elspec.2017.05.011

BESSY II specialities: chopping the camshaft bunch



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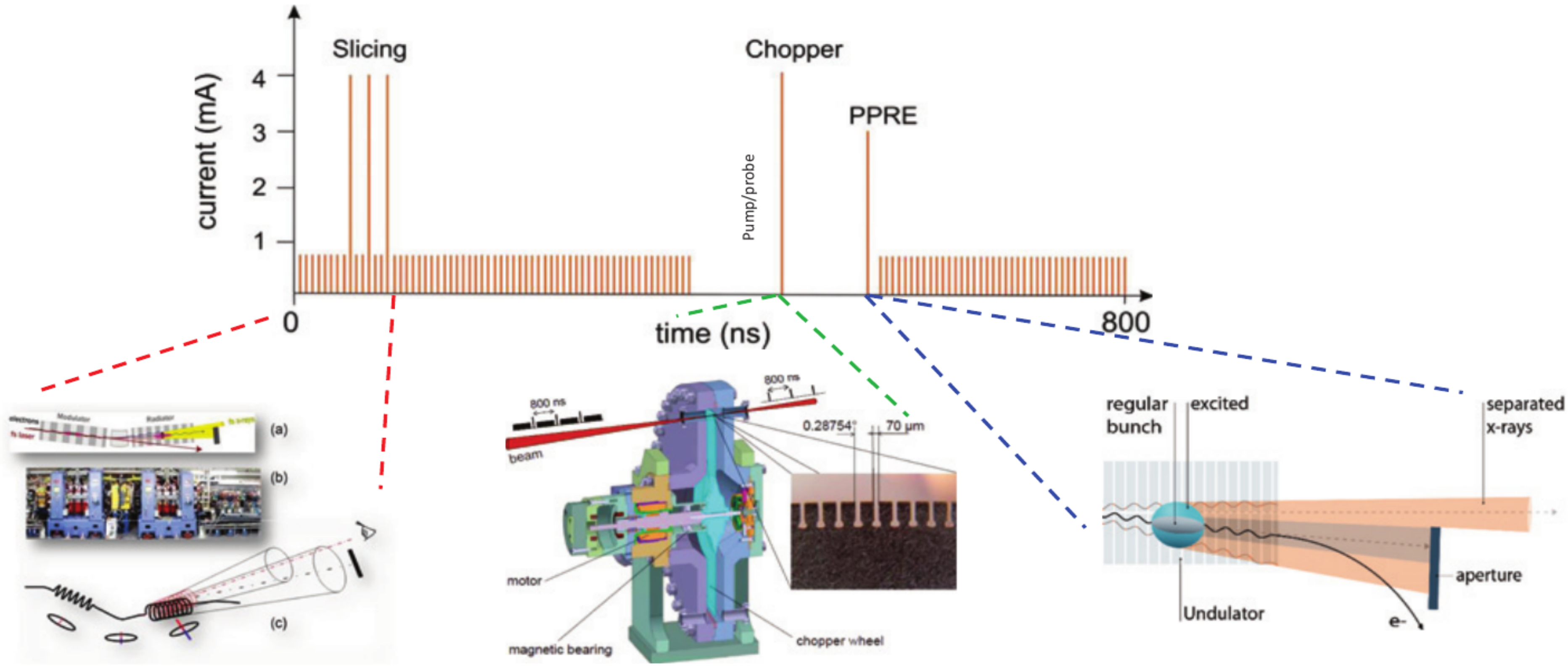
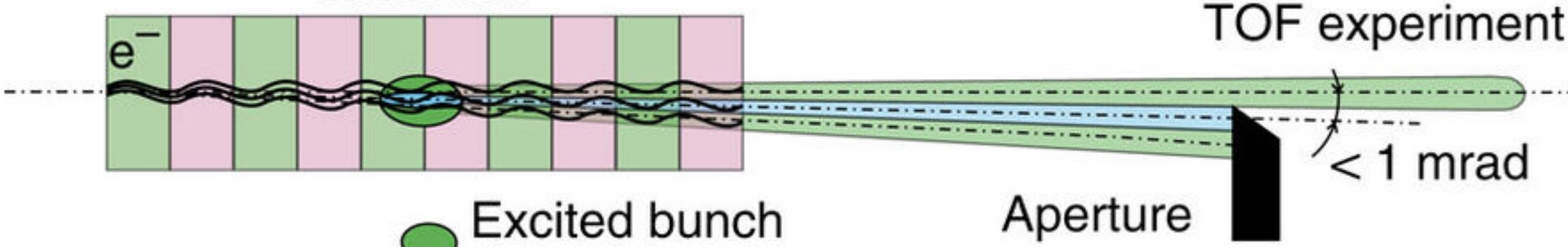

Slicing
Chopper
PPRE
current (mA)
4
3
2
1
Pump/probe
0
time (ns)
800
(a)
(b)
(c)
800 ns
800 ns
beam
0.28754°
70 µm
motor
magnetic bearing
chopper wheel
regular bunch
excited
separated x-rays
aperture
Undulator
e-

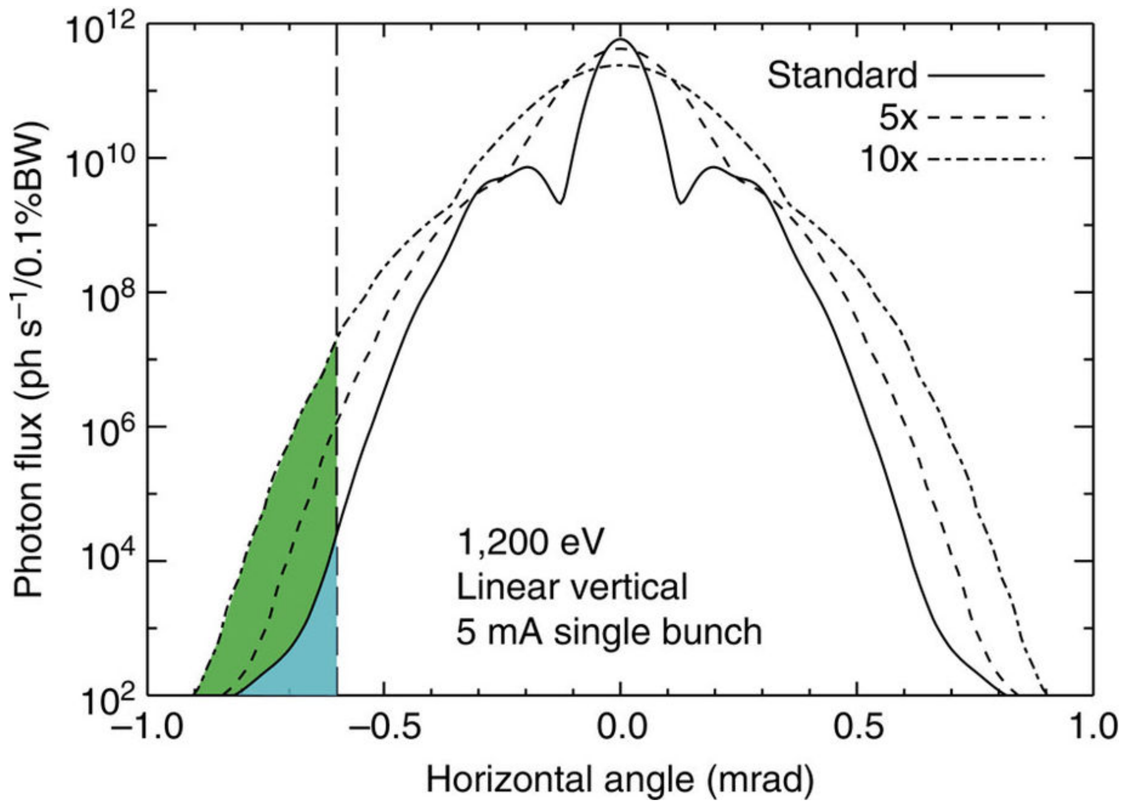
BESSY II specialities: pulse picking by quasi resonant excitation



nature COMMUNICATIONS

K. Holldack, et al., „Single bunch X-ray pulses on demand from a multi-bunch synchrotron radiation source“, DOI: 10.1038/ncomms5010, May, 2014

Extremely small photon flux requires very sensitive detection schemes



BESSY II specialities: ARTOF

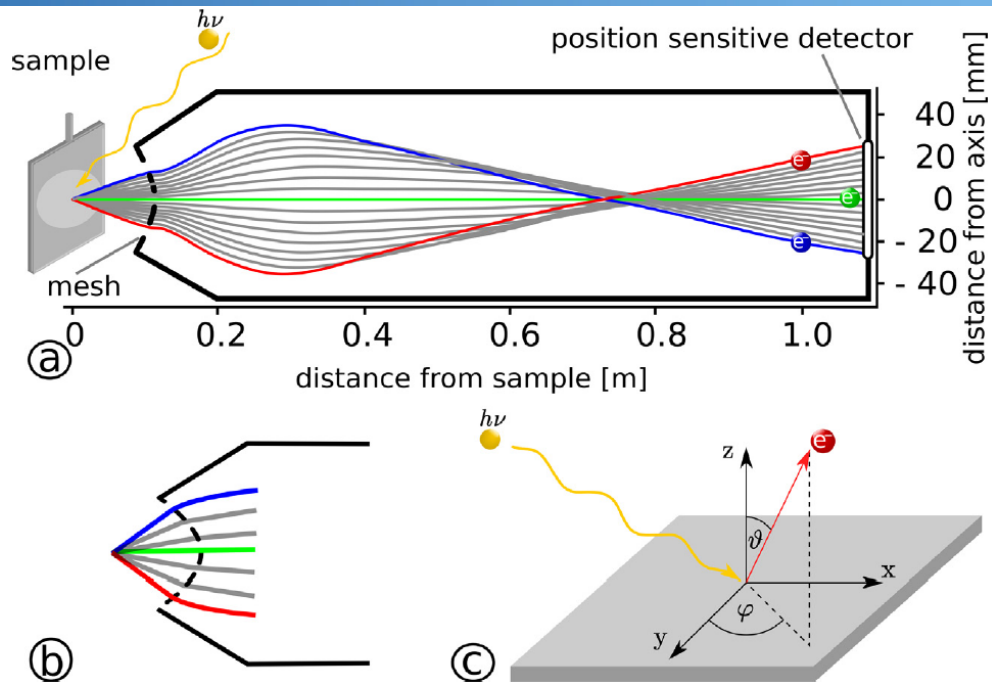


Fig. 1. a) Schematic drawing of the 60° wide angle acceptance ARTOF. Electrons emitted from the sample under high angles with respect to the surface normal (red and blue lines), are deflected strongly towards the optical axis (green line) when entering the spectrometer entrance due to the retardation mesh. Depicted electrons close to the detector mark equal flight times. b) Insight of the ARTOF entrance c) Photoemission geometry.

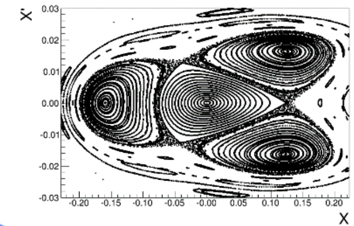
Arival time and position are related to emission angle and energy of photo electrons
Large acceptance angle (30° – 60°) and high transmission efficiency (300 – 800 times higher) – suitable for low dose experiments requiring small incoming photon flux

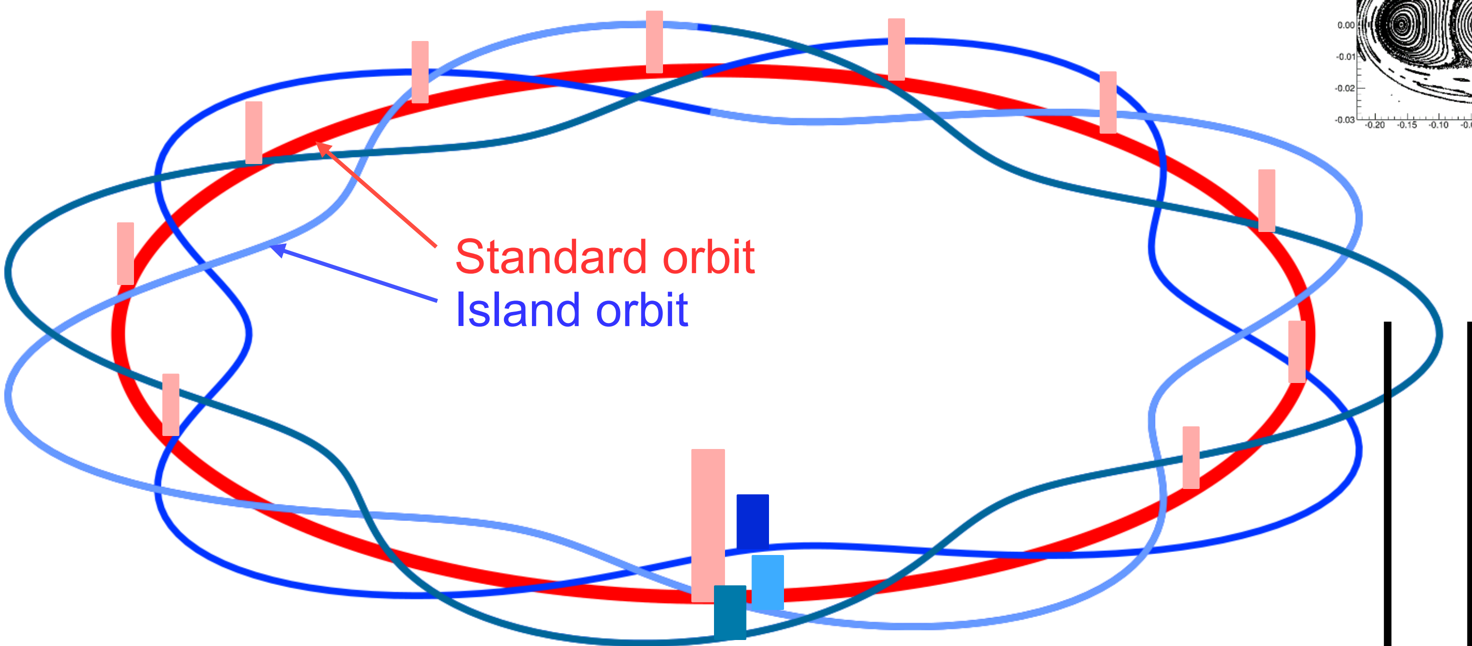
article in press: D. Kühn, et al., Capabilities of Angle Resolved Time of Flight electron spectroscopy with the 60° wide angle acceptance lens, J. Electron Spectrosc. Relat. Phenom. (2017), http://dx.doi.org/10.1016/j.elspec.2017.06.008

Alternative to mechanical chopper (long gaps) and kick-and-cancel scheme (ALS)

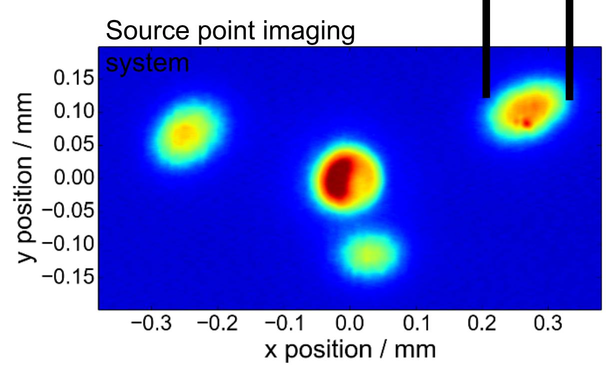
Separation scheme using Transverse Resonance Island Buckets (TRIBs)

3rd order resonance - island orbit closes after 3 turns





population of islands with bunch-by-bunch feedback



One week test run with more users and in top-up mode, February 2018

Driving forces behind TRIBs – G.Wüstefeld, M.Ries, P.Goslawski
M. Ries et al., Proceedings of IPAC2015, Richmond, VA, USA, MOPWA021
P. Goslawski et al., Proceedings of IPAC2017, Copenhagen, Denmark, WEPIK057

BESSY II specialities: single and few bunch

C. Tusche, P. Goslawski et al., App. Phys. Lett. 108, 261602, (2016)

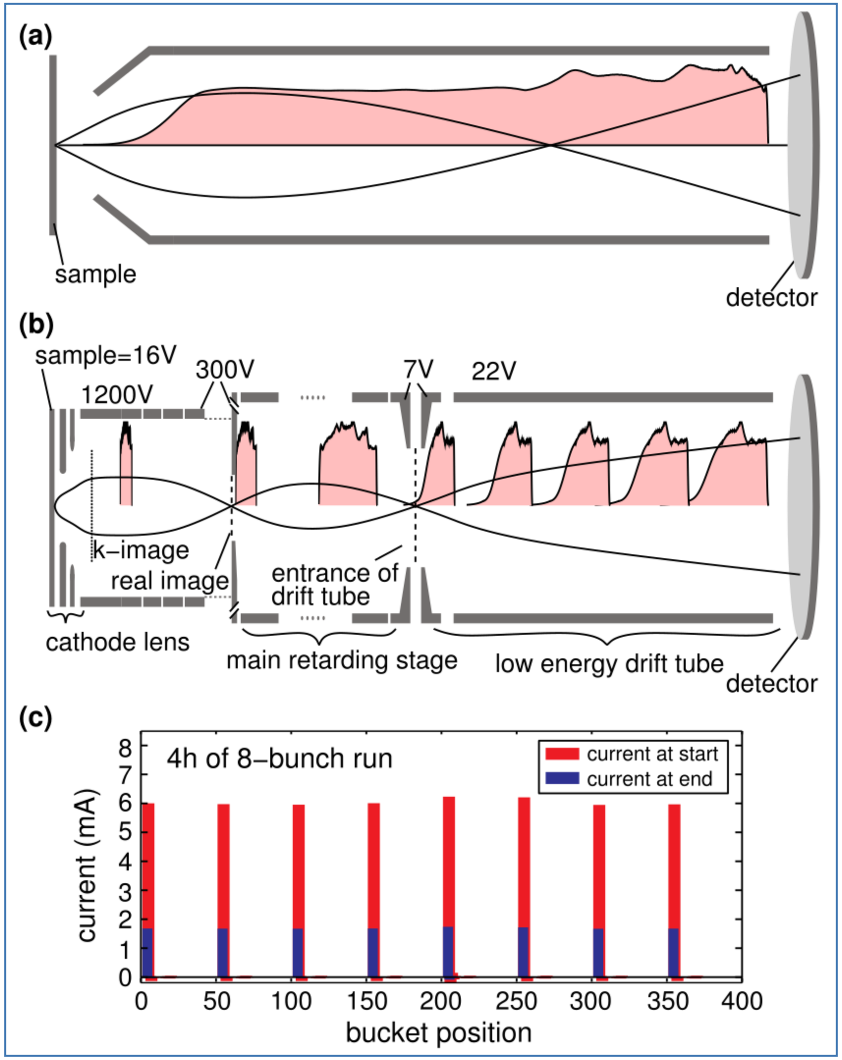
Timing Experiments are well supported @ BESSY II

2 - 4 weeks true single bunch (SB):
  1.25 MHz, 800ns, 13.5 mA, 27 ps

Since 2017 few bunch:
SB weeks weekends
  5 MHz, 200ns, 32mA,
  4 bunches x 8 mA / bunch, 21 ps

or

  10 MHz, 100 ns, 8 bunches



APPLIED PHYSICS LETTERS **108**, 261602 (2016)

Multi-MHz time-of-flight electronic bandstructure imaging of graphene on Ir(111)

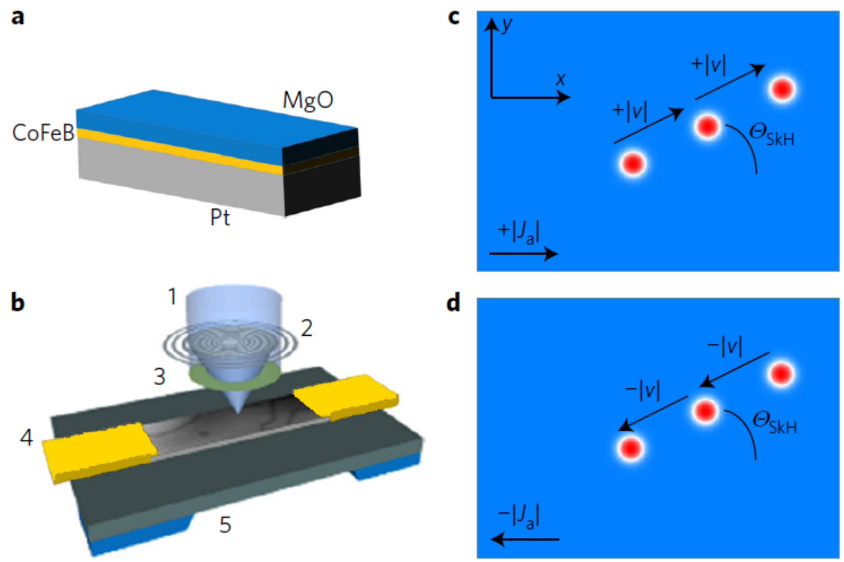
C. Tusche,[1,2,a)] P. Goslawski,[3] D. Kutnyakhov,[4] M. Ellguth,[1,4] K. Medjanik,[4,5] H. J. Elmers,[4] S. Chernov,[4] R. Wallauer,[4] D. Engel,[3] A. Jankowiak,[3] and G. Schönhense[4]

Timing Experiments are well supported @ BESSY II

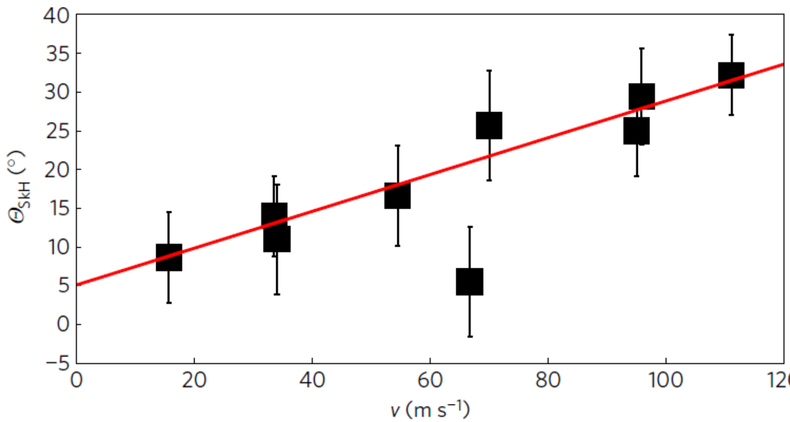
STXM, XMCD, RF-pump-and-probe setup for time resolved imaging of magneto dynamics by stroboscopic technique:

- flexible repetition rates
- time resolution <100ps
- spatial resolution <30nm

Litzius, K.; Lemesh, I.; Krüger, B.; Bassirian, P.; Caretta, L.; Richter, K.; Büttner, F.; Sato, K.; Tretiakov, O.A.; Förster, J.; Reeve, R.M.; Weigand, M.; Bykova, I.; Stoll, H.; Schütz, G.; Beach, G.S.D.; Kläui, M.: Skyrmion Hall effect revealed by direct time-resolved X-ray microscopy. , Nature Physics 13 (2017), p. 170-175 doi:10.1038/nphys4000



Schematic description of technique and observed skyrmion Hall effect.



Experimentally observed skyrmion Hall angles of the skyrmion displacement with respect to the current flow direction for different

BESSY II specialities: low α_c operation

M. Abo-Bakr et al., Phys. Rev. Lett. 88, 254801 (2002)

R.Müller et al., Proceedings of IPAC2016, Busan, Korea, WEPOW011

K. Holldack, C. Stamm, HZB, in preparation

Timing Experiments are well supported @ BESSY II

2 - 4 weeks low α_c operation: 0.045 mA or 0.3 mA / bunch, 3 ps
15 mA or 100 mA (non-bursting or bursting)
CSR- and short pulse users

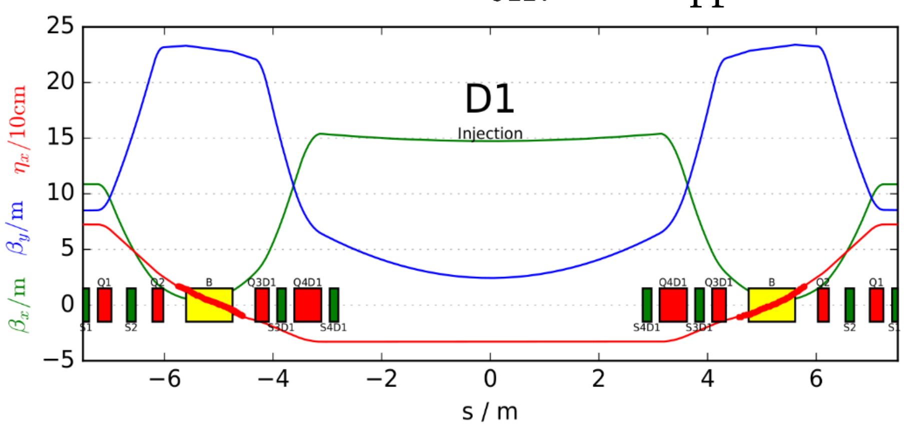
Short bunches with low α_c:

$$\sigma_0 = \delta_0 \cdot \sqrt{\frac{E_0}{f_0}\frac{\alpha_c}{V'}}$$

$$\alpha_c = \frac{1}{L_0}\oint \frac{D_x}{\rho}\, ds$$

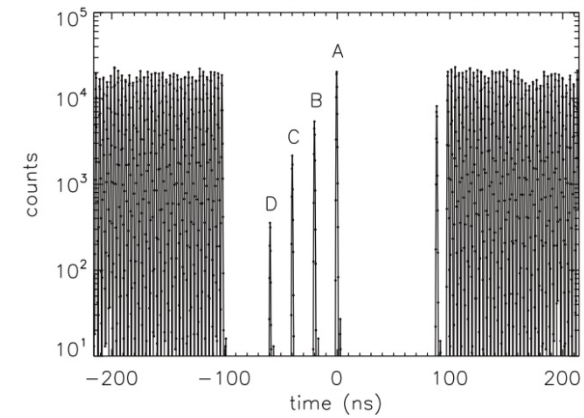
J. Feikes et al., Proceedings of EPAC2004, Lucerne, Switzerland, WEPLT051

$$I_{\text{th.}} \sim \alpha_c \qquad I_{\text{th.}} \sim V'_{\text{rf}}$$

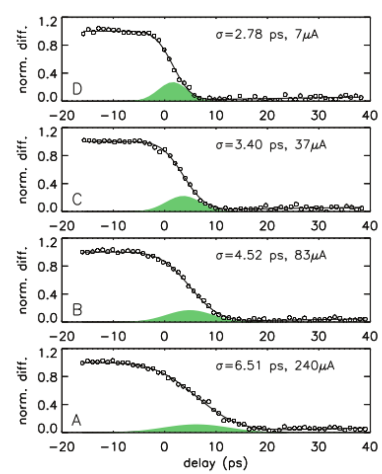


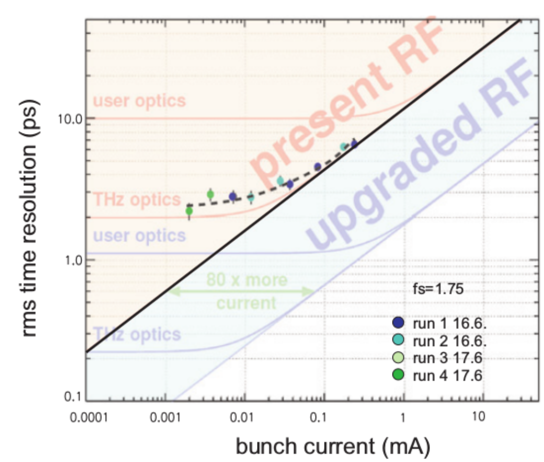
Further development:

Exotic filling – VSR
Target bunch current on demand with BBFB
240 µA - 6.5 ps
7µA - 2.8 ps



For x-ray magnetic circular dichroism (XMCD) transmission pump probe at GdFeCo

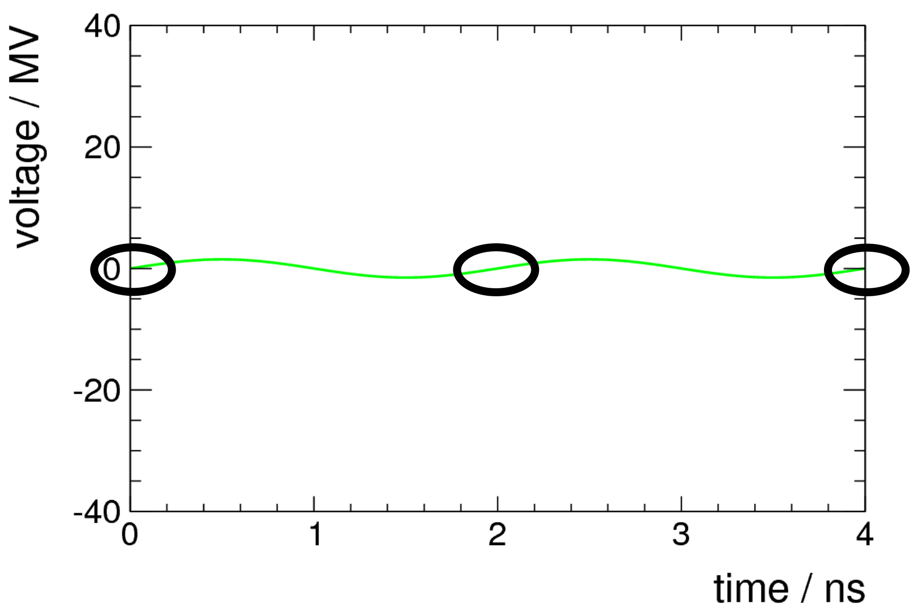


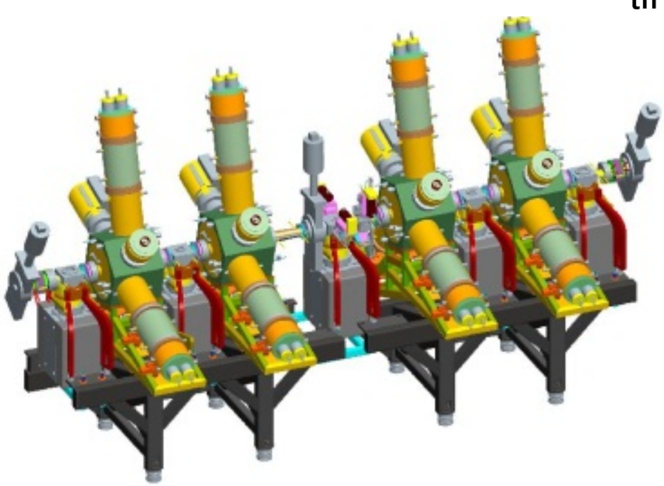


Voltage beating scheme

G. Wüstefeld, et al., Proceedings of IPAC2011, San Sebastian, Spain, THPC014

Short and long bunches simultaneously





Cavity system for gradient manipulation

- Normal installed rf cavity
- V' = 2π 0.5 1.5 GHz MV

Voltage beating scheme

G. Wüstefeld, et al., Proceedings of IPAC2011, San Sebastian, Spain, THPC014

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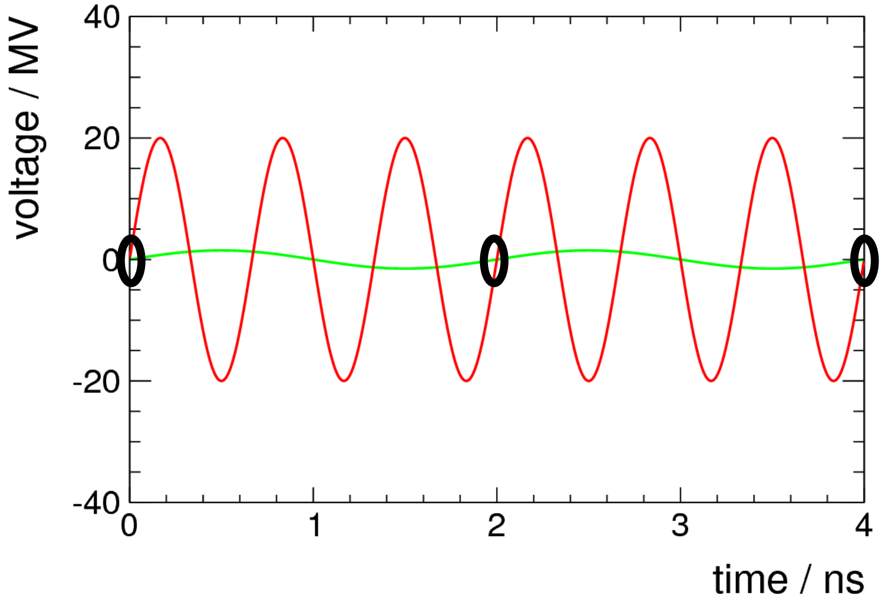
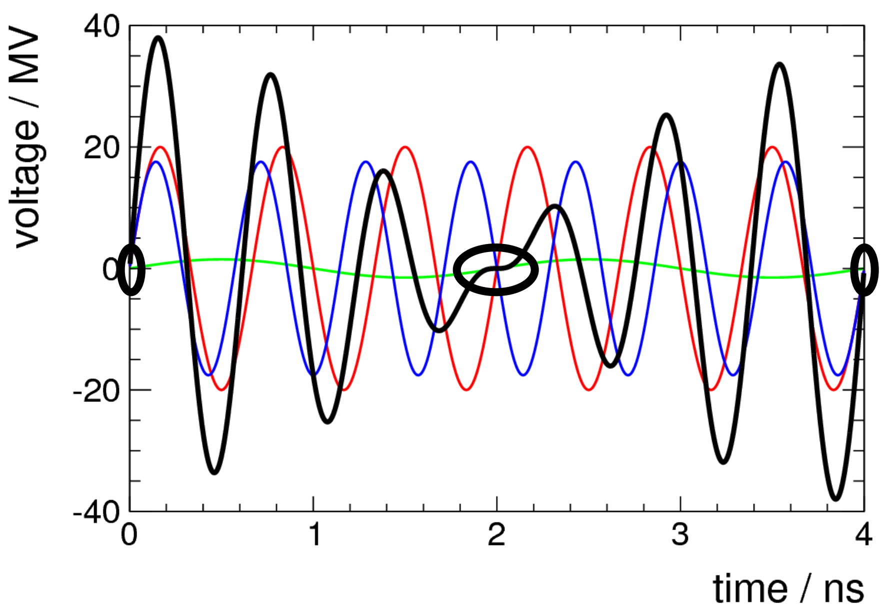


Cavity system for gradient manipulation

- Normal installed rf cavity
- V' = 2π 0.5 1.5 GHz MV
- 1st SC RF cavity, 3rd harmonic
- V' = 2π 1.5 20 GHz MV

G. Wüstefeld, et al., Proceedings of IPAC2011, San Sebastian, Spain, THPC014

Short and long bunches simultaneously



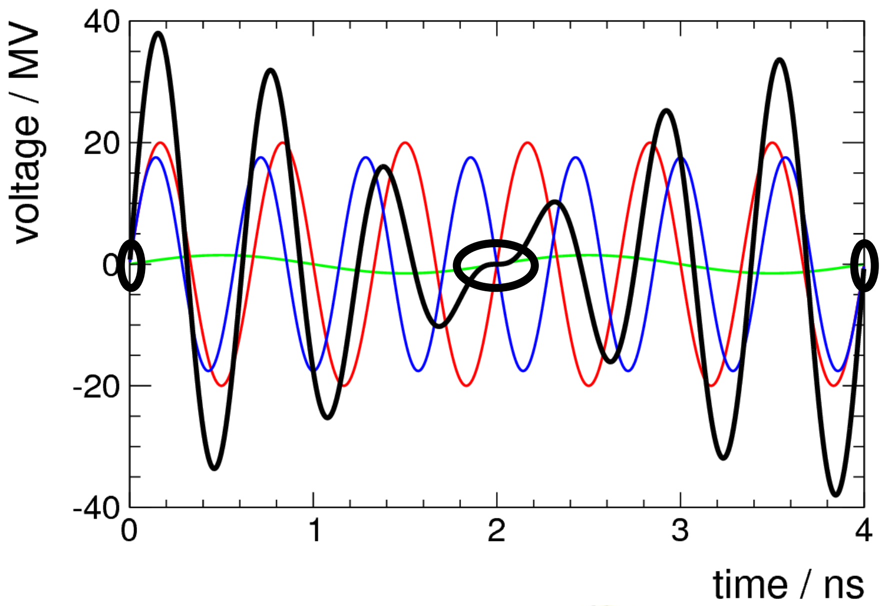
Cavity system for gradient manipulation

- Normal installed rf cavity
- V’ = 2π 0.5 1.5 GHz MV
- 1st SC RF cavity, 3rd harmonic
- V’ = 2π 1.5 20 GHz MV
- 2nd SC RF cavity, 3.5th harmonic
- V’ = 2π 1.75 17 GHz MV
- In total V’(BII)= 2π 0.75 GHz MV
- V’(VSR)= 2π 60.0 GHz MV

Voltage beating scheme

G. Wüstefeld, et al., Proceedings of IPAC2011, San Sebastian, Spain, THPC014

Short and long bunches simultaneously



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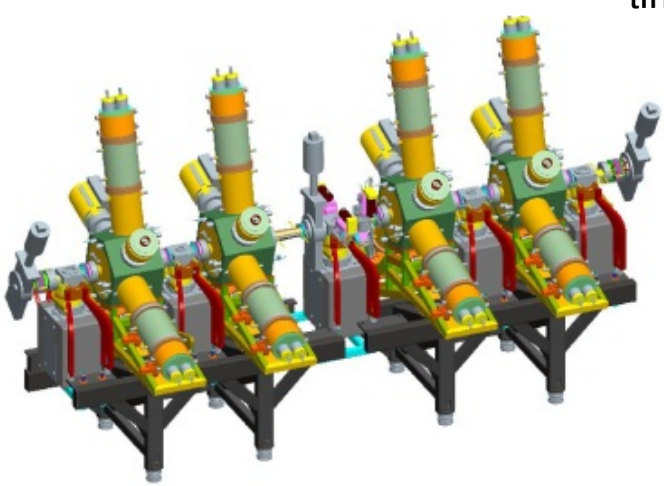
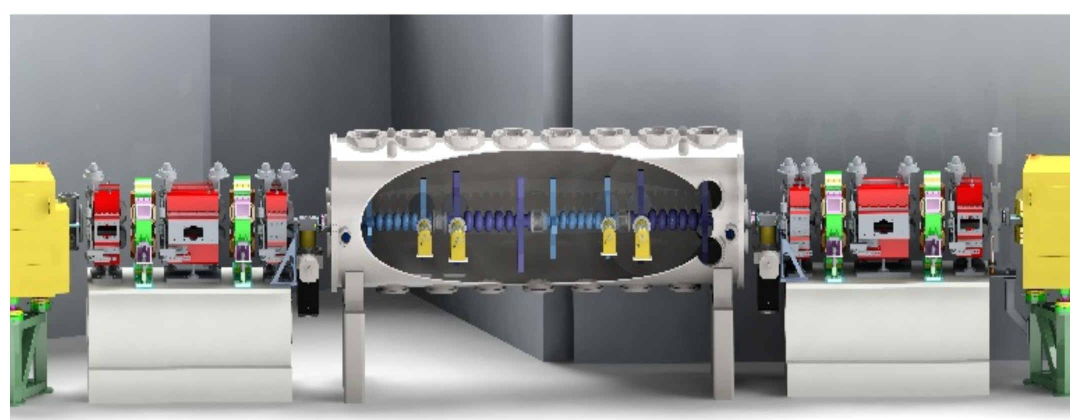
- In total V'(BII)= 2π 0.75 GHz MV
- V'(VSR)= 2π 60.0 GHz MV
- Voltage beating results in alternating large and small V'





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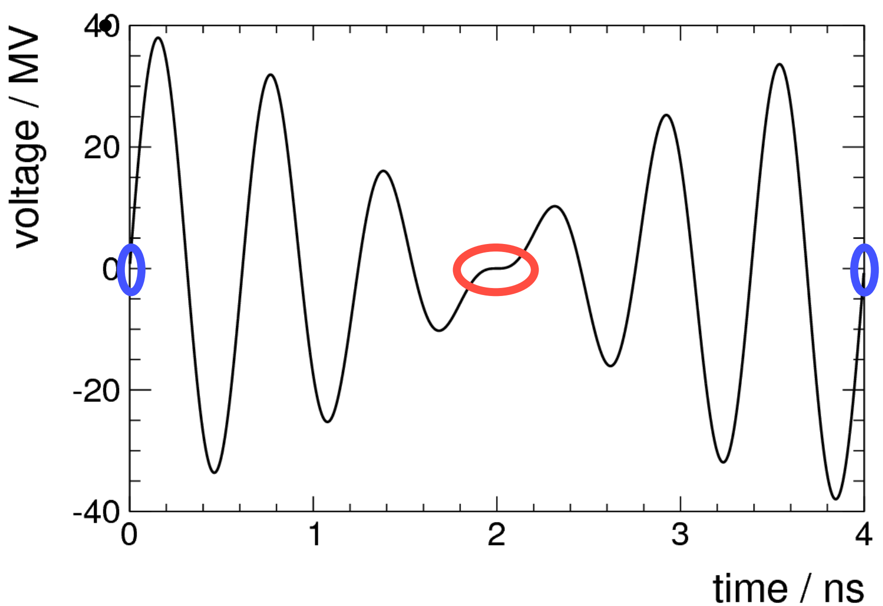

Cavity system for gradient manipulation

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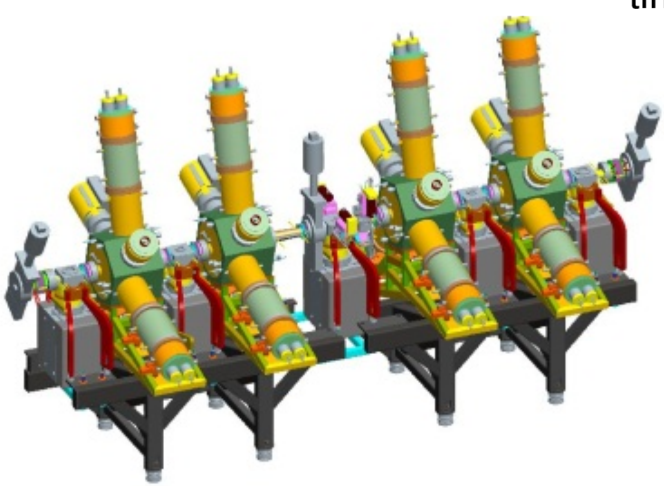
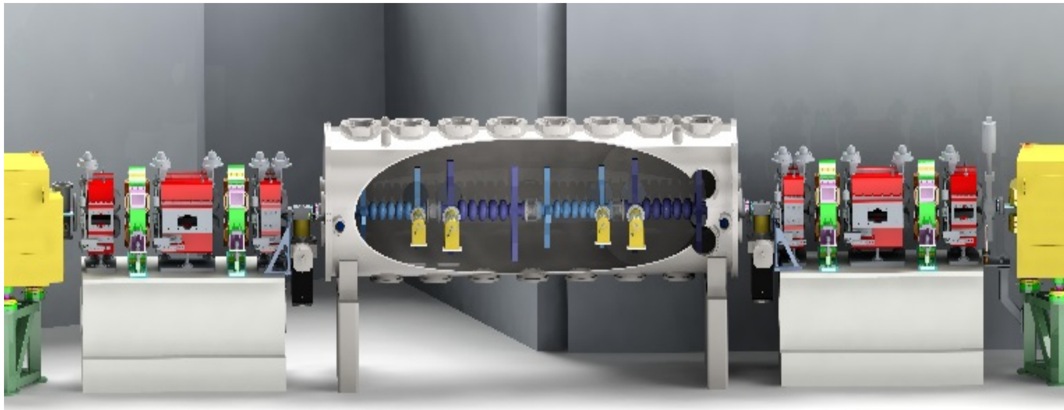
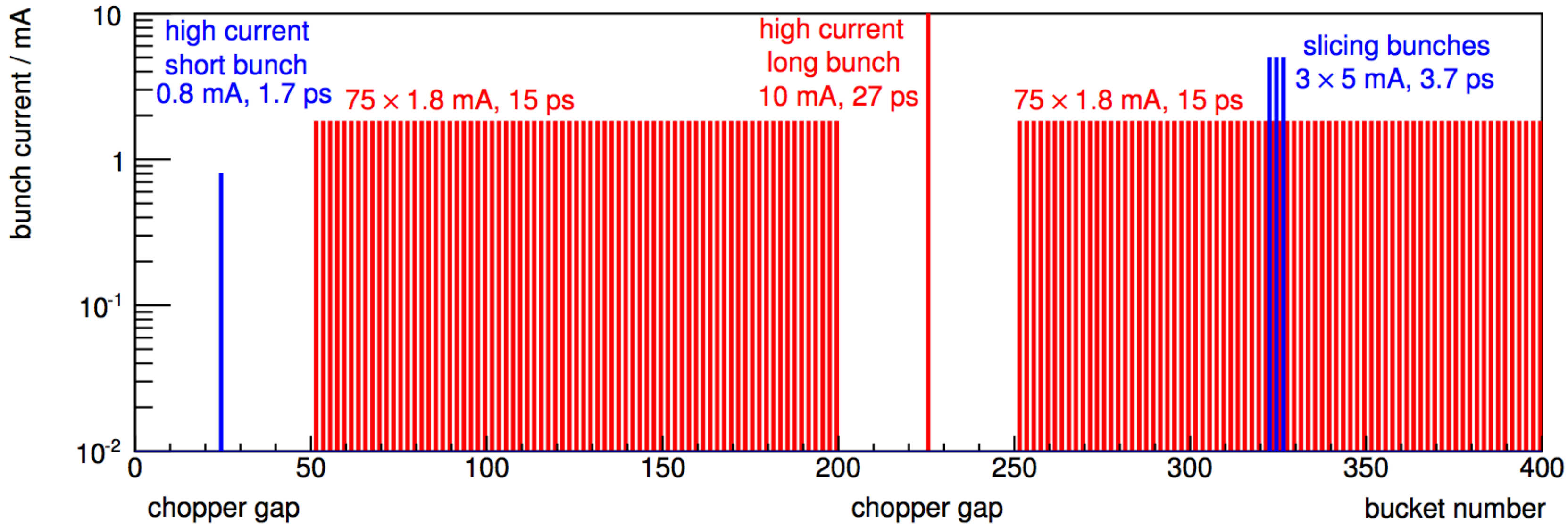




BESSY VSR project parameters

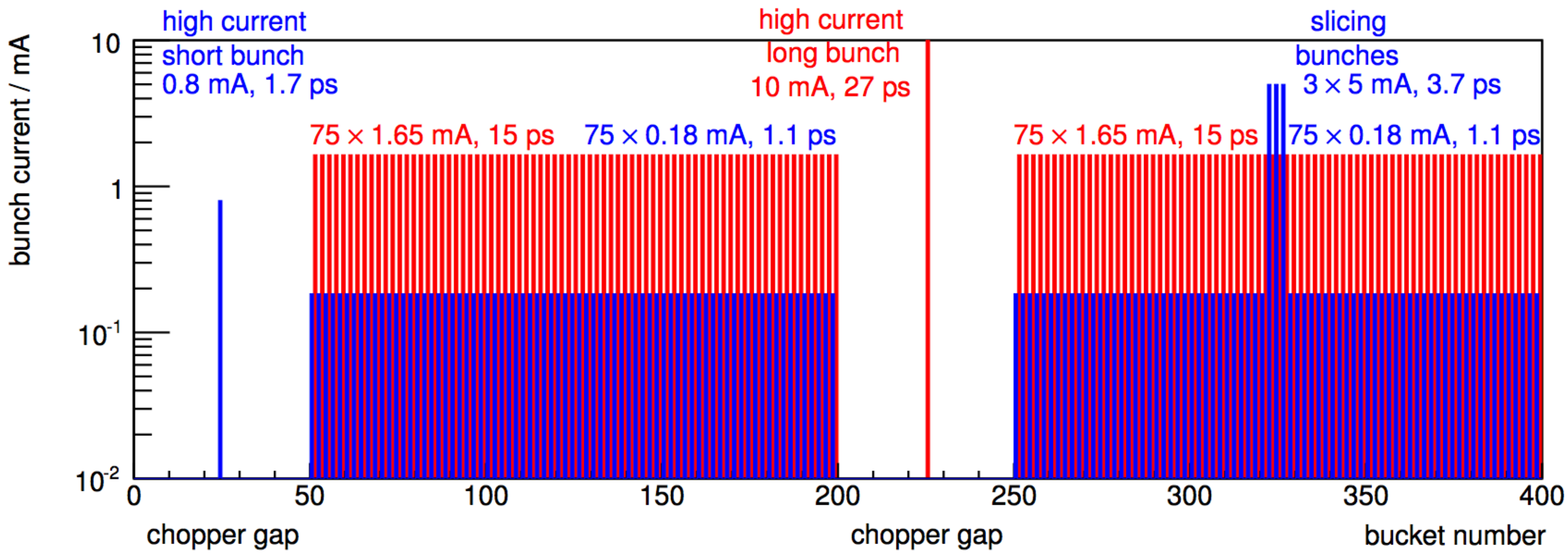


BESSY VSR multi functional fill pattern:

- ps short single bunch -> short intense X-Ray pulse for timing exp.
- -> short slicing bunches -> 5 times more photons, high current camshaft bunch
- -> multi-bunch train for high average brilliance

- Preserving BESSY II emittance and top-up capabilities
- ε_x = 5 nm rad, lifetime > 5 h, average injection efficiency > 90 %

BESSY VSR project parameters



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- -> background of intense CSR/THz radiation bunches
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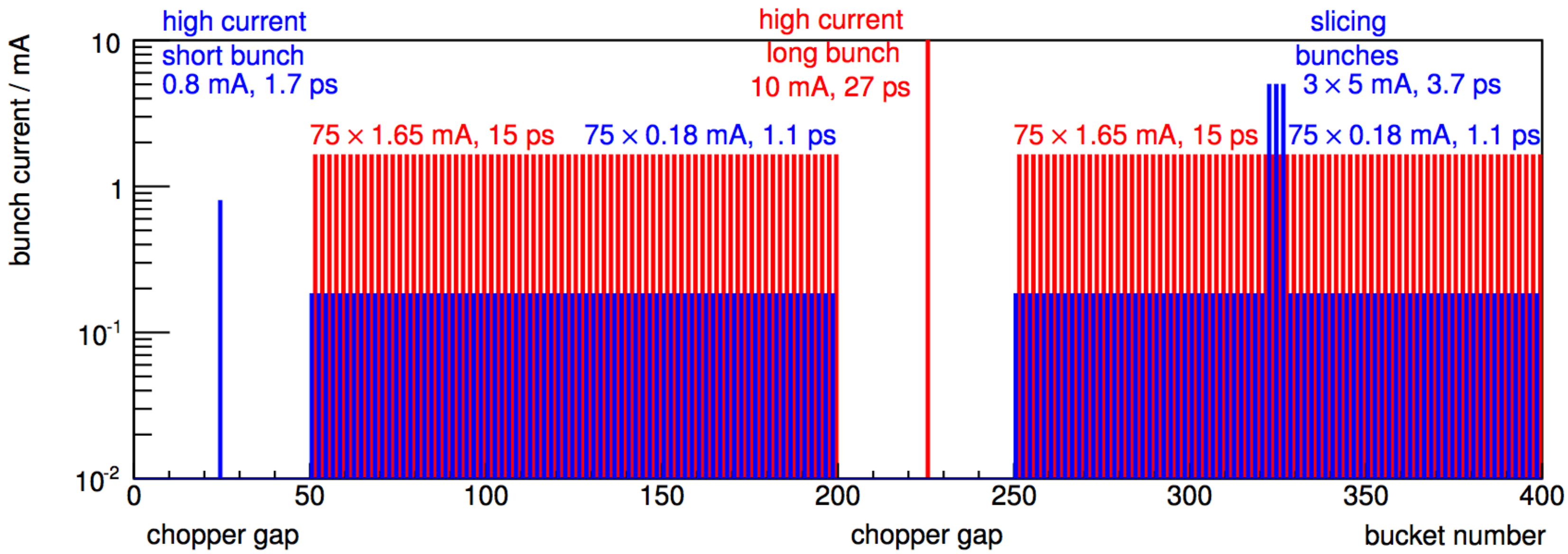
BESSY VSR project parameters



In low α_c mode:
400 fs @ 0.04 mA / bunch

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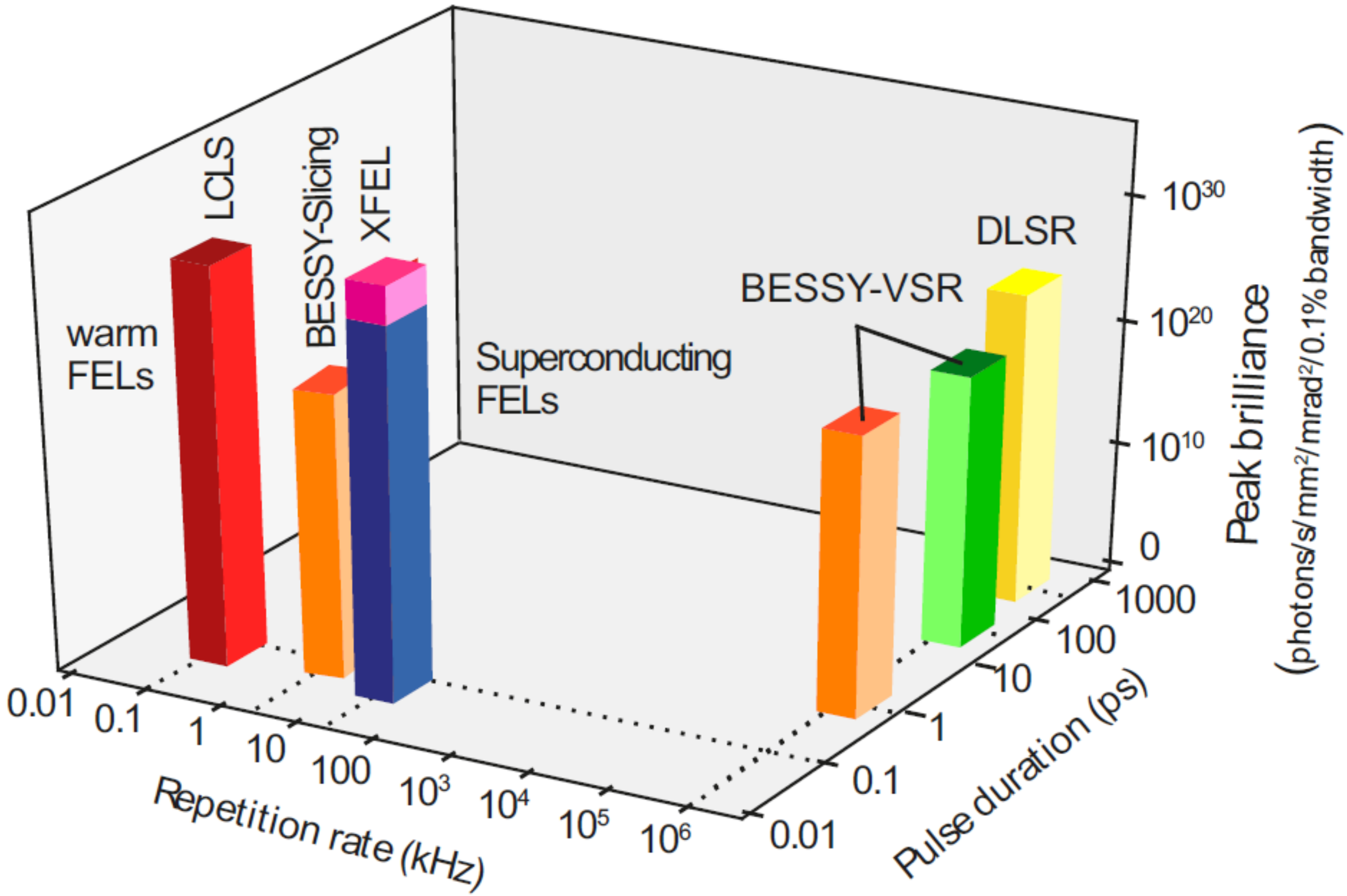
"Beating the complexity of matter through the selectivity of soft X-rays"



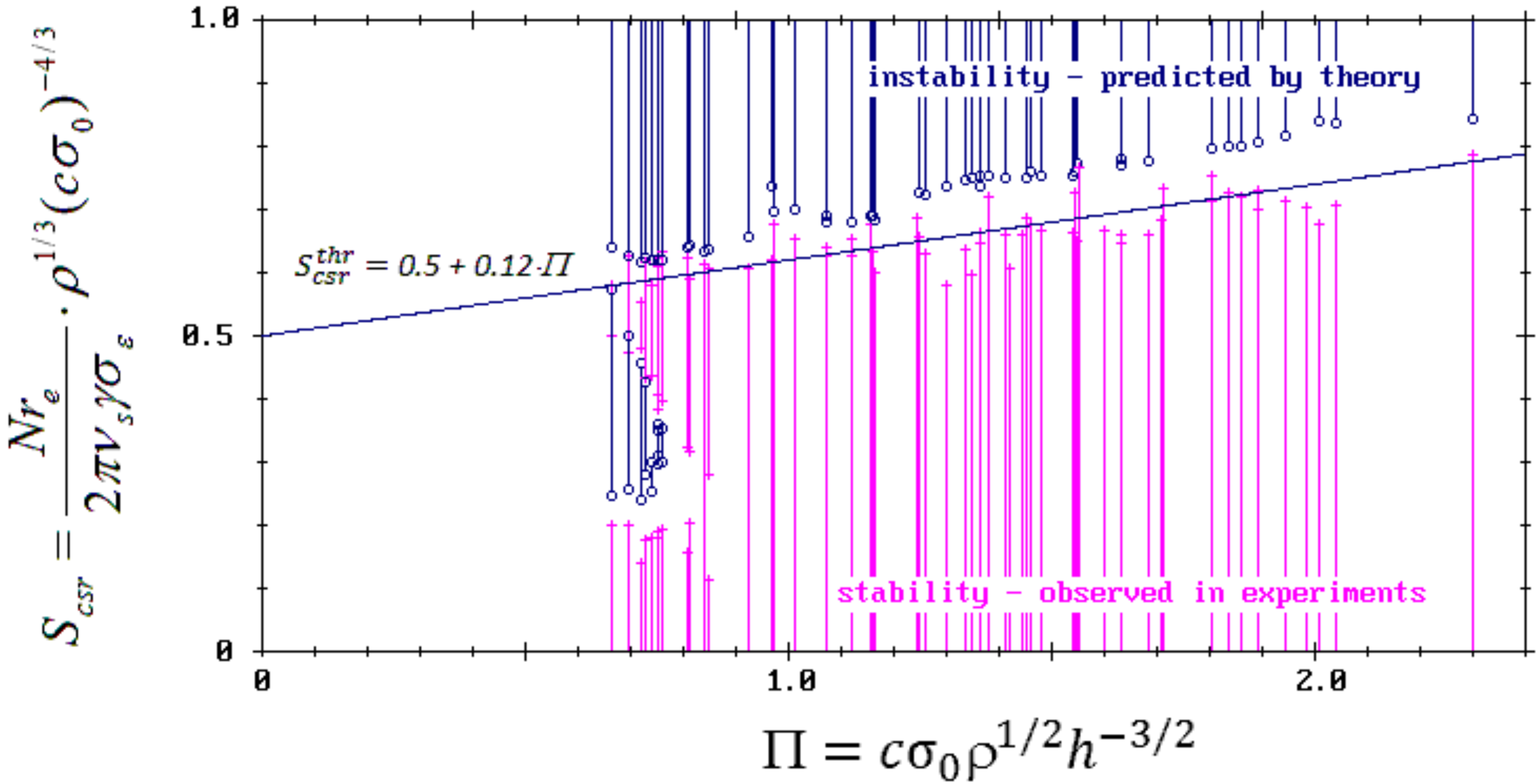
Alexander Föhlisch

BESSY VSR main challenges

- Short intense bunches - scaling behavior bunch-length vs. current
- Developement and operation of high gradient superconducting cavities
  - 1.5 GHz and 1.75 GHz @ 20 MV/m gradient in cw
  - -> 200W @ 1.8 K cooling plant (30% margin)
  - -> particle free (clean) vacuum araound cavity straight, 10^{-10} mbar
- Control of coupled bunch instablilites
  - Induced by sc cavitiy impedance, higher order modes
  - -> proper HOM damping desgin of sc cavities, waveguide HOM dampers
  - -> sufficiently strong bunch-by-bunch feedback
- Operation with large transient beam loading
  - Phase shift over bunch train, lifetime reduction
  - -> careful set up and control of RF-parameters
  - -> appropriate low-level RF-control
- TopUp operation: injection into short VSR bunches
  - Bunch lenght from booster 60 ps, injection efficiency > 60% / 90%
  - -> bunch compression in booster at least by factor 2 needed

P. Kuske, Proceedings of IPAC2017, Copenhagen, Denmark, thpab007
M. Brosi, et al., Proceedings IPAC2016, Busan, Korea, TUPOR006, and to be published

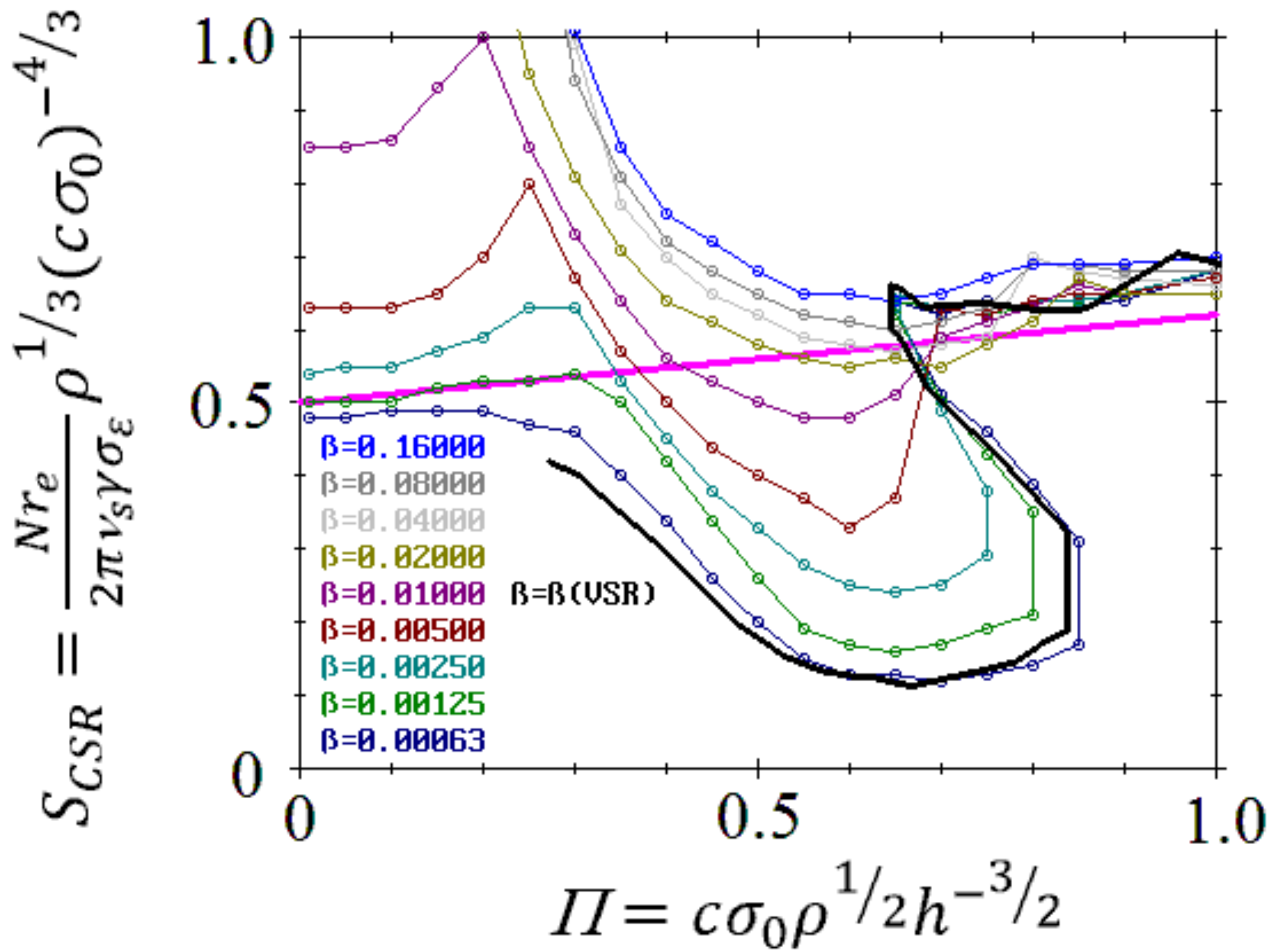
CSR-driven longitudinal instability of short bunches – predictions of VFP-solver with parallel plate model in comparison with observations at ANKA



BESSY II specialities: understanding short bunch limits

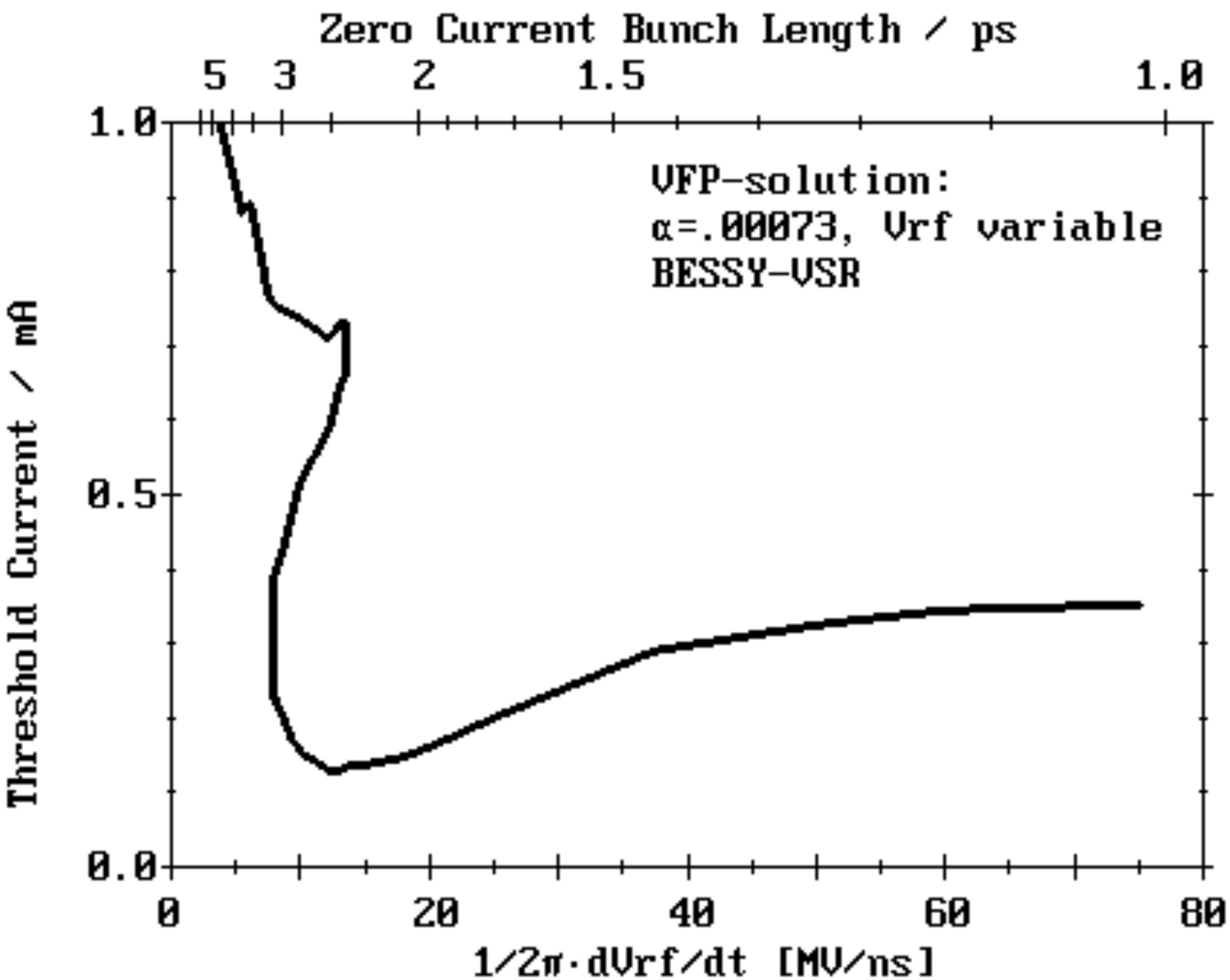
P. Kuske, Proceedings of IPAC2017, Copenhagen, Denmark, thpab007
P. Kuske, Proceedings of IPAC2013, Shanghai, China, WEOAB102

CSR-driven longitudinal instability of short bunches – predictions of VFP-solver with parallel plate model for BESSY VSR (in black)



P. Kuske, Proceedings of IPAC2017, Copenhagen, Denmark, thpab007
P. Kuske, Proceedings of IPAC2013, Shanghai, China, WEOAB102

CSR-driven longitudinal instability of short bunches – predictions of VFP-solver with parallel plate model for BESSY VSR (in black)



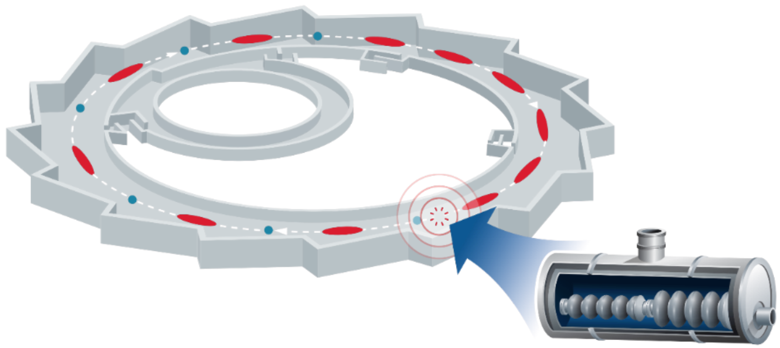
BESSY II Near Future -> BESSY VSR

Near term and fully funded upgrade path:

BESSY VSR – **V**ariable **P**ulse Length Storage **R**ing

- Conserving photon brilliance for all users and
- Add short intense pulse operation at all beam lines in parallel
- Shaping the longitudinal phase space by additional cavities **(local upgrade)**

Strengthen the Timing Experiment Community @ BESSY II / VSR



Future beyond 2025 => light source of the next generation

Over the years BESSY has kept a focus on time resolved experiments and invested resources to build up and strengthen the corresponding user community – important for next generation light sources as well