Single Particle Tracking for BESSY^{VSR}

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Outline

I Introduction to BESSY^{VSR} :
A Variable Pulse Length Storage Ring

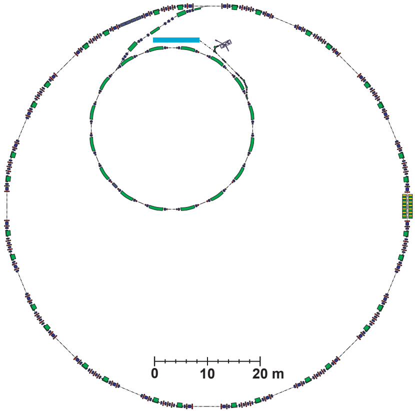
II Simulations (single particle dynamics)

- Ramping of RF cavities
- RF jitter

BESSY II: 3rd generation light source

BESSY II Parameters

Lattice	DBA
Circumference	240 m
Energy	1.7 GeV
Current	300 mA
RF frequency	500 MHz
RF voltage	1.5 MV
Bunch length (rms)	15 ps
Emittance	6 nm rad



Synchrotron radiation: THz . . . soft X-ray

BESSY^{VSR}

BESSY^{VSR} : A Variable Pulse Length Storage Ring

(G. Wüstefeld et al., IPAC 2011, San Sebastián, Spain, p. 2936)

Objectives:

- Long and short pulses simultaneously
- Enter *new domain* of short bunches in storage rings:

1.5 ps (rms) at 800 μA per bunch,
300 fs (rms) at 20 μA per bunch

- Availability at all beam ports

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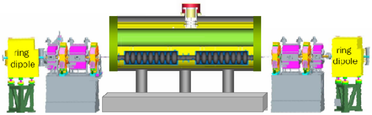
$\boxed{\begin{array}{c}\text{1.5 ps (rms) at 800 } \mu\text{A per bunch,} \\ \text{300 fs (rms) at 20 } \mu\text{A per bunch}\end{array}}$

- Availability at all beam ports

Realization:

- **Adding sc multi cell RF cavities!**
- 1.5 GHz (3rd) and 1.75 GHz (3.5th)



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Major upgrade from BESSY II to BESSY^{VSR}

BESSY II: Short bunches

bunch length: $\sigma \propto \sqrt{\frac{\alpha}{V'}}$

α	Momentum compaction factor
V'	Time derivative of accelerating voltage $V' = \mathrm{d}V/\mathrm{d}t$

BESSY II: Short bunches

bunch length: $\sigma \propto \sqrt{\frac{\alpha}{V'}}$

modes presently available at BESSY II

	low-α optics	**standard user optics**
α	$4 \cdot 10^{-5}$	$7.3 \cdot 10^{-4}$
Bunch length	3 ps	15 ps
Current	14 mA*/100 mA	300 mA
No. of shifts	**12 days per year**	all other shifts

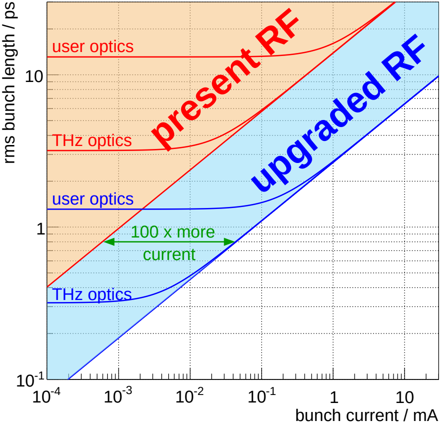
* threshold of the bursting instability

Drawback: Short bunches available only in dedicated shifts!

BESSY^{VSR} : Short bunches with high RF gradients

bunch length: $\sigma \propto \sqrt{\frac{\alpha}{V'}}$

Bunch length vs. current scaling



RF upgrade:

- **100 $\times$ RF gradient V'**

CSR bursting threshold:

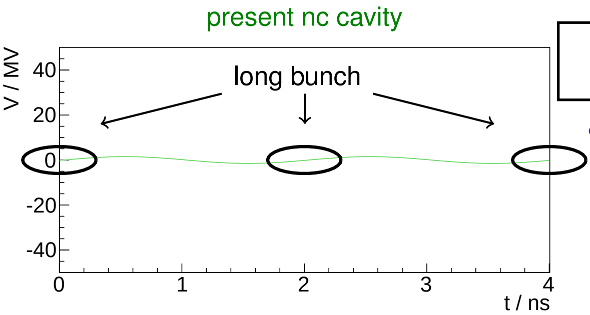
$$\boxed{I \propto \alpha}$$

100 $\times$ more current

Possibility to operate ps and sub-ps bunches at reasonably high currents!

BESSY^{VSR} : Simultaneous long and short bunches

Voltage vs. time of *three cavity types* (beating!)



$$\text{Gradient: } V' = \frac{\mathrm{d}V}{\mathrm{d}t} = f \cdot V$$

- $f = 0.5$ GHz, $V = 1.5$ MV
  $V' = \underline{0.75\,\text{MV}\,\text{GHz}}$

BESSY^{VSR} : Simultaneous long and short bunches

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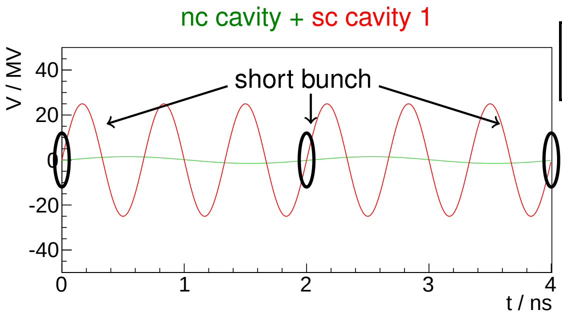


$$\text{Gradient: } V' = \frac{dV}{dt} = f \cdot V$$

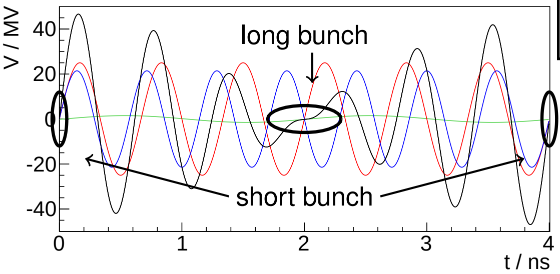
- $f = 0.5$ GHz, $V = 1.5$ MV
  $V' = \underline{0.75\ \text{MV GHz}}$
- $f = 1.5$ GHz, $V = 25$ MV
  $V' = \underline{37.5\ \text{MV GHz}}$

why not only short bunches? $\Rightarrow$ issue of lifetime
and impedance heating

BESSY^{VSR} : Simultaneous long and short bunches

Voltage vs. time of *three cavity types* (beating!)

nc cavity + sc cavity 1 + 2



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- $f = 1.75$ GHz, $V = 21.4$ MV
  $V' =$ 37.5 MV GHz

$\Rightarrow$ maintain basic operation with long bunches

BESSY^{VSR} : Simultaneous long and short bunches

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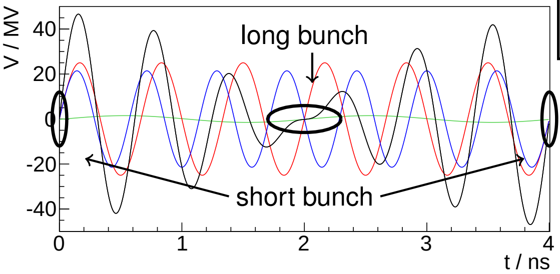

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- 15 ps and 1.5 ps bunches simultaneously at all beam ports

BESSY^{VSR} : Expected parameters

- various fill pattern possible
- all beam ports + all IDs available
- present transverse user optics applied ($\varepsilon = 6$ nm rad)

Single bunch currents: Comparison

	BESSY II		BESSY^{VSR} *	
	user optics	low-α optics	user optics	low-α optics
bunch length	15 ps	3 ps	1.5 ps	0.3 ps
sb-current	0.8 mA	0.04 mA	0.8 mA	0.02 mA

* short bunches

Current limiting collective effects (work ongoing)

- Touschek lifetime
- CBIs driven by interaction of beam with HOMs of sc cavities
  $\rightarrow$ *considered as major challenge*

BESSY^{VSR} : Project status

→ *will be pushed as major upgrade of the BESSY II facility*

Physics design study 2012 - 2014

1. Beam dynamics: *HZB Institute for Accelerator Physics*

- single particle dynamics
- multi particle dynamics (collective effects)

2. SRF technology: *HZB Institute SRF - Science and Technology*

- cavity design
- cryo module design

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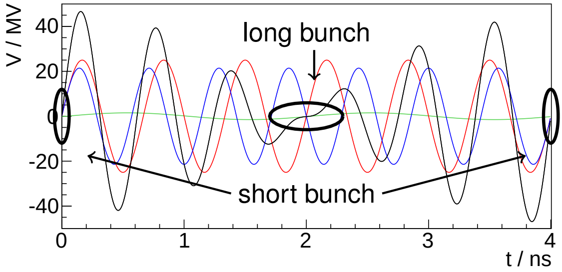
Ramping of sc RF cavities in BESSY^{VSR} : Motivation

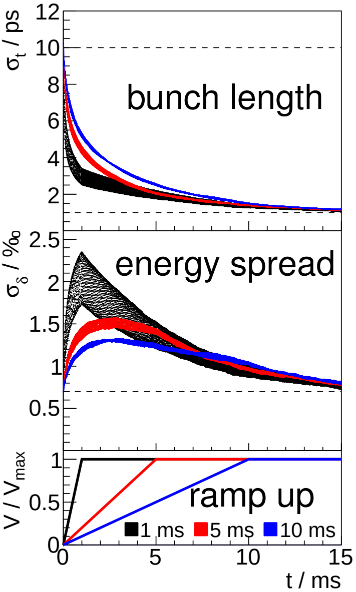


Difficulty: How to fill short bunches?

Proposition: Ramp cavities down shortly for injection!

Question: What happens to the energy spread? Loss of halo particles?

Ramping of sc RF cavities in BESSY^{VSR} : Simulation



- Linear voltage ramp (first guess)
- Damping time $\tau \approx 8$ ms
- Nat. energy spread $\sigma_\delta \approx 7 \cdot 10^{-4}$
- Expected technical limit: $\approx 2 \ldots 12$ ms

All simulations performed with `elegant 25.1.0` (M. Borland, APS, Argonne).

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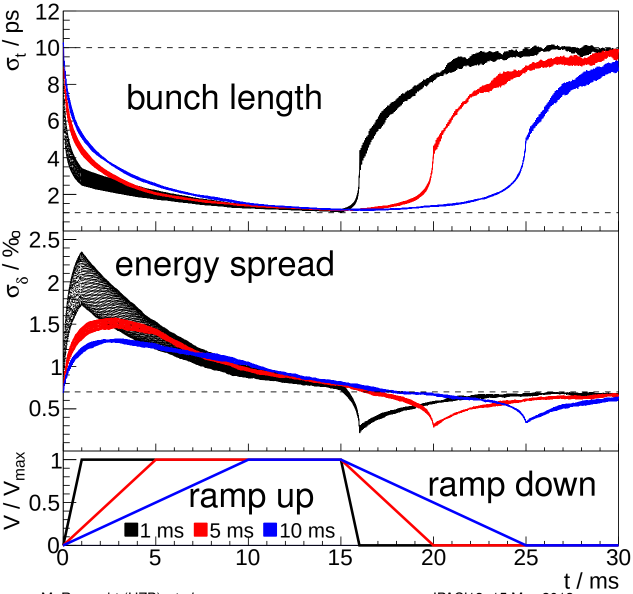

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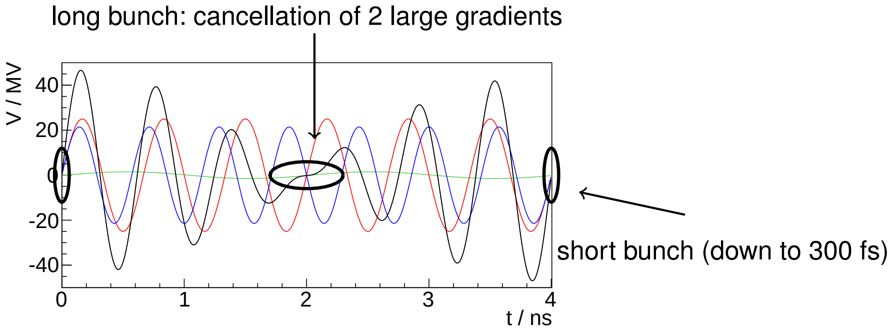
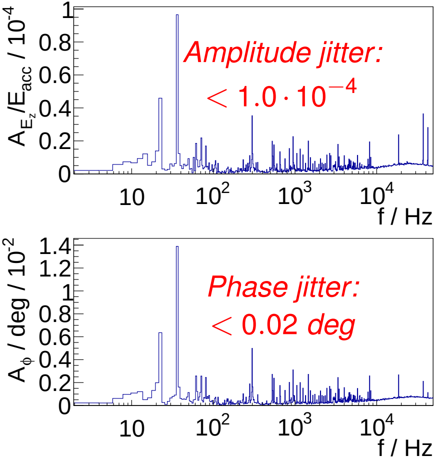
RF jitter: Motivation



Difficulty: Sensitive to RF jitter!?

Question: Effect on bunch length or energy spread?

RF jitter: Realistic input for simulation



CW measurements at HZB of TESLA cavity *(A. Neumann et al., SRF 2011, p.262)*

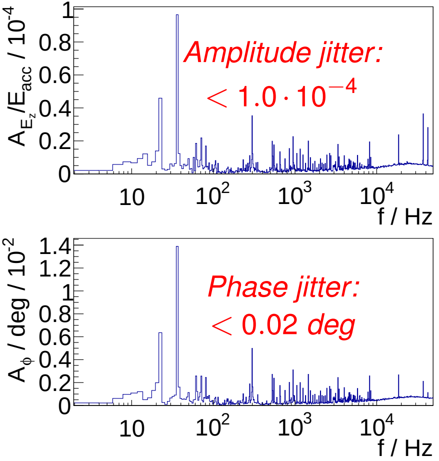
RF jitter: Realistic input for simulation

This study:

- I Single frequency jitter
- II Measured noise spectrum
- III Enhanced jitter (10x, 100x) to estimate limits

Jitter applied on 1.75 GHz cavity

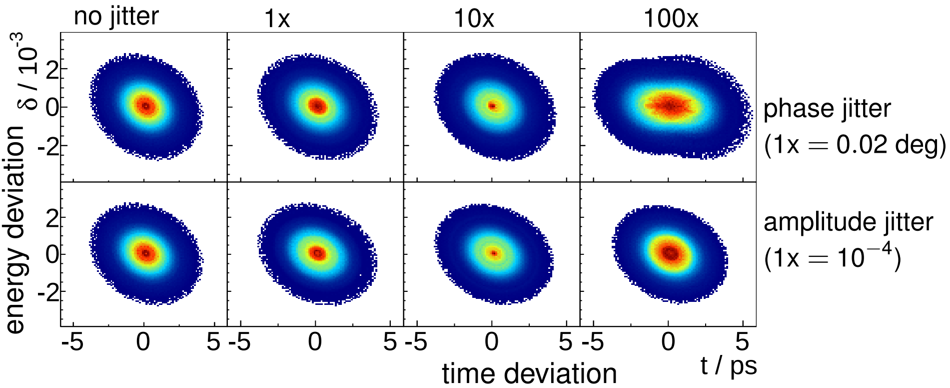
All simulations performed with `elegant`



CW measurements at HZB of TESLA cavity *(A. Neumann et al., SRF 2011, p.262)*

RF jitter: Simulation short bunch (1 ps)

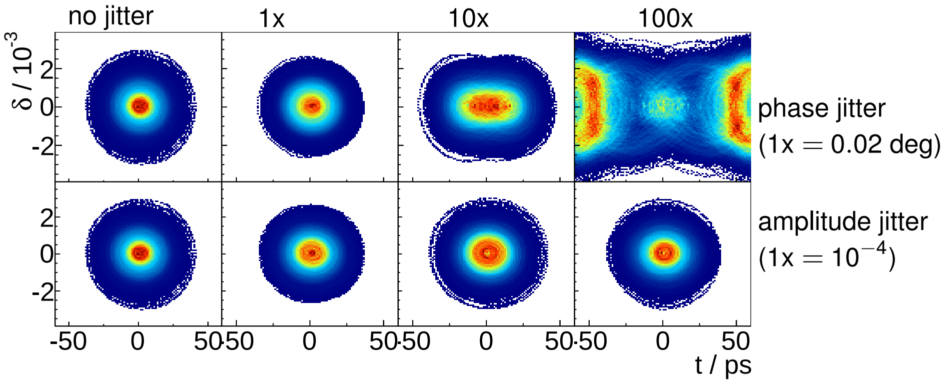
Jitter simulated at $f = 700$ Hz
1 particle tracked for $1 \cdot 10^6$ turns



Short bunch very robust

RF jitter: Simulation long bunch (10 ps)

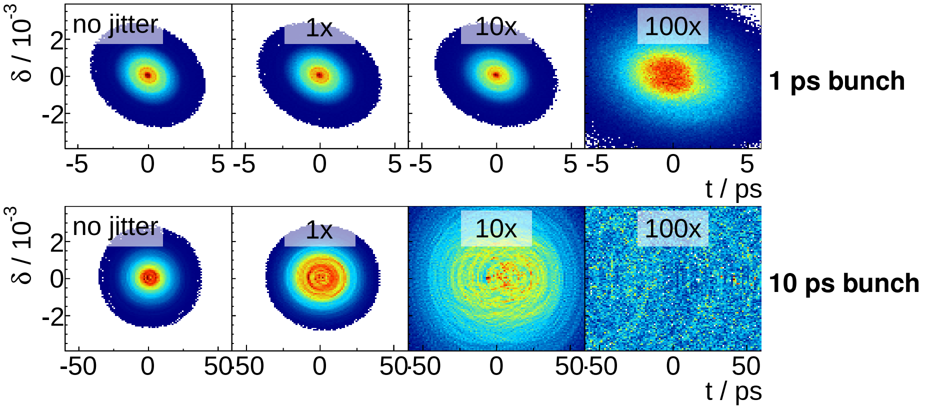
Jitter simulated at $f = 700$ Hz
1 particle tracked for $1 \cdot 10^6$ turns



Realistic jitter: no effect on bunch length

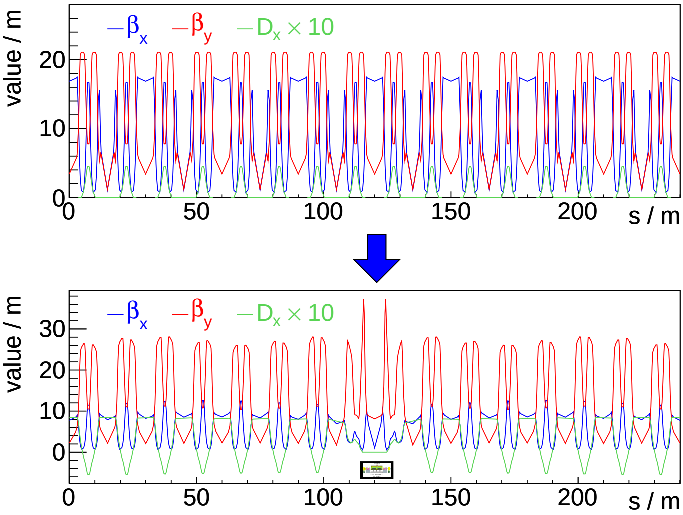
RF jitter: Simulation with measured noise spectrum

Phase jitter with measured noise spectrum
1 particle tracked for $6.5 \cdot 10^5$ turns



Realistic jitter not critical

Ultra short bunches (300 fs)

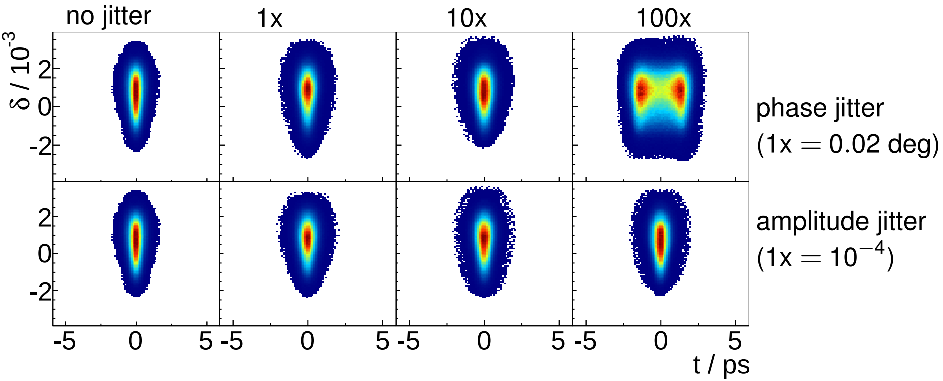


standard user optics

modified low α optics:
$D_x = 0$ at sc cavities

RF jitter: Simulation ultra short bunch (300 fs)

Jitter simulated at $f = 700$ Hz
1 particle tracked for $2 \cdot 10^6$ turns



300 fs bunch also unaffected by realistic jitter

RF jitter: Summary phase jitter measured noise spectrum

measured noise spectrum	300 fs		1 ps		10 ps	
	σ_t	σ_δ	σ_t	σ_δ	σ_t	σ_δ
	ps	10^{-4}	ps	10^{-4}	ps	10^{-4}
no jitter	0.33	8.5	1.0	7.1	9.8	6.9
$\times 1$	0.34	8.0	1.0	7.0	13	9.3
$\times 10$	1.0	19	1.0	7.0	31	26

Summary and outlook

Summary:

- ☑ Fast RF ramping feasible w.r.t. beam dynamics
- ☑ Expected RF jitter not critical

Future studies:

- ☐ High current effects

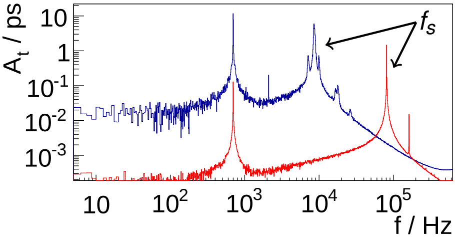

thank you

backup

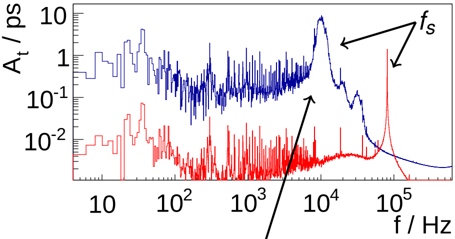
RF jitter: Single freq, jitter vs. real spectrum jitter

Phase jitter: FFT spectrum of t

10x enhanced $f = 700$ Hz jitter



10x enhanced real spectrum



Blue: Long bunch (10 ps, $f_s = 8$ kHz),

Red: Short bunch (1 ps, $f_s = 80$ kHz)

➡ Influence of jitter very small unless $f \approx f_s$