BESSY VSR

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Intra Beam scattering at BESSY II, MLS and BESSY VSR

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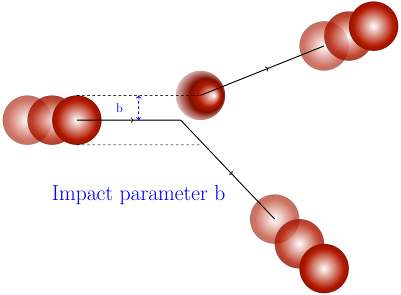
What is Intra Beam Scattering?

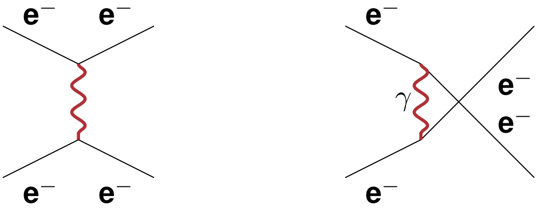
Particle scattering

- Coulomb scattering within a bunch or beam
- Two ”types” of collision effects :
  - Single collision with large angle : When momentum is transfered from transverse to longitudinal plane this is amplified with relativistic γ, and if the particle lost we call it Touschek effect
  - Multiple collisions with small angles : This causes beam size growth in all dimensions (like gas diffusion) and is referred to as IBS

Classical approach (1970's) using Rutherford scattering (Le Duff,Piwinski,Sacherer,Mohl,...)



Quantum Field Theory approach (1980's) using Möller scattering Bjorken-Mtingwa



Growth rates

$$\frac{1}{\tau} = \frac{N\,(\mathrm{clog})}{\gamma^4\ \varepsilon_x \varepsilon_y \sigma_\delta \sigma_s} \times \cdots$$

Coulomb Logarithm

$$\text{clog} = \log\left(\frac{b_{max}}{b_{min}}\right),$$

with b_{max} the maximum considered impact parameter and b_{min} the minimum considered impact parameter.

- Minimum and maximum impact parameter not clearly defined
- For electrons a tail cut is often considered, with the motivation that the Gaussian tails are not well populated (increasing b_{min})
  - **BESSY II** : the clog changes from 21 without tail cut to 10 when a tail cut is applied
  - **MLS** : the clog changes from 22 without tail cut to 11 when a tail cut is applied
- For BESSY II and MLS gives a factor two difference in growth rates

Motivation

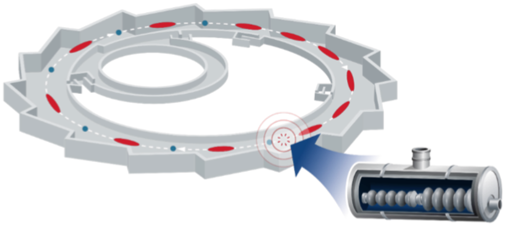
Growth rates

$$\frac{1}{\tau} = \frac{N(\text{clog})}{\gamma^4 \varepsilon_x \varepsilon_y \sigma_\delta \sigma_s} \times \cdots$$

where γ is the relativistic γ, clog is the Coulomblog, N is the number of particles in the bunch, $\varepsilon_x, \varepsilon_y$ are the transverse emittances, σ_s is the bunch length and σ_δ is the energy spread.

Low emittance - short bunch machines

- Low emittance machines : $\varepsilon_i \searrow \longrightarrow \frac{1}{\tau} \nearrow$
- Short bunch machines : $\sigma_s \searrow \longrightarrow \frac{1}{\tau} \nearrow$ (BESSY VSR 1.2 ps RMS zero-current)

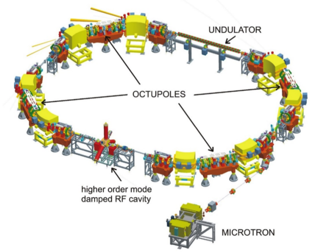


- BESSY II
- Third generation light source
- Circumference : 240 m
- Energy : 1.7 GeV
- VSR : Triple RF system (0.5,1.5,1.75 MHz)

Beam parameters

	ε_x [nmrad]	ε_y [nmrad]	σ_s [mm]	τ_x^{RAD} [ms]	τ_y^{RAD} [ms]	$\tau_{\sigma_\delta^2}^{RAD}$ [ms]
BESSY II	7.5	0.057	5	7.8	7.7	3.8
MLS	36	0.18	7	13	11	5
BESSY VSR	7.5	0.057	0.4	7.8	7.7	3.8

Berlin light sources



- Metrology Light Source (MLS)
- Third generation light source
- Circumference : 48 m
- Energy : range 50 – 630 MeV
- Ramped

Beam parameters

	ε_x [nmrad]	ε_y [nmrad]	σ_s [mm]	τ_x^{RAD} [ms]	τ_y^{RAD} [ms]	$\tau_{\sigma_\delta^2}^{RAD}$ [ms]
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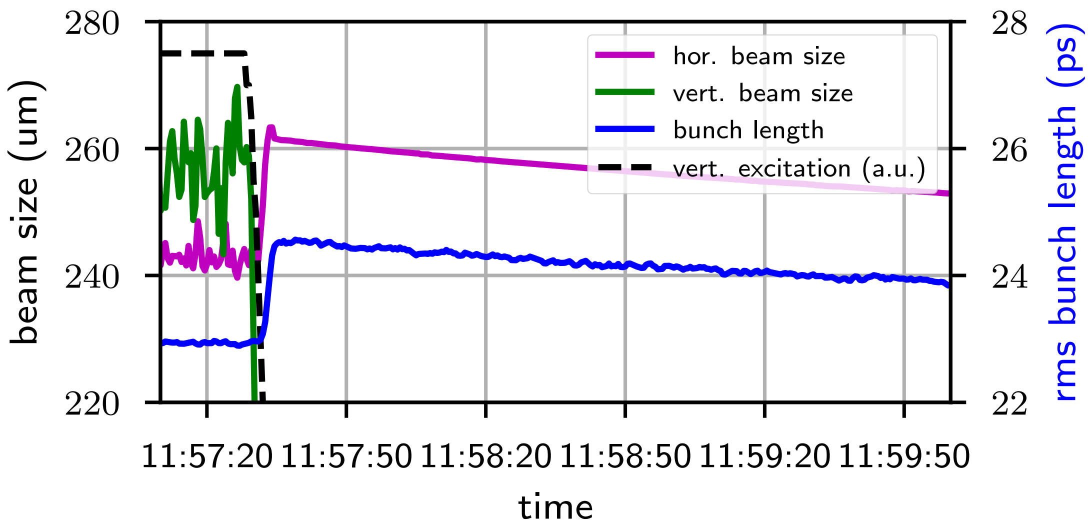
MLS - IBS support



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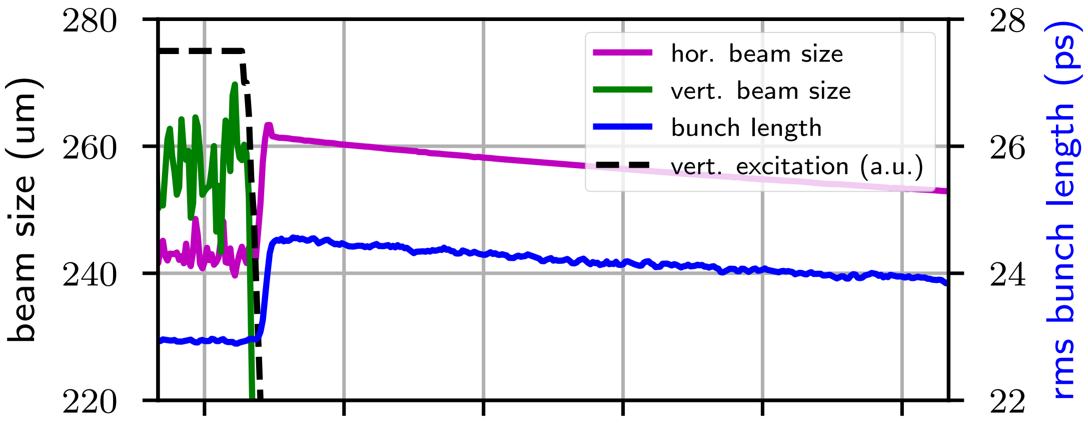

Turning off the vertical beam excitation, reflects immediately in an increase in horizontal and longitudinal bunch size. Pointing towards IBS

The questions are:

- MLS : Are the observed increase in emittances and bunch length caused by IBS?
- BESSY II: Can we observe IBS effects?
- BESSY VSR: Are expected IBS contributions to equilibrium beam sizes within acceptable limits?

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ODE Evolution Equations

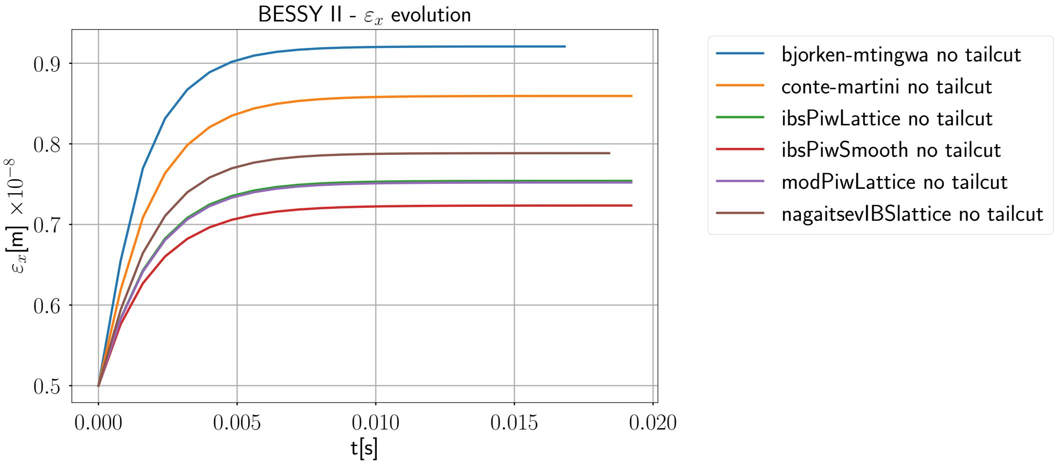
$$\frac{d\epsilon_i}{dt} = -\frac{1}{\tau^{\mathrm{RAD}}_{\epsilon_i}}(\epsilon_i - \epsilon_i^{\infty}) + \frac{\epsilon_i}{\tau^{\mathrm{IBS}}_{\epsilon_i}}, \quad \epsilon_i = \epsilon_{x,y}, \sigma_\delta^2 \tag{1}$$

where ϵ_i^{∞} are the radiation damping equilibrium beam sizes with quantum excitation, $\tau^{\mathrm{RAD}}_{\epsilon_i}$ the radiation damping times and $\tau^{\mathrm{IBS}}_{\epsilon_i}$ the IBS lifetimes.

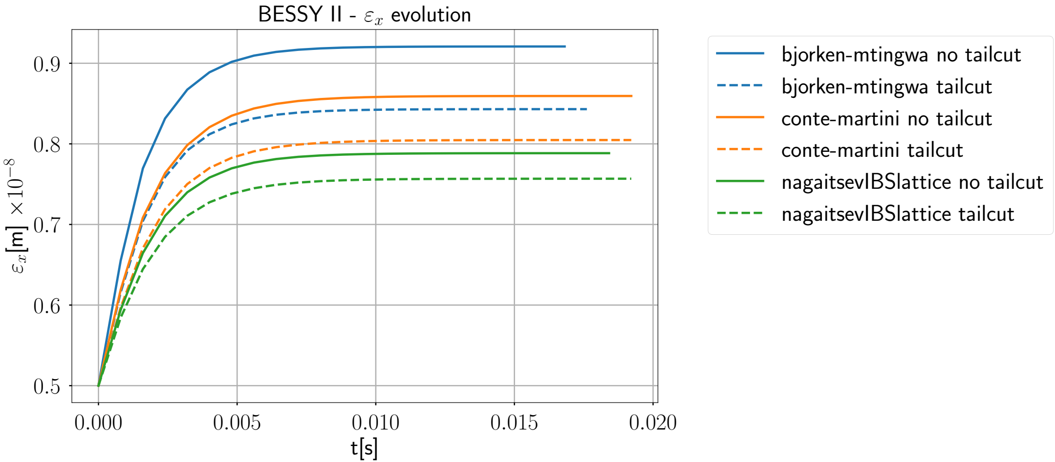
Particle Tracking

- 6D macro particle distribution tracking
- Turn-by-turn distribution update
- Physics routines applied sequentially
- IBS: longitudinal slicing of the bunch $\longrightarrow$ longitudinal density used in determining the kick amplitude applied to the particles

Comparing IBS models

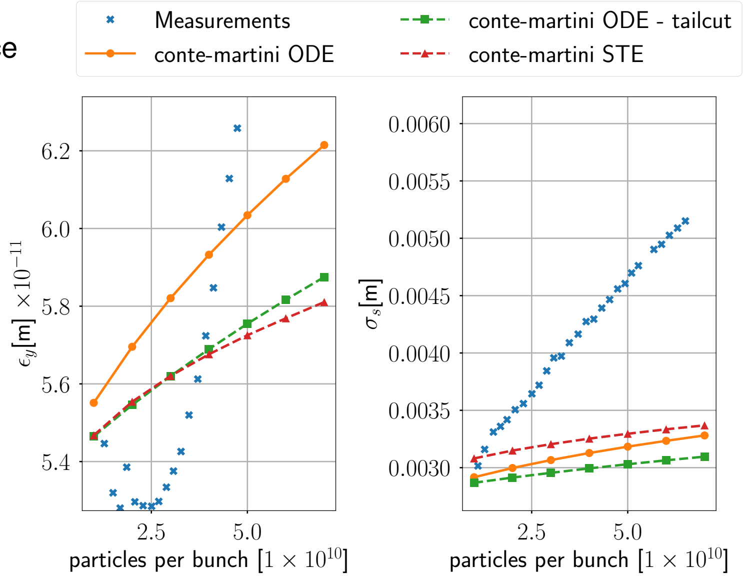


Tail cut effects



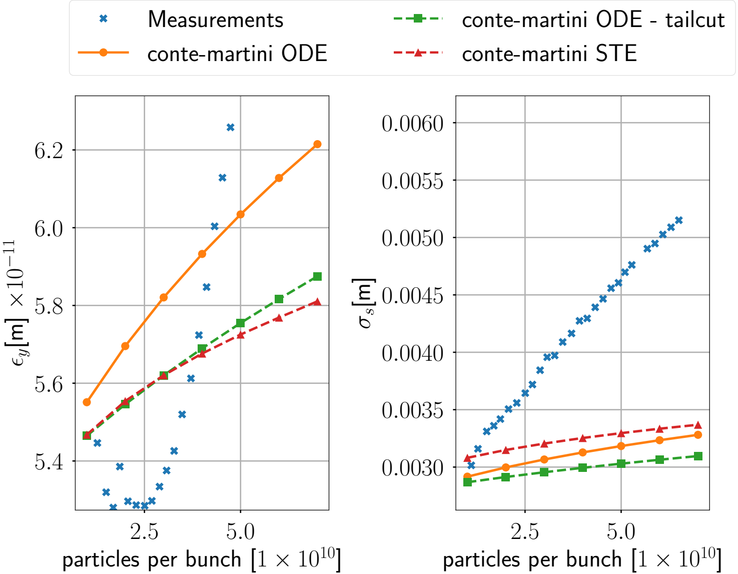
Simulation: vertical emittance from coupling (0.0075%)

Plotted: equilibrium values for different currents



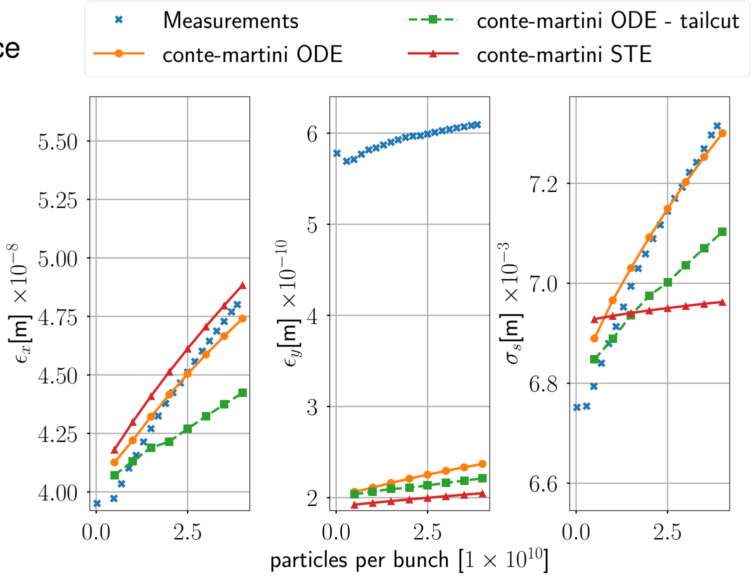
Not IBS dominated.

Impedance, CSR, Potential Well distortion

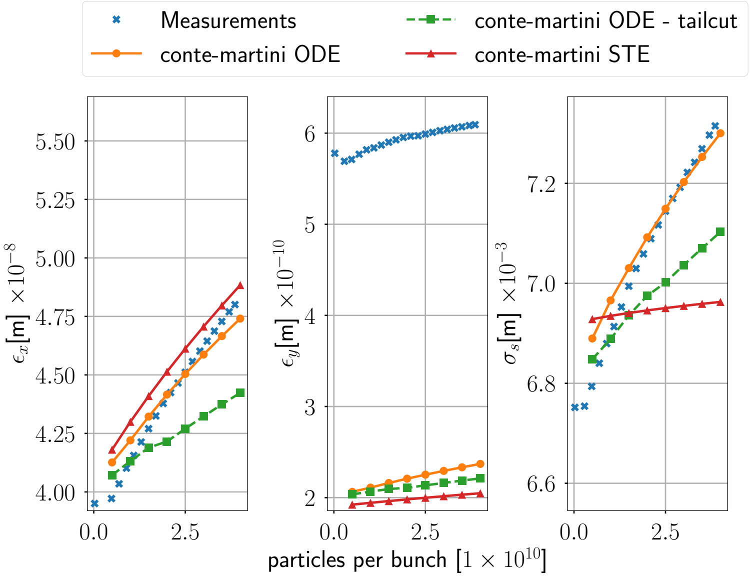


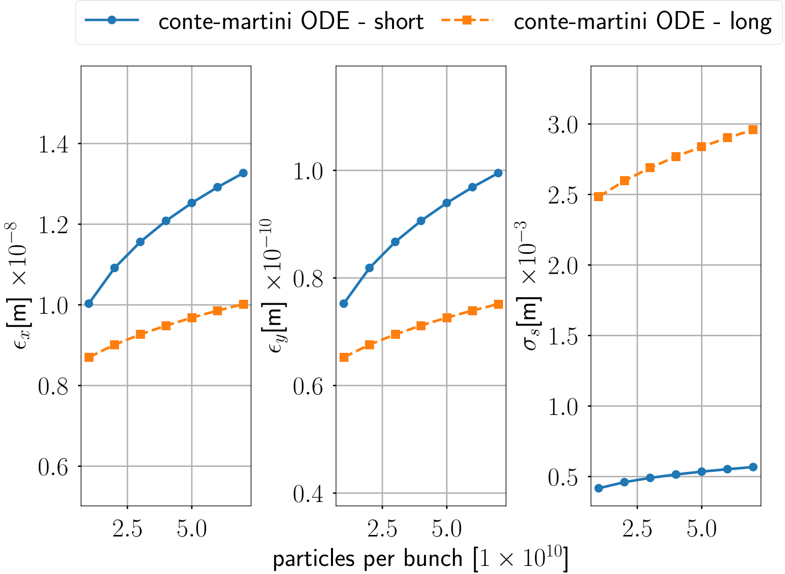
Simulation: vertical emittance from coupling (0.005%)

Plotted: equilibrium values for different currents



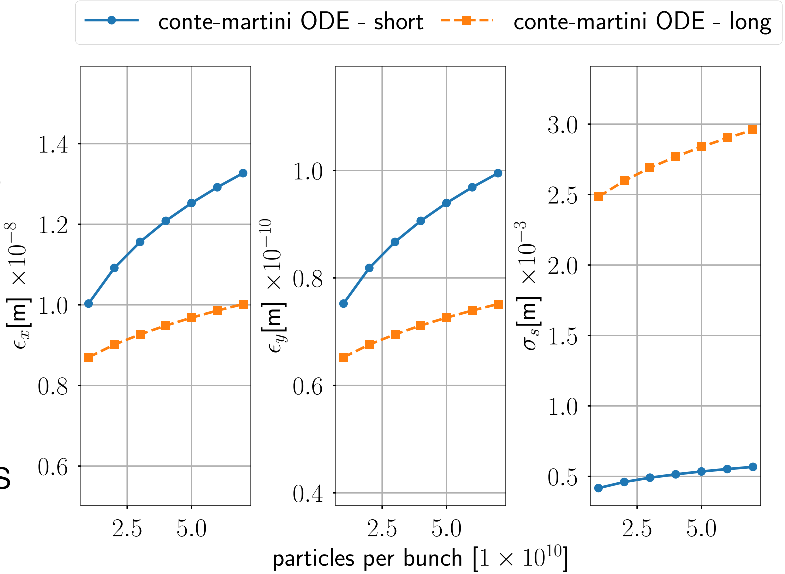
IBS dominated assuming ϵ_y from coupling (0.5%).




conte-martini ODE - short
conte-martini ODE - long
ϵ_x[m] $\times 10^{-8}$
1.4
1.2
1.0
0.8
0.6
ϵ_y[m] $\times 10^{-10}$
1.0
0.8
0.6
0.4
σ_s[m] $\times 10^{-3}$
3.0
2.5
2.0
1.5
1.0
0.5
2.5
5.0
particles per bunch $[1 \times 10^{10}]$

IBS
has only
small ($\sim$ 25%)
impact
assuming
ϵ_y
from coupling
(0.75%).

current = 1 mA
σ_t = 1.2 ps RMS



Conclusions

Answering the questions:

- **MLS : Are the observed increase in emittances and bunch length caused by IBS?**
- Data consistent with IBS with some assumpations about coupling and vertical beam size. To be confirmed with further experiments.
- BESSY II: Can we observe IBS effects?
- No indication of IBS at BESSY II, dominated by other effects.
- BESSY VSR: Are expected IBS contributions to equilibrium beam sizes within acceptable limits?
- Simulations estimate an increase of 25% for the bunch length with the expected currents ($1\,\mathrm{mA}$) for the short bunches, assuming there are no other dominating effects that change the beam sizes. No IBS effects are expected for the long bunches.

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