IBS studies at the Swiss Light Source storage ring

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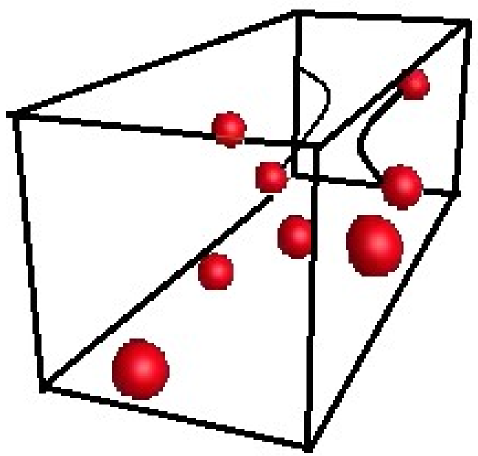
Intra-beam scattering



- Two different approaches for the probability of scattering:
  - Classical approach (Piwinski):
    - Rutherford cross section
  - Quantum approach (Bjorken-Mtingwa):
    - The relativistic “Golder Rule” for the 2-body scattering process
  - The tracking codes use the classical Rutherford c.s. as well

- Small angle multiple Coulomb scattering effect
  - Redistribution of beam momenta
  - Beam diffusion
    - Luminosity decrease in colliders
    - Brightness reduction in light sources
- Several theoretical models and approximations developed over the years
  - At strong IBS regimes not always agreement between them
  - Gaussian beams assumed
  - Coupling not included
- Multi-particle tracking codes recently developed (SIRE, IBStrack) to study interesting aspects of IBS such as:
  - Impact on beam distribution and on damping process
  - Include coupling

IBS calculations with SR

Horizontal, vertical and longitudinal **equilibrium states** and **damping times** due to SR damping

The IBS growth rates in one turn (or one time step)

$$\frac{1}{T_i} = \langle f_i \rangle$$

$$\frac{d\varepsilon_x}{dt} = -\frac{2}{\tau_x}(\varepsilon_x - \varepsilon_{x0}) + \frac{2\varepsilon_x}{T_x(\varepsilon_x, \varepsilon_y, \sigma_p)}$$

$$\frac{d\varepsilon_y}{dt} = -\frac{2}{\tau_y}(\varepsilon_y - \varepsilon_{y0}) + \frac{2\varepsilon_y}{T_y(\varepsilon_x, \varepsilon_y, \sigma_p)}$$

$$\frac{d\sigma_p}{dt} = -\frac{1}{\tau_p}(\sigma_p - \sigma_{p0}) + \frac{\sigma_p}{T_p(\varepsilon_x, \varepsilon_y, \sigma_p)}$$

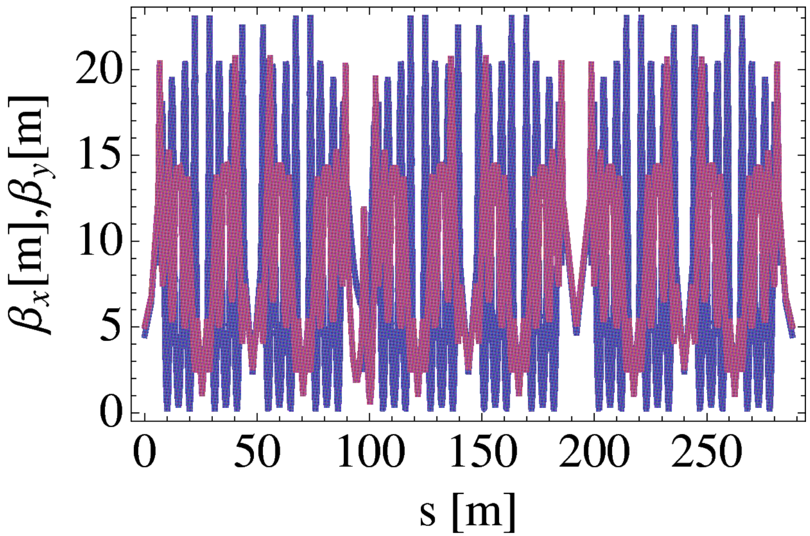
If = 0 → **Steady State emittances**

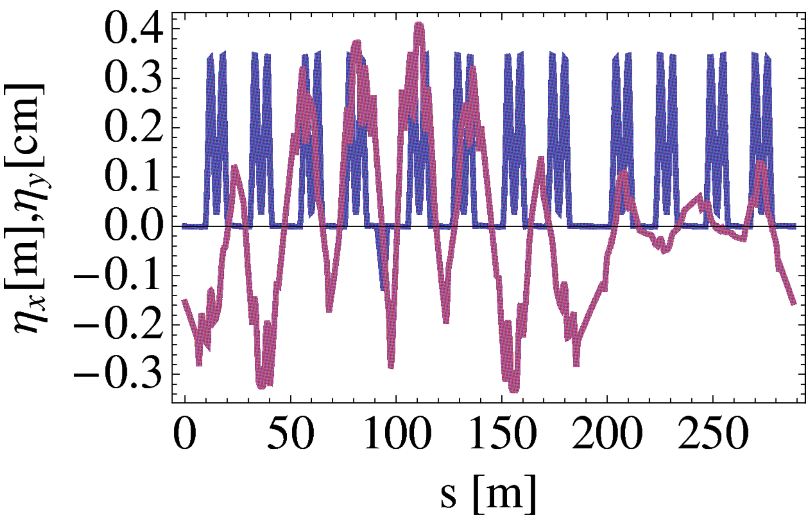
If ≠0

Complicated integrals averaged around the ring.

All theoretical models consider the uncoupled frame and Gaussian beams!

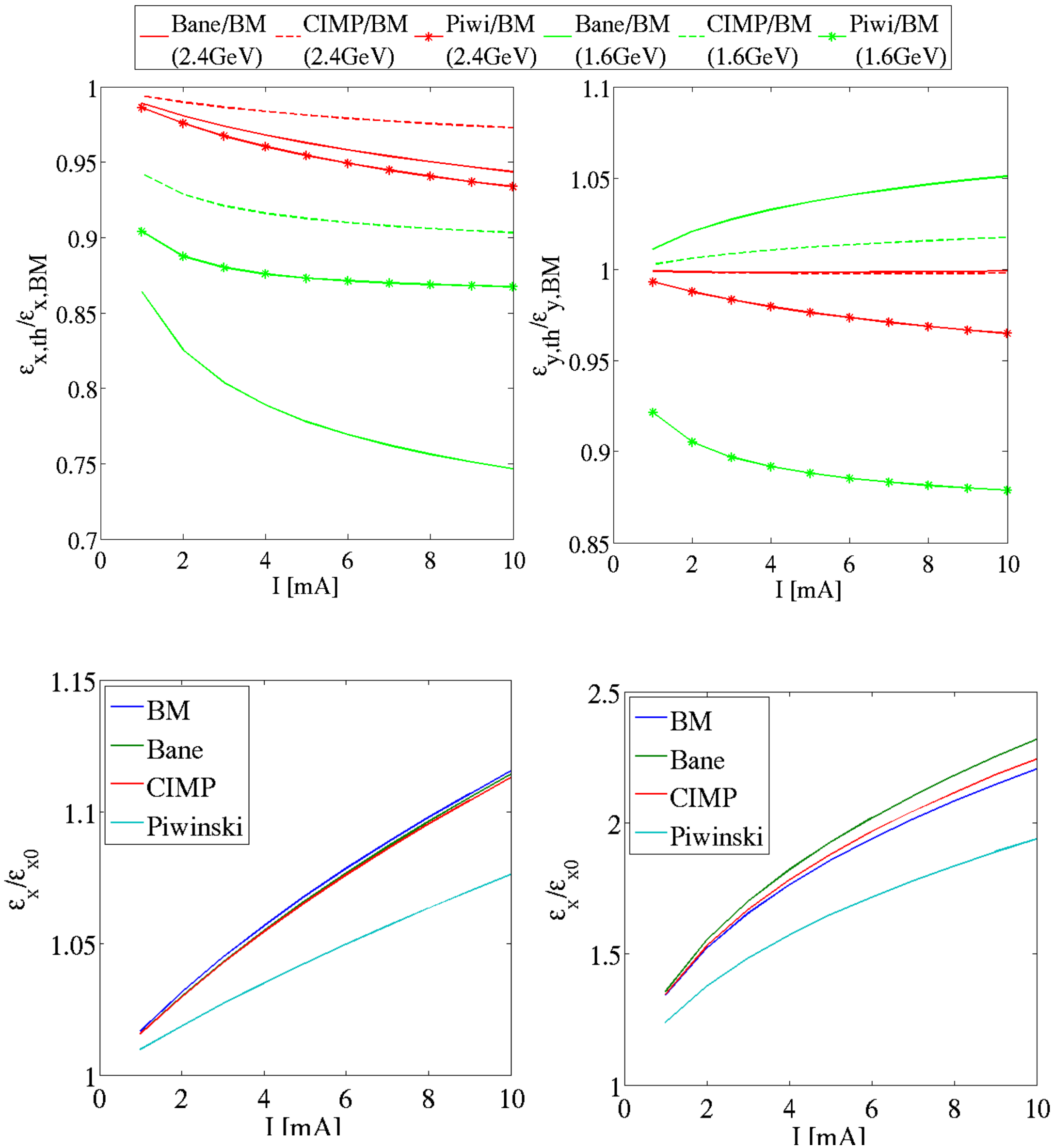
The SLS as a testbed for measurements





- The SLS is an ideal testbed for IBS studies as it has:
  - Recently achieved a record vertical emittance of 1 pm rad at nominal energy (2.4 GeV)
  - Availability of emittance monitoring diagnostics (hor./vert. beam size monitors and streak camera for bunch length)
  - Ability to run at lower energies
- Participation in 2 sets of measurements
  - Nominal energy Run (March 2012)
  - Low energy Run (May 2012)

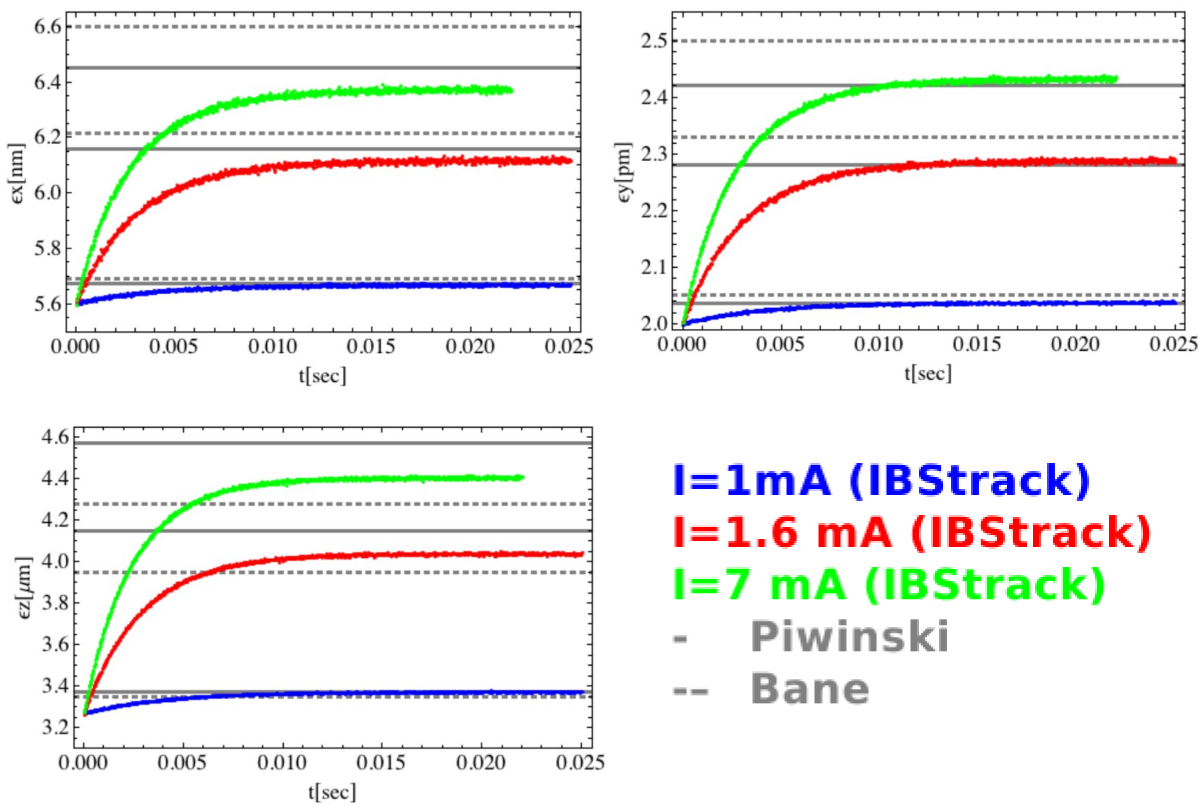
Theoretical models comparison for the SLS



- Very good agreement between theoretical models when the IBS effect is weak (nominal energy, low current)
- At strong IBS regimes the disagreement gets stronger
- Piwinski always underestimates the effect with respect to the others
- Bane diverges at strong IBS regimes
  - The approximations not valid if the vertical dispersion is zero or very small

Models-Code comparison

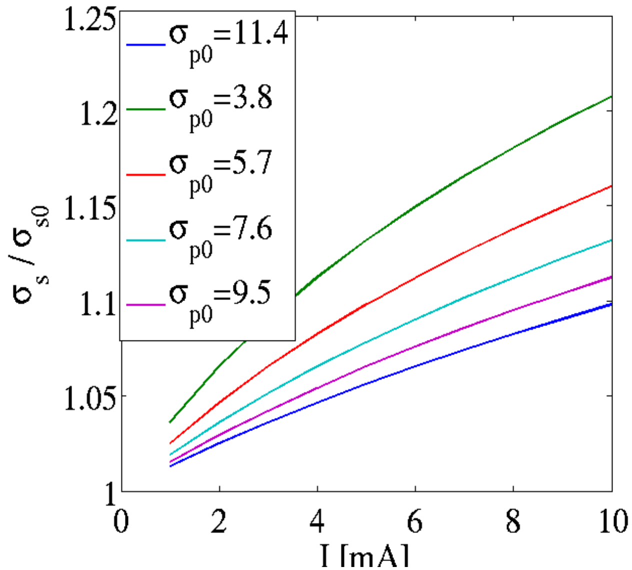
T. Demma

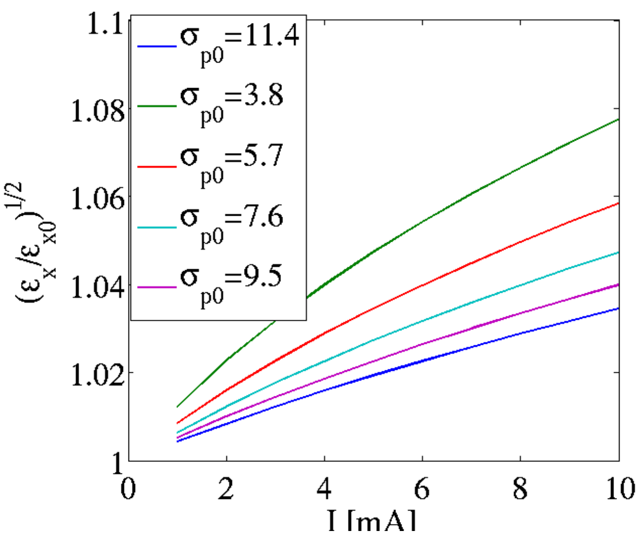


See the talk by M. Pivi tomorrow

- Comparison between the multiparticle tracking code IBSTrack and the theoretical models Piwinski (solid line) and Bane (dashed line) for the nominal energy for the horizontal (top, left), vertical (top, right) and longitudinal (bottom) emittance
- The three curves correspond to different bunch currents: 1 mA (blue), 10 mA (red) and 17 mA (green)
- Excellent agreement when the effect is small.
- Good agreement when the effect gets larger

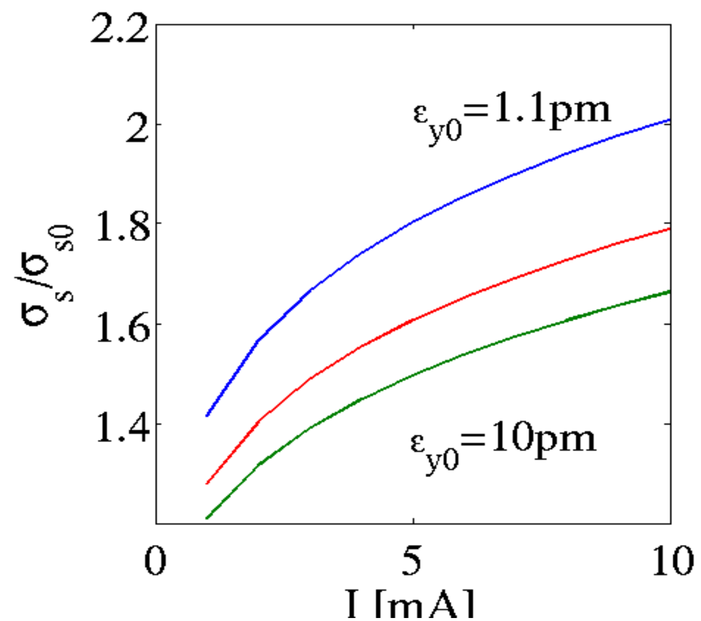
IBS dependence on the SLS parameters

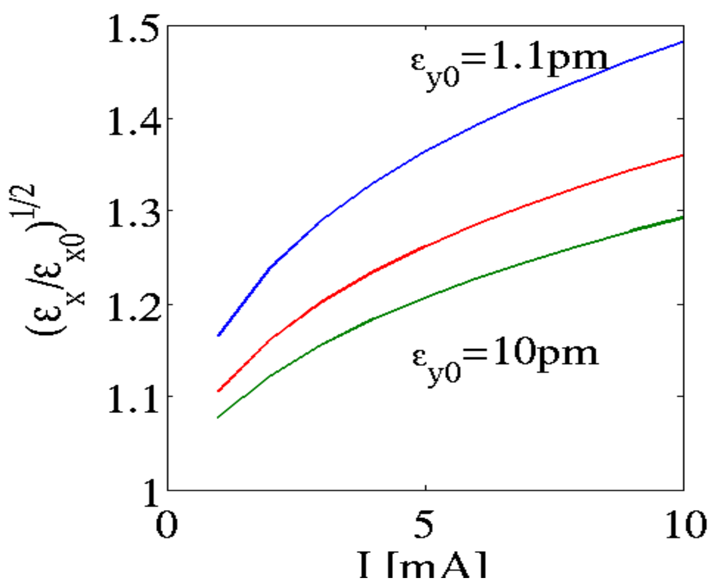




- The bunch length and energy spread at the SLS dominated by the microwave instablility (MI)
  - Defines new equilibrium states in the longitudinal plane
  - Onset around 0.6 mA at nominal energy
  - Bunch lengthening & energy spread widening
  - Energy spread measurement very important!
- The IBS effect in bunch length (top) and horizontal emittance (bottom) for different equilibrium bunch lengths
  - IBS measurements at nominal energy very difficult due to the MI

IBS dependence on the SLS parameters

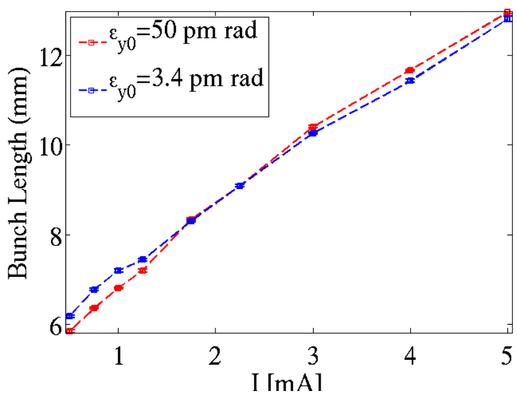




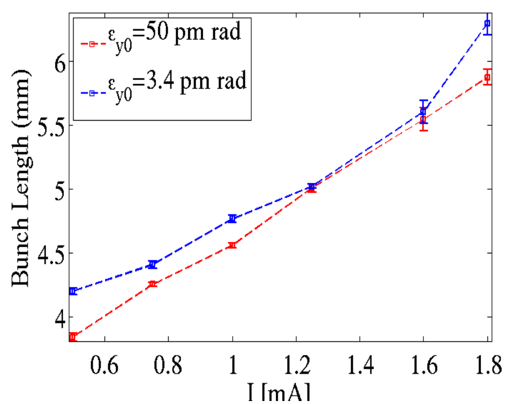
- The vertical emittance of 1 pm rad was demonstrated at nominal energy
  - We cannot assume that this will be the case for the lower energy too
- The IBS effect in bunch length (top) and horizontal emittance (bottom) for different equilibrium vertical emittances shows that the effect is appreciable even at high vertical emittance and low current
- IBS measurements at low energy at the SLS very attractive *!*

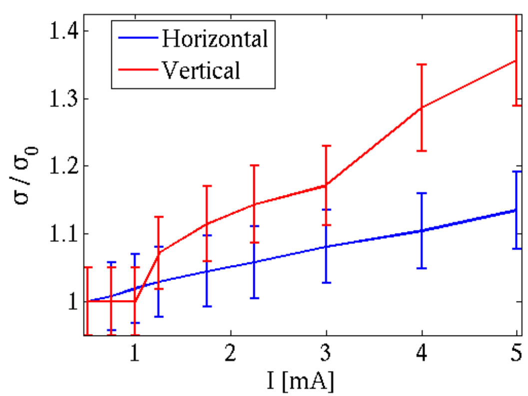
Low energy measurements

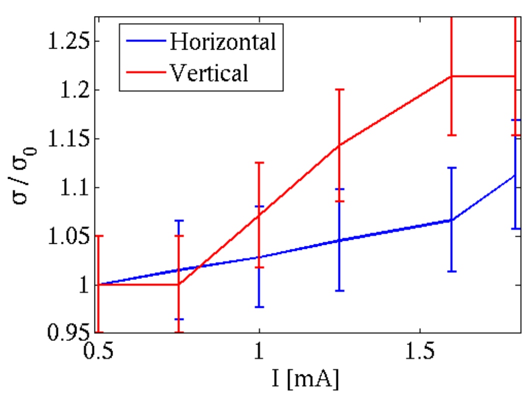
Vrf = 600 kV



Vrf = 2 MV

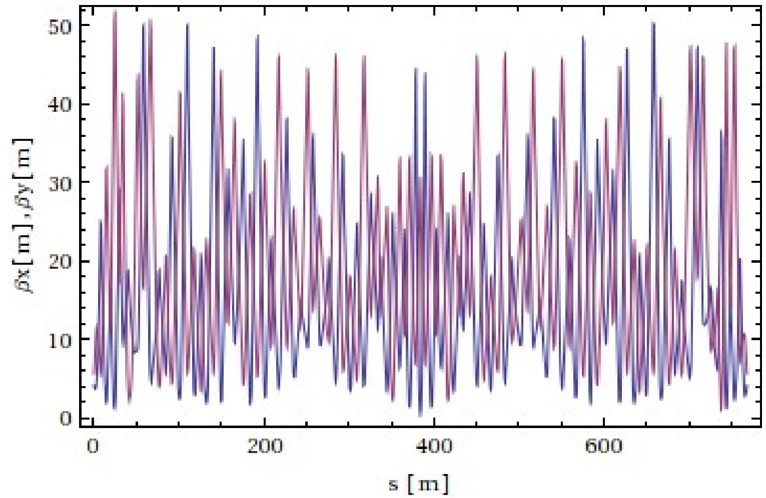


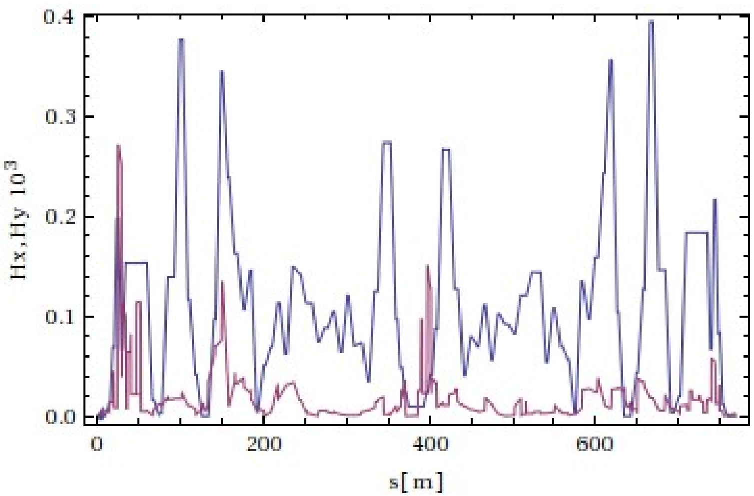




- 2 set of measurements for different RF Voltage settings (V1=600kV, V2=2MV)
- For each voltage, measurements at corrected vertical emittance at 3.4 pm-rad and vertical emittance blown up at 50 pm-rad
- IBS indications
  - At low voltage (longer bunch) the bunch length dominated by the MI
  - At high voltage (shorter bunch) larger bunch length blow up for the small vertical emittance and larger blow up in horizontal and vertical beam size
- The MI model for the energy spread and bunch length very important for the comparison with theoretical models
  - Energy spread measurement methods currently under investigation

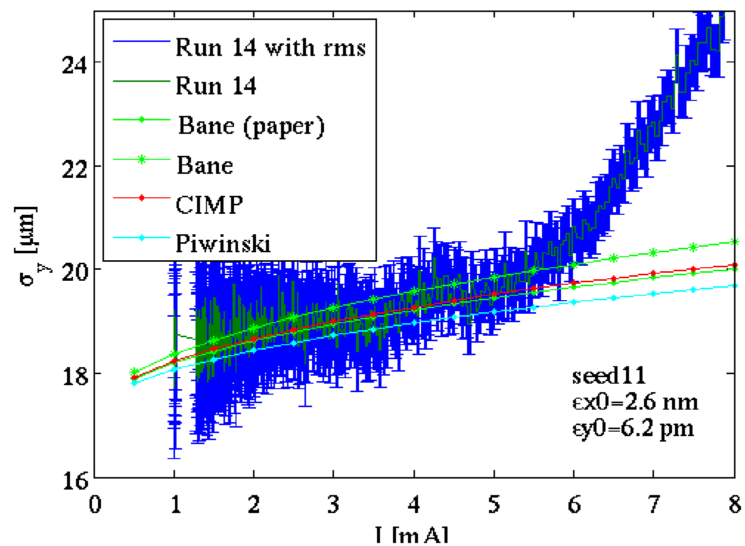
IBS measurements at CESRTA

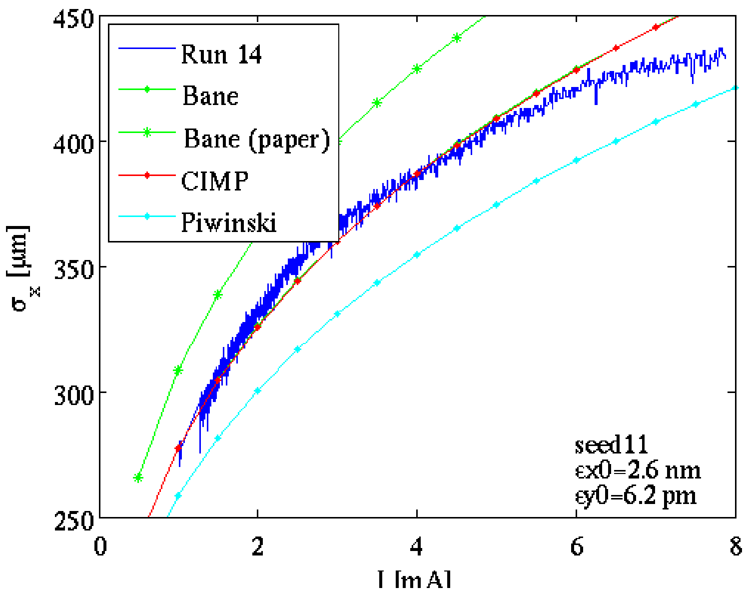




- CESRTA is a very good testbed for IBS studies due to the:
  - Ability to run at different energies
  - Availability of emittance monitoring diagnostics (horizontal and vertical beam size monitors and streak camera for bunch length measurements)
- Participation in IBS measurements of December 2011 Run
- Ongoing studies by the CESRTA IBS Group

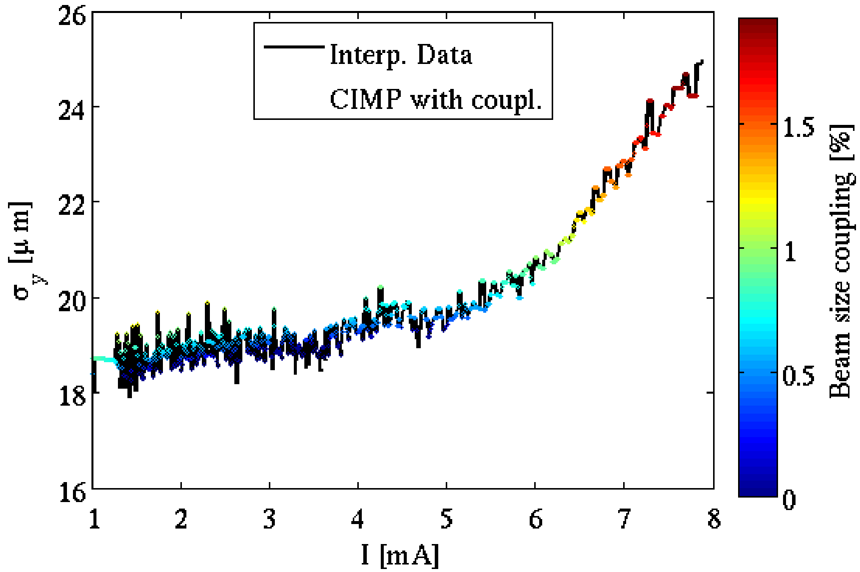
IBS measurements at CESRTA

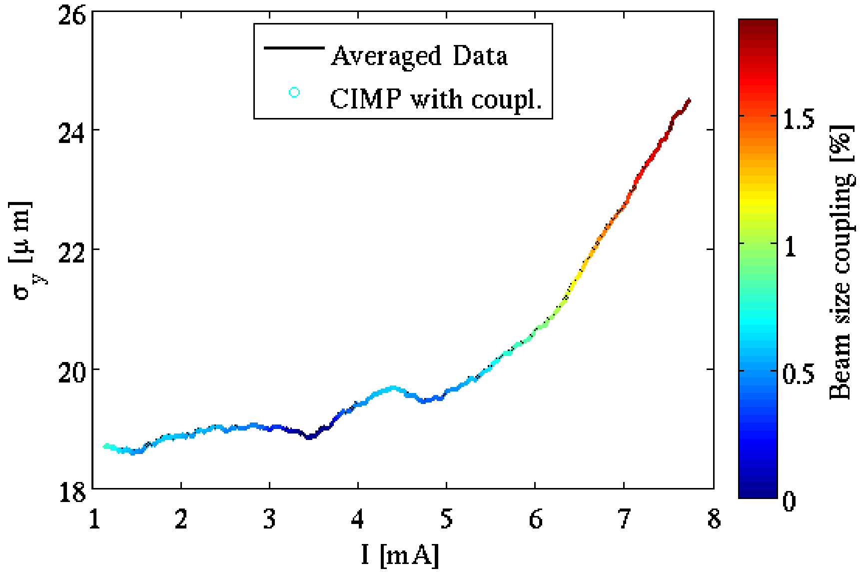




- Data from December 2011 Run
- Partial agreement of all theoretical models in the vertical plane (for low currents).
- In the horizontal plane, Bane and CIMP agree very well while, Piwinski predicts smaller emittance blow-up for high currents.
- Note that the mismatching of the data to the prediction curve at high currents seems to be correlated with the sadden blow up in the vertical plane
- Related to coupling or an istability which blows up the vertical emitance?

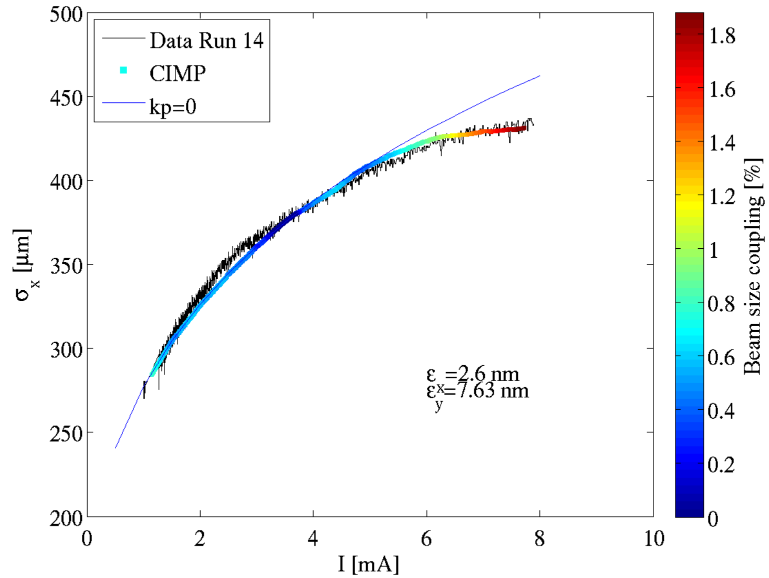
Coupling change with current

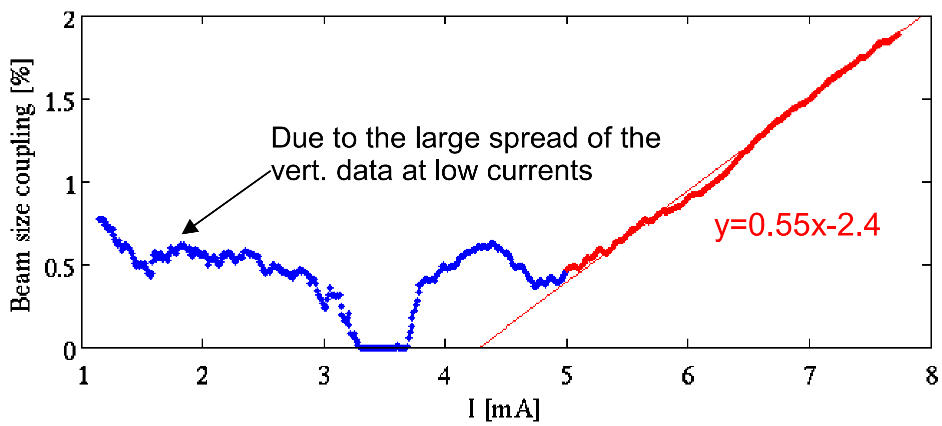




- In order to study the effect of betatron coupling (with coefficient kp) on the theoretical predictions, the output emittances for each current were calculated for different kp values.
- Top: Vertical beam size versus current. The data are shown in black while the colorcode shows the kp for which the theoretical predictions match with the data. Bottom: After smoothing out of the data.
- Note that coupling is not included in the theoretical models and is added artificiallyCM

Coupling change with current





- After choosing a kp value for each current in order to match the vertical beam size data, the respective vertical beam size is calculated and plotted on top of the data colorcoded with the kp value.
- Very good agreement in the horizontal plane too!!
- Good indication of coupling change with current, probably introduced by orbit offsets due to impedance kicks.

Summary

- IBS is a small angle multiple Coulomb scattering effect leading to beam dilution.
- Dominant effect at low energy/high current damping rings, B-factories and new generation light sources.
- Theoretical models and tracking codes diverge at strong IBS regimes
- The bench-marking of the theoretical models and tracking codes with data is crucial for studying the effect in strong IBS regimes and the impact of it on the damping process and the beam shape.
- The measurements are not trivial as one needs to disentangle from other current depended effects
- The SLS is an ideal test-bed for IBS studies
  - First measurements give encouraging results, however not all the information is there
  - MI model for energy spread and bunch length very important!
  - More measurements at low energy are very important in order to have all the pieces of the puzzle!
- IBS studies at CESRTA are also on-going by the CESRTA IBS group
  - Interesting results in a different machine, in a different IBS regime.

Acknowledgments

- SLS team: Andreas Streun, Natalia Milas, Michael Boege, Masamitsu Aiba, Angela Saa Hernandez
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- IBS colleagues: Mauro Pivi, Theo Demma

THANK YOU!