IBS experimental studies at CESRTA and SLS

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- IBS experimental studies at CESRTA
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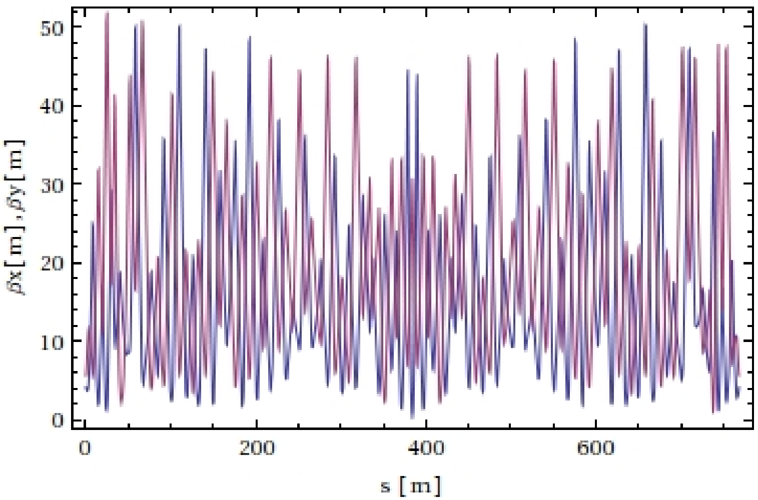
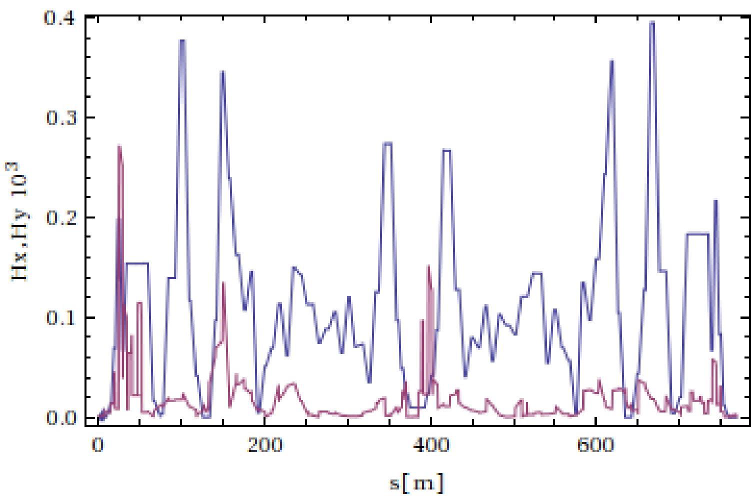
- Acknowledgments

Motivation for IBS measurements

- Intra-beam scattering (IBS) is a multiple coulomb scattering effect leading to emittance blow up in all three planes.
- The output emittances of the CLIC Damping Rings are dominated by the IBS effect.
- Several theoretical models and approximations were developed over the years describing the effect, however:
  - At strong IBS regimes there is not always agreement between them (disagreement can be up to 20-30 %)
  - They consider Gaussian distribution of the beam, while it is not clear if the IBS preserves the Gaussian shape of the beam
- Two multi-particle tracking codes were recently developed in order to study interesting aspects of IBS as its impact on the damping process and on the shape of the beam.
- Benchmarking with measurements both for theoretical models and tracking codes is crucial!

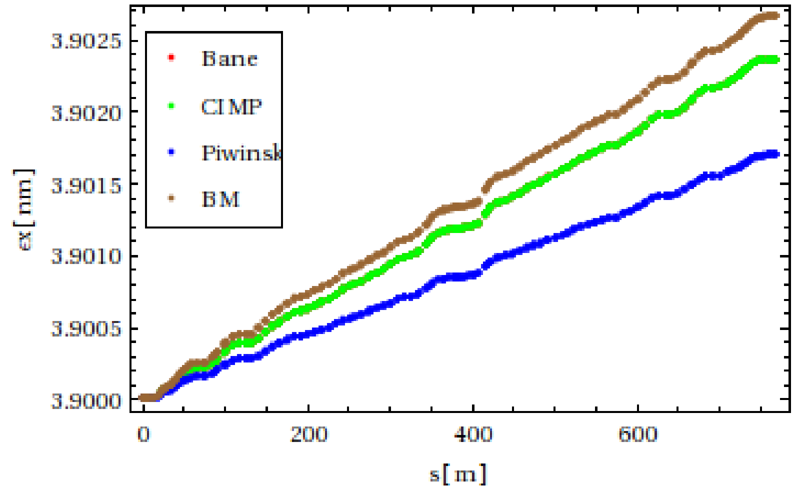
Experimental studies at CESRTA

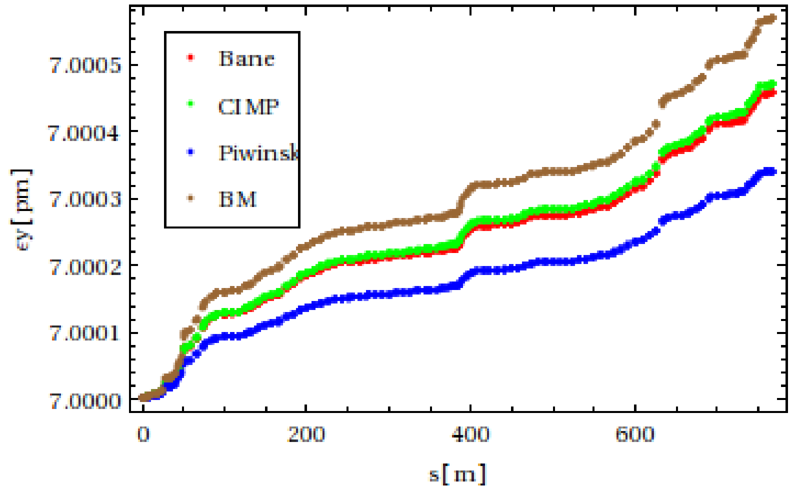


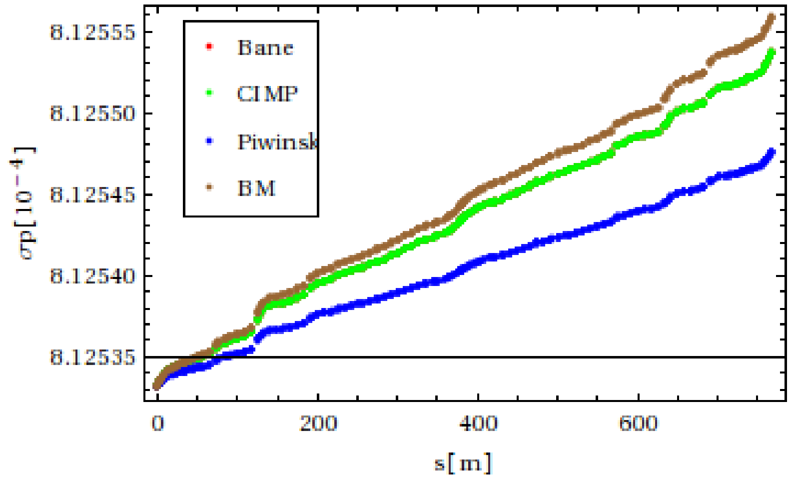


- CESRTA is a very good testbed for IBS studies due to the:
  - Ability to run at different energies
  - Availability of emittance monitoring diagnostics (horizontal and vertical beam size monitors and streak camera for bunch length measurements)
- Measurements from the December 2011 Run were analyzed

Comparison between theoretical models for the CESRTA lattice



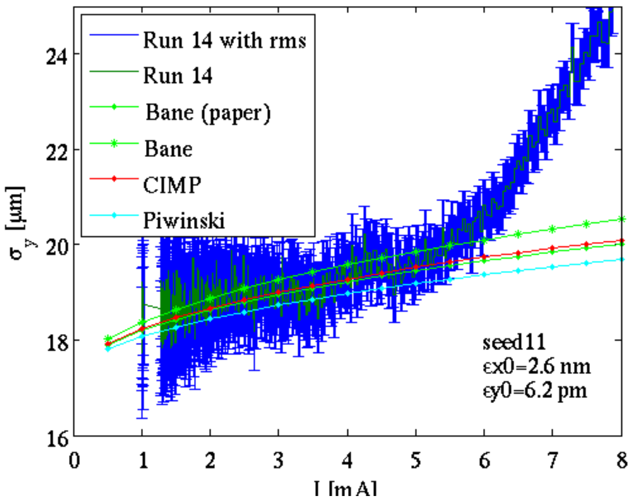


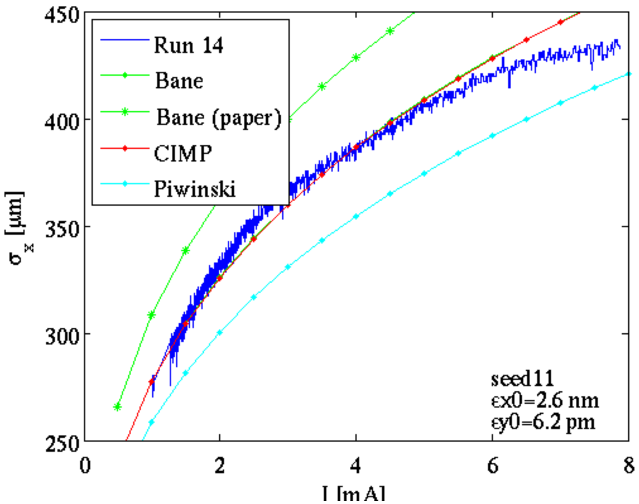


- The full modified Piwinski (blue), BM (brown) theories and their high energy approximations Bane (red) and CIMP (green) are compared for the CESRTA lattice
- One turn evolution of the h/v emittances and energy spread
- Excellent agreement between CIMP and Bane

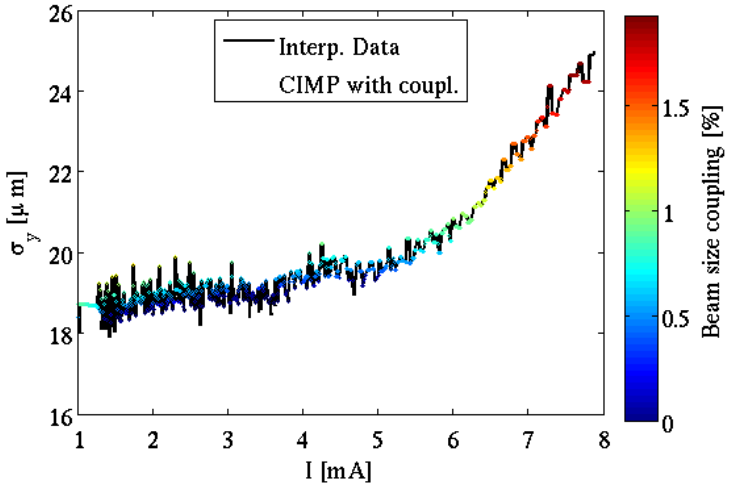
Data comparison to theories

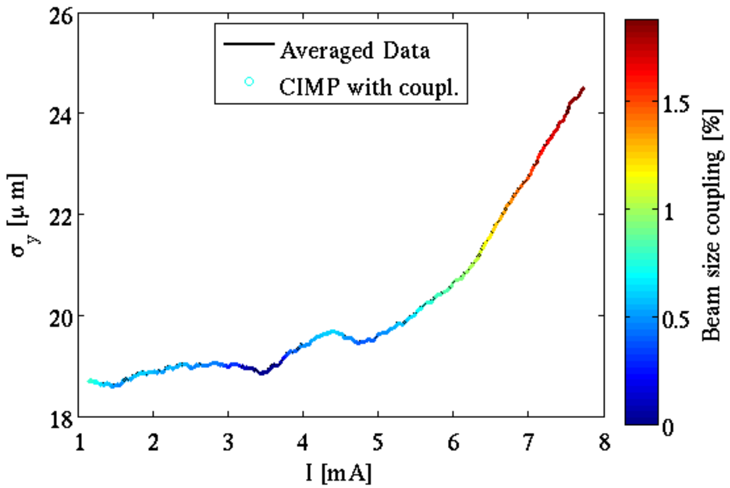
- Data from December 2011 Run
- Partial agreement of all theoretical models in the vertical plane (for low currents).
- In the horizontal plane, Bane and CIMP agree very well while, Piwinski predicts smaller emittance blow-up for high currents.
- Note that the mismatching of the data to the prediction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





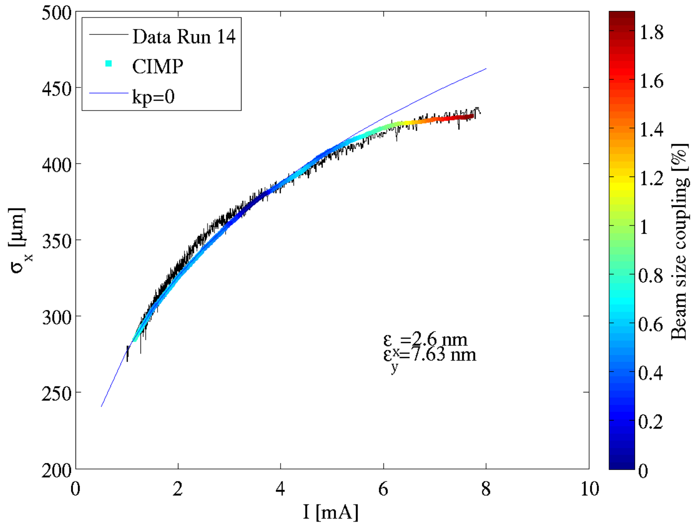
Coupling versus current

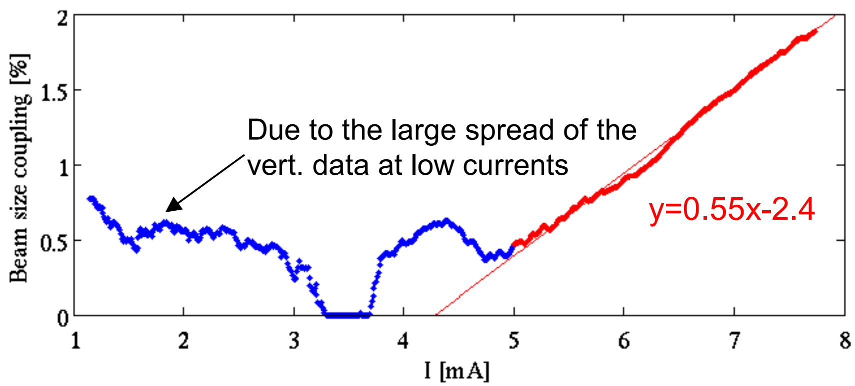




- In order to study the effect of betatron coupling (with coefficient kp) on the theoretical predictions, the output emittances for each current were calculated for different kp values.
- Top: Vertical beam size versus current. The data are shown in black while the colorcode shows the kp for which the 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 artificially

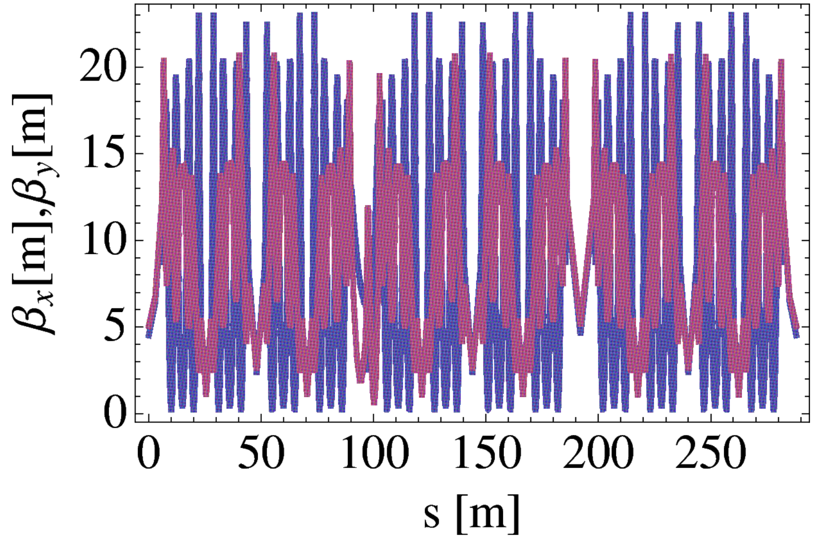
Coupling versus current

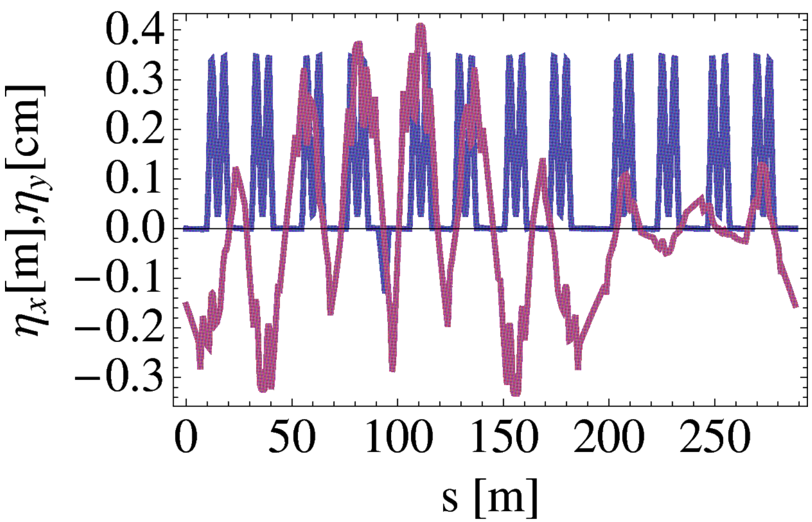




- After choosing a kp value for each current in order to match the vertical beam size data, the respective vertical beam size is calculated and plotted on top of the data colorcoded with the kp value.
- Very good agreement in the horizontal plane too!!
  - Good indication of coupling change with current,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

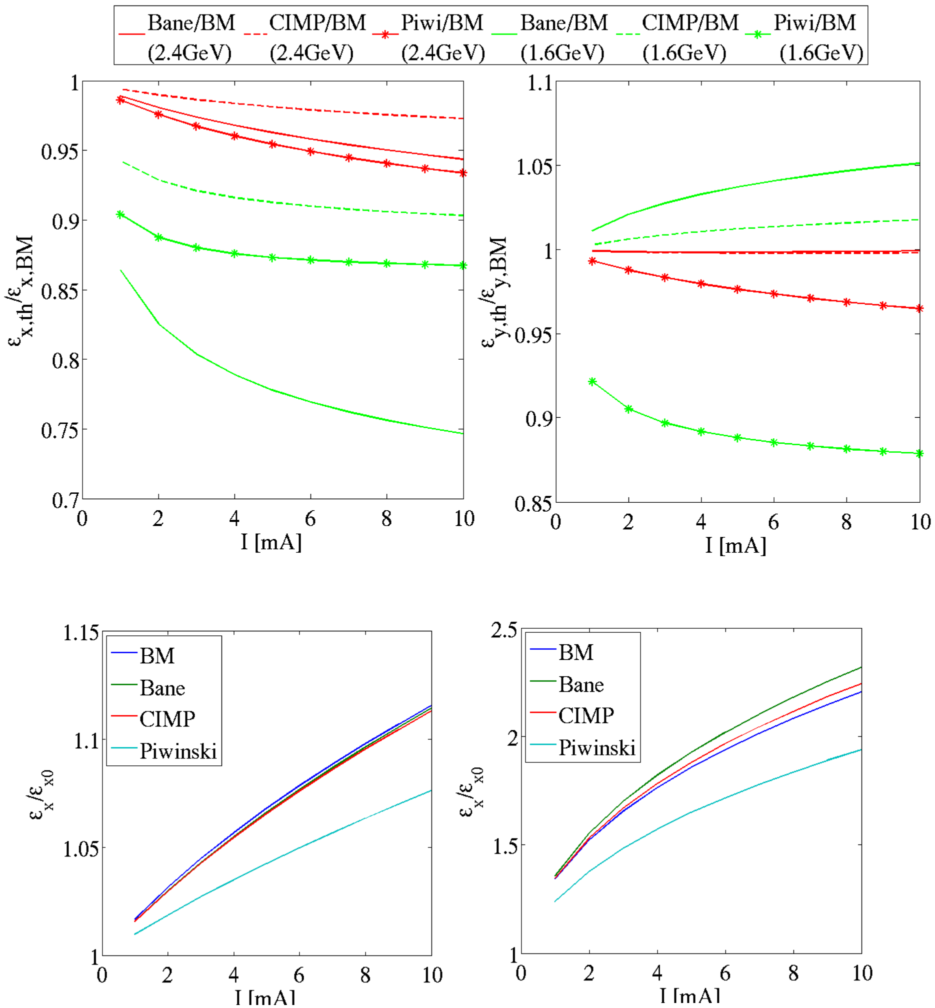
Experimental studies at the SLS





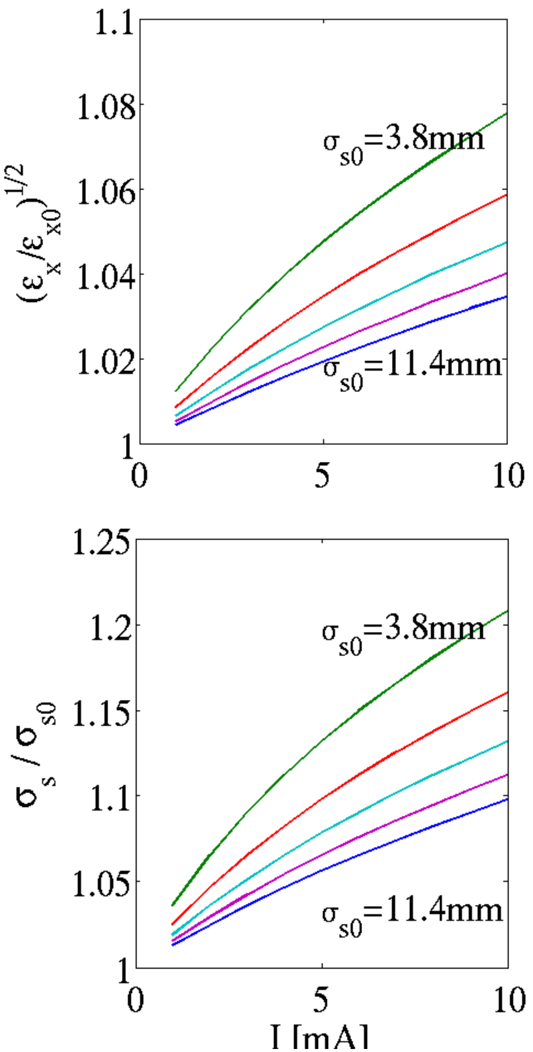
- The SLS is an ideal testbed for IBS studies as it has:
  - Recently achieved a record vertical emittance of 1pm-rad at nominal energy (2.4 GeV)
  - Availability of emittance monitoring diagnostics (hor/vert/bunch length)
  - Ability to run at lower energies
- Participation on 2 set of measurements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

Theoretical models comparison for the SLS



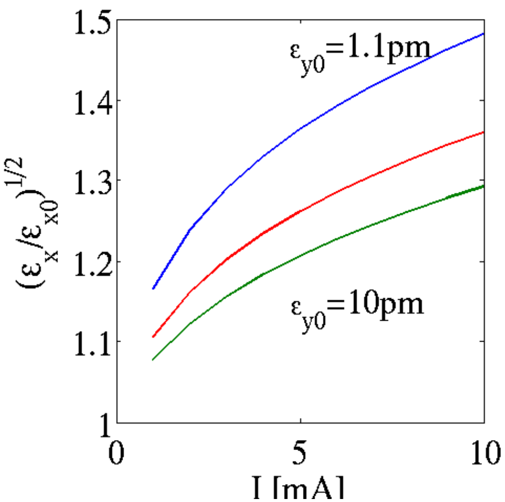
- Very good agreement between the theoretical models when the IBS effect is small (nominal energy, low current)
- At strong IBS regimes the disagreement gets stronger.
- Bane diverges at strong IBS regimes due to the low vertical dispersion

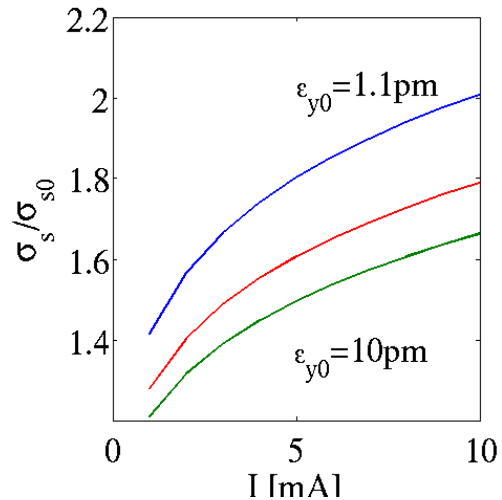
IBS dependence on SLS parameters



- The bunch length at the SLS is dominated by the turbulent bunch lengthening effect (TBL)
  - Onset around 1mA
  - Bunch lengthening and energy spread widening
- It defines new equilibrium states in the longitudinal plane.
- The IBS effect in the horizontal plane (top) and bunch length (bottom) for different σl0 at nominal energy shows that the TBL will make the IBS measurements at nominal energy very difficult.

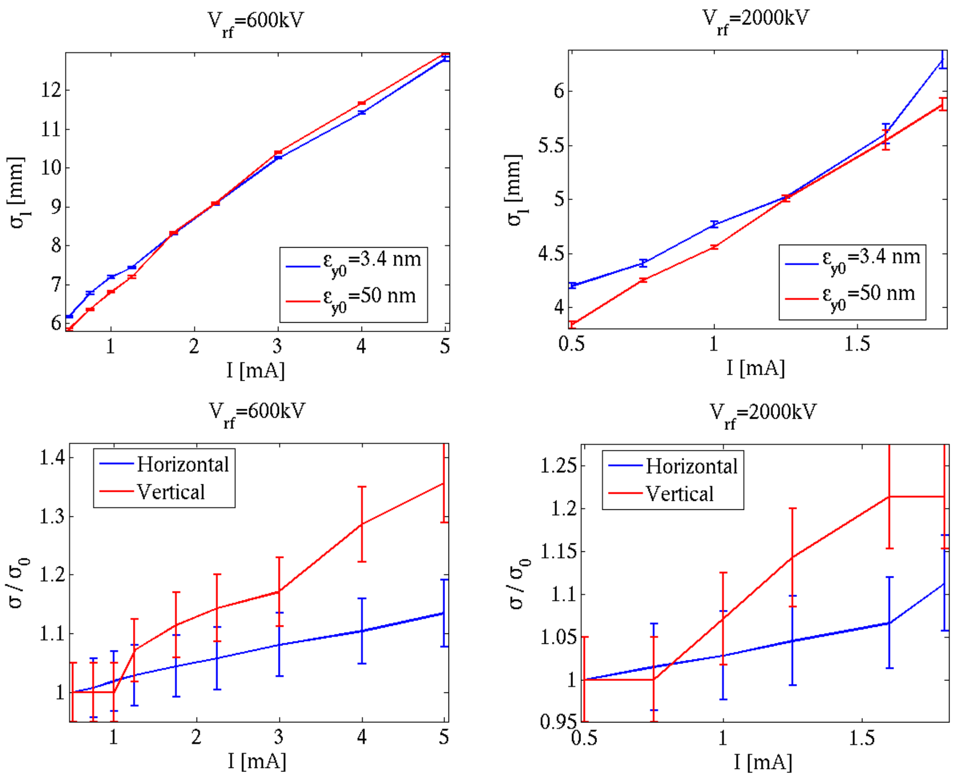
IBS dependence on SLS parameters





- The ultra low emittance of 1pm rad was demonstrated at nominal energy
  - We cannot assume that this will be the case for the low energy
- The IBS effect in the horizontal emittance (top) and bunch length (bottom) for different zero current vertical emittance valus at low energy (1.6 GeV) shows that the IBS effect is measurable even at high vertical emittance and low current
- The IBS measurements at low energy at the SLS very attractive

Low energy measurements



Top: Bunch length versus current for low (blue) and large (red) vertical emittance for Vrf=600kV (left) and Vrf=2000kV (right)
Bottom: The IBS effect on the horizontal (red) and vertical (blue) beam size.

- Two RF voltage settings for measurements with different bunch lengths.
- Measurements with corrected vertical emittance of 3.4 pm rad (IBS dominated) and blown up to 50 pm rad in order to be TBL dominated for constructing a TBL model.
- A way to construct a TBL model is under study.

Low energy measurements

- At low voltage (longer bunch) the bunch length seems to be dominated by TBL
  - No difference between the low and the high zero current vertical emittance ($\varepsilon y0$) data.
- At high voltage (shorter bunch), larger bunch length blow up was observed for the low $\varepsilon y0$ data
  - Indication of IBS effect
- Horizontal and vertical beam size blow up with current which gets stronger for the high voltage (shorter $\sigma s0$) measurements
  - Strengthens the indication of IBS
- However, the vertical blow up is much larger than expected
  - Could be due to coupling change with current as at CESRTA
- We cannot extract any information for the horizontal emittance as the beam size monitor is placed in a dispersive area
  - Energy spread measurement and TBL very important!
  - Currently studying a method for the energy spread measurement through the height of the synchrotron sidebands.

Conclusions

- IBS measurements are very important for understanding the effect, especially in strong IBS regimes
- IBS has to be disentangled from other current depended effects in order to be studied
  - Not an easy enterprise!
- The theoretical models consider uncoupled beams
  - Coupling has to be introduced artificially
- The theoretical models consider Gaussian beams, however this may not be true, especially in strong IBS regimes
  - Generation of non-Gaussian tails?
- Multi-particle tracking algorithms are very important in order to study interesting aspects of IBS that are not included in the theoretical models

Acknowledgments

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THANK YOU!!