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IBS measurements at the Swiss Light Source storage ring

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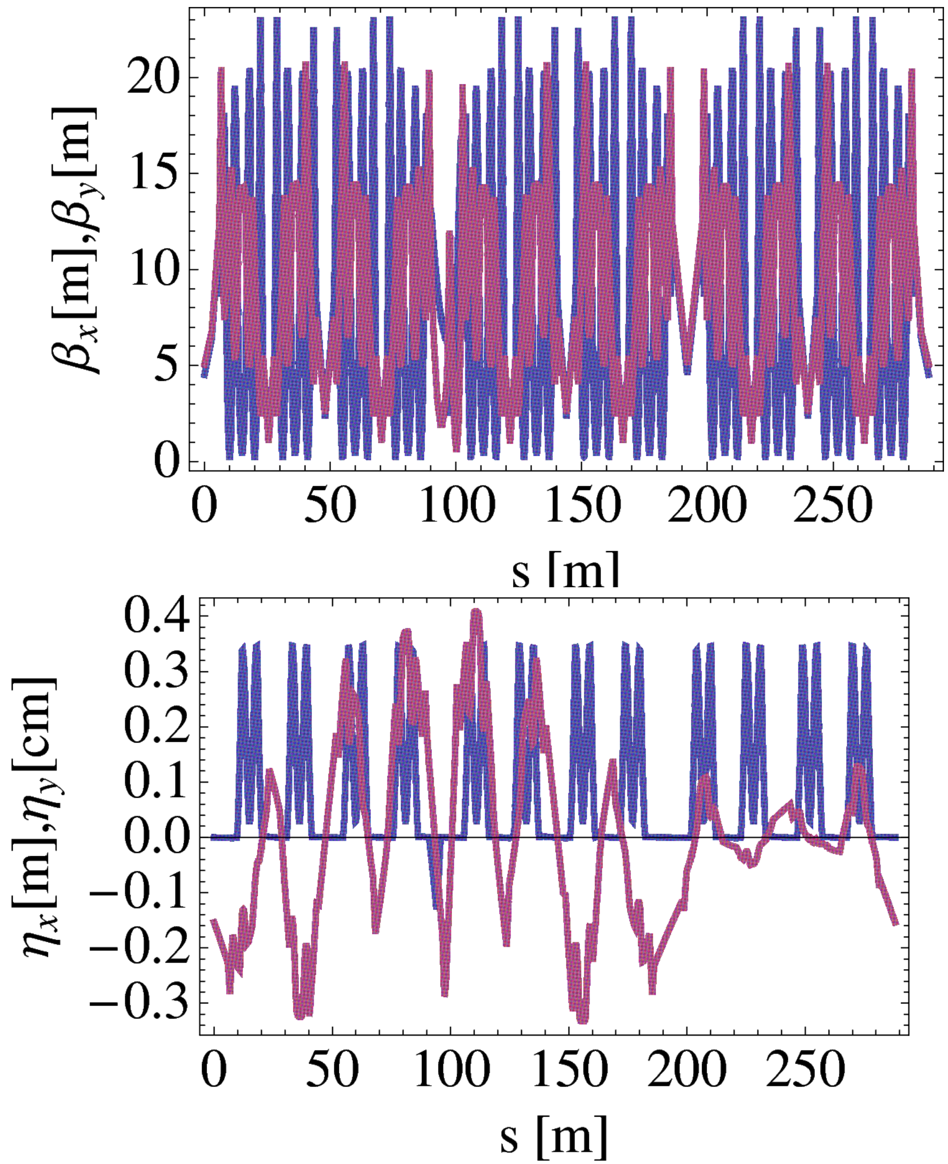
The SLS as a test-bed for IBS measurements



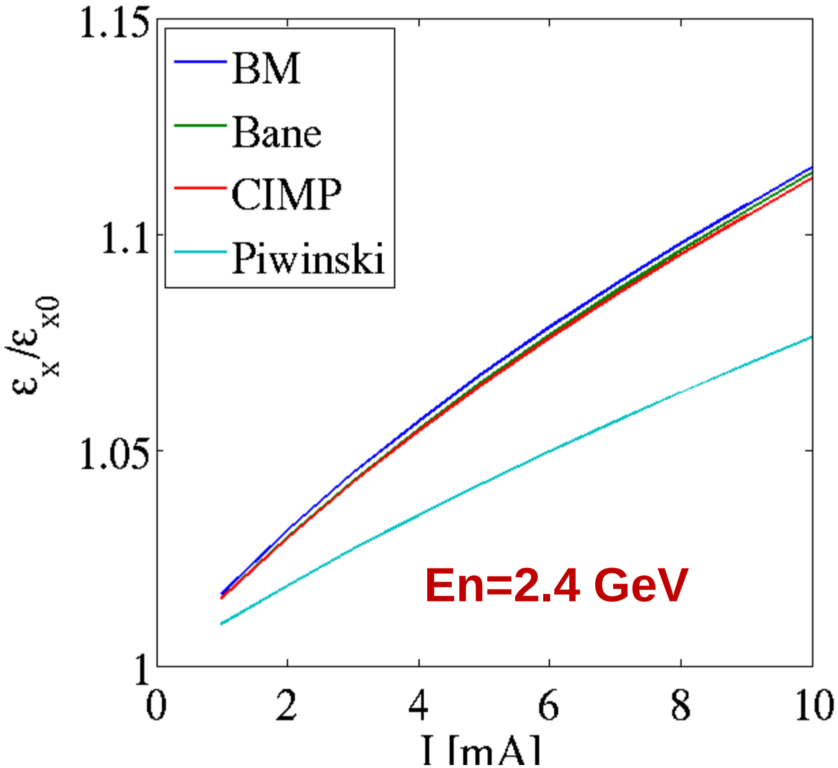
- The SLS is an ideal testbed for IBS studies:
  - Recently achieved a record vertical emittance of 1 pm rad at nominal energy (2.4 GeV)
  - Availability of emittance monitoring diagnostics:
    - horizontal and vertical beam size monitors
    - streak camera
  - Ability to run at lower energies

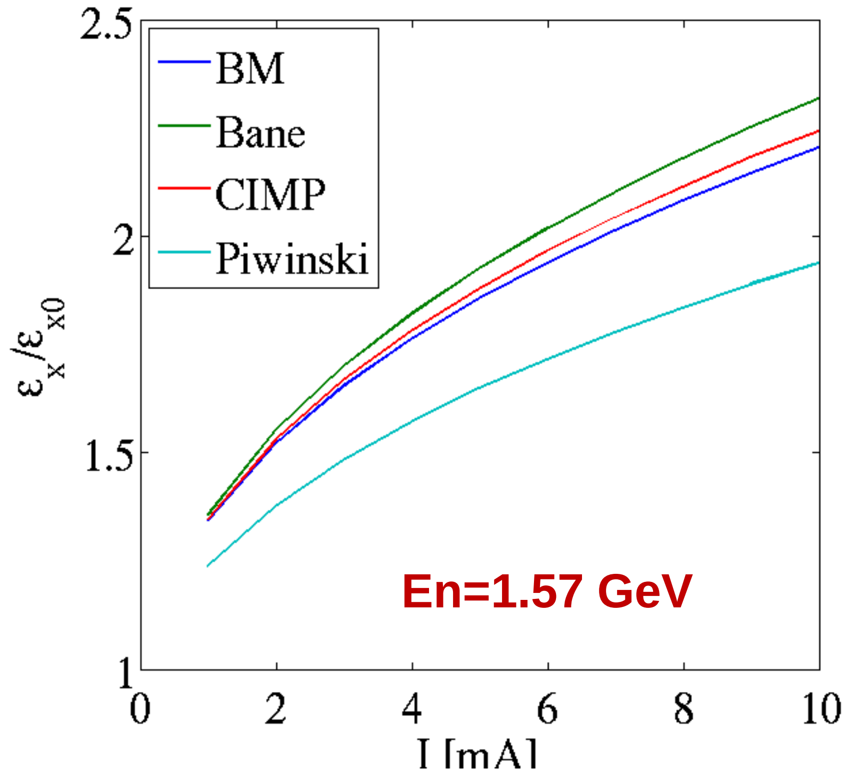
The SLS as a test-bed for IBS measurements

Parameter [Unit]	SLS nominal	SLS low En.
En [GeV]	2.411	1.57
Circumference [m]	290	
Number of bunches		-
Current/bunch [mA]	0.5	-
Momentum Compaction Factor		6 x 10^{-4}
Geom. Hor. Emittance [nm · rad]	5.6	2.4
Geom. Vert. Emittance [pm]	2	1-10
Bunch Length [mm]	6	11.2-6.8 ps
Energy Spread [%]	0.09	0.056
RF Voltage [MV]	2.1	0.6-2.1
Synchrotron frequency [kHz]		4.3-8.0

- SLS parameters at nominal energy (2.4 GeV) and at low energy (1.57 GeV)

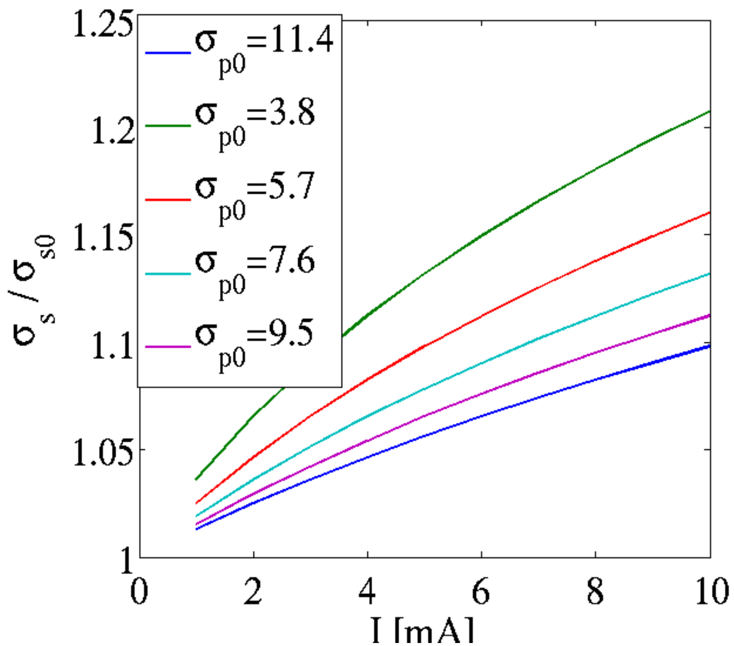
Theoretical models comparison for the SLS

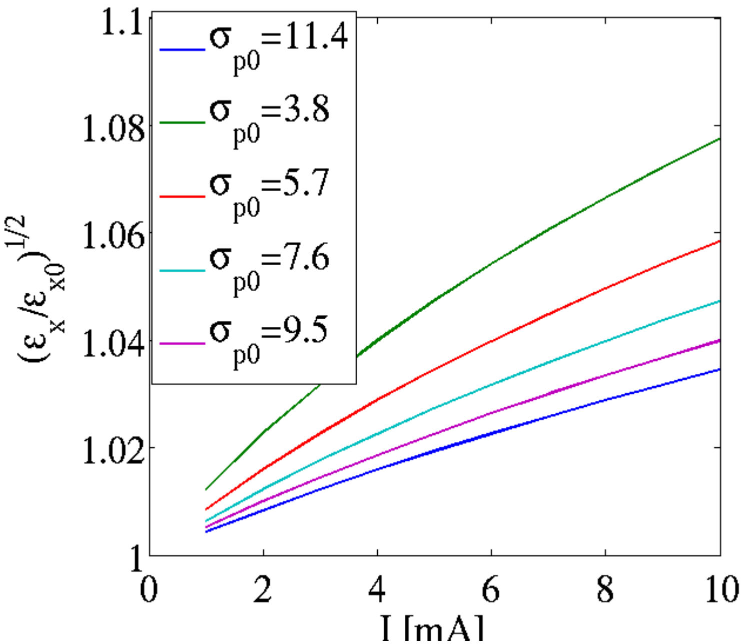




- At nominal energy the effect is very small even at high currents
- At low energy the effect is appreciable even at low currents

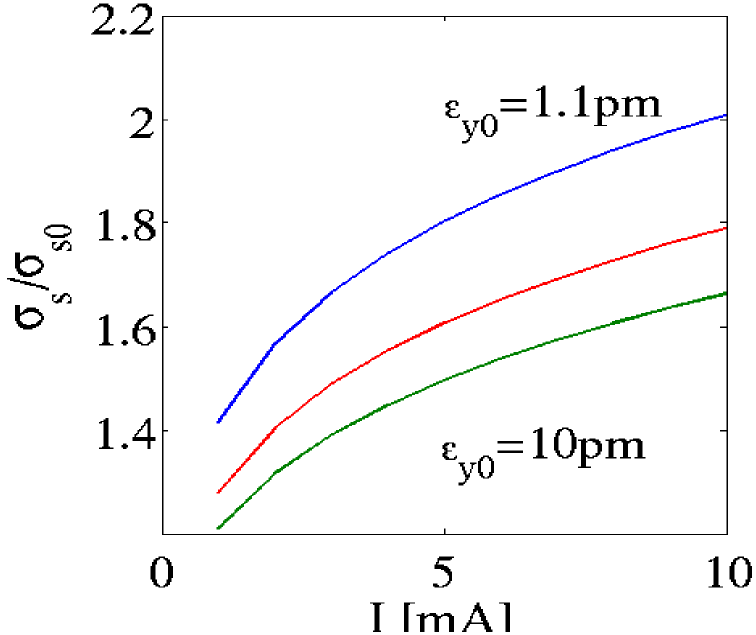
IBS dependence on the SLS parameters

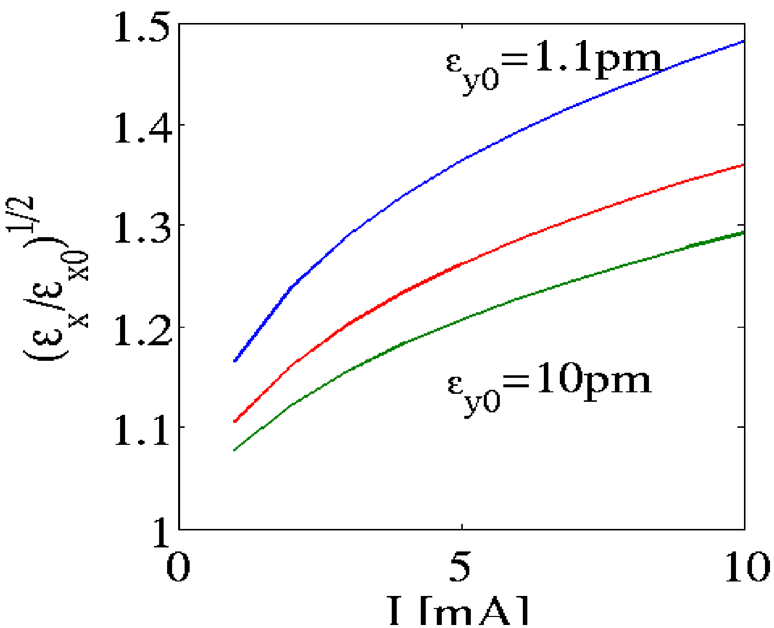




- The bunch length and energy spread at the SLS dominated by the microwave instablility (MI)
  - Defines new equilibrium states in the longitudinal plane
  - Onset around 0.6 mA at nominal energy
  - Bunch lengthening & energy spread widening
  - Energy spread measurement is necessary
- The IBS effect 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

Preparation for IBS measurements

- Set up of the low energy optics
  - Scaling of the 2.4 GeV optics to 1.57 GeV and change of the extraction timing from the booster
  - Verification of the optics using turn-by-turn (TBT) measurements indicated that it was close to the one at 2.4 GeV, as expected, and the residual beta-beat was below 10% in both planes.

- Instrumentation
  - X-ray pinhole camera for the horizontal beam size measurements
  - vis-UV π-polarized light method for vertical beam size measurements (can resolve very small beam sizes)
  - Streak camera for bunch length measurements -> Enables to measure the bunch length of individual bunches with a precision better than 2 ps for currents of the order of 0.1 mA.

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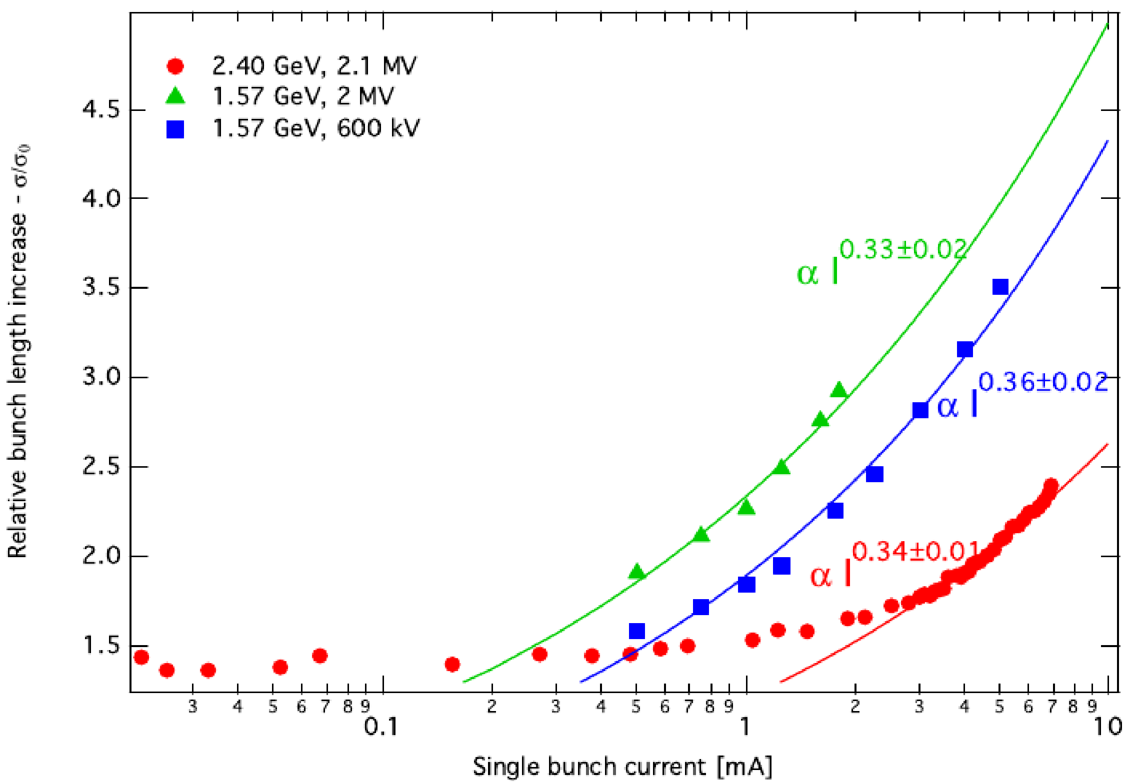
Machine characterization: MI model



$$x = \left(K \left| \frac{Z_{||}}{n} \right|_0^{bb} I_b \right)^A \quad \text{for} \quad \mathrm{I_b} > \mathrm{I_b^{th}}$$

$$K = \frac{C}{(2\pi)^{3/2}\alpha(E/e)\sigma_e^2\sigma_s}$$

$$\ln x = A \ln \left(K \left| \frac{Z_{||}}{n} \right|_0^{bb} \right) + A \ln I_b = B + A \ln I_b$$

Energy [GeV]	Cavity voltage	$I_{th}[mA]$	$\lvert Z/n \rvert \ [m\Omega]$
2.41	2.1 MV	0.57±0.02	432±2
1.57	2.0 MV	0.08±0.01	482±1
1.57	600 kV	0.16±0.02	417±1

- The longitudinal phase space dominated by the MI instability beyond the threshold current
- The 1/3 power fits verify the MI behavior
- MI model for the bunch length not known

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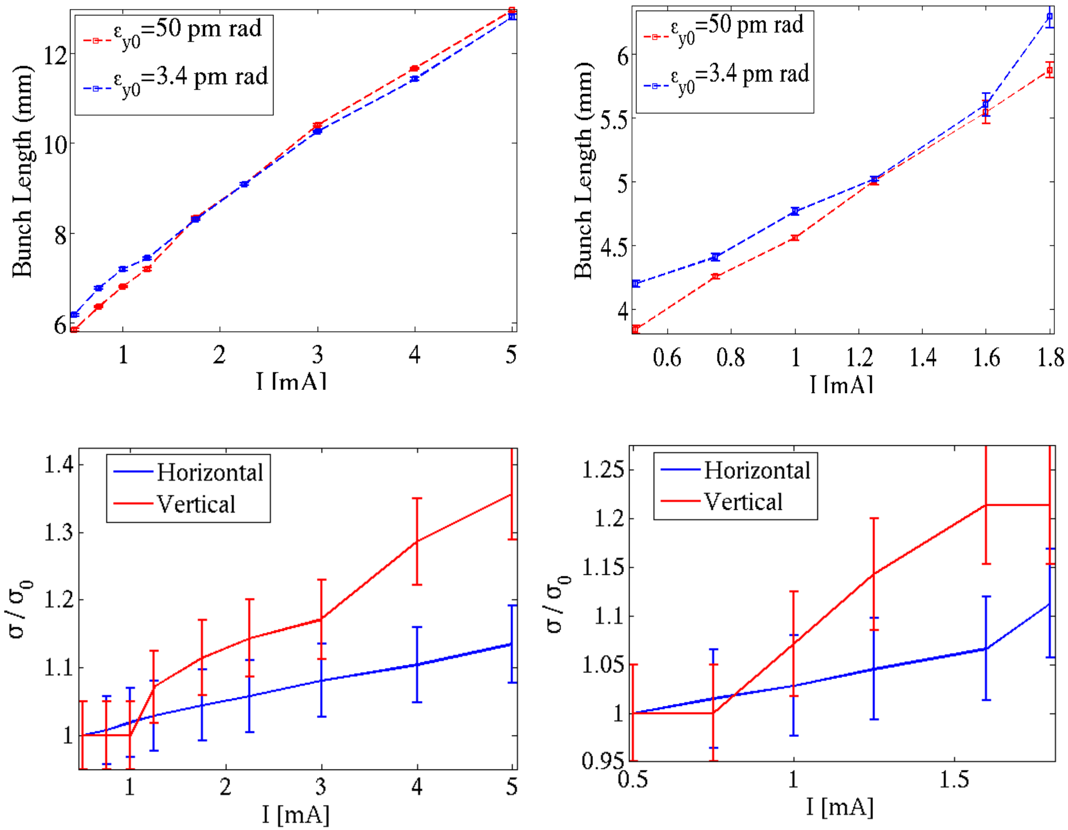
Low energy measurements – May 2012

Vrf = 600 kV

Vrf = 2 MV



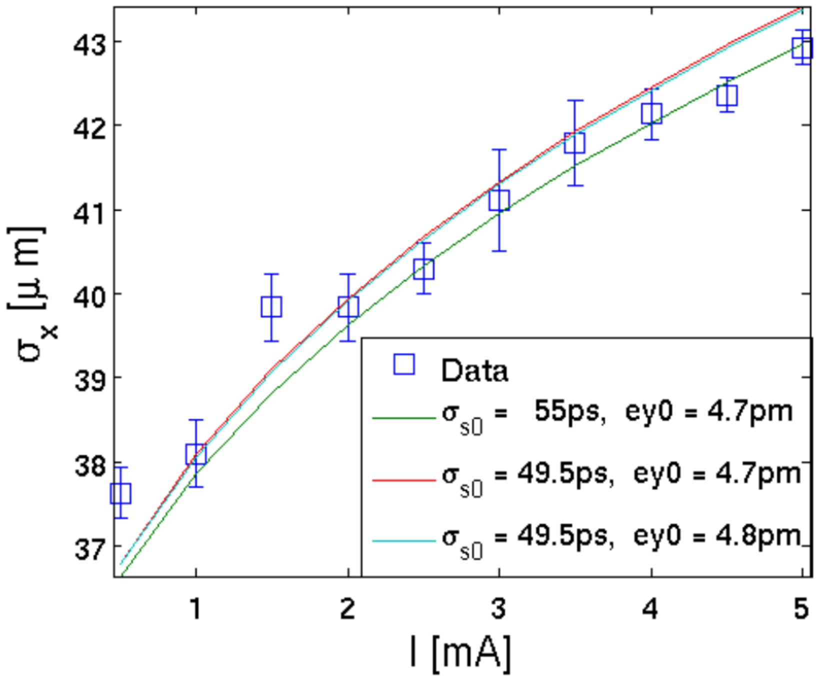
The MI model for the energy spread and bunch length very important for the comparison with theoretical models

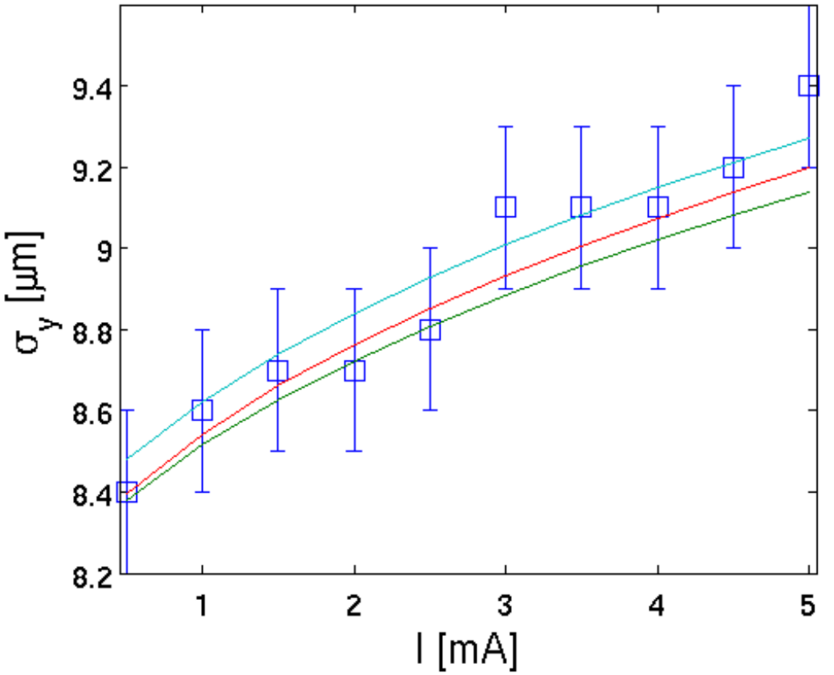
- Both horizontal and vertical beam size measurements taken with the vis-UV monitor
  - Technical problem of the pinhole camera
- Single bunch measurements
- 2 set of measurements for different RF Voltage settings (V1=600kV, V2=2MV)
- For each voltage, measurements at corrected vertical emittance at 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

Low energy measurements – August 2012

- Smoother performance of the machine than in May shift
- Both hor. and vert. beam size monitors in operation
- In order to have good performance of the pinhole camera the minimum total current of the machine needed to be kept at ~ 60-70 mA
  - Not possible to have single bunch measurements
- Random filling pattern was the best choice in order to avoid multi-bunch instabilities
- The contribution of the 3rd harmonic cavity to the bunch length is now large due to the high total current.
  - Important to keep the total current always constant
  - **The MI seem to be suppressed!**

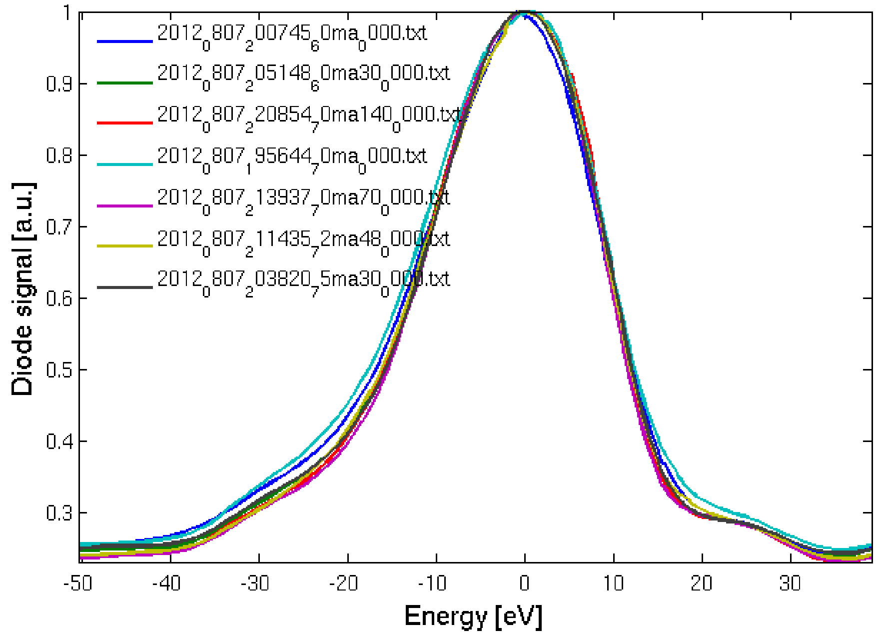
Low energy measurements – August 2012

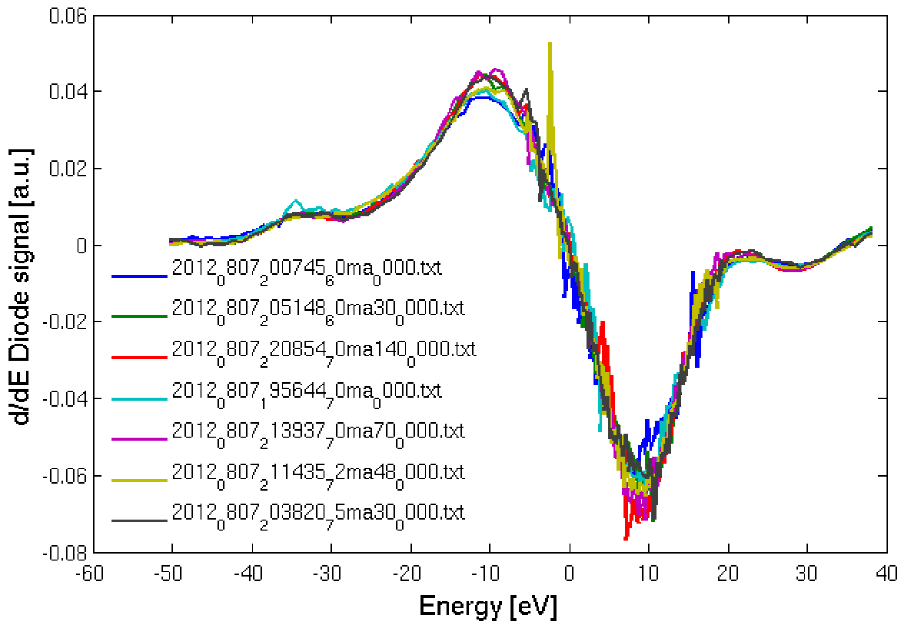




- Comparison between the data (blue squares) and the IBS predictions (straight lines) seem promising:
  - CIMP method is used
  - The different color curves correspond to different assumptions for the zero current vertical emittace and bunch length
  - The zero current measurements in all three planes are needed
  - Understanding the longitudinal motion and the dominant effects (third harmonic cavity, MI instability, PWD, etc.) is crucial

Low energy measurements – August 2012





- Estimation of the energy spread from the width of one of the high harmonics of the undulator spectrum
- Test data were taken for each current.
  - The amplitude (top) and the derivative (bottom) are shown on the figure.
- No effect is visible
  - The energy spread contribution is covered by other effects
- More dedicated measurements are planned
- Another method under study is through the ratio of the amplitudes of the sidebands to the main tune

Summary

- The SLS is an ideal test-bed for IBS studies
  - Very good instrumentation
  - Ability to run at lower energies
- IBS is not visible at the nominal operational energy of the SLS but is enhanced at low energy
- 2 measurement campaigns up to now at low energy and more are planned
  - Slow procedure as the SLS is a users machine
- Last results are promising but still many things to be understood
  - Description of the longitudinal phase space
  - Single bunch measurements → MI regime
  - Multi-bunch measurements → Contribution from the 3rd harmonic cavity
- Energy spread measurement methods under study
  - From the height of the tune side-bands
  - From the undulator spetrum lines

Acknowledgements

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THANK YOU