Intrabeam Scattering Studies at CesrTA

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What is IBS?

- In context of e^+/e^- storage rings: A single-bunch, collective effect that limits the density of particle beams.
  - $\epsilon_0 \Rightarrow \epsilon(I)$
  - Interpret as either a current limit or a lower bound on emittance.
  - Constrains damping ring parameters in future colliders, or limits brightness of light sources.
- Mechanism: Scattering amongst the particles that compose a bunch exchanges momentum between the 3 beam dimensions, changing the emittance in all 3 dimensions.
- IBS has been observed to have a significant impact on hadron machines such as RHIC, Tevatron, LHC, and has been observed at electron machines such as ATF and CesrTA.
  - We require additional experimental and theoretical understanding of IBS in low-emittance rings in order to properly design the next generation of machines.

Why Study IBS at CesrTA?

- CesrTA is a low-emittance wiggler-dominated e+/e- machine capable of high single-bunch currents.
  - **Small beam sizes:** $\langle \sigma_x \rangle \approx 240\ \mu\text{m}\ ,\ \langle \sigma_y \rangle \approx 12\ \mu\text{m}$
  - **Single Bunch Current:** $10^9 \text{ to } 10^{11} \text{ part/bunch}$
  - **Variable Beam Energy**
  - **e^- and e^+**
  - **Versatile Optics (knobs for emittance, dispersion in wigglers and instrumentation source points)**
  - **Variable RF Voltage**
- Instrumented for simultaneous measurement of projected beam sizes in all 3 dimensions
- Because we can:
  - CesrTA is in a position to gather comprehensive measurements on current-dependent effects in low-emittance, high-intensity lepton beams.

Modeling IBS

- Goals
  - Determine correct methods for using theory to predict machine performance
  - Evaluate and develop IBS theory
- Analytic Approaches
  - Twiss-based formalisms
    - Piwinski and Bjorken-Mtingwa
    - Commonly used, but less versatile
  - Sigma matrix-based formalisms
    - Kubo, Oide, Nash
    - Less common, but more versatile
- Monte Carlo Approach
  - Takizuka & Abe’s plasma collision algorithm
  - Very Robust, but Slow

Parameterizing the Model

- Want to keep free parameters to a minimum
- Zero-Current Emittances: ϵ_x, ϵ_y
  - Encapsulates all current-independent effects
- Longitudinal Inductance: L
- Lattice with Misalignments: $\eta_y(s)$
  - Misalignments chosen to generate vertical dispersion that corresponds to measured ϵ_y
- Plug in what the machine looks like at zero current, and the model tells us what should happen as we add charge.

Zero-current Horizontal Emittance

- Design emittance is: $\epsilon_a \approx 3.0 \text{ nm}$
- Measured emittance is: $\epsilon_x \approx 6 \text{ nm}$
- IBS results to be shown are based an "effective horizontal emittance":

$$\epsilon_x = \frac{1}{\beta_x}\left(\sigma_x^2 - (\sigma_p \eta_x)^2\right)$$

Observed Quantities

- Horizontal dispersion in the RF cavities generates longitudinal coupling
  - Impacts modeling and measurements
- Simulations suggest using effective emittance is accurate

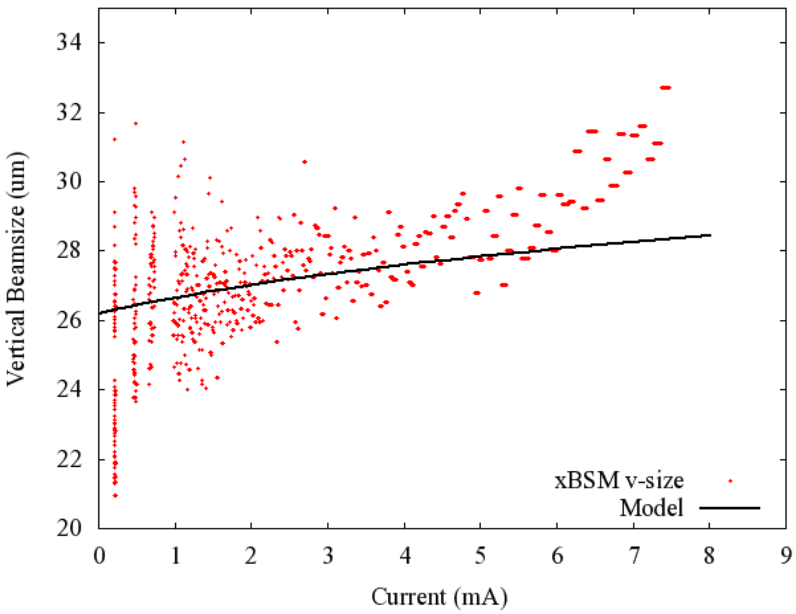
Experimental Procedure

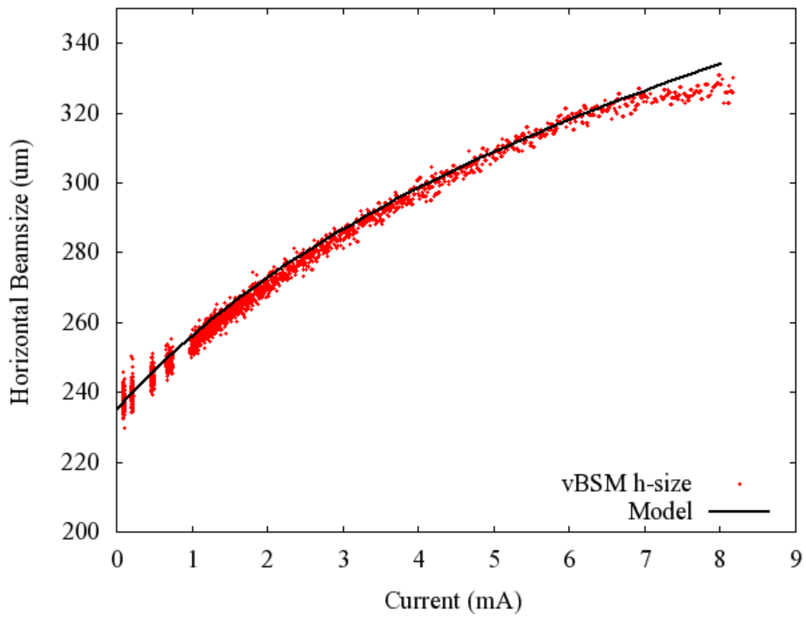
1. Set RF voltage and locate "quiet" region of tune plane
2. Apply LET corrections
3. Adjust zero-current emittance to desired value using closed coupling & dispersion knob
4. Charge single bunch to 10+ mA
5. Cut injection and take data as beam decays
   - Decay due to Touschek scattering
   - Each run lasts about 30 minutes
   - Decay at low current is slow, scraping is used to speed things up.

Data Sets

1. 4B: Positrons in LET conditions
2. 53: Positrons with vertical beam size increased
3. 68: Electrons in LET conditions
4. 6B: Electrons with vertical beam size increased

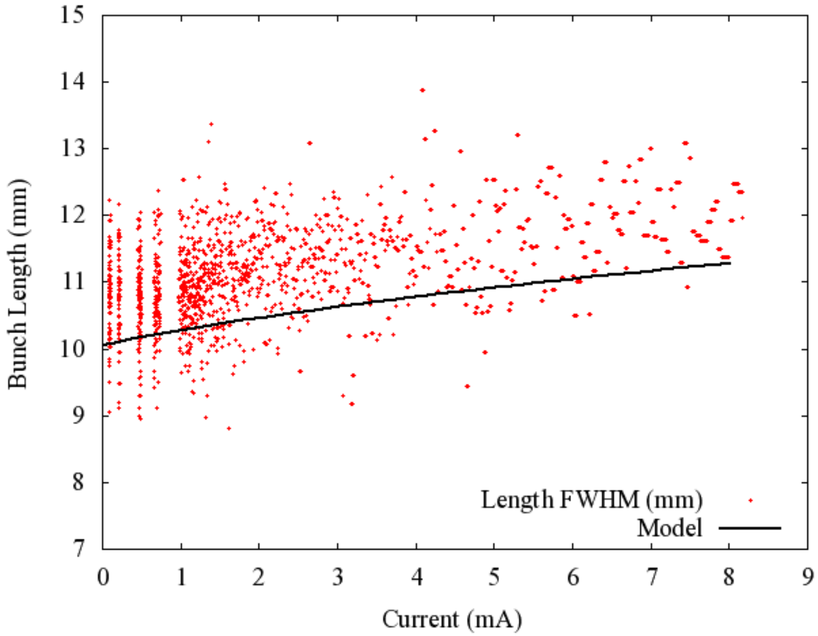
Run 4B: positrons, LET





Effective Vertical Emittance: 16.3 pm
Effective Horizontal Emittance: 6.8 nm
Long. Inductance: 17 nH

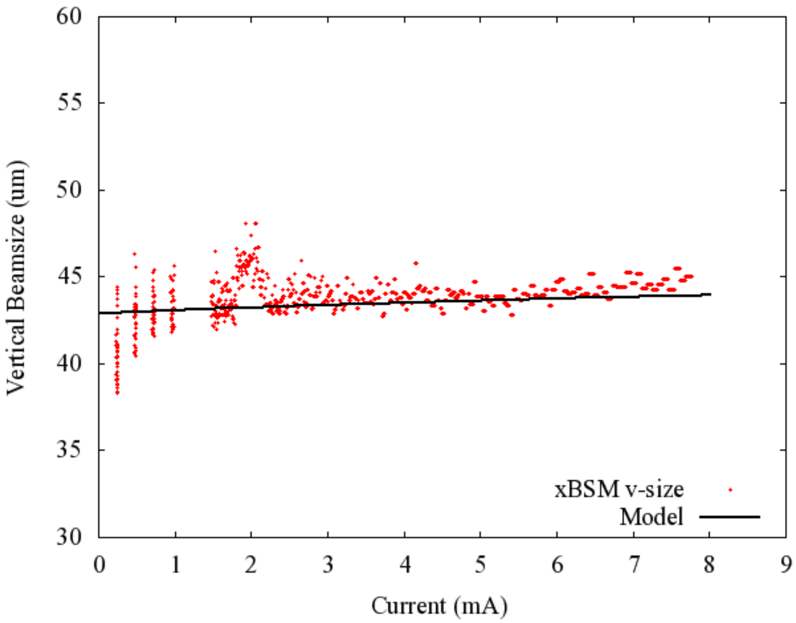
- Observed discrepancies with model:
  - Anamolous vertical blowup above 6 mA.
  - Vertical scatter at low current.
  - 1 mm systematic in bunch length

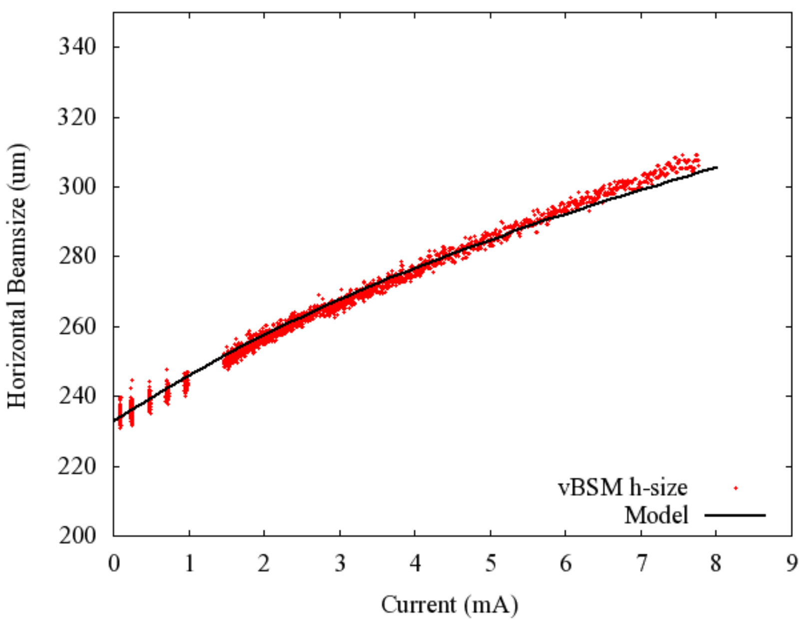


Contributions to Current Dependent Beamsizes

- Things we can model:
  - IBS: Increases Beamsize, including length
  - Potential Well Distortion (PWD): Lengthens Bunch
- Other possible sources of real growth:
  - Current-Dependent Tune Shift: Beam moves towards or away from resonance lines
  - Space Charge
- Instrumentation:
  - Response of instrumentation can change with current (calibration)

Run 53: positrons, C9 -> 46 um

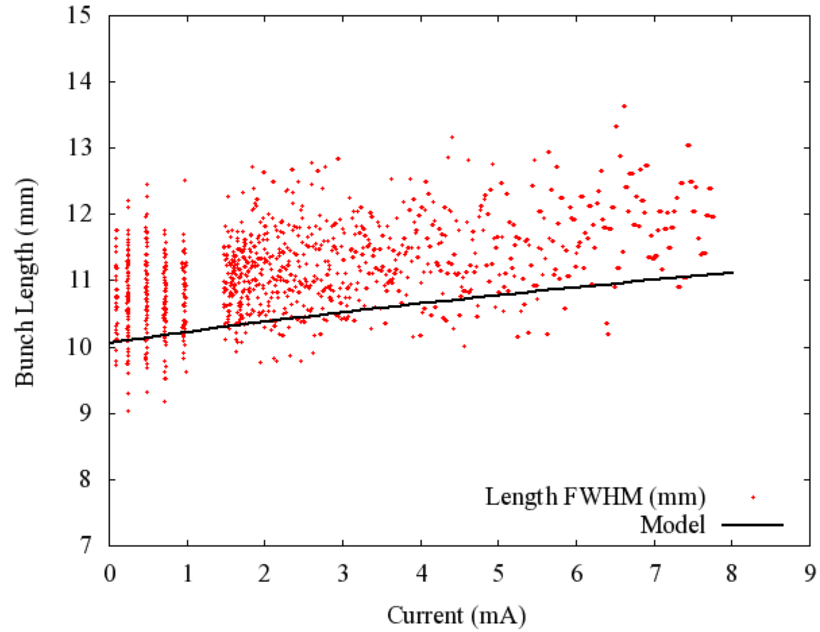




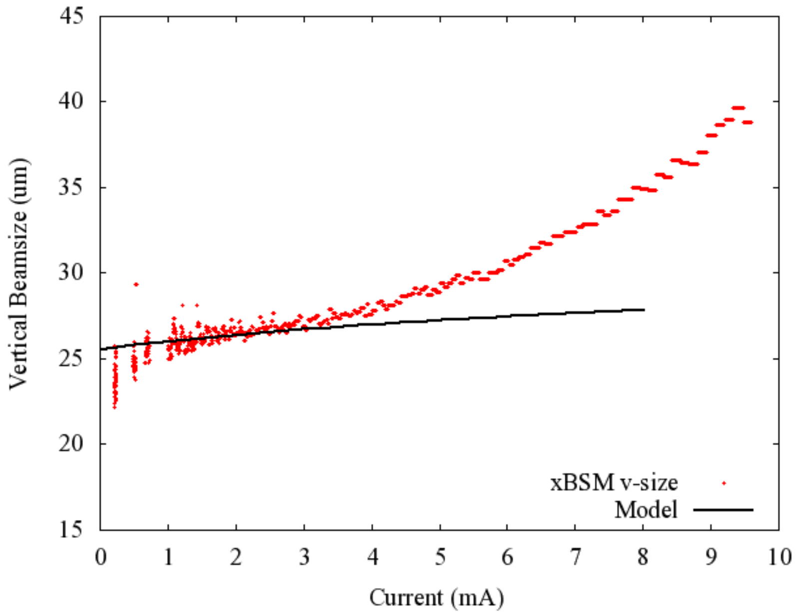
Eff. Vertical Emittance: 43.2 pm
Eff. Horizontal Emittance: 6.6 nm
Long. Inductance: 17 nH

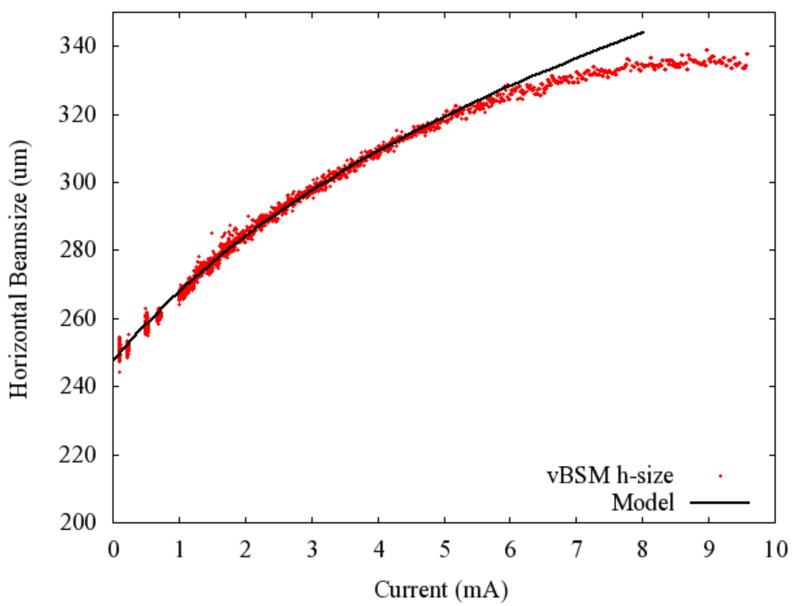
- Vertical emittance 2.7 times larger

- Longitudinal behavior does not change significantly with reduced particle density.
    - Supports PWD hypothesis



Run 68: electrons LET

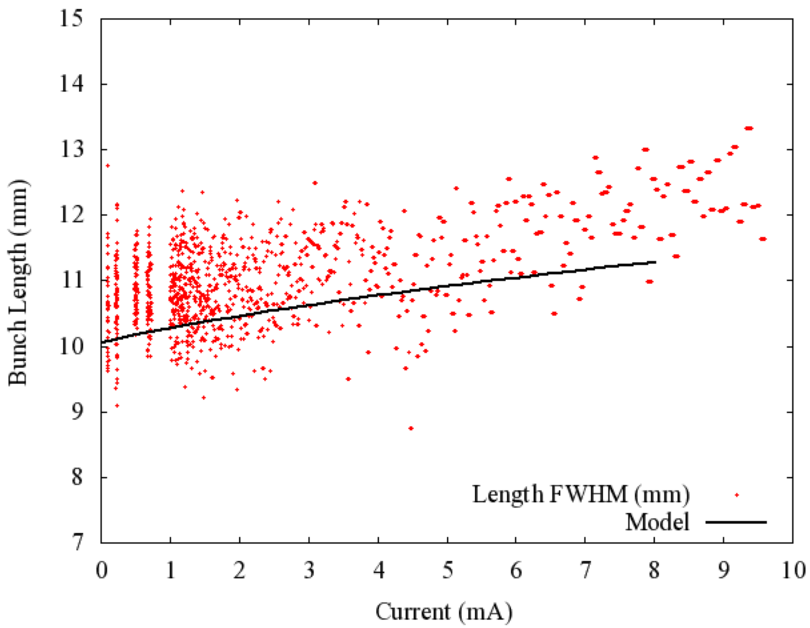




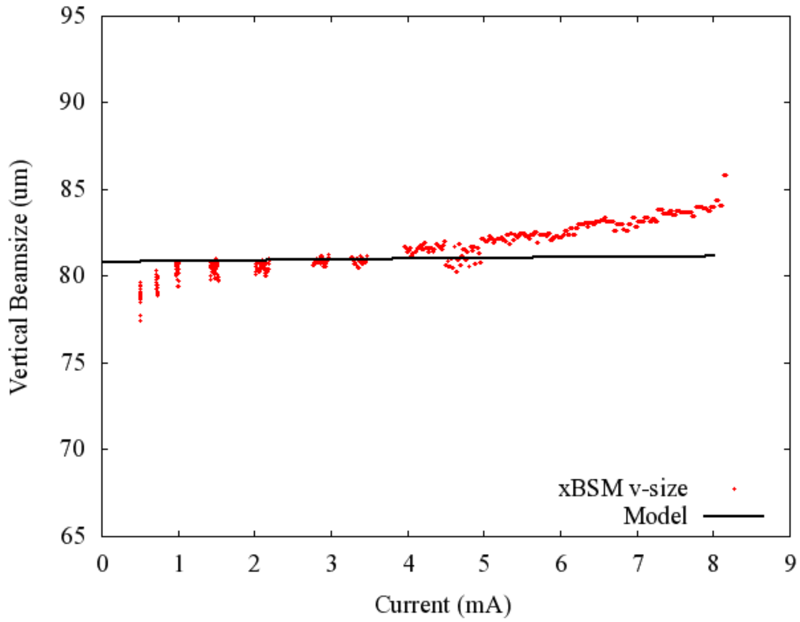
Eff. Vertical Emittance: 15.2 pm
Eff. Horizontal Emittance: 7.45 nm
Long. Inductance: 17 nH

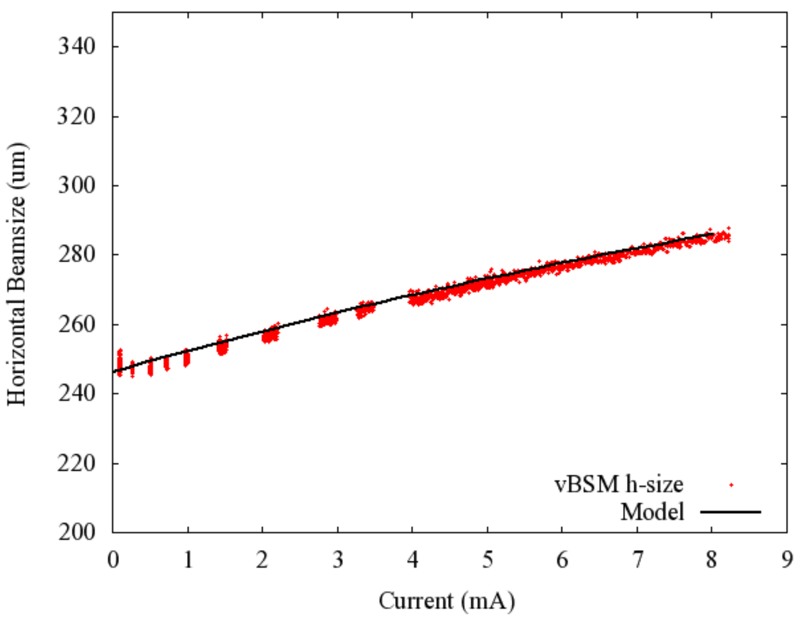
Note that positron and electron data is gathered by different instrumentation.

Blow-up at high current is different for electron and positron bunches.



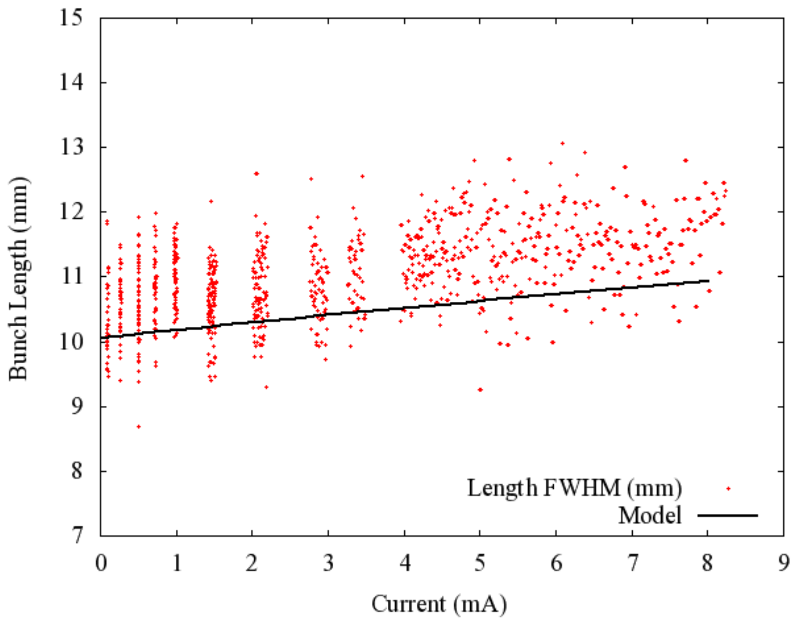
Run 6B: electrons, C9 -> 80 um



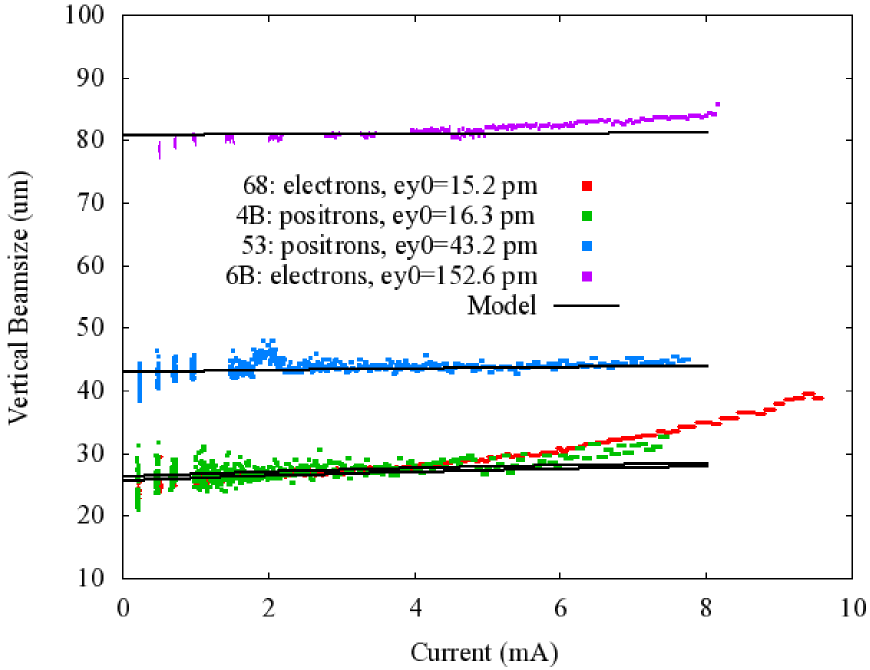


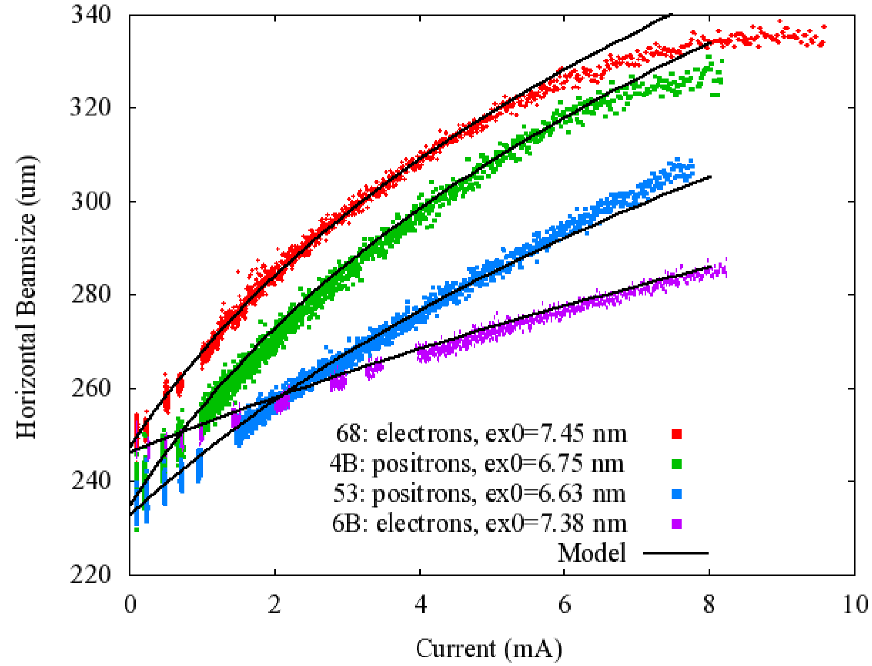
Vertical Emittance: 152.6 pm
Horizontal Emittance: 7.38 nm
Long. Inductance: 17 nH

Vertical emittance 10 times larger



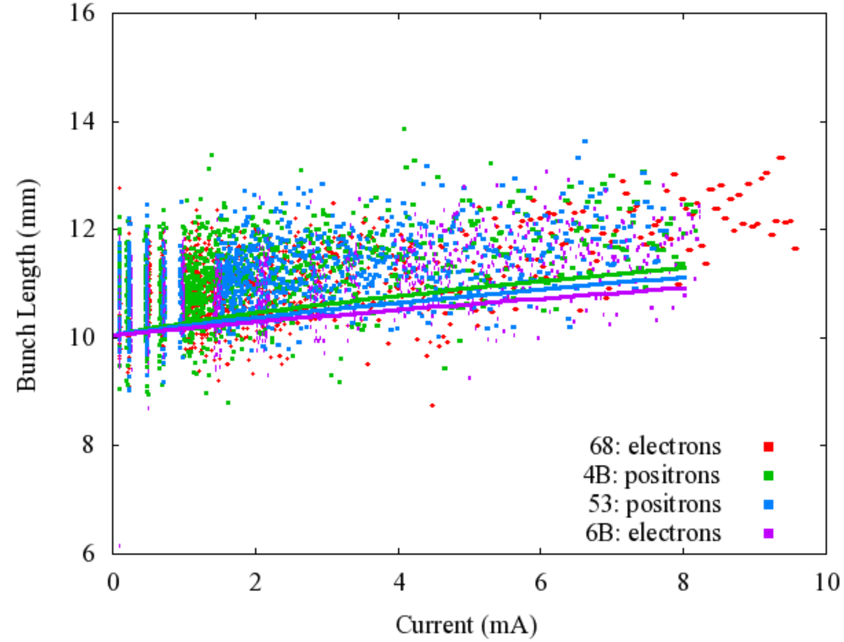
Combined Plots



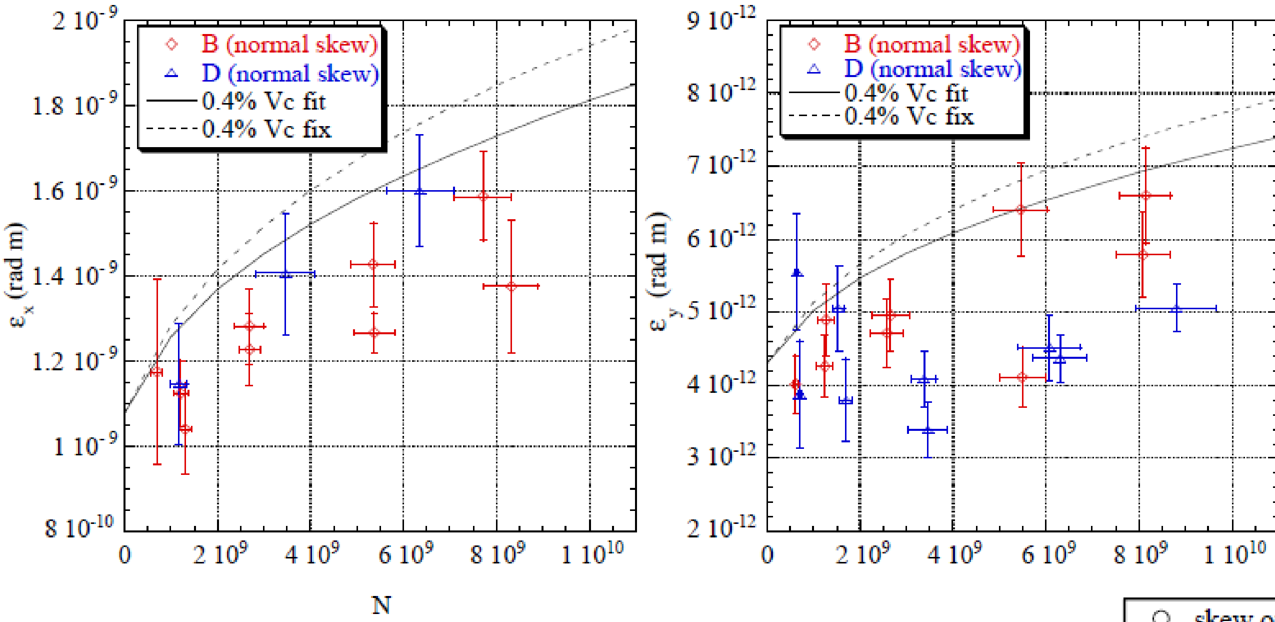


- Dependence of horizontal beamsize on current agrees with IBS theory

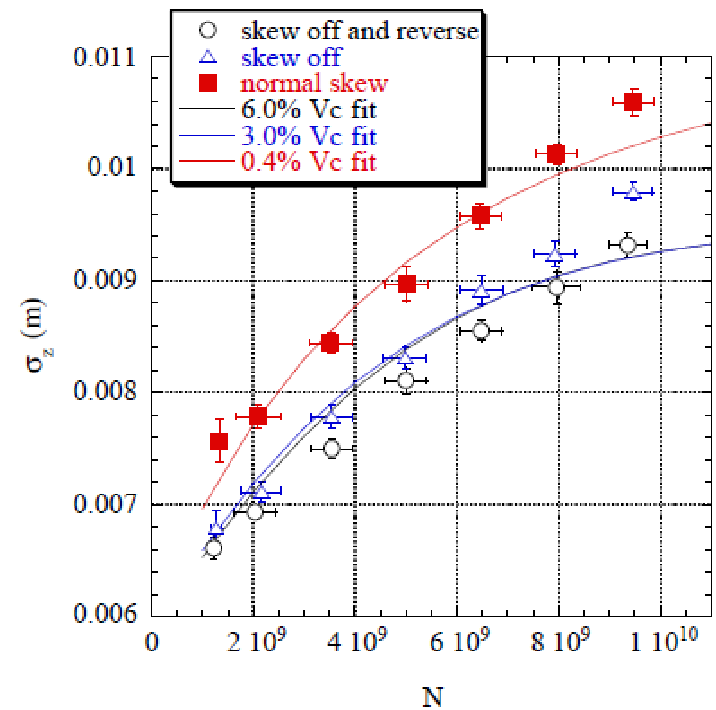
- Above 4 to 6 mA, data diverges from model. Additional collective effects suspected.



Compare to Existing Results (ATF)



- ATF results presented at 2007 IBS Workshop at Daresbury
- Maximum current is 10^{10} part/bunch
- CesrTA offers a significant improvement over currently available IBS data
    - This is needed to properly design future machines and upgrades



Current and Future Efforts

- Lattices with smaller projected horizontal emittance
- Understand scatter at low current
- Understand blow up at high current
  - Combination of effects
    - Tune plane
    - Instrumentation
    - Other physics
- IBS at different energies
- Implementation and development of more robust IBS calculation methods

Conclusion

- IBS is an important effect for the next generation of accelerators (CLIC, ILC, USRs)
- IBS theory gives good agreement with proton[1] and ion machines[2]
- CesrTA is good laboratory for studying IBS in lepton machines
  - Results thus far are encouraging
  - Reasonable models give good agreement with the data
- Have observed anomalies in the data which seem to be non-IBS effects
- Goals:
  1. Gather data on IBS dominated lepton beams
  2. Determine correct methods for using theory to predict machine performance
  3. Evaluate and develop IBS theory

[1] *V. Lebedev, AIP Conf. Proc. 773(1), 440 (2005)*
[2] *A. Fedotov et al, HB2006, p. 259*

Variation between seeds

- Out of 100 seeds, 10 are within the range:
  - Natural ε_y between 10 pm and 20 pm
  - η_y between 14.5 mm and 17 mm
- Measured Machine values are $\varepsilon_y \approx 16.3$ pm $\eta_y \approx 15$ mm