Intrabeam Scattering Studies at CesrTA

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Outline

- 17 slides after this one

1. Introduction to IBS
2. Introduction to CesrTA IBS Program
3. Briefly discuss modeling
4. Show data and modeling results
5. Program directions

What is IBS?

- In context of e^+/e^- storage rings: A single-bunch, collective effect that limits the density of particle beams.
  - Interpret as either a per-bunch current limit or a lower bound on emittance.
  - Constrains damping ring parameters in future colliders.
- Mechanism:
  - In a storage ring, the average momentum of the 3 bunch dimensions are unequal. i.e. the temperatures are not in equilibrium.
  - Scattering transfers momentum from the “hotter” dimensions to the “cooler” dimensions.
  - Additionally, scattering that occurs in a dispersive region increases the total momentum of the 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.

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 to 10^{11} 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
  - Bunch-by-bunch, turn-by-turn beam diagnostics
- Because we need to
  - The next generation of colliders (and light source) will be low-emittance lepton machines whose design will be impacted by IBS predictions.

Experimental Setup

- A consequence of CesrTA's versatility is that the machine requires specific setup and tuning prior to each experiment
- vBSM, xBSM, and Streak Camera are multi-purpose devices and require configuration and monitoring
- 5 or 6+ people on shift
- Conditions are set:
  - Beam energy (1.8, 2.1, 2.3 GeV)
  - Operating Point (Tunes) Set
  - Set RF Voltage (range is >6.3 MV to <3.0 MV)
  - LET Corrections and Optics Choice
  - Closed orbit & dispersion bump knob for vertical emittance adjustment

Experimental Procedure

1. Configure machine as just mentioned
2. Charge single bunch to 10+ mA
3. Cut injection and take data as beam decays
   - Decay due to Touschek scattering
   - Each run lasts about 30 minutes
     - Decay to 4 mA in about 3.5 minutes.
     - Decay from 4 mA to 1 mA in about 21 minutes.
     - Below 1 mA, decay is very slow. Scraping is used to speed things up.
       - Gaps in upcoming Beam Size vs. Current plots are due to scraping

Model Results

- Model results will be shown along with data
  1. Twiss based: Piwinski, Bjorken-Mtingwa, and descendants.
     - Commonly used
  2. Sigma-matrix based: Kubo and Oide[1]. Uses Eigendecomposition of the sigma matrix, rather than Twiss parameters. Normal modes.
     - Natural handling of coupling between the three dimensions[2]
  3. Monte-Carlo: Tracking code with SR. Application of Takizuka and Abe's plasma collision algorithm in the rest frame of the bunch.
     - Robust, but CPU-intensive
     - Options for OpenMP and OpenMPI parallelization
- Implemented in BMAD simulation suite
  - Symplectic tracking, field maps for wigglers, normal mode computations, sextupoles, multipoles, synchrotron radiation, hooks to Etienne's PTC
  - Misalignment & correction scheme

[1] Code is templated on SAD and formalism discussed in SAD Manual. [2] Not yet validated by experiment

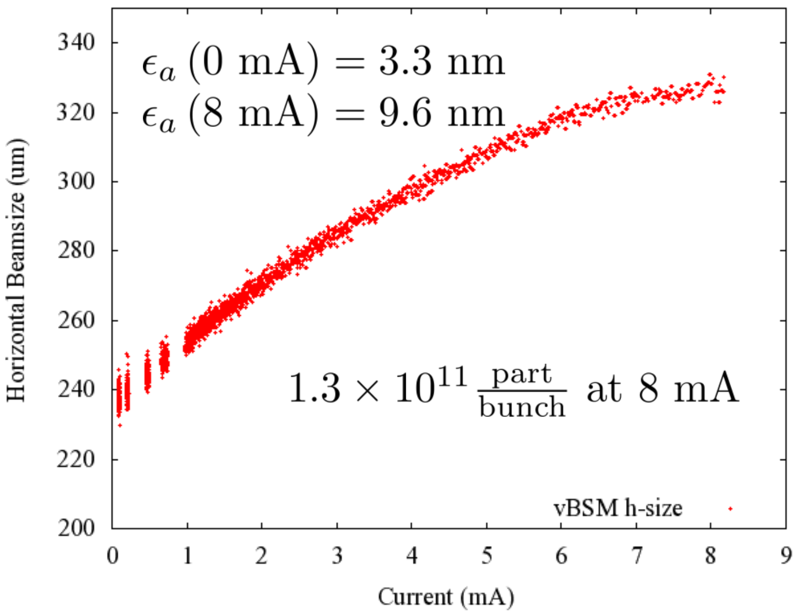
Additional Current-Dependent Effects

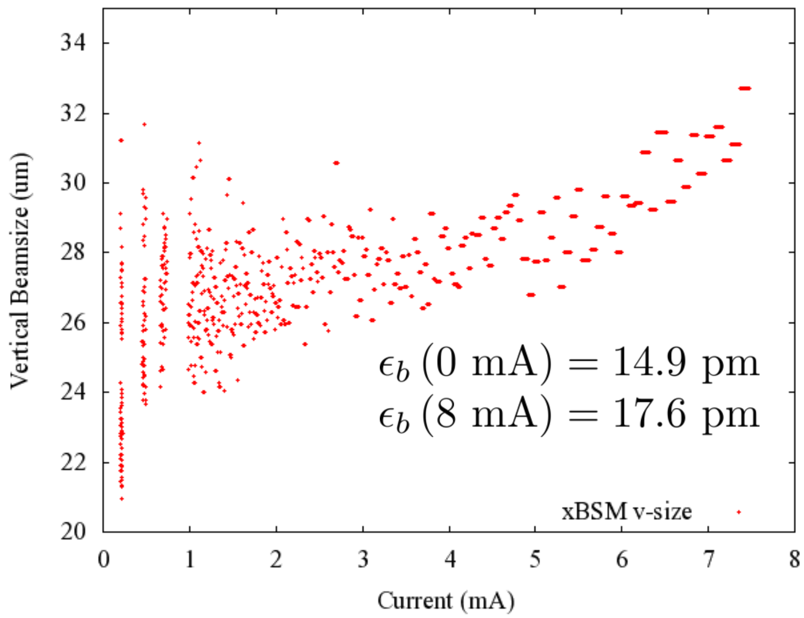
- Additional current-dependent effects observed in the CesrTA IBS Experiments
  - Potential Well Distortion
    - Causes bunch lengthening
    - Does not impact energy spread
      - Energy spread has been measured to be constant
    - Strength of effect depends on bunch length, but not transverse dimensions
  - Current-Dependent Tune Shift
    - Tunes of machine change with current
    - ~0.5 kHz/mA
    - Brings operating point towards or away from resonance lines

Data Sets

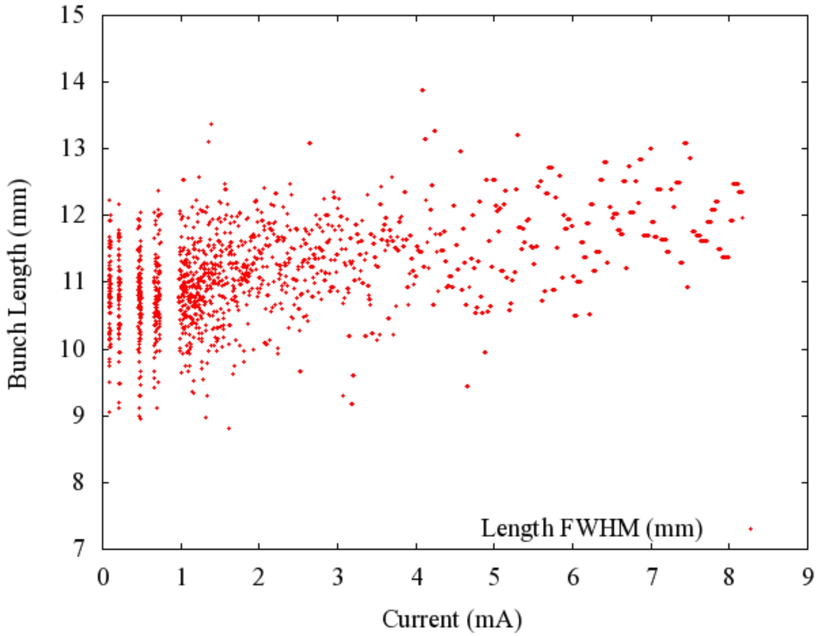
1. Positrons in LET conditions
   1. Bare data
   2. Method Comparison
   3. With just sigma-matrix model
2. Positrons with vertical beam size increased
3. Electrons in LET conditions
4. Electrons with vertical beam size increased

e^+, LET Conditions

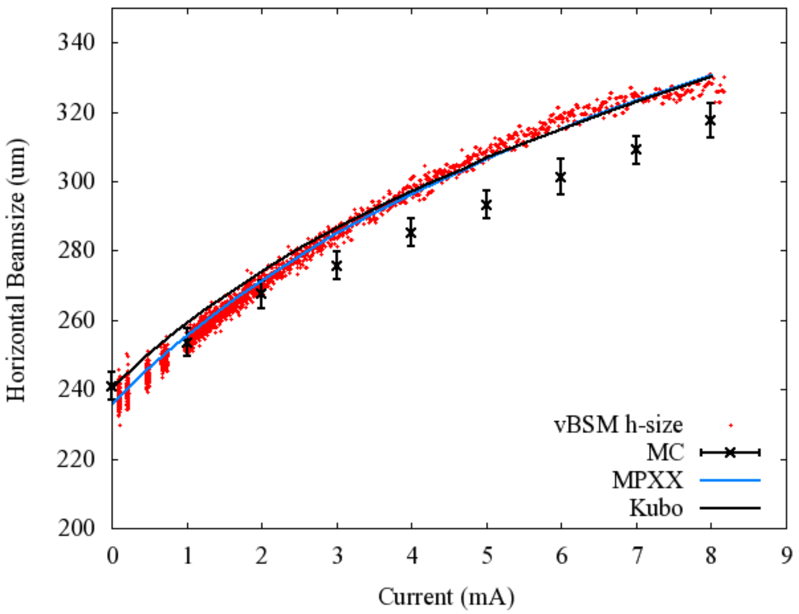


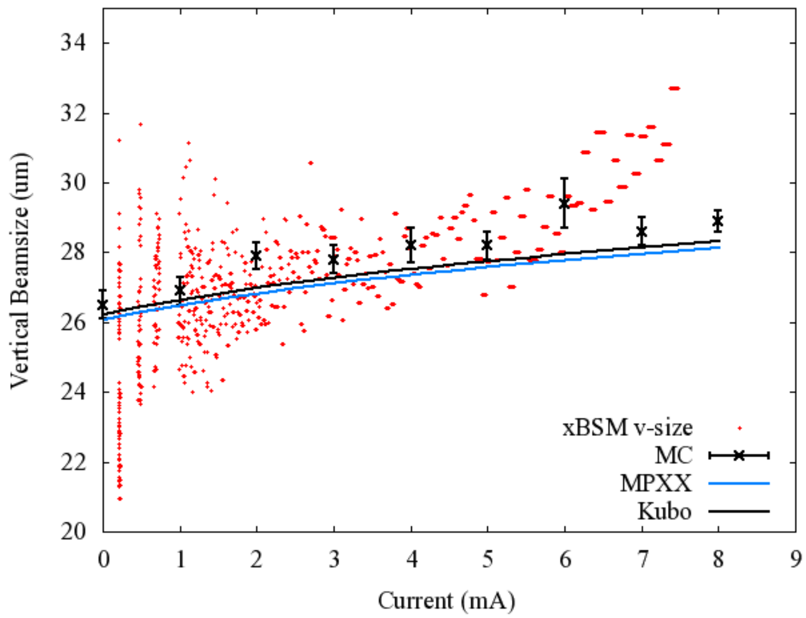


- Data from April 2012 CesrTA Run
- Positrons with small vertical beamsize
- 2.1 GeV
- Fractional tunes:
  - Qx = 0.624
  - Qy = 0.590
- Large horizontal blow up due to large horizontal dispersion
- Small vertical blow up due to small vertical dispersion



Still e^+, LET: Method Comparison





MPXX: Modified Piwinski with Tail Cut

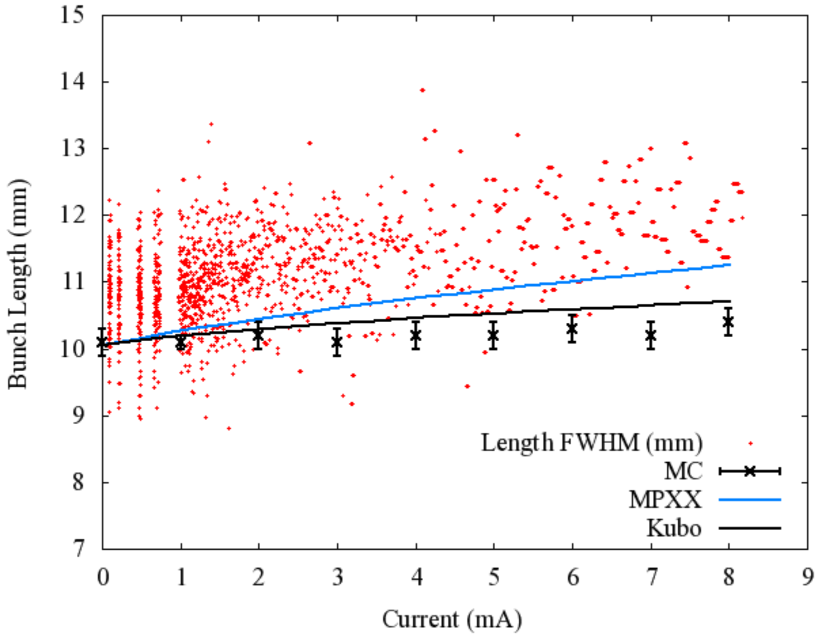
- Assumes this → $\sigma_{x,y} = \sqrt{\epsilon_{x,y}\beta_{x,y} + (\sigma_p \eta_{x,y})^2}$
- Fitted ε_x = 6.85 nm
- Fitted ε_y = 17.0 pm
- Includes PWD model

Kubo: Sigma-matrix. Based on SAD

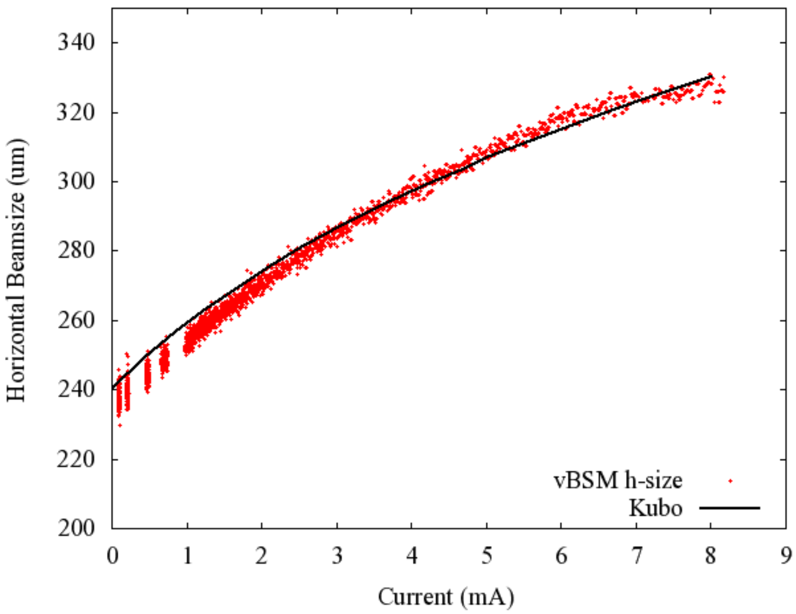
- Beamsize calculated from normal mode projection
- Natural ε_a = 3.34 nm
- Natural ε_b = 14.9 nm
- Does not yet include PWD model

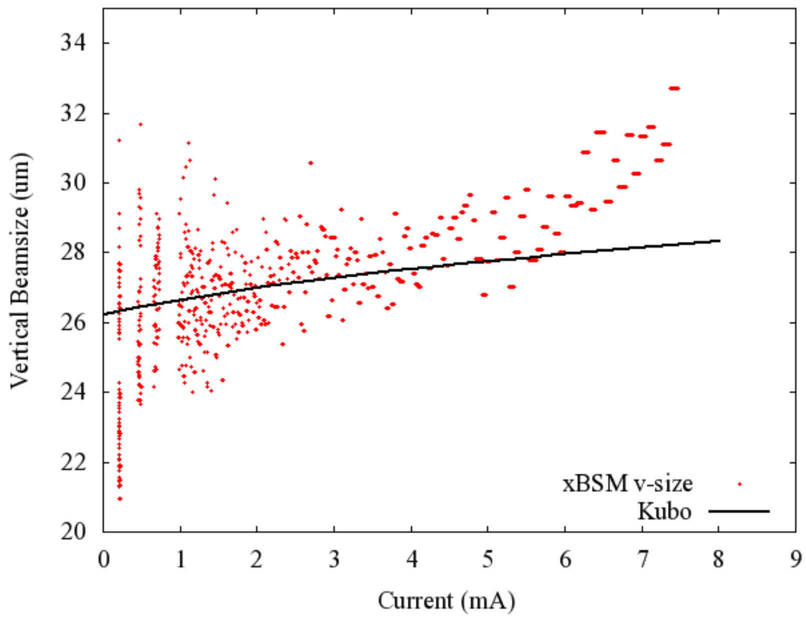
Monte Carlo: Takizuka & Abe

- Emittance is a result of trackin
- Does not yet include PWD model



Still e^+, LET: Σ-matrix IBS formalism





- Zero current emittances obtained from Etienne Forest's PTC
  - ε_a = 3.34 nm
  - ε_b = 14.9 nm

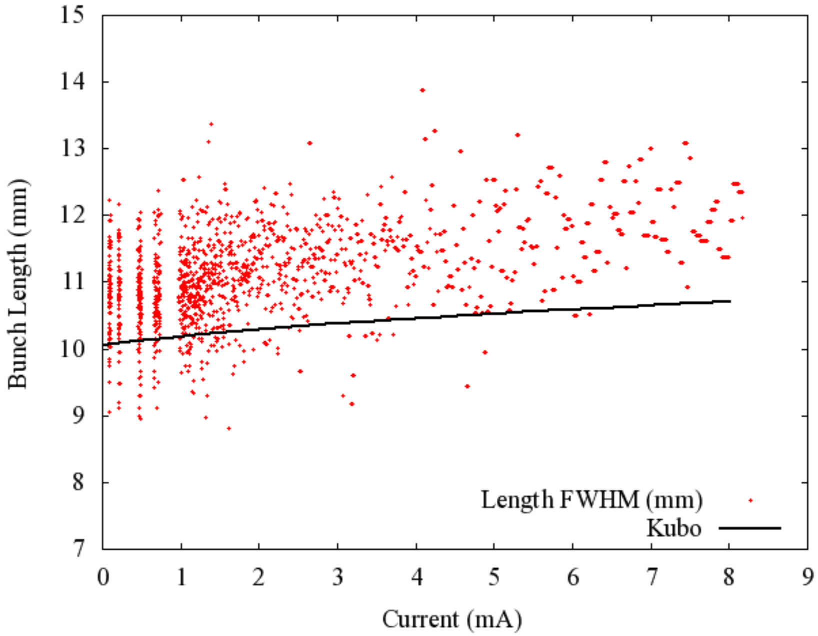
•Observed discrepancies with model:

•Vertical blow-up above 6 mA.

•Vertical scatter at low current.

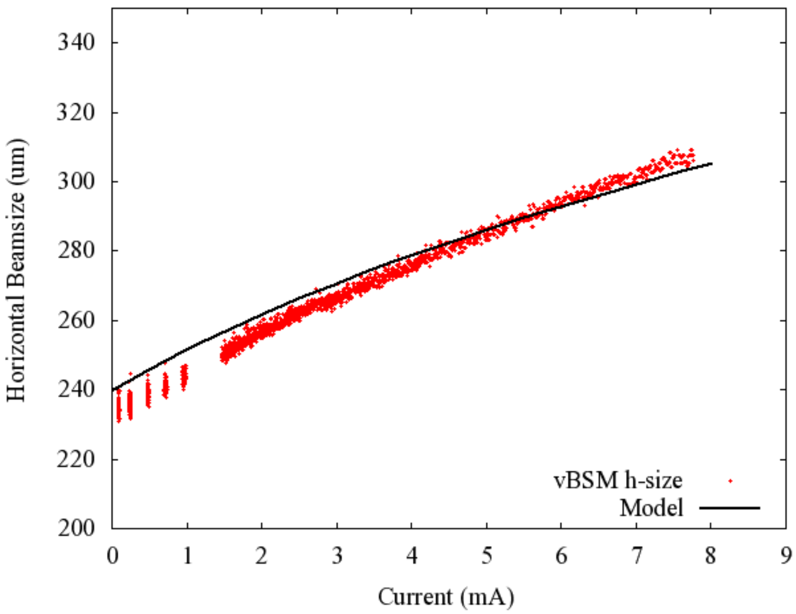
•1 mm systematic in bunch length

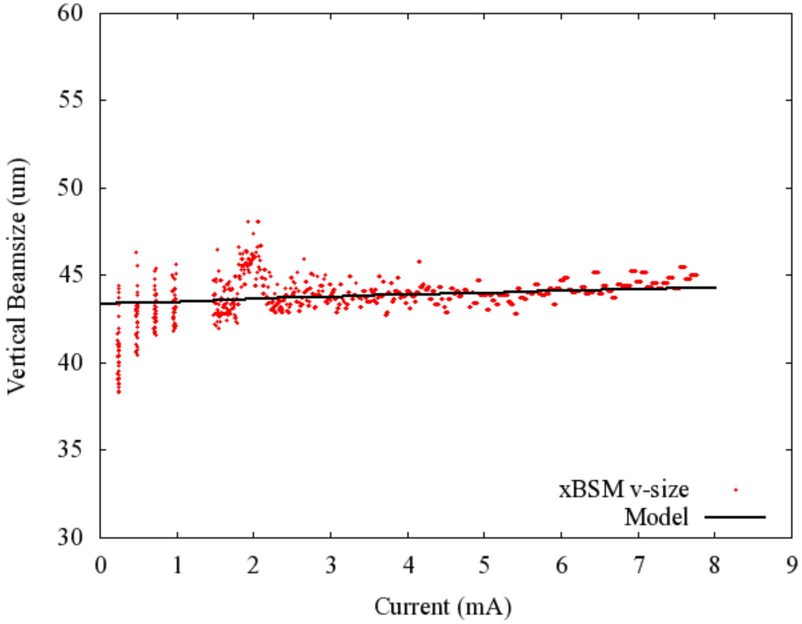
•Energy spread measured, found to be constant



Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Positrons, Coupling Knob σ_y -> 43 μm

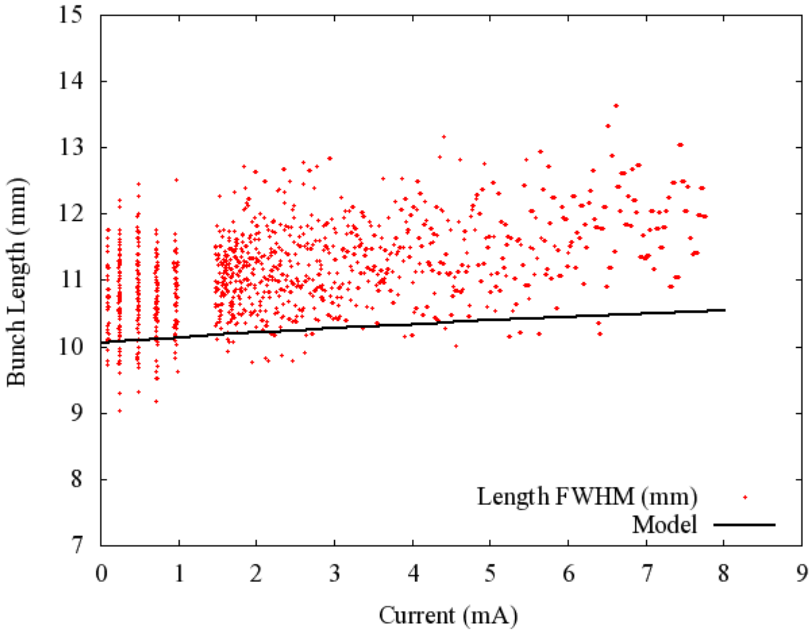




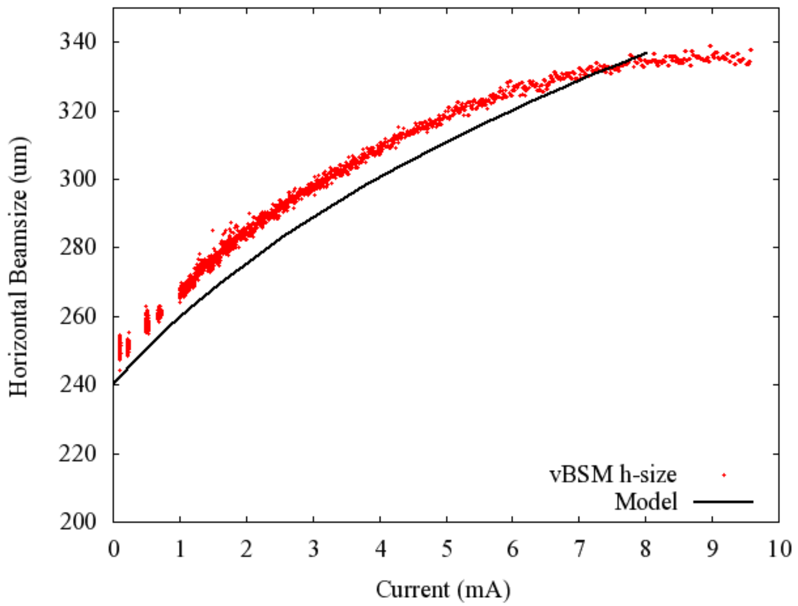
- Closed coupling & dispersion bump (through wigglers) used to generate vertical emittance
- Natural ε_a = 3.34 nm
- Vertical Emittance (fitted): ε_b = 43.2 pm
  - 4 times larger than LET

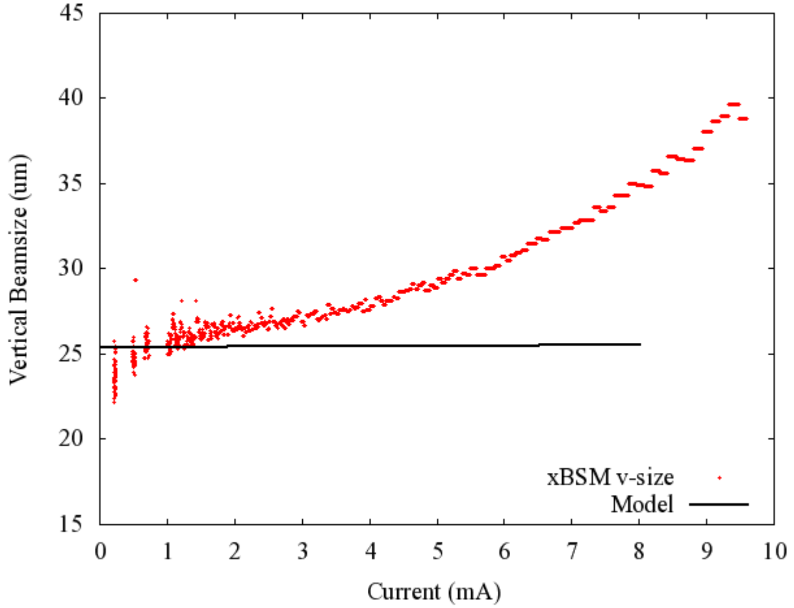
•Longitudinal behavior does not change significantly with reduced particle density.

•Supports PWD hypothesis



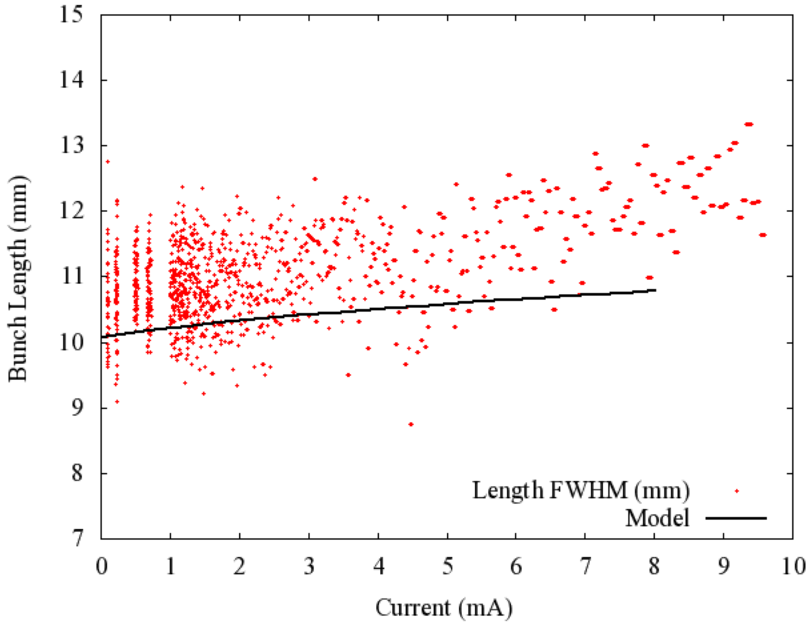
Electrons, LET



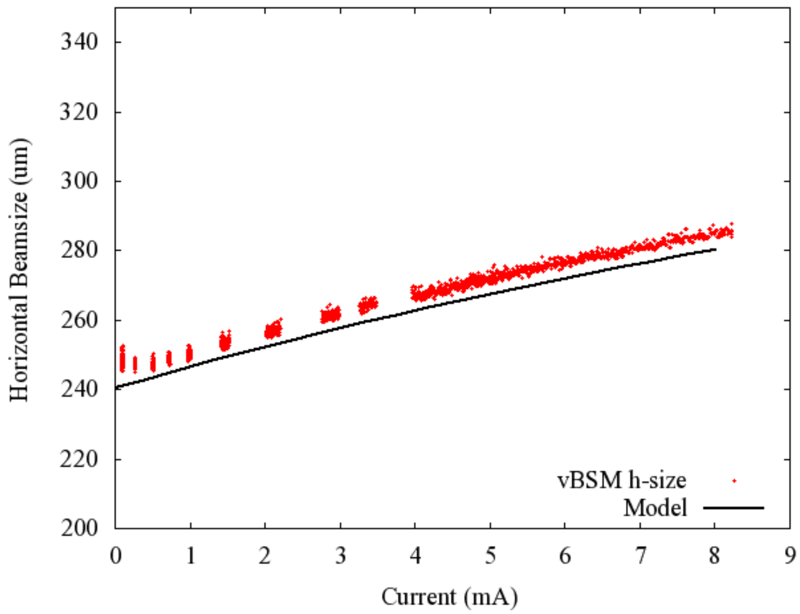


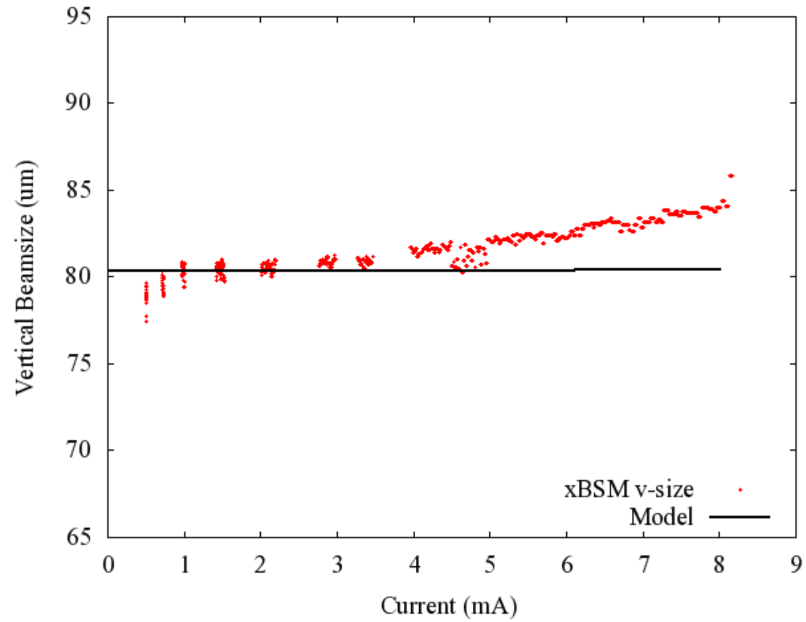
- Same natural emittances as e^+ case:
- Natural ε_a = 3.34 nm
- Natural ε_b = 14.9 nm
- Different instrumentation source points

- Blow-up at high current is different for electron and positron bunches.
  - •Species-Dependent Tune Shift?
  - •Ions?



Electrons, σ_y -> 80 um

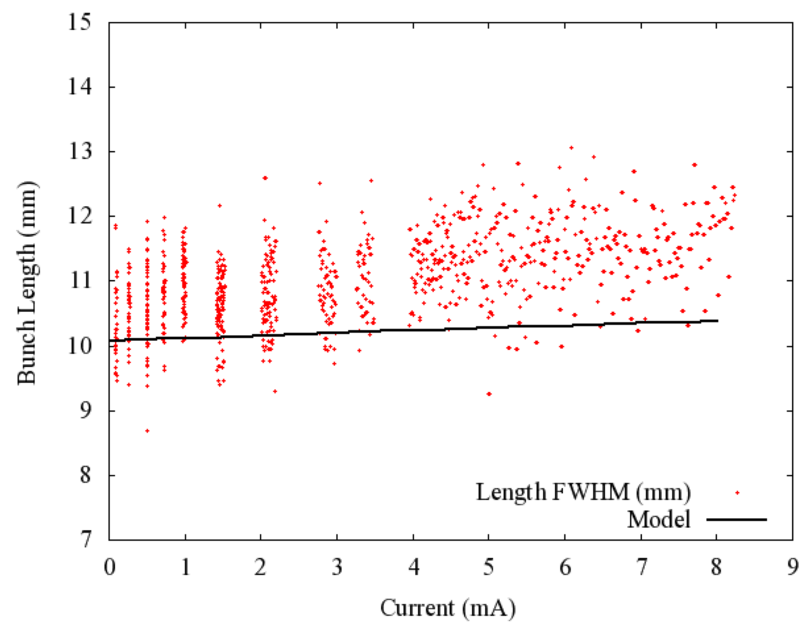




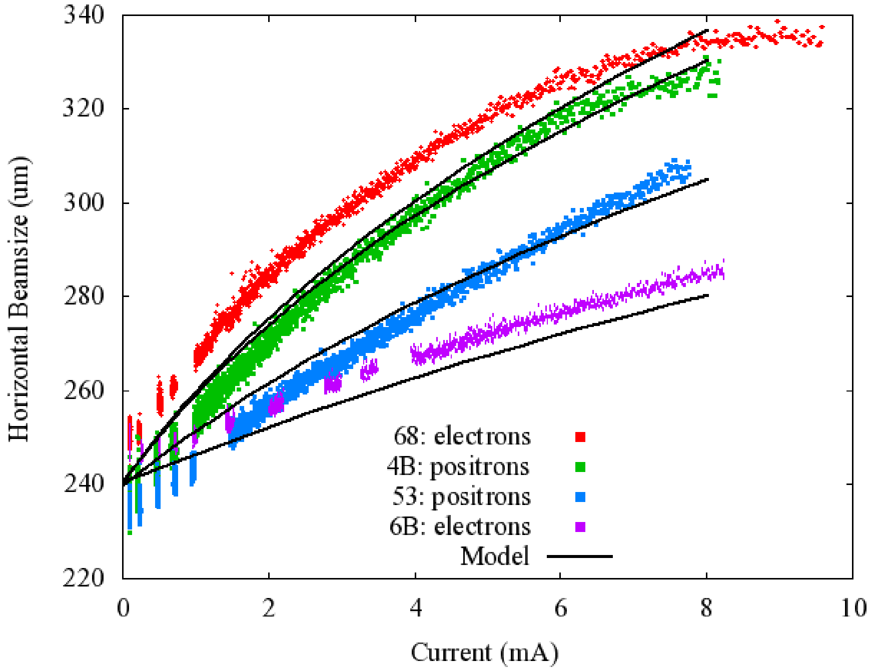
- Closed coupling & dispersion bump used to generate vertical emittance

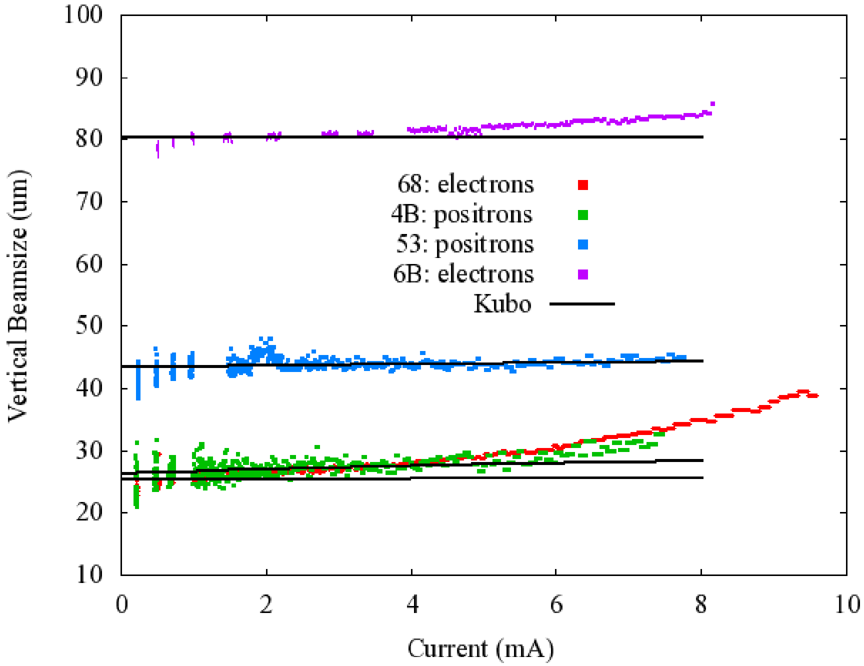
- Natural ε_a = 3.34 nm
- Fitted ε_b = 149.6 pm

- Vertical emittance 10 times larger than LET

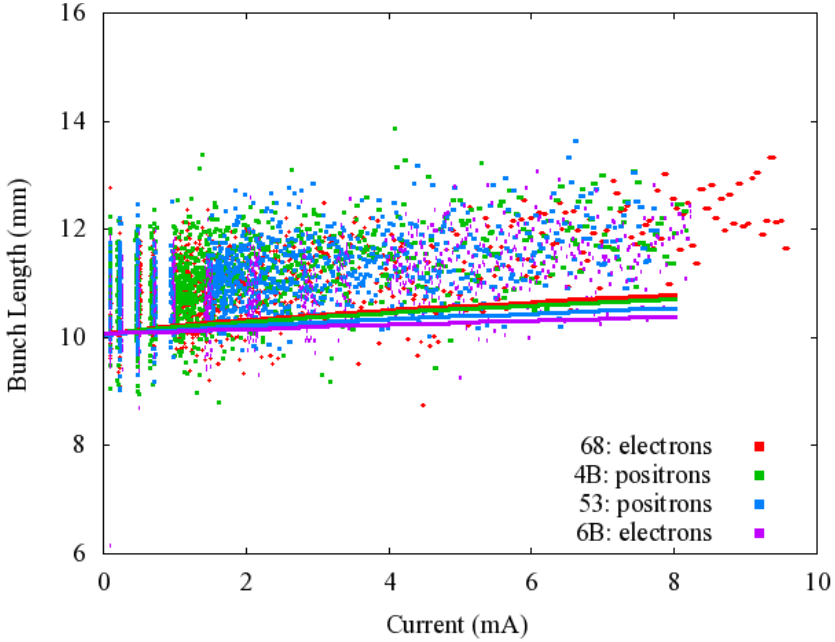


Combined Plots

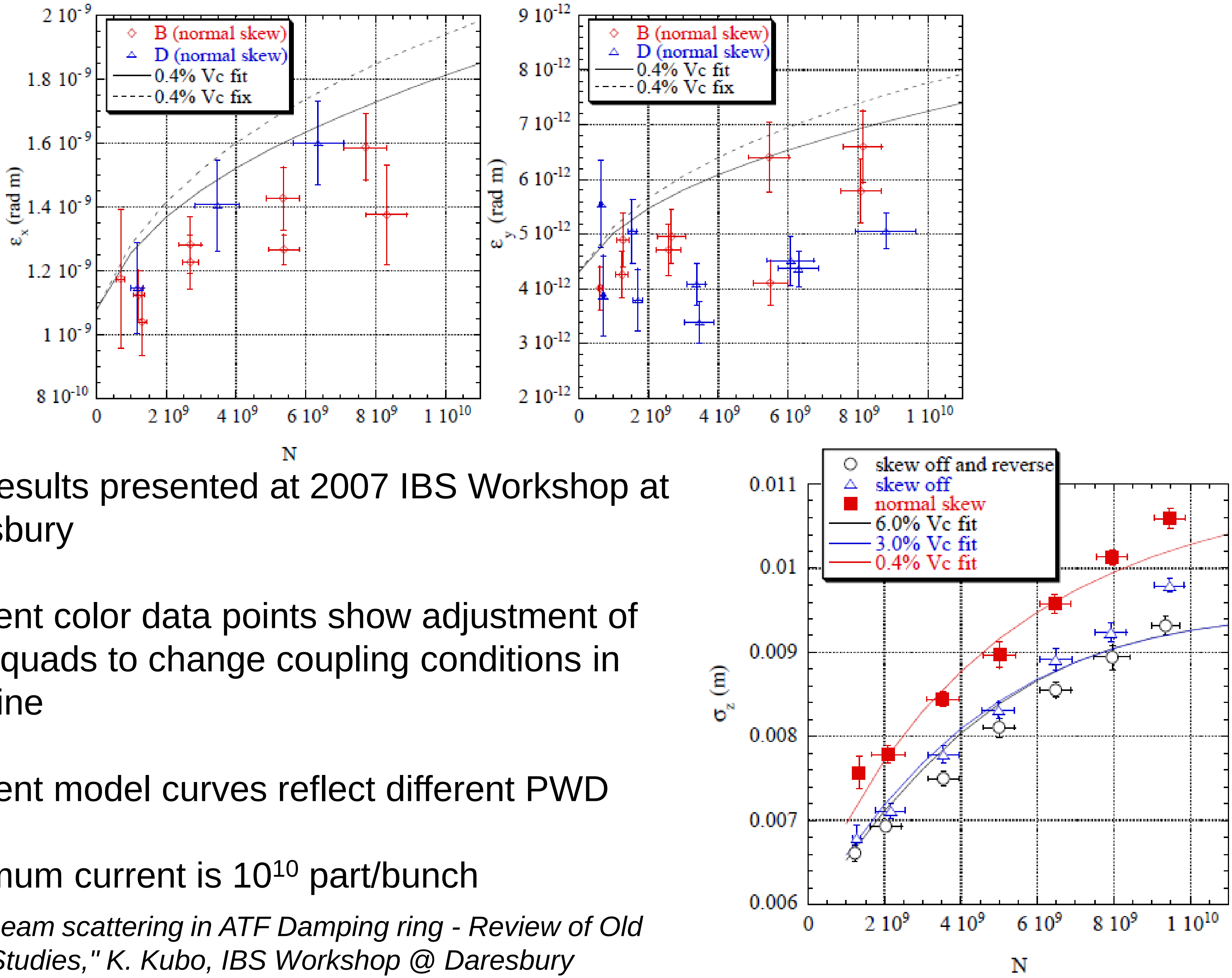




- Slope of horizontal data decreases as vertical size is increased
- Above 4 to 6 mA, vertical data is influenced by something that does not fit IBS description



Compare to Existing Results (ATF)



- ATF results presented at 2007 IBS Workshop at Daresbury
- Different color data points show adjustment of skew quads to change coupling conditions in machine
- Different model curves reflect different PWD
- Maximum current is 10^{10} part/bunch

"Intrabeam scattering in ATF Damping ring - Review of Old Studies," K. Kubo, IBS Workshop @ Daresbury

Current and Future Efforts

- Understand scatter at low current
  - Recent developments point to noise
- Understand blow up at high current
  - Combination of effects
    - Species dependent tune shift
    - Tune plane
    - Noise
    - Other physics (space charge, ions, ???)
- IBS at 1.8 GeV and 2.3 GeV
- Use lattices that manage V_{15} and other coupling terms
- Manipulate coupling terms to thoroughly validate Σ-matrix based IBS formalisms

Conclusion

- IBS is an important effect for the next generation of colliders (and light sources)
- IBS theory gives good agreement with proton[1] and ion machines[2]
- CesrTA is good laboratory for studying IBS in lepton machines
  - Versatile optics and instrumentation
  - Different energies and species
  - Damping wigglers
- We also encounter the other current-dependent effects that show up in small, intense beams
- Goals:
  1. Generate beams where IBS effects are dominant and can be separated from other effects
  2. Thorough investigation of the available IBS modeling formalisms
     1. Twiss-based
     2. Σ-matrix based
     3. Monte Carlo
  3. Gain experience and understanding of the other single-bunch, current-dependent effects that may be encountered in collider damping rings

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