Recent Results From CesrTA Intrabeam Scattering Investigations

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Overview

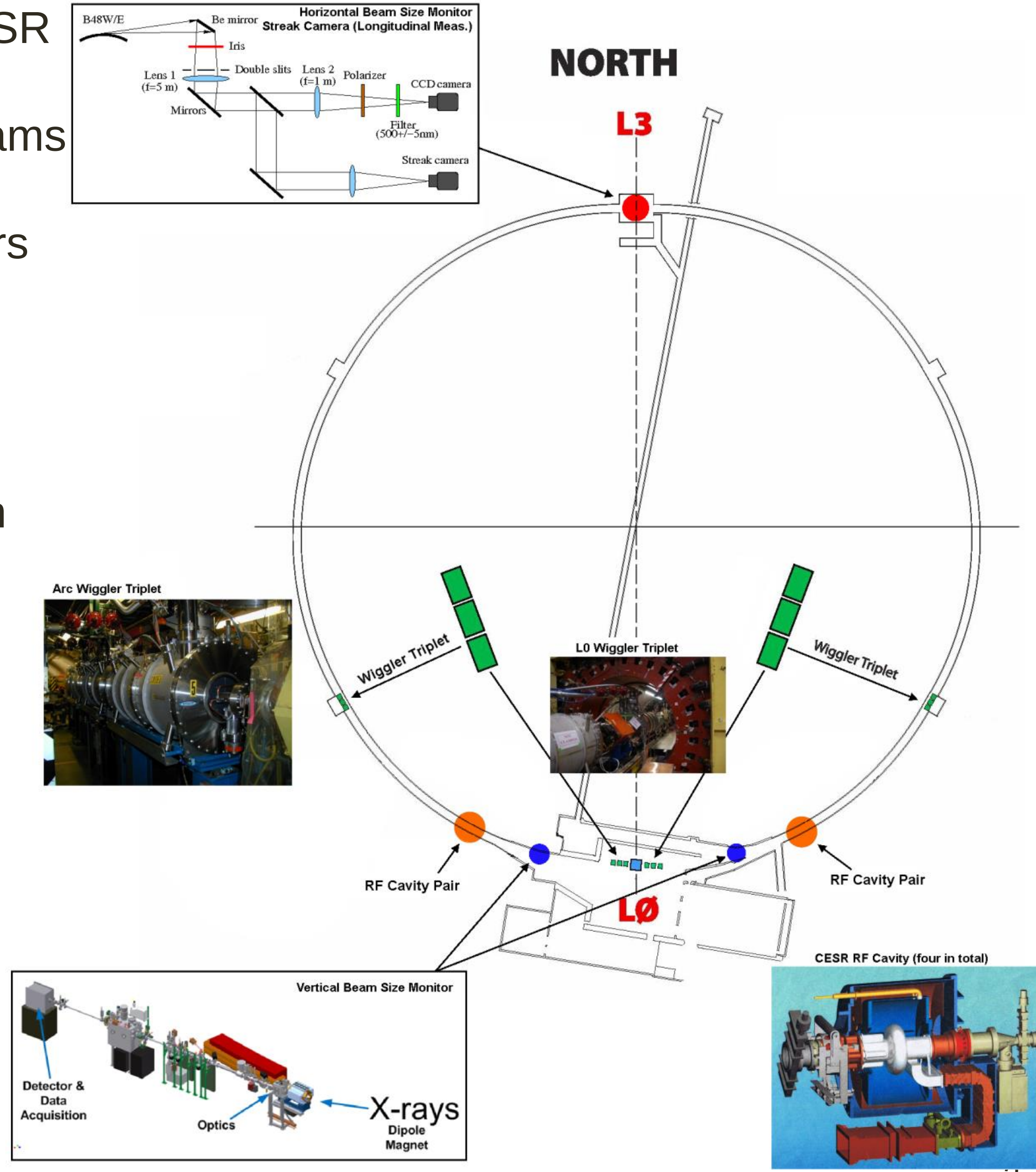
- Description of CESR and CesrTA program
- Intrabeam scattering (IBS) theory and our model
- Results of IBS experiments
  - Size vs. current at various energies and vertical beam sizes
  - Size vs. RF voltage
- Vertical data with puzzling current dependence
- Directions and conclusion

CesrTA Program

- CesrTA is a reconfiguration of CESR dedicated to studying the physics and technology of stored e^+/e^- beams
  - 768 m
  - Twelve 1.9 T damping wigglers
  - 1.8 to 5.3 GeV
  - ~3 nm·rad by ~10 pm·rad
  - Independently powered quadrupoles
  - Turn-by-turn, bunch-by-bunch instrumentation

- Multi-bunch studies
  - Electron Cloud
  - Fast Ion

- Single-Bunch Effects
  - Intrabeam Scattering (IBS)
  - Coherent Tune Shift
  - Incoherent Tune Shift
  - Optics Correction



Accelerator Environment for IBS Studies

- Machine Setup
  - 6 or 12 wigglers powered
    - 100 ms or 50 ms damping time (500 ms without wigglers)
  - 6.3 MV RF provided by four 500 MHz superconducting cavities
    - Adjustable down to ~1 MV
    - ~10 mm bunch lengths
  - Single-bunch charges from ~10^9 up to ~10^{11} particles
    - Lifetime dominated by Touschek scattering
- Beam Physics
  - Intrabeam Scattering
    - ε_x increase of ~ 300% (~1 m horizontal dispersion)
    - ε_y increase of < 20% (very low vertical dispersion and coupling)
  - Potential Well Distortion
  - Coherent Tune Shift -0.5 kHz/mA
    - Resonance lines up To 6th order observed
  - Vertical Behavior is Puzzling
    - Anomalous blow up at high current

What is Intrabeam Scattering

- Multiple small-angle scattering events among the particles that compose a bunch couples single-particle emittances, and in the presence of dispersion can increase the total emittance of the beam.
- Results in a current-dependent emittance
  - A lower bound on beam size for a desired current, or a upper bound on current for a desired size
- Limits:
  - Luminosity lifetime in hadron machines
  - Per-bunch luminosity in a linear collider
  - Peak brilliance in a light source
- IBS in e^+/e^- accelerators, in contrast to hadron machines
  - Fast rise time due to high density of short bunches
    - Increased equilibrium size
  - Gaussian Core + Lightly Populated Tails (theory modified by tail-cut)
  - Growth rates have γ^{-4} dependence

- Formalism by Kubo and Oide
  - Generalization of Bjorken & Mtingwa's formalism
  - Uses eigen-decomposition of beam Σ-matrix, rather than Twiss parameters

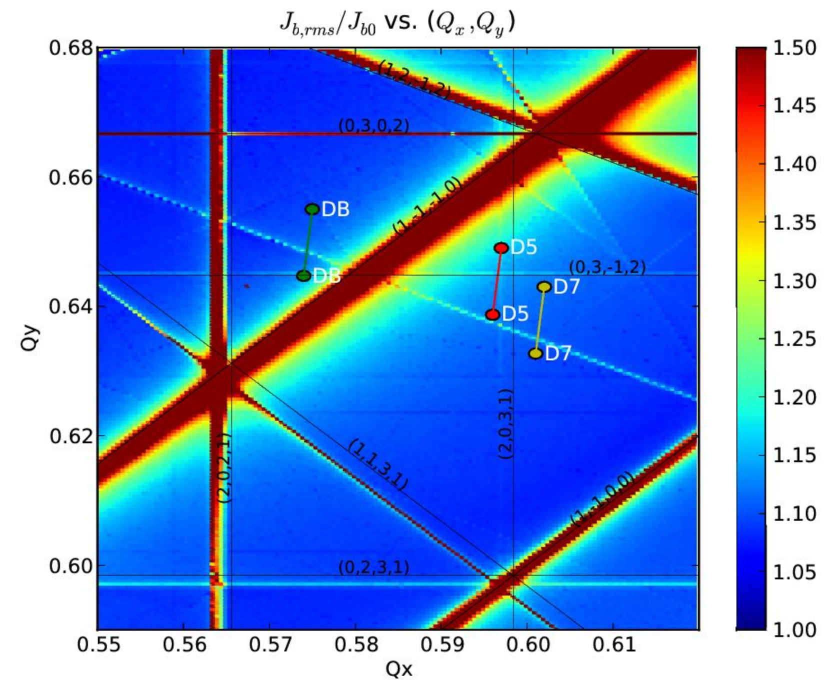
$$\mathbf{\Sigma} = \left(\begin{array}{ccc:ccc} \langle xx\rangle & \langle xy\rangle & \langle xz\rangle & \langle xp_x\rangle & \langle xp_y\rangle & \langle xp_z\rangle \\ \langle yz\rangle & \langle yy\rangle & \langle yz\rangle & \langle yp_x\rangle & \langle yp_y\rangle & \langle yp_z\rangle \\ \langle zx\rangle & \langle zy\rangle & \langle zz\rangle & \langle zp_x\rangle & \langle zp_y\rangle & \langle zp_z\rangle \\ \hdashline \langle p_x x\rangle & \langle p_x y\rangle & \langle p_y x\rangle & \langle p_x p_x\rangle & \langle p_x p_y\rangle & \langle p_x p_z\rangle \\ \langle p_y x\rangle & \langle p_y y\rangle & \langle p_y z\rangle & \langle p_y p_x\rangle & \langle p_y p_y\rangle & \langle p_y p_z\rangle \\ \langle p_z x\rangle & \langle p_z y\rangle & \langle p_z z\rangle & \langle p_z p_x\rangle & \langle p_z p_y\rangle & \langle p_z p_z\rangle \end{array}\right)$$

  - Natural handling of coupling
    - Normal mode emittances
    - No "coupling" parameters
  - Incorporates tail-cut
    - Central Limit Theorem
    - Excludes rare, large-angle scattering events (< 1 event/particle/τ_{damp})

Simulation Overview

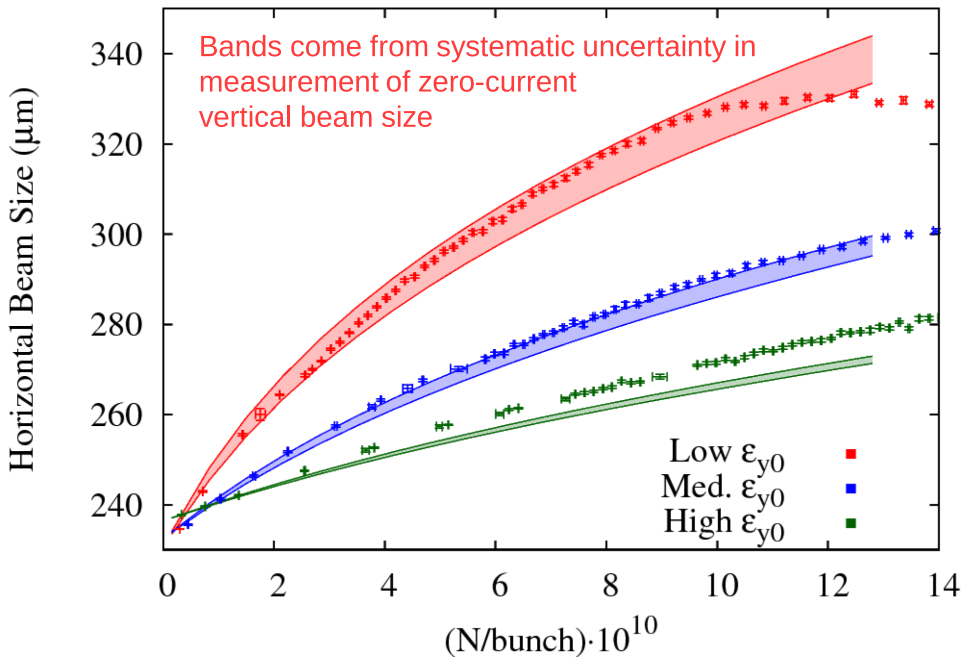
- Cornell's BMAD Simulation Suite
  - Native normal modes environment
- Element-by-element model of CesrTA lattice including multipole terms and field-map wiggler models
- IBS blow up calculated by Kubo & Oide formalism
- Potential well distortion (PWD) calculated by Billing's effective impedance formalism
  - Current-dependent effective RF voltage
- Beam sizes obtained from beam Σ-matrix
- Simulation has 3 significant free parameters
  1. Zero-current horizontal emittance
  2. Zero-current vertical emittance
  3. Effective longitudinal inductive impedance

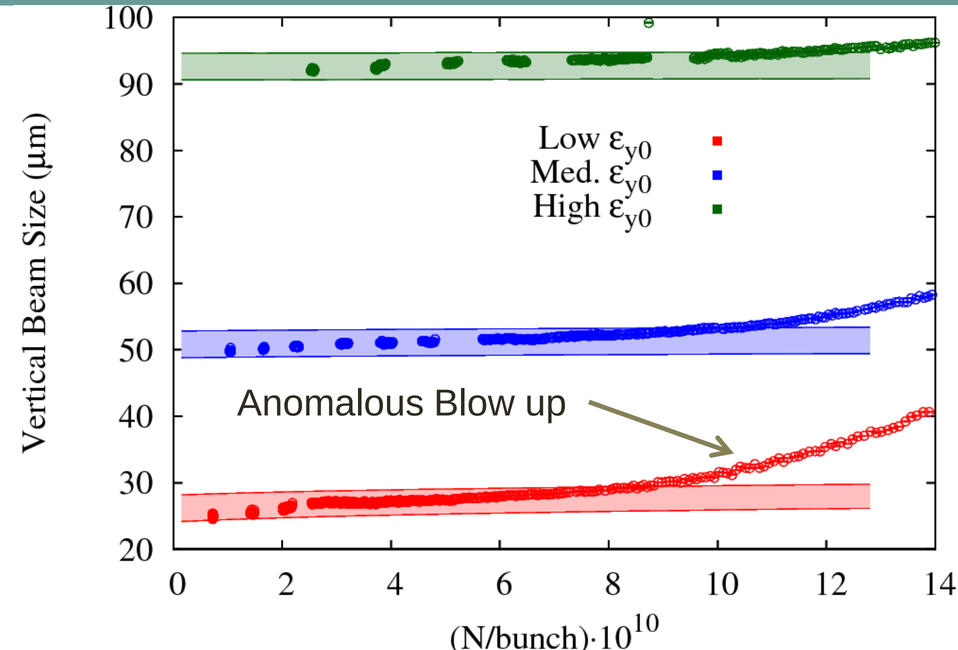
Experiment Overview



- Working point is selected
  - Vertical coherent tune changes by ~4 kHz from low current to high current
- Apply optics corrections
  - Phase and Orbit
  - Dispersion and Coupling
- If desired, increase ε_{y0} using closed coupling and dispersion bumps
- Charge single bunch to > 10^{11} particles
- Cut injection and take beam size measurements as the beam decays
  - Vertical by x-ray beam size monitor
  - Horizontal by visible light beam size monitor
  - Longitudinal by streak camera
- Decay due to Touschek lifetime
  - Experiment takes about 30 minutes

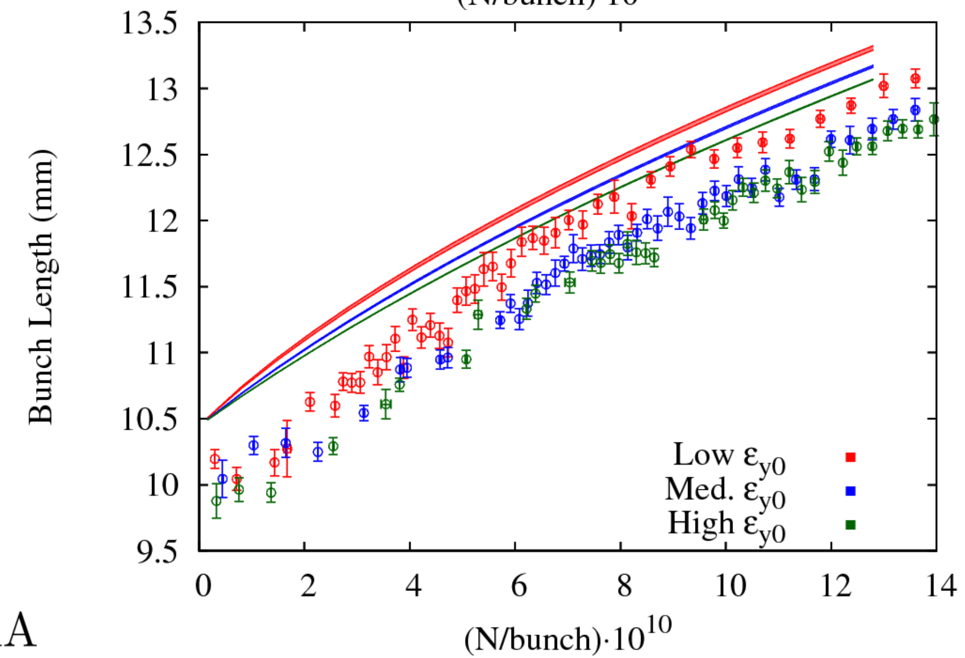
2.1 GeV Results



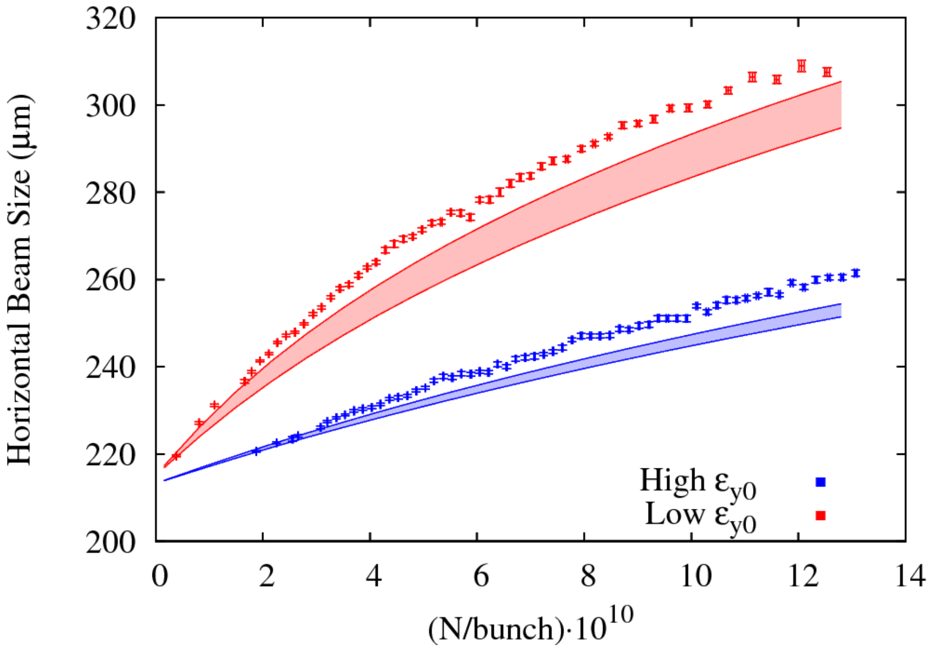


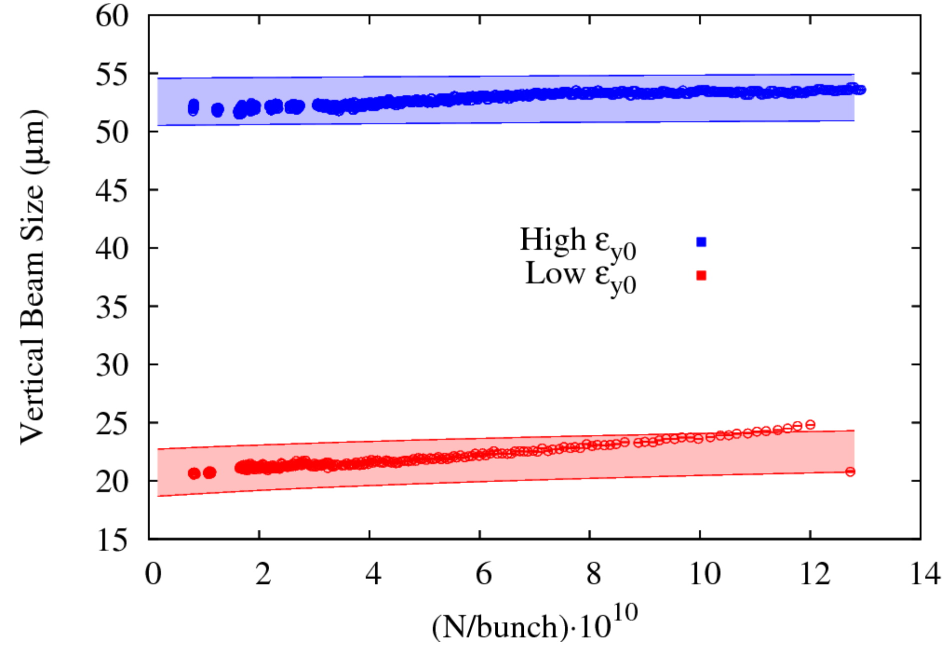
	Input Parameters		Result at high current
Run ID	ε_{y0} (pm)	ε_{x0} (nm)	ε_x (7.5 10^{10} part) (nm)
Low ε_{y0}	12.7 - 17.9	3.1	7.83
Med ε_{y0}	57.1 - 67.2	3.2	5.73
High ε_{y0}	200.8 - 219.2	3.4	4.69

$^*7.5 \times 10^{10}$ part. ≈ 12 nC ≈ 5 mA



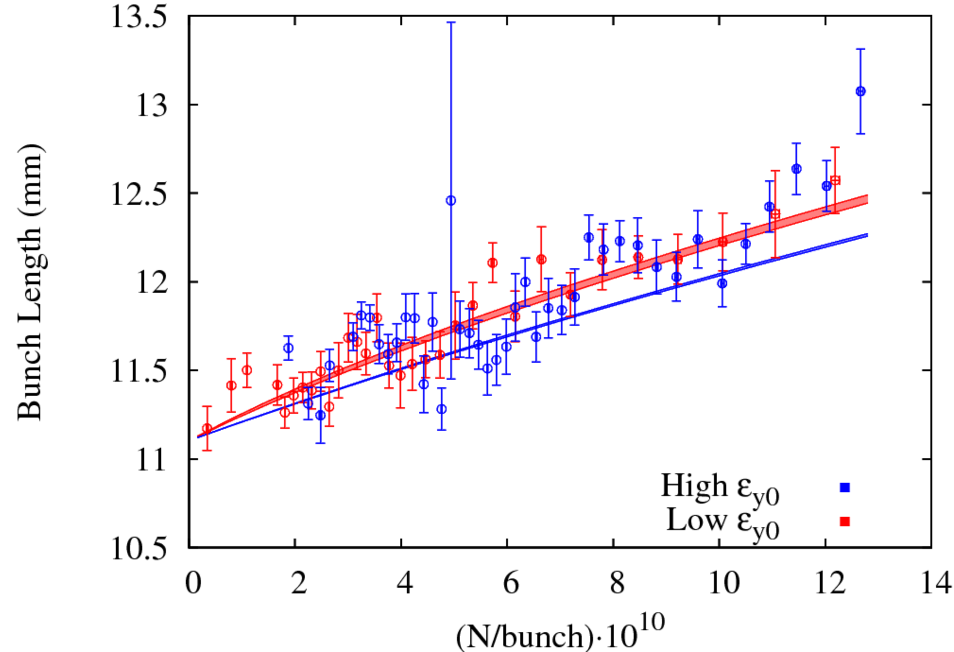
2.3 GeV Results



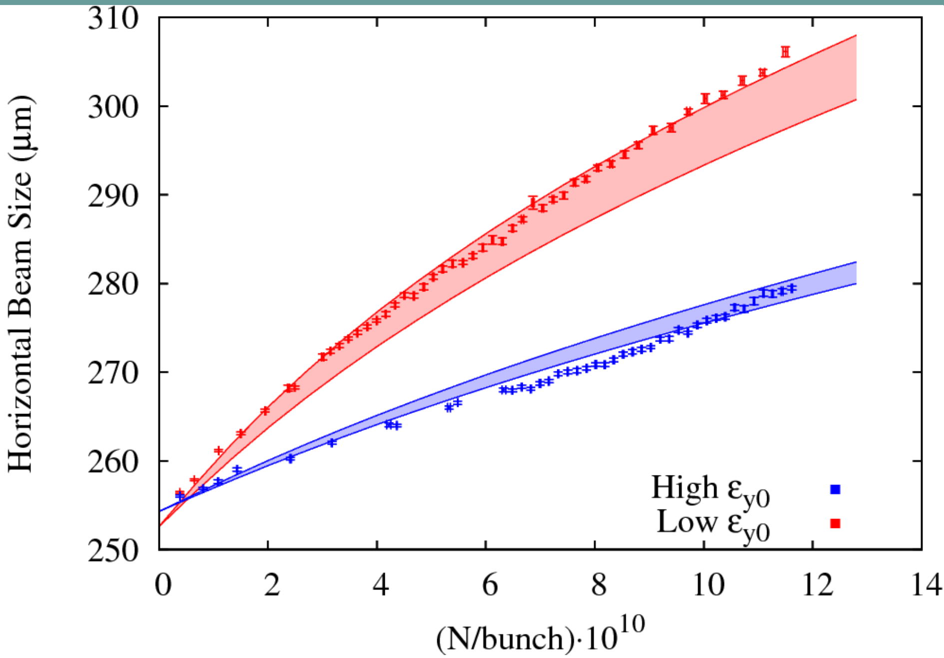


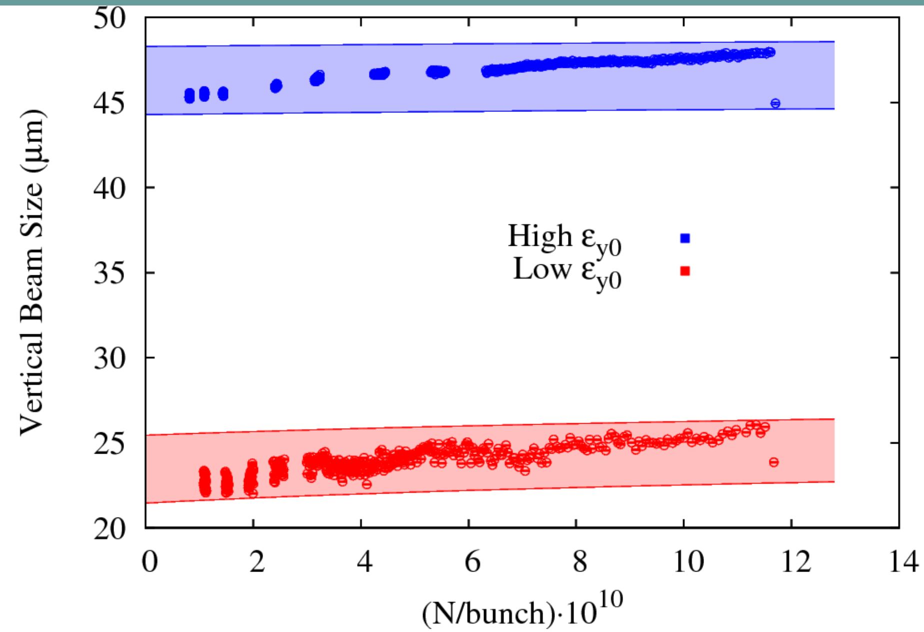
- IBS rates have γ^{-4} dependence

	Input Parameters		Result at high current
Run ID	ε_{y0} (pm)	ε_{x0} (nm)	ε_x (7.5 10^{10}) (nm)
Low ε_{y0}	7.01-11.2	5.7	9.41
High ε_{y0}	62.0-72.6	5.6	7.06

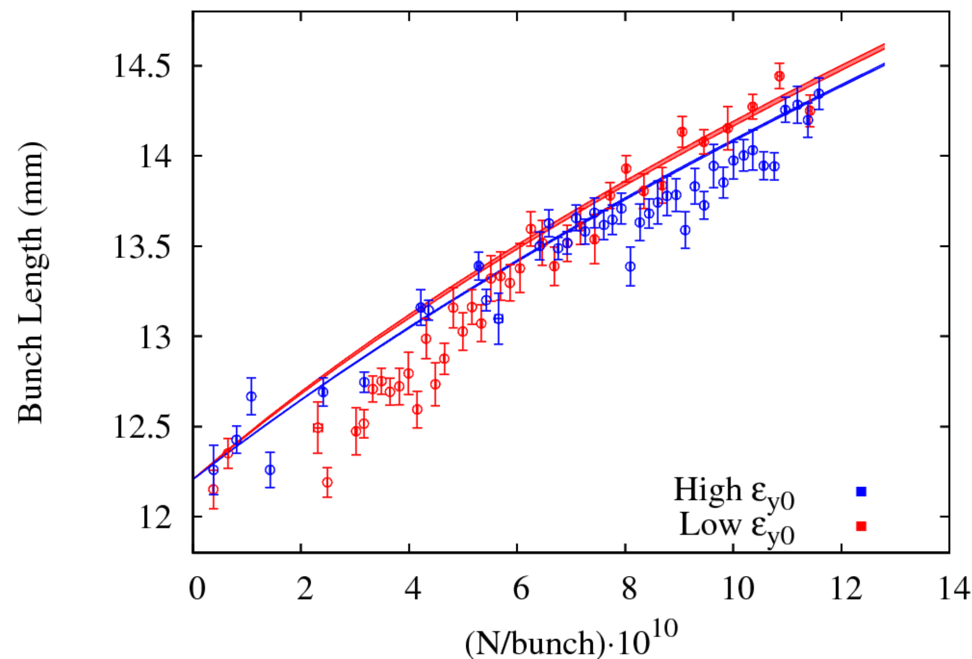


2.5 GeV Results





	Input Parameters		Result at high current
Run ID	ε_{y0} (pm)	ε_{x0} (nm)	ε_x (7.5 10^{10}) (nm)
Low ε_{y0}	9.9 – 14.6	4.4	6.83
High ε_{y0}	47.6 – 56.9	4.5	5.62



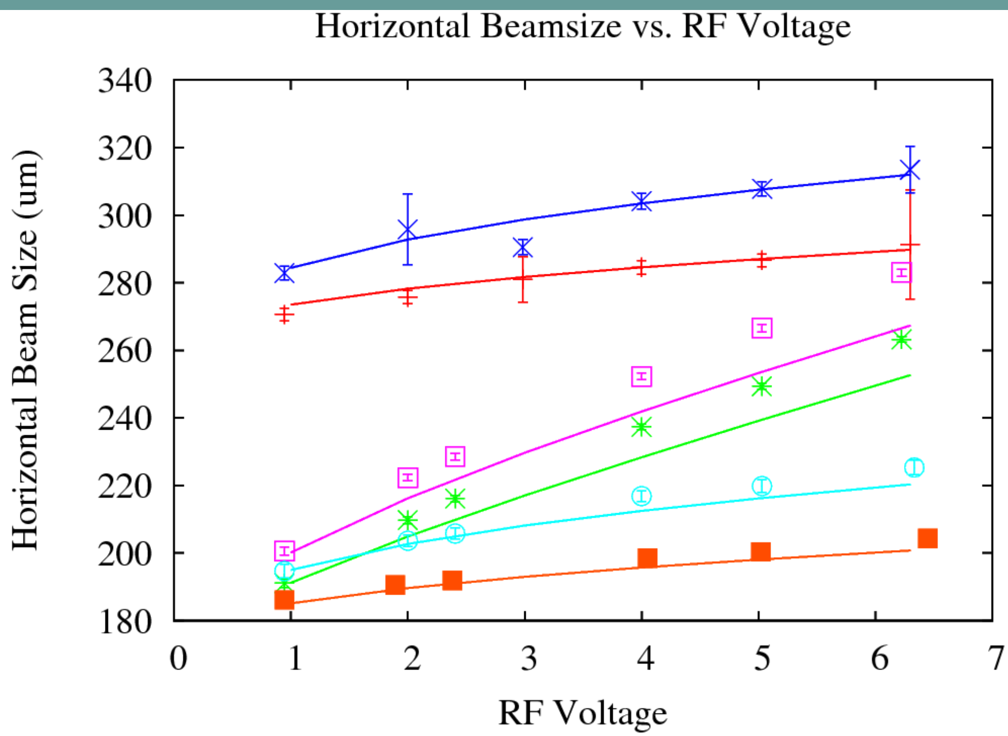
Relative Increase in Emittance

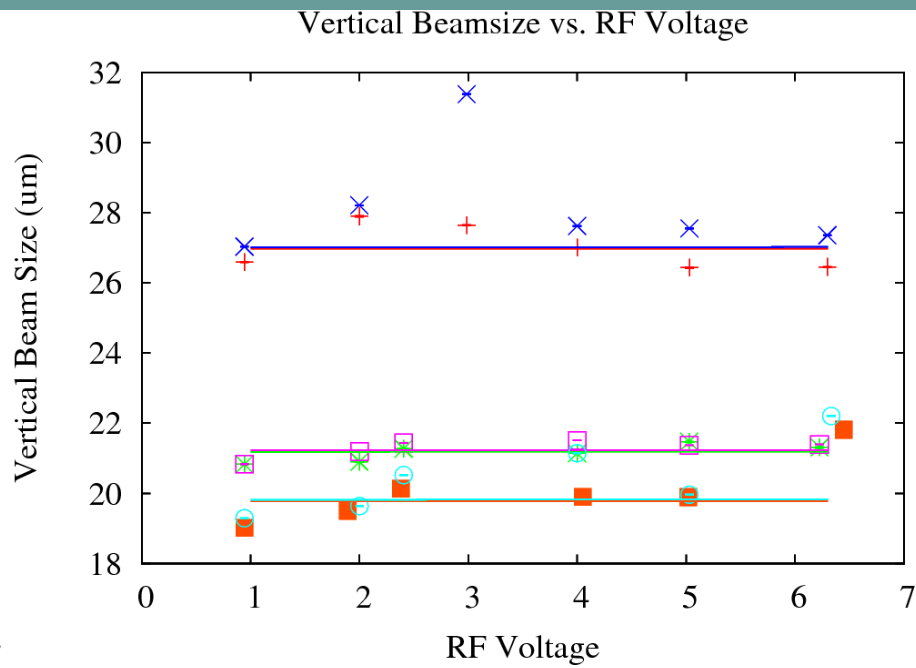
- ~1 m RMS horizontal dispersion leads to significant horizontal blow up
- IBS rise times have γ^{-4} dependence

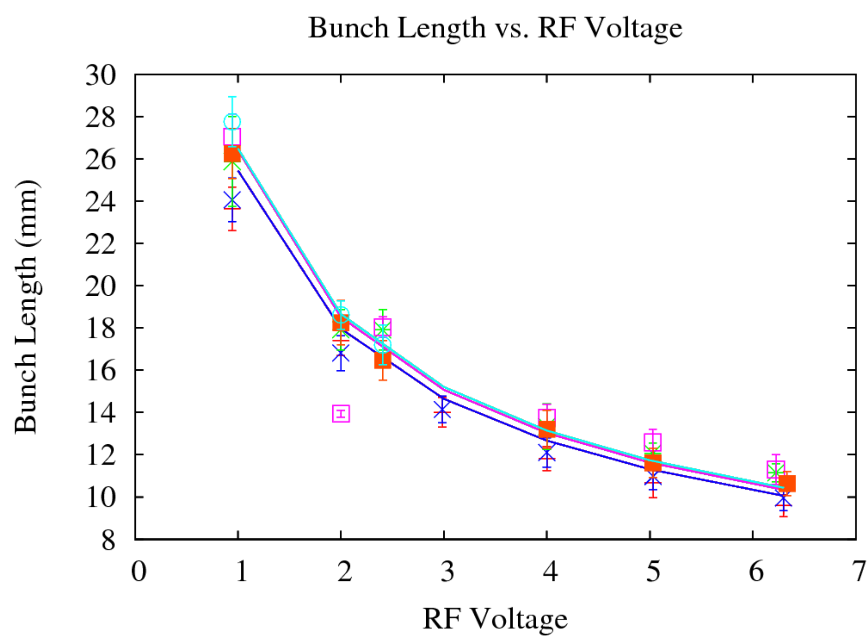
Energy (GeV)	ϵ_{y0} (pm)	ϵ_{x0} (nm)	ϵ_x $(7.5 \times 10^{10}$ parts.) (nm)	
2.1	12.7 – 17.9	3.1	7.83	← 253% Blow Up
2.1	57.1 – 67.2	3.2	5.73	
2.1	200.8 – 219.2	3.4	4.69	
2.3*	7.01 – 11.2	5.7	9.41	← 165% Blow Up
2.3*	62.0 – 72.6	5.6	7.06	
2.5	9.0 – 14.6	4.4	6.65	← 151% Blow Up
2.5	47.6 – 56.9	4.5	5.57	

*Note: 2.3 GeV lattice uses distinct horizontal optics

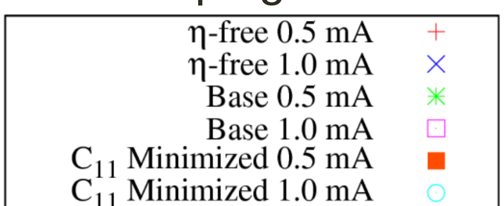
Size vs. RF Voltage (Low Current)





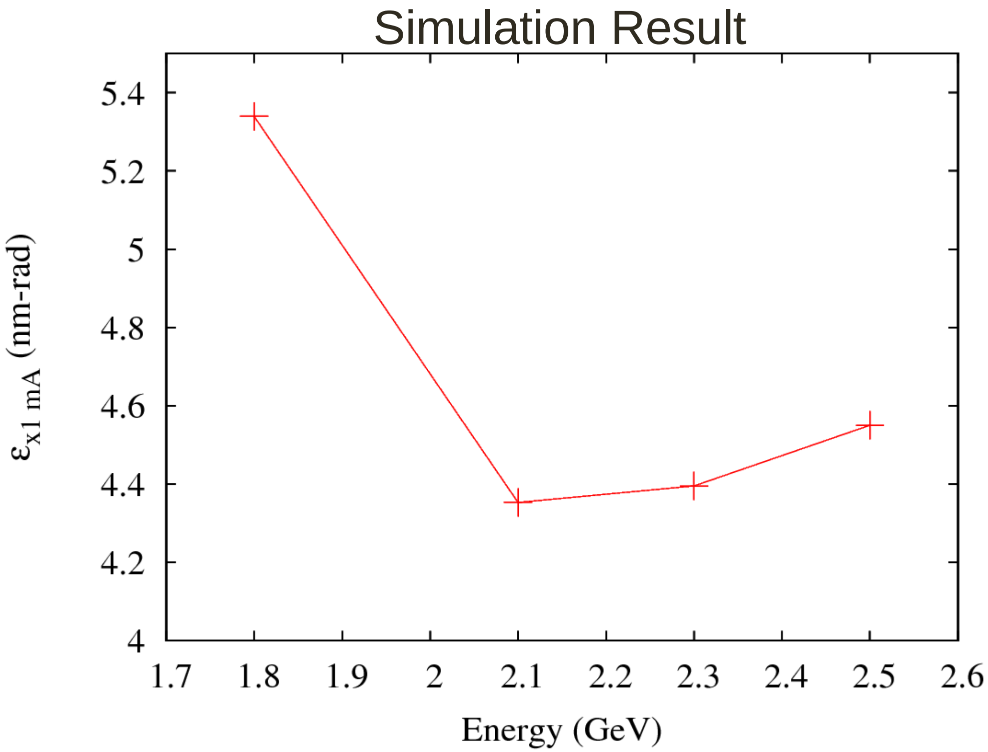


- Measurements at 0.5 and 1.0 mA
  - IBS seen as larger size at 1.0 mA
- Three Distinct Lattices (all ideal)
  1. Original CesrTA Lattice
  2. Lattice with x-z tilt minimized
  3. Lattice with half the damping and no tilt



Emittance Vs. Energy

- For a given vertical emittance, current, and wiggler field what is the energy to minimize horizontal emittance?
  - ε_{x0} goes as γ^2
  - IBS rates go as γ^{-4}

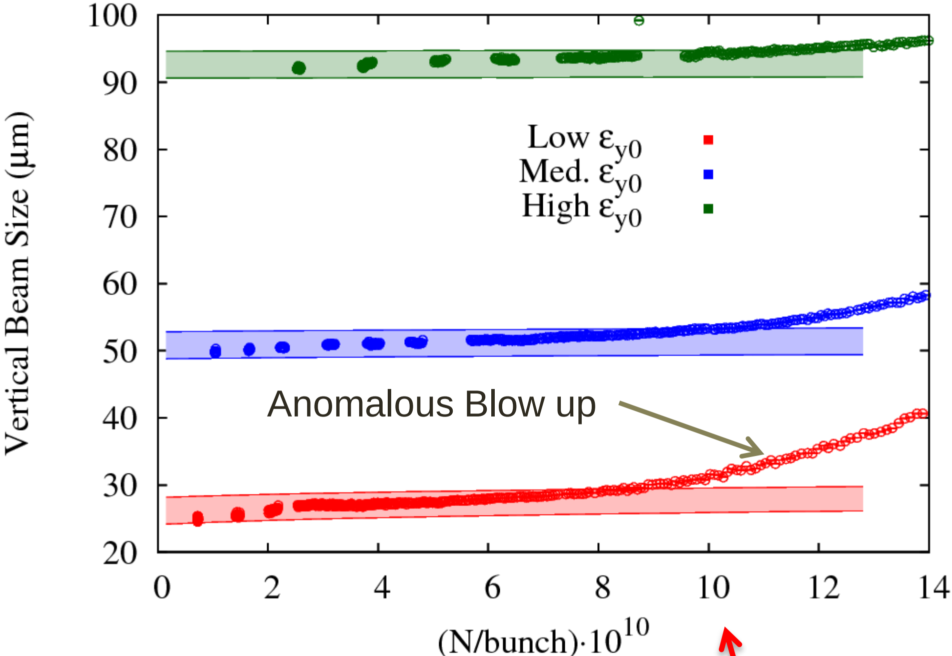


<u>Assumptions</u>
ε_{y0} = 10 pm-rad
I = 1 mA (1.6x10^{10} parts. or 3 nC)
Twelve 1.9 T wigglers

Anomalous Vertical Blow-Up

Fishing for ideas …

- Not consistent with IBS model
  - IBS size vs. current plot would be "log like"
- Species-independent
- Sensitive to betatron and synchrotron tunes
- Not sensitive to chromaticity
- FFT of vertical centroid and size does not show a strong signal above noise
- Energy spread measured to be constant, no threshold behavior seen in energy spread vs. current.
- Seen even in large beams
- Coupling (Cbar12) vs. current measured to be constant
- Coherent tune shift plays a part, but not the whole story
- Incoherent tune shift is a suspect, cannot be whole story
  - direct space charge



16 nC
~10^{22} part/m^3

Directions

- Beam size vs. current with different damping rates.
- Measurements on beams with global coupling.
  - Significant vertical IBS growth rate.
- Measurements at 1.8 GeV.
  - Requires instrumentation development.
- Understanding vertical behavior at high current.
  - Model higher current behavior.
  - Impedance model with wake fields.
- Lower emittances.

Conclusion

- IBS data has been gathered over a range of energies, particle densities, and RF voltages.
- Model developed that gives good agreement with horizontal and longitudinal data.
  - IBS and PWD effects
- Model for high-current vertical data yet to be found.
- Directions: global coupling, various damping rates, 1.8 GeV, and lower vertical emittance