Electron Cloud Induced Beam Dynamics at CesrTA

Kiran Sonnad

List of Contributers

Experiments

Laurel Bartnik*
Mike Billing*
Mike Forster*
John Flanagan[%]
Robert Holtzapple[#]
Kiran Sonnad*[,%]

Simulation

Lillian Pentecost[$]
Mauro Pivi[&]
Kiran Sonnad

Data Analysis

Robert Holtzapple
Lillian Pentecost
Kiran Sonnad
Sam Tucker[#]

* CLASSE Cornell University
$ Colgate University
# California Polytechnic State Univ
% KEK
& SLAC

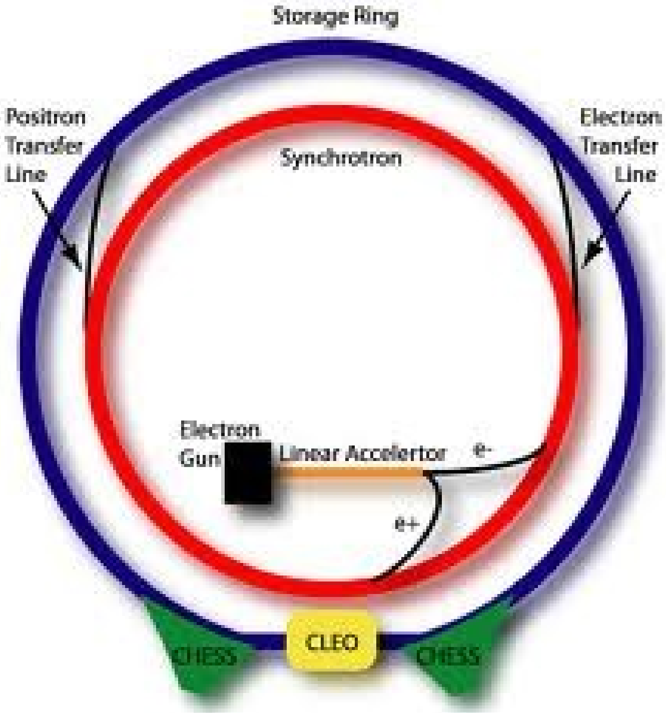
Special Thanks to K. Ohmi, Gerry Dugan, Brian Heltsley
Nate Rider, Robert Meller and Cesr Operators

About CesrTA

The Cornell Electron Storage Ring (CESR) was colliding electrons and positrons in the CLEO detector.

Since 2008, the storage has been reconfigured as a test facility to study damping rings.

The detector region has a series of damping wigglers installed.

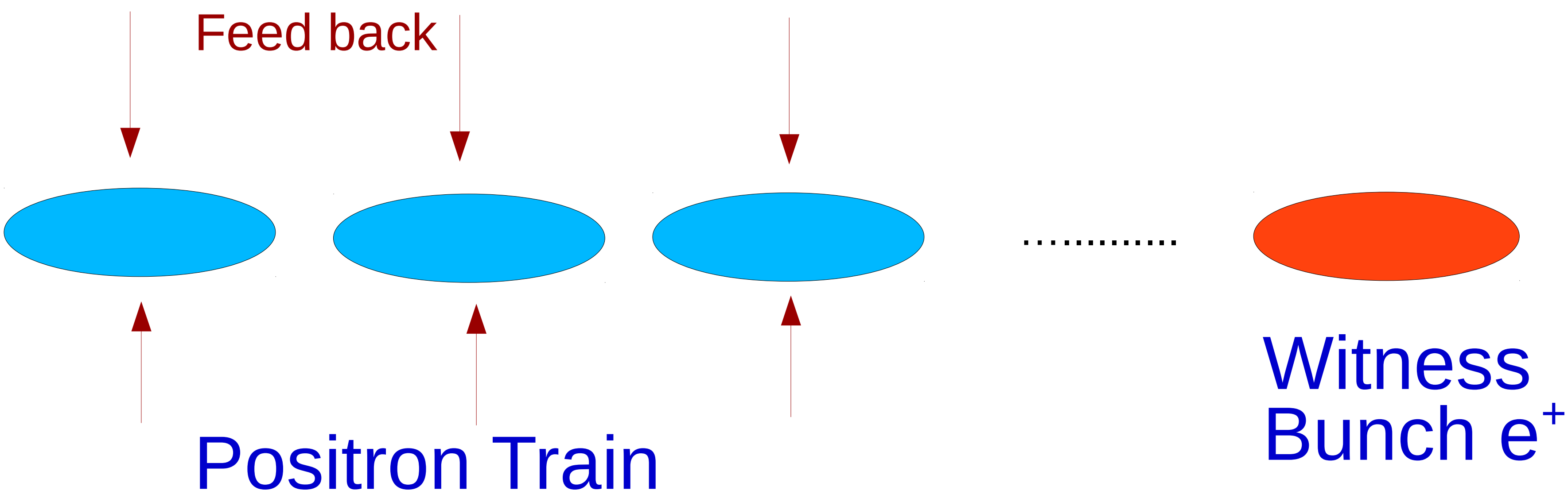


The CesrTA program has involved understanding electron clouds in positron storage rings, tuning the machine for lower beam emittances, understanding other collective effects such as intrabeam scattering and fast ion effects.

The program has made valuable contributions toward the conceptual design report (CDR) of the ILC.

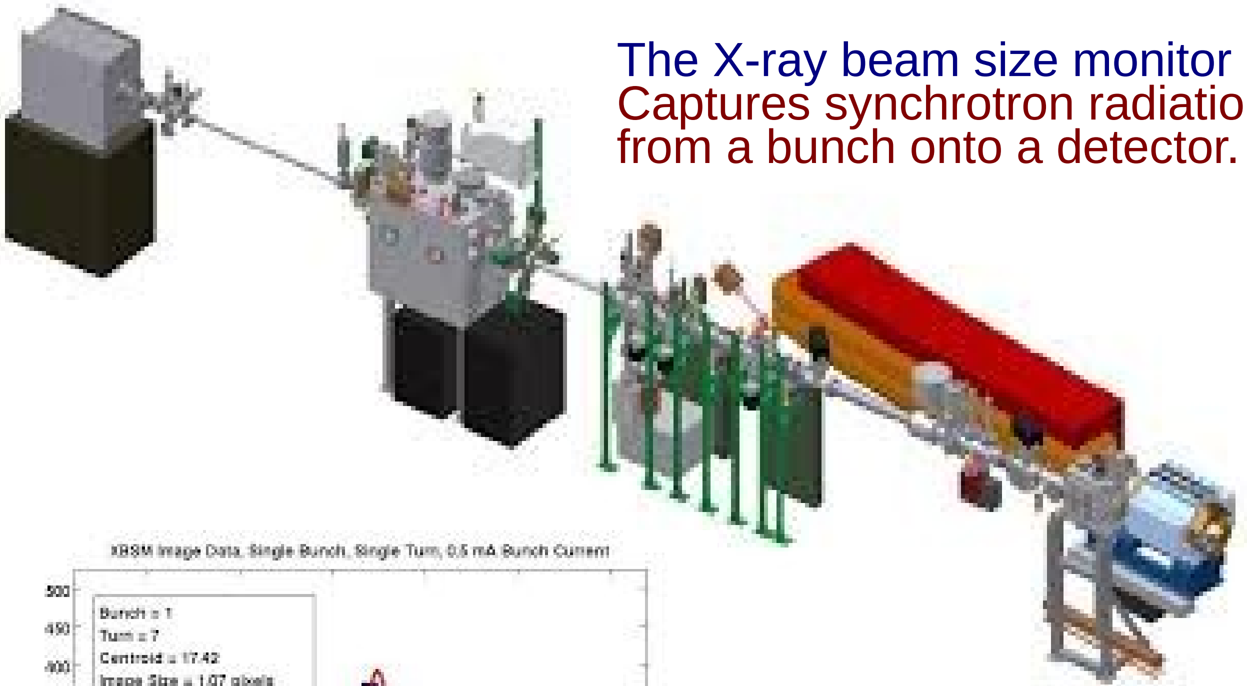
Several advances in modeling/simulating the system under different conditions have been made and compared against experiments. These same simulations programs, once validated at CesrTA can be used to study designs of future facilities.

The “Witness Bunch” Experiment

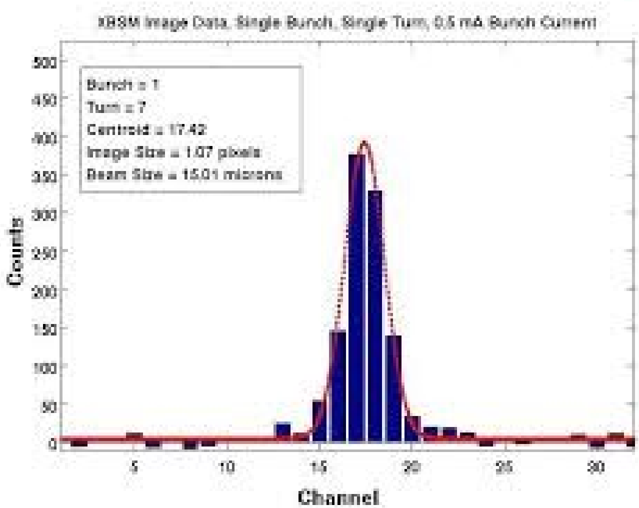


- Use the train to generate the electron cloud
- Observe the behaviour of the witness bunch
- Alter the properties of the witness bunch
  - position behind the train
  - charge
  - feed back (on/off)
  - emittance, chromaticity

Instrumentation used for our studies

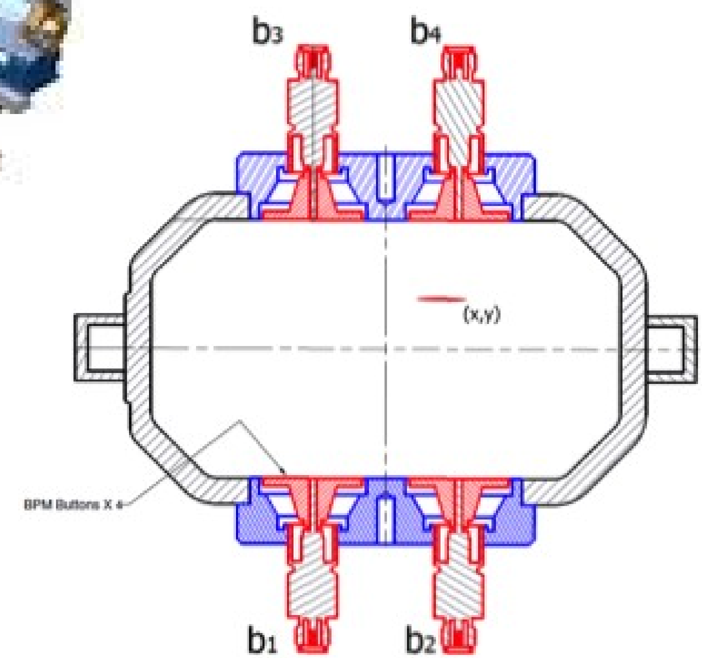


The X-ray beam size monitor (xbsm)
Captures synchrotron radiation emitted from a bunch onto a detector.

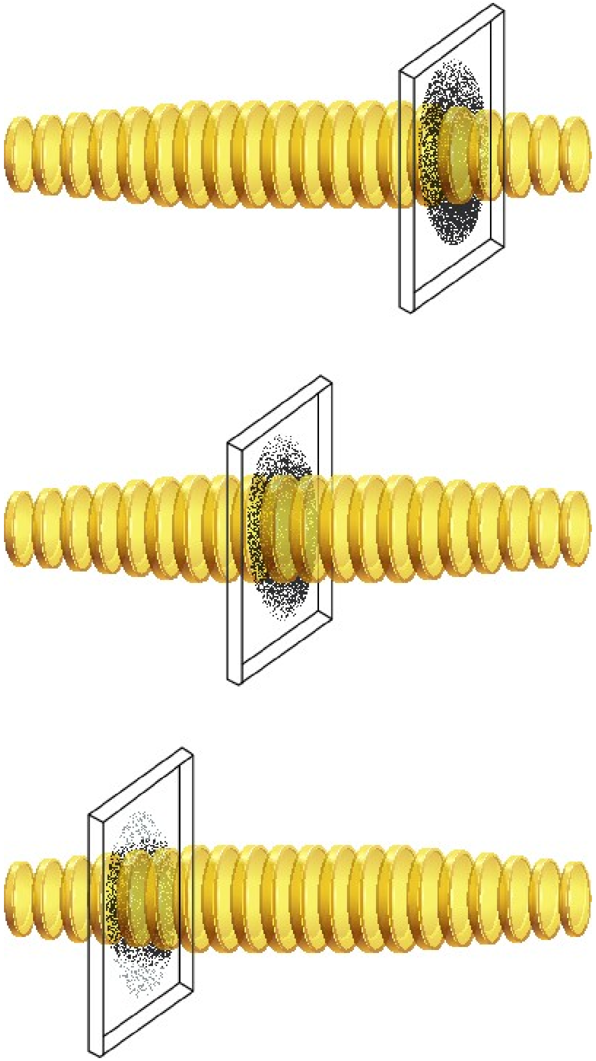


A typical signal produced on the xbsm with an estimated beam size

A beam position monitor (BPM), that consists of four "buttons" that pick up signal from the beam



Simulation method: CMAD



*The accelerator is divided into several Segments which contain electron cloud.

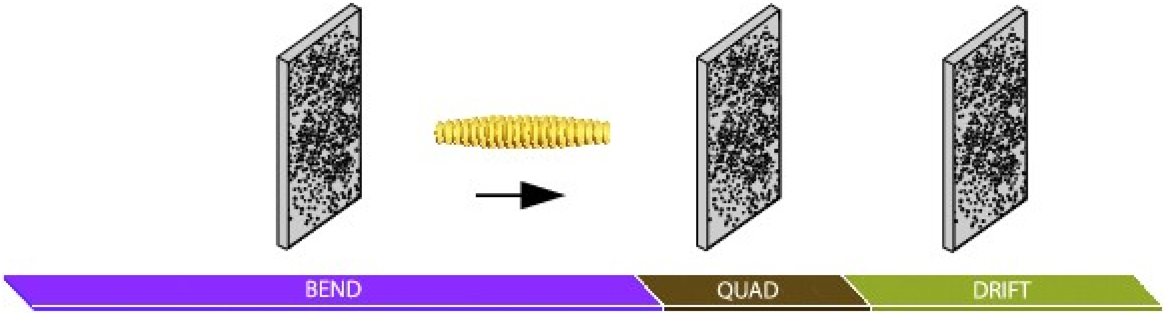
*The electron cloud of each segment is collapsed onto a 2D mesh.

*The beam is divided into several slices represented by a series of 2D meshes.

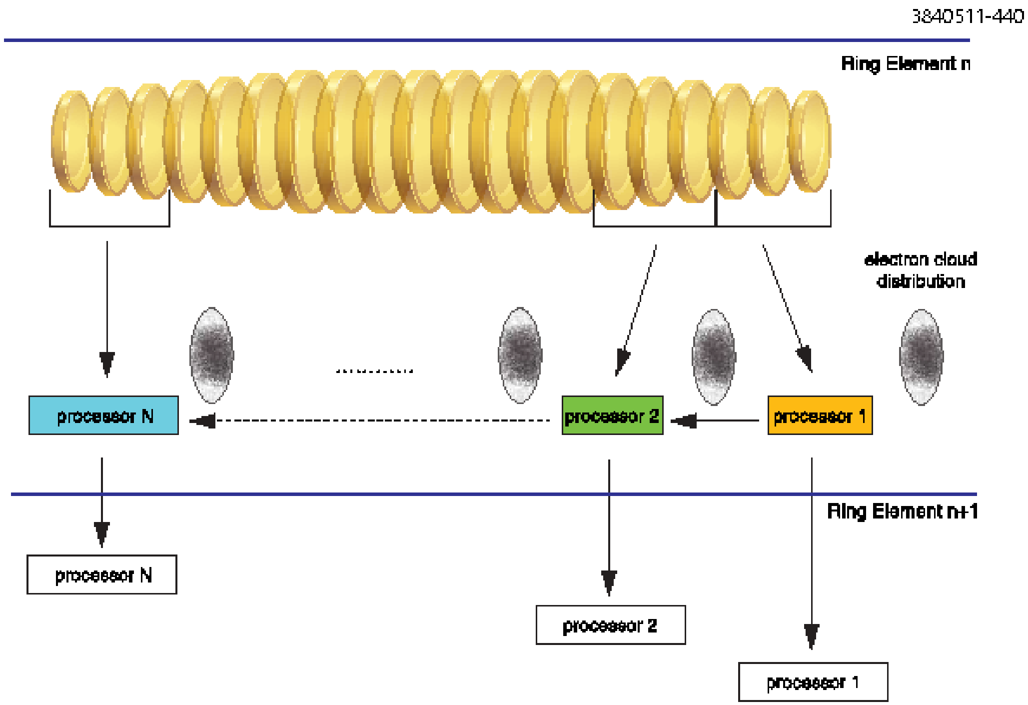
*The beam passes through the cloud slice by slice.

*Both the species are evolved during this process.

Program originally developed by Mauro Pivi



Computation Method



*The computation is distributed over several processors using MPI routines.
*Each processor handles one or more slice-cloud interaction.
*Once the beam distribution of the slices, belonging to a processor is evolved, they can proceed to the next interacting point independent of slices from other processors.
*The beam particles from all slices/processors collected and distributed once per turn.

The computations are performed at the NERSC supercomputers located in Berkeley.

Program originally developed by Mauro Pivi

Table of Parameters: Experiments and Computation

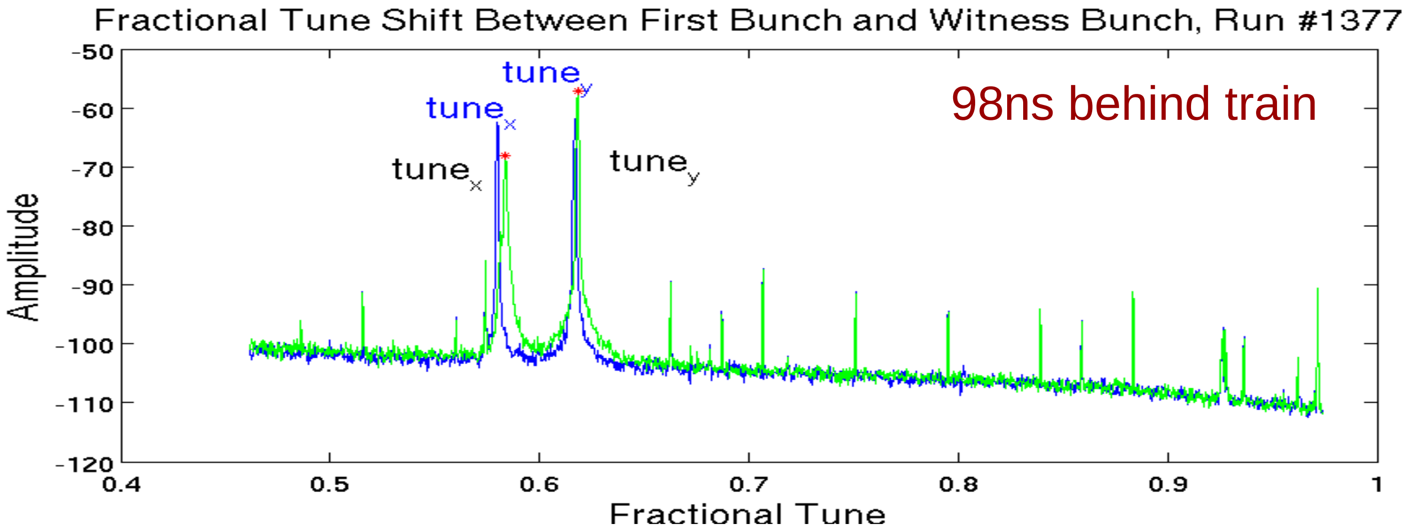
Physical Parameters

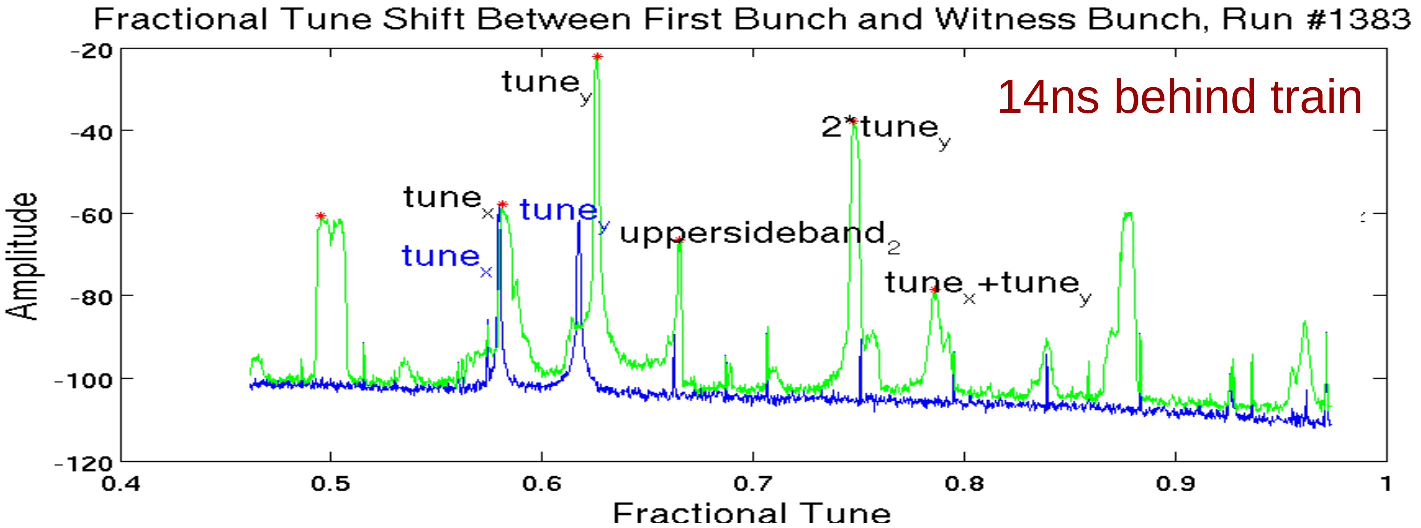
Circumference	768.4 m
Energy	2.085GeV
Bunch Length	1.22cm
Emittance	2.6nm(x) 20pm(y)
Chromaticity	~0
Tunes	14.571(x) 9.628(y)
Bunch Charge	1.28-2.56 nC
Bunch Spacing	14ns

Simulation Parameters

number of IPs	900
(x,y) extent	20Xσ
Extent in "z" -	8Xσ
# of macro e^+	300000
# of macro e^-	100000
# of grid cells	128X128
# bunch slices	96
# of processors	96

Observed Tune Shifts – using spectrum analyzer





*Shift in tune Between 1st bunch In train and witness Bunch.

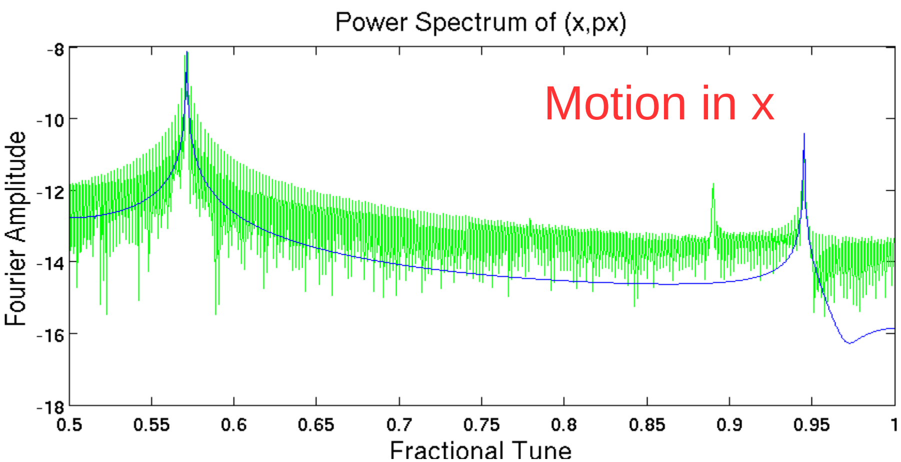
*Tune Shift occurs mostly in "y" in the bottom figure..

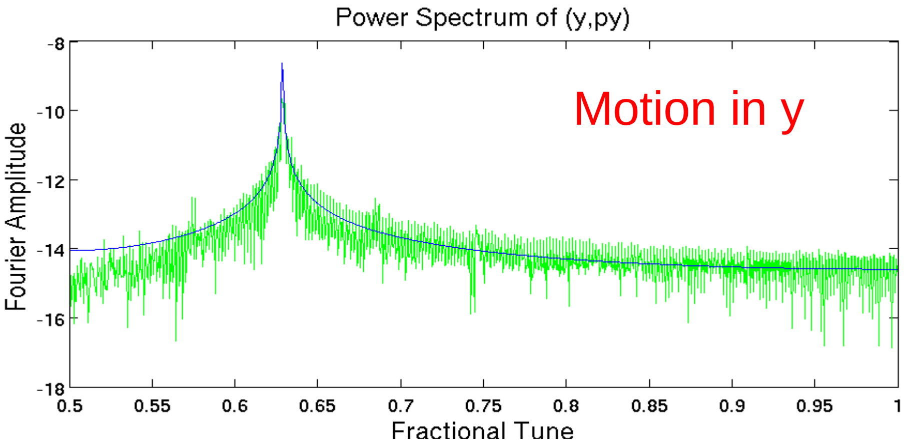
*Several other lines appear along with a large tune shift.

Conditions:
45 Bunch train,
14 ns spacing
0.5mA/bunch or
1.28nC/bunch.

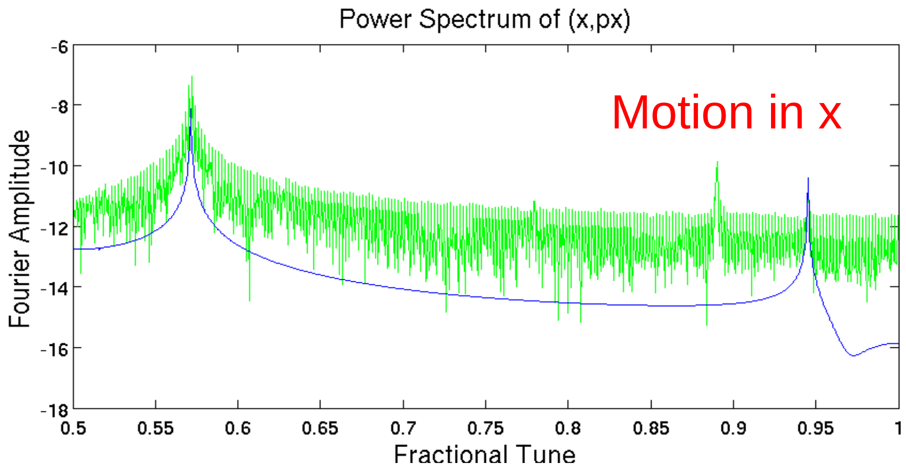
Witness bunch at same charge as bunch in train.

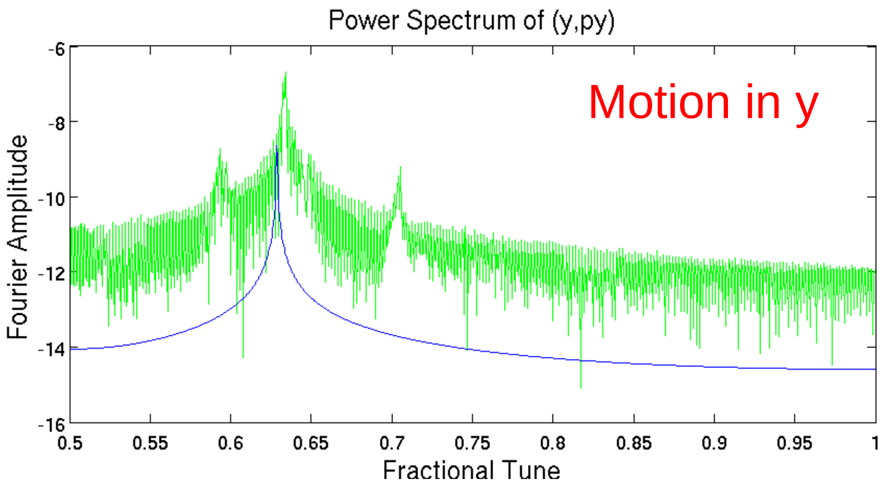
Tune Shift – between Simulations with and without electron cloud





Electron cloud at 1e11/m^3

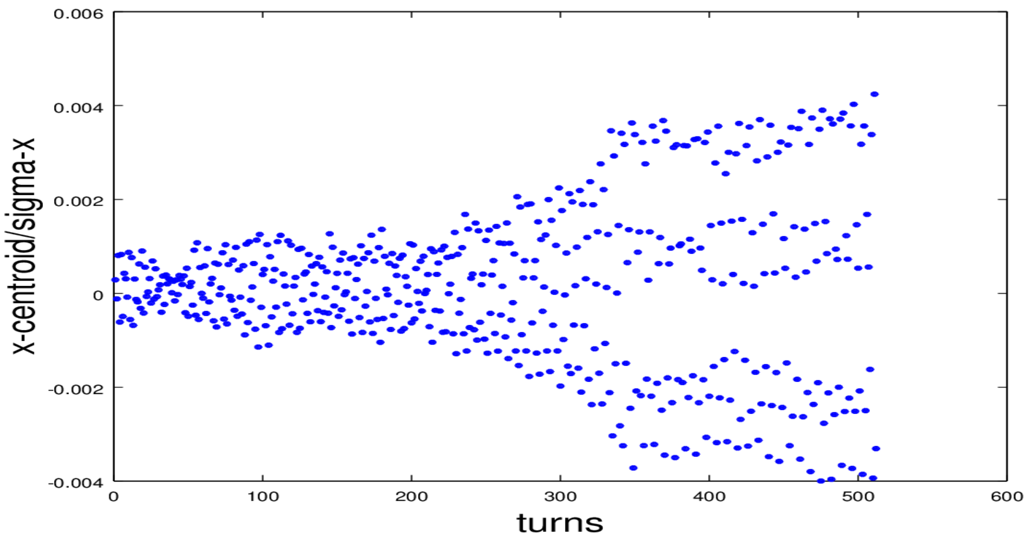


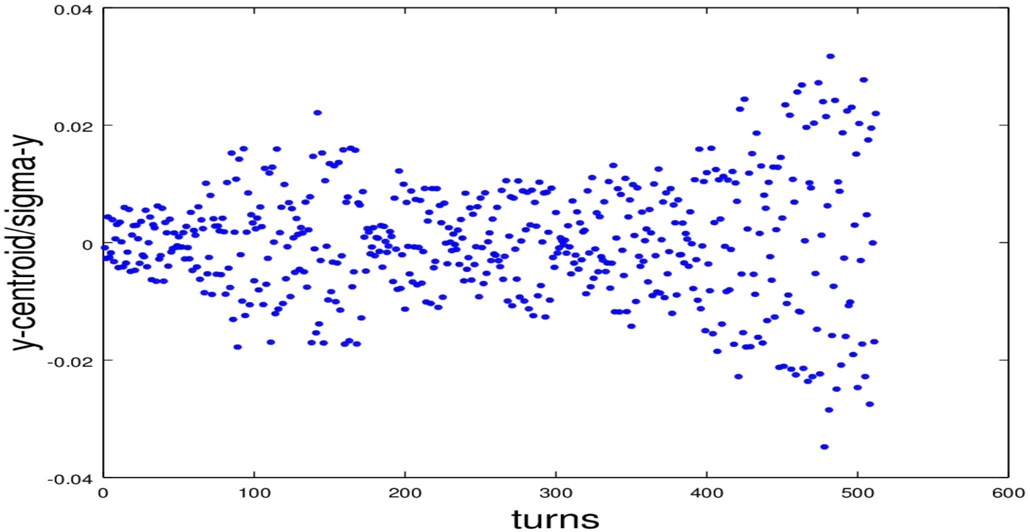


Electron cloud at 1e12/m^3

Same bunch charge as previous slide; We see a tune shift only in “y” as in experiments

Amplitude of oscillation of beam centroid in simulations





Cloud density = $10^{12}/m^3$

x-sigma = 0.1 mm

y-sigma = 0.013 mm

Centroid motion is self excited. and is noisy because of the small amplitude of oscillation.

We must redo the calculations with an initial beam offset for a cleaner fft and better tune shift calculations.

Estimation of Cloud density from tune Shift.

Cloud density can be estimated by

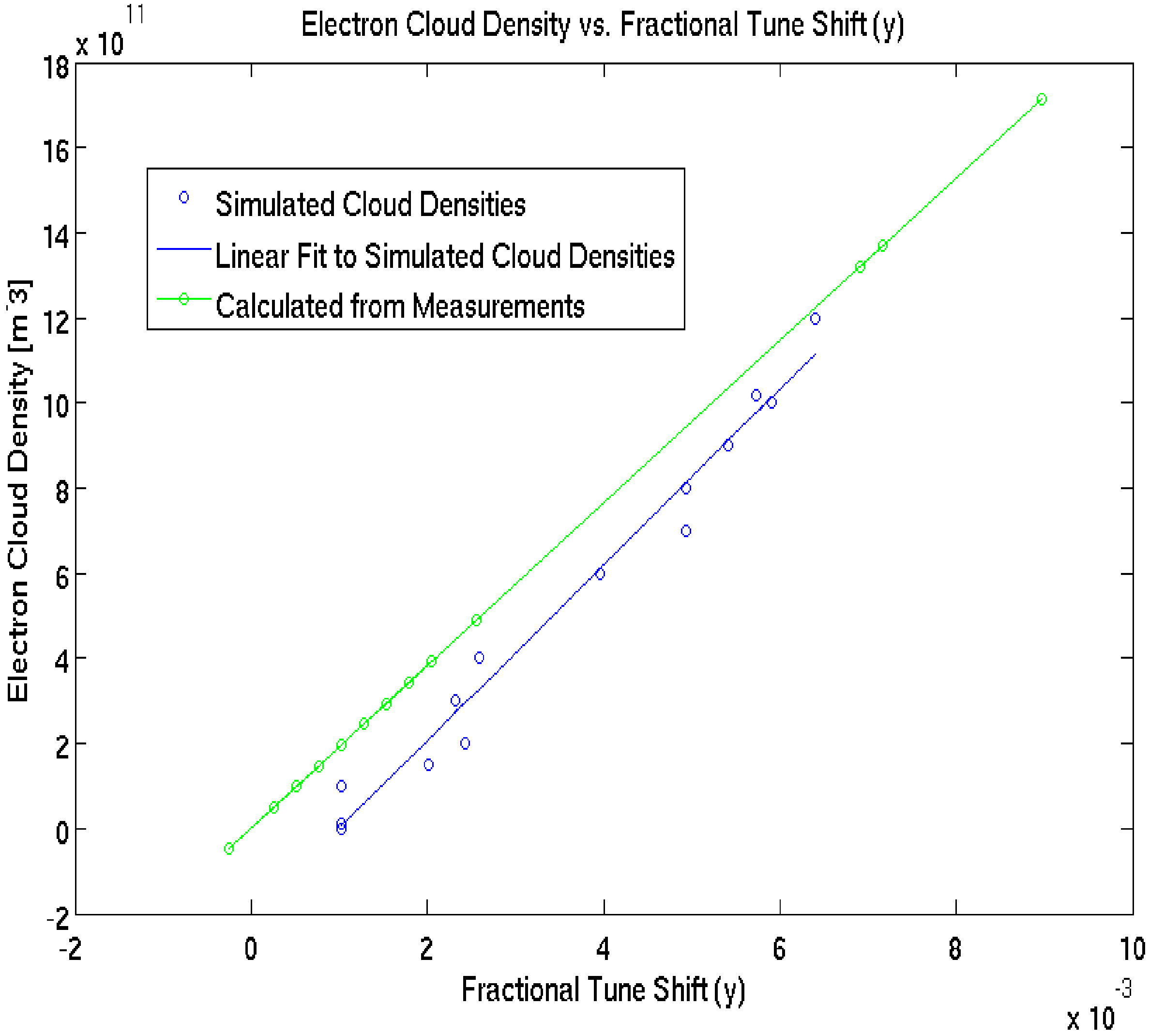
$$\langle \rho \rangle = \gamma \cdot \frac{2\Delta Q_y}{r_e C \langle \beta_y \rangle}$$

from: K Ohmi - PAC 2001

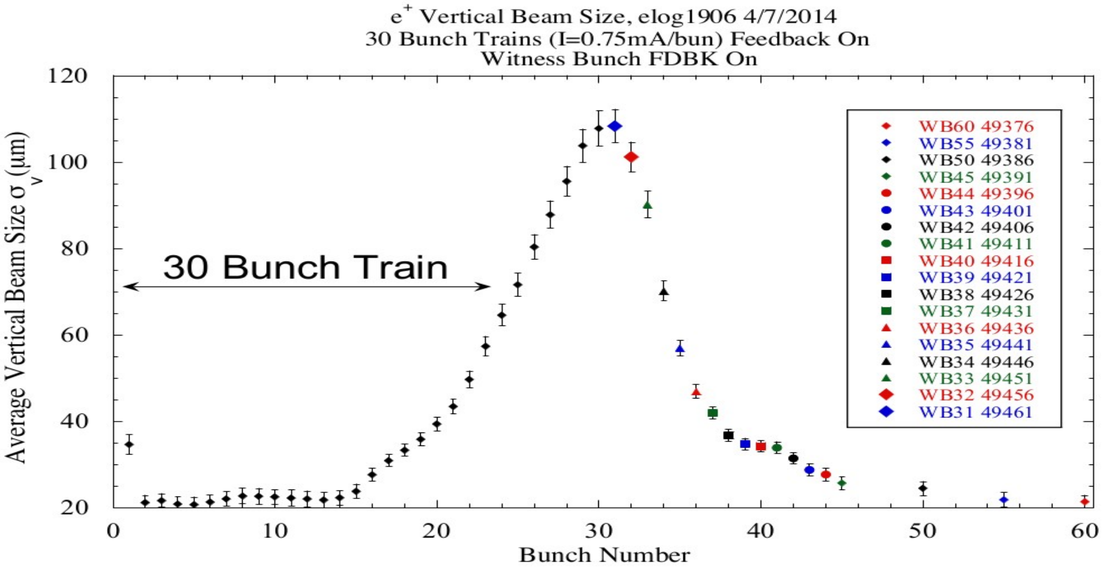
Electron cloud density can be estimated using the above formula.

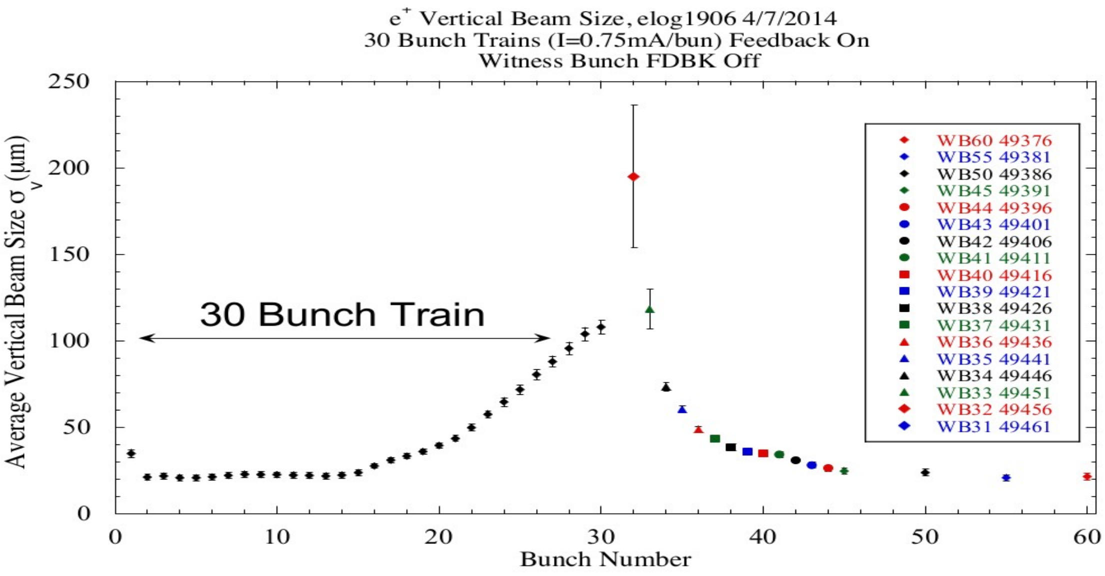
In experiments, only the tune shift is known.

In simulations, cloud density and tune shift are known



Beam size measurements, 30 bunch train feedback on + witness bunch feedback on/off





Note: The train is under feed back in both cases. Thus, multi bunch effects are minimized

Witness bunches just behind the train have a much larger beam size in the absence of feedback.

Significant beam size expansion is seen even with feedback.

We dont have an explanation for the first bunch expansion!

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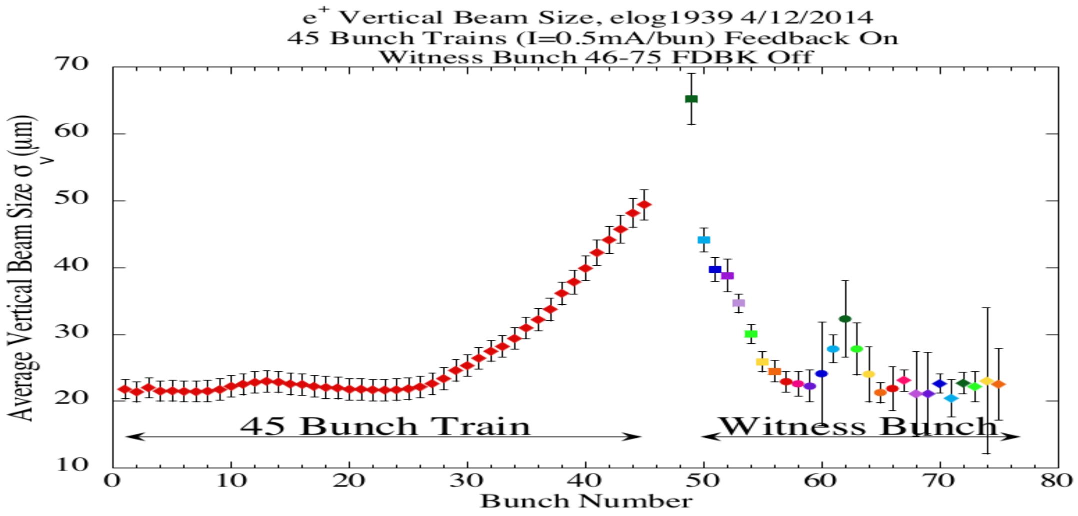
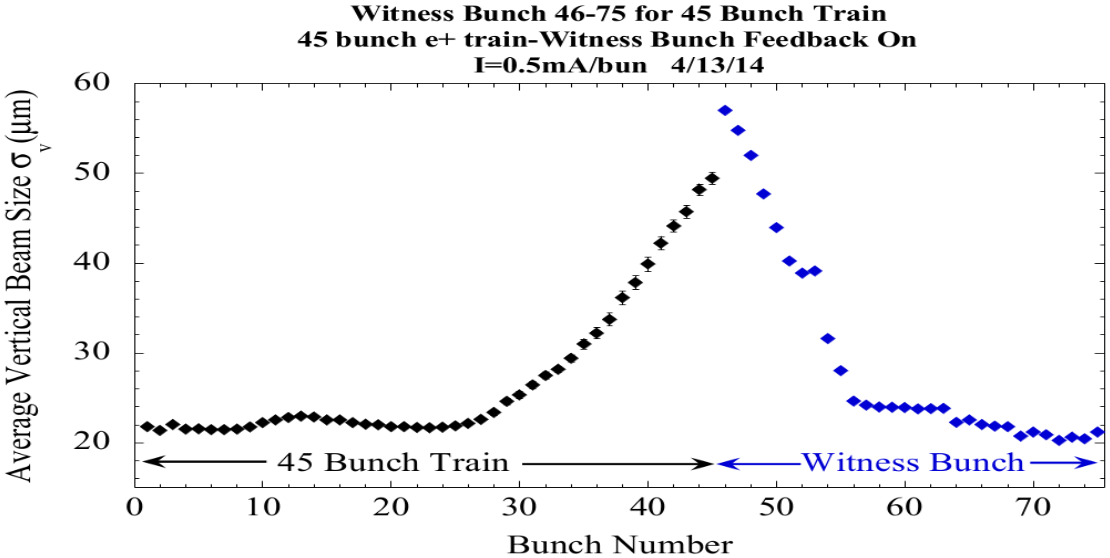
Beam Size measurements 45 bunch train (feed on) + witness Bunch (feedback on/off)



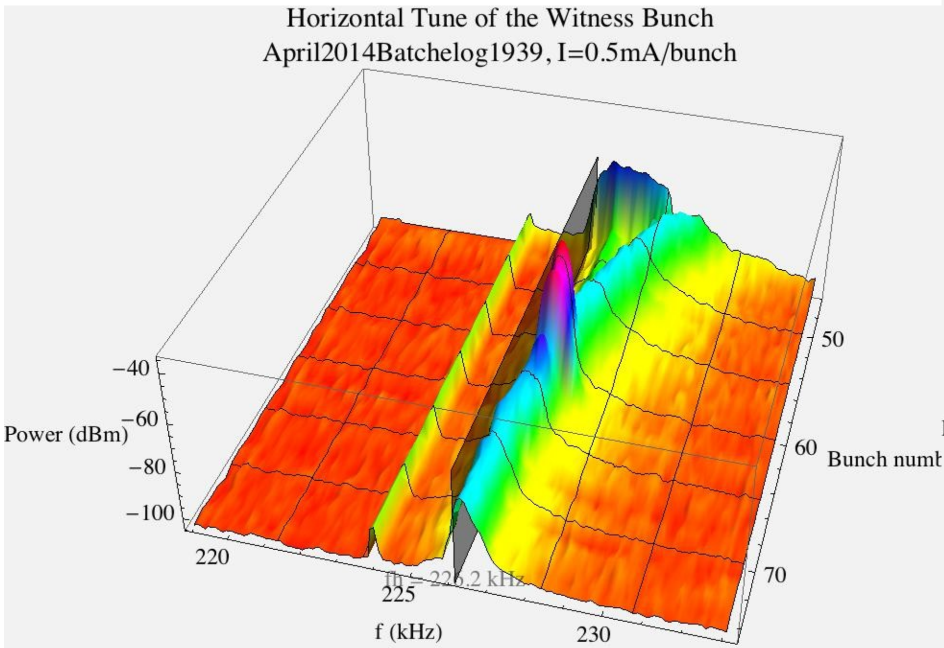


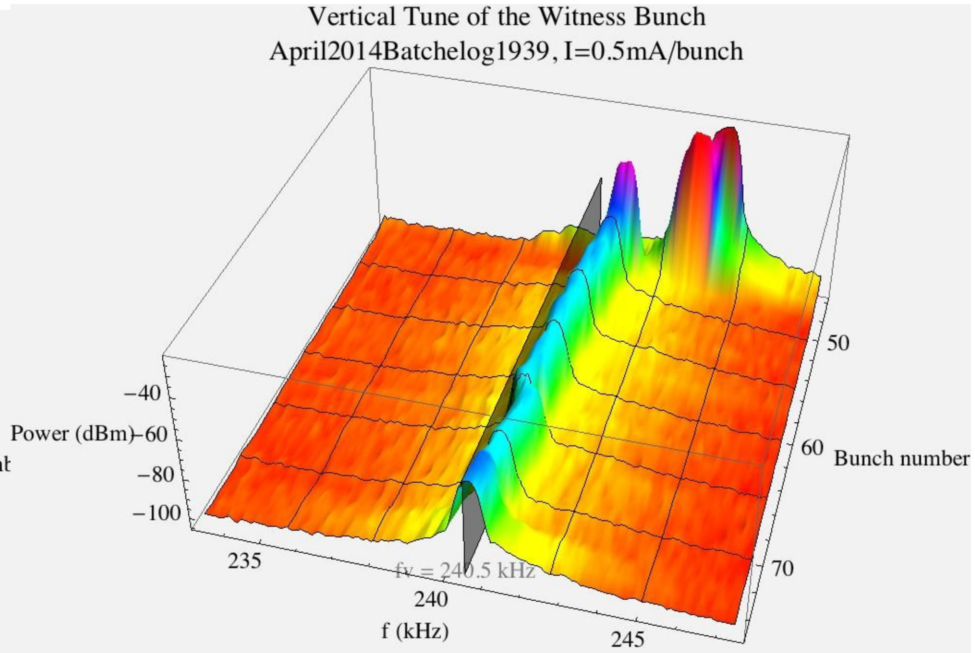
Longer train, less charge per bunch.

We do not see the lead bunch blow up in this configuration.

The results are otherwise similar to previous case.

The “hump” near witness bunch 65 is most likely not due to electron cloud.



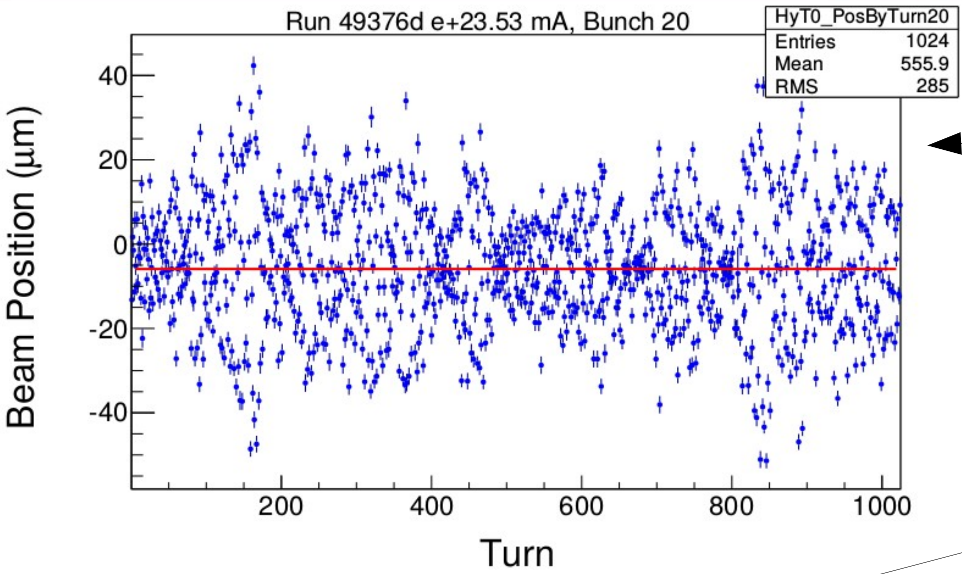


Tune shift of all witness bunches for the 45 bunch train case

The “Hump” in horizontal tune peak corresponds to the “Hump” in vertical beam size of previous slide.

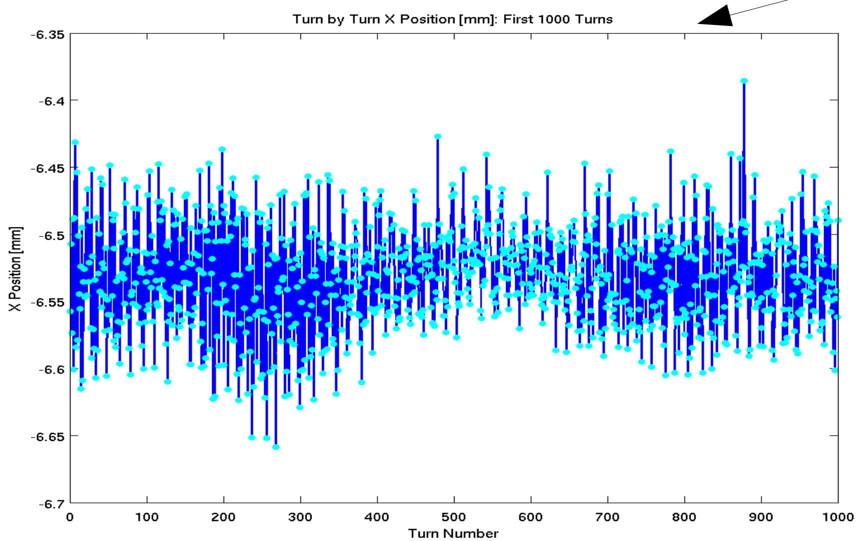
The appearance of the large peaks in the vertical tune corresponds to the transition in beam size increase Of the witness bunch in the previous slide

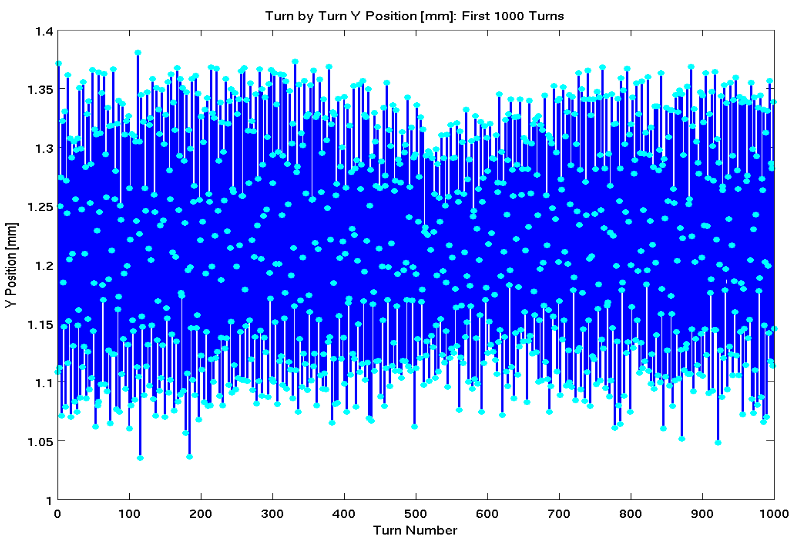
Sample of oscillation amplitude of bunch with and without feedback



Measurement from xbsm, Beam under feedback 20th bunch of 45 bunch train

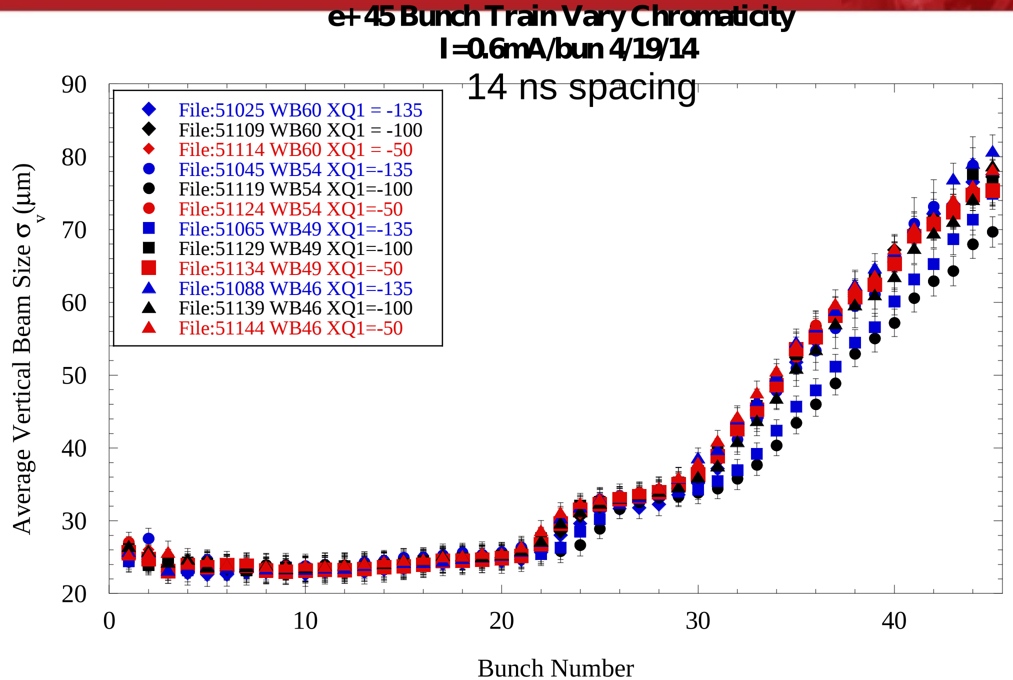
BPM data of witness Bunch 33 behind 30 Bunch train





NOTE: The conditions and location of the two do not match so they are not corresponding data sets. The number must be regarded as “Typical” values.

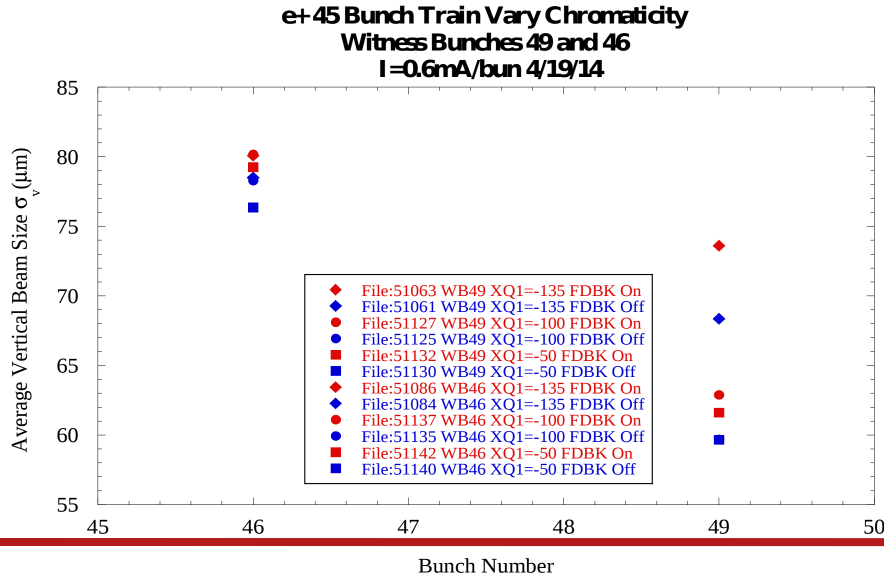
Effect of variation of chromaticity

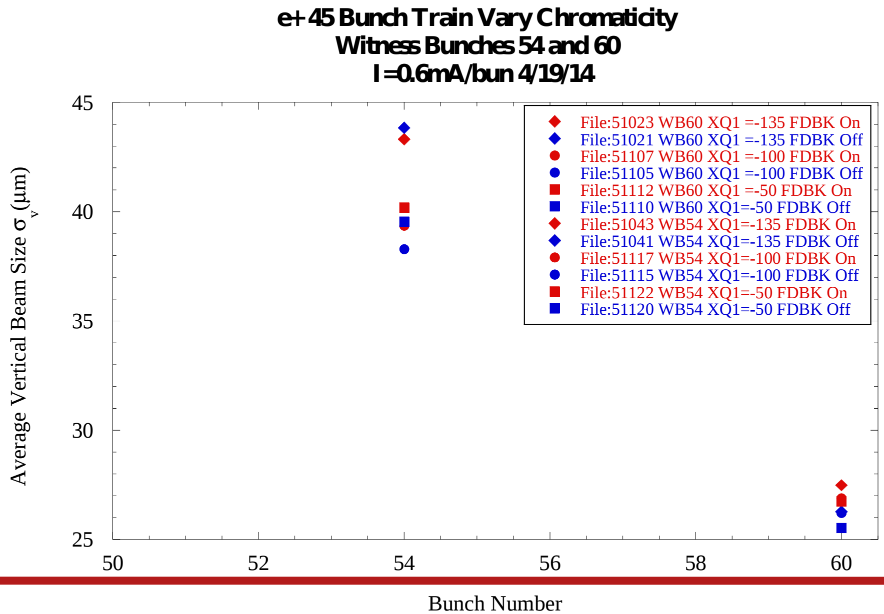


Place 0.6mA witness bunch at number 46, 49, 54, and 60.

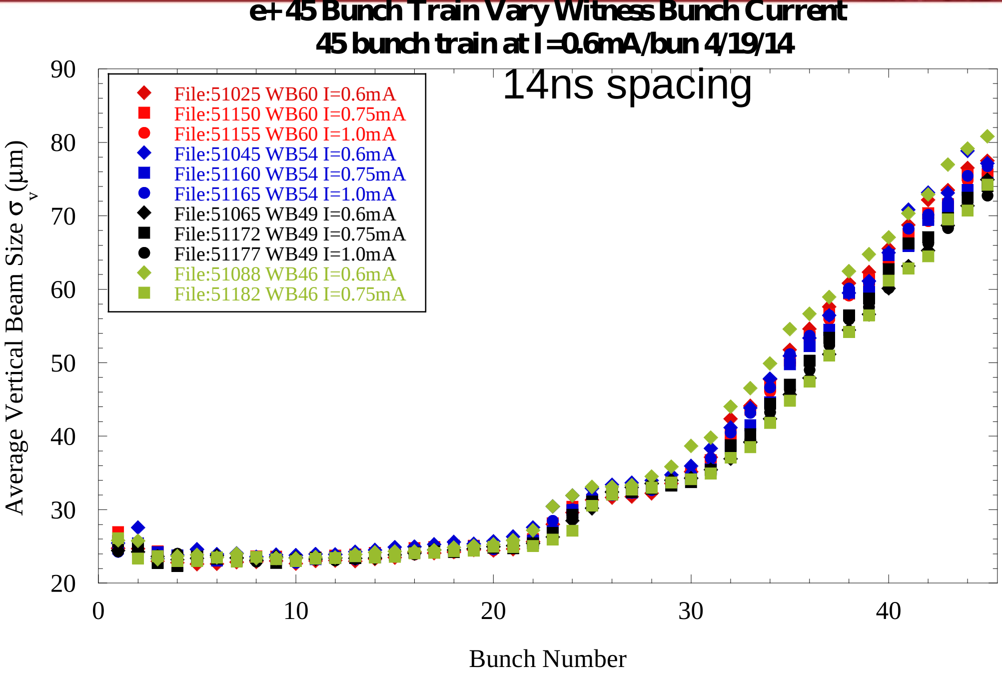
Larger vertical beam size with feedback on.

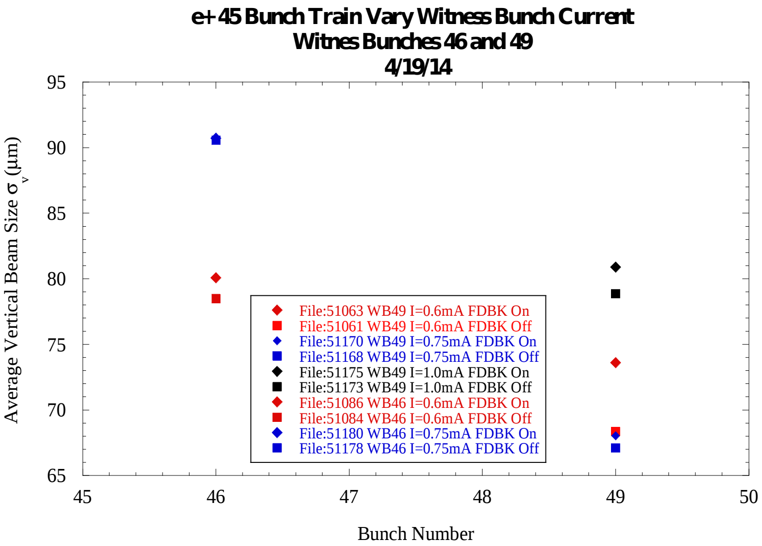
Typically, Lower chromaticity provides larger beam size





Effect of Variation of current in witness bunch

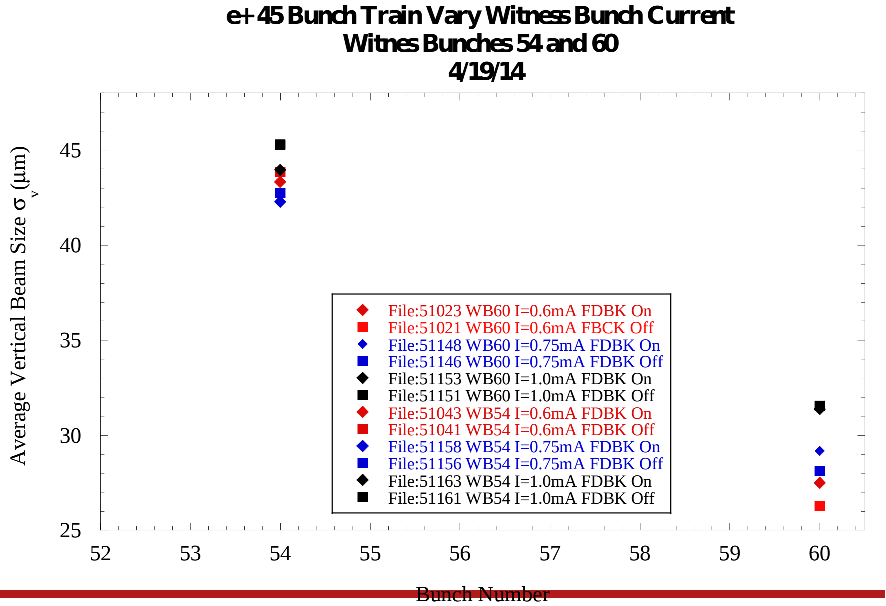




Place 0.6, 0.75, 1mA witness bunch at number 46, 49, 54, and 60.

Larger vertical beam size with feedback on.

Higher witness bunch current provides larger beam size in most cases.



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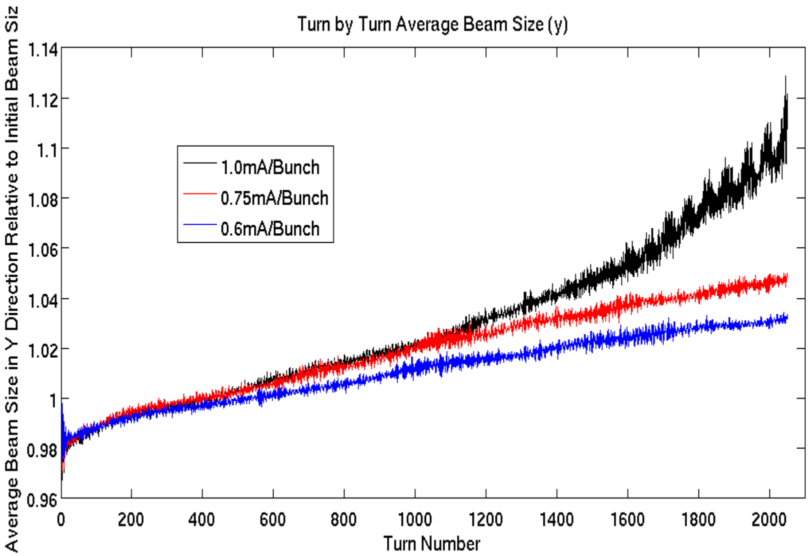
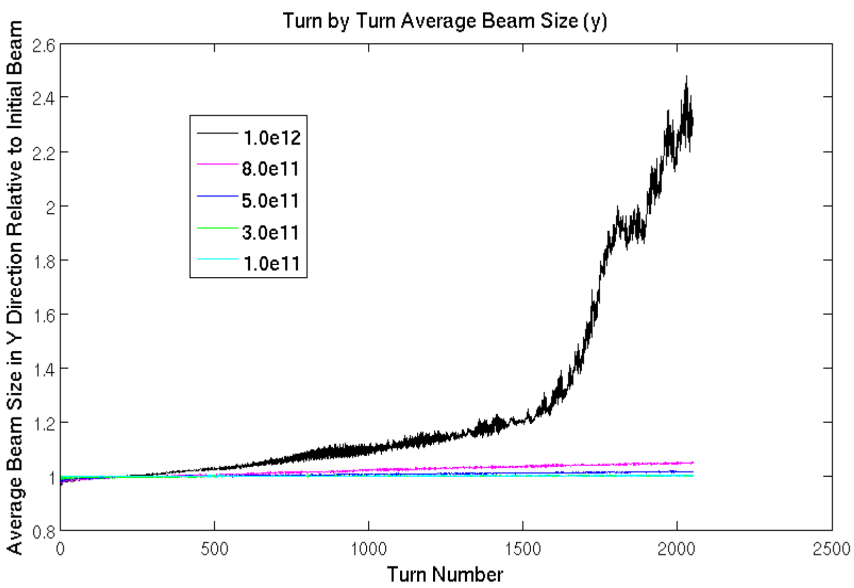
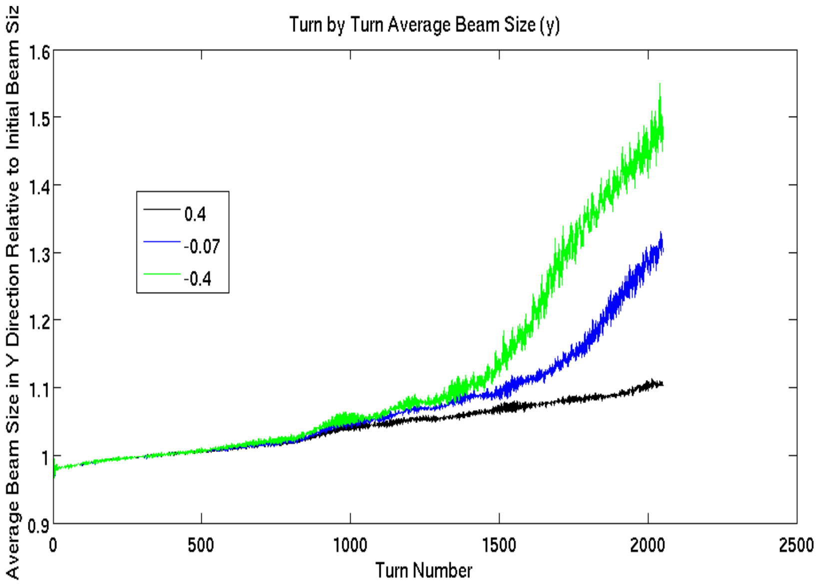
Effect of varying cloud density, chromaticity And bunch current in simulations.





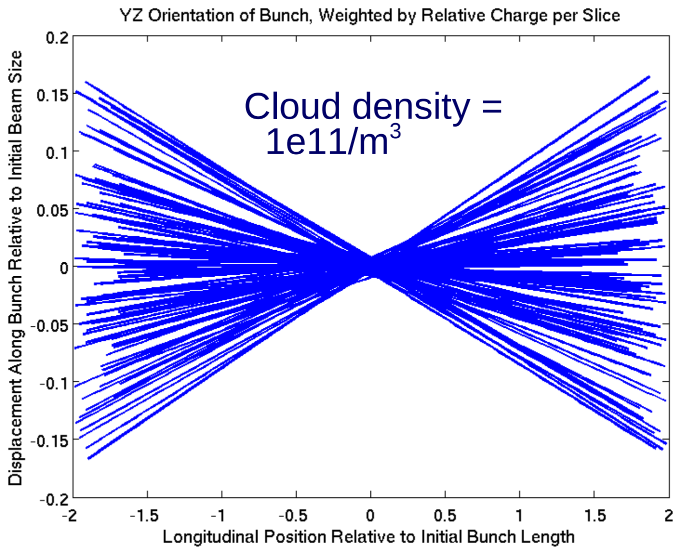


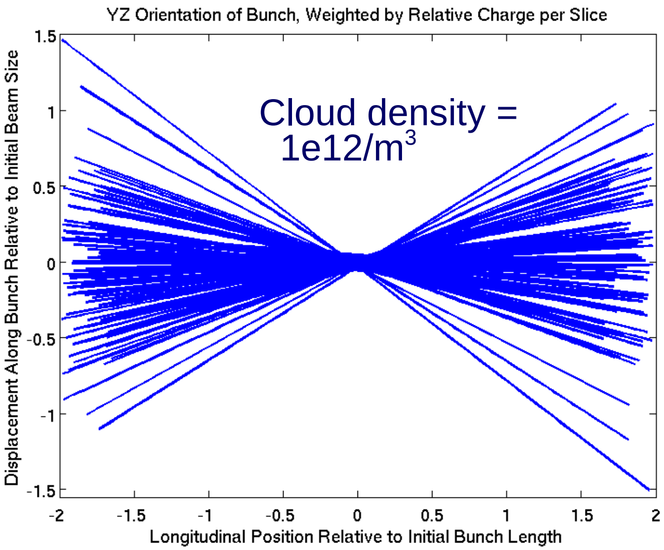
*Increase in beam size with increased cloud density and a transition to rapid beam size growth rate.

*Increase in beam size growth rate with increased bunch charge.

*Increase in beam size growth rate with decrease in chromaticity.

First order Head-Tail Motion from Simulations



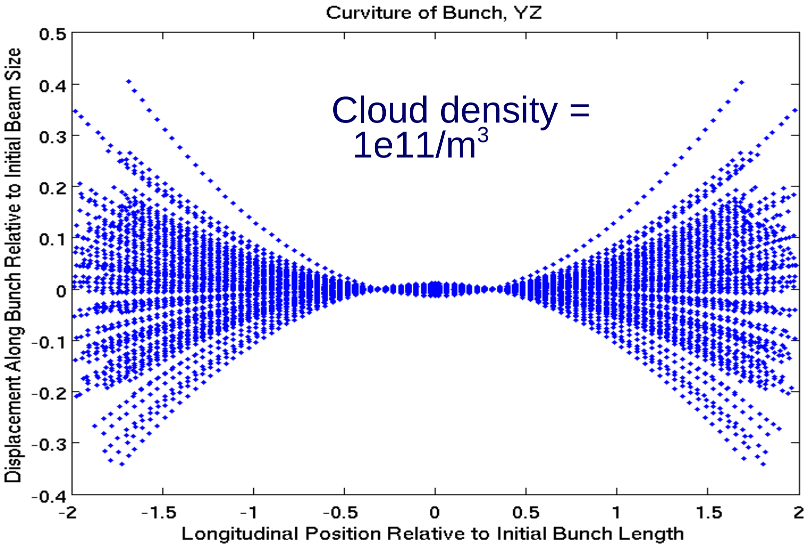


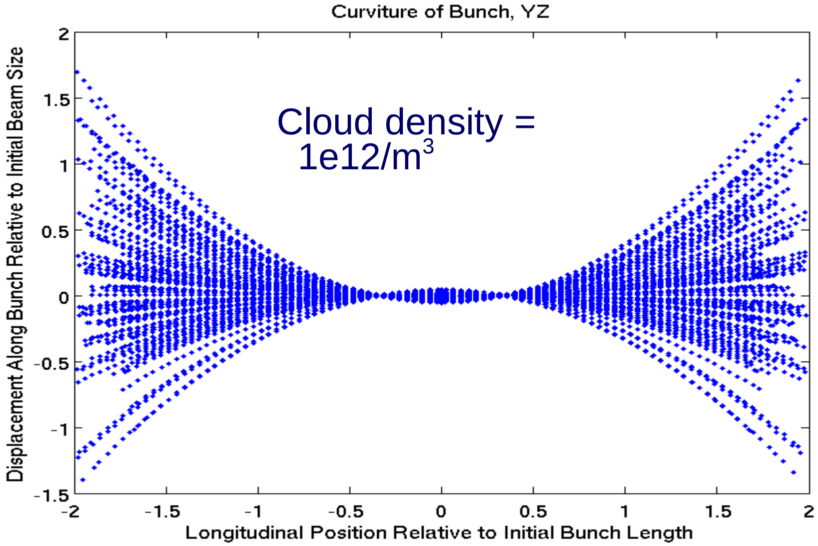
Perform a linear fit over the centroid of all the bunch slices for every turn. Motion of bunch centroid is removed in the fit.

Amplitude of head-tail oscillation (m=1 mode) increases by An order of magnitude with increase in cloud density by a factor of 10.

Note: The head tail motion is self induced by the electron cloud.

Second order Head-Tail Motion, from simulations





Remove the centroid motion and orientation of bunch, and perform a parabolic fit over all the bunch slices for every turn.

The amplitude of this mode increases by an order of magnitude When the cloud density is increased by a factor of 10

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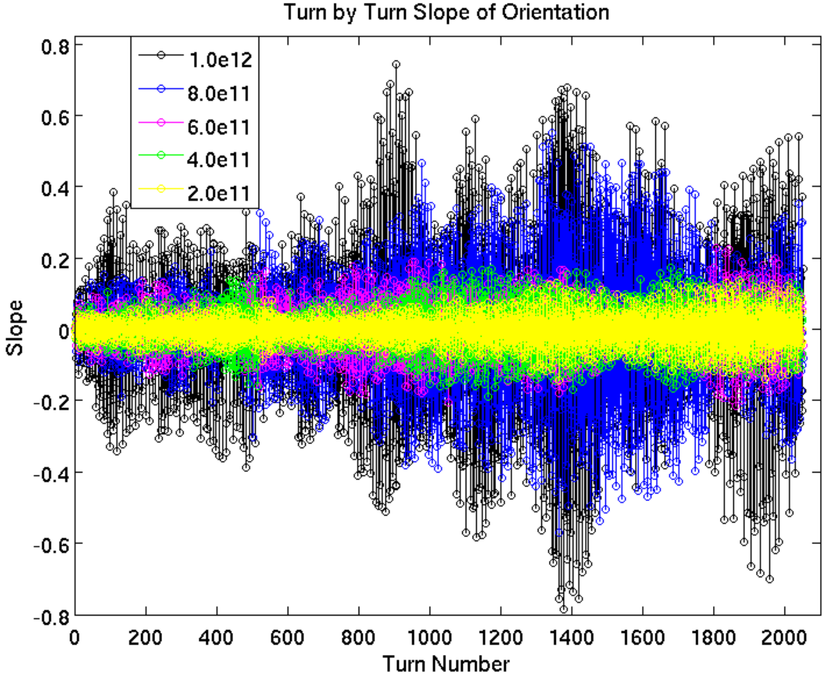
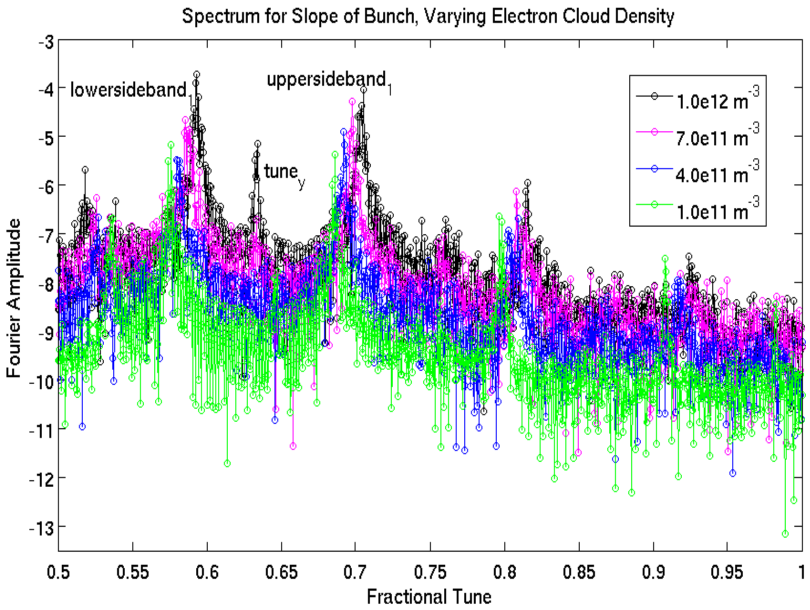
Turn by Turn variation of linear slope: varying cloud densities



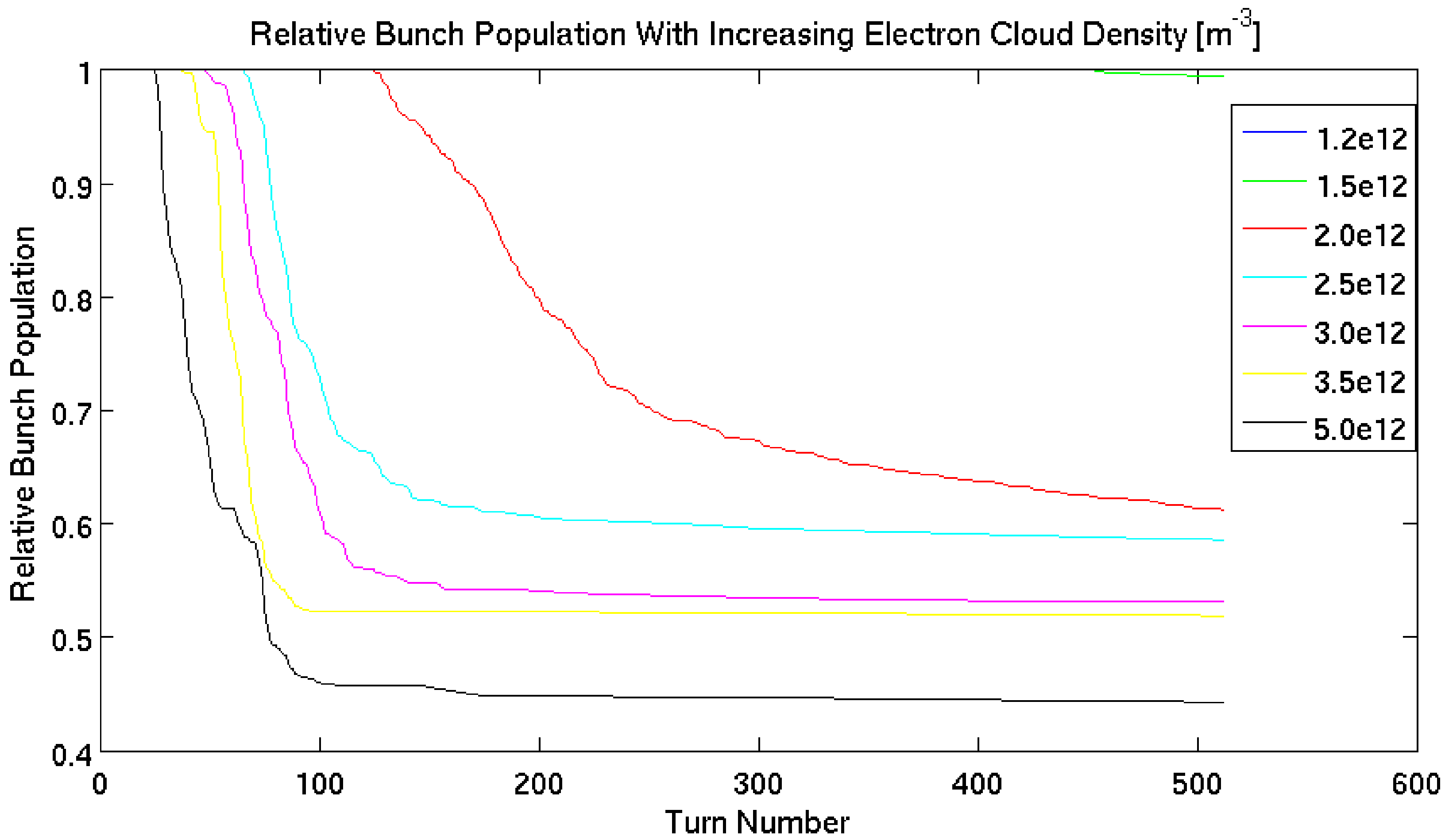


The magnitude of the slope is obtained from linear fit for every turn.

The amplitude of oscillation of slope clearly increases with increased cloud density.

Spectrum shows strong synchrotron side bands, and a peak at betatron tune only for higher cloud density.

Total Charge in Bunch Turn by Turn, Varying Electron Cloud Density



Initial Bunch Population = 0.8e10 Positrons

Conclusion

- We worked on a series of experiments designed for observing single bunch dynamics induced by electron clouds on positron beams.
- Simulations were performed using the program CMAD.
- We observed emittance growth with increased cloud density, decreased chromaticity, increased bunch current.
- Simulations showed a similar behavior when the above parameters were varied.
- Simulations showed that head tail motion was induced from electron clouds and is directly co-related with increased emittance growth.
- Significant emittance growth was observed even when bunch oscillation was suppressed with feedback.