Measurement and Simulation of Electron Cloud induced Emittance Growth at CesrTA

Kiran Sonnad

KEK

List of Collaborators

Experiments	Simulation	Data Analysis
Laurel Bartnik*	Lillian Pentecost[$]	Robert Holtzapple
Mike Billing*	Mauro Pivi[&†]	Lillian Pentecost
Mike Forster*	Kiran Sonnad	Sam Tucker[#]
John Flanagan[%]		Kaitlin McArdle[#]
Robert Holtzapple[#]		Mikhail Miller[#]
Kiran Sonnad*[,%]		Kiran Sonnad

Gerry Dugan*, K Ohmi[%] - expertise, help and advise
Brian Heltsley, Nate Rider - beam size measurements,
Robert Meller and all Cesr Operators

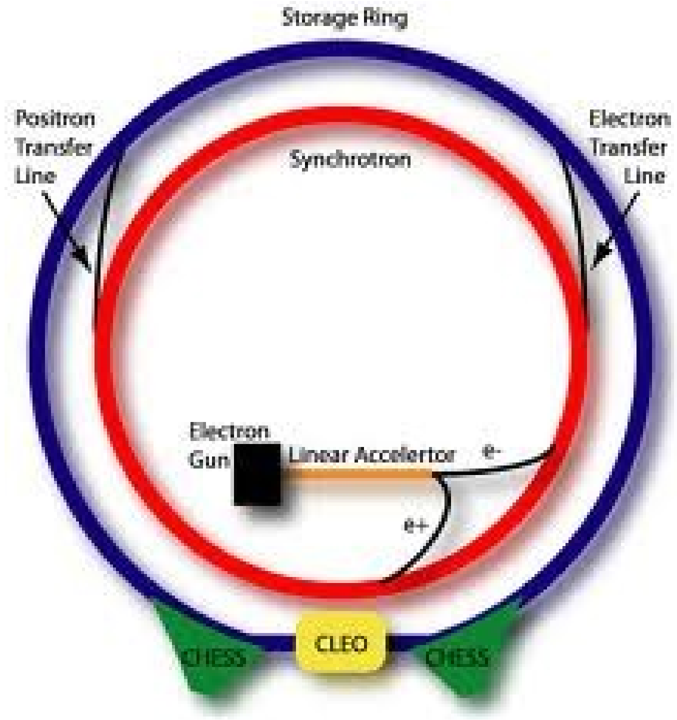
* CLASSE Cornell University
# California Polytechnic State Univ
& SLAC
$ Colgate University
% KEK
† MedAustron

About CesrTA

The Cornell Electron Storage Ring (CESR) was colliding electrons and positrons in the CLEO detector for ~30 years.

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.

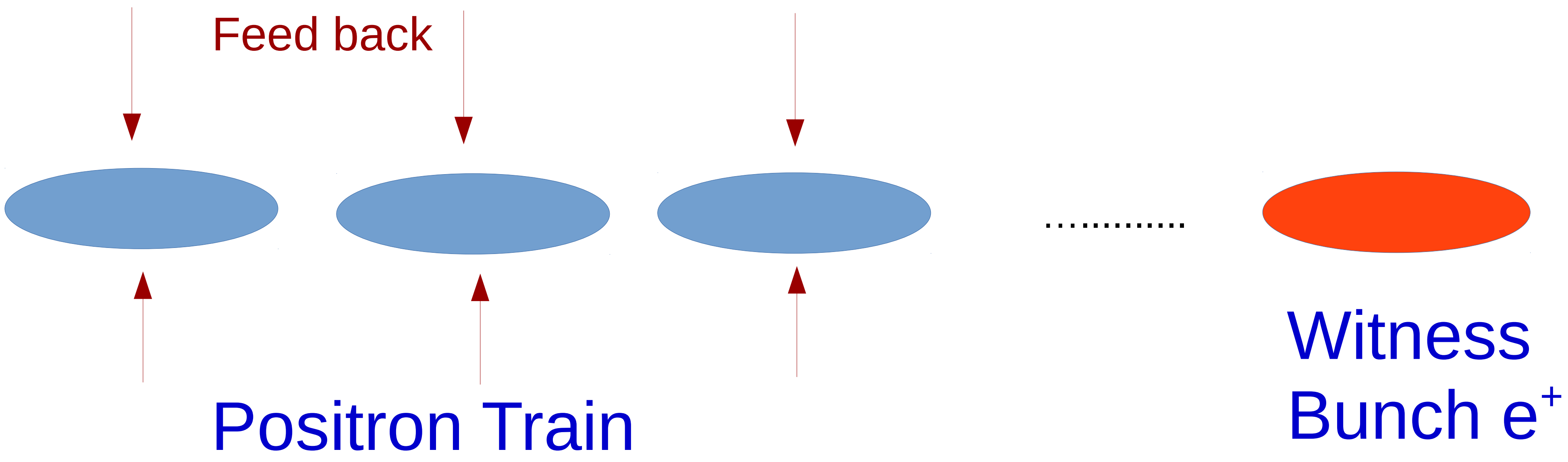


The main thrusts of the CesrTA program has involved understanding electron clouds in positron storage rings, tuning the machine for lower beam emittances, understanding other collective effects such as intrabeam scattering and fast ion effects.

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.

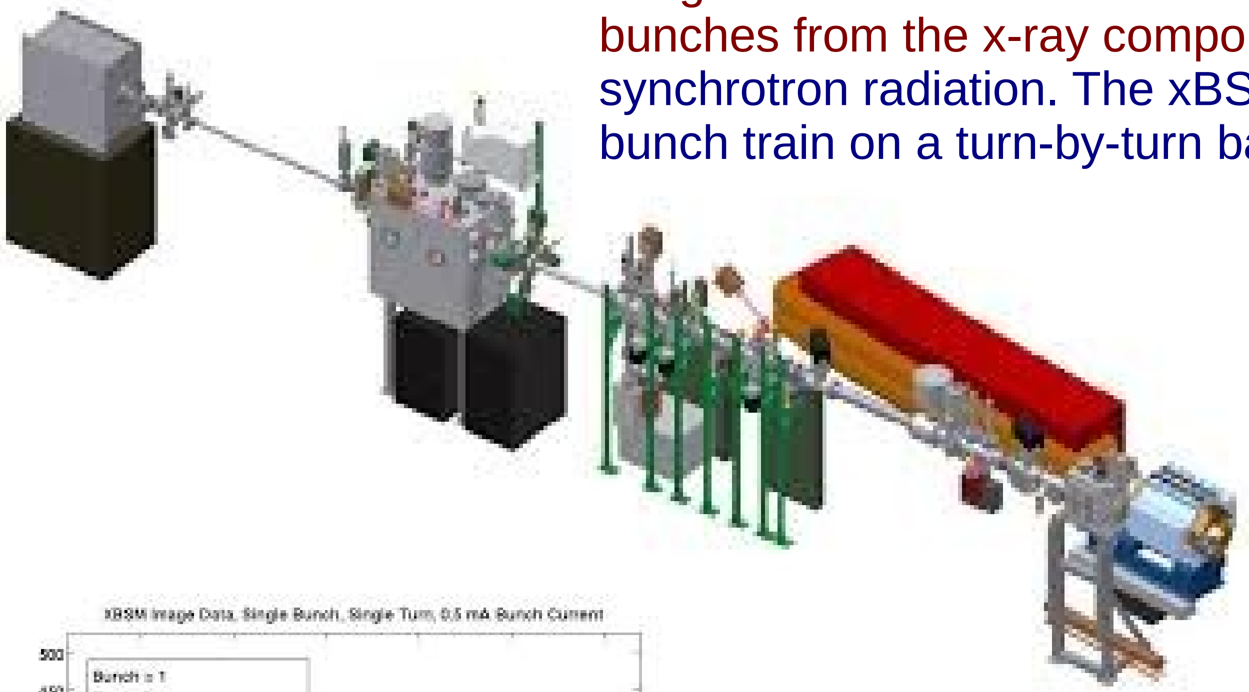
The "Witness Bunch" Experiment



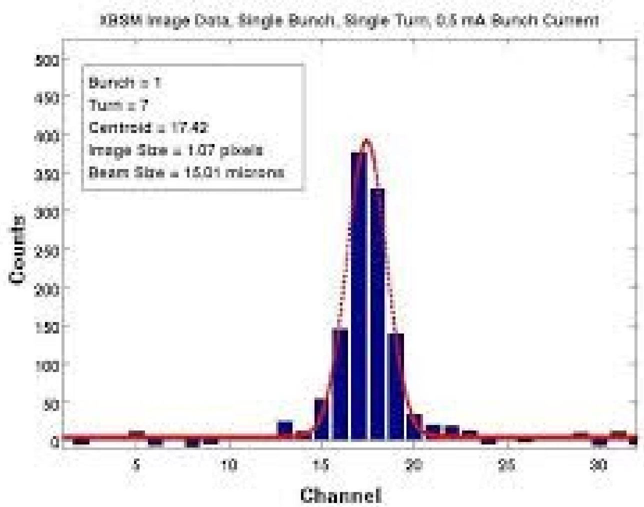
A witness bunch is placed after the train to observe the bunch-cloud beam dynamics

- 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
  - feed back (on/off)
  - emittance, chromaticity, charge

Instrumentation used for our studies

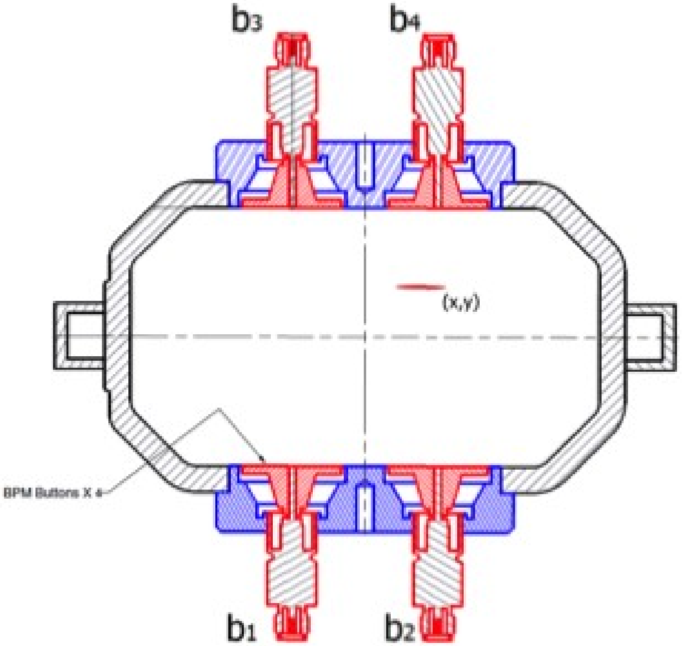


Images the vertical beam size and position of electron or positron bunches from the x-ray component of the synchrotron radiation. The xBSM can resolve single bunches in a bunch train on a turn-by-turn basis.

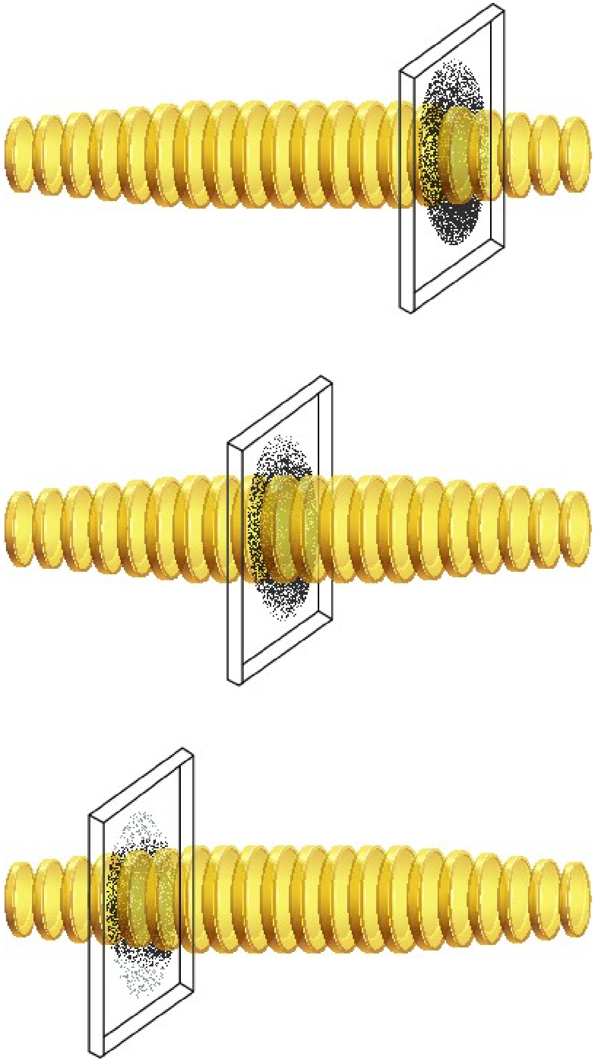


A typical signal produced on the xbsm with an estimated beam size

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.

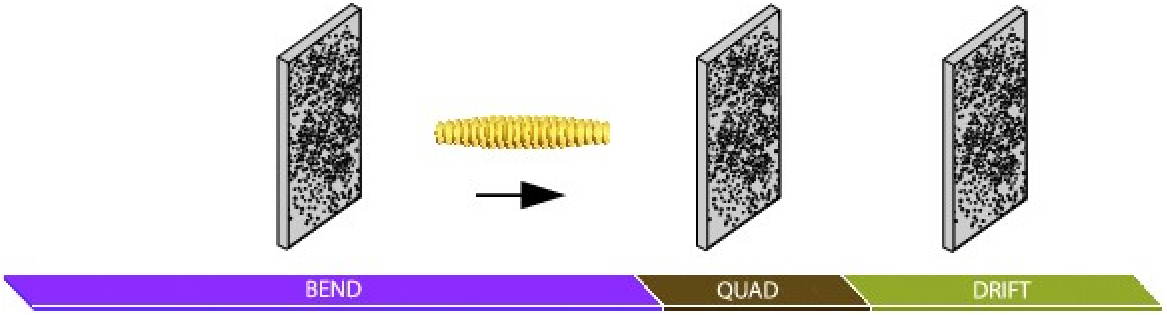
*The electron cloud of each segment is collapsed onto a 2D mesh.

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

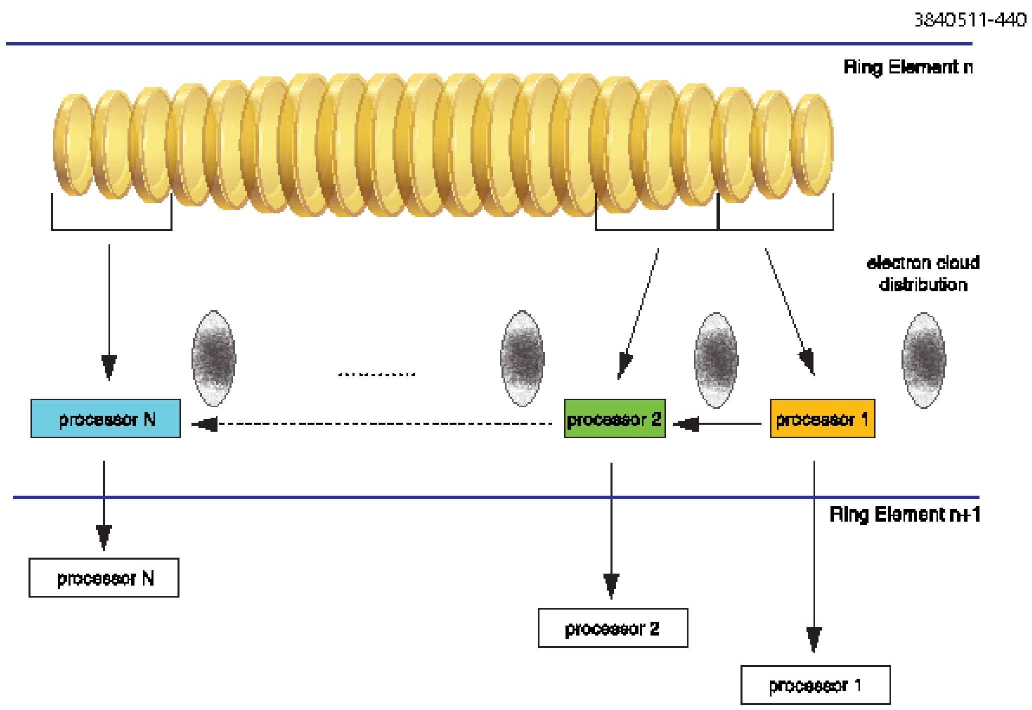
*The beam passes through the cloud slice by slice.

*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 at LBNL Berkeley.

Program originally developed by Mauro Pivi

Table of Parameters: Experiments and Computation

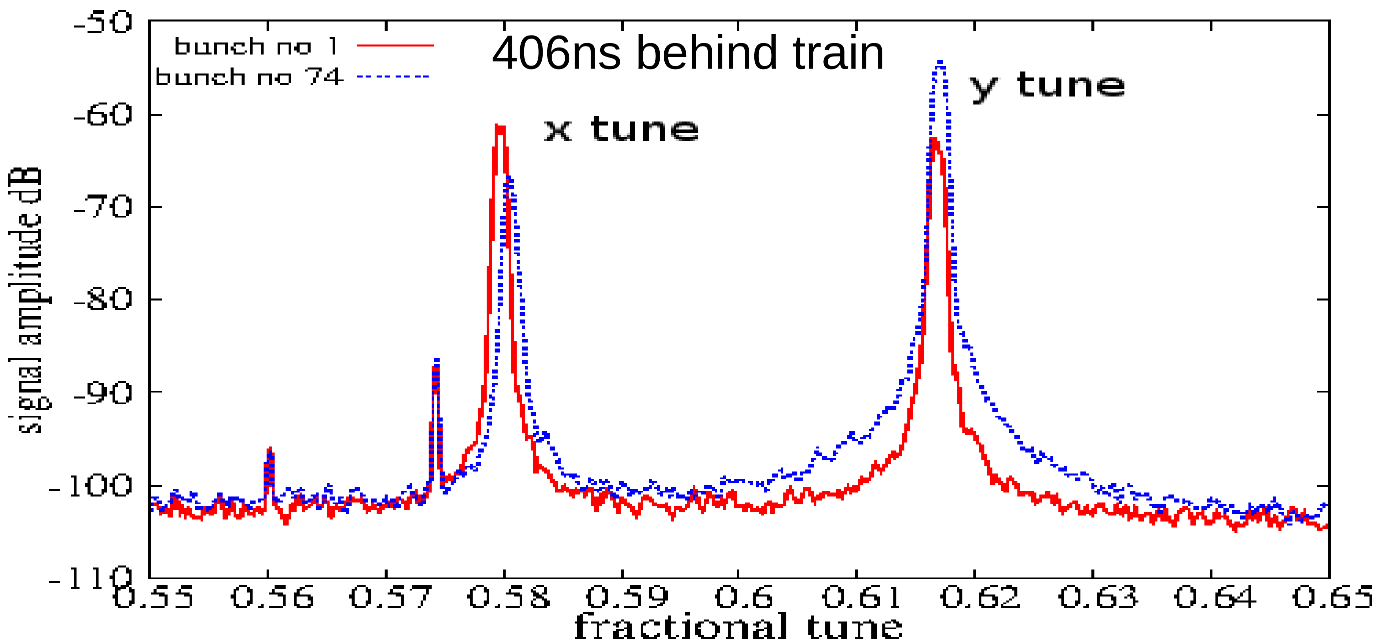
Physical Parameters

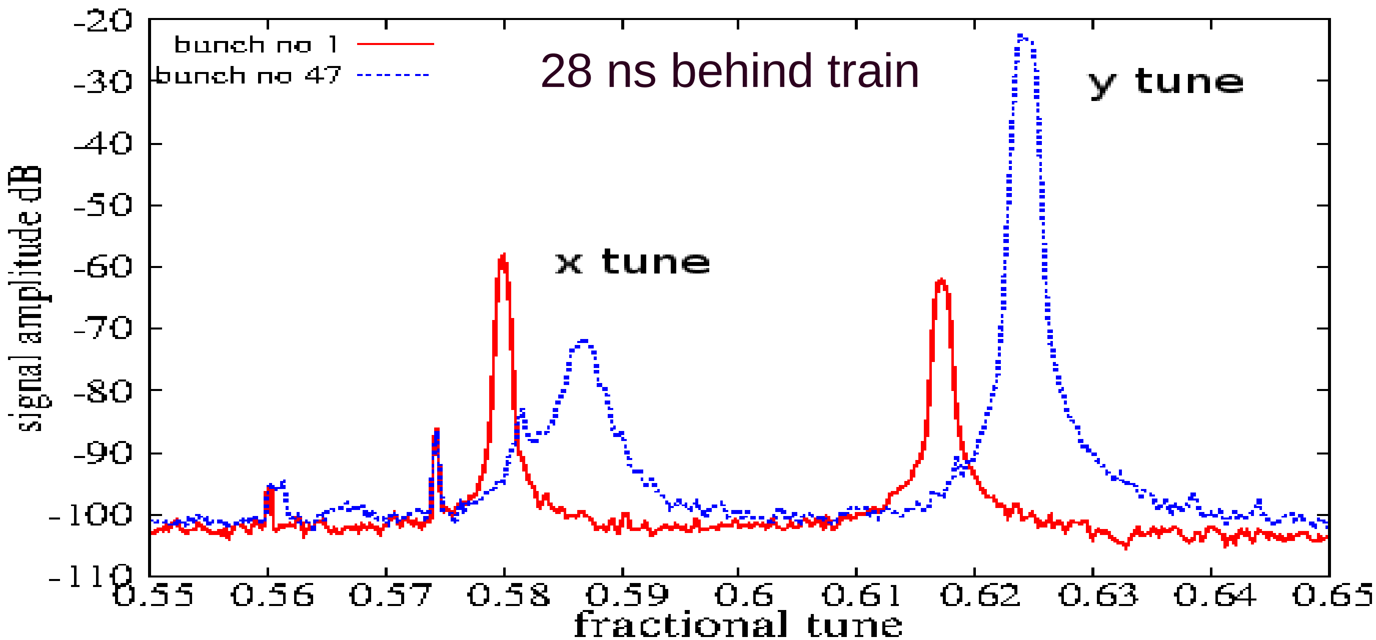
Circumference	768.4 m
Energy	2.085GeV
Bunch Length	1.22cm
Emittance	2.6nm(x) 20pm(y)
Chromaticity	~0
Tunes	14.571(x) 9.628(y)
Bunch Charge	1.28-1.92 nC
Bunch Spacing	14ns

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 BPM + spectrum analyzer



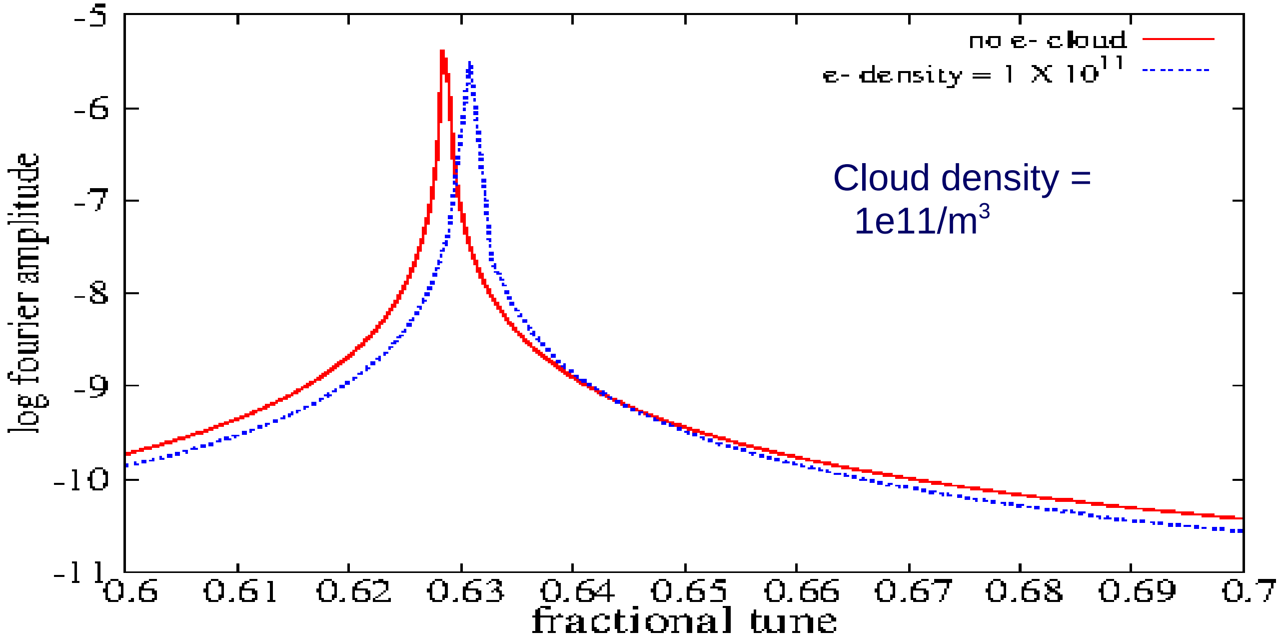


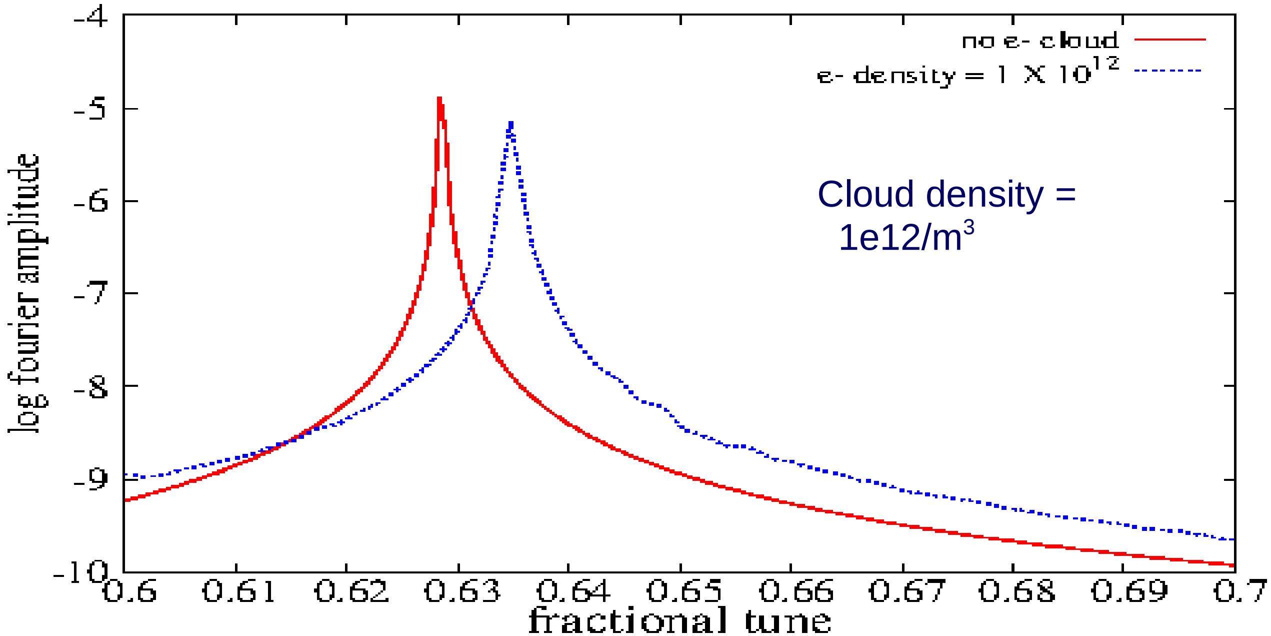
*Shift in tune Between 1st bunch In train and witness Bunch.

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

Witness bunch at same charge as bunch in train.

Vertical Tune Shift – between simulations with and without electron cloud





Displace bunch slightly in desired direction and study the resulting spectrum

Estimation of Electron Cloud density from tune shift.

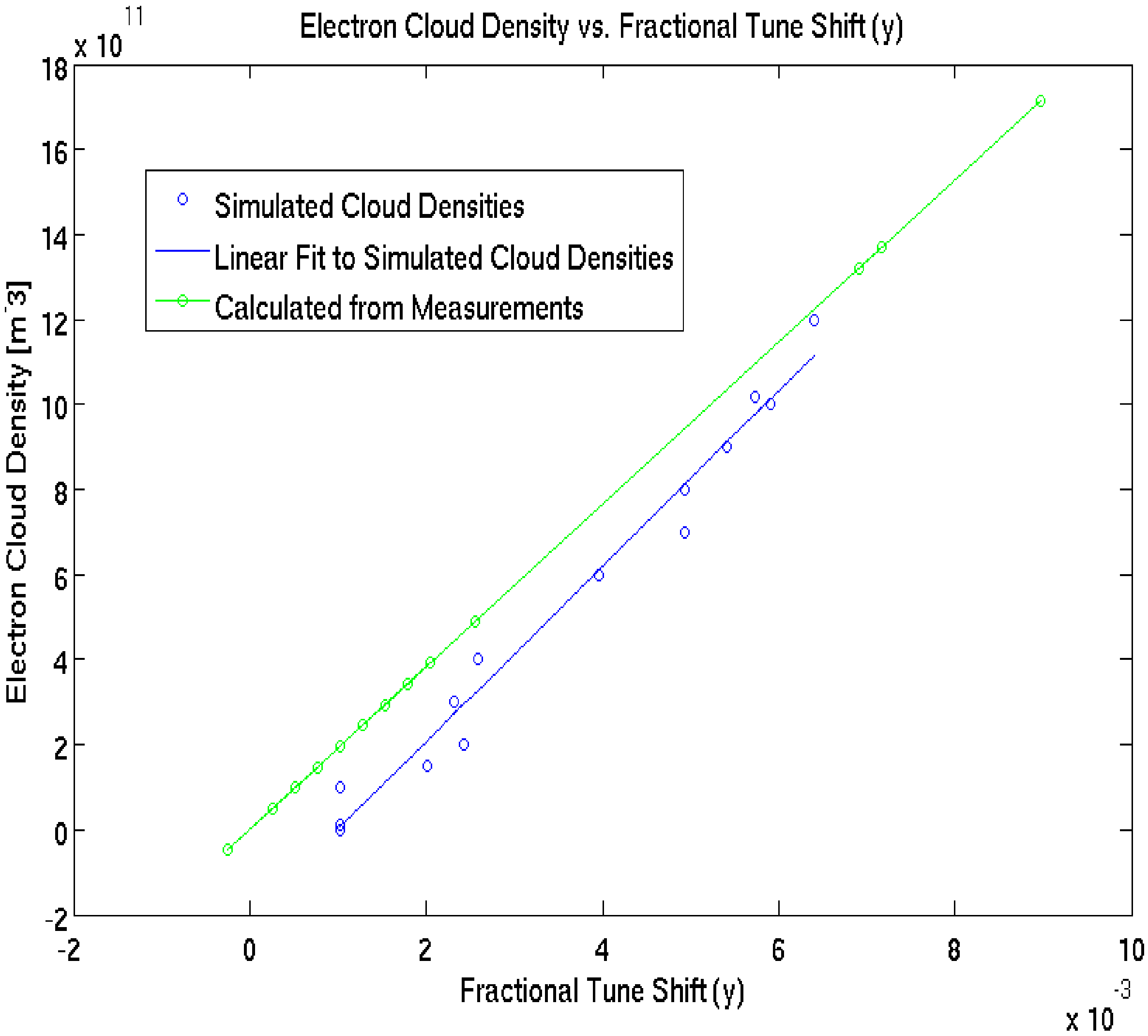
Cloud density can be estimated by

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

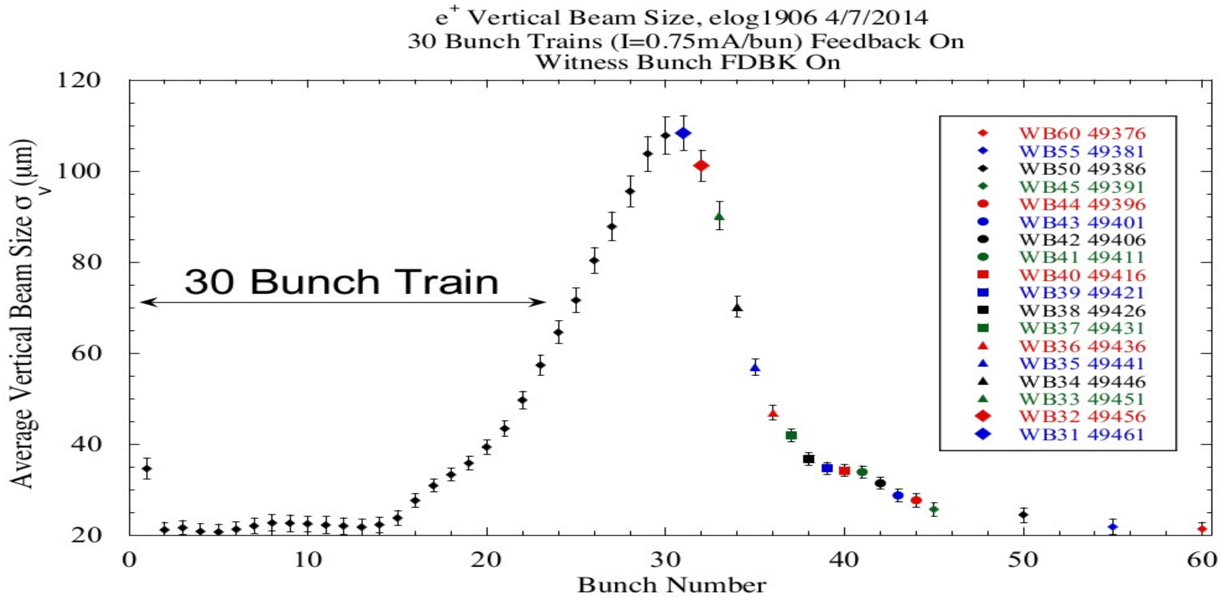
from: K Ohmi - PAC 2001

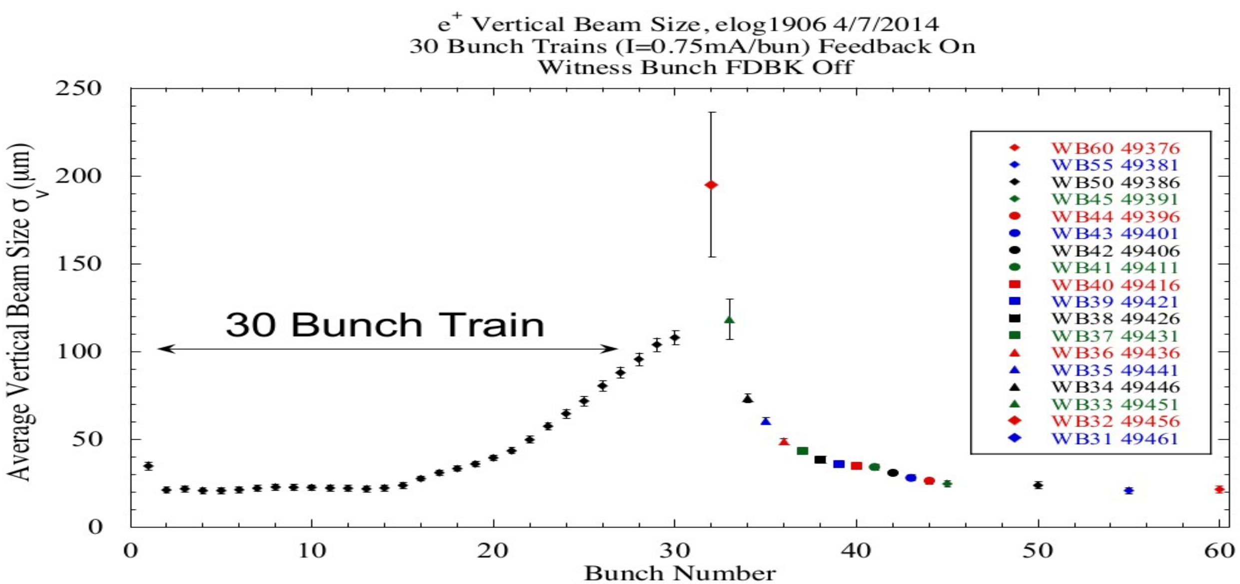
In experiments, only the tune shift is known.

In simulations, cloud density and tune shift are known



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





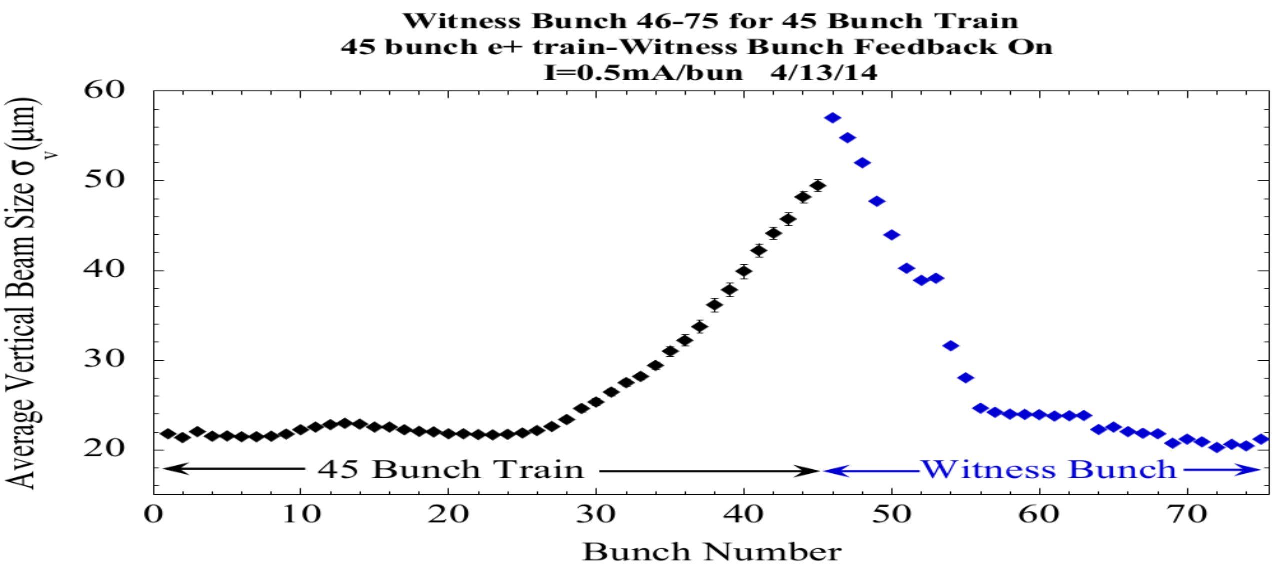
Note: The train is under feed back in both cases. Thus, multi-bunch effects are minimized

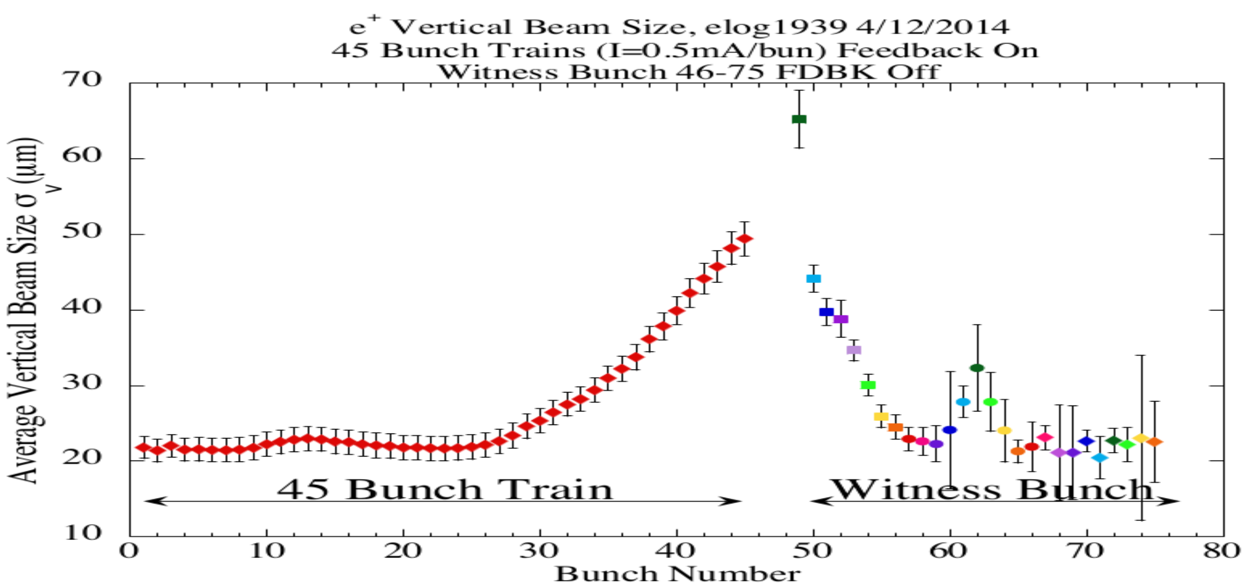
Witness bunches just behind the train have a much larger beam size in the absence of feedback.

Significant beam size expansion is seen even with feedback.

We dont have an explanation for the first bunch expansion!

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





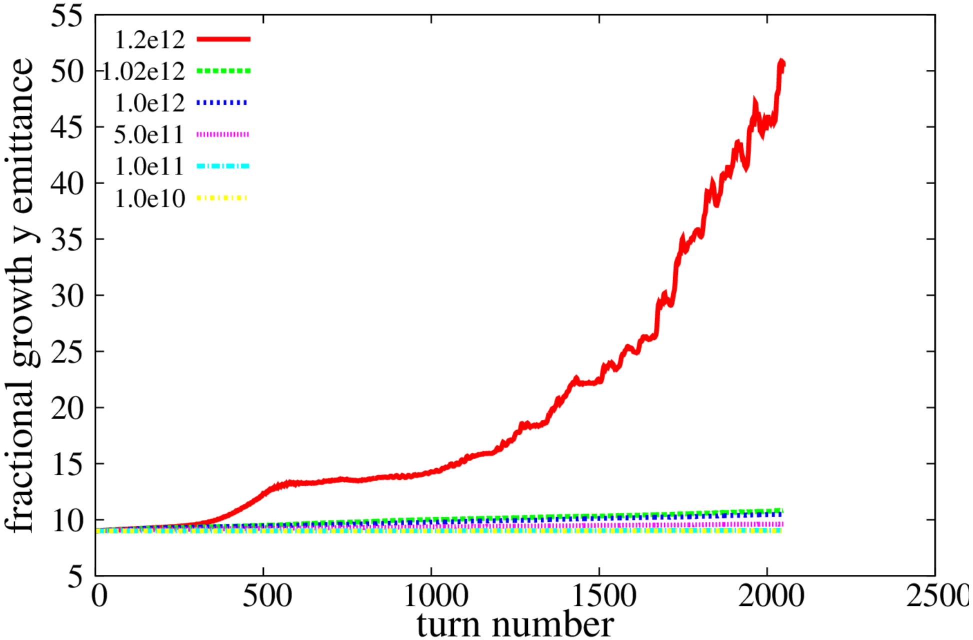
Longer train, less charge per bunch.

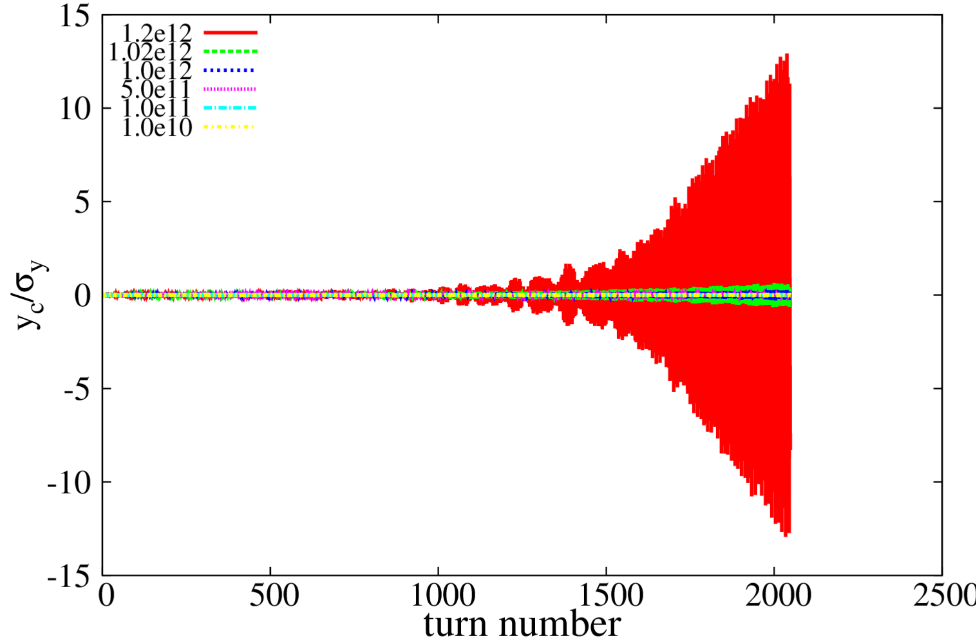
We do not see the lead bunch blow up in this configuration.

The results are otherwise similar to previous case.

The “hump” near witness bunch 65 was due to an unexpected horizontal instability, unrelated to electron clouds

Varying cloud density in simulations: Transition to large emittance growth rate and growth in bunch oscillations





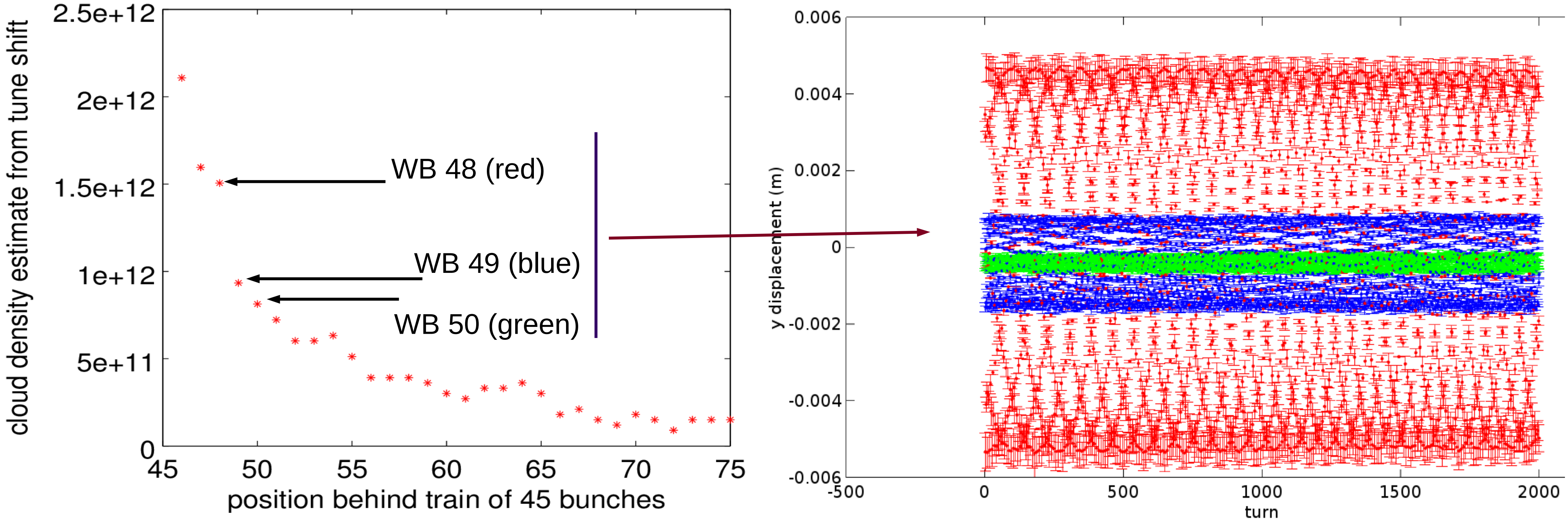
Large oscillations are observed beyond 1 X 10^12 m^3 cloud density

Transition to large amplitude oscillations at similar electron densities observed in simulations and experiments bunch charge = 1.28nC (0.5mA current)

Note that these are still in a transient state, while experimental observations are made for bunches that have reached a steady state.

Similar calculations of transition were made for the ILC damping ring parameters
J.A. Crittenden et al   Phys. Rev. ST Accel. Beams 17, 031002

Experimental observation of transition to large oscillation and estimation of witness bunch cloud density

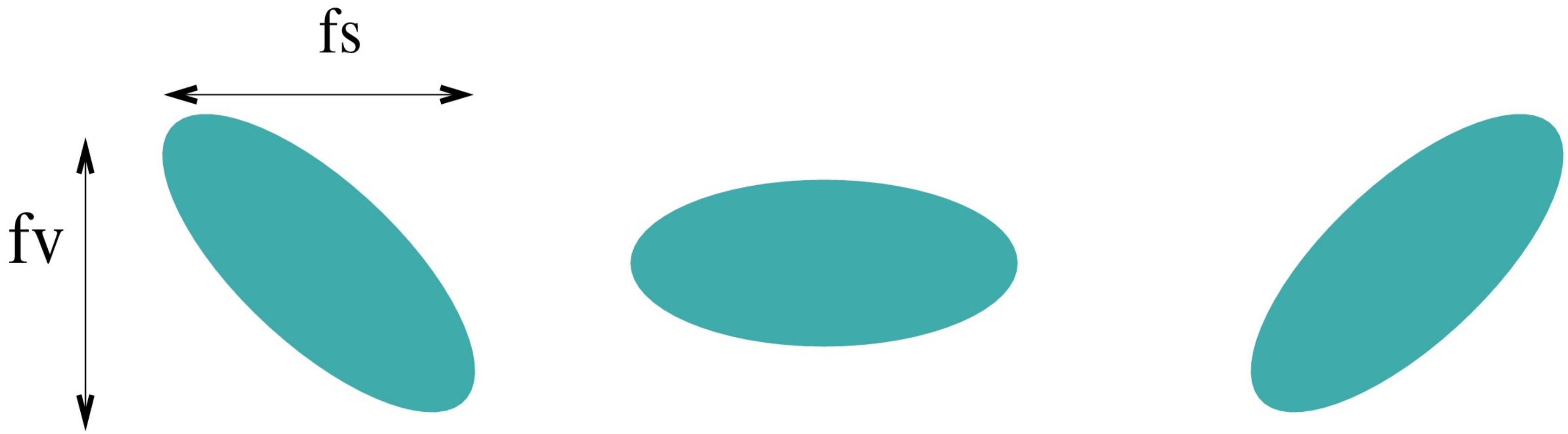


Estimate cloud density of witness bunched from measured tune shift

Look at corresponding bunch oscillation from BPM data.

Transition to large vertical oscillation occurs at ~1.2e12 /m^3 cloud density in measurements and simulations

Head tail motion of bunch: A consequence of electron clouds



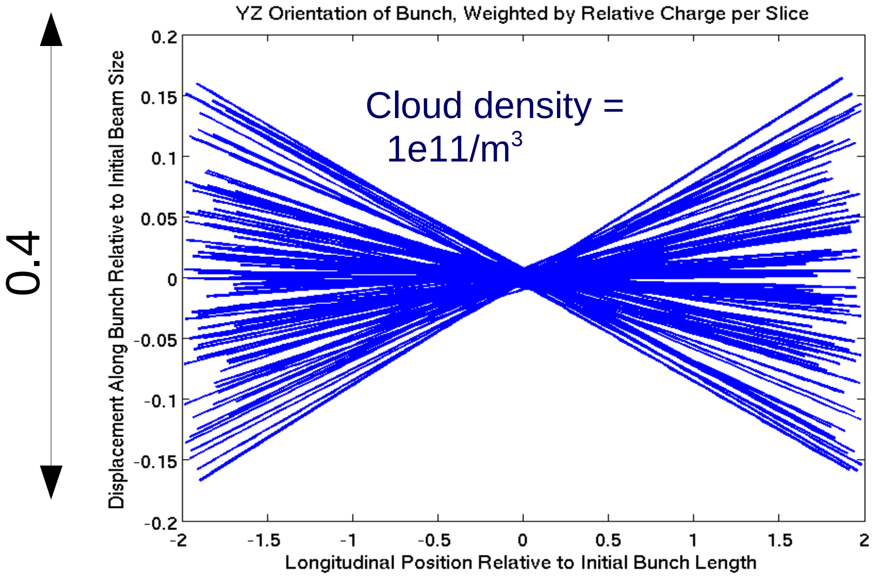
*Simulation results show evidence of this motion

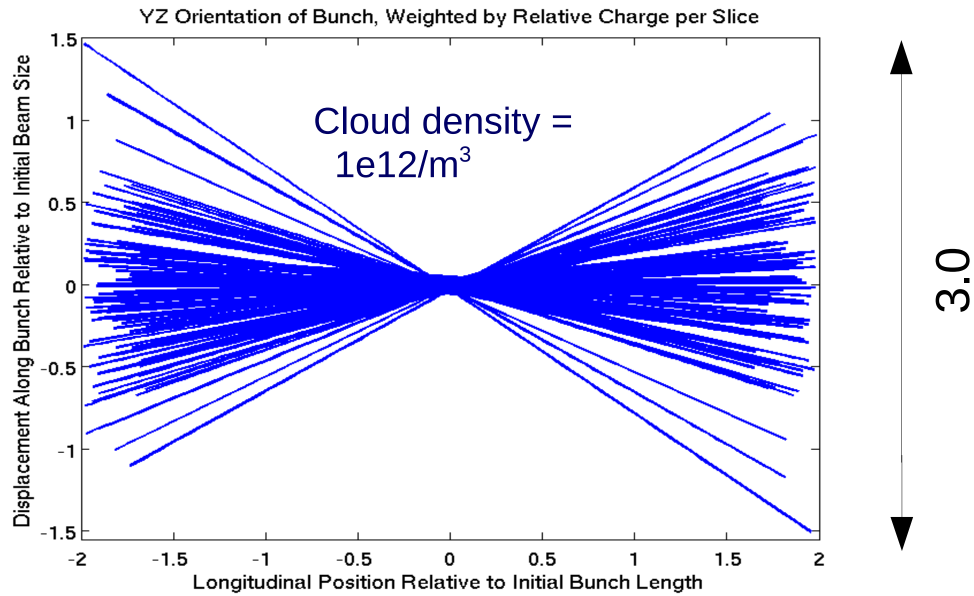
*Cloud pinching results in head-tail interaction.

*Need to look for methods to observe this directly

fv is the frequency of vertical oscillation (betatron frequency)
fs is the frequency of longitudinal oscillation (synchrotron frequency)

First order Head-Tail Motion from Simulations



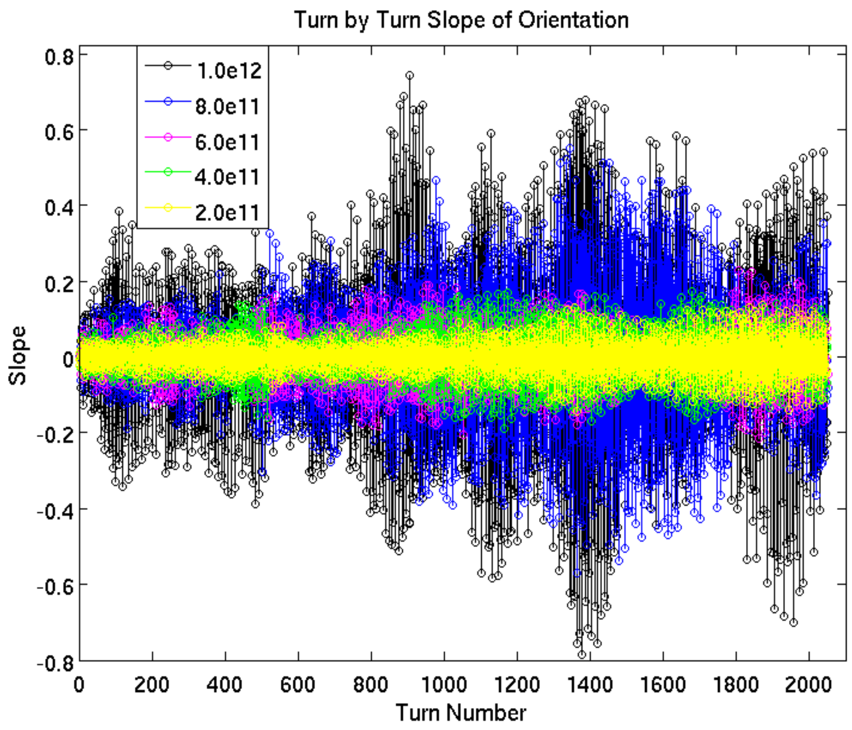


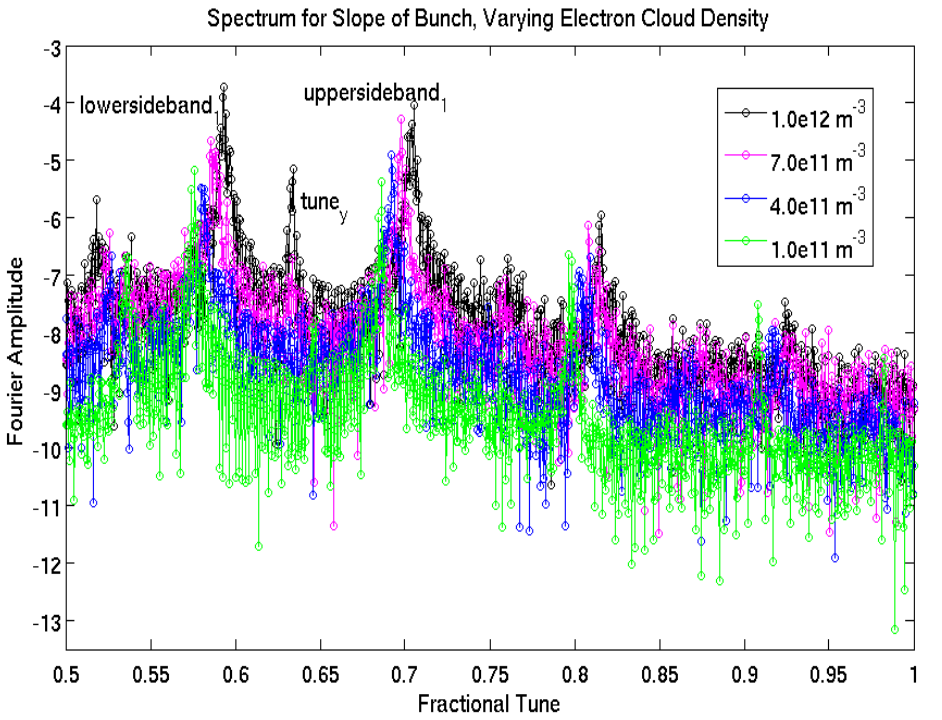
Perform a linear fit over the centroid of all the bunch slices for every turn. Motion of bunch centroid is removed in the fit.

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.

Spectrum of bunch orientation from simulations



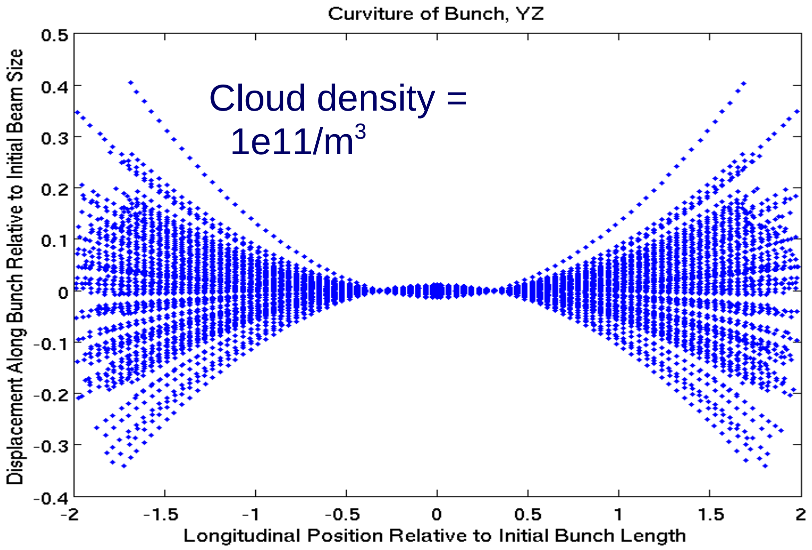


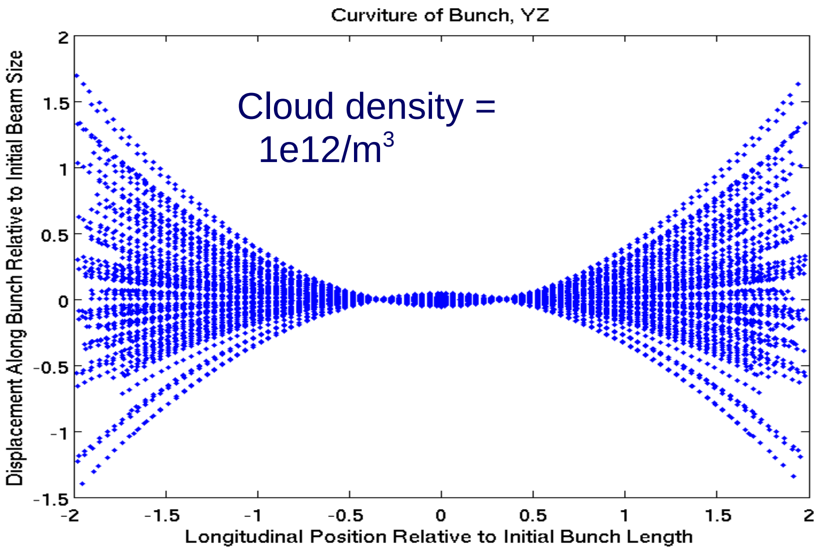
The magnitude of the slope is obtained from linear fit for every turn.

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.

Second order head-tail motion, or curvature of bunch: from simulations





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

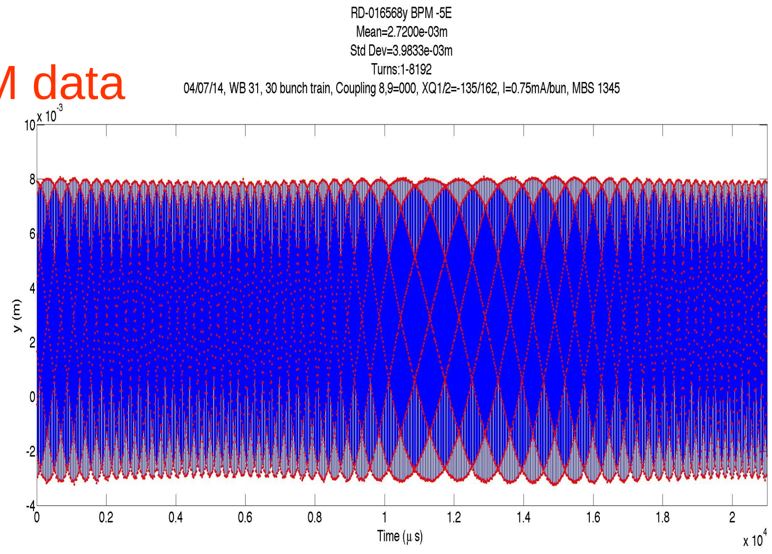
The amplitude of this mode increases by an order of magnitude when the cloud density is increased by a factor of 10

Conclusion

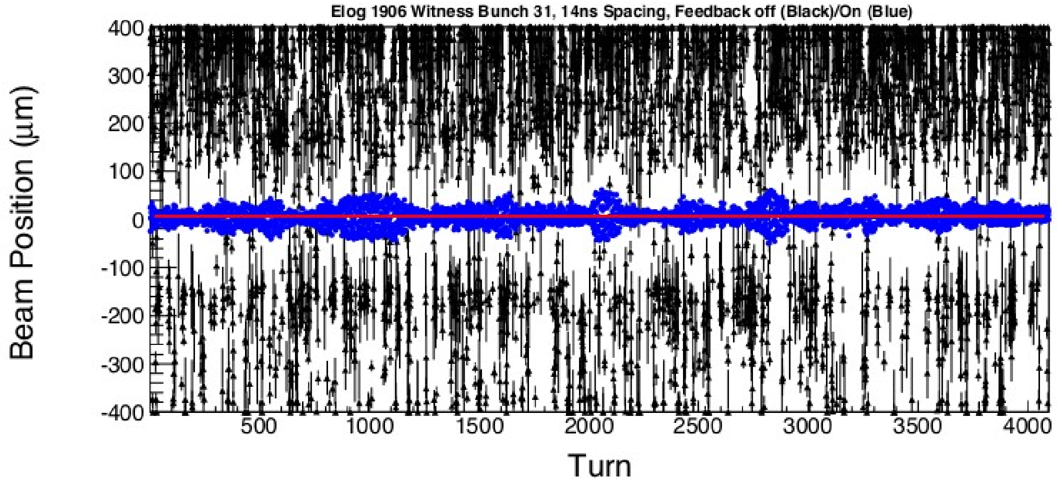
- We worked on a series of experiments designed for observing single bunch dynamics induced by electron clouds on positron beams.
- Simulations were performed using the program CMAD.
- We observed emittance growth with increased cloud density and a transition to large bunch oscillations.
- Simulations showed a similar transition to large bunch oscillation, accompanied “exponential” emittance growth rate.
- 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 in experiments even when bunch oscillation was suppressed with feedback.
- These results help validate simulation studies done for other systems such as the ILC positron damping ring.

Effect of feed back

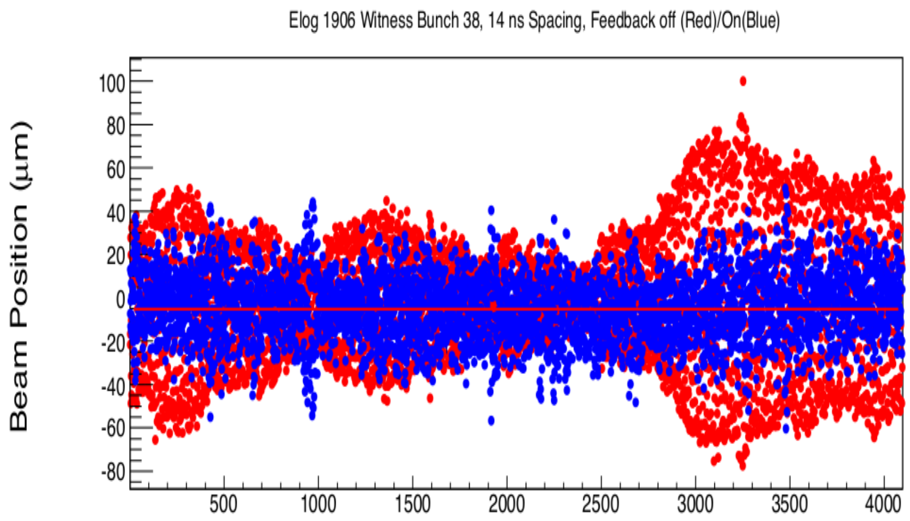
BPM data



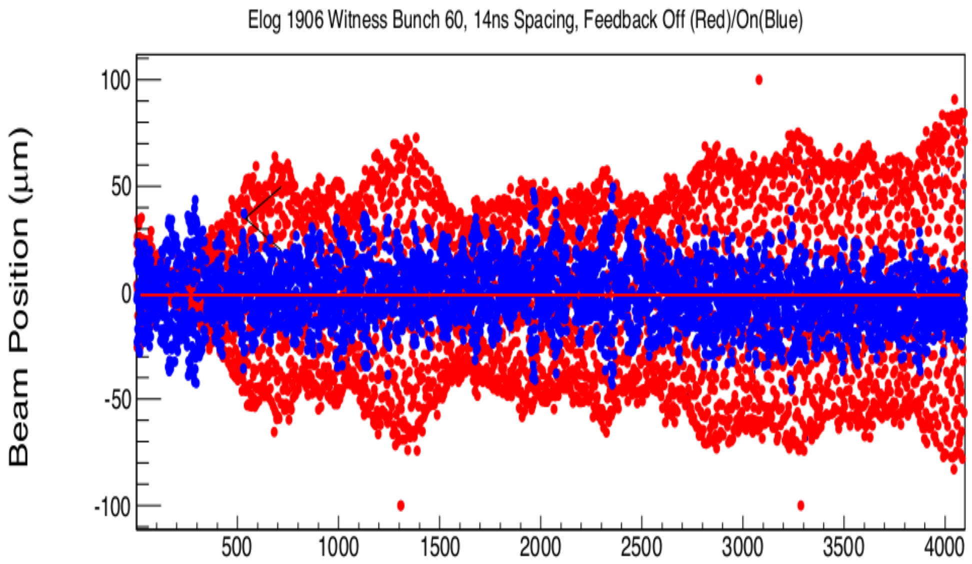
XBSM data



Bunch 31(14ns) behind 30 bunch train, with 0.75 mA (1.92nC) per bunch

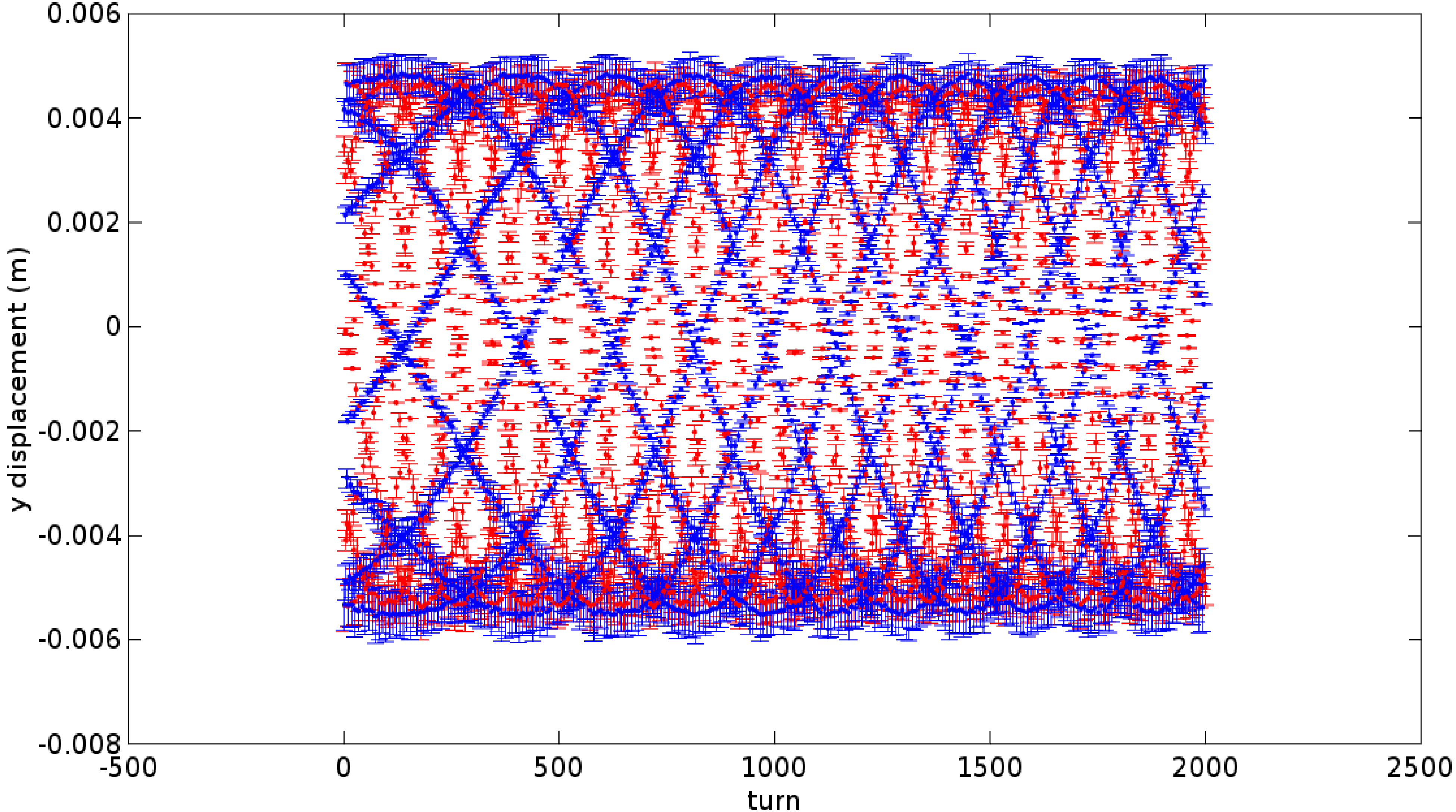


Xbsm data bunch 38 (112ns) behind train



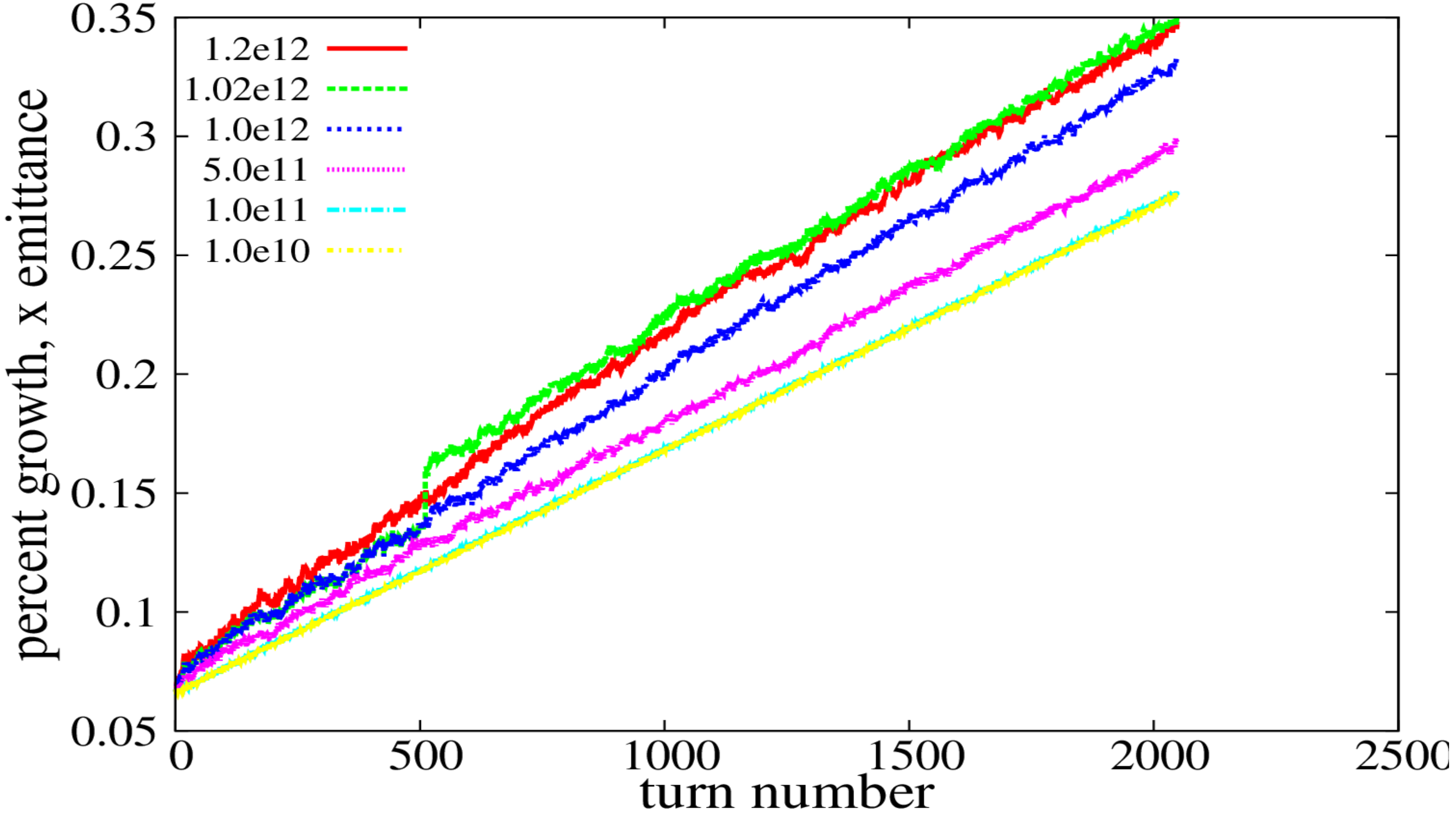
Xbsm data bunch 60 (840ns) behind train

WB 48 and 47



0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
y displacement (m)
-500
0
500
1000
1500
2000
2500
turn

Horizontal emittance



Variation of chromaticity