The CESRTA Electron Cloud R&D Program

May 15, 2012

Mark A. Palmer

for the CESRTA Collaboration

The CESRTA Program was approved in 2007 as a joint NSF-DOE effort to provide critical R&D needed as input to the ILC Damping Ring Design

- Last year's summary of the program reported on where we stood on the R&D program
- As of now, we have incorporated the results into the DR conceptual design and are in the process of studying the expected DR performance using tools that have been developed in conjunction with the program

Outline

- Summary of the CESRTA Phase I R&D Program
  - Program Overview
  - R&D Highlights
  - Reporting
- ILC DR Design & Simulation: *Application of the Phase I Results*
  - Vacuum System Conceptual Design
  - Simulation Efforts
- Looking Ahead
  - Where work remains
  - The CESRTA Phase II Program
- Conclusion

CESRTA R&D Goals

– Electron Cloud Build-Up Studies
- Study **EC growth** and **mitigation methods**
- **Benchmark and extend** simulation codes
  ⇨ **validate projections to the ILC DR**

– Low Emittance Operations
- Target ε_y**<20 pm-rad** for beam dynamics studies
- **Beam instrumentation** for ultra low emittance beams
- **LET tools**

– Electron Cloud-Induced Beam Dynamics at Ultra Low Emittance
- **Measure instability thresholds** and **emittance growth**
- **Benchmark EC dynamics simulations**
  ⇨ **validate projections to the ILC DR**

– Inputs for the ILC DR Technical Design

The CESRTA R&D Program – Phase I…

2008 | 2009 | 2010 | 2011 ⇨

March 1, 2008: Formal Start of Program

Start of Phase II Funding

CESR Reconfiguration

Convert CESR to DR Configuration

Add EC Experimental Regions

Instrumentation Upgrades

- BPM
- xBSM
- Vacuum Diagnostics

Experimental Program

EC Growth/Mitigation Studies

LET

- Instrumentation
- Techniques
- Machine Correction

EC Dynamics

- Methods
- Systematic Studies

Updated Simulation Tools

Phase II R&D

Document/ Implement

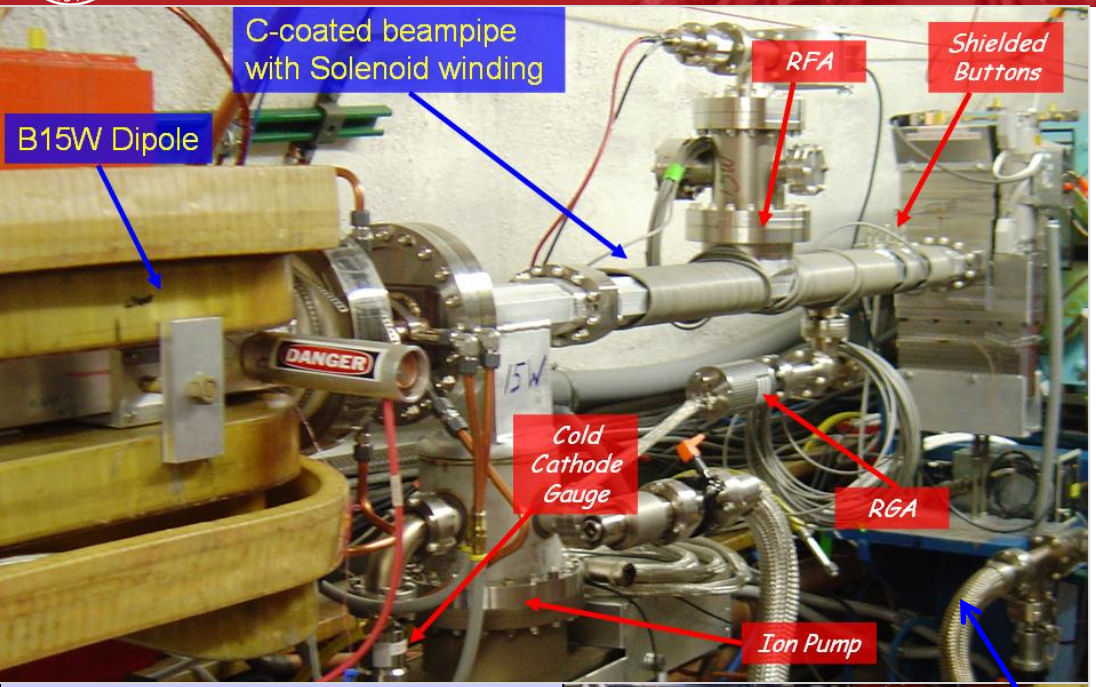
Phase I Report

Inputs to the Technical Design

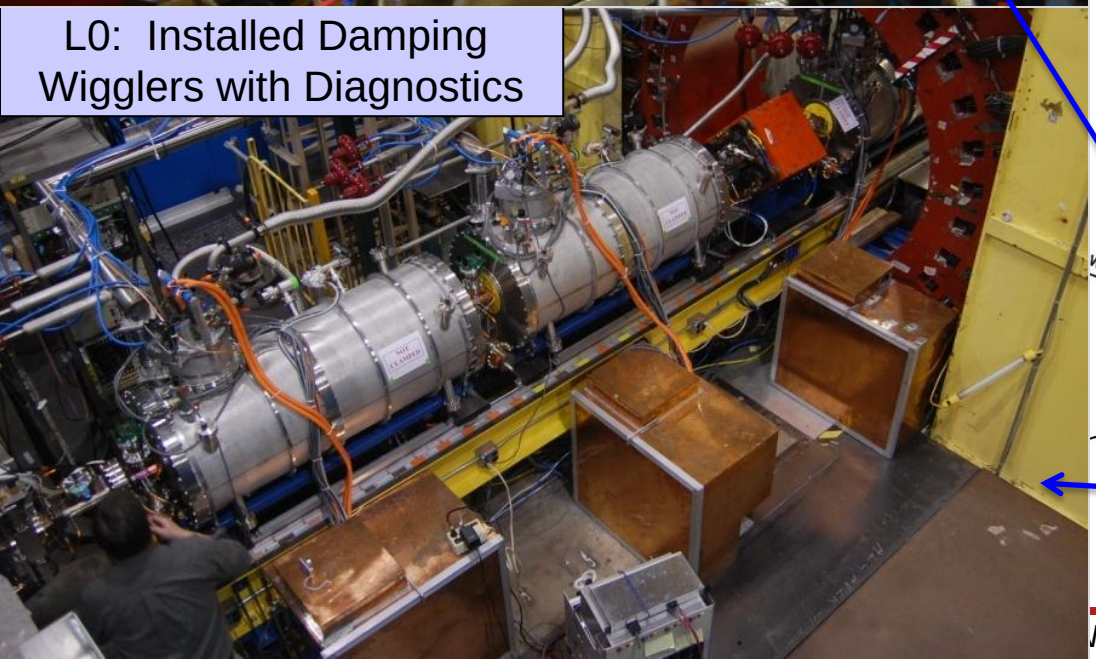
Identify Critical Issues for Further Study

Publish Results

2008 Conversion: CESR ⇨ Damping Ring



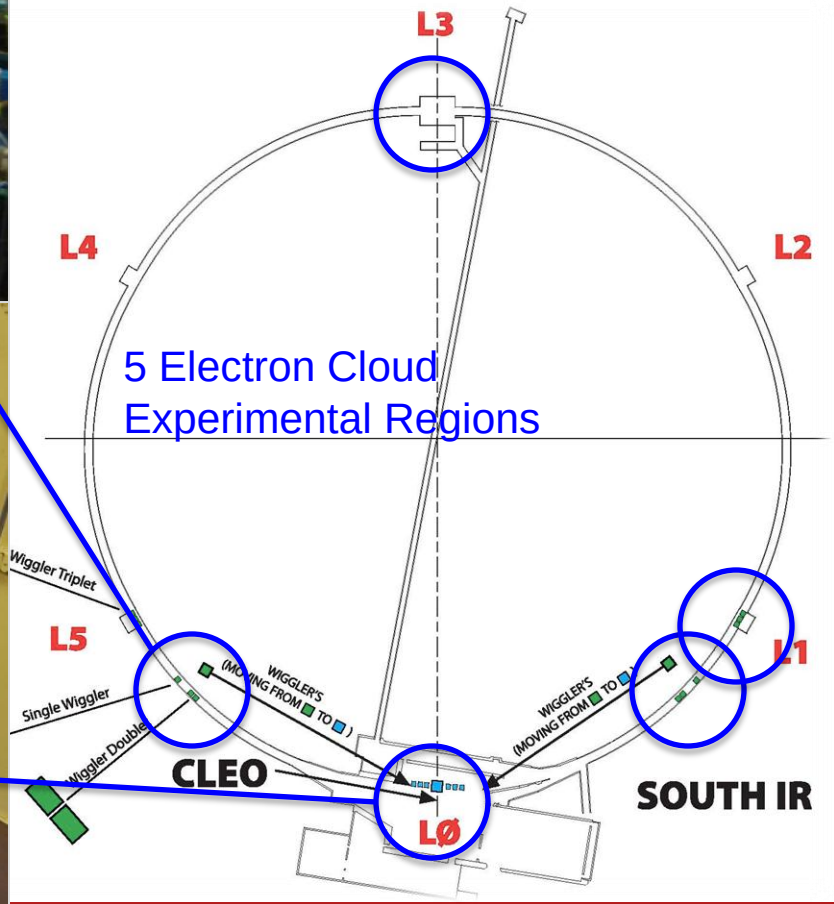
L0: Installed Damping Wigglers with Diagnostics



Damping Wiggler Straight

Zero Dispersion for ultra low emittance operation

Instrumented for electron cloud studies (RFAs, TE Wave)



CESR Reconfiguration: CesrTA Parameters

Lattice Parameters

Ultra low emittance baseline lattice

Energy [GeV]	2.085	5.0	5.0
No. Wigglers	12	0	6
Wiggler Field [T]	1.9	—	1.9
Q_x	14.57		
Q_y	9.62		
Q_z	0.075	0.043	0.043
V_{RF} [MV]	8.1	8	8
ε_x [nm-rad]	2.5	60	40
$\tau_{x,y}$ [ms]	57	30	20
α_p	6.76×10^{-3}	6.23×10^{-3}	6.23×10^{-3}
σ_l [mm]	9	9.4	15.6
σ_E/E [%]	0.81	0.58	0.93
t_b [ns]	≥4, steps of 2		

Range of optics implemented

Beam dynamics studies

Control γ flux in EC experimental regions

E[GeV]	Wigglers (1.9T/PM)	ε_x[nm]
1.8	12/0	2.3
2.085	12/0	2.5
2.3	12/0	3.3
3.0	6/0	10
4.0	6 /0	23
4.0	0 /0	42
5.0	6/0	40
5.0	0/0	60
5.0	0/2	90

IBS Studies

5.3 GeV CHESS-type optics also utilized for EC build-Up measurements

The CESRTA Collaboration

- The program has involved senior researchers, post-docs and graduate students from a dozen laboratories and universities from around the globe
  - Over 50 senior researchers
  - Over 35 students

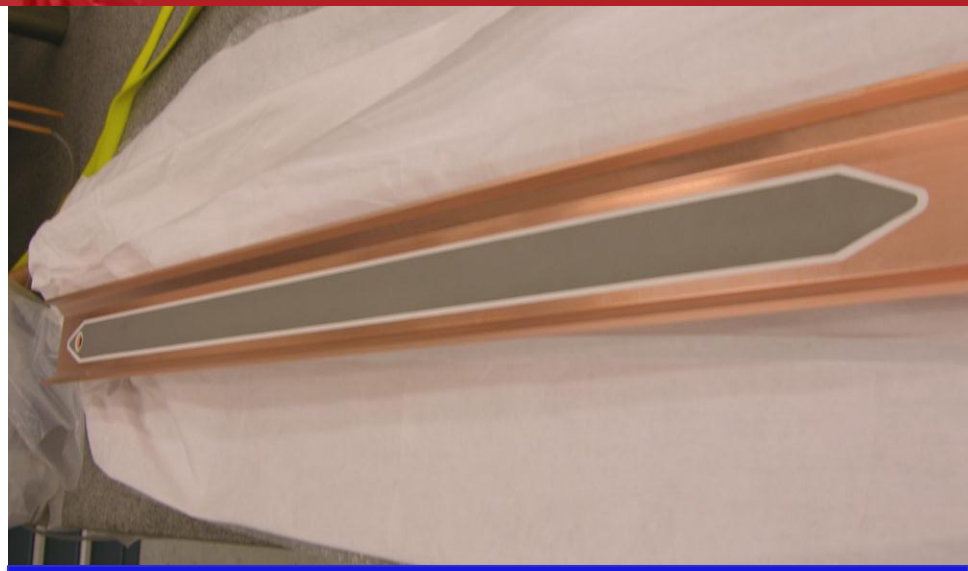
R&D Highlights

DETAILS AVAILABLE IN THE CESRTA PHASE I REPORT

HTTPS://WIKI.LEPP.CORNELL.EDU/ILC/PUB/PUBLIC/CESRTA/CESRTAPHASEIREPORT/CESRTA_PHASEI_REPORT.PDF

Overview

- CESR Configuration
  - Damping ring layout
  - 4 dedicated EC experimental regions
  - Upgraded vacuum/EC instrumentation
  - Energy flexibility from 1.8 to 5.3 GeV
- Beam Instrumentation
  - xBSM for positrons and electrons
  - High resolution digital BPM system
  - Horizontal beamsize interferometer
  - Streak camera for longitudinal beamsize
  - Feedback system for 4ns bunch spacing



Wiggler Clearing Electrode

- EC Diagnostics and Mitigation
  - ≥30 RFAs presently deployed at any given time
  - TE wave measurement capability in each experimental region
  - Time-resolved measurement capability ⇨ now in drift and dipole chambers
  - Over 20 individual mitigation studies conducted in Phase I
- Low Emittance Tuning and Beam Dynamics Studies
  - Regularly achieving <10pm vertical emittance
  - Continuing to explore the emittance reach of new instrumentation and techniques for Intrabeam Scattering Experiments
  - Systematic studies of beam instability thresholds and emittance dilution (continuing)

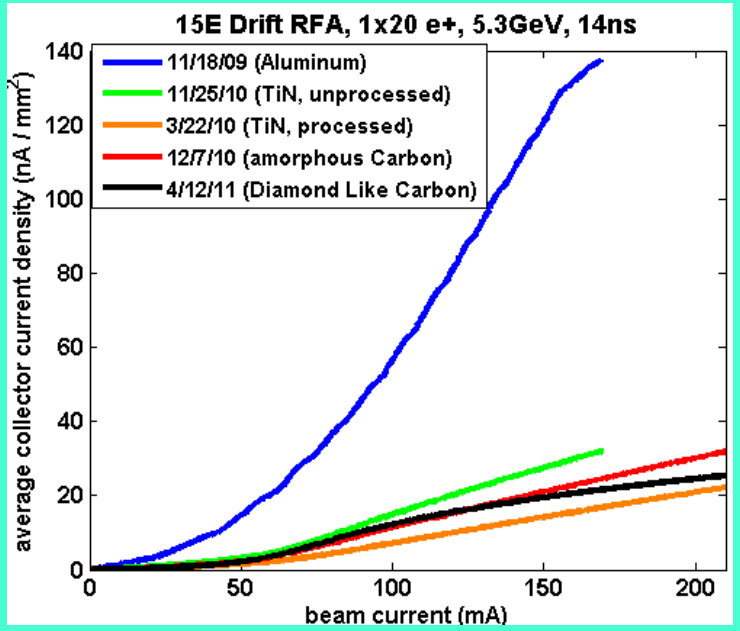
EC Mitigations

	Drift	Quad	Dipole	Wiggler	VC Fab
Al	✓	✓	✓		CU, SLAC
Cu	✓			✓	CU, KEK, LBNL, SLAC
TiN on Al	✓	✓	✓		CU, SLAC
TiN on Cu	✓			✓, ✗	CU, KEK, LBNL, SLAC
Amorphous C on Al	✓				CERN, CU
NEG on SS	✓				CU
Diamond-like C on Al	✓				CU, KEK
Solenoid Windings	✓				CU
Fins w/TiN on Al	✓				SLAC
Triangular Grooves on Cu				✓	CU, KEK, LBNL, SLAC
Triangular Grooves w/TiN on Al			✓		CU, SLAC
Triangular Grooves w/TiN on Cu				✓	CU, KEK, LBNL, SLAC
Clearing Electrode				✓	CU, KEK, LBNL, SLAC

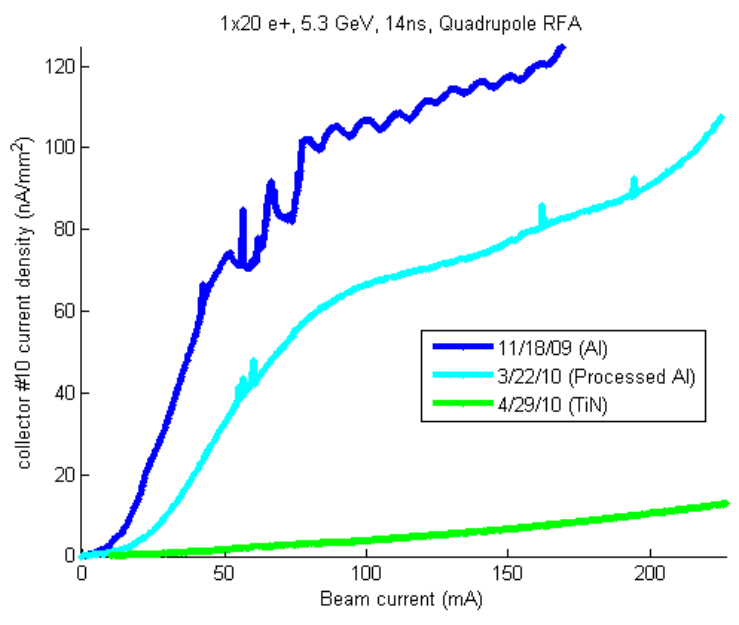
✓ = chamber(s) deployed ✗ = deployed in CESR Arc, Jan 2011 Time-resolved studies

Comparitive Mitigation Studies

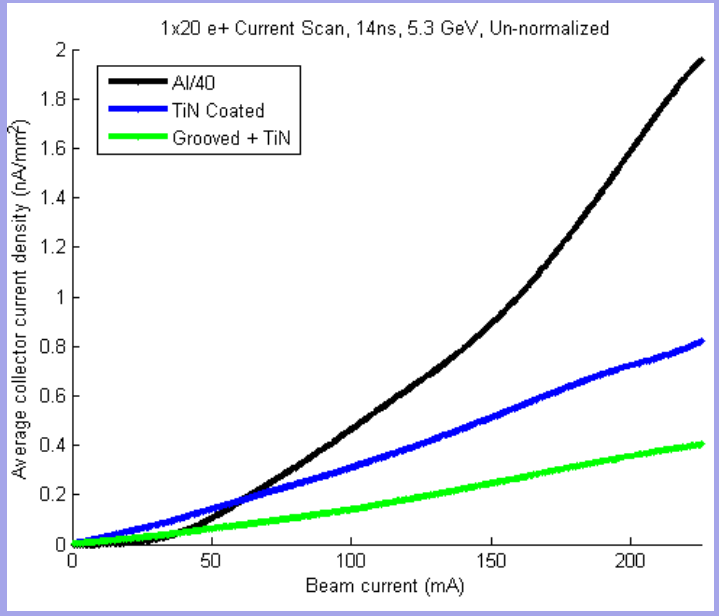
Drift Comparisons



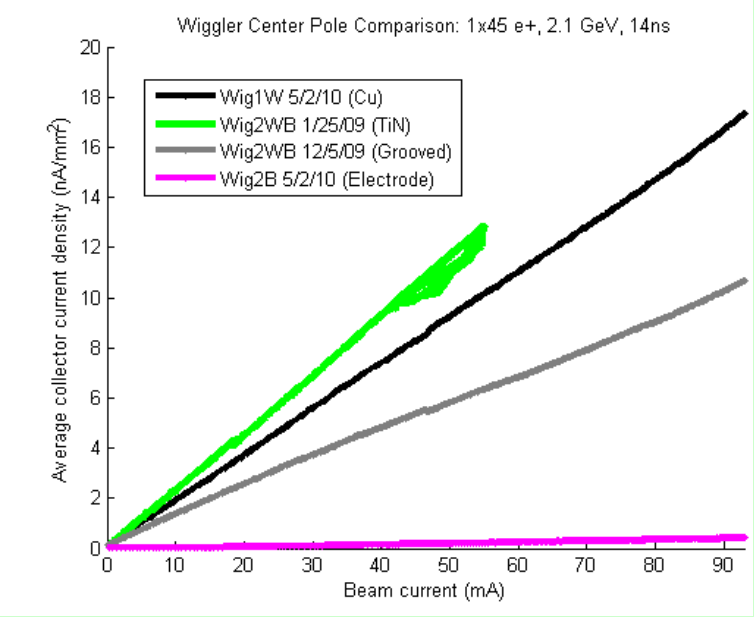
Quadrupole Comparisons



Dipole Comparisons



Wiggler Comparisons



EC Working Group Baseline Mitigation Plan

Mitigation Evaluation conducted at satellite meeting of ECLOUD`10 (October 13, 2010, Cornell University)

EC Working Group Baseline Mitigation Recommendation				
	Drift*	Dipole	Wiggler	Quadrupole*
Baseline Mitigation I	TiN Coating	Grooves with TiN coating	Clearing Electrodes	TiN Coating
Baseline Mitigation II	Solenoid Windings	Antechamber	Antechamber	
Alternate Mitigation	NEG Coating	TiN Coating	Grooves with TiN Coating	Clearing Electrodes or Grooves

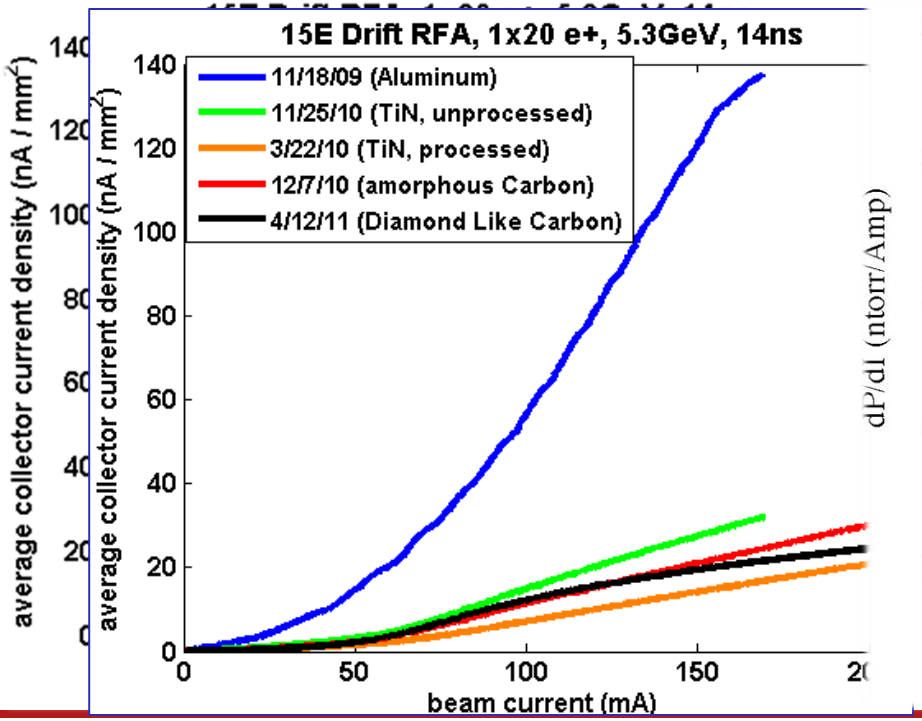
*Drift and Quadrupole chambers in arc and wiggler regions will incorporate antechambers

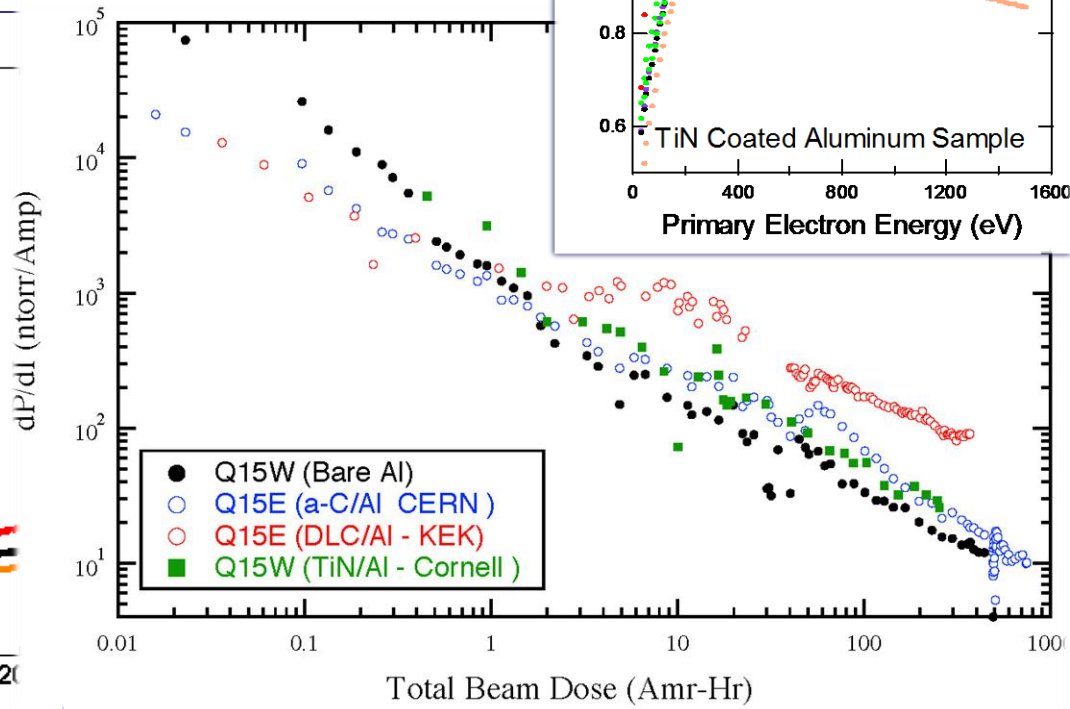
- Preliminary CESRTA results and simulations suggest the presence of *sub-threshold emittance growth*
  - Further investigation required
  - May require reduction in acceptable cloud density ⇨ reduction in safety margin
- An aggressive mitigation plan is required to obtain optimum performance from the 3.2km positron damping ring and to pursue the high current option

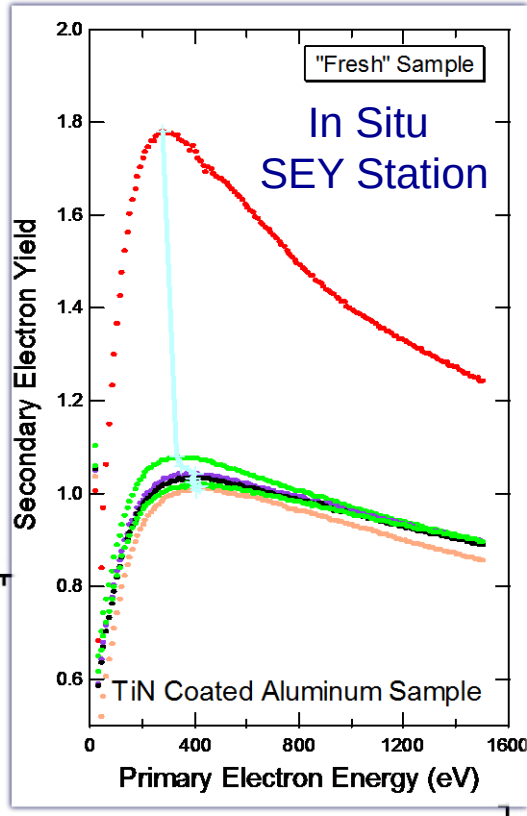
S. Guiducci, M. Palmer, M. Pivi, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group

Some Drift Region Observations

- Q15 E/W Arc Studies ⇨ Coating Tests
  - Bare Al vs TiN, aC, and DLC (all on Al)
  - Vacuum performance poorer for coatings
  - EC performance of TiN and the carbon coatings in a *similar* range ⇨ consistent with *in situ SEY* studies
- Time-resolved studies ⇨ **PE model & δ(0)**







Benchmark & Extend Simulations

- Goal:

  Evaluate surfaces under a wide range of conditions to evaluate in situ surface parameters using the RFA data

  – Vary:
  Bunch charge & spacing, species, beam energy, RFA retarding voltage

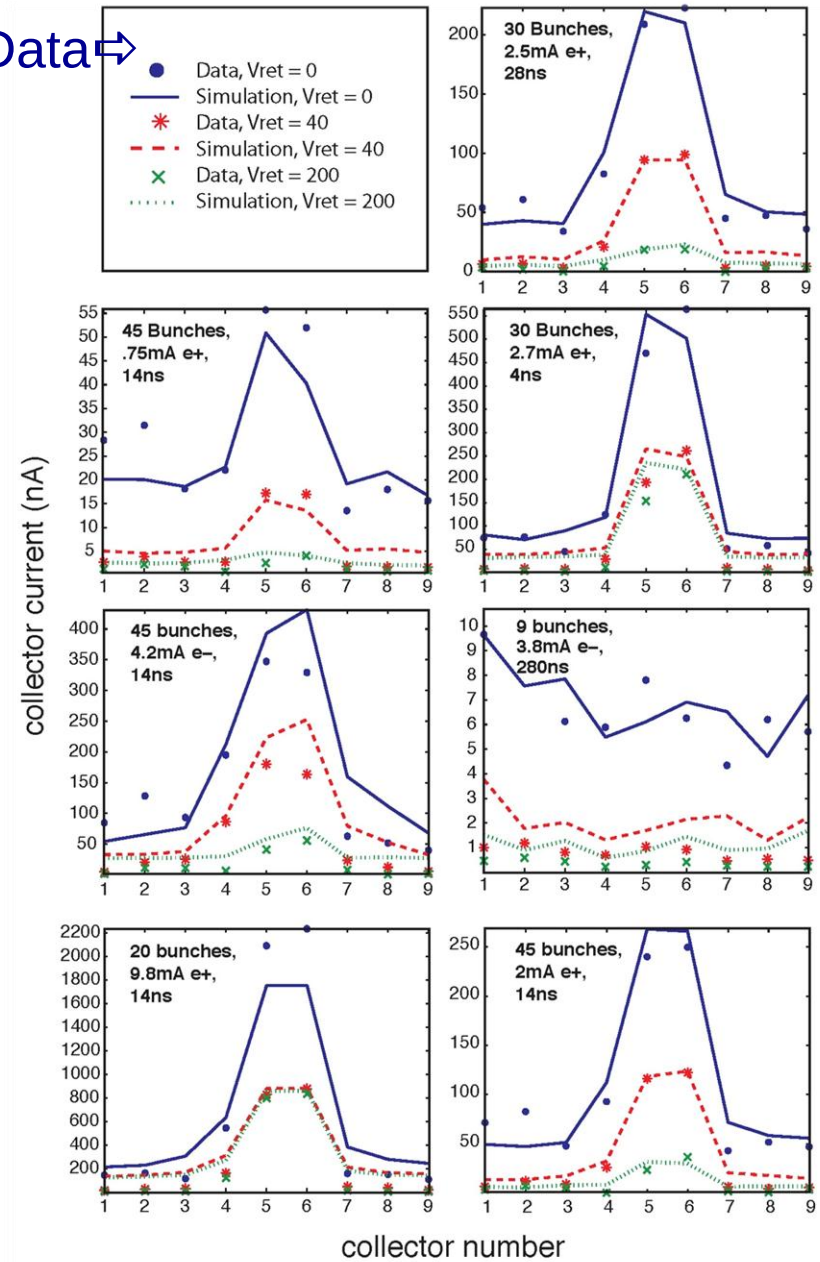
  – Fit for:
  Peak value of the true SEY
  Energy of the SEY peak
  Elastic scattering fraction, $\delta(0)$
  Rediffused scattering fraction
  Quantum effeiciency

- Additional constraints from:

  – Time-resolved detector data

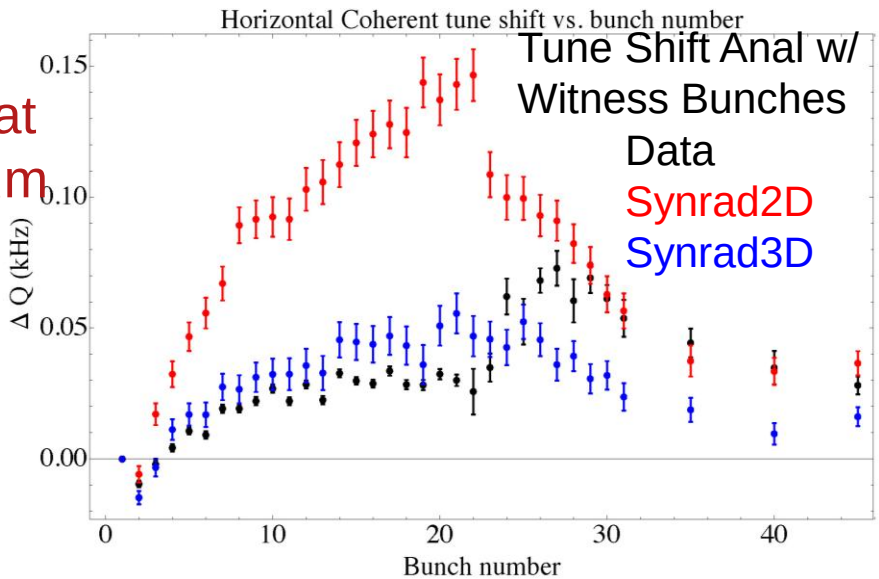
  – 3D photon transport model (Synrad3D)

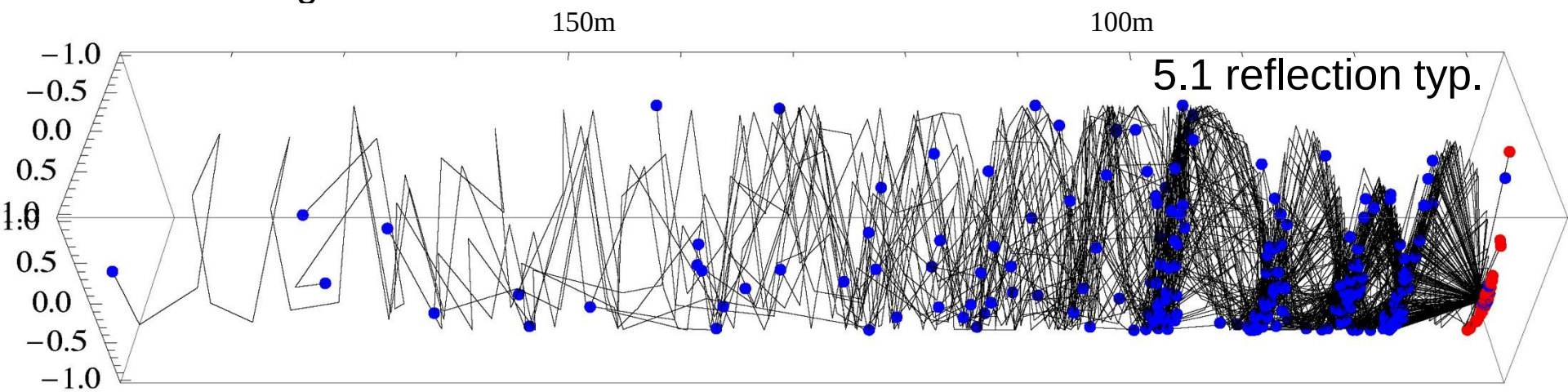
5.3GeV Data⇨



Photons and PEY

- Better photon reflection and transport model needed for simulations and data analysis
- Time-resolved measurements indicate that we also need to have a better PE spectrum (fitting of RFA data also requires this)
- Synrad3D (Sagan, et al.) answers this need, but work remains
  - Fully validate real VC geometries
  - Diffuse scattering issues (see next slide)
  - Surface roughness issues

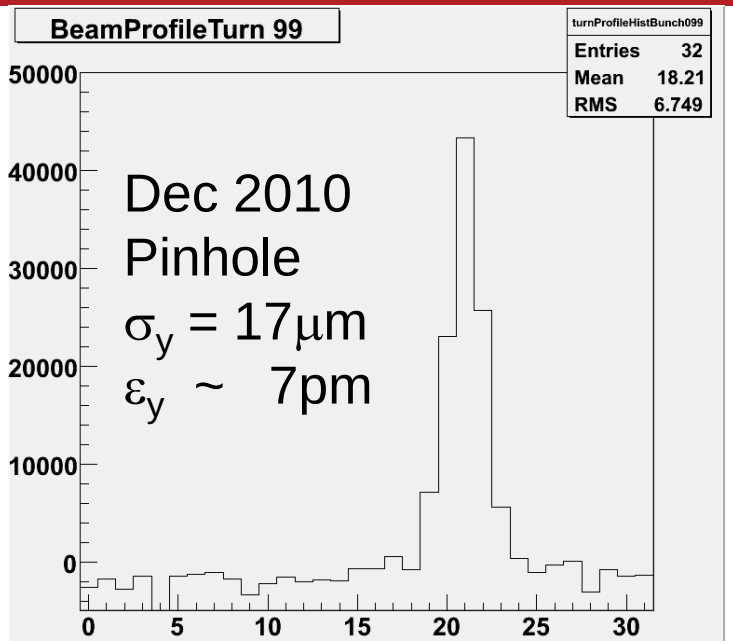


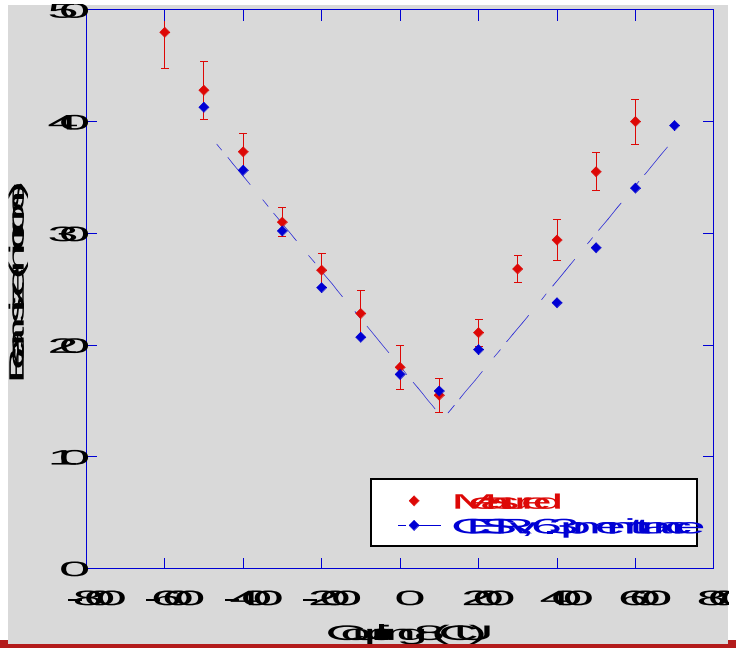


Requirements for PE control in the ILC and CLIC DRs ⇨ High Priority

Low Emittance Tuning

- Low ε Correction Procedures
  1. Measure & correct orbit.
  2. Measure (via resonant excitation method) & correct betatron phase and coupling.
  3. Re-measure orbit, phase and coupling. Measure dispersion by resonant excitation of synchrotron tune. Simultaneously fit & correct.
  4. Measure emittance with xray beam size monitor
- Full correction "loop" in minutes
- Further improvements feasible

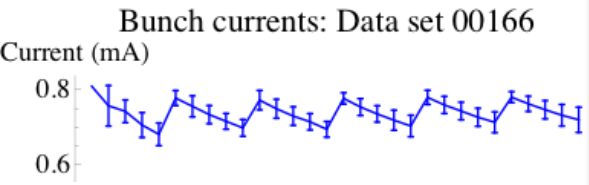


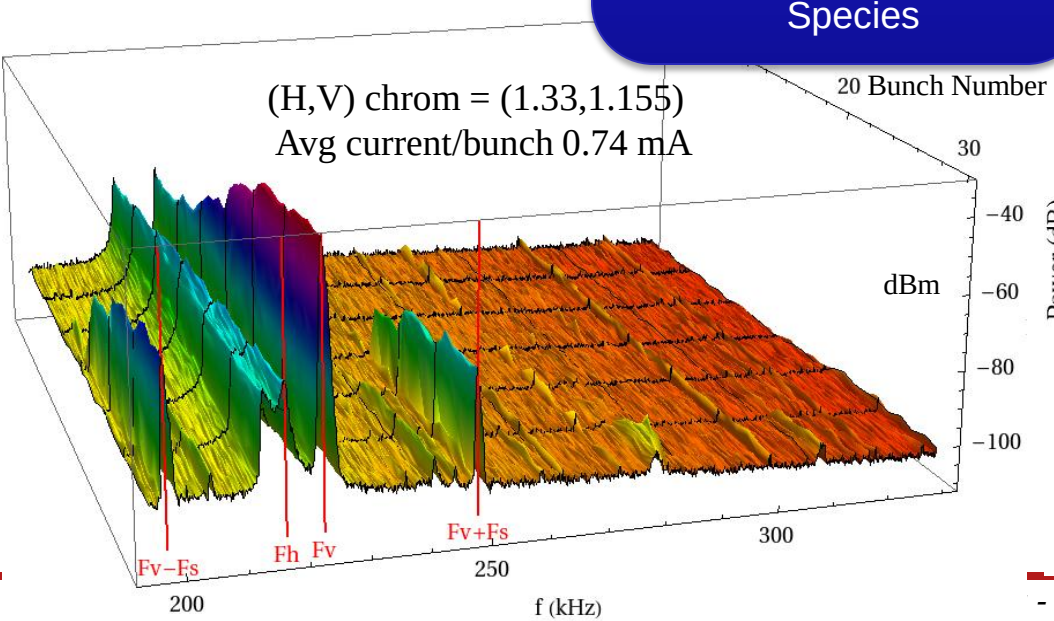


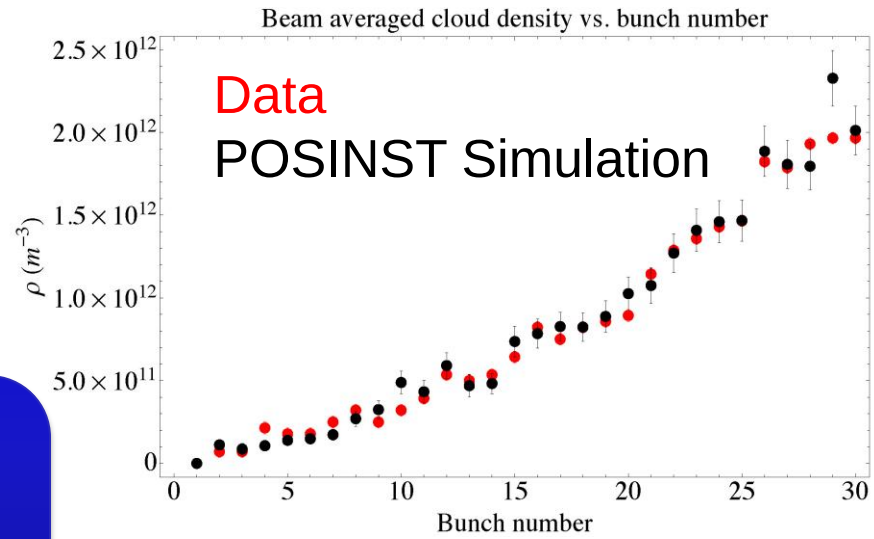
Systematic Studies of Instability Thresholds

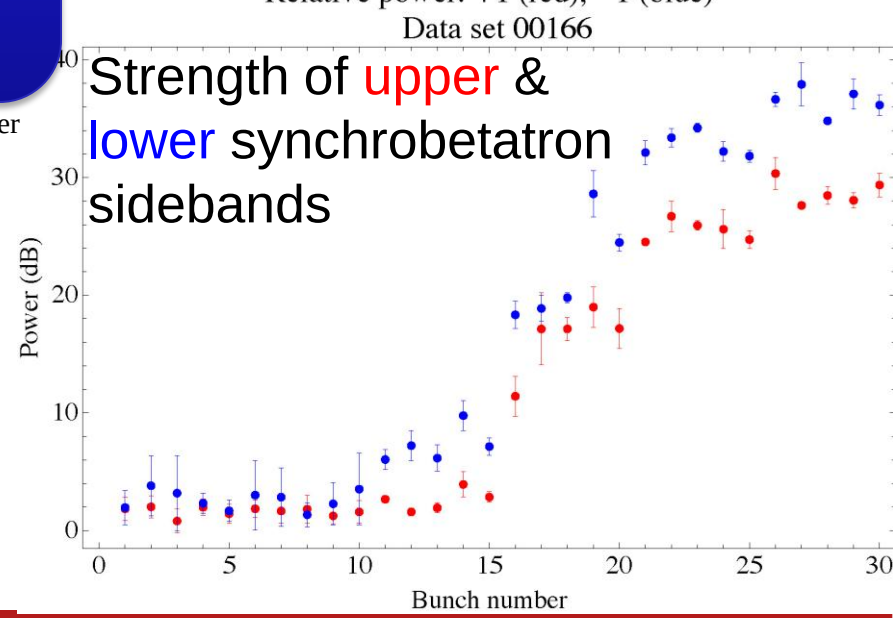
- Spectral methods ⇨ self-consistent analysis of the onset of instabilities
  - Tune shifts along train ⇨ ring-wide integrated cloud density near beam
  - Onset of synchrobetatron sidebands ⇨ instability thresholds

Explore: Bunch spacing
Intensity
Chromaticity
Feedback
Emittance
Beam Energy
Species



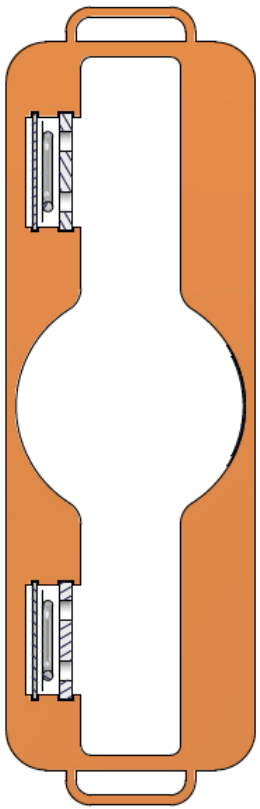




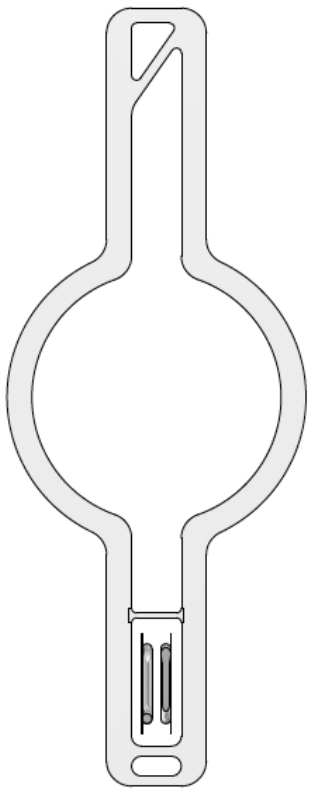


ILC DR:
Design & Simulation

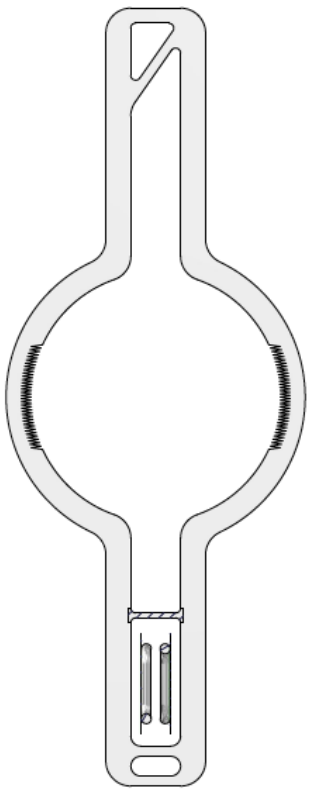
DR Vacuum System Conceptual Design



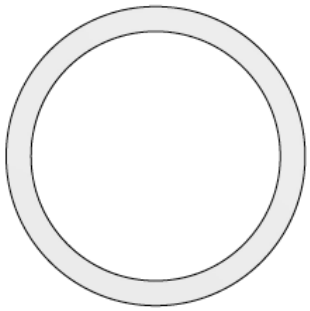
WIGGLER CHAMBER



ARC CHAMBER



DIPOLE CHAMBER



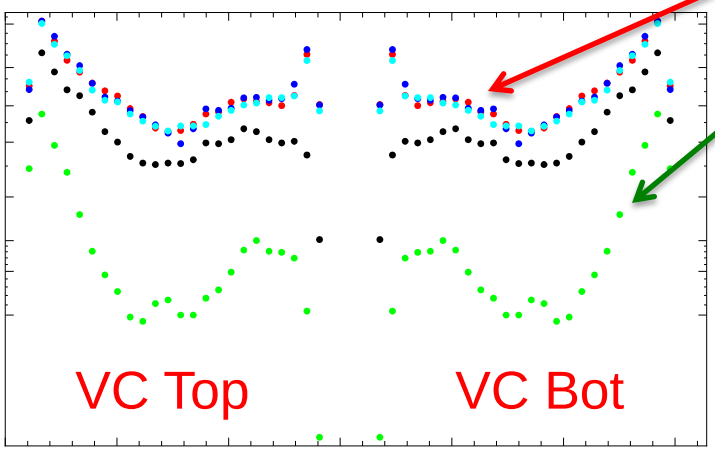
DRIFT CHAMBER

Antechamber designs optimized using SYNRAD3D Analysis

TiN-Coated

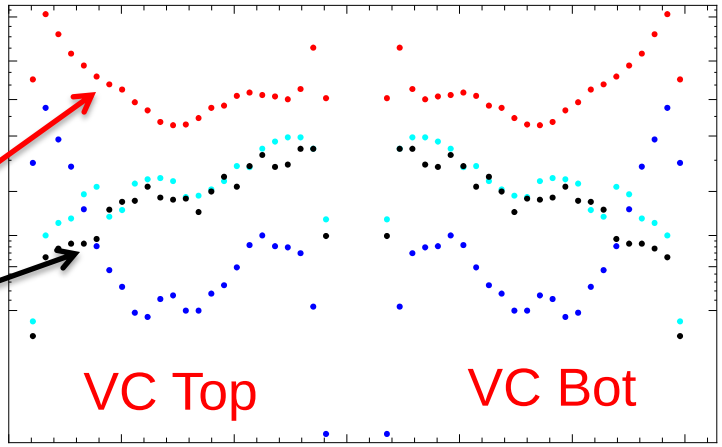
Interaction Between VC Design and EC Simulation

Impact of "ideal" antechamber performance on scattered photons



0.044 γ/m

0.011 γ/m



0.044 γ/m

0.015 γ/m

Simulated performance of physically realizable antechamber geometry

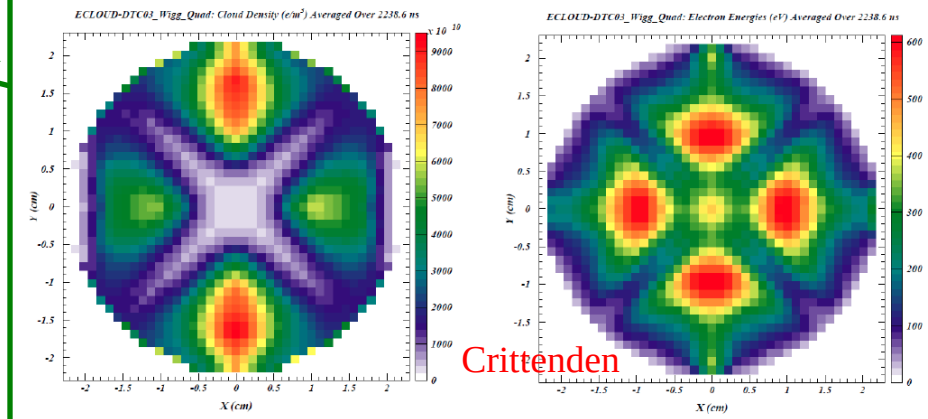
Snapshot @KILC12

- EC Mitigations & Status
- Vacuum System Design/Costing
  - SuperKEKB VCs in production with similar design to ILC DR

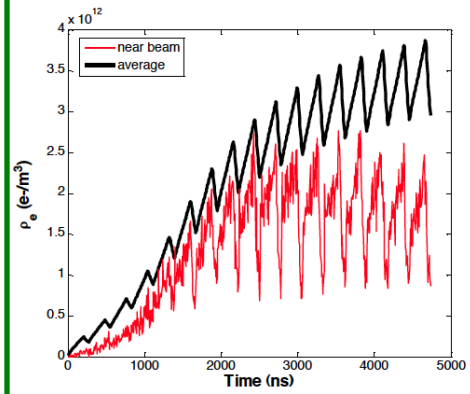
Pivi Talk

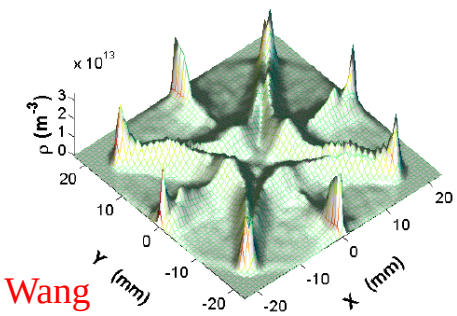
EC Build-up in Quads in Wiggler Straight

Electron cloud density (e/m^3) | Electron energies (eV)



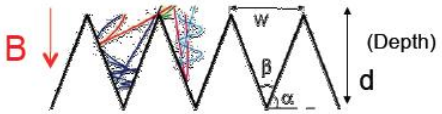
Crittenden





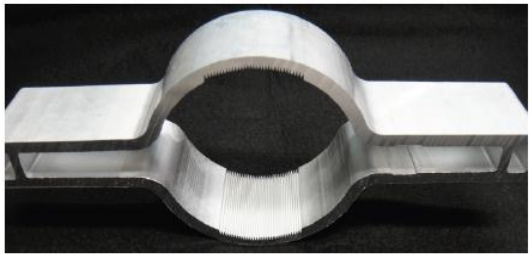
Wang

SuperKEKB Dipole Chamber Extrusion



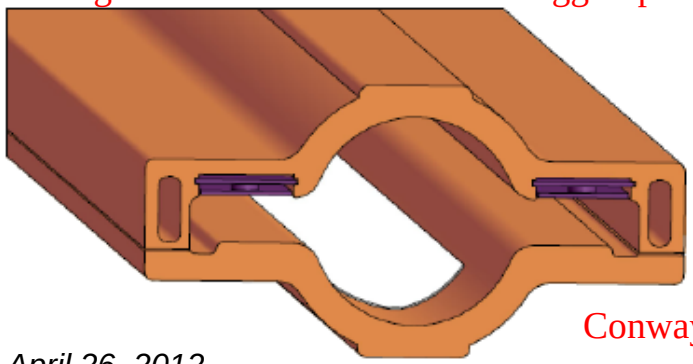
et al.

Valley : R0.1~0.12
Top : R0.15
Angle : 18~18.3°



Y. Suetsugu

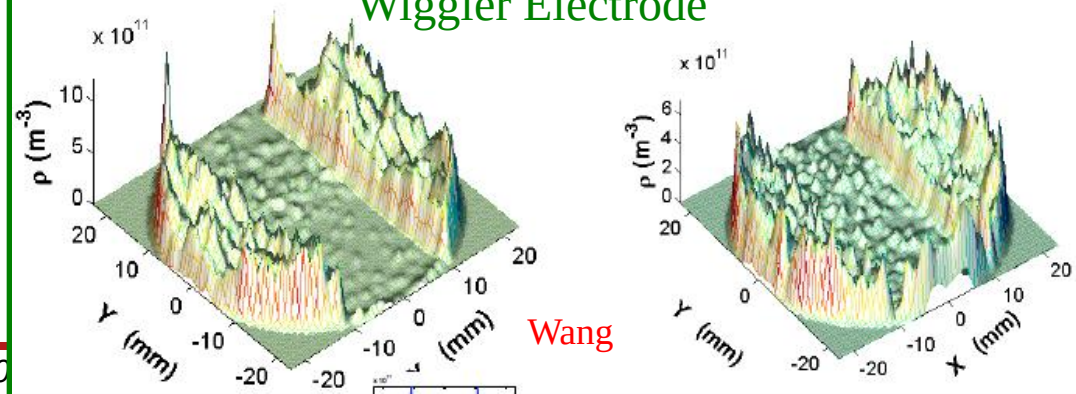
DR Wiggler chamber concept with thermal spray clearing electrode – 1 VC for each wiggler pair.



Conway/Li

EC Suppression by Wiggler Electrode

+400V | +100V



Wang

Where Do We Stand?

ILC Damping Ring

- Results and Tools resulting from CESRTA have now been incorporated into the ILC DR Vacuum Design

- An updated evaluation of the EC impact on the 3.2 km ring (for the "Low Power" configuration) is presently underway and should conclude in June.
  NOTE: Preliminary estimates indicate stable low emittance operation of the ring.

- *The current simulation exercise is a refinement which sets the stage for evaluating whether we can achieve a "High Power" configuration (approximately doubling the ring current) without necessitating a 2nd positron ring…*

Looking Ahead

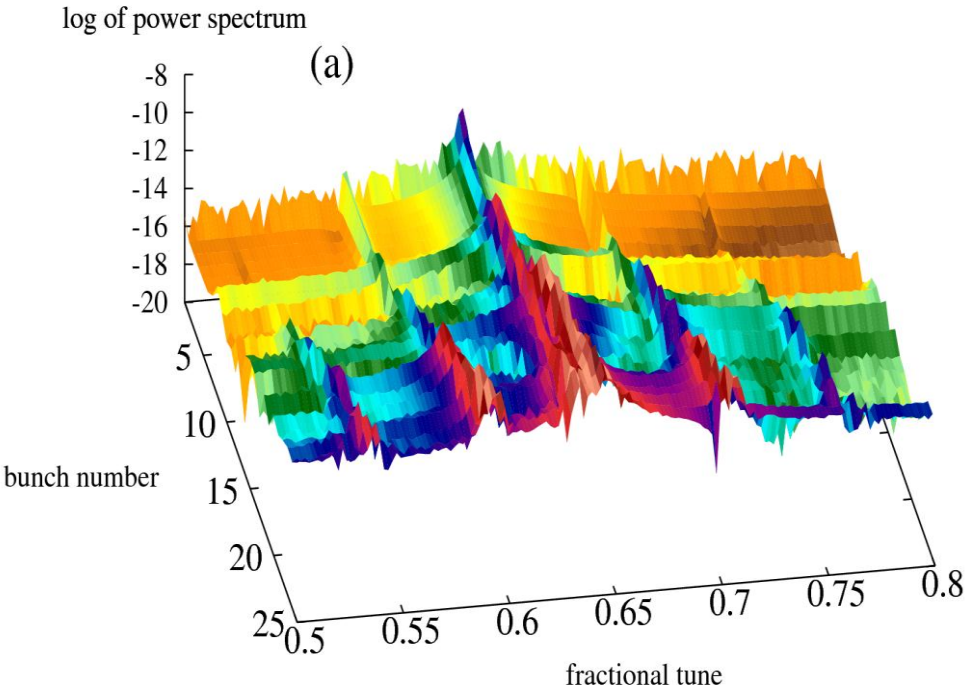
Continued refinement based on Phase I results

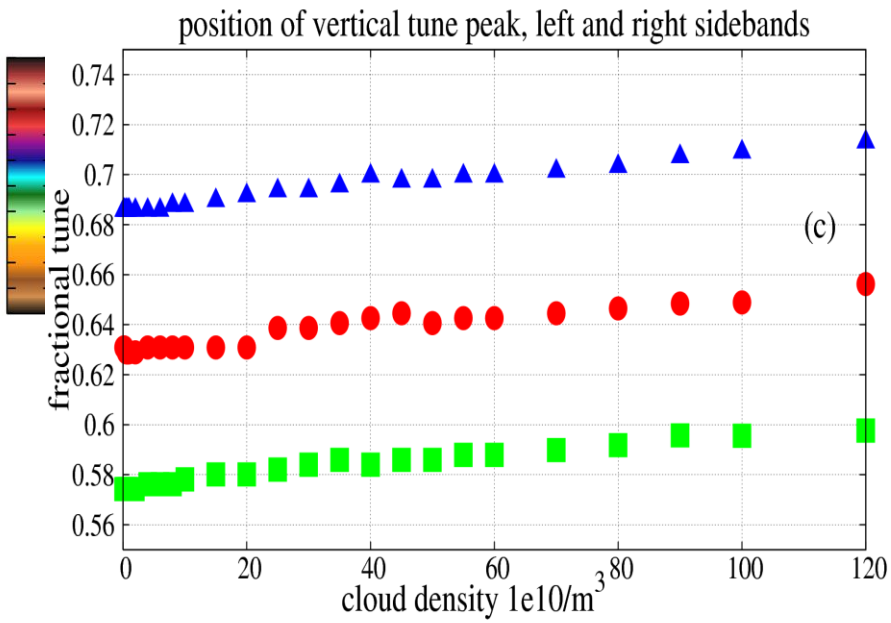
- CESRTA
  - Phase II program is now underway (3 years)
  - Continue to compare simulation and data in a low emittance regime which approaches the ILC DR specification
  - Validate EC simulations against data (including critical extensions to models)
  - Time-resolved studies in dipoles and quadrupoles
  - Continued evaluation of the durability of coatings
  - Photon Reflectivity Collaboration
- Extended program allows for new studies
  - IBS studies and detailed comparison with simulation are of particular importance for the CLIC DR design
  - Tools and diagnostics are applicable to Fast Ion Instability studies
  - Continue the development of instrumentation and techniques useful for low emittance rings
- SuperKEKB Utilizes a Similar Mitigation Plan
  - Detailed operational tests with a fully configured ring
  - Dipole Chamber test planned in CESRTA

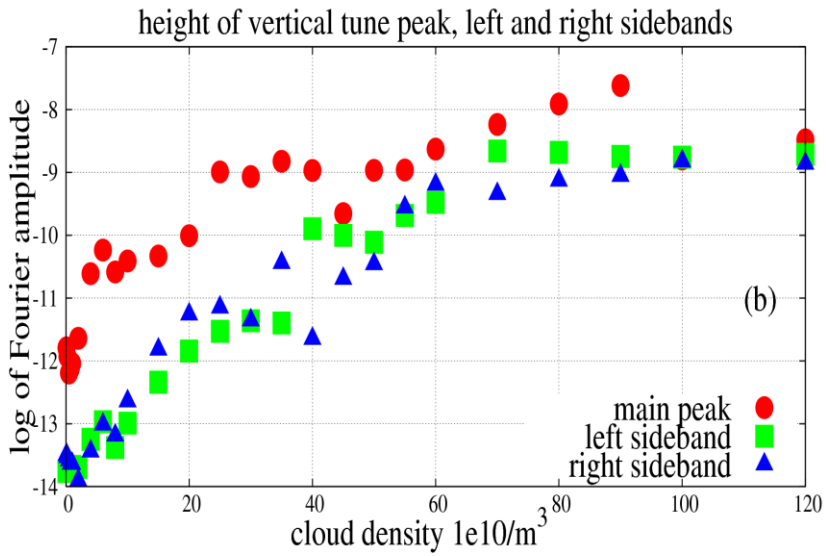
CESRTA PHASE II: Refinements for Improved Predictions

A FEW EXAMPLES…

CMAD Development



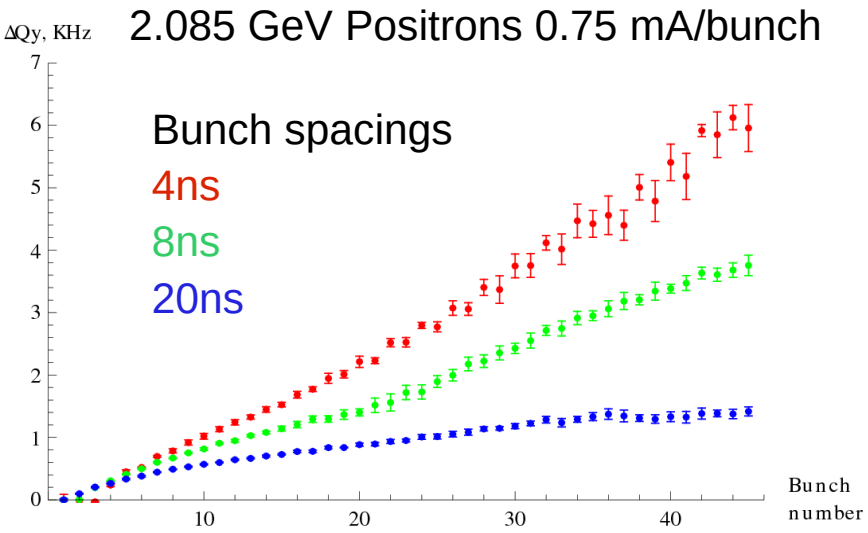


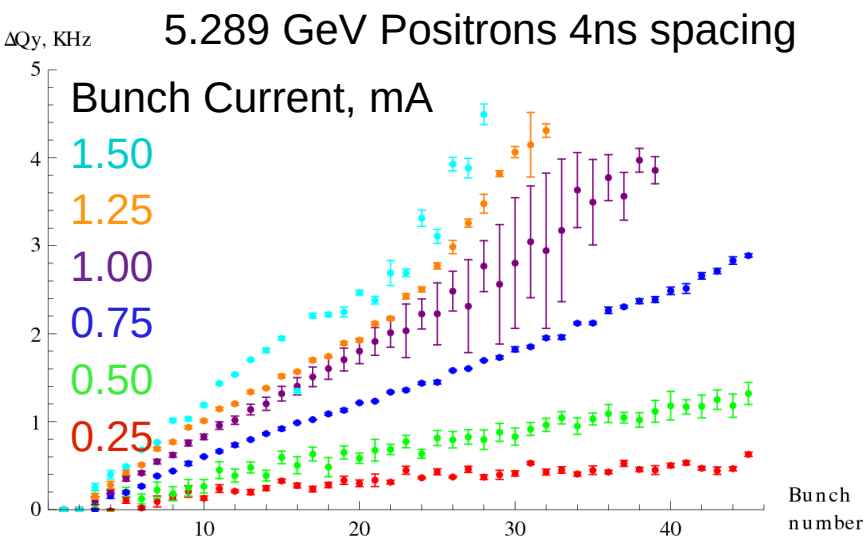


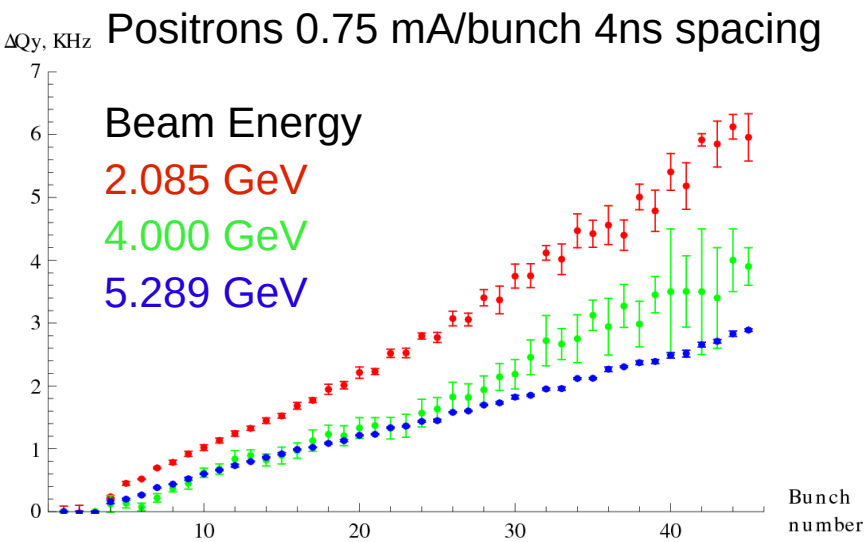
Simulations with 1mA bunch current and varying cloud densities

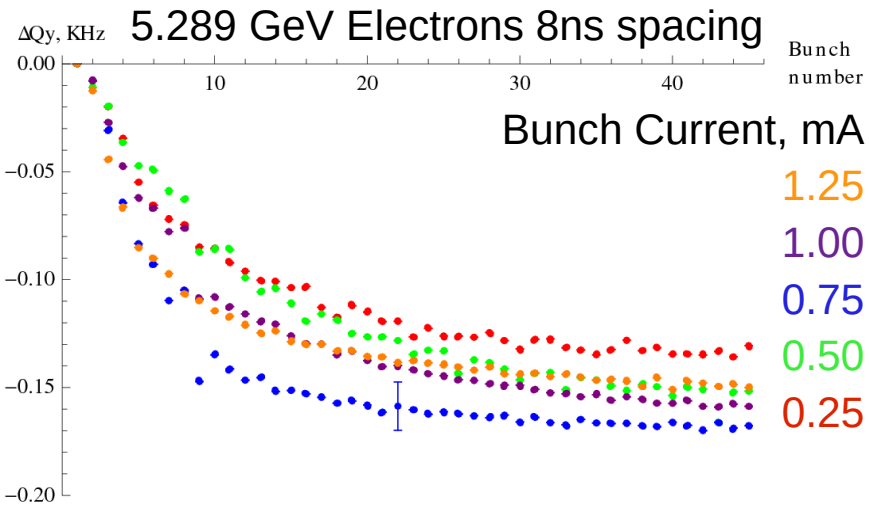
Spectra show presence of synchrotron sidebands (1st and 2nd order) as well as cloud induced tune shift

Systematic Studies of Tune Shifts



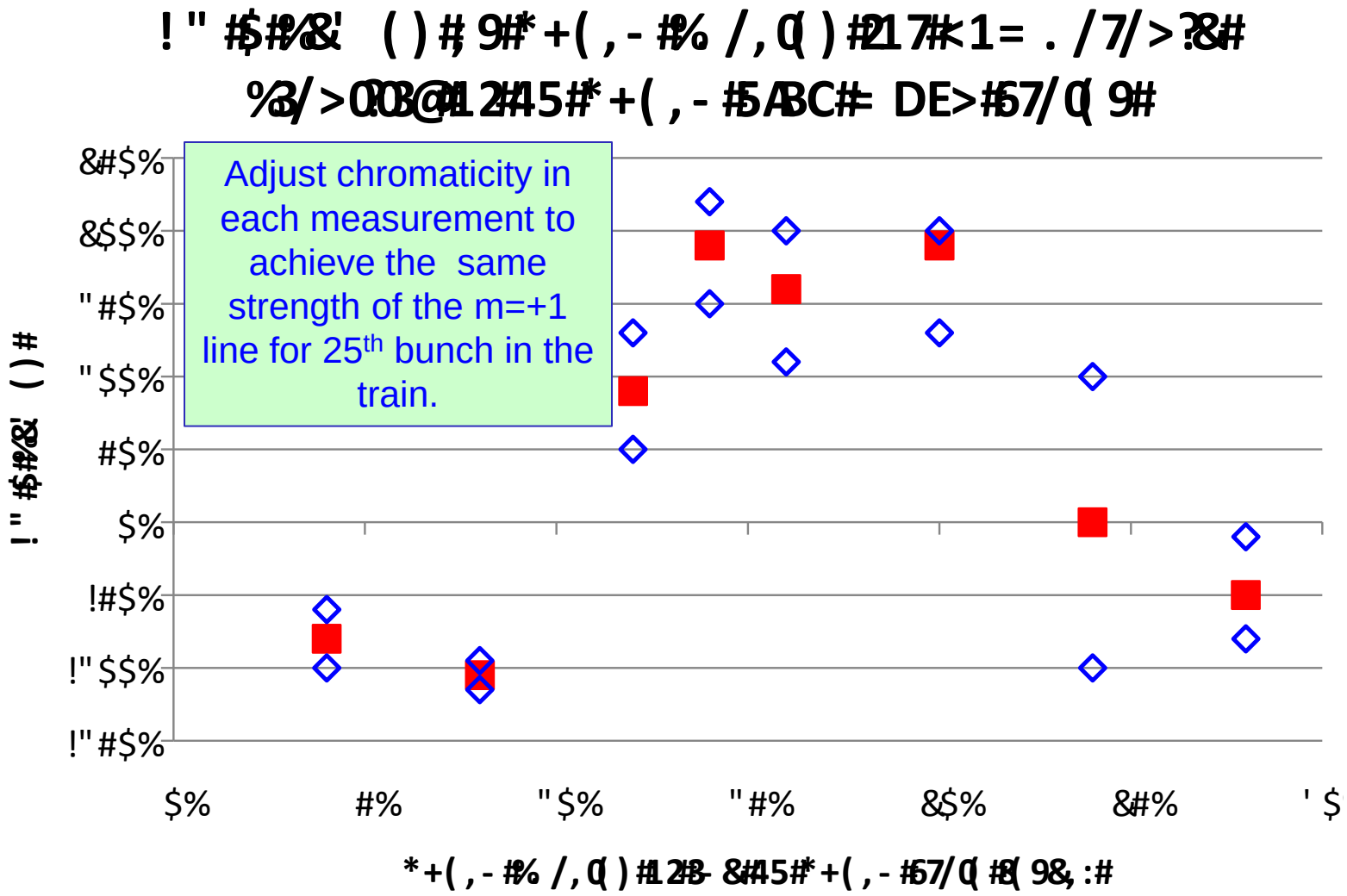




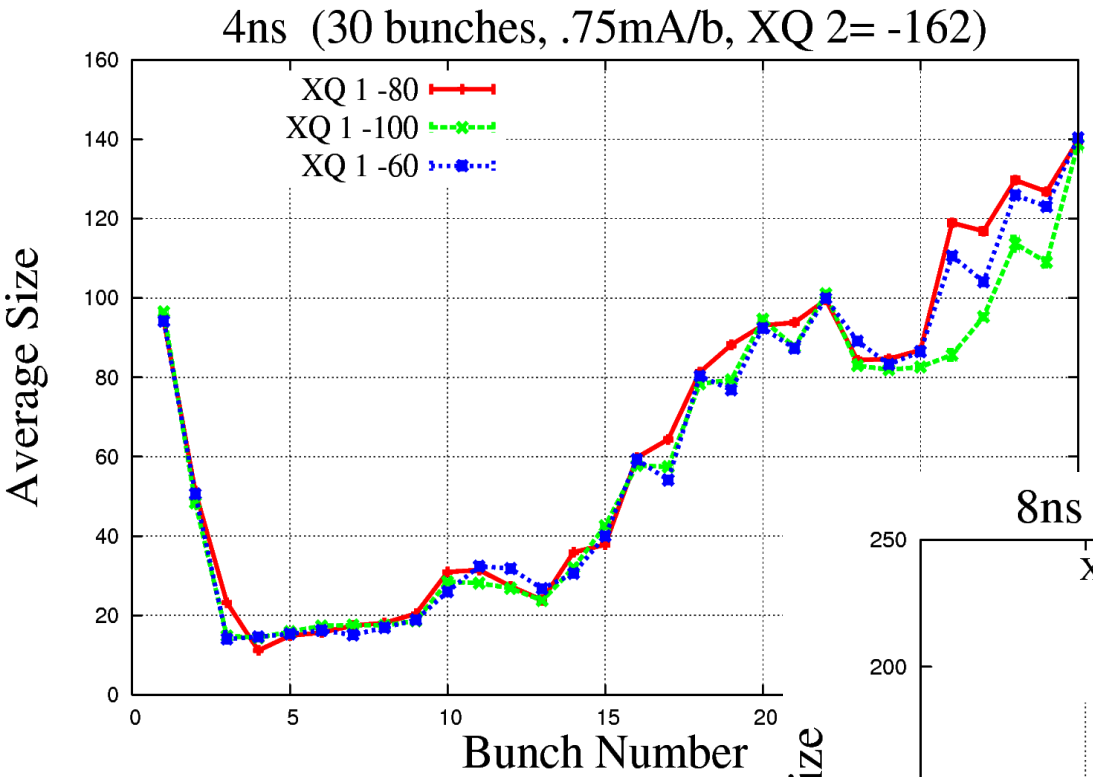


EC Stability Versus Bunch Spacing

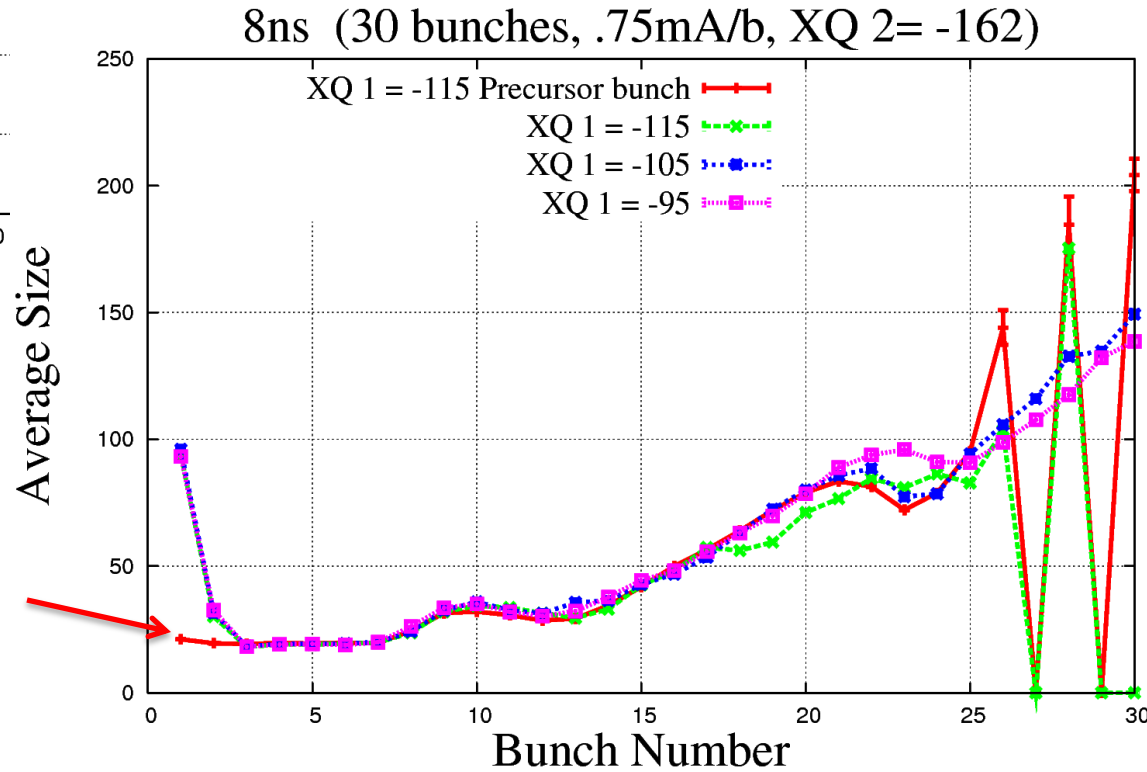
- Chromaticity for comparable line strength versus bunch spacing in trains



Comparison of Beam Sizes: 4 ns, 8 ns



Observed beam size independent of chromaticity

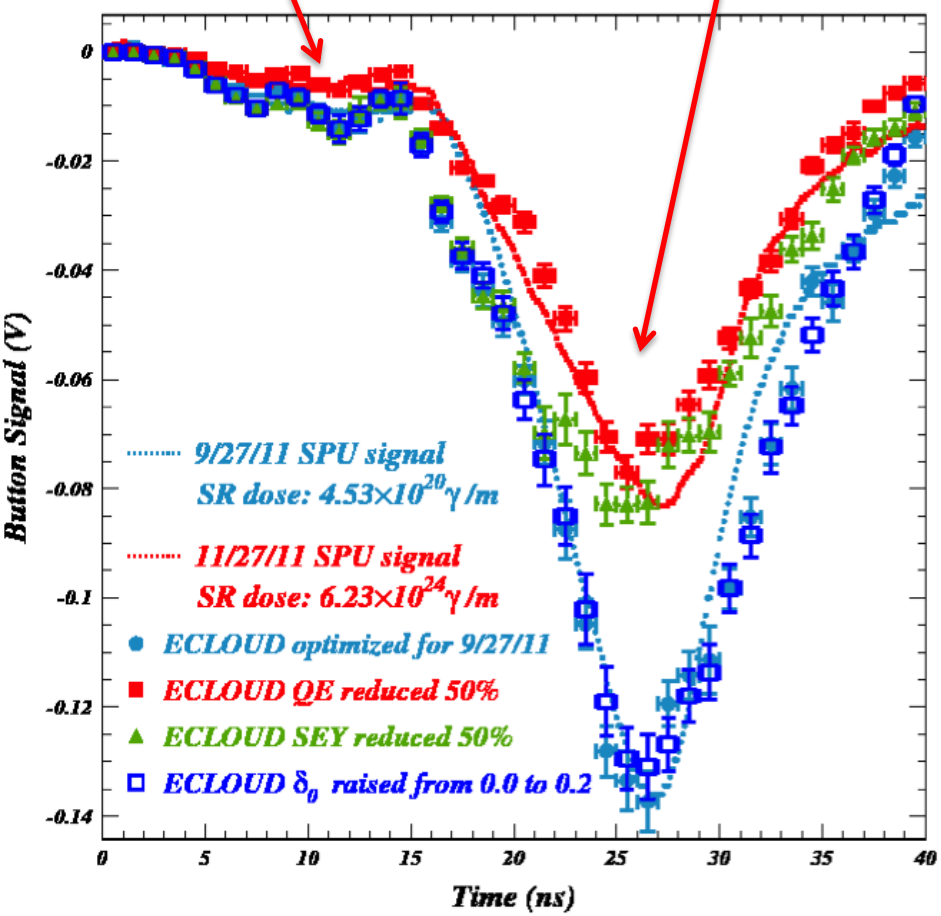


Precursor bunch ~160ns ahead of train

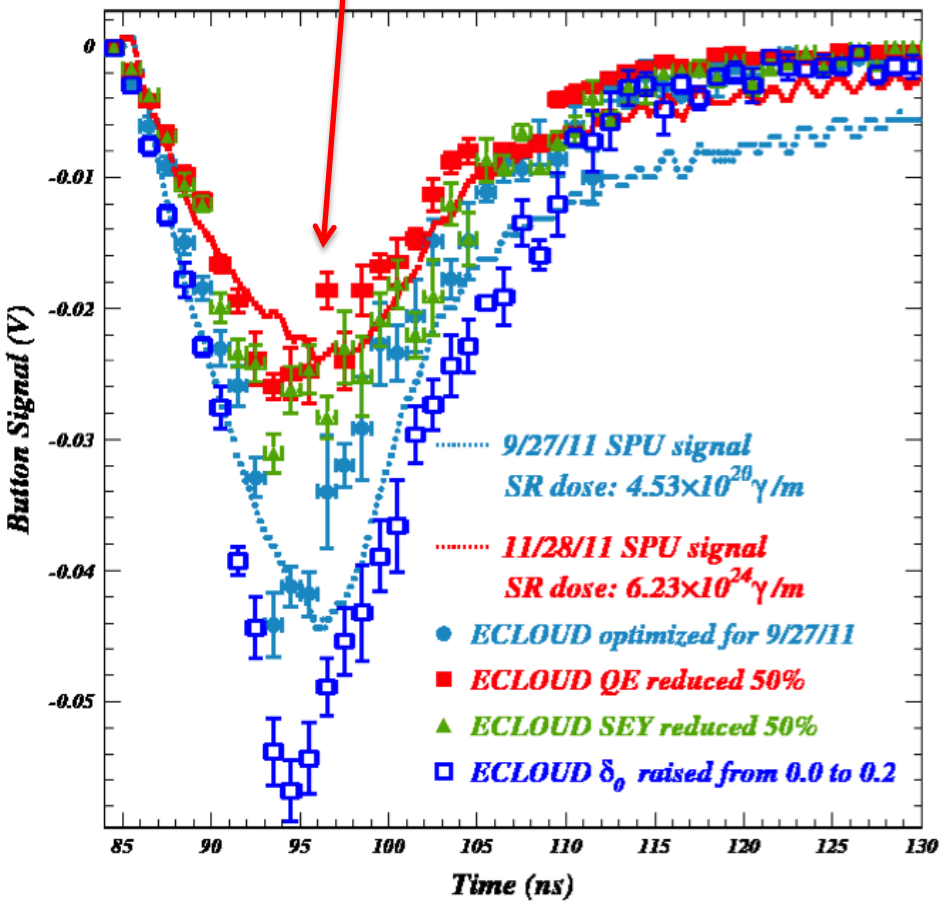
Processing Effects

Cloud Signal from Bunch 1

Cloud Signal from Bunch 2 w/14 ns delay



Cloud Signal from Bunch 2 w/84 ns delay



Conclusion

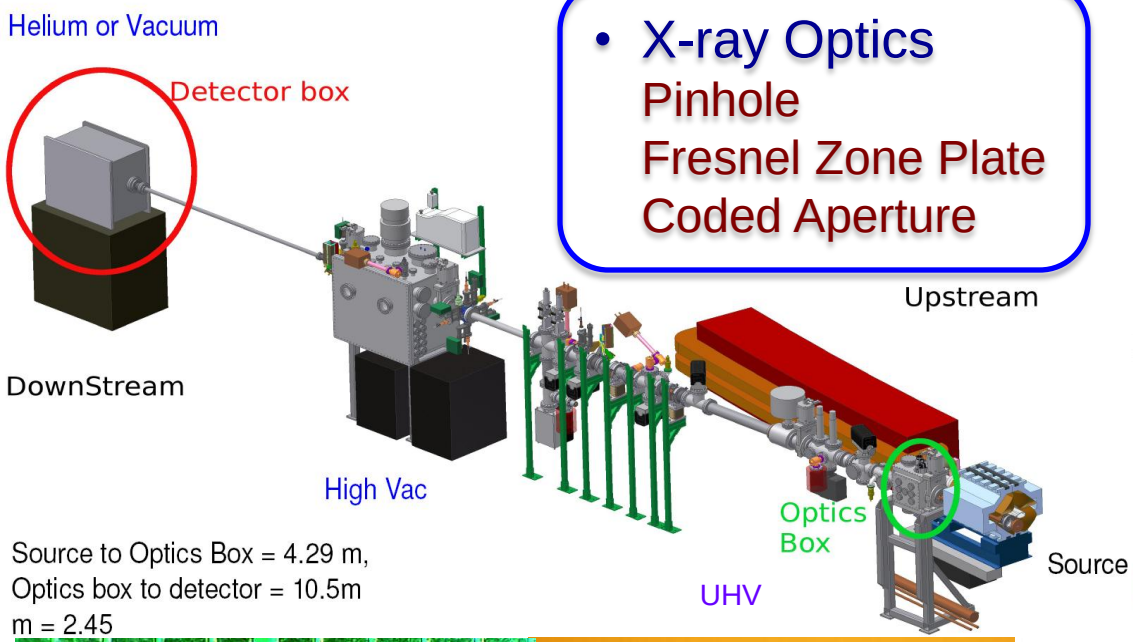
- CESRTA Phase I
  - Results have been incorporated into the ILC DR EC Mitigation Plan
  - Conceptual designs are in place for the DR vacuum system
- CESRTA Phase II
  - Work continues to obtain more detailed agreement between data and simulation
    ⇨ improved predictive power
  - Broadened experimental program underway (LET, IBS, etc)
- SuperKEKB
  - Will offer the first integrated test of the latest techniques in the ultra low emittance regime

Backup Slides Follow

Outline

- Summary of the CESRTA Phase I R&D Program
  - 2 pages program overview
  - 6 pages R&D overview
- Application of the Phase I Effort to the ILC DR Design
  - 3 pages simulation
  - 3 pages vacuum system
- Looking Ahead
  - Where work remains
    - Key R&D Issues
    - SuperKEKB results
  - Phase II Program – First Look…
  - Reporting
- Conclusion

CESR Conversion: Low ε Instrumentation



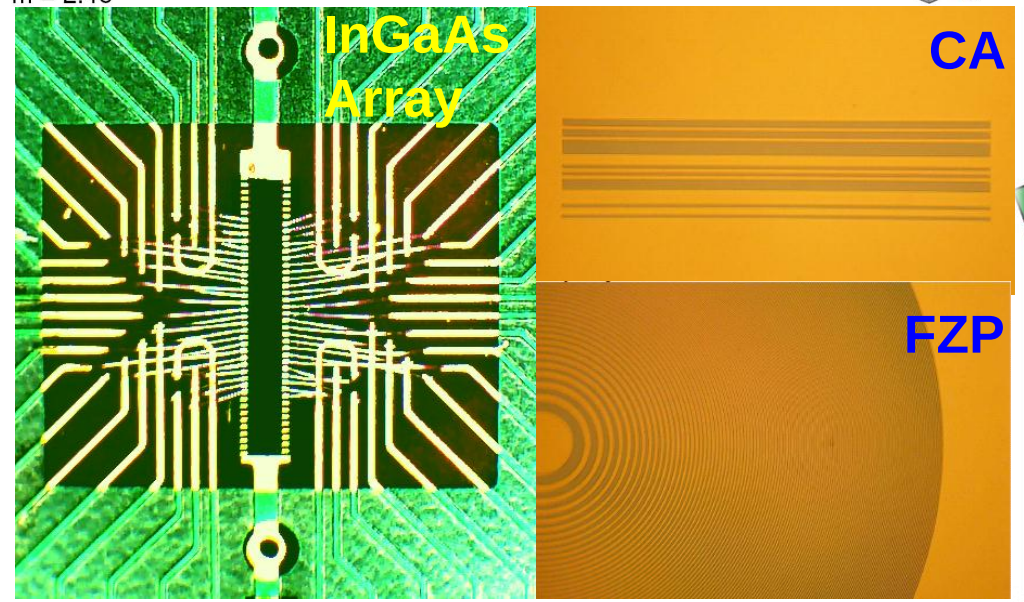
Source to Optics Box = 4.29 m,
Optics box to detector = 10.5m
m = 2.45

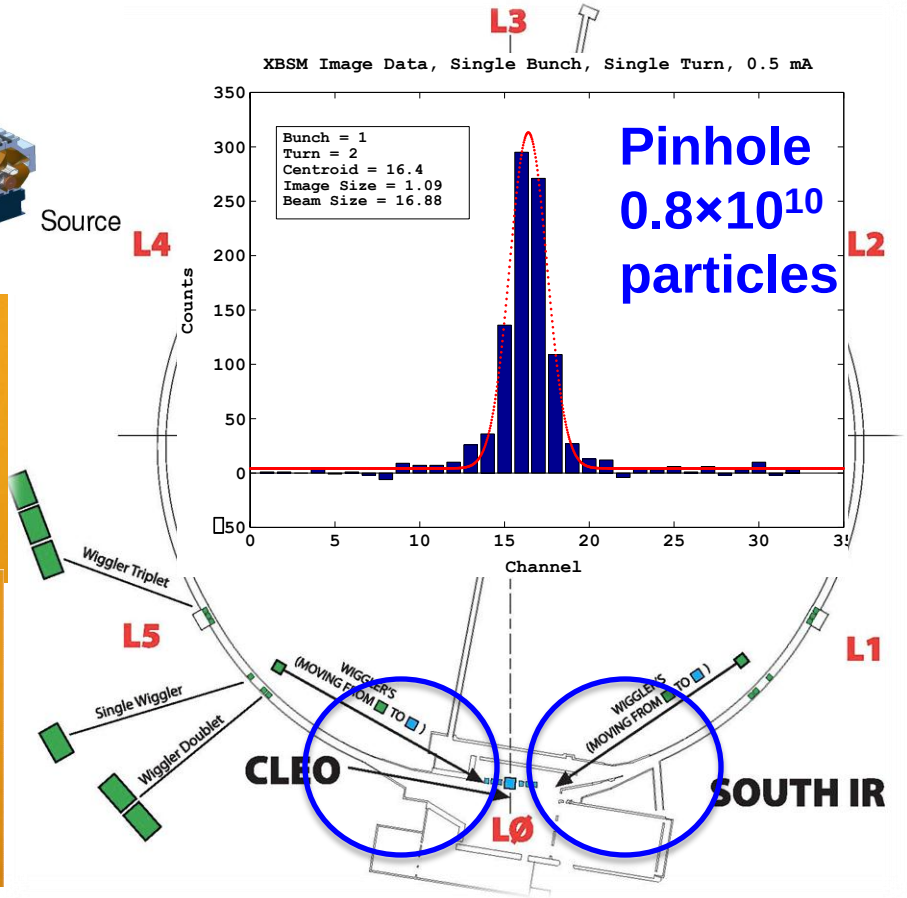
- X-ray Optics
  - Pinhole
  - Fresnel Zone Plate
  - Coded Aperture

x-Ray Beamsize Monitor-xBSM

- Single pass measurement capability
- Targeted at ~10 μm beams

BPM system upgrade





Drift Region Mitigation Evaluations

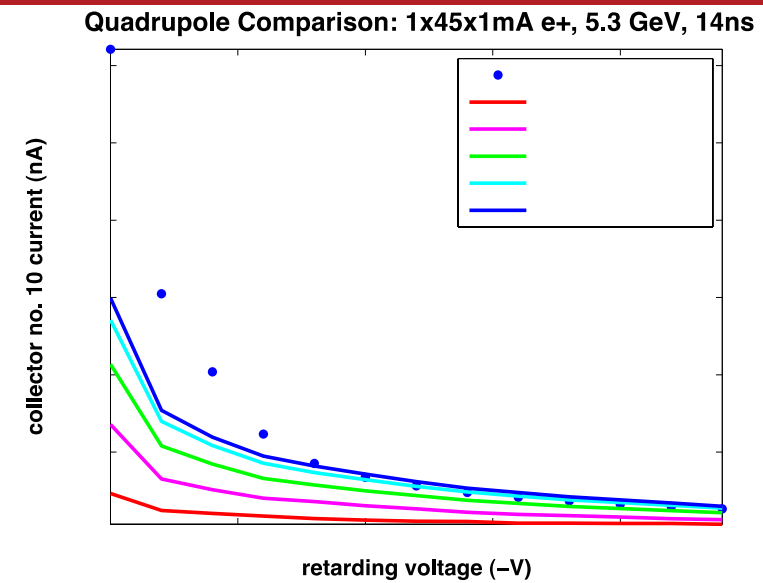
- Efficacy
  - Relative comparisons ⇨ TiN, after extended scrubbing, has achieved slightly better performance than the carbon coated chambers that we have deployed.
  - In situ SEY station measurements with TiN and aC show peak SEY values around 1, processing towards lower values with TiN
  - The use of solenoid coils in addition to any of the coatings would likely assure acceptable EC performance in the drifts

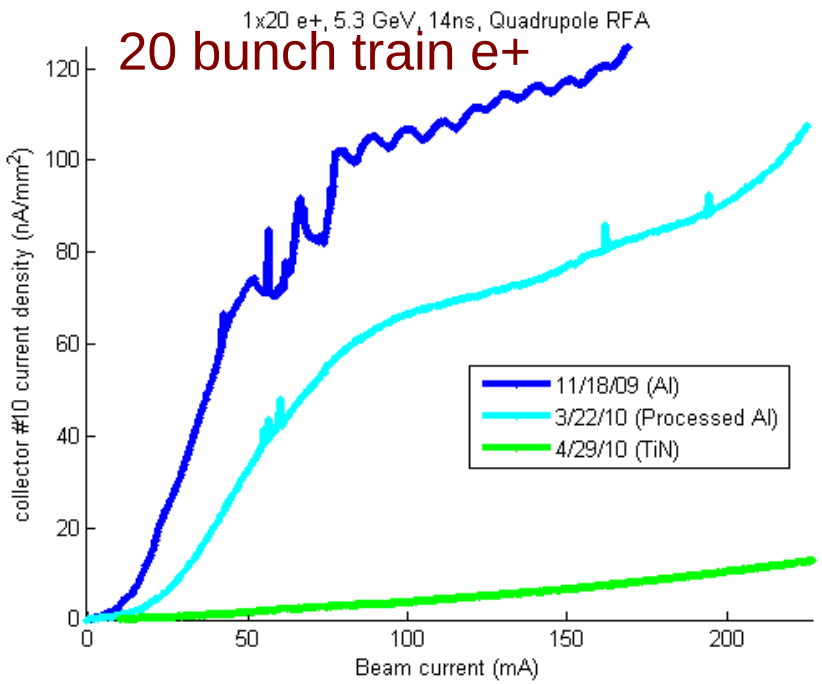
- Risks
  - Further monitoring of aging performance is desirable
  - Possible Si contamination?
    - CERN tests of 2 samples sent back after acceptance tests ⇨ presence of Si contamination in a-C chamber
    - Follow-on test of 1st a-C chamber (entire chamber sent to CERN) did not detect Si after beam exposure
  - Surface parameter analysis is still maturing ⇨ some caution should be exercised.

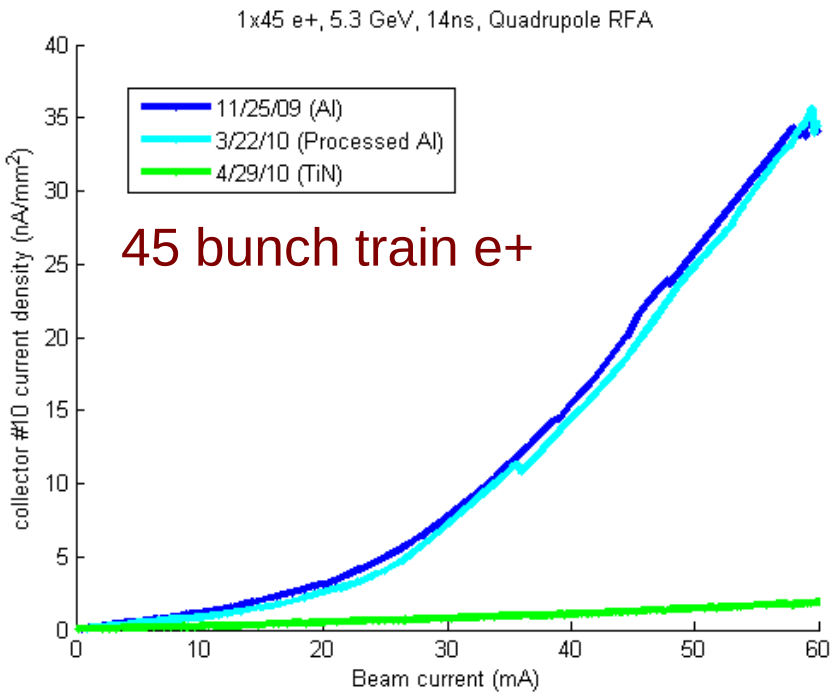
- Impact on Machine Operations and Performance
  - NEG would benefit overall machine vacuum performance, but activation requirements are difficult.
  - a-C and TiN show somewhat higher beam-induced vacuum rise than bare Al. DLC very high.

Quadrupole Observations

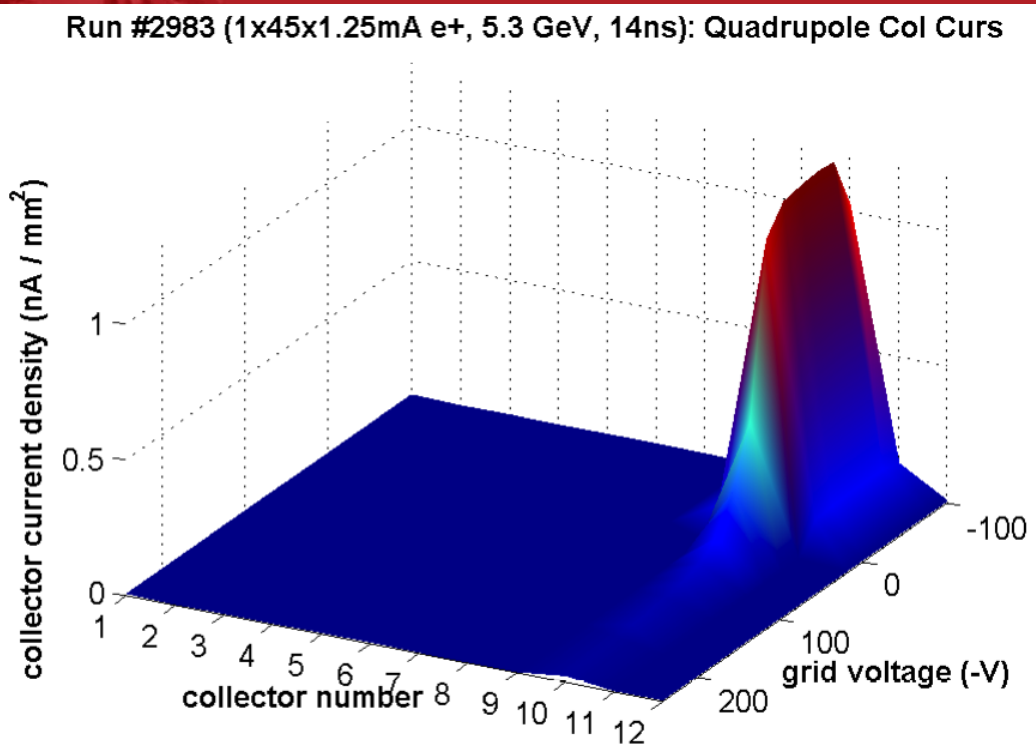
- RFA currents higher than expected from "single turn" simulations
  - Turn-to-turn cloud buildup
  - ~20 turn effect
  - Issue also being studied in wigglers
- Clear improvement with TiN







Quadrupole Evaluation

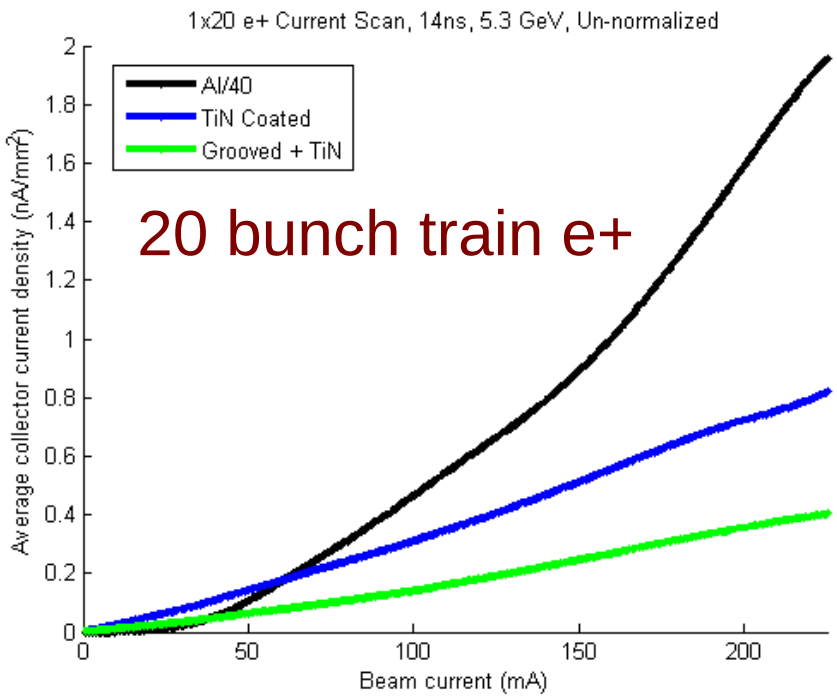


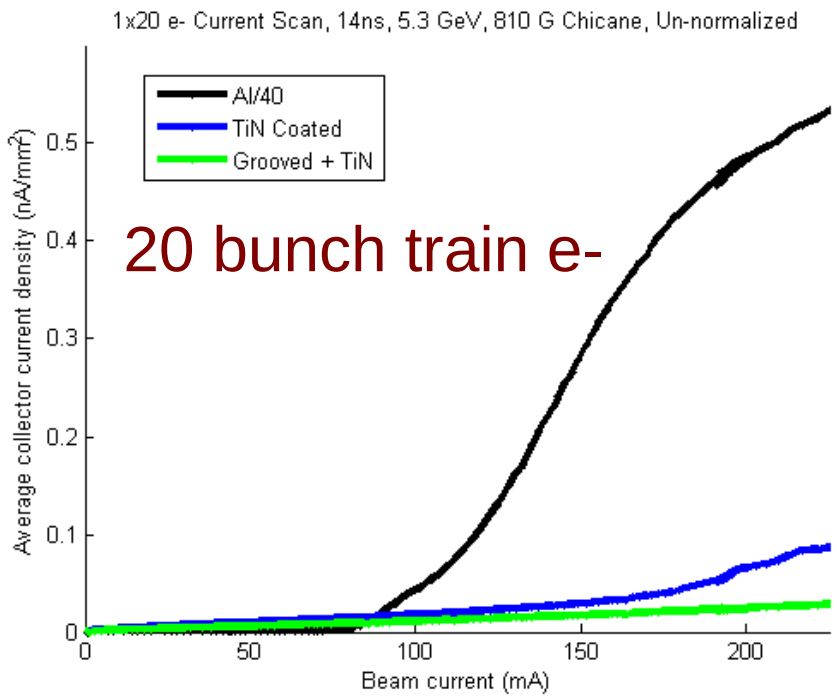
- Efficacy
  - Strong multipacting on Al surface significantly suppressed with TiN coating
- Risks
  - Appear minimal with coating
  - Concerns about trapped EC (multi-turn build-up)
  - Final evaluation of acceptable surface parameters in quadrupoles is needed to decide whether coating (as opposed, say, to coating+grooves) is acceptable.
    - ILCDR EC working group effort underway

Dipole Observations

- Data shown: 5.3 GeV, 14ns
  - 810 Gauss dipole field
  - Signals summed over all collectors
  - Al signals ÷40

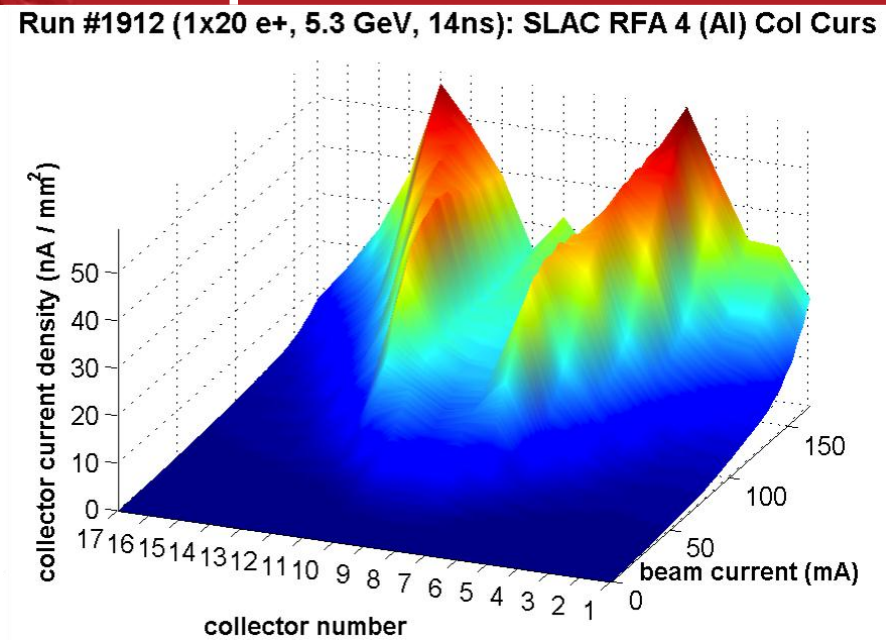
Longitudinally grooved surfaces offer significant promise for EC mitigation in the dipole regions of the damping rings

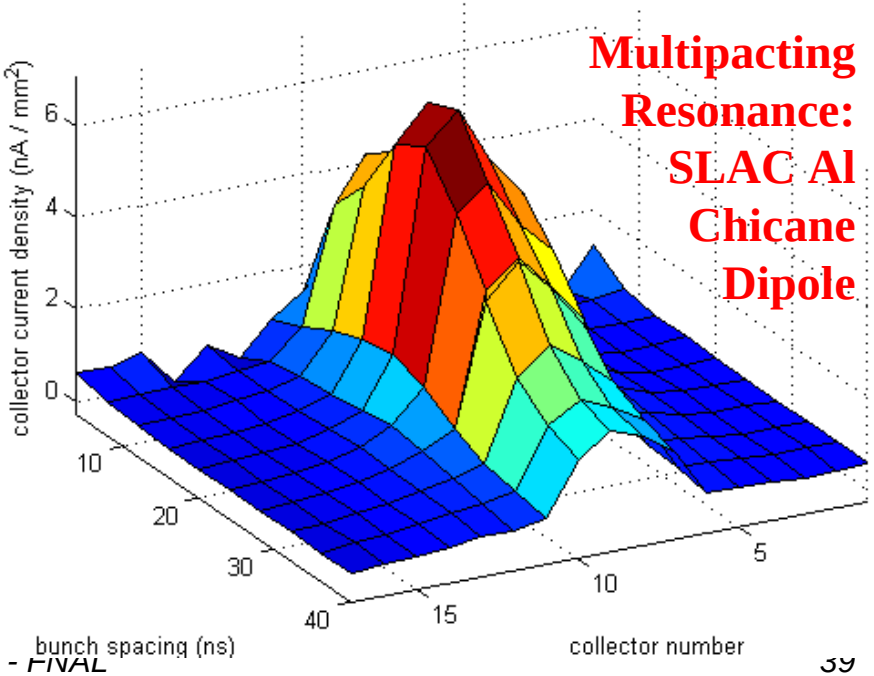




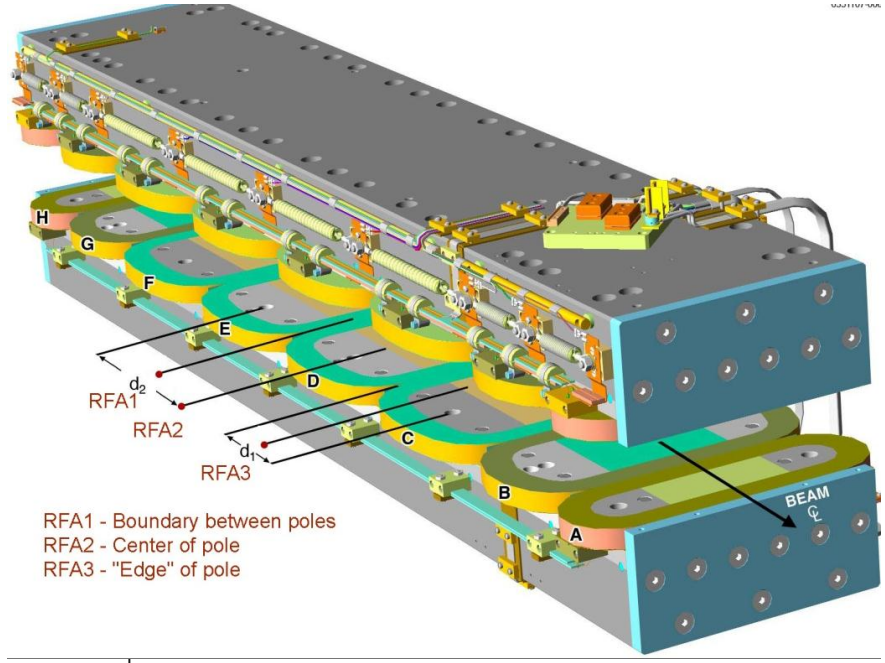
Dipole Evaluation

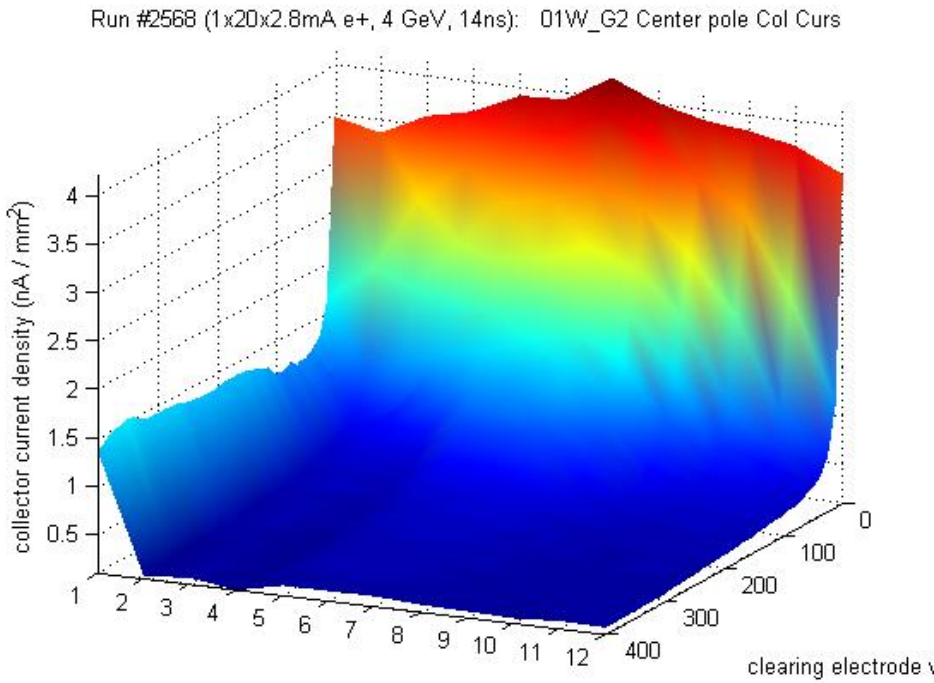
- Efficacy
  - Of the methods tested, a grooved surface with TiN coating has significantly better performance than any other. Expect that other coatings would also be acceptable.
  - NOTE: Electrodes not tested (challenging deployment of active hardware for entire arc regions of the ILC DR)
- Risks
  - Principal concern is the ability to make acceptable grooved surfaces via extrusion
    - "Geometric suppression" limited by peak and valley sharpness
    - Coating helps ameliorate this risk
  - Machined surfaces of the requisite precision are expensive and challenging
- Impact on Machine Performance
  - Simulations (Suetsugu, Wang, others) indicate that impedance performance should be acceptable

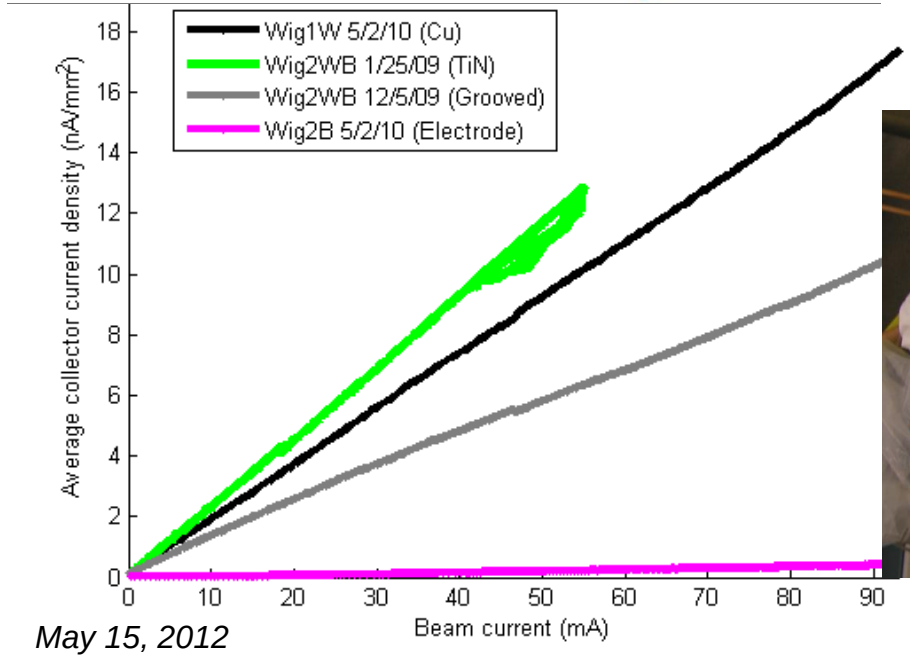


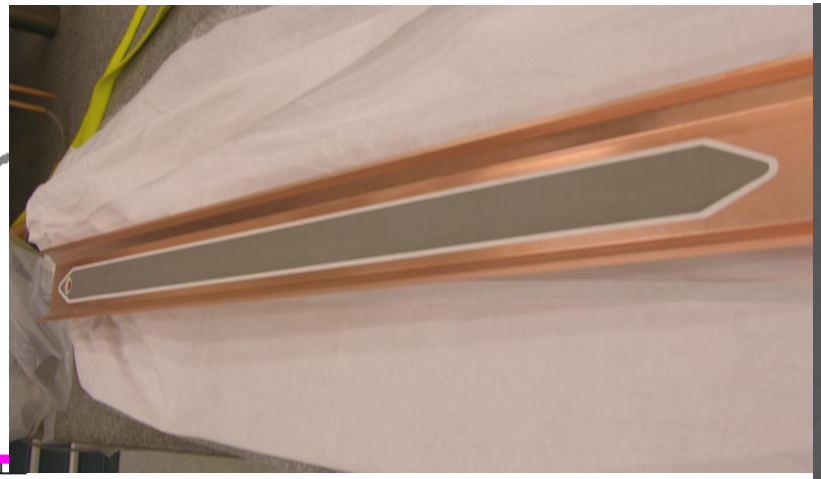


Wiggler Observations

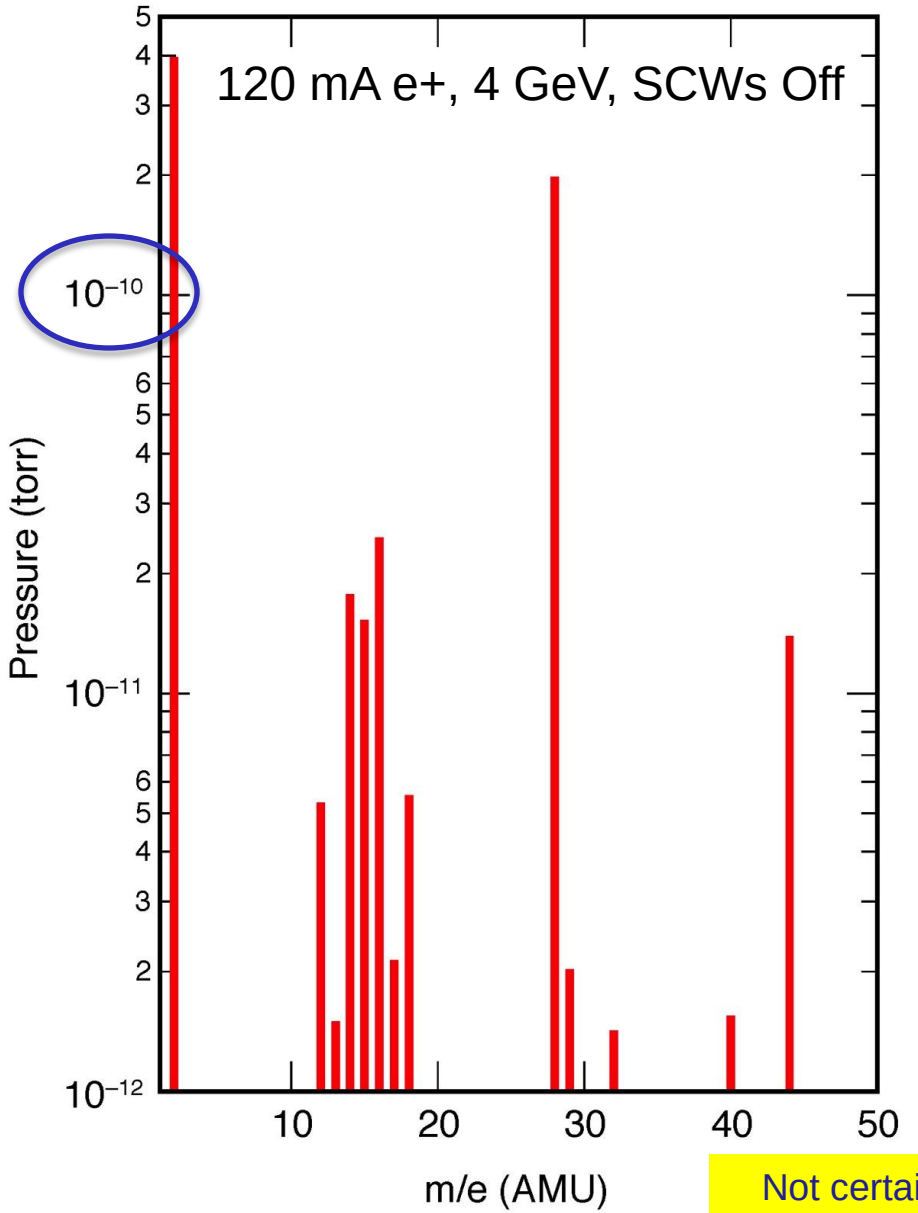


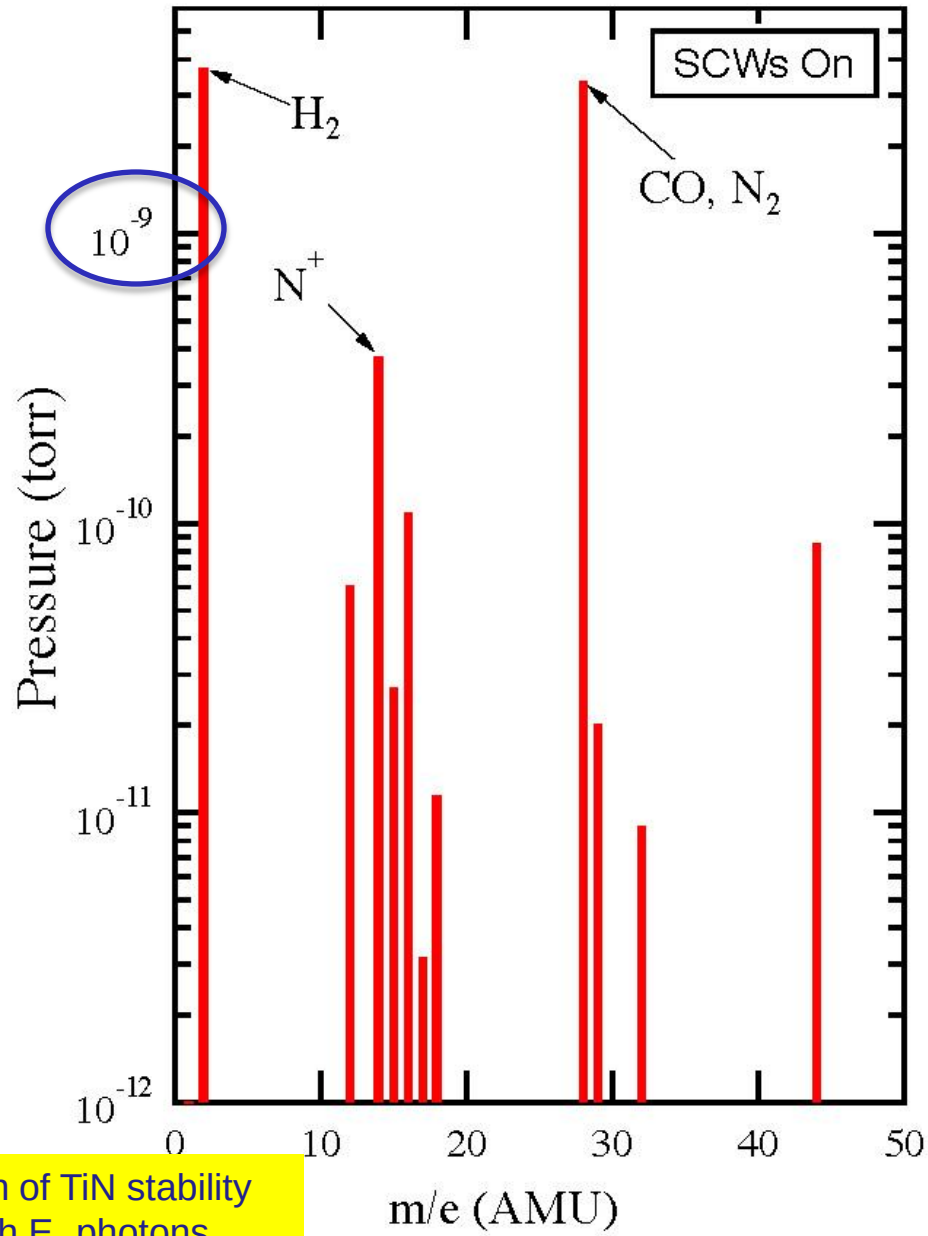






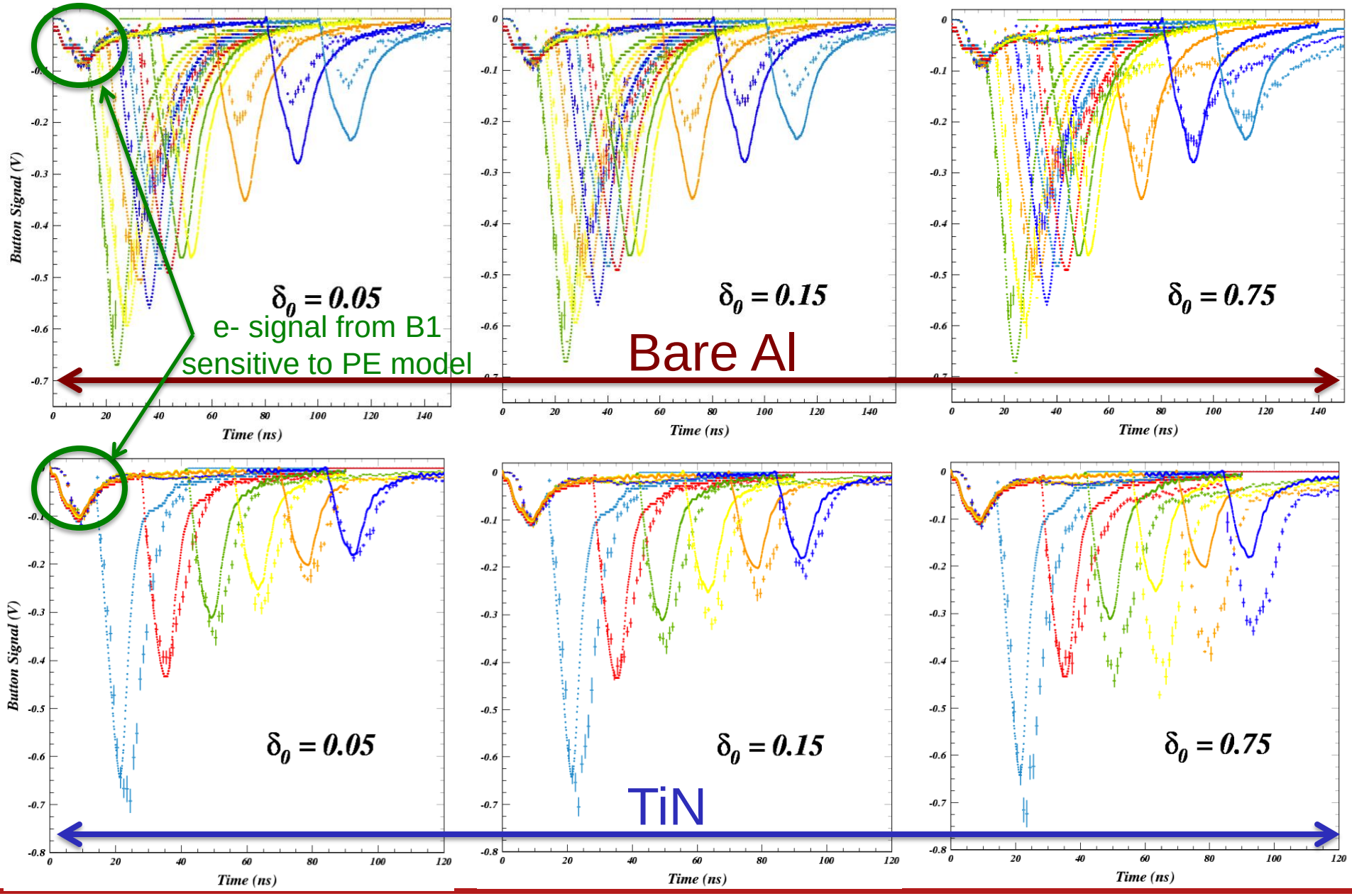
L0 Wiggler Straight Vacuum





Not certain of TiN stability with high E_c photons

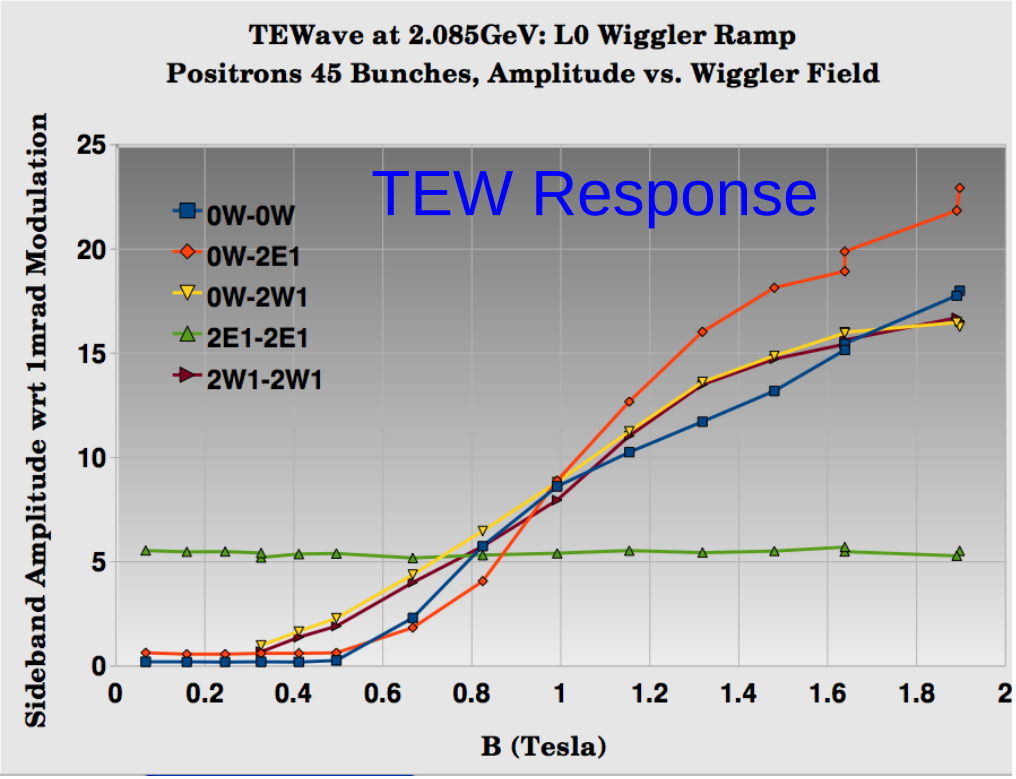
Time-Resolved (SPU) Comparisons: δ(0) ⇨ Cloud Persistance

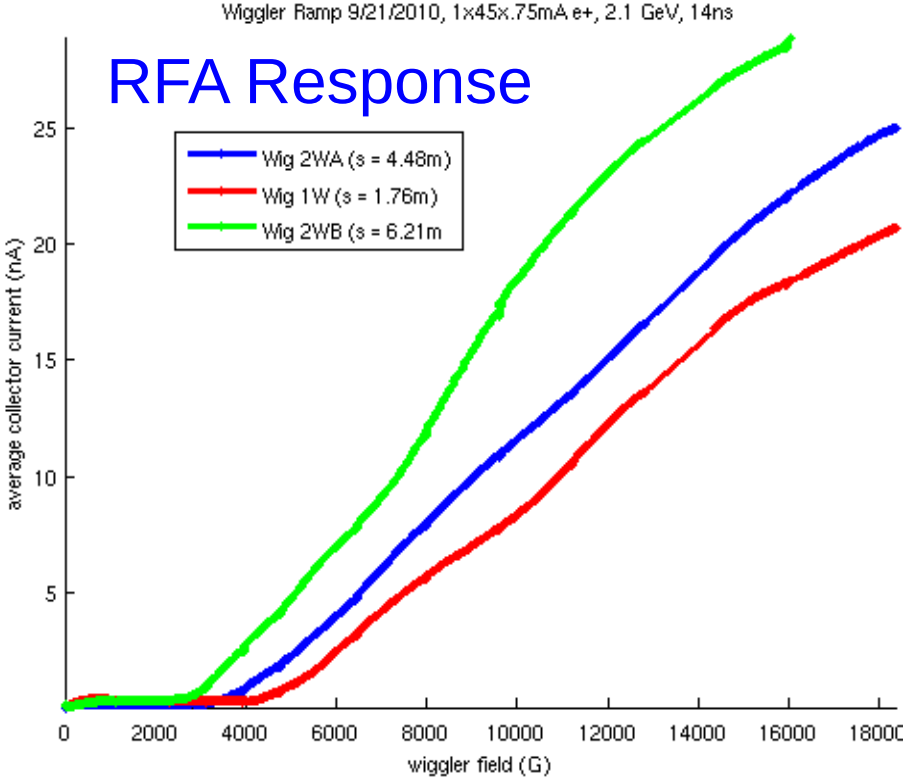


Wiggler Ramp

- Plots show TE Wave and RFA response as a function of wiggler field strength
- Large increase in signal as soon as radiation fan begins to strike local VC surface ⇨ significant diffuse scattering component

1x45x0.75mA e+, 2.1 GeV, 14ns bunch spacing



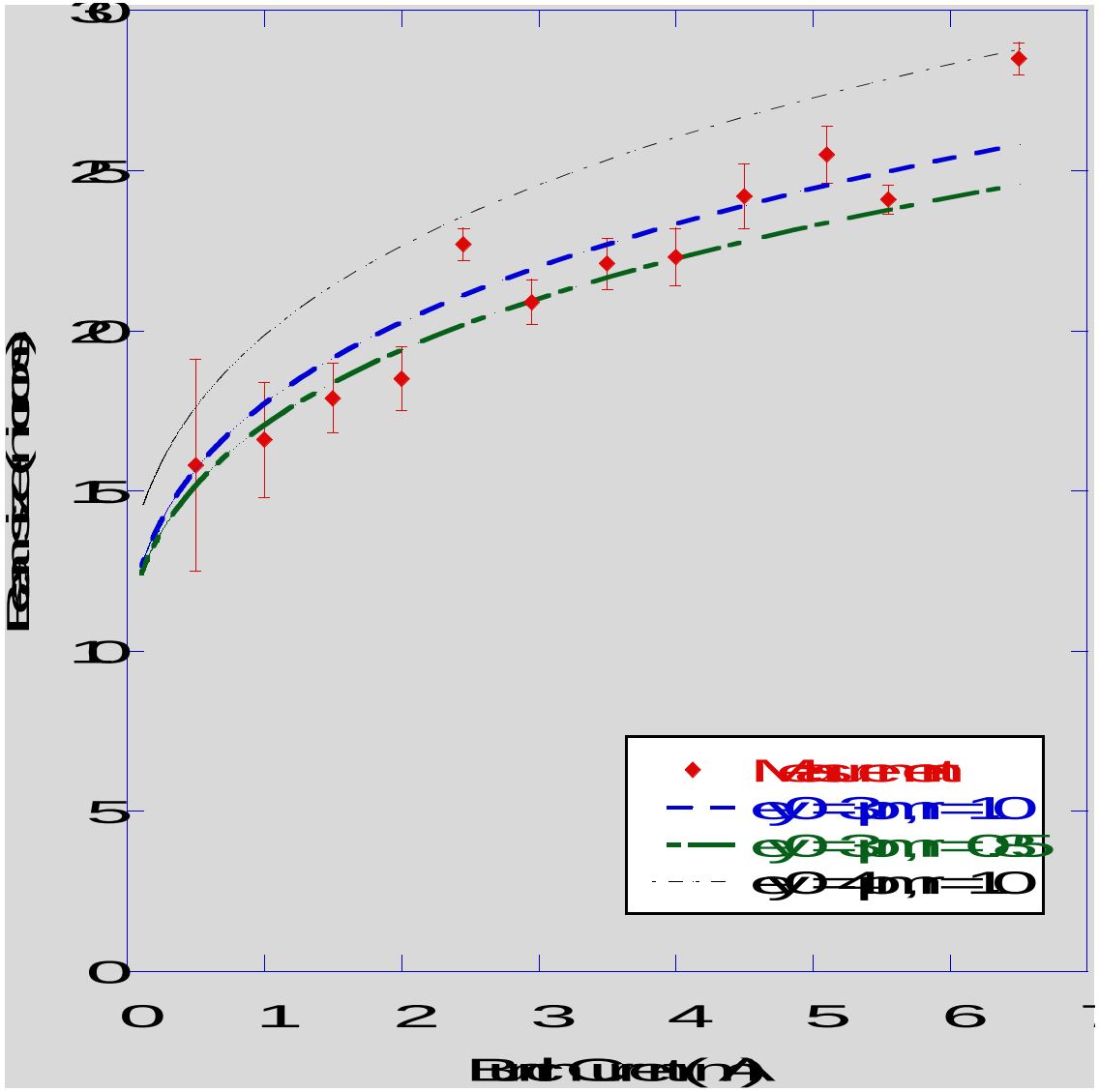


Wiggler Evaluation

- Efficacy
  - Best performance obtained with clearing electrode
- Risks
  - Electrode reliability
    - Thermal spray method offers excellent thermal contact
    - Ability to create “boat-tail” shape with no structural concerns helps to minimize HOM power
    - Feedthrough and HV connection performance probably single largest concern
- Impact on Machine Operation and Performance
  - Impedance should be acceptable for the limited length of the wiggler section (see, eg., ECLOUD10 evaluation by Y. Suetsugu)
  - Additional hardware required
    - Power supplies
    - Loads for HOM power

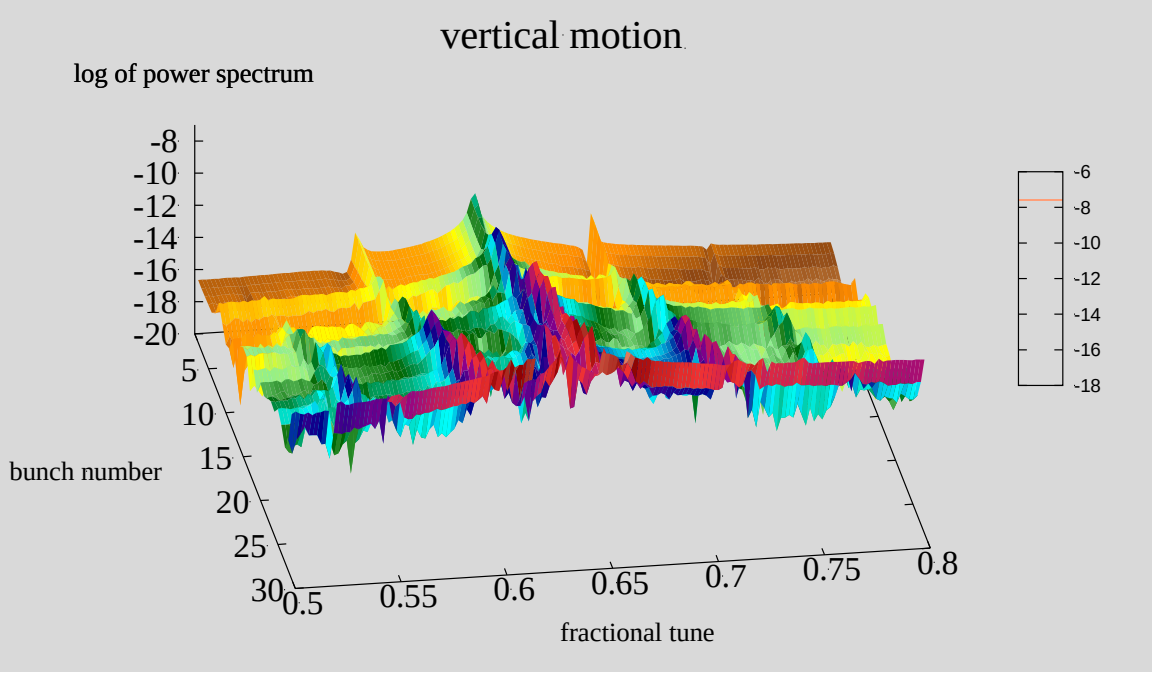
LET – New Look at IBS

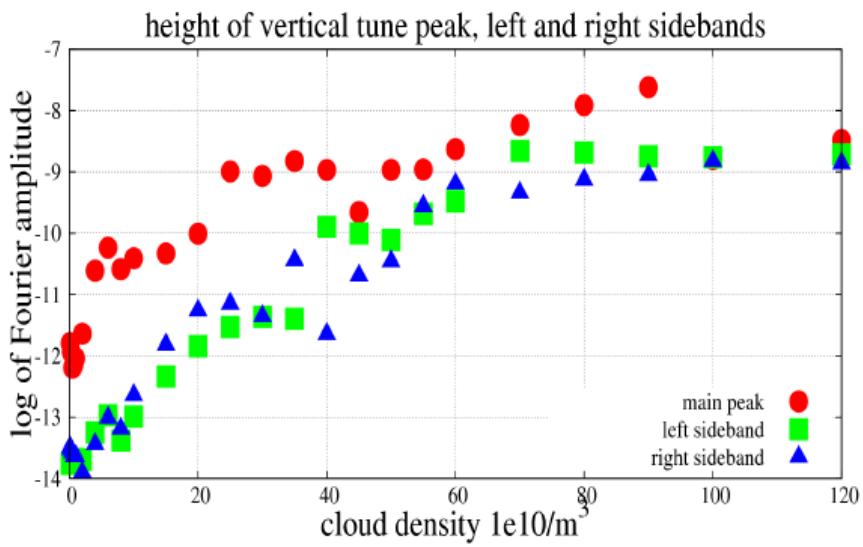
- IBS Checks
  - April 2011 Study
  - Vertical emittance is dispersion dominated
  - Projection to zero current consistent with $\varepsilon_y(0) \sim 3$pm

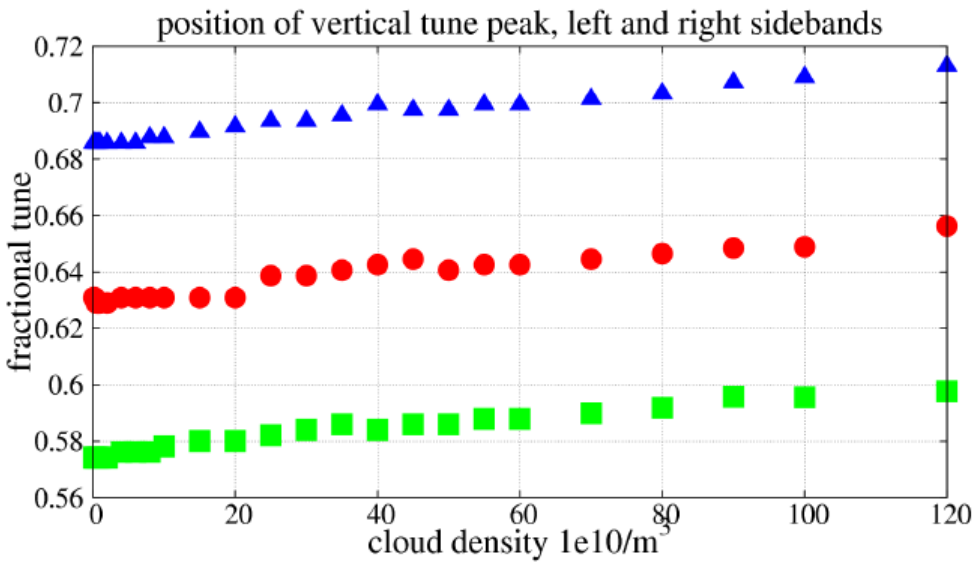


Simulation Program

- CMAD simulations are being validated against CESRTA measurements and applied to analysis of the ILC DR

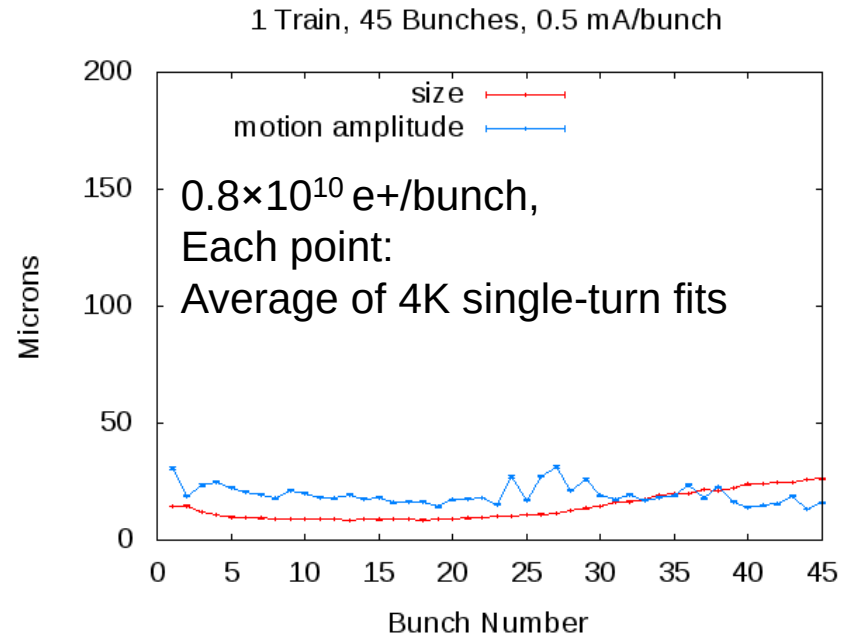


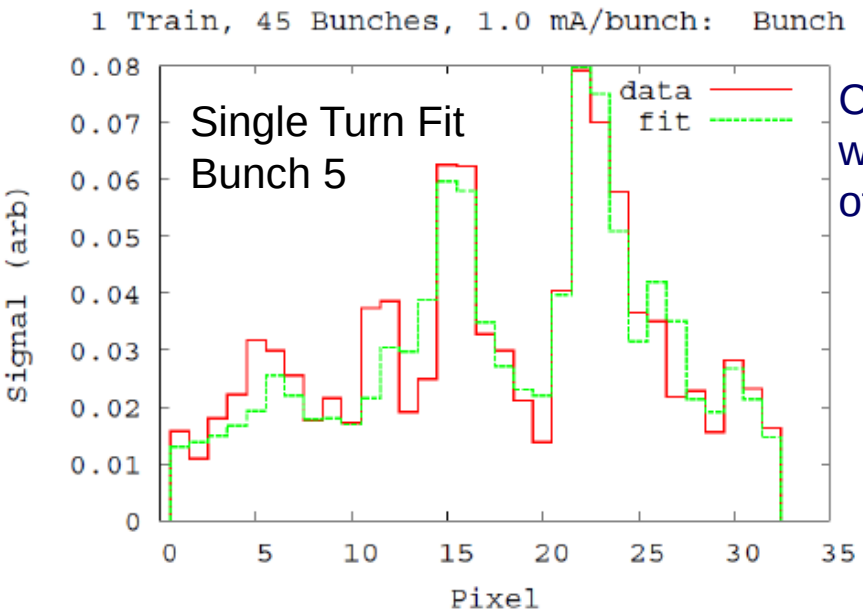


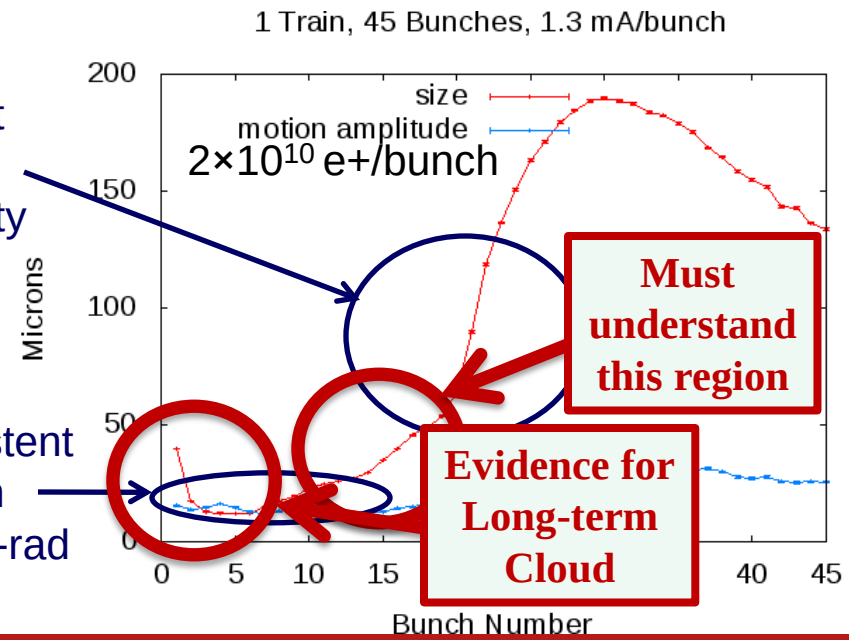


Beam Size

- Measure Bunch-by-Bunch Beam Size
  - Beam size enhanced at head and tail of train
    Source of blow-up at head appears to be due to a long lifetime component of the cloud
    Bunch lifetime of smallest bunches consistent with observed single bunch lifetimes during LET (Touschek-limited) consistent with relative bunch sizes.
  - Beam size measured around bunch 5 is consistent with $\varepsilon_y \sim 20$pm-rad [σ_y=11.0±0.2 μm, β_{source}=5.8m]

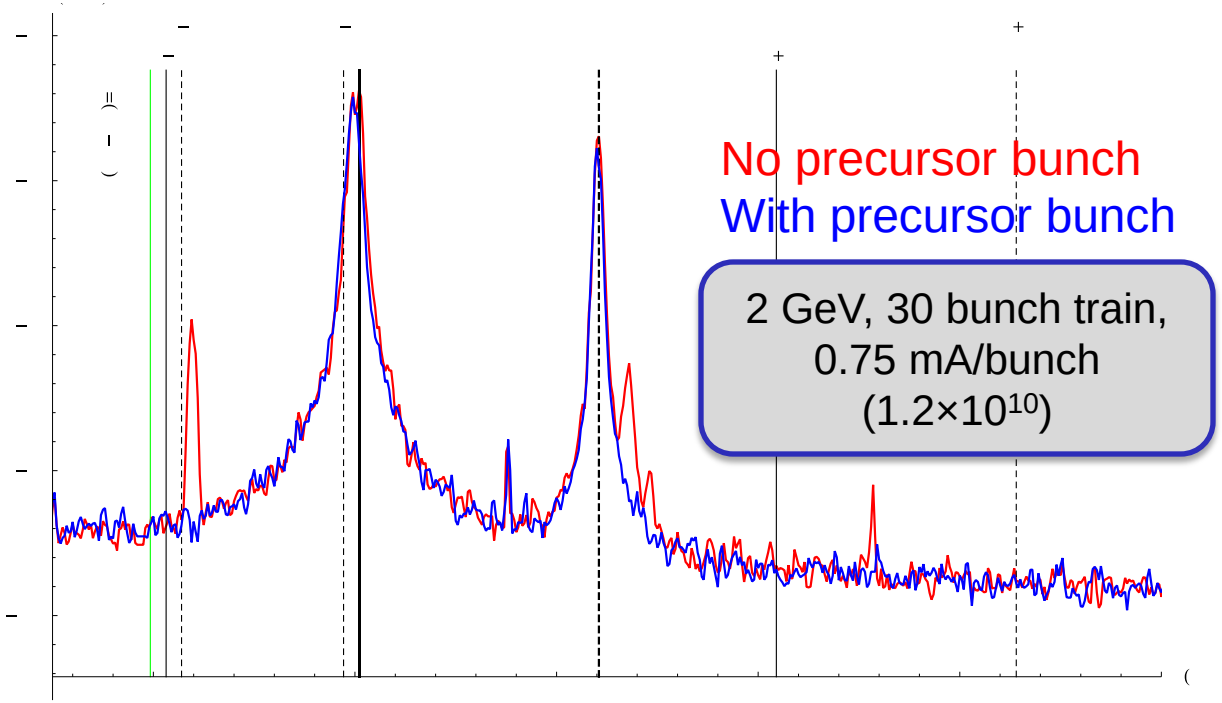






Implications for the ILC DR

- Overall we see reasonable agreement between data and simulation for the onset of the instabilities
  - Provides confidence in our evaluations of head-tail instability thresholds
  - Work is still ongoing to understand the impact of sub-threshold emittance growth
- Trapped EC in the quadrupoles and wigglers has taken on greater significance given recent obesrvations
  - Simulation and experimental efforts will continue in this area



Inputs for the ILC Technical Design

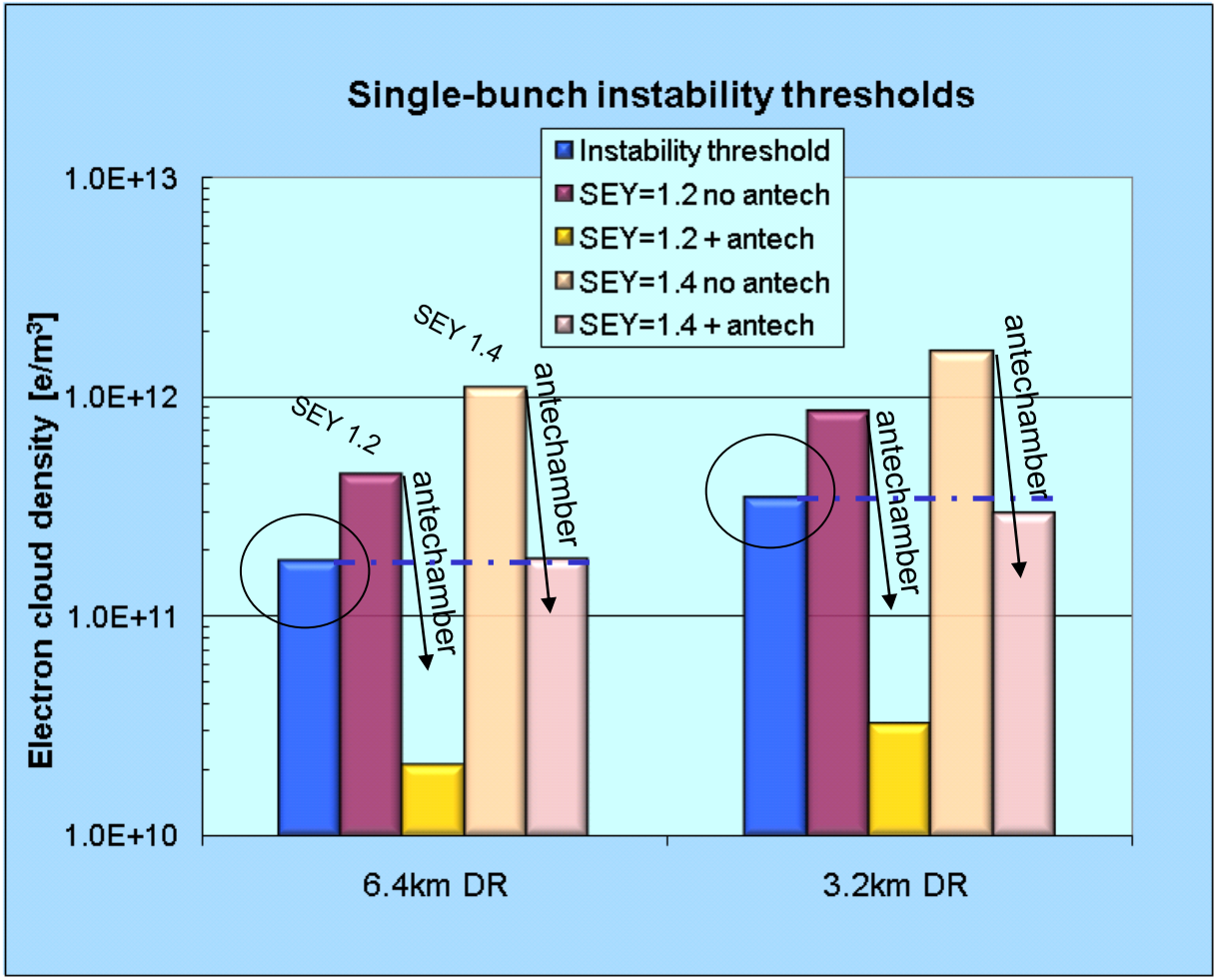
– ECLOUD `10 – October 8-12, 2010, Cornell University

- Presentation of all key CESRTA results allowed review and feedback from the EC community
- Satellite Meeting of the ILC DR EC Working Group on October 13, 2010
  - Baseline EC mitigation plan for the ILCDR using CESRTA results along with results obtained from our collaborating laboratories (particularly CERN, INFN-LNF, KEK, SLAC)
- Evaluations of the beam dynamics studies suggest that our projections of head-tail instability thresholds for the ILC DR are reasonable
  - One area of particular concern identified:
    Sub-threshold emittance growth ⇨ more margin may be required

– 3.2 km ILC Damping Ring Design

- Phase I results on EC mitigations are consistent with the low power option (1300 bunches) achieving its design goals!
- Sufficient margin exists such that this design appears viable even in the event that the allowed EC density in the ring is lowered due to concerns about sub-threshold emittance growth. Further effort to make this statement more quantitative is highly desirable!
- Concerns remain about moving to the high power option (2600 bunches) with a single positron ring (baseline plan is to add another e+ ring). Further effort to determine whether we can avoid this option is desirable!

Comparison of 6.4 and 3.2 km DR Options

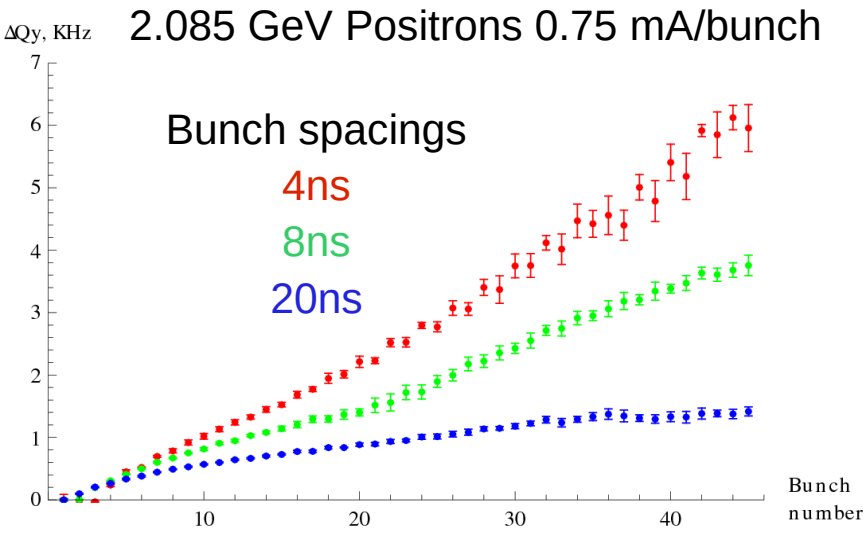


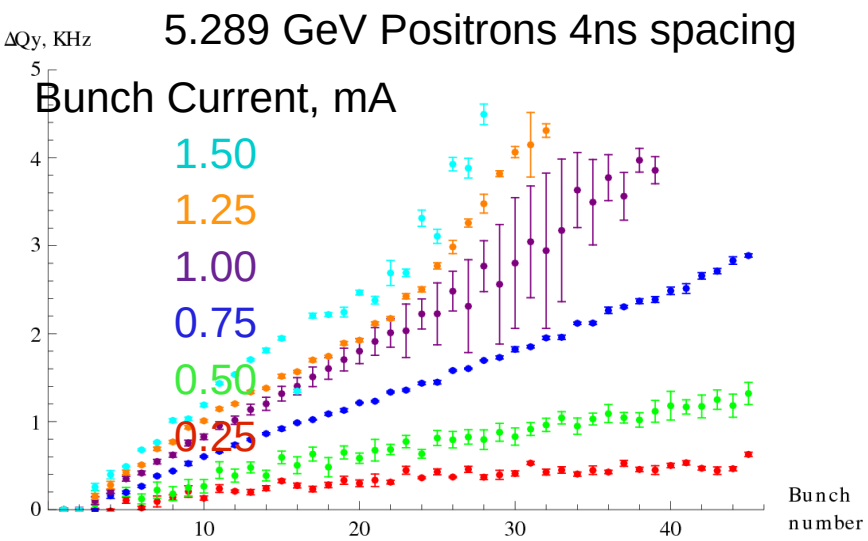
Summer 2010 Evaluation

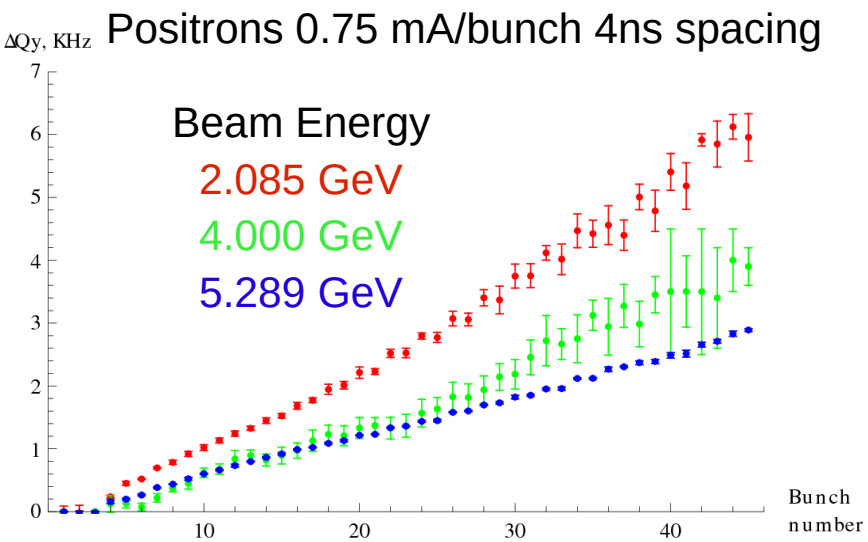
- Comparison of Single Bunch EC Instability Thresholds for:
  - 6.4km ring with 2600 bunches
  - 3.2km ring with 1300 bunches
  - ⇨ same average current
- Both ring configurations exhibit similar performance

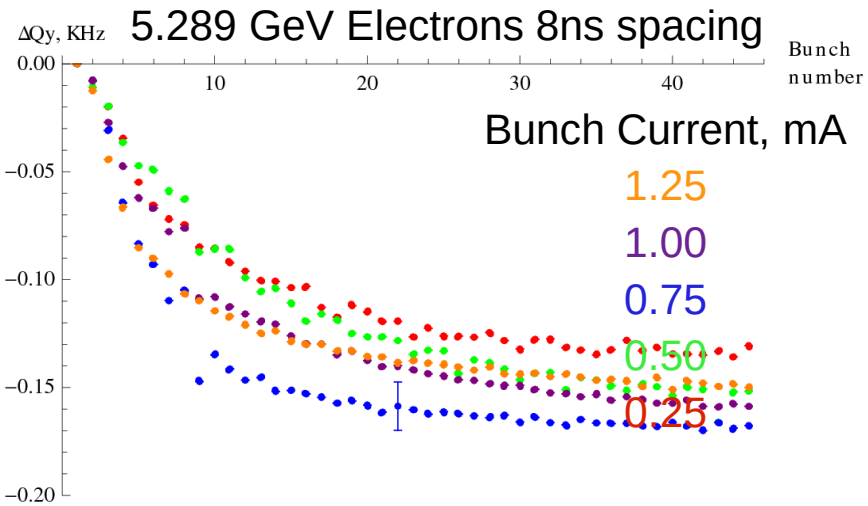
⇨ 3.2km ring (*low current option*) is an **acceptable** baseline design choice

S. Guiducci, M. Palmer, M. Pivi, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group


2.085 GeV Positrons 0.75 mA/bunch
ΔQy, KHz
Bunch spacings
4ns
8ns
20ns
Bunch number


5.289 GeV Positrons 4ns spacing
ΔQy, KHz
Bunch Current, mA
1.50
1.25
1.00
0.75
0.50
0.25
Bunch number


Positrons 0.75 mA/bunch 4ns spacing
ΔQy, KHz
Beam Energy
2.085 GeV
4.000 GeV
5.289 GeV
Bunch number


5.289 GeV Electrons 8ns spacing
ΔQy, KHz
Bunch number
Bunch Current, mA
1.25
1.00
0.75
0.50
0.25

Electron Cloud Dynamics: Beam Stability

May 8, 2012

Mike Billing, Kaitlin Butler, Mike Forster, John Flanagan,
Gabriel Ramirez, Nate Rider, Jim Shanks,
Kiran Sonnad, Heather Williams

General Overview

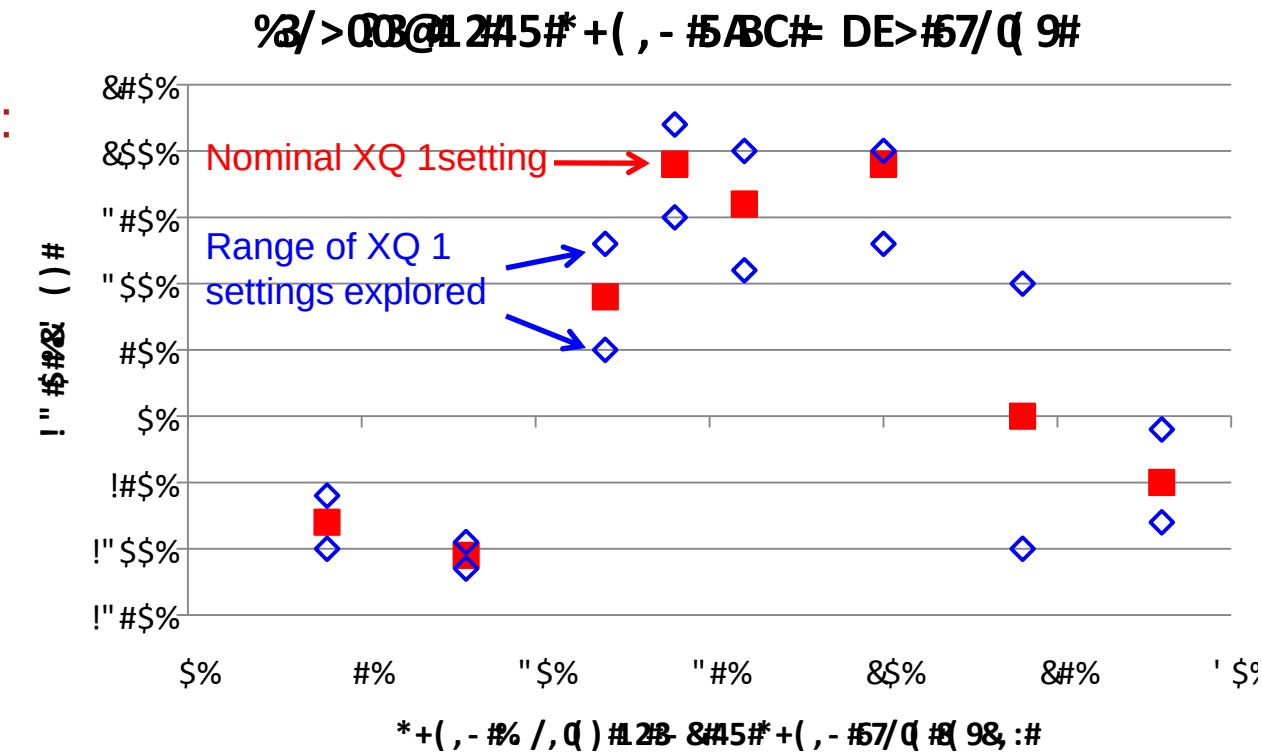
- Main Focus of Measurement Sets
  - Study stability of 30 bunch-trains 0.75 mA/bunch
  - As function of Bunch Spacing
    - 4 ns, 8 ns, 12 ns, 14 ns, 16 ns, 20 ns, 24 ns, 28 ns
  - While varying Vertical Chromaticity
    - Why? Q'v affects the damping of coherent motion
- Secondary Focus
  - Better measurement of Coherent Damping Rates
    - For Vertical Modes: Dipole (m=0) & Head-Tail (m=±1)
      i.e. at frequencies of Fv & Fv ± Fs
    - As function of Vertical Chromaticity
    - As function of Dimtel Feedback gains

EC Stabilty vs Bunch Spacing

Positrons:
30 bunch trains
With 0.75 mA/b

For a given bunch spacing:

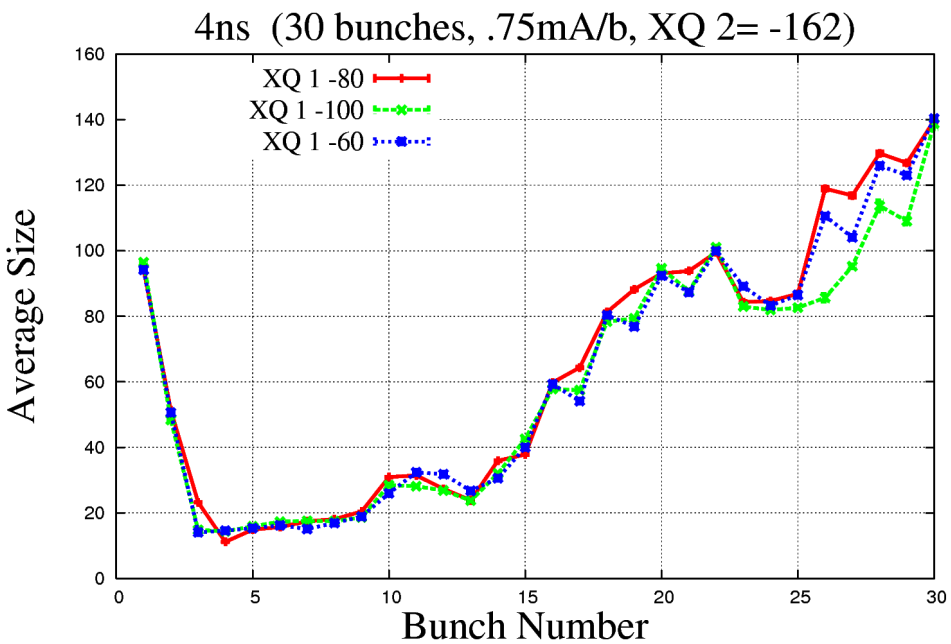
1) Observe the coherent motion of bunch 25
2) Adjust the vertical chromaticity to achieve approximately a similar level of (m=+1) HT motion
3) Take spectral & xBSM data at that chromaticity & higher and lower settings

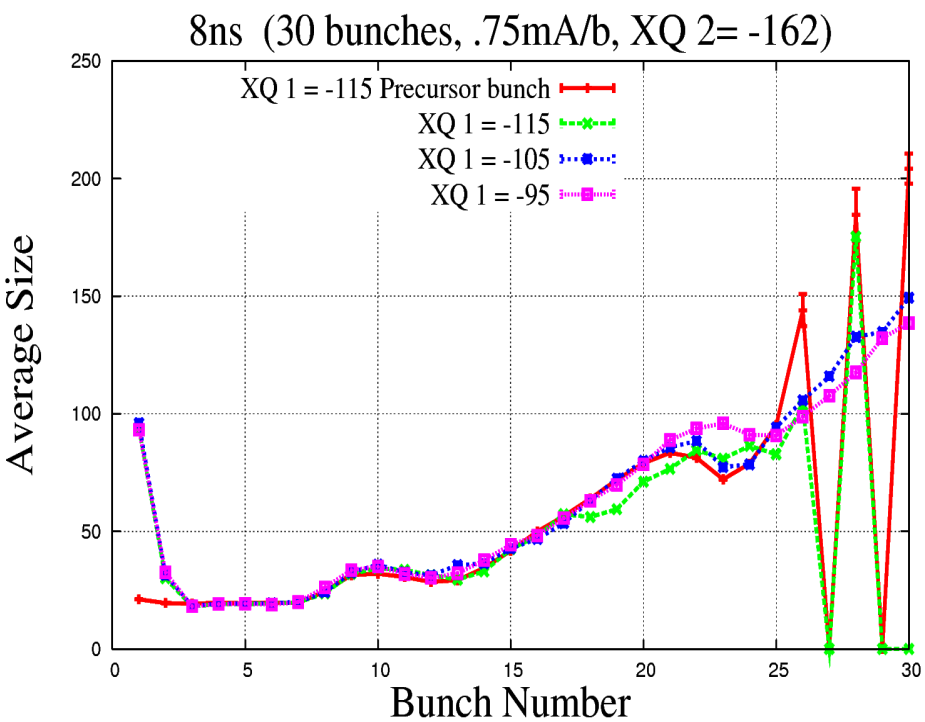


Results indicate:

Trains with spacings from 12-20 ns are less stable vertically, since they require more vertical chromaticity, Q'_v, to attain approximately the same amplitudes of self-excitation

Comparison of Beam Sizes: 4 ns, 8 ns



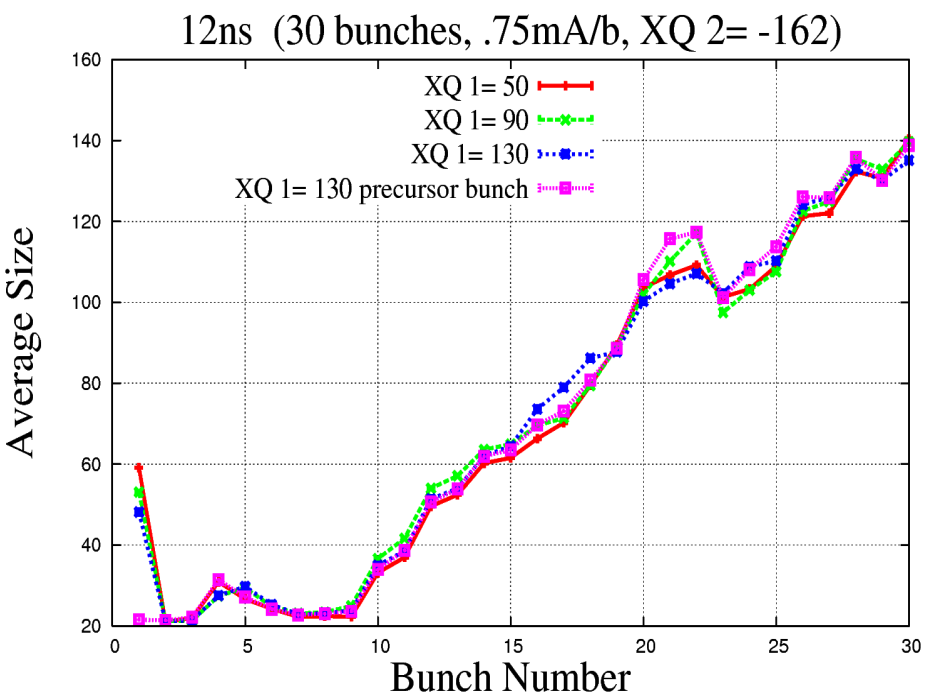


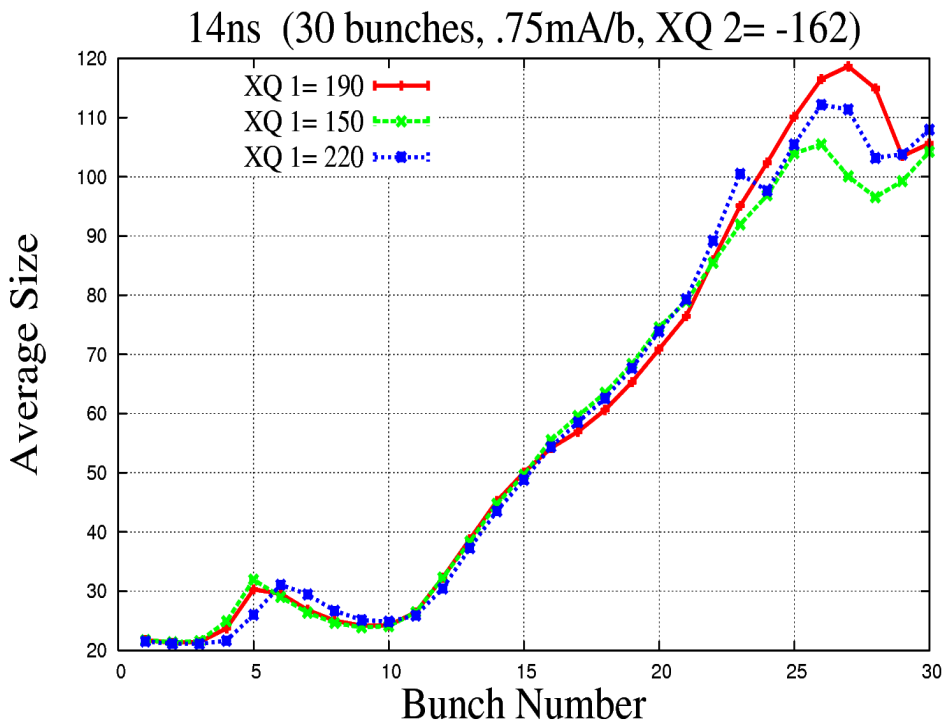
Beam sizes averaged over all turns

Precursor bunch @ ~160 ns ahead of train

Beam size does not depend on chromaticity

Comparison of Beam Sizes: 12 ns, 14 ns

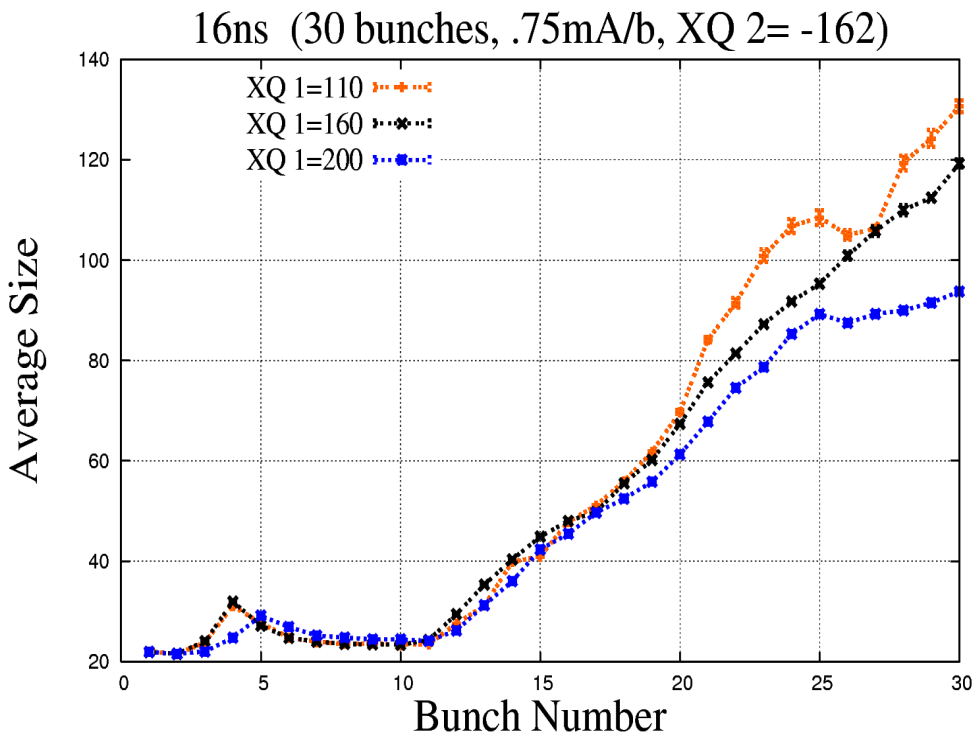


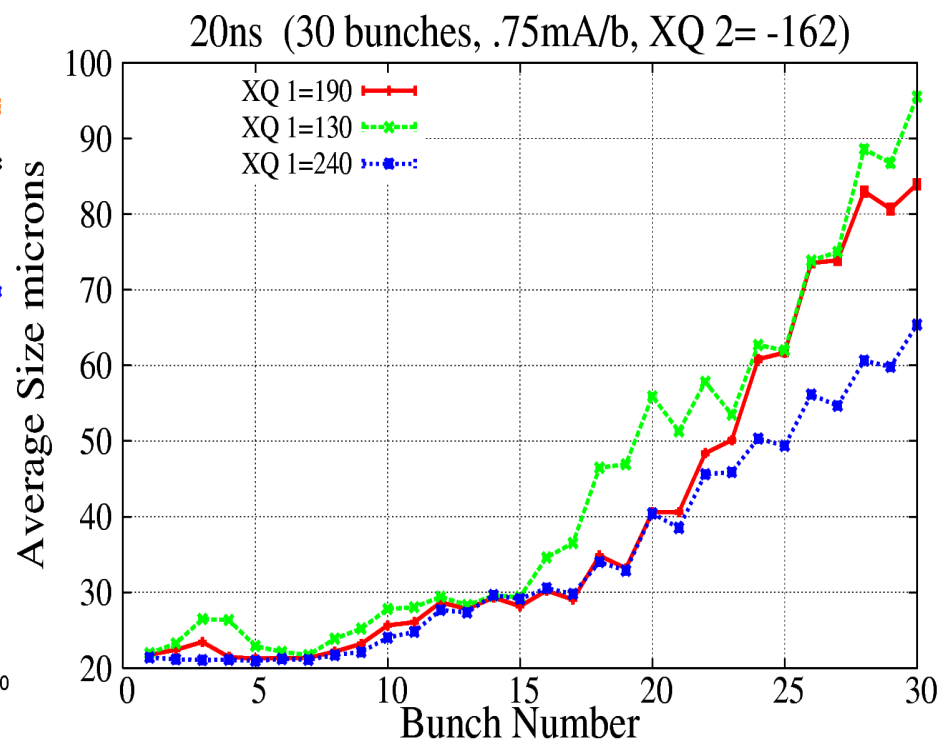


First bunch does not blow up at 14 ns but does at 12 ns

Beam sizes independent of chromaticity

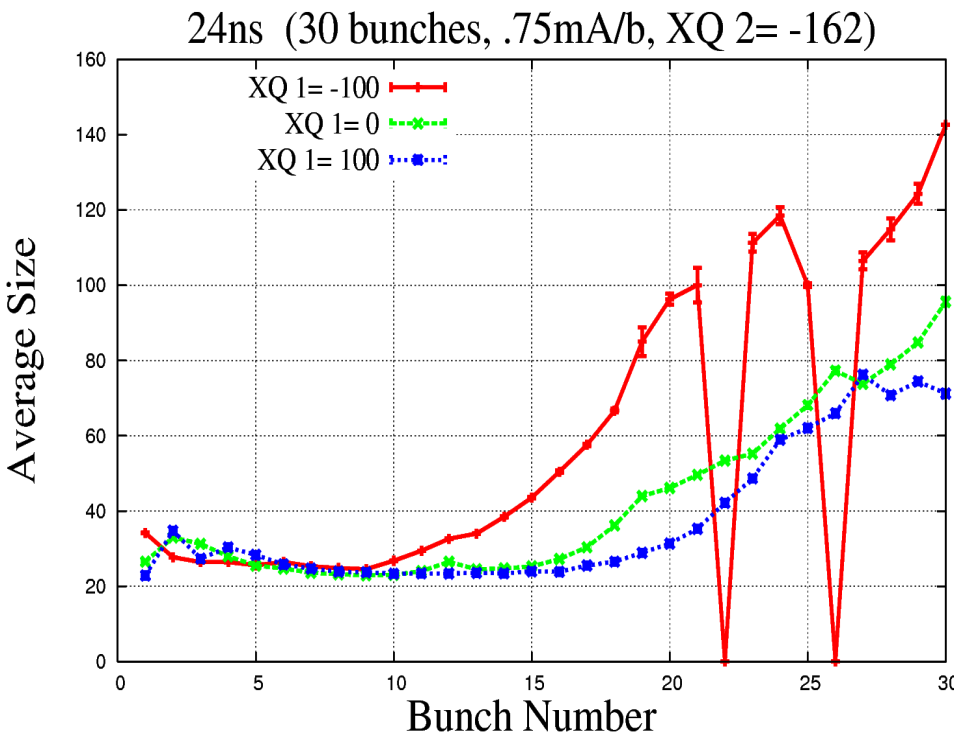
Comparison of Beam Sizes: 16 ns, 20 ns

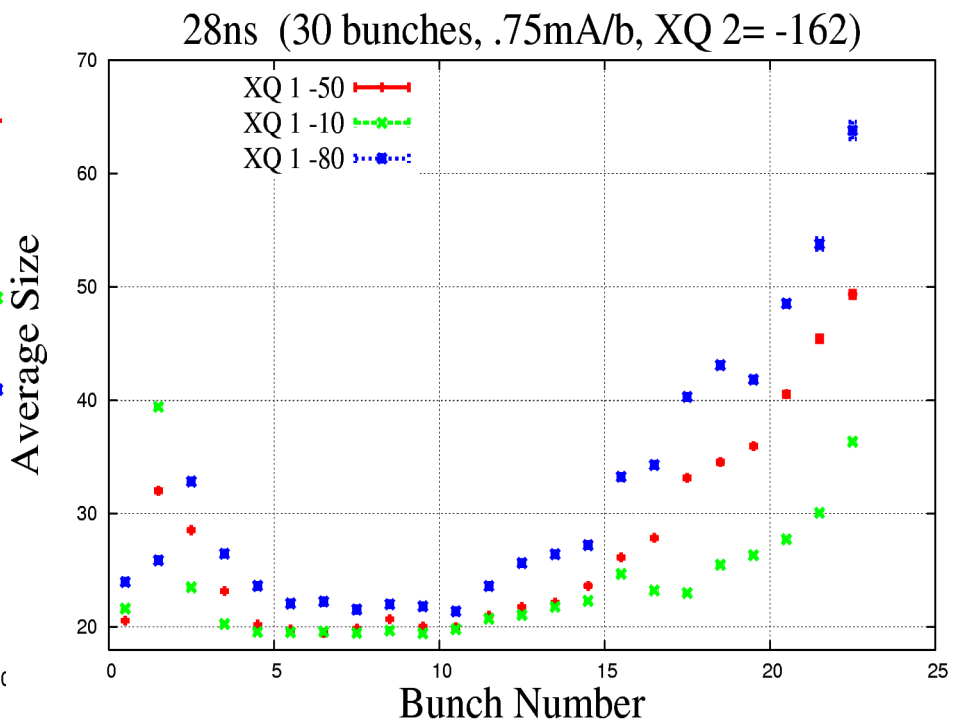




Clear dependence of beam size on chromaticity for later bunches

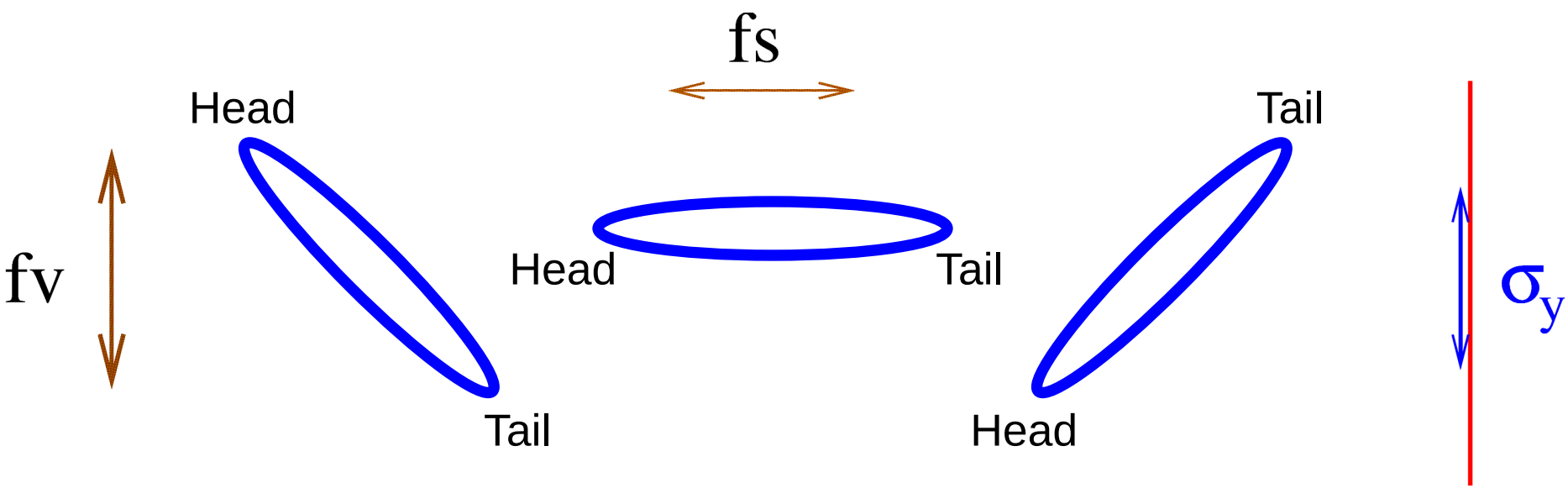
Comparison of Beam Sizes: 24 ns, 28 ns





Strong dependence of beam size on chromaticity

Head-tail Motion About Bunch Centroid



Expect the beam size to oscillate at 2 Fv with modulations at 2 Fs

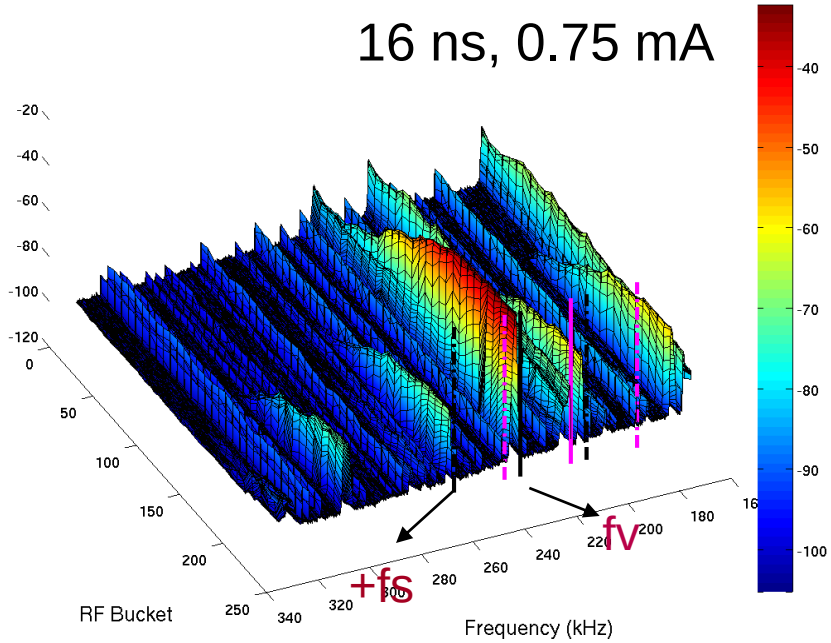
Expect beam centroid to oscillate at Fv with modulations at Fs

Unlike what is shown, the motion need not be symmetric about head and tail due to cloud pinching

Bunch Spectra from BPMs Measurements

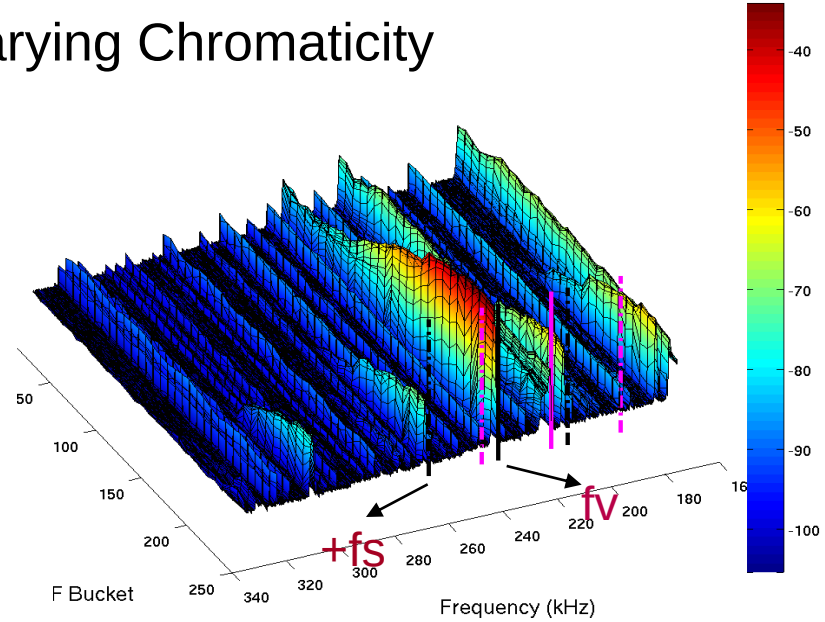
MBS Number: 000991

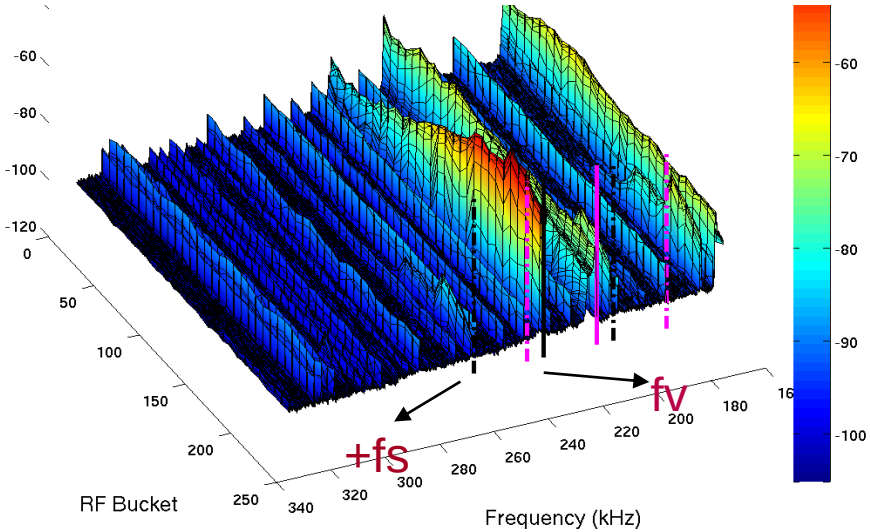
16 ns, 0.75 mA



MBS Number: 000993

Varying Chromaticity





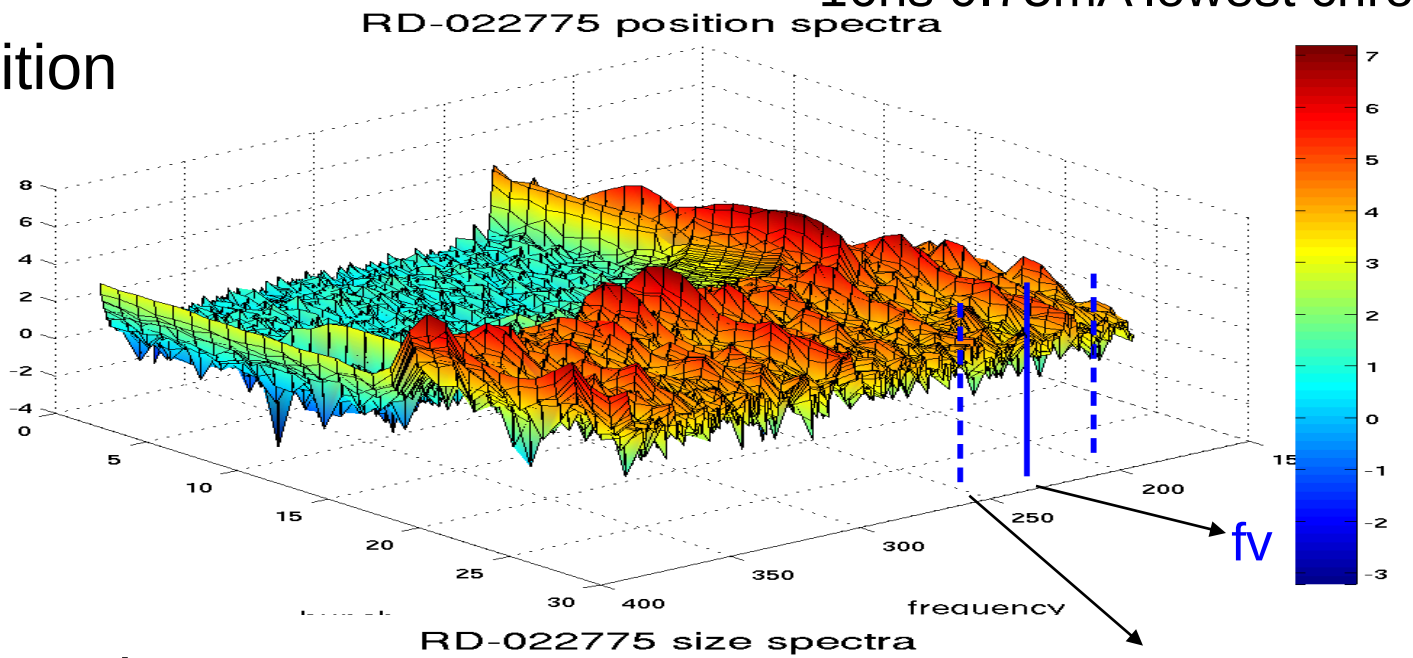
Synchrotron sidebands become smaller with increase in chromaticity

Need to analyze all cases more quantitatively and also correlate this with beam size measurements

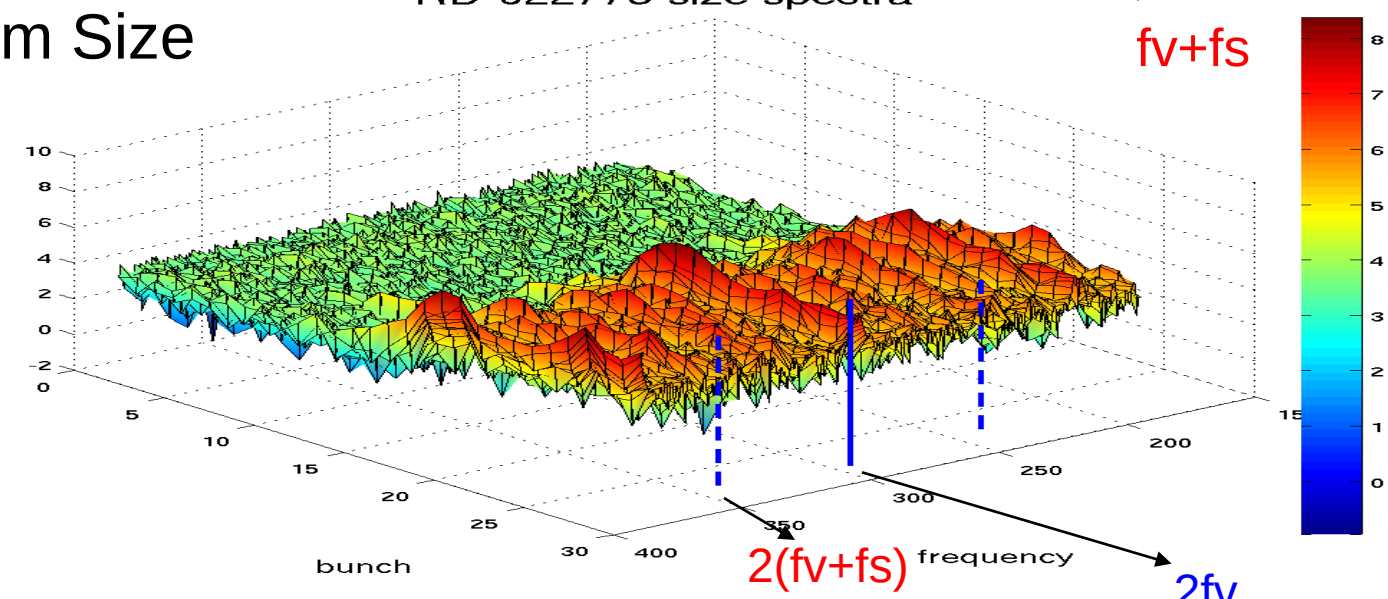
Position and size spectra of xbsm data

16ns 0.75mA lowest chromaticity case

Position



Beam Size

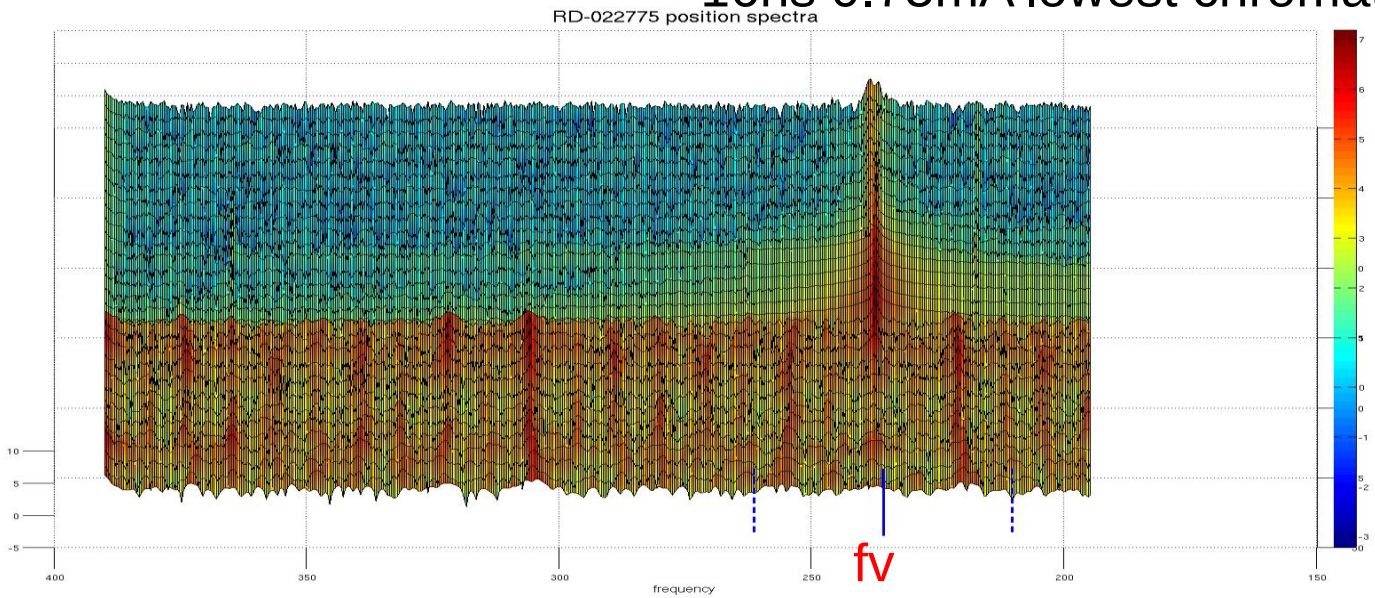


2D version
Next slide

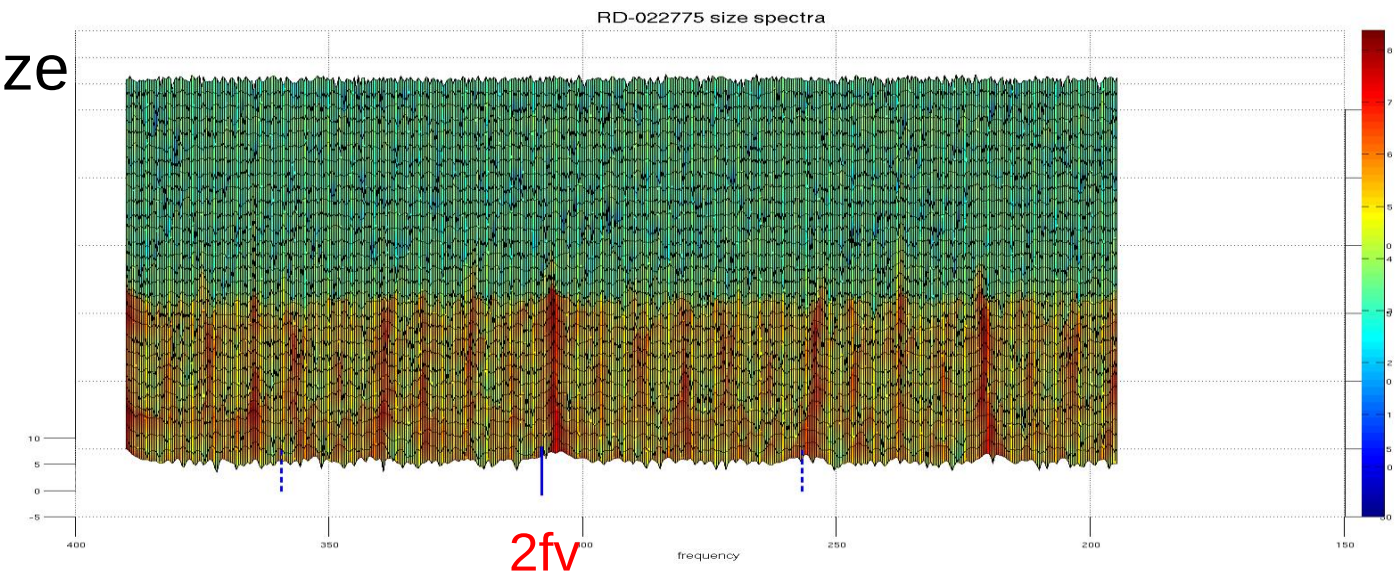
xbsm position and size spectra – 2d versions

16ns 0.75mA lowest chromaticity case

Position

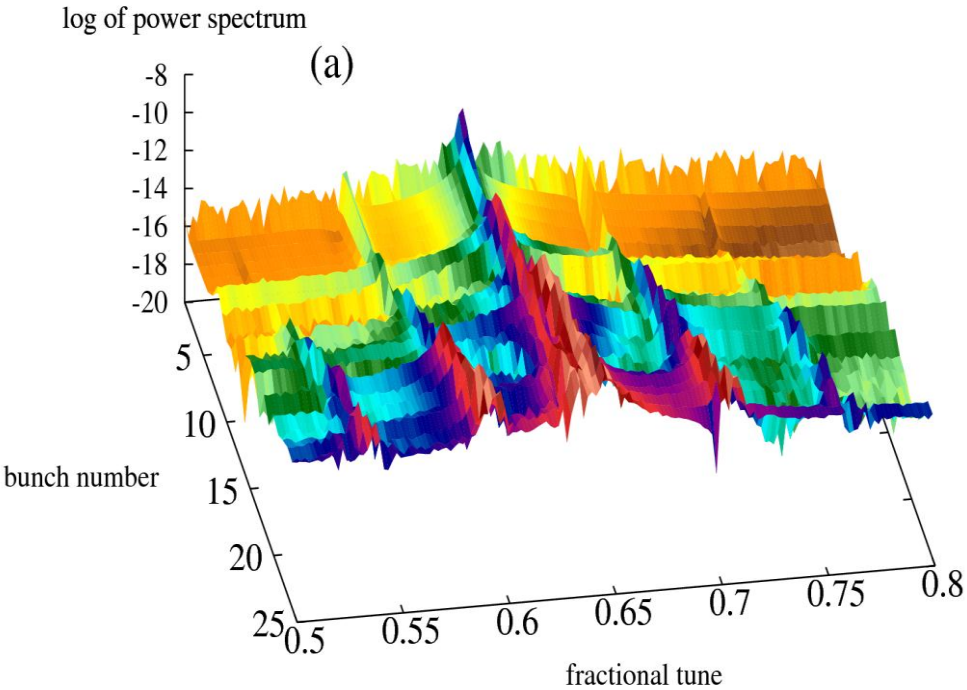


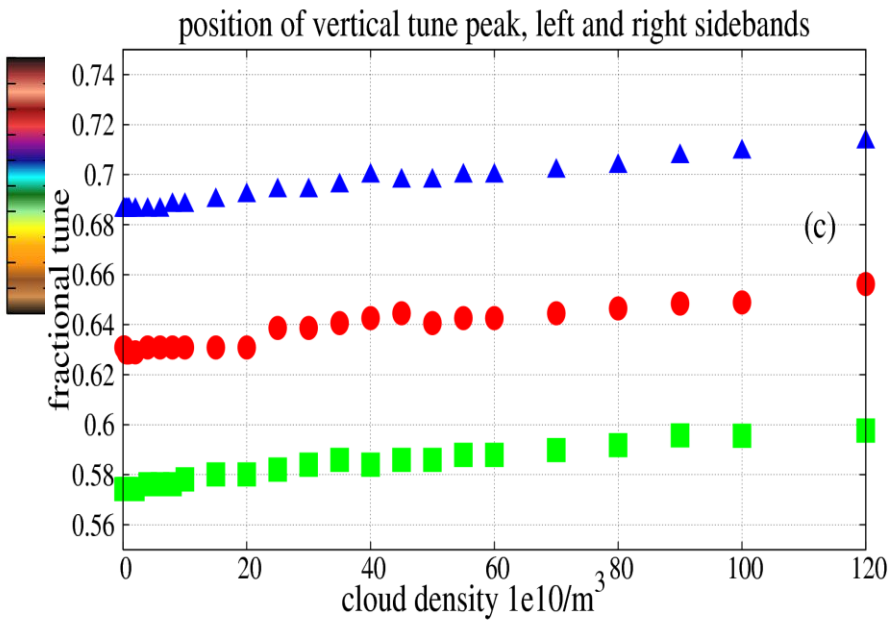
Beam Size

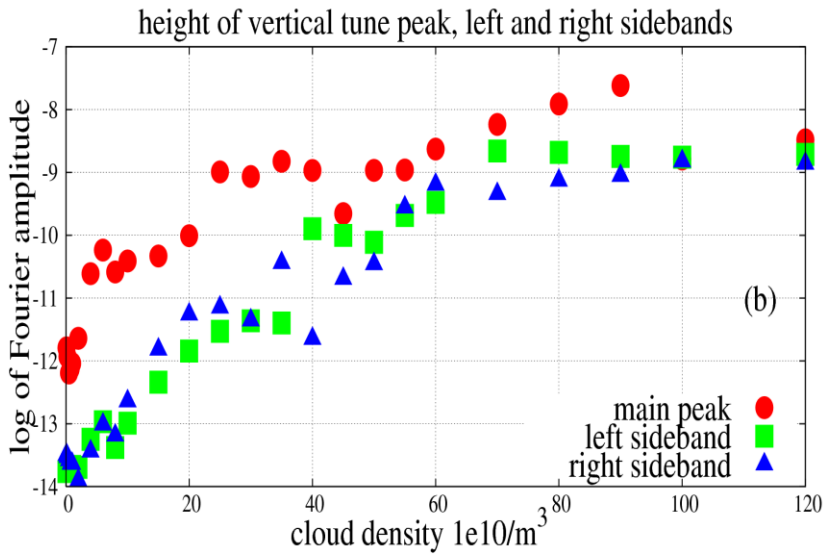


Summary

- Examined electron induced beam instabilities for various bunch spacings and chromaticities
- Beam gets most unstable at around 14 – 20 ns spacing
- Synchrotron sidebands get suppressed with increase in chromaticity – we have seen this in previous measurements as well
- xBSM shows beam size blow up is more sensitive to chromaticity at higher bunch spacing
- We have just started looking spectra from xBSM data

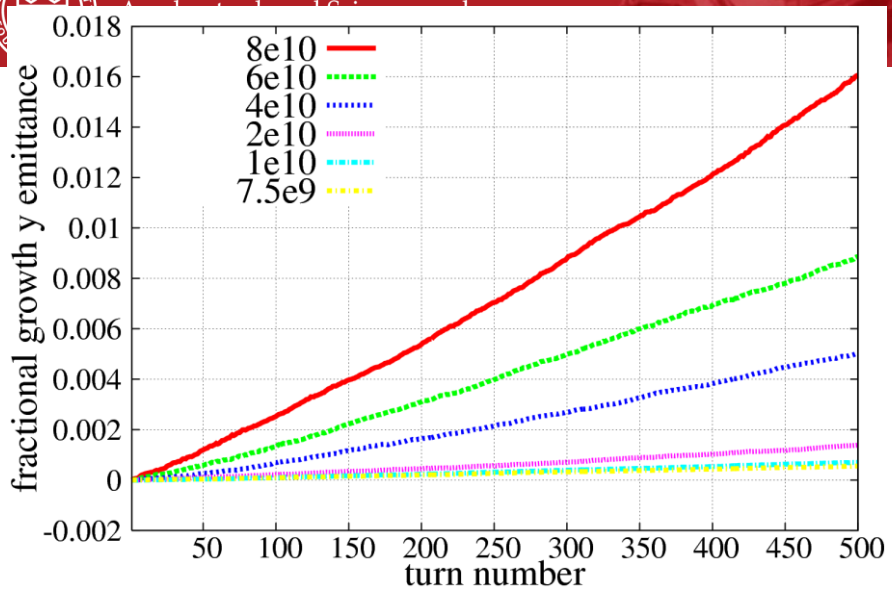


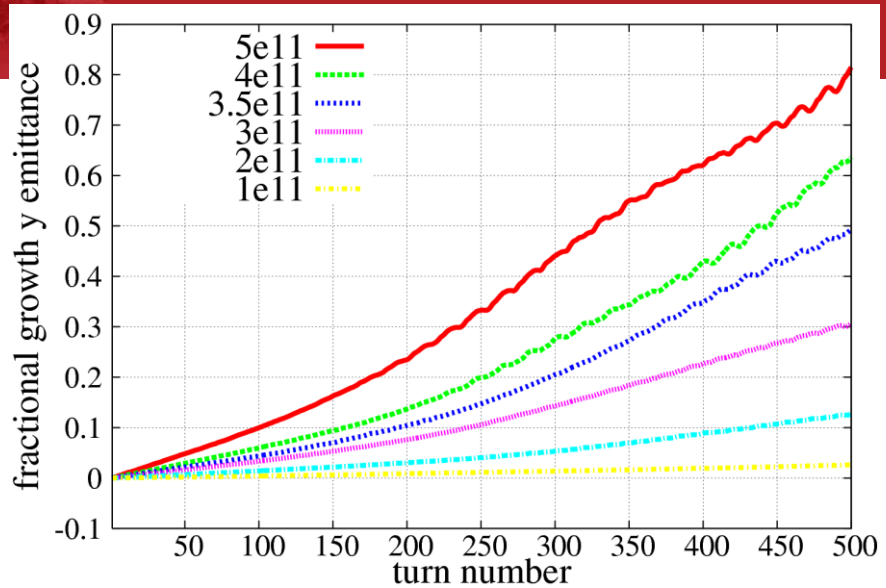


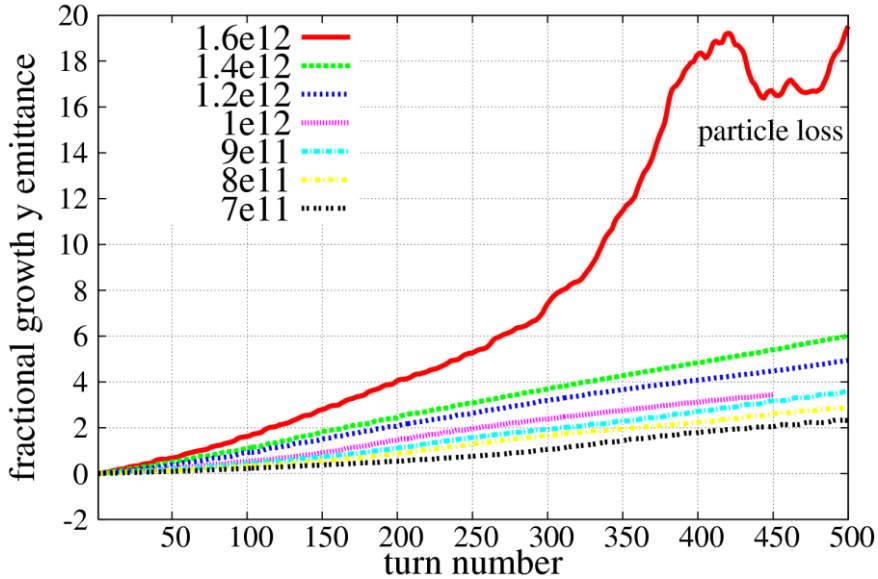


CMAD simulations
1mA bunch current,
varying cloud densities

Spectra shows presence of synchrotron sidebands (1st and 2nd order), we also see tune shifts: see 2d plots







Vertical Emittanc
1mA bunch for va
Densities Initial e