CESRTA Preliminary Recommendations for the ILC Damping Rings

Mark Palmer

Disclaimer

- This talk represents what is essentially the first pass (of several which are anticipated) at taking the results from a wide range of experiments that have been conducted at CESRTA and incorporating them into design recommendations for the ILC damping rings
  - ***But…***
    - The CESRTA data is still under active analysis
    - Many of the analyses are still being developed
    - There is still cross-checking to do with both observations and analyses developed at other machines
    - There is still a great deal of cross-checking to do for internal consistency and validity of our results
  - ***Nevertheless…***
    - A number of preliminary conclusions can be readily drawn
- So, this is a project director’s summary of a work still in progress…

Outline

- The CESRTA Electron Cloud Program
  - Goals & Capabilities
  - Brief Program Review
  - Status
- Inputs for ILC Damping Ring Design Choices
  - Mitigation Studies
    - Overview
    - Drift
    - Quadrupole
    - Bend
    - Wiggler
    - Photons and PEY
  - Beam Dynamics Studies
- Conclusion

R&D Goals

- Studies of Electron Cloud Growth and Mitigation
  - Study EC growth and methods to mitigate it (particularly wigglers and dipoles).
  - Benchmark and expand existing simulation codes
    ⇨ validate projections to the ILC DR.

- Low Emittance Operations
  - EC beam dynamics studies at ultra low emittance
    (CesrTA vertical emittance target: ε_v<20 pm-rad).
  - Beam instrumentation for ultra low emittance beams
    - x-Ray Beam Size Monitor targeting bunch-by-bunch (single pass) readout
    - Beam Position Monitor upgrade
  - Develop LET tuning tools

- Studies of EC Induced Instability Thresholds and Emittance Dilution
  - Measure instability thresholds and emittance growth at ultra low emittance
  - Validate EC simulations in the low emittance parameter regime.
  - Confirm the projected impact of the EC on ILC DR performance.

- Inputs for the ILC DR Technical Design

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 photon flux in EC experimental regions

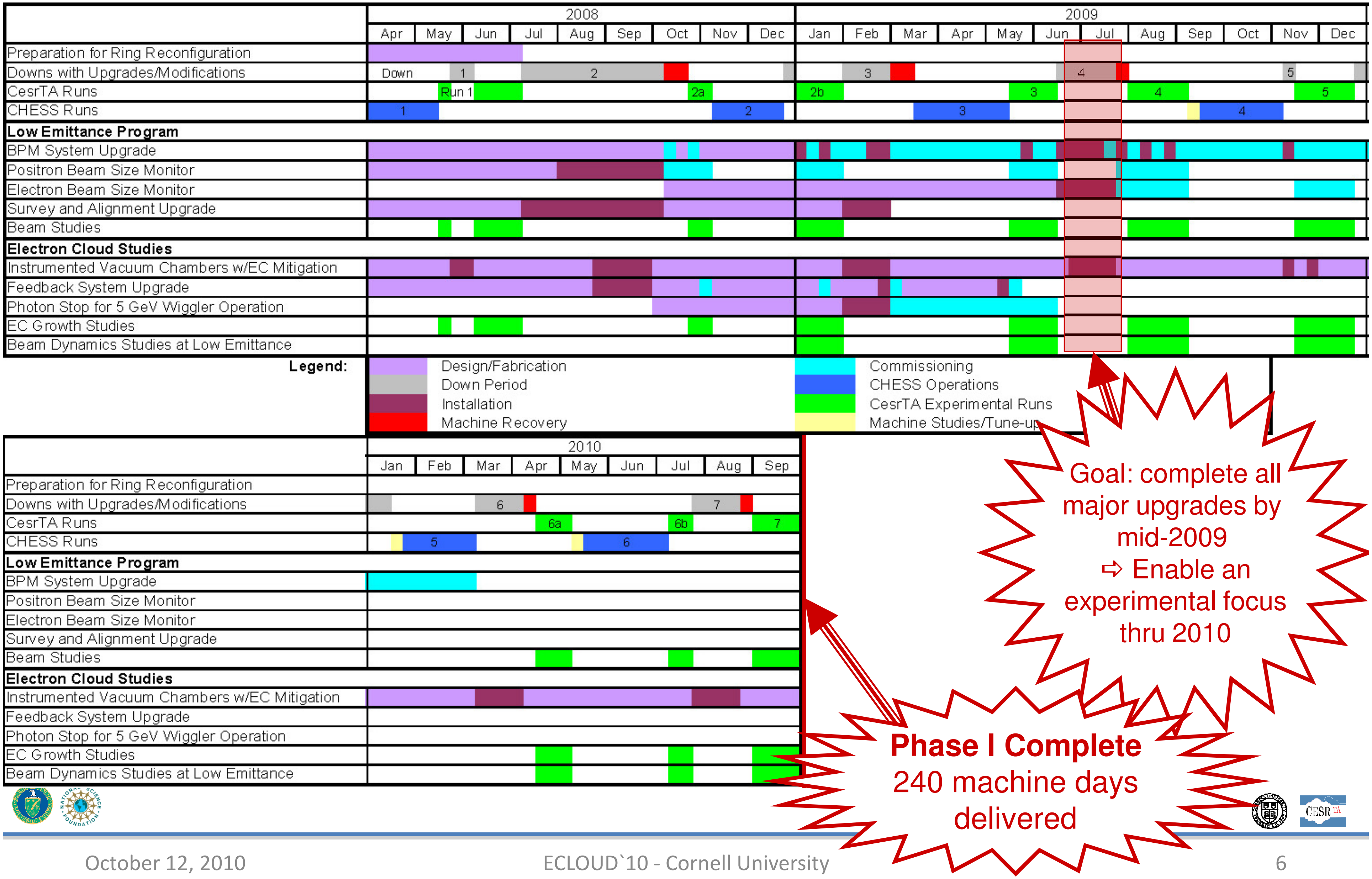
E[GeV]	Wigglers (1.9T/PM)	ε_x[nm]
1.8*	12/0	2.3
2.085	12/0	2.5
2.3	12/0	3.3
3.0	6/0	10
4.0	6 /0	23
4.0	0 /0	42
5.0	6/0	40
5.0	0/0	60
5.0	0/2	90

IBS Studies (1.8, 2.085, 2.3 GeV)

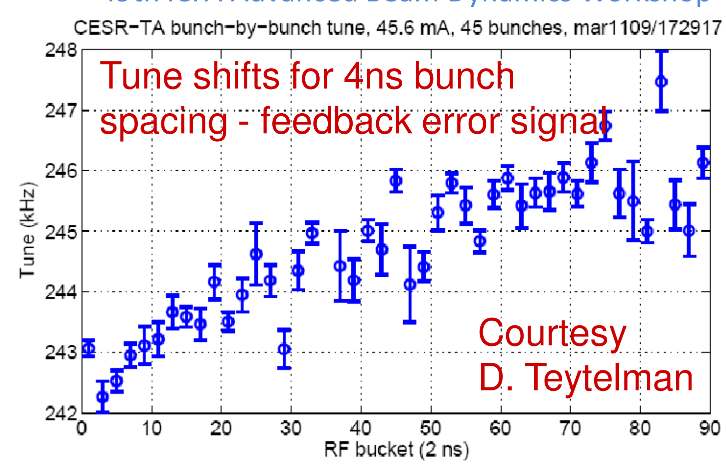
* Orbit/phase/coupling correction and injection but no ramp and recovery. In all other optics there has been at least one ramp and iteration on injection tuning and phase/coupling correction

CesrTA Phase I

- 2.5 year program



Status



- CESR is now configured with
  - 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
  - Feedback system upgrade for 4ns bunch spacing is operational
- EC Diagnostics and Mitigation
  - ~30 RFAs presently deployed
  - TE wave measurement capability in each experimental region
  - Time-resolved shielded pickup detectors in 3 experimental locations (2 with transverse information)
  - 20 individual mitigation studies conducted in Phase I
    - 18 chambers
    - 2 sets of in situ SEY measurements
    - Additional studies in preparation for Phase II extension of program
- Low Emittance Tuning and Beam Dynamics Studies
  - Operating at our target vertical emittance of 20pm
  - Continuing effort to take advantage of new instrumentation
  - A range of beam dynamics studies carried out ⇨ numerous additional tests envisioned

Where to from here?

- The next steps
  - Through mid-2011, we expect to focus heavily on analysis and detailed documentation of the studies that we've completed so far
    - Provide inputs for the ILC Technical Design
    - Identify key areas for follow-up
  - Expect that we will want to conduct a number of additional experiments for further clarification
    - 2 week run planned for late December
    - Waiting on funding for Phase II program

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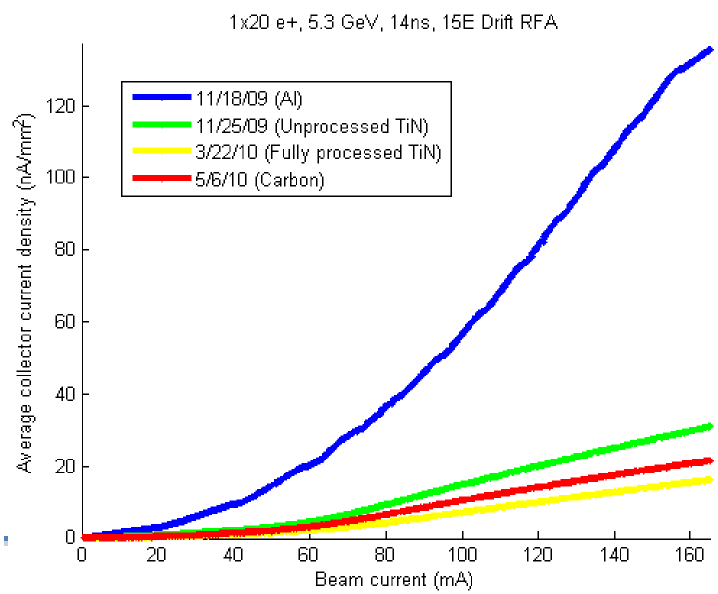
Overview of Mitigation Tests

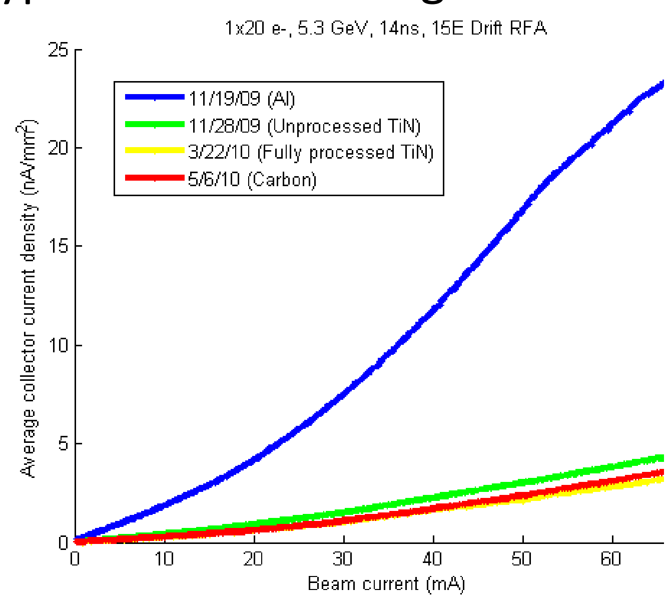
	Drift	Quad	Dipole	Wiggler	VC Fab
Al	✓	✓	✓		CU, SLAC
Cu	✓			✓	CU, KEK, LBNL, SLAC
TiN on Al	✓	✓	✓		CU, SLAC
TiN on Cu	✓			✓	CU, KEK, LBNL, SLAC
Amorphous C on Al	✓				CERN, CU
NEG on SS	✓				CU
Solenoid Windings	✓				CU
Fins w/TiN on Al	✓				SLAC
Triangular Grooves on Cu				✓	CU, KEK, LBNL, SLAC
Triangular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

✓ = chamber(s) deployed ✓ = planned

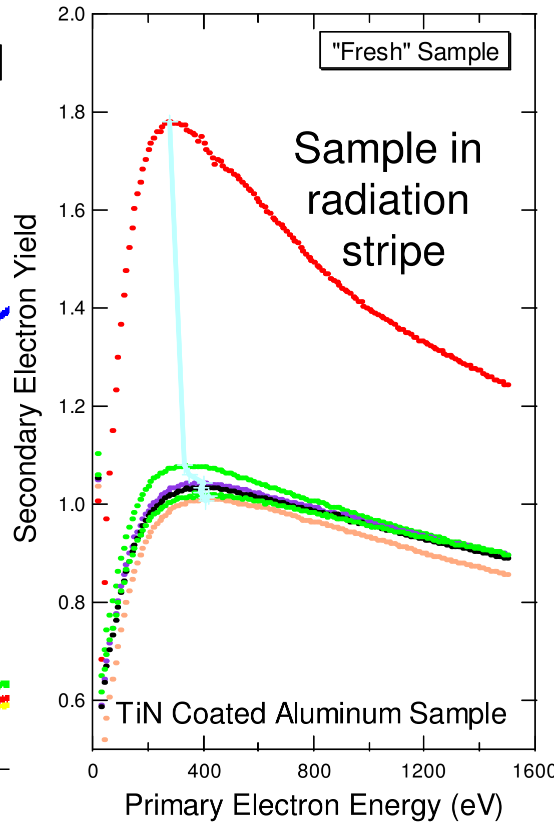
Drift Observations

- Bare Al vs TiN coating vs amorphous C coating comparisons have been carried out using the Q15E/W test regions
  - Allows for detailed relative comparison as well as comparison with simulation to determine key surface parameters (talk and poster by J. Calvey)
  - EC performance of TiN and a-C found to be quite similar in regimes with significant SEY contributions as well as regimes which should be most sensitive to PEY
- NEG tests carried out in L3 region
  - Makes detailed comparison with Q15E/W tests more challenging
- Preliminary analysis of surface parameters indicates good SEY performance by each of these 3 coatings
- Tests with other chamber types around the ring



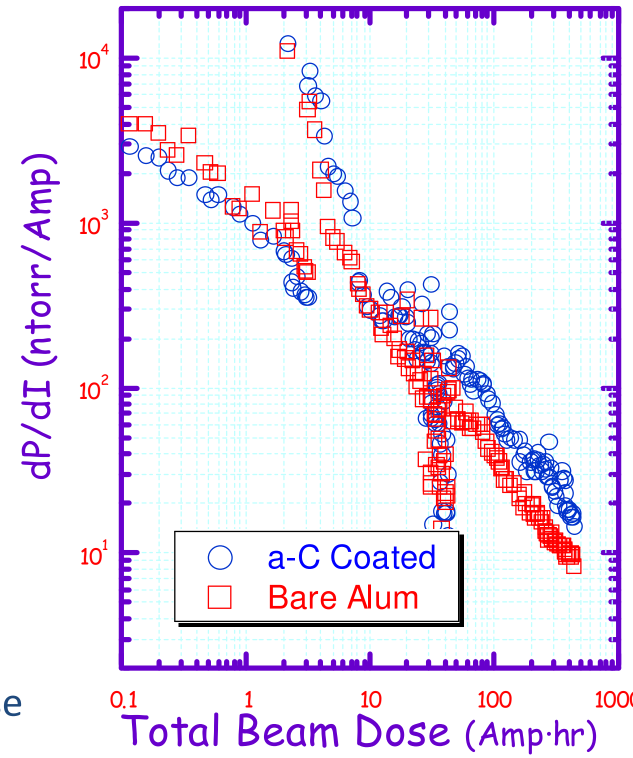


In Situ SEY Station



Drift Region Evaluation

- Efficacy
  - At our present level of evaluation, TiN, a-C and NEG show performance consistent with peak SEY values near 1.
- Cost
  - TiN coating is simplest and cheapest, however, coating costs are not a major contribution to the overall DR cost
  - The use of NEG for vacuum does require that the ring design accommodate space for heating elements for activation
- Risks
  - Further monitoring of aging performance is desirable
  - The use of solenoid coils in addition to any of the coatings would likely assure acceptable EC performance in the drifts
- Impact on Machine Performance
  - NEG would benefit overall machine vacuum performance
  - a-C and TiN show somewhat higher beam-induced vacuum rise than bare Al



- Caveats:
  - 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 not mature. Some caution should be exercised.

Overview of Mitigation Tests

	Drift	Quad	Dipole	Wiggler	VC Fab
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Cu	✓			✓	CU, KEK, LBNL, SLAC
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Amorphous C on Al	✓				CERN, CU
NEG on SS	✓				CU
Solenoid Windings	✓				CU
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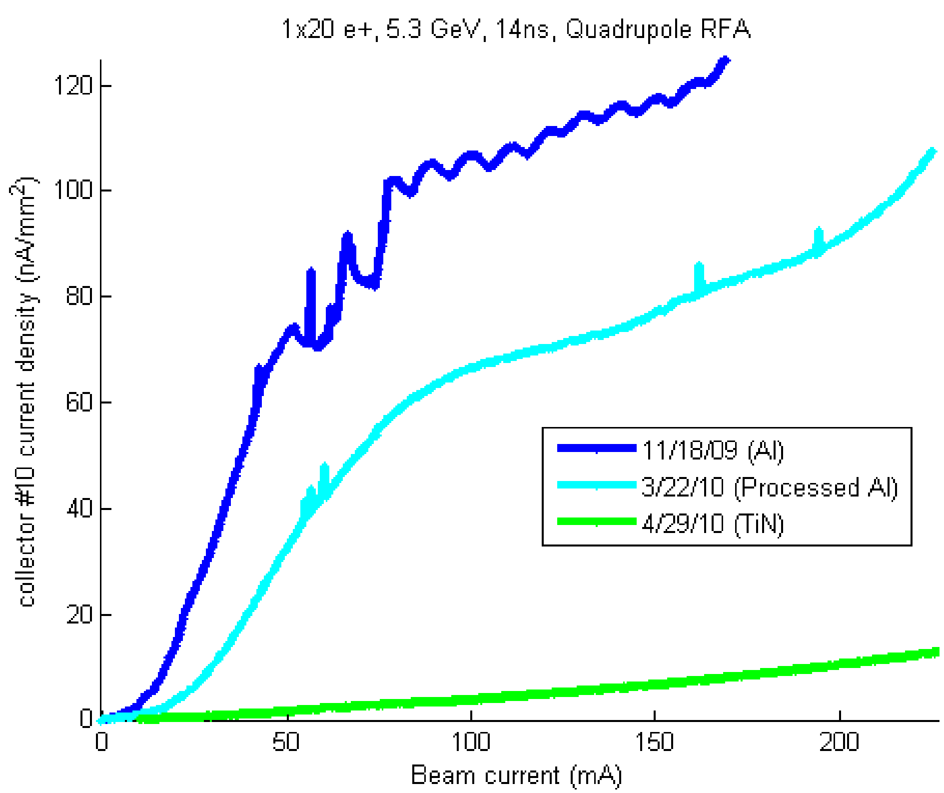
✓ = chamber(s) deployed ✓ = planned

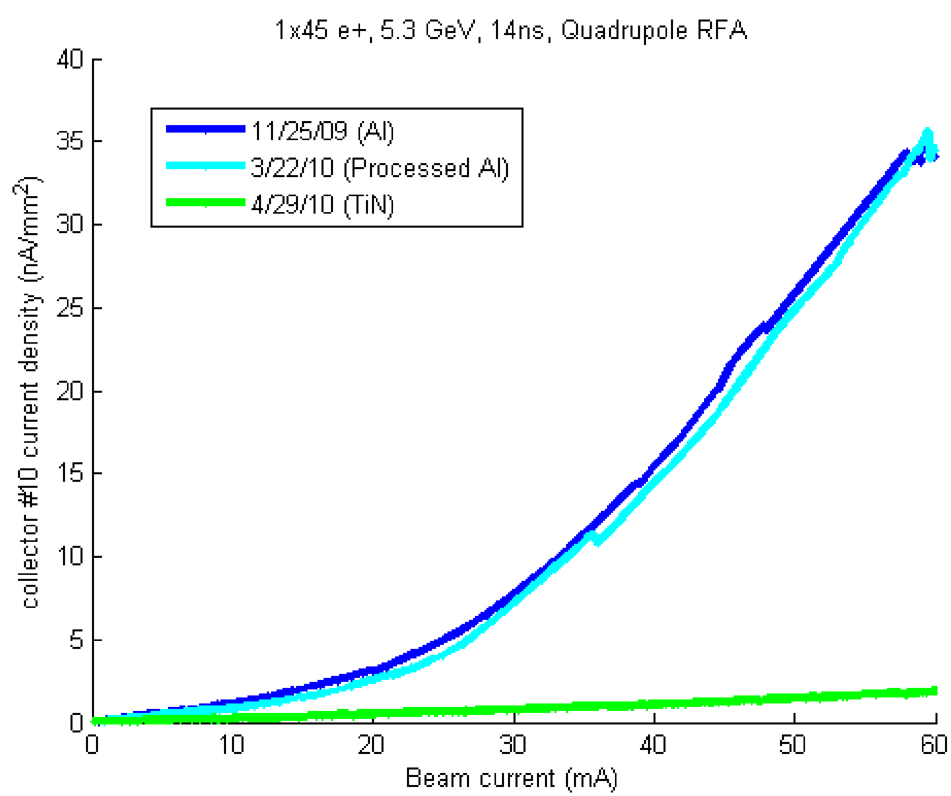
Quadrupole Observations

- Left: 20 bunch train e+
- Right: 45 bunch train e+

⇨ Clear improvement with TiN

- Currents higher than expected from "single turn" simulations
  - Turn-to-turn cloud buildup
  - Issue also being studied in wigglers





Quadrupole Evaluation

- Efficacy
  - Strong multipacting on Al surface significantly suppressed with TiN coating
- Cost
  - ----
- Risk
  - Appears to be minimal with coating
  - Final evaluation of acceptable surface parameters in quadrupoles needed to decide whether coating (as opposed, say, to coating+grooves) is acceptable
- Impact on Machine Performance
  - ----

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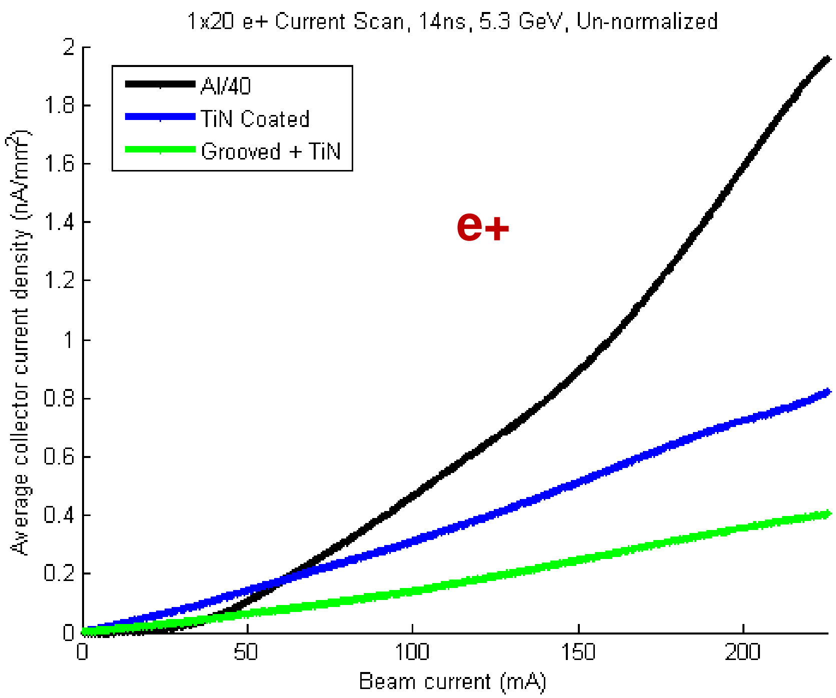
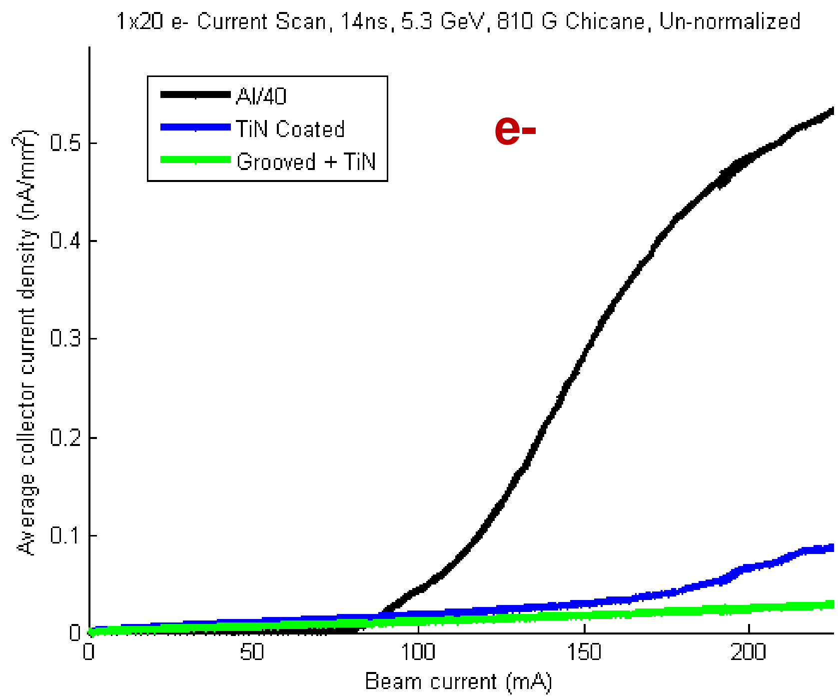
Dipole Observations

- 1x20 e+, 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)
- Cost
  - If grooves can be extruded, cost impact will not be high
- Risk
  - Principal concern is the ability to make acceptable grooved surfaces via extrusion
    - "Geometric suppression" limited by how sharp the tips and valleys of the grooves can be made
    - Coating helps ameliorate this risk
  - Machined surfaces of the requisite precision are both expensive and challenging
- Impact on Machine Performance
  - Simulations (Suetsugu, Wang, others) indicate that impedance performance will likely be acceptable

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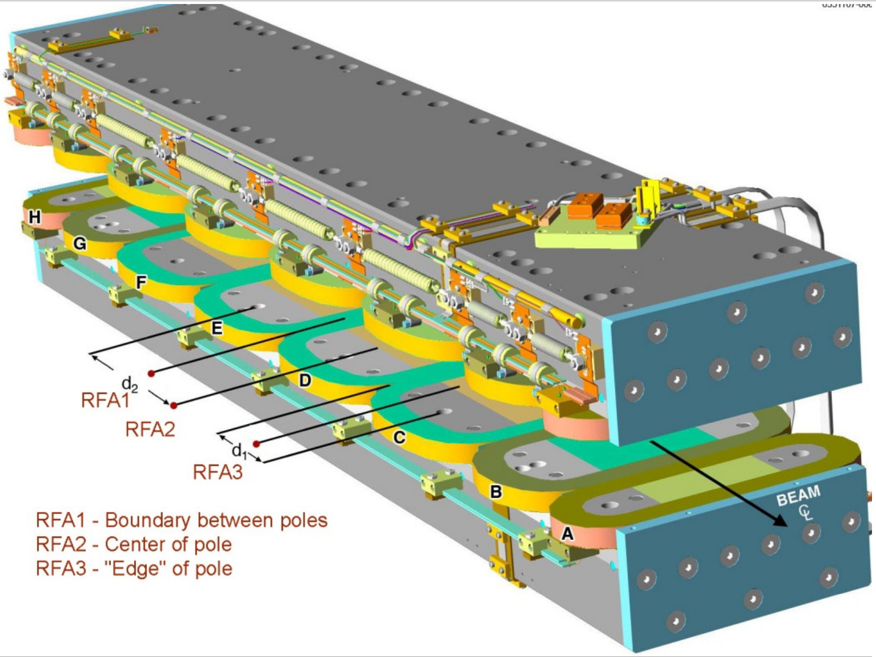
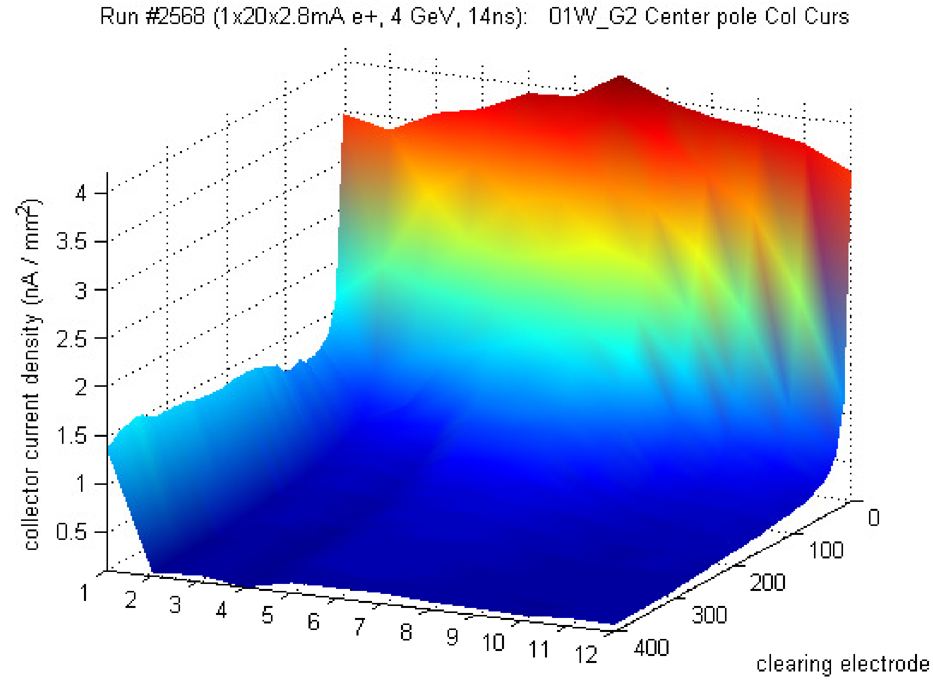
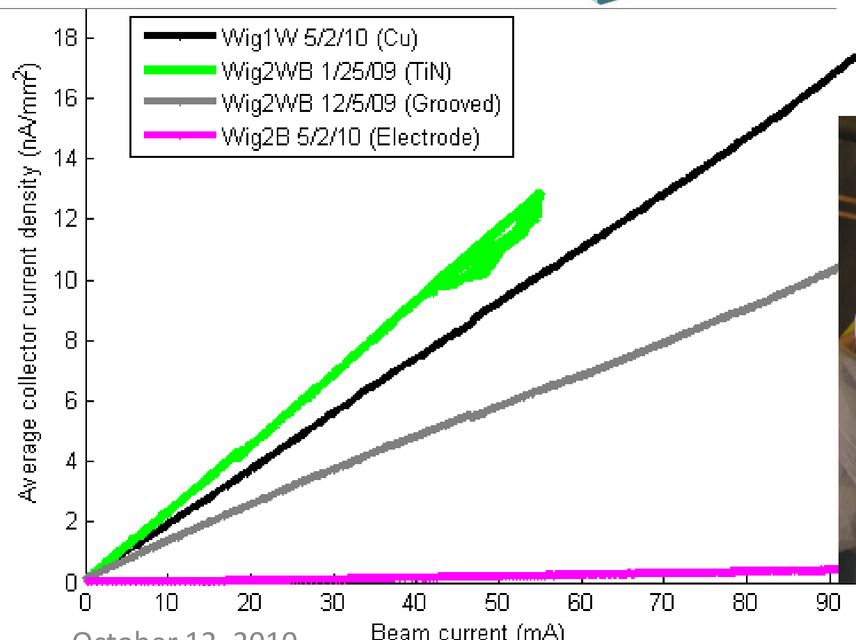
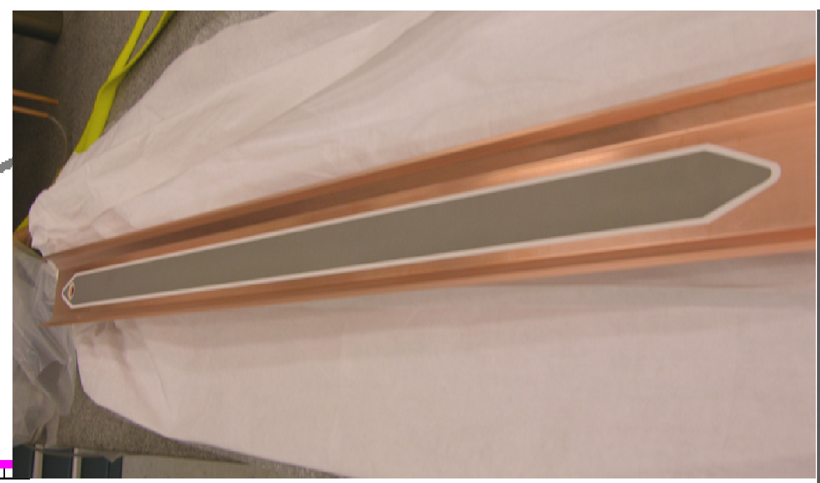
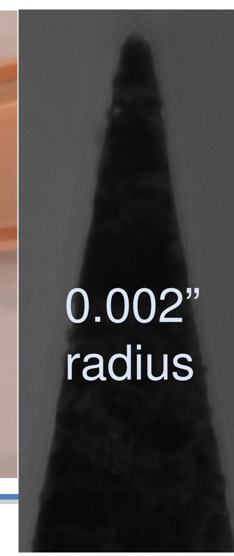
Wiggler Observations



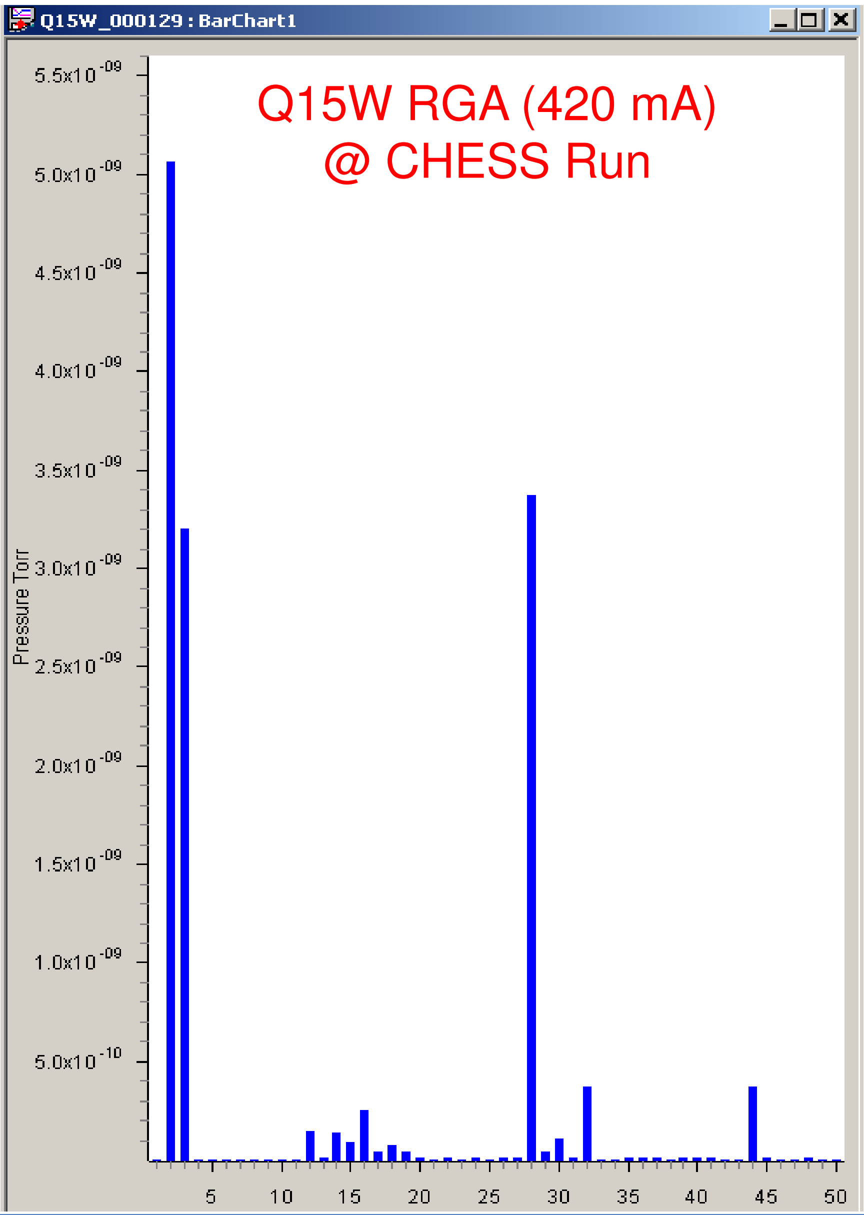








RGA Spectra


Q15W_000129 : BarChart1
Q15W RGA (420 mA)
@ CHESS Run
Pressure Torr
5.5x10-09
5.0x10-09
4.5x10-09
4.0x10-09
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3.0x10-09
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2.0x10-09
1.5x10-09
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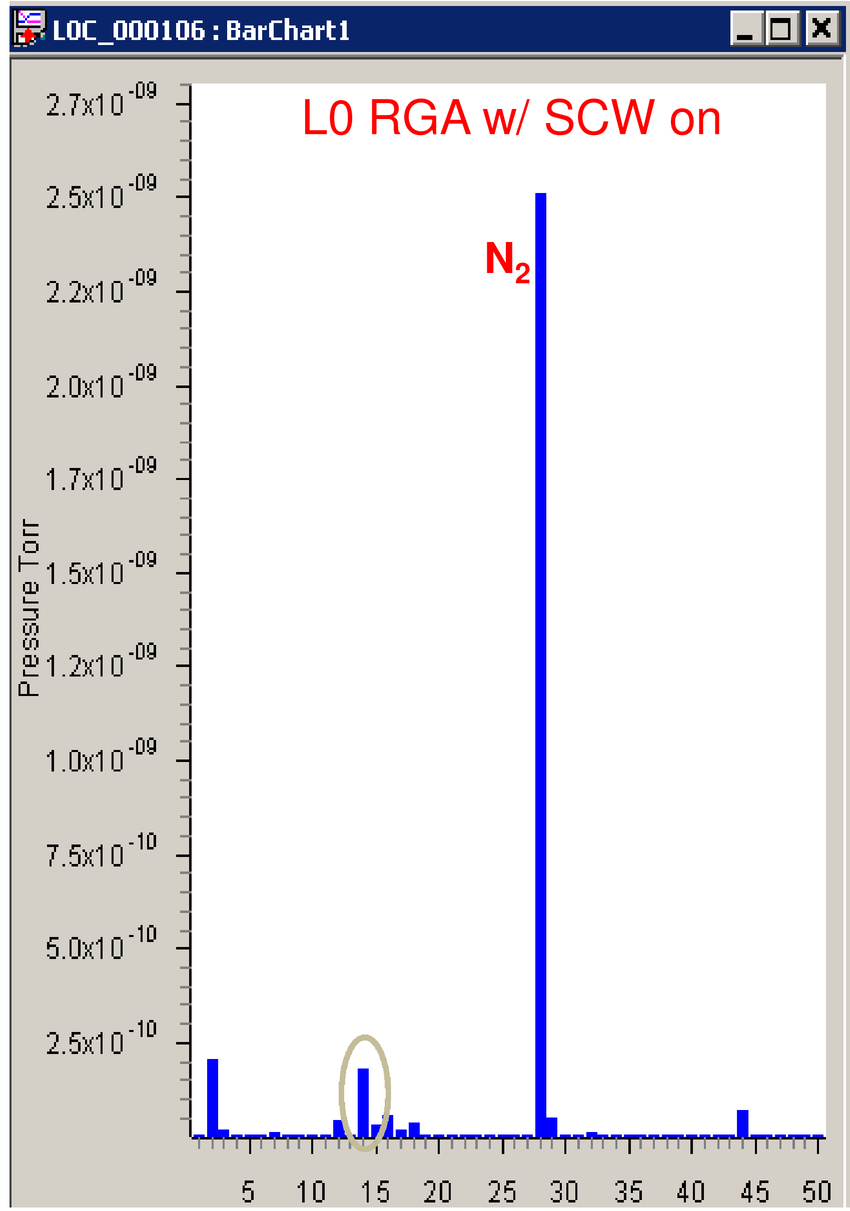
5.0x10-10
5 10 15 20 25 30 35 40 45 50


LOC_000106 : BarChart1
L0 RGA w/ SCW on
N2
Pressure Torr
2.7x10-09
2.5x10-09
2.2x10-09
2.0x10-09
1.7x10-09
1.5x10-09
1.2x10-09
1.0x10-09
7.5x10-10
5.0x10-10
2.5x10-10
5 10 15 20 25 30 35 40 45 50

Wiggler Evaluation

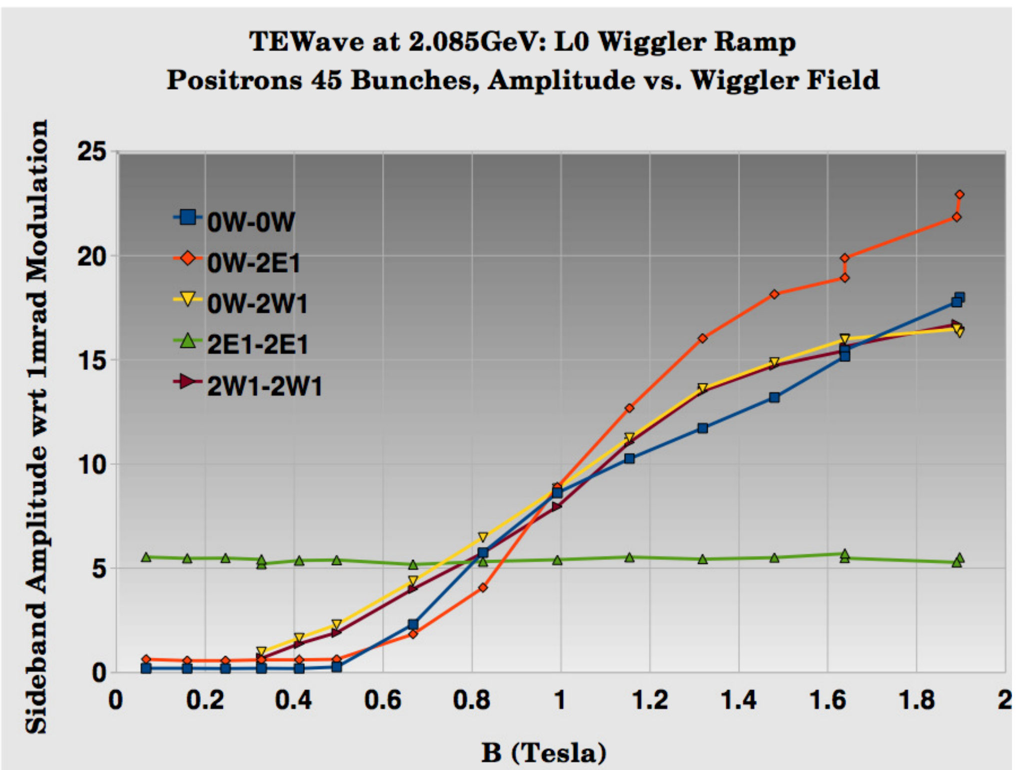
- Efficacy
  - Best performance obtained with clearing electrode
- Cost
  - Requirement for electrode application (addition E-beam welds) and HV vacuum feedthroughs will increase chamber cost
  - Also need power supplies and hardware to absorb HOM power
- Risk
  - Always concerns about electrode reliability
    - 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 Performance
  - Impedance should be acceptable for the limited length of the wiggler section (see, eg., evaluation by Y. Suetsugu)

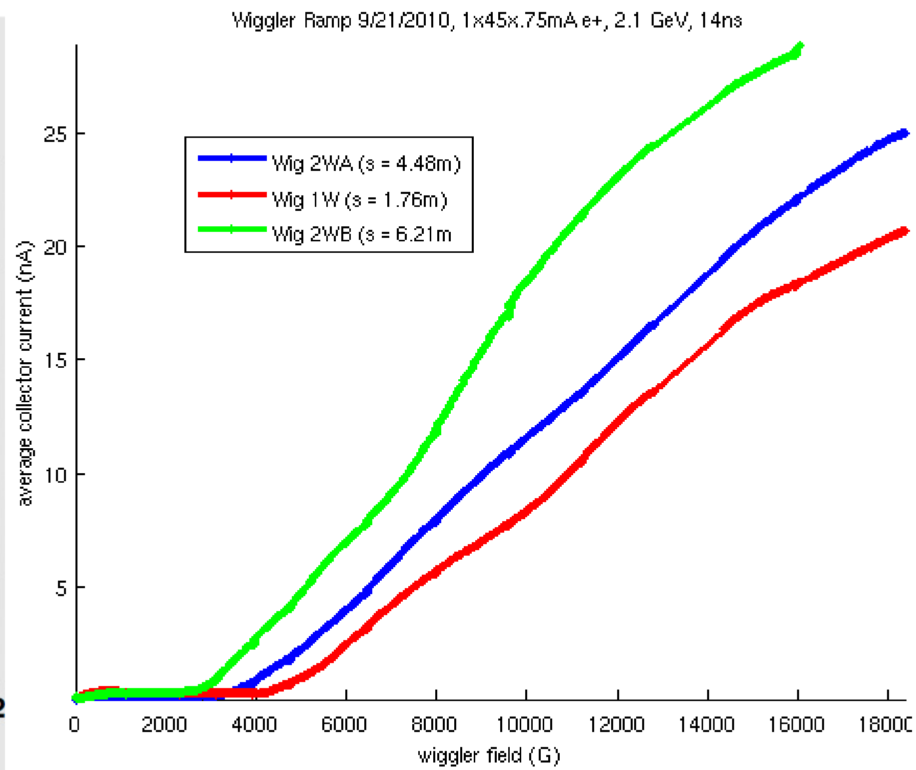
Photons and PEY

- Our simulations and data indicate that we need to have a better photon and reflection transport model (QE fits in J. Calvey's talk, APS absorber-region data in K. Harkay's talk)
- Time-resolved measurements indicate that we also need to have a better PE spectrum (fitting of RFA data also requires this)
- Synrad3D offers a better reflection model, but there is still significant work to do
- Items still needing to be addressed
  - Diffuse scattering
    - As confirmed by our recent L0 wiggler measurements (talks by J. Calvey, S. De Santis)
  - Surface roughness issues
    - As discussed yesterday
- Requirements for control of PE in the ILC DR (also the CLIC DR) make this a high priority for the upcoming months

Wiggler Ramp

- Plots show TE Wave and RFA response as a function of wiggler field strength
  - Beam conditions:
    - 1x45x~.75mA e+,
    - Normalized to beam current
    - 2.1 GeV, 14ns





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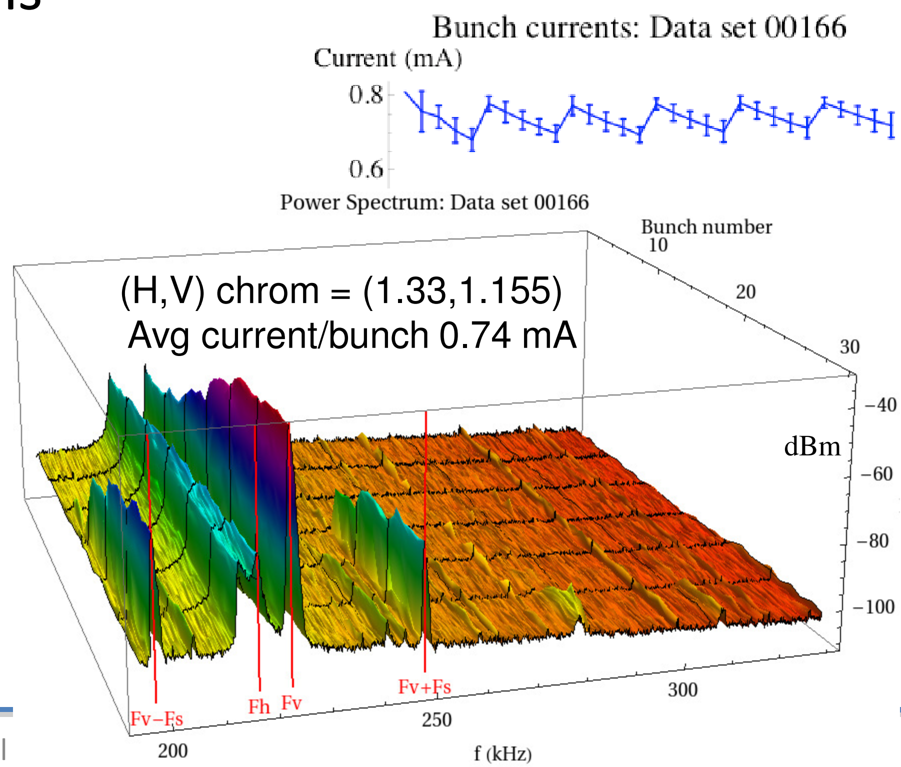
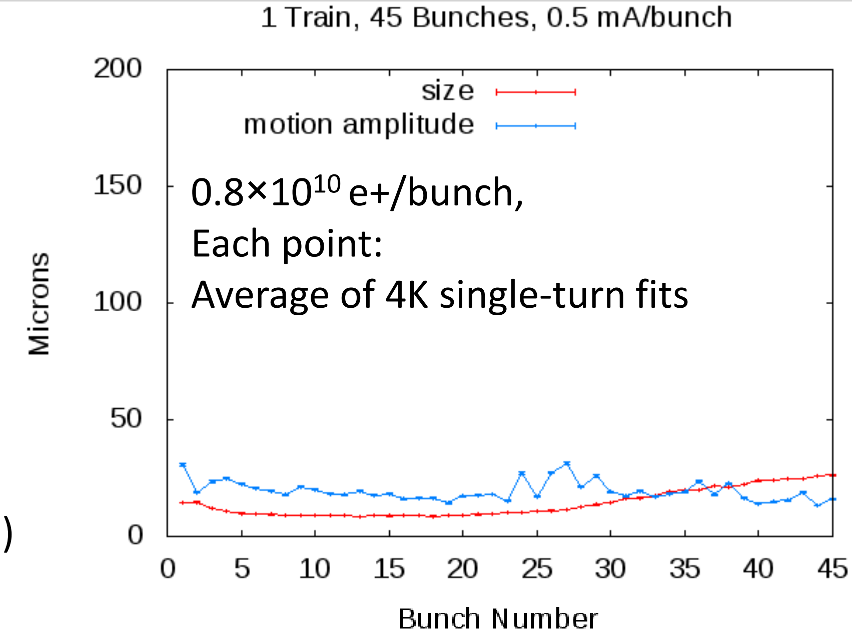
Systematic Studies of Instability Thresholds

- The implemented spectral methods offer a powerful tool for self-consistent analysis of the onset of instabilities
  - Tune shifts along train ⇨ ring-wide integrated cloud density near beam with minimal bias
  - Onset of synchrobetatron sidebands allows one evaluations of the relevant thresholds
- Have explored a range of conditions during most recent run
  - Much more to study
  - Need to further explore regime where can correlate with beam size measurements
  - Higher currents, longer trains, different bunch spacings, energy, ….
- Most importantly, more detailed data-simulation comparisons

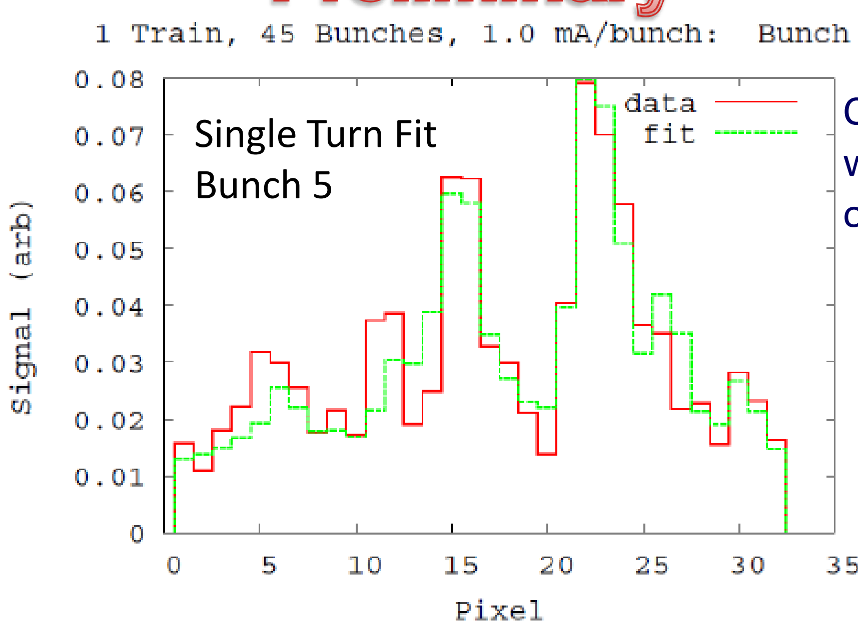


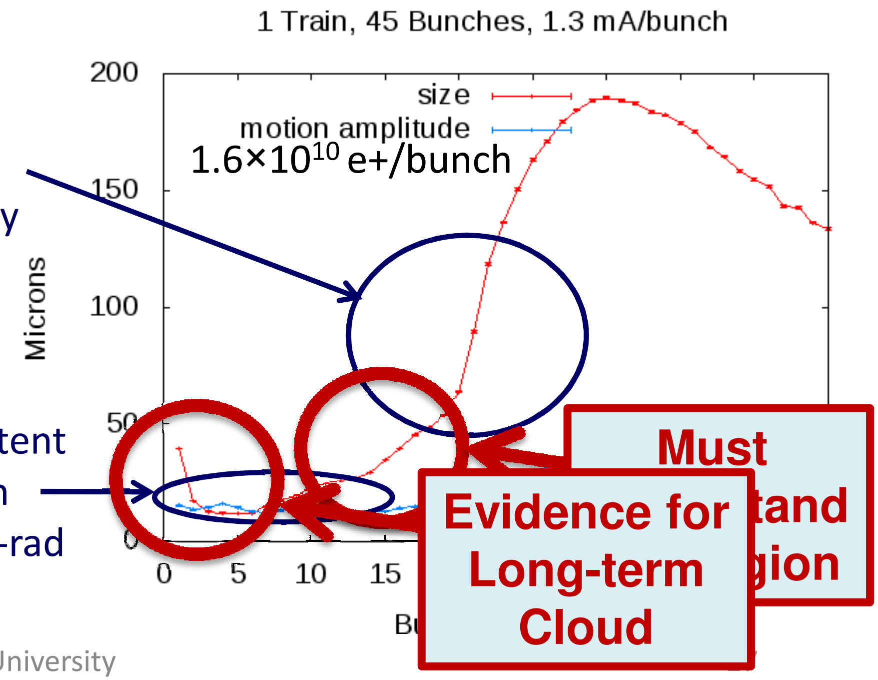
Beam Size

- 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 (Dugan talk)
    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 ε_y ~ 20pm-rad (σ_y=11.0±0.2 μm, β_{source}=5.8m)



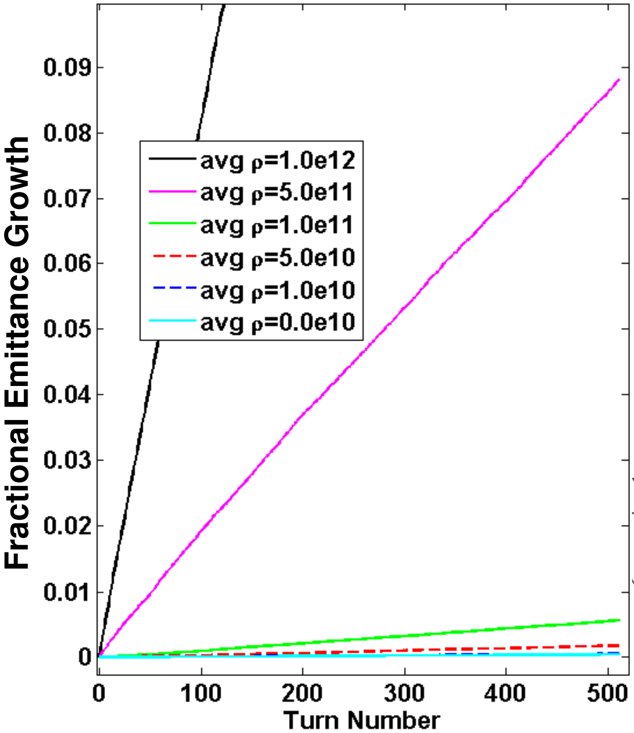
Preliminary

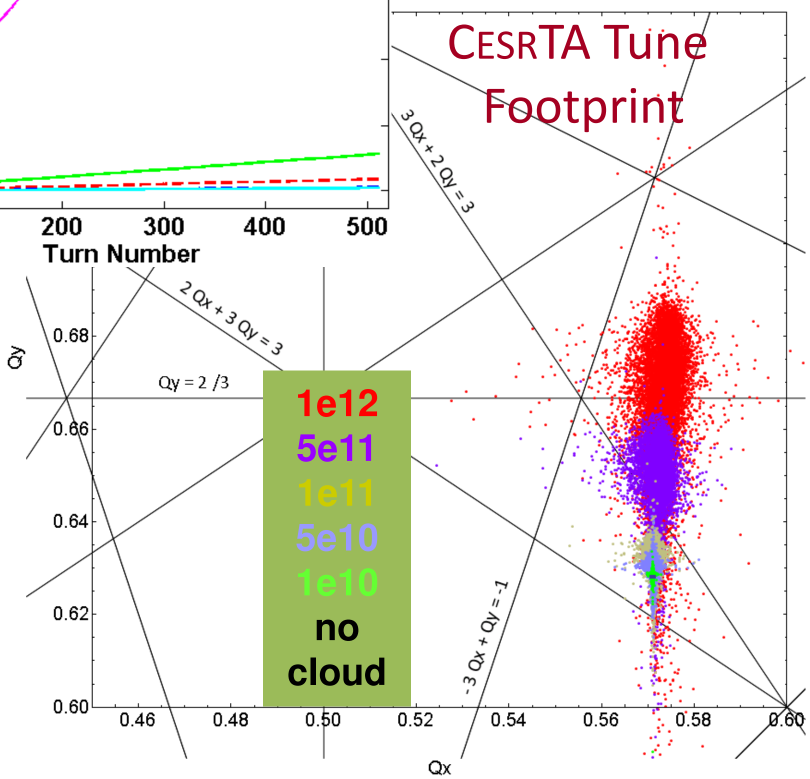




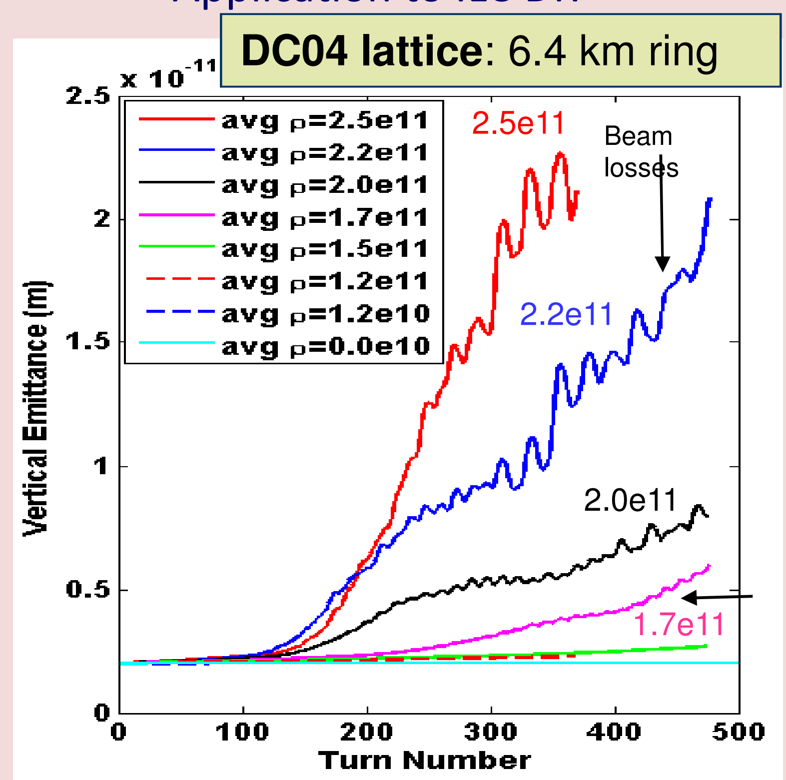
Simulation of Incoherent ε_y Growth & Instabilities

- CMAD simulation (Pivi, Sonnad)
- CMAD: tracking and e-cloud beam instability parallel code (M.Pivi SLAC)
  - Distribute EC in every magnetic element of ring: ~1,000 elements including drift, dipoles, quad, sext, etc.
  - Apply beam-cloud IP in every element





Application to ILC DR



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Conclusion I

- Mitigation performance:
  - Grooves are effective in dipole/wiggler fields, *but challenging to make when depth is small*
  - Amorphous C, TiN and NEG show similar levels of EC suppression so both coatings can be considered for DR use
    - TiN and a-C have worse dP/dI than Al chambers at our present level of processing
    - In regions where TiN-coated chambers are struck by wiggler radiation (high intensity and high E_c), we observe significant concentrations of N in the vacuum system
  - EC suppression with the clearing electrode in the wiggler is very good
    - No heating issues have been observed with the wiggler design in either CESRTA or CHESS operating conditions
  - Further work remains to take RFA measurements in chambers with mitigations and convert these to the effective SEY of the chamber surfaces
    - Agreement between data and simulation continues to improve
    - Magnetic field region model requires full inclusion of RFA in simulation
  - In situ SEY measurements raise the question of how the SEY varies around the chamber azimuth

Conclusion II

- Trapping and build-up of the EC over multiple turns in quadrupole and wiggler chambers
  - Experimental signature and seen in simulation
  - Further evaluation of impact on the beam is required
- Time-resolved studies (shielded pickups)
  - Being applied to understand SEY at ~0 energy, $\delta(0)$, which determines EC decay rates
  - Have already shown discrepancies in the PEY spectra being used (e- beam data)
- Photon transport models
  - Detailed 3D simulation show significant differences from models typically used
  - Significant implications for modeling assumptions in regions with high photon rates (arc and wiggler regions)
  - Likely still need to add some features (diffuse scattering, surface roughness) to the modelling
- Instabilities and sub-threshold emittance growth
  - Measurement tools are rapidly maturing
  - Coordinated simulation effort with a focus on testing predictions
  - Systematic studies, so far, are showing many features that we can understand with our models, but also some surprises
  - This area needs continued effort including more detailed data-simulation comparisons