Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

CesrTA Results

October 19, 2010

Mark Palmer

for the CesrTA Collaboration

Outline

- The CESRTA R&D Program
  - Goals & Capabilities
  - Brief Program Review
  - Status
- Overview of Electron Cloud R&D
- Inputs for the ILC DR Design

CesrTA R&D Goals

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

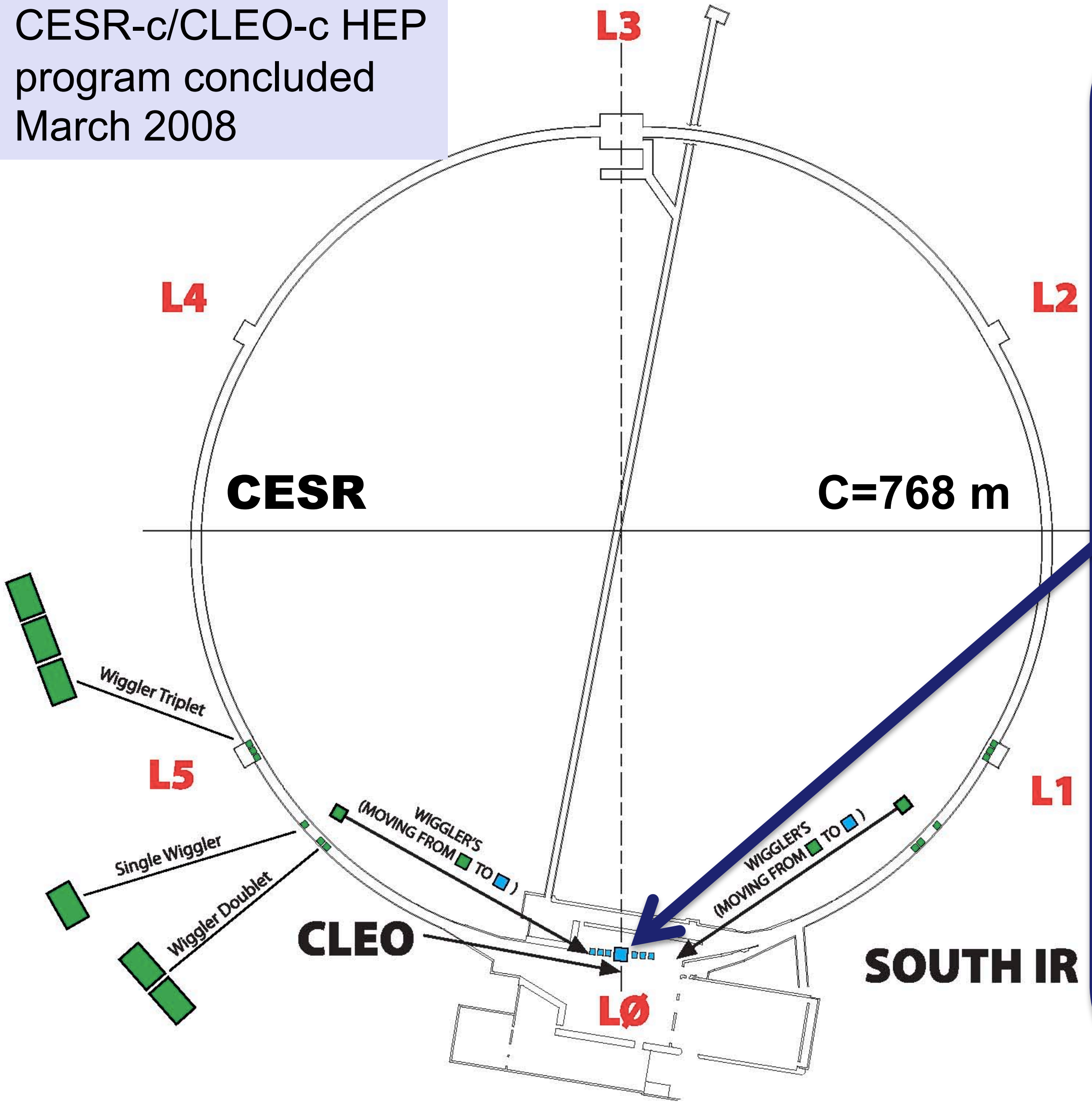
– Low Emittance Operations
  - EC beam dynamics studies at ultra low emittance (CesrTA Phase I vertical emittance target: **ε_v<20 pm-rad**).
  - Beam instrumentation for ultra low emittance beams
    - x-Ray Beam Size Monitor targeting bunch-by-bunch (single pass) readout
    - Beam Position Monitor 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: L0 Modifications

CESR-c/CLEO-c HEP program concluded March 2008



L0 Region

⇨ Experimental Wiggler Straight

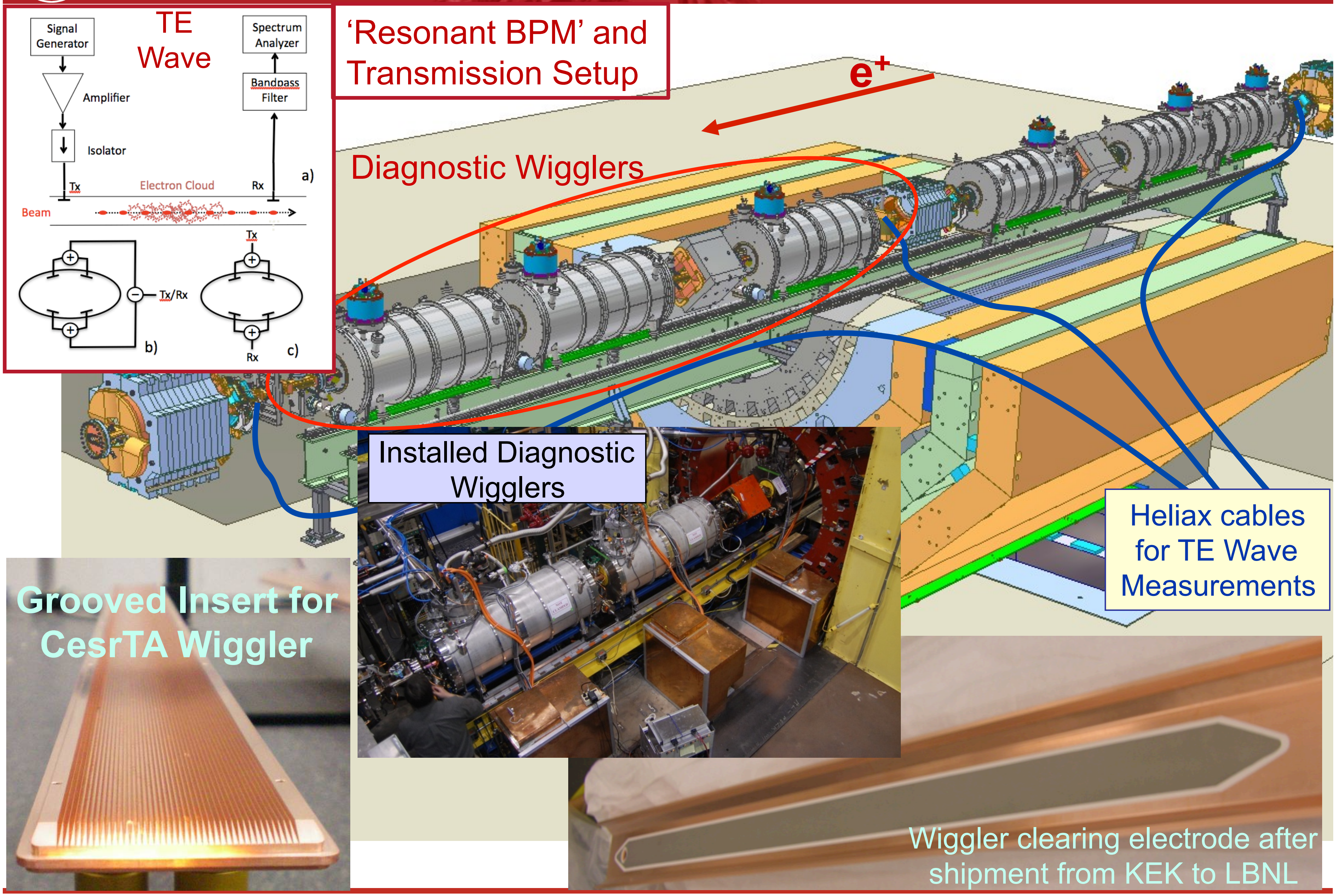
CLEO detector sub-systems removed

6 wigglers: CESR arcs ⇨ 0-dispersion straight

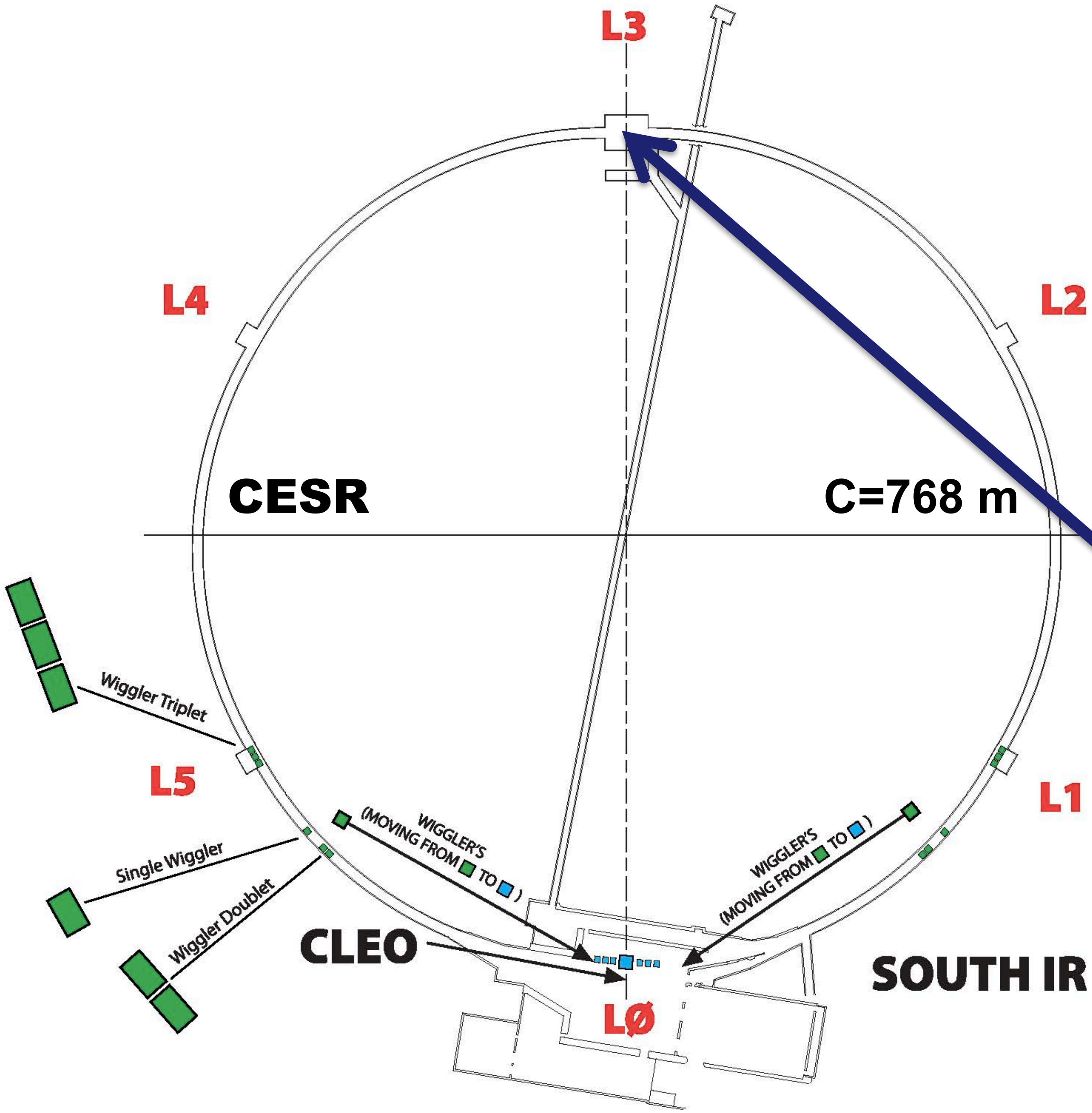
Region instrumented with EC diagnostics (RFA, vacuum, TE Wave,…)

Wiggler chambers with retarding field analyzers and various EC mitigation methods [fabricated at LBNL - CU/SLAC/KEK/LBNL collaboration]

CESR Reconfiguration: L0 Modifications



CESR Reconfiguration: L3 Experimental Region



L3 Region

⇨ EC Experimental Region

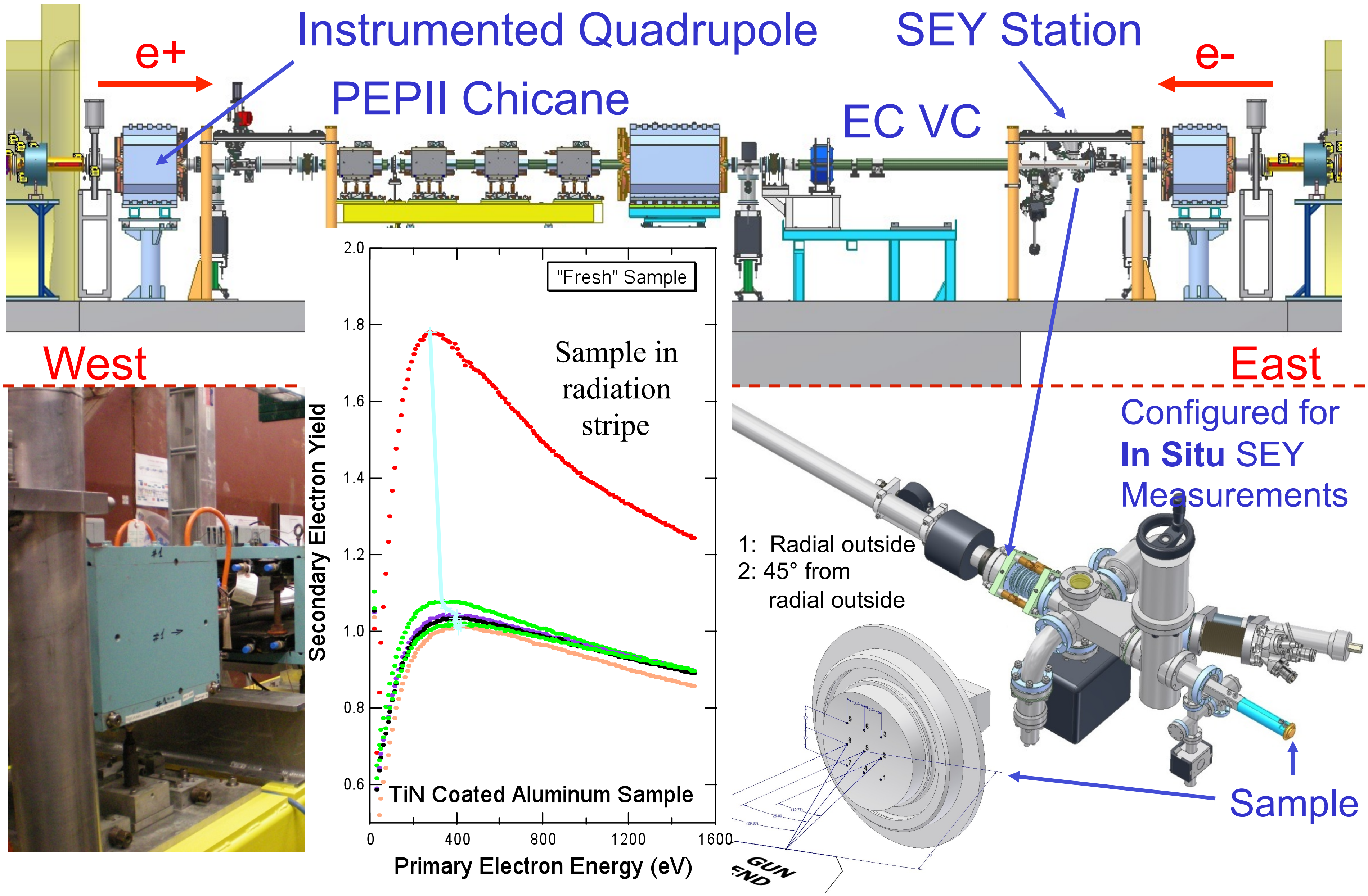
PEP-II EC Hardware: Chicane, upgraded SEY station (in situ operation)

Drift and Quadrupole diagnostic chambers

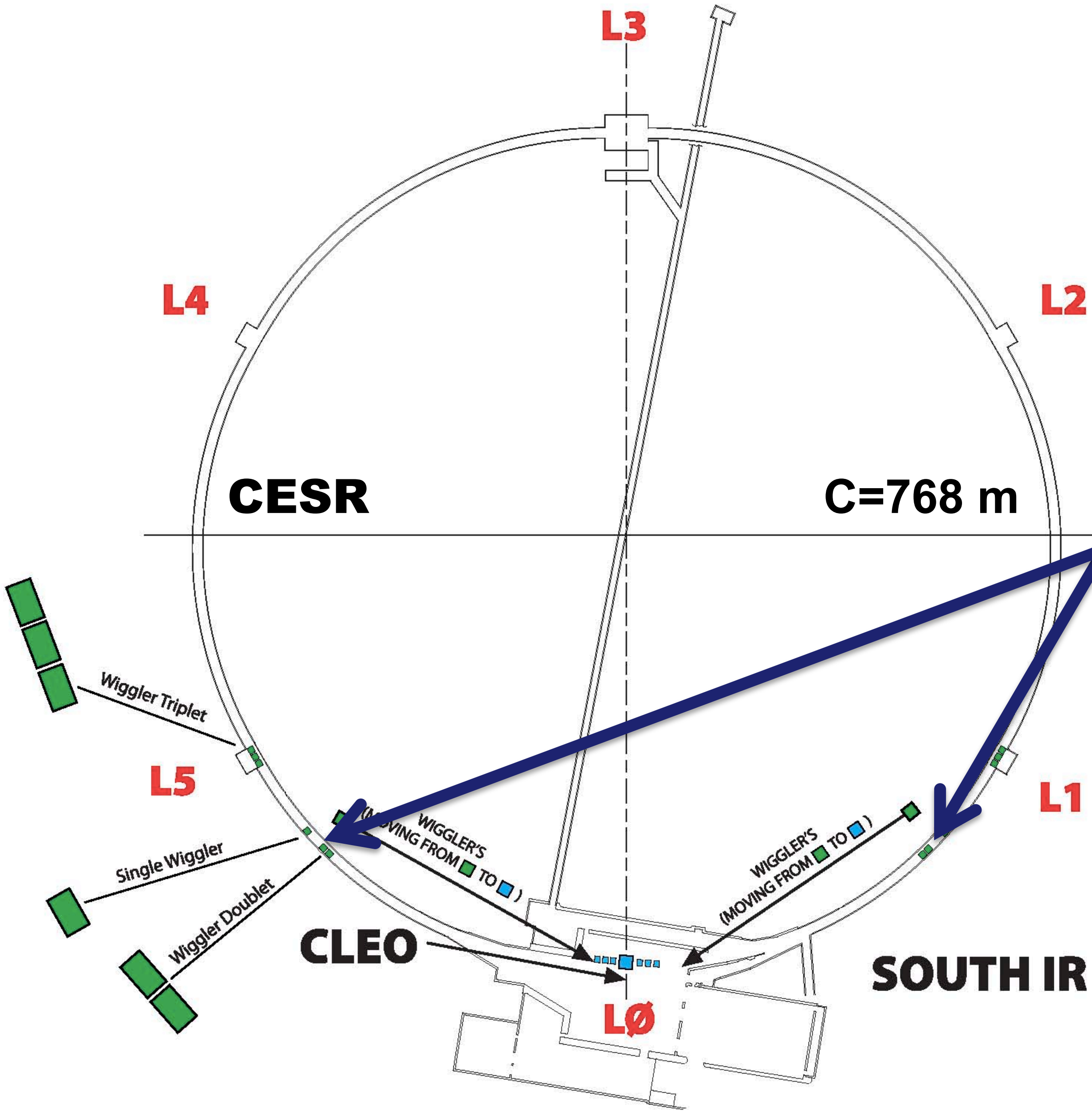
NEG test section

Upgraded visible synchrotron light diagnostics

CESR Reconfiguration: L3 Experimental Region



CESR Reconfiguration: Arc Regions



Arc Regions

⇨ Utilize space available after wiggler moves

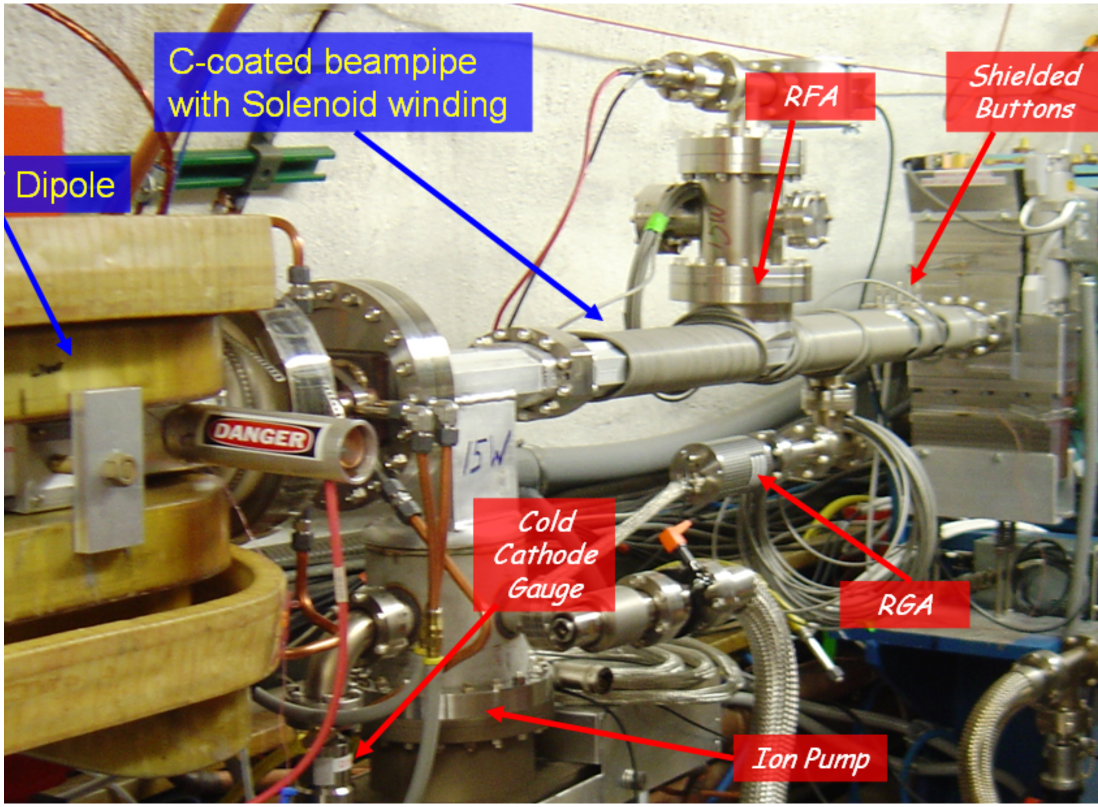
Locations to characterize RFA performance

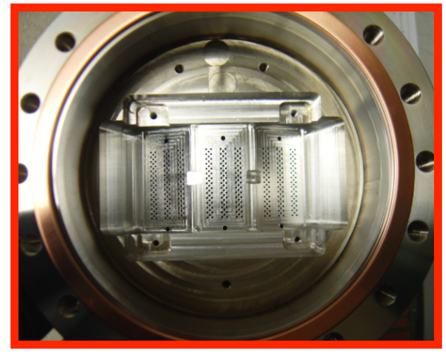
Time-resolved measurement capability

Two test chamber locations with significant synchrotron radiation flux to characterize various coatings

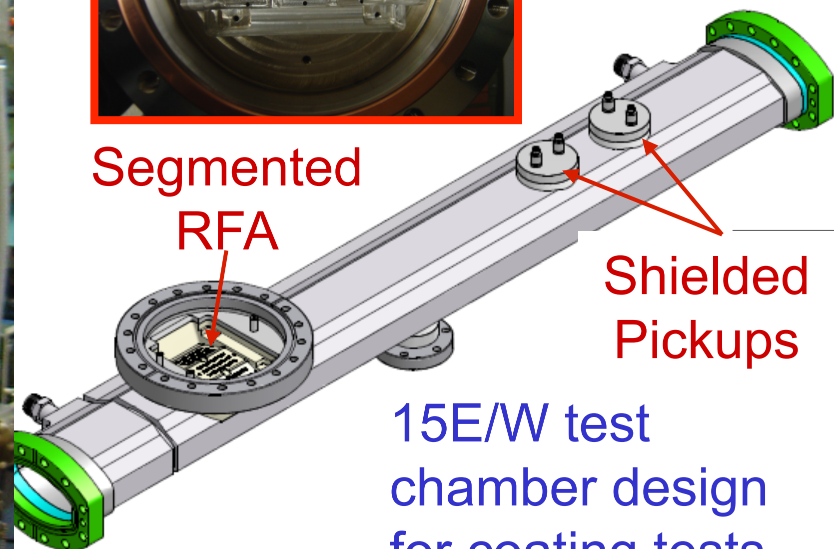
CESR dipole test chamber

CESR Reconfiguration: Arc Regions

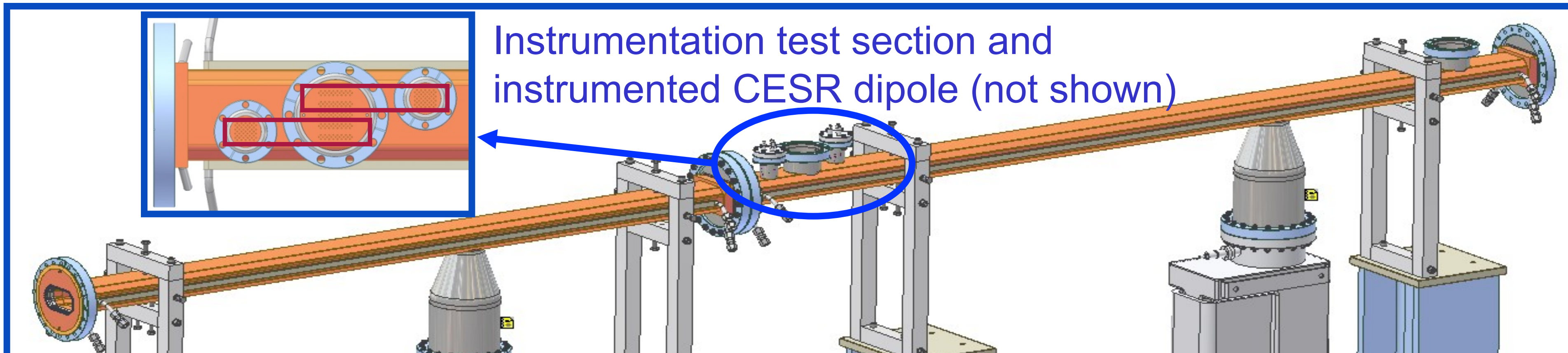




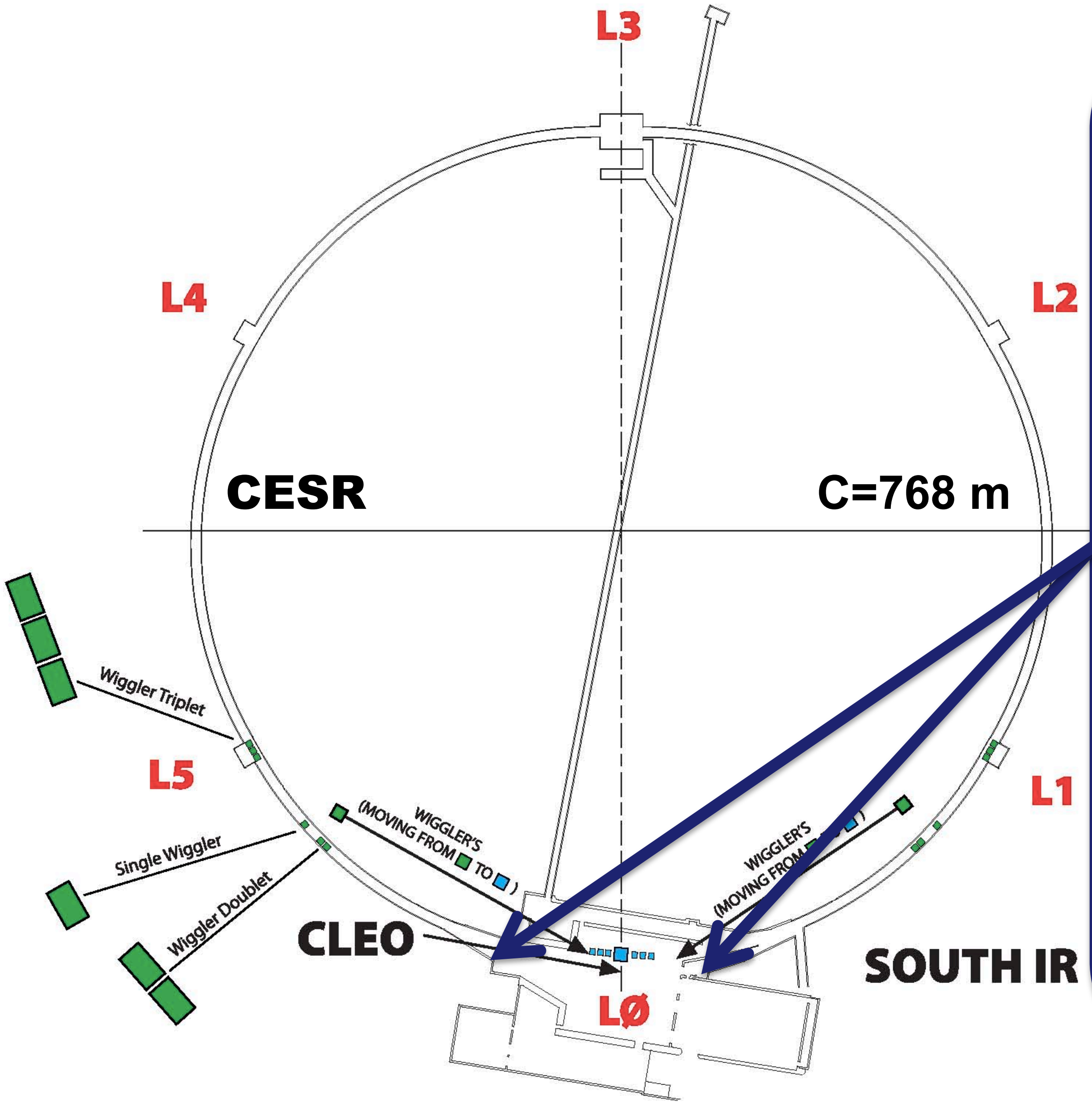
Segmented
RFA



15E/W test
chamber design
for coating tests



CESR Reconfiguration: X-Ray Lines



X-Ray Lines

⇨ Positron and Electron Beam Size Measurement

Windowless (all vacuum) x-ray line Upgrade ⇨ single pass measurement capability

Dedicated x-ray optics box at start of each line

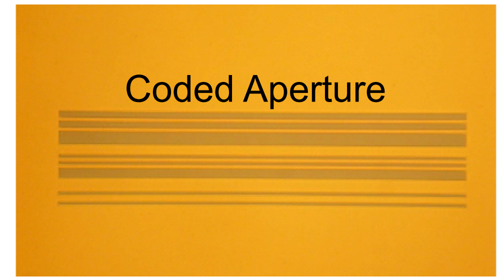
xBSM detectors share space in CHESS experimental hutches

CESR Reconfiguration: X-Ray Lines

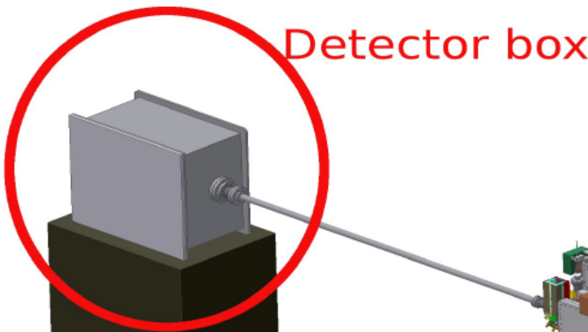
Detector: InGaAs Array
Single-pass readout
Few micron resolution

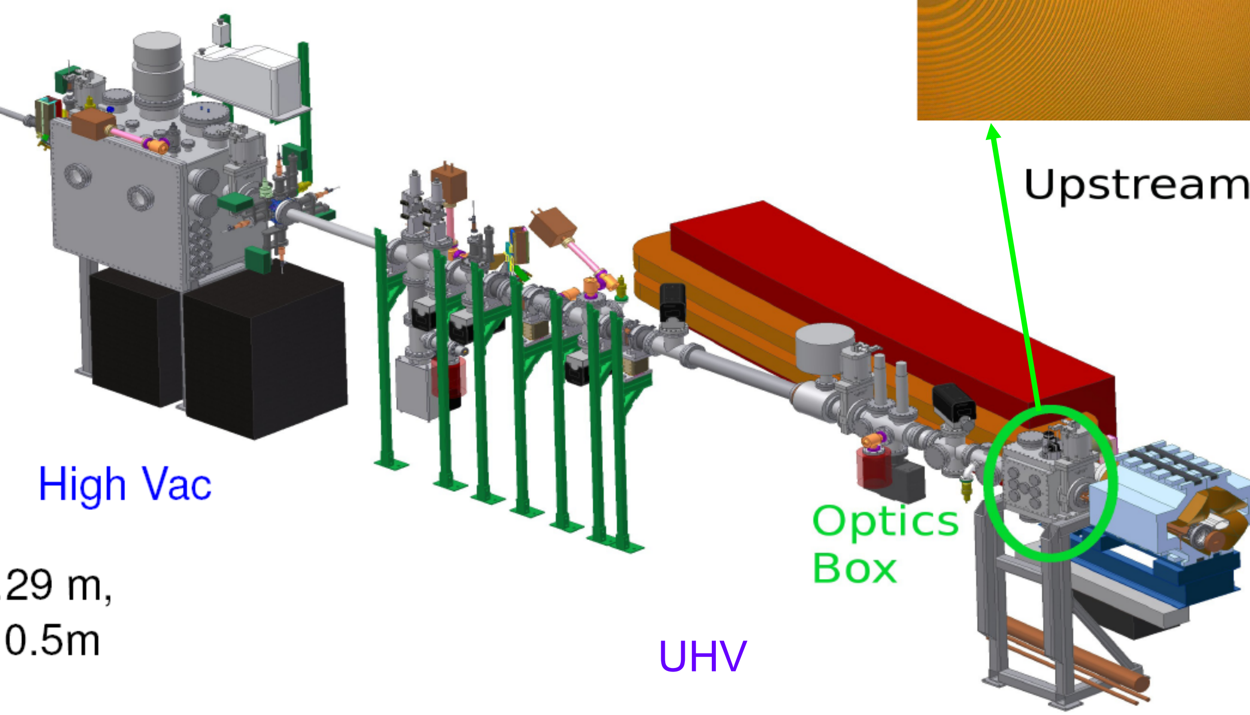
New all-vacuum optics lines installed in collaboration with CHESS:

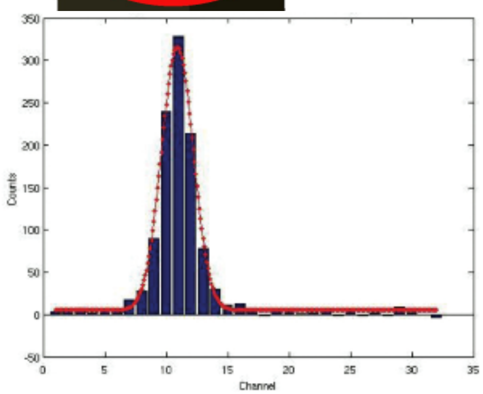
- Positron line (shown) deployed summer 2008
- Electron line completed summer 2009



Helium or Vacuum







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

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

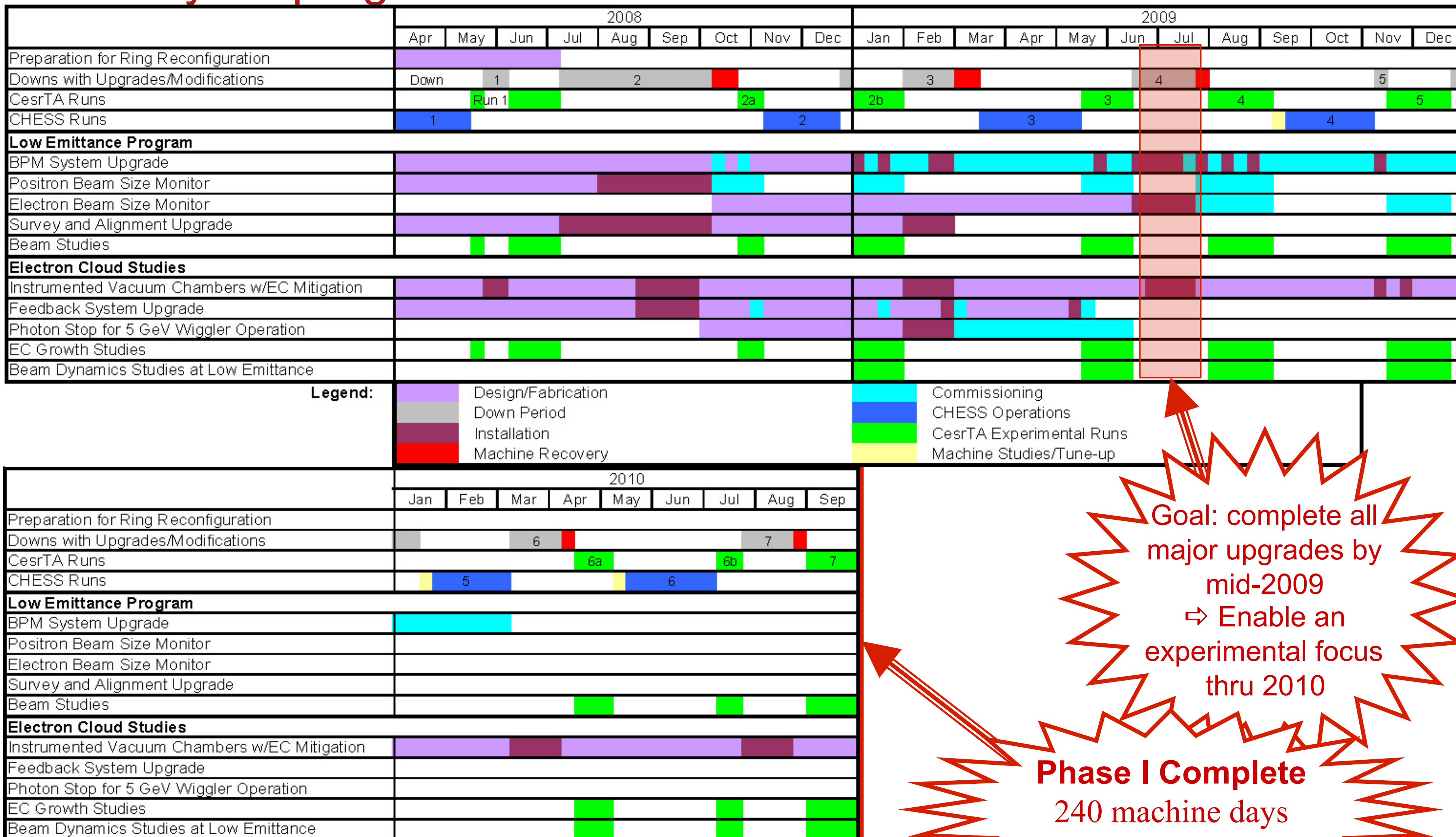
Control photon flux in EC experimental regions

E[GeV]	Wigglers (1.9T/PM)	ε_x[nm]	
1.8*	12/0	2.3	IBS Studies
2.085	12/0	2.5	IBS Studies
2.3	12/0	3.3	IBS Studies
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	

* 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

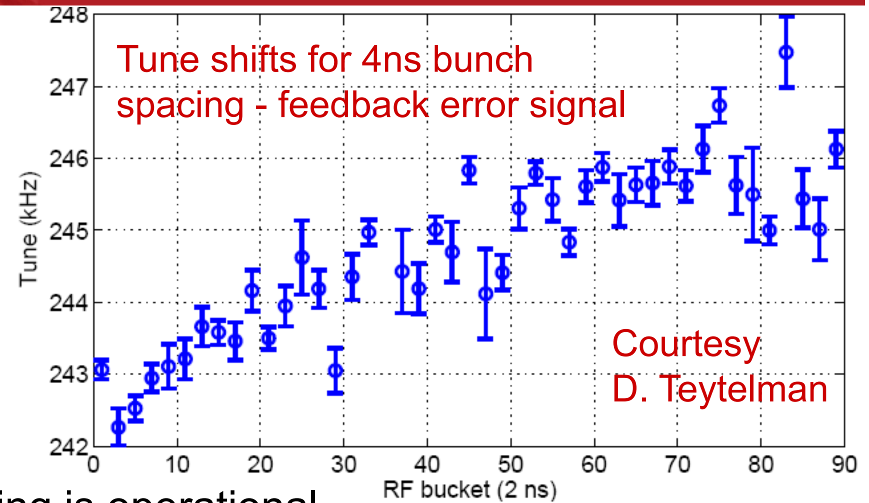


Goal: complete all major upgrades by mid-2009
⇨ Enable an experimental focus thru 2010

Phase I Complete
240 machine days delivered

Planning underway for Phase II

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
  - Studies of EC-induced instability thresholds and emittance growth

Collaboration

- The productivity of the program is determined by the range of collaboration involved:
  - Vacuum chambers with EC mitigation:
    - CERN, KEK, LBNL, SLAC
  - Low Emittance Tuning and Associated Instrumentation
    - CalPoly, CERN, Cockcroft, KEK, SLAC
  - EC Instrumentation
    - FNAL, KEK, LBNL, SLAC
  - *In Situ* SEY Station
    - Carleton, FNAL, SLAC
  - Simulation
    - CERN, KEK, INFN-Frascati, LBNL, Postech, Purdue, SLAC
  - Technical Systems Checks
    - BNL, CERN, KEK

Overview of EC Studies

Simulations:

- Code Benchmarking
  - CLOUDLAND
  - ECLOUD
  - POSINST
- Modeling EC Build-up
  - RFA Modeling: Local data ⇨ EC model parameters of surface
  - TE Wave Modeling: probe regions not accessible to RFA measurements (eg, through length of wiggler)
- Coherent tune shifts
  - Characterize integrated EC contributions around ring
  - Constrain EC model parameters
  - Confirm inputs for instability studies
- Time-resolved Build-up
  - Characterize the EC model parameters in instrumented regions
- Improvements to EC Simulations
  - 3D simulations in wigglers
  - Simulations of SR photon production and scattering
- Instabilities and emittance growth
  - Detailed comparisons with data in the ultra low emittance regime
  - Validate projections for the ILC DR

Measurements:

- RFA and TE Wave studies to characterize local EC growth
  - Wigglers, dipoles, drifts, quadrupoles
  - 2 GeV to 5 GeV studies
  - Variety of bunch train lengths, spacing and intensities
  - Studies with electron and positron beams
- Mitigation Comparisons
  - Drift, Quadrupole, Dipole and Wiggler
  - See table on next slide
- Tune shift measurements and systematic checks
- Time-resolved measurements
  - Important cross-checks of EC models
- Instability and emittance growth (w/ xBSM) measurements

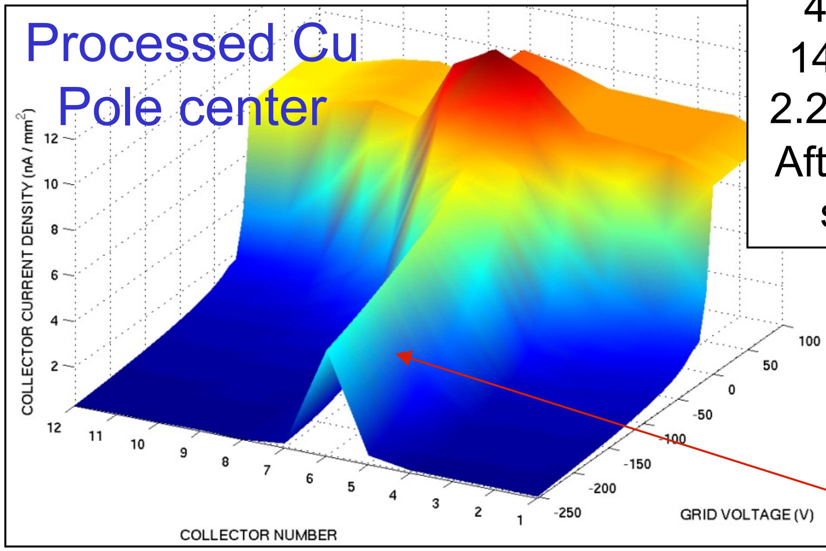
Will touch on a few studies. Further details in WG2 parallel sessions

Mitigation Tests

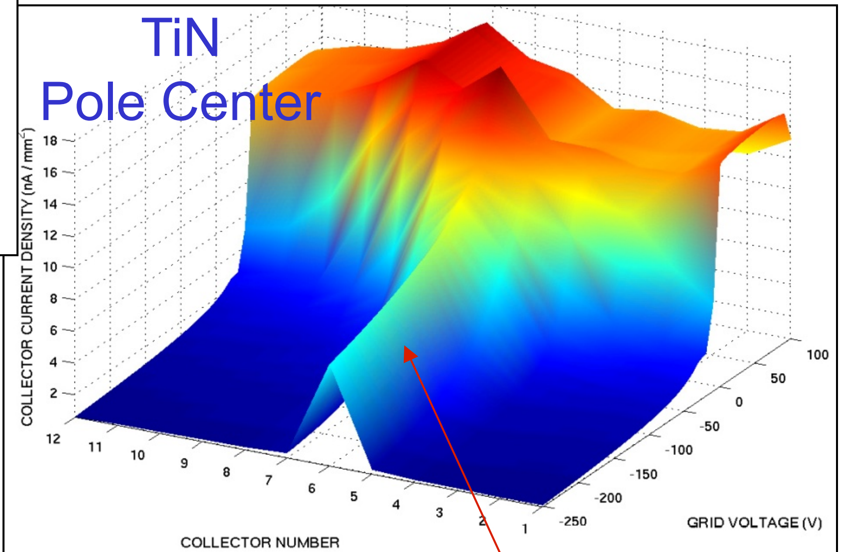
	Drift	Quad	Dipole	Wiggler	VC Fab
Al	✓	✓	✓		CU, SLAC
Cu	✓			✓	CU, KEK, LBNL, SLAC
TiN on Al	✓	✓	✓		CU, SLAC
TiN on Cu	✓			✓	CU, KEK, LBNL, SLAC
Amorphous C on Al	✓				CERN, CU
NEG on SS	✓				CU
Solenoid Windings	✓				CU
Fins w/TiN on Al	✓				SLAC
Triangular Grooves on Cu				✓	CU, KEK, LBNL, SLAC
Triangular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

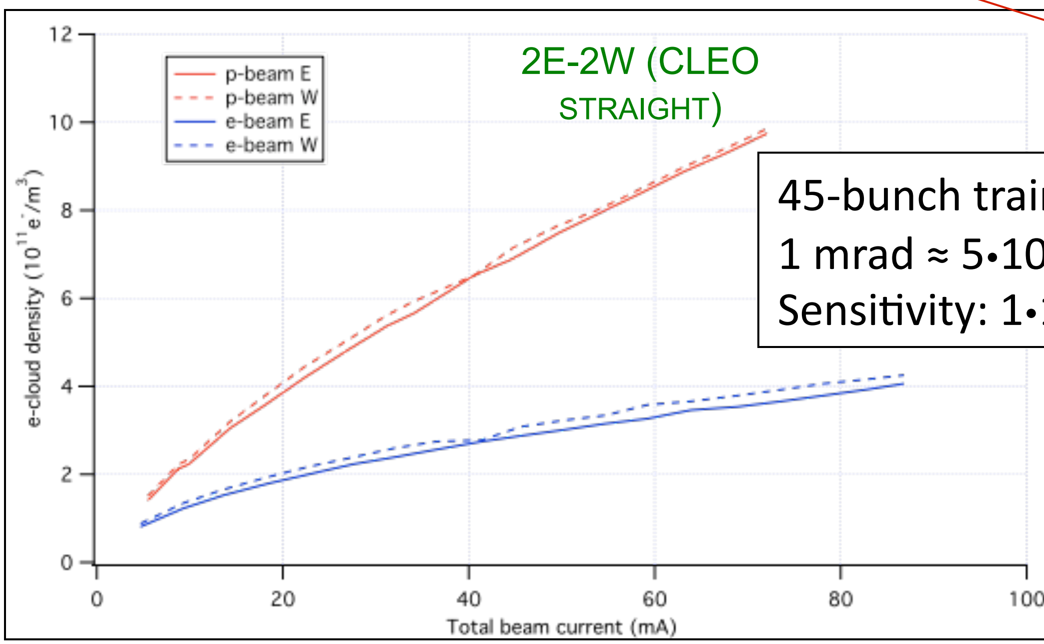
✓ = chamber(s) deployed ✓ = planned

TE Wave & RFA Measurements in L0



45 bunches
14ns spacing
2.2×10^{10}/bunch
After extended scrubbing

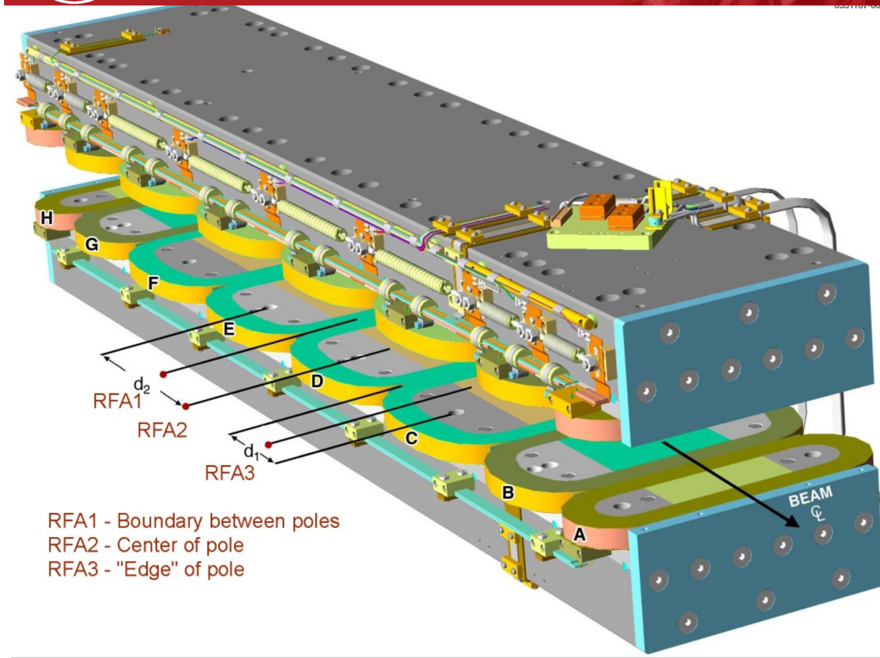


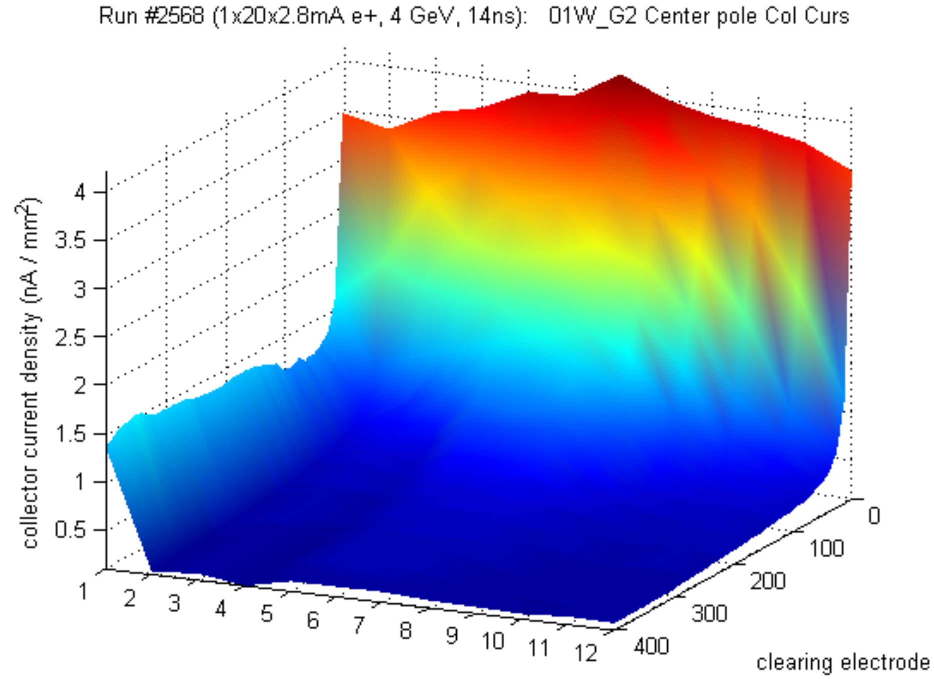


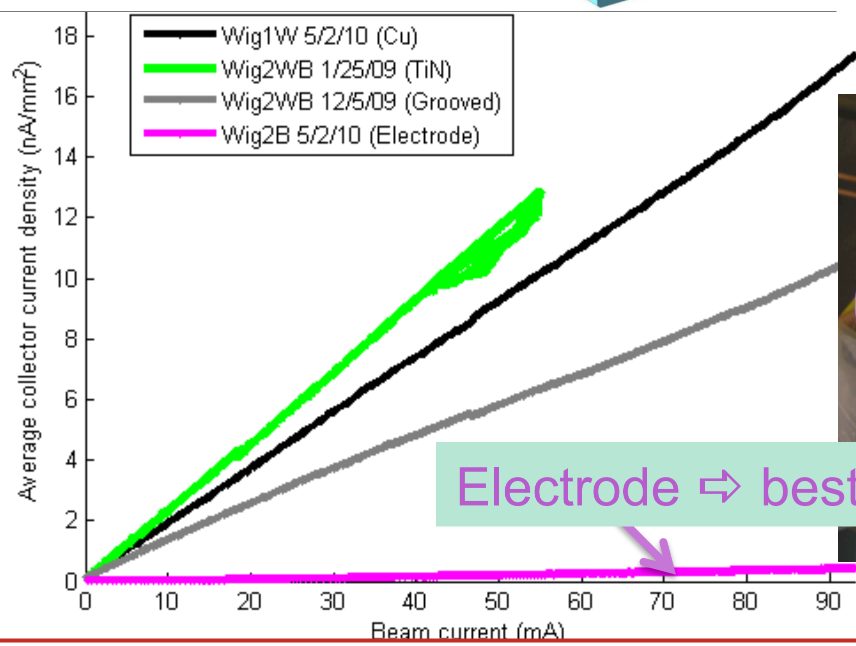
45-bunch train (14 ns)
1 mrad ≈ $5\bullet10^{10}$ e$^-$/m^3
Sensitivity: $1\bullet10^{9}$ e$^-$/m^3 (SNR)

Similar performance observed

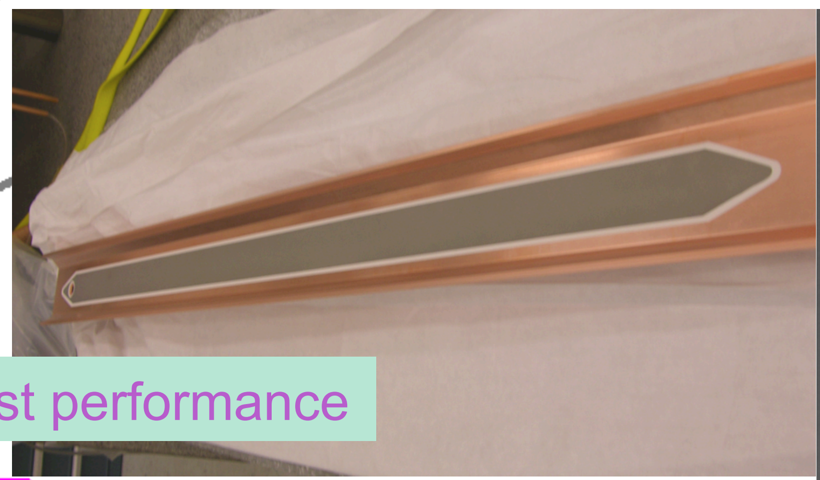
Wiggler Observations







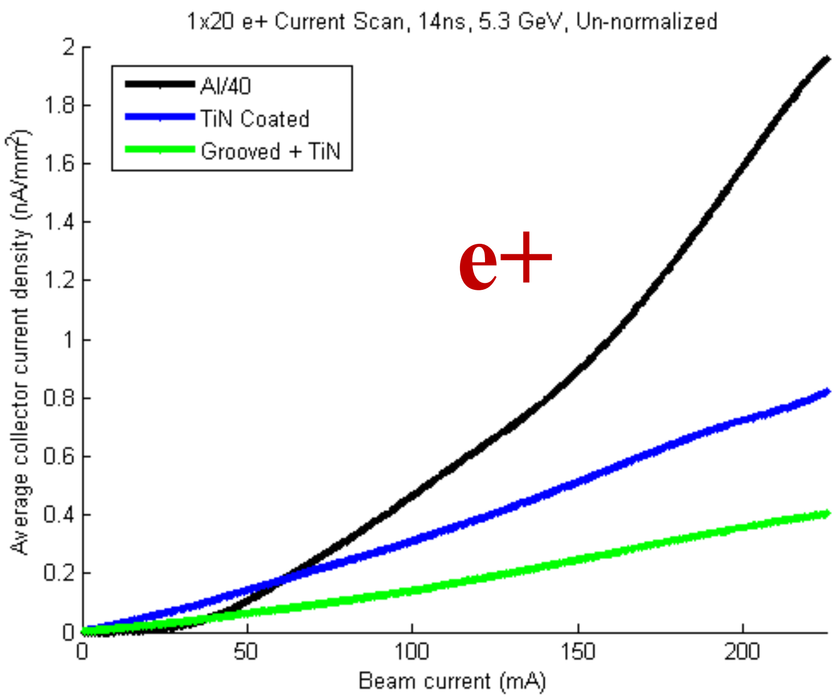
Electrode ⇨ best performance

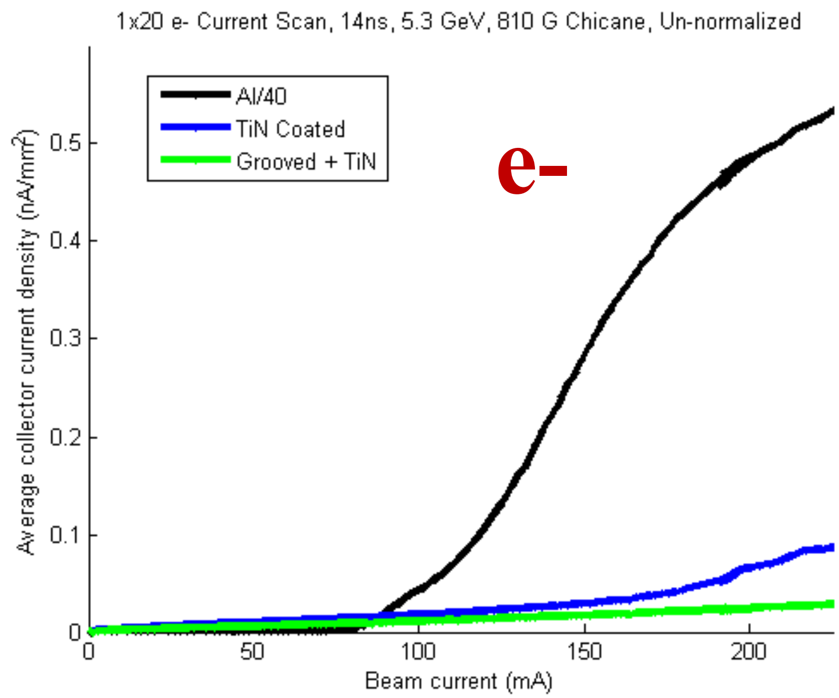


Mitigation Performance in Dipoles (e+ & e⁻)

- 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



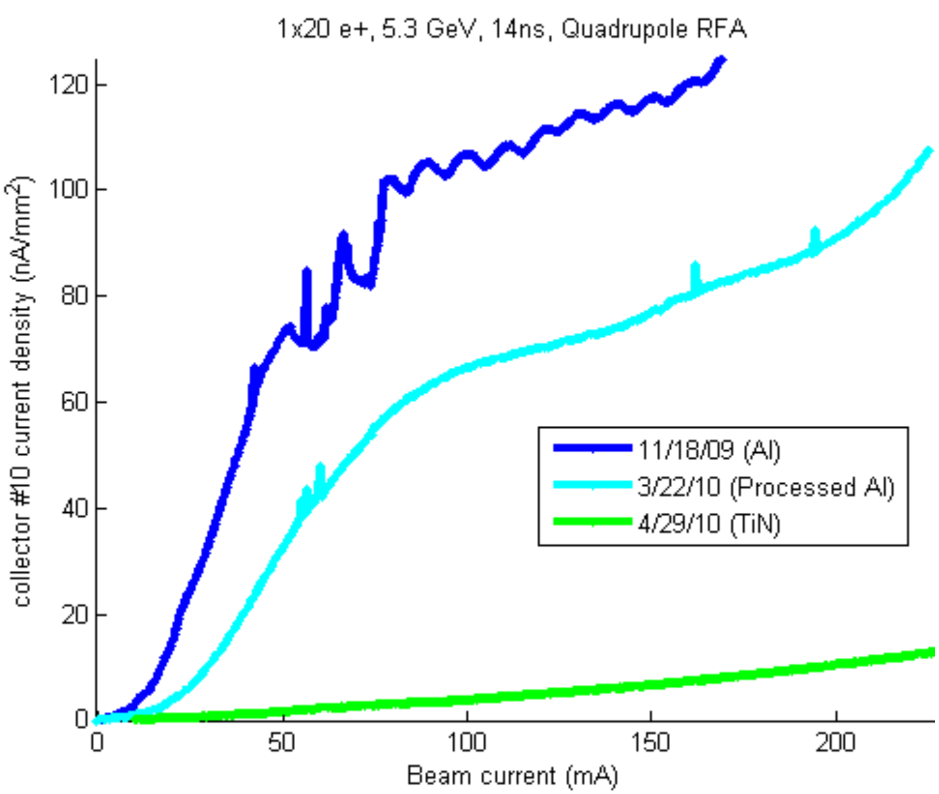


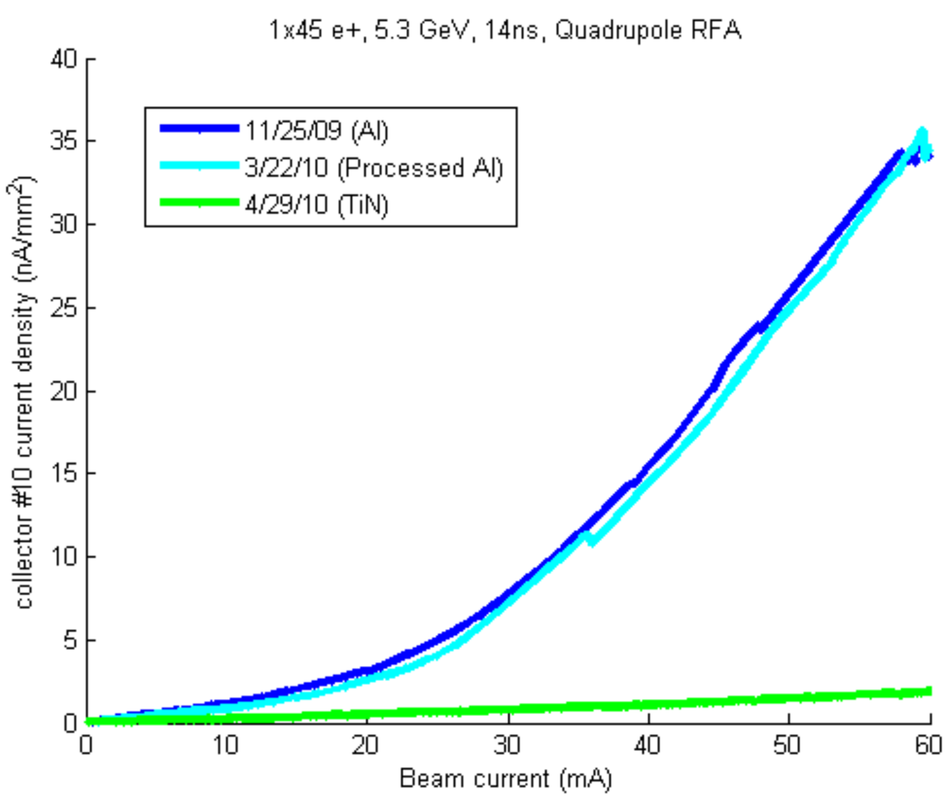
Quadrupole Observations

- 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

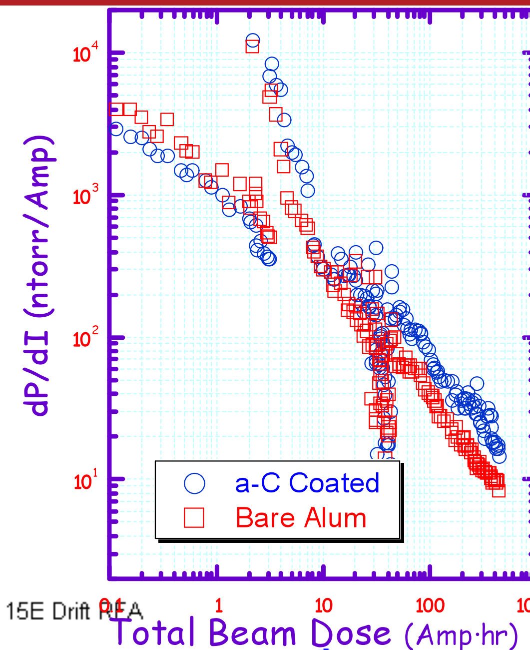


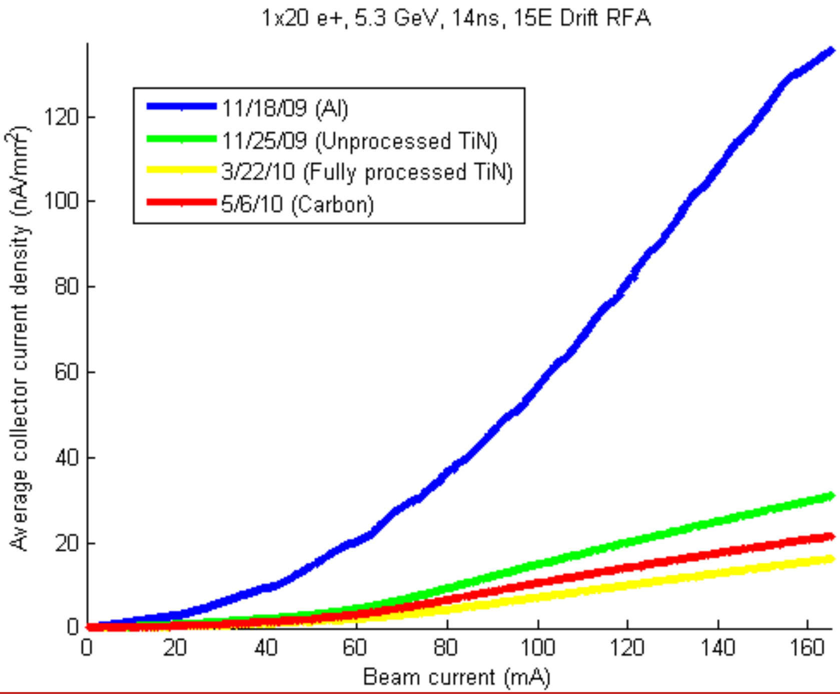


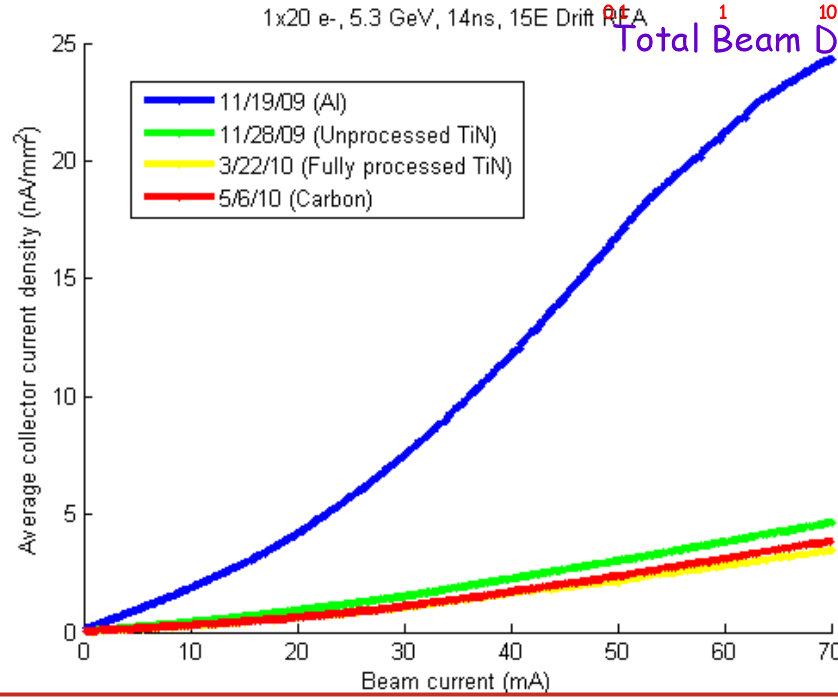
Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

15E Drift RFAs

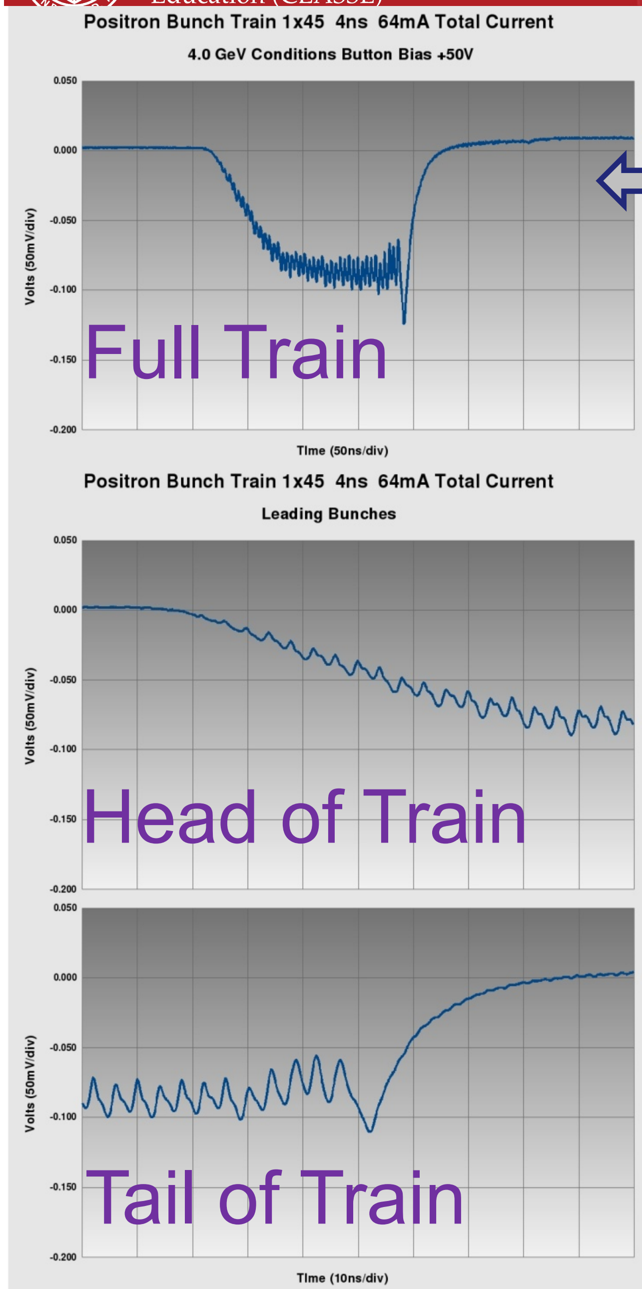
- Bare Al vs TiN coating vs amorphous C coating comparisons have been carried out using the Q15E/W test regions
- a-C and TiN show greater beam-induced vacuum rise than bare Al
- Preliminary analysis of surface parameters indicates good SEY performance by each of these coatings
- Comparison tests with other chamber types around the ring





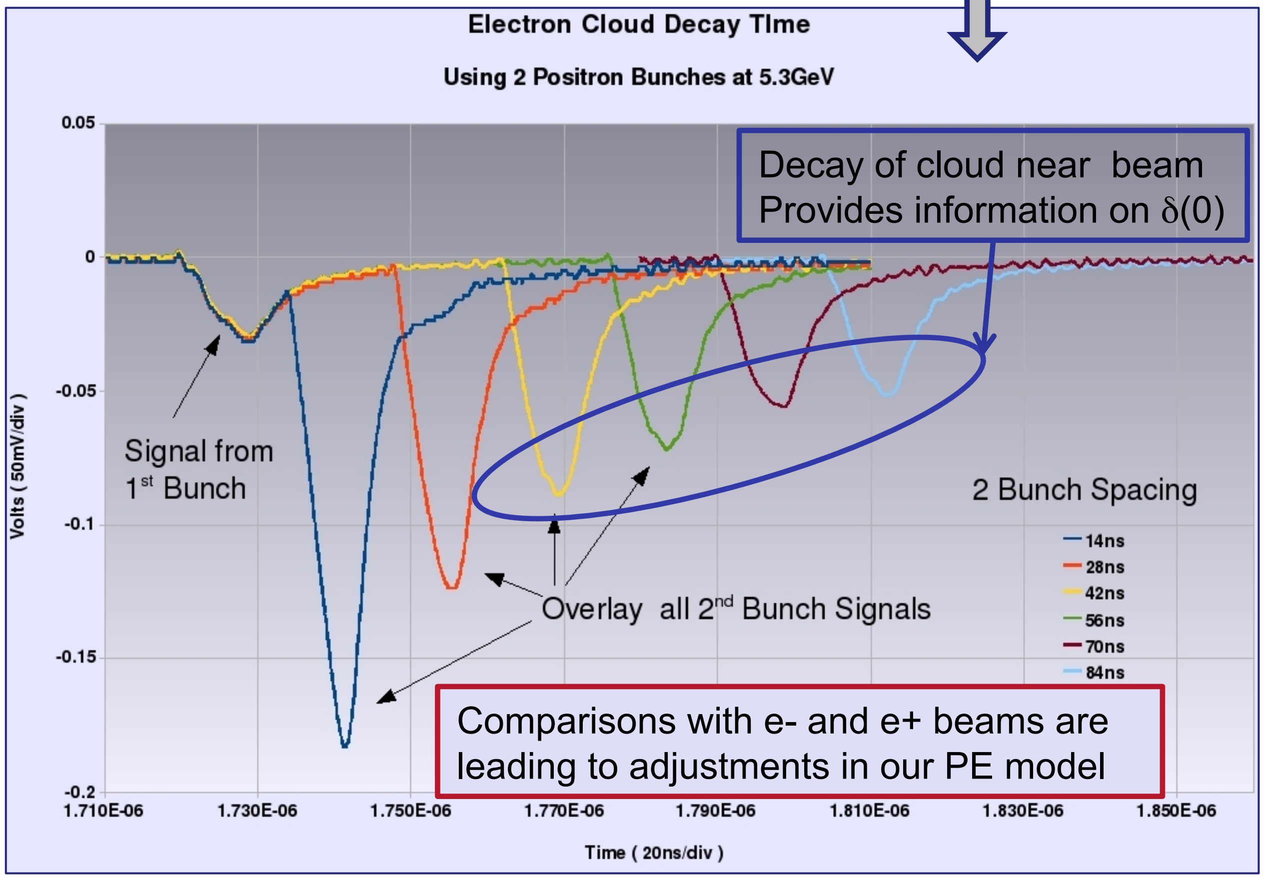


Time Resolved Measurements



45 bunch train
4ns bunch spacing
~2.3×10^{10} e+/bunch

Witness Bunch Studies:
EC-generating Bunch
Trailing Probe Bunch



Decay of cloud near beam
Provides information on $\delta(0)$

Comparisons with e- and e+ beams are leading to adjustments in our PE model

Higher BW Version of CERN Technique
Mahners, *et al.*, PRSTAB 11 094401 (2008)

Coherent Tune Shifts

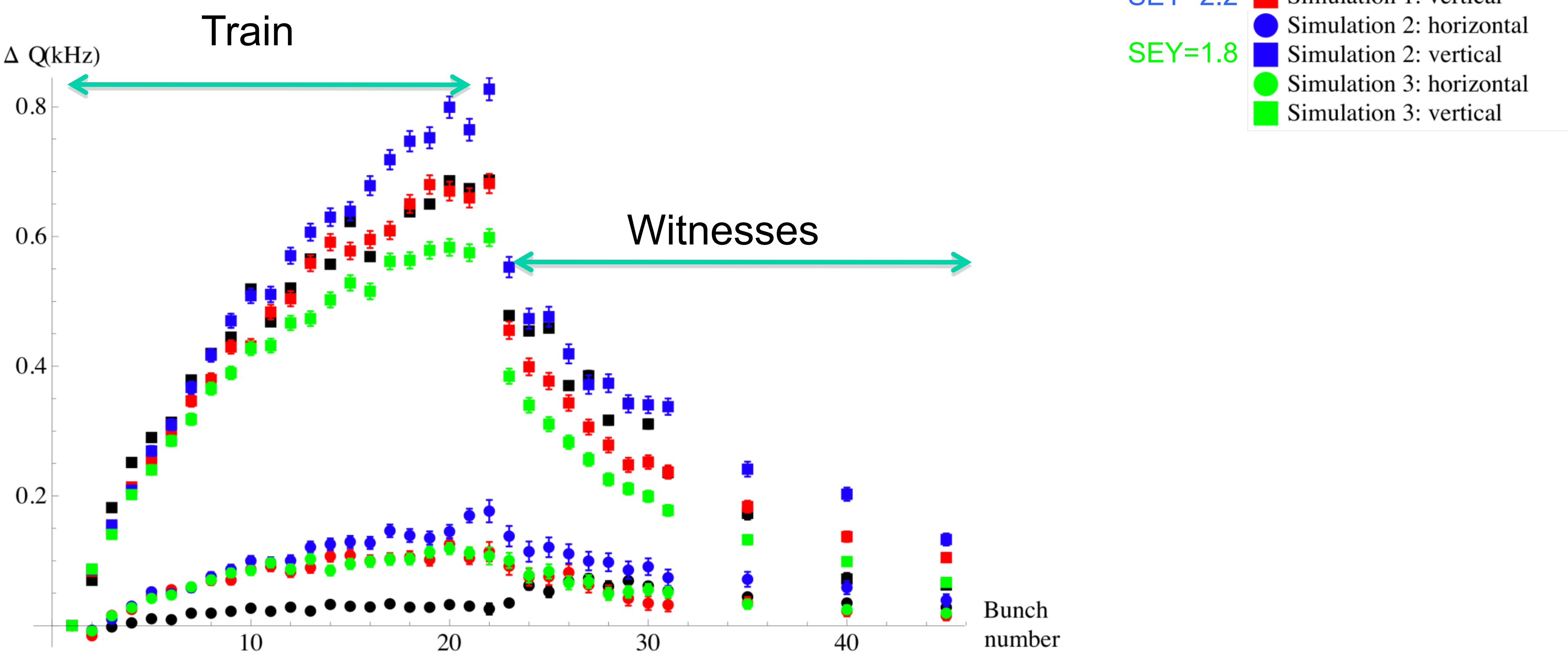
- Characterize ring-wide impact of the cloud
- Measurements of bunch-by-bunch coherent tune shifts:
  - Along bunch trains and with witness bunches
  - Positron and electron beams
  - For a wide range of:
    - Beam energies
    - Emittances
    - Bunch currents
    - Bunch spacings
    - Train lengths
- Comparison with predictions:
  - POSINST
  - ECLOUD
- Fit all data ⇨ 6 EC model parameters:
  - Peak SEY
  - Photon reflectivity
  - Quantum efficiency
  - Rediffused yield
  - Elastic yield
  - Peak secondary energy

Example: Positron Witness Bunch Study at 2GeV

Peak SEY Scan

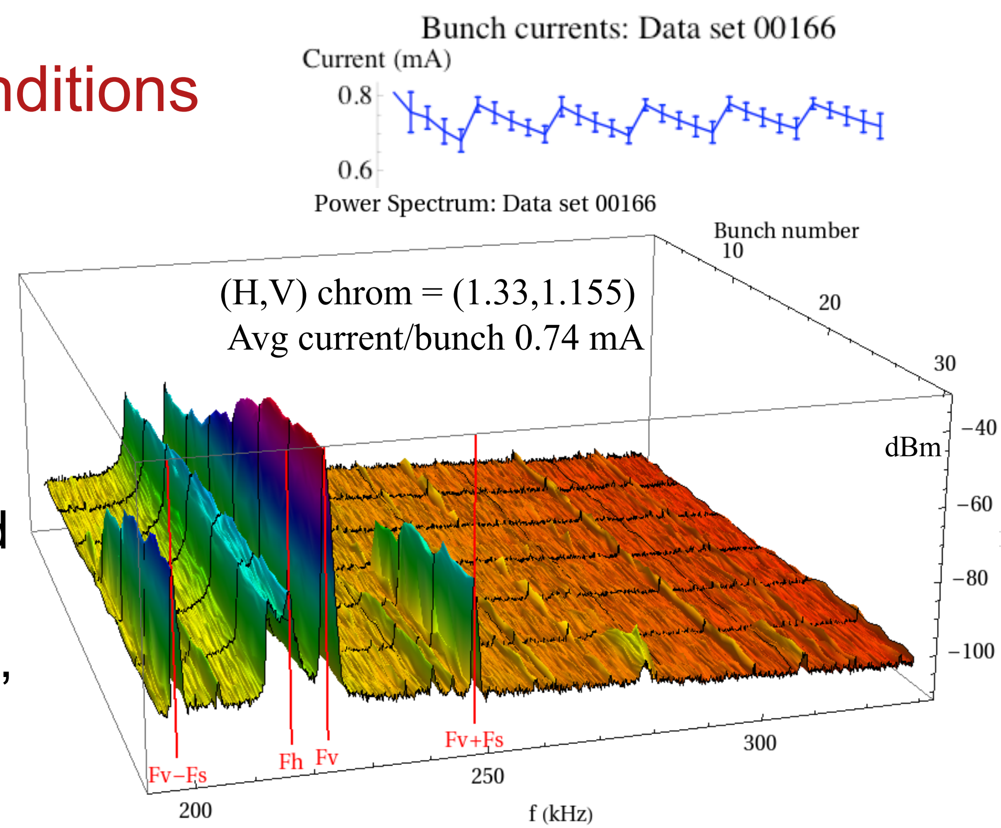
Coherent Tune Shifts (1 kHz ~ 0.0025), vs. Bunch Number

- 21 bunch train, followed by 12 witness bunches
- 0.8×10^{10} particles/bunch
- 2 GeV.
- Data (black) compared to POSINST simulations.



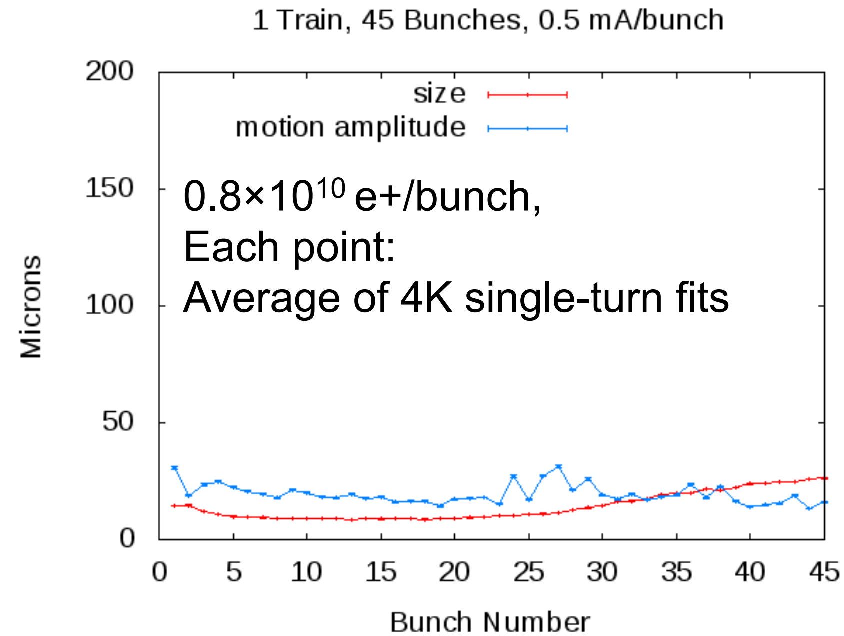
Systematic Studies of Instability Thresholds

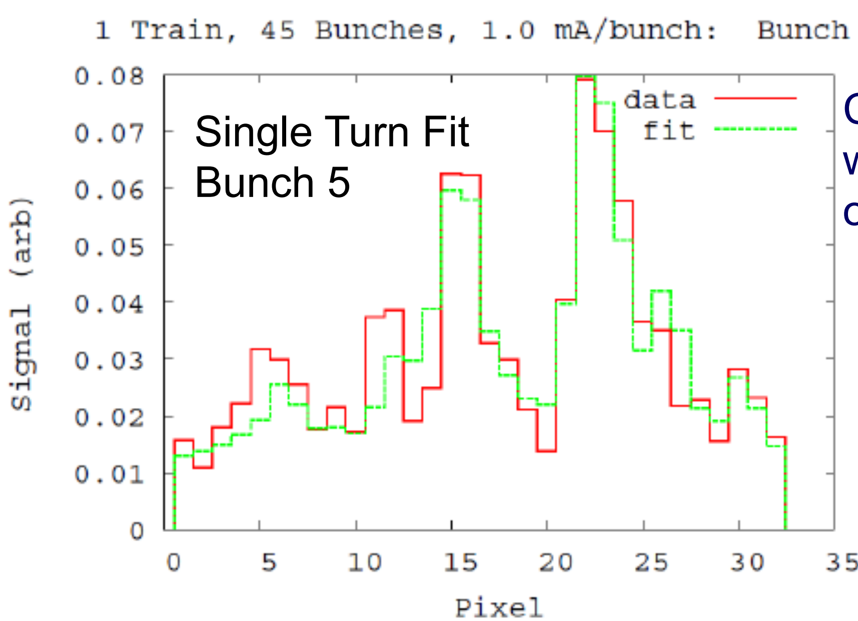
- Spectral methods offer a powerful tool for self-consistent analysis of the onset of instabilities
  - Tune shifts along train ⇨ ring-wide integrated cloud density near beam with minimal bias
  - Onset of synchrobetatron sidebands allows evaluation of the instability thresholds
- Have explored a range of conditions during recent runs
  - Find qualitative agreement with simulations
  - Detailed data-simulation comparisons underway
  - A range of parameters explored but additional systematic studies are highly desirable (eg, currents, train configuration, energy,…)

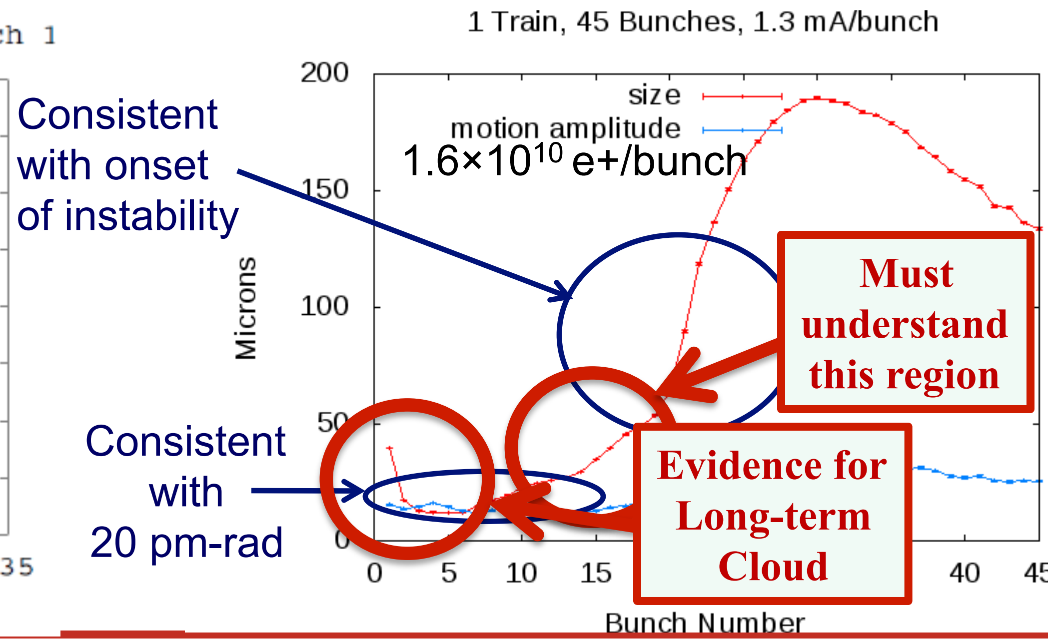


EC-Induced Emittance Growth

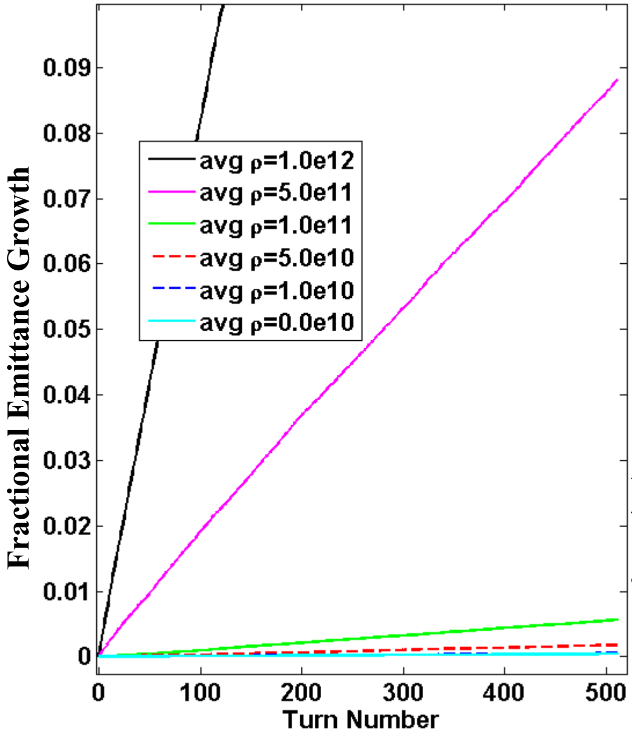
- Measure Bunch-by-Bunch Beam Size
  - Beam size enhanced at head and tail of train
    Source of blow-up at head appears to be due to a long lifetime component of the cloud.
    Bunch lifetime of smallest bunches consistent with observed single bunch lifetimes during LET (Touschek-limited) and with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



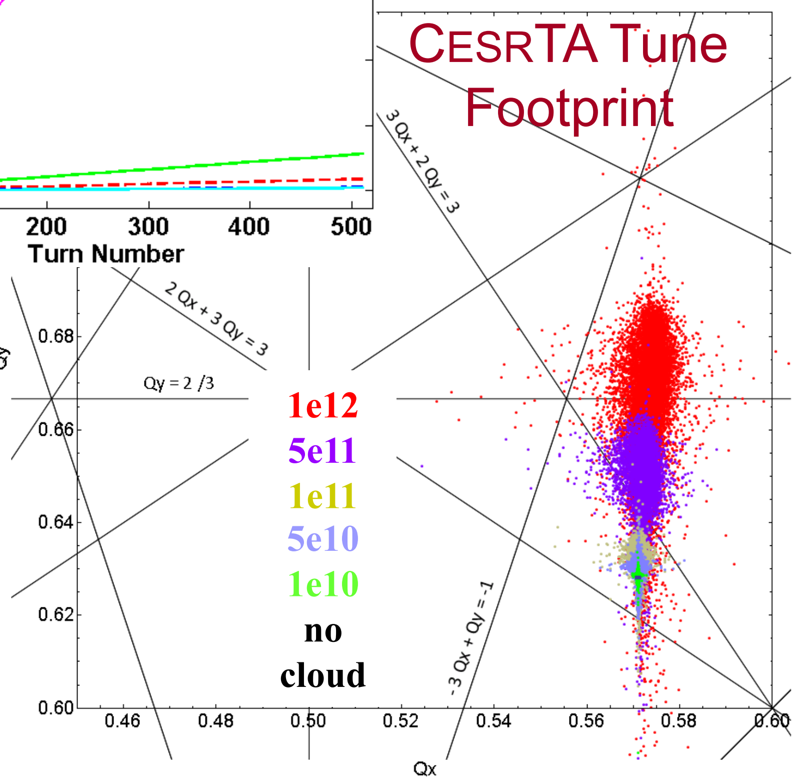


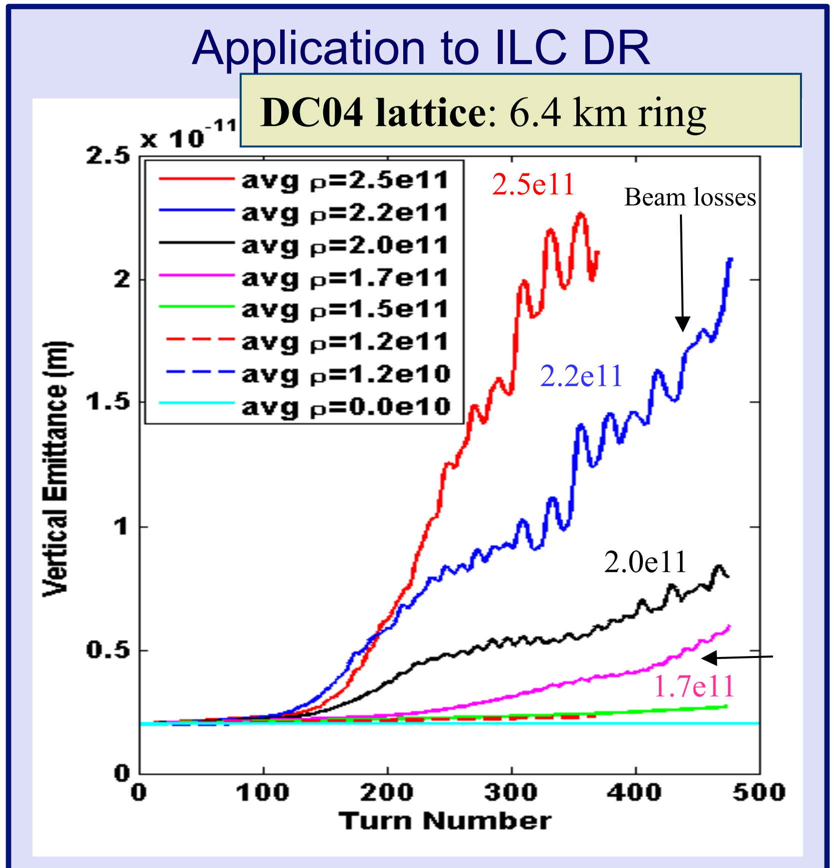


Simulation of Incoherent ε_y Growth & Instabilities



- 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





CESRTA Summary I

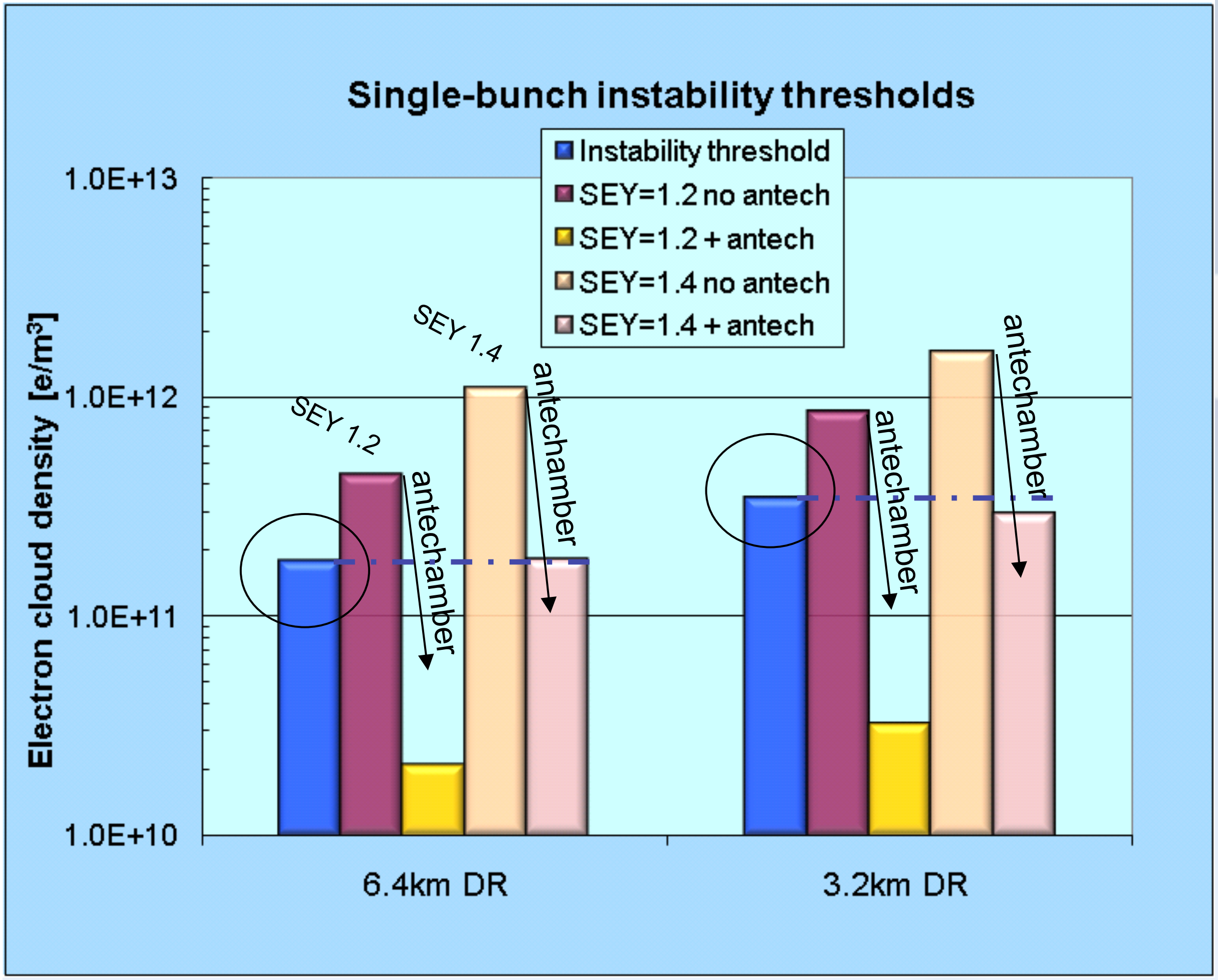
- Mitigation performance:
  - Grooves are effective in dipole/wiggler fields, *but challenging to make when size is small*
  - Amorphous C, TiN and NEG show similar levels of EC suppression so each is a potential candidate for DR use
    - TiN and a-C have worse dP/dI than Al chambers at our present 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 significantly better than other options
    - No heating issues have been observed with the wiggler design in either CESRTA or CHESS operating conditions
  - Work is in progress to take RFA measurements in chambers with mitigations and convert these to the effective SEY of the chamber surfaces
    - Agreement between data and simulation looks very promising
    - Magnetic field region model requires full inclusion of RFA in simulation
  - Trapping and build-up of the EC over multiple turns in quadrupole and wiggler chambers
    - Simulation and experimental evidence
    - Further evaluation of impact on the beam is required

CESRTA Summary II

- Time-resolved studies (shielded pickups)
  - Being applied to understand SEY at zero incident energy, $\delta(0)$, which determines EC decay rates
  - Have shown discrepancies in the PE spectra being used
- Photon transport models
  - Detailed 3D simulations show significant differences from models typically used
  - Important contribution to modeling in regions with high photon rates (arc and wiggler regions)
- Instabilities and sub-threshold emittance growth
  - Comparisons now available between data and simulation for instability thresholds
  - Many consistent features between data and simulation, but considerable analysis work remains
  - Emittance growth below the threshold for the head-tail instability is a particular point of concern. *Potentially will result in a lowering of the acceptable EC density in the positron damping ring.*
  - Follow-on measurements are planned to further clarify emittance growth issues and to allow improved ILC DR projections

Results now being analyzed and incorporated into the ILC DR design

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

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

Thank you for your attention