Electron Cloud at Low Emittance in CESRTA

Mark Palmer for the CESRTA Collaboration

May 25, 2010

IPAC2010 – Kyoto, Japan

Outline

- Project Overview
  - Motivation
  - Project Goals
  - CESR Reconfiguration
  - Status
- R&D Effort
  - Low Emittance Correction and Tuning
  - EC Studies: Experimental and Simulation
    - Build-Up and Mitigation
    - EC Beam Dynamics
- Conclusion

The ILC Damping Rings

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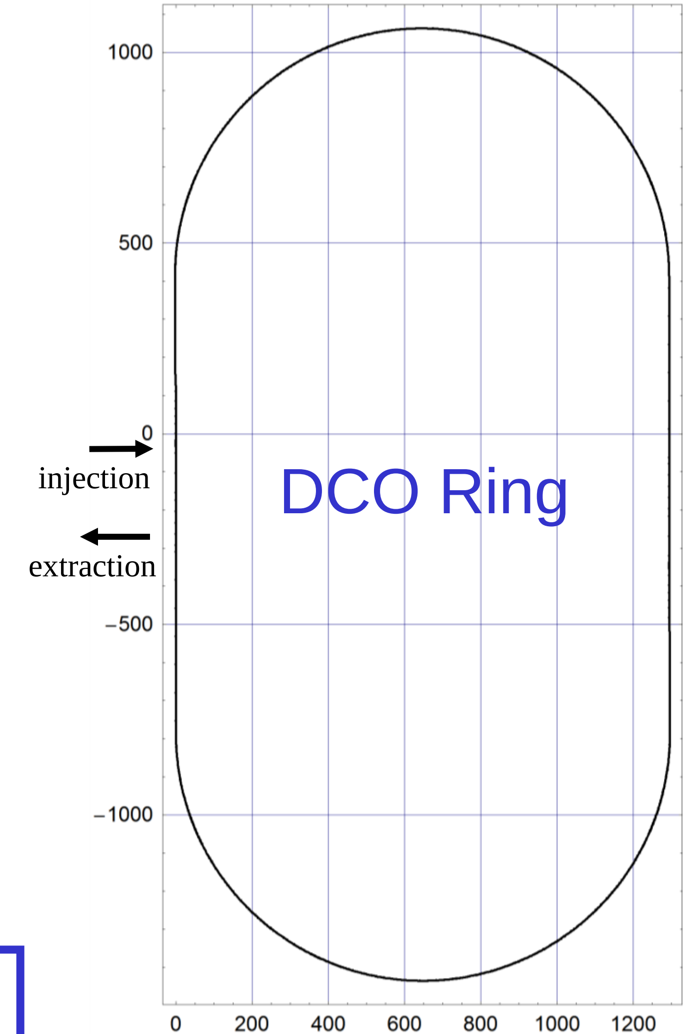
Beam energy	5 GeV
Circumference	6476.44 m
RF frequency	650 MHz
Harmonic number	14042
Injected (normalised) positron emittance – $\gamma\varepsilon_{x,y}$	0.01 m
Extracted (normalised) emittance $\gamma\varepsilon_x \times \gamma\varepsilon_y$	8 μm × 20 nm
Extracted energy spread	<0.15%
Average current	400 mA
Maximum particles per bunch	2×10^{10}
Bunch length (rms)	6 mm
Minimum bunch separation	3.08 ns

250 km main linac bunch train is "folded" into the DRs

2 pm-rad geometric emittance

Present Baseline Design



ILC R&D Board S3 Task Force (Damping Rings) identified 12 *very high priority* R&D items that needed to be addressed for the technical design:

- Lattice design for baseline positron ring
- Lattice design for baseline electron ring
- Demonstrate < 2 pm vertical emittance
- Characterize single bunch impedance-driven instabilities
- Characterize electron cloud build-up
- Develop electron cloud suppression techniques
- Develop modelling tools for electron cloud instabilities
- Determine electron cloud instability thresholds
- Characterize ion effects
- Specify techniques for suppressing ion effects
- Develop a fast high-power pulser

Targeted for CesrTA effort with low emittance e^+ beam

R&D Goals

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– 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
  - Support an experimental program to provide key results on the 2010 timescale

Project Elements

- 4 Major Thrusts:
  - Ring Reconfiguration: Vacuum/Magnets/Controls Modifications
  - Low Emittance R&D Support
    - Instrumentation: BPM system and high resolution x-ray Beam Size Monitors
    - Survey and Alignment Upgrade
  - Electron Cloud R&D Support
    - Local EC Measurement Capability: RFAs, TE Wave Measurements, and develop Time-resolved Measurement Capability
    - Feedback System upgrade for 4ns bunch trains
    - Photon stop for wiggler tests over a range of energies (1.8 to 5 GeV)
    - Local SEY measurement capability
  - Experimental Program
    - Provide ~240 running days over a 2+ year period
    - Early results to feed into final stages of program

Large parameter range – see next slide

- Schedule coordinated with Cornell High Energy Synchrotron Source (CHESS) operations

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

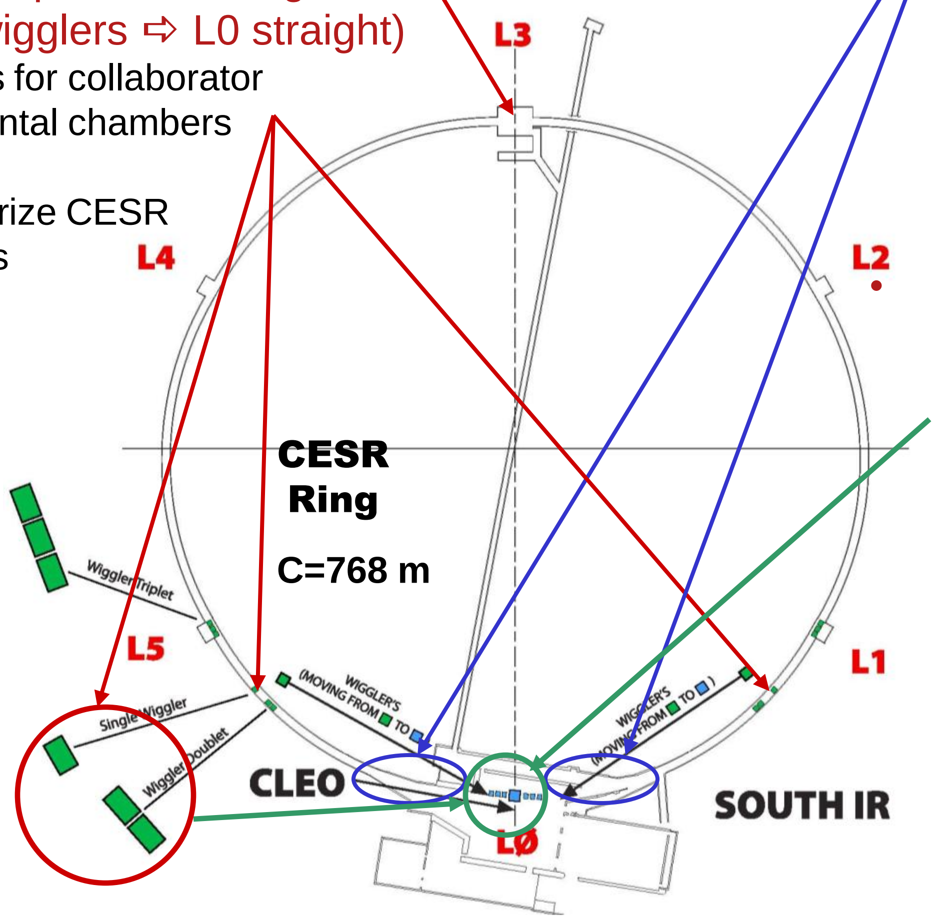
E[GeV]	Wigglers (1.9T/PM)	ε_x[nm]
1.8*	12/0	2.3
2.085	12/0	2.5
2.3	12/0	3.3
3.0	6/0	10
4.0	6 /0	23
4.0	0 /0	42
5.0	6/0	40
5.0	0/0	60
5.0	0/2	90

IBS Studies

* 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

CESR Reconfiguration

- L3 EC experimental region
  - PEP-II EC Hardware: Chicane, upgraded SEY station
  - Drift and Quadrupole diagnostic chambers
- New EC experimental regions in arcs (wigglers ⇨ L0 straight)
  - Locations for collaborator experimental chambers
  - Characterize CESR chambers



- CHESS C-line & D-line Upgrades
  - Windowless (all vacuum) x-ray line upgrade
  - Dedicated x-ray optics box at start of each line
  - CesrTA xBSM detectors share space in CHESS experimental hutches
- L0 region reconfigured as a wiggler straight
  - CLEO detector sub-systems removed
  - 6 wigglers moved from CESR arcs to zero dispersion straight
  - Region instrumented with EC diagnostics and mitigation
  - Wiggler chambers with retarding field analyzers and various EC mitigation methods (fabricated at LBNL in CU/SLAC/KEK/LBNL collaboration)

CESR Reconfiguration: L0 Modifications

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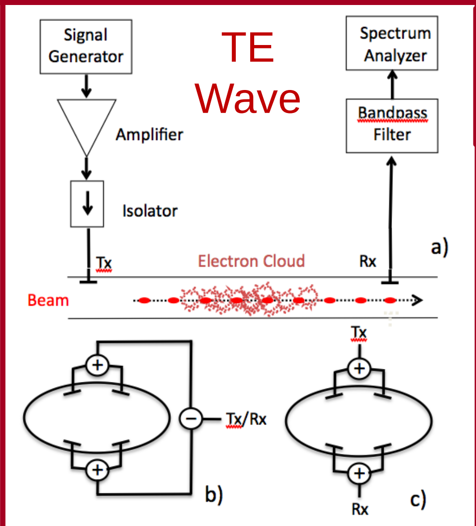
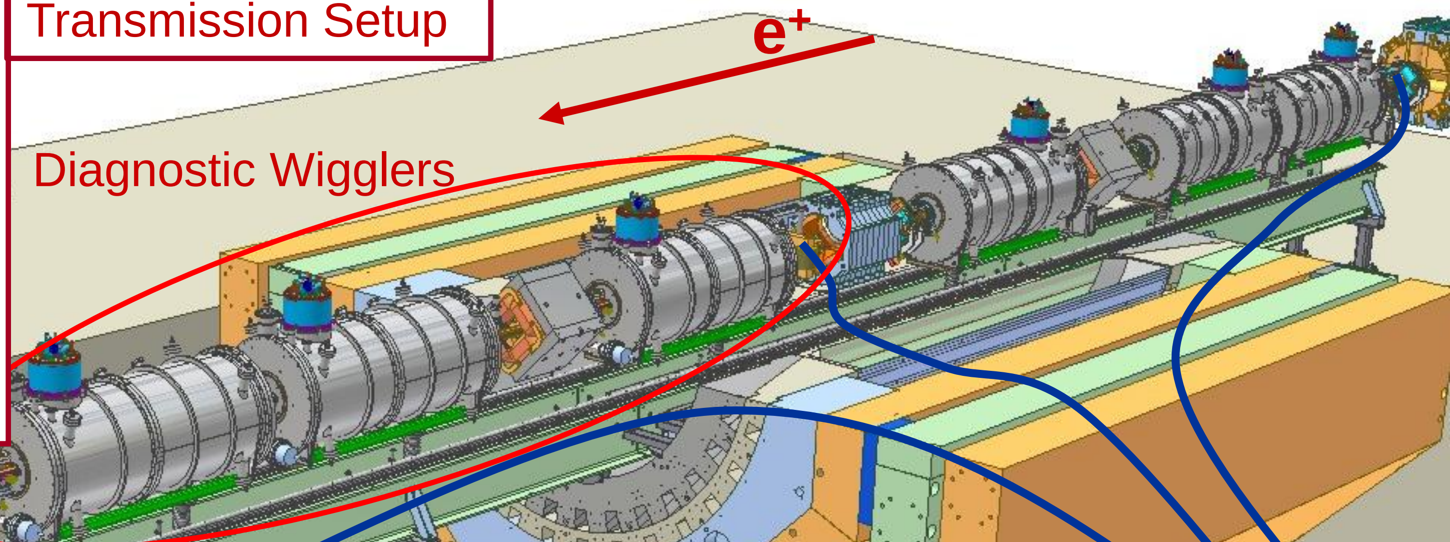
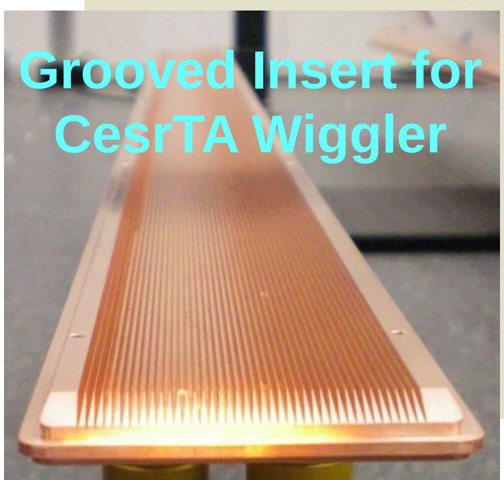


'Resonant BPM' and Transmission Setup



Installed Diagnostic Wigglers

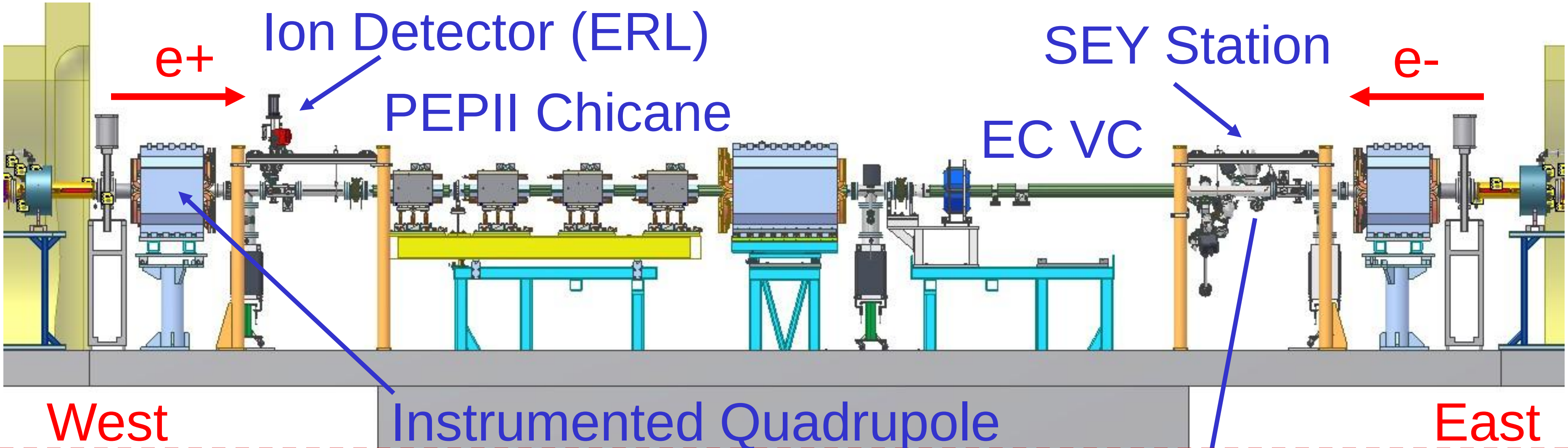
Heliax cables for TE Wave Measurements

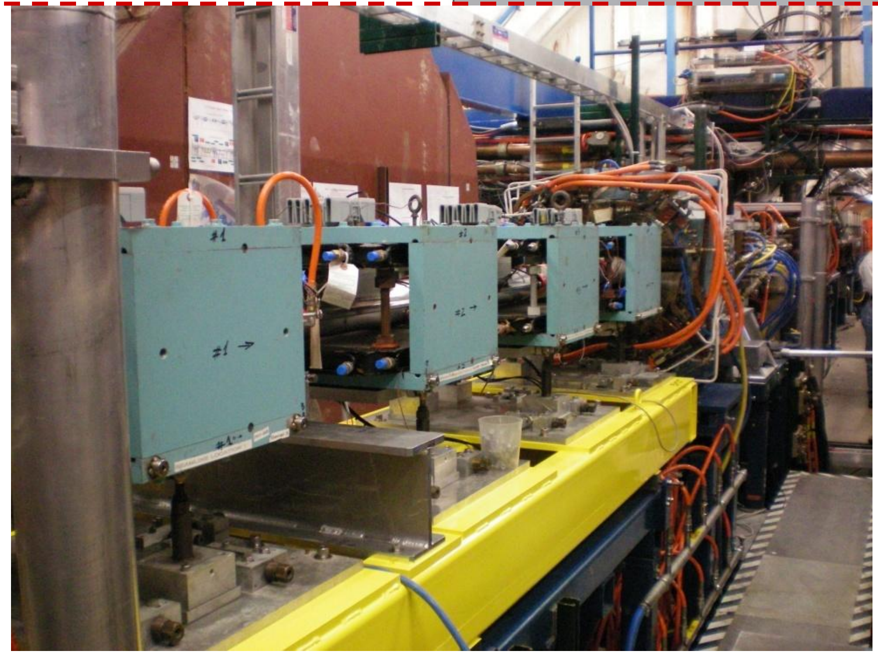


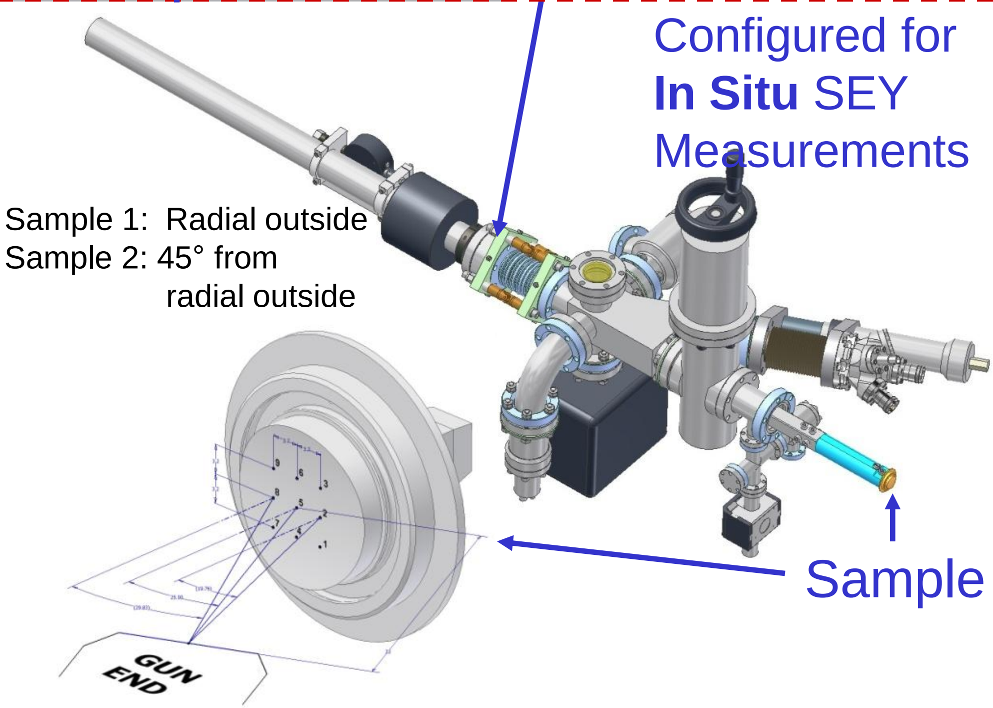
Grooved Insert for CesrTA Wiggler

Wiggler clearing electrode after shipment from KEK to LBNL

CESR Reconfiguration: L3 Experimental Region







CESR Reconfiguration: L3 Experimental Region

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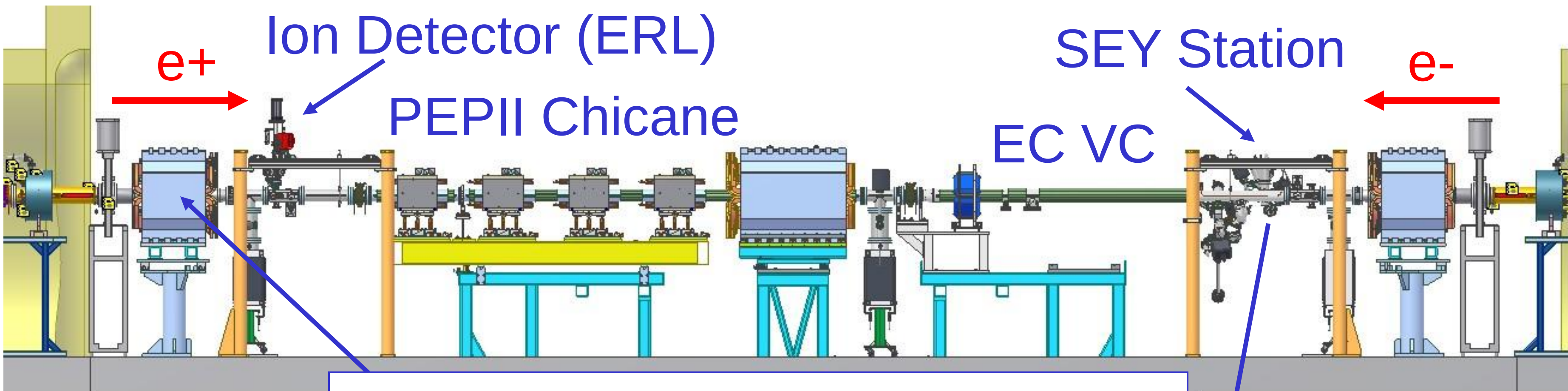
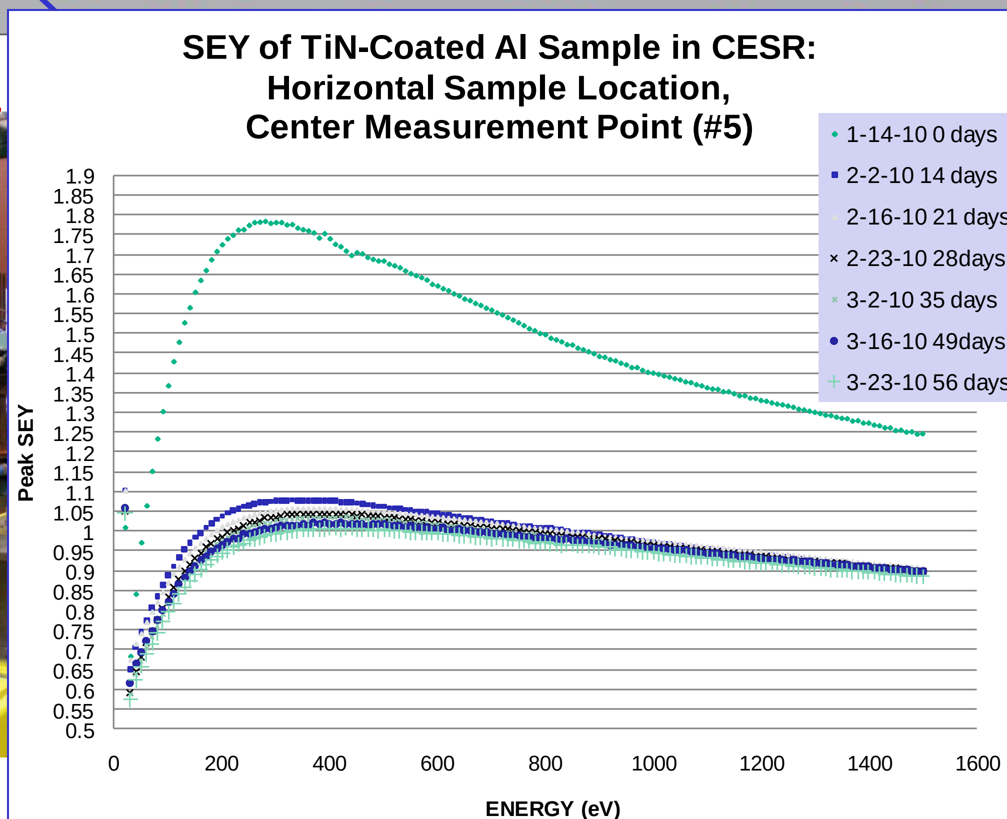
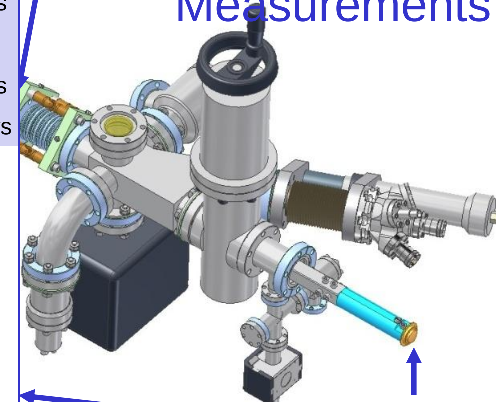


West

East



Configured for **In Situ** SEY Measurements



Sample

CESR Reconfiguration: L3 Experimental Region

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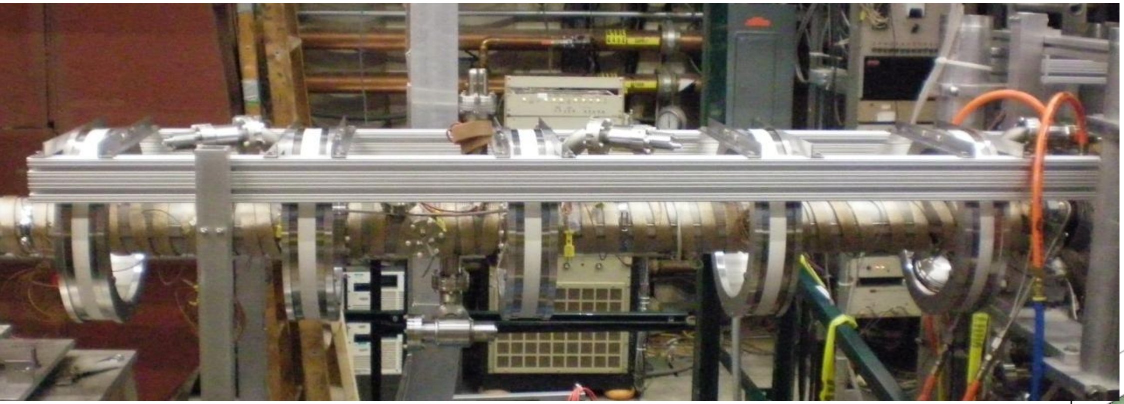
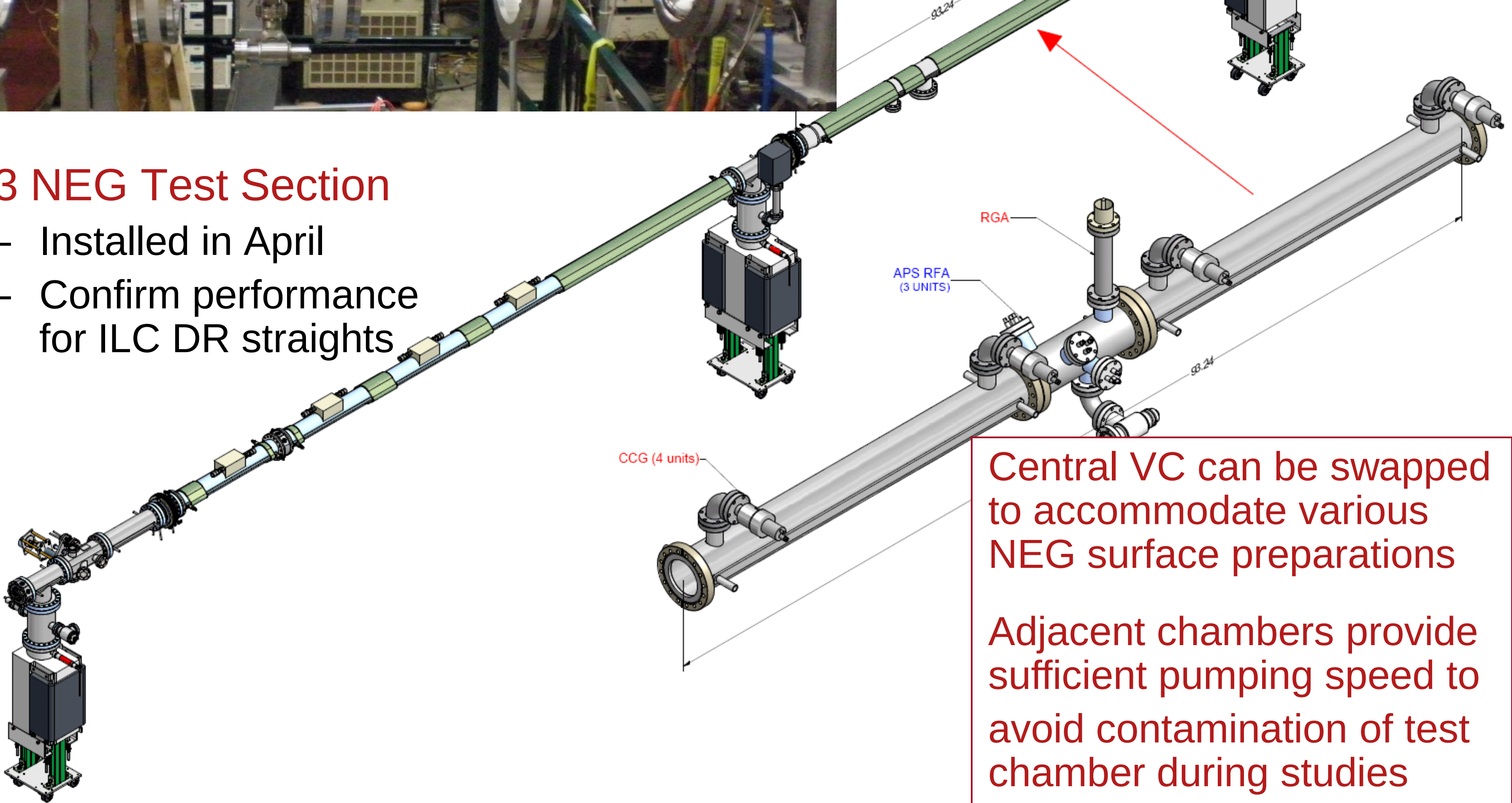


- L3 NEG Test Section
  - Installed in April
  - Confirm performance for ILC DR straights



Central VC can be swapped to accommodate various NEG surface preparations

Adjacent chambers provide sufficient pumping speed to avoid contamination of test chamber during studies

CESR Reconfiguration: CESR Arcs

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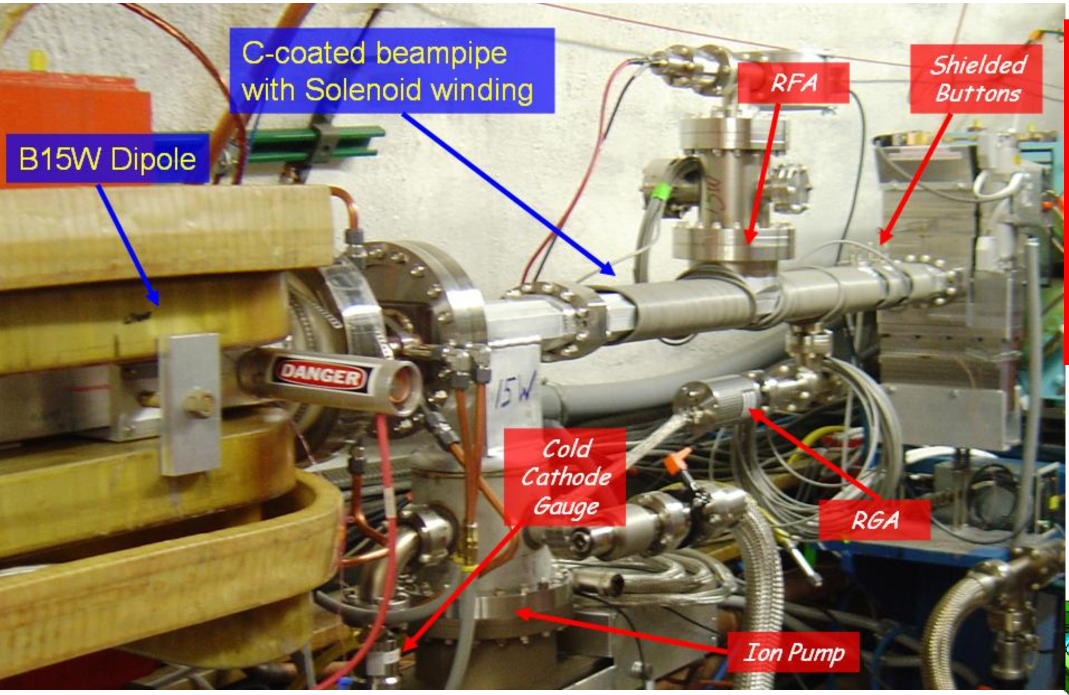
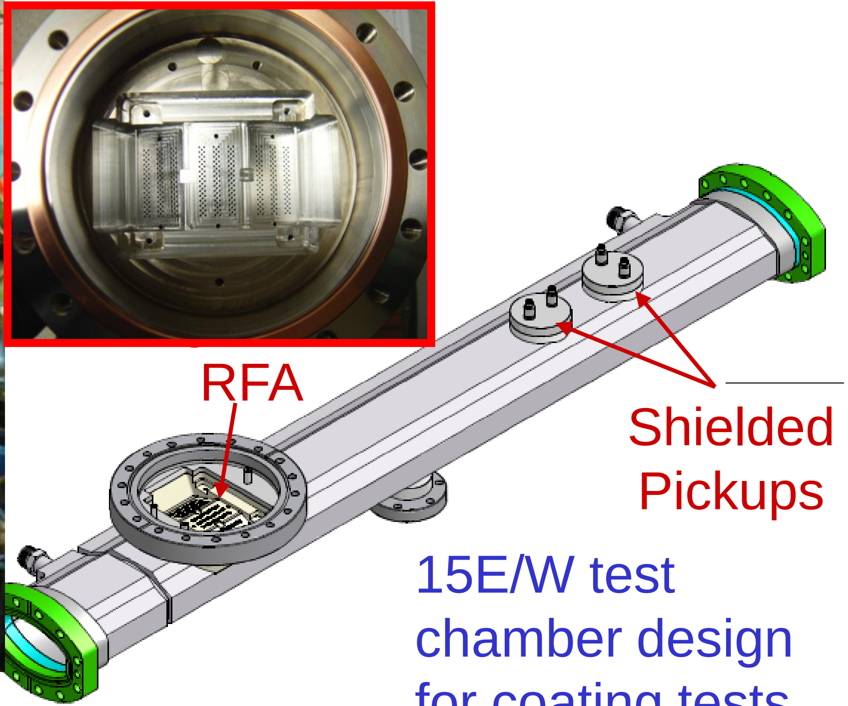
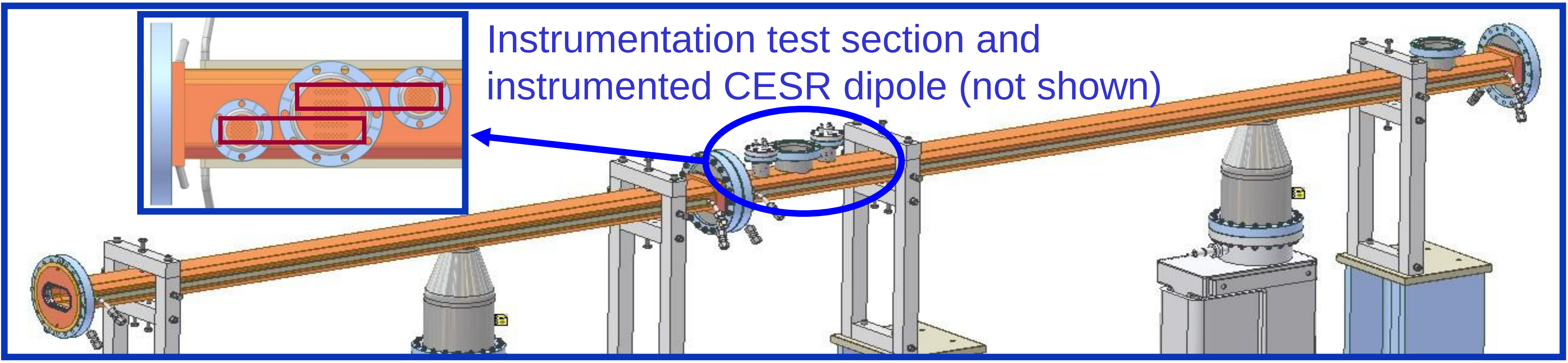




15E/W test
chamber design
for coating tests



Instrumentation test section and
instrumented CESR dipole (not shown)

CESR Reconfiguration: X-Ray Lines

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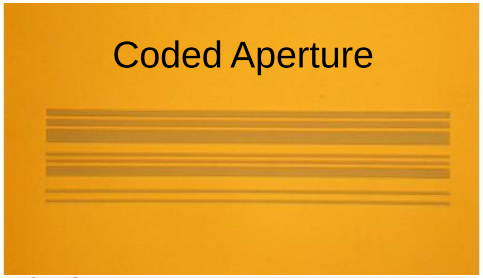
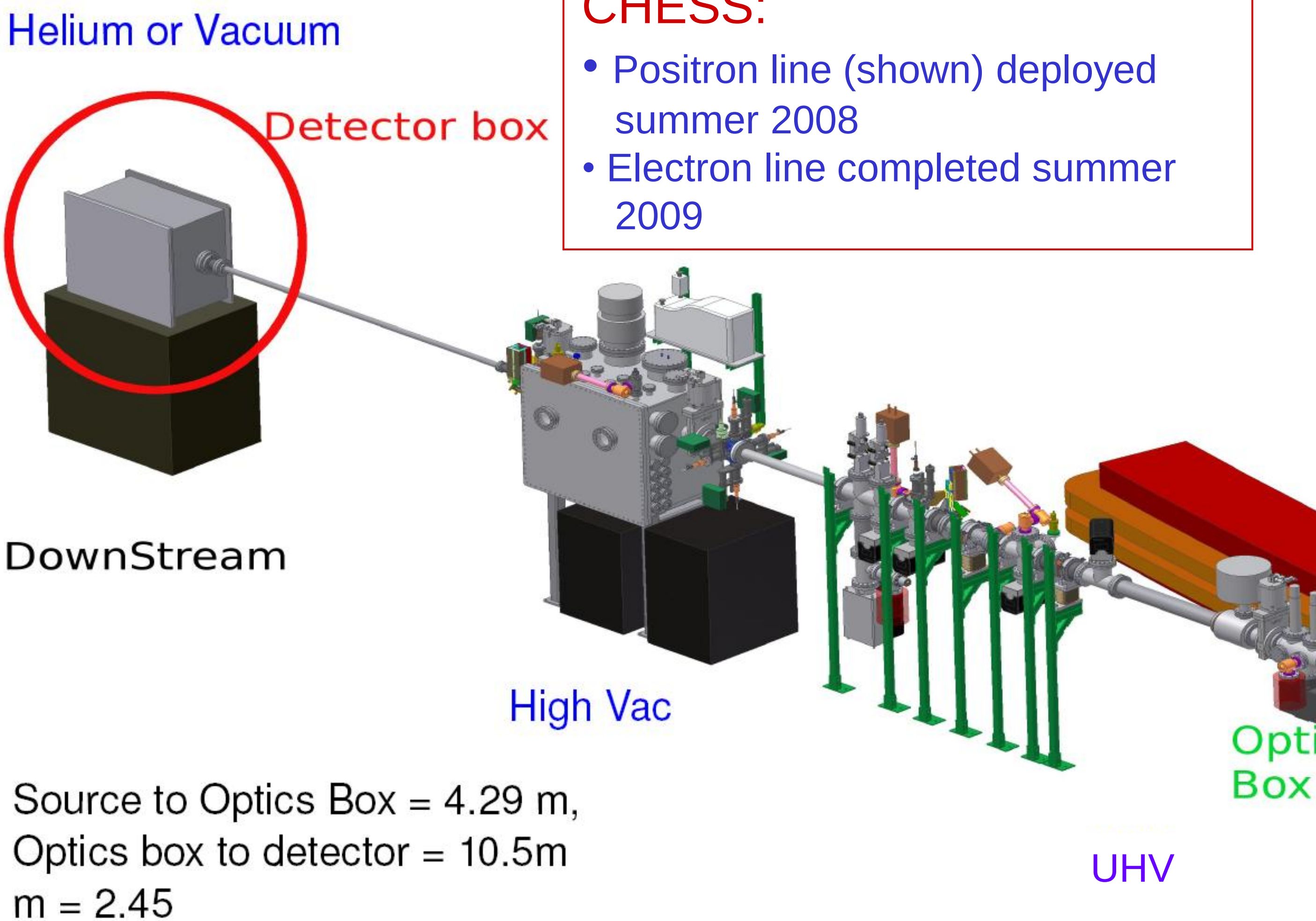
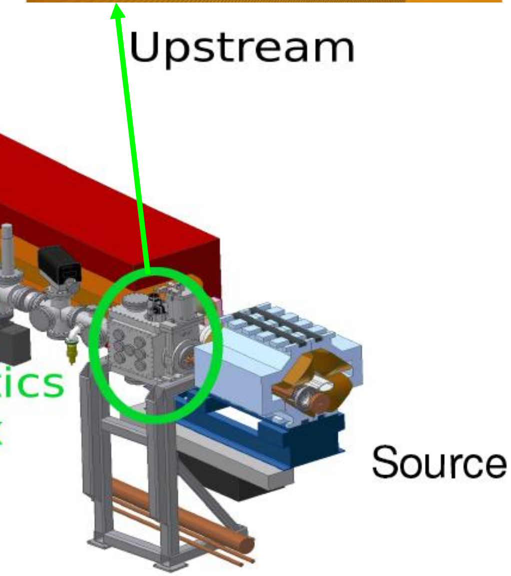
Detector: InGaAs Array
Single-pass readout
Few micron resolution

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

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

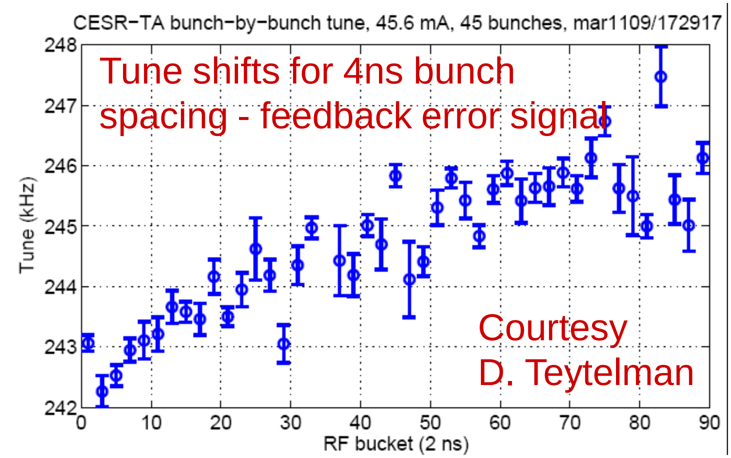


Source to Optics Box = 4.29 m,
Optics box to detector = 10.5m
m = 2.45

Status and Ongoing Effort

- Ring Reconfiguration **Complete**
  - Damping ring layout
  - 4 dedicated EC experimental regions
  - Upgraded vacuum/EC instrumentation
- Beam Instrumentation
  - xBSM positron and electron lines operational
    - Continued x-ray optics and detector development
  - Digital BPM system operational
    - Continued effort on data acquisition and experimental data modes
  - 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)
  - Mitigation tests are ongoing
- Low Emittance Tuning and Beam Dynamics Studies
  - Approaching target vertical emittance of 20pm (see following slides)
  - Continuing effort to take advantage of new instrumentation
  - Continuing to work towards providing low emittance conditions for beam dynamics studies

R&D Effort

- Will Highlight A Few Items
- Low Emittance Correction and Tuning
- EC Studies
  - Build-Up and Mitigation
  - EC Beam Dynamics
  - Simulation Program

⇩

Status Report on a Work In Progress !

My apologies to the collaboration for the many things that there is no time to show!

CESRTA-Related Posters

MOPE007:	**J. Flanagan, *et al.*,**	**xBSM for LET & EC**
MOPE088:	**S. De Santis, *et al.*,**	**TE Wave Measurements**
MOPE089:	**M. Palmer, *et al.*,**	**BPM System for LET & EC**
MOPE090:	**D. Peterson, *et al.*,**	**xBSM for LET & EC**
MOPE091:	**M. Billing, *et al.*,**	**Overview of Experimental Techniques**
TUPEB014:	**Y. Susaki, *et al.*,**	**EC Instability Simulation**
TUPEC077:	**L. Wang, *et al.*,**	**EC Trapping (Quads, Wigglers)**
TUPD019:	**G. Penn, *et al.*,**	**TE Wave Simulation**
TUPD022:	**J. Calvey, *et al.*,**	**RFA Modeling**
TUPD023:	**J. Calvey, *et al.*,**	**RFA Experimental Results**
TUPD024:	**J. Crittenden, *et al.*,**	**Beam Dynamics Modeling**
WEPEB058:	**K. Artoos, *et al.*,**	**CLIC Stability Tests**
WEPE097:	**M. Pivi, *et al.*,**	**ILC DR Working Group**
THPE046:	**J. Shanks, *et al.*,**	**LET**

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

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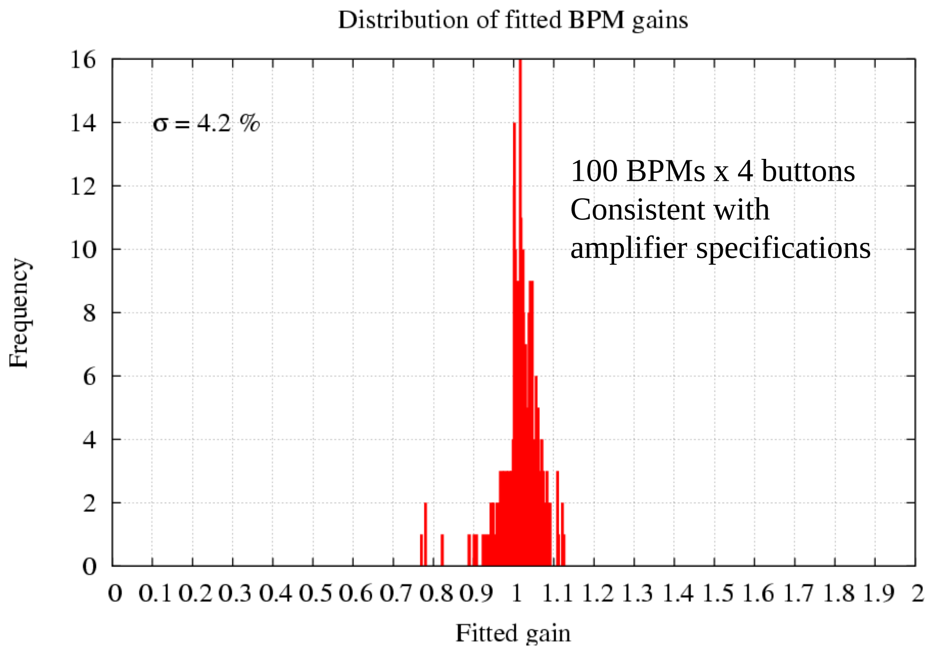
LET Procedure

1. Collect turn by turn data with resonant excitation of horizontal and vertical motion
2. Fit BPM gains
3. Measure and correct
   - Orbit, with steerings
   - Betatron phase and coupling, with quads and skew quads
4. Measure dispersion by resonant excitation of synch tune
5. Fit simultaneously – coupling,vertical dispersion and orbit using vertical steerings and skew quads and load corrections



December Run – Measured ε_y =31pm with xBSM.

MOPE007
MOPE089
MOPE090
THPE046

Low Emittance Working Point

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Vertical beam size, measured with x-ray beam size monitor vs tune

- Pinhole x-ray optic:
  β_y=17m at source limits $\sigma_y \geq 16\mu m$
- Q_s = 0.066

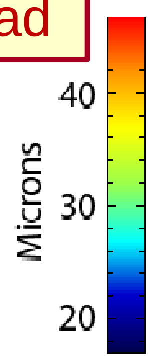
σ_y = 20 μm

⇨ ε_y = 23 pm-rad

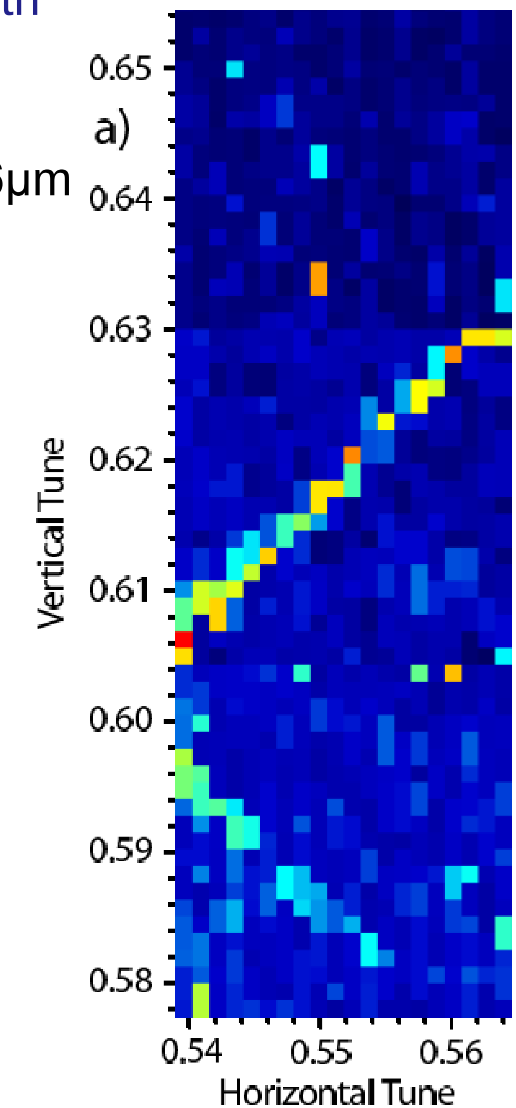
May Run:

σ_y = 18±5 μm

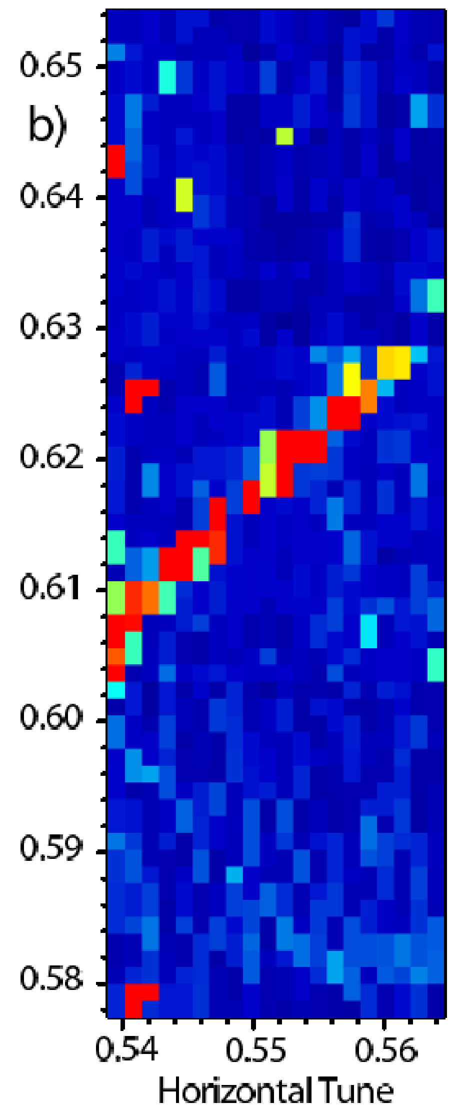
⇨ ε_y ~ 19 pm-rad



2 family sextupole distribution



Sextupoles optimized to minimize resonance driving terms



Status 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

Surface Characterization & Mitigation Tests

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	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

TE Wave & RFA Measurements in L0

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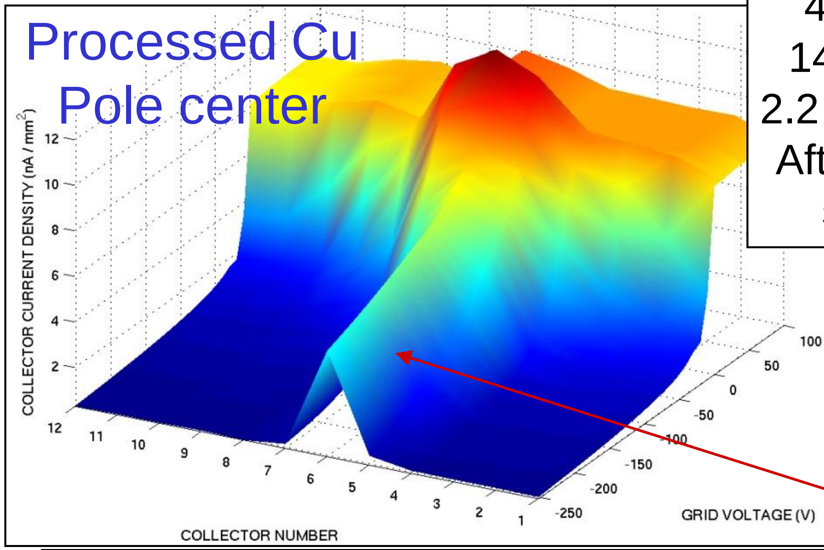
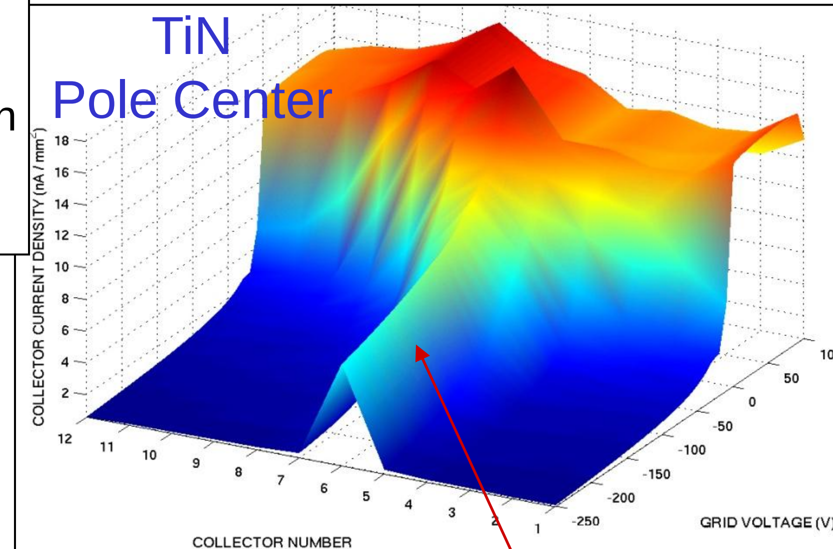
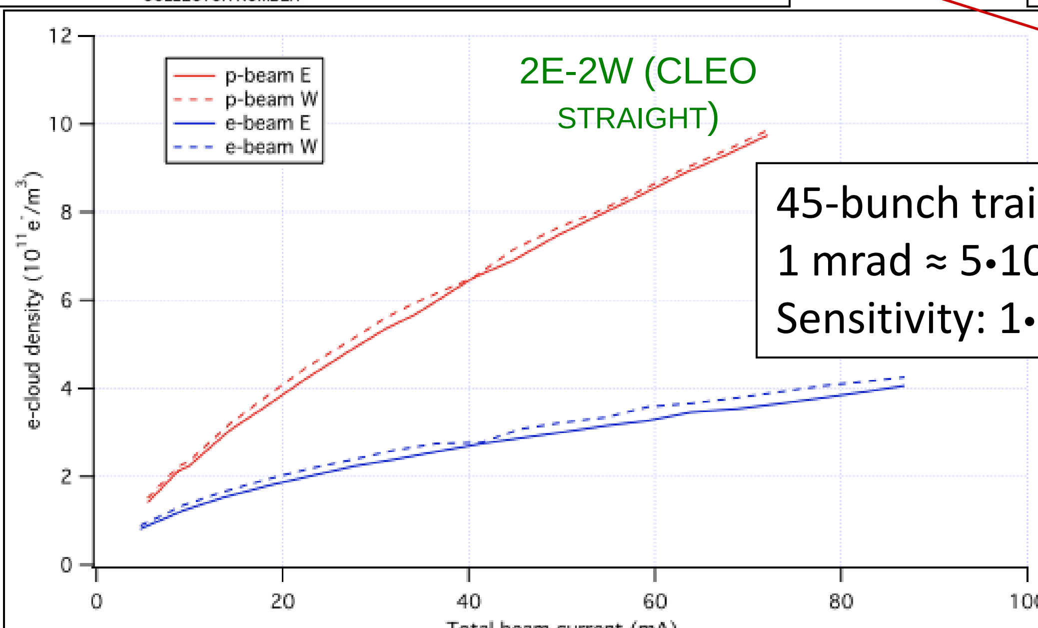


45 bunches
14ns spacing
2.2×10^{10}/bunch
After extended scrubbing





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

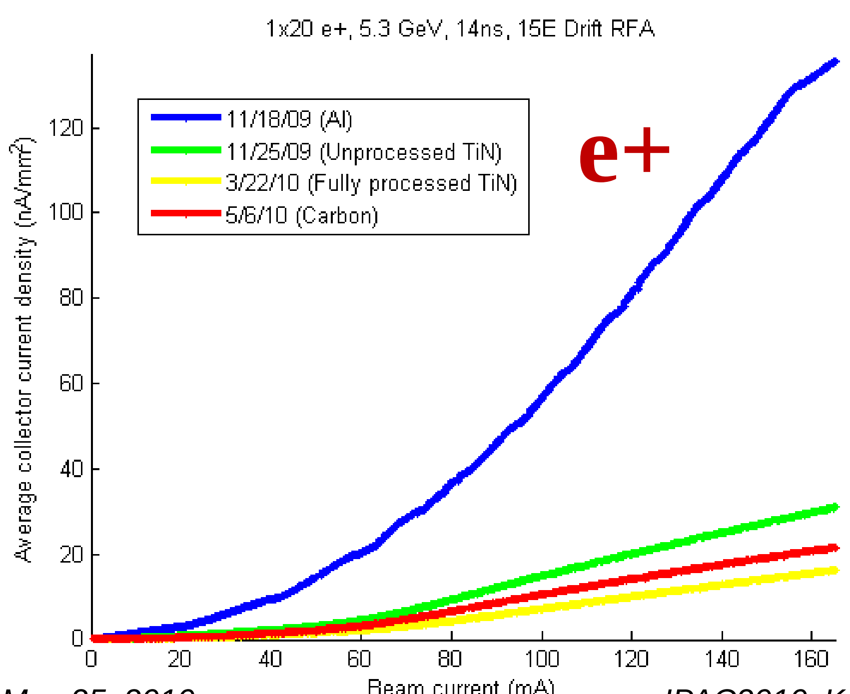
Similar performance observed

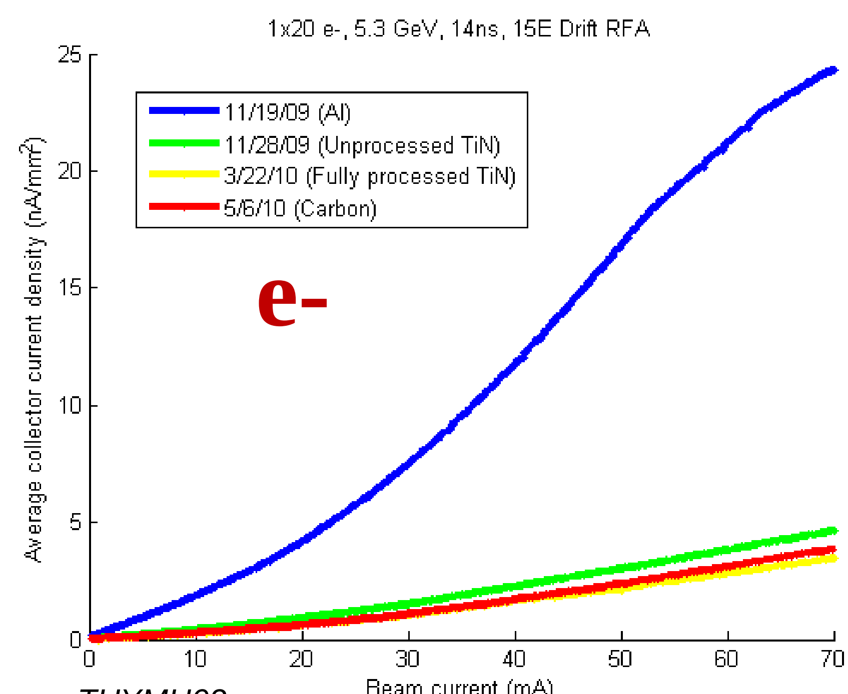
See this afternoon's posters for a discussion of RFA modeling

MOPE088
MOPE091
TUPD022
TUPD023

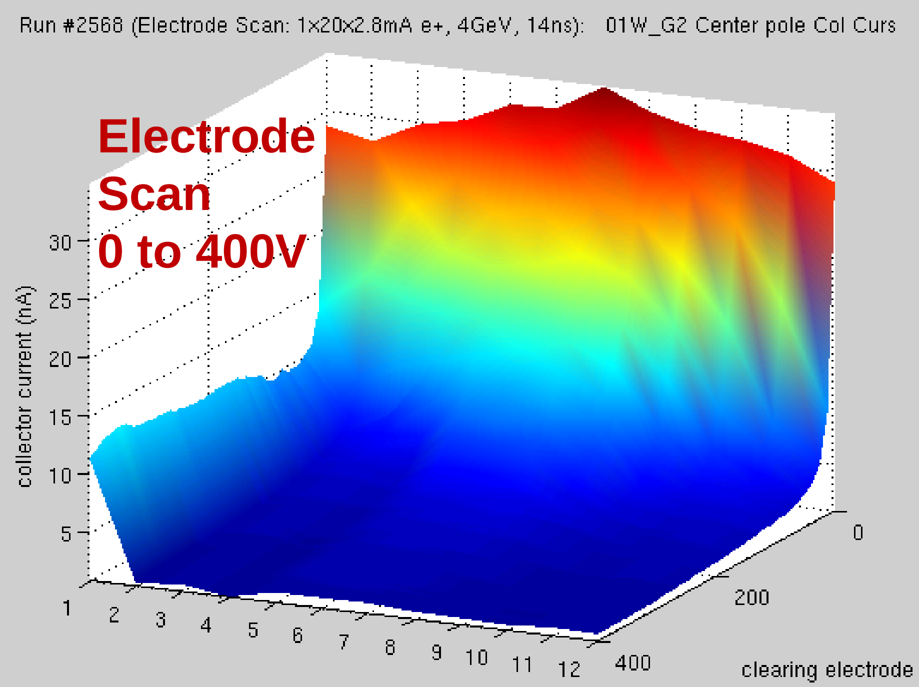
15E Drift RFAs

- April 2010 Down
  - Install amorphous C chamber (CERN) in location first occupied by Al chamber and then by TiN chamber
- 1x20, 5.3 GeV, 14ns
  - Compare three different chambers (Al – blue, TiN – green, Carbon – red) that were installed in 15E test location at different times
  - Both coatings show similar performance, much better than Al – Carbon (early in scrubbing process) currently lies in between processed and unprocessed TiN.
  - Will make final comparisons for scrubbed chambers (July 2010 run)





Wiggler Clearing Electrode



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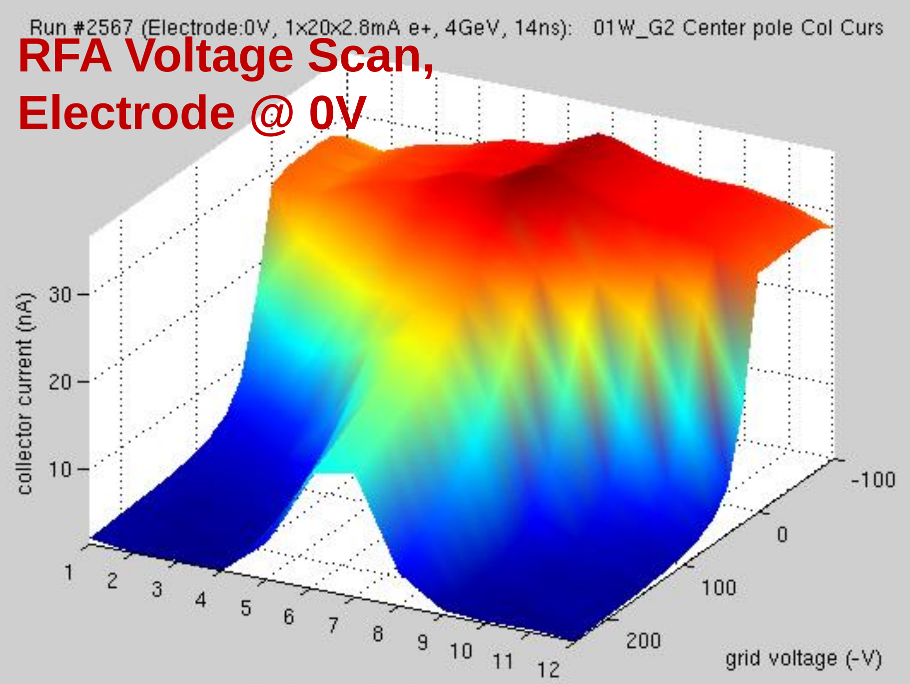
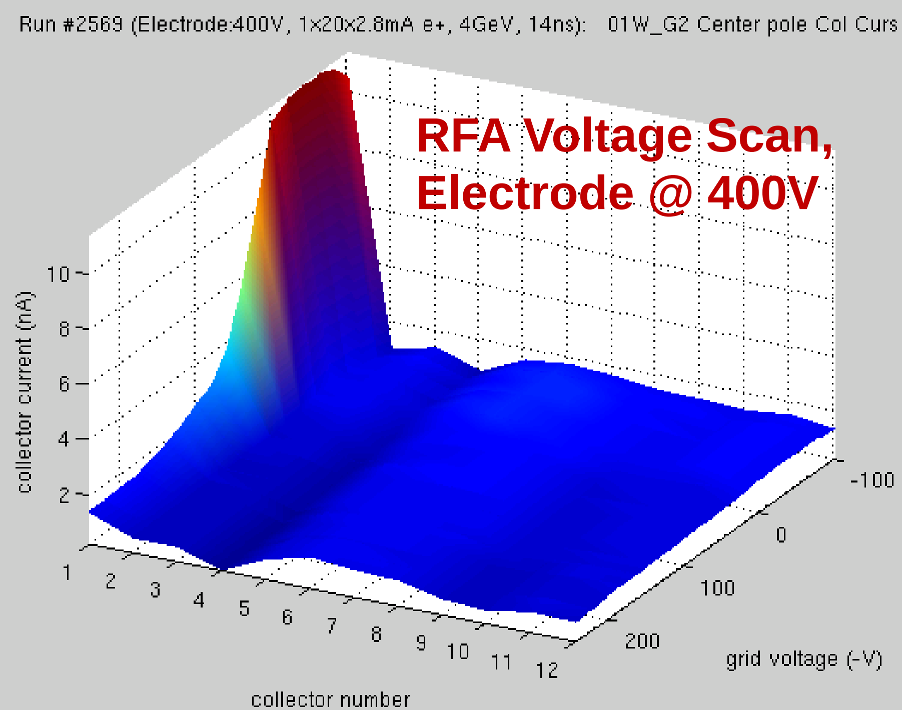
- 20 bunch train, 2.8 mA/bunch
  - 14ns bunch spacing
  - E_{beam} = 4 GeV with wigglers ON
- Effective cloud suppression
  - Less effective for collector 1 which is not fully covered by electrode





L3 Chicane (SLAC): Measurements & Simulations

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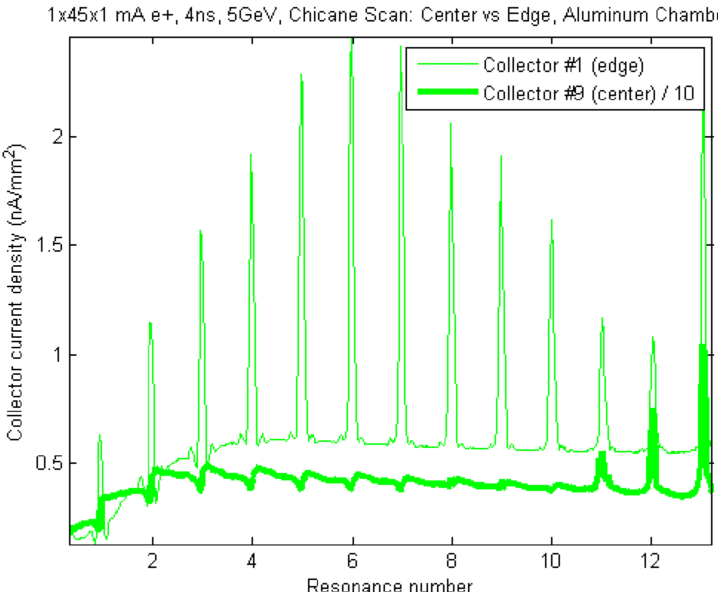
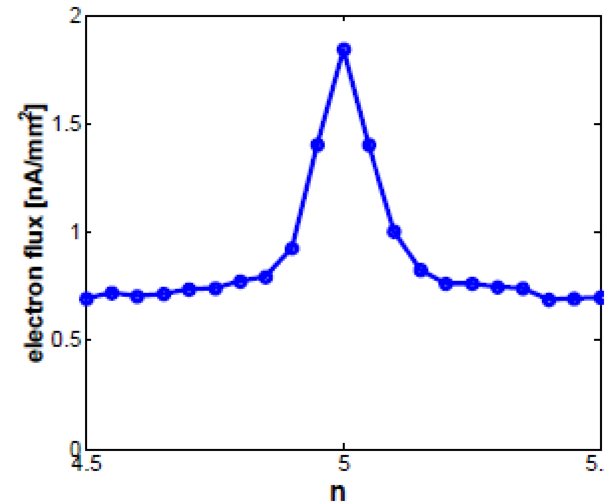
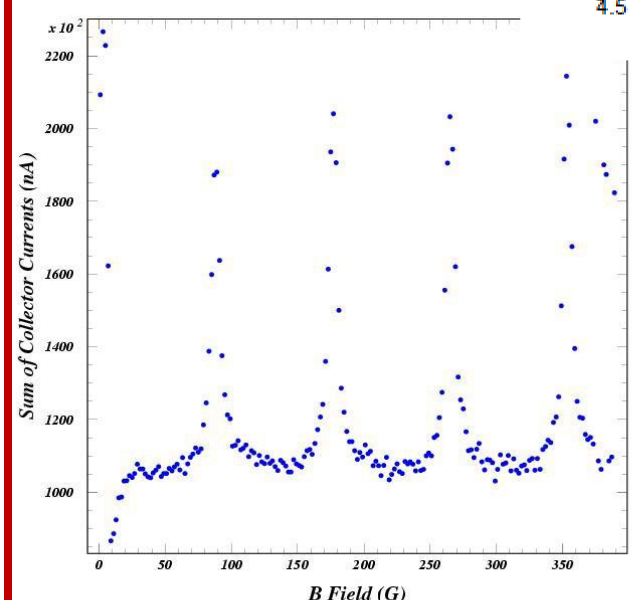


Cyclotron resonances can be reproduced in both ECLOUD and CLOUDLAND

- Plots are of the sum of all collectors for 45 bunches, positrons, 4ns spacing, δ_{max} = 2.0
- Dips are harder to reproduce



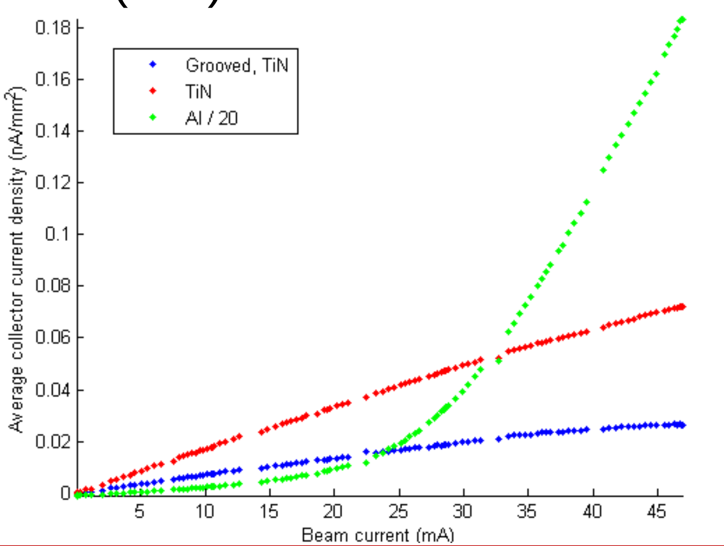
CLOUDLAND (L.Wang)



ECLOUD (J. Crittenden)

Mitigation Comparisons

Al (÷20) vs TiN vs TiN+Grooves



Mitigation Performance in Dipoles (e+ & e-)

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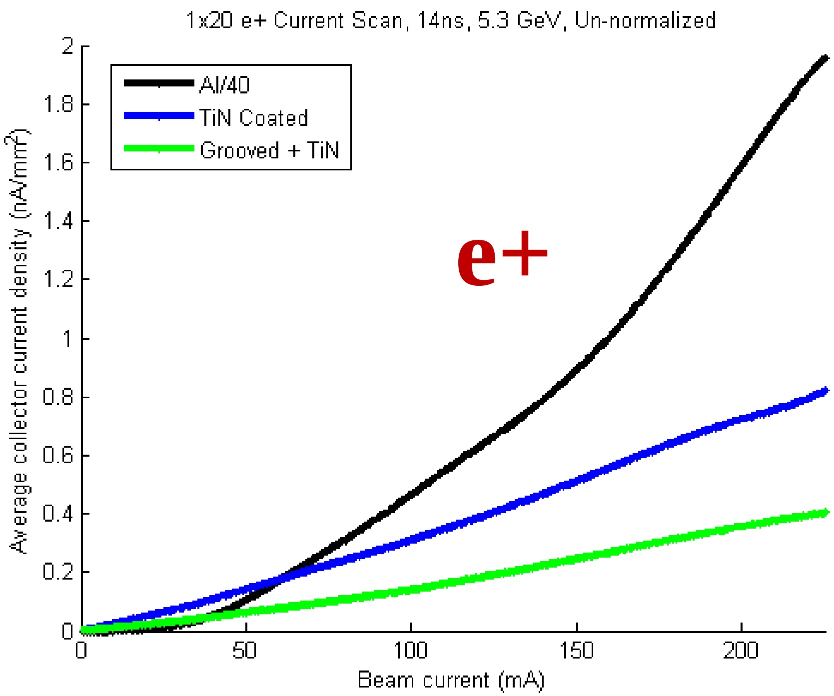
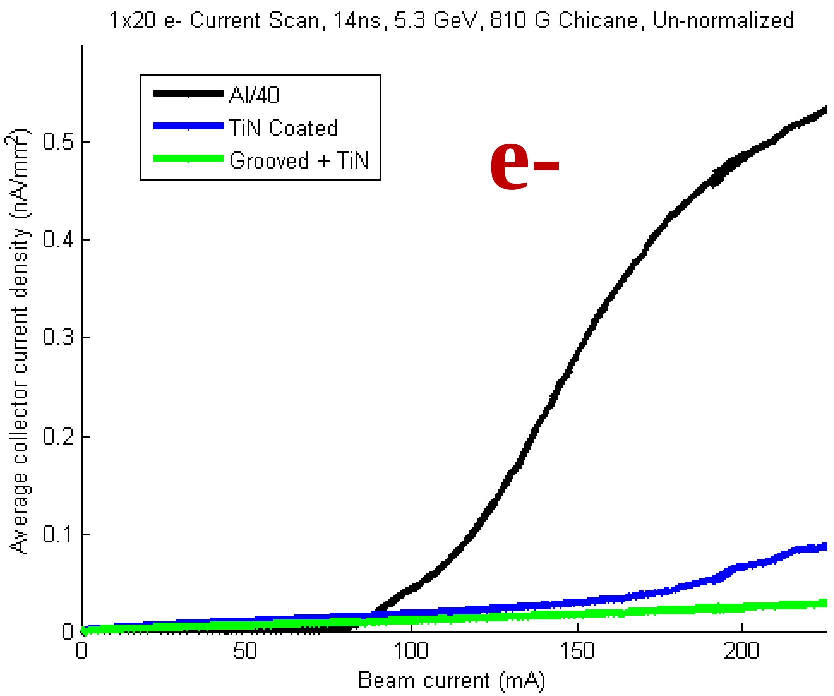
May 23–28, 2010

- 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

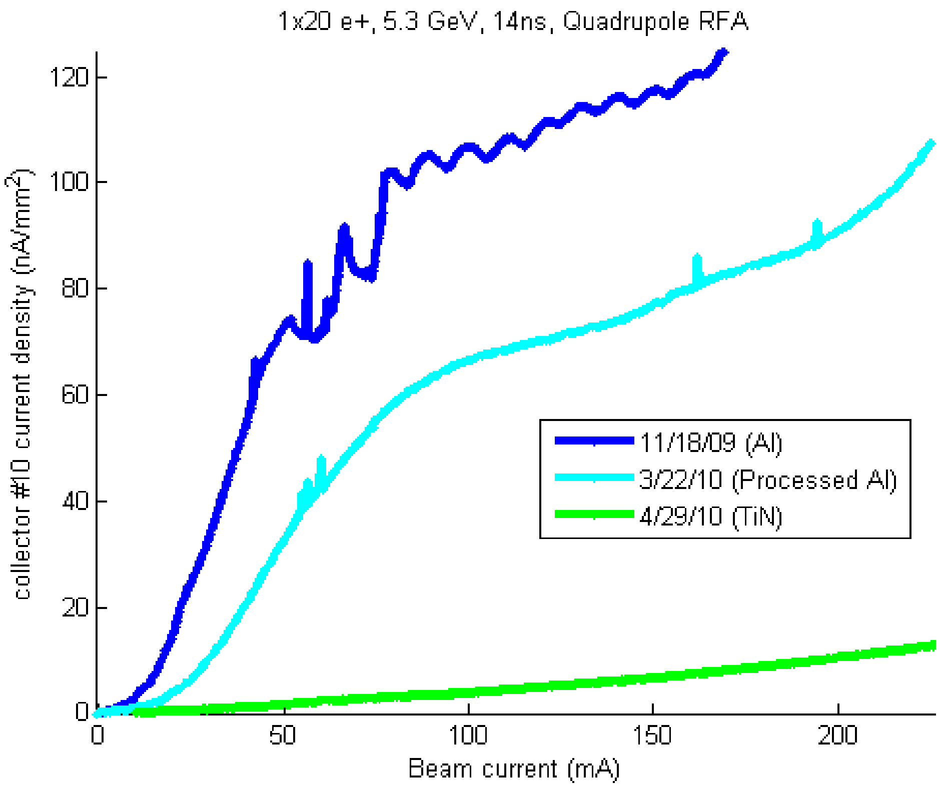


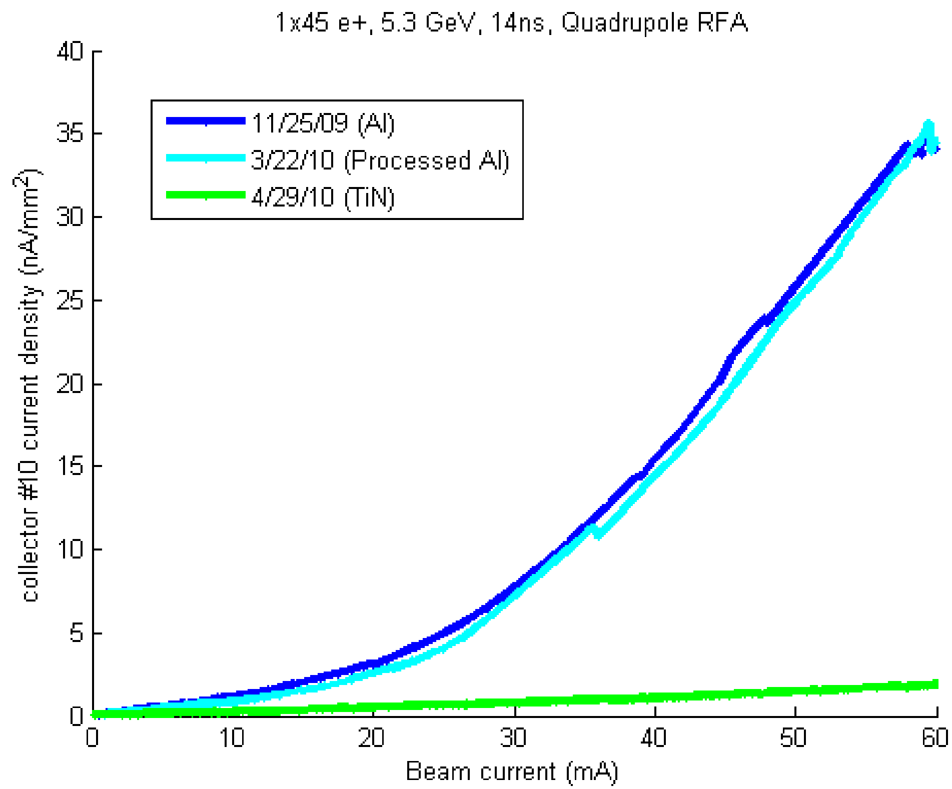


Quadrupole Measurements

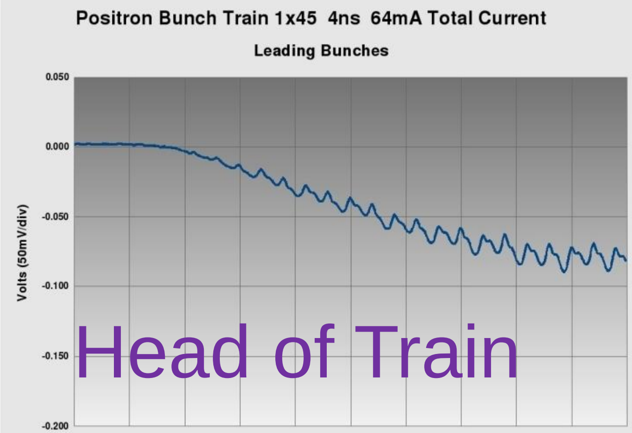
- Left: 20 bunch train e+
- Right: 45 bunch train e+ ⇨ Clear improvement with TiN
- Currents higher than expected from “single turn” simulations
  - Turn-to-turn cloud buildup
  - Issue also being studied in wigglers

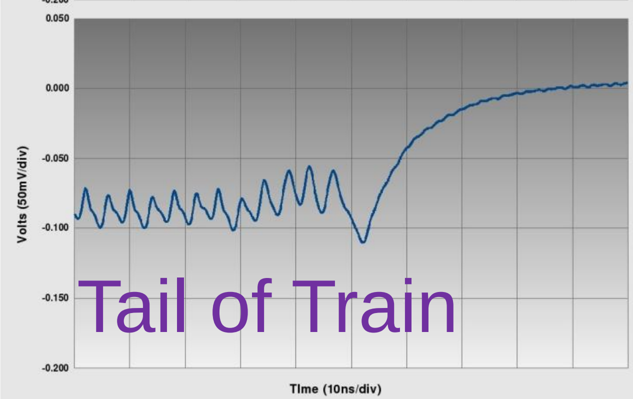
TUPD023
TUPEC077





Time Resolved Measurements





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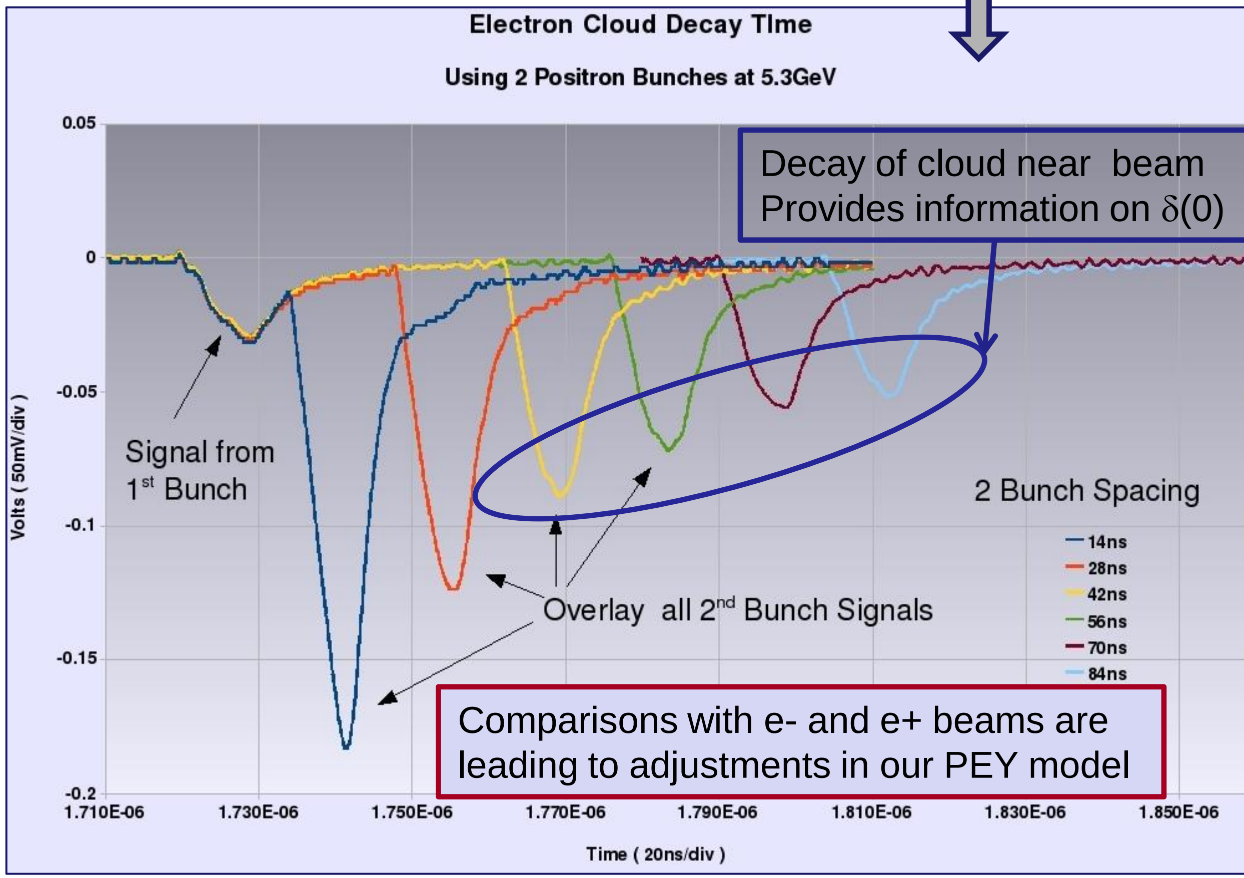
45 bunch train
4ns bunch spacing
~2.3×10^{10} e+/bunch

Witness Bunch Studies:
EC-generating Bunch
Trailing Probe Bunch



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

MOPE091

Coherent Tune Shifts

- 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
- Methods: Excite coherent oscillations of whole trains using a single-turn pinger
  Observe tune of self-excited bunches (Dimtel system diagnostics)
  Excite individual bunches using a fast kicker
- Comparison with predictions (dipoles & drifts): 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

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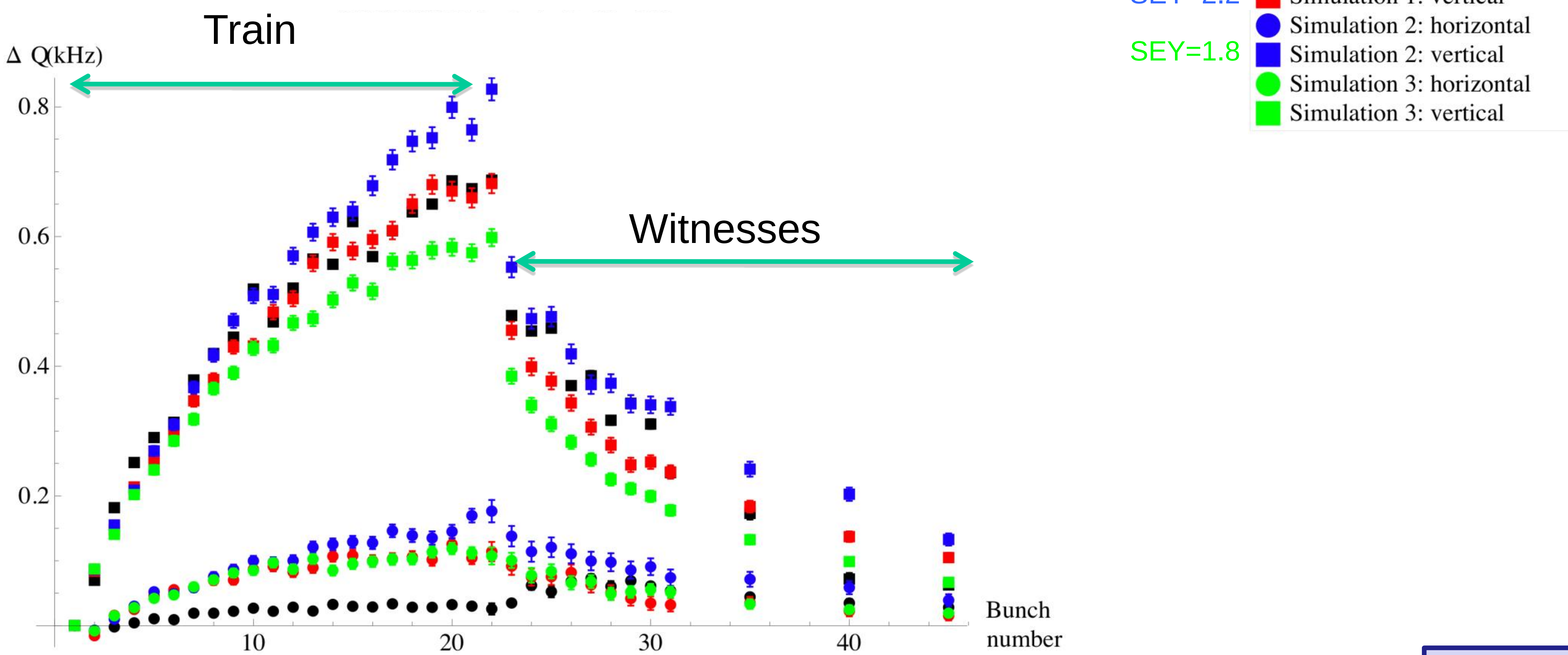
Peak SEY Scan

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.



MOPE089
TUPD024

Coherent Tune Shift Comparisons

14 ns spacing
Measure coherent train motion

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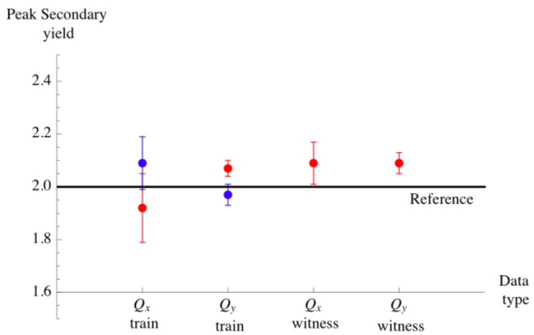
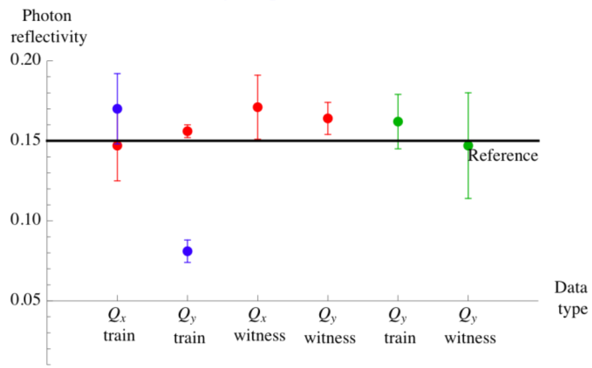
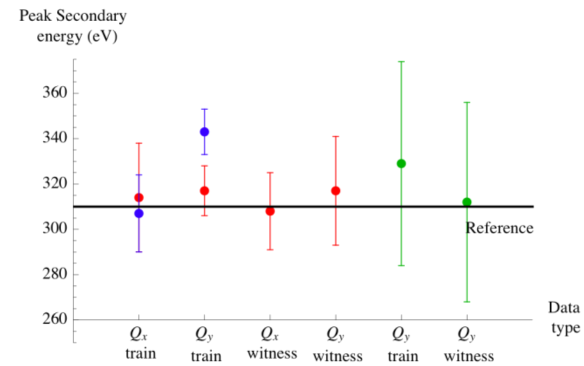
Peak Secondary yield from best single-parameter fit to data
2007-2008 data: • 2009 data: •



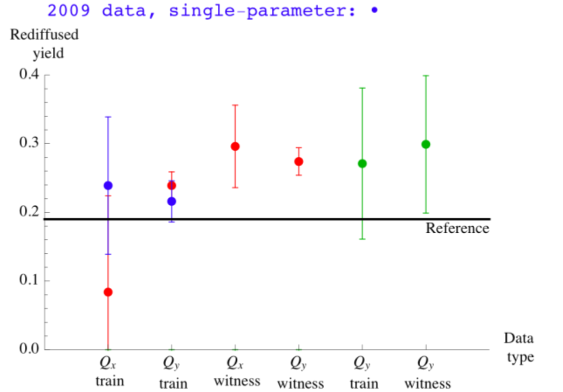
Photon reflectivity from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •



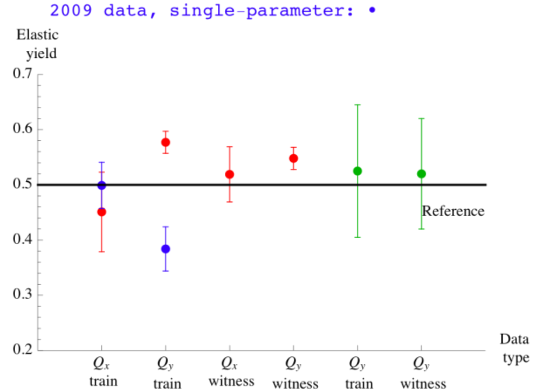
Peak Secondary energy (eV) from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •



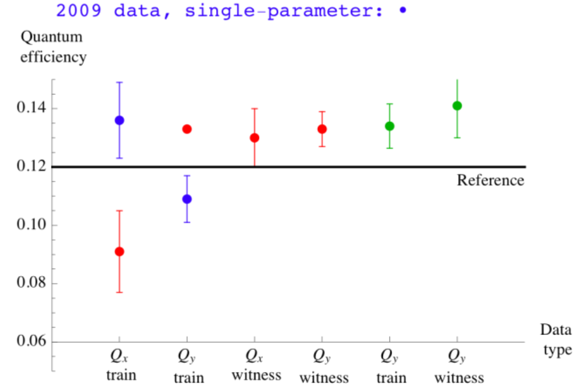
Rediffused yield from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •



Elastic yield from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •



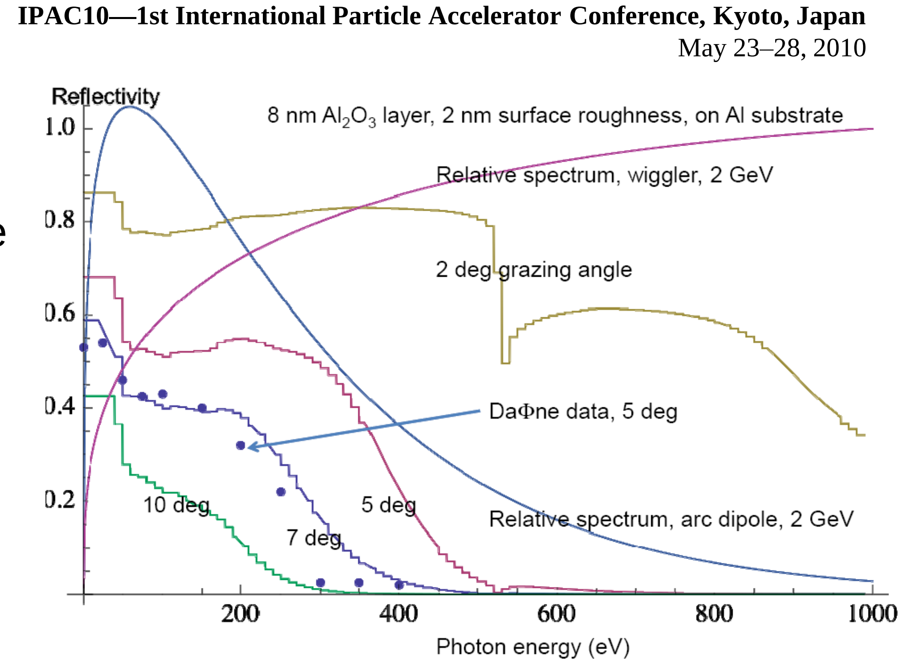
Quantum efficiency from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •

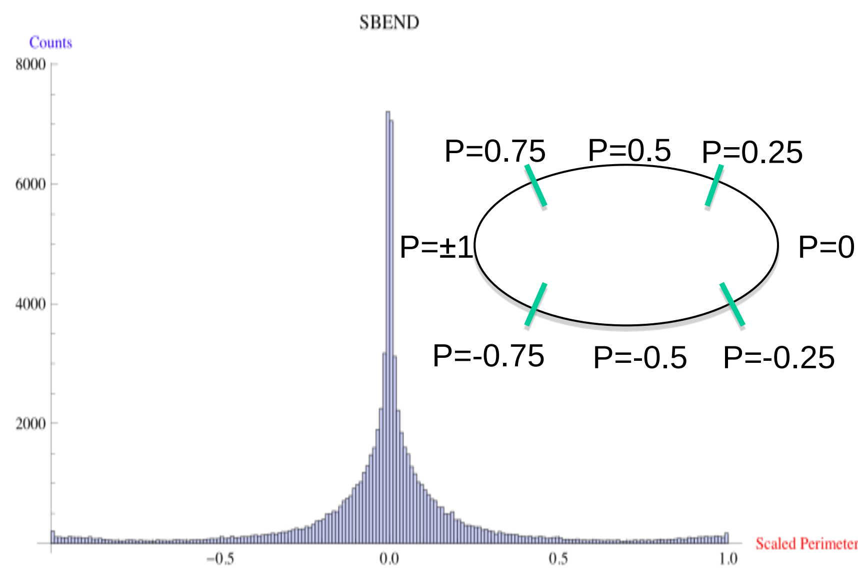


The ability to obtain a set of EC model parameters which works for a wide range of conditions validates the fundamental elements of the cloud model.

Synchrotron Radiation Simulations

- SYNRAD3D (Sagan *et al.*): computes the direct and reflected synchrotron radiation distributions
  - Parameterizes X-ray scattering data from the LBNL online database.
  - Provides azimuthal distributions around the vacuum chamber of photon absorption sites at each ***s*** position around the ring.
- Results needed to understand photon distributions in CESRTA instrumented vacuum chambers
  - Resulting photon distributions show significant differences from typical values obtained from models which ignore reflections – both in azimuthal and in longitudinal distributions
  - For CESRTA simulations, photon rates in key areas can vary by a factor of several
- Work underway to incorporate these results into the RFA and Coherent Tune Shift analyses





Beam Instabilities & Emittance Growth

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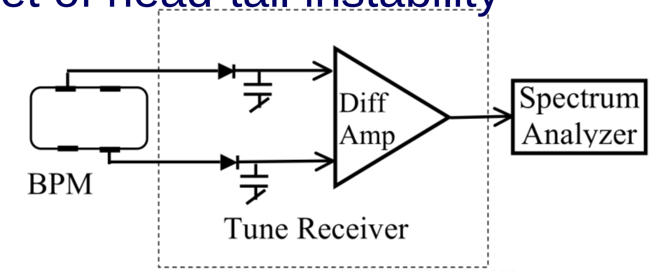
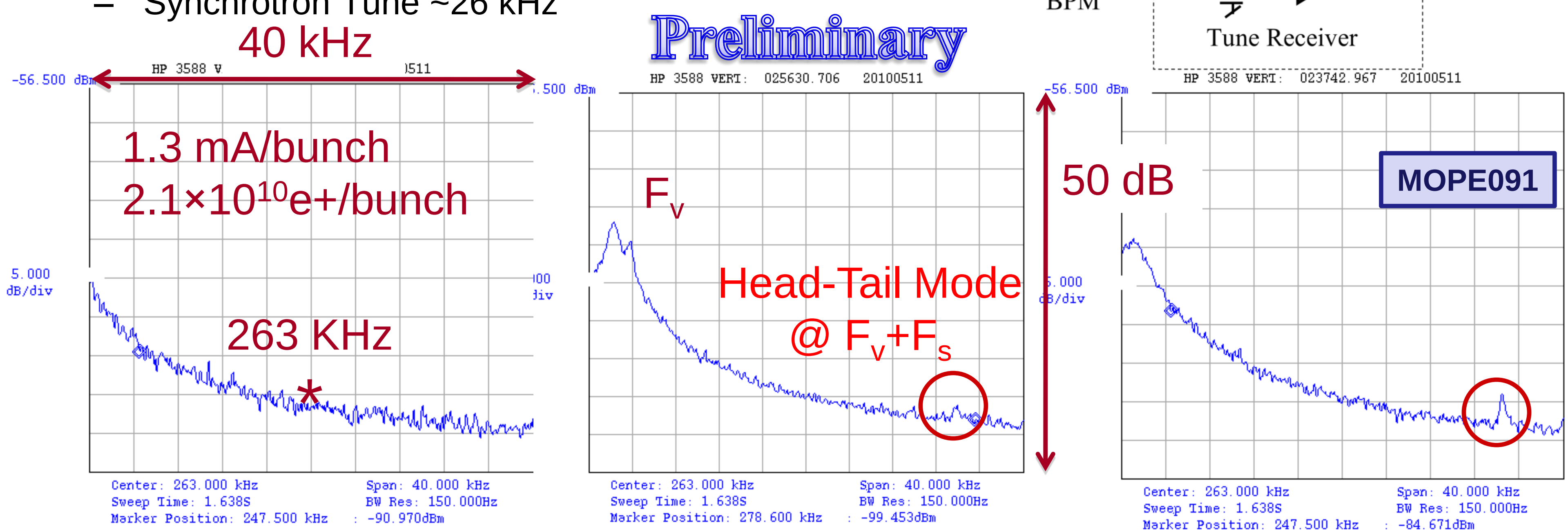
- Bunch-by-bunch measurements - xBSM
- Single-bunch (head-tail) – spectral methods and growth rates
- Multi-bunch modes via feedback and BPM system
- Modeling: KEK-Postech (analytical estimates and simulation)
  SLAC-Cornell (CMAD)
  Frascati (multi-bunch instability)

- Current scan in 45 bunch positron train ⇨ Look for onset of head-tail instability
- 2 GeV Low Emittance Lattice, 14ns bunch spacing
  - F_v & Head-Tail Mode spectra (expected at $F_v + F_s$)
  - Synchrotron Tune ~26 kHz





Bunch #1 Bunch #25 Bunch #40

Beam Size

- Measure Bunch-by-Bunch Beam Size

Same current scan as on preceding page

  - Beam size enhanced at head and tail of train
    Source of blow-up at head requires further investigation (resonance? other?).
    Beam lifetimes (Touschek) consistent with center of train having smallest size.
  - Beam size measured around bunch 15 is consistent with $\varepsilon_y \sim$ 20pm-rad (σ_y=11.0±0.2 μm, β_{source}=5.8m)

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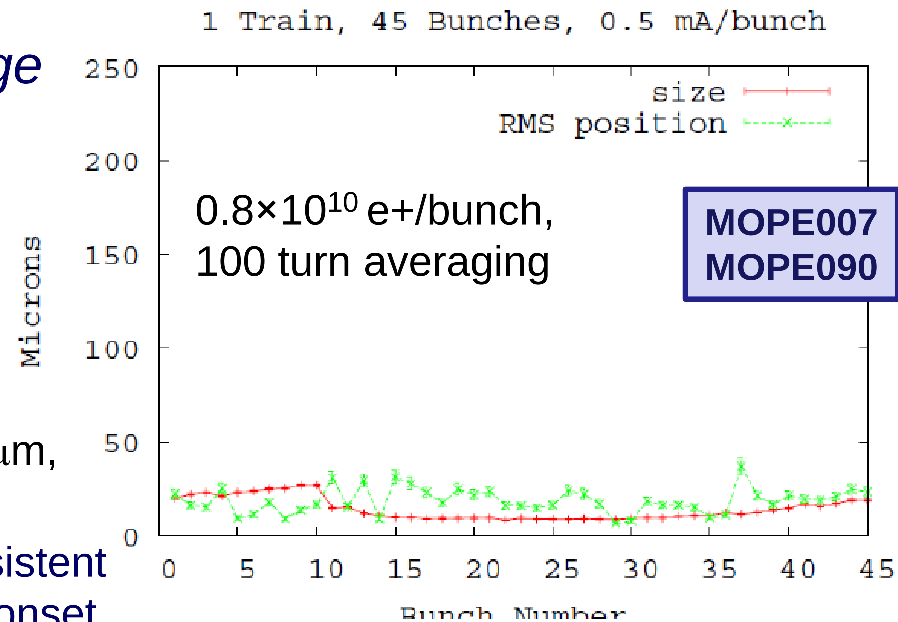
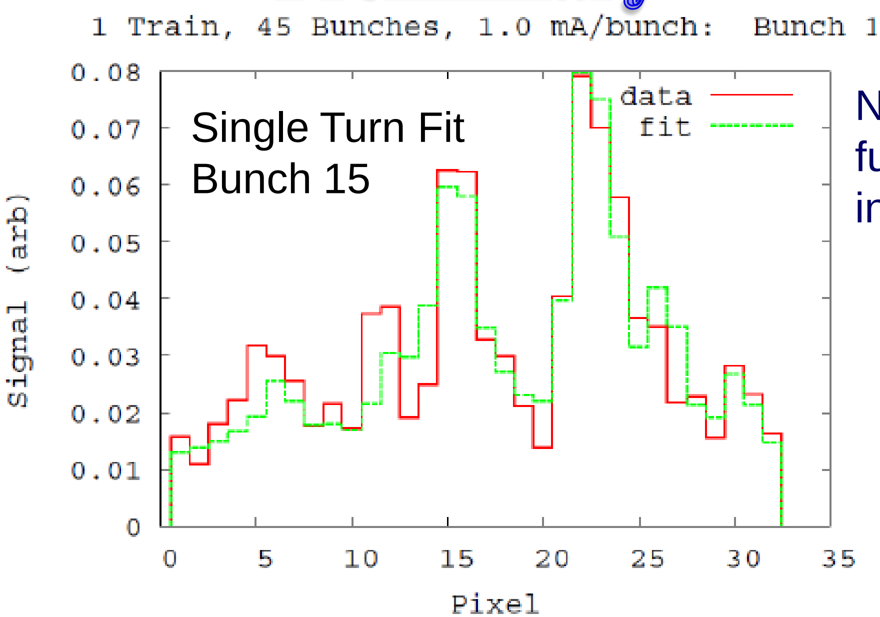


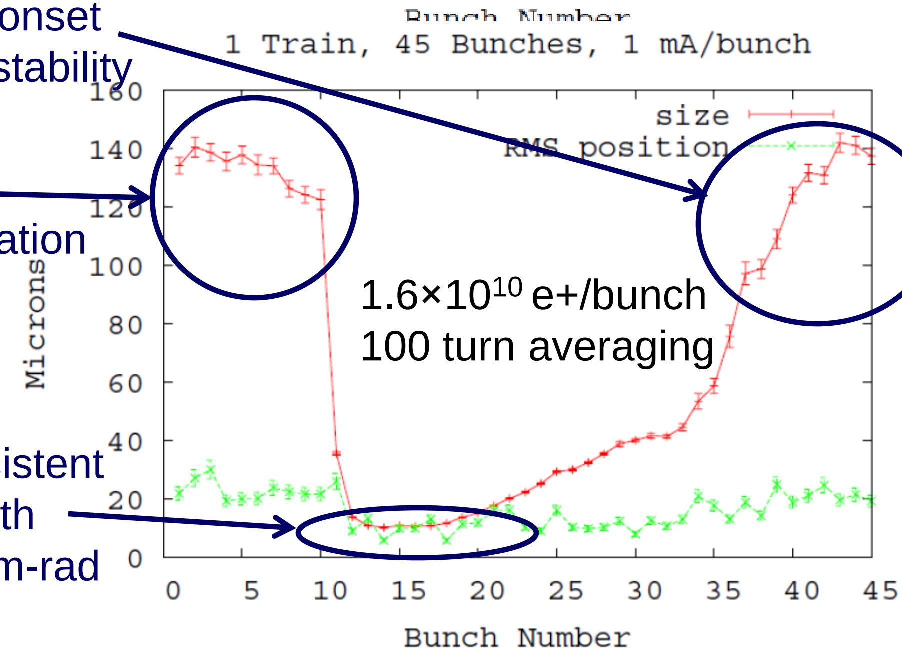
Preliminary



Consistent with onset of instability

Needs further investigation

Consistent with 20 pm-rad



Simulation of Incoherent ε_y Growth & Instabilities

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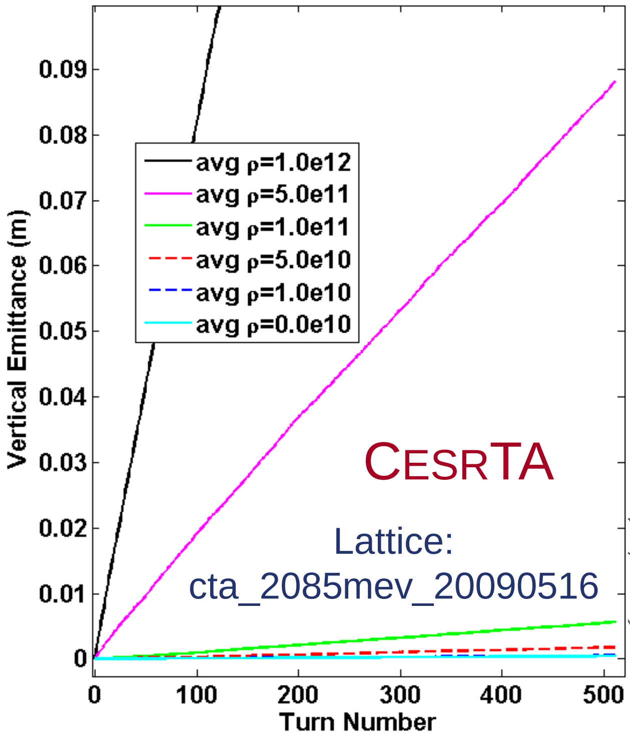
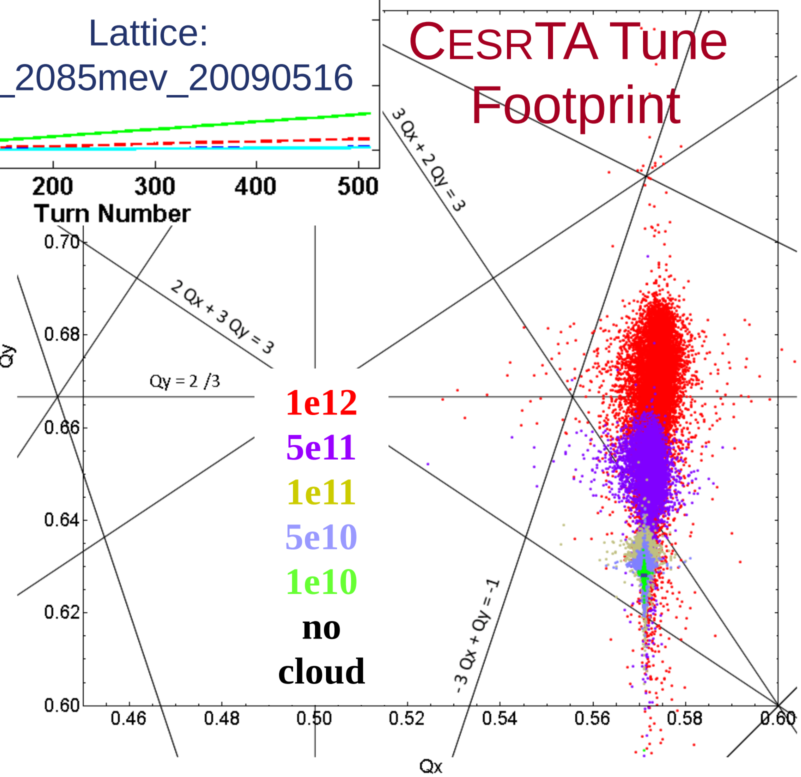
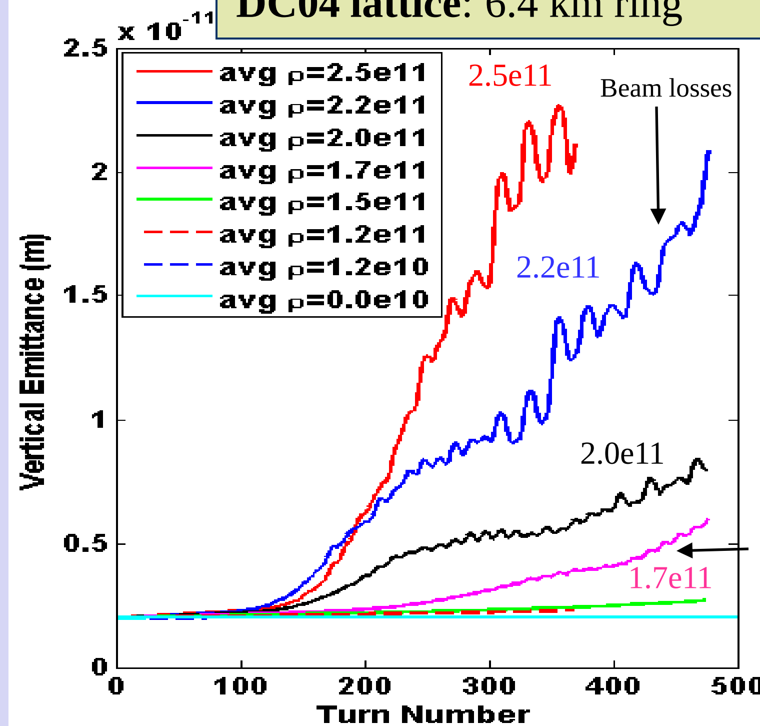
- CMAD simulation (Pivi, Sonnad)
- CMAD: tracking and e-cloud beam instability parallel code (M.Pivi SLAC)
  - Distribute EC in every magnetic element of ring: ~1,000 elements including drift, dipoles, quad, sext, etc.
  - Apply beam-cloud IP in every element





Application to ILC DR

DC04 lattice: 6.4 km ring



Also see:

TUPEB014

Conclusion

- The CESR reconfiguration for CESRTA is complete
  - Low emittance damping ring layout
  - 4 dedicated experimental regions for EC studies with significant flexibility for collaborator-driven tests
  - Instrumentation and vacuum diagnostics installed (refinements ongoing)
- Recent results include:
  - Machine correction nearing our emittance target ε_y ~ 20pm
  - EC mitigation comparisons
  - Bunch-by-bunch beam size measurements to characterize emittance diluting effects
  - Extensive progress on EC simulations
- ~50 machine development days remain in 2010. Will focus on:
  - LET effort to validate our target emittance of $\varepsilon_y \leq$ 20pm
  - Continued EC mitigation studies
  - Continued EC simulation effort
  - Detailed characterization of instabilities and sources of emittance dilution in the ultra low emittance regime
  - ***Application of our results to the damping rings design effort***
- ILC DR Electron Cloud Working Group
  - Baseline mitigation recommendation for ILC DR targeted for October 2010

The End

Thank you for your attention!