CESRTA Program: Damping Ring Hardware and Diagnostics

Mark Palmer for the CesrTA Collaboration

January 12, 2010

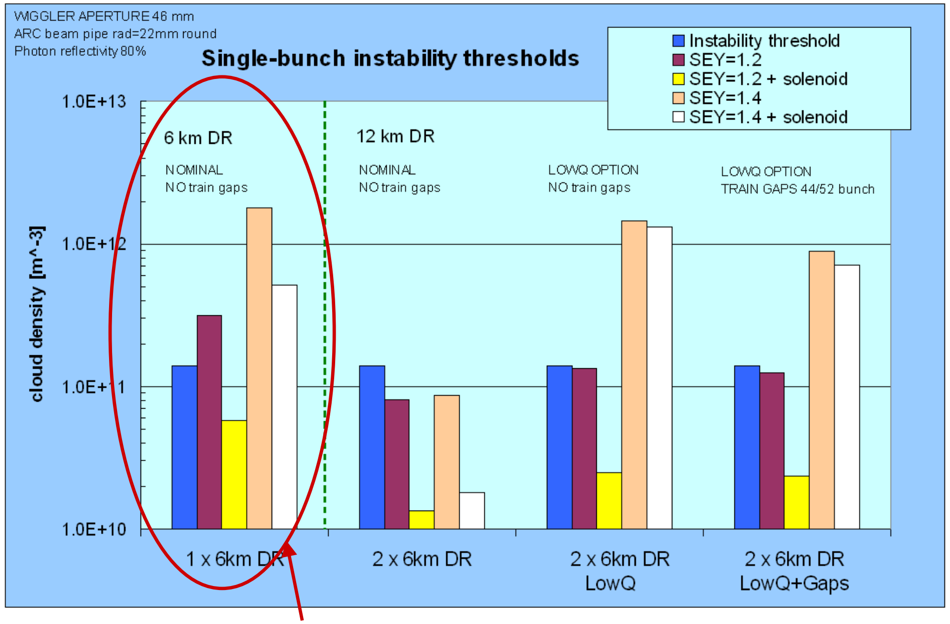
Low Emittance Rings 2010 - CERN

CLIC

Outline

- Project Overview
  - Why CesrTA?
  - Project Goals
  - Reconfiguration
  - Status
- Damping Ring Hardware and Diagnostics
  - Damping Wigglers
  - Electron Cloud Instrumentation
  - Low Emittance Instrumentation
- R&D Examples
- Conclusion

Why CesrTA?



- ILCDR06 Evaluation
  - M. Pivi, K. Ohmi, *etal.*
  - Single ~6km positron DR
    - Nominal ~2625 bunches with 6ns bunch spacing and $N_b=2\times10^{10}$
    - Requires SEY values of vacuum chamber surfaces with $\delta_{max}\leq1.2$ (assuming solenoid windings in drift regions) in order to operate below EC instability thresholds
    - Dipole and wiggler regions of greatest concern for EC build-up

- In 2007, the ILC R&D Board's S3 Task Force identified a set of critical research tasks for the ILC DR, including:
  - Characterize EC build-up
  - Develop EC suppression techniques
  - Develop modelling tools for EC instabilities
  - Determine EC instability thresholds
- CesrTA program targets:
  - Measurements with positron beams at ultra low emittance to validate projections to the ILC DR operating regime
  - Validation of EC mitigation methods that will allow safe operation of the baseline DR design and the possibility of performance improvements and/or cost reductions

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R&D Goals

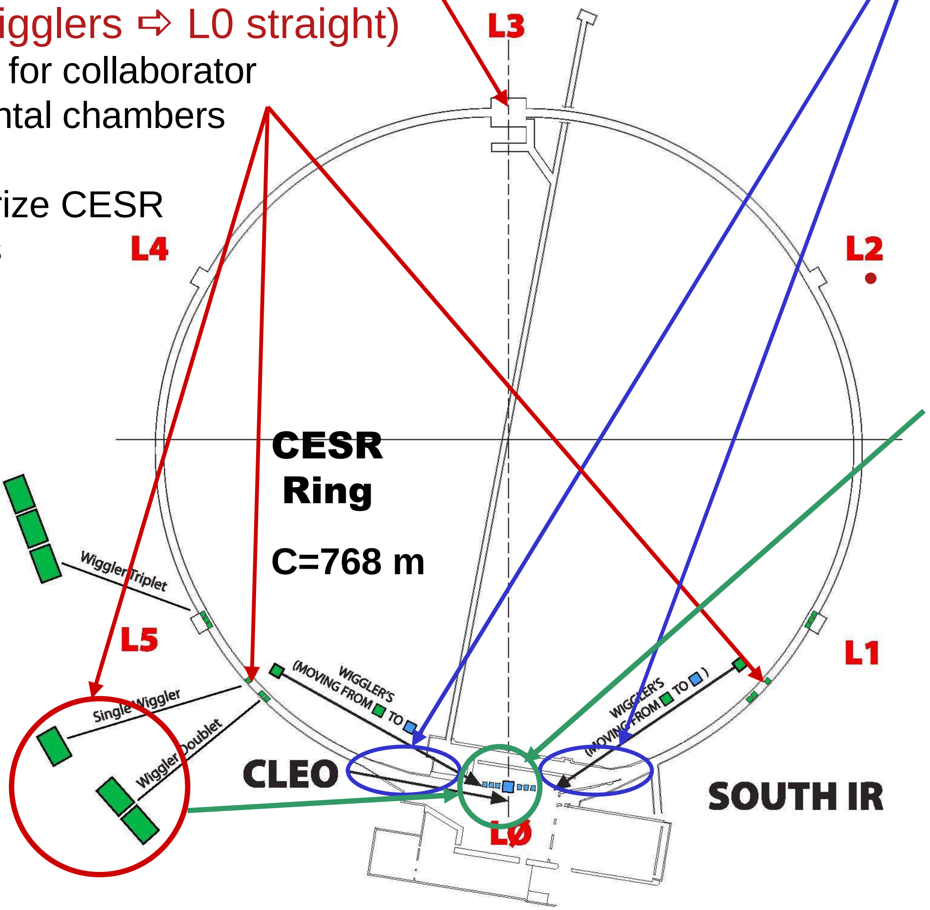
- Studies of Electron Cloud Growth and Mitigation
  - Study EC growth and methods to mitigate it, particularly in the wigglers and dipoles which are of greatest concern in the ILC DR design.
  - Use these studies to benchmark and expand existing simulation codes and to validate our projections for the ILC DR design.
- Studies of EC Induced Instability Thresholds and Emittance Dilution
  - Measure instability thresholds and emittance growth due to the EC in a low emittance regime approaching that of the ILC DR.
  - Validate EC simulations in the low emittance parameter regime.
  - Confirm the projected impact of the EC on ILC DR performance.
- Low Emittance Operations
  - Support EC studies with beam emittances approaching those specified for the ILC DR (CesrTA vertical emittance target: ε_v<20 pm-rad).
  - Implement beam instrumentation needed to achieve and characterize ultra low emittance beams
    - x-Ray Beam Size Monitor targeting bunch-by-bunch readout capability
    - Beam Position Monitor upgrade
  - Develop tuning tools to achieve and maintain ultra low emittance operation in coordination with the ILC DR LET effort
- 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, Shielded Pickups
    - 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 sufficient running time to commission hardware, carry out planned experiments, and explore surprises
      ⇨ ~240 running days over a 2+ year period
    - Early results to feed into final stages of program
- Schedule coordinated with Cornell High Energy Synchrotron Source (CHESS) operations

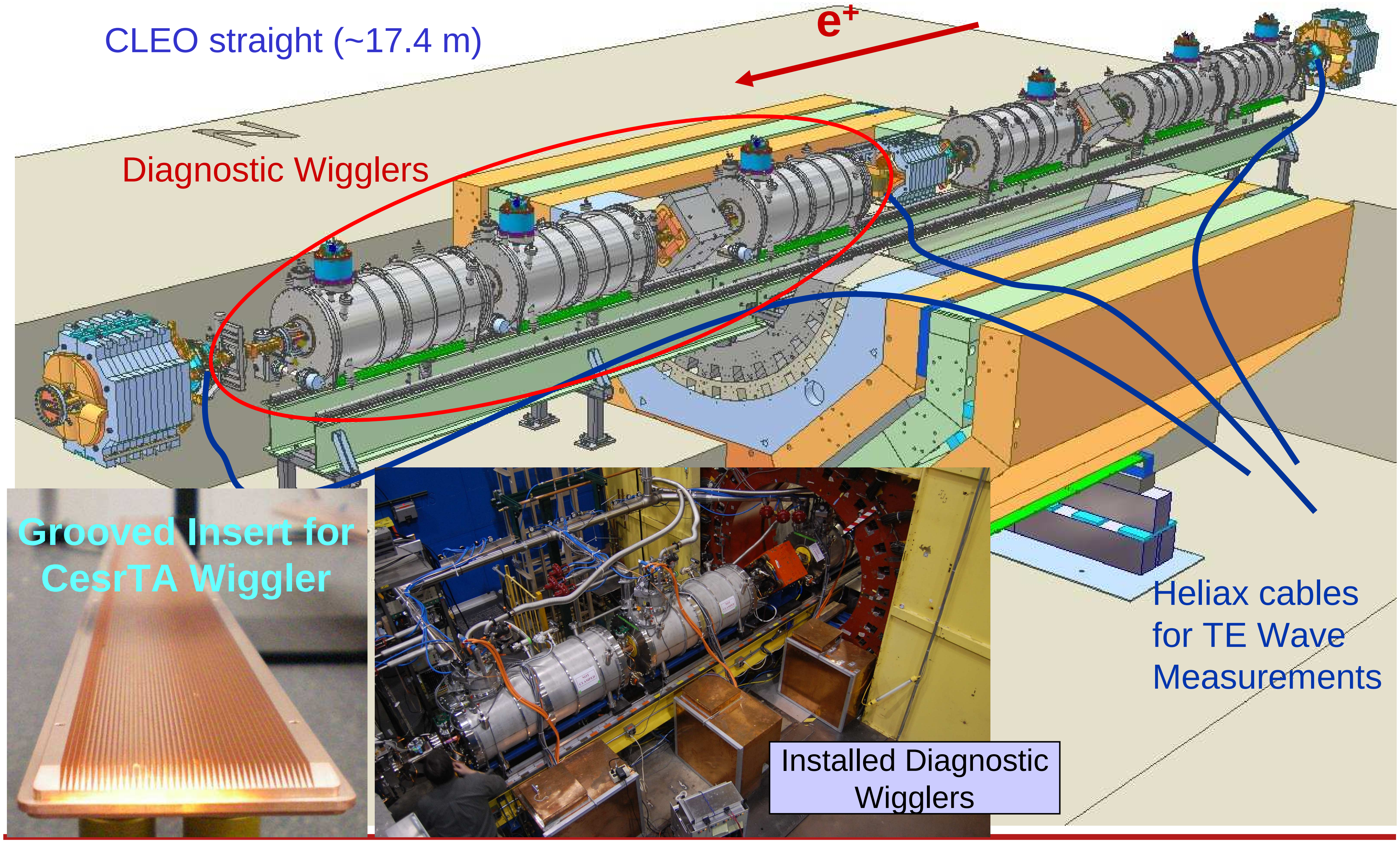
CESR Reconfiguration

- 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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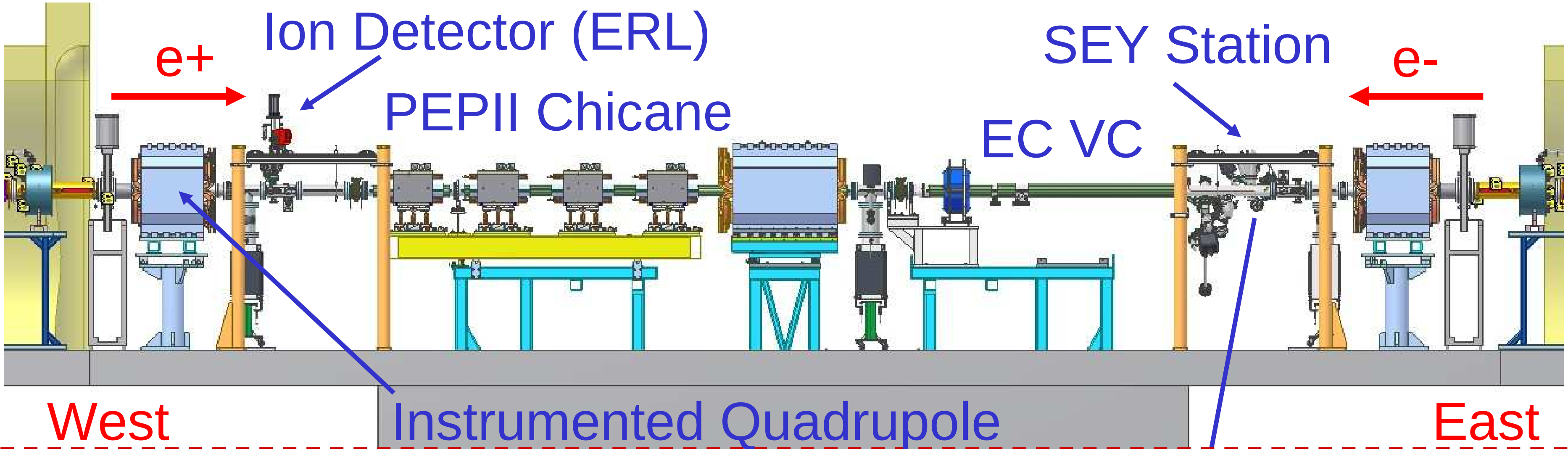
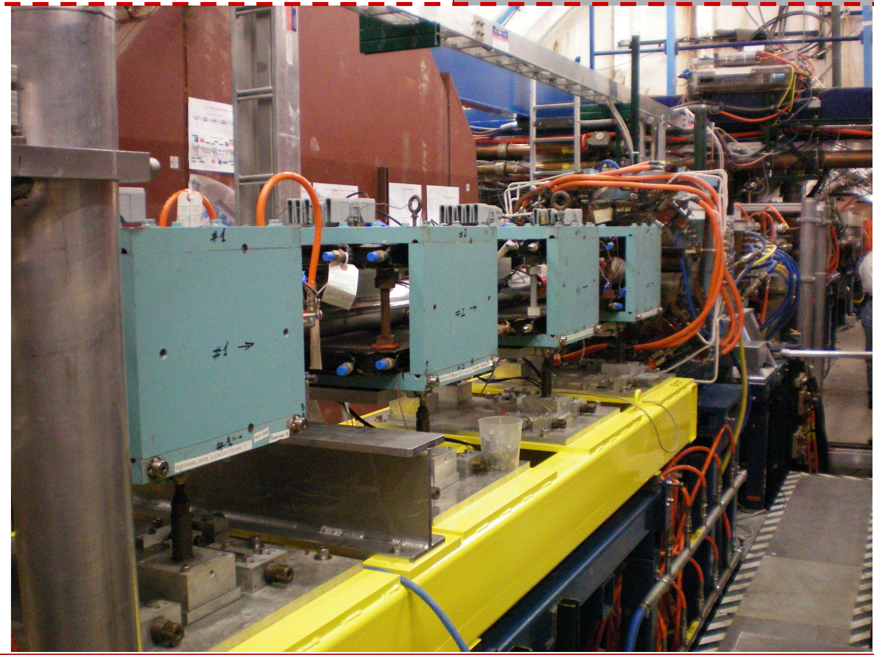
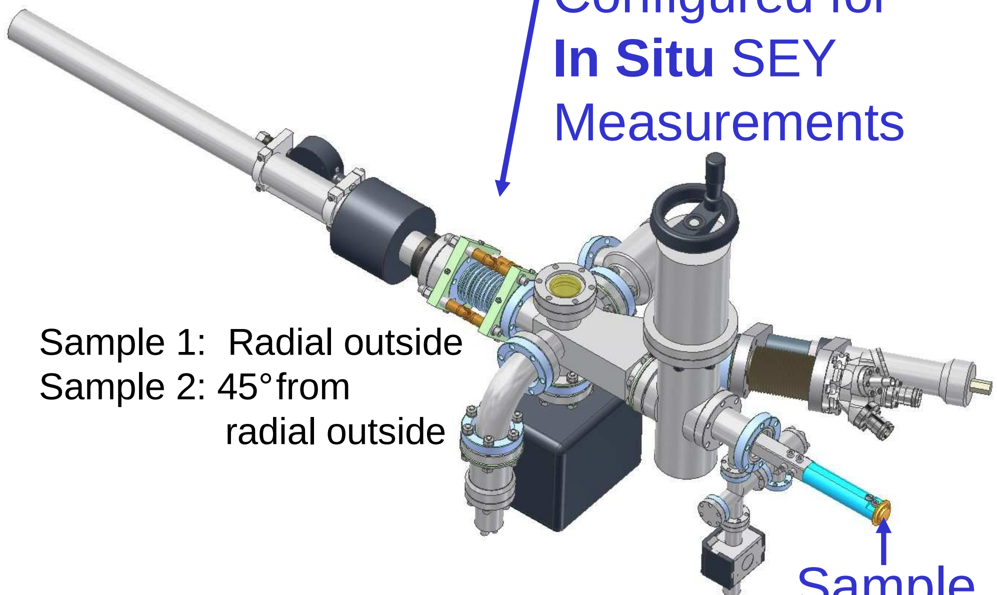
CESR Reconfiguration: L3 Experimental Region

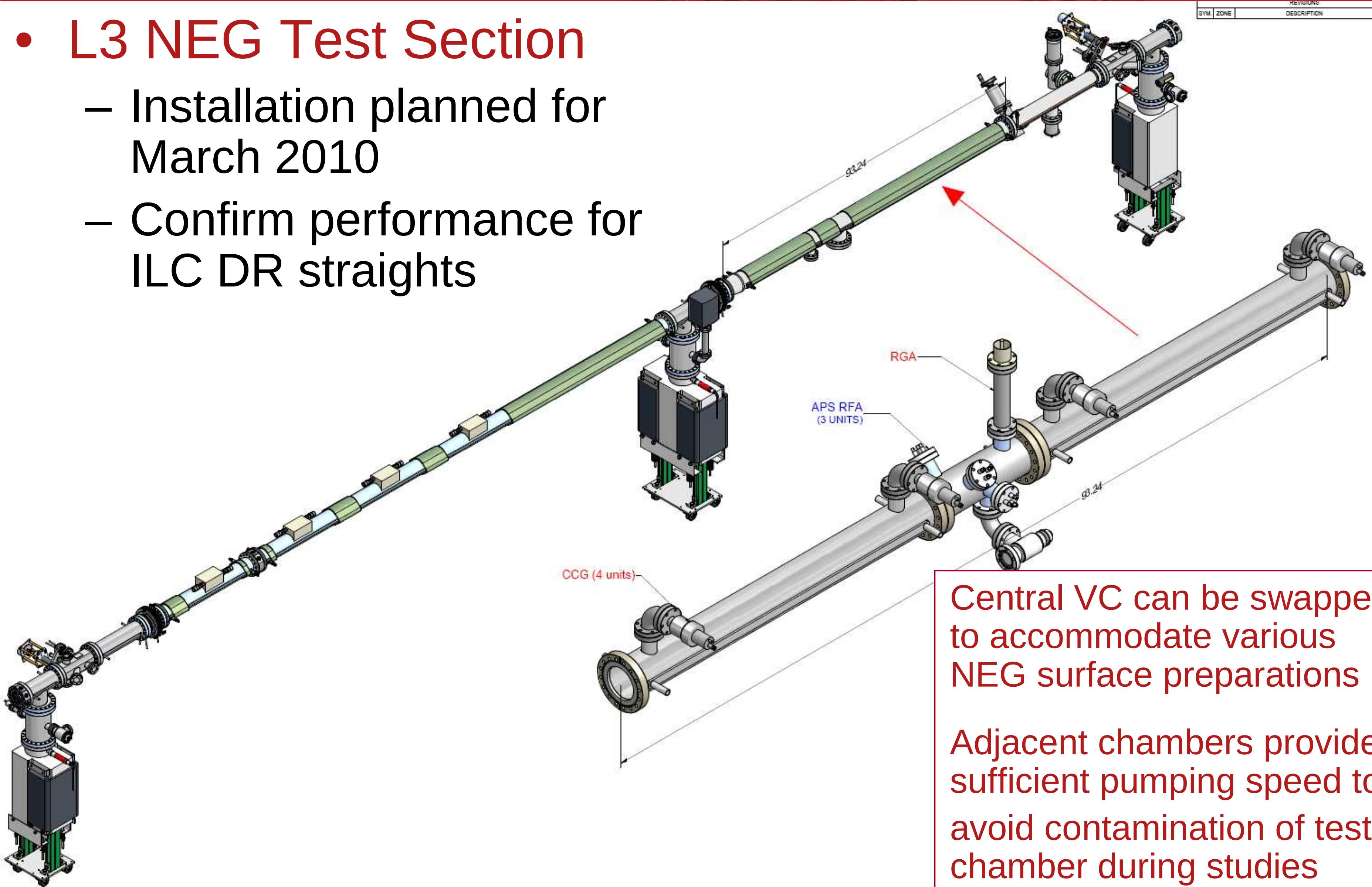






CESR Reconfiguration: L3 Experimental Region

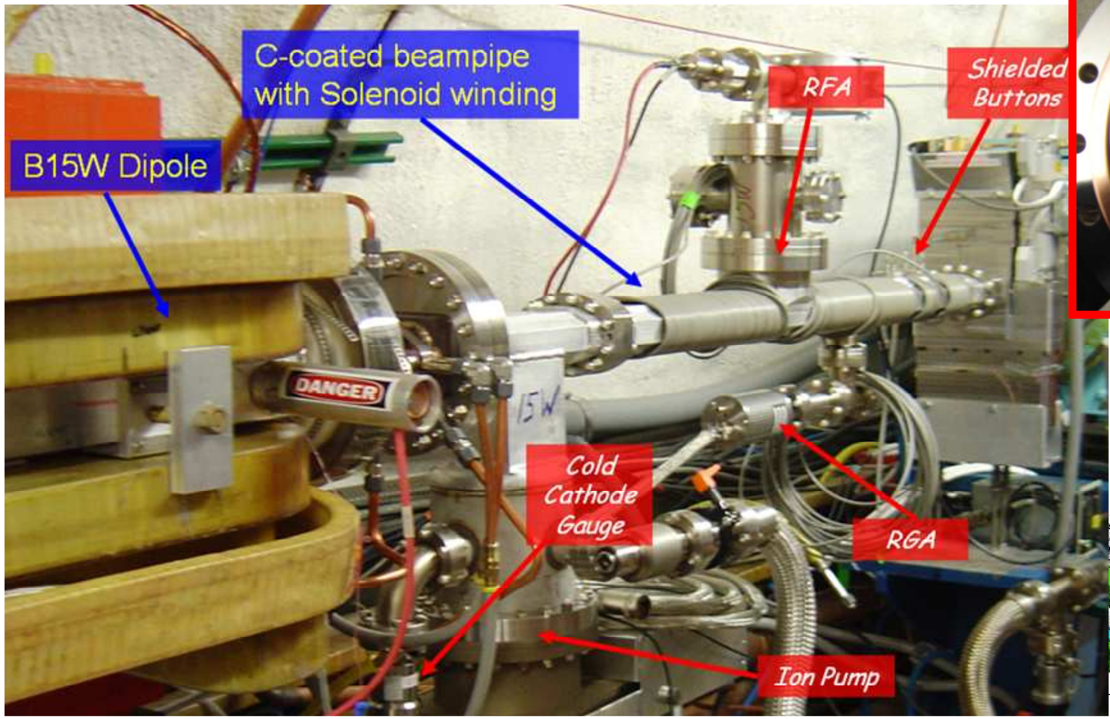
- L3 NEG Test Section
  - Installation planned for March 2010
  - Confirm performance for ILC DR straights

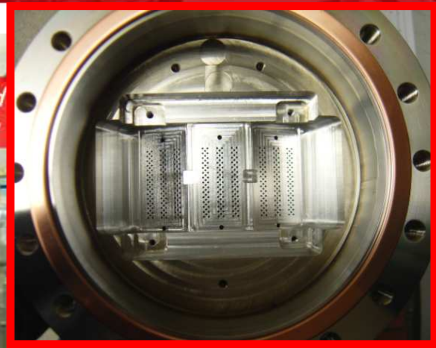


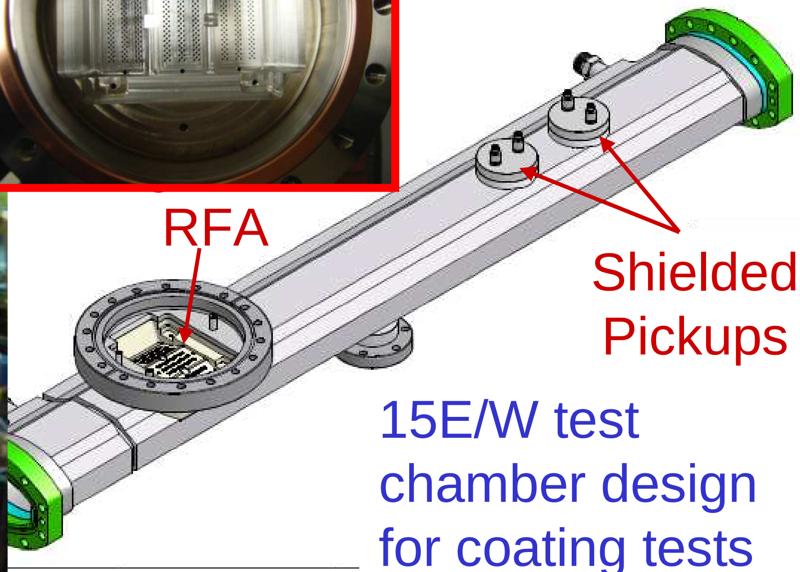
Central VC can be swapped to accommodate various NEG surface preparations

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

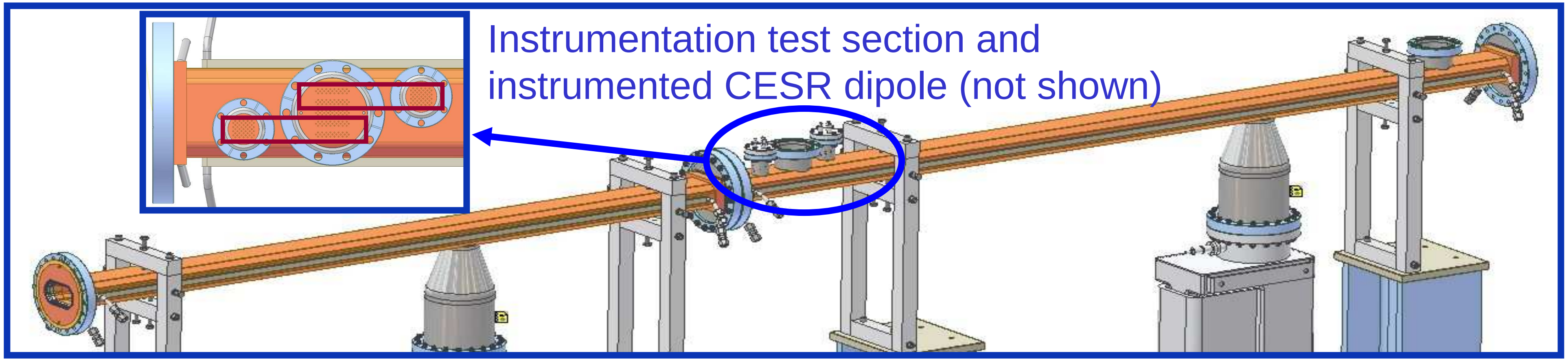
CESR Reconfiguration: CESR Arcs







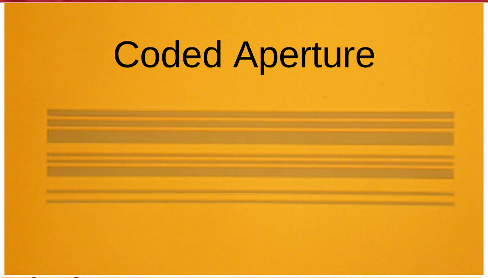
15E/W test chamber design for coating tests

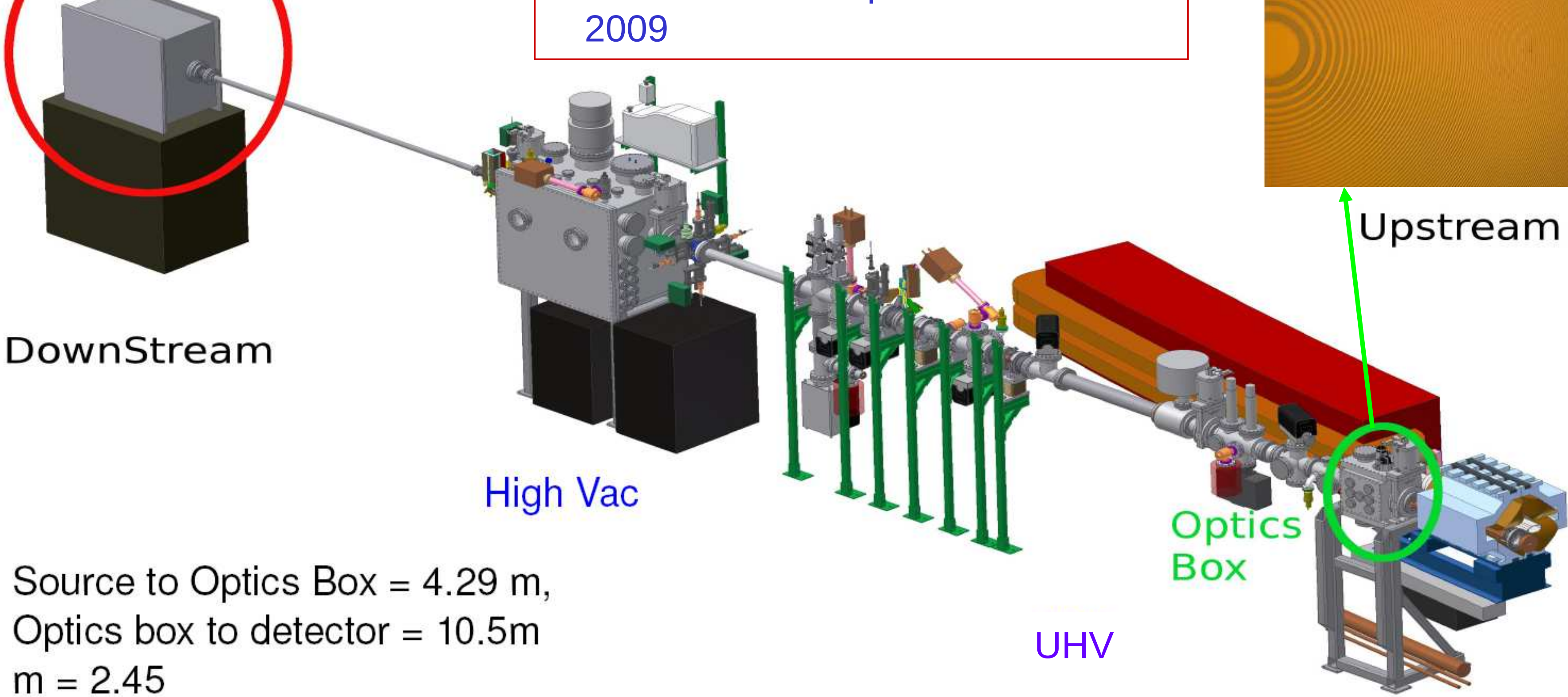


CESR Reconfiguration: X-Ray Lines

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

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

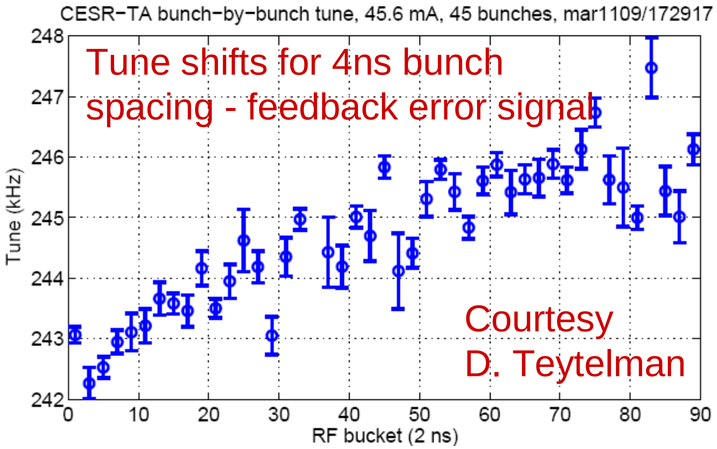
Control photon flux in EC experimental regions

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 (rows 1.8*, 2.085, 2.3)

* 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

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 optics and detector development
  - Digital BPM system operational
    - Continued effort on data acquisition and experimental data modes
  - vBSM
    - Significant progress has been made on vertical polarization measurements which can provide a useful cross-check with the xBSM in the ultra low emittance regime
    - New optics line for transverse and longitudinal measurements in L3 have just been installed
  - 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
  - Mitigation tests are ongoing
- Low Emittance Tuning and Beam Dynamics Studies
  - We are within a factor of 2 of our emittance targets (presently ≤40 pm and aiming for 20pm before next September)
  - Continuing effort to take advantage of new instrumentation
  - Continuing to work towards providing low emittance conditions for beam dynamics studies

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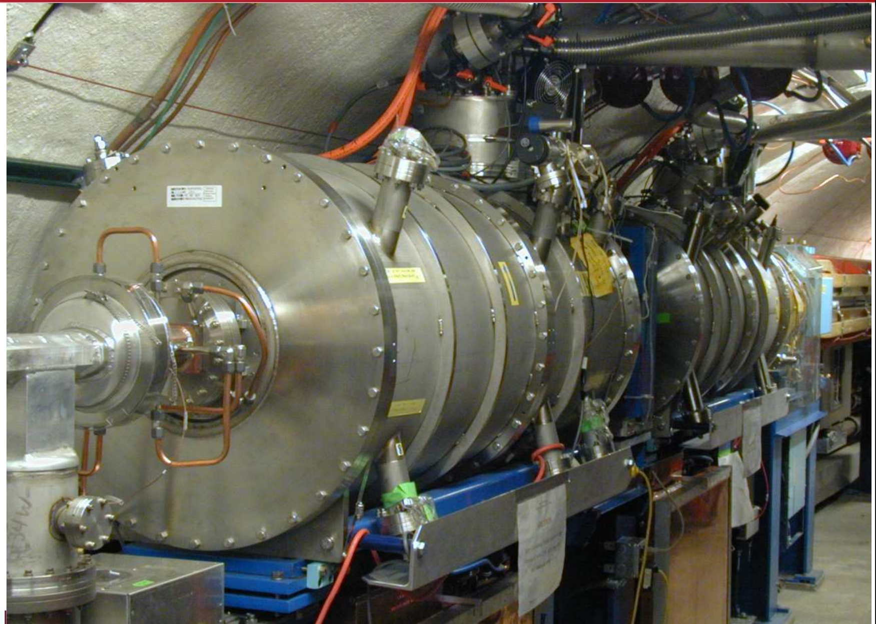
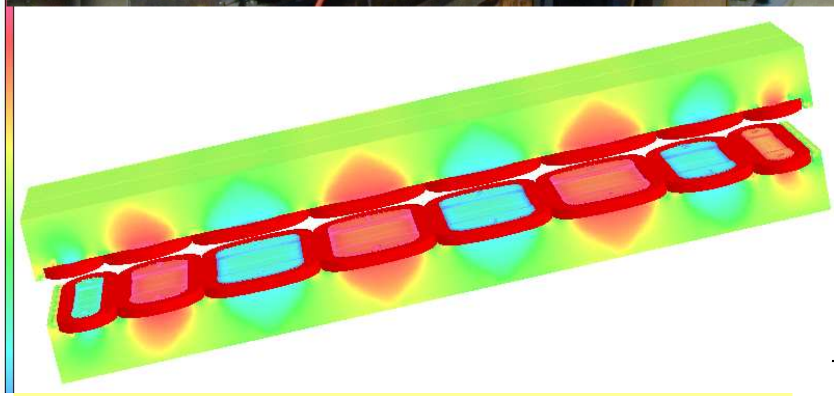
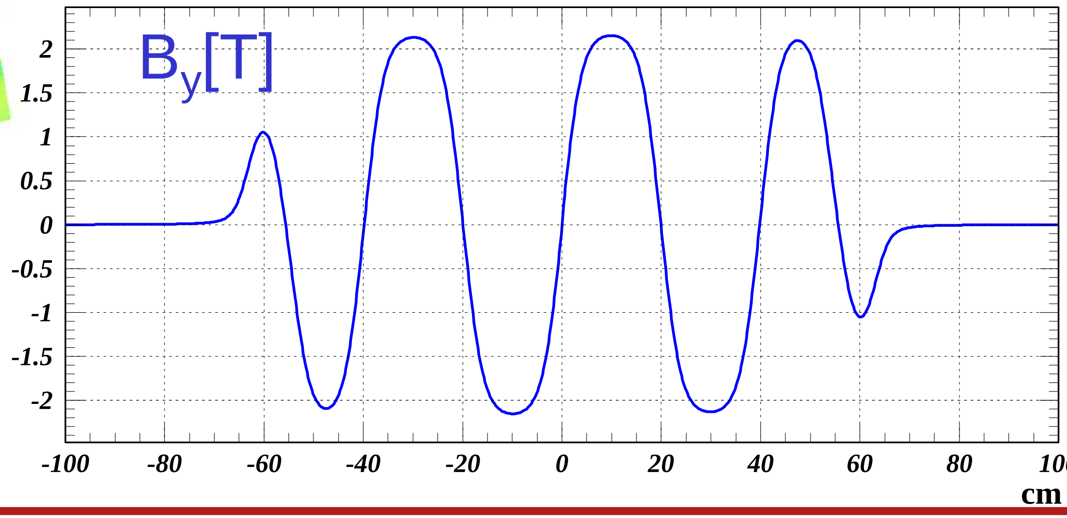
CESR-c Damping Wigglers



B_{peak} [T]	2.1
Period [cm]	40
Pole gap [cm]	7.65
Beam Stay Clear [cm]	5.0
No. Poles	8
ΔQ_y	~0.1/wiggler
Magnetic Length [m]	1.3
Transverse Field Roll-Off	+0.0, -0.3% @ ±20mm
Static Heat Load @ 4K [W]	~1.3W
Static Heat Load @77K [W]	~40W





Further details:

PAC03 Paper (D. Rice *etal)*

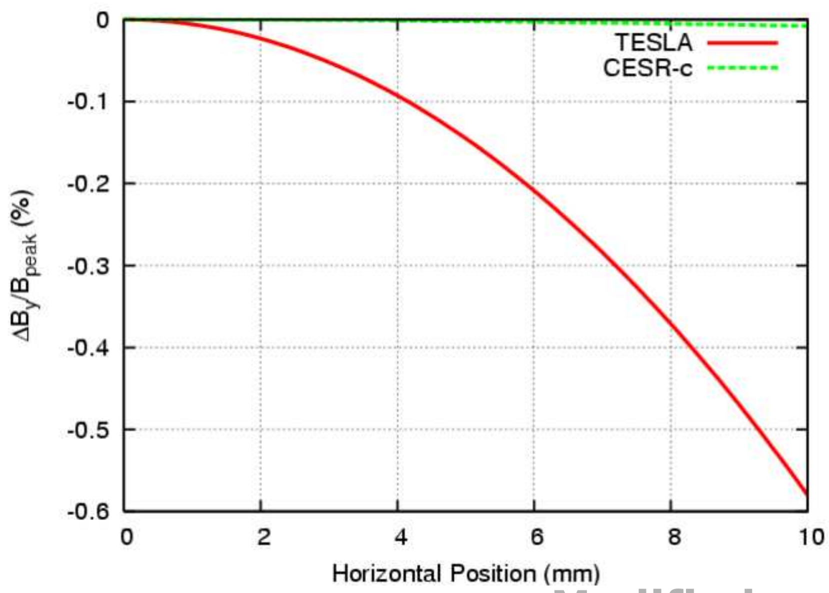
http://accelconf.web.cern.ch/accelconf/p03/PAPERS/TOAB007.PDF

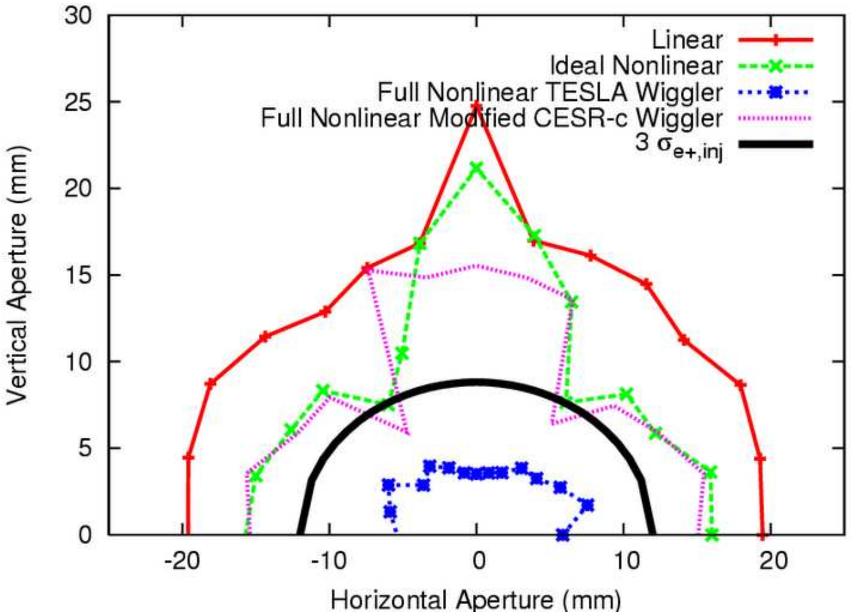
WIGGLE05 talk (A. Temnykh)

http://www.lnf.infn.it/conference/wiggle2005/talks/Temnyk.pdf

ILC DR Wiggler Choice

- Basic Requirements
  - Large Physical Aperture
    - Acceptance for injected e+ beam
    - Improved thresholds for collective effects
      - Electron cloud
      - Resistive wall coupled bunch instability
  - Dynamic Aperture
    - Field quality
    - Wiggler nonlinearities



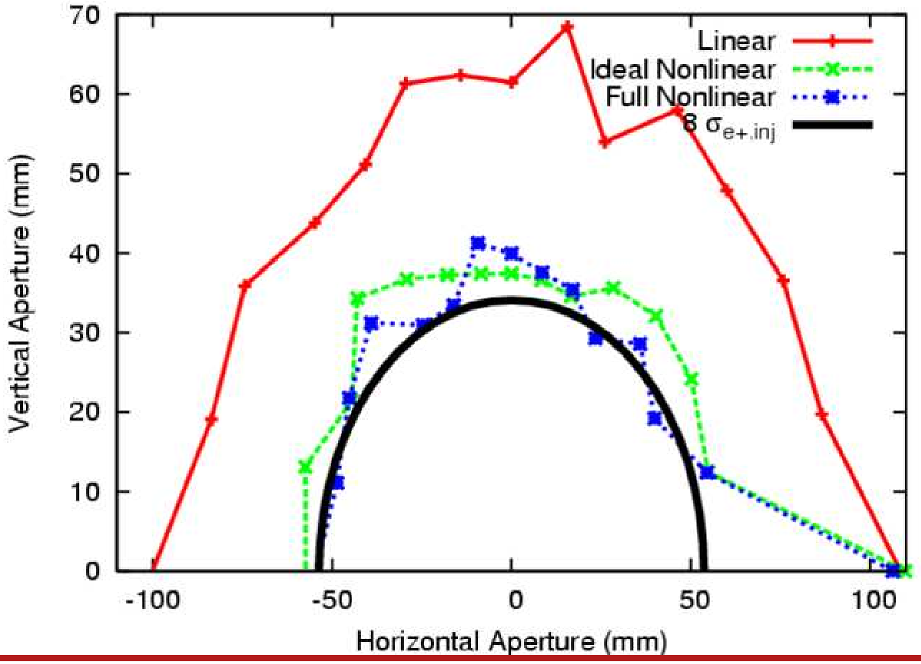


	TESLA	CESR-c	Modified CESR-c
Period	400 mm	400 mm	400 mm
$B_{y,peak}$	1.67 T	2.1 T	**1.67 T**
Gap	25 mm	76 mm	76 mm
Width	60 mm	238 mm	238 mm
Poles	14	8	**14**
Periods	7	4	**7**
Length	2.5 m	1.3 m	2.5 m

Optimized Wiggler

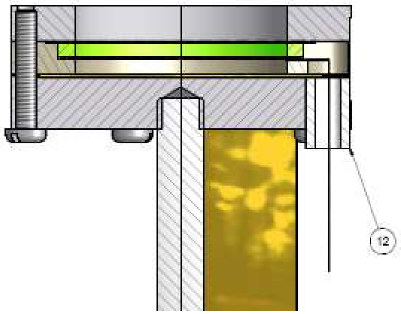
- Superferric ILC Optimized Wiggler
  - 12 poles
  - Period = 32 cm
  - Length = 1.68 m
  - $B_{y,peak}$ = 1.95 T
  - Gap = 86 mm
  - Width = 238 mm
  - I = 141 A
  - τ_{damp} = 26.4 ms
  - $\varepsilon_{x,rad}$ = 0.56 nm·rad
  - σ_δ = 0.13 %

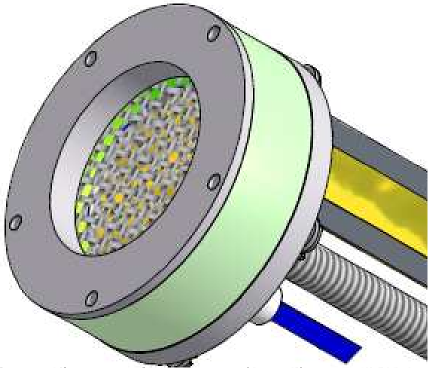
Engineering Design and Cost Optimization using RDR lattice design (J. Urban, etal):
- No. Poles
- Period
- Gap
- Width
- Peak Field

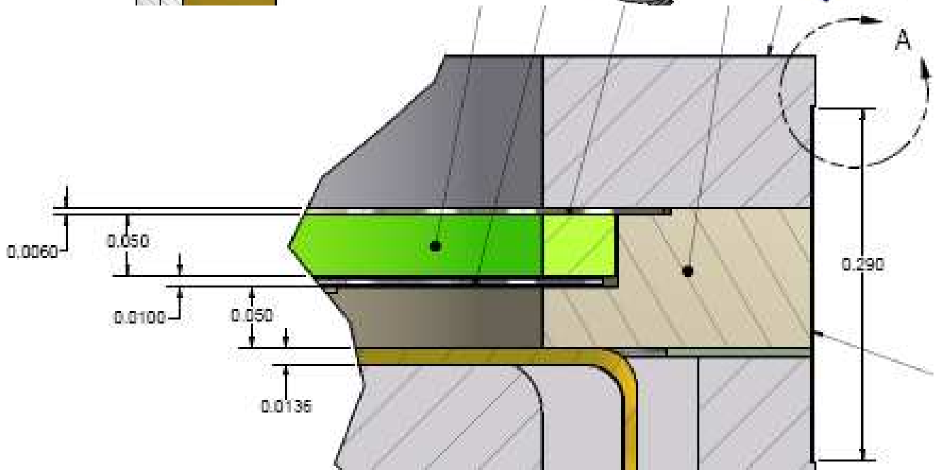


Electron Cloud Instrumentation: Thin RFA Design

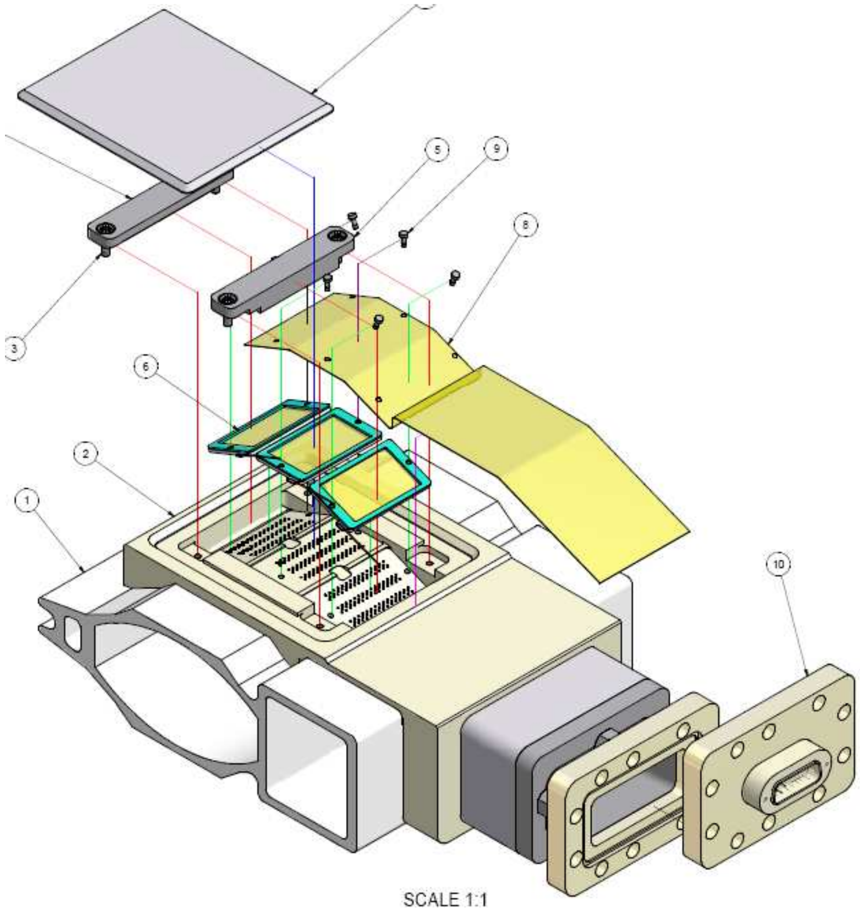
- Thin structure developed for use in limited aperture locations
  - CESR dipoles
  - CESR-c wigglers
- Custom readout system with sensitivity of <50pA/channel







- Application to CESR Dipole



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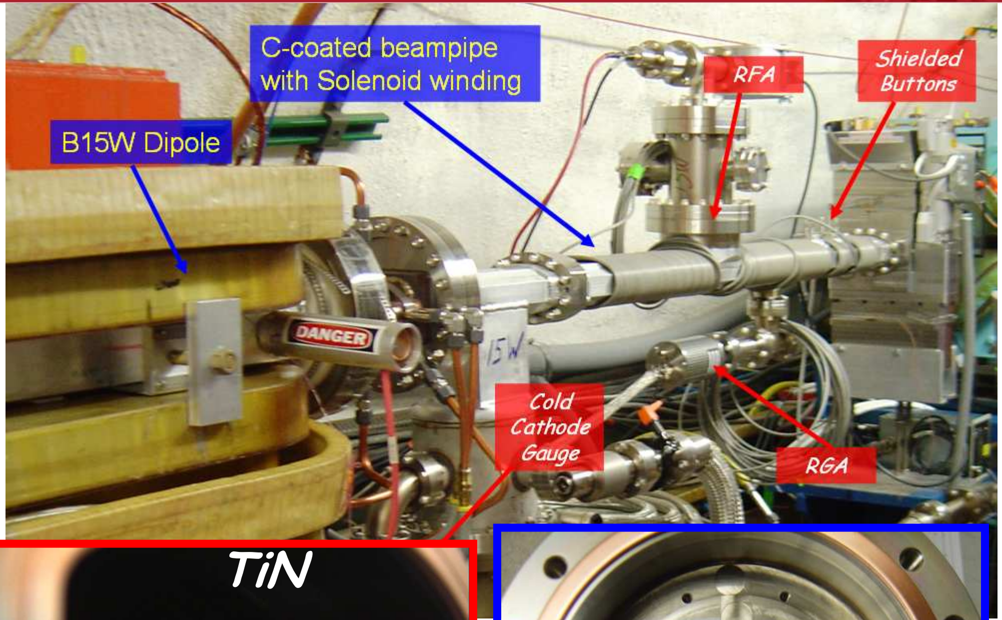
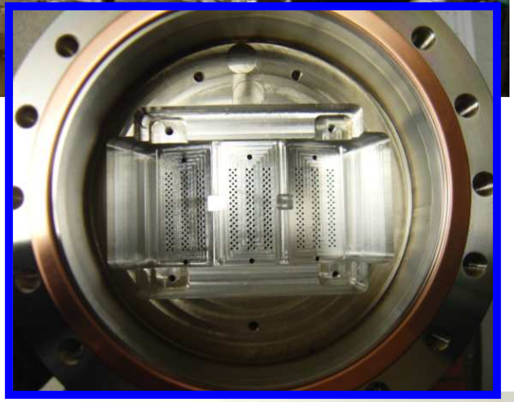
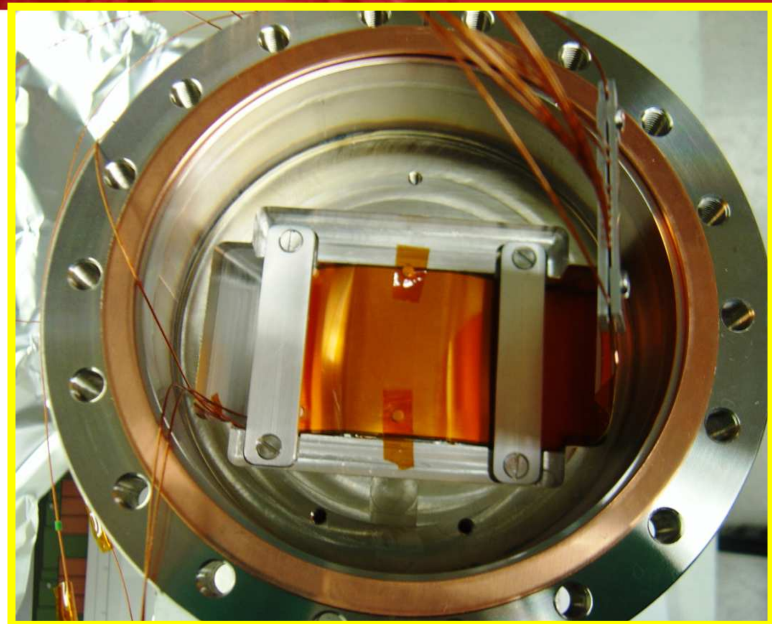
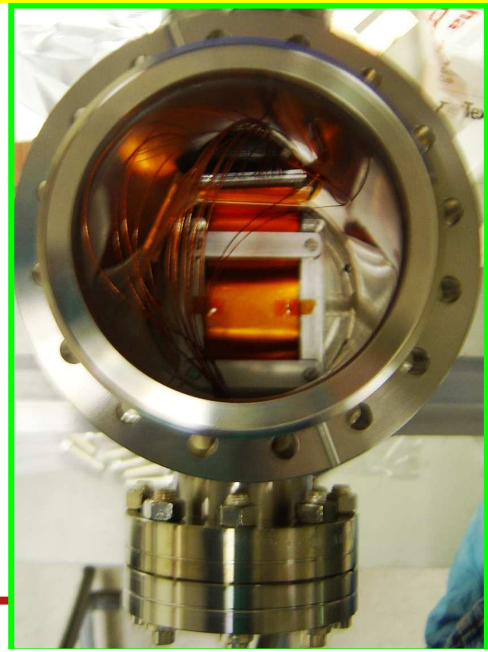
Electron Cloud Instrumentation: 15E/W Test Chambers







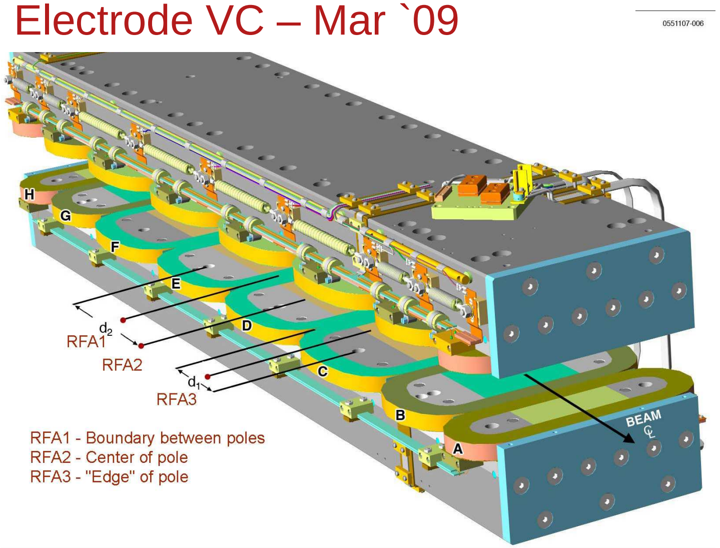


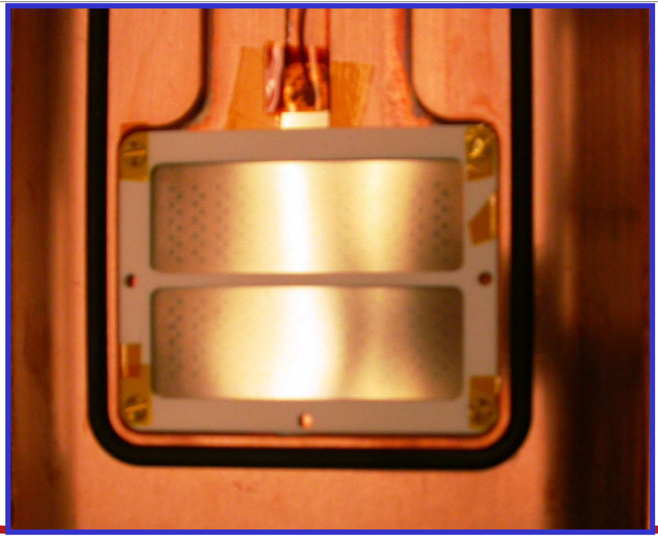
Electron Cloud Instrumentation: Instrumented Wigglers

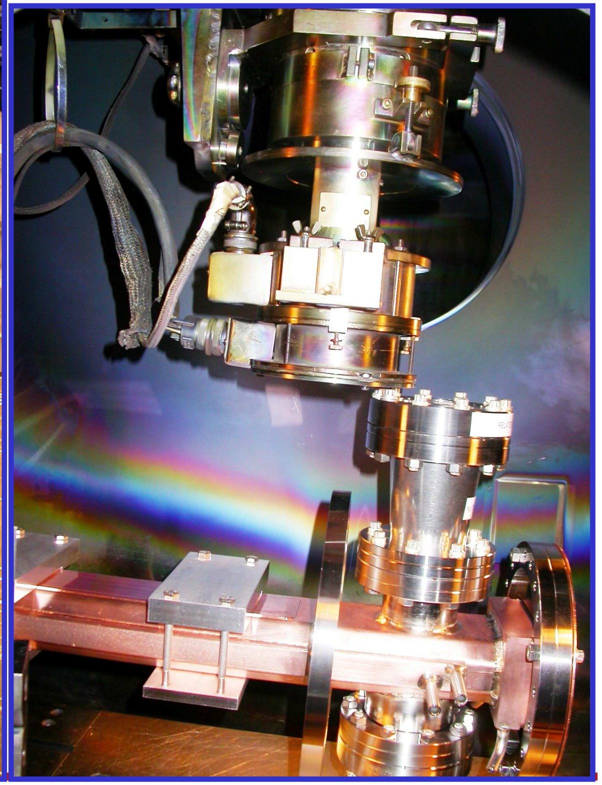
Cu & TiN-coated VCs – Oct `08

Grooved VC – Jul `09

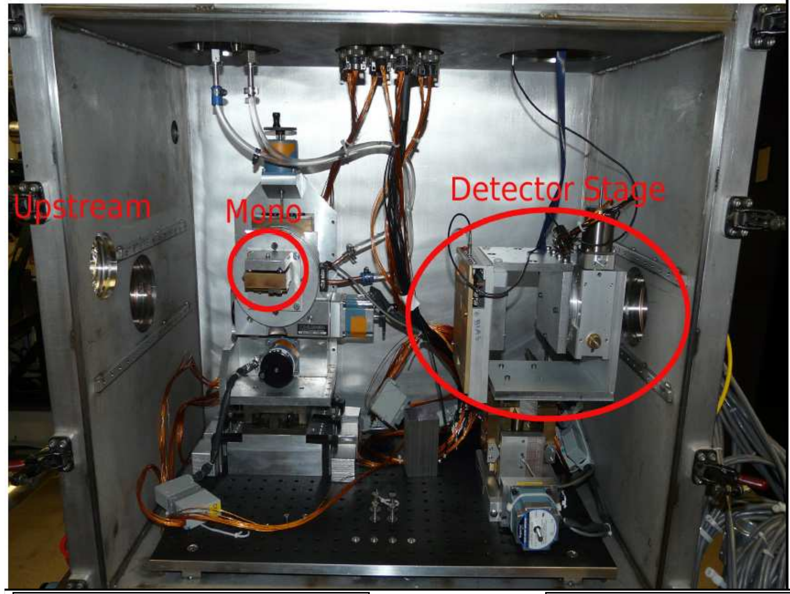
Electrode VC – Mar `09





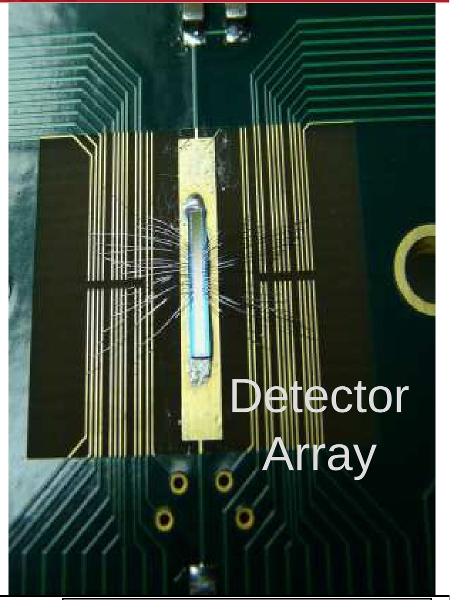


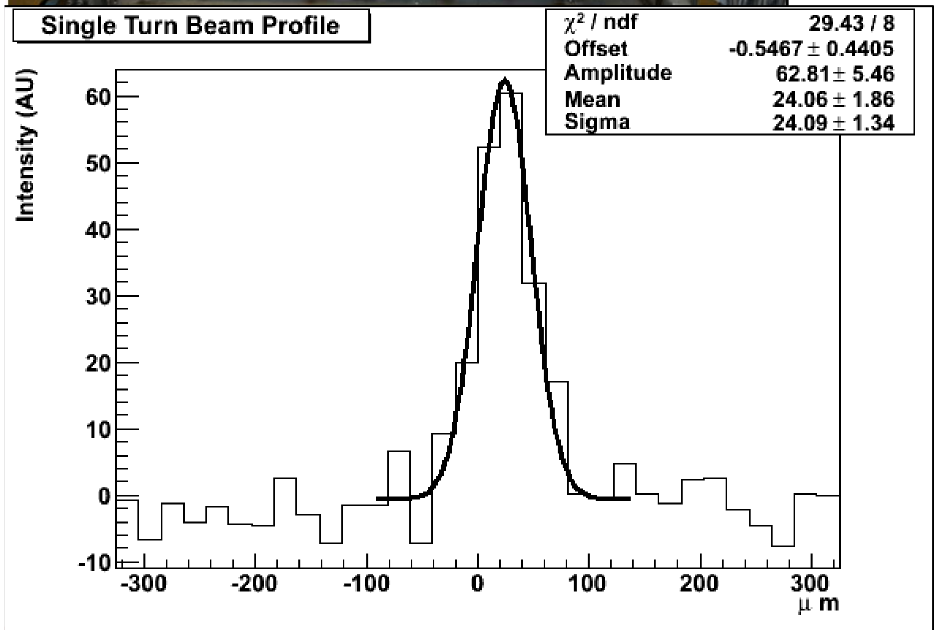
Low Emittance Instrumentation: xBSM Detector

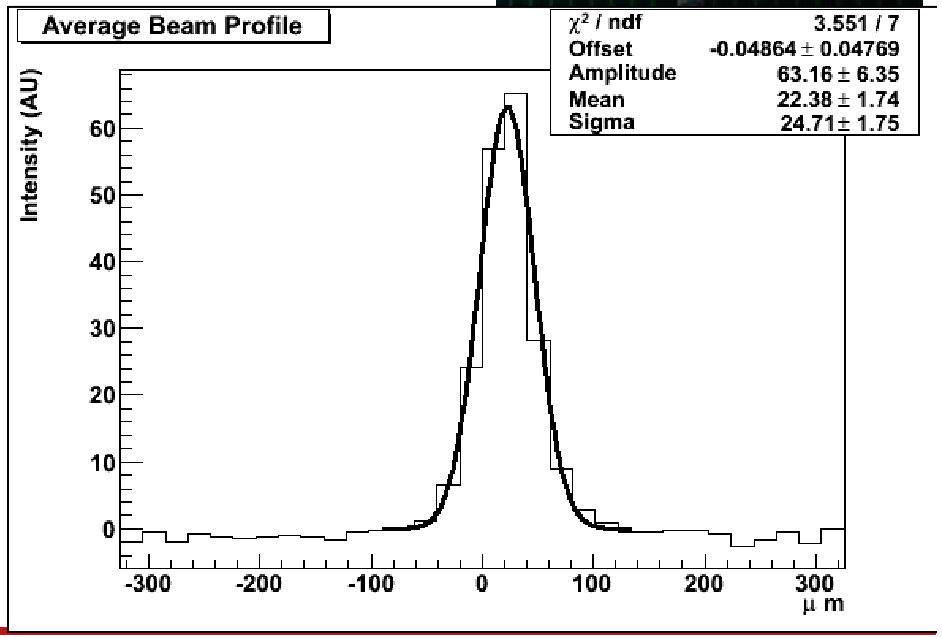


Fast InGaAs Diode Array:

- Single-pass readout
- Few micron resolution with coded aperture and Fresnel imaging optics



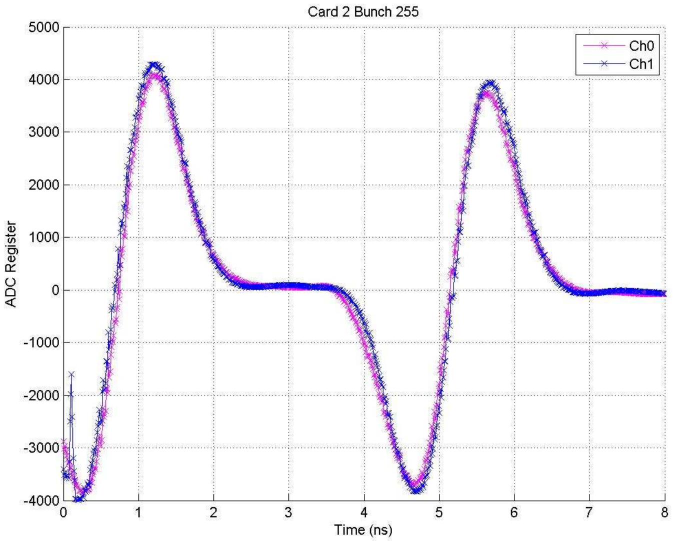


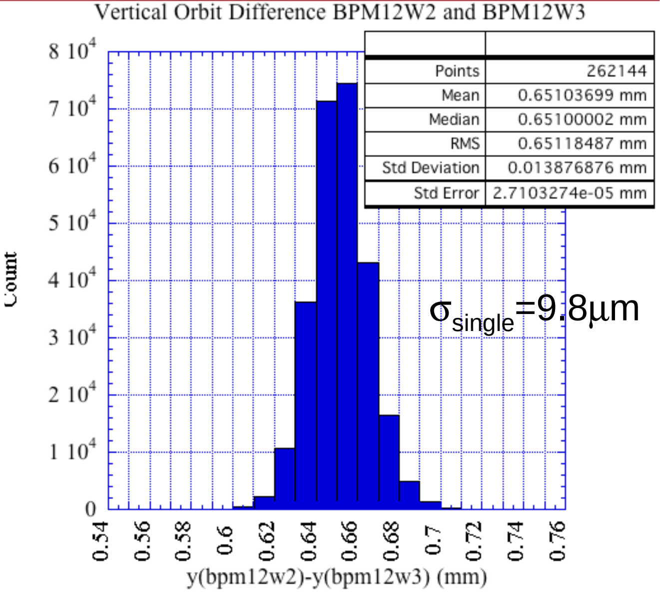


Low Emittance Instrumentation: BPM System Upgrade

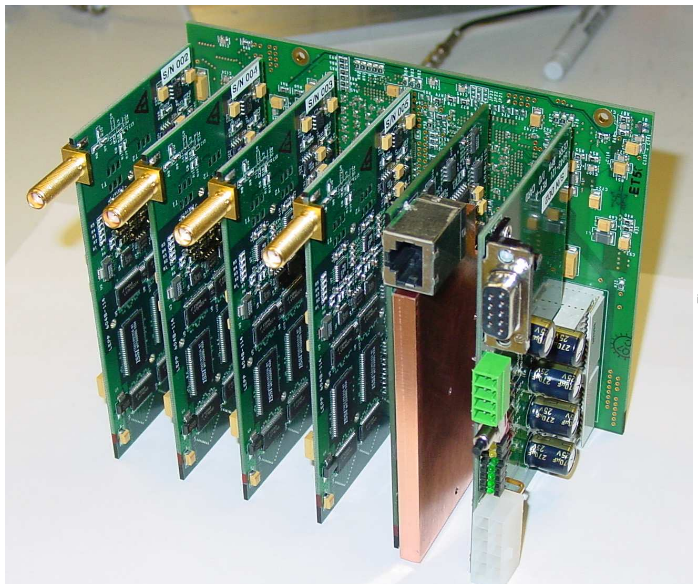
- Ring upgraded to new multi-bunch turn-by-turn electronics
  - 12% Generation 1
  - 88% Generation 2
- Full integration into operational data acquisition in progress

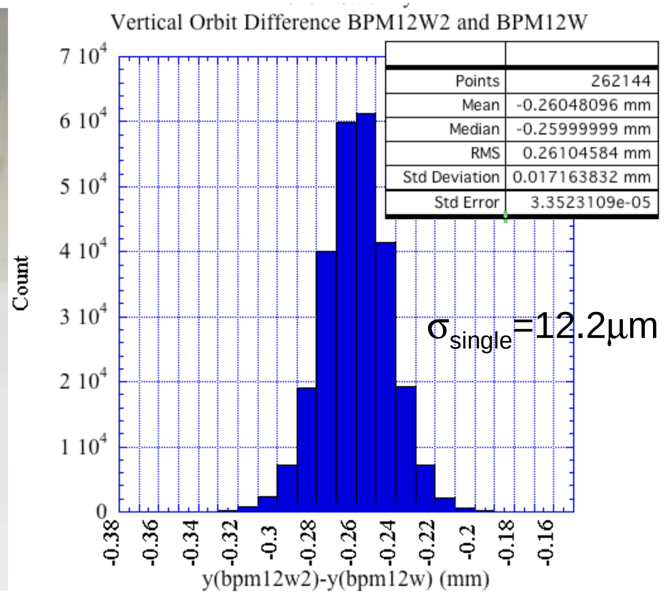
⇨ major focus of December LET run





Front End Bandwidth for 4ns Bunch-Train Operation	500 MHz
Single Shot Resolution Target	<10 μm
Timing Resolution Target	<10 ps
Short-Term Repeatability Target	<10 μm
Long-Term Repeatability Target	<50 μm





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R&D Effort

- Optics and LET
  - More details during this afternoon's talk by Dave Rubin
- Electron Cloud R&D
  - Broad range of studies underway
  - Gerry Dugan will discuss EC-induced coherent tune shifts and characterization of the cloud around CESR tomorrow
  - A brief overview during the remaining few minutes of my talk…

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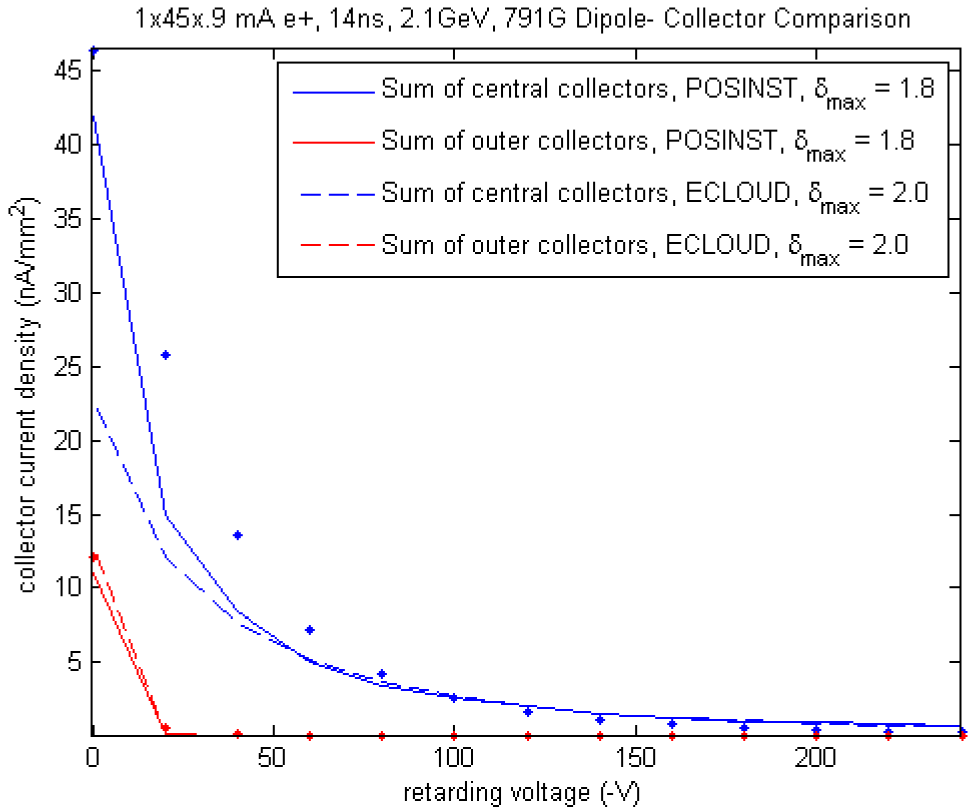
Status of EC Studies

- Simulations:
  - Code Benchmarking (CLOUDLAND, ECLOUD, POSINST)
  - Modeling for RFA and TE Wave measurements
  - Tune shift calculations
    - Characterize the integrated SEY contributions around the ring
    - Now calculated for coherent oscillations of the beam
  - Instability estimates and emittance growth
- 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
  - Mitigation Comparisons
    - SC Wigglers:
      - Presently installed: Cu, TiN-coated Cu, Grooves (Cu, 2mm/20°)
      - Next: Clearing Electrode (Spring 2010)
    - Drifts:
      - Presently installed: Al, Cu, TiN-coated Cu, Amorphous C-coated Al, TiN-coated Al
      - Next:NEG chambers in L3 (Spring 2010)
    - Dipole:
      - CESR Dipole: Al
      - L3 Chicane: Al, TiN-coated Al, Grooves (5mm/20°)+TiN-coated Al
    - Quadrupole:
      - Al
      - TiN-coated Al (Spring 2010)
  - Tune shift measurements and systematic checks
    - Pinged beam
    - Feedback system error signal
    - Witness bunch studies for dynamics
  - Instability and incoherent emittance growth (w/xBSM) studies will be a major focus of upcoming runs

Now will look at a few build-up measurements and simulations…

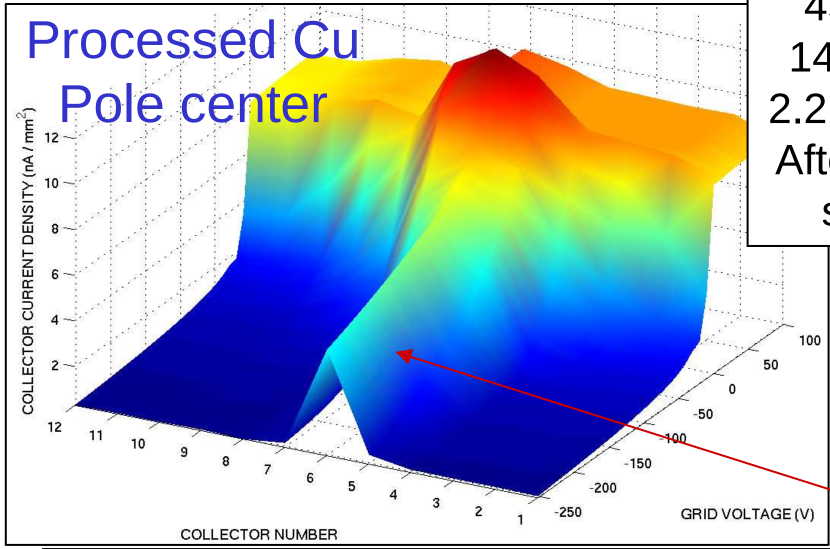
Dipole Data vs Simulation

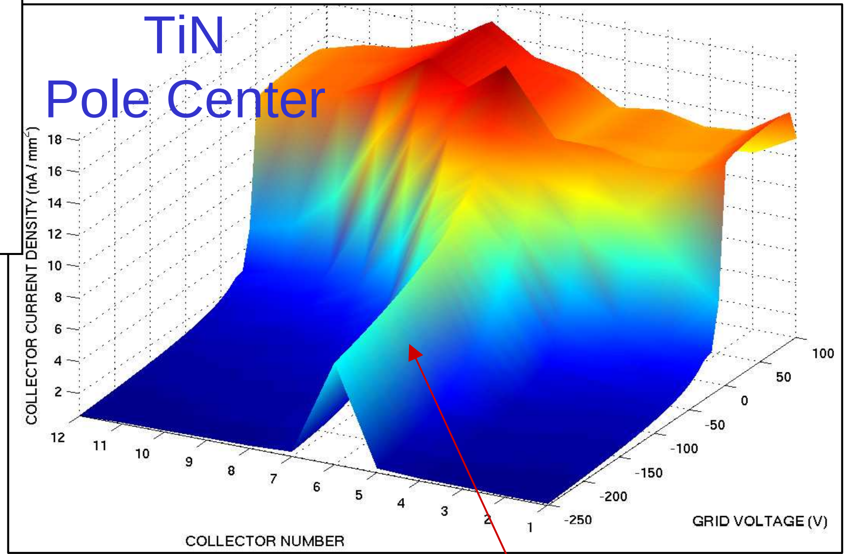
- Conditions: 1x45x.9 mA e+, 14ns, 2.1GeV, 791G dipole
- Plot of POSINST and ECLOUD predictions vs data
  - Note that the ECLOUD simulation was done with a peak SEY of 2.0, while POSINST used 1.8
  - Secondaries generated in RFA holes ignored
- Agreement also very good at high energy
- Have also obtained good agreement for drift regio

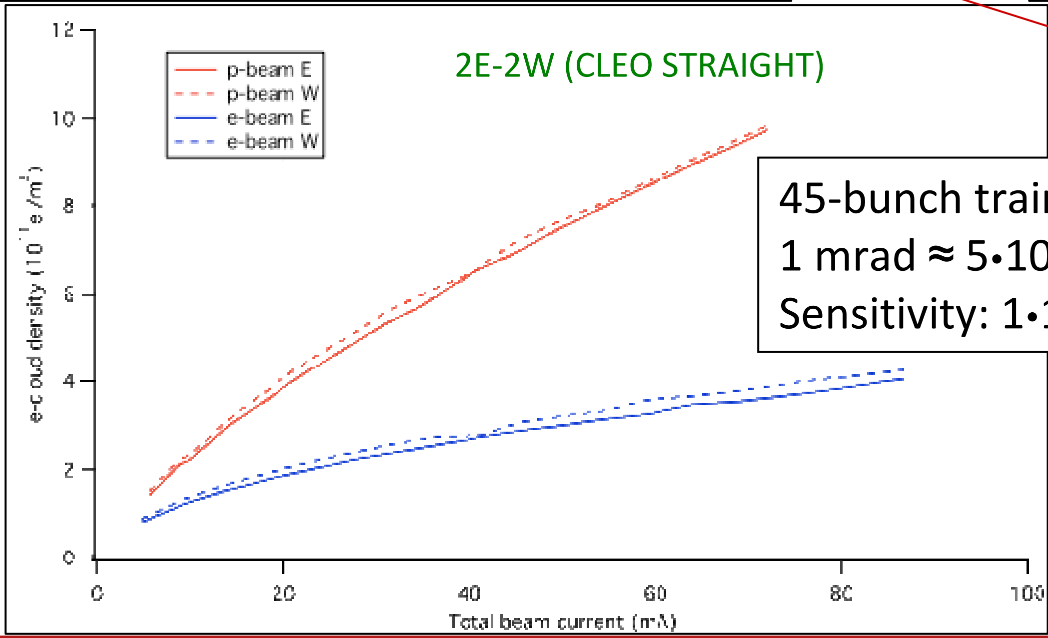


TE Wave & RFA Measurements in L0

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





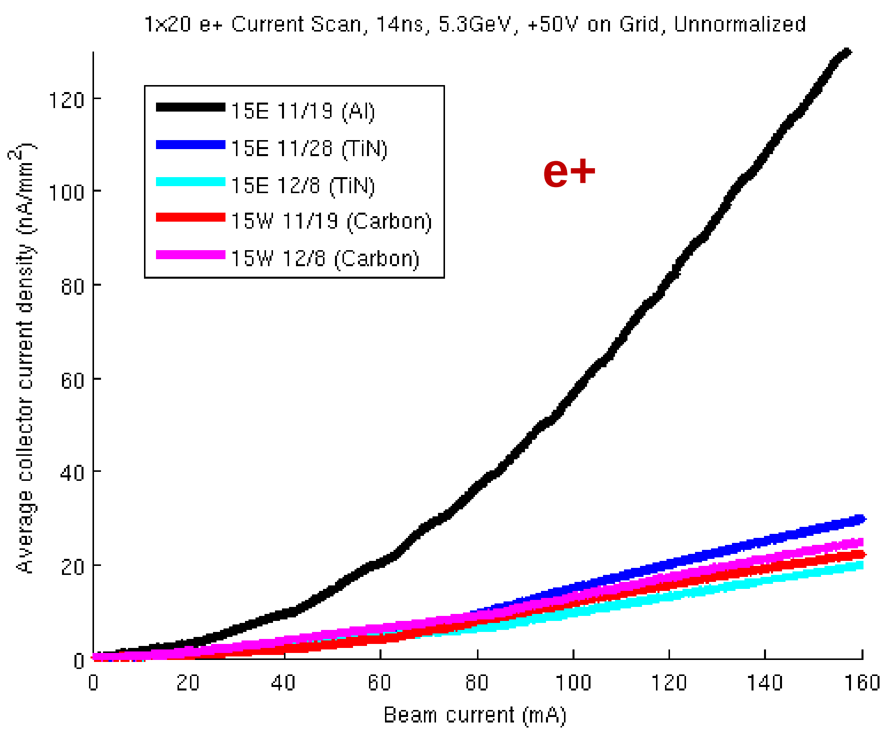


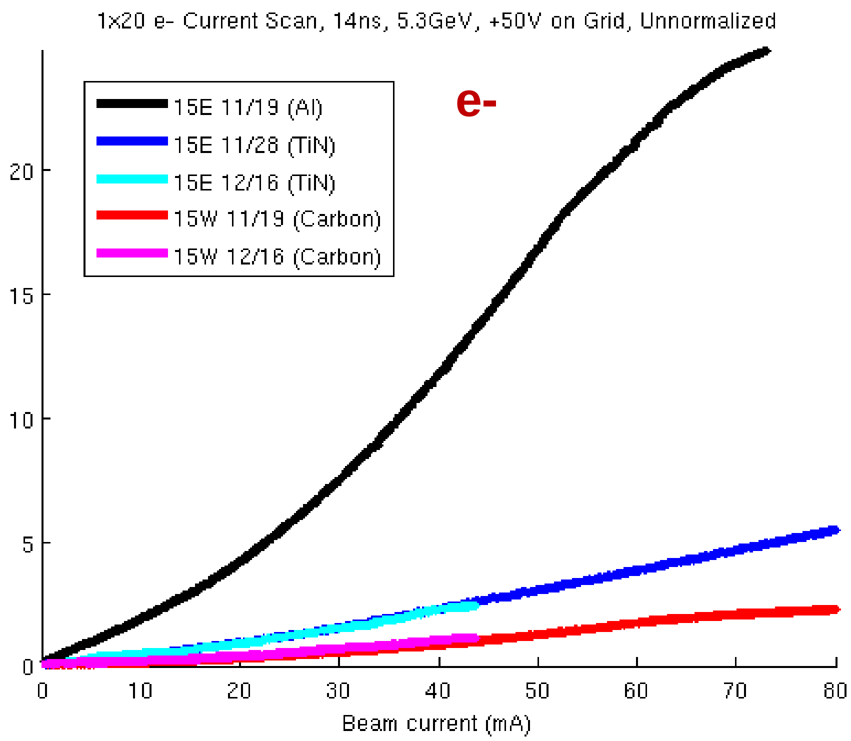
45-bunch train (14 ns)
1 mrad ≈ $5 \cdot 10^{10}$ e^-/m^3
Sensitivity: $1 \cdot 10^9$ e^-/m^3 (SNR)

Similar performance observed

Mitigation Comparisons I: 15E/W Test Chambers

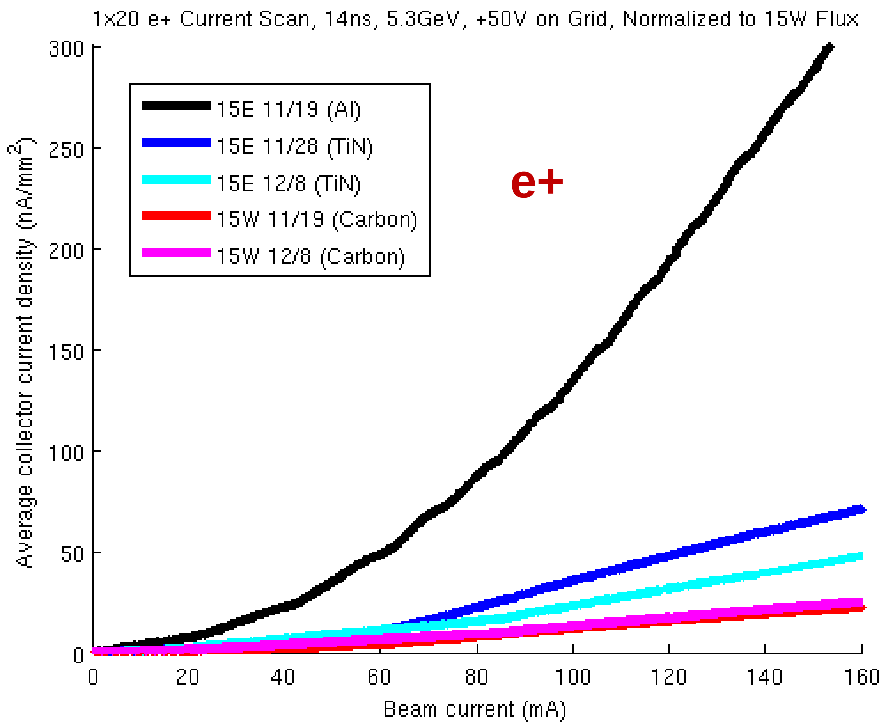
- Conditions: 1x20 e+, 14ns, 5.3 GeV, +50V on grid
- Plots NOT normalized to photon flux
- Both TiN and Carbon coating (CERN) show significantly lower signal than Al surface (*note: some Si contamination on surface of C-coated chamber – 2nd chamber to be tested later this year*).
- Conditioning can be observed in TiN chamber (recently installed)

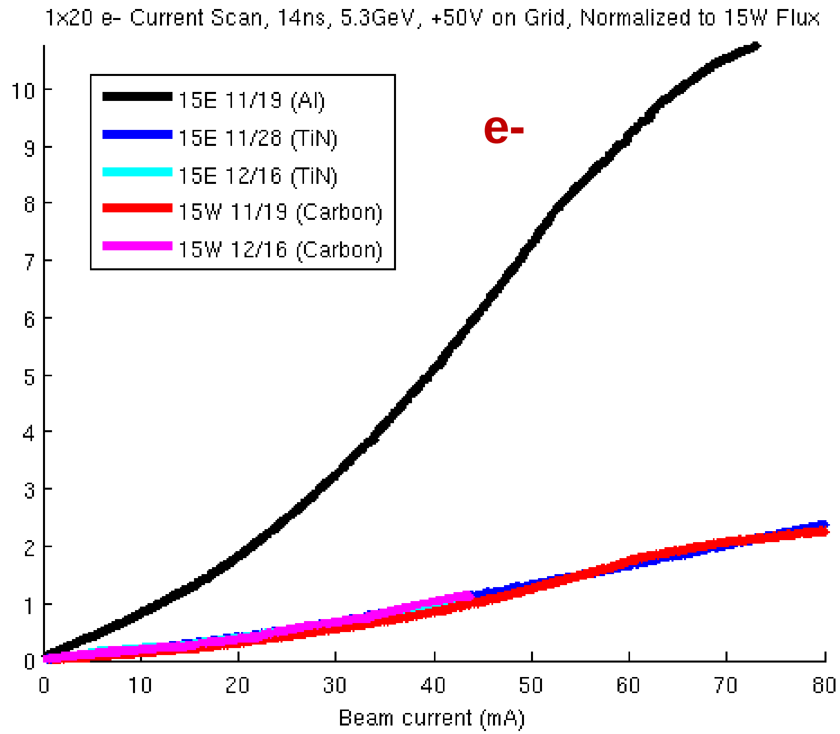




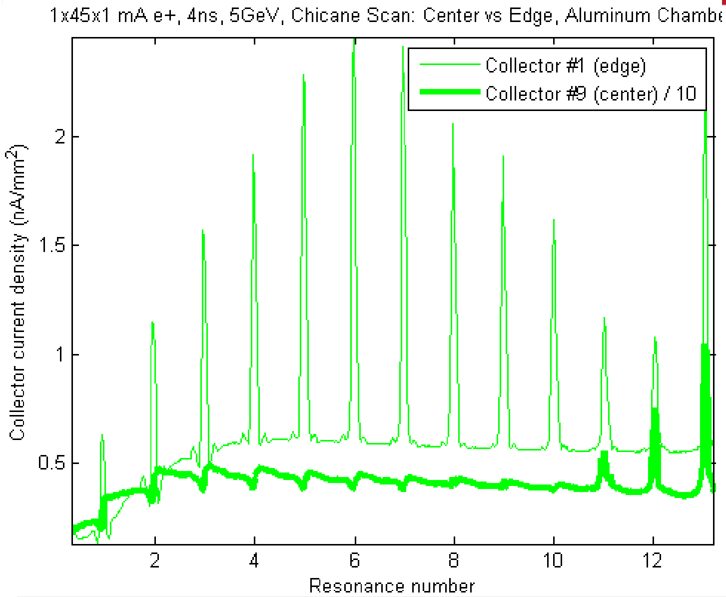
Mitigation Comparisons II: 15E/W Test Chambers

- Conditions: *Same as preceding page*
- Plots now NORMALIZED to (15W) photon flux
- Carbon slightly better than TiN
  - Not sure whether TiN conditioning is complete
    ➪ *Measure again after upcoming CHESS run*





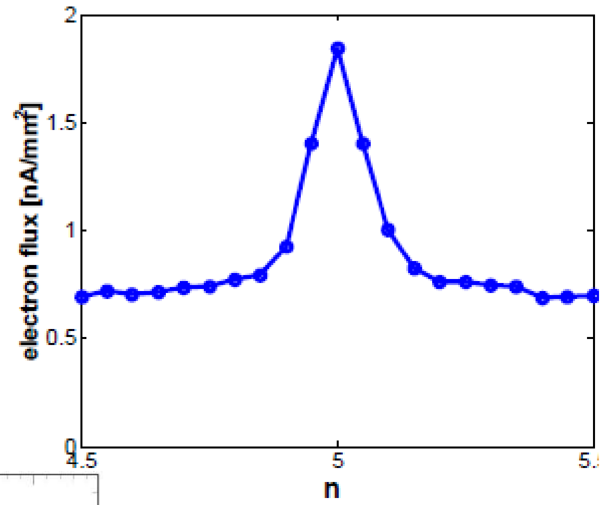
L3 Chicane (SLAC): Measurements & Simulations



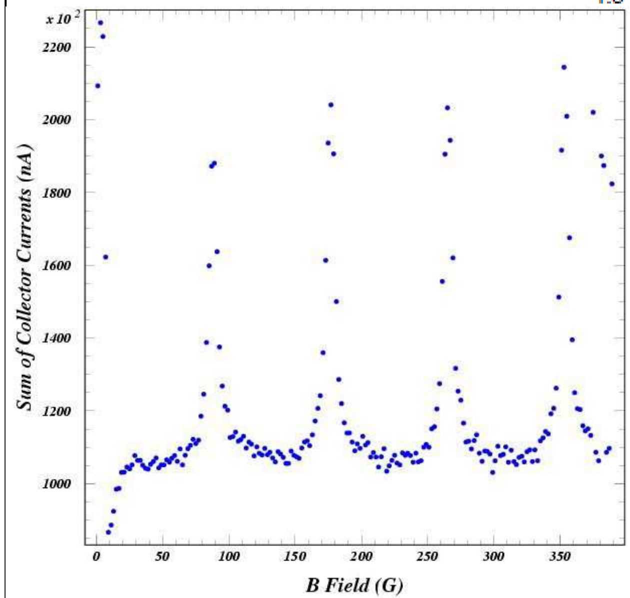
Cyclotron resonances can be reproduced in both ECLOUD and CLOUDLAND

– Plots are of the sum of all collectors for 45 bunches, positrons, 4ns spacing, δ_{max} = 2.0

– Dips are harder to reproduce



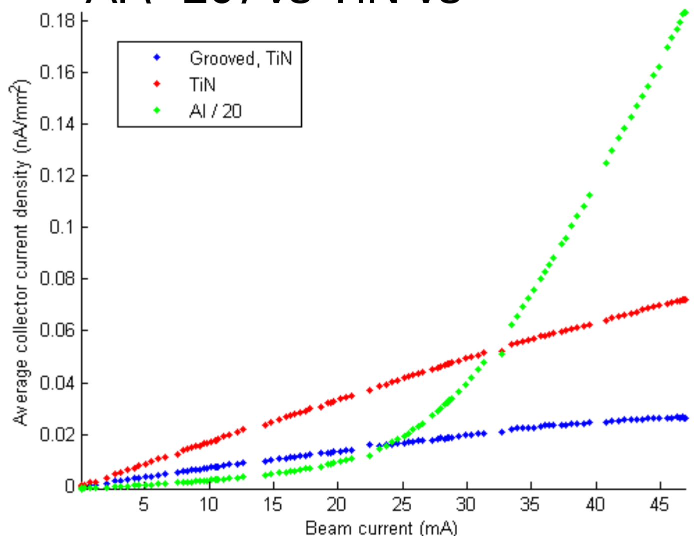
CLOUDLAND (L.Wang)



ECLOUD (J. Crittenden)

- Mitigation Comparisons

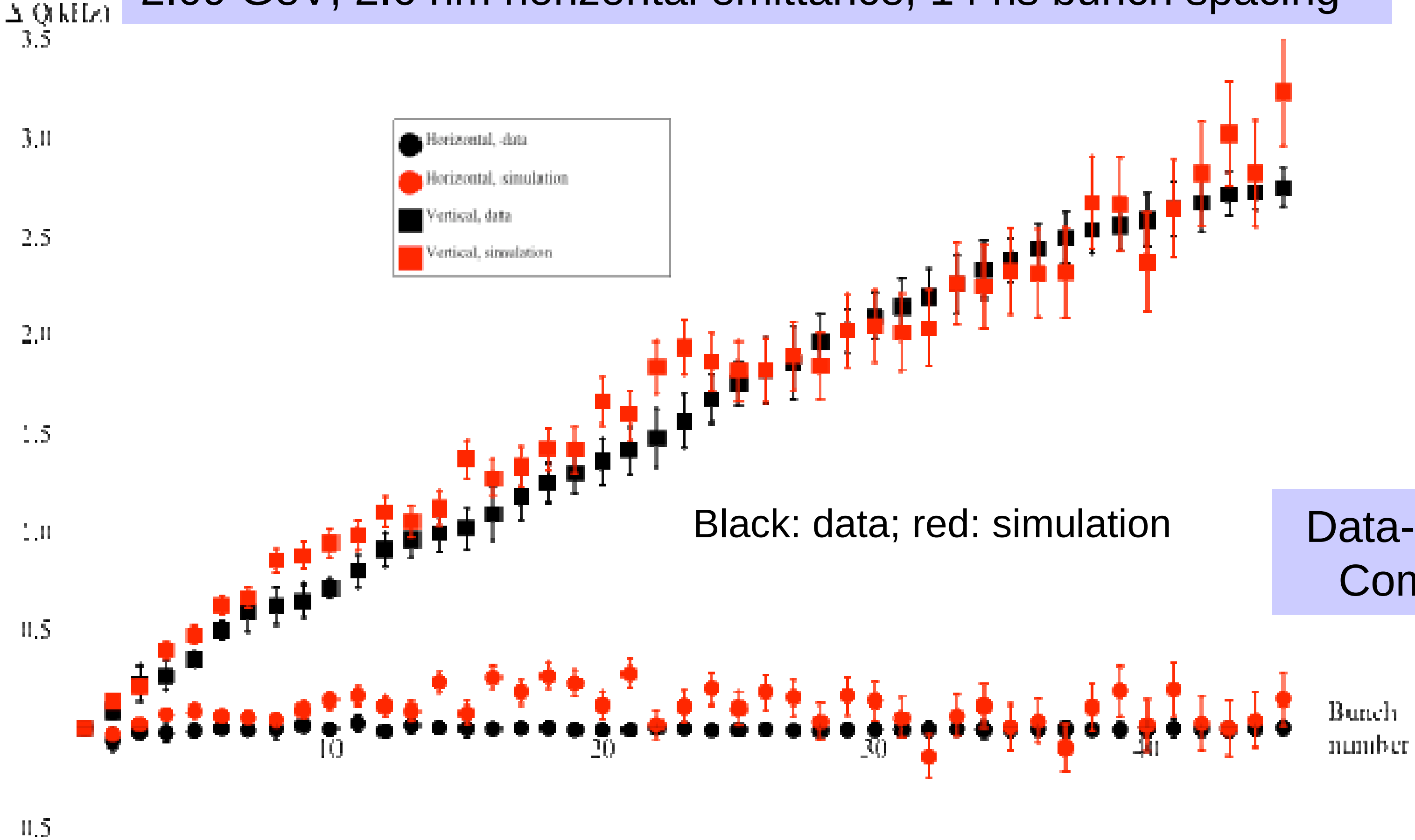
Al (÷20) vs TiN vs



Coherent Tune Shifts

Long train data was taken in January, 2009, using low emittance lattice. Same cloud model parameters as used for a range of other configurations (See GFD talk)

Positrons, 45 bunch train with 1.2×10^{10} particles/bunch
2.09 GeV, 2.6 nm horizontal emittance, 14 ns bunch spacing



Black: data; red: simulation

Data-POSINST Comparison

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 to ε_y < 40pm (within factor of 2 of target)
  - Preliminary EC mitigation comparisons
  - First single-pass bunch-by-bunch beam size measurements to characterize emittance diluting effects
  - Extensive progress on EC simulations
- ~70 machine development days scheduled in 2010. Will focus on:
  - Fully exploiting our new ring instrumentation
  - LET effort to reach a target emittance of $\varepsilon_y \leq$ 20pm
  - Completion of our targeted EC mitigation studies
  - Detailed characterization of instabilities and sources of emittance dilution in the ultra low emittance regime (including first detailed IBS studies)
  - ***Application of our results to the damping rings design effort***
- *Have recently undergone a review by the US NSF for a 3 year extension to the R&D program – the closeout session with the review committee was quite positive!*

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 Instrumentation
    - CalPoly, CERN, Cockcroft, KEK, SLAC
  - EC Instrumentation
    - FNAL,KEK, LBNL
  - SEY Station
    - Carleton, FNAL, SLAC
  - Simulation
    - CERN, KEK, INFN-Frascati, LBNL, SLAC
  - Technical System Checks
    - BNL, CERN, KEK

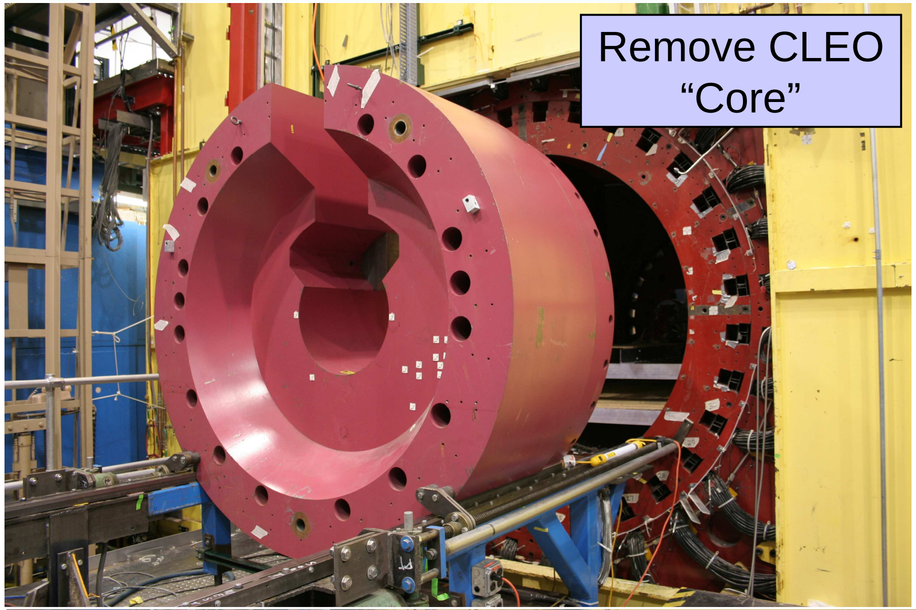
- Backup Slides Follow

Unique Features of R&D at CESR

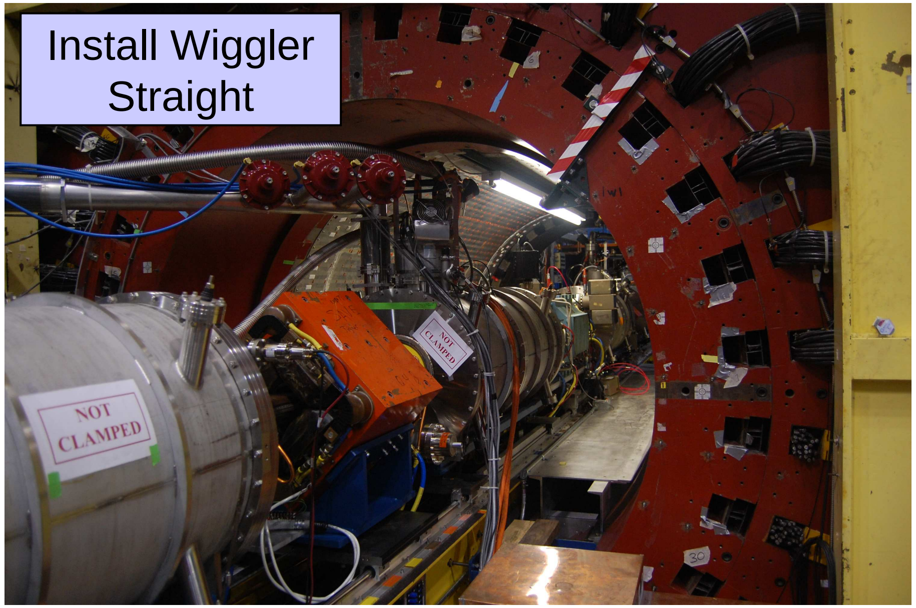
CESR offers:

- An operational wiggler-dominated storage ring
- The CESR-c superconducting damping wigglers
  - Technology choice for the ILC DR baseline design
    - Physical aperture: Acceptance for the injected positron beam
    - Field quality: Critical for providing sufficient dynamic aperture in the damping rings
- Flexible operation with ***positrons*** *and* ***electrons***
- Flexible bunch spacing suitable for damping ring tests (≥ 4ns)
- Flexible energy range from 1.5 to 5.5 GeV for EC growth and beam dynamics studies
- Dedicated focus on damping ring R&D for significant running periods
  - Support for collaborator experiments
  - Support for electron cloud hardware (eg, PEP-II experimental hardware has been re-deployed in CESR to complete the SLAC measurement program)
- A useful set of damping ring research opportunities…
  - The ability to operate with positrons and with the CESR-c damping wigglers offers a unique experimental reach in the ultra low emittance regime

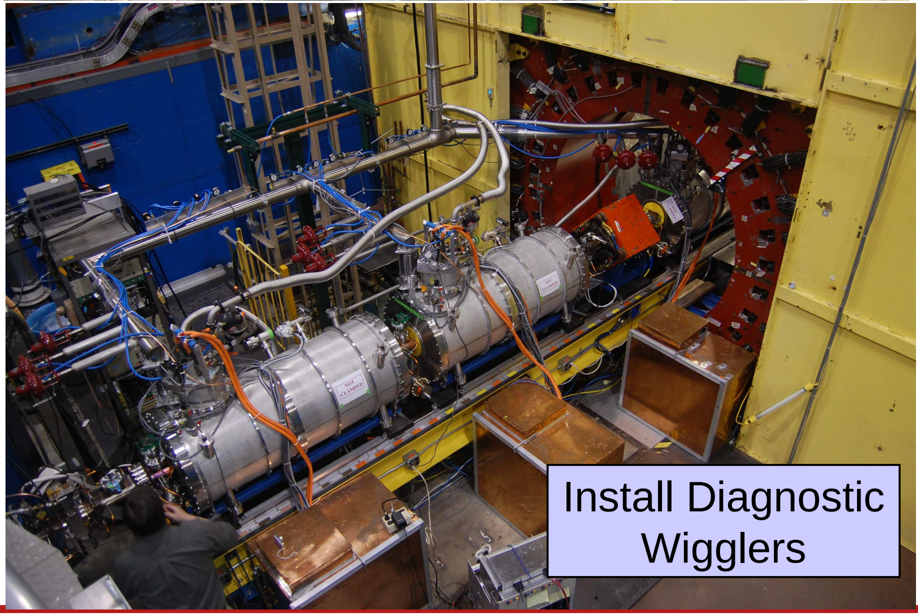
CESR Reconfiguration: L0 Modifications



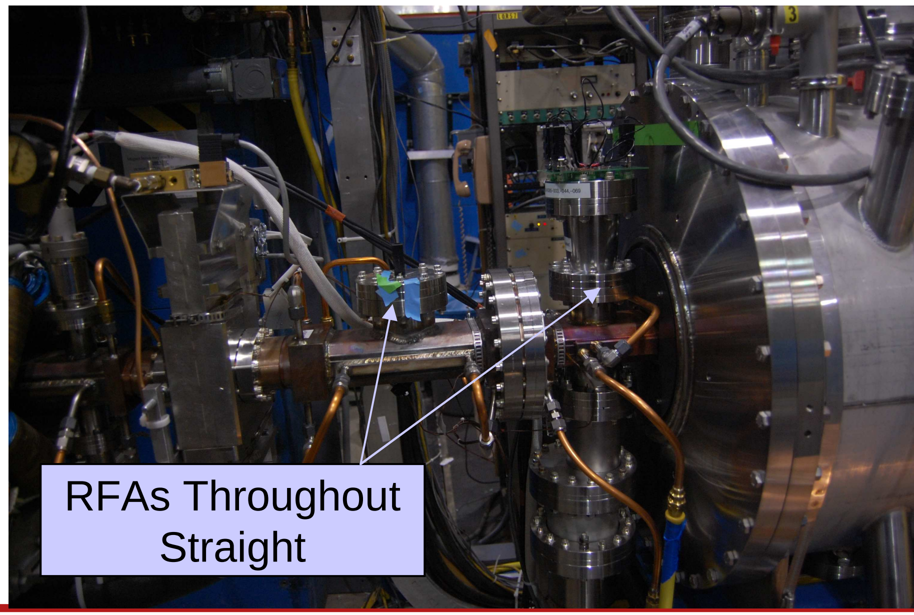
Remove CLEO "Core"



Install Wiggler Straight



Install Diagnostic Wigglers



RFAs Throughout Straight

R&D Effort

- Major components of our remaining R&D effort are:
  - Low emittance tuning and achieving <20pm vertical emittance
  - EC mitigation studies
  - EC instability studies
  - Detailed comparisons with simulation
- Specific priorities were identified at CTA09 (June 25-26)
  https://wiki.lepp.cornell.edu/ilc/bin/view/Public/DampingRings/CTA09/WebHome
  - 3 Working Groups
    - EC Build-Up and Mitigation
      - Conveners: K. Harkay, Y. Suetsugu, R. Zwaska
      - 27 Deliverables with 21+ contributors identified
      - 3 Broad Catgories
        - » EC Build-Up
        - » Instrumentation
        - » Mitigation
    - EC Simulation and Beam Dynamics
      - Conveners: G. Dugan, J. Flanagan
      - 32 Deliverables with 16 contributors identified
      - Divided into beam measurement and simulation categories
    - LET
      - Conveners: M. Billing, S. Guiducci, J. Shanks
      - 16 Deliverables with 19 contributors identified
      - Divided into LET and instrumentation categories
- Detailed discussion in the next two talks, however, will briefly summarize here…

Integration into the ILC DR Design

- We expect by 2010 to have placed the positron damping ring on a more solid foundation by having confirmed and updated our performance projections
  - Detailed comparisons of data and simulation in the low emittance regime will lead to significantly more reliable estimates in our DR simulations
  - Results will confirm, or cause us to re-evaluate, our plans to move to a smaller circumference layout

- Testing of a range of mitigations in operational vacuum chambers will provide the necessary inputs for the technical design
  - Will allow the damping rings group to proceed with detailed design work and costing on an updated baseline vacuum system
  - Fully expect that there will be significant ongoing work to validate the design details
    - Prototyping
    - Some tests such as durability checks of newer coatings may still await final results
  - We anticipate that these inputs can largely be incorporated as incremental changes to the DR design work presently underway