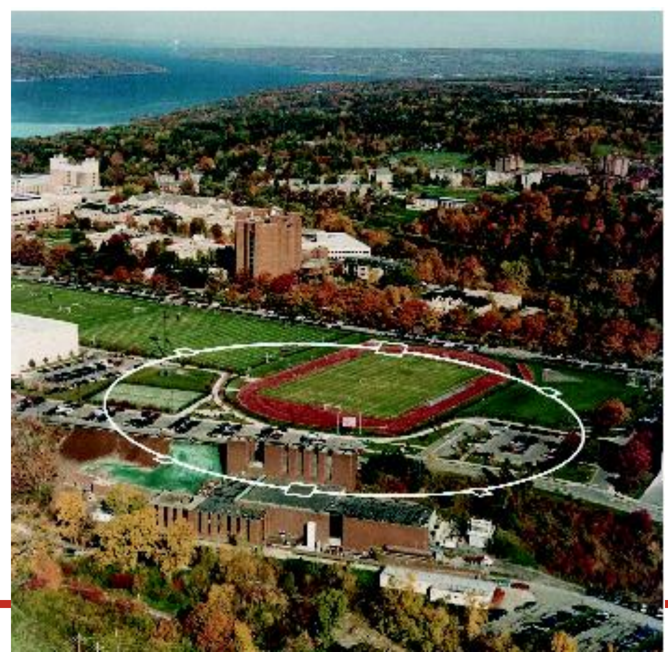
Introduction to CesrTA

David Rubin

September 11, 2012



Questions

- Consider the positron storage ring:
  1. What is the threshold beam current for emittance dilution and instability due to the electron cloud ?
  2. What are the most effective techniques for mitigating the growth of the electron cloud ?
  3. What are the relevant material properties of the mitigations?
  4. How do we extrapolate our findings to other machines ?

Program: Question 1

- To address the first question (emittance dilution threshold ?)
  - Create low emittance (both horizontal and vertical) CESR configuration so that we can explore the beam physics in the appropriate regime =>
    - Superconducting damping wigglers to reduce emittance
    - Instrumentation for beam based measurement and optics correction, to minimize residual coupling and dispersion
    - Instrumentation for measuring emittance
  - Develop techniques for generating an electron cloud of arbitrary (ring averaged) density
  - Instrumentation to measure emittance growth and instabilities as a function of the cloud density

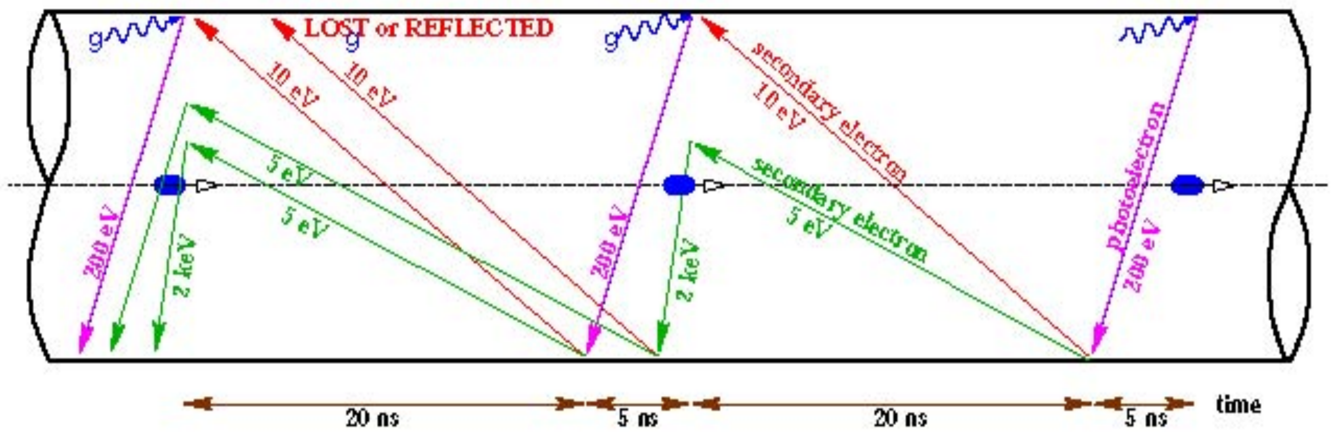
Program Questions 2-3

- To address the second (effectiveness of mitigations ?)
  - Detectors for measuring local electron cloud density in a controlled environment including:
    - Flux of synchrotron radiation
    - External magnetic field (dipole, quadrupole, wiggler, drift)
    - Vacuum chamber geometry and surface treatment
    - Beam energy, current and bunch configuration

  (Retarding field analyzers, shielded pickups, TE wave)
- And the third (material properties ?)
  - Detectors that can provide temporal information about the growth and decay of the cloud

  (Shielded pickups and time resolving RFAs)

Electron Cloud



- Synchrotron radiation photons strike chamber walls emitting photo-electrons.
- Electrons are accelerated by the circulating positron bunches into the opposite wall, producing secondaries
- *Interaction of the positron beam with the accumulating cloud generates instabilities and dilutes vertical emittance*

4 – Extrapolation to Other Machines

- Physics of the electron cloud is incorporated into models
  - The "Complete" model includes

1. Emission of photons from circulating positrons
2. Tracking of photons to the vacuum chamber. Generation of a photoelectron, or a reflection. If reflected continue tracking.
3. Simulation of the emission of photoelectrons at the photon-wall absorption point.
4. Evaluation of forces that act on the electrons (from the beam, space-charge and external fields).
5. Application of forces to the electrons and propagation of electron trajectories.
6. Simulation of secondary emission as the electrons hit the walls of the chamber.

Many details are parameterized in the model:

- Dependence of photon scattering angle on chamber surface (roughness). (Experimental program to verify reflectivity model is underway – Reflectivity collaboration)
- Quantum efficiency, angular and energy distribution of photo-electrons depends on photon energy and chamber surface properties
- Secondary emission depends on primary energy and incident angle as well as surface chemistry

- Measurements inform the models and constrain the parameters
- The models are the basis of the simulations that predict storage ring performance

CESR Conversion

CESR Conversion

- Reconfigure CESR layout for low emittance operation
- Develop/install instrumentation for measuring electron cloud
  - Retarding field analyzers, - measurement of local density, spatial and energy distribution of the cloud
  - Shielded pickups – local measurement of time evolution of the cloud
  - TE-wave – semi-local measurement of density
  - Bunch dependent tune shifts (global measure of cloud density)
- Develop/install instrumentation for tuning low emittance (correcting β-phase, coupling, dispersion) and measuring effect of cloud on the beam
  - High bandwidth/high precision beam position monitors
  - Turn by turn/bunch by bunch x-ray beam size monitor (to measure vertical emittance)
- Deploy survey reference grid for routine magnet alignment
- Develop/install instrument for direct measurement of SEY of materials in storage ring environment

CESR Conversion - constraint

Preserve compatibility with CHESS x-ray operation.

- Transition from CesrTA low emittance single beam optics, to CHESS electron/positron configuration must be routine (1-2 hours)
- Gate valves suitably deployed to minimize effect on CESR vacuum and CHESS operation when swapping test chambers

Machine Layout, Optics and Instrumentation for Low Emittance operation

CESR Conversion – Low Emittance Optics

- CESR lattice has long dipoles and a relatively low density of quadrupoles
  => relatively high emittance
- To attain low emittance we rely on damping wigglers
- At 2GeV, the 12, 1.3m long, 1.9T superconducting wigglers, decrease radiation damping time by 10 from 0.5 secs to 50 msec.
  => 4 fold reduction in horizontal emittance *providing* we can eliminate dispersion
- To that end we re-locate 6 wigglers from arc to L0 straight.
- And design optics with the appropriate constraints

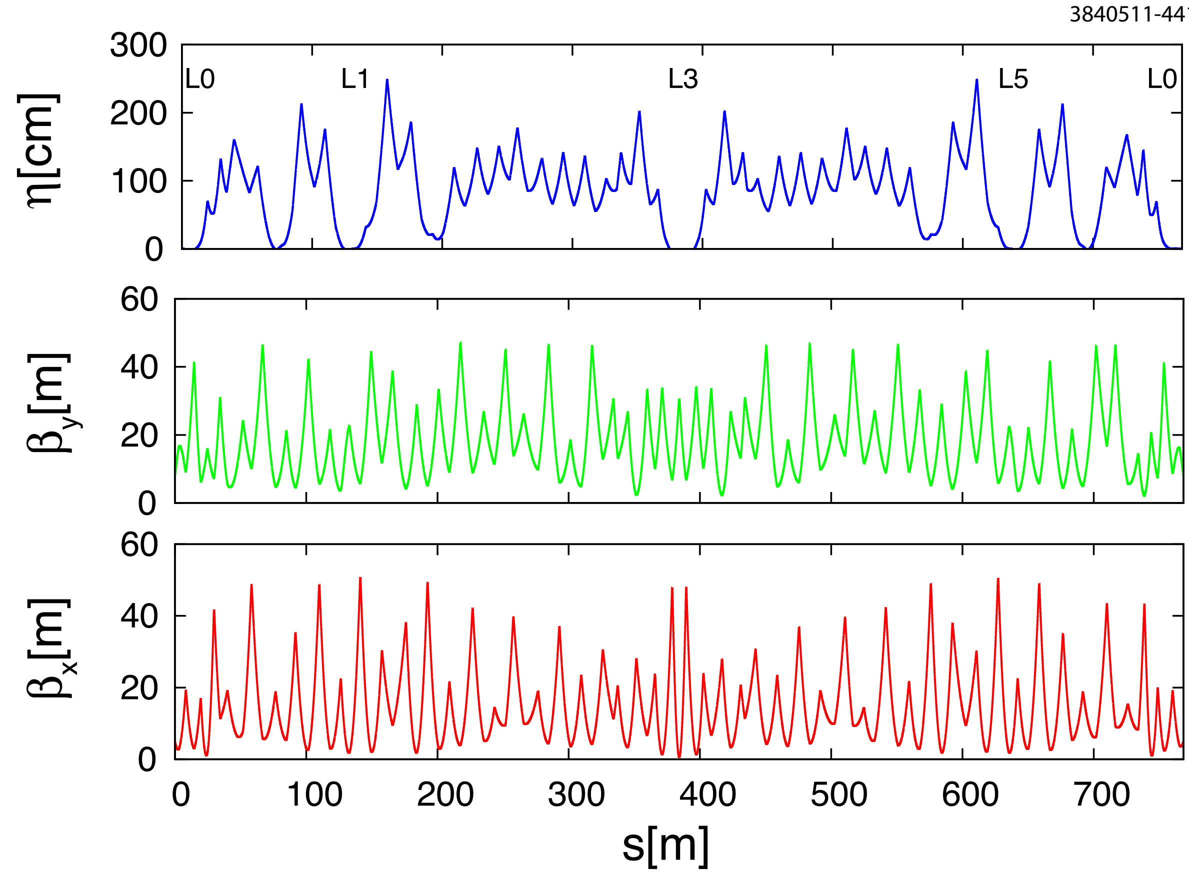
Low emittance lattice functions

Flexible magnetic optics

All 100 quadrupoles and 78 sextupoles are independently powered

E = 2.1 GeV

ϵ_x =3 nm-rad

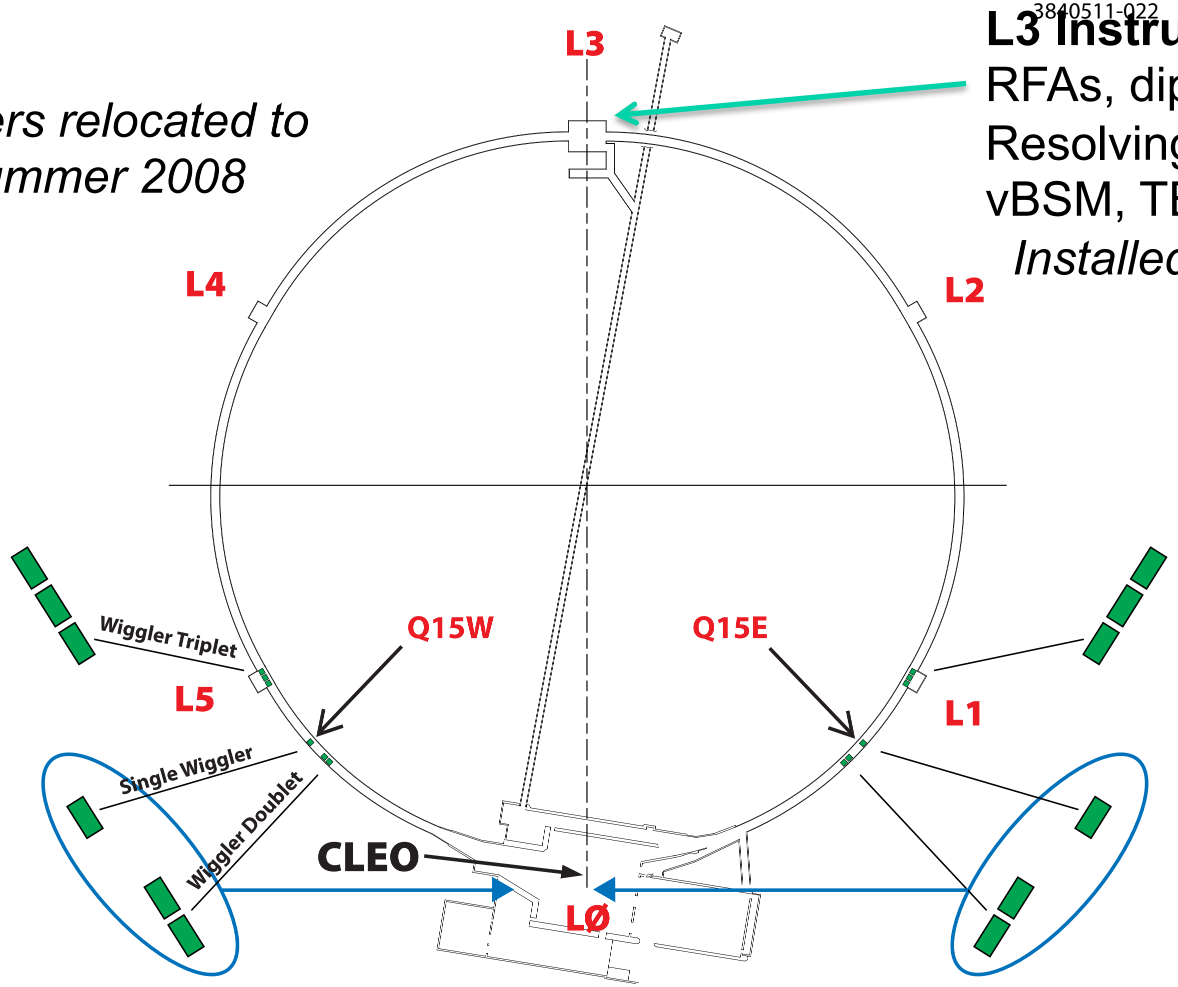


More than a dozen distinct lattice configurations for operation at energies from 1.8 - 5.3 GeV have been implemented and used for various studies

CESR Conversion

Wigglers relocated to L0, summer 2008

L3 Instrumentation
RFAs, dipole chicane, Time Resolving RFA, in-situ SEY, vBSM, TE-wave
Installed 2009-2012



Wigglers moved from 15E/W to L0. Mitigations tested in L0 wigglers
Available space at 15E/W used to test mitigations in field free region with SPU, RFA, TE-wave – dipole RFA

Damping wigglers

Damping wigglers redeployed to zero dispersion straight

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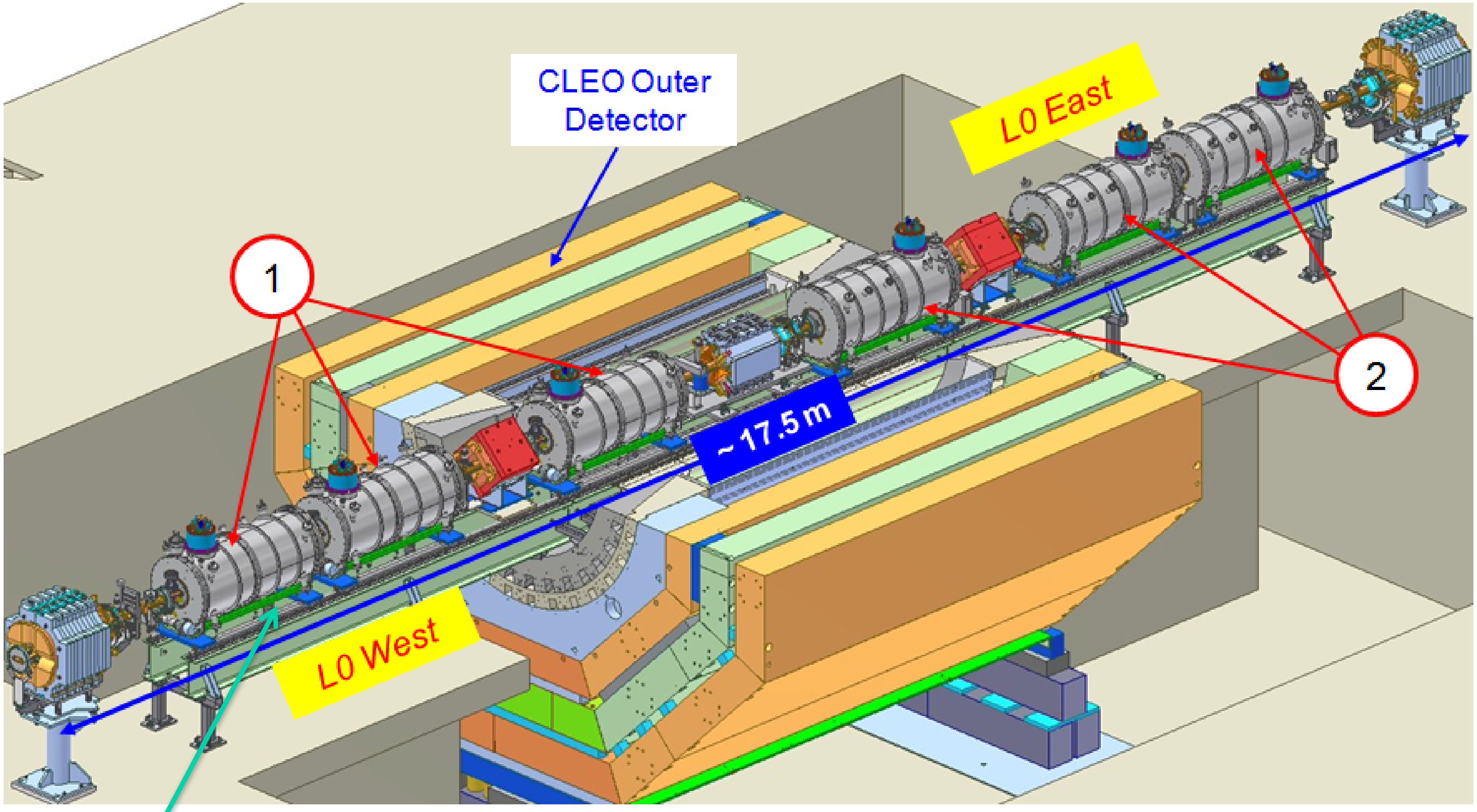


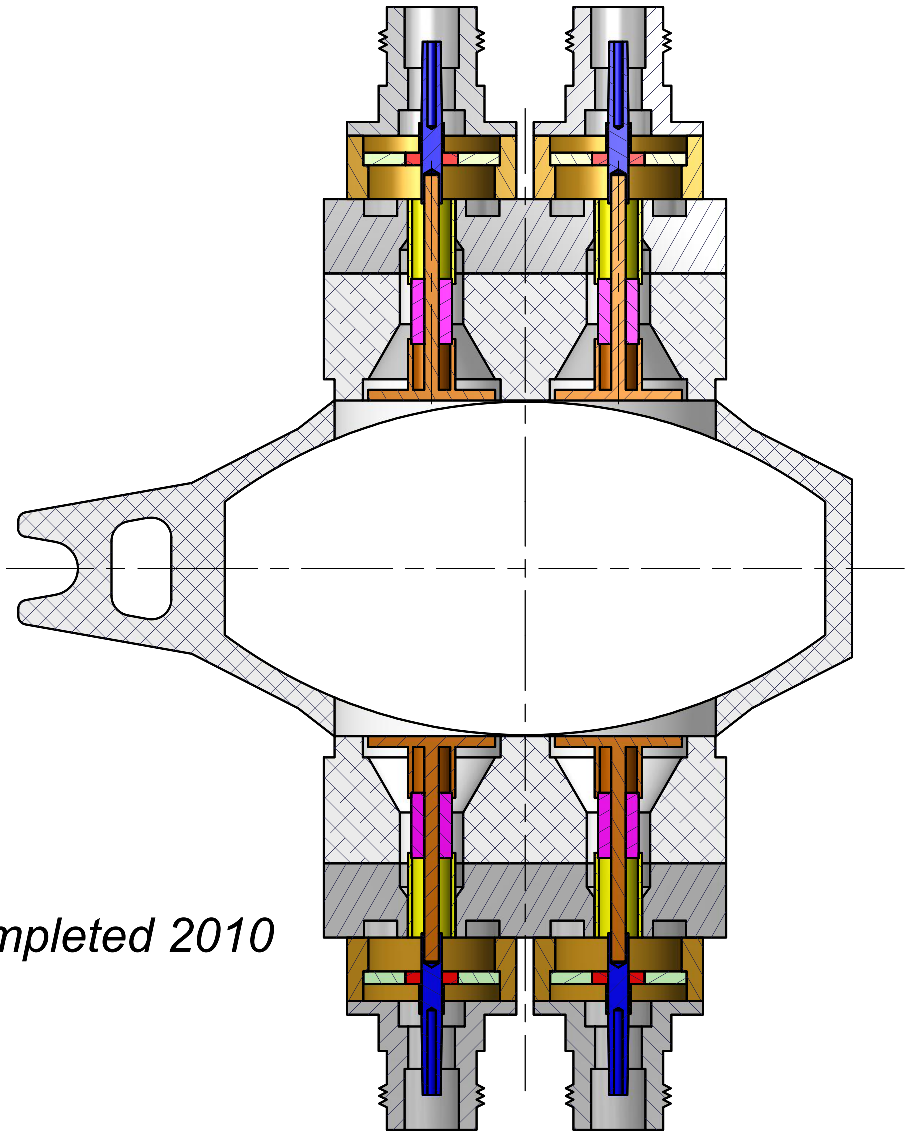
Wigglers instrumented with mitigations and RFAs

Precision beam position monitors

Turn by turn/bunch by bunch
~10 micron single pass precision

Routine tuning
for low emittance is essential to the experimental program.

Beam based characterization of machine optics depends on high bandwidth/high precision beam position monitors.

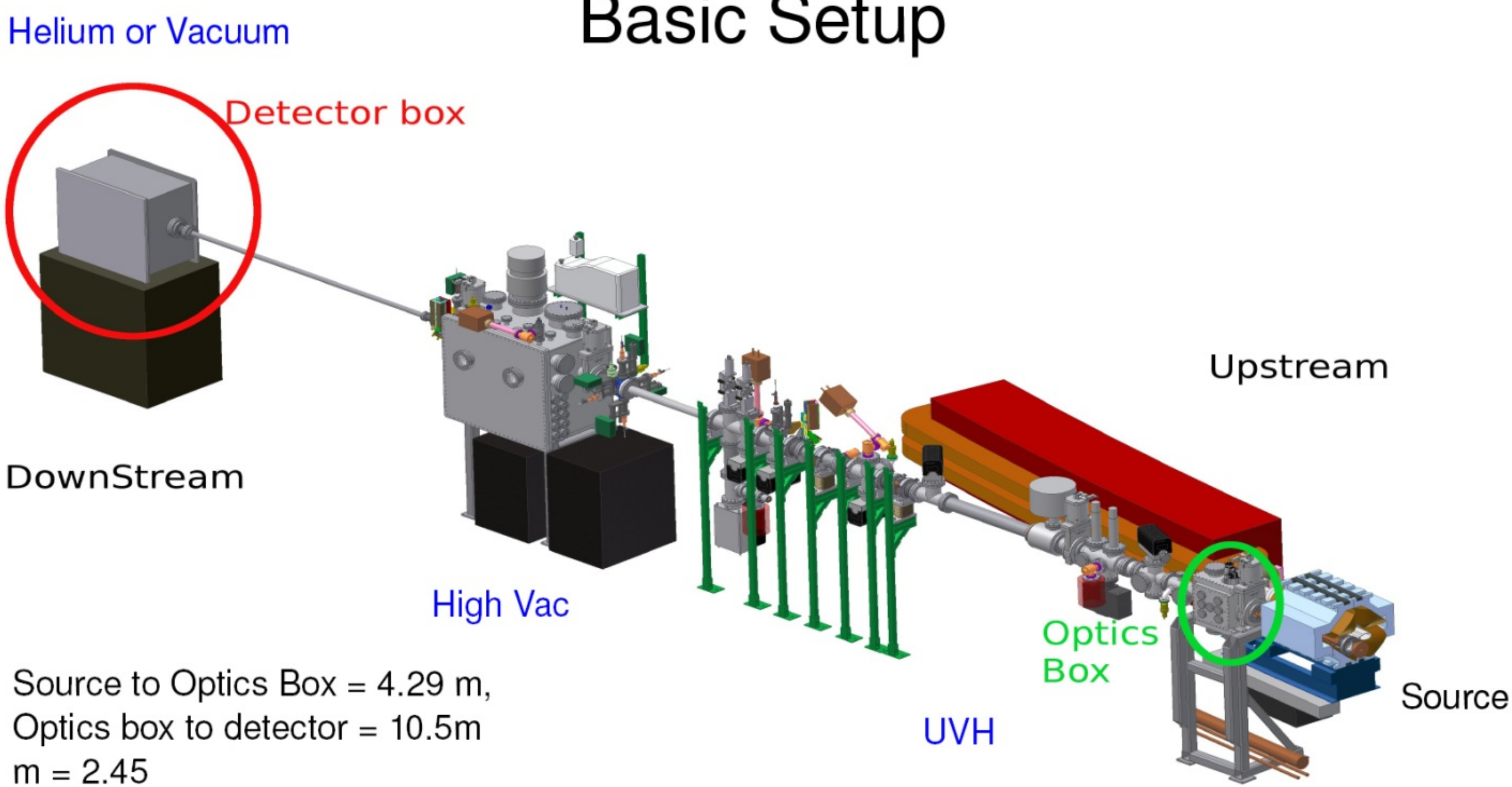


Upgrade to digital readout electronics completed 2010

Xray beam size monitor

Xray beam size monitor
- Measure vertical beam size to ~ 10 microns => vertical emittance
- Turn by turn/bunch by bunch to 4 ns => bunch dependent emittance

Basic Setup

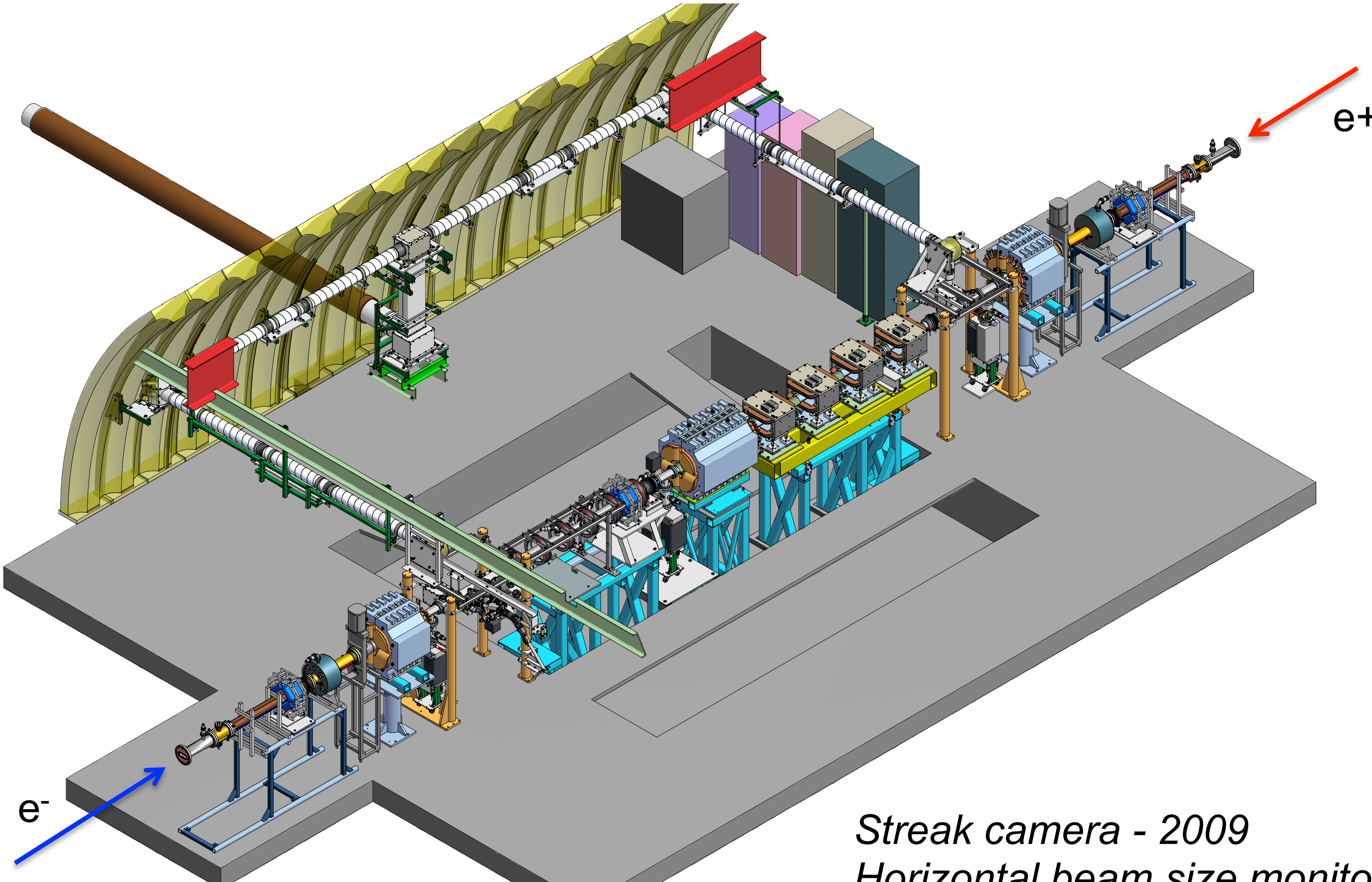


Source to Optics Box = 4.29 m,
Optics box to detector = 10.5m
m = 2.45

xBSM Commissioning – Positrons 2009-2010, Electrons 2011

Visible light beam size monitor

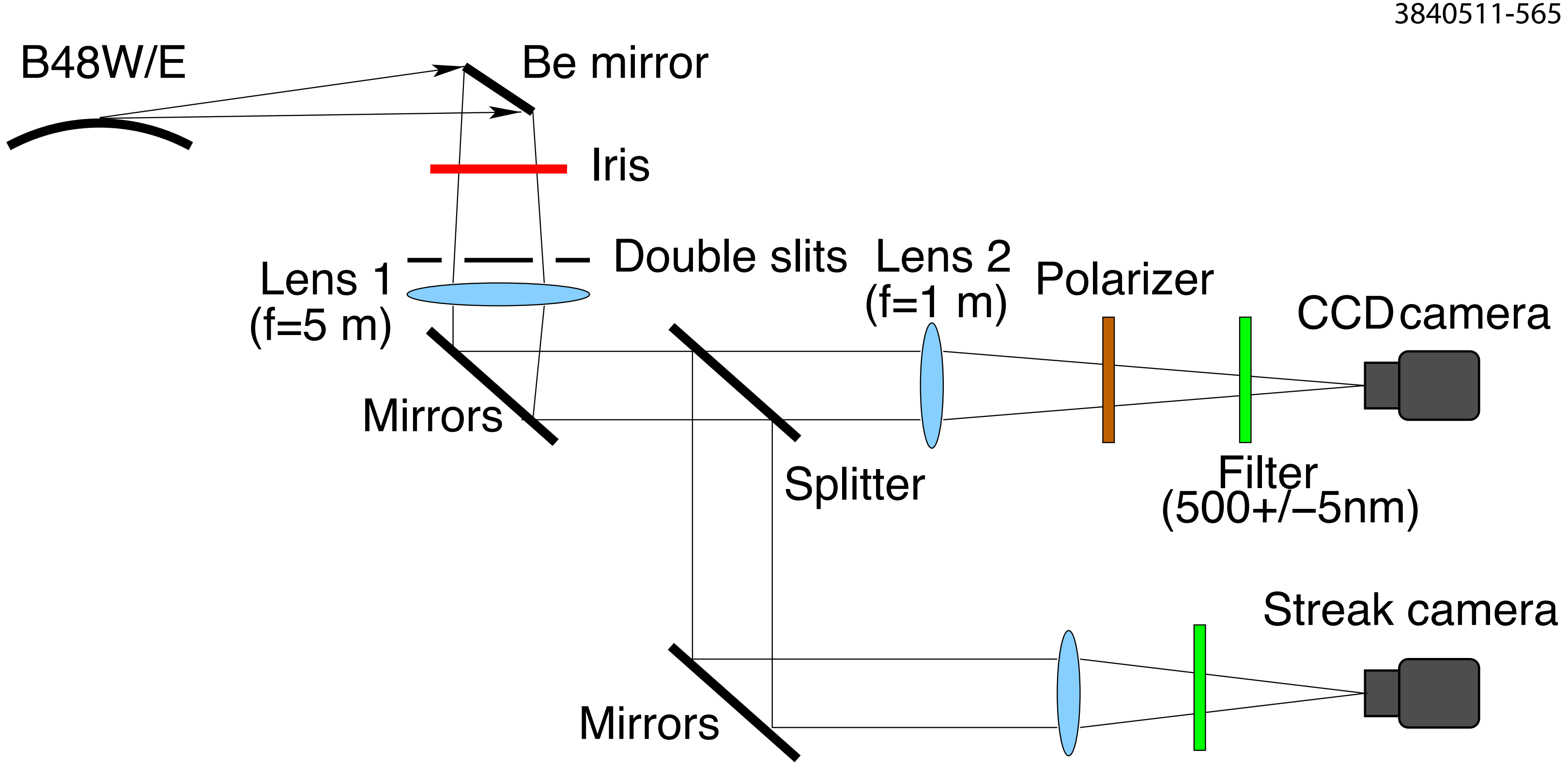
Visible light beam size monitor
- Double slit interferometer => horizontal beam size (emittance and energy spread)
- Streak camera => bunch length



Streak camera - 2009
Horizontal beam size monitor - 2011

Visible light beam size monitor

Schematic of visible light optics



Optical path length 17m from source at B48 to camera

Low emittance configuration

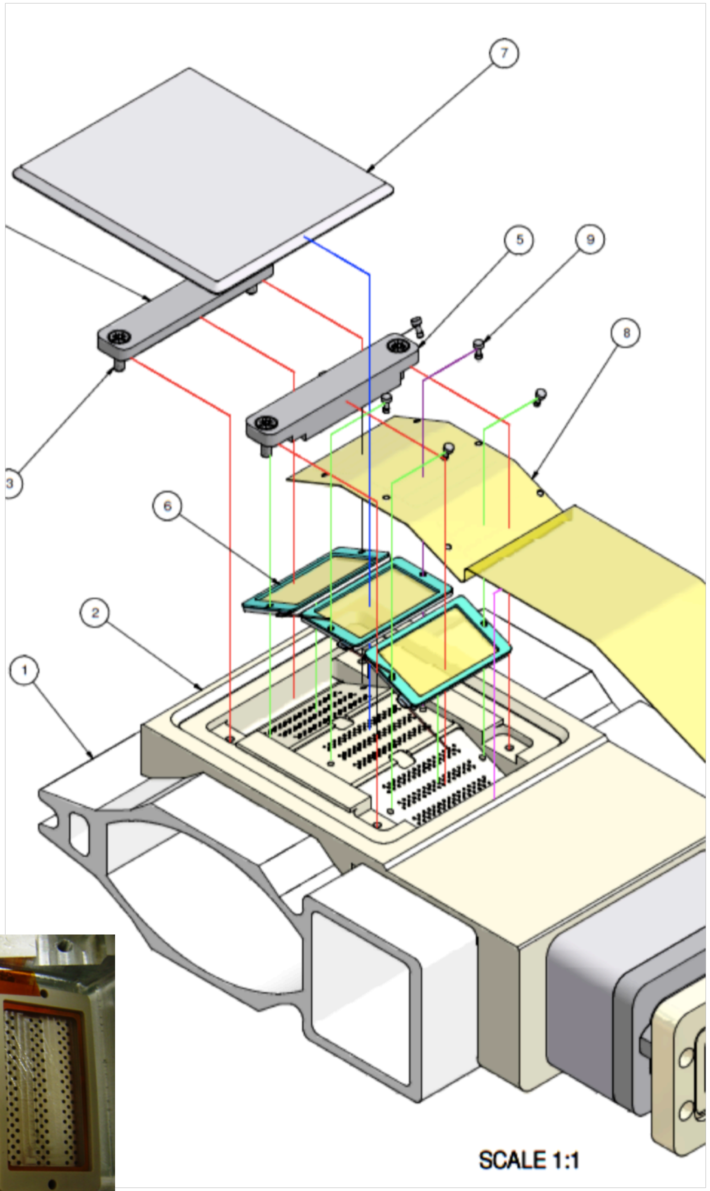
- Wigglers relocated to zero dispersion straight. (L0)
- Survey reference system established, and magnet alignment completed
- Instrumention deployed for tuning low emittance with capability to measure
  - Turn by turn position
  - Width, height, length of single bunch
  - And turn by turn and bunch by bunch measure of vertical size

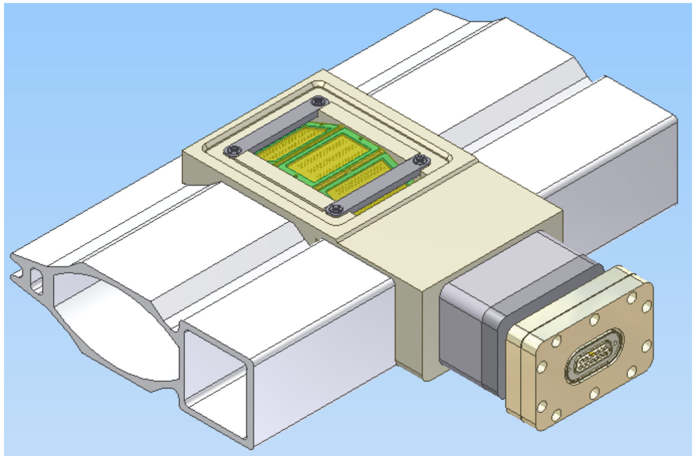
Instrumentation for measuring electron cloud and characterizing mitigations

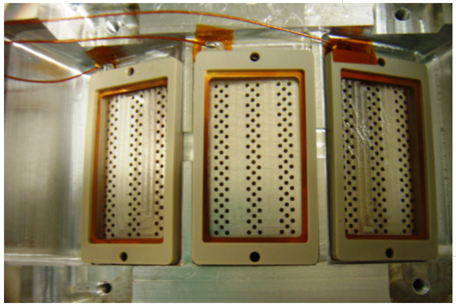
Retarding field analyzers

Local measurement of time averaged flux of electrons into wall of chamber

- Measures the energy spectrum of the time-average cloud current which impacts the chamber wall.
- Most devices are segmented, so that some position information is also available.
- Placed in drifts, dipoles, quadrupoles, and wigglers.
- In chambers with mitigations, RFAs measure their effectiveness



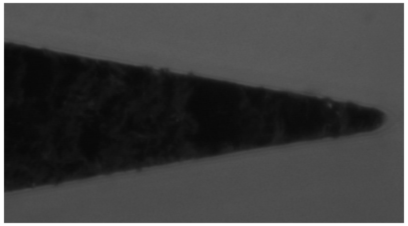


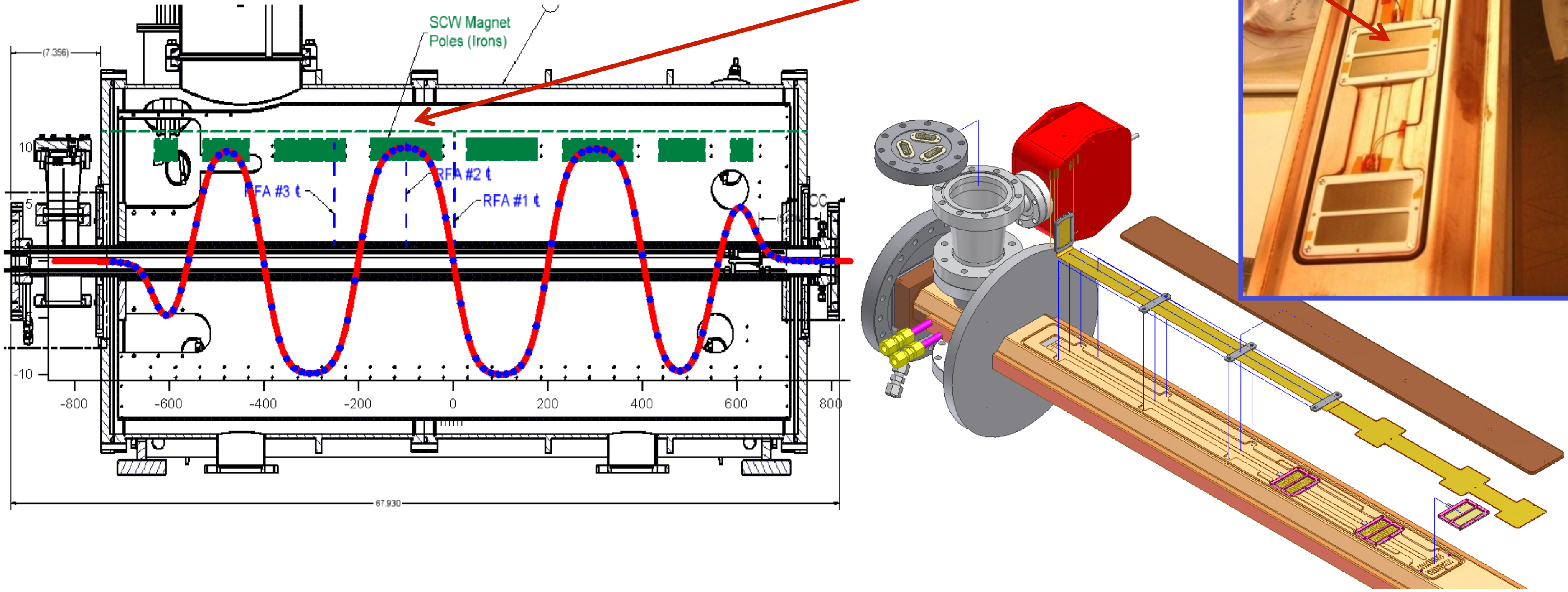


Retarding field analyzers

- Four wigglers are instrumented with RFAs
  - Bare Cu
  - TiN coated
  - Grooves
  - Clearing electrode
- Each wiggler has three RFAs

Groove tips/valley radius < 0.002" !!





Wiggler mitigations

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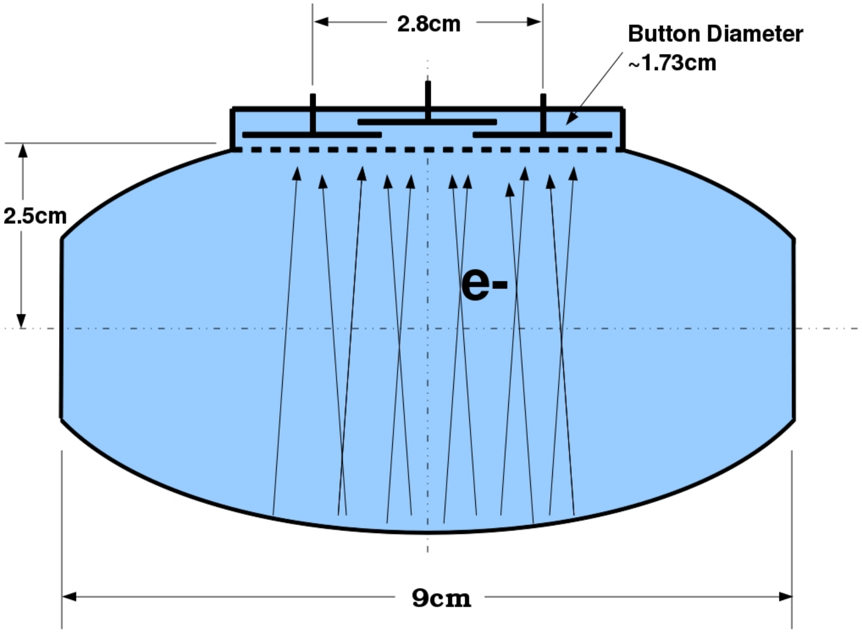
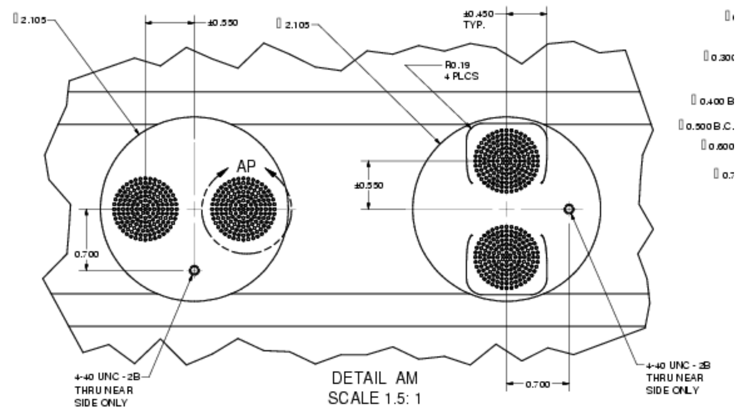
Clearing electrode

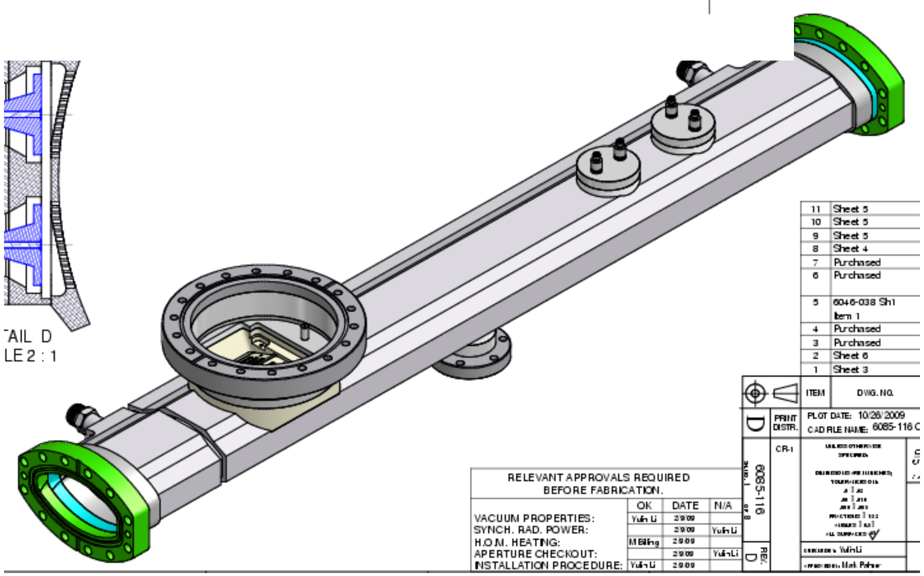
Grooved copper insert

Shielded pickup



Shielded pickups have nanosecond temporal resolution and inform time development and decay of cloud





Experimental region 15W

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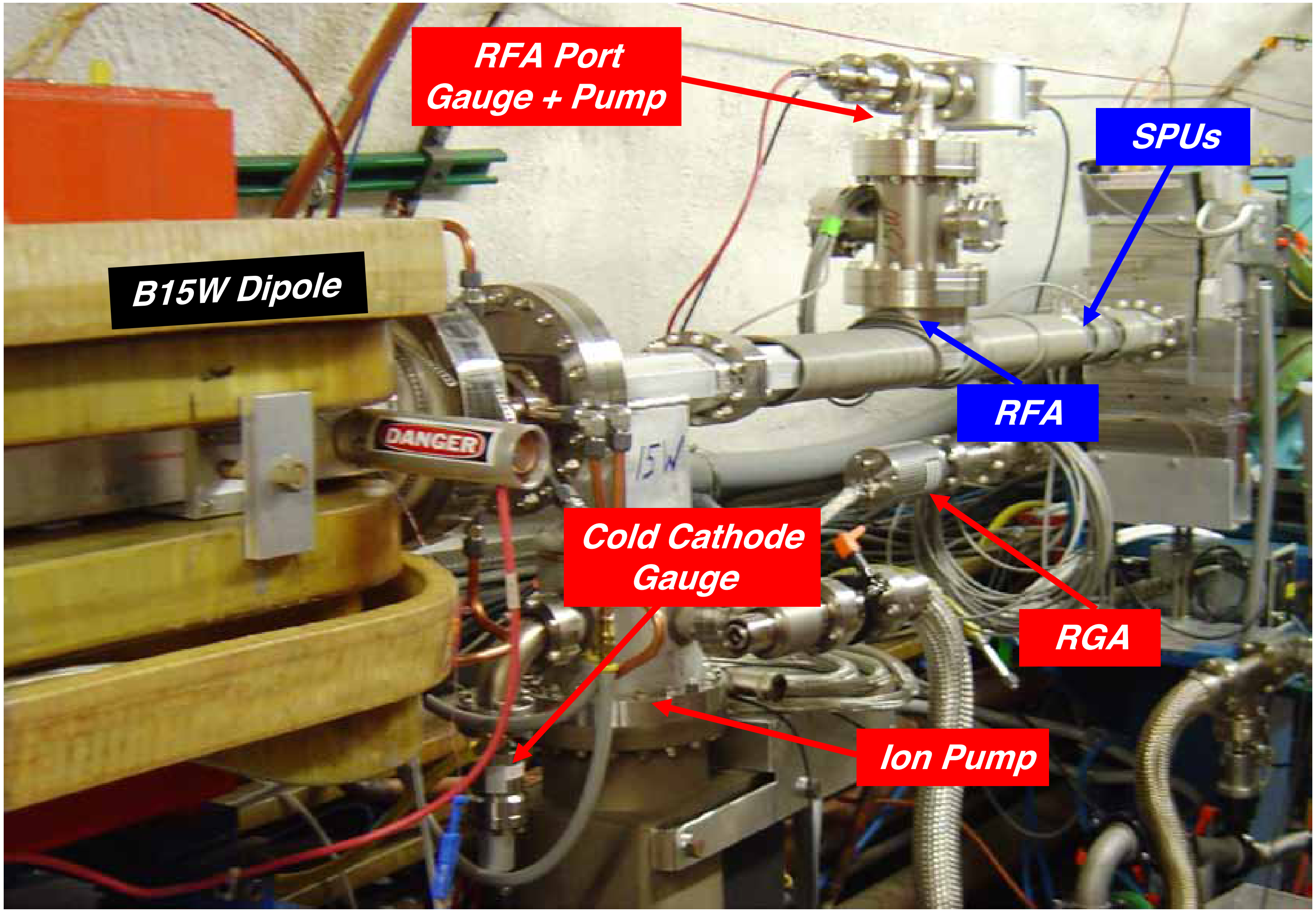
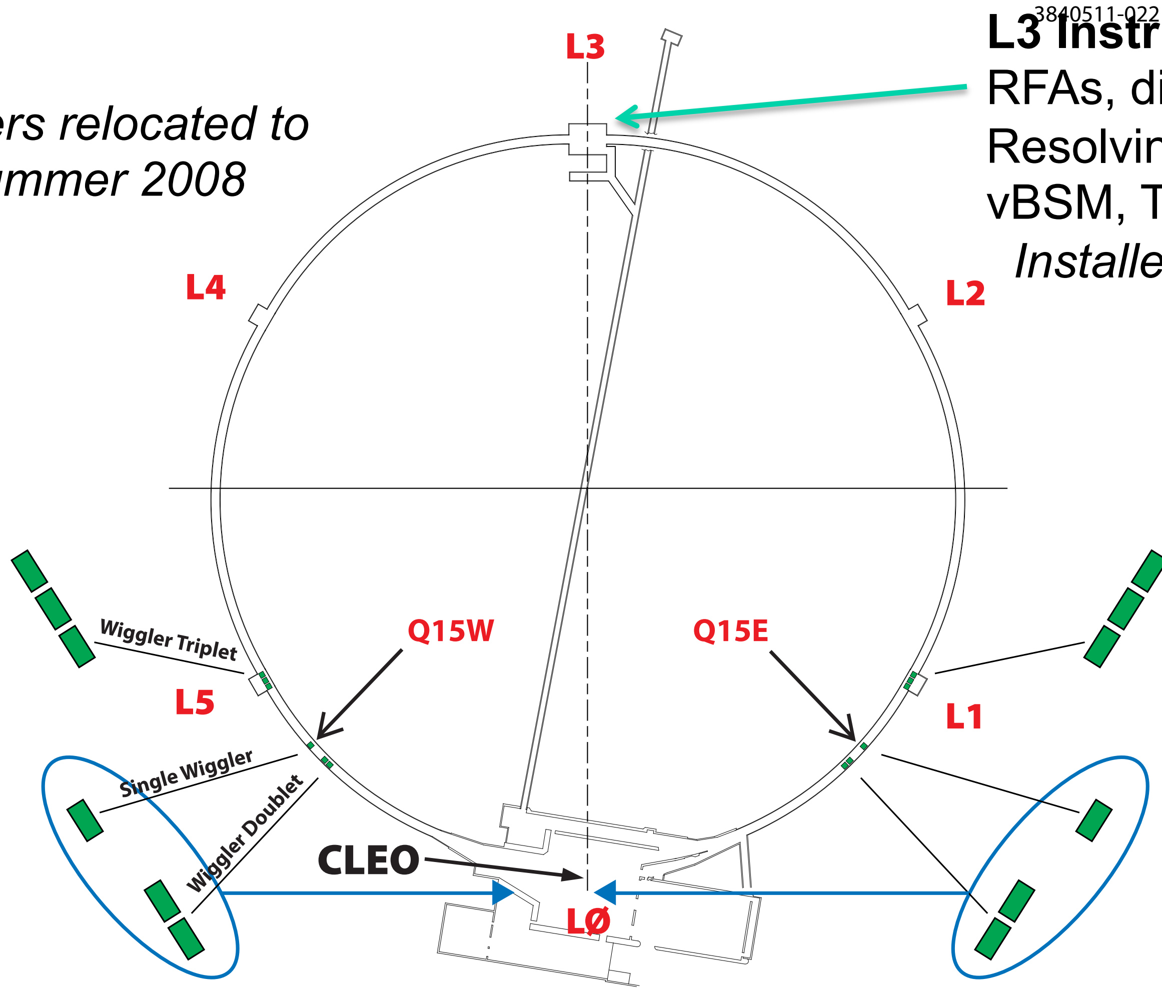


Chambers with various mitigations are tested in 15W and 15E regions
=> providing comparison in standardized synchrotron radiation environment

Electron Cloud Instrumentation

Wigglers relocated to L0, summer 2008

L3 Instrumentation
RFAs, dipole chicane, Time Resolving RFA, in-situ SEY, vBSM, TE-wave
Installed 2009-2012



Wigglers moved from 15E/W to L0. Mitigations tested in L0 wigglers
Available space at 15E/W used to test mitigations in field free region with SPU, RFA, TE-wave – dipole RFA

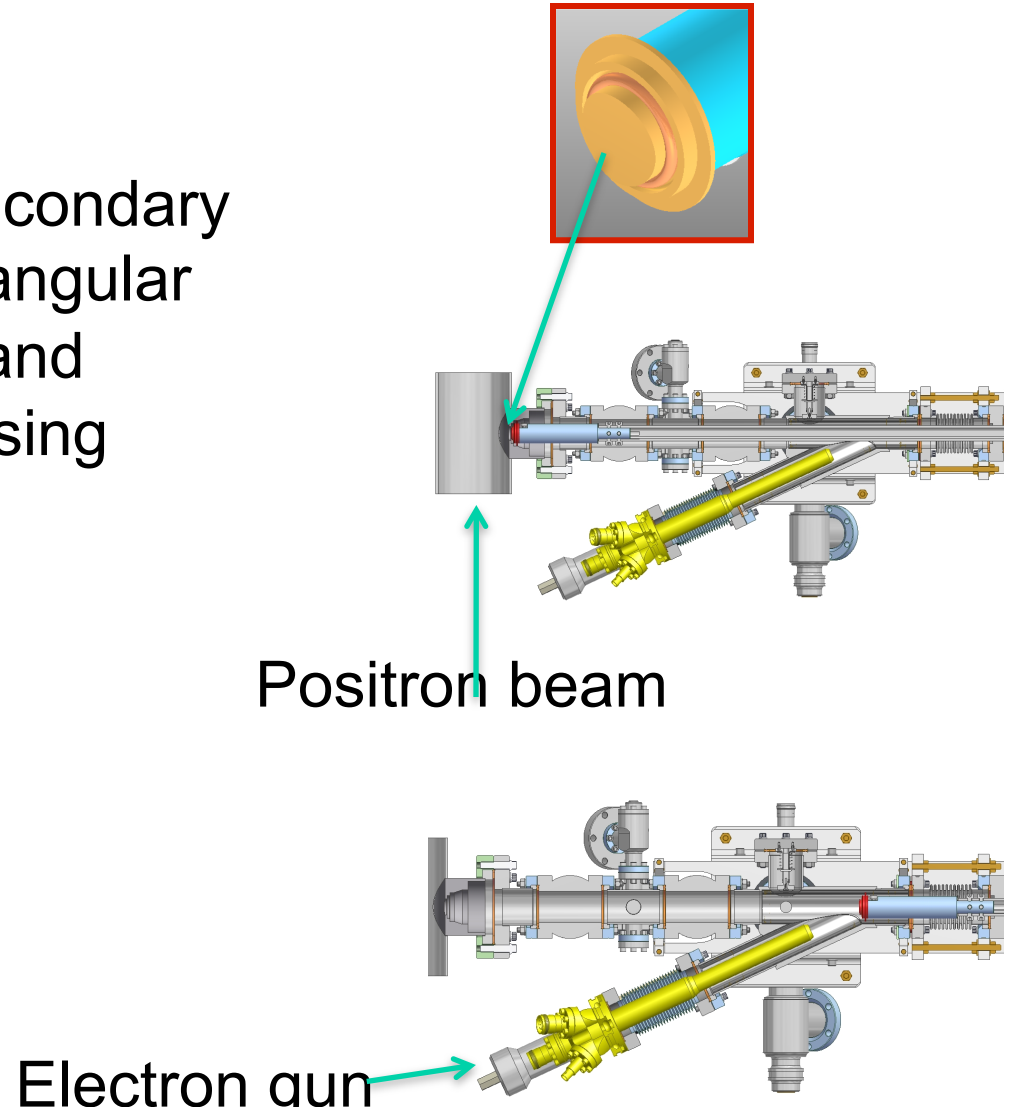
Tested Mitigations

Mitigation	Drift	Quadrupole	Dipole	Wiggler	Institutions Providing Chambers
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
Diamond-like C on Al	✔				CU, KEK
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

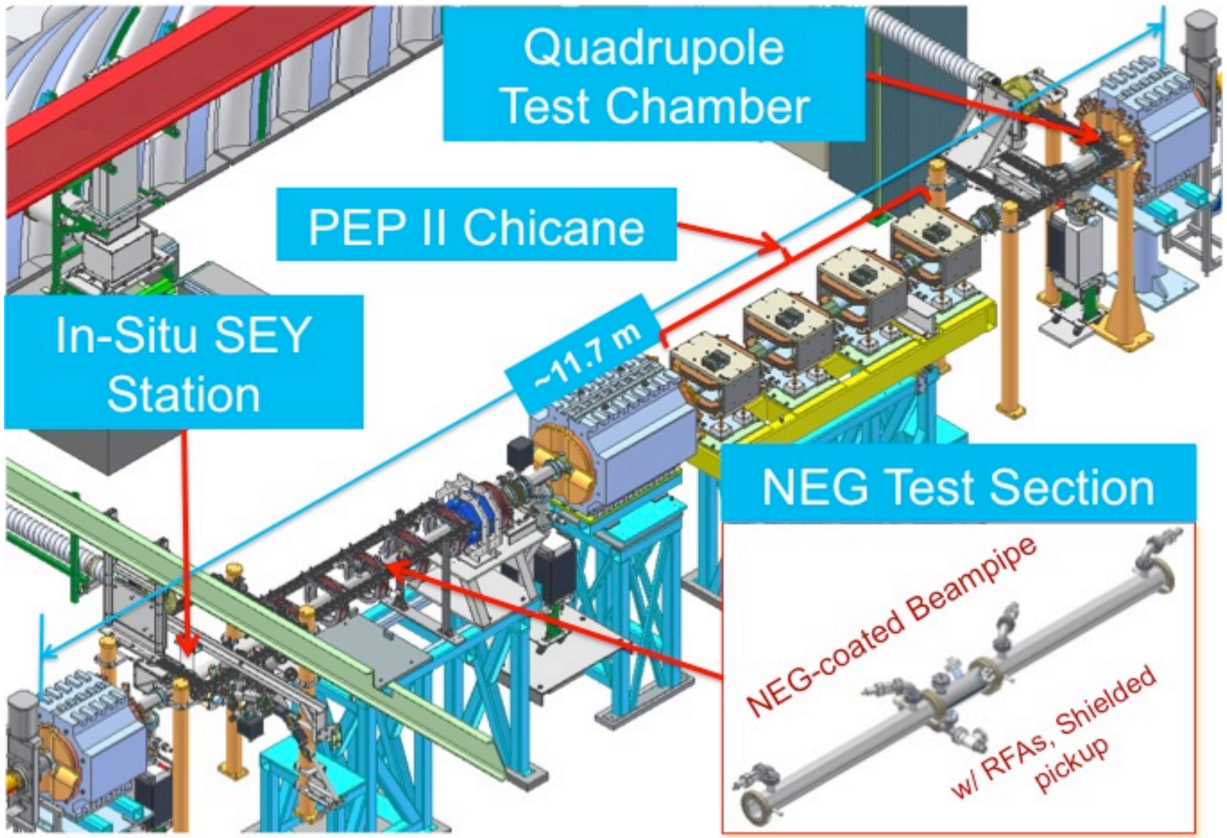
2009-2012

Ecloud model – SEY measurement

Direct measurement of secondary emission yield, including angular and energy dependence and the effect of beam processing



L3 instrumentation



- Contributions to ILC DR design - *2012*
  - Specification of vacuum chamber and mitigations for the ILC damping ring, based on CesrTA measurements
  - Electron cloud simulation codes
    - Developed in parallel to CesrTA experimental program,
    - Benchmarked against CesrTA data

  ⇒That demonstrate that with the recommended mitigations, the electron cloud density will be well below threshold for emittance blowup
  - Emittance tuning methodology developed for CesrTA is used to establish damping ring alignment and instrumentation specifications

- Intra-beam scattering
  - Tuning techniques routinely yield ~ 10-15 pm-rad vertical emittance
  - Instrumentation for measuring multi-bunch size and spectra is well suited to investigate collective effects (not just electron cloud)
  - In low emittance CesrTA, 2GeV optics, intra-beam scattering makes significant (measurable) contribution to equilibrium beam size
  - Measurements with both particle species allow us to distinguish electron cloud, ion, "other" effects

And we have investigated IBS in some detail *(2011-2012)*

Machine Studies TIme

- Nearly 240 days of dedicated studies time *(2008 – 2012)*
- Approximately one dozen lattice configurations implemented, tuned, tested
- With many dozens of "knobs" to adjust coupling, dispersion, horizontal & vertical emittance, beta …
- Experiments at 1.8, 2.1, 2.3, 3.0, 4.0, 5.3 GeV with both electrons and positrons
- Extensive measurements of ecloud, and low emittance beam physics

Today's Agenda

- Instrumentation – John Sikora
- SEY and RFA studies – Walter Hartung
- Shielded Pickup studies – Jim Crittenden
- Electron cloud beam dynamics studies – Gerry Dugan
- Emittance tuning – Jim Shanks
- Intra-beam scattering – Mike Ehrlichman
- CesrTA Collaboration – Mike Billing
- Super KEK-B ecloud mitigation and instrumentation - John Flanagan
- Future plans – D. Rubin

Thank you for your attention

Low Emittance Optics

- Exploit damping wigglers to reduce emitttance
- At 2.0 GeV, 12-1.3m long 1.9T superconducting wigglers increase radiation damping rate 2/sec to 20/second.
- If the wigglers are in a zero dispersion straight, there is an (almost) corresponding decrease in horizontal emittance.

Not quite because the wigglers themselves generate dispersion internally.

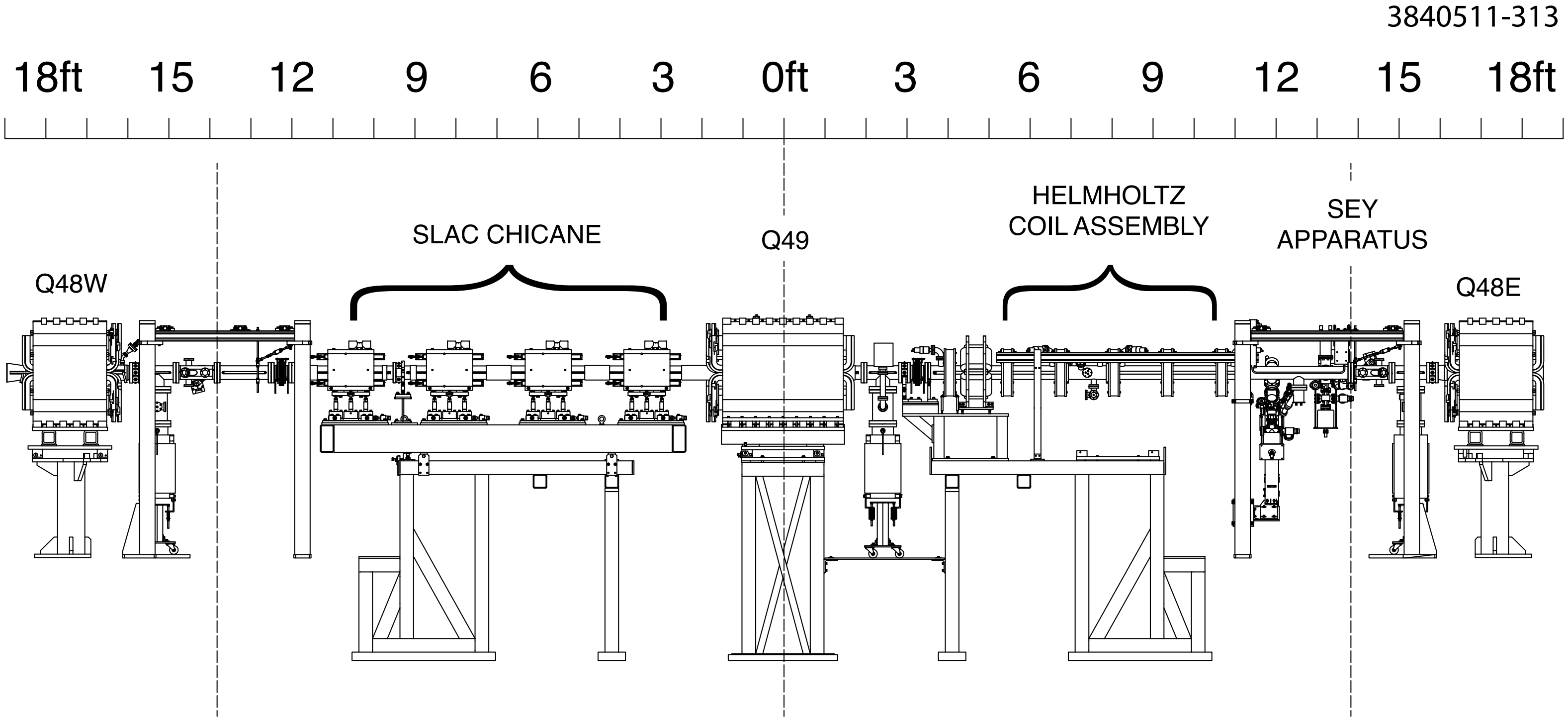
- =>2.5 - 3 nm-rad

CesrTA Program Goals

- Electron cloud
  - Mitigation
    - Material properties: SEY, QE, beam processing, durability
  - Modeling
    - Cloud growth and beam-cloud interactions
  - Dynamics
    - Cloud induced tune shift, emittance dilution, instability

  To answer the question: For a given vacuum chamber design, what is the threshold current for emittance dilution and instability from the electron cloud?
- Emittance tuning
  - To determine sensitivity of low emittance beams to electron cloud effects, in a variety of lattice configurations (beam energy, horizontal emittance etc) we need set of beam based measurements and correction techniques for routine application
  - Requires precision bpm to measure residual coupling and vertical dispersion, and beam size monitors for measuring emittance and a good understanding of systematic measurement errors
- Collective effects
  - While the electron cloud has been the principle focus of the effort, CesrTA is now well instrumented for exploring other collective effects including intr-beam scattering, fast ion instability, and limits to ultra-low emittance operation

	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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18ft
15
12
9
6
3
0ft
3
6
9
12
15
18ft
SLAC CHICANE
Q49
HELMHOLTZ
COIL ASSEMBLY
SEY
APPARATUS
Q48W
Q48E

Introduction

- Goals of the CesrTA R&D program
- Emittance tuning
- Electron cloud research
- Intra-beam scattering
- ILC positron damping ring
- CESR conversion
- Summary and plan for the day