CesrTA Electron Cloud R&D Overview

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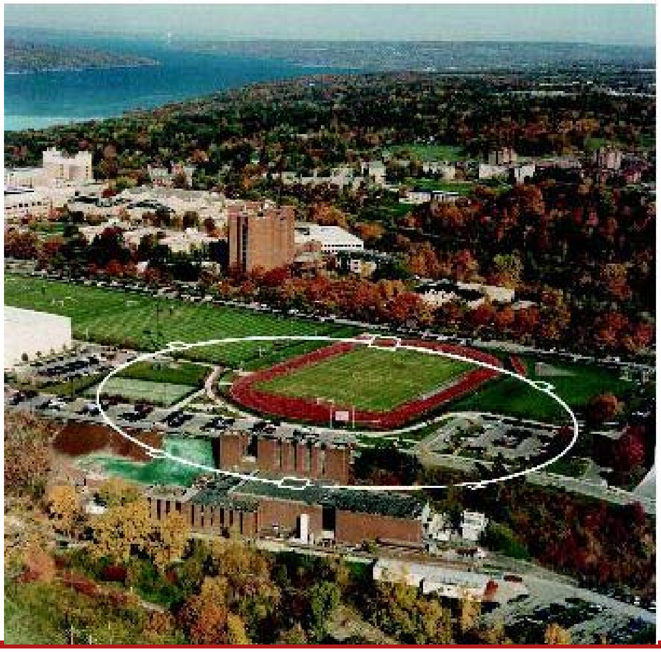


Outline

- Experimental Goals & Techniques
  - Electron Cloud Growth Studies
  - Beam Dynamics Studies
  - Measurement techniques studied to date
- Engineering Preparations
- Collaboration

CesrTA Goals I

- Electron Cloud Growth Studies
  - Provide a “laboratory” for the study of EC growth
    - Particularly in regions of greatest concern for DR : wigglers and dipoles
    - Provide suitable diagnostics to characterize the growth in all key regions
  - Characterize the performance of mitigation techniques in dipoles, quadrupoles and wigglers
  - Explore a parameter regime that approximates the ILC DR
    - Bunch train configuration
      - Bunch charge, length, spacing, emittance
      - Inter-train gaps
    - Energy
    - Investigate parameter dependence

⇨ Detailed data with which to benchmark ILC simulations

⇨ Demonstrate suitable vacuum chamber technologies

CesrTA Goals II

- Electron Cloud Induced Instability and Emittance Dilution
  - Characterize the impact of the cloud on witness bunches/trains trailing an initial EC-generating train
    - Provide sufficient local diagnostics to characterize EC growth and decay in all representative chambers
    - Control EC density and distribution around ring by witness bunch delay and/or intensity of generating train
    - Explore a range of witness bunch parameters (emittance, charge, energy etc)
    - Species-dependent studies in same chamber
      - Distinguish impedance effects

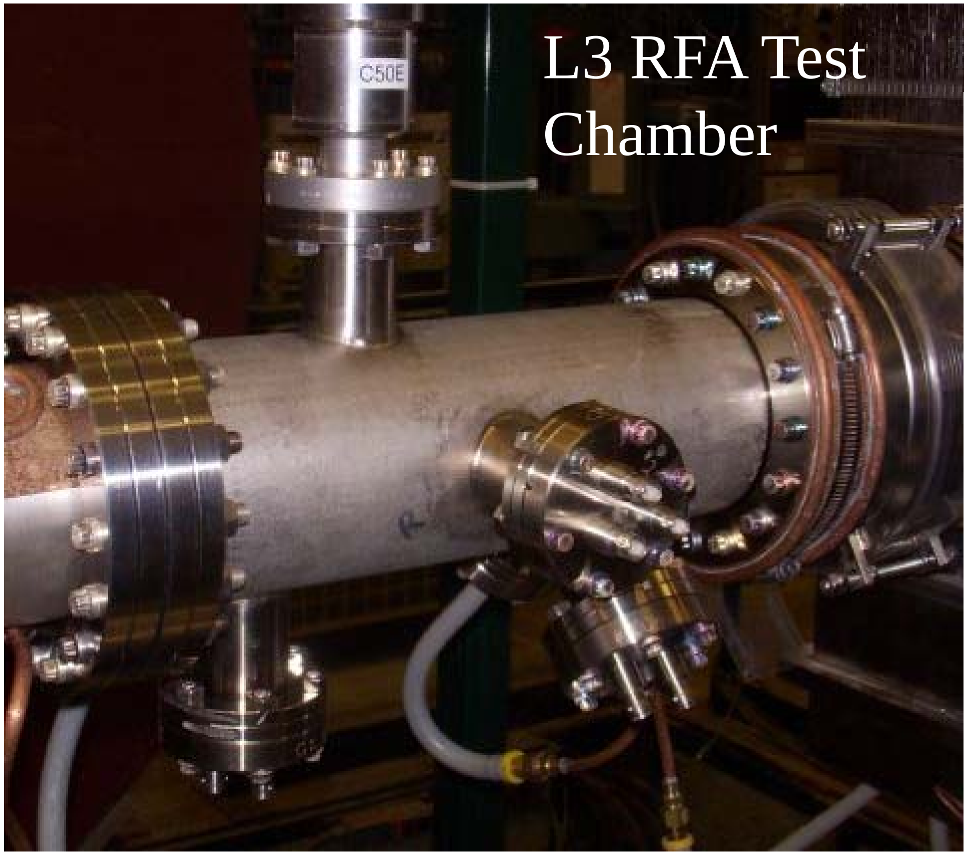
⇨ Detailed data with which to benchmark ILC simulations

CesrTA EC Program Summary

- CesrTA will provide:
  - Detailed local EC growth measurements with which to benchmark the relevant simulation codes
  - Detailed studies of EC mitigation in critical vacuum chambers
  - Beam dynamics measurements over significant parameter ranges to verify key inputs to the instability modeling codes and to benchmark their performance
- The goal of our program is to demonstrate key EC mitigation technologies, measure instabilities and emittance growth, and validate EC simulations in a regime approaching that of the ILC DR on a timescale consistent with the EDR.

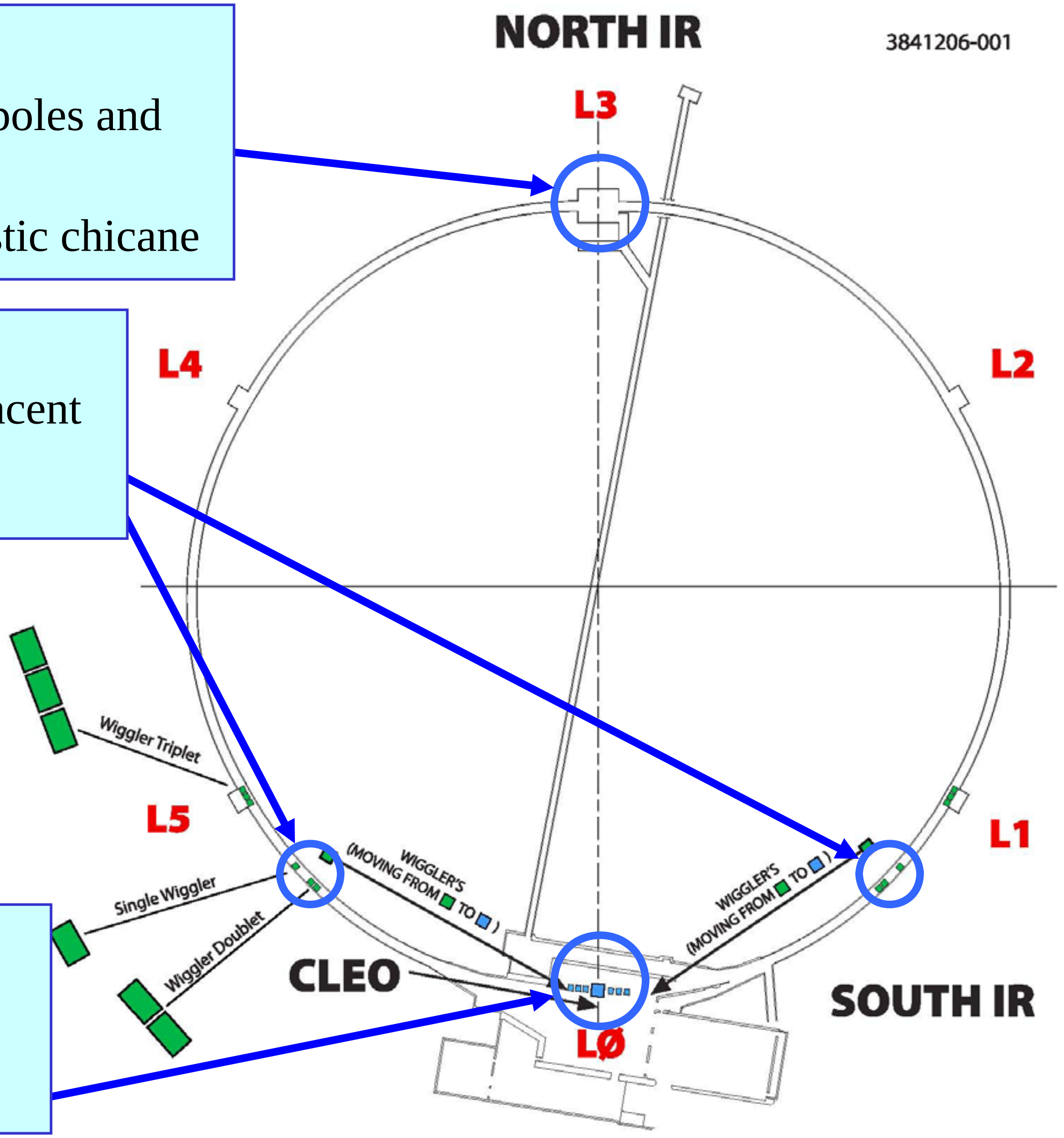
EC Growth Studies

- Install chambers with EC growth diagnostics and mitigation
  - Goal is to have implemented diagnostics in each representative chamber type by mid-2009
    - Heavy reliance on segmented Retarding Field Analyzers
  - Wiggler chambers in L0 straight w/mitigation
  - Dipole chambers in arcs w/mitigation
  - Quadrupole chambers w/mitigation
    - L0 and L3 straights
  - Drifts
    - Diagnostics adjacent to test chambers
    - Solenoids
  - Some components to be provided by collaborators



Components of the EC Growth Plan

- L3 Straight
  - Instrument large bore quadrupoles and adjacent drifts
  - Proposed location for diagnostic chicane
- Arcs where wigglers removed
  - Instrumented dipoles and adjacent drifts
- Pressure bump capability planned for major diagnostic regions
  - Impact on ECE (and FII?)
- L0 Straight
  - Instrumented wiggler straight and adjacent sections

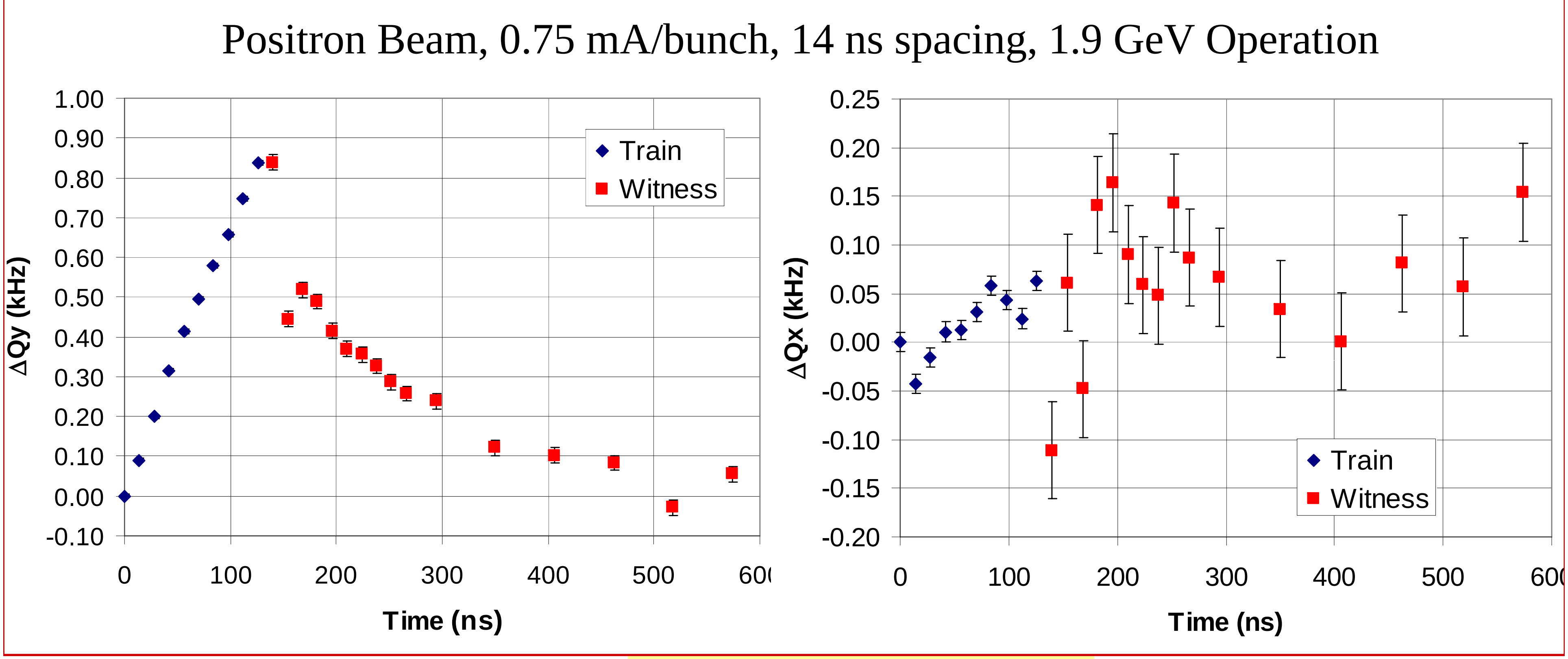


Beam Dynamics Studies

- Prerequisites
  - Instrumentation to characterize bunch trains at ultra low emittance
    - Multibunch detectors and readouts
    - High resolution beam profile monitor
  - Ring operation at ultra low emittance
- Instability Studies
  - Focus on witness bunch studies where EC density controlled by intensity of leading train and delay to witness bunches
  - Detailed study of instability thresholds and emittance growth versus the witness bunch-train parameters
  - Detailed electron-positron comparisons to help distinguish the dynamics and to evaluate EC impact on the electron beam
  - Have de-scoped plans to study fast ion effects for the electron beam as part of this program
    - Measurements of instabilities and emittance growth along electron bunch trains
    - Explore the dependence on emittance, bunch charge and spacing, train gaps and vacuum pressure

Witness Bunch Studies – e^+ Vertical Tune Shift

- Initial train of 10 bunches ➪ generate EC
- Measure tune shift and beamsize for witness bunches at various spacings
- Bunch-by-bunch, turn-by-turn beam position monitor



Error bars represent scatter observed during a sequence of measurements

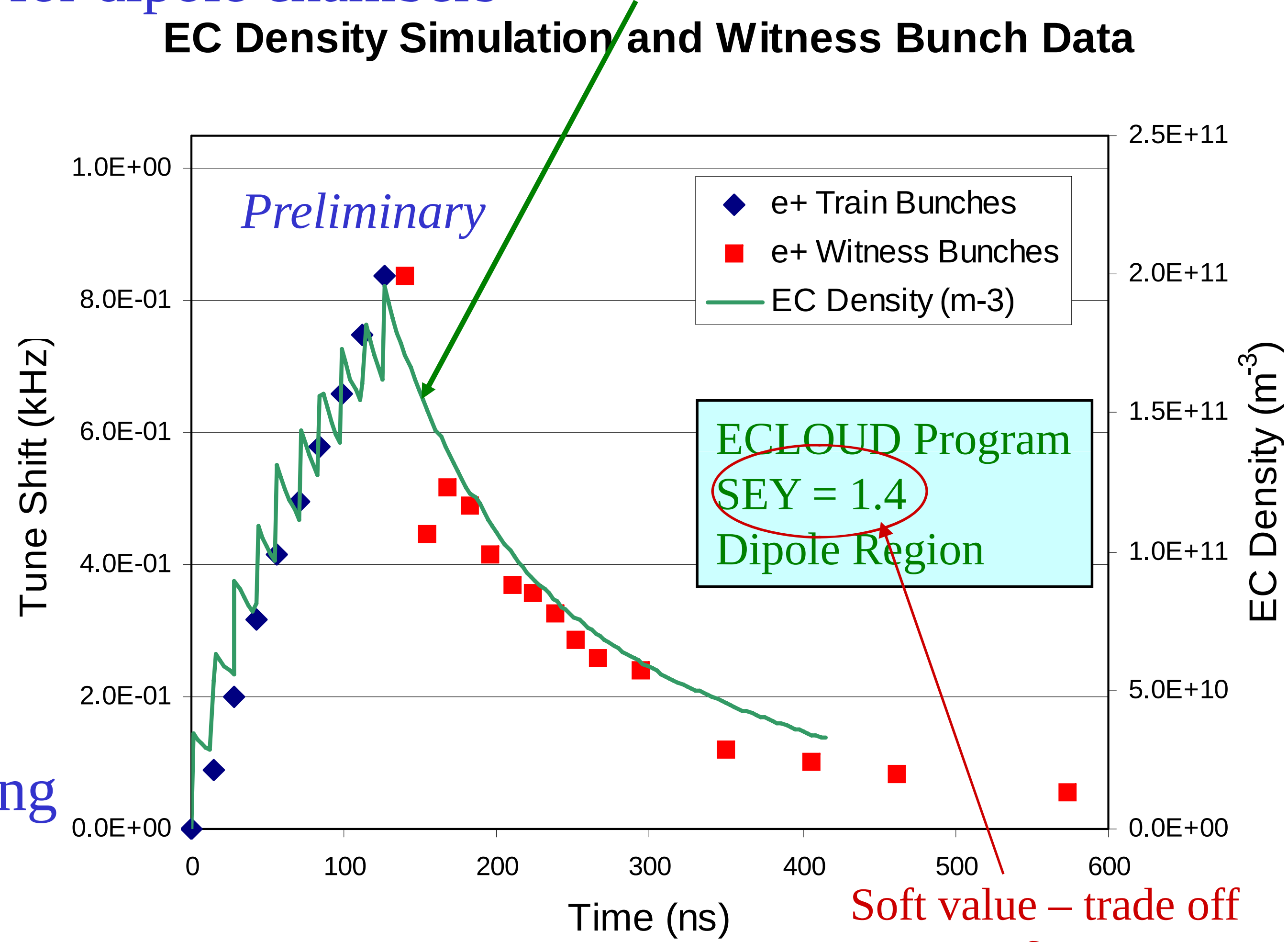
1 kHz ➪ $\Delta\nu=0.0026$
$\rho_e \sim 1.5 \times 10^{11}\ m^{-3}$
Ohmi, etal, APAC01, p.445

Preliminary

Data and Simulation

- Initial comparisons for CESR
  – Growth modeling for dipole chambers
  – Initial level of agreement is promising
- Ongoing Effort
  – Model full ring and explore parameter space
  – Limited MS opportunities during final CLEO-c run

Overlay simulated EC density on vertical tune shift data



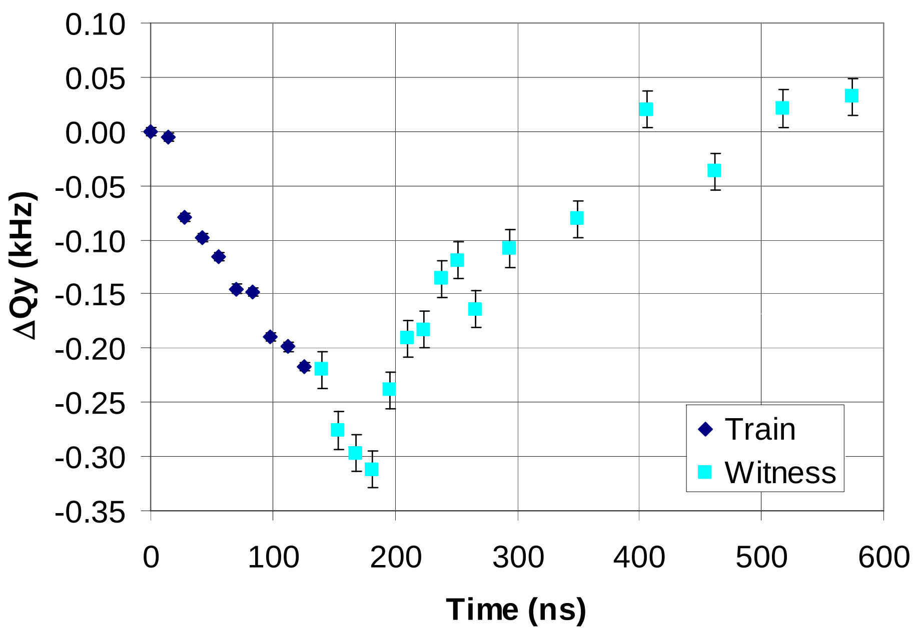
Soft value – trade off Between δ_{max} and E_{peak}

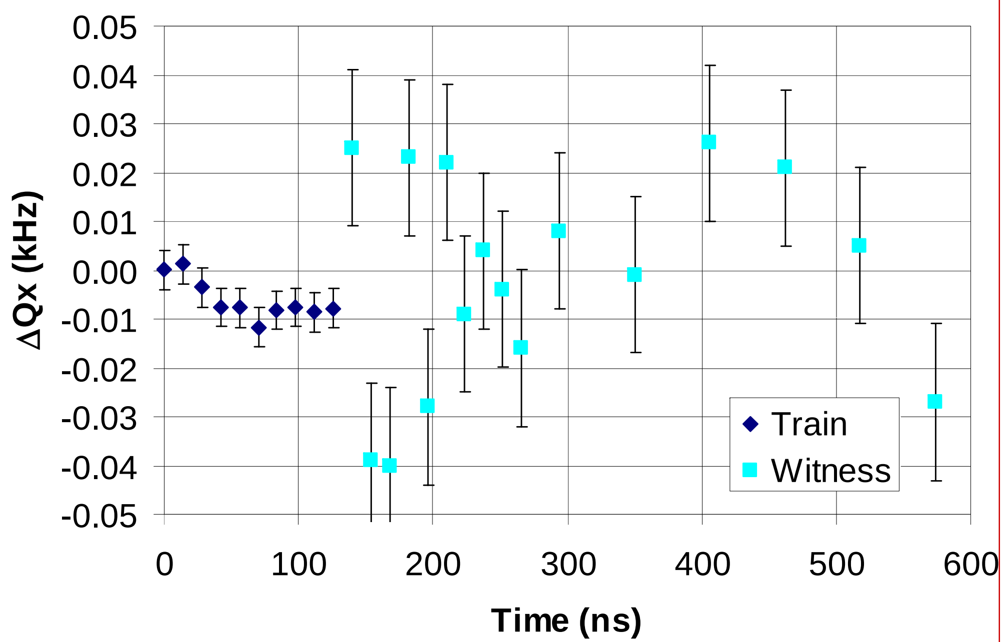
Witness Bunch Studies – e^- Vertical Tune Shift

Cornell University
Laboratory for Elementary-Particle Physics

- Same setup as for positrons
- Negative vertical tune shift and long decay consistent with EC
  - Implications for the electron DR?

Electron Beam, 0.75 mA/bunch, 14 ns spacing, 1.9 GeV Operation



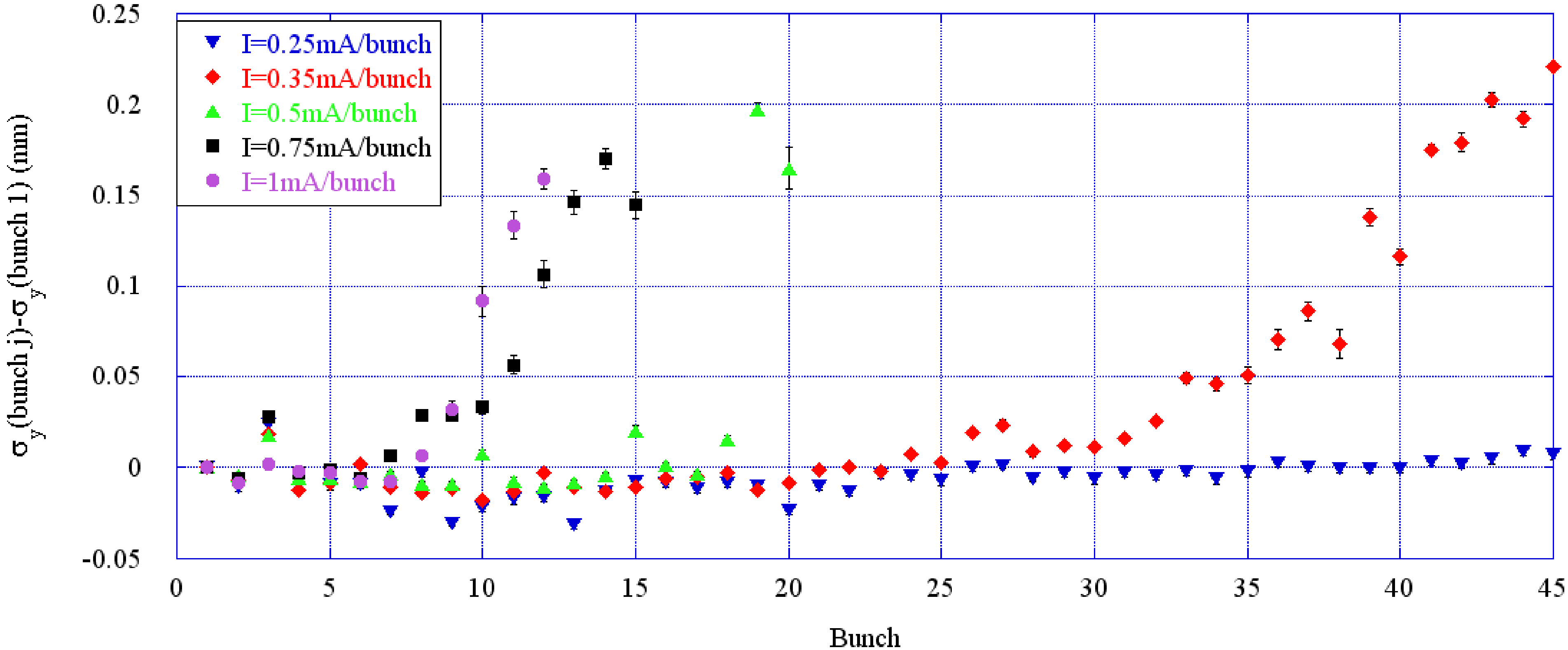


Negative vertical tune shift along train ⇨ consistent with EC
Magnitude of shift along train is ~1/4th of shift for positron beam
NOTE: Shift continues to grow for 1st 4 witness bunches!

Preliminary Results

EC Induced Instability

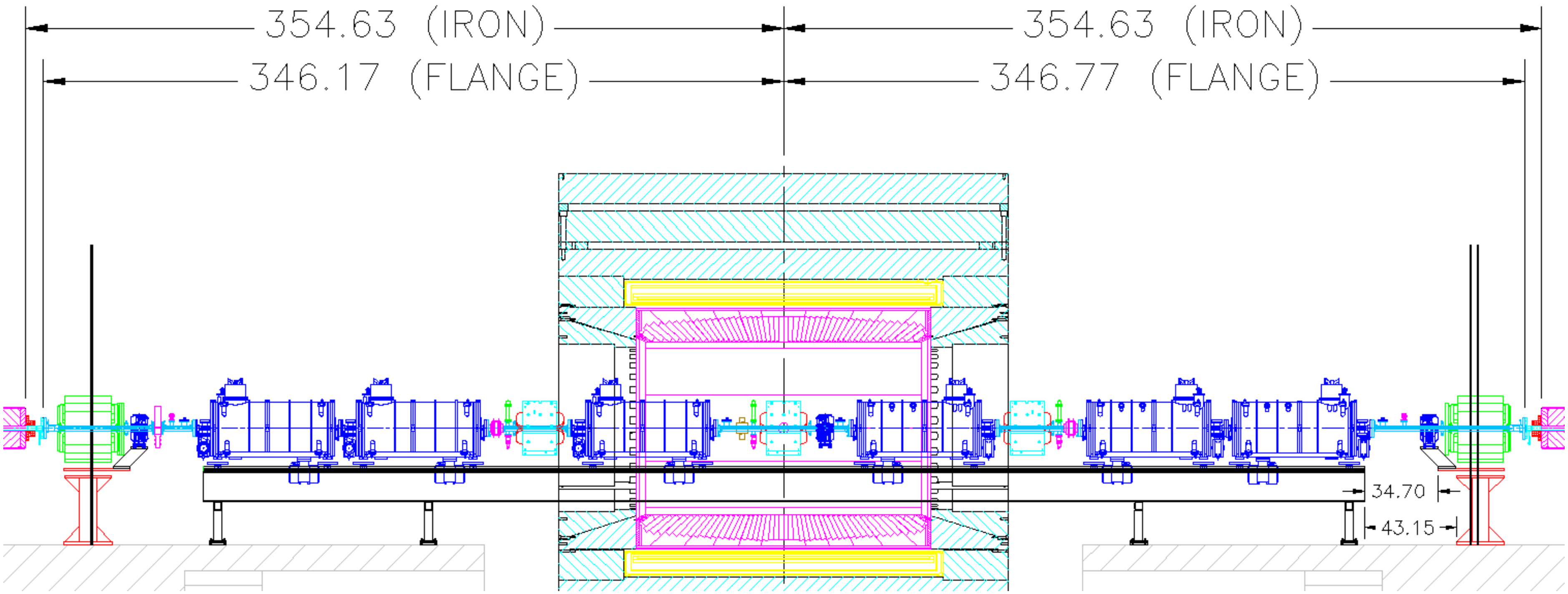
- Vertical beam size along 45 bunch e+ trains (2 GeV, 14 ns bunch spacing)
  - Range of bunch currents
  - 200 50-turn averages collected for each point
- Observe onset of instability moving forward in train with increasing bunch current – consistent with EC



Present Focus – Engineering Prep

- During final CLEO-c production run
  - Limited machine studies time
  - Main focus on engineering preparations for CesrTA downs in May and July
- Key pieces for EC program
  - L0 wiggler experimental area
  - EC diagnostics
    - Retarding Field Analysers
    - Suitable readout electronics
  - Vacuum chamber designs
  - Instrumentation preparation

L0 Wiggler Region

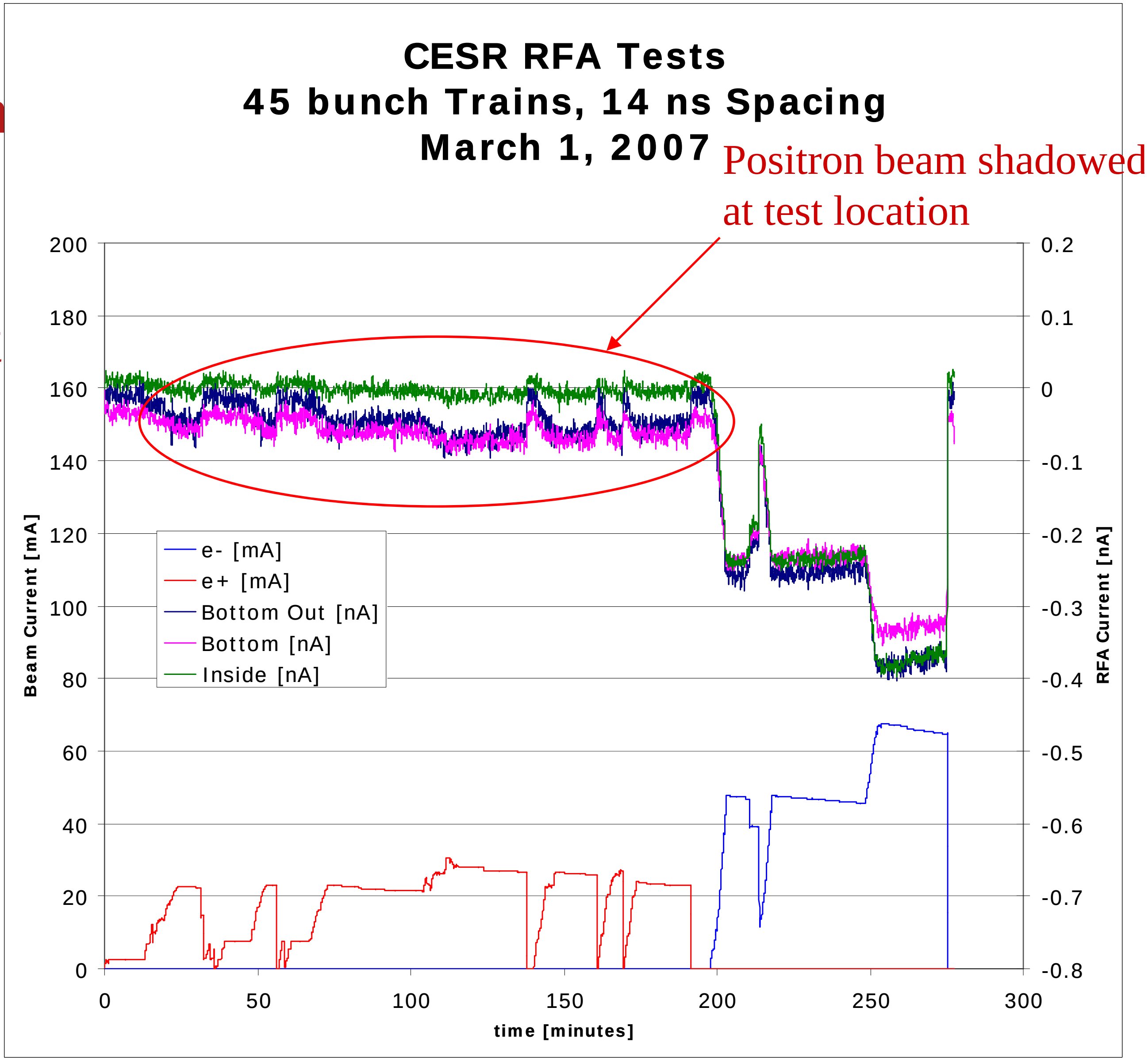


MAIN COMPONENT POSITIONS

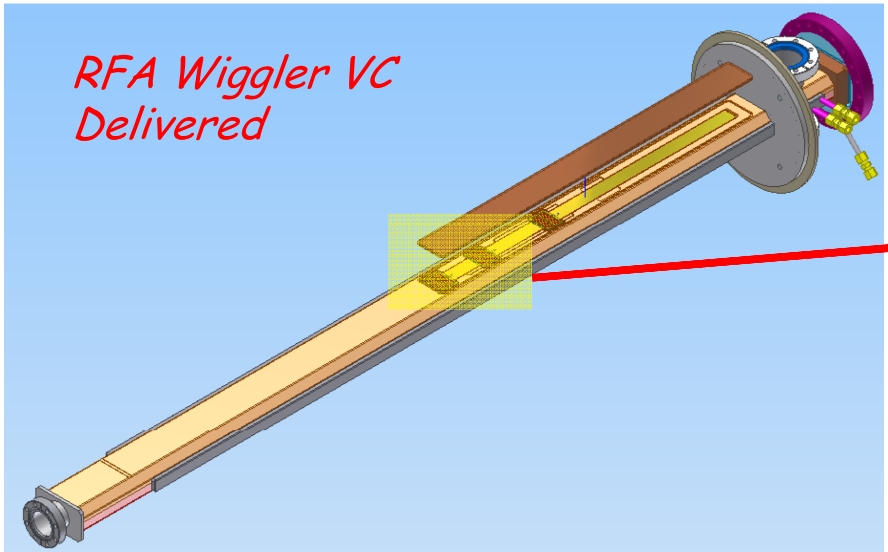
- L0 wiggler experimental region design work well underway
  - Installation during July down
  - Heavily instrumented throughout with vacuum diagnostics
  - Targeting full design review this month followed by full scale production
- Note: Part of CLEO will remain in place
  - At present unable to remove full detector
  - Time savings

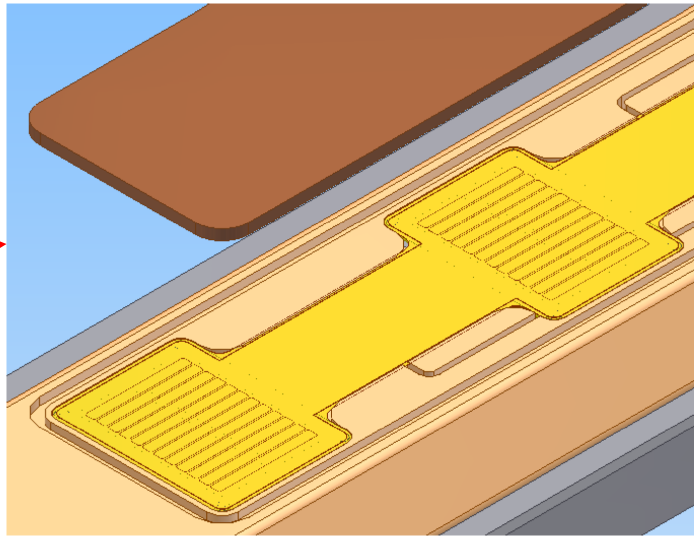
Retarding Field Analysers

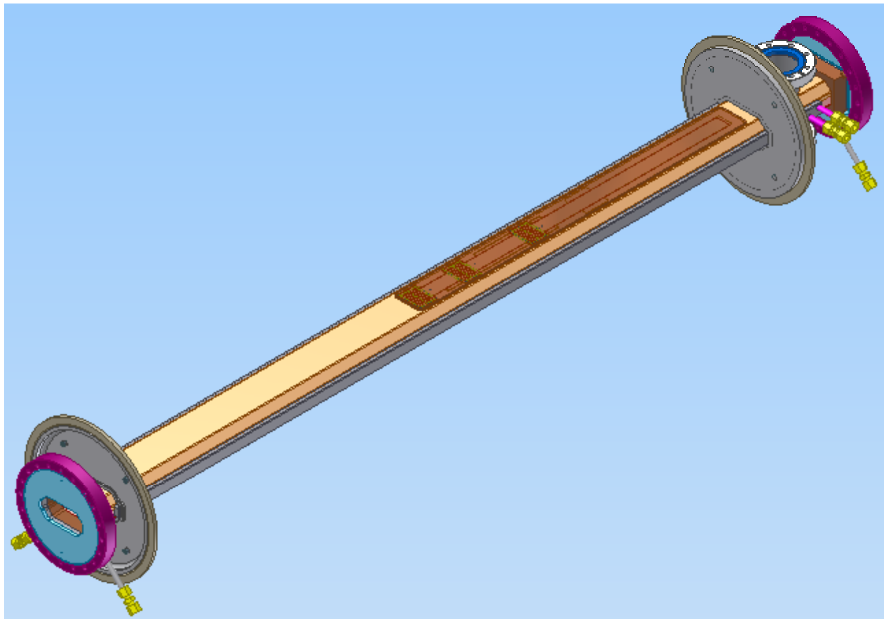
- Beam tests have continued through CLEO-c conclusion
- Upgraded readout electronics for large channel count RFAs are now ready for production
- Thin RFA structure performing well



Chambers with Thin RFAs

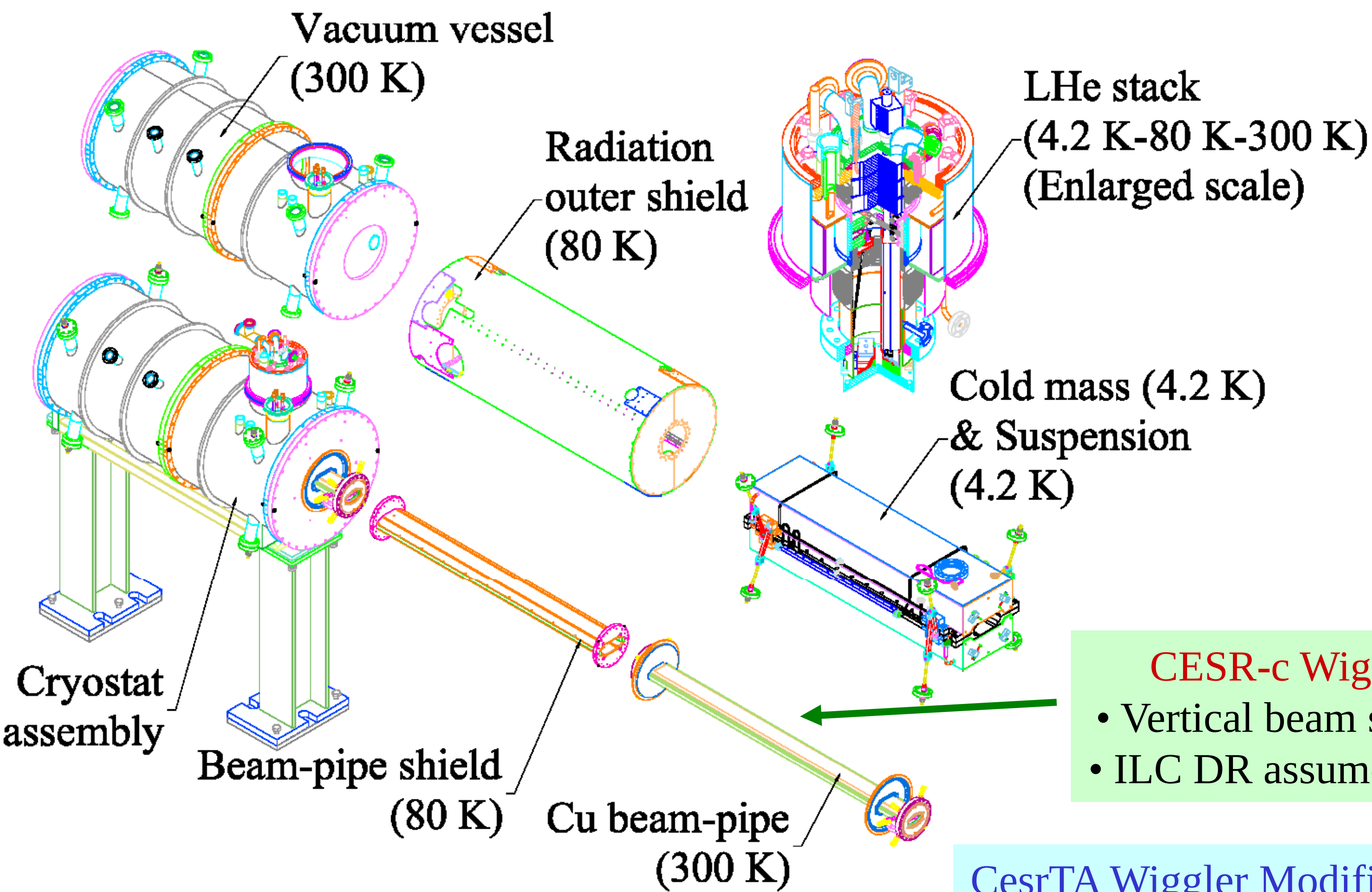






- Loss of US collaborators impacted development heavily
  - Cornell has picked up detailed design
  - Now ready for final design review
  - Working with KEK to see whether construction support might be available

CesrTA Vacuum Chambers



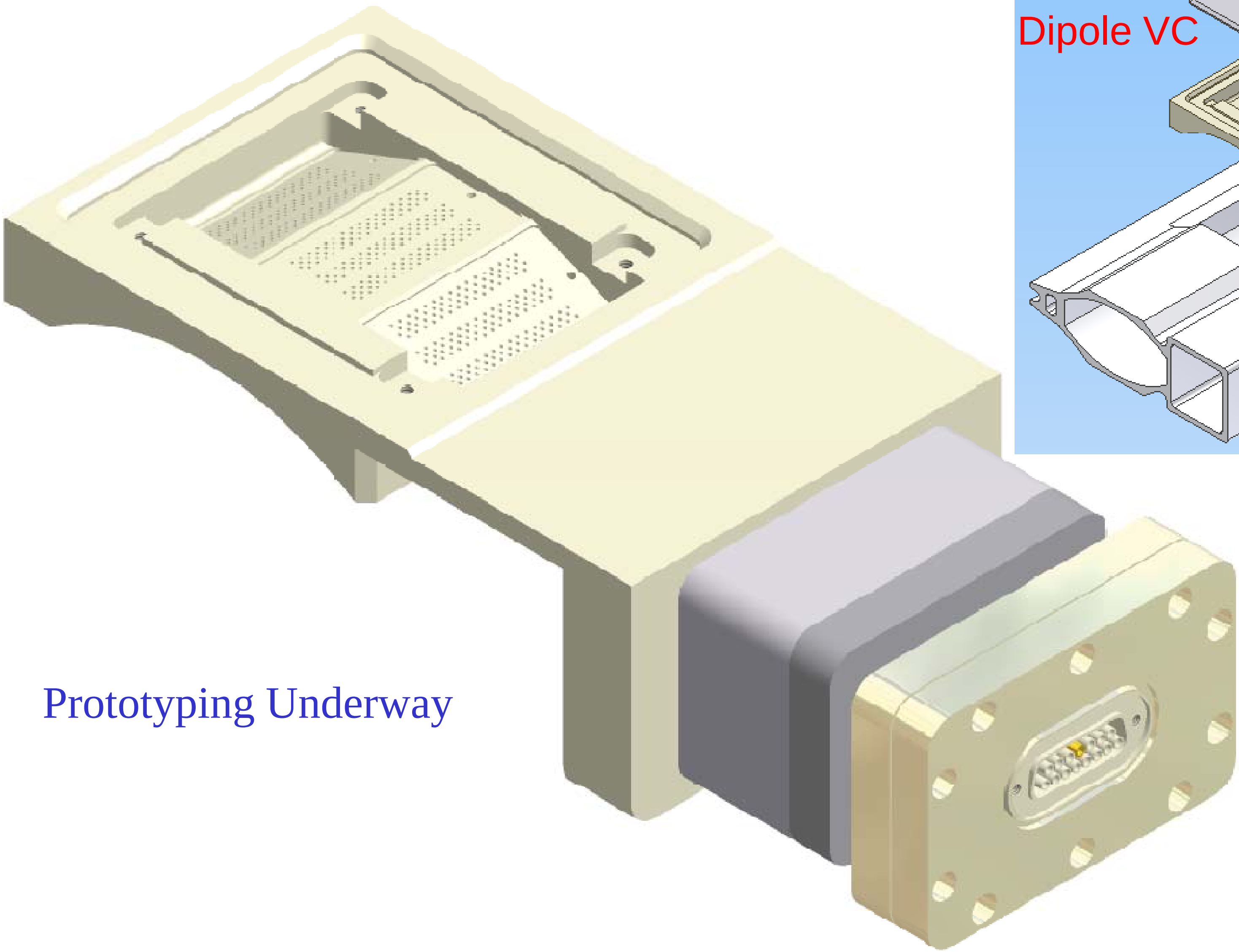
CESR-c Wiggler Chambers

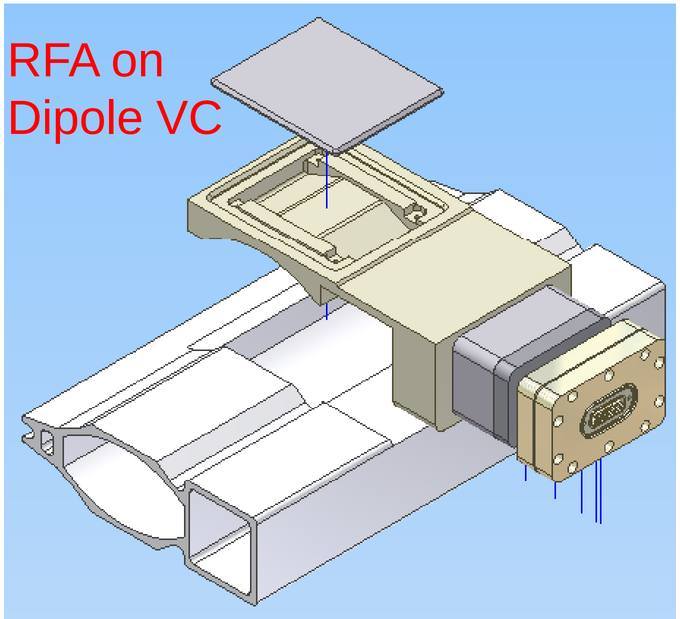
- Vertical beam stay-clear: 50mm
- ILC DR assumes 46mm dia. pipe

CesrTA Wiggler Modifications

- Remove Cu beam-pipe
  - Replace with beam-pipe having EC suppression and diagnostics

CESR Dipole Chamber RFA





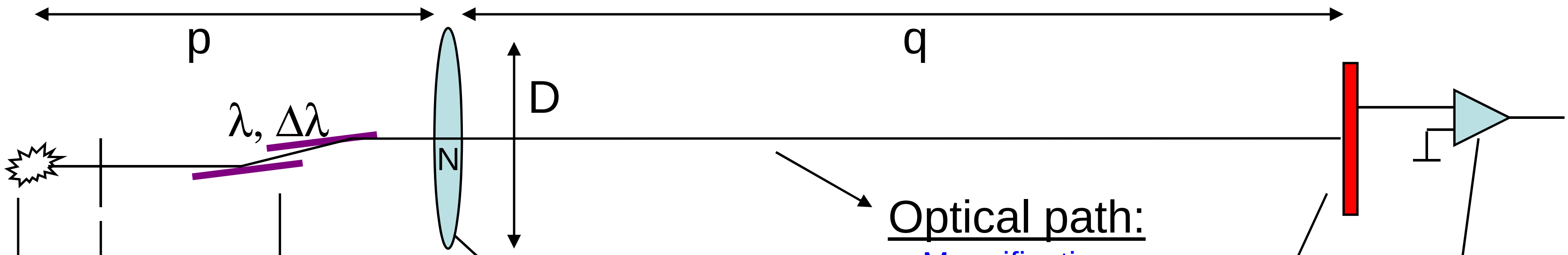
Prototyping Underway

X-Ray Beam Size Monitor for CESRTA

Bunch-by-bunch measurements of beam profile for fast emittance determination

- Image individual bunches spaced by 4ns.
- Transverse resolution << 10~15μm beam size
- Non-destructive measurement.
- Flexible operation.
- Start simple, allow various upgrade paths.

Features that affect performance



Optical path:
Magnification
Backgrounds

Zone Plate:
Diffraction - finite D
Chromatic aberration
Transparency

Detector:
Pixel size
Absorption
Carrier mobility

Monochromator:
Surface quality - flatness
λ, λ
Bandwidth Δλ/λ
Reflectivity

Readout:
Equivalent noise charge
Bandwidth

Vacuum window:
Absorption
Uniformity

Source:
Diffraction from source of known angular divergence
Bunch current, critical energy, etc

Color coding:
Photon yield
Resolution
Distortions
Speed

Interrelationships and Optimization

- $D^2 = 4N\lambda f$ Fresnel Criterion
- $\sigma = \frac{\lambda\gamma}{2}\sqrt{\frac{3\lambda_c}{\lambda}}$ Diffraction limited resolution (SR fan)
- $\frac{D}{p} \geq \frac{1}{\gamma}$ Objective lens encompasses all of SR fan
- $\frac{1}{N} = \frac{\Delta\lambda}{\lambda}$ Match bandwidth of monochromator
- $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ Image-object-focal length relation
- $M = \frac{q}{p}$ Magnification of one-lens system
- $M = \Delta x / \sigma_y$ Set magnification for optimal sampling in pixel detector

7 Equations in 9 unknowns. optimize over remaining variables: source-lens distance (p), and x-ray wavelength (λ).

Parameters for CESRTA xray Beam Size Monitor

Beam and Radiation Parameters

Parameter	Value	Units
Beam energy	2.0	GeV
Bunch current	1.0	mA
Bunch Charge	1.6×10^{10}	
Vertical size (σ_y)	$10 \sim 15$	μm
Lorentz γ	3914	
Dipole bend radius	31.654	m
Critical energy	0.564	keV
Critical wavelength	2.2	nm
Photon energy	2.0	keV

Optical System Parameters

Parameter	Value	Units
Source to lens distance	4.0	m
Lens to detector distance	12.0	m
Height of synch rad fan at lens	0.63	mm
Image magnification factor, M	3.0	
Detector Pixel Size	25	μm
Lens diameter	1.02	mm
Number of Fresnel zones	140	
Focal length	3.0	m
Transparency	0.18	
Multilayer mirror bandwidth	0.010	
Multilayer reflectivity	0.36	
Overall transmission factor	0.023	
Energy transmitted, per bunch	1.04	MeV
Ionization charge in detector	39.9	fC
Resolution: detector pixellation	2.4	μm
diffraction at source	1.3	μm
chromatic aberration	0.5	μm
Fresnel zone plate PSF	0.3	μm
Total resolution	2.8	μm
Number of photons on detector	521	

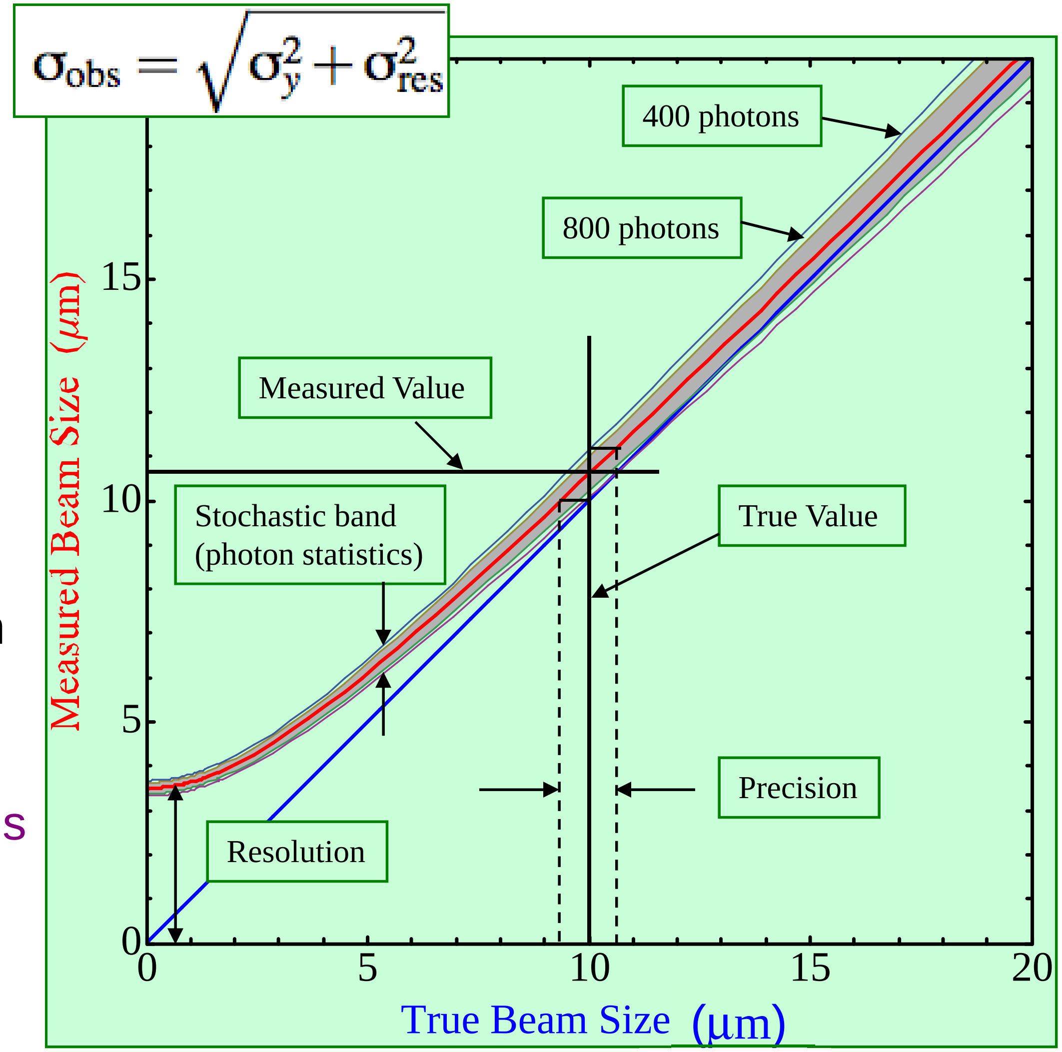
Sidebar: Resolution, Precision, and Photon Statistics

- Optical transfer function is characterized by a resolution (point spread function). This is a *fixed property* of the optical system.

  For CESRTA design, it is 2-3μm. (Figure at right assumes 3.5 μm)

- Photon statistics (and electronic noise, if applicable) fluctuate from snapshot to snapshot.

- The *measurement precision* of this system is determined by the stochastic element, not the fixed correction*.



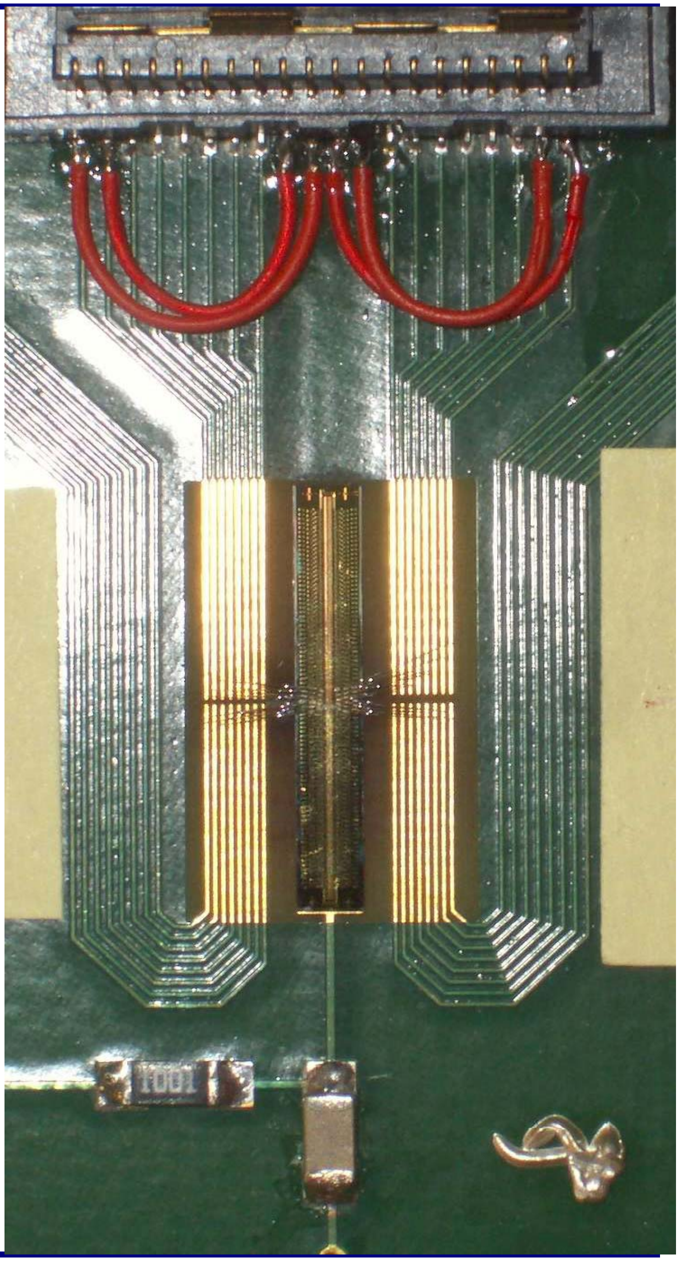
* Residual uncertainty in the optical resolution will appear as a systematic error

Sensors

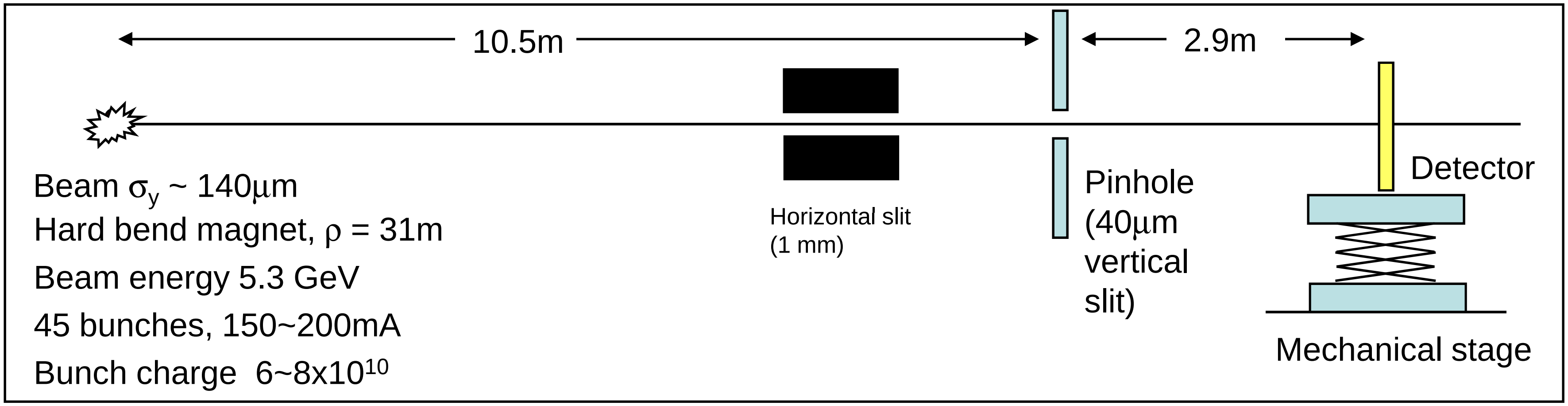
- GaAs/InGaAs 1-dim photodiode array
  - 512 diodes, 25µm x 500µm
  - Hamamatsu G9494-512D
  - Off-the-shelf
- Why GaAs?
  - High carrier mobility (8400 cm^2/Vs) & drift velocity (200 µm/ns)
  - High Z, high density
    - short abs length
    - ~ 1µm at 2.5keV

  } Fast: << 1ns

  - Room temperature ops.
  - Good radiation hardness
  - Commodity parts available;
    - IR receivers for 10Gbps optical ethernet



Prototype study, in CHESS (Slide 1)



Single GaAs photodiode (46µm dia)

Optics: pinhole. (40µm vertical slit)

White beam (no monochromator)

Data acquisition: *72MHz (14ns interval); 12 bit ADC.*

Mechanically scanned vertically and horizontally through the beam -- "synthetic aperture camera"

Single bunch, single pass data - no averaging over turns.

Prototype study, in CHESS (Slide 2)

Single bunch, single pass snapshots

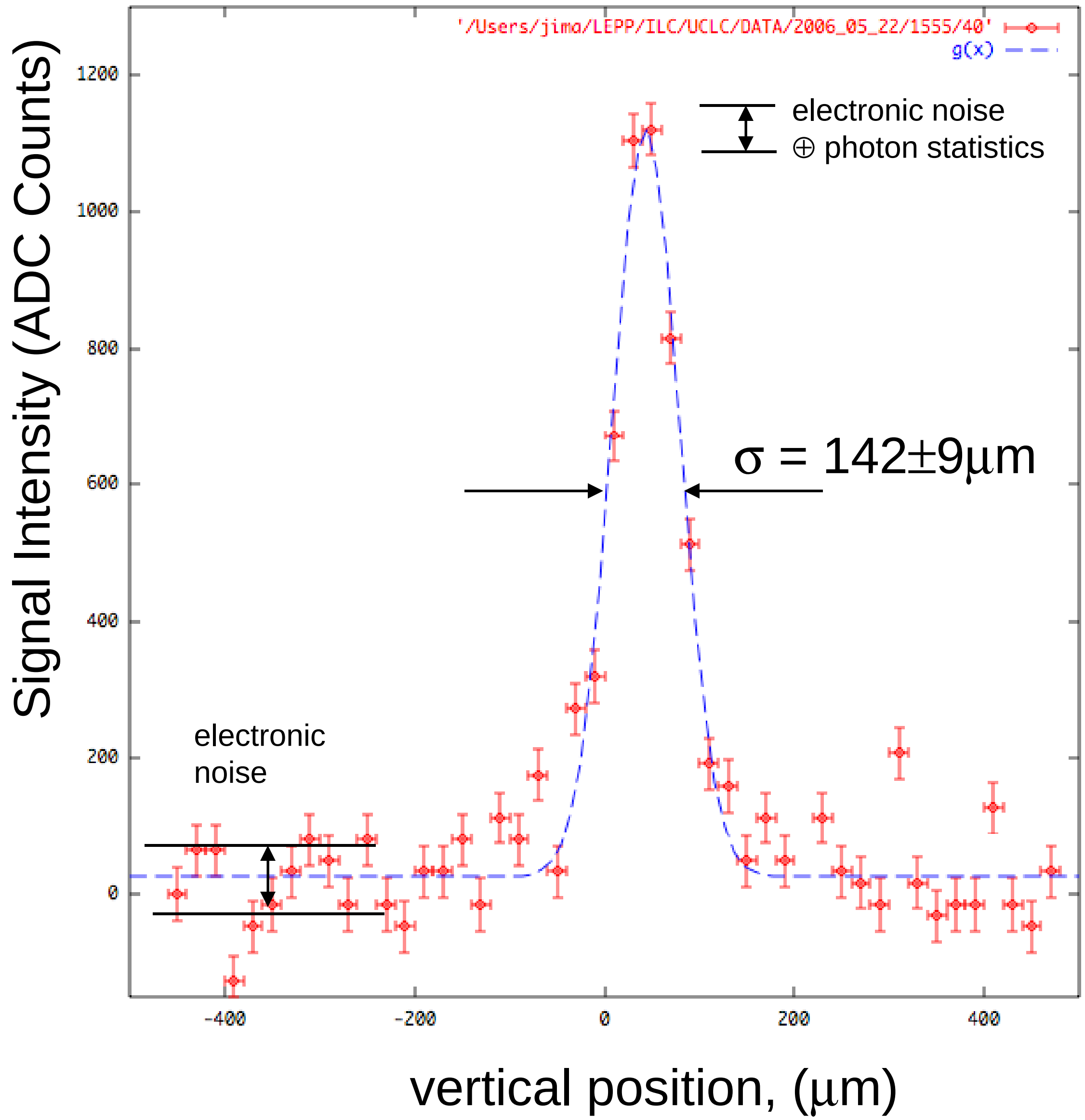
Result of vertical beam scan
(single pixel)

Measured:
- $S/N_e = 27$
- photons per bunch is ~400
- Signal risetime << 300ps
- Observed beam size 142±9µm (expect ~150)

Calculated:
- Energy abs'd/bunch 6.0 MeV
- Ionization per bunch 230 fC
- Averge photon energy: 13keV

Radiation damage post-study: 700GRad over 4 days, diode current dropped x2.

(Comment: electronic noise was *not* optimized!)



Prototype study, in CHESS (Slide 3)

Beam size (σ_y) measurement.

Finite optical resolution:

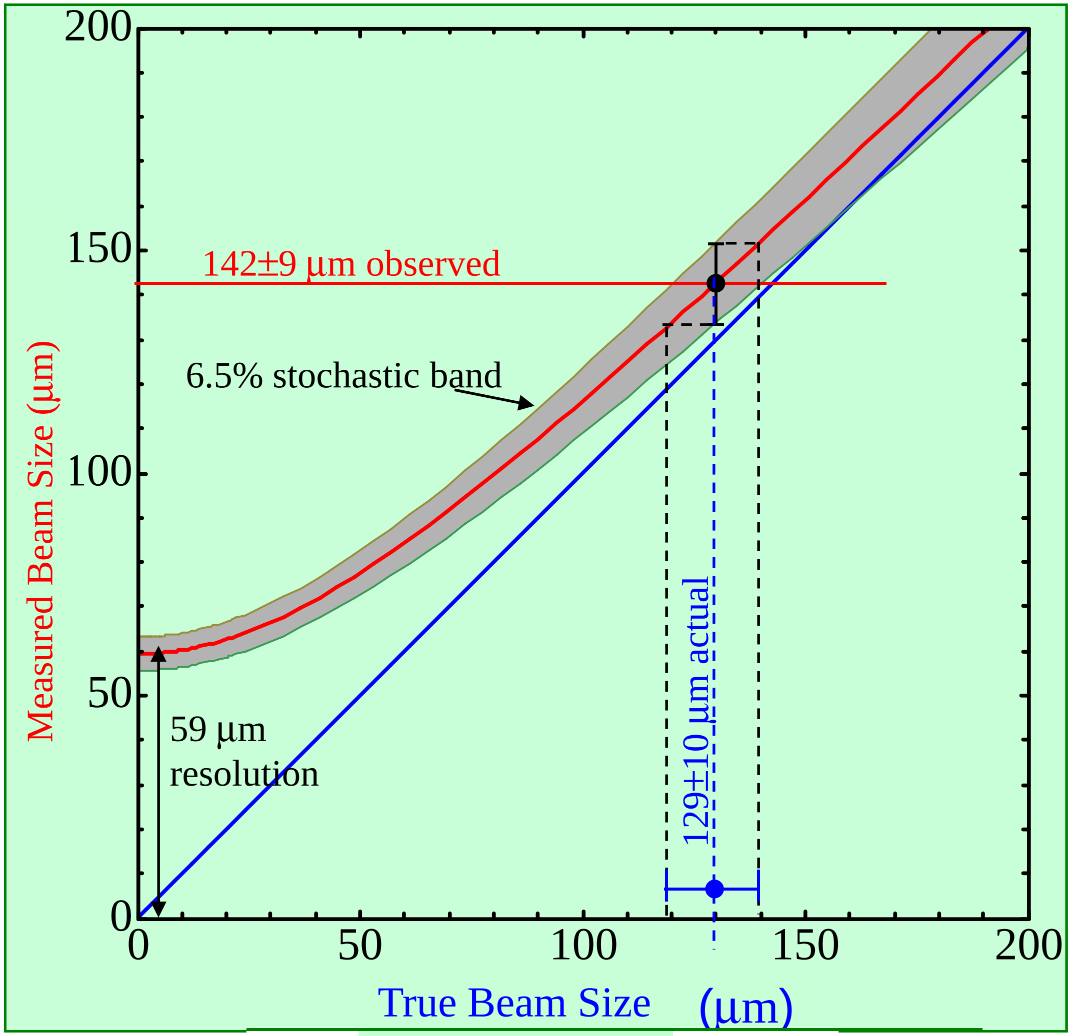
Fixed offset in σ_y measurement $\rightarrow$ fixed correction.

59µm here.

Finite photon statistics:

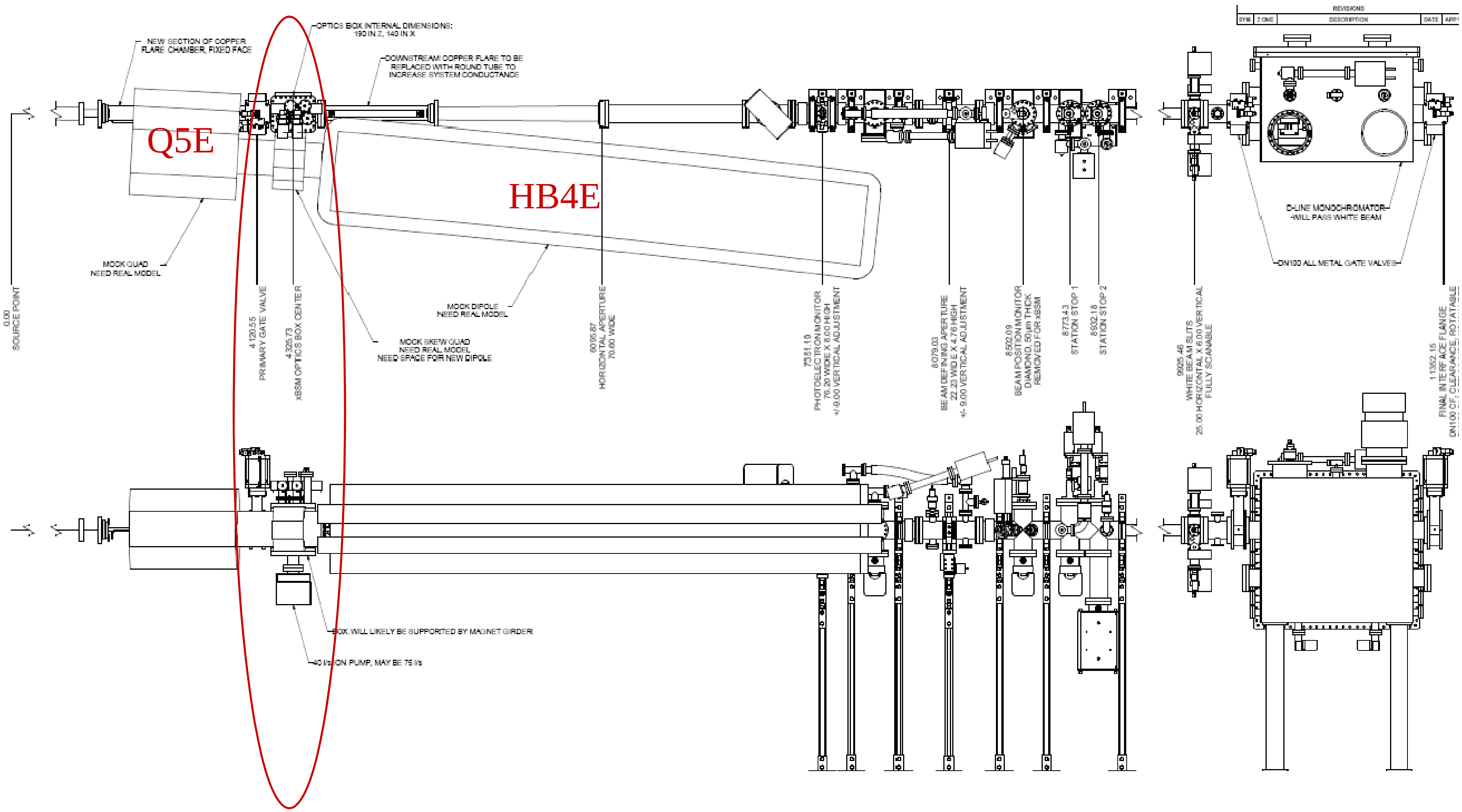
Stochastic error from one measurement to the next.

6.5% here*



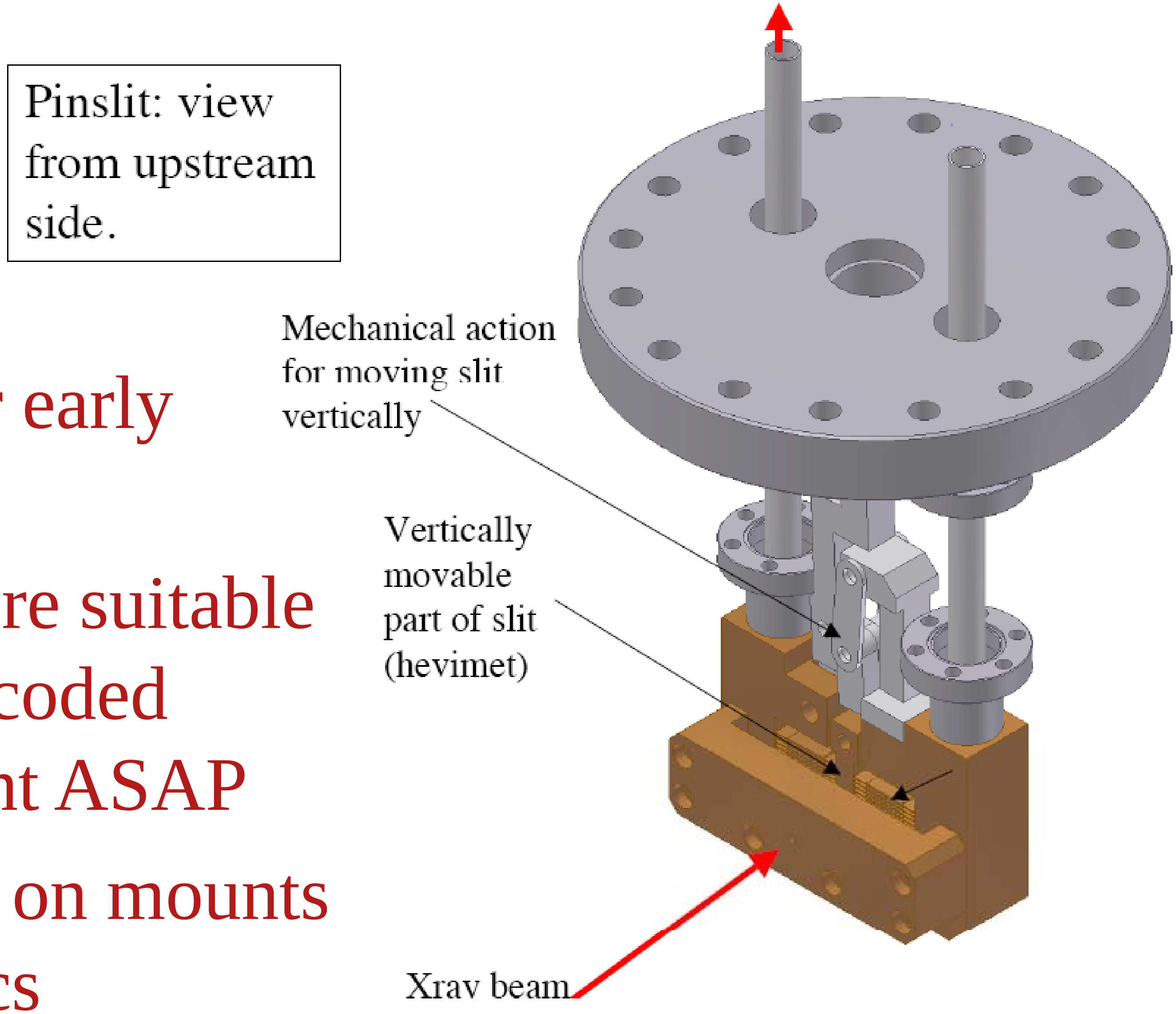
*includes electronic noise

xBSM Positron Optics Line



Upstream Optics Box for xBSM

Slit Mounting Structure



- Slit mount for early studies
- Want to explore suitable assembly for coded aperture mount ASAP
- Also working on mounts for other optics

Collaborator Issues

- As stated previously, a key part of the CesrTA proposal was collaborator involvement
- The following slide is taken verbatim from the Joint NSF/DOE Review of the CesrTA proposal last July…

Dealing with Challenges and Risks

- Experimental program is designed to deal with discoveries and changes in direction through the course of the R&D
  - Schedule allows for re-evaluation of key physics issues and technologies as the program proceeds
    - Course corrections are expected along the way
    - This makes the program robust against short term technical and/or physics surprises
  - Technology down-selects can be employed as data is obtained to optimize the program along the way
  - Program relies heavily on support from collaborators
- Key technical drivers for the program are:
  - Electron Cloud Growth Studies
    - Chamber construction
    - Implementation of diagnostics
  - Beam Dynamics Studies
    - Issues affecting our ability to achieve ultra low emittance (see later talks)
    - Issues affecting our implementation of high resolution emittance diagnostics (see later talks)
- Key assets
  - A well-understood machine
  - An experienced accelerator staff
  - A highly expert group of collaborators

Taken from
Joint NSF/DOE Review
of the CesrTA Proposal
July, 2007

Collaboration Issues

- Present funding situation has several major impacts
  - Plans for providing experimental hardware must be revamped
    - Wiggler chamber design and fabrication
    - Support for coating tests
  - Loss of experimentalists to participate in CesrTA running
    - Revamping run plan to accommodate a smaller number of experimenters
    - Preserving ~240 running days during program
  - Loss of simulation and analysis support
    - In US, base program support may cover portions of this
    - Exploring Project X collaboration
    - Hope to work closely with colleagues from KEK, CERN and elsewhere
- Presently working to fill remaining gaps

Conclusion

- CESR offers
  - Damping wigglers meeting the ILC specification
  - Flexible energy and emittance range for experimental studies
  - Experimental studies with electrons and positrons in the identical environment
  - Experienced staff and well-developed tools
- The CesrTA program will provide
  - Detailed studies of electron cloud growth and validation of mitigation techniques in time for the ILC TDP-I
  - Beam dynamics results on electron cloud in time for the ILC TDP-I
  - Assurance that the ILC DR design is feasible by benchmarking our simulations with data in the relevant parameter regime