Electron Cloud Studies at CESR-TA

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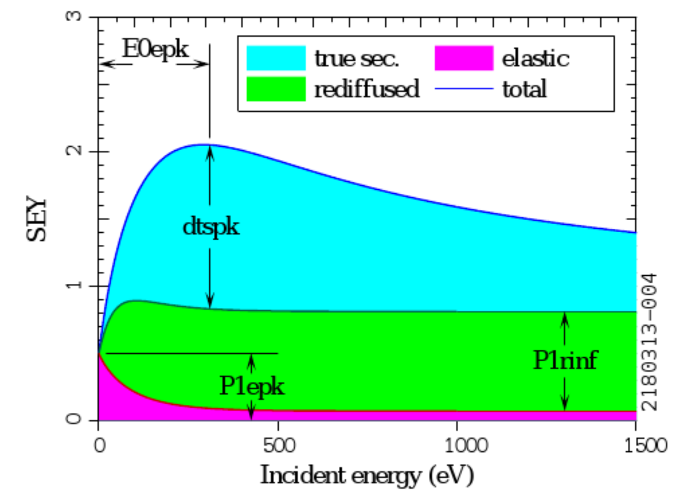
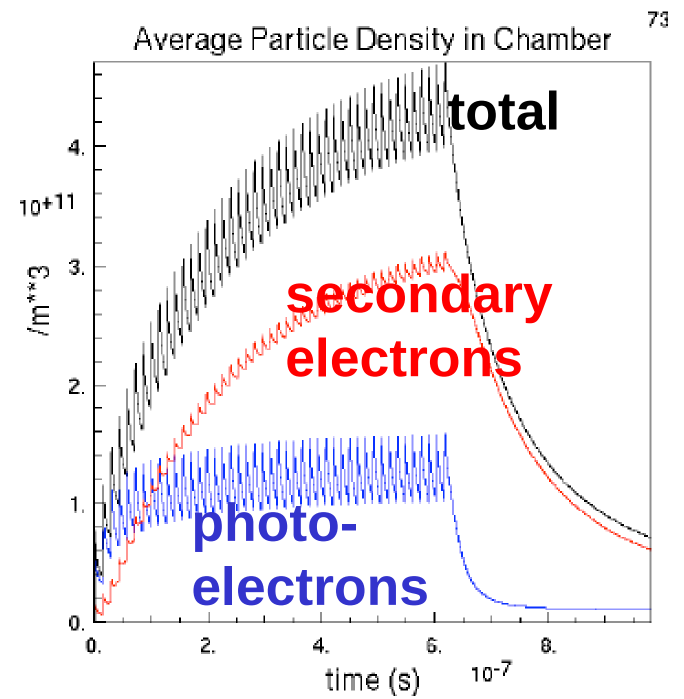
Outline

- Overview
  - Electron cloud
  - CESR-TA program
- Electron cloud detectors
  - Retarding field analyzers
  - Shielded button electrodes
  - Time resolved RFAs
  - Microwave measurements
- Selected results
  - Mitigation comparisons
  - Detailed cloud modeling
  - Time resolved dipole measurements
  - Cloud trapping in quadrupole

What is electron cloud?

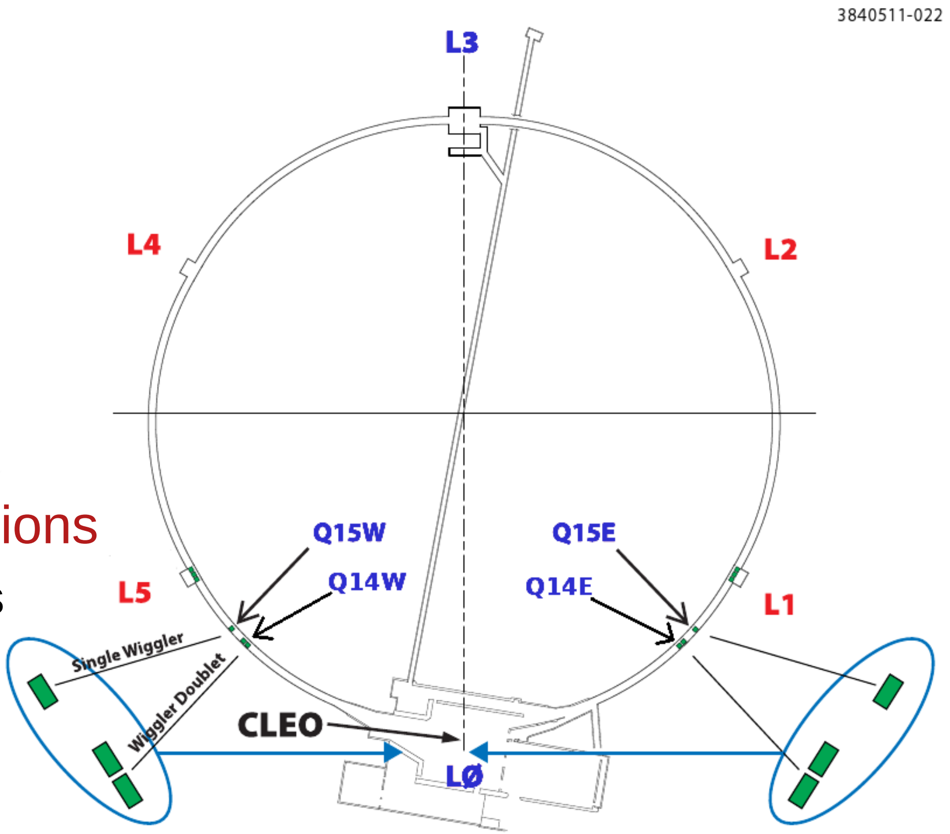
- Buildup of low energy electrons inside vacuum chamber
  - Typical density ~ 10^{11} - 10^{13} e- / m^3
  - Typical energy ~< 200 eV
- Seeded by photoelectrons from synchrotron radiation
  - Or ionization of residual gas, beam particle loss, etc
- Additional electrons from secondary emission
  - Determined by secondary yield emission (SEY) curve
  - Usually low energy (< 20 eV)
- Electrons gain energy from beam kicks
  - If average SEY > 1, exponential cloud growth
- Cloud growth ultimately limited by space charge
- Decays after bunch passage
  - Decay time ~100 ns
- Why study electron cloud?
  - Causes a wide variety of undesirable effects
    - Tune shifts, emittance growth, instabilities, heat load, beam loss…
  - Especially bad for high current, low emittance, positively charged beams
  - Effects observed at many facilities
    - KEK PF, KEKB, PEP-II, PSR, APS, DAFNE…
    - LHC: instability observed at 25 ns operation
  - Concern for future machines
    - LHC upgrade, ILC/CLIC DR, light sources(?)

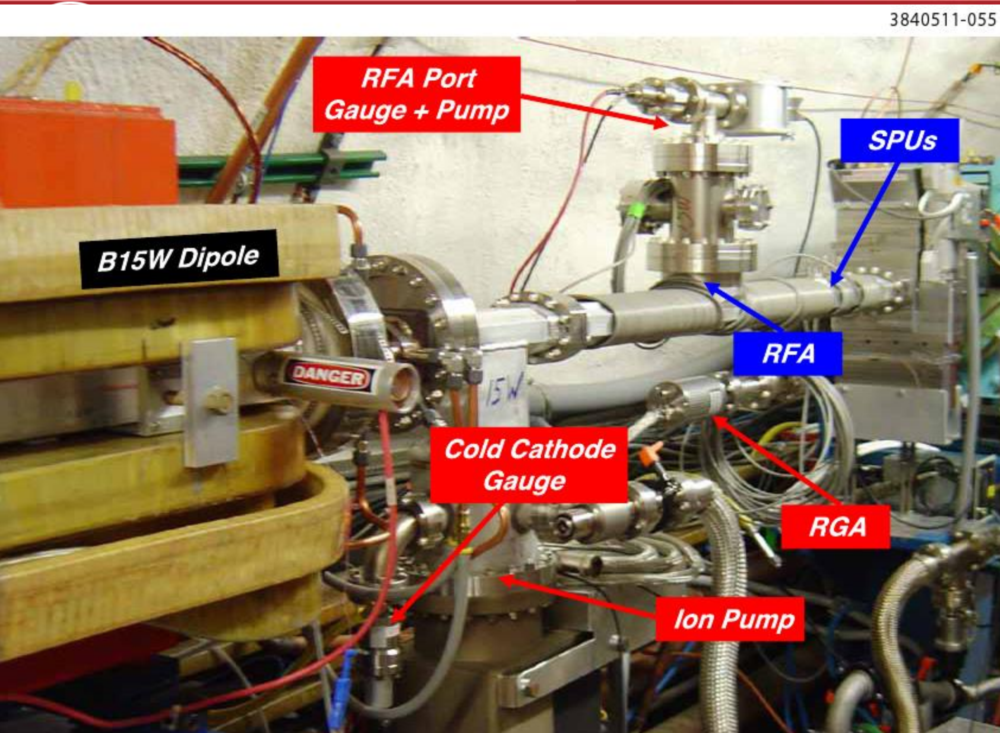


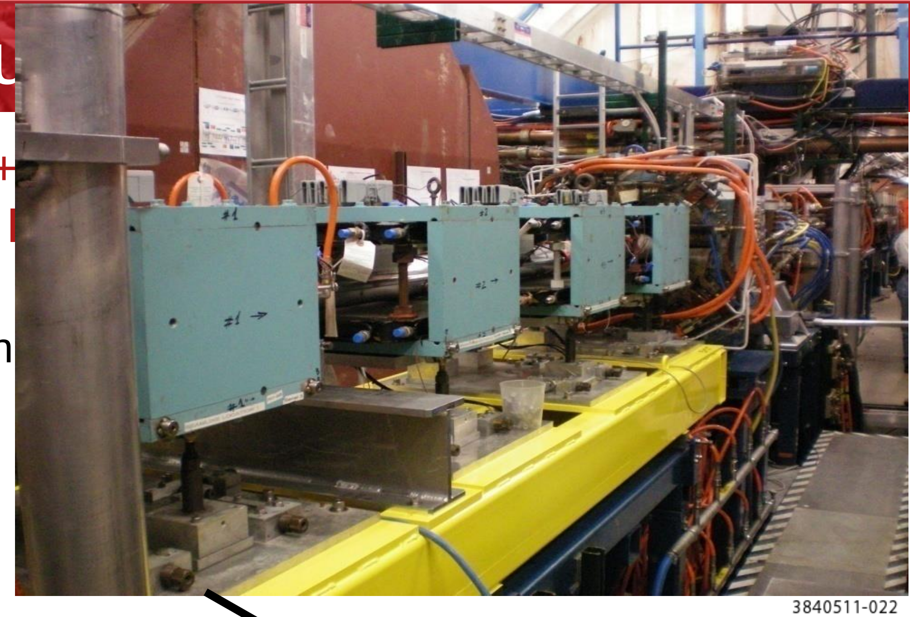


CESR-TA Electron Cloud Program

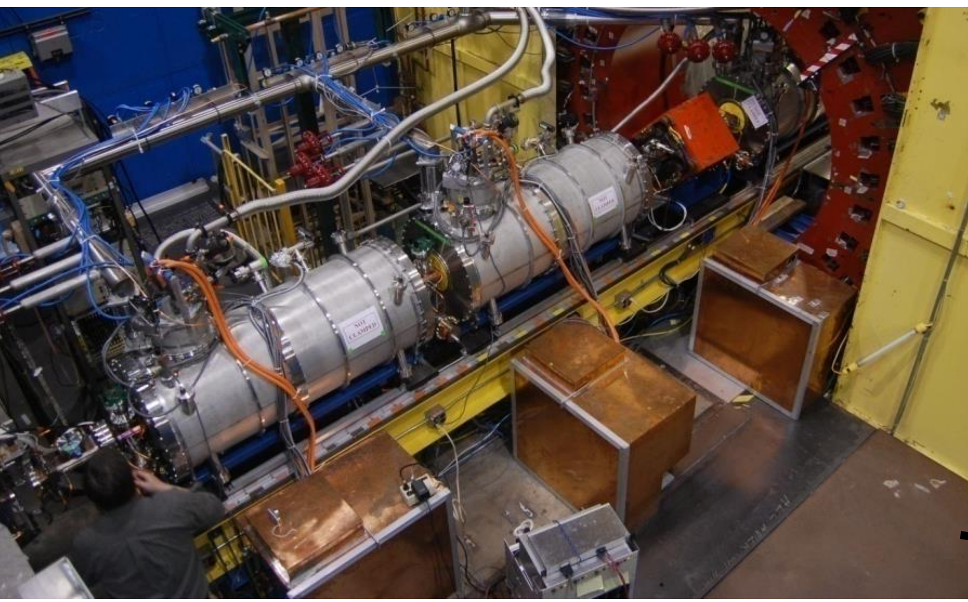
- In mid 2008 CESR was converted from a e+/e- collider to a “damping ring” configuration, to study issues related to the ILC damping ring (e.g. electron cloud). Goals include:
  - Study EC under different beam conditions and magnetic field environments
  - Evaluate EC mitigation techniques
    - Beam pipe coatings (TiN, aC, DLC, NEG)
    - Grooves
    - Solenoids
    - Clearing electrode
  - Study beam conditioning over time
  - Validate and improve on EC models
- CESR is very flexible
  - Electron or positron beams
  - Beam energy: 1.8 – 5.3 GeV
  - Bunch population: 0 – 1.6e11
  - Bunch spacing: 4 – 280 ns
- Main electron cloud experimental regions
  - Q15 E/W: drift mitigation experiments
  - L3: chicane dipoles, quadrupole
  - L0: wigglers







– Validate and improve on EC models



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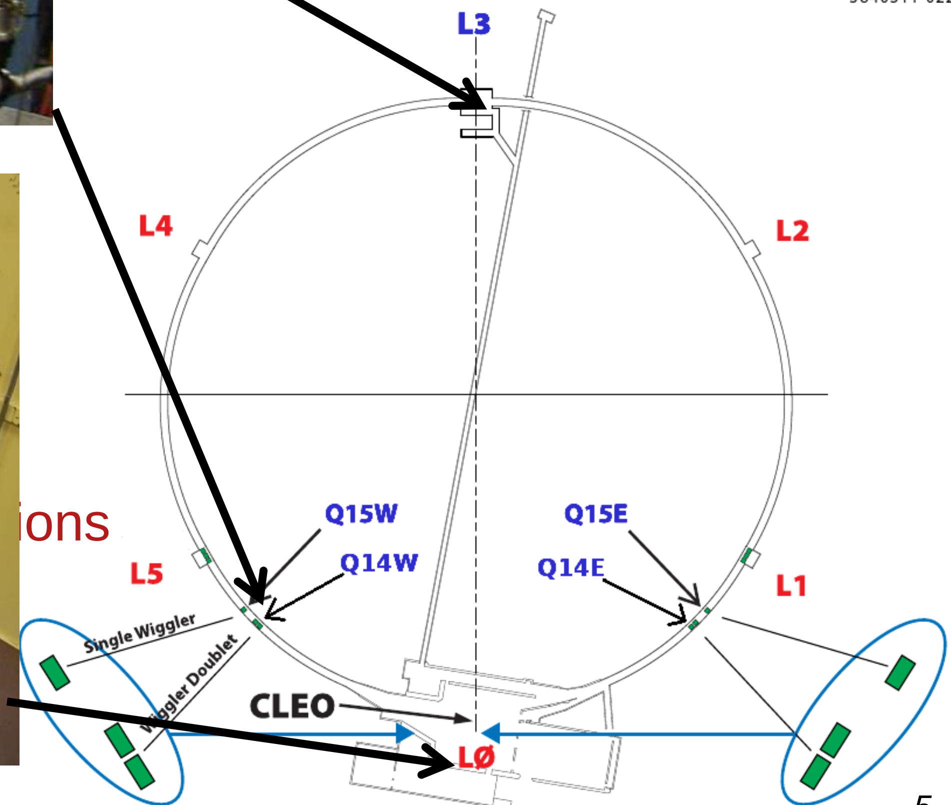
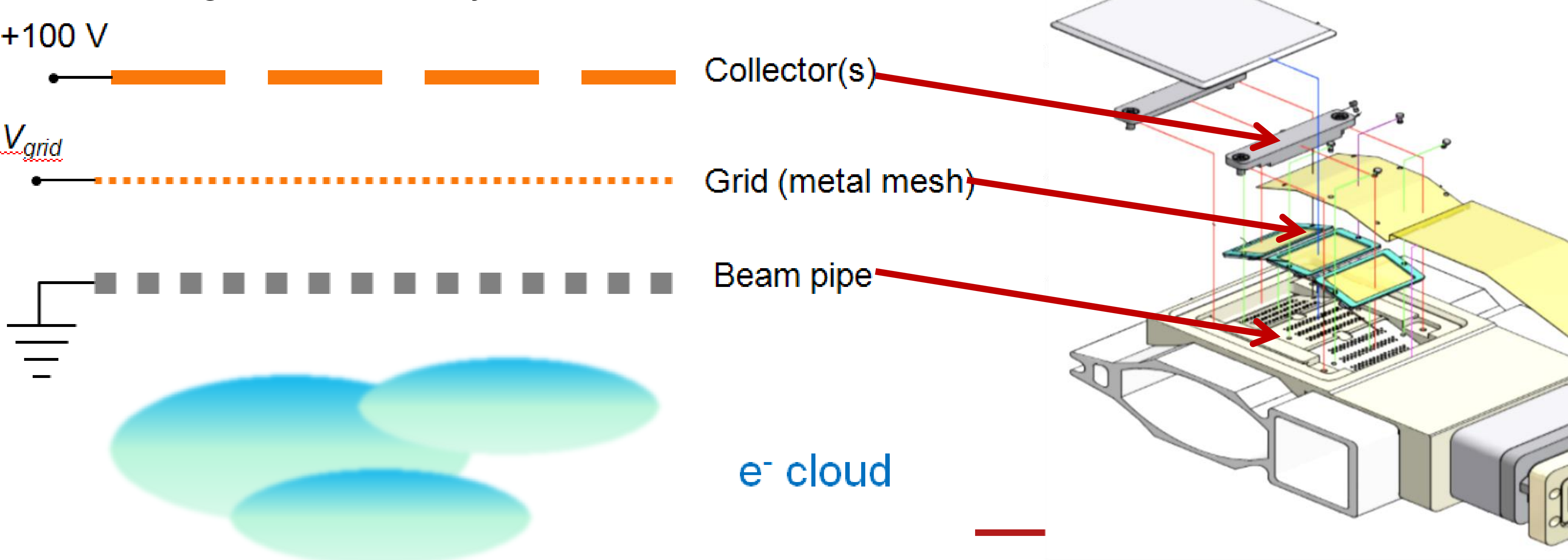


Retarding Field Analyzers

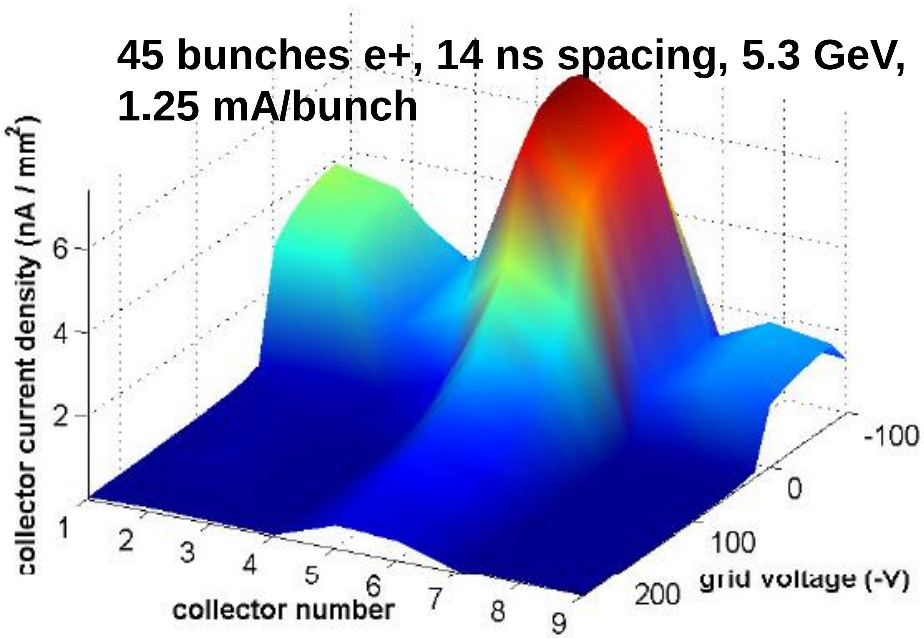
- A method to measure the local electron cloud wall flux, and infer the cloud density, energy, and transverse distribution. They consist of:
  - Holes drilled in vacuum chamber wall (allow electrons to enter device)
  - Retarding grid (reject electrons with $E < V_{grid}$) → energy resolution
  - One or more segmented collectors → transverse resolution
- Huge RFA program at CesrTA
  - Many RFAs (currently 34) deployed in CESR
  - Designs for insertion in confined spaces
  - Large data set, 5+ years of measurements



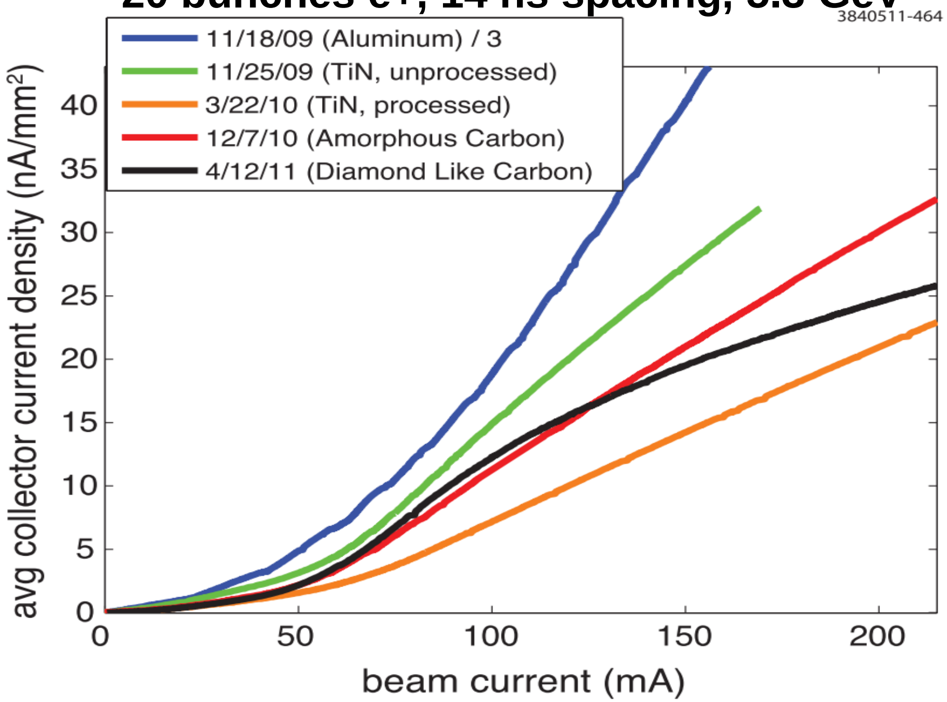
RFA Measurements: Drift

- Left plot shows voltage scan done with Q15W drift RFA
  - Shows collector signal vs retarding voltage (~integral of energy) and collector number (~transverse position)
  - Mostly low energy, peaked at center (beam position)
- Several beam pipe coatings tested at 15E/W locations
  - Cycling different chambers at the same locations in CESR allows for direct comparison of their effectiveness
    - All coated chambers show significant improvement relative to aluminum
    - Note conditioning of TiN coating
    - Most coatings (with possible exception of DLC) show stable long term behavior

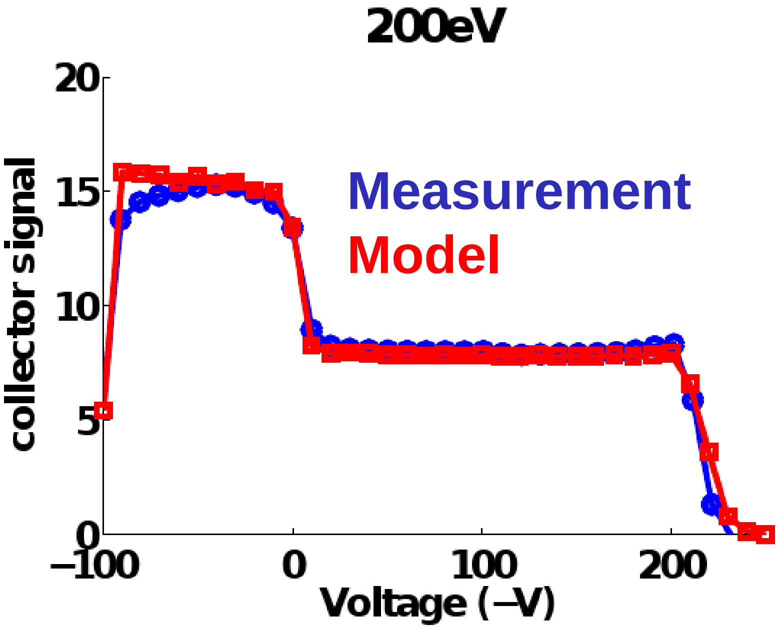
45 bunches e+, 14 ns spacing, 5.3 GeV, 1.25 mA/bunch



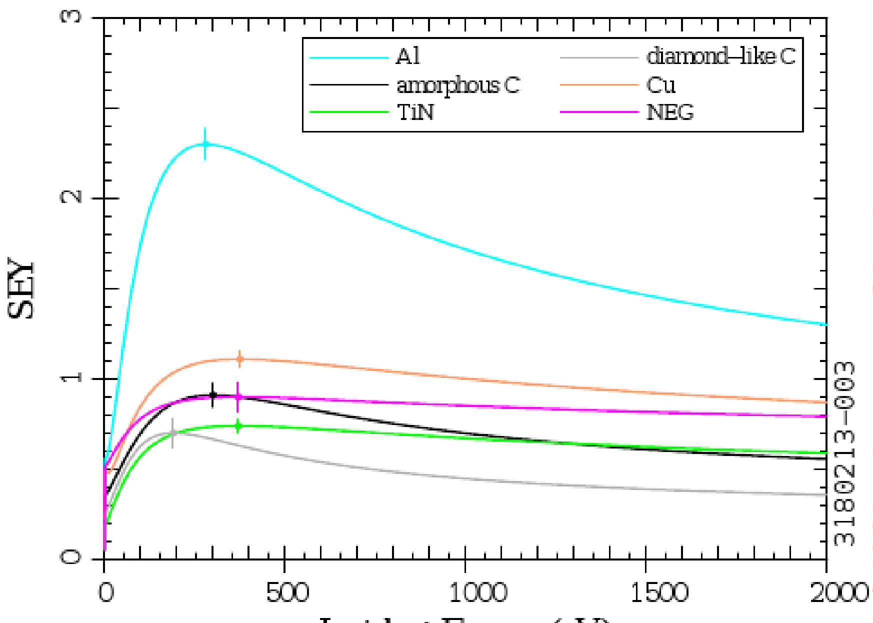
20 bunches e+, 14 ns spacing, 5.3 GeV

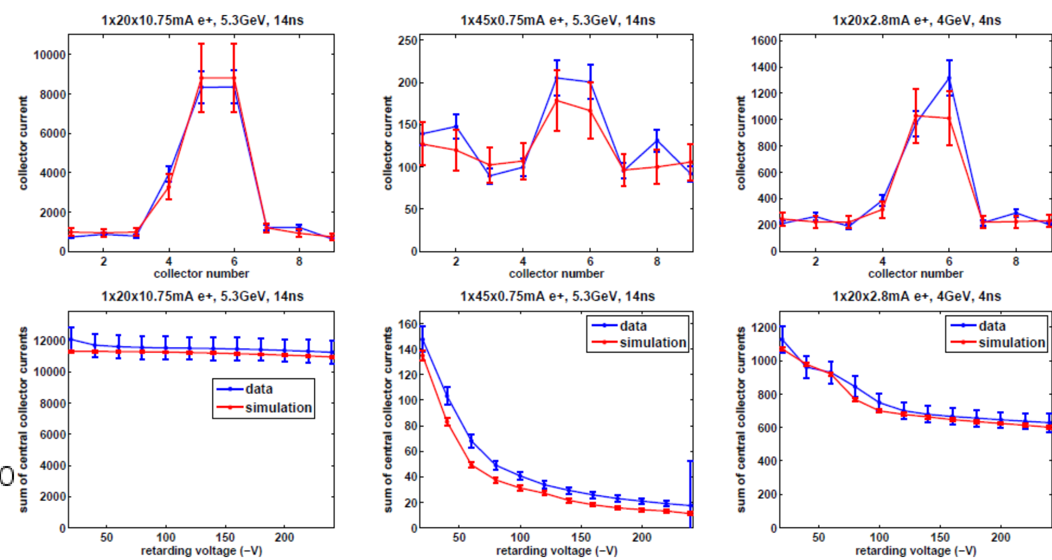


Drift RFA Simulations

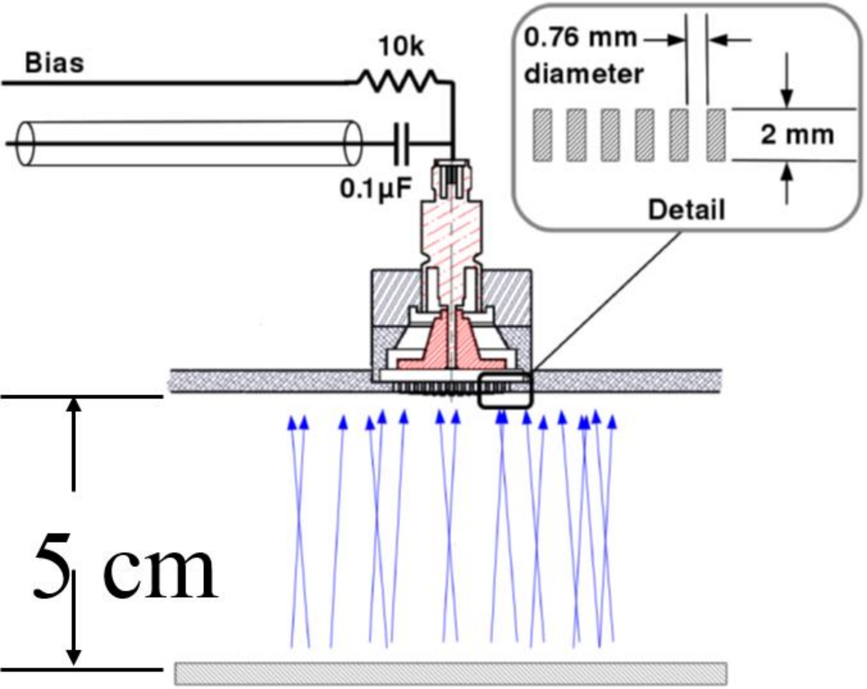


- Simulations done with POSINST
- Model of the RFA integrated into the code
  - Includes secondaries produced in RFA
  - Model cross-checked with bench measurements done with electron gun
- Use chi-squared minimization technique to fit simulations to data taken under a wide variety of beam conditions
  - Different simulation parameters are sensitive to different beam conditions
    - E.g. High current, short bunch spacing → peak SEY
  - Result: best fit SEY and PEY parameters for instrumented chambers
  - Also: validation of buildup codes

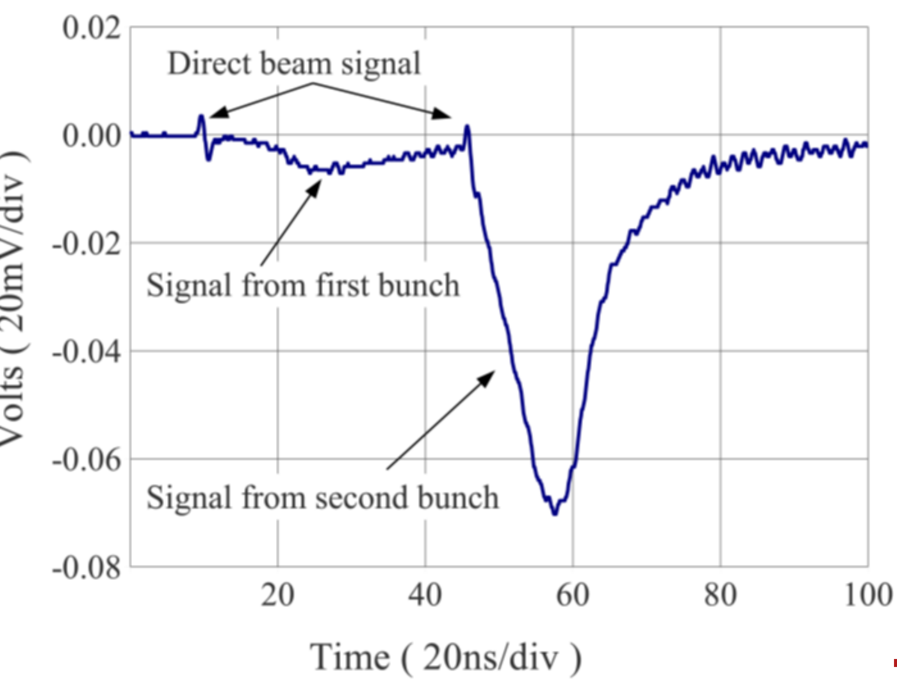


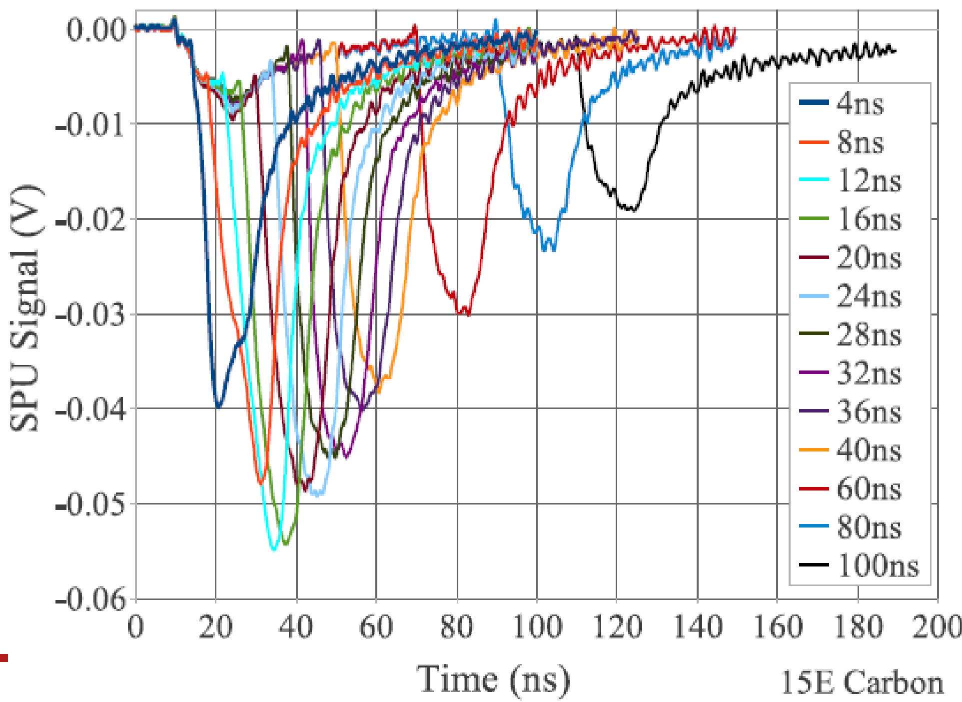


Shielded Button Electrode (SBE)



- Time resolved measurement of EC wall flux
  - BPM electrode shielded from direct beam signal, and positively biased to capture electrons
  - ~100 ps resolution
- Example: 2 bunches, 36 ns apart
  - Second bunch samples cloud generated by first
  - Shape of cloud sensitive to electron energy distribution
- Measure buildup, decay by varying separation between bunches
  - Buildup ~14 ns, decay ~100 ns

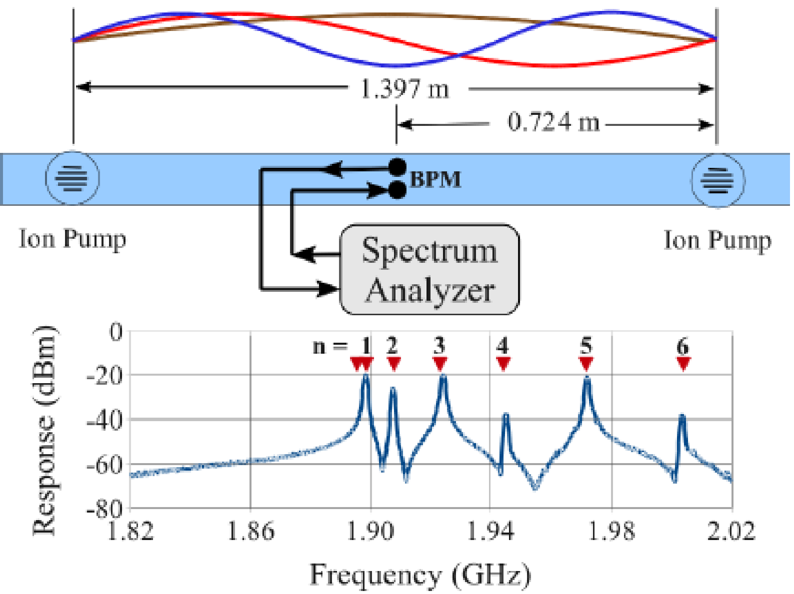




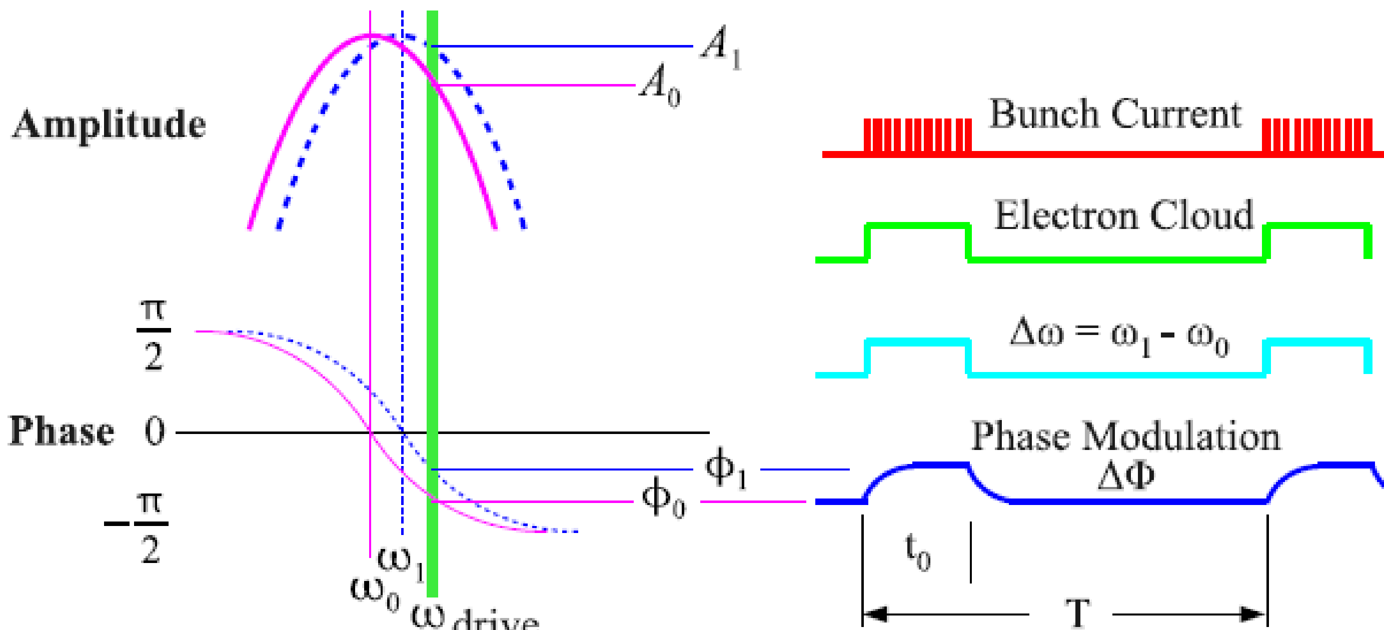
Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Microwave Resonance (MR)

Resonant Beam-pipe

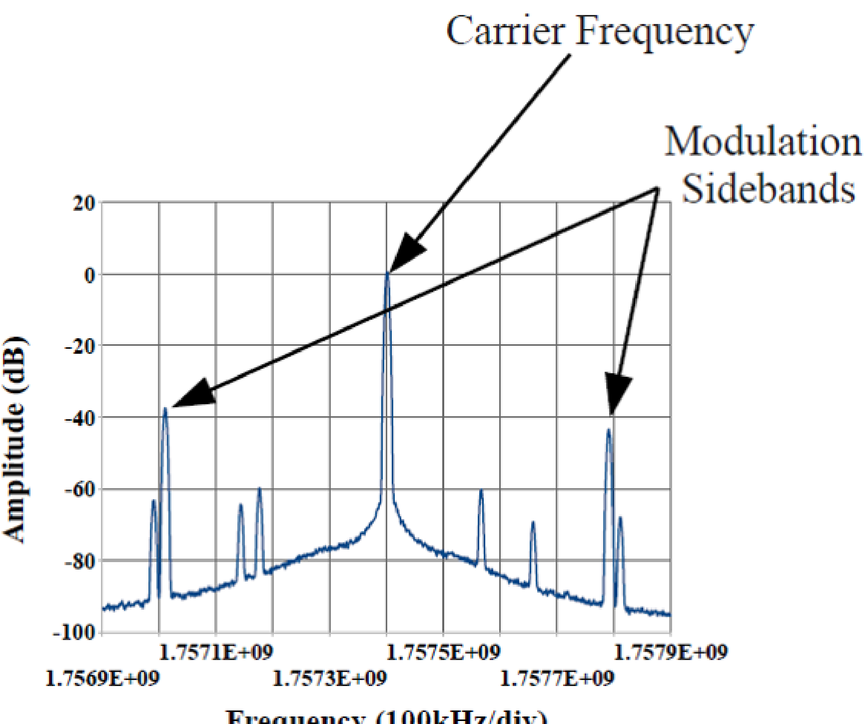


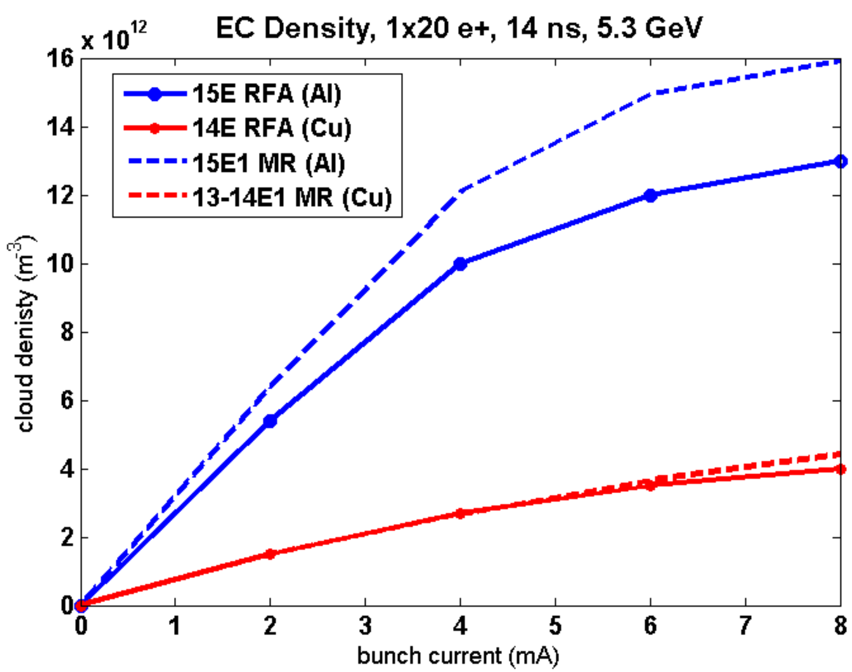
- Excite microwaves in accelerator chamber using BPM buttons
- Accelerator structures (e.g. ion pumps) cause reflections, forming a "resonant cavity"
- Electron cloud (when present) causes shift in resonant frequency of chamber
- This results in a periodic phase shift of drive signal

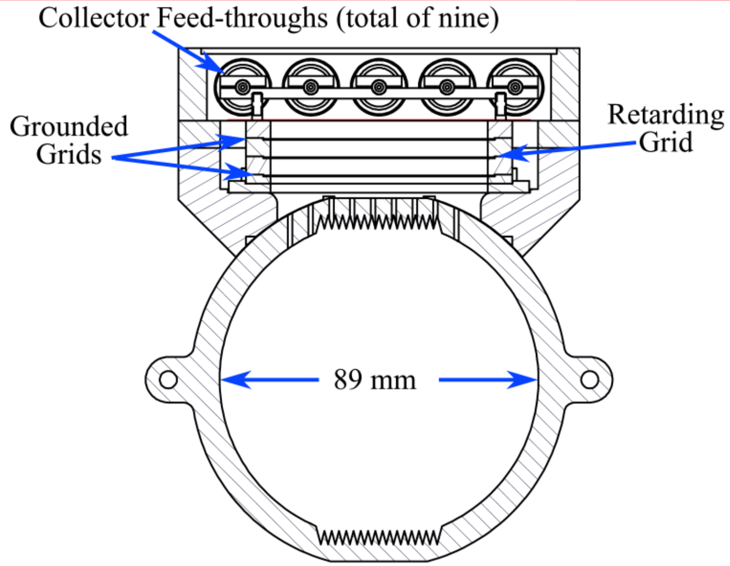


Cloud Density Measurement

- Periodic modulation of signal (by revolution frequency) results in sidebands in frequency spectrum
- EC density can be calculated from strength of sidebands
- Right plot shows measured density at different locations vs bunch current
  - Compared with nearby RFAs (density estimated from simulation)



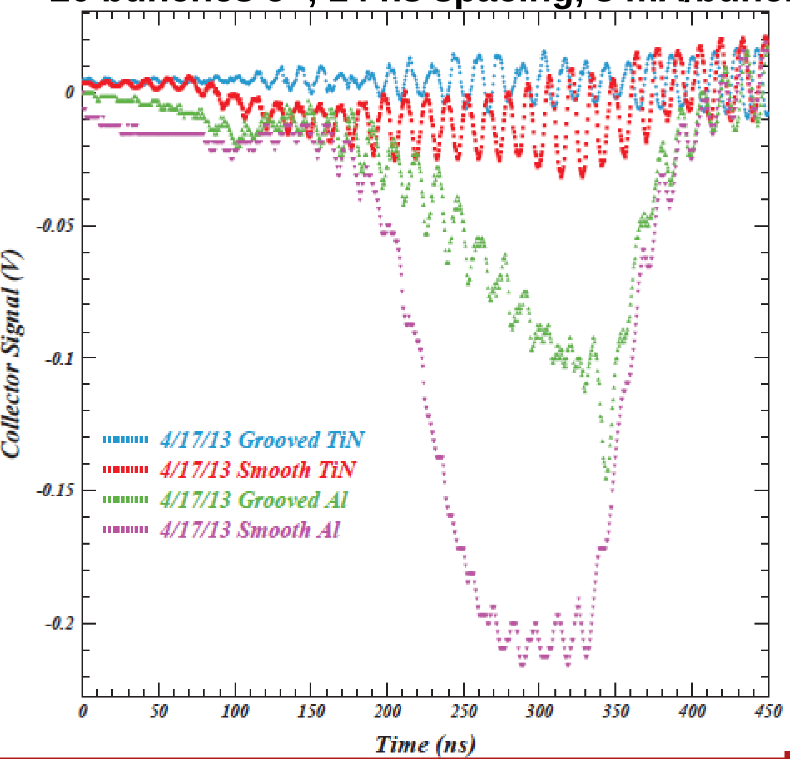


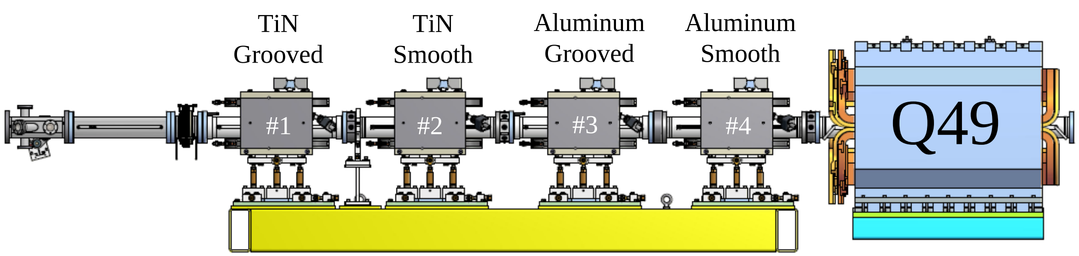


Dipole Time Resolved RFAs

- Dipole measurements done with chicane of four dipoles built at SLAC
  - Each magnet chamber has different mitigation
- Previously installed RFAs recently replaced with time resolved version
- Need large currents for good signal/noise
  - Signal “ringing” also an issue
  - Plans to move to higher radiation environment
- Mitigation comparison shows different time structure for different chambers
  - Grooved chamber signal low
  - TiN signal very low
  - Grooved TiN at the noise floor

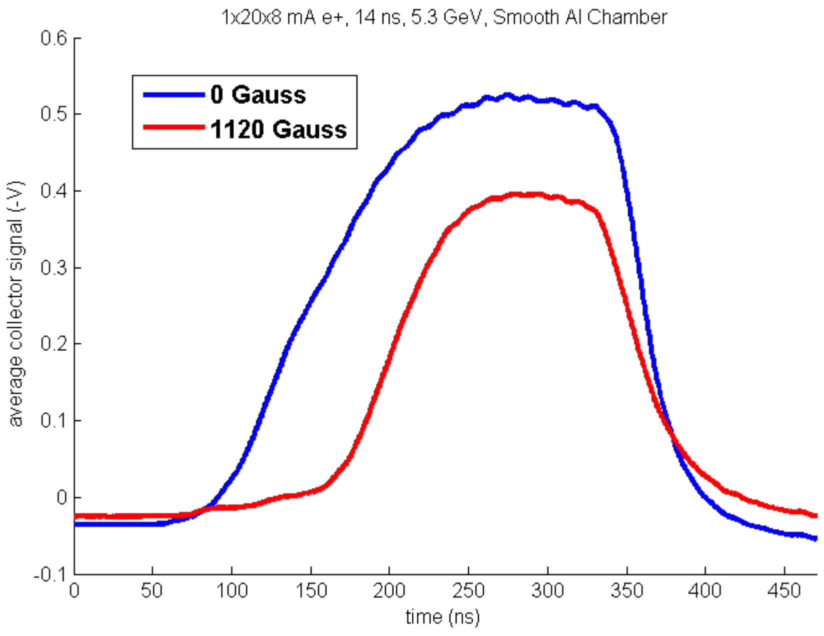
20 bunches e+, 14 ns spacing, 8 mA/bunch

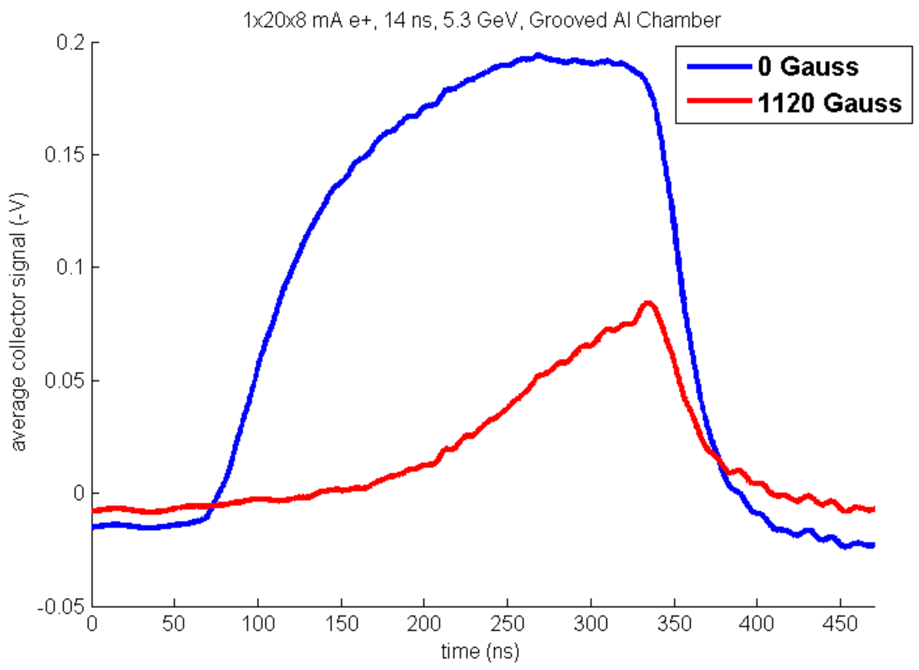




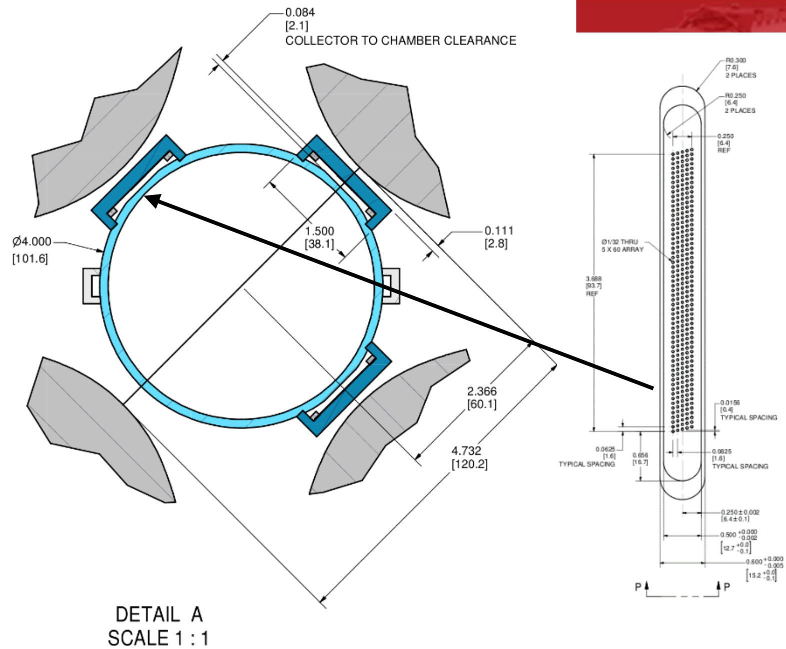
Chicane Field Comparison

- Compare TR-RFA signal with field on/off
  - Integrating out ringing
  - With 1120 Gauss field, Al chamber signal (left) somewhat smaller, later
  - Grooved chamber signal (right) much lower, but does not saturate after 20 bunches



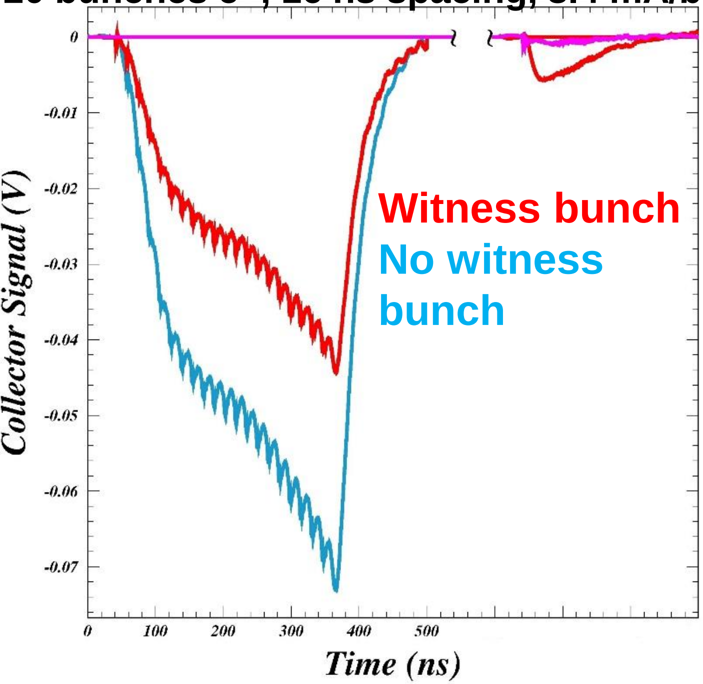


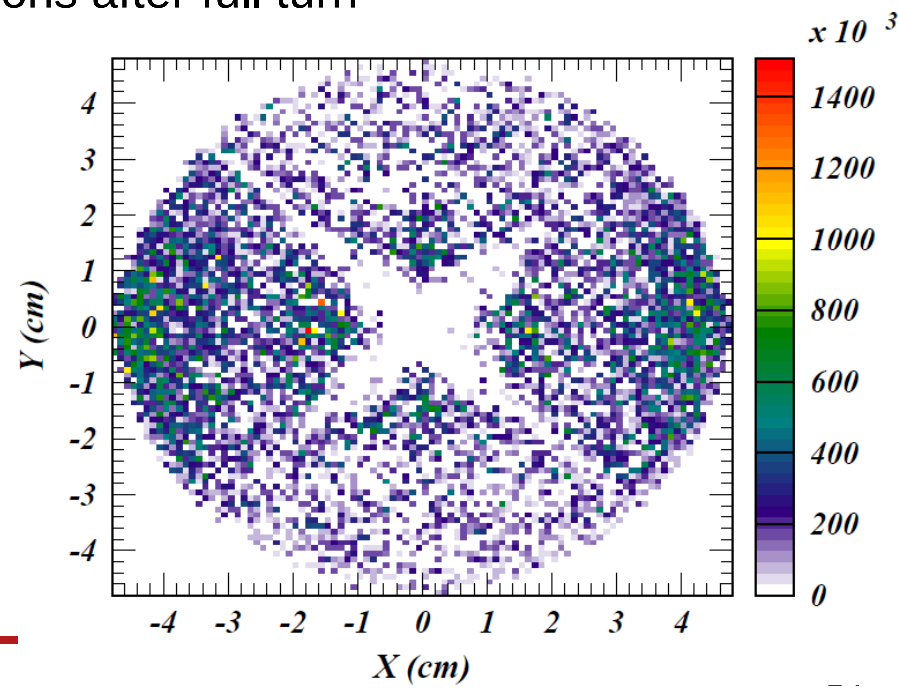
Quad Shielded Pickup



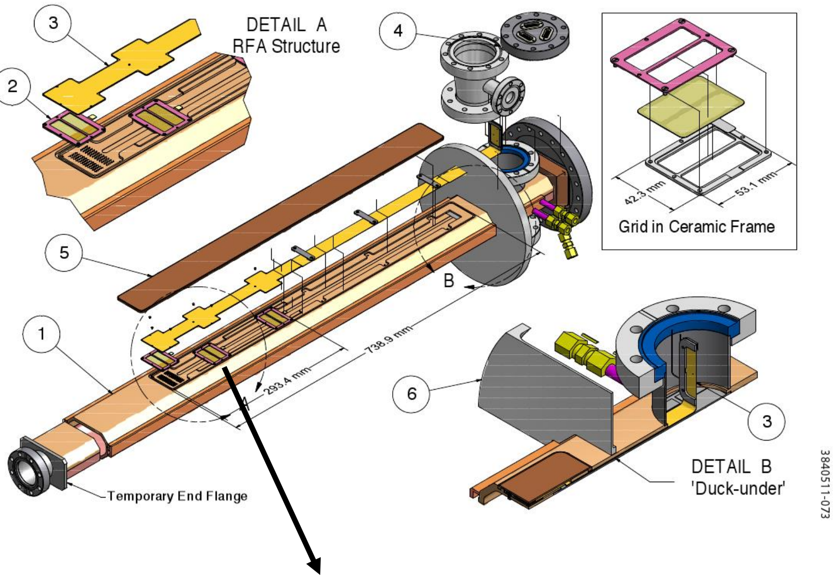
- Time resolved detector installed in quadrupole
  - Strip aligned with quad pole tip, where electrons are guided by field lines
- Strong evidence that cloud can remain long after bunch passage
  - Cloud cleared by “witness bunch” ~1μs after train
  - Simulations show cloud trapped in certain regions after full turn

20 bunches e+, 16 ns spacing, 8.4 mA/bunch

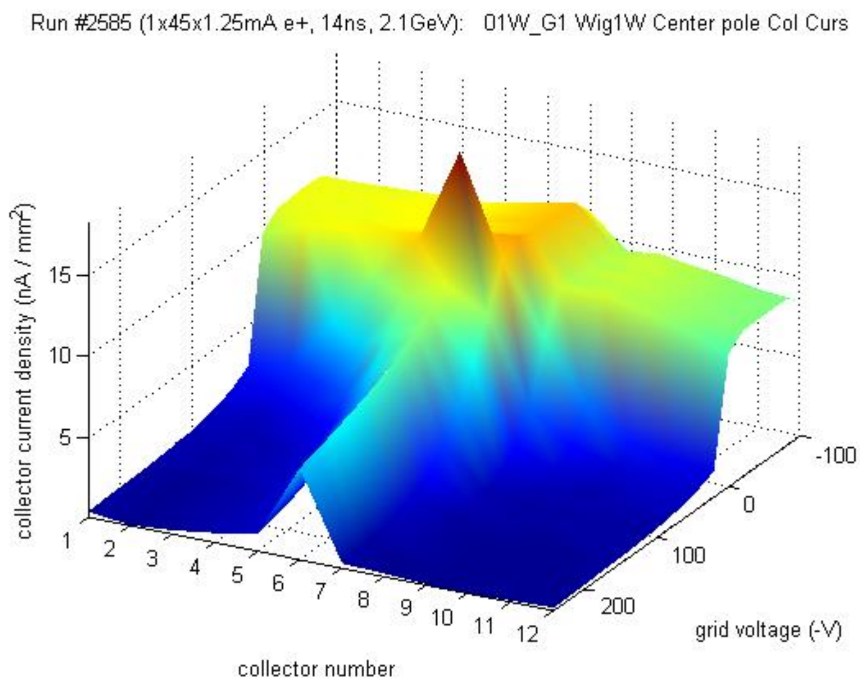


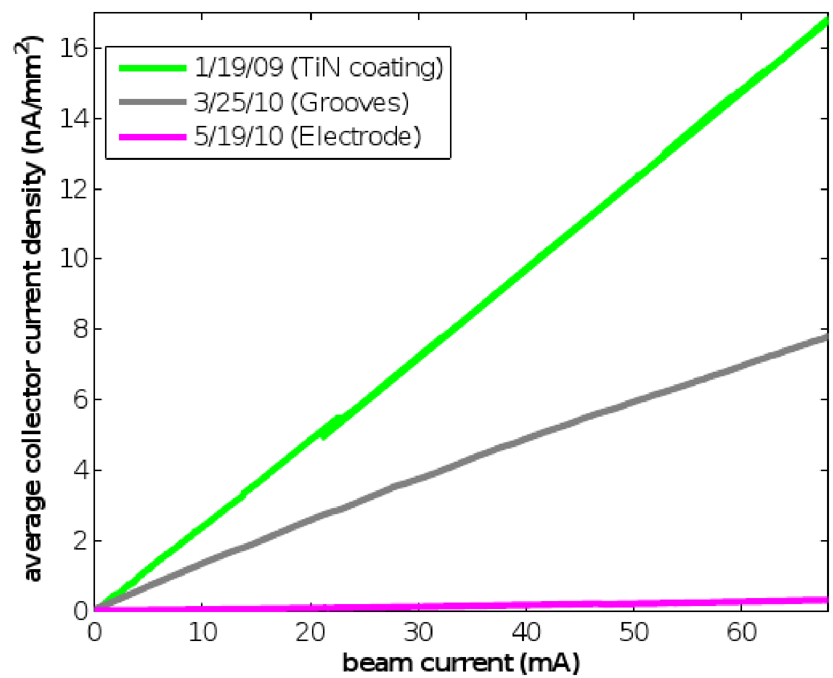


RFA Measurements: Wigglers



- L0 straight contains six superconducting wigglers (1.9 T peak field), three with RFAs
- RFAs in wiggler pole center, between poles, and intermediate region
  - Shown: pole center (~1.9 T dipole)
- Spike at low (but nonzero) retarding voltage, due to interaction between RFA and cloud
  - From secondary electrons produced on retarding grid
- Mitigations cycled through the same two locations in L0 straight
  - Clearing electrode clear winner





Summary

- Electron cloud detectors installed around CESR ring, in drifts, dipoles, quadrupoles, and wigglers
  - Detector properties listed in table
- Direct comparisons of different cloud mitigations
  - Used as input to ILCDR design
- Recent Results include:
  - Detailed cloud modelling
    - Parameter fits for different chambers and coatings
  - Direct measurement of cloud density
  - Time resolved dipole data
  - Cloud trapping in quad

	Measures:	Time res?	Energy res?	Trans. Res?	Issues:
RFA	wall flux		X	X	secondaries
SBE	wall flux	X			secondaries
TR-RFA	wall flux	X	X	X	signal / noise
MR	central density				interpretation

Thanks for your attention!

REFERNENCES

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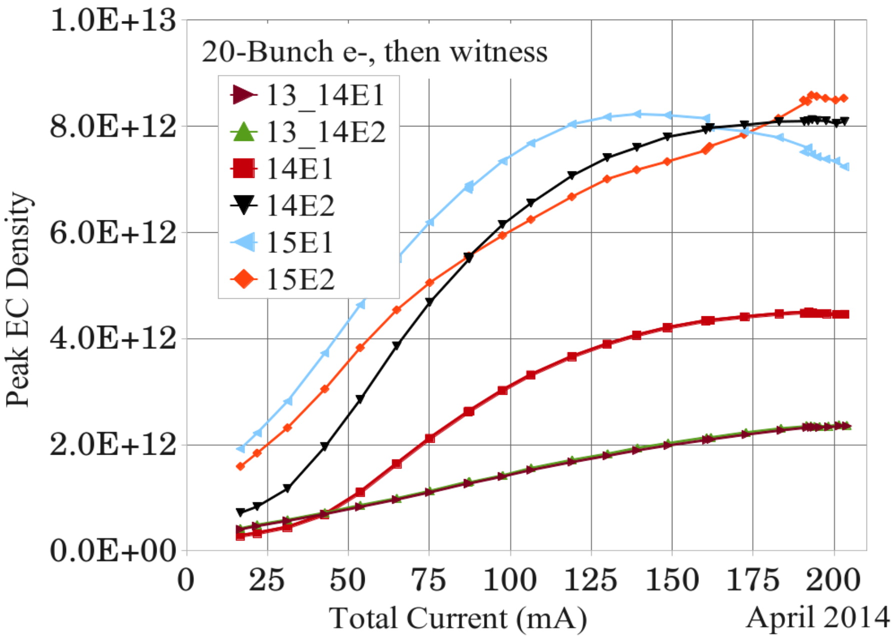
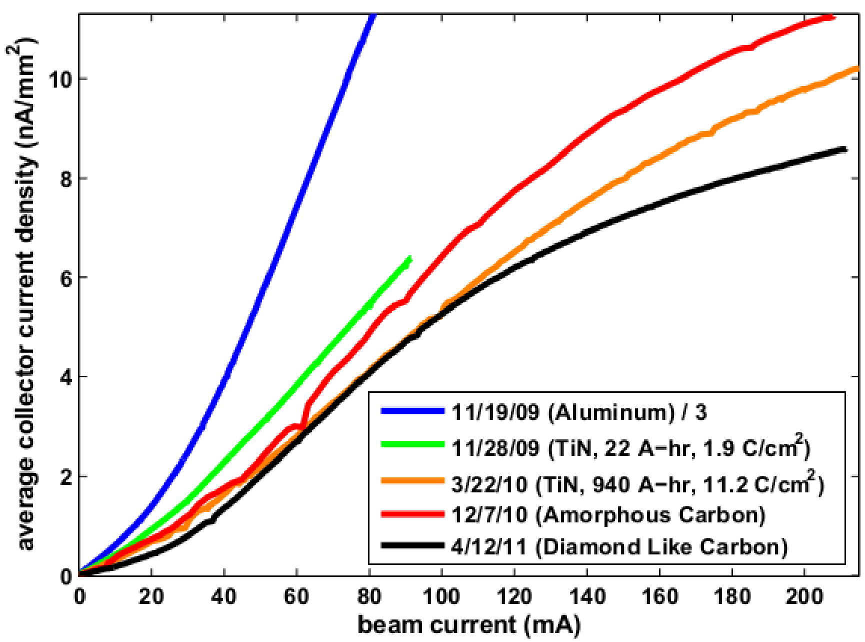
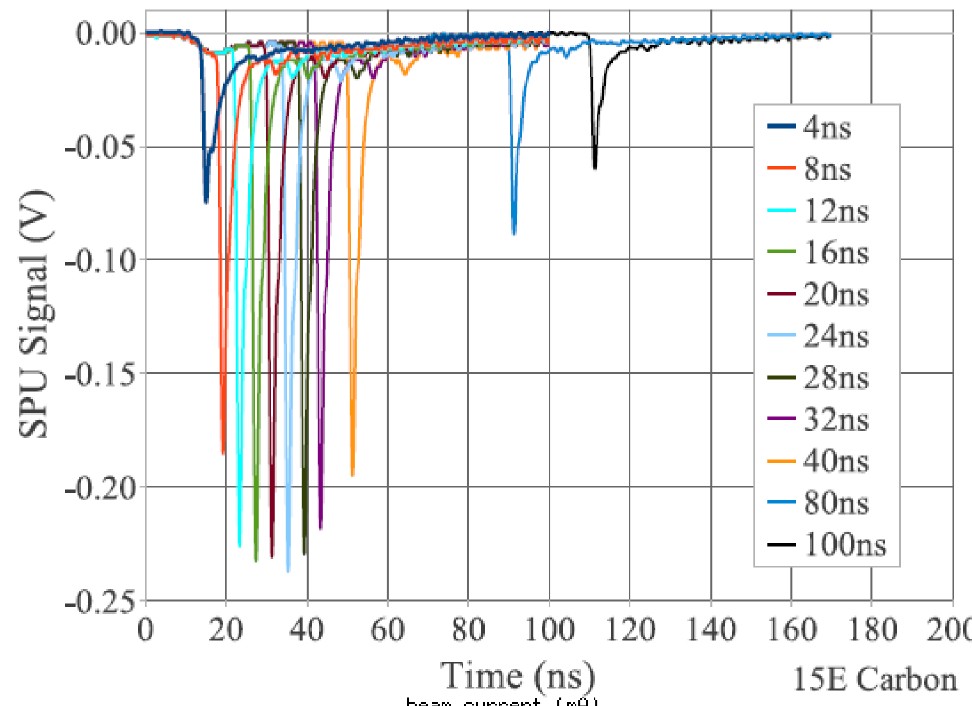
Bonus Slides

Electron Beam Measurements



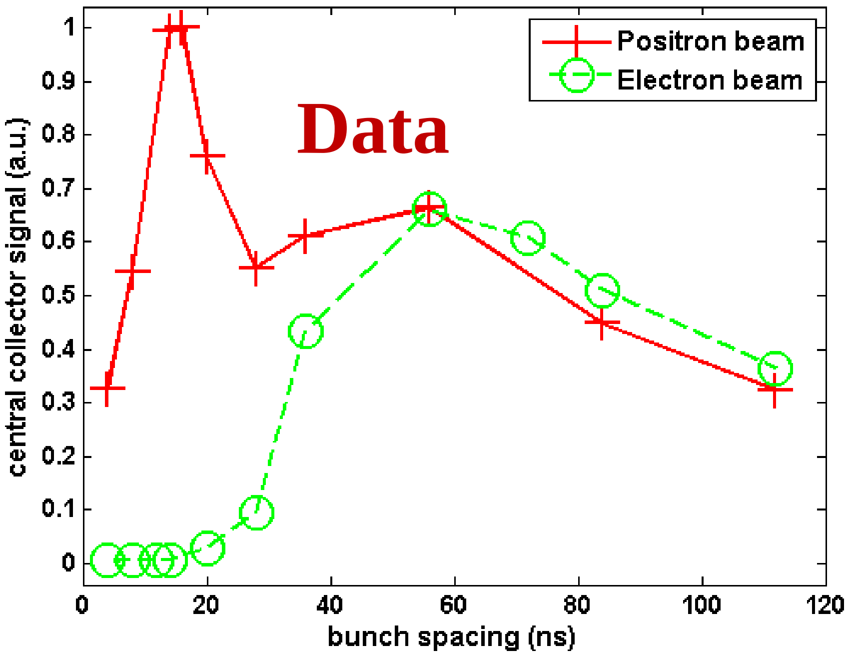
- We do observe significant electron cloud with electron beams
  - Though less than with positrons, of course

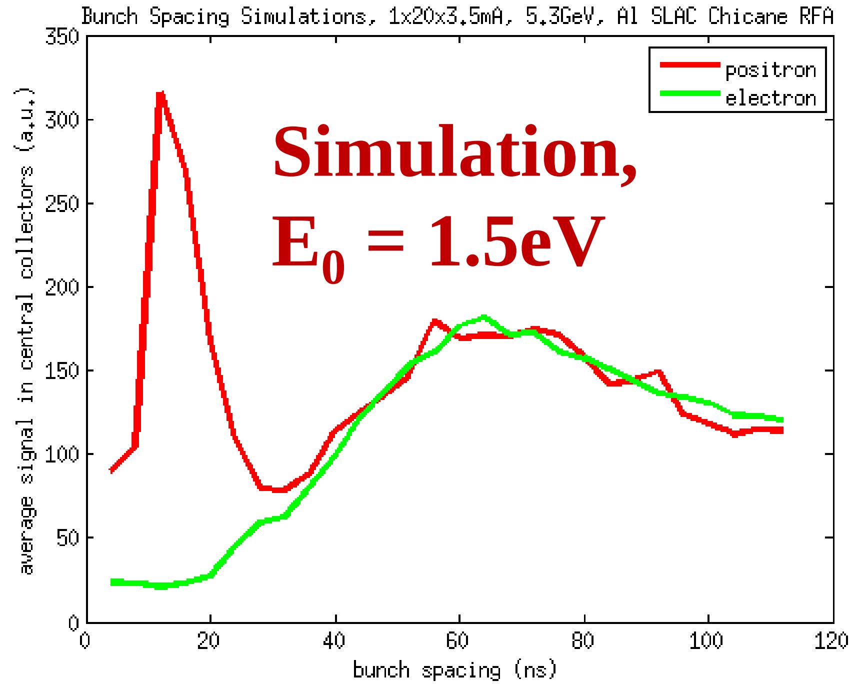




Multipacting Simulations

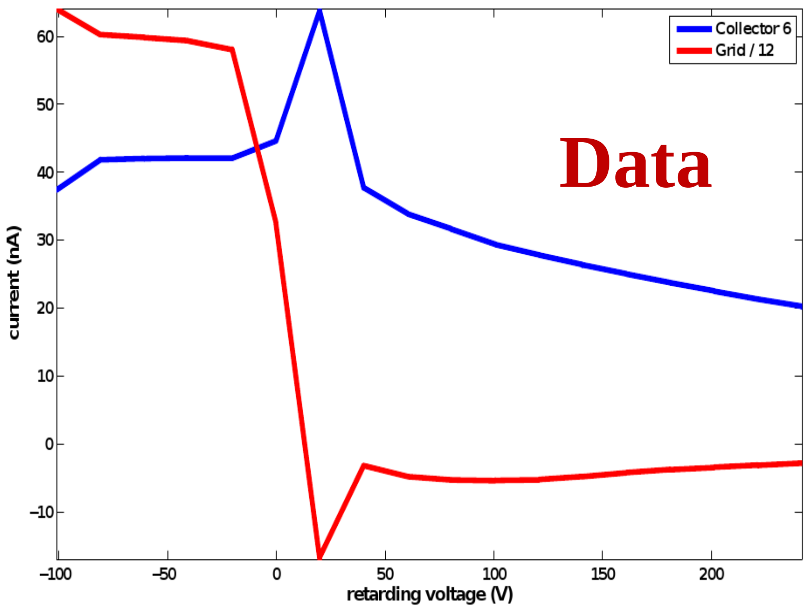
- Looking at data taken vs bunch spacing, 1x20x3.5mA, 5.3GeV
  - Aluminum SLAC chicane RFA
- Both data and simulation show:
  - Broad peak at ~60ns in both electron and positron data
    - = time for secondary electron to drift into the center of the chamber
    - Sensitive to secondary emission energy (= 1.5 eV)
  - strong peak at ~12ns in positron data
    - n = 2 resonance

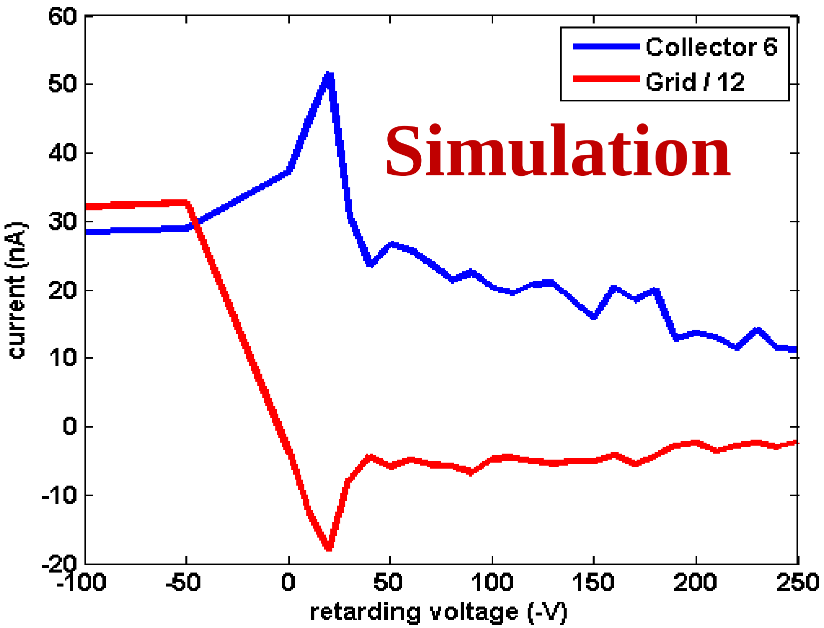




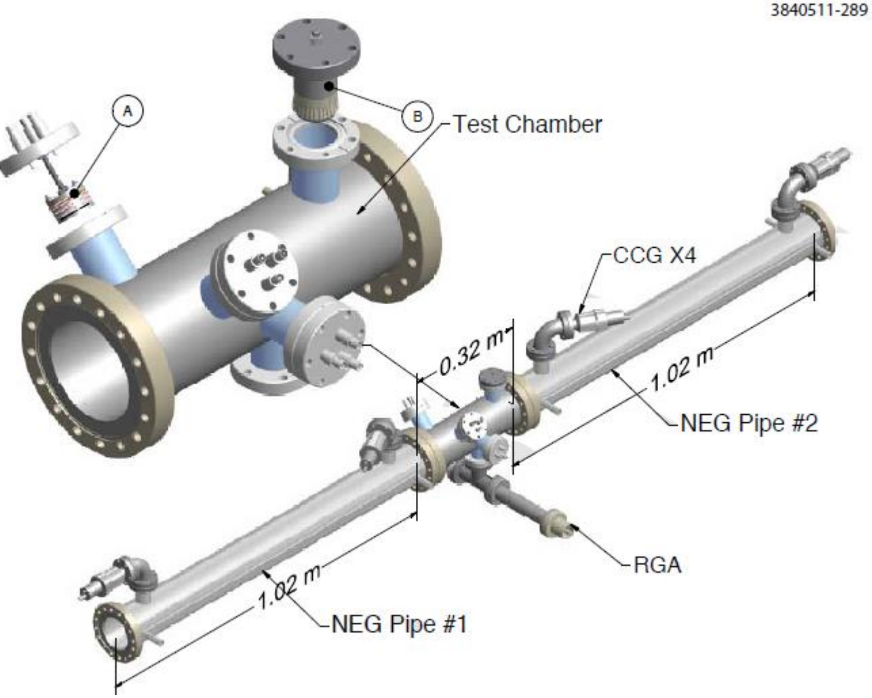
Wiggler RFA Simulations

- Analytical model assumes no significant interaction between RFA and cloud
  - Misses some features of the data in high magnetic fields
  - Ex: In the wiggler data, we observe an anomalous spike in current at low (but nonzero) retarding voltage
    - Due to a resonance between the voltage and bunch spacing
    - Extra signal comes from secondaries produced on the retarding grid
  - Need full particle tracking model to observe this in simulation
    - Track electron in RFA, using native POSINST routines
    - Need to do a separate simulation for each retarding voltage





NEG Chamber



- 2m section of L3 straight coated
- Bakeout at 250 degrees C for 48 hrs
- Activation reduces both SEY and dynamic pressure rise
- RFA signals stable over long term