Electron Cloud Mitigation Investigations at CesrTA

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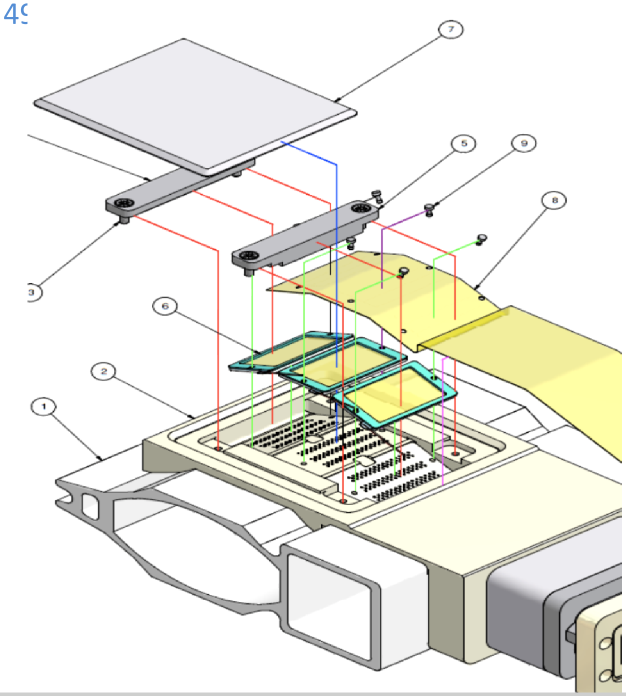
Introduction

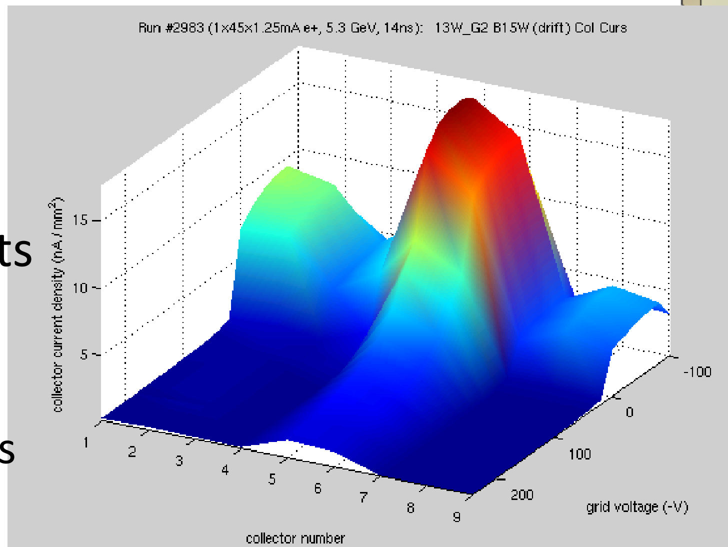
- The density and distribution of the electron cloud can depend strongly on several parameters that can vary substantially throughout an accelerator. These include…
  - Local photon flux
  - Vacuum chamber shape and material
    - Primary and secondary emission properties of the material
  - Magnetic field type and strength
- Therefore it is useful to have a detector that can sample the electron cloud locally. At CesrTA we have used…
  - Retarding field analyzers (focus of this talk)
  - TE-Wave transmission (see talk by S. DeSantis, poster by J. Sikora)
  - Shielded pickups (poster by J. Crittenden)
- Several EC mitigation techniques have been proposed, many of which have been studied at CESR…
  - Beam pipe coatings (TiN, amorphous Carbon, NEG)
  - Grooved beam pipes (in dipole regions)
  - Solenoids (in drift regions)
  - Clearing electrodes

Retarding Field Analyzers (RFAs)

- RFAs consist of…
  - Holes drilled into the beam pipe to allow electrons to pass through
  - A "retarding grid" to which a negative voltage can be applied, rejecting any electrons which have less than a certain energy
  - A collector which captures any electrons that make it past the grid
    - Often there are several collectors arranged transversely across the top of the beam pipe
  - Left: CESR thin drift RFA

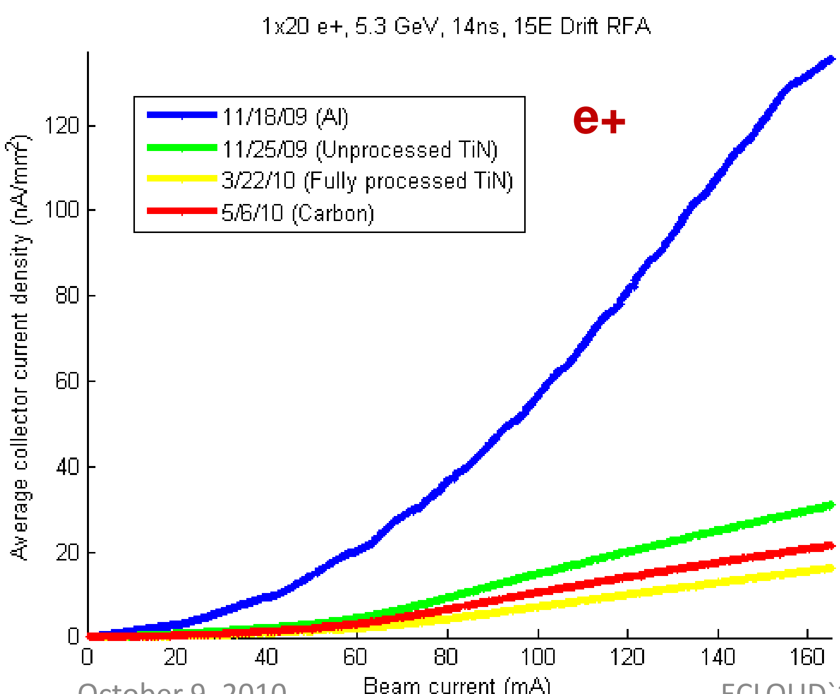


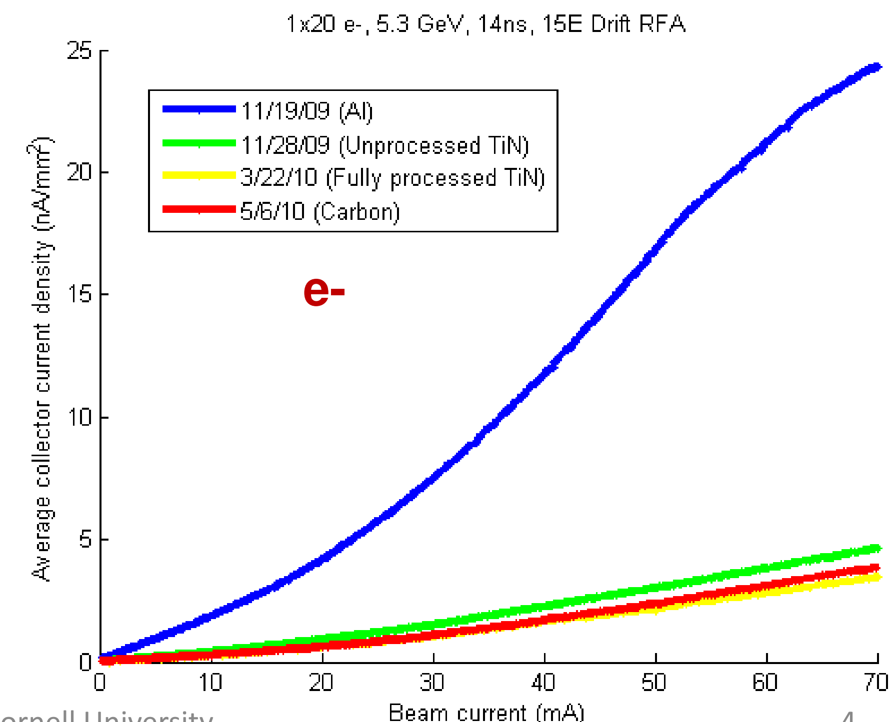
- So RFAs provide a local measure of the electron cloud density, energy distribution, and transverse structure
- There are two common types of RFA measurements
  - "Voltage scans," in which the retarding voltage is varied, typically between +100 and -250V
  - "Current scans," in which the RFA passively monitors while the beam current is gradually increased



Drift Mitigation

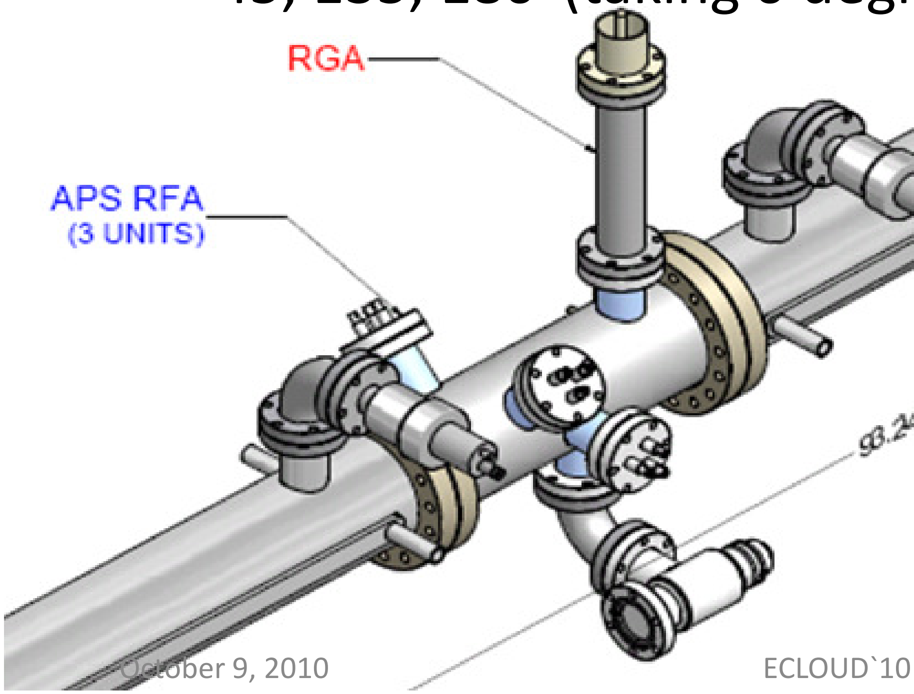
- We have installed chambers with different beam pipe coatings in the same place in CESR, to do as direct a comparison as possible
- Plots show average collector current vs beam current for a 20 bunch train of positions, 5.3 GeV, 14ns spacing
  - Comparing three different chambers (Al – blue, unprocessed TiN – green, processed TiN- yellow, Carbon – red) that were installed in 15E at different times
  - Both coatings show similar performance, much better than Al
    - Carbon chamber did not show significant processing



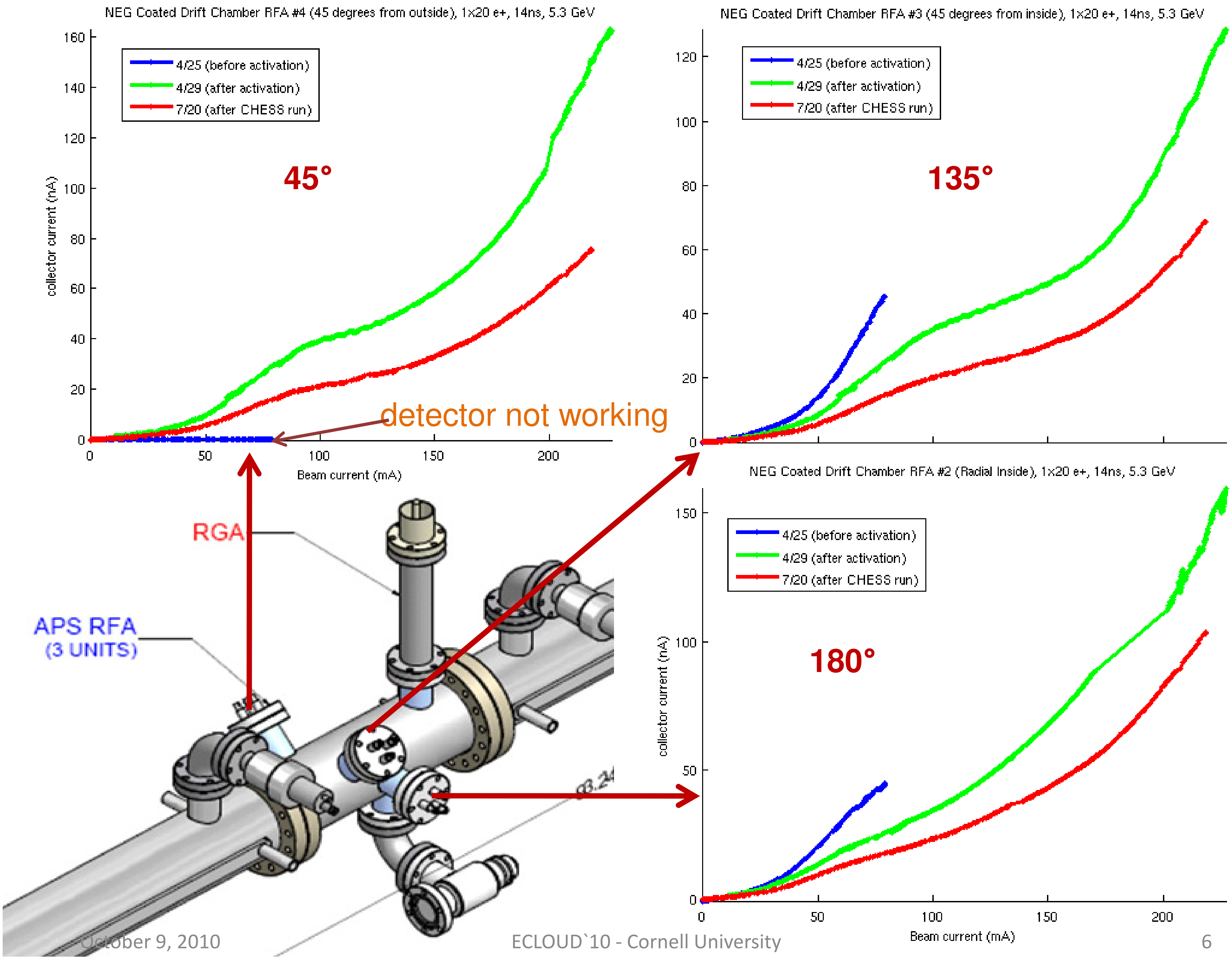


L3 NEG Chamber

- Installed in L3 straight before April run
  - NEG activated on 4/28
  - Plots compare signal before activation, after activation, and after CHESS run
- 3 single collector ("APS style") RFAs located at different azimuthal locations in the chamber
  - 45, 135, 180°(taking 0 degrees as source point)



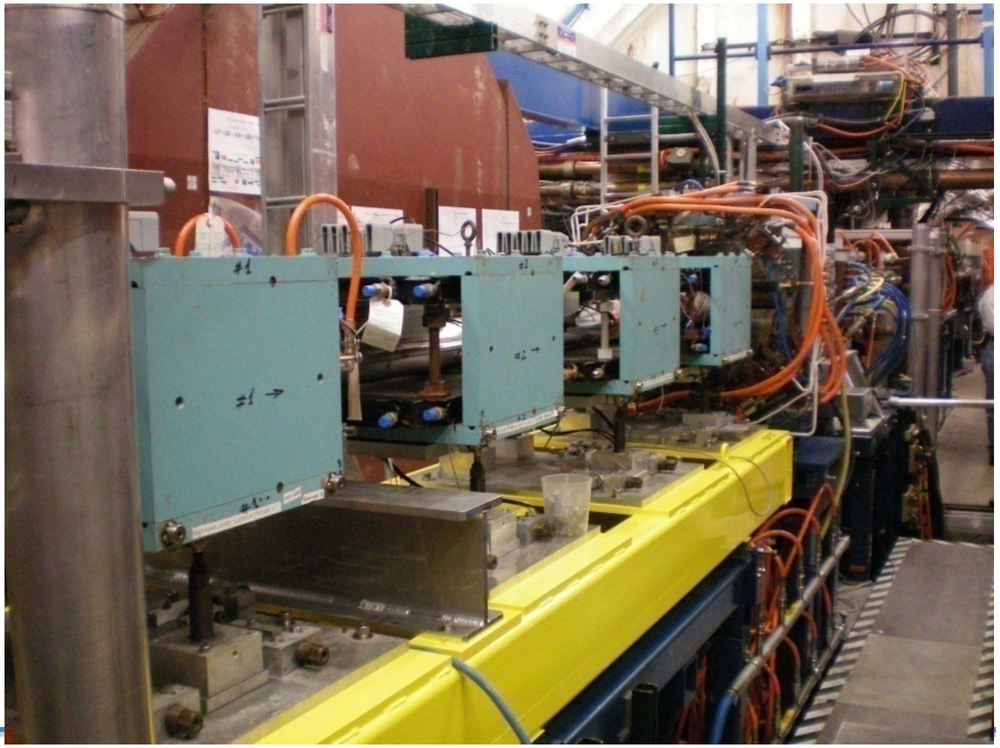
•Signal in all three RFAs was reduced significantly by activating the NEG, and further reduced by processing during the CHESS run.



NEG Coated Drift Chamber RFA #4 (45 degrees from outside), 1x20 e+, 14ns, 5.3 GeV
4/25 (before activation)
4/29 (after activation)
7/20 (after CHESS run)
45°
collector current (nA)
Beam current (mA)
detector not working
NEG Coated Drift Chamber RFA #3 (45 degrees from inside), 1x20 e+, 14ns, 5.3 GeV
4/25 (before activation)
4/29 (after activation)
7/20 (after CHESS run)
135°
NEG Coated Drift Chamber RFA #2 (Radial Inside), 1x20 e+, 14ns, 5.3 GeV
4/25 (before activation)
4/29 (after activation)
7/20 (after CHESS run)
180°
collector current (nA)
Beam current (mA)
RGA
APS RFA
(3 UNITS)

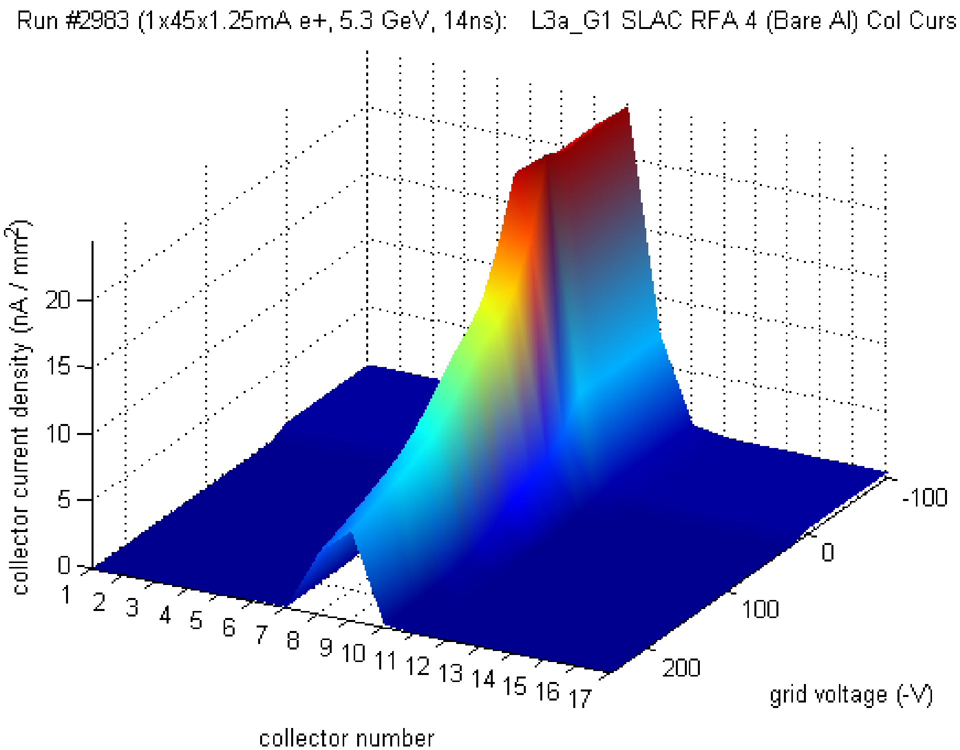
Dipole RFAs

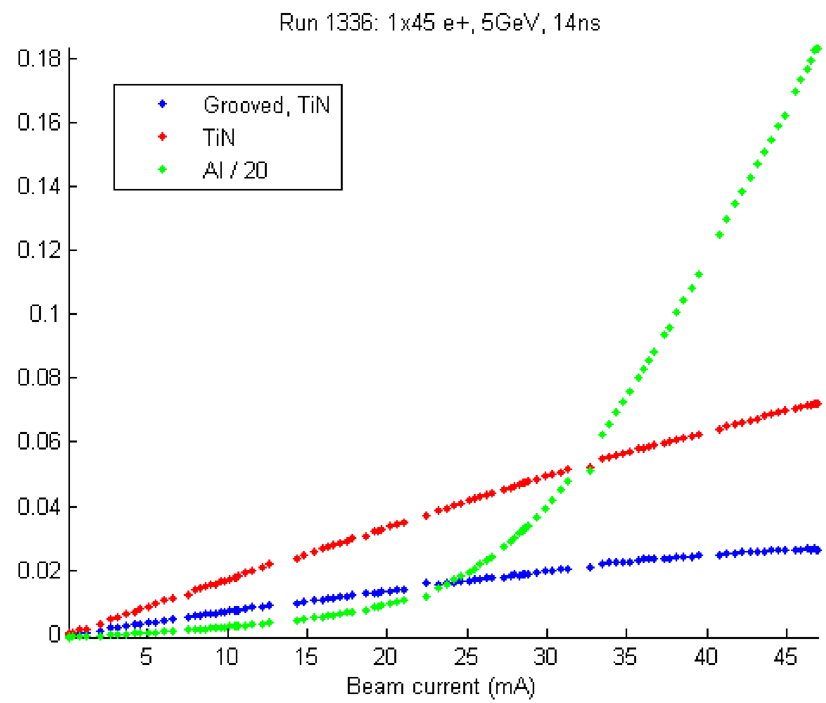
- We have installed the PEP-II chicane in our L3 straight region
  - Each magnet is instrumented with a 17 collector RFA
  - This allows us to investigate the behavior of the cloud as a function of magnetic field
    - Range: ~25 - 1100 Gauss
- Two different mitigation techniques are employed
  - TiN coating (2 magnets)
  - Grooves + TiN coating (1 magnet)
  - The last magnet is bare Aluminum



Dipole Mitigation

- Left plot is typical voltage scan for Al RFA, 1x45x1.25mA e+, 14ns, 5.3GeV,
- Left plot is current scan, 1x45 e+, 14ns, 5GeV
- Both mitigation techniques show drastic improvement relative to Aluminum
  - Note that Al signal is divided by 20
  - Al shows significant mutipacting
  - TiN actually seems to saturate
  - Groove + TiN is even better than just TiN

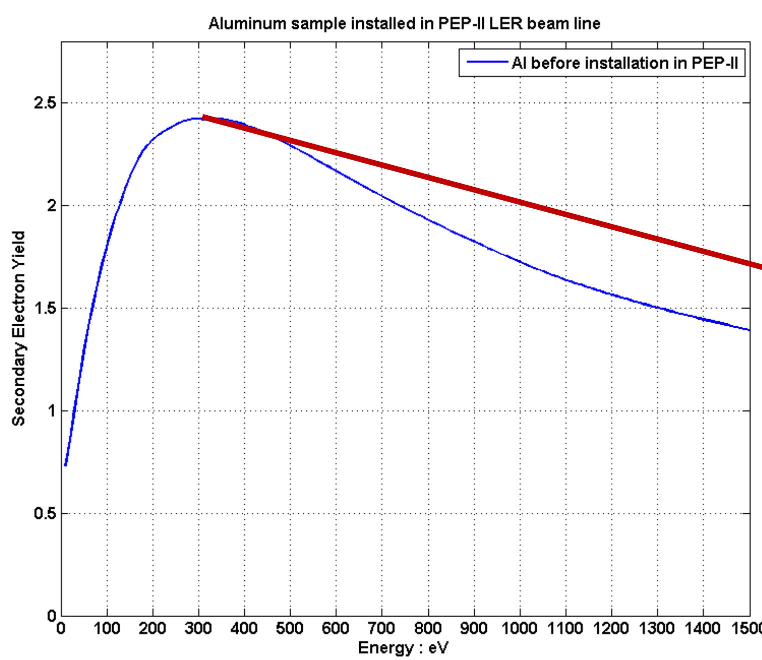


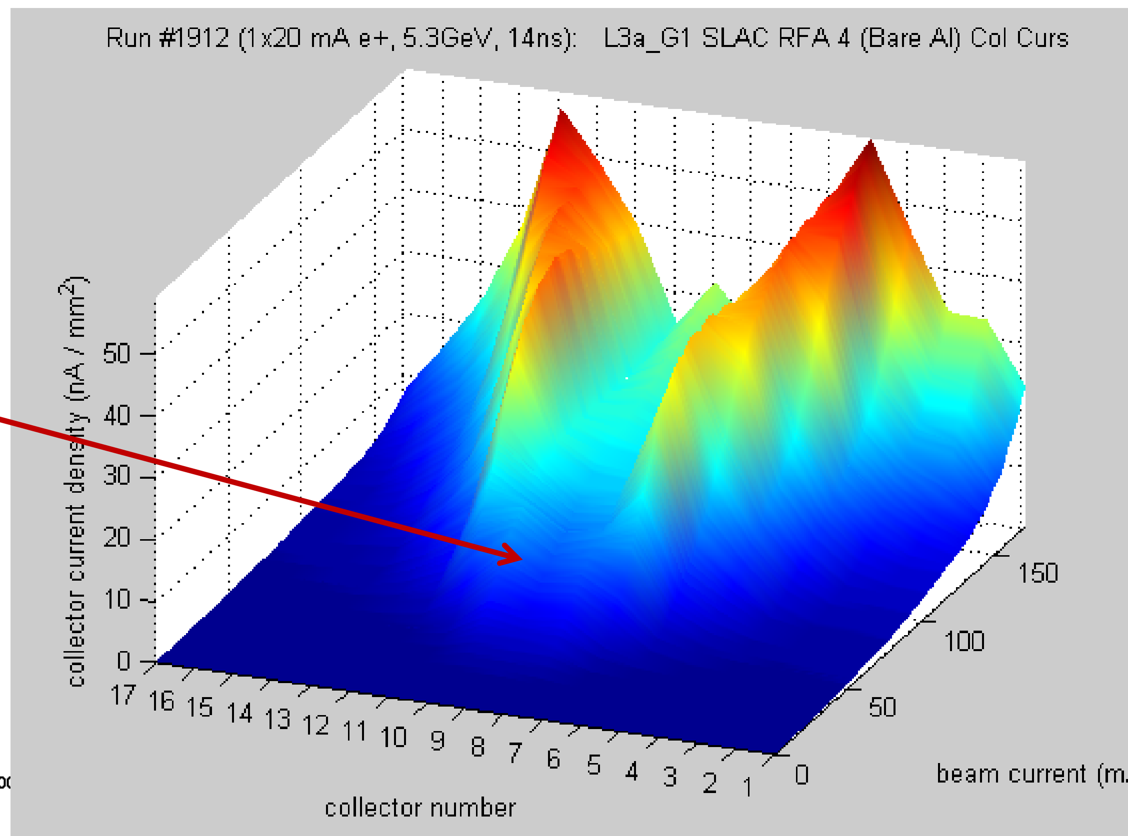


Bifurcation of Peak Density

- With sufficient bunch current, one can push the average cloud energy in the center of the pipe past the SEY peak
  - This causes a bifurcation of the peak density
- Conditions: 1x20 e+, 5.3 GeV, 14ns, +50V on grid
- Plot shows collector currents vs beam current (~cloud energy) and collector number (horizontal position)
  - Aluminum SLAC RFA

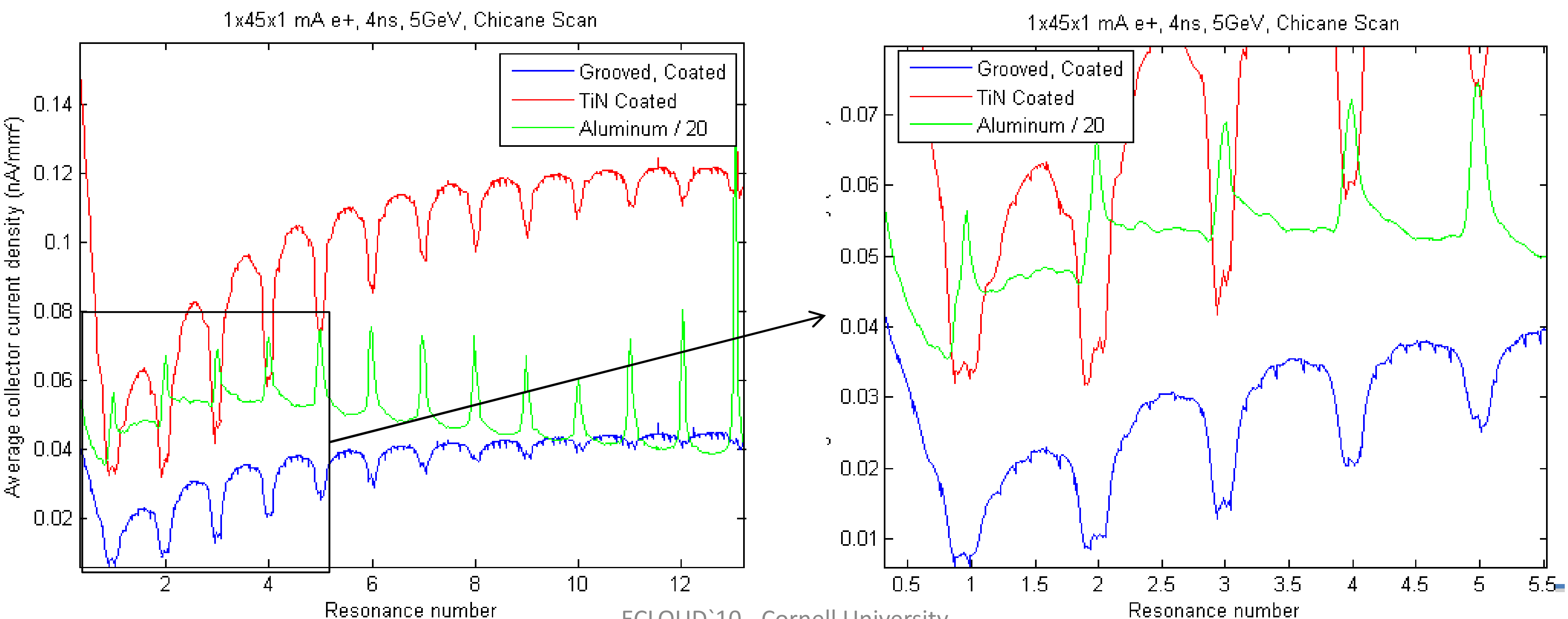
  (in chicane), ~700G dipole field





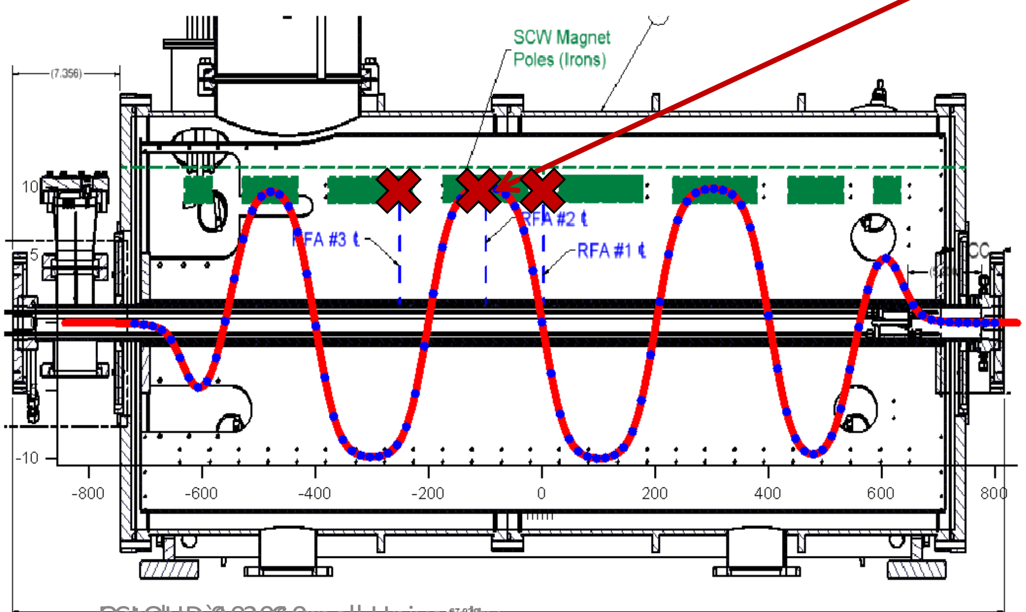
Chicane Field Scan

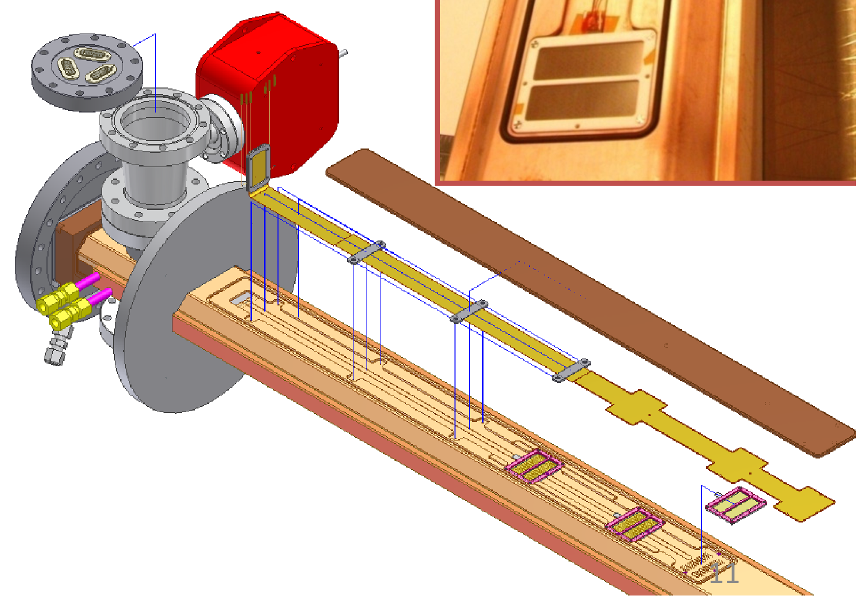
- RFA currents monitored while chicane dipole fields are increased
- We are looking for "cyclotron resonances"
  - When the bunch spacing is an integral multiple of the cyclotron period of an electron
  - Data are plotted against "resonance number" (= bunch spacing / cyclotron period)
- 1x45x1 mA, 4ns, 5GeV, positrons
- On resonance, there are peaks in the Al chamber and dips in the TiN and grooved chambers
  - Both dips and peaks are exactly on resonance
  - Not clear what causes dips vs peaks



Wiggler Mitigation

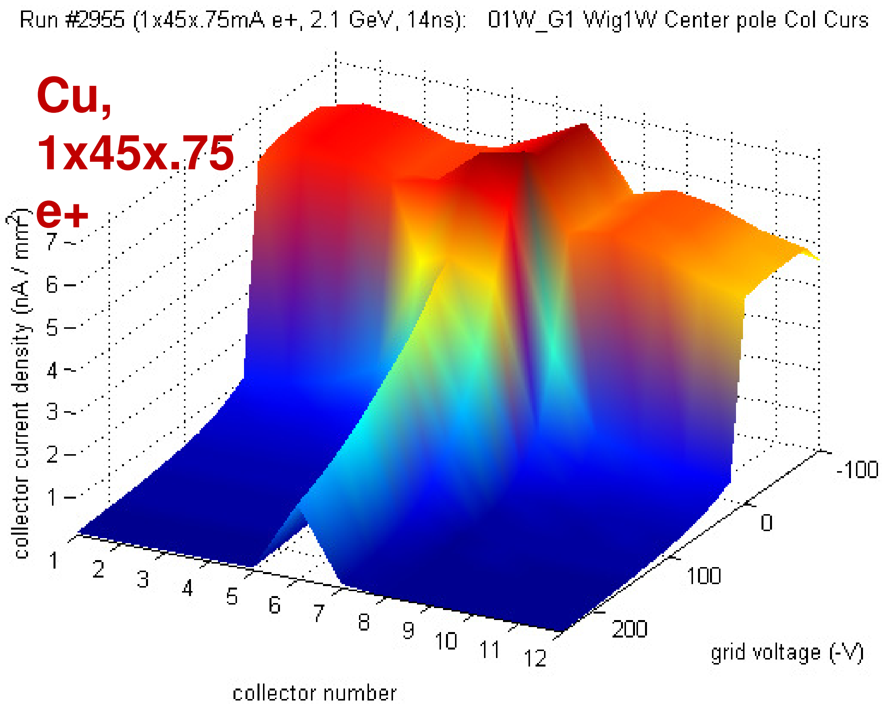
- We have three wigglers instrumented with RFAs
  - Bare Cu
  - TiN coated
  - Clearing electrode
  - Previously installed: grooved
- Each wiggler has three RFAs
  - Plots shown will be for an RFA in the center of a wiggler pole
  - There are also RFAs in a longitudinal and intermediate field
  - RFAs have 12 collectors and are built into the beam pipe

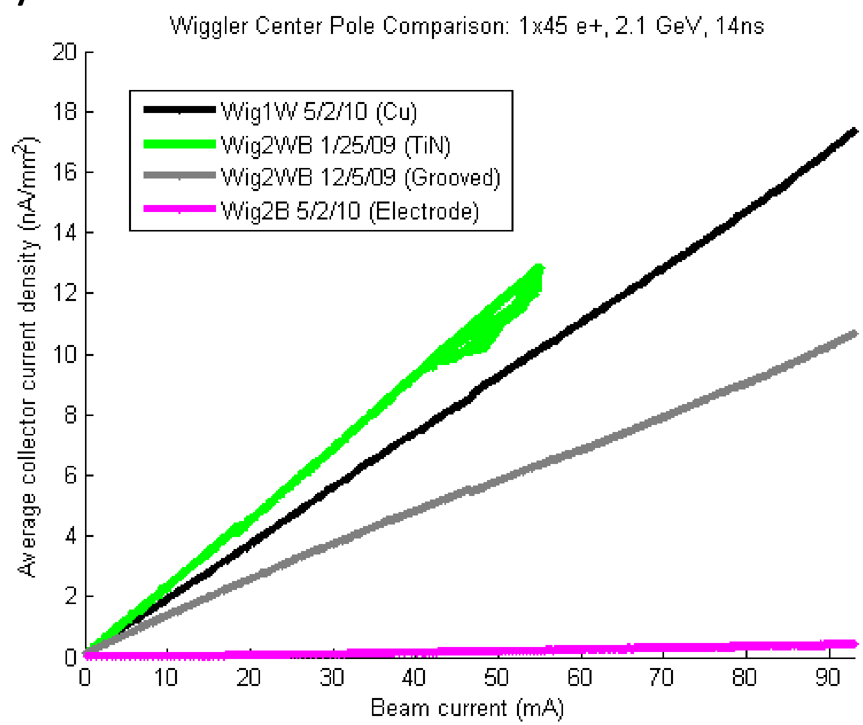




Wiggler Data

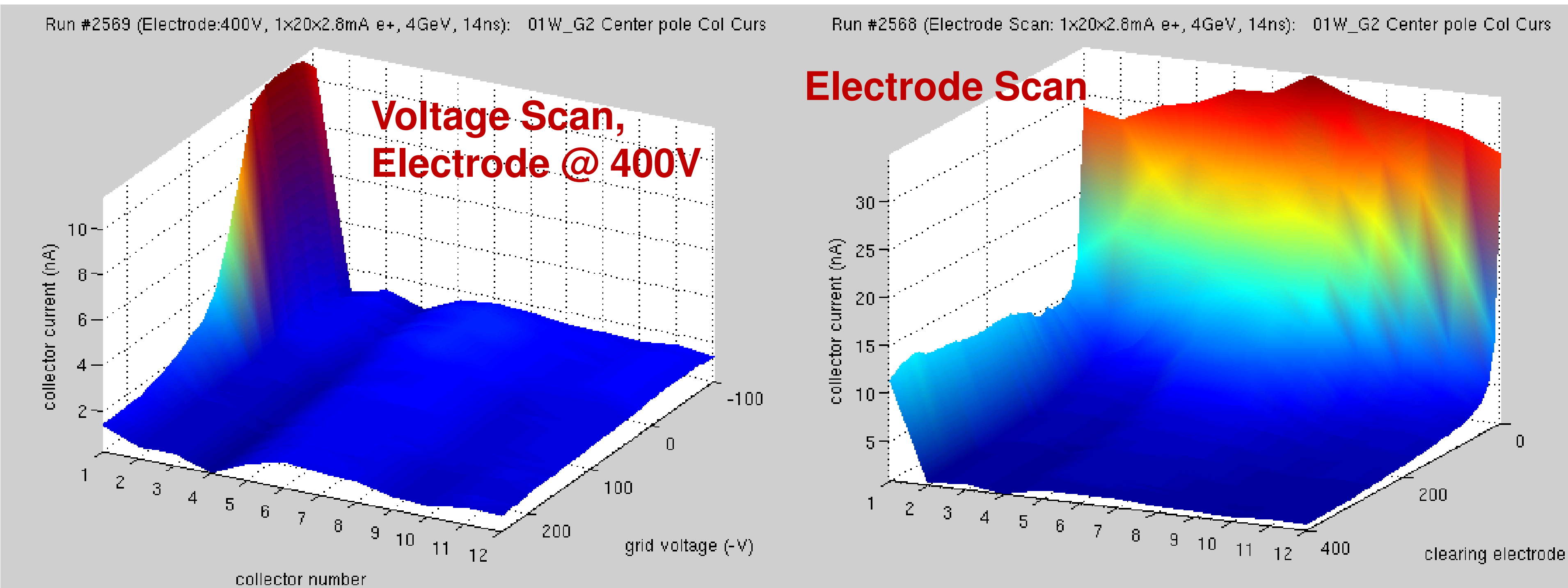
- Left plot shows typical voltage scan in Cu center pole wiggler
- Right plot shows average collector current density vs beam current
  - 1x45 e+, 2.1 GeV, 14ns
  - TiN, Grooved, Electrode chamber all in same location at different times
- Cu, TiN, and grooved chambers all within a factor of two
  - Electrode chamber does significantly better





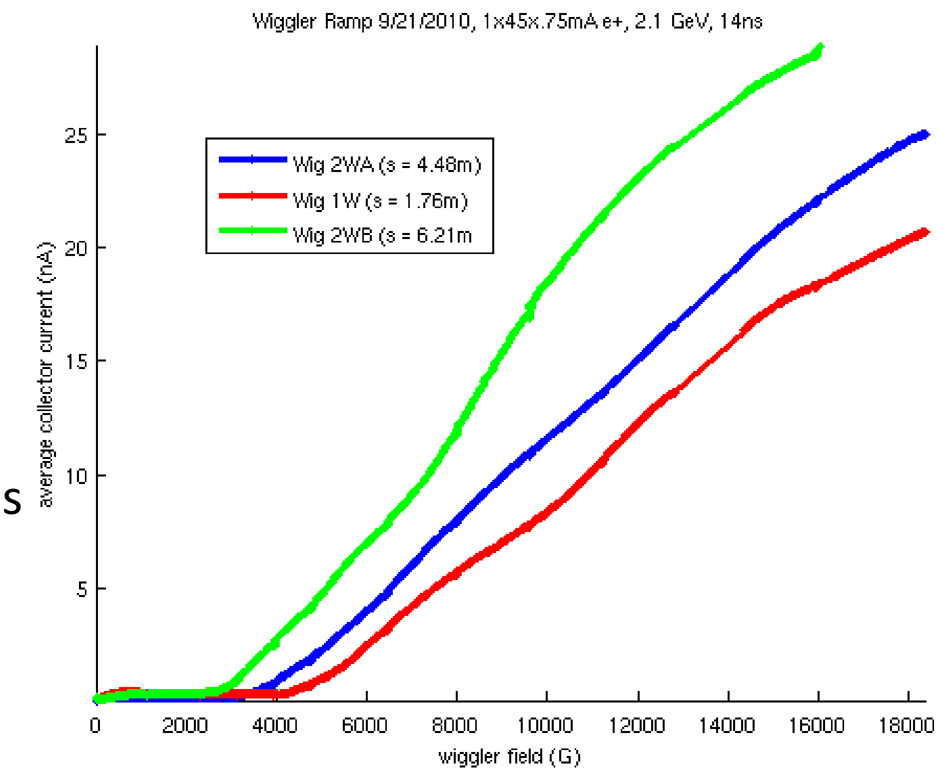
Clearing Electrode Scan

- Goes up to 400V
- 1x20x2.8 mA e+, 14ns, 4 GeV, wigglers ON
- Cloud suppression is very strong, except on collector 1
  - Electrode is exactly the width of the RFA
  - In other collectors, signal is essentially gone by 100V



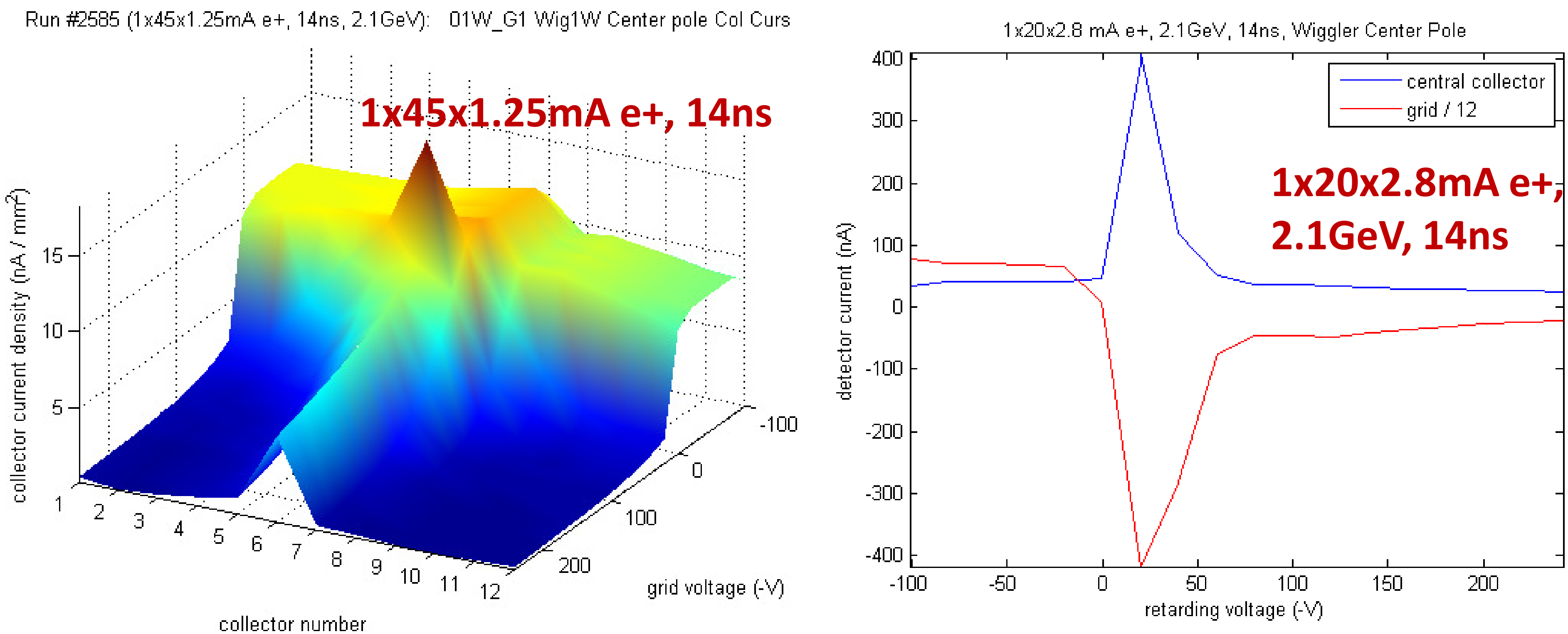
Wiggler Ramp

- L0 RFA currents were monitored while wigglers were ramped down
- Plot shows average collector current in wiggler center pole RFAs as a function of wiggler field strength
  - Note "turn on" of signal at each RFA, presumably as photons from upstream wigglers hit the beam pipe at that location
    - Further downstream wigglers turn on sooner
  - Beam conditions:
    - 1x45x~.75mA e+,
    - Normalized to beam current
    - 2.1 GeV, 14ns
- Helpful, since photon flux is difficult to calculate in straight sections (depends strongly on reflections)



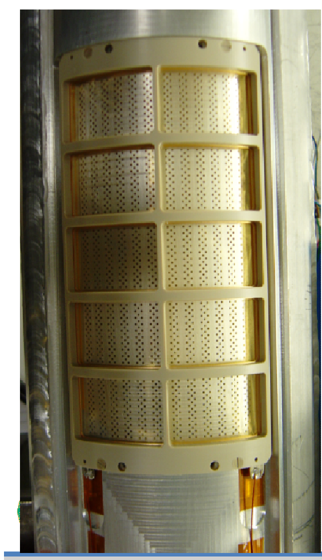
Resonant Enhancement

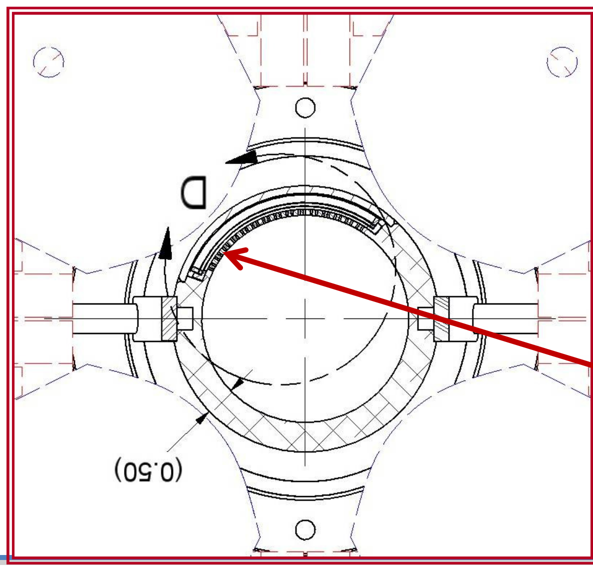
- In a high magnetic field (e.g. wiggler pole center), electrons are strongly pinned to the field lines
- Secondary electrons produced on grid can be accelerated through retarding voltage back out into vacuum chamber
- End result is a resonant condition between retarding voltage and bunch spacing
  - Leads to an enhancement in signal at low (but nonzero) retarding voltage

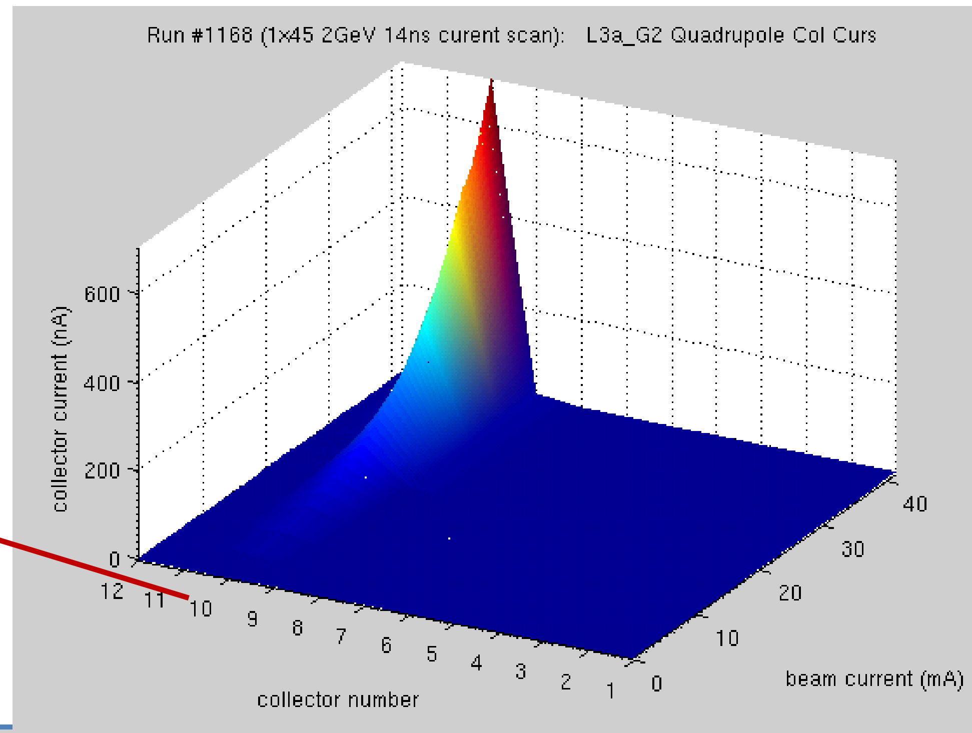


Quadrupole Mitigation

- We have instrumented a quadrupole chamber with an RFA
- One collector sees a huge amount of current
  - This is where the electrons are guided by the quad field lines
- There have been both bare Al and TiN coated chambers installed in the same location

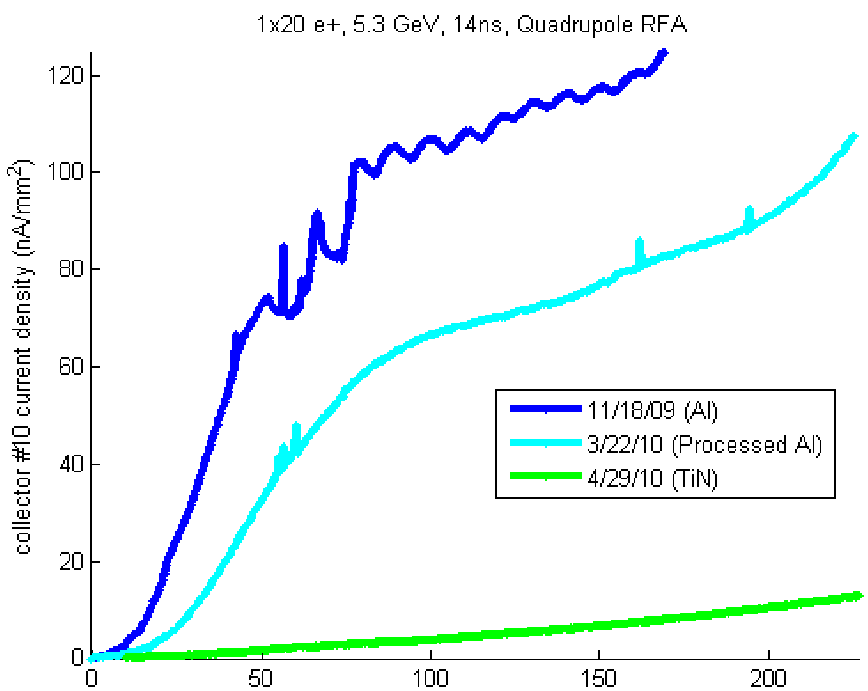


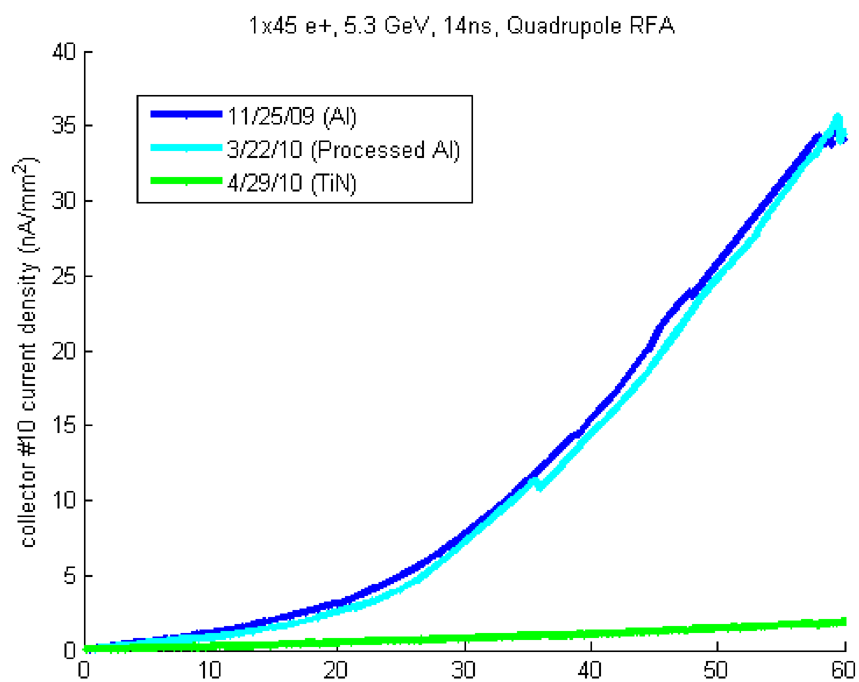




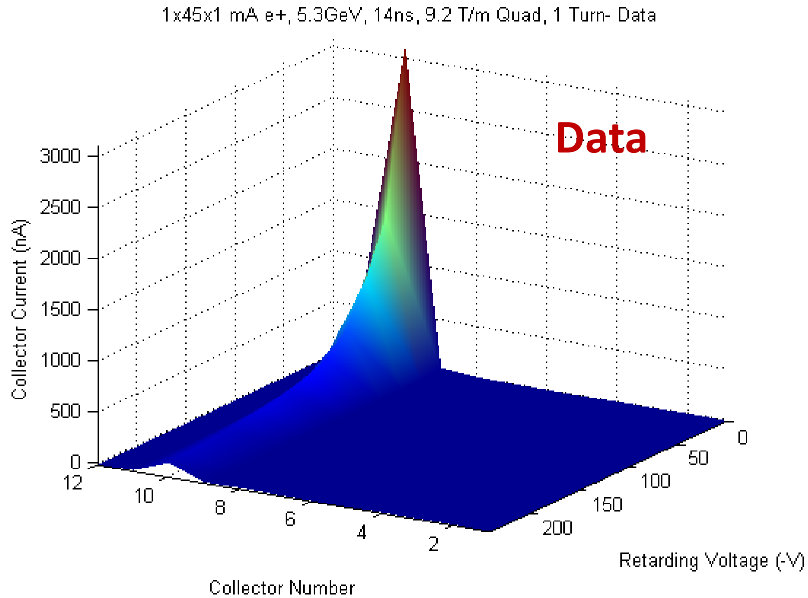
TiN Coated Quad

- Plotting current in collector #10 (the one that sees a large signal)
- TiN shows improvement of well over an order of magnitude

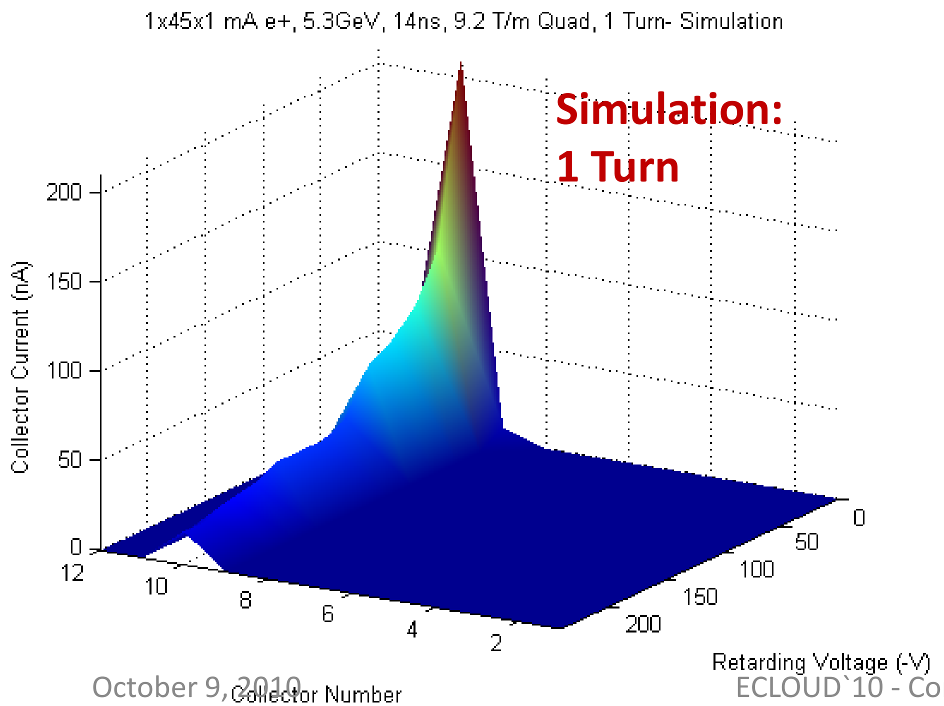


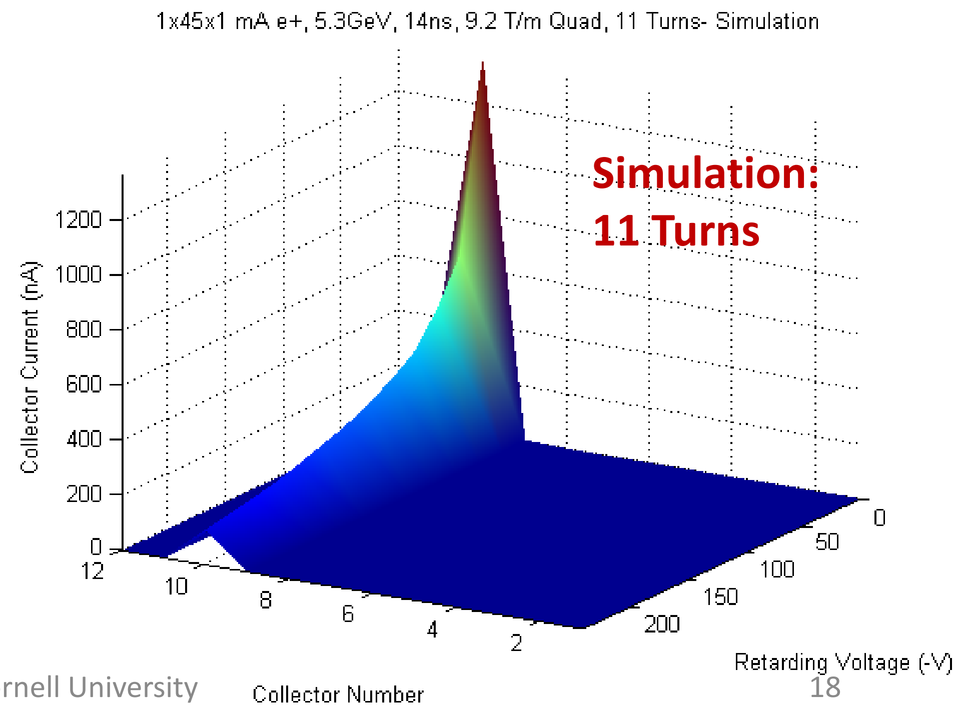


Slow Buildup in Quadrupole



- 1x45x1 mA e+, 5.3GeV, 9.2 T/m
- 1 turn simulation underestimates data by more than an order of magnitude
- 11 turn simulation is quite close at high energy, within a factor of 2 at low energy
- This indicates cloud is building up over several turns before it reaches equilibrium
    - So it must be persisting over the ~2μs between trains



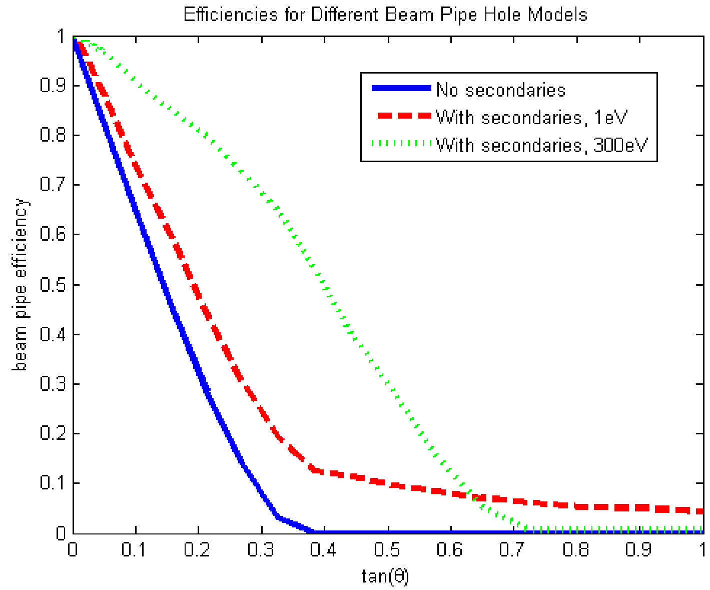


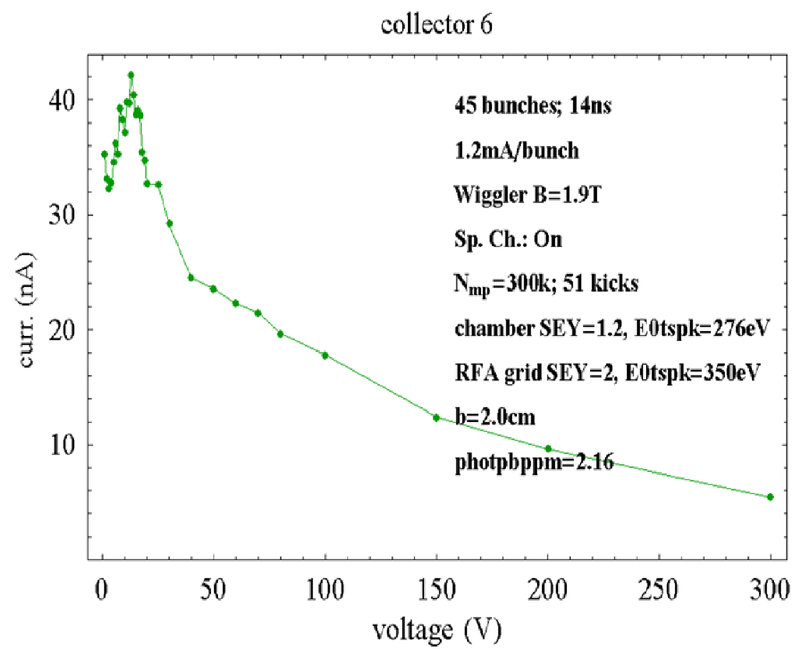
Simulations

- Goal: Use RFA data to provide constraints on the surface parameters of the chamber --> a challenging exercise
- Requires cloud simulation program (e.g. POSINST or ECLOUD)
- Also need a model of the RFA itself
  - Method 1: post-processing
    - Perform a series of calculations on the output of a simulation program to determine what the RFA would have seen had it been there
    - Relatively easy, can perform an entire "voltage scan" on the output of one simulation
  - Method 2: integrated model
    - Put a model for the RFA in the actual simulation code
    - More self-consistent, can model effects of the RFA on the development of the cloud
    - Need to do a separate simulation for each retarding voltage

Subtleties

- **Beam pipe hole secondaries**
  - Secondary electrons can be generated in the beam pipe holes in front of the RFA, leading to a low energy enhancement in the RFA signal.
  - We have developed a specialized particle tracking code to quantify this effect.
  - This code indicates low energy electrons maintain some probability of a successful passage even at high incident angle (due to elastic scattering)
  - High energy electrons have a higher efficiency at intermediate angles (due to the production of "true secondaries."
- **Photoelectron model:**
  - The traditionally used low energy photoelectrons do not provide sufficient signal for electron beam data with high bunch current.
  - A Lorentzian photoelectron energy distribution with a wide width (~150 eV) has been added to POSINST.
- **Interaction with cloud:**
  - The “resonant enhancement” has been observed qualitatively with integrated models in ECLOUD in POSINST





"Linear Parameter" Method

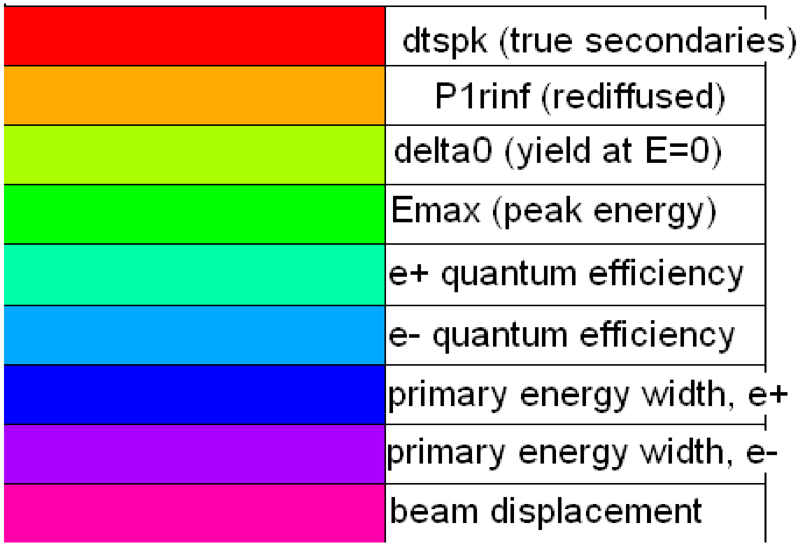
- Need a systematic method to extract best fit simulation parameters from large amount of data.

1. Choose a set of (related) voltage scans
2. Choose a set of simulation parameters
3. Do a simulation with the nominal values for each parameter
4. Postprocess the output of simulations to obtain a predicted RFA signal
5. For each data set and each parameter, do a simulation with a high and low value of the parameter, and determine the predicted RFA signal
6. For each data point in the simulated voltage scan, do a best linear fit to the curve of RFA signal vs parameter value. The slope of this line determines how strongly this point depends on the parameter
7. Try to find a set of parameters that minimizes the difference between data and simulation, assuming linear dependence of each voltage scan point on each parameter.
8. Repeat the process until fits stop getting better

- Simulations have been done for beam conditions shown in table

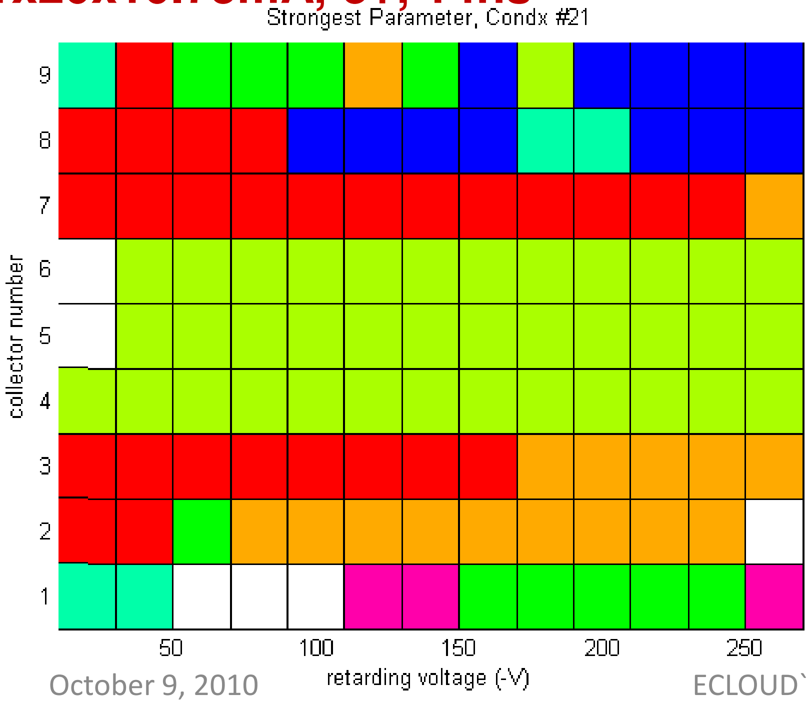
Condx #	Run #	Bunches	Spacing (ns)	Energy (GeV)	Bunch Current (mA)	Species
20	2615	20	14	5.3	2.8	e+
21	2619	20	14	5.3	10.75	e+
22	2624	45	14	5.3	0.75	e+
23	2626	45	14	5.3	1.25	e+
24	2628	45	14	5.3	2.67	e+
25	2632	9	280	5.3	4.11	e+
26	2635	20	14	5.3	2.8	e-
27	2642	20	14	5.3	10.75	e-
28	2647	45	14	5.3	0.8	e-
29	2651	45	14	5.3	1.25	e-
30	2655	9	280	5.3	3.78	e-

Parameter “Domains”

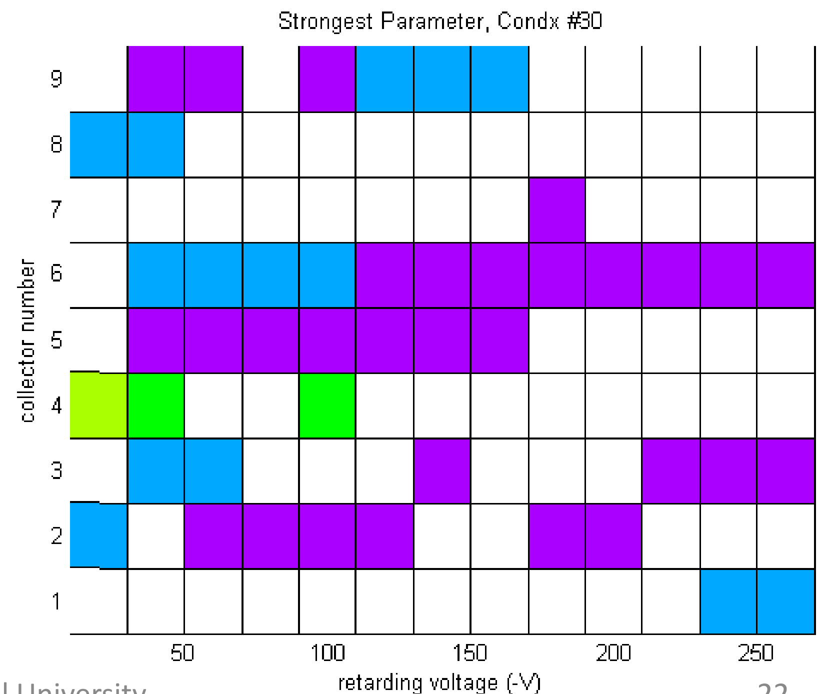


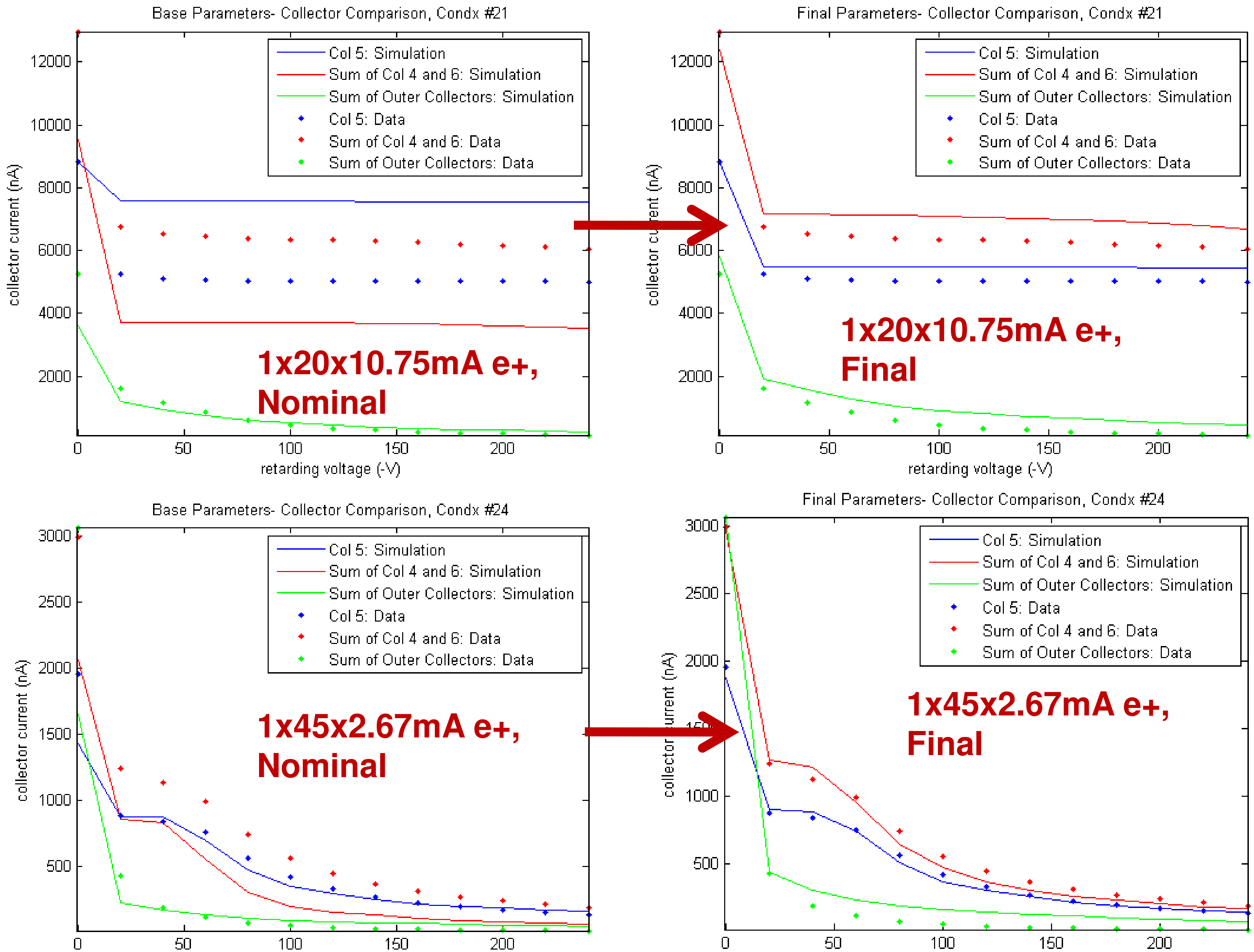
- We want to understand where each parameter matters the most
  - Plots show the “strongest” (i.e. highest slope) parameter, as a function of retarding voltage and collector number, for various conditions
  - Color coded according to legend to the left
- Examples shown are for Aluminum chamber

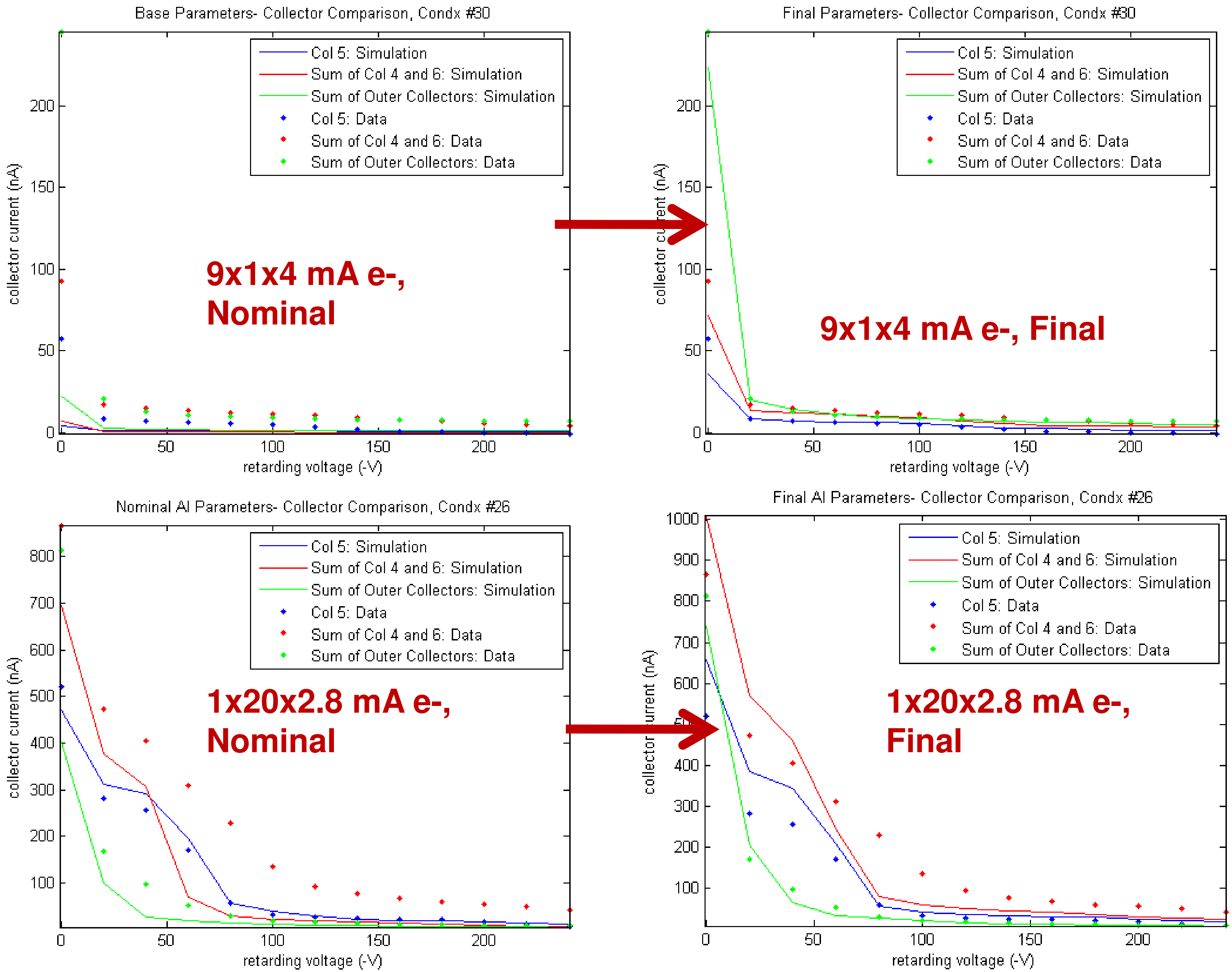
1x20x10.75mA, e+, 14ns



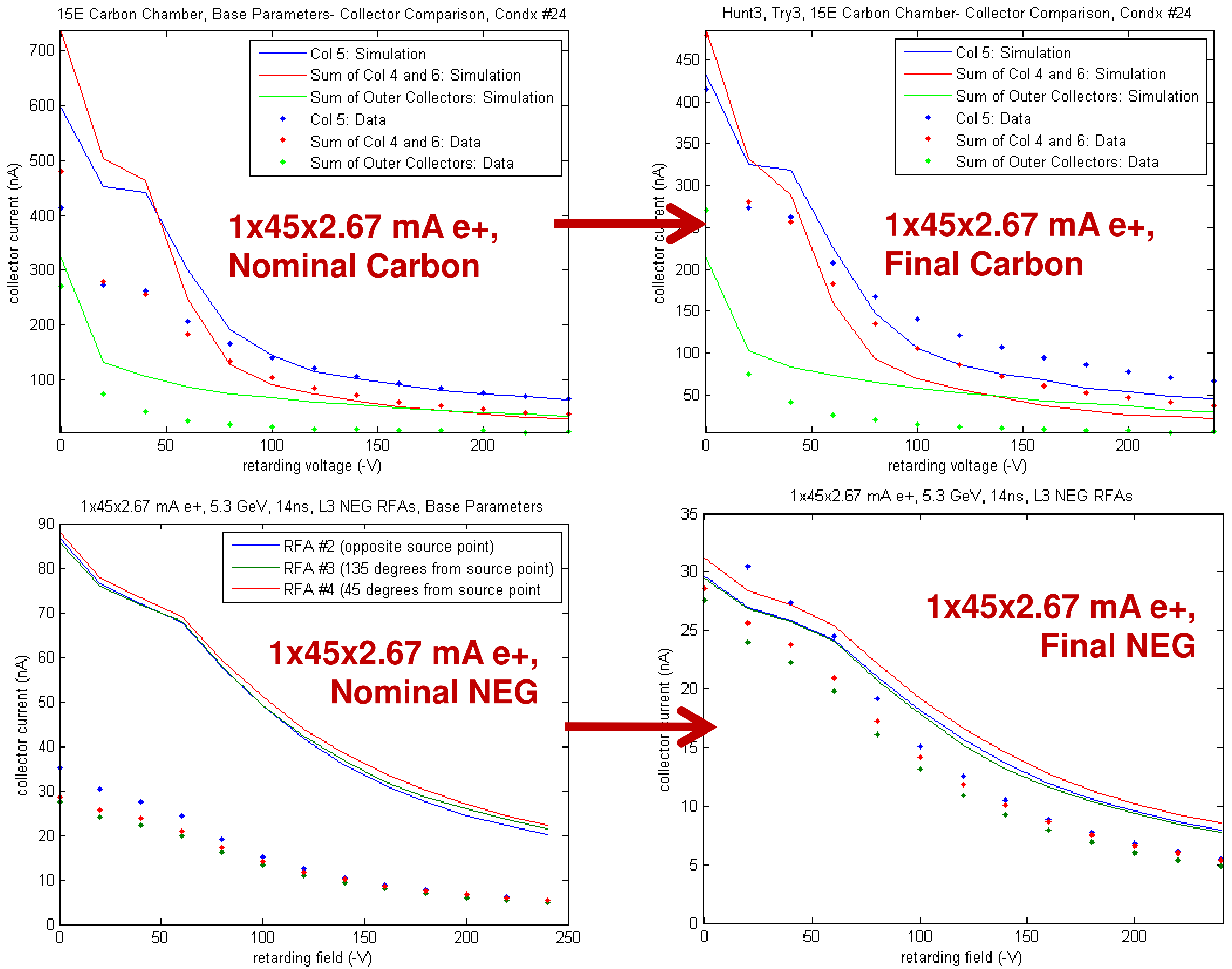
9x1x4 mA, e-, 280ns




Base Parameters- Collector Comparison, Condx #21
Final Parameters- Collector Comparison, Condx #21
Base Parameters- Collector Comparison, Condx #24
Final Parameters- Collector Comparison, Condx #24
Col 5: Simulation
Sum of Col 4 and 6: Simulation
Sum of Outer Collectors: Simulation
Col 5: Data
Sum of Col 4 and 6: Data
Sum of Outer Collectors: Data
collector current (nA)
retarding voltage (-V)
1x20x10.75mA e+, Nominal
1x20x10.75mA e+, Final
1x45x2.67mA e+, Nominal
1x45x2.67mA e+, Final



Base Parameters- Collector Comparison, Condx #30
Col 5: Simulation
Sum of Col 4 and 6: Simulation
Sum of Outer Collectors: Simulation
Col 5: Data
Sum of Col 4 and 6: Data
Sum of Outer Collectors: Data
collector current (nA)
retarding voltage (-V)
9x1x4 mA e-, Nominal
Final Parameters- Collector Comparison, Condx #30
Col 5: Simulation
Sum of Col 4 and 6: Simulation
Sum of Outer Collectors: Simulation
Col 5: Data
Sum of Col 4 and 6: Data
Sum of Outer Collectors: Data
collector current (nA)
retarding voltage (-V)
9x1x4 mA e-, Final
Nominal Al Parameters- Collector Comparison, Condx #26
Col 5: Simulation
Sum of Col 4 and 6: Simulation
Sum of Outer Collectors: Simulation
Col 5: Data
Sum of Col 4 and 6: Data
Sum of Outer Collectors: Data
collector current (nA)
retarding voltage (-V)
1x20x2.8 mA e-, Nominal
Final Al Parameters- Collector Comparison, Condx #26
Col 5: Simulation
Sum of Col 4 and 6: Simulation
Sum of Outer Collectors: Simulation
Col 5: Data
Sum of Col 4 and 6: Data
Sum of Outer Collectors: Data
collector current (nA)
retarding voltage (-V)
1x20x2.8 mA e-, Final


15E Carbon Chamber, Base Parameters- Collector Comparison, Condx #24
Col 5: Simulation
Sum of Col 4 and 6: Simulation
Sum of Outer Collectors: Simulation
Col 5: Data
Sum of Col 4 and 6: Data
Sum of Outer Collectors: Data
collector current (nA)
retarding voltage (-V)
1x45x2.67 mA e+,
Nominal Carbon
Hunt3, Try3, 15E Carbon Chamber- Collector Comparison, Condx #24
Col 5: Simulation
Sum of Col 4 and 6: Simulation
Sum of Outer Collectors: Simulation
Col 5: Data
Sum of Col 4 and 6: Data
Sum of Outer Collectors: Data
retarding voltage (-V)
1x45x2.67 mA e+,
Final Carbon
1x45x2.67 mA e+, 5.3 GeV, 14ns, L3 NEG RFAs, Base Parameters
RFA #2 (opposite source point)
RFA #3 (135 degrees from source point)
RFA #4 (45 degrees from source point
collector current (nA)
retarding field (-V)
1x45x2.67 mA e+,
Nominal NEG
1x45x2.67 mA e+, 5.3 GeV, 14ns, L3 NEG RFAs
retarding field (-V)
1x45x2.67 mA e+,
Final NEG

Preliminary Results

- Best fit parameters shown below
  - Note very low peak SEY (~.9) for Carbon and NEG coatings
  - Very low quantum efficiency for NEG is probably due to overestimation of photon flux
    - NEG chamber is in a straight section, far from any dipoles, so flux is difficult to estimate

Parameter	Description	Nominal Value(s)	Final Value: Al	Final Value: Carbon	Final Value: NEG
dtspk	Peak "true secondary" yield	1.8 (Al), .8 (C, NEG)	2.18	0.618	0.715
P1rinf	"Rediffused" yield at infinity	0.2	0.227	0.221	0.173
dt0pk	Total peak yield (δmax)	2.0 (Al), 1.0 (C, NEG)	2.447	0.879	0.928
P1epk	Low energy elastic yield (δ(0))	0.5	0.416	0.26	0.452
E0tspk	Peak yield energy (Emax)	310 (Al), 500 (C, NEG)	314	486	500
queffp	Quantum efficiency	0.1	0.106	0.096	0.027

Conclusions

- A great deal of RFA data has been taken throughout the CesrTA program
  - RFAs have been installed in drifts, dipoles, quadrupoles, and wigglers
- Several mitigation techniques have been investigated
  - In drifts, beam pipe coatings (TiN, Carbon, and NEG) all seem quite effective in suppressing secondary yield
    - Primary electrons could still be an issue
  - In dipoles, TiN coating was found to be very effective
    - Grooves + TiN is even better
  - TiN also suppresses the cloud in quadrupoles
  - A clearing electrode was found to be most effective in a wiggler chamber
    - Also gets rid of primary electrons
- A systematic method has been used to improve agreement between RFA data and simulation, and best fit simulation parameters have been obtained.
- Future work includes:
  - Quantifying errors and correlations in best fit parameters
  - Repeating analysis for RFAs in magnetic fields
  - Continuing development of integrated RFA models
  - Detailed comparisons of RFA, SPU, and TE-Wave measurements