Electron Cloud Mitigation Studies at CesrTA

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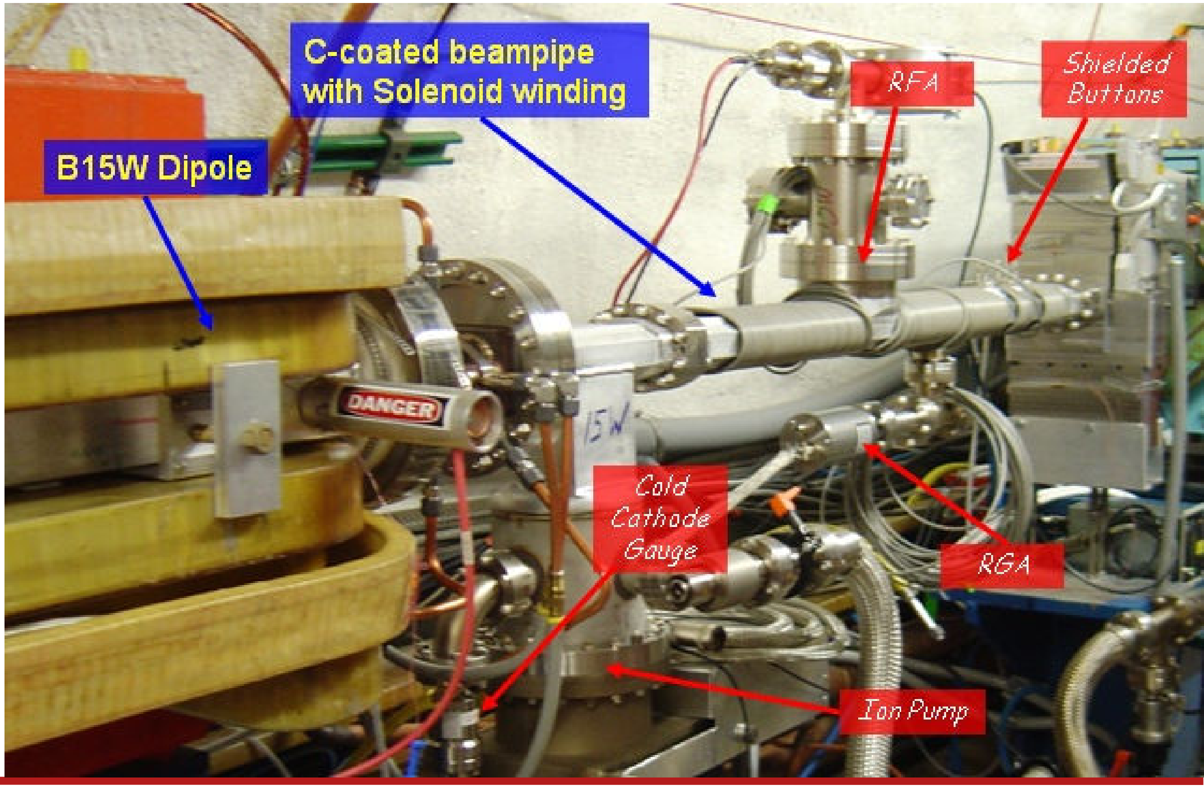
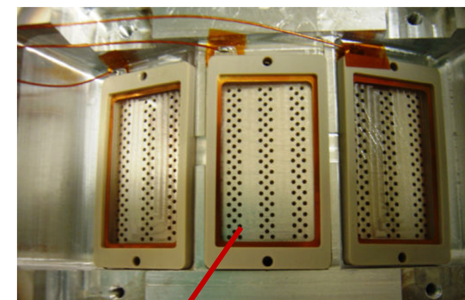
Introduction

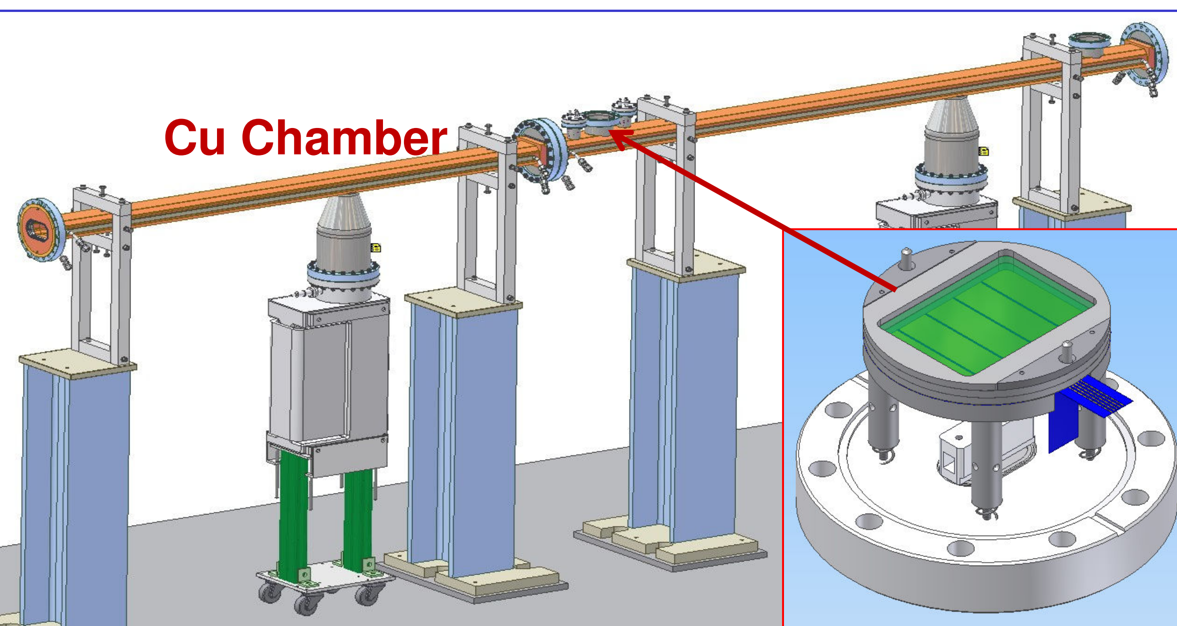
- The electron cloud effect is a potential limiting factor in future linear collider damping rings, so it is important to find the cheapest and most effective method for mitigating this effect.
- There are several different types of mitigation techniques currently under investigation at CesrTA
  - Beam pipe coatings
    - TiN
    - Amorphous carbon
  - Grooves
  - Solenoids
  - Clearing electrodes (planned)
- These techniques are applied in different magnetic field regions
  - Drift
  - Wiggler
  - Chicane (dipole)
  - Quadrupole
- Local e- cloud density is measured with retarding field analyzers

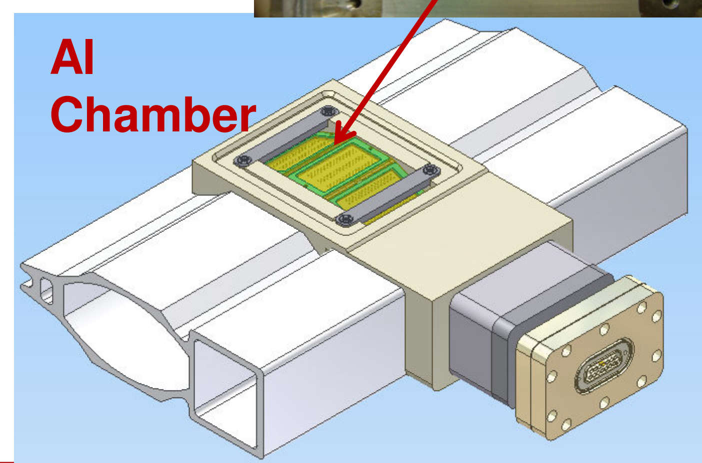


Drift Mitigation

- We are investigating mitigation techniques in drift chambers made of different materials
  - Aluminum
    - RFA has 9 collectors and is integrated into beam pipe
    - To be compared with amorphous carbon coated aluminum chamber
      - At a symmetric location to the bare Al chamber
      - Photon flux for Al chamber with e+ beam = photon flux for αC chamber with e- beam
  - Copper
    - RFA has 5 collectors and sits on top of beam pipe
    - To be compared with TiN coated copper chamber
      - Next to the bare Cu chamber

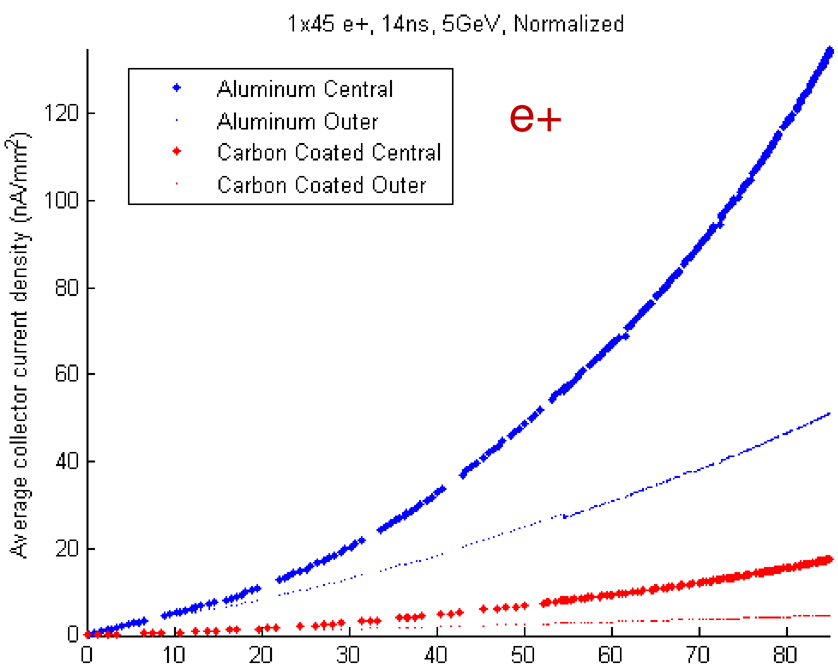


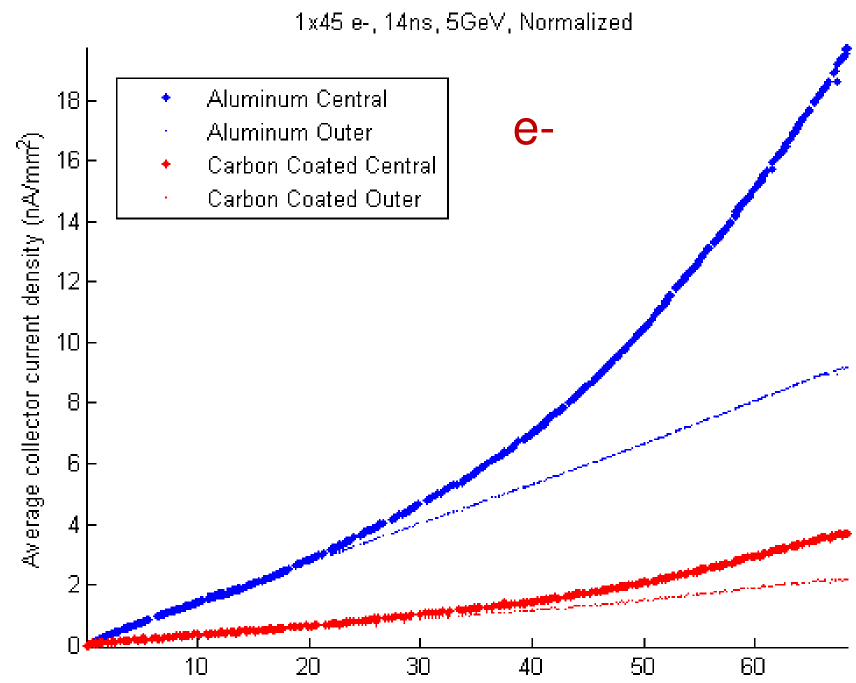




Drift Mitigation- Al

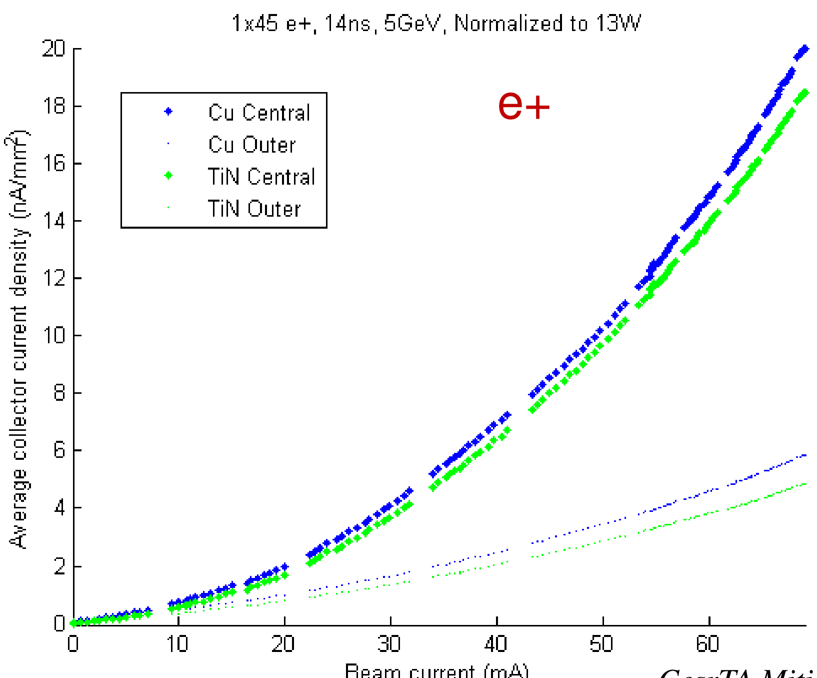
- Plots show RFA collector current vs beam current
  - Comparing carbon coated chamber (red) to bare Al (blue)
    - Thick line: central 3 collectors
      - More sensitive to multipacting
    - Thin line: outer six collectors
  - In units of nA/mm^2
    - RFA transparency has been taken into account
  - Also normalized to 15W (carbon coated chamber) photon flux
- Uncoated chamber shows significantly more response for both electron and positron beams, particularly in the central collectors

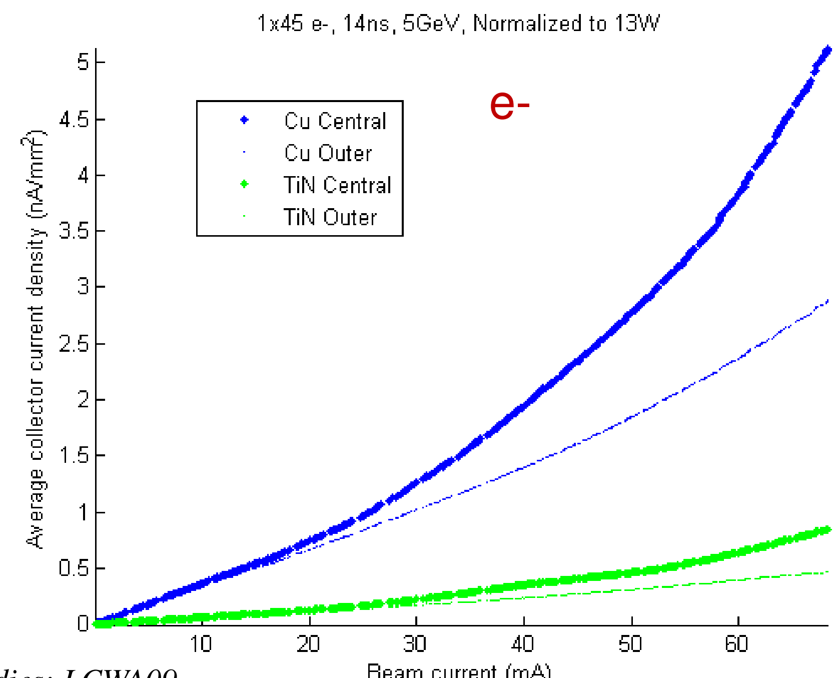




Drift Mitigation- Cu

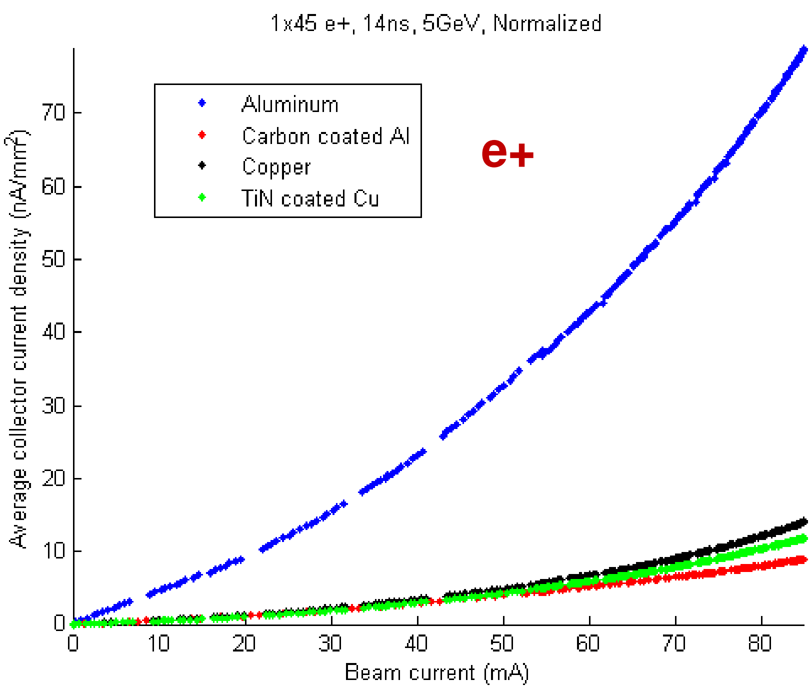
- Plots show RFA collector current vs beam current
  - Comparing TiN coated chamber (green) to bare Cu (blue)
    - Thick line: central collector
      - More sensitive to multipacting
    - Thin line: outer four collectors
  - In units of nA/mm^2
    - RFA transparency has been taken into account
  - Also normalized to 15W (carbon coated chamber) photon flux
- Normalized response is very similar for positron beam, but TiN chamber seems to perform much better for electron beam
  - May be due to conditioning in the Cu chamber, or slightly incorrect photon flux (more on this later)

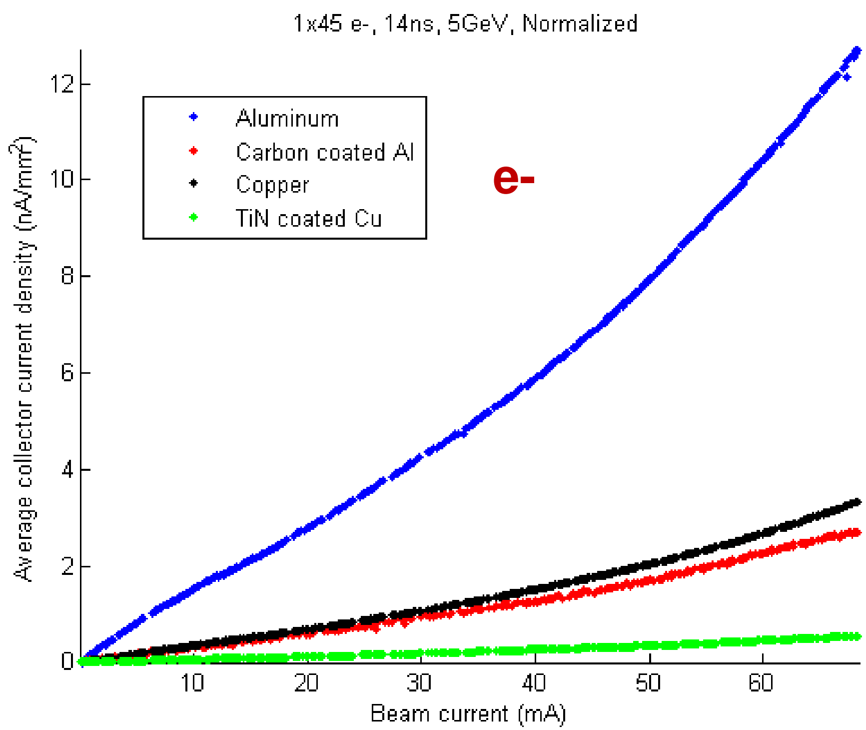




Drift Mitigation Summary

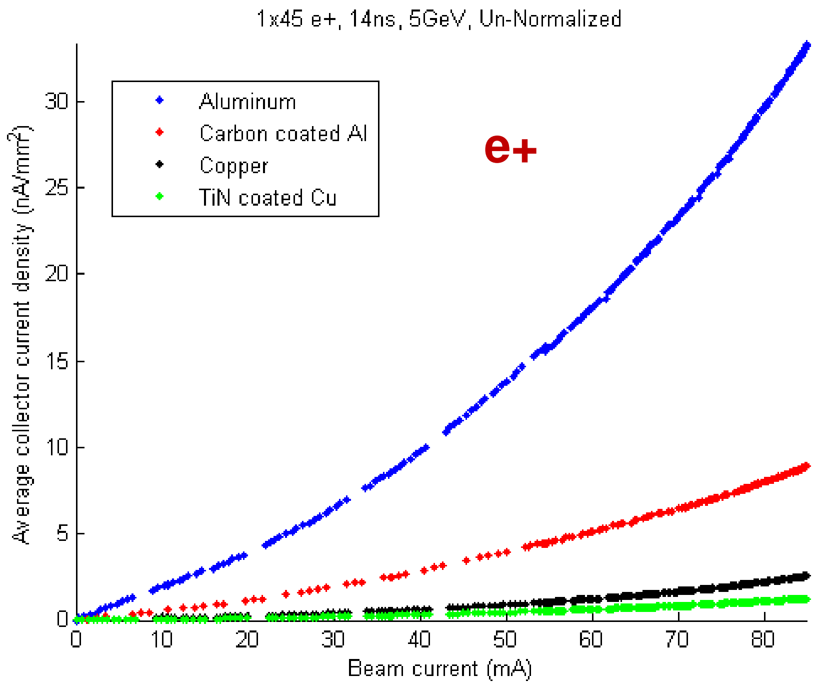
- Plots show average of all collectors for all drift RFAs
- In general, the most cloud is seen in the bare Al chambers (blue)
  - Much less in copper chambers (black)
  - Less still in coated chambers
    - TiN: green
    - Carbon: red

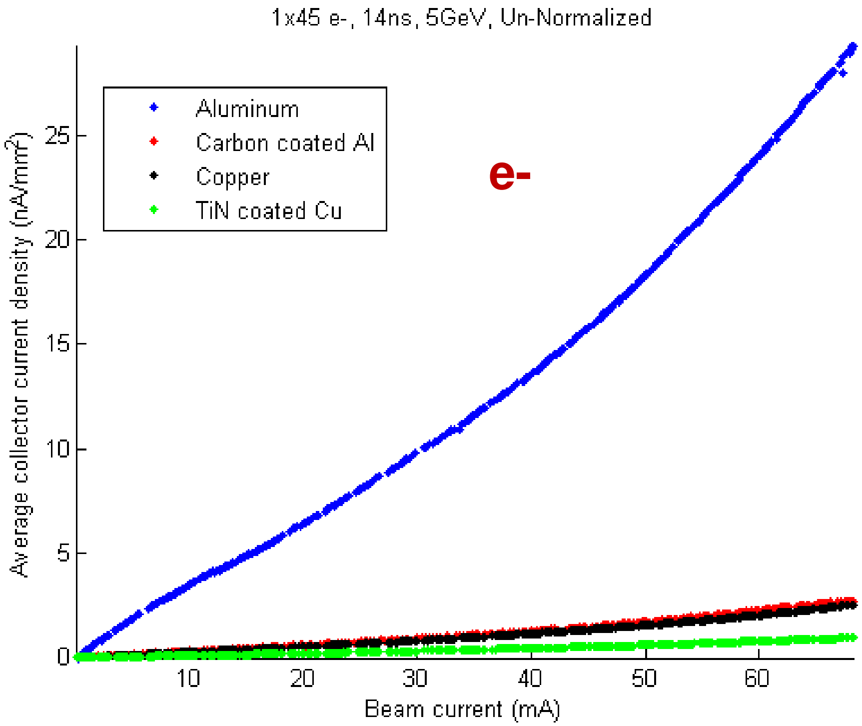




Drift Mitigation Summary II

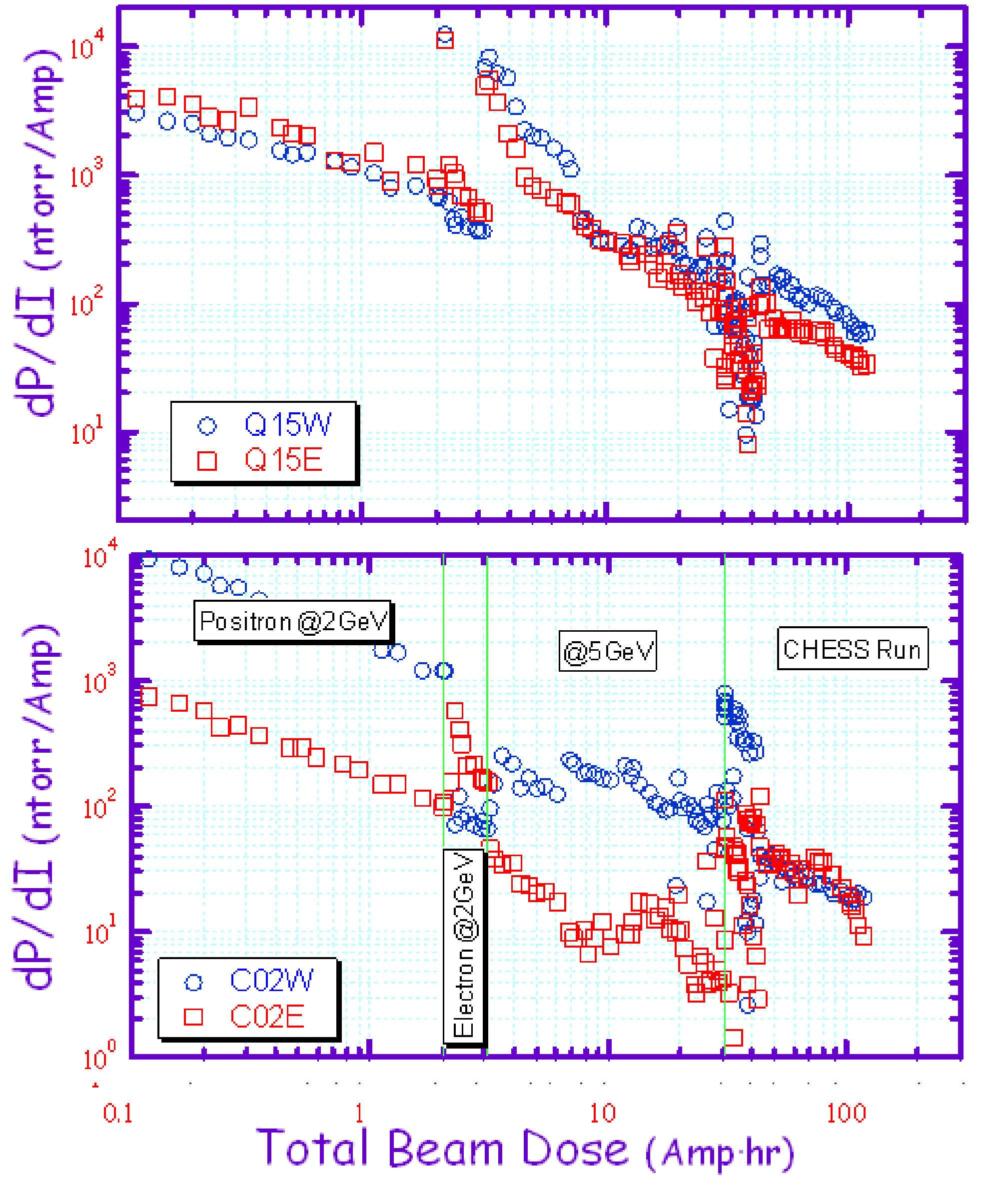
- Same plots as last slide, but not normalized to photon flux
- Al is still by far the worst, but normalization makes some difference in the relative strength of the signal in the other chambers
  - Current calculation of photon flux assumes no reflections
  - A new synchrotron radiation program, which will include reflections, is under development





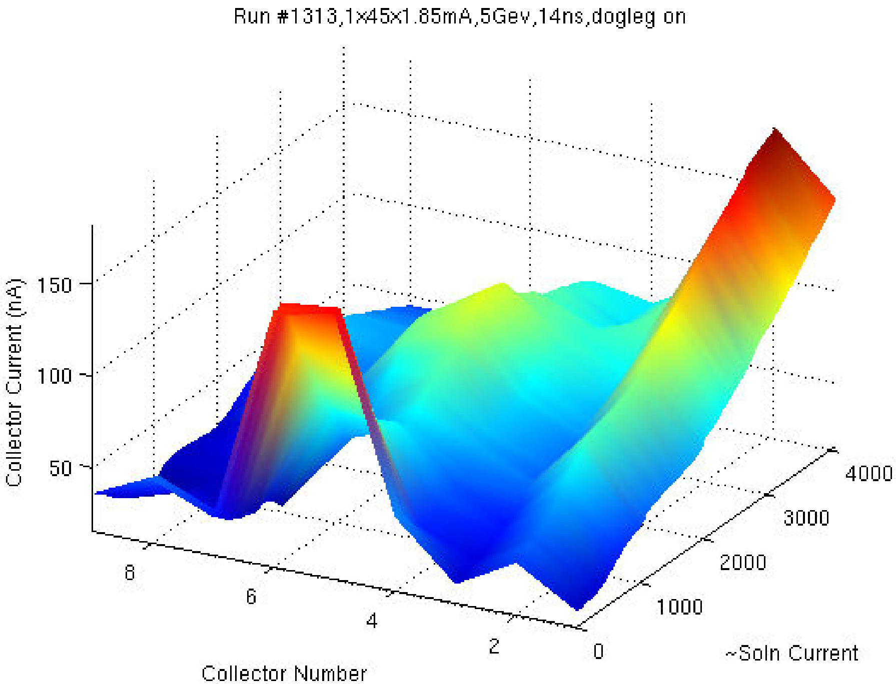
Vacuum Data

- Plots show dynamic pressure rise vs beam dose
  - Top plot shows pressure rise near carbon coated chamber (blue) is slightly higher than near Al chamber (red)
  - Bottom plots shows that pressure rise is much higher near TiN coated wiggler (blue) than near Cu wiggler (red)
- This is indirect evidence that TiN has somewhat worse vacuum properties



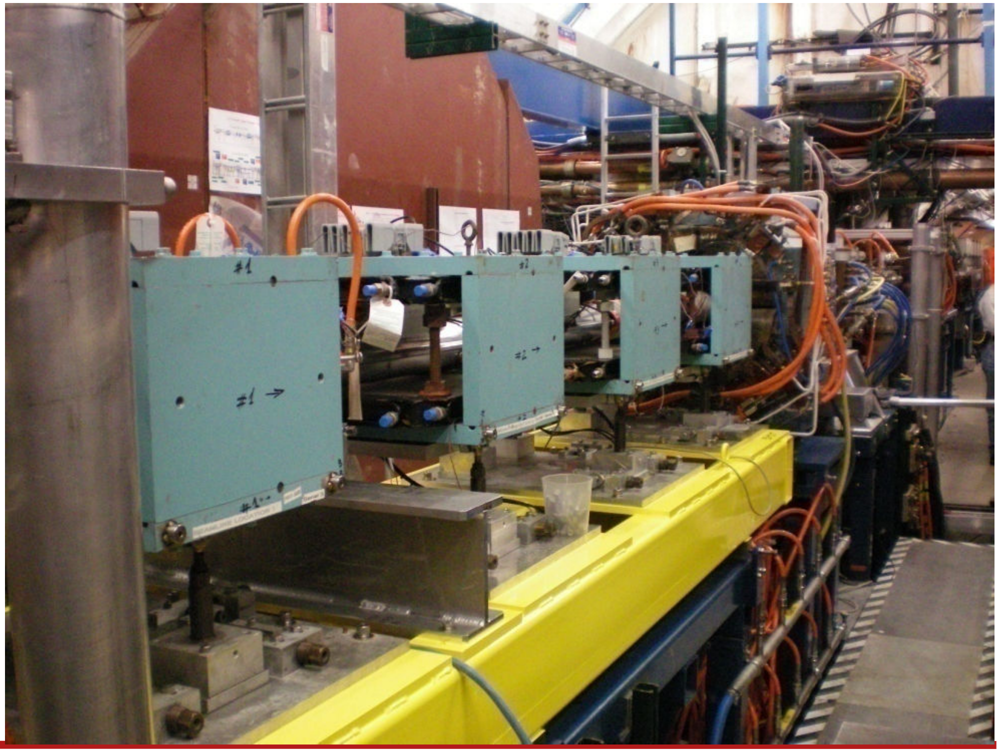
Solenoid Mitigation

- We are in the process of winding solenoid coils along all the drift regions at CESR
- When complete, we can test the effectiveness of this method by measuring the tune shift with solenoids on and off
- In the meantime, we looked at RFA response as an adjacent solenoid magnet was ramped up (0 – 70G)
  - Beam conditions: 1x45x1.85 mA e+, 5GeV, 14ns
  - As expected, a significant cloud suppression is observed in most collectors
  - However, collectors near the inside of the chamber actually see an increased response
    - This is probably due to electrons streaming from a nearby distributed ion pump



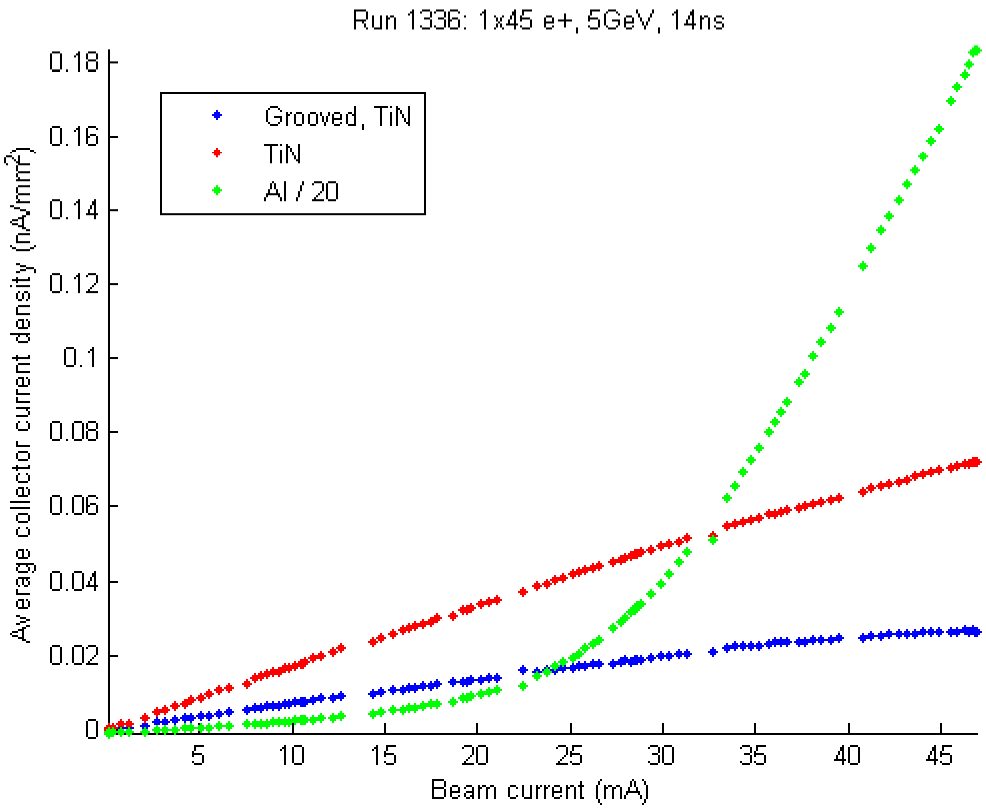
Chicane Mitigation

- 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
- We are looking for
- "cyclotron resonances"
  – These occur when the bunch spacing is an integral multiple of the cyclotron period of an electron
  -- Data shown is plotted against "resonance number"
  (= bunch spacing / cyclotron period)



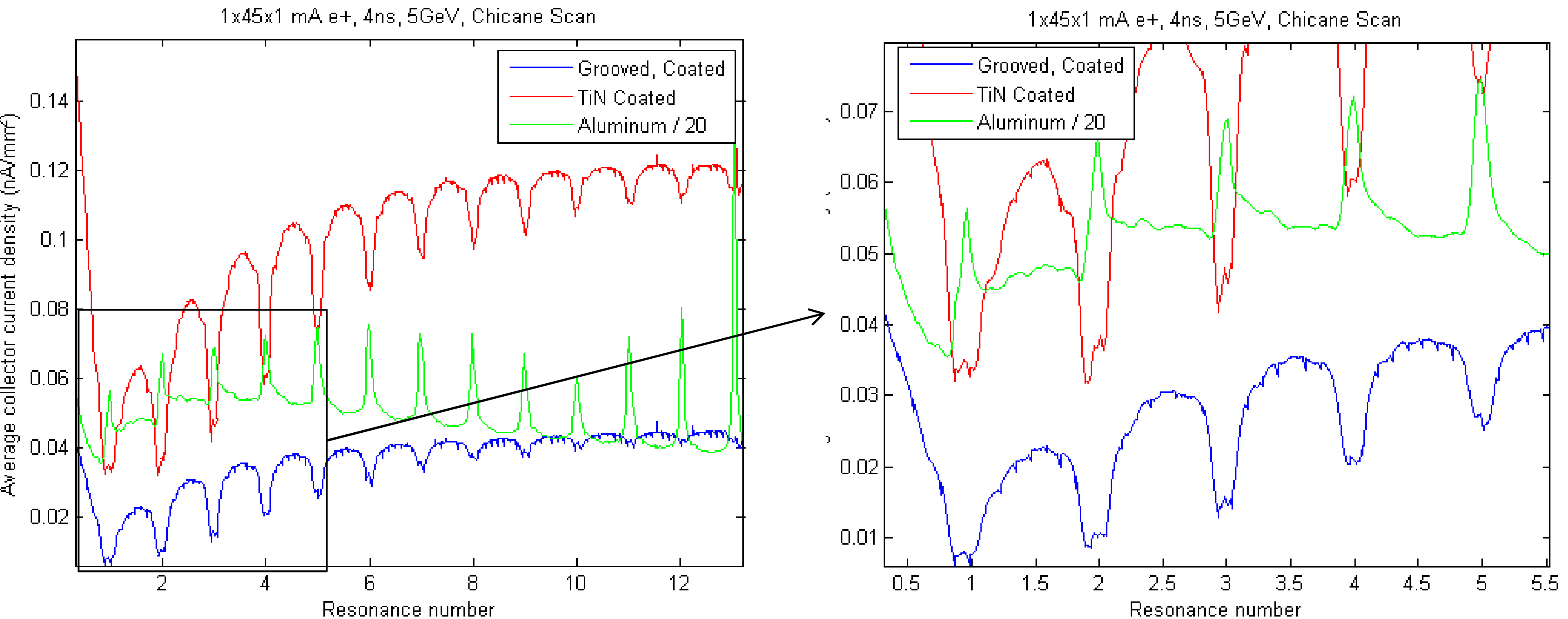
Chicane Current Scan

- 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



Chicane Field Scan

- 1x45x1 mA, 4ns, 5GeV, positrons
- Plots show sum of all collectors in each RFA
  - Note that Aluminum RFA signal is divided by 20
  - In terms of absolute current, Al >> TiN > Grooved + TiN
- 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



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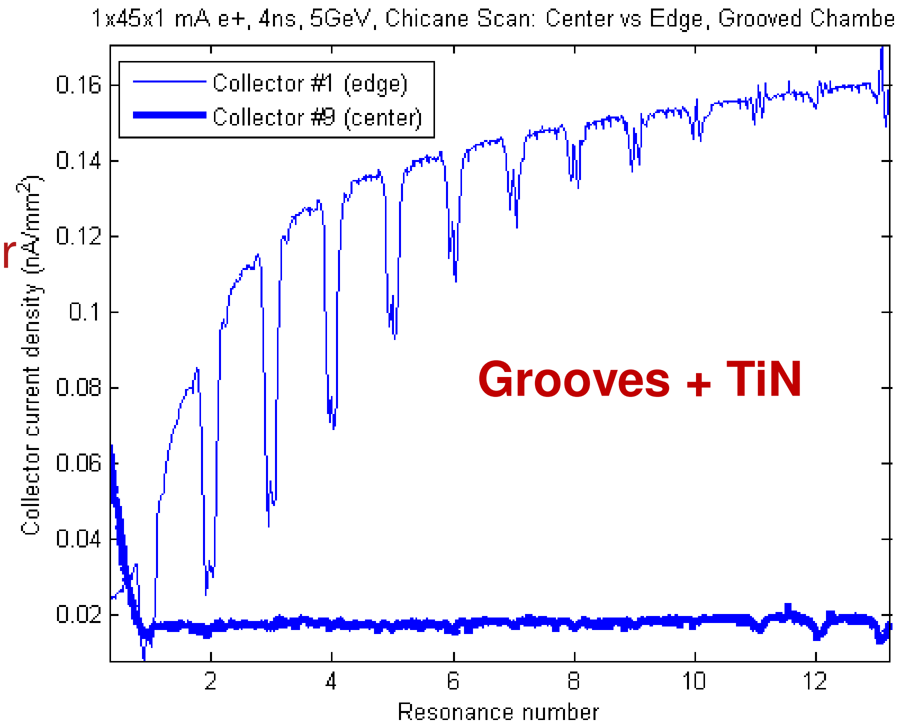
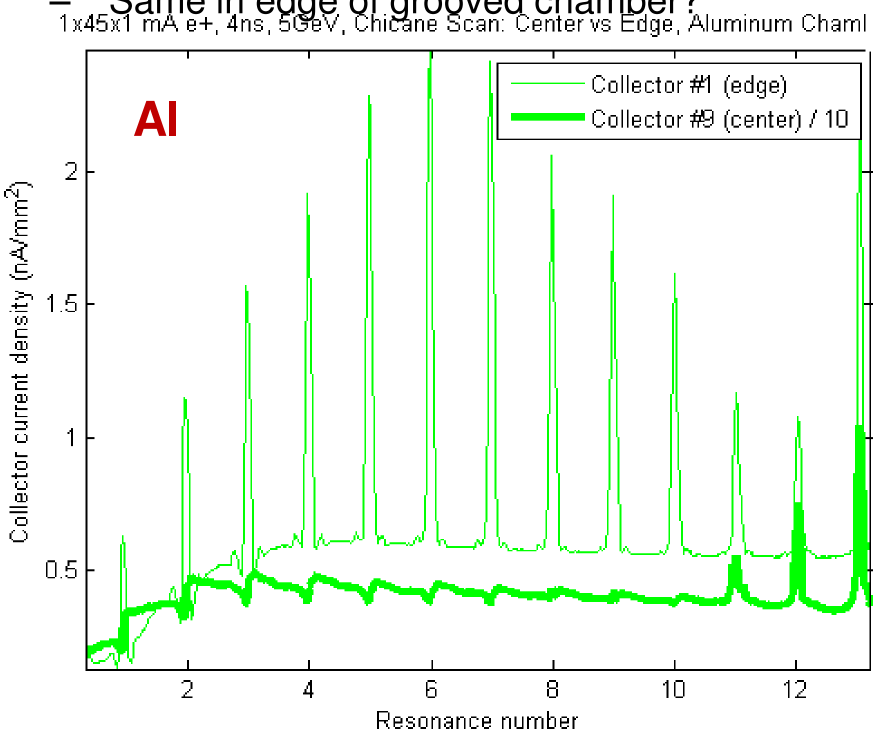
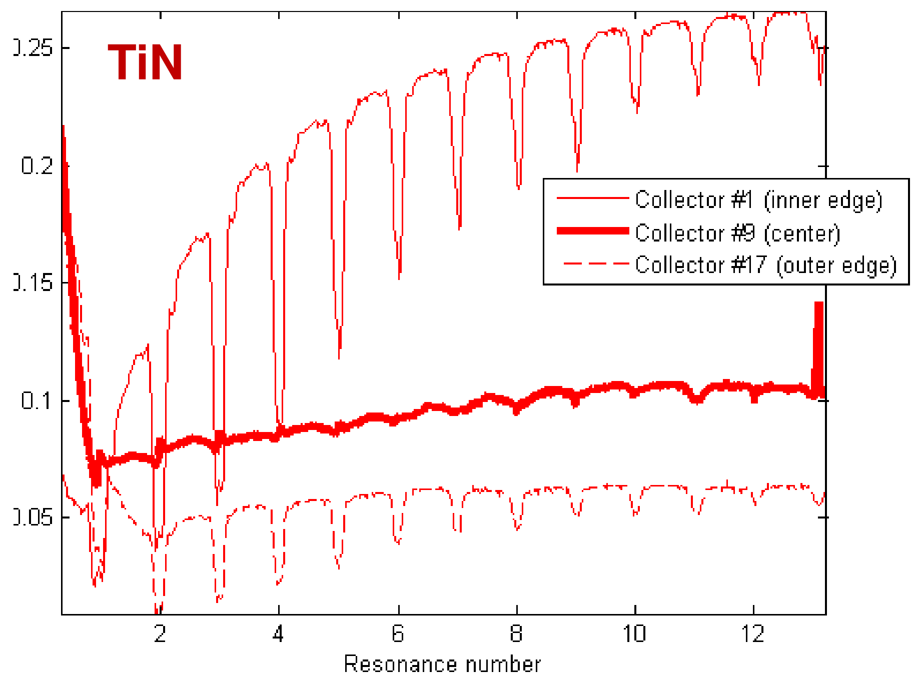
- **1x45x1 mA, 4ns, 5GeV, e+**
- Plots show outer and center collectors for the Al, TiN, and Grooved chambers
- Resonance tends to be much more pronounced in outer collectors
- TiN chamber is asymmetric
- Structure seems to be starting to change at high field
  - Dips -> peaks in central Aluminum collector
  - Same in edge of grooved chamber?



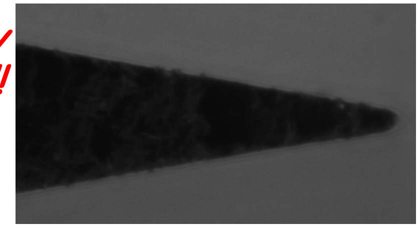


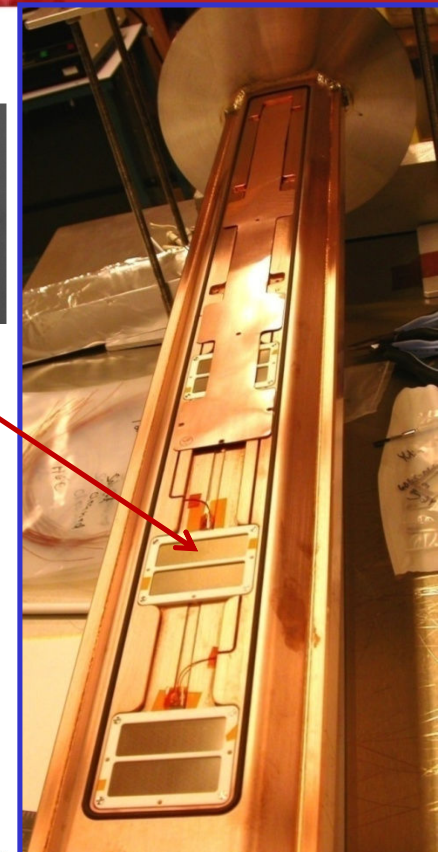


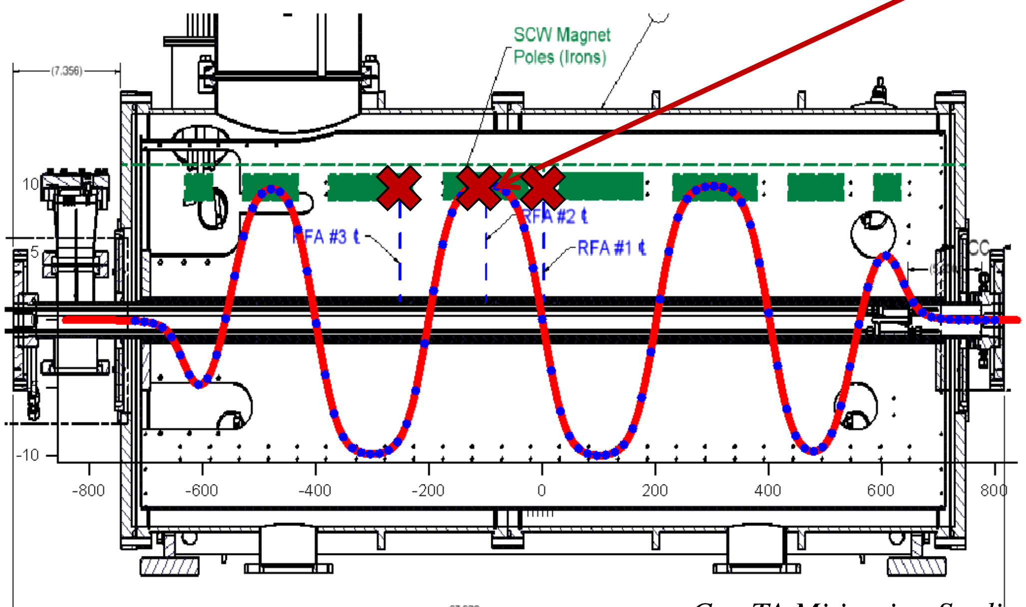
Wiggler Mitigation

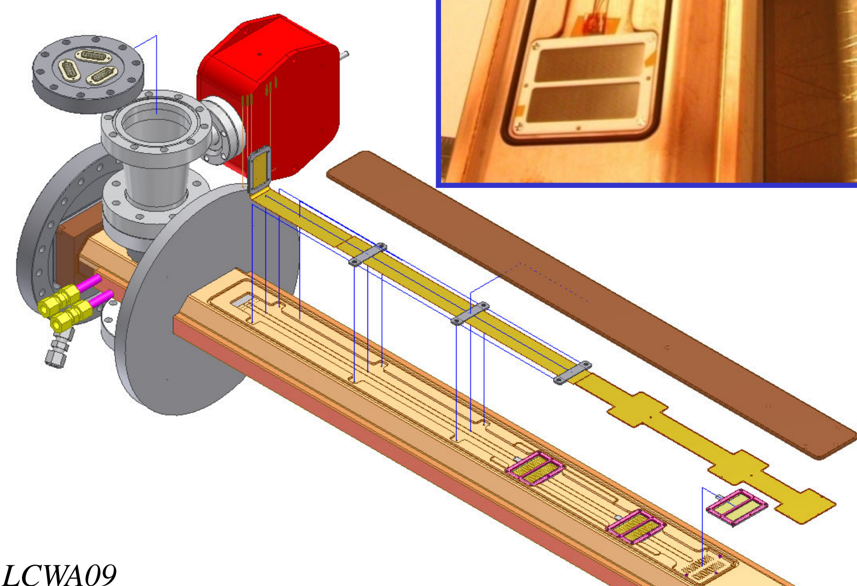
- We have three wigglers instrumented with RFAs
  - Bare Cu
  - TiN coated
  - Grooved
- Each wiggler has three RFAs
  - Plots shown will be for an RFA in the center of a wiggler pole
  - There are also RFAs in a longitudinal and intermediate field
  - RFAs have 12 collectors and are built into the beam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

Groove tips/valley radius < 0.002" !!



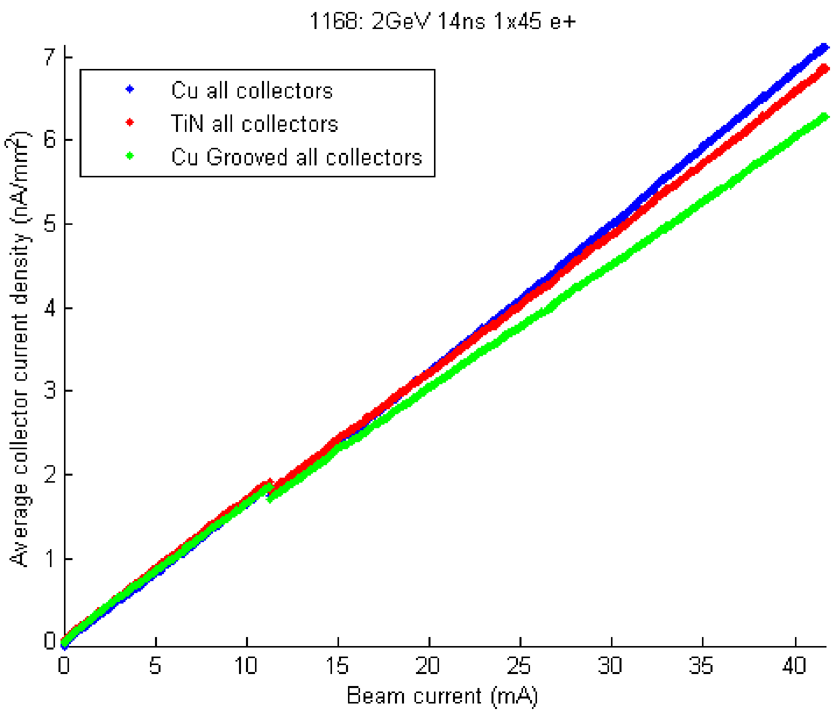


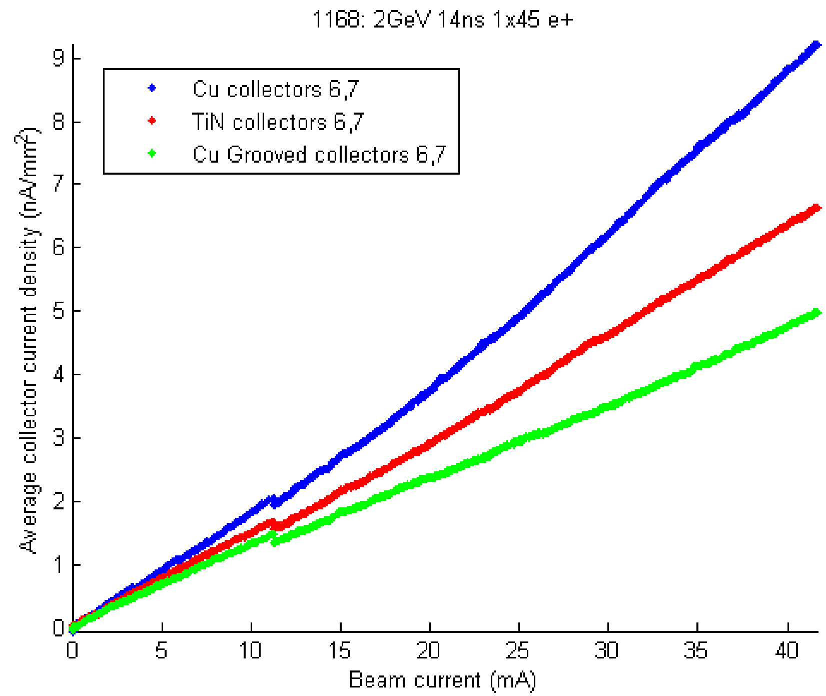




Wiggler Current Scan

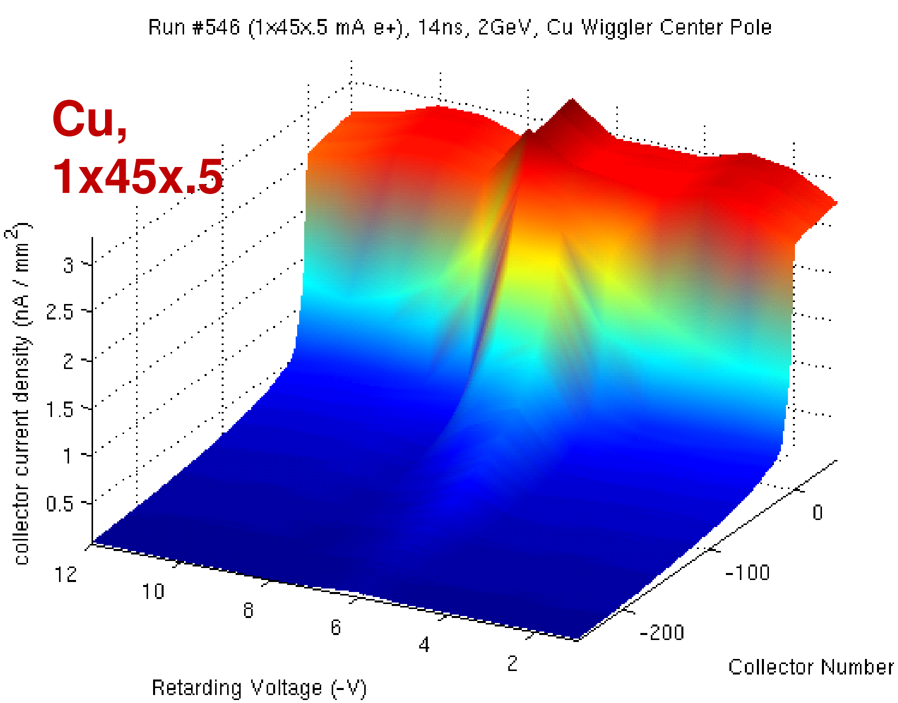
- Plots show average collector current density vs beam current
  - 1x45 e+, 2 GeV, 14ns
- Cu, TiN, and grooved chambers all have comparable responses (when normalized to photon flux)
  - Central collectors (right plot) show a more significant difference
    - This where one expects multipacting to occur

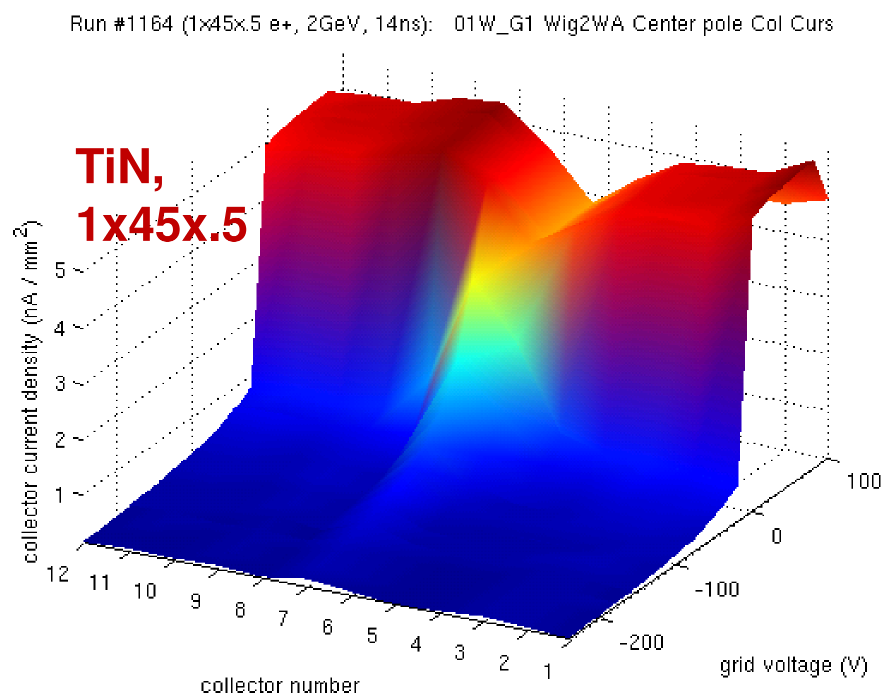




Voltage Scans

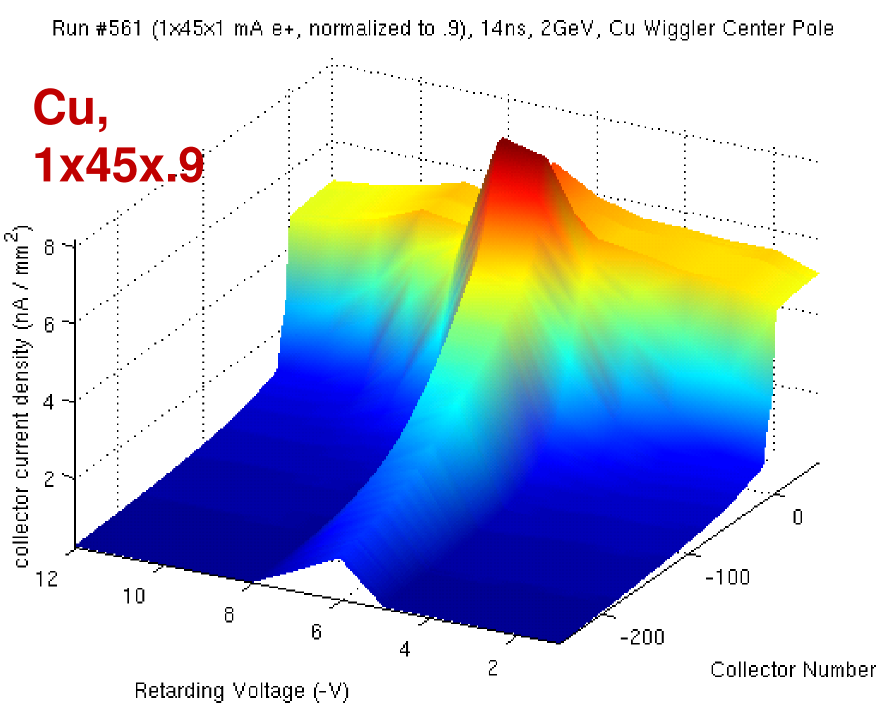
- Plots show collector response as a function of retarding voltage and collector number, normalized to photon flux
- Beam conditions: 1x45x.5 mA e+, 14ns, 2 GeV
- Data is from two different runs
  - The wigglers were shuffled around between runs, so these two plots are actually from the same longitudinal position
  - Cu (left) shows less response than TiN (right)
    - Is it possible TiN has a slightly higher quantum efficiency?

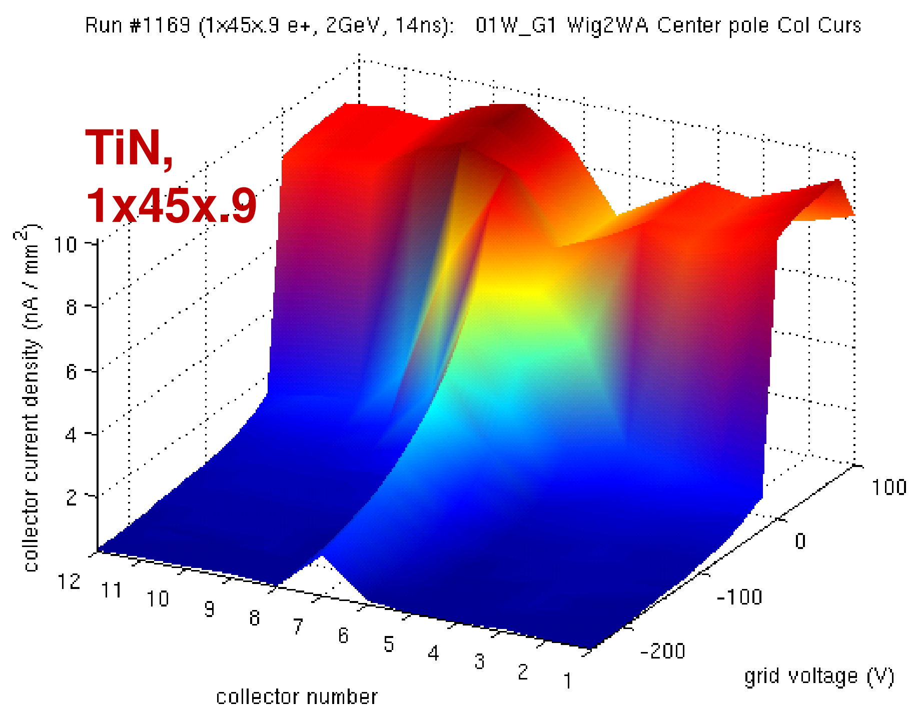




Voltage Scans II

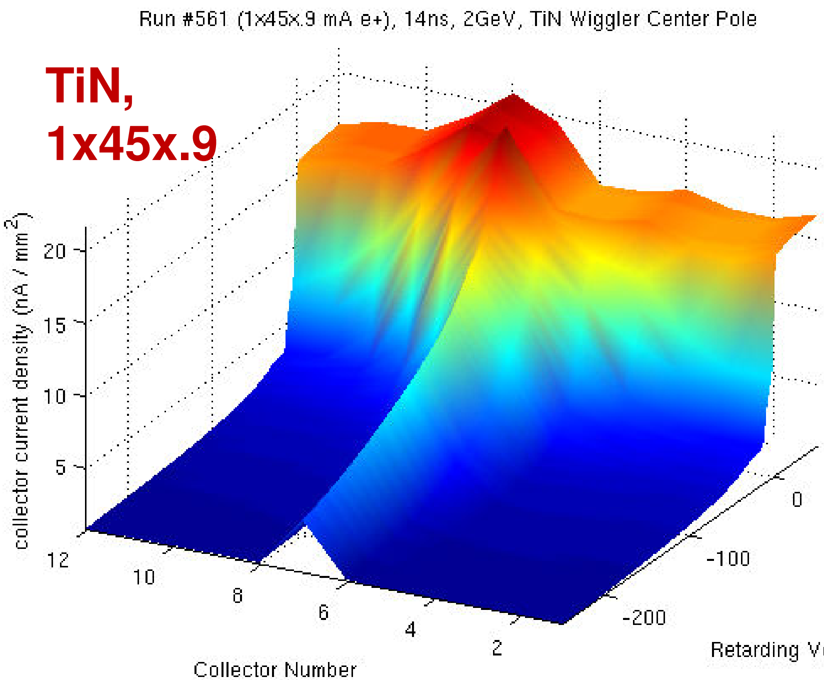
- Plots show collector response as a function of retarding voltage and collector number
- Beam conditions: 1x45x.9 mA e+, 14ns, 2 GeV
- Data is from two different runs
  - The wigglers were shuffled around between runs, so these two plots are actually from the same longitudinal position
  - Multipacting is stronger in Cu chamber

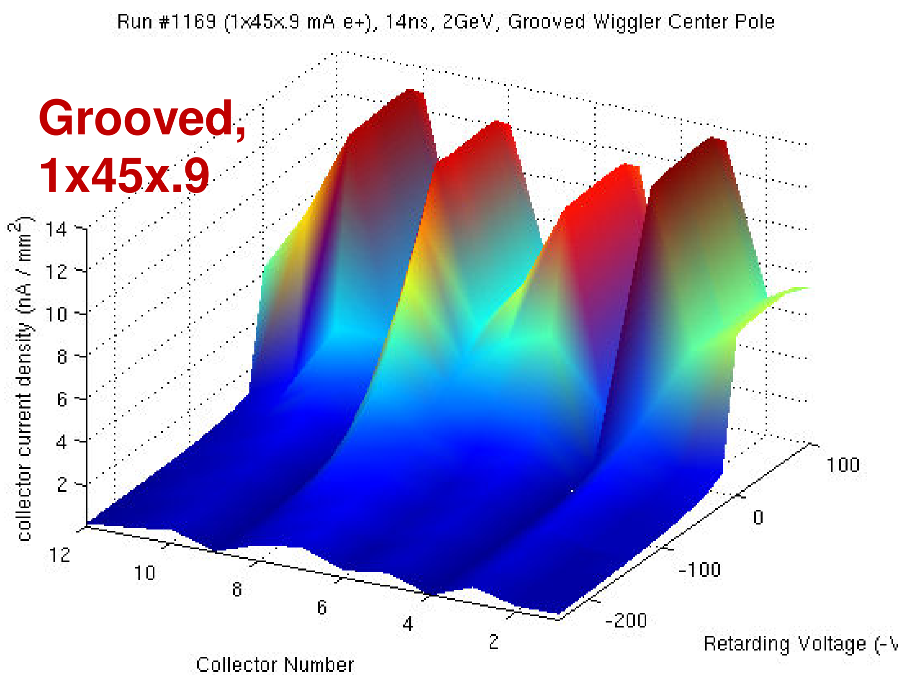




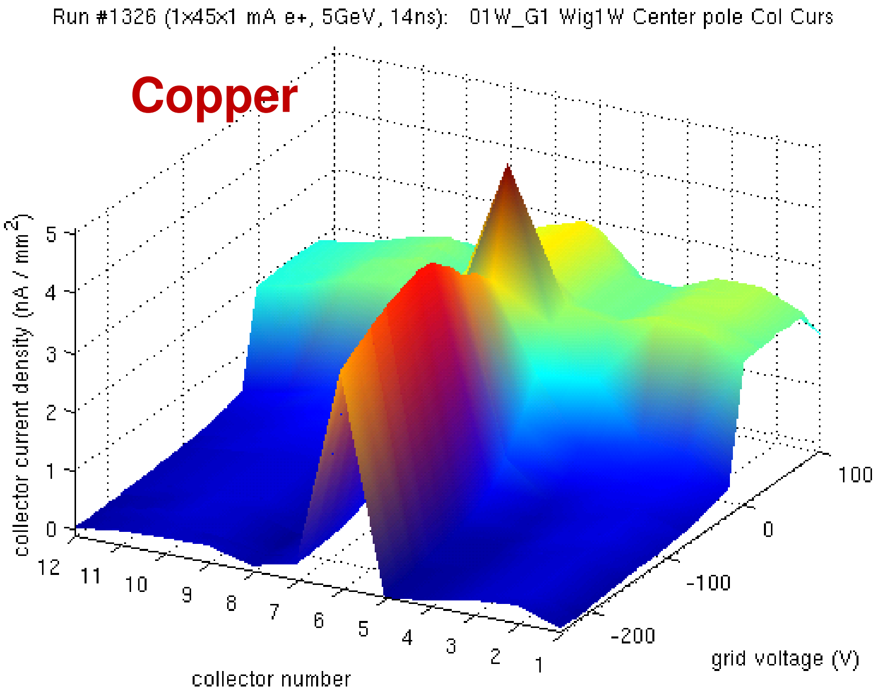
Voltage Scans III

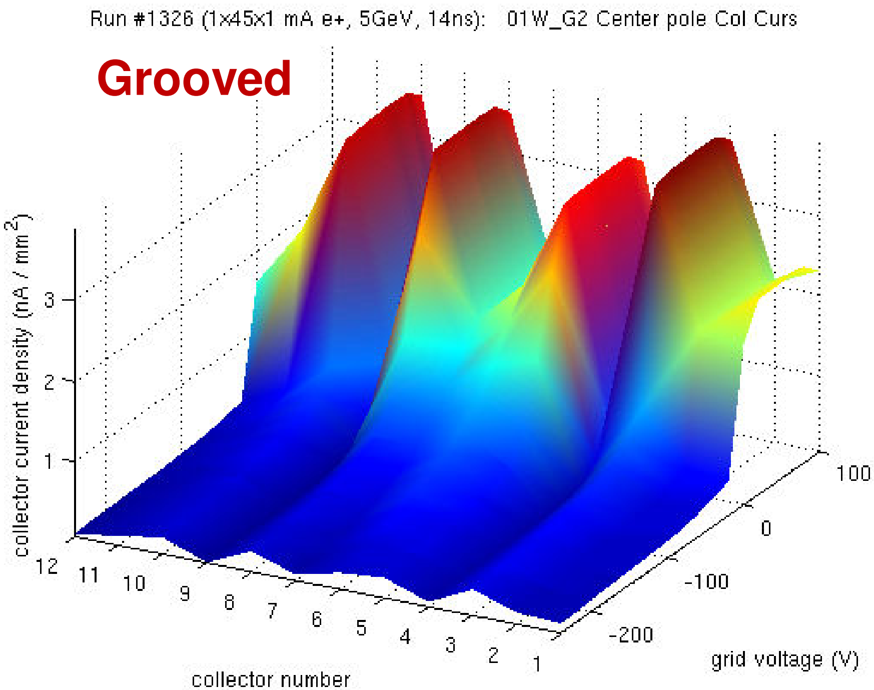
- Beam conditions: 1x45x.9 mA e+, 14ns, 2 GeV
  - The wigglers are in the same longitudinal position
  - Grooves seem more effective than TiN
  - Grooved structure very obvious
- But why don't the two TiN plots match when normalized to photon flux?
  - Photon flux normalization incorrect?
    - Synchrotron radiation pattern varies quickly over wiggler region
  - Processing?
    - We have not seen much evidence of this in Cu in the short term, but we will investigate long term processing in our November run



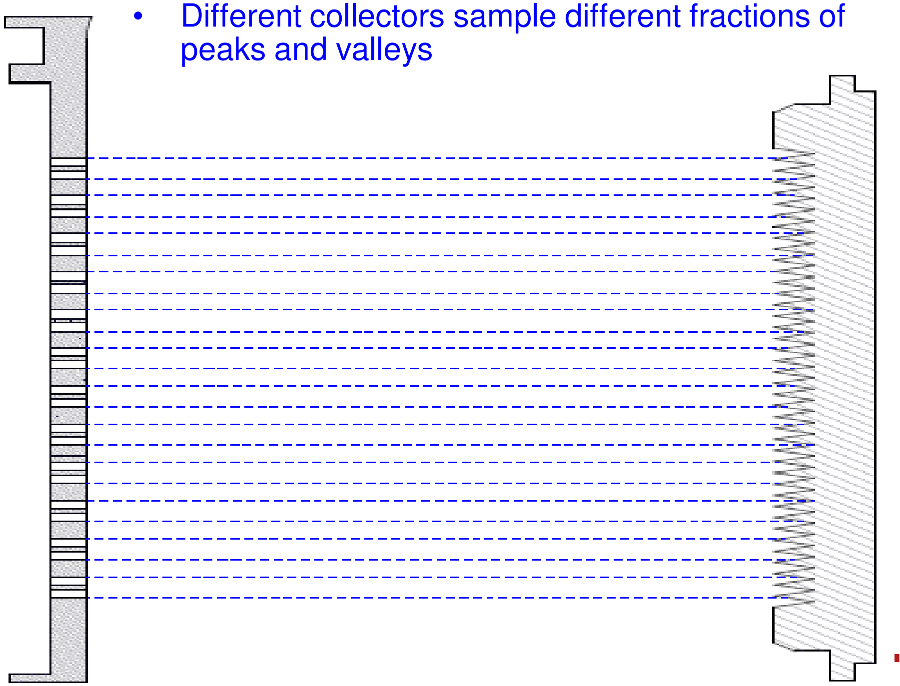


Voltage Scans IV



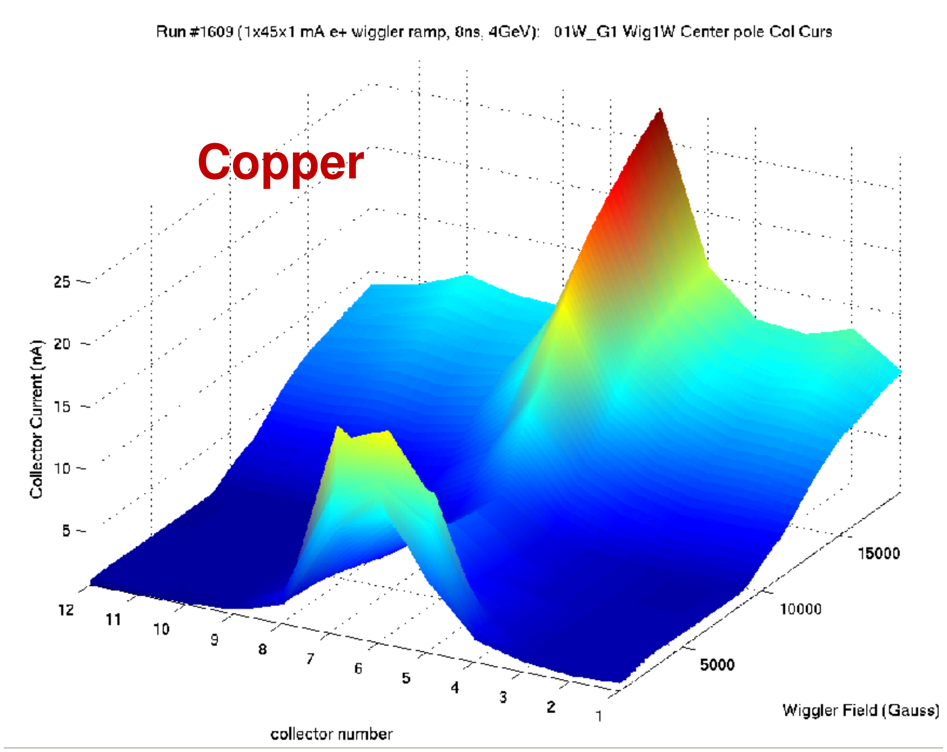


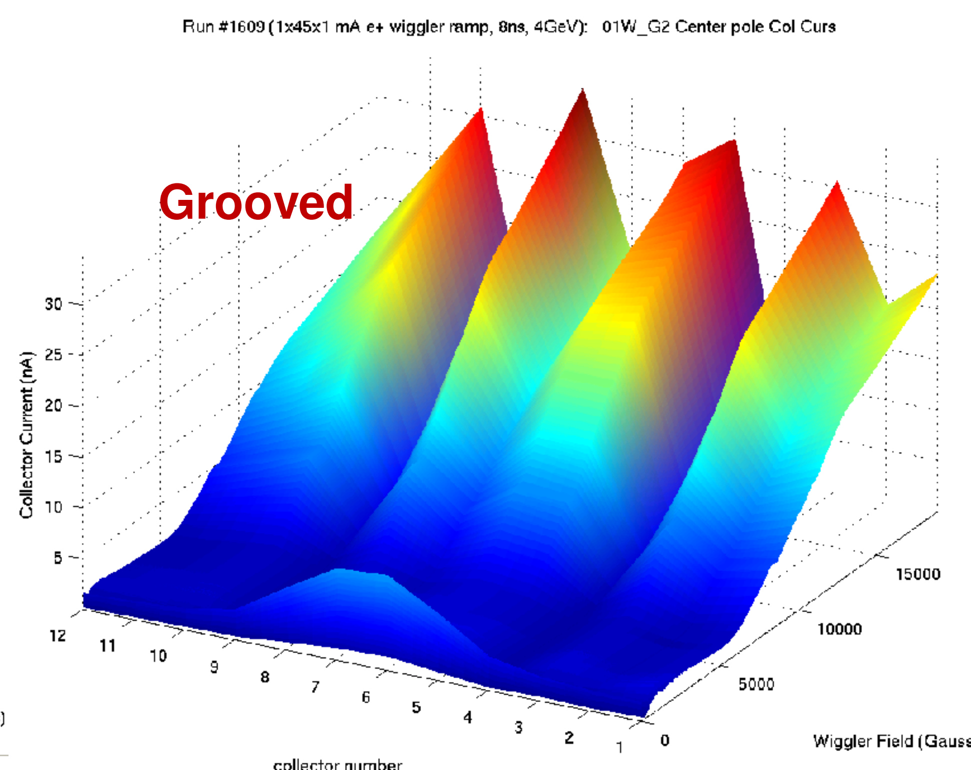
- 1x45x1 mA e+, 5GeV, 14ns
  - Photon flux actually lower at 5GeV
  - These plots are not normalized to flux
  - Multipacting much more obvious in Cu chamber
    - Odd structure due to idiosyncratic behavior of RFA, which needs to be incorporated into simulations
  - We have enough resolution in our RFA to pick up the structure of the grooved chamber
    - Different collectors sample different fractions of peaks and valleys



Wiggler Ramp

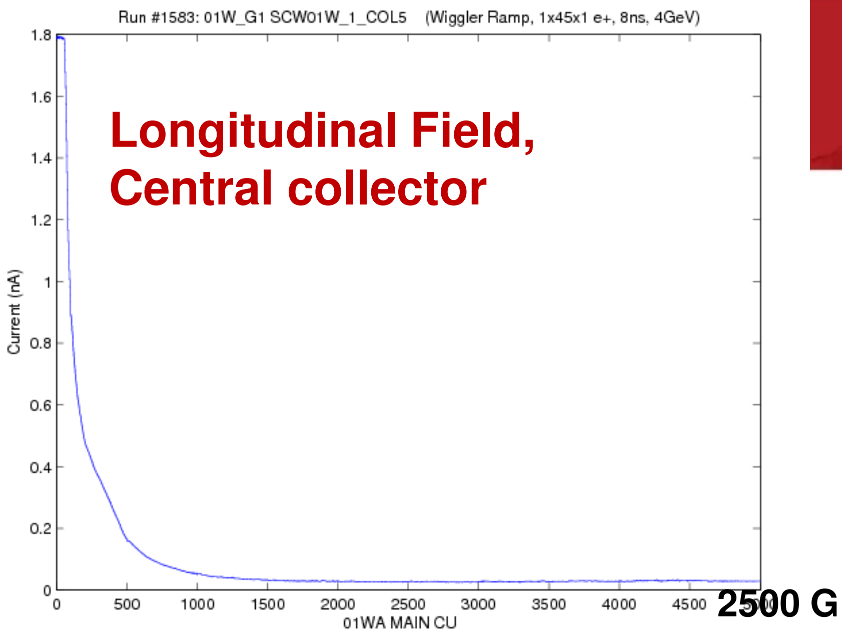
- RFA currents were monitored while the L0 wigglers were ramped from 0 to 1.9T
- Beam conditions: 1x45x1 mA e+, 8ns spacing, 4 GeV
- Plots show collector currents vs wiggler field (.2 – 1.9T) and collector number for pole center RFAs
- Copper chamber sees a transition from “dipole” regime (large central peak) to “wiggler” regime (peak with broad shoulders) around 5000 Gauss
- Structure emerges in grooved chamber at about the same field value

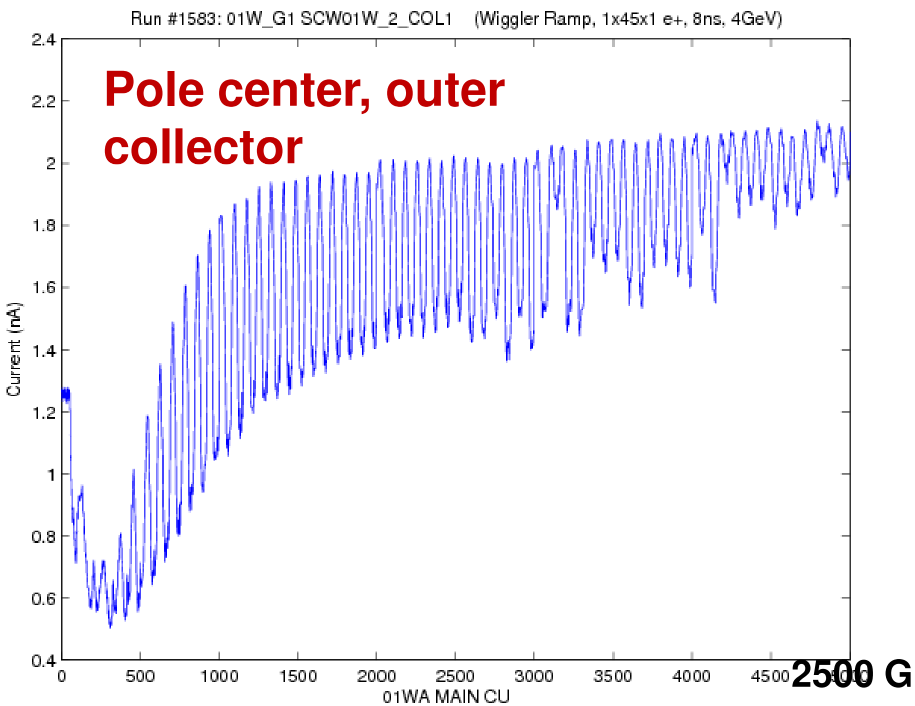


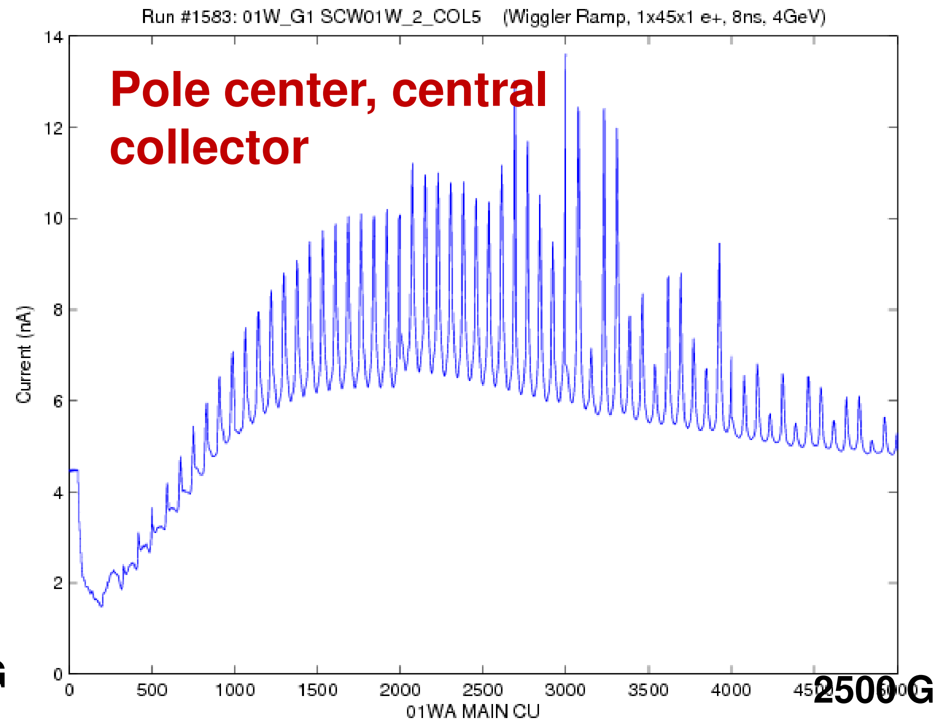


Low Field Structure

- Signal in longitudinal field collectors disappears by ~500 Gauss
- Cyclotron resonances are clearly visible in the Cu center pole RFA
  - Clear peaks in central collector
  - Less clear in outer collectors
- TiN coated and grooved RFAs also see the resonances, though less prominently

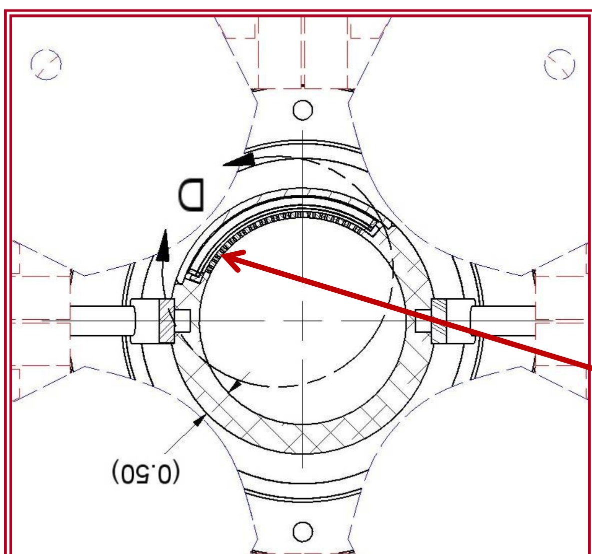


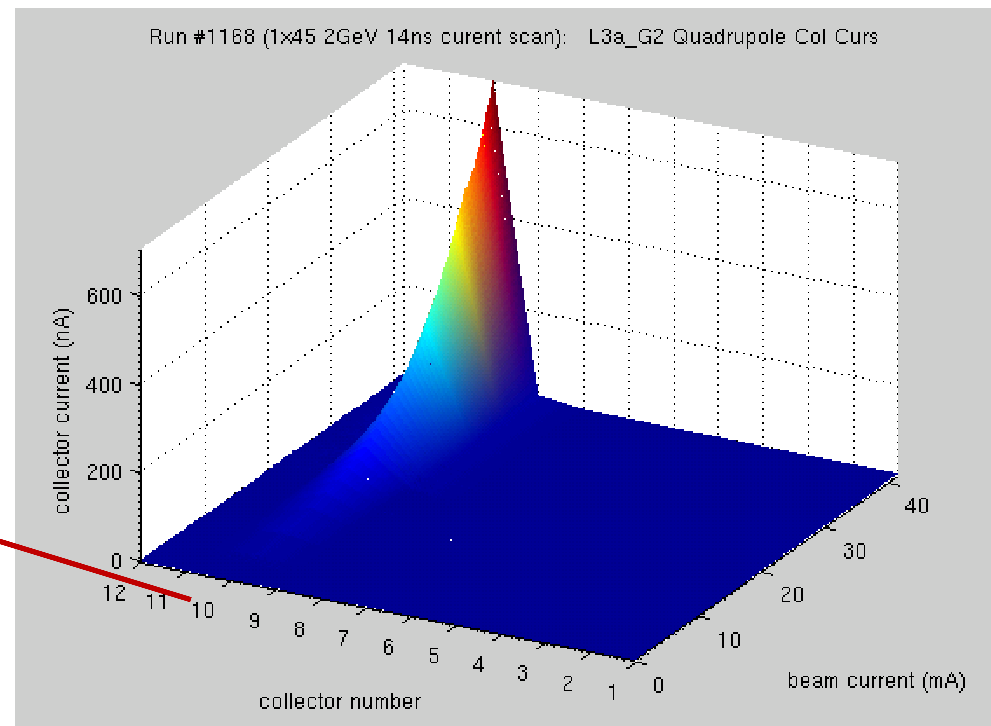




Quadrupole Mitigation

- 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
- We are installing a TiN coated quad chamber





Conclusions

- In a drift space, both TiN and carbon coating show a significant improvement relative to aluminum, but a more modest improvement relative to copper
  - Solenoids are probably also effective, but we will take more data with the ion pumps turned off
    - We can also test this with tune shift measurements
- In a chicane (dipole field), TiN coating is very effective compared to Al, and TiN coated grooves are even better
  - We clearly observe cyclotron resonances in a field scan
- Grooves appear to be the most effective mitigation in a wiggler, but more quantitative conclusions will need to wait until we have a better understanding of processing and photon reflectivity
  - Cyclotron resonances are also observed vs wiggler field
  - We also plan to install a clearing electrode in a wiggler
- We have installed a quadrupole RFA, and will test the effectiveness of TiN coating in this magnet
- We have taken a great deal of RFA data in a variety of beam conditions and magnetic field regions, and welcome any help in analyzing this data