CesrTA Program Overview

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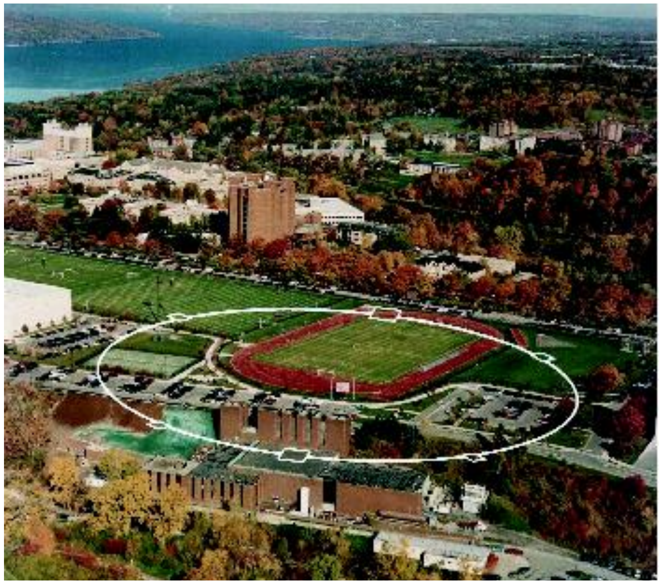
October 9, 2010



CesrTA Objectives

- Characterize the growth and decay of the electron cloud
- Measure the effect of the electron cloud on low emittance beams
  - Tune shift
  - Emittance growth
  - Instability
- Test electron cloud mitigations
- Develop instrumentation and techniques for measuring electron cloud and its effects
- Develop instrumentation and techniques for low emittance tuning and operation

CesrTA
Instrumented Damping Ring

- Configured as test accelerator
  - Superconducting Damping Wigglers and low emittance optics
- Instrumentation for characterizing electron cloud and consequences
  - RFA – time averaged cloud density
  - Gated spectrum analyzer – spectrum of individual bunches in a train
  - Shielded pickup – cloud decay, electron energy,
  - Xray beam size monitor – measurement of the ε_v of bunches in a train
  - TE wave phase shift – non invasive measure of local electron density
- Characterization of mitigations in all guide fields
- Characterization of SEY of vacuum materials
- Beam based techniques for low emittance tuning
- Modeling and Simulations to interpret the measurements

CesrTA Parameters

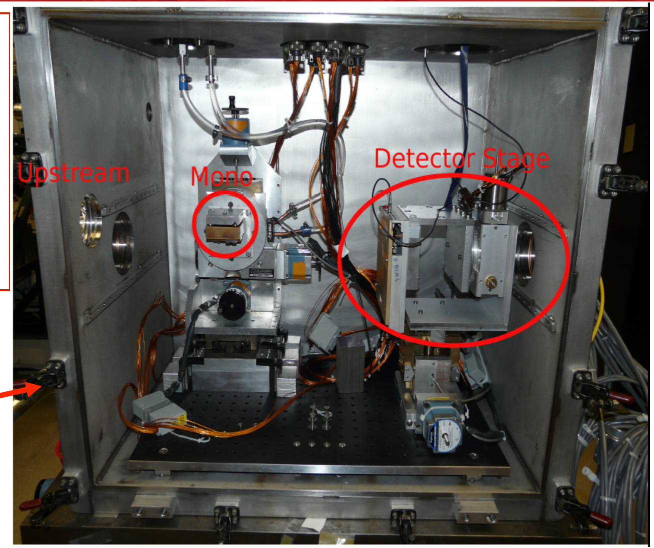
Energy [GeV]	2.085	2.085	5.0	5.0
No. Wigglers	12	12	0	6
Wiggler Field [T]	1.9	1.9	—	1.9
Q_x	14.57			
Q_y	9.6			
Q_z	0.055	0.075	0.043	0.043
V_{RF} [MV]	4.5	8.1	8	8
ε_x [nm-rad]	2.6	2.6	60	35
$\tau_{x,y}$ [ms]	57	57	30	20
α_p	6.76×10^{-3}	6.76×10^{-3}	6.23×10^{-3}	6.23×10^{-3}
σ_l [mm]	12.2	9	9.4	15.6
σ_E/E [%]	0.81	0.81	0.58	0.93
t_b [ns]	≥4, steps of 2			

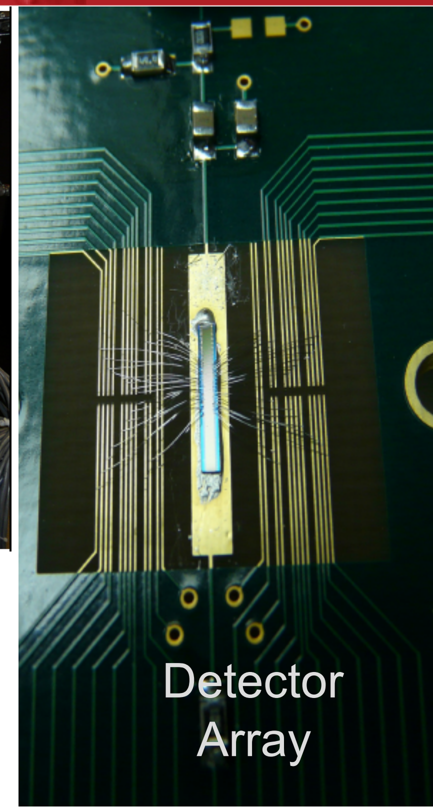
- Operating energies between ~1.5 and ~5.5 GeV
  - Intermediate energy optics available for beam dynamics studies
  - Allows significant control of primary photon flux in EC experimental regions

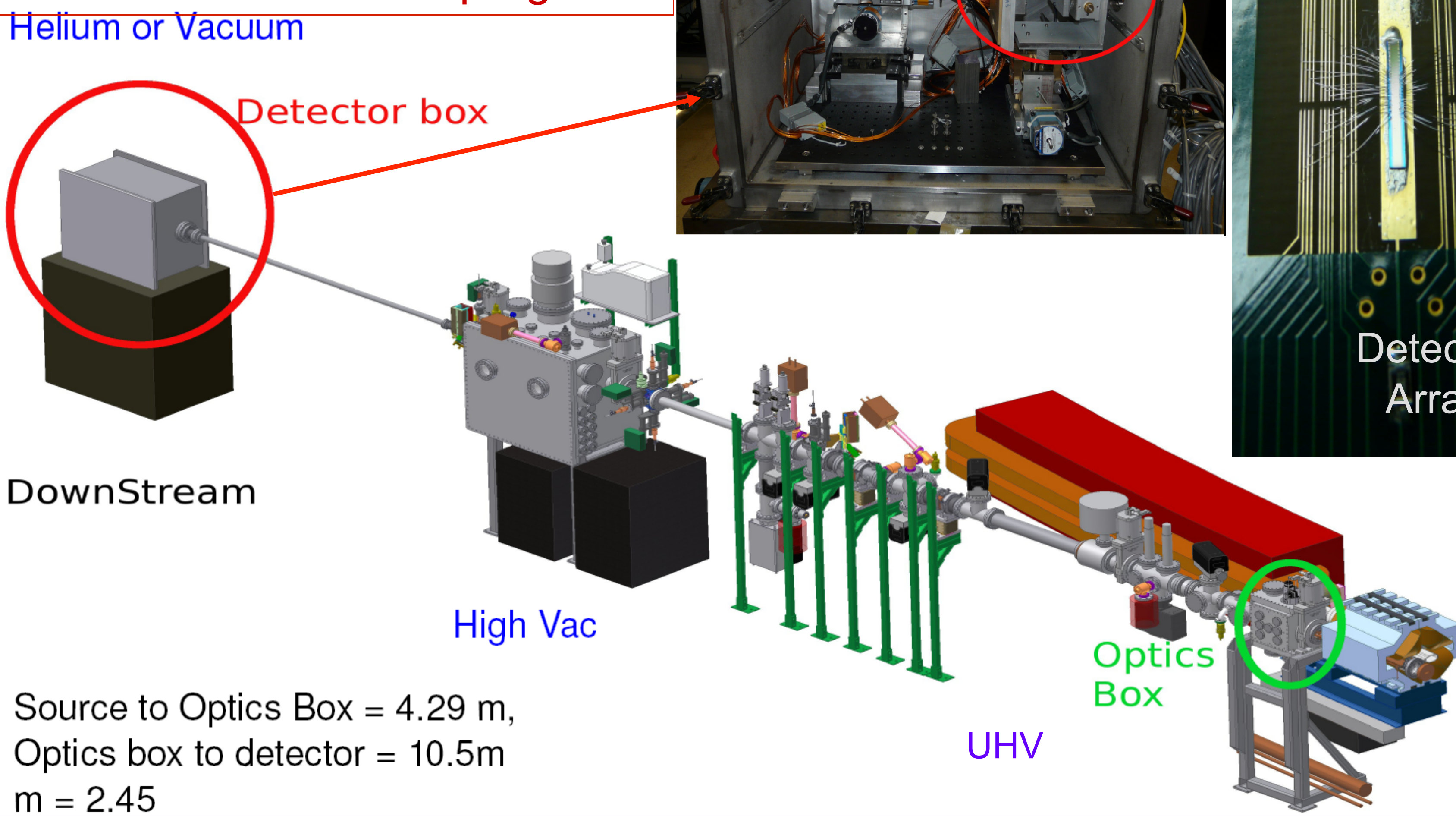
Upgrade Program: xBSM Optics Line & Detector

New all-vacuum optics line for e+ beam in collaboration with CHESS

2nd line for e- beam in progress





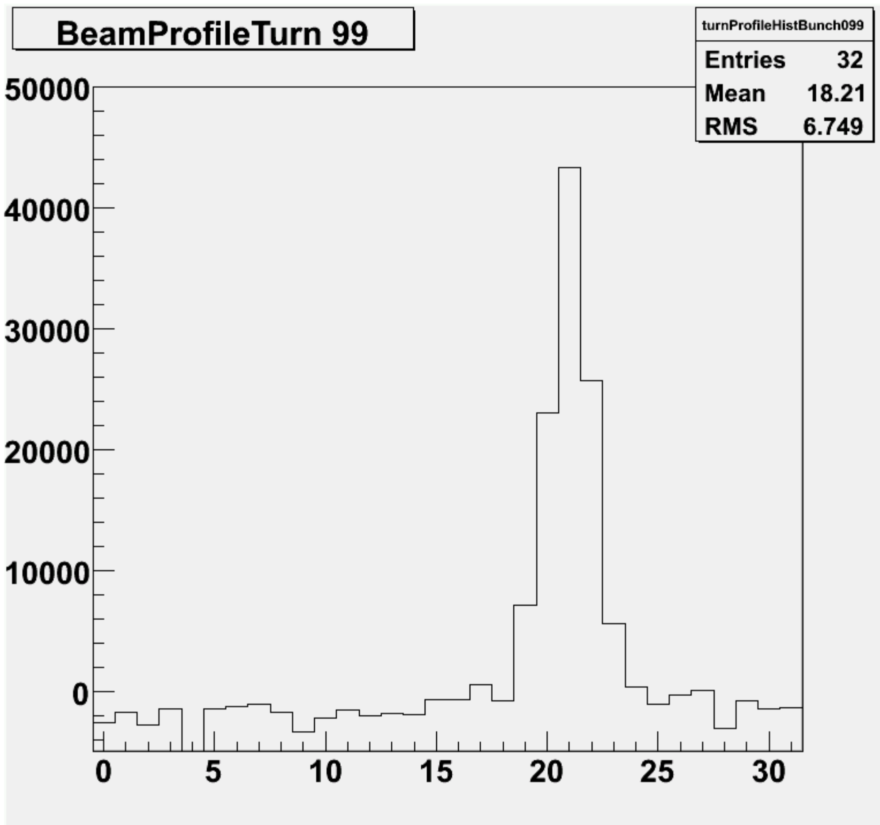


Source to Optics Box = 4.29 m,
Optics box to detector = 10.5m
m = 2.45

D-line xbsm - positrons

$\sigma = 17\mu m$

$\varepsilon_v = 18pm$

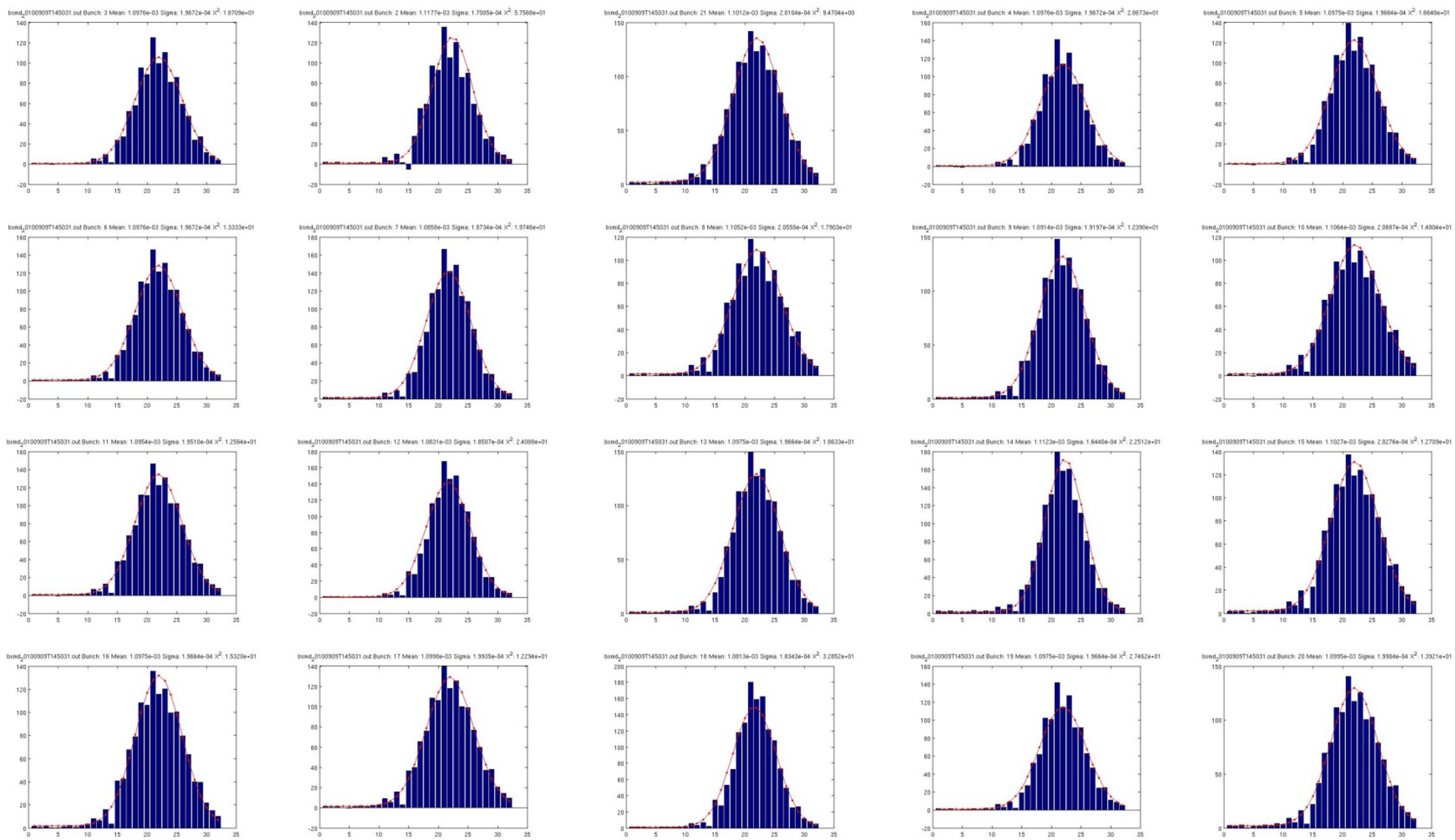


Low emittance tuning procedure typically yields sub 20pm in one or two iterations

C-line – electron beam size

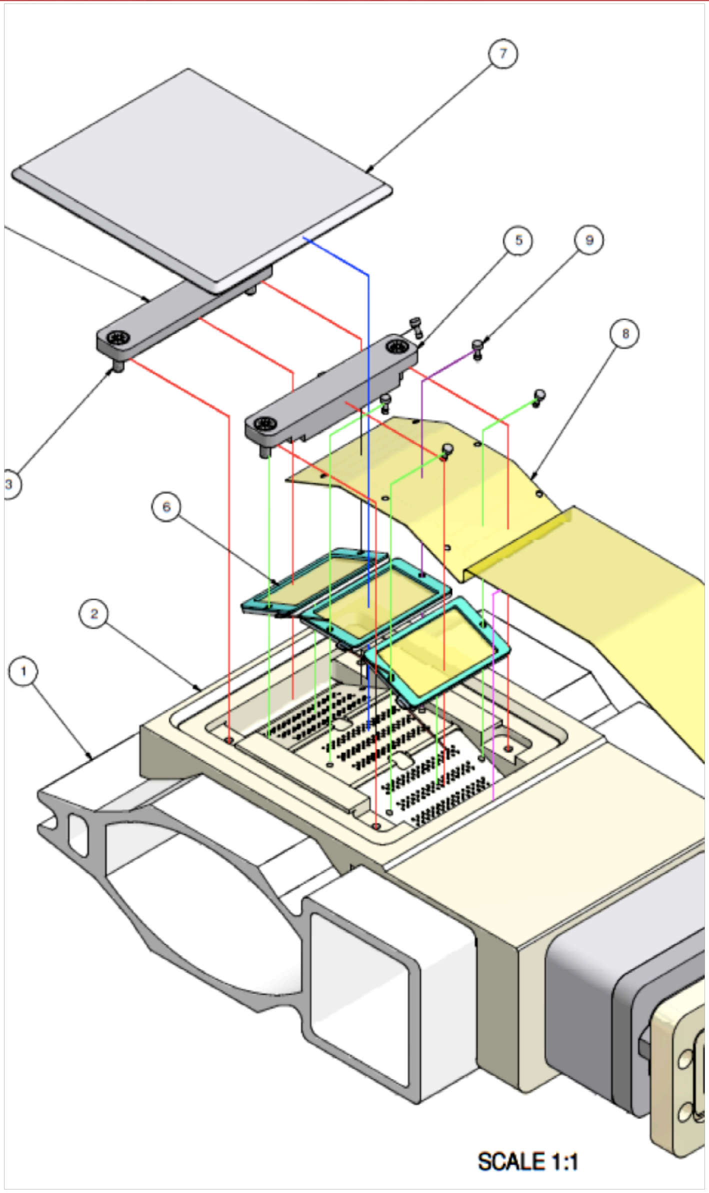
20 bunches,14 ns spacing, 32 channels, pinhole optics

Capability to measure bunches spaced by as few as 4ns



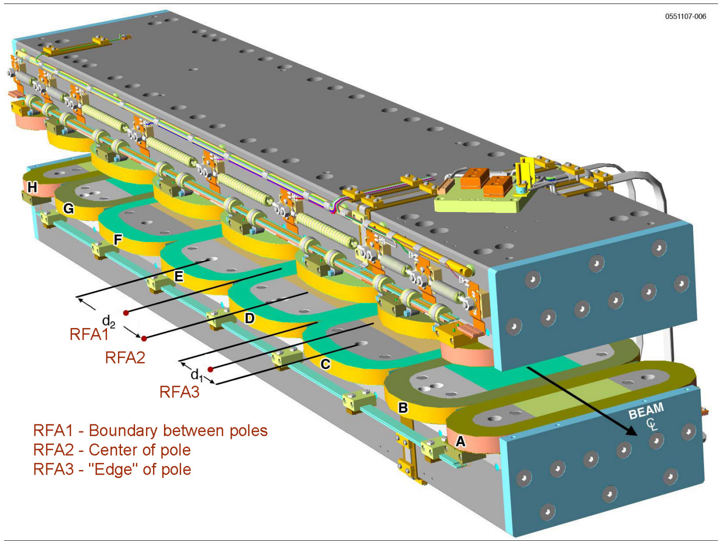
Retarding field analyzers

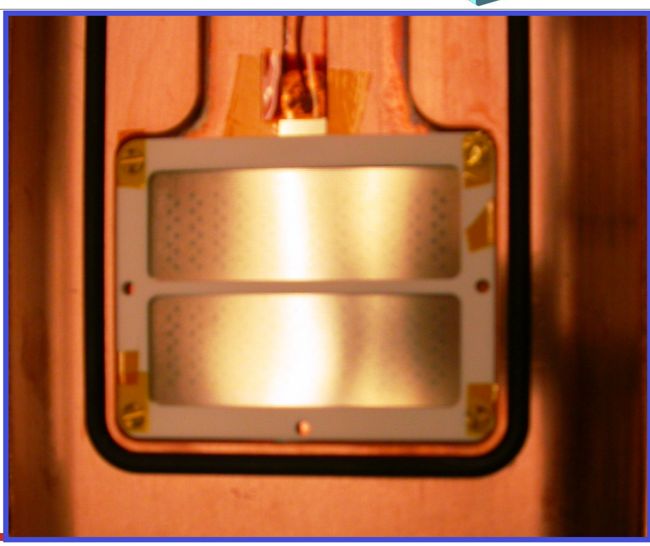
- These devices measure the energy spectrum of the time-average cloud current density which impacts the chamber wall. Most devices are segmented, so that some position information is also available.
- These devices can be placed in drifts, dipoles, quadrupoles, and wigglers.
- RFA's placed in chambers to which mitigation techniques have been applied will be used to measure the effectiveness of these techniques.

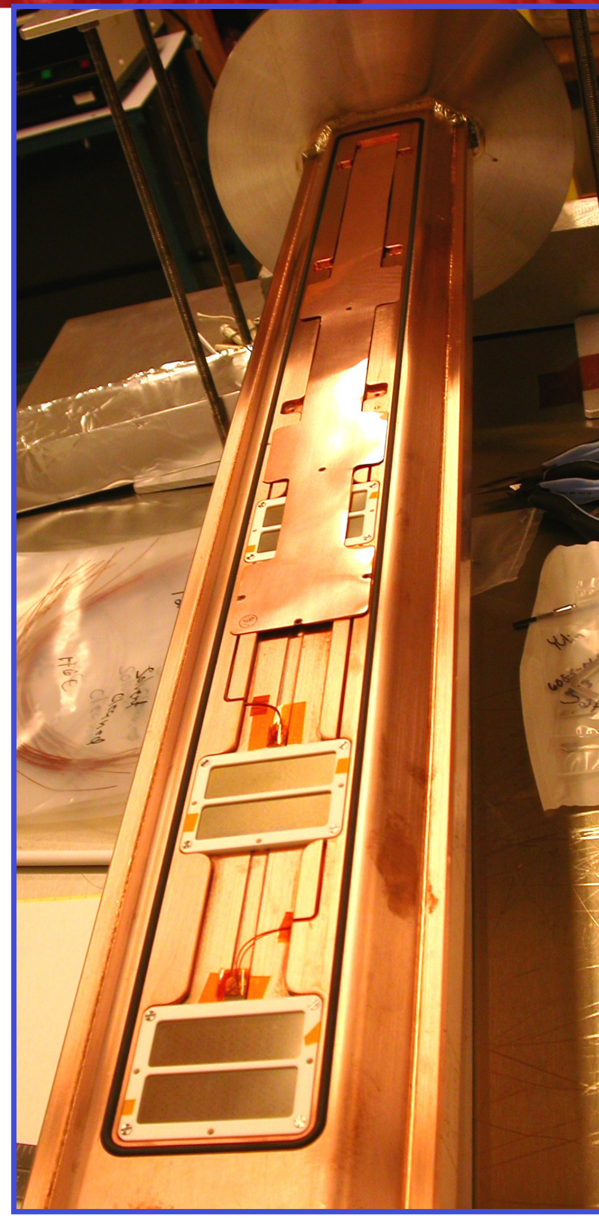


Instrumented Wigglers

- Installed Oct 23-24, `08
  - 1 Cu VC; 1 TiN-coated VC



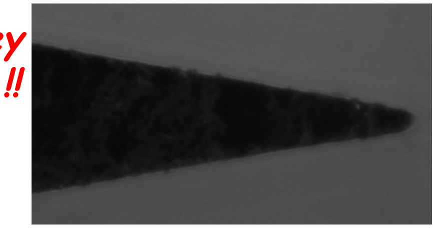




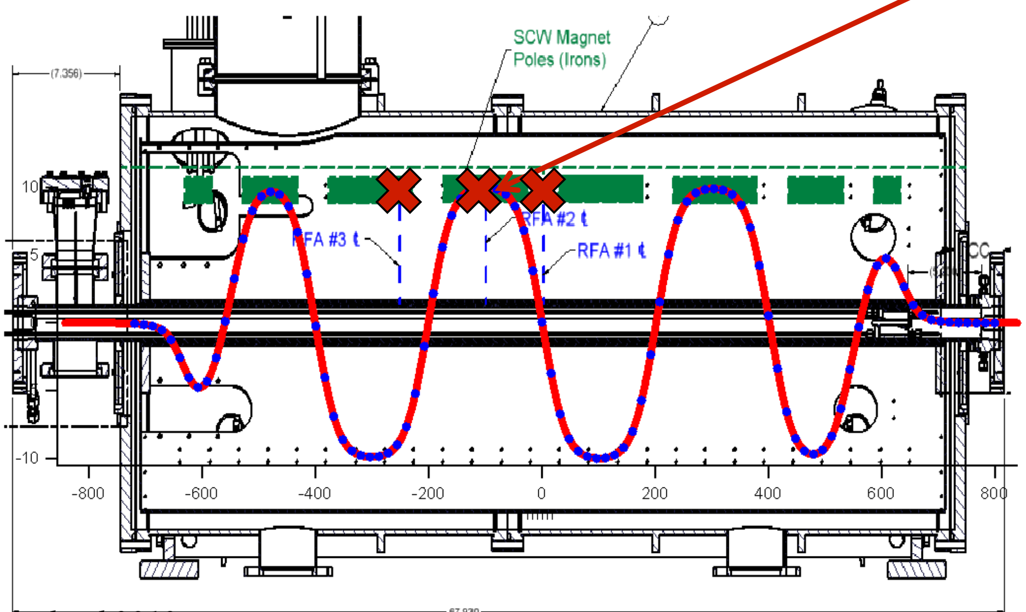
Wiggler Mitigation

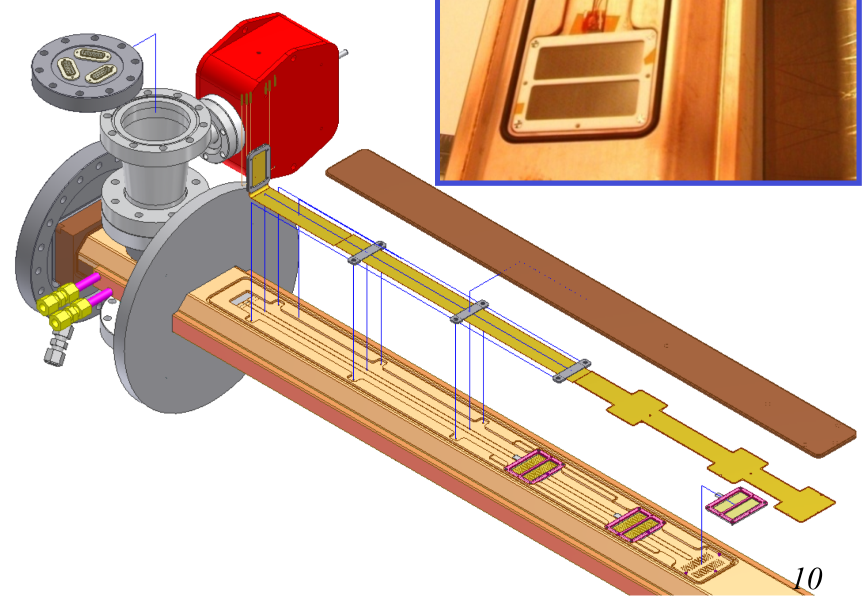
- We have three wigglers instrumented with RFAs
  - Bare Cu
  - TiN coated
  - Grooved, clearing electrode

Groove tips/valley radius < 0.002" !!



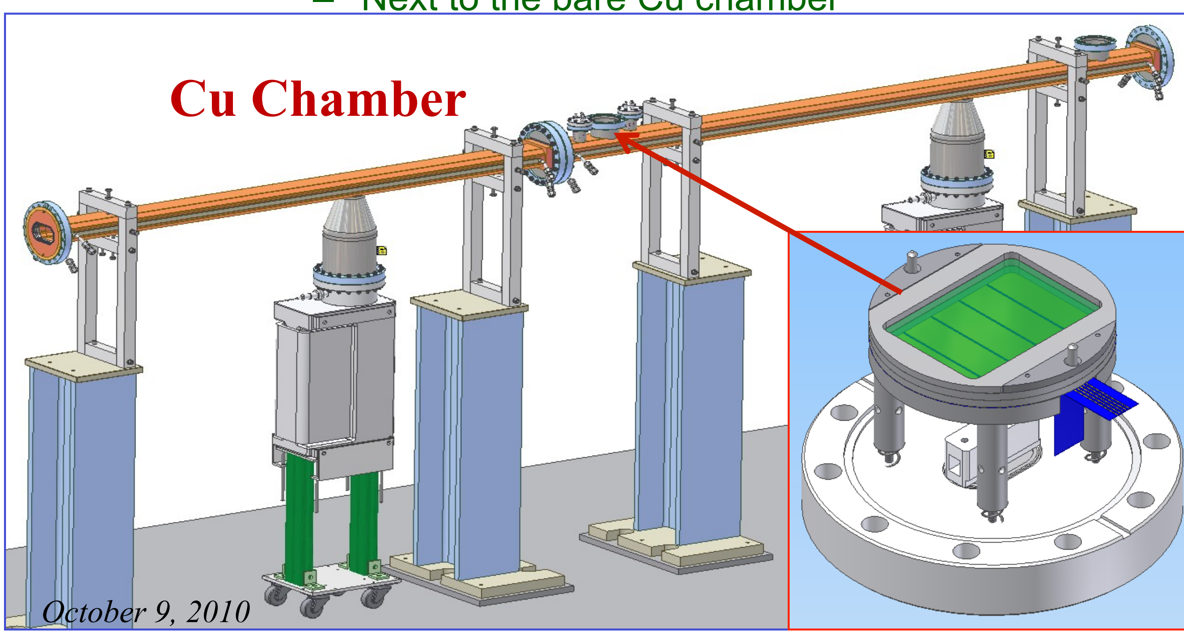
- Each wiggler has three RFAs
  - Plots shown will be for an RFA in the center of a wiggler pole
  - There are also RFAs in a longitudinal and intermediate field
  - RFAs have 12 collectors and are built into the beam pipe

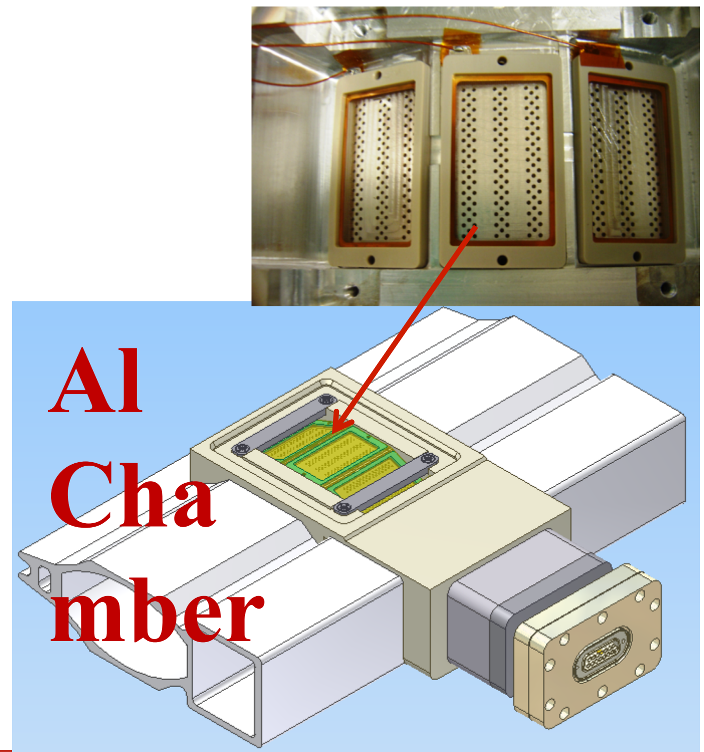




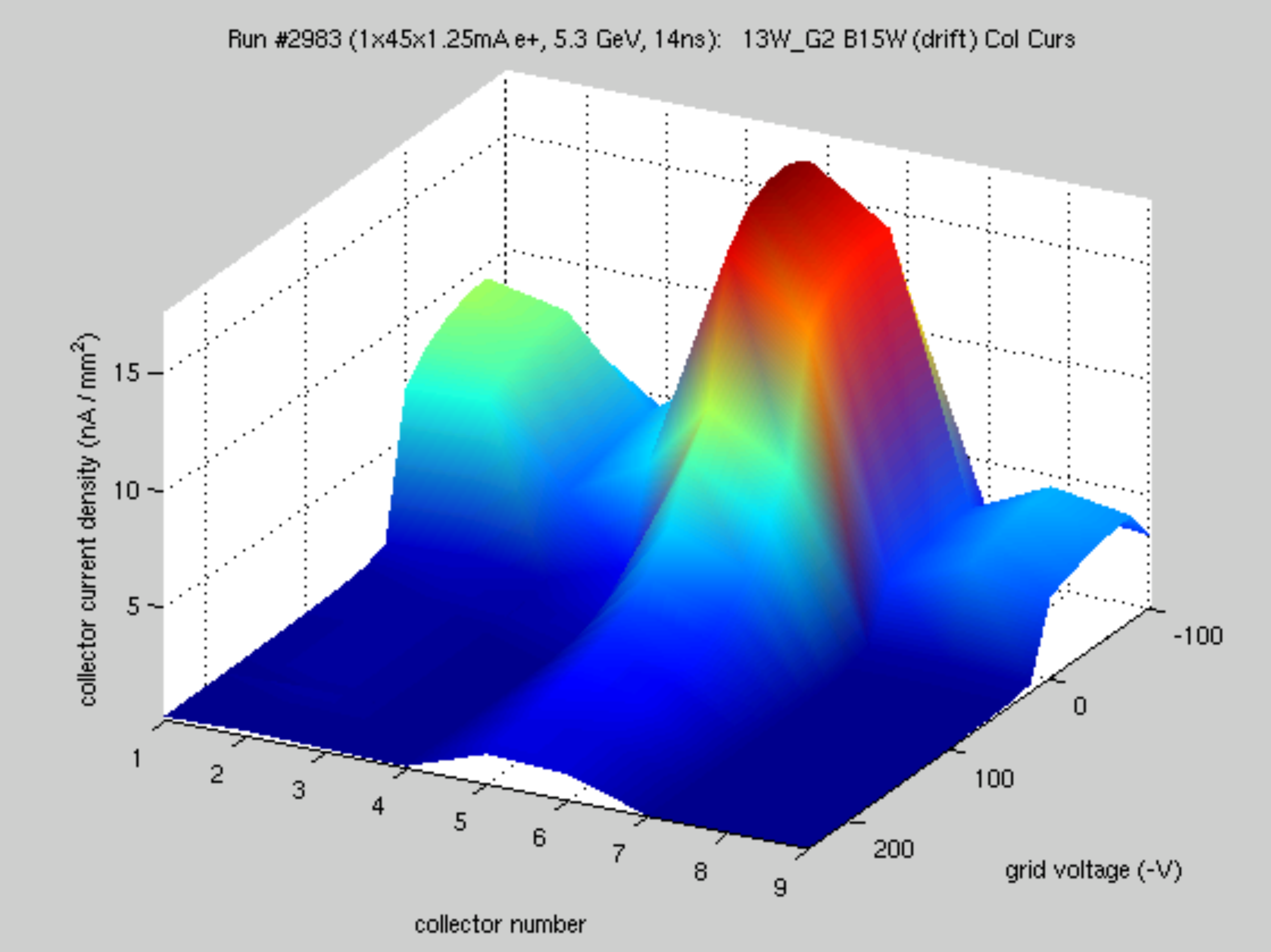
Drift Mitigation

- 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



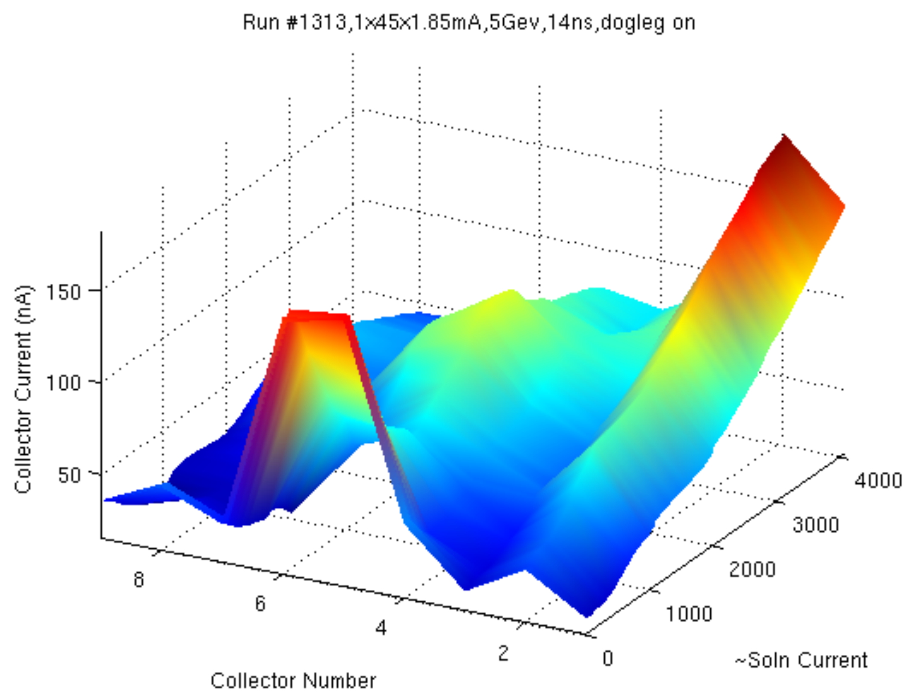


RFA


Run #2983 (1x45x1.25mA e+, 5.3 GeV, 14ns): 13W_G2 B15W (drift) Col Curs
collector current density (nA / mm²)
15
10
5
1
2
3
4
5
6
7
8
9
collector number
-100
0
100
200
grid voltage (-V)

Solenoid Mitigation

- RFA response as an adjacent solenoid magnet was ramped up (0 – 70G)
  – Beam conditions: 1x45x1.85 mA e+, 5GeV, 14ns
  – 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



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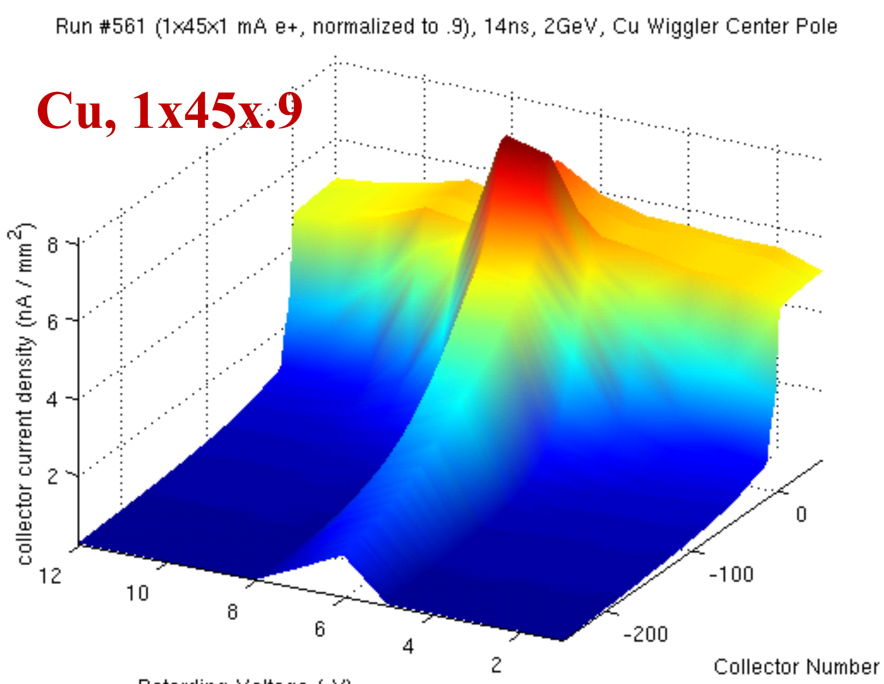
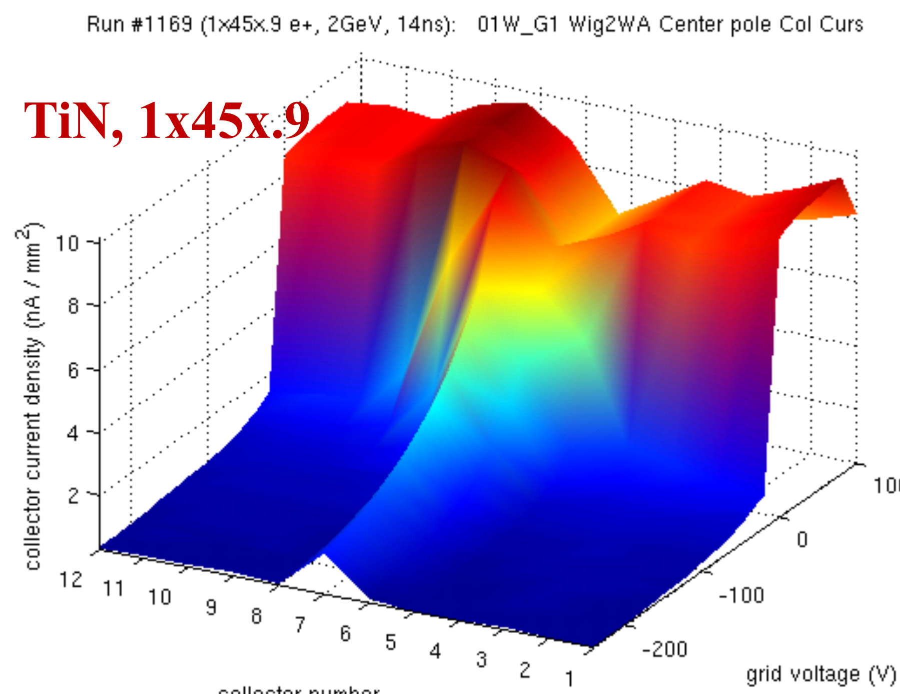
Wiggler Voltage Scans II

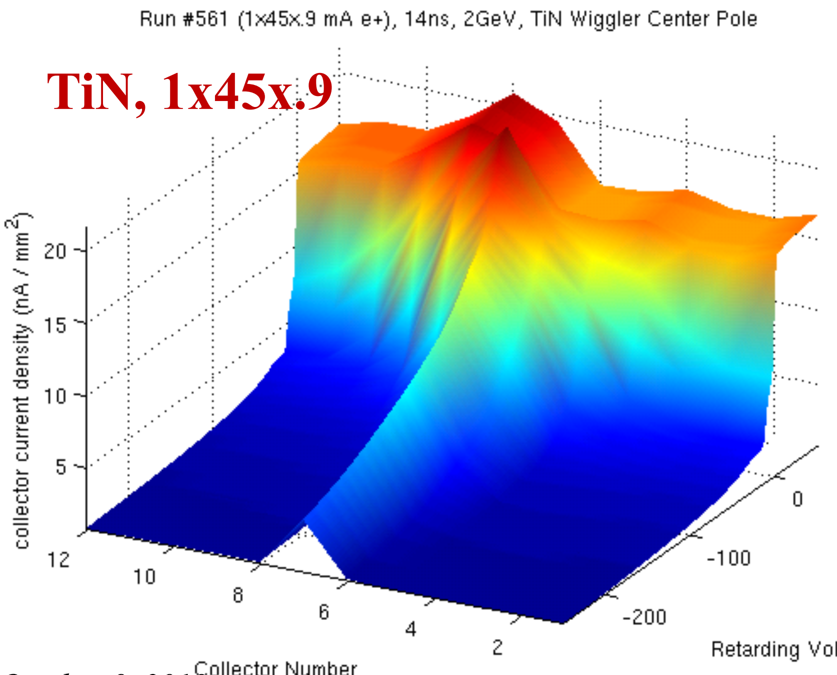
- Plots show collector response as a function of retarding voltage and collector number
- Beam conditions: 1x45x.9 mA e+, 14ns, 2 GeV
- Data is from two different runs
  - The wigglers were shuffled around between runs, so these two plots are actually from the same longitudinal position

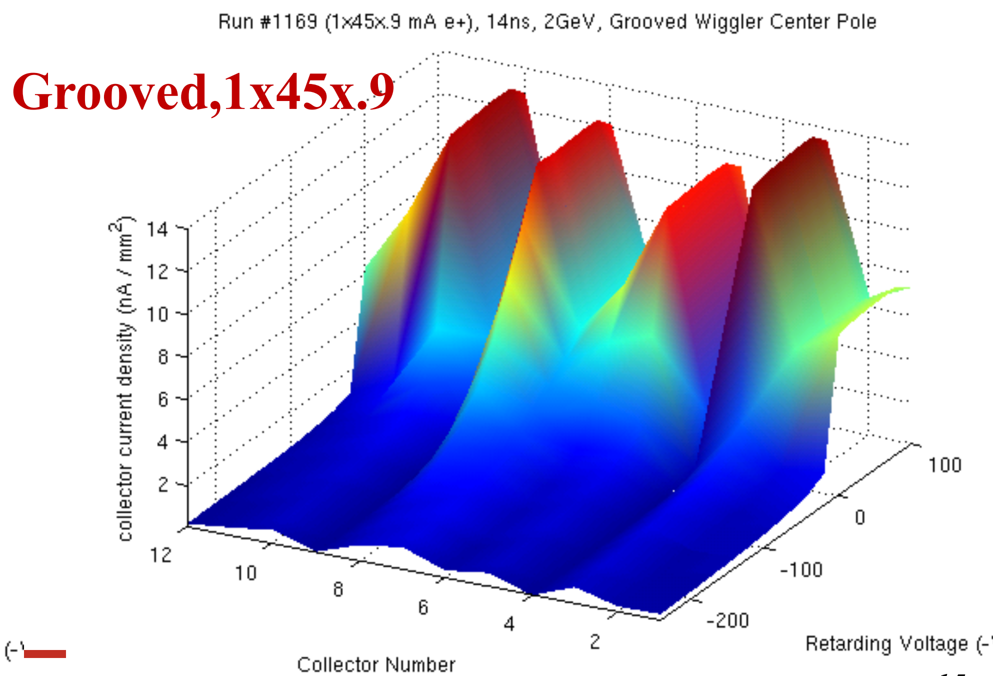




Mitigation

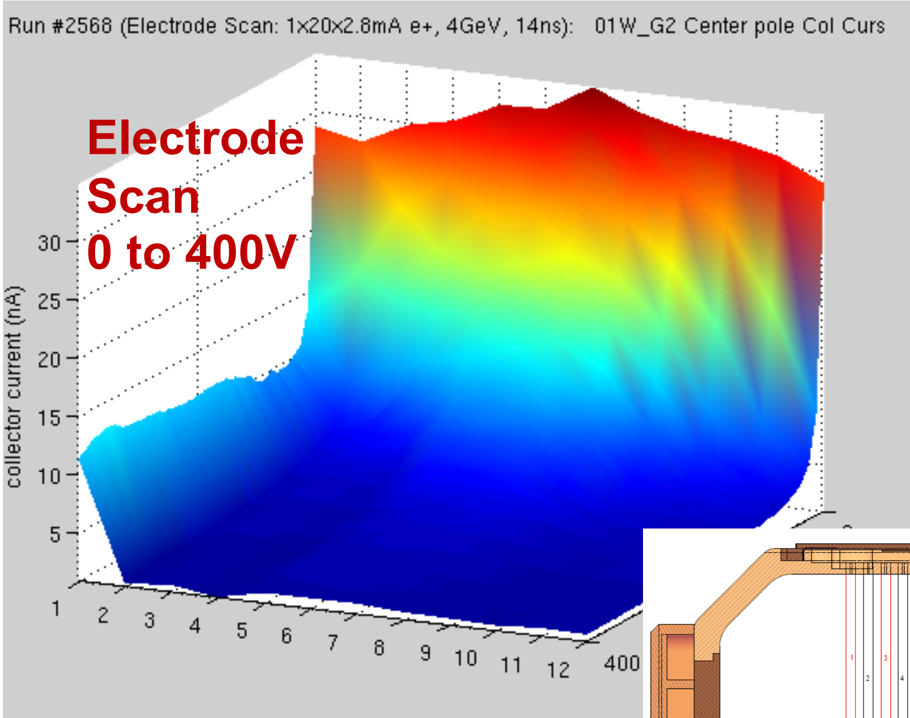
- Beam conditions: 1x45x.9 mA e+, 14ns, 2 GeV
  - The wigglers are in the same longitudinal position
  - Grooves seem more effective than TiN
  - Grooved structure very obvious

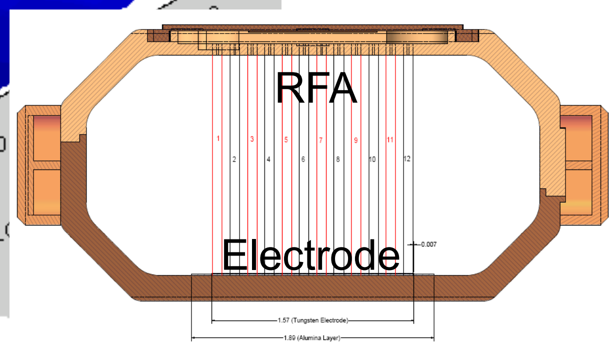


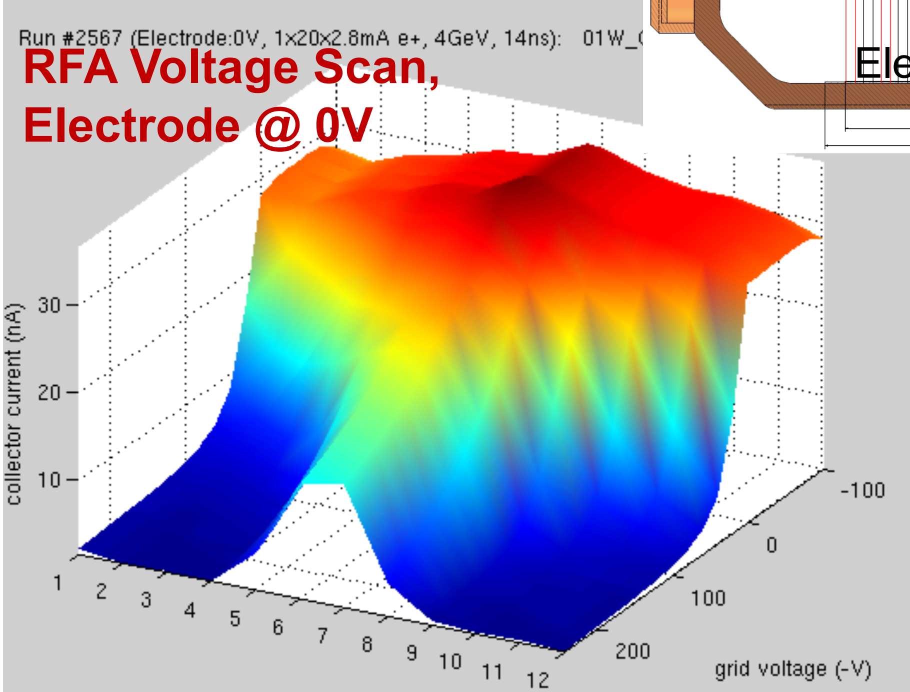


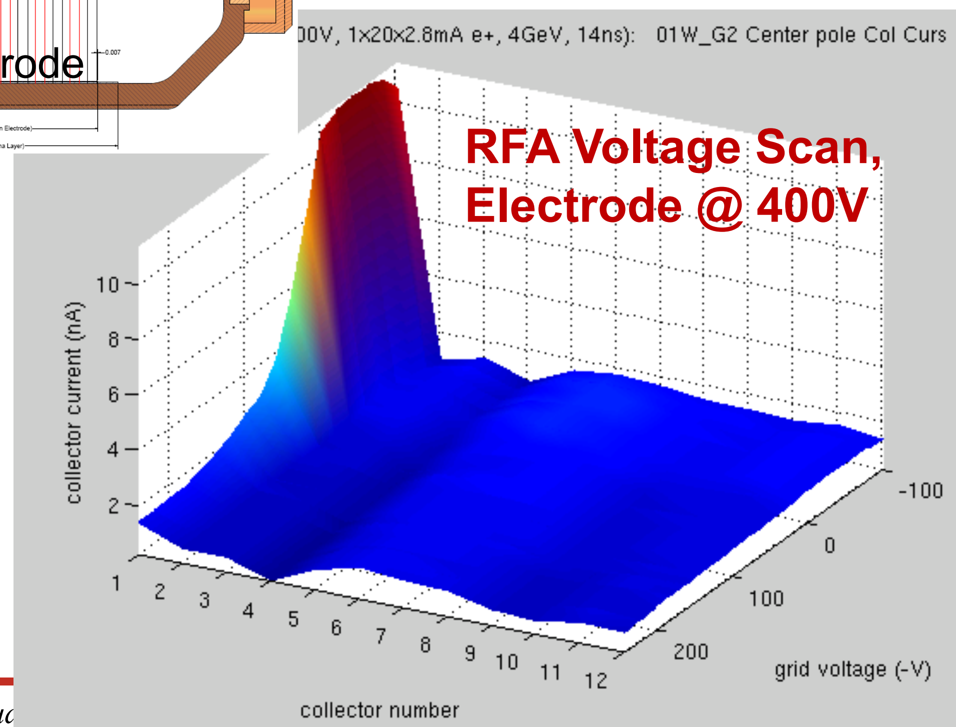
Wiggler Clearing Electrode

- 20 bunch train, 2.8 mA/bunch
  - 14ns bunch spacing
  - E_{beam} = 4 GeV with wigglers ON
- Effective cloud suppression
  - Less effective for collector 1 which t fully covered by electrode





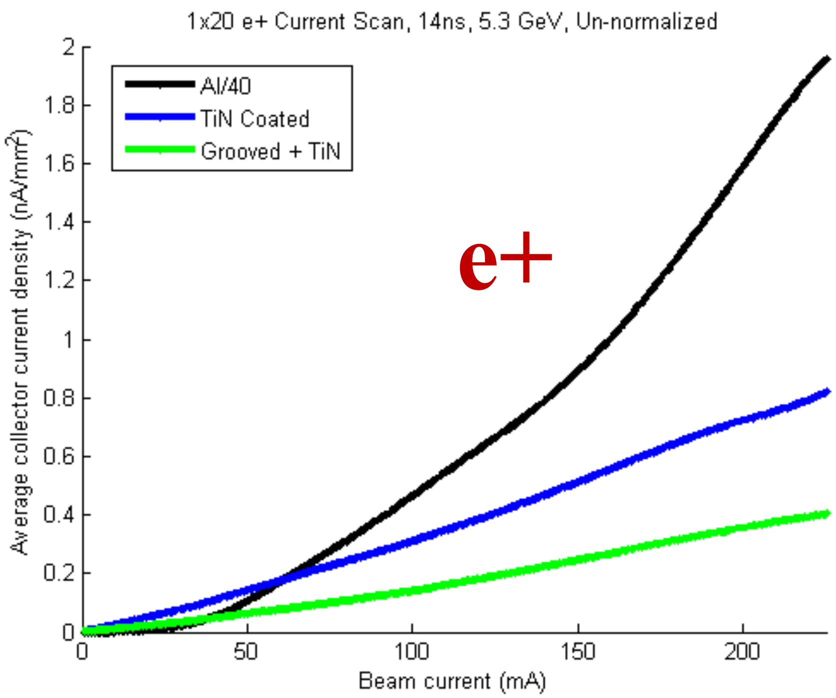


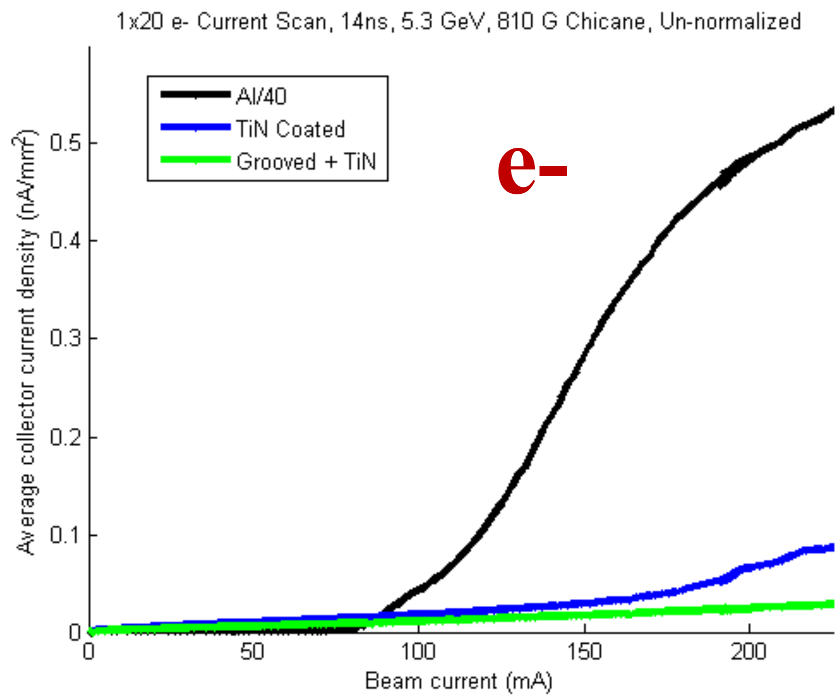


Mitigation Performance in Dipoles

- 1x20 e+, 5.3 GeV, 14ns
  - 810 Gauss dipole field
  - Signals summed over all collectors
  - All signals ÷40

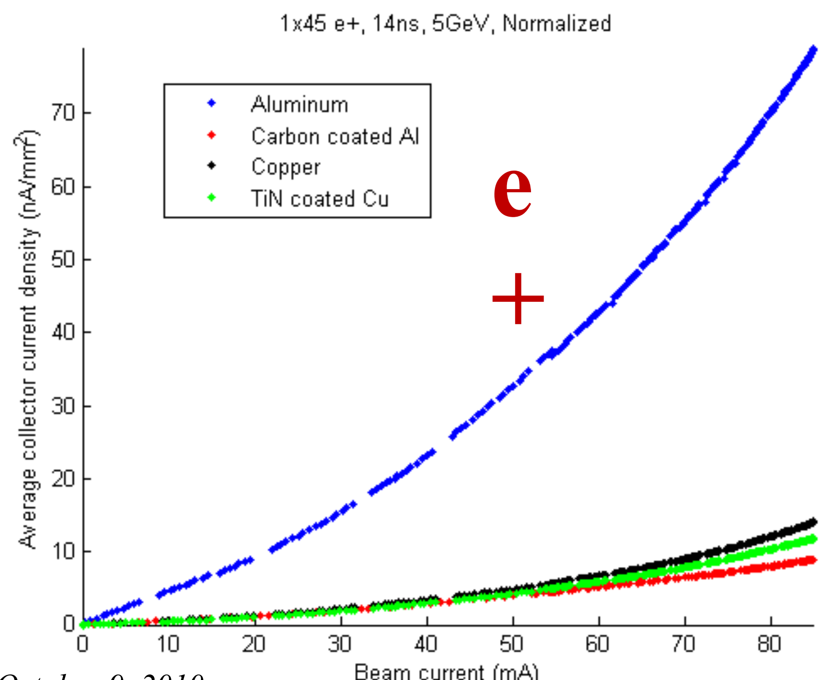
Longitudinally grooved surfaces offer significant promise for EC mitigation in the dipole regions of the damping rings

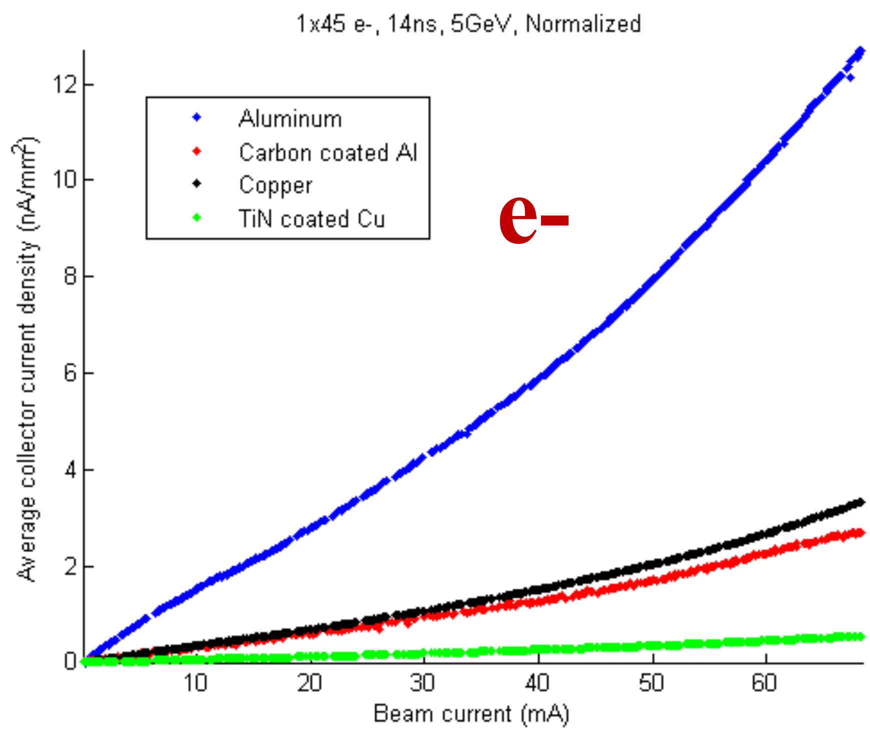




Drift Mitigation

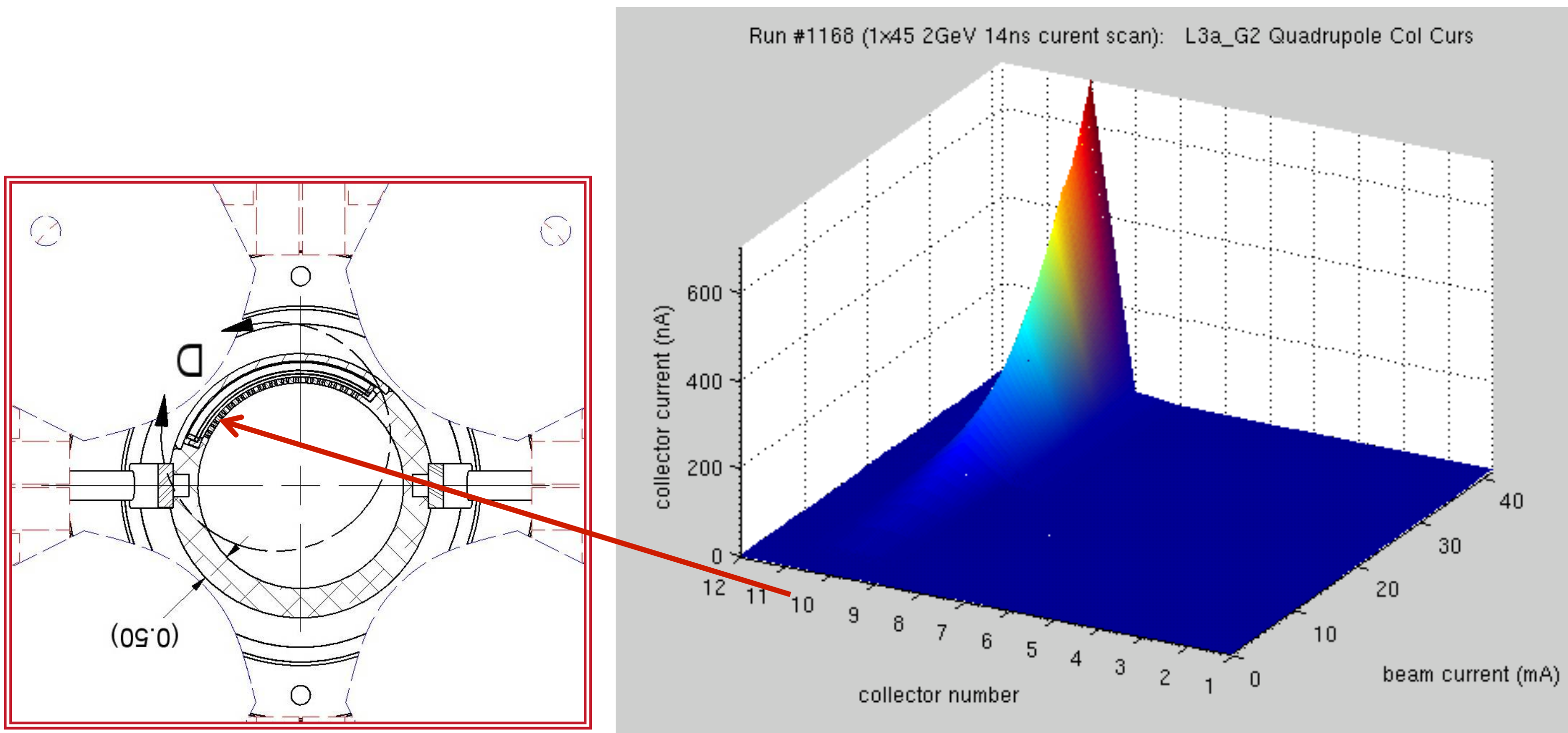
- Plots show average of all collectors for all drift RFAs
- In general, the most cloud is seen in the bare Al chambers (blue)
  - Much less in copper chambers (black)
  - Less still in coated chambers
    - TiN: green
    - Carbon: red





Quadrupole RFA

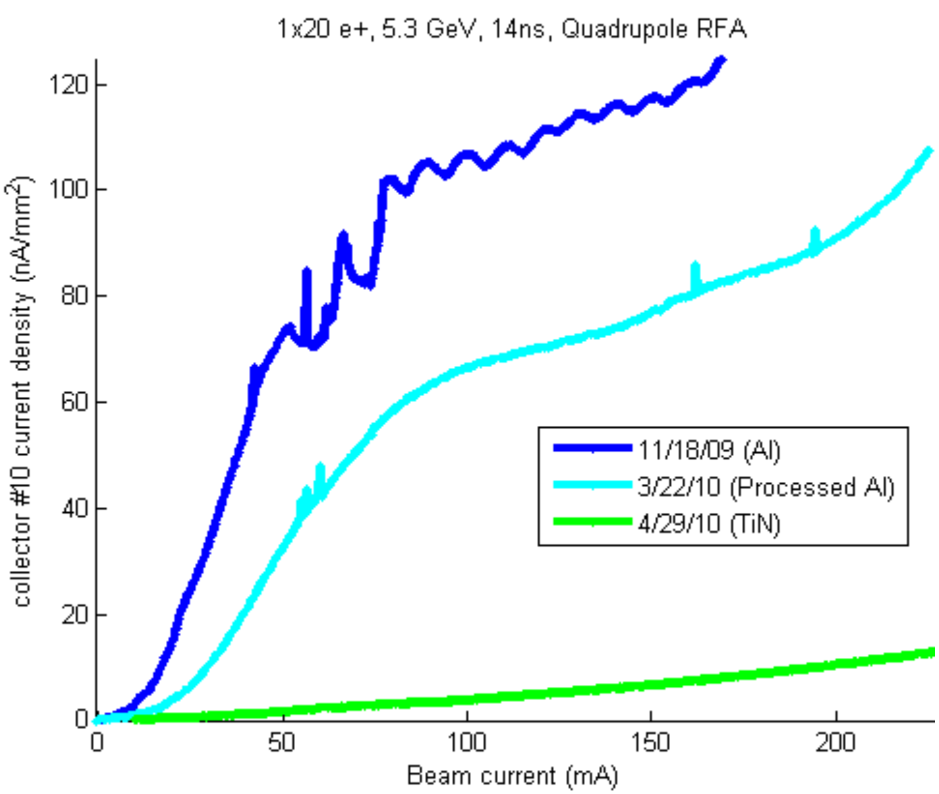
- Quadrupole chamber RFA
- One collector sees a huge amount of current
  - This is where the electrons are guided by the quad field lines
- 12 azimuthal collectors

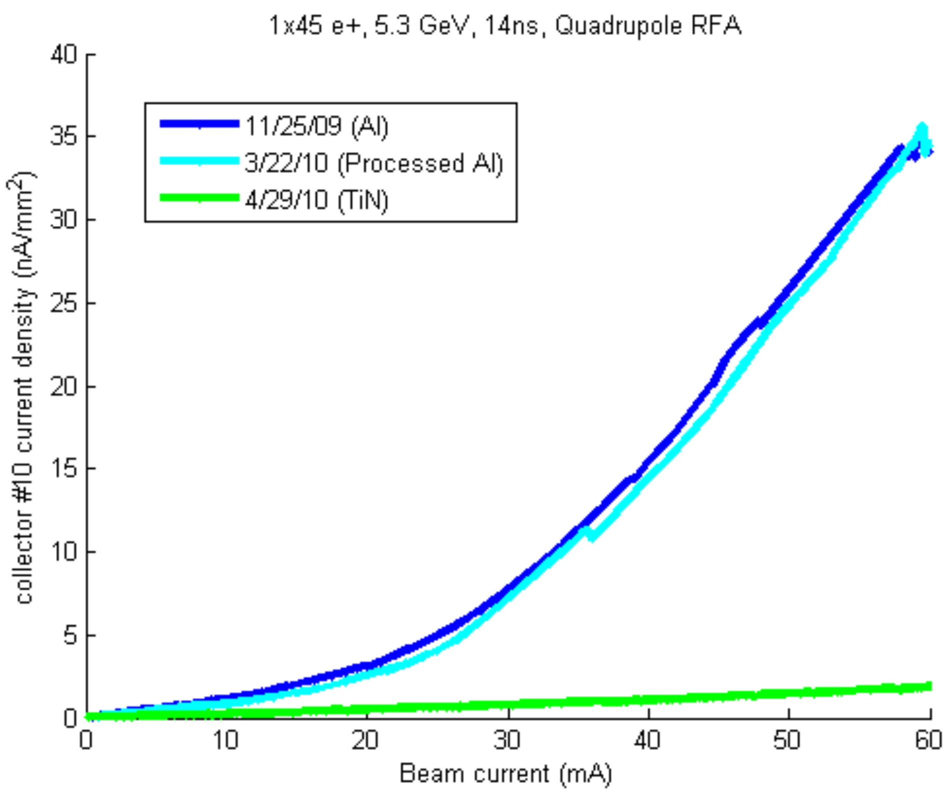


Quadrupole Measurements

- Left: 20 bunch train e+
- Right: 45 bunch train e+

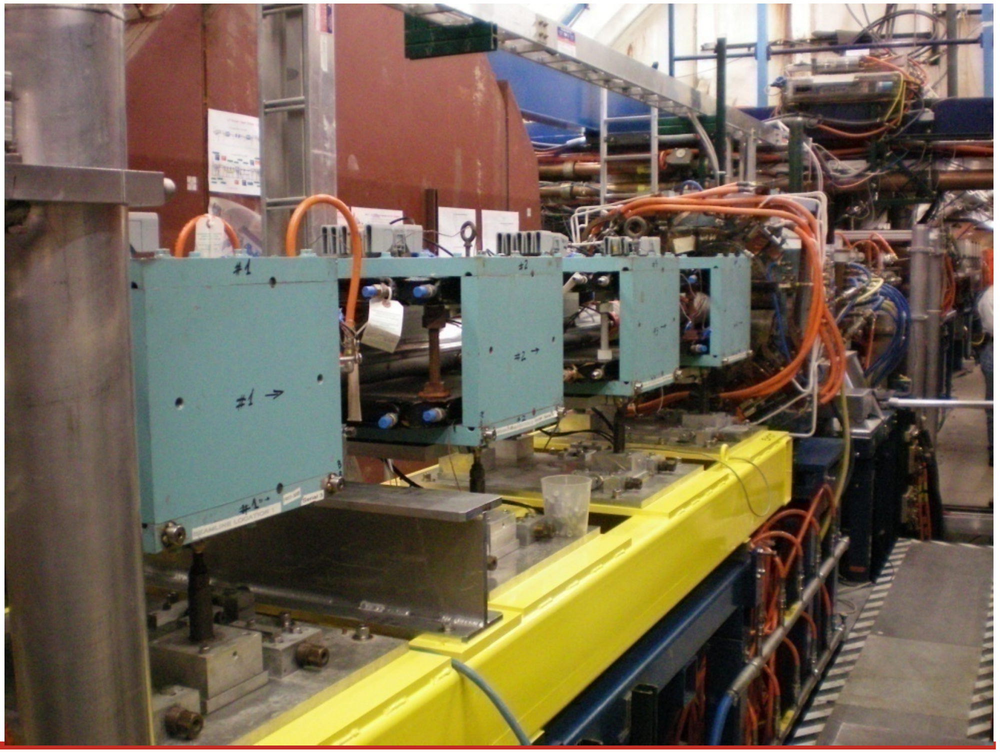
⇨ Clear improvement with TiN





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)

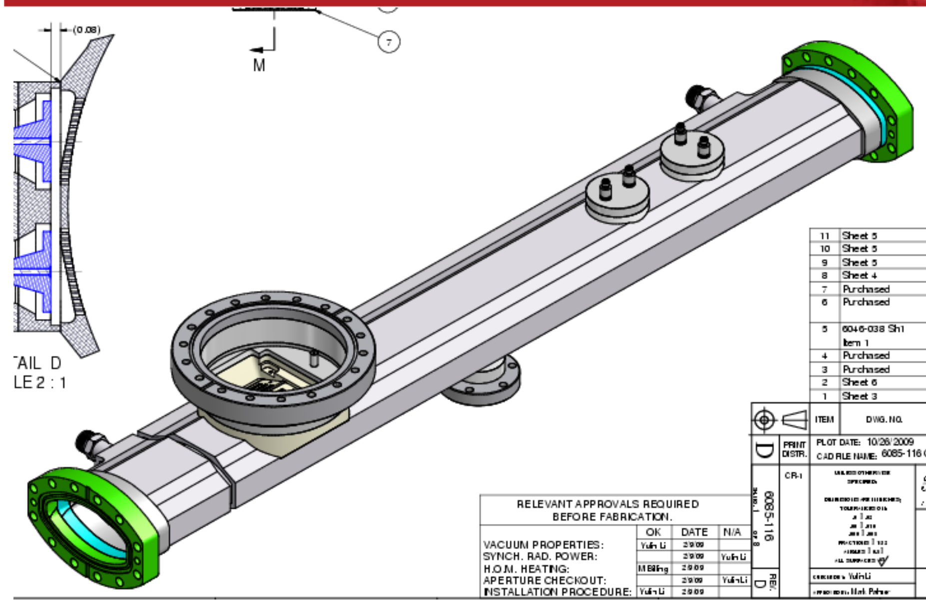


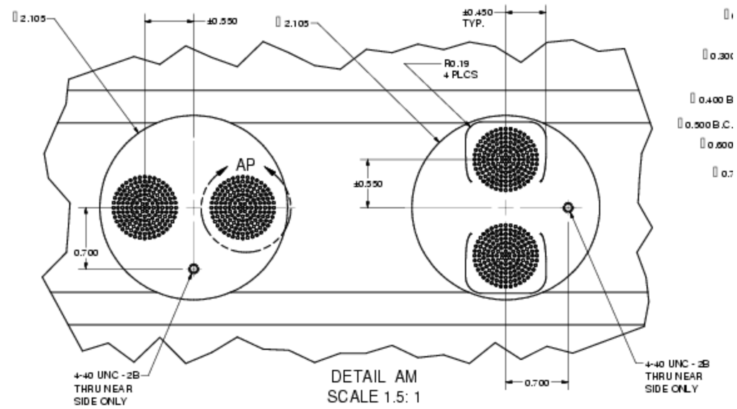
Surface Characterization & Mitigation Tests

	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				✓ (planned)	CU, KEK, LBNL, SLAC
Clearing Electrode				✓	CU, KEK, LBNL, SLAC

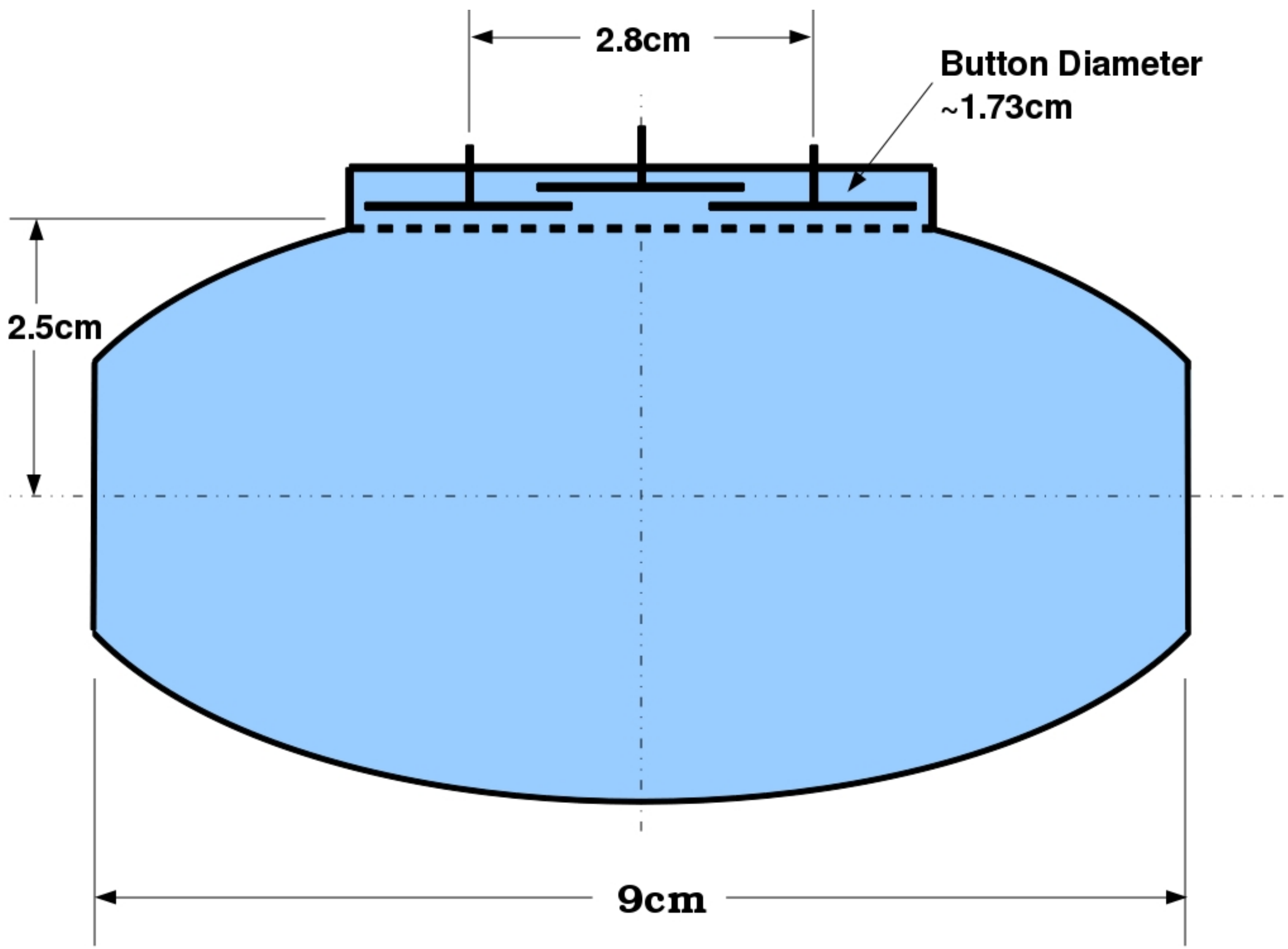
✓ = chamber(s) deployed ✓ = planned

Shielded pickup

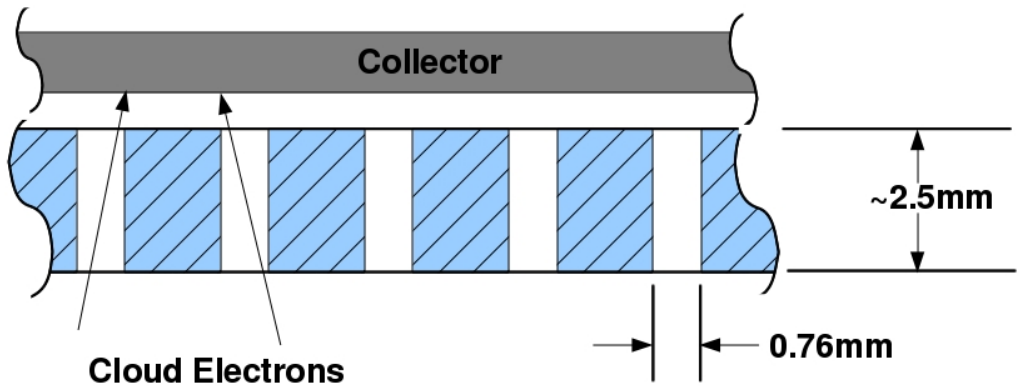




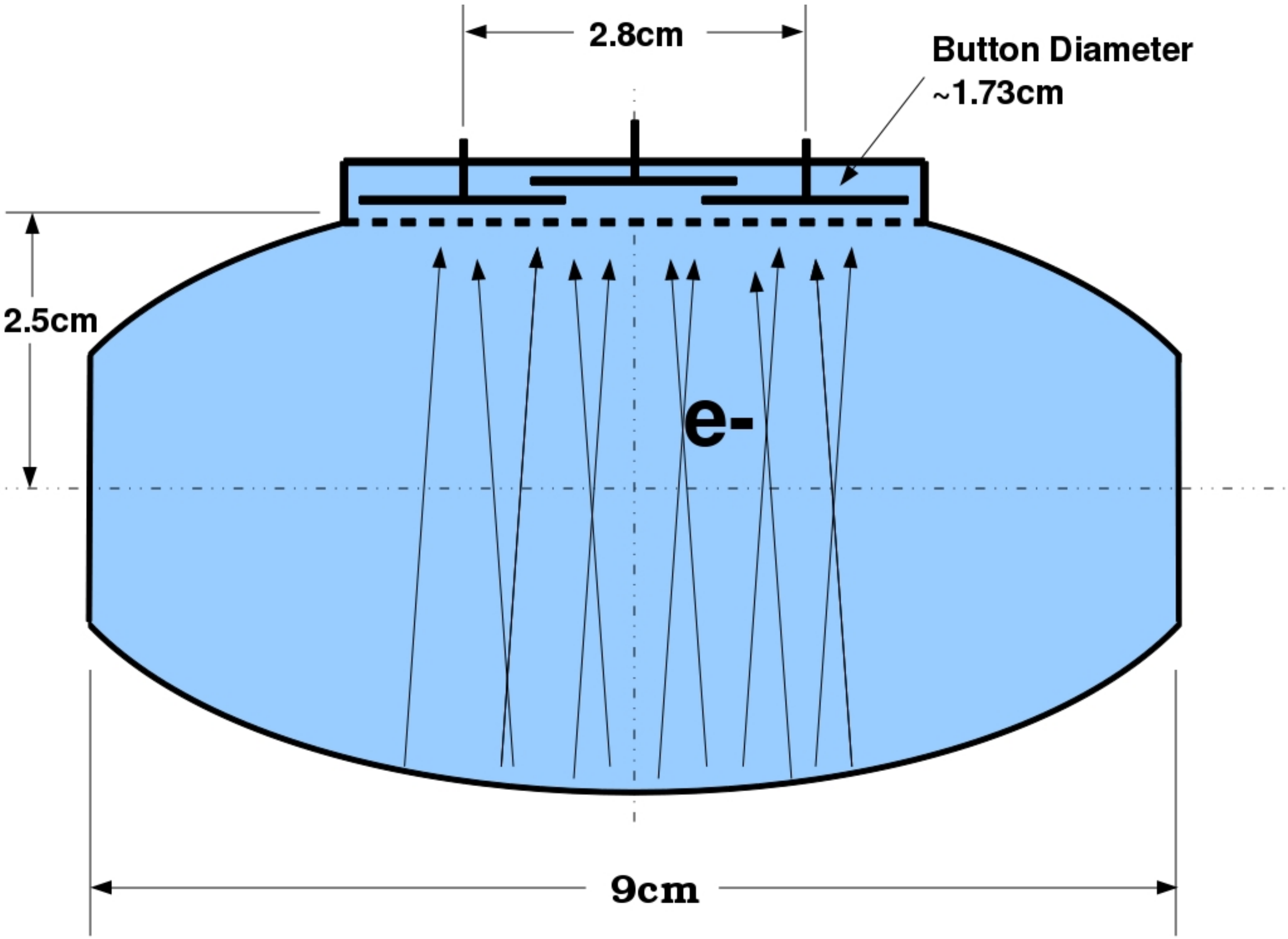
Shielded pickup



Shield



Shielded Pickup

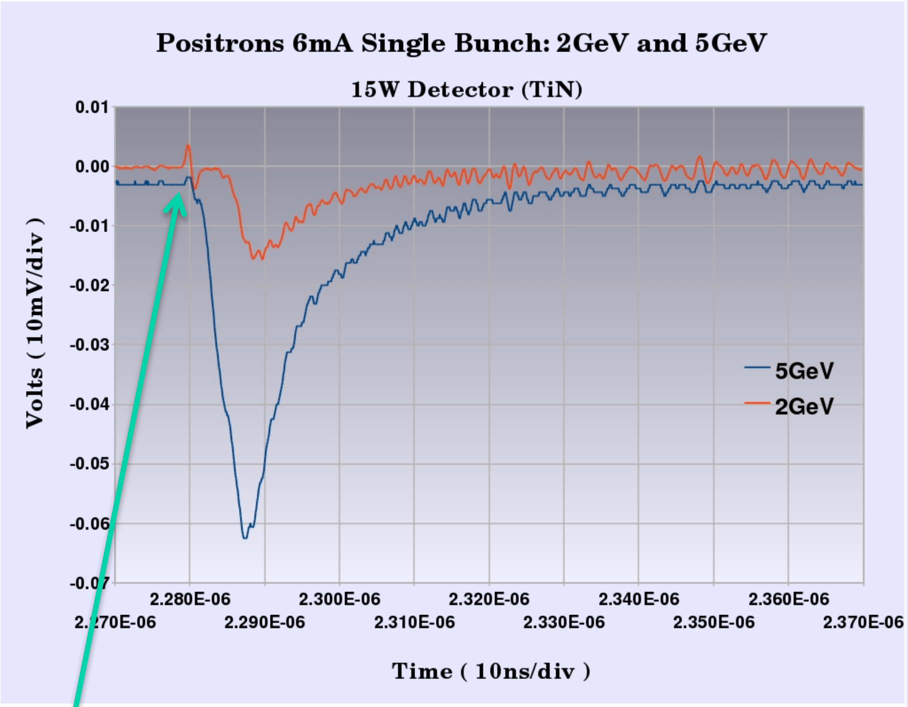


With no magnetic field, electrons come from the floor of the chamber

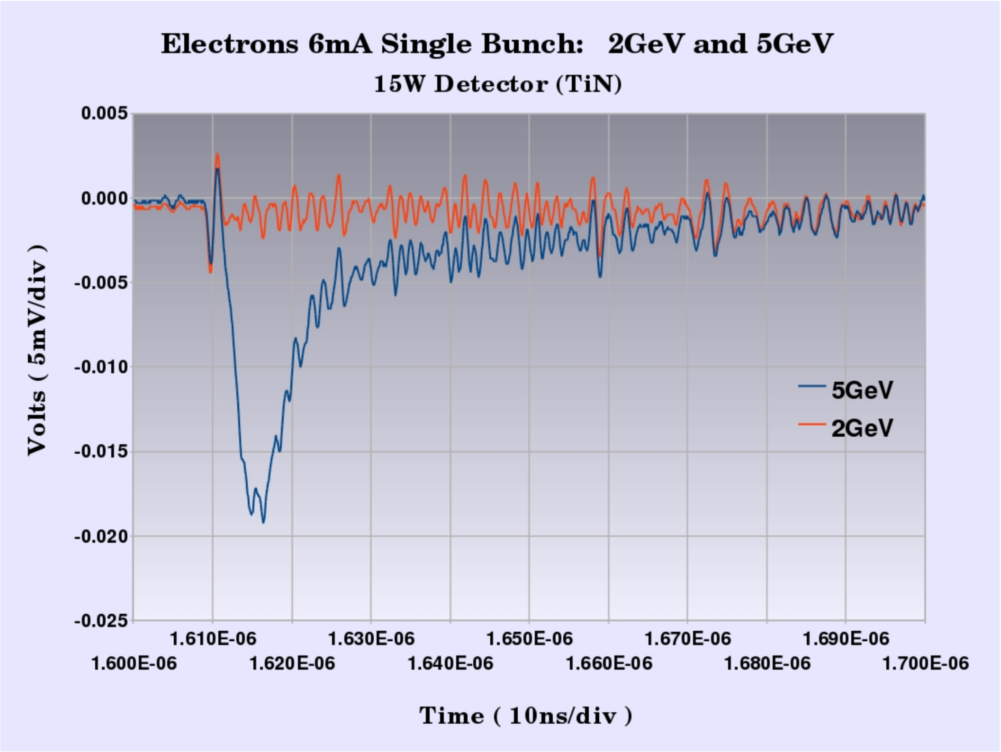
Shielded pickup

Single bunch

positrons

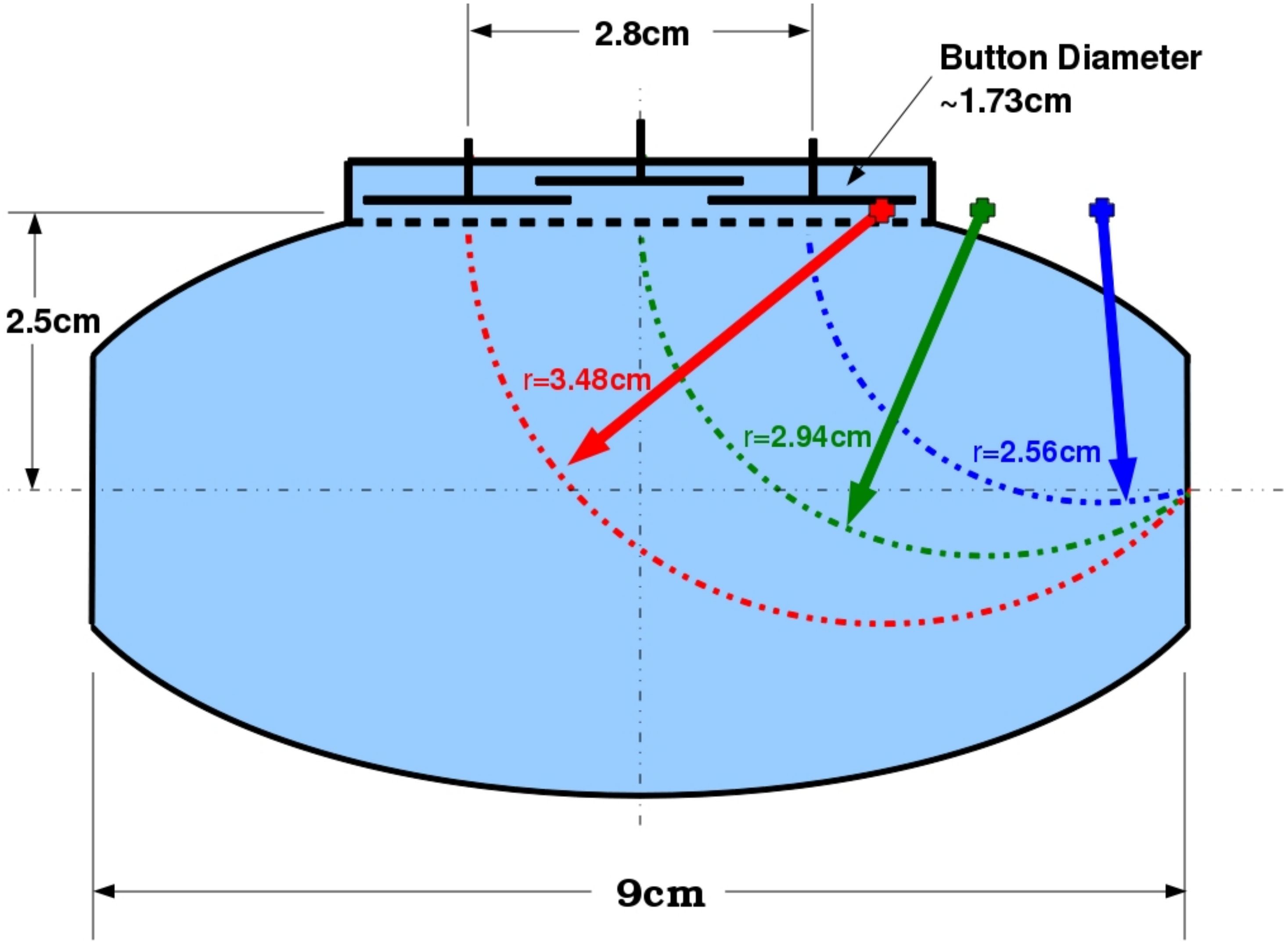


electrons

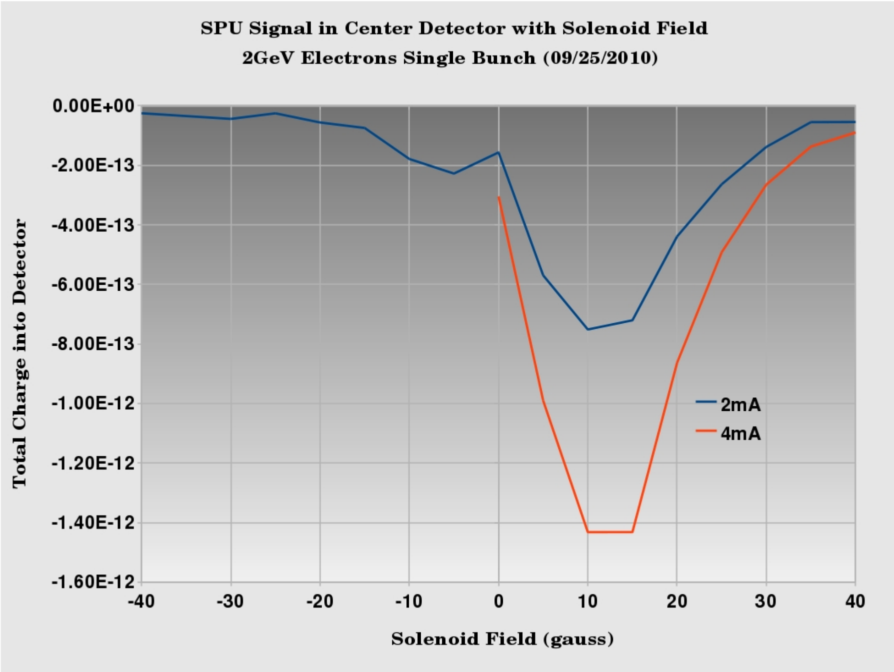


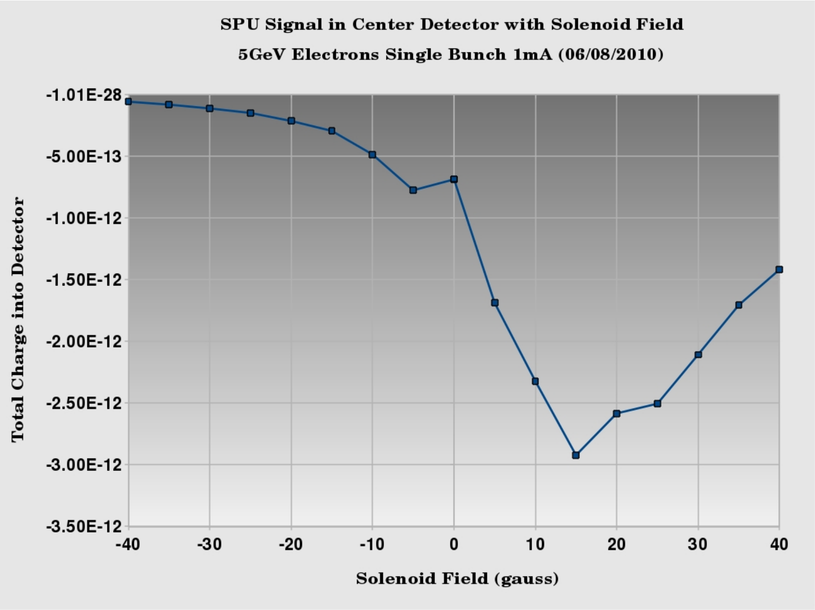
Direct beam signal

Solenoid field



Single bunch – SPU vs solenoid field

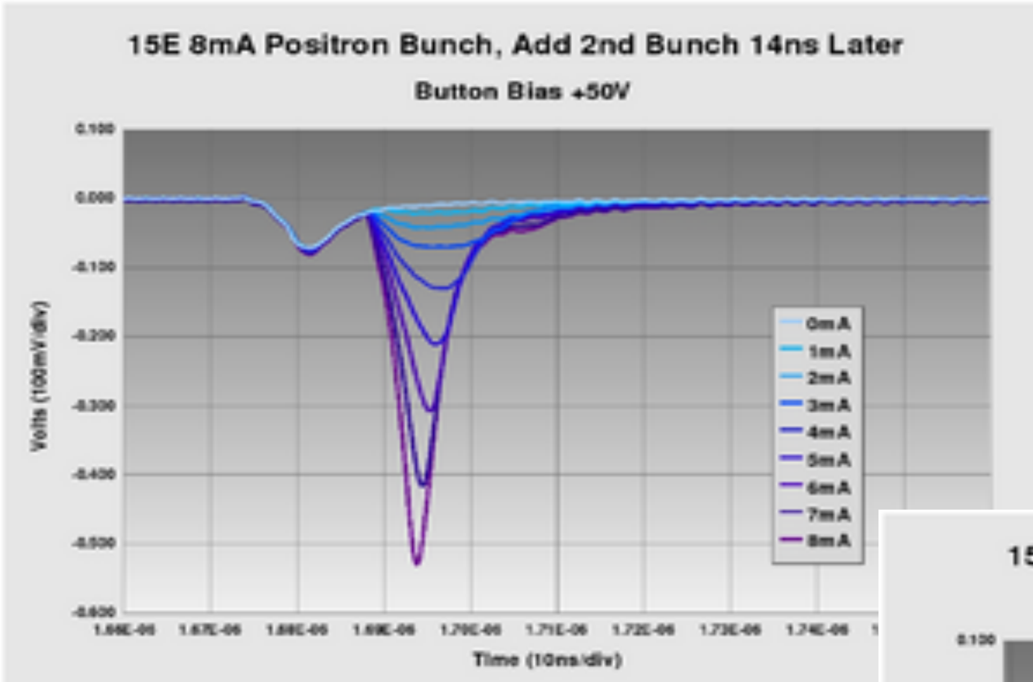




2gev

5gev

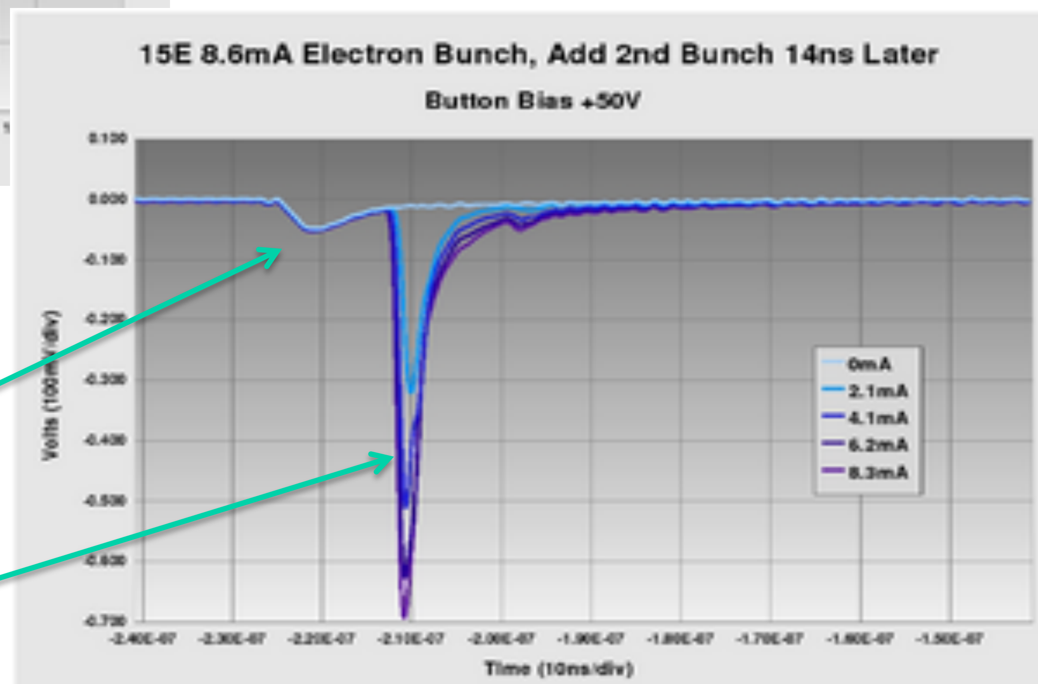
Shielded pickup



Witness bunch method

Electrons from the ceiling

Electrons from the floor



First bunch

witness

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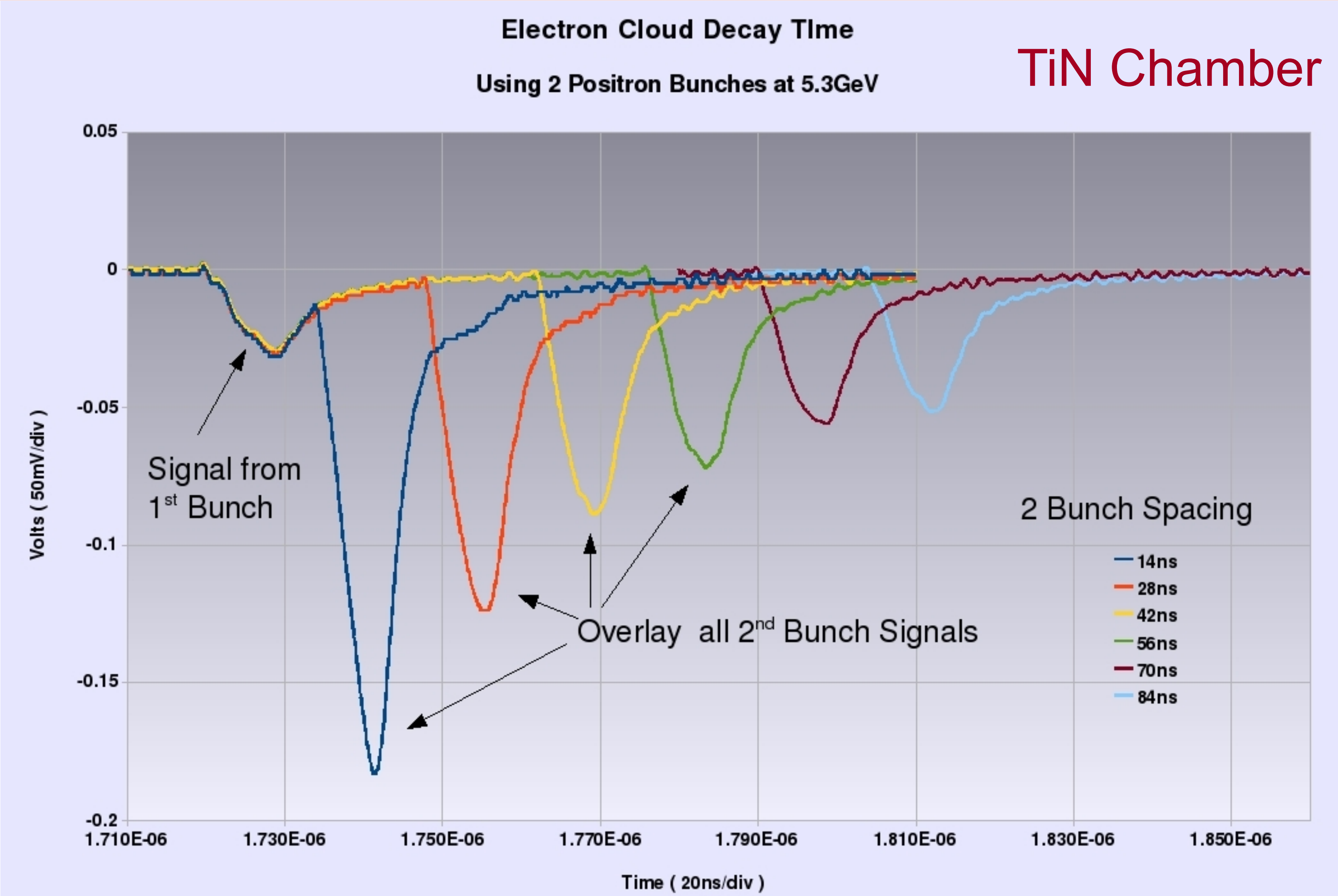
Cloud Evolution: Witness Bunch Studies



Consistency with simulation has a strong dependence on the elastic yield parameter.

Beam dynamics experiments

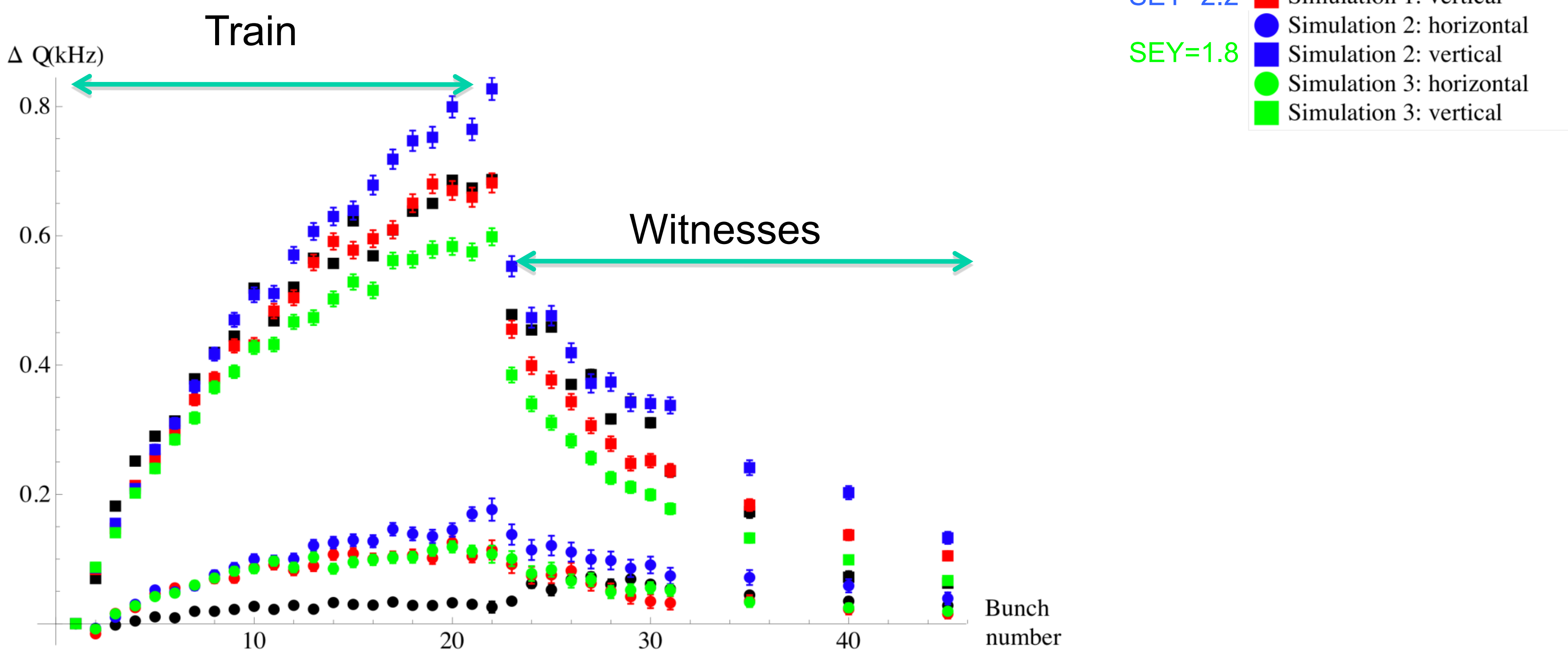
- Electron cloud focuses the beam and shifts the tune
  - Measurement of tune shift of bunches along the train yields electron density
- Electron cloud also couples the head and tail of the bunch
  - Measurement of the spectral content of each bunch indicates instabilities.
- Tune shift measurements
  - Kick the entire train and use turn by turn position to extract tune of each bunch.
  - Gated spectrum analyzer gives a measure of the self excited tune in each bunch
- Gated spectrum analyzer also reveals bunch dependence of synchrobetatron sideband

Example: Positron Witness Bunch Study at 2GeV

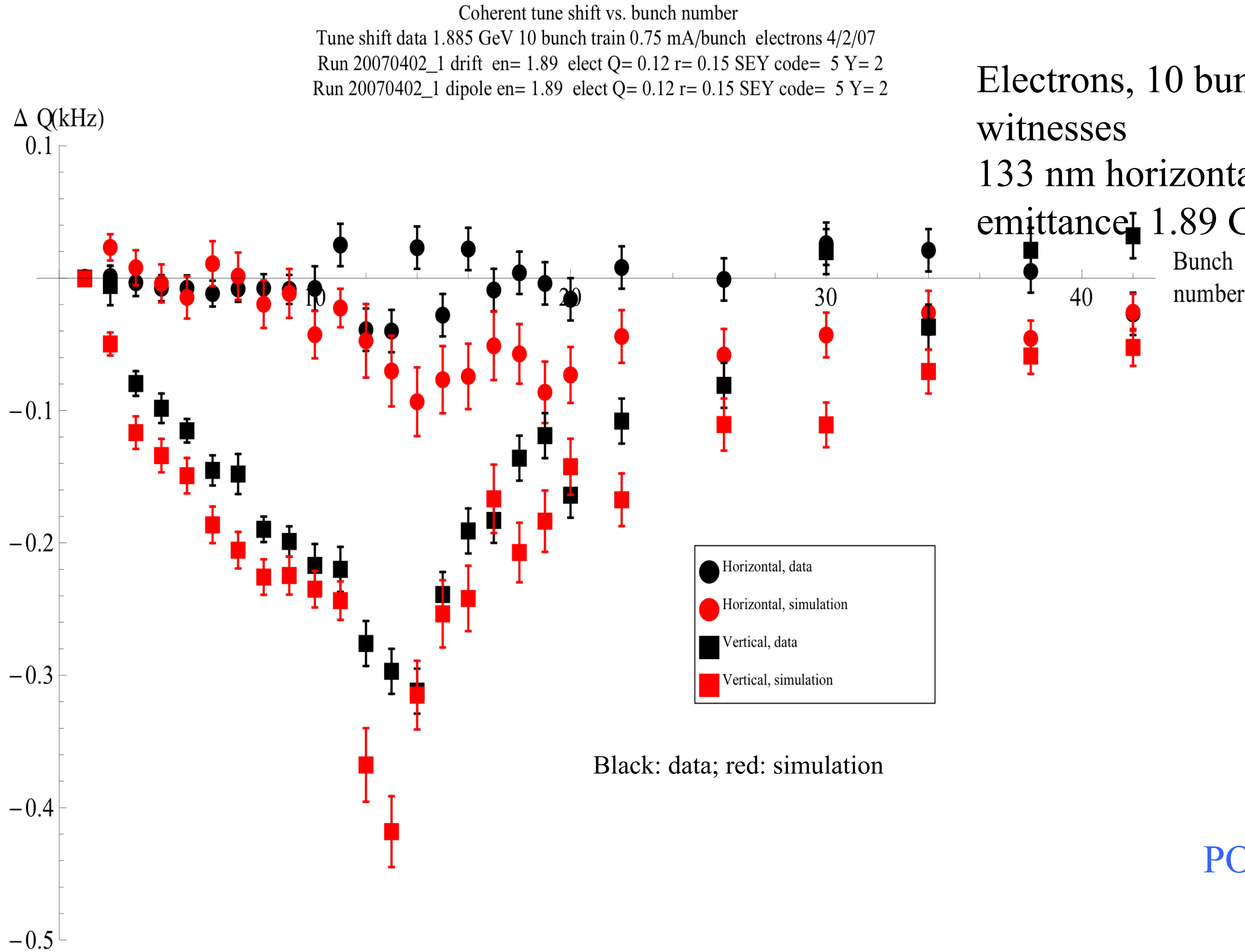
Peak SEY Scan

Coherent Tune Shifts (1 kHz ~ 0.0025), vs. Bunch Number

- 21 bunch train, followed by 12 witness bunches
- 0.8×10^{10} particles/bunch
- 2 GeV.
- Data (black) compared to POSINST simulations.



Coherent tune shifts (2)



Electrons, 10 bunch train + witnesses
133 nm horizontal emittance, 1.89 GeV

POSINST

Coherent tune shifts (4)

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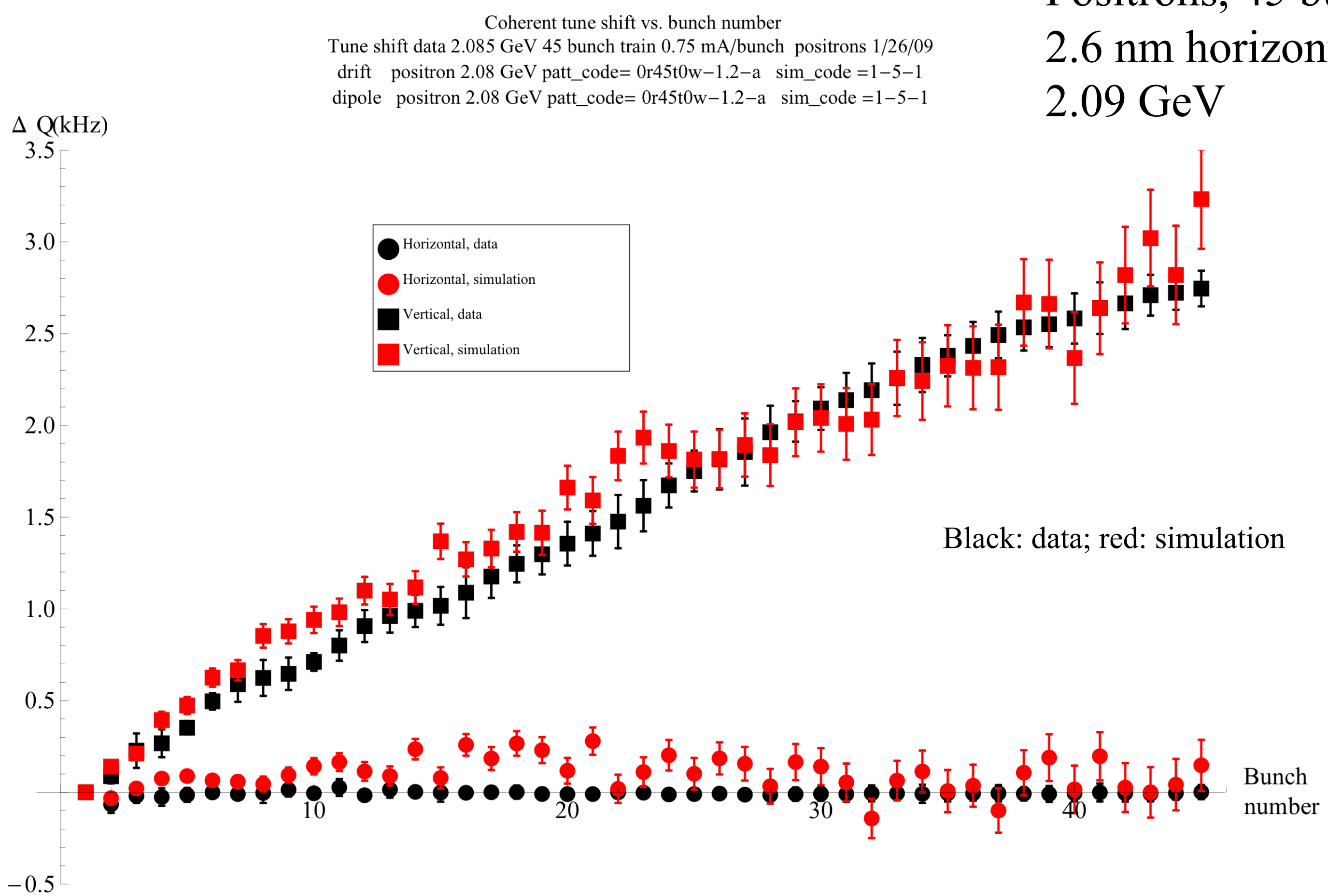
Long train data was taken in January, 2009, using low emittance lattice.

Positrons, 45 bunch train
2.6 nm horizontal emittance,
2.09 GeV



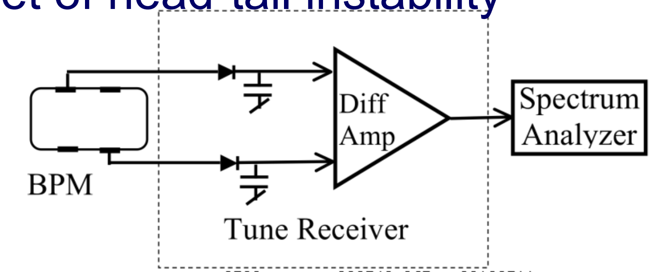
Black: data; red: simulation

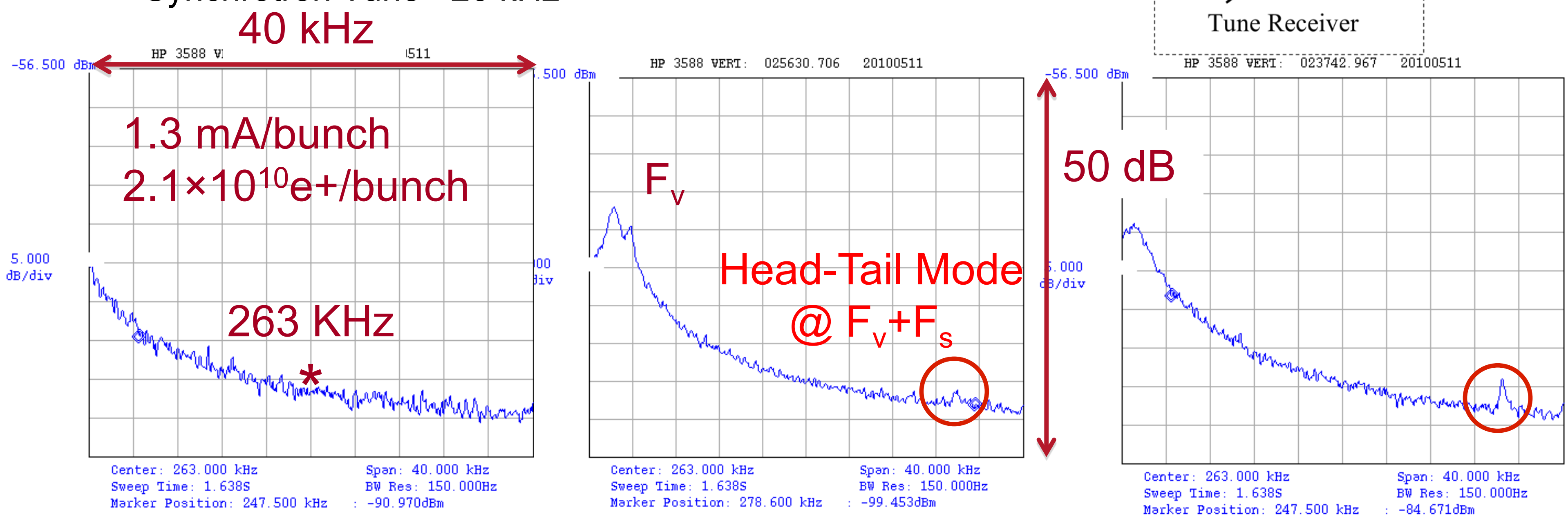
POSINST

Beam Instabilities & Emittance Growth

- Single-bunch (head-tail) – spectral methods and growth rates
- Multi-bunch modes via feedback and BPM system
- Modeling: KEK-Postech (analytical estimates and simulation)
  SLAC-Cornell (CMAD)
  Frascati (multi-bunch instability)

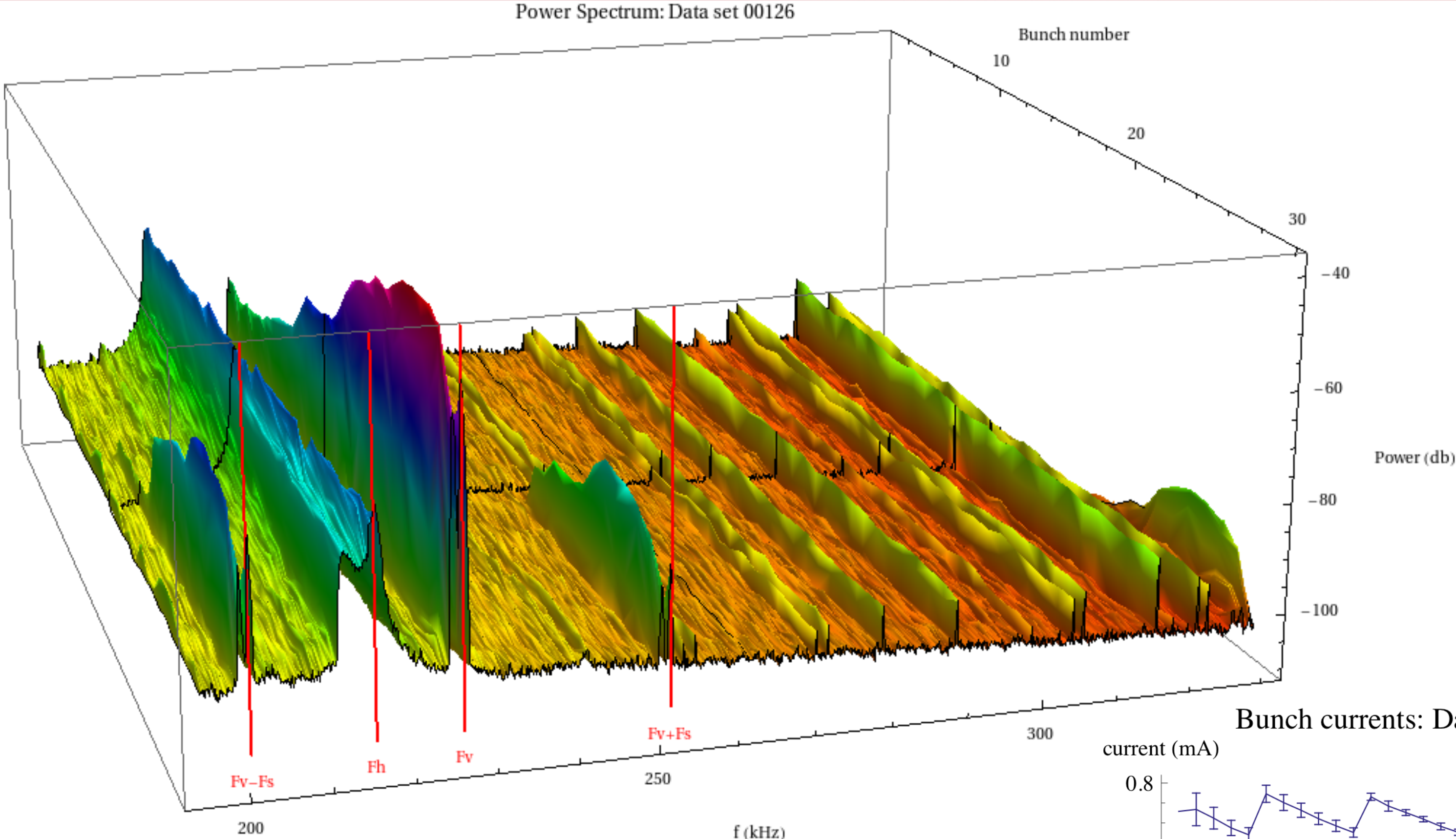
- Current scan in 45 bunch positron train ⇨ Look for onset of head-tail instability
- 2 GeV Low Emittance Lattice, 14ns bunch spacing
  - F_v & Head-Tail Mode spectra (expected at $F_v + F_s$)
  - Synchrotron Tune ~26 kHz



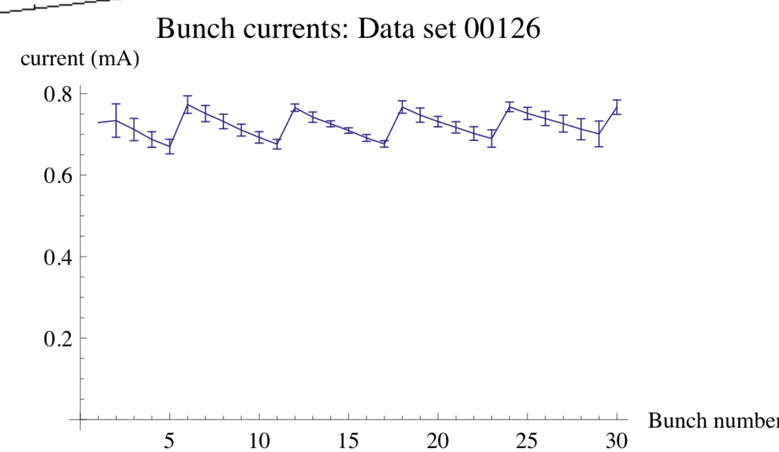


Bunch #1 Bunch #25 Bunch #40

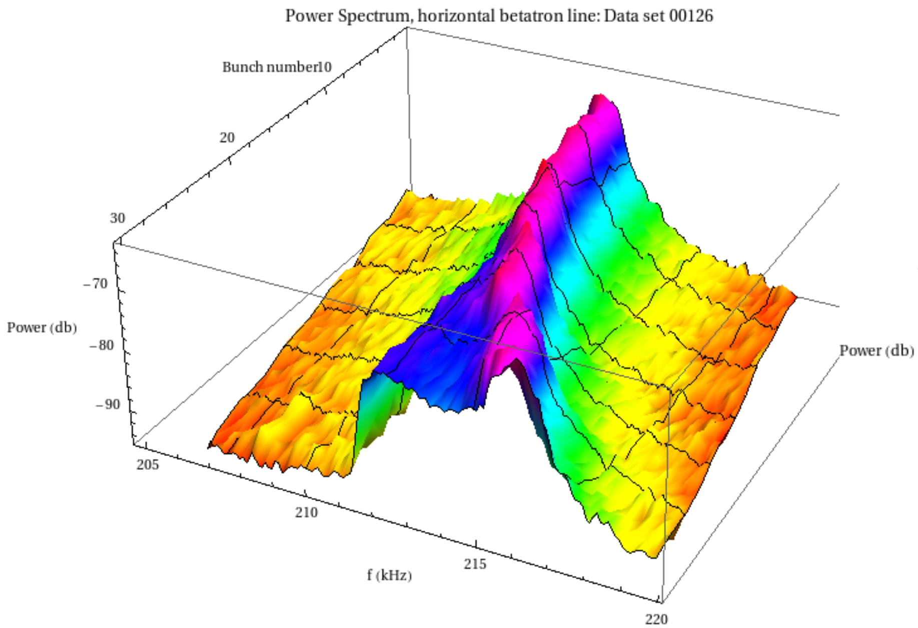
Bunch-by-bunch power spectrum-00126

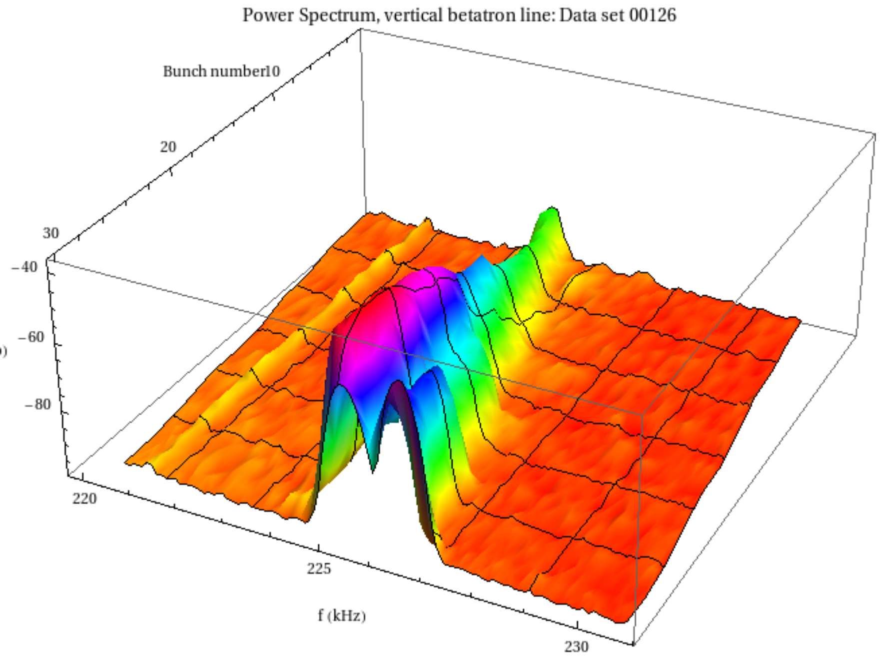


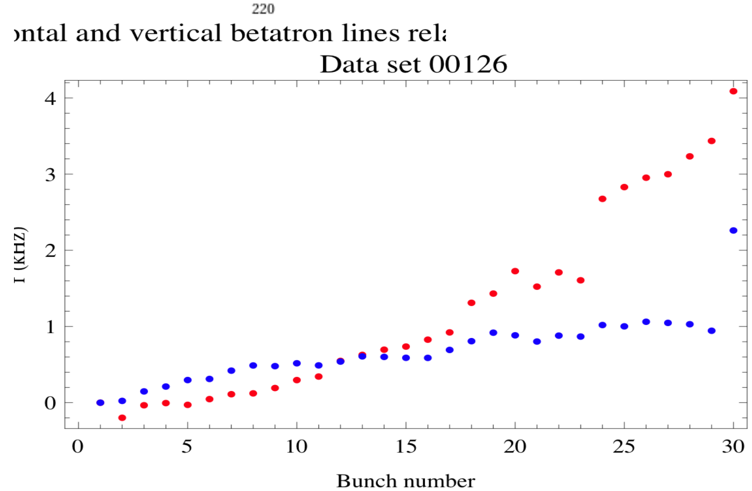
V Chromaticity = 2.67749
H Chromaticity = 1.1775
Positron feedback (H,V,L) =
-400 0 0
Nominal current/bunch (mA) =
0.7233457365496874



Horizontal and vertical betatron lines



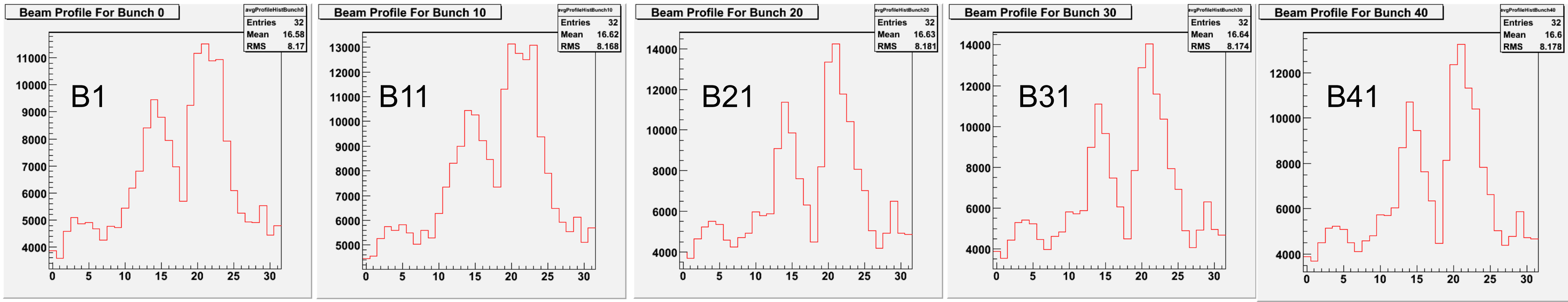




Note bifurcation of lines for bunches ~23-30

Emittance Growth

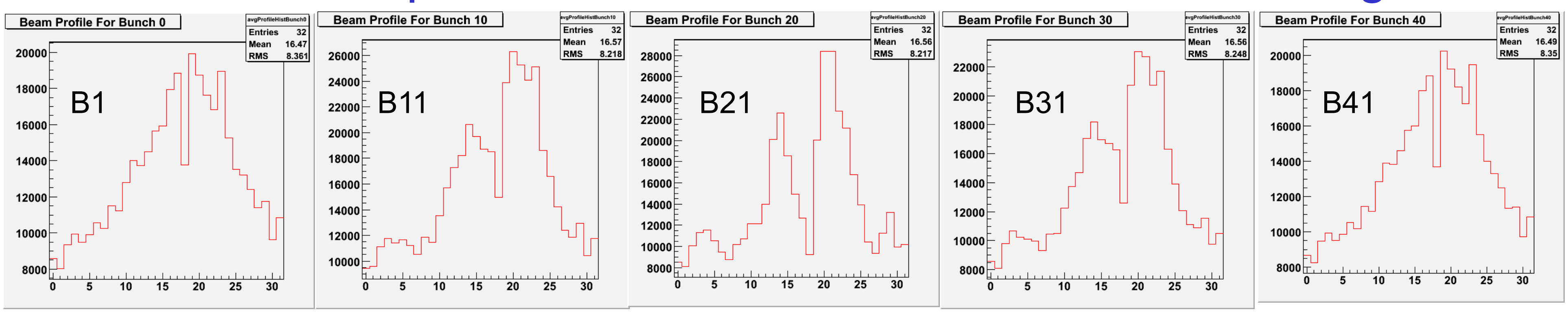
Fast Coded Aperture: 0.5 mA/bunch - 4096 turns averages



Greater depth in structure ➪ smaller beam size

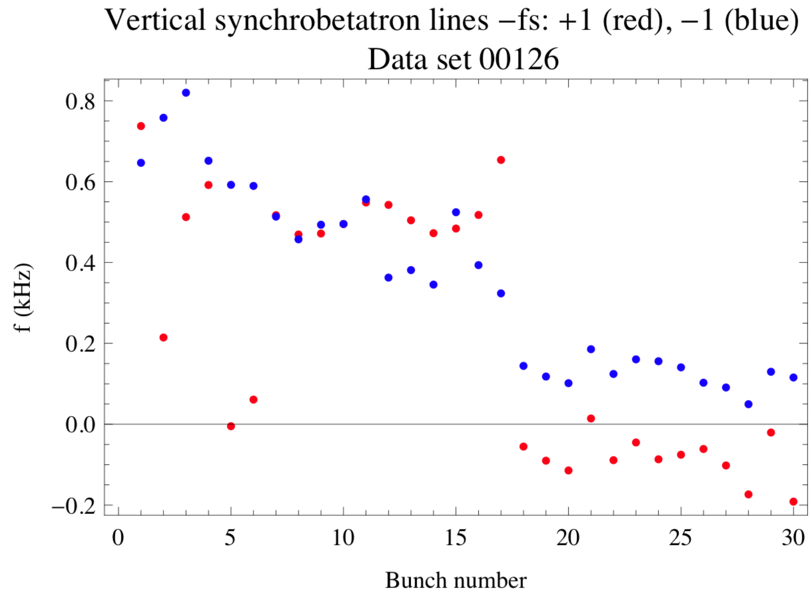
Head of train likely experiencing blow-up from nearby resonance

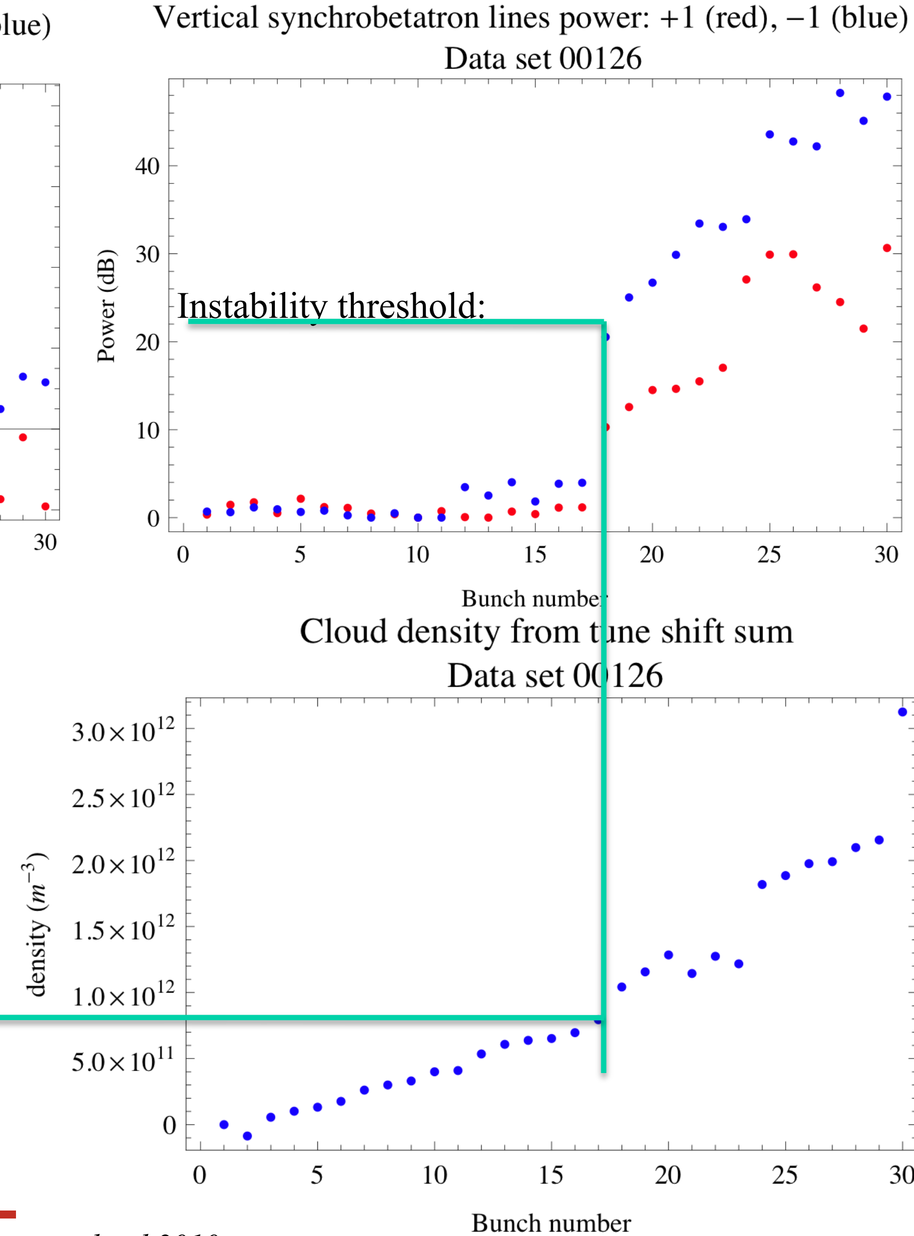
Fast Coded Aperture: 1.0 mA/bunch - 4096 turns averages



Turn-by-turn analysis in progress!

Vertical synchrobetatron lines





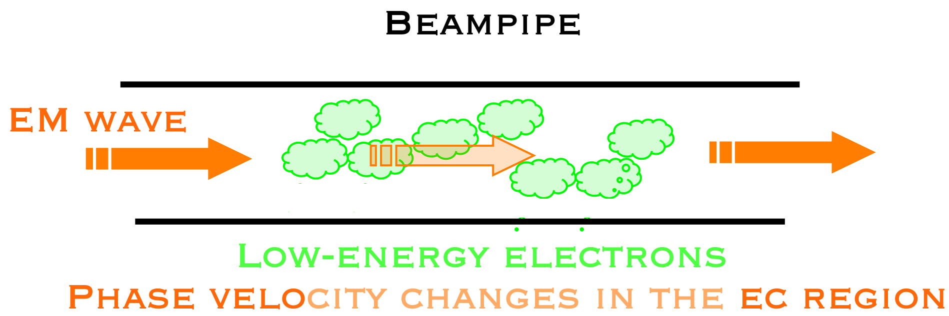
Cloud density at threshold: ~7x10^{11}/m^3

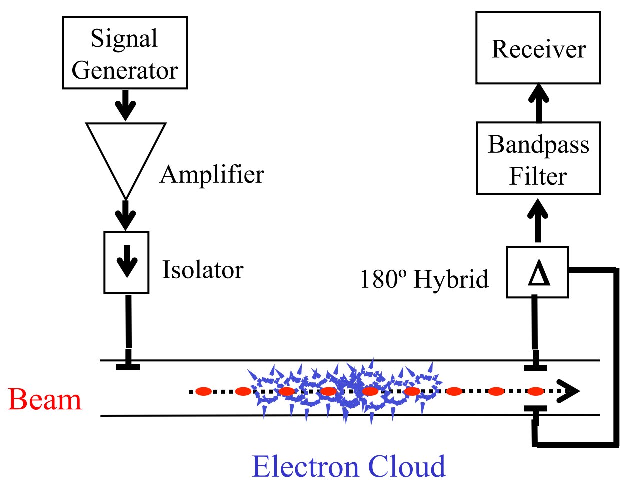
TE Wave Measurements

The electron cloud density modifies the wavenumber associated with the propagation of EM waves through the beampipe.

$$k^2 = \frac{\omega^2 - \omega_c^2 - \omega_p^2}{c^2}$$

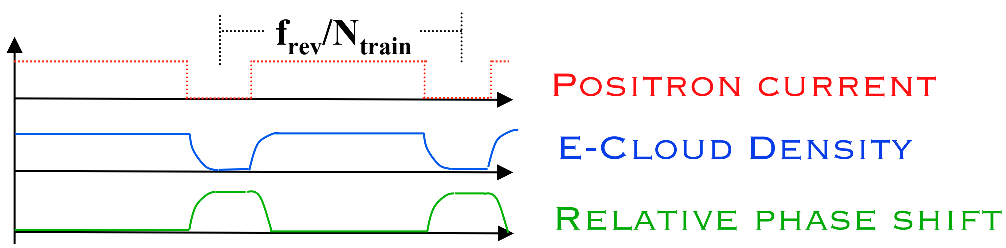
plasma frequency
$2c(\pi\rho_e r_e)^{1/2}$





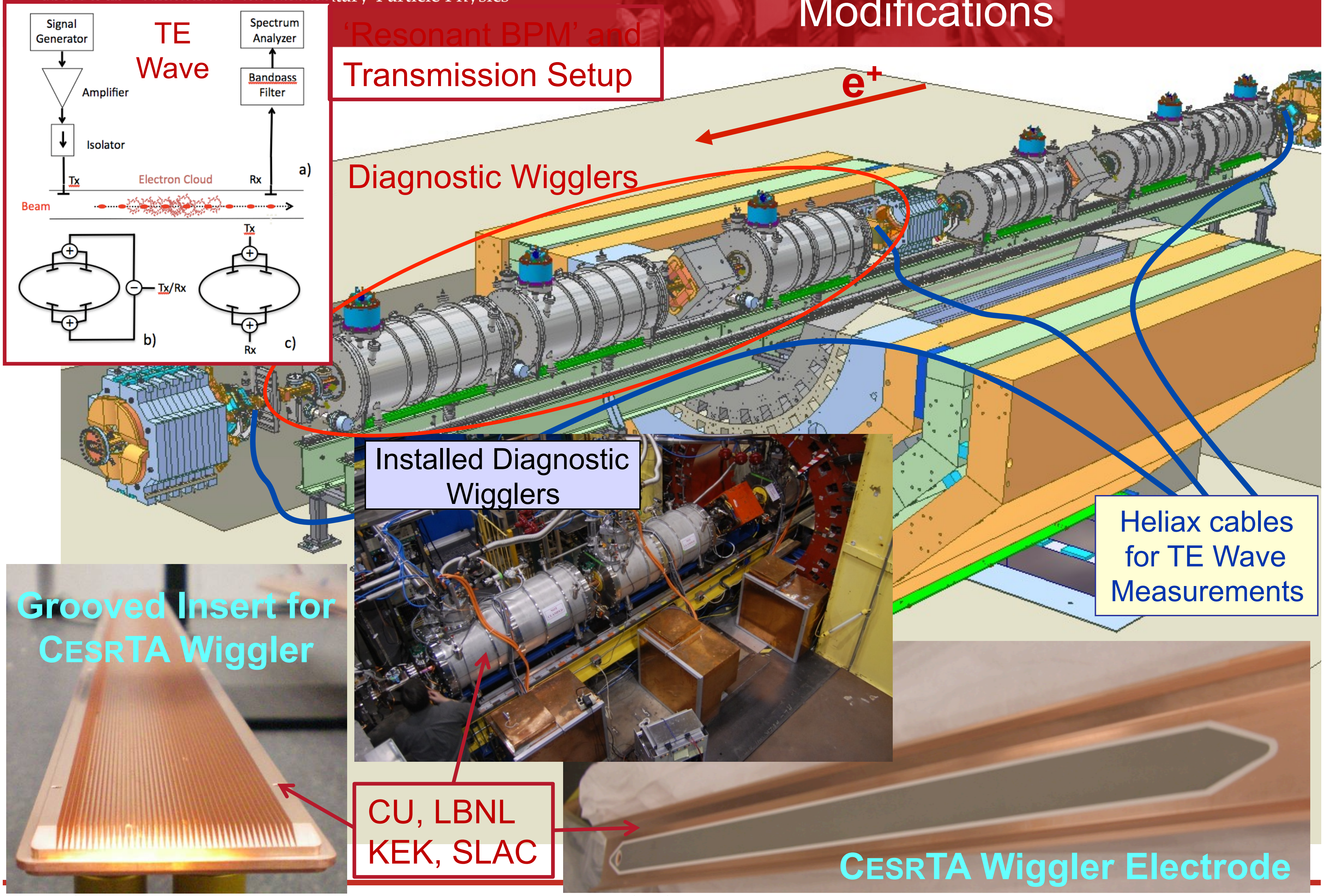
Experimental apparatus

Gaps in the fill pattern result in a modulation of the phase shift. In the frequency domain, this results in sidebands of the fundamental frequency. The amplitude of the sidebands is related to the cloud density.



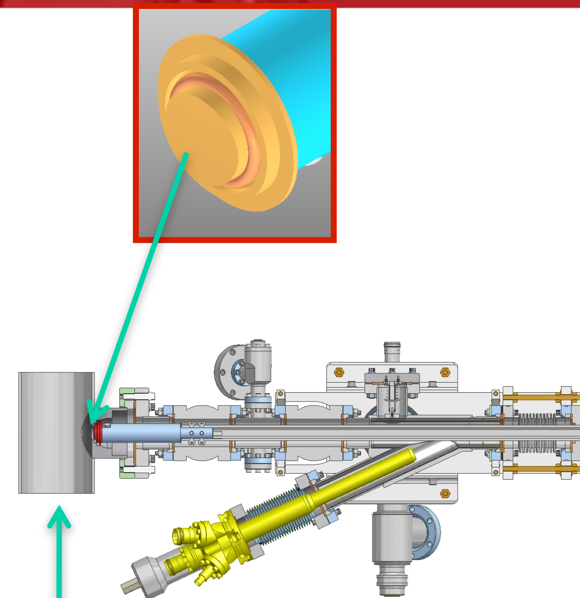
Cornell University
Laboratory for Elementary-Particle Physics

CESR Reconfiguration: L0 Modifications

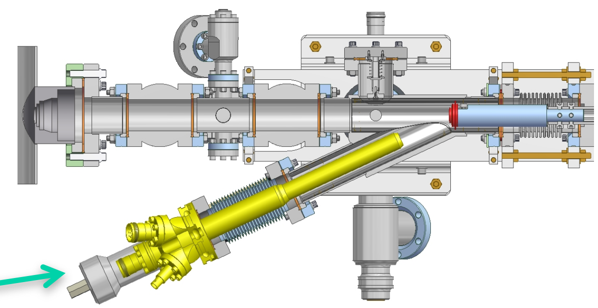


In situ – SEY measurement

Measure secondary emission yield
And the effect of beam processing

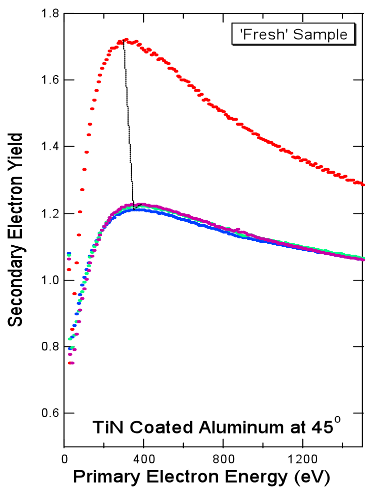


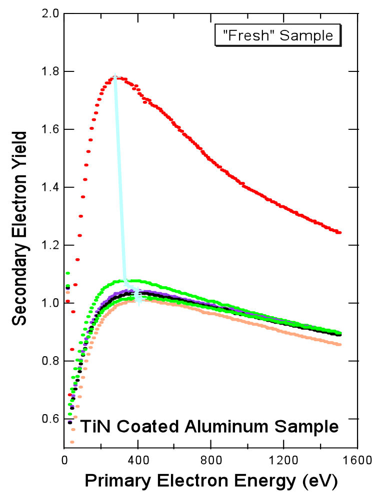
Positron beam

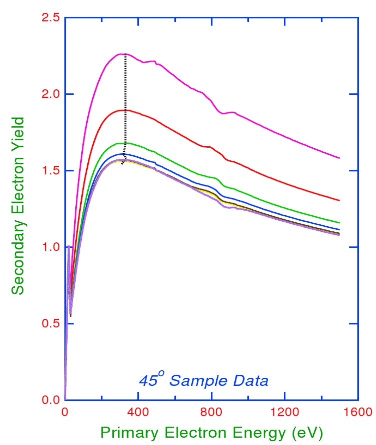


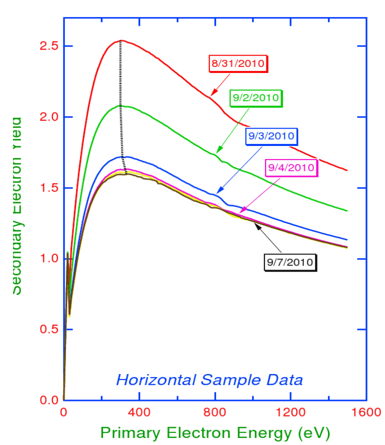
Electron gun

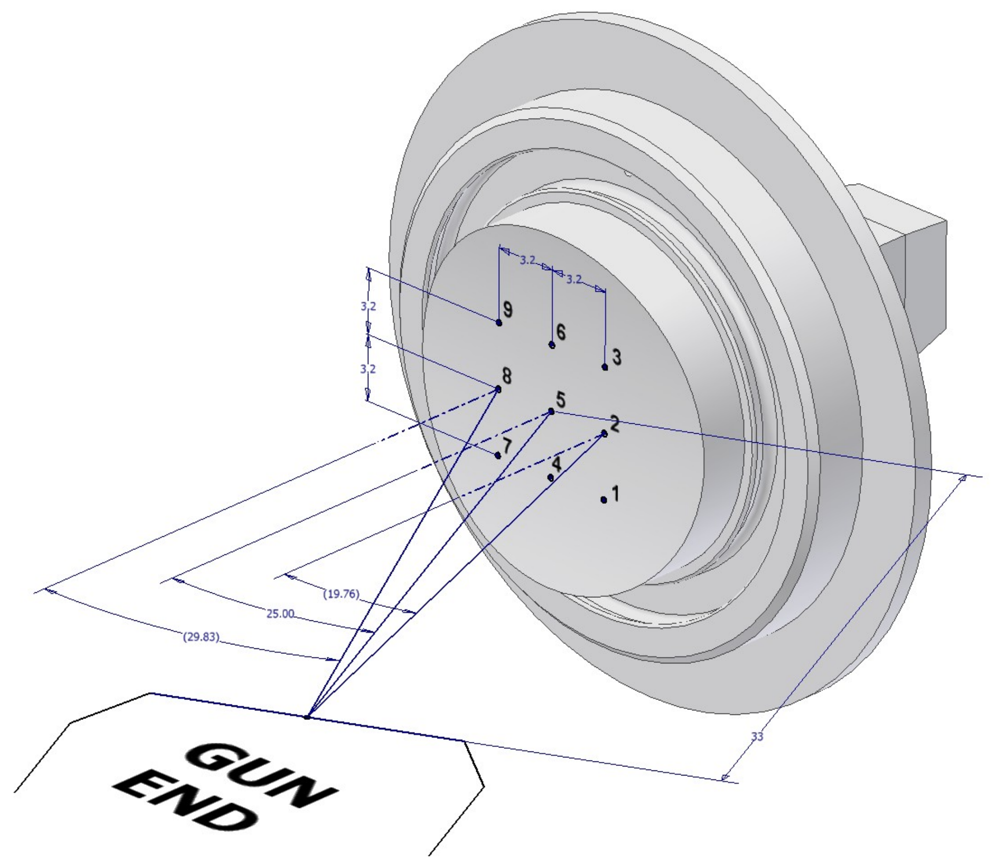
In Situ Sey


'Fresh' Sample
Secondary Electron Yield
TiN Coated Aluminum at 45°
Primary Electron Energy (eV)
0
400
800
1200
0.6
0.8
1.0
1.2
1.4
1.6
1.8


"Fresh" Sample
Secondary Electron Yield
TiN Coated Aluminum Sample
Primary Electron Energy (eV)
0
400
800
1200
1600
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0


Secondary Electron Yield
45° Sample Data
Primary Electron Energy (eV)
0
400
800
1200
1600
0.0
0.5
1.0
1.5
2.0
2.5

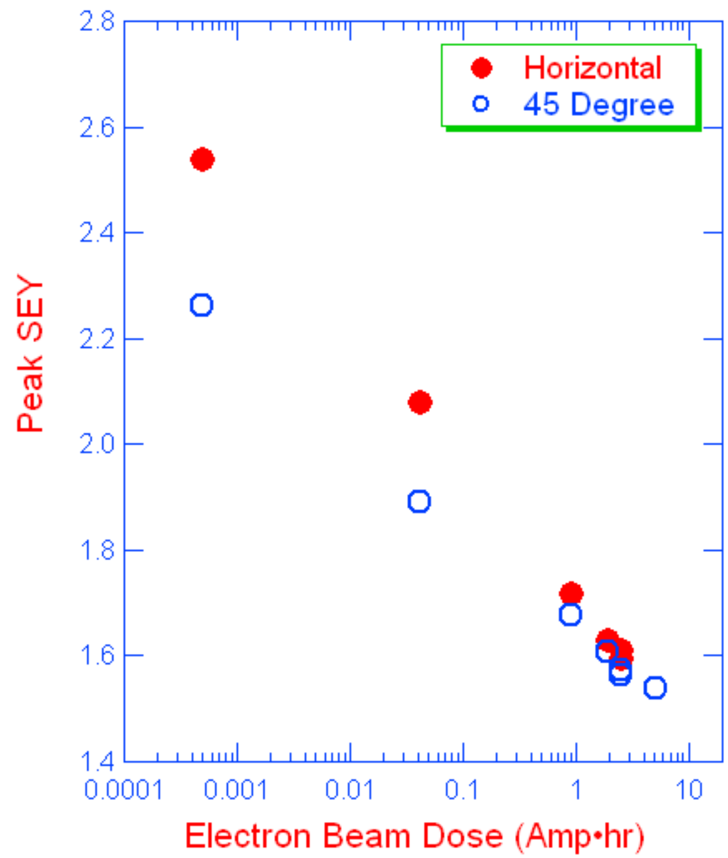

8/31/2010
9/2/2010
9/3/2010
9/4/2010
9/7/2010
Horizontal Sample Data
Primary Electron Energy (eV)
0
400
800
1200
1600
0.0
0.5
1.0
1.5
2.0
2.5


3.2
3.2
3.2
3.2
9
6
3
8
5
2
7
4
1
(19.76)
25.00
(29.83)
33
GUN
END

Sey

•Data shows a steady logarithmic decrease in SEY peak with increased beam dosage

•45 deg system has a consistently higher SEY than the horizontal system for Al TiN sample



Summary

- CesrTA is instrumented for characterization of electron cloud effects in low emittance damping ring
  - RFA - cloud growth and its dependence on
    - Magnetic environment
    - Mitigation
    - Beam current and bunch configuration and beam energy
  - Bunch by bunch tune shift
    - Global electron density and cloud decay
    - In connection with simulation gives us information about modeling parameters
  - Bunch by bunch synchrotron sideband intensity
    - Instability threshold
  - Bunch by bunch beam size measurement
    - Cloud induced emittance growth
  - Shielded pickup
    - Energy of cloud electrons
    - Decay of the cloud
    - And in connection with simulation – more constraints on model parameters
  - TE Wave propagation
    - Local cloud density
  - In situ SEY measurement
    - Effect of beam processing on secondary emission yield
  - High bandwidth precision beam position monitors
    - Beam based measurements essential to low emittance tuning procedure

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