Electron cloud generation, trapping and ejection from quadrupoles at the Los Alamos PSR

Robert Macek, 10/11/2010, EC2010 workshop

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Outline

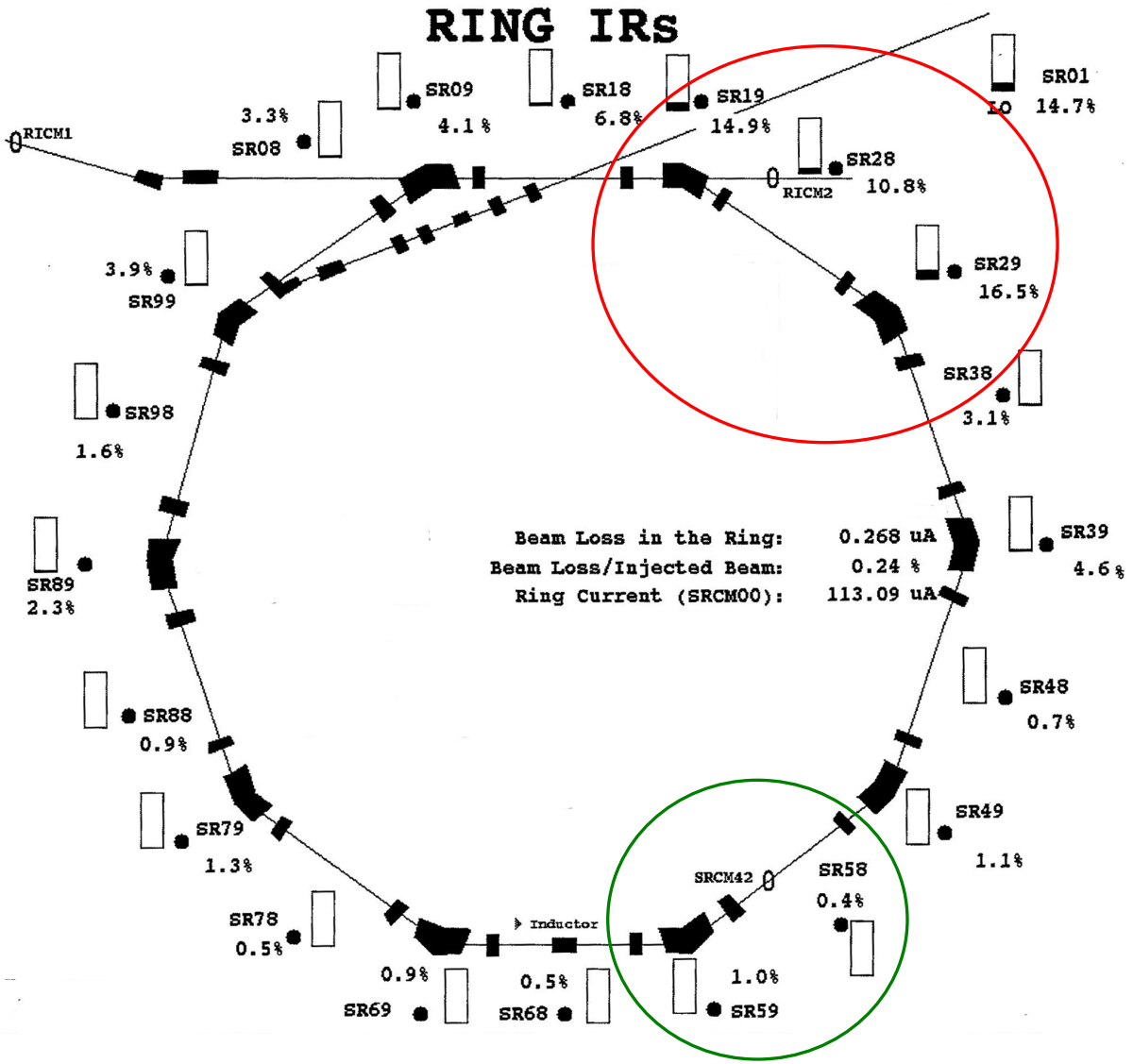
- **Motivation of recent studies**
  - Clarify role of Electron Clouds (EC) in quadrupoles and electrons ejected from quads
- **Experimental Setup**
- **Experiments using "electron mirrors" in Sect 4 to isolate the drift space EC diagnostic from electrons ejected from quadrupoles**
- **Vacuum chamber surface "tracking" as an indicator of EC activity**
- **Summary & Conclusions**

Studies of EC generation, trapping and ejection from quads

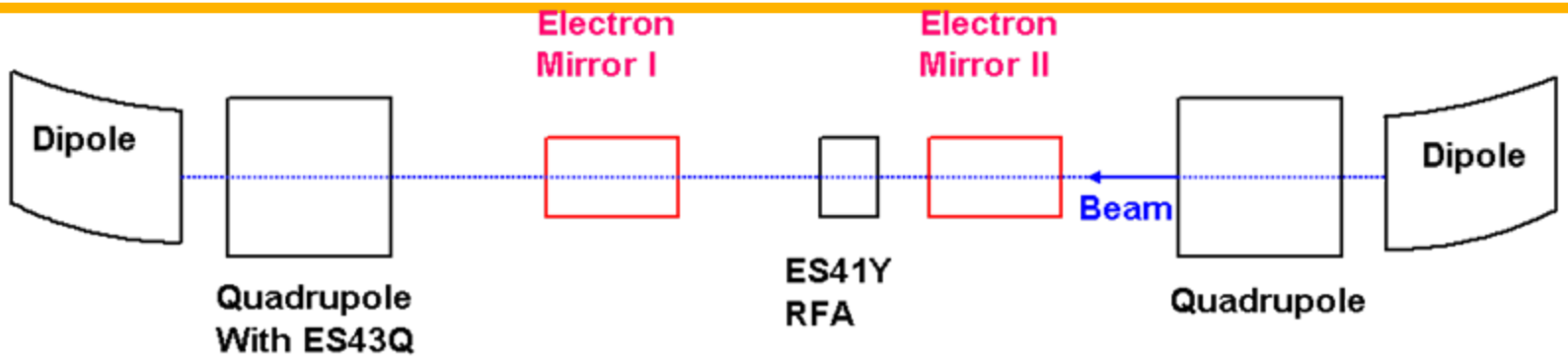
- **For a variety of reasons, our recent focus has been on EC generation in quads**
- **Suppression of electron cloud generation by clearing fields, weak solenoids (also TiN coatings) in drift spaces suppressed EC signals (flux of e's at wall) but had little or no effect on e-p thresholds, suggesting that the main source is elsewhere**
- **Production of "seed" electrons by grazing angle beam losses is expected to be highest in quads where beta functions peak and are largest**
- **Electrons can be trapped in the mirror-like fields of quads**
- **Significant EC may also be generated in dipoles but difficult to introduce RFA diagnostics in PSR dipoles**
- **Analytical calculations and simulations showed significant ejection of electrons from quads by ExB drift mechanism into nearby drift spaces**
  - Are these the main "source" of EC signals in drifts rather than those seeded by direct losses in the drift?

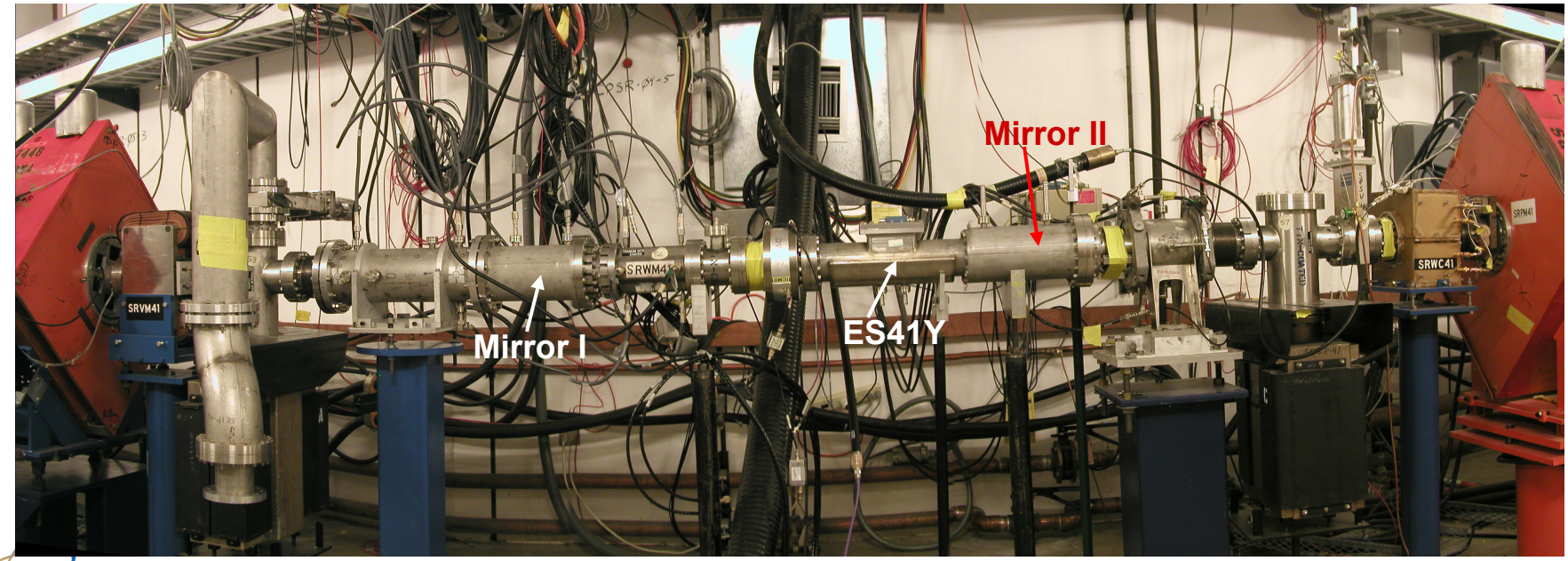
Ring Loss Monitor Map for PSR (6/18/2008)

- 20 Ion Chamber (IR) loss monitors are located at beam height on the wall around the ring tunnel
- All IR's have the same gain
- High loss regions are around injection (SR19&29) and near extraction
- Location of EC diagnostics in section 4 are a low loss area (SR49&59)

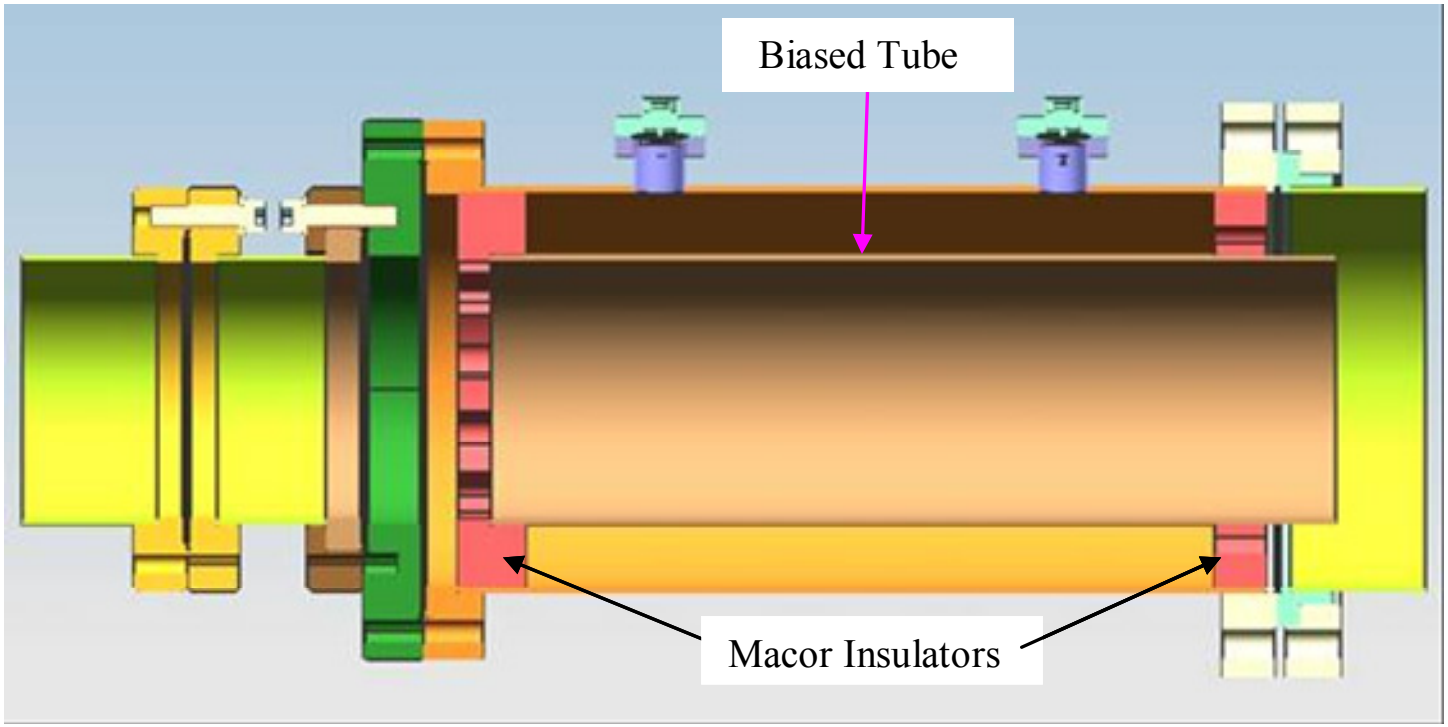


Layout in sect. 4 showing diagnostics used for recent EC studies



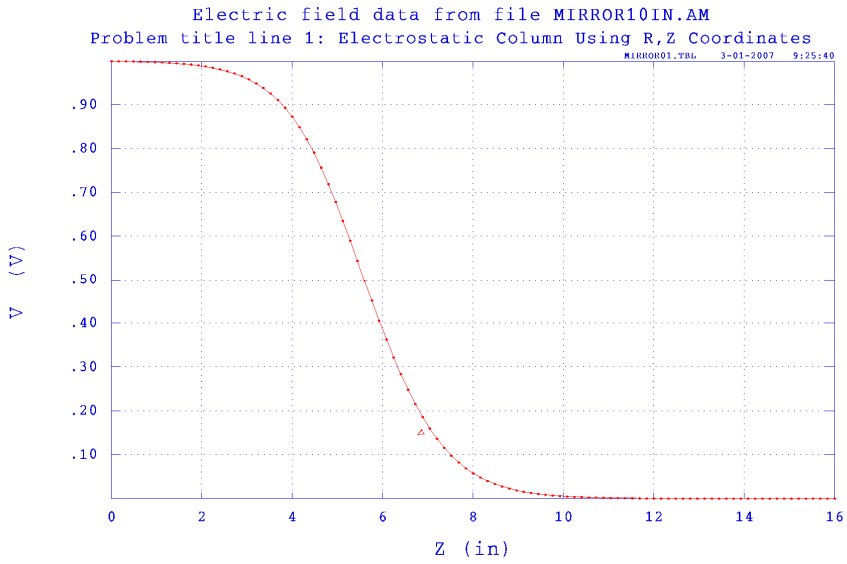


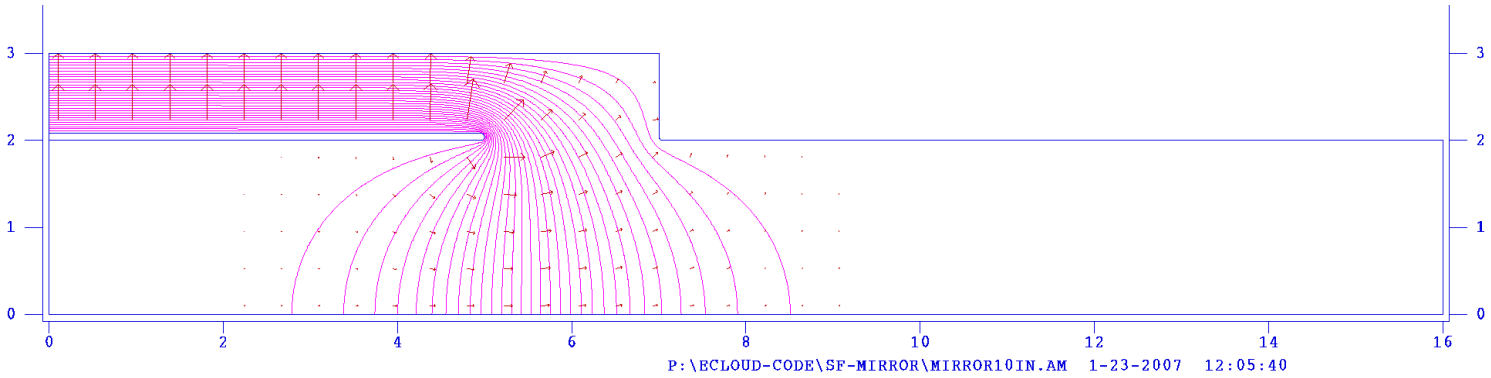
Electron longitudinal barrier “mirror”



Two mirrors biased to -2kV or so isolate the drift space detector region from electron ejected from the nearby quadrupoles

Normalized mirror potential

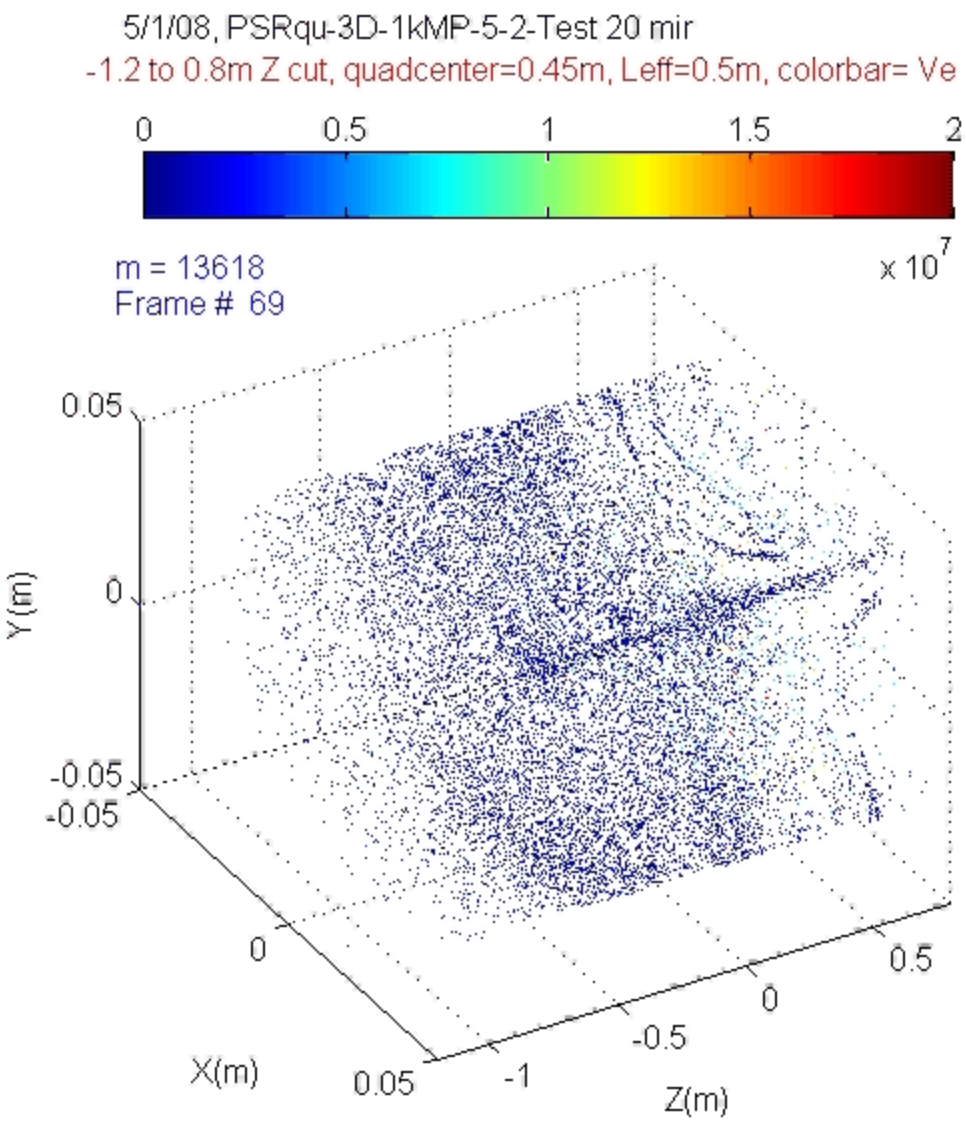


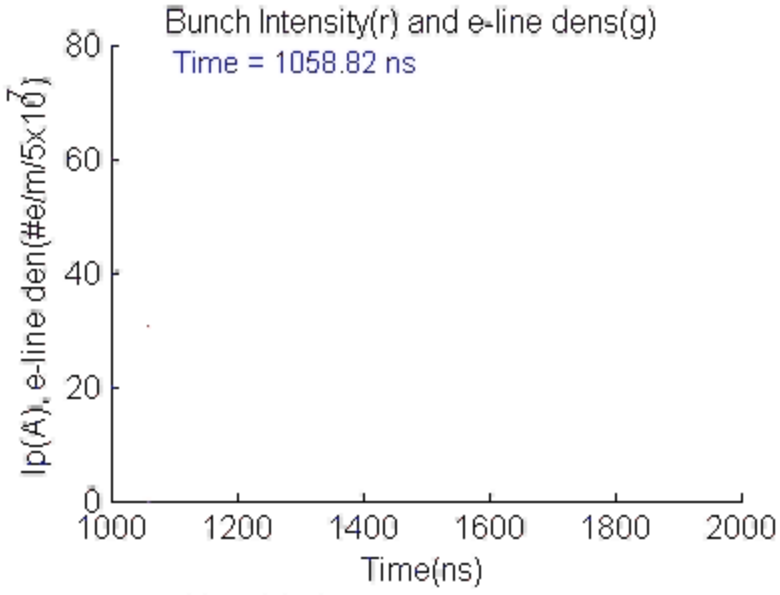


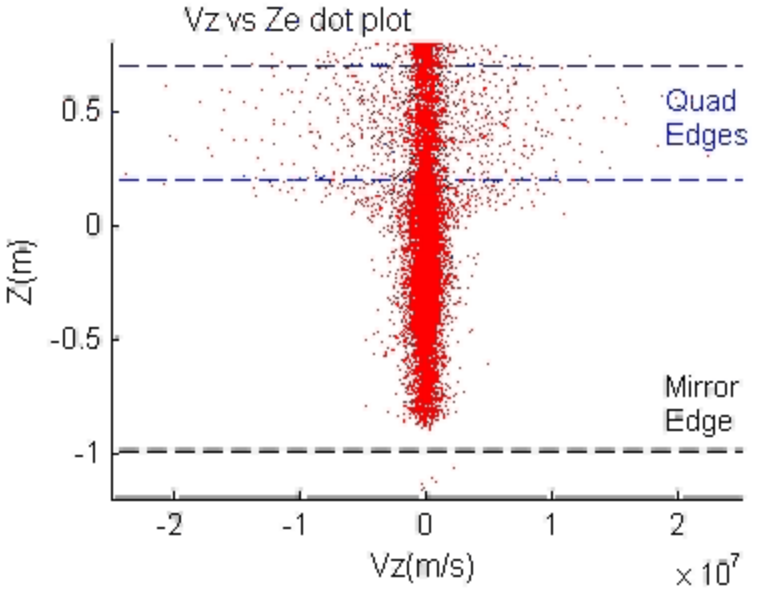
Show simulation of electrons ejected from quad

PSRqu_Vz_Zcorr_new_axis4.avi

- Seed electrons generated uniformly only in the quad, none elsewhere
- Mirror included upstream of quad

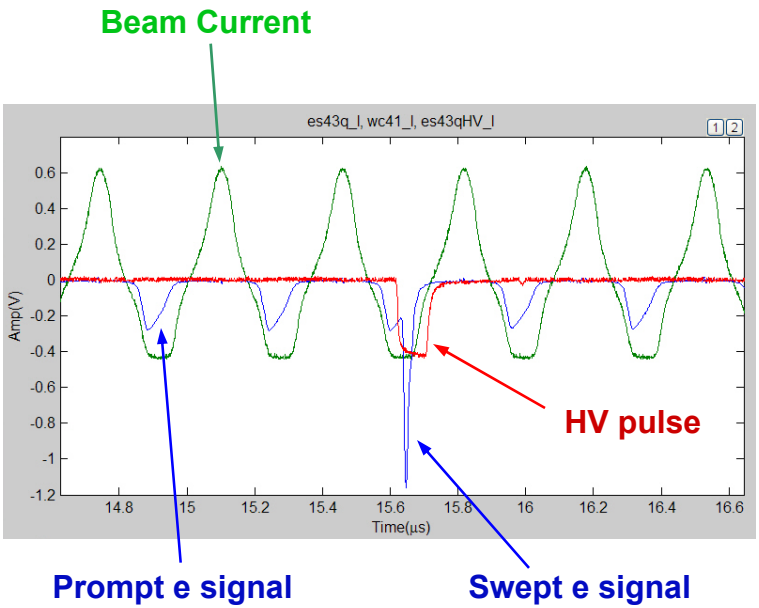

5/1/08, PSRqu-3D-1kMP-5-2-Test 20 mir
-1.2 to 0.8m Z cut, quadcenter=0.45m, Leff=0.5m, colorbar= Ve
0
0.5
1
1.5
2
x 10^7
m = 13618
Frame # 69
0.05
0
-0.05
Y (m)
-0.05
0
X(m)
0.05
-1
-0.5
0
0.5
Z(m)

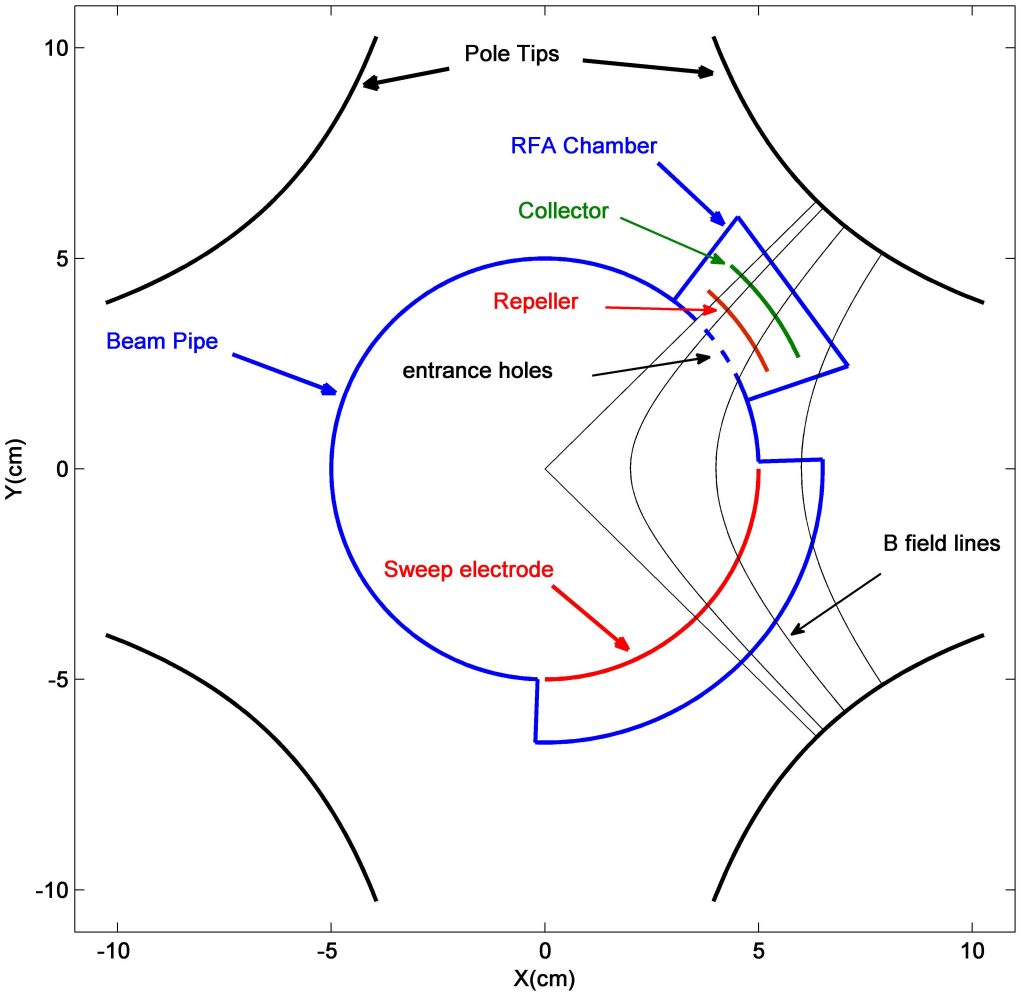

Bunch Intensity(r) and e-line dens(g)
Time = 1058.82 ns
Ip(A), e-line den(#e/m/5x10^7)
80
60
40
20
0
1000
1200
1400
1600
1800
2000
Time(ns)


Vz vs Ze dot plot
Quad
Edges
Mirror
Edge
0.5
0
-0.5
-1
Z(m)
-2
-1
0
1
2
Vz(m/s)
x 10^7

Quadrupole diagnostic layout (ES43Q)

- Original orientation shown
- Rotated by 90° in September, 2007



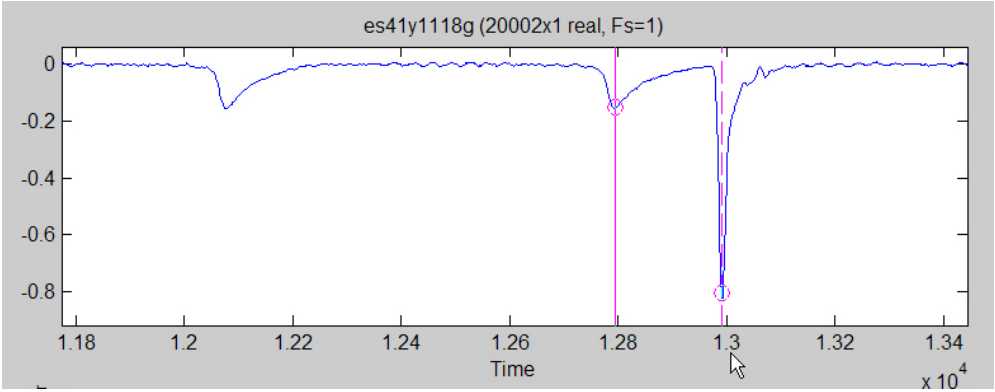


Example of electron wall current and line densities from EC diagnostic signals for 6.9 μC beam

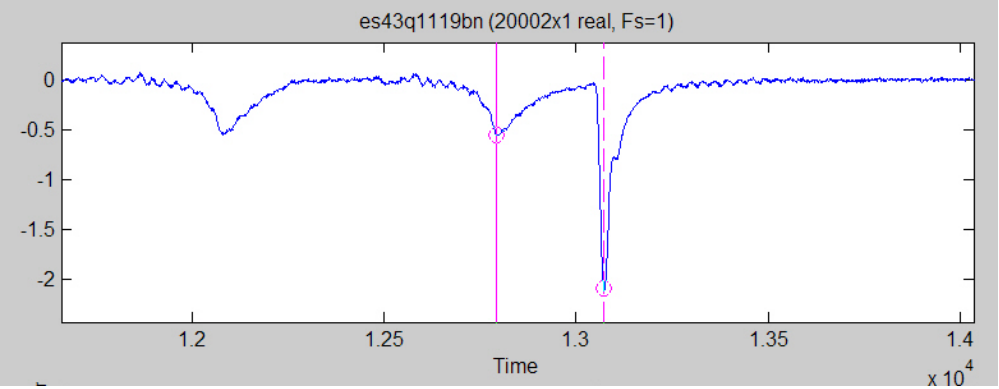
- Data from 11/18/06 beam studies
- Convert prompt amplitude to flux using detector area and transimpedance of electronics
- Convert integral of swept signal (at end of gap) to line density using acceptance of detector and electron spatial distribution from simulations
- Find that the drift space and quadrupole have comparable numbers despite very different multipactor gains

Device	Prompt flux ($\mu A/cm^2$)	E Line density (nC/m)
ES41Y drift	8.8	0.39
ES43Q quad	8.1	0.45

ES41Y drift space



ES43Q Quadrupole

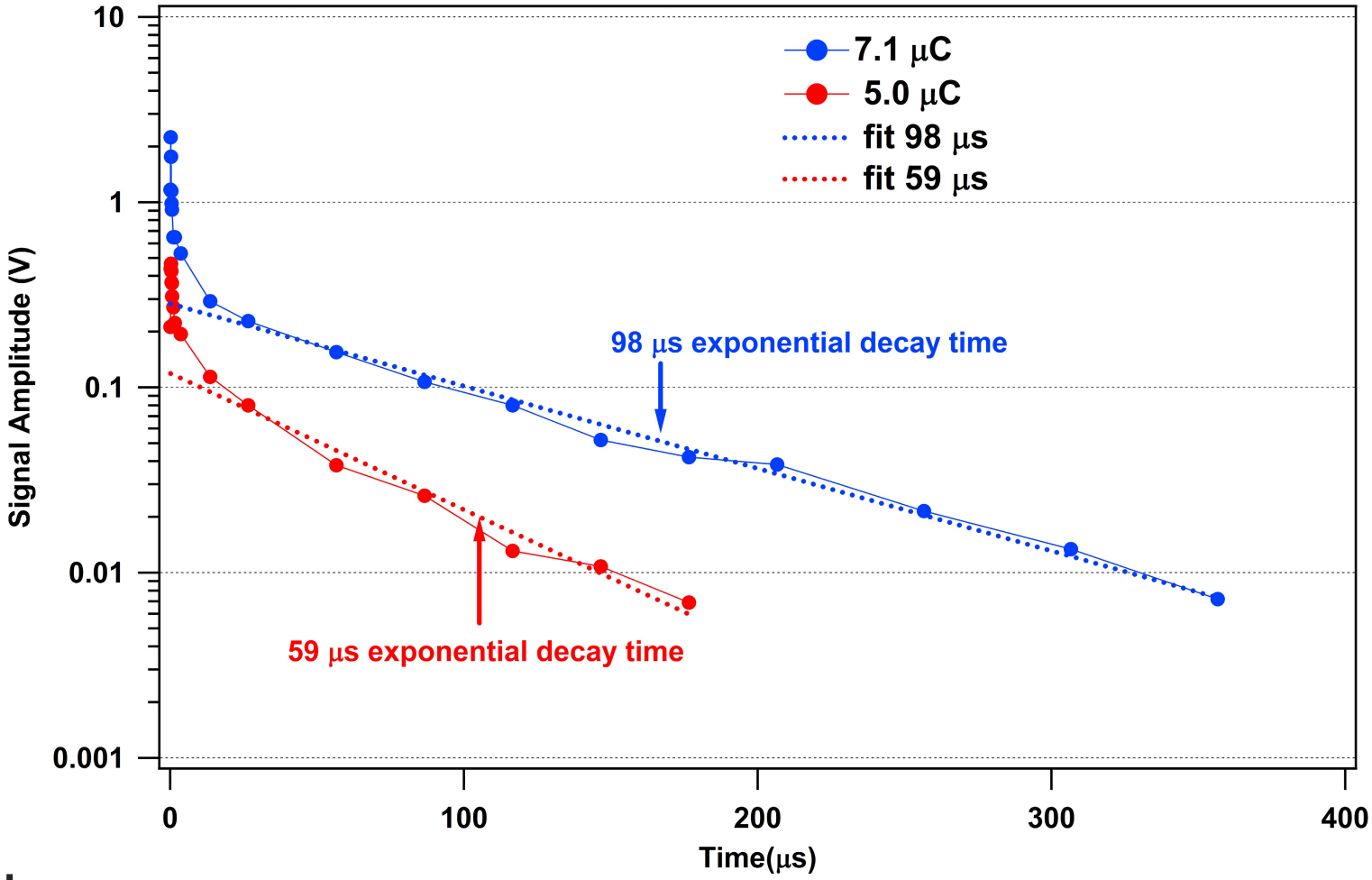


Electrons trapped in quadrupoles

Electrons can be trapped in the mirror-like magnetic fields of quads.

With the sweeping detector in a quad, we measure electrons trapped the quad long after the beam has been extracted (plot on next slide)

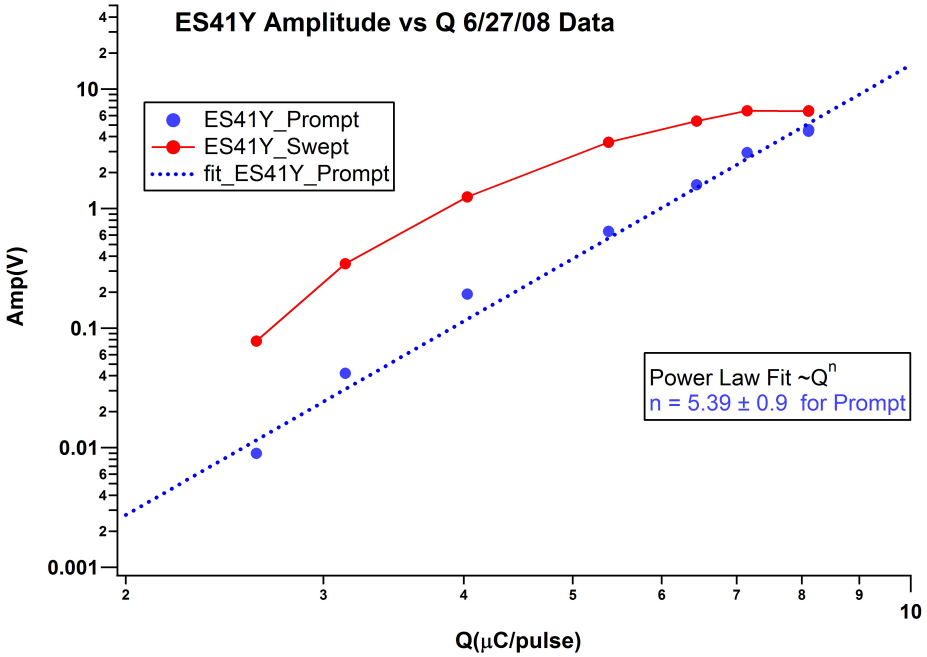
Decay time for electrons trapped in the quad (9/16/06)

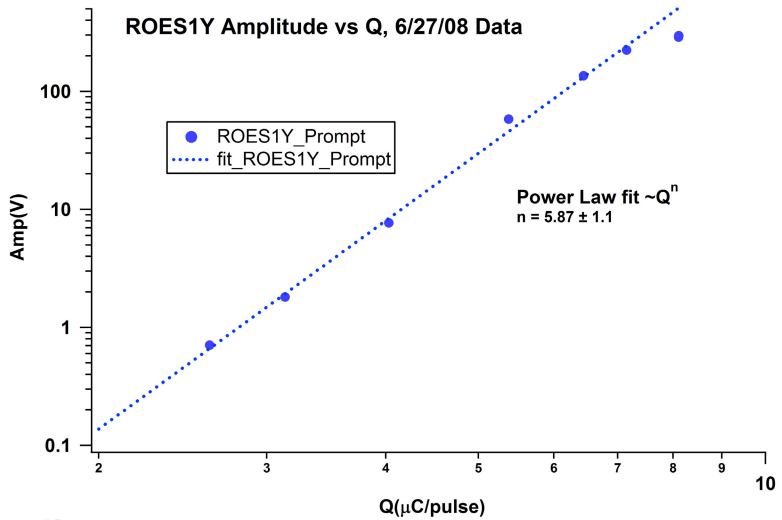


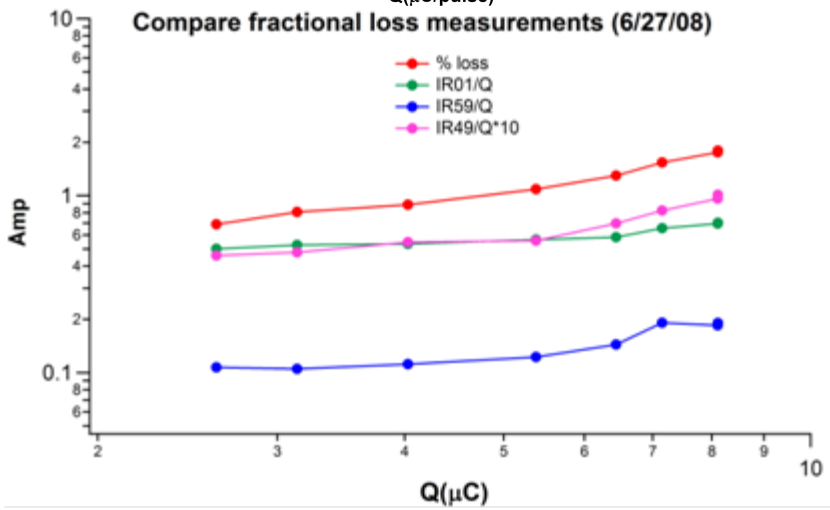
Factors influencing EC signal amplitude

- **Beam Losses**
- **Changes in SEY**
  - Beam scrubbing lowered amplitude by factor of ~30 since 2000 operations
- **Beam intensity has strong effect (next slides)**

Electron signal amplitudes as a function of intensity

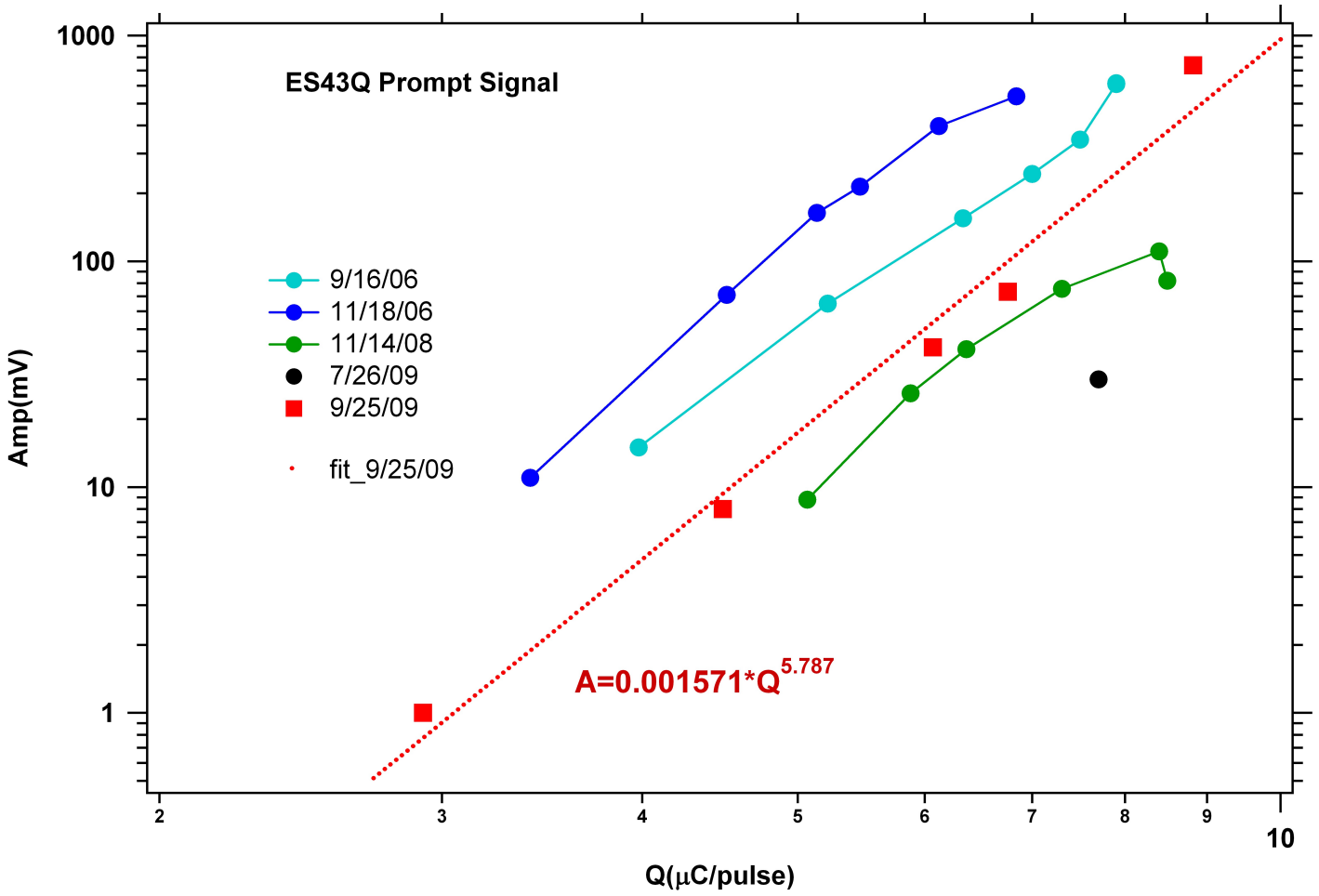




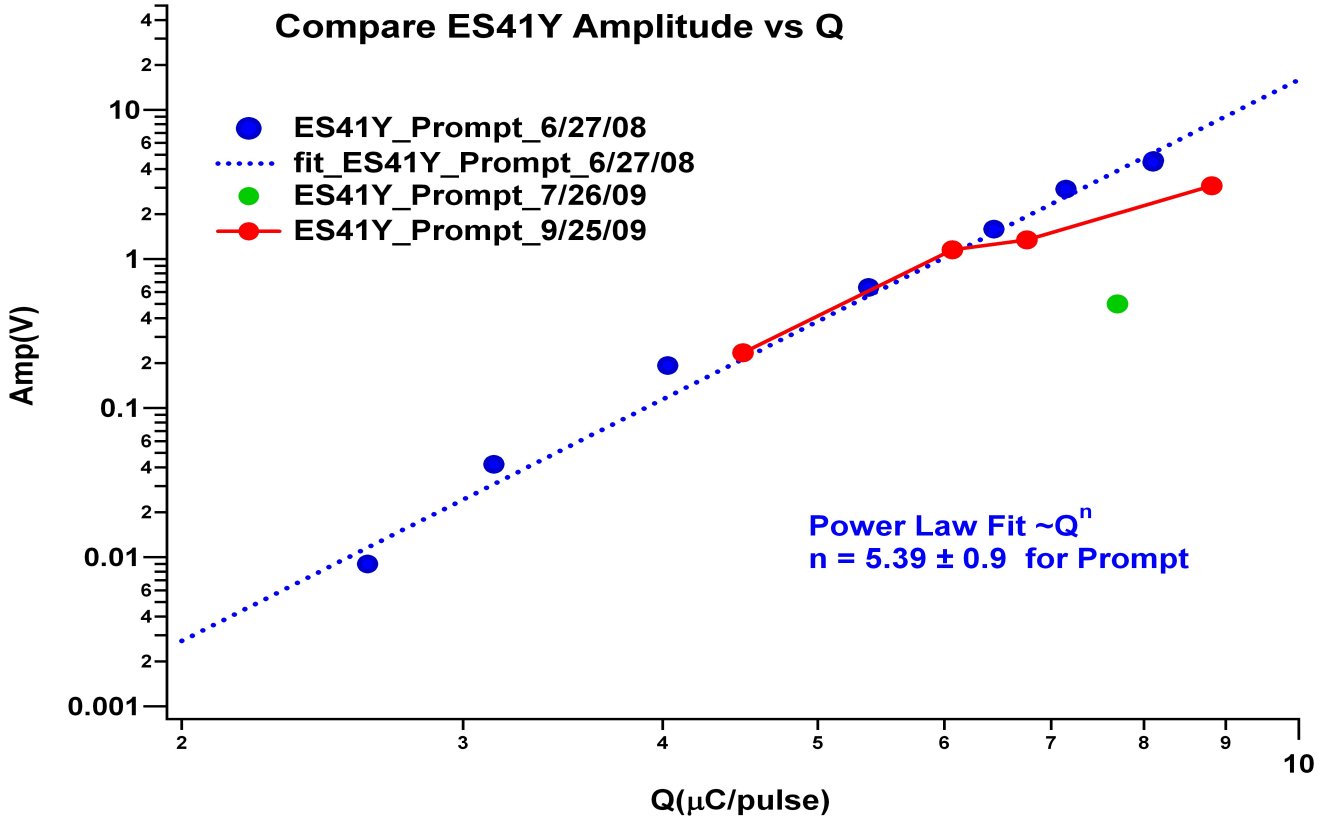


- **Contemporaneous data collected 6/27/08 Intensity varied by "1/n" countdown**
- **Fractional loss measurements show factor of 2 or less variation over full intensity range (2.6 to 8.1 μC)**

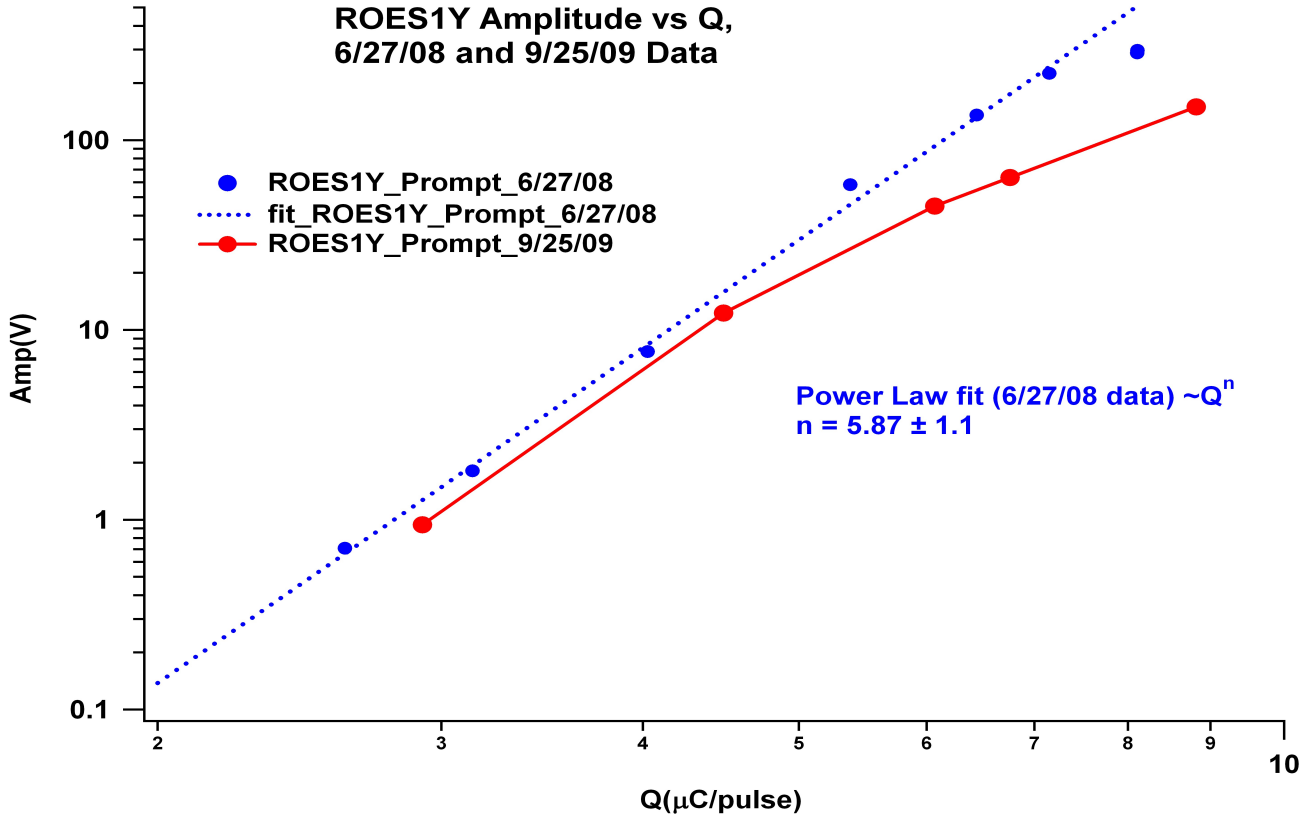
Compare quad ED (ES43Q) data with previous years



Compare drift space ED (ES41Y) result with 2008 data



Compare ROES1Y Prompt with 2008 data



- Note that signal amplitude is much higher here than at ES41Y. Much less beam scrubbing at ROES1Y which sees only single pass beam.

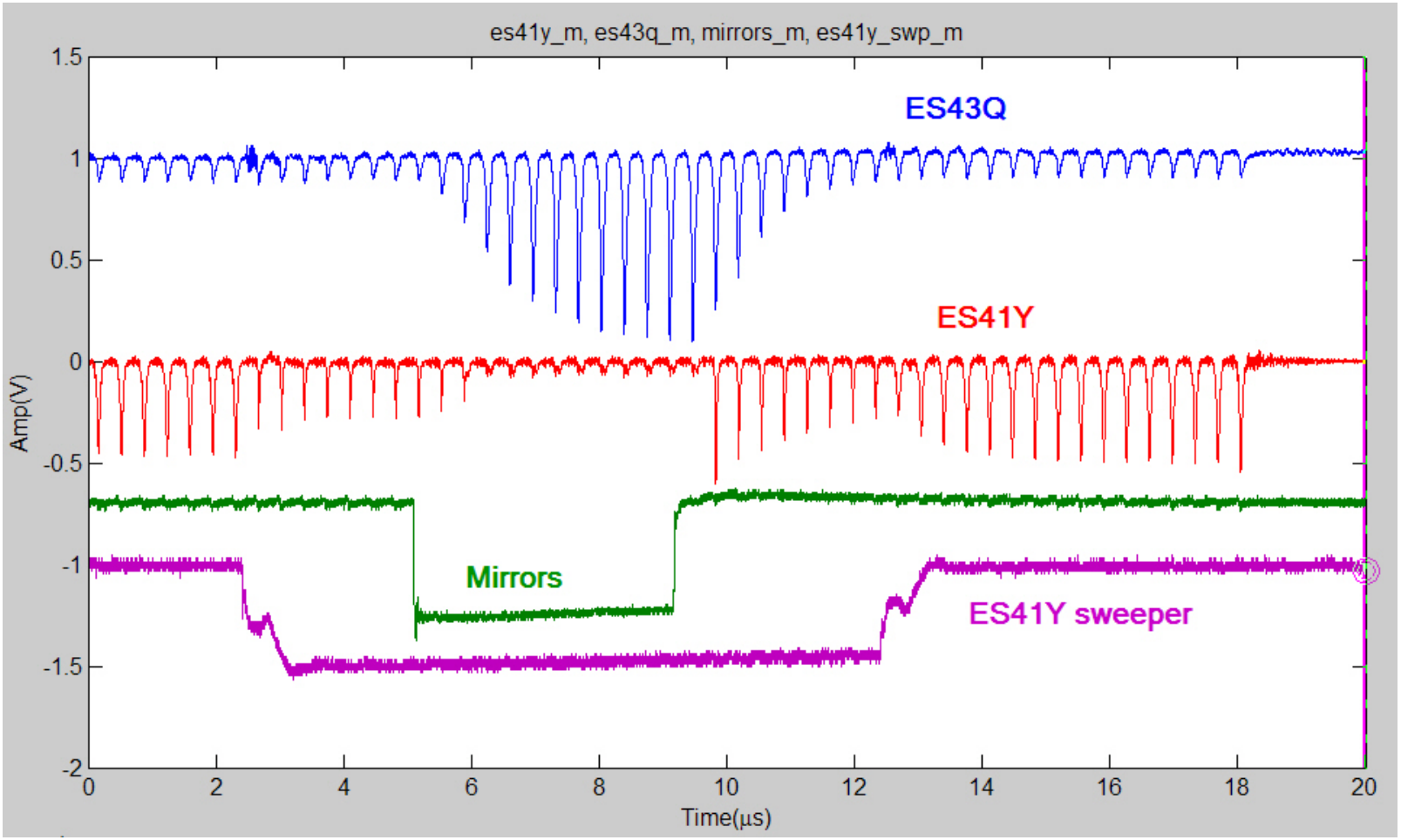
Simulations show weaker dependence on intensity

- **POSINST simulation assuming seed electron production proportional to beam intensity (constant fractional losses) show considerably weaker dependence**
  - See Y. Sato PRSTAB 11 024201 (2008)
- **One way out: higher than linear rate of seed electron production with beam intensity**
  - Can't measure directly
- **Something else?**
- **Still a puzzle in my view**

Experiments with electron “mirrors”

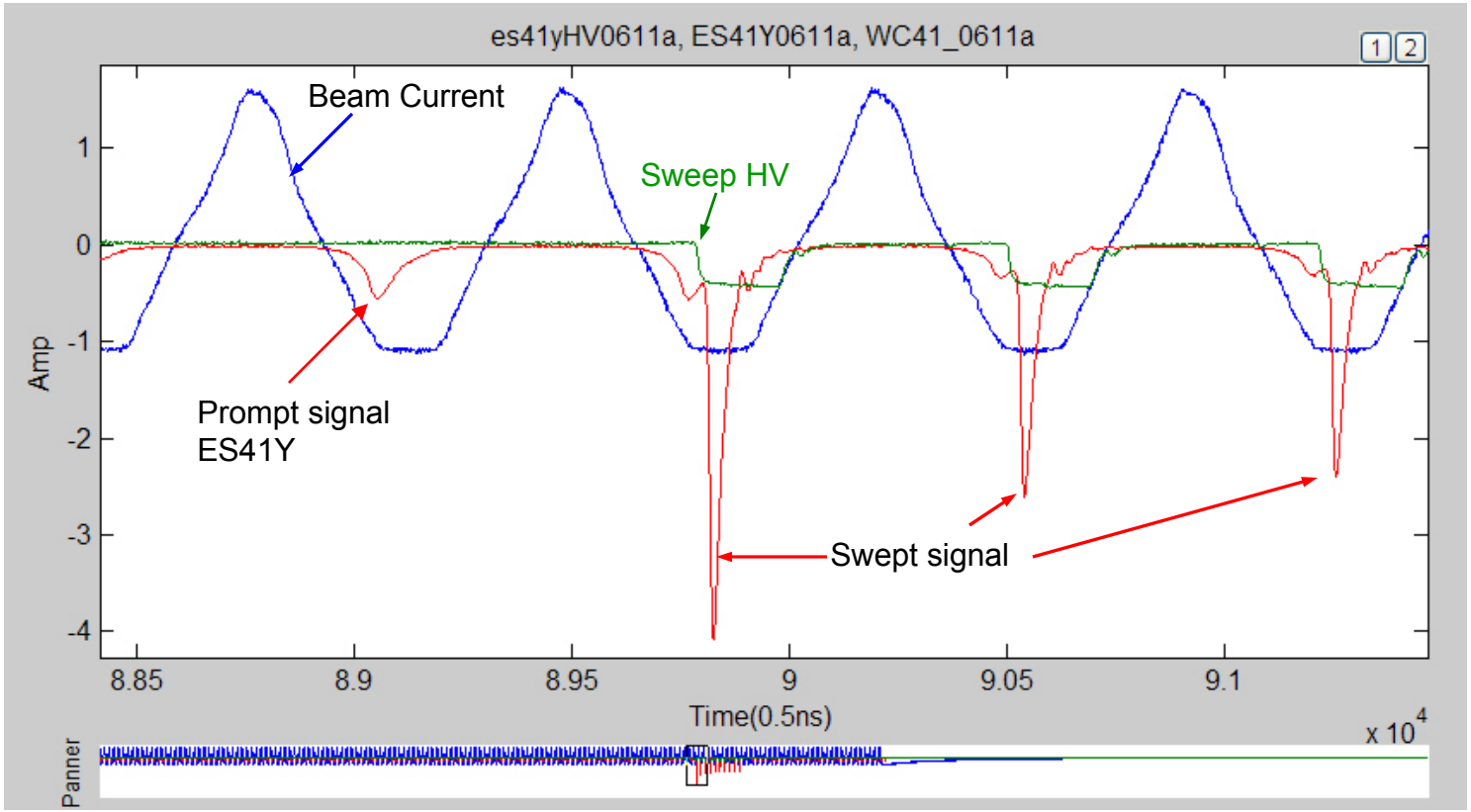
Use mirrors to prevent electrons ejected from quads from reaching drift space detector

Experiment pulsing mirrors and es41y sweeper



Data of 7/1/07, 5.8 μC

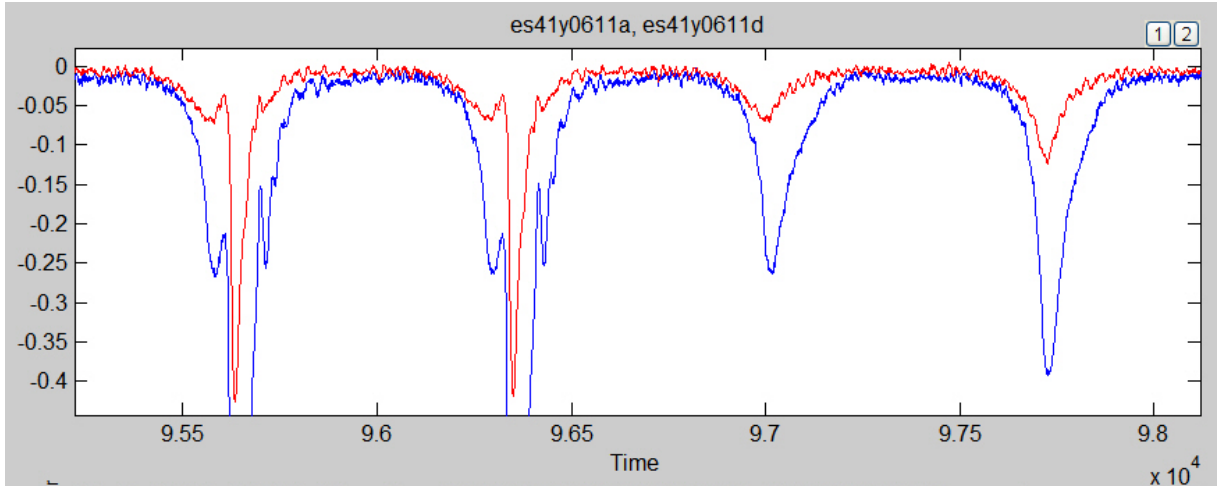
Experiment with ED sweeping using turn by turn sequence of 10 short pulses at the end of gap between turns (drift space ED)

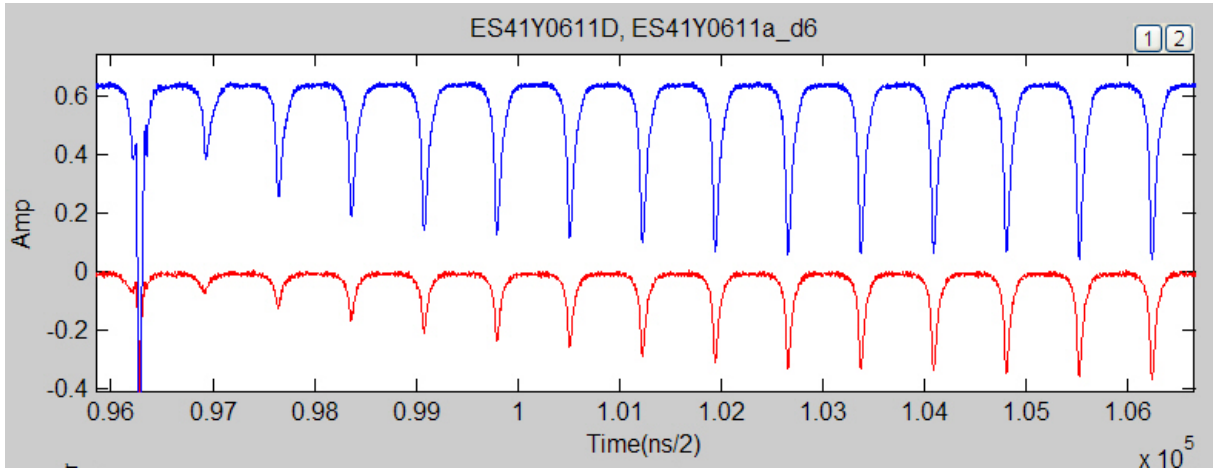


- **Only first 3 swept pulses are shown for clarity, mirrors off**

Compare EC signals with mirrors off and on near end of 10 turn sequence of previous slide

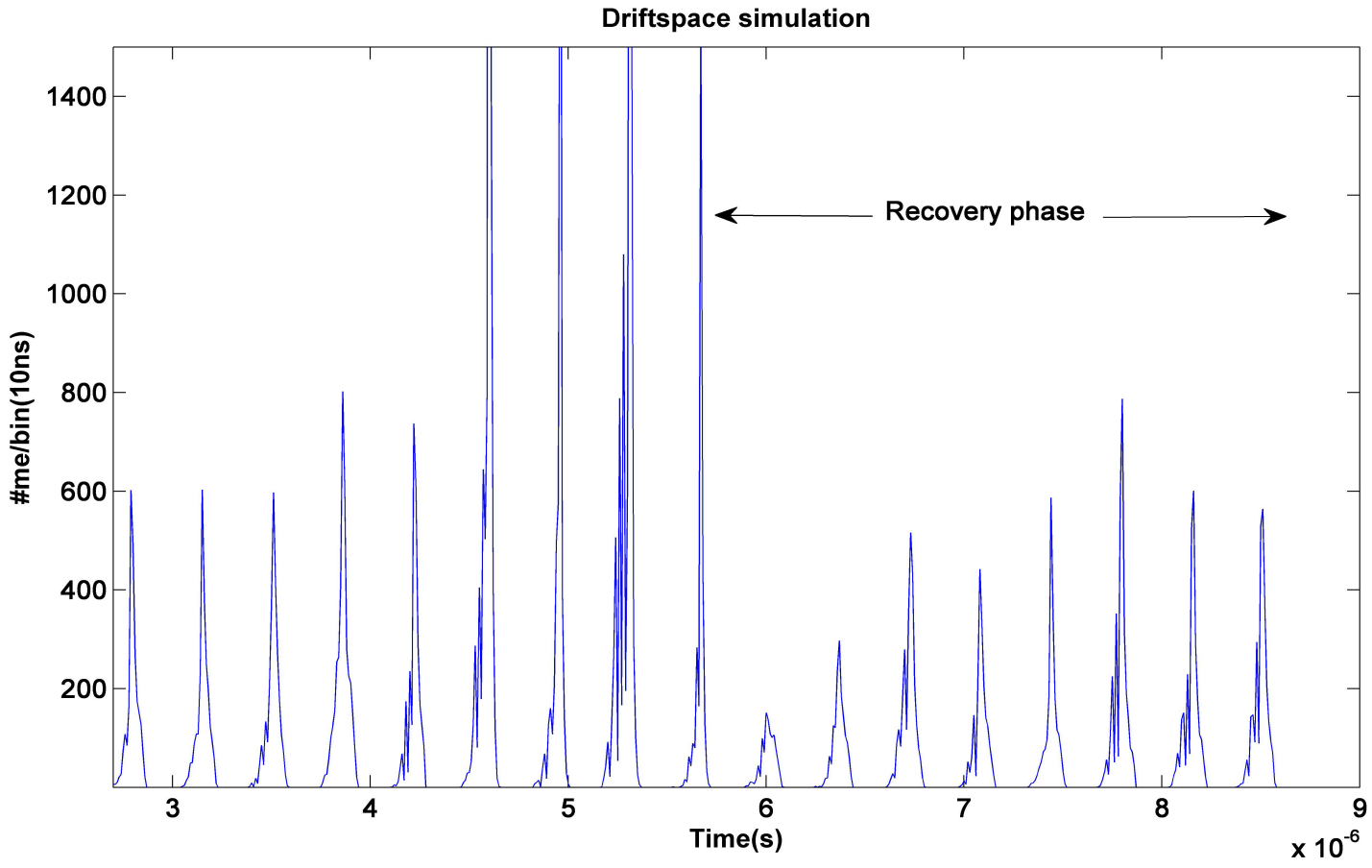
- **Blue traces**, mirrors off
- **Red traces**, mirrors on
- 1st Prompt after swept gap is down factor of ~4 with mirrors on
- Shows that a good fraction (~75%) of the wall current in the drift is **seeded by electrons** ejected from the quads for this intensity
- Note several turn recovery especially when mirrors are on



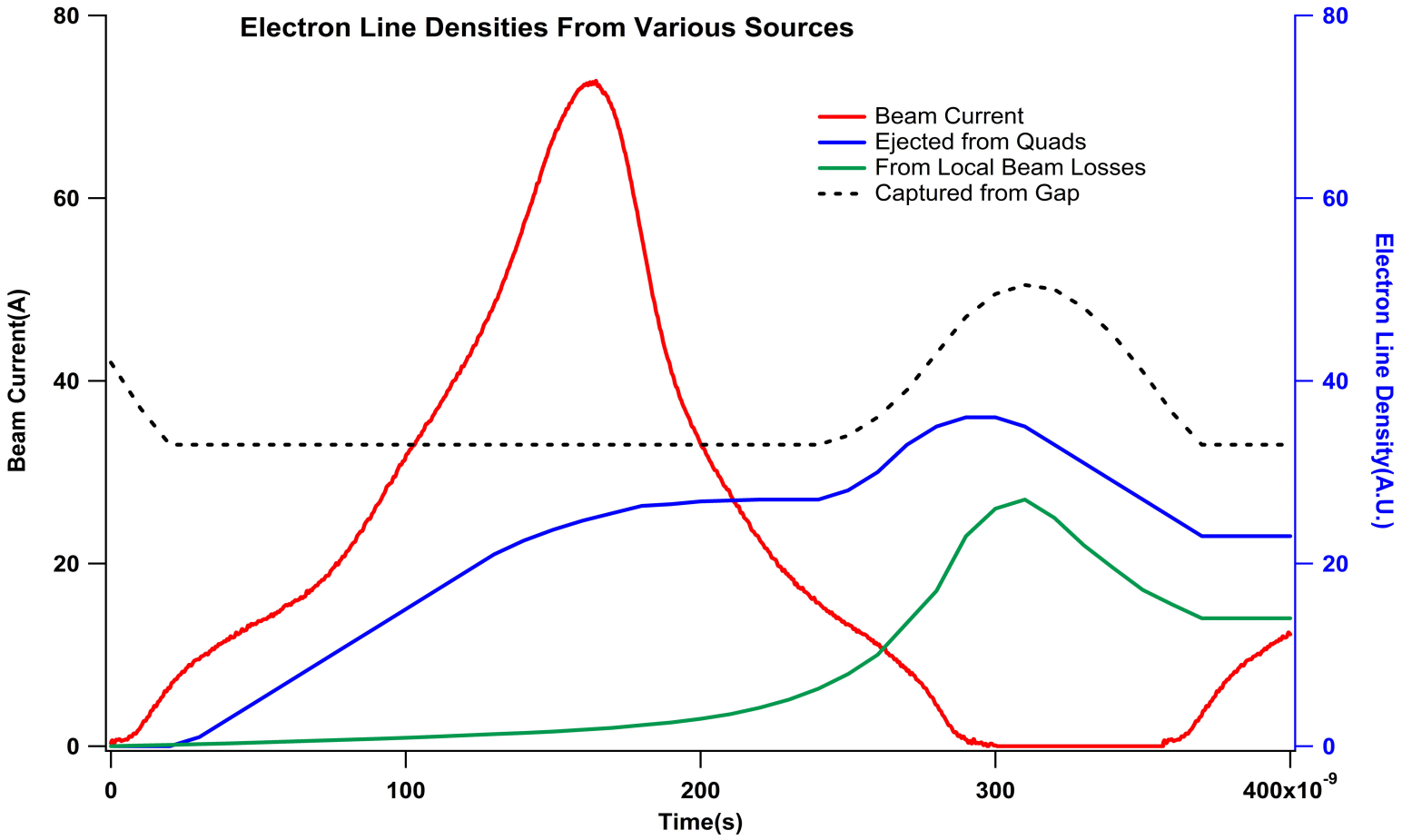


Data 6/11/08, 5.5 μC beam

Simulation of recovery after sweeping



Qualitative description of e-cloud sources in drift space

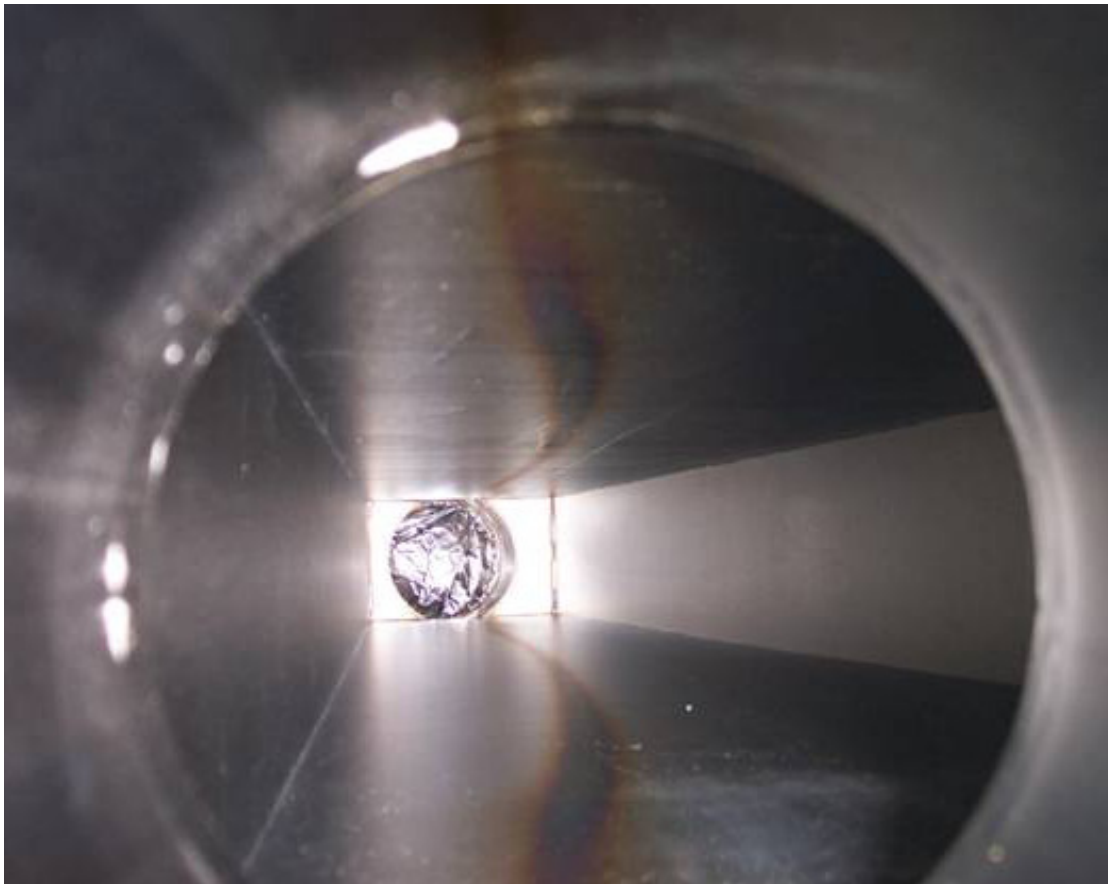


Tracking as another indicator of EC activity

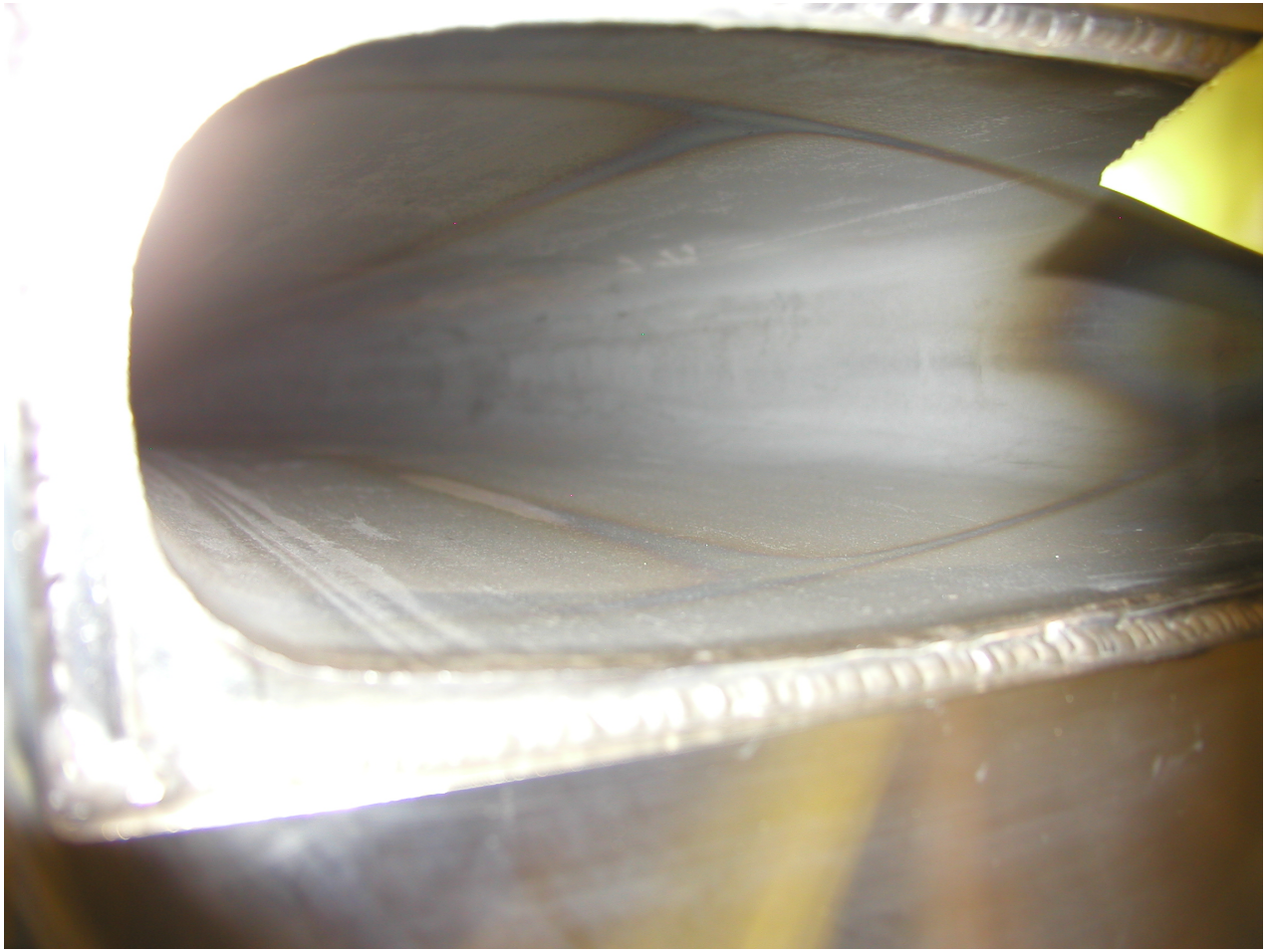
We see tracking in the vacuum chambers where multipacting electrons hit the wall

Tracking in dipole chamber (SRBM11, 6/20/07)

- Brown colored tracks follows the beam curved trajectory in the dipole
- βx function is small at entrance and increases along trajectory
- We have observed similar tracking in 3 other dipole chambers including one removed prior to the direct H- upgrade in 1998



Tracking in SRBM91 down stream end, removed 2005

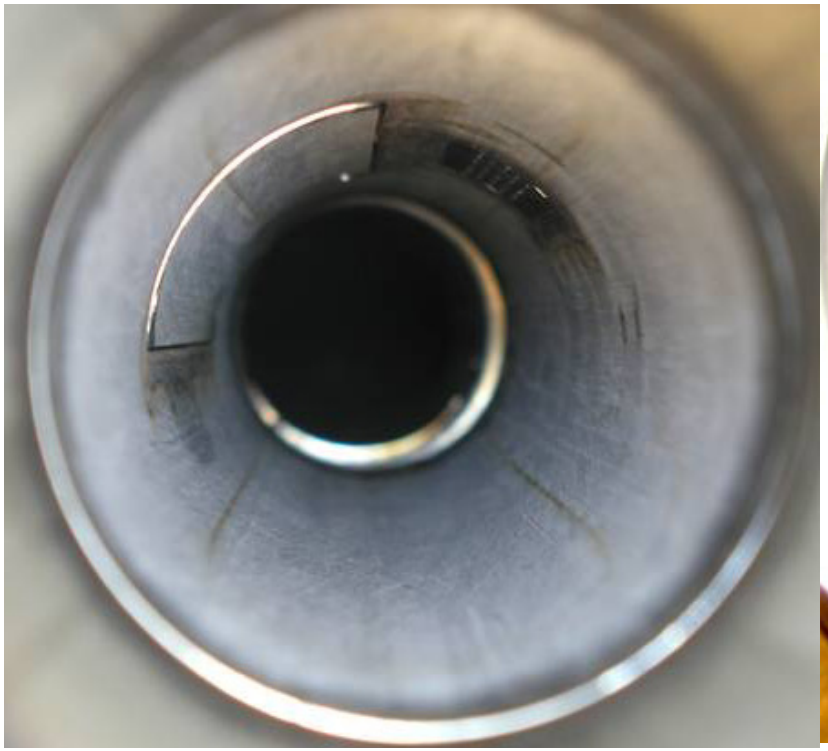


Tracking in 6 inch quadrupole chamber (SRQF11)

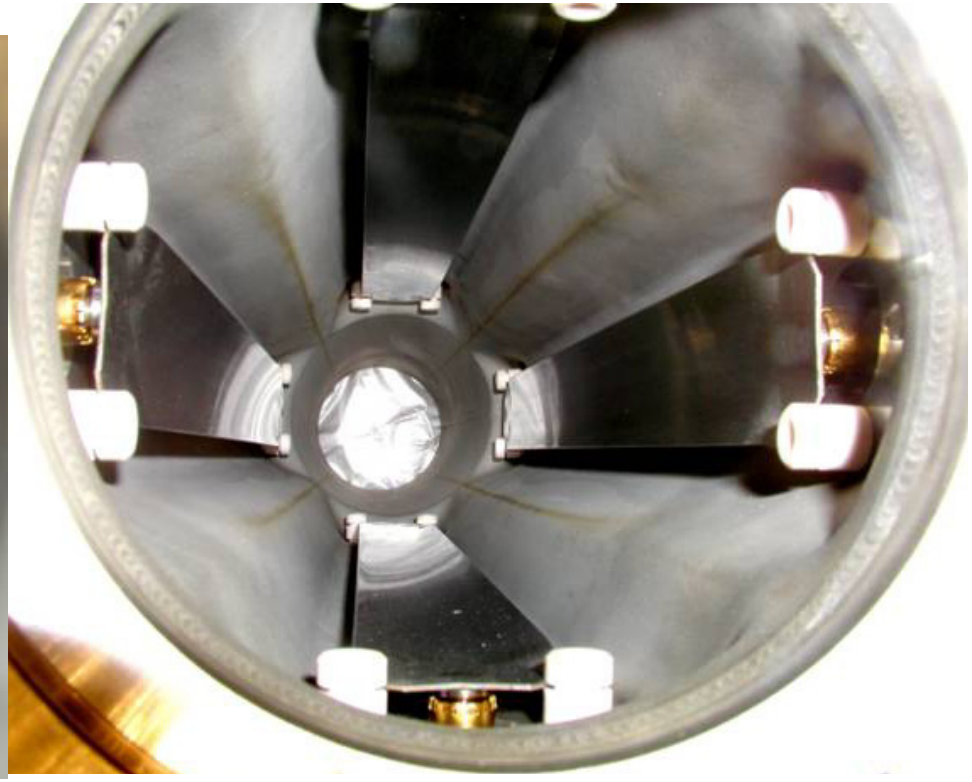
- Narrow tracks similar to these have been observed in 3 other quadrupole chambers
- No brownish tracks have been observed so far in drift space chambers

Tracking in 4 inch quadrupole (SRQU01)

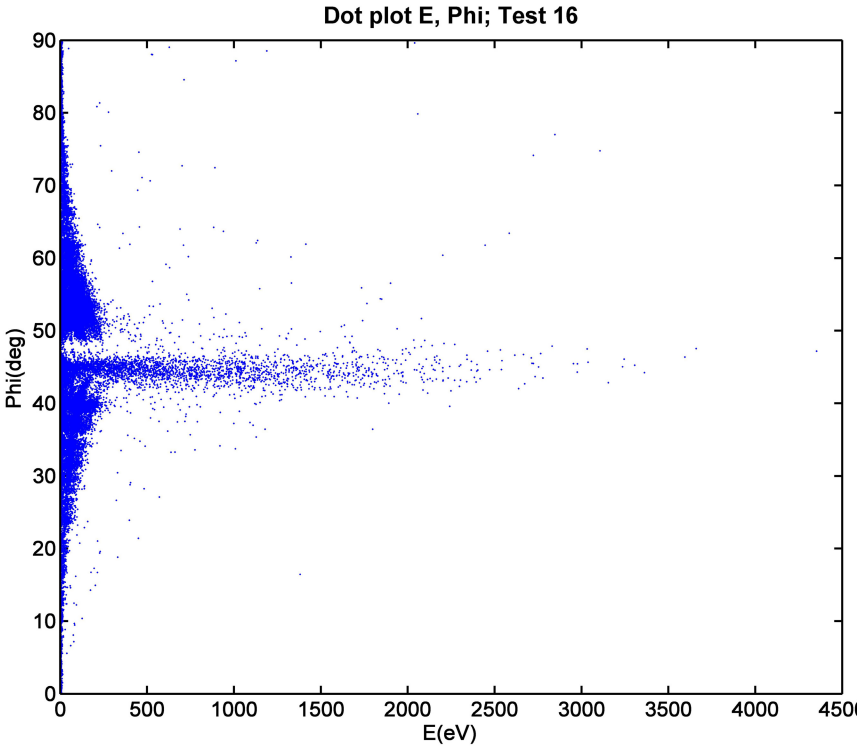
- **Quad ED (ES43Q) in SRQU01, 3/25/08**

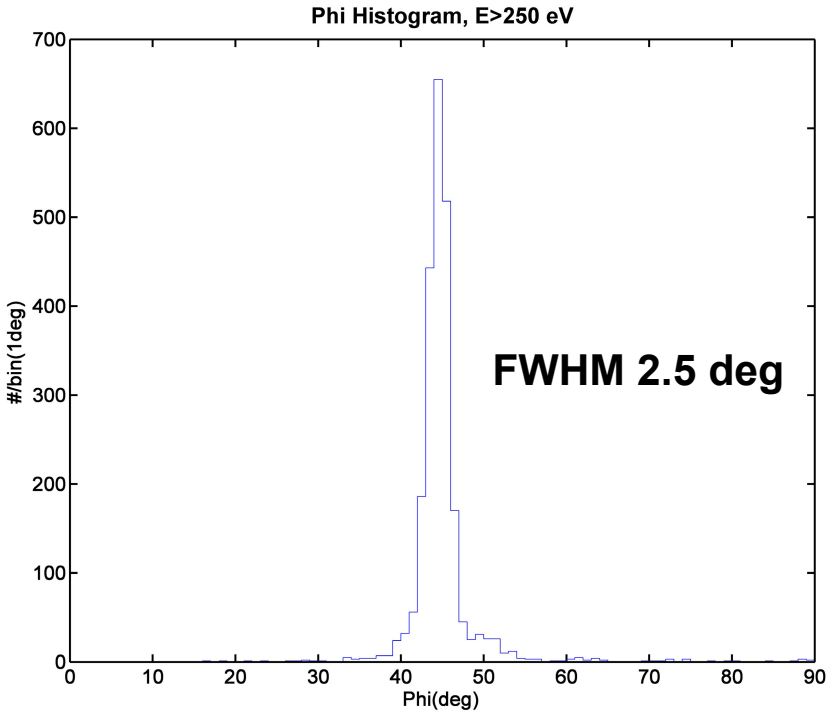


- **SRQU01, 8/28/06**



Simulated wall collision distributions for 3D quadrupole*





- **FWHM of 2.5 deg agrees with width of tracks in ES43Q shown in previous slide**

*** Modified version of POSINST12.1**

Summary and conclusions from recent EC studies

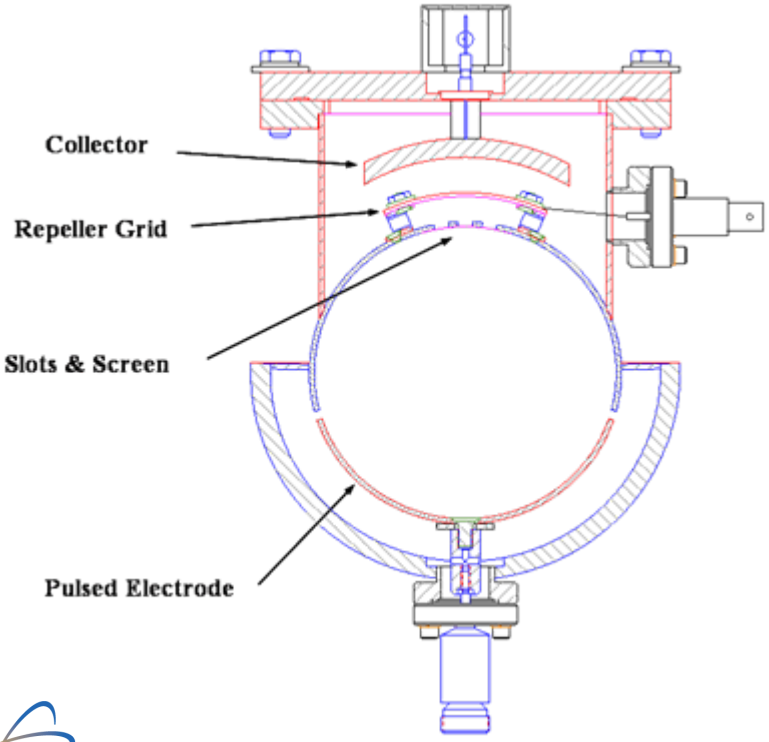
- **Find that drift space and quadrupole have comparable electron line densities despite very different multipactor gains**
- **Experiments with the electron mirrors in sect. 4 show good evidence that ~75 % of the drift space multipacting signal (wall current) in section 4 is seeded by electrons ejected from nearby quadrupoles.**
  - Ejection of electrons from quadrupoles may also explain null effect of solenoids on e-p instability at PSR
- **Simulations to date have mixed success in reproducing experimental results**
- **Brown tracking on dipole and quadrupole vacuum chamber walls may be a useful qualitative indicator of electron cloud activity. We have observed strong tracking in the regions of high beam losses where we would expect intense EC generation.**
- **Our working hypothesis considers the high loss regions of PSR as the likely locations of EC driving the e-p instability but saturation of the EC density at the end of the gap between bunch passages could mean more regions of the ring are important**

Backup slides follow

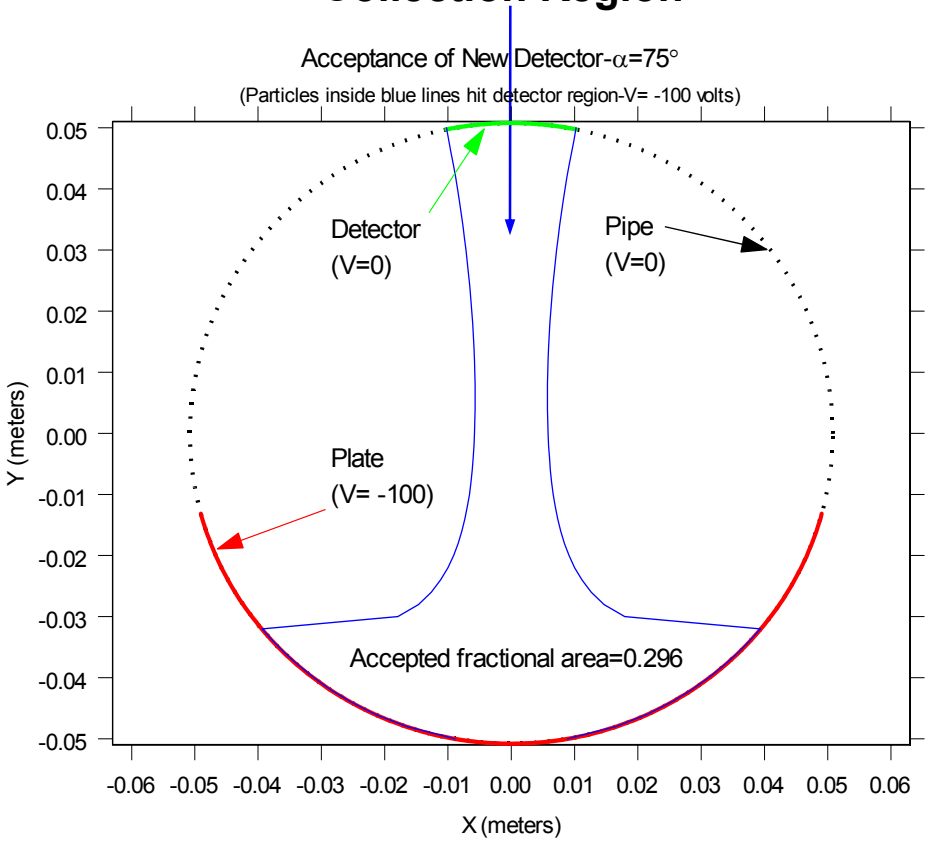
Electron Sweeping Diagnostic (ESD)

Short HV (-500V) pulse is applied to electrode to sweep electrons into RFA

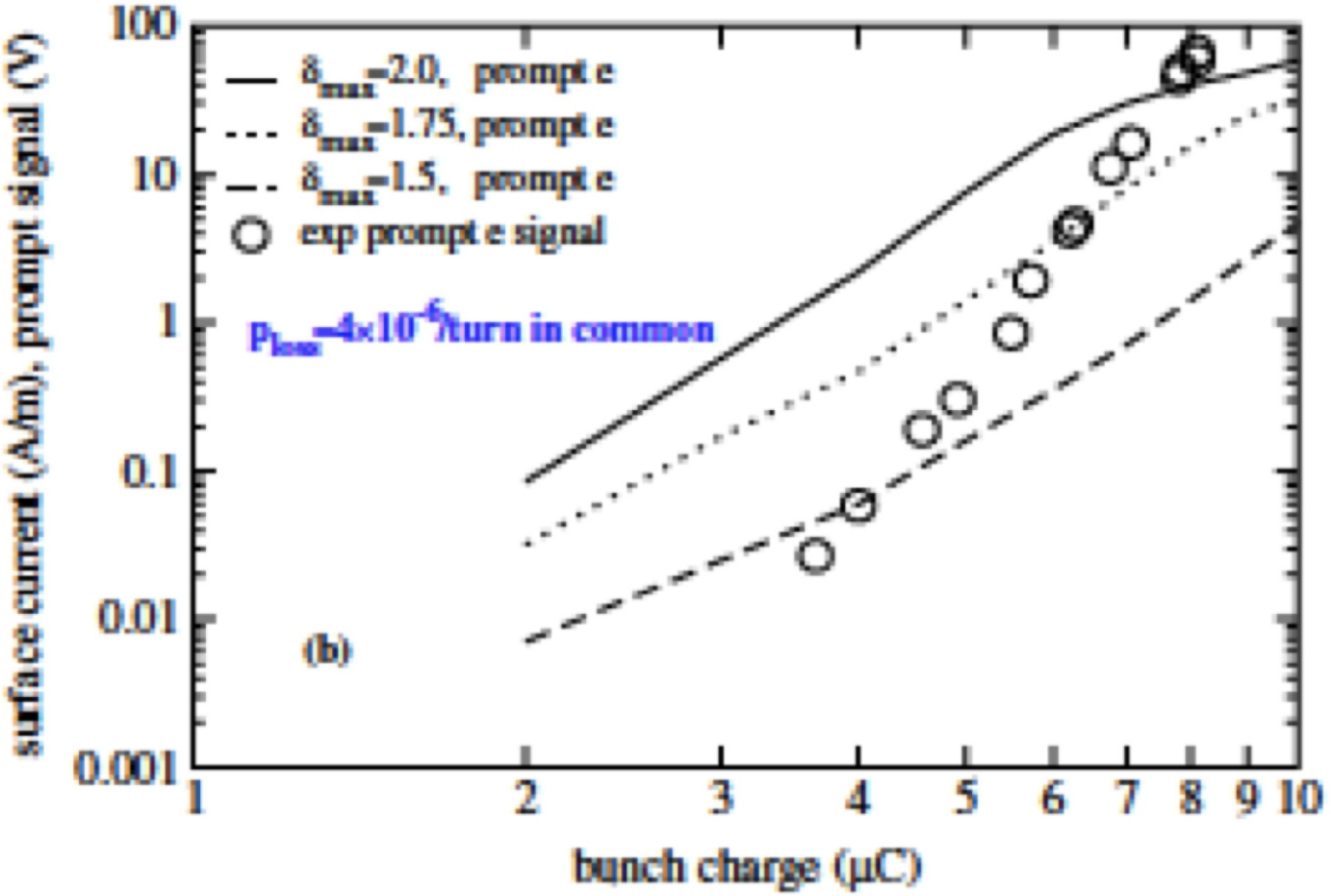
Cross-section



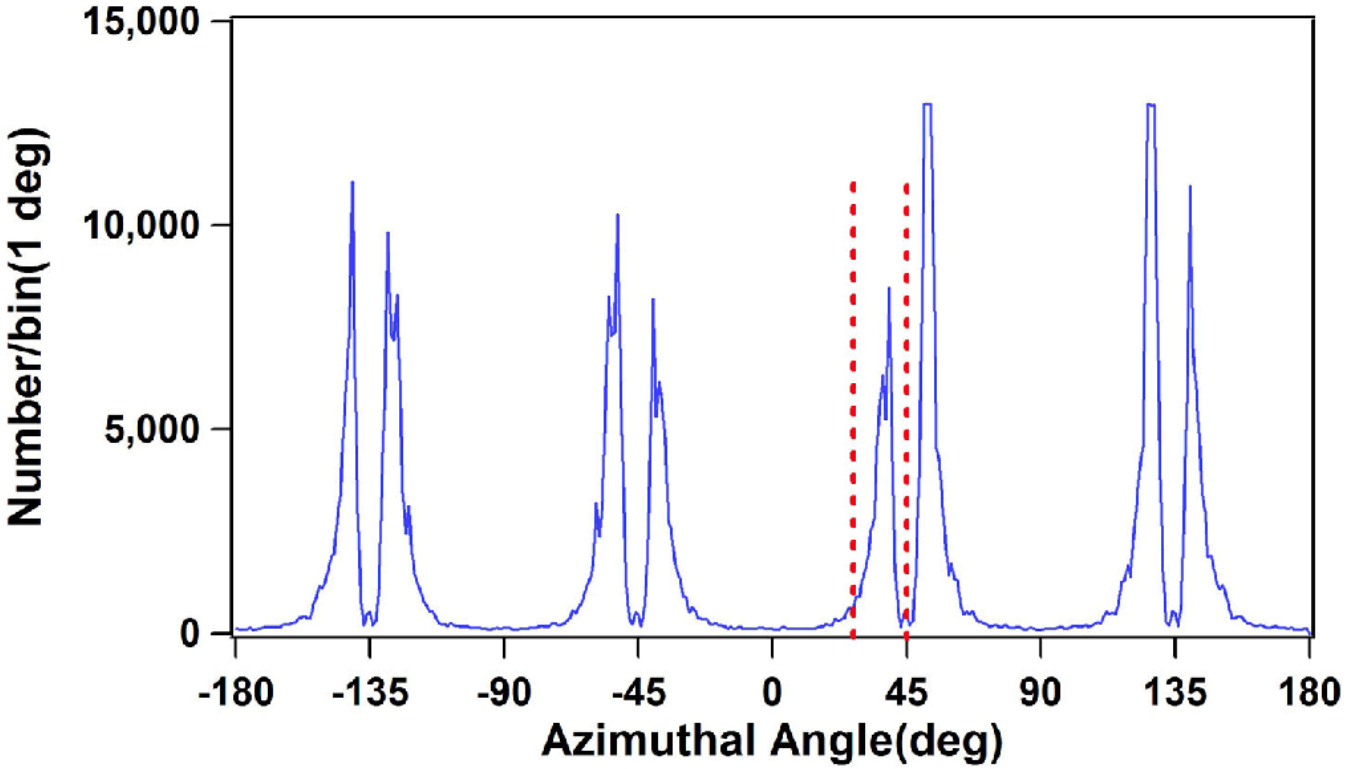
Collection Region



Sato simulation compared with data



Simulation of quad RFA signal



ES43Q signals vs Q