Recent Observations, Experiments and Simulations of Electron Cloud Effects at the LANL PSR

Robert Macek, 8/26/08, HB2008

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Outline

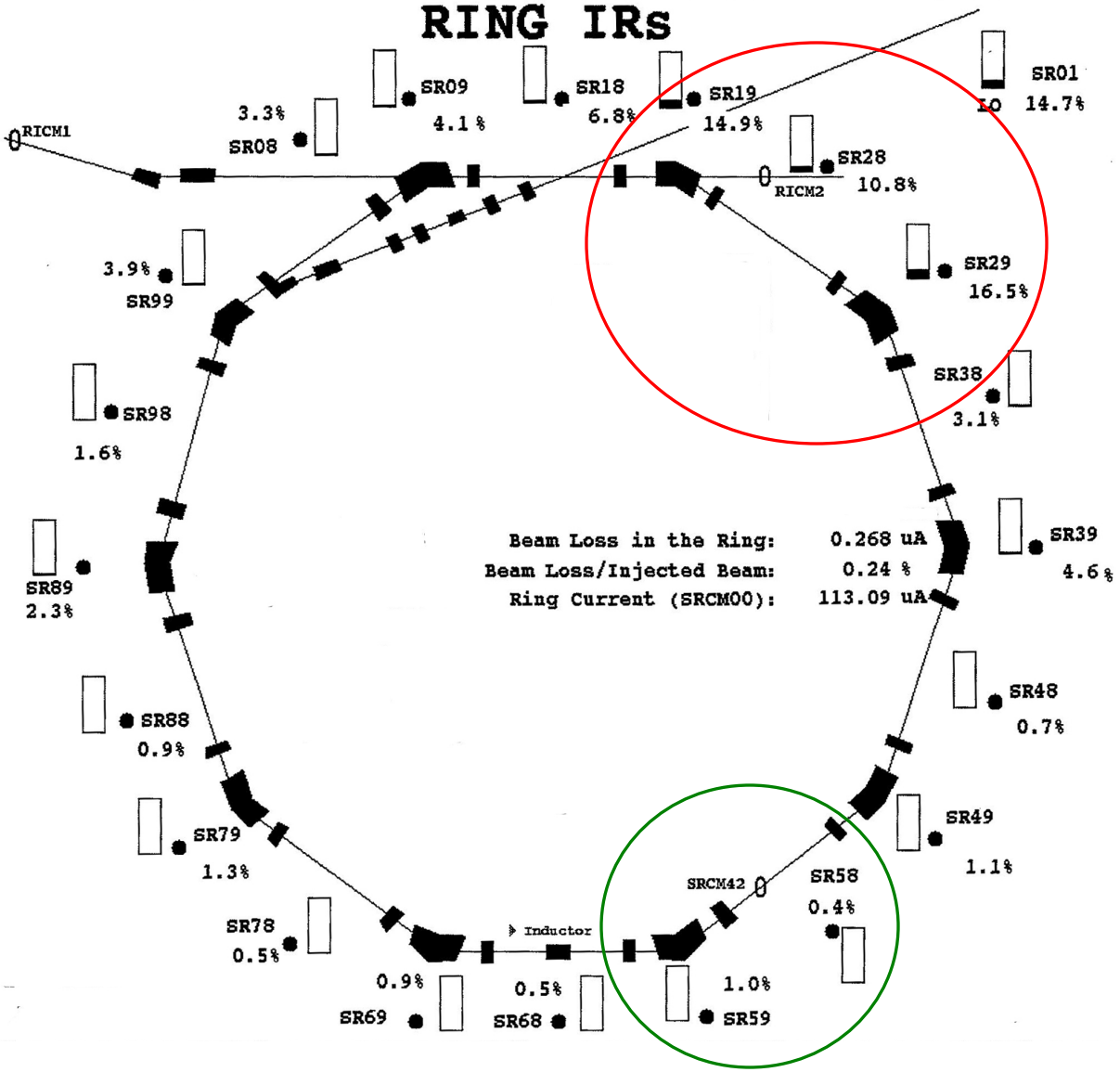
- **Introduction & Motivation of recent studies**
  - Locate and characterize the dominant electron clouds (EC) driving the e-p instability
  - Resolve some puzzles regarding EC and e-p observations
- **Experimental Setup**
- **Measurements and Simulations relating EC signals and beam Losses**
- **Experiments 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**

Some issues regarding e-p at PSR

- **Where are the electron clouds (EC) driving the instability?**
  - Drifts, quads, dipoles or some combination?
  - We have seen electron signals of one sort or another in all of these components
  - Important to know if you want to use e-cloud suppression as a mitigation method
- **Suppression of EC by beam scrubbing in the 2000-2002 period did change the e-p threshold curves and also changed the EC signals by large factor in several drift spaces**
- **Suppression of electron cloud generation by clearing fields, weak solenoids (also TiN coatings) in drift spaces suppressed EC signals (wall current signals) but had little or no effect on e-p thresholds, suggesting that the main source is elsewhere**
- **Increasing foil scattering losses increase the EC prompt signals but has no effect on instability thresholds, why? Is it saturation of the electrons captured by the beam?**
- **Very difficult for us to measure e-cloud in PSR dipoles**
  - Used biased collection electrodes in 1999 at SRBM51, obtained significant signal but not easily interpreted
  - Tracking observed in beam chambers may provide some clues
- **For simulations, need to know detailed distributions of seed electrons from losses but we have no means of accurate measurements**
  - ORBIT simulations that reproduce loss monitor measurements are probably our best hope

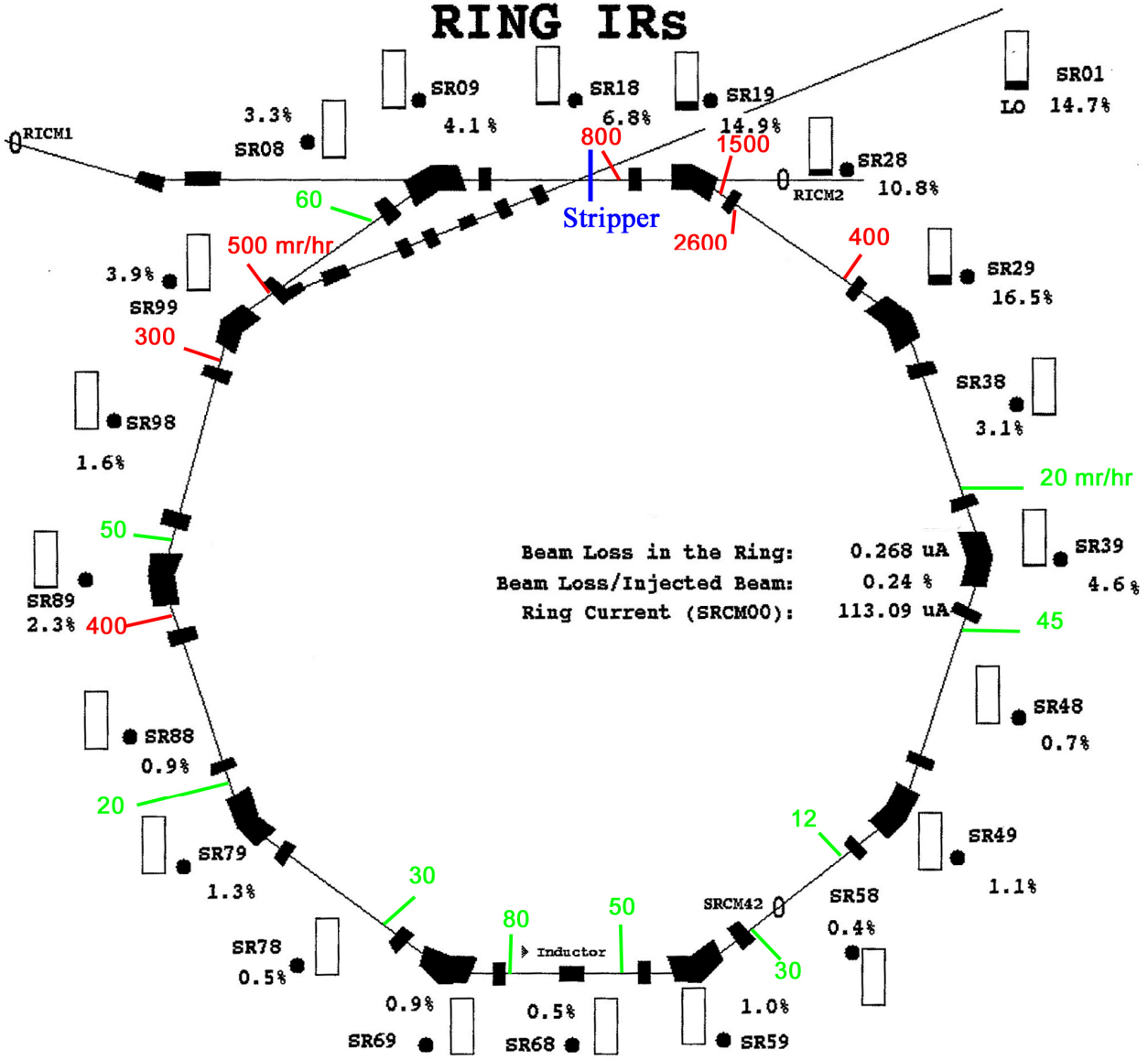
Recent Ring Loss Monitor Map for PSR

- 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)

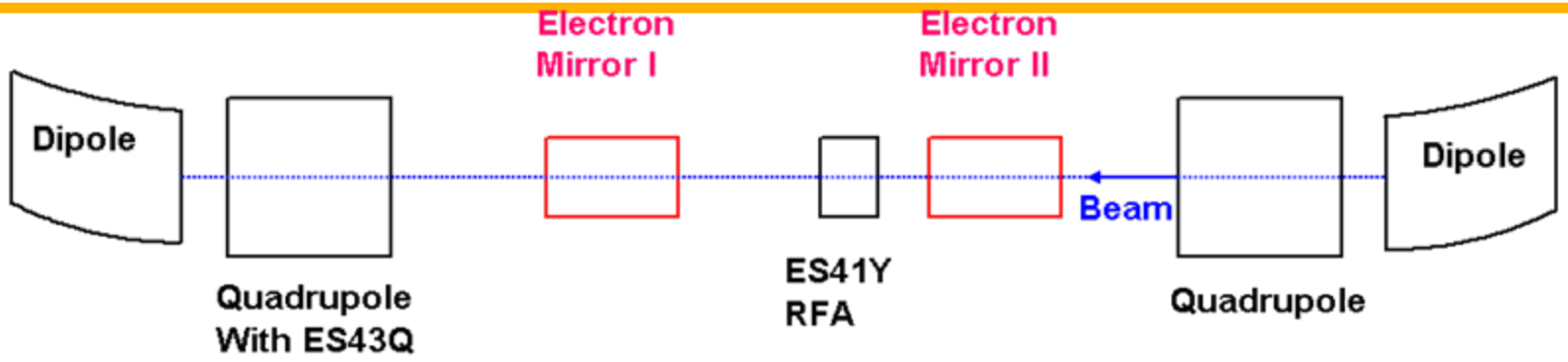


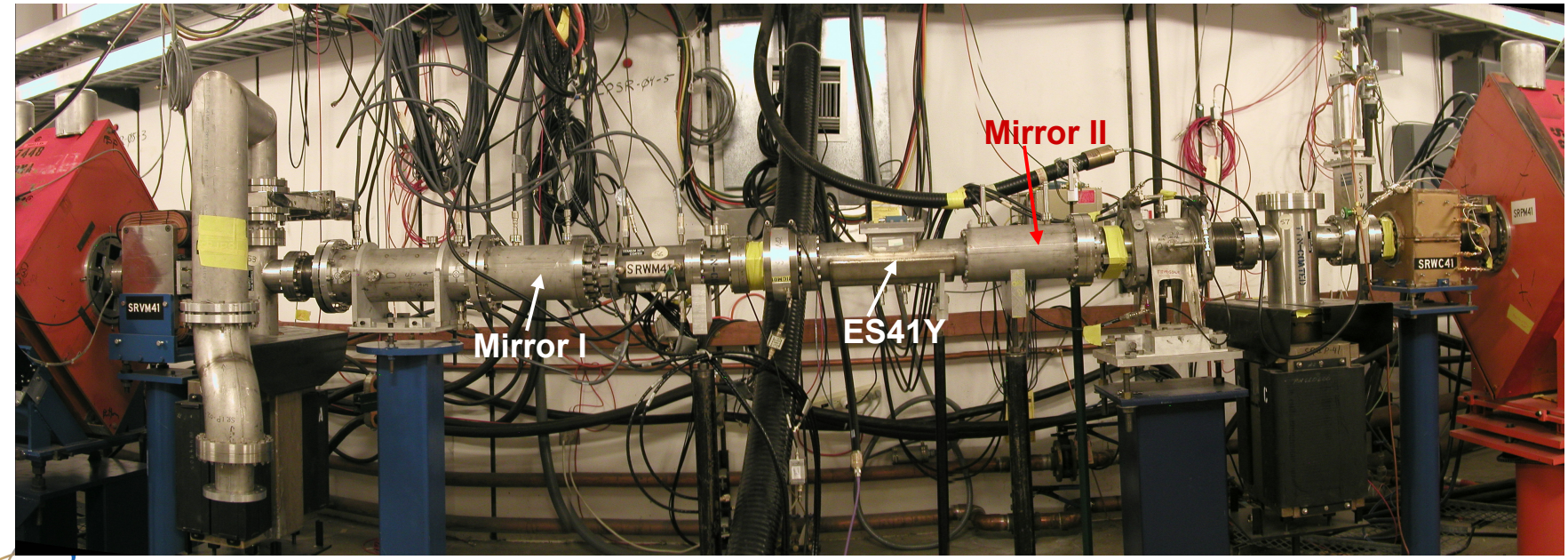
Now add Activation Data for PSR

- Activation data (shown in color) are from a recent survey taken after a day of cool down, measurements are at 30cm from beam pipe
- Activation tracks the loss monitor data



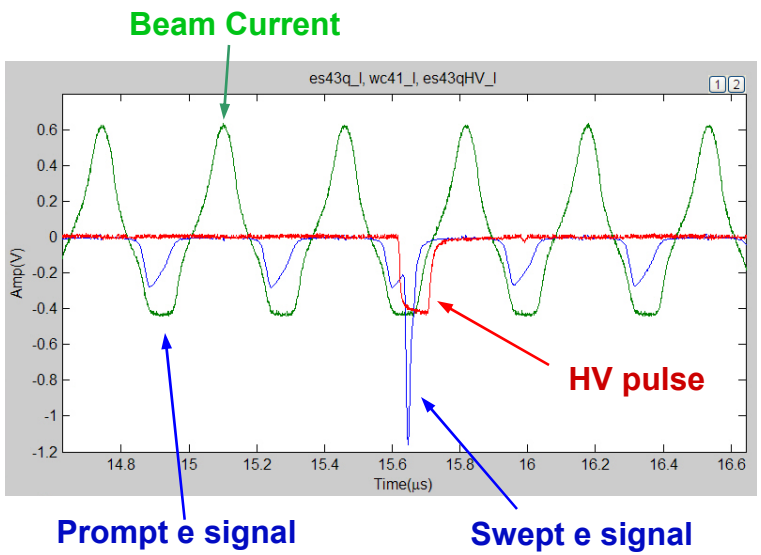
Layout in section 4 showing diagnostics used for these studies

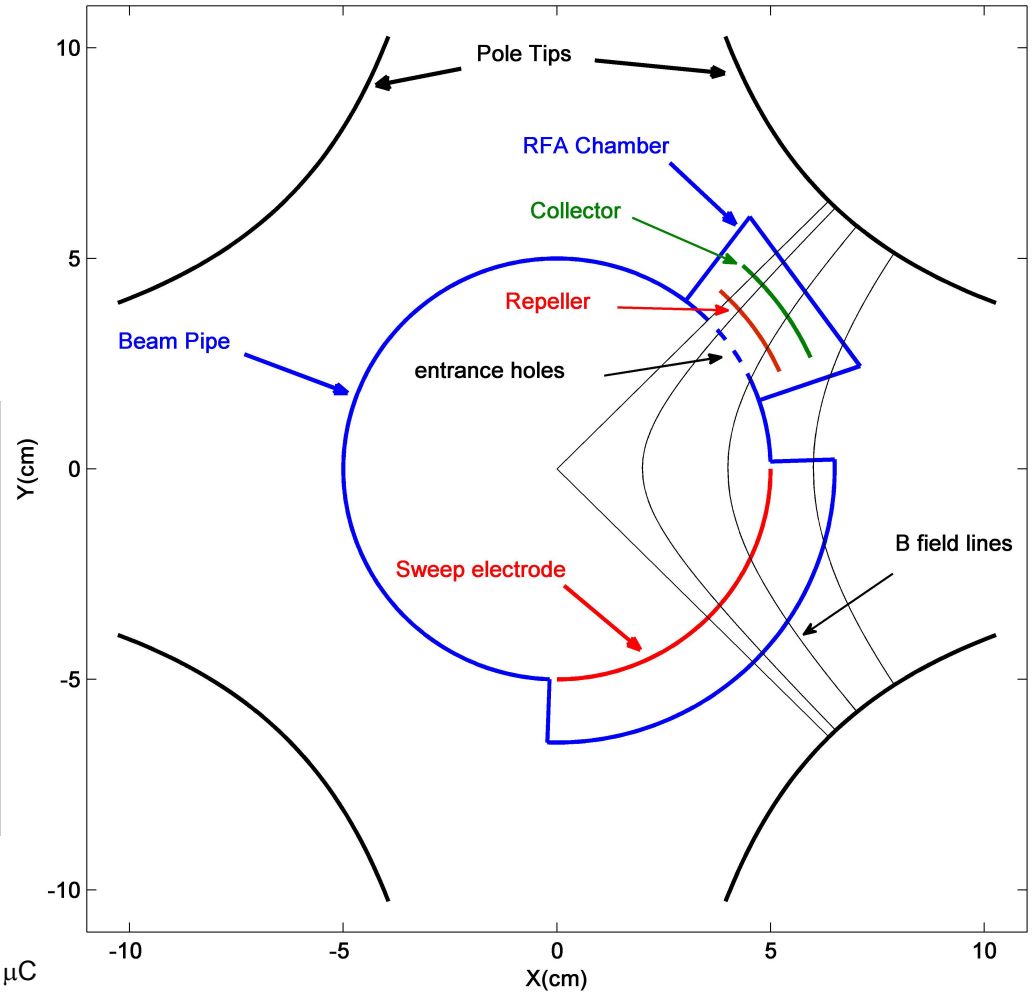




Quadrupole diagnostic layout (ES43Q)

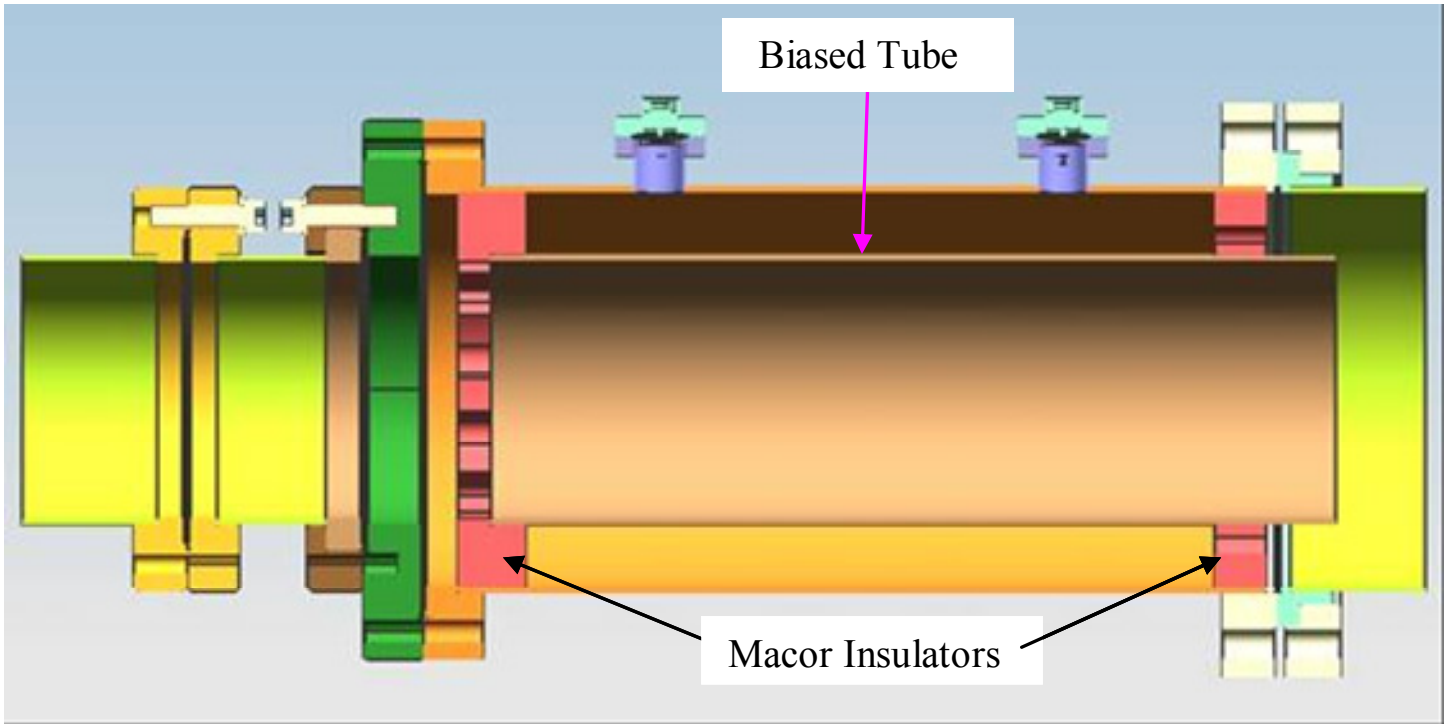
- Original orientation shown
- Rotated by 90° in September, 2007





Data of 10/25/07, 5.2 μC

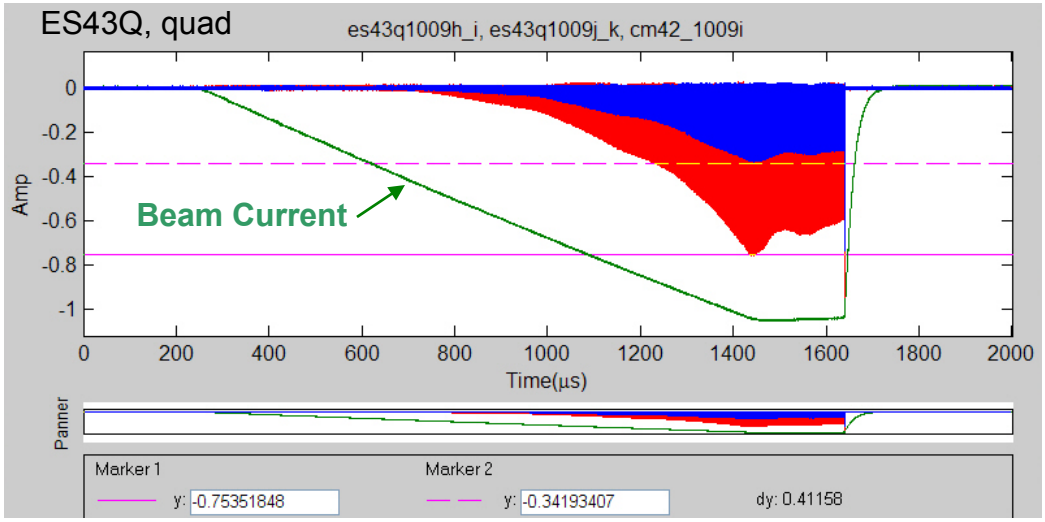
Electron longitudinal barrier “mirror”

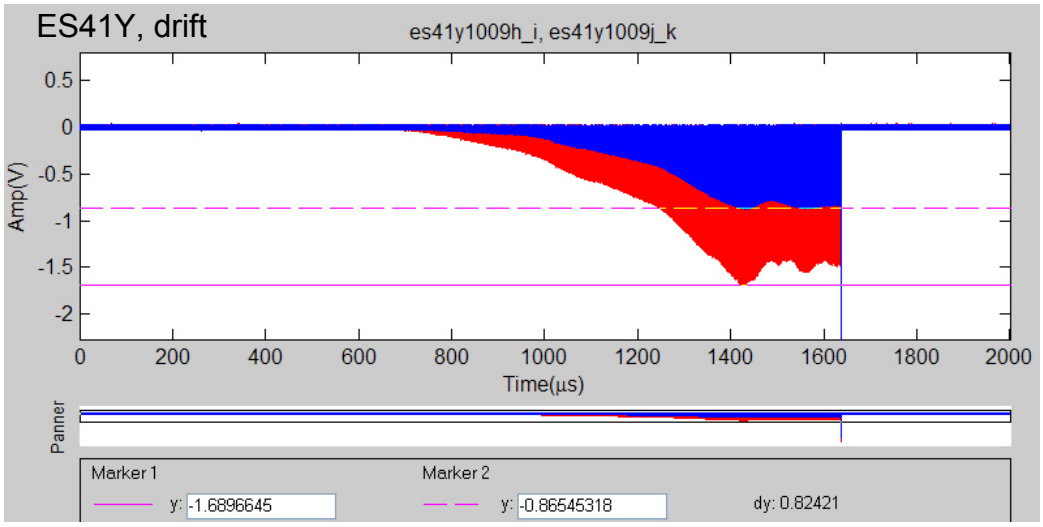


Two mirrors biased to -2kV or so isolate the drift space detector region from electron ejected from the nearby quadrupoles

Prompt electron signals (wall flux) change with losses

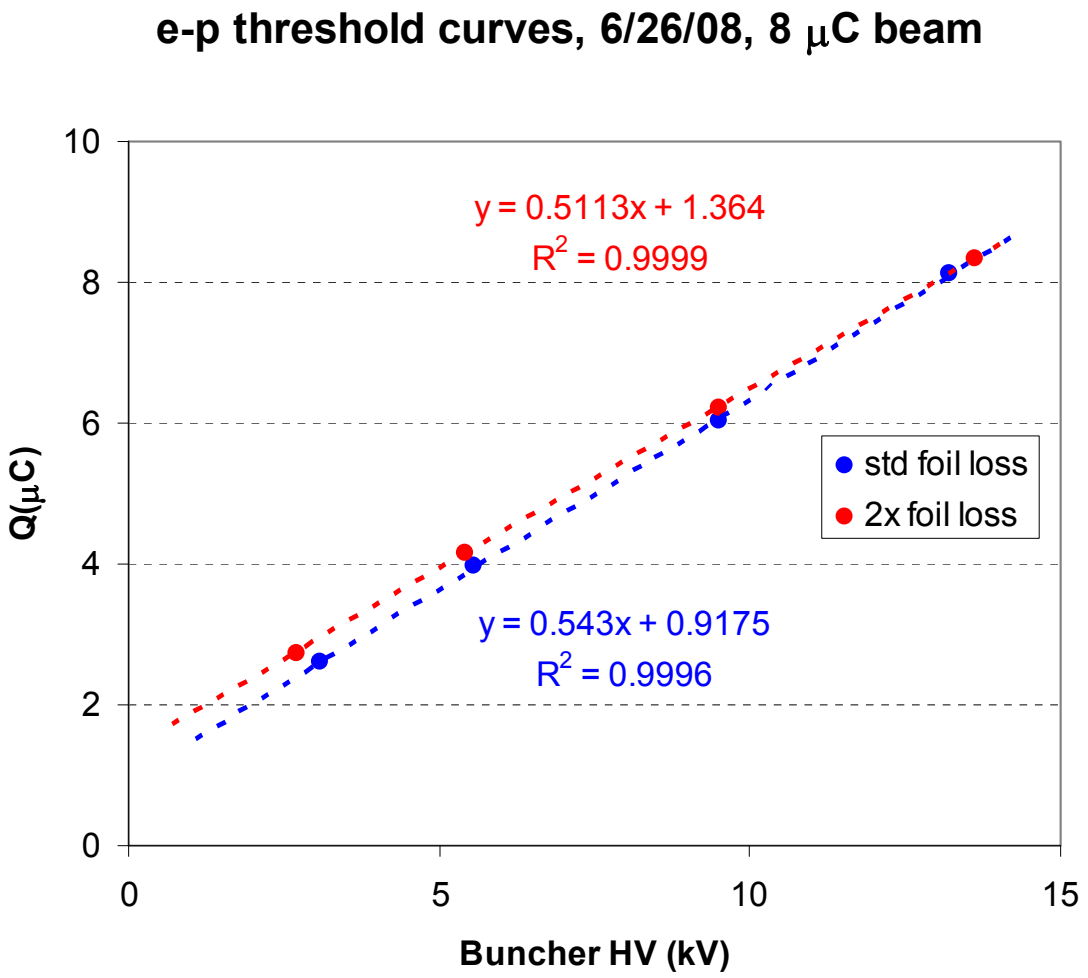
- EC data (envelope) from 2006 for 5.5 μC/pulse beam with small emittance
- Moved foil in ~1mm in x&y which increased foil hits by ~3 (from foil current monitor)
- Prompt e's in quad (es43q, top plot) went up factor ~2.3
- Prompt e's in drift (es41y, lower plot) up a factor of ~2
- Swept e's at end of gap in drift (es41y) up only a factor of ~1.3, suggests e's that survive gap are saturating w.r.t. seed electrons from beam losses



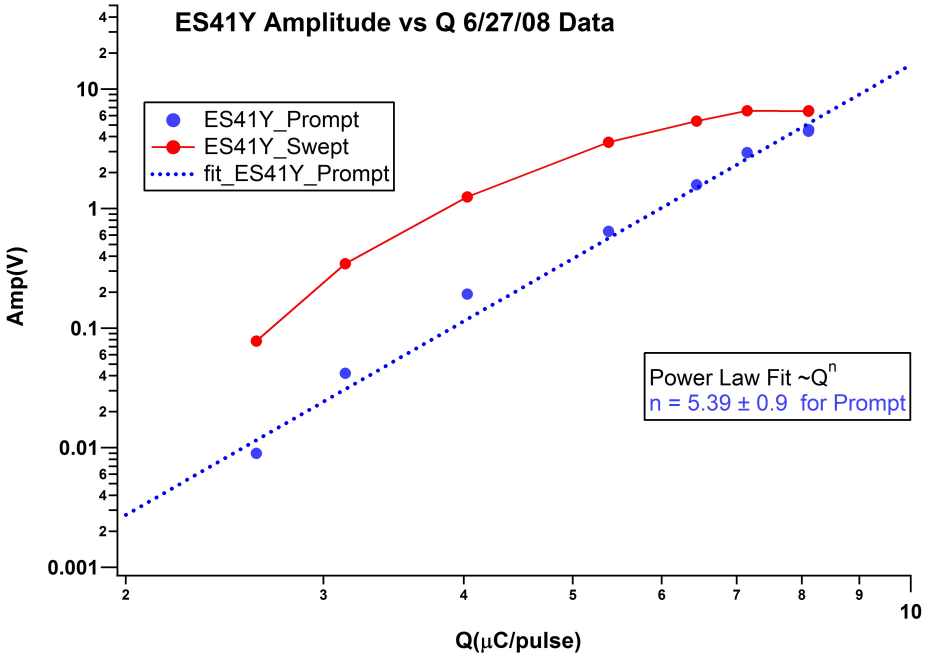


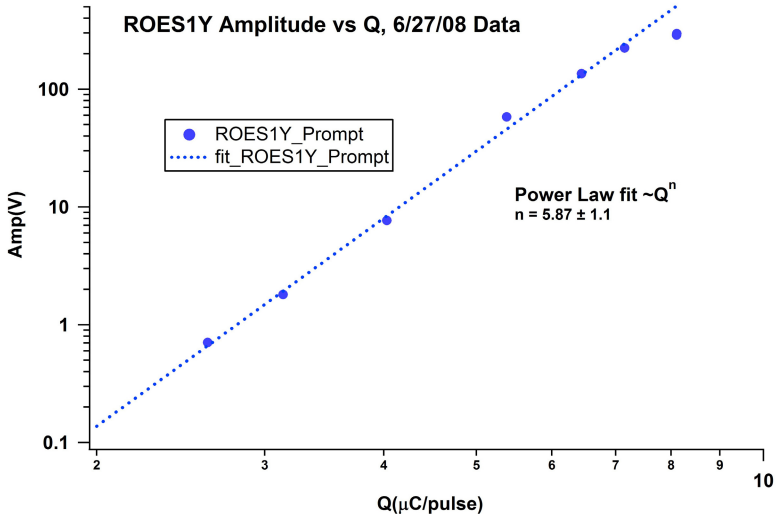
Effect on e-p instability of increasing foil scattering losses

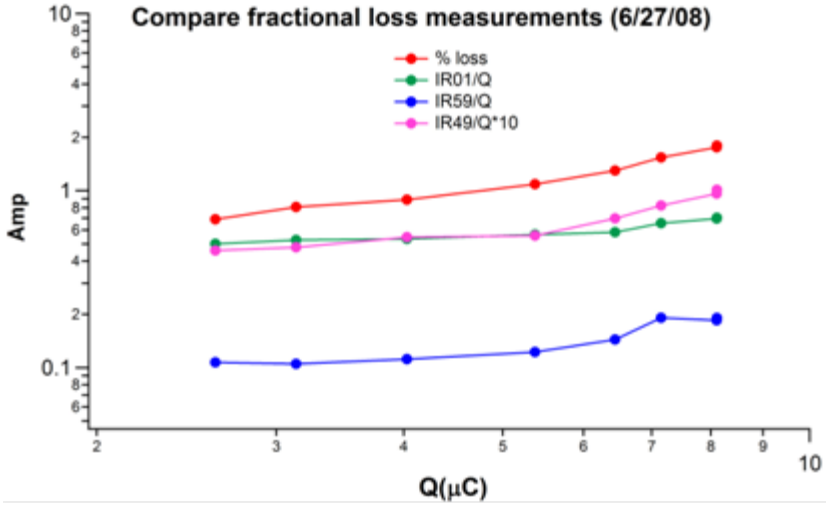
- **Changing losses by a factor of 2 had no significant effect on e-p threshold**
- **Results support the hypothesis that the EC driving the instability saturate at the nominal losses**



Electron signal amplitudes as a function of intensity



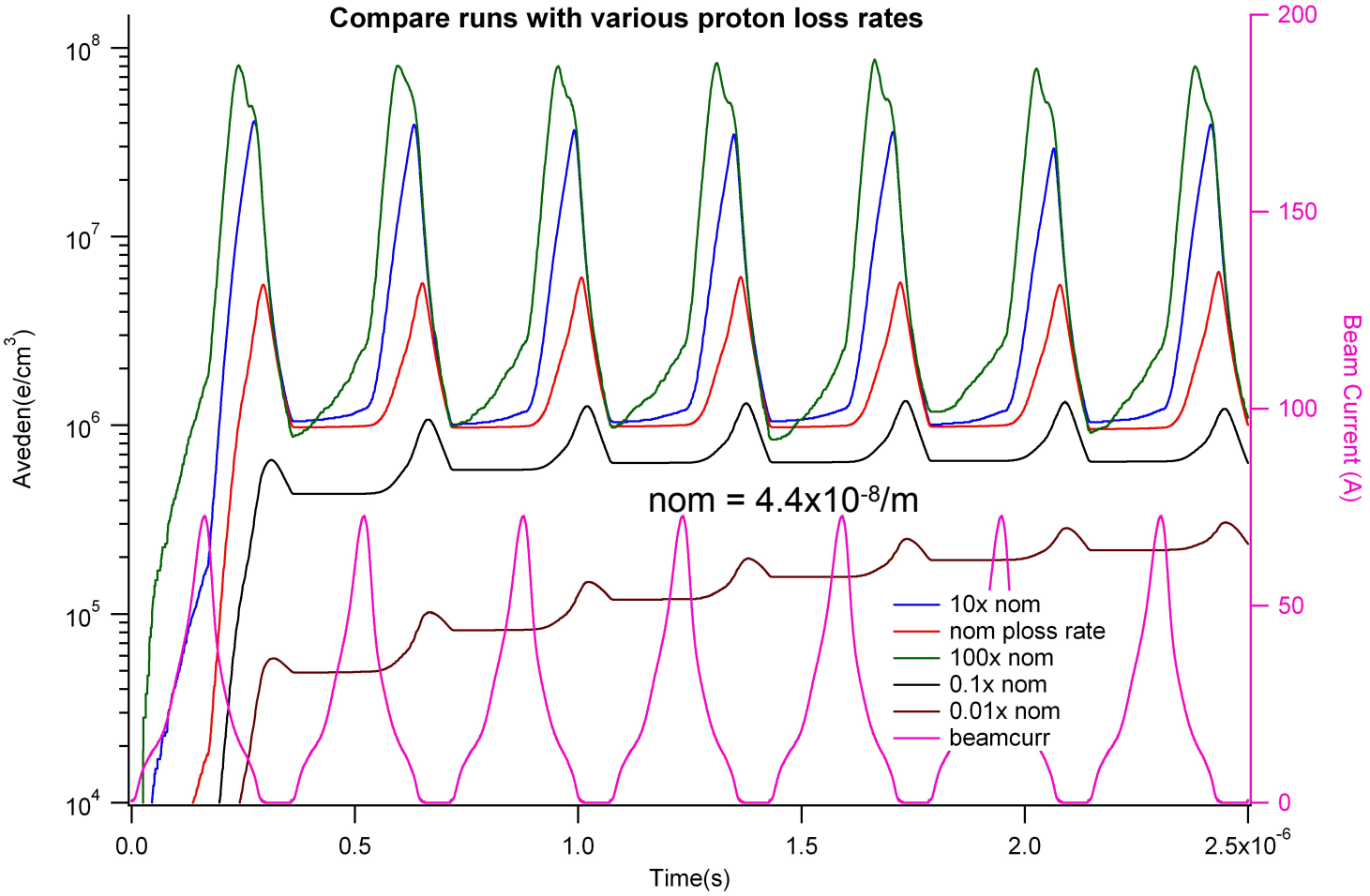




- **Contemporaneous data collected 6/27/08 Intensity varied by "1/n" countdown**
- **Fractional loss measurements show factor of 2 or less variation over full intensity range (2.6 to 8.1 μC)**

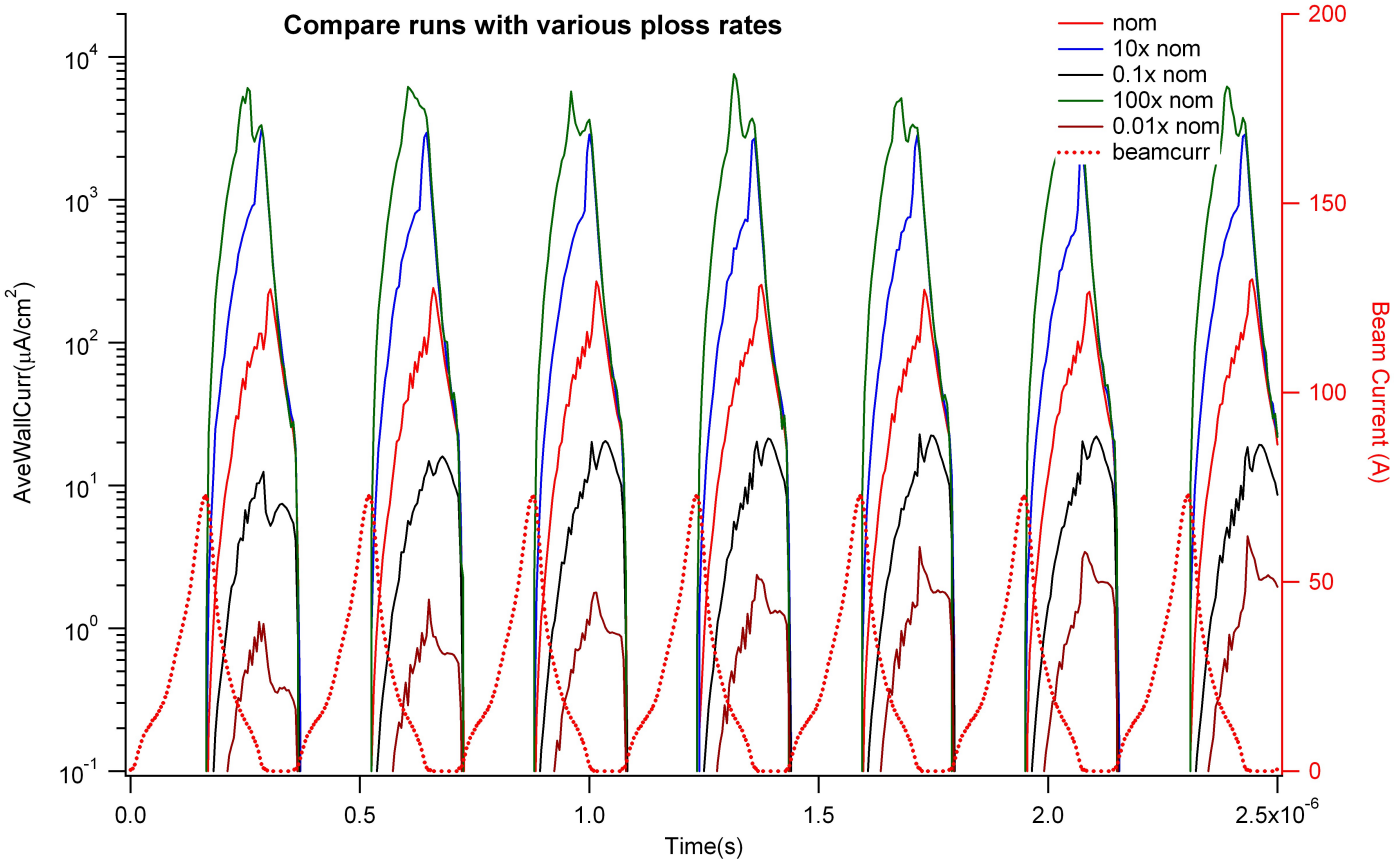
Simulations* of effect of proton loss rate on EC density in drift

- 8 μC beam intensity (5x10^8 ppp)
- 0.5 m drift region modeled
- **Aveden** = average e density over the chamber
- **ploss** = proton fractional loss rate (p/p/m)
- Note several turn buildup of aveden for lowest ploss (brown curve) (also studied by Y. Sato for his PhD thesis)



*** Modified version of POSINST12.1**

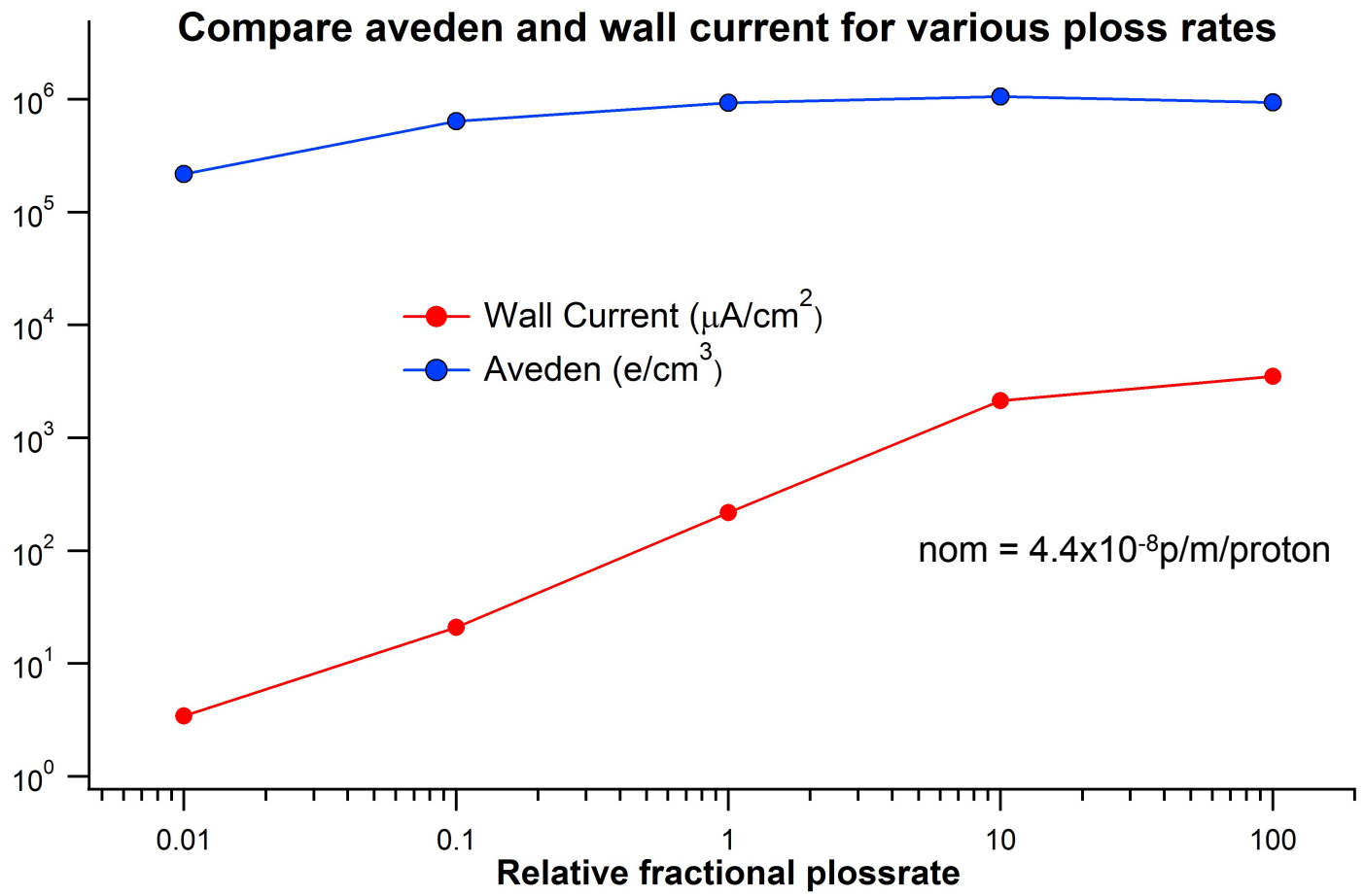
Effect of proton loss rate on electron flux at wall



- **Shows that wall current (related to prompt signal) ~proportional to ploss**
- **Saturates for 100x nom**

8/25/08

Plot of aveden at start of turn 7 & wall current at end of turn 6

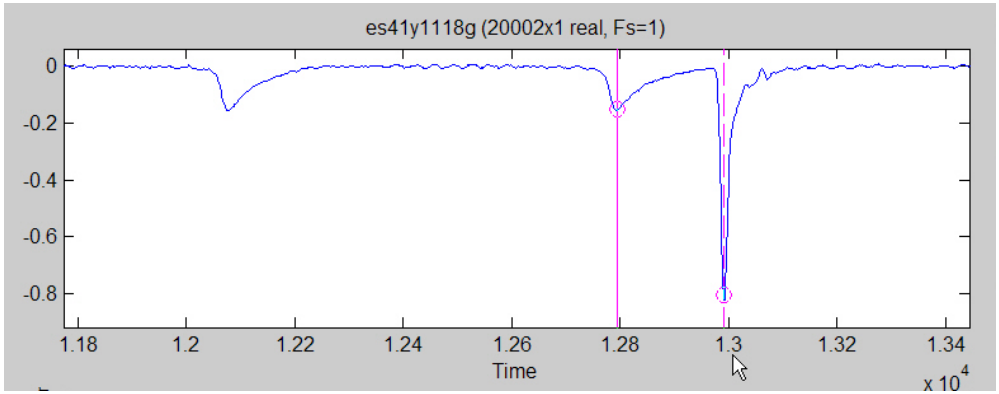


Example of electron wall current and line densities from EC diagnostic signals for 6.9 μC beam

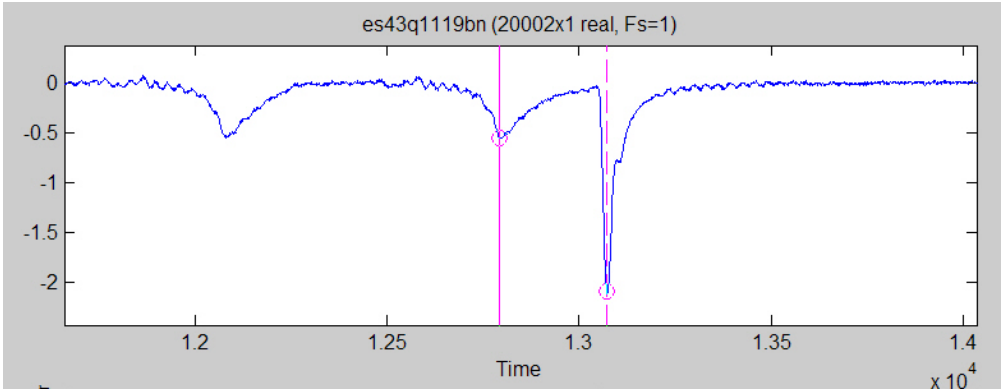
- Data from 11/18/06 beam studies
- Convert prompt amplitude to flux using detector area and transimpedance of electronics
- Convert integral of swept signal (at end of gap) to line density using acceptance of detector and electron spatial distribution assumption
- Find that the drift space and quadrupole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

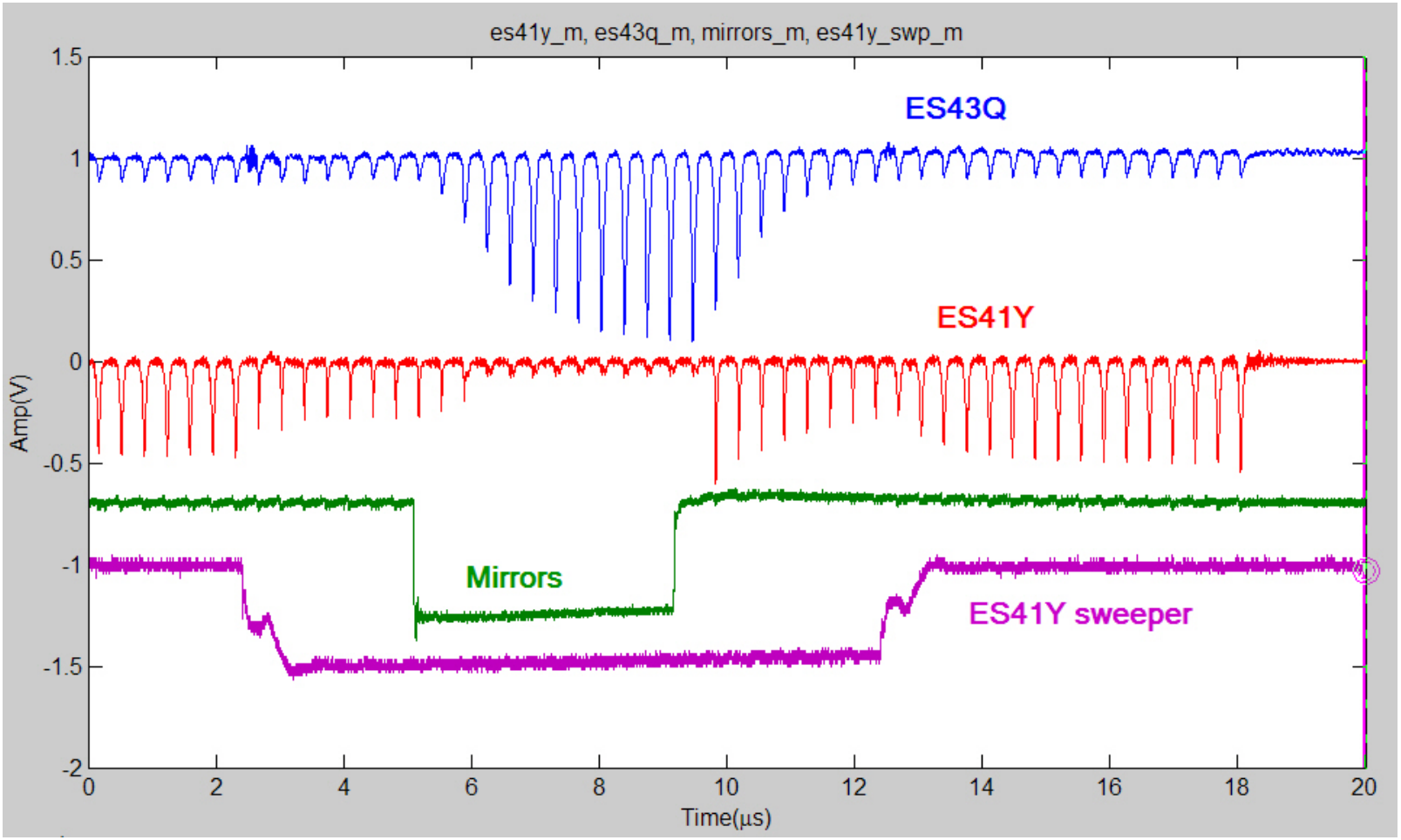


ES43Q Quadrupole



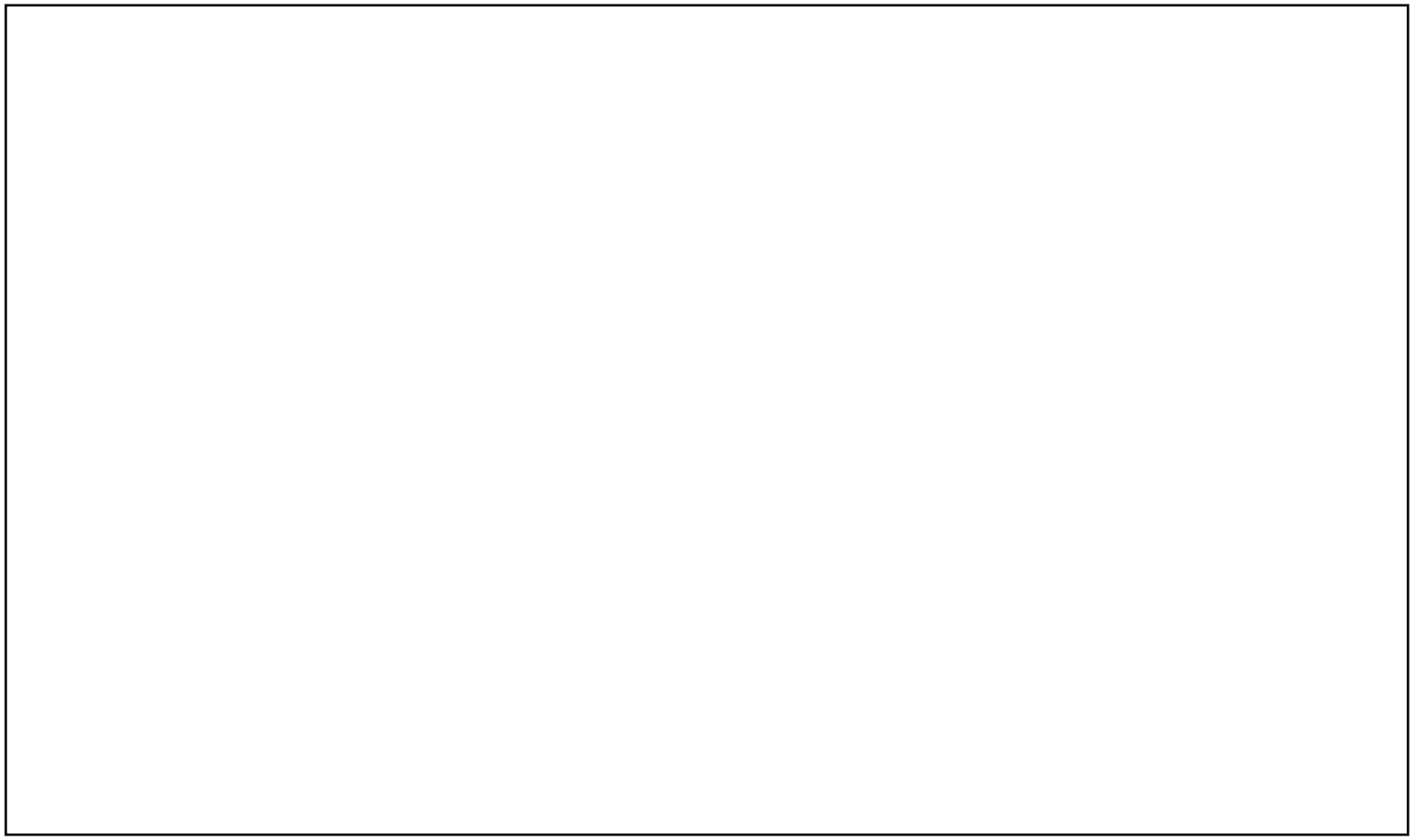
Data of 11/18/06, 6.9 μC

Experiment pulsing mirrors and es41y sweeper

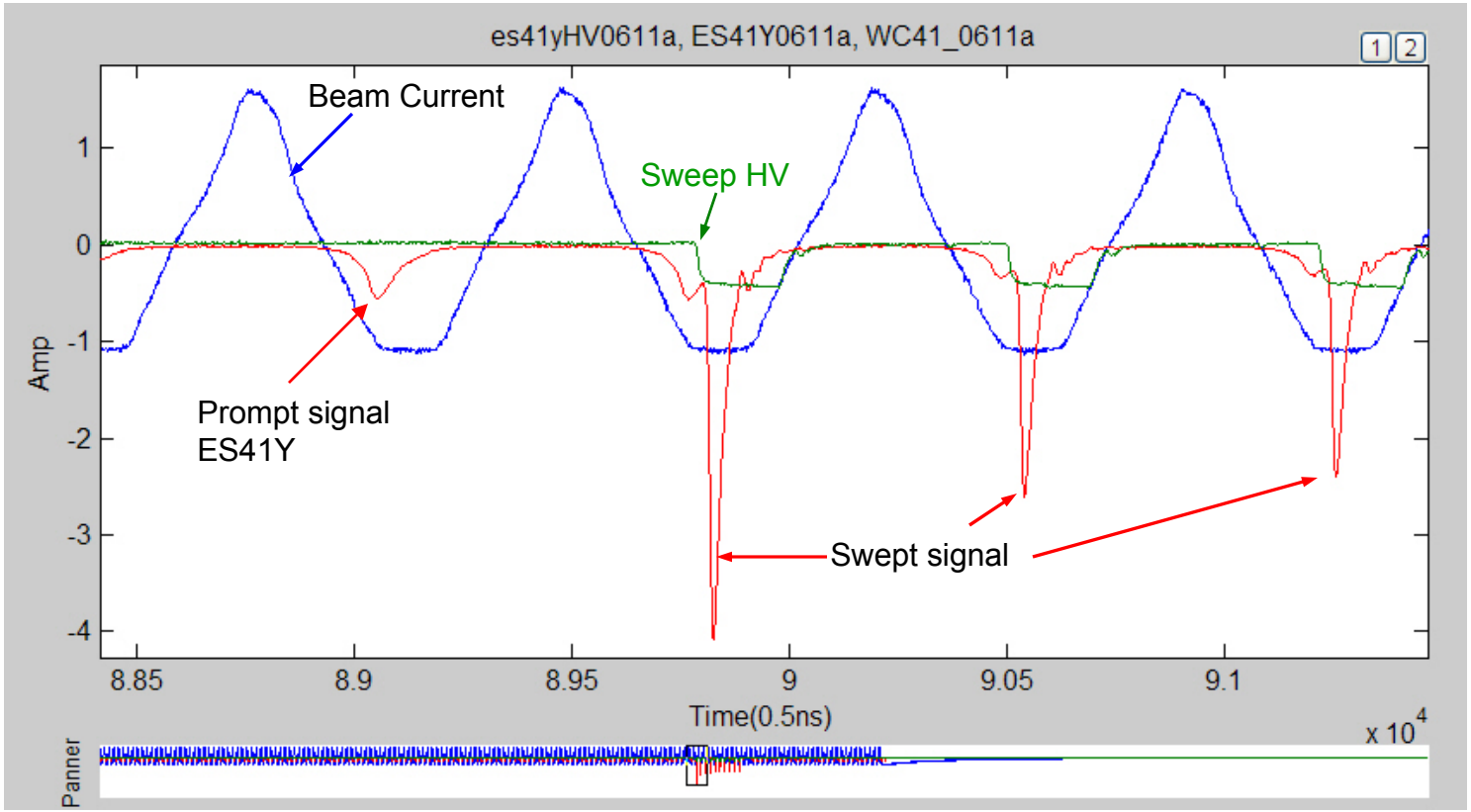


Data of 7/1/07, 5.8 μC

Double click in movie box to play animation



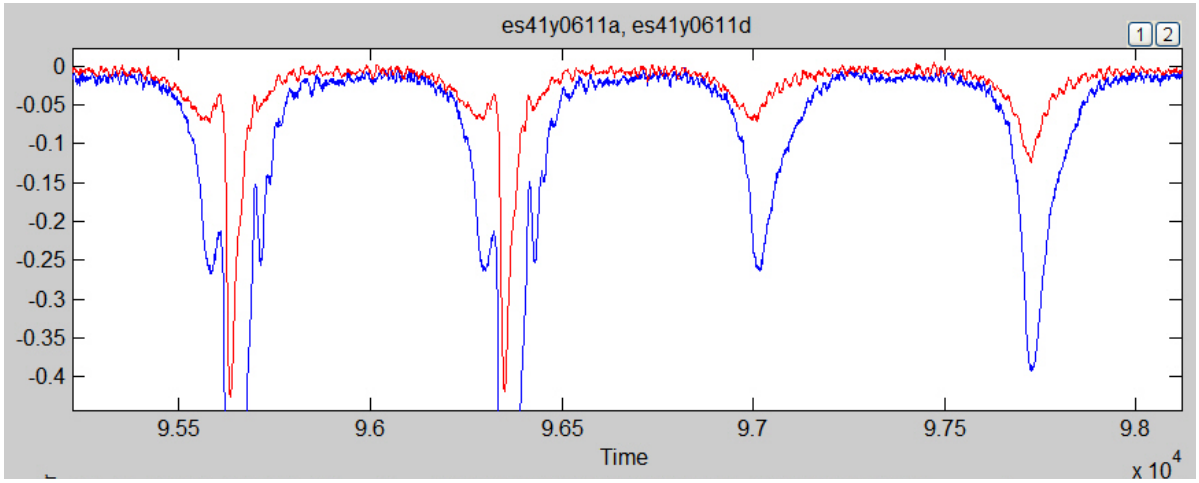
Experiment with ED sweeping using turn by turn sequence of 10 short pulses at the end of gap between turns

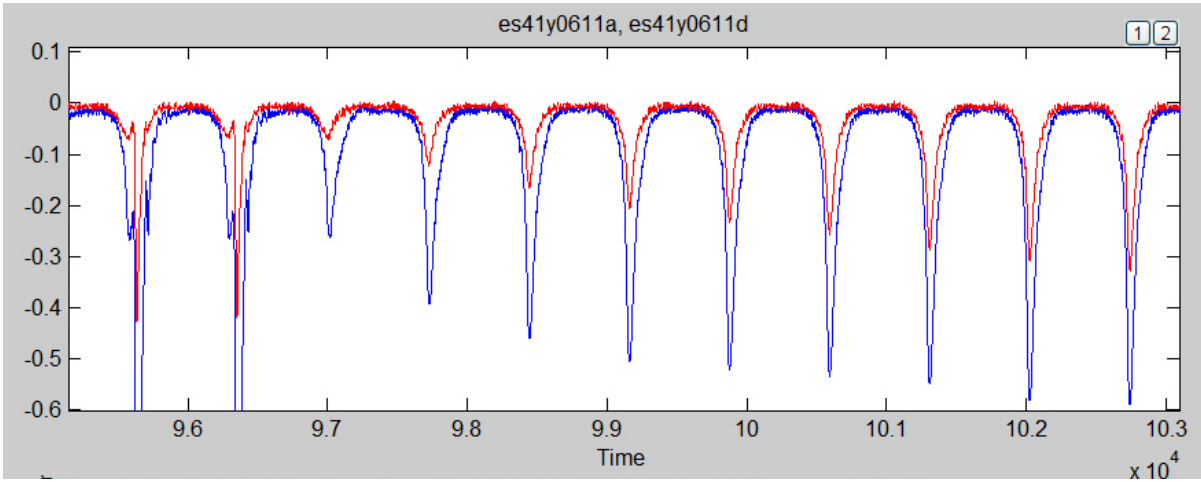


- **Only first 3 swept pulses are shown for clarity, mirrors off**

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

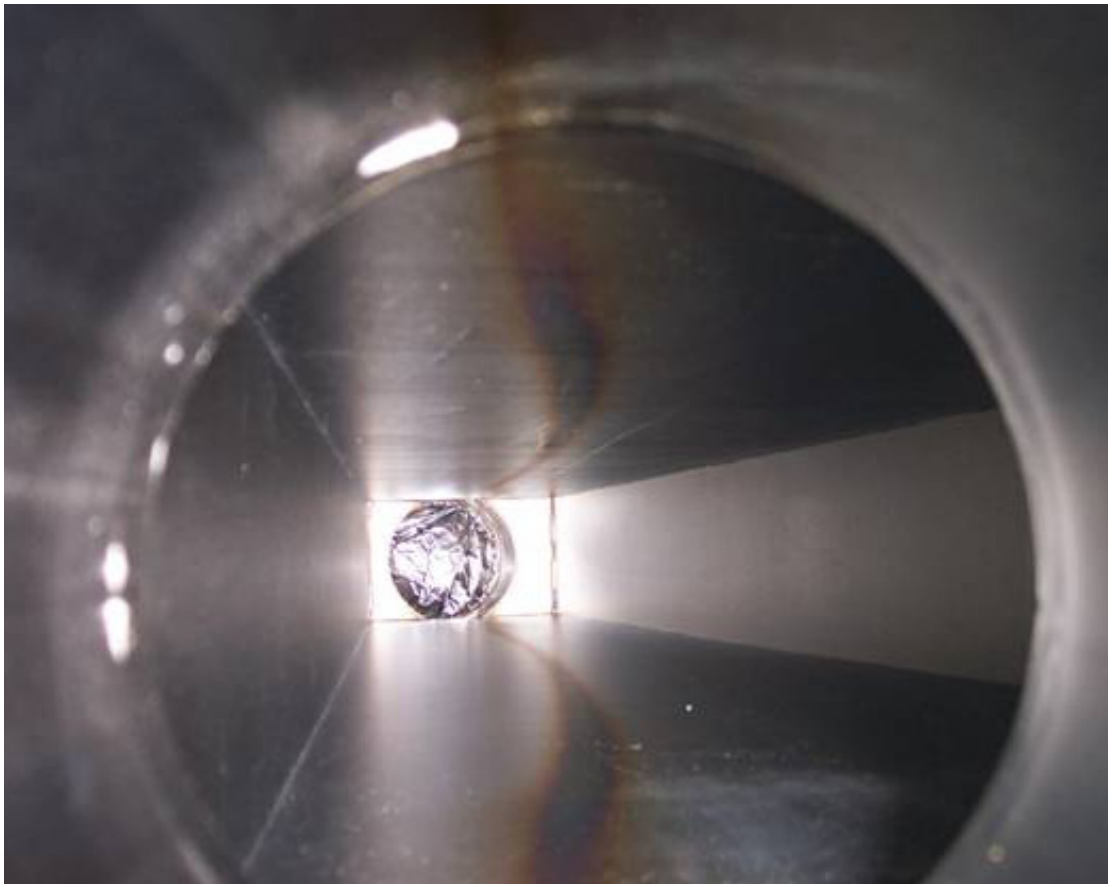




Data 6/11/08, 5.5 μC beam

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



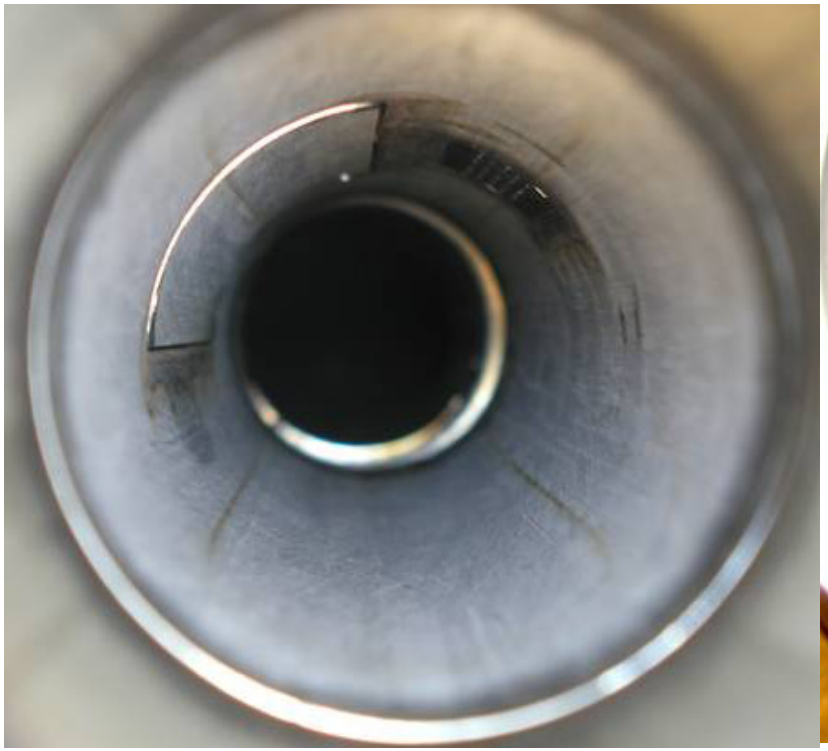
Tracking in 6 inch quadrupole chamber (SRQF11)

- 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

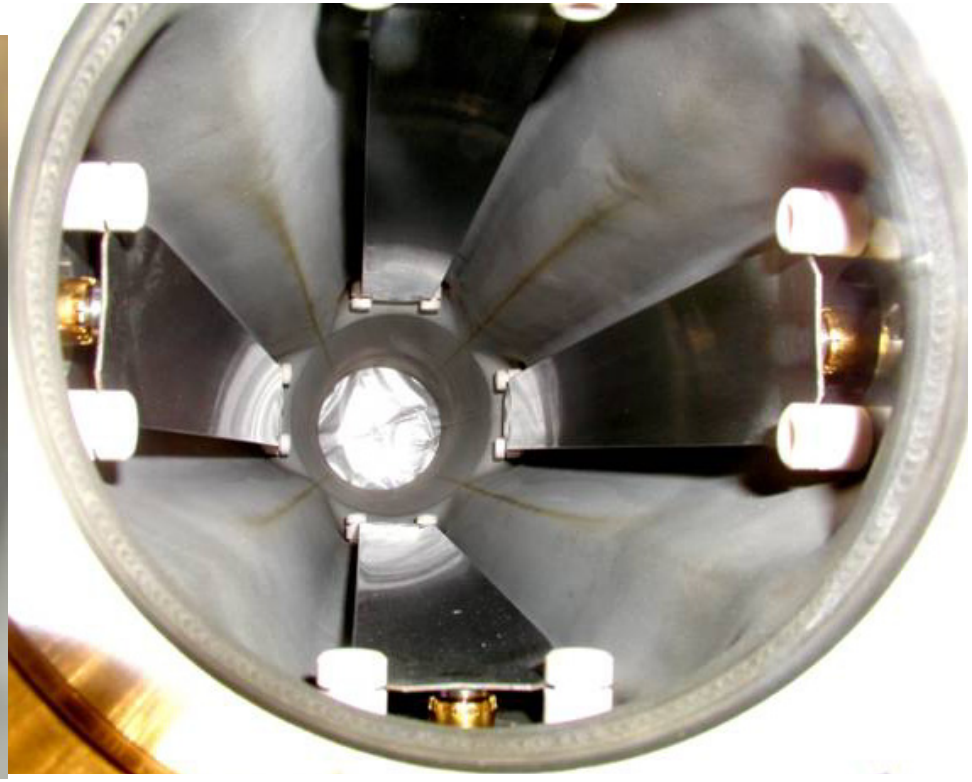


Tracking in 4 inch quadrupole (SRQU01)

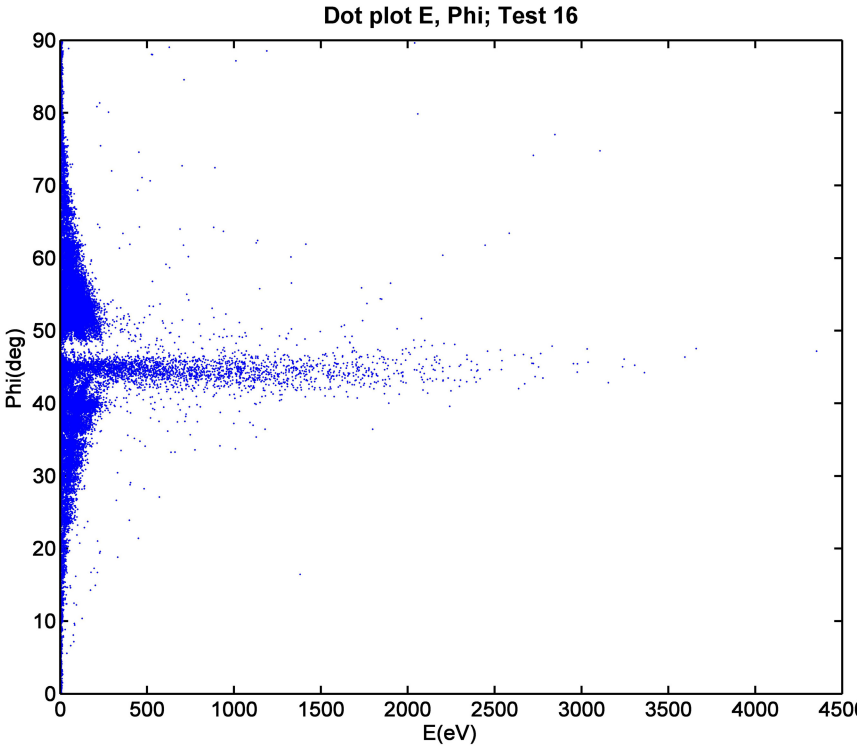
- **Quad ED (ES43Q) in SRQU01, 3/25/08**

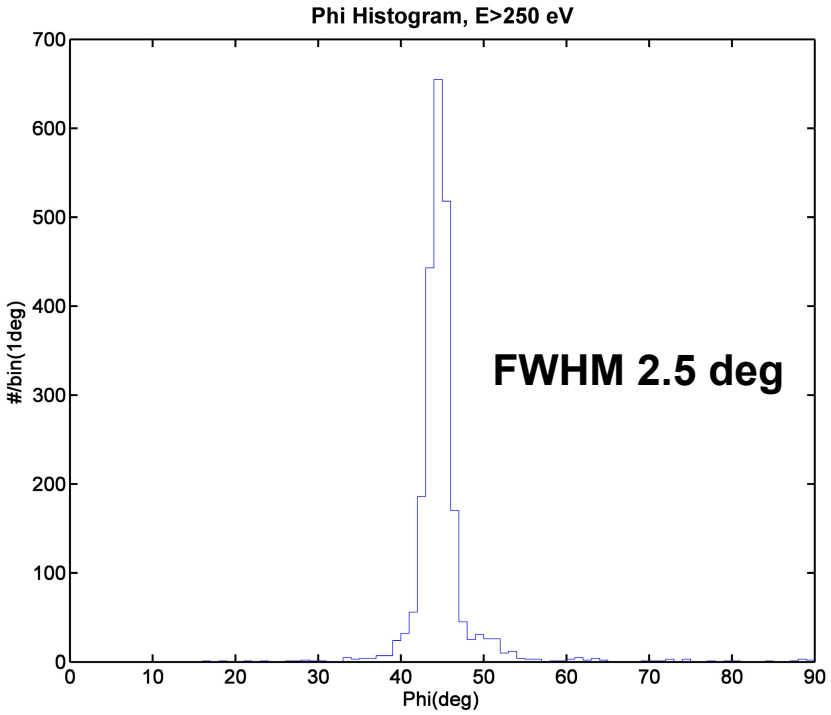


- **SRQU01, 8/28/06**



Simulated wall collision distributions for 3D quadrupole*





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

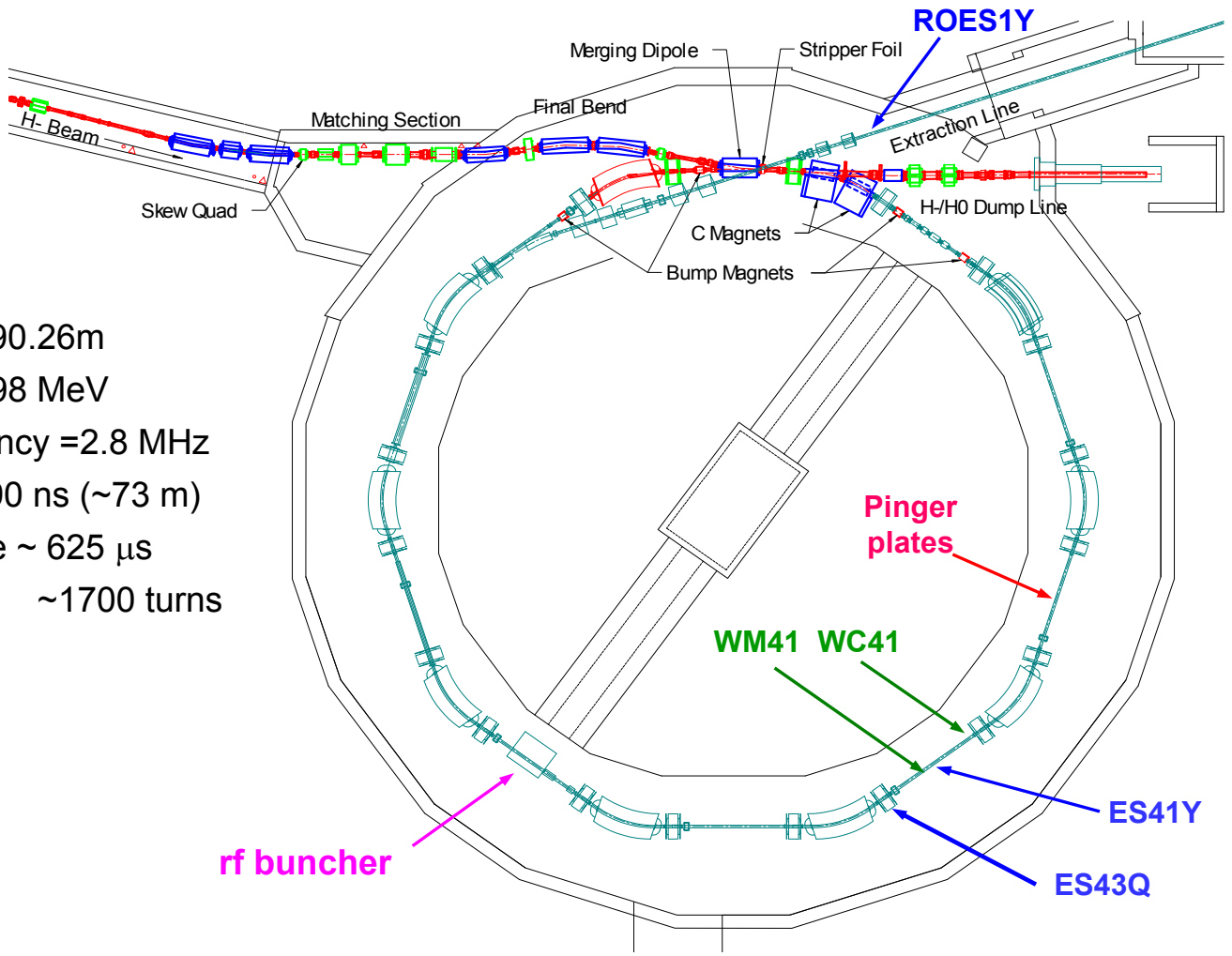
*** Modified version of POSINST12.1**

Summary and conclusions

- **Find that drift space and quadrupole have comparable electron line densities despite very different multipactor gains**
- **The null effect on e-p threshold of changing foil scattering losses may be explained by saturation of the EC (at end of gap) w.r.t beam loss**
  - Saturation is supported by simulations as well as experimental results presented here
- **Experiments with the electron mirrors in section 4 show good evidence that ~75 % of the drift space EC signal 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
- **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 all regions of the ring are important**
- **We need/plan more effort on simulations to include better treatment of EC space charge (especially in a 3D quadrupole), simultaneous treatment of multiple elements, and including lattice function/spot size variations**

Backup slides follow

PSR Layout with present EC & e-p Diagnostics



Circumference = 90.26m

Beam energy = 798 MeV

Revolution frequency =2.8 MHz

Bunch length ~ 290 ns (~73 m)

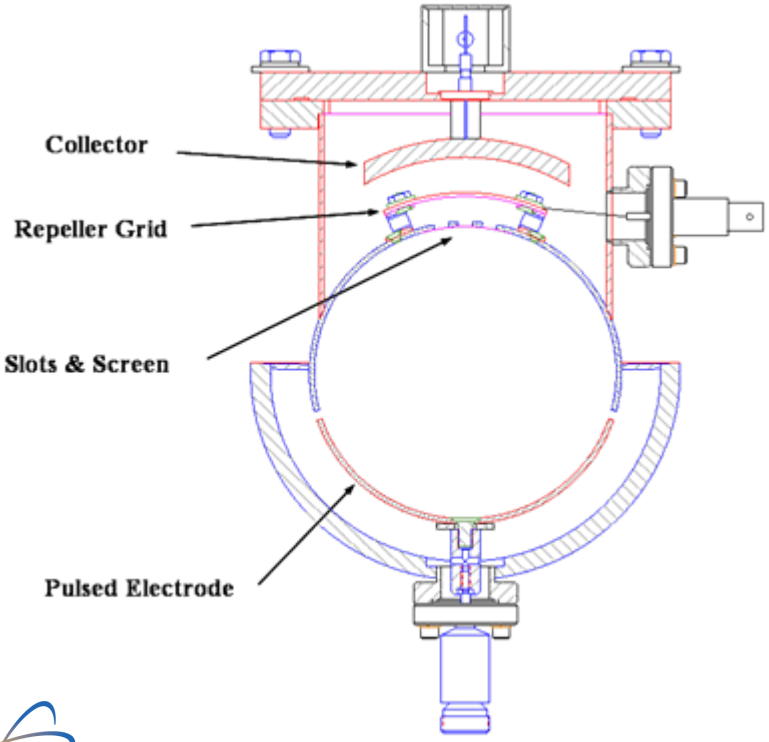
Accumulation time ~ 625 μs

~1700 turns

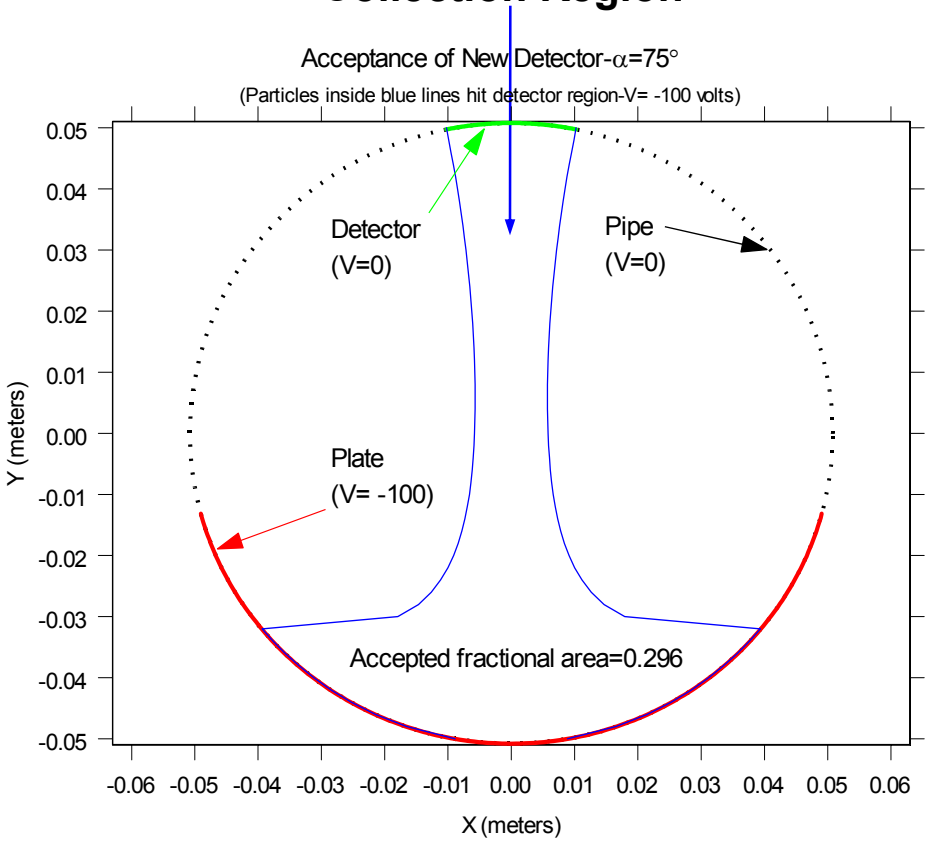
Electron Sweeping Diagnostic (ESD)

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

Cross-section

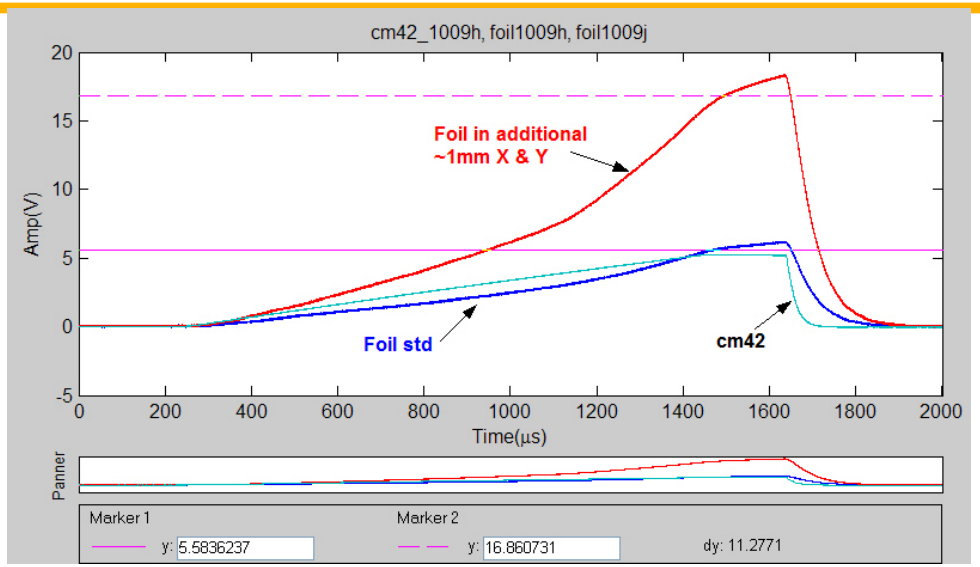


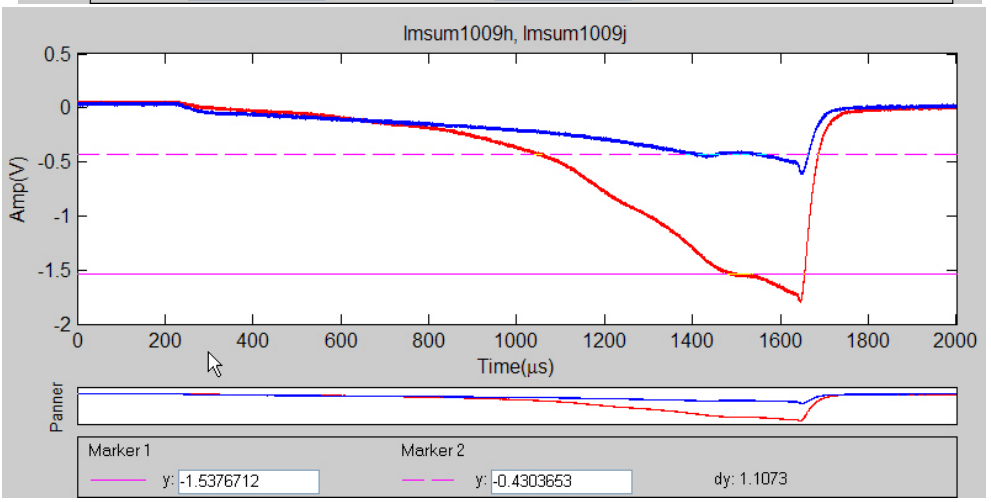
Collection Region



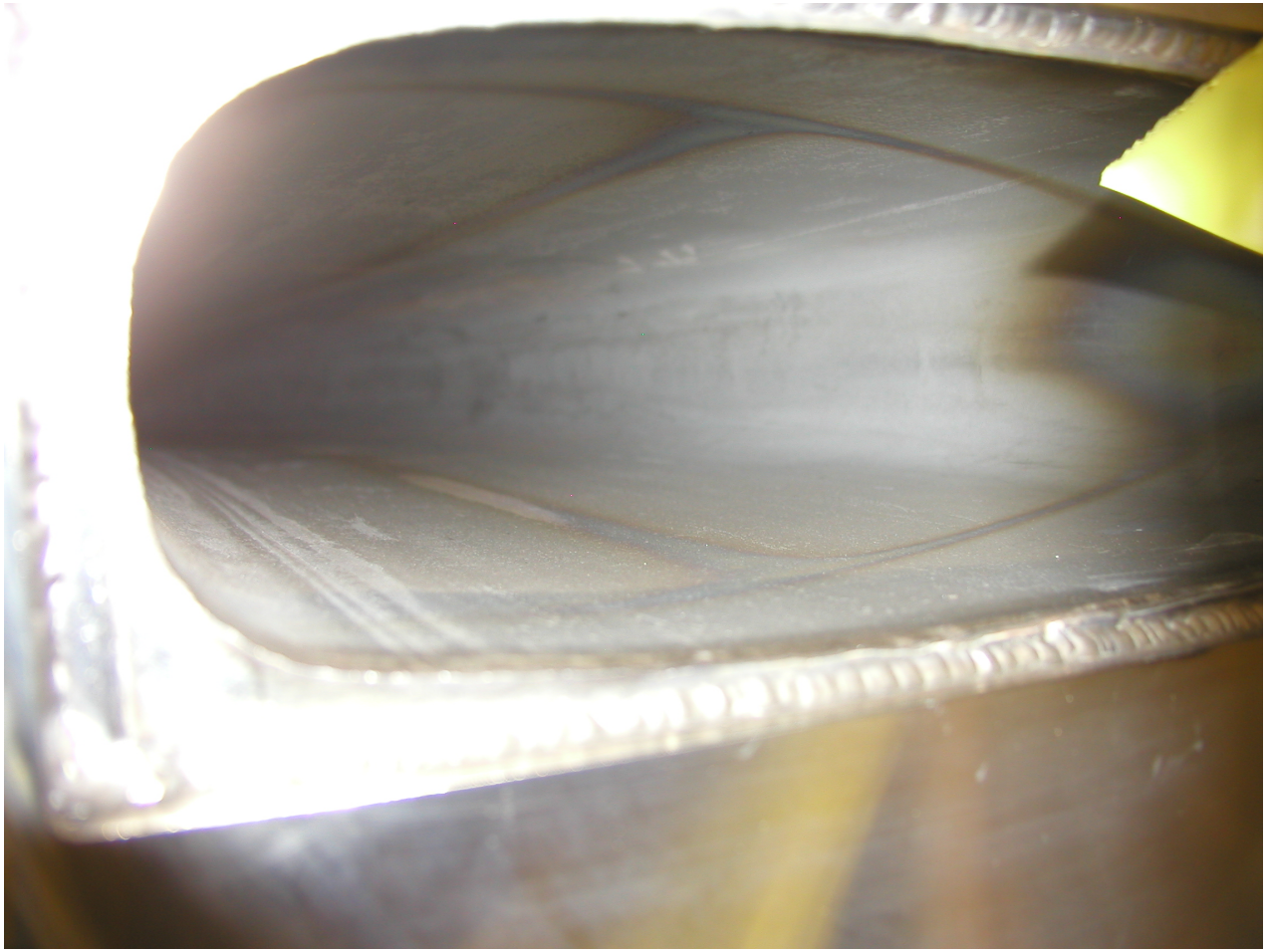
Vary foil scattering hits & losses

- Foil hit and loss data for experiment showing prompt electrons track losses
- The standard foil position minimizes beam losses
- Moving foil in ~1 mm in x and y increased foil hits and total losses by factor of ~3
- Loss monitor signal (not shown) for section 4 up factor of ~3.4
- 5.5 μC/pulse small emittance beam





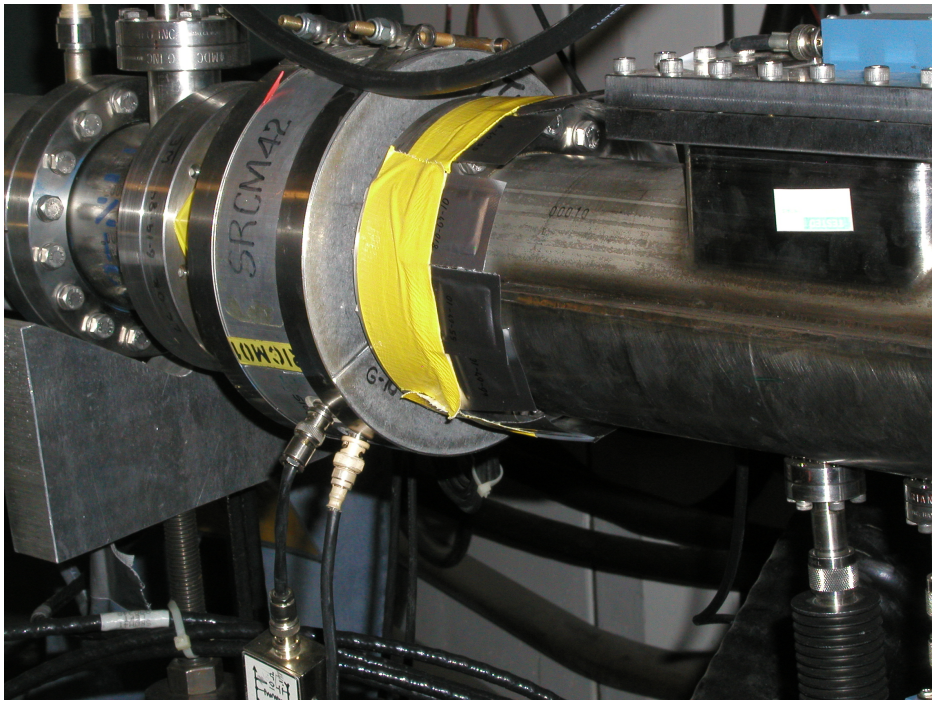
Tracking in SRBM91 down stream end, removed 2005



Samples of radiochromic film in section 4



SRQU41 entrance,
RSP52, VM41



Front of CM42, part of ES41Y