Recent Experimental Studies of the Electron Cloud at the Los Alamos PSR

Robert Macek, 9/11/01 - KEK Workshop

Co-authors: A. Browman, D. Fitzgerald, R. McCrady, T. Spickermann and T. S. Wang

Los Alamos Neutron Science Center

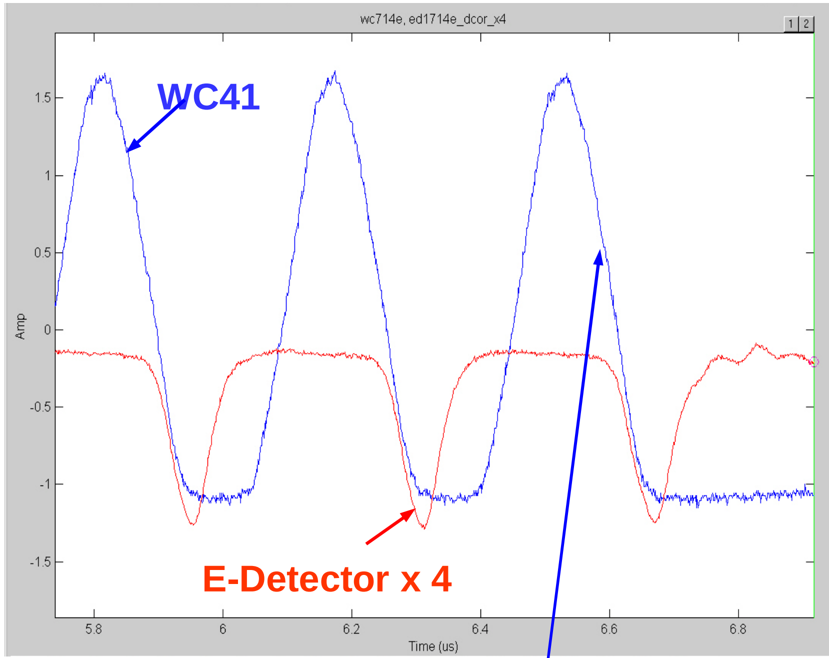
Outline

- **Background: Electron Cloud Issues for PSR**
- **Electron Cloud Diagnostics at PSR**
  - **Biased collection plates**
  - **Harkay-Rosenberg RFA**
  - **Electron Sweeping Detector**
- **Results from the Electron Sweeper**
  - **Electron signal**
  - **Electrons surviving a long gap**
  - **Recovery from gap “clearing”**
- **Electron Cloud Measurements in a Weak Solenoid**
- **Some Remaining Puzzles**
- **Summary and Conclusions**

Some Important Electron Cloud Issues at PSR

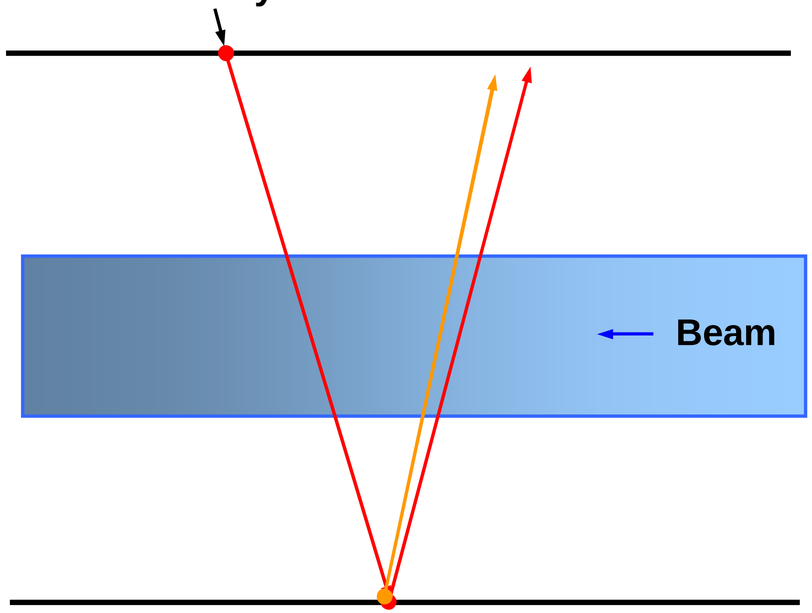
- **The strong, fast, transverse instability at PSR is almost certainly e-p, based on the many observed characteristics of the unstable proton beam motion**
  - **See Macek etal, FOAB007 PAC2001 and references therein, also ICANS-XV paper**
- **However, the origin and important characteristics of the electron cloud are less well understood**
- **Key issue: can we make a compelling case that electron suppression by TiN coatings and/or solenoids will cure the instability?**
  - **TiN coatings nicely suppress the copious e's striking the wall at the end of each bunch ("prompt e's"), but are these the one that drive the instability?**
  - **Prompt e's striking the wall are strongly dependent on beam intensity, beam losses and vacuum pressure but this is not reflected in the instability threshold behavior, why?**
  - **Trailing edge multipactor generates many electrons but what fraction survives passage of the gap to be captured by the following beam pulse?**
  - **Is multi-turn accumulation of electrons significant?**
  - **The electron density in the beam (neutralization) is the critical factor for e-p dynamics but is difficult to measure directly**

Mechanism #1: “trailing edge” multipactor



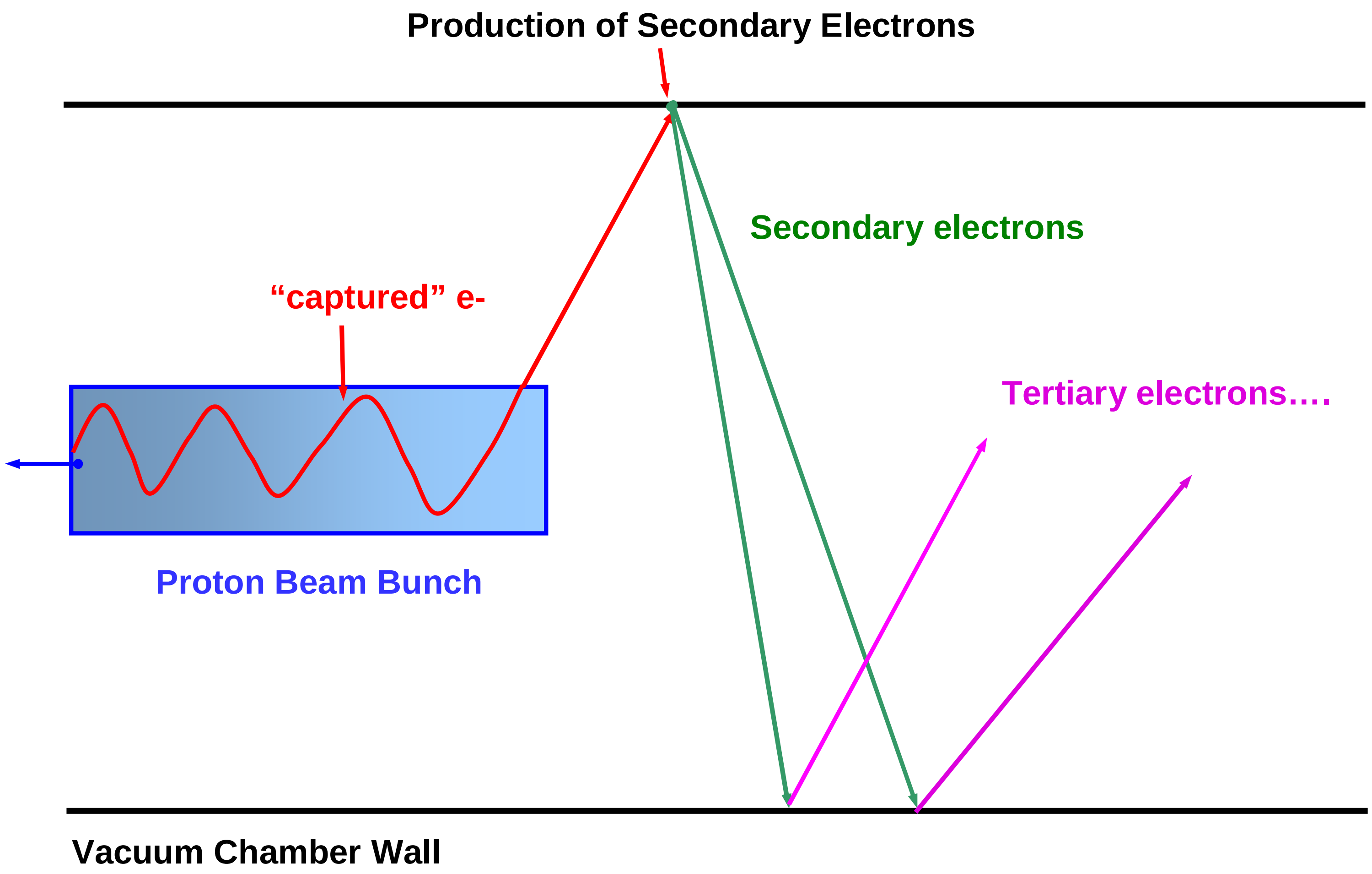
Energy gain is possible in wall-to-wall traversals on trailing part of beam pulse

Electron born at wall from say losses



Energy gain in one traversal is high enough for multiplication

Mechanism #2: production by “captured” electrons



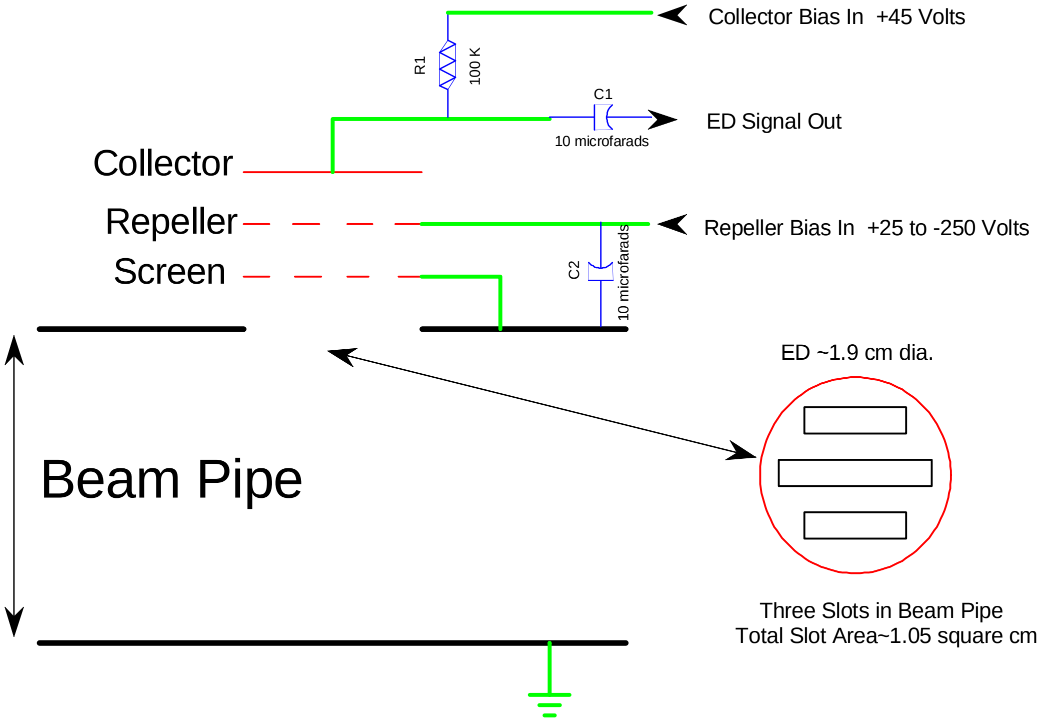
Electron Cloud Diagnostics at PSR

- **Available electron diagnostics in PSR provide valuable information that helps constrain simulations but do not directly measure beam neutralization**
  - **DC-biased collecting plates are slow and perturb the beam/wall environment but are our only device that can be used inside magnets**
  - **ANL Retarding Field Analyzers (RFA) measure the electrons striking the wall**
  - **The pulsed electron sweeping detector comes the closest in that it can measure electrons in the pipe at various times during passage of the gap**
    - — electron line density at end of gap is a lower bound on electrons captured by the next passage of the beam pulse
    - — also can be used to clear the gap of electrons (locally)

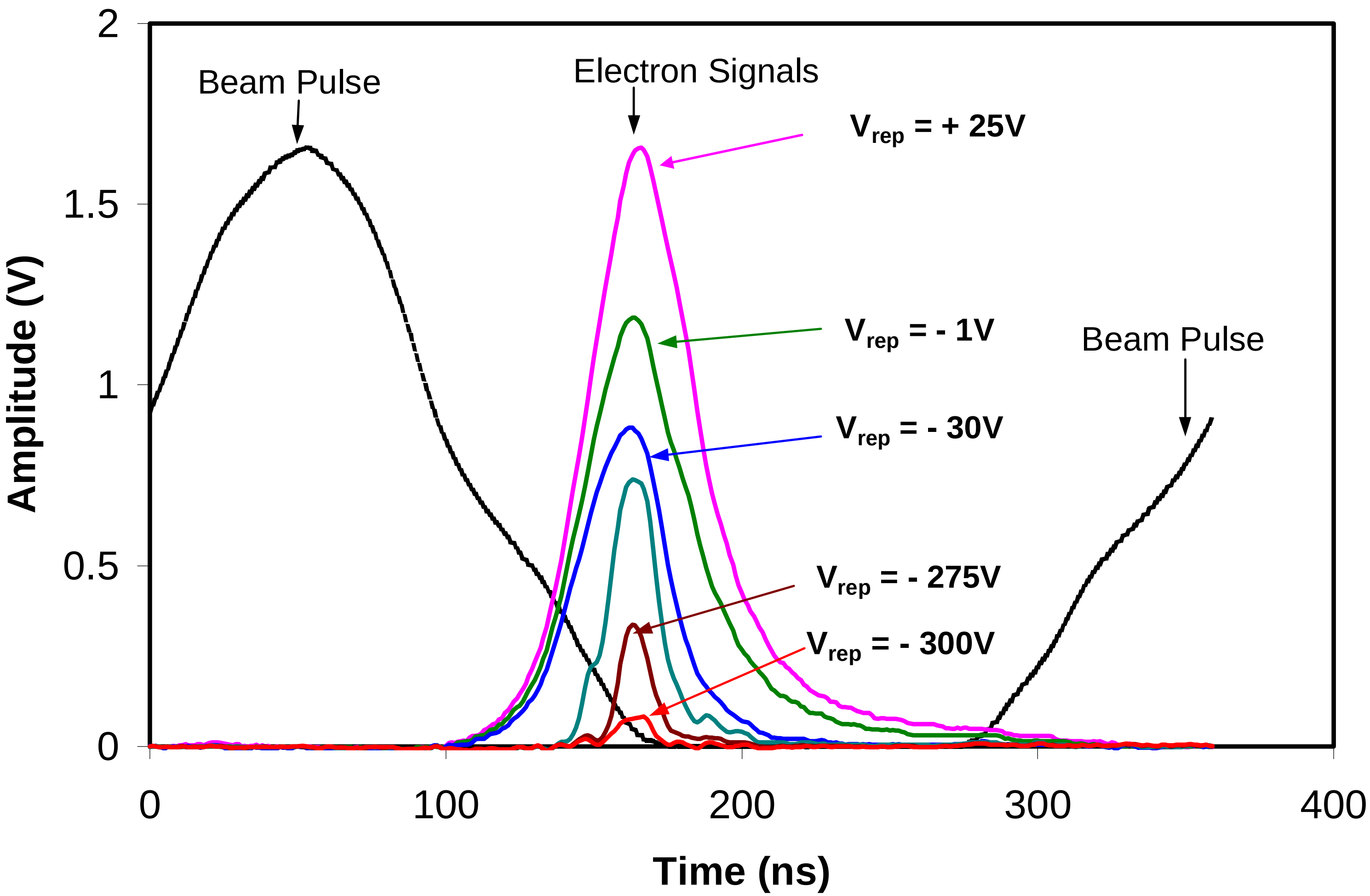
Retarding Field Analyzer

- Described in R. Rosenberg and K. Harkay, NIM A 453 (2000) p507-513.
- LANL augmentation is fast electronics (~80 MHz) on the collector output
- Minimal perturbation of beam/wall environment
- Use of repeller permits collecting a cumulative energy spectrum
- Obtain data on e-flux, time structure and energy spectra
- Measures electrons striking the wall, not electrons remaining in the pipe

Simplified RFA Installation Sketch

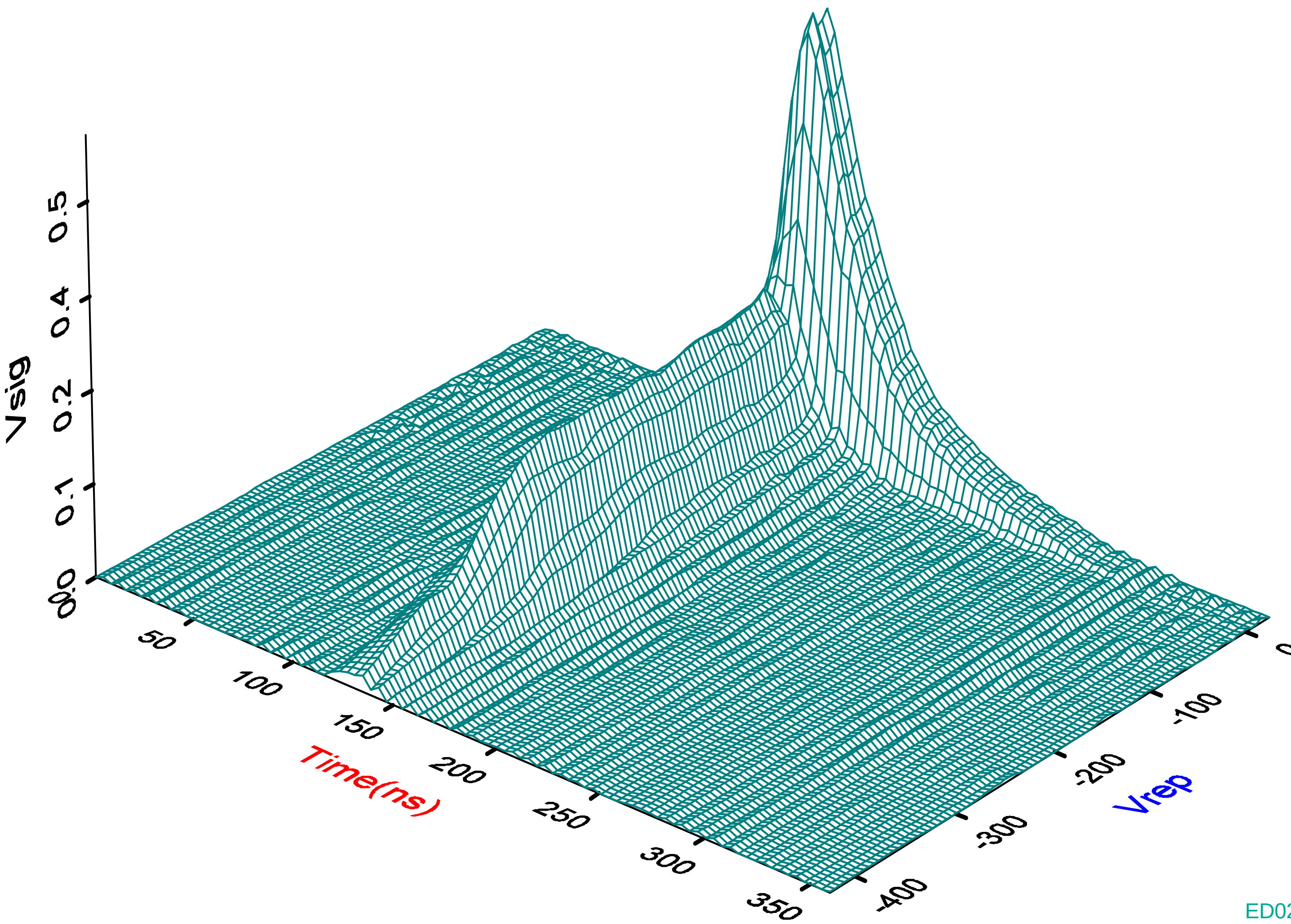


Electron signals from RFA in straight section 4



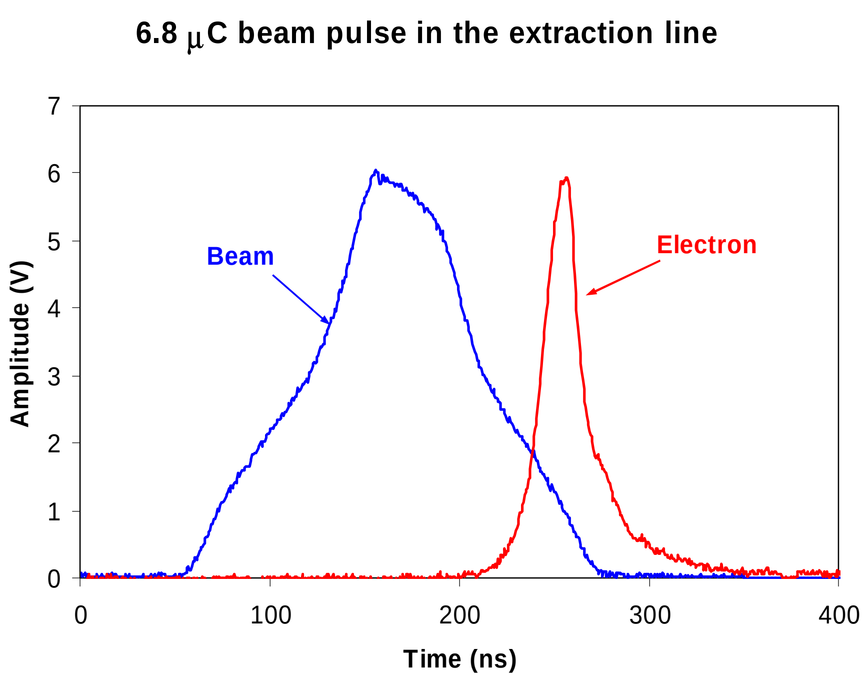
Signals averaged for 32 beam macropulses, ~ 8 μC/pulse beam intensity, device is labeled ED42Y, Transimpedance = 3.5 kΩ, opening ~1 cm^2

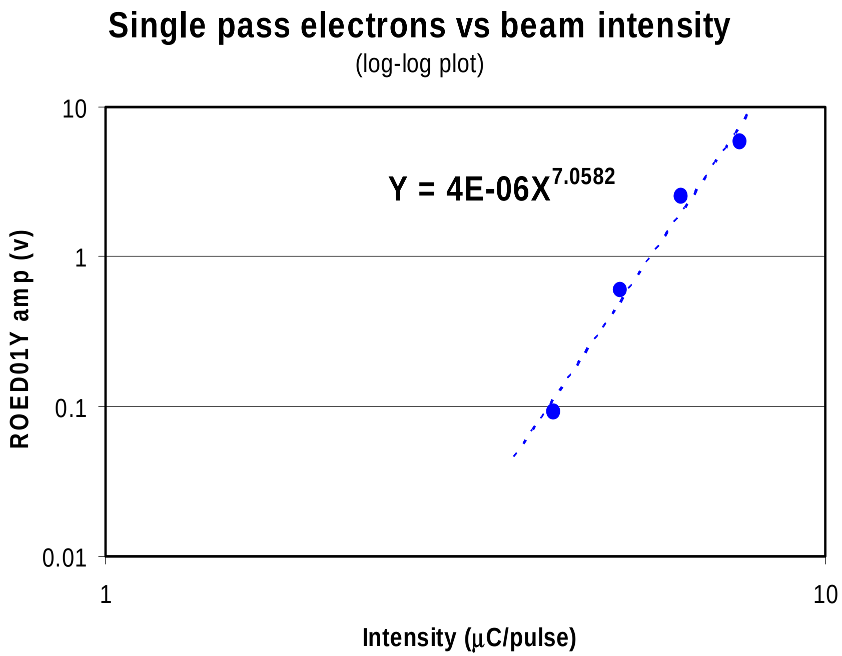
Electron energy cumulative spectrum (3D profile)



ED02x, ~8 μC

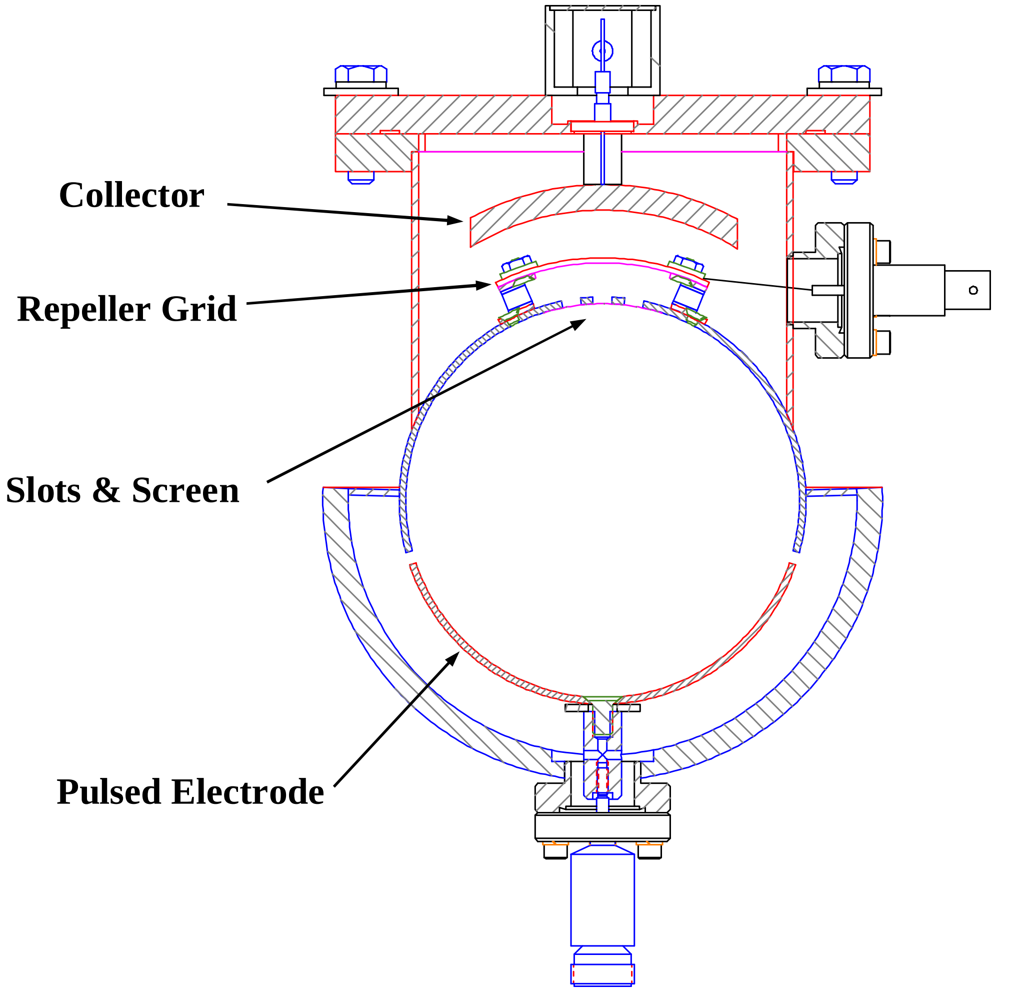
RFA signals in a single pass experiment



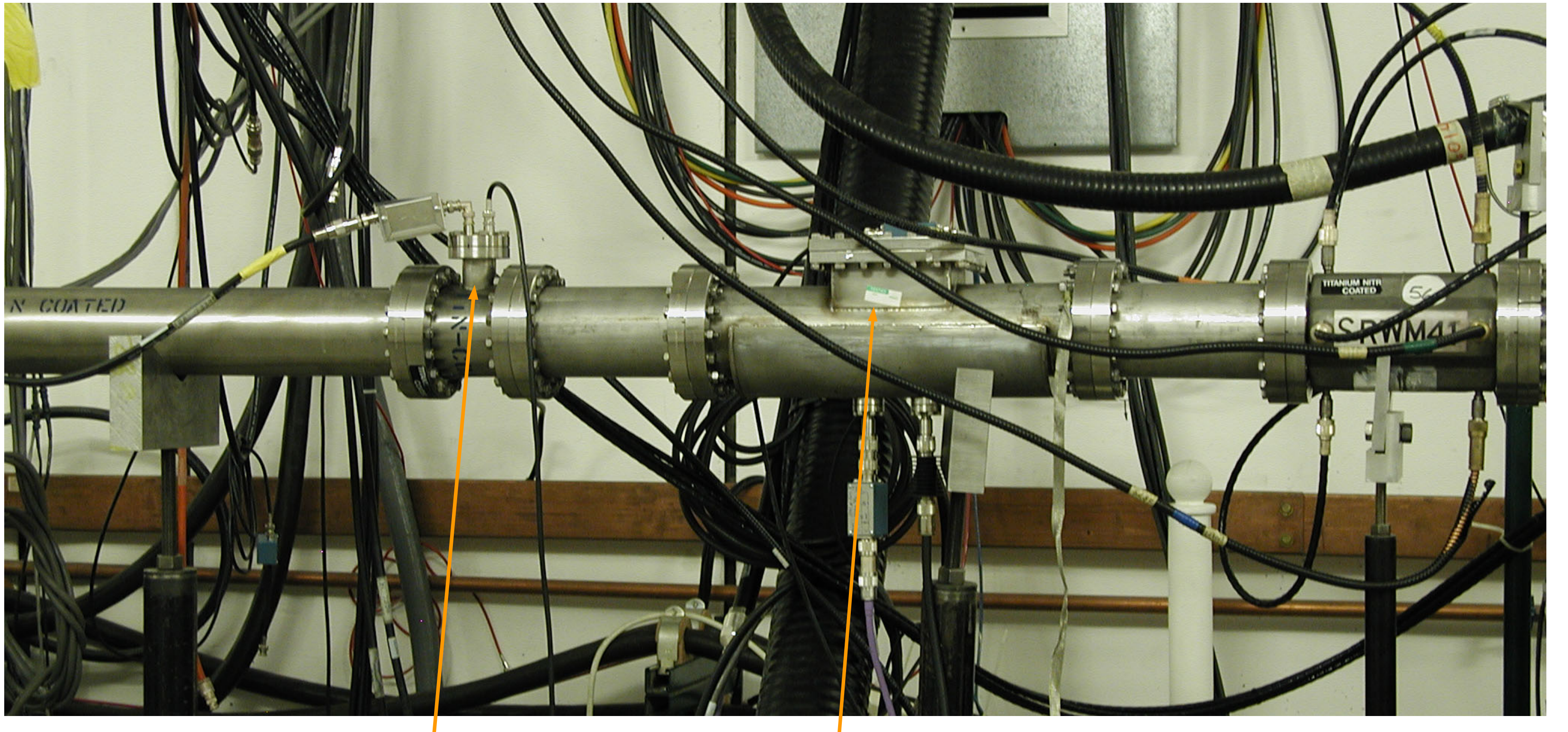


- RFA electron signal is very similar to signals in the ring wrt e-flux, time structure, energy spectra and dependence on beam intensity
- Of the two mechanisms considered, only trailing edge multipactor can produce the signals observed in this experiment

Electron-sweeping Detector Layout

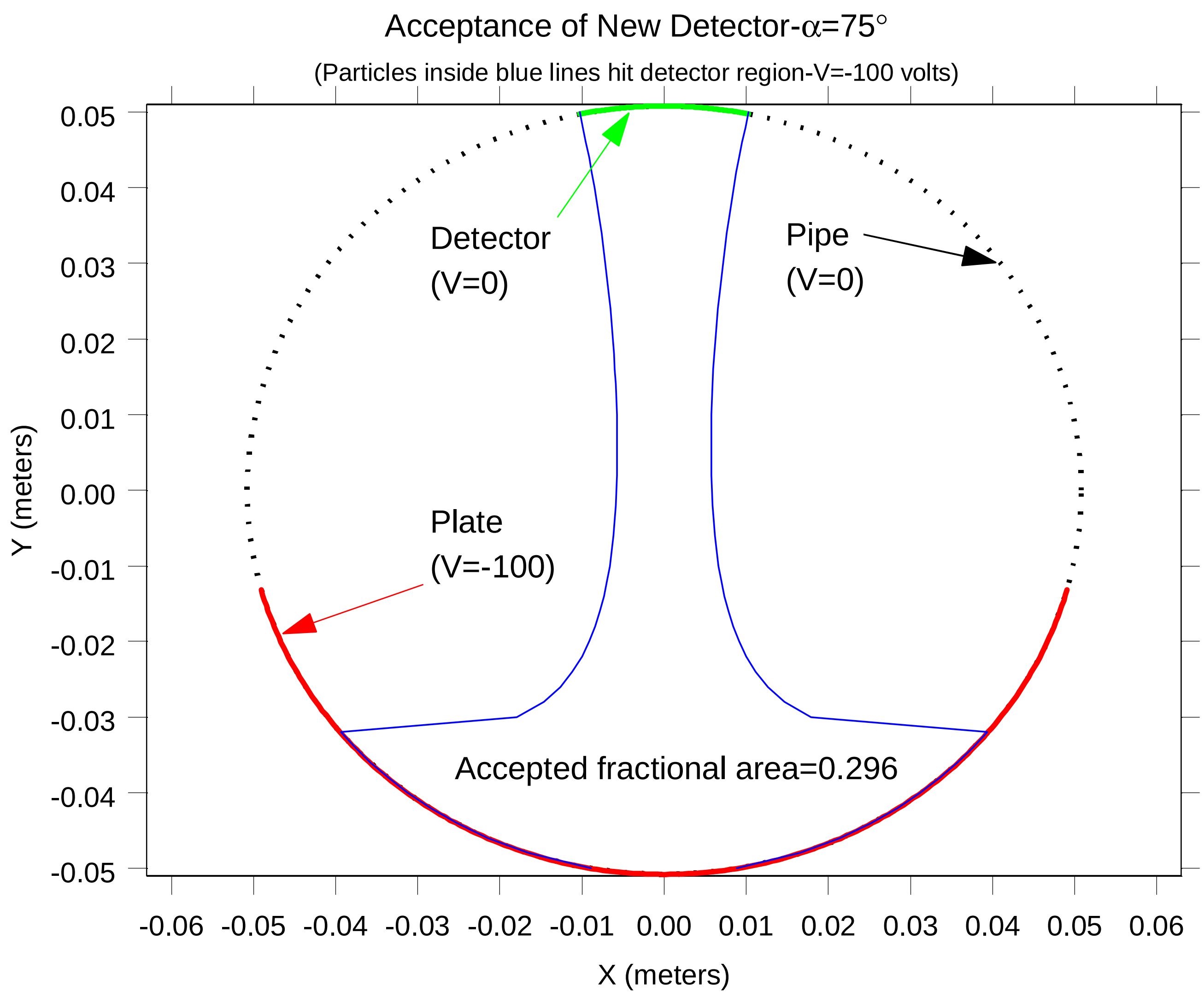


Picture of installed electron sweeper



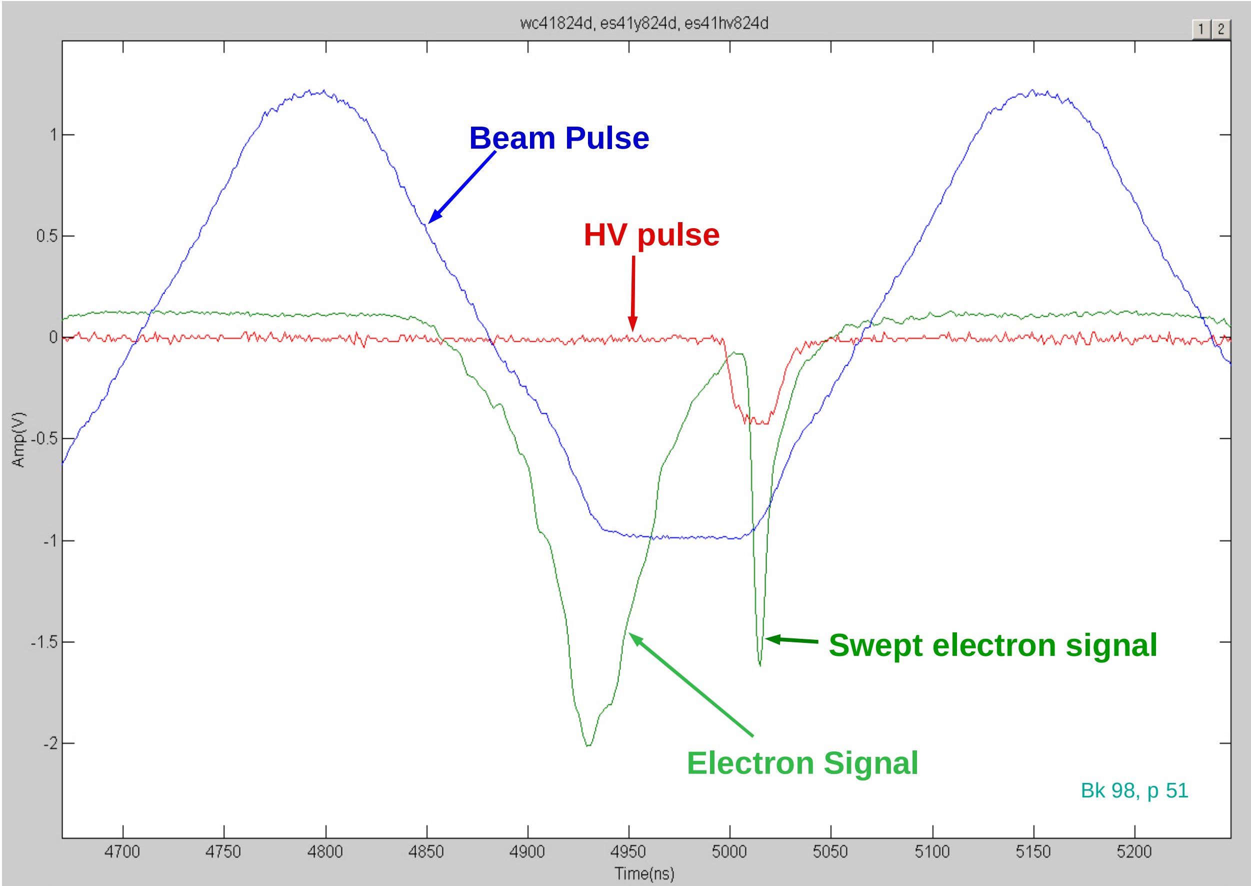
ED42Y **E-sweeper, ES41Y**

Electron Sweeper Collection Region



Sample Electron Data from Electron Sweeper

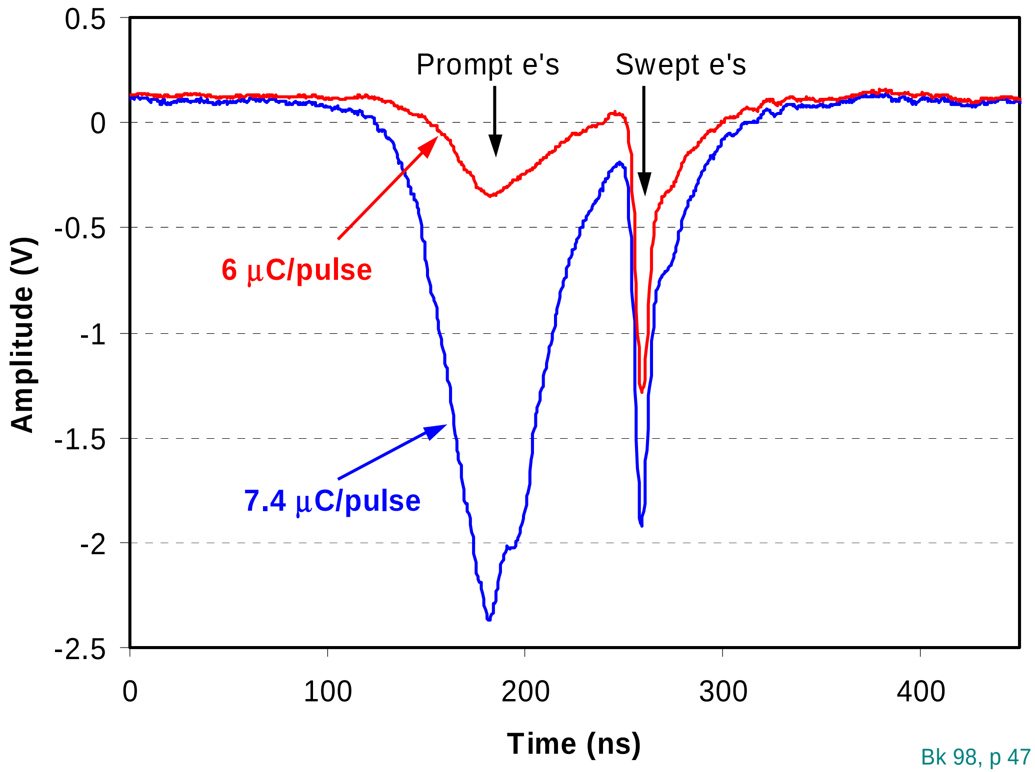
- **Signals have been timed correctly to the beam pulse (wall current monitor)**
- **"Prompt" electrons strike the wall peak at the end of the beam pulse; basically acts a large area RFA until HV pulse applied**
- **Note ~10 ns transit time delay between HV pulse and swept electron signal is expected**
- **Swept electron signal is narrow (~10 ns) with a tail that is not completely understood**
  - **May be due to secondaries created at ground screen, walls of slots and repeller screen**
  - **Reduced by higher repeller voltage**



7.7 µC/pulse, bunch length = 280 ns, 30 ns injection notch, signals averaged for 32 macropulses, repeller = - 25V, HV pulse = 500V

“Prompt” and “Swept” Electrons at Two Intensities

- **“prompt” electrons strike the wall at the end of the beam bunch**
- **Signals taken at last pulse in the ring**
- **Swept electron signal taken at 50 ns after end of beam pulse**
- **Note the strong dependence of prompt signal on intensity (~ I^7) while swept electron signal scales ~ with intensity**
  - **At larger delays swept e signals are nearly the same size**
  - **Implies that e’s surviving the gap scale ~ with intensity or fractional neutralization is ~ constant!**
- **Swept e signal amplitude implies ~10 pC/cm line density at end of gap or a lower limit on beam neutralization of ~ 1%**



Bk 98, p 47

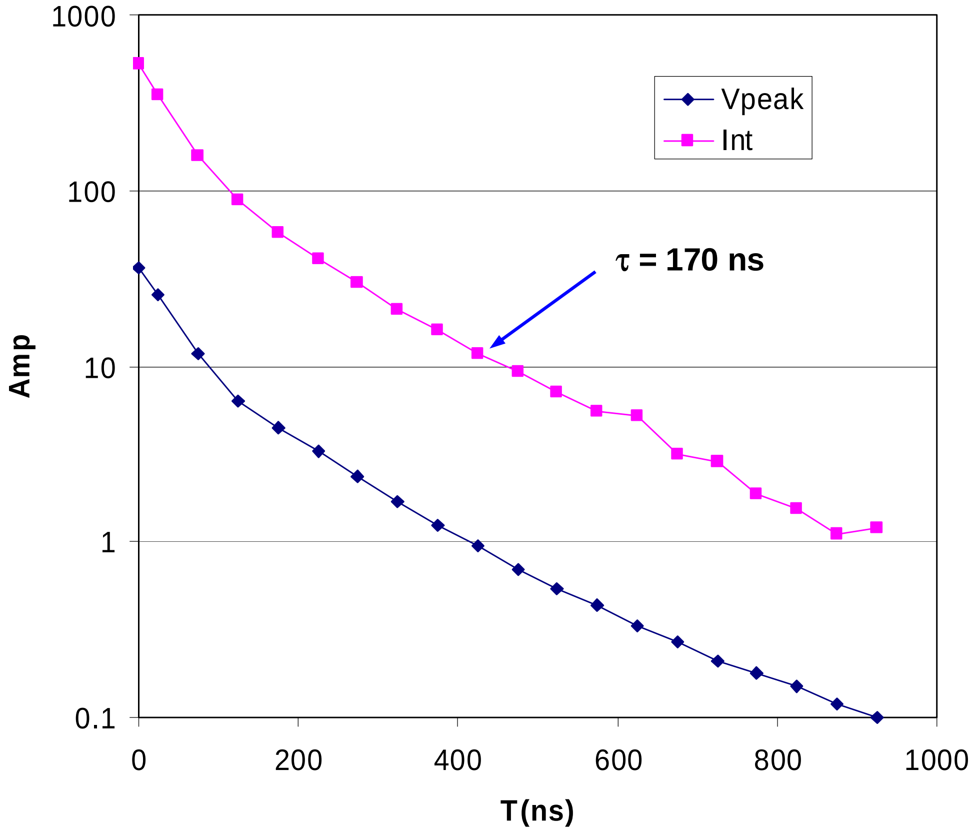
Signals averaged for 32 macropulses, bunch length = 280 ns
HV=500V, repeller = -25V, ES impedance 2.5 kΩ

Electron survival after end of beam pulse

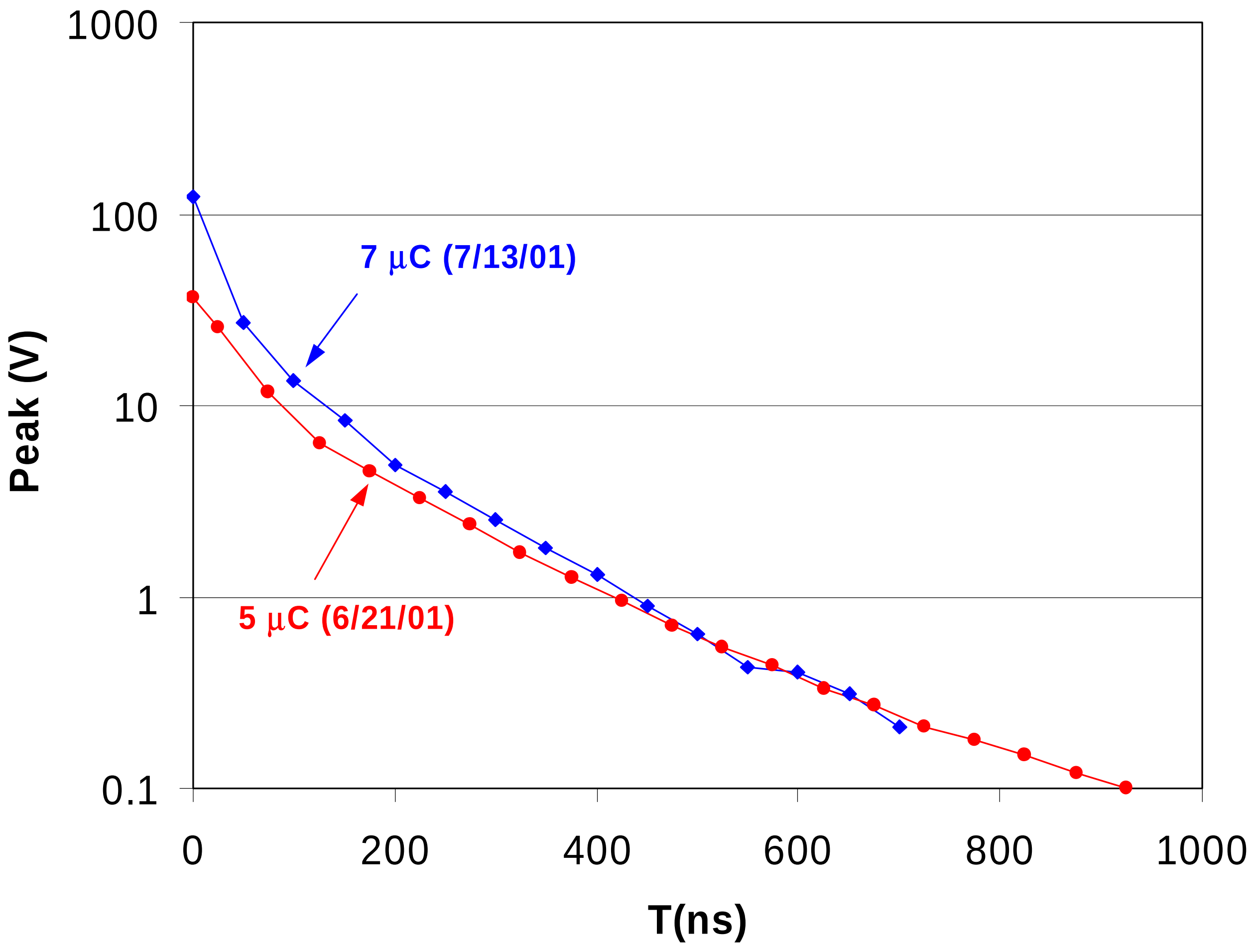
- **Early results from electron sweeper for 5μC/pulse looking just after extraction**
- **Peak signal or integral have essentially the same shape curve**
- **Long exponential tail seen with ~170 ns decay time**
- **Still see electrons after 1 μs**
- **Implies a high secondary yield (reflectivity) for low energy electrons (2-5 eV)**

$$\delta_{\mathbf{eff}} = \exp\left[-\frac{\mathbf{d}}{\mathbf{c}\cdot\tau}\cdot\sqrt{\frac{\mathbf{m_e}\cdot\mathbf{c}^2}{2\mathbf{E}}}\right] \approx 0.5$$

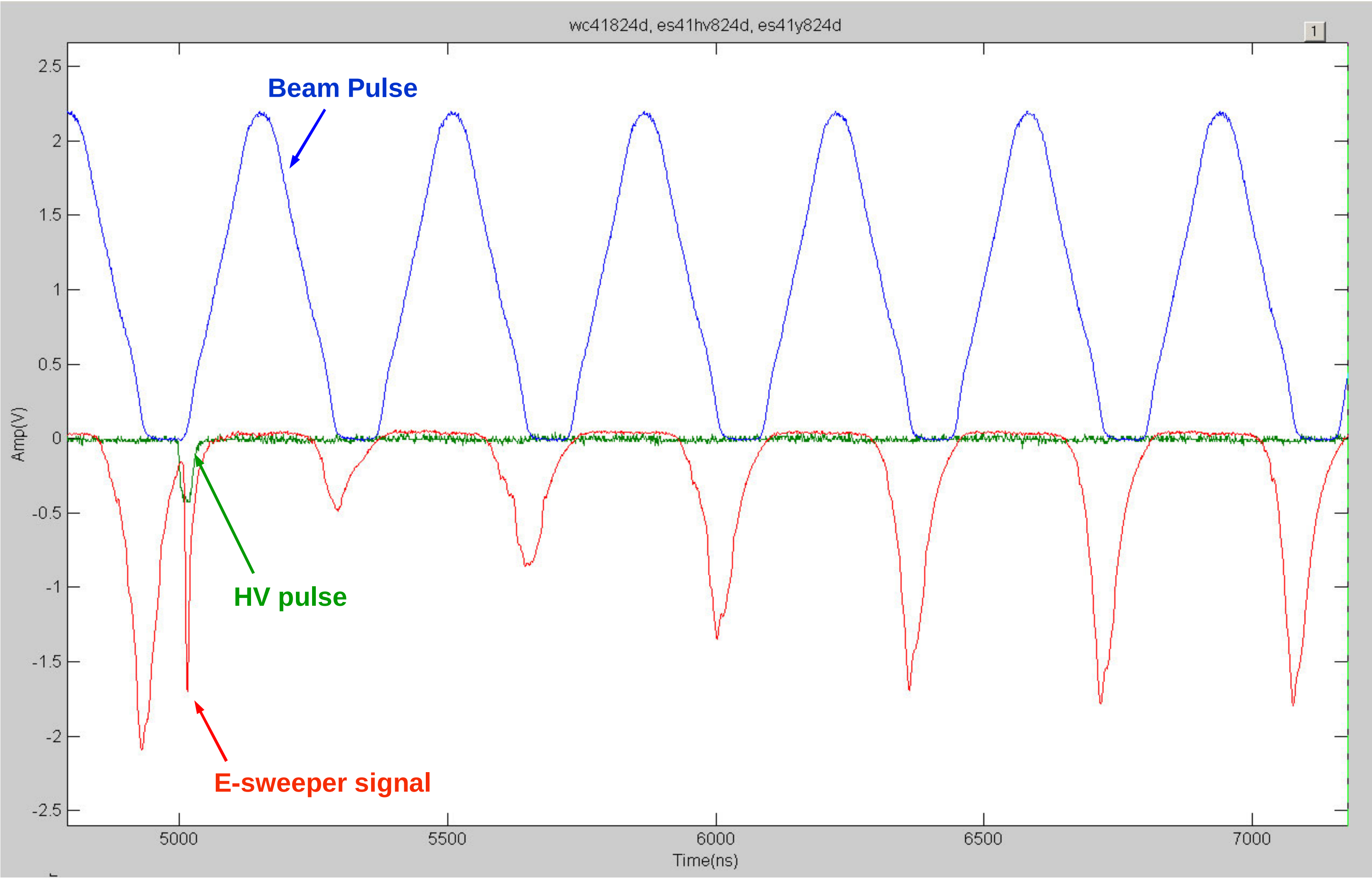
- **Implies neutralization lower limit of ~1.5% based on swept electron signal at the end of the ~100ns gap**



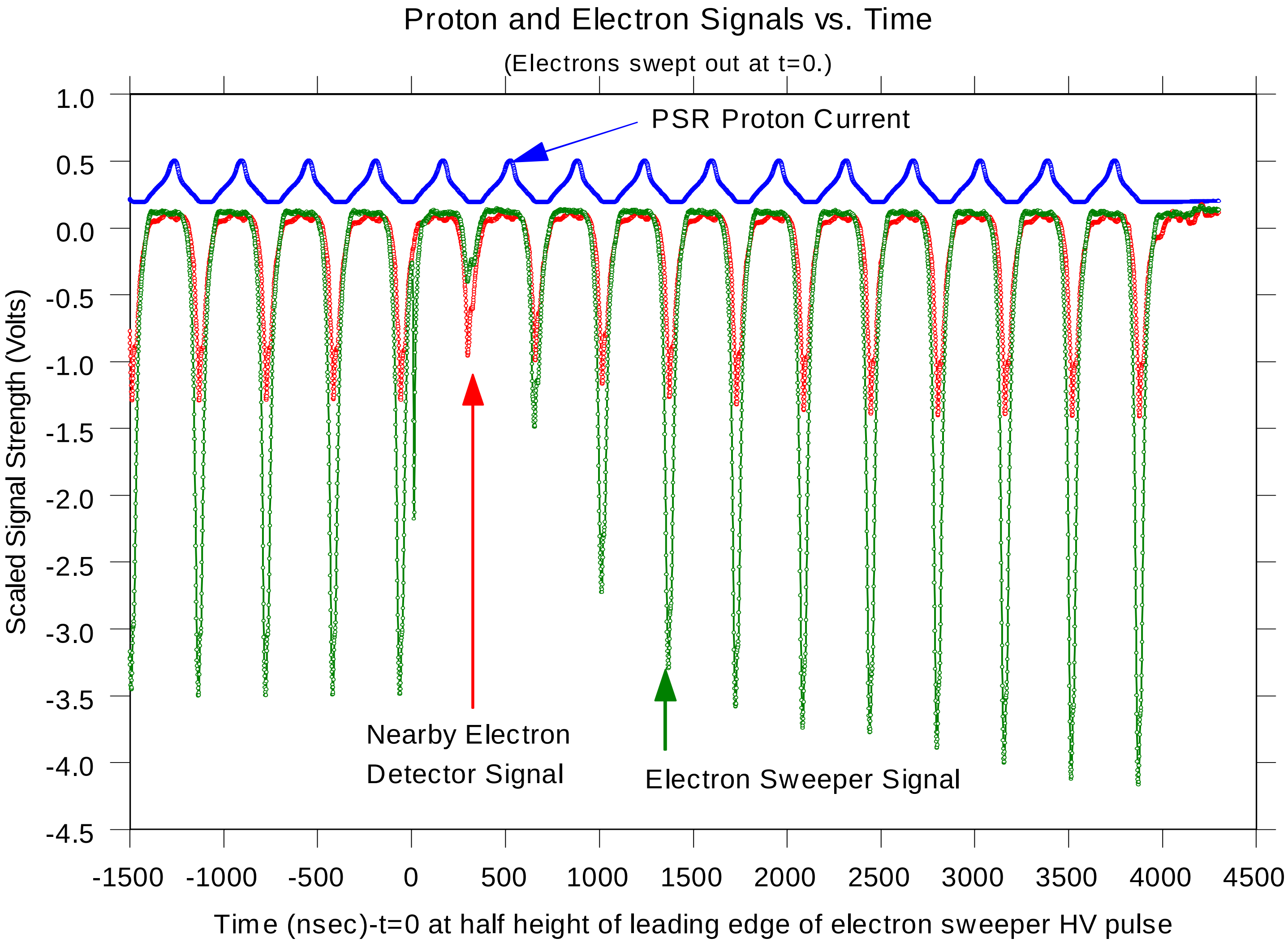
Comparison of electron survival curve for two intensities



Recovery after locally clearing gap of electrons



Correlations in Recovery



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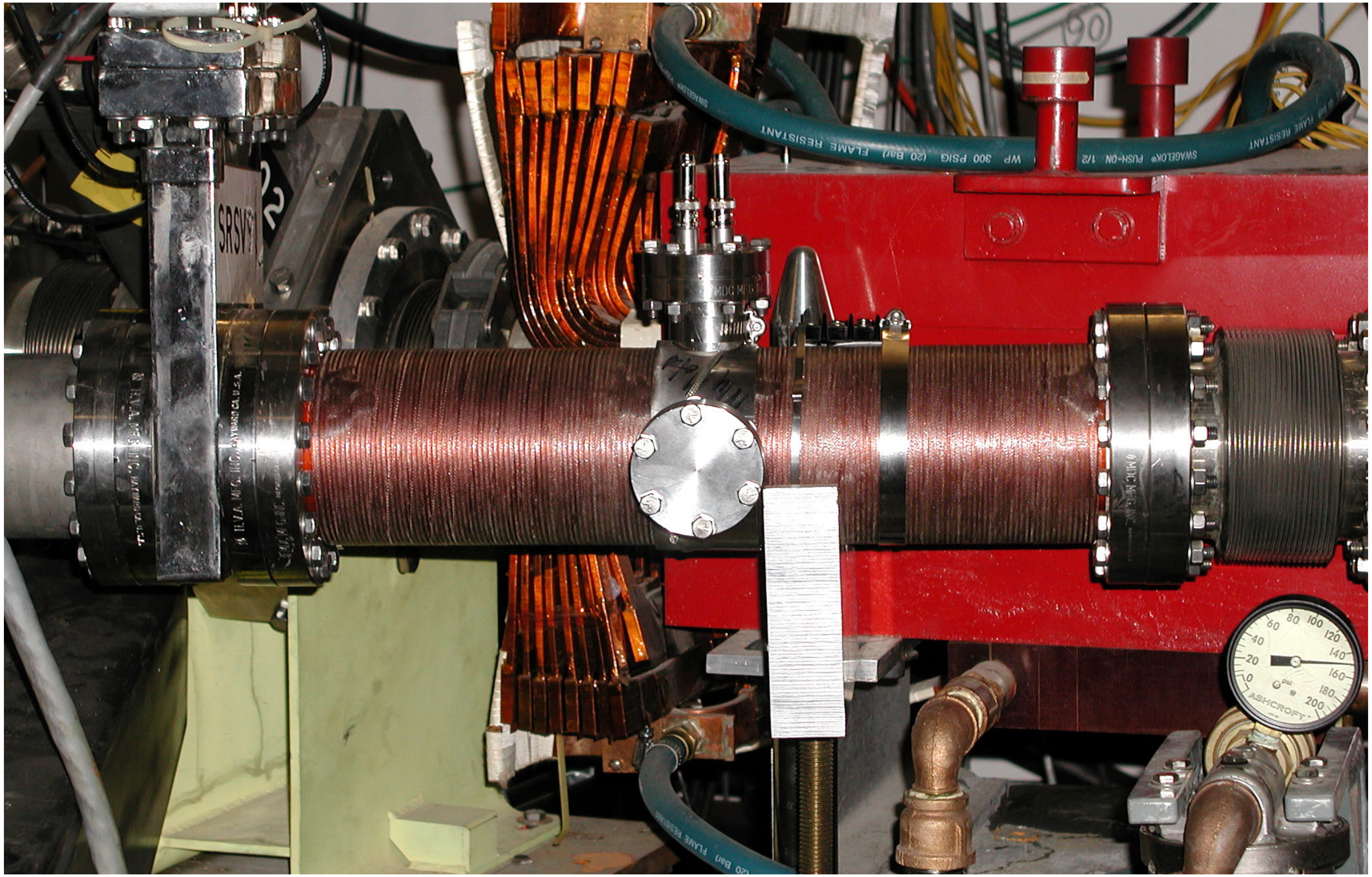
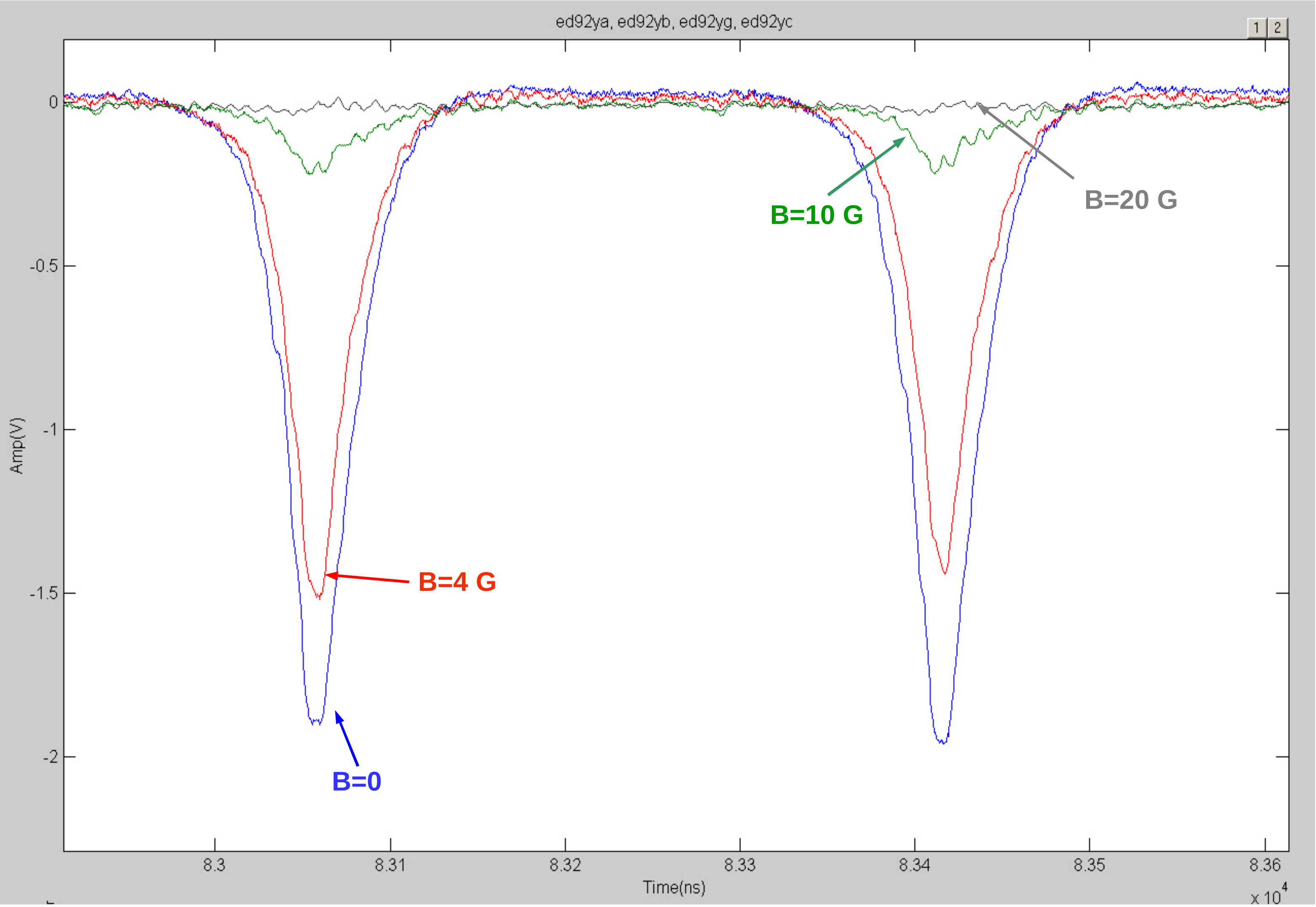
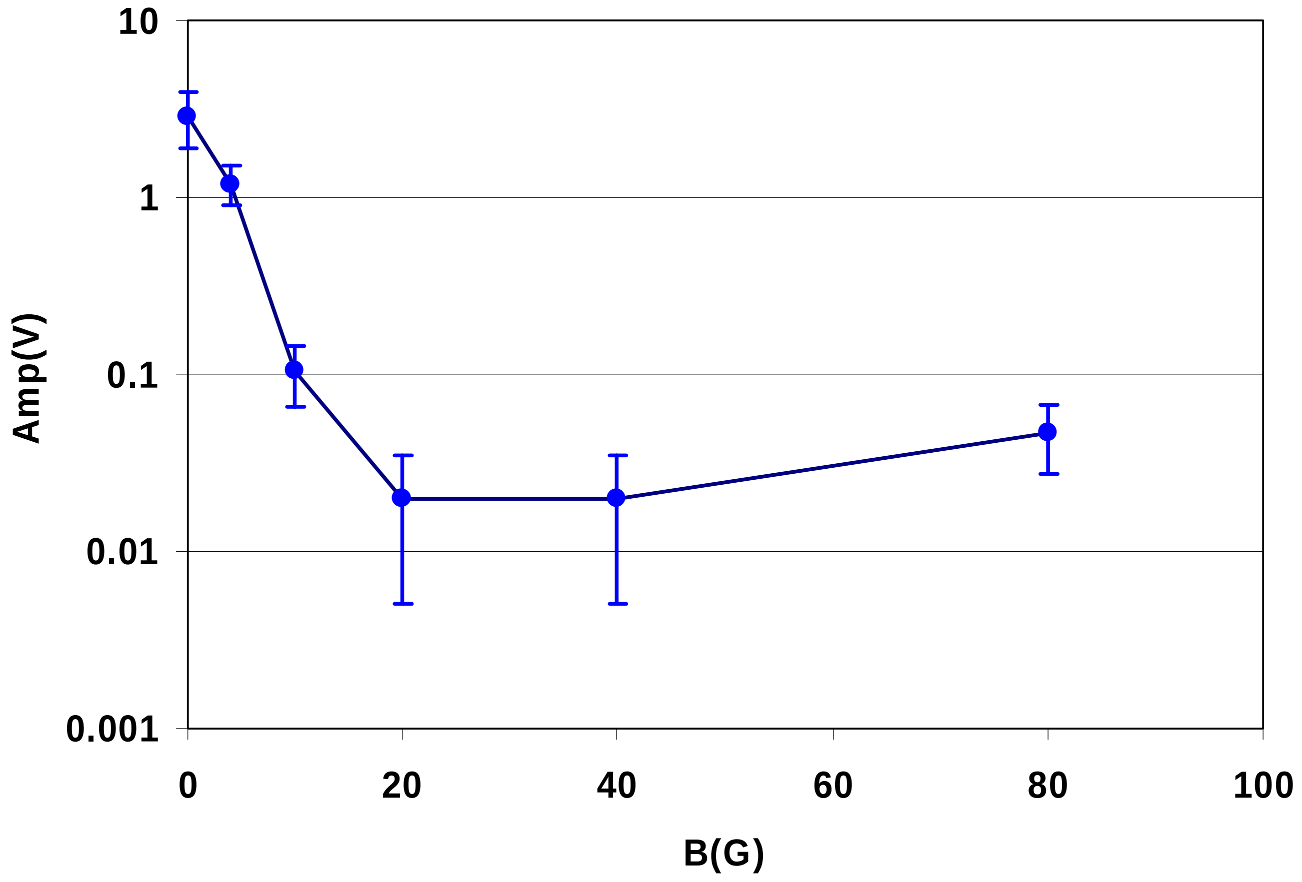
Picture of Solenoid Section with RFA



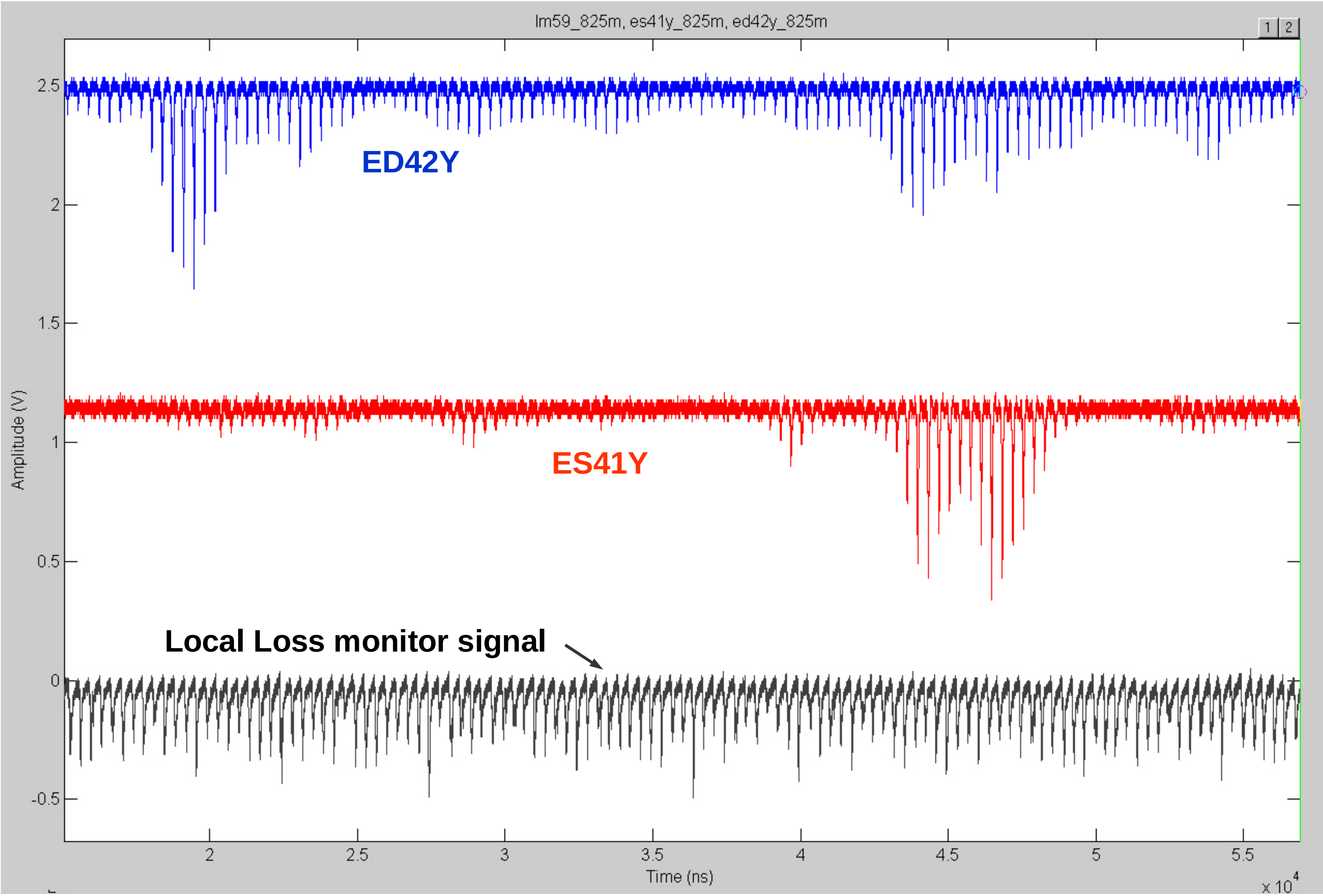
RFA Signals in a Weak Solenoid Field



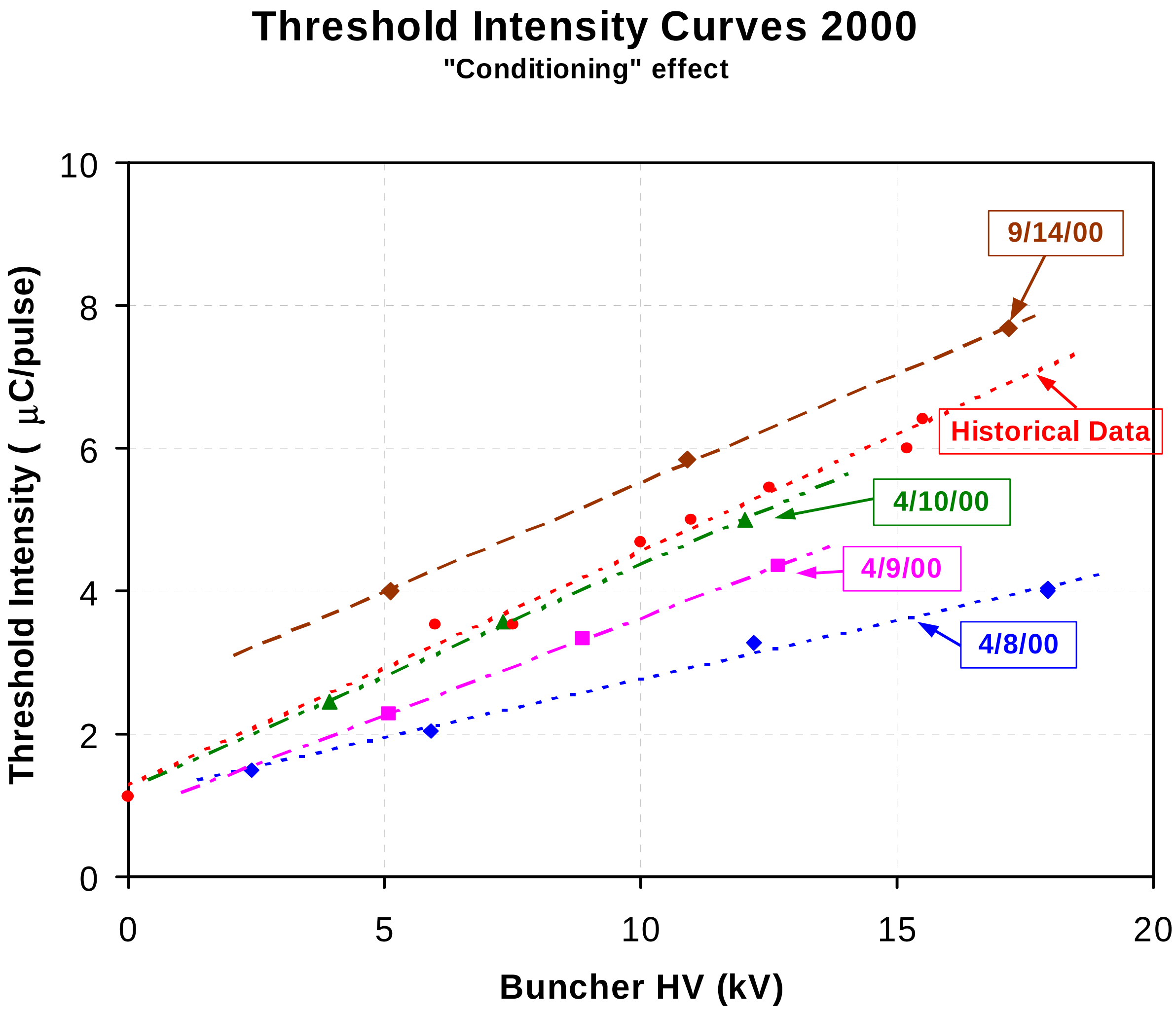
Effect of Solenoid on RFA Signal Amplitude



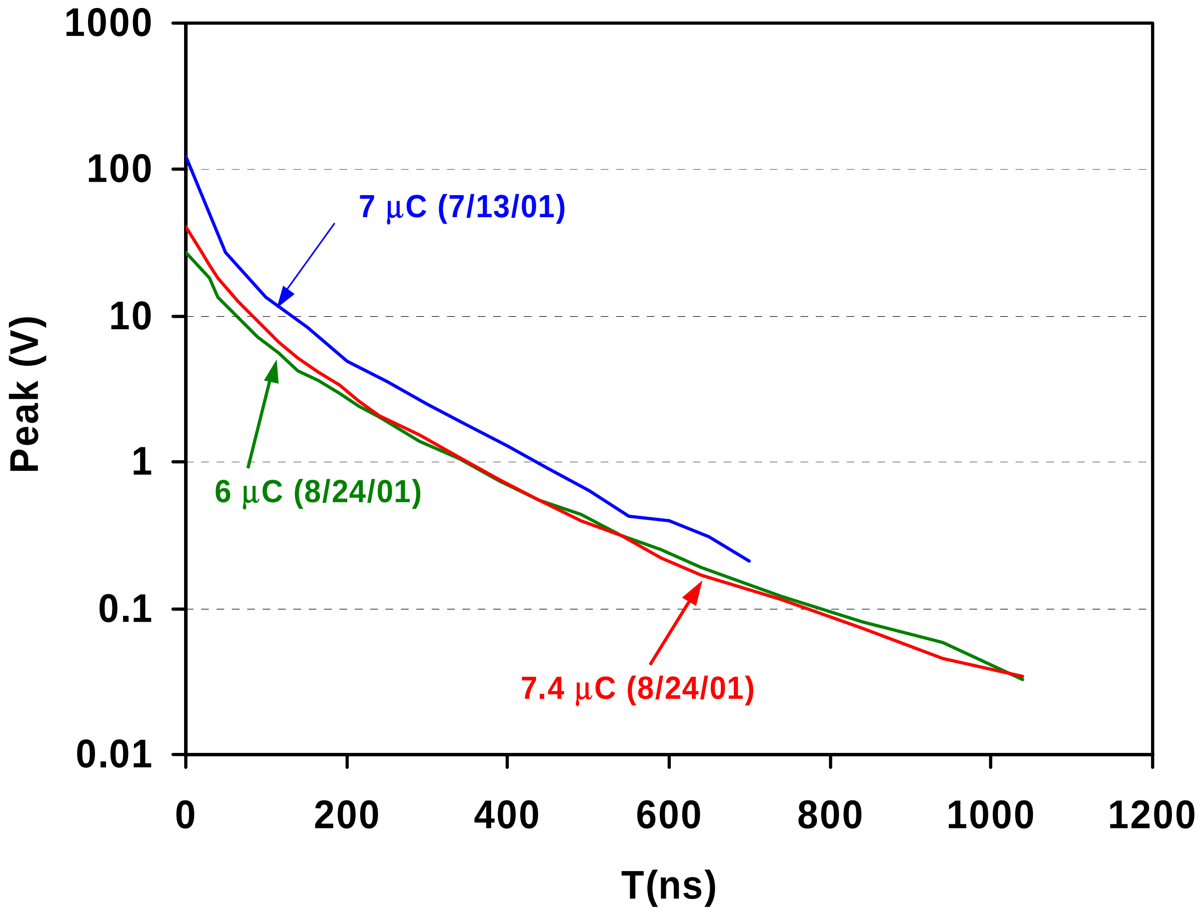
“Electron burst” phenomenon



Conditioning effect



Conditioning effect in swept e's?



Data at 100 ns delay show factor of ~1.7 reduction in electrons surviving the gap over a period of 40 days

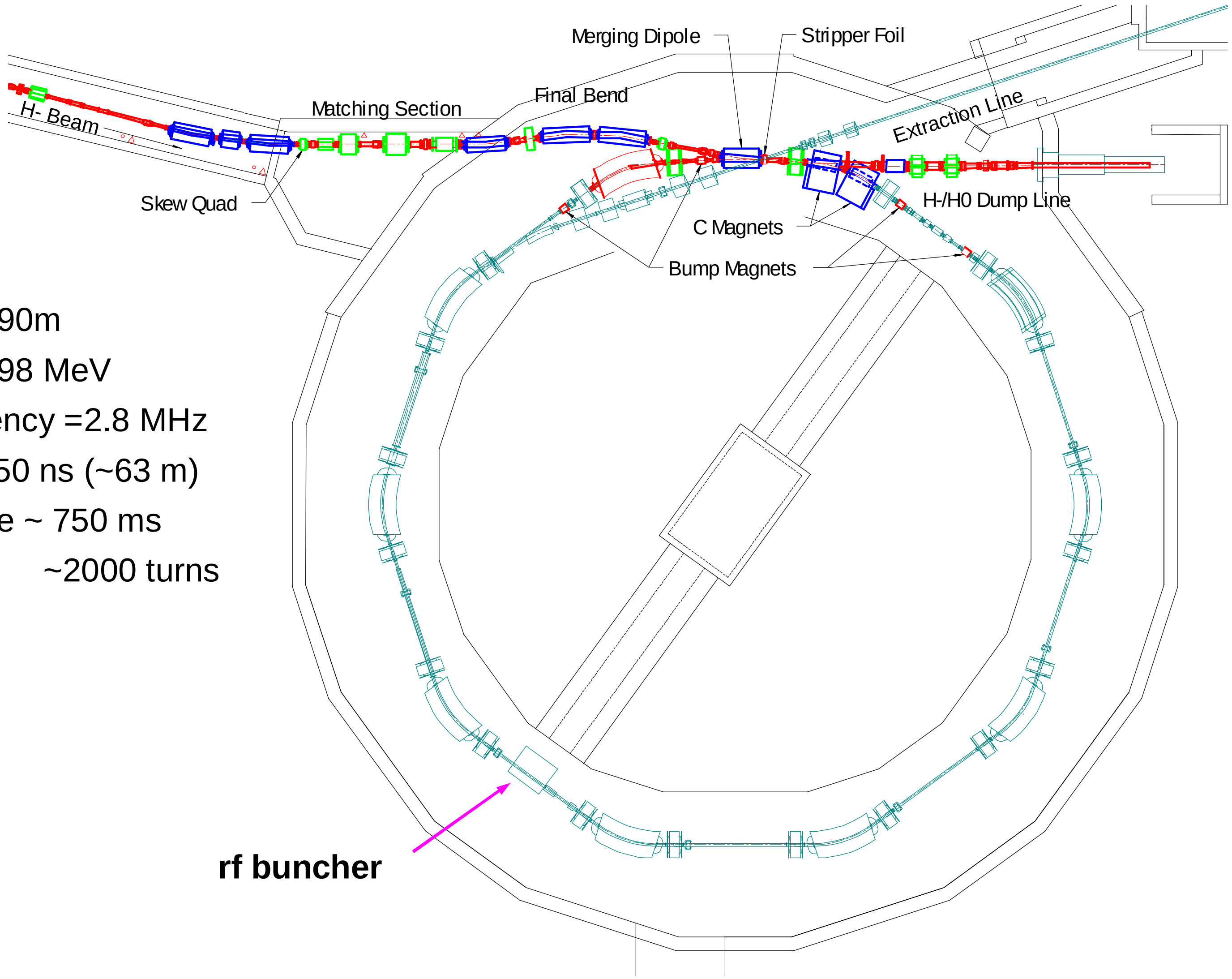
Summary and Conclusions

- Fast timing information from both the RFA and electron sweeper has been a valuable tool in understanding the electron cloud in PSR
- The electron sweeping detector works about as excepted and has provided several important results
  - Electrons decay slowly (~170 ns time constant) after the end of beam pulse implying a high total secondary yield (~0.5) for low energy (2-5 eV) electrons
  - Recovery after clearing the gap of electrons takes several turns and shows that multi-turn accumulation makes a sizeable contribution to electrons striking the wall
  - Electrons surviving the gap are not nearly as dependent on beam intensity as the "prompt" electrons striking the wall at the end of the beam pulse
  - Data on electrons surviving the gap implies a roughly constant fractional neutralization of ~1-1.5% (lower bound), which is more in keeping with observed threshold behavior of the e-p instability
- The relationship between "prompt" electrons striking the wall and those surviving the gap is not completely understood
- The electron burst phenomenon is an unresolved puzzle at this time
- A weak solenoid (~20 Gauss) attenuates the electrons striking the wall (RFA signal) by a factor of ~20 or more
- Open issue: Will electron suppression by TiN coatings of all vacuum surfaces and/or solenoids cure the instability?

Future Plans

- **Exploit electron sweeping detector to study factors that affect electrons surviving the gap and presumably the beam neutralization**
  - Can we explain why the instability threshold is not sensitive to losses and vacuum pressure when it clearly affects the electrons striking the wall? i.e., is the fractional neutralization insensitive to beam losses and vacuum pressure?
  - Install an electron sweeper coated with TiN and measure electrons surviving the gap in coated section
  - Measure effect of bellows, ceramic breaks, and TiN coating on both "prompt" electrons and those surviving the gap
  - Measure the electrons surviving the gap when small amounts of beam are introduced in the gap
- **Try to discover the cause(s) of the electron "burst" phenomenon**
- **Attempt to observe coherent transverse motion of electron cloud during unstable beam motion**
- **Use a combination of TiN coatings and solenoid windings to suppress electrons in a significant fraction of the ring in an attempt to raise the instability threshold**

PSR Layout



Circumference = 90m

Beam energy = 798 MeV

Revolution frequency =2.8 MHz

Bunch length ~ 250 ns (~63 m)

Accumulation time ~ 750 ms

~2000 turns

rf buncher