Status Report on Experimental Studies of ECE at PSR*

Robert Macek and PSR Development Team, LANL, 4/19/04

Co-authors

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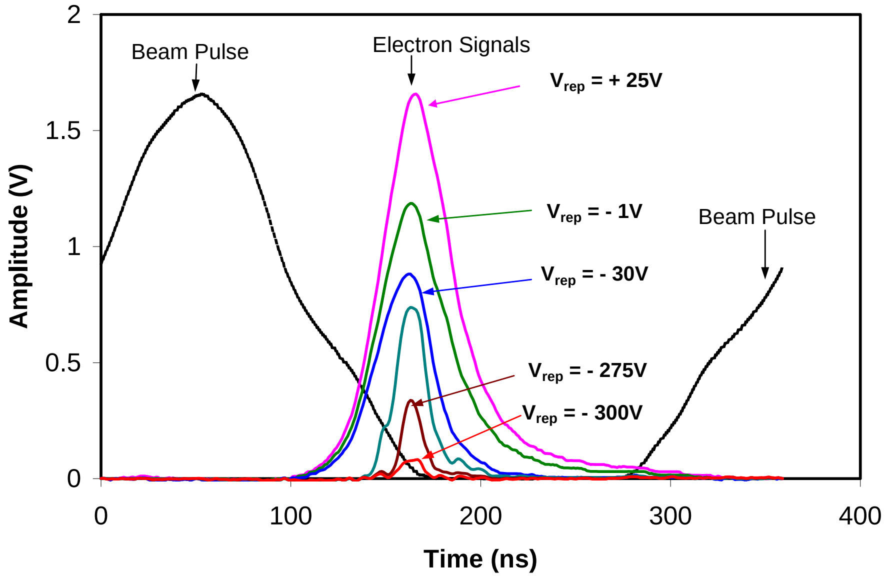
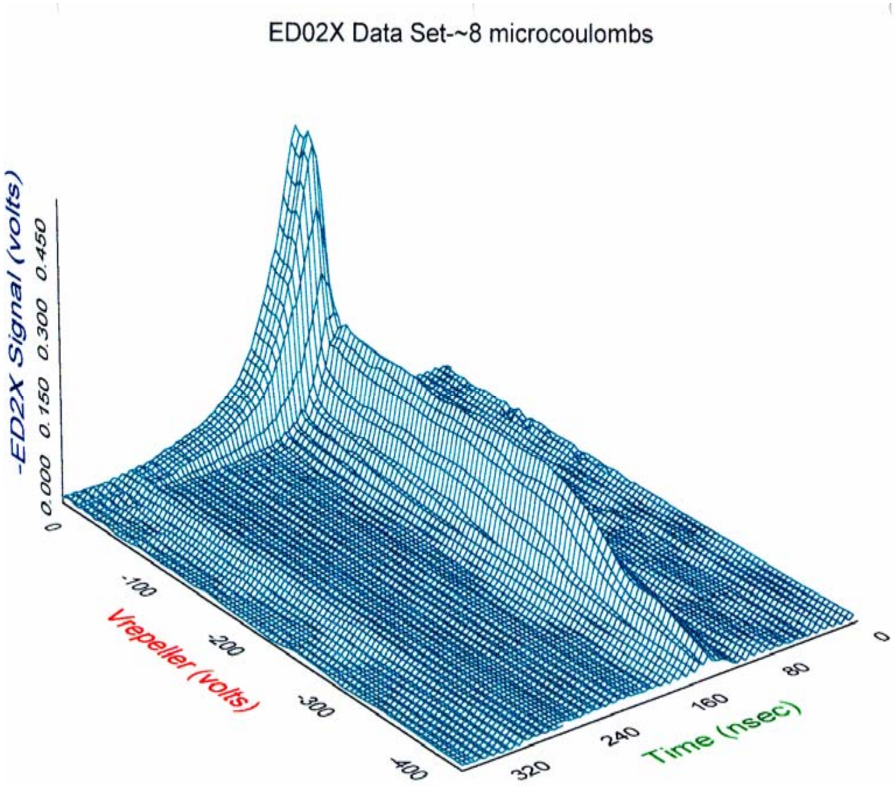
Outline

- **Introduction: Short summary of electron cloud effects (ECE) at PSR**
  - **Trailing edge multipactor & electrons surviving the gap**
  - **The two-stream e-p instability characteristics are approximately explained in centroid models, given the # of electrons surviving the gap**
  - **For more information, see a recent comprehensive set of talks (3/15-18, e-p feedback collaboration meeting) on the MAP website: http://physics.indiana.edu/~shylee/ap/mwapc/ and PRSTAB special edition – Two-stream SC**
- **Ongoing issues and results of recent studies**
  - **Focus for past 2-3 years has been on electron cloud buildup issues**
  - **Parametric studies of e-cloud signals**
  - **Studies of the source strength of the important source(s) of "seed" electrons, which is a crucial input to simulations**
  - **Mixed results on electron suppression by TiN**
  - **Some unresolved issues under study**
    - Electron "burst" phenomenon
    - Recovery of "prompt" electron signal (multipactor) following sweeping the gap
    - 1st pulse instability
    - Beam response to weak kick
- **Proposal for future work**
  - **Electrons produced and captured in quadrupoles**

Electron signals from RFA in straight section

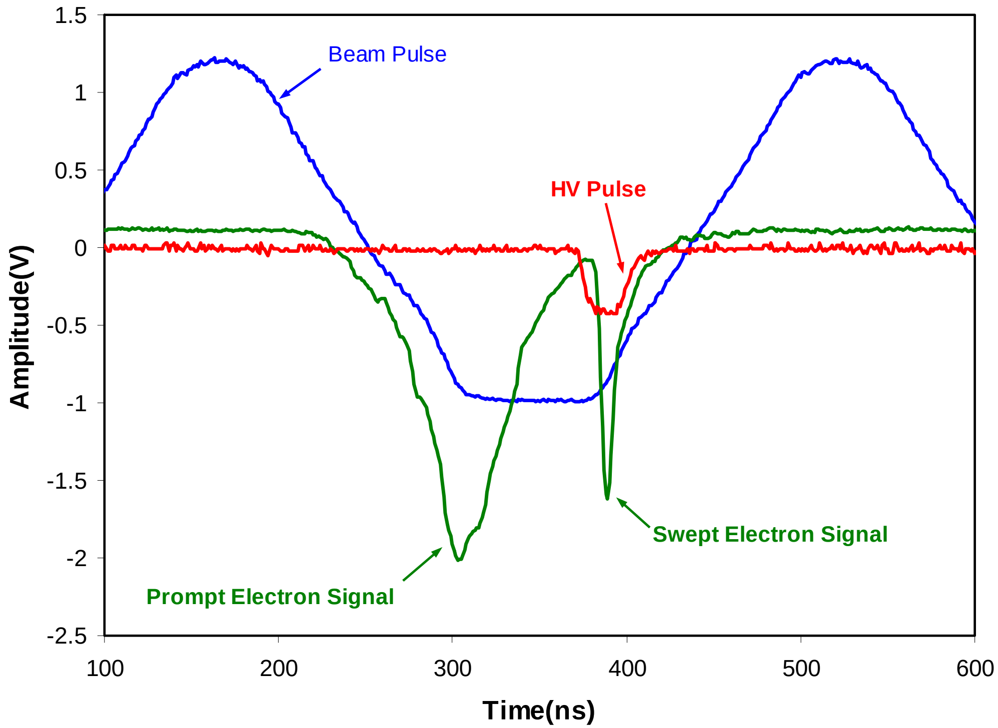




Signals averaged for 32 beam macropulses,
~ 8 μC/pulse beam intensity,
Device is labeled ED42Y,
Transimpedance = 3.5 kΩ, opening ~1 cm^2

Sample Electron Data from Electron Sweeper

- **Signals have been timed correctly to the beam pulse**
- **Device basically acts a large area RFA until HV pulse applied**
- **"Prompt" electrons strike the wall and peak at the end of the beam pulse. Contributions from:**
  - **Trailing edge multipactor**
  - **Captured electrons released at end of beam pulse**
- **"Swept" electron signal is a narrow (~10 ns) pulse collected from ~30% of the cross-sectional area of the pipe**
- **~10 ns transit time delay between HV pulse and swept electron signal is expected**



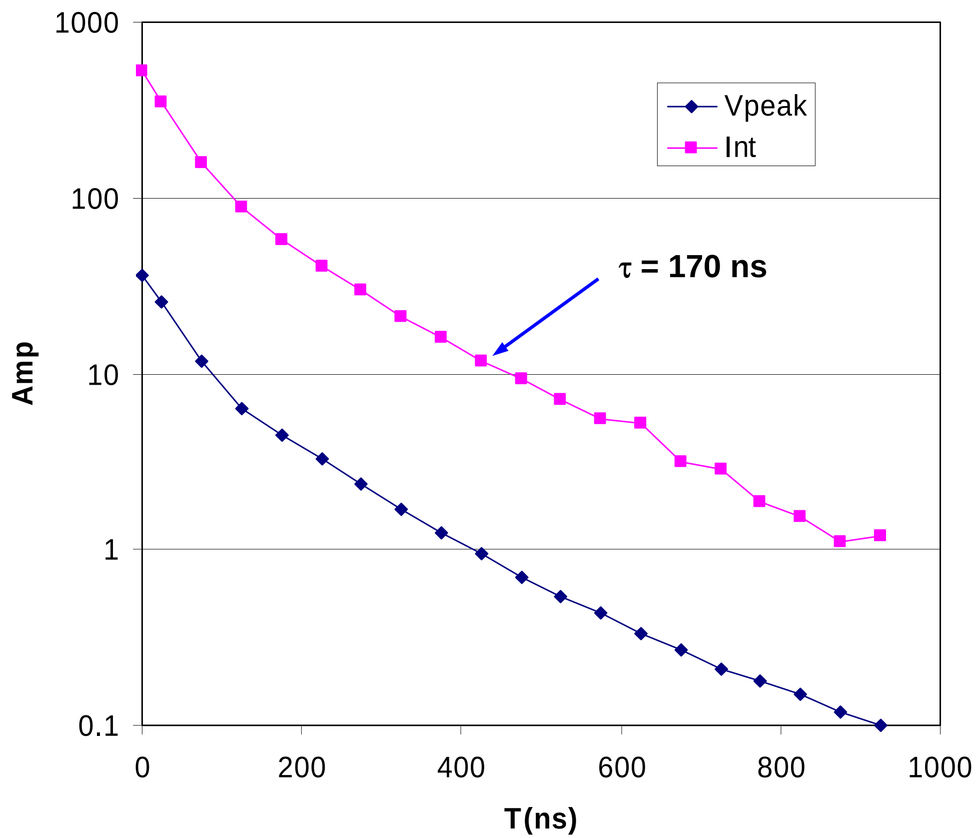
7.7 μC/pulse, bunch length = 280 ns, 30 ns injection notch, signals averaged for 32 macropulses, repeller = - 25V, HV pulse = 500V

Electron cloud survival (dissipation) curves
(Swept electrons in pipe vs time after end of beam pulse)

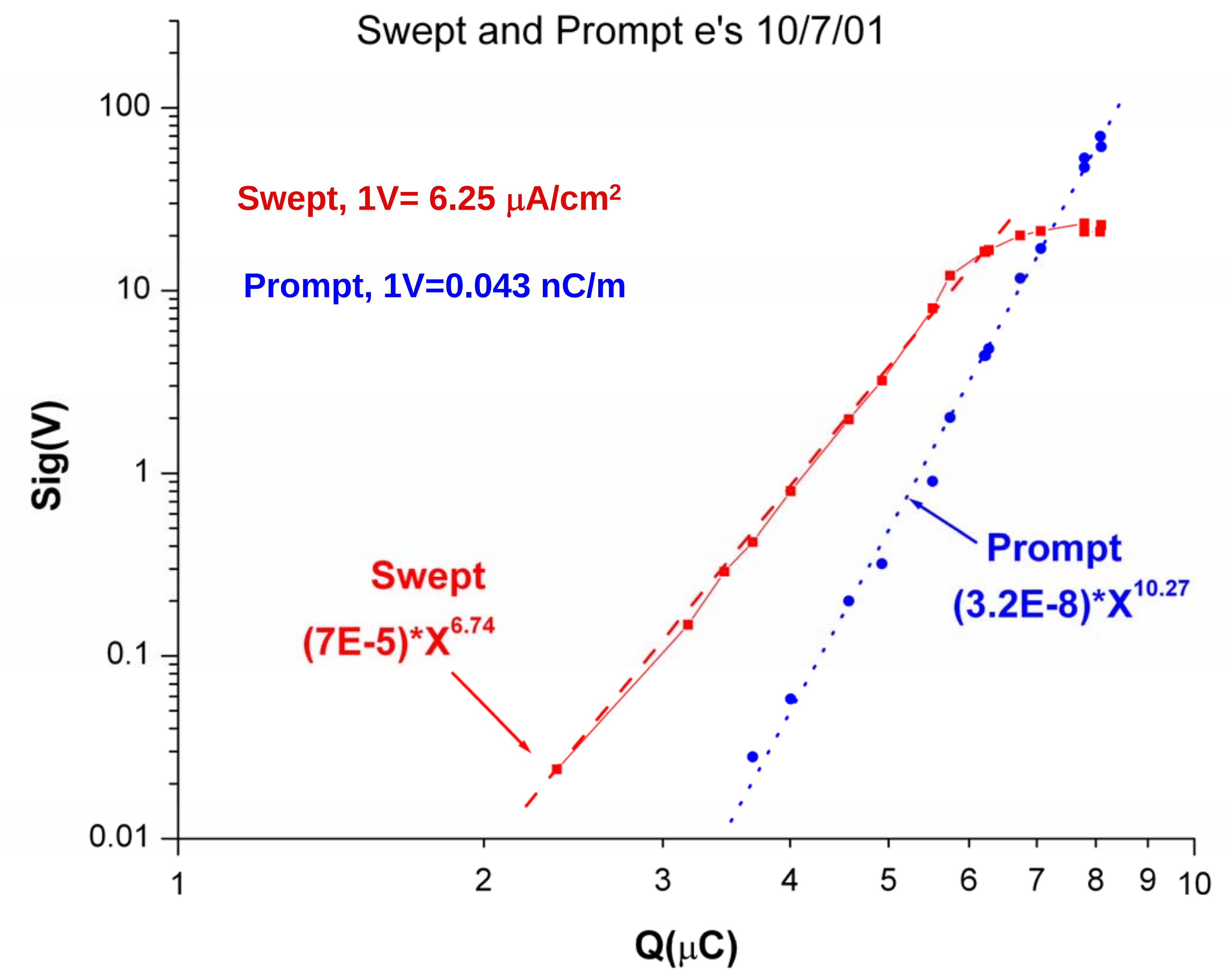
- **Early results from electron sweeper for 5μC/pulse looking just after extraction**
- **Peak signal or integral have essentially the same shape curve**
- **Long, approximately exponential tail seen with ~170 ns decay time**
- **Still see electrons after 1 μs**
- **Implies a high secondary yield (reflectivity) 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% based on swept electron signal at the end of the ~100ns gap**
- **Decay time is insensitive to several parameter variations i.e., beam intensity, TiN, beam scrubbing, and location**



Prompt and Swept Electrons (ES41Y) vs Beam Intensity



List of parametric studies on e-cloud at PSR

- **Signal of trailing edge multipacting measured in retarding field analyzers (RFA) in drift spaces and studied as functions of:**
  - **Beam intensity, bunch shape, transverse beam profile, beam scrubbing, beam losses, vacuum pressure, several locations in the ring and in the extraction line, TiN coatings, and weak solenoidal magnetic fields (all for stable beams)**
  - **Cumulative energy spectra from RFA have been measured as a function of intensity, location in the ring, beam scrubbing, and TiN coatings**
  - **Also some observations in presence of sub-threshold coherent motion as well as some for unstable beams**
- **Studies of electrons surviving the gap between bunch passages and electron survival curves in beam-free and field-free regions**
  - **Measured with electron sweeping diagnostic and studied as functions of:**
    - Intensity, beam scrubbing, TiN coatings, at two locations (ring and extraction line)
  - **No appreciable change in decay time observed for any of these variations**

Summary results from parameter variations

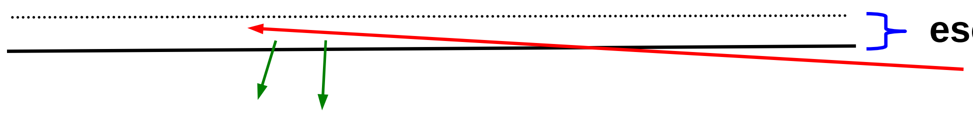
Variable	Effect on Prompt signal	Other notes
Beam Intensity	Strong effect ~ I^n	n = 2 – 10, depending on location and conditioning
Bunch long. shape	Significant effect	Changed bunch shape in several ways
Transverse shape	Strong effect	e's largest in direction of major axis
Beam Scrubbing	Significant effect	Factor ~5 reduction over several months of ops (2002)
Beam losses & ring vacuum	Linear in both	(See graphs later in talk)
Location in ring	significant	Related to losses, beam transverse shape, vacuum and seed electrons from foil
TiN	Mixed results	
Weak solenoid field	Strong reduction	Factor of ~ 50 reduction at ~20 G

Comparisons with simulations

- Some simulations of e-cloud build up in PSR have been carried out (Furman, Pivi, Blaskiewicz, L. Wang) that can be compared directly with PSR data
  - Primarily one intensity: ~$5x10^{13}$ protons/pulse (8 μC/pulse)
  - Simulated RFA signals in drift spaces
  - Cumulative energy spectra
  - Electron survival curve (in beam-free drift spaces)
  - Effect of elliptical transverse beam profile
- Reasonable agreement with experiments given uncertainties of key input parameters (# of seed electrons, δ_{max})
- L. Wang has been undertaking simulations of effect of certain parameter variations that might be compared with PSR data
  - Intensity
  - Beam transverse profile and longitudinal bunch shape
  - Chamber size
  - Weak magnetic solenoid field
- We have much data on numerous parameter variations that could be used for more extensive benchmarking of codes

Sources of initial electrons for PSR

- **Crucial input for simulations of what we can measure at PSR**
- **Assumption that intial e's are from grazing angle losses, uniformly distributed around the ring with 100 e/lost proton is not accurate enough for detailed simulations of PSR experiments**
  - **The ~100e/proton comes from model by Sternglass for grazing angle (cos θ <0.002) scrapping at a surface and is supported by measurements of Thieberger etal**



escape zone ~ 1nm

e/proton ~ cos(θ)$^{-1}$

  - **Loss rates are not uniform, rate can vary by factor of ~ 1000 around the ring**
  - **Grazing angle losses occur mainly in the quads (~10% of circumference) and here it is mostly confined to those in the region of injection and extraction (~25% of the quads)**
  - **Only scattered beam reaches the regions where electron detectors are located (drift spaces). These strike the walls at 10's of mr.**
    - **e/scattered particle down factor 10 or more**
  - **We simply do not have detailed knowledge of the angular distribution of lost beam striking the walls**

Other problems with simplified model for seed electrons

- We consistently have seen more prompt electrons in section 4 than in sections 2 and 9 where losses were considerably higher

section	Ratio of e's to sect 4	Ratio of local losses to sect 4	Ratio of activation to sect 4
9	~1/3	~17	7 - 35
2	~1/2.5	~7	~ 2
1	~6	~55	~ 50

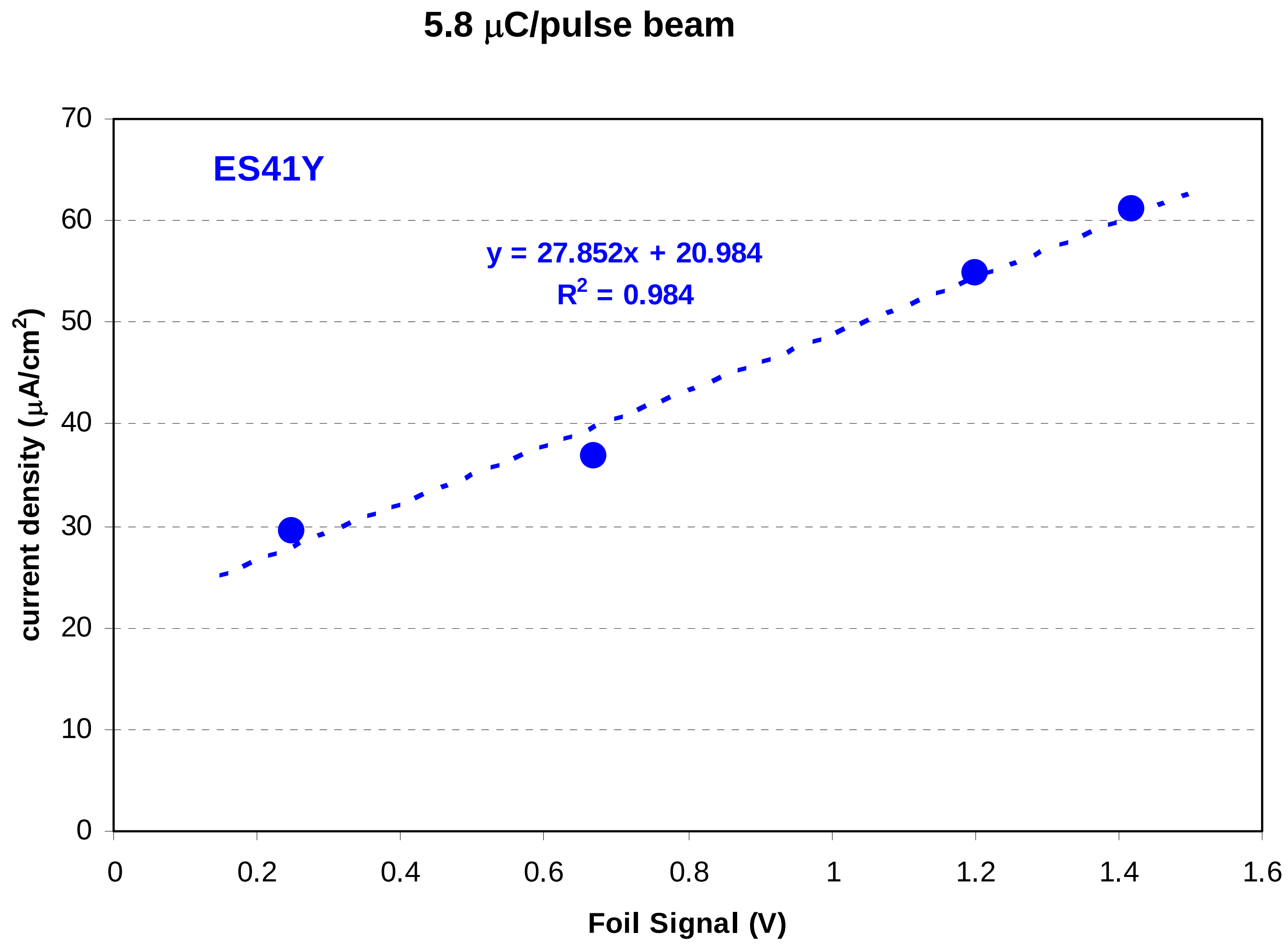
- What could be the explanation?
  - Local electron production does not track loss signal and activation very well
  - SEY is not measured for these regions
  - Beam pulse transverse profile can be somewhat different
  - Vacuum (section 4 was worse by ~ factor of 5-10, when these data were collected)

- Need detailed simulation and tracking of lost protons and their secondary products to determine seed electron production
- Electrons from residual gas ionization are often neglected as being few in number and born near the beam not at the walls

Experiments on effect of beam losses and vacuum

- **Changed beam losses two ways**
  - **Move stripper foil into the beam**
    - Changes amount of foil scattering but all other beam parameters fixed
    - Monitor foil current
  - **Introduce local closed orbit bumps, measure losses with local loss monitor (scintillator with ~ 10 ns resolution, if desired)**
  - **Find that prompt electron signal in RFA is linear in relative losses over considerable range**
- **Changed vacuum in several sections by turning off ion pumps**
  - **Find that prompt electron signal in RFA is linear over range of 10-1000 nTorr**
  - **Electrons surviving the gap unchanged at intensities studied**
- **Note that ions from residual gas ionization are driven to the wall in 1-3 turns and hit with ~ 2 keV. These can create secondaries electrons at the wall. Effect not in simulations.**

Effect of losses (moving foil into beam)



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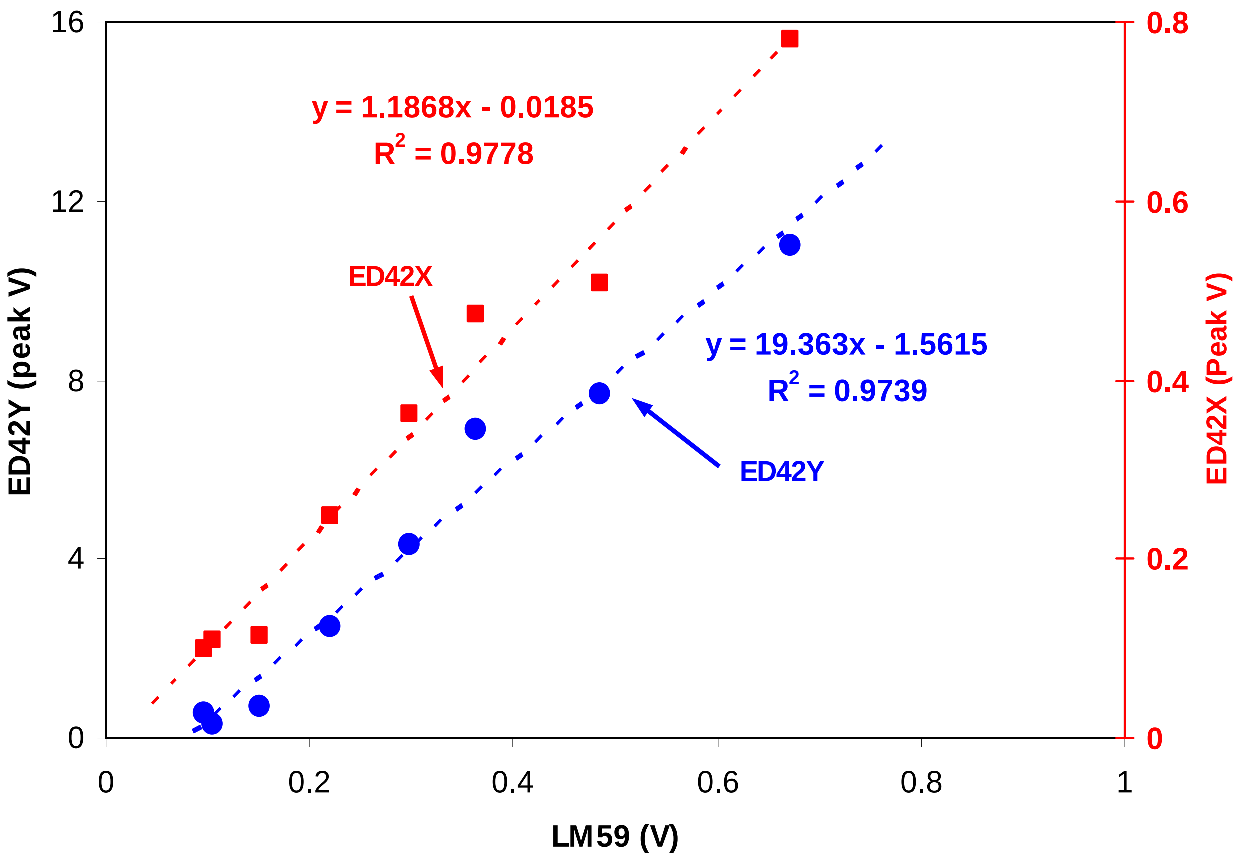
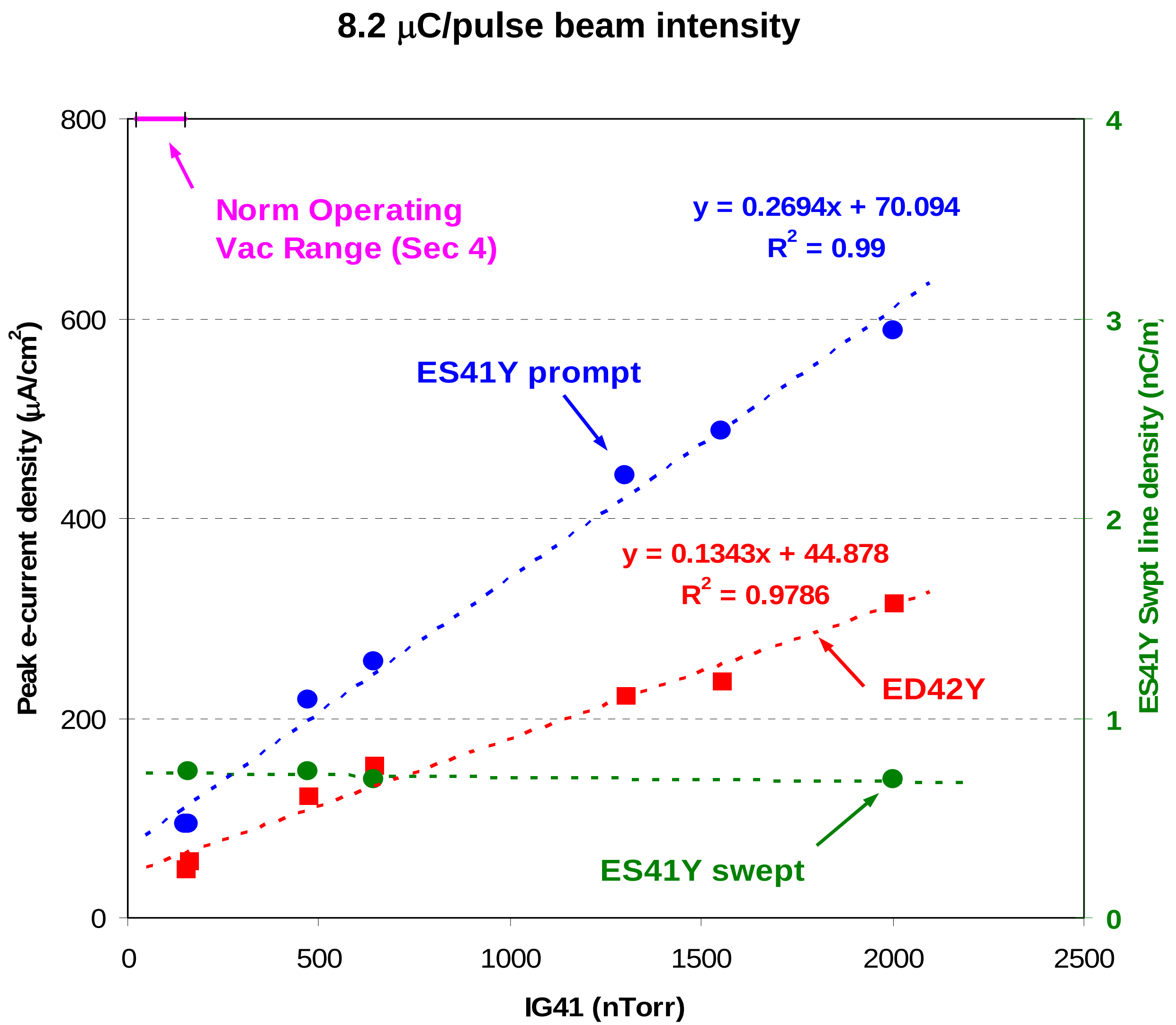
Effect of changing losses by local bump

Signals from horizontal and vertical RFAs plotted as function of local loss monitor as horizontal bump was varied from -6 to + 8 mm. Beam intensity was 8.1 μC/pulse



Effect of changing vacuum pressure in Sect 4



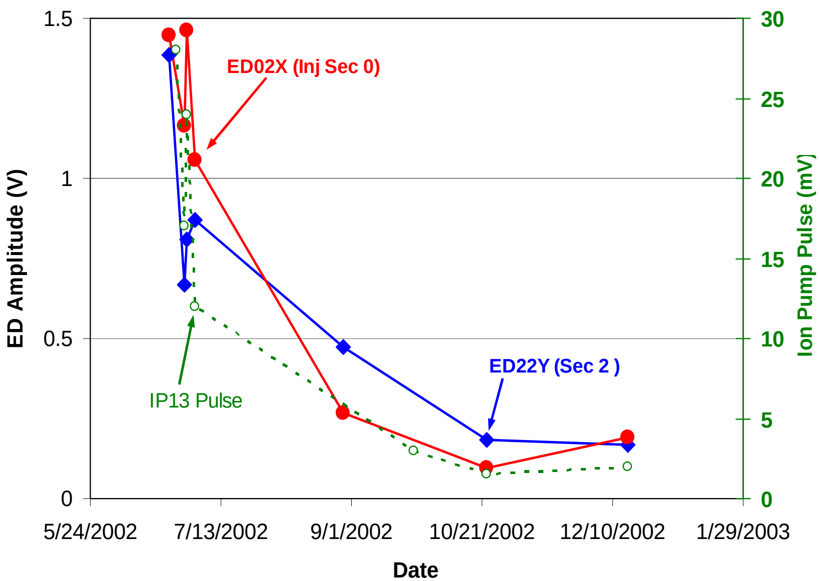
Studies of suppressing e-cloud buildup

- **TiN coatings gave mixed results**
  - **suppressed "prompt" electrons by a factor of 100 or more in tests in section 5 of PSR in 1999,**
  - **perhaps a factor of 40 in section 9 but**
  - **no improvement in section 4 in 2002 tests**
- **Weak solenoid magnetic field suppressed prompt electrons by factor of ~ 50 in a 0.5 m section in PSR**
  - **Solenoids over ~12% of circumference had no effect on instability**
- **Beam conditioning over time reduced prompt electron signals and improved the instability threshold curves**
  - **Electrons surviving the gap also showed some reduction with beam conditioning for higher intensity beams (~8 μC/pulse)**

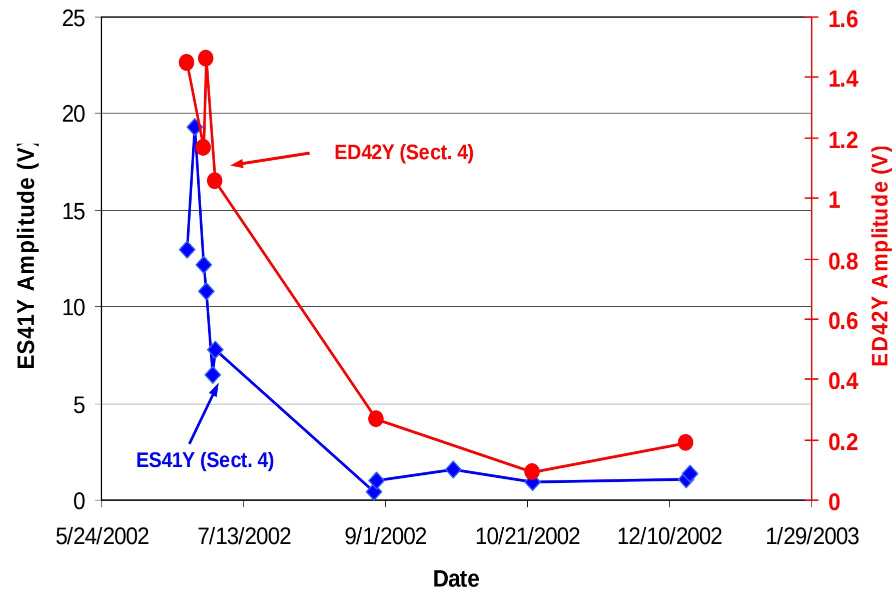
Effect of beam scrubbing on prompt electron signals

Data for 8 μC/pulse beam

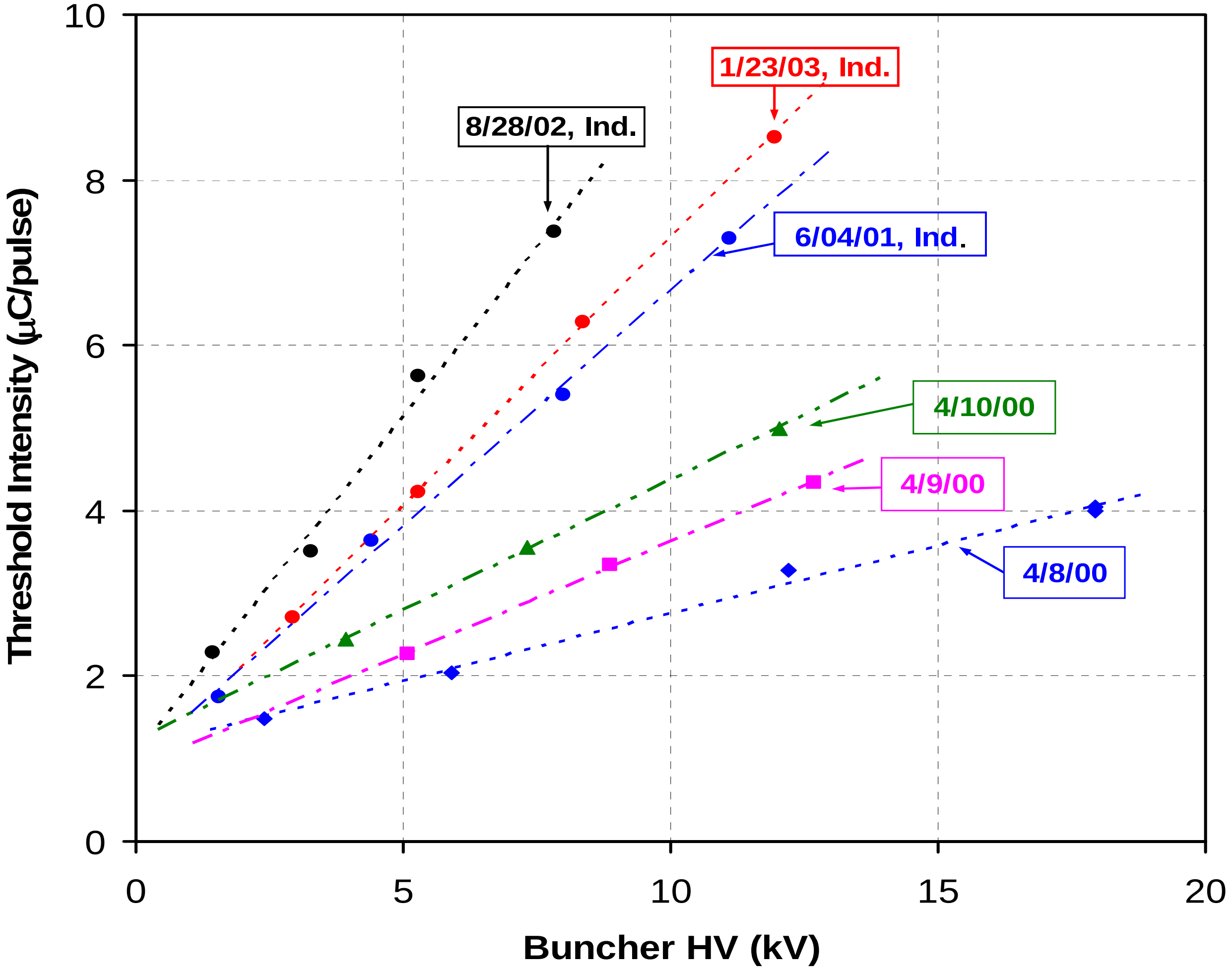
ED02X, ED22Y



ED42Y, ES41Y



Effect of beam conditioning on e-p instability threshold curves



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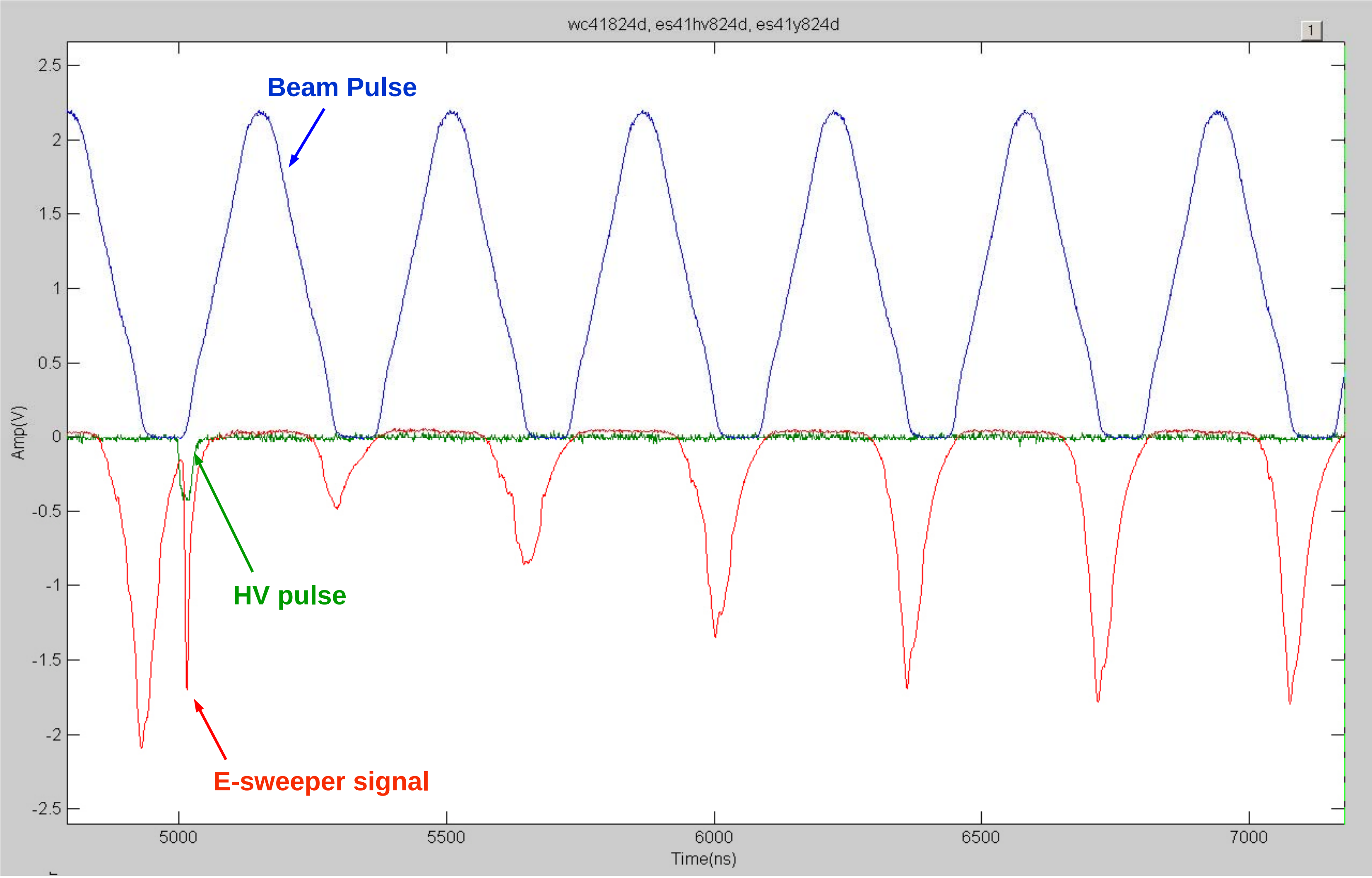
Some puzzling features of ECE in PSR

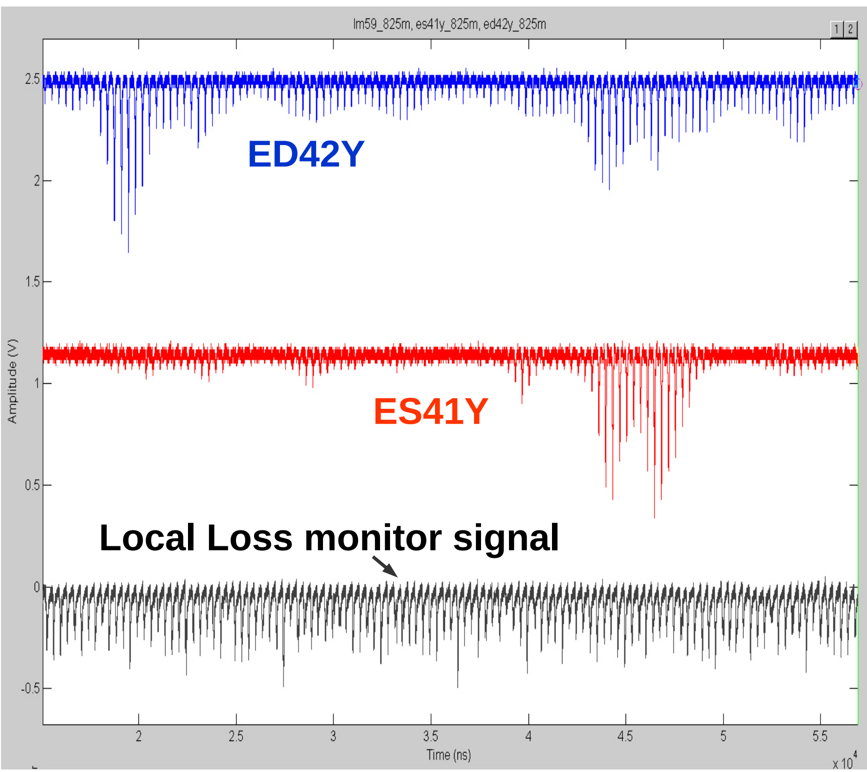
- Recovery after sweeping
- Bursts
- 1st pulse instability

Recovery after "Clearing Gap" of electrons



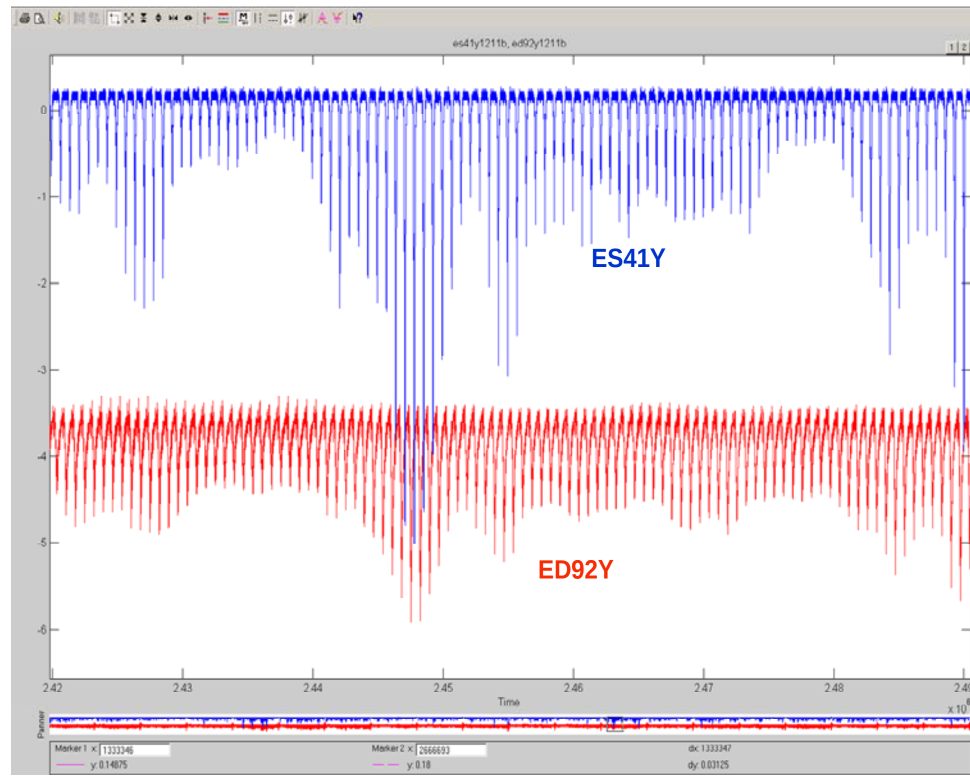
“Electron burst” phenomenon

110 turns, example of large variations



Bk 98, p 53

Correlations between sec 4 and sec 9

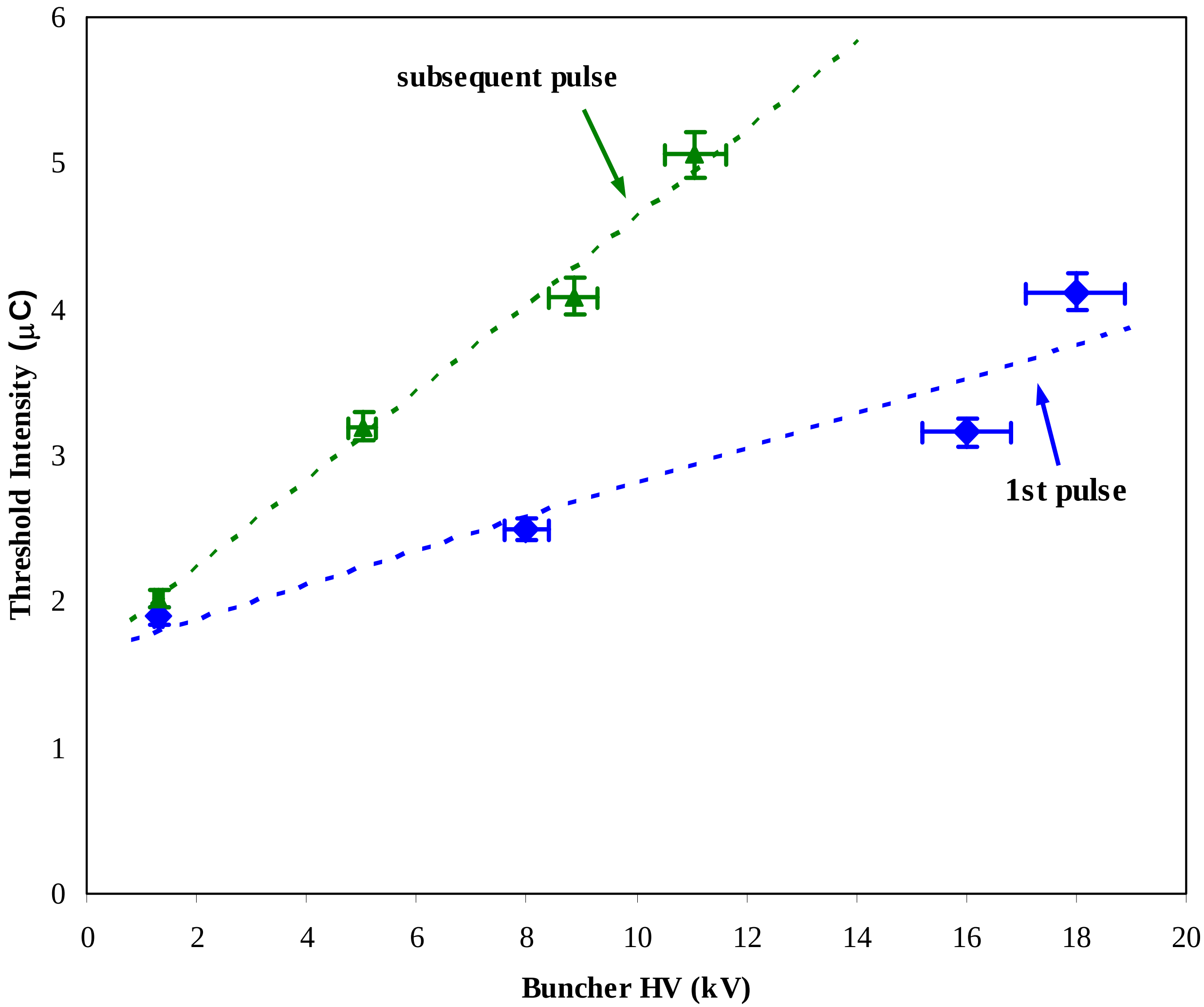


Bk 99, p 102

1st pulse instability

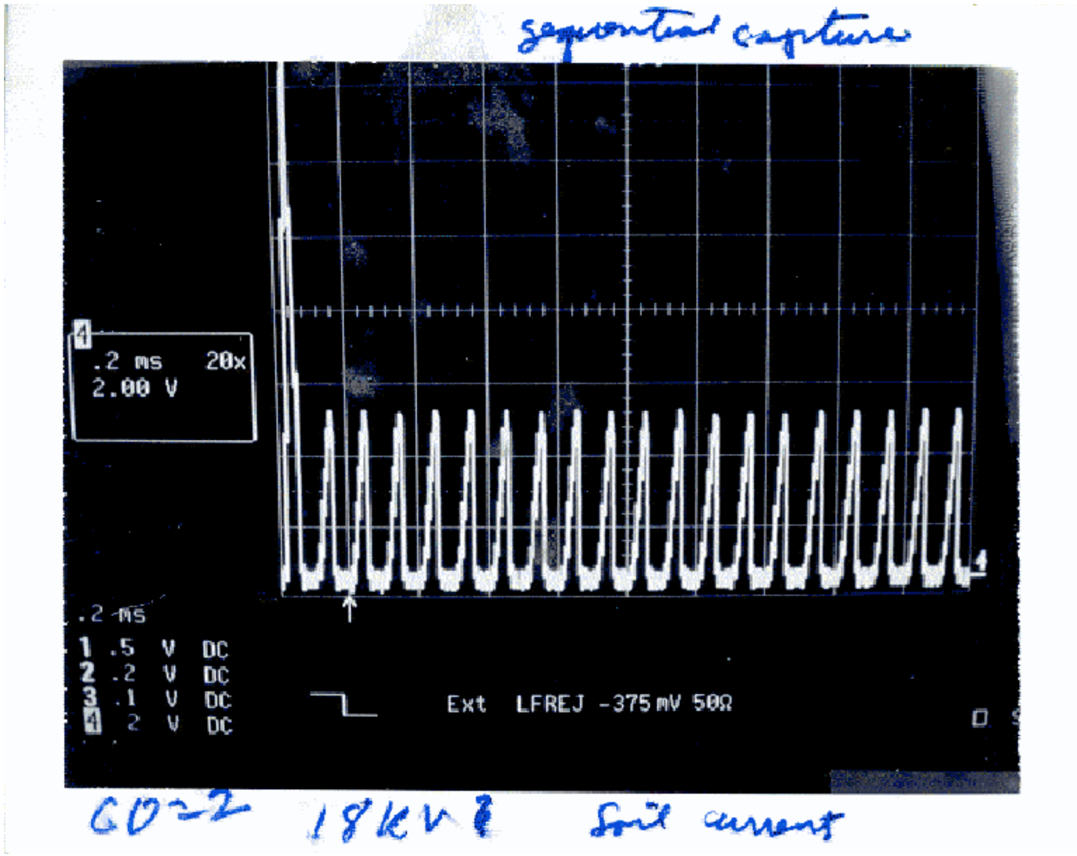
- After beam has been off for several minutes (3 – 10), the first pulse is e-p unstable with a threshold that is considerably lower than for subsequent pulses (see graph)
- The minimum wait time for the 1st pulse instability gradually increased with time (a few weeks) during beam development and beam operations until it disappeared.
- Some data that shows foil current much higher after a several minute wait even for stable beam
- Operators found that a low intensity (CD=50) precursor shortly before full intensity pulse generally prevents 1st pulse instability
- This has occurred after several long shutdowns (4-6 months each) for annual maintenance with portions of the ring up to air
- Phenomenon disappears after a few weeks of beam operations, presumably due to beam scrubbing

Threshold curves for 1st pulse and subsequent pulses



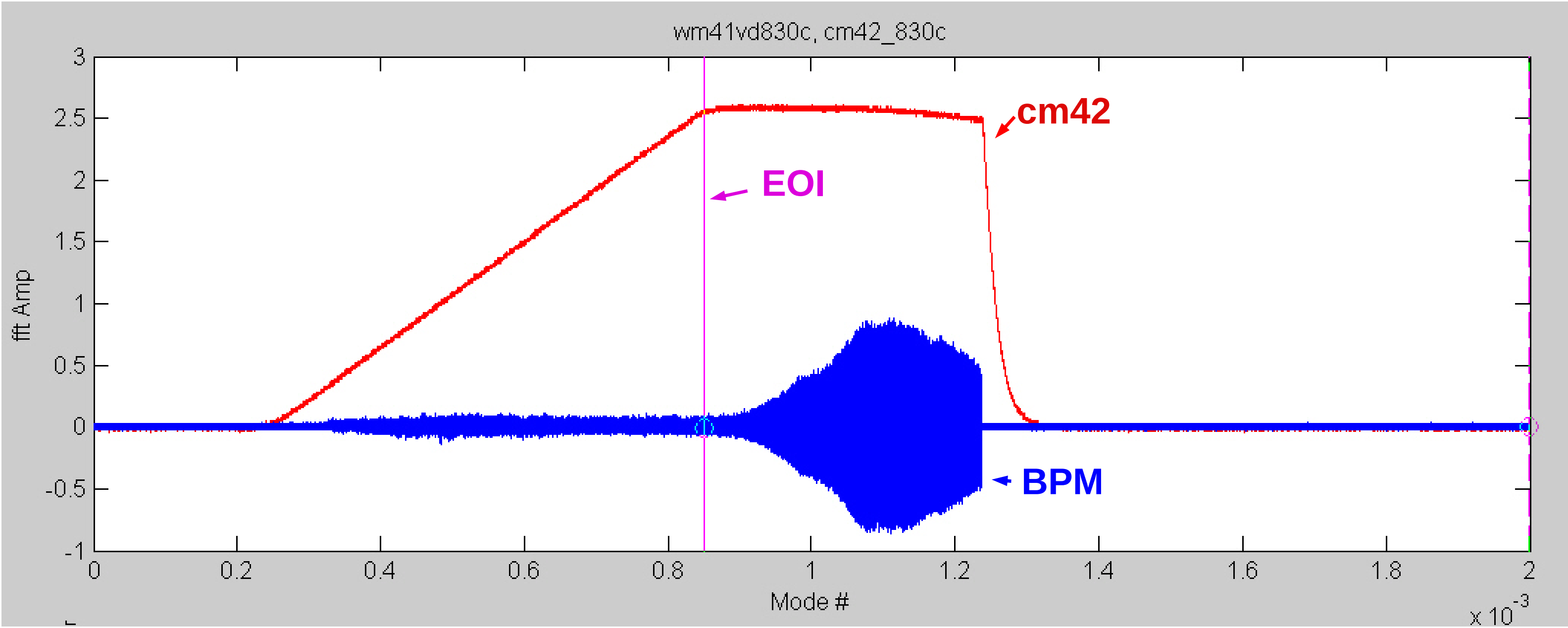
Foil current on 1st and subsequent pulses

- Stable beam on first pulse after a several minute wait
- Foil emission on first pulse factor of ~3 higher on 1st pulse



Beam response to weak kick

- Motivated by possibility of obtaining wake functions/impedance
- 5 μC/pulse beam stored for 400 μs
- Buncher at 11 kV, about twice as much as at instability threshold for this intensity
- ±1 kV kick on pinger at EOI for 1 turn
- Large beam losses near end of response



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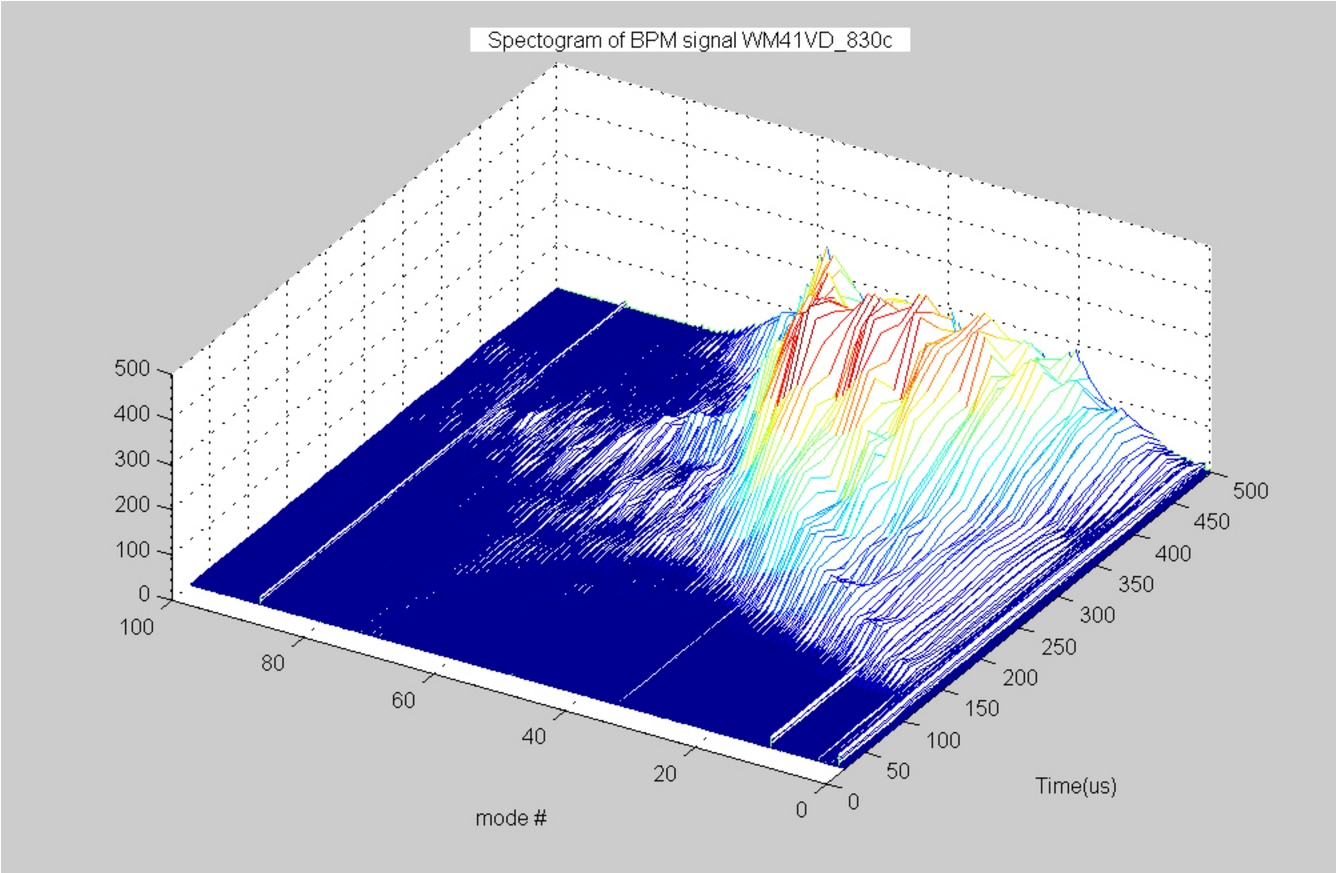
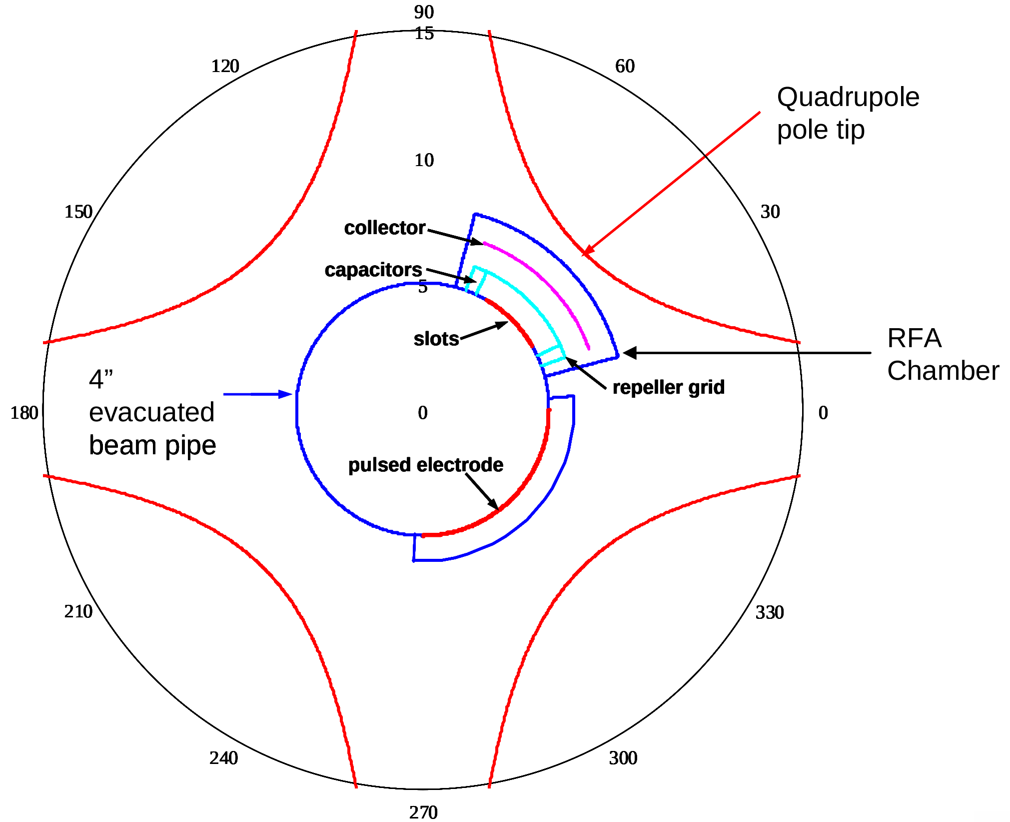
Spectrogram of beam response



Have more data on beam response over a grid of intensities, kick strength and "distance" from instability threshold

Proposal for future work

- **Electrons in quadrupoles are an unresolved issue for PSR**
  - **Simulations of Pivi indicate significant multipacting plus trapping in mirror fields of quad**
  - **Source terms for seed electrons from grazing proton losses should be largest in quads**
  - **Results from biased BPM plates striplines suggest many electrons in PSR quad**
- **Concept for detector in PSR quad**

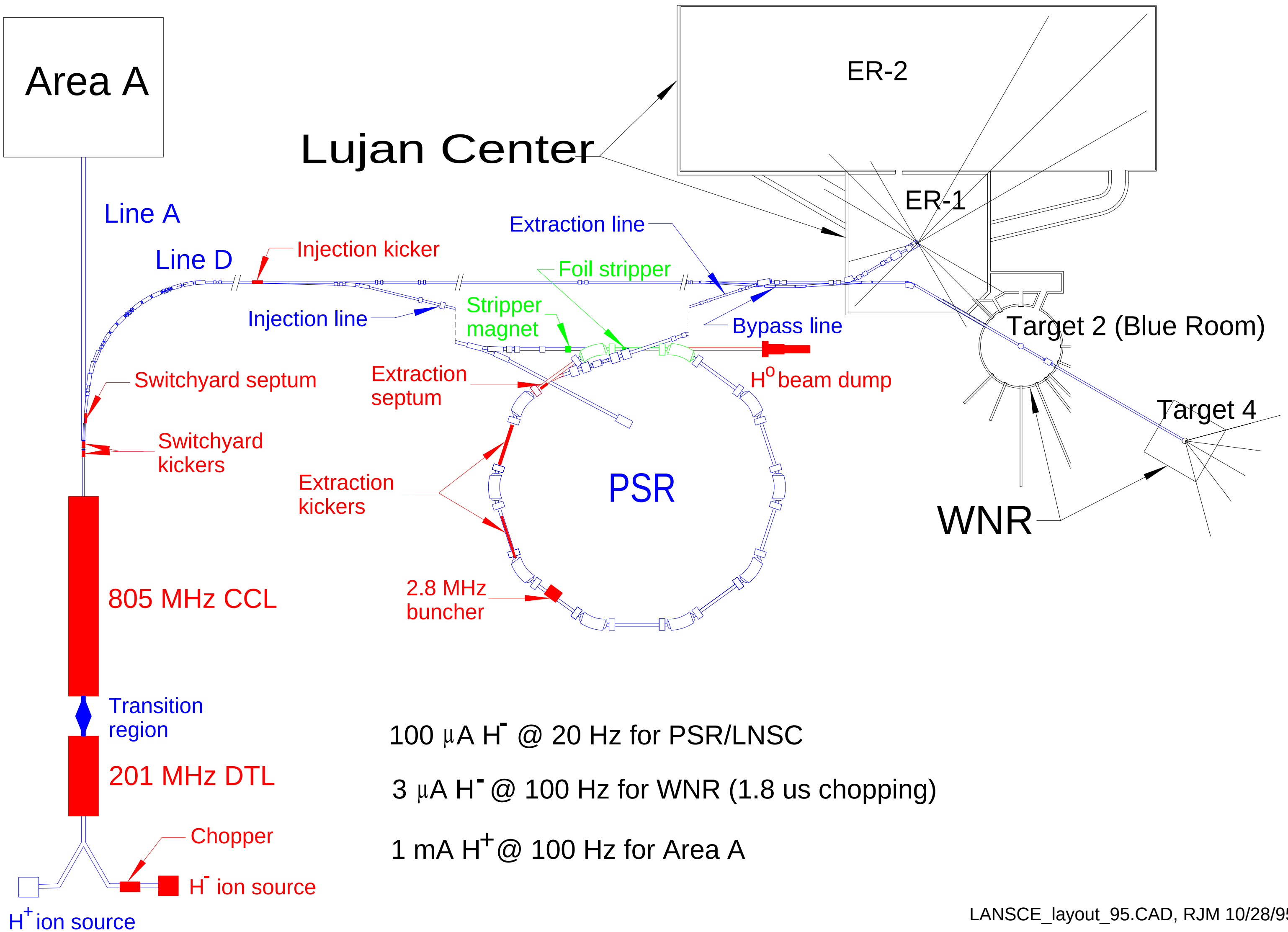


Summary and Conclusions

- We have made numerous parametric studies (experiments) on e-cloud signals
  - Reasonable comparisons with simulations for selected parameter variations
  - Simulations of certain other parametric variations are underway and others could provide more complete benchmarking
- Source strength of seed electrons from losses is very uncertain but could be improved with appropriate beam loss simulations
- We have mixed results on methods for suppressing trailing-edge multipactor as a cure for e-p
  - TiN coatings gave mixed results on suppression of multipacting signal
  - Weak solenoids suppress the multipacting signal but had no effect on the instability
  - However, beam conditioning has been effective in improving the instability threshold
- Beam response to a weak kick is interesting but awaits detailed analysis
- The 1st pulse instability is an unexplained puzzle
- Other open issues:
  - What causes the electron burst behavior and the recovery phenomenon following a sweeper pulse?
  - How is the electron cloud generation modified in dipoles and especially quads at PSR?
  - Can active damping be effective in controlling this instability?

Backups

LANSCE Layout



100 μA H$^-$ @ 20 Hz for PSR/LNSC

3 μA H$^-$ @ 100 Hz for WNR (1.8 us chopping)

1 mA H$^+$ @ 100 Hz for Area A

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