

Possible Cures to e-cloud Problems

Robert Macek, LANL, 4/17/02

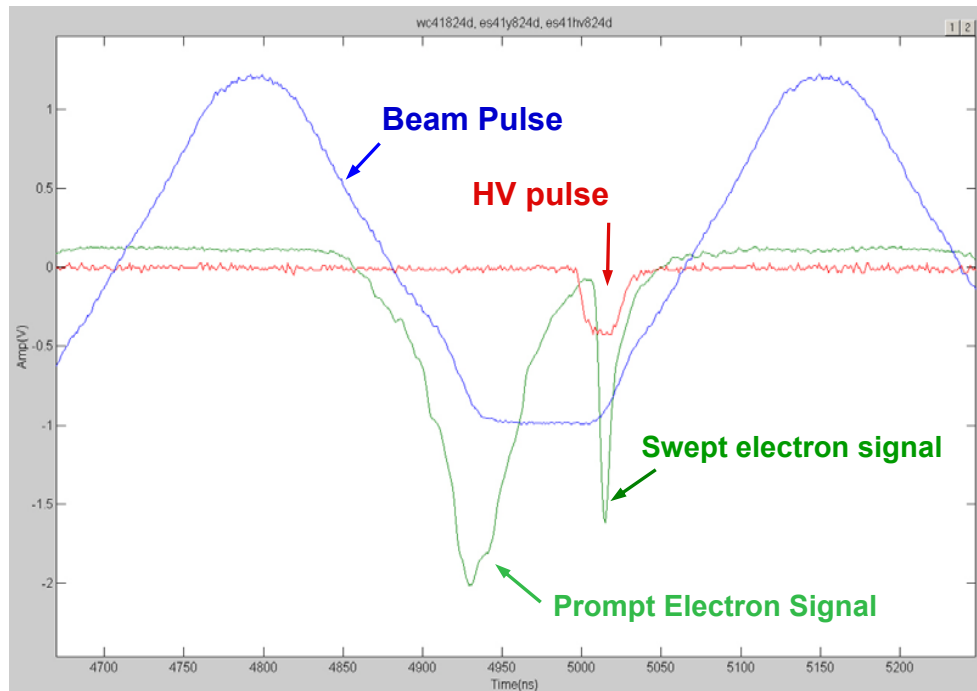
With grateful acknowledgement to many contributions from the PSR development team and the e-p instability collaboration

Outline

- **Important e-cloud characteristics at PSR**
- **Electron cloud effects on ring performance**
 - ◆ **Emittance growth and instabilities**
 - ◆ **Vacuum degradation**
 - ◆ **Adverse impact on diagnostics**
 - ◆ **Heat load on cryogenic systems (LHC)**
- **Cures by suppression of electron cloud formation**
 - ◆ **Suppress or control generation of primary electrons**
 - ◆ **Reduce multipactor “gain”**
 - ◆ **Reduce trapping/retention of e’s during passage of the gap**
- **Control or mitigation of symptoms**
 - ◆ **Landau damping of instabilities**
 - ◆ **Active damping**
 - ◆ **Bias fields on diagnostics**
- **Conclusions**

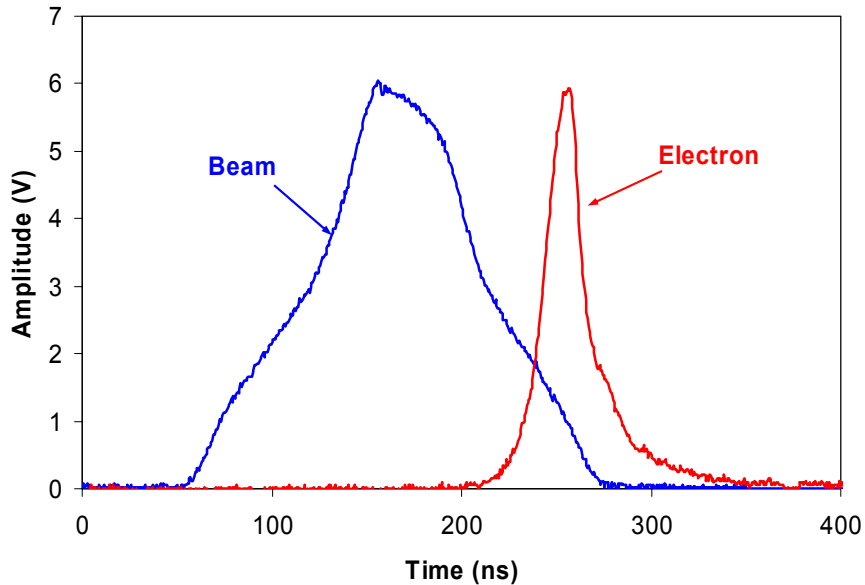
Present picture of e-cloud in PSR

- Electrons **captured** by the beam pulse from the “cold” electron cloud surviving the gap drive the e-p instability and contribute to the “prompt” signal
- **Multipacting electrons** from trailing edge multipactor strike the wall and produce much of the “**prompt**” signal observed in an RFA or e-sweeping detector
- Low energy cloud (**gap electrons**) that lingers in the **gap** but die away in time with an exponential tail,
 - ◆ Measured by electron sweeper (**swept electrons**)



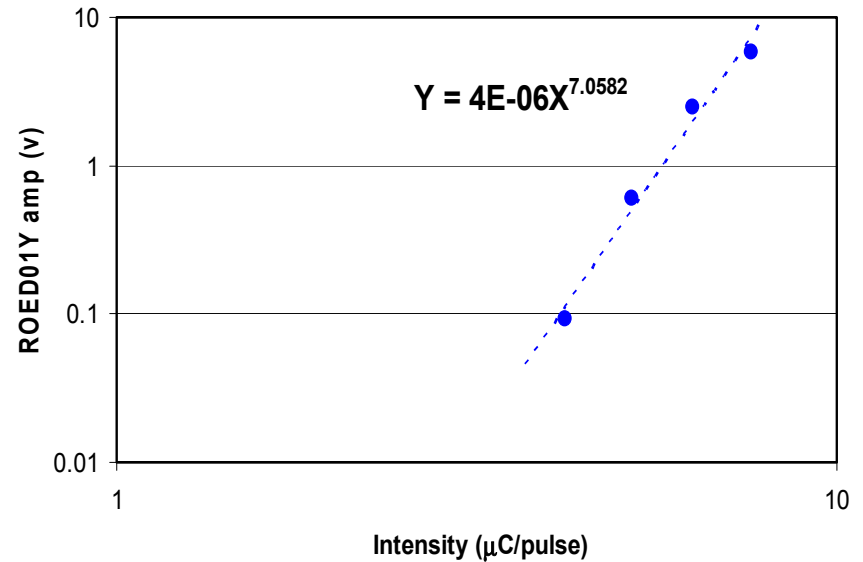
Electron signals in a single pass experiment

6.8 μC beam pulse in the extraction line



Single pass electrons vs beam intensity

(log-log plot)



- **Electron signal is very similar to signals in the ring wrt e-flux, time structure, energy spectra and dependence on beam intensity**

Important cloud problems are application-specific

- **Two-stream instability at PSR**
 - ◆ Electrons surviving the gap (“swept” e’s) dominate the average beam neutralization and drive the instability
 - ◆ “Prompt” (multipactor+ captured) electrons striking the wall generate the low energy cloud at the beginning of the gap
 - Multipacting electrons don’t directly drive the instability
 - ◆ Need to reduce the captured electrons to improve the instability threshold
- **Effect on diagnostics**
 - ◆ Electron flux (net) striking (“prompt” e’s) the diagnostic surfaces generate the spurious signals
 - eg secondary emission based devices such as wire scanners
 - Background signal on PSR extraction line wire scanners at ~0.5% level
 - Electrostatic pickups
 - ◆ Bias fields to repel electron cloud helps diagnostics at PSR
 - Factor of 10 reduction in background signal for halo measurements
- **Vacuum degradation (electron stimulated gas desorption)**
 - ◆ Function of e-flux striking the wall (mainly prompt signal)
 - Pressure pulse tracks prompt signal at PSR
- **Heat load for superconducting components**
 - ◆ Flux times energy deposited (prompt or multipactor electrons)

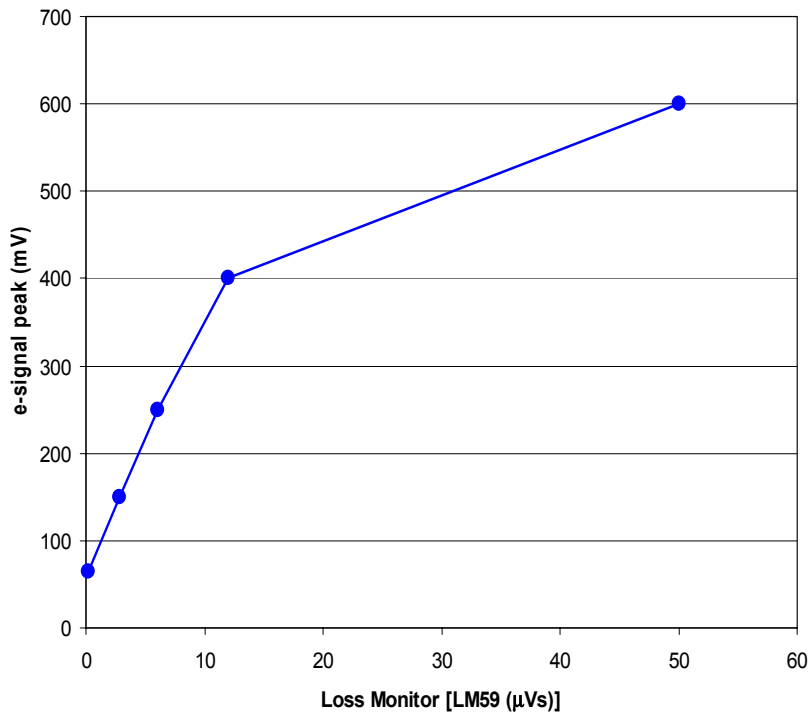
Control of the generation of primary (“seed”) electrons

- Antechamber to control photoelectrons where synchrotron radiation is significant (APS, PEP-II)
- Reduce beam losses in the ring
 - ◆ Should reduce prompt signal but need large reduction to affect e’s surviving the gap because of “saturation”
- Improve vacuum
- Reduce electrons from the stripper foil
 - ◆ Control “convoy” electrons at stripper foil
 - ◆ Reduce foil hits to suppress SEY
 - ◆ Bias foil to suppress SEY and thermionic emission
 - ◆ Keep foil temperature below significant thermionic emission
- Manipulation of the primary electrons changes prompt electrons but has not improved the instability threshold at PSR
 - ◆ Might be useful in combination with other methods

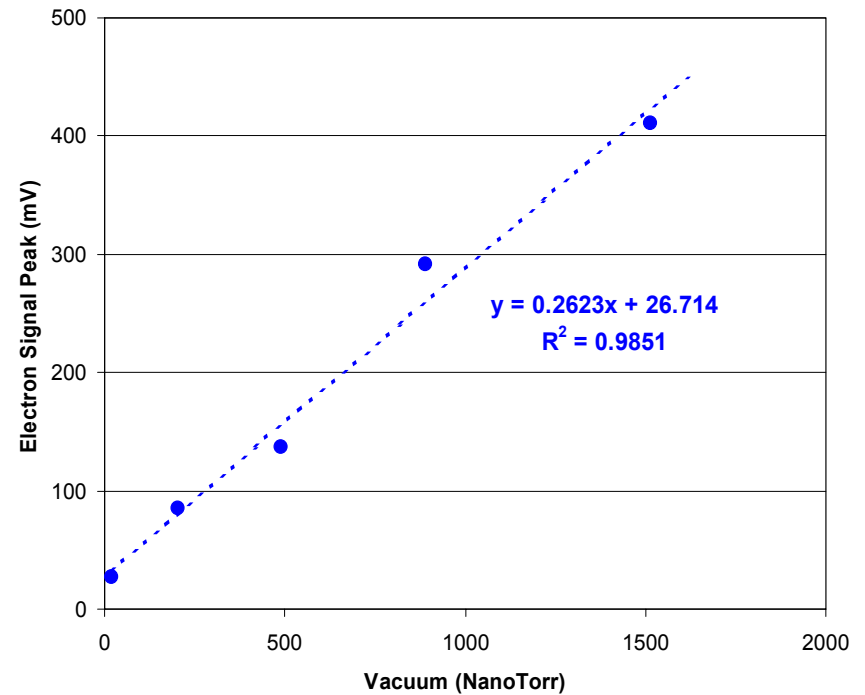
Prompt e's vs losses and vacuum pressure at PSR

- Prompt e's (RFA) increase with both local losses and higher vacuum pressure
 - ◆ If prompt e's are reduced sufficiently, expect the e's surviving the gap to come out of saturation and also be reduced

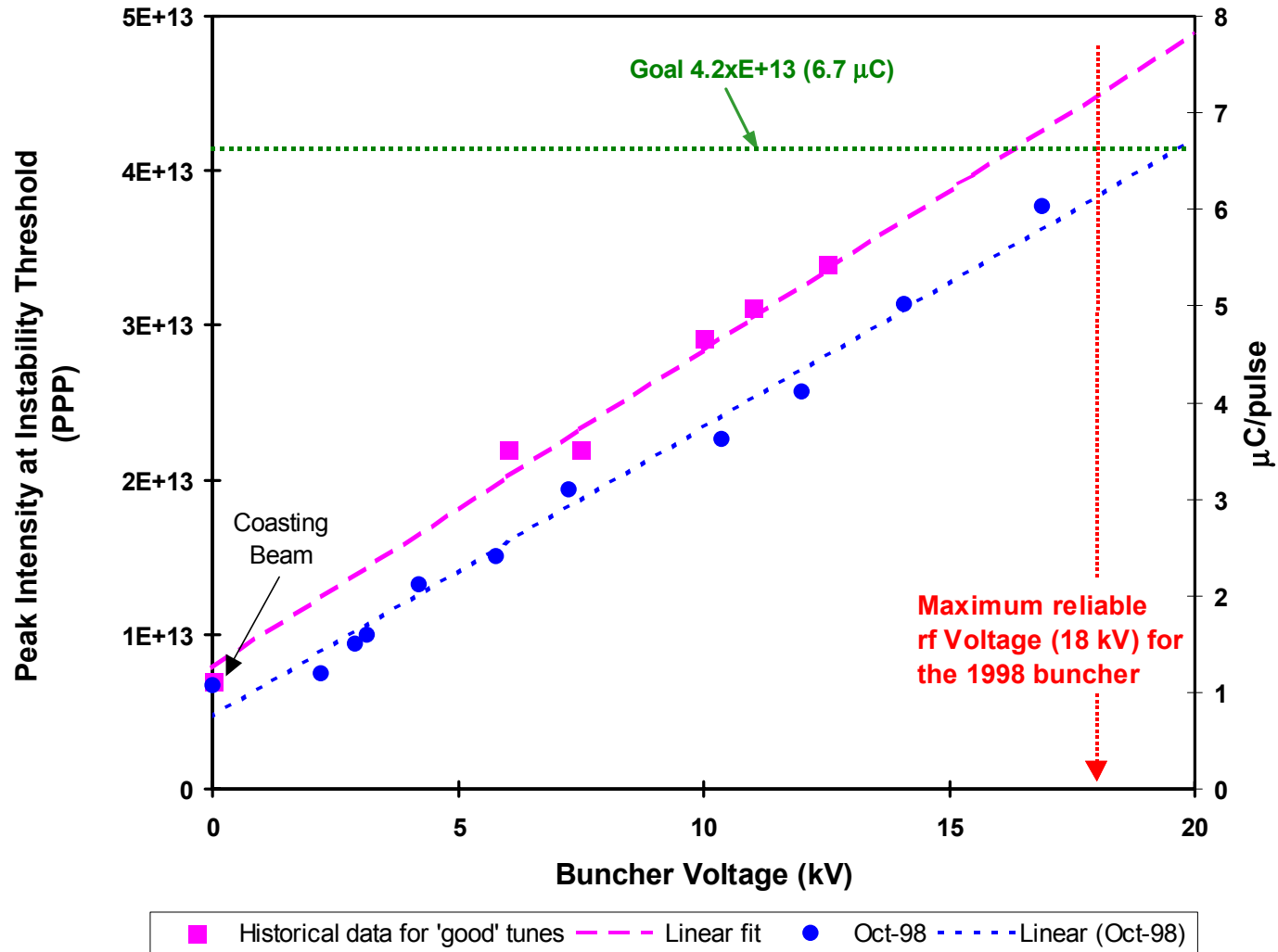
e-signal vs Local Losses



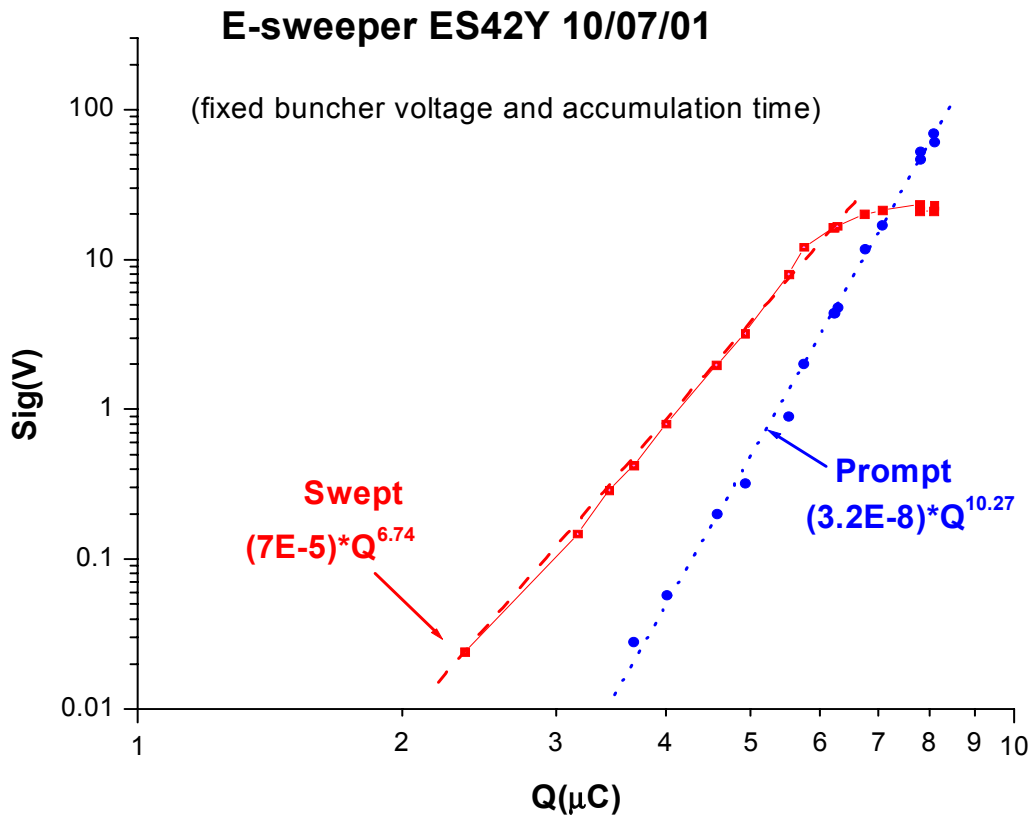
e-signal vs Local Vacuum Pressure



Instability threshold intensity curves before and after '98 upgrade

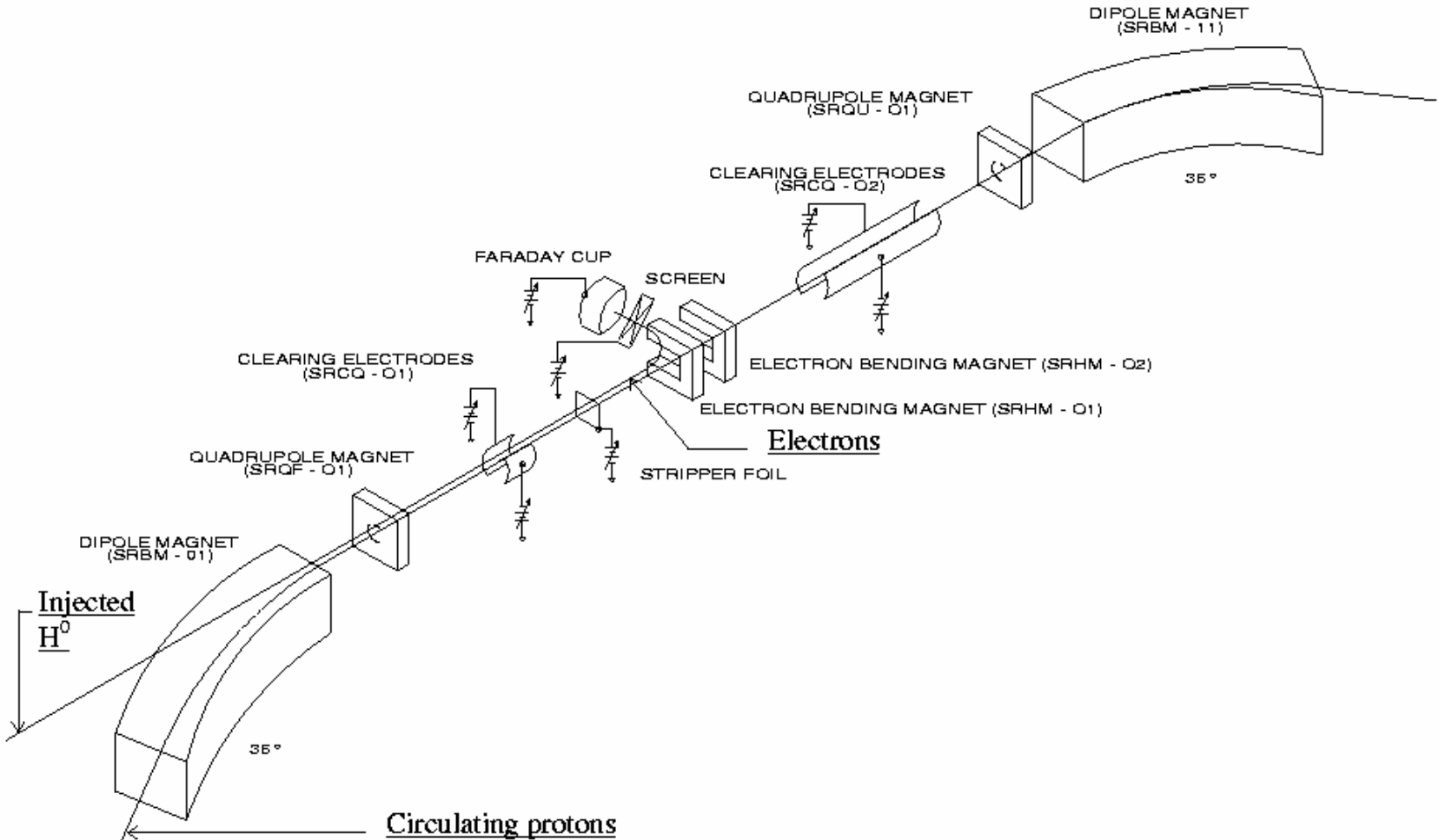


Prompt and Swept Electrons vs Beam Intensity



- The saturation of swept electrons above $5 \mu\text{C}/\text{pulse}$ is not restricted to variations of beam intensity but includes other variables that affect the prompt signal such as:
 - ◆ Variation in beam loss
 - ◆ Bursts
 - ◆ Changes in pulse shape
- Saturation explains several puzzles:
 - ◆ Why instability threshold is unchanged by increases in losses or vacuum pressure
 - ◆ Why the threshold intensity curves vs buncher voltage do not plateau at some intensity

Electron Clearing Devices in Injection Section (Pre H- Injection Upgrade)



Methods to reduce multipactor gain

- **Vacuum chamber coatings**

- ◆ **Titanium Nitride**

- Good for factor of 100 or more reduction in prompt electrons at PSR @ ~8-9 μC

- ◆ **Other coatings - C, neg, Cr_2O_3 , passivated Stainless Steel may be worth investigating further**

- **Conditioning/beam scrubbing**

- ◆ **Good improvement at PSR in 10 – 100 days of operation (2000)**

- ◆ **Observed several times earlier after recovery from long shutdowns**

- ◆ **Observed significant reduction in prompt signal at e-sweeper in first few weeks of operation**

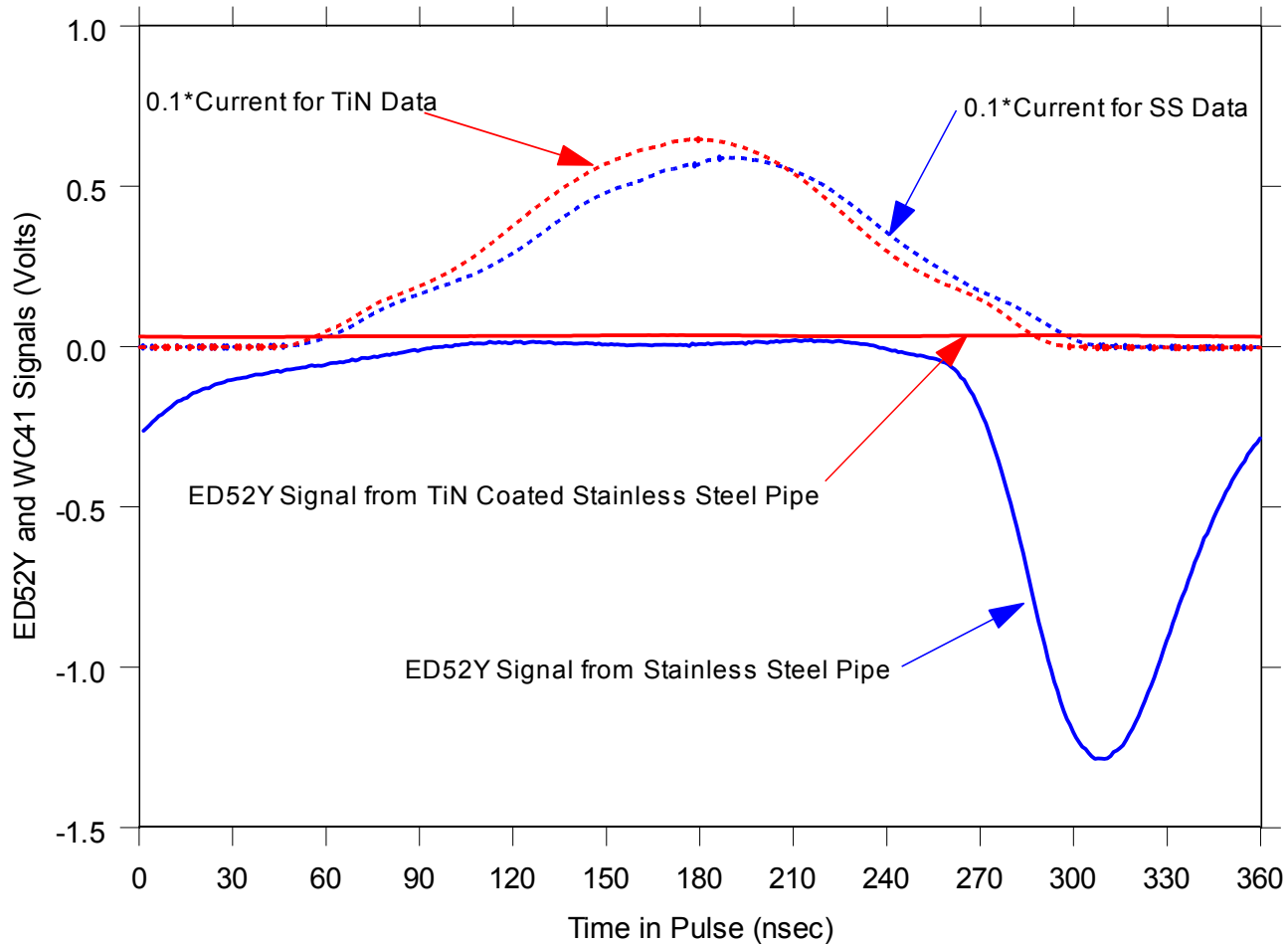
- **Weak solenoids**

- ◆ **Good for factor ~50 reduction in prompt e's**

- **Tailor pulse shape**

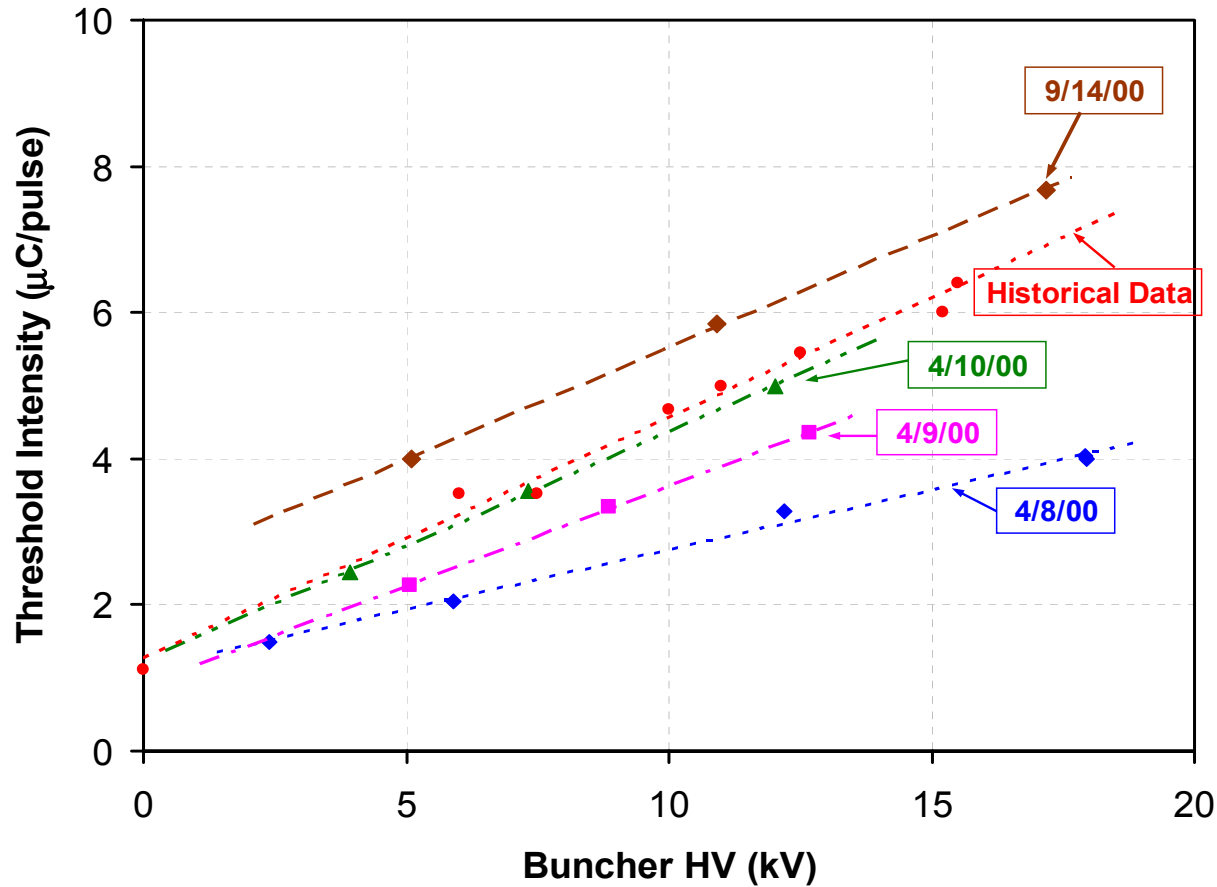
Effect of TiN Coating on Electron Flux

TiN/SS Beam Currents and ED52Y Signals vs. Time

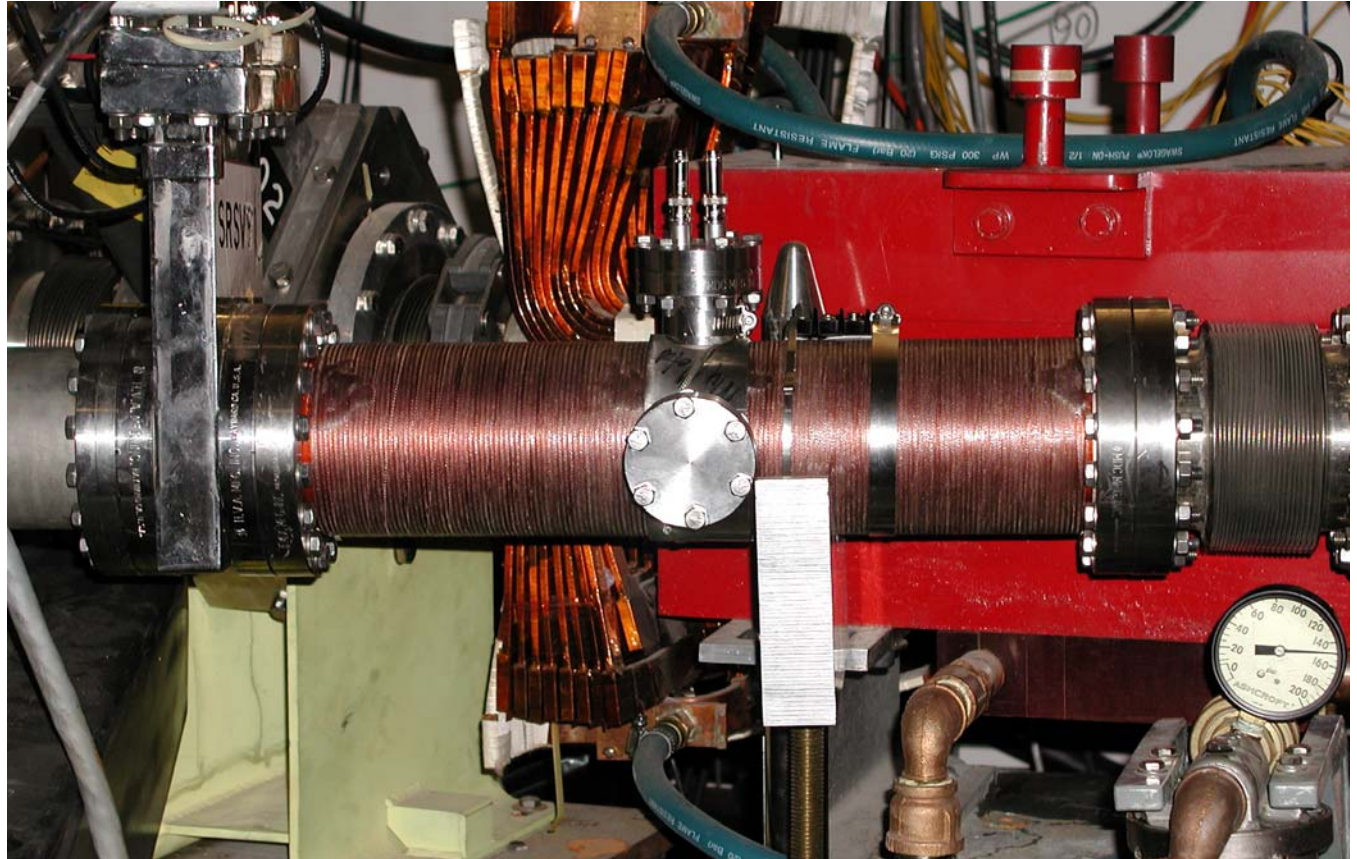
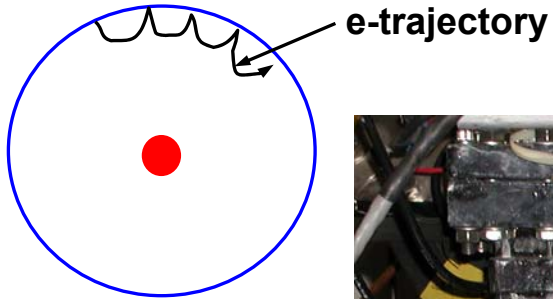


Conditioning or beam scrubbing effect

Threshold Intensity Curves 2000, no inductors
"Conditioning" effect

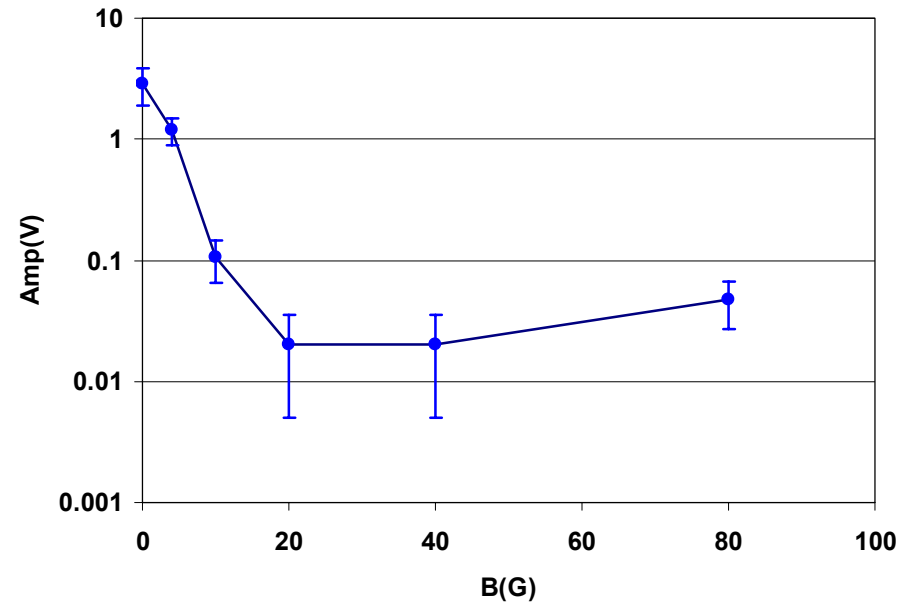
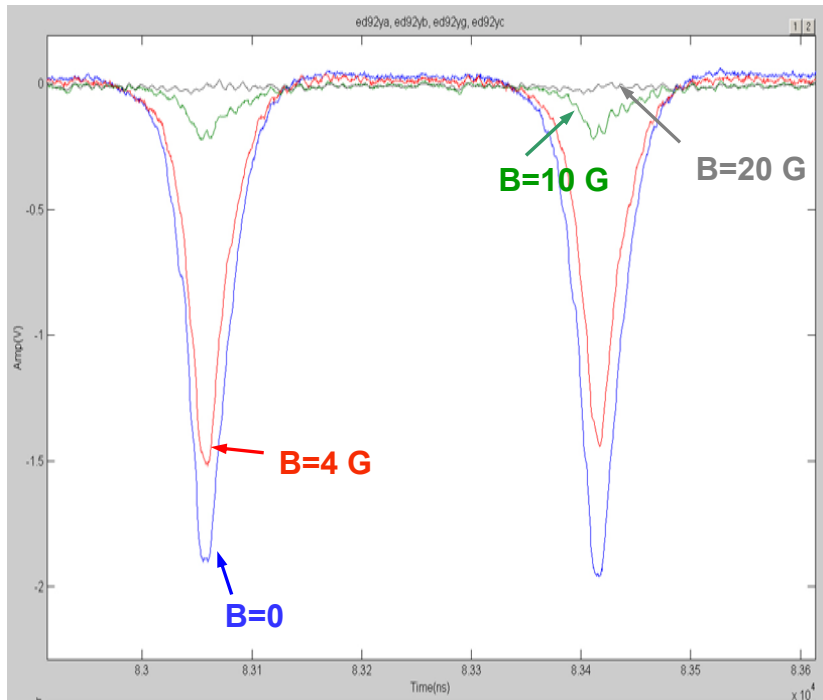


Picture of Solenoid Section with RFA



Suppression of prompt e's in a weak solenoid field

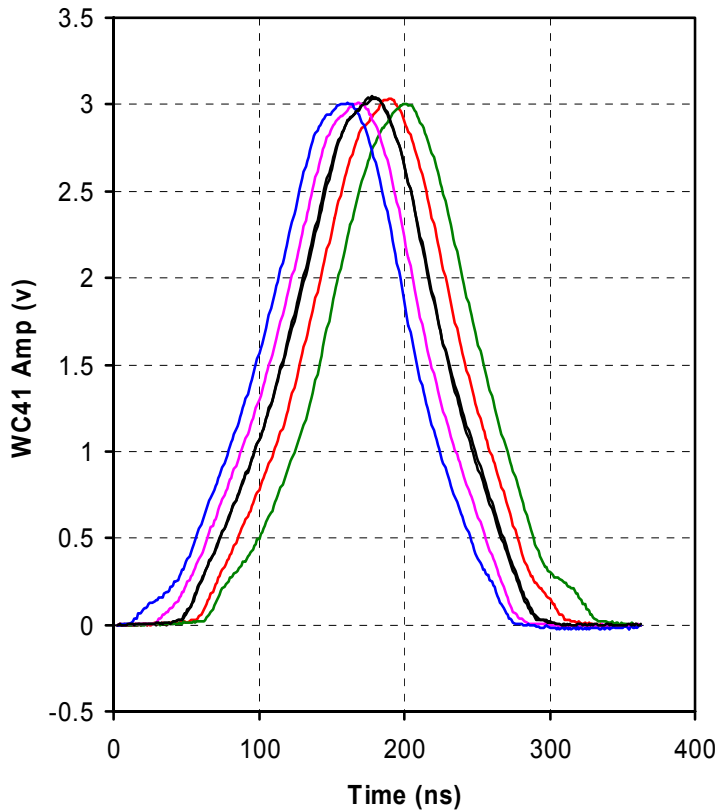
RFA signals in a weak solenoid fields



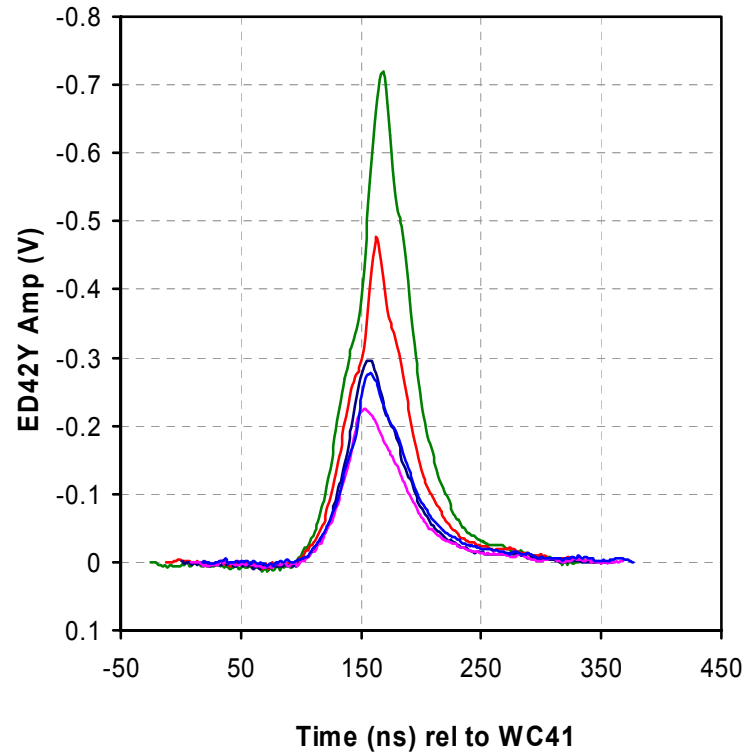
Electron signals vs bunch shape

- Data obtained for $\sim 7.4 \mu\text{C}/\text{pulse}$ beam

Effect of rf Buncher phase variations



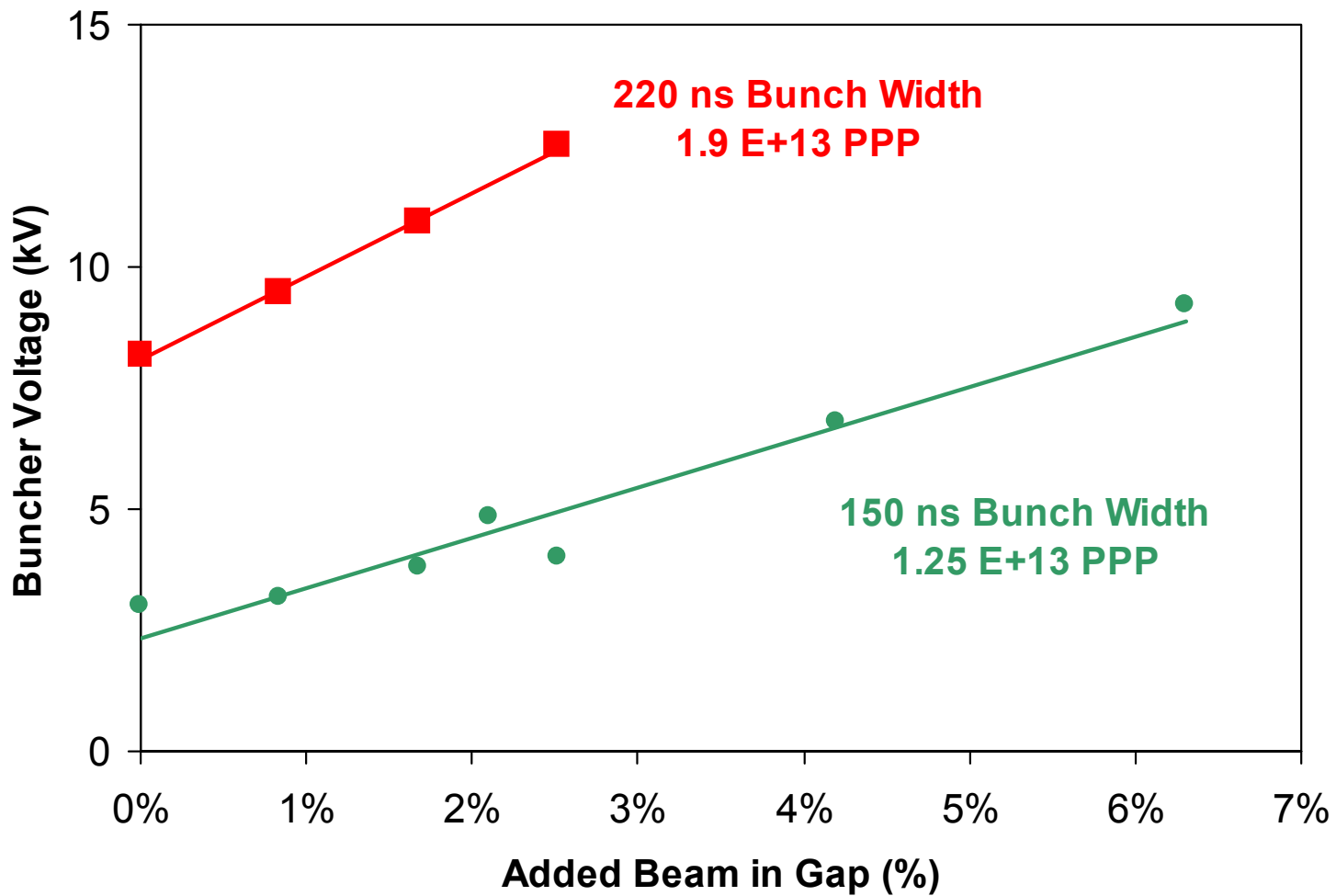
ED42Y signals for rf phase changes



Methods to reduce retention of e's in the gap

- **Keep gap free of beam, below 0.1%, preferably < 0.01%**
 - ◆ **Normally beam-in-gap <0.05% at PSR**
- **Will TiN, beam scrubbing reduce the decay time of e's in the gap hence the number surviving the gap?**
 - ◆ **CERN measurements on Cu suggest electron bombardment /beam scrubbing can be effective**
 - ◆ **Reduction might be inferred from conditioning effect at PSR**
 - ◆ **Measurements of swept e's in TiN coated chambers planned for 2002 run cycle at PSR**

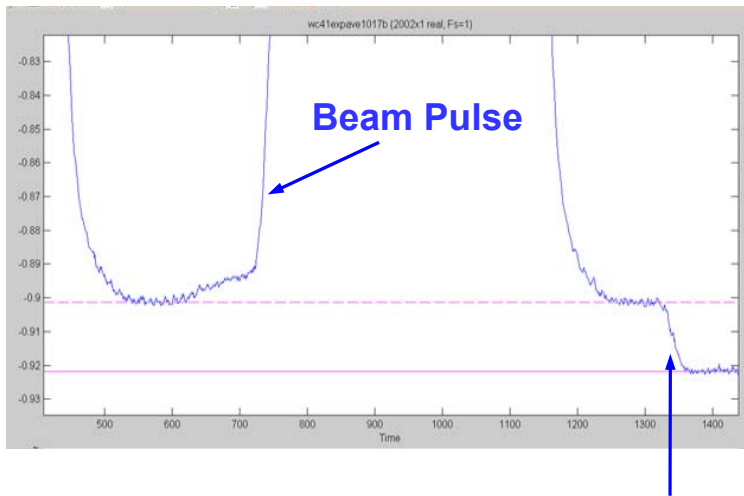
Effect of Added “Beam in the Gap” on Instability Threshold



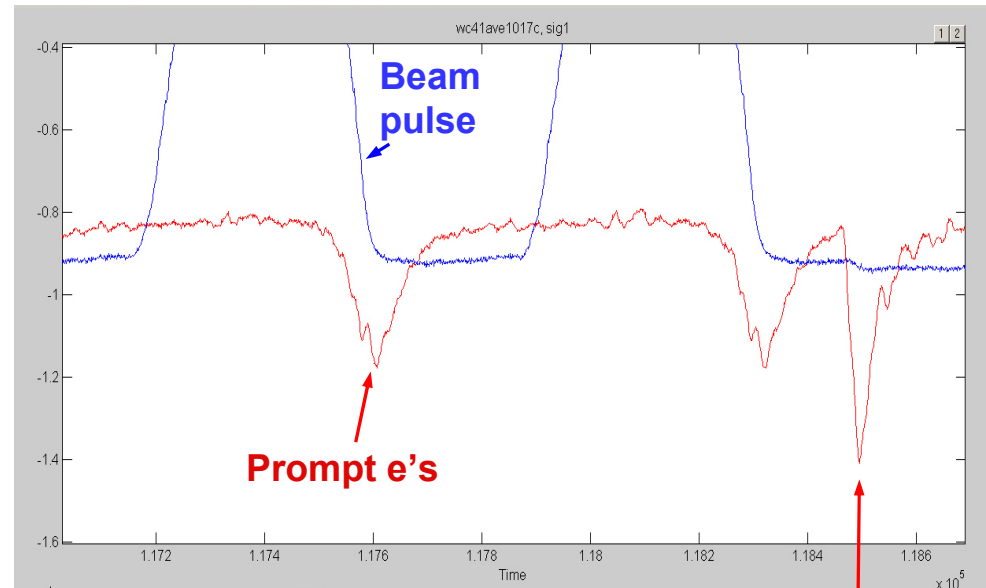
Effect on e-cloud of 1% added beam-in-the gap

- Added beam in the gap by injecting a number of turns (2%) with no 2.8 MHz chopping at the end of accumulation
 - ◆ Provides beam in gap that is ~1% of peak of beam pulse
- Measured beam in gap and prompt and swept e-signals for ~7 μC /pulse beam intensity

Expanded vertical scale on beam pulse from wall current monitor

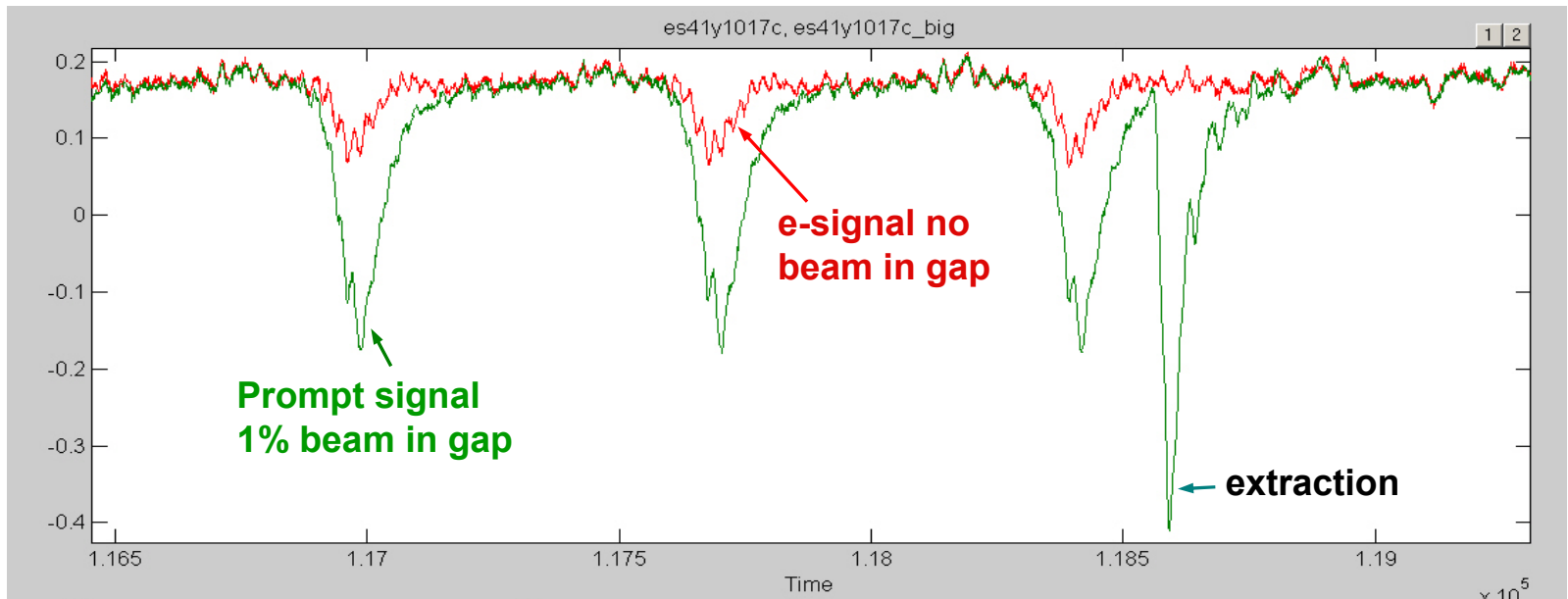


Extraction time



Extraction time

Comparison of prompt e's with and without beam in gap



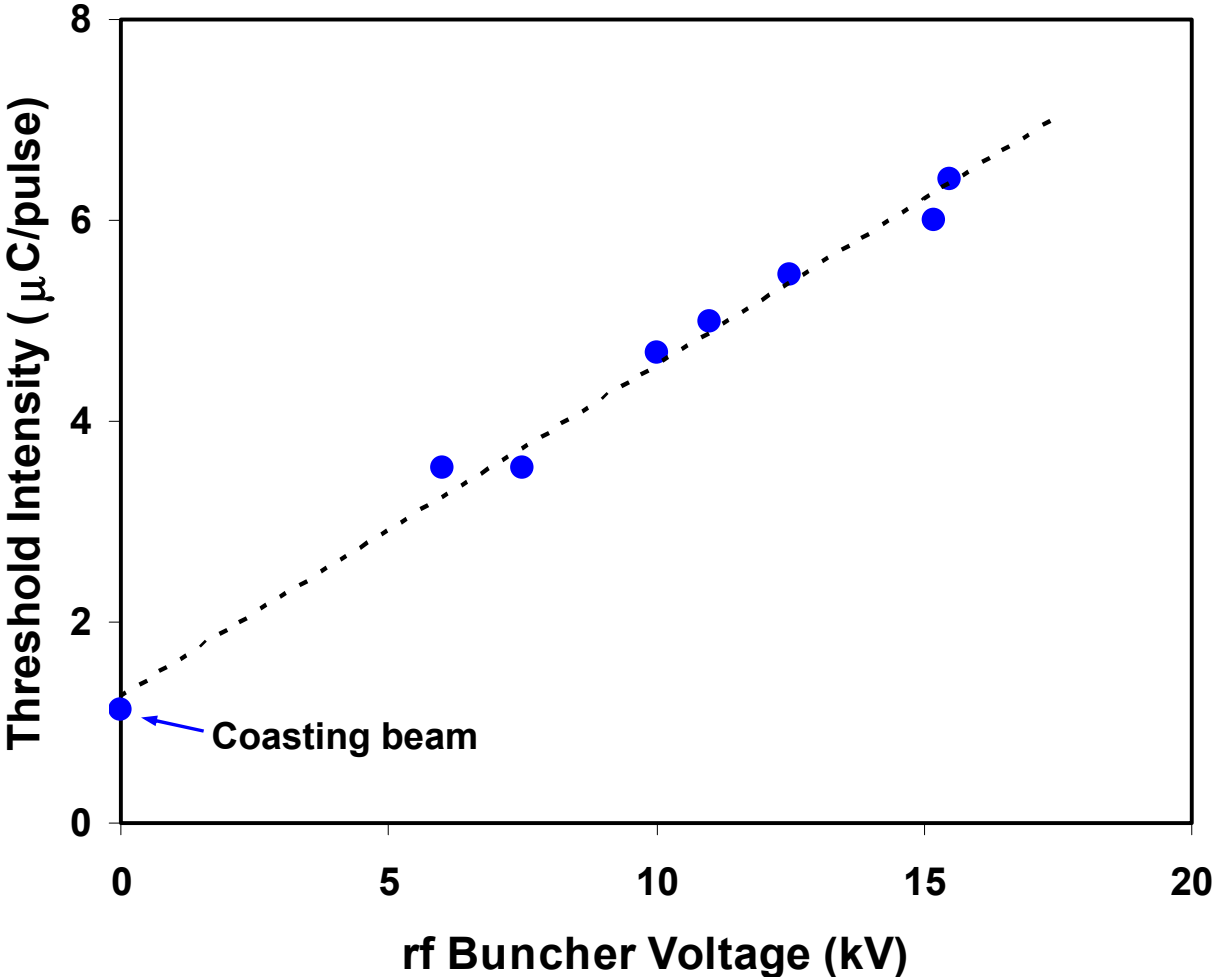
- 7.1 μC /pulse beam intensity
- Both traces have the same beam parameters except for beam in gap
- See a factor of ~ 3 more prompt e's with beam in gap
 - ◆ Somewhat surprising that it is this large

Tests of various methods for damping the e-p instability

- **Increased rf buncher voltage (increases $\Delta p/p$)**
- **Traditional Landau damping from multipoles**
- **Coupled Landau damping via a skew quad**
 - ◆ **X,Y coupling permits sharing of the stabilizing tune spread and growth rates in both planes thereby providing extra damping**
- **Inductive inserts**
 - ◆ **Passive compensation of longitudinal space charge forces**
 - ◆ **Equivalent to more rf with suitable harmonics which passively compensate longitudinal space charge voltage**
 - ◆ **Helps prevent leakage of beam into gap**
 - ◆ **Increased bucket height i.e., increased momentum spread for more Landau damping**

Effect of rf buncher voltage on instability threshold

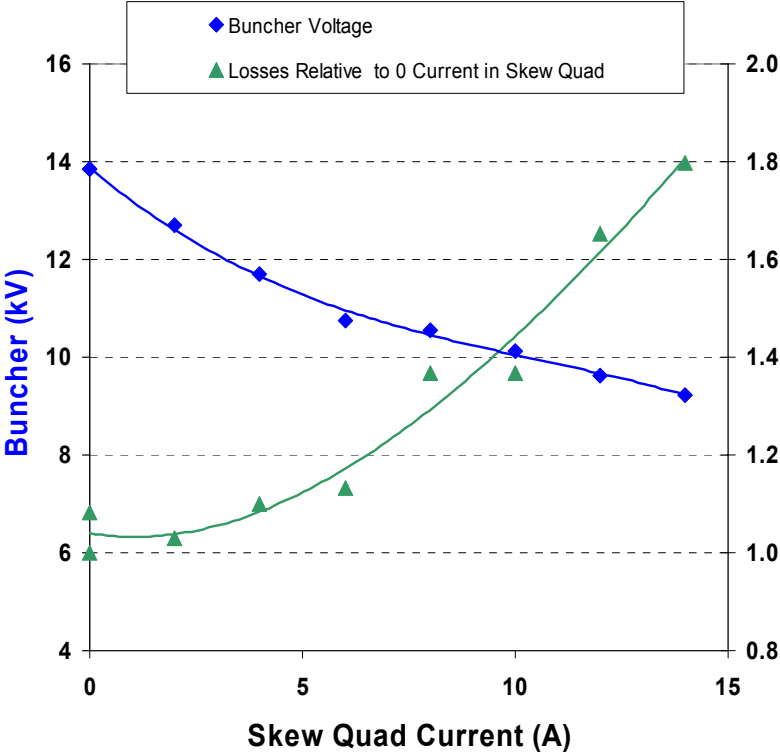
Historical data for good tunes



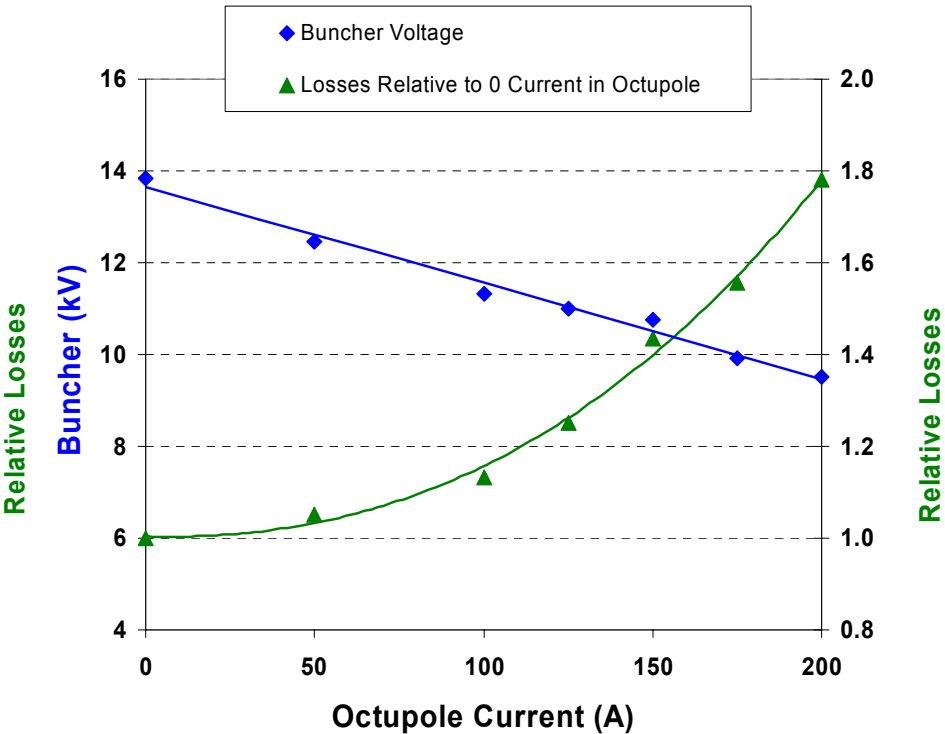
Effects of skew quad and octupole on instability and losses

Results for 5 $\mu\text{C}/\text{pulse}$ peak beam intensity

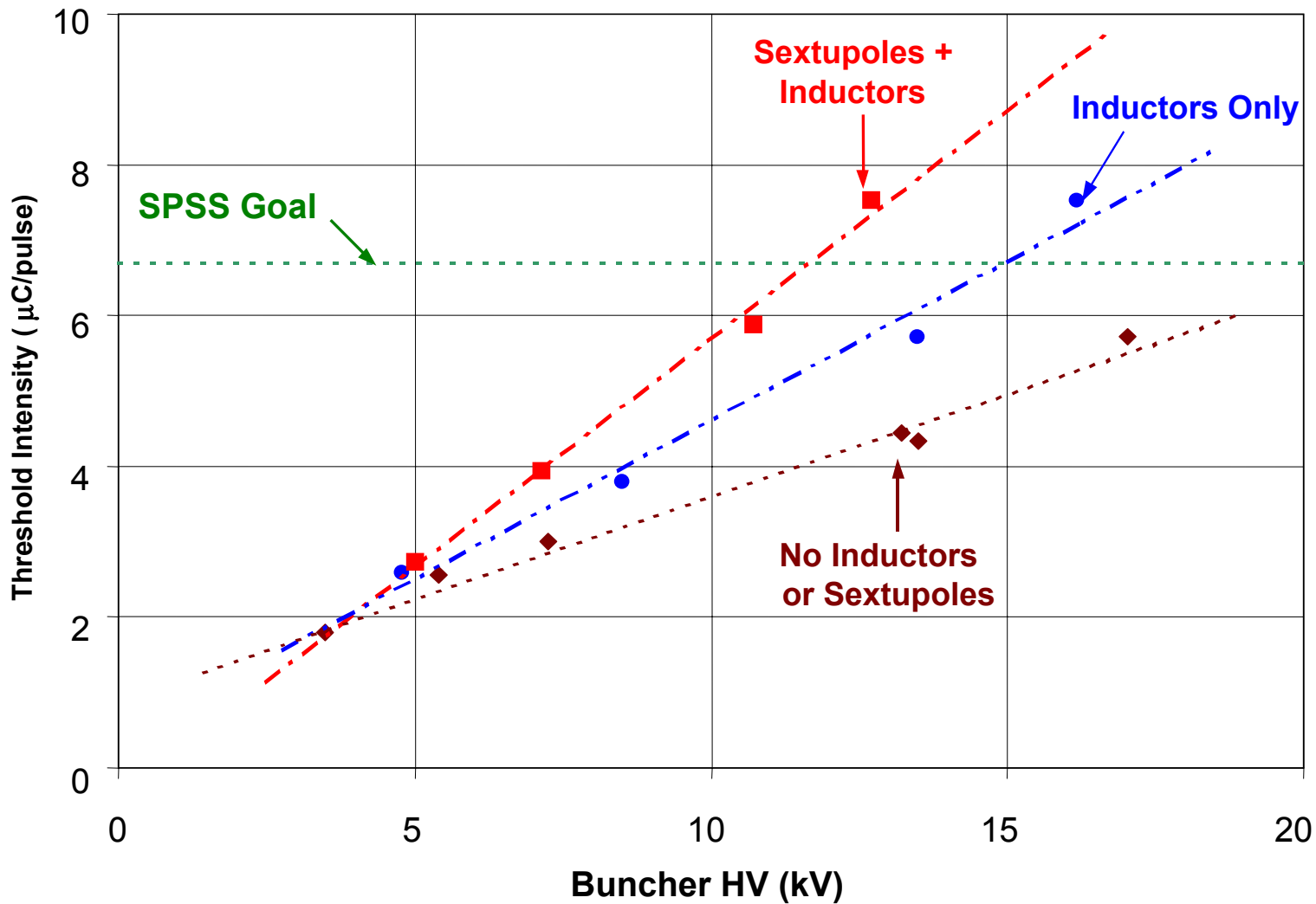
Instability Threshold vs. Skew Quad Current



Instability Threshold vs. Octupole Current



Effect of Inductors & Sextupoles on Instability Threshold Curves



Summary and Main Conclusions

- **Suppression of e-cloud by reduction of primary e's:**
 - ◆ is helpful for reducing multipactor electrons
 - ◆ is very difficult for e-cloud-in-the-gap but might be effective in combination with other methods
- **Beam scrubbing or conditioning is effective in raising the e-p instability threshold at PSR**
- **TiN coatings (and weak solenoids) suppress the prompt electrons but we don't know if they will eliminate electrons in the gap**
- **Landau damping by increased rf voltage, (X,Y) coupling, multipoles and inductive inserts significantly raises the instability threshold but with some increase in beam losses**
- **Bias fields to repel electrons help some PSR beam diagnostics**
- **Open issues and future work:**
 - ◆ **Will TiN coatings of all vacuum surfaces cure the instability?**
 - Will measure gap electrons in TiN section with e-sweeper this summer
 - ◆ **Can active damping be effective in controlling this instability?**
 - ◆ **Why is the e-p instability not seen at ISIS? Is there any e-cloud at ISIS?**