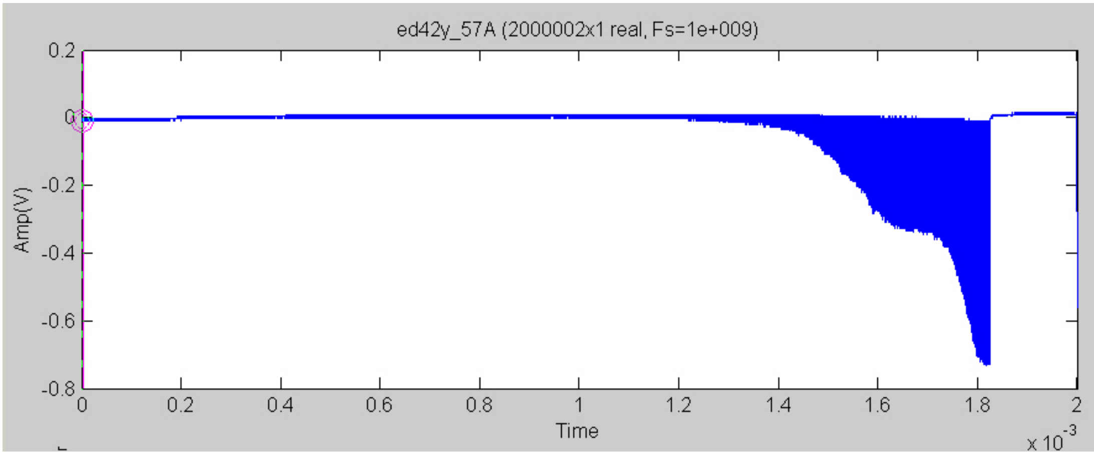
Gas Desorption, Pressure Rise and other ECE at PSR

Robert Macek and the PSR Development Team, LANL, 12/10/03

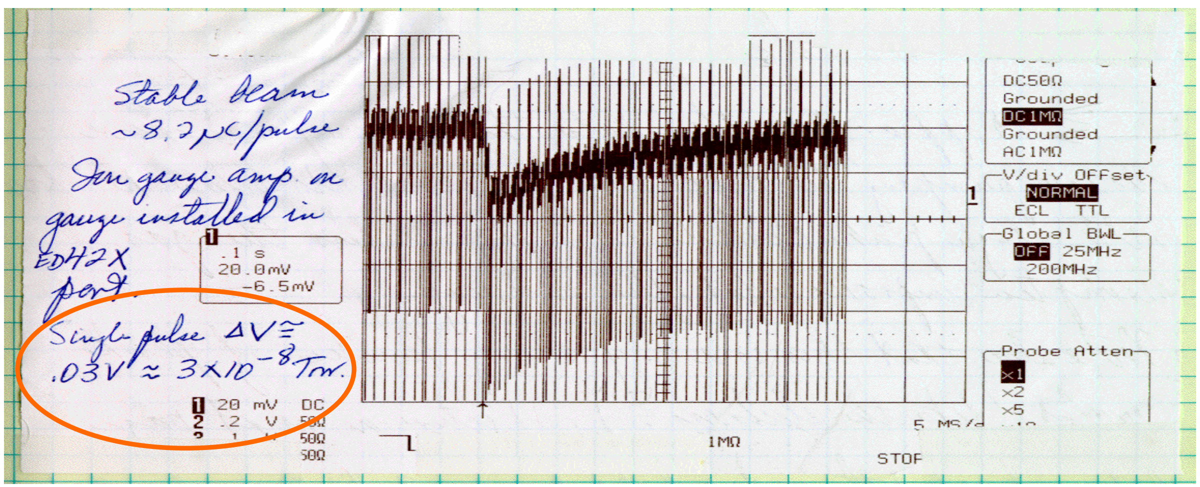
Outline

- Gas desorption, pressure rise observations (stable beams)
  - Fast ion gauge
  - Ion pump pulse
- "first pulse instability"
  - Might be related to gas desorption and re-adsorption
- Status of other e-cloud issues at PSR
  - Sources of initial electrons, which are amplified by trailing edge multipactor
    - Beam losses
    - Residual gas ionization
    - Stripper foil
  - Why does suppression of e's not help the e-p instability?
    - Solenoids on 10% of circumference had no effect on e-p
    - Beam scrubbing effective on e-p in prior years but not so in 2002/3 despite reduction in e-cloud
  - Electron bursts still not understood

Pressure rise for high intensity stable beam (May 2000)22



Electron Signal from RFA (ED42Y)

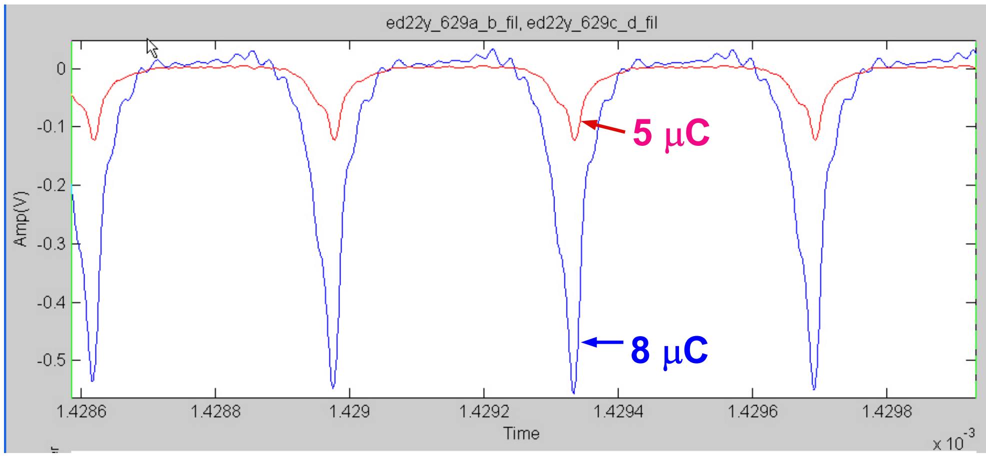


Fast ion gauge signal (installed in a RFA port ED42X)

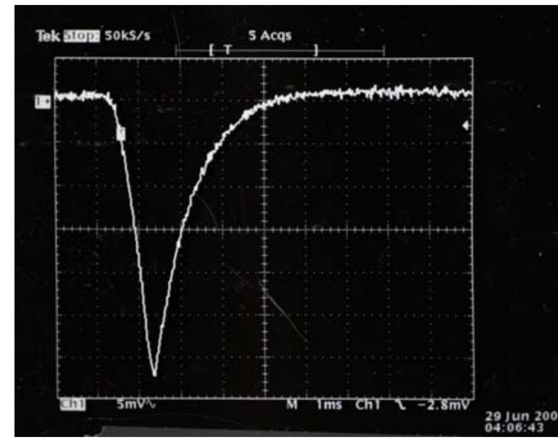
Pressure change from $4x10^{-9}$ Torr to $3.5x10^{-8}$ Torr, rise time ~ 8 ms, decay time ~ 0.5 s

Correlation of Ion Pump Pulse (IP13) with nearest Electron Signal (ED22Y) (effect of beam intensity)

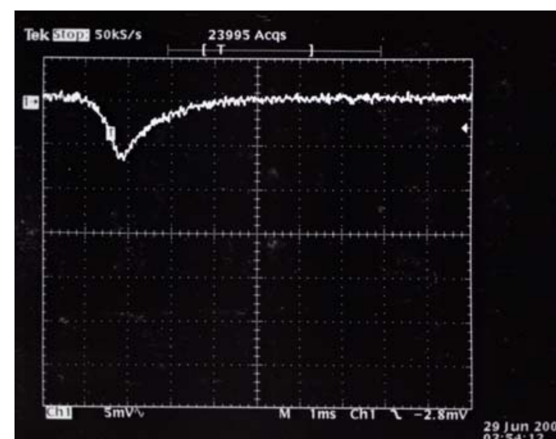
ED22Y Signal Amplitudes at end of accumulation and store



8 μC/pulse 6/29/02



5 μC/pulse 6/29/02



Ratio of ED22Y Amp. (8μC/5μC) = 4.7

Ratio of IP13 Amp. (8μC/5μC) = 5.1

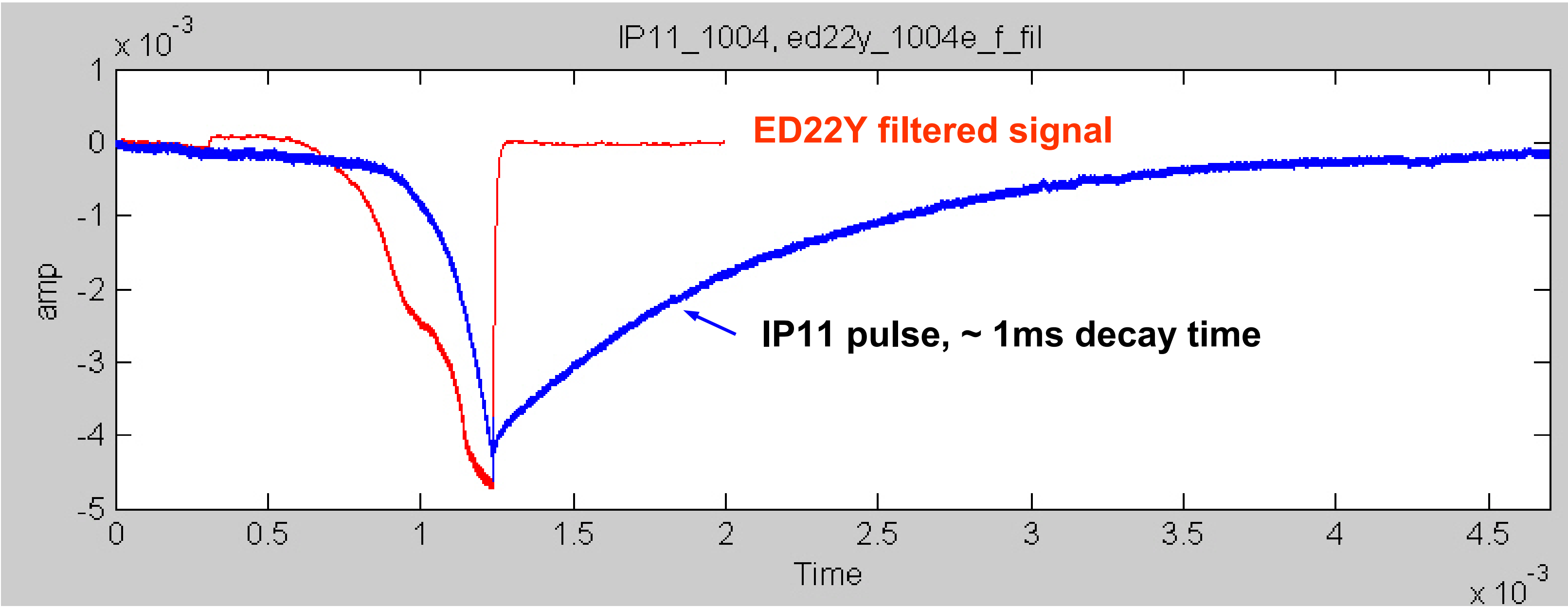
Ion pump pulse scales with beam intensity ~ the same as the RFA signals

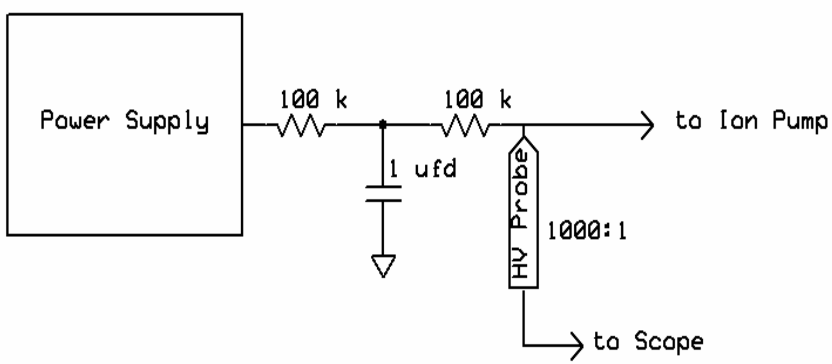
Los Alamos Neutron Science Center

Vacuum Pressure Rise from electron cloud

- Electron Stimulated Desorption (ESD) by e-cloud
- Pressure rise tracks e-cloud signal – factor of 4-5 reduction in both in going from 8.2 to 6.7 μC/pulse
- Pressure rise time (~ 8ms) on previous slide is consistent with conductance of 10 cm beam pipe and housing of ion gauge
- Pressure decay time (~0.3-0.5 s) is consistent with conductance of 10 cm beam pipe and pumping speed of 500 L pumps
- Pressure rise implies we would have a problem at 20 or 30 Hz
  - Implies pressure would be ~ 10^{-6} Torr
  - Beam scrubbing since 2000 reduces it considerably (factor of ~10)
- Pressure rise compared with electron flux hitting the walls implies ~ 1 molecule desorbed per 70 electrons hitting the wall
  - Consistent with ESD cross-section ~10^{-17} cm^2 and coverage of ~ 1 (full monolayer)

SRIP11 Ion Pump Pulse Current (7.1 μC/pulse, 10/04/03)

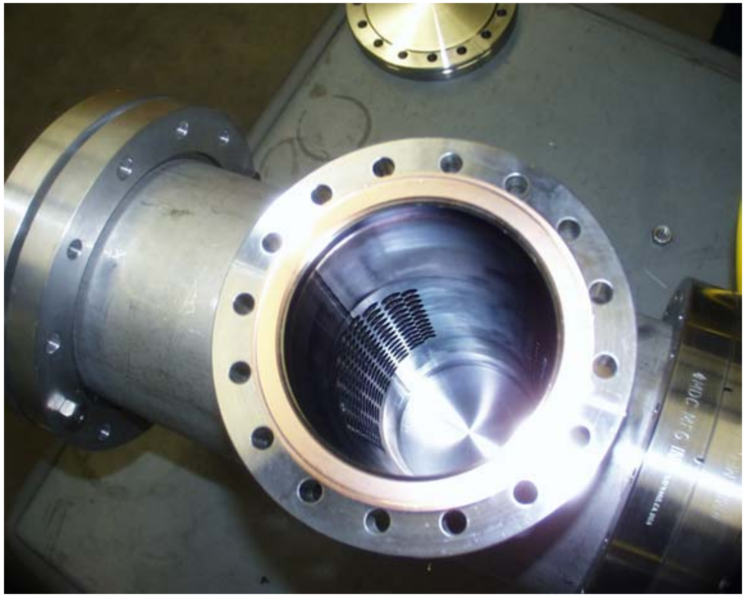




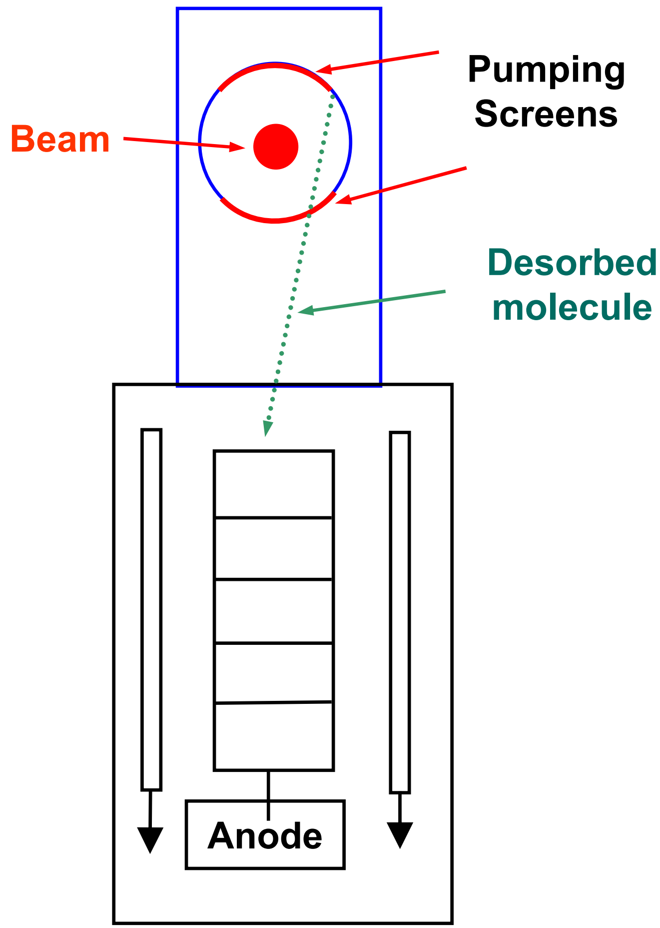
Ion Pump layout

SRIP11

Screened Pump Port



Model for ion pump pulse



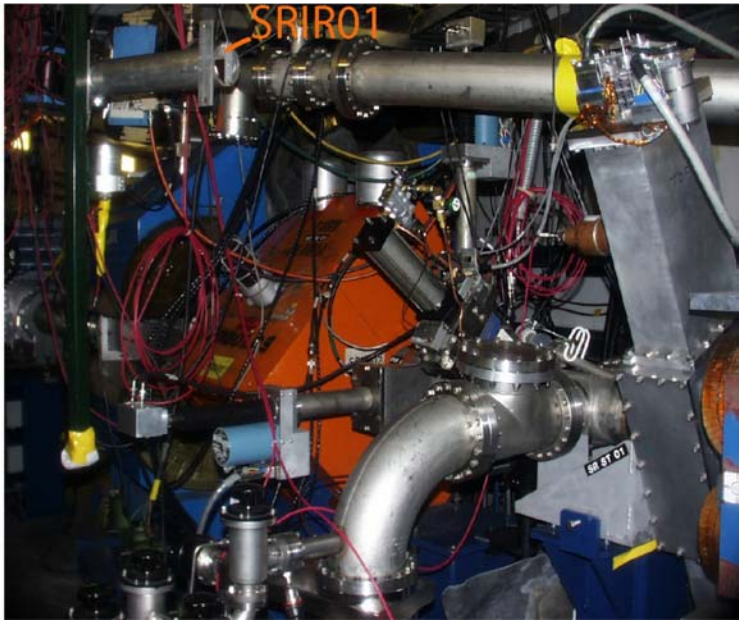
- ESD gas molecules are estimated to come off with ~0.2 eV *
- Those with line of sight to pump interior will arrive in ~50 – 250 μs (at typical pump), depending on molecular weight.
- Some multipacting electrons may also get through the screen and desorb gas closer to the pump interior.
- Sorption pumping speed of interior of pump is ~ 4000 l/s
  - Implies decay of ~ 35/4000 or ~ 1ms
- Bulk of desorbed gas is thermalized and pumped through conductance limited beam pipe by 400 l/s ion pumps
  - Decay time of ~ 0.3-0.5 s

* e.g. N_2O on Ru see Z.W. Gortel and Z. Wierzbicki, Phys. Rev. B 43 (1991) 7487.

Other evidence in support of model

- No signals where line-of-sight is blocked (IP02, IP31, IP32)
- Strong signal at IP52
  - 15 cm beam pipe, only one screen
  - Short drop (larger solid angle)
  - Changes with added store time
- Pump signal tracks electron detector signal
  - As intensity changes
  - Over time (beam scrubbing)

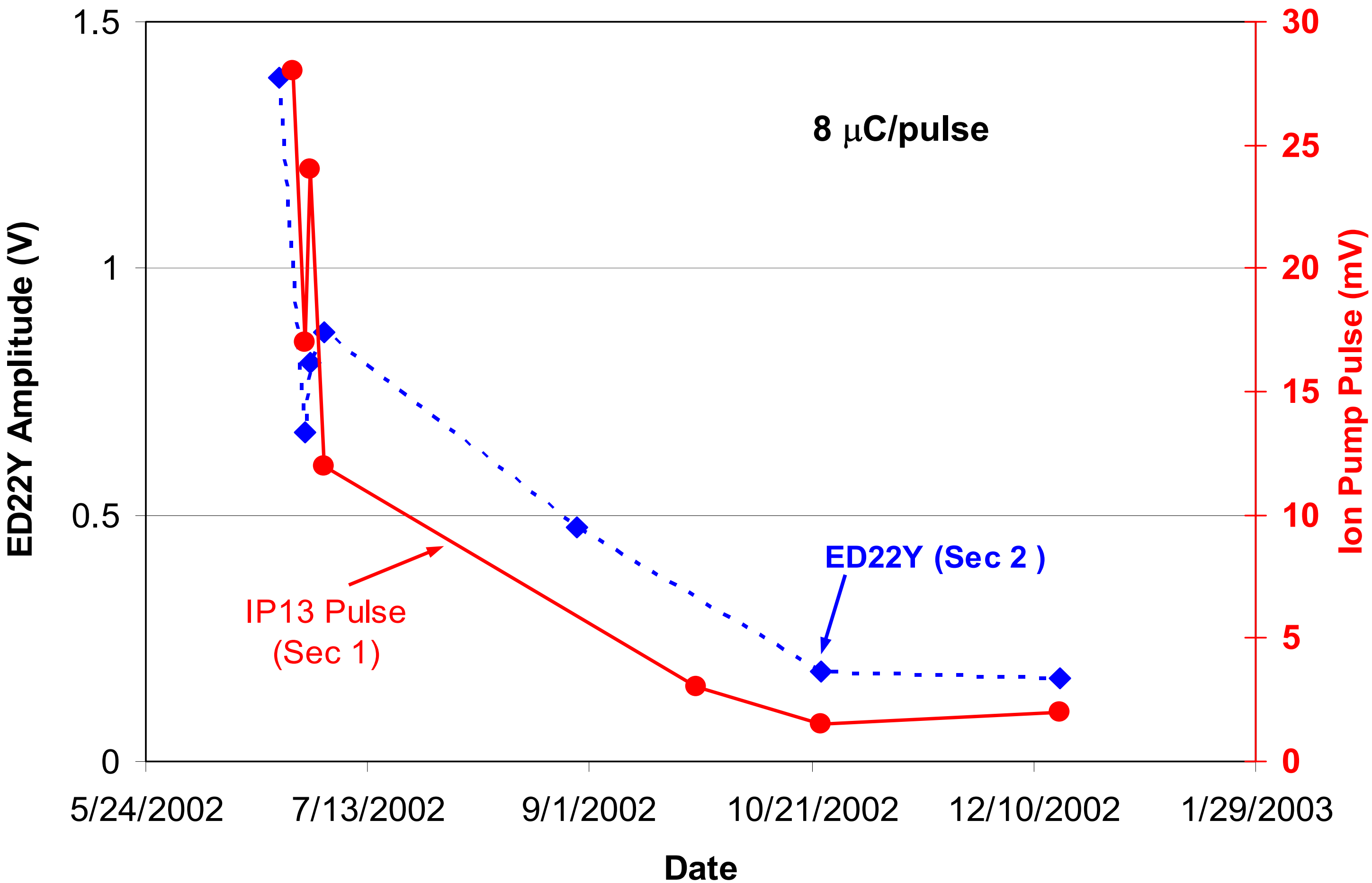
Layouts for Ion Pumps IP02 and IP51/52



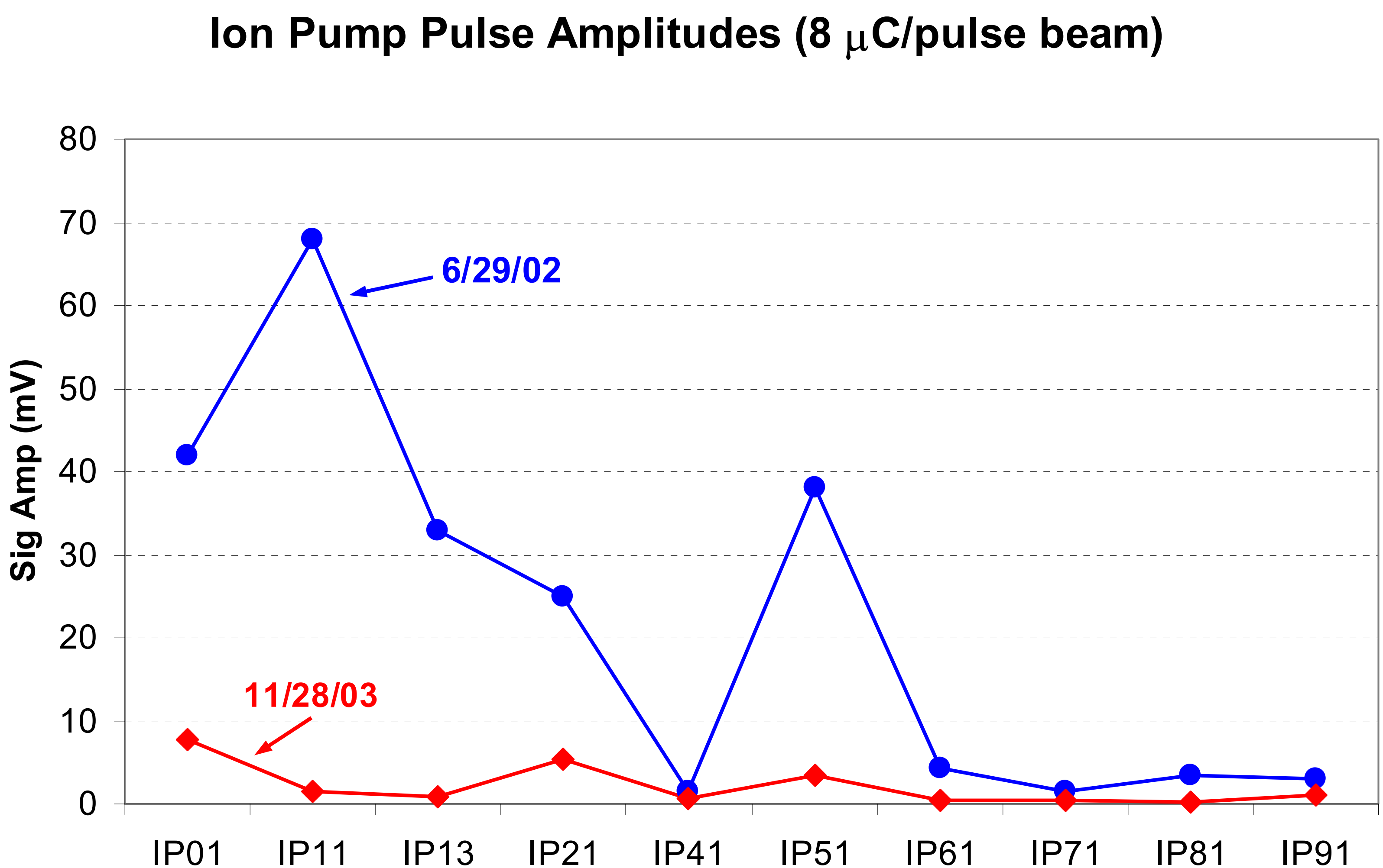
IP02 at Stripper Foil Location

IP51/52 layout

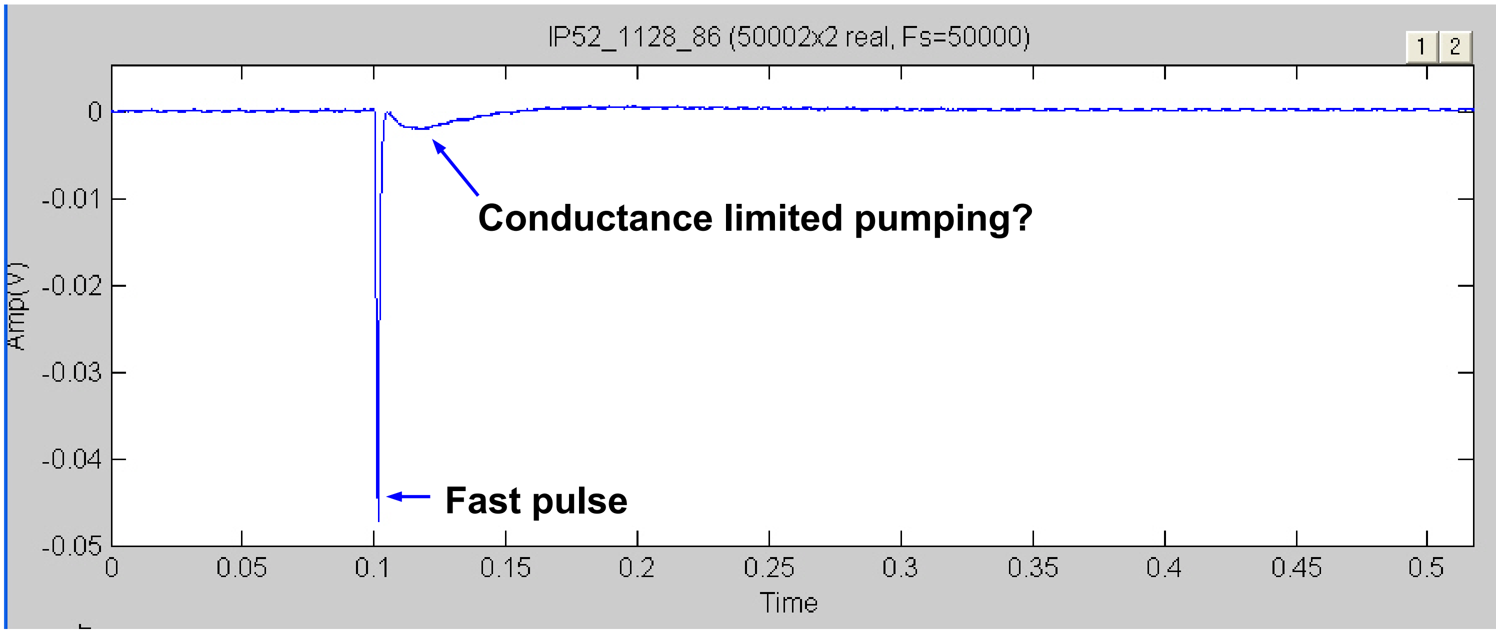
Correlation of Ion Pump Pulse with Electron Signal
(effect of beam scrubbing in 2003)



Comparison of data 11/28/03 with 6/29/02



Can we observe conductance-limited pumping of thermalized gas?



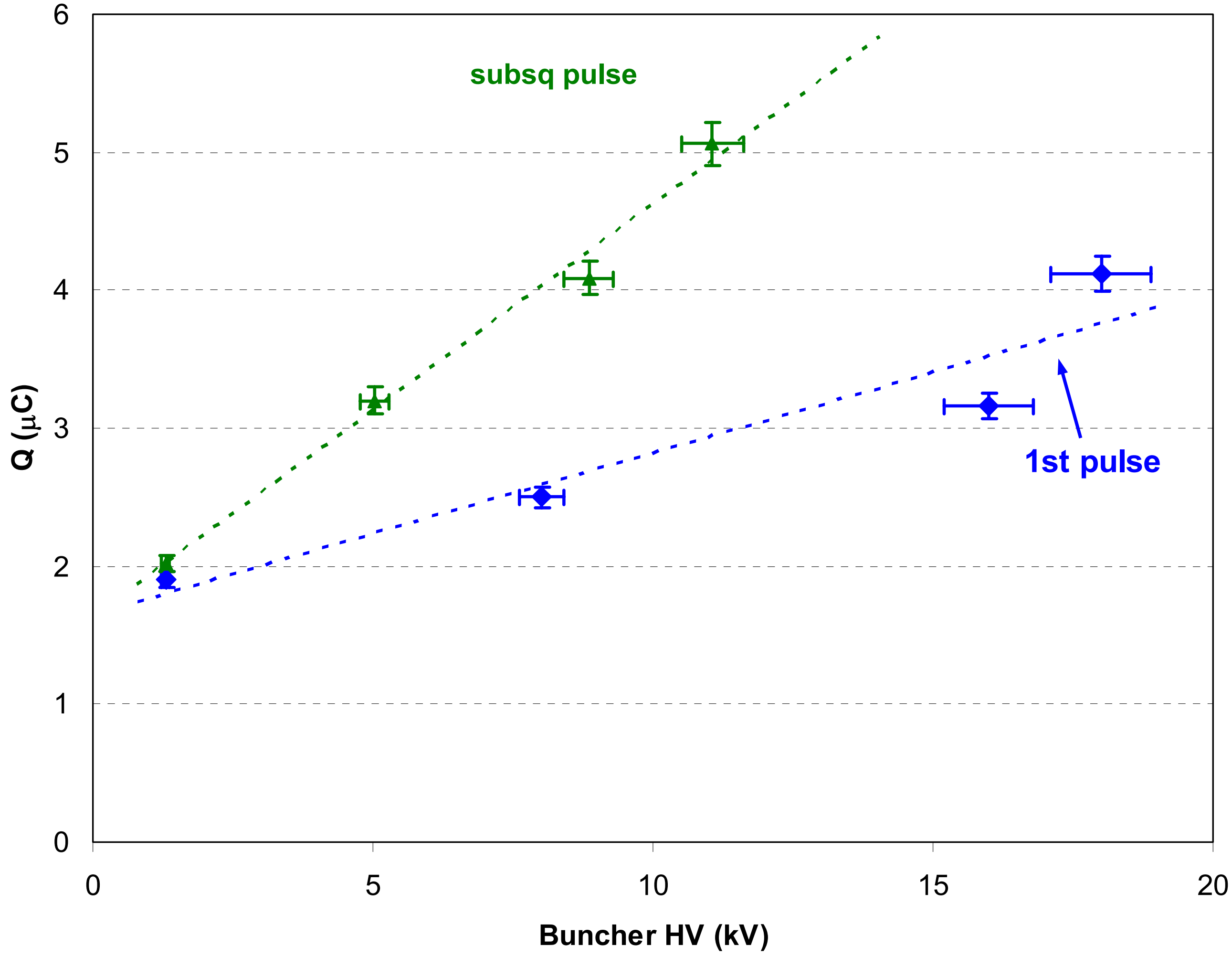
Assessment of Ion Pump Pulse as an E-cloud diagnostic

- A simple diagnostic to implement, gives a more complete sampling over the ring
- Tracks nearby RFA signals over a few months time, which suggests it can be a useful relative monitor of e-cloud generation
  - Will this still hold true as surface “coverage” changes? Or as adsorbate composition changes?
- Appears to be responding primarily to desorbed gases with line-of-sight path to pump interior
  - As such, samples gas desorption by e-cloud in small region around pumping port
  - Implies signal is a function of both e-cloud flux striking the wall and the surface chemistry/physics
- Not a substitute for e-detectors but provides useful additional information on ECE

"1st Pulse Instability" Phenomenon at PSR

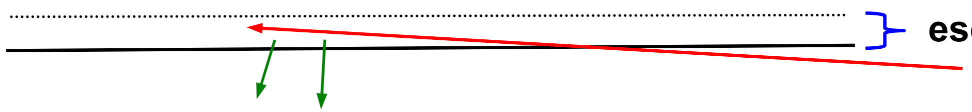
- Usually observed in single pulse PSR to WNR operations
  - Typically have long wait (10-100 minutes) between high intensity pulses
- After beam is off for several minutes, 1st intense beam pulse is unstable while subsequent (within seconds) pulses of the same intensity are stable
- All the characteristics of e-p except 1st pulse has lower threshold
- Typically occurs at start up after long shutdown for maintenance etc
- Minimum wait time for 1st unstable pulse starts out at 2-3 minutes (mono layer formation time?), over a period of 2-3 weeks grows to ~15 min, then disappears (beam scrubbing?)
- Don't have a satisfactory model for this phenomenon but imagine that gas desorption and re-adsorption play a role
  - Some evidence that SEY at foil changes markedly on first pulse after a few min wait
  - Precursor pulse ~1/50 the intensity a few seconds before the intense pulse appears to prevent the 1st pulse instability (need to verify this in a more control setting)

1st Pulse Instability Threshold Curves 6/22/02



Sources of initial electrons for PSR

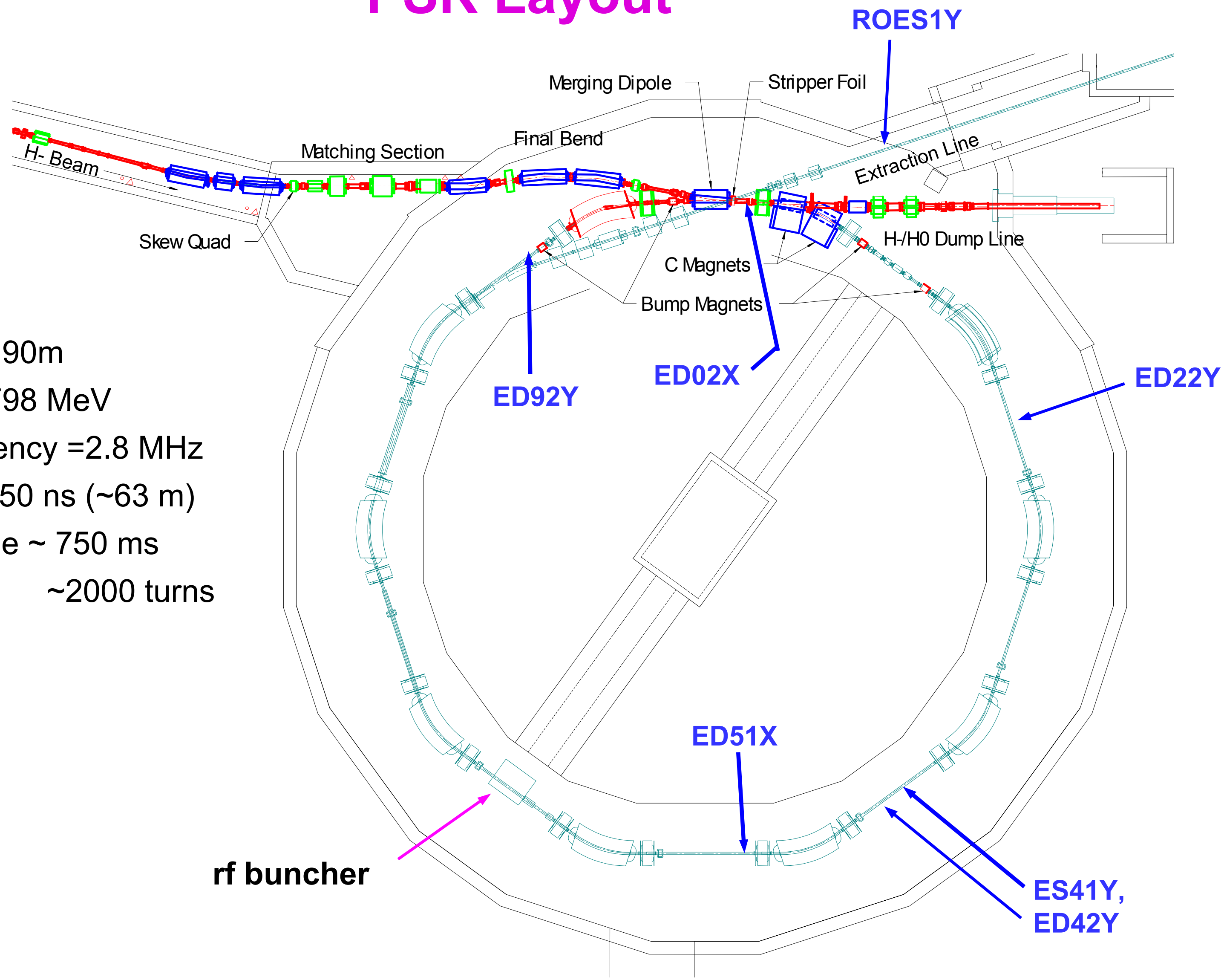
- Crucial input for simulations of what we can measure at PSR
- Assumption that intial e's are from grazing angle losses, uniformly distributed around the ring with 100 e/lost proton is too simplistic for realistic simulations of PSR experiments
  - The 100e/proton comes from model by Sternglass for grazing angle (cos θ <0.002) scrapping at a surface and is supported by measurements of Thieberger etal



e/proton goes ~ with $\cos(\theta)^{-1}$

  - Losses are anything but 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). This strikes the walls at 10's of mr.
    - e/scattered particle down factor 10 or more
  - Electrons from residual gas ionization are often neglected as being few in number and born near the beam not at the walls

PSR Layout



Circumference = 90m

Beam energy = 798 MeV

Revolution frequency =2.8 MHz

Bunch length ~ 250 ns (~63 m)

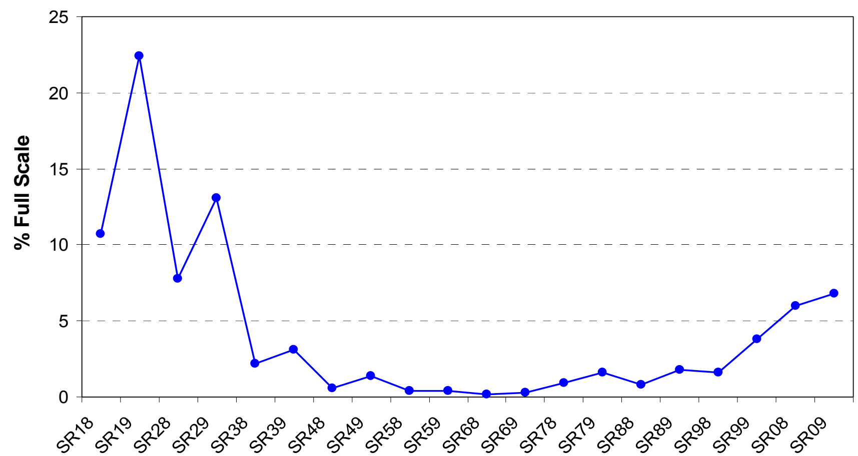
Accumulation time ~ 750 ms

~2000 turns

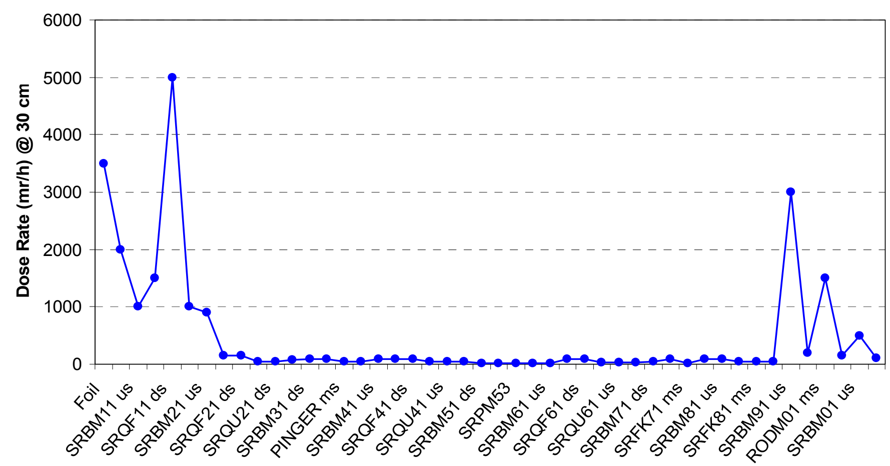
Ring Beam Loss and Activation

- Ring losses are from
  - Foil scattering (60-70%)
    - Nuclear and Large Angle Coulomb
    - Lost in sect 0, 1 and at extraction region
  - Production of excited states of H0 (n=3,4..) that field strip part way into first dipole d.s. of stripper
    - Lost in first 2-3 sections after foil
- Ring Losses concentrated at injection and extraction
- Ring Loss Monitors
  - Max = 22.4
  - Min = 0.2
  - Ratio Max/Min = 112
- Ring Activation @ 30 cm
  - Max = 5000 mRad/h
  - Min = 10 mRad/h
  - Ratio Max/Min = 500

Ring Loss Monitors 1/15/03 119 μA@20 Hz



Ring Activation 12-02-2002 (2 h after shutdown)



Other Problems with Simplistic Loss Model

- We consistently see more prompt electrons in section 4 than in sections 2 and 9 where losses are considerably higher

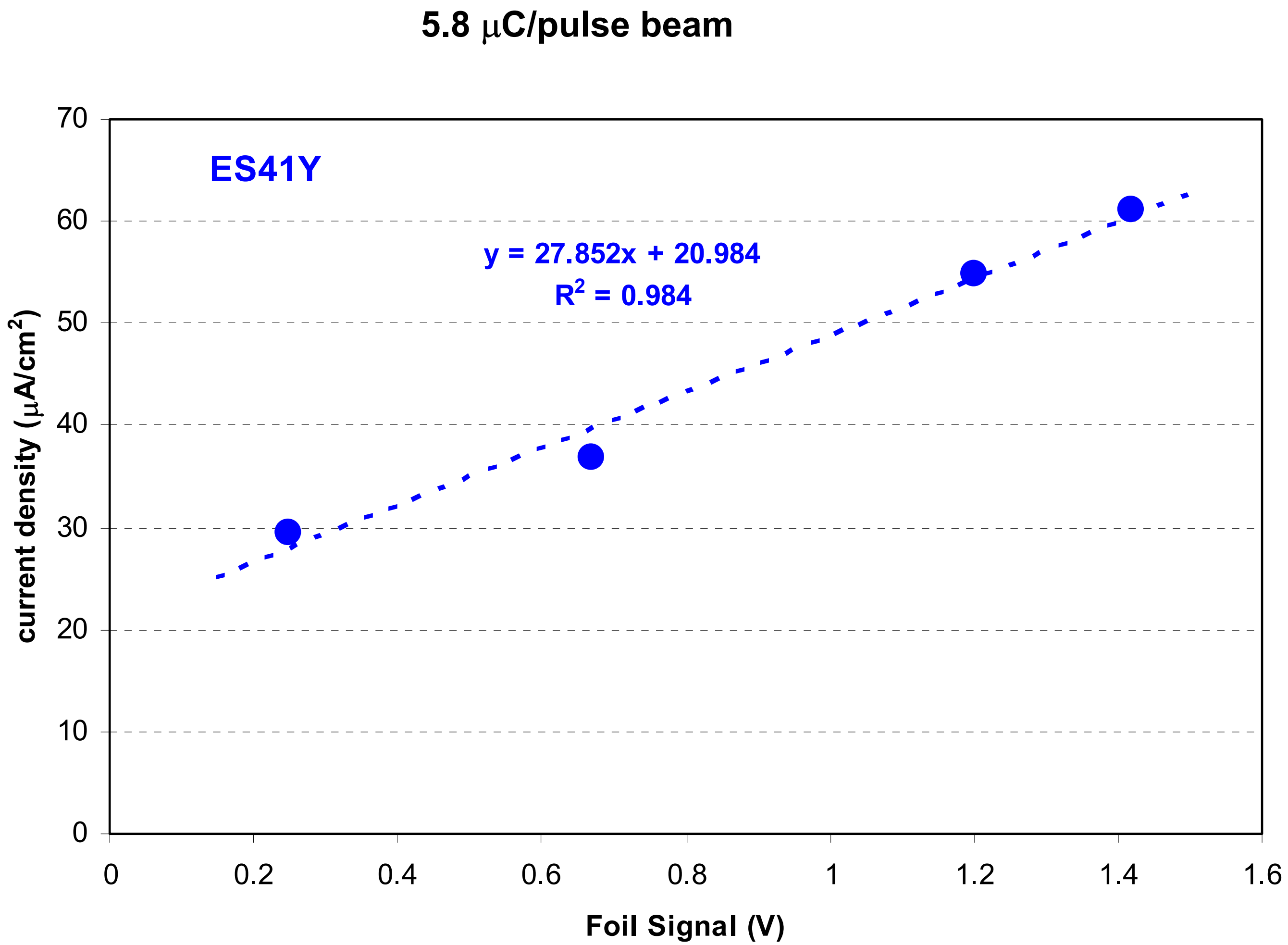
section	Ratio of electrons to section 4	Ratio of losses to section 4	Ratio of activation to section 4
9	~1/3	~17	7 - 35
2	~1/2.5	~7	~ 2
1	~6	~55	~ 50

- What could be different?
  - Loss signal and activation measures don't track local electron production very well
  - SEY is not measured
  - Beam pulse transverse profile
  - Vacuum (section 4 is worse by ~ factor of 5-10)

Experiments on effect of beam losses and vacuum

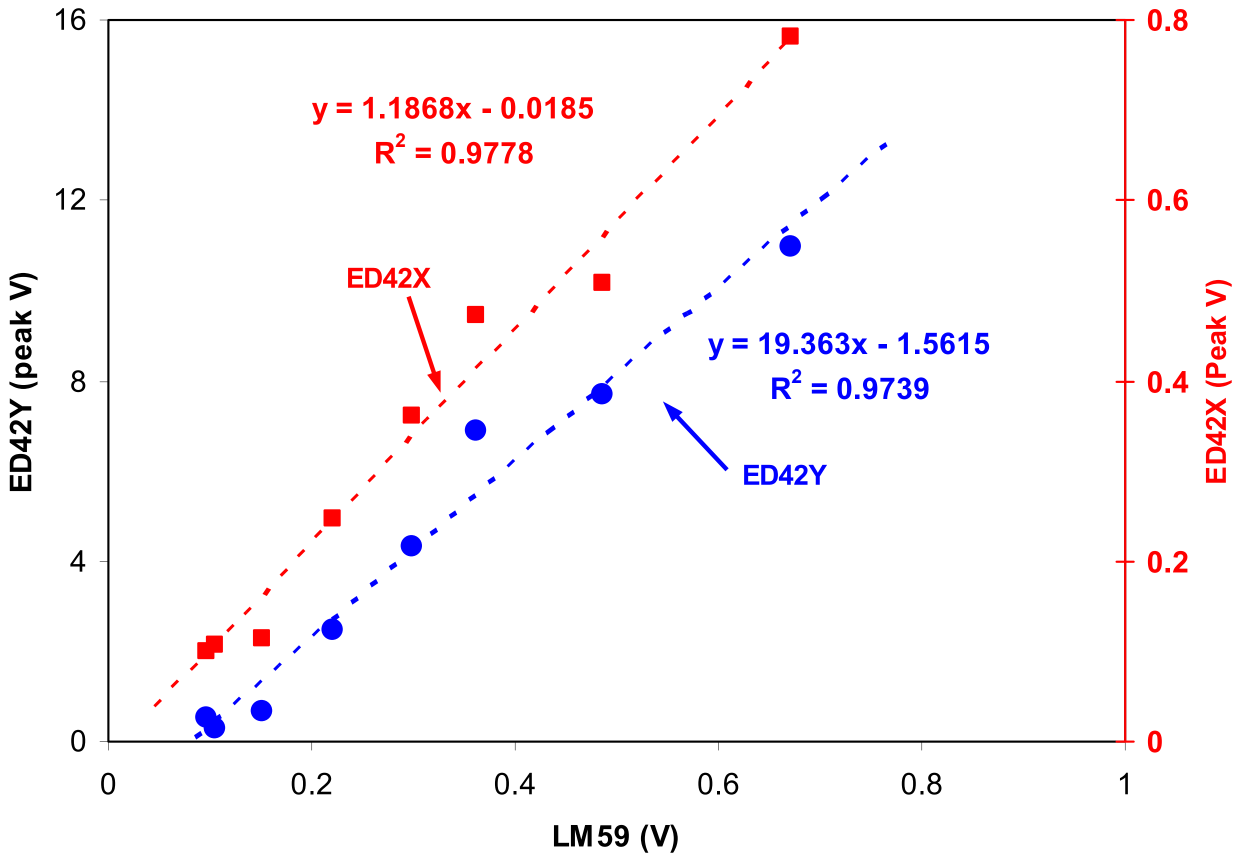
- **Changed beam losses two ways**
  - **Move stripper foil into the beam**
    - Changes amount of foil scattering but all other beam parameters fixed
    - Monitor foil current
  - **Introduce local closed orbit bumps, measure losses with local loss monitor (scintillator with ~ 10 ns resolution, if desired)**
  - **Find that prompt electron signal in RFA is linear in 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**
- **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)

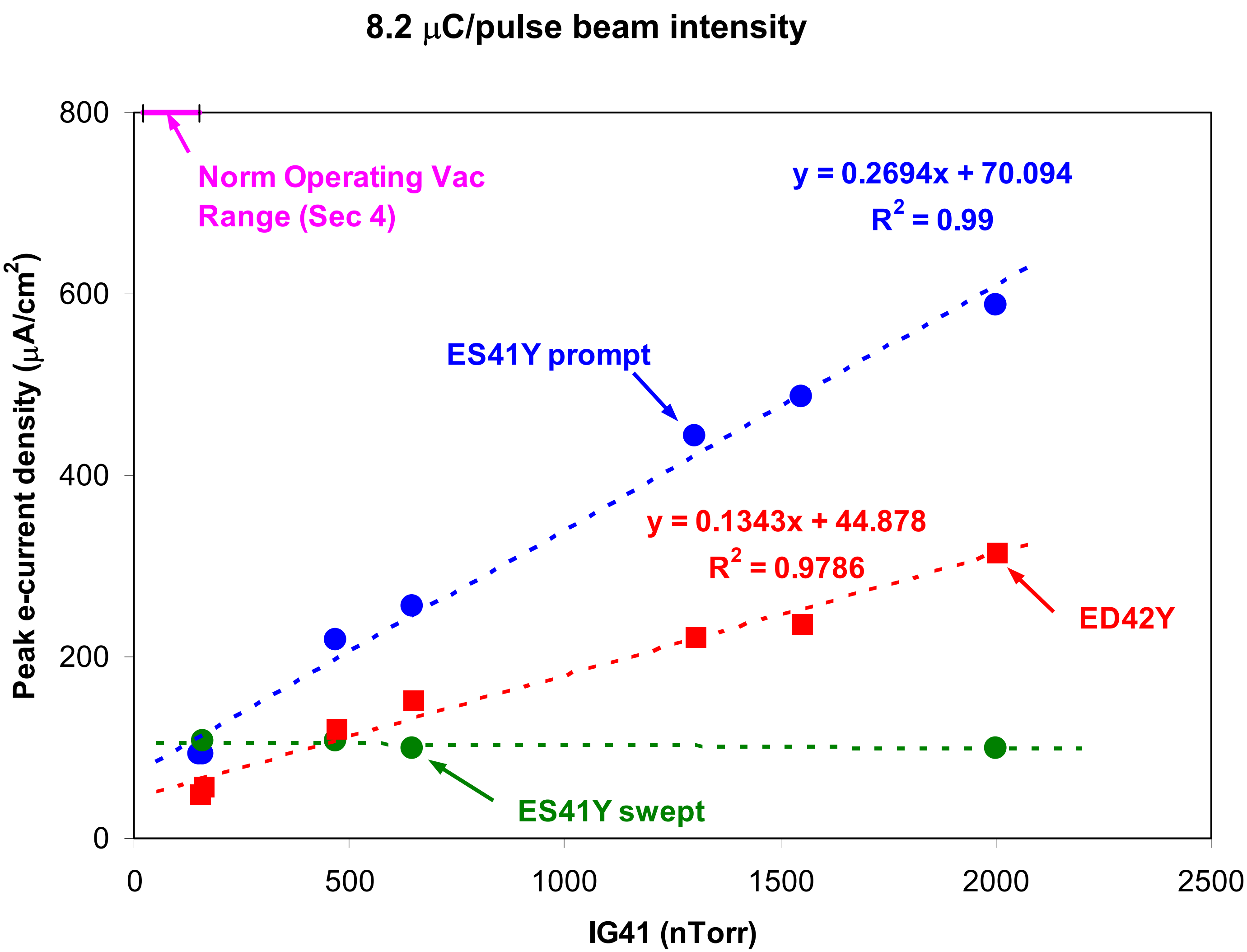


Effect of changing losses by local bump

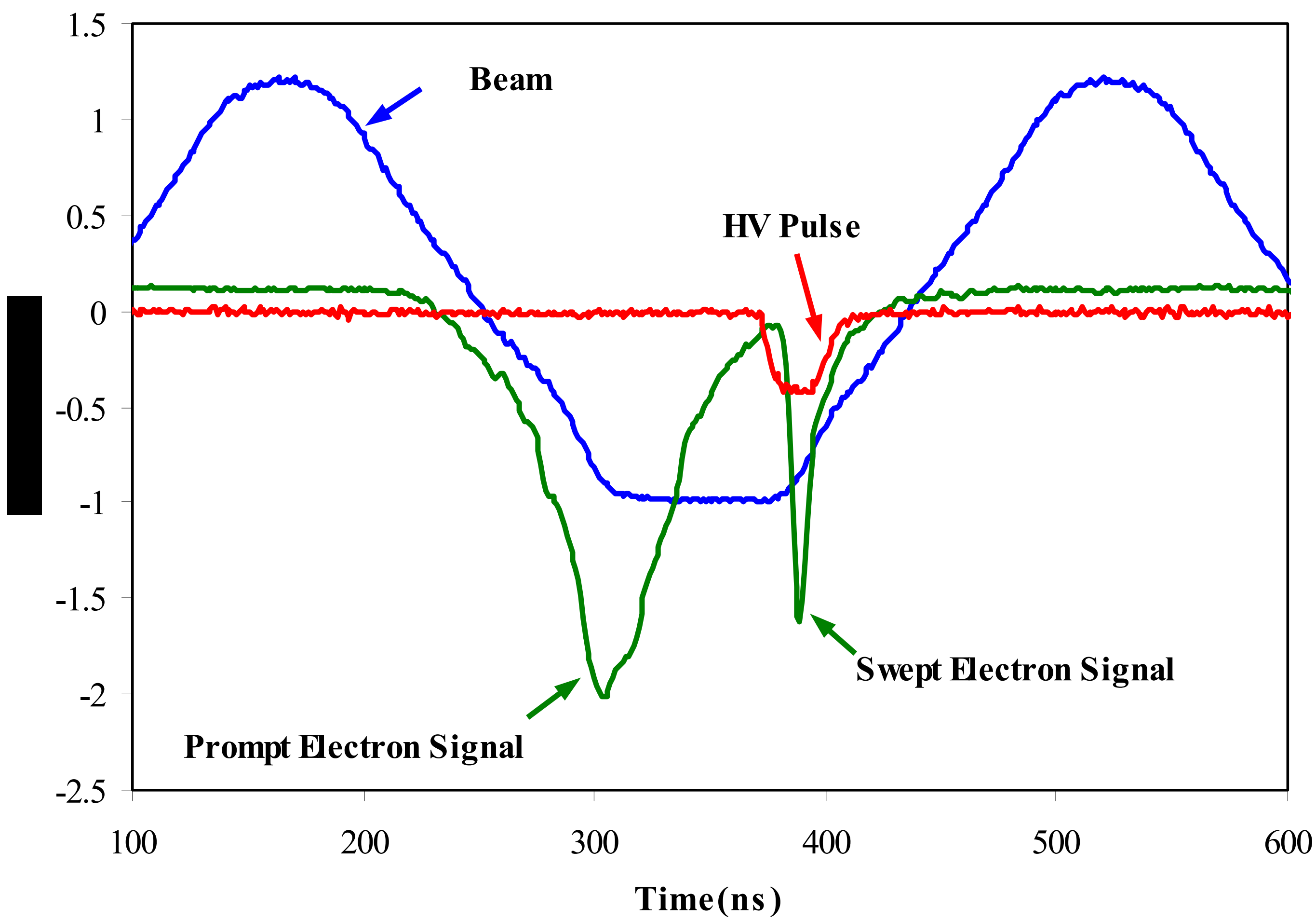
Signals from horizontal and vertical RFAs plotted as function of local loss monitor as horizontal bump was varied from -6 to + 8 mm. Beam intensity was 8.1 μC/pulse



Effect of changing vacuum pressure in Sect 4



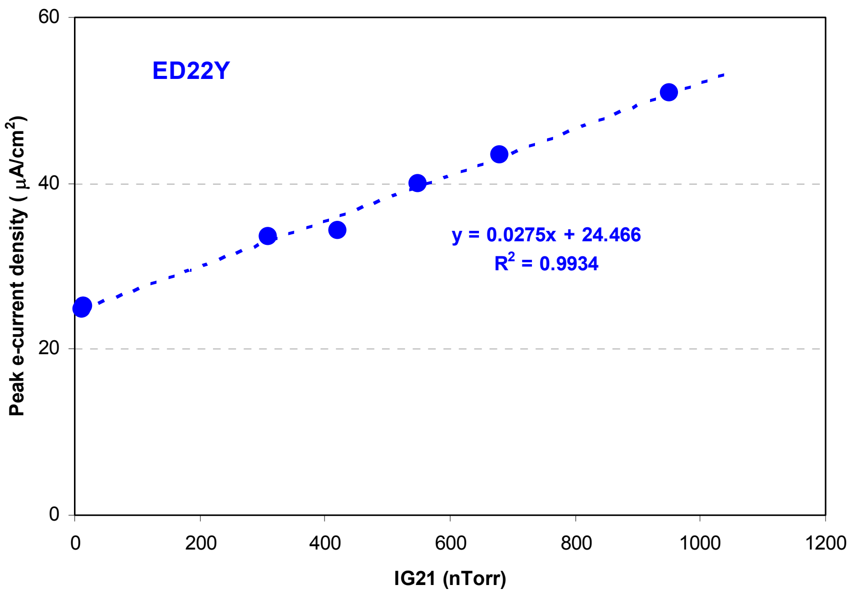
Measurement of electrons surviving the gap



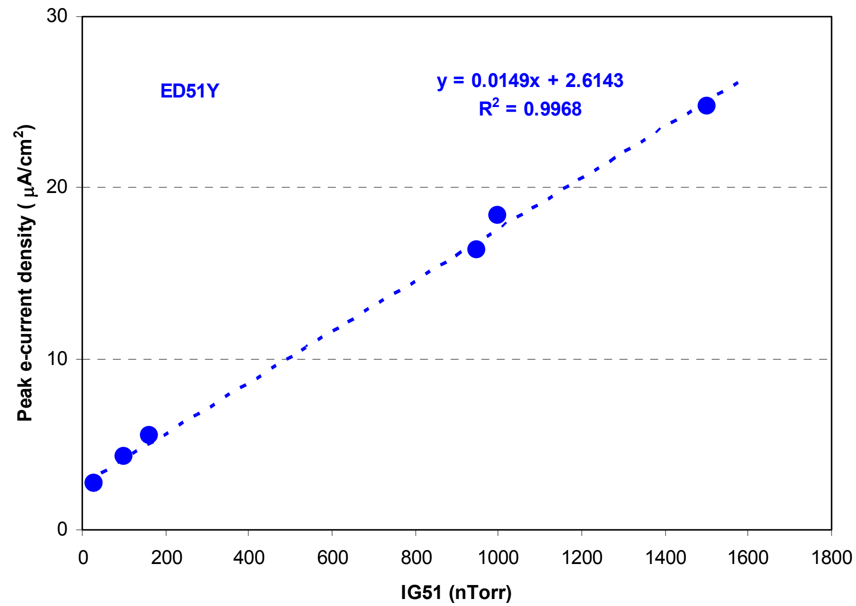
Effect of changing vacuum pressure

At beam intensity of 8.2 μC/pulse

Section 2



Section 5



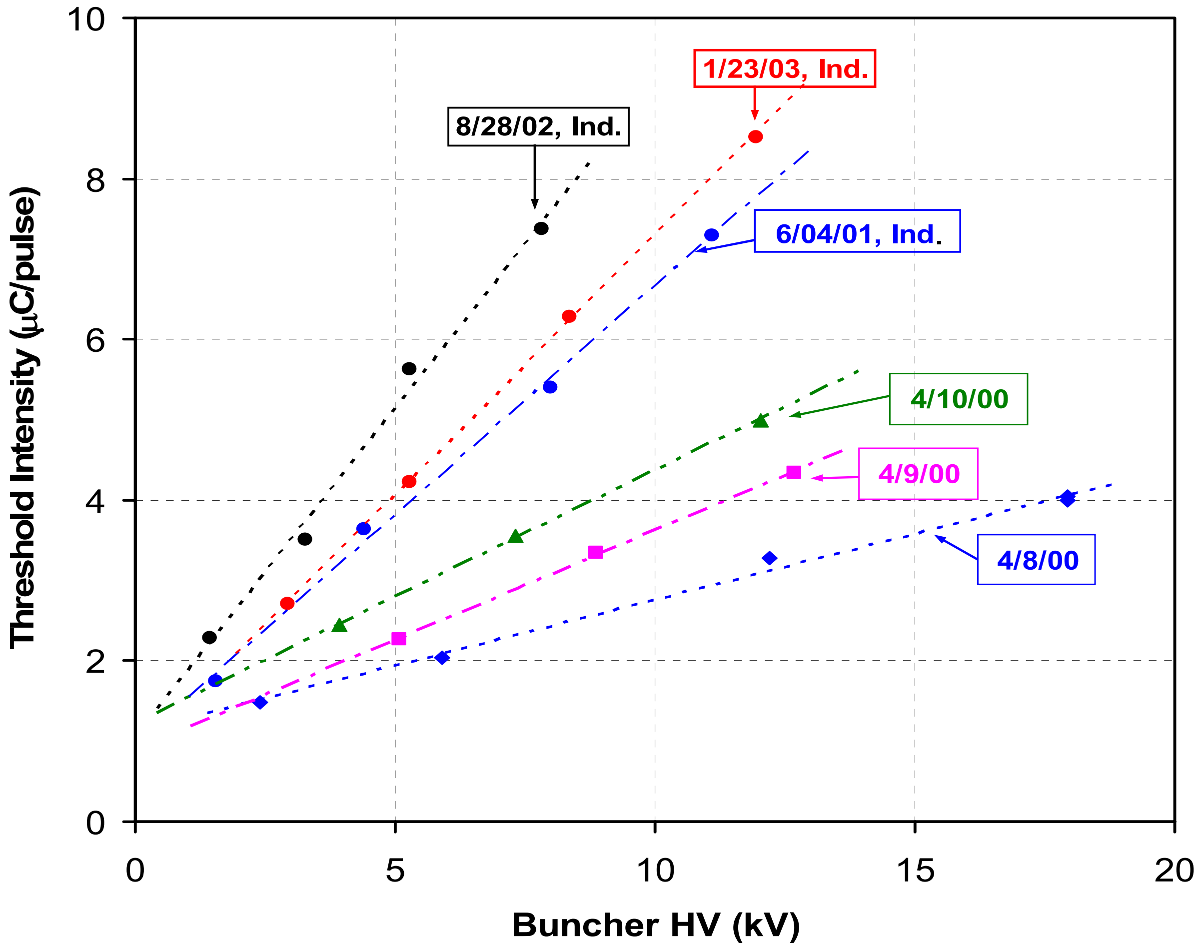
Electron suppression has not yet provided a cure for e-p at PSR

- **In 2002 tried weak solenoids over 10% of the circumference in drift spaces with no effect on instability threshold**
- **Beam scrubbing in 2000-2001 was effective in improving e-p instability threshold and has continued to reduce prompt electrons in 2002 and 2003 but no improvement in e-p threshold in 2002/3**
- **Experience with TiN gave mixed results**

Test	**Date**	**Beam Intensity**	**Prompt e reduction factor**	**Swept e reduction factor**
Section 5	1999	8.5 μC/pulse	>100	N. A.
Section 4	2002	8 μC/pulse	no intial reduction	none
Section 9	2002	7 μC/pulse	~40	N. A.
Section 4 after 2 months of conditioning	2002	8 μC/pulse	~ 5	None in the saturation region

Summary of Beam Scrubbing at PSR

Effect on e-p instability threshold curves

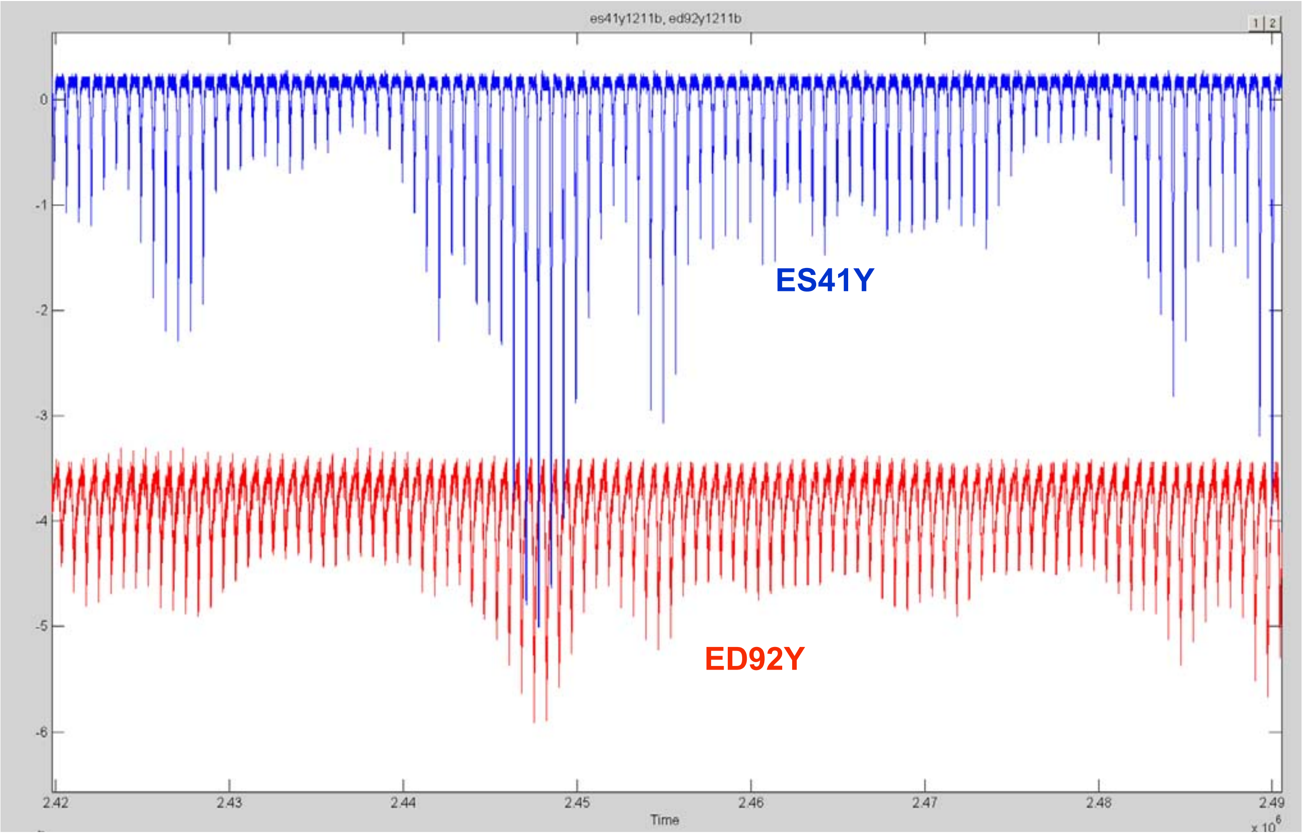


Summary/Conclusions of e-cloud observations at PSR

- **Multipactor gain (prompt signal) is a strong function of beam intensity**
  - **also depends on beam pulse shape, SEY (beam scrubbing)**
  - **shows no sign of saturation in drift spaces**
  - **will it saturate elsewhere especially in quads?**
- **Transverse coherent motion of the beam also increases the prompt signal**
  - **Electrons strike wall with higher energy**
  - **More initial electrons from higher losses**
- **Prompt signal depends linearly on initial electrons from losses and vacuum pressure**
  - **At foil also depends on various sources of electrons from foil**
    - Stripped electrons, secondary emission and thermionic emission
- **Electrons surviving the gap saturate in drift spaces at ~ 3-4 pC/cm (line density) or ~2.6-3.5 x 10^5/cm^3 (spatial density)**
  - **Presumably so do those in dipoles**
  - **What happens in quadrupoles? Higher density of trapped electrons?**

Electron Bursts are not understood

- **Some evidence that effect is carried by the beam**

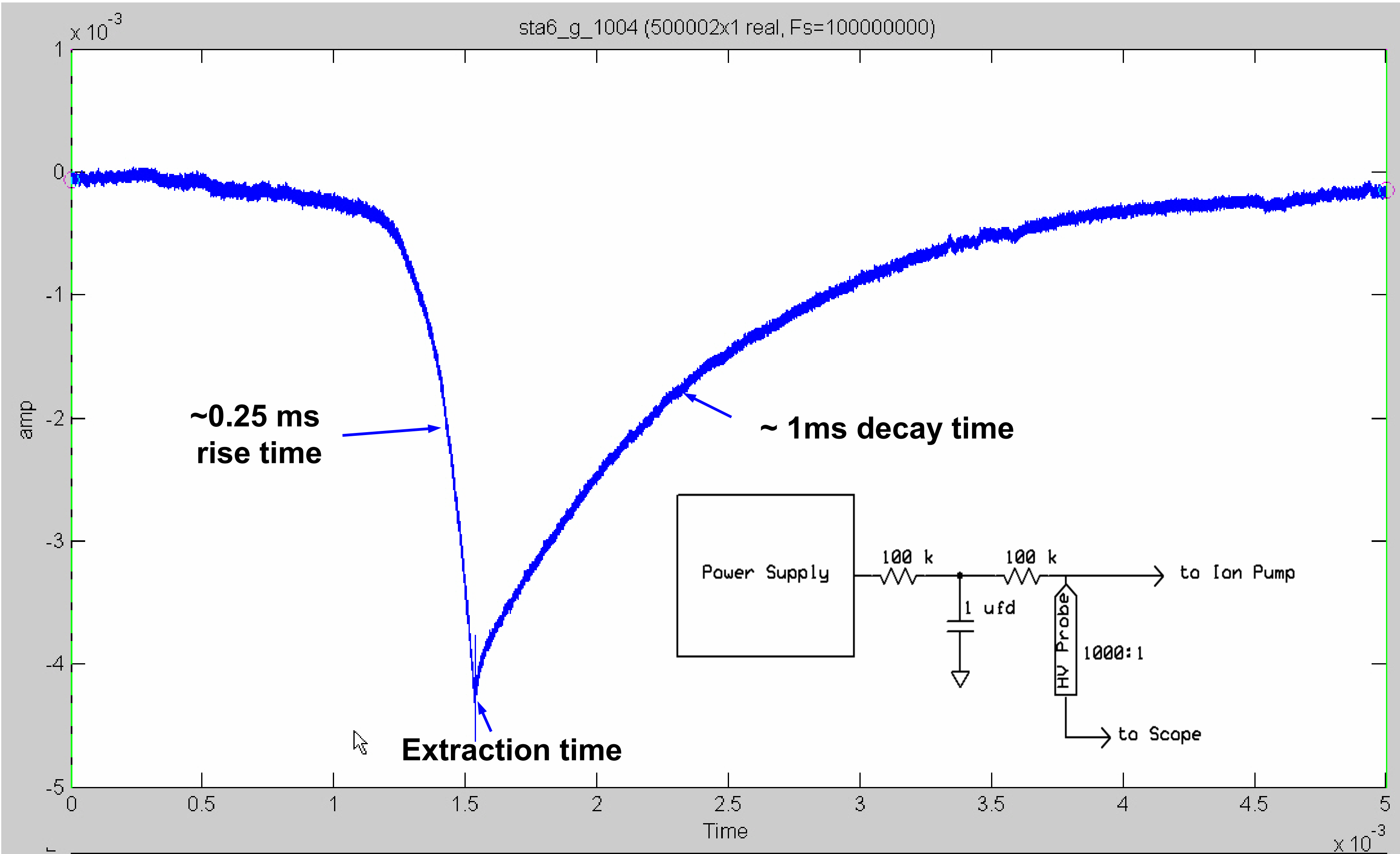


Summary and Conclusions

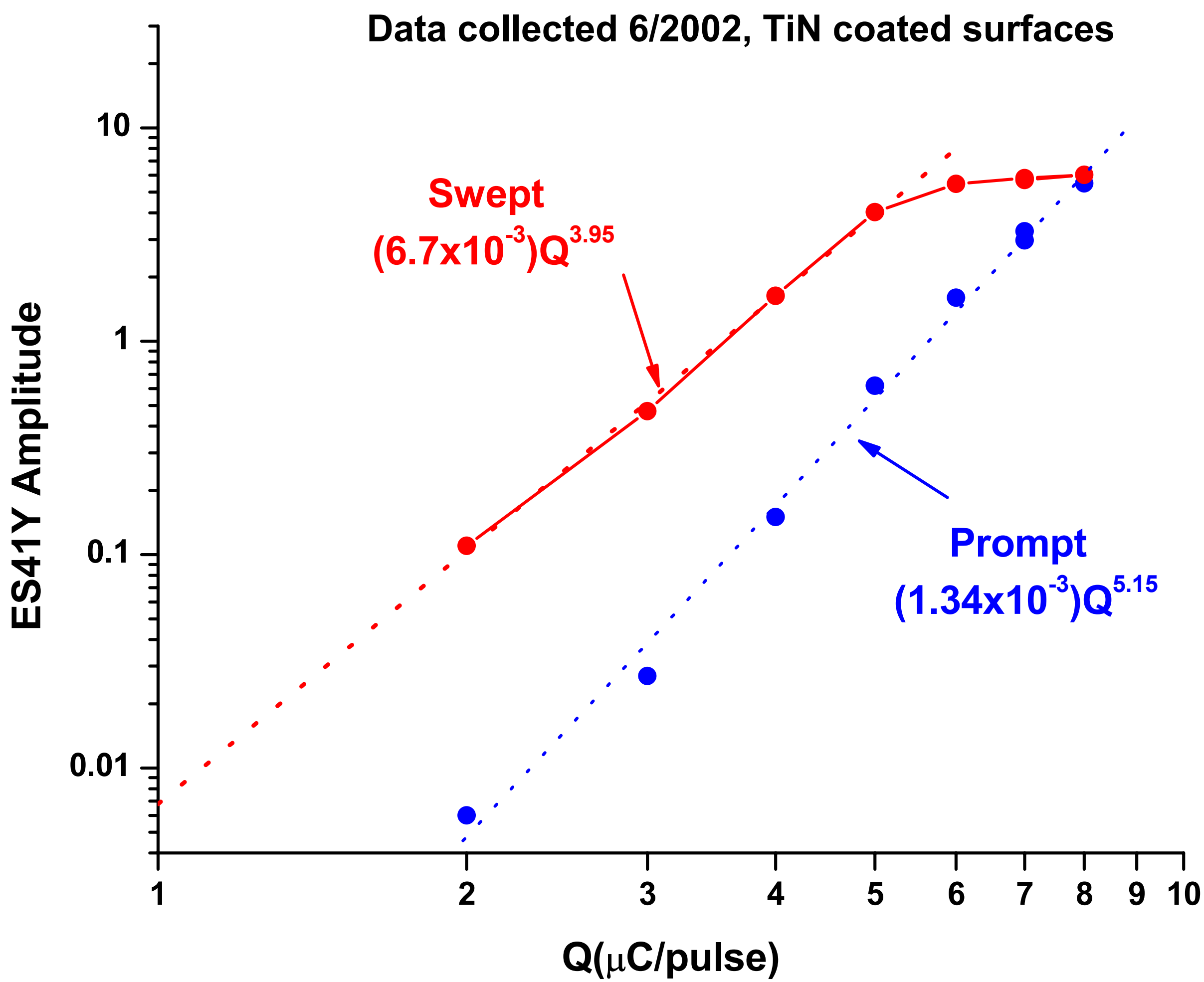
- Gas desorption occurs at PSR but the pressure rise is not an operational problem as once feared
  - Benefit of beam scrubbing
  - Low duty factor ~2%
- Ion pump pulse is a simple diagnostic, provides useful information, but not a substitute for good electron detectors
- The 1st pulse instability phenomenon at PSR is not understood
- Both beam losses and residual gas ionization are sources of initial electrons at PSR
  - Beam losses are likely the dominant source in most situations at PSR and are not uniformly distributed around the ring
  - Initial electron from losses are very properly determined
- Need to study electron cloud generation and trapping in PSR quadrupoles
  - Initial electrons from beam losses should be highest here
  - Electron trapping in quadrupoles could be crucial
- Beam scrubbing is still reducing the strength of the e-cloud in PSR but no longer affects the e-p instability threshold
- Weak solenoids over 10% of the circumference had no effect on e-p threshold
- Experience with TiN coatings gave mixed results
- Electron bursts are still a mystery
- Still need to find a way to suppress the electrons driving the e-p instability

Backups

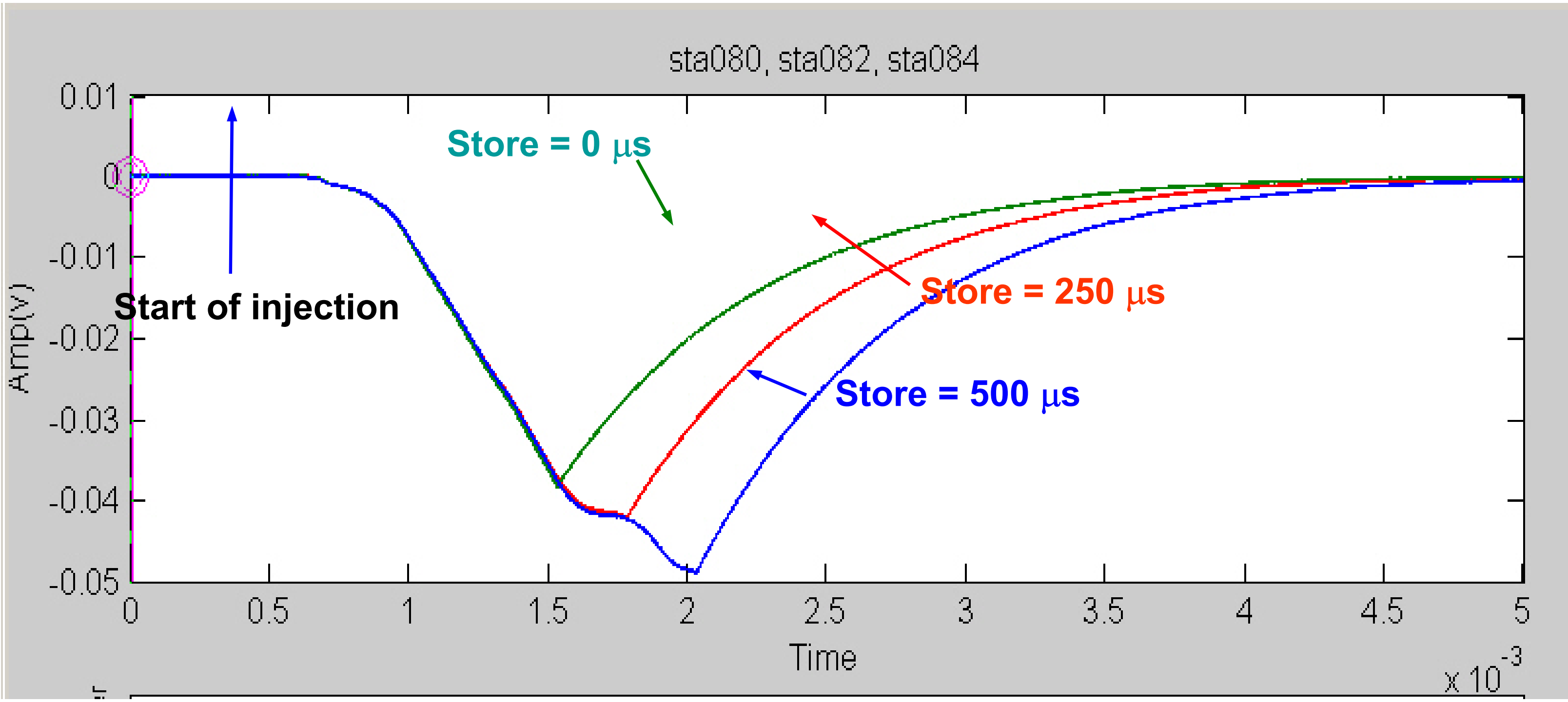
SRIP11 Ion Pump Pulse Current (7.1 μC/pulse, 10/04/03)



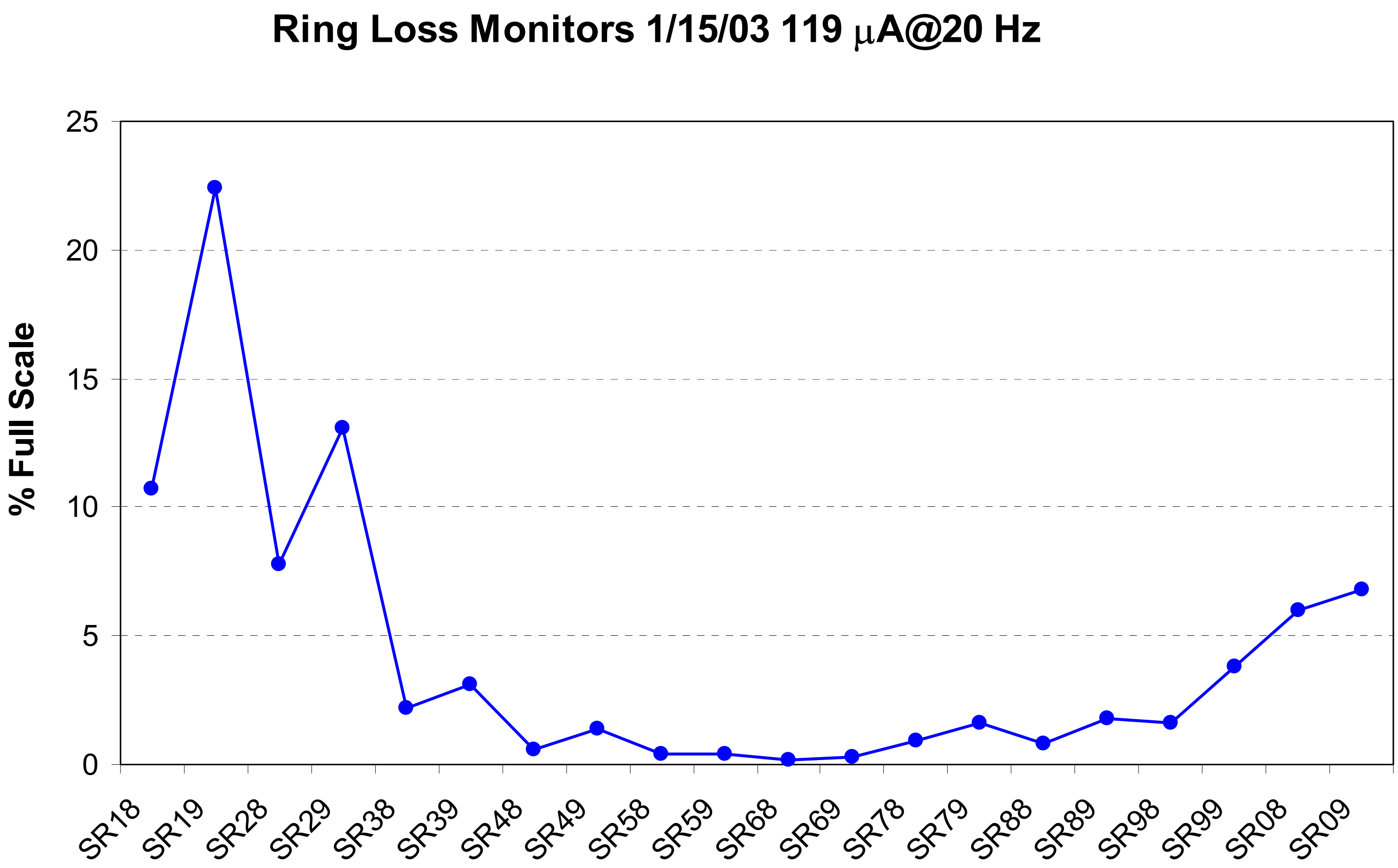
Saturation of electrons surviving the gap



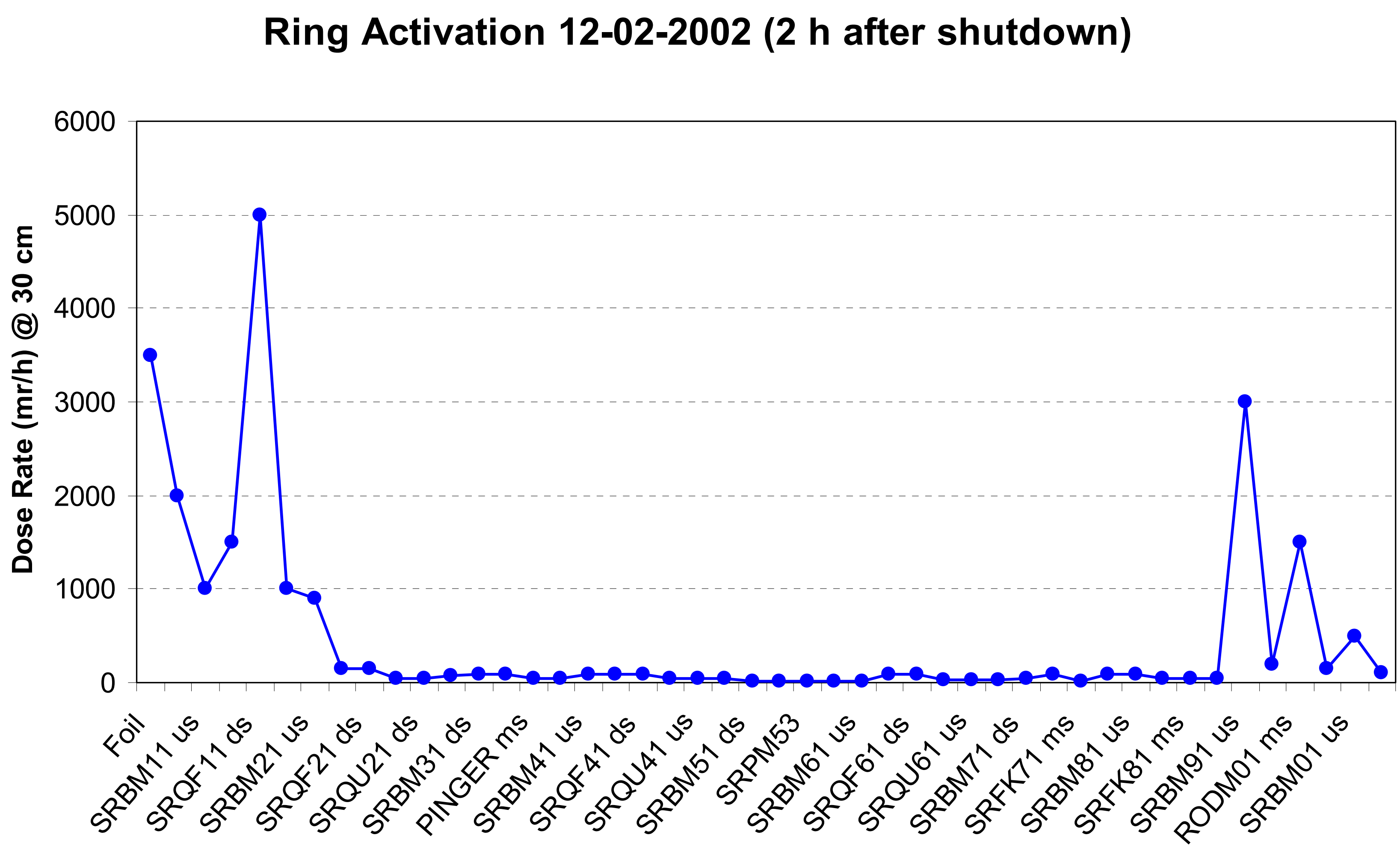
Effect of Added Store Time on IP52 11/28/03



Ring Beam Loss Monitor Distribution



Ring Activation



Some remaining issues

- **Where are the electrons driving the instability?**
  - **Those surviving the gap in drift spaces fall off rapidly with intensity below ~ 5 μC/pulse (~I^6) too fast for linear threshold intensity curves**
  - **Are they the ones trapped in quads? We really need some observations of electrons in quads**
- **How to suppress the e's driving the instability**
  - **Very large suppression of multipactor electrons to bring them well out of saturation**
    - Large reduction in losses is difficult at PSR without a rebuild
    - Large reduction in SEY beyond beam scrubbing (NEG materials?)
  - **Clearing fields are tricky**
- **Are other impedances (steps, stripper cavity etc) contributing to e-p?**
- **Will active damping cure e-p at PSR?**