Electron Cloud Generation and Trapping in a Quadrupole Magnet at the LANL Proton Storage Ring

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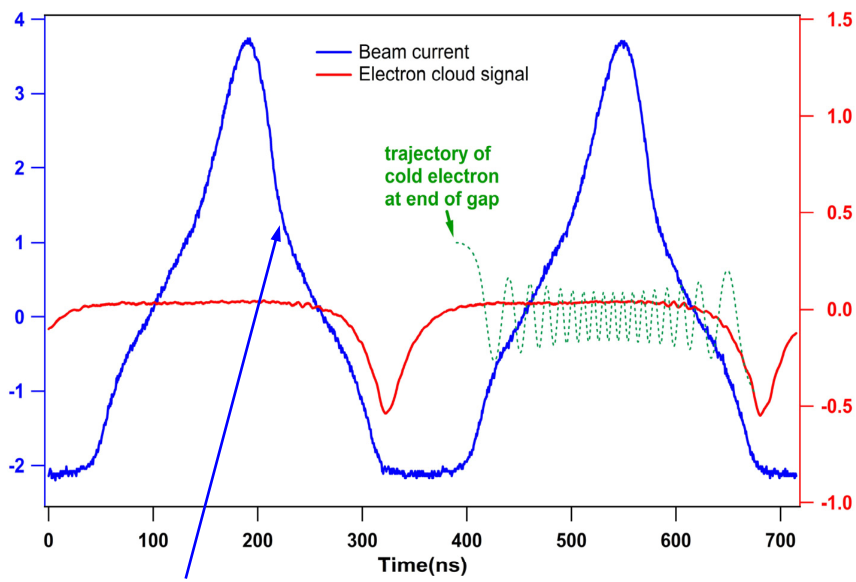
Related PAC07 papers:
Mechanical Design of Electron Cloud Detector : J. F. O'Hara et al, FRPMS054
Simulations for a drift space: Y. Sato et al, THPAS013

Outline

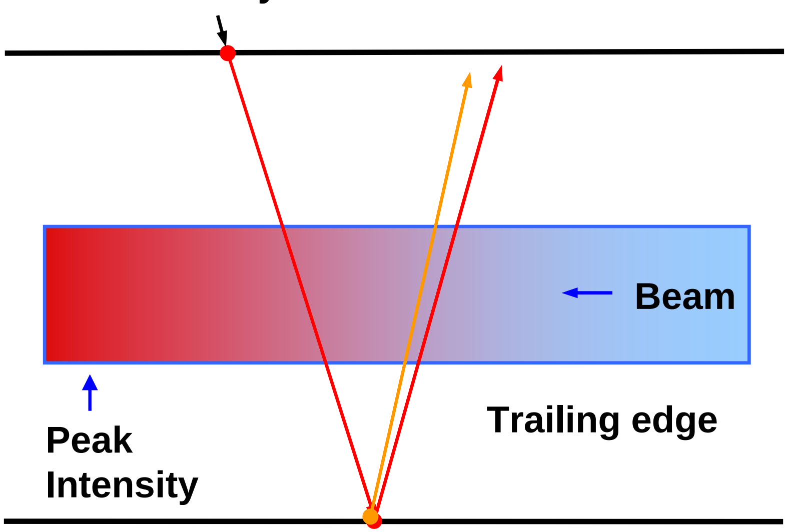
- **Motivation:**
  - **Find dominant sources of e-cloud driving the e-p instability at PSR**
- **Diagnostic Concept and Design**
- **Some Experimental Results**
  - **Signals for "prompt" and 'swept" electrons in quadrupole**
    - Comparable to or more intense than in nearby drift space
  - **~100 μs decay time for electrons trapped in the quadrupole**
  - **Electron cloud signals as a function of beam intensity**
  - **Evidence for significant numbers of electrons ejected from quadrupole into drift space**
- **Conclusions from experimental data**

Present picture of the e-p instability at PSR

- Available evidence points to two-stream instability from coupled motion of proton beam and low energy electron cloud
- Electron cloud generation
  - Primary (aka "seed") electrons from beam losses are amplified by multipactor on the ~130 ns long trailing edge of the ~270 ns long proton beam pulse
  - Sufficient electrons survive the ~90 ns gap between bunch passages to be captured by the following bunch and drive the instability
  - Largest uncertainty is the distribution of primary electrons at the chamber walls



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



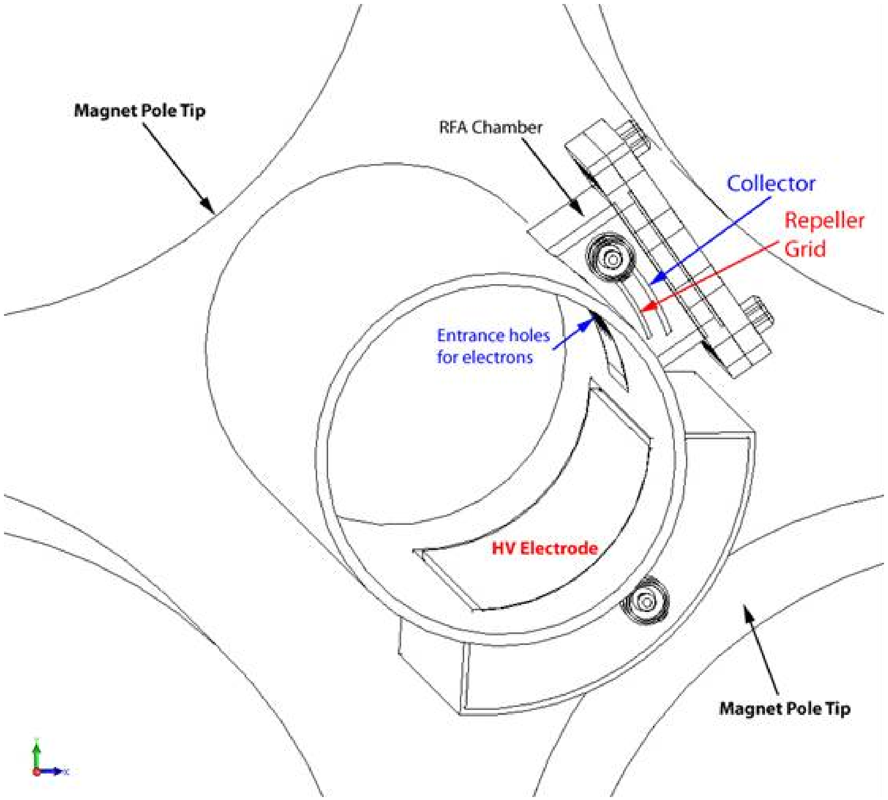
Energy gain in one traversal is high enough for multiplication

Motivation for e-cloud diagnostic in quadrupole

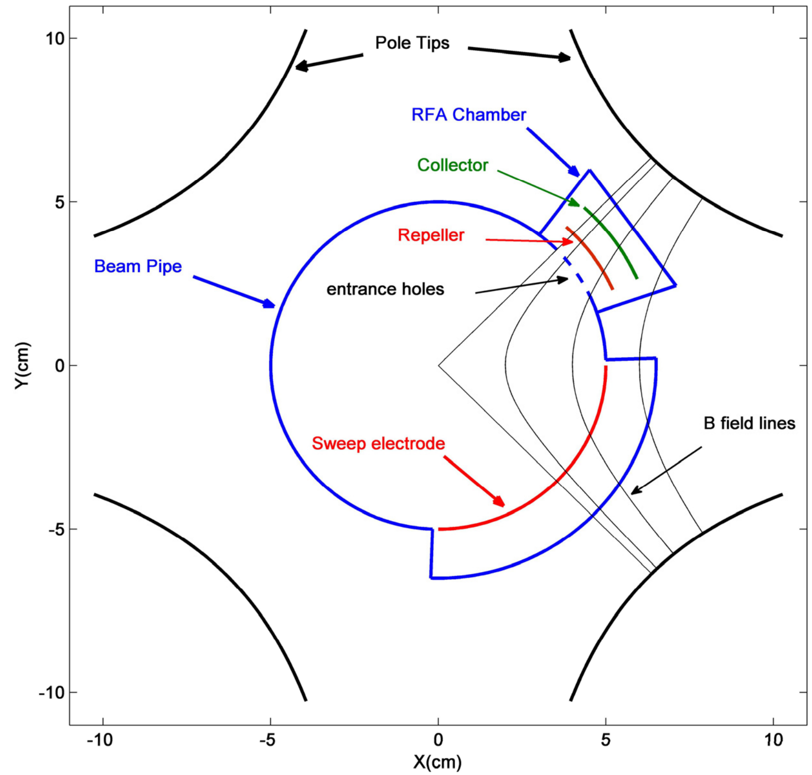
- **For some time we have suspected that quadrupoles may be a strong source of the electron cloud in PSR**
  - **Expect surface density of "seed" electrons born at the wall to be highest in quadrupoles by as much as a factor of 10-100 compared with drifts or dipoles**
    - Electrons from beam losses are a strong function of grazing angle (~1/cos(θ))
    - Grazing angle beam losses from foil scattering and beam halo are largest in quads where β-functions (beam size) are largest
  - **Collection of electrons from biased BPM electrodes in 1999 gave largest signal in a quadrupole compared with drift and dipole.**
  - **At the CERN SPS, strip detector in quadrupole gave larger signal than for dipole or drift.**
- **Quadrupoles can trap electrons during the passage of the beam-free gap**
  - **These are available to drive the instability during passage of the beam pulse**
  - **Simulations show long lifetime after beam has left the quad**
- **In addition, simulations show ExB drifts in 3D-quads eject significant numbers of electrons into adjacent drift spaces.**
  - **Could be a significant source of seed electrons in drift space**

Diagnostic Concept

Schematic Layout in PSR Quadrupole

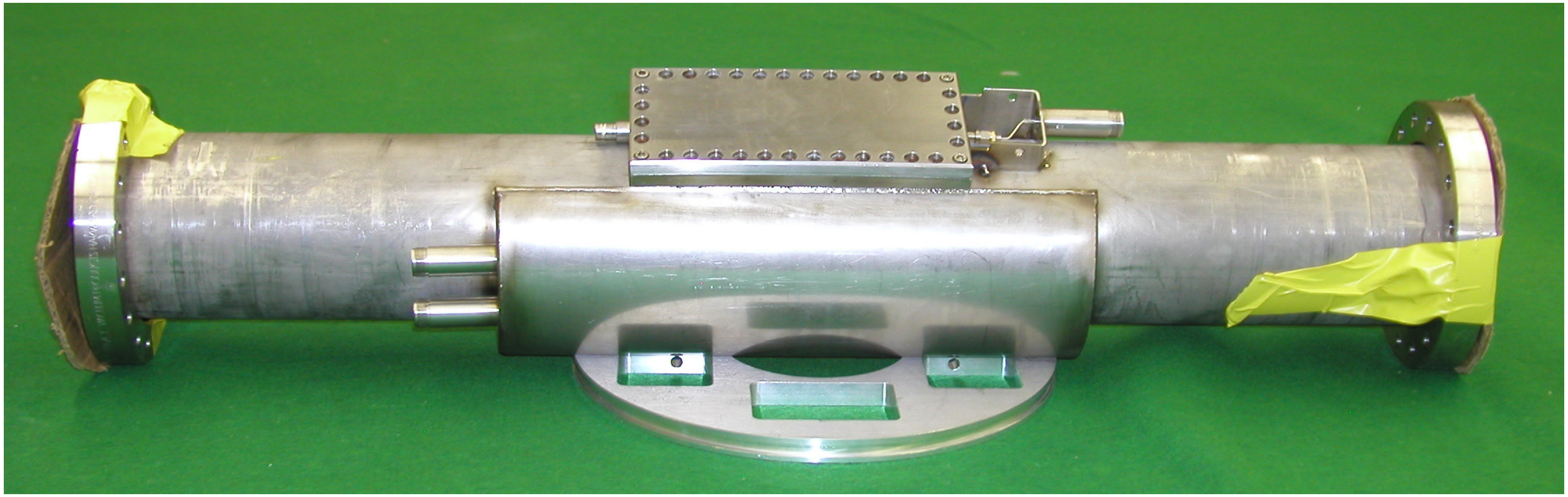


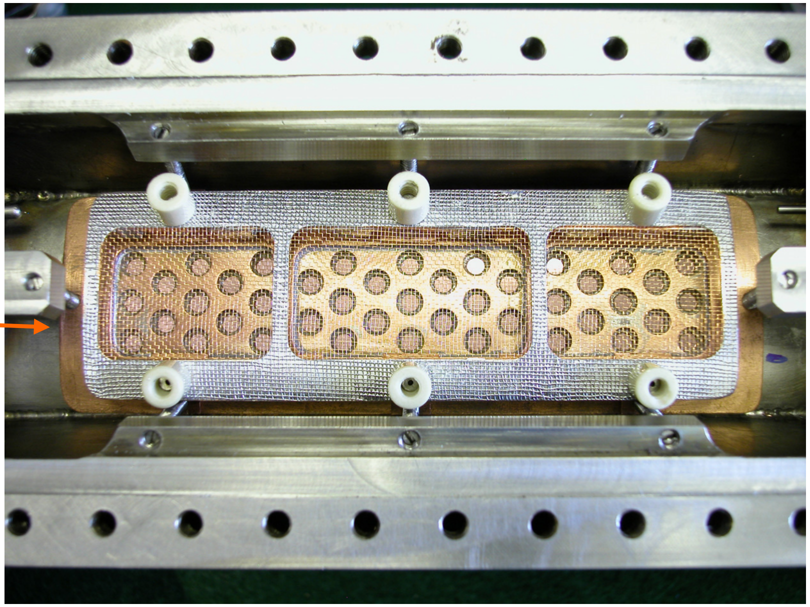
Cross-section



- Electrons striking the RFA entrance holes with E>Vrep pass through repeller grid and create signal at collector which is then amplified by electronics close to the quad
- RF shielding of Collector: Entrance holes (2.7 mm) covered with 40 mesh Cu screen and repeller grid (40 mesh Cu) has rf capacitors to provide high frequency AC ground

Detector Assembly 8/21/06

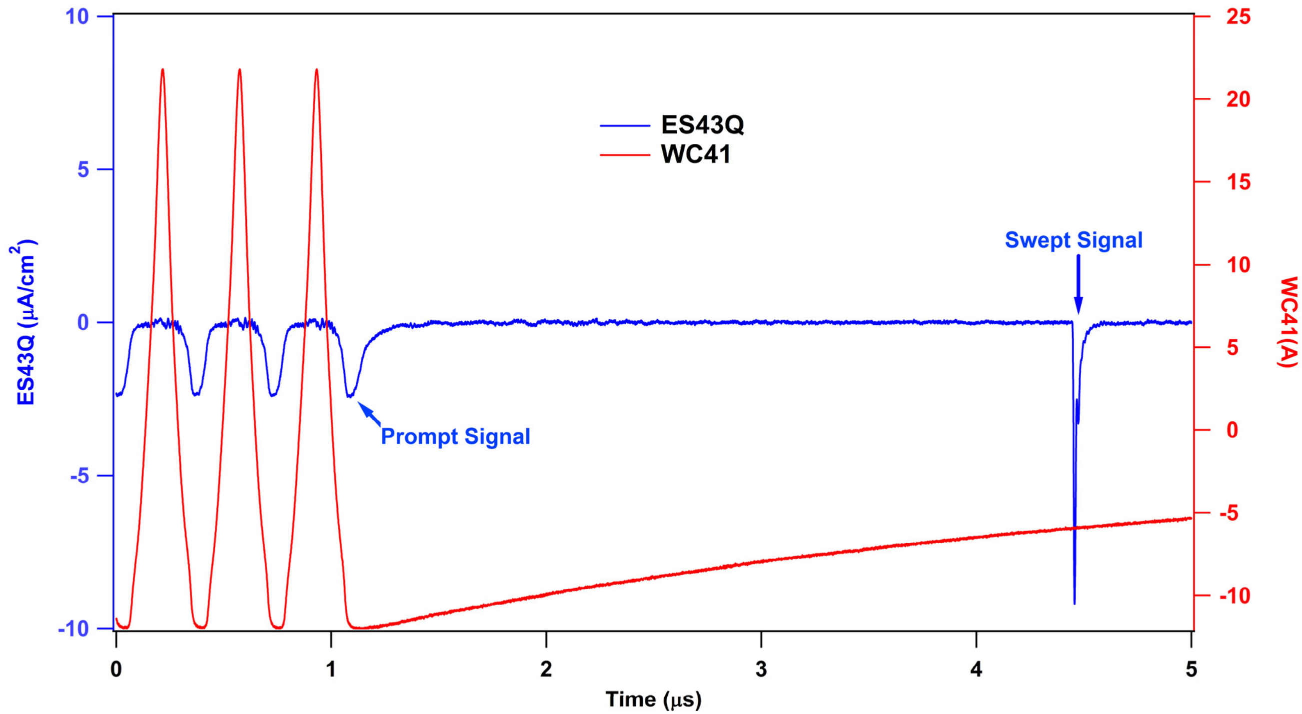




RFA components:

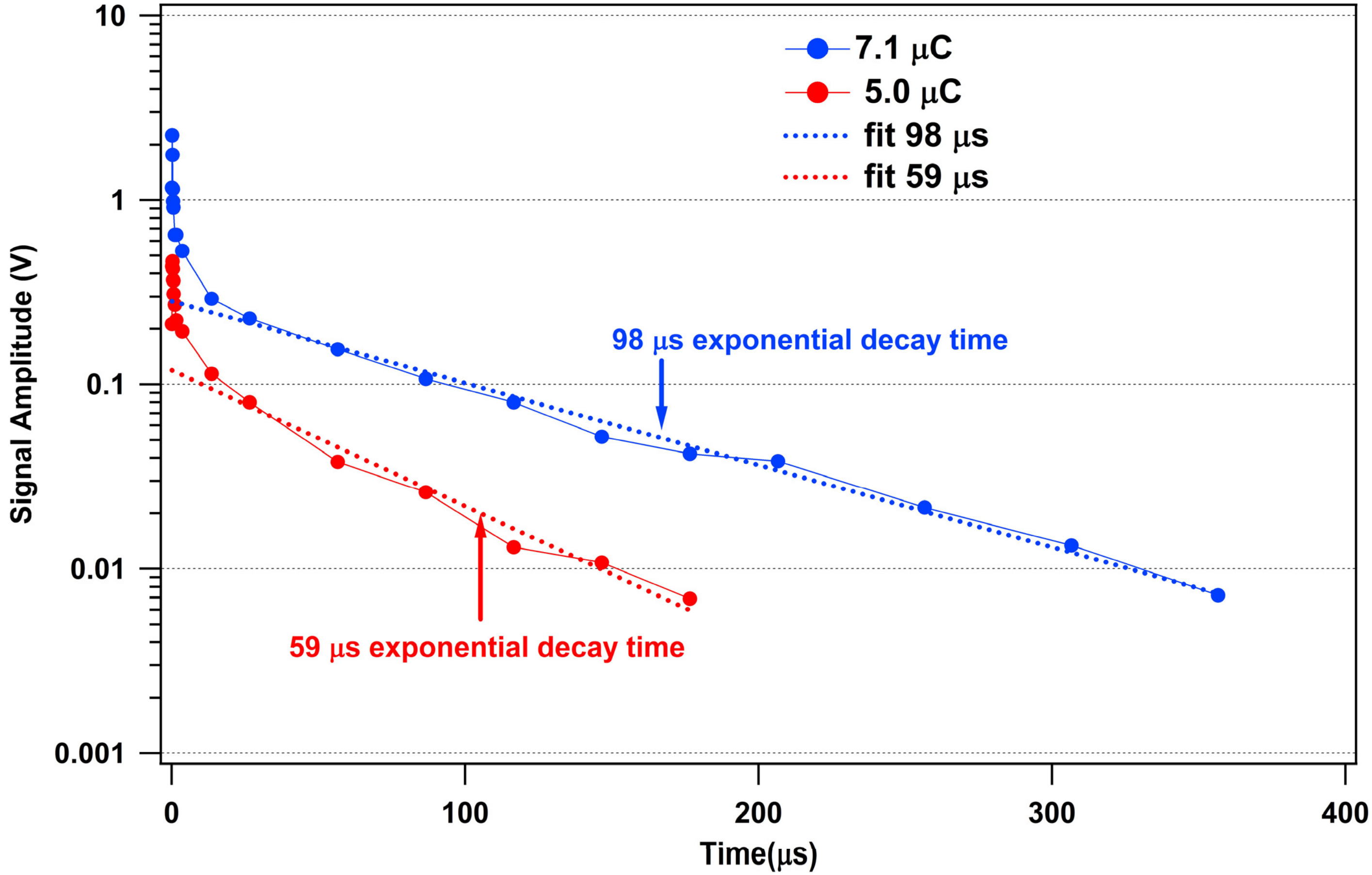
E-filter (with 3mm holes), repeller grid and standoffs for collector plate

Electron signal (4.3 μC/pulse production beam)



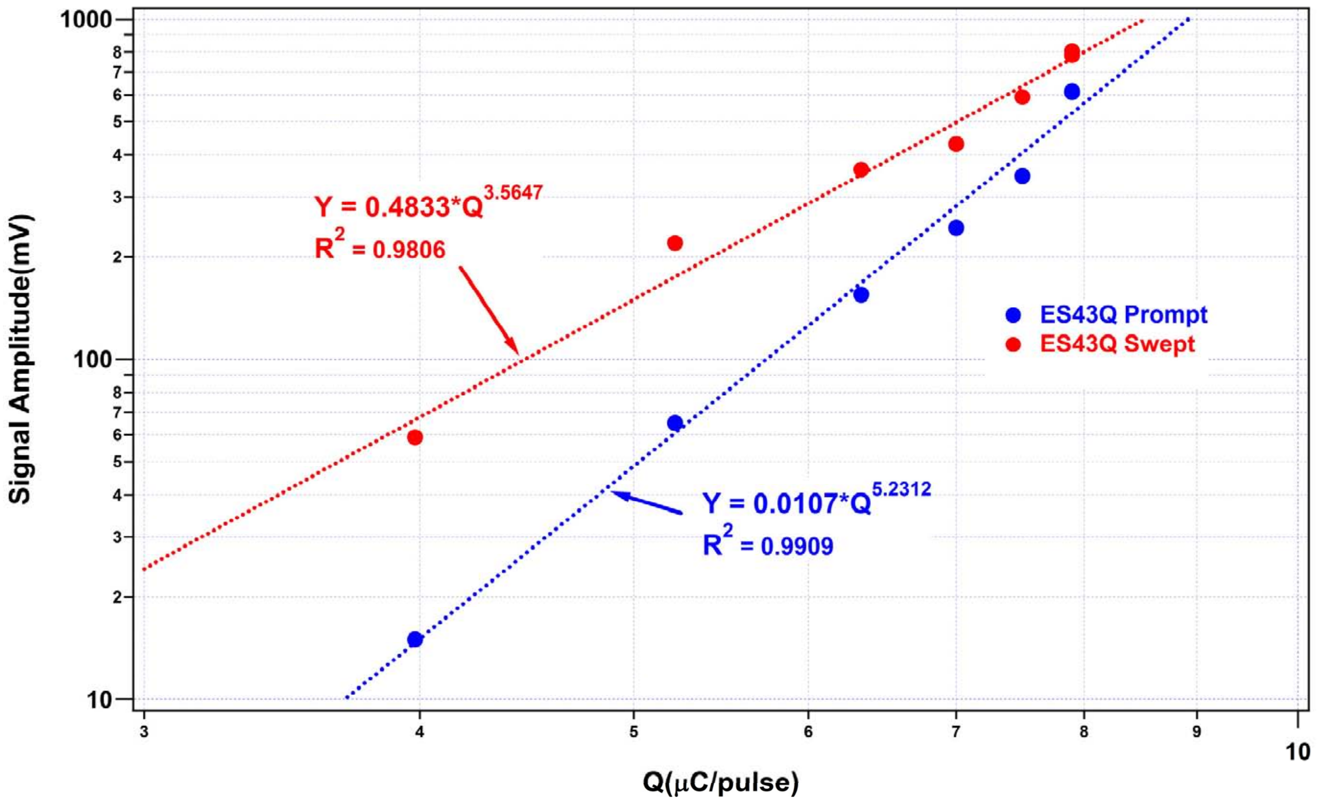
- **Prompt e-signal in quad (ES43Q) translates into electron flux at the wall that is ~1-3 times larger than the flux at the wall in the adjacent drift space detector (ES41Y) for ~100 μA production beam**
  - **Implies factor of >25 more seed electrons from loss in the quad than in the drift space**

Dissipation of trapped electrons at 2 intensities



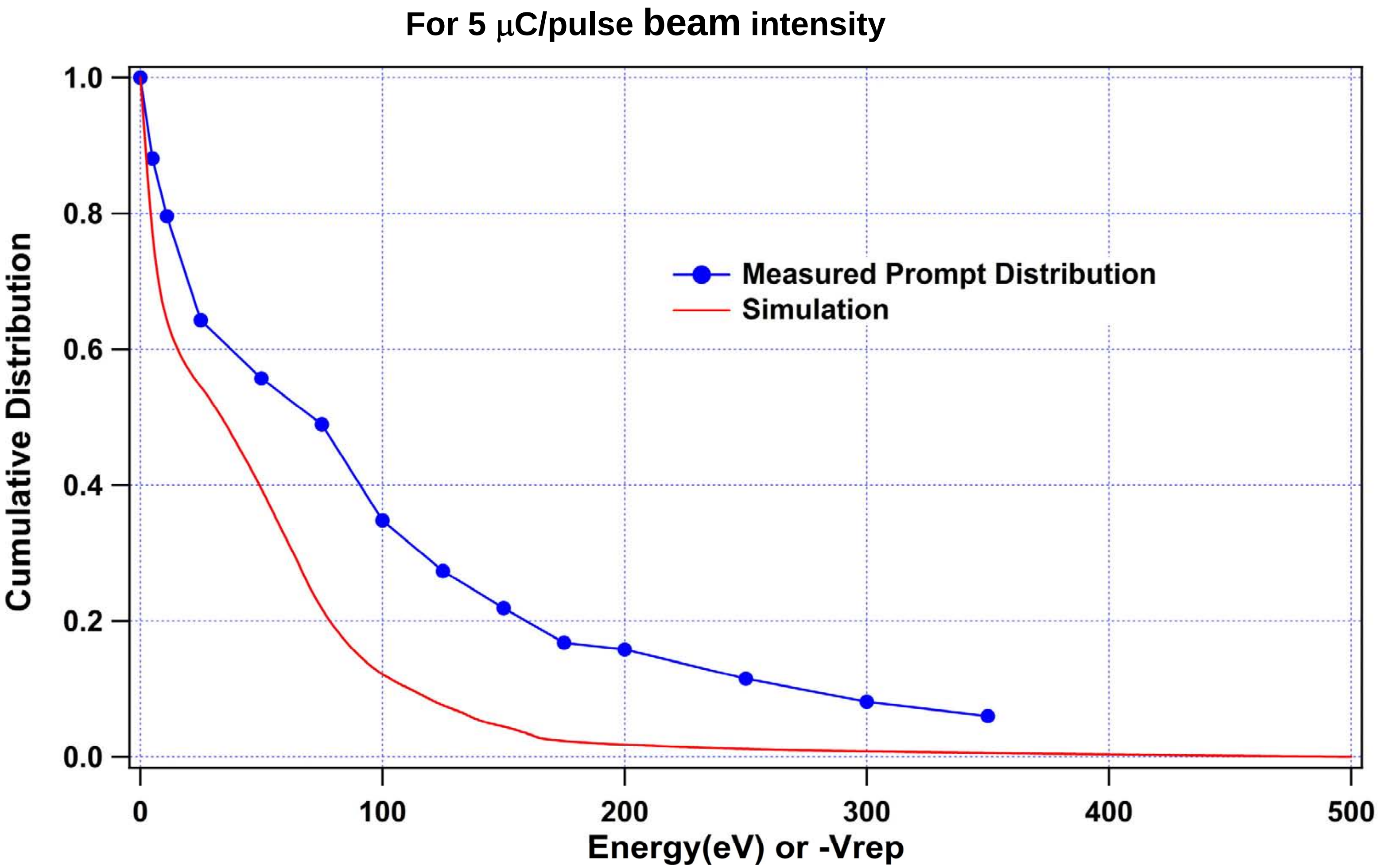
- **POSINST_12.1 Simulations show comparable decay time**

Dependence of Quad ED signals on beam intensity



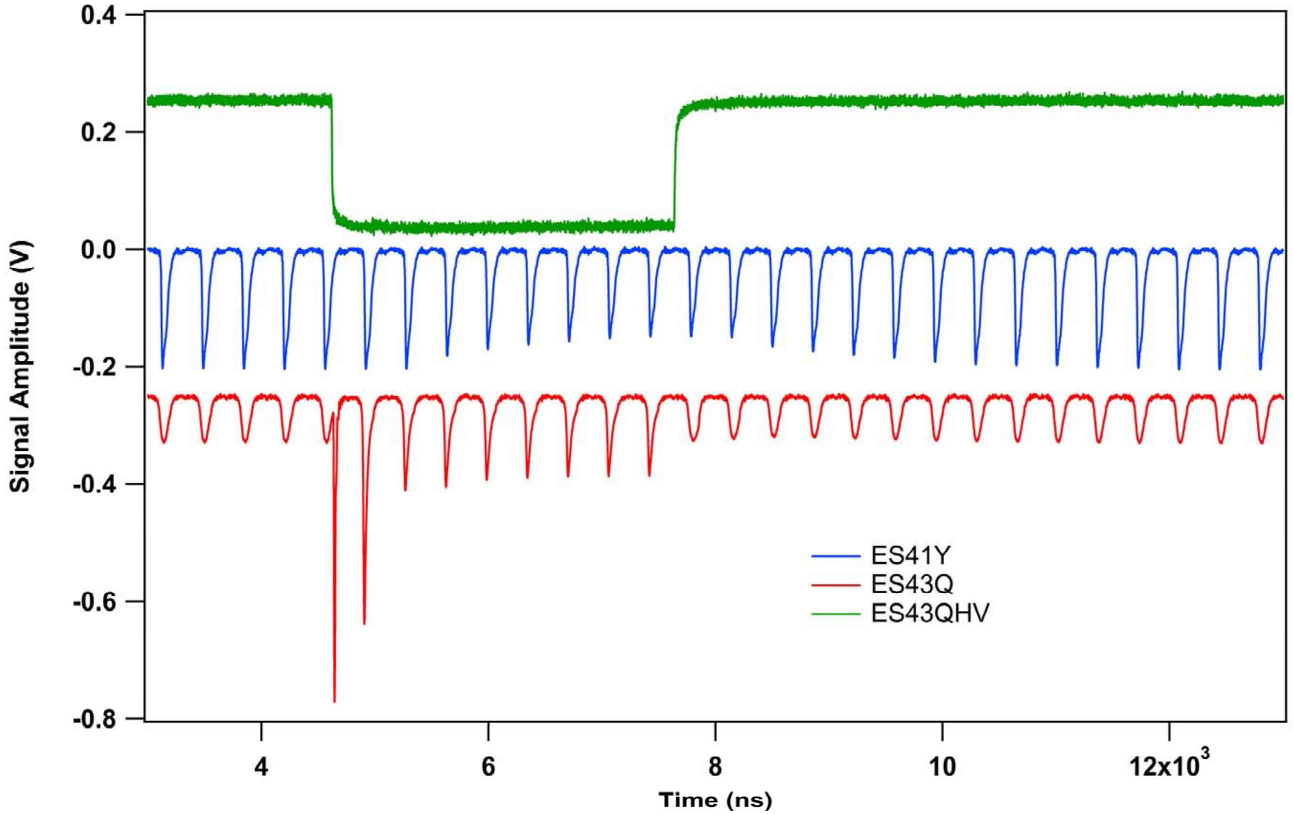
- **Simulations with primary electron production proportional to intensity produces a much weaker signal variation with intensity**
  - **Implies primary electrons are stronger than a linear function of intensity**
  - **Similar to behavior in drift space**
    - (see THPAS013 for discussion of simulations in a drift space)

Energy spectrum of "prompt" electrons



Sweeping Quad ED near end of accumulation

95 μA production beam (4.75 μC/pulse)



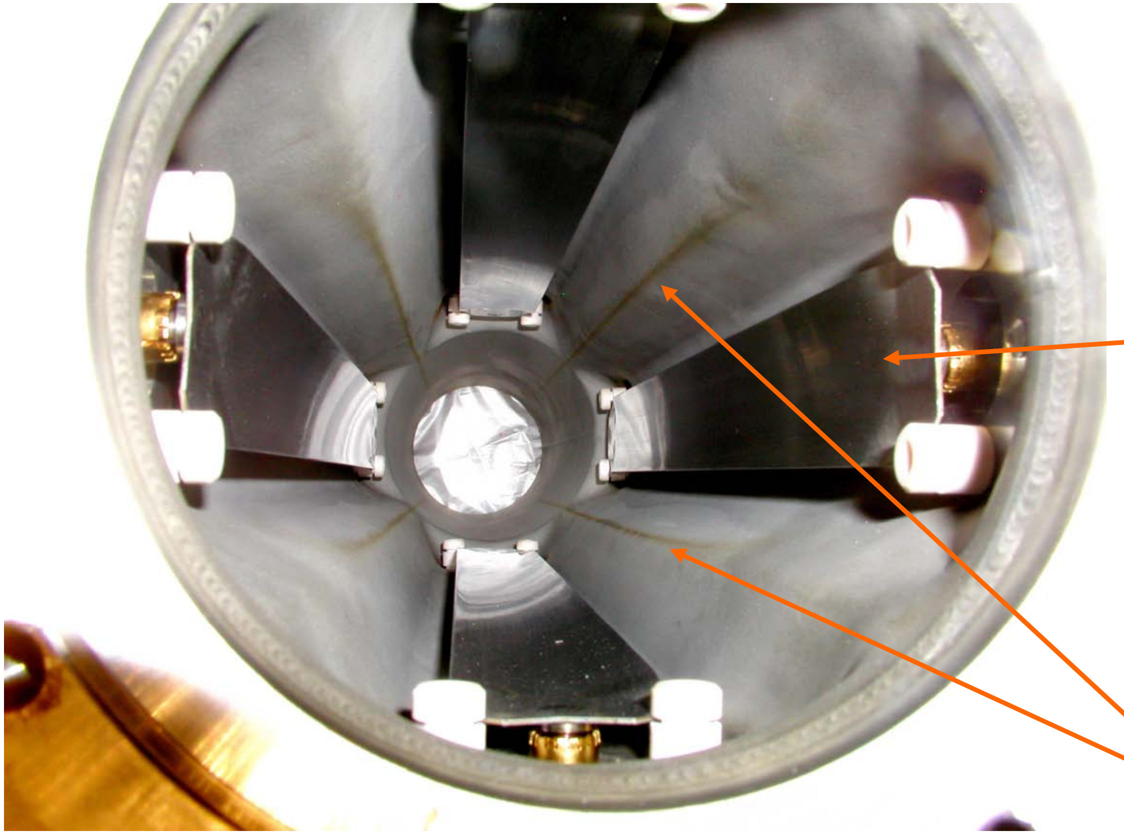
- **Sweeping ES43Q will remove a fraction of the electrons available to be ejected into the drift space**
- **At ES41Y see significant suppression of electrons during the sweeping pulse**

Implications of e-cloud data from the quadrupole

- **For ~100 μA production beam (5μC/pulse), the prompt e-signals in the quadrupole translate into electron flux at the wall that is 1 to 3 times larger than the flux at the wall in the drift space at ES41Y**
  - **Implies factor of >25 more seed electrons from beam losses in the quadrupole than in the drift space**
- **For ~100 μA production beam, the swept e-signal at the end of the 80ns gap translates into electron line density of ~0.5-1nC/m (~1-2% of proton line density) captured during passage of the beam pulse**
- **The ~25% reduction of ES41Y signal during sweeping in the quad implies that a significant portion of the drift space signal (direct or from seeding multipacting in the drift space) is due to electrons ejected from the quad**
  - **Sweeper electrode covers ~ ½ the effective length of quad**
  - **The upstream quad will also eject electrons into the drift space**
- **Much of the drift space signal (ES41Y) could be due to seed electrons ejected from the two nearby quads**

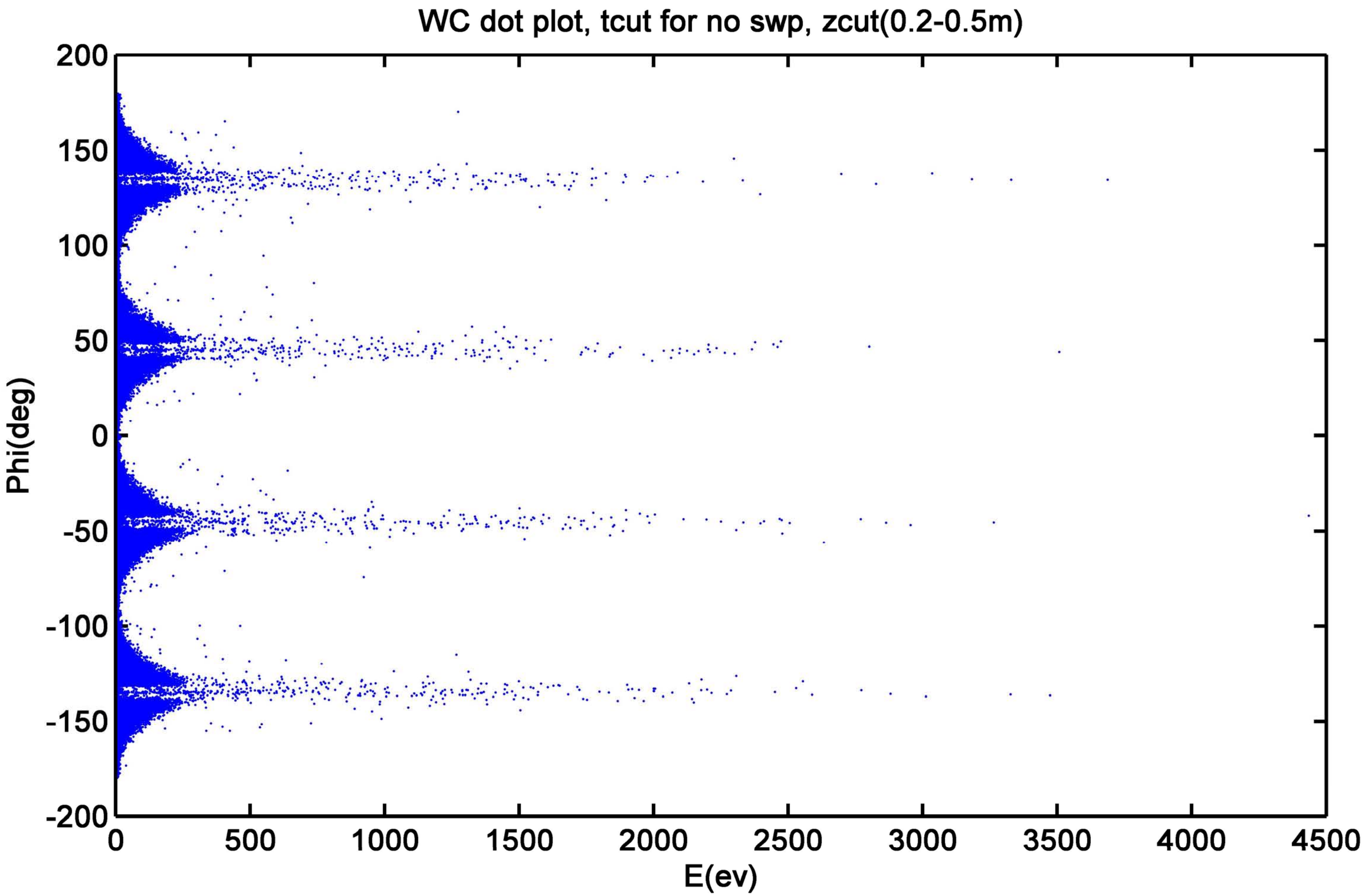
Backups

Photo of "Tracking" in Quadrupole Chamber



- **Brown track located at each pole tip of quad**
- **Graphization by energetic electrons of EC is suspected**

Wall Collision distribution from simulations



PSR Layout with EC & e-p Diagnostics

Circumference = 90m

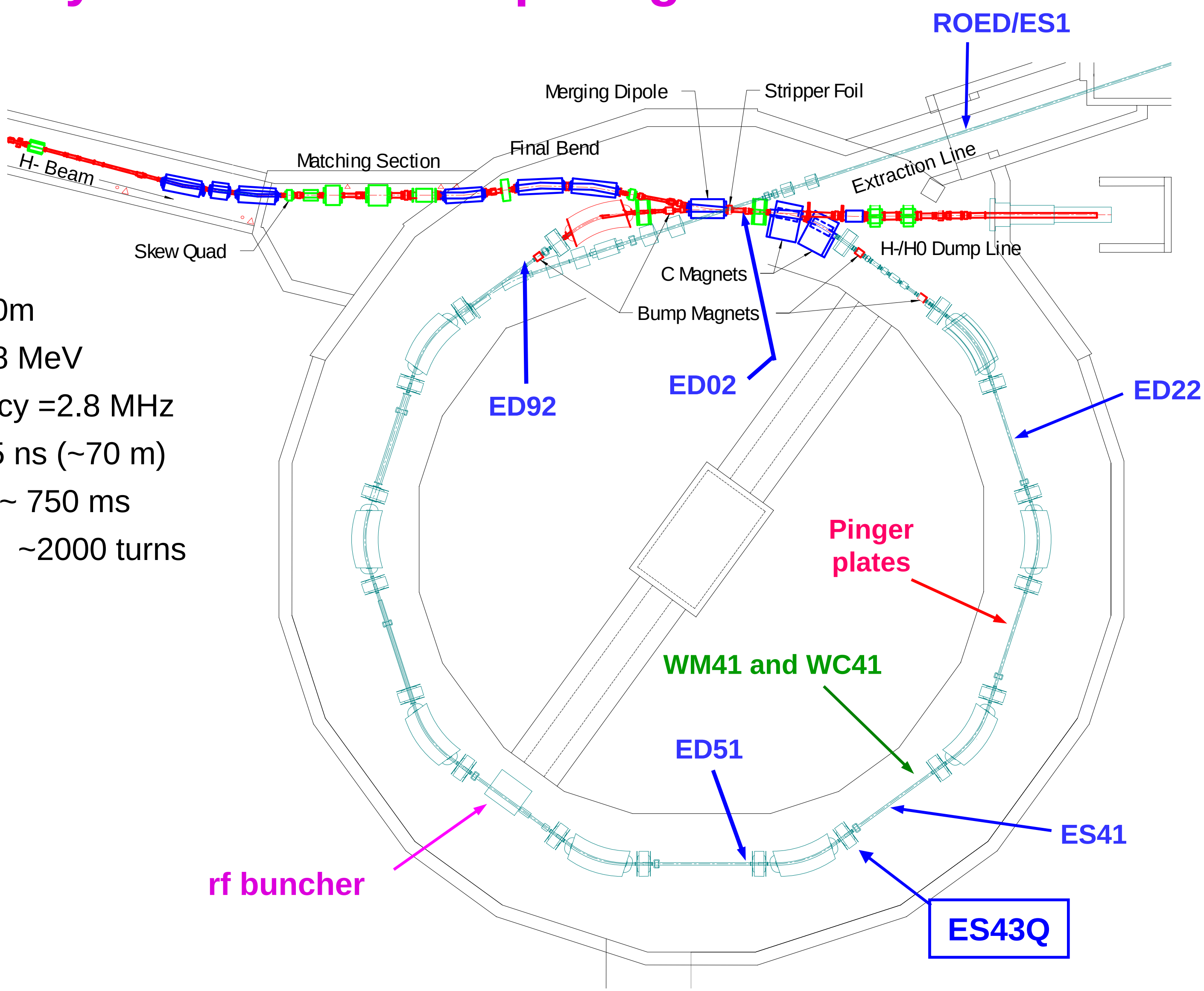
Beam energy = 798 MeV

Revolution frequency =2.8 MHz

Bunch length ~ 275 ns (~70 m)

Accumulation time ~ 750 ms

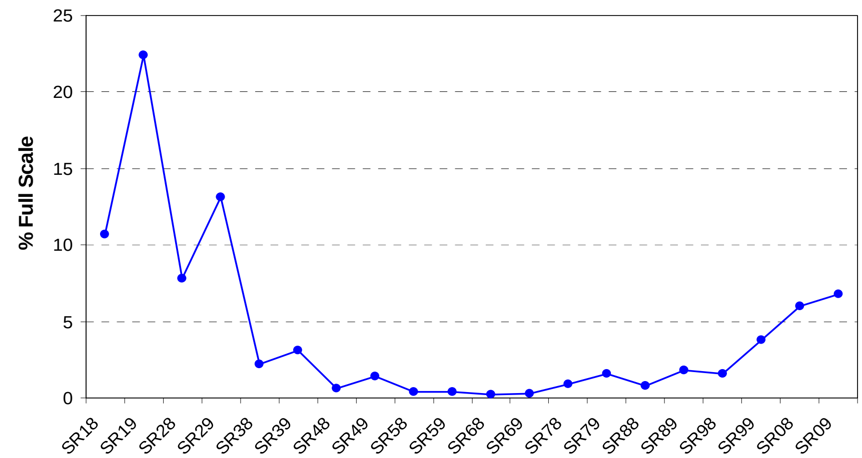
~2000 turns



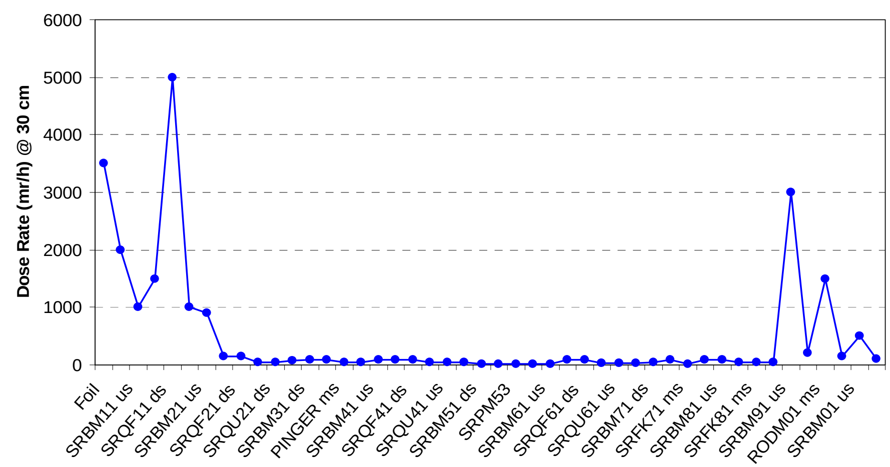
Ring Beam Loss and Activation

- **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

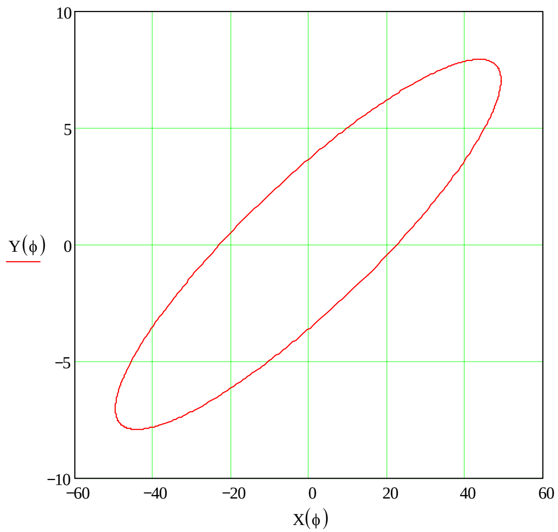


Ring Activation 12-02-2002 (2 h after shutdown)

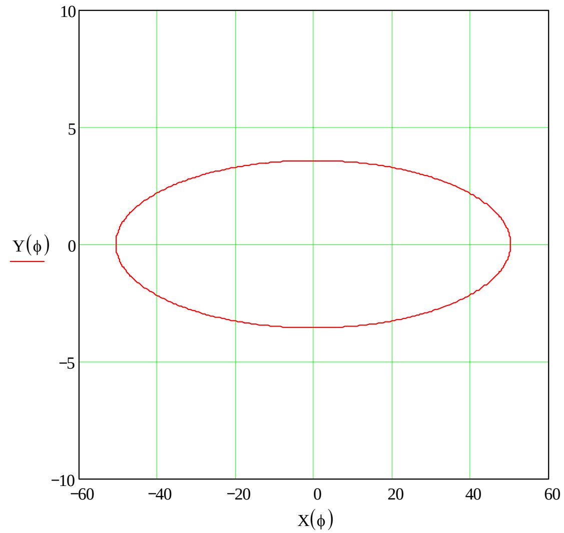


Variation in seed electron yield in SRQU41at 3 Z locations

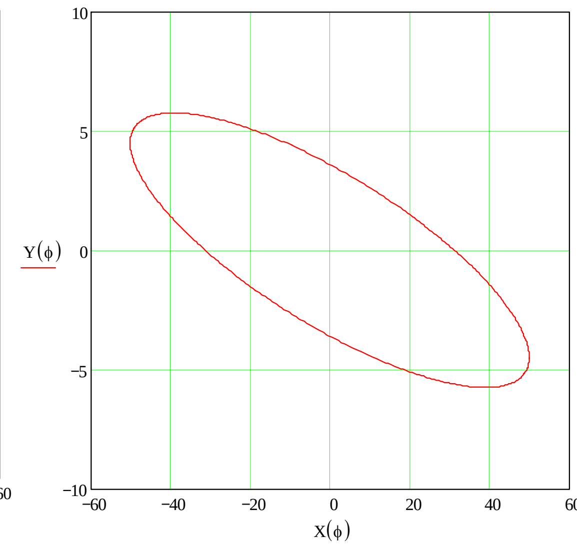
Entrance



Midpoint



Exit



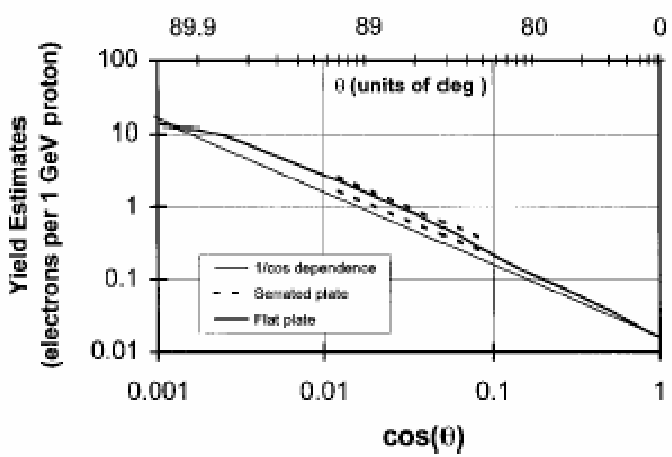


FIG. 8. Estimated electron yields for 1-GeV protons incident on smooth (solid lines) and serrated (dotted lines) SS surfaces. The

- **Beam ellipse (vert plane) touches the pipe at 7, 0 and -5 mrad respectively for the 3 locations**
- **Graph on left from Thieberger et al, Phys. Rev. A, Vol 61, 042901, (2000)**
- **Data in this paper implies e-yield down factor of ~4.5 at entrance and ~3.5 exit of the quad**