A Halo Measurement Diagnostic for the Extracted Beam at PSR

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Outline

- Motivation and Requirements
- Limitations of our standard wire scanners
- Design choices
- Results from the prototype
- Electronics implementation

Motivation and Requirements

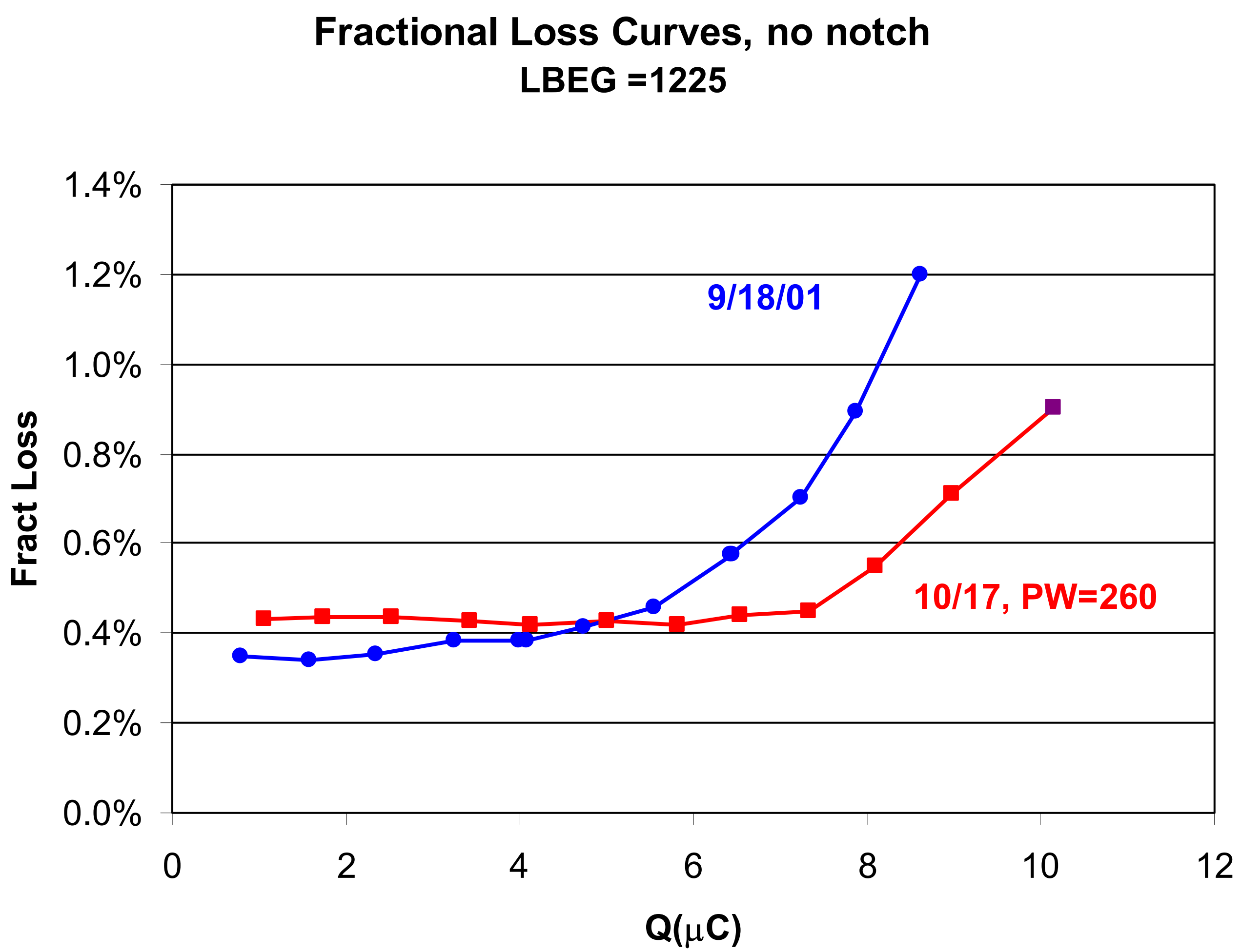
- Interested in beam halo at the 10^{-4}-10^{-5} level to better understand beam losses in the ring and extraction line

- At present operation (6 μC/pulse) losses are
  - ~2.5×10^{-3} during accumulation in the ring and are a factor limiting higher peak intensities @20 Hz
  - 10^{-3} to 10^{-4} at a critical region in the extraction line where shielding is weak

- Perhaps 80-90% of the ring losses are understood in terms of foil scattering and production of excited states of H^0
  - Simulations and tracking codes predict the general features of the losses correctly to the level of ~5×10^{-4} (fractional loss) but are limited by accuracy of various input parameters

- Above 6.5-7 μC/pulse the fractional losses in the ring increase rapidly, presumably from space charge effects

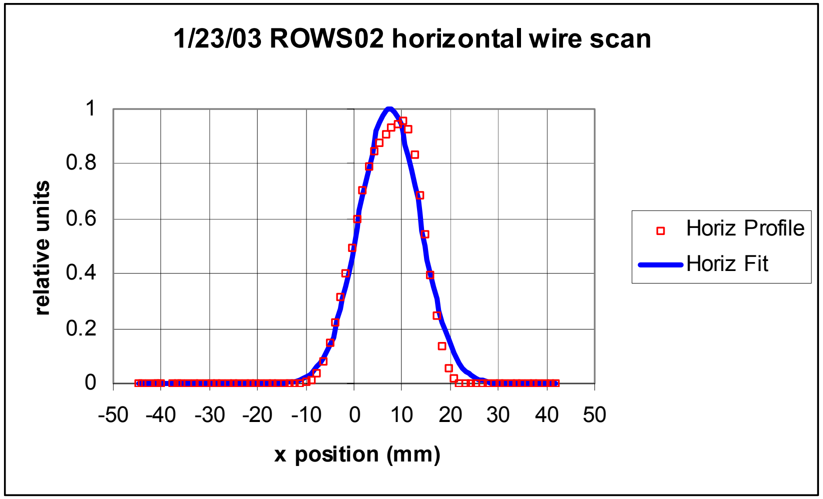
Fractional Loss Curves, 2 cases

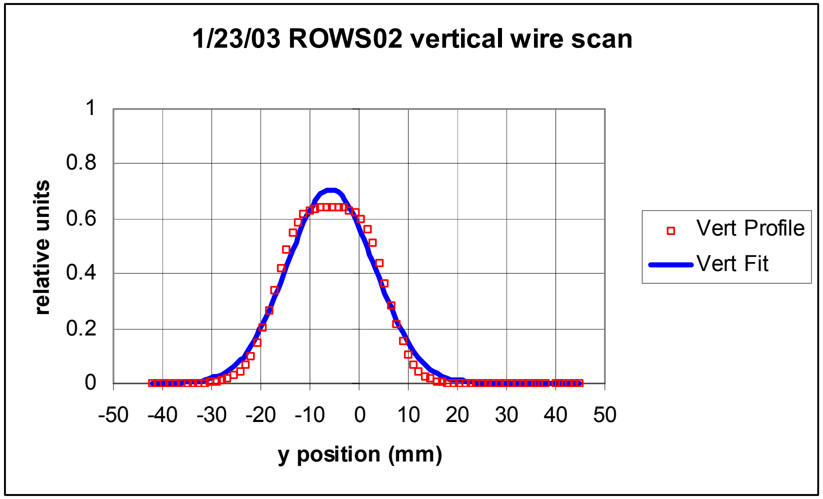


LANSCE-standard wire scanner features

- **Two wires (Horiz and Vert 4 mil SiC) on single actuator**
- **The signal is applied to a low-bandwidth, integrating amplifier (RC=100 μsec).**
- **Background is subtracted in software.**
- **Gain selection of 1, 10, 100, and 1000.**
- **Profile resolution is determined by the 12-bit A/D converter and is limited to approximately 3 orders of magnitude.**

Horizontal and vertical profiles from a standard wire scanner on the extraction line.





<u>Design considerations</u> for a new amplifier with six-orders-of-magnitude peak/noise ratio.

- **Extracted PSR beam:**
  - **triangle-shaped ~270 nsec pulse at up to 20 Hz rate.**
  - **range - nanocoulombs to 10 μC charge per pulse.**
- **Scanner wire secondary emission coefficient of ~ 2%.**
  - **Peak wire currents range from a few microamps to 10 milliamps**
  - **Peak (integrated) charge on the wire is a fraction of 1 pC to 2 nC.**
- **Halo features of interest are 4-5 orders of magnitude below peak signals.**
- **PSR noise level is typically 1 mV_{rms}.**

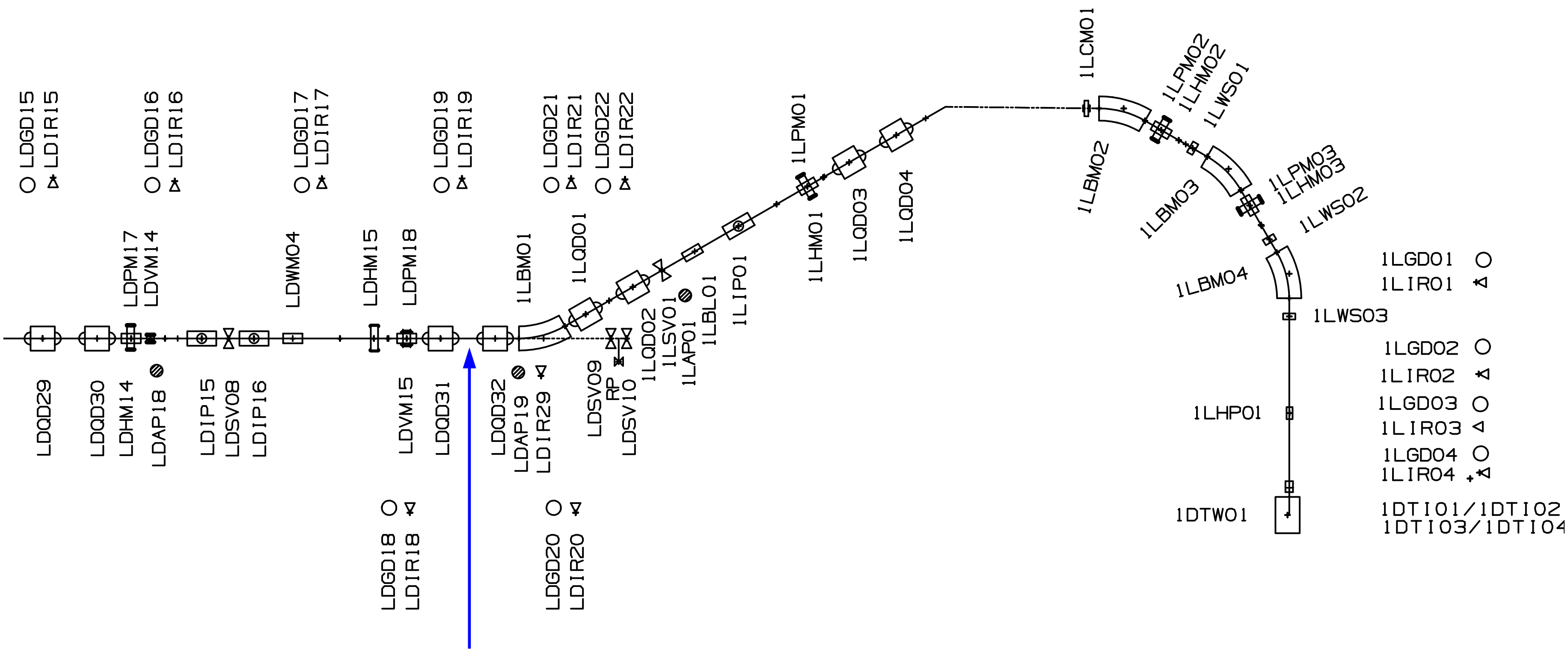
<u>Design choices</u> for a new amplifier with six-orders-of-magnitude peak to noise ratio.

- **Integrate the wire scanner signal – acquire the average profile of beam.**
- **Locate the electronics at the beam line:**
  - **Improve the S/N ratio**
  - **Minimize the effect of cable pickup noise.**
  - **Lifetime is an issue - radiation damage is a possibility!**
- **Use non-linear amplification (a transimpedance logarithmic amplifier)**
  - **lowest-level signals have proportionately more of the output range.**
  - **12-bit digitizers are sufficient.**
- **Emphasis on noise suppression:**
  - **minimize the integration time.**
  - **limit circuit bandwidth after the integrator.**
  - **background subtraction of active wire**
  - **auto zeroing of leakage currents and offset voltages.**
  - **suppression of 60 Hz pickup.**

Results from Prototype

- Wire scanner located in a low loss region of transport line between two quadrupoles
  - 5 inch diameter beam compared with 4 inch upstream
  - electron cloud background lower because of low losses and larger diameter pipe
  - in fringe field of two quads (~40 G)
- Uses existing beam box, single wire scanning mechanism, A/D converters and analysis software
- Data to be shown were converted offline to input current at the log amplifier

1L Line Device Map



Prototype halo wire scanner location

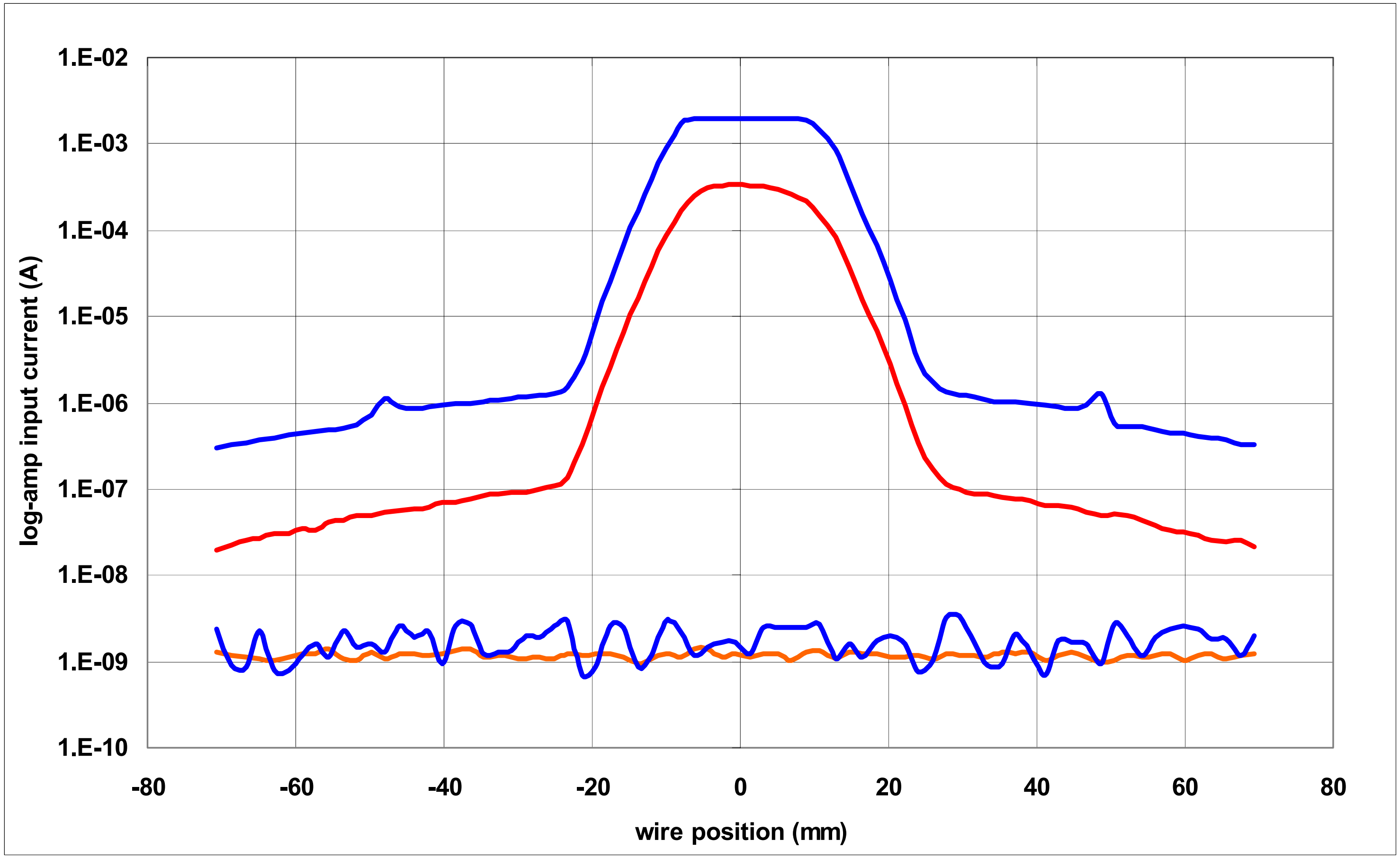
The y-axes on the charts are scaled as "log-amplifier input current." The relationship between log-amplifier input current and charge on the integrating capacitance is:

$$V_o = G V_y \log\left(\frac{I_{in} + I_{offset}}{I_z}\right)$$

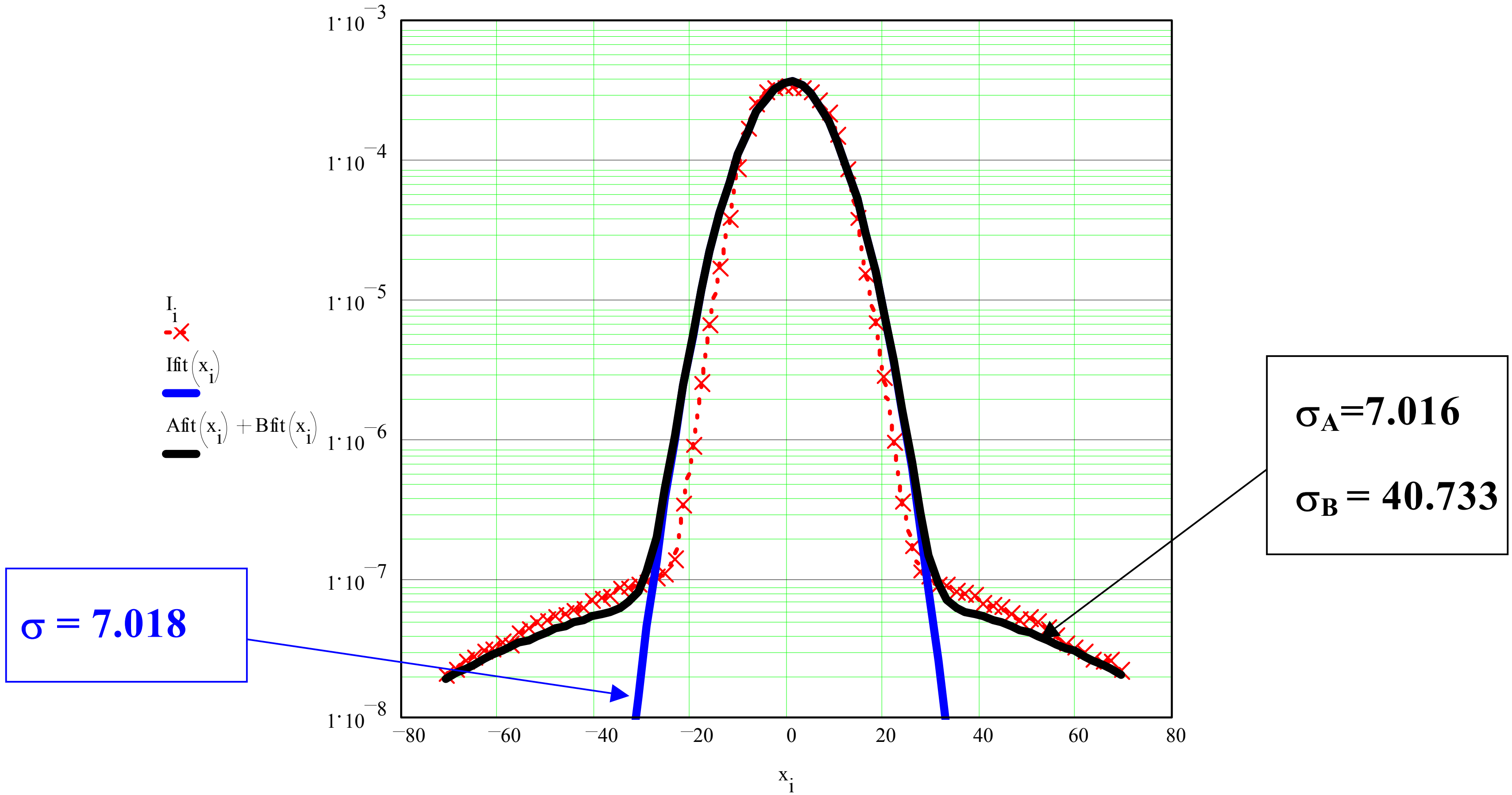
$$Q_{wire} = I_{in} R C_{\text{int}}$$

V_o – amplfier output voltage
I_{in} - log amp signal input current
Q_{wire} – charge on the wire

G - output amplifier gain (5)
V_y - slope voltage (200 mV/decade)
I_{offset} - offset current (1 nA)
I_z - intercept current (100 pA)
R_{in} – log-amp input resistance (5 kΩ)
C_{int} – integrating capacitance (10, 100 or 1000 pF)



Profiles of a 3.6 μC beam taken with amplifier gains of 1 (red trace) and 10 (blue trace) are shown in the chart. Baseline scans without extracted beam were also taken at these gains to demonstrate amplifier noise characteristics. Amplifier saturation occurs for this beam charge when a gain of 10 is selected.



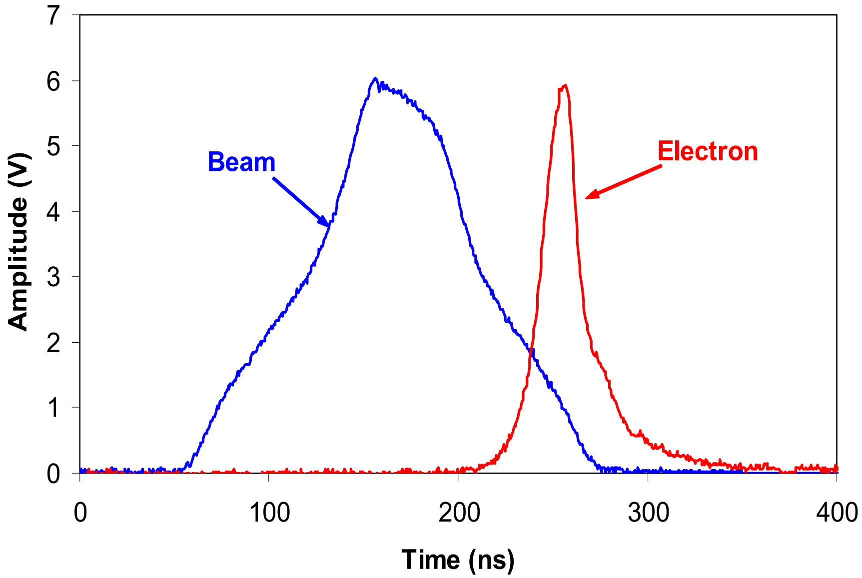
The nature of the beam "halo" has not yet been determined. **A normal function shown in solid blue has been fit to the data (red x's). A sum of two normal functions is shown in solid black. The X-axis is scaled as scanner position in mm's and the Y-axis is log-amp input current in Amps.**

Possible Sources of “Halo” Signal

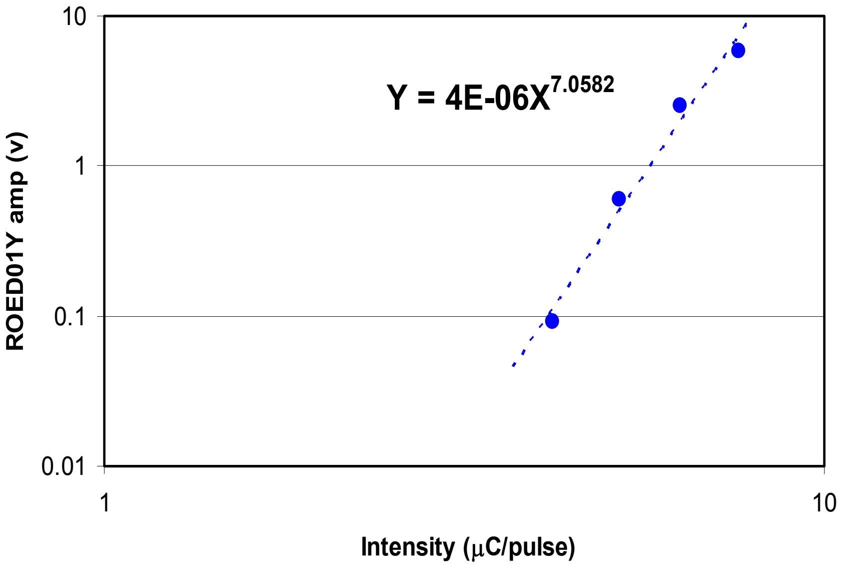
- Mechanisms in the ring
  - Foil scattering
  - Excited state production
  - Space charge
- Protons scattered from upstream losses on the pipe
  - Need a simulation (LAHET or successors)
- Photons produced from upstream losses
- Electron Cloud in extraction line
  - Strong function of beam intensity
  - Have seen a noticeable effect of -500V bias on an earlier version in another location at 7.4 μC/pulse
  - No effect on the present prototype at 3.6 μC/pulse
  - Plan -5000V bias capability

Electron Cloud in the Extraction Line

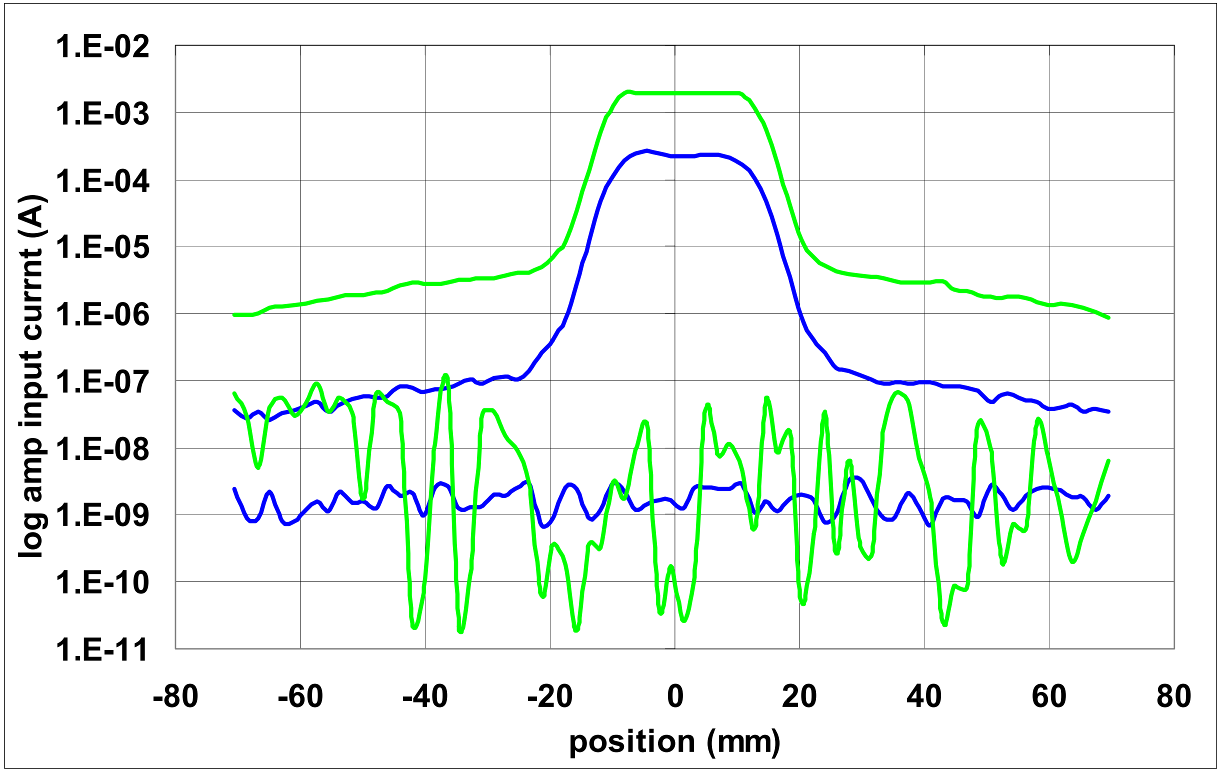
6.8 μC beam pulse in the extraction line



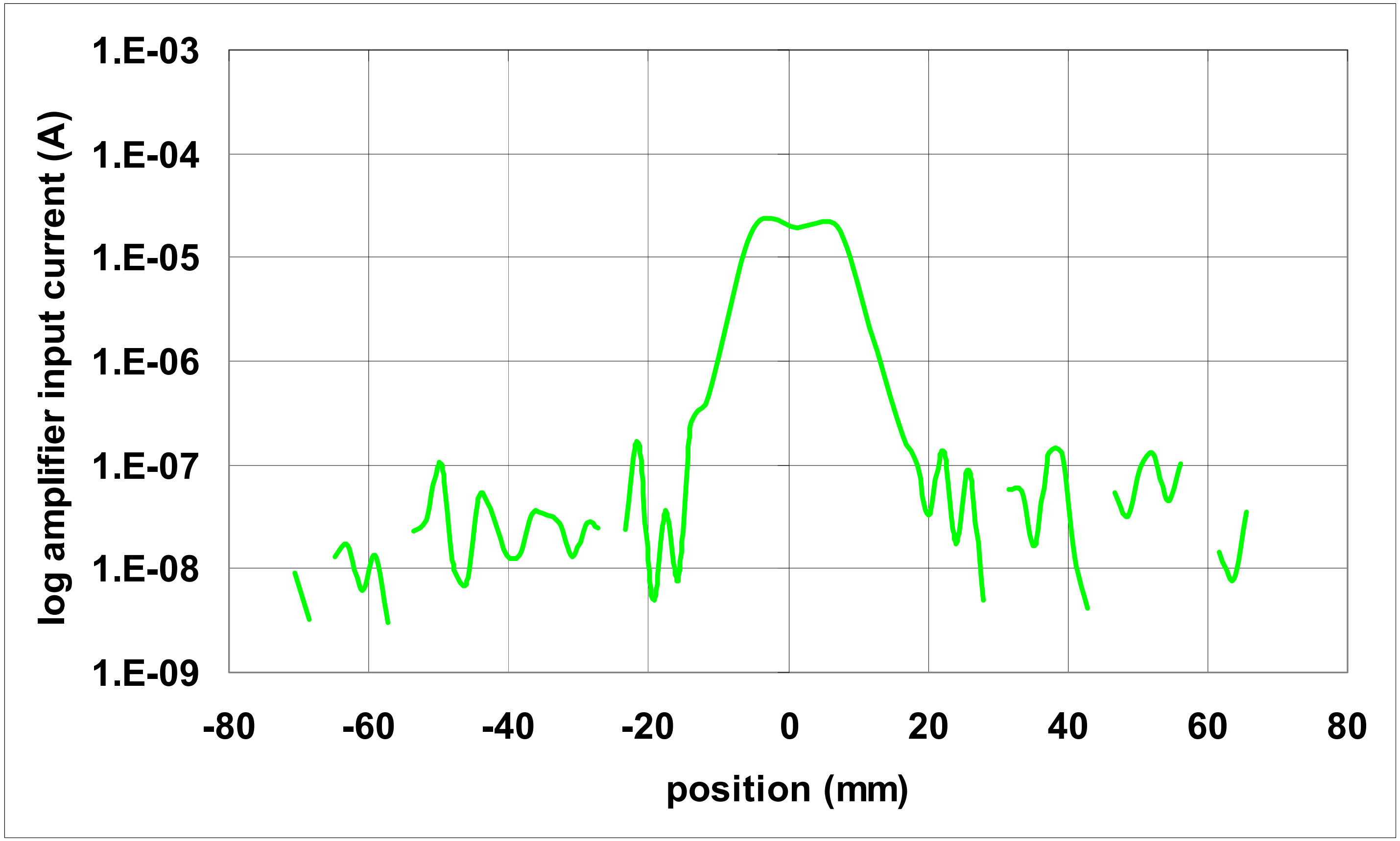
Single pass electrons vs beam intensity
(log-log plot)



- Electron cloud in single pass is strong function of beam intensity, $\sim I^7$
  - Electron signal is very similar to signals in the ring wrt e-flux, time structure, energy spectra and dependence on beam intensity
  - Trailing edge multipactor is likely source



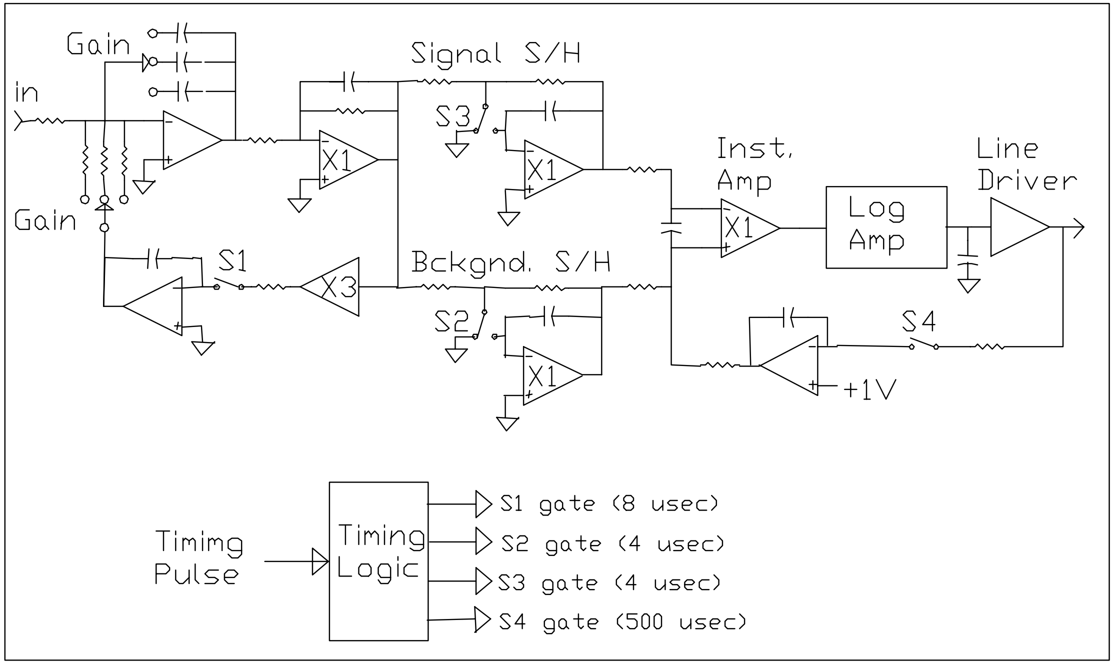
Profiles of a 0.36 µC beam taken with gains of 10 (blue trace) and 100 (green trace) are shown in the chart. Baseline scans, scans with no extracted beam, were also taken at these gains to characterize measurement noise. Noise is a function of gain-bandwidth and is larger at the higher gains.



Profile of a "single shot" 2 nC beam, produced by accumulating beam in the PSR for a single turn followed by normal extraction timing, taken with gain of 100. Increased averaging of the samples will likely aide in the ability to resolve "halo" at low beam currents. The peak signal shows some evidence of a hollow beam.

Amplifier Block Diagram

Integrator with gain selection



Two active feedback circuits eliminate offset errors

Timing for the four switches is provided by a single master timer pulse with individual switches driven by pulses derived from the master timer pulse and fixed in time by on-board circuits.

Noise suppression techniques:
- **Minimize integration time.**
- **Limit bandwidth.**
- **Background subtraction.**
- **Auto-zero error sources.**

Summary and Conclusions

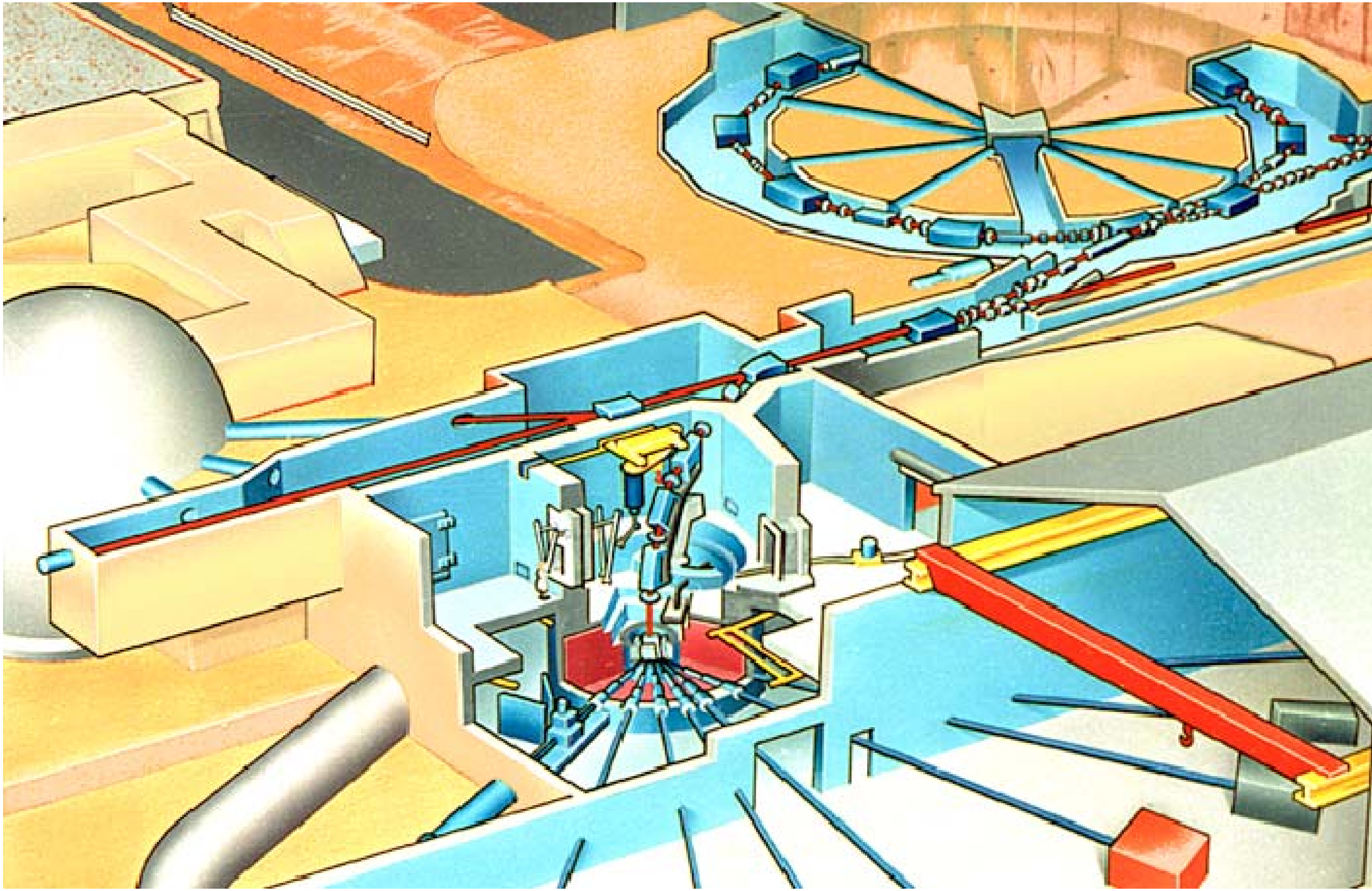
- Have developed and tested a wide dynamic range wire scanner with front-end electronics located in the beam tunnel
  - Wide dynamic range integrating amplifier
  - Sample and hold
  - Auto zero and background subtraction features
  - Log amplifier
  - Line driver
- Results imply 6 orders of magnitude range on peak/noise at 10μC/pulse beam intensity
- Nature of the halo signal observed at the 10^{-4} level is not yet understood
- Will add capability for -5kV bias to eliminate any electron cloud background

Backups

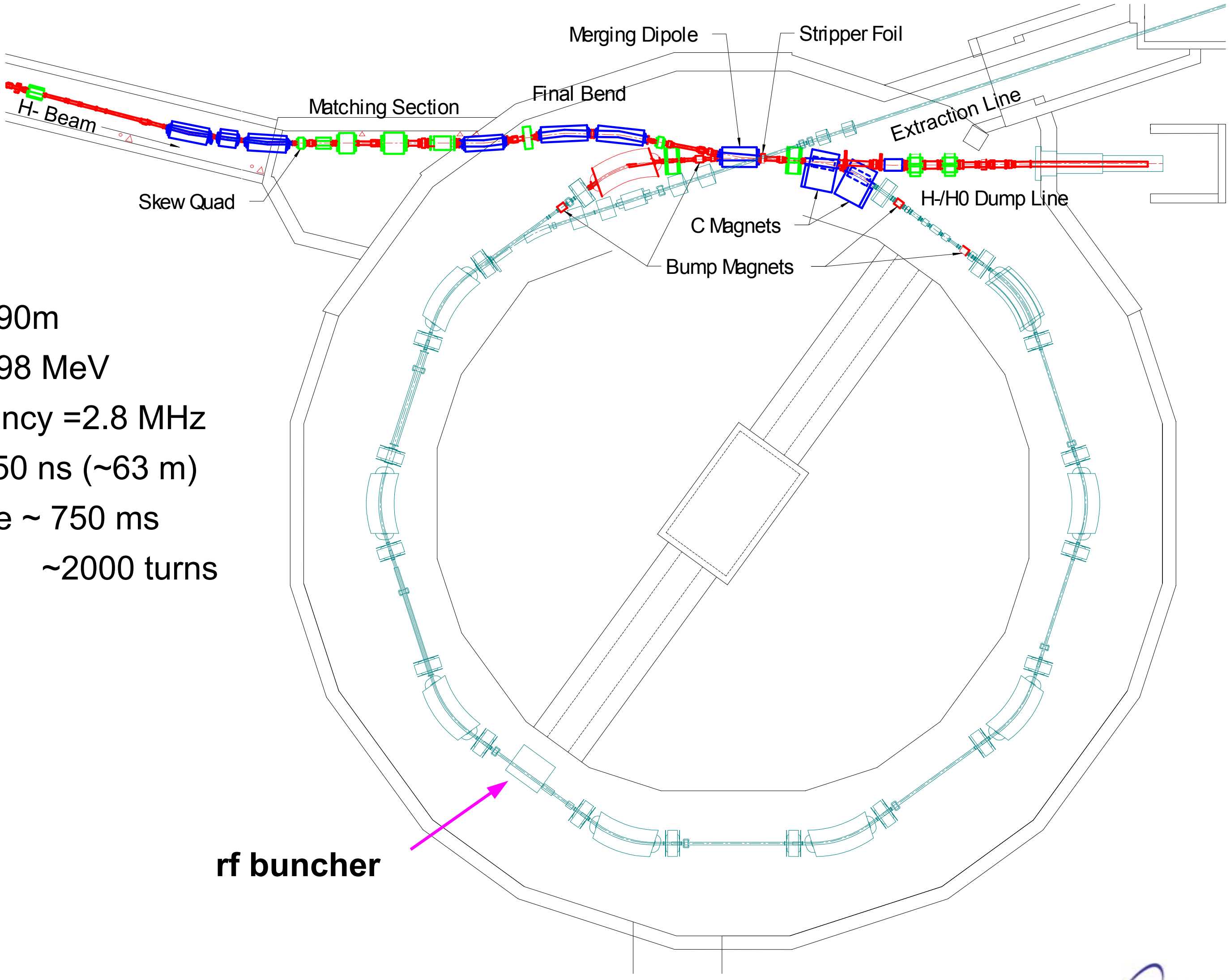
SUMMARY

To significantly improve the experimental determination of the beam halo in the extracted beam from the Los Alamos Proton Storage Ring, an improved wire scanner has been developed, tested and installed in the extraction line. To enhance the signal-to-noise ratio, an amplifier consisting of a wide dynamic-range, integrating amplifier, sample-and-hold circuit, log amplifier and line driver is located near the beam line. Errors at the input of the amplifiers are actively cancelled and timing gates are derived from a single input pulse. The new amplifier and scanner uses existing beam line diagnostic boxes, A/D converters and computer software to measure profile features that span as much as six orders of magnitude. Future efforts will focus on increasing the wire bias and characterizing the nature of the "halo" discovered in the profiles.

Neutron Production Target Cell



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

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Abstract

The spatial beam density distribution beyond 2.5 to 3 standard deviations of the beam center is an important property for undertanding the relatively small fractional losses of high intensity beams at the Los Alamos Proton Storage Ring (PSR) and transport lines to the neutron production target. This part of the distribution (sometimes referred to as beam halo) is not well determined by the LANSCE-standard wire scanner system nor is it yet reliably predicted by the simulation codes. To significantly improve the experimental determination of the beam halo, an improved wire scanner has been developed, tested and installed in the extraction line. To enhance the signal-to-noise ratio, an amplifier consisting of a wide dynamic-range, integrating amplifier, sample-and-hold circuit, log amplifier and line driver is located near the beam line. Offset errors at the input of the amplifiers are actively cancelled and timing gates are derived from a single input pulse. We will describe the prototype instrument, discuss our encouraging test results and report our experience with the instrument in the PSR extraction line.