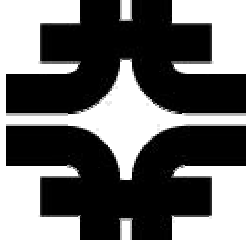

Aging in the Large CDF Axial Drift Chamber

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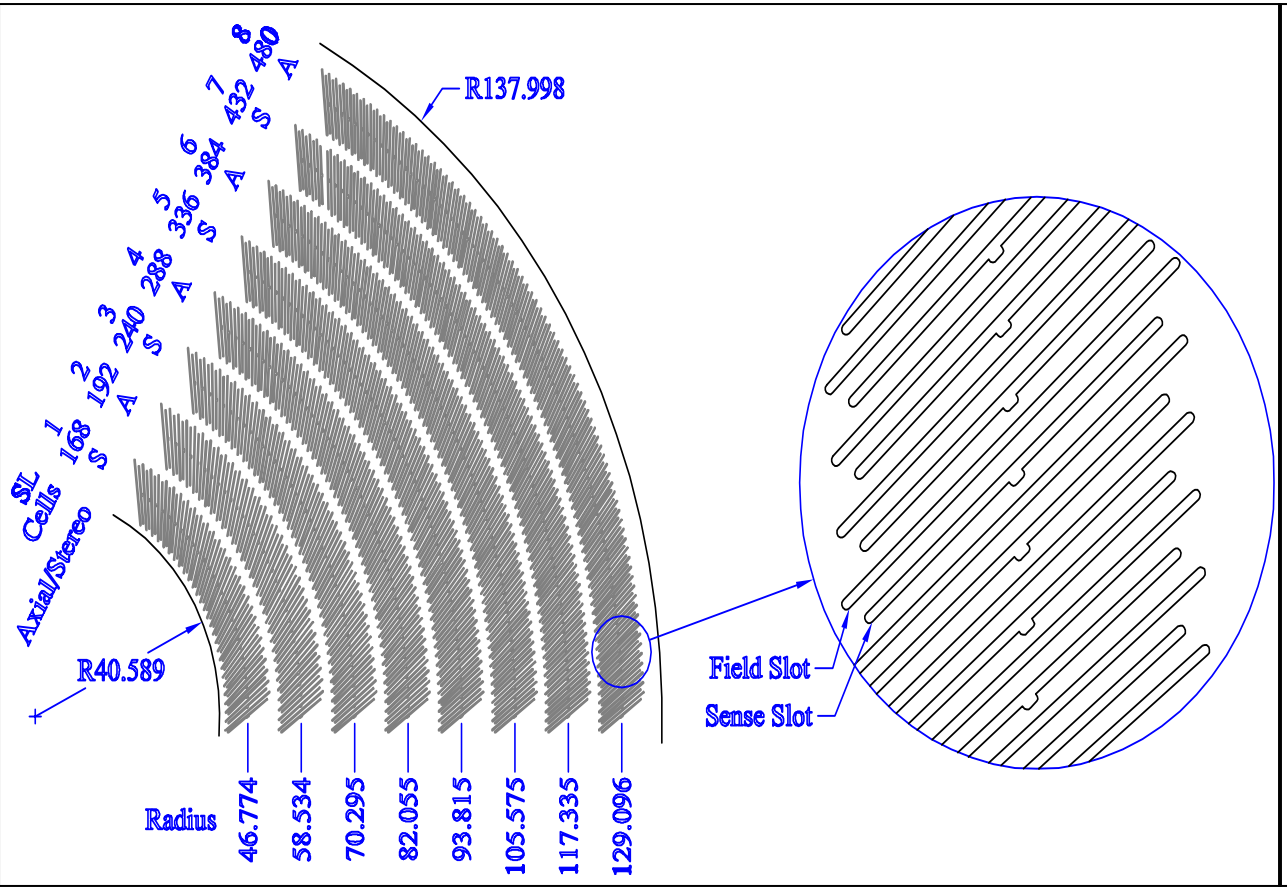
CDF Large Axial Drift Chamber: COT

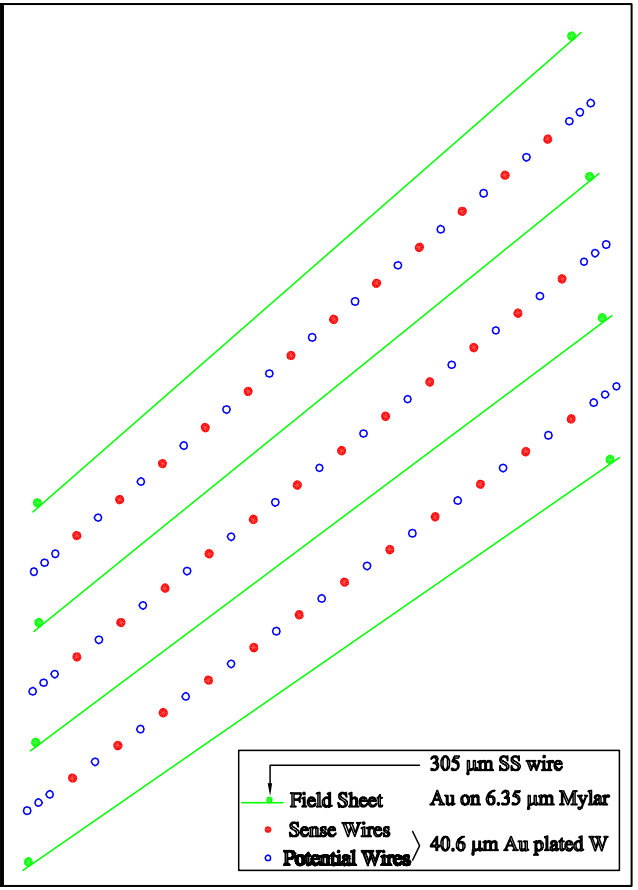
- At the center of the CDF detector (in 1.4 T field).
- Cylindrical: 3 meters long by 3 meter diameter.
- Argon/Ethane 50/50 with 1.7% isopropanol; Gas volume exchange every 30 hours.
- Jet Cell configuration:
  - 8 super-layers, 4 axial and 4 stereo, 35° cell tilt.
  - 12 sense wire layers per super-layer (96 total)
  - Sense, potential wires: 40 um gold plated tungsten
  - Cathode planes: vapor-deposited gold on mylar film
- Test monitor chambers showed no aging.

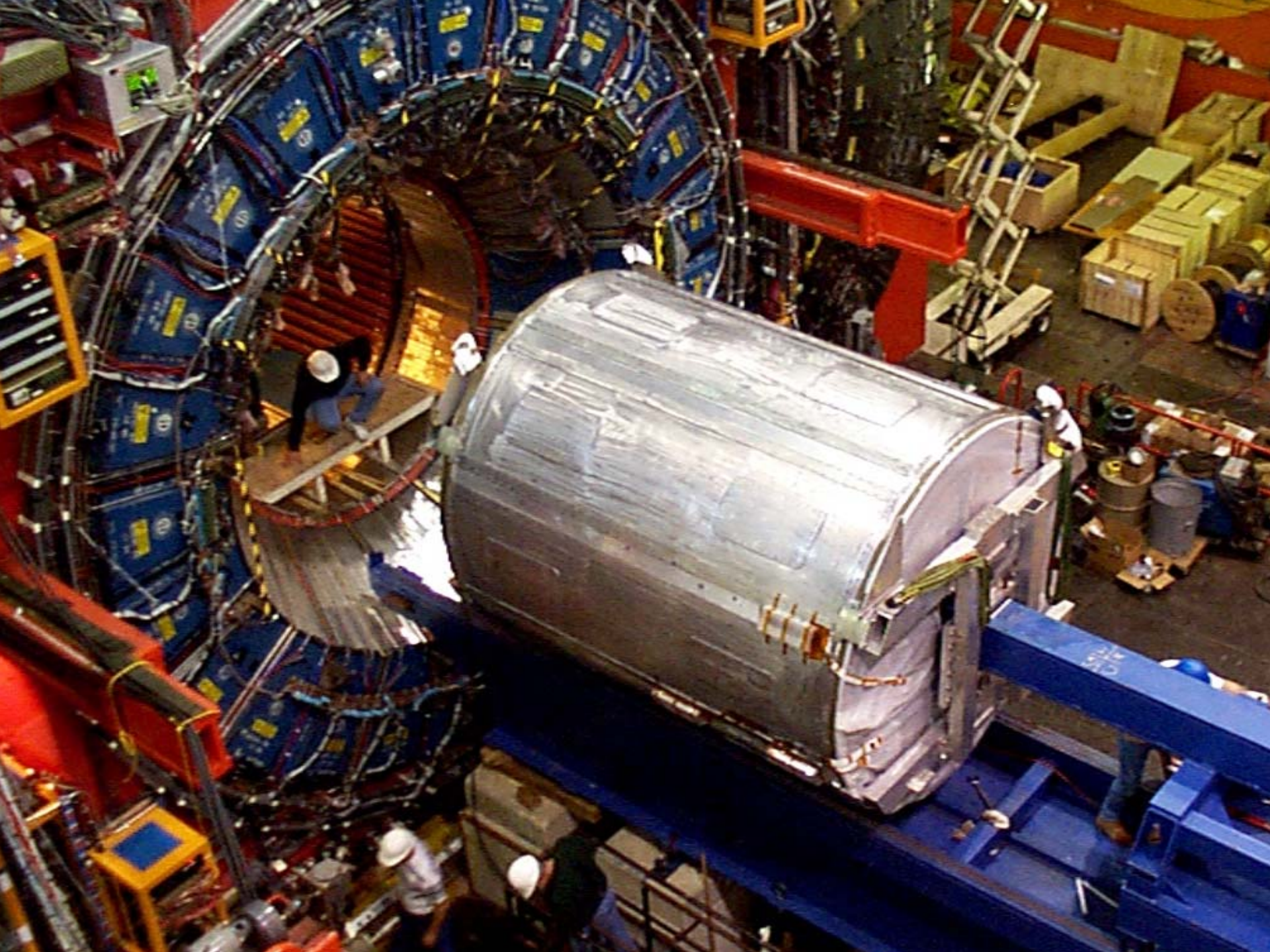
Cell configuration in the COT

1/6 section of the COT endplate. The enlargement shows the sense and field slot geometry in detail.



Three cells in SL2 looking along the beam direction.





Gain Monitoring in the COT

- Archives of the high voltages and high voltage currents are kept (readings every ~10 minutes).
- Archives are also kept of the Tevatron luminosity and some loss monitor rates.
- To facilitate dE/dx measurements, the output pulse width of the amplifier-shaper-discriminator is generated proportional to the integrated input charge. The widths of all hits are stored in CDF physics data sets allowing a determination of the gain as a function of position in the chamber.

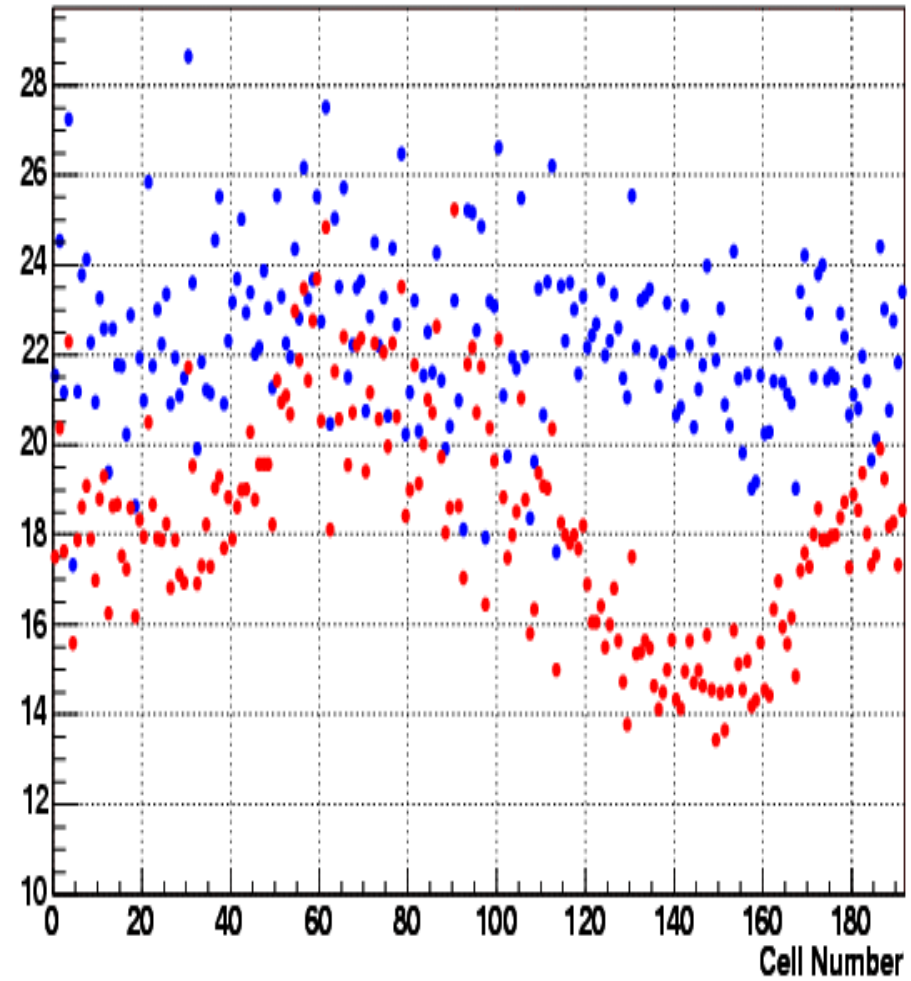
Problems detecting aging in the COT

- COT temperature profile changed as the SVX cooling increased making gain difficult to track.
- There was no easy mechanism in place to correlate the HV currents and luminosity which were stored in different archives.
- With 96 radial layers, the offline tracking efficiency was little affected by chamber inefficiencies.

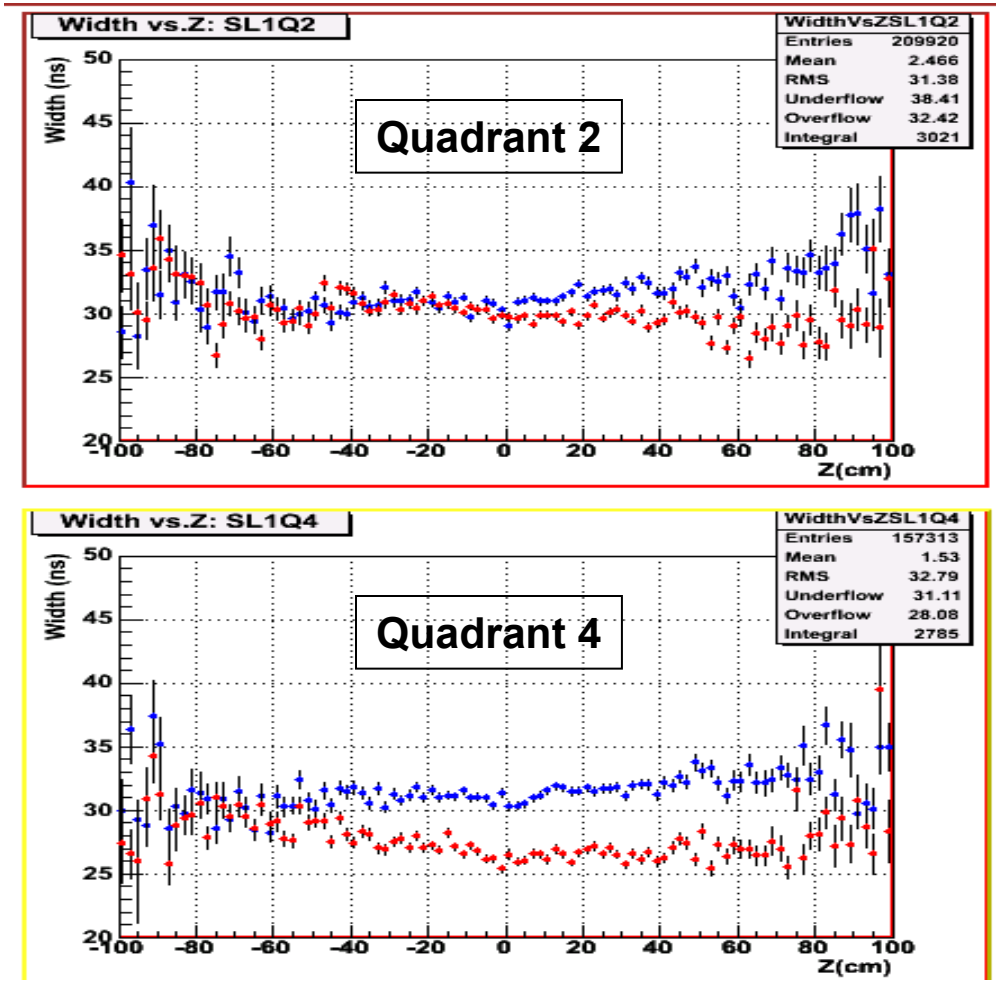
Definite evidence for aging in Nov/Dec 2003

- Phi dependent tracking inefficiencies were noticed in the online trigger (limited redundancy) during summer 2003.
- A careful study of the pulse widths of hits on good tracks as a function of position in the chamber showed more definitive evidence for aging in Nov/Dec 2003:
  - Gain reduced in the inner super-layers relative to outer.
  - Gain reduced more at the exhaust end of chamber.
  - Gain reduced more below the beam than above.
- In March 2004, electron microscope analyses showed a coating on sense wires from an inner super-layer. The coating was mostly carbon and hydrogen with a little oxygen. Most of the molecular bonds were CH and CC.

Comparison of an early run before significant aging (blue) to a later run (red) showing the phi (cell number) and z dependence of the aging. Cell 0 and 96 are horizontal; cell 48 and 144 are vertical. Phi dependence is presumably affected by temperatures and gas convection currents.

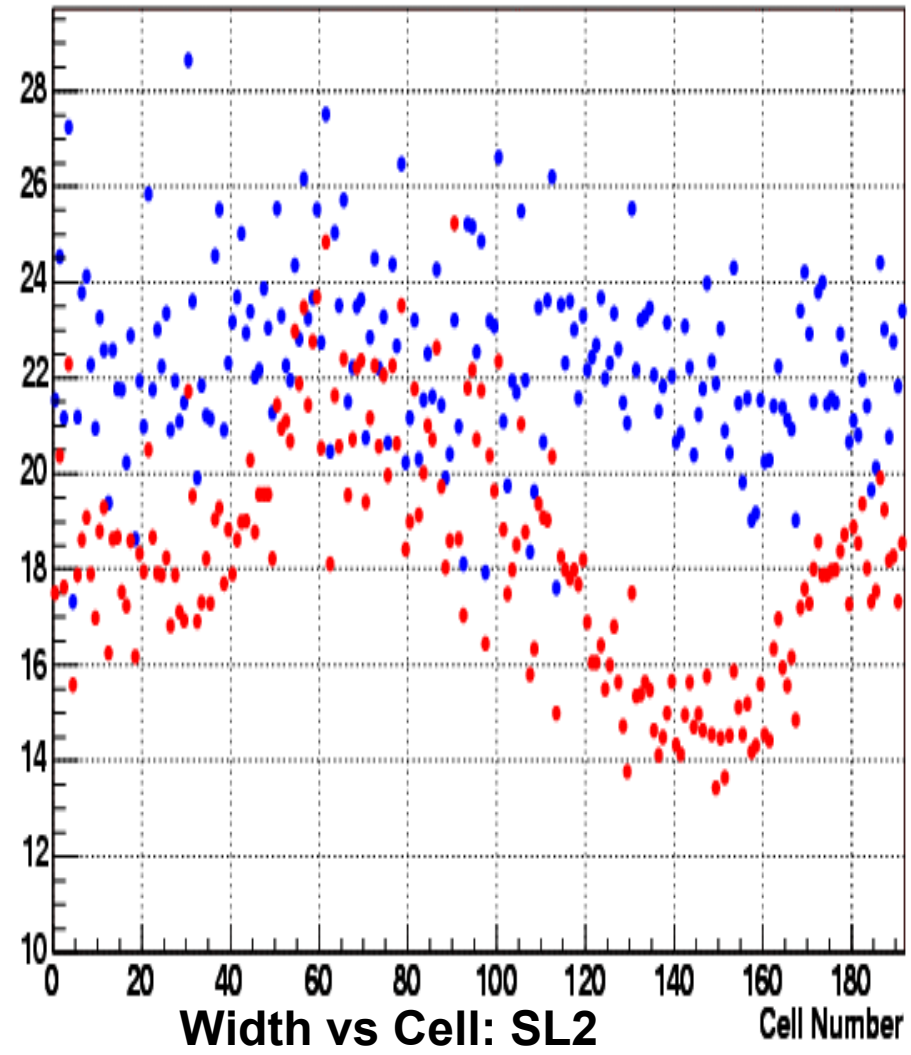


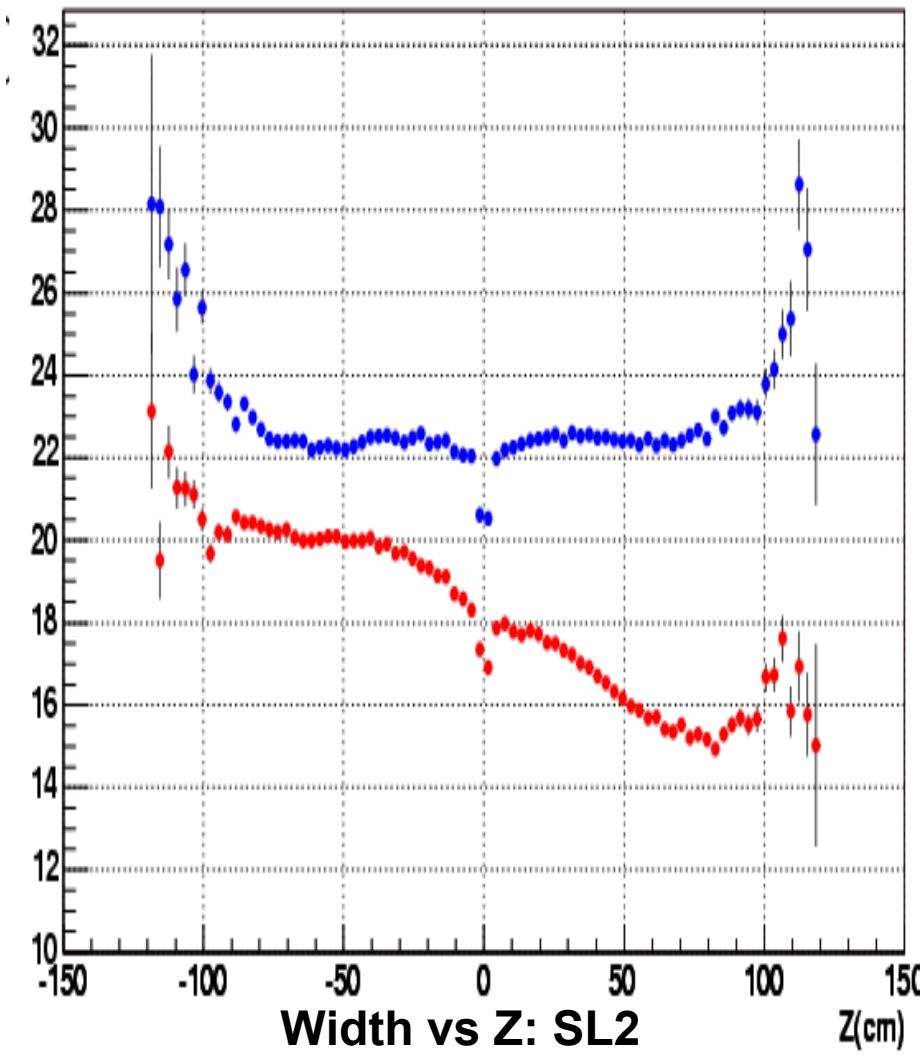
Width vs Cell: SL2



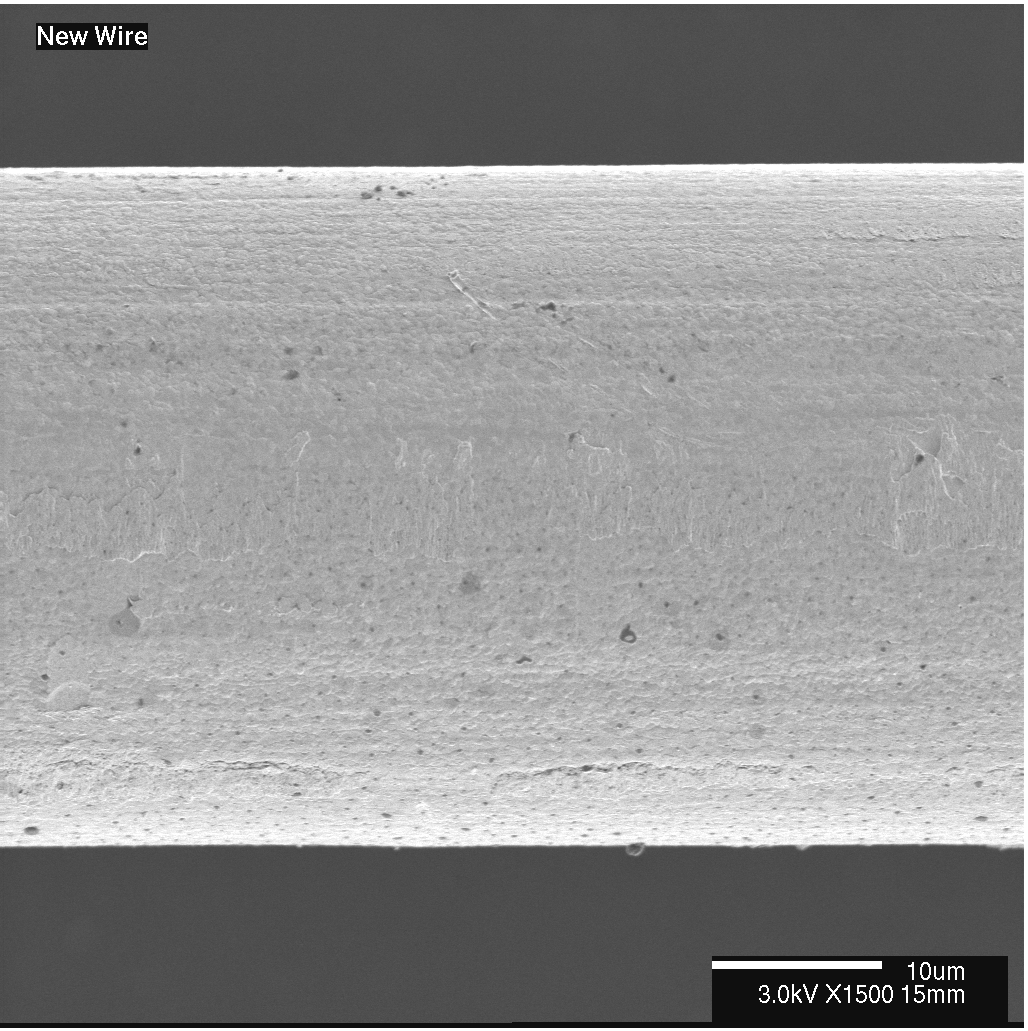
Width vs Z: SL1

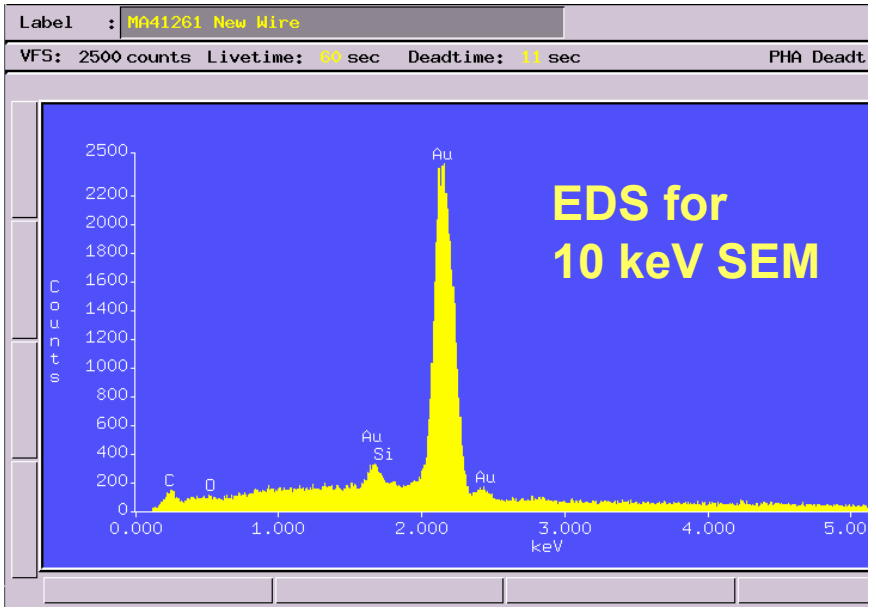
Comparison of an early run before significant aging (blue) to a later run (red) showing the phi (cell number) and z dependence of the aging. Cell 0 and 96 are horizontal; cell 48 and 144 are vertical. The z plot averages over all phi and has more statistics and corrections than the last slide.





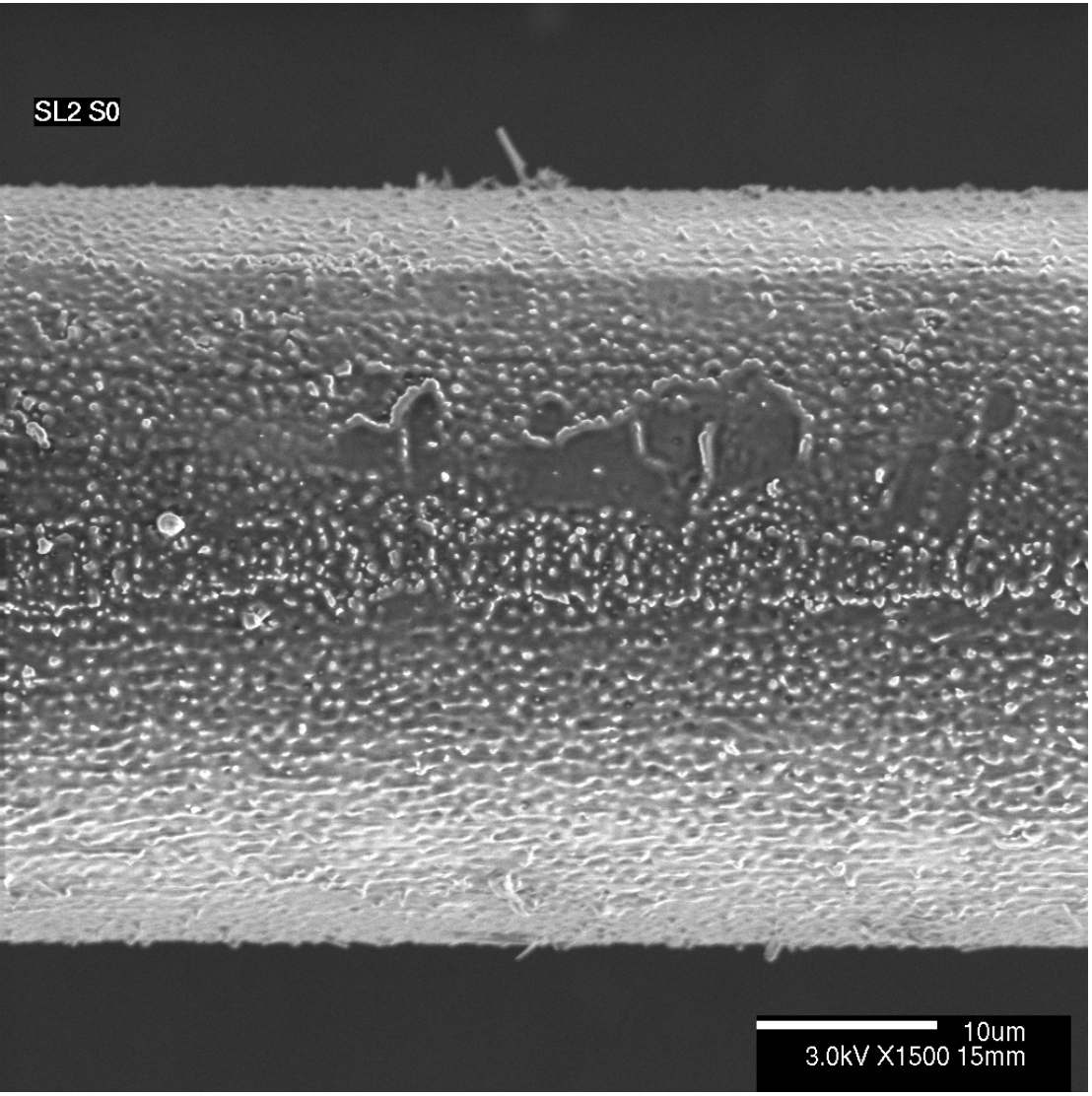
High resolution SEM picture of a new wire on left. On the right is a EDS spectra of a new wire.

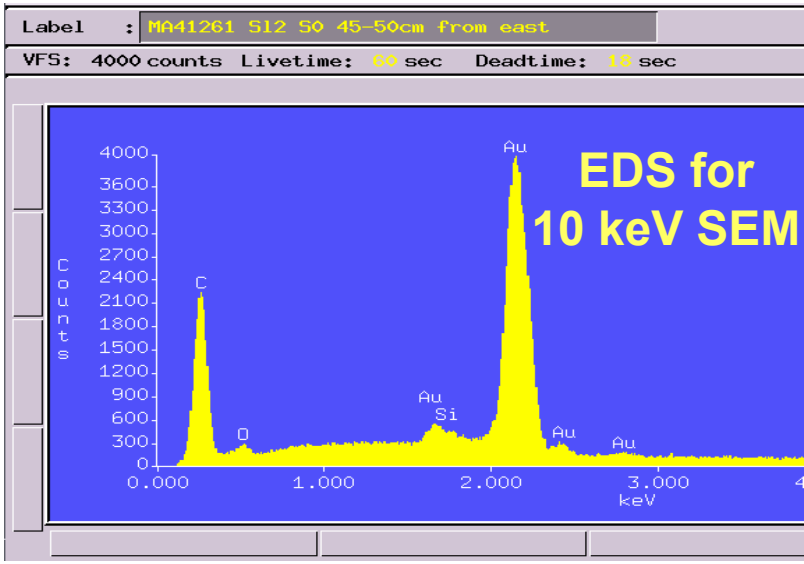


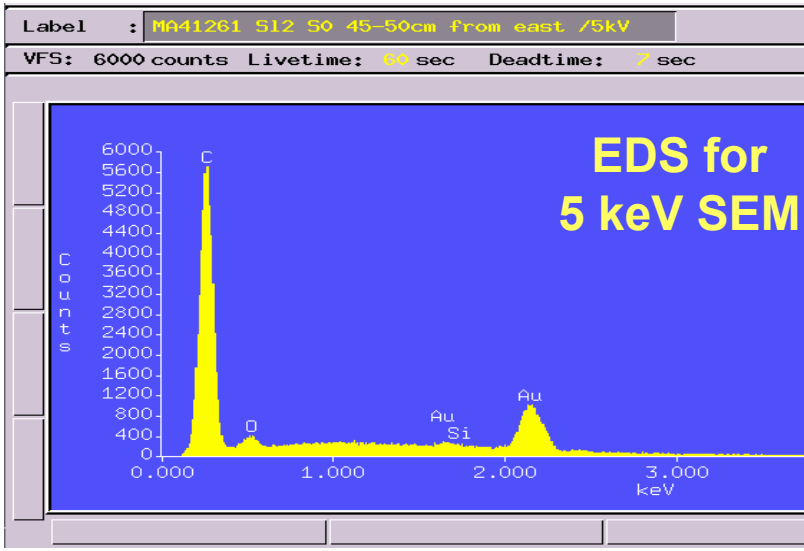


Electron Dispersive Spectroscopy (EDS) uses an electron beam to eject electrons from inner shells of atoms. The x-ray spectrum generated when these states are refilled give a measure of the elemental makeup of the sample.

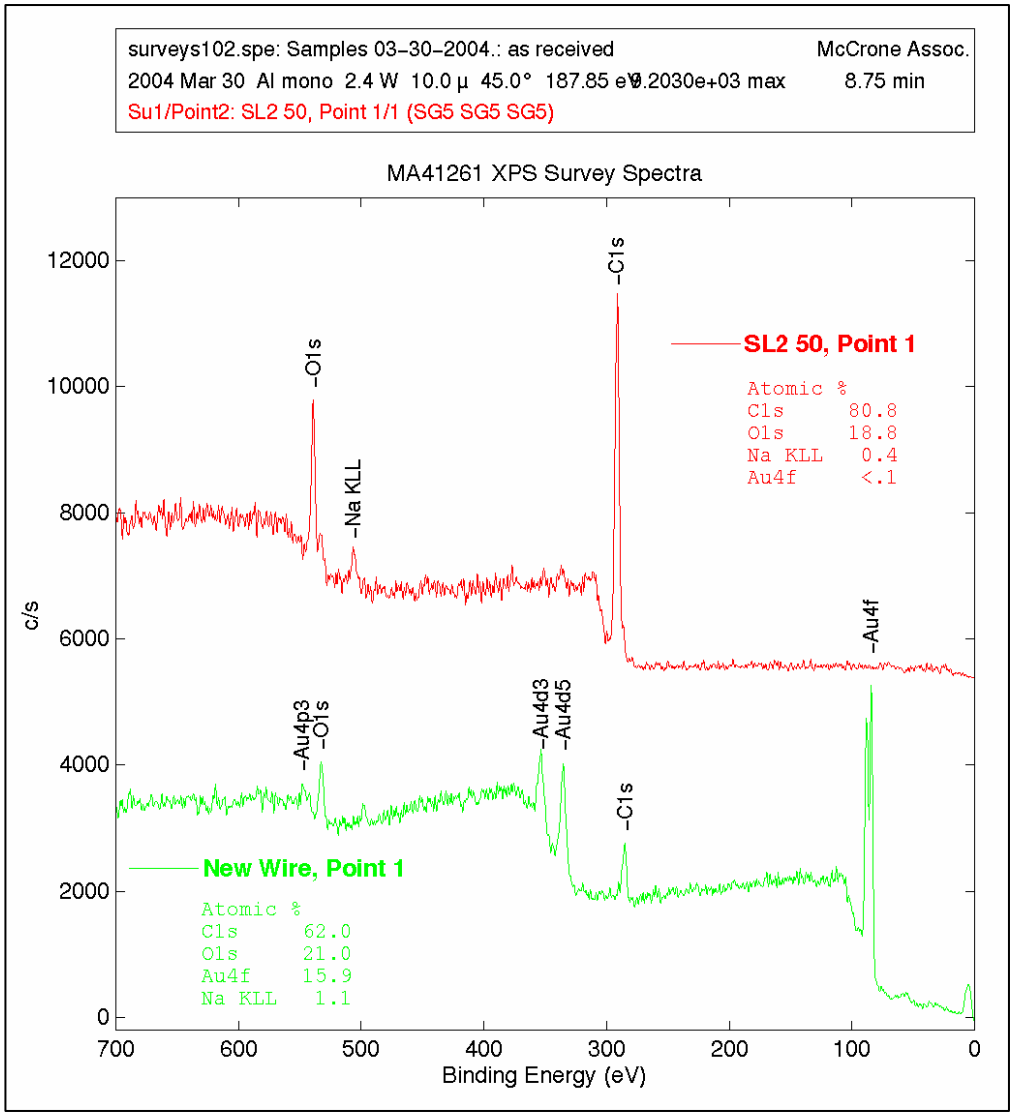
SEM picture on left shows dark coating on aged wire with submicron nodules. EDS spectra at right shows mostly carbon with a little oxygen (lower energy sees more coating).

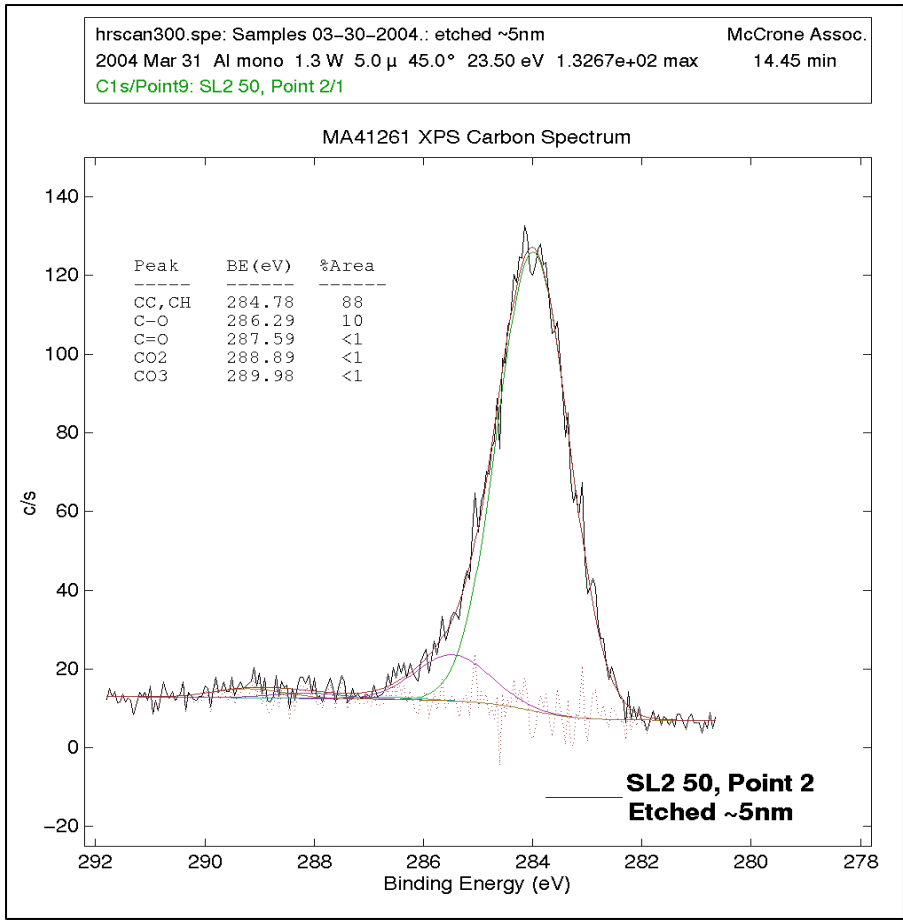






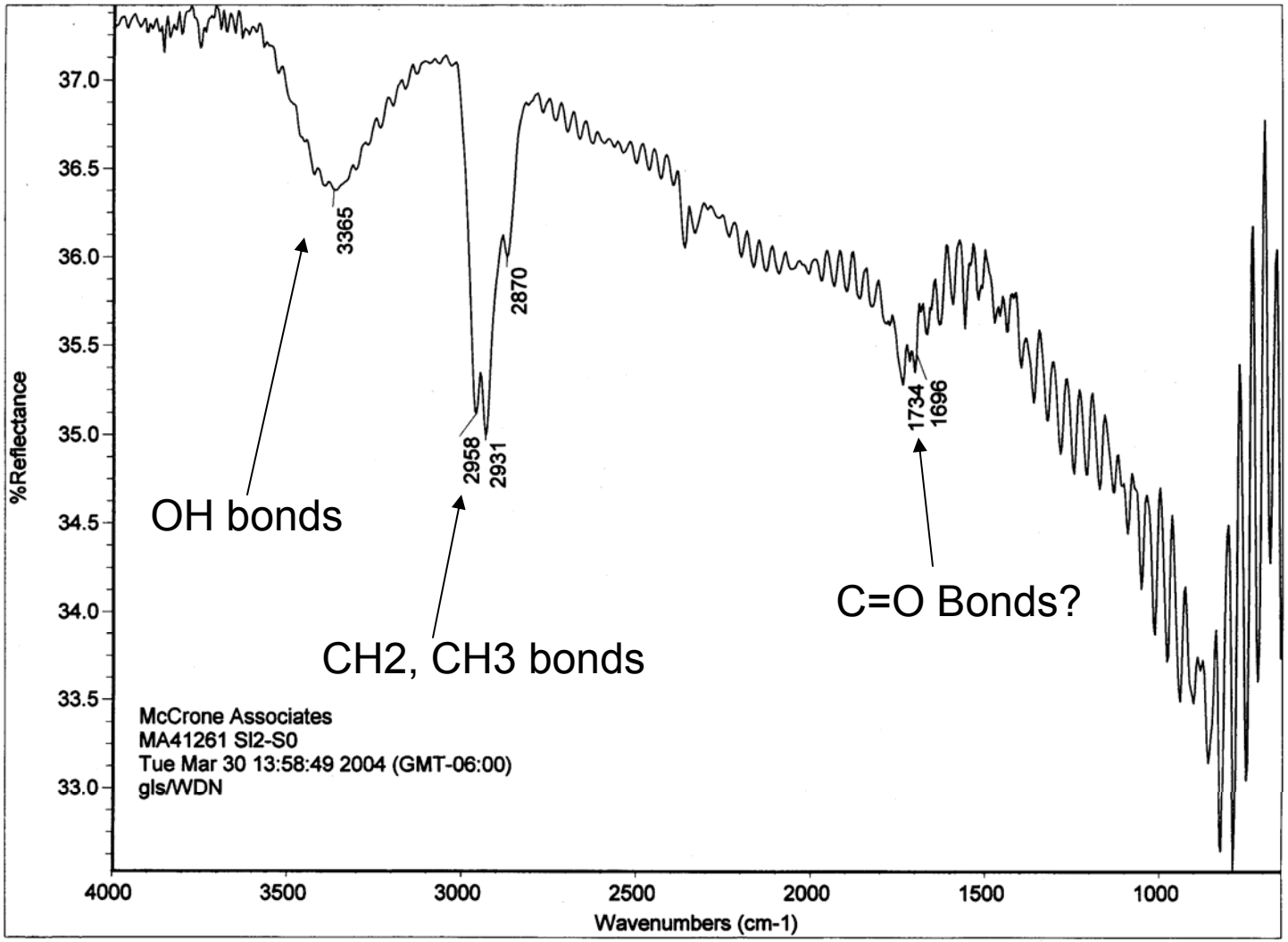
XPS scanning measures the molecular bonds. A precision scan of C1s peak on left shows mostly CC, CH bonds with some C-O bonds.



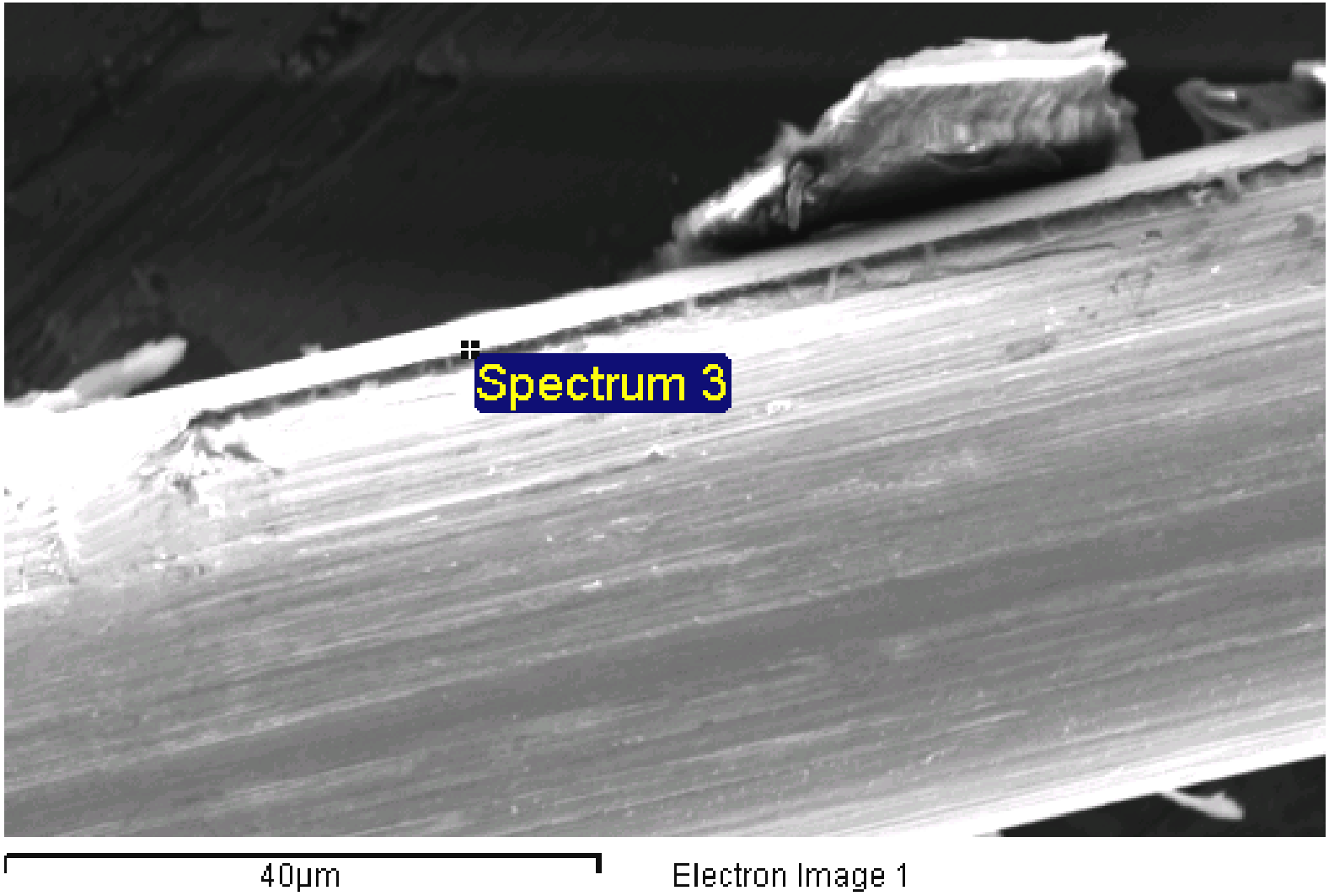


XPS scan measures the energy spectrum of electron emitted when the sample is irradiated with Xrays.

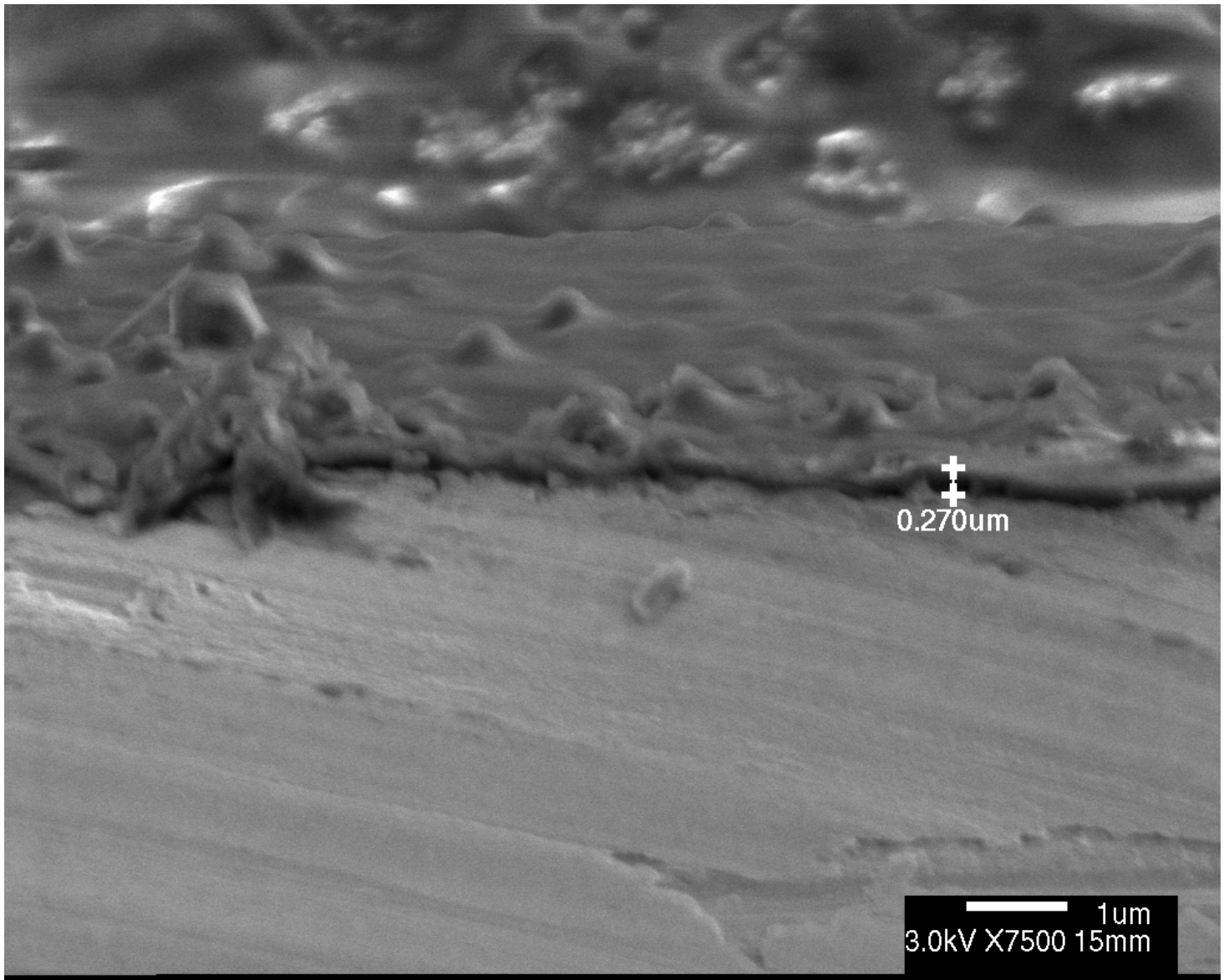
Fourier Transform Infrared (FTIR) analysis also gives a measure of the molecular bonds. Sample is irradiated with broadband infrared and the surface is penetrated a short distance. The reflected spectrum is examined for absorption bands. Dips near 2300 may be background CO2.



SEM picture of an aged COT wire that has been scraped. In the foreground is bare tungsten and in the background is a dark polymer coating. Under the dark coating is a narrow gold band. The dark coating appears to be 1.5-2.0 microns thick.



Another picture with a higher resolution SEM showing an area on an aged wire where the coating had been accidentally removed. The thickness is only ~0.3 micron.



The effect of the coating on gain

The following is an empirical formula for wire gain:

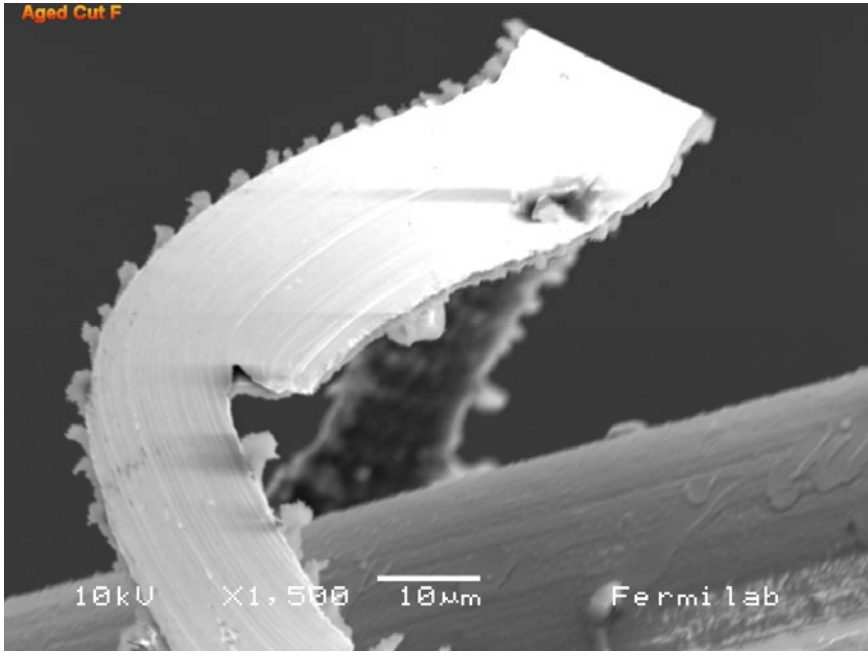
$$\text{Gain} = .00005 \times \exp((0.034317 + 0.047461 \times (d0/25) \times Es)$$

d0 = dia. in μm; Es = surf. field in kV/cm =180 kV/cm for 20000 gain.

If the coating is conductive and the voltage remains constant, then the change in capacitance must be included: $C \approx C0 \times (1 + 0.12 \times (\Delta d/d0))$.

Including this effect the gain for a 1.0 μm coating is decreased by 19.7% and for a 2.0 μm coating by 39.3%. The larger thickness measurements are probably consistent with the COT gain loss; the smaller ones are not.

If the resistivity $\rho \geq 10^6$ ohm×cm then it may have a significant effect on the gain, depending on the thickness. The inner SL current is 4-8 na/cm.



Basics of Aging in the COT

- Aging is due to a coating on the sense wires.
- It is presumably polymers, strings made of CH_2 groups that grow in the environment of the avalanches as the gas flows down the wires.
- When the strings become long enough, they plate out on the wire. This “condensation” is temperature dependent. H1 saw similar effect.
- Probably there is also ablation in the avalanches and aging depends on the balance between ablation and deposition.
- No evidence for contamination in the COT gas, however can’t rule out some hydrocarbon.

Thoughts on reducing aging

- Increase gas flow in the chamber so that the polymers are vented before they grow long enough to deposit. Many groups have found that high gas flow is important.
- Increase temperature of the chamber so that polymers must grow longer to deposit.
- Add something in addition to alcohol to inhibit polymerization such as oxygen. This worked!
- Switch to a gas than is not a hydrocarbon such as argon/CO_2 or argon/CF_4.

Sequence of events in solving problem

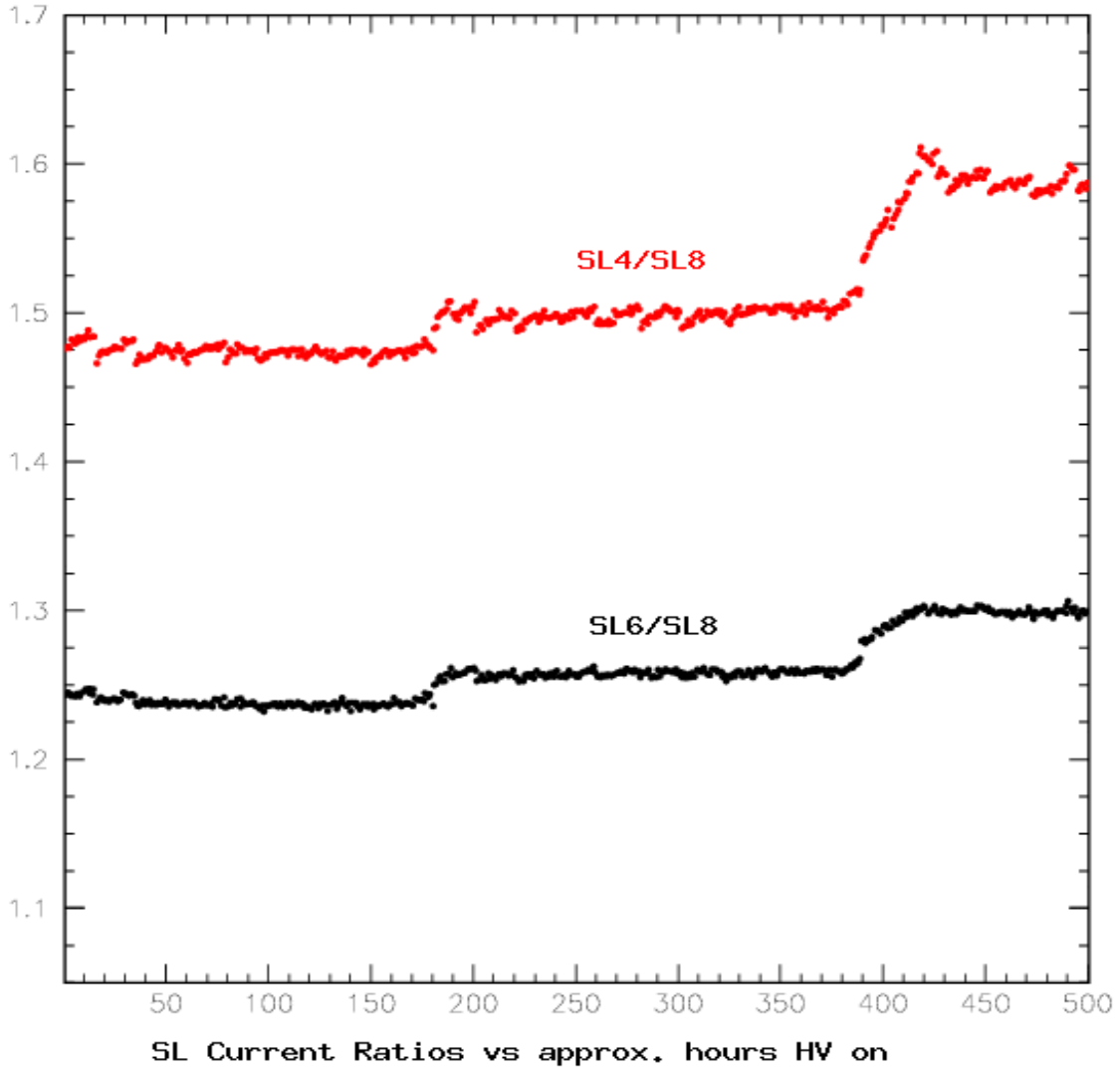
- Doubled the gas flow to one volume exchange every 15 hours (40 SCFH).
- Added a gas recirculation system (initial goal was one exchange every 3 hours). Gas cleanup was left for future, but we expected to improve gas flow patterns and to dilute the polymers in the inner super-layers. Cleanup was expected to be difficult because of the large alcohol content.
- Changed filters and the alcohol bath more often.

Our experience increasing gas flow

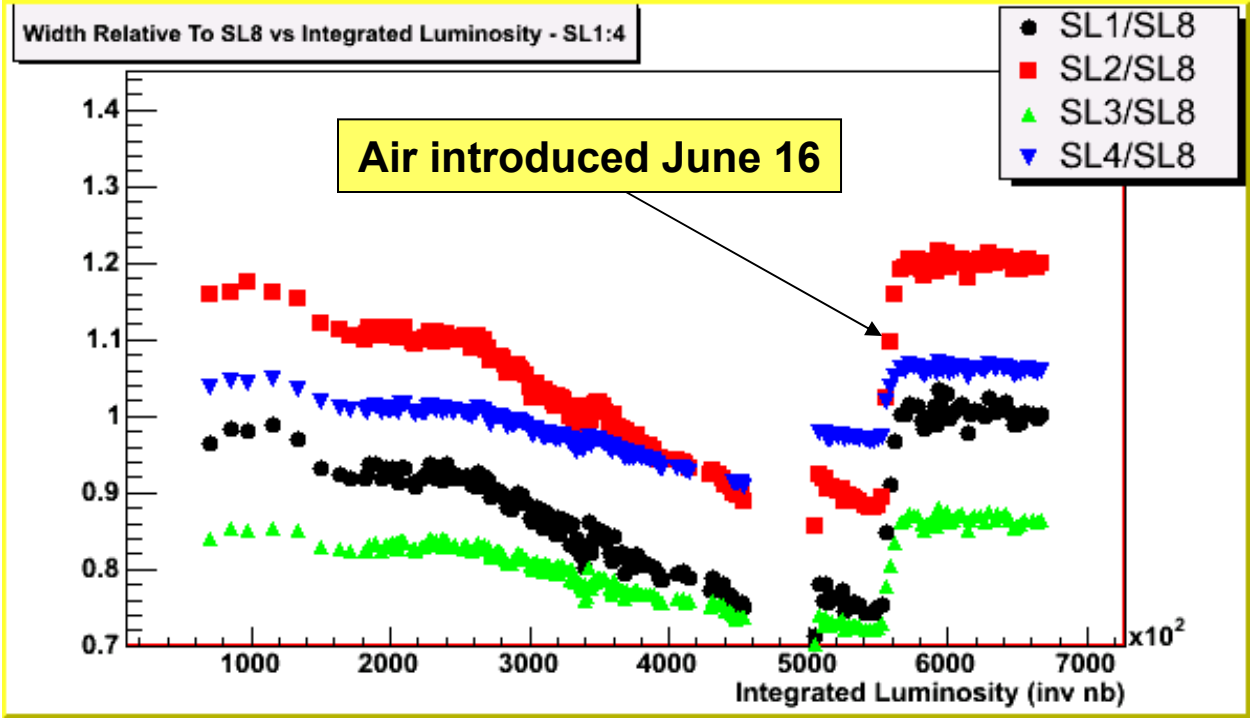
- Both peak and integrated luminosity increased significantly during 2004. This mostly offset the effect of increased input gas. The recirculation system was not run long enough by itself for a definitive measure of its effect.
- A side effect of building and commissioning the recirculation system was that at two well defined points in time we introduced air (oxygen) into the COT gas.
- Finally in early June we made the right plot that showed reverse aging correlated with 100-200 ppm of oxygen (from air leaks)!

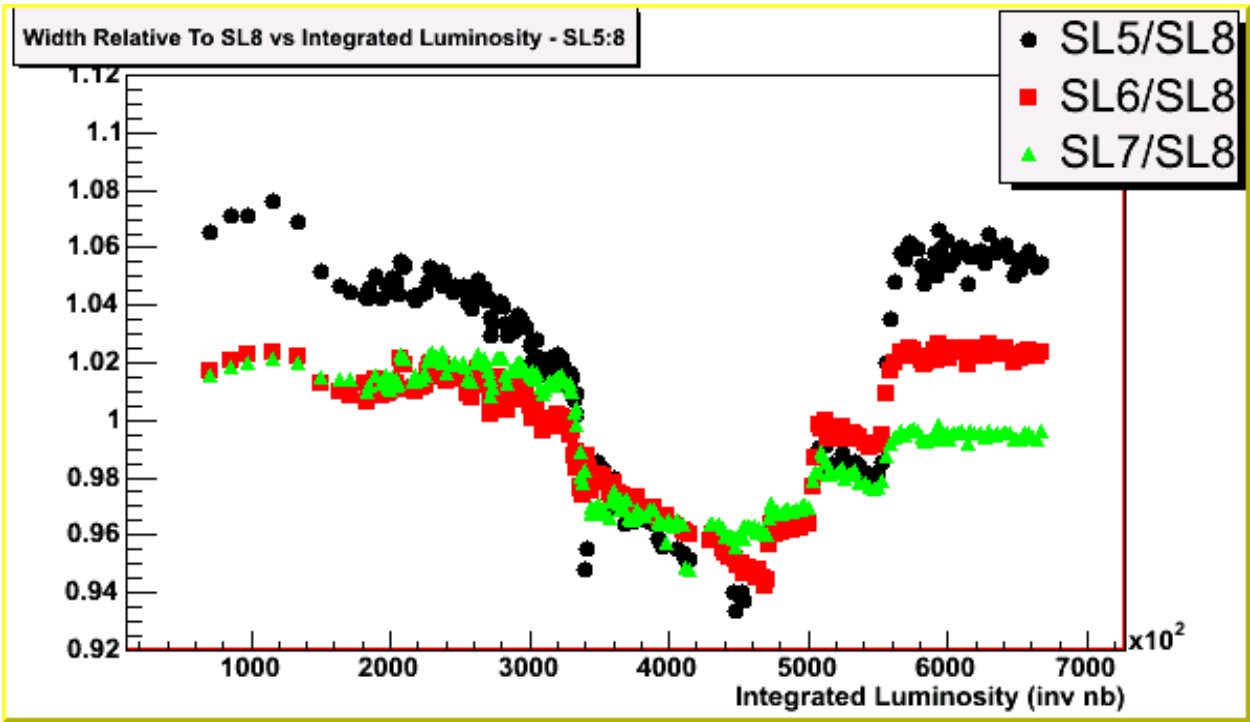
HV current ratios with air (oxygen) in COT

This plot shows the hourly current ratios from March 28th to June 1st 2004. The first recovery period, hours 181-189, was after air entered the COT during a valve installation. The second recovery period, hours 380-418, was during the commissioning of the recirculation system. With recirculation, the COT exhaust manifold ran sub-atmospheric allowing air to enter through leaks. The leaks were fixed at hour 418. If the leaks had not been fixed, recirculation might have been given the credit?

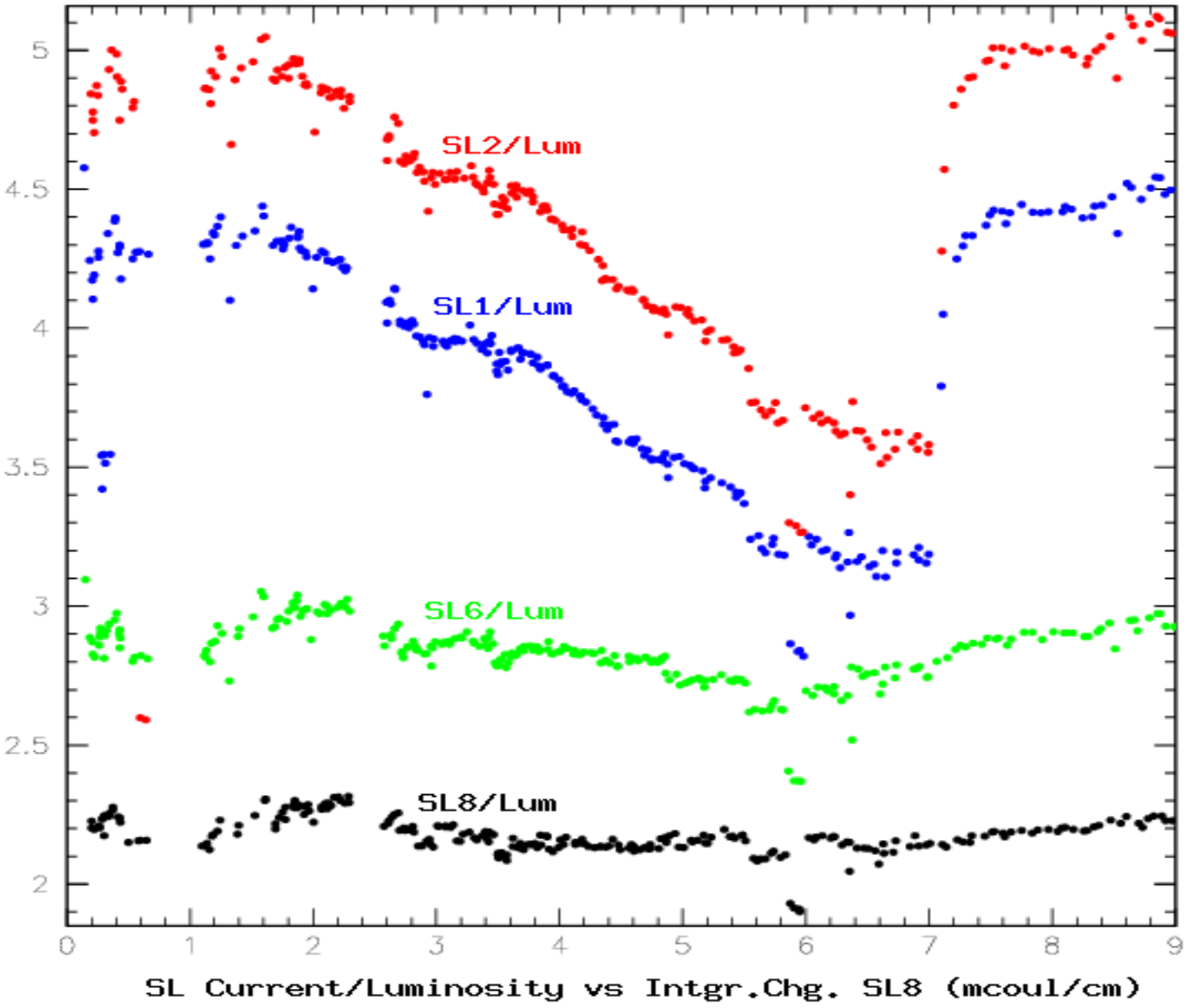


Widths normalized to SL8 width vs the integrated luminosity are shown at the right for the whole run. By normalizing to SL8, which had very little aging, fluctuations due to pressure and some temperature uncertainties are removed.



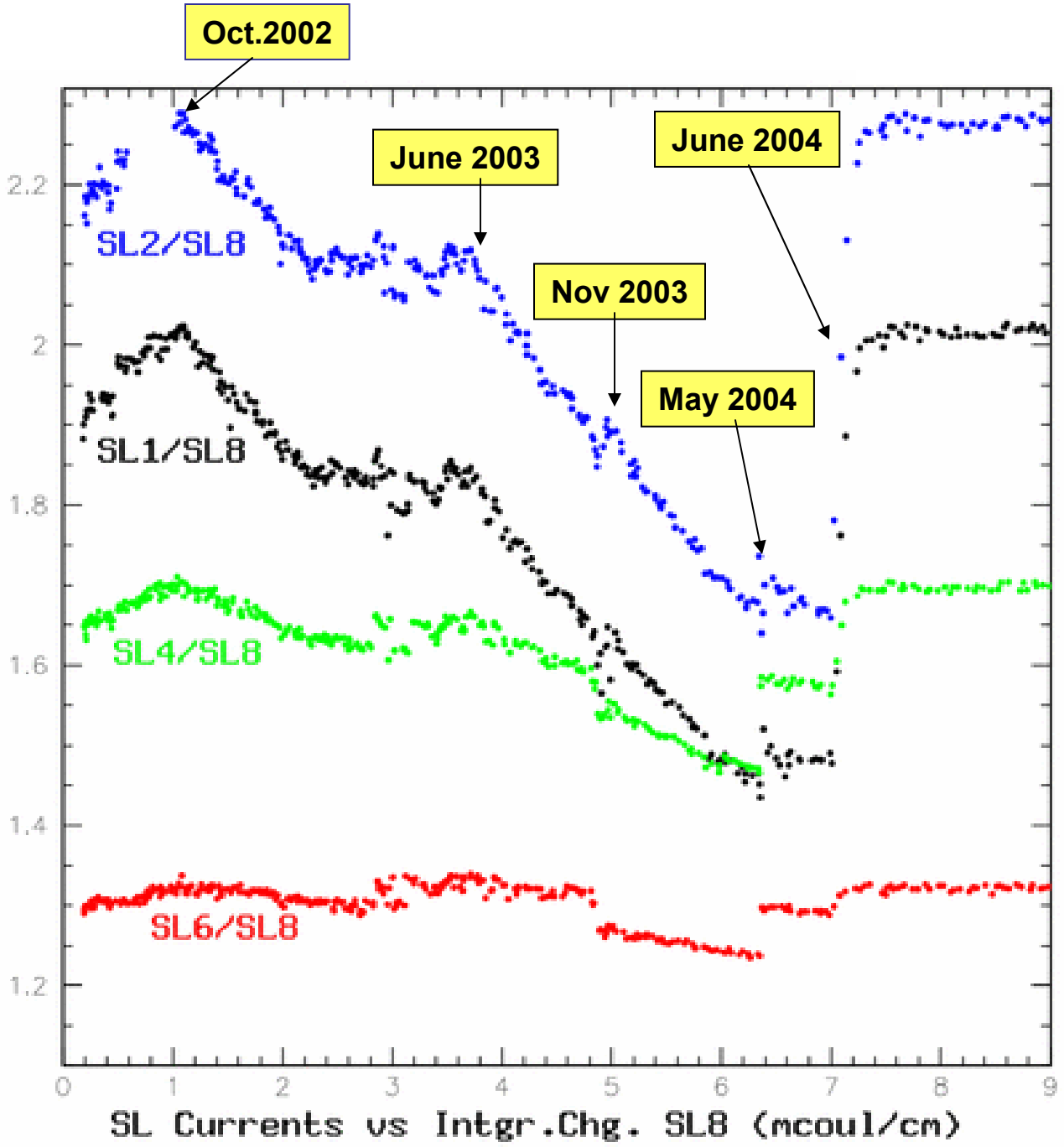


SL Currents/Luminosity for the whole run

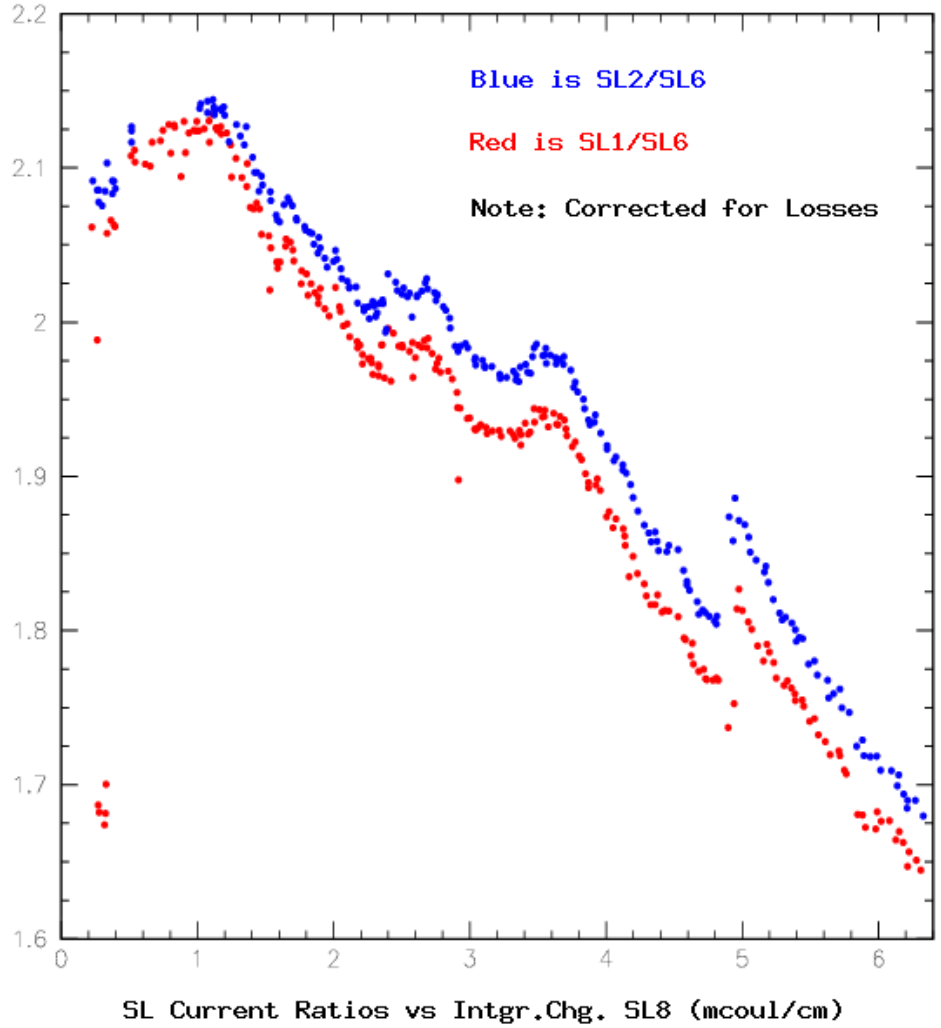


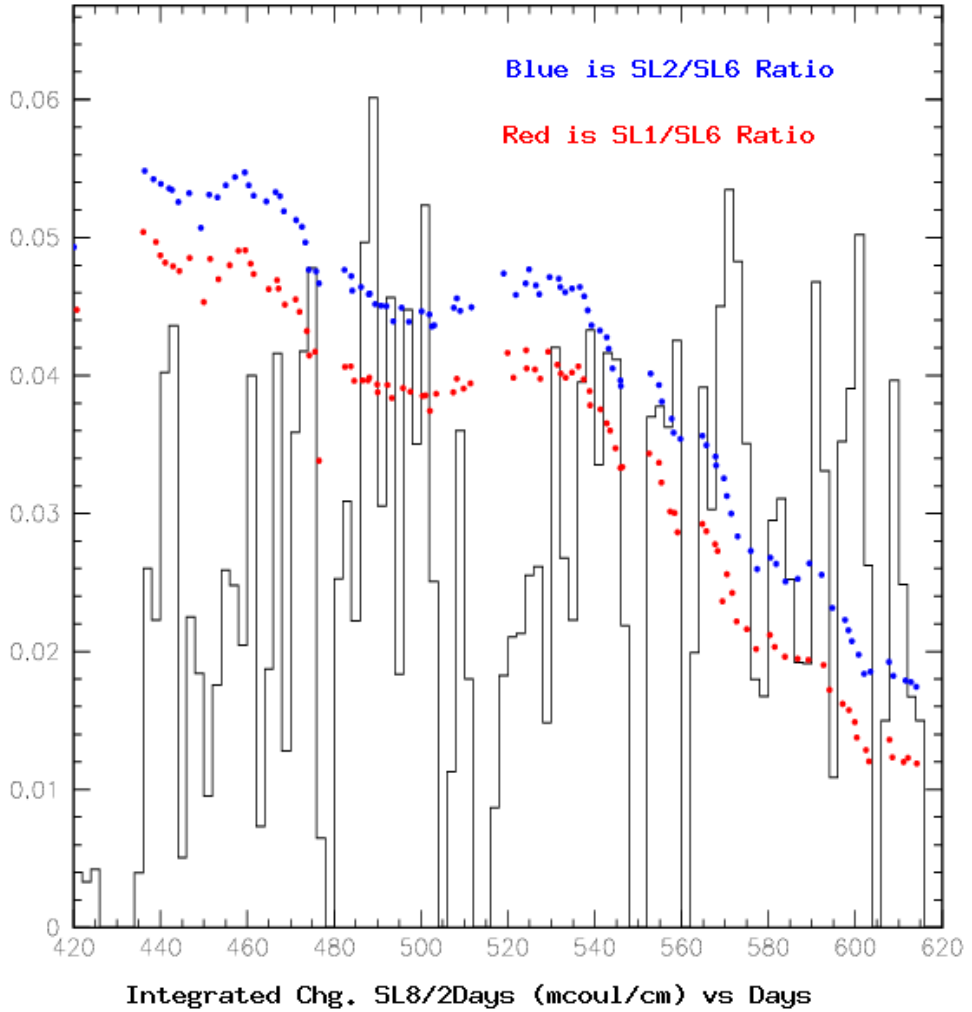
COT HV currents normalized to SL8 since the beginning of the run plotted against the integrated charge in SL8.

There is a sharp rise at 7.1 mC/cm when oxygen was introduced. The ratios are plotted only for those time periods that SL1 and SL2 were on! There is a factor of 5.7 for the integrated charge in SL1, SL2 relative to SL8.



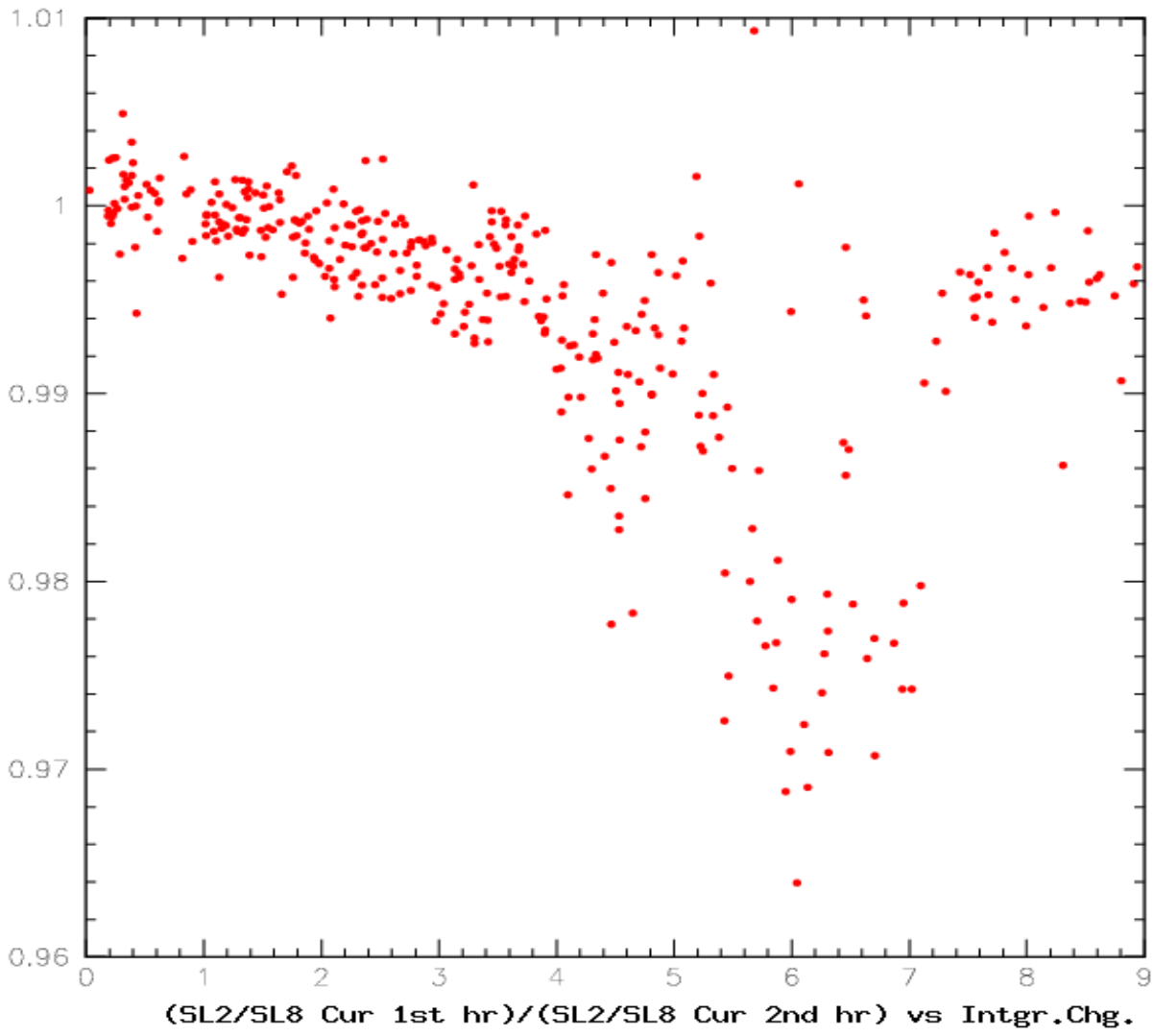
There were brief periods of recovery in the inner super-layers with respect to the outer super-layers as shown by the peaks at 2.6 mC/cm and 3.6 mC/cm in the plot on the left. The plot at the right shows the peaks relative to the integrated charge. The peaks follow periods of lower integrated charge.



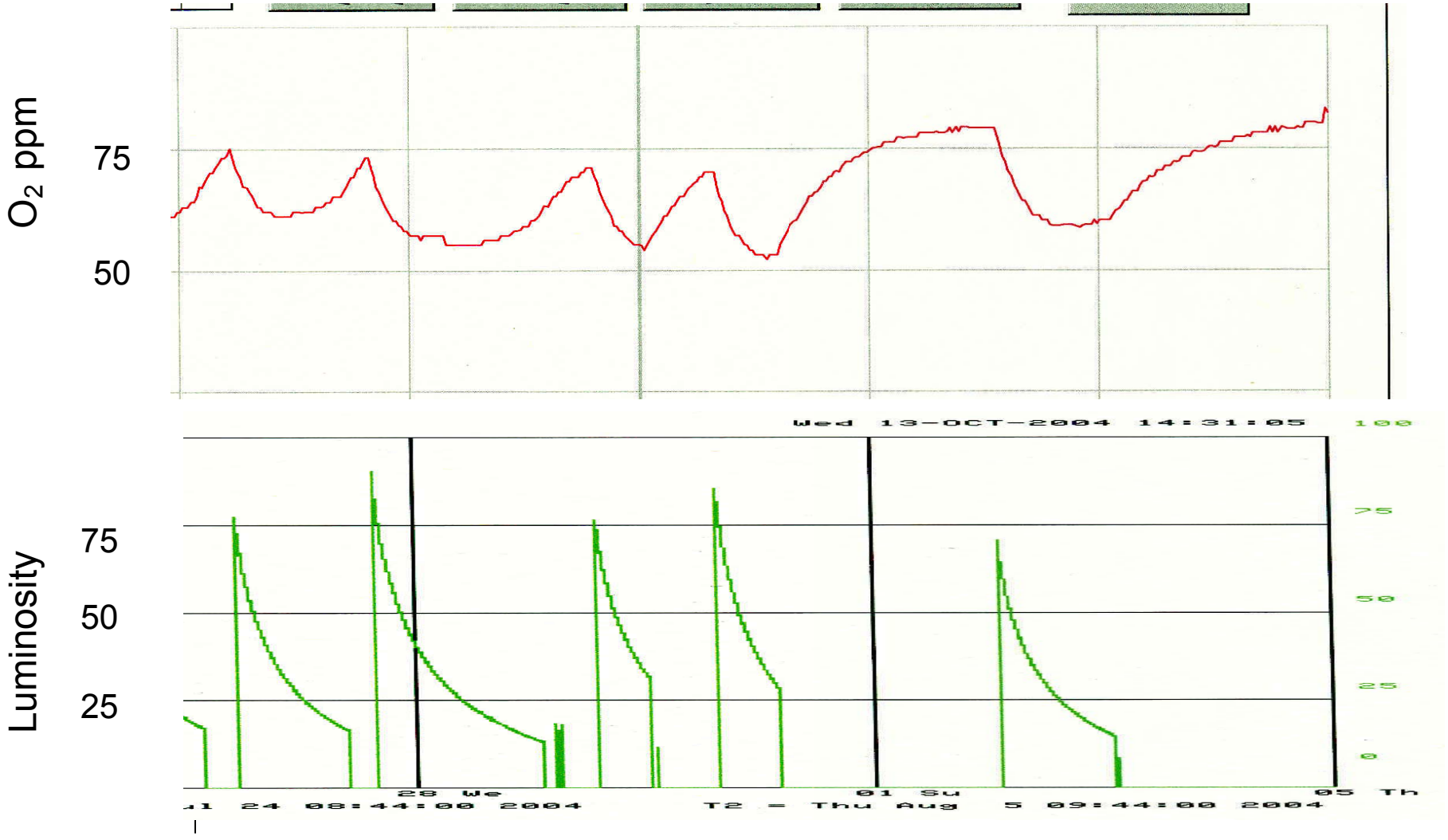


Reverse aging at the beginning of a store. Ratio of gains: Gain(hour1)/Gain(hour2).

This plot shows the fractional current change in SL2 normalized to SL8 for the first two hours of a store. SL8 is used to normalize SL2 since there is little aging in SL8. When the effects of aging were large, there was a 2-3% increase in SL2 gain suggesting that polymers are deposited or lost between stores and more must be grown again before deposition dominates over ablation.



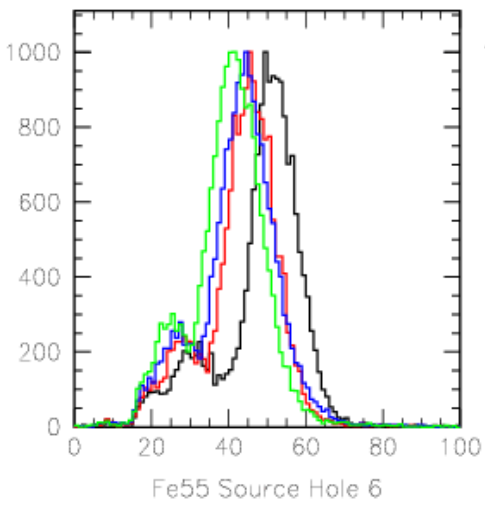
Variations the in O_2 level compared with the luminosity

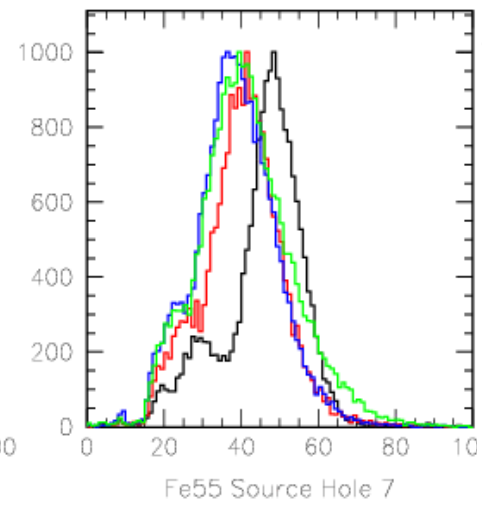


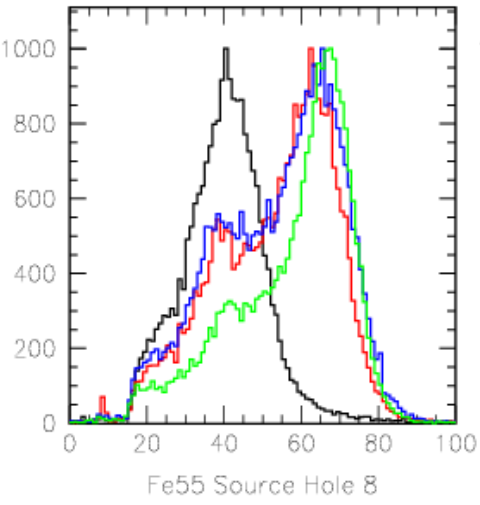
Aged wires removed from the COT were reverse aged with sources

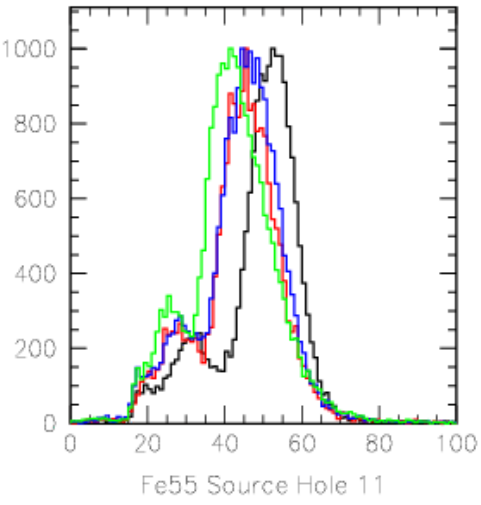
- An aged plane of wires was removed from SL2 in the COT in March 2004.
- Aged wires from this plane were irradiated with at Sr^{90} source in a small chamber.
- Gases were standard argon/ethane (50/50) plus 1.7% isopropanol, argon/CO_2 (80/20), and COT exhaust gas.
- The gain was monitored by looking at the Fe^{55} spectra. A second wire plane made of new wires was used to normalize the gain.
- After long enough irradiation, the coating was removed from an aged wire and the Fe^{55} spectra looked normal.

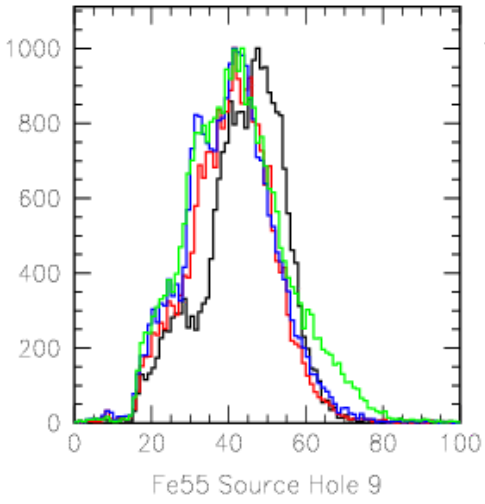
Fe^{55} spectra from wires reverse aged in a small chamber using standard COT gas. The black histograms were taken before irradiation, then sequentially the red, blue, and green. The Sr^{90} source was on hole 8. The gain under the other holes in general decreased. When reverse aged in argon/CO_2 the gain under the other holes increased or stayed the same.

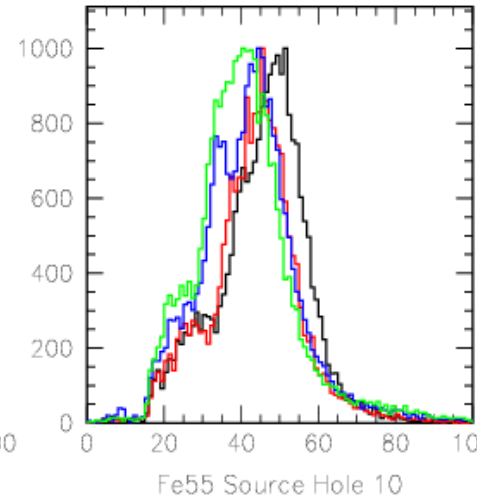


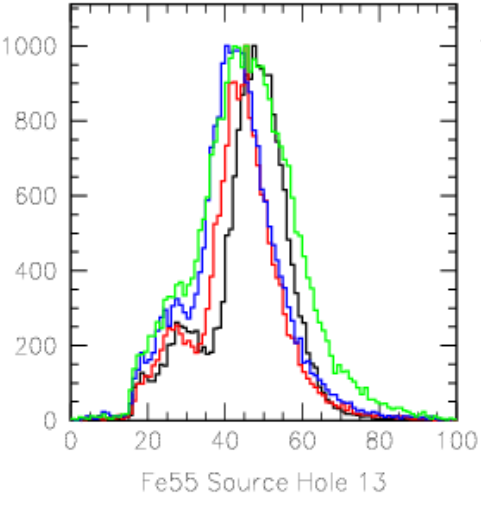


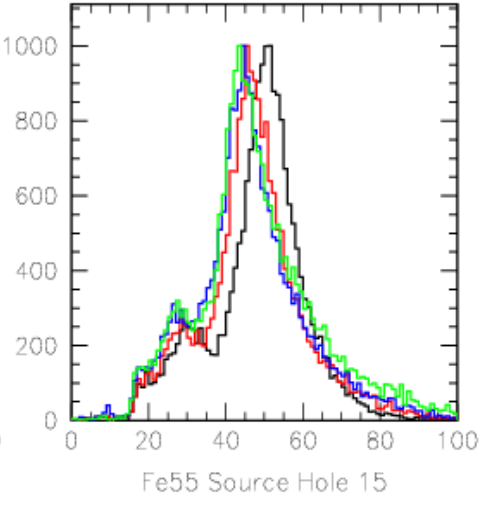




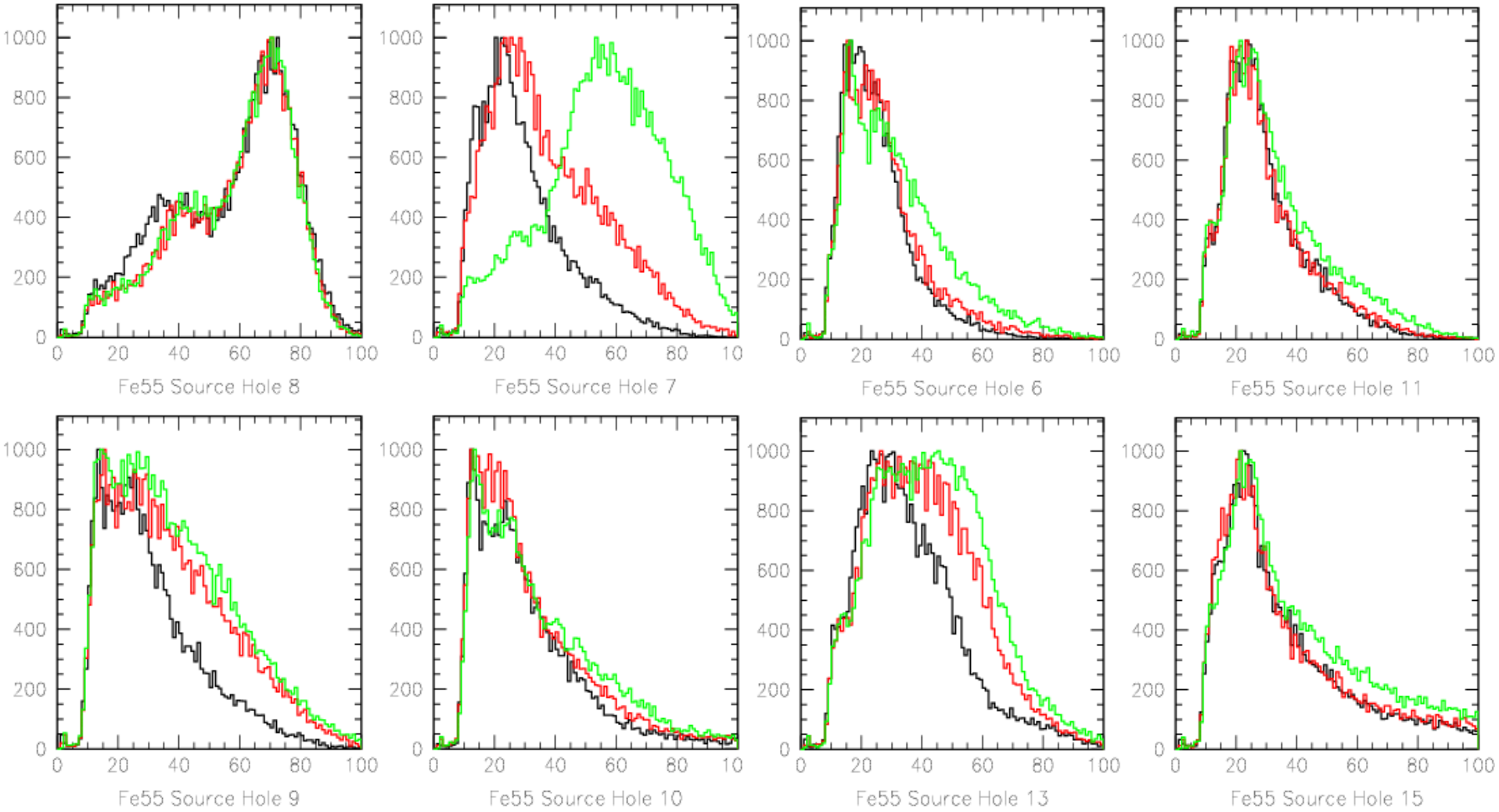








Fe^{55} spectra from wires aged ireverse aged in a small chamber using argon/CO_2 gas. The black histograms were taken before irradiation, then sequentially the red and green. The Sr^{90} source was on hole 7. The gain under other holes increased or stayed the same.



What does the oxygen do?

- Oxygen is consumed in a chemical reaction.
- Oxygen is supposed to inhibit polymerization (probably better than alcohol, water, etc.) by combining with CH_2 radicals or attaching to ends of polymer chains.
- There is probably a natural ablation that takes place in an avalanche. We see reverse aging under a localized source and at the beginning of a store (under all the conditions that we have been able to observe).
- Aging probably depends on the balance between this ablation and polymer deposition. Presumably if O_2 inhibits the polymerization, then ablation wins.
- Does O_2 react directly with the coating making volatiles? Probably. But if that were the dominant effect, we probably would not have seen more aging away from the source in in the test chamber with standard COT gas.

Conclusions for chambers with hydrocarbon gases.

- Small test chambers with localized sources do not in general give a good measure of aging.
- Test chambers without controlled amounts of oxygen do not give a good measure of aging.
- Temperatures probably have a significant effect on aging. Presumably convection currents also.
- A small amount of oxygen (100 ppm) completely changes the aging equation. This oxygen is consumed in a chemical reaction.
- Aging is a multi-step process that does not depend linearly on the radiation rate.

/www-cdf.fnal.gov/~binkley/aging/