The Ecloud Measurement Setup in the Main Injector

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Overview

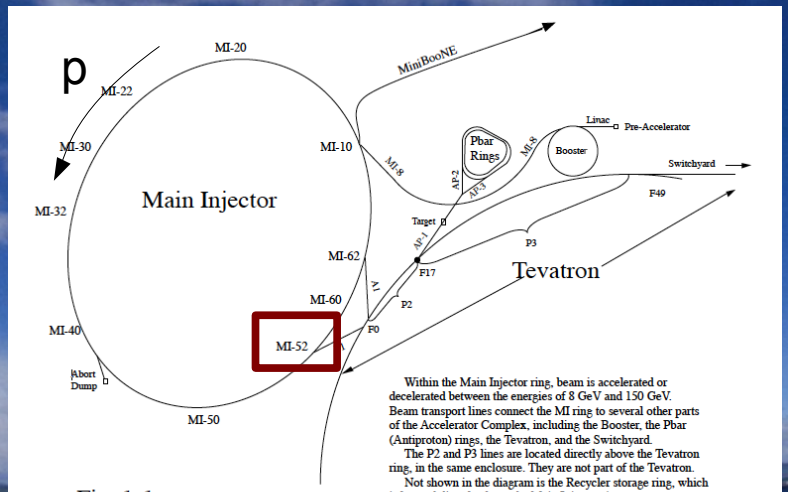
- The FNAL complex and Setup at MI-52
- The detectors
  - RFA design and performance
  - Magnetic probes
  - BPMs used for Microwave measurements
- Experimental results
  - Comparing TiN, aC and Steel
    - Energy spectrum
    - Conditioning characteristics
    - Possible problems with aC

The Complex

MI is ~ 2 mile ring.
Injection energy: 8GeV
Extraction energy: 120GeV for experiments and pbar production.
150GeV for Tevatron injection.

Highest intensity beam is for NuMI experiment ~40e12 per spill (11 batch slip stacking)

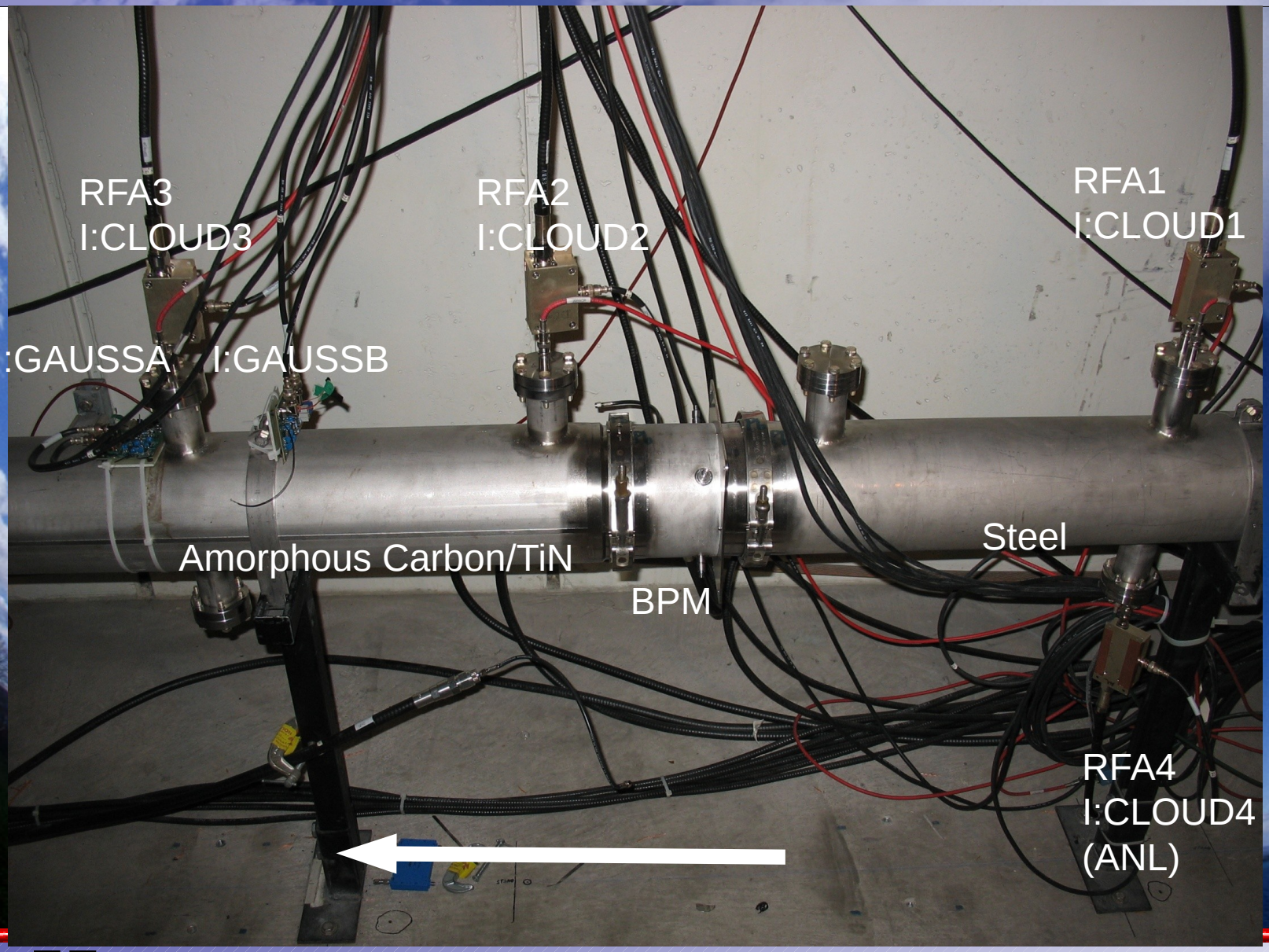
Ecloud experimental setup is at MI-52.



Within the Main Injector ring, beam is accelerated or decelerated between the energies of 8 GeV and 150 GeV. Beam transport lines connect the MI ring to several other parts of the Accelerator Complex, including the Booster, the Pbar (Antiproton) rings, the Tevatron, and the Switchyard.
The P2 and P3 lines are located directly above the Tevatron ring, in the same enclosure. They are not part of the Tevatron.
Not shown in the diagram is the Recycler storage ring, which is located directly above the Main Injector ring.
The distance between the Main Injector and Tevatron rings has been exaggerated in order to show the A1 and P1 lines more clearly.

Fig. 1-1
Fundamental Geography of the Main Injector

Measurement Setup

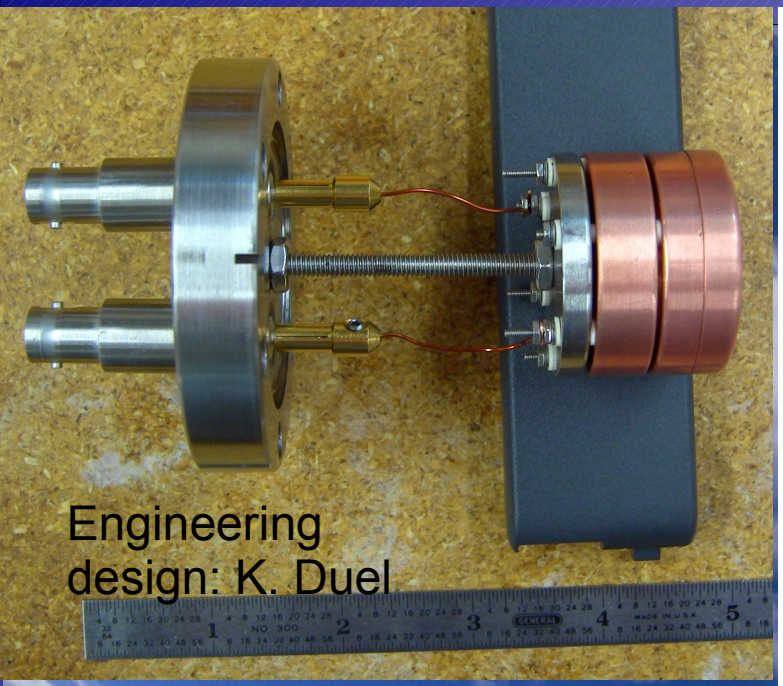


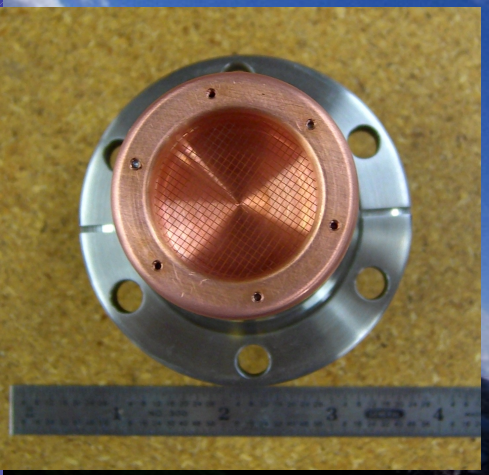
Located in MI-52 straight section 6” diameter beam pipe, 1 m long sections of aC or TiN

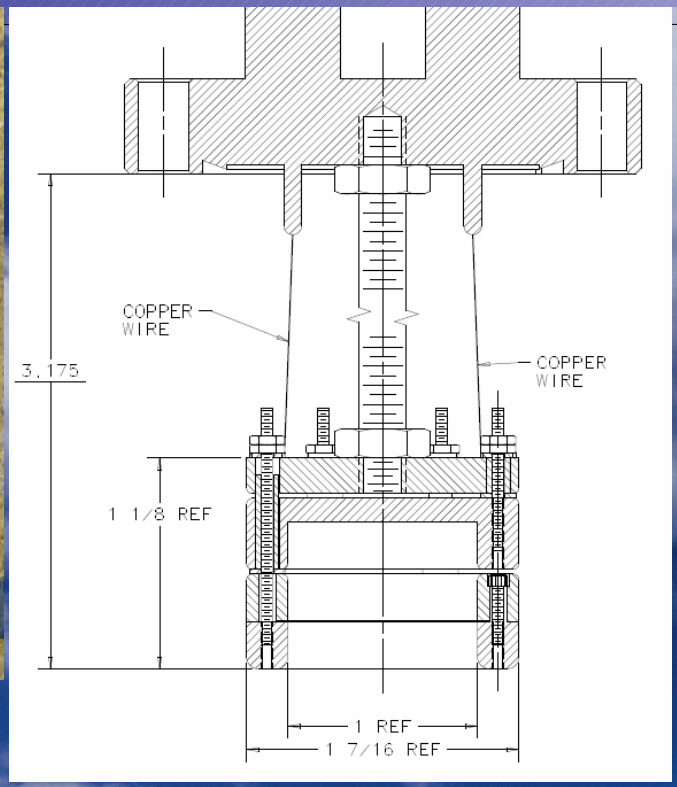
The Detectors

- 4 RFAs
  - 3 FNAL style
  - 1 ANL style
- 2 magnetic probes
  - Designed to be non directional
- 3 sets of BPMs for RF measurements
  - Traveling and resonant method
  - Absorbers to attenuate RF outside the measurement setup.
    - Removed when aC beampipe was installed.

FNAL RFA



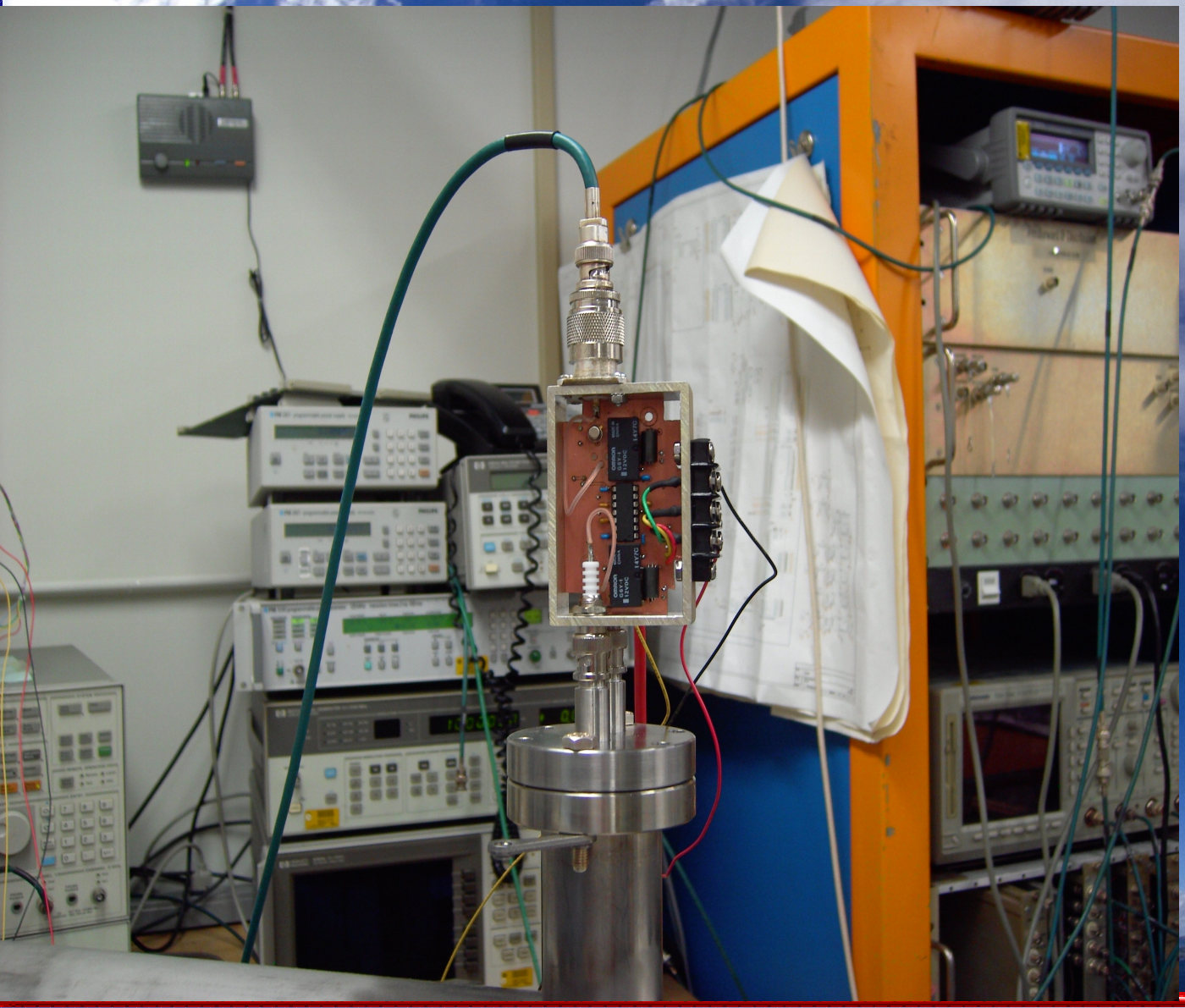




- Designed using SIMION
- Surface area larger than ANL RFA by 1.8x
- Better focusing
  - Captures +/- 10° cone w.r.t. axis of symmetry.
- 1 grid compared to 2 grids
  - Every grid reduces capture by about 20%. (25 lines/inch).
- Cup rather than flat capture surface.
- Empirical evidence shows that FNAL RFA is 3x more sensitive than ANL RFA.

For optimum performance, RFA is coupled to dedicated high gain amplifier.

RFA Electronics



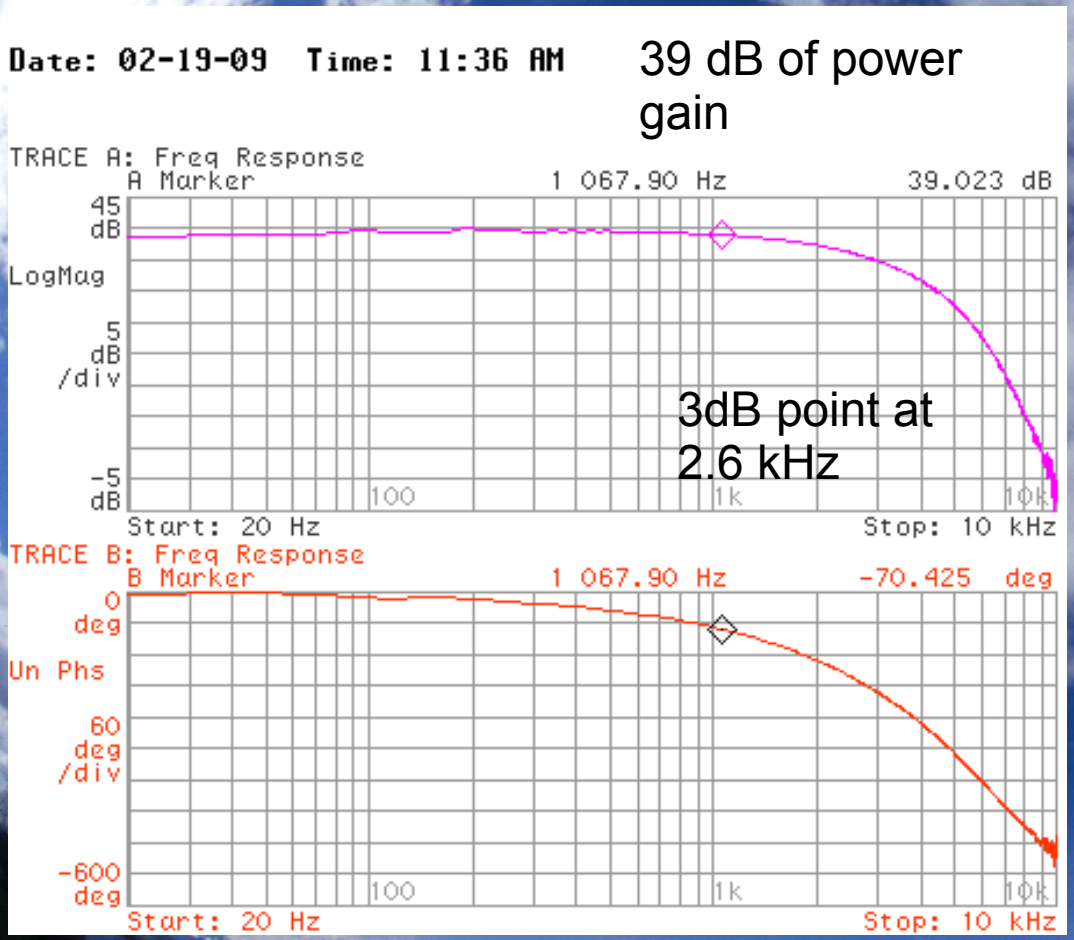
High gain electronics connected directly to the RFA to reduce noise.

Designed so that amplifier can be bypassed if necessary.

RAD hard opamp (HS-5104ARH)

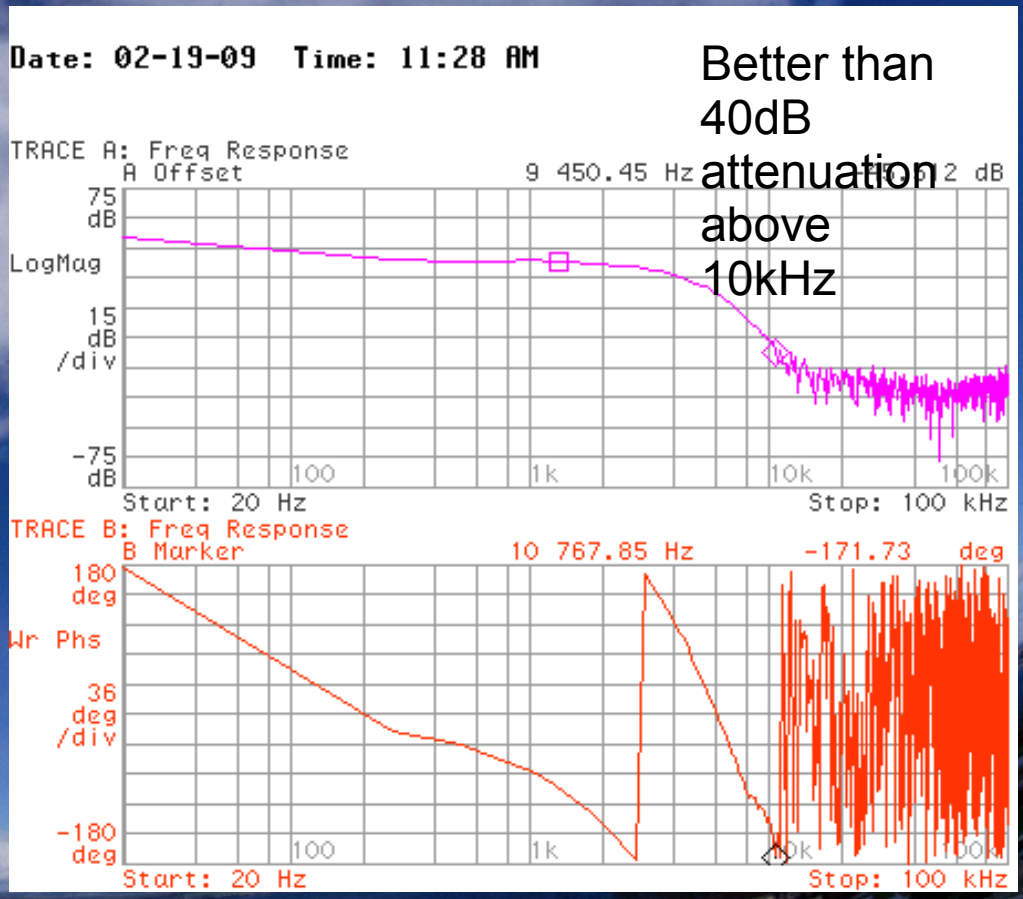
Electronic ground is isolated from beam pipe ground to reduce beam noise.

Frequency Response



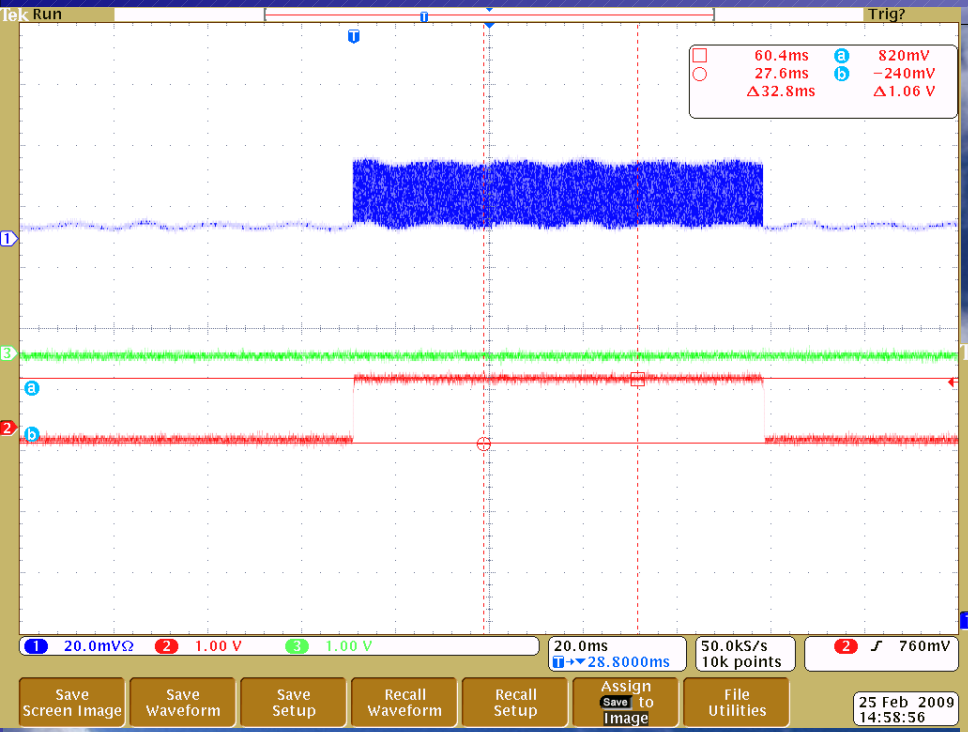
39 dB of power gain

3dB point at 2.6 kHz

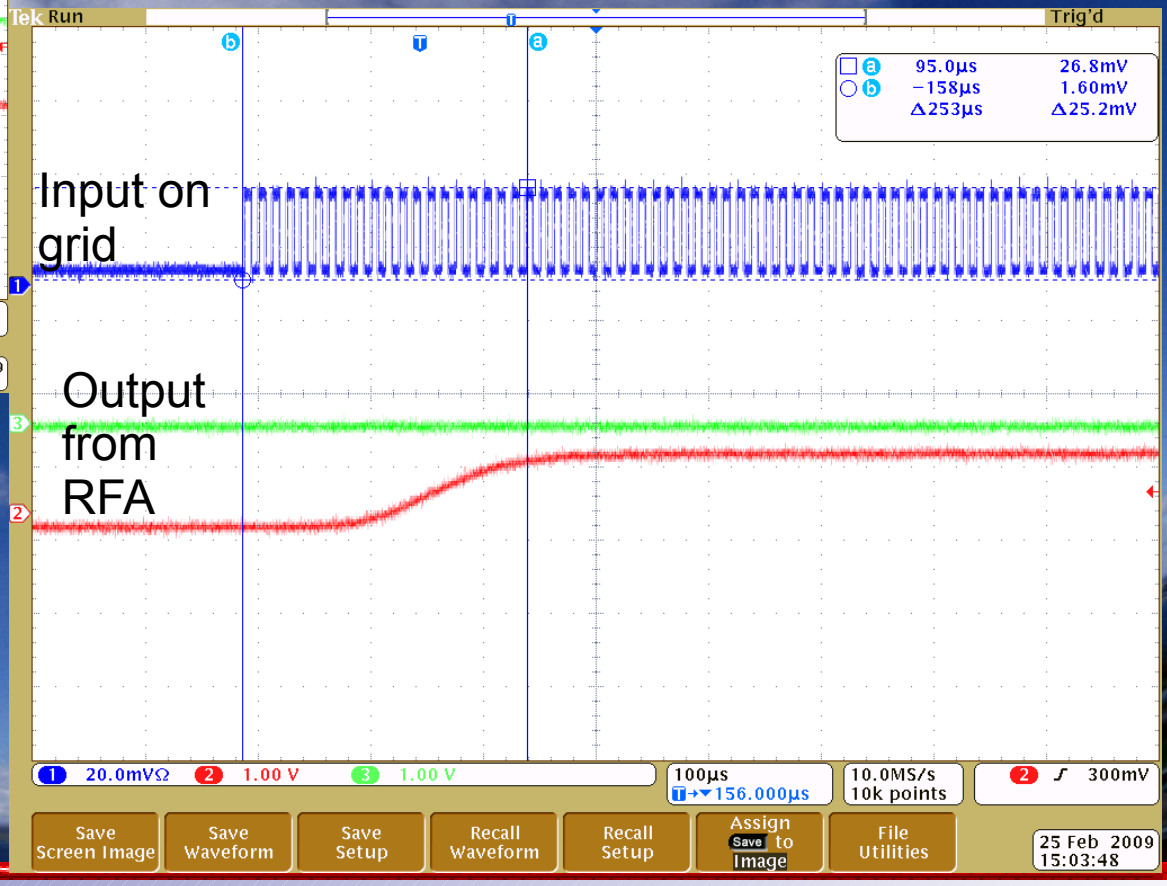


Better than 40dB attenuation above 10kHz

Time Domain Response

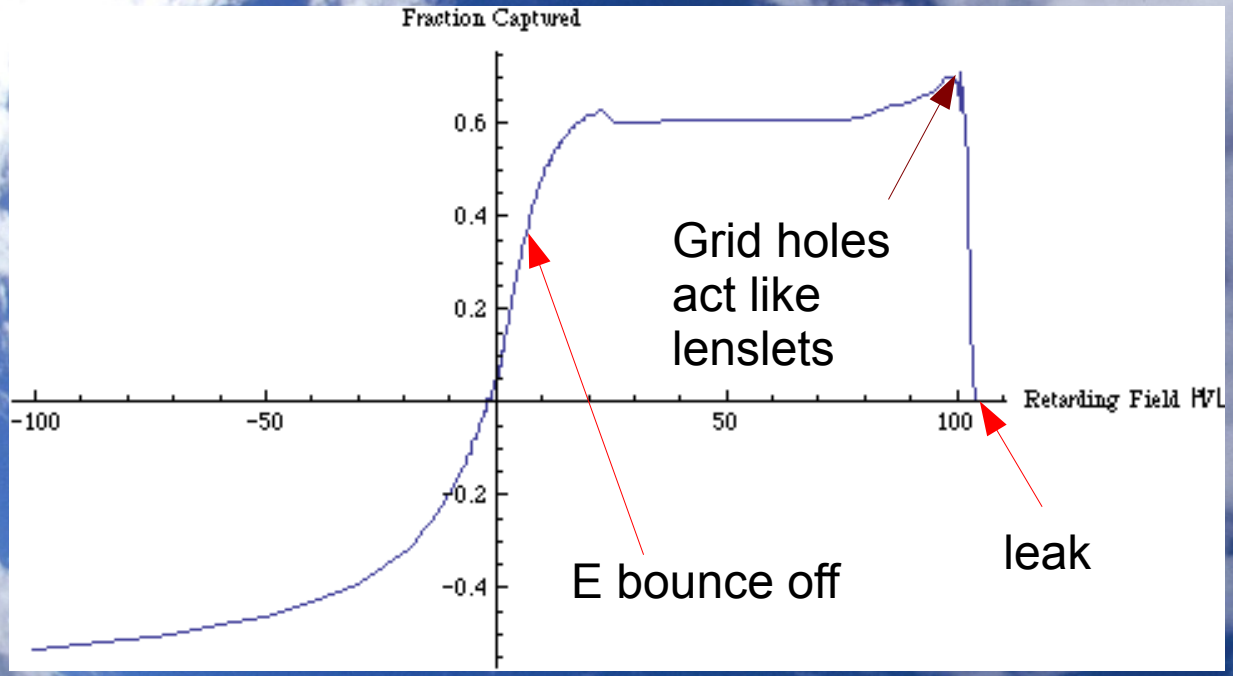


Takes 20 revolutions to get a peak value



All the responses were measured for each installed RFA with amps in situ so that they can be compared if questions arise as to whether the RFA is functioning.

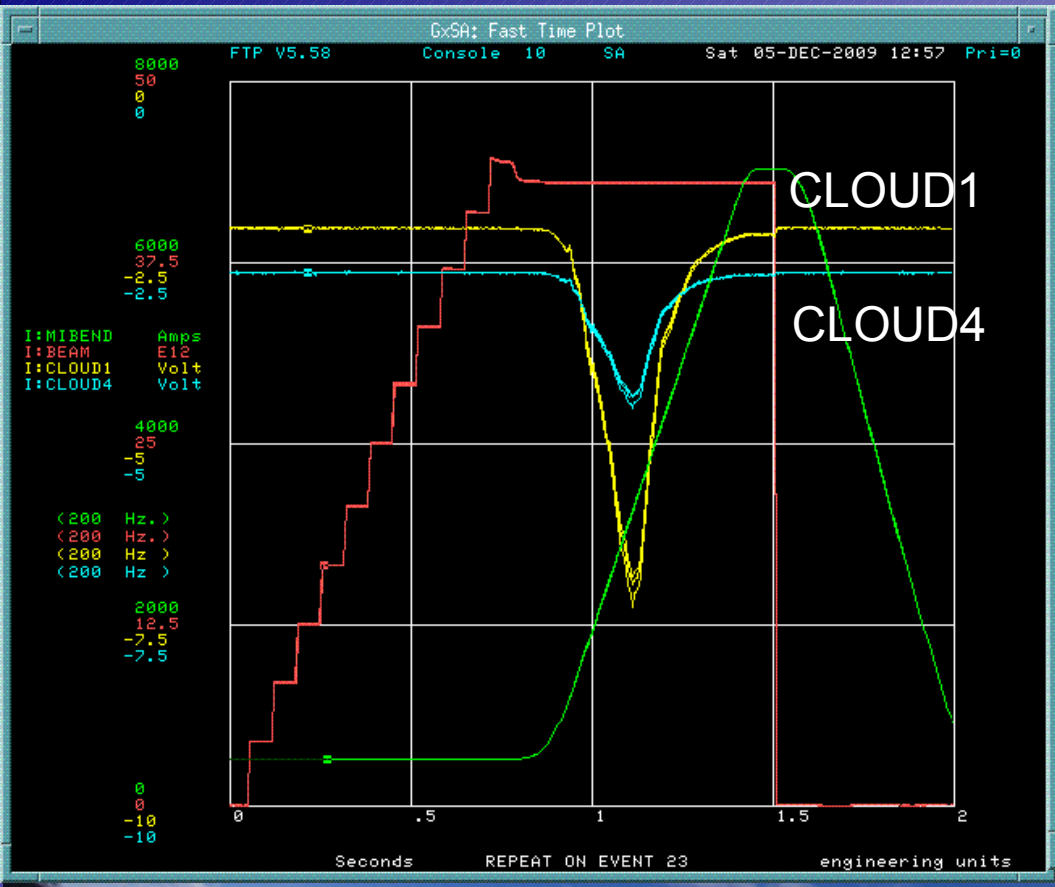
Electron Beam Test

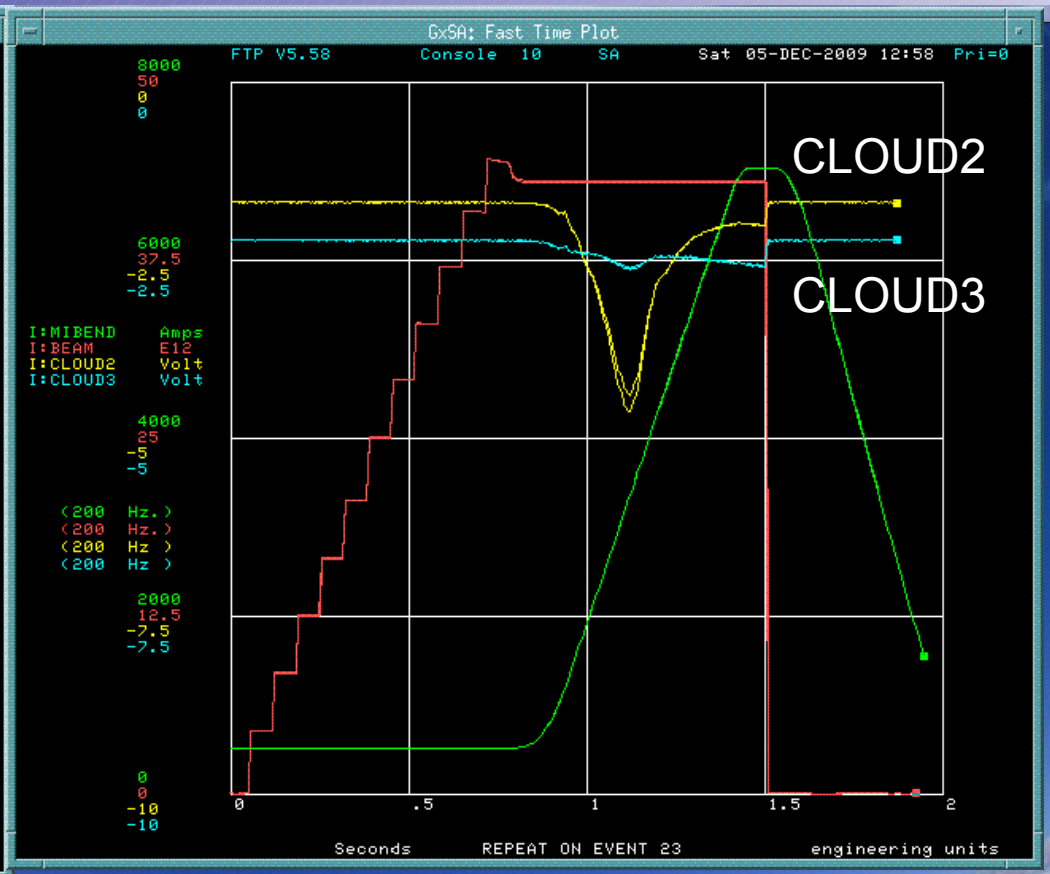


Electron beam test on the bench (L. McCuller)
+Vg is retarding electrons.
100eV electrons used.

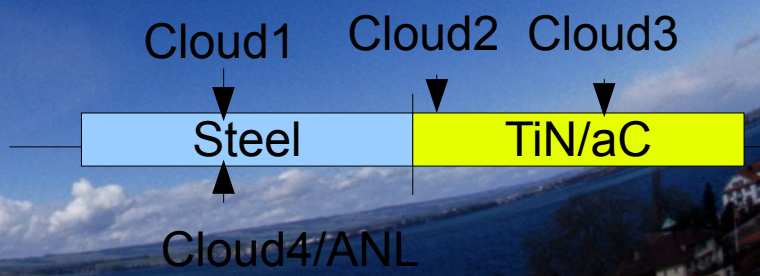
- Even if electron energy < Vg, some electrons will leak through. (Seen in sims for finite sized holes in grid)
- Electrons bounce off RFA if Vg < 20V
- Similar results for higher energy electron beam (up to 600eV)

Typical Signals (with amps on)

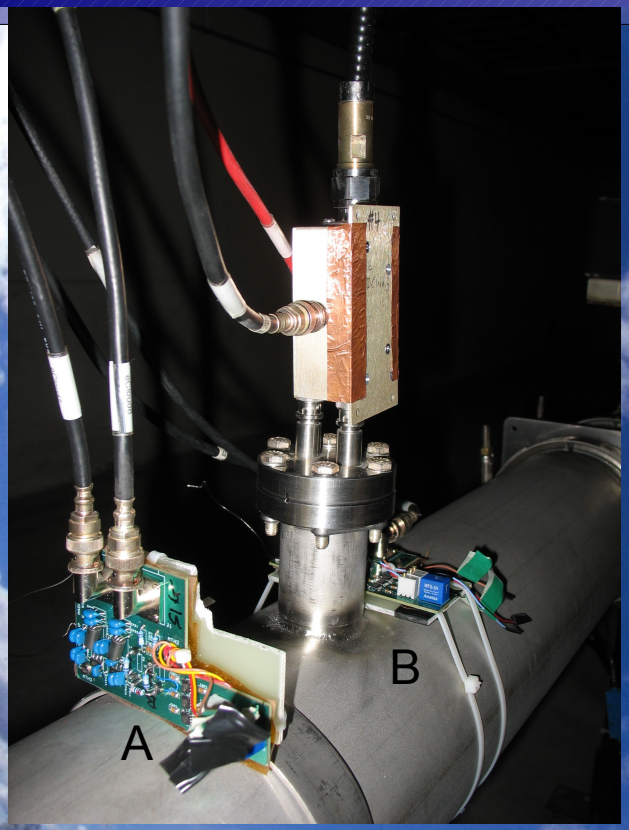


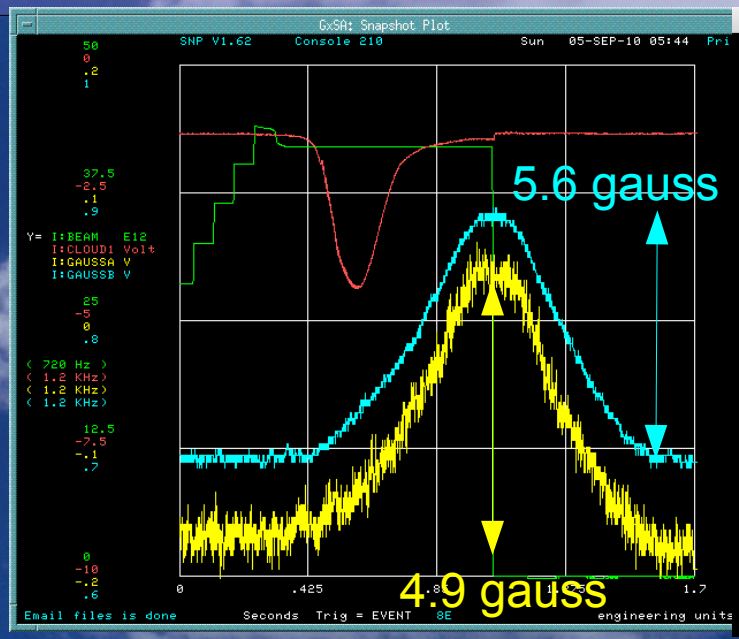


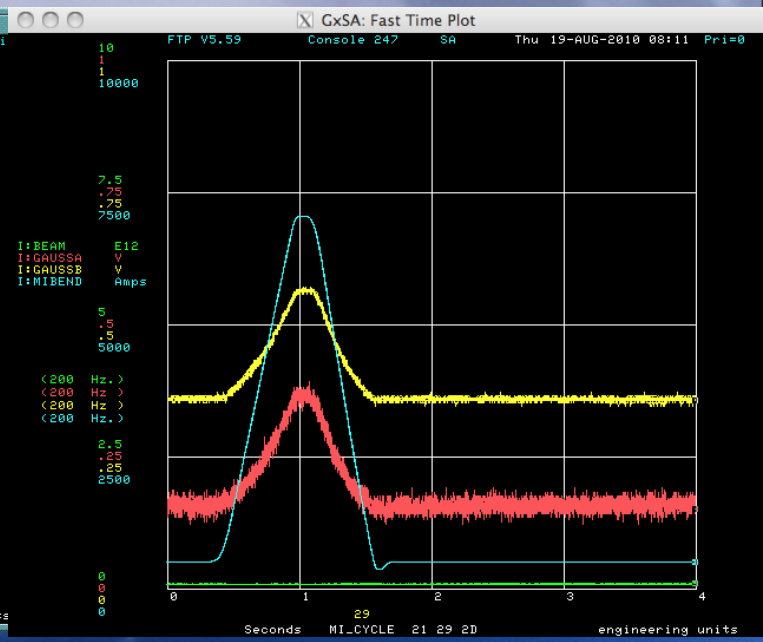
Cloud 1 and 4 on steel
Cloud 2 and 3 on TiN (mu metal shielding)
Maximum dip around transition 20GeV

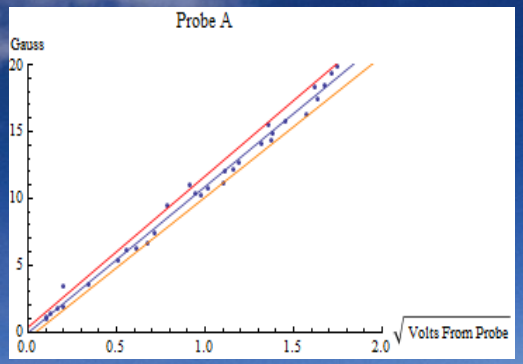


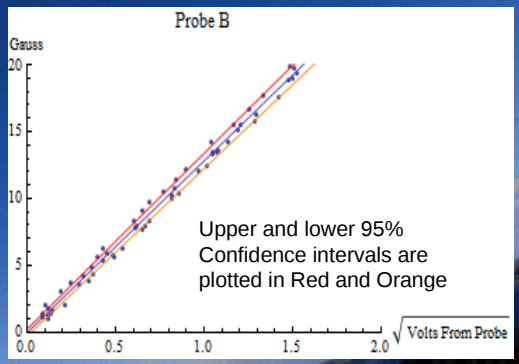
Magnetic Probes





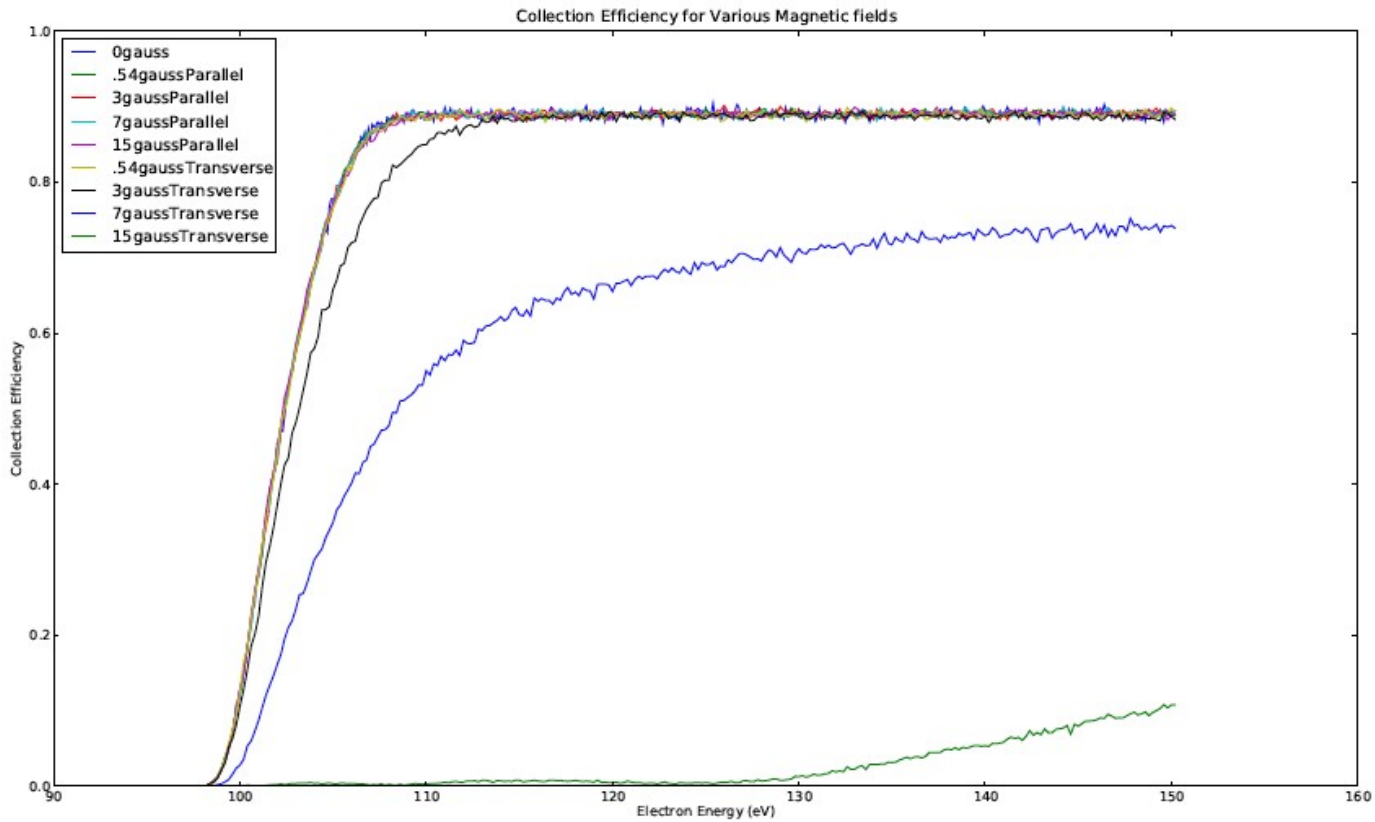






- Probes axis independent
- Magnetic probe is based on MFS3A
- Differential outputs to reduce noise from ramp.
- Calibrated on bench with Helmholtz coil and Lakeshore Hall probe.

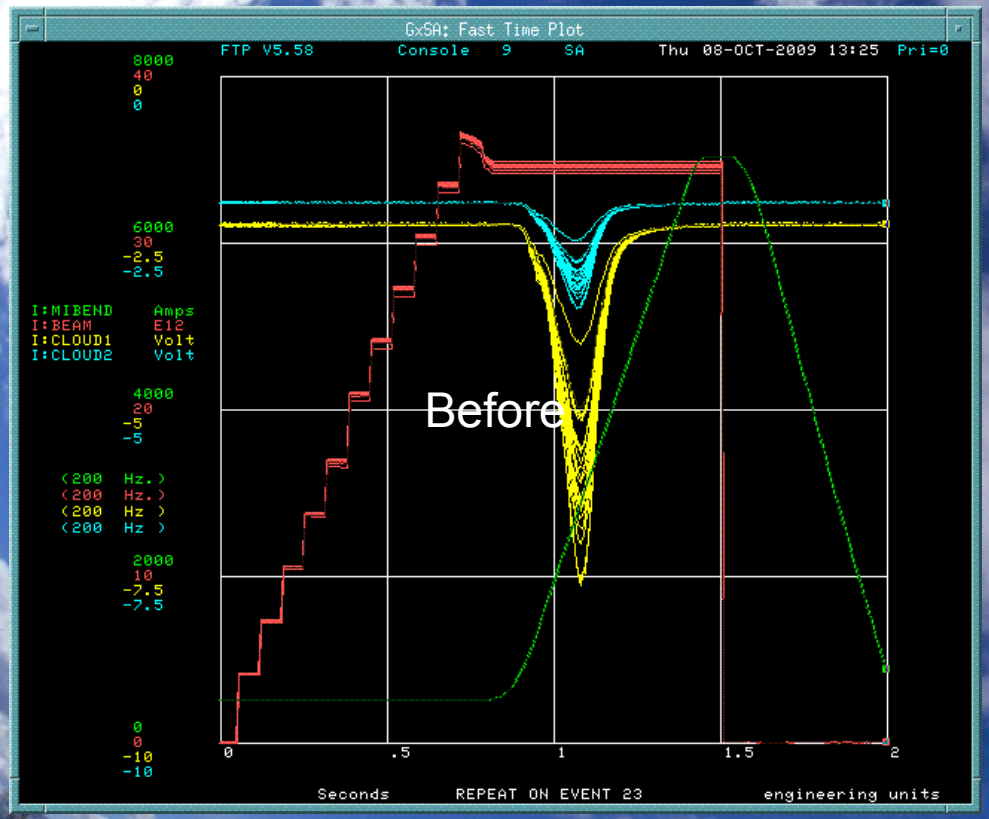
Magnetic Field Affects Ecloud Collection

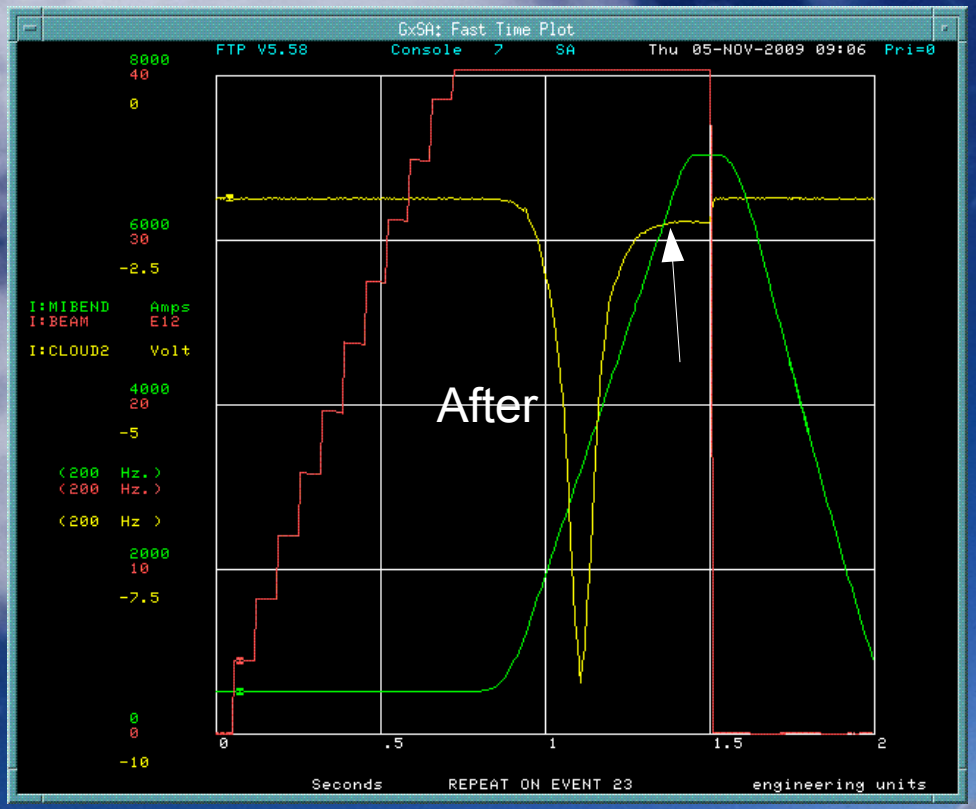


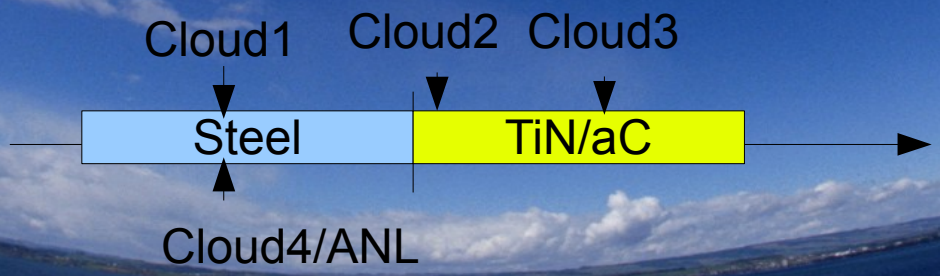
Depending on the direction of the B-field, collection efficiency is affected. (Simulation by L. McCuller)

Mu Metal shield

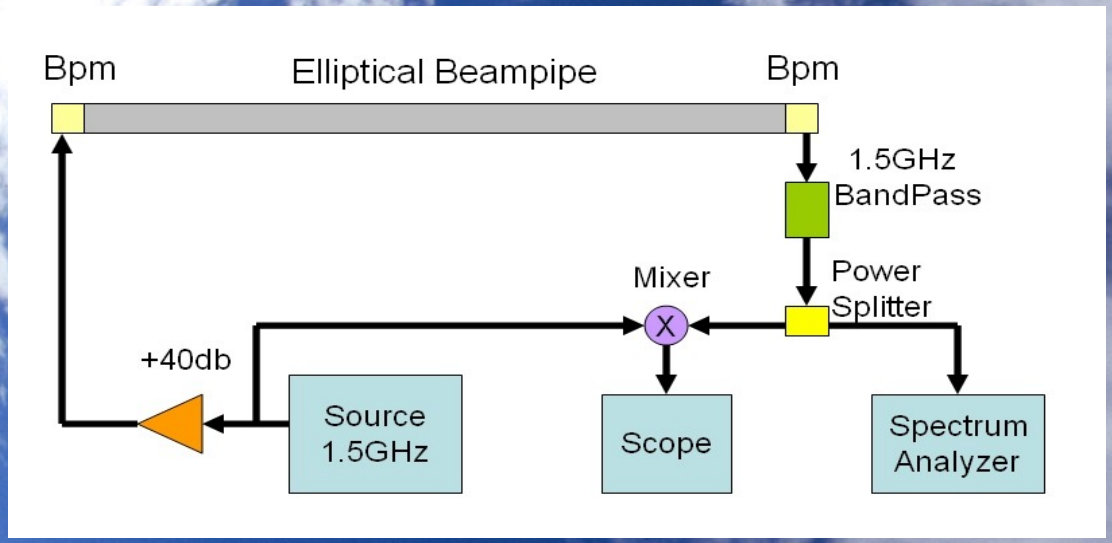
Small change at the end of the ramp

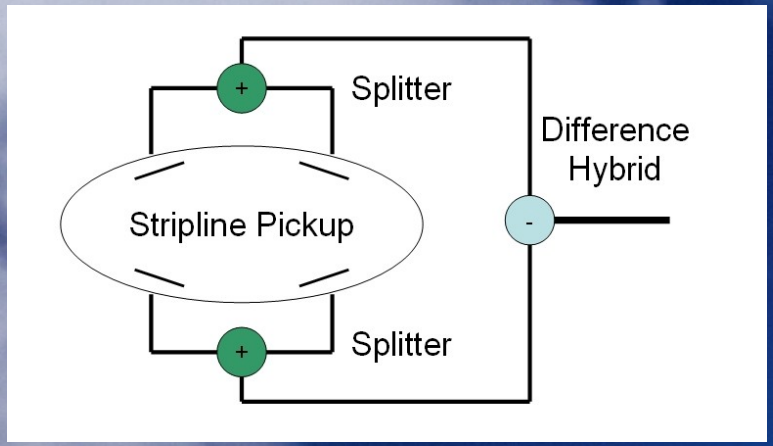


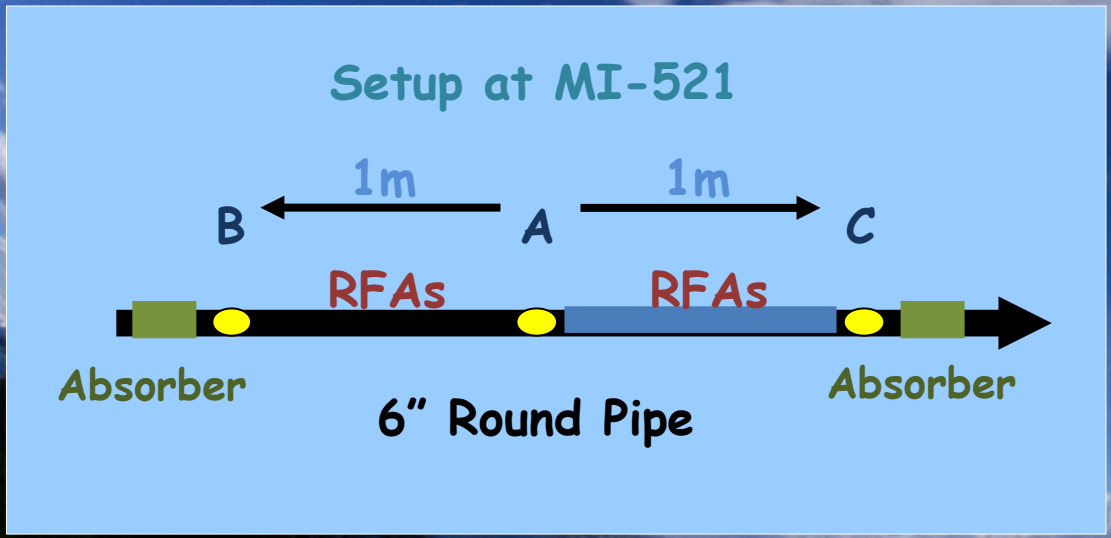




Microwave Setup







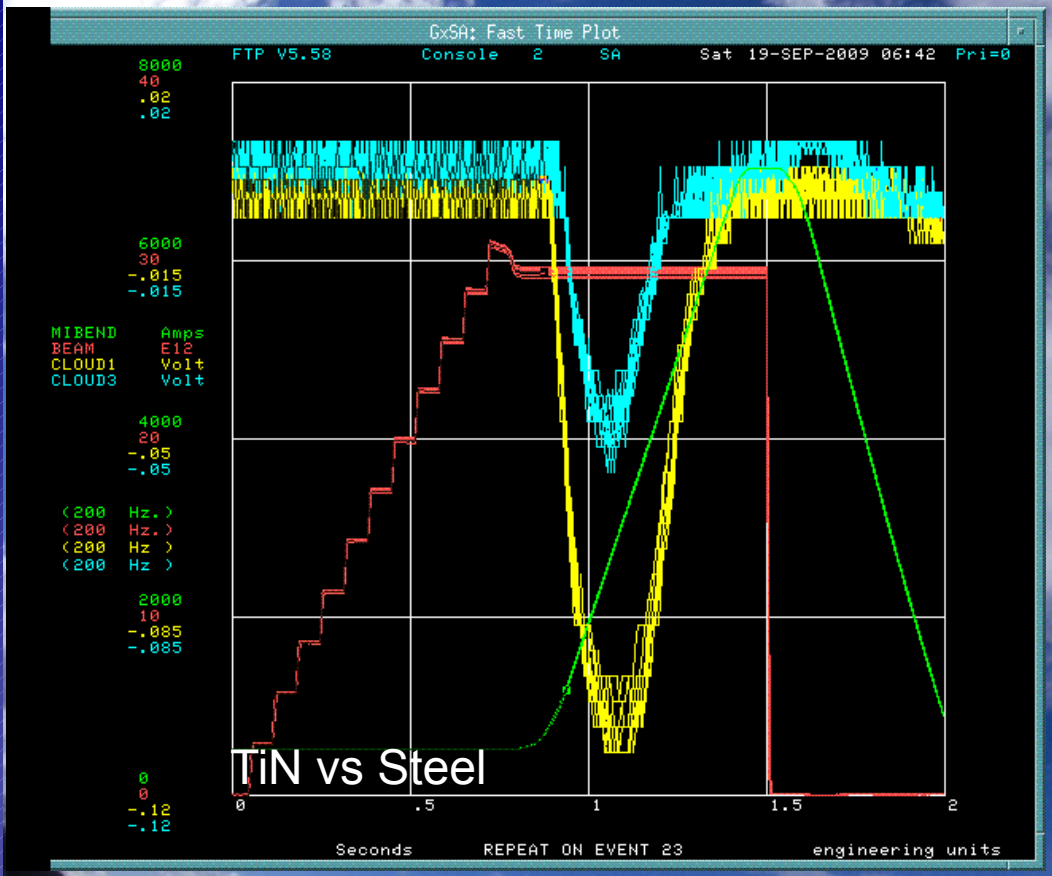
BPMs are too close for traveling wave method.

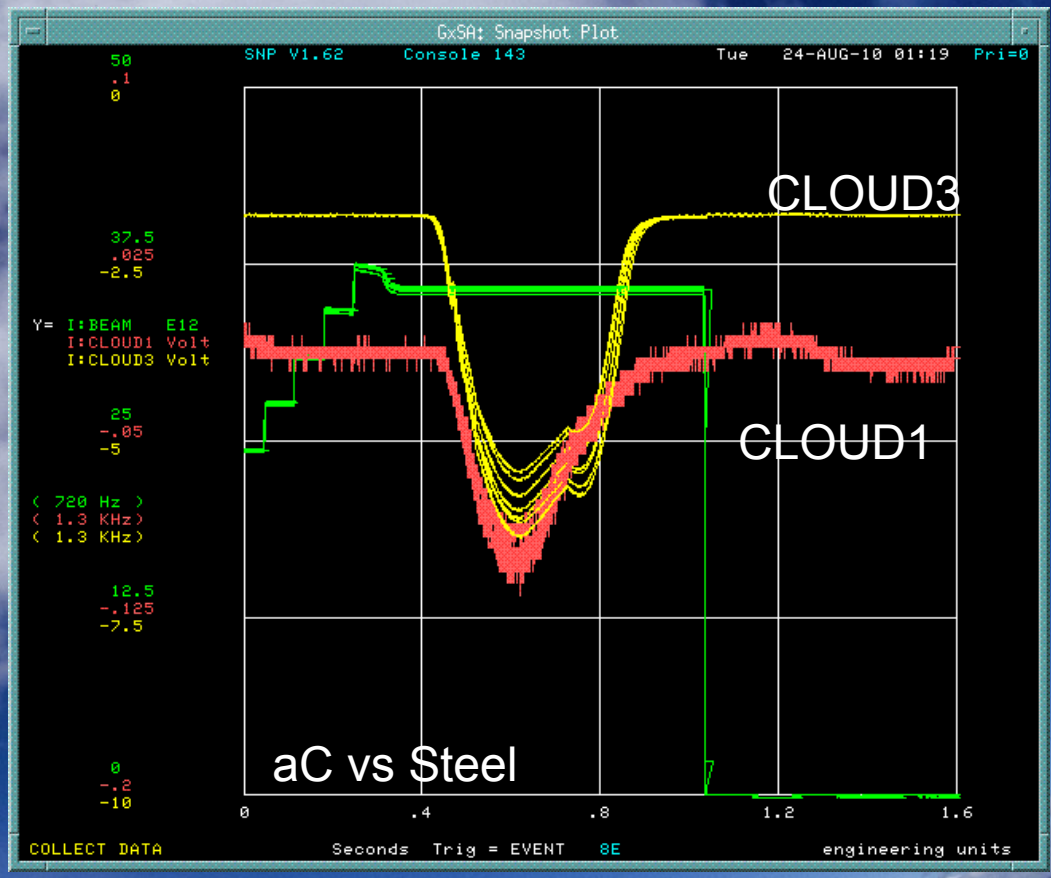
For other methods, see C. Thangaraj's talk.

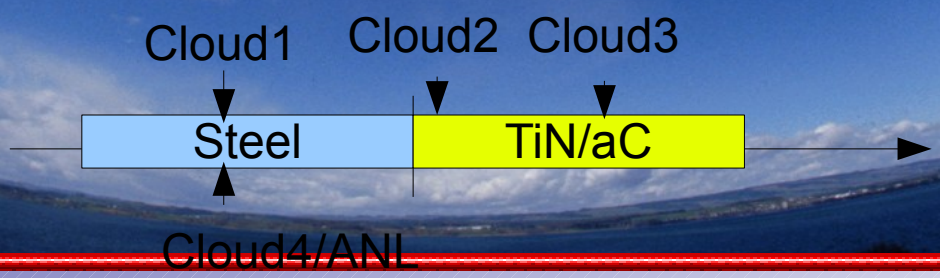
Cartoons courtesy of N. Eddy

Experimental Results
(M. Backfish)

Comparing TiN, aC and Steel

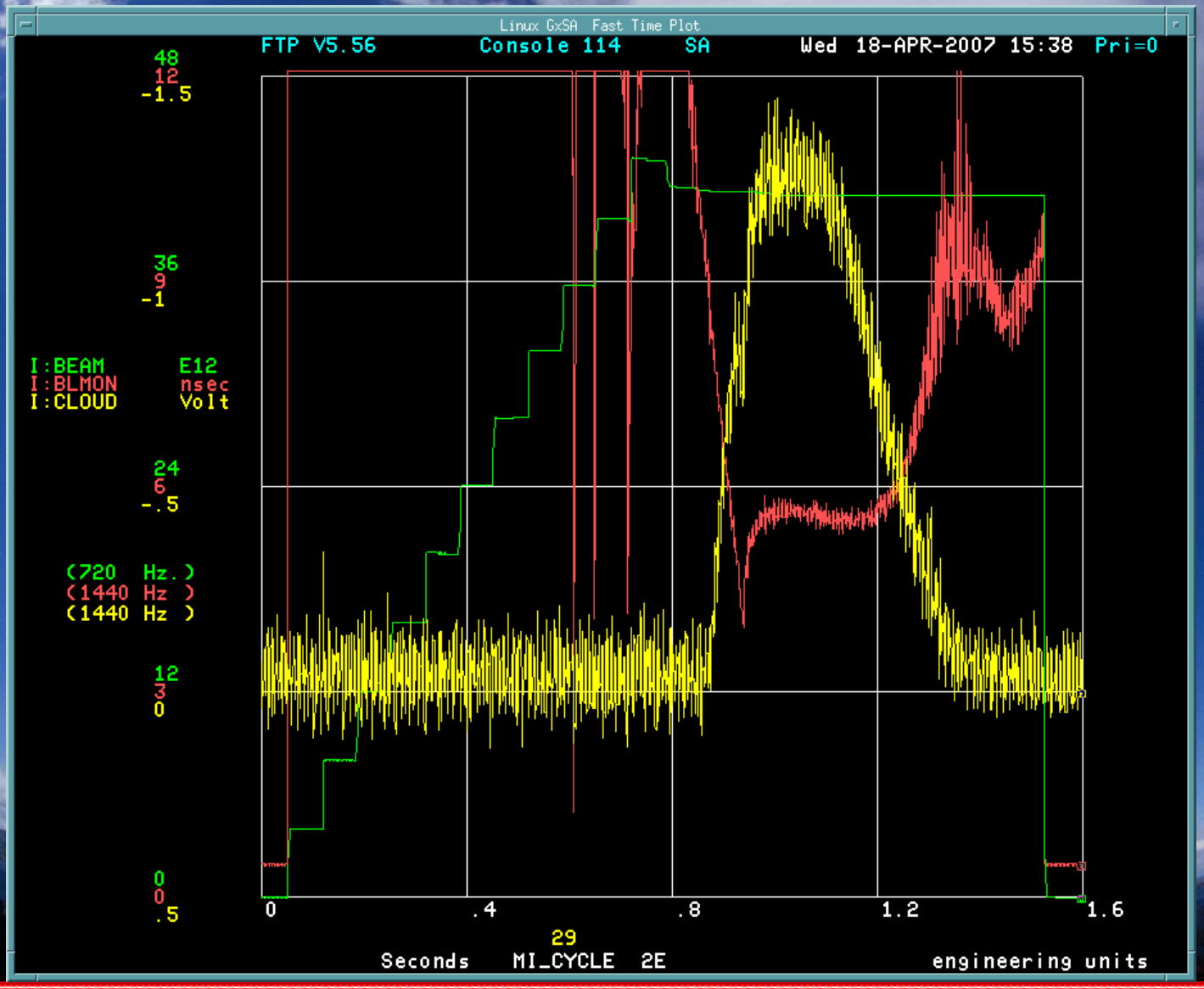




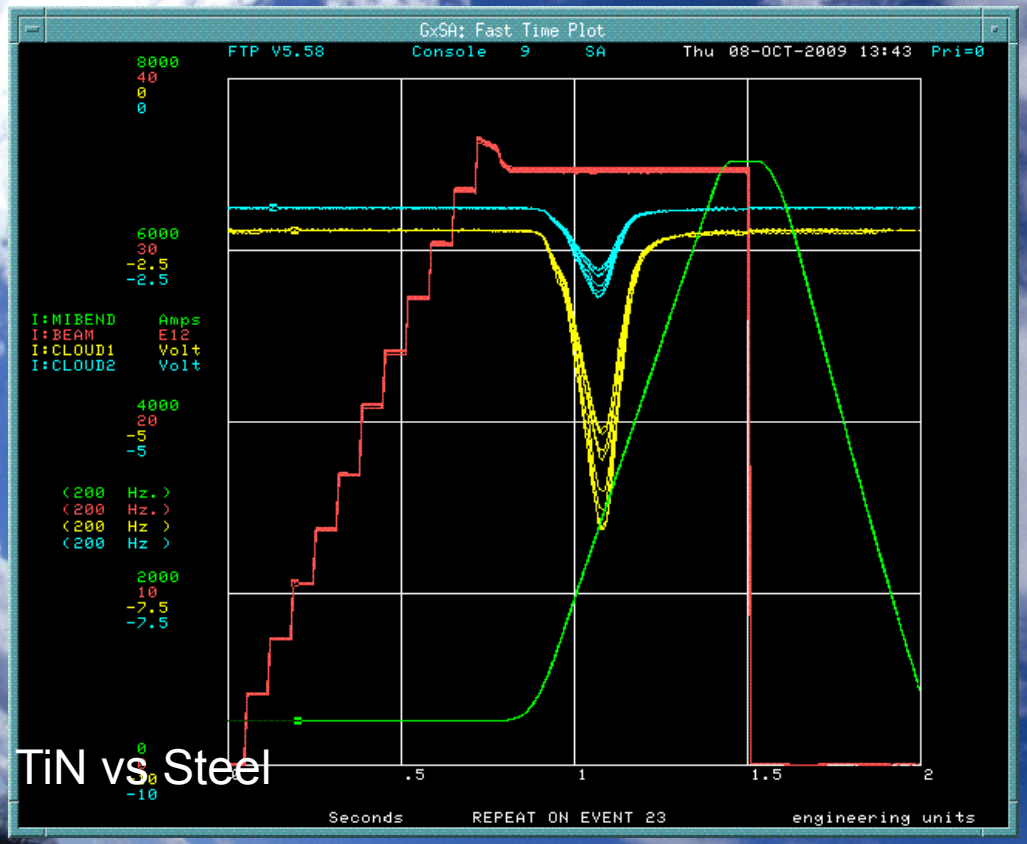


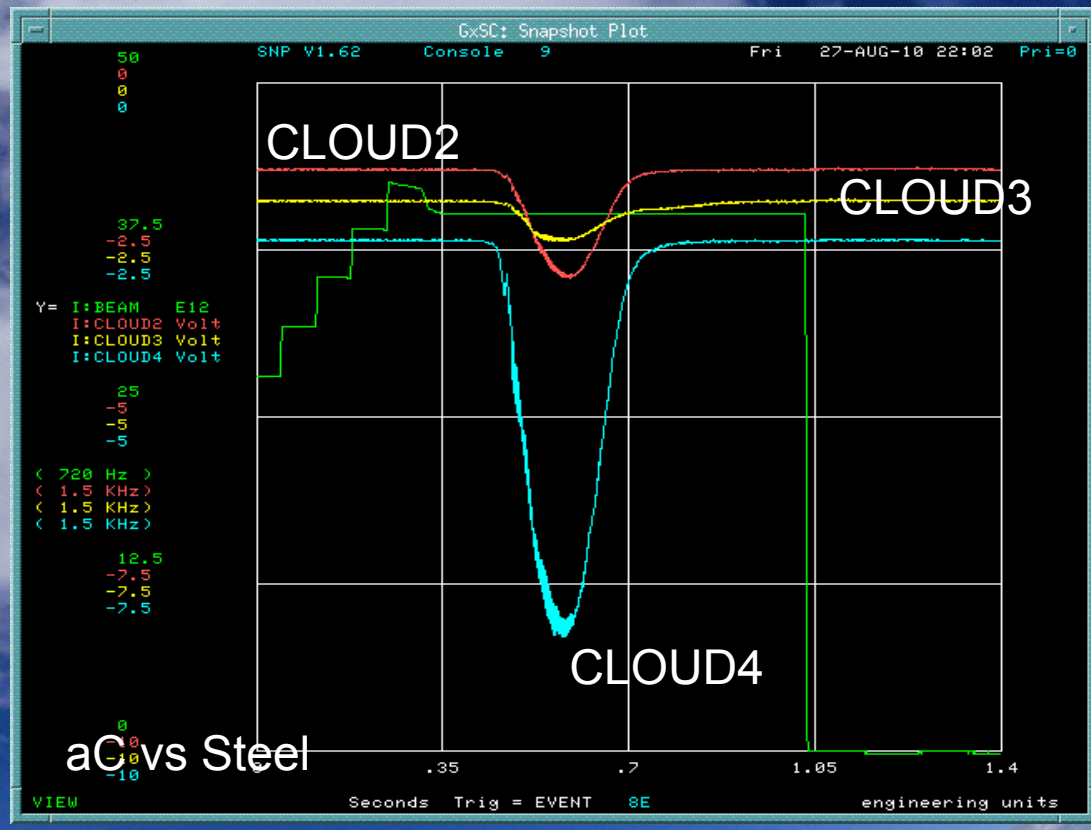
Double hump also seen on scope without amps

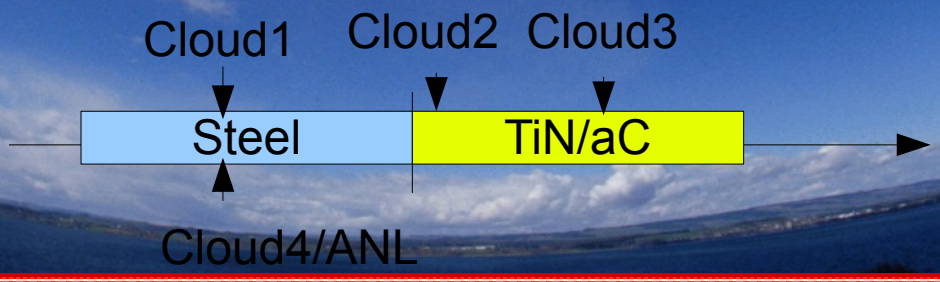
Zoomed in view on Steel (old data)



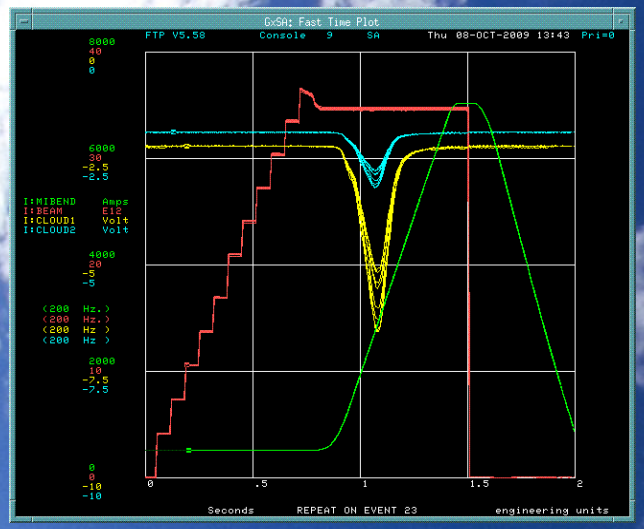
Time Evolution



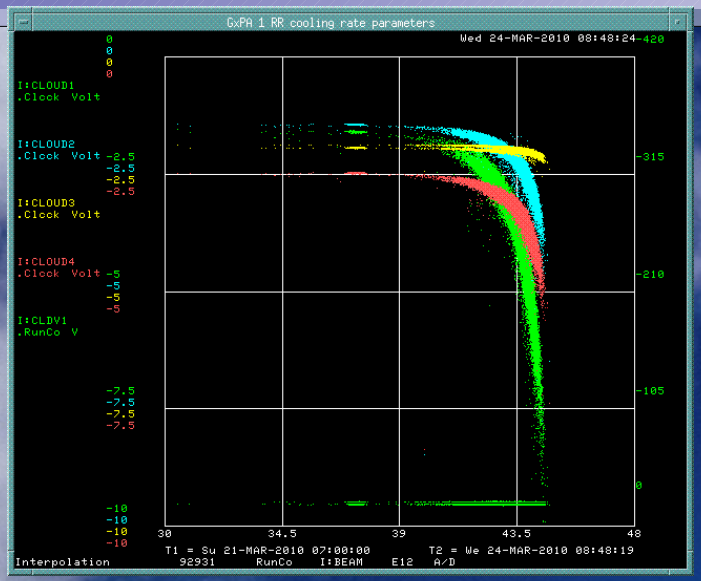




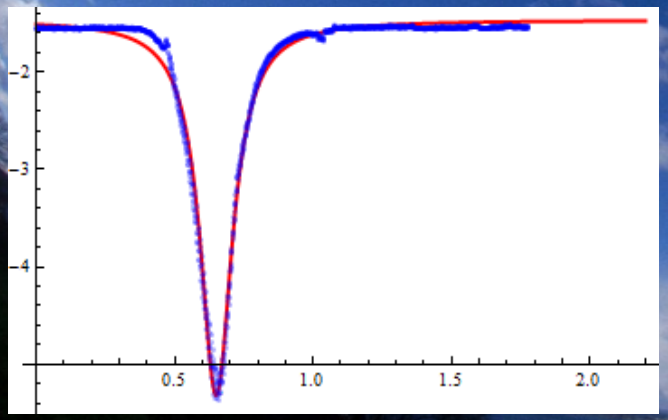
How Evolution is tracked



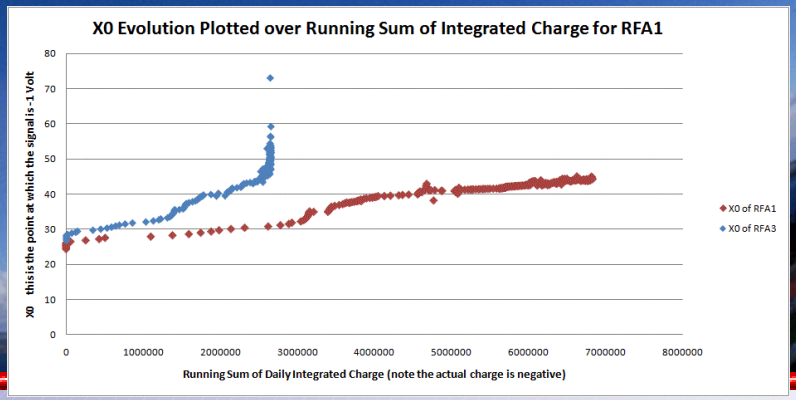
Dips are tracked and datalogged

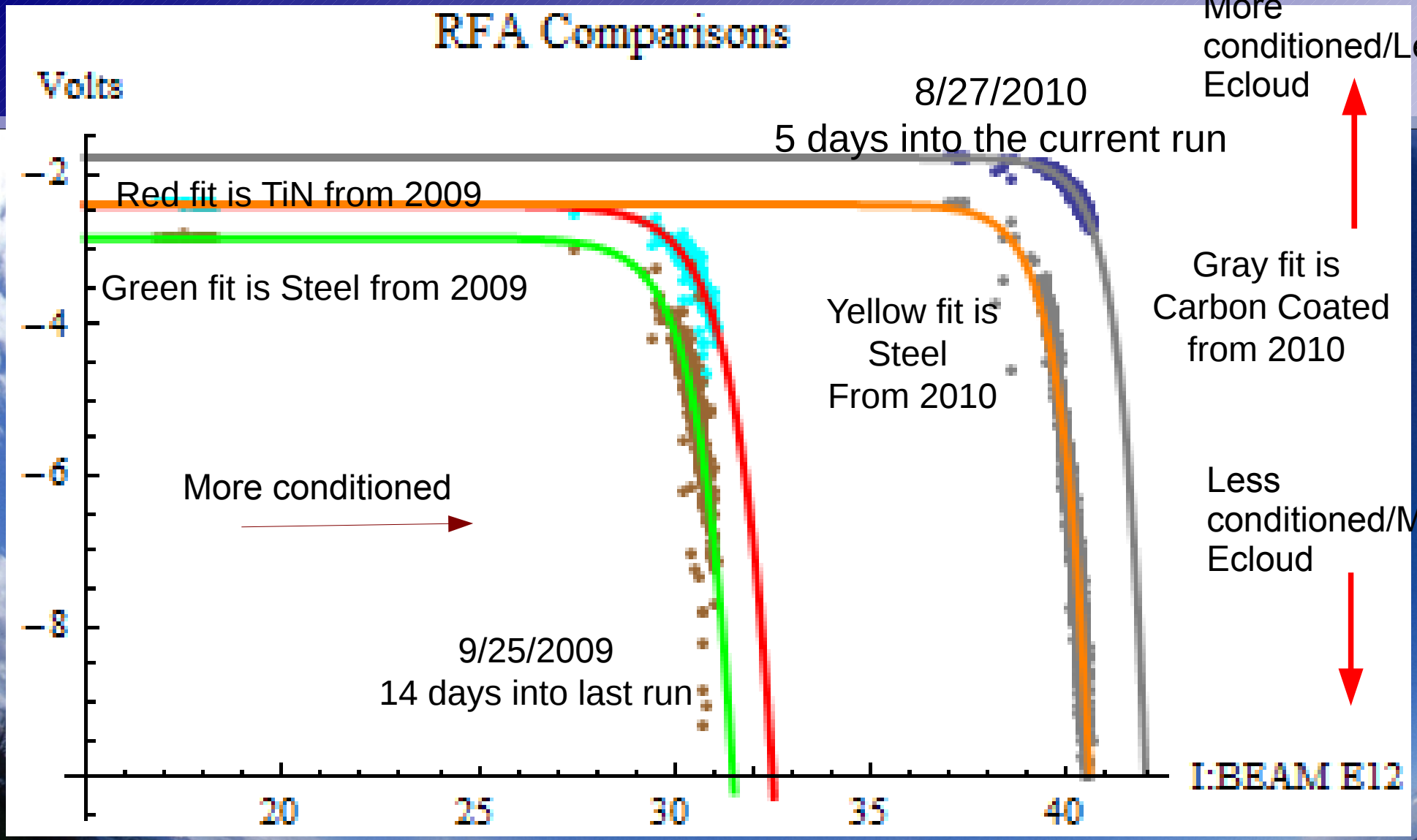


Track the knee defined to be the ecloud threshold



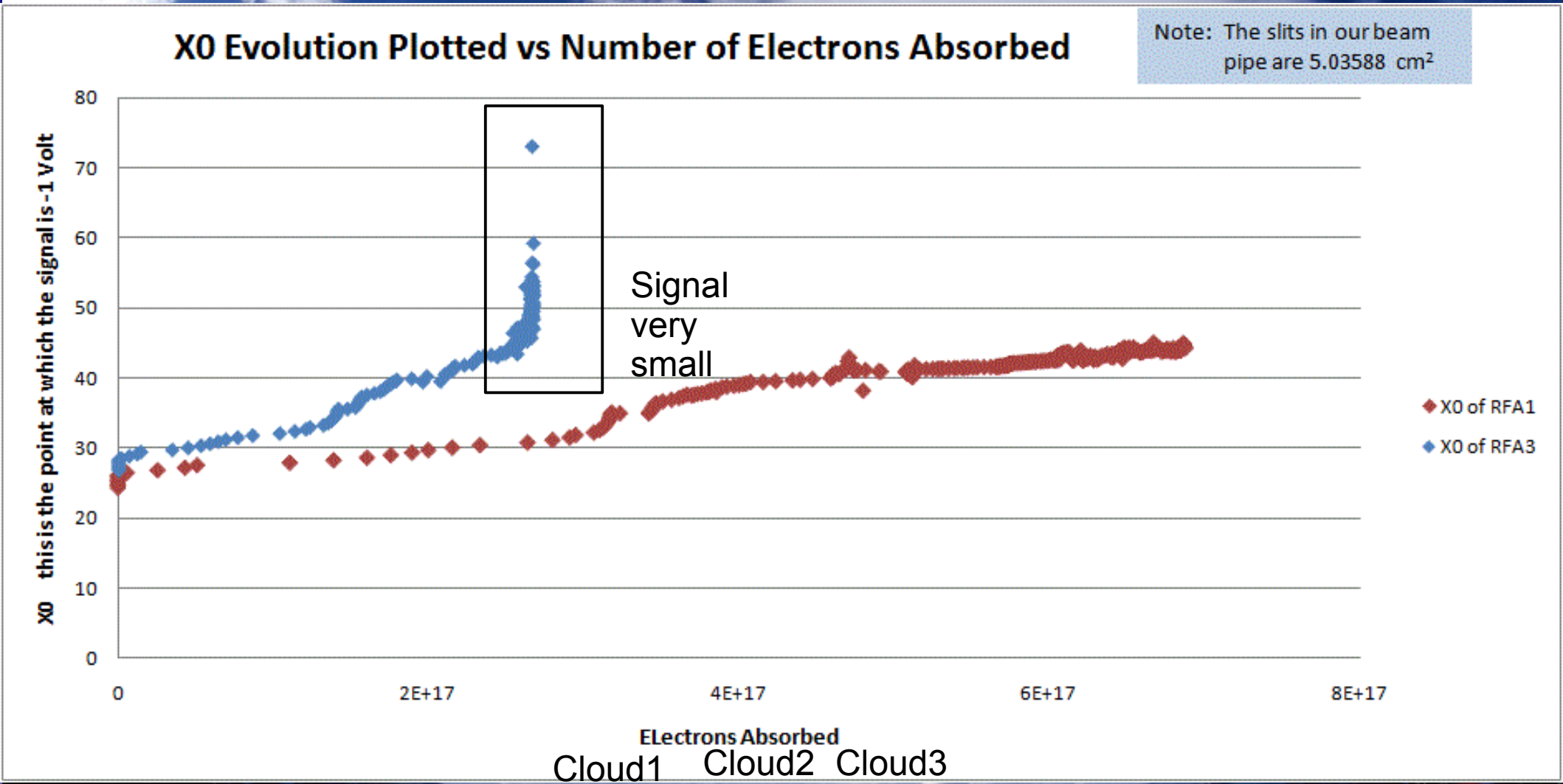
Fits integrated to get total e charge

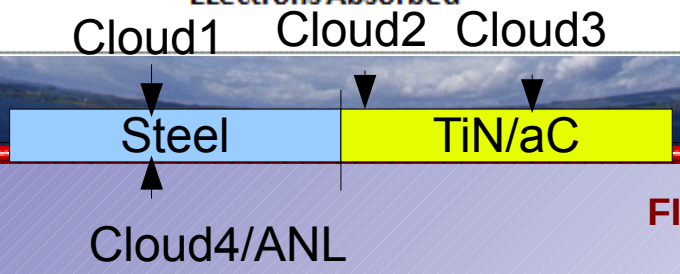




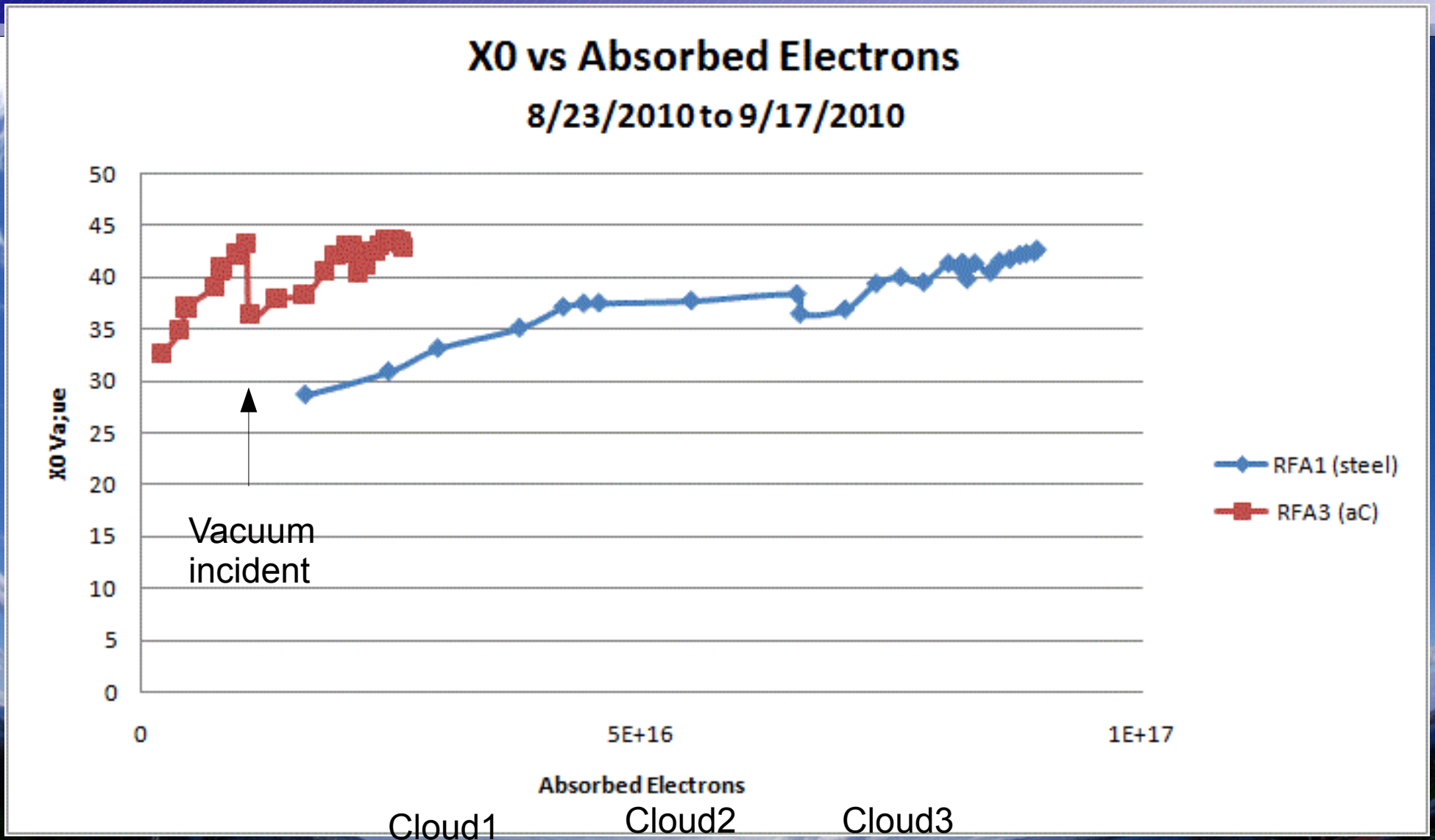
Note: The beam pipe seems to have conditioned more rapidly this run. This is due to higher initial intensities in MI.

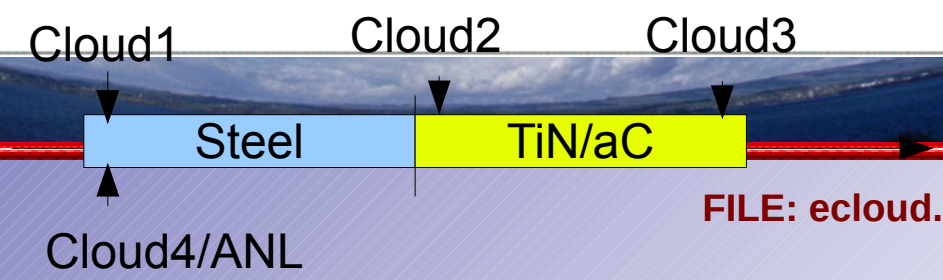
Conditioning of TiN and Steel



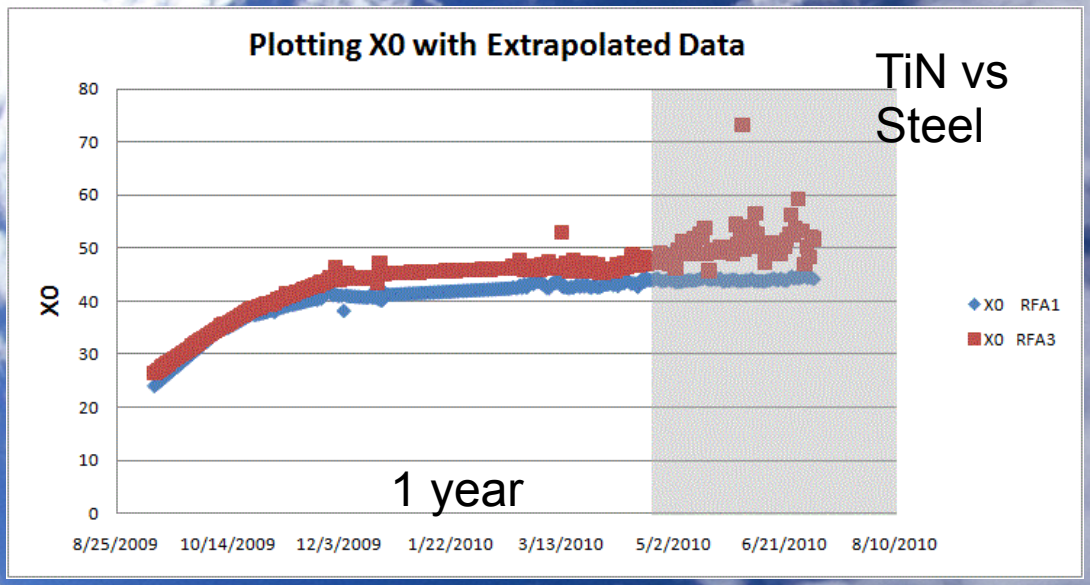


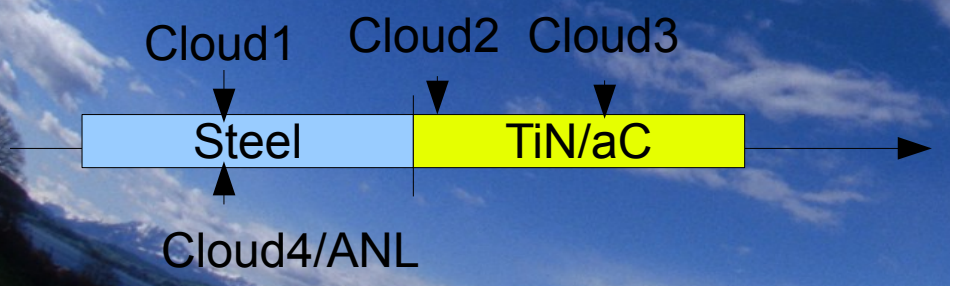
Conditioning of aC and Steel

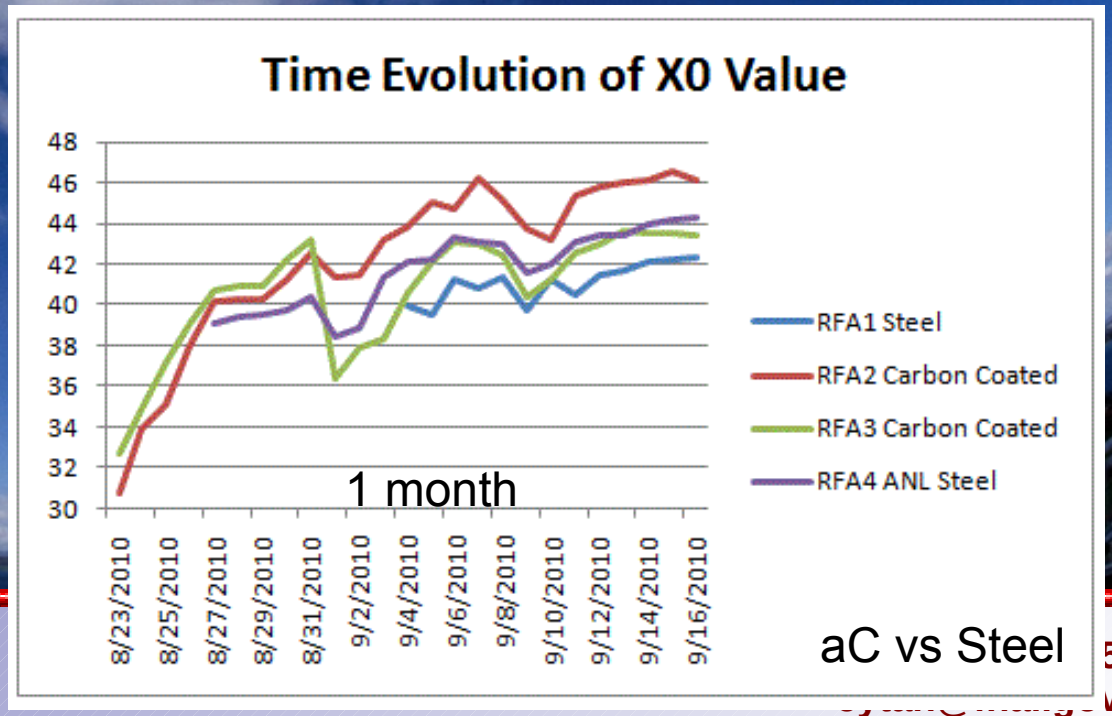




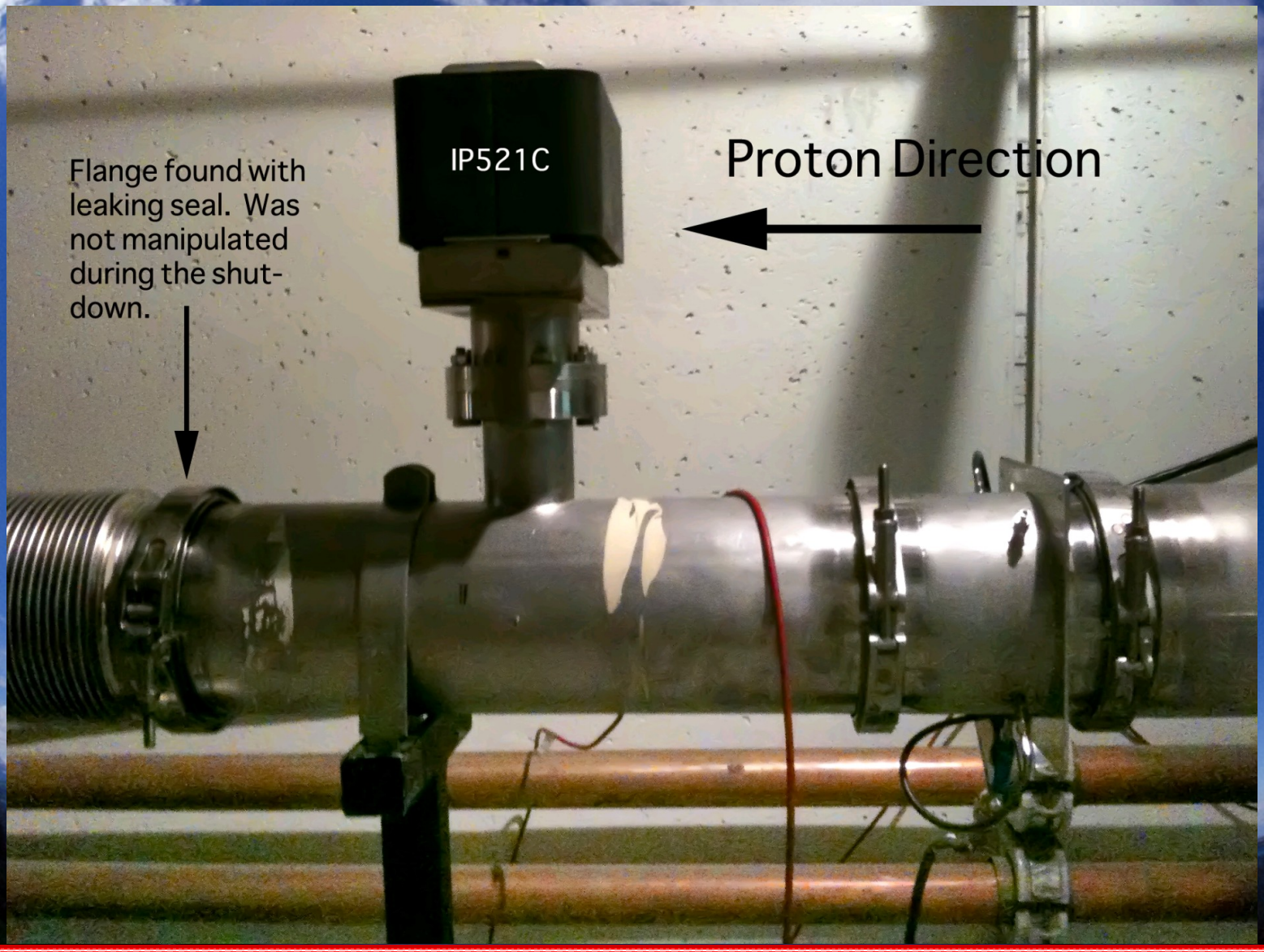
Comparing TiN, aC and Steel



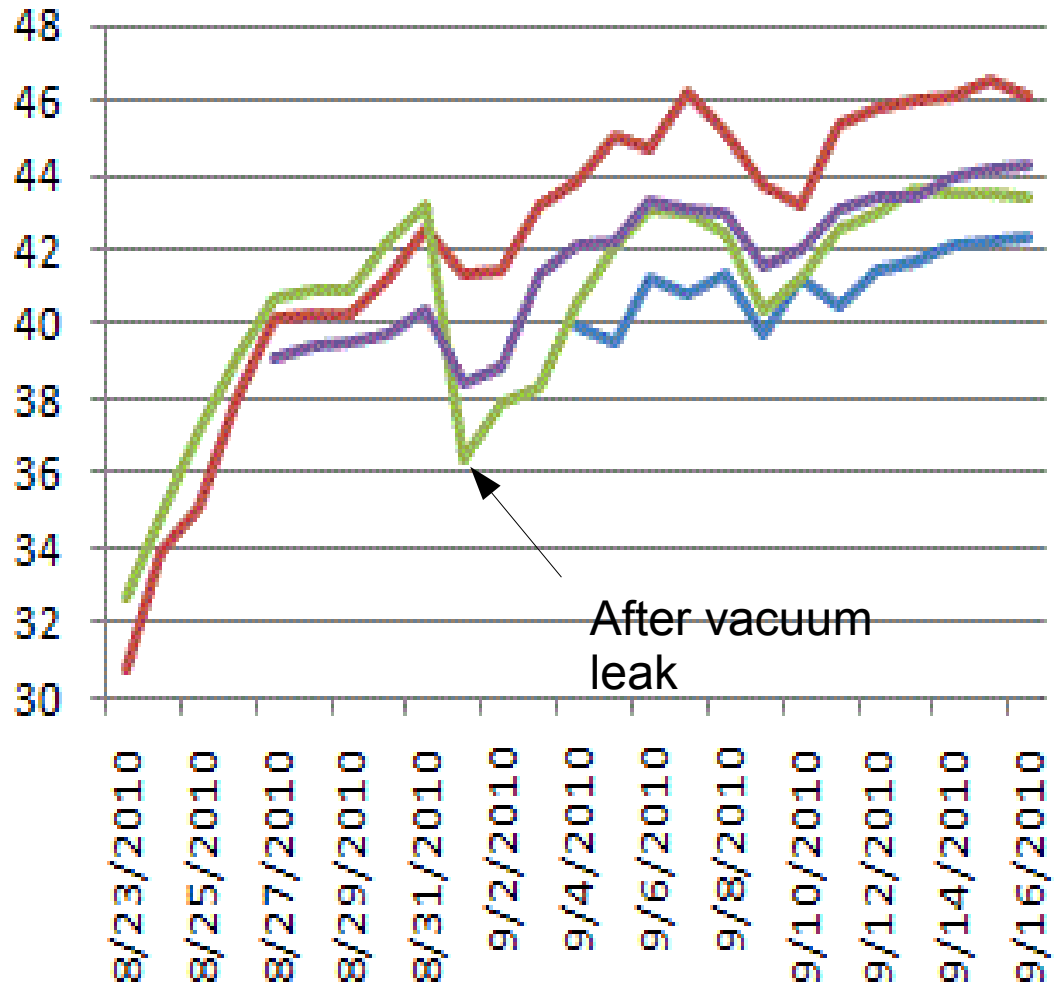




Vacuum Leak closest to CLOUD3

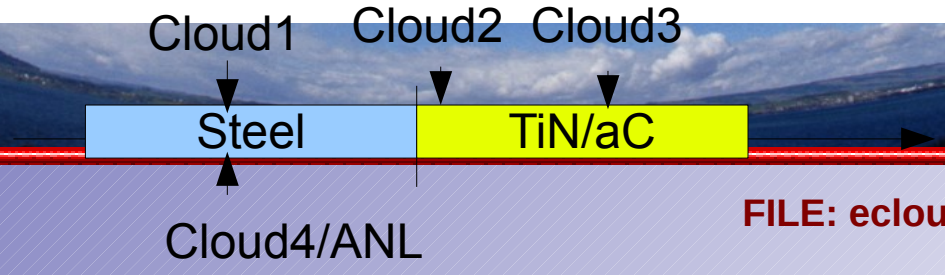


Time Evolution of X0 Value

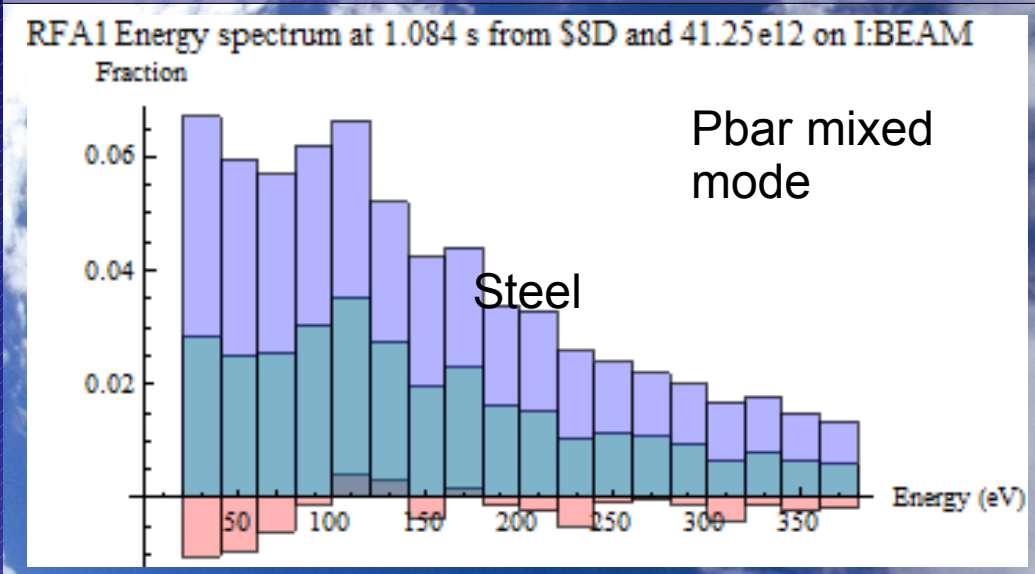


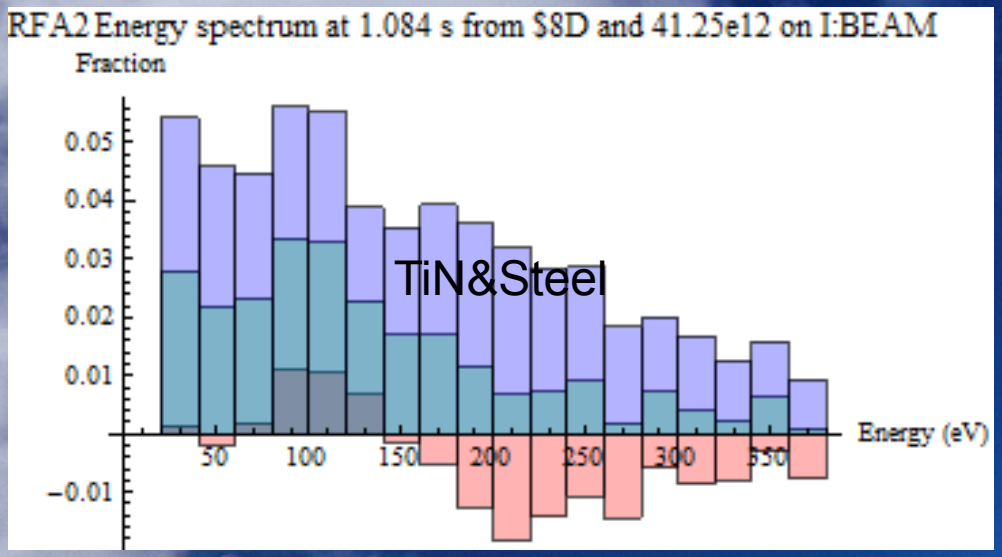
Normal procedure in leak repair.
Leak did not get up to atmosphere ~1e-6 torr (1e-8 normal).
Repair was in atmosphere.

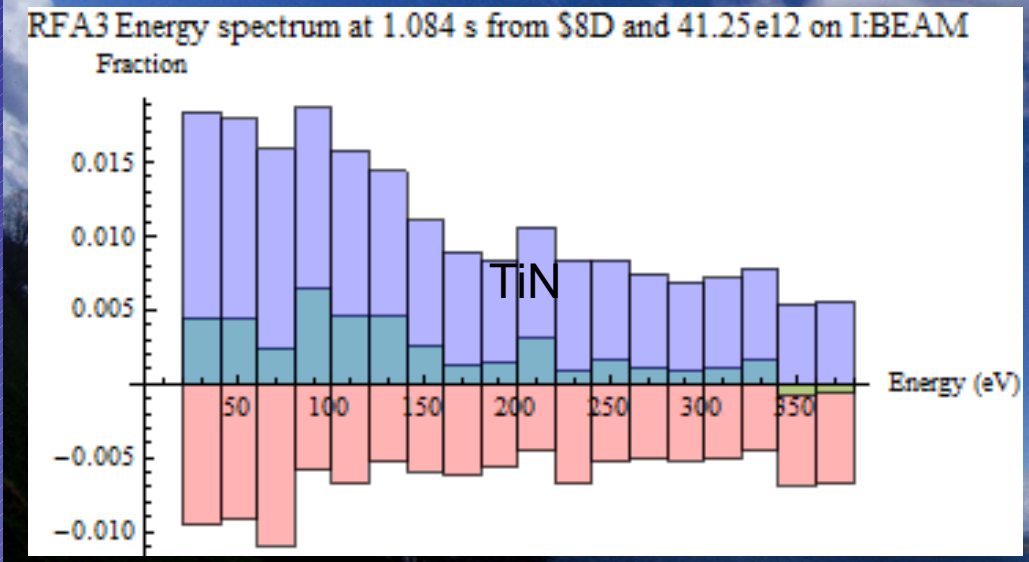
RFA1 Steel
RFA2 Carbon Coated
RFA3 Carbon Coated
RFA4 ANL Steel

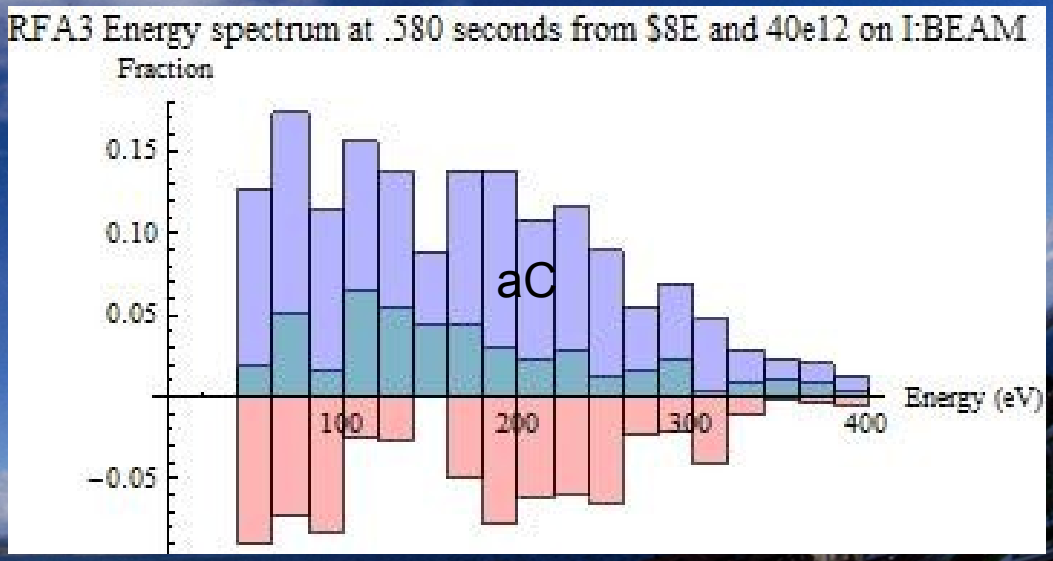


Energy Spectra









Conclusion

- RFAs have performed very well for about 1.25 years
  - RFAs have been very well characterised on the bench and in simulations.
  - RAD hard parts may not have been necessary.
- Magnetic probes installed this shutdown.
  - Still working after about 3 months.
- Microwave method needs more understanding.
- Data from TiN, aC and Steel still being analyzed
  - Preliminary results show that TiN and aC are comparable in performance
  - aC may not be very robust.