Electron Cloud Studies at the Fermilab Main Injector

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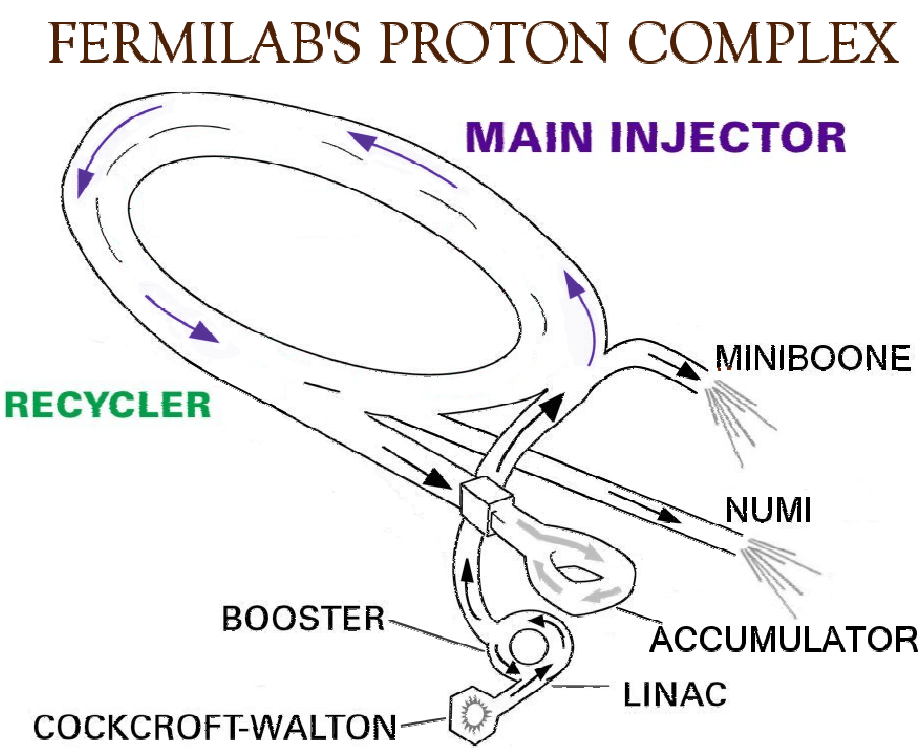
Driving Protons at the Main Injector

- Main Injector today produces 120 GeV proton beams for neutrinos ant antiprotons
  - 400 kW average power
  - 4E13 protons per pulse
- Near future upgrades (NOvA)
  - 700 kW, 4-5E13
- Upgrades in planning – Proton Driver or Project X
  - 2+ MW
  - 15+ E13
- Electron cloud on the top of our minds as a problem for tripling the beam intensity



Contributors

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Bob Kirby, Mauro Pivi – *SLAC*

Mark Palmer – *Cornell LEPP*

Pardis Niknejadi – *UCLA*

Fritz Caspers – *CERN*

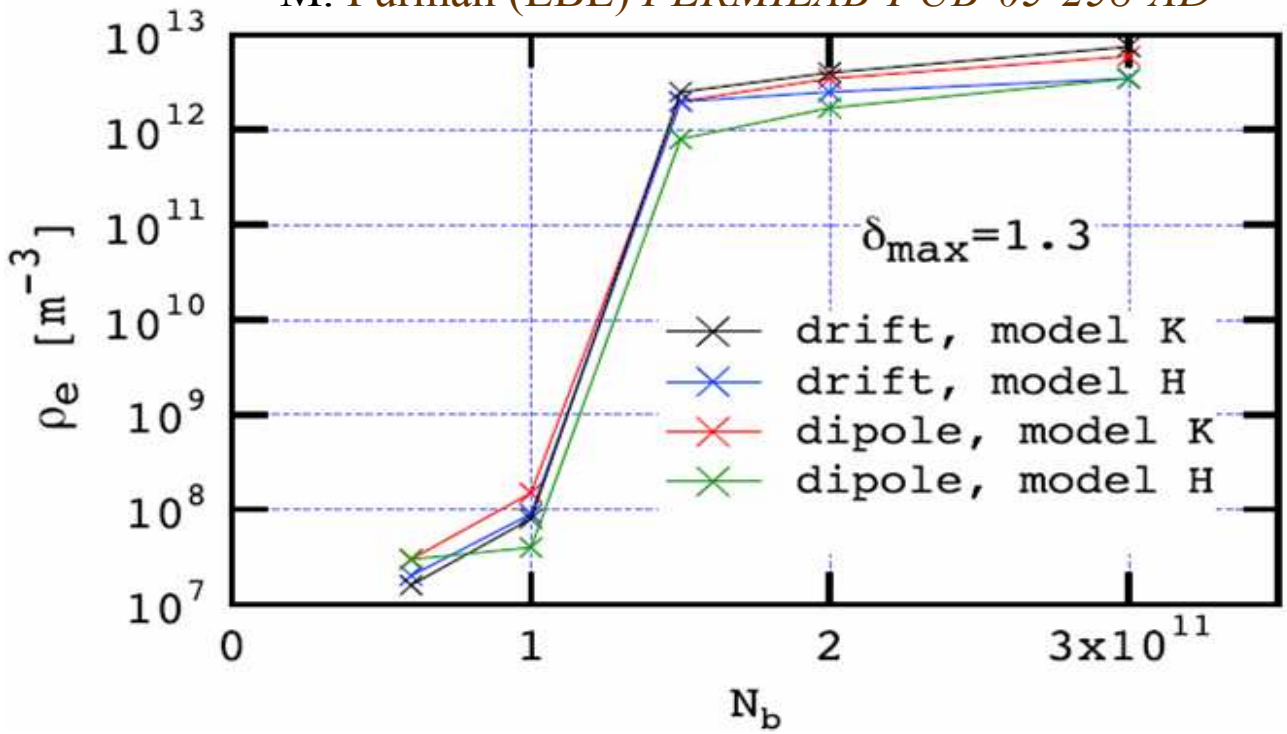
Outline

- Measurements made at the Main Injector
  - Observation of cloud buildup
- Considerations for Project X
- Plans for future study

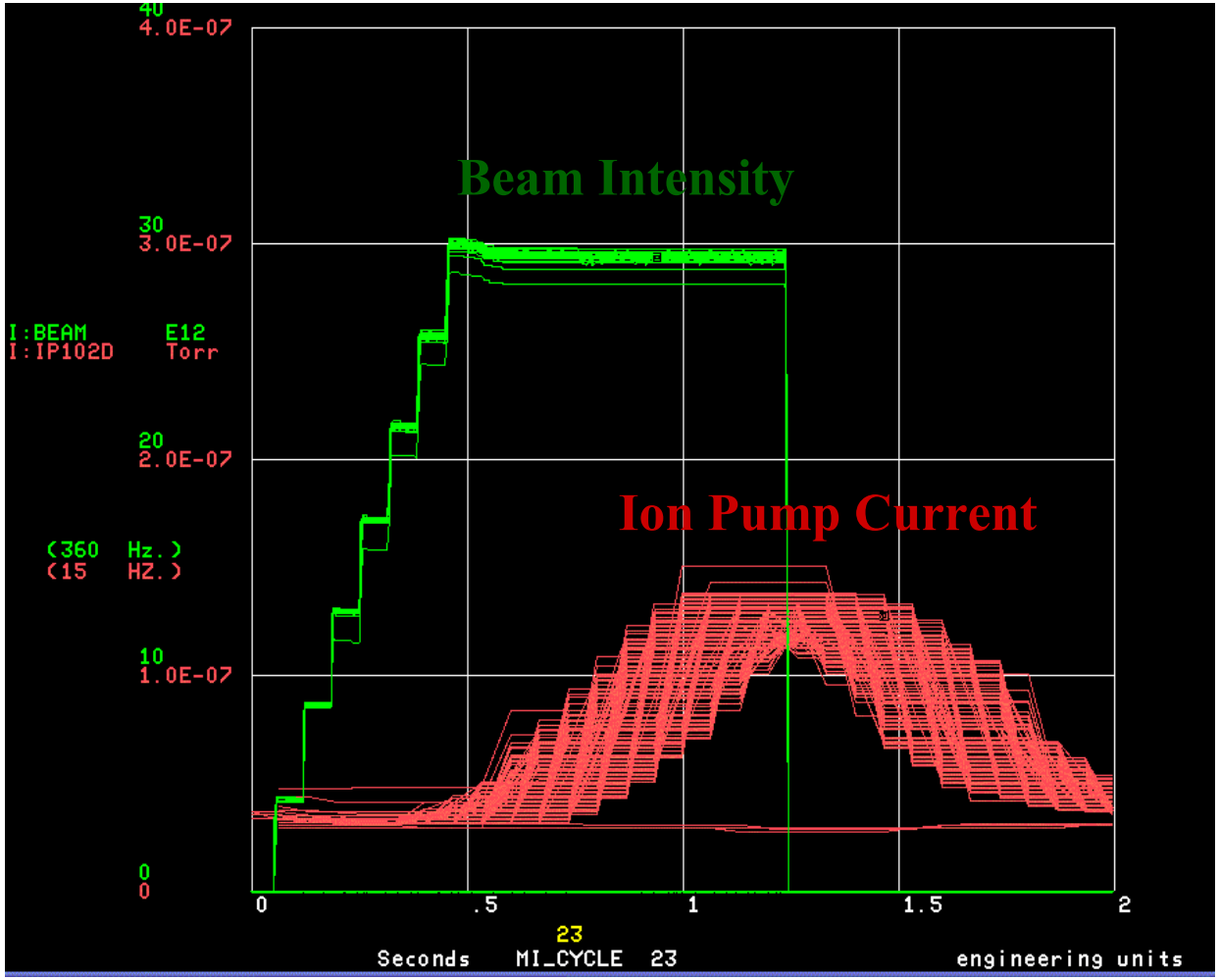
First Simulation Input

- Simulations suggested that MI might be near a threshold for electron cloud formation
  - 4-5 orders or magnitude increase of cloud density with a doubling of bunch intensity
- Led to a program of studies:
  - Try to find evidence of a cloud with present MI
  - Expand simulations
  - Look at secondary emission in the MI

M. Furman (LBL) *FERMILAB-PUB-05-258-AD*



Dynamic Pressure Rise

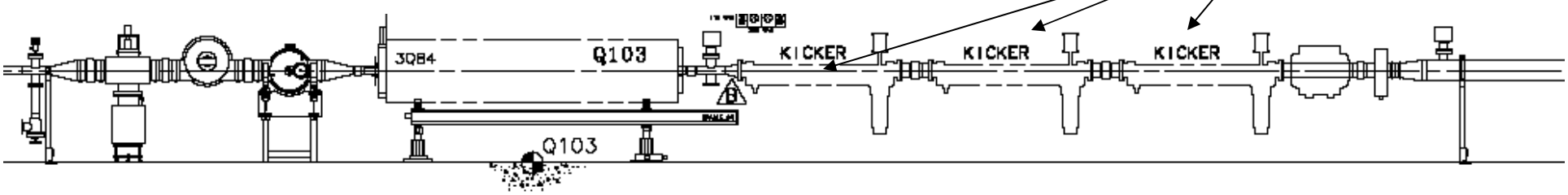


See fast rise over the course of a cycle (1s)

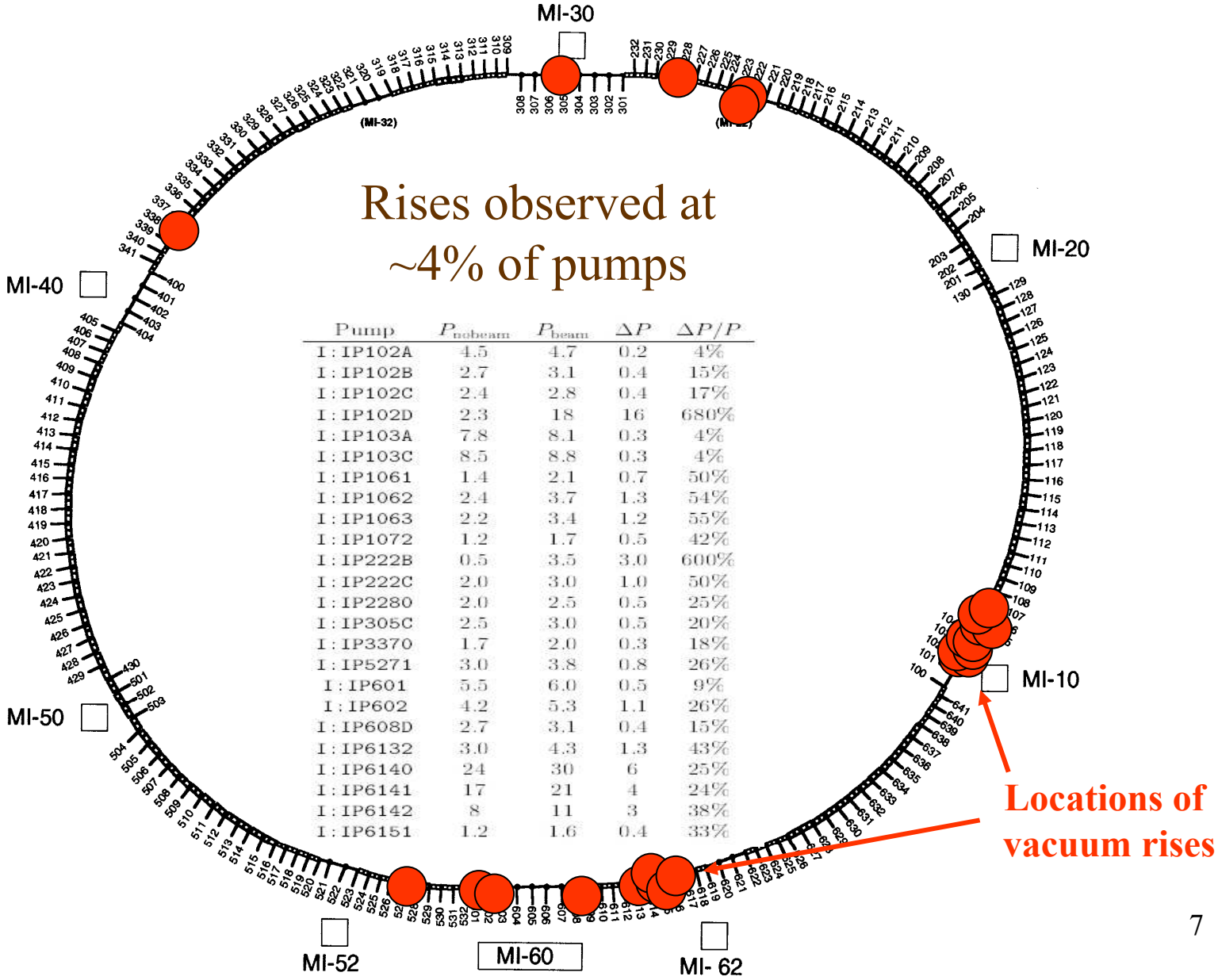
The control system induces delay

Occurs only at location of uncoated ceramic

Ceramic beam pipes



Dynamic Rises Around the Ring

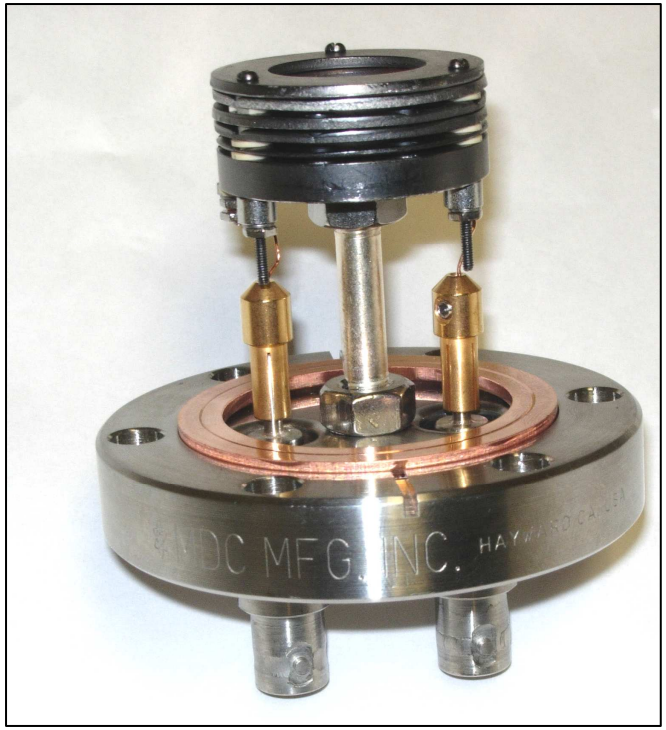


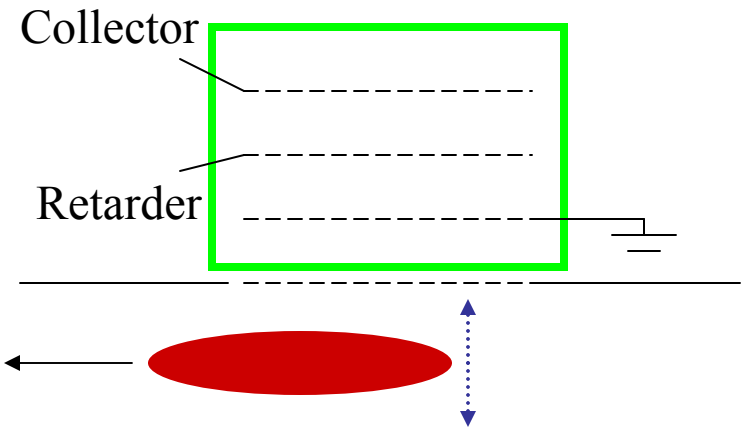
Rises observed at ~4% of pumps

Pump	P_{nobeam}	P_{beam}	ΔP	$\Delta P/P$
I:IP102A	4.5	4.7	0.2	4%
I:IP102B	2.7	3.1	0.4	15%
I:IP102C	2.4	2.8	0.4	17%
I:IP102D	2.3	18	16	680%
I:IP103A	7.8	8.1	0.3	4%
I:IP103C	8.5	8.8	0.3	4%
I:IP1061	1.4	2.1	0.7	50%
I:IP1062	2.4	3.7	1.3	54%
I:IP1063	2.2	3.4	1.2	55%
I:IP1072	1.2	1.7	0.5	42%
I:IP222B	0.5	3.5	3.0	600%
I:IP222C	2.0	3.0	1.0	50%
I:IP2280	2.0	2.5	0.5	25%
I:IP305C	2.5	3.0	0.5	20%
I:IP3370	1.7	2.0	0.3	18%
I:IP5271	3.0	3.8	0.8	26%
I:IP601	5.5	6.0	0.5	9%
I:IP602	4.2	5.3	1.1	26%
I:IP608D	2.7	3.1	0.4	15%
I:IP6132	3.0	4.3	1.3	43%
I:IP6140	24	30	6	25%
I:IP6141	17	21	4	24%
I:IP6142	8	11	3	38%
I:IP6151	1.2	1.6	0.4	33%

Electron Probe

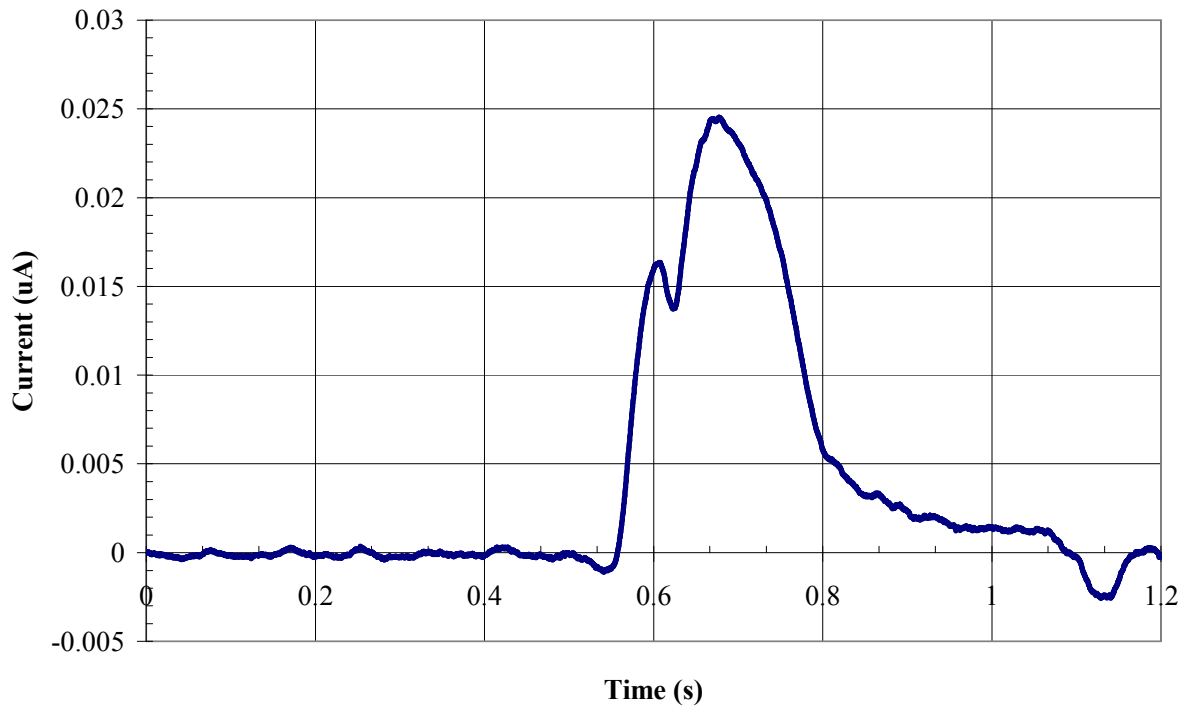
- Retarding Field Analyzer
  - Borrowed from Argonne
  - Installed in drift region
- Suffers from interference
  - Magnet bus (grounds)
  - RF & beam signals (RF noise)
- Being used as an electron counter
  - Not biasing retarder
  - Output current is amplified and recorded





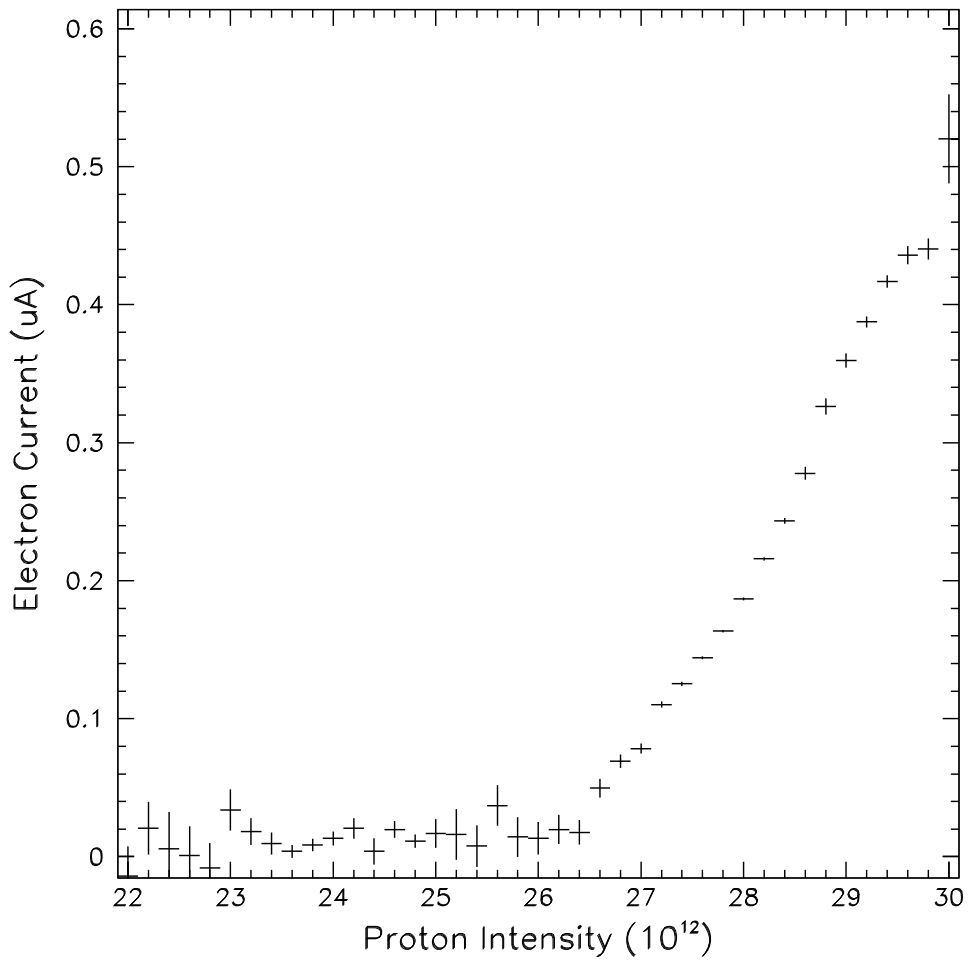
Cycle Measurement

- DC signal seen to spike at middle of cycle
  - Around the time of transition
- Rapid increase of signal occurs into acceleration
  - Dip occurs at transition
  - Maximum occurs shortly after transition
  - Electron count decreases toward the end of the cycle



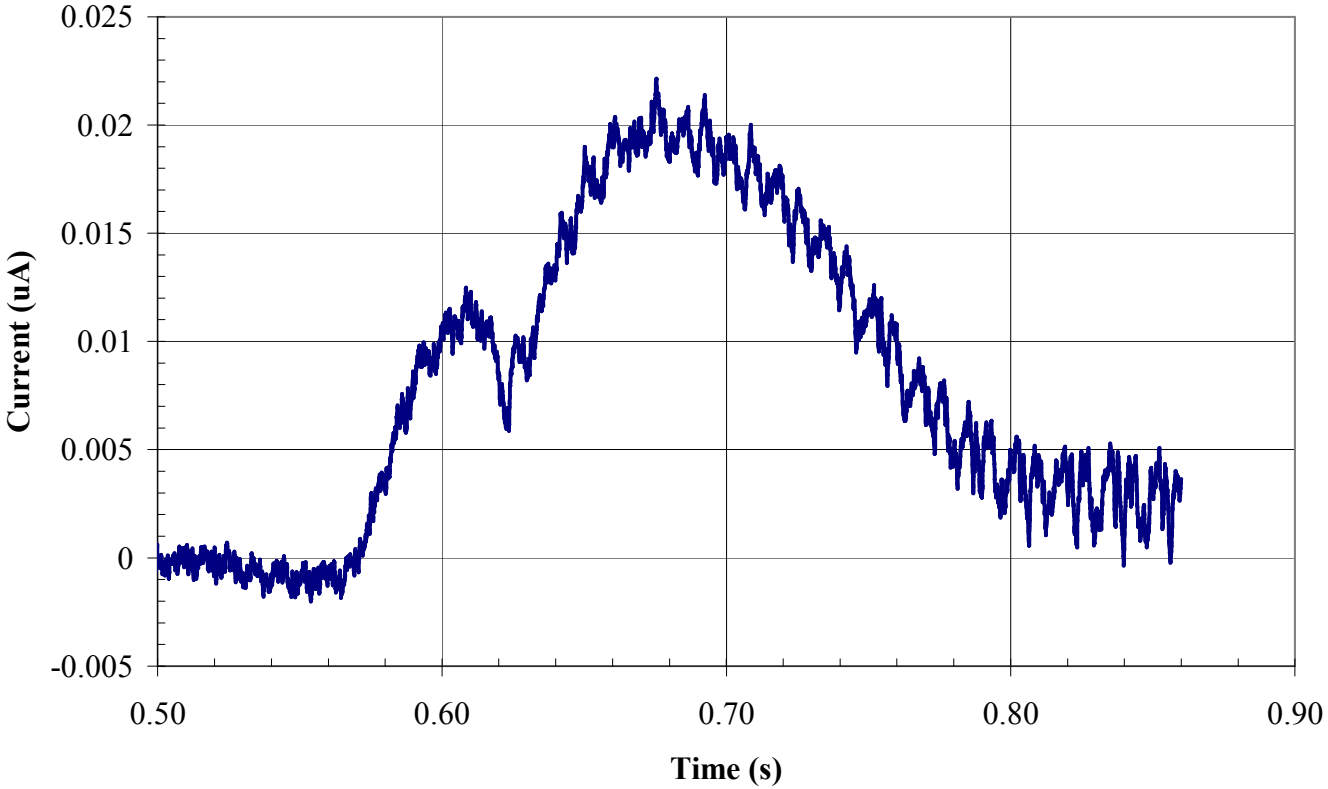
Collected results

- Large number of cycles sampled at maximum current
- Clear turn-on at higher intensities
  - Threshold at ~ 26e12
- Noise is bad due to amplifier/MADC system
- 0.2 uA ~ 1% neutralization

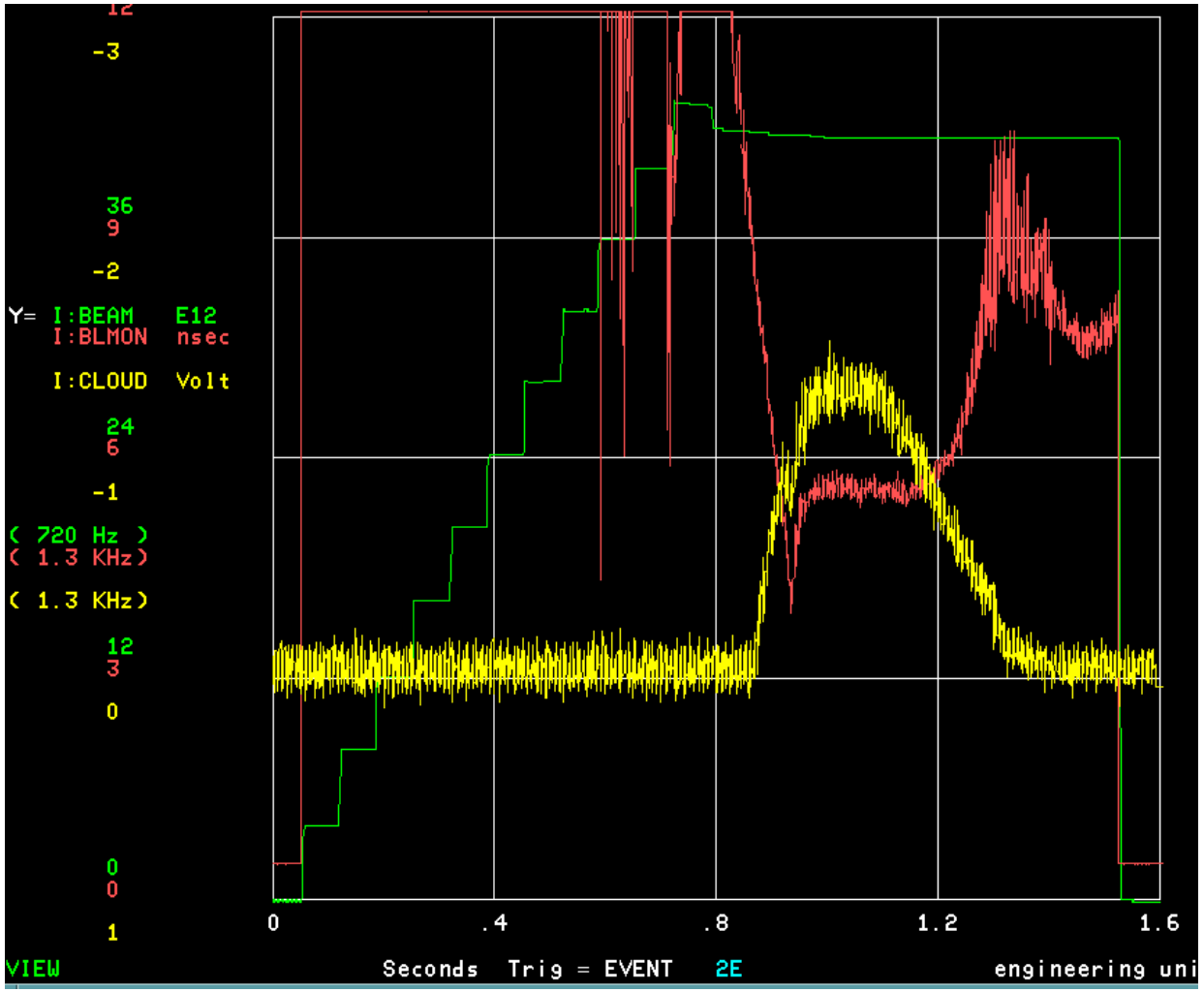


Closer look at Transition

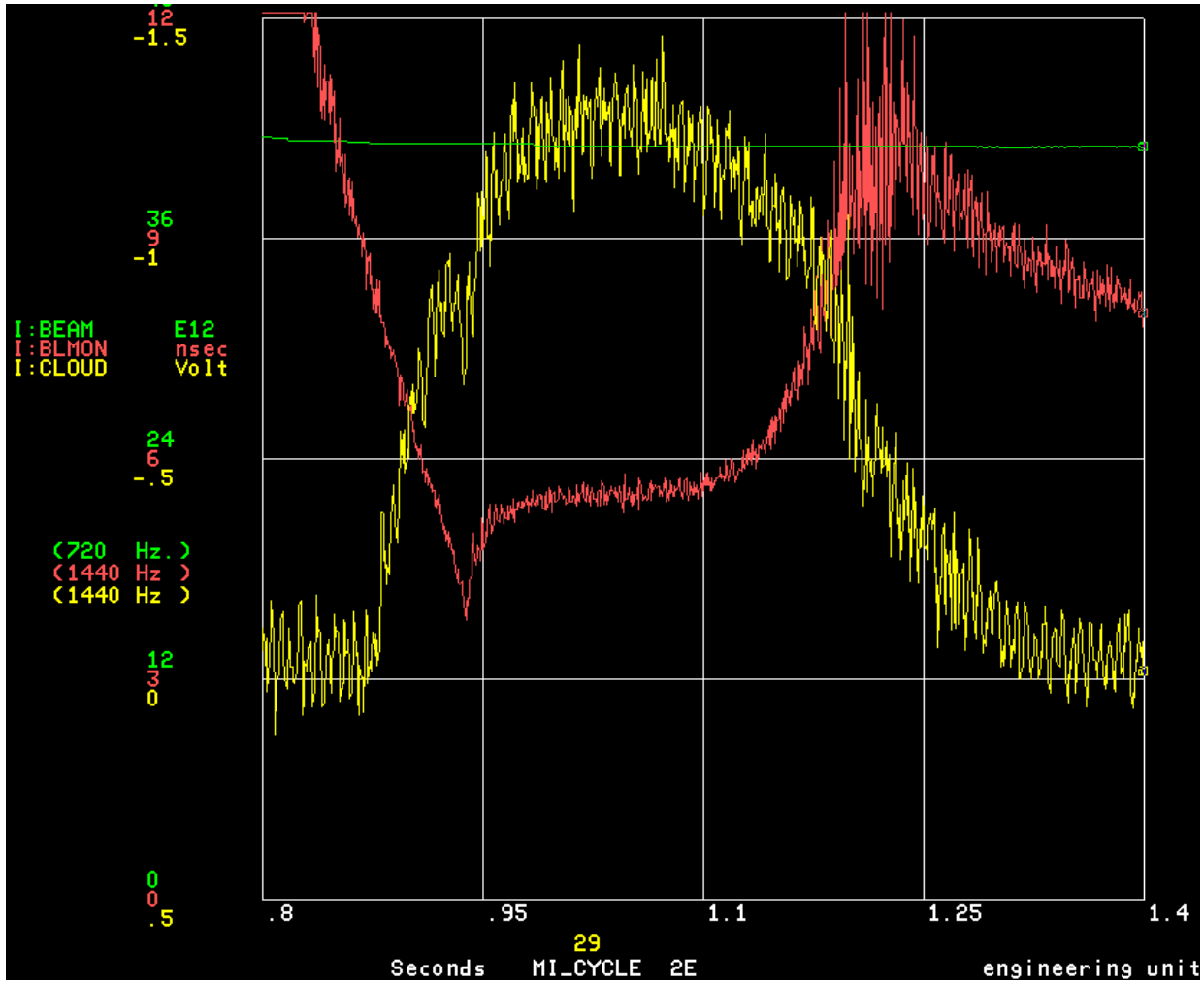
- Cloud increases rapidly as size decreases
- Decreases temporarily at minimum bunch length
  - Wasn't expected, but repeatable



Online Cloud Measurements

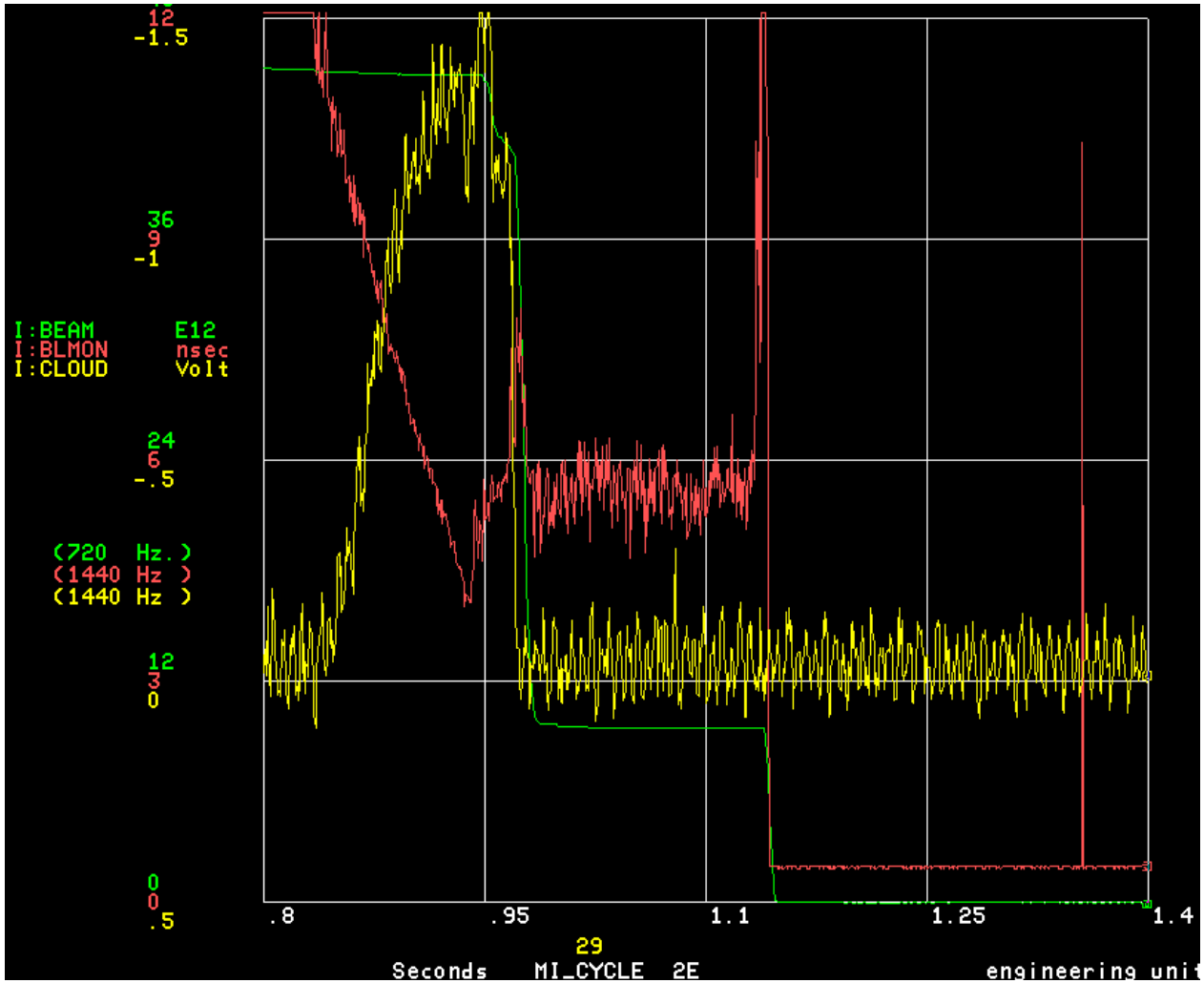


Zoom of Transition Region

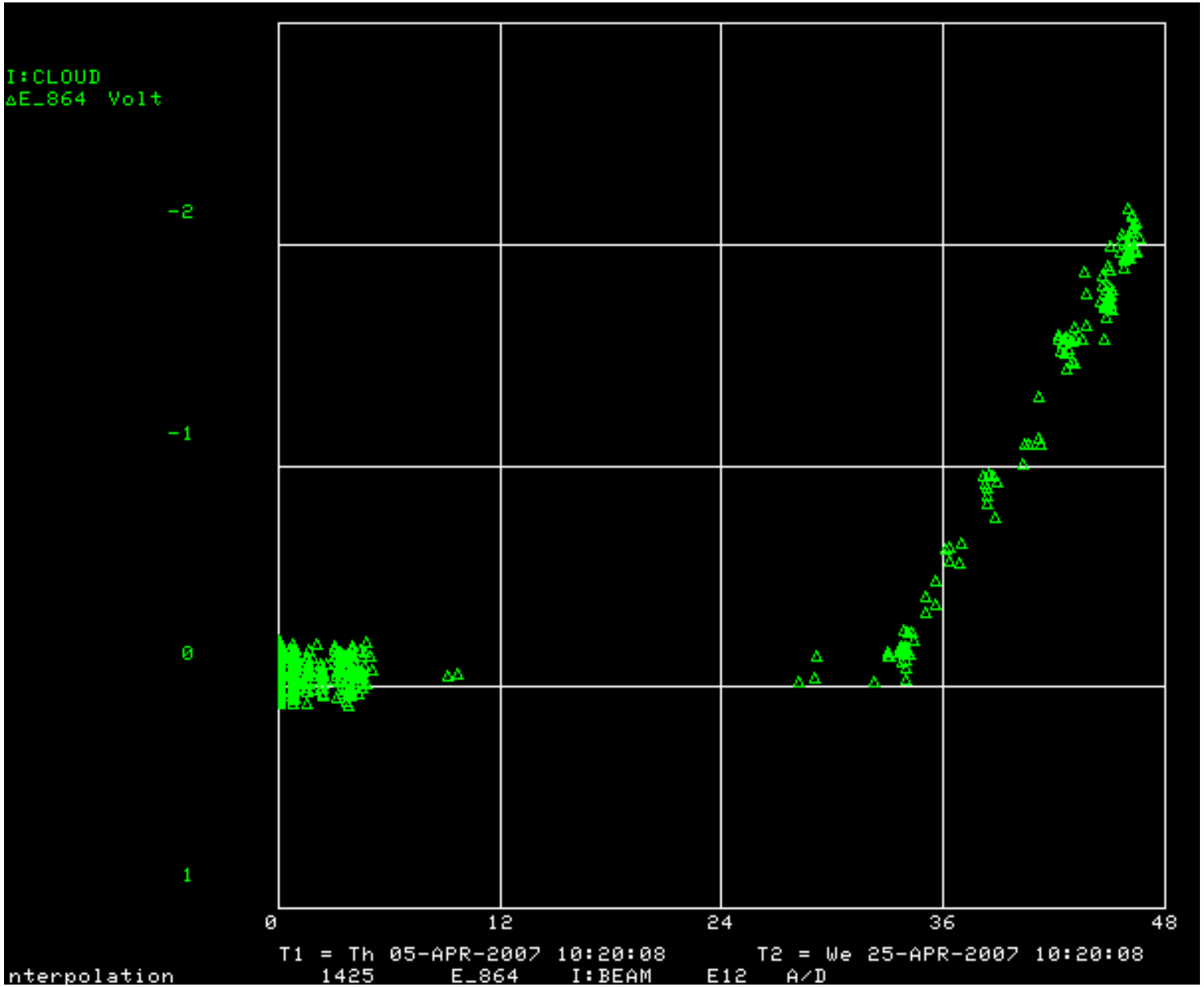


Sudden Beam Loss

- Loss was caused by RF feedback tuning
- ECloud signal drops immediately



High-Intensity Operation

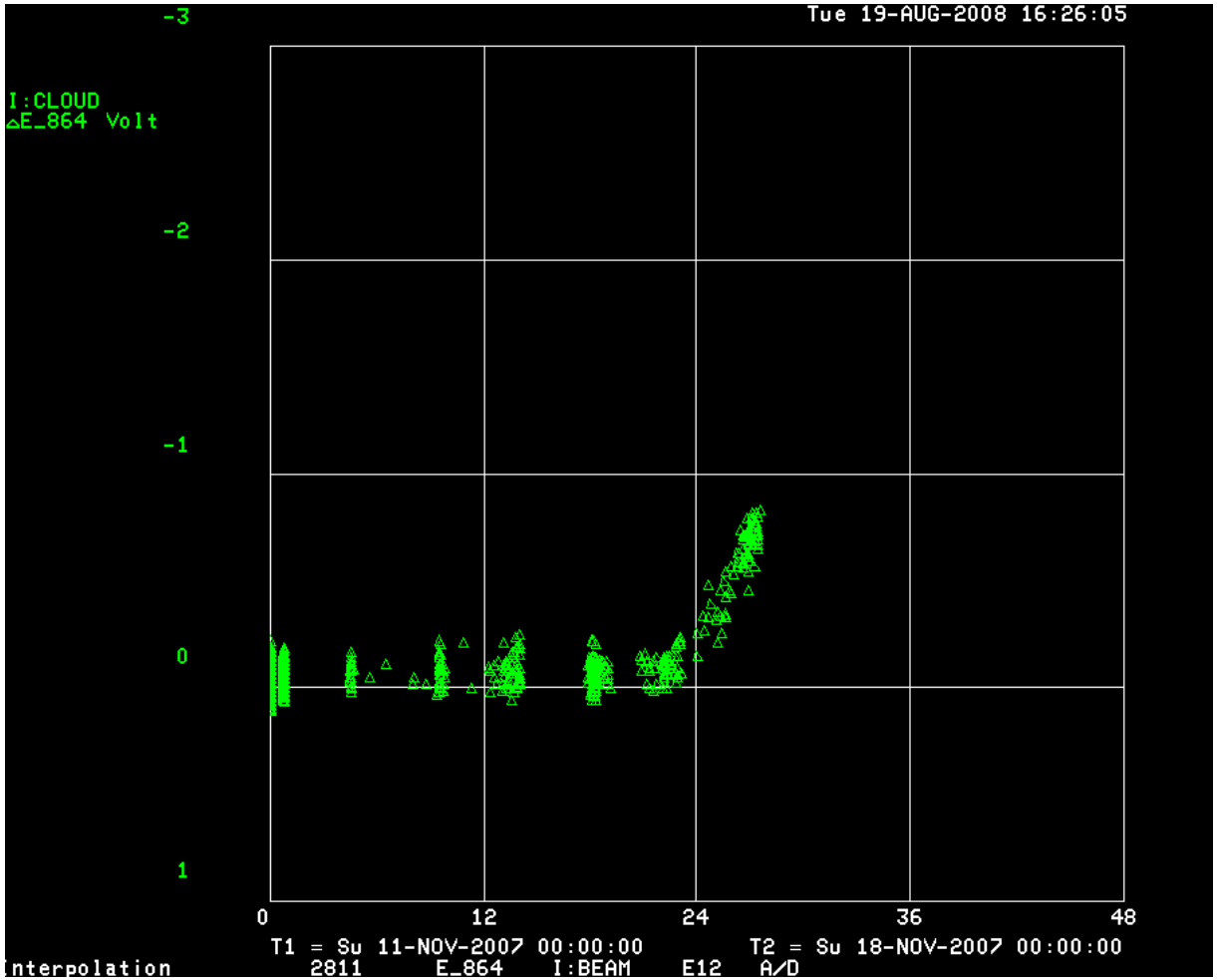


2006-2007 Run Summary

- Threshold quickly rose to and stayed constant at 34e12
- High-intensity running was limited to studies
- Above threshold, RFA current increased at ~ 0.15 uA per 1e12
  - Corresponds roughly to several % neutralization
- No instability observed in conjunction with ECloud
  - However, a small instability would not be noticed because of broadband damping performed for RW instability

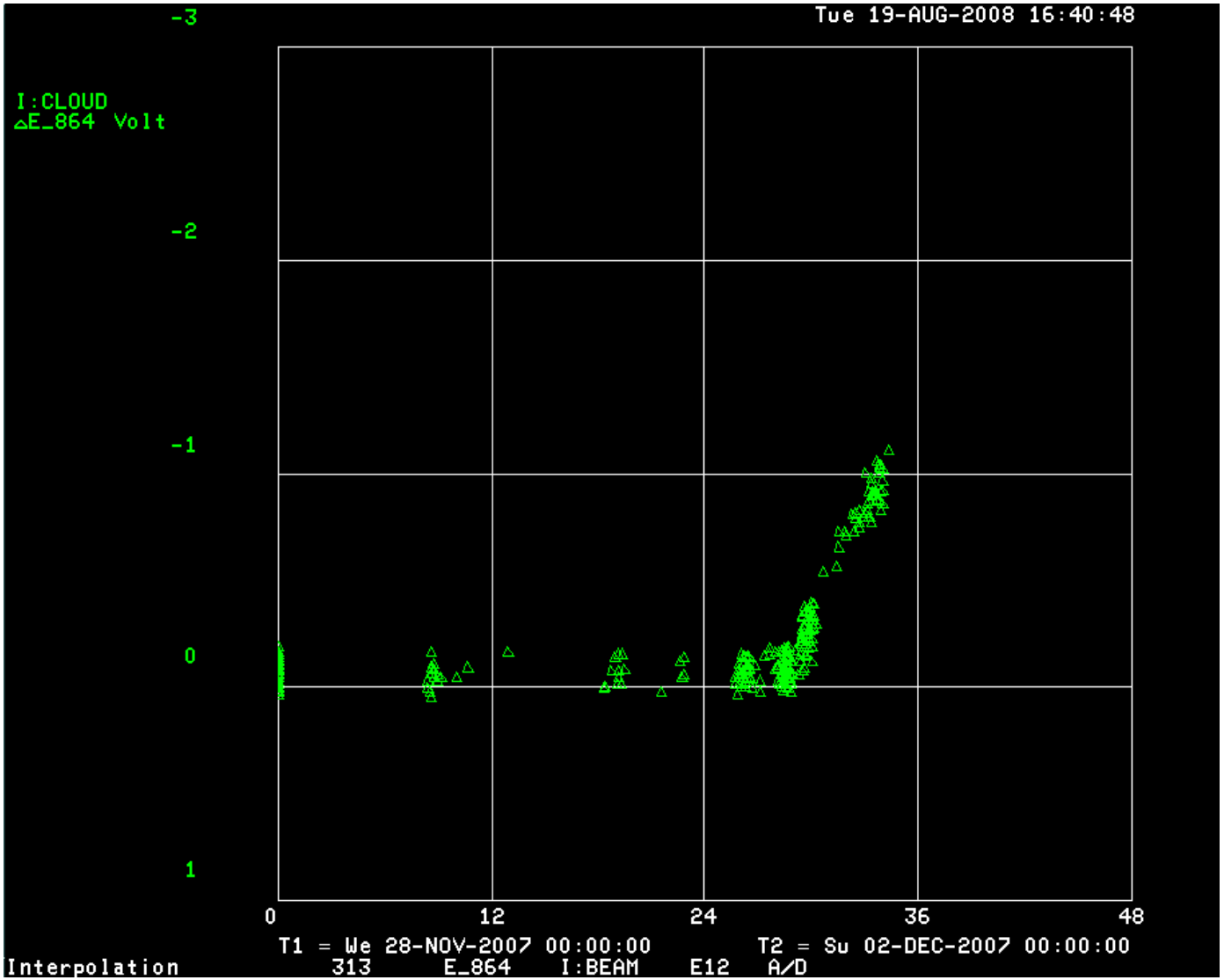
Restart after Shutdown

- Threshold has dropped to ~ 20e12
  - Vacuum in region had been opened



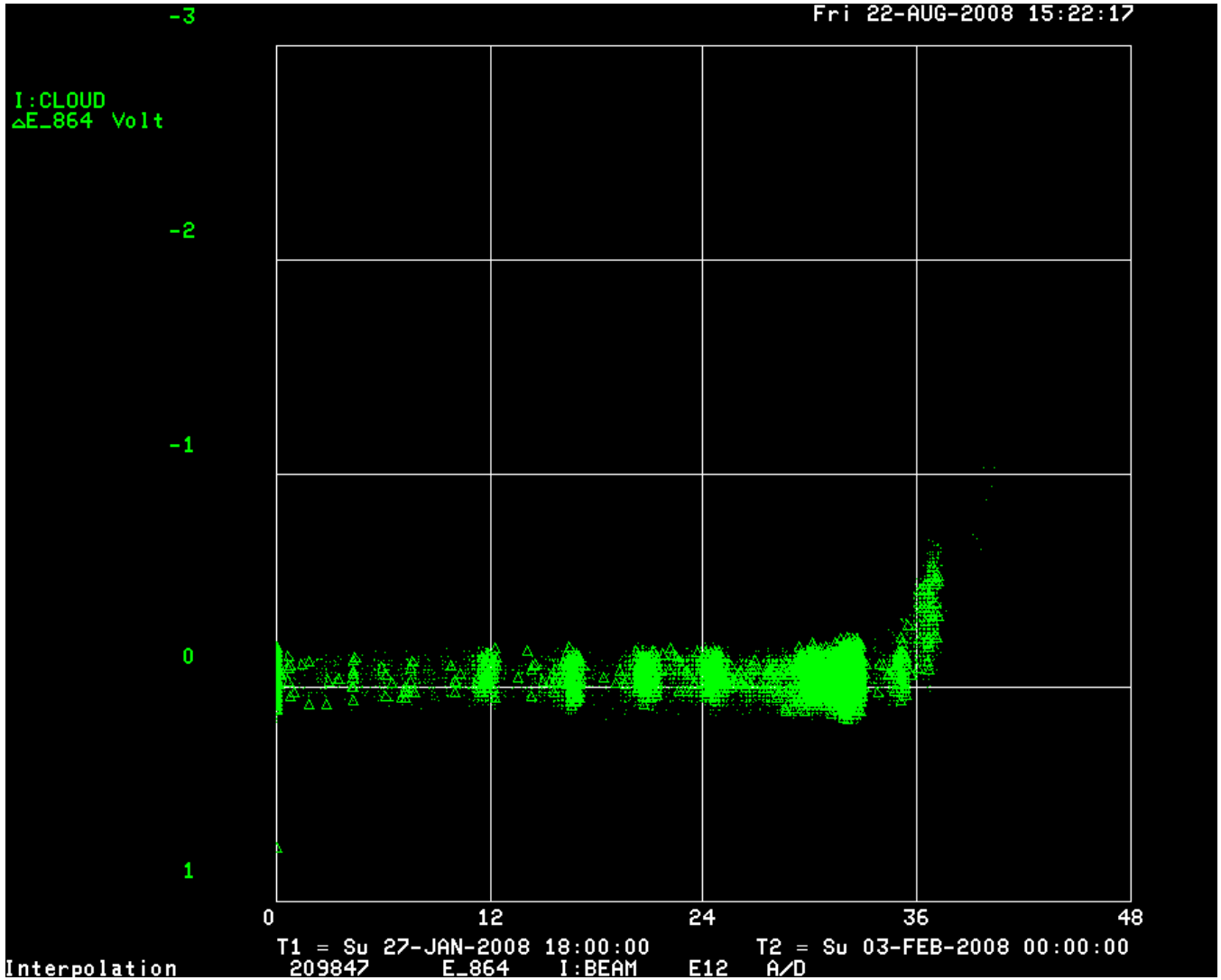
MI Intensity Increases

- Threshold increases



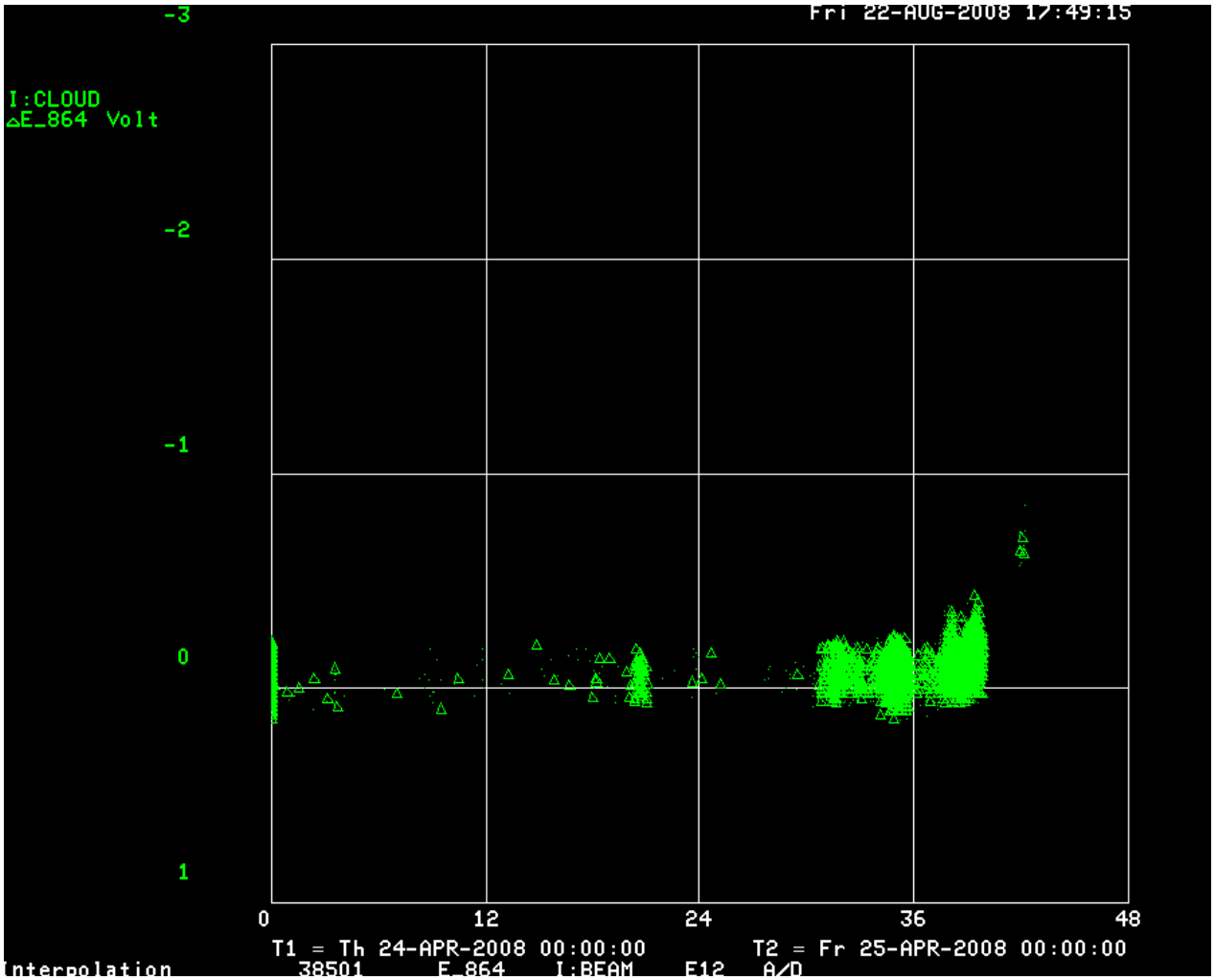
11-Batch Operation Starts

- Threshold increases more quickly



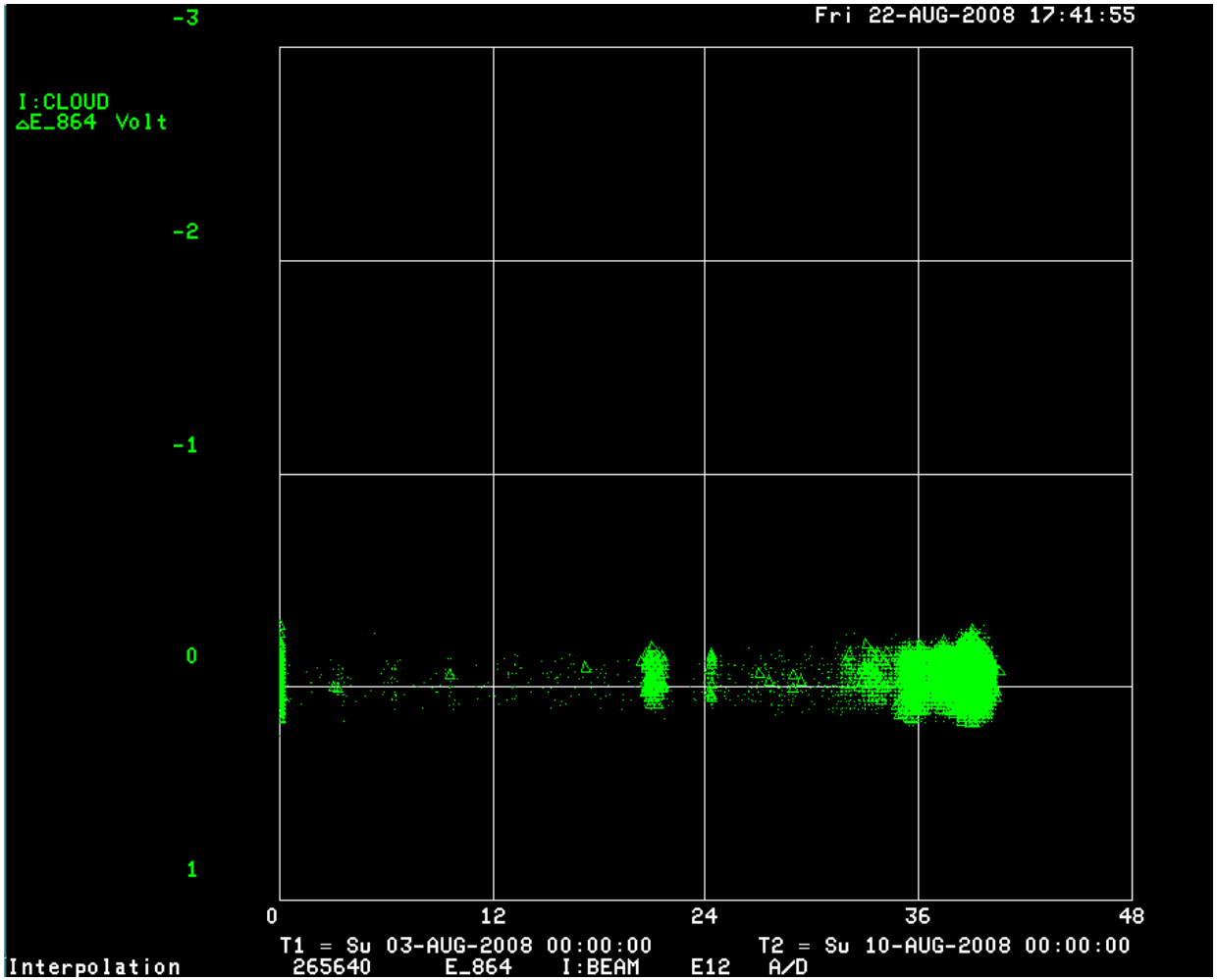
Last Sighting

- Last definitive measurement of ECloud on Apr. 25



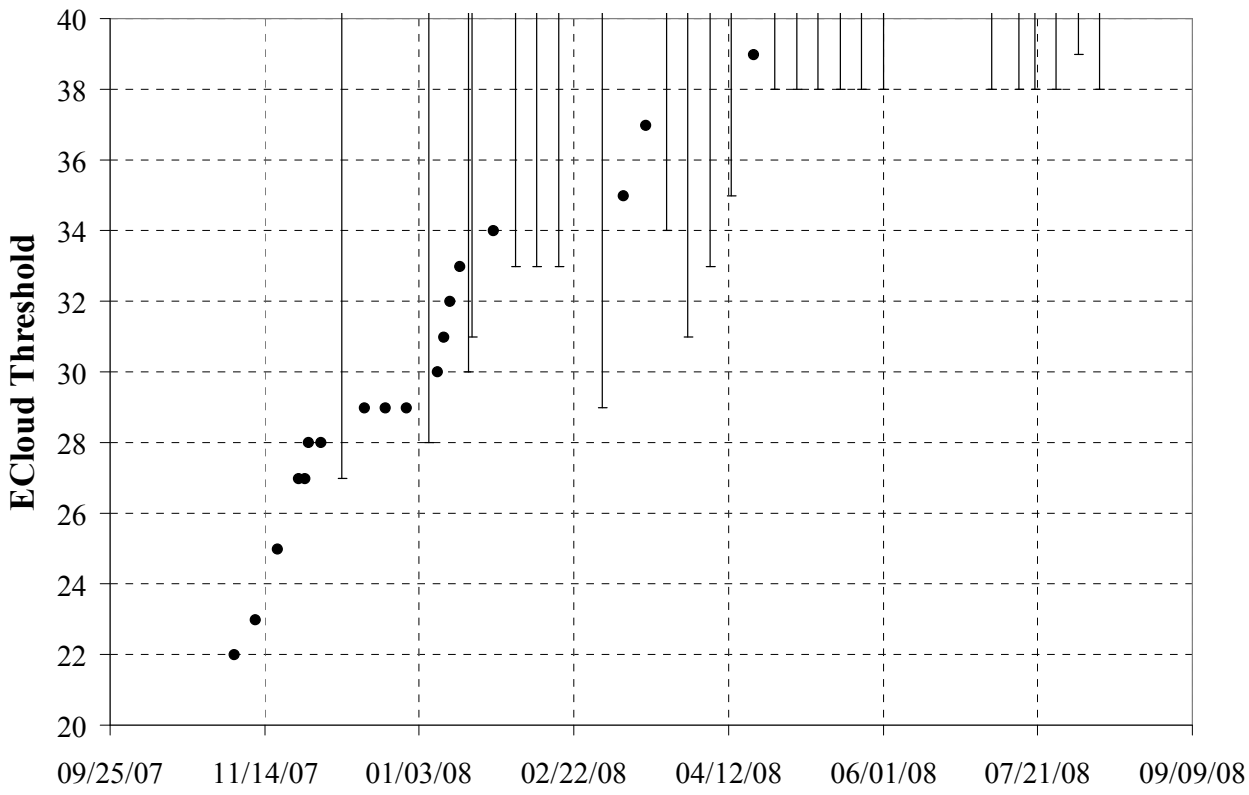
Present Operation

- Cloud signal is not above noise floor
- MI has not revisited its record intensities
- If MI gets back to >46e12, I expect a threshold at ~ 42e12



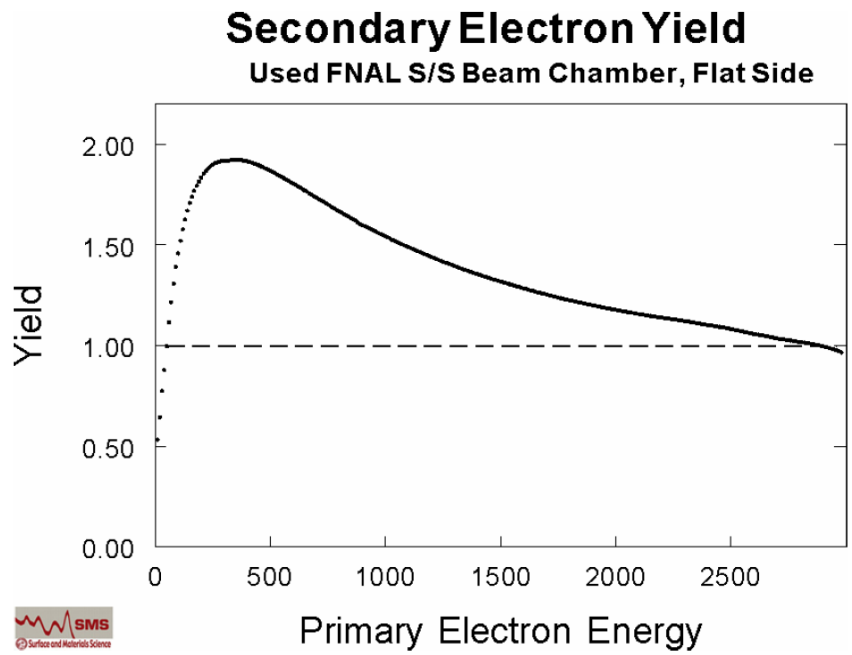
2007-2008 Run Summary

- Threshold started low and moved up to ~ 30e12 with beam studies
- When 11 batch became operational, threshold increased quickly
- Threshold is now beyond the range of normal MI operation ~ 42e12
  - MI should be able to return to ~ 48e12 sometime this run
  - Expect to see the ECloud reappear



Secondary Emission Measurement

- Measured at SLAC's facility with actual MI beam pipe
  (Bob Kirby)
- SEY was measured to be very high (1.9-2.0)
- Now, well understood to be the loss of conditioning by contact with atmosphere
  - Can't be fixed by bakeout
- Can we infer SEY from MI measurements and simulation?
- Look into other ways to measure SEY (later slides)



Plans for PrX

- Encouraging signs of conditioning of the MI's stainless
  - However, it is difficult to be confident to a tripling in intensity
- Considering coating all of the MI's length in TiN
  - Beam pipes are captured in dipoles
  - Some *in situ* method needs to be developed
- Plan to install test chambers of raw SS and TiN-coated SS this spring
  - Compare ECloud build-up in the 2
  - Validate the effect of TiN coating

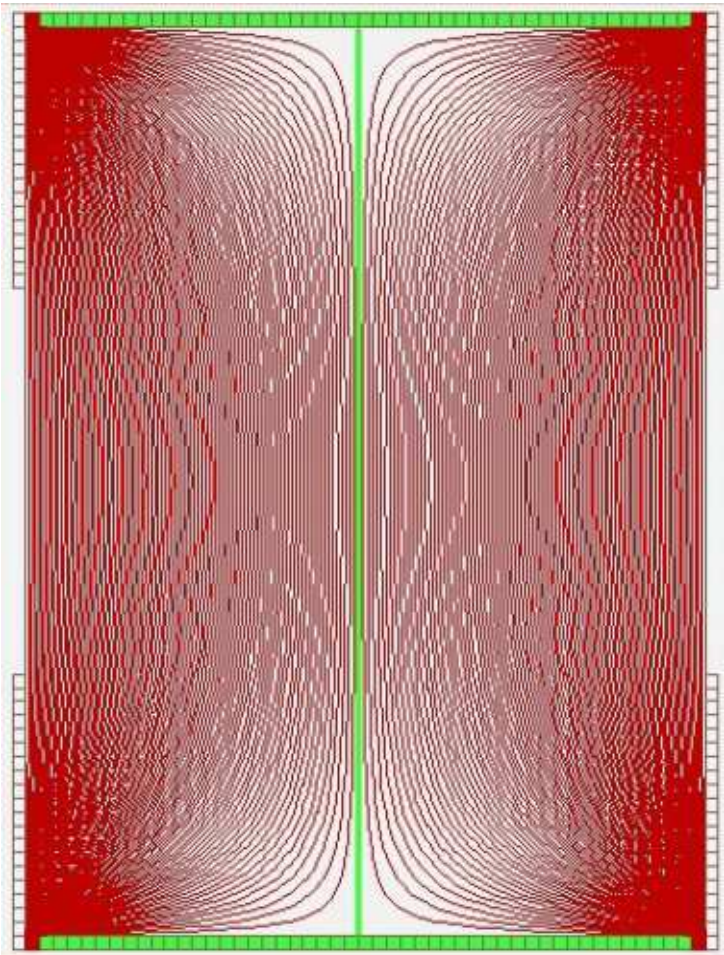
New ECloud Detector

C.Y. Tan

- Designing new RFAs
- Need to clarify our observations in the MI
  - Compare to simulation
- Need several new detectors for test stands

- Design is based off of APS RFA
  - Optimizing energy filter behavior
  - Maximize signal collection
  - Reduce interference
  - Perform detailed calibration

Simion Simulation



New Simulations

Synergia – Paul Lebrun

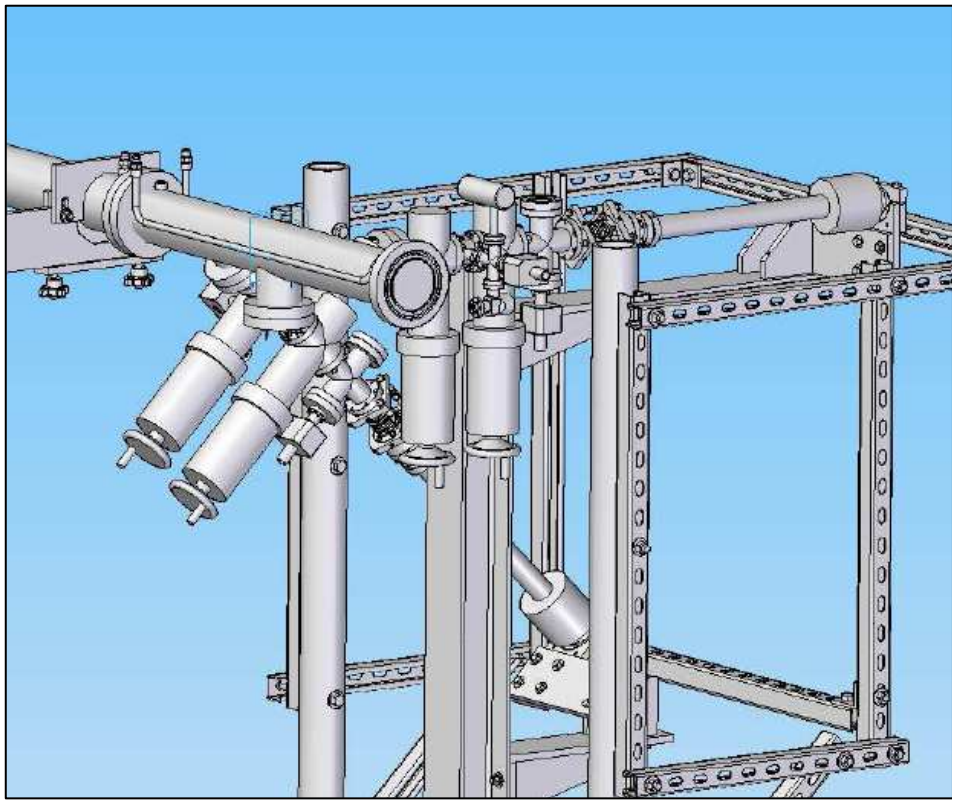
- Beam Dynamics code framework
  - 3-D self-consistent (if possible)
- Being modified to include ECloud

ORBIT – Leonid Vorobiev

- Developing new ECloud module in ORBIT
- Simulate ECloud for multiple bunches

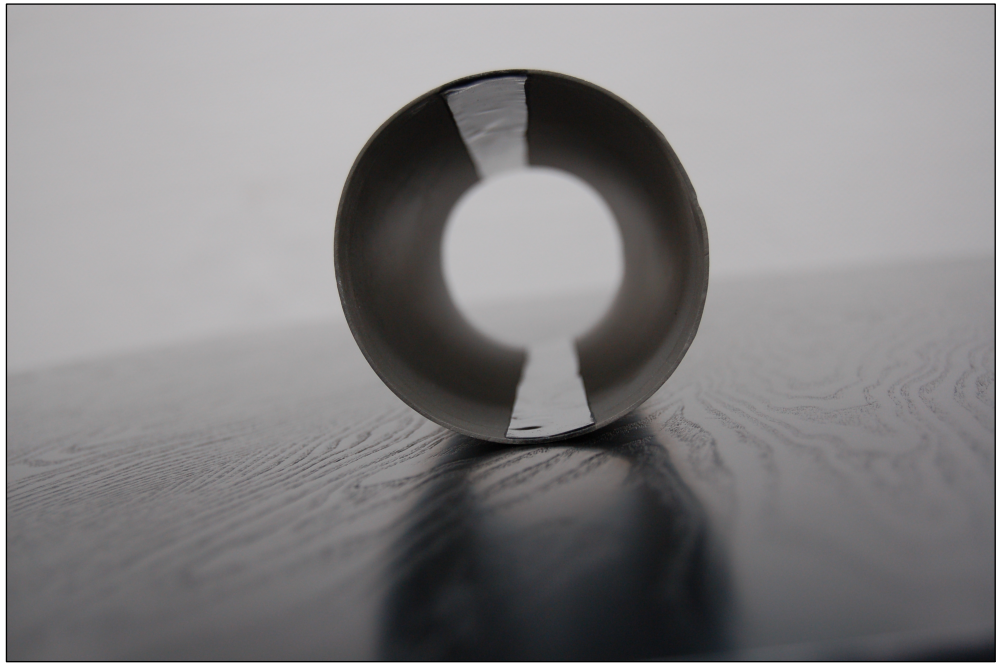
ECLOUD1

- SLAC teststand for measuring beam conditioning effects on surface materials
  - Surface "buttons" can be removed without breaking vacuum
- Presently transferred to Cornell for CesrTA run
- Will then transfer to Fermilab for MI installation (1-2 years)



Enameled chamber at Cornell

- Will install an enameled, high-resistance electrode in CESR
  - Test ECloud suppression
- May not be a workable solution for Project X
  - Can’t replace beampipe
- Studying for future machines



Other Measurements

- Microwave Propagation
  - ECloud induces phase shift of microwaves propogating along beam pipe
  - Phase shift is modulated by beam structure
  - Plan to test in MI soon
    - Ramping may provide unique opportunity to test for ECR
  - Consider permanent installation

- Optical Detection
  - Detect the light produced by electron bombardment of beam tube
  - May be a nice to peak inside of magnets
  - Also considering scintillating fibers
  - Looking into these – no plans yet

Summary

- Need to understand MI electron cloud in the context of intensity upgrades
- Measurements of electron cloud formation in MI
  - Vacuum pressure rise & Direct electron detection
    - Suggest few % neutralization
  - Threshold of formation is observed
    - Threshold increases over time – consistent with surface conditioning
  - Dip of electron current at transition
    - Perhaps due to SEY/geometry/bunch length effects
    - Needs to be remeasured with new instrumentation
  - No instability observed in MI die to ECloud
- Several types of new instrumentation are under development
- Plan to continue getting guidance from simulation
  - POSINST and new codes.

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