Electron Cloud R&D at Fermilab

Bob Zwaska

Linear Collider Workshop of the Americas

October 1, 2009

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Contributors

Michael Backfish, David Capista, Jim Crisp, Kevin Duel, Nathan Eddy, Jim Fitzgerald, Ioanis Kourbanis, Paul LeBrun, Lee McCuller, Bill Ng, C.Y. Tan, Linda Valerio, Leonid Vorobiev, Manfred Wendt, Xiaolong Zhang , Bob Zwaska

Electron Cloud Working Group: Physicists and engineers working on experiments, instrumentation, and simulation.

Motivation

FERMILAB'S PROTON COMPLEX

- Fermilab's ECloud R&D is focused towards proton upgrades of Main Injector
  - NOvA (700kW)
  - Project X (2+ MW)
- Program consists of experimentation and simulation to build Project X
- Additionally, look for general advancement of the question for future machines (e.g. ILC)

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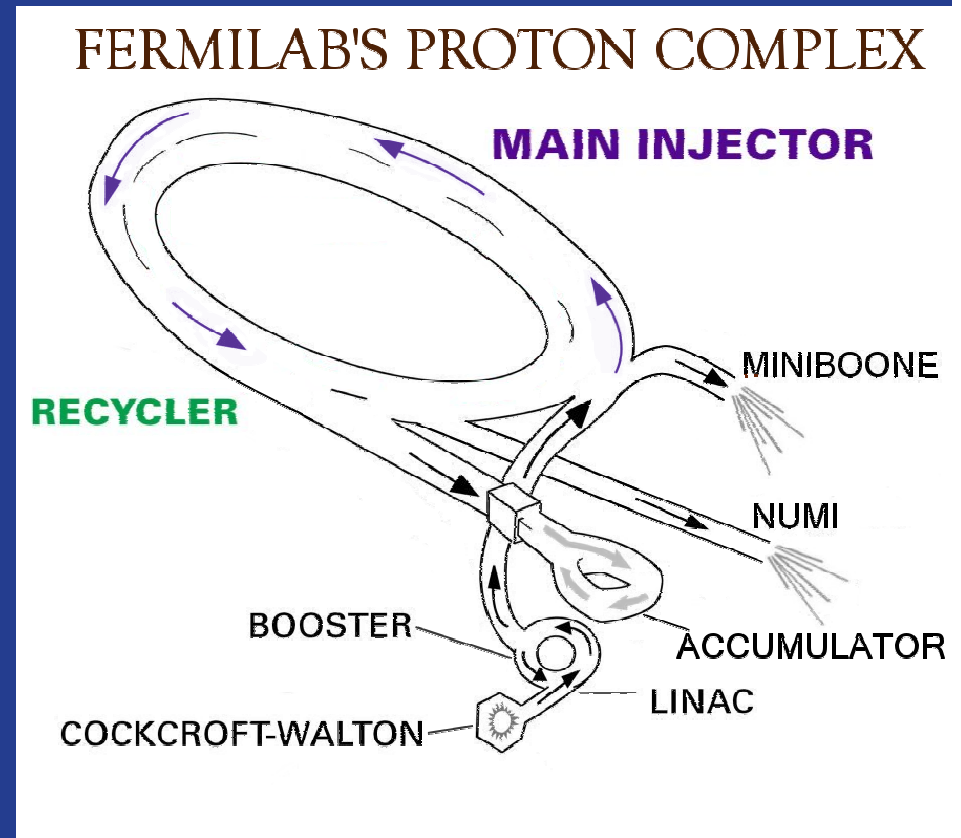
Overview of Activities

- Simulation Input from LBL

- Initial ECloud experimental installation

- Development of instrumentation
  - RFA and microwave

- New ECloud experimental installation
  - Some Preliminary Measurements

- Simulations

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LBL Simulation

M. Furman

- POSINST simulation suggested that the Main Injector might be near a threshold for electron cloud formation
  - 4-5 orders or magnitude increase of cloud density with a doubling of bunch intensity
- Further simulations have been performed to match measurements
  - Success of comparison has been mixed
  - Progress made in different beam configurations
  - Consistent basic behavior for bunched proton beams:
  - Strong threshold when secondary emission runs away

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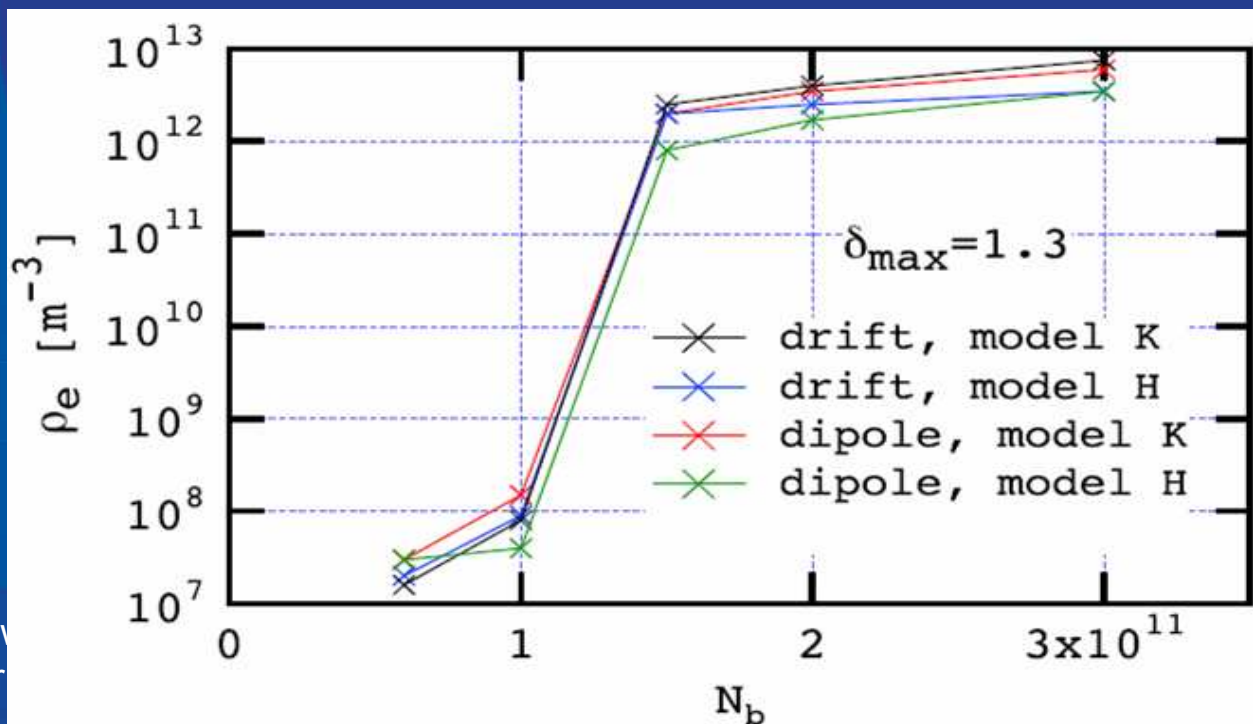
Initial Installation & Measurements

- Argonne RFA (Borrowed)
  - Installed in drift region of MI
- Allowed direct observation of Cloud
 - Time- (energy-) dependent signal
  - Qualitatively
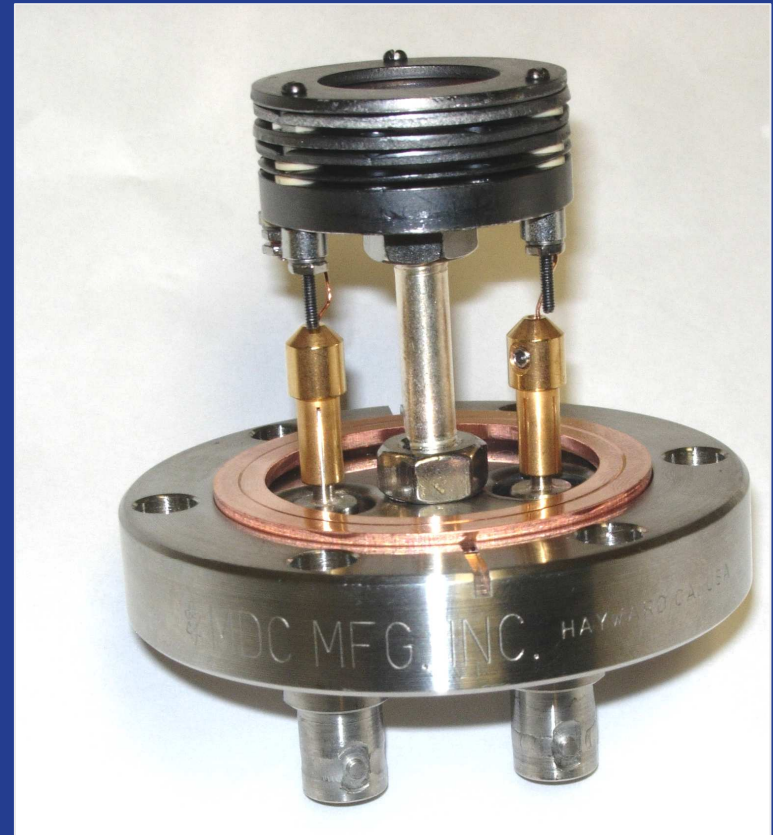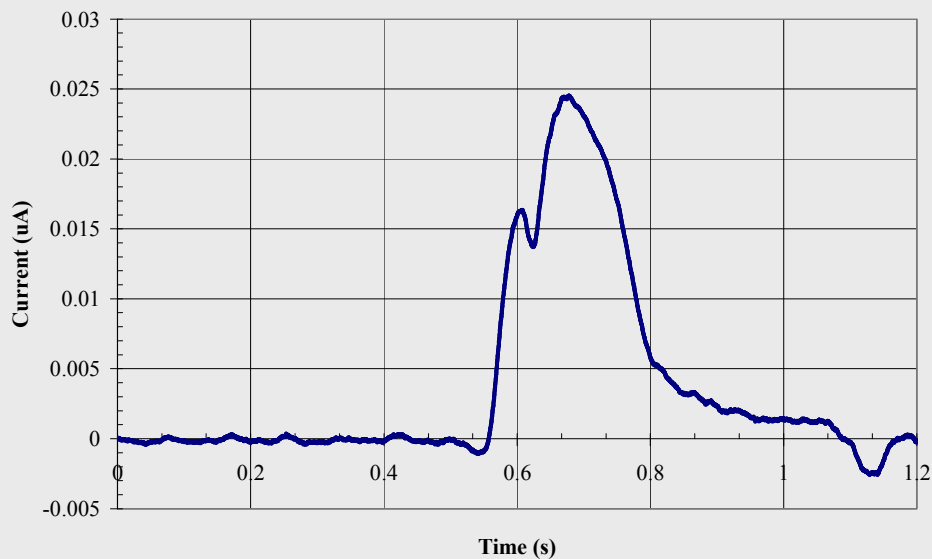
Threshold

- Large number of cycles sampled at maximum current

- Clear turn-on at higher intensities
  - Threshold at ~ 26e12 protons
  - Threshold later moved higher

- Allowed fitting of Furman's simulation to data, giving an SEY

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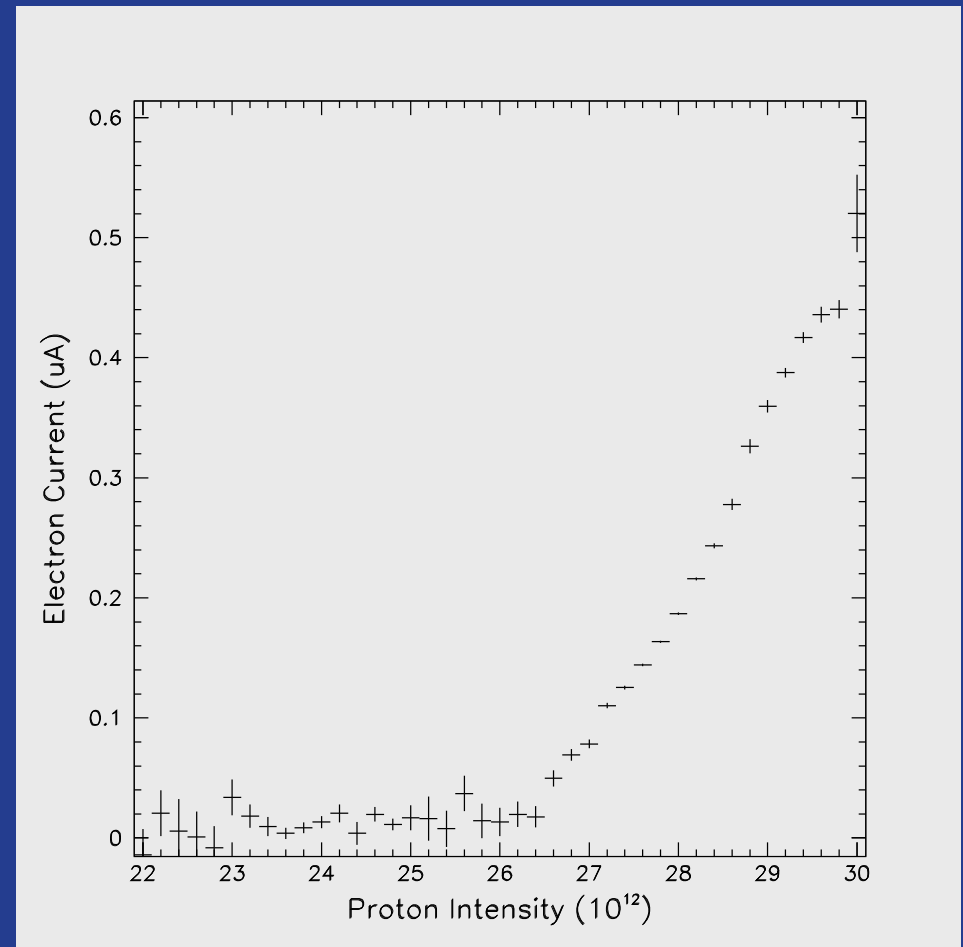
Beam Pipe Surface Conditioning

- Threshold evolved with time, moving higher as MI established higher-intensity operation
- When 11 batch became operational, threshold increased quickly (Jan, 2008)
- As beam intensity increased to 40e12, the threshold eventually increased beyond range (March, 2008)
- Conclude that SS conditions well to 40e12 protons, will it to 150e12?

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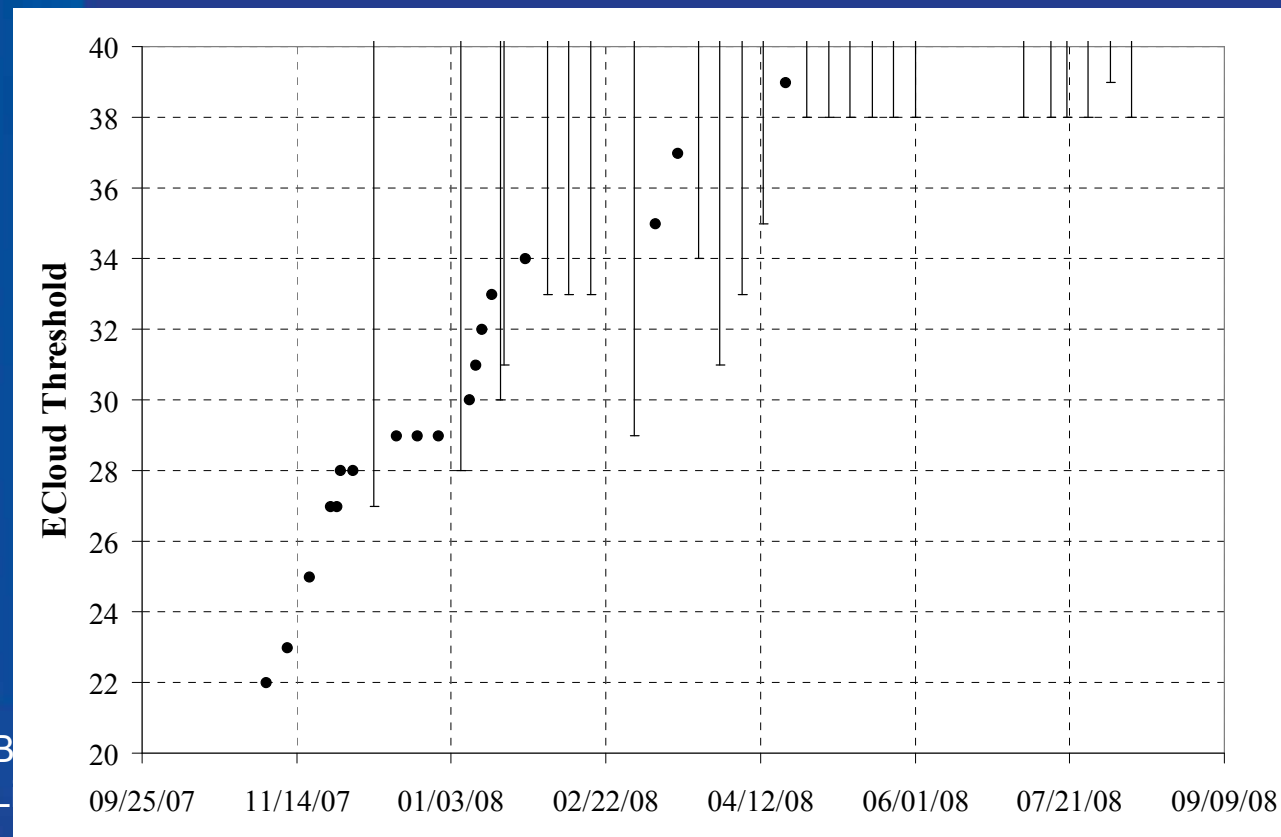
Microwave Measurements
N. Eddy, J. Crisp, M. Wendt

- Sideband and direct phase measurements
  - Very good time-resolution
- Allows measurement in dipole sections
- Will have direct comparison with RFAs
- Need better theoretical understanding of phase shift, particularly in magnets
- See data in Manfred's talk
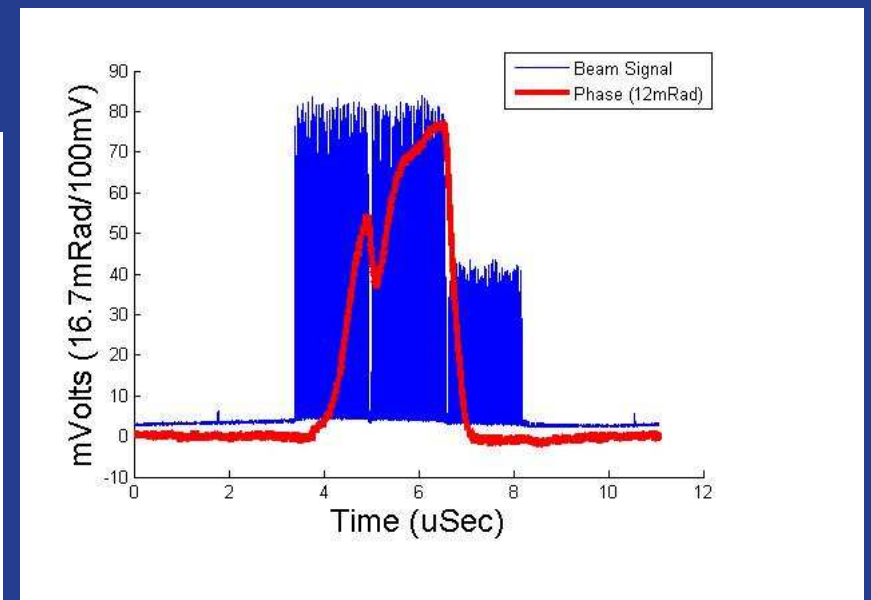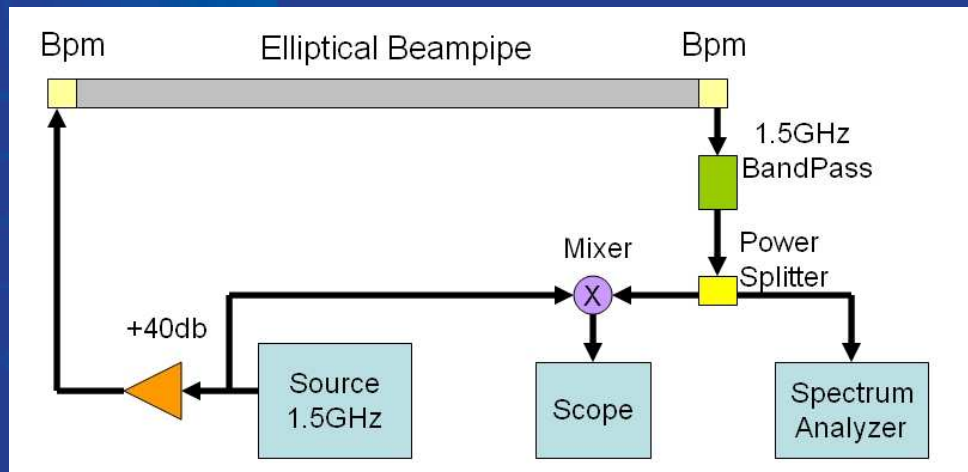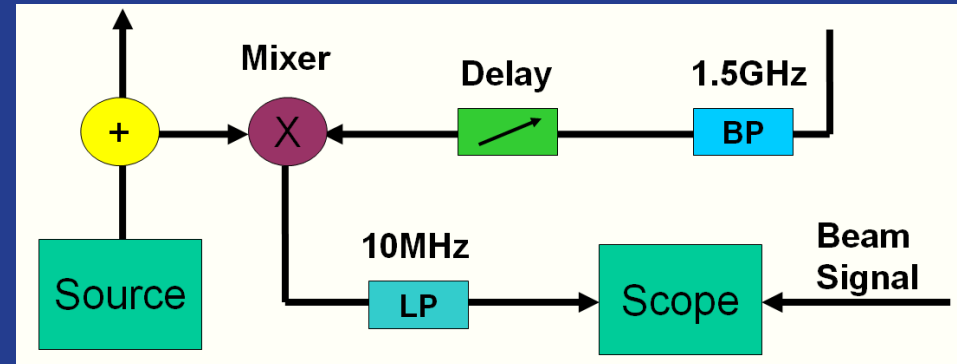
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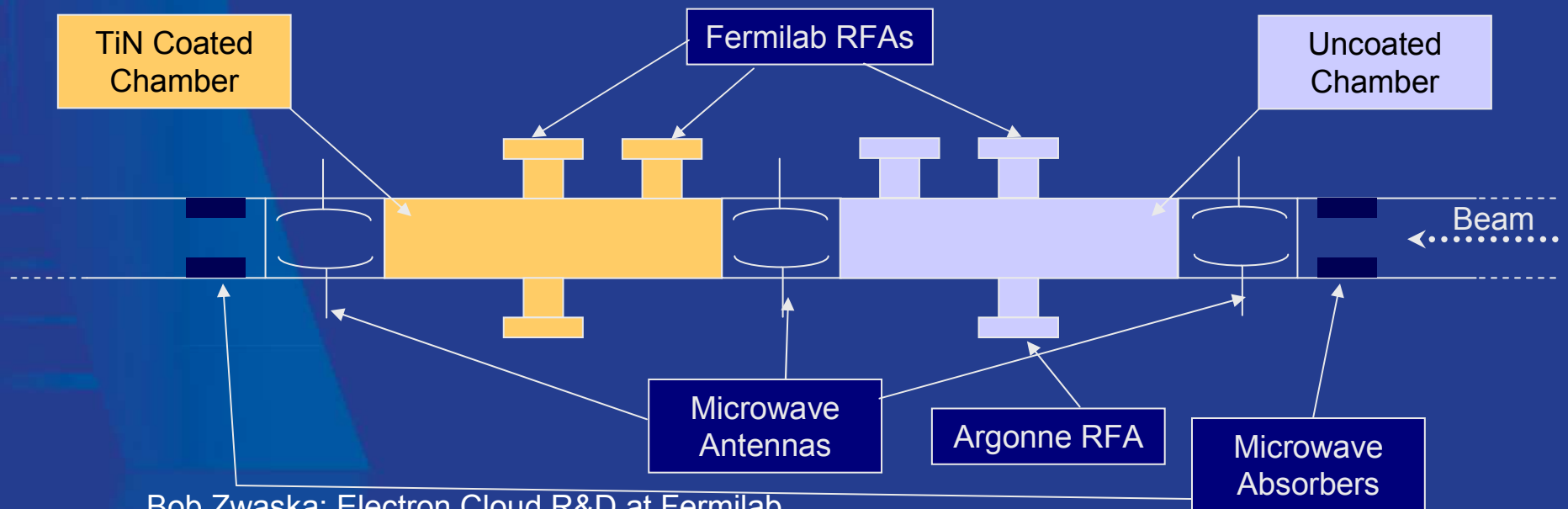‡ Fermilab

Project X Plan

- Expect to have to mitigate ECloud
  - < 10% of the machine is open drift space
    - Solenoids don't provide much help
  - Beam Pipes are captured in magnets
    - Grooves and electrodes not practical
  - Will try to optimize beam properties (frequency/distribution)
- Coating is the most straightforward option
  - TiN is well known, also investigate others

- Project X R&D:
  - Test TiN or other coating in MI
  - Develop process to coat entire MI (and maybe RR)
  - Advance simulations and provide enough experimental cross-checking that we can extrapolate TiN's properties to Project X beam currents

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Electron Cloud Experimental Upgrade - 2009

Major upgrade just finished installation, this summer

- 2 New experimental Chambers
  - Identical 1 m SS sections, except that one is coated with TiN
- 4 RFAs (3 Fermilab & 1 Argonne)
- 3 microwave antennas and 2 absorbers
  - Measure ECloud density by phase delay of microwaves

- Primary Goal: validate TiN as a potential solution for Project X
- Secondary Goals:
  - Remeausure threshold and conditioning
  - Further investigate energy-dependence
  - Measure energy spectrum of electrons
  - Test new instrumentation
  - Directly compare RFA and Microwave
  - Measure spatial extinction of ECloud

TiN Coated Chamber

Fermilab RFAs

Uncoated Chamber

Beam

Microwave Antennas

Argonne RFA

Microwave Absorbers

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New Detectors

- New RFAs evolved from Argonne style
- Maximize signal with enlarged area and by removing ground grid
  - Ground is provided by the beam pipe
- Shaping of electrodes optimizes energy filter performance
  - Also, more hermetic
- Amplifier/filter in tunnel
 - Better-quality cables to surface

Detector Simulation
CY Tan, L McCuller

- Electrode layout optimized with SimIon simulation
- Track electrons through a detailed grid
- Summer student added secondary emission functionality
  - Still being validated, but looks promising

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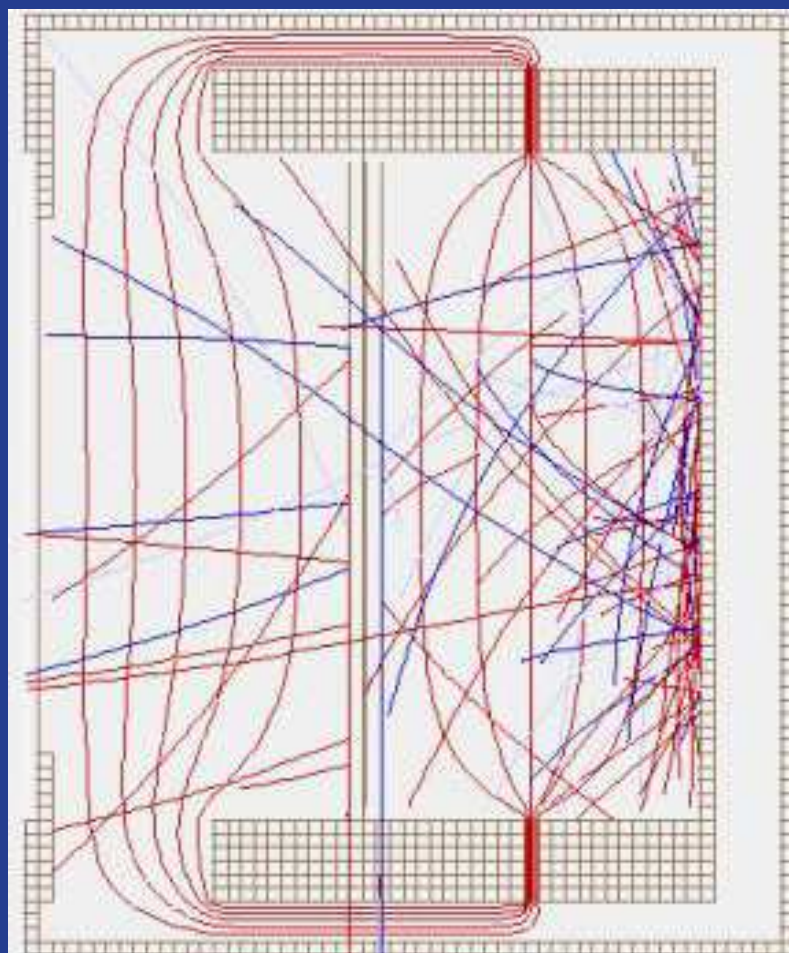
Test Stand

- Test new detectors with electron gun

- Demonstrated that the detectors work as expected

- Will allow further exploration of detector effects
  - Secondary emission
  - Magnetic Field
  - Detailed calibration

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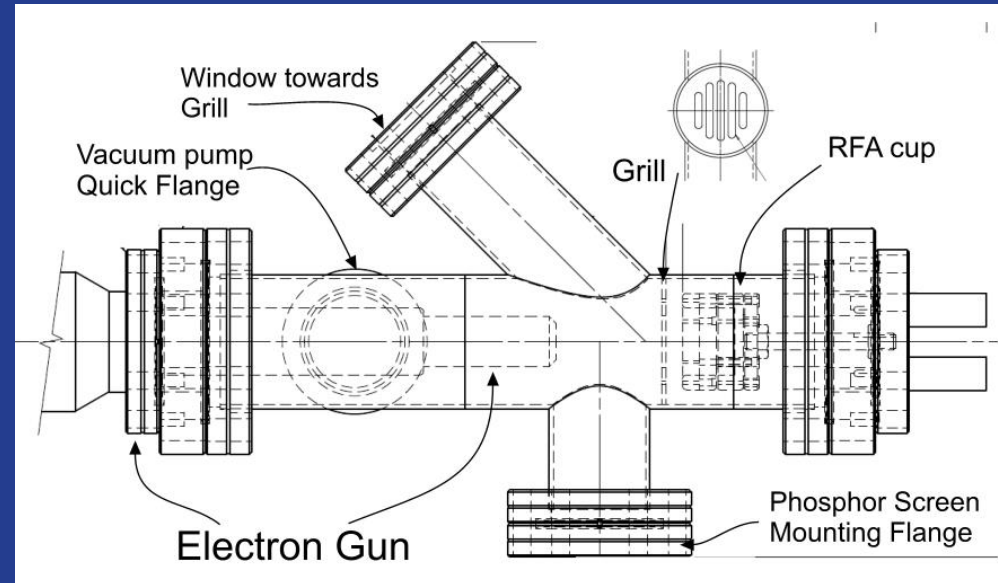
TiN Coating

Linda Valerio

- Coating of test chambers performed at BNL

- Will need to adapt this procedure for *in situ* coating of 3000 m of Main Injector

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Status of New Installation

- Main Injector beam started 2 weeks ago
  - Intensity has been gradually rising (near maximum now)

- All apparatus have been exercised
  - Starting to understand data

- Initials RFA signals very strong and thresholds low
  - Rapid scrubbing ensued
  - Electron energy scans difficult due to ramping nature

- Microwave data taken, but requires understanding
  - Very short paths (1 m)
  - Cavity behavior? - absorbers were too mitigate
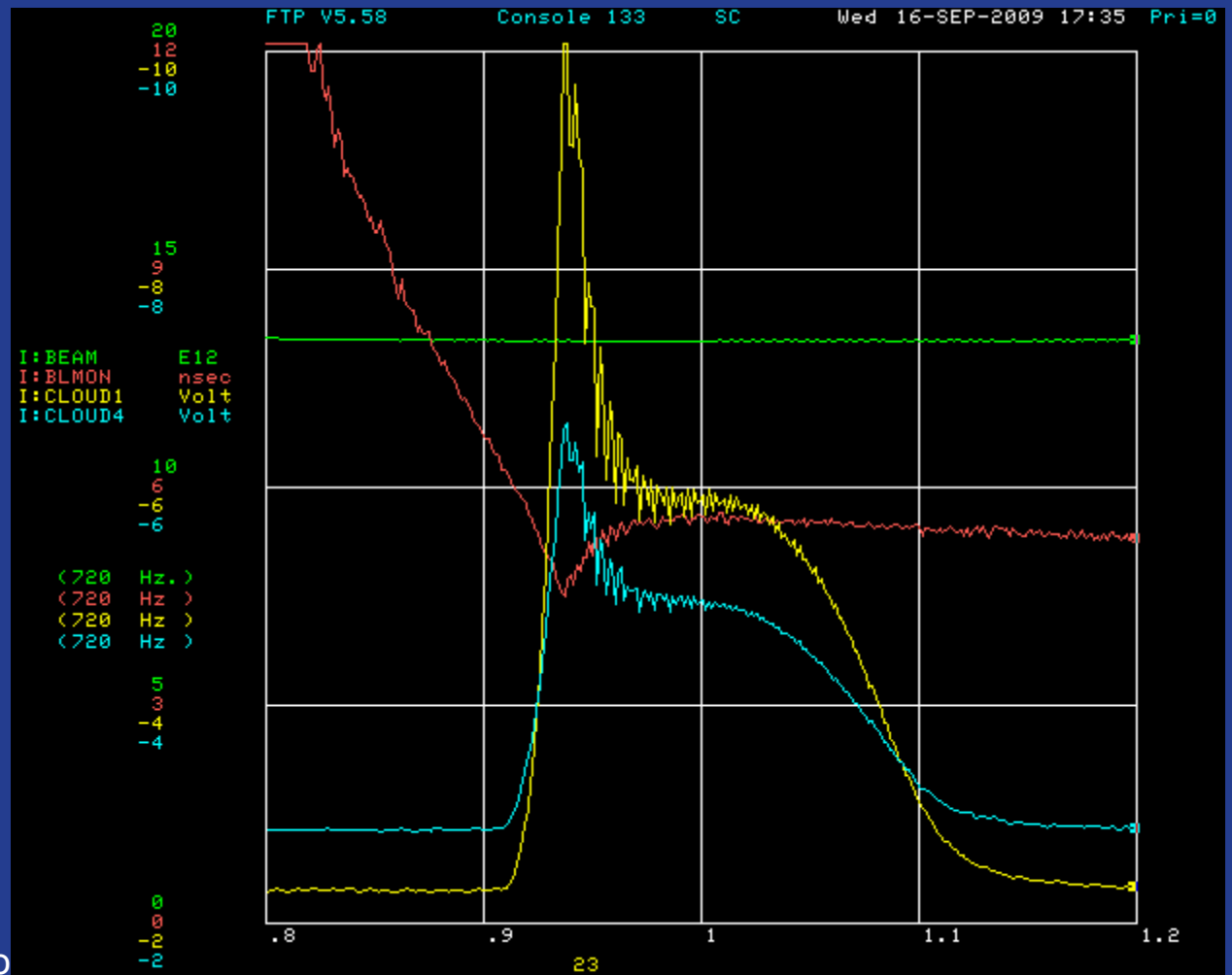 - May show qualitative agreement with RFAs

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Preliminary Data - 9/16/09: 12e12 on 6-batch

- Uncoated (FNAL): 280 nA
- Uncoated (ANL): 110 nA
- Coated (5"): 25 nA
- Coated (mid): 15 nA

- FNAL/ANL ≈ 2.5
- Uncoated/Coated ≈ 18
- Longitudinal Penetration Distance ≈ 4 cm (e-folding)
- Temporal structures are mostly similar, and similar to what was seen before

MI Cycle

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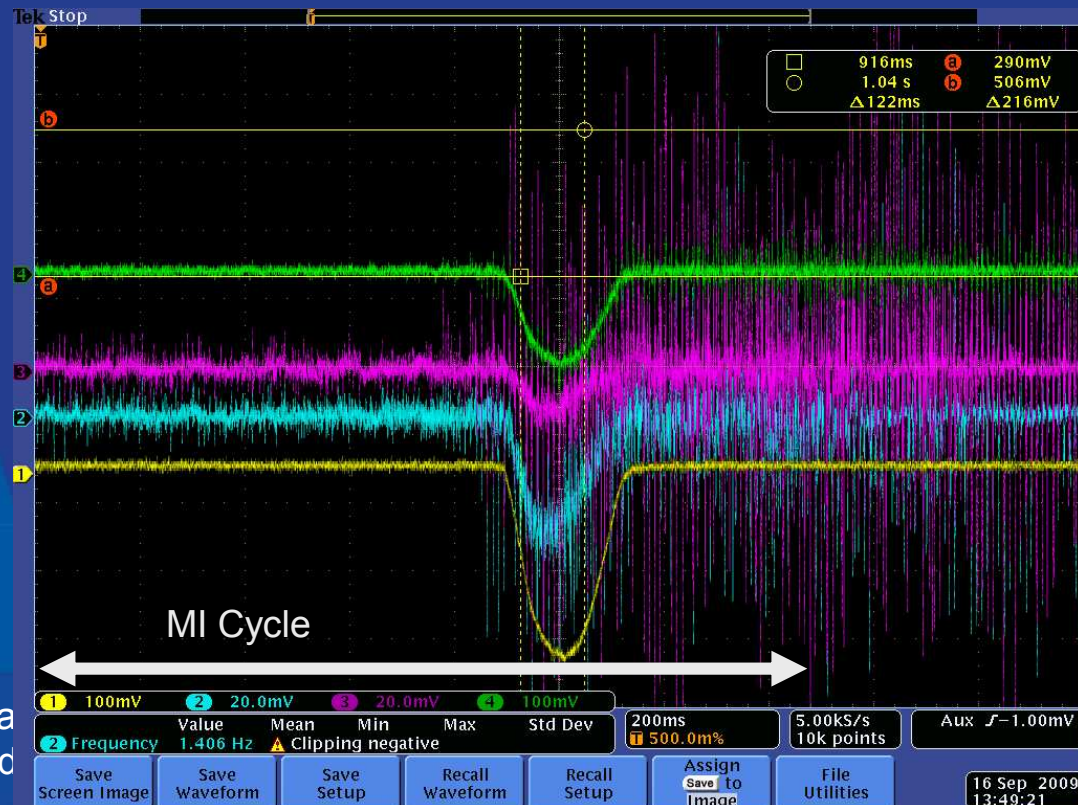
Preliminary Data - 9/16/09: 13e12 on 11-batch

- Biased at 120 V

- Red line shows bunch length

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Preliminary Data - 9/18/09: 26e12 on 11-batch

- Time duration is much larger
  - Extends to end of cycle
- Max current: 1.8 uA
- Uncoated/coated

  is ~ 2 in peak
  - Greater in tails
  - Both in deep saturation

    at max
 - Differential scrubbing
- BPM shows skew

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Preliminary Data - Early Conditioning Summary

Rough Thresholds – more precise numbers when data fully analyzed

Date	Uncoated	Coated
9/16	10	13
9/17	12	15
9/18	18	19
9/19	22	26
9/20	27	28
9/21	29	30
9/22	29	30
9/23	32	32
9/24	32	33
9/25	32	>33
9/26	33	>33
9/27	33	>34
9/28	34	>34
9/29	34	>34
9/30	35	>35

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Preliminary Data – ECloud Energy Spectrum

- Energy spectra created by collecting many individual pulses and differentiating
  - For now, sample size is small
- At the mercy of pulse-to-pulse variation
  - Intensity variation
  - Bunch length variation
- Initial data appears consistent with POSINST simulation
  - Bulk of electrons around 40 eV for 6e10 per bunch

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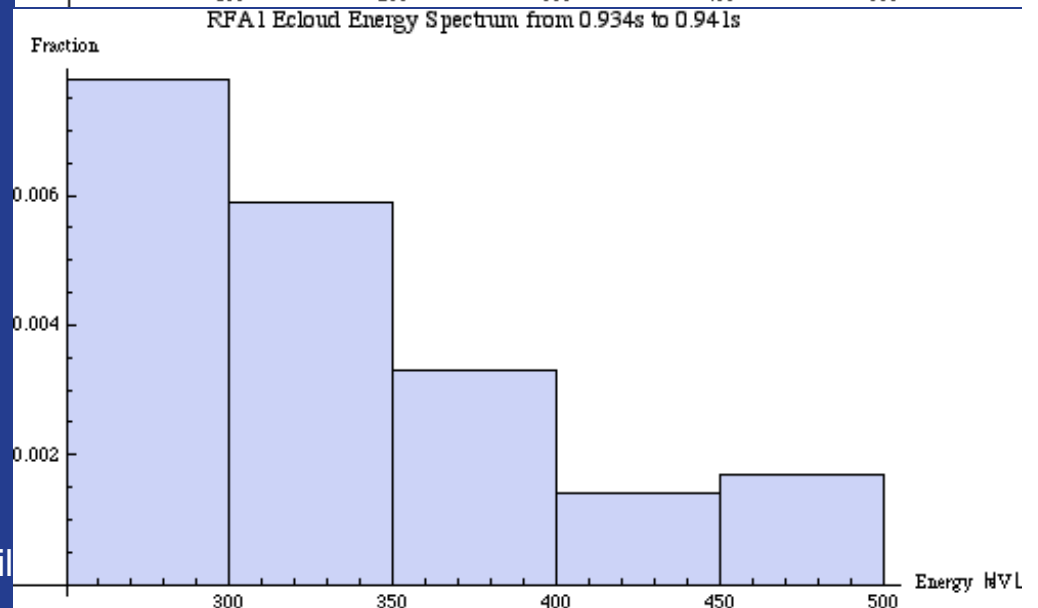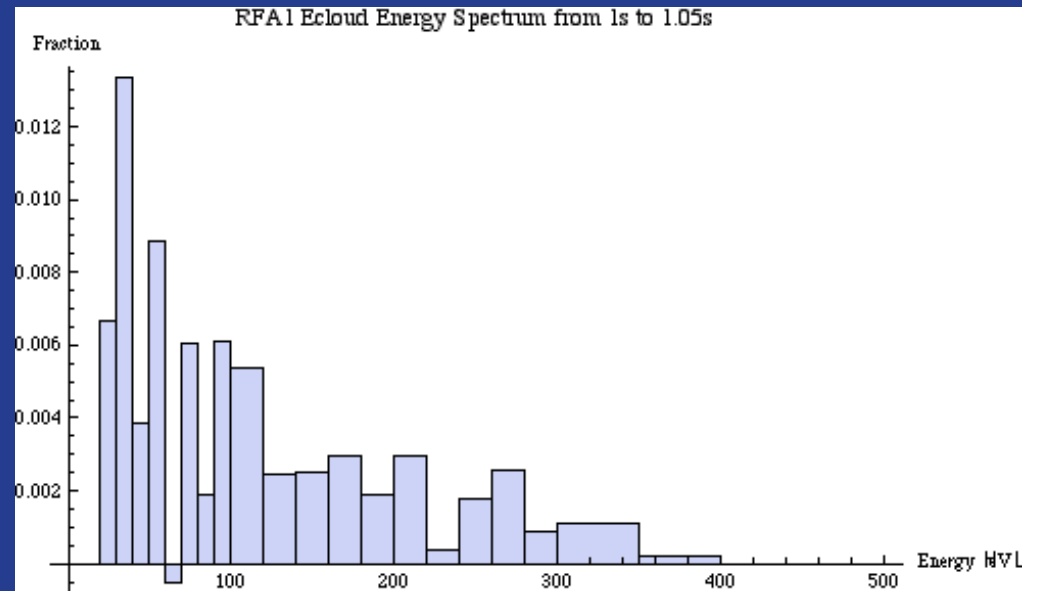
Synergia Simulation

Paul Lebrun

- Have a working electron code simulation
  - Concentrating on simulating microwave measurements
- Linear approximations (Sonnad and others) verified in low-intensity regime
- Larger (more realistic) intensities and microwave amplitudes have more complicated effects
  - Paul feels strongly that AM may be contaminating PM signals (ruins normalization)
 - Looking for resonance effects (ECR and lower frequencies)

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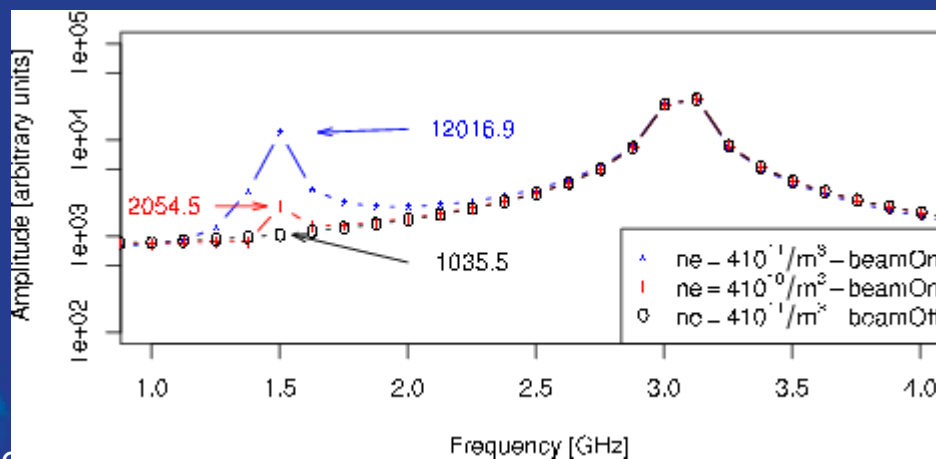
ORBIT Simulations
Leonid Vorobiev

- Adopting ORBIT simulations to MI case
  - Multibunch is crucial feature in MI beam – not working well with ORBIT model
  - Electron cloud module already rewritten for shorter bunches, but need more for multiple bunches and beam feedback

- Considering integrating other codes

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Future Plans

- Chief experiment is comparing the conditioning histories for TiN and SS pipes
  - Pushing maximal intensity is also crucial

- Extrapolation to PrX intensity requires a number of hooks
  - Plan to install ECLOUD1 (SLAC) when Cornell is finished with it
  - Perhaps ECLOUD3 as well

- Simulation goal is a full ECloud simulation that can also simulate multiple-bunch instabilities
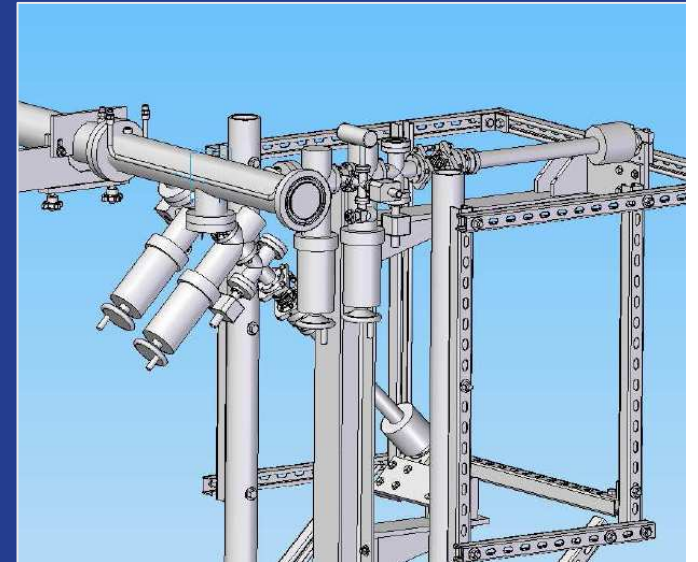
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Summary

- Proton upgrades at Fermilab are our chief focus
- Major upgrade of the ECloud experimental area in the Main Injector is complete
  - Instrumentation works – collecting a lot of data
  - Initial data looks qualitatively similar to previous measurements
- TiN shows a clear suppressive effect
  - But, it needs conditioning too, and conditions more slowly
- New data will allow further cross-checks to simulation
- Planning further upgrades to installation
  - Considering the ECLOUD1 & ECLOUD3 stands from SLAC
- Need to combine simulation with experiment to be confident in solutions for Project X

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