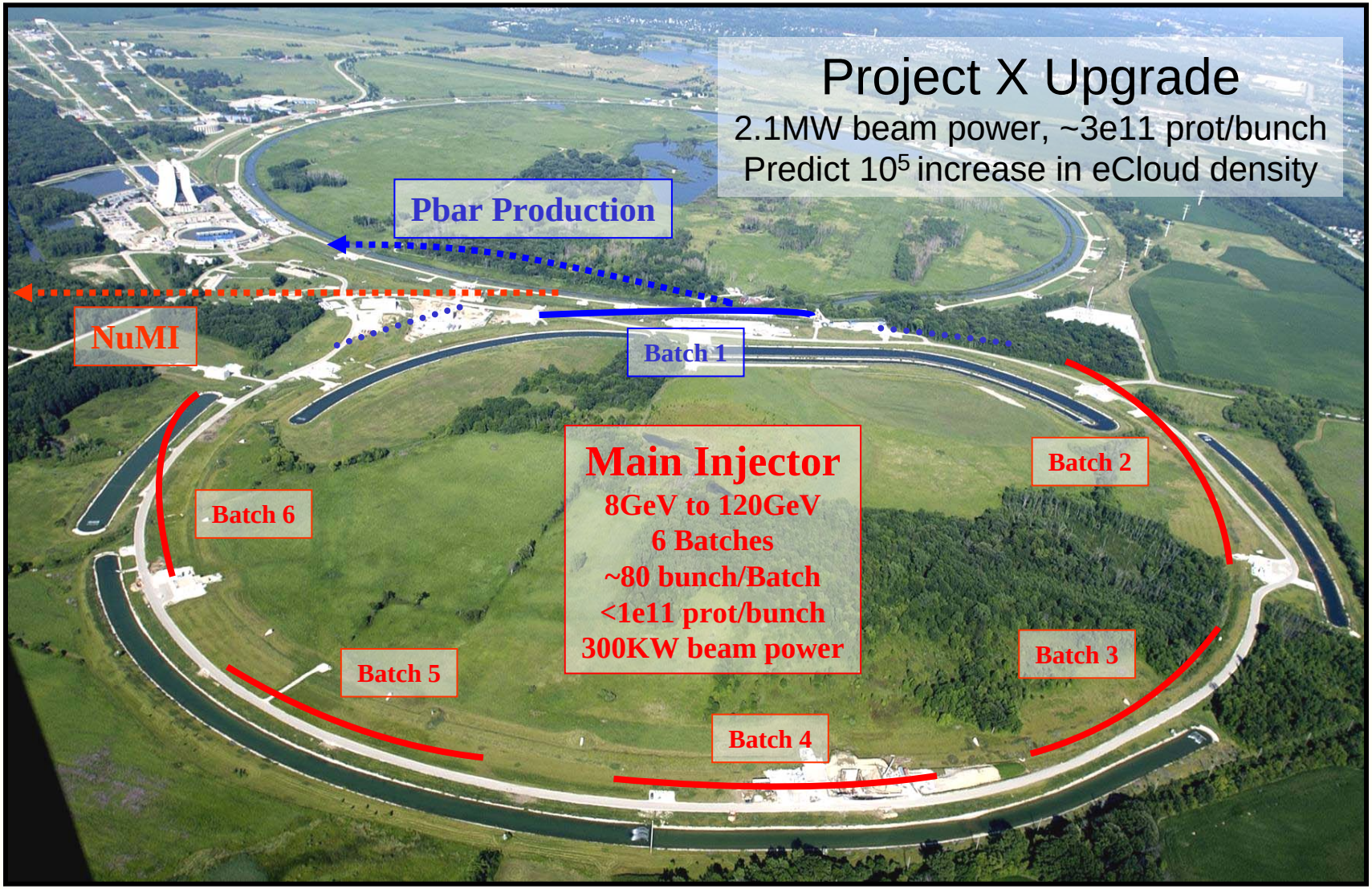
# Measurement of eCloud Development in the Fermilab MI using Microwave Transmission

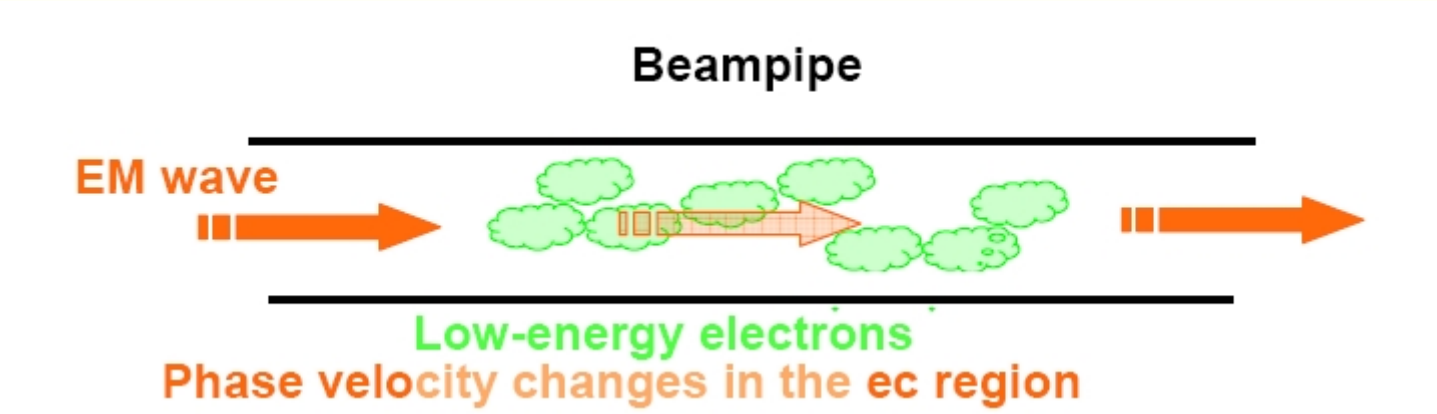
**Nathan Eddy, Jim Crisp, Ioanis Kourbanis, Kiyomi Seiya, Bob Zwaska, *FNAL***

**Stefano De Santis, *LBNL***

# Fermilab Main Injector



# Microwave Transmission

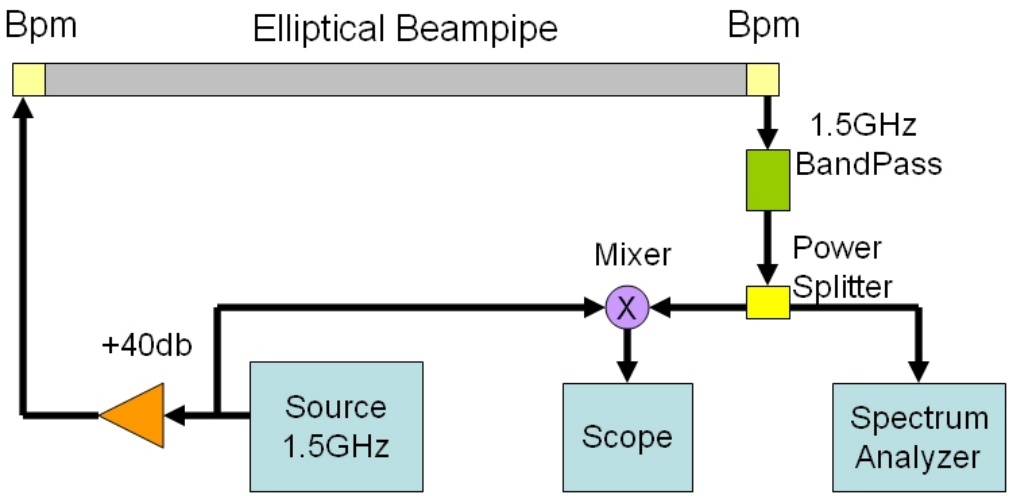


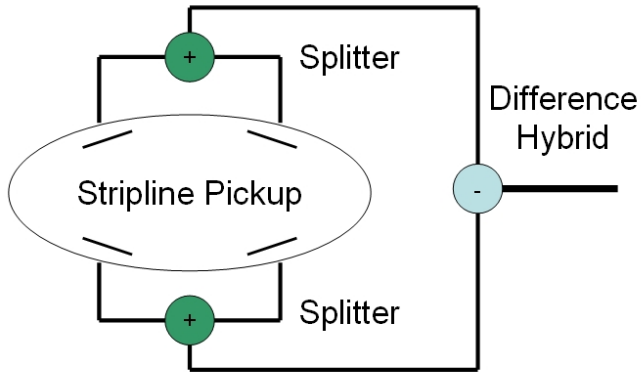

From plasma physics, expect a microwave travelling down a waveguide to experience a phase shift due to a homogeneous plasma
From the microwave dispersion relation

$$k^2 = \frac{\omega^2 - \omega_c^2 - \omega_p^2}{c^2} \quad \Rightarrow \quad \frac{\Delta\phi}{l} = \frac{\omega_p^2}{2c\sqrt{\omega^2 - \omega_c^2}}$$

For an electron cloud $\omega_p^2 = 4\pi\rho_e r_e c^2$ is proportional to *e* density

# Measurement Setup



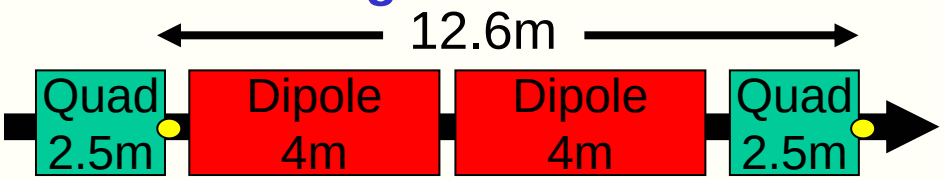

- **Made three different measurements of the phase shift**
  - **Measure sideband spectrum of 1.5GHz carrier with SA, for Phase Modulation**

$$e(t) \approx A\left[\cos\omega_c t + \frac{\beta}{2}\cos\left((\omega_c+\omega_m)t+\phi_m\right) - \frac{\beta}{2}\cos\left((\omega_c-\omega_m)t-\phi_m\right)\right]$$

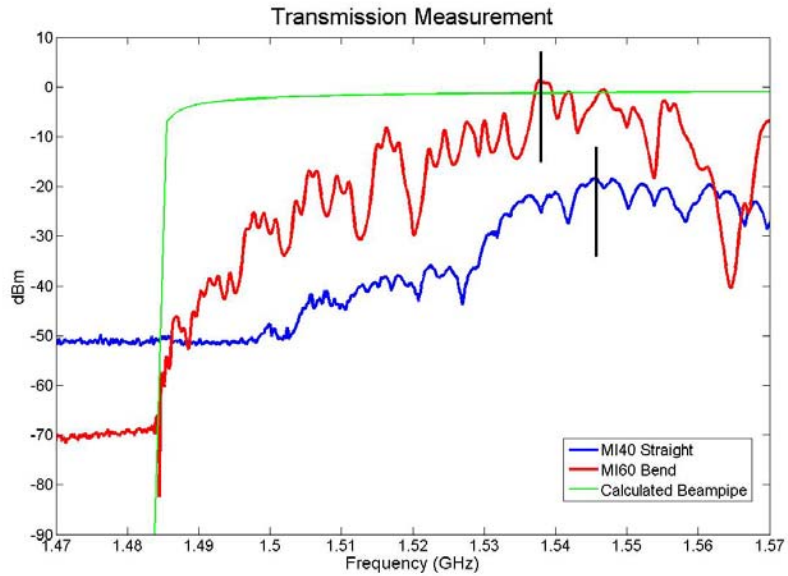
  - **Where $\beta$ is the phase modulation amplitude, sideband dbc = 20log($\beta$ /2)**
  - **Measure 1st sideband over a full MI ramp (800ms) in zero span mode with SA**
  - **Mix down to baseband and record IF with deep memory scope (10MHz BW)**
- **Pickup connections to optimize coupling to $TE_{11}$ mode**
  - **Measure -20db transmission for two pickups and 15m of beam pipe**
  - **Cutoff for beam pipe is just below 1.5GHz**

# Measurement Locations

## MI60 Bend Region

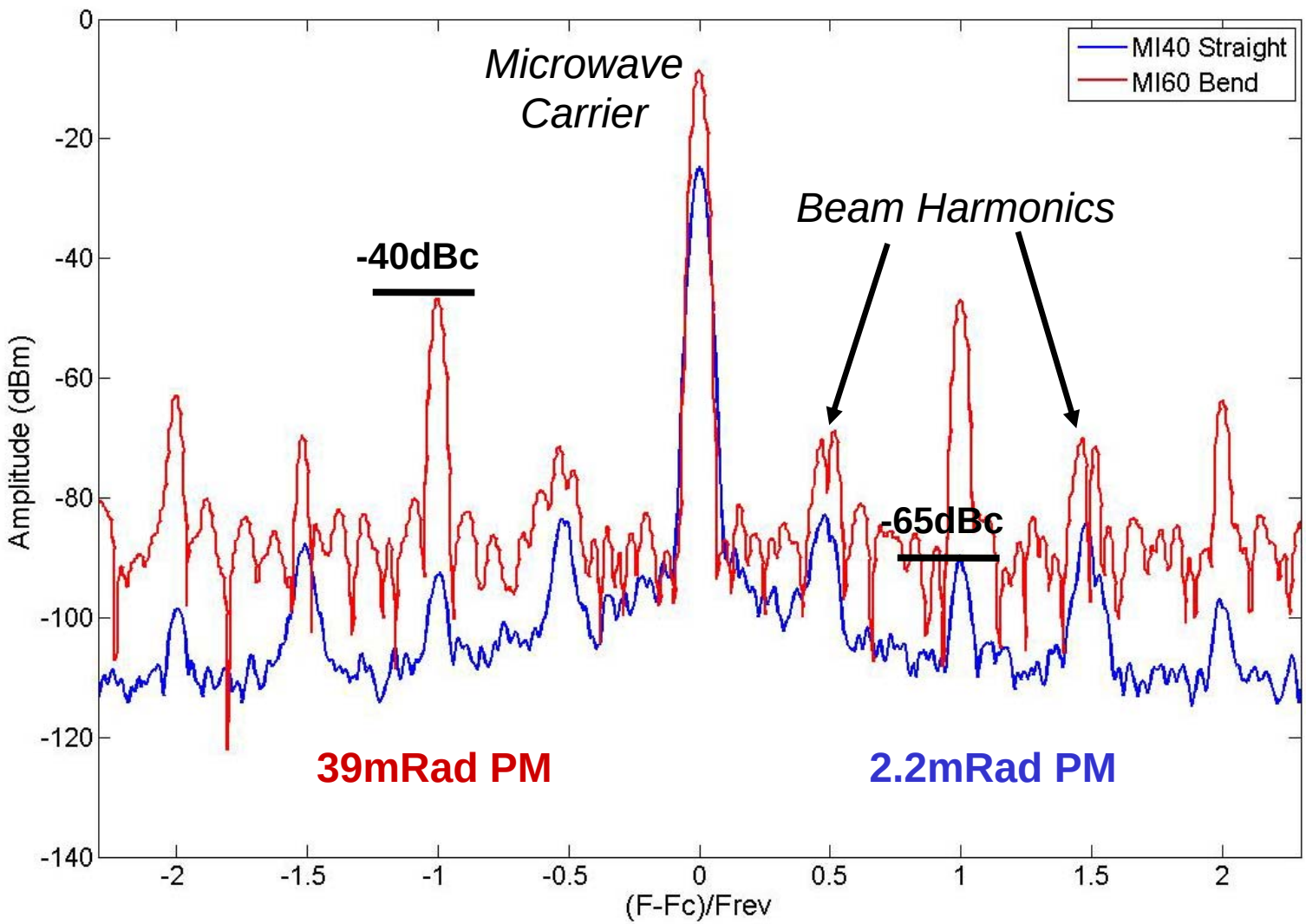



## MI40 Straight Region

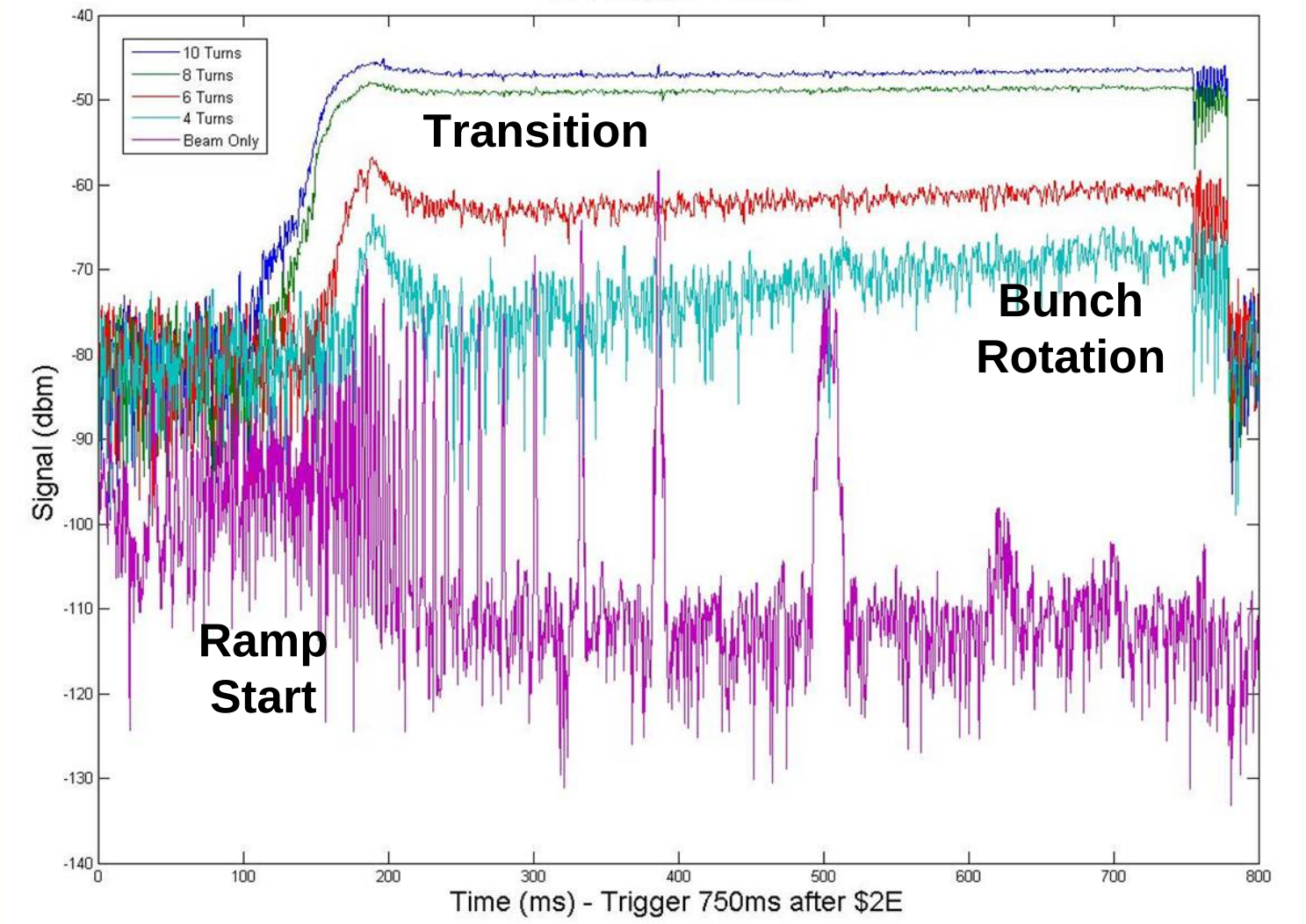

- **Necessary to access MI Tunnel to reconfigure bpms**
  - **Bpms no longer available for operation**
  - **Can be months between MI access opportunities**
  - **Severely limits which bpms are available**
- **At MI60 Bend Region able to use spare Heliax cable**
- **At MI40 Straight Region have to use RG8 bpm cable**
  - **See an addition 20db of attenuation on transmitted signal**
  - **Appear to get coupling between the cables**
  - **Put the 40db drive amplifier in the tunnel at this location**

# Sideband Spectrum



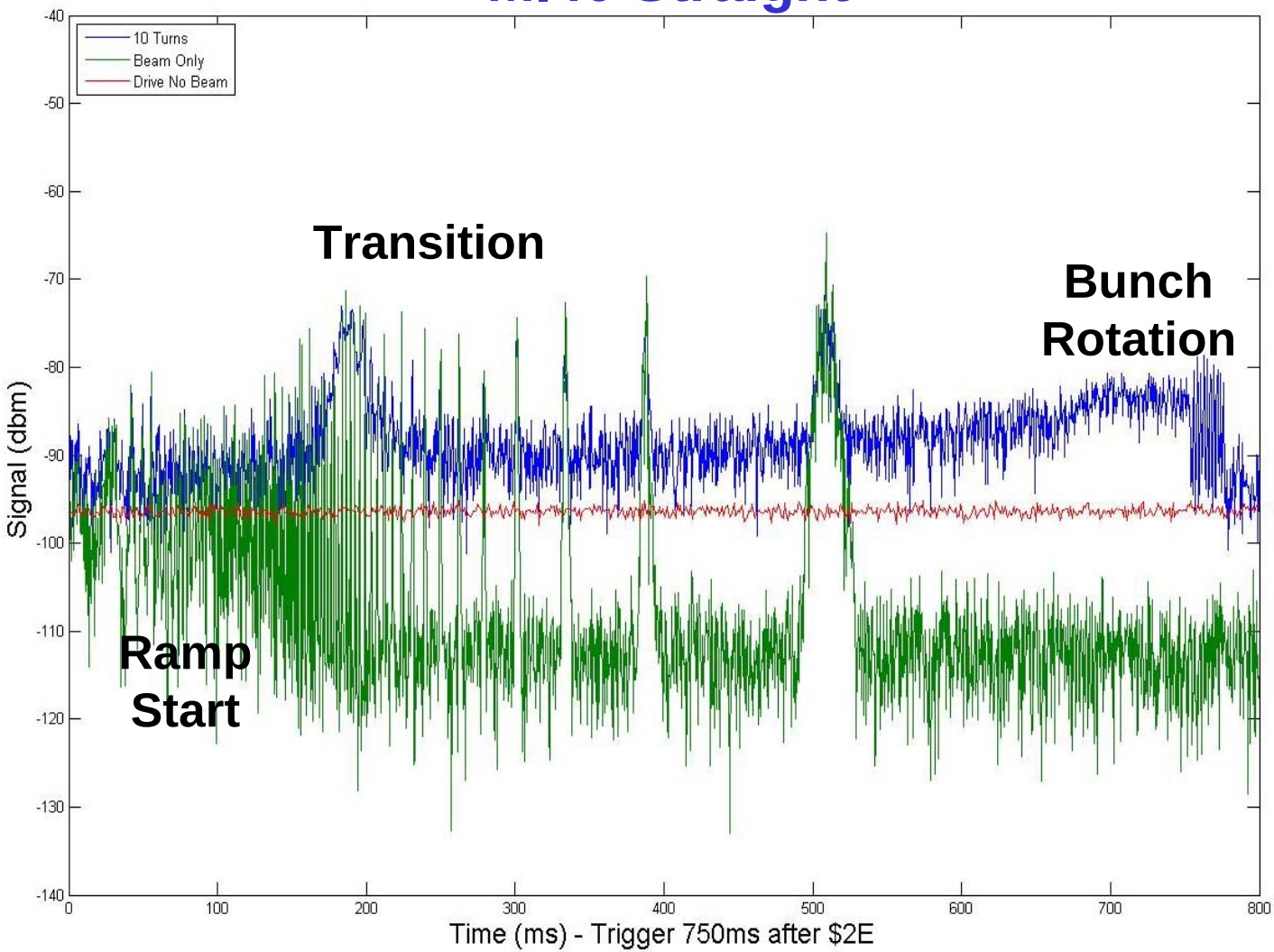
# Zero Span Sideband

## MI60 Bend

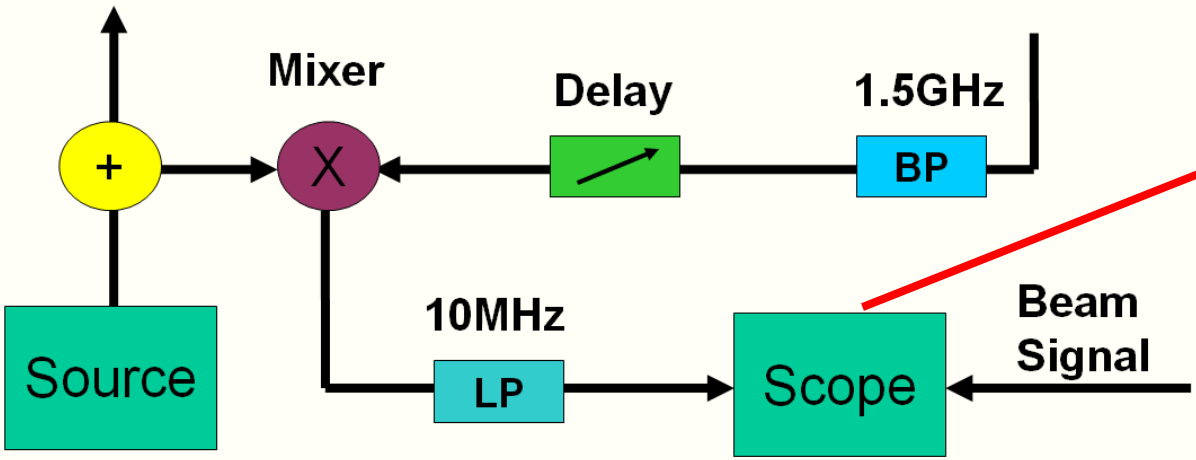


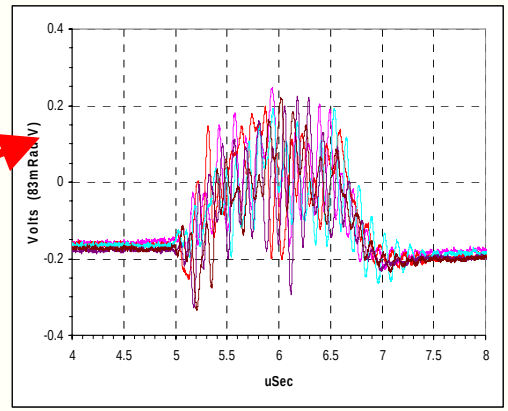
# Zero Span Sideband

## MI40 Straight



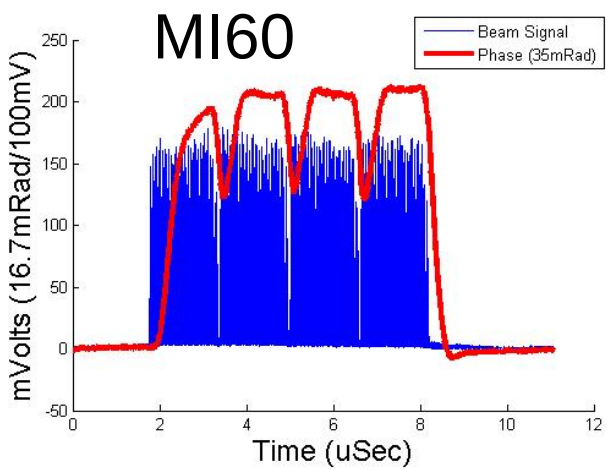
# Direct Phase Shift Technique

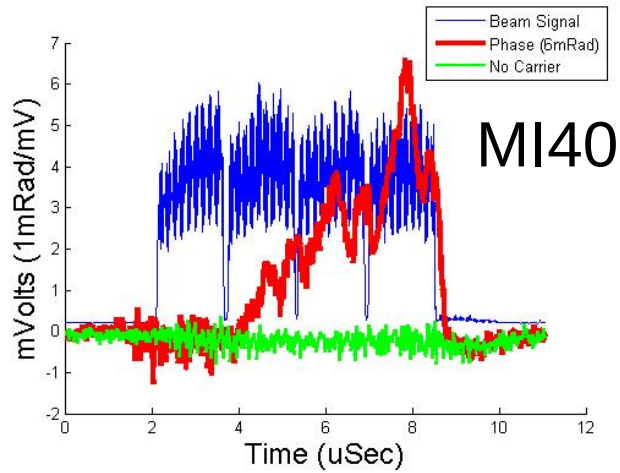


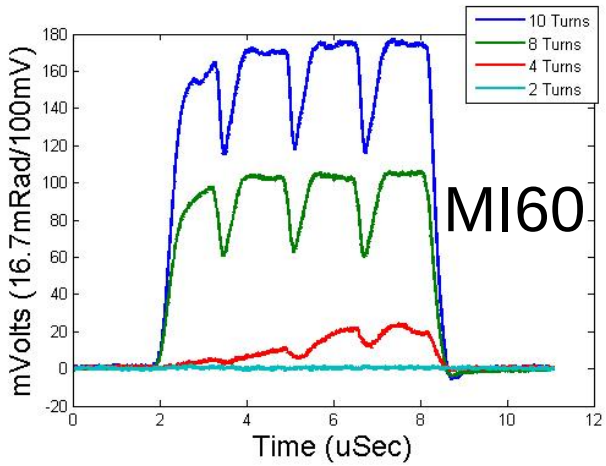



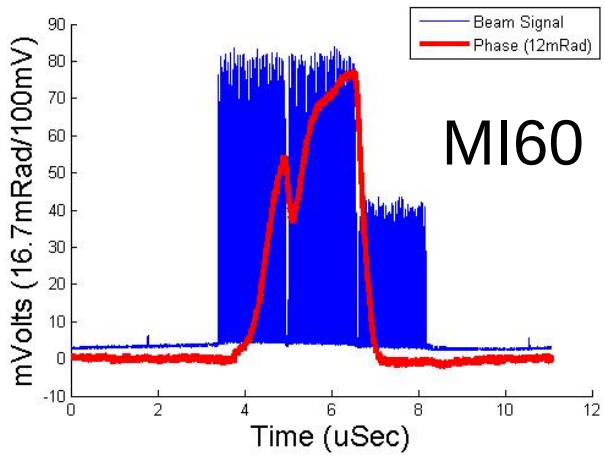

- **Mix the transmitted microwave signal to baseband**
  - **Use the delay to effect 90° phase shift (zero DC offset)**
  - **Theoritically, should only see PM modulation as AM cancels**
- **Scope aquires from 2ms to 20ms sampling at either 500MS/s or 100MS/s respectively**
  - **Expect eCloud induced phase shift to be the same each turn**
  - **The beam harmonics behave as noise which averages away**
    - **Use 100 turn average at MI60 and 1700 turns at MI40**
  - **Size of the beam harmonics impacts the dynamic range**

# Direct Phase Shift Results



# Summary and Plans

- To calculate the eCloud density is difficult
  - Non-homogeneous plasma, magnetic fields, possible reflections
  - Efforts underway to simulate the microwave transmission
  - See TH5PFP019 and FR5PFP089
- Right now, have very interesting measurements of microwave phase shifts under a variety of beam intensities
  - Strong evidence that these are eCloud induced
  - Use demodulation to uniquely identify PM and AM
- The end goal is to see good agreement between measurements and simulation for current MI intensities
  - Must rely upon simulation to predict what measures are needed to mitigate the eCloud for Project X
  - The direct phase shift in the time domain can be directly compared with the simulation of a single machine turn
  - See TH5PFP032
- During the upcoming summer shutdown, a dedicated system will be installed
  - 2 pickups in dipole bend, 3 pickups in ~2m straight where two 1m coated beam pipes are being installed along with absorbers
  - Facilitate ease of measurements
  - Implement dedicated digital receiver – measure only PM, improve S/N