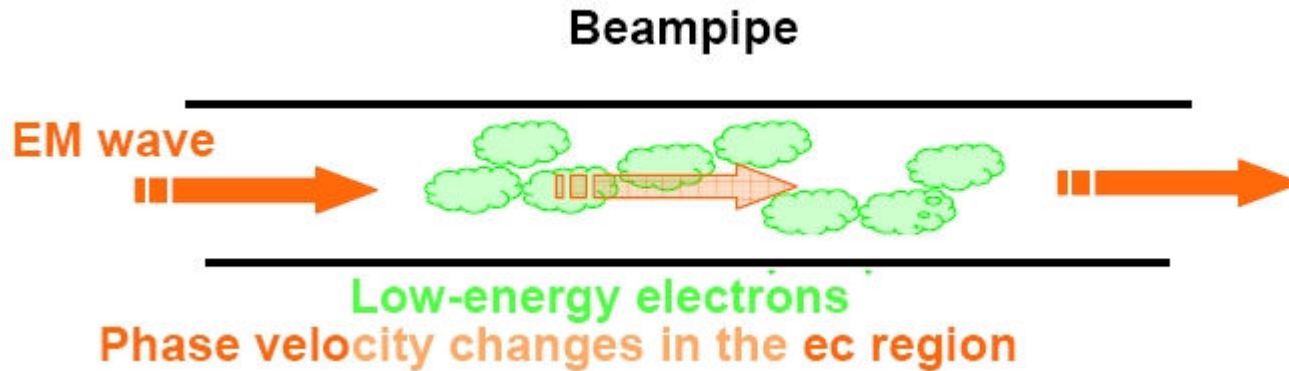

TE-Mode Microwave e-Cloud Measurements in the Fermilab Main Injector

Jim Crisp

Nathan Eddy

Manfred Wendt

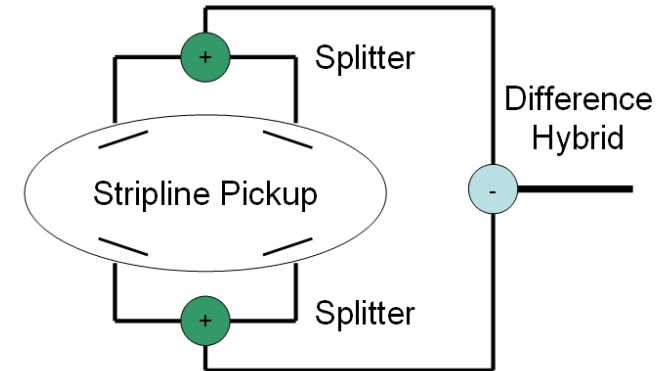
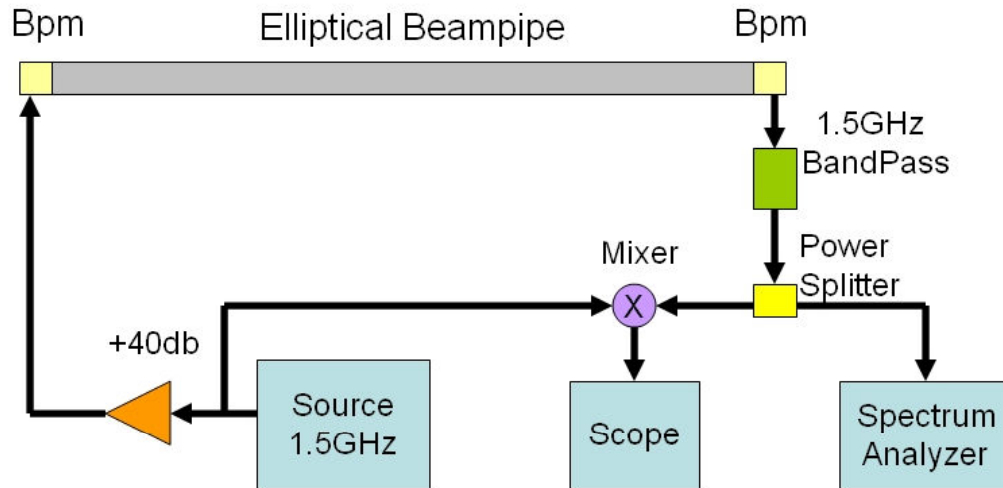
October 1, 2009



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

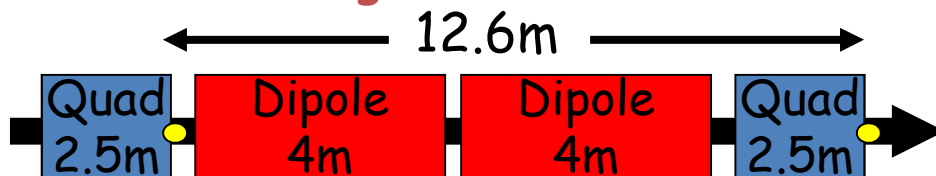
$$k^2 = \frac{\omega^2 - \omega_c^2 - \omega_p^2}{c^2} \quad \Rightarrow \quad \frac{\Delta\phi}{l} = \frac{\omega_p^2}{2c\sqrt{\omega^2 - \omega_c^2}}$$

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

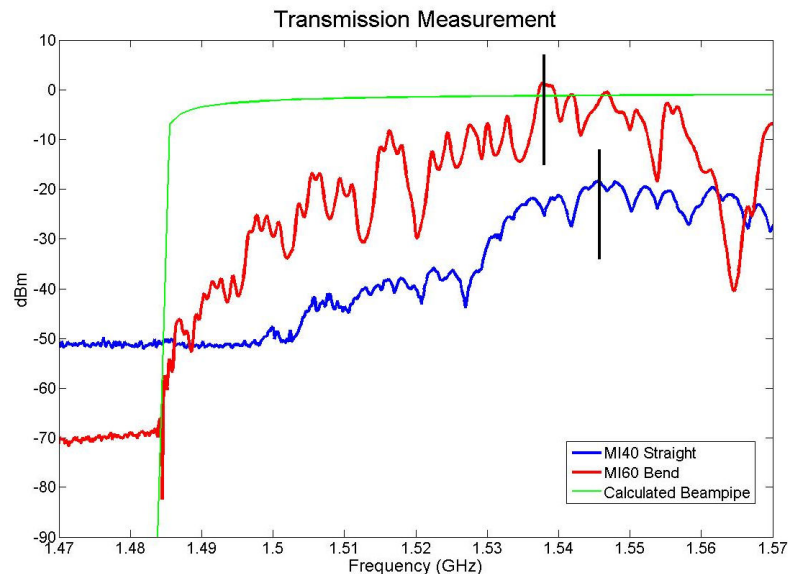
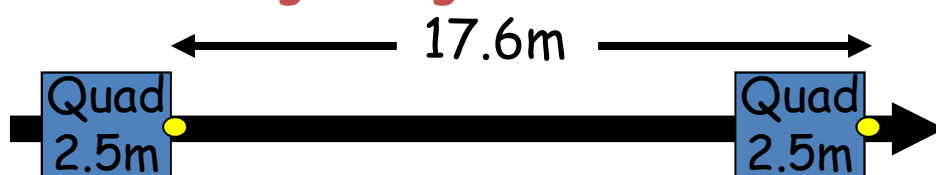


- Made three different measurements of the phase shift
 - Measure sideband spectrum of 1.5GHz carrier with SA
For phase modulation of amplitude β , sideband dbc = $20\log(\beta/2)$
 - Measure 1st sideband over a full MI ramp (800ms) in zero span mode with SA
 - Mix down to baseband and record IF with 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

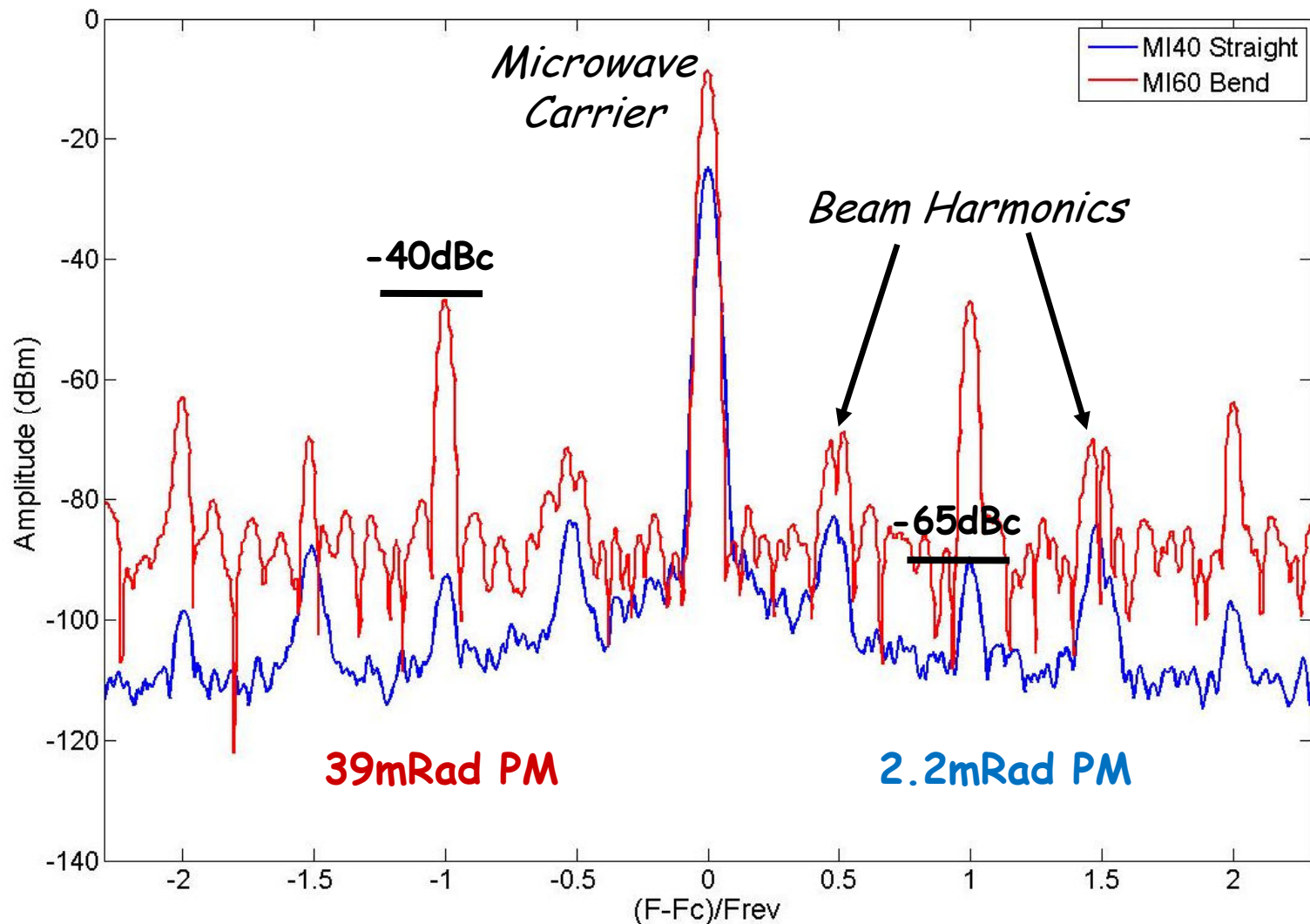
MI60 Bend Region

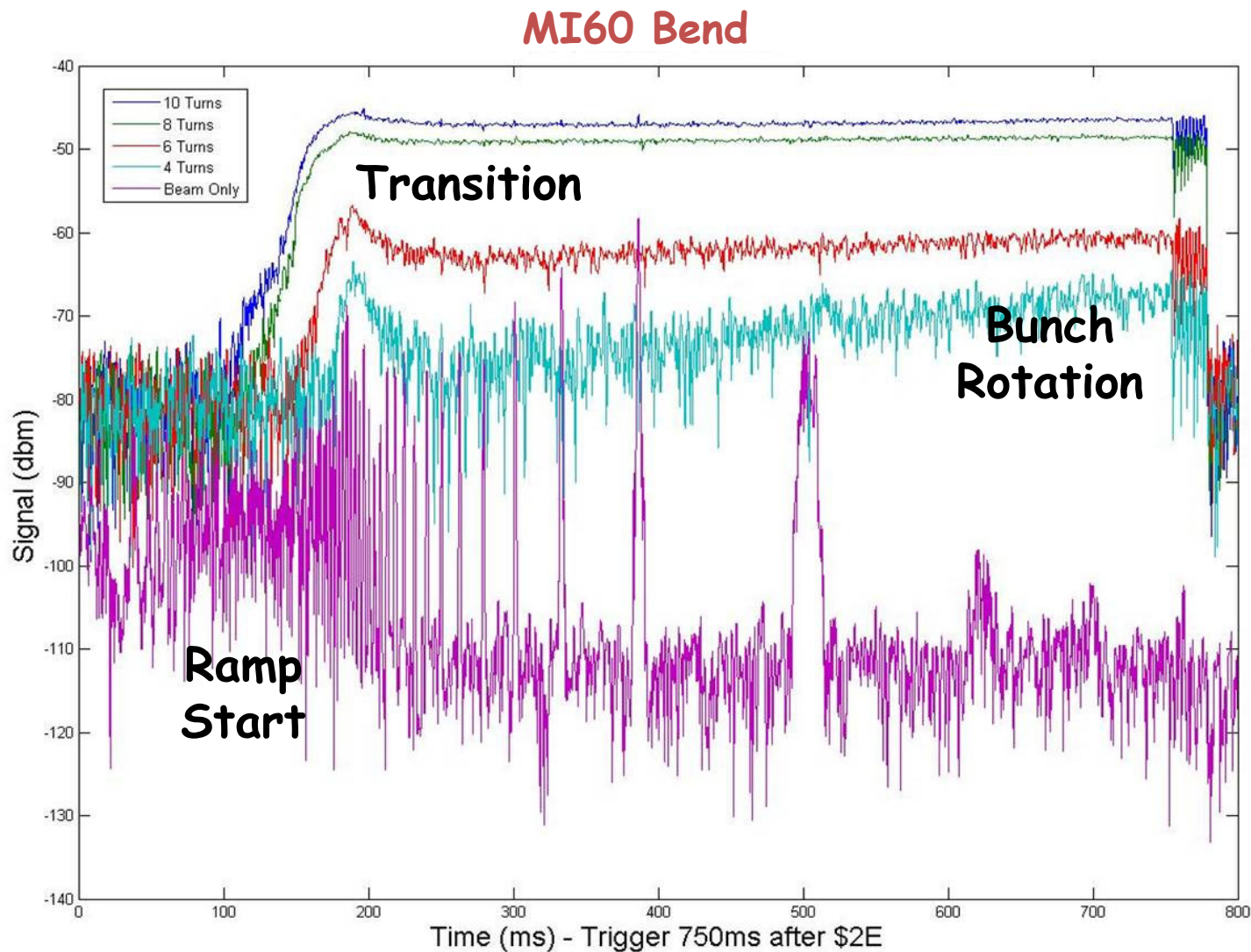


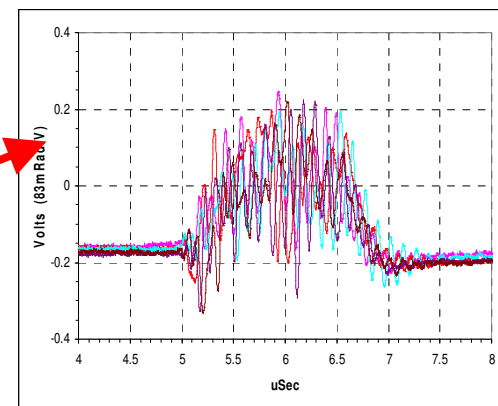
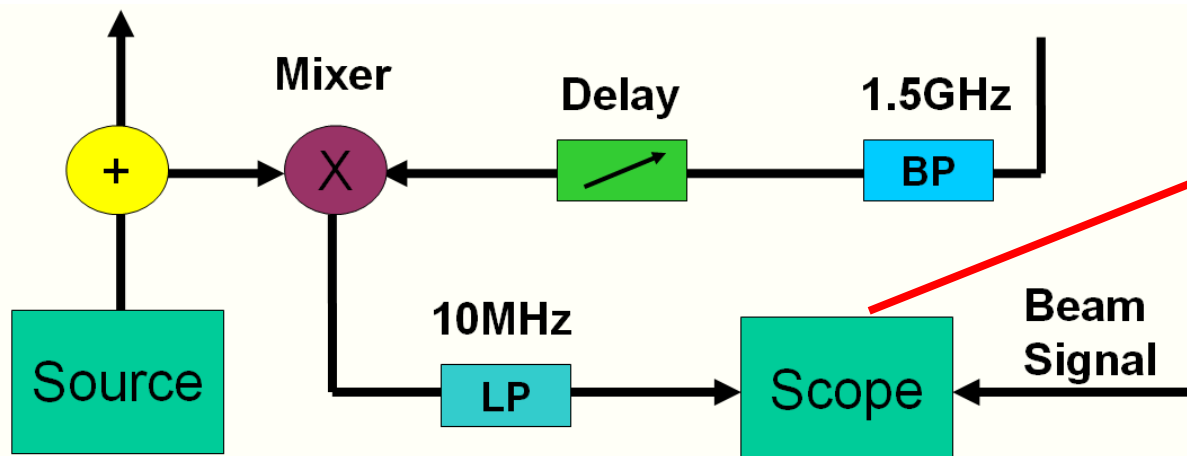
MI40 Straight Region



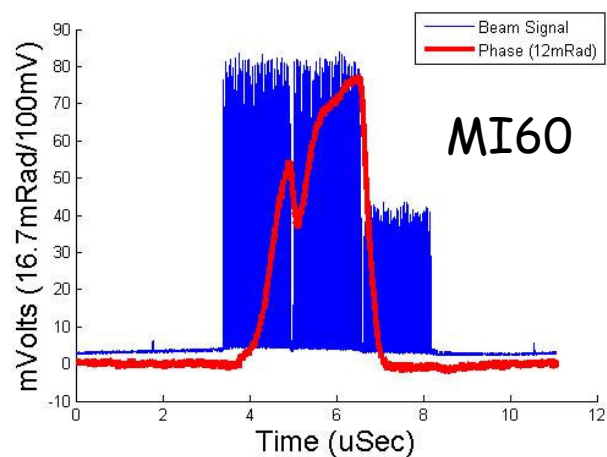
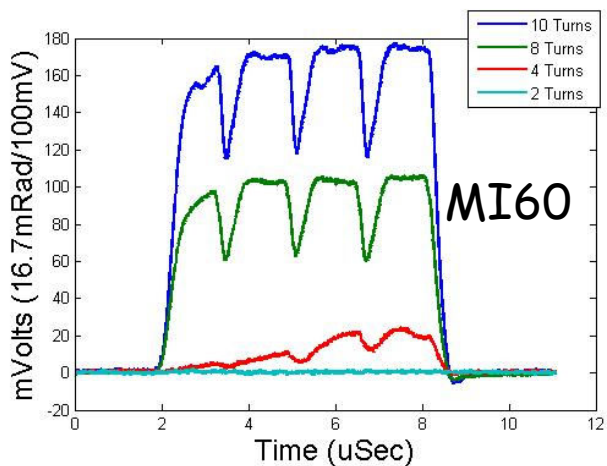
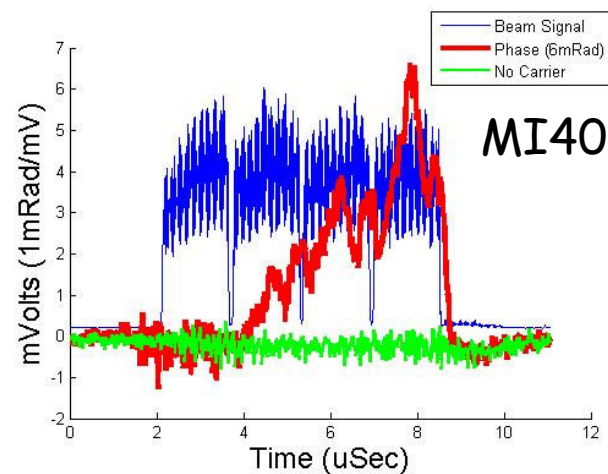
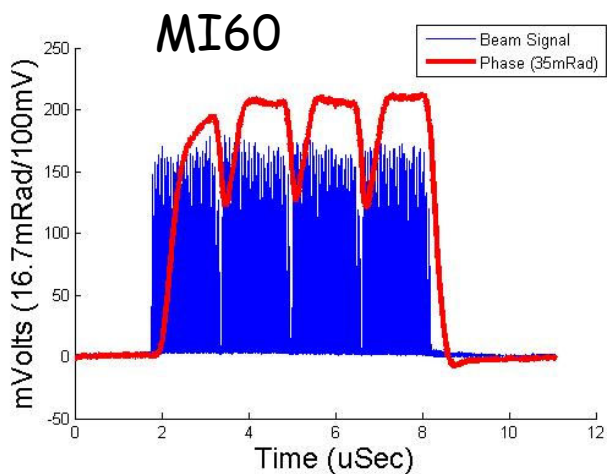
- At MI60 Bend Region able to use spare Heliax cable
- At MI40 Straight Region have to use RG8 bpm cable
 - See an addition 20db of attenuation on transmitted signal
 - Appear to get coupling between the cables
 - Put the 40db drive amplifier in the tunnel at this location



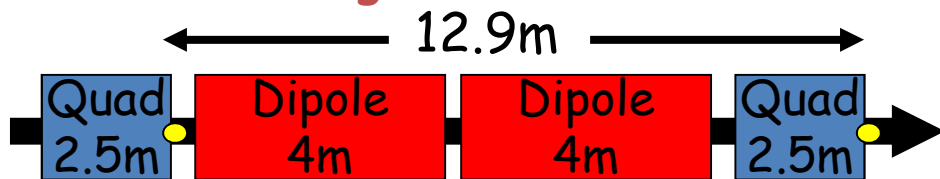




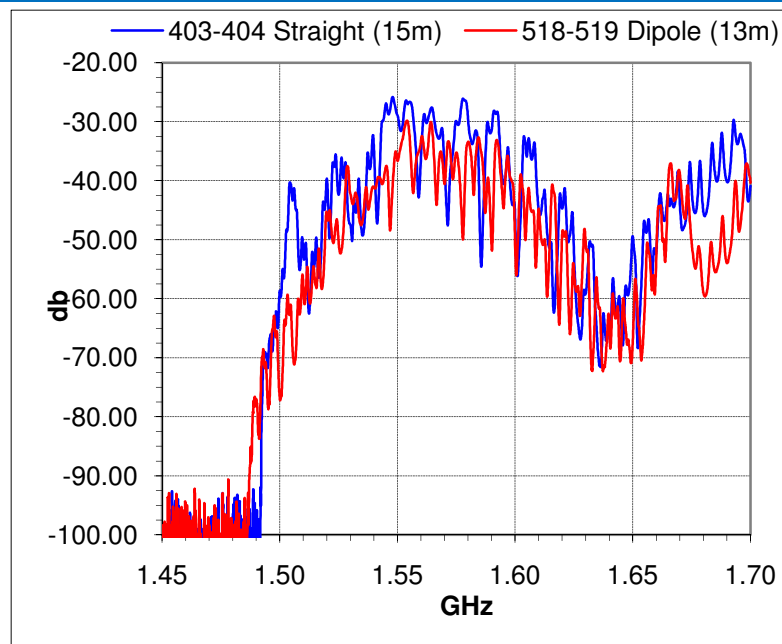
- Mix the transmitted microwave signal to baseband
 - Use the delay to effect 90° phase shift (zero DC offset)
 - Theoretically, should only see PM modulation as AM cancels
- Scope acquires from 2ms to 20ms sampling at either 500MS/s or 100MS/s respectively
 - Expect eCloud induced phase shift to be 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



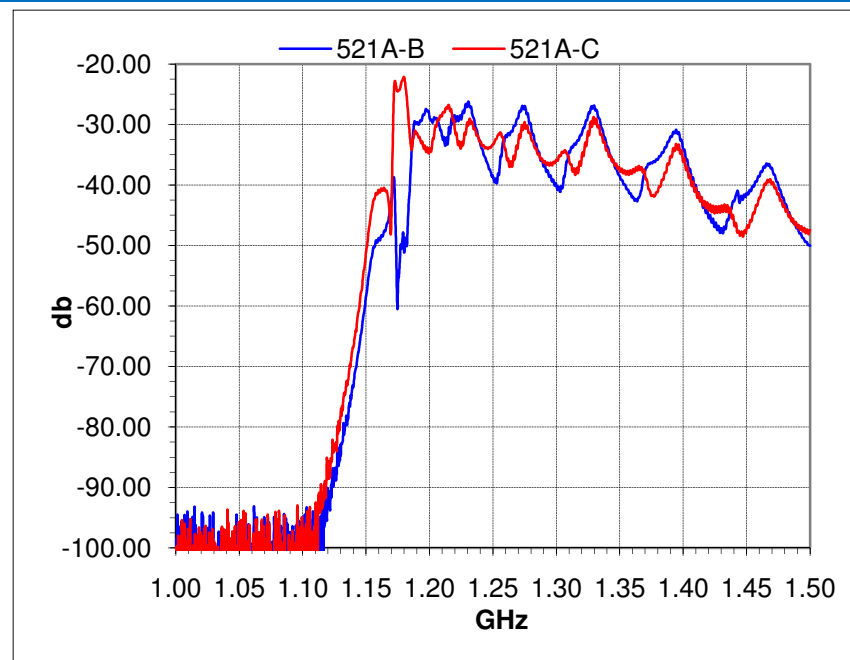
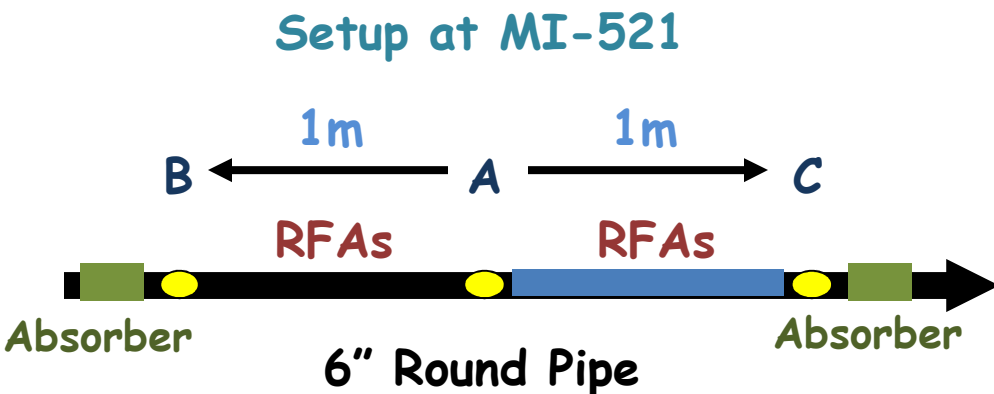
MI52 Bend Region



MI40 Straight Region



- Dedicated BPMs installed at MI52 Bend and MI40 Straight
 - Standard elliptical beam pipe and pickups
 - Completely field free at MI40 straight
- Good quality heliax cable pulled for each BPM
 - Expect improved sensitivity for MI40 Straight



- Three Large Aperture BPMs have been installed around 1m long test pipes at MI-521
 - Cutoff for the 6" round pipe is just below 1.2GHz
 - As measured phase shift is proportional to length → -23db sensitivity
- Will provide direct comparison with RFA
 - Expect to be very useful in understanding $\Delta\phi$ → e density

- Crosscheck Measurements and Sensitivity at New Locations
 - Can now make measurements at each location under similar conditions rather than weeks or months apart
 - Expect stronger signals before conditioning
- Demodulate transmitted signal to separate PM & AM
 - Verify we are observing Phase Modulation
 - Verify expectation of no Amplitude Modulation
- Calibrate phase shift to electron density
 - Comparison with RFA measurements
 - Comparison with simulation results
- We welcome anyone interested in helping!