Measuring Electron Cloud Density at CesrTA by Microwave Transmission

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ILC Damping Ring R&D Workshop 2008

July 9th, 2008

Other Co-Authors

- **M.Pivi**

- **A. Krasnykh**   *Measurements on PEP-II LER*

- **K. Sonnad**

- **F. Caspers**

- **T. Kroyer**   *Measurements on SPS*

The Microwave transmission method was initially developed by F. Caspers and T. Kroyer at CERN (ECLOUD'04).

Summary

- **Physical principles of the measurement method.**

- **How to make the measurement in practice.**

- **Experimental setup on the CesrTA**

- **Measurement results.**

- **Cyclotron resonances.**

- **Future Plans**

Measurement by microwave transmission

Beampipe

EM wave

Low-energy electrons
Phase velocity changes in the ec region
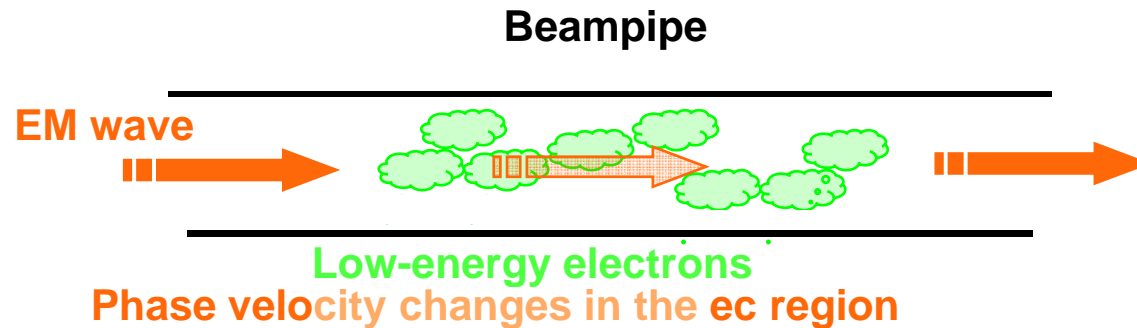
Propagation through the electron plasma introduces an additional term to the standard waveguide dispersion:

$$k^2 = \frac{\omega^2 - \omega_c^2 - \omega_p^2}{c^2}$$

Plasma frequency
$2c(\pi\rho_e r_e)^{1/2}$

Beampipe cut-off frequency

The presence of the "electron plasma" affects the propagation of the wave, while there is essentially no interaction with the ultrarelativistic beam.
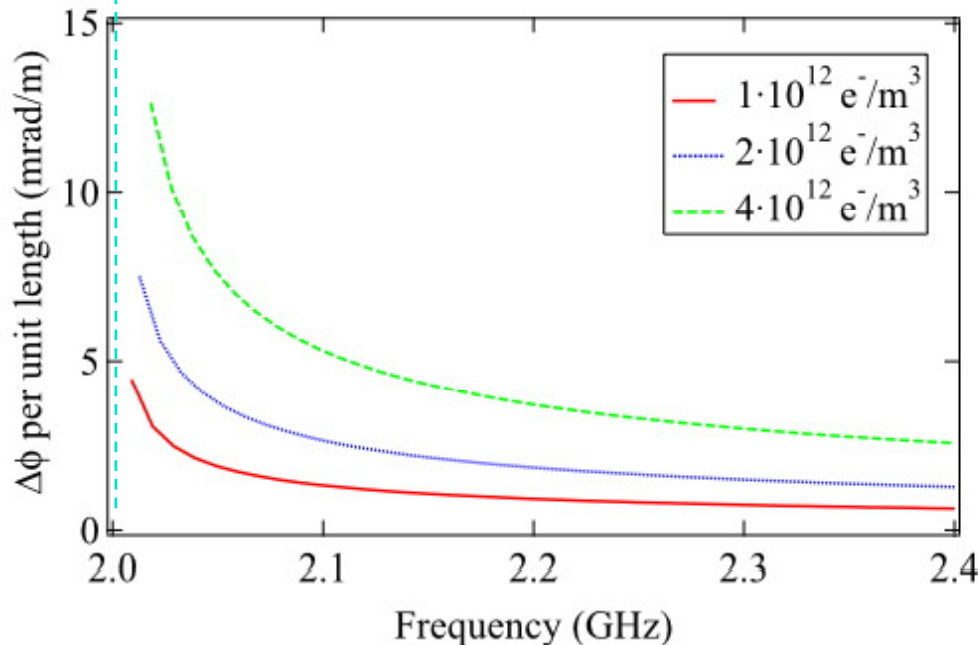
Induced additional phase delay

The resulting phase shift per unit length is:

By measuring $\longrightarrow$

...one calculates and

$$\frac{\Delta\varphi}{L} = \frac{\omega_p^2}{2c(\omega^2 - \omega_c^2)^{1/2}}$$

$$\rho_e \approx \frac{f_p^2}{80} \ (e^- / m^3)$$

Beampipe cut-off

Frequencies closer to cut-off experience larger phase shifts. Their attenuation is generally larger in actual beampipes, though.

Formulas valid only when B=0

Practical Difficulties

- **Low phase shift values (few mrad). Can we increase it ?**
  - Frequency closer to beampipe cut-off ⇔ higher attenuation
  - Longer propagation distance ⇔ higher attenuation

- **Noisy environment: direct beam signals !**

- **BPM not optimized for TE-wave transmission/reception.**
  - Typical Tx/Rx losses > -60 dB

- **Temperature related phase shift (beam on, beam off).**

Phase Shift Time Dependence

Positron bunch train

Gap

PEP-II LER

EM Wave
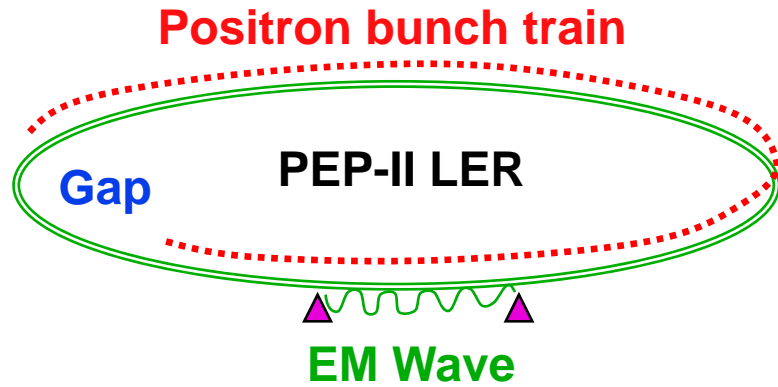
Gap length ≈ 100 ns
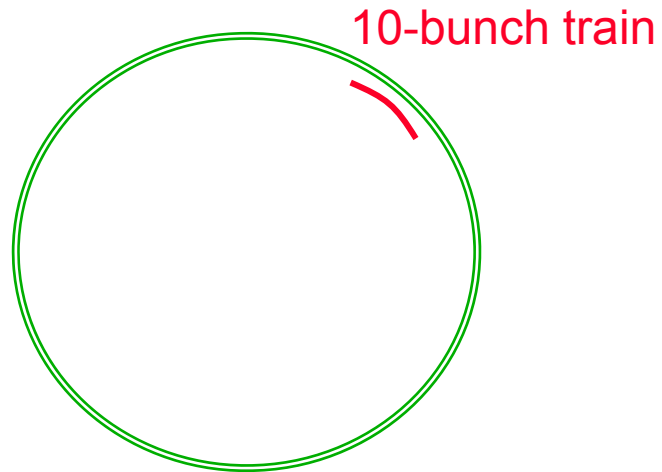Revolution period ≈ 7.3 μs
Bunch spacing ≈ 4 ns

136.4 kHz
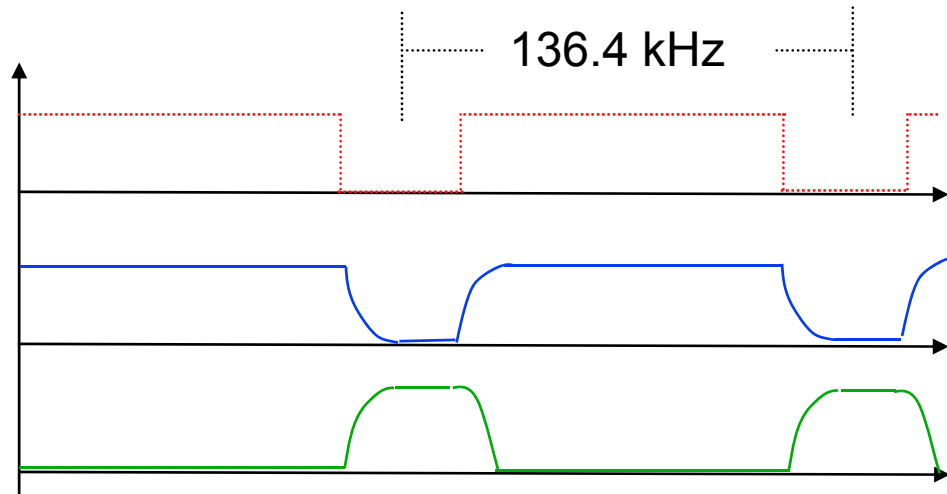
Positron current

E-Cloud Density
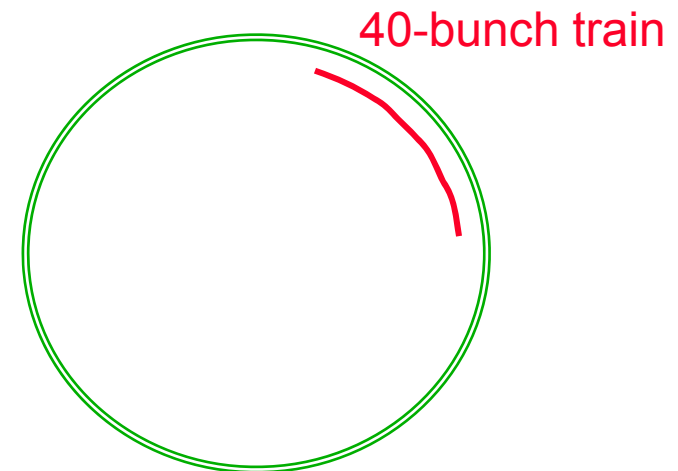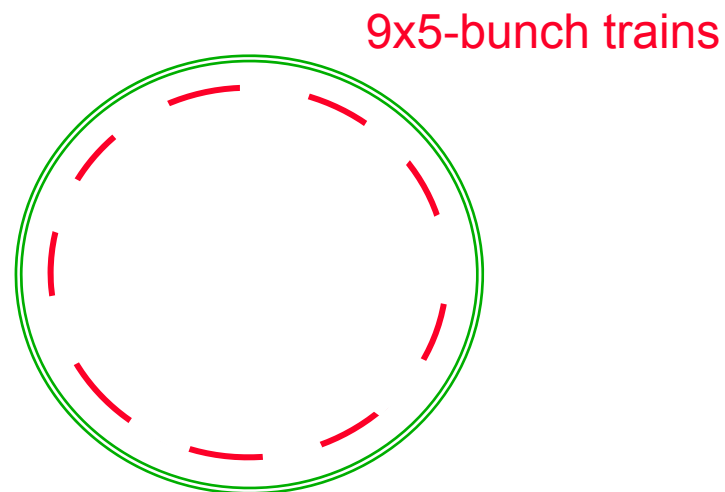
Relative phase shift

The phase shift changes at a frequency equal to the (gap) revolution frequency !!!
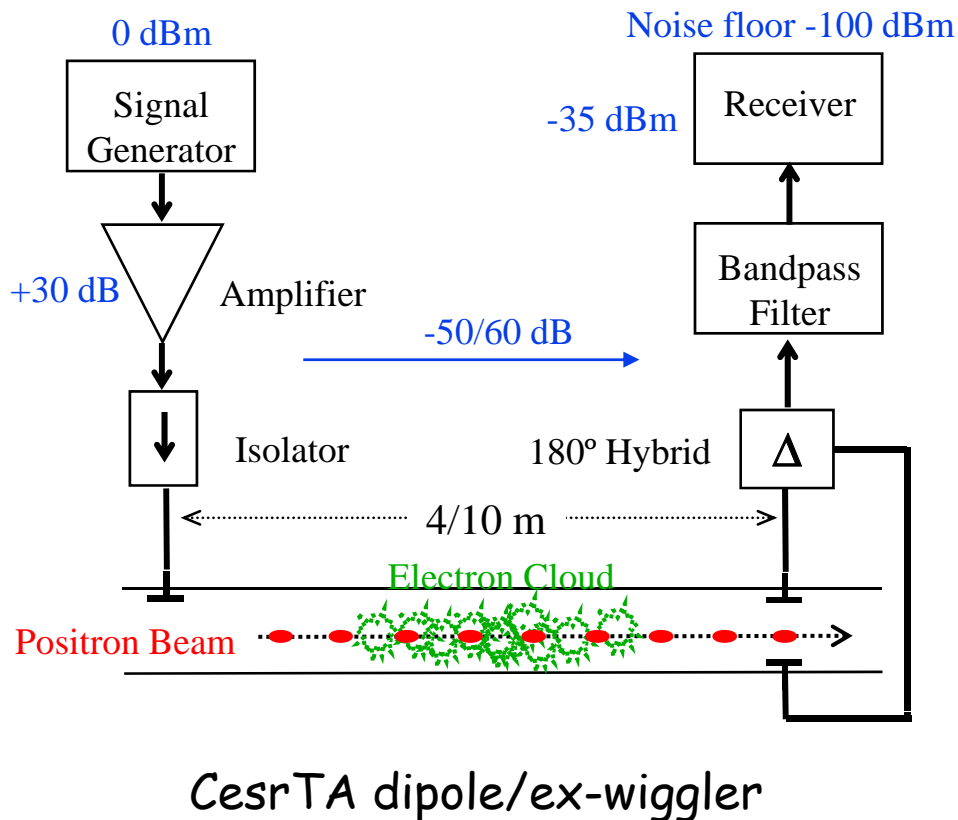
CesrTA Fill Patterns (e⁺/e⁻)

10-bunch train

Energy = 2 - 5.2 GeV
Gap length ≈ 210 ns - 2.4 µs
Revolution frequency ≈ 390 kHz
Bunch spacing ≈ 14 ns

40-bunch train

9x5-bunch trains

in this case the gap revolution frequency is 9 x f_{rev}

Experimental Setup

0 dBm

Signal Generator

+30 dB   Amplifier

Isolator

-50/60 dB

4/10 m

Electron Cloud

Positron Beam

CesrTA dipole/ex-wiggler

Noise floor -100 dBm

-35 dBm   Receiver

Bandpass Filter

180º Hybrid   Δ

- The hybrid reduces the direct beam signal picked up by the receiver (spectrum analyzer)

- A BPF is used to further reduce beam power on the receiver. Total received power < 100 mW.

- The 20 dB isolator protects transmitter and amplifier.

- Transmission attenuation is around 50/60 dB, with a 60+ dB SNR at the receiver.

# Transmitter/Receiver Positions

We had 3 BPM available for the measurement, to be used either as transmitting or receiving port.

By trying all the possible combination, we were able to test the effects of different vacuum chambers, different propagation lengths, and different propagation direction between e$^+$ or e$^-$ beam and TE wave.

The measurements were taken at both 2.0 and 5.2 GeV, with a variety of fill patterns.
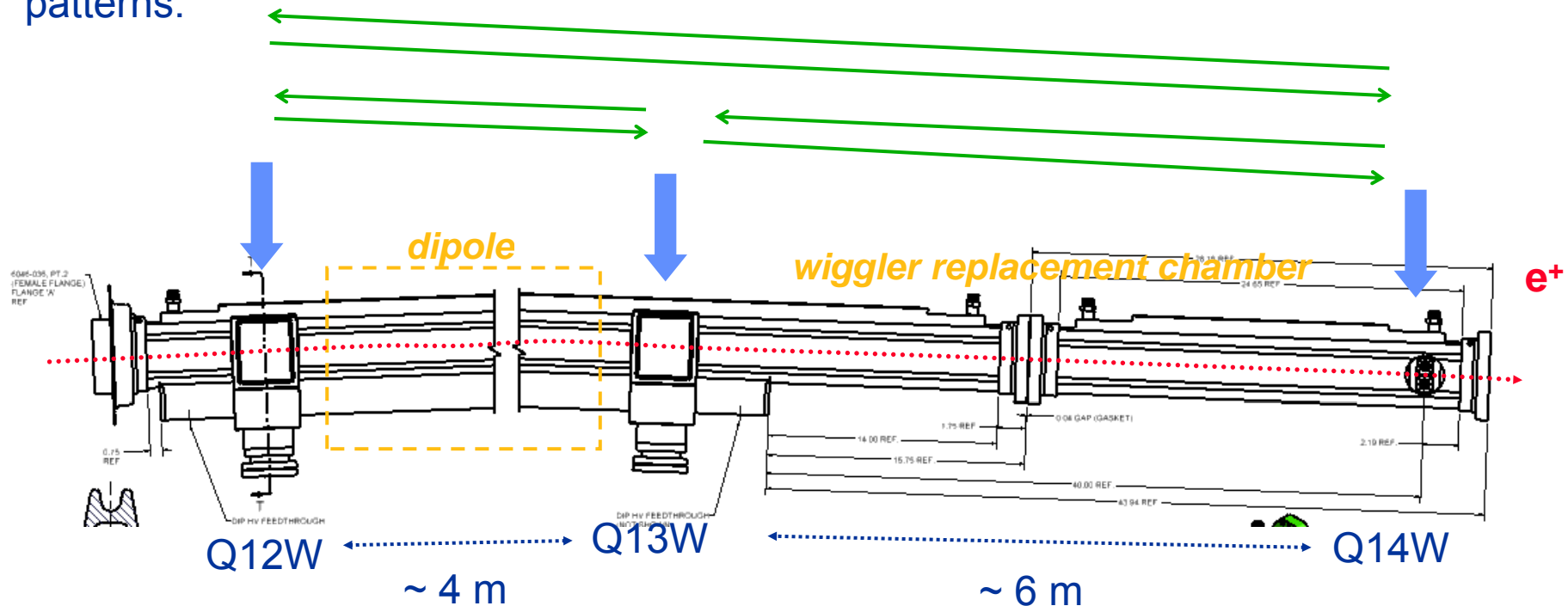
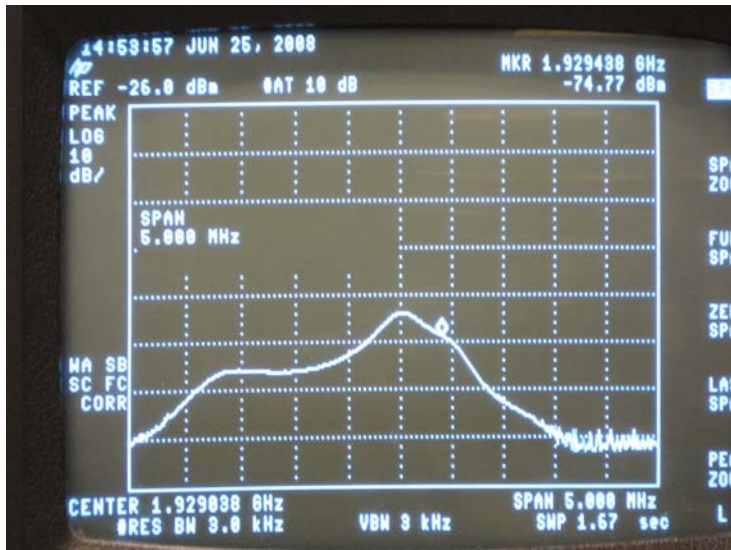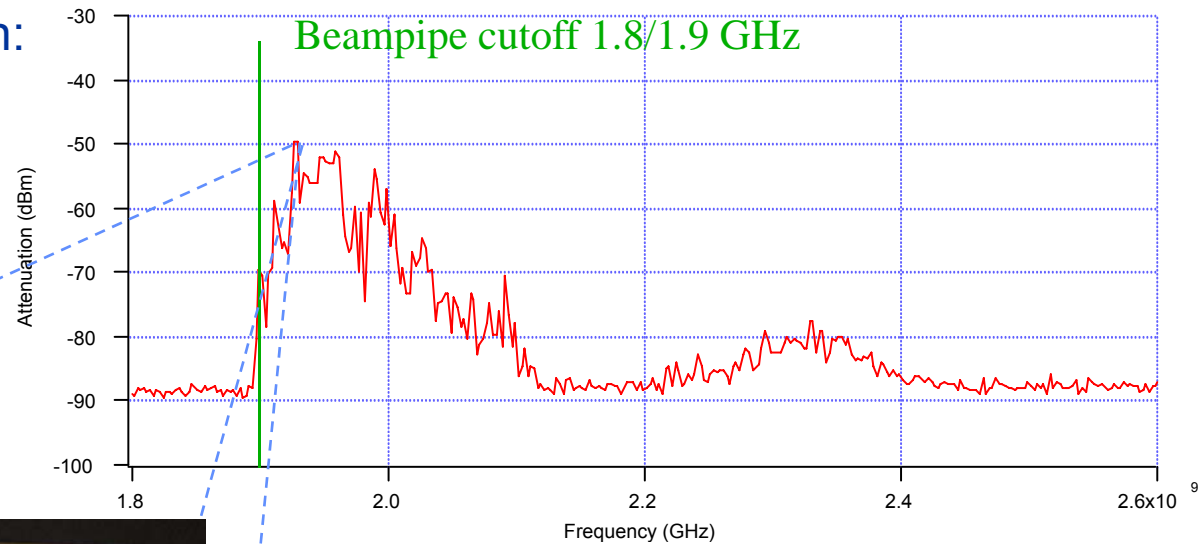# Closed-loop Transfer Function (cables)
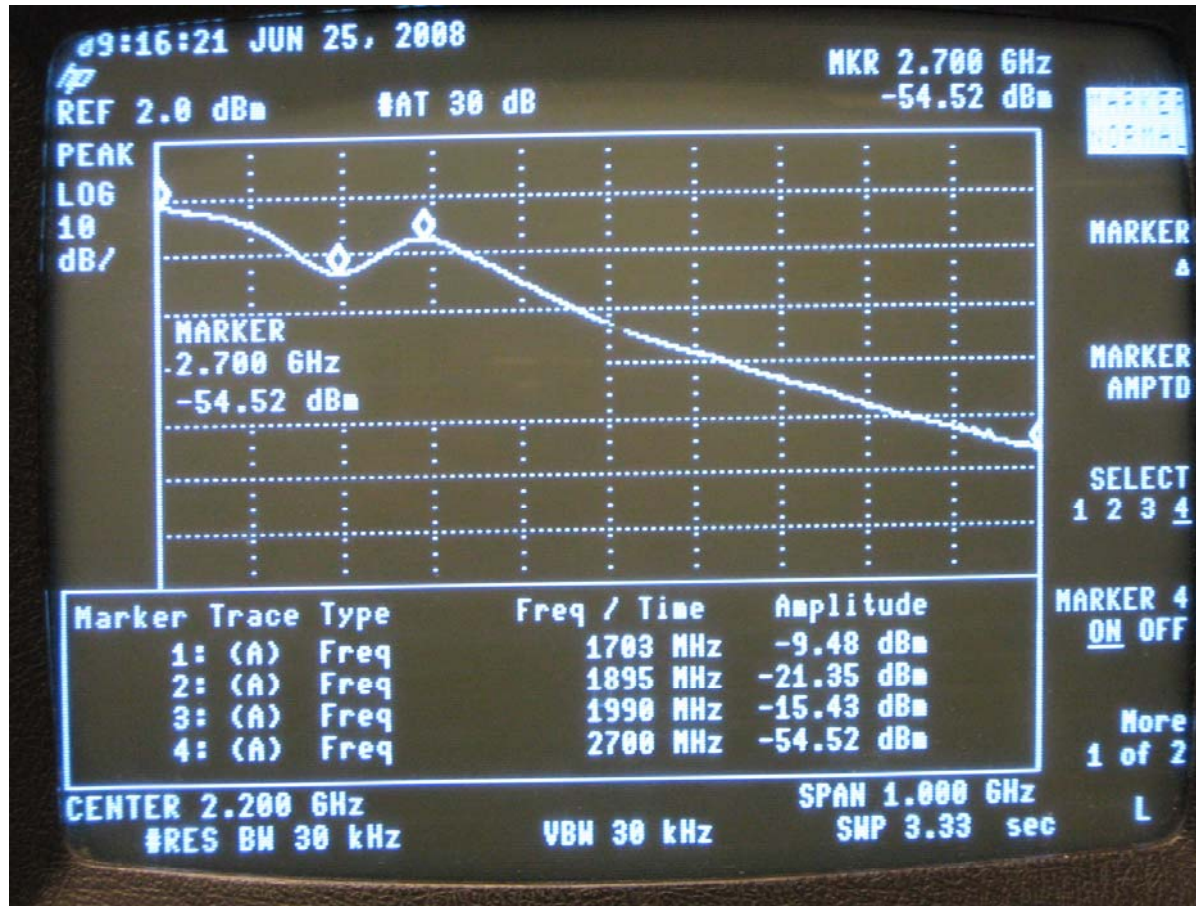
Includes: cables, receiver, amplifier

Beampipe Transfer Function

Choice of measurement region:
- Close to cutoff
- Low attenuation
- Reasonably "flat"

Search for origin of reflections and/or resonances in the beampipe did not turn out conclusive results (gate valves, pumping holes, RF cavity)
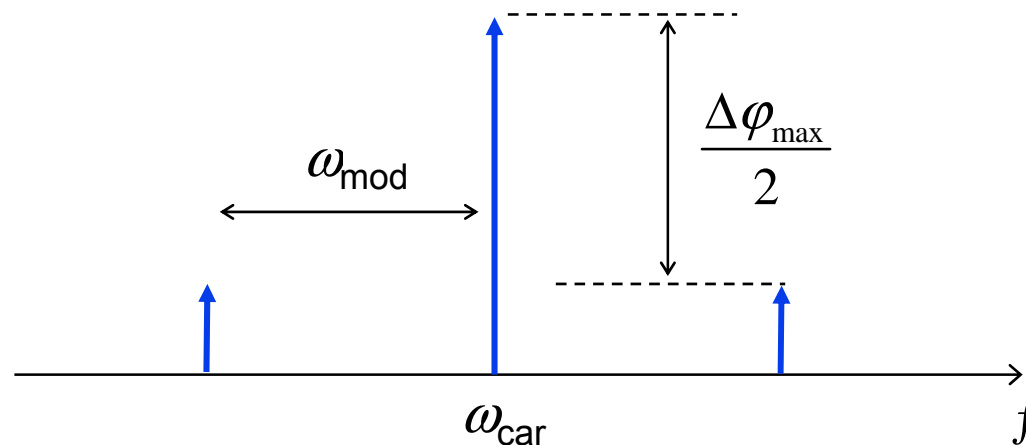
Received Signal

Phase Modulation

The *periodic clearing of the electron cloud* by the gap, when it passes between our Tx and Rx BPM's *phase modulates the transmitted signal*:

$$s(t) = A\cos[\omega_{car}t + \Delta\varphi(t)]$$

• What happens if the gap is not long enough to completely clear the electrons ?
• What happens if the gap is shorter than the distance between Tx and Rx ?

If $\Delta\varphi(t) = \Delta\varphi_{max}\sin(\omega_{mod}t)$

Measurements at CesrTA

- **Compare positron and electron beam**
  - *Build-up of low-energy electrons has also been observed with an electron beam.*

- **Compare measurements with TE wave propagating in the same and in the opposite direction of the beam.**

- **Dependence on gap length and beam/bunch current**

- **Effects of different vacuum chamber shapes**
  - *Arc and wiggler replacement pipes.*

- **Dependence on beam energy**
  - *More photoelectrons generated in the dipole at 5.2 GeV*

- **Cyclotron resonance**
  - *Dipole field is 792 G at 2 GeV, f_{cycl}=2.22 GHz*
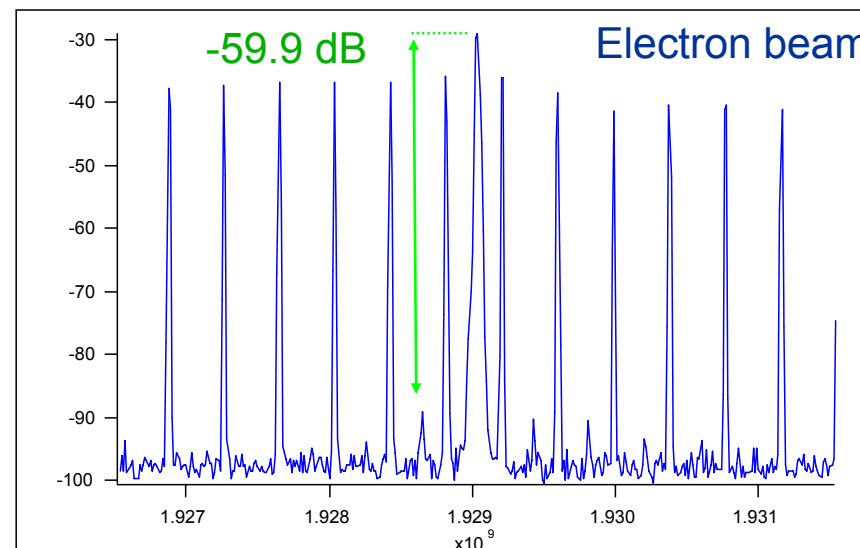
Electron vs. Positron Beam

2 GeV - Dipole region (Q12W-Q13W) 10 bunches x 1 mA

Difference in the relative sideband amplitude between electron and positron beam, in otherwise identical machine conditions.

The low-energy electron density in the presence of a positron beam has a ~3 times higher value than with an electron beam.
This effect is due to the multiplication of secondary electrons caused by resonant interaction of beam and e-cloud.
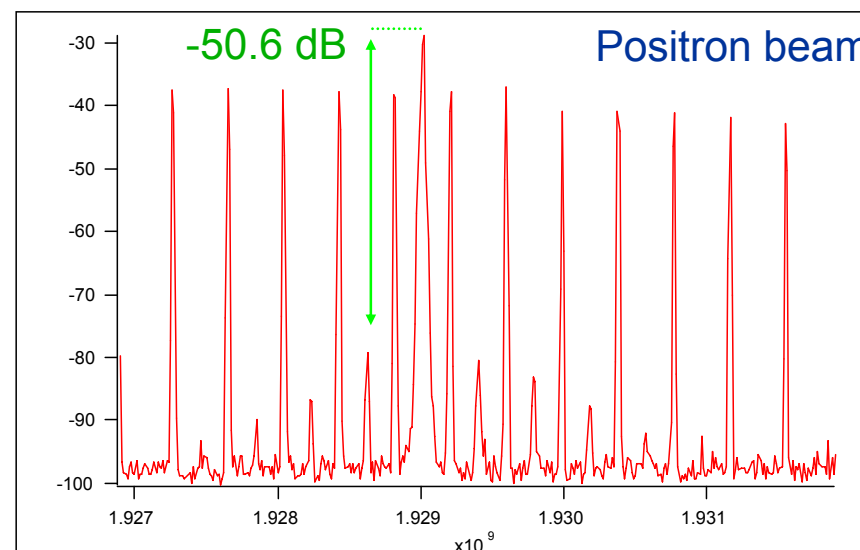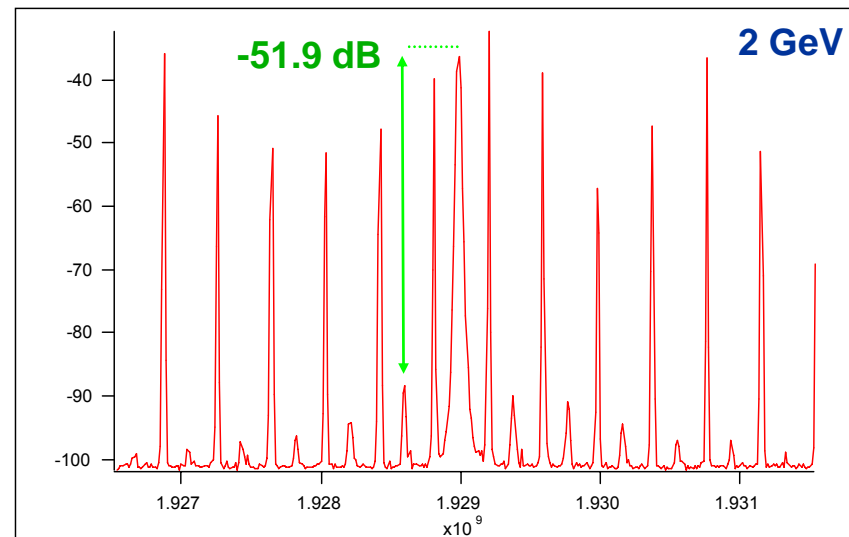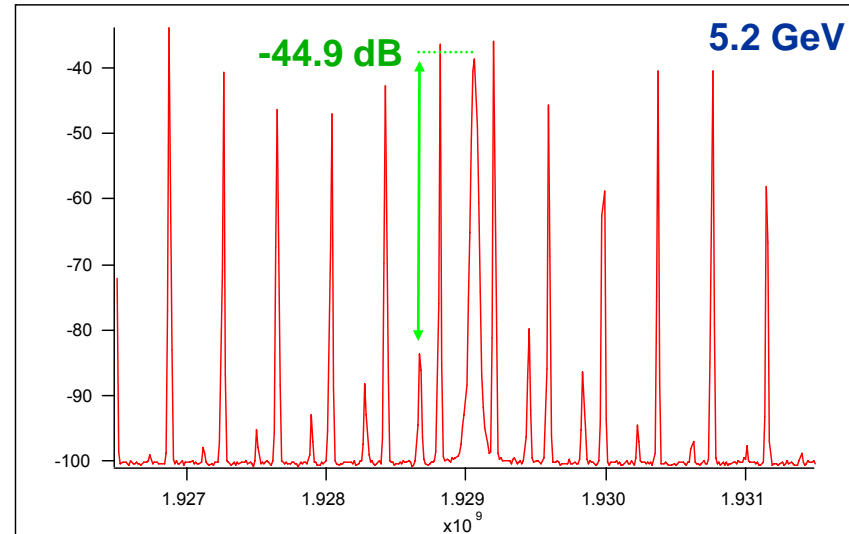
2 Gev vs. 5.2 Gev Measurements

Ex-Wiggler region (Q13W-Q14W) 10 bunches x 1 mA

Difference in the relative sideband amplitude between two different beam energies (positron beam).

At higher beam energy the enhanced production of photoelectrons increase the low-energy electron density by a factor greater than 2.
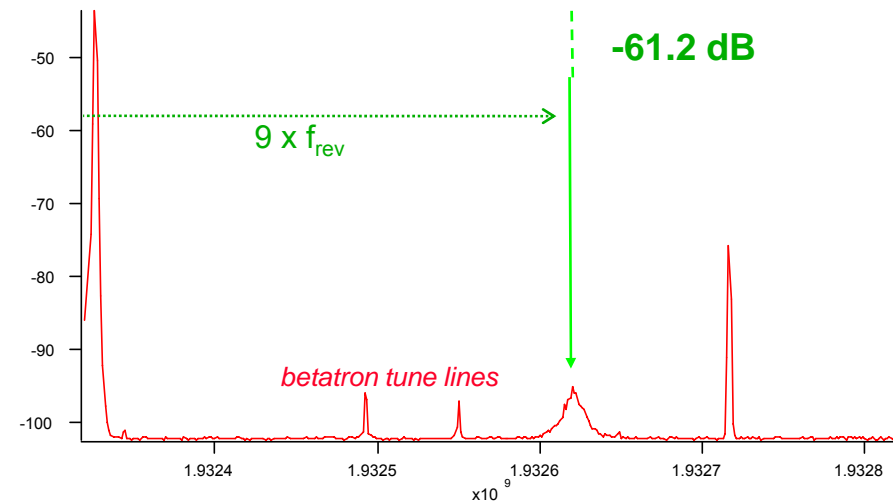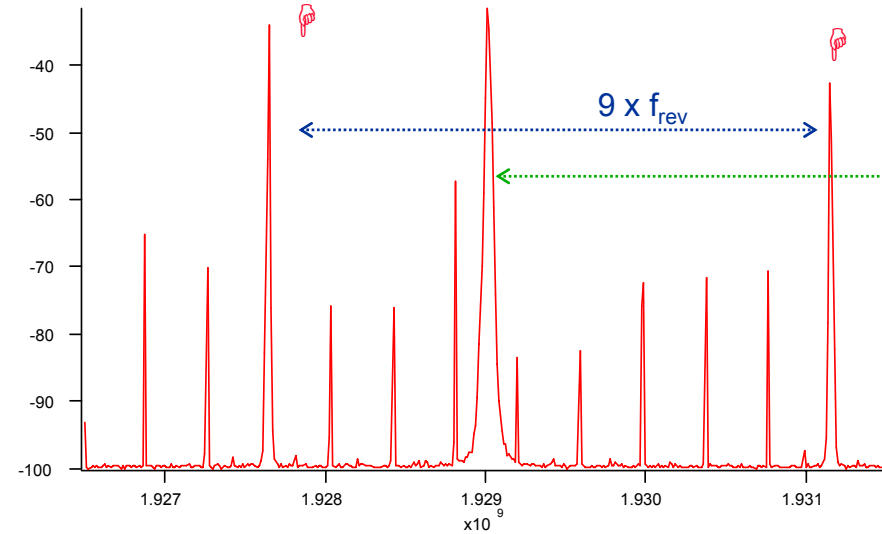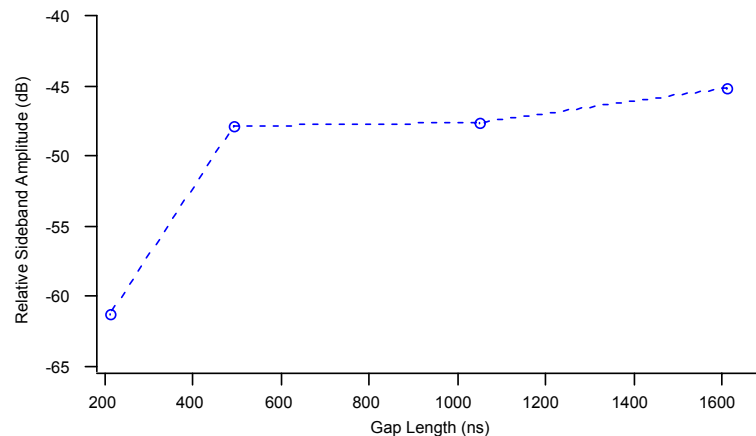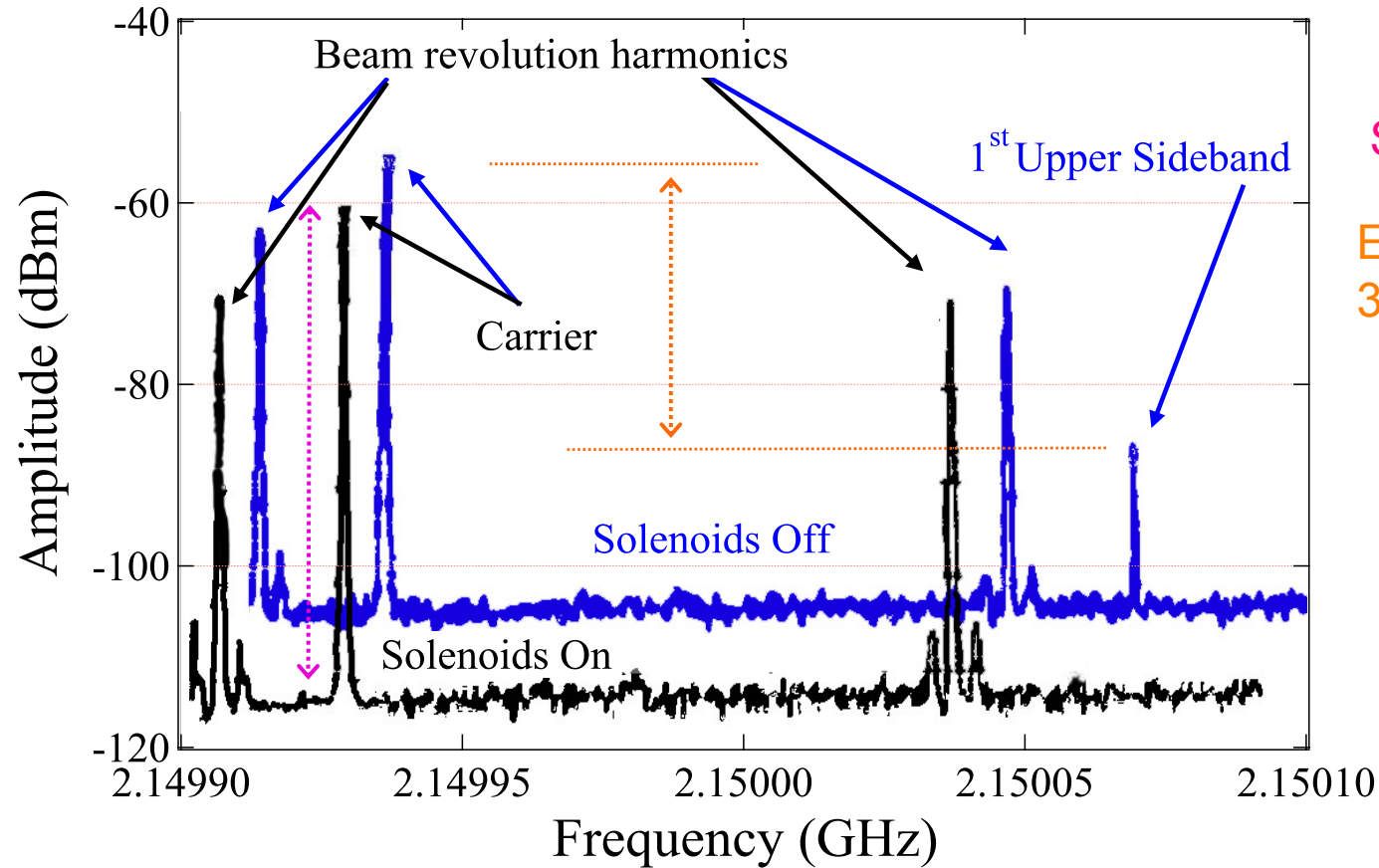
9 x 5 Bunch Fill Pattern

Ex-Wiggler region (Q14W-Q13W) 45 bunches x 1 mA

Effects of the bunch periodicity are evident (enhancement of the ninth revolution harmonic ☞).
Although total current is higher (45 vs. 10 mA). The much shorter gap (210 ns) induces a much smaller modulation depth. The ninth sideband is also enhanced.
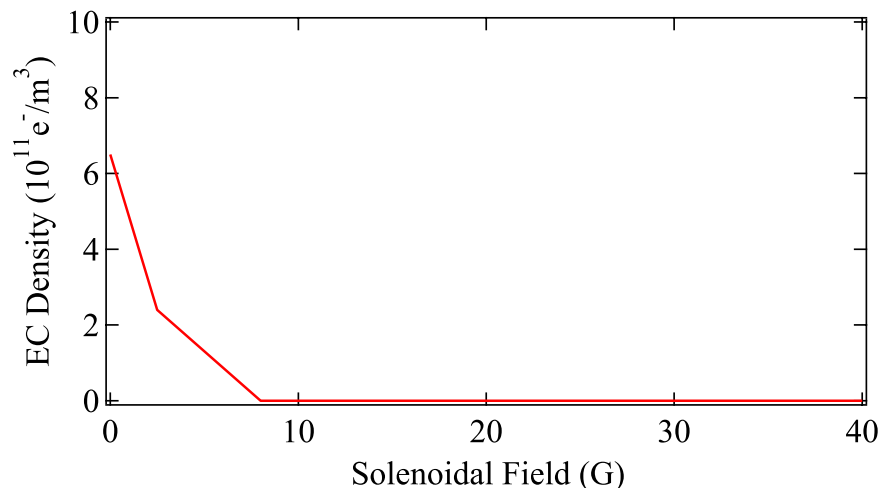
Clearing Solenoids (PEP-II)

Although the time evolution of the e-cloud density is not simply sinusoidal, the simple model already gives results in good agreement with other estimates (codes)
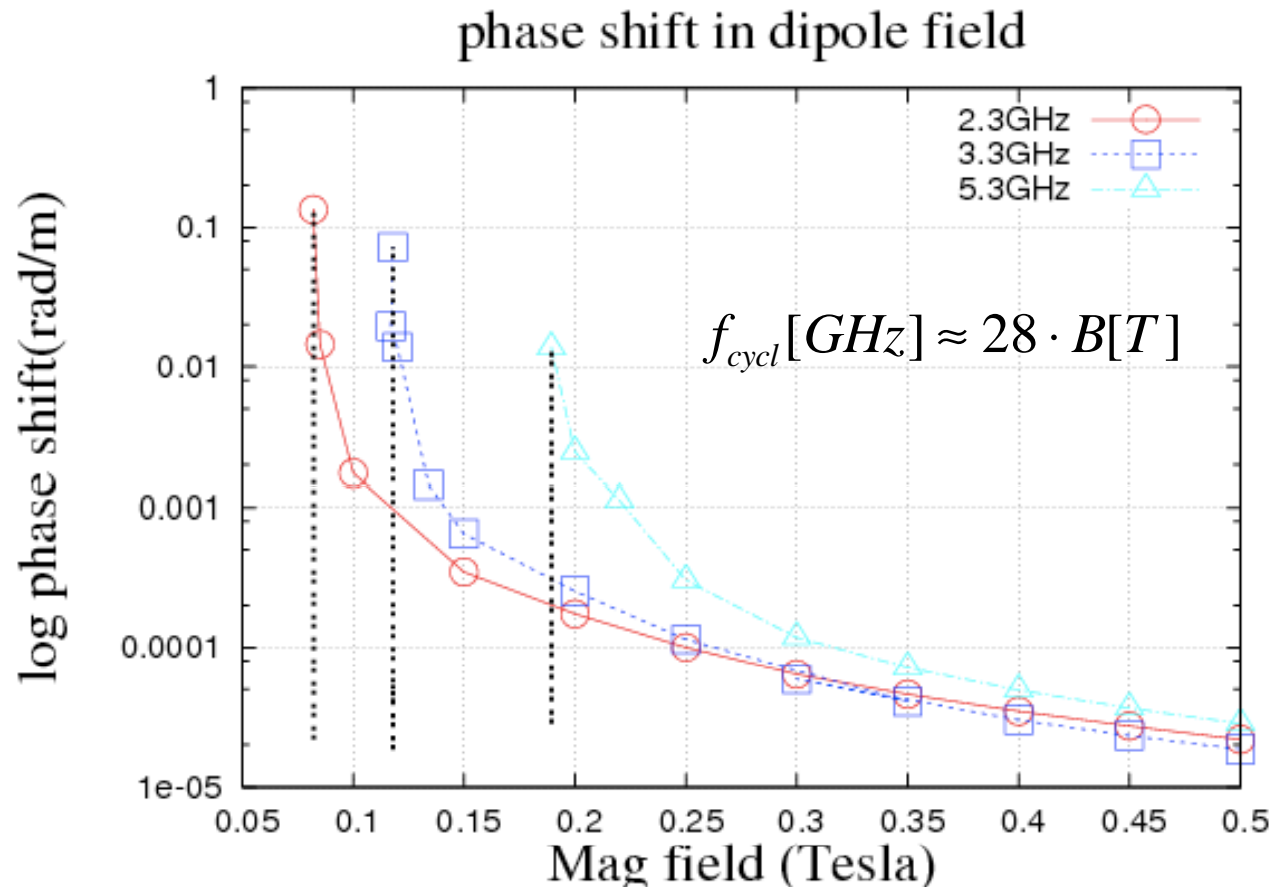
Experimental Results (PEP-II)

Excellent tool for studying the efficiency of any e-cloud clearing scheme.

Multiple sidebands linked to the bandwidth of modulation process (Carson's rule).
Complete demodulation yields the ECD time evolution.

Cyclotron Resonance

phase shift in dipole field
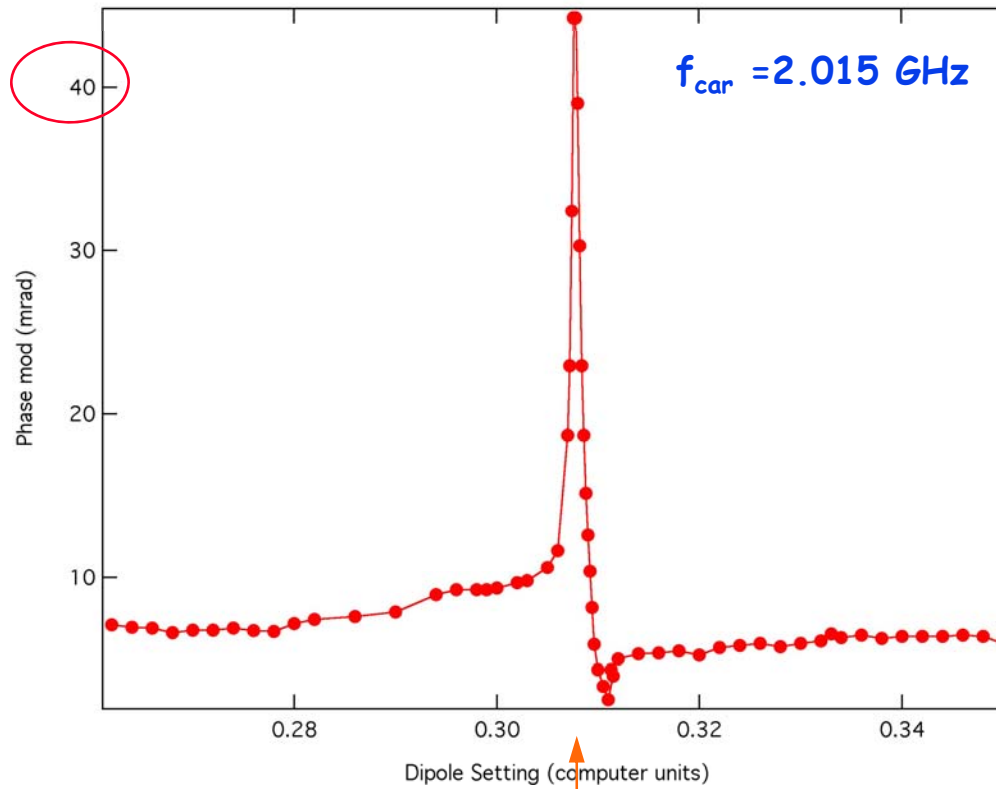
$$f_{cycl}[GHz] \approx 28 \cdot B[T]$$
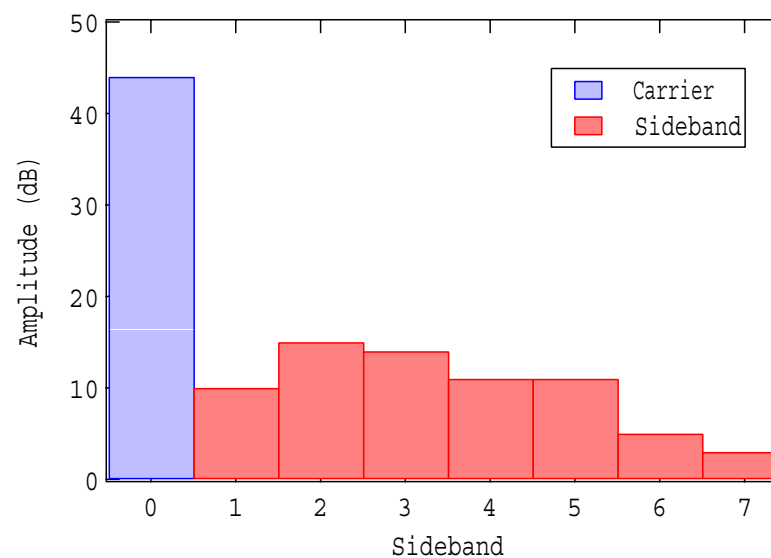
But what is the relationship between this phase shift and the e-cloud density ?
Are we measuring the ECD, or rather the magnetic field strength ?

Cyclotron Resonance Measurement

Unequivocal measurement of a cyclotron resonance
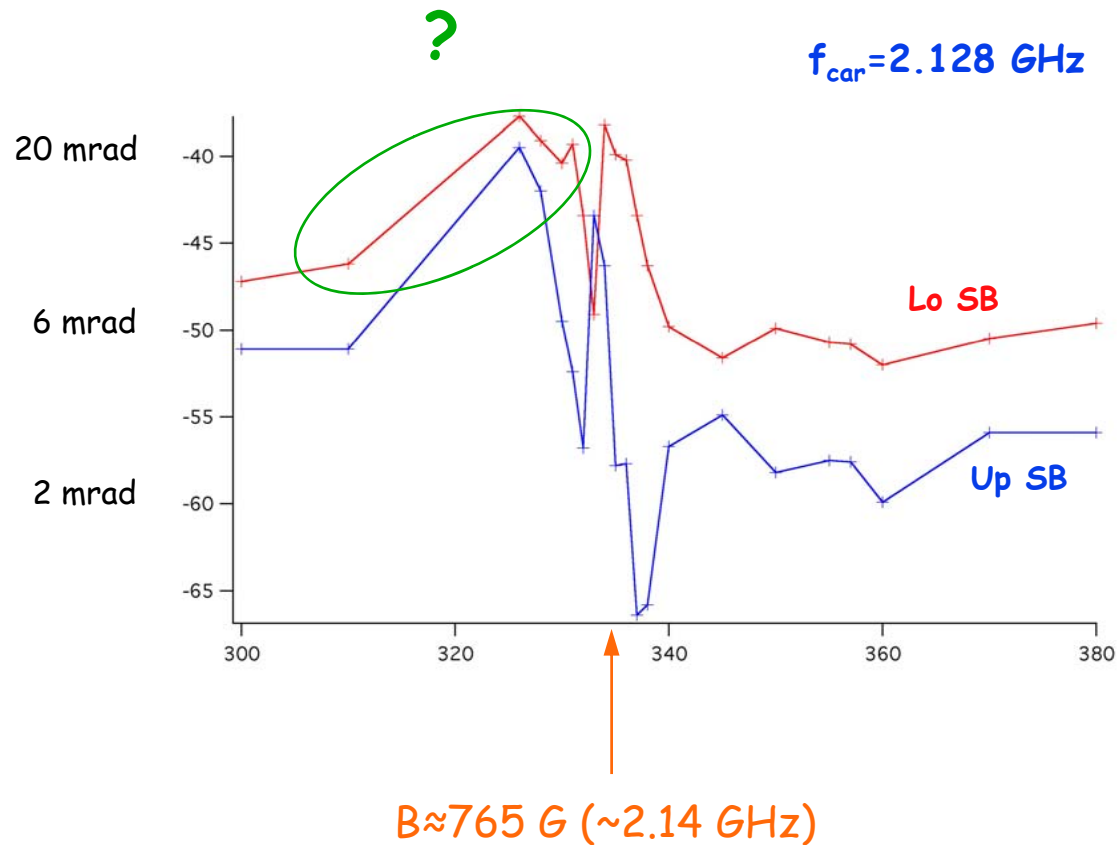

40+ mrad over a length of only 4 meters !

f_{car} =2.015 GHz

B≈700 G (~1.96 GHz)

More Experimental Results

Difference between upper and lower sideband evidence of AM/PM mod.

f_{car}=2.128 GHz

B≈765 G (~2.14 GHz)

Future Activities

- **How to improve the measurements ?**
    - Better hardware. Bigger amplifier ?
    - From BPM's to dedicated couplers optimized for TE mode.

- **More beamtime**
    - CesrTA (cyclotron resonance, time domain measurements)
    - KEK-B ?

- **Better understanding of cyclotron resonances**

    - More analytical work and modelling

- **Development of a dedicated receiver**
    - Full demodulation of received signal