

Measurements of the Electron Cloud Density in the PEP-II Low Energy Ring

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...and many thanks to the PEP-II people.

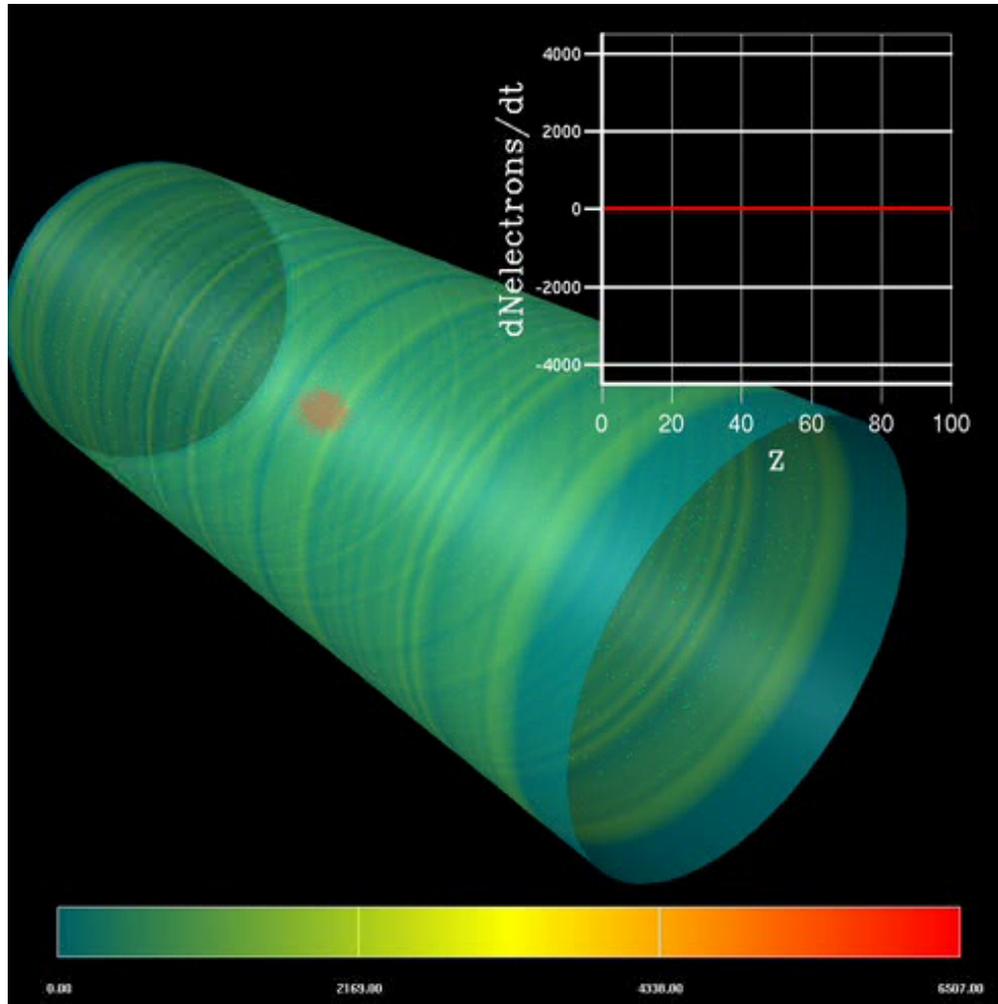
*Method initially developed by F. Caspers and T. Kroyer at CERN
Attempted measurements on the SPS. Unfavourable conditions.*

Summary



- The electron cloud.
- Physical principles of the measurement method.
- How to make the measurement in practice.
- Experimental setup on the PEP-II LER (straight).
- Measurement results.
- New setup (chicane): cyclotron resonances.
- Experimental results.
- Unanswered questions and future plans (CesrTA).

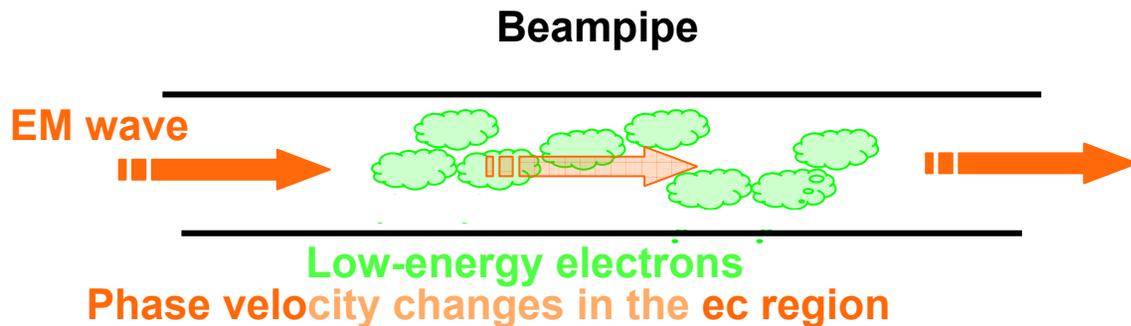
What is the electron cloud ?



1. Beam generates low-energy electrons (synchrotron radiation, residual gas ionization, stray particles)
2. Transverse resonance with circulating bunches.
3. $SEY > 1$

(courtesy of VACET)

Measurement by microwave transmission



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
 $2c(\pi r_e n_e)^{1/2}$

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

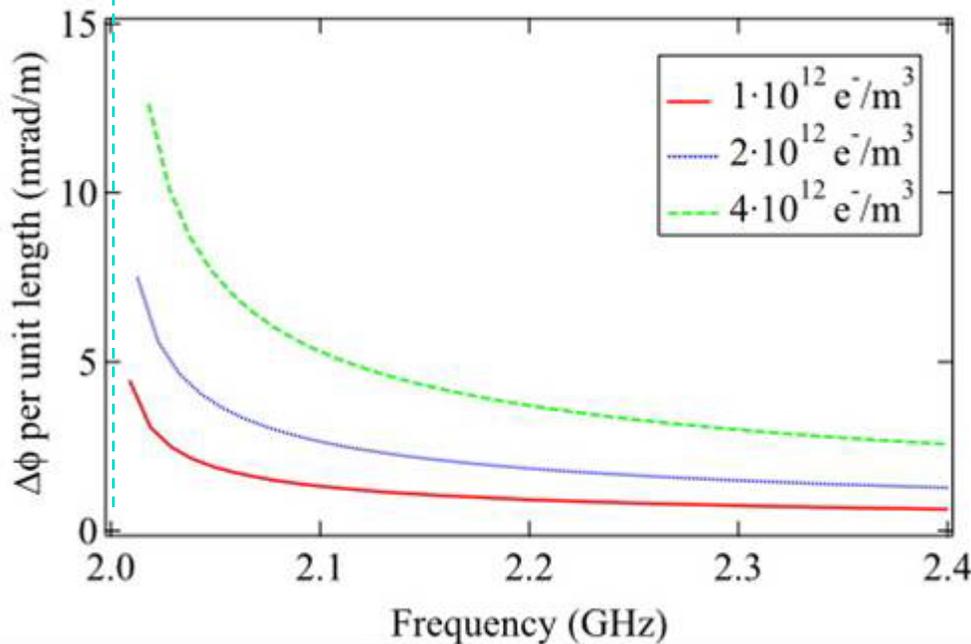


The resulting phase shift per unit length is:

By measuring $\Delta\phi$ \rightarrow $\frac{\Delta\phi}{L} = \frac{\omega_p^2}{2c(\omega^2 - \omega_c^2)^{1/2}}$ \leftarrow ...one calculates and

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

Beampipe cut-off



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

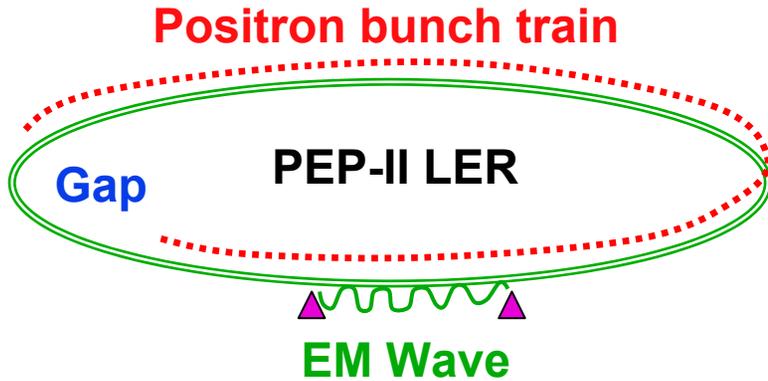
Formulas valid only when B=0

Practical Difficulties

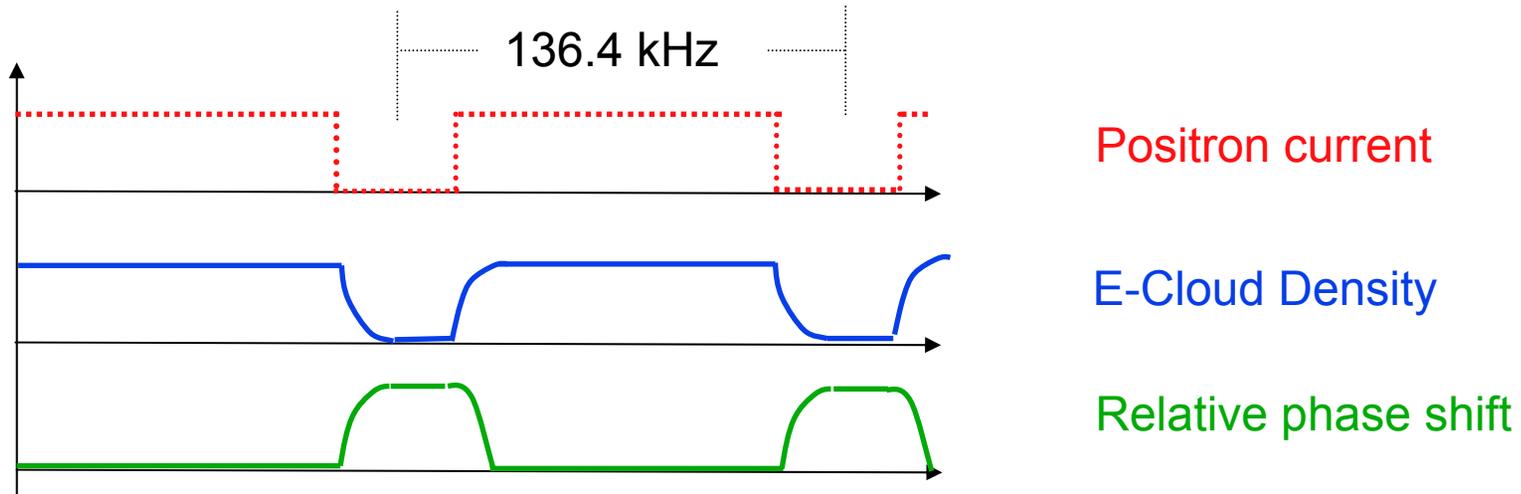


- **Low phase shift values (few mrad). Can we increase it ?**
 - Frequency closer to beampipe cut-off \Leftrightarrow higher attenuation
 - Longer propagation distance \Leftrightarrow higher attenuation
- **Noisy environment: direct beam signals !**
- **BPM not optimized for TE-wave transmission/reception.**
 - Typical Tx/Rx losses > -60 dB
- **Temperature related phase shift (beam on, beam off).**

Phase Shift Time Dependence



Gap length ≈ 100 ns
Revolution period ≈ 7.3 μ s
Bunch spacing ≈ 4 ns



The phase shift changes at a frequency equal to the (gap) revolution frequency !!!

Phase Modulation

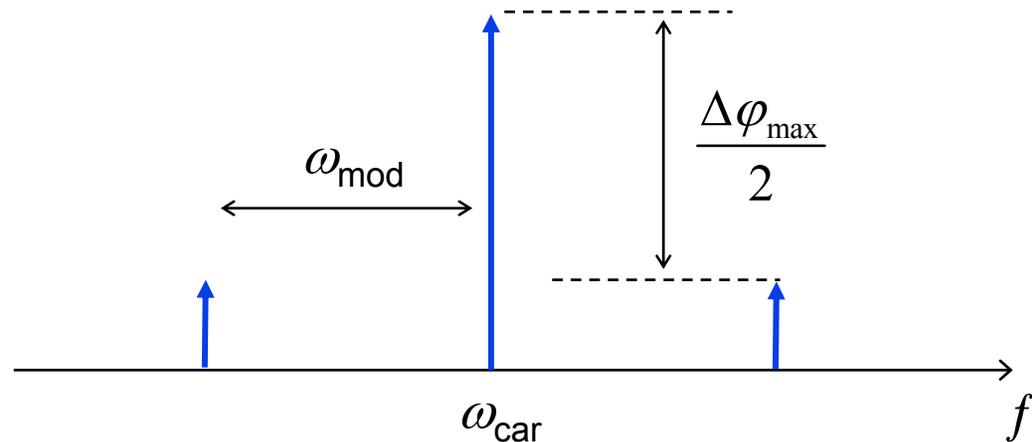


The periodic clearing of the electron cloud by the gap, when it passes between our Tx and Rx BPM's phase modulates the transmitted signal:

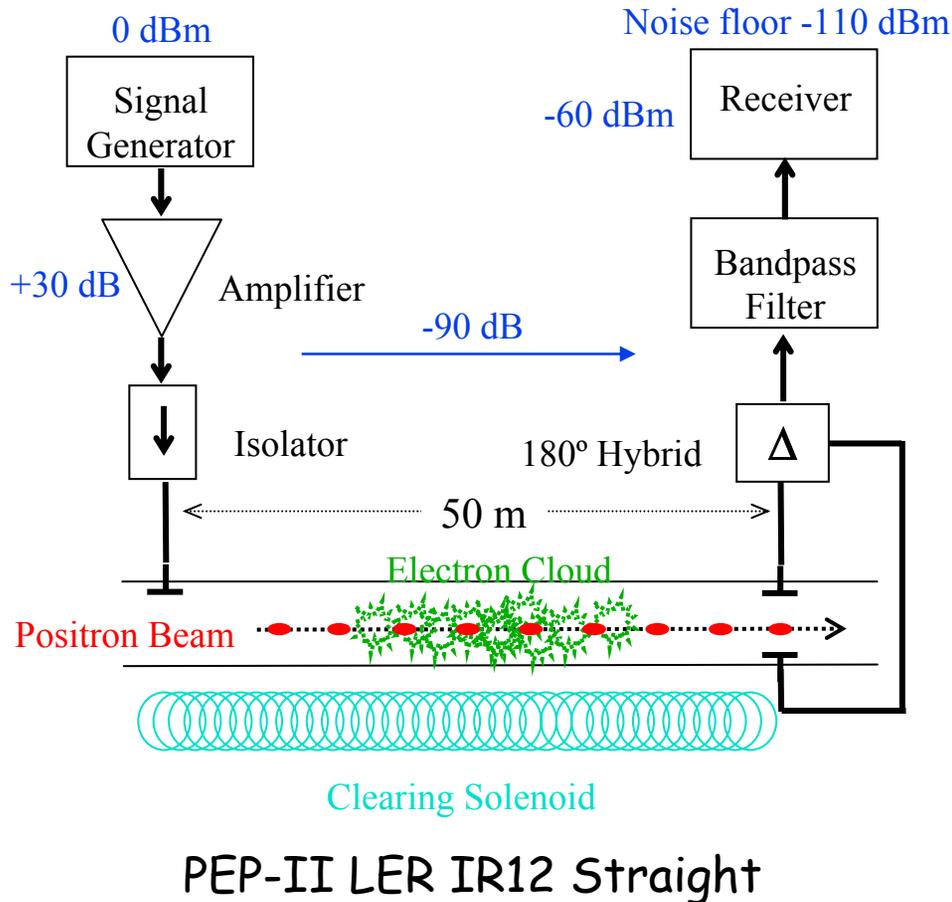
$$s(t) = A \cos[\omega_{car}t + \Delta\varphi(t)]$$

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



Experimental Setup



- Clearing solenoids wrapped around the beampipe can generate a magnetic field up to 40 G.
- 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 instead.
- Transmission attenuation is around 90 dB, with a 50 dB SNR at the receiver.

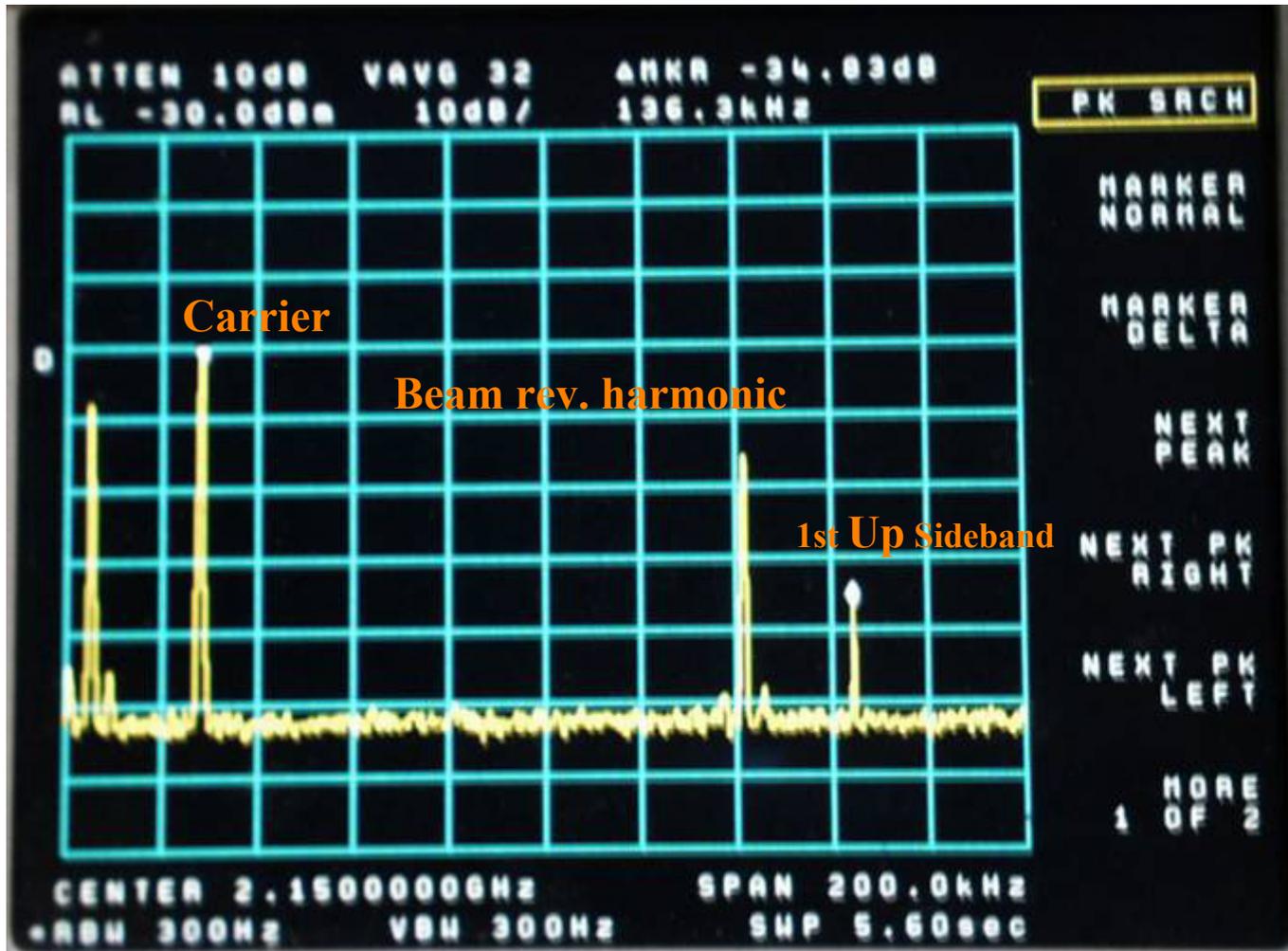
Beam Spectrum (After BPF)



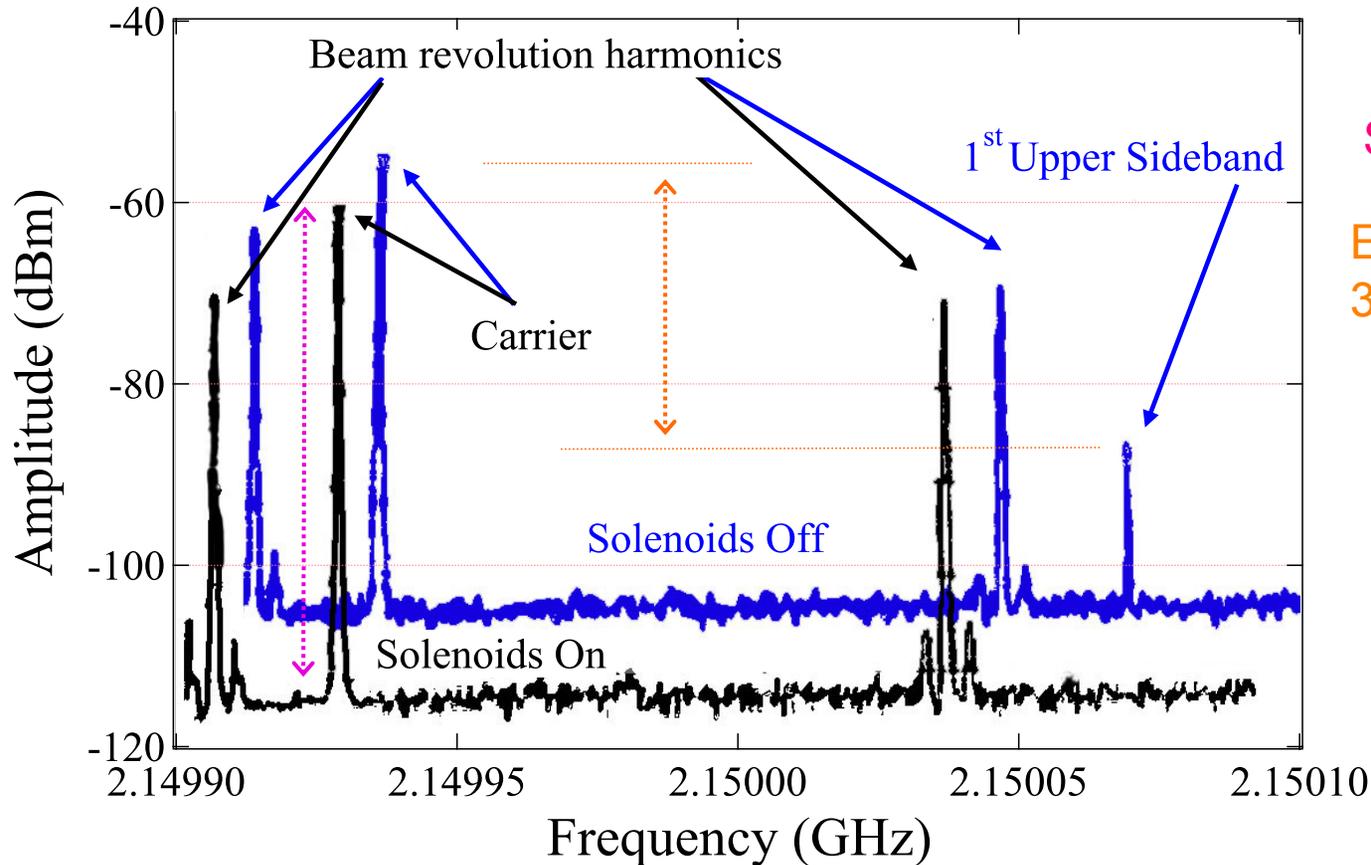
RF harmonics

Beampipe cutoff

Received Signal



Experimental Results

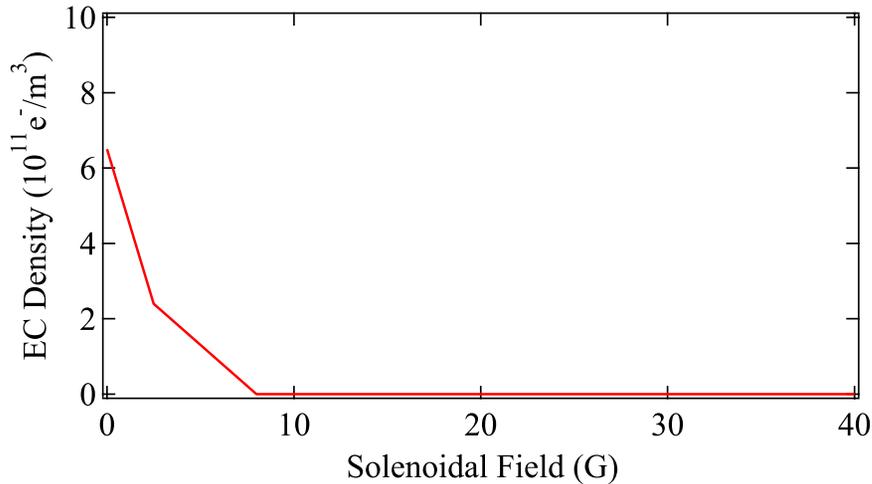


SNR: 50 dB

ECD resolution:
 $3 \cdot 10^{10} \text{ e-/m}^3$

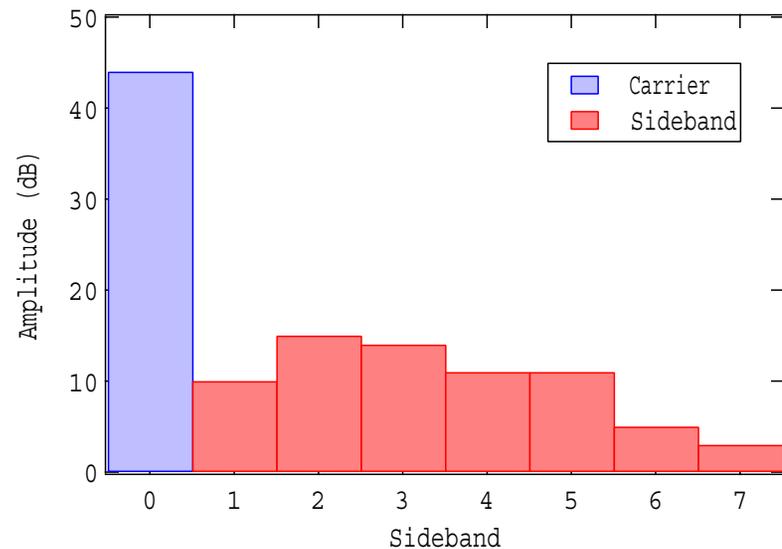
Although the time evolution of the e-cloud density is not simply sinusoidal, the simple model already gives results in good agreement with other estimates (codes)

More Experimental Results



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.

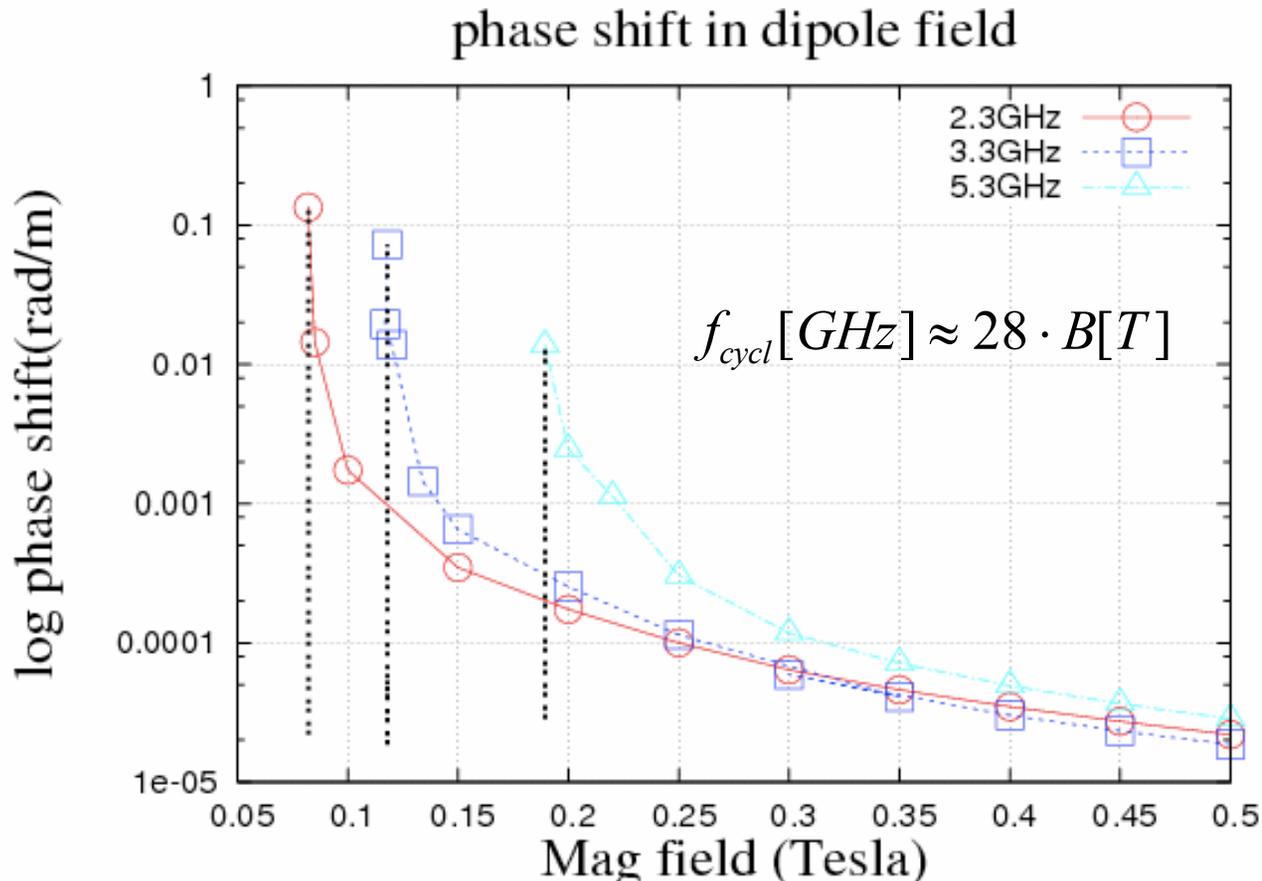


New Experimental Setup (Chicane)



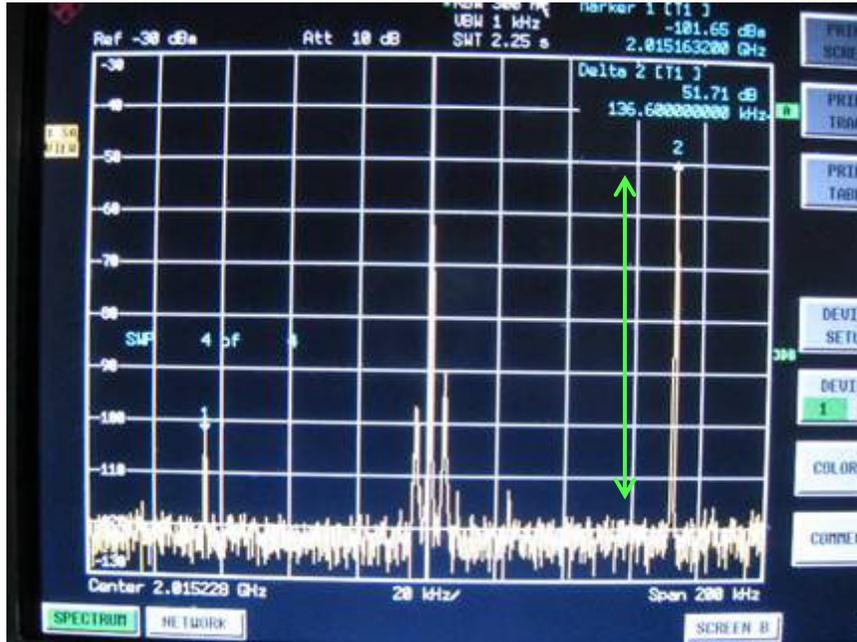
- **4 meter distance between BPM's**
 - Flat vacuum chamber (rather than round) and shorter distance give better transmission attenuation (+10 dB)
- **New carrier frequency and improved spectrum analyzer.**
 - Noise floor @ -120 dBm
- **50% of the length without solenoids (dipoles)**
 - Switching solenoids off not required
- **High dipole magnetic field (up to 1000 G)**
 - Allows observation of cyclotron resonances (2 GHz = 714 G)

Cyclotron Resonance



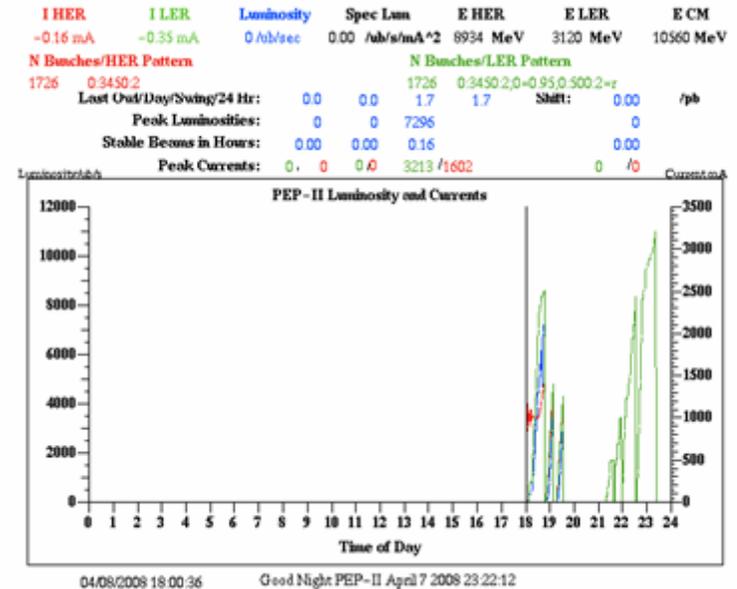
But what is the relationship between this phase shift and the e-cloud density ?
Are we measuring the ECD, or rather the magnetic field strength ?

Experimental Results



SNR = 70 dB

We were able to measure e-cloud at a substantially lower beam current: 1.7 A, down from 2 A in the straight.



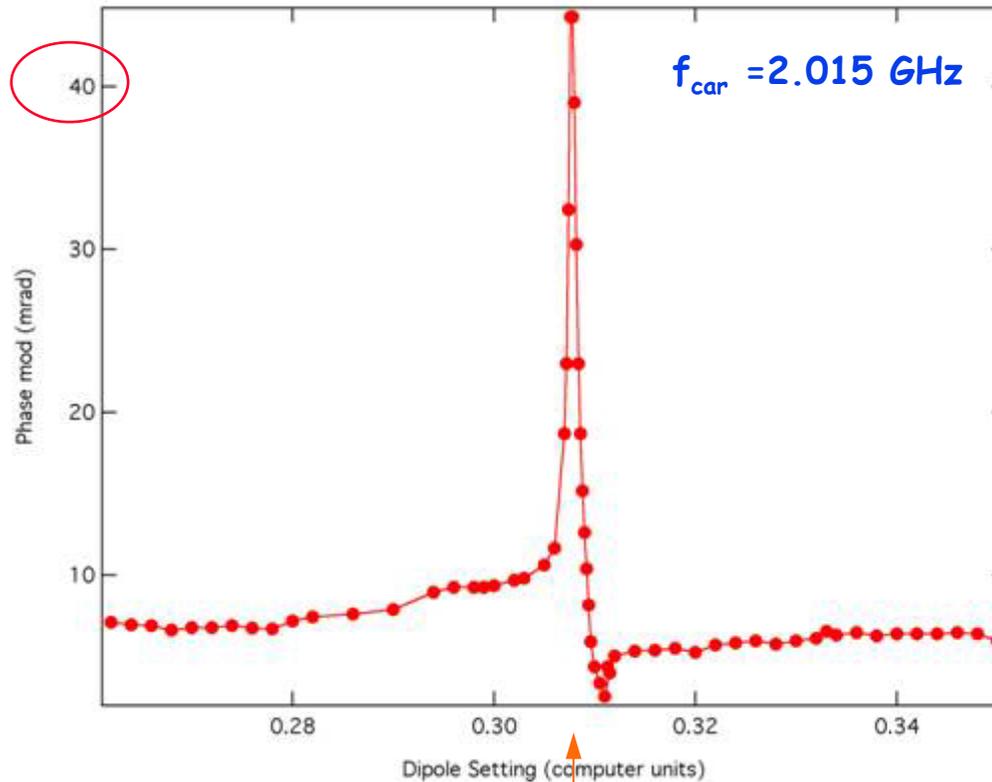
...but, due to the premature PEP-II demise we couldn't undertake a systematic measurement campaign.

More Experimental Results



Unequivocal measurement of a cyclotron resonance

40+ mrad over a length of only 4 meters!

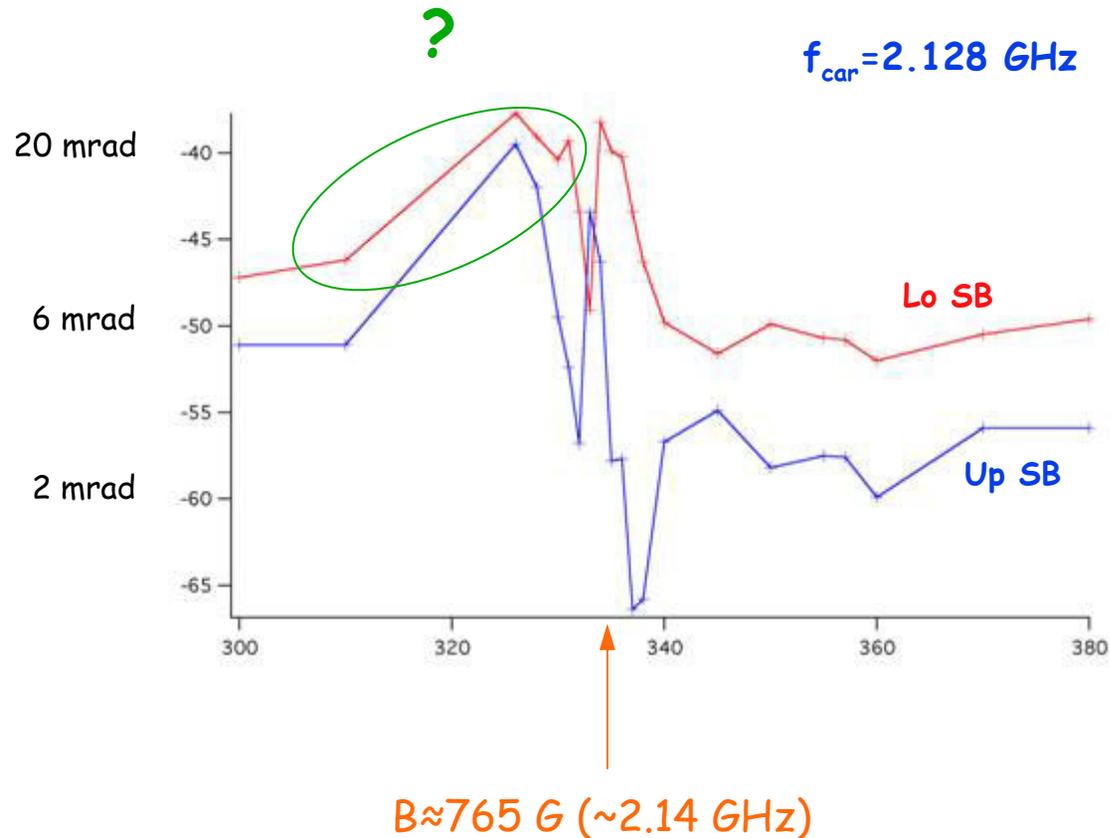


$B \approx 700 \text{ G} (\sim 1.96 \text{ GHz})$

More Experimental Results



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



Future Activities



- **How to improve the measurements ?**
 - Better hardware. Bigger amplifier ?
 - From BPM's to dedicated couplers optimized for TE mode.
- **More beamtime**
 - CsrTA (Wiggler, Straight, Dipole ?)
 - KEK-B ?
 - Variable gap studies
- **Better understanding of cyclotron resonances**
 - More analytical work and modelling
- **Development of a dedicated receiver**
 - Full demodulation of received signal