Electron Cloud Studies at LBNL

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Center for Beam Physics

AREAS OF ACTIVITY

- Simulations and theoretical studies
  - Code development (WARP-POSINST) and application to e-cloud formation studies, cyclotron resonances and *witness bunch* measurements in Cesr-TA.
- Beam measurements
  - TE Wave measurements of e-cloud density in Cesr-TA and general development of the technique.
- Accelerator engineering
  - Wiggler/RFA vacuum chamber fabrication. Implementation of e-cloud suppression techniques (grooved chamber, clearing electrodes).

ILC Activities at LBNL

- Theoretical studies of the e-cloud accumulation in wigglers and in the presence of strong magnetic fields (C.Celata, G. Penn)
- Modelling of tune shift induced by the e-cloud in various accelerator elements and application to Cesr-TA measurements (M. Venturini)
- Experimental measurements of the e-cloud density in various portions of the Cesr-TA ring by TE wave transmission method (S. De Santis)
- Fabrication of wiggler chambers for Cesr-TA in different configurations (coating, grooves, clearing electrode) for study of e-cloud mitigation techniques (D. Munson)

POSINST simulations of Cesr-TA coherent tune measurements

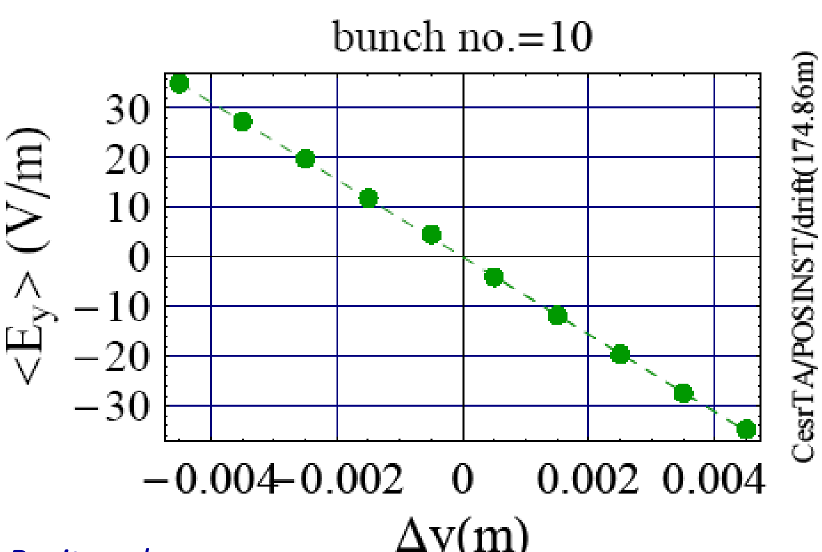
- Tuneshift measurements along trains of bunches are one of the most direct ways to probe e-cloud and harvest useful info.
- POSINST capabilities have been expanded to allow for calculation of 3D averages of the electric field over bunches (directly related to measurable coherent tuneshifts).
- LBNL simulations complement effort already on going at Cornell (in part carried out using earlier versions of POSINST).
- We have carried out simulations of contributions to tuneshift from **drifts** and **regular dipoles** for **positron beams** and **electron beams** (ongoing) with the April-07 machine setting (11 bunches train + 1 witness bunch)
- We started to explore scaling with respect to key parameters.
- We found that in dipoles (horizontal plane) offsetting the trailing bunches affects significantly the tuneshift of a following bunch
  - This configuration is believed be closer to the experimental situation.
  - The simulations with an offset in the trailing bunches yield a noticeable smaller value of the horizontal tuneshift than w/o offset. More in line with the measurements.

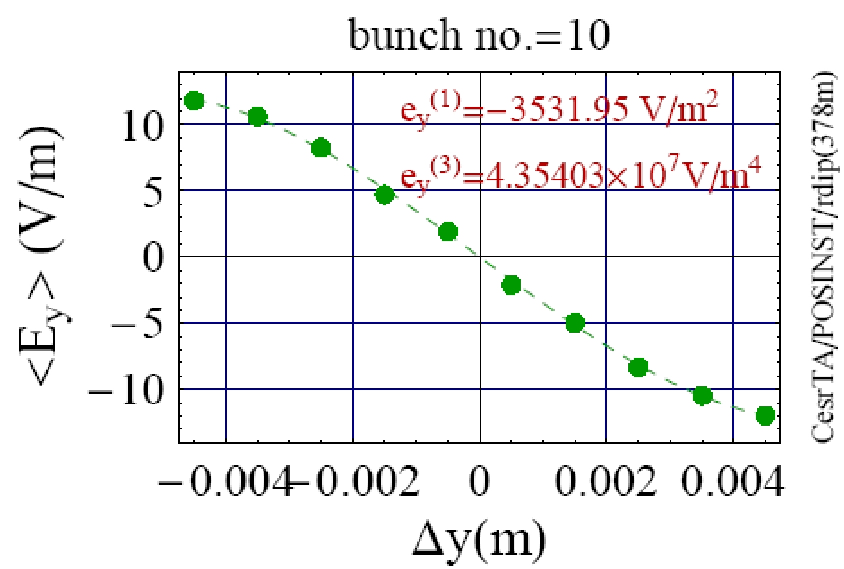
Modelling of tuneshift measurements using POSINST

- Coherent tuneshifs are among the most direct and easy-to-measure manifestations of electron cloud.
- Simulations can provide bench mark of existing numerical models and can be used to infer ranges of critical parameters (SEY, reflectivity etc).

In drifts restoring y-force on offset bunches is fairly linear against offset …

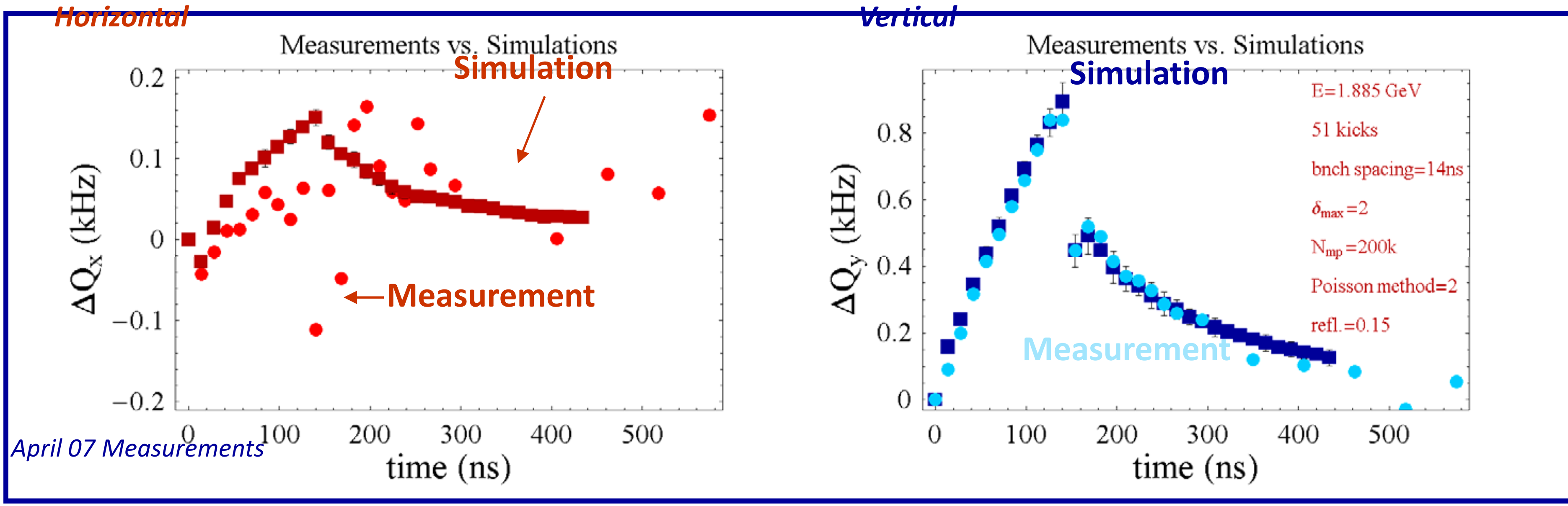
… but in dipoles nonlinear effects become apparent at larger amplitudes





Positron beam

With appropriate choice of parameters simulations can reproduce measurements closely in vertical plane



- Agreement measurements *vs.* simulations looks good in y less so in x.
- But:
  - Shown simulated tuneshift includes contribution from ecloud in all dipoles and drifts spaces (it does not include contribution from any other elements)
  - Other elements (quads, wiggler, sext …) occupy ~50% of total drift space (if they behave like drifts add ~0.25kHz and ~0.05kHz to top values of ΔQ_y and ΔQ_x)

Note: in figs above data points for time <=126ns are for the 10-bunch train; others are for witness bunches

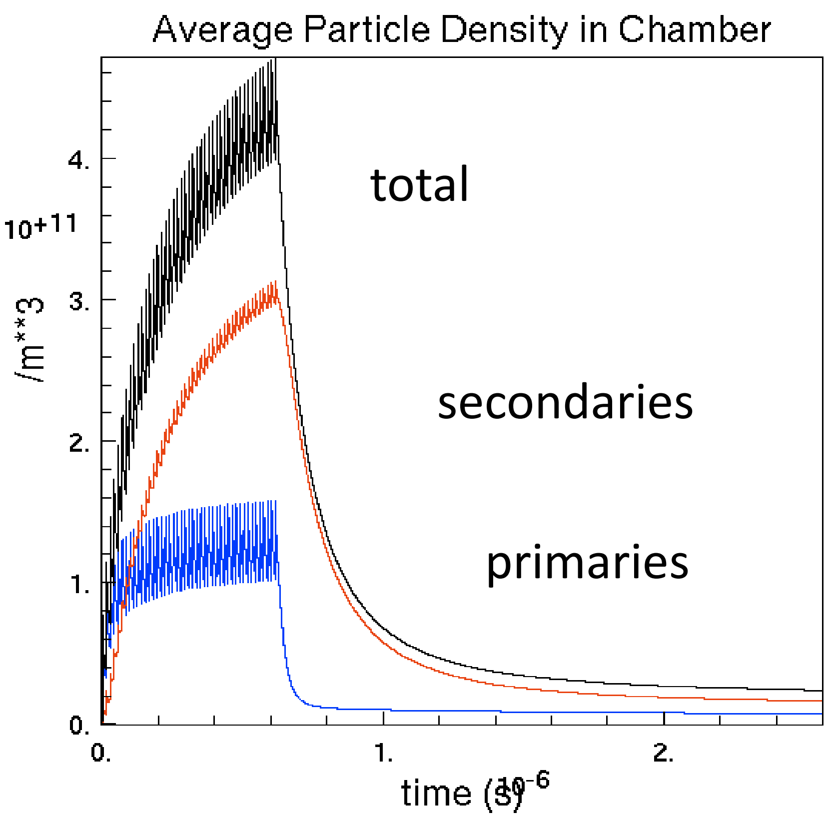
Our 3D Code, WARP-POSINST, is being used to simulate CesrTA experiments

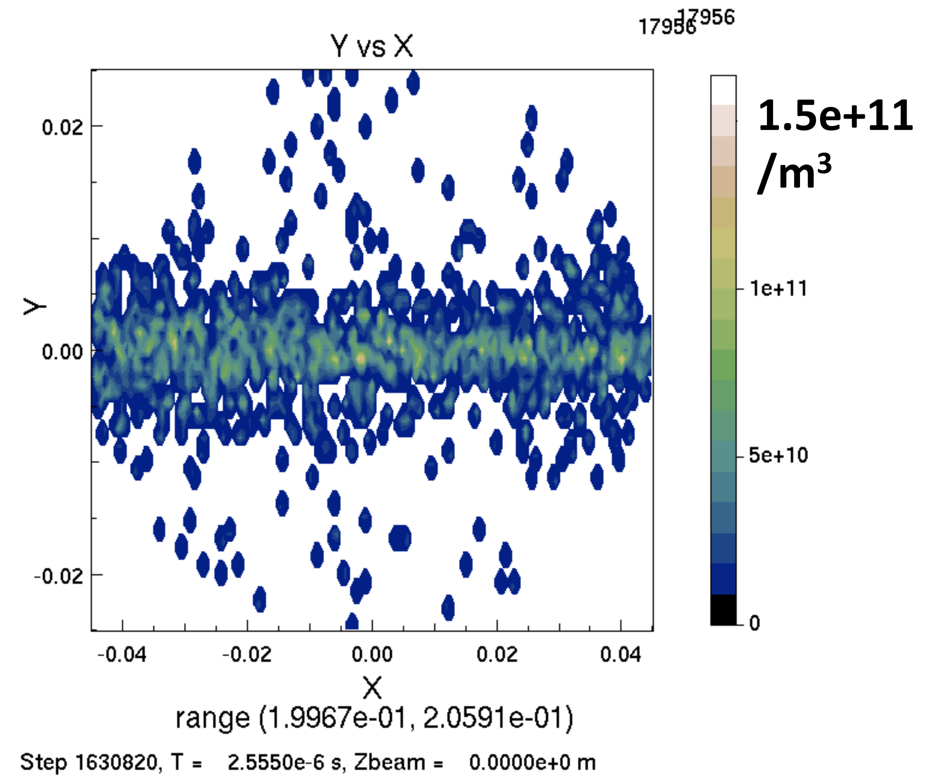
- Goals:
- Simulate ecloud formation & effect on beam in CesrTA wiggler. Investigate role of cyclotron resonances.
- Where we are:
- - Investigating ecloud formation with 3D particle-in-cell code, using CesrTA parameters and wiggler field
- - Simplifications at present:
- cyclotron resonances not resolved yet in z (requires extremely fine resolution ~ μm)
- beam bunches do not evolve
- - Interesting and complicated results starting to come out
- What next?
- - Understand movement of electrons in 3D, and cloud generation
- - Vary parameters to try to fit data
- - Resolve cyclotron resonances

After time for 1 turn of 45-bunch train, electrons remain at B_y=0

Total number of electrons vs. time

Density in x-y Plane at z where B_y=0

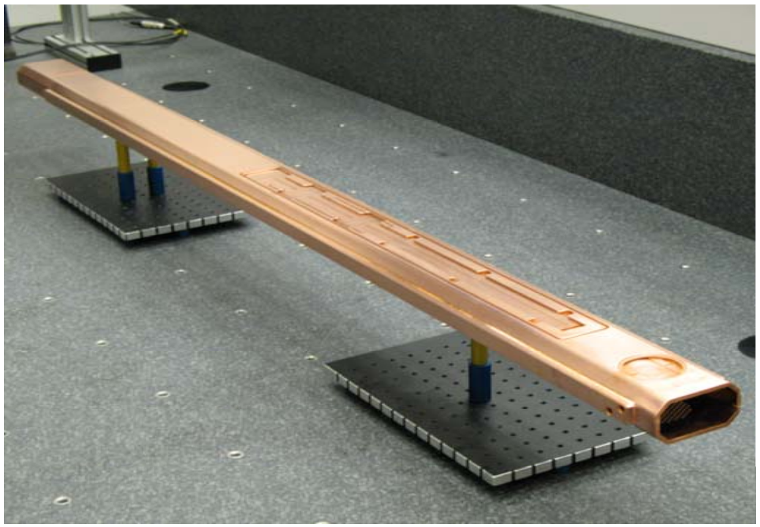




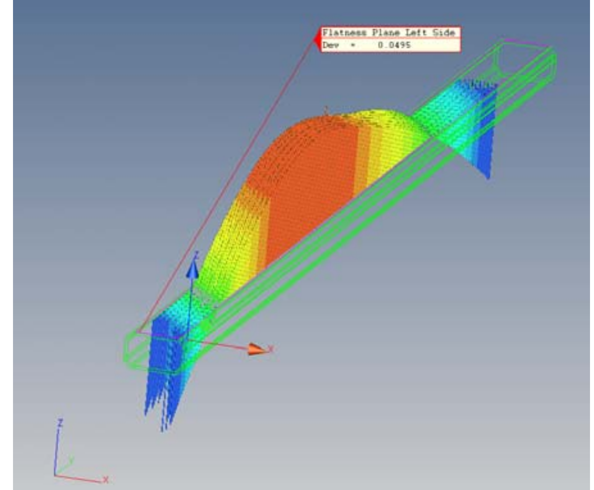
No electron cloud remains at z of peak B_y

Wiggler chambers fabrication

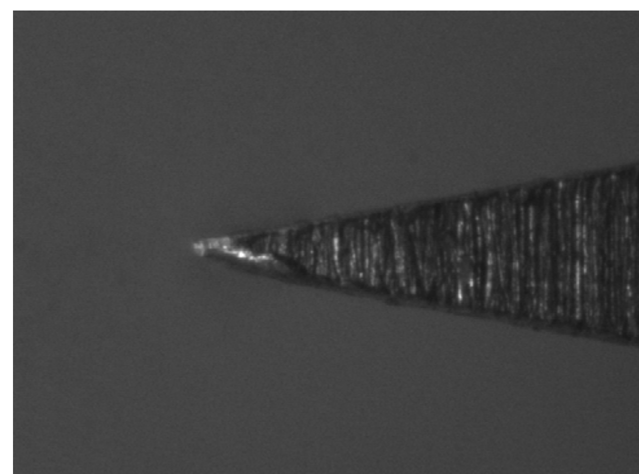
CHAMBER WITH RFA HOLES AND COOLING CHANNELS



FLATNESS MEASUREMENT



GROOVE TIP DETAIL



Fabrication of 4 instrumented wiggler vacuum chambers for testing of e-cloud mitigating techniques: reference, coating (TiN), grooves, clearing electrode.

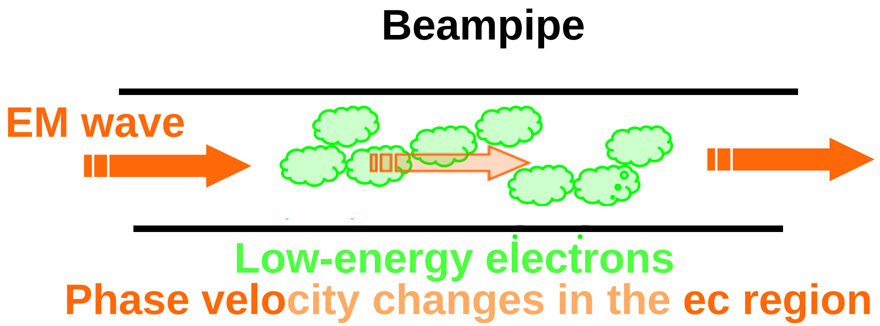
First two chambers already delivered.

TE-Wave Measurements

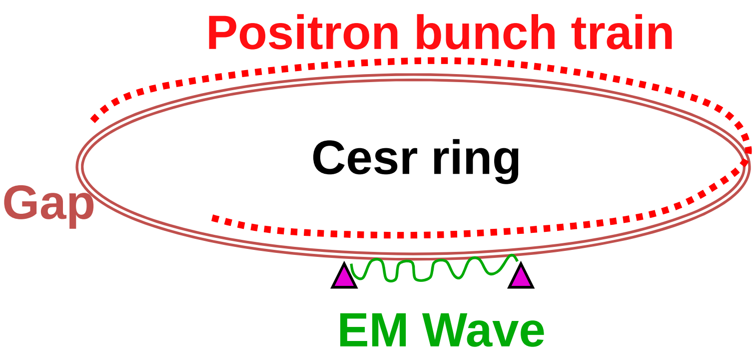
- New set of measurements taken in January
  - New instrumentation hardware. Dipole and wiggler measurements.
- Implementation of new techniques
  - "Resonant-wave" measurement. Phase detector.
- Applications
  - Comparison with RFA measurements; primary vs. secondary electron contribution (e^- vs. e^+ beam); dependence on vacuum chamber shape (CLEO E vs. W); cyclotron resonance; dependence on total beam current, bunch current, train length.

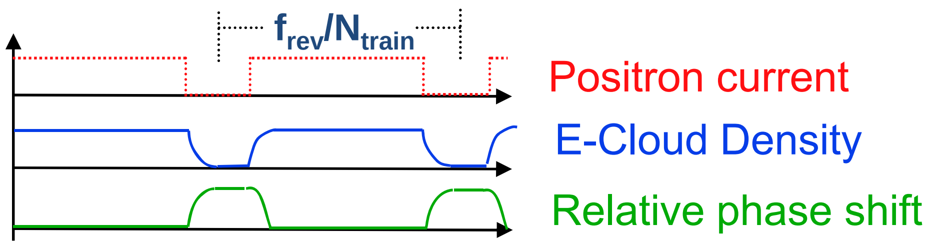
TE-Wave Method for Electron Cloud Density Measurements

Induced phase modulation in the propagation of EM waves through the beampipe



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





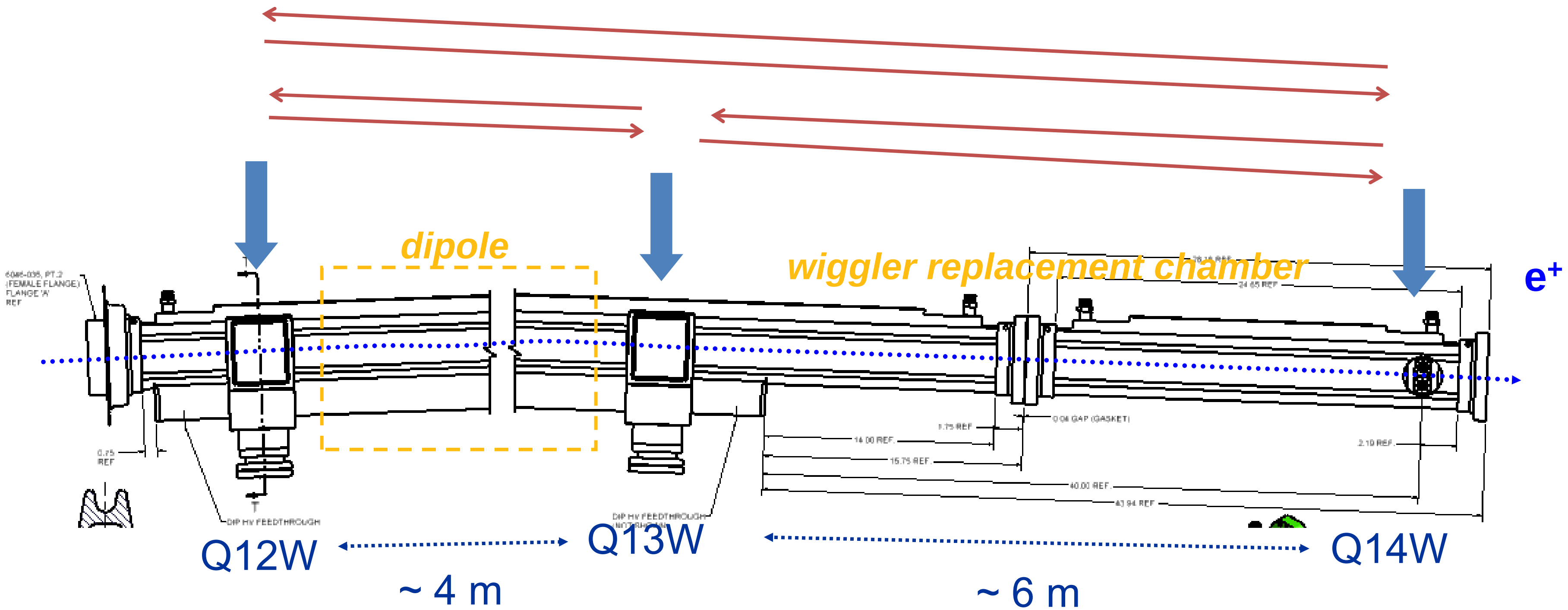
Gaps in the fill pattern set the fundamental modulation frequency (1st sideband). Higher order components depend on the transient ecloud time evolution during the gap passage.

Transmitter/Receiver Positions (*g-line*)

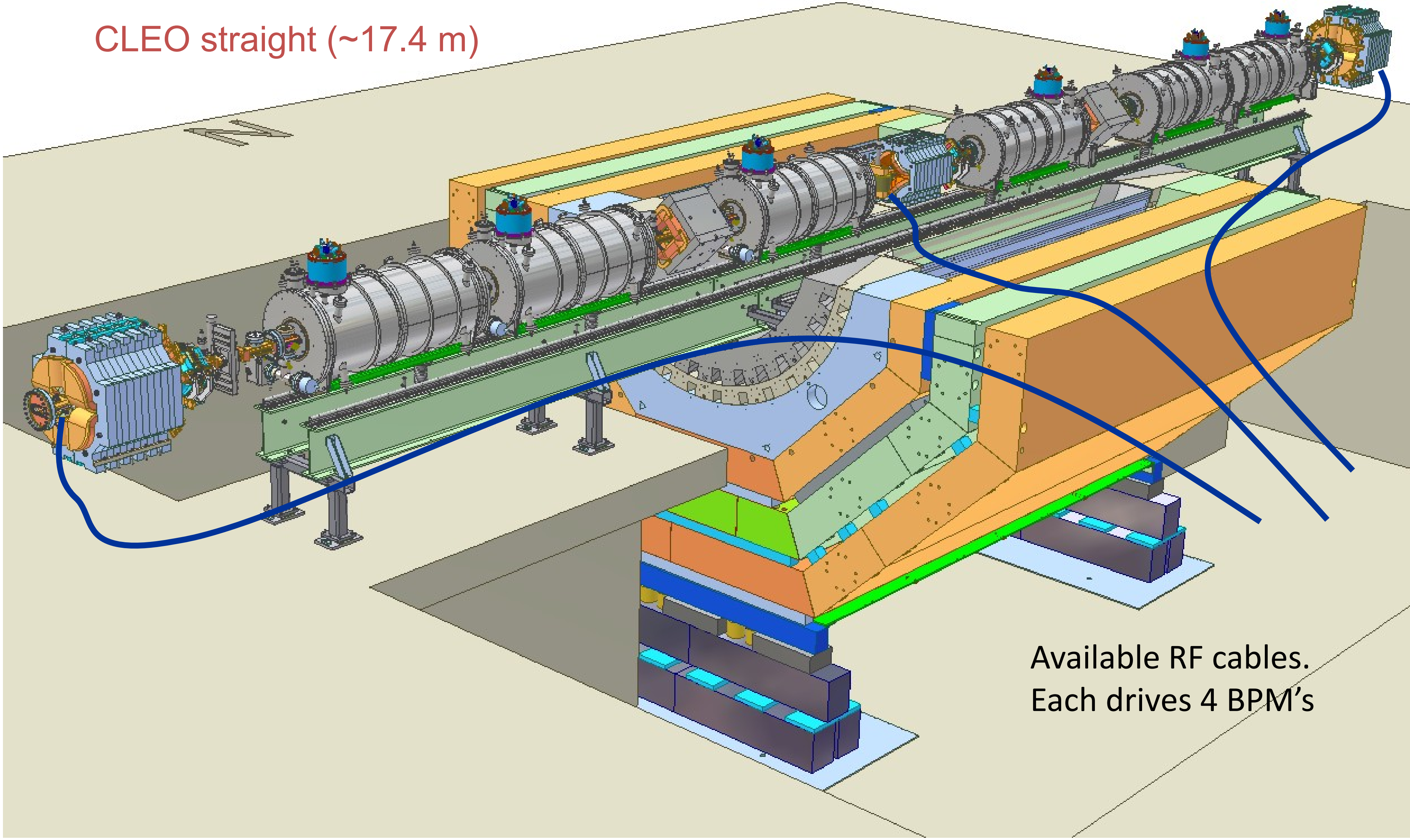
We had 3 BPM available for the measurement, to be used either as transmitting or receiving port.

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.

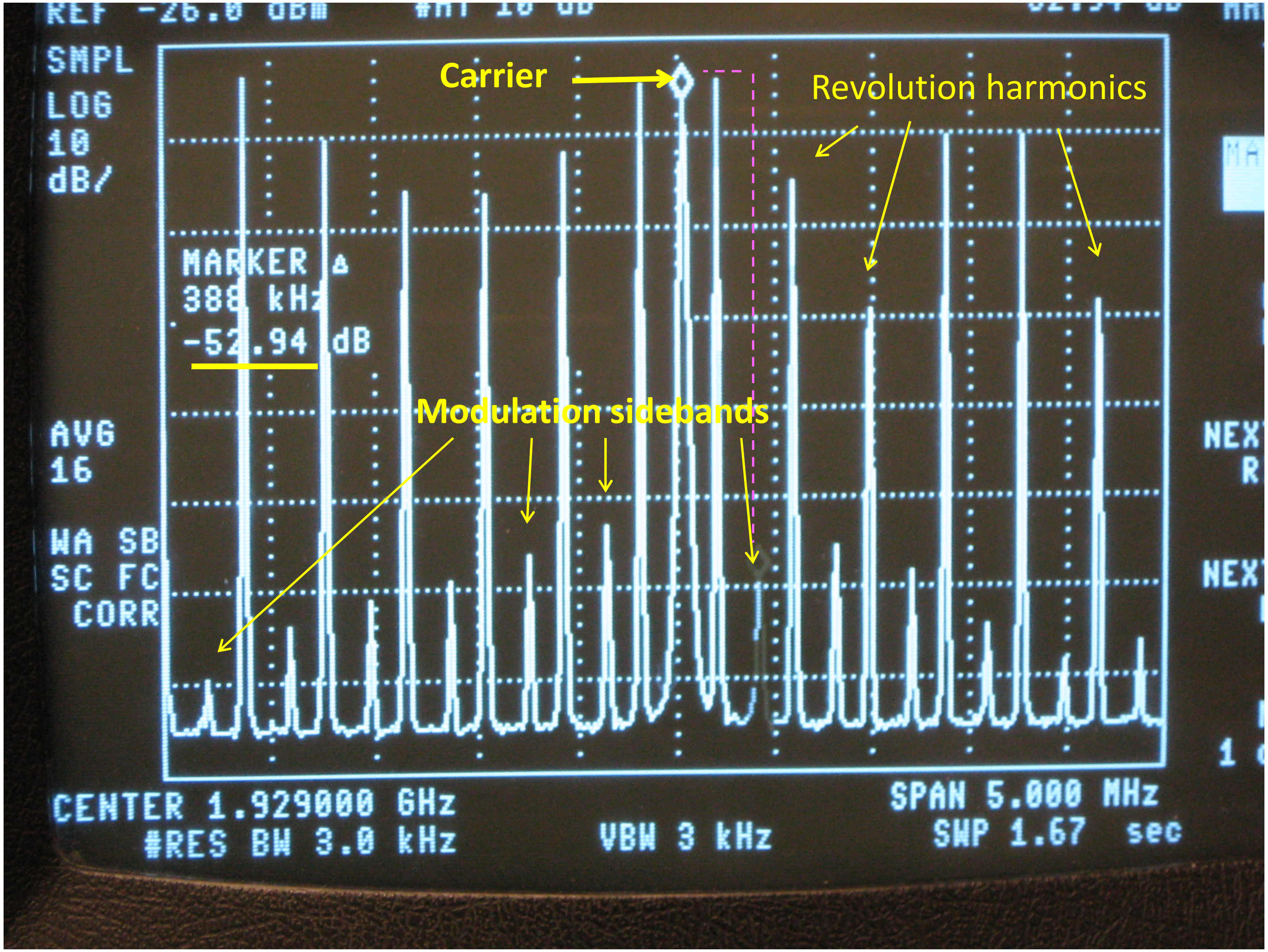
The measurements were taken at both 2.0, with a variety of fill patterns.



Transmitter/Receiver Positions (*L0*)



Example of received signal



EM field generation

↓

Signal detection

↓

Phase shift

↓

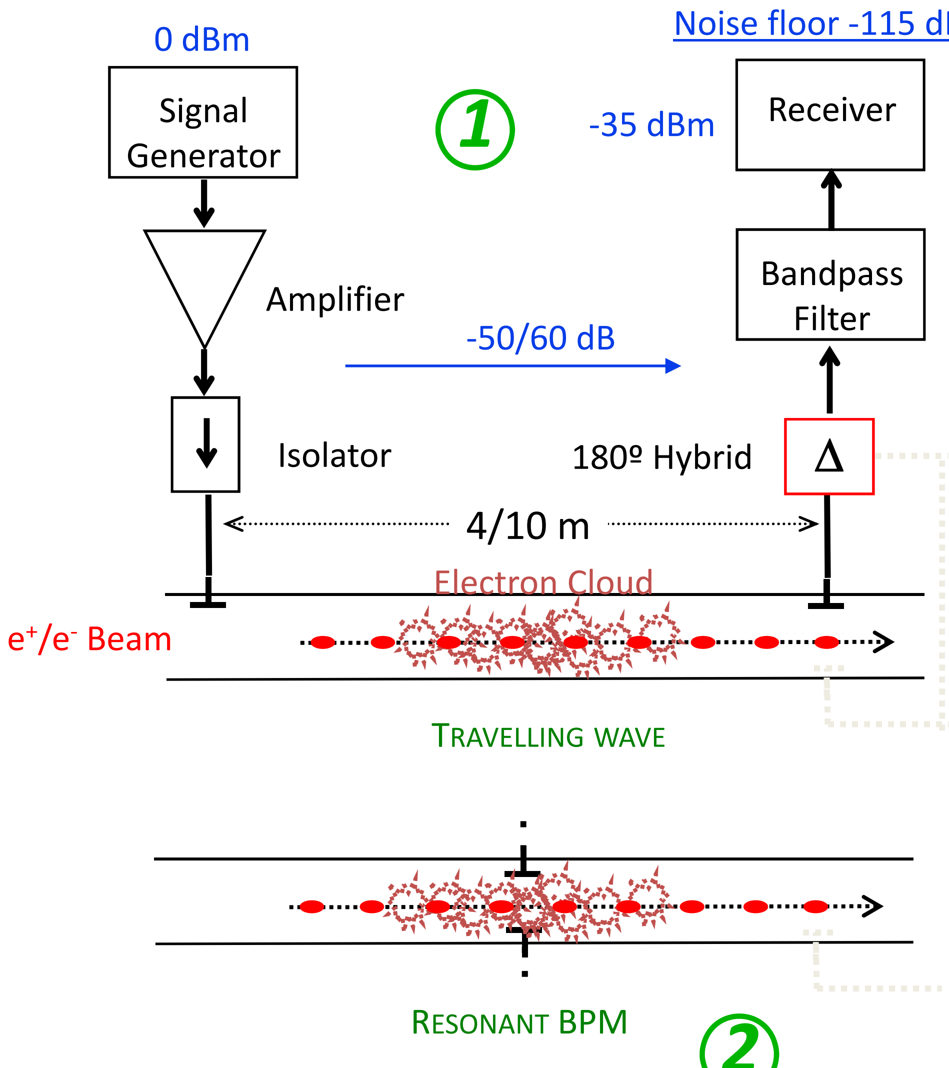
e-cloud density

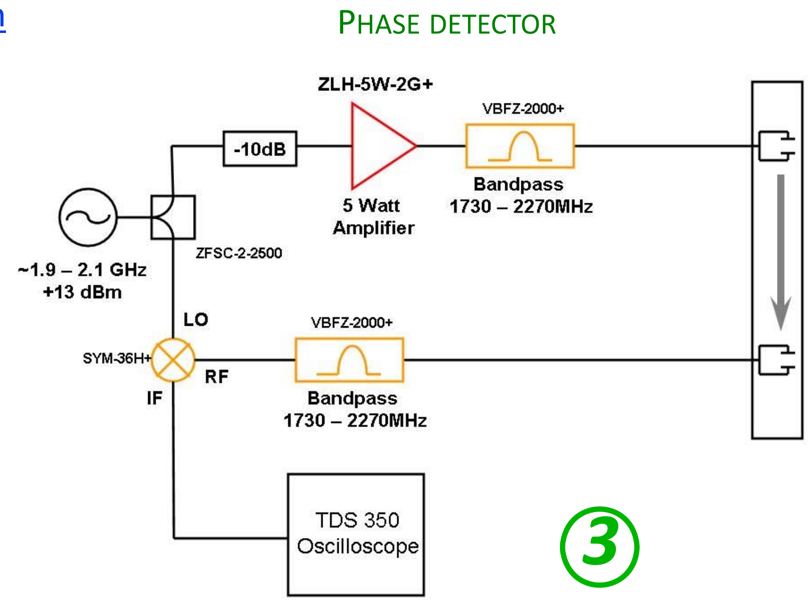
Signal attenuation
S/N ratio (direct beam signal !)
Frequency resolution

Time dependence of ECD
AM component

Longitudinal distribution
Transverse distr. (B field !)
Electron plasma temperature
Effects of gap length
Wave reflections, etc.

Phase shift detection methods





Signal attenuation
S/N ratio (direct beam signal !)
Frequency resolution
AM component

Filtering, more sophisticated receiver and transmitter, vector meas., alternative schemes (2,3)

Effect of ECD Time Dependence

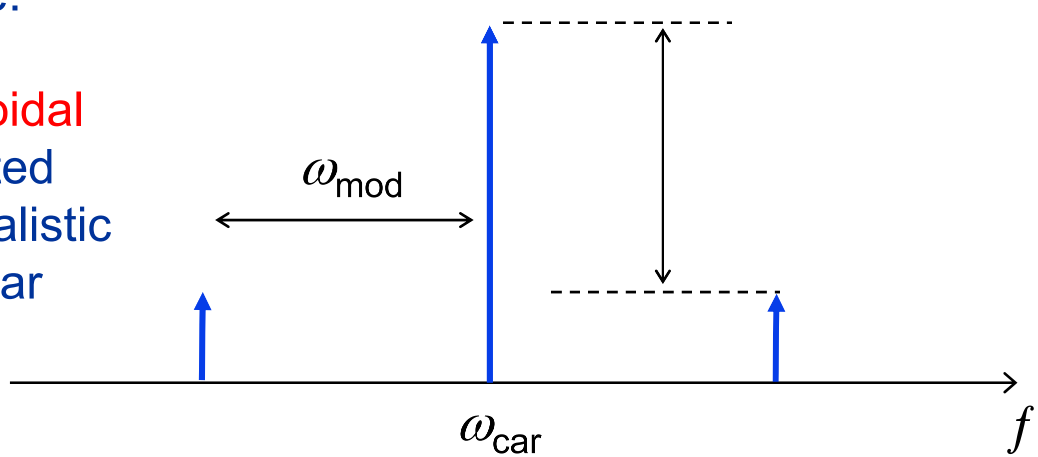
The *periodic clearing of the electron cloud* by the gap, when it passes between our Tx and Rx BPM's *phase modulates the transmitted signal*:

- 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 ?

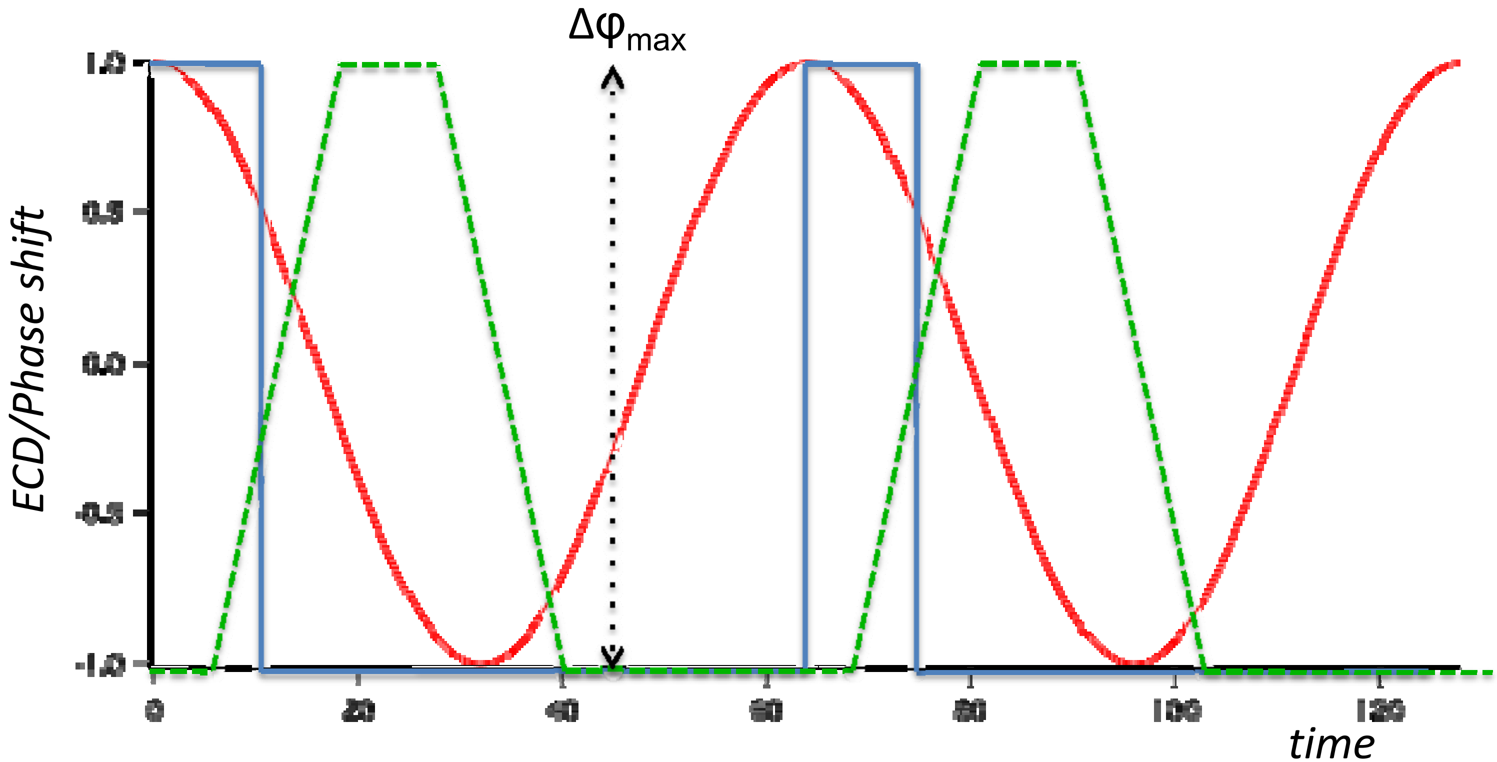
Amplitude modulation ? (Caspers)
At very low modulation depth AM and PM are undistinguishable.

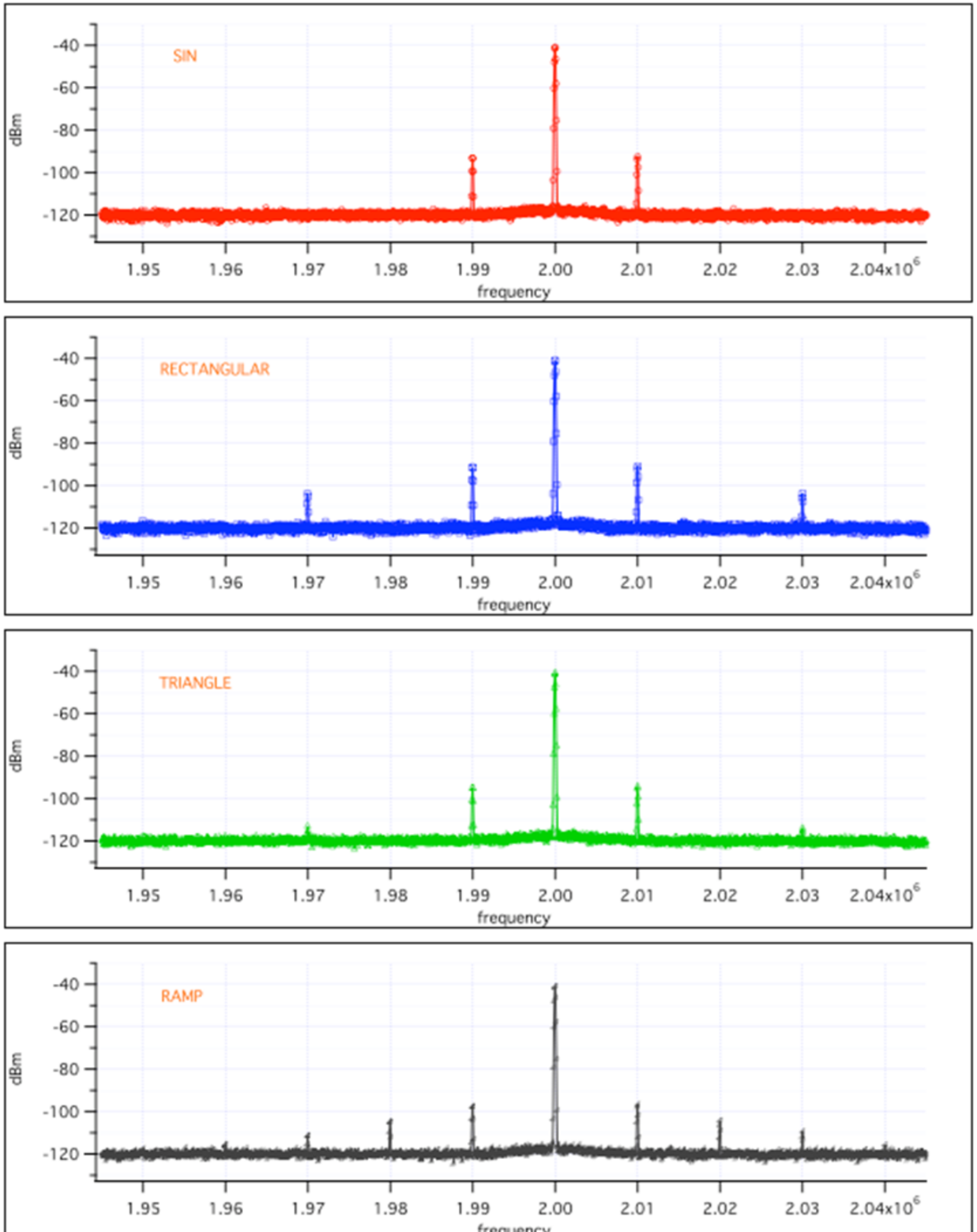
$\beta = \Delta\varphi/2$ is valid only for sinusoidal modulation. We have calculated correction factors for more realistic modulating signals (rectangular wave, sawtooth,…)

If



Different time evolutions of the electron cloud density correspond to different modulation spectra, even though they have the same modulation depth (i.e. maximum value of the ECD)

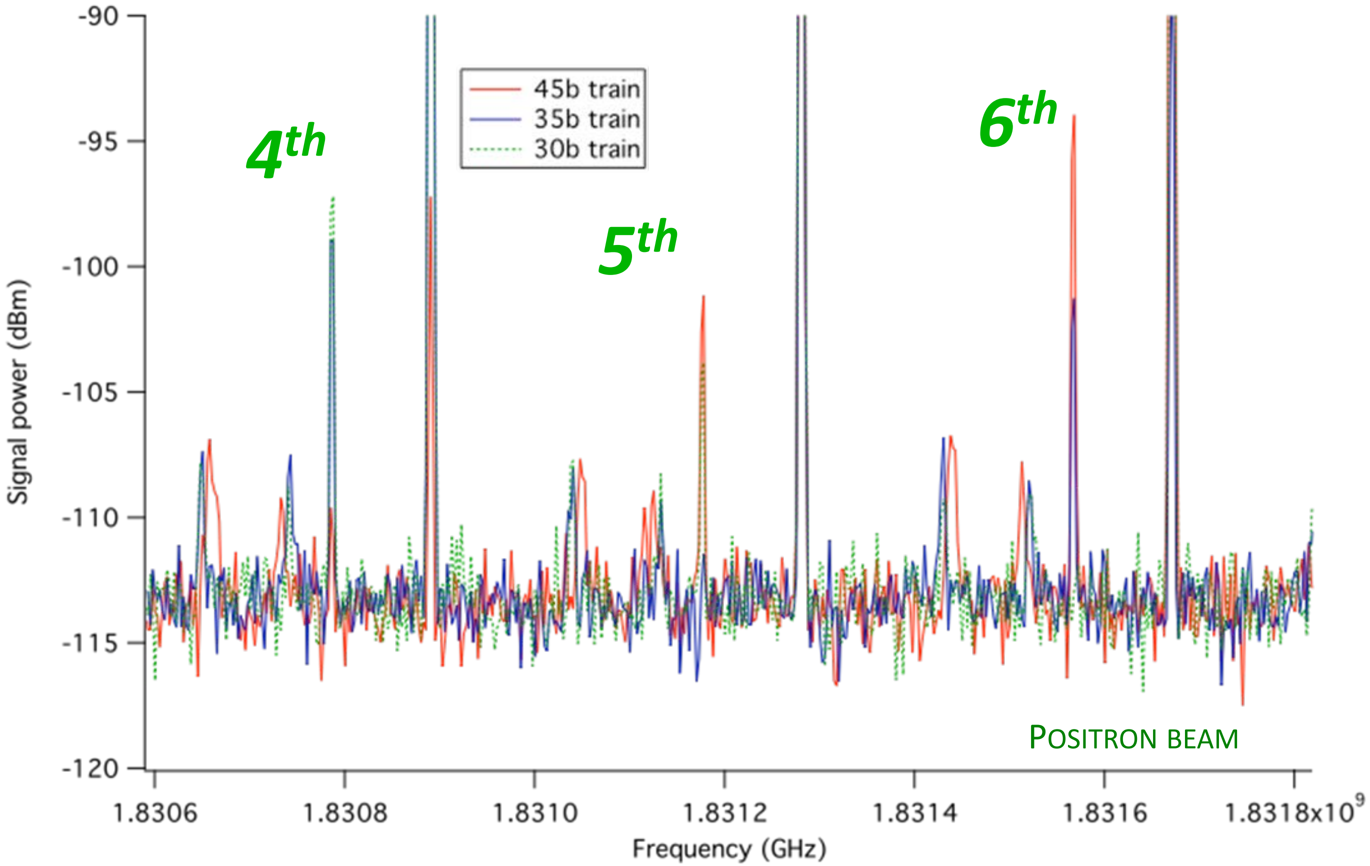


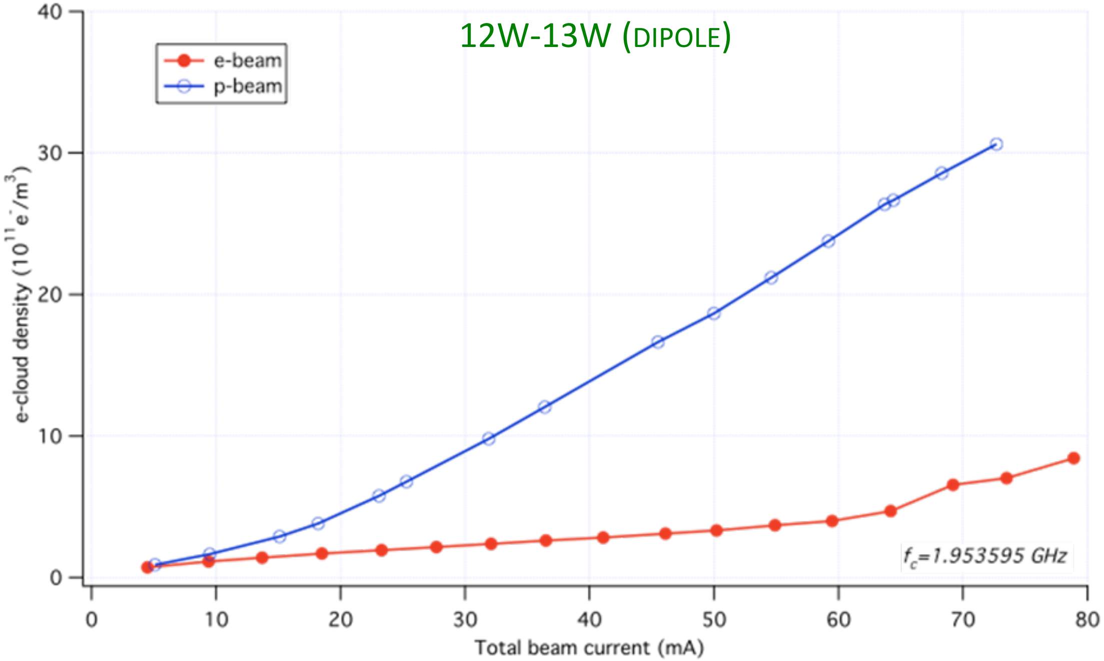


Knowledge of the modulating function shape allows to calculate the sideband amplitude corresponding to a given modulation depth.

Different modulation types produce different sidebands. Correction factors can be calculated.

For a rectangular modulation the n-th sideband is null when n=period/dutycycle





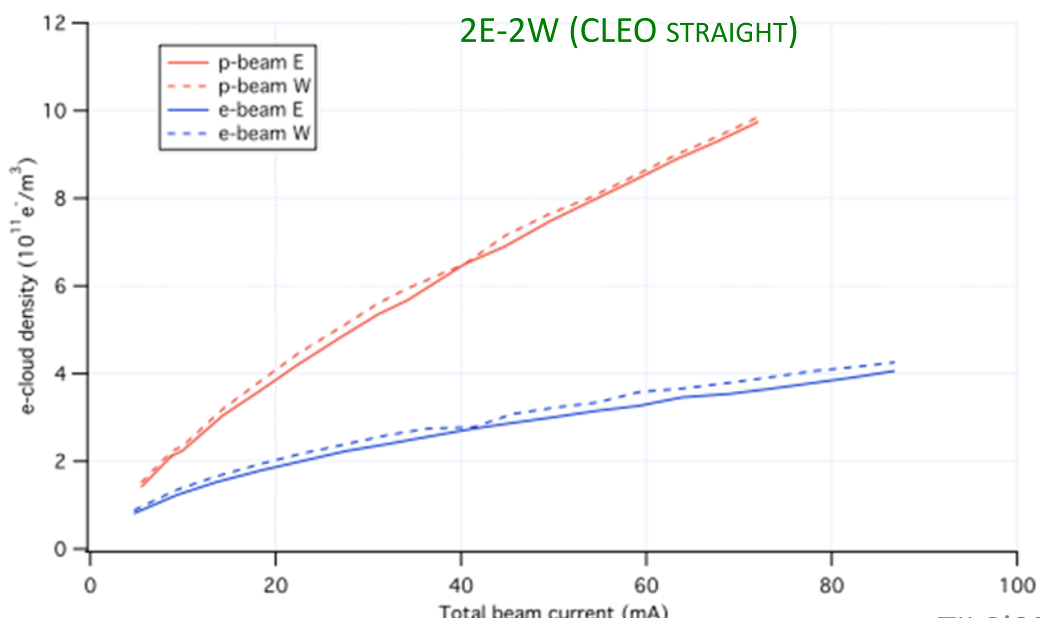
MODULATION FACTOR

45-bunch train (14 ns)

1 mrad ≈ 10^{11} e^-/m^3

Sensitivity: 2•10^9 e^-/m^3 (SNR)

Wave transmitted from the center of the straight and switched to its E and W ends.

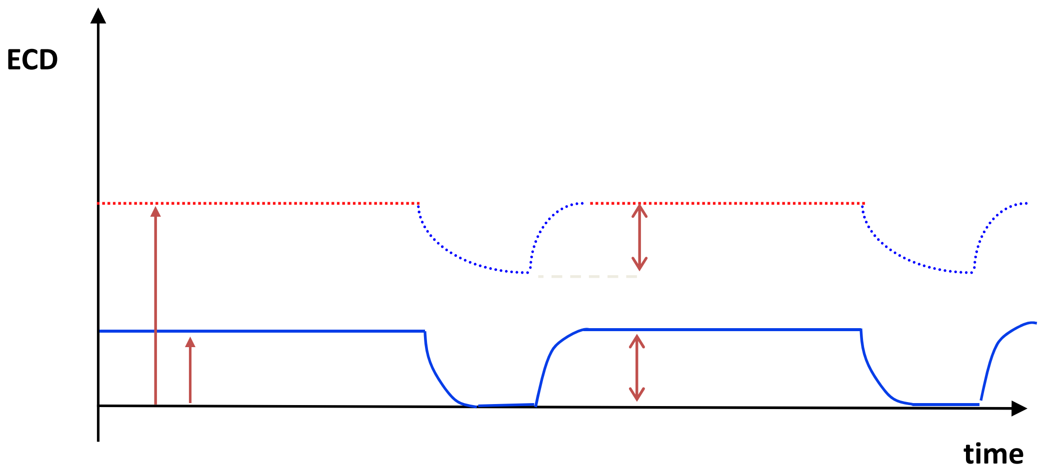


45-bunch train (14 ns)

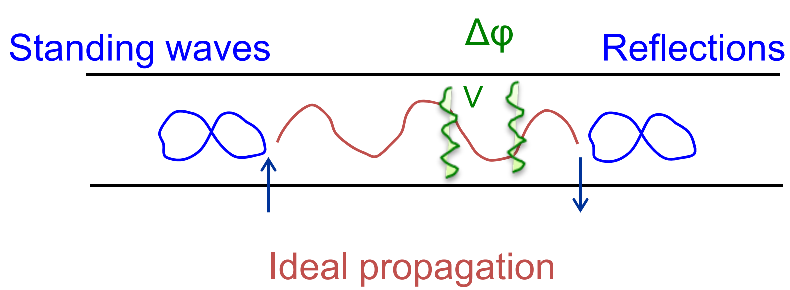
1 mrad ≈ 5•10^{10} e^-/m^3

Sensitivity: 1•10^9 e^-/m^3 (SNR)

Effect of Gap Length, Reflections and Obstacles



Much larger electron cloud density, but same modulation depth. The gap is not long enough to completely clear the low energy electrons in the ----- case and the signal observed is about the same for two very different densities. Gap length studies, if possible, can help correct for this effect.



Reflections can increase effective propagation length, without us knowing it!
Obstacles can add to the phase shift.

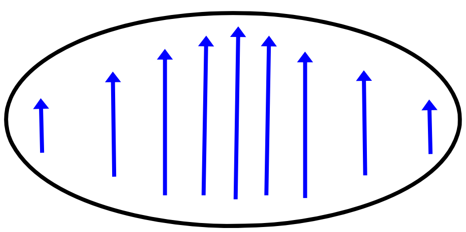
Propagation in a real accelerator environment is not simple. Detailed computer modelling, resonant BPM scheme and time-domain measurements can help

Effect of ECD transverse Distribution

Same average ECD can produce very different phase shifts

no magnetic field *strong vertical magnetic field*

Different transverse distribution of the ECD. Formulas assume a uniform value, but dipole fields can concentrate low energy electrons in the centre of the pipe.



TE wave E-field

Furthermore, the ECD distribution is “sampled” by the TE field which is not uniform over the pipe transverse section: Conditions in the pipe centre count more towards the overall phase delay.

Propagation in a Warm Plasma

The formula usually used to calculate the average e-cloud density from the plasma frequency is valid for a cold plasma

This can be seen as a new term in the propagation constant

Its effect seems to be on the order of just a few percent, from initial estimates.

Summary

- A number of effects can affect the measurement of the e-cloud density based on the propagation properties of EM waves in the vacuum chamber.
- We have already found a variety of solutions for eliminating several of them and other are under study.
- Comparison with computer simulations and the results of other measurement methods, when they are available, is beneficial. In any case, the TE wave method can at least give relative quantitative measurements of the e-cloud density in a large number of locations around the ring.