Cross-Calibration of Three Electron Cloud Density Detectors at CESRTA

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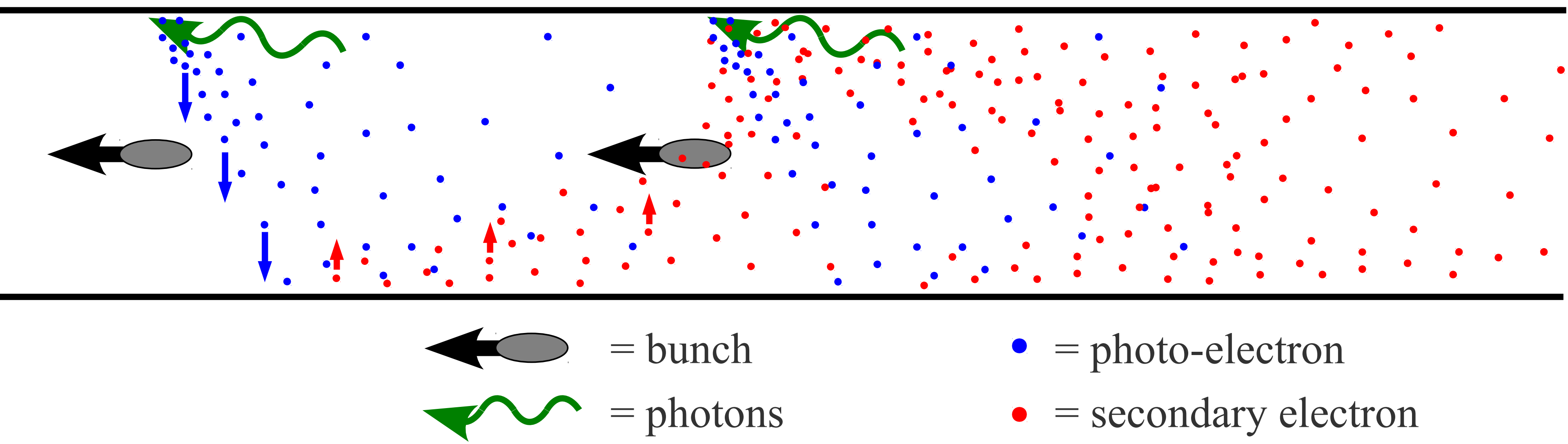
Example: Electron Cloud with Two Positron Bunches

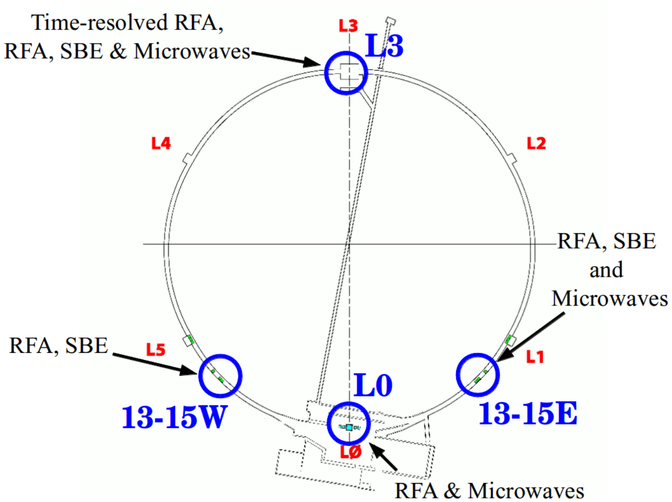


- Synchrotron radiation produces photo-electrons (blue).
- Photo-electrons generate secondary electrons (red).
- The second bunch also accelerates the electrons produced by the first bunch, giving the existing cloud some additional energy which will generate more secondary electrons.

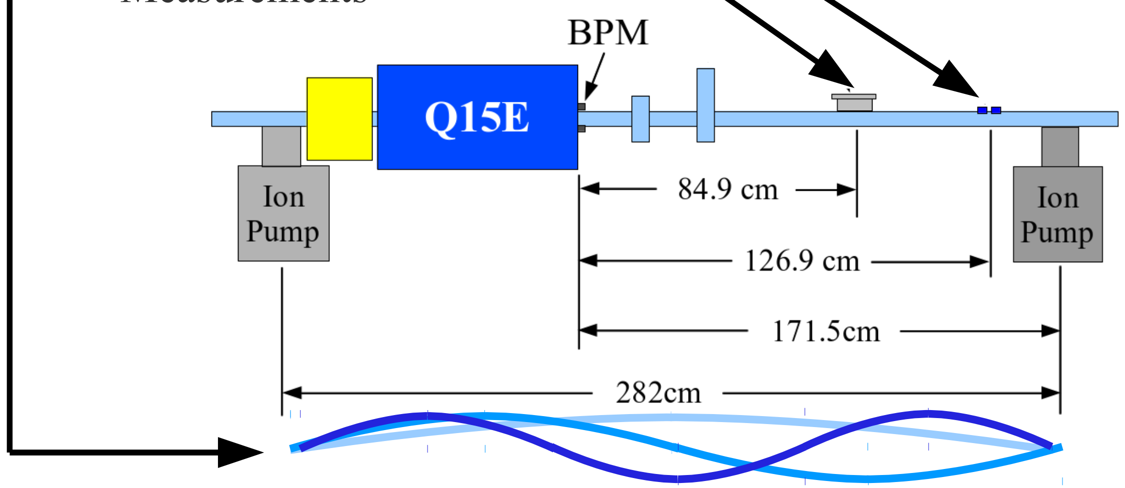
- At densities of ~10^{12} e^-/m^3, an electron cloud can produce instabilities, especially in positively charged beams.
- Simulations are needed when designing new accelerators to predict EC effects.

CESRTA: Electron – Positron Storage Ring, 1.8 → 5.3 GeV

Locations of EC Measurement
Hardware at CESRTA

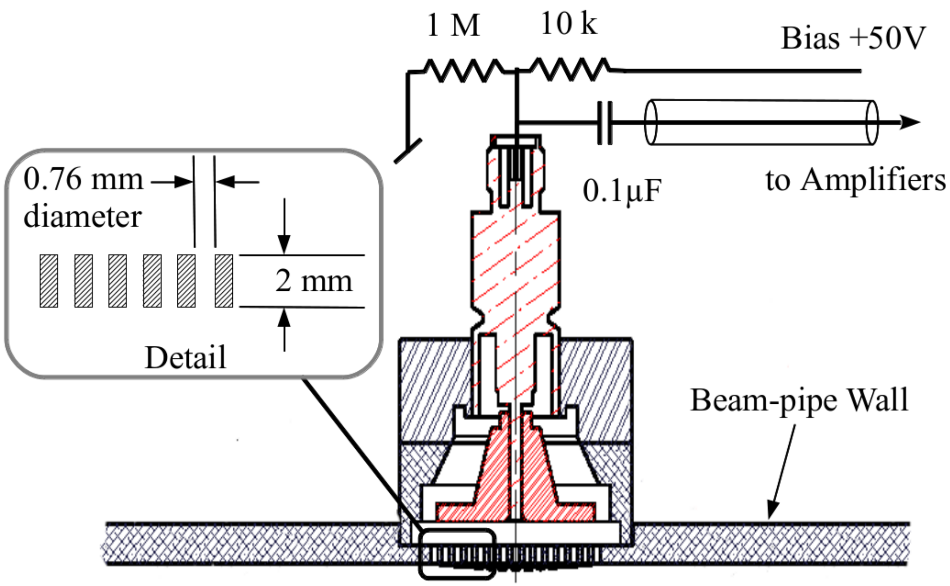


15E: Aluminum Chamber with
Shielded Button Electrode (SBE)
Retarding Field Analyzer (RFA)
And
Resonant Microwave
Measurements

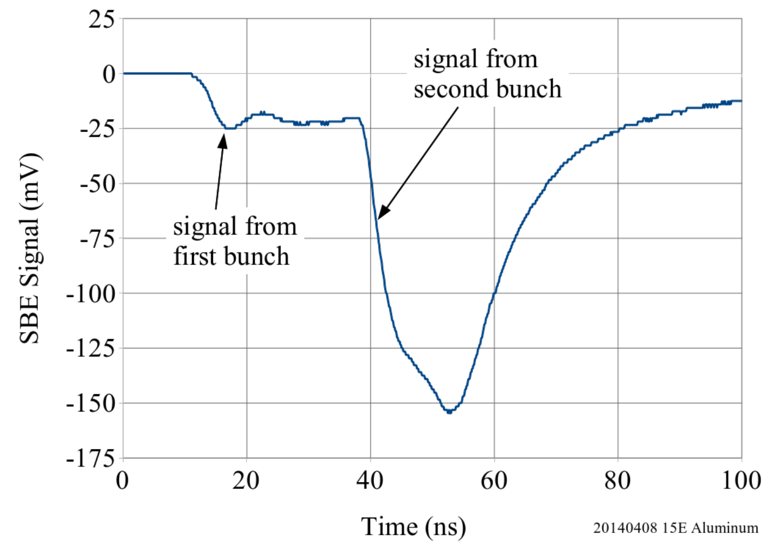


- Electron cloud simulation parameters are fit to data obtained with beam.
- Data from the Retarding Field Analyzer (RFA) are used for POSINST simulations
- Data from the Shielded Button Electrode (SBE) are used for ECLOUD simulations
- Microwaves provide an alternative measurement technique for comparison.

Shielded Button Electrode[1] (SBE)



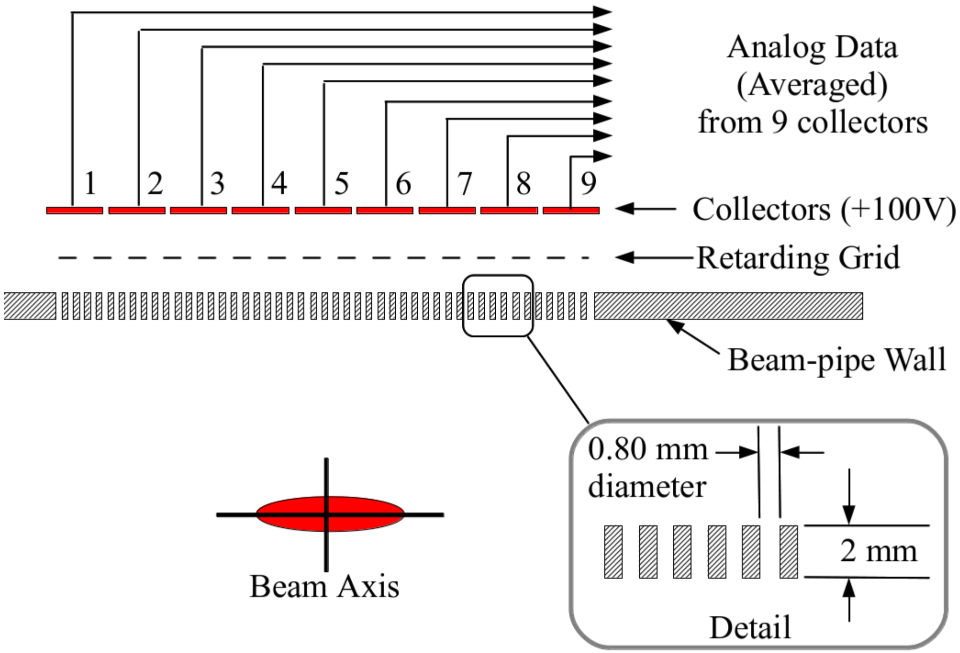
Accelerator Vacuum and Electron Cloud

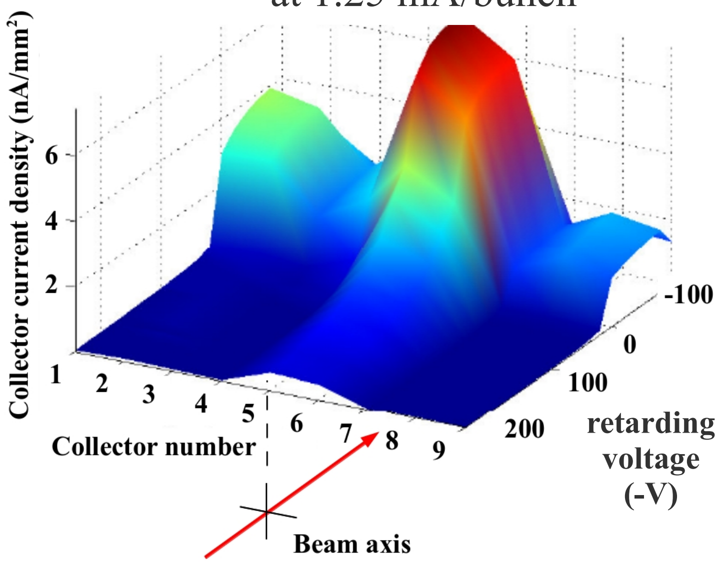


SBE data from two 5.3 GeV positron bunches 28 ns apart at 4.8 x 10^{10} e^{+}/bunch (3 mA/bunch).

- The SBE samples the flux of electrons onto the beam-pipe surface.
- Electrons pass through an array of small holes onto a positively biased collector.
- The SBE collector signal is amplified by +20 dB and recorded with an oscilloscope.
- The signal with two equally populated 5.3 GeV positron bunches is shown.

Retarding Field Analyzer[2] (RFA)





- The RFA also samples the flux of electrons onto the beam-pipe surface using a horizontal array of nine collectors.
- There is a retarding grid that can be biased to reject lower energy electrons.
- The signal is time-averaged to give a DC current measurement on each collector.
- A typical plot is shown, with the collector currents plotted vs. retarding grid voltage.

Challenges in Connecting Simulation with Measurement

• The SBE and RFA need simulations in order to obtain an EC density from the data. The SBE uses ECLOUD simulations; the RFA uses POSINST simulations.

•There are many physical parameters.

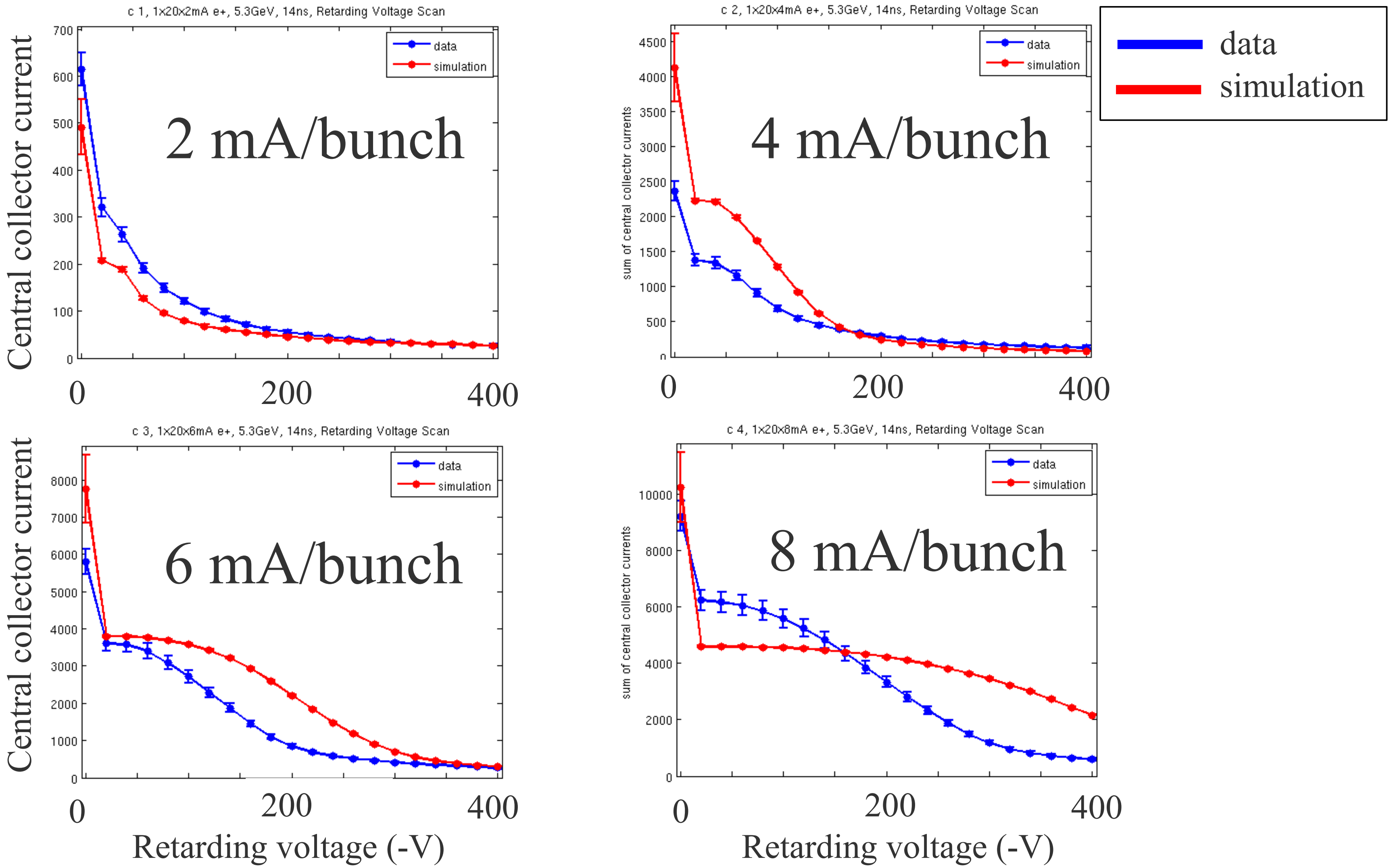
- Photon distribution including scattering
- Quantum efficiency with angular and energy dependence
- Secondary yield components with angular and energy dependence

• The full simulation includes the electron cloud buildup AND the detector response.

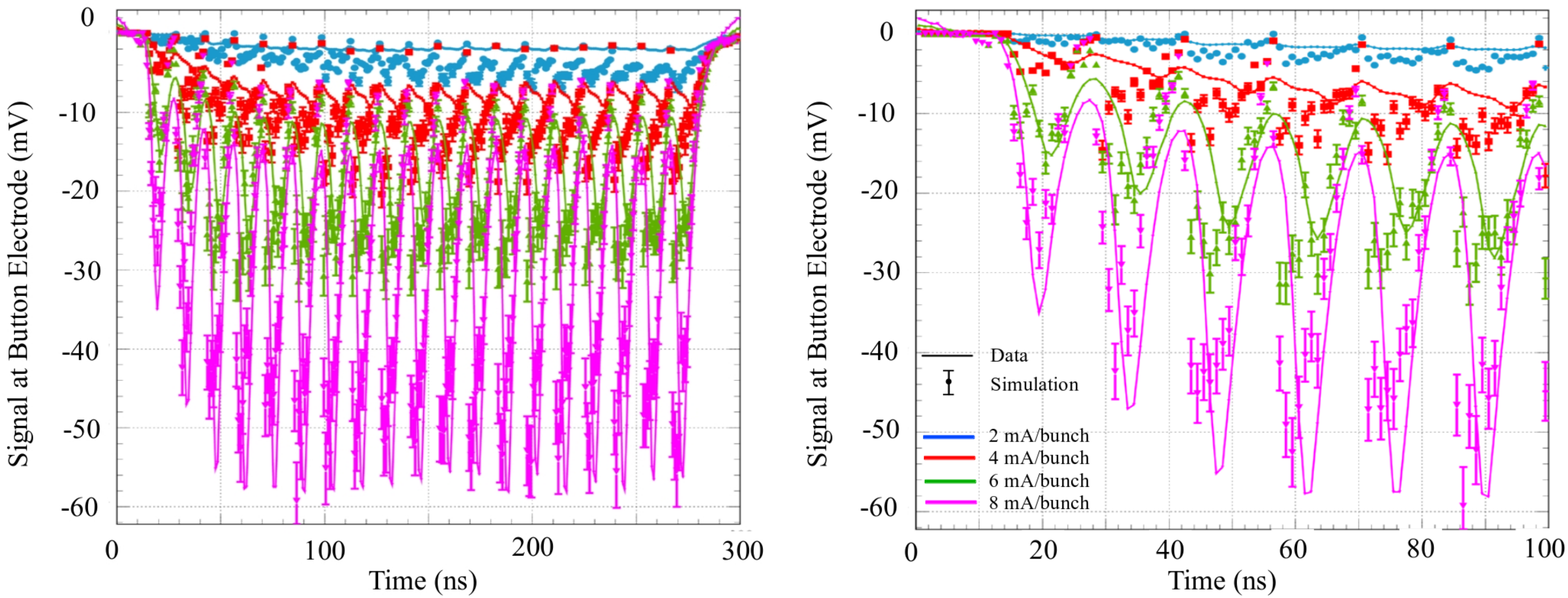
- The detector response depends on the trajectories of the electrons.
- Secondary electrons are produced in the holes, which increases the signal.

• As a result, fitting the simulation parameters to the data is not straightforward.

POSINST: Simulation Fit to 20-bunch RFA Data

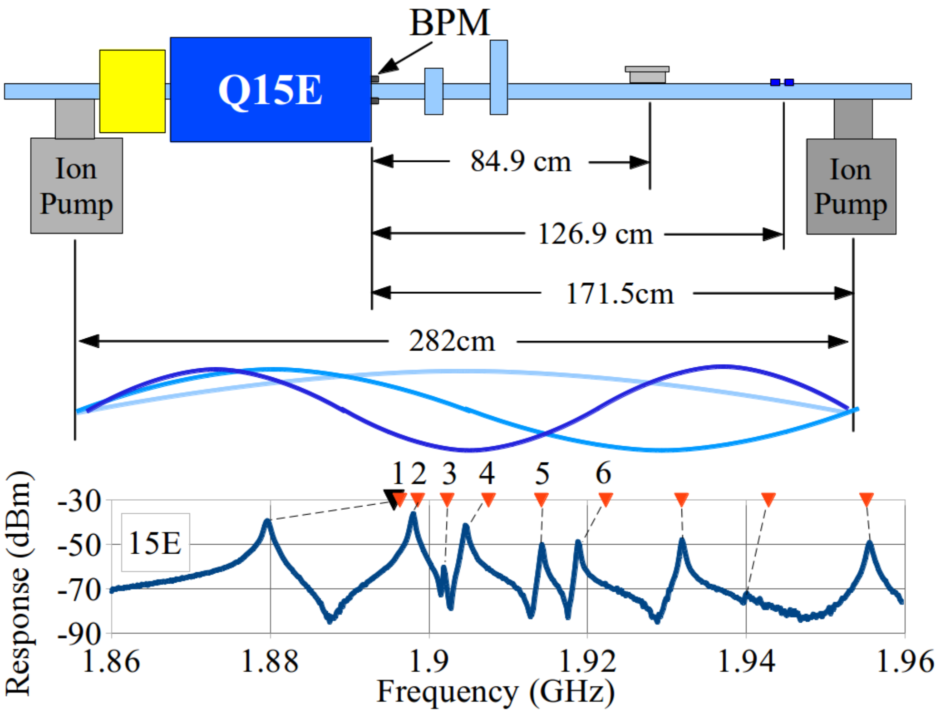


ECLOUD: Simulation Fit to 20-bunch SBE Data



- The ECLOUD fit to SBE data is reasonable at the highest beam current, but at lower beam currents the simulation is higher than the data.

Resonant Microwave Measurements[3]



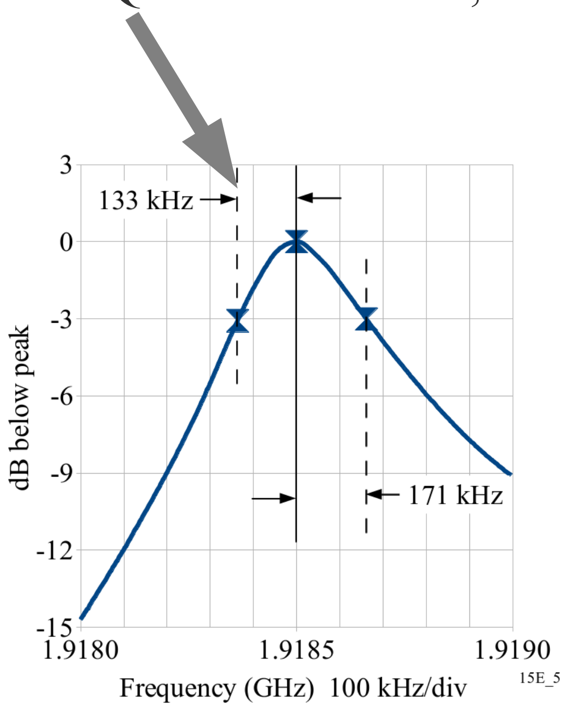
Electron Cloud Density

$$\frac{\Delta\omega}{\omega_0} \approx \frac{e^2}{2\varepsilon_0 m_e \omega_0^2} \frac{\int_V n_e E^2 dV}{\int_V E^2 dV}$$

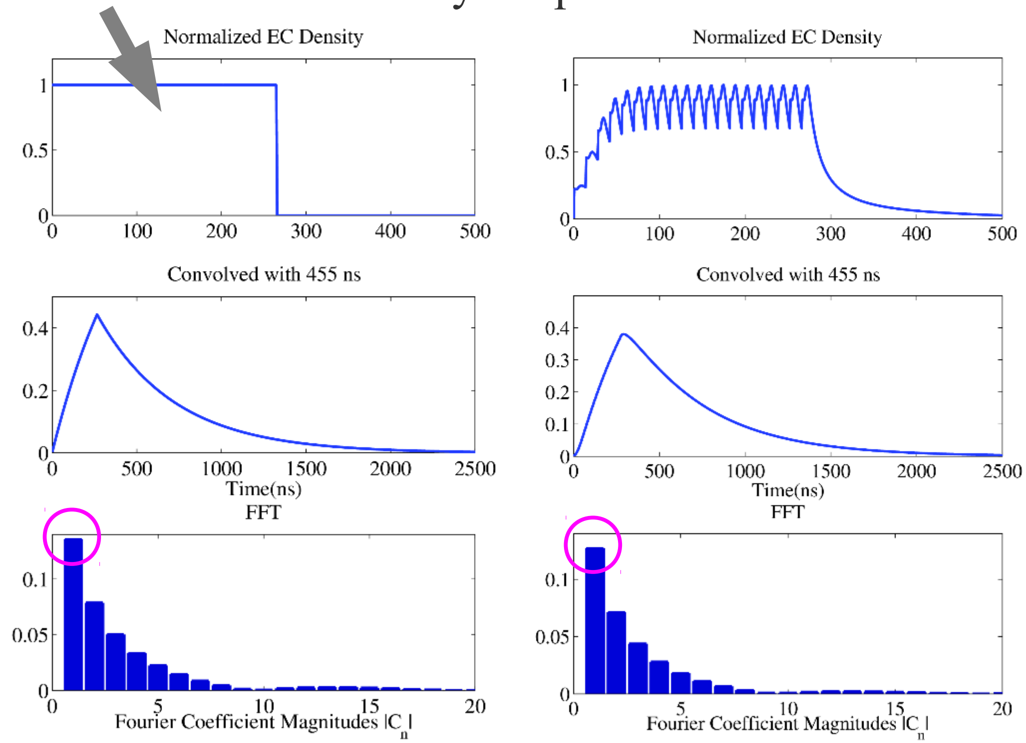
- Microwaves are coupled in/out of the beam-pipe using beam position monitor (BPM) buttons.
- Reflections from longitudinal slots at the two ion pumps produce resonances at several frequencies.
- .The resonant frequencies will be shifted by the (periodic) electron cloud.

Challenges for Microwave Measurements

- Calculation of EC density has a number of steps:
  - Frequency shift → phase shift, convolution, Fourier components, sideband amplitudes
- Additional measurements or approximations affect the absolute calibration:
  - Q of the resonance, EC density vs. time and EC density vs. position



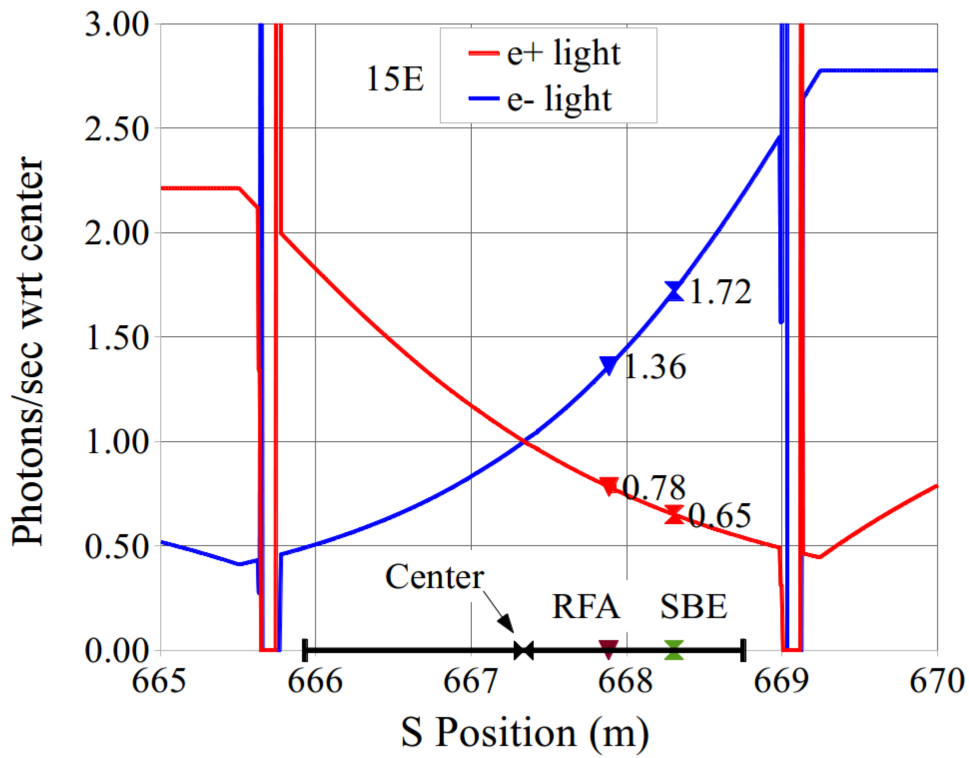
The Q affects the calibration, both in the amplitude of the sidebands and in the required convolution of the EC density.



The estimate for EC density vs. time will change the calibration through the spectrum it produces. The first sideband amplitude for the simulation at 8 mA is only about 10% lower than the value obtained using the rectangular approximation

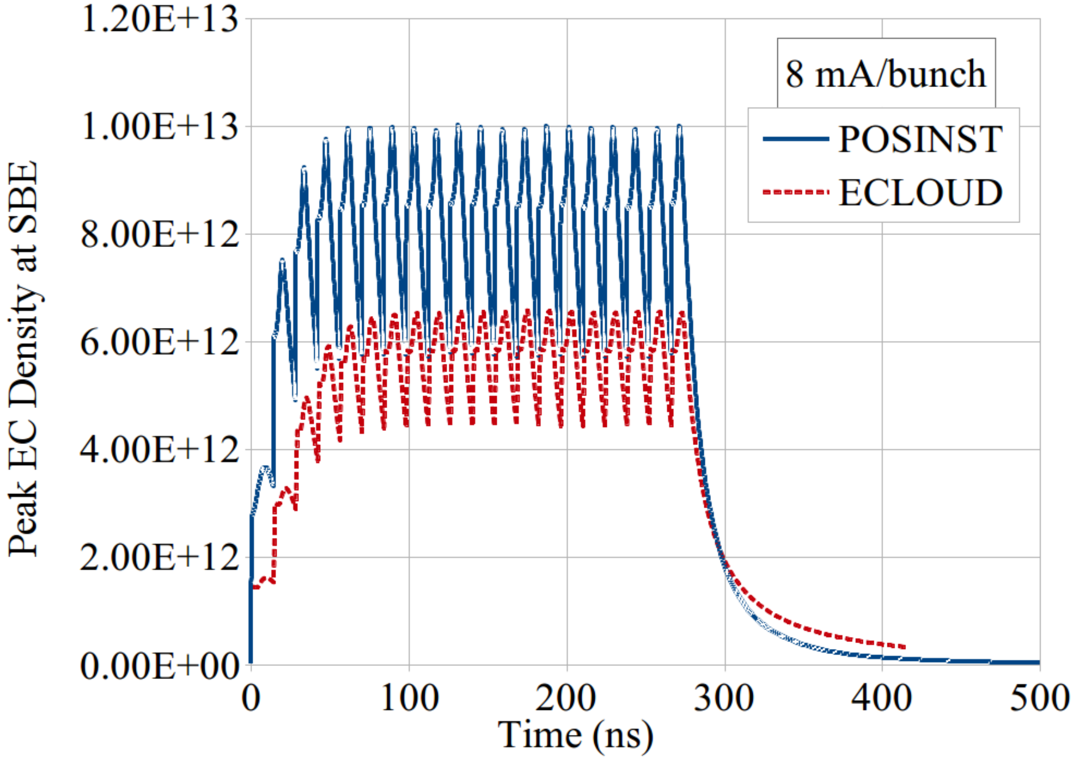
EC Density versus Position

- The three detectors are at slightly different positions and may have different EC densities.
- If the EC density is proportional to photon rate, this can be used to estimate the EC density vs. position. (This ignores the effects of magnetic fields and EC saturation at high densities).
- The RFA and SBE measurements are localized and can be scaled.
- Microwave measurements can also compensate for this effect (See WEPF21) .



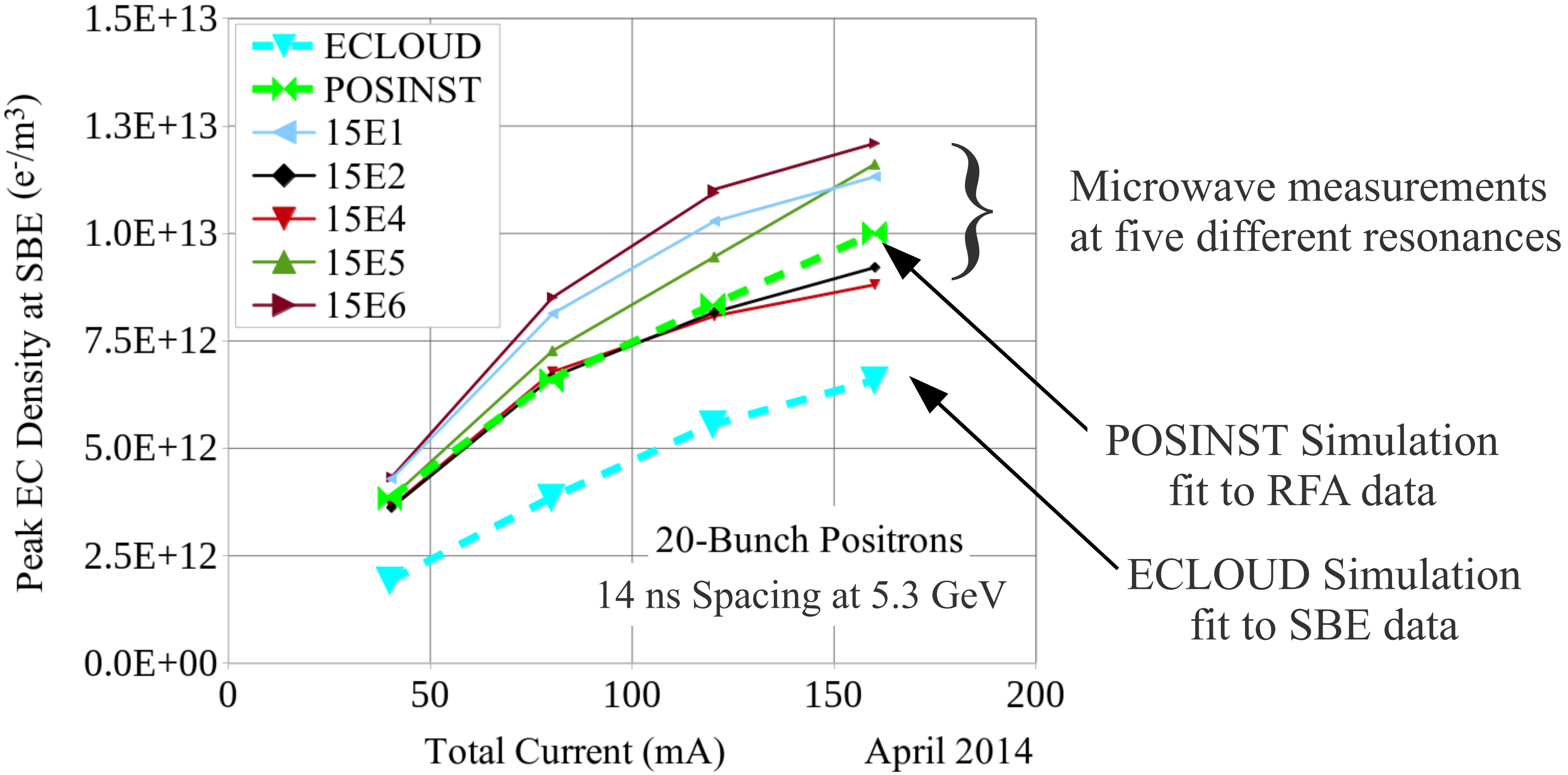
Comparison of POSINST and ECLOUD

- The EC density output from POSINST and ECLOUD are shown for simulations with a 20-bunch train of 5.3 GeV positrons at 8 mA/bunch (1.28 x 10^{11} particles/bunch).
- The POSINST value has been scaled to the position of the SBE using the SYNRAD values.



	POSINST	ECLOUD
True Secondary Yield	1.41	1.5
Rediffused	0.2	0.2
Elastic Yield	0.33	0.60
Quantum Efficiency	15%	15%

Results with All Three Detectors versus Current



- Fit ECLOUD and POSINST simulations to data.
- Microwave measurements use simulated EC density vs. time and measured Qs.
- Approximate the EC density as proportional to the local photon rate.
- Scale the density obtained by each method to the value at the location of the SBE

Summary

- When the simulation parameters are fit to the data at 15E the best fits are reasonable, but imperfect.

- Comparing the EC density obtained with the three measurements methods:
  - The simulations differ by about 40% at this beam energy and current range.
  - The microwave measurements are in better agreement with POSINST.
  - The microwave measurements vary by about 30%, depending upon the resonance.

- Future work:
  - Simulations: Continue to verify the models with data over a wide range of beam energies, bunch populations, magnetic fields and vacuum chamber surfaces. This will ensure that robust simulations are available for EC density predictions.
  - Microwaves: Need better a measurement of Q, the electric field distribution of the standing waves and estimates for the EC density vs. position. This will improve the accuracy of the technique in providing measurements of absolute EC density.

Details on these measurement techniques can be found in the following NIM/arXiv articles:

[1] **Shielded Button Electrode (SBE):**
J.A. Crittenden, *et al.*, Nuclear Instruments & Methods in Physics Research A (2014), http://dx.doi.org/10.1016/j.nima.2014.02.047, Preprint, arXiv:1311.7103 [physics.acc-ph].

[2] **Retarding Field Analyzer (RFA):**
J.R. Calvey, *et al.*, Nuclear Instruments & Methods in Physics Research A (2014), http://dx.doi.org/10.1016/j.nima.2014.05.051, Preprint, arXiv:1402.7110 [physics.acc-ph].

[3] **Resonant Microwave Measurements:**
J.P. Sikora, *et al.*, Nuclear Instruments & Methods in Physics Research A (2014), http://dx.doi.org/ 10.1016/j.nima.2014.03.063, Preprint, arXiv:1311.5633 [physics.acc-ph].

Thank you for your attention!

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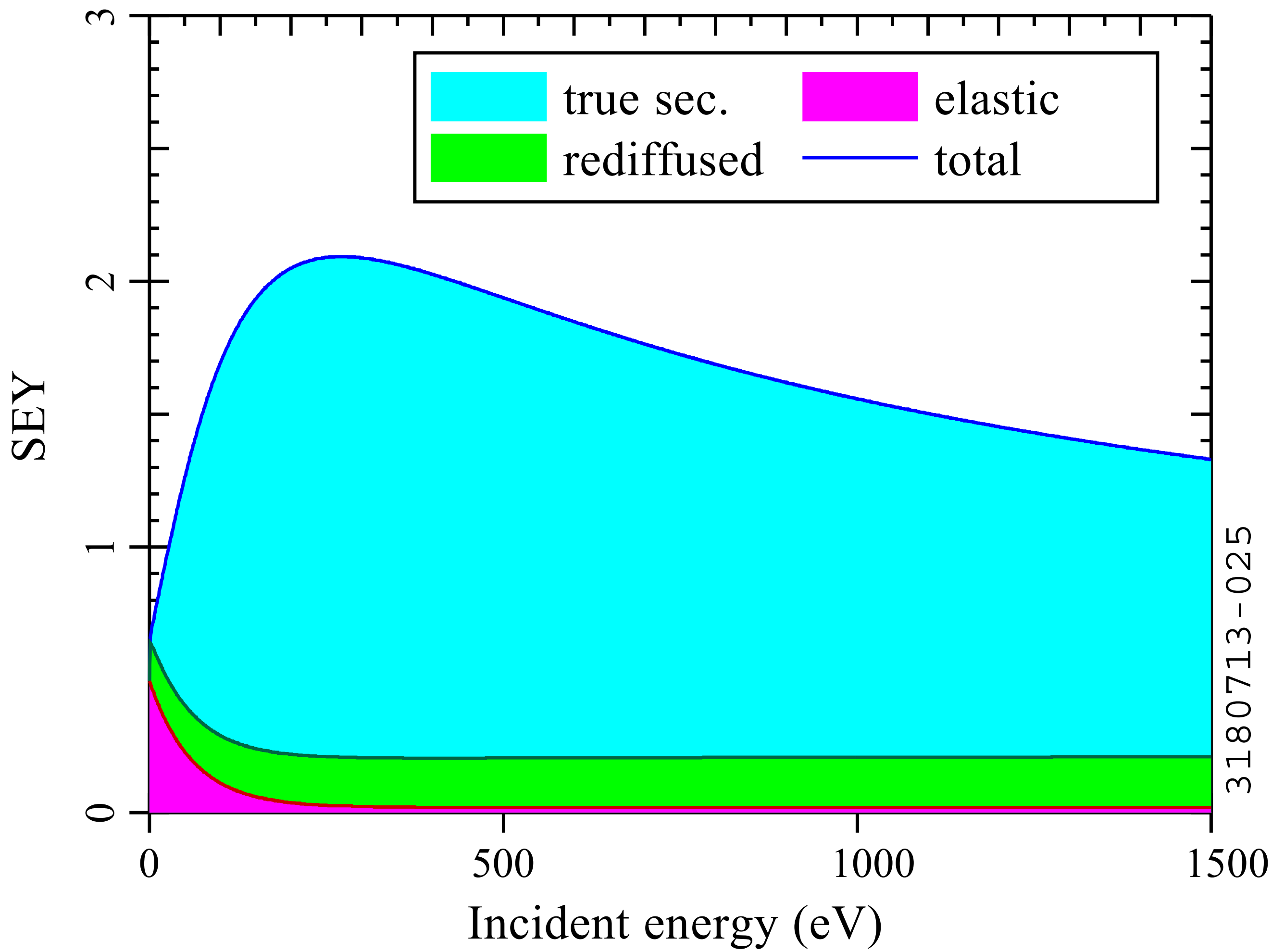
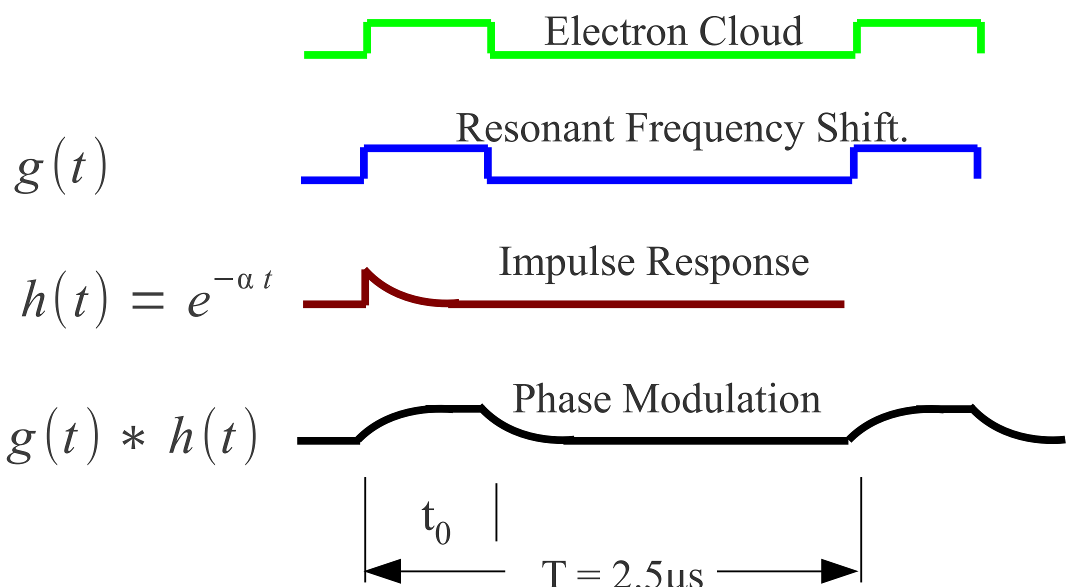
Extra Slides for Questions/Discussion Follow



SEY vs incident energy at normal incidence for copper (using Cu parameters for SEY model from M. Furman & M. Pivi, PR-STAB 2002)

Phase Modulation Sideband Amplitudes

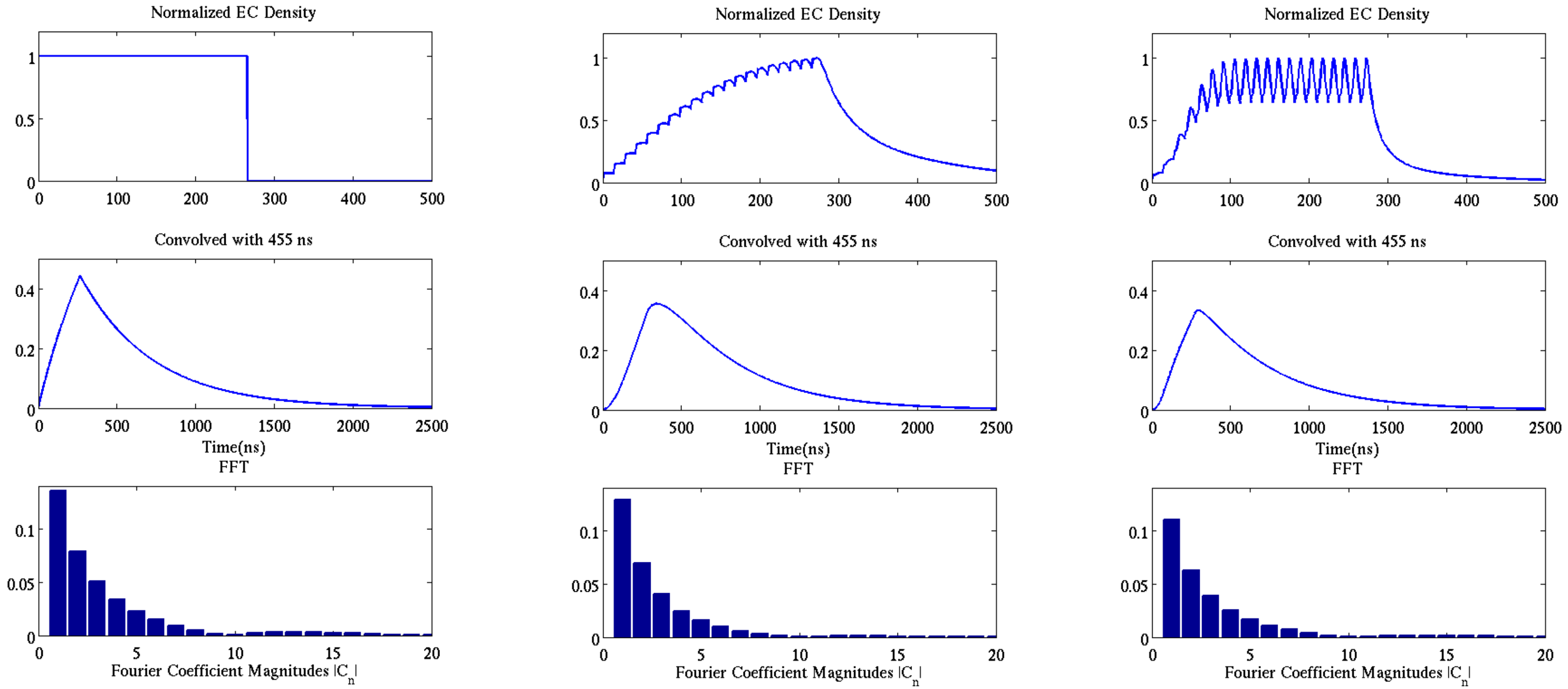


- The phase of the resonant field cannot change instantaneously.
- The phase can be calculated by convolution with the damping α of the resonance.
- This periodic change in phase can be expressed as a Fourier series.
- For a rectangular EC density, the Fourier components are given by the analytic expression

$$C_n = \frac{2}{\pi}\sin\left(n\pi\frac{t_0}{T}\right)\left[\frac{1}{n} - \frac{n\,\omega_0^2}{\alpha^2+(n\,\omega)^2} - j\frac{\alpha\,\omega_0}{\alpha^2+(n\,\omega_0)^2}\right] \qquad \omega_0 = \frac{1}{T}$$

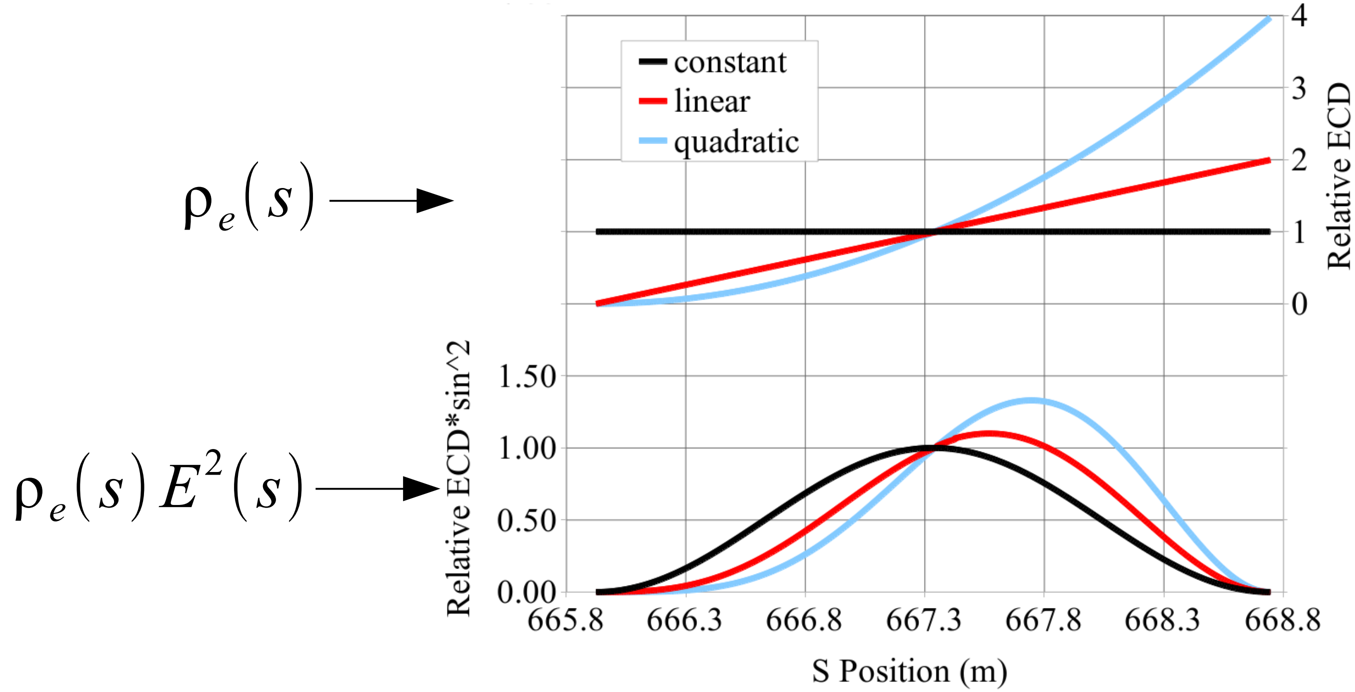
Spectral Components from Simulations

Rectangular | 4 mA/bunch | 8 mA/bunch



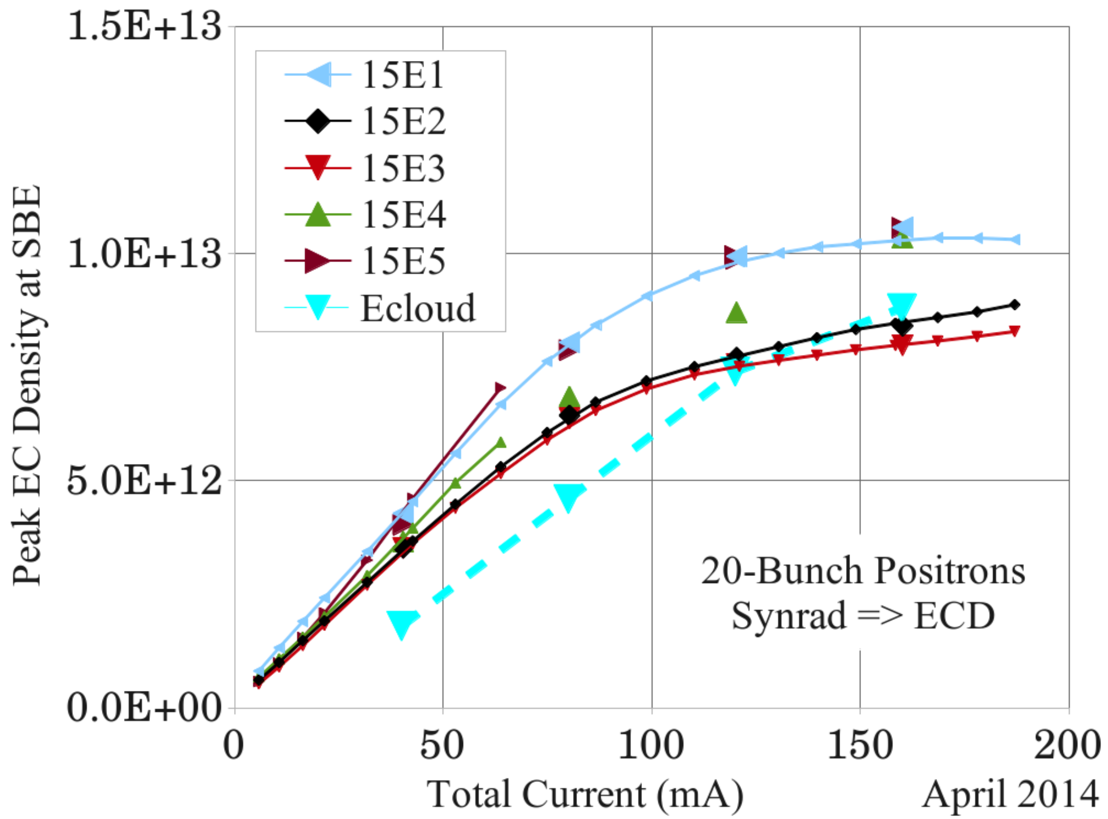
- For an arbitrary modulation, the Fourier components can be obtained with a Matlab script.
- The plots above show the spectra for normalized EC densities including rectangular modulation and the output of two ECLOUD simulations for 20 bunches at 4 and 8 mA/bunch.

The Effect of Changes in EC Density vs. Position



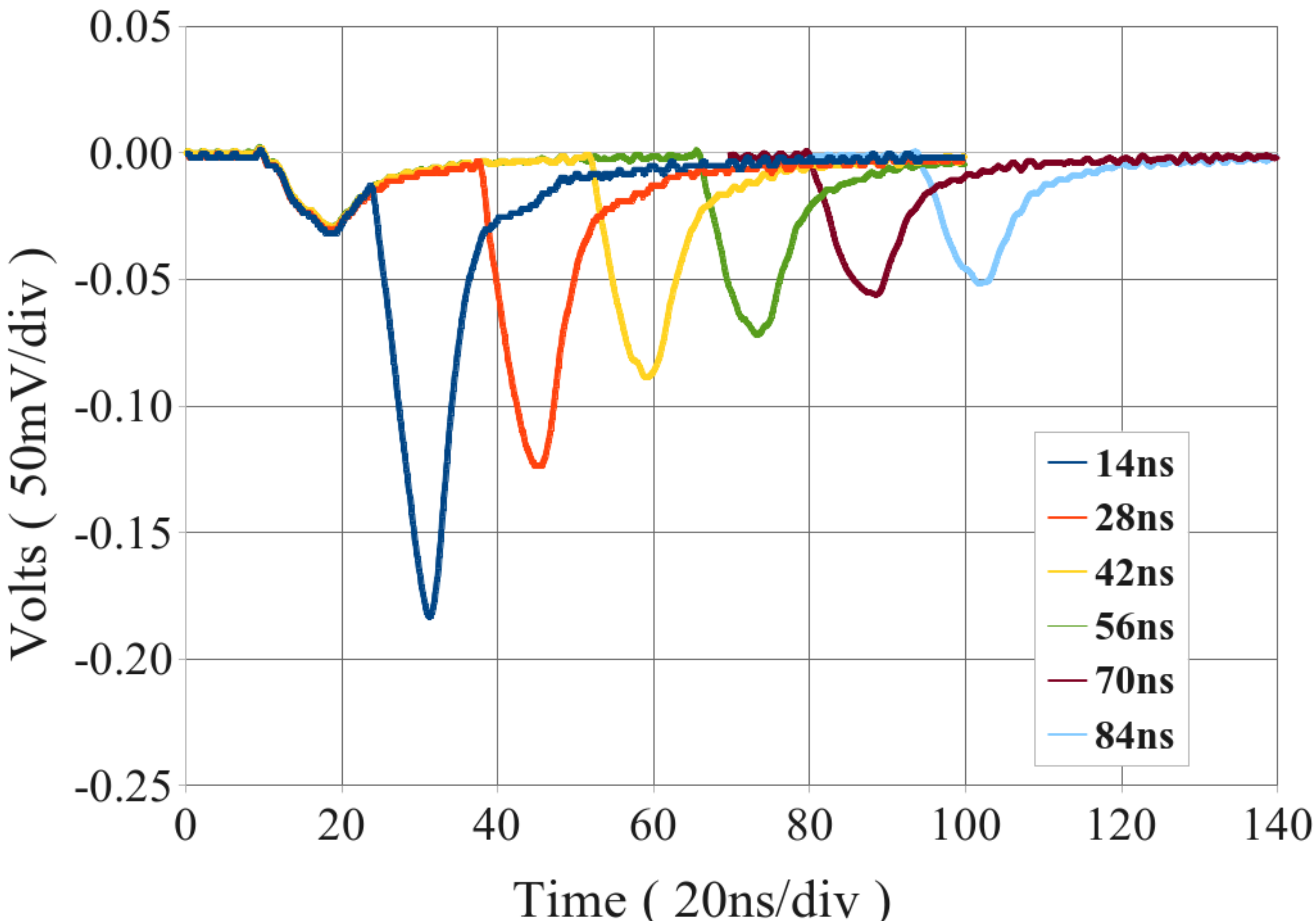
- The resonant frequency shift is proportional to the integral of $\rho(s)E^2(s)$.
- A linear change in EC density will give the same integral (frequency shift) as a uniform EC density equal to the density at the center of the resonant section.
- A quadratic change (for example) gives a frequency shift that is larger than this.
- The correction using the curvature of the Synrad output at 15E is only about 3%.

Rectangular Approximation



- Use a rectangular approximation for the EC density vs. time.
- Correct the measurement to obtain the value at the microwave center.
- Scale the value at the center to obtain the density at the SBE.
- Compare with ECLOUD.

Data from Six Bunch Spacings of 5.3 GeV Positrons



March 2010

This overlay of 2-bunch SBE data shows the decay of the electron cloud as the second bunch samples the cloud at different times after the first bunch in a TiN coated chamber.