Longitudinal Wake due to Electron Cloud

Giovanni Rumolo, Frank Zimmermann, CERN

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- Computational approach
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Plasma Physics Estimate

maximum electric field in a plasma ('cold wavebreaking'):

$$E \approx \frac{m_e c \omega_p}{e}$$

where

$$\omega_p = \sqrt{\frac{4\pi \rho_e e^2}{m_e}}$$

in engineering units

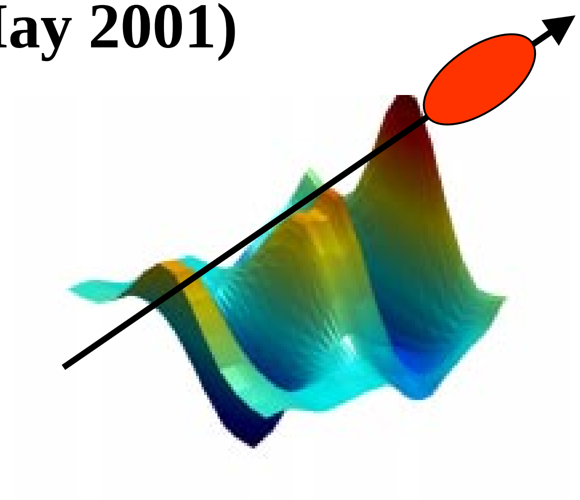
$$E \approx \sqrt{(\rho_e)}\ \mathrm{V/cm} \approx 100\mathrm{kV/m}$$

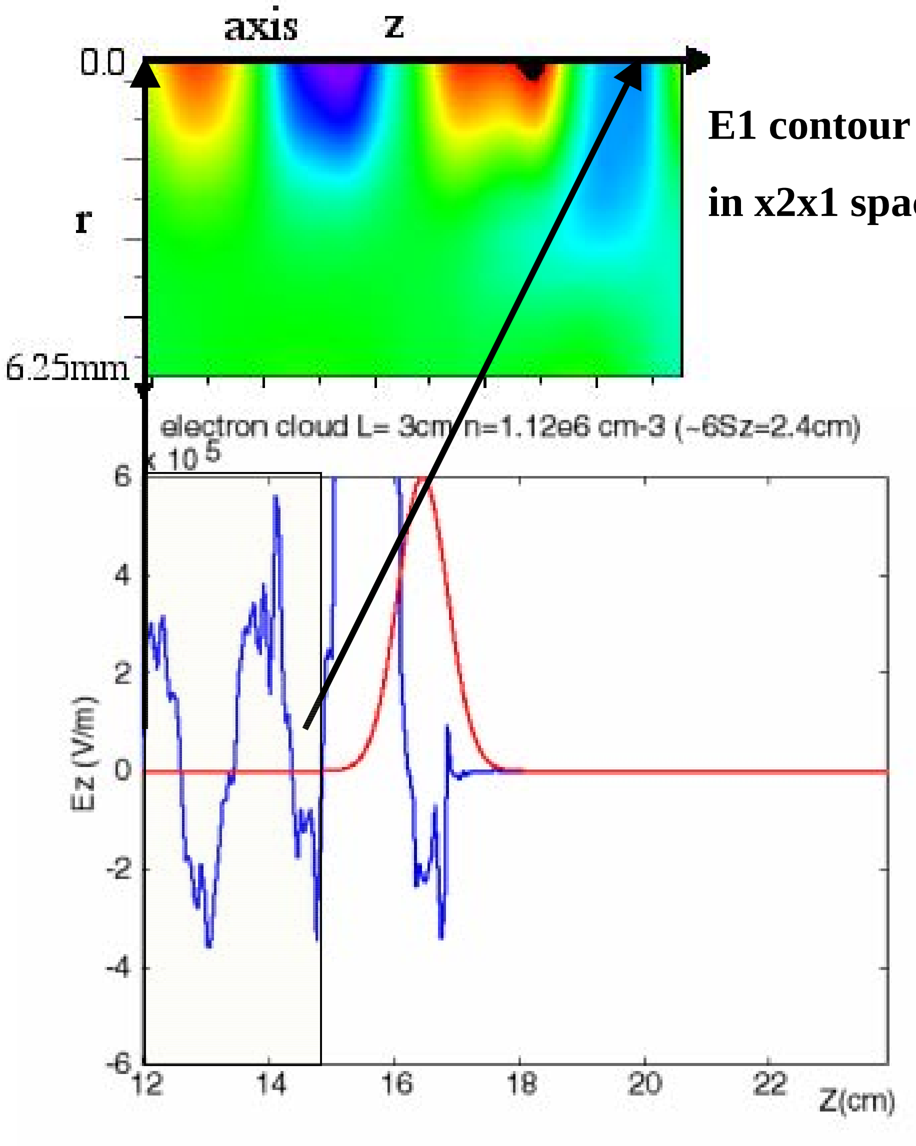
expect enormous effect!?

PIC simulations
(S. Lee, T. Katsouleas, USC, May 2001)

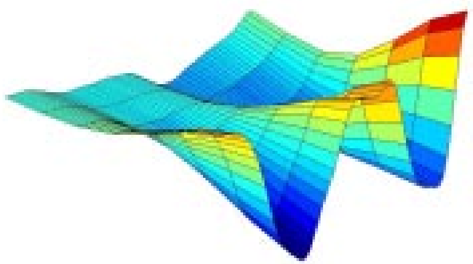
longitudinal el. field E1 in V/m

electron cloud density 1.12e6 cm-3





E1 contour plot in x2x1 space.



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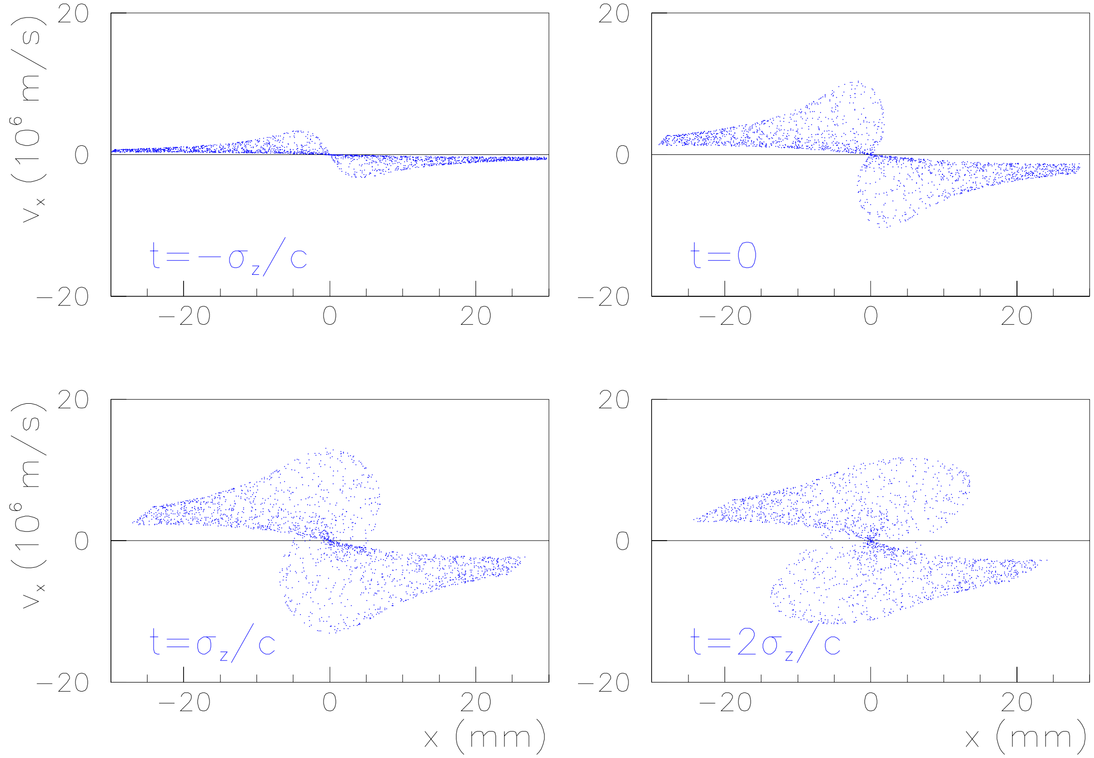
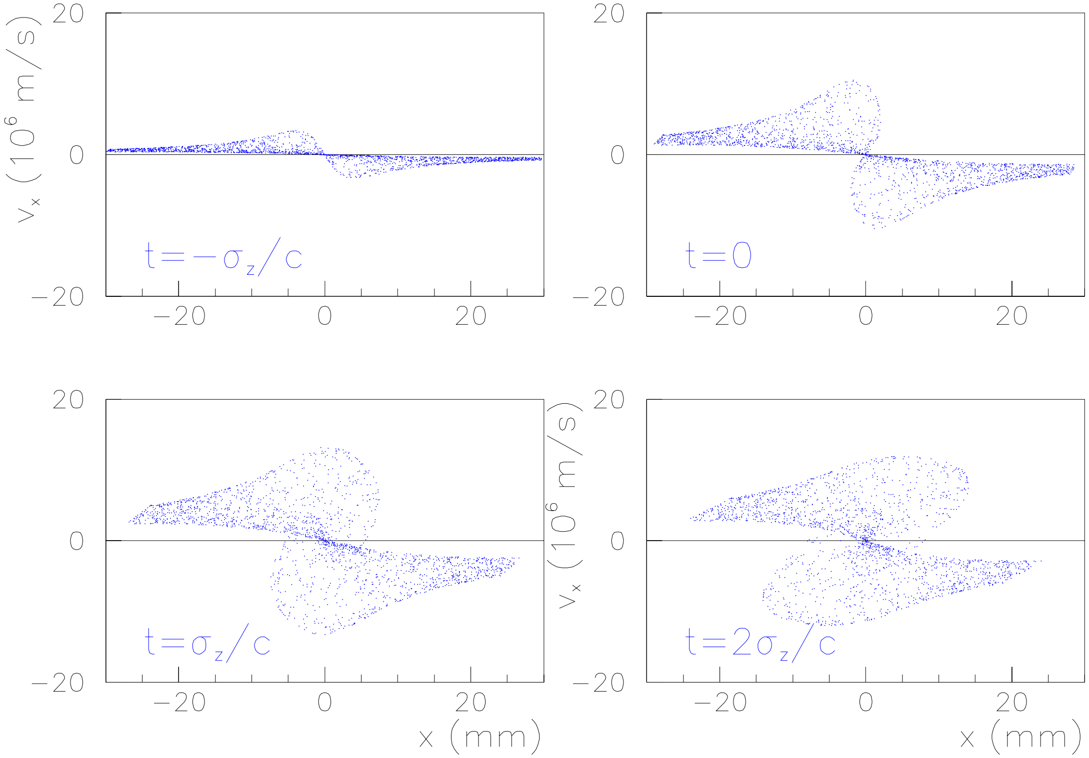


Snap shots of horizontal electron phase space during the passage of an SPS proton bunch computed by 2-D PIC simulation ($N_b = 10^{11}$, $\sigma_{x,y} = 3$ mm, $\sigma_z = 0.3$ m, $\rho_e = 10^{12}$ m^{-3}). Electron self-field is included.



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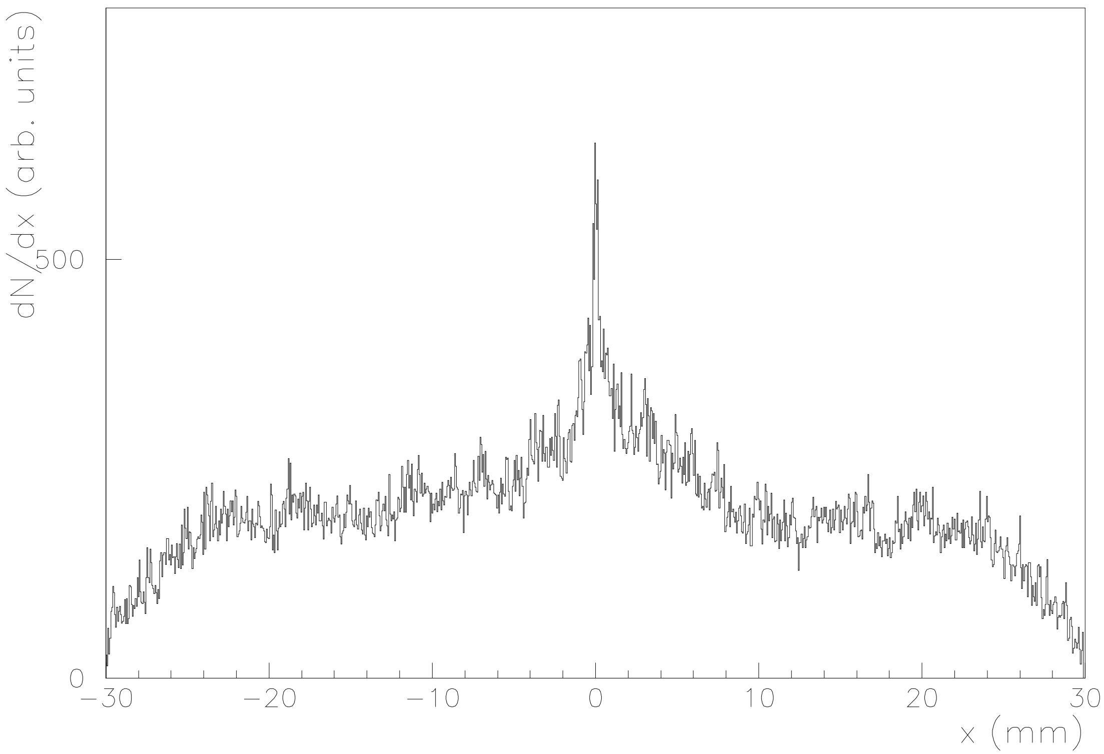
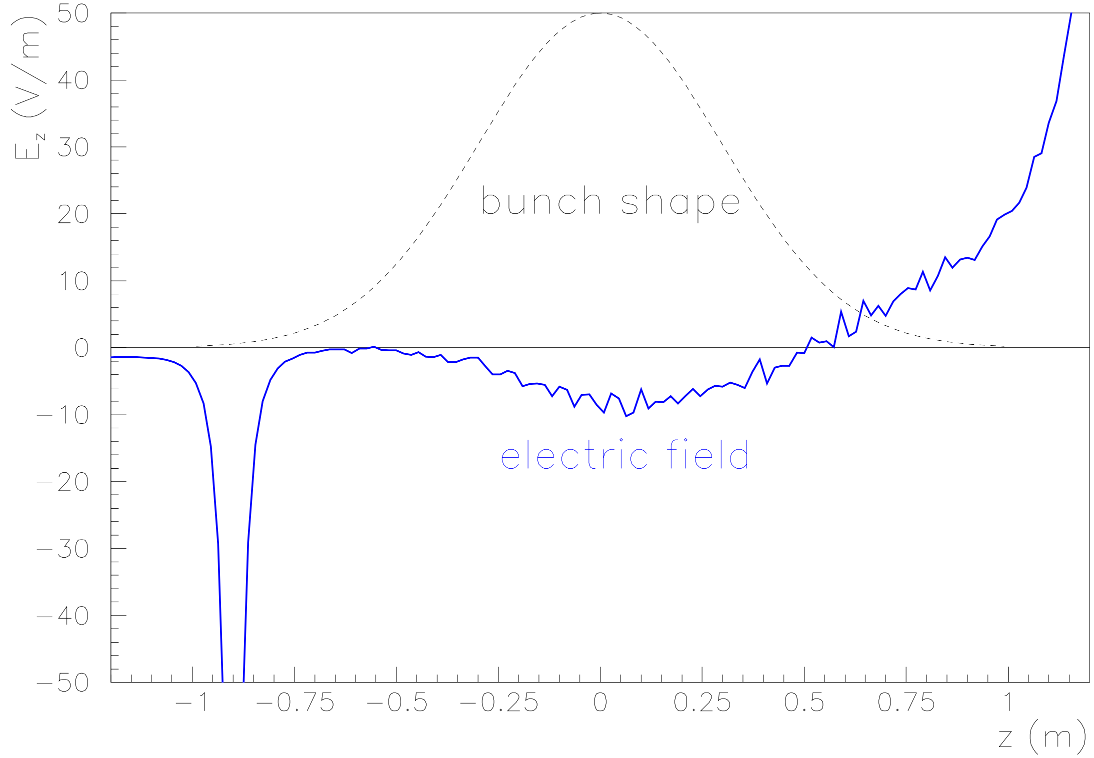


Horizontal electron distribution projected over $\pm 2\sigma_z$ and $\pm 10\sigma_y$ about the bunch center. Shown is a fraction 1/250 of the simulated macro-electrons.

- longitudinal electric field from 2-D PIC simulation
- e^- concentrated at a single point
- bunch passes through
- different time steps correspond to different positions along the bunch
- compute field on 3-D grid, by identifying time with z
- to get local field E_z apply reduction factor $\Delta z/C$ to number of electrons
- assume a uniform e$^-$ distribution in front of the bunch



Longitudinal electric field due to electron cloud for a Gaussian bunch in the SPS. Bunch head is on the left.

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Compute bunch density expected from potential well as

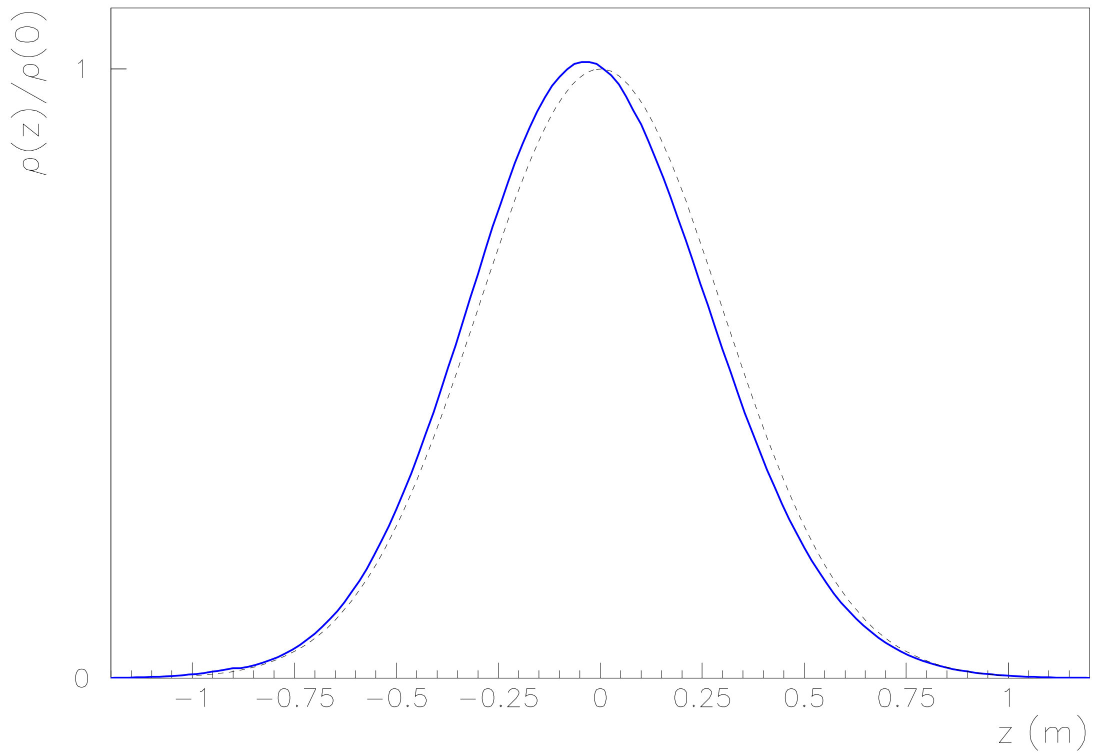
$$\rho(z) = \rho(0) \exp \left[-\frac{1}{2} \left(\frac{\omega_s z}{\eta c \sigma_\delta} \right)^2 \right.$$

$$\left. - \frac{r_0}{\eta \sigma_\delta^2 \gamma C} \int_0^z dz' \int_{-\infty}^{z''} dz'' \, W_0(z'' - z') \right]$$

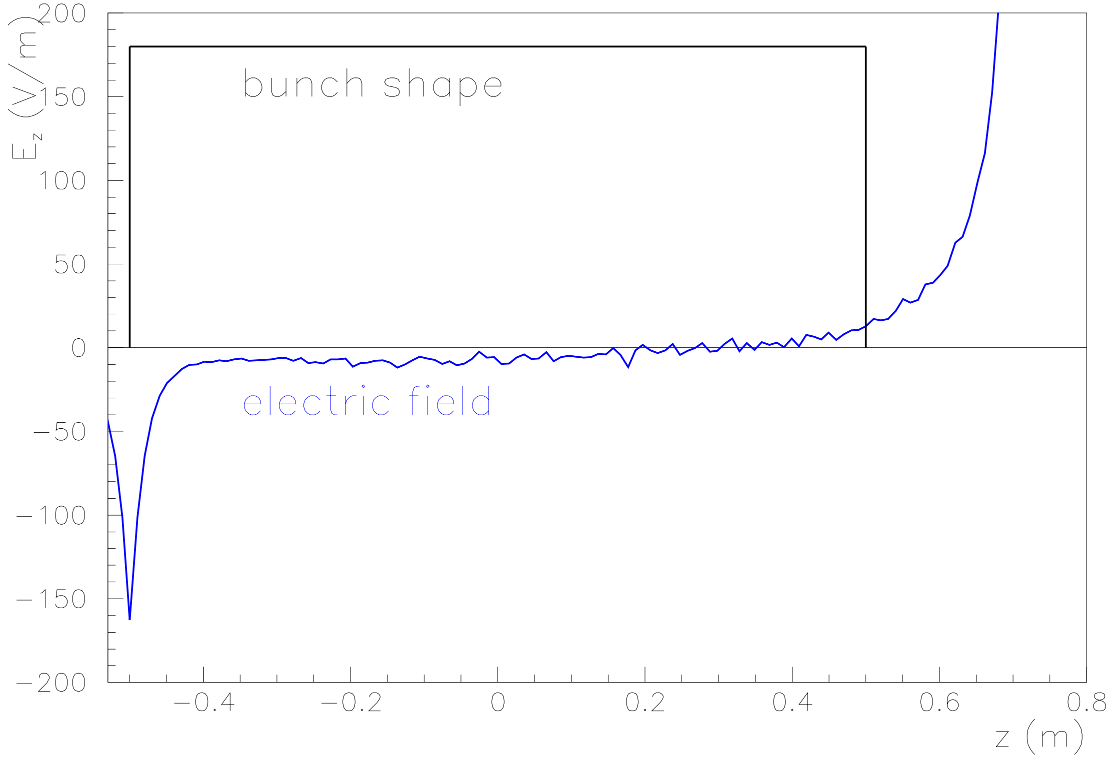
$$= \rho(0) \exp \left[-\frac{1}{2} \left(\frac{\omega_s z}{\eta c \sigma_\delta} \right)^2 - \frac{r_0}{\eta \sigma_\delta^2 \gamma C} \int_0^z dz' W_z(z') \right]$$

('quasi-Haissinski solution') where

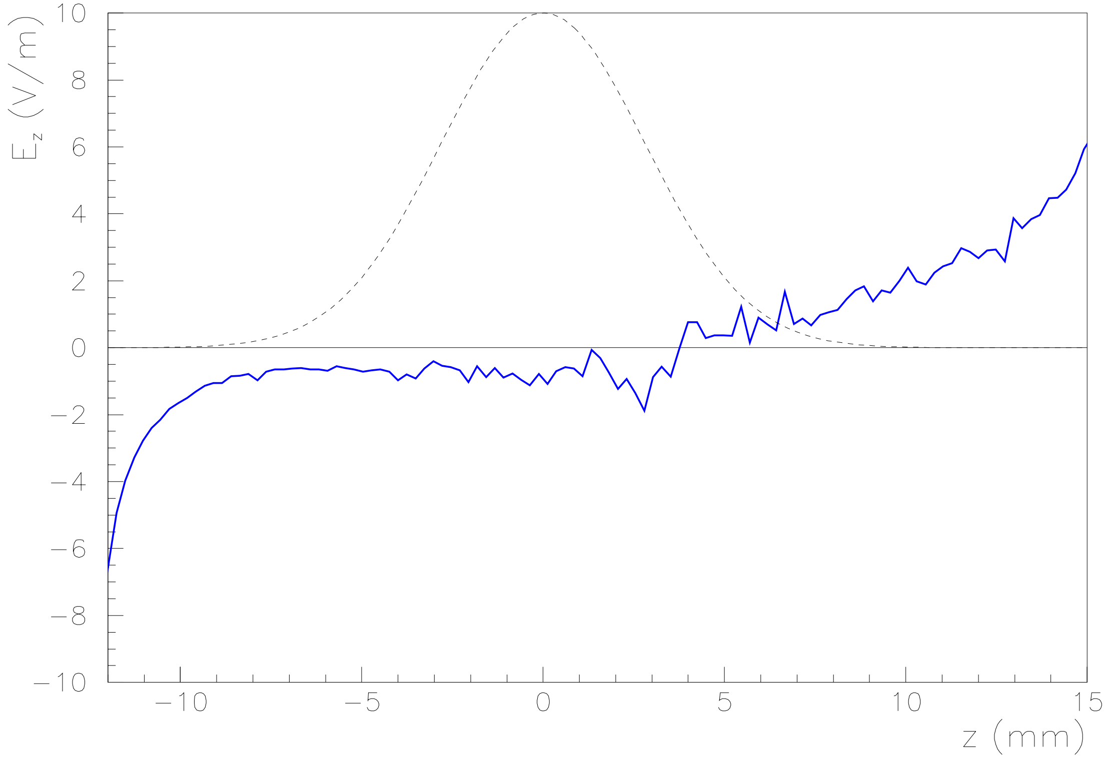
$$W(z) \approx -\frac{E_z(z)}{e} \left(\frac{4\pi}{Z_0 c} \right) C$$



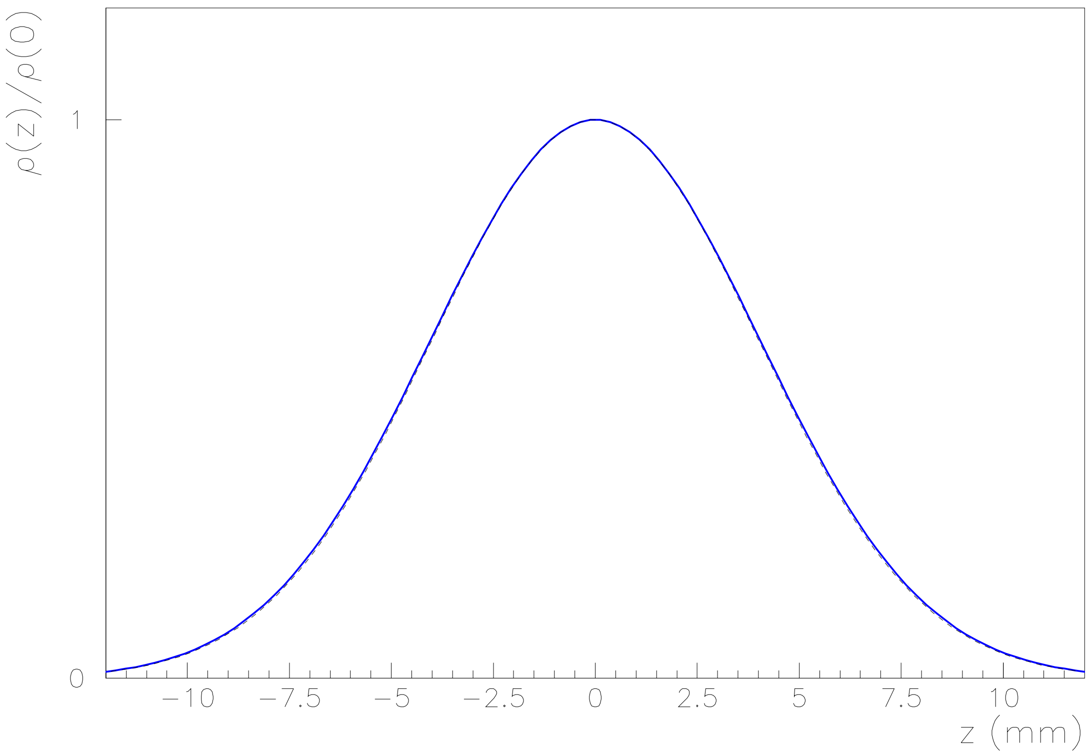
Equilibrium bunch density computed from the wake for a Gaussian bunch in the SPS. The Gaussian is slightly shifted.



Longitudinal electric field due to electron cloud for a flat bunch in the SPS. Bunch head is on the left.



Longitudinal electric field due to electron cloud for a Gaussian bunch in the KEKB LER. Bunch head is on the left.



Equilibrium bunch density computed from the wake for a flat bunch in the KEKB LER. The potential well distortion due to the cloud is insignificant.

Conclusion

- longitudinal electric field due to e^- cloud computed using 2-D PIC code
- effect is smaller than expected, and negligible at KEKB