Space-charge Effects in Ionization Beam Profile Monitors

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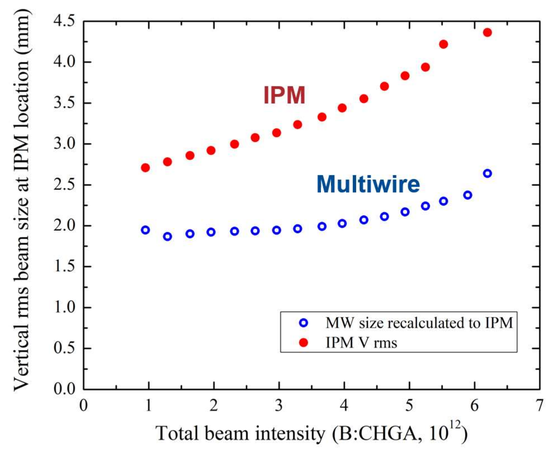
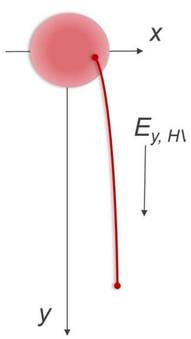
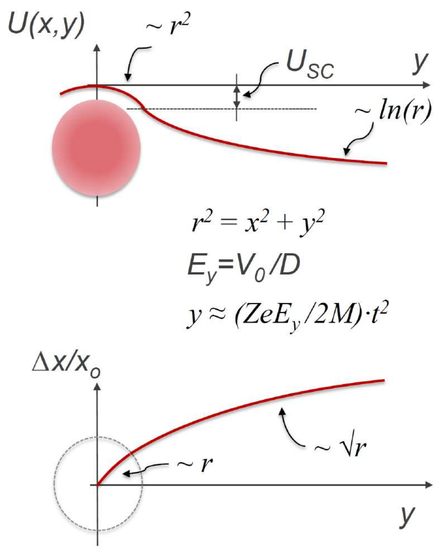
Abstract:

Ionization profile monitors (IPMs) are widely used in accelerators for non-destructive and fast diagnostics of high energy particle beams. At high beam intensities, the space-charge forces make the measured IPM profiles significantly different from those of the beams. We analyze dynamics of the secondaries in IPMs and develop an effective algorithm to reconstruct the beam sizes from the measured IPM profiles. Efficiency of the developed theory is illustrated in application to the Fermilab 8 GeV proton Booster IPMs..

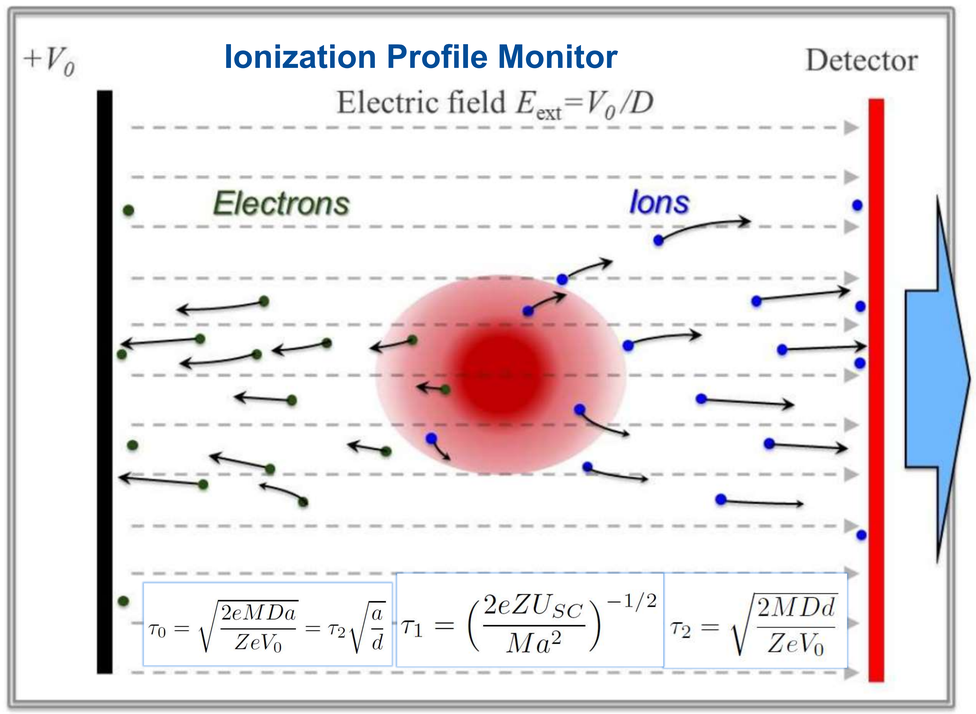


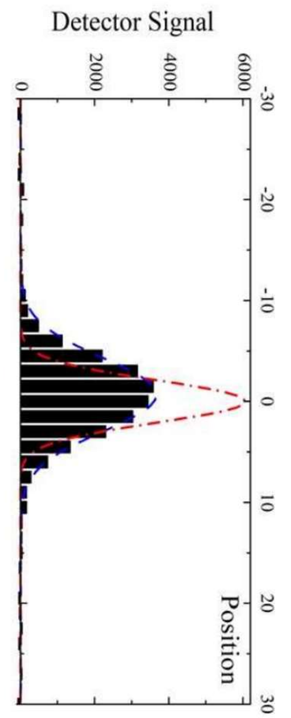




$$x''(t) = \frac{Ze}{M}E_{\text{ext}} + \frac{Ze}{M}E_x^{\text{SC}}(x,y,t)$$

$$y''(t) = \frac{Ze}{M}E_y^{\text{SC}}(x,y,t)$$





Ion motion inside the proton beam

$$y(t) \approx y_0 \mathrm{ch}(t/\tau_1) + v_{0,y}\tau_1 \mathrm{sh}(t/\tau_1)$$

Outside the beam

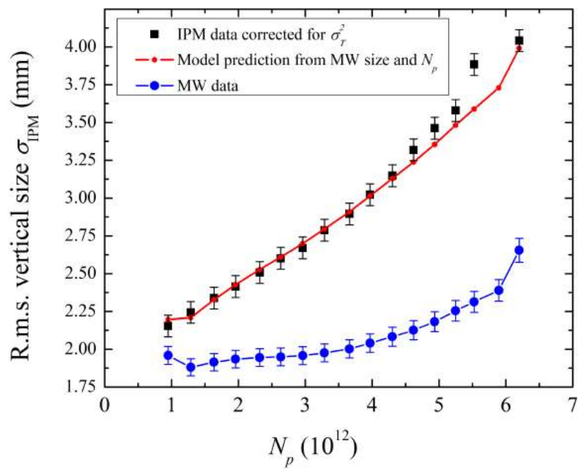
$$y_{[1]}(t) = y_0 \cdot \left[1 + \frac{\tau_0^2}{\tau_1^2}\left(\frac{t}{3\tau_0}\left(\Gamma(\tfrac{1}{4}) - \Gamma(\tfrac{1}{4}, \tfrac{t^4}{\tau_0^4})\right) - \frac{1}{2}\sqrt{\pi}\,\mathrm{erf}(\frac{t^2}{\tau_0^2}) + \frac{\tau_0^2}{6t^2}(1 - \exp(-\frac{t^4}{\tau_0^4}))\right)\right]$$

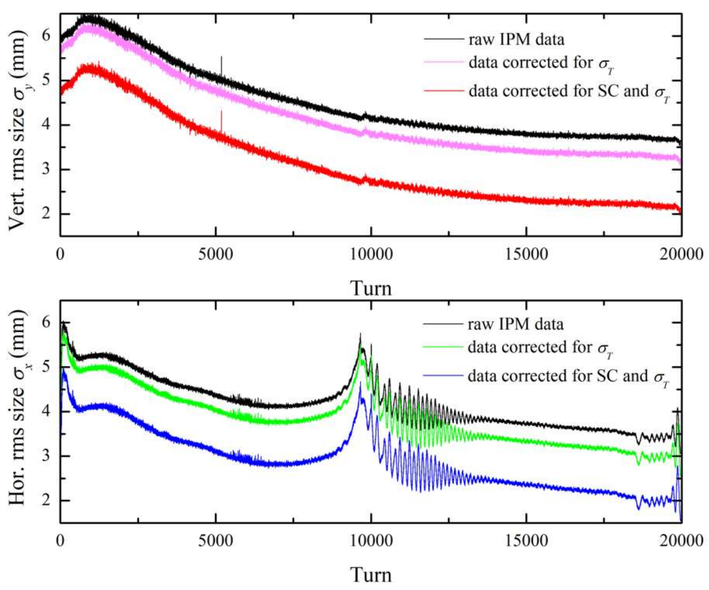
IPM rms size vs original size::

$$\sigma_m = \sigma_0 \cdot h \approx \sigma_0 \cdot \left[1 + \frac{2U_{SC}}{E_{\text{ext}}\sigma_0}\left(\frac{\Gamma(\frac{1}{4})}{3}\sqrt{\frac{d}{\sigma_0}} - \frac{\sqrt{\pi}}{2}\right)\right]$$

Reverse (solve) the equation:

$$\sigma_0 \approx \frac{\sigma^*}{(1 + cN_p/\sigma^{*3/2})(1 + \alpha c^2 N_p^2/\sigma^{*2})}$$





Also, bunch spacing effect:

$$U_{SC} \rightarrow U_{SC}(1 + 0.8\,t_b/\tau_0)$$

Thermal velocities

$$\sigma_m^2 = \sigma_0^2 h^2(U_{SC}, \sigma_0, V_0, D, d) + \left(\frac{4\mathcal{E}_i dD}{ZeV_0}\right)$$

See also Jeff Eldred's talk WEXB08

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"**Beam Size Reconstruction from Ionization Profile Monitors**"