Space-charge and other effects in Fermilab Booster and IOTA Ring IPMs

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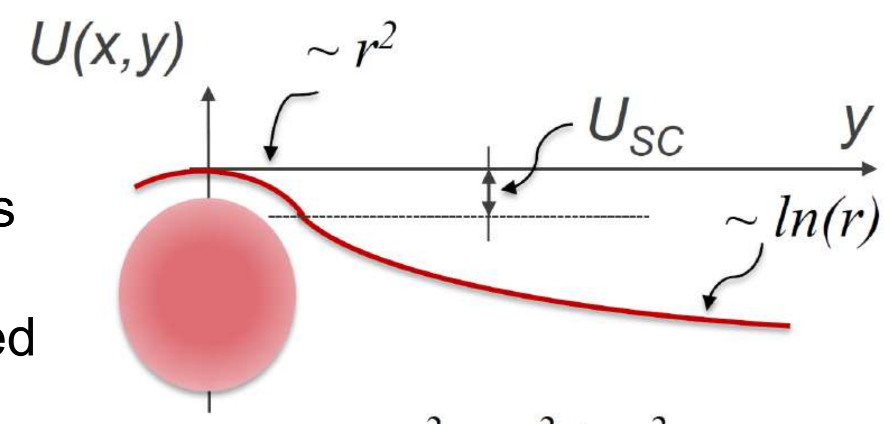
Abstract:

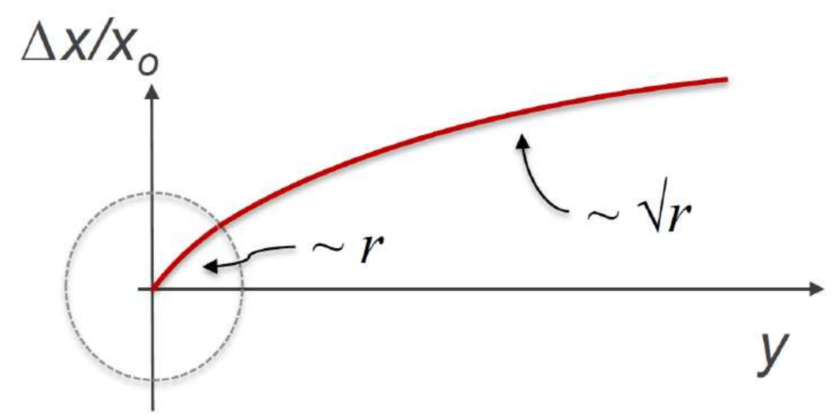
Ionization profile monitors (IPMs) are widely used in accelerators for non-destructive and fast diagnostics of high energy particle beams. At low beam intensities, initial velocities of the secondaries to collect (ions or electrons) result in the IPM profile smearing. At high beam intensities, the space-charge forces make the measured IPM profiles significantly different from those of the beams. We analyze dynamics of the secondaries in IPMs, describe an effective algorithm to reconstruct the beam sizes from the measured IPM profiles and apply it to the Fermilab 8 GeV proton Booster and 70 MeV/c IOTA ring IPMs.

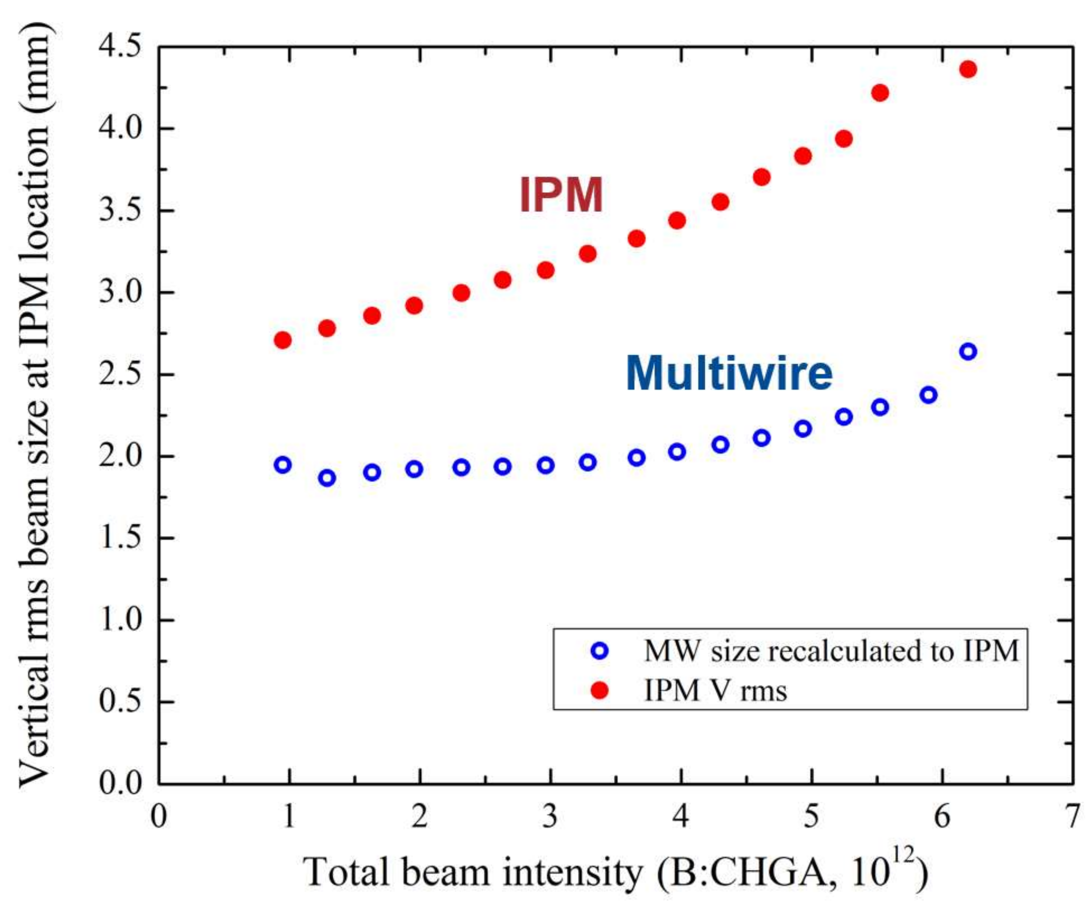


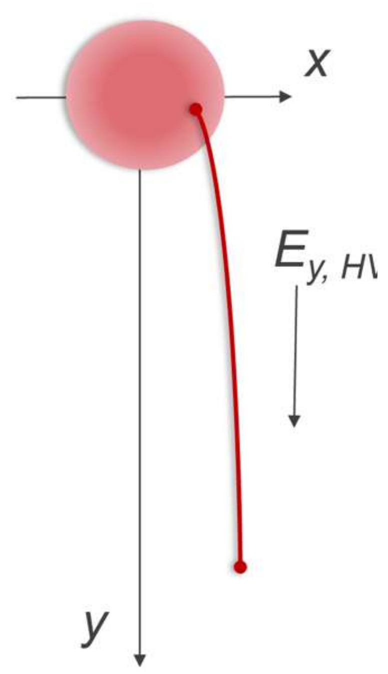
$r^2 = x^2 + y^2$

$E_y = V_0/D$

$y \approx (ZeE_y/2M)\cdot t^2$

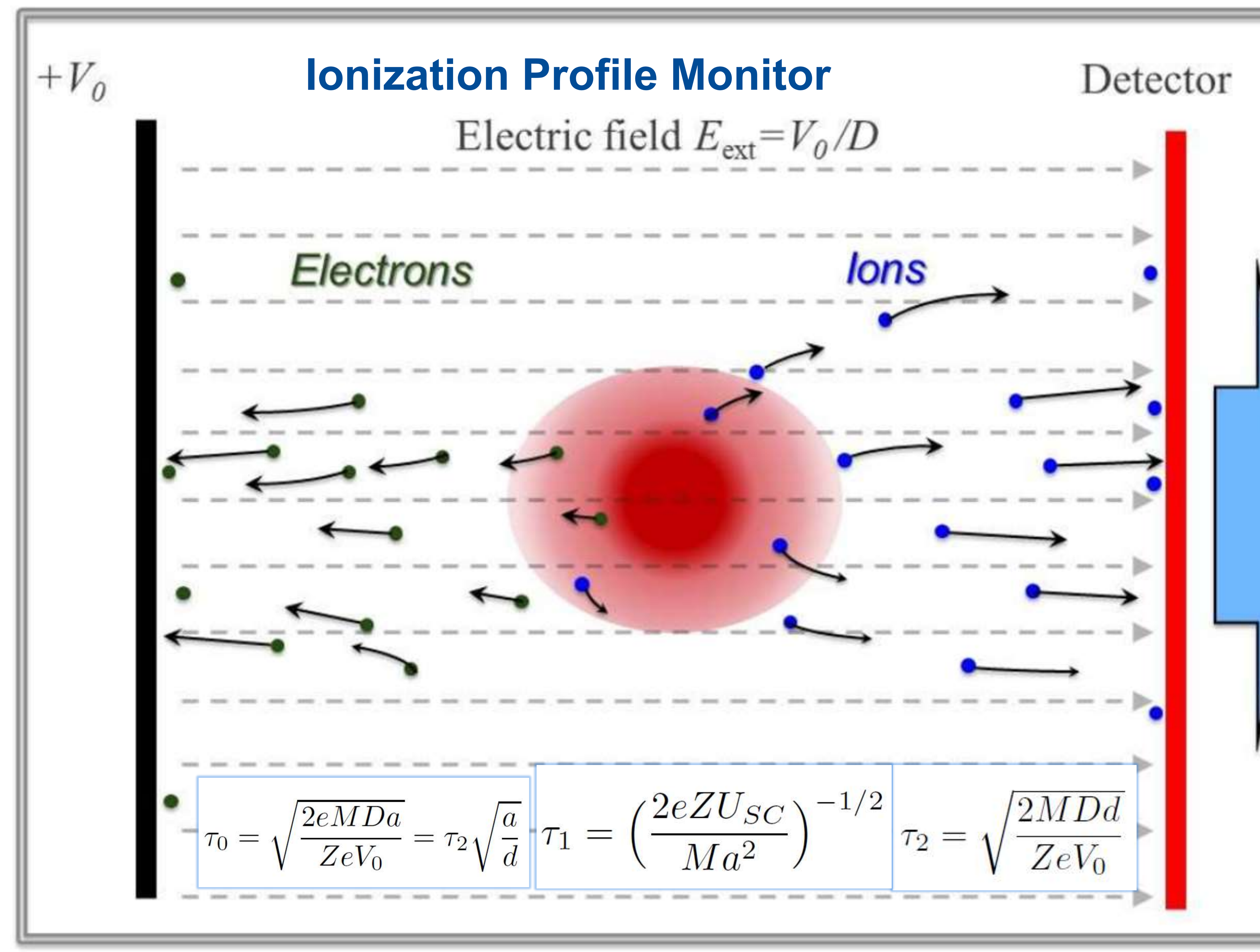


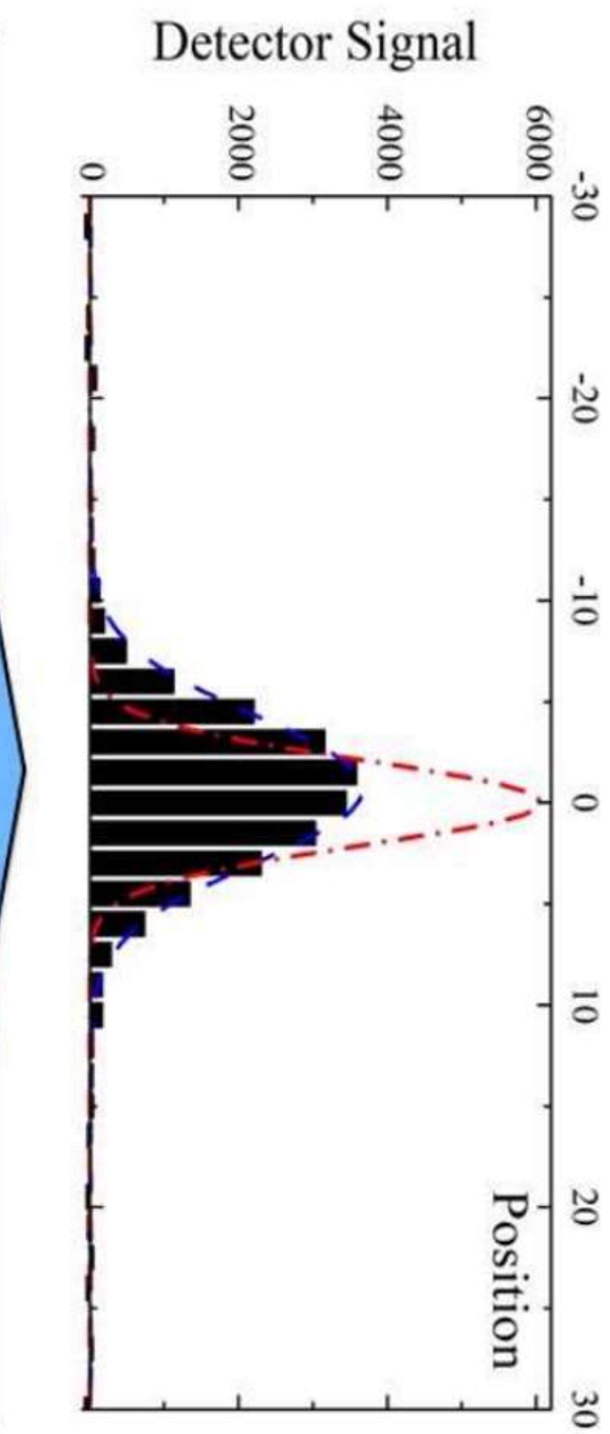




$$x''(t) = \frac{Ze}{M}E_{\rm ext} + \frac{Ze}{M}E_x^{\rm SC}(x,y,t)$$

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





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

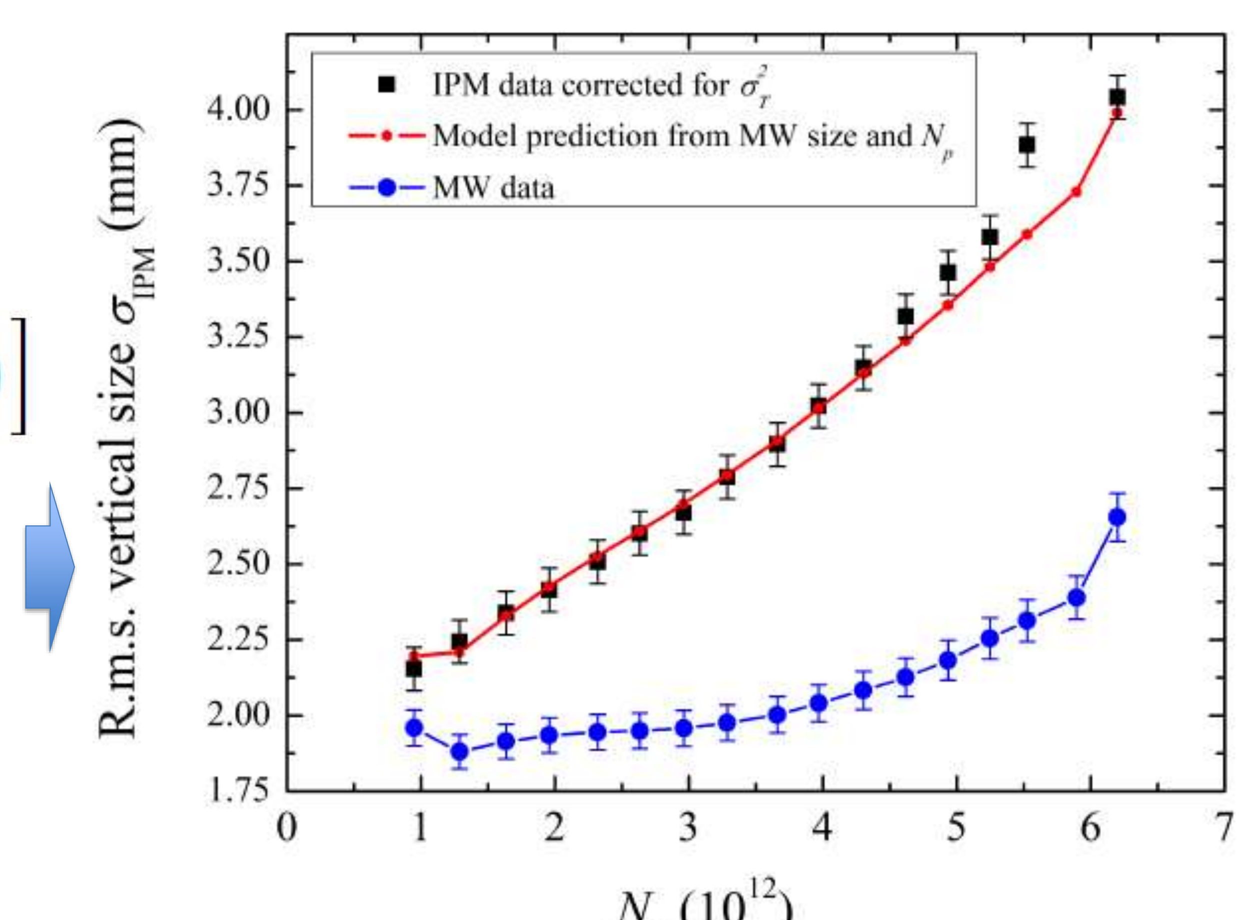
$$y_{[1]}(t) = y_0 \cdot \left[1 + \frac{\tau_0^2}{\tau_1^2}\left(\frac{t}{3\tau_0}\left(\Gamma\left(\frac{1}{4}\right) - \Gamma\left(\frac{1}{4}, \frac{t^4}{\tau_0^4}\right)\right) - \frac{1}{2}\sqrt{\pi}\,\mathrm{erf}\left(\frac{t^2}{\tau_0^2}\right) + \frac{\tau_0^2}{6t^2}\left(1 - \exp\left(-\frac{t^4}{\tau_0^4}\right)\right)\right)\right]$$

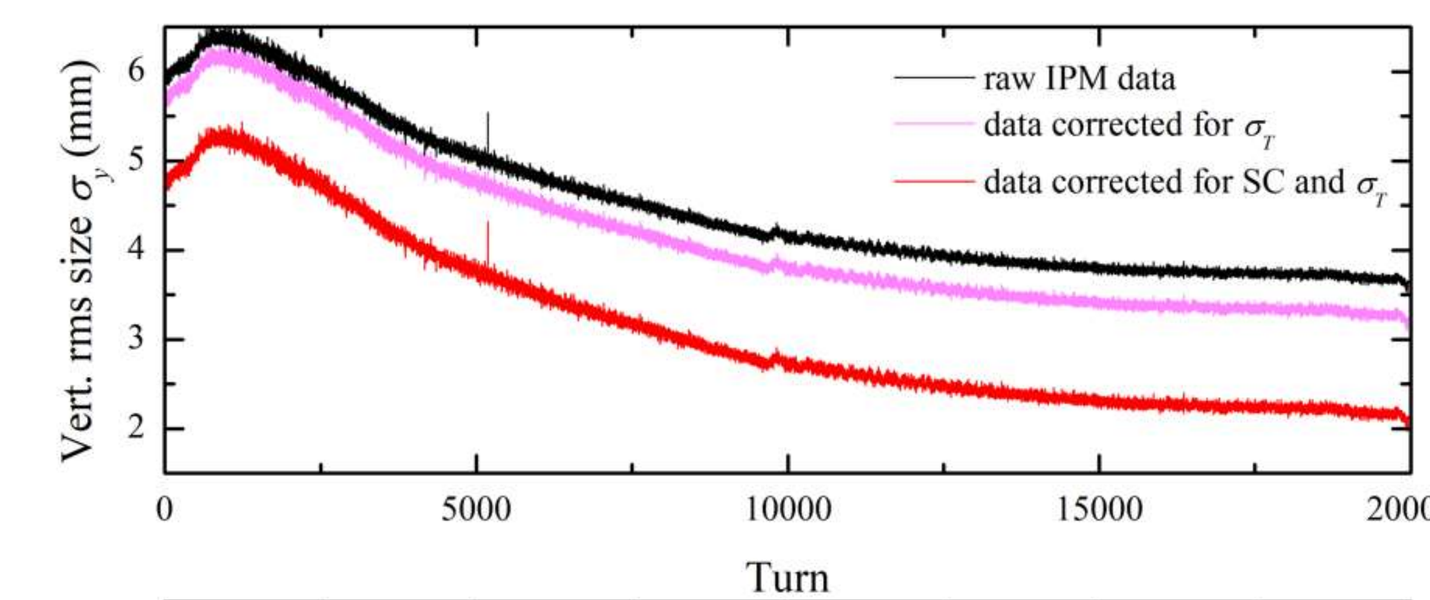
IPM rms size vs original size::

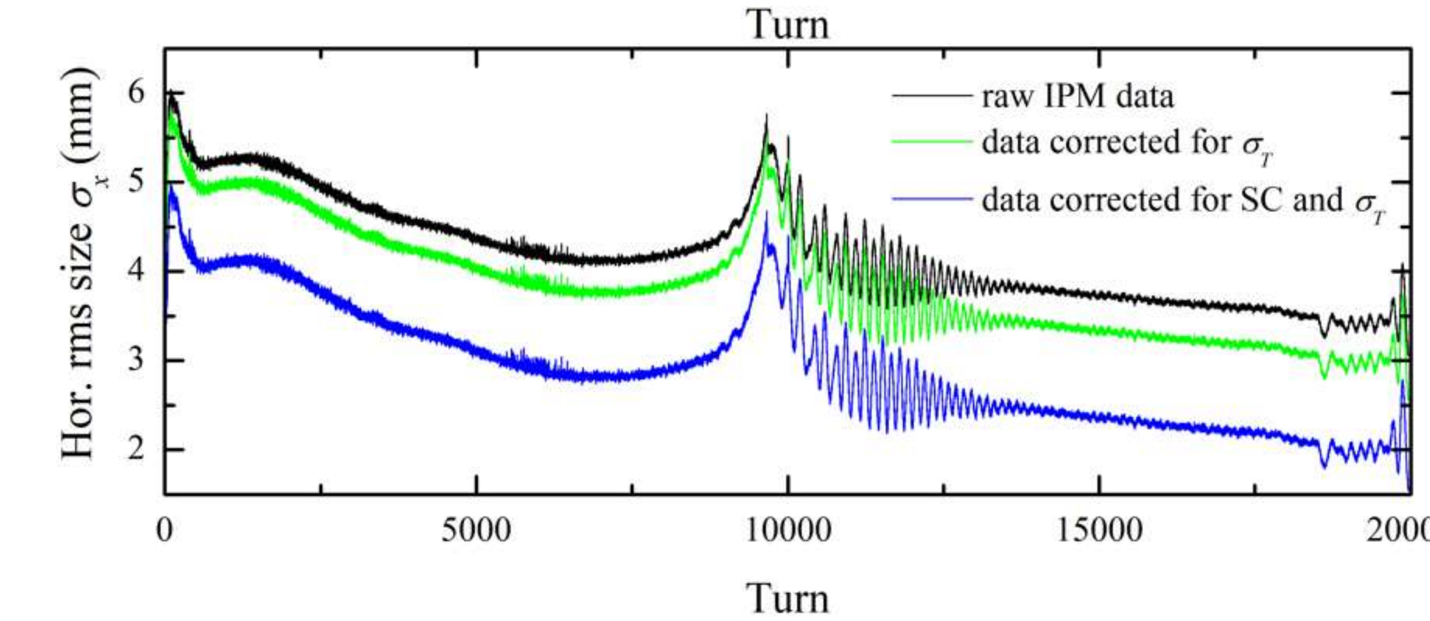
$$\sigma_m = \sigma_0 \cdot h \approx \sigma_0 \cdot \left[1 + \frac{2U_{SC}}{E_{\rm ext}\sigma_0}\left(\frac{\Gamma(\frac{1}{4})}{3}\sqrt{\frac{d}{\sigma_0}} - \frac{\sqrt{\pi}}{2}\right)\right]$$

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:

V.Shiltsev NIM A 986 (2021): 164744
"**Beam Size Reconstruction from Ionization Profile Monitors**"