Bunch Length Measurements Using Beam Position Monitors (BPMs)

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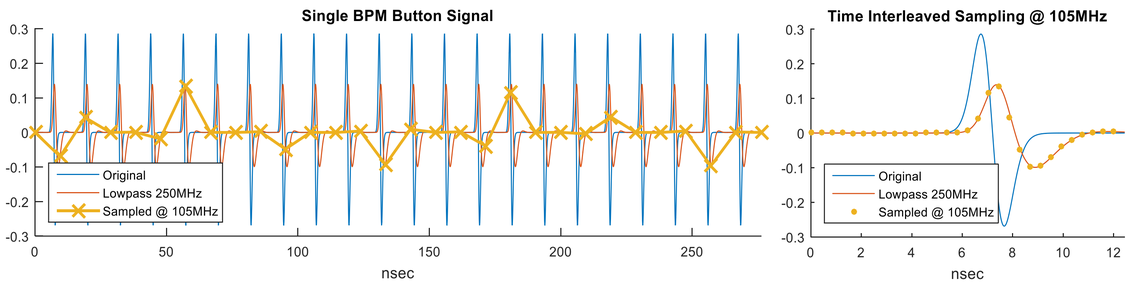
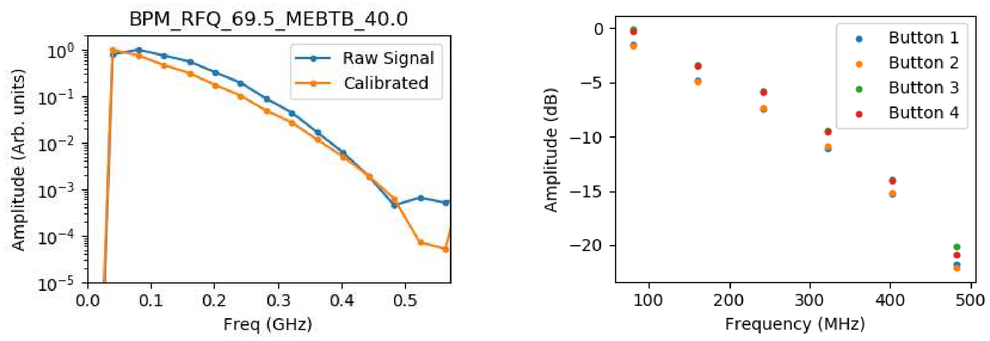
Signals Measured by BPMs

- Broad band signals measured using time interleaved sampling
  - 40.25 MHz signal is sampled at 119 MHz
  - Results in an effective sampling rate of 2.737 GHz



- The signals need to be calibrated for effects from the digitizer, 500 MHz low pass filtering, and dispersion from the cables connecting the pick ups to the digitizer
  - Harmonics of 80.5 MHz were input into the cables for each button on a BPM and measured with the digitizer
- The signals must also be corrected for the impedance of the buttons



- The calibrated signals represent the field distribution measured by the buttons, not the bunch distribution
  - For a transversely and longitudinally longitudinal bunch the field on the pipe wall is

$$\sigma_{\text{wall}}(\omega, z_m, \phi_m) = D_\omega \cos\left[\frac{\omega}{\beta c}(z_m - z_0)\right] \int dA_{\text{beam}} \sum_{n=0} \frac{I_n(gr/R_p)}{\pi N I_n(g)} \cos[n(\phi_m - \phi)] e^{-\frac{(x-x_0)^2}{2\sigma_x^2} - \frac{(y-y_0)^2}{2\sigma_y^2}} \qquad g = \frac{\omega R_p}{\gamma \beta c},$$

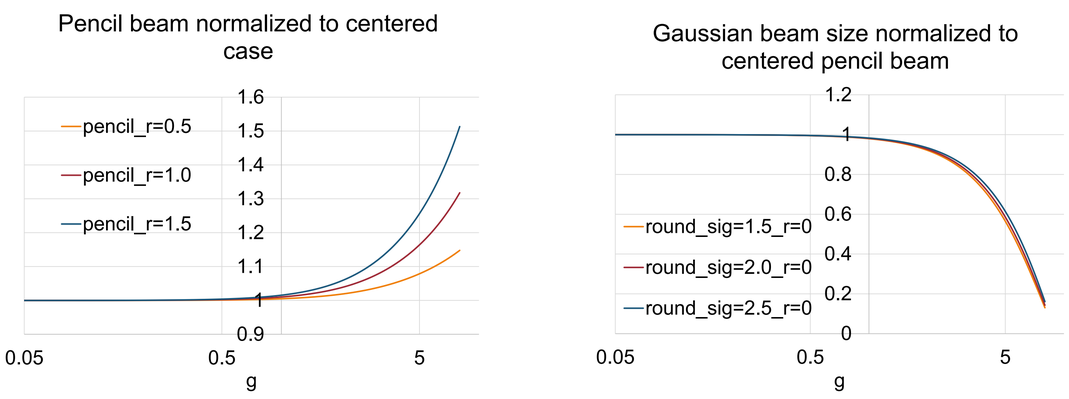
J. Cuperous, NIM, 1977

- The round button geometry is accounted for with a transit time factor
  - This factor is calculated for each azimuthal mode separately

$$T(\omega) = \frac{2}{n} \int_{-R_b}^{R_b} \mathrm{d}z_m \cos\left[\frac{\omega}{\beta c}(z_m - z_0)\right] \sin\left[\frac{n}{R_p}\sqrt{R_b^2 - z^2}\right]$$

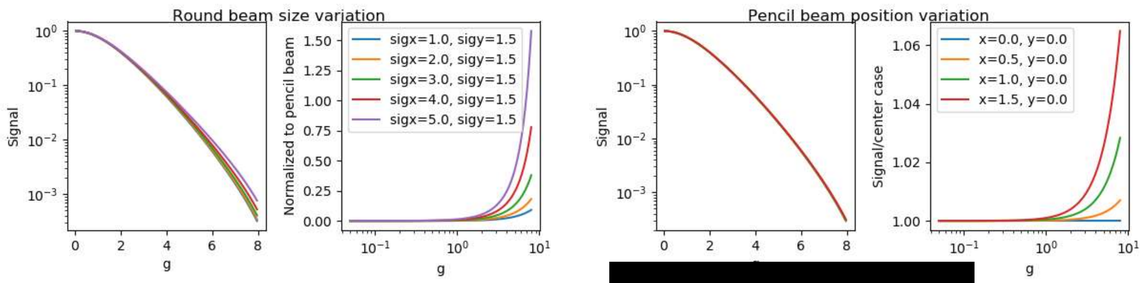
Scaling with Transverse Properties

- Scalings with g
  - Need to account for transverse properties up to g~1
  - In FRIB MEBT, ß=0.032 corresponding to g~1-6 for measurable bandwidth



Button Sum Scaling

- By adding the button signals, the measurements are less dependent of the transverse distribution
  - Offsetting a pencil beam 1.5 mm deviates by ~6% from centered case. For a single button the deviation is ~50%
- But, the beam position and transverse sizes cannot be uniquely determined with this method

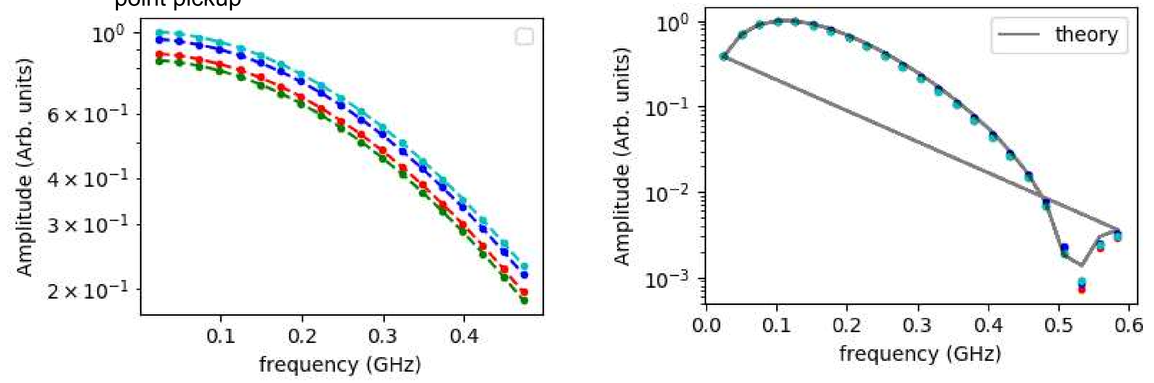


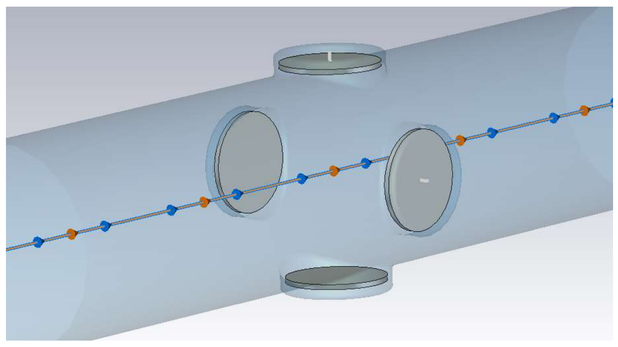
Simulations

- CST Studio simulations confirm the analytic field distribution at the pipe wall
  - Simulated pencil beam and uniform beam distributions for different offsets, beam sizes, and velocities
  - Measured field at points on wall and with a BPM model

x0=1 mm, y0=0.5 mm, σ_z=0.5 ns, ß=0.15, point pickup

x0=0 mm, y0=0 mm, σ_z=0.2 ns, ß=0.033, button pickup

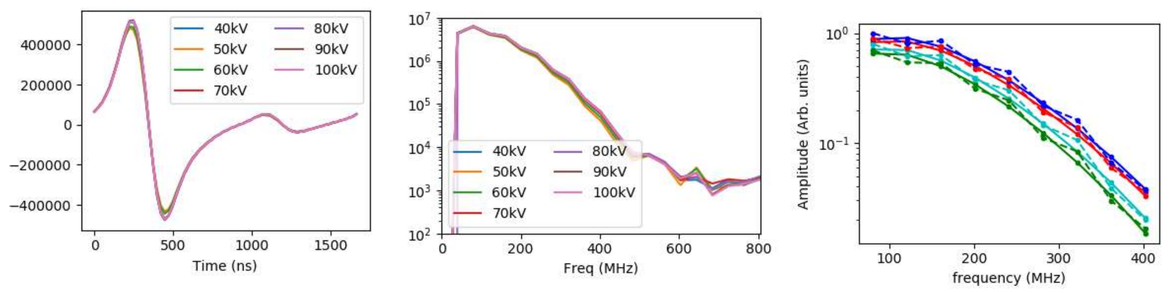




BPM model with pencil beam

FRIB MEBT Measurements

- Fit the field equation with TTF to measured signals using seven fit parameters
  - Fit parameters: amplitude, noise offset, x_0, y_0, σ_x, σ_y, σ_z



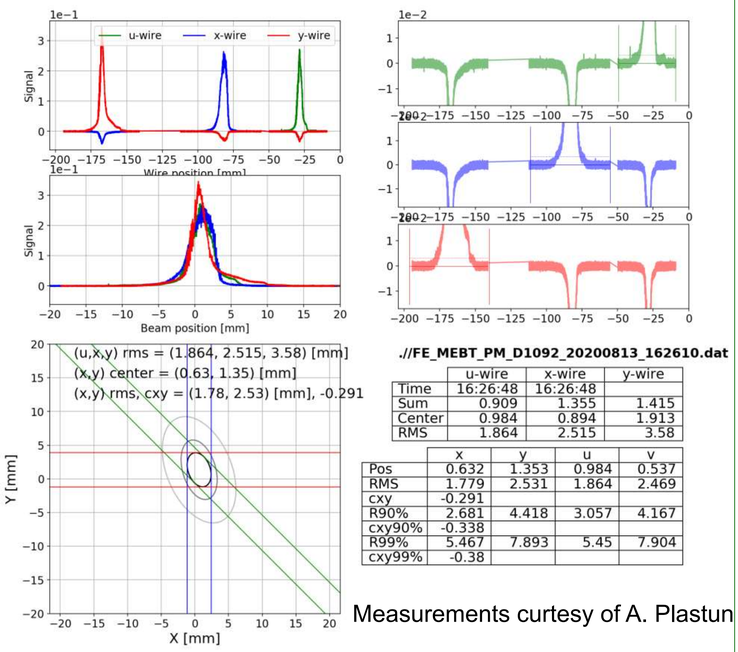
- Fitting the parameters needs improvements
  - The transverse position and beam size match measurements from the BPMs and wire profile scanner
  - Longitudinal beam size from fitting fails to follow trend of simulation when scanning the voltage of a buncher cavity

Parameters from BPM signal fitting

X0	Y0	Sig x	Sig y
1.67	0.93	1.66	2.19

Parameters from wire scan

X0	Y0	Sig x	Sig y
1.67	0.93	1.78	2.53



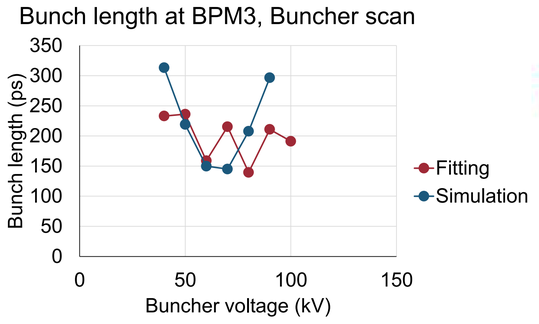
.//FE_MEBT_PM_D1092_20200813_162610.dat

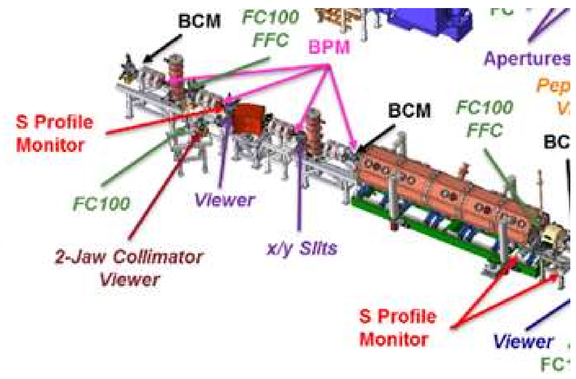
	u-wire	x-wire	y-wire
Time	16:26:48	16:26:48	
Sum	0.909	1.355	1.415
Center	0.984	0.894	1.913
RMS	1.864	2.515	3.58

	x	y	u	v
Pos	0.632	1.353	0.984	0.537
RMS	1.779	2.531	1.864	2.469
cxy	-0.291			
R90%	2.681	4.418	3.057	4.167
cxy90%	-0.338			
R99%	5.467	7.893	5.45	7.904
cxy99%	-0.38			

Measurements curtesy of A. Plastun

Bunch length at BPM3, Buncher scan





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