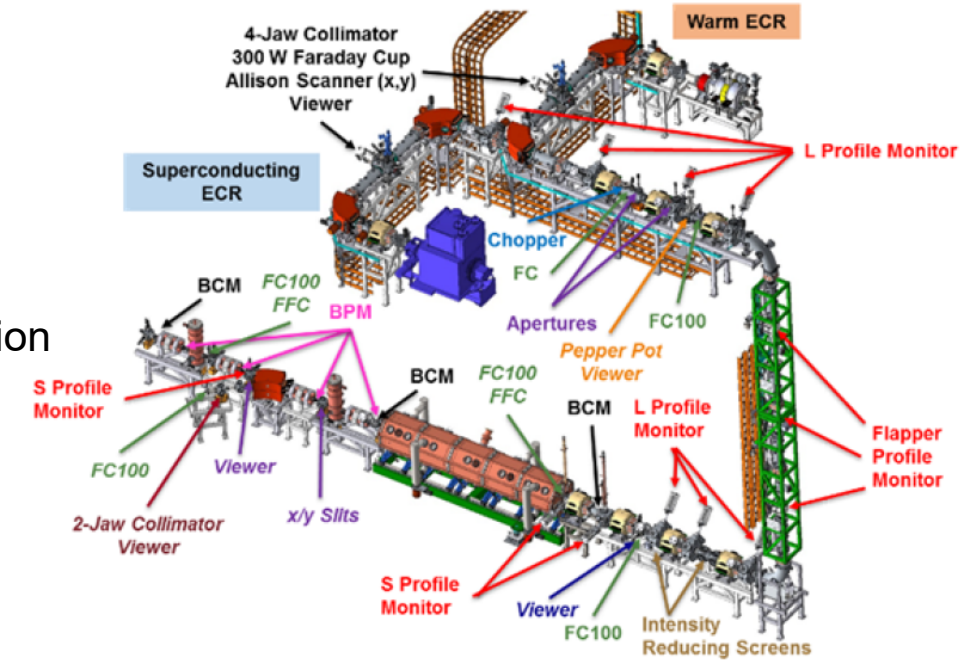
Analysis Techniques and Measurements of Non-Relativistic Hadron Beams (part 2)

Chris Richard

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Beam Position Monitors



- BPMs are the most prevalent diagnostic in accelerators
  - Passive non-intercepting devices – simple and can use during operation
  - Position measurements are needed for tuning
  - Small size makes them easier to fit into beamline
- What information about the beam can we get from BPM signals?
  - More information → better tuning
- Presented measurements taken in the Facility for Rare Isotope Beams (FRIB) MEBT
  - Low energy to increase length of electric field on the pipe to decrease the required bandwidth
  - Button BPMS, 20 mm diameter buttons, 47 mm diameter beam pipe

FRIB MEBT beam parameters	
Species	Heavy ions
Energy	0.5 Mev
Bunch rep rate	40.25 or 80.5 MHz
Transverse rms size	~ 3mm
Longitudinal rm size	~200 ps

FRIB BPM

Analytic BPM pickup response

ω = measurement frequency
R_p = pipe radius
I_n = modified Bessel function
ω_c = cut off frequency of pickup
N = 2 if n=0, 1 else

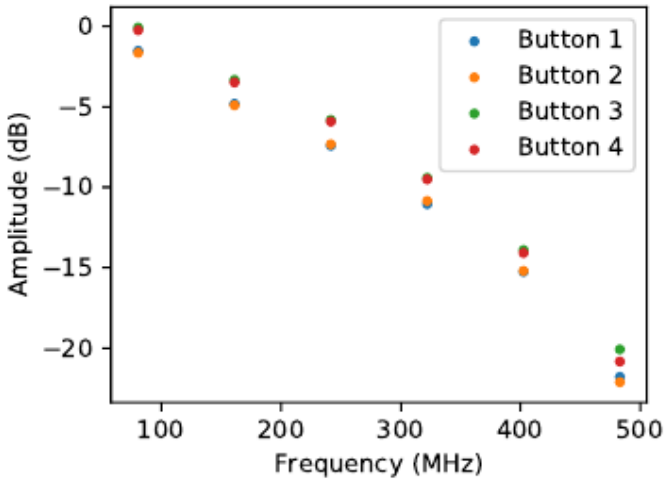
$$g = \frac{\omega}{\gamma_r \beta_r c}$$

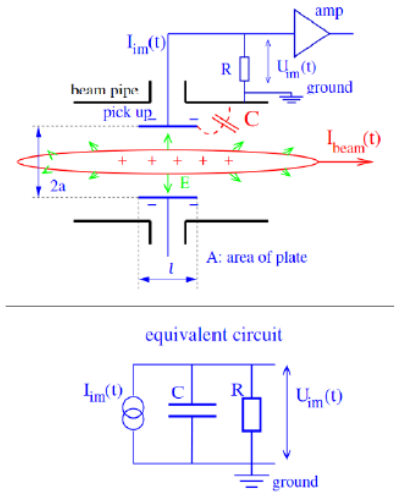
Filtering — Longitudinal beam distribution — Transverse beam distribution

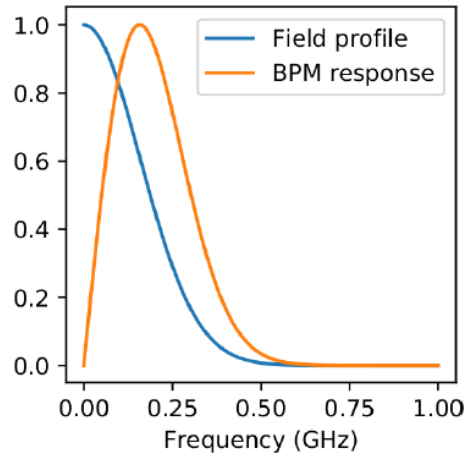
$$I_{\mathrm{meas}}(\omega) = A_{\mathrm{calib}} \cdot \frac{\omega/\omega_c}{\sqrt{1+(\omega/\omega_c)^2}} \cdot D_\omega \cdot \iint r\,\mathrm{d}r\,\mathrm{d}\phi \sum_{n=0} \frac{I_n(gr)}{N\pi I_n(gR_p)} \cos[n(\phi_p+\phi)] \cdot T_{\mathrm{beam}}(r,\phi) \cdot \iint \mathrm{d}\phi_m \mathrm{d}z T_{\mathrm{pickup}}(z,\phi_m)$$

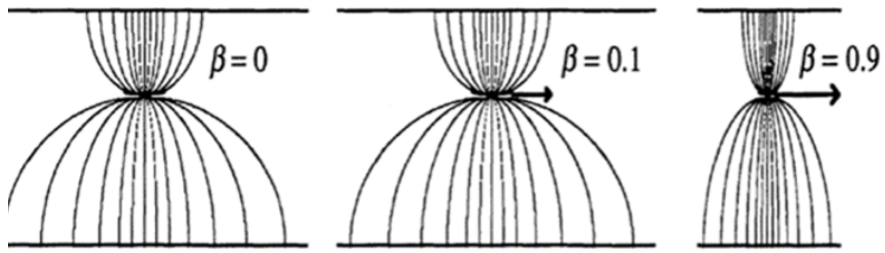
Pickup impedance — Field profile correction — Pickup shape

- Response of a BPM pickup centered at ϕ_p on the pipe wall to a beam traveling at v=βc with transverse profile T and longitudinal profile D
- Field profile correction accounts for non-relativistic effects
- Pickup shape correction assumes bunch length > pickup length. i.e. no transient ‘stripline’ behavior





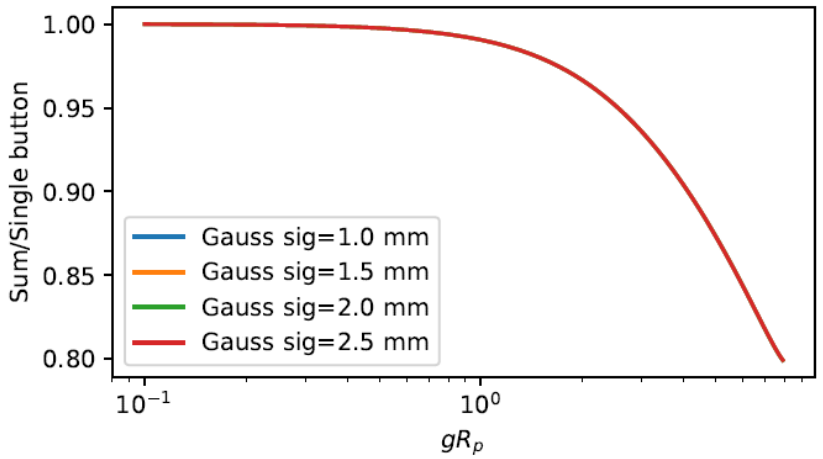




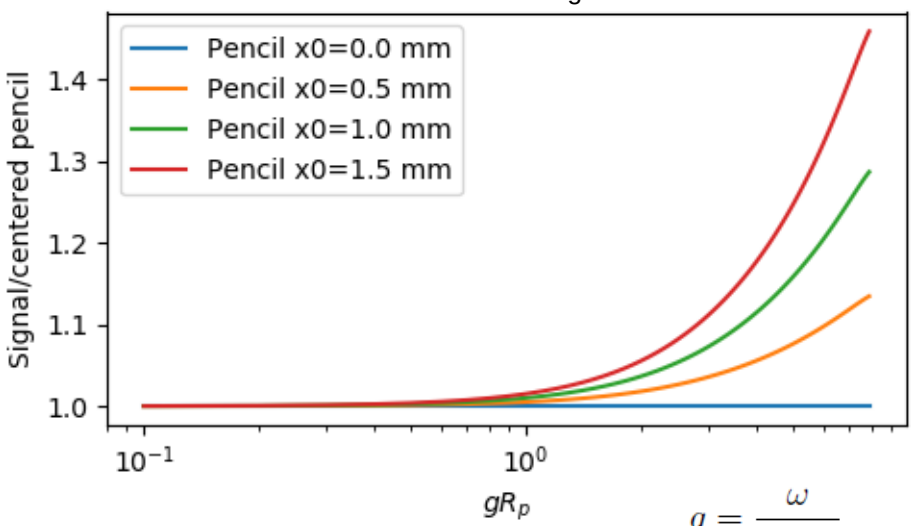
BPM response scaling with transverse distribution

- Measured signal on the picksups depends on the pickup shape, transverse and longitudinal distributions, and beam offset
- The transverse distribution and offset can be ignored if gR_p < 1. i.e. relativistic beams
  - By summing the four pickup signals, the transverse dependence can be reduced
- FRIB MEBT:
  - Measure 40.25 - 483 MHz, β=0.033, R_p=24 mm → gR_p 0.6 – 7.2

Summed button signals

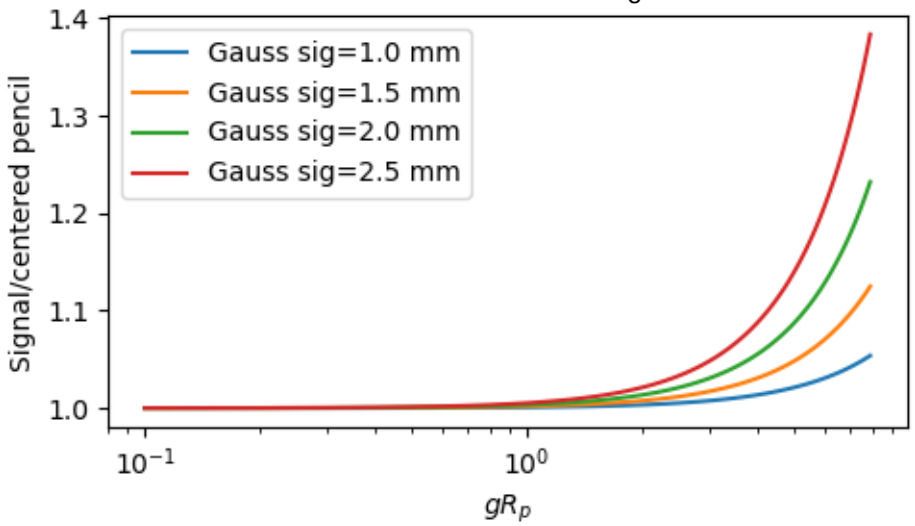


Offset scaling



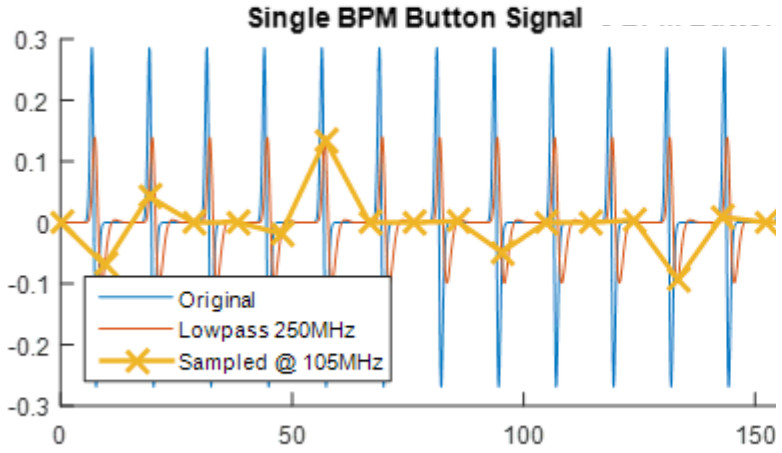
$$g = \frac{\omega}{\gamma_r \beta_r c}$$

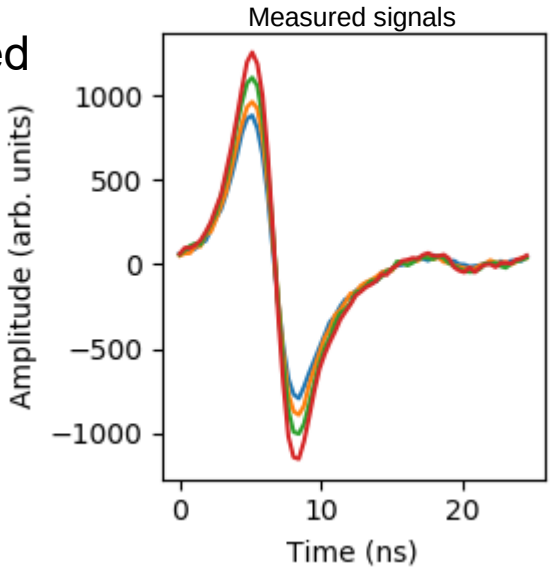
Transverse size scaling

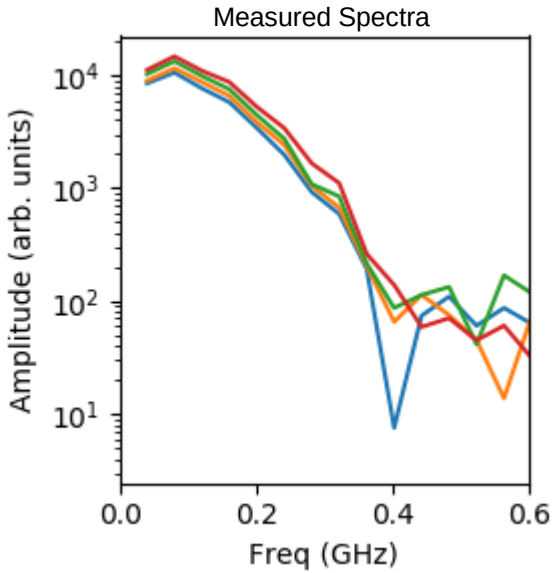


Measuring broadband BPM pickup response

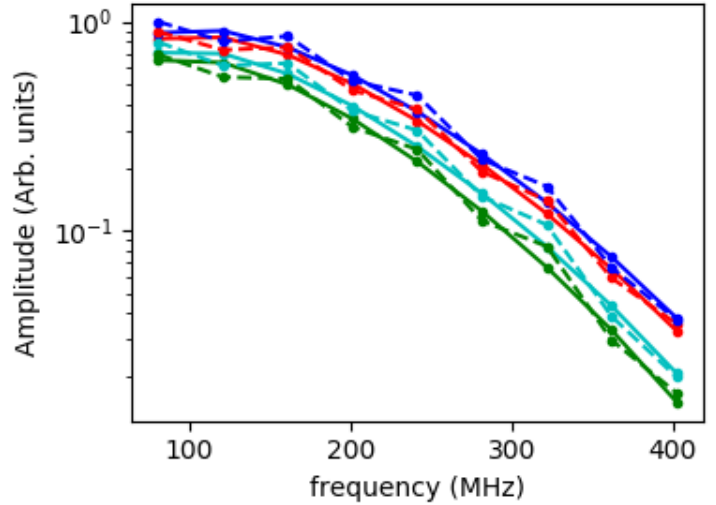
- Measure multiple harmonics with BPM using a Time Interleaved Sampling (TIS) method
  - BPM picks up signal from bunches at 40.25 MHz repetition rate
  - Signal goes to digitizer which samples at 119 MHz giving effective sampling rate of 2.737 GHz. Resolves harmonics of 40.25 MHz up to 1.3 GHz
- Spectra measured in FRIB MEBT were fit to the above equation assuming Gaussian transverse and longitudinal distributions
- RFQ frequency = 80.5 MHz, only every other bucket filled
  - But, the empty buckets are partially filled distorting the 80.5 MHz harmonics





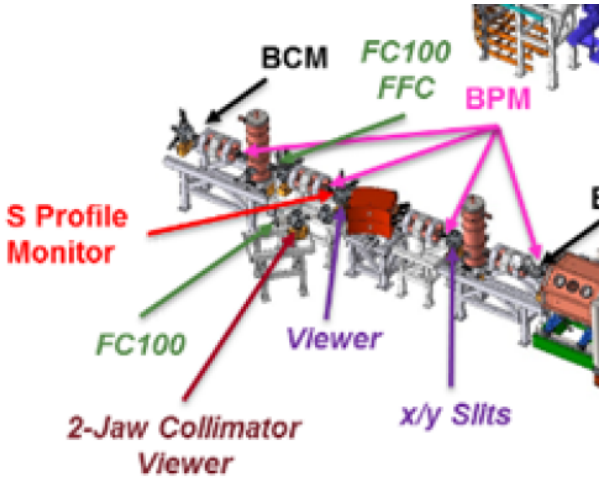


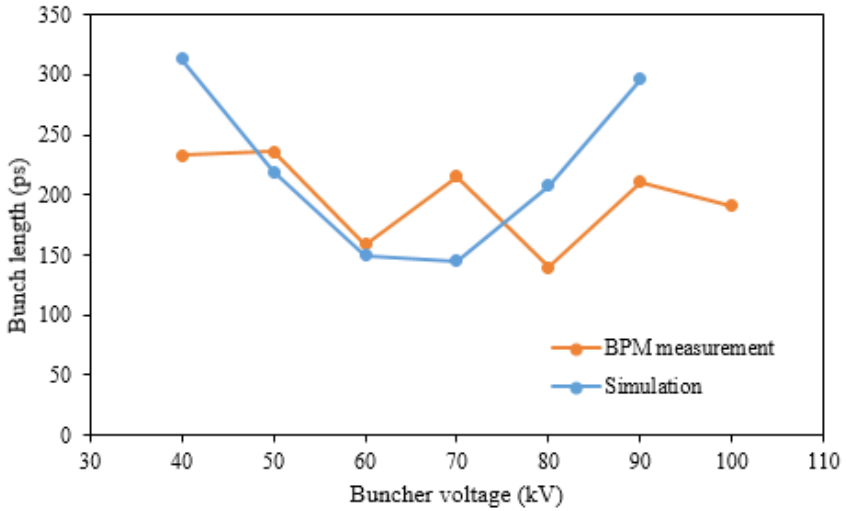
Buncher voltage scan

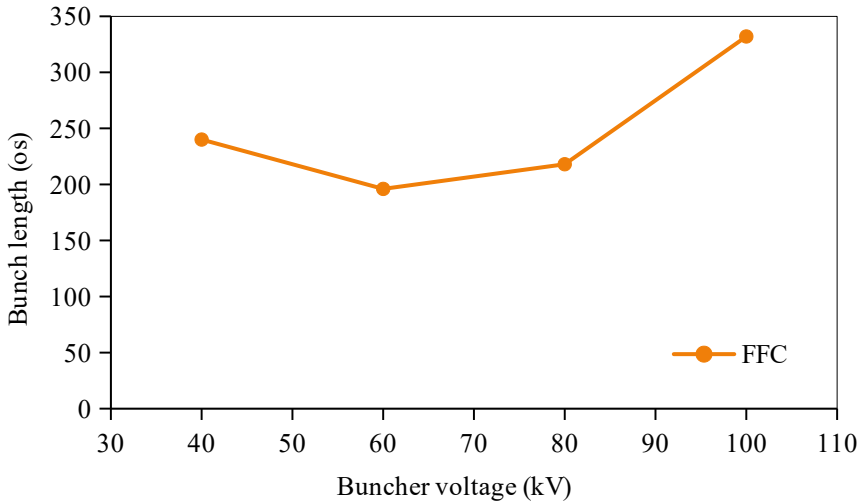


- Tested method by varying the longitudinal size by varying a buncher voltage
  - Fit the measured spectra assuming transverse and longitudinal Gaussian profiles
  - Good fit within ±10%. Errors primarily due to offset 80.5 MHz harmonics
- The BPM measurements fail to replicate the expected longitudinal size from simulations
  - Simulated behavior was verified by measurements with a downstream fast Faraday cup

FRIB MEBT diagnostics

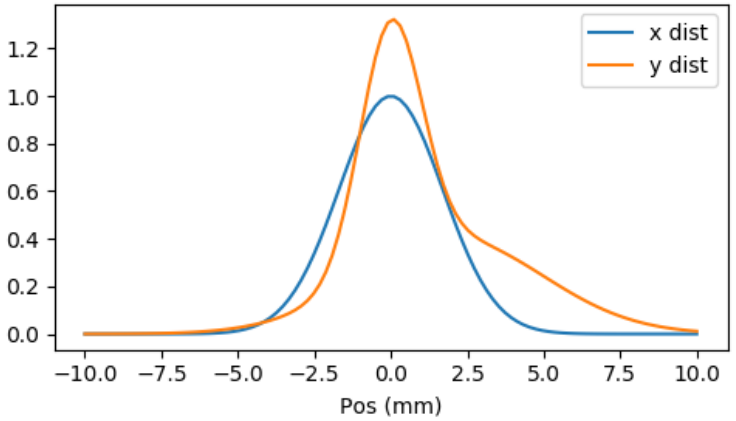


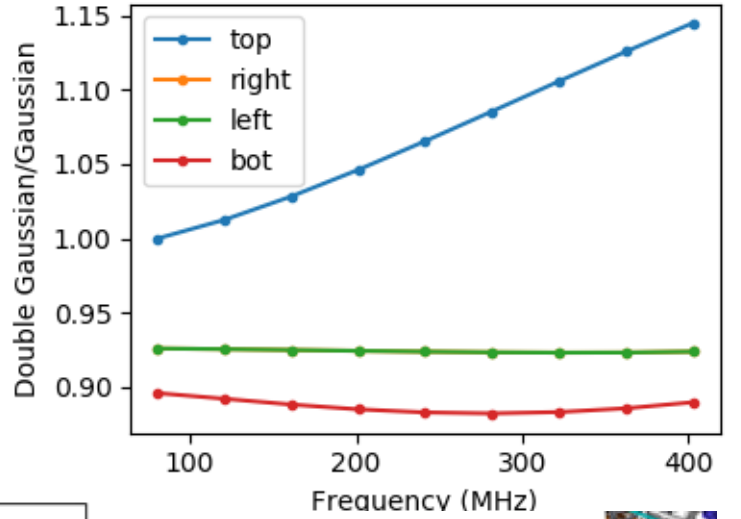


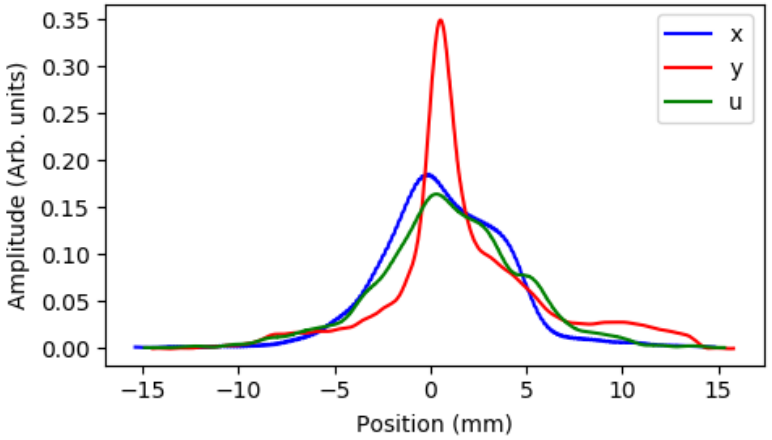


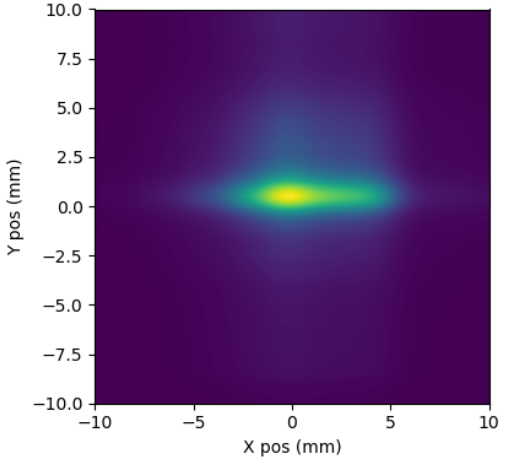
Non-Gaussian transverse distributions

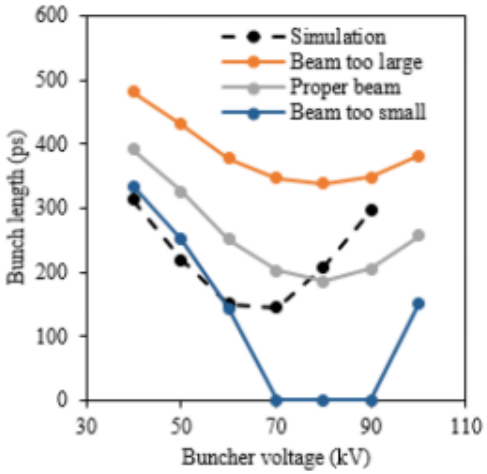
- At high g, the measured spectra are dependent on the exact transverse distribution of the beam.
  - Fitting assumes a Gaussian beam. Wire scanner measurements show non-Gaussian beam
- Using a model with the same first and second order moments is insufficient
- Can improve agreement by measuring the transverse distribution and only fitting the longitudinal distribution
  - Measured ε_z = 0.166 keV ns. Simulated ε_z = 0.153 keV ns. Error within 10%

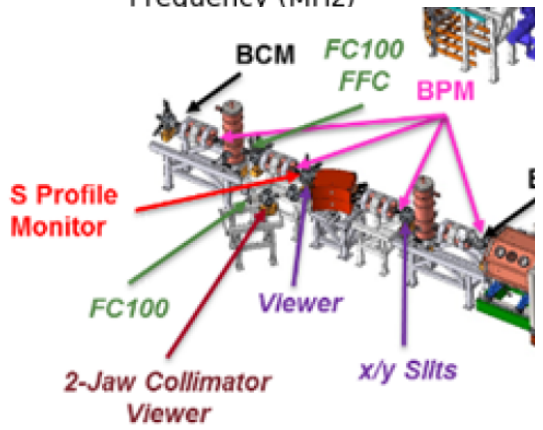












Summary

- BPM spectra measurements can be used to determine bunch sizes
  - But, these measurements are challenging at high g due to dependence on transverse distribution
- Measurements at low g, i.e. relativistic beams, should be more successful, and can only measure the bunch length
  - Possible at FRIB at end of LS1, but BPMs were not calibrated for multiple harmonics
  - Energy 20 MeV/u. gR_p = 0.19-1.14