



# Pole Face Winding Scan

Simulation Updates

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## **Introduction**

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# Previous Results

## MD4224: Approaching the integer tune

High brightness beam static tune scan in Proton Synchrotron using Low Energy Quads (LEQs).

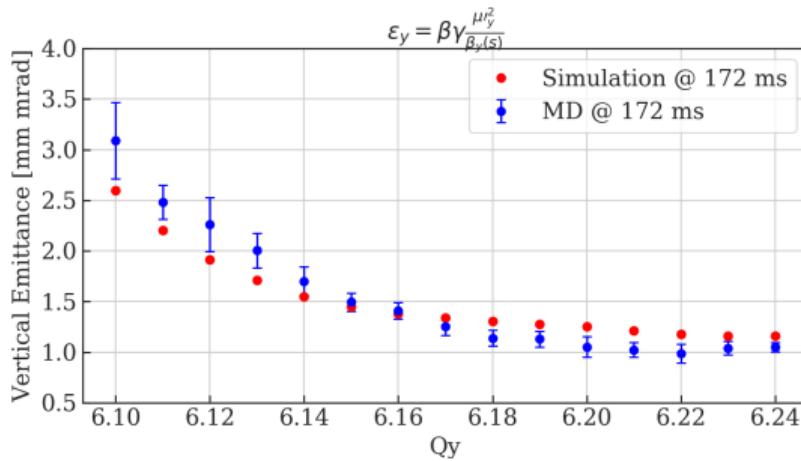


Figure: Result of MD4224 Vertical tune scan.

# Motivation

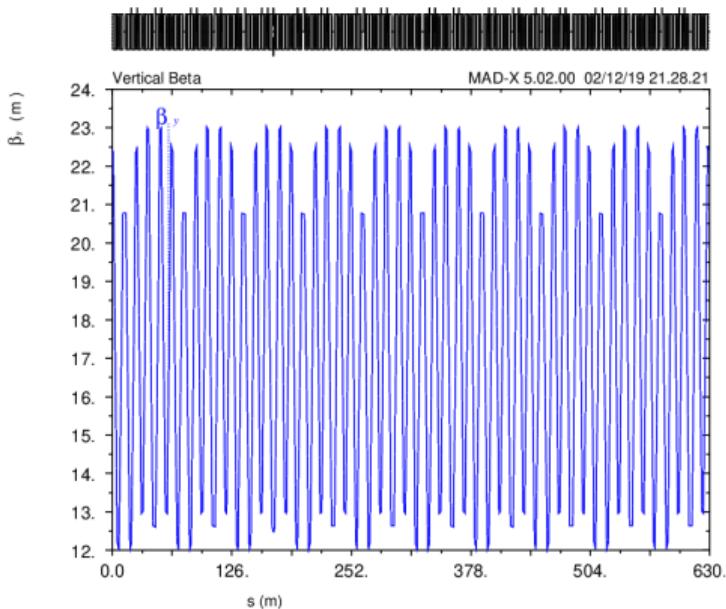
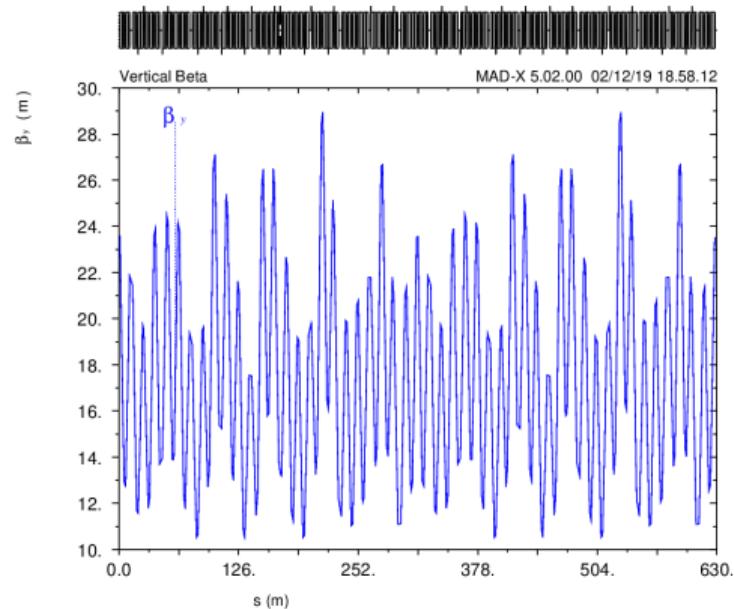
Found emittance growth as tune is brought closer to the integer. Believe this to be due to the bunch interacting with the quadrupolar stop-band, which is exacerbated by the use of the LEQs to modify the tune.

- ▶ If we switch off the LEQs and modify the tune with the Pole Face Windings (PFWs), do we excite the quadrupolar stop-band?
- ▶ Can we stimulate similar emittance growth with a single quadrupolar error in the lattice?

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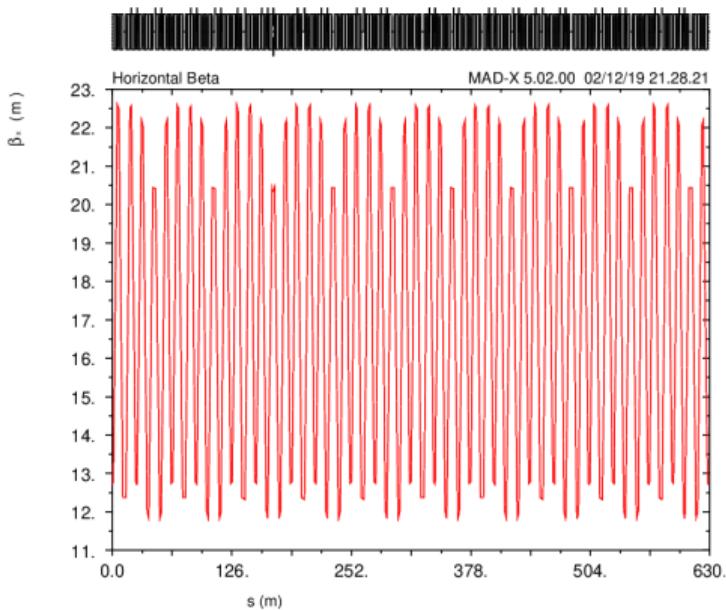
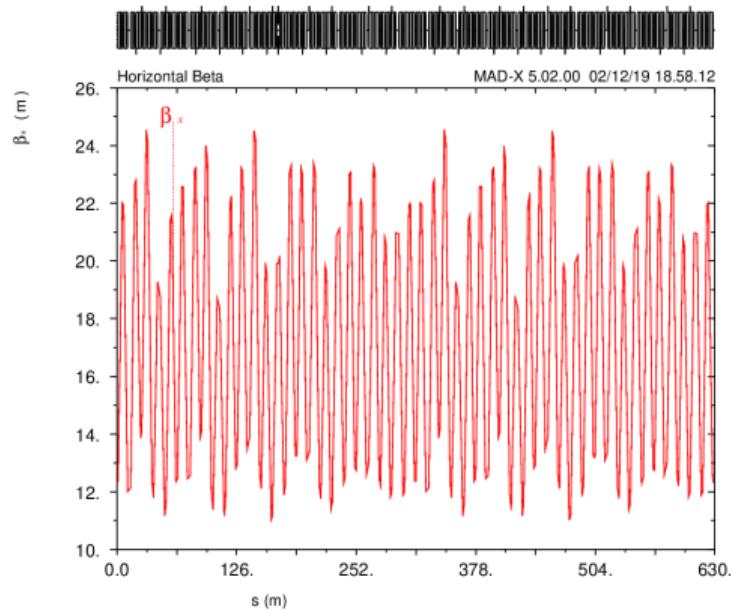
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# Optics Comparison: Vertical Beta



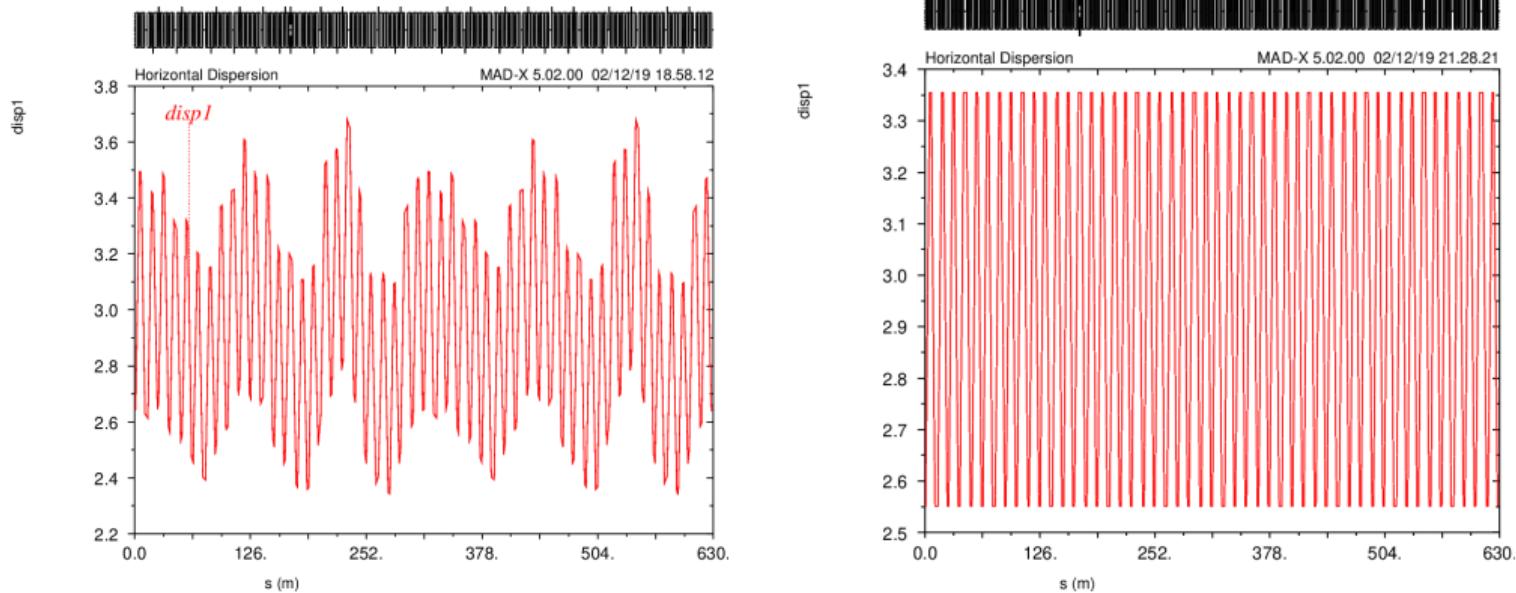
**Figure:** Comparison of vertical beta function when using LEQs (left) or PFWs (right) to modify the vertical tune.  $(Q_x, Q_y) = (6.21, 6.10)$  - most extreme point in vertical scan.

# Optics Comparison: Horizontal Beta



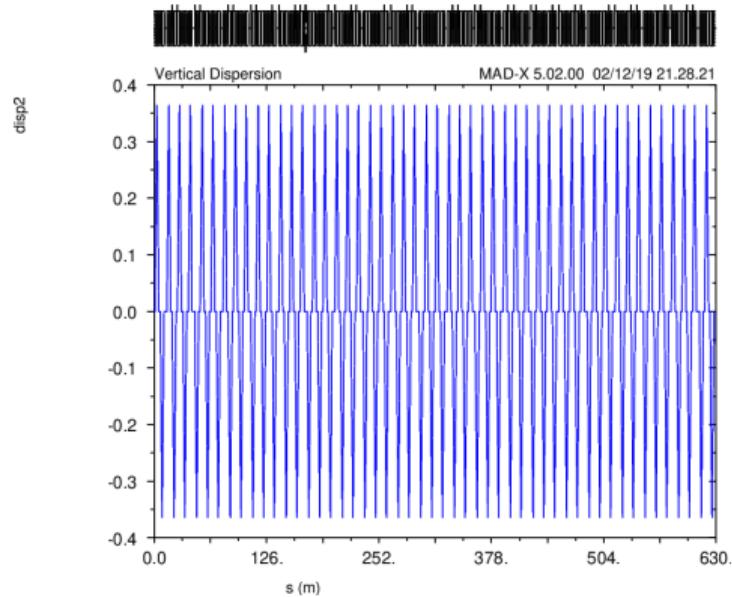
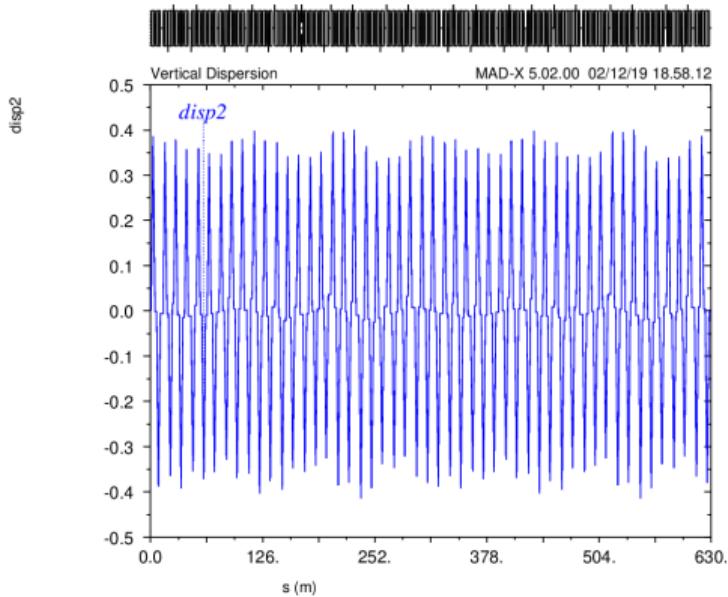
**Figure:** Comparison of horizontal beta function when using LEQs (left) or PFWs (right) to modify the vertical tune.  $(Q_x, Q_y) = (6.21, 6.10)$  - most extreme point in vertical scan.

# Optics Comparison: Horizontal Dispersion



**Figure:** Comparison of horizontal dispersion function when using LEQs (left) or PFWs (right) to modify the vertical tune.  $(Q_x, Q_y) = (6.21, 6.10)$  - most extreme point in vertical scan.

# Optics Comparison: Vertical Dispersion

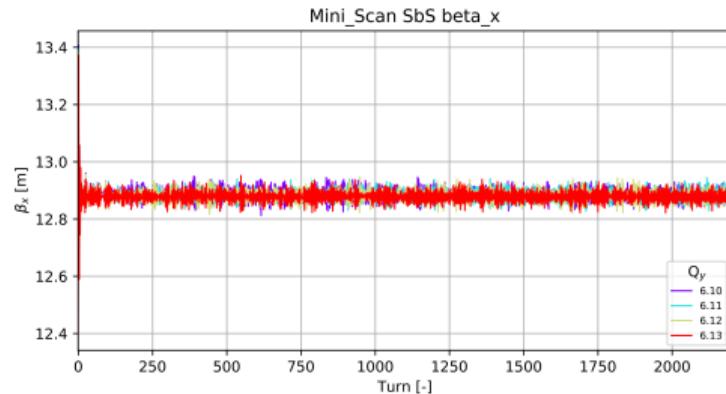
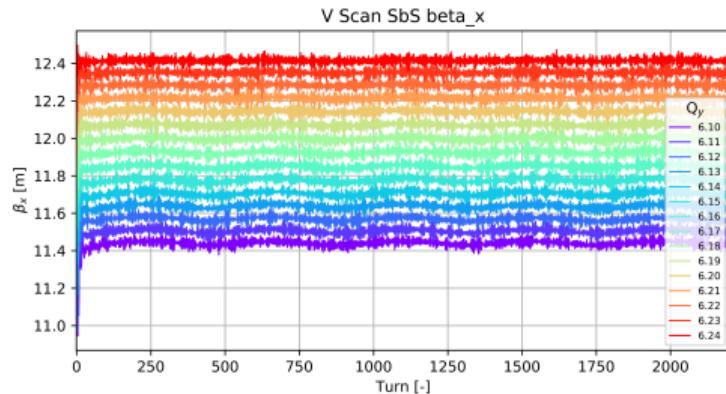


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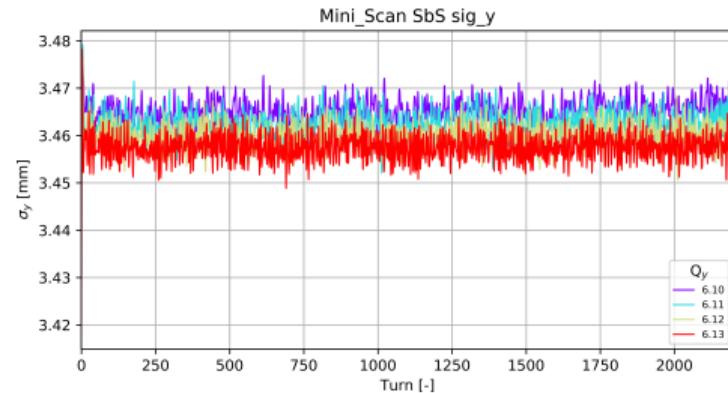
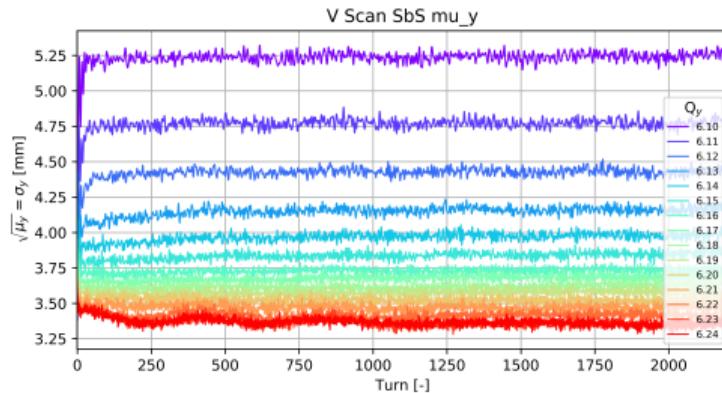
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# Vertical Scan: Vertical Beta Function



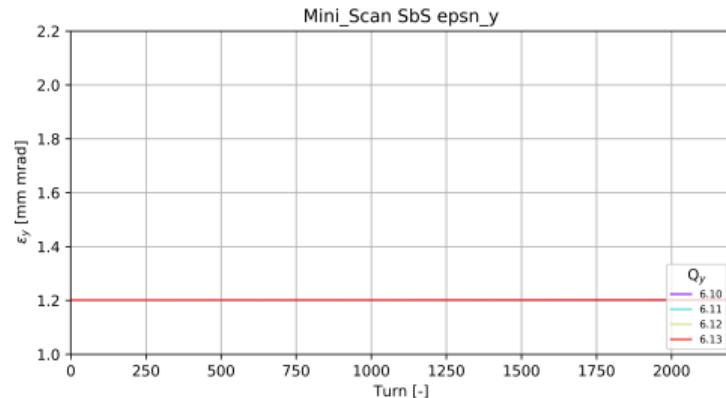
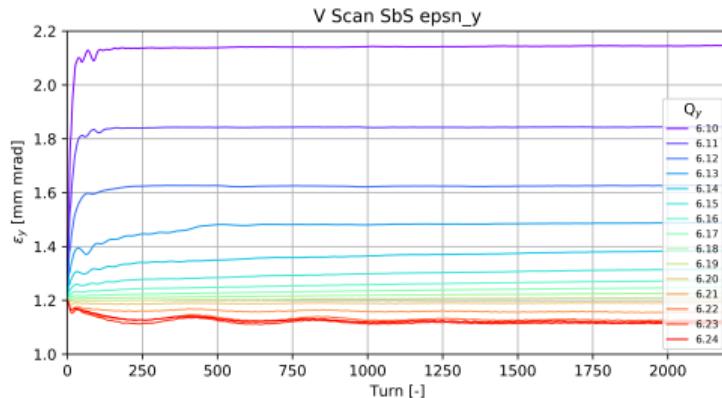
**Figure:** Comparison of vertical beta function at the position of the vertical wire scanner (BWSV64) when using LEQs (left) or PFWs (right) to modify the vertical tune.

# Vertical Scan: Vertical Beam Size



**Figure:** Comparison of vertical beam size at the position of the vertical wire scanner (BWSV64) when using LEQs (left) or PFWs (right) to modify the vertical tune.

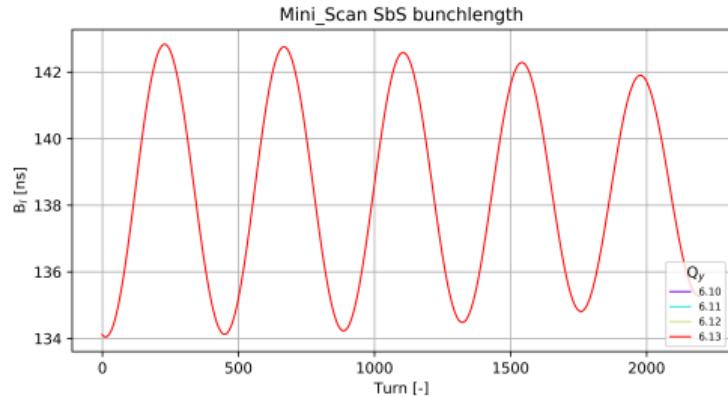
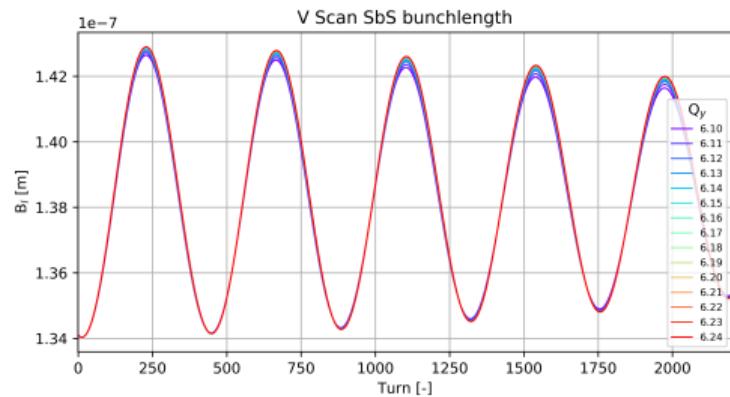
# Vertical Scan: Vertical Emittance



**Figure:** Comparison of vertical emittance at the position of the vertical wire scanner (BWSV64) when using LEQs (left) or PFWs (right) to modify the vertical tune.

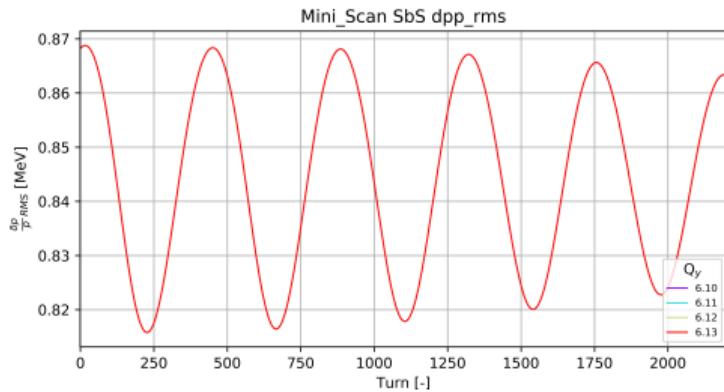
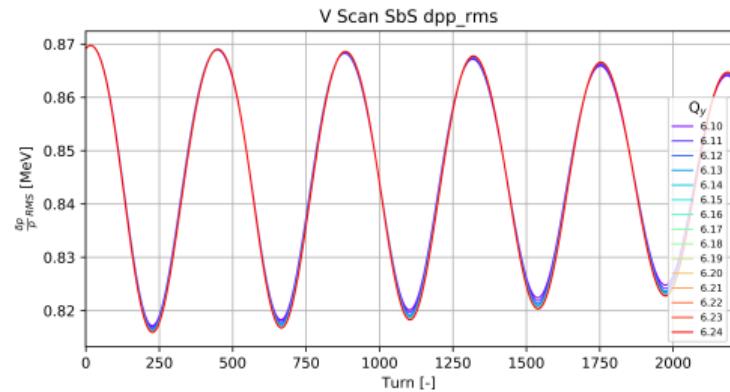
**Conclusion: PFWs do not excite the quadrupolar stop-band.**

# Vertical Scan: Longitudinal Motion



**Figure:** Comparison of bunch length at the position of the vertical wire scanner (BWSV64) when using LEQs (left) or PFWs (right) to modify the vertical tune.

# Vertical Scan: Longitudinal Motion



**Figure:** Comparison of momentum offset  $\frac{\delta p}{p} \text{ RMS}$  at the position of the vertical wire scanner (BWSV64) when using LEQs (left) or PFWs (right) to modify the vertical tune.

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# PFW With Quadrupolar Error

## Add quadrupolar error to single LEQ (QDN72)

Perform scan in beta-beating. All LEQs off except single error.

# Beta Beating

Equation for beta-beating taken from H. Bartosik's JUAS 2019 lecture on linear imperfections and correction:

$$\frac{\delta\beta}{\beta_0} = -\frac{1}{2 \sin(2\pi Q)} \int_{s_1}^{s_1+l} \beta(s) \delta K(s) \cos(2\psi - 2\pi Q) ds \quad (1)$$

Single quadrupole error  $\Delta K$ , normalised quadrupole strength.

$$\Delta K = \frac{2 \sin(2\pi Q)}{\beta_{max}} \left( \frac{\delta\beta}{\beta_0} \right) \quad (2)$$

## Scan in Beta-Beating

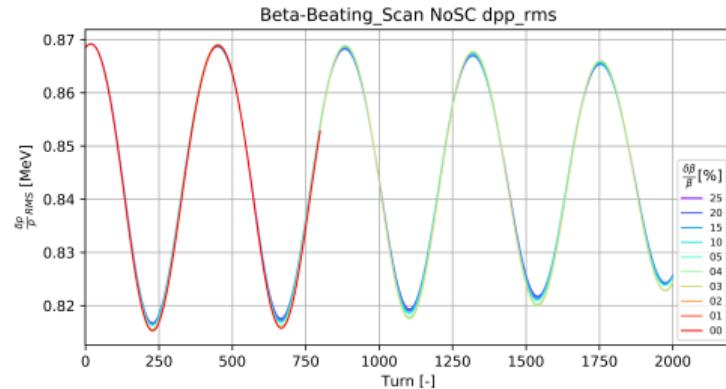
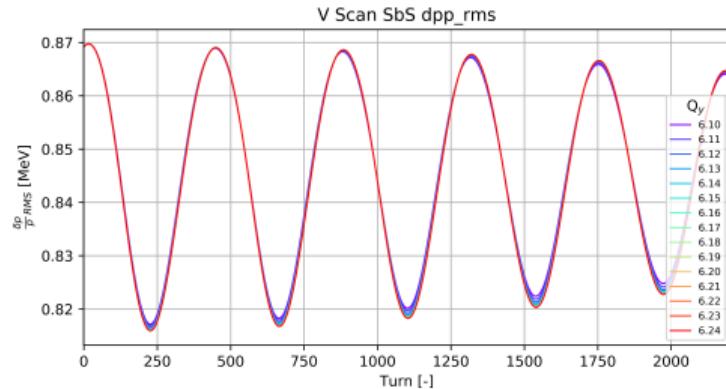
$$Q_y = 6.10, \beta_{max} = 23.01757, \beta_0 = 23.0095$$

$$\Delta K = 0.0510425 \left( \frac{\delta\beta}{\beta_0} \right) \quad (3)$$

$\frac{\delta\beta}{\beta}$ estimated [%]	$\Delta K$	$\beta_{max}$	$\delta\beta$	$\frac{\delta\beta}{\beta}$ $out$ [%]
1	0.000510425	23.24475	0.22718	0.987
10	0.00510425	23.3844	2.36683	10.283
20	0.0102085	27.9566	4.93903	21.46
25	0.0127606	29.3158	6.29823	27.4

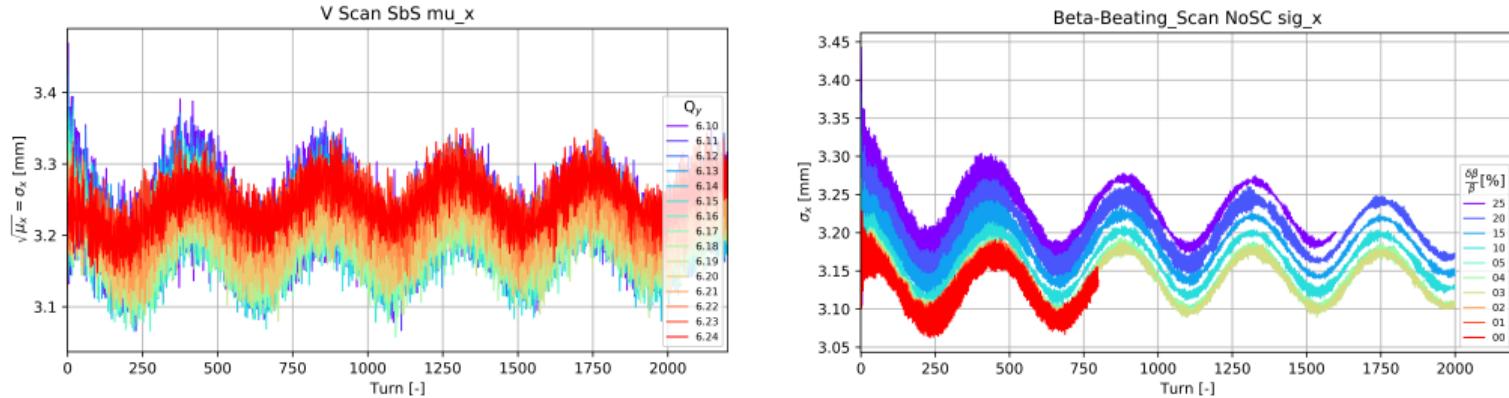
**Table:** Quadrupole error  $\Delta K$  and corresponding  $\frac{\delta\beta}{\beta}$   $out$ .

# PFW with Quadrupolar Error: Longitudinal Motion



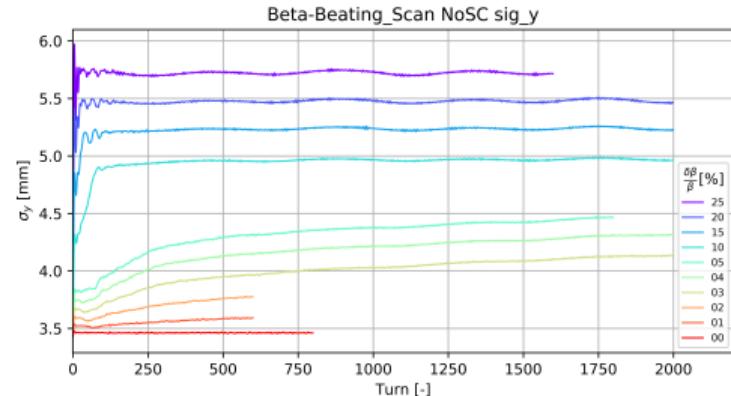
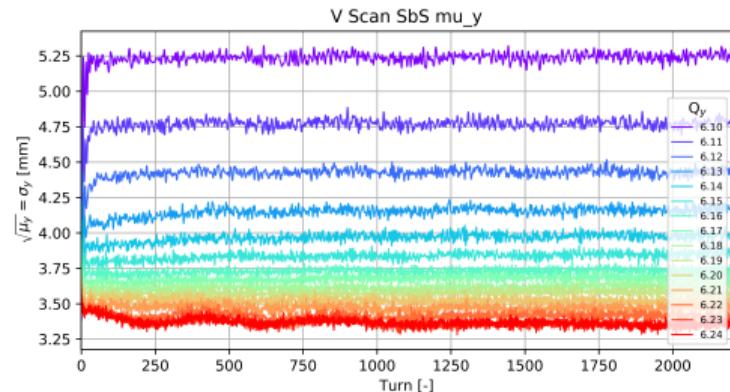
**Figure:** Comparison of momentum offset  $\frac{\delta p}{p_{RMS}}$  at the position of the vertical wire scanner (BWSV64). The left plot shows a static tune scan using LEQs to modify the tune. The right plot shows a fixed tune of (6.21, 6.10) with a beta-beating error (indicated in legend) applied via a single quadrupolar error on the LEQ QND72.

# PFW with Quadrupolar Error: Horizontal Beam Size



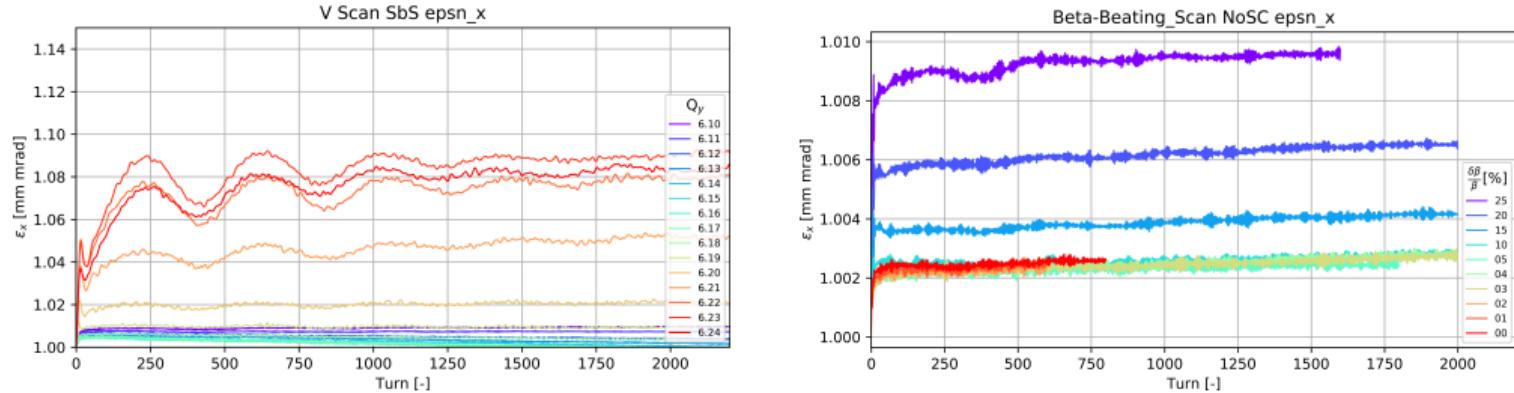
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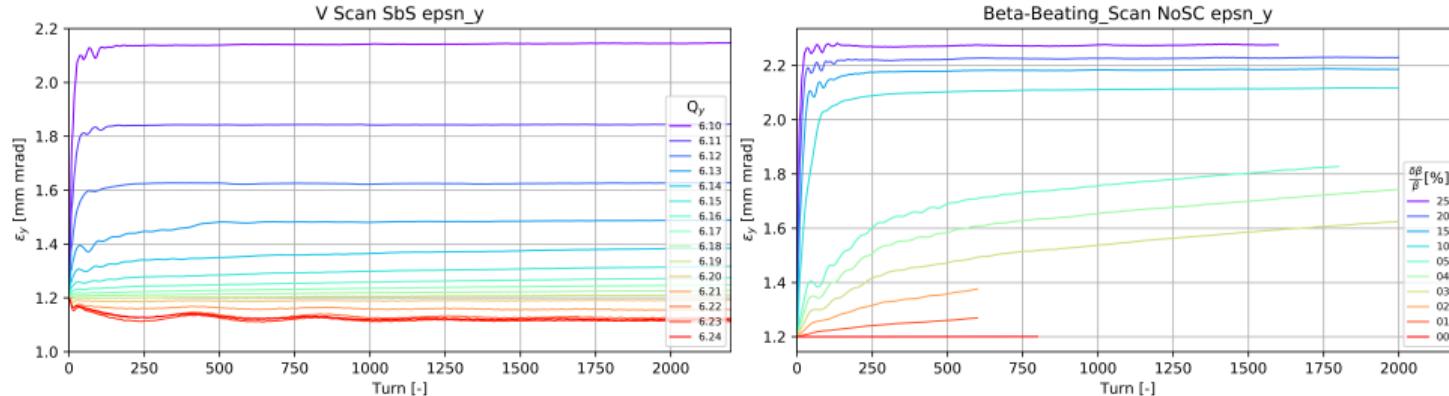
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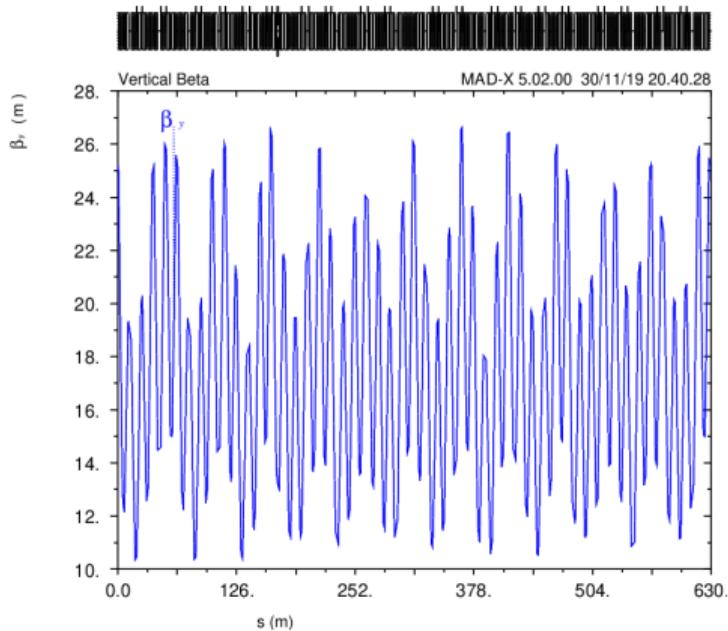
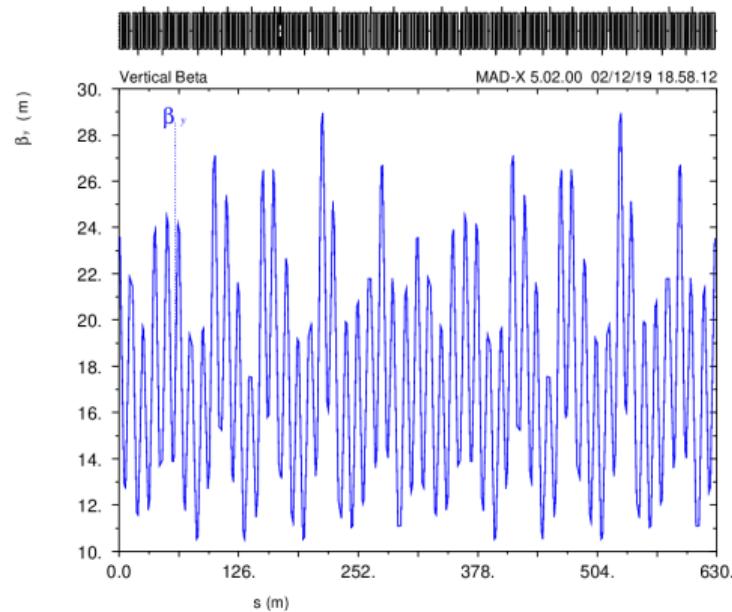


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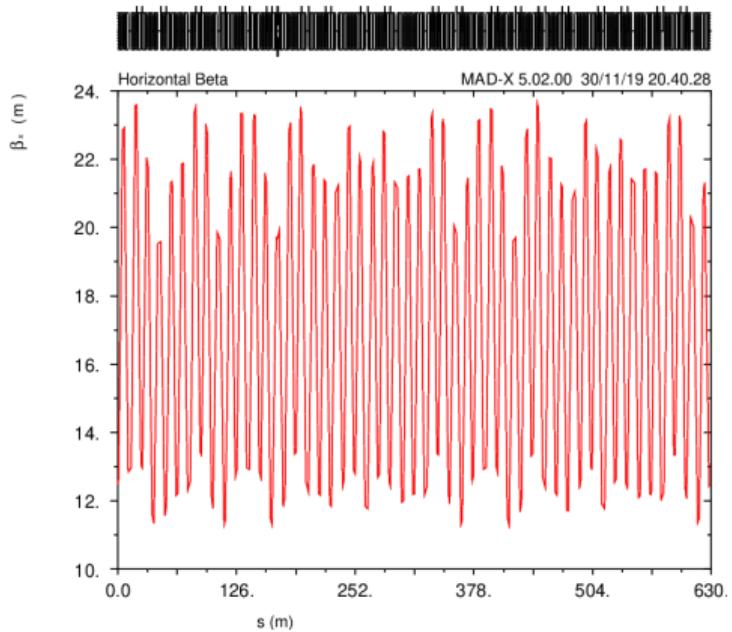
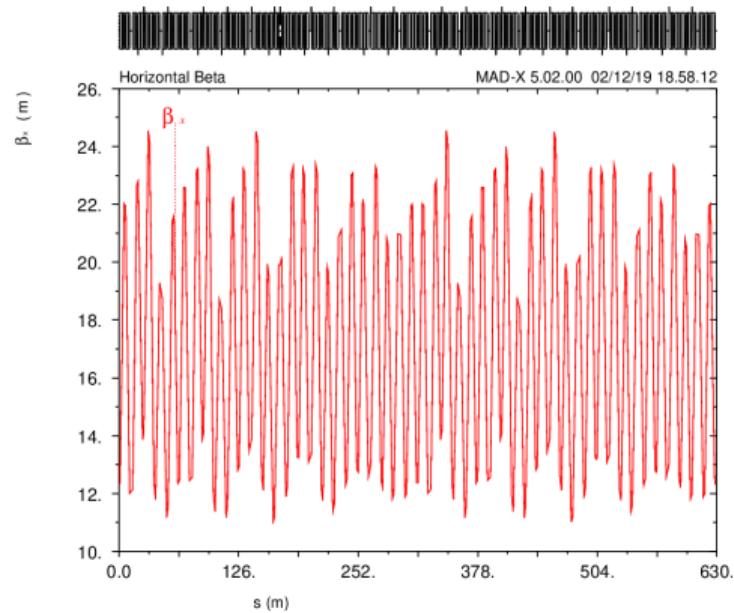
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# Optics Comparison: Vertical Beta



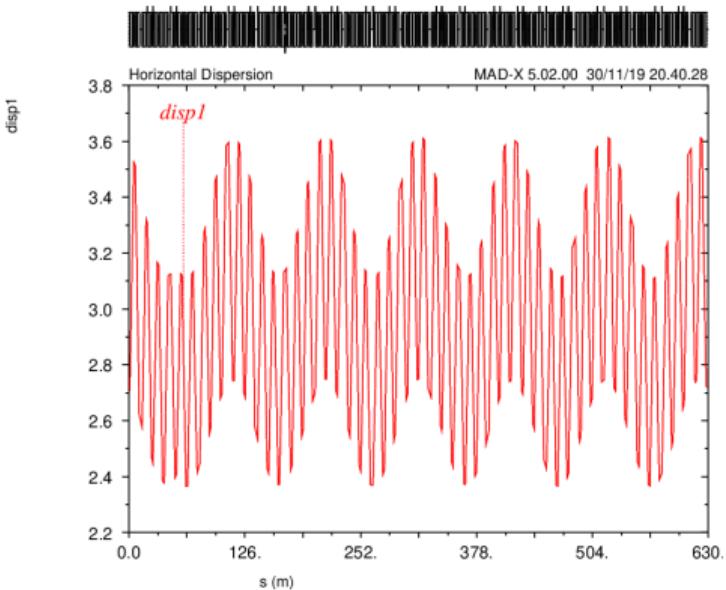
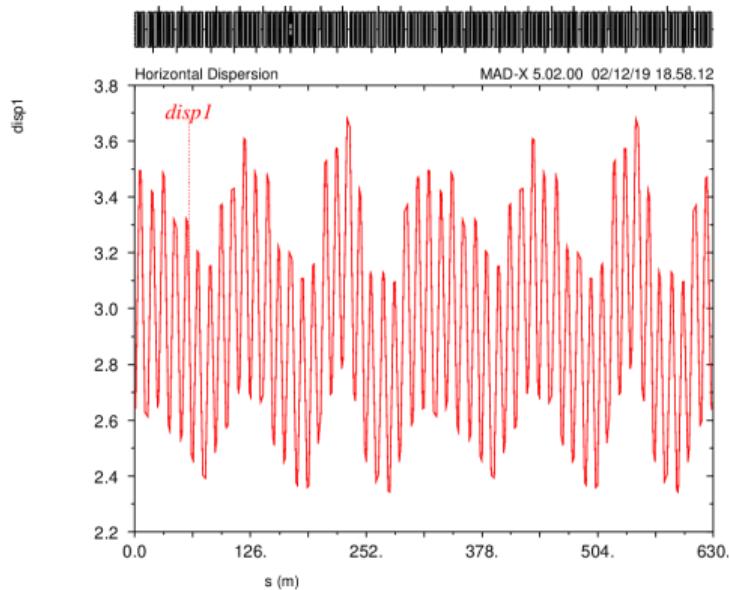
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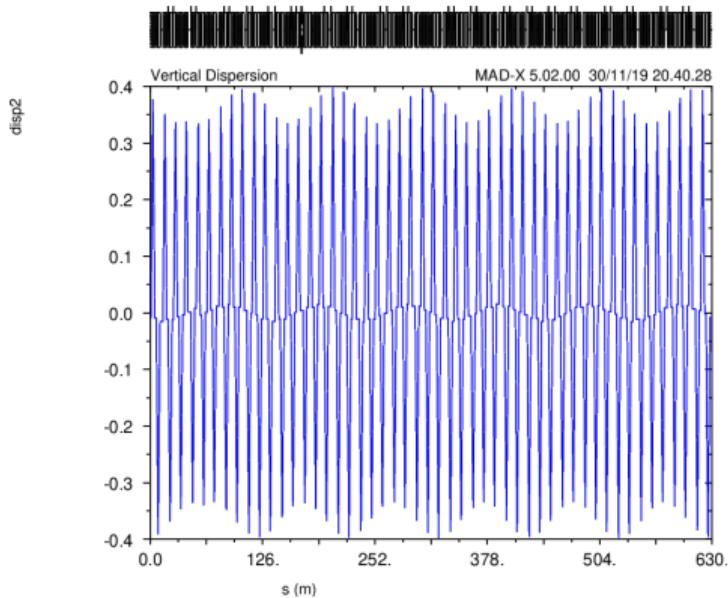
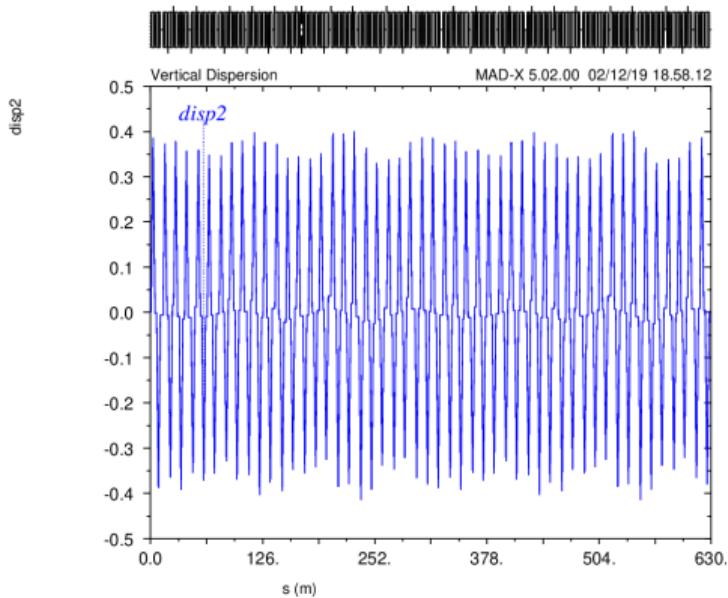
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# Optics Comparison: Horizontal Dispersion



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# Optics Comparison: Vertical Dispersion



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# Conclusions

- ▶ PFW static tune scan shows no emittance growth with tune change - PFWs don't excite the quadrupolar stop-band at the (half) integer.
- ▶ Single quadrupolar error on QDN72 gives beta-beating - defined a scan in beta-beating from 1 - 25%.
- ▶  $\approx 15\%$  beta-beating on top of PFW scan gives similar emittance growth as LEQ scan.



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