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MD4224: Integer Resonance Investigation in the Proton Synchrotron

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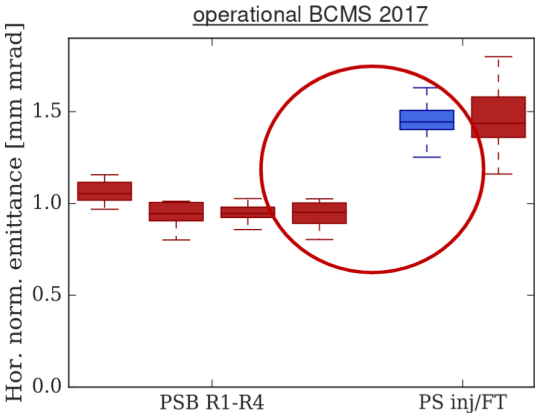
PSB -> PS Emittance Blow-up



Background

- **Observed Emittance Blow-up!** 30% - 40% in **horizontal** between PSB and PS.
- **Possible Contributors:** Dispersion mismatch in transfer line, systematic errors in emittance measurement in both machines, injection bump tune swing, ...
- **Does Space Charge Contribute?** Perform an MD to probe space charge effects on PS injection.
- **Compare MD with Simulations:** Perform simulations to understand MD results.
- **Iterative Process:** Compare MD and Simulation Data -> Improve Models -> Improve Understanding.

MD Summary

- **What We Did:** Perform a static tune scan investigating the bea, behaviour close to the integer tune in each plane separately. Using the low energy quadrupoles (LEQs) to vary tune and pole face windings (PFWs) to maintain low chromaticity.
- **Beam:** Clone of operational BCMS: MD4224_LHC_BCMS25_2018_PSB_PN2 MD4224_48b_BCMS

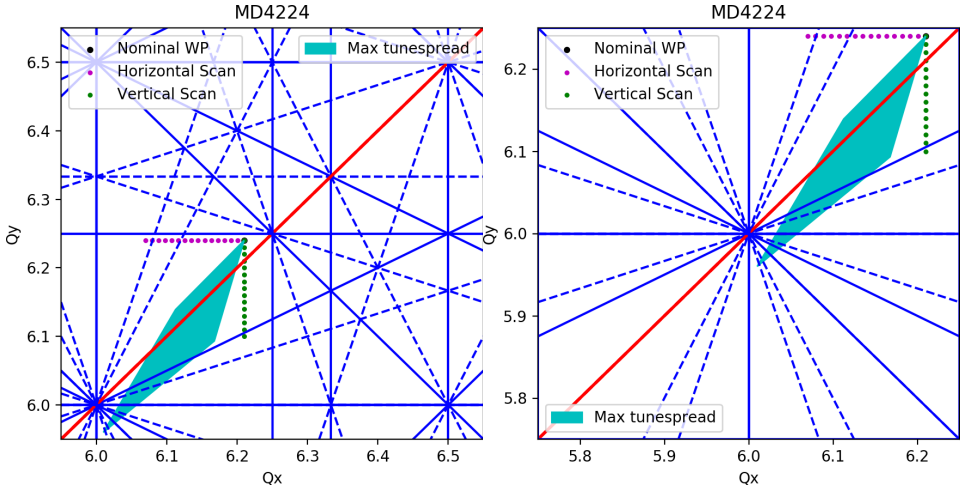
Horizontal Scan:

- Q_x = 6.07 - 6.21
- Q_y = 6.24

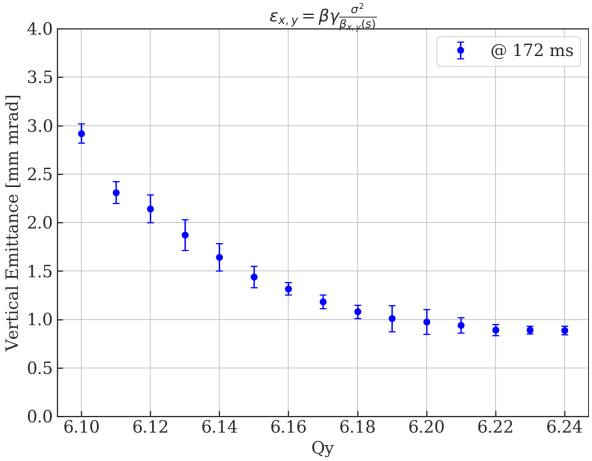
Vertical Scan:

- Q_x = 6.21
- Q_y = 6.10 - 6.24

Static Tune Scan



MD Result


$\varepsilon_{x,y} = \beta\gamma\frac{\sigma^2}{\beta_{x,y}(s)}$
@ 172 ms
Vertical Emittance [mm mrad]
Qy
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
6.10
6.12
6.14
6.16
6.18
6.20
6.22
6.24

MD4224 Parameters

Parameter	MD	Simulation
Intensity N_p [10^{10}]	≈72.5	72.5
Normalised horizontal RMS emittance ϵ_x^n [mm mrad]	1.2	1.2
Normalised vertical RMS emittance ϵ_y^n [mm mrad]	1	1
Bunch length σ_t[ns]	140	140
Momentum spread $\frac{\Delta p}{p}$ [10^{-3}]	0.87	0.87
Horizontal maximum tune spread $\Delta Q_{x,\max}$	0.2	0.16
Vertical maximum tune spread $\Delta Q_{y,\max}$	0.28	0.24
Harmonic number h	9	9
RF voltage V_{rf} [kV]	21.2	21.2
Horizontal chromaticity Q'_x	0.77	0.80
Vertical chromaticity Q'_y	-2.85	-3.05
Kinetic energy of the stored beam [GeV]	1.4	1.4
Relativistic β	0.916	0.916
Relativistic γ	2.4921	2.4921
Synchrotron Frequency [Hz]	634	634

Table 1: Beam and machine parameters

Simulation Parameters

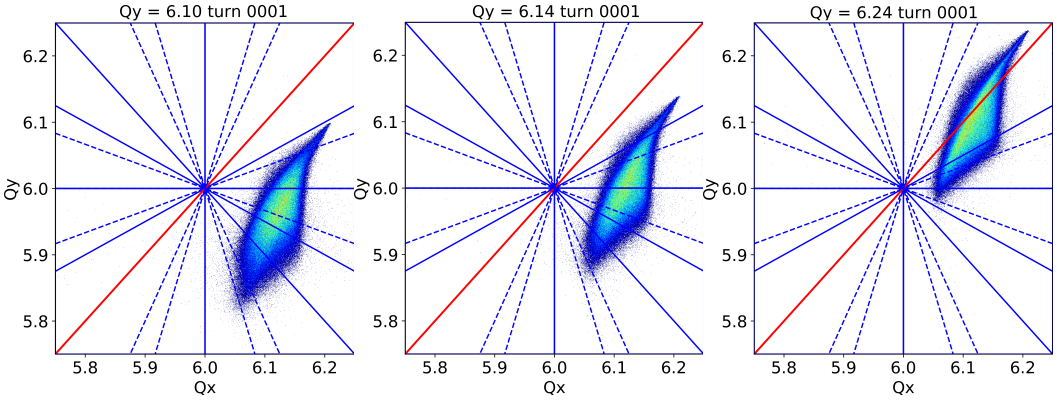
Parameter	Simulation
SC Method	Slice-by-Slice with Longitudinal Kick
SC Grid x	128
SC Grid y	128
SC Grid z	64
N_{mp}	$0.5 \cdot 10^6$
Turns	2200

Table 2: Simulation parameters

Simulation Setup

- Initial distribution identical for all tune points.
- Initial distribution matched to linear optics and tomo for tunes (6.21, 6.24).

Tune Footprints



PyORBIT Emittance Calculation

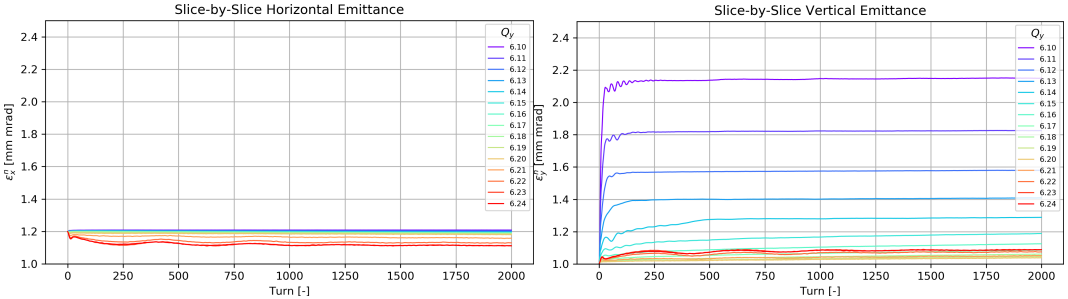
$$\epsilon = \sqrt{\left(< x^2 > - \frac{< x\ dE >^2}{< dE^2 >}\right)\left(< x'^2 > - \frac{< x'\ dE >^2}{< dE^2 >}\right) - \left(< x\ x' > - \frac{< x\ dE >< x'\ dE >}{< dE^2 >}\right)^2} \quad (1)$$

$$\epsilon^n = \epsilon \beta_L \gamma_L \quad (2)$$

Emittance

Fast emittance growth porportional to tune

Montegue Resonance results in emittance exchange near 6.21.



Beam Profiles

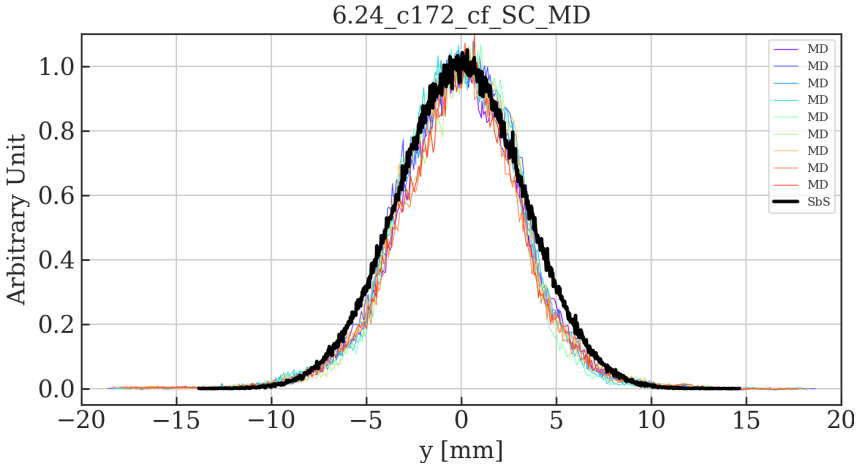
Measured and simulated beam profiles

PS turn $\approx$ 2.287 μs. Using maximum of each data set to normalise to 1.

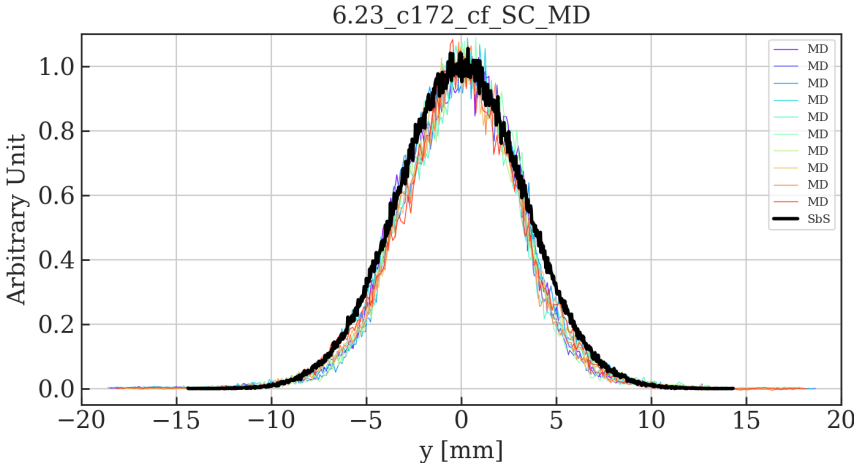
MD measurement times:

- c172 = 172 ms = 875 turns
- c175 = 175 ms = 2186 turns (not plotted)
- c185 = 185 ms = 6559 turns (not plotted)

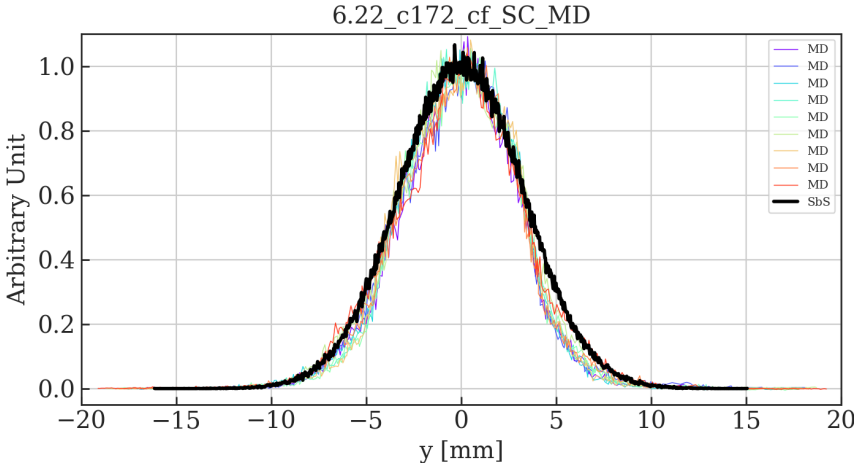
Q_y = 6.24, t = 172 ms



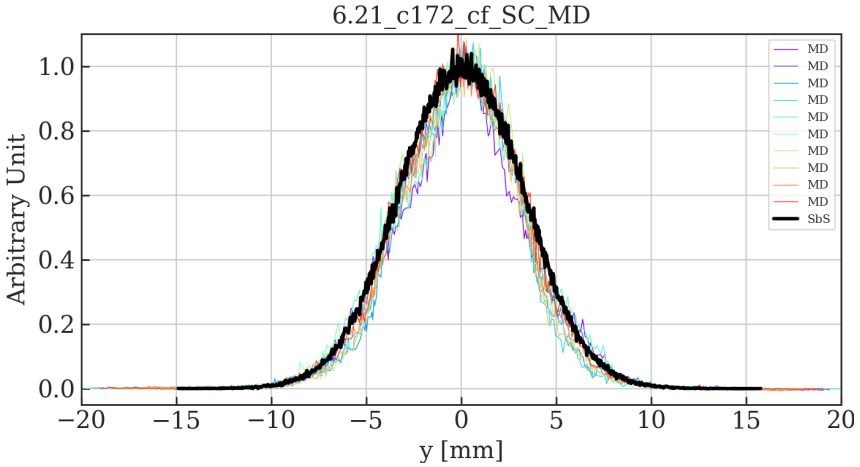
Q_y = 6.23, t = 172 ms



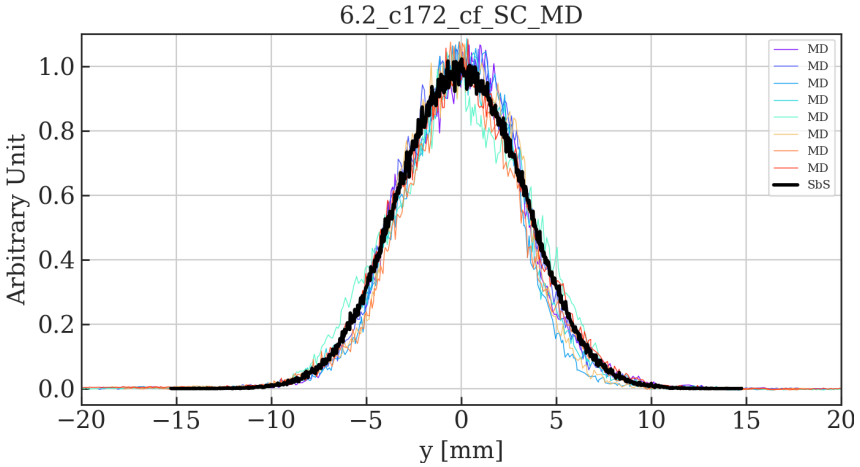
Q_y = 6.22, t = 172 ms



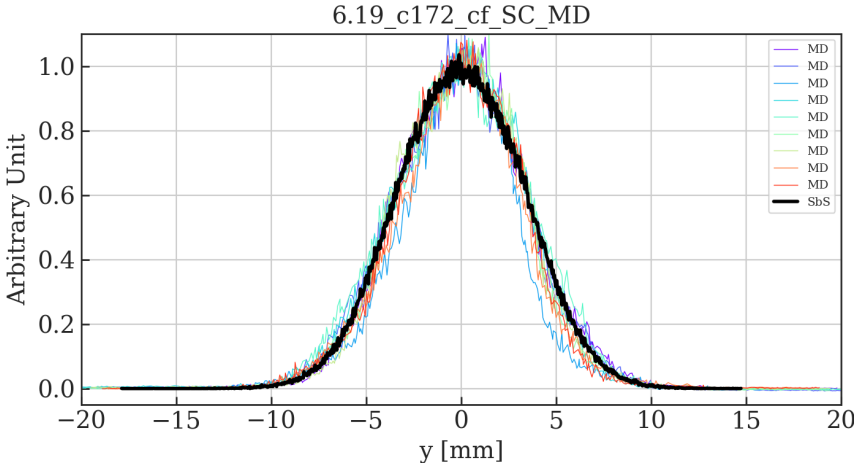
Q_y = 6.21, t = 172 ms



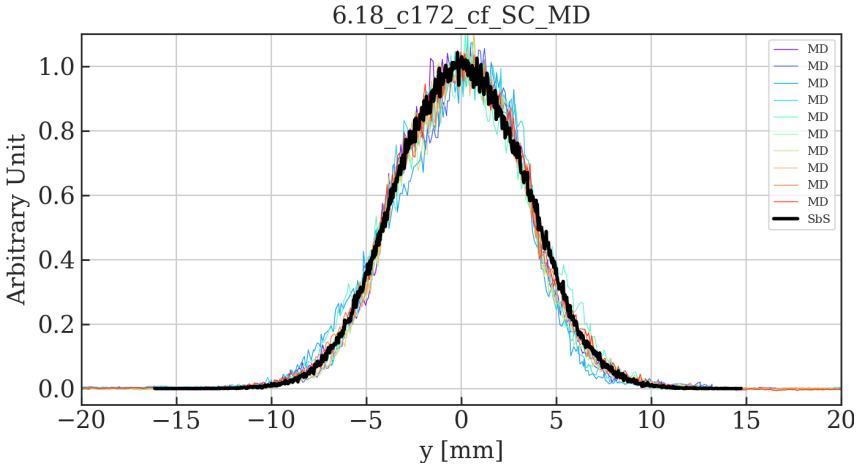
Q_y = 6.20, t = 172 ms



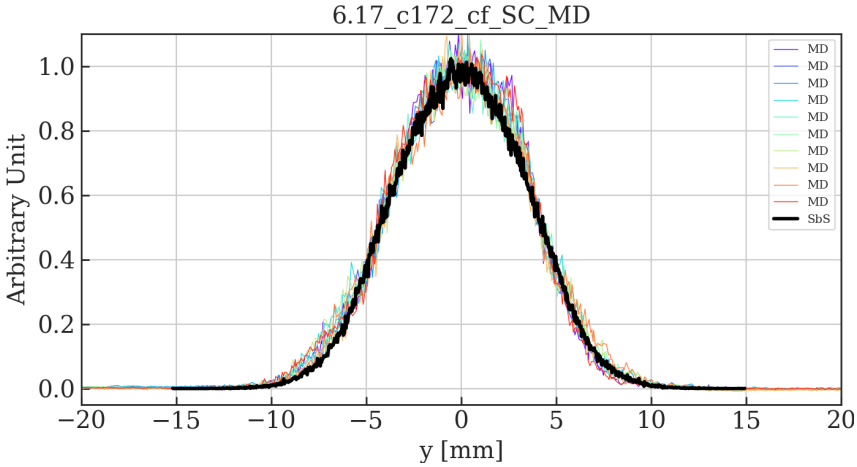
Q_y = 6.19, t = 172 ms



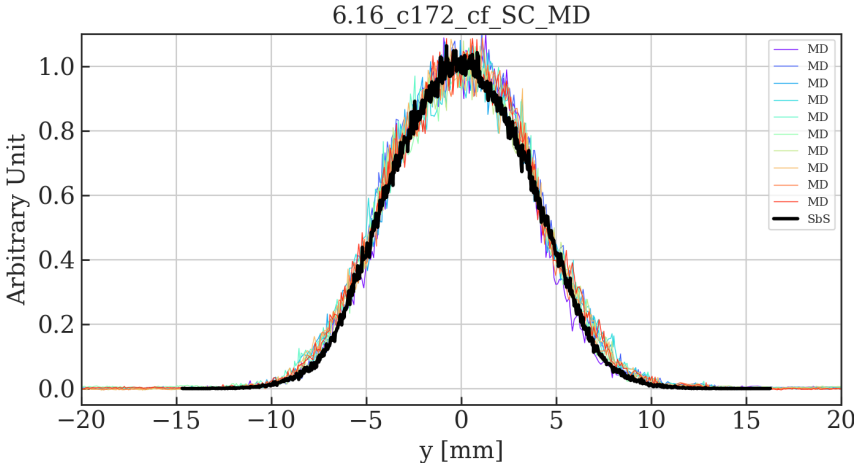
Q_y = 6.18, t = 172 ms



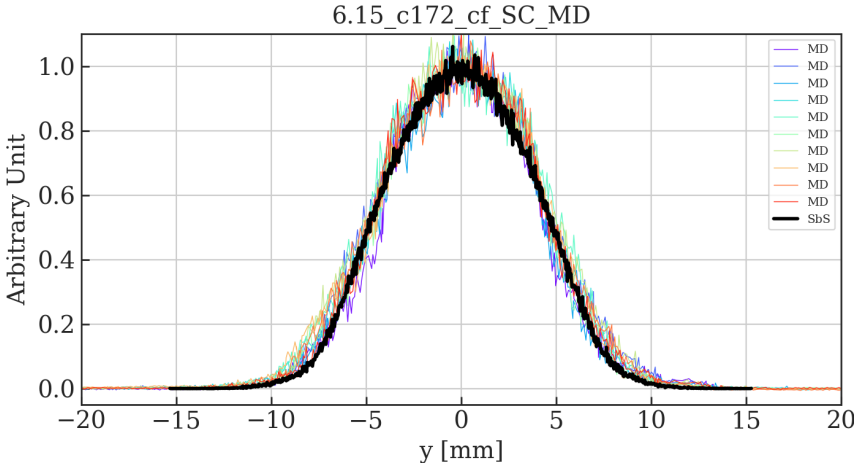
Q_y = 6.17, t = 172 ms



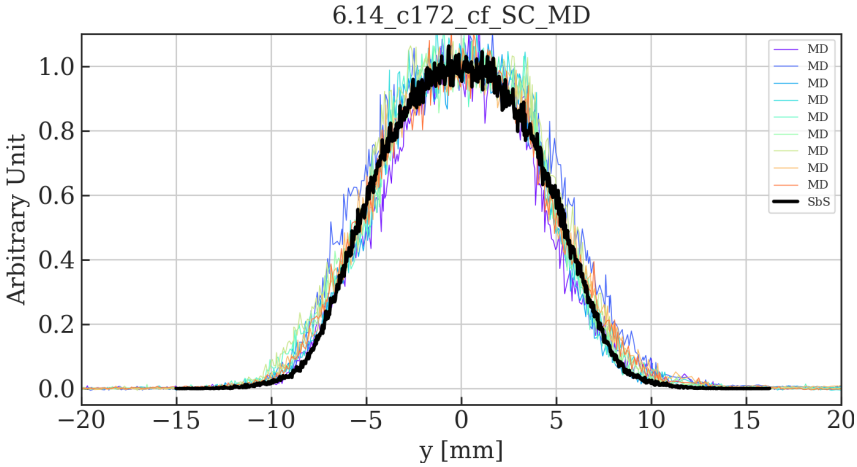
Q_y = 6.16, t = 172 ms



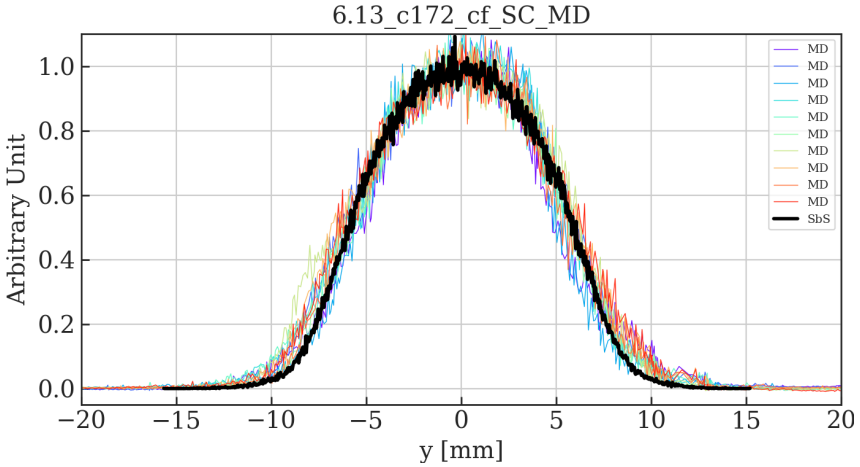
Q_y = 6.15, t = 172 ms



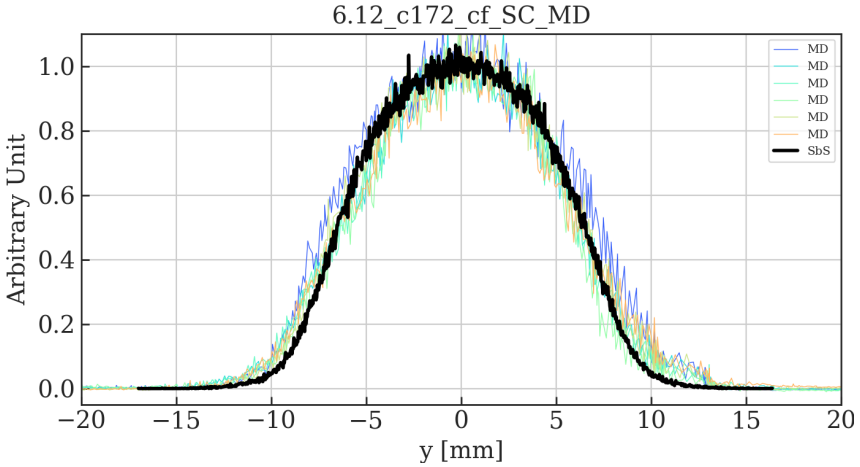
Q_y = 6.14, t = 172 ms



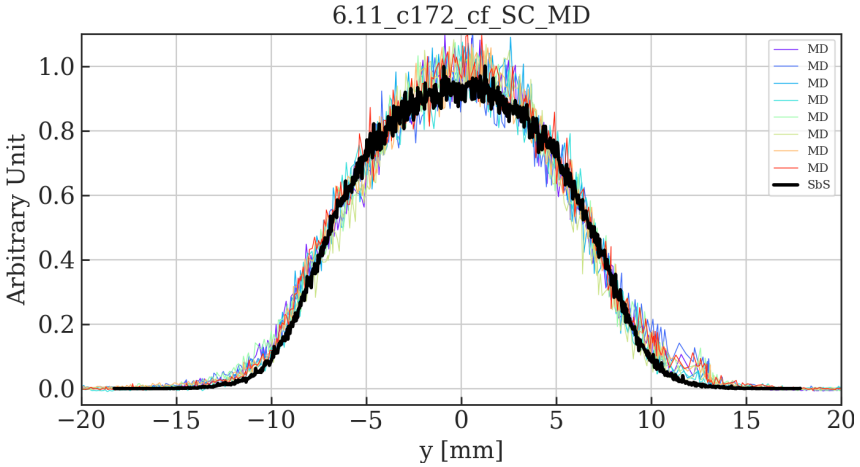
Q_y = 6.13, t = 172 ms



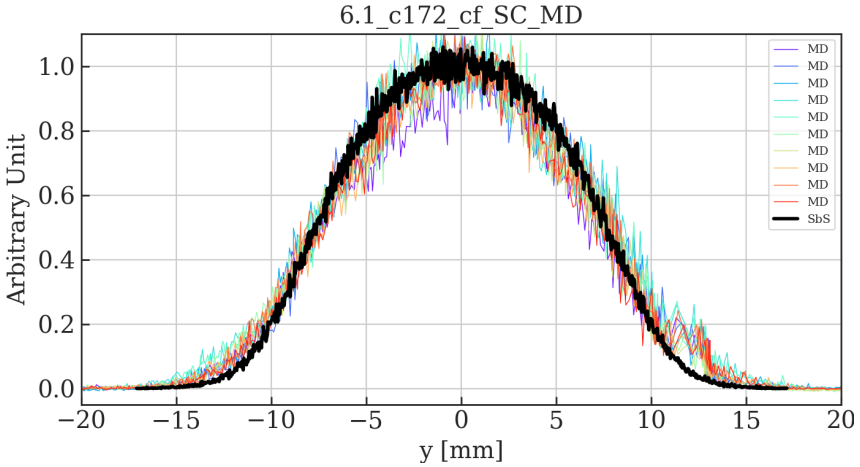
Q_y = 6.12, t = 172 ms



Q_y = 6.11, t = 172 ms



Q_y = 6.10, t = 172 ms

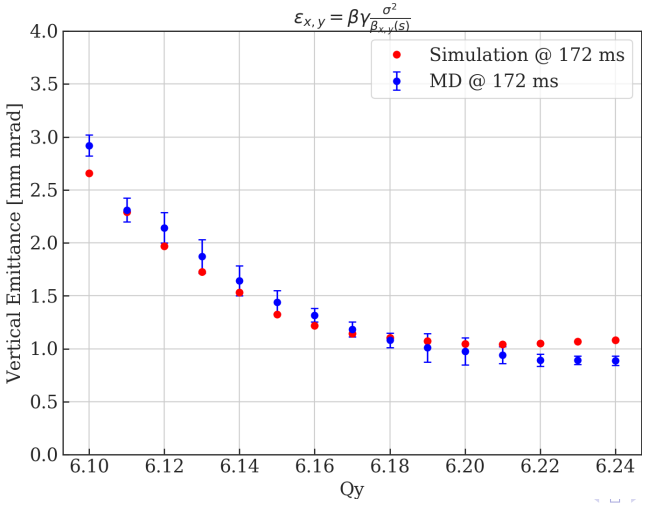


WS / Simulated Profile Treatment

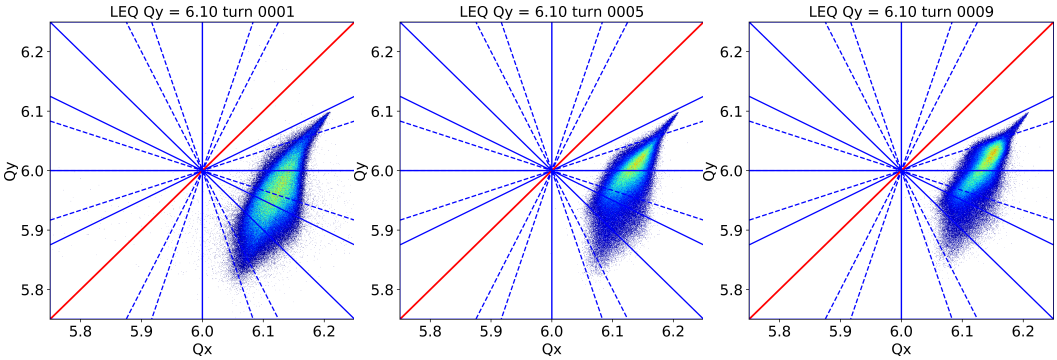
- 5 parameter Gaussian fit to find mean and σ.
- $\pm$ 6 σ cut to find slope. Remove slope.
- 3 parameter Gaussian fit to find centre.
- Use σ and match optics (statistical $\beta_{x,y}$ from simulated bunch) to calculate emittance. Note vertical dispersion is negligible.

$$\epsilon_{x,y} = \beta\gamma\frac{\sigma^2}{\beta_{x,y}(s)} \tag{3}$$

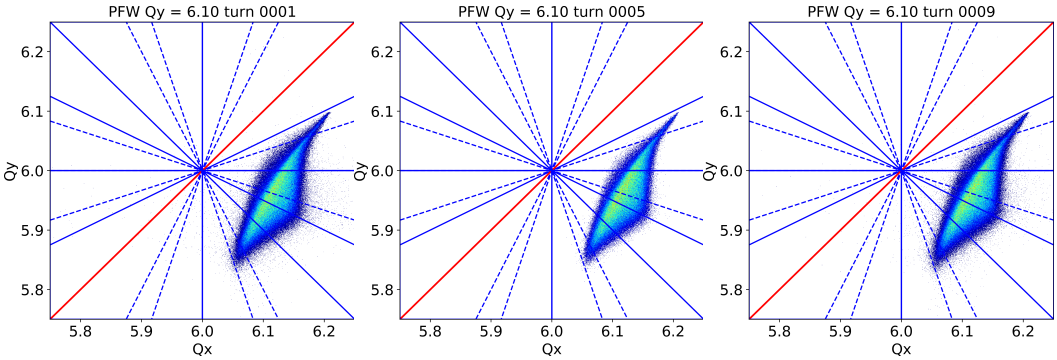
Emittance Using Simulation Optics and beam size σ



Footprint Evolution: LEQs

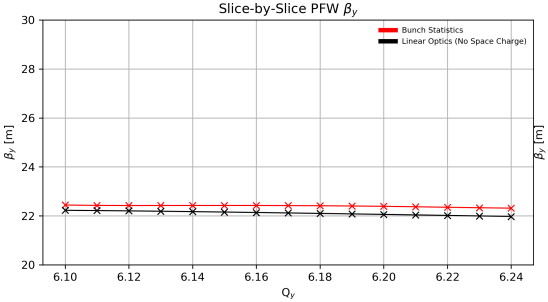


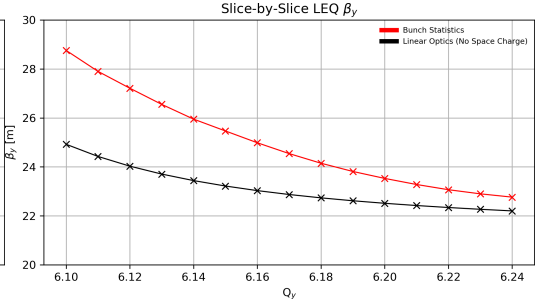
Footprint Evolution: PFWs



Optics Comparison

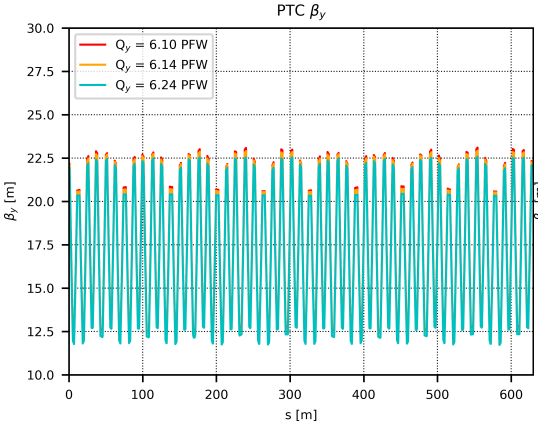
Compare Linear Optics and Statistical Bunch Optics @ WS 64 V

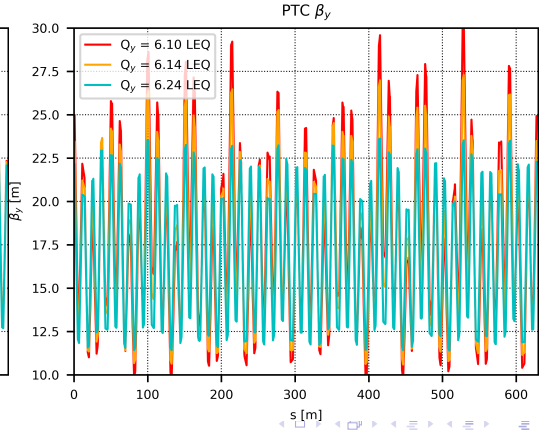




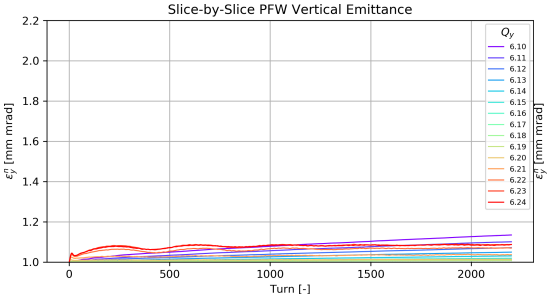
Optics Comparison

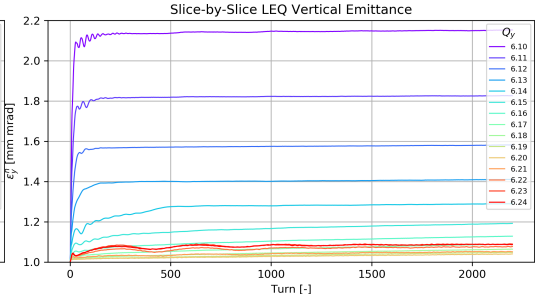
Linear Optics





Emittances PFW & LEQ





Next Steps

- Add single quadrupole error to gauge strength that results in non-periodic β function.
- Add injection bump (induces a tune swing).
- Horizontal Scan.

Conclusion

- MD224 Vertical scan and simulation campaign progressing well.
- Vertical emittance growth is fast (< 200 turns). Horizontal emittance growth is negligible.
- Montegue resonance causes emittance exchange near tune (6.21, 6.21).
- Measured beam profiles and simulated beam profiles agree well.
- Performing emittance calculation from profiles, simulation and MD agree well.
- Comparison of varying tune using PFWs and LEQs shows effect of quadrupole errors.
- Next steps well defined.

Acknowledgements

- F. Asvesta, M. Kaitatzi: MD assistance, discussions, etc.
- PSB PS Operators: MD setup and assistance.
- S. Albright, A. Santamaria Garcia, E. K. Platia: Assistance with tomoscope -> PyORBIT tomo distribution.
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- G. Sterbini: MD analysis SWAN/python Toolbox.


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