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PS Transfer Line Dispersion Mismatch: Simulation Updates

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PS PSB Emittance Blowup

- 2018: Detailed studies show $\approx$ 25% horizontal emittance blow-up between PSB and PS.
- We expect $\approx$ 10% from dispersion mismatch.
- Investigate injection in the PS with turn-by-turn SEM grid measurements.

MD Setup

- Low Chroma BCMS, coupling corrected.
- $Q_x \approx 6.21$, $Q_x \approx 6.23$.
- RF OFF, TFB ON.
- Single bunch from PSB Ring 3, I = 65 $\cdot 10^{10}$.
- ReMatched (ReM) optics designed and tested by Vincenzo Forte [link to HB18 paper].
- Beam profiles measured turn-by-turn using BSGH52 - only 30 turns to protect wire grid.
- Insertion of SEM grid blocks whole accelerator complex - measurements performed in a few hours on the last dedicated proton MD day.

Three Optics Scenarios

For following simulations, only the following values differ between simulations. ‘Model’ values are given by PTC.

Case	D_{x_0}	D'_{x_0}
Model	2.35	-0.00744
Operational	2.633	-0.1104
ReMatched	2.683	-0.012

Table: Optics cases used for simulations.

Measured Dispersion

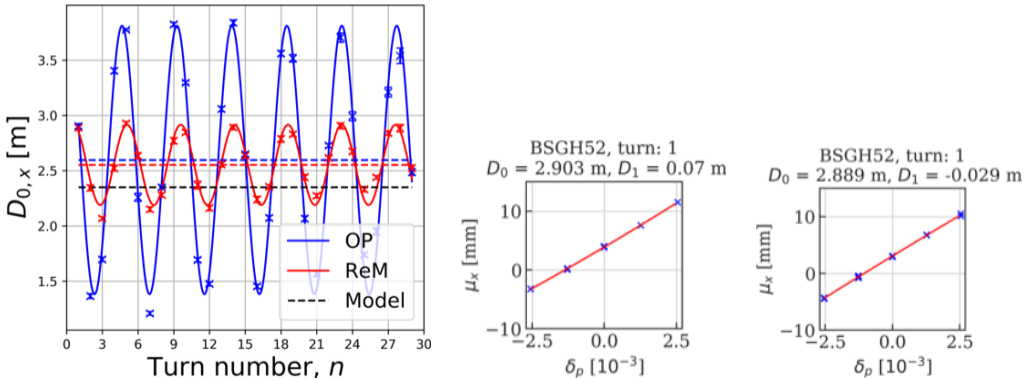

Figure: Left: Measured Dispersion with harmonic fit for operational (OP), rematched (ReM), and Model optics.
Middle: Dispersion measurement for a single turn when using operational optics.
Right: Dispersion measurement for a single turn when using rematched optics.

Normalised Measured Dispersion

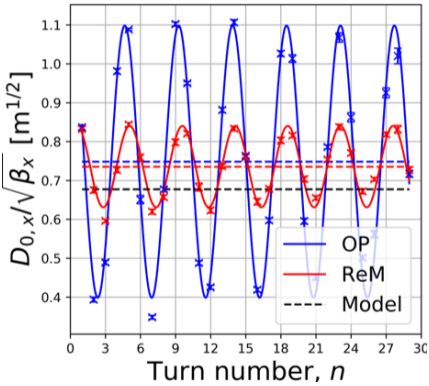

Figure: Measured normalised dispersion with harmonic fit for operational (OP), rematched (ReM), and Model optics.

Normalised Non-Linear Measured Dispersion

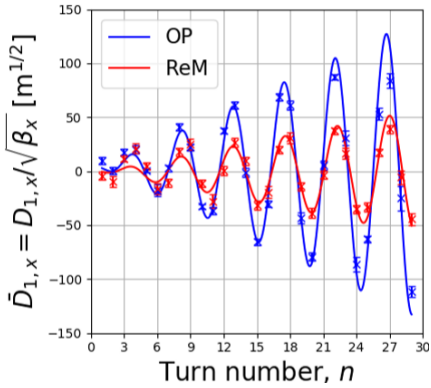

Figure: Measured normalised dispersion non-linear component with fit for operational (OP), rematched (ReM), and Model optics.

Tracking Simulations

- Latest PS optics model acc-models by A. Huschauer [https://gitlab.cern.ch/ahuschau/acc-models].
- Maps computed in MAD-X PTC, exported from tracking using python, implemented in Maptrack by F. Velotti [https://gitlab.cern.ch/fvelotti/maptrack], used and tested extensively for SX studies(?).
- PTC-PyORBIT on CERN AFS maintained by H. Bartosik & H. Rafique [https://github.com/hannes-bartosik/py-orbit].

Initial Distribution: Dispersion Vector

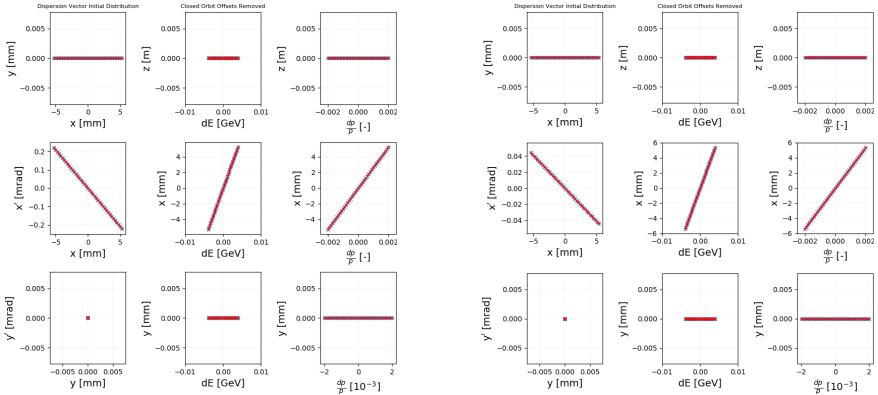

Figure: Identical initial distribution, red points generated by M. A. Fraser for MapTrack simulations, corresponding PyORBIT distribution is shown in blue. Operational optics (left) are compared to ReMatched optics (right).

Dispersion Beating Turn-By-Turn

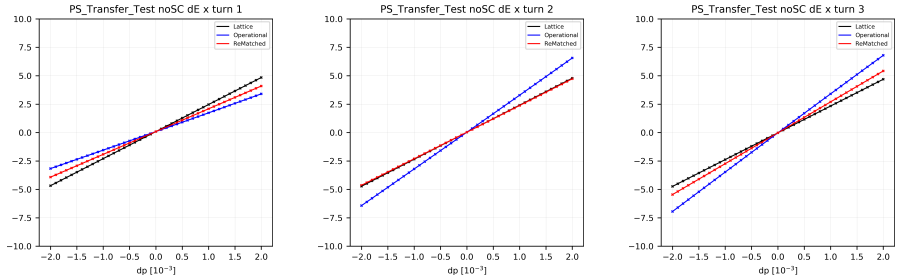

Figure: Dispersion vector plots for first 3 turns for all simulation cases indicating the different beam behaviour.

Fitting Dispersion Vector

We can fit the dispersion vector (δp, x) to find the linear and non-linear dispersion, turn-by-turn, using a cubic fit:

$$y = bx^3 + ax^2 + mx + c \tag{1}$$

We know that:

- $m = D_{x_0}$ linear dispersion.
- $a = D_{x_1}$ non-linear dispersion.
- $b = D_{x_2}$ higher order terms ignored as negligible.

Thus we may describe our vector as:

$$x = D_{x_2}\ \delta p^3 + D_{x_1}\ \delta p^2 + D_{x_0}\ \delta p + c \tag{2}$$

Fitted Dispersion Vector: Operational & ReMatched

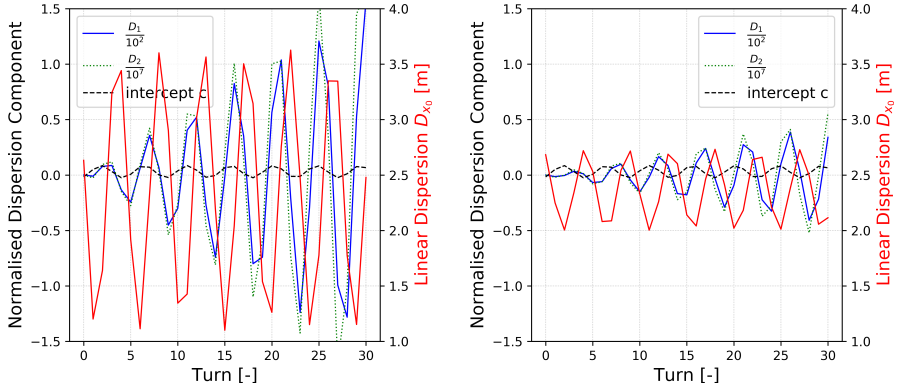

Figure: Dispersion components as calculated from dispersion vector fitting as a function of turn. Operational optics are shown on the left, ReMatched optics on the left.

Fitted Dispersion Vector: Model

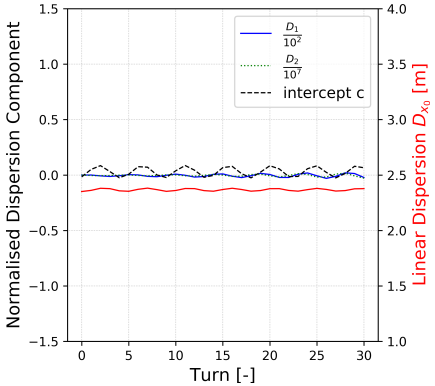

Figure: Dispersion components as calculated from dispersion vector fitting as a function of turn. Model optics are shown.

Fitted Dispersion Vector Intercepts

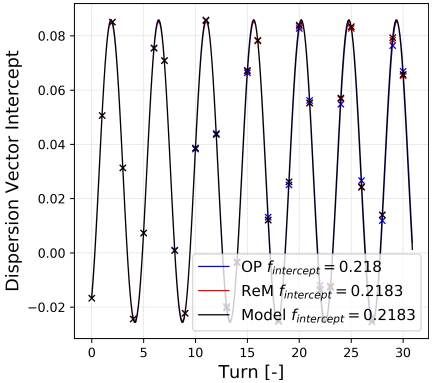

Figure: Dispersion vector intercepts as calculated from dispersion vector fitting as a function of turn. A comparison of all optics are shown, with frequencies. The intercept oscillation corresponds to the betatron tune; the beam centroid oscillation.

Fitting Dispersion Oscillations

We have our linear and non-linear turn-by-turn dispersion, calculated by fitting the simulated dispersion vector. We define the normalised linear dispersion:

$$\bar{D}_{x_0} = \frac{D_{x_0}}{\sqrt{\beta_x}} \tag{3}$$

- D_{x_0}: Linear dispersion.
- $\bar{D}_{x_0}$: Normalised linear dispersion.
- β_x: Beta function at position of measurement.

Fitting Linear Dispersion Oscillation

We may express the total dispersion as a function of turn:

$$\bar{D}_x(n) = \bar{D}_{x_0}(n) + \bar{D}_{x_1}(n)\delta p + \mathcal{O}(\delta p^2,\ \delta p^3, ...) \tag{4}$$

Where the higher order terms $\mathcal{O}(\delta p^2,\ \delta p^3, ...)$ are negligible. The normalised linear dispersion $\bar{D}_{x_0}(n)$ can be fitted with a fit of form $y = a + b\cos(cx + d)$:

$$\bar{D}_x(n) = \bar{D}_{x_0}(n) + M_D \cos\left(\theta + 2\pi(n-1)\ q_x\right) \tag{5}$$

- n: Turn. Note the $(n-1)$ term accounts for measured data starting at turn at 1.
- M_D: Mismatch amplitude.
- q_x: Horizontal betatron tune.
- θ: Initial phase offset.

Linear Dispersion Beating

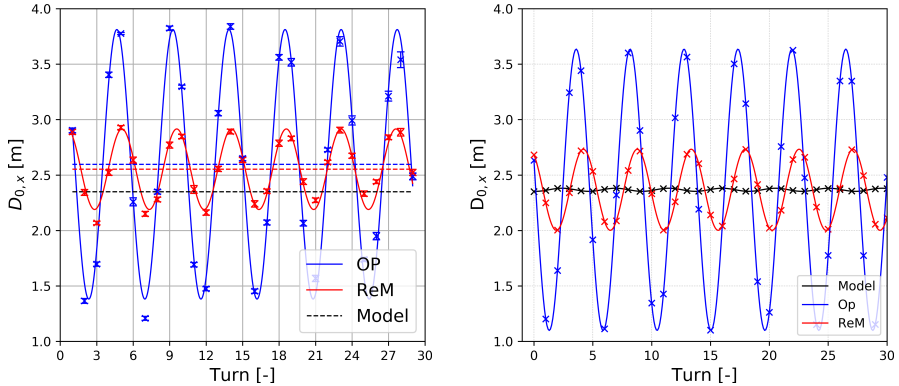

Figure: LEFT: Measurement. RIGHT: Simulated dispersion beating for three cases, with harmonic fit as described in equation 5.

Fitting Normalised Dispersion Oscillation

As before fit normalised linear dispersion $\bar{D}_{x_0}(n)$ with linear fit of form:

$$a + b\cos(cx + d) \tag{6}$$

Fit normalised non-linear dispersion $\bar{D}_{x_1}(n)$ with non-linear fit of form:

$$a + b(x-1)\cos(c(x-2) + d) \tag{7}$$

Normalised Linear Dispersion Beating

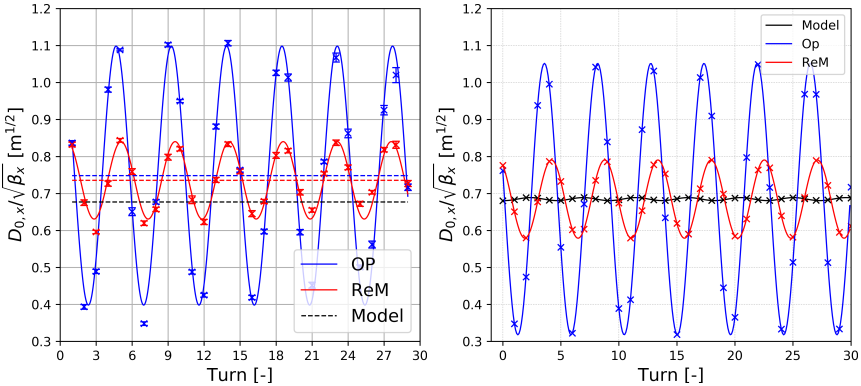

Figure: LEFT: Measurement. RIGHT: Simulated dispersion beating for three cases, with harmonic fit as described in equation 5.

Normalised Non-Linear Dispersion Beating

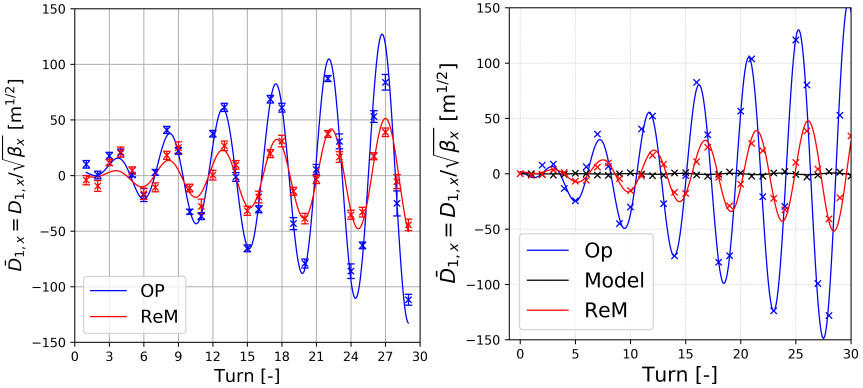

Figure: LEFT: Measurement. RIGHT: Simulated dispersion beating for three cases, with harmonic fit as described in equation 7.

Three Optics Scenarios: Fitting Parameters

Case	D_{x_0}	D'_{x_0}	M_D (PyORBIT)	M_D (MapTrack)
Model	2.35	-0.00744	0.00082	-
Operational	2.633	-0.1104	0.3669	0.35
ReMatched	2.683	-0.022	0.1058	0.107

Table: Mismatch amplitude M_D calculated from dispersion vector simulations for the three optics cases.

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Measurements
5D Simulations
Bunch Simulations

Chromaticity Scan
Beam Profiles
Beam Size Oscillation Frequency - Coherent Dispersive Mode

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No Space Charge, No RF

Repeat Matt's 5D simulations to check consistency. 30 turns only.

NoSC NoRF

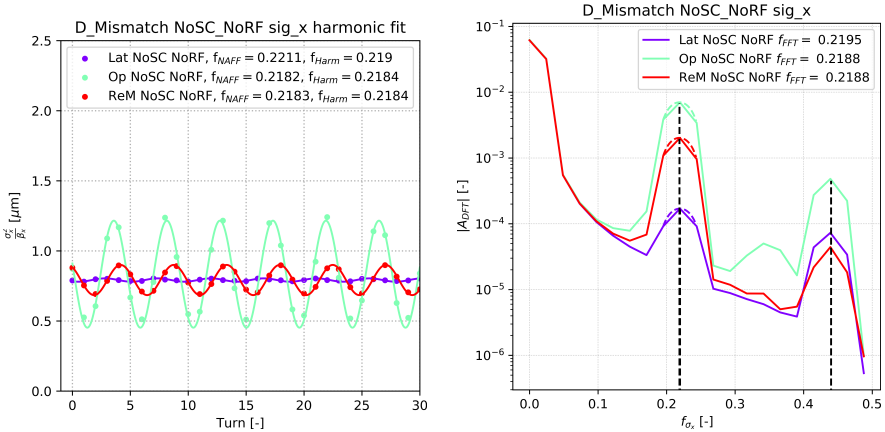


Figure: Horizontal beam size.

SC RF

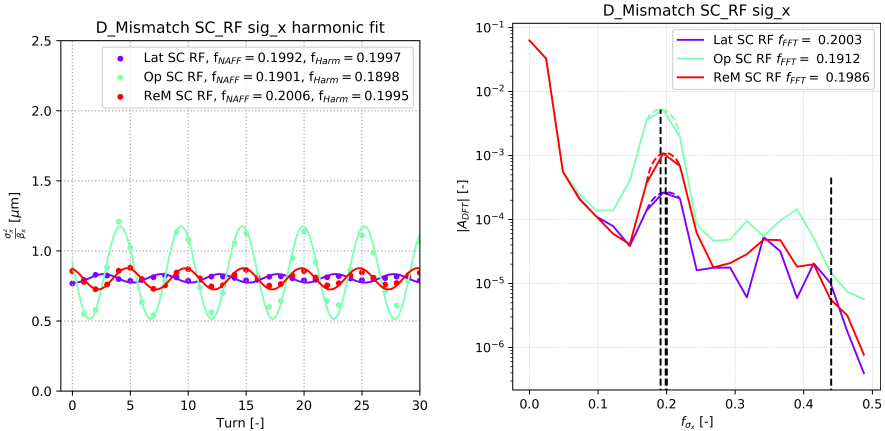


Figure: Horizontal beam size.

Comparison

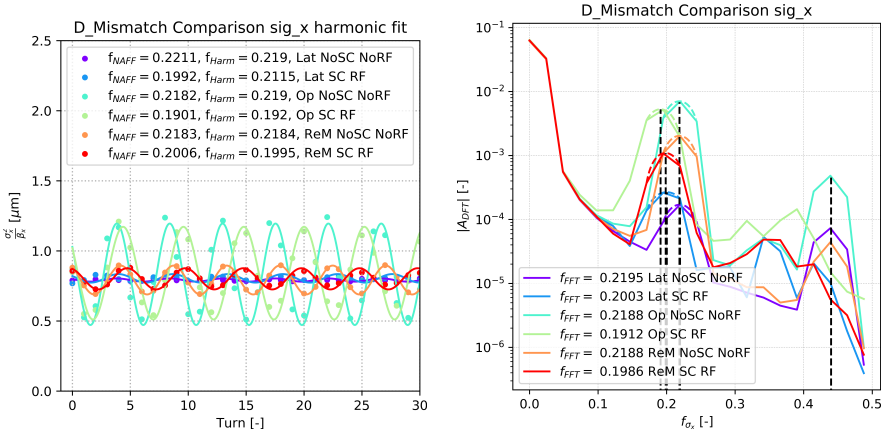
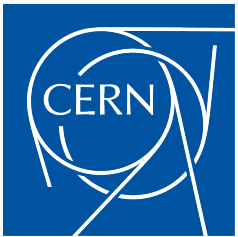


Figure: Horizontal beam size.

Full Bunch Simulations

5E5 particles, 2200 turns, 128x128x64 SC grid.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