IOTA Run 4 NIO Progress Update

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On behalf of IOTA NIO collaboration

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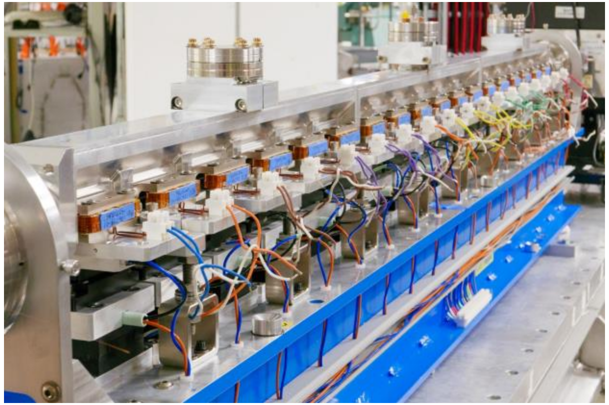
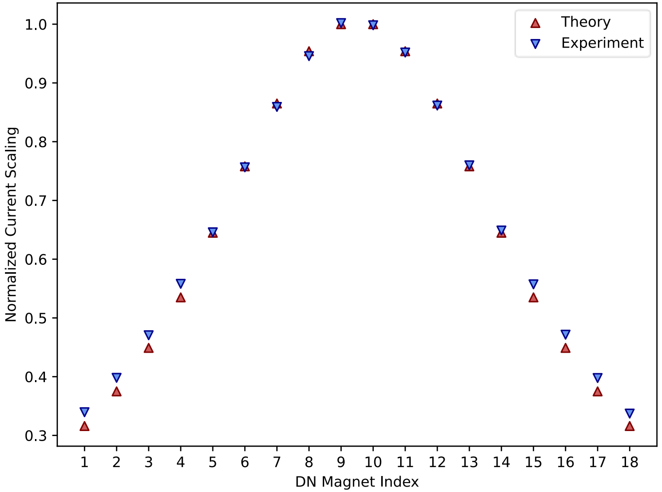
DN Current Scaling Calibration

- Individual elements must be scaled to match the beta function in the insert region
- First order of multipole expansion is quadrupole
- Direct calibration measured using small amplitude quadrupole tune shift
- Fit tune dependence on current for calibration

$$\Delta Q_{x,y} = \pm \frac{1}{4\pi} \int \beta(s) \frac{\Delta B_1}{B\rho} ds$$

$$B_y + iB_x = -t \frac{B\rho}{\beta(s)} \sum_{n=1}^{\infty} \frac{2^{2n-1} n!(n-1)!c}{(2n-1)!\sqrt{\beta(s)}} \left(\frac{x+iy}{c\sqrt{\beta(s)}} \right)^{2n-1}$$





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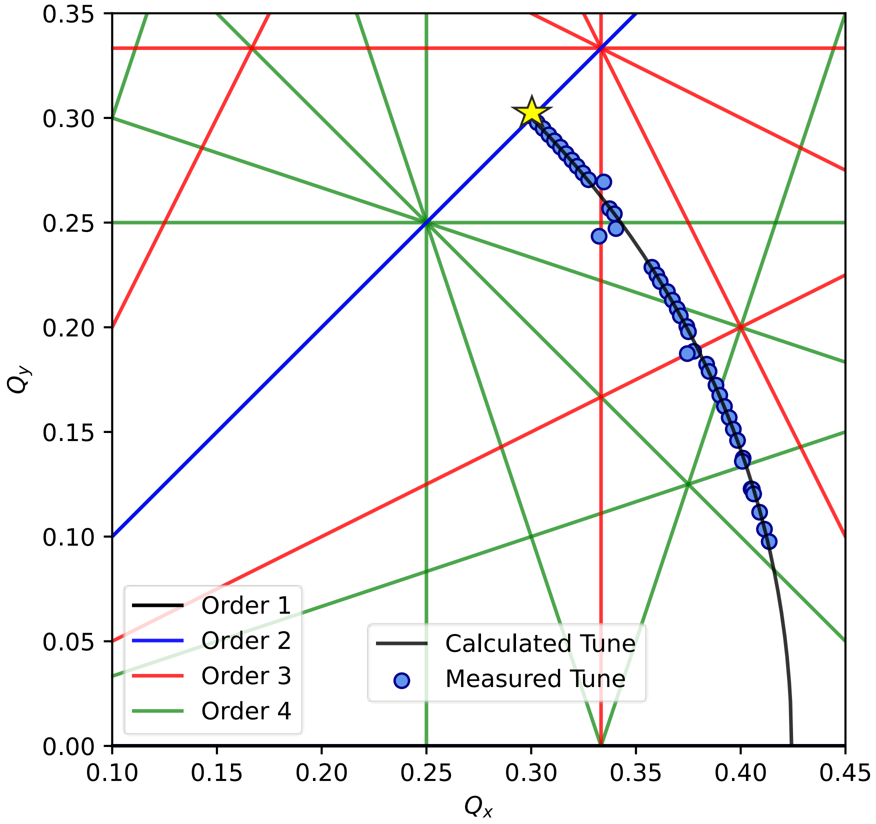
Nonlinear Insert Detuning

- Evaluate Calibration by measuring nonlinear element detuning
- Compare to theoretical calculation of small amplitude detuning
- Kick to 4.2% of nonlinear c-parameter for small amplitude approximation
- Sextupole effects visible

$$Q_x = Q_o\sqrt{1+2t}$$
$$Q_y = Q_o\sqrt{1-2t}$$



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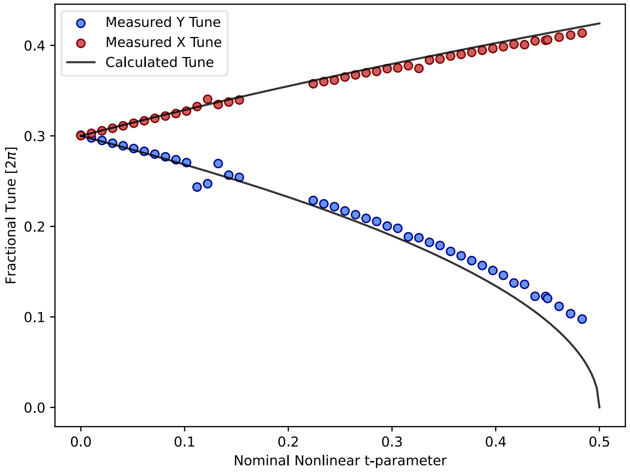
Nonlinear Detuning Calibration

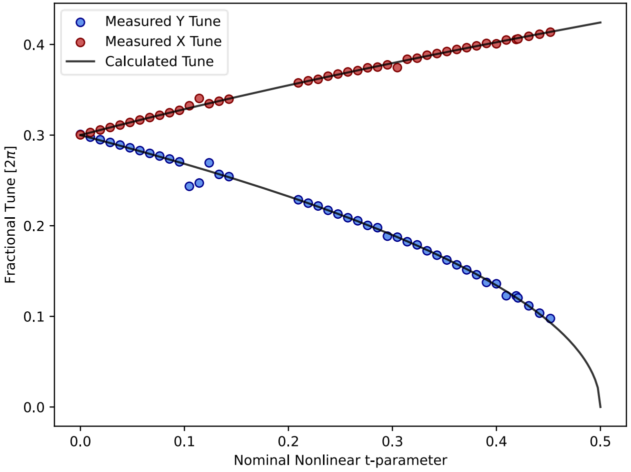
- Verified detuning ratio, need to verify absolute calibration
- Tune vs t-parameter shows some discrepancy in scaling
- Fit measured data to theoretical expression with scaling parameter

$$Q = Q_o\sqrt{1 \pm 2at}$$

$$a = 1$$

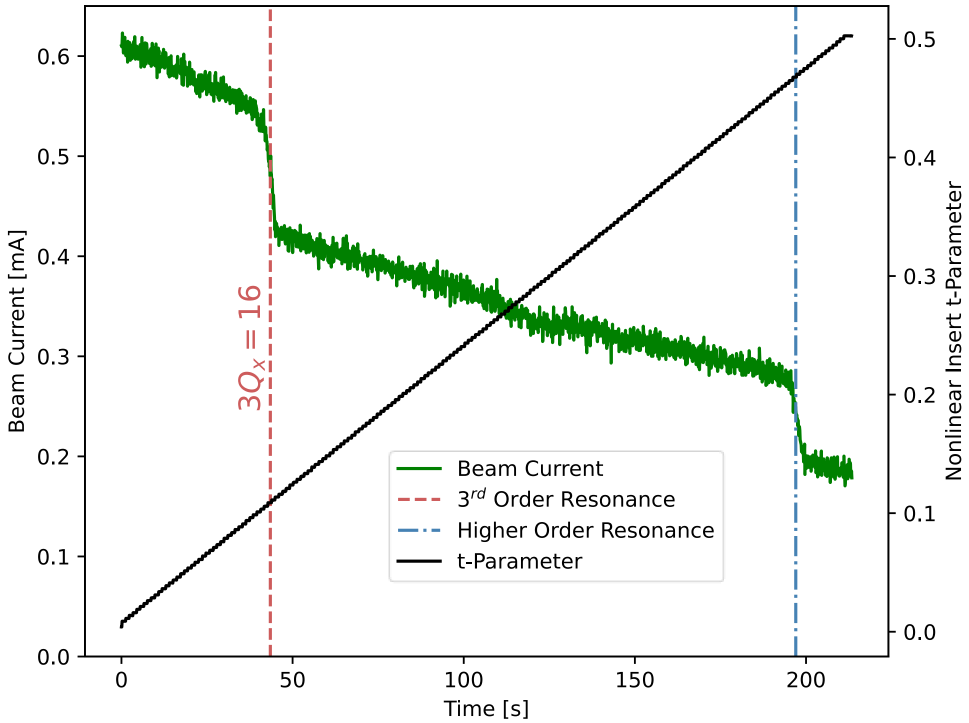


$$a = 0.935$$



Nonlinear Scaling Losses

- Investigate calibration by looking at circulating beam current as nonlinear t-parameter scales
- Slow transition losses visible at sextupole resonance, fast transition suppresses this
- Additional losses at t ~0.46, source unclear
- No significant losses at the integer resonance



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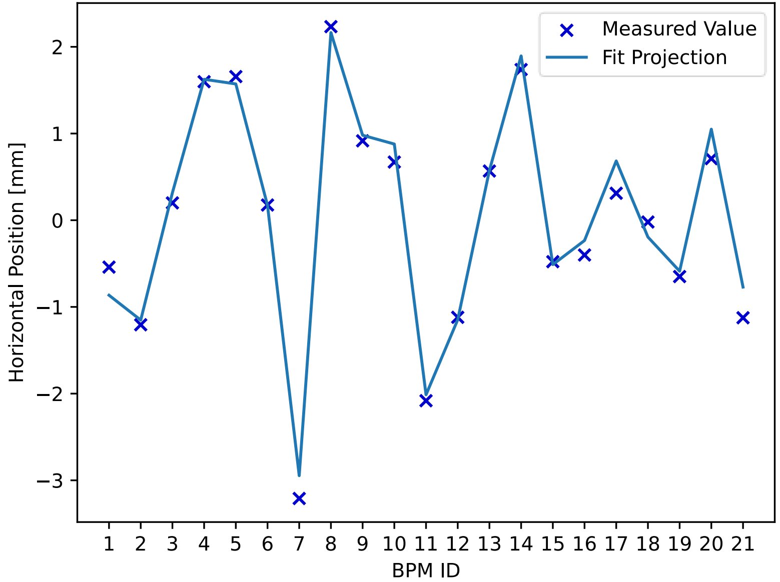
Nonlinear Invariant Calculations

- Best Demonstration of NIO for electron program would be quantitative demonstration of turn-by-turn invariant conservation
- Requires reconstruction of full 4-D transverse coordinates from BPM measurements, currently using fit of 21 BPMs



$$\begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ \vdots \\ q_n \end{bmatrix} = \begin{bmatrix} M_{11}(i \to 1) & M_{12}(i \to 1) \\ M_{11}(i \to 2) & M_{12}(i \to 2) \\ M_{11}(i \to 3) & M_{12}(i \to 3) \\ \vdots & \vdots \\ M_{11}(i \to n) & M_{12}(i \to n) \end{bmatrix} \begin{bmatrix} q_i \\ p_i \end{bmatrix}$$

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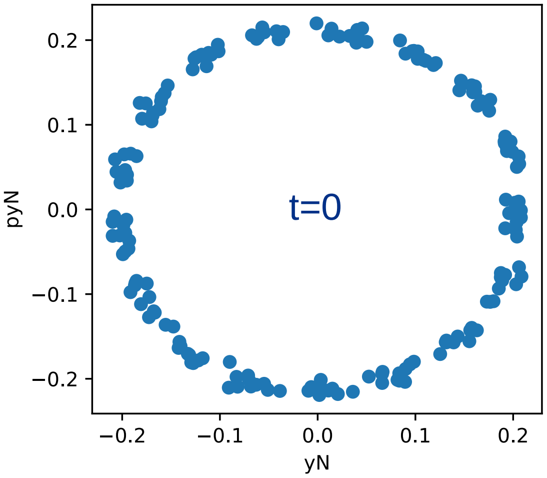
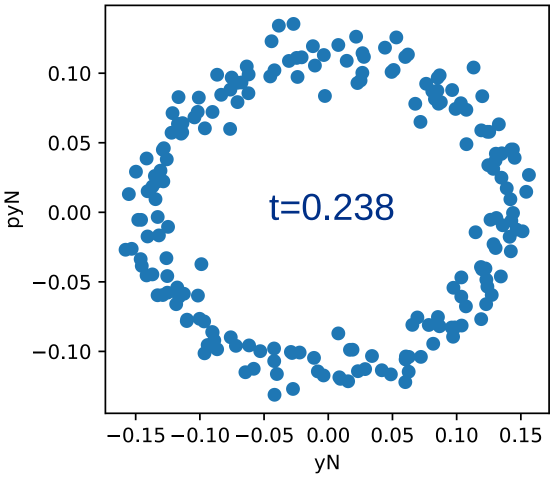
Nonlinear Invariant Calculations Cont.

- From 4D-position measurements the turn-by-turn invariant values may be calculated and evaluated for conservation about the mean
- Benchmarking methods with Courant-Snyder invariants for bare lattice
- Decoherence presents a significant challenge





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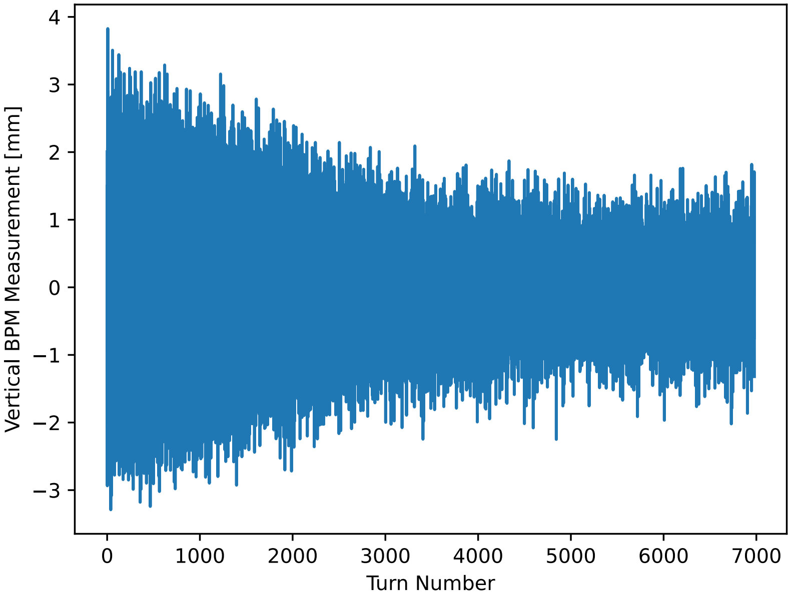
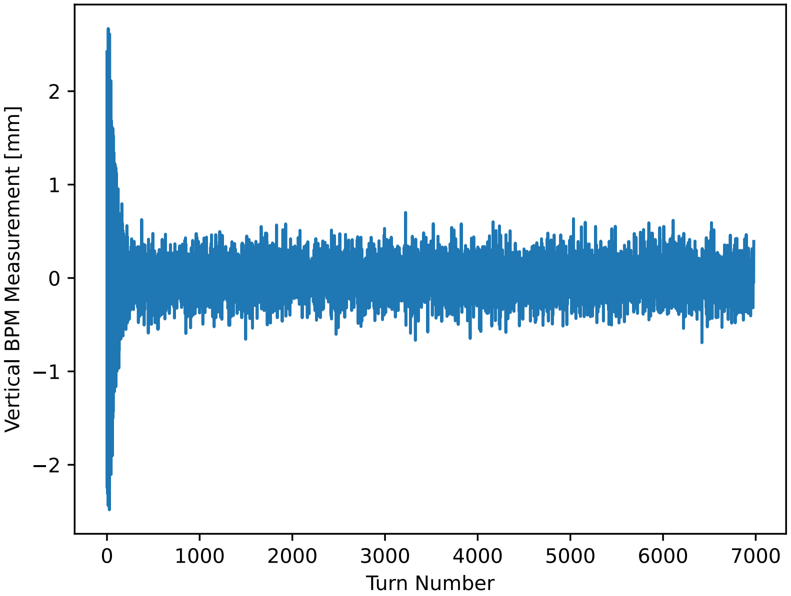
Raw BPM Data Decoherence

- Decoherence limits useful turns available and changes amplitude of invariant turn-by-turn

t=0



t=0.238



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