A first look into other nonlinear elements in IOTA

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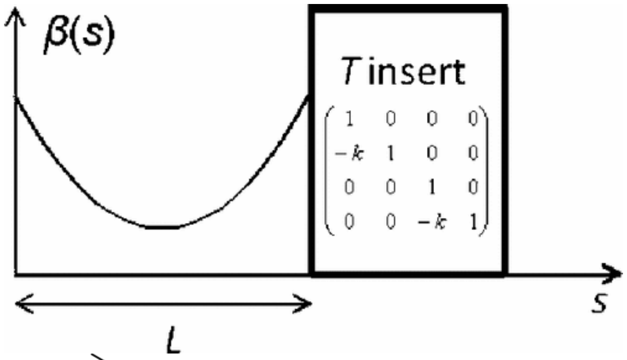
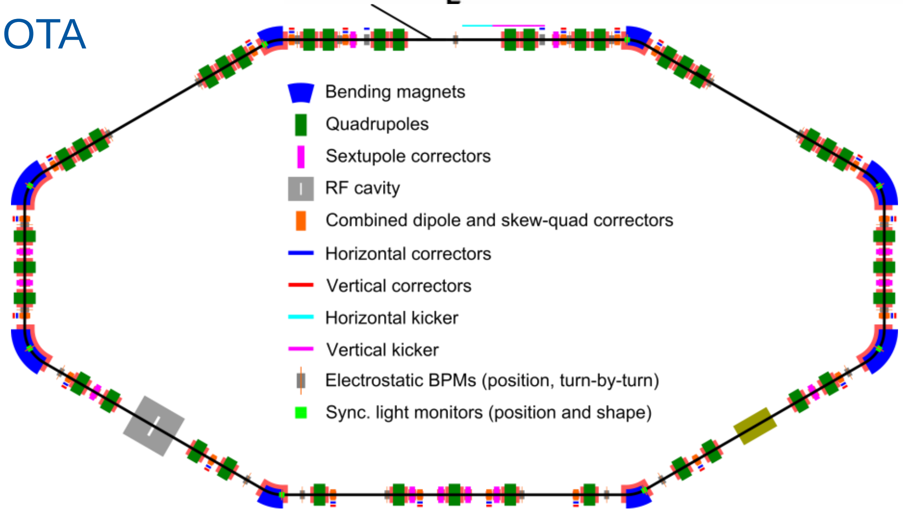
Introduction

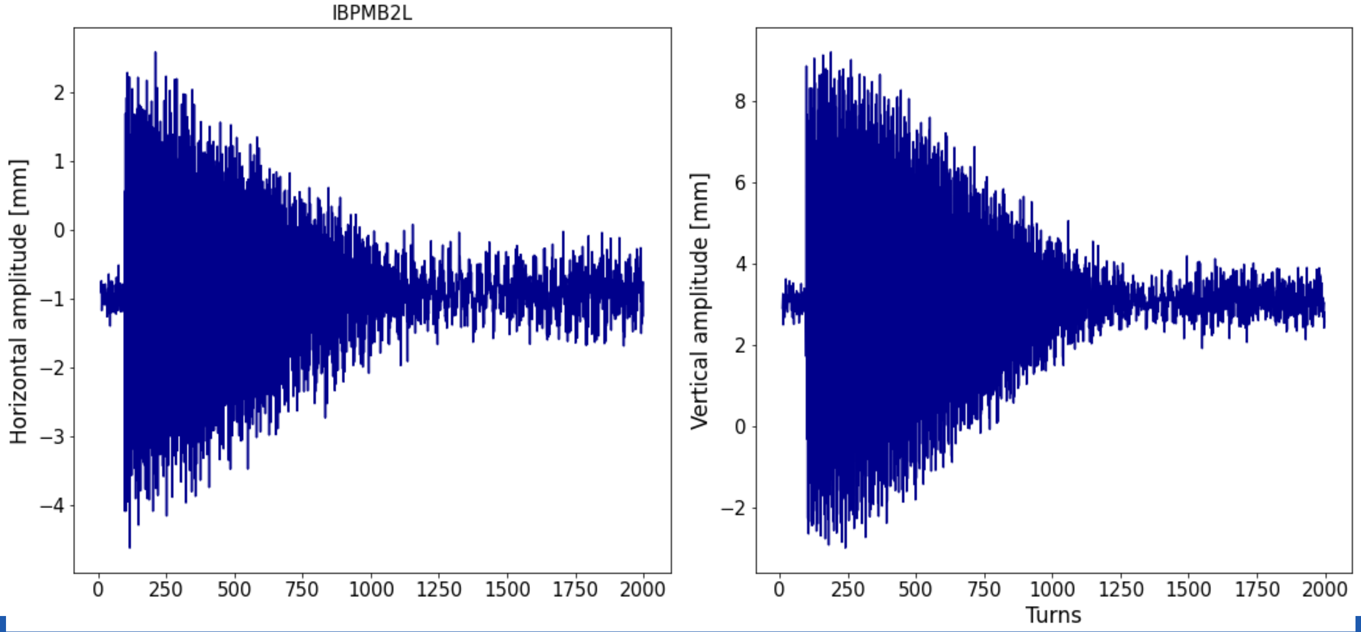
- One of the study topics in IOTA is the NL integrable optics
  - See prev. presentations on octupole string and DN-magnet
- Goal of this study is assessment of contributions from other nonlinear magnetic elements in IOTA
  - Particular focus on sextupole sources
  - Benchmark of model and possible refinement
  - Parasitically, also linear optics available
- 3 shifts of data taking
  - In conjunction with NIO shifts based on the similar nature and procedural requirements





General procedure

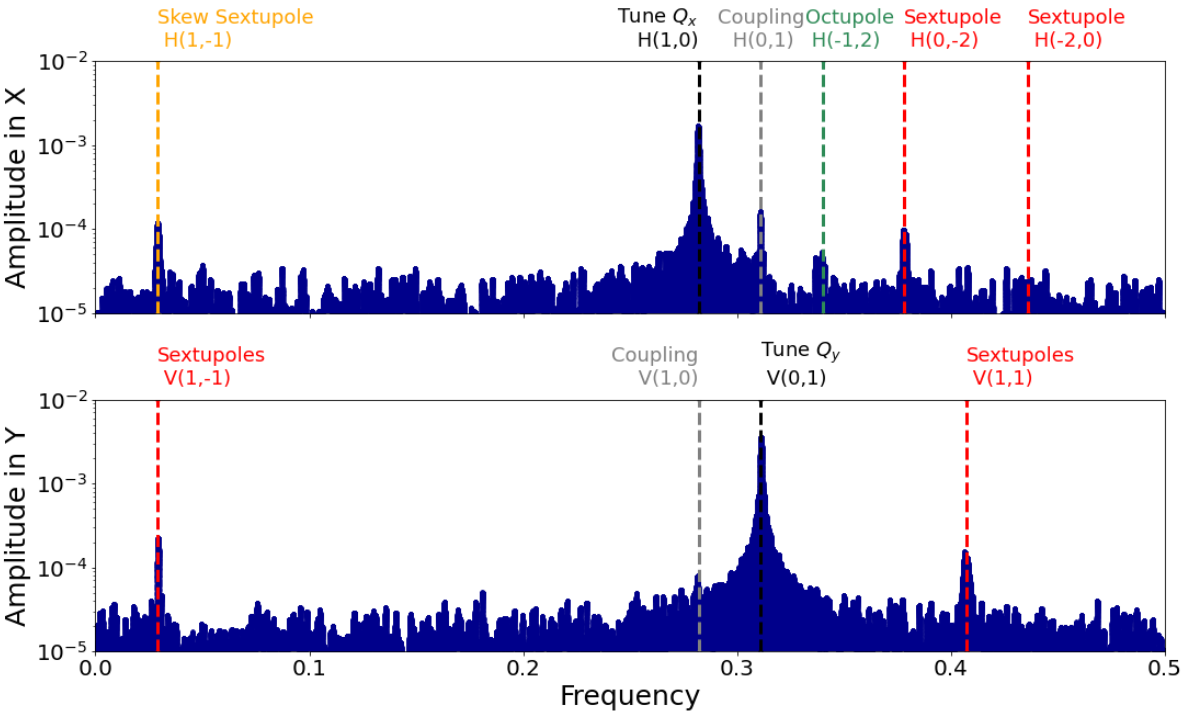
- Transverse excitation with Kicker/Pinger
  - DN-magnet and octupole string turned off



General procedure

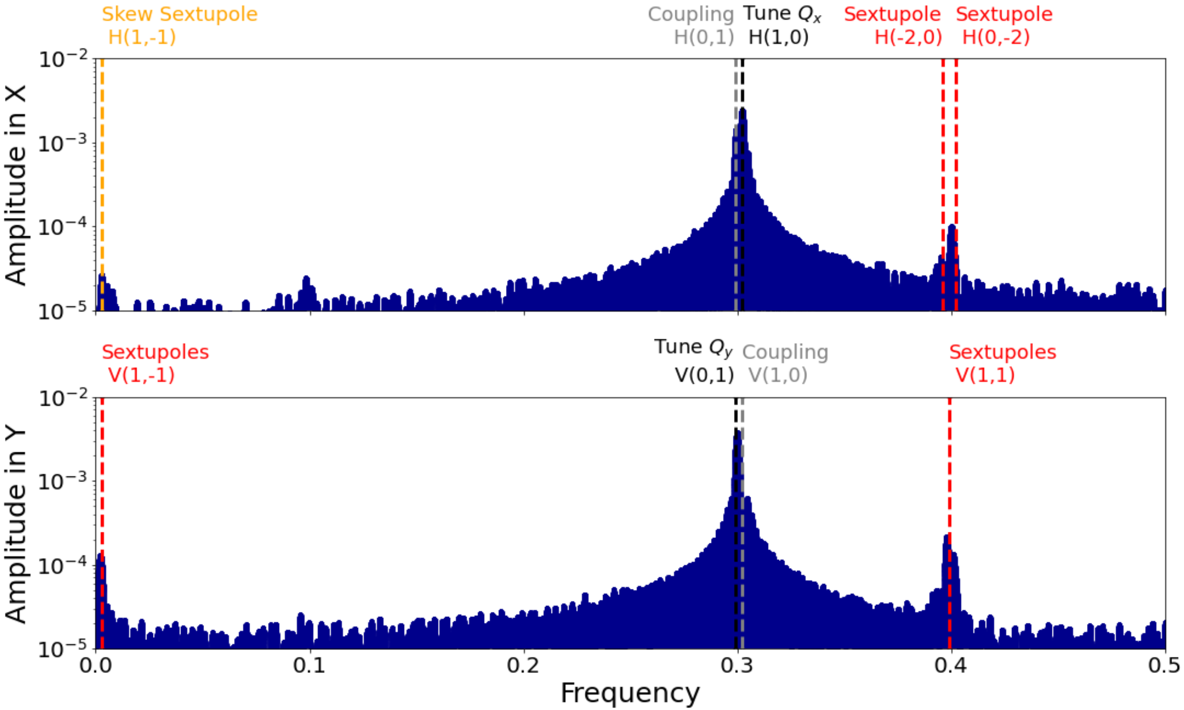
- FFT on captured turn by turn data from the BPMs and further post-processing

- Note: studies presented here were conducted at $Q_x = 0.28$ / $Q_y = 0.31$



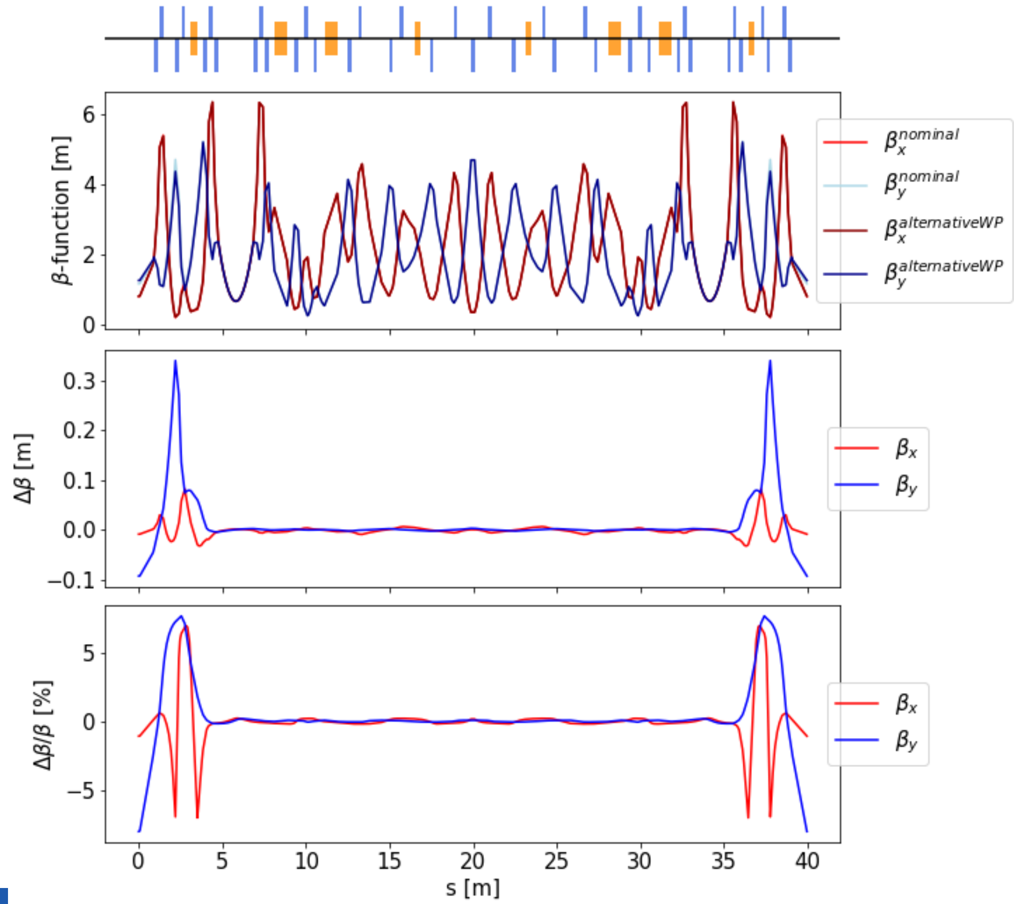
General procedure

- Avoids overlapping lines present in nominal optics with $Q_x = 0.3$ / $Q_y = 0.3$
- Downside:
  Optics, coupling etc. modified



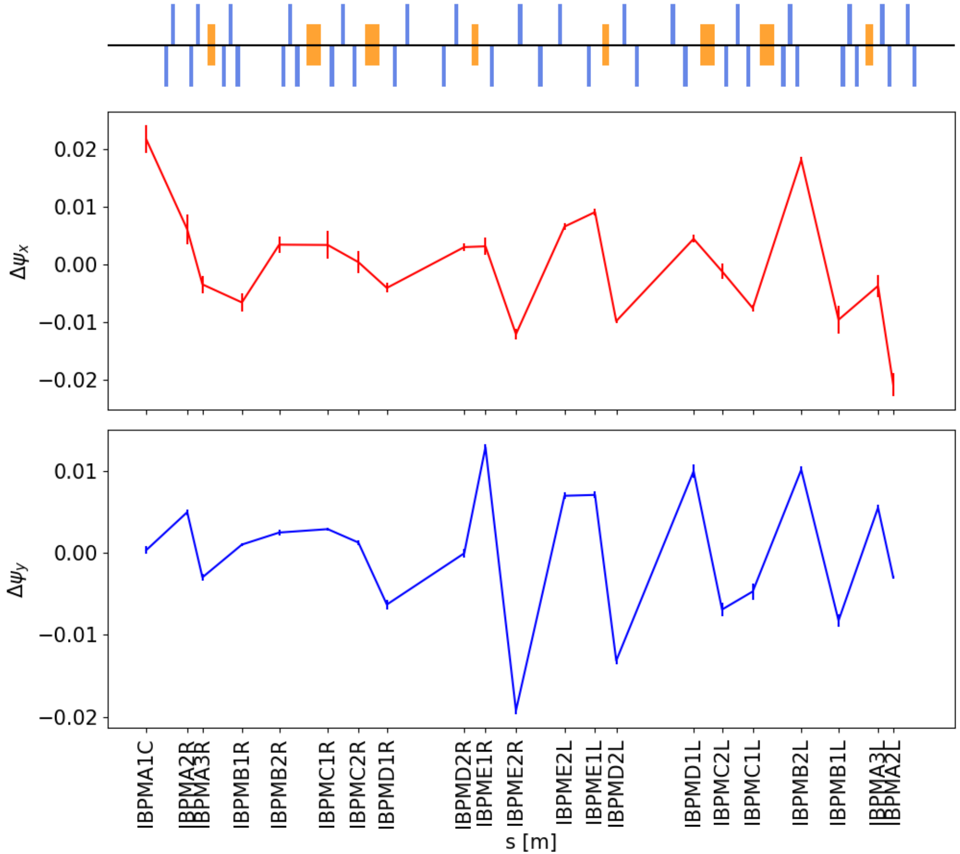
Model

- Operational Tune knob from 6Dsim imported to MAD-X model
  - Max. 5% change in β, mostly in injection straight
  - Not yet verified against 6Dsim



Linear Optics

- BPM to BPM phase deviation higher than expected (target for DN-magnet ~ 10^{-3})
  - Horizontal plane suffering from smaller No. of available turns
  - Potential quad-error between BPM.D2R – BPM.E1R



Linear Optics

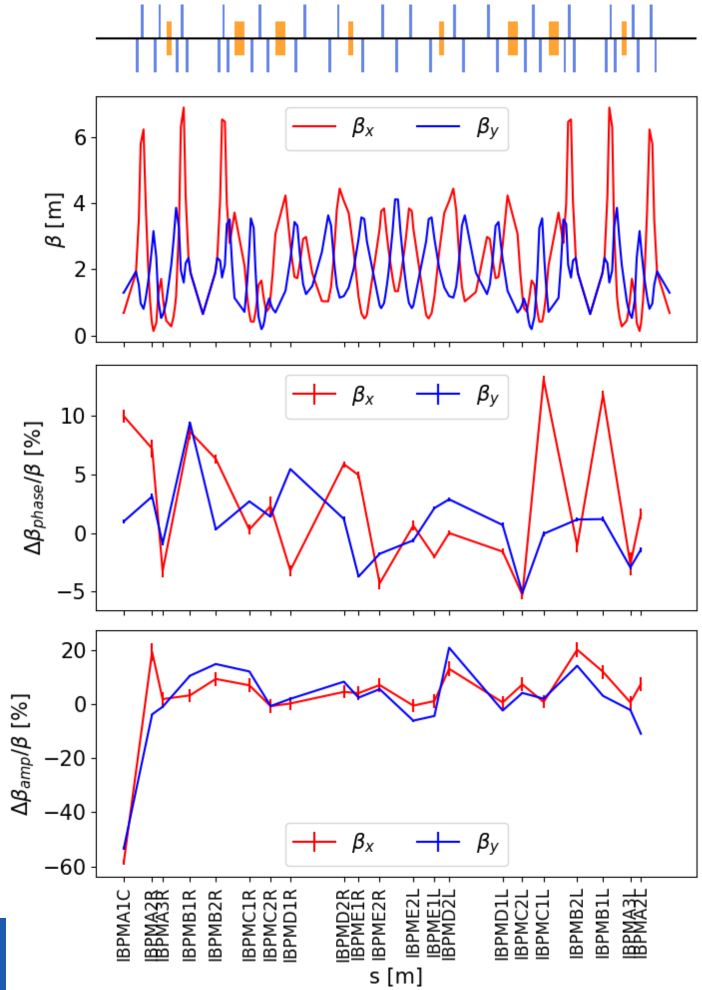
- Linear optics from two different methods
  - β from phase [1, 2]:

$$\beta_{BPM.B} = \frac{\cot\Delta\psi_{AB} - \cot\Delta\psi_{BC}}{\cot\Delta\psi_{AB}^{model} - \cot\Delta\psi_{BC}^{model}}\beta_{BPM.B}^{model}$$

  - β from oscillation amplitude [3]:

$$\beta_{BPM} = \frac{(Calib_{BPM} * Oscillation\ Amplitude)^2}{2J}$$

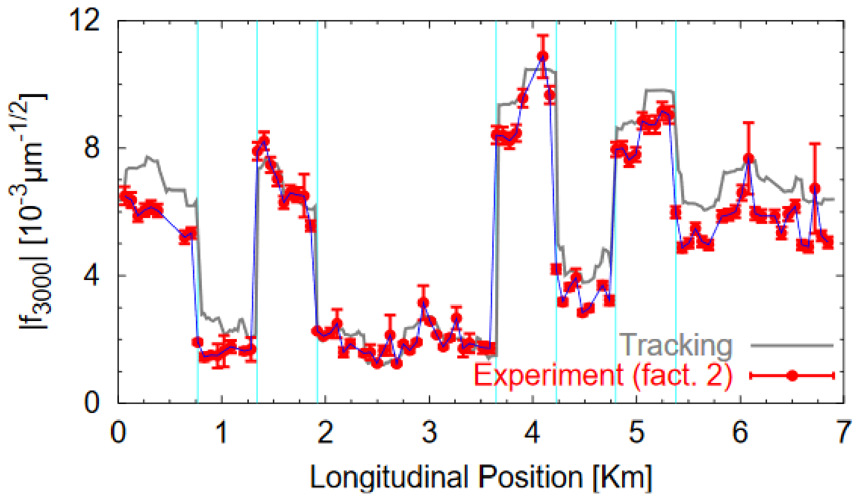
- Issues:
  - Horizontal β^{phase} suffers from lower No. of turns
  - Calibration for IBPMA1C might be off
  - Model to be checked



Resonance Driving Terms

$$h_x^- = x - ip_x = \sqrt{2I_x}e^{i(2\pi\nu_x N+\psi_{x_0})}$$
$$-2i\sum_{jklm} jf_{jklm}\left(2I_x\right)^{(j+k-1)/2}\left(2I_y\right)^{(l+m)/2}$$
$$\times\, e^{i[(1-j+k)(2\pi\nu_x N+\psi_{x_0})+(m-l)(2\pi\nu_y N+\psi_{y_0})]}$$

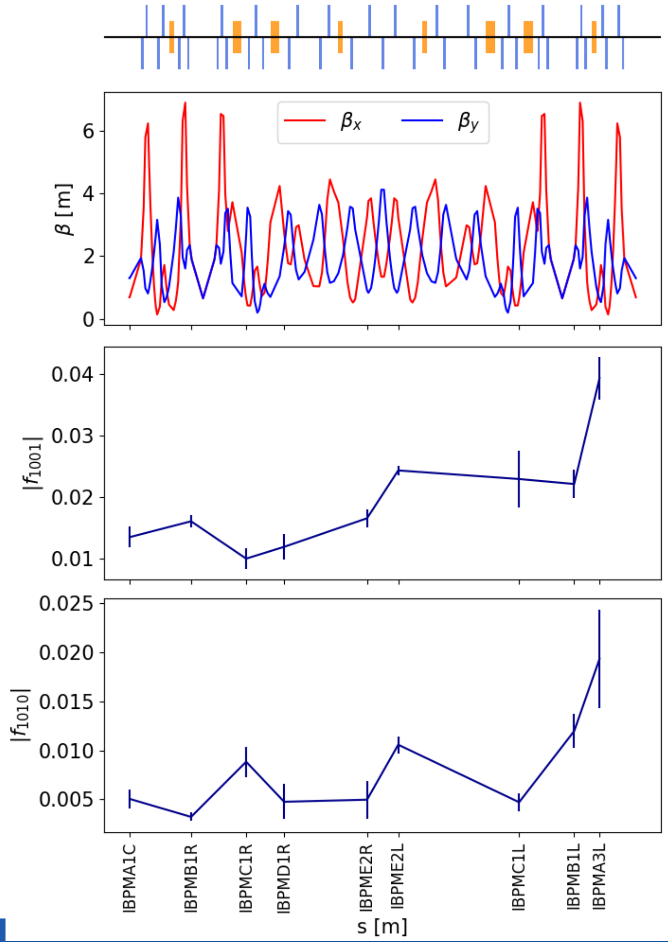
- Resonance driving terms (RDT):
  - Localized measure of the distortion in phase space due to particular resonance
    - Resonance $(j-k)Q_x + (l-m)Q_y = p$ to RDT f_{jklm}
  - Longitudinal variation of amplitude of RDT can be used to determine sources of nonlinearities
  - Limitation: Data of two BPMs is required and assumed that no strong source lie in-between
    - $\hat{p}_i = \frac{\hat{x}_{i+1}}{\cos(\Delta\psi-\pi/2)} + \hat{x}_i \tan(\Delta\psi - \pi/2)$ with $\hat{x} = x/\sqrt{\beta}$



Early RDT measurements in SPS [4]

Coupling RDT

- For coupling 2 RDTs of interest:
  - f_{1001} corresponding to $Q_x - Q_y$ resonance
  - f_{1010} corresponding to $Q_x + Q_y$ resonance
- Low number of BPMs due to constraint on phase or distance to next BPM
- Checking via approximation for closest tune approach[5]
  $C^- \approx 4\left|Q_y - Q_x\right|\langle|f_{1001}|\rangle \approx 2\cdot 10^{-3}$
- To be further cross-checked with data from other working points



Combined RDTs

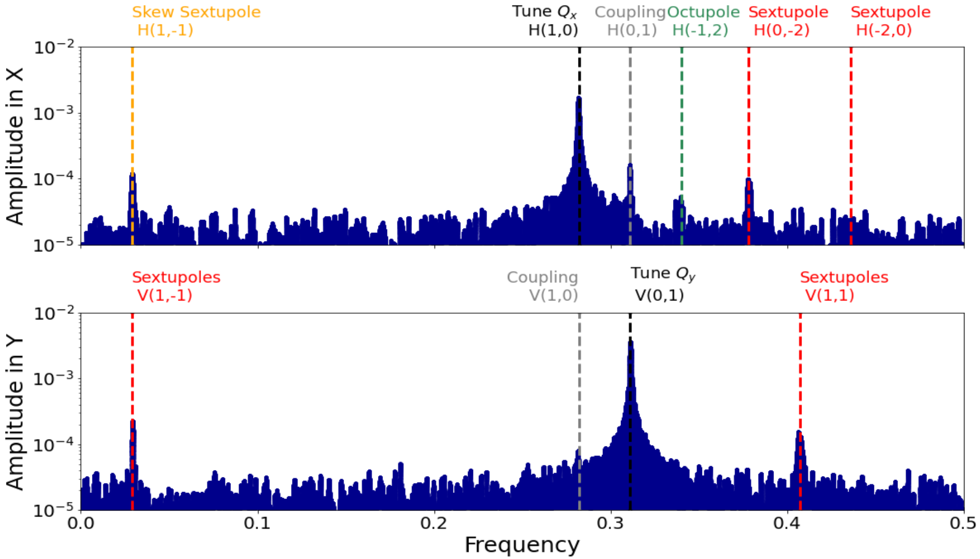
- Combined RDT [6]:
  - Only single BPM data is required
  - Combination of 2 different RDTs
    - For normal sextupoles, 4 CRDTs:

CRDT $V(1,-1) = 2f_{0120} - f_{0111}$

CRDT $V(1,1) = 2f_{1020} - f^{*}_{0111}$

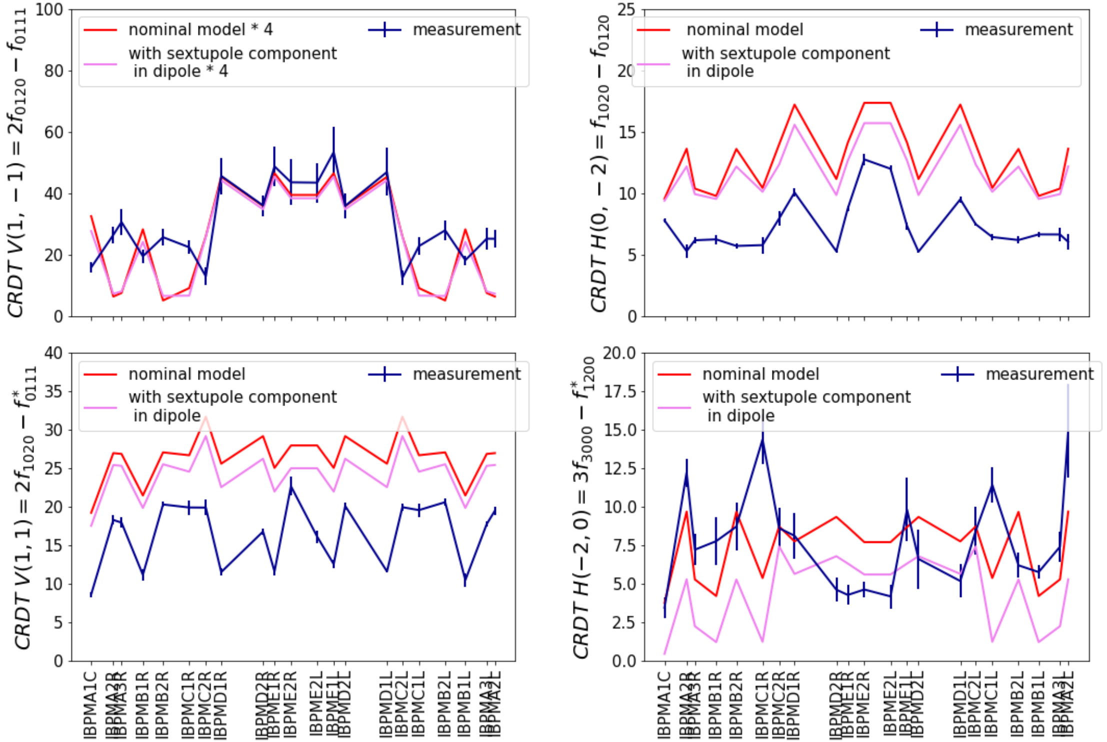
CRDT $\mathrm{H}(0,-2) = f_{1020} - f_{0120}$

CRDT $\mathrm{H}(-2,0) = 3f_{3000} - f^{*}_{1200}$



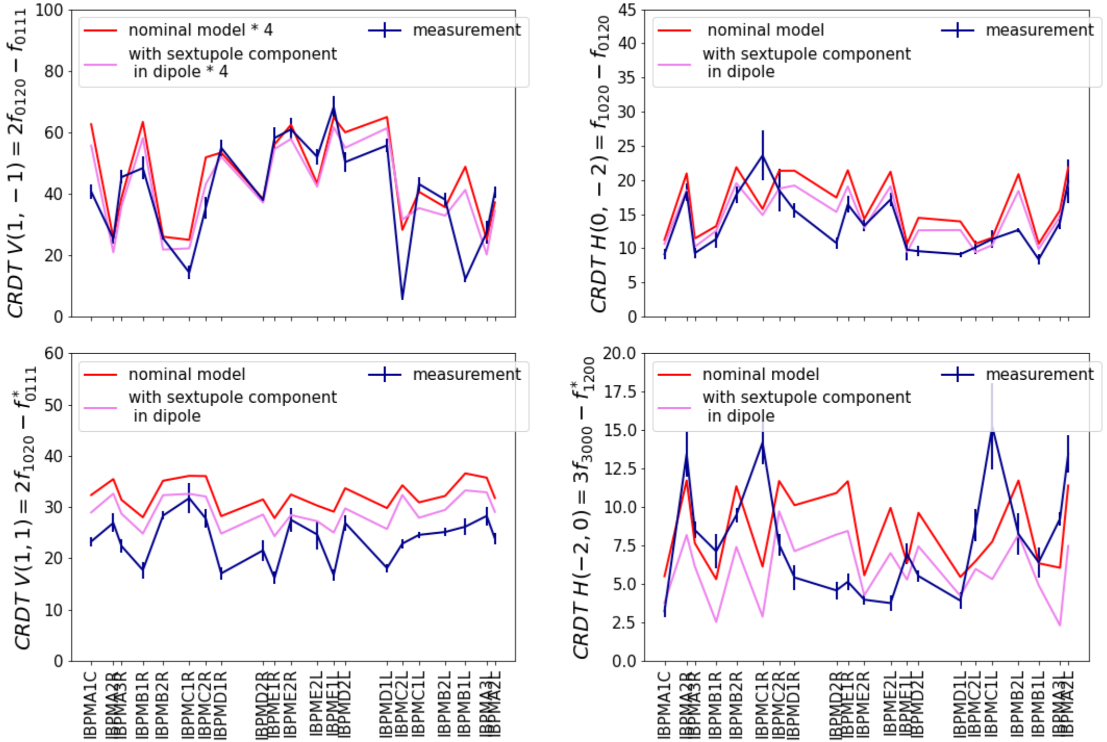
Combined-RDTs Analysis

- CRDT analysis performed for nominal sextupole settings
  - Model behaviour well reproduced
  - As line H(-2,0) not observed in prev. spectra, CRDT measurement unreliable
  - Amplitude not yet corrected for decoherence



Combined-RDTs Analysis

- Measurements repeated with different sextupole configuration
  - Sextupole in section R3 turned off and chroma corrected by sextupoles in section L3
  - Again, vertical CRDTs reproduce model
  - Potential sextupole component in 60° dipoles to be further looked into



Conclusion

- Study nonlinear elements other than DN-magnet & octupole string in IOTA
  - Linear optics from TbT data obtained

  - Preliminary sextupole CRDT analysis for two sextupole configurations
    - Model behaviour reproduced, amplitude to be corrected for decoherence
    - Potential contribution from sextupole component in dipoles to be further investigated

- Further studies:
  - Analysis of TbT-data at other working points
    - Chromatic optics and amplitude detuning
  - Coupling, Skew sextupole and octupole (C-)RDTs
    - Potential to infer sextupole tilts

Thank you for your attention