Precise optics measurements in storage rings

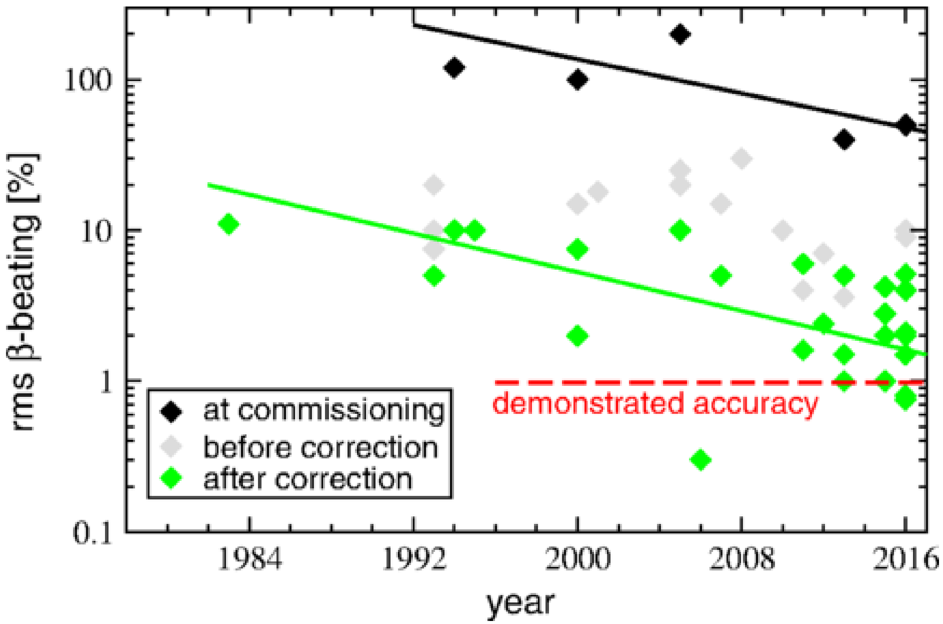
L. Malina

[1]

Beam optics

- May deteriorate accelerator performance in multiple ways, for example:
  - Too large beam size
  - Too low acceptance for injection
  - Beam losses
- Tighter tolerances in future accelerators, for example[2]
- Needs to be well **measured** and controlled

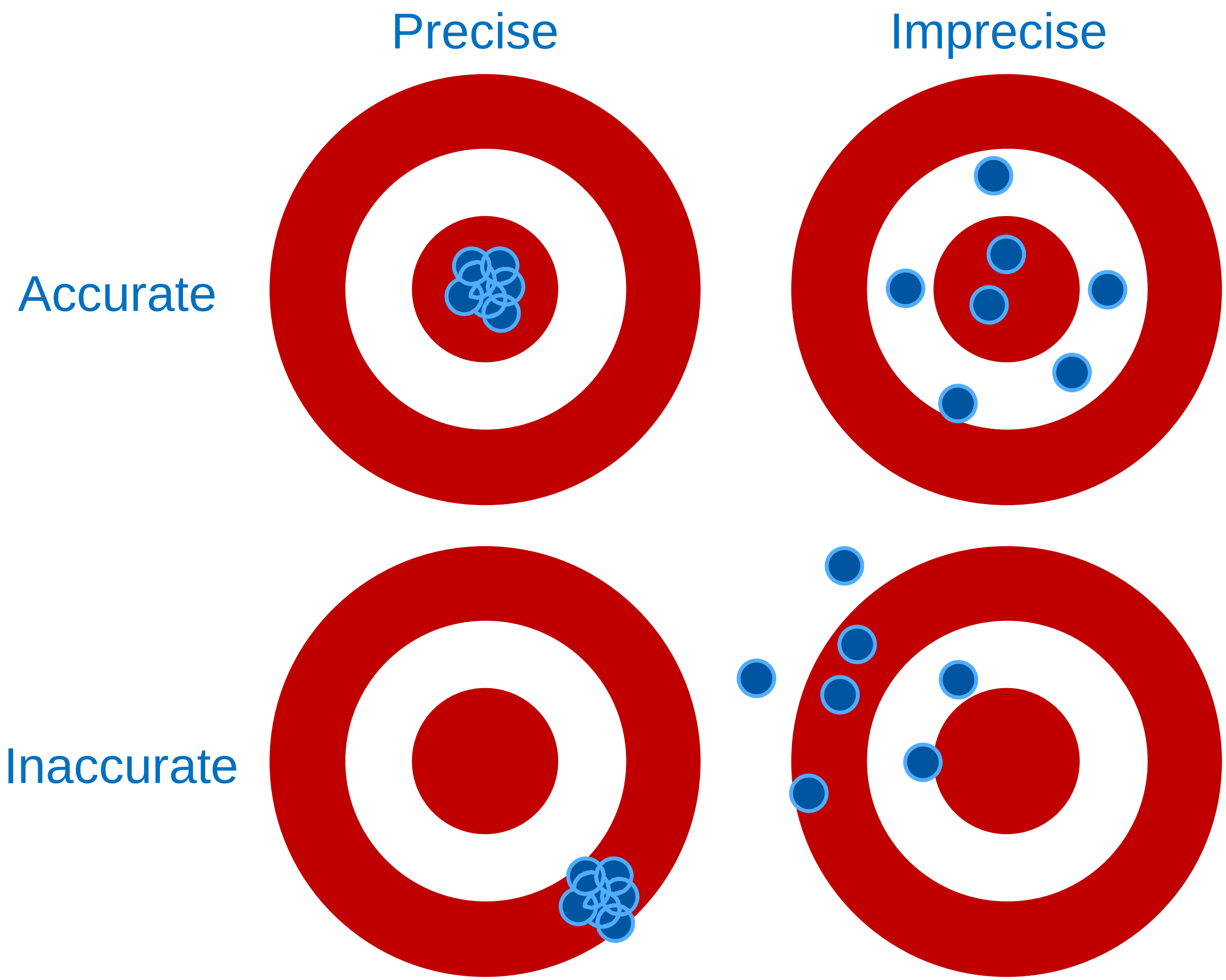
β-beating measurements



[3]

- Orbit-like methods
- **Turn-by-turn methods**
  - Coherent betatron motion induced by kickers
- Accuracy of 1 %
  - Until 2015

Precision / Accuracy

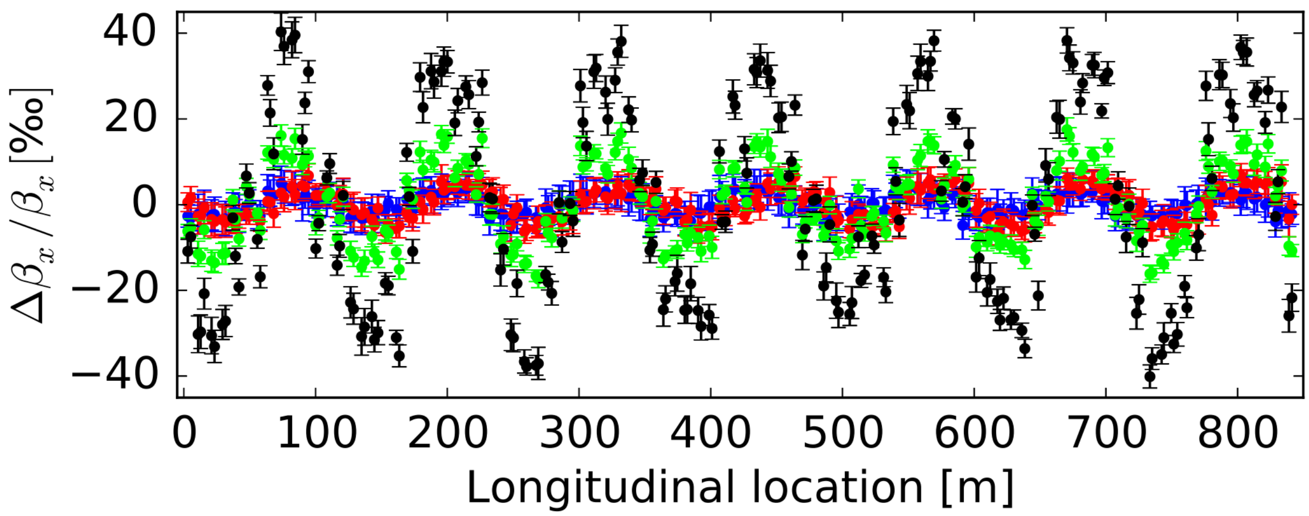


Error analysis in ESRF

- Turn-by-turn analysis of beam coherent betatron motion after a pulsed excitation
- Focused on N-BPM method[4]
- Key ingredients
  - Kick amplitude
  - Number of turns
  - Same tune imposed for all BPMs
  - Phase refined (Damping effect corrected)

Kick Amplitude

- Limited by non-linearities – simulation
- However has to be high enough
  - with respect to BPM resolution
  - Decoherence and number of turns

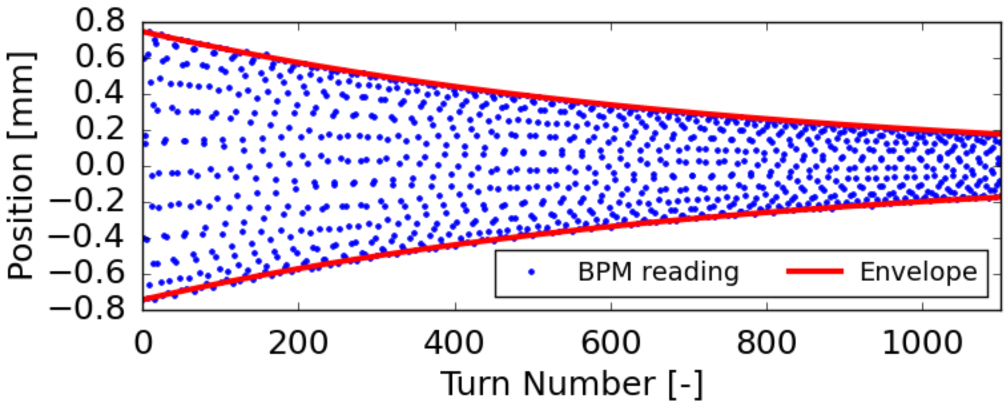


Simulated kicks
@ β = 38 m

0.73 mm
1.46 mm
2.92 mm
4.32 mm

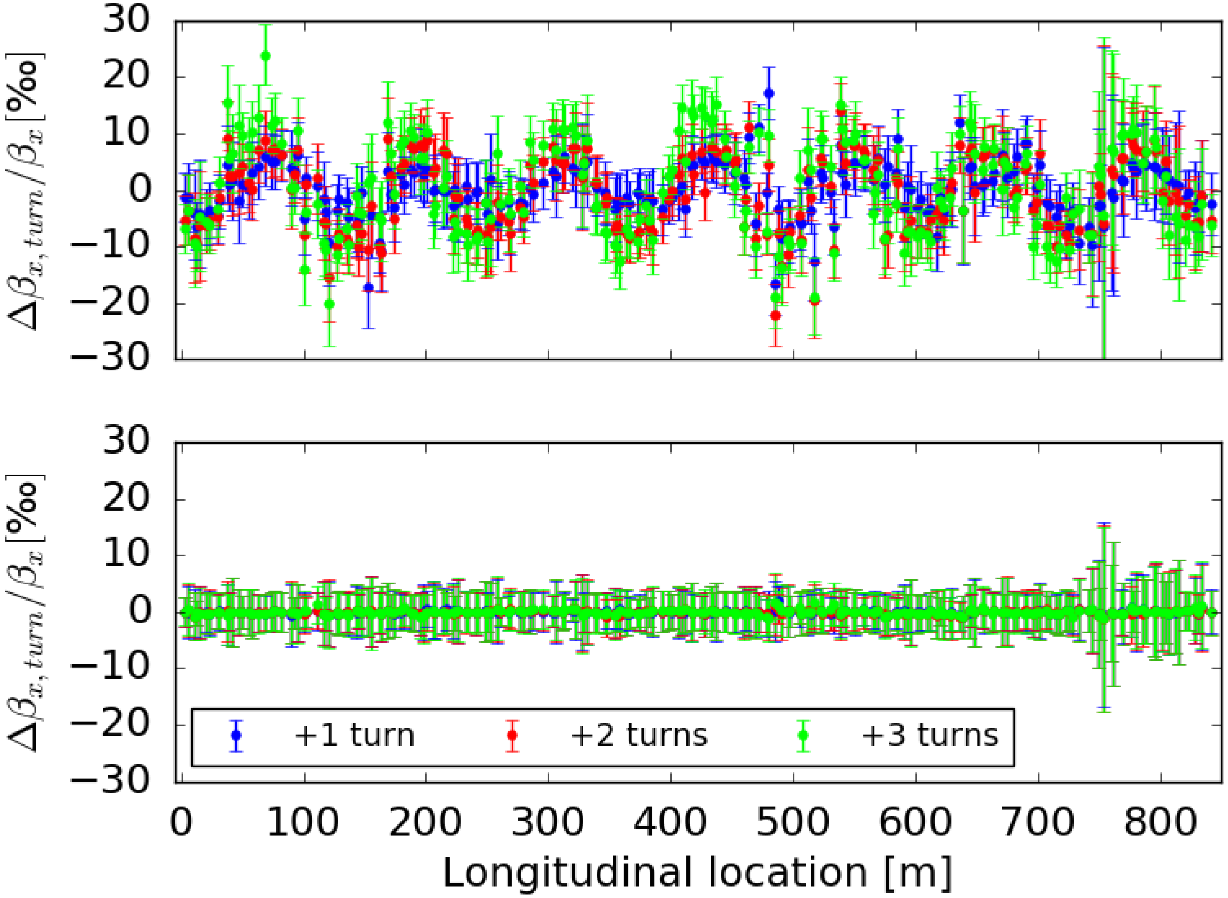
Tune and phase correction

- Same tune imposed for all BPMs
  - Corrects the phase and amplitude
- Phase output of frequency interpolated FFT is corrupted due to damping of transverse oscillations



- Phase correction [5]
- Exponential envelope measurement

Phase correction - ESRF



Raw

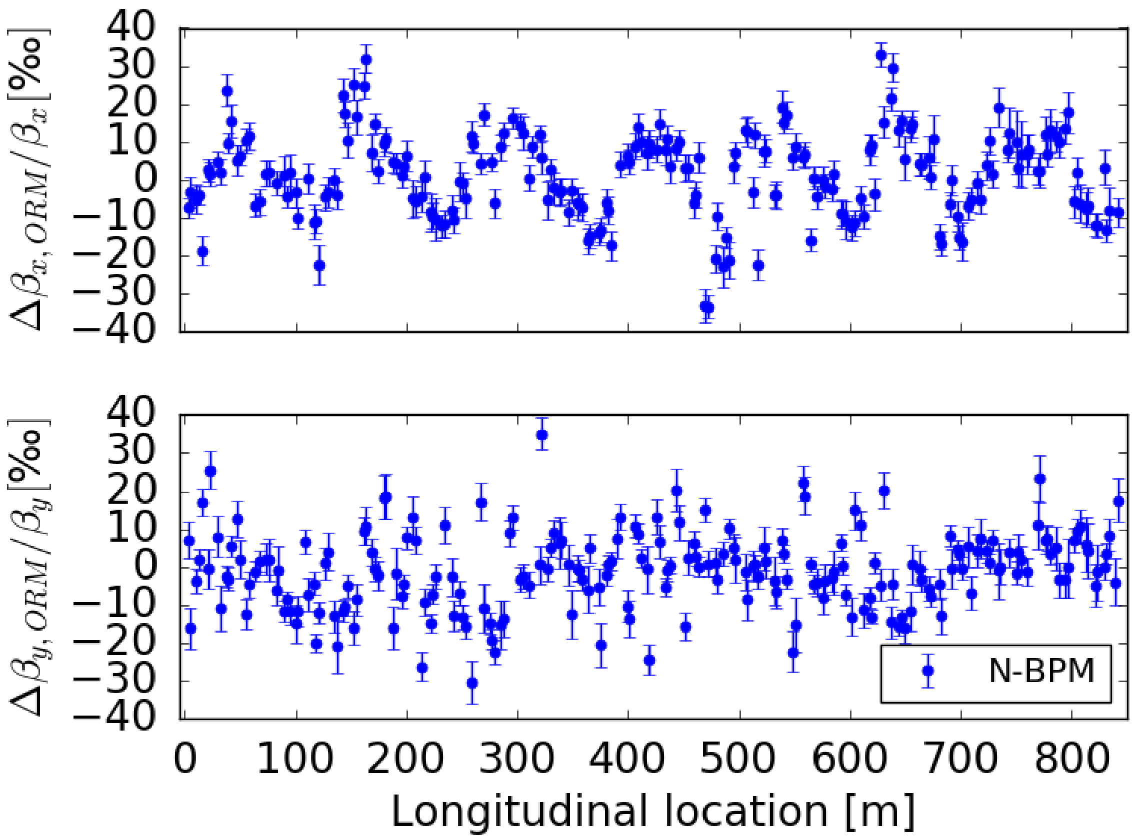
Corrected

Error contributions

- Statistical errors the most significant (machine vibrations, drifts, each kick is different)
- Random lattice imperfections (from Monte Carlo simulations)
- Non-linearities due to large kick size (from Monte Carlo simulations, only N-BPM)

Mean error Method	β_x-beating [‰]	β_y-beating [‰]
N-BPM	4	4
ORM	6	4

Beta-beating in ESRF



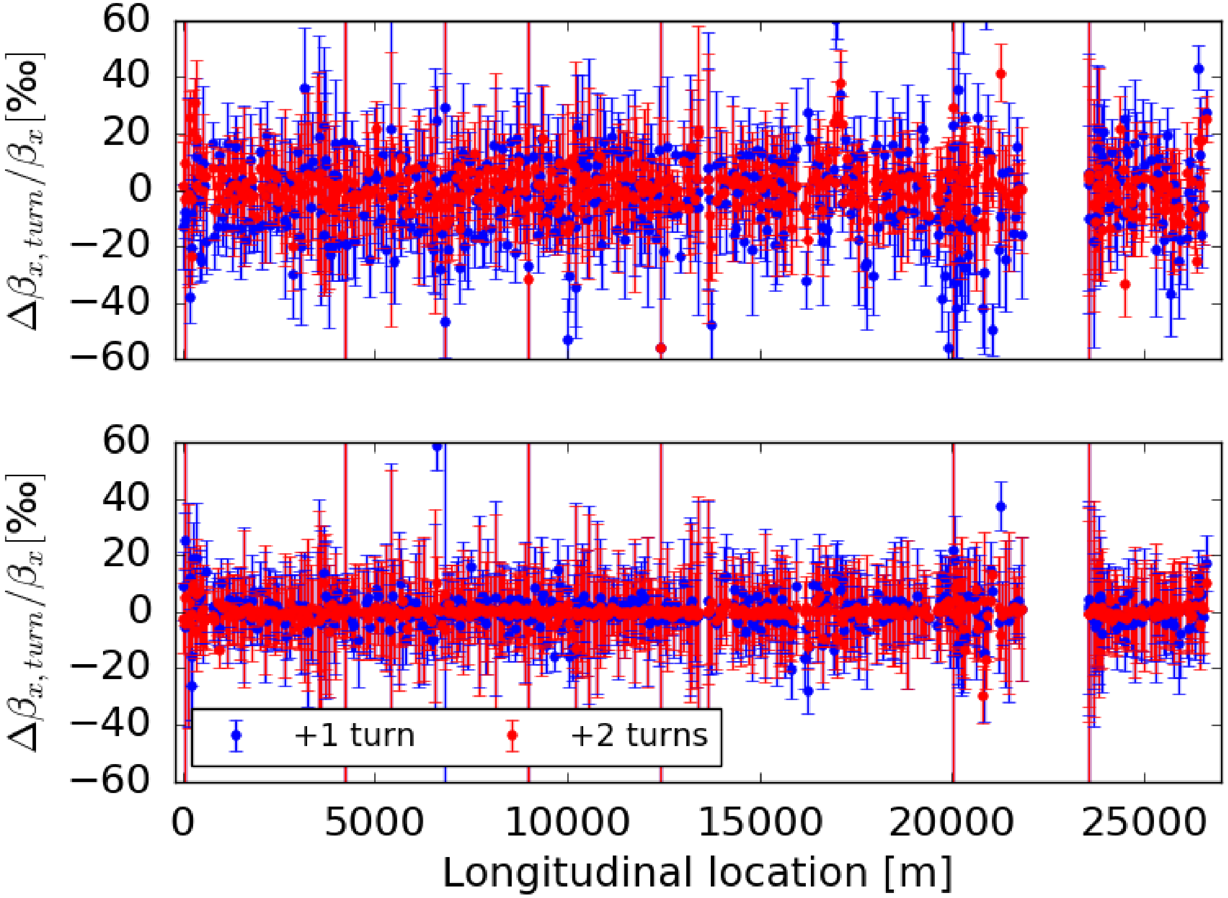
- Comparison between N-BPM and ORM inferred model
  - Independent methods
- Agreement to 11 ‰ in horizontal β-beating and 9 ‰ in vertical β-beating
- About 5 ‰ can be accounted to orbit drift

Sub-% accuracy

Results in ESRF

- β-function measurements precision pushed down to 4 ‰ and sub-% accuracy was demonstrated ESRF
  - N-BPM and ORM methods
  - For low decoherence optics
- Optimized kick size and number of turns analysed
- Tune averaging (over all BPMs)
- Phase correction (damping compensation)

Phase correction in LHC



Raw

Corrected

Applicability of pulsed excitation

- Useful in all synchrotrons
- Decoherence[6] - limits useful number of turns – ORM not limited
- Emmittance growth (hadrons) - need for reinjection

AC-dipoles vs kickers

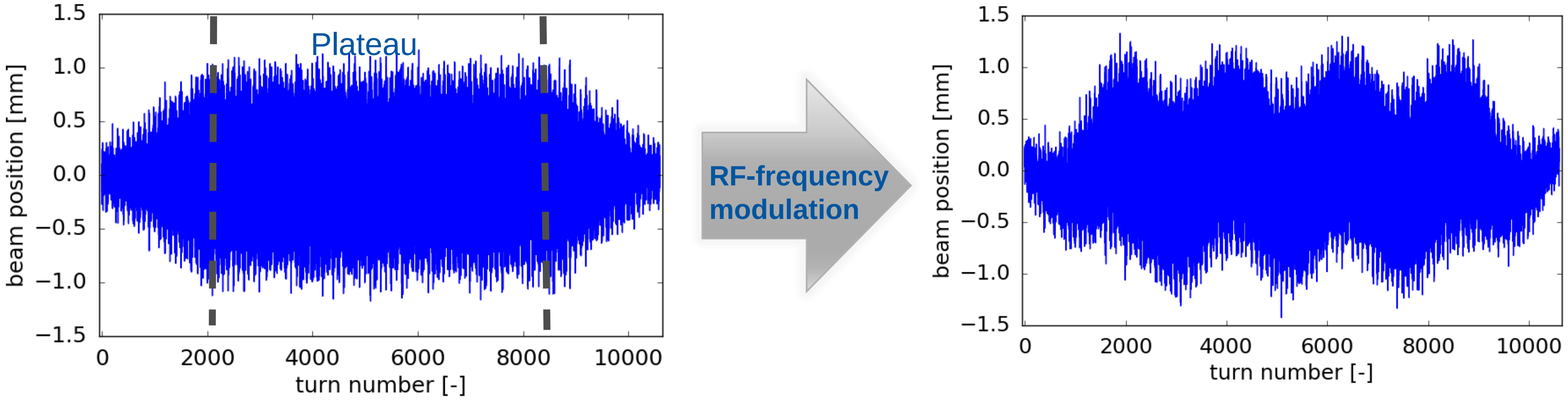
Pulsed Excitation by a kicker

- Easy to operate
- No cancelation needed
- Decoherence[6]
  - Limits useful number of turns
- Emmittance growth
  - limits the number of measurements without re-injection

Driven oscillation by AC-Dipole[7]

- Driven oscillation (more complex)
- Need to cancel the effect on the optics (quadrupole – to the first order)[8]
- No decoherence
- No significant emittance growth[9]
- Machine safety?

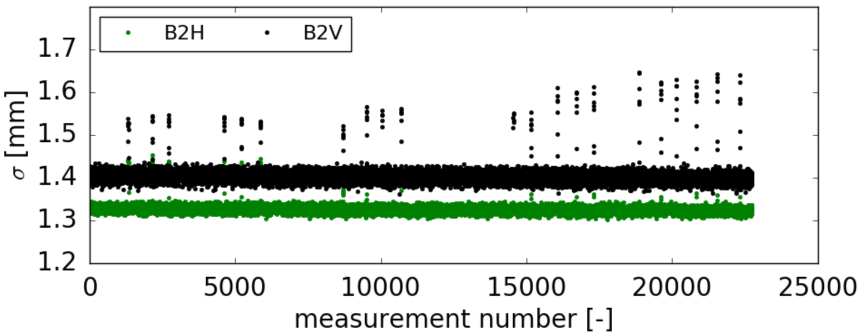
3D driven excitation



- On-momentum and off-momentum properties in a single shot
- Demonstrated in the LHC

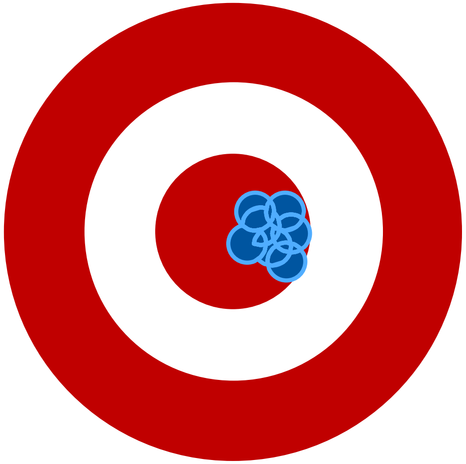
No emittance blow-up

- Beam size measured during the 3D driven optics measurements
- Beam blow up would show as steps
- Trends are flat - > no beam blow up
- Beam useful after the measurement



Conclusion and Outlook

- β-function measurements precision pushed down to 4 ‰ and sub-% accuracy was demonstrated ESRF
- AC-dipole driven oscillations may overcome quick decoherence and emittance growth in TbT methods



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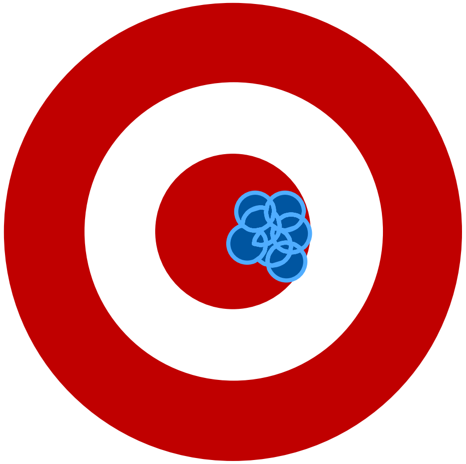
Thank you for your attention!



References

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3. R. Tomás, M. Aiba, A. Franchi and U. Iriso, PRAB, **20**, 054801, 2017.
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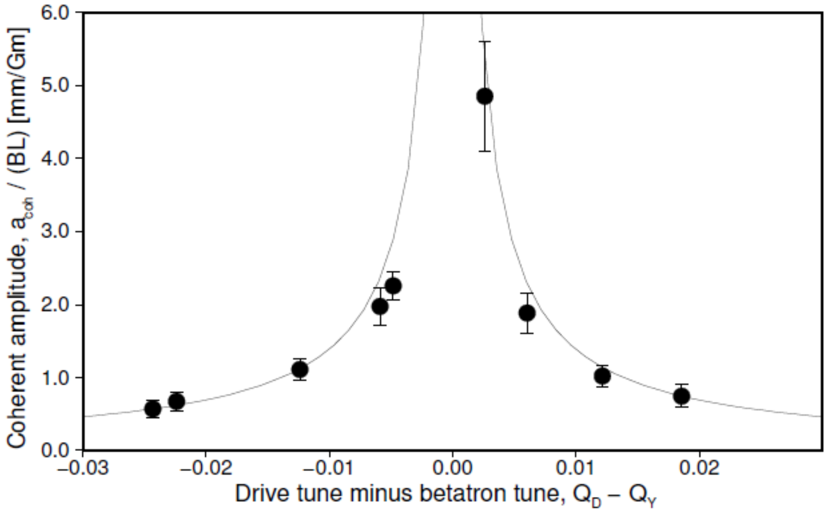
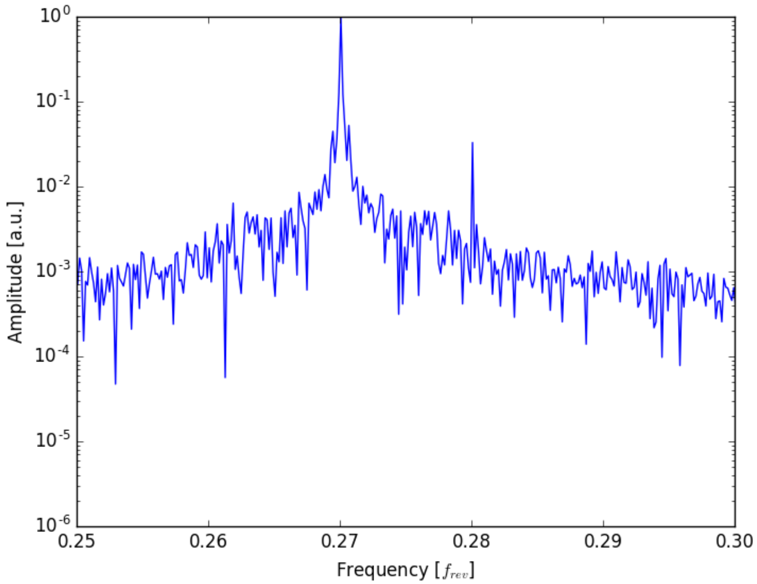
Driven oscillations

Amplitude ≈ as $1/\Delta Q$ [7]





May behave resonantly if one kicks “on the tune”

Phase Correction

$$x_i = Ae^{-\alpha\theta_i}\cos(\nu\theta_i + \phi + \epsilon),$$

where $\theta_i = 2\pi i$, A and α are the amplitude and the damping coefficient determined from other methods. ϵ is the correction to the phase ϕ, ϵ is given by

$$\epsilon = \frac{e_1 - e_2}{e_3 - e_4}$$

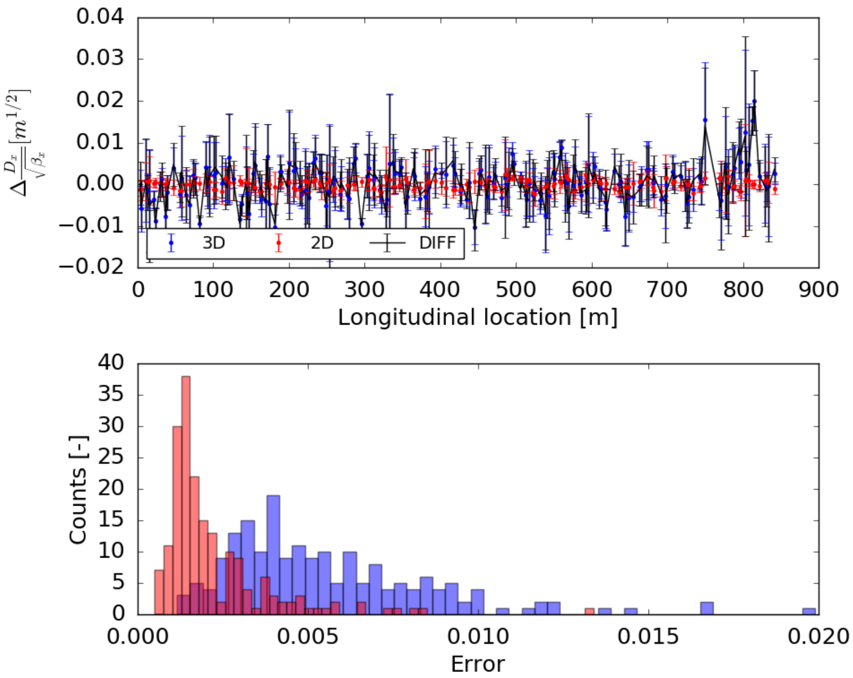
where

$$\begin{aligned}
e_1 &= \sum_i \frac{A}{2}\exp(2\alpha\theta_i)\sin 2(\nu\theta_i + \phi) \\
e_2 &= \sum_i x_i \exp(\alpha\theta_i)\sin(\nu\theta_i + \phi) \\
e_3 &= \sum_i x_i \exp(\alpha\theta_i)\cos(\nu\theta_i + \phi) \\
e_4 &= \sum_i A\exp(2\alpha\theta_i)\cos 2(\nu\theta_i + \phi).
\end{aligned}$$

[5]

- Imposing of the same tune for all BPMs
- Subtraction of average orbit
- Robust estimates of input parameters (Amplitude and damping coefficient)

Normalized dispersion - ESRF



- From natural synchrotron oscillations
- 30 times smaller excitation than in reference 2D measurement