K-Modulation Plans

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3. Limitations
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   - Knowledge of quadrupole strength
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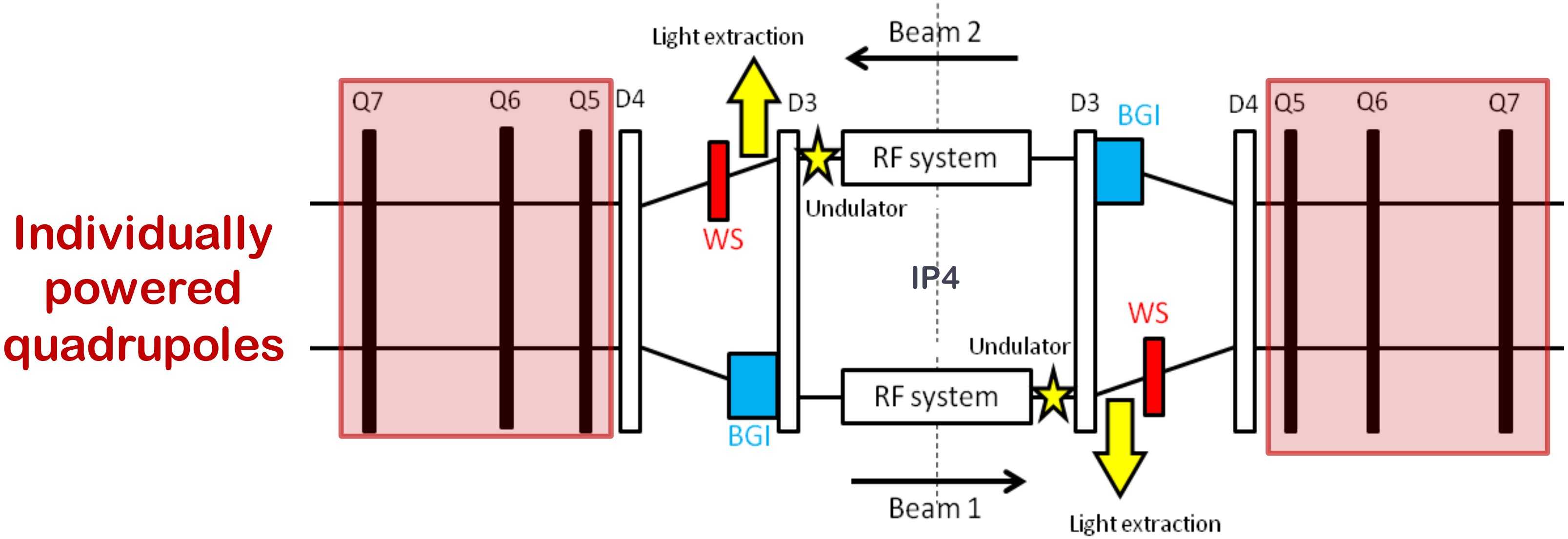
Motivation

- Alternative method for measuring β functions at locations with individually powered quadrupoles

- Essential for locations with non-optimum phase advance between BPMs for turn-by-turn phase advance measurement
  - e.g. β*, IR4

- Model independent

- Example IR4:
  - Essential for absolute emittance measurement



K-Modulation Method

- Requires individually powered quadrupoles
- Method:
  - Vary quadrupole strength k
  - Measure consequent beam tune change ΔQ
  - determine β at quadrupole location

- Average β function along magnet length l :
  - From trace of transport matrix for one turn

$$\beta = \frac{2}{l \cdot \Delta k}\left[\cot(2\pi Q) - \frac{\cos\left(2\pi(Q+\Delta Q)\right)}{\sin(2\pi Q)}\right]$$

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CAVEAT: NOT SUITABLE TO MEASURE BETA FUNCTIONS AROUND THE WHOLE RING - TOO TIME CONSUMING

$$\beta = \frac{2}{l \cdot \Delta k}\left[\cot(2\pi Q) - \frac{\cos\left(2\pi(Q + \Delta Q)\right)}{\sin(2\pi Q)}\right]$$

- For small tune changes far from integer and half integer tune resonances:

  $(2\pi\Delta Q < 1)$

$$\beta_{x,y} \approx 4\pi \frac{\Delta Q_{x,y}}{l \cdot \Delta k}$$

➔ Accurate measurement of ΔQ and precise knowledge of Δk

Example – 2012 Measurements (1)

- Measured β at quadrupoles in IR4 at injection, flattop and with squeezed optics

Beam 1	MQY.5L4.B1	MQY.5R4.B1	MQY.6R4.B1	MQM.7R4.B1
Beam 2	MQY.5L4.B2	MQY.5R4.B2	MQY.6L4.B2	

- One quadrupole at a time
  - "manual" measurement via LSA Trim Editor

- Required beam conditions:
  - Transverse damper off
  - Injection tunes (less coupling)
  - Only few bunches

- Offline analysis, transported measured β values at quadrupole to transverse profile monitor locations

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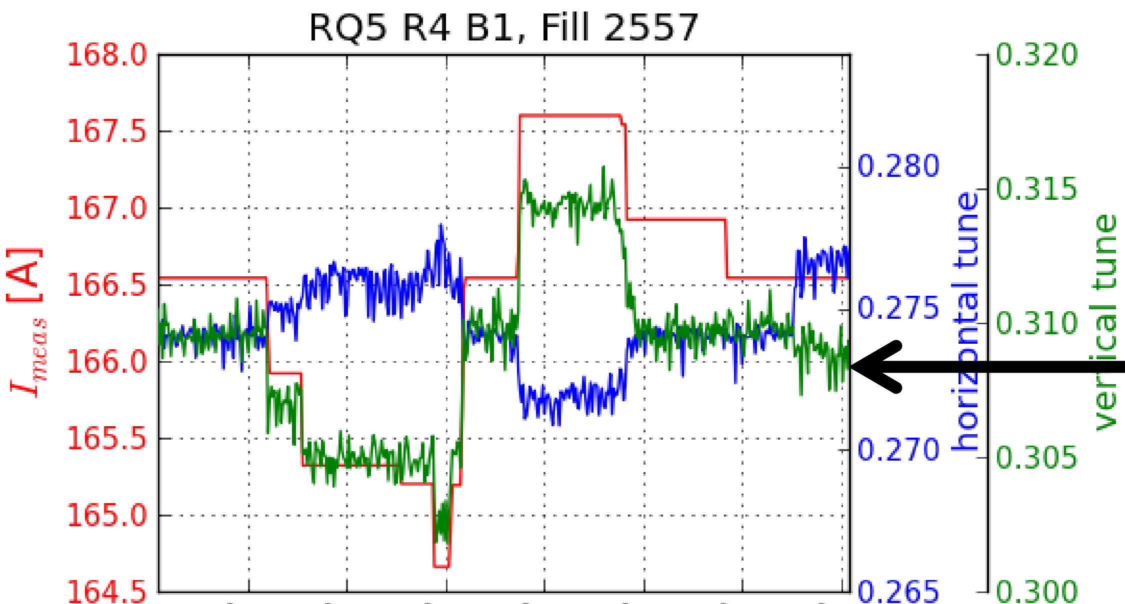
Example – 2012 Measurements (2)



Quadrupole strength k

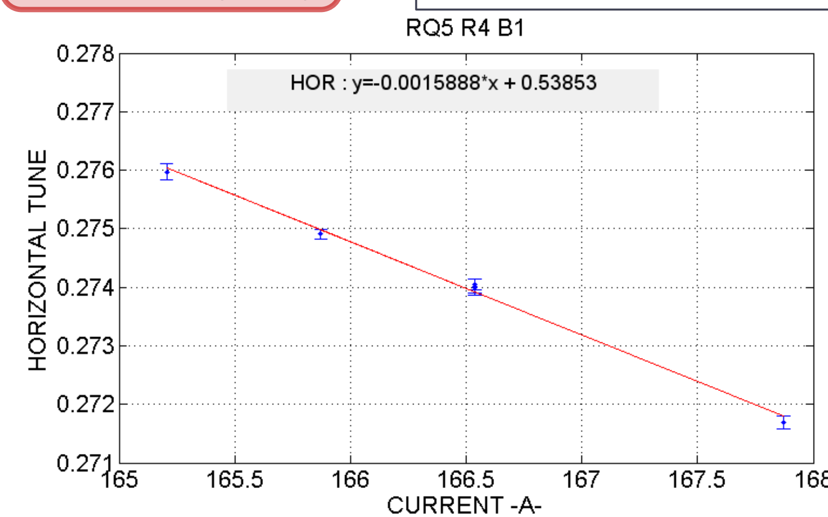
↓

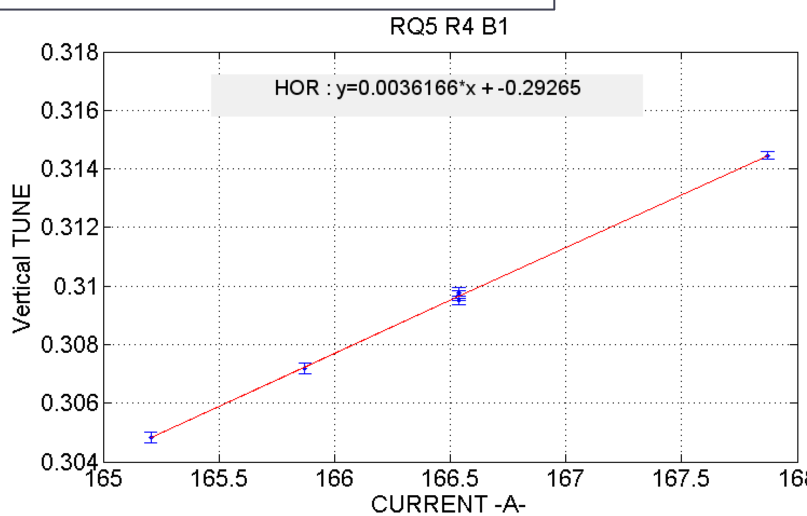
current I varied in steps

Tune noise ~ 10^{-3}!!!

$$\beta_{x,y} \approx 4\pi \frac{\Delta Q_{x,y}}{l \cdot \Delta k}$$

Linear fit to determine $\Delta Q(\Delta I)$
transfer function from LSA to determine β





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Example – 2012 Measurements (3)

- Quadrupole β ➔ beam instrumentation location β
  - Analytical method: interpolation via transfer matrices
  - Matching with MADX
- Results: errors reduced wrt turn-by-turn phase advance measurement, but still large…

	Beam 1 Horizontal	Model	Beta-beat	K-mod Analytical	K-mod Matching
450 GeV	Wire Scanner	165.48	158.83 ± 13 %	181.2 ± 6.45 %	183.7 ± 11.5 %
	Undulator	178.14	174.93 ± 13.2 %	199.9 ± 9.75 %	196.8 ± 13.3 %
4 TeV	Wire Scanner	165.48	151.74 ± 12.1 %	159.2 ± 6.45 %	173.3 ± 12 %
	Dipole D3	172.97	158.7 ± 8.76 %	165.4 ± 5.35 %	177.3 ± 12 %
Squeeze	Wire Scanner	165.48	159.27 ± 23.6 %	161.7 ± 7.5 %	179.9 ± 16 %
	Dipole D3	172.97	167.43 ± 24.5 %	174.5 ± 7.77 %	

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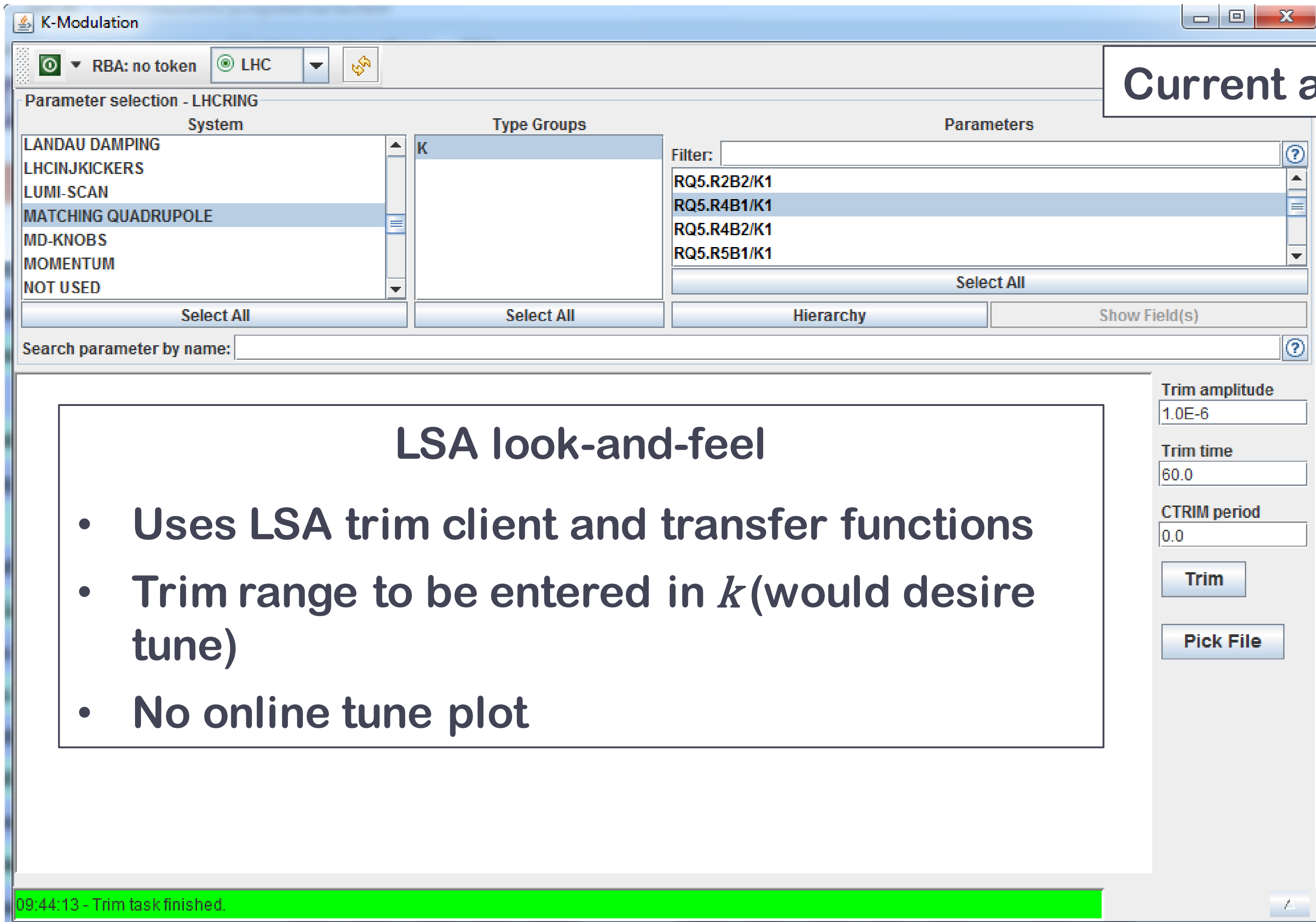
Limitations (1)

- “Manual” trims on k – time consuming, error prone
  - Application was in pipeline, could not be fully debugged
  - Application offered only basic functionality



Current application

LSA look-and-feel

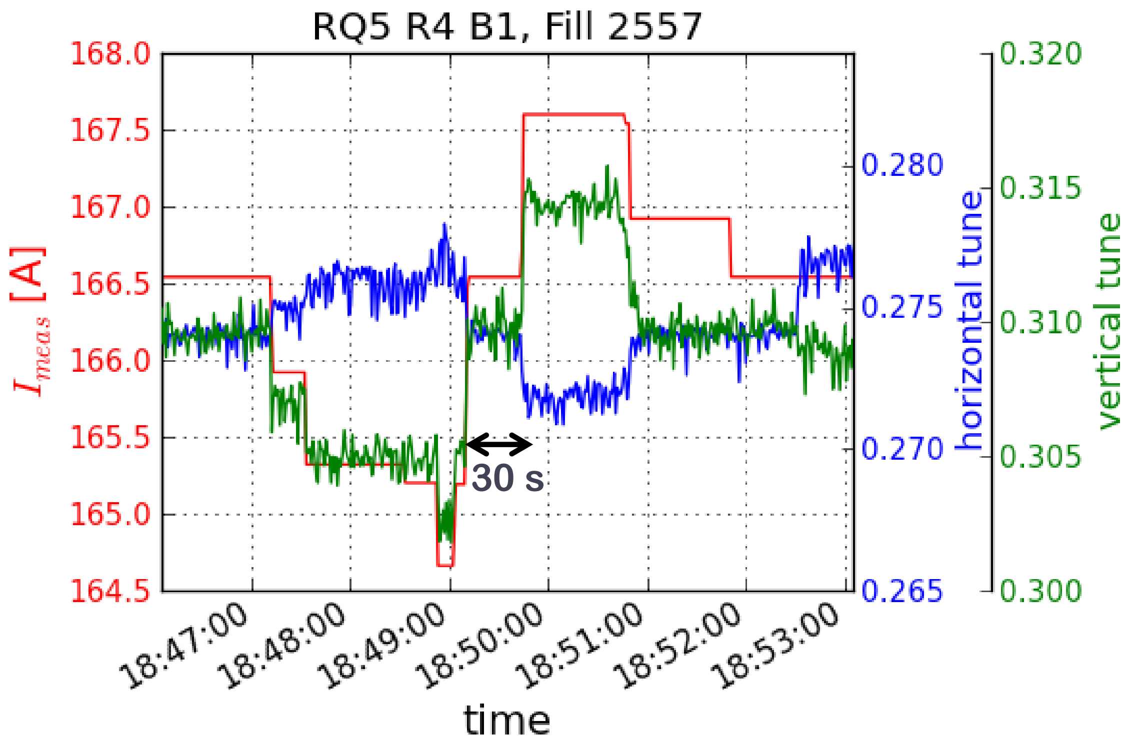
- Uses LSA trim client and transfer functions
- Trim range to be entered in k (would desire tune)
- No online tune plot

Limitations (2) – Tune Precision

- Tune noise level with damper off: 10^{-3}

  ➔ **require total tune change in range of 10^{-2} for k-modulation**

  – (Max. possible tune change = 1.5 x 10^{-2})



- Time estimate per beam mode ~ 10 min

  – 1 – 2 min per quadrupole

  – Machine set up to reduce tune noise (coupling correction, tune separations, …) most time consuming

- Parasitic measurements with physics beam excluded

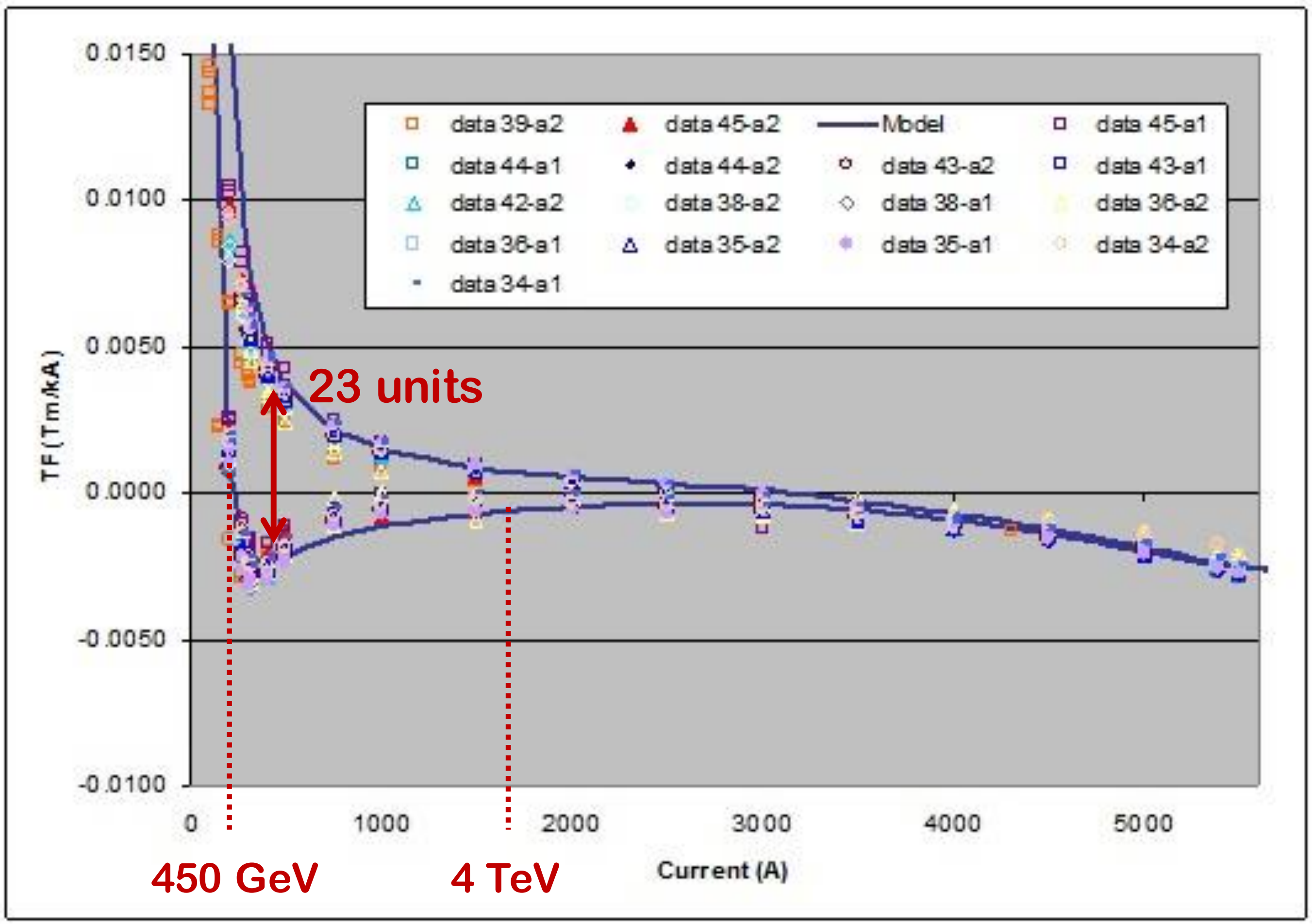
  – Unless using sacrificial 6 bunches and excitation

  – (K-modulation with colliding beams not possible)

Limitations – Knowledge of Δk

- Absolute error on transfer function ~ 0.1 – 0.2 %
- Transfer function error from hysteresis ~ 0.2 % or smaller

➔ Total estimated error on β ~ 10 % (mainly due to tune noise)



Measurement of the transfer function for MQM (similar for MQY)

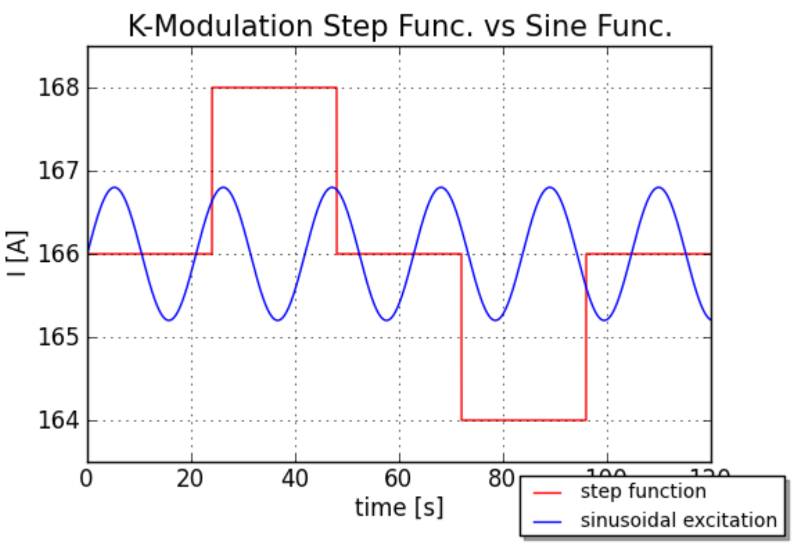
Example: MQM.7R4.B1

W. Venturini

Plans for K-Modulation Tool Post LS1

- Modify and debug existing application
  - Add tune acquisition + filtering
  - Possibility to enter steps in "tune change" instead of trims on k, using LSA knowledge
  - Interpolation – calculate β at any point
  - Integrated into LHC control system (LSA, JMAD,...)
  - **ONLINE ANALYSIS**

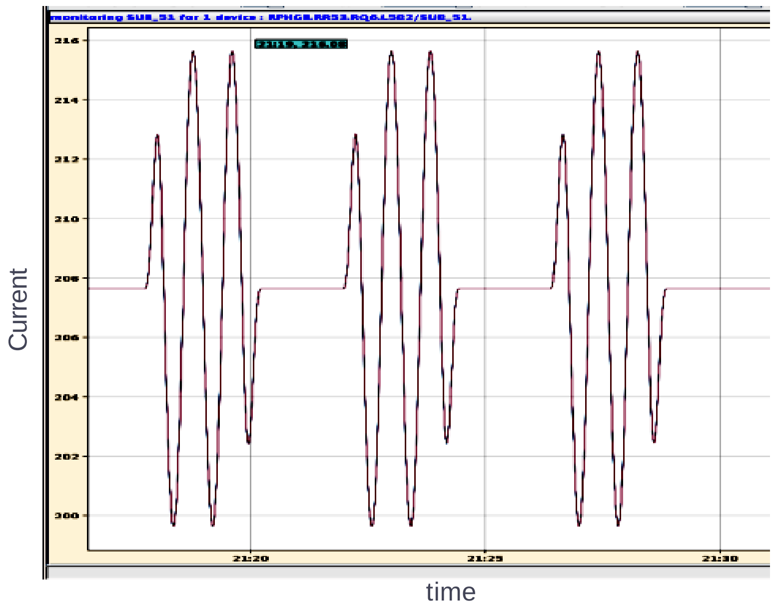
- Additional measurement mode: **SINSOIDAL EXCITATION**
  - Smaller amplitude and higher frequency than for step function
  - More quadrupoles at the same time with different frequencies
  - Details (QPS limits,...) to be checked

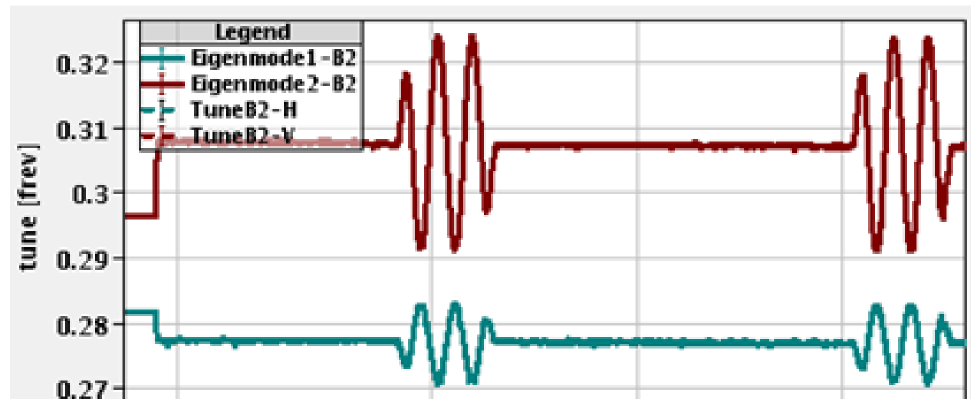


Sinusoidal K-Modulation

- Example measurements (2010):

ATS-Note-2011-043 MD



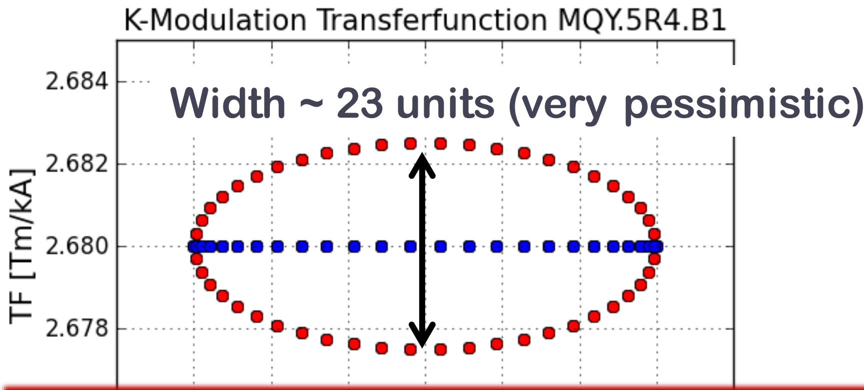


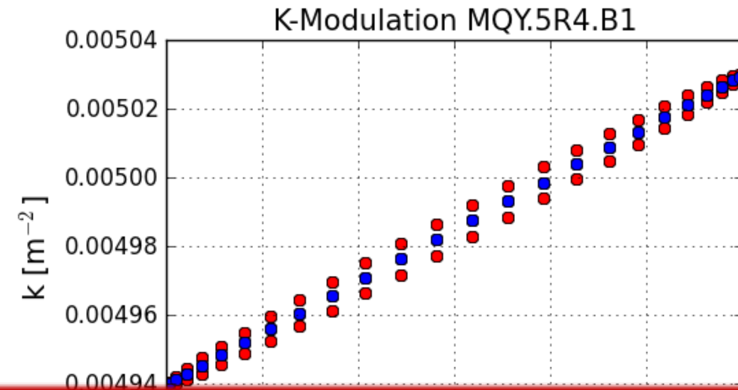
- Sinusoidal strength modulation to quadrupole directly at power converter
  - Power converter parameters: number of periods, amplitude, frequency ω_0
  - ...triplet model more complicated
- Fit tune response with $\Delta Q = \Delta Q_0 \cdot \sin(\omega_0 t + f)$

Sinusoidal Excitation - Simulation

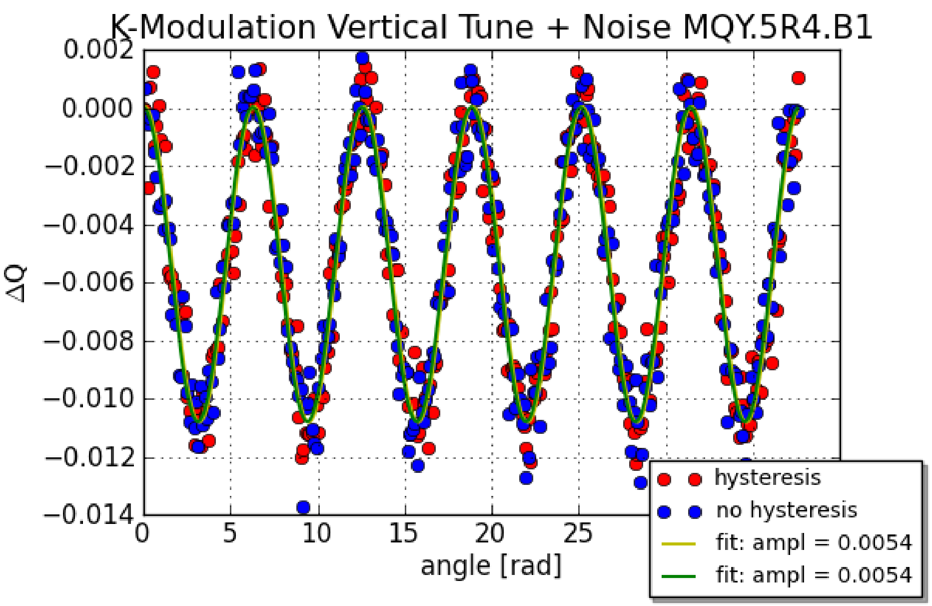
- A first look at hysteresis

$f_{sampling}$ = 1 Hz
$f_{oscillation}$ = 0.02 Hz





- **Hysteresis has no measurable effect on β function determination**
- **Noisy tune signal gives large β errors**



β_y [m]	430.99
Noisy tune	425.53 ± 20.39
hysteresis	430.99 ± 3 x 10^{-4}
Noisy tune	438.00 ± 22.58

~ 5 % error!
with 10^{-3} tune noise

Conclusion

- Alternative method for measuring β functions: k-modulation
  - For locations with individually powered quadrupoles

- Was successfully used in 2011/12
  - No dedicated tools operational
  - Results only obtainable offline

- β function measurement accuracy via k-modulation in the LHC mainly limited by tune noise

- Online tool for K-modulation planned for post LS1 LHC run
  - Will also offer sinusoidal excitation of quadrupoles

- Application to be tested in the SPS in 2014

BACKUP

Motivation: Emittance

- Transverse profile monitors located in IR4

- Normalized transverse emittance:

$$\varepsilon_{x,y} = \frac{\gamma}{\beta_{x,y}}\left(\sigma^2 - D^2\left(\frac{dp}{p}\right)^2\right)$$

dispersion negligible (at location of transverse profile monitors in IR4)

- Accuracy of emittance measurement depends on

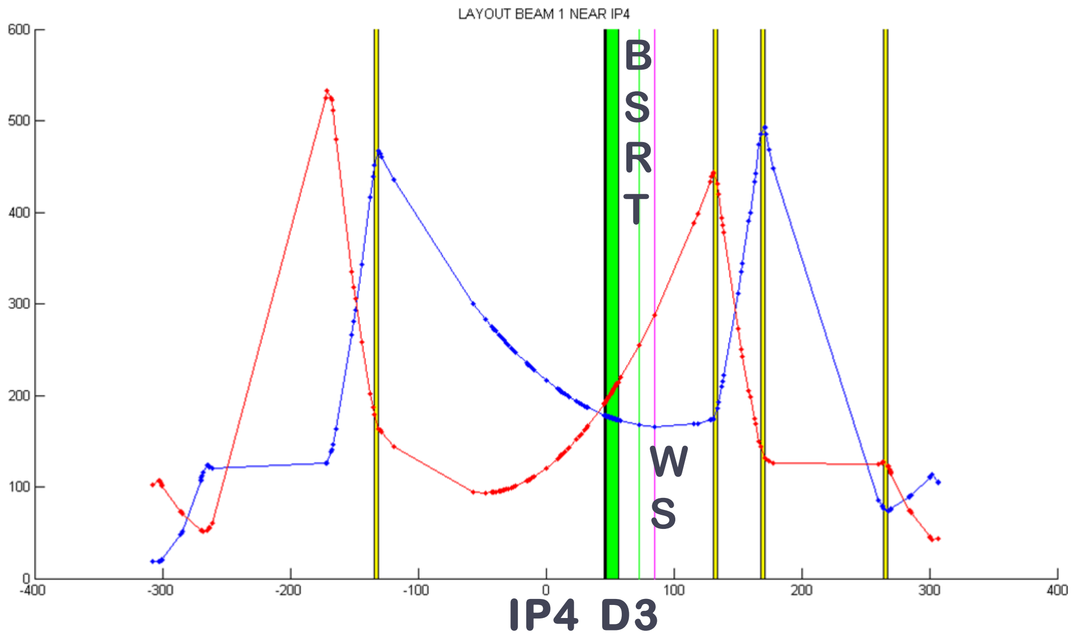
$$\frac{\delta\varepsilon}{\varepsilon} = \sqrt{\left(\frac{\delta\sigma^2}{\sigma^2}\right)^2 + \left(\frac{\delta\beta}{\beta}\right)^2}$$

transverse profile measurement precision

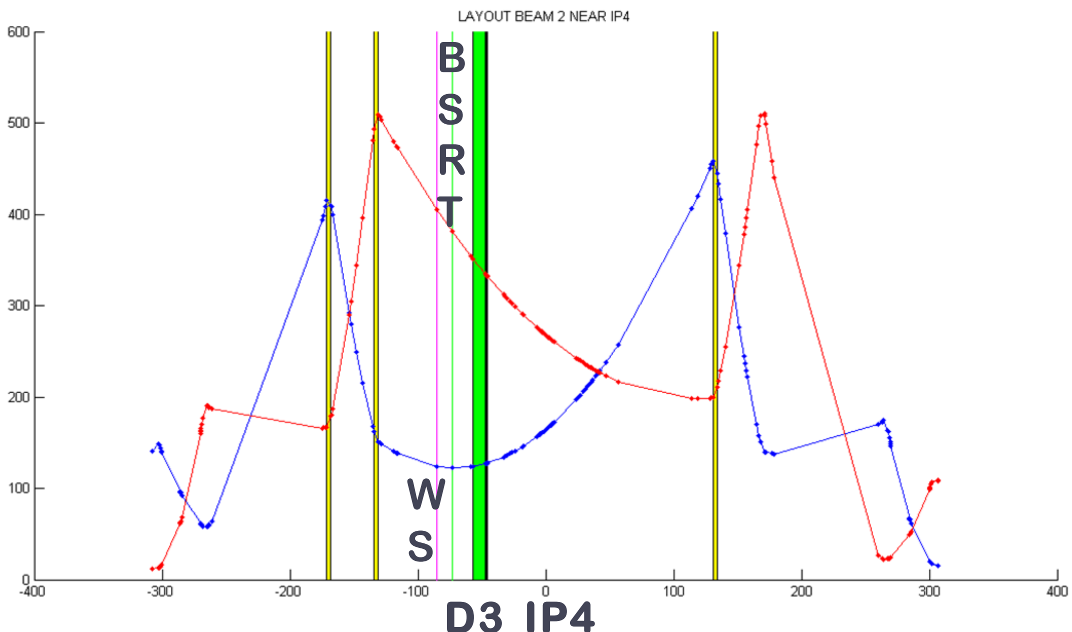
uncertainty on β function measurement

β Functions in IR4

Beam 1



Beam 2



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